**NRC «Kurchatov Institute»**
**Saint Petersburg State University**
**Joint Institute for Nuclear Research**

NATIONAL RESEARCH CENTER "KURCHATOV INSTITUTE"

LXXI INTERNATIONAL CONFERENCE

# «NUCLEUS-2021»

## NUCLEAR PHYSICS AND ELEMENTARY PARTICLE PHYSICS. NUCLEAR PHYSICS TECHNOLOGIES.

# BOOK OF ABSTRACTS

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# LXXI МЕЖДУНАРОДНАЯ КОНФЕРЕНЦИЯ

# «ЯДРО-2021»

## ЯДЕРНАЯ ФИЗИКА И ФИЗИКА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ. ЯДЕРНО-ФИЗИЧЕСКИЕ ТЕХНОЛОГИИ.

# СБОРНИК ТЕЗИСОВ

*Онлайн*

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**Санкт-Петербург**

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# Plenary

## PHENIX OVERVIEW

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Relativistic heavy ion collisions have been considered as a unique way to create and study the quark-gluon plasma (QGP) where the quarks and gluons are de-confined. PHENIX, which stands for the Pioneering High Energy Nuclear Interaction eXperiment, was operated for 16 years until 2016, and has been producing physics results from the data taken until then. Over this period, collision data were recorded spanning nine collision energies from 7.7 GeV to 510 GeV, and nine collision systems using Au, U, Cu, Al, p, and d. PHENIX is capable of detecting a wide variety of particles such as leptons, photons, light and heavy hadrons, with which many observables including but not limited to jets, particle correlations, single hadron spectra and flow have been measured and studied. Much progress is still being made in analysis of the data we took.

In this overview PHENIX talk, we will report the latest results from PHENIX, both on soft and hard probes from small to large systems.

# BELLE II: STATUS AND PROSPECTS

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The Belle II experiment at the SuperKEKB energy-asymmetric $e^+e^-$ collider is a substantial upgrade of the B factory facility at the Japanese KEK laboratory. The target luminosity of the machine is $6\times10^{35}$ $cm^{-2}s^{-1}$ and the Belle II experiment aims to record 50 $ab^{-1}$ of data, a factor of 50 more than its predecessor. With this data set, Belle II will be able to measure the Cabibbo-Kobayashi-Maskawa (CKM) matrix, the matrix elements and their phases, with unprecedented precision and explore flavor physics with B and charmed mesons, and $\tau$ leptons. Belle II has also a unique capability to search for low mass dark matter and low mass mediators. We also expect exciting results in quarkonium physics with Belle II. In this presentation, we will review the status of the Belle II detector, the results of the planned measurements with the full available Belle II data set, and the prospects for physics at Belle II.

# CURRENT STATUS OF THE MPD@NICA PROJECT

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The Multi-Purpose Detector (MPD) is currently under construction in JINR, Dubna as part of the NICA Accelerator Complex. The MPD is designed to study the properties of the strongly interacting matter in the regime of maximum baryonic density expected to be reached in heavy-ion collisions at the center of mass energy of 4-11 GeV. The detector will operate in the collider mode and is equipped to measure various hadronic, leptonic and photonic signatures of the phase transition and critical point in a wide and uniform acceptance and dynamic range. In this talk, we review the current status of the MPD construction and the physical potential of the apparatus in the first years of its operation.

# PHYSICS WITH SPD EXPERIMENT AT NICA COLLIDER

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A brief overview of the Spin Physics Detector (SPD) experiment is presented.
SPD is a future multipurpose experiment foreseen to run at the NICA collider, which is currently under construction at the Joint Institute for Nuclear Research (JINR, Dubna, Russia).
The physics program of the experiment is based on collisions of longitudinally and transversely polarized protons and deuterons at c.m.s. NN energy up to 27 GeV and luminosity up to $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.
SPD will operate as a universal facility for the comprehensive study of the unpolarized and polarized gluon content of the nucleon, using complementary probes such as: charmonia, open-charm, and prompt-photon production processes.
Possible SPD studies at the first stage of the NICA collider operation with unpolarized proton and deuteron beams are also discussed.

# OVERVIEW OF HEAVY-ION RESULTS FROM CMS

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Recently, CMS collaboration presented important results to widen our knowledge of Quark-Gluon-Plasma (QGP) state, known as the state of the early universe, by using high energy heavy ion collisions. In this presentation, I would like to introduce them and share the detailed news including hard and soft probes produced in the heavy ion collisions at $\sqrt{s_{NN}}$ = 5.02 TeV and analyzed with Run ll data, corresponding luminosity to 1.7nb$^{-1}$.

## NUCLEAR PHYSICS AT ISOLDE-CERN

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The ISOLDE Facility at CERN is the world's leading facility for the production of radioactive ion beams (RIBs) using the ISOL (Isotope Separation On-Line) method. Over 1000 isotopes of more than 70 elements have been produced by the impact of a 1.4 GeV proton beam on a variety of targets and using different ion sources for providing beams at 40-50 keV energy. Purified isotope/isomer beams can be further accelerated to about 10 MeV/u using the HIE-ISOLDE post-accelerator.
The low-energy and accelerated beams are used for a wide variety of experiments in nuclear structure research, but also for studying astrophysical processes, for materials properties research, for biochemical and biomedical research and for fundamental interaction studies.
This presentation will introduce the ISOLDE facility and RIB production, including some recent examples of experiments addressing open questions in nuclear physics.

# APPLYING HEAVY-ION STORAGE RINGS FOR PRECISION EXPERIMENTS AT THE INTERSECTION OF ATOMIC, NUCLEAR AND ASTRO-PHYSICS

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The storage of freshly produced radioactive particles in a storage ring is a straightforward way to achieve the most efficient use of such rare species as it allows for using the same rare ion multiple times. Employing storage rings for precision physics experiments with highly-charged ions (HCI) at the intersection of atomic, nuclear, plasma and astrophysics is a rapidly developing field of research. Until very recently, there were only two accelerator laboratories, GSI Helmholtz Center in Darmstadt, Germany (GSI) and Institute of Modern Physics in Lanzhou, China (IMP), operating heavy-ion storage rings coupled to radioactive-ion production facilities. The experimental storage ring ESR at GSI and the experimental cooler-storage ring CSRe at IMP offer beams at energies of several hundred A MeV. The ESR is capable to slow down ion beams to as low as 4 A MeV ($\beta$=0.1). Beam manipulations like deceleration, bunching, accumulation, and especially the efficient beam cooling as well as the sophisticated experimental equipment make rings versatile instruments. The number of physics cases is enormous. The focus here will be on the most recent highlight results achieved within FAIR-Phase 0 research program at the ESR.

First, the measurement of the bound-state beta decay of fully-ionized $^{205}$Tl was proposed about 35 years ago and was finally accomplished in 2020. Here, the ESR is presently the only instrument enabling precision studies of decays of HCIs. Such decays reflect atom-nucleus interactions and are relevant for atomic physics and nuclear structure as well as for nucleosynthesis in stellar objects.

Second, the efficient deceleration of beams to low energies enabled studies of proton-induced reactions in the vicinity of the Gamow window of the p-process nucleosynthesis. Proton capture reaction on short-lived $^{118}$Te was attempted in 2020 in the ESR. Here, the well-known atomic charge exchange cross-sections are used to constrain poorly known nuclear reaction rates.

The performed experiments will be put in the context of the present research programs at GSI/FAIR and in a broader, worldwide context, where, thanks to fascinating results obtained at the presently operating storage rings, a number of new exciting projects is planned. Experimental opportunities are being now dramatically enhanced through construction of dedicated low-energy storage rings, which enable stored and cooled secondary HCIs in previously inaccessible low-energy range. The first such facility, CRYRING, has been employed at GSI for first experiments with decelerated beams of HCIs from the ESR.

Thanks to the fascinating results obtained at the ESR and the CSRe as well as to versatile experimental opportunities, there is now an increased attention to the research with ion-storage rings worldwide. An isochronous storage ring for mass measurements, R3, has just been commissioned at RIKEN. Dedicated ring facilities are proposed for ISOLDE at CERN, TRIUMF, FRIB, LANL, and JINR.

# THE BERGEN PROTON CT PROJECT – PROTON TRACKING IN A HIGH-GRANULARITY DIGITAL TRACKING CALORIMETER

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**Introduction:** Particle therapy, a non-invasive technique for treating cancer using protons and light ions, has become more and more common, e.g. Norway has decided to build two particle treatment facilities, one of which will be located in Bergen. Being able to position the Bragg peak accurately is a major advantage of protons and light ions, but incomplete knowledge about the tissue properties and their relative position limits the precision. Range uncertainties of several millimetres may arise, mainly due to the — not one-to-one — conversion of photon attenuation maps from computed tomography (CT) scans into relative stopping power. A proton/alpha CT scanner provides direct information about the stopping power and has the potential to reduce range uncertainties from current values of 3-10 mm to about 1 mm.

**Proton CT:** For a proton CT scan the particles — typically protons or alpha particles — need to be energetic enough to traverse the patient completely, so that the Bragg peak is positioned in a calorimeter. The trajectories of every outgoing proton, as well as the residual energy/range, is measured. The calculation of the proton trajectory inside the target region and the measured residual proton energy/range provide a 3D-map of the relative stopping power. During a scan, the patient needs to be rotated to obtain projection data from a set of different angles. Prototypes of pCTs have been built and tested in beams (see e.g. [1,2]); however, readout rates are currently limited to several MHz. In order to use a pCT in a clinical environment, the total scanning time has to be reduced to the order of minutes or, even better, seconds.

**Digital tracking calorimeter:** A (pre-)clinical prototype of an extremely high-granularity digitial tracking calorimeter has been designed and is being constructed. The latest developments in Monolithic Active Pixel Sensors (MAPS) technology allow the fabrication of extremely-high granularity, low material budget and large area silicon detectors with integration times of microseconds and sparsification/zero-suppression of the data on the sensor itself (see e.g. [3]). The prototype is a silicon/absorber sandwich calorimeter with 41 sensitive layers of MAPS [4,5]; the absorber material is aluminium. The first two tracking planes (27cm x 18cm) are ultrathin layers of sensors thinned to 50 $\mu$m, bonded onto thin flex cables and mounted on a carbon fibre carrier. The sensor layers consist of ALPIDE chips originally developed for the upgrade of the inner tracking system of the ALICE experiment at the LHC.

**Clinical requirements:** The pCT system is designed to operate under clinical treatment conditions, i.e. pencil beam scanning. This implies (1) that the trajectories of the incoming protons are taken from the beam optics (beam spot position, size and divergence) and only the outgoing protons' trajectories and thus their range are measured on a track-by-track basis with high precision and (2) that the proton tracking calorimeter has to handle high local intensities.

**Simulations:** A complete CT reconstruction of a simulated anthropomorphic paediatric head phantom shows that the concept of a single-sided detector setup and realistic pencil beam parameters gives a spatial resolution sufficient for proton therapy treatment planning [6].

**Beam tests:** Modules of ALPIDE sensors mounted on thin flexible PCBs and on aluminium absorber plates have been produced. The sensors are read out by an FPGA-based data acquisition system (Kintex Ultrascale FPGA). Stacks of modules were tested in proton, helium and carbon beams at HIT.

The expected performance based on simulations and first beam test results will be presented, e.g. proton tracking accuracy, dE/dx capability, occupancy and rate capability, radiation hardness and 3D spatial resolution after CT reconstruction.

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# RADIOSENSITIZATION OF CANCER CELLS USING NANOPARTICLES IN X-RAY AND ION BEAM THERAPY

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Many different tumor-targeted strategies have been developed worldwide to limit the side effects and improve the effectiveness of cancer therapies, such as chemotherapy, intensity modulated radiation therapy, biology-driven personalized radiotherapy, ion beam radiotherapy, target-alpha-therapy, high intensity focused ultrasound therapy, etc. Recent advances in nanotechnology have also given rise to trials with various types of metal nanoparticles (NPs). Different metal-based NPs, e.g. gold, gadolinium, titanium, silver, hafnium and bismuth have been evaluated to enhance the radiosensitization of the cancer cells while reducing or maintaining the normal tissue complication probability during radiation therapy. When X-rays or a charged particle hit a metal, there are multiple possibilities of eventual outcome. Among the several emissions that occur, the most relevant to cancer radiotherapy are scattered X-rays/photons, photoelectrons, Compton electrons, Auger electrons and fluorescence photons. The energy of the X-rays is important, since the photoelectric effect is decided by $(Z/E)^3$, where E is the energy of the incoming photon and Z is the atomic number of the molecule being targeted. The photoelectric effect is therefore dominant at lower energies and is prevailing until the photon energy reaches a medium energy (e.g., around 500 keV for gold (Z = 79)) with a cross section varying with $Z^4$ or $Z^5$, depending on the material. When using X-rays, mainly the inner electron shells are ionized, which creates cascades of both low and high energy Auger electrons. The use of higher Z NPs (e.g., gold or platinum) along with X-rays, leads to enhanced photoelectric and Compton effects, making these NPs more radio-sensitizing than others with lower Z. Gold is a promising radio-sensitizer in this regard due to its high atomic number and higher mass energy absorption coefficient in relation to soft tissue. In addition to that it, it is very inert and it is highly biocompatible. When using high LET particles, e.g., carbon ions for therapy, mainly the outer shells are ionized, which produce electrons with lower energies compared to X-rays. However, the amount of the produced low energy electrons is higher when exposing NPs to ions than when exposing them to X-rays. Since ions traverse the material along tracks, and therefor give rise to a much more inhomogeneous dose distributions than X-rays, there might be a need to introduce a higher amount of NPs when using ions compared to when using X-rays to create enough primary and secondary electrons to get the desired dose escalations. This raises the questions of toxicity. Though, even below the ionization threshold, electrons can induce molecular damage via Dissociative Electron Attachment (DEA) and production of highly reactive oxygen species, such as OH•, H•, $O_2$-, $H_2O$+ from the surrounding water molecules via radiolysis or DEA. The same effects apply to both Auger and photo electrons. This paper will discuss the need for systematic studies of the behavior of NPs, when exposed to different kinds of ionizing radiation, depending on the Z, surface treatment, sizes, ionizing radiation, etc.

# RADIATION THERAPY AND FLASH

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Cancer is a critical societal issue. Worldwide, in 2018 alone, 18.1 million cases were diagnosed, 9.6 million people died, and 43.8 million people were living with cancer. Radiation therapy (RT) is a fundamental component of effective cancer treatment and control. It is estimated that about half of all cancer patients would benefit from radiotherapy for treatment of localised disease, local control, and palliation.

The most frequently used modality of RT uses high-energy (6 to 10 MeV) photons. However, conventional photon RT is characterised by almost exponential attenuation and absorption, and consequently delivers the maximum energy near the beam entrance but continues to deposit significant energy at distances beyond the cancer target. RT has progressed rapidly with the development of new technologies and innovation leading to remarkable improvements in every phase of RT, related to treatment - from simulation to planning to delivery (image guided beams), with the aim to tailor treatment to the specific anatomy of individual patients given as result a high-precision RT.

Hadron Therapy (HT) is a precise form of RT that uses charged particles (protons and other light ions) instead of photons to deliver a dose. RT with hadrons offers several advantages since it can overcome the limitations of photons as hadrons deposit most of their energy at the end of their range (Bragg peak) and these beams can be shaped with great precision. This allows for more accurate tumour treatment, destroying the cancer cells more precisely with less damage to surrounding tissues. However, despite the recent progress of HT, numerous challenges are yet to be addressed to maximize clinical outcomes and cost-effectiveness of this advanced therapy modality to make it: (a) applicable for treating larger number of tumours, (b) accessible for a greater number of patients globally.

A simple way to boost radiation therapy efficacy is to escalate the dose to the tumour without causing normal tissue injury. Optimization of this so-called differential effect remains the holy grail of radiation therapy; a goal that may soon be reached with extreme spatial and/or temporal irradiation protocols, such as ultra-high dose rate so called FLASH-Radiotherapy where the relevant dose is delivered in fractions of a second.

FLASH-RT is causing tremendous excitement in the radio-oncology field as it may revolutionize modern day RT. Supported by radiobiological studies, FLASH-RT is a paradigm-shifting method for delivering doses within an extremely short irradiation time (tenths of a second) and Ultra High Dose in the pulse. FLASH-RT has been shown to preserve normal tissue in various species (mice, pig, cat, zebrafish) and various organs (brain, lung, gut, skin, hematopoietic system) while still maintaining anti-tumour efficacy equivalent to conventional RT at the same dose level when delivered in a single fraction or hypo-fractionated. This effect has been called the "FLASH effect" and involves in part, a decreased production of toxic reactive oxygen species.

Recent developments offer the possibility of reaching Ultra High Doses with proton-PBS, proton broad-beam as well as very high energy electron (VHEE). While, FLASH-RT has shown impressive normal tissue sparing and remarkable tumour control in *in vivo* experiments, the benefit of Proton-FLASH and VHEE-FLASH must be confirmed.

# DEVELOPMENT OF RADIATION TECHNOLOGIES IN THE 21ST CENTURY

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The total number of ionizing radiation sources in the world is more than 14 million units, of which X-ray tubes are ~ 4 million units, and radioactive sources of various types are ~ 10 million units. Including modern technological diagnostic installations ~ 94 thousand units, and installations for radiation therapy ~ 20 thousand units.
Radiation technologies are used in many industries – nuclear power, nuclear medicine (radiation diagnostics and radiation therapy), industry and construction (modification of the properties of substances, creation of new materials, sterilization of products, flaw detection, production of radiopharmaceuticals), agriculture (disinsection of grain, processing of products to extend the shelf life, increasing seed germination), solving environmental problems (treatment of flue gases of coal-fired thermal power plants, wastewater treatment, decontamination of contaminated areas) and much more.
At present time there are more than 150 thousand units of ionizing radiation sources, including devices, installations and complexes using X-ray radiation ~ 65 thousand units In Russia. Installations, devices, closed sources using radionuclides, and reactors, storage facilities for radioactive substances and waste from nuclear reactors in the country’s economy ~ 80 thousand units, including radioisotope devices and installations ~ 15 thousand units and 128 nuclear reactors. Storage facilities for radioactive substances and waste from nuclear reactors ~ 650 units. Charged particle accelerators in our country ~ 500 units. (~ 400 units electron accelerators and ~ 90 units of protons and ions), in other organizations, structures, etc. ~ 8400 sources of ionizing radiation. Including ~ 200 in medicine, ~ 50 in scientific and educational organizations, ~ 250 in the national economy (including accelerators at customs, Rosatom structures and other enterprises).
The rate of emergence and spread of high-tech radiation technologies in various industries is extremely high, and their number doubles approximately every seven years. The most important direction is the search for new ideas for increasing the acceleration rate and reducing the size of accelerators, and the creation of compact accelerators on “cold” magnets, which will significantly (several times) reduce the size of installations.
This research was performed according to the Development program of the Interdisciplinary Scientific and Educational School of Lomonosov Moscow State University «Photonic and Quantum technologies. Digital medicine»

# RADIOPHARMACEUTICALS FOR DIAGNOSTIC AND THERAPY IN MODERN NUCLEAR MEDICINE

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In nuclear medicine methods the early diagnostics and detection of malignancies is an important problem. To obtain information about functional, anatomic, metabolic processes in the tumors or in the metastatic nodes one can effectively use the different radiopharmaceuticals. These substances have a mixture of a biochemical agent and of a radionuclide which emits gamma-quants (methods of Single Photon Emission Computed Tomography) or positrons (methods of Positron Emission Tomography). The diagnostic information provided by radiopharmaceuticals (radionuclide imaging) has to be reflected all physiologic and pathologic conditions within the human body.

The other greatest challenge in nuclear medicine methods is to target delivering of the corresponding radiopharmaceuticals to the cancer cells for the next non-surgical treatment of all tumors. Also the quantity of radiopharmaceuticals used in diagnostic imaging procedures and targeted therapy should be realize a principle of "as low as reasonable achievable", in particular in pediatric field [1]. The combining of radionuclide imaging methods with methods of radionuclide therapy to Theranostics, it can give us an excellent result for the treatment and diagnosis of a cancer with minimal side effects. In this case we have to investigate the proton induced nuclear reactions (with the evaporation of one or more nucleons in the final stages) for production of new medical radionuclides which are used for effective early diagnosis and treatment of various localized oncological tumors [2].

Therefore in present work the experimental and theoretical studies of the (p,n) reaction excitation functions for medium mass nuclear systems from 114Sn to 124Sn with production of the antimony radionuclides in final channels in the energy range 6-20 MeV were carried out. Such antimony radionuclides can emit Auger electrons, which is very perspective for use in precision targeted therapy due to their short radii of action and high energies of transfer and also can emit gamma-quants which are registered by the modern Single Photon Emission Computed Tomography. Therefore one can consider these radionuclides as the prospective for the Theranostics methods. For investigated reactions the processes and mechanisms of antimony radionuclides formation were considered and their cross-sections have been obtained.

Acknowledgments: the reported study was supported by RFBR, research project No. 20-02-00295.

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# PROSPECTS OF THEORETICAL NUCLEAR SPECTROSCOPY OF LIGHT NUCLEI

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The modern theory of the structure of light nuclei is dynamically developing due to the introduction of ab initio (from first principles) methods of describing nuclear systems. An essential place among such methods is occupied by various versions of No-Core Shell Model (NCSM) (see, for example, [1]) that uses realistic NN potentials to describe the interaction of nucleons. Usually, these potentials are derived from Chiral Effective Field Theory. The discussed approach makes it possible to successfully describe the spectra of nuclei up to masses A ~ 16 in a wide range of energies. The radii and electromagnetic moments of the low-lying states of nuclei and, in part, the electromagnetic M1 and E2 transitions are also described satisfactorily.

In the literature, there are also several successful attempts to describe the total widths of the nucleon and cluster decay of nuclear states [2,3]. In our works [4, 5], we developed a method that makes it possible to solve the problem of multichannel decay of nuclei and calculate the partial widths of decay into a variety of channels. The talk demonstrates the capabilities of the developed approach: a wide range of studied levels, the quality of description of level energies, total and partial widths known from experiment. The decay characteristics of the known and not yet discovered states, as well as the energies of the latter, are predicted. The most striking prediction seems to be the prediction of a new previously not observed rotational band of strongly clustered states 0+, 2+, 4+ in the 8Be nucleus.

As a result, it is demonstrated that the complex of NCSM-based approaches developed to date by various theoretical groups has great predictive power and, in the near future, will become the basis of the direction that can be called theoretical nuclear spectroscopy of light nuclei.

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# STUDYING COMPTON DOUBLE IONIZATION OF HELIUM ATOM WITH COLTRIMS DETECTOR

**Authors:** Lothar Ph. Schmidt[1]; Igor Volobuev[2]; Max Kircher[1]; Ochbadrakh Chuluunbaatar [3]; Reinhard Doerner [1]; Yuri Popov[2]; Florian Trinter[4]; Markus S. Schoeffler[1]; Salim Houamer [5]; Sven Grundmann[1]; Till Jahnke[1]; Vela-Perez Isabel[1]

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In the report the recent results of the big international team of theorists and experimenters on the Compton double ionization (CDI) of the helium atom with use of the COLTRIMS (COLd Target Recoil Ion Momentum Spectroscopy) technique is presented. In these experiments, only the momentum of the nucleus of the helium atom and one of the electrons (slow) are measured for coincidence. As a result, the total differential cross section is integrated over the momentum of the final photon at an initial photon energy of 40 KeV. Further, in order to increase the experimental yield, various single scattering cross sections are measured.
The experiment is compared with the theory within the A2 approximation. Various models of the initial and final states of the atom are used, including states with high electron correlation. Unfortunately, in the presented experiments it is not possible to exclude the scattering of the final photon into the front cone, where exchange processes make a large contribution, and where both electrons have relatively low energies. In such a situation, it is not possible to realize kinematics with a large difference in the energies of electrons, which manifested itself in the so-called (e, 3e) impact electron reactions as a method for studying electron correlations in a target. Nevertheless, even in this implementation, single differential cross sections show an obvious dependence on the quality of a pair of initial and final (double continuum) wave functions.

# MEMORY OF A. B. MIGDAL

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This March marks the 110th anniversary of the birth of academician Arkady Benediktovich Migdal. For several decades, A. B. Migdal worked at the Institute named after I.V. Kurchatov and concurrently as a professor at the Department of Theoretical Nuclear Physics of MEPhI. In the report, the author proposes to share memories of an outstanding Personality, an outstanding Scientist and an unforgettable Teacher.

# STRUCTURE AND PROPERTIES OF NUCLEAR ISOMERS. ON THE 100TH ANNIVERSARY OF THE DISCOVERY OF NUCLEAR ISOMERISM

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In some nuclei, there are metastable states with "anomaly" long lifetimes, called nuclear isomers [1]. The report mentions the main events of the history of the discovery and research of the phenomenon of nuclear isomerism. The properties of isomeric states with a lifetime of more than 1 second (605 isomers in 548 nuclides) are considered on the base of the ENSDF 2021 file [2].
Studying the isomer properties is an excellent test of the correctness of our ideas about the structure of the nucleus. It is possible to distinguish isomerism by spin (in deformed nuclei – by the spin projection), by the equilibrium form, in particular the intruder states and fission isomers, and by the excitation energy. In the latter case, the transition energy is so small, for example, at $^{235}$U or $^{229}$Th, that the electromagnetic lifetime becomes large even in the absence of other prohibitions.
Nuclear isomers are energy accumulators, so the search for controlled deexcitation methods would open the way to a new energy source [3]. The discovery of the neutron acceleration in an "isomeric" medium, when thermal neutrons, inelastic scattering on isomers, carry away their energy, proves that such a statement of the question makes sense. The cross-section of such a process at the isomeric state of $^{180m}$Hf is $\sigma_{in} = 52(13)$ bn [4].
The excitation of isomers in the neutron capture allows us to study the influence of the resonant environment on their lifetime. For example, for the $^{119m2}$Sn isomer, an increase in the observed lifetime of 5% was obtained, depending on the increase in the concentration of tin nuclei and the creation of Moessbauer resonance conditions [5]. The continuation of these studies opens up new prospects for the use of this phenomenon in nuclear technologies.

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# STATUS AND PHYSICS POTENTIAL OF JUNO

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The Jiangmen Underground Neutrino Observatory (JUNO) is a neutrino experiment under construction in a 700 m deep underground laboratory near Jiangmen in South China. The main neutrino target will consist of 20 kton of liquid scintillator held in a spherical acrylic vessel. The experiment is designed for the determination of the neutrino mass ordering, one of the key open questions in neutrino physics. This measurement will be done by studying the fine spectral structure of reactor antineutrino vacuum oscillations at a baseline of 53 km, requiring an unprecedented energy resolution of 3% at 1 MeV. The light produced by the scintillator will be seen by about 20,000 large PMTs (20") and about 25,000 small PMTs (3"). The OSIRIS detector will monitor the radio-purity of the liquid scintillator during the months-long filling of the main detector, while the unoscillated spectrum from one reactor core is planned to be closely monitored by the Taishan Antineutrino Observatory (TAO). JUNO will also significantly improve the precision of already measured neutrino oscillation parameters. Astrophysical measurements of solar, geo, supernova, DSNB, atmospheric neutrinos, as well as searches for proton decay or dark matter are also a part of the vast physics programme. The presentation will review the physics goals, design, as well as the status of the JUNO project.

# THE SPHENIX EXPERIMENT AT RHIC

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The sPHENIX experiment at RHIC is currently under construction and on schedule for first data in early 2023. Built around the excellent BaBar superconducting solenoid, the central detector consists of a silicon pixel vertexer adapted from the ALICE ITS design, a silicon strip detector with single event timing resolution, a compact TPC, novel EM calorimetry, and two layers of hadronic calorimetry. The hybrid streaming/triggered readout of the detector enables full exploitation of the luminosity provided by RHIC. The experiment will deliver unprecedented data sets for a wide variety of multi-scale measurements at RHIC, including studies of jet modification, upsilon suppression and open heavy flavor production in p+p, p+Au and Au+Au collisions. The talk will describe the readiness of the experiment for operations, present current projections of key jet and heavy flavor measurements, and discuss their potential scientific impact.

# OVERVIEW OF RECENT MEASUREMENTS BY NA61/SHINE AT THE CERN SPS

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NA61/SHINE at the CERN SPS performed a unique two-dimensional scan of system size and collision energy with a goal to search for a critical point of the strongly interacting matter and to explore properties of matter at the onset of deconfinement. This talk will cover highlights from recent measurements in p+p, Be+Be, Ar+Sc, and Pb+Pb reactions. The results concern hadron yields and their ratios, charged hadron directed and elliptic flow, proton intermittency, electromagnetic effects, higher-order moments of multiplicity and net-charge fluctuations. A comparison with model predictions and data from other experiments in the SPS energy range will be also shown. The physics case and status of the ongoing upgrade of the NA61/SHINE facility will be discussed.

# HIGHLIGHTS FROM THE STAR EXPERIMENT

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One of the main aims of the relativistic nuclear physics is an exploration of the properties of hot and dense nuclear matter produced in heavy-ion collisions. The Relativistic Heavy Ion Collider (RHIC) provides a unique opportunity to map the QCD phase diagram colliding different nuclei species and varying the energy of collisions. The second phase of the Beam Energy Scan (BES) program at RHIC covers a broad energy range for gold-gold collisions $\sqrt{s_{NN}}$= 7.7–27 GeV. The Fixed-target Program (FXT) extends collision energy range available for the analysis down to $\sqrt{s_{NN}}$= 3.0 GeV.
In this talk, we will present recent results from the STAR experiment and the future plans.

# RECENT RESULTS FROM ICECUBE

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IceCube neutrino observatory is 1km$^3$ detector located at the South Pole in Antarctica. Its construction with was completed in 2010. Since then it has continuously collected data: cosmic rays with IceTop, cosmic rays induced muons with in-ice arrays, low energy atmospheric neutrinos with Deep Core, and high energy atmospheric and astrophysical neutrinos with IceCube. The unexpectedly large astrophysical diffuse neutrino flux has been discovered by IceCube in 2013. Its spectrum has been characterized with all-flavor neutrino events starting in the detector, muon neutrino induced tracks as well as cascades events, which are dominated by electron and tau neutrino flavors. The energy spectrum is well described by a single power law with a spectral index of 2.5. The origin of astrophysical diffuse neutrino flux remains largely unknown. Data samples utilizing various event topologies have been used to search for astrophysical point sources. So far, IceCube has found an evidence of astrophysical neutrinos originating from two point sources, the TXS 0506+056 blazar and from the NG 1068 active galaxy. High statistics of atmospheric neutrinos collected with the DeepCore array are used for neutrino oscillation analyses and for searches of sterile neutrinos. In this talk we will present most recent physics results from IceCube with astrophysical and atmospheric neutrinos as well as cosmic ray results with IceTop.

# KATRIN: CURRENT STATUS OF PROJECT AND RESULT ON THE NEUTRINO MASS.

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The KArlsruhe TRItium Neutrino experiment (KATRIN) is designed to improve the existed direct limit on the effective electron antineutrino mass by an order of magnitude, with a projected sensitivity of 0.2 eV/c$^2$ at the 90% confidence level. To achieve this KATRIN is using a windowless gaseous molecular tritium source containing up to 100 GBq activity and electrostatic spectrometer with adiabatic magnetic collimation with resolution at 1 eV level.
At May,2021 five data taking runs (with duration about two month each) are completed. First two runs are analyzed and provide new neutrino mass limit $m_\nu$ < 0.8 eV/c$^2$. First data run is analyzed for the presence of light sterile neutrino signal. With current level of sensitivity KATRIN data can't neither confirm nor exclude Neutrino-4 experiment claim of observed sterile neutrino signal. Currently, the main efforts of the KATIN team are aimed at reducing the spectrometer background and achieving stable data collection parameters. In the historical introduction are considered main milestones of neutrino mass search, particularly contribution of Leningrad - St.Petersburg physicists.

# BAIKAL-GVD NEUTRINO TELESCOPE: STATUS AND FIRST RESULTS

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The Baikal Gigaton Volume Detector (Baikal-GVD) is the km$^3$-scale underwater neutrino telescope designed for the study of high-energy astrophysical neutrino flux. The Baikal-GVD sensitivity range extends from 100 GeV to multi-PeV neutrinos and beyond. The telescope is being in its construction phase and presently consists of 64 strings carrying 2304 optical sensors providing an effective volume for high-energy cascade detection of 0.4 km$^3$. An overview of the detector construction, the status and prospects of the detector deployment and of the first results from partially built telescope is given in this talk.

# FIRST EXPERIMENTAL PROOF OF CNO FUSION CYCLE IN SUN WITH THE BOREXINO EXPERIMENT

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Borexino, an ultra-pure liquid scintillator detector located at the Laboratori Nazionali del Gran Sasso in Italy, has detected solar neutrinos from the CNO fusion cycle for the first time in history. The CNO cycle is predicted to be the dominant energy production process in massive stars, while it is a secondary mechanism for the solar energy production. Its small associated neutrino flux, as well as the similarity of the spectral shapes of electrons scattered off CNO and *pep* solar neutrinos and electrons from the decays of $^{210}$Bi background, make measurement of CNO solar neutrinos very challenging. The proof of the existence of CNO fusion process in Nature has been made possible by carrying out several campaigns of purification of Borexino liquid scintillator and in 2016, thermal stabilization of the detector. This talk, on the behalf of the Borexino collaboration, will present the overview of the challenges along with their solutions adopted to extract the CNO solar neutrino signal with the rejection of the null hypothesis with greater than 5sigma significance at 99% C.L as well as the implications of this result for solar physics.

# DETECTION OF STERILE NEUTRINOS IN THE NEUTRINO-4 EXPERIMENT, COMPARISON WITH THE RESULTS OF OTHER EXPERIMENTS AND THE 3 + 1 NEUTRINO MODEL

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The results of measurements of the dependences of the flux of reactor antineutrinos and their spectrum on the distance to the center of the active zone of the SM-3 reactor (Dimitrovgrad, Russia) in the range of 6 – 12 meters are presented. We observe the effect of oscillations at a confidence level of $3\sigma$ in the vicinity of the parameter values $\Delta m_{14}^2 = \left(7.3 \pm 0.13_{st} \pm 1.16_{\text{syst}}\right)$ eV$^2$ and $\sin^2 2\theta = 0.36 \pm 0.12_{\text{stat}}$ $(2.9\sigma)$. The paper presents a comparison of this result with the results of other experiments on the search for sterile neutrinos. Combining the results of the Neutrino-4 experiment with the results of gallium and reactor anomalies, we obtained the value $\sin^2 2\theta_{14} \approx 0.19 \pm 0.04(4.6\sigma)$. The results of the Neutrino-4 experiment are compared with the results of other reactor experiments NEOS, DANSS, STEREO, PROSPECT and with the results of the accelerator experiments MiniBooNE, LSND and with the results of the IceCube experiment. An analysis of the results within the framework of the $3+1$ neutrino model is presented. The mass of sterile neutrinos from the Neutrino-4 experiment (assuming that $m_4^2 \approx \Delta m_{14}^2$) is $m_4 = 2.68 \pm 0.13$eV. Using estimates of mixing angles from other experiments, the following masses for electron neutrinos, muon neutrinos, and tau neutrinos can be calculated: $m_\beta = (0.58 \pm 0.09)$eV, $m_\mu = 0.42 \pm 0.24$eV$, m_\tau \leq 0.65$eV. The PMNS matrix for four states together with sterile neutrinos is presented, as well as a scheme for mixing neutrino flavors with sterile neutrinos for direct and inverse mass hierarchies.

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# PRESENT AND FUTURE UPGRADES OF ALICE

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ALICE is currently completing major upgrades for LHC Run 3 and in the meantime further projects are already underway. ALICE is developing thinned wafer-sized monolithic active pixel sensors to replace the inner tracking layers during the Long Shutdown 3. This resulting detector will have an unprecedented low material budget, and consequently drastically reduced interaction probabilities and unparalleled vertexing performance. Furthermore, we plan to install a Forward Calorimeter (FoCal) comprising a Si-W electromagnetic calorimeter with pad and pixel readout and a hadronic calorimeter with conventional metal-scintillator technology with optical readout, covering $3.4 < \eta < 5.8$. Finally, a proposal of a next-generation heavy-ion experiment for LHC Run 5 is also in preparation and will be discussed. This new apparatus foresees an extensive usage of thin silicon sensors for tracking and a modern particle identification system, combining a silicon-based time of flight detector, a RICH and preshower detector. The advantages of extremely low material budget, fast read-out and high resolution will enable novel measurements of electromagnetic and hadronic probes of the QGP at very low momentum.

## HIGHLIGHTS OF RECENT RESULTS FROM ATLAS

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Recent results from ATLAS will be presented. These include highlights of heavy ion physics as well as measurements of properties of the Higgs boson and the top quark, diboson production, and searches for supersymmetry and exotics.

## OVERVIEW OF LHCB RESULTS

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The LHCb detector at the LHC specialises in studying decays of beauty and charm hadrons, with excellent tracking, secondary vertex reconstruction and particle identification capabilities. Here we present an overview of recent highlighted results from the broad physics programme at LHCb, including the flavour anomalies and precise determination of CKM parameters. Specific attention is paid to the topic of hadron physics, covering both exotic and conventional hadron spectroscopy.

# RECENT RESULTS WITH ALICE AT THE LHC

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A Large Ion Collider experiment (ALICE) at the LHC allows to study different aspects of strong interaction physics. This talk gives an overview of its experimental programme based on selected recent results.
Measurements based on jets and hadrons containing charm and beauty quarks at the LHC allow to constrain the interaction between the quark-gluon plasma and partons, to learn about radiation in quantum chromodynamics and about hadronisation in different environments. We discuss new results on these topics in proton-proton, proton-nucleus and nucleus-nucleus collisions.
The highly relativistic collisions involving charged ions at the LHC allow to identify photon-induced interactions. Recent ALICE measurements as a probe of hadron structure and the initial state of heavy-ion collisions are presented.
Collisions at ultra-relativistic energies at the LHC produce large numbers of hadrons and nuclei of variable light-flavour quark content. They can be used to perform production and correlation measurements sensitive to the production mechanisms and the inter-particle interactions. Furthermore, the detector material can be used to study particle absorption cross sections. The talk will show unique measurements provided by ALICE and mention their connection to other fields as the equation of state of neutron stars and dark matter searches in space.

# CMS DETECTOR UPGRADE

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The CMS Upgrade projects, both Phase-1 and Phase-2, are aimed for the improvement of detector systems to provide the necessary physics performance under the challenging conditions of high luminosity at the HL-LHC. In this second phase of the LHC physics program, it's being planned to increase the instantaneous luminosity by $5.0^{34}$ cm$^{-2}$ s$^{-1}$ with the goal of integrating some 3000 fb$^{-1}$ by the end of 2037. The corresponding mean number of collisions (pileup) per bunch crossing will be 140, with the possibility to increase it up to 200. Installation of the upgraded detector systems started in LS2 and is planned to be completed in LS3, presently scheduled for 2025 to mid-2027. CMS detectors need to be modernised in order to improve the ability to isolate and precisely measure the products of the most interesting collisions.

## OVERVIEW OF CMS RESULTS

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In this overview, the physics highlights of the CMS results are presented, with a focus on the latest results obtained with the full LHC Run 2 statistics.

# PHOTONUCLEAR RESEARCH: STATUS OF EXPERIMENTS

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The majority of total and partial photoneutron reaction cross sections were obtained for about 150 nuclei from 3H to 239Pu at Livermore (USA) and Saclay (France) [1]. Those data [2] are widely used in many basic research and applications. For 19 nuclei ($^{51}$V, $^{75}$As, $^{89}$Y, $^{90}$Zr, $^{115}$In, $^{116,117,118,120,124}$Sn, $^{127}$I, $^{133}$Cs, $^{159}$Tb, $^{165}$Ho, $^{181}$Ta, $^{197}$Au, $^{208}$Pb, $^{232}$Th, and $^{238}$U) investigated at both laboratories it was found [3] that photoneutron yield reaction cross sections (σ(⊠,xn) = σ(⊠,1n) + 2σ(⊠,2n) + 3σ(⊠,3n) + …) obtained in various experiments disagree to each other by about 10% but partial reaction cross sections, first of all σ(⊠,1n) and σ(⊠,2n), disagree much more – up to 100% of values. Those disagreements are definitely systematic, because as a rule σ(⊠,1n) have larger values at Saclay, but σ(⊠,2n) – vice versa at Livermore. Such disagreements mean that nobody knows which results are reliable. Using the experimental-theoretical method for evaluation of partial reaction cross sections based on the objective physical criteria of data reliability it was shown that many data under discussion obtained in both laboratories using the method of neutron multiplicity sorting are not reliable because significant uncertainties of procedures for separation the events with 1 and 2 as well as with 2 and 3 neutrons. New reliable reaction cross sections were evaluated for ~50 nuclei, primarily for many of 19 nuclei mentioned above [4]. Using the detail comparison of evaluated and experimental cross sections it was shown that disagreements between those (as well as between Livermore and Saclay once) are the results of various systematic uncertainties. The main reasons of those in many cases are unreliable (erroneous) procedures of separation the neutrons from the various partial reactions. Additional systematic uncertainties of experiments carried out at Livermore are because of errors of separation the neutrons from the reactions (⊠,2n) and (⊠,1n1p) in the cases of relatively light nuclei ($^{51}$V, $^{59}$Co, $^{75}$As), and the loss of many neutrons from the reaction (⊠,1n) in the cases of $^{75}$As, $^{127}$I, $^{181}$Ta, and $^{206,207,208}$Pb. All reliable evaluated cross sections are included into the international nuclear reaction database [2] and were used for updating of the IAEA digital photoneutron data library.

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# Section 1. Experimental and theoretical studies of the properties of atomic nuclei

## EQUILIBRIUM GROUND-STATE DEFORMATION OF MEDIUM AND HEAVY NUCLEI CALCULATED ON THE BASIS OF DEFORMED WOODS–SAXON POTENTIAL WITH VARIABLE SURFACE DIFFUSENESS

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Potential energy surfaces in $(\beta,\gamma)$ coordinates and equilibrium ground-state deformations of nuclei with $50 \leq A \leq 240$ are calculated using a simple model based on the Mottelson–Nilsson approach where the potential energy of deformation is taken as a sum of occupied levels in an ellipsoidally deformed one-particle potential well. Parameters of the real part of the global optical potential [1] evaluated at the Fermi surface are taken as the initial undeformed spherical Woods–Saxon potential. In the course of deformation the thickness of the diffuse surface layer in the direction of the normal to the surface is kept constant by the requirement that the gradient of the form-factor is independent on the angular variables. The enclosed volume of the deformed potential is equal to the volume of the initial spherical case. It was found, however, that in order to adequately describe experimental data the diffuseness parameter of the potential had to be adjusted with a small correction factor less than 1\%, represented as a function of the deformation parameters $\beta$ and $\gamma$. Such correction can serve as an indirect way of inclusion of residual interaction in the model, selecting the correct local minimum of the potential energy. Connection between the diffuseness parameter and the value of the surface energy is demonstrated on the example of spherical and deformed nuclei. The pairing effect is taken into account using the BCS model.

Predicted deformations of about 100 isotopes are compared with the nuclear deformation database [2], based on experimental compilation of static electric quadrupole moments [3], and with other theoretical calculations.

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# SELF-CONSISTENT STUDY OF NUCLEAR CHARGE RADII IN Ca REGION

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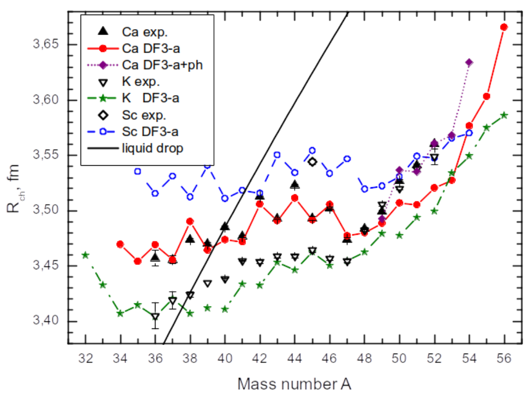
Fully self-consistent study of the charge radii in the long chains of the Ar to Sc isotopes is presented. The neutron-deficient and neutron-rich nuclei with pairing in both neutron and proton sectors, as well as the (semi-) magic nuclei around the closed neutron shells at N=20, 28, 32 are treated within the Energy Density Functional (EDF) approach with the Fayans functional DF3-a [1]. A comparison with its new options is done, namely Fy(stand) and more recent Fy(Δr,HFB) [2].
The performance of the DF3-a is analysed in describing both absolute radii and OES effects found in the CERN-ISOLDE experiments for $^{36-52}$Ca [3] and $^{36-52}$K [4] isotopes (Figs.1,2). In addition to a large-scale parametric fitting of the Fayans EDF suggested in [2], a new physics related to a higher power density gradient terms in its surface and pairing parts is of importance. A self-consistent account for the A-dependent fluctuating contribution due to the quasiparticle-phonon coupling explained strong increase of the radii at N>28 in Ca isotopes [5]. It is expected to be responsible for observed local anomalies in isotopic dependence of the absolute radii [3,4].
Supported by the grant of Russian Scientific Foundation (RSF 21-12-00061).



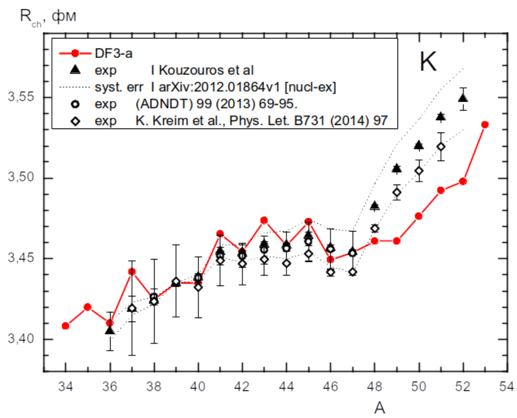




Figure 1: The charge radii of K, Ca, Sc isotopes calculated within the DF3-a functional compared to the data [3,4] and calculations[5]. For Ca isotopes, the DF3-a calculation with phonon corrections is shown.
Figure 2: The charge radii of K isotopes calculated within the DF3-a functional with the gradient paring term compared to the data [3,4].

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# STABILITY OF LIGHT EXOTIC Λ-HYPERNUCLEI WITH UNSTABLE CORES

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In strangeness nuclear physics, exotic hypernuclei with a proton or neutron excess are of particular interest now [1]. Such systems loosely studied experimentally so far can be produced in heavy ion collisions [2] at NICA complex developed at JINR. Properties of exotic hypernuclei can bring new knowledge on subtle features of the hyperon-nucleon and hyperon-nucleus interactions. Specifically, density dependence of the ΛN interaction, ability of the hyperon to distort the nuclear core, charge symmetry breaking ΛN interaction can be investigated [3].

Due to the glue-like role of the Λ hyperon, there is a chance to stabilize systems with unstable nuclear cores. Particularly, we test the possibility of the 9ΛC hypernucleus to be bound. We use the Skyrme-Hartree-Fock approach, which has been widely and successfully applied to Λ hypernuclei including the light ones (e.g., [4,5]) and carefully examine various Skyrme potentials known from the literature. We predict that $^{9}$C with extreme Z/N=3 (impossible in nonstrange nuclei) is bound. We study also the stability of exotic boron, nitrogen and oxygen hyperisotopes.

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# FROM QUARK AND NUCLEON CORRELATIONS TO NUCEAR DRIP LINE

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We propose a quark model of nuclear structure, where quark correlations lead to nucleon–nucleon correlaions and arrangement of them into lattice–like structure.
The model is based on the quark model of nucleon structure, Strongly Correlated Quark Model (SCQM), in which valence quarks are strongly correlated within a nucleon. Nuclei are constructed due to junctions of SU(3) color fields of quarks of neighbor nucleons [1]. At any junction two quarks should be of different color (r,g,b), different flavor (u,d), and have parallel spins.
Application of the model to larger collections of nucleons reveals the emergence of the face-centered cubic (FCC) symmetry at a nuclear level where nucleons are arranged in alternating spin–isospin layers [2]. The model of nuclear structure becomes isomorphic to the shell model and, moreover, composes the features of the liquid drop and cluster models. Binding of nucleons in stable nuclei are provided by quark loops which form three and four nucleon correlations. On a quark level the nuclear shell closures correspond to the octahedral or truncated tetrahedral symmetry. Thus all nuclei even with closed shells are non-spherically symmetric. The quark loop that can be identified with three nucleon force results in a pairing "effect andhalo" nuclei. And namely quark loops leading to four-nucleon correlations are responsible for the binding energy enhancement in even-even nuclei which are formed by virtual alpha-clusters. Closure of a subsequent shells (*p-, d-, f-, …*) rearranges the previous shells (*s-, p-, d-, f-, …*) in such a way, that nucleons of the previous shell become the common ones for neighbour virtual alpha-clusters. At the same time, the common nucleons become binding between pairs of virtual alpha-clusters [3]. According to the model For medium and heavy nuclei the arrangement of nucleons is modified by Coulomb repulsion of protons. This effect together with quark/nucleon correlations leads to deviation from the shell model expectations. The model can predict the boundary of the maximal numbers of proton and neutron excess, i.e. proton and neutron drip lines.

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# MICROSCOPIC THEORY OF PYGMY- AND GIANT RESONANCES: ACCOUNTING FOR COMPLEX 1P1H⊗PHONON AND TWO-PHONON CONFIGURATIONS

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The self-consistent Theory of Finite Fermi Systems (TFFS) [1,2] is consistently generalized for the case of accounting for phonon coupling (PC) effects in the energy region of pygmy- and giant multipole resonances (PDR and GMR) in magic nuclei with the aim to consider particle-hole (ph) and both complex 1p1h⊗phonon and two-phonon configurations. The article is the direct continuation and generalization of the previous article [3], where 1p1h- and only complex 1p1h⊗phonon configurations were considered. The newest equation for the TFFS main quantity, the effective field (vertex), which describes the nuclear polarizability, has been obtained. It has considerably generalized the results of the previous article and accounts for two-phonon configurations. Two variants of the newest vertex equation have been derived: (1) the first variant contains complex 1p1h⊗phonon configurations and the full 1p1h-interaction amplitude Γ instead of the known effective interaction F in [3], (2) the second one contains both 1p1h⊗phonon and two-phonon configurations. Both variants contain new, as compared to usual approaches, PC contributions, which are of interest in the energy region under consideration and, at least, should result in a redistribution of the PDR and GMR strength, which is important for the explanation of the PDR and GMR fine structure. The qualitative analysis and discussion of the new terms and the comparison to the known time-blocking approximation are performed.

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# THE ROLE OF SPIN-SPIN FORCES IN CALCULATIONS OF TRANSITION PROBABILITIES BETWEEN THE FIRST ONE-PHONON STATES.

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The self-consistent method for studying second-order anharmonic effects, within the framework of many-body quantum theory, is used for the first time to investigate the role of spin-spin forces in the probabilities of transitions between low-lying one-phonon states. Our approach includes accounting for: 1) self-consistency between the mean field and effective interaction based on the use of the energy density functional method with the proven parameters of Fayans functional DF3-a [1], 2) three-quasiparticle correlations in the ground state, 3) nuclear polarizability effects and 4) spin-spin interactions. E1-transitions between one-phonon 3-1 and 2+1 states in semimagic tin isotopes were studied. Good agreement with experiment [2] was obtained. It is shown that three-quasiparticle correlations in the ground state make a significant contribution to the value under study, as in our previous calculations for the EL transitions between first 3- and 2+ states in magic nuclei [3]. The specificity of this problem in nuclei with pairing and the effects of the spin components of the phonon creation amplitude are considered.

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# CONVERGENCE OF CALCULATIONS IN OSCILLATOR BASIS

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We study general convergence trends of binding energy calculations in oscillator basis depending on two basis parameters, the oscillator frequency, $\hbar\Omega$, and maximal oscillator quanta, $N$. We propose and test a new method which suggests extending the Hamiltonian matrix by the kinetic energy matrix elements. We study also convergence of calculations with smoothed potential matrix elements [1].

We use the SS-HORSE (single-state harmonic-oscillator representation of scattering equations) approach [2] extended to the case of bound states [3]. Within this method, we extract the $S$ matrix from the results of variational calculations with oscillator basis and locate the $S$-matrix poles associated with bound states. The respective binding energies improve the variational results and provide an extrapolation of the variational binding energies to the infinite basis space. A great advantage of our approach as compared with other extrapolation techniques suggested in current literature [4–6] is that it makes possible to calculate also asymptotic normalization constants.

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# LIMITING TEMPERATURE OF NUCLEI WITHIN EFFECTIVE RELATIVISTIC MEAN-FIELD THEORY

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The recent detection of the gravitational wave GW170817, accompanied by a $\gamma$-ray burst and electromagnetic afterglow from the merger of neutron-star binary, has opened a new era of nuclear astrophysics. With neutron stars as a predominant laboratory for testing infinite nuclear matter, it has become easy to fine-tune the equation of the state (EoS) of nuclear matter using observational constraints. The nuclear matter EoS is of utmost importance for calculating infinite matter properties besides giving reasonable input about finite nuclei. Understanding the ground state of nuclear matter is essential, but its behaviour at finite temperature is equally significant for various terrestrial and astrophysical processes such as multi-fragmentation in nucleus and supernova explosion [1]. The estimation of limiting temperature $T_l$ (the maximum temperature that a nucleus can sustain) of a nucleus is extremely important to extract relevant nuclear properties. The analysis of this limiting temperature helps to understand the qualitative behaviour of liquid-gas phase transition in an excited nucleus and astrophysical processes such as the structure of proto-neutron star and supernova explosion etc.

We have used the effective relativistic mean-field theory (E-RMF) to analyze the limiting temperature of the excited nucleus using several parameter sets which satisfy various observational constraint of EoS [2]. We add the Coulomb interaction and surface tension due to the finite size effect of the nucleus and solve the coexistence equation for phase equilibrium. Surface tension is a function of the critical temperature ($T_c$) of infinite matter [3], which is not a good constraint variable [4], unlike other infinite nuclear matter saturation properties. Therefore, we look for the possible correlation of the limiting temperature of nuclei with zero and critical temperature properties. These correlations might help to understand observables that could not be measured directly in experiments.

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# THERMAL SHIFT OF ATOMIC LEVELS IN HYDROGEN: INFLUENCE ON THE DETERMINATION OF THE PROTON RADIUS

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The Quantum Electrodynamics theory for bound states at finite temperatures is discussed. The details of theory can be found in [1] where the derivation of thermal photon propagator in different forms and gauges is presented. The constructed theory is used to find the "thermal Coulomb interaction" and its asymptotic at large distances. Finally, the thermal effects of the lowest order in the fine structure constant and temperature are discussed in detail. Such effects are represented by the thermal one-photon exchange between a bound electron and the nucleus, thermal one-loop self-energy, thermal vacuum polarization, and recoil corrections and that for the finite size of the nucleus. As a result, the influence of thermal effects on the finding the proton radius and Rydberg constant from the hydrogen spectroscopy experiments is discussed.

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# SELF-CONSISTENT CALCULATIONS OF THE GROUND STATE AND β–DECAY PROPERTIES IN C, N, O REGION.

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Including the light neutron-rich nuclei to the r-process network is known to change the resulting heavy element abundances [1]. However, large-scale predictions of input data, in particular the β–decay rates are usualy obtained in the HF+BCS Quasiparticle Random Phase (QRPA) approximations. In case of the light neutron-rich nuclei they have to be taken with some care. In loosely bound isotopes close to the particle continuum in which a weak pairing approximation does not work, the cluster effects dominate [2].
The applicability limit of self-consistent description of the beta-decay properties using iterative HF+BCS for the ground state and continuum pnQRPA [3] is carefully checked for very neutron-rich C, N, O nuclei around the neutron shells at N=8,16 and compared with relativistic RHB+RQRPA [4] and FRDM+RPA [5] frameworks.
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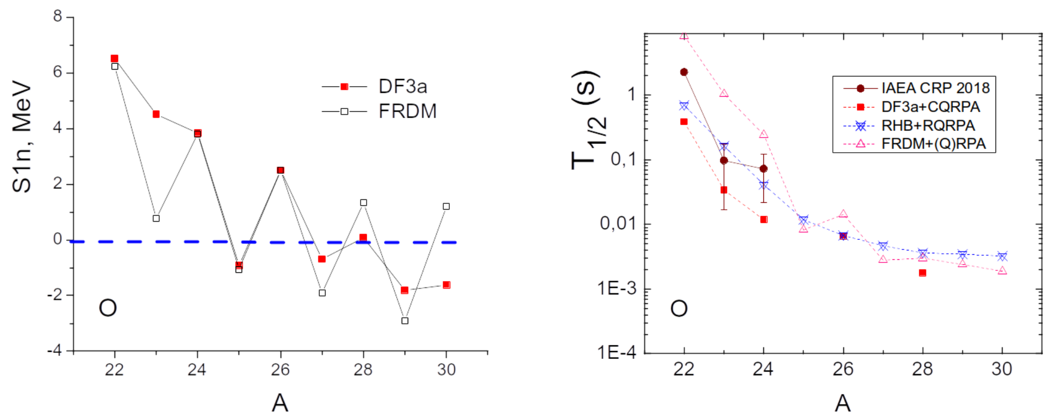


Figure 1: The $S_{xn}$-values within the DF3a functional and FRDM in $^{22-30}O$ isotopes.
Figure 2: The $T_{1/2}$ and total Pn-values calculated from DF3a+CQRPA and RHB+RQRPA in O isotopic chain compared with AME-2020.

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# BINDING ENERGIES OF LIGHT HYPERNUCLEI

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Light hypernuclei are a natural laboratory for studying $YN$ and $YY$ interactions [1]. The repulsive nature of the $\Lambda N$ interaction leads to the fact that bound states in light nuclei are generated due to the $N - Y - N$ interaction. The decisive role in this interaction is played by the $\Lambda N \rightarrow \Sigma N$ conversion of one type of hyperons into another. Experimental data on hyperon separation energies $B_\Lambda[^4_\Lambda\mathrm{He}(0^+)]$-$B_\Lambda[^4_\Lambda\mathrm{H}(0^+)]$=$+0.35$ MeV from ground states of $^4_\Lambda$He, $^4_\Lambda$H hypernuclei also shows the charge dependence of $YN$ interactions [2]. In this work, the binding energies of light hypernuclei are obtained by solving the homogeneous Faddeev and Faddeev-Yakubovsky intergral equations for 3 and 4 particles in phase space with model $YN$ and realistic $NN$ interactions. The main attention is paid to the comparison of the counting tactic based on the partial-wave expansion [3] of the matrix elements of the transition operators with given separable potentials, and counting tactic [4] that allows direct integration of the matrix elements in a few-body phase space with given local potentials. The procedure [4] for searching T-matrix for three-bodies of different masses without partial-wave expansion is generalized. Direct calculations have confirmed a good agreement between the two methods for calculations the hyperon separation energies in the lightest hypernuclei. The influence of higher partial waves of realistic separable potentials, its charge dependence, and the accuracy of the procedure for solving the Lippman-Schwinger equation by the Noyes-Kowalski method for given local potentials are also discussed.

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# STUDY OF NEUTRON DECAY CHANNELS OF LIGHT NEUTRON-EXCESS NUCLEI USING AB INITIO METHODS

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In recent decades, research related to low-energy nuclear physics has shown two basic trends. In experimental research, there has been a rapid transition from the study of stable and long-lived nuclei to the study of exotic, including nucleon-unstable systems. In theoretical research, an increasing place is occupied by high-precision microscopic approaches, in particular ab initio (from first principles) methods of describing nuclear systems.
The energy levels of light exotic nuclei are the subject of a large number of the investigation of such a type. Usually ab initio approaches are based on the use of NCSM model together with realistic nucleon-nucleon potentials. The problem of ab initio studies of nucleon- or cluster-decay properties of the states of nuclei looks more complicated. A number of methods to solve it are presented in literature [1-3] but they all have rather narrow ranges of applicability.
Being motivated by that we developed [4-7] a new theoretical scheme adopted for investigating of the decay properties of light nuclei and successfully applied it for the study of the energy levels and decay properties of $^{7}$Li and $^{8}$Be nuclei. A rather good description of the experimental data was achieved. The properties of a number of states which have not been observed were predicted.
In the present talk an advanced version of the method and the results of study of the spectra and neutron decay channels characteristics of unstable neutron-excess nuclei $^{7}$He and $^{10}$Li are presented. The predictions have been made may serve as a theoretical support of modern experiments which are performed at FLNR JINR.

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# LARGE-SCALE CALCULATION OF NUCLEAR GROUND-STATE PROPERTIES

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Presently, the nuclear energy density functional theory is known as the most convenient and powerful theoretical tool for the calculation of the properties of nuclei throughout the nuclear chart. In this work, large-scale calculations are performed using the self-consistent Hartree-Fock-Bogoliubov method [1-2] for even-even nuclei between $8 \leq Z \leq 114$. The Skyrme-type functionals are used in the particle-hole channel of the calculations, and zero-range density-dependent pairing force of the surface, mixed, and volume type are employed in the particle-particle channel. Binding energies, two-particle separation energies, charge radii, deformation, and neutron skin thickness properties of nuclei are studied and compared with the available experimental data. The impact of the usage of the different types of pairing forces on the properties of nuclei and location of the particle drip lines are also studied.

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# AN ALTERNATE WAY FOR CALCULATING THE DEUTERON FORM FACTORS

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Let us remind that in the one-photon-exchange approximation (OPEA) the elastic e-d scattering amplitude is proportional to the contraction $T(ed \to e'd') = \varepsilon_\mu(e,e')\langle \mathbf{q}\, M'|J^\mu(0)|\mathbf{0}\, M\rangle$ where we have introduced the notation $\varepsilon_\mu(e,e') = \bar{u}_{e'}(k')\gamma_\mu u_e(k)$. Here the operator $J^\mu(0)$ is the Nöther current density $J^\mu(x)$ at the point $x = (t, \mathbf{x}) = 0$, sandwiched between the eigenstates of a "strong" field Hamiltonian $H$, viz., the deuteron states $|\mathbf{P}, M\rangle$. These states meet the eigenstate equation $P^\mu|\mathbf{P}, M\rangle = P_d^\mu|\mathbf{P}, M\rangle$ with $P_d^\mu = (E_d, \mathbf{P})$, $E_d = \sqrt{\mathbf{P}^2 + m_d^2}$, $m_d = m_p + m_n - \varepsilon_d$, the deuteron binding energy $\varepsilon_d > 0$ and eigenvalues $M = (\pm 1, 0)$ of the third component of the total (field) angular-momentum operator in the deuteron center-of-mass (details in [1]). Further, $u_e(k)$ $(u_e'(k'))$ the Dirac spinor for incident (scattered) electron. In its general form, relativistic deuteron electromagnetic current $\langle \mathbf{q}\, M'|J^\mu(0)|\mathbf{0}\, M\rangle$ can be expressed (see, e.g., survey [2]) through the charge monopole ($G_C$), magnetic dipole ($G_M$) and charge quadrupole ($G_Q$) form factors (FFs) of the deuteron. Such static quantities as the deuteron charge $e_d$, its magnetic moment $\mu_d$ and quadrupole moment $Q_d$ are given by $e_d = G_C(0)\, e$, $\mu_d = G_M(0)\, e/2m_d$, $Q_d = G_Q(0)\, e/m_d^2$. Other our contribution is devoted to a fresh field-theoretical calculation of these moments. In parallel, for our attempts to ensure gauge independent treatment of similar electromagnetic (EM) processes we prefer to employ a generalization [3] of the Siegert theorem, in which the amplitude of interest is given by
$T(ed \to e'd') = [\omega\varepsilon(e', e) - \mathbf{q}\varepsilon_0(e', e)]\, \mathbf{D}(\mathbf{q}) + [\mathbf{q} \times \varepsilon(e', e)]\, \mathbf{M}(\mathbf{q})$ with the so-called generalized electric

$$\mathbf{D}(\mathbf{q}) = -i\omega^{-1} \int_0^1 \frac{d\lambda}{\lambda} \nabla_\mathbf{q} \left\{ \left[ \sqrt{\lambda^2 \mathbf{q}^2 + m_d^2} - m_d \right] \langle \lambda\mathbf{q}; M'|\rho(0)|\mathbf{0}; M\rangle \right\}$$

and magnetic

$$\mathbf{M}(\mathbf{q}) = -i \int_0^1 d\lambda \nabla_\mathbf{q} \times \langle \lambda\mathbf{q}; M'|\mathbf{J}(0)|\mathbf{0}; M\rangle$$

dipole moments. We will show the links between the deuteron FFs and these quantities. In addition, to be more constructive we consider the following expansion for the "clothed" current operator
$J^\mu(0) = W J_c^\mu(0) W^\dagger = J_c^\mu(0) + [R, J_c^\mu(0)] + \frac{1}{2}[R, [R, J_c^\mu(0)]] + ...,$
in the $R$-commutators (see Eq. (13) in [3]), where $J_c^\mu(0)$ is the initial current operator in which the bare operators $\{\alpha\}$ are replaced by the clothed ones $\{\alpha_c\}$ and $W = \exp R$ the corresponding unitary clothing transformation. This decomposition involves one-body, two-body and more complicated interaction currents. In case of the deuteron whose states belong to the clothed two-nucleon sector, our consideration leads to division $J^\mu(0) = J^\mu_{one-body} + J^\mu_{two-body}$. The operator $J^\mu_{two-body}$ is analogue of the meson exchange current in the conventional theory. Special attention is paid to finding such contributions to the deuteron form factors.

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# SPECTROSCOPY OF HEAVY HELIUM ISOTOPE $^{9}$He IN REACTIONS OF STOPPED PION ABSORPTION

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The unbound heavy helium isotope $^{9}$He has one of the largest neutron-to-proton ratios. In spite of a significant number of experimental and theoretical works, the problem of the spectroscopy of $^{9}$He remains open [1, 2]. Even for the ground state, there is uncertainty in determining the resonance energy and spin-parity ($1^-$ or $1^+$). The situation with the excited states of $^{9}$He is also uncertain. The results obtained in different studies differ more strongly than the given measurement errors. One of the reasons for this discrepancy is poor statistics. Highly excited ($E_x$ ~ 7 MeV) states were observed only in two works [3, 4]. In this work, the study of $^{9}$He spectroscopy is carried out on the basis of a joint analysis of the results obtained in three absorption reactions of stopped pions: $^{11}$B($\pi^-$,*pp)X*, $^{14}$C($\pi^-$, $p^4$He*)X* and $^{14}$C($\pi^-$, $d^3$He*)X*. The experiment was taken at low energy pion channel of LANL with two-arm multilayer semiconductor spectrometer. In these measurements missing mass resolution was 1 MeV for $^{11}$B target and 3 MeV for $^{14}$C target.

The advantages of using this method are the ability to study a wide range of excitation energies (up to 30 MeV) with sufficiently high statistics, which was previously demonstrated by us for $^{6\text{-}8}$He isotopes [5-7]. Reaction ($\pi^-$,*pp)* has a pronounced selectivity: the yield of the ground state of the residue is strongly suppressed [7].

The *s*-wave resonance in $^{9}$He just above threshold is not observed in all three reactions. The position of the lowest-lying state ($E_r$ =1.3(3) MeV) is consistent with the results of most other measurements [1, 2]. For the first time highly excited states are observed in following reactions: $^{11}$B($\pi^-$,*pp)X* ($E_r$ =10.5(2) MeV and $\Gamma$ = 1.5(5) MeV) and $^{14}$C($\pi^-$, $p^4$He*)X* ($E_x \approx$ 12.5 MeV and $\Gamma \approx$1.5 MeV).

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# SEARCH FOR CLUSTER STATES IN $^{13}$C

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$^{13}$C is a good example of a "normal" nucleus that is well described in the framework of the shell model. Its level scheme is reliably determined up to excitation energies ~ 10 MeV. However, not so long ago, in the framework of the development of the theory of the α-condensation in light nuclei (αBEC), the existence of exotic cluster states in light nuclei with a significantly increased, by 40-70%, size was announced. One of the most likely candidates was the Hoyle state ($0_2^+$, $E$ = 7.65 MeV) in $^{12}$C. It was expected that analogues of the Hoyle state would appear in some neighboring nuclei, for example, the 1/2$^-$ ($E$ = 8.86 MeV) state of $^{13}$C. This was successfully shown by the the Modified Diffraction Model (MDM) method, but obtained radius was much smaller than that predicted by the αBEC theory.
However, some open questions remain regarding the structure of low-lying $^{13}$C states. This leads to increased attention to $^{13}$C so far.
In 2014, our group announced the discovery of a state of $^{13}$C with an abnormally small radius. In the framework of the MDM method, when analyzing data on α-scattering on $^{13}$C at energies of 65 and 90 MeV, it was shown that this state has a radius reduced by 10%. At the same time, in the works of theoreticians dilute structure and increased radius were predicted for this state, and in part of the works, assumptions were made about the rotational structure of this state and the possibility of the formation of a rotational band on it.
Another important question is the search for possible analogues of the Hoyle state in $^{13}$C in highly excited states. At present confirmed analog of the Hoyle state is 1/2$^-$ (8.86 MeV) state in $^{13}$C. Other possible candidate is the state 1/2$^-$ 11.08 MeV. Increased radius close to the radius of the state of 8.86 MeV $^{13}$C was obtained within MDM method analysis. However, this result was obtained only at one energy, on the applicability boundary of the MDM method.
Moreover, the presence of a rotational band based on the Hoyle state in $^{12}$C was confirmed. A reasonable question arises about the existence of rotational bands on analogues of the Hoyle state in $^{13}$C. In [1] a hypothesis was put forward about a new type of symmetry in the $^{13}$C structure - D'$_{3h}$ symmetry. Earlier in the work of the same team of authors, a similar type of D$_{3h}$ symmetry was predicted for the $^{12}$C nucleus. On the basis of D'$_{3h}$ symmetry, the rotational nature of a whole group of low-lying $^{13}$C states was predicted. If this hypothesis is confirmed, our understanding about the $^{13}$C structure will radically change. In the work, 6 rotational bands were proposed, that is, almost all low-lying $^{13}$C states were distributed among the rotational bands.
Thus, a critical analysis of the available data is required to answer the question about the nature of low-lying excited $^{13}$C states.

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# HYPER-RADIAL ASYMPTOTIC OF THE WAVE FUNCTION OF THREE PARTICLES WITH COULOMB INTERACTION IN THE CONTINUUM

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The asymptotic form of the wave function of a three-particle system interacting via Coulomb potentials in the continuum is described. The hyperradial asymptotic behavior of the wave function is found by study the weak asymptotic of the three-body wave function [1,2] and then applying to the asymptotic solutions of the Schroedinger equation in the hyper-spherical representation. The perspective of applications to the analysis of the few nucleon system is discussed.

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# SPECTRAL DENSITY FOR A DISCRETIZED CONTINUUM

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Different approaches which employ discretization of continuum, for example, by projecting the operators and wave functions into some finite $L_2$ basis, are widely used nowadays as efficient techniques to solve the scattering problems. Here we discuss how to extract information about scattering from the discretized spectra of unperturbed and total Hamiltonians. It is shown that if the discrete eigenvalues $E_j$ lie on some smooth curve $\lambda(x)$ (i.e. $E_j = \lambda(x = j)$) then one can construct a smooth integrated spectral density (ISD) for the corresponding Hamiltonian by using the inverse function. The difference of ISDs for the total and unperturbed Hamiltonians gives the spectral shift function which is proportional to the scattering phase shift. Also, one can define separate spectral densities for the Hamiltonians as derivatives of the above ISDs. Although each spectral density doesn't correspond to the initial continuous spectrum and depends on the way of the discretization, the difference of these densities for the total and unperturbed Hamiltonians does define a proper continuum level density (CLD) for the initial problem in question. In particular, this CLD can be used to find resonances in the system. Thus, a rather simple treatment of discretized spectra of unperturbed and total Hamiltonians allows to find scattering observables in a wide energy region without solving scattering theory equations.

The approach represents a generalization of the discrete spectral shift method [1,2] developed by the authors previously. As illustrations, we consider several examples from atomic and nuclear physics, including p-$^{12}$C scattering, by using the Gaussian basis representation. Also, relations between the suggested method and the known approaches, such as the SS-HORSE [3] and the $R$-matrix, are discussed.

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# OPTIMAL BOUNDS ON THE QUANTUM SPEED OF SUBSPACE EVOLUTION

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By a quantum speed limit one usually understands an estimate on how fast a quantum system can evolve between two distinguishable states. The most known quantum speed limit is known in the form of the celebrated Mandelstam-Tamm inequality that bounds the speed of the evolution of a state in terms of its energy dispersion. In contrast to the basic Mandelstam-Tamm inequality, we are concerned not with a single state but with a (possibly infinite-dimensional) subspace which is subject to the Schr\"odinger evolution. By using the concept of maximal angle between subspaces we derive optimal bounds on the speed of such a subspace evolution. These bounds may be viewed as further generalizations of the Mandelstam-Tamm inequality. In the present work we extend some of our previous results [1] to the case of unbounded Hamiltonians.

This is a joint work with Sergio Albeverio.

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# DETERMINATION OF ASYMPTOTIC NORMALIZATION COEFFICIENTS BY ANALYTIC CONTINUATION OF DIFFERENTIAL CROSS SECTIONS

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Asymptotic normalization coefficients (ANC) are fundamental nuclear characteristics important both in nuclear reaction and nuclear structure physics. The role of ANCs is especially substantial in determining the cross sections for astrophysical nuclear reactions inaccessible for direct measurement due to the large Coulomb barrier [1]. ANCs are on-shell observables, as distinct from the spectroscopic factors which are off-shell quantities and cannot be reliably extracted from experimental data.

In the present work, we discuss the possibility of determining ANCs by analytic continuation of the differential cross sections of transfer reactions to the pole point in the scattering angle $\theta$ lying in the unphysical region $\cos\theta > 1$. Special attention is paid to the corrections to the pole contribution to the differential cross section due to the Coulomb interaction in the initial and final states of the reaction (see [2] and references therein). The role is discussed of kinematic singularities arising in the case of nonzero orbital angular momenta at the vertices of the pole diagram, which determines the transfer mechanism. The discussed method was applied to the reaction $^{12}\mathrm{C}(d,p)^{13}\mathrm{C}^*\ (1/2^+; 3.09\mathrm{MeV})$. Five experimental differential cross sections corresponding to the deuteron energy in the range of $5-30\mathrm{MeV}$ were used to determine the important ANC $C$ for the vertex $^{13}\mathrm{C}^* \to {}^{12}\mathrm{C} + n$ by analytic continuation. The $C$ values obtained from the analysis of the $(d,p)$ reaction at different energies turned out to be close to each other. The average value of the squared ANC obtained by the method of analytic continuation with account of the Coulomb corrections is $C^2 = 3.52\mathrm{fm}^{-1}$.

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# THEORETICAL STUDY OF WEAKLY-BOUND TRIATOMIC SYSTEMS WITH DISCRETE VARIABLE REPRESENTATION METHOD

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The interest to weakly-bound triatomic systems is stimulated by their connection with Efimov physics. There is a variety of systems including helium and helium-alkali triatomic molecules [1] whose states are close to Efimov regime. Some of these systems have bound states with nonzero orbital momentum. These latter states are much less studied than the states with the zero angular momentum.

Another interesting problem is connected with possible resonance states of systems under discussion. Study of resonance states is an interesting area of few-body quantum physics [2]. Resonance states are usually associated with the poles of the analytic continuation of the resolvent or $S$-matrix. There exist various methods of their calculations. In this work, the complex rotation method [3] is used.

Both above mentioned problems result in additional computational complexity, so a computationally effective approach is required. To speed up calculations, we use the discrete variables representation [4] based on the basis of functions, which are in some way localized on the grid in the angular space. The method has been generalized to complex functions to make it applicable to calculation of resonance states.

In this report, the bound and resonance energies of few weakly-bound triatomic systems including $He_2Li$ and $He_2Na$ have been calculated with the variational approach and the DVR expansion. The results are compared with results of other authors.

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# STUDY OF LIGHT NUCLEI WITHIN THE SS-HORSE-NCSM APPROACH

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We present investigations of resonant states of exotic $^7$He nucleus and calculations of bound states and resonances of $^9$Li nucleus. Our results are obtained within an analysis of the $S$-matrix based on calculations within the no-core shell model (SS-HORSE-NCSM approach [1, 2]) using the realistic nucleon-nucleon interaction Daejeon16 [3].

Results for the $5/2^-$ and low-lying $3/2^-$ resonances in $^7$He are in reasonable agreement with experiment. There is a contradictory experimental information about energy and width of the $1/2^-$ resonance in $^7$He. In our calculations, the energy $E_r$ of this resonance is 2.7 MeV and the width $\Gamma$ is about 4 MeV. We predict in $^7$He also wide overlapping resonances $3/2^-$, $3/2^+$ and $5/2^+$ with energies around 4-5 MeV which are supposed to form an experimentally observed wide resonance at 6 MeV of unknown spin-parity.

The binding energy of the $^9$Li ground state is in reasonable agreement with experimental data. The calculated excitation energy of the first exited state of $^9$Li is 3.54 MeV which is larger than the experimental value of 2.691 MeV. We predict in our approach also the asymptotic normalization coefficients for these bound states. Experimentally there are $^9$Li resonances of unknown spin-parity with $E_r = 0.232$ MeV and $\Gamma = 0.1$ MeV and $E_r = 1.316$ MeV and $\Gamma = 0.6$ MeV; we obtain $^9$Li resonant states $5/2^-$ ($E_r = 0.27$ MeV, $\Gamma = 0.21$ MeV) and $3/2^-$ ($E_r = 1.53$ MeV, $\Gamma = 2.39$ MeV).

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# DIRECT CALCULATION OF QUASI-STATIONARY STATES OF THE NEUTRON PLUS NONSPHERICAL NUCLEUS SYSTEM.

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The states of the $Be^{11}$ nucleus as a core of $Be^{10}$ plus a neutron are studied in [1, 2], as well as many others. The $Be^{10}$ nucleus is an almost ideal object for studying the effects associated with the non-spherical shape of the nucleus. It has the largest deformation parameter for stable and long-lived nuclei. Usually the coupled channel method is used, the problem is reduced to a system of equations in a spherical symmetric field. In this work the method of direct solution of scattering by an axially symmetric potential has been used. Resonances in scattering, which are obviously also quasi-stationary states, have been calculated.

The differences arising from these two approaches are shown. The main effect is the nature of the resonances. Resonances are the result of the interaction of a nuclear potential and an analogue of a centrifugal potential. This follows from a direct calculation using the axial symmetry of the problem. The resonances here are equivalent to the states of a complex nucleus, which is a neutron and a deformed core.

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# THREE-BODY SCATTERING IN THE TOTAL ANGULAR MOMENTUM REPRESENTATION

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Scattering problem for three-body systems is of great importance for many areas of physics. The complicated boundary conditions at large distances, especially for Coulomb potentials, are a major difficulty for studying of this problem [1]. While several methods have been developed for the solution to this problem, mathematically sound and computationally effective approaches are still in demand.

In this report, we present an approach based on splitting the reaction potential into a short-range part and a long range tail part to describe few-body scattering in the case of the Coulomb interaction [2,3]. The solution to the Schroedinger equation for the long range tail of the reaction potential is used as an incoming wave. This reformulation of the scattering problem into an inhomogeneous equation with asymptotic outgoing waves makes it suitable for solving with the exterior complex scaling technique. The potential splitting approach is illustrated with calculations of scattering processes in systems with non-zero angular momentum. The accuracy of the approach is analyzed.

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# INCOMING WAVE BONDARY CONDITIONS IN SUB-BARRIER HEAVY ION FUSION REACTIONS

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We analyze sub-barrier heavy ion fusion reactions based on the coupled-channels description with the correct incoming wave boundary conditions, implemented by means of the finite element method. With the aid of the Woods-Saxon potential the experimental cross sections and the so-called S factors of these reactions are remarkably well reproduced within the sudden approximation approach with the correct incoming wave boundary conditions. We found that accounting for the nondiagonal matrix elements of the coupling matrix, traditionally neglected in the conventional coupled-channels approaches in setting the entangled left boundary conditions inside the potential pocket, and its minimal value are crucially important for the interpretation of experimental data.

# NEW INSIGHTS INTO NUCLEAR PHYSICS AND WEAK MIXING ANGLE USING ELECTROWEAK PROBES

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In this talk, we will present the first measurement of the neutron skin of cesium and iodine using electroweak probes, coherent elastic neutrino-nucleus scattering and atomic parity violation. This measurement, differently from hadronic probes, is model-independent and suggests a preference for nuclear models which predict large neutron skin values, with implications that range from neutron stars to heavy-ion collisions.

Moreover, we will show a new determination of the low-energy weak mixing angle, with a percent uncertainty, fully determined from electroweak processes and independent of the neutron radius of cesium, allowed to vary in the fit. This will permit to put reliable constraints to theories beyond the standard model.

# PAIRING ENERGIES OF ODD ACTINIDE NUCLEI IN FIXED QUANTUM STATES

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The pairing energies (PE) of nonmagic atomic nuclei with $A \geq 50$ can be derived from the odd nuclei masses $M$ provided it is possible to present $M$ as a sum of two terms [1]:
1) a smooth function of nucleon numbers having the same form of Tailor series expansion for even-even and odd nuclei;
2) PE: $P_n(N', Z)$ and $P_p(N, Z')$, where $N\,(N')$ and $Z\,(Z')$ denote even (odd) numbers of neutrons and protons and indices $n(p)$ refer to neutron (proton) PE.

Traditionally the masses of two adjacent odd nuclei is used for calculations of PE and this procedure smoothes out the influence of the state of odd nucleon on PE. To overcome this problem, we have proposed [2] the expression for PE, which includes only one odd nucleon mass. This expression is based on the assumptions 1), 2) and Taylor series expansion of mass surface up to the third order in the number of nucleons. For example,

$$P_n(N', Z) = M(N', Z) - \frac{9}{16}\left[M(N'+1, Z) + M(N'-1, Z)\right] + \\ + \frac{1}{16}\left[M(N'+3, Z) + M(N'-3, Z)\right]$$

The results of calculations of pairing energies of deformed U(Z $= 92$) and Pu(Z $= 94$) actinide nuclei with Nilsson quantum numbers $K^\pi\,[Nn_z\lambda]$ of odd neutron quasiparticles are given in the Table. The masses of nuclei are taken from Atomic Mass Evaluation - AME2020 [3]. The results obtained confirm our conclusion about the dependence of PE on the state of an odd nucleon.

| $N'$ | $Z$ | $P_n$, keV | $K^\pi\,[Nn_z\lambda]$ neutrons | $N'$ | $Z$ | $P_n$, keV | $K^\pi\,[Nn_z\lambda]$ neutrons |
|---|---|---|---|---|---|---|---|
| 141 | 92 | 573 | $5/2^+[633]$ | 143 | 94 | 564 | $7/2^-[743]$ |
| 143 | 92 | 626 | $7/2^-[743]$ | 145 | 94 | 520 | $1/2^+[631]$ |
| 145 | 92 | 578 | $1/2^+[631]$ | 147 | 94 | 551 | $5/2^+[622]$ |
| 147 | 92 | 574 | $5/2^+[622]$ | 149 | 94 | 454 | $7/2^+[624]$ |

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# NUCLEAR RADII SYSTEMATICS BASED ON AN ARTIFICIAL NEURAL NETWORK WITH FUZZY LOGIC

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This paper develops the first experience of using a fuzzy hybrid network model for the systematics of nuclear radii [1]. The root-mean-square charge radii of atomic nuclei measured by different methods are collected in the NuRa database [2]. A good result for the radii of all nuclei is given by the parametrization (the smooth curve in Fig.1).)
$R = (r_0 + r_1 A^{1/3}) \cdot A^{1/3}$ , if $r_0 = 1.07$ fm, $r_1 = -0.0236$ fm.
In the hybrid model, all nuclei were divided into four groups: light (Z≤17), medium (18≤Z≤31), medium-heavy (32≤Z≤51), and heavy nuclei (Z≥52). Parameters of the hybrid network were separately defined in each group of nuclei. After combining, they created a single model for describing the radii of all nuclei, which was the basis for systematics.
Figure 1 shows how the hybrid model (polyline) describes the experimental data (black circles) in the group of light nuclei. The model reproduces jumps and characteristic fractures in the mass dependence of radii in isotopic chains. When the domain of definition is expanded by $A$ and $Z$, the model errors increase dramatically [1]. Further development of the model is associated with the attraction of additional information about the nuclear binding energy and deformation.

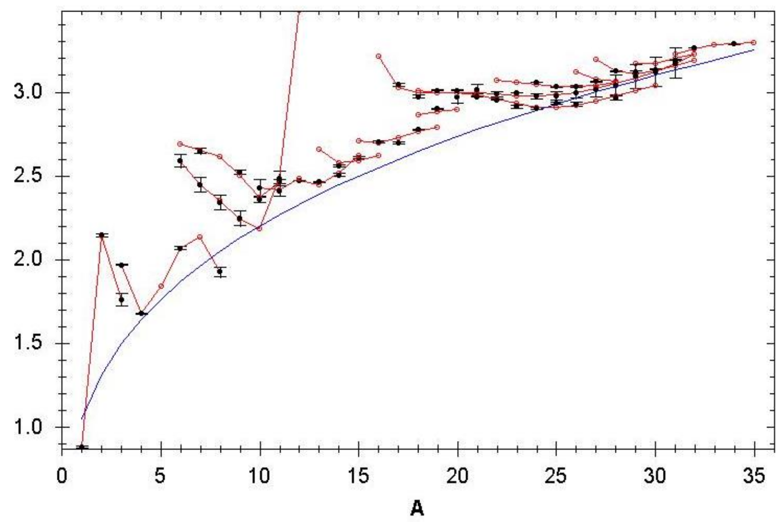


Figure 1: The root-mean-square charge radii of light nuclei with Z≤17.

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# EXPERIMENTAL STUDY OF HALO IN ISOBAR-ANALOG STATES

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One of the most striking discoveries in nuclear physics made at the end of the last century was the discovery of the neutron halo in the ground states of some light nuclei located near the neutron stability boundary.
The discovery of the halo led to a revision of many existing ideas in nuclear physics. The purpose of this research is to search and study halo in isobar - analog states of light nuclei. The study of states with a halo in isobar analogs allows one to investigate the manifestation of isotopic invariance at new objects and to relate the properties of the neutron and proton halo. The question of the existence of halo in isobar - analog states has so far not been practically raised in the experimental plan.
The proposed approach is based on measuring the radii of states in which the halo exists or can exist. Its first application made it possible to determine the proton halo in an unbound state of $^{13}$N. Isobaric invariance leads to the fact that the states of two neighboring nuclei obtained by replacing a neutron with a proton are analogous, i.e. have in the first approximation the same structure. In the case of isobar analogs having a halo, the situation is more complicated, since such a change leads to a change in the thresholds that determine the very fact of the appearance of the halo. The data on the radii can give new information for solving the long-standing problem of a single description of the halo in both parts of the spectrum - discrete and continuous. It is proposed to solve problem: Experimentally determine the radii of a number of states in which there can be a halo in nuclei from $^{6}$Li to $^{14}$O, forming isobar - analog doublets and triplets.
We have discovered new possible candidates for a halo in the isobar-analog multiplets A = 12 and A = 14. Signs of a halo were found for the $2^-$ and $1^-$ states in the A = 12 multiplet members: 1.19 and 1.80 MeV in $^{12}$B, 16.57 MeV and 17.23 MeV in $^{12}$C and 1.67 and 2.62 MeV in $^{12}$N. In the multiplet A = 14, the $1^-$ 8.06 MeV state in $^{14}$N turned out to be a candidate for the halo. It should be noted that this is a rather nontrivial result. First, most of the states lie in the continuous spectrum. Secondly, the results were obtained within the framework of two independent methods: ANC (method of asymptotic normalization coefficients) and MDM method (Modified diffraction model). A great achievement was the development of the ANC method for studying resonance states, which made it possible to identify new cases of a proton halo in isobaric analog states. The research results correspond to the world level.

# SOME FEATURES OF THE LONG ROTATIONAL BANDS IN HEAVY AND SUPERHEAVY EVEN-EVEN NUCLEI

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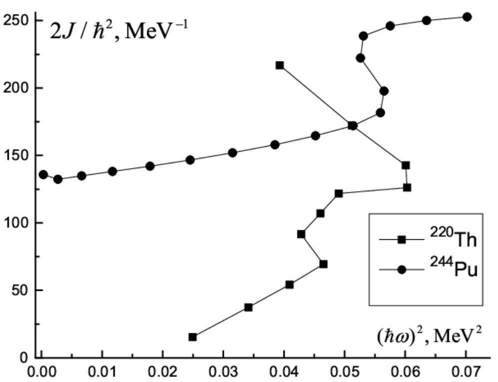
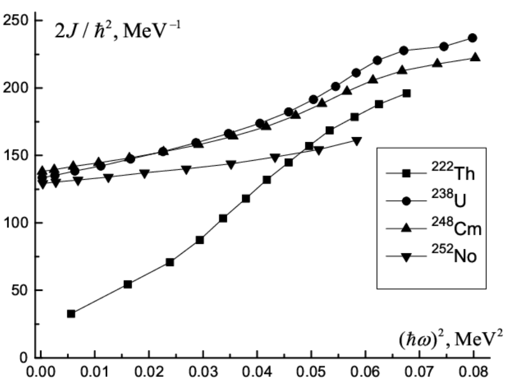
In transactinide nuclei the collectivity of low-lying states is greatly developed. This manifests itself in both small (from 42 to 50 keV) of the energies of lowest states $E(2_1^+)$, and in the weak indirect manifestation of quasiparticle excitations. Because of the high collectivity, the yrast-band states in transuranium nuclei can be successfully described 1 up to high spins in the framework of the traditional version of the IBM1. The absence of backbanding (except for the cases of near-semi-magic Th and $^{244}$Pu isotopes) also support the hypothesis about high collectivity of the low-energy states in transactinide nuclei. For the nucleus $^{220}$Th first backbending is observed at spin $I = 10^+$, when the second one at spins $I = 18^+,\ 20^+$. In $^{244}$Pu the backbending is observed at $I = 24^+,\ 26^+$ (fig.1).
In others transactinide nuclei in the best case, there is only some anomaly in the dependence of the moment of inertia from the square of the rotation speed. Such anomaly appear as a nonlinear increasing of the moment of inertia and can be called ''nod up", or more traditionally [2] – ''upbending". Most strongly upbending manifests itself in $^{222}$Th, $^{238}$U, $^{248}$Cm, and $^{252}$No (fig.2). In the considered transactinide region the phenomenon of backbending is replaced by upbending. In lighter than actinide deformed nuclei, as a rule, the backbending effect is manifested almost invariably. However, a similar upbending phenomenon was observed and discussed in the microscopic calculation [3] within the framework of the microscopic version of IBM1 [4] for $^{116-120}$Xe. It turns out that in the wave functions $^{116-120}$Xe there is a smooth decrease in the purely collective component, which remains principal up to spin $I = 18^+$.
In the considered transactinide nuclei with $N > 126$, the effect of a soft and very smooth substitution of the collective component in the wave functions with increasing of spin by components containing high-spin pairs occurs at high (of the order $I = 26^+$) spins. There are two reasons for the lack of backbending. First – large values of moments of inertia or small energies of collective states of yrast-bands. The second, which is seen to be especially important for nuclei with high deformation energy, may be connected with the presence of quasiparticle excitations. As a result, the configuration space, in which collective modes are formed, decreases and the bands built on quasiparticle modes shift towards large energies.

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# THE EXPERIMENTAL ARRANGEMENT AND PRELIMINARY RESULTS OF SEARCH FOR LIGHT NEUTRON CLUSTERS IN $^{235}$U NUCLEI DECAY

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**THE EXPERIMENTAL ARRANGEMENT AND PRELIMINARY RESULTS OF SEARCH FOR LIGHT NEUTRON CLUSTERS IN 235U NUCLEI DECAY**

The problem of light clusters of neutrons existence, such as dineutron, tetraneutron, hexaneutron, octaneutron is under study for at least 60 years, but it is still of interest both for theoretical and experimental research. The most recent reviews [1,2] published this year prove this.
In our experiment the method of search for neutron clusters, proposed in [3] is used. Light neutron clusters are registered after their escape from heavy nuclei ($^{232}$Th, $^{235}$U, $^{238}$U). These clusters may split into k free neutrons which are detected more efficiently than the spontaneous fission neutrons (average number of fission neutrons $N_n$ = 2) of these nuclei.
The experimental arrangement used to search for neutron clusters is shown in Fig. 1. A neutron emitter sample (E) containing heavy decaying nuclei is placed between two neutron counters (ND). The possible contribution of background events caused mainly by cosmic muons is suppressed using anti-coincidence system with the scintillation detectors (1-12) surrounding the neutron counters. The output signal from detectors is registered by two digital oscilloscopes, and then the information about registered events (neutrons multiplicity, time of neutron and background events registration) is processed online. The long-time measurements are being performed at this moment with thin UO3 film weighing 2.2 g (90% $^{235}$U, 10% $^{238}$U), which is used as emitter. The preliminary results will be reported.

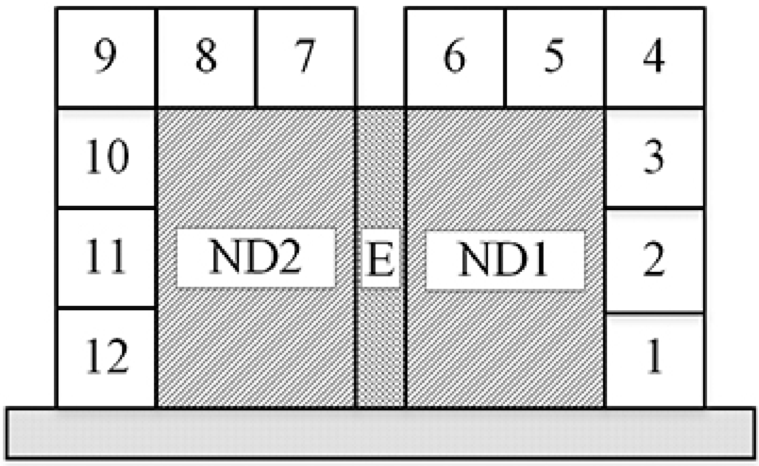


Figure 1: The experimental arrangement for light neutron cluster investigation: dotted – Plexiglas sheet, unfilled (1-12) – scintillation detectors, line-filled (ND) – neutron detectors, cross-filled (E) – neutron emitter sample

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# IN-SOURCE LASER SPECTROSCOPY OF SHORT-LIVED ISOTOPES IN THE LEAD REGION

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Systematic study of the evolution of the nuclear charge radii, deformation, configurations and other ground and isomeric states characteristics near the proton shell closure (Z = 82) is actual and important task. It will enable to construct the two-dimensional picture (with N and Z varied) of the changes of these fundamental nuclear characteristics.

One of the most efficient method for far-from-stability nuclear structure study is the method of resonance laser ionization in the laser ion source (LIS) [1], developed and firstly applied for in-source laser spectroscopy at the IRIS facility (PNPI). This method provides information about isotope shift (IS) and hyperfine structure (hfs) of optical lines. From these data changes in the mean squared nuclear charge radius, nuclear dipole magnetic and quadrupole electric moments, nuclear spins can be deduced. It was enable to obtain a wealth of new information about shape evolution and shape coexistence in atomic nuclei in the lead region: jump-like odd-even shape staggering in Hg isotopic chain [2]; early onset and gradual increase of deformation at N < 113 for Po nuclei [3], etc.

This contribution will discuss laser spectroscopy measurements for Bi nuclei (Z = 83) performed at IRIS (PNPI) and ISOLDE (CERN) facilities. The most interesting experimental results are as follows:

1) large nuclear shape staggering at A=188 ($^{205}$Bi), which is similar to the Hg shape staggering and appears at the same N;

2) large isomer shift, corresponding to more deformed configuration for intruder even-N Bi isomers ($I^{\pi}$ = $1/2^{+}$) with N = 108-118, which is the signature of shape coexistence in the corresponding nuclei;

3) marked deviation from the nearly spherical behavior for ground states of the even-neutron Bi isotopes at N < 109 in contrast to the Pb and Tl isotopic chains.

New data will contribute to the better understanding of the shape coexistence phenomena in this region.

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# СВОЙСТВА СОСТОЯНИЙ ОТРИЦАТЕЛЬНОЙ ЧЕТНОСТИ ЯДРА $^{156}$Gd

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В настояшей работе исследуются неадиабатические эффекты в октупольноколебательных полосах ядра $^{156}\mathrm{Gd}$. Соответствующие экспериментальные данные оценены и систематизированы в работе [1]. В частности, в спектре $^{156}\mathrm{Gd}$ выделены четыре ротационные полосы отрицательной четности с квантовыми числами оснований $\mathrm{K}^\pi = 0^-, 1^-$ и $2^-$. Нижайшая из указанных четырёх полос - полоса с основанием $\mathrm{K}^\pi = 1^-$ и энергией $\mathrm{E_x} = 1.2425$М В. Эта полоса прослежена до спина $I^\pi = 25^-$, в ней нарушена последовательность уровней с четными и нечётными спинами. Неадиабатичность видна также и в отношениях вероятностей $E1$ переходов с уровней этой полосы на уровни основной полосы. В полосе с $\mathrm{K}^\pi = 0^-$ и энергией основания 1.3665М В известны три уровня с $I^\pi = 1^-, 3^-, 5^-$. Две другие полосы построены на основаниях с $\mathrm{K}^\pi = 2^-$ и энергиями 1.7805М МВ и 1.9342М В, в них известны по три уровня: $I^\pi = 2^-, 3^-, 4^-$.

В данной работе для изучения свойств состояний отрицательной четности ядра $^{156}$ Gd предложена простая феноменологическая модель, которая учитывает смешивание состояний полос с $\mathrm{K}^\pi = 0^-$ и $1^-$. Получены аналитические выражения для расчета энергий и волновых функций ротационных уровней. Модель ядра, изучаюшая кориолисово смешивание ротационных полос была также использована в [2]. Смешивание с полосами $\mathrm{K}^\pi = 2^-$ не учитывалось, поскольку они расположены значительно выше по энергии. Рассчитаны энергии и структура волновых функций состояний, а также вероятности E1-переходов из октупольных состояний на уровни основной полосы. Использованная модель хорошо описывает экспериментальные значения энергий. Нарушение четно-нечетной последовательности уровней в ротационной полосе $\mathrm{K}^\pi = 1^-$ и неадиабатичность в отношениях вероятностей $E1$ переходов объясняются смешиванием состояний октупольных полос $\mathrm{K}^\pi = 0^-$ и $1^-$.

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# DETERMINATION OF BAND-HEAD SPIN OF 193PB SUPERDEFORMED BAND

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We present an analysis of all the known superdeformed (SD) bands in $^{193}$Pb using the modified variable moment of inertia (VMI) model to obtain the values of unknown band-head spin (I0) along with the level spin. The band-head spin so estimated is not known experimentally in band-7, 8 and 9. A total of 9 experimentally known SD bands of $^{193}$Pb have been analyzed. Quantitatively good results of the γ energies and the spins for Pb band are successfully obtained. We also examine the ratio of transition energies over spin Eγ/2I (RTEOS) to confirm the correct spin of the band-head and level spins by theVMI equation. The calculated and observed transition energies agree quite well. In the present paper, we have reported the band-head spin for the $^{193}$Pb (b7-b9) superdeformed band. Out of the available 9 SD bands, the band-head spin is predicted for 3 SD bands, where the band-head spins are not known experimentally. As an important outcome of our study, we propose the spin assignments and level energies of the $^{193}$Pb (b7-b9). We resolve the tentative nature of the assignments and present the unique level schemes. These results may be useful for the future studies.

# CONFIRMATION OF A NEW ISOMERIC STATE IN THE $^{186}$RE NUCLEUS

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In laser plasma, stimulated de-excitation of the $^{186m}$Re isomer ($T_{1/2,m}$ = 2.0·105 y) was observed from the time dependence of the intensity $I_{137}$ of 137 keV gammas from the decay of the ground state of the $^{186}$Re nucleus after laser irradiation of the $^{186m}$Re target [1]. The nonmonotonicity of this time dependence made it possible to assume the existence in the $^{186}$RRe nucleus of a new low-lying isomeric level with a half-life of 10 d order, which is populated upon de-excitation of $^{186m}$Re in the laser plasma.
In ref. [2], we tried to observe this new isomer by obtaining the $^{186}$Re nuclei in the (p, n) reaction irradiating $^{186}$W target with 15 MeV protons. Population in this reaction of a new isomer for γ-quanta from an irradiated source would lead to the dependence of the intensity $I_{137}$ (t) on the time t after the formation of $^{186}$Re nuclei, which differs from the simple exponential dependence associated with the decay of the ground state of $^{186}$Re with a period of $T_{1/2,g}$ = 89.239±0.026 h [3] (error is at the level of one standard deviation). In ref. [2], the measurement of $I_{137}$ (t) was started at small t and at the beginning there was no noticeable deviation of the decay curve from a simple exponential with $T_{1/2,g}$. However, at t > 30 d at a low intensity of $I_{137}$, a hint of a deviation of the decay curve from a net exponent appeared. This deviation could be associated with the formation of a new isomer. The known isomer with $T_{1/2,m}$ = 2.0·105 y cannot be observed in such experiments due to its very low radioactivity.
In this work, the source with 186Re was prepared according to the method [2], to reduce the relative activity of the ground state of the $^{186}$Re nucleus, we waited 30 d and only then began to measure $I_{137}$ (t) of the irradiated source in the well of the HPGe
γ-detector at the initial intensity $I_{137} \approx 50\ s^{-1}$. Due to the later start of measurements, it was possible to measure the $I_{137}$ (t) dependence at much longer times t than in ref. [2]. This dependence unambiguously indicates the presence of a new long-lived isomeric level in the 186Re nucleus. At t = 60 d, the $I_{137}$ (t) dependence corresponds to a half-life of 24 ± 0.4 d.

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# ON DETERMINATION OF $^{82}$Se TWO-NEUTRINO DOUBLE BETA DECAY MECHANISM AND STERILE NEUTRINOS CONTRIBUTION

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It is presented the calculation of the amplitude of 2⊠2⊠ decay of $^{82}$Se on the basis of High-States Dominance (HSD) and Single-State Dominance (SSD) mechanisms [1]. The ground state of the intermediate nucleus $^{82}$Br for 2⊠2⊠ decay of $^{82}$Se has quantum numbers 5-, so contribution of this state in the transition amplitude is very suppressed hence it is needed to take into account exited $1^+$ states of $^{82}$Br [2]. In 82Se decay the excited state of the bromine-82 ($^{82}$Br$^*$, $11^+$) with $E_x$ = 75 keV offers a large strength of the Gamow-Teller transition B(GT)=0.338, while high-lying exited $1^+$ states of the bromine-82 with $E_x$ < 2 MeV exhibit transition strength of order of magnitude lesser. As a consequence one can assume that the SSD hypothesis holds. The alternative is when a transition occurs through a large number of intermediate high excited states then the HSD mechanism takes place and choosing of the mechanism has influence on differential intensities of the decay. The SSD mechanism is supported by measurement data for the electron energy distribution gained at the NEMO-3 [3]. Measurements obtained in the CUPID-0 experiment also point to the SSD superiority for the total electron energy distribution as compared with HSD [4]. Experimental investigation of an electron energy distribution, which is sensitive to a nuclear mechanism, can be used for differentiation of these theoretical approaches [3]. It is found the dependences for the differential intensity of the decay on an electron energy corresponded to HSD and SSD mechanisms. Possible presence of sterile neutrinos also affects a phase factor value [5, 6] that should be taken into account for computation of a no removal background and sensitivity evaluation for experiments in the search for $^{82}$Se neutrinoless double beta decay.

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# BETA-DELAYED NEUTRON EMISSION FROM THE $^{123}$Ag NUCLEUS

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The integrated quantities of beta-decay (such as half-live and probability of delayed (multi) neutron emission P1(x)n) are in general the first available for very neutron-rich nuclei. Even at low production yield down to a few counts per second, their measurements can be achieved using high-sensitivity or high-efficiency detectors. In those conditions, they can be truly viewed as a first step towards spectroscopy — viz., in the case of systematic P1n measurements, towards spectroscopic studies of the neutron-threshold region of the excitation spectrum.
TETRA is a decay detection station constructed by collaboration of scientists from JINR, Dubna and IJCLab, Orsay to study the integrated quantities of beta-decay (such as half-live and probability of delayed (multi) neutron emission P1(x)n) of neutron-rich species produced at ALTO ISOL facility. TETRA is equipped by the 4π $^3$He long neutron counter TETRA, a 4πβ plastic scintillator detector and a HPGe detector to allow for simultaneous measurements of three types of radioactivity accompanied β-decay of nuclei [1,2].
TETRA is operated at ALTO ISOL facility which provides beams of neutron-rich radioactive isotopes in the vicinity of N = 50, 82 closed neutron shells. Beta-decay gross-properties in these regions are served as important input parameters for different astrophysical scenarios. Since experimental data is not yet rich enough the input parameters derived from a range of theoretical models. The particular interest is attracted to vicinity of neutron closed shells. Due to high Qbeta values it expected that role of forbidden transitions in beta decay will increase with the neutron number [2]. As the neutron excess increases the giant resonances and the low-lying collective states can be dramatically affected.
As a consequence of neutron excess, neutron separation energy will drop resulting in higher, Pxn value. Thus direct measurements of integrated properties of beta-decay provide a play-ground to figure out, for example, relative contributions of allowed and forbidden decays to adjust theoretical models in the regions. The concentration of E1 strength (PDR) resonance in the vicinity of the particle separation energy threshold, can influence the neutron capture cross section by orders of magnitude. Consequently, the rate of the astrophysical r-process nucleosynthesis will be affected. In case of the neutron-rich nuclei in the vicinity of A ≈ 130, the E1 strength could be significantly more important than in nuclei close to the valley of β-stability. Therefore, in the presentation we discuses the beta-delayed neutron emission in the vicinity of $^{132}$Sn nucleus. New measurements on beta-decay $^{123}$Ag nucleus, the first nucleus studied at ALTO in the $^{132}$Sn region [3].
TETRA@ALTO was considered as the first step in the vast scientific program to be carried out at GANIL (DESIR). The performance of TETRA@ALTO and the importance of the obtained results highlight the advantage of the TETRA installation at DESIR low energy branch of the SPIRAL2 facility.

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# PAIRING AND (9/2)n CONFIGURATION IN THE NEUTRON-RICH NI ISOTOPES

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Neutron-rich nickel isotopes in vicinity of $^{78}$Ni present an excellent opportunity to study the way in which neutron excess affects the properties of nuclear shell structure. Studies in this region of isotopes also provide insight in the nuclear mechanism of r-process responsible for their synthesis. The path of the consequent reactions constituting r-process is dictated by the shell structure of nuclei far from stability.

As experimental investigations kept advancing and a wealth of new spectroscopic information in various nickel isotopes was obtained, in particular, at the RIBF facility operated by RIKEN Nishina Center in Tokyo [1], the number of variants of their model description is growing, primarily the shell model approach. Neutron-rich $^{70-76}Ni$ are of particular interest due to the significantly different scheme of low-lying states and the $E2$ decay pattern in comparison with other $g_{9/2}$ nuclei, for example, $^{94}$Ru and $^{96}$Pd [2]. The new data in these isotopes may allow to test the conservation of seniority, the quantum number referring to the number of nucleons not coupled with total angular momentum $J = 0$. Seniority as a good quantum number can shed light on the properties of excited states such as their modes of decay.

We study the spectra of neutron-rich nickel isotopes $^{70-76}$Ni. To this end, pairing forces in form of surface delta interaction are employed to account for formation of the ground state multiplet (GSM) with seniority $= 2$ states. GSM splitting is described with mass relations or masses of neighbouring nuclei. Subsequently, seniority model is used to reproduce or predict the states $= 3$ in odd-odd isotopes and ν = 4 in even-even isotopes. Earlier in this approach, we considered multiplets of ν = 2 and ν = 4 states in isotones with $N = 50$ [3]. It is shown that the approximation of delta interaction is not sufficient to reproduce the energy of first $J = 2$ state. Correct account of this state should allow for description of reversed order of states $J = 4$ with ν = 2 and ν = 4 observed in experiment.

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# GIANT NEUTRON HALO IN Ce ISOTOPES NEAR THE NEUTRON DRIP LINE

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Neutron halo is one of the most intriguing properties of nuclei with sufficient excess of neutrons. Neutron halo was first observed experimentally in $^{11}$Li. The giant neutron halo of more than two neutrons was predicted also theoretically in medium and heavy mass nuclei near the neutron drip line, in particular in Ca, Zr, Ce. The halo and giant halo forms in $^{186-190}$Ce and $^{192-198}$Ce isotopes respectively according to the calculations within the relativistic HFB and RMFPC-CMR-BCS theories [1,2].
We investigated the neutron single-particle structure of Ce isotopes by the dispersive optical model (DOM) [3]. The method to construct dispersive optical model potential is given, for example, in [4]. The evolution of the neutron single-particle energies (see Fig.1) was calculated in the assumption that diffuseness parameter $a_{HF}$ of the potential increased from 0.65 for $^{184}Ce$ to 0.8 fm for $^{198}Ce$. The halo in Ce isotopes near the neutron drip line forms when neutrons occupy low-l states $4s_{1/2}$, $3d_{5/2}$ and $3d_{3/2}$. The calculated root mean square radii $R_{\mathrm{rms}}$ of these states are in the interval approx. from 10 to 12 fm, whereas the radii $R_{\mathrm{rms}}$ of the neighboring states equal to 6 - 7 fm. The total number of neutrons in halo states exceeds 2 for N > 134. The neutron density distributions of the $^{184}$Ce with traditional magic neutron number N = 126 and $^{198}$Ce with N = 140 are shown in Fig.2. For the latter isotope, the neutron density demonstrates the long tail, which can be attributed to the giant halo.

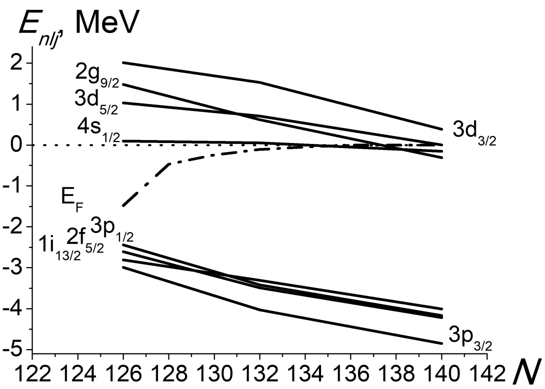


Figure 1

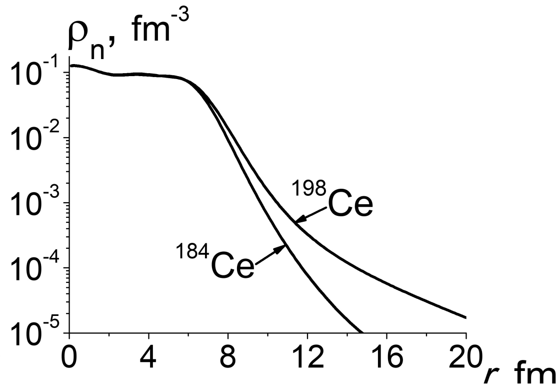


Figure 2

# FIRST CALCULATION OF THE $\gamma\gamma$-DECAY WIDTH OF A NUCLEAR $2^+_1$ STATE: THE CASE OF $^{48}$Ca

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In Ref. [1], the $\gamma\gamma$-decay of a nuclear transition in competition with an allowed $\gamma$-decay has been discovered. This is the observation of the $\gamma\gamma$-decay of the first excited $J^\pi = 11/2^-$ state of $^{137}$Ba directly competing with an allowed $\gamma$-decay to the $J^\pi = 3/2^+$ ground state.The branching ratio of the competitive $\gamma\gamma$-decay of the $11/2^-$ isomer of the odd-even nucleus $^{137}$Ba to the ground state relative to its single $\gamma$-decay was determined to be $(2.05 \pm 0.37) \times 10^{-6}$. This discovery has very recently been confirmed and the data were made more precise, in particular with respect to the contributing multipolarities [2].
The competitive double-$\gamma$ decay of the $2^+_1$ state of an even-even spherical nucleus is studied for the first time. The coupling between one-, two- and three-phonon terms in the wave functions of excited states is taken into account within the microscopic model based on the Skyrme energy density functional. The approach enables one to perform the calculations in very large configurational spaces [3,4]. We estimate the generalized electric dipole polarizabilities involved in the $\gamma\gamma/\gamma$ decay process and make a prediction for the branching ratio of the competitive $\gamma\gamma$-decay relative to its single $\gamma$-decay calculated to be $3 \times 10^{-8}$ for the case of $^{48}$Ca [5].

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# DESCRIPTION OF THE SPECTRA OF THE LOWEST STATES FOR A CHAIN OF Zr ISOTOPES BASED ON THE GEOMETRIC COLLECTIVE MODEL

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The work is devoted to the description of the spectra of the lowest states and transition probabilities for the chain of zirconium isotopes $^{92-102}$Zr in the framework of the geometric collective model. As the mass increases, these isotopes undergo a transition from the spherical structure of the ground state to the deformed one; in $^{96}$Zr, the coexistence of spherical and deformed states is observed. The consideration is based on the collective Bohr quadrupole Hamiltonian, taking into account the triaxial degree of freedom. The selection of the potential parameters for each nucleus was carried out in such a way as to minimize the standard deviation between the available experimental data and the calculated values. The obtained potentials are close in shape to the potentials of the mean field models. Fairly good agreement with experimental data is observed. The deviations of the calculated data for isotopes with a spherical shape are analyzed.

# SINGLE-PARTICLE ASYMPTOTIC NORMALIZATION COEFFCIENTS IN MIRROR MEDIUM-MASS NUCLEI

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The asymptotic normalization coefficients (ANCs) show how likely nucleons can stay in classically forbidden region and their knowledge if important for studying peripheral reactions such as proton capture in stellar environments.
We investigate relations between neutron, $C_n$, and proton, $C_p$, ANCs in mirror nuclear states for medium-mass nuclei, 40 ≤ A ≤ 100, using a two-body potential model with local and nonlocal nucleon-core interactions. Assuming that nuclear potential wells in mirror states are the same, we calculate ratios $R_b = (C_p/C_n)^2$ and compare them to predictions of model-independent analytical formula (7) from [1]. We found that despite increasing strength of the Coulomb interaction with nuclear mass this formula has an accuracy similar to that found in earlier investigations for light nuclei. The analytical formula works better for nonlocal than for local potentials, with the accuracy on most cases within 5%.

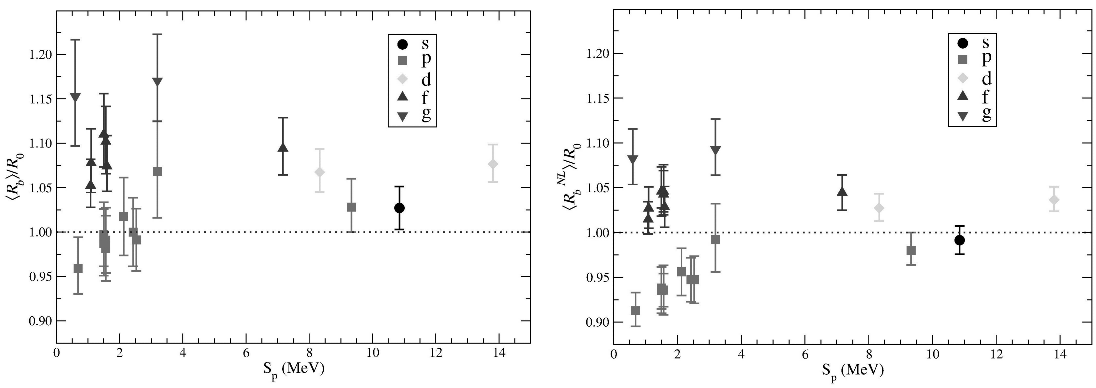


Figure 1: Ratio $R_b$ in terms of analytic estimate $R_0$ as a function of proton separation energy $S_p$ for different orbital momentum of removed nucleon, calculated in local (left panel) and nonlocal (right panel) models. The spread of $R_b$ reflects different choice of nucleon-core potentials.

The study is extended to bound-unbound mirror pairs by assessing relations between $C_n$ and the width $\Gamma_p$ of a mirror proton resonance. The deviation of the calculated ratio $\Gamma_p/C_n^2$ from prediction of analytical formula (see expression (8) in [1]) is similar to that obtained for bound-bound mirror pairs. The knowledge of the ratio $\Gamma_p/C_n^2$ can be used to determine widths of narrow proton resonances of astrophysical importance by measuring ANCs of mirror neutron states in peripheral transfer reactions.

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# INVESTIGATION OF LOW-LYING RESONANCES IN BREAKUP OF HALO NUCLEI WITHIN THE TIME-DEPENDENT APPROACH

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We investigate the Coulomb breakup of $^{11}$Be halo nuclei on a heavy target from intermediate (70 MeV/nucleon) to low energies (5 MeV/nucleon) within the non-perturbative time-dependent approach. The convergence of the computational scheme is demonstrated in this energy range including $n$+$^{10}$Be low-lying resonances in different partial and spin states. We have found a considerable contribution of the $5/2^+$ resonance ($E_r$= 1.23 MeV) to the breakup cross section at 30 MeV/nucleon and lower, while at higher energies, the resonant states $3/2^-$ and $3/2^+$ (with $E_r$= 2.78 and 3.3 MeV) make most visible contributions. The obtained results are in good agreement with experimental data available at 69 and 72 MeV/nucleon. Comparison with the existing theoretical calculations of other authors for 20 and 30 MeV/nucleon is also made. The developed computational scheme opens new possibilities in the investigation of the Coulomb, as well as nuclear, breakup of other halo nuclei on heavy and light targets.

# A SEMI-MICROSCOPIC DESCRIPTION OF ISOSCALAR GIANT MULTIPOLE RESONANCES IN MEDIUM-MASS CLOSED SHELL NUCLEI

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Being a microscopically based extension of the standard [1] and nonstandard [2] versions of the continuum-random-phase approximation (cRPA), by taking the spreading effect into account, the semi-microscopic particle-hole (p-h) dispersive optical model (PHDOM) has been proposed [3] and successfully implemented for describing properties of various giant resonances (GRs) in medium-heavy mass closed-shell nuclei (See Ref. [4] and references therein). Within the model, the main relaxation modes of (p-h)-type states, associated with GRs, are together taken into account. These modes are: (i) Landau damping; (ii) coupling mentioned states to the single-particle continuum, and; (iii) coupling to many-quasiparticle configurations (the spreading effect). Landau damping and coupling to the continuum are described microscopically (in terms of a phenomenological mean field and Landau-Migdal p-h interaction), while the spreading effect is treated phenomenologically (in terms of the energy-averaged p-h self-energy term). That allows one to describe within PHDOM the main GR characteristics for a wide excitation-energy interval: (i) double transition density; (ii) strength distribution, and one-body "projected" transition density both related to an appropriate probing operator, and (iii) probabilities of direct one-nucleon decay.

The PHDOM version proposed in Ref. [3] in a rather general form has been adopted in Ref. [4] for describing main characteristics of isoscalar Multipole GRs in medium-heavy mass closed-shell nuclei. The L = 0 - 3 multipole resonances together with L = 0, 2 multipole overtones have been considered and a rather reasonable description of available experimental data has been obtained for the 208Pb nucleus, taken as an appropriate example. Some of results obtained within cRPA (i.e., in neglecting the spreading effect) were found in agreement with the results obtained within the microscopic RPA-based approach of self-consistent Hartree-Fock, using Skyrme-type forces [5].

The present work is a direct continuation of the above-described study of Ref. [4]. The study is extended to medium-mass closed-shell nuclei $^{40,48}$Ca, $^{90}$Zr, and $^{132}$Sn. Calculation results are compared with available experimental data. Some of cRPA results are compared with the results of Ref. [5].

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# ANALOG RESONANCES AND LOCAL INTERACTION PARAMETERS

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Isobaric analog resonances (AR) are investigated within the framework of the microscopic theory of finite Fermi systems (TFFS) and in an approximate approach. These studies began about 50 years ago [1–3] and are currently being successfully continued in the self-consistent TFFS approach [4]. The calculations were performed for a large number of spherical and deformed nuclei, and the calculated energies $E_{AR}$ are in good agreement with the experimental data. Since the $E_{AR}$ energies are linearly related to the Coulomb energies $Q_{EC}$ and, in the model approximation, to the charge radii $R_C$ of atomic nuclei, the corresponding recalculations for $Q_{EC}$ and $R_C$ were carried out and good agreement with the experimental data was obtained.
The most complete experimental studies of charge-exchange excitations in 9 tin isotopes with A = 112 – 124 were carried out [5] in the Sn( 3He, t)Sb reaction. Recently, studies have been carried out on charge-exchange resonances in the neutron-rich isotope 132Sn [6] in the 132Sn(p, n) 132Sb reaction. Comparison of the obtained data with calculations by TFFS made it possible to determine the parameter of the local isospin – isospin interaction [7] and demonstrated a linear dependence of the energy $E_{AR}$ on the isotopic parameter $(N–Z)/A$. Calculations for Sn isotopes were carried out up to the value A = 140.

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# A SEMI-MICROSCOPIC DESCRIPTION OF $0^+$ GIANT RESONANCES IN THE EVEN $^{112\text{-}124}$Sn PARENT NUCLEI

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The semi-microscopic particle-hole dispersive optical model (PHDOM), originally formulated and successfully implemented for describing main properties of various giant resonances in medium-heavy closed-shell nuclei (see Ref. [1] and references therein), is extended to account for nucleon pairing in open-shell spherical nuclei. In the present work (which is a direct continuation of the incomplete study of Ref. [2]), nucleon pairing in even-even parent nuclei is approximately (in the “high-energy limit”) taken into account within a simplest version of the BCS-model. The extended PHDOM version is implemented for describing properties of isoscalar and isovector (charge-exchange) giant monopole resonances (ISGMR and IVGMR$^{(\mp)}$, respectively), and the isobaric analog resonance (IAR) in the even $^{112-124}$Sn parent nuclei. For ISGMR and IVGMR$^{(\mp)}$, the strength functions and one-body “projected” transition density both related to an appropriate probing operator, and probabilities of direct one-nucleon decay are evaluated within the model. For IAR, the main object for studying is the anomalously small spreading width. In describing IAR and IVGMR$^{(\mp)}$, we use the “Coulomb description” of isospin-forbidden processes, which is incorporated into PHDOM [3]. In calculations, most of model parameters (related to a mean field, Landau-Migdal forces, and particle-hole self-energy term responsible for the spreading effect) are taken from independent data [1]. Only the spreading strength parameter (chosen as the universal quantity for nuclei under consideration) is adjusted to describe reasonably the observable values of the ISGMR total width and IAR spreading width. These and other calculation results are compared with available experimental data.
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# DIBARYON RESONANCES AND THREE-BODY FORCES IN LARGE-ANGLE PD SCATTERING AT INTERMEDIATE ENERGIES

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The large-angle proton-deuteron (*pd*) scattering at intermediate energies 200-1000 MeV is a long-standing puzzle. While the small-angle scattering can be described well by the Glauber diffraction model or, at energies $Tp$ < 400 MeV, by the exact solution of Faddeev equations, the strong discrepancies between theoretical predictions and experimental data at large angles need a careful treatment of 2 $N$ interactions and also 3 $N$ forces.
The large-angle *pd* scattering is accompanied with high momentum transfers and thus is related to the short *NN* distances where the quark structure of the nucleon can be manifested. While the accurate incorporation of the quark and gluon degrees of freedom in hadronic processes at intermediate energies is a very complicated and non-trivial task, the quark structure of the nucleon in the short-range *NN* interaction can be effectively treated by means of 6 $q$ bags dressed by meson clouds (the dressed dibaryons). The dibaryon model for the *NN* interaction was proposed by the Moscow-Tuebingen group twenty years ago, but only recently found new experimental confirmation in *NN* elastic scattering and *NN*-induced meson production. The model has been updated to include inelastic processes and new experimental data and proved to be an adequate tool for describing both elastic and inelasctic *NN* scattering in the basic *S*, *P*, and *D* partial waves in a wide energy range from zero to about 1 GeV [1]. The dibaryon mechanism of the short-range *NN* interaction leads to the emergence of new three-body forces acting between the dibaryon and the third nucleon, which can give a significant contribution to the large-angle *pd* scattering.
In the talk, we present the preliminary calculation of the pd elastic cross section and some spin observables using the phenomenological model, which combines the basic traditional mechanisms such as one-nucleon exchange and the Δ-isobar excitation with the new dibaryon-induced mechanisms. We extensively use the results obtained in a model [2] for the $pp \longrightarrow d\pi +$ reaction and the dibaryon parameters found experimentally. We show the important role of the known isovector dibaryons in description of the cross section and spin observables of large-angle pd scattering. This result seems to be promising in resolving the long-standing puzzles in *pd* scattering and, more generally, in the processes involving few-nucleon systems and high momentum transfers.

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# MICROSCOPIC DESCRIPTION OF ISOSCALAR GIANT MONOPOLE RESONANCE: THE CASE OF $^{132}$Sn

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The study of nuclear giant resonances has long been a subject of extensive theoretical and experimental research. The multipole response of nuclei far from the beta-stability line and the possible occurrence of exotic modes of excitation present a growing field of research. In particular, the study of the isoscalar giant monopole resonances (ISGMR) in neutron-rich nuclei is presently an important problem not only from the nuclear structure point of view [1] but also because of the special role they play in many astrophysical processes such as prompt supernova explosions [2] and the interiors of neutron stars [3]. One of the successful tools for describing the ISGMR is the quasiparticle random phase approximation (QRPA) with the self-consistent mean-field derived from Skyrme energy density functionals (EDF) [4]. Due to the anharmonicity of the vibrations there is a coupling between one-phonon and more complex states [5]. The main difficulty is that the complexity of calculations beyond standard QRPA increases rapidly with the size of the configuration space, and one has to work within limited spaces. Using a finite rank separable approximation for the residual particle-hole interaction derived from the Skyrme forces one can overcome this numerical problem [6-8].
In the present report, we study the effects of phonon-phonon coupling on the monopole strength distributions of neutron-rich tin isotopes. Using the same set of the EDF parameters, we describe available experimental data for $^{118,120,122,124}$Sn [9] and give prediction for $^{132}$Sn [10]. The effects of the phonon-phonon coupling leads to a redistribution of the main monopole strength to lower energy states and also to higher energy tail. We analyze thoroughly the properties of the low-energy $0^+$ spectrum of two-phonon excitations of $^{132}$Sn. We give prediction for the excitation energy of the lowest two-phonon state around $E_x = 8$ MeV in comparison to 11.5 MeV in the case of the lowest $0^+$ state within the random phase approximation.

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# NEW MASS EVALUATION AND ITS IMPLICATION FOR THE NEUTRON-RICH NUCLEOSYNTHESIS PRODUCT YIELD

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Estimates for experimentally unknown nuclear masses are obtained by a phenomenological approach based on a local mass relation for the residual neutron-proton interaction. The local mass relations method provides both high accuracy of isotope mass predictions and mathematical simplicity of calculations [1, 2]. Results based on different databases AME2012-2020 [3] are presented. Neutron-rich isotopes in the r-process region are considered in detail.
The rates of neutron capture reactions at temperatures of 0.1-10 GK are calculated using the TALYS program [4] with the obtained mass estimates. The resulting rates are compared with calculations based on other mass prediction approaches. The resulting rates are also applied to calculate the r-process products yield in standard scenarios using the SkyNet library [5].
The results presented in this work demonstrate sensitivity of nucleosynthesis calculations to nuclear characteristics and neutron dripline localization.

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# A FRESH FIELD-THEORETIC CALCULATION OF THE DEUTERON MAGNETIC AND QUADRUPOLE MOMENTS

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We continue our explorations [1] of the electromagnetic properties of the deuteron with help of the method of unitary clothing transformations (UCT) [2,3]. It is the case, where one has to deal with the matrix elements $\langle \mathbf{P}', M'|J^\mu(0)|\mathbf{P}, M\rangle$ (to be definite in the lab. frame). Here the operator $J^\mu(0)$ is the Nöther current density $J^\mu(x)$ at the point $x = (t, \mathbf{x}) = 0$, sandwiched between the eigenstates of a “strong” field Hamiltonian $H$, viz., the deuteron states $|\mathbf{P}, M\rangle$. Latter belong to the two-clothed-nucleon subspace with the Hamiltonian $H = P^0 = K_F + K_I$ and the boost operator $\mathbf{B} = \mathbf{B}_F + \mathbf{B}_I$, where free parts $K_F$ and $\mathbf{B}_F$ are $\sim b_c^\dagger b_c$ and interactions $K_I$ and $\mathbf{B}_I$ are $\sim b_c^\dagger b_c^\dagger b_c b_c$. Further, we use the expansion in the $R$-commutators
$J^\mu(0) = W J_c^\mu(0) W^\dagger = J_c^\mu(0) + [R, J_c^\mu(0)] + \frac{1}{2}[R,[R,J_c^\mu(0)]] + ...,$
where $J_c^\mu(0)$ is the initial current in which the bare operators $\{\alpha\}$ are replaced by the clothed ones $\{\alpha_c\}$ and $W = \exp R$ the corresponding UCT. In its turn, the operator being sandwiched between the two-clothed-nucleon states contributes as $J^\mu(0) = J^\mu_{one-body} + J^\mu_{two-body}$. By keeping only the one-body contribution we arrive to certain off-energy-shell extrapolation of the so-called relativistic impulse approximation (RIA) in the theory of e.m. interactions with nuclei (bound systems). Of course, the RIA results [1] should be corrected including more complex mechanisms of e-d scattering (see other our contribution). Starting from the operator of the magnetic dipole moment $\mu = \frac{1}{2}\int d\mathbf{x}\,\mathbf{x} \times \mathbf{J}(x)$ (reminiscent of the Biot-Savart formula from magnetostatics) one can show that the magnetic dipole moment of the deuteron being defined after Sachs as $z$-component of the matrix elements between narrow wave packets of the vector $\mu$ for the stretched configuration, looks as

$$\mu_d = \lim_{\mathbf{q}\to 0}\left[-\frac{i}{2} curl_{\mathbf{q}}\langle\frac{\mathbf{q}}{2};1|\mathbf{J}(0)|-\frac{\mathbf{q}}{2};1\rangle\right]^z,$$

where the matrix elements $\langle\frac{\mathbf{q}}{2}; M_J|\mathbf{J}(0)|-\frac{\mathbf{q}}{2}; M_J'\rangle$ ($M_J = (\pm 1, 0)$ projection of the total angular momentum) determine the corresponding current in the Breit frame. In this way the deuteron magnetic dipole moment can be expressed as

$$\mu_d = \frac{1}{m_d}\langle\mathbf{0};1|\frac{1}{2}\left[\mathbf{B}\times\mathbf{J}(0)\right]^z|\mathbf{0};1\rangle$$

with the deuteron state $|\mathbf{0};1\rangle$ in the rest frame. In parallel, considering interaction energy of the system with the charge density $\rho(x) = J^0(x)$ in static external electric field and expanding it in the Cartesian electric moments one encounters the quadrupole moment tensor
$Q_{ij} = \int d\mathbf{x}\,[3x_i x_j - \delta_{ij}\mathbf{x}^2]\rho(\mathbf{x})$ $(i, j = 1(x), 2(y), 3(z))$. Then repeating the same trick with wave packets one gets the matrix elements

$$\langle JM_J'|Q_{ij}|JM_J\rangle = -\lim_{\mathbf{q}\to 0}\left[\left\{3\frac{\partial^2}{\partial q_i \partial q_j} - \delta_{ij}\frac{\partial^2}{\partial q_l^2}\right\}\langle\frac{\mathbf{q}}{2}|\rho(0)|-\frac{\mathbf{q}}{2}\rangle\right]$$

to introduce electric quadrupole moment $Q = \langle JJ|Q_{33}|JJ\rangle$. These formulae have been a departure point for our preceding RIA calculations [1]. Here we will show our results with the meson exchange currents and boost ($\mathbf{B}_I$ part) contributions included.

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# Z(4)-DDM: A γ-RIGID SOLUTION OF THE BOHR HAMILTONIAN WITH DAVIDSON POTENTIAL FOR β AND γ = 30°

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In this work we modify the Davydov-Chaban Hamiltonian describing the collective motion of $\gamma$-rigid atomic nuclei by allowing the mass to depend on the nuclear deformation. We construct Z(4)-DDM (Deformation-Dependent Mass) model by considering the Davidson potential, and solve the problem by techniques of asymptotic iteration method (AIM). We compare the results of the calculated spectra and $B(E2)$ transition rates for series of $^{108-116}$Pd and $^{190-198}$Pt isotopes with experimental data as well as with other theoretical models. Exact analytical expressions are derived for spectra and normalized wave functions of Davidson potential. The obtained results show an overall agreement with the experimental data and an important improvement in respect to other models. Prediction of a new candidate nucleus for triaxial symmetry is made.

# ON THE TRUE AND FICTITIOUS ENHANCEMENTS OF THE FUNDAMENTAL SYMMETRY BREAKING EFFECTS

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All the enhancements of the P-violation effects in γ-transitions between the compound-nucleus states were analyzed in the classical paper [1] by I.S. Shapiro. The source of these effects is the weak interaction $V_W$ leading to the fact that the wave function $\psi$ of this state contains, besides the wave function of a definite parity $\psi_1$ , the small admixture of the opposite parity state $\psi_2$:

$$\psi = \psi_1 + c\psi_2 \tag{1}$$

The effect is defined by the ratio of the P-forbidden transition normalized by the total transition value:

$$R = \frac{c(A_a \cdot A_f)}{(A_a + cA_f)^2} \approx \frac{cA_f}{A_a} \equiv \frac{n}{d} \tag{2}$$

Here $A_a$ and $A_f$ are the amplitudes of the P-allowed and P-forbidden transitions. The review [1] indicates 3 types of enhancement: 1) kinematical enhancement, 2) structural enhancement and 3) dynamical enhancement. The kinematical enhancement appears when the allowed transition is the magnetic one which is smaller than the forbidden electric of the same multipolarity by the factor $(v/c) \approx 10$. The structural enhancement appears when the allowed transition amplitude comes to be unusually small due to some suppression caused by the structure of the initial and final states. One should point that both the kinematical and structural enhancements arise because of the decrease of the denominator $d$ in Eq. (2). Only the dynamical enhancement is caused by the increase of the admixture coefficient: $c = \frac{<\psi_1|V_w|\psi_2>}{E_1 - E_2} = \frac{v_P}{D}$
in the numerator $n$ of (2). Here $v_P$ is the weak interaction matrix element, while the enhancement of the admixture for the high-lying exited states is caused by their strongly decreased level spacing. It is assumed that the largest magnitude of the symmetry-breaking effect allows to measure it with the largest accuracy (i. e. with the smallest relative error). This assumption is shown to be often misleading. Indeed, the experimentally measured value (2) is the ratio of the normally distributed numbers of numerators $n$ to denominators $d$. Taking their absolute errors to be σ and neglecting the correlation between them, one obtains for the relative error of the measured effect: $\frac{\sigma_R}{R} \approx \sqrt{\frac{\sigma^2}{n^2} + \frac{\sigma^2}{d^2}}$. We see that the dynamical enhancement of $n$ decreases the relative error and indeed leads to the enhanced accuracy of the effect’s measurement. However, the other two enhancements lead only to the slight increase of the relative error and to the poorer accuracy of the effect’s measuring. Usefulness of the relative error approach to transmission measurements is also discussed.

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# THREE-NUCLEON FORCES WITHIN THE REPRESENTATION OF CLOTHED PARTICLES

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We will show a detailed derivation of matrix elements (in momentum space) of the three-nucleon interaction operator [1] built up within the field theoretical approach based on the method of unitary clothing transformations (UCTs) [2,3,4]. As before, we start from the instant form of relativistic dynamics after Dirac with the total field Hamiltonian $H$ for Yukawa-type couplings between $\pi-$, $\eta-$, $\delta-$, $\omega-$, $\rho-$, $\sigma-$ mesons and nucleons and anti nucleons [4]. So, our approach is relativistic from the beginning and does not need in supplementary efforts to get any relativistic results. Recall that the UCT method is aimed at reformulating the theory in terms of the so-called clothed-particle creation (annihilation) operators $\alpha_c$, e.g., $a_c^\dagger(a_c)$ for mesons, $b_c^\dagger(b_c)$ for nucleons and $d_c^\dagger(d_c)$ for antinucleons via UCTs $W(\alpha_c) = W(\alpha) = \exp R$, $R = -R^\dagger$ with help of the similarity transformation $\alpha = W(\alpha_c)\alpha_c W(\alpha_c)$ that connects a primary set $\alpha$ in the bare-particle representation (BPR) with the new operators in the clothed-particle representation (CPR). Of course, such a transformation can be done if following [5] one composes certain physical constraints on the unitary operator $W$. The $3N$ interaction operator of the $b_c^\dagger b_c^\dagger b_c^\dagger b_c b_c b_c$-type stems from the commutator $[V]^3 \equiv [R,[R,[R,V]]]$ that is constructed by using a recursive procedure exposed in [3]. Here operator $V$ denotes a primary interaction between the fields included. We will compare the part of the matrix element $\langle \mathbf{p}_1'\mathbf{p}_2'\mathbf{p}_3'|[V]^3|\mathbf{p}_1\mathbf{p}_2\mathbf{p}_3\rangle$ due to the pion exchange with the Tucson-Melbourne $2\pi$-exchange three-nucleon potential [6].

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# EFFECT OF TENSOR CORRELATIONS ON THE GAMOV-TELLER STRENGTH DISTRIBUTION IN CLOSED-SHELL PARENT NUCLEI

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The effect is studied within a properly modified version of the continuum-random-phase-approximation (cRPA). Numerical results are obtained for the Gamow-Teller (GT) strength distribution in $^{208}$Bi. For this distribution, the experimental data concerned with the main-peak energy and the respective fraction of the Ikeda sum rule ($x^{(-)}_{\text{peak}}$) [1], and also the low-energy part distribution (total fraction $x^{(-)}_{<}$) [2] are available. Within the study, a realistic partially self-consistent phenomenological mean field (with parameters taken from independent data) and the spin-isovector component of Landau-Migdal forces (with the dimensionless strength g’) are exploited. In various calculations of the GT strength distribution (some results are shown in the Table), the parameter g’ is adjusted to reproduce the observed main-peak energy. There are two sources of considered tensor correlations (the latter mean a mixture of GT and respective $1^+$ spin-quadrupole excitations): (i) the mean-field spin-orbit term, and (ii) the appropriate component of tensor forces. Correlations of the first type are taken into account within the so-called non-symmetric version of cRPA. The corresponding equations can be found in Ref. [3]. These equations are directly extended by inclusion of the related contact tensor forces (with dimensionless strength $g_t^{'}$ ). The separable tensor forces are exploited in Ref. [4].
The calculation results obtained for various $g_t^{'}$ values (a part of results is given in the Table, where the total fraction $x^{(-)}_{\text{tot}}$ evaluated for the excitation energy interval 0-70 MeV is also shown) allow us to conclude: (i) the effect of definitely existing tensor correlations of the first type is weak; (ii) accounting for second-type correlations seems questionable and needs further consideration.

| Approximation | $x^{(-)}_{<}, \%$ | $x^{(-)}_{\text{peak}}, \%$ | $x^{(-)}_{>}, \%$ | $x^{(-)}_{\text{tot}}, \%$ |
|---|---|---|---|---|
| Symmetric, $\text{g}' = 0.78$ | 7.7 | 77,5 | 12.0 | 97.2 |
| Non-symmetric, $\text{g}' = 0.73$ | 7.4 | 72,9 | 16.0 | 96,4 |
| Non-symmetric, $\text{g}' = 0.80,\ \text{g}'_t = 0.15$ | 7.4 | 76.9 | 13.3 | 97.5 |
| Non-symmetric, $\text{g}' = 0.71,\ \text{g}'_t = -0.15$ | 7.4 | 69.1 | 18.3 | 94.8 |
| Experiment $[2, 1]$ | $18 \pm 5$ | $60 \pm 15$ | $--$ | $--$ |

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# Analysis of random vectors, frequencies of discrete distributions of reference streams, by the method of complex moments

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Sequences of small volume samples of $n \leq 10$ numbers of reference $k_j$ particle fluxes with mean $0 \leq \bar{k} \leq 5$ correspond to random vectors $(\mathrm{RV} - v(.)\ )$ of frequencies $v_j\left(k_j\right)$ of values $k_j : v(.) = \left(v_0, v_1, \ldots, v_l\right), n = \sum_{j=0}^{i} v_j\left(k_j\right)$ and RV of relative frequencies $v_j^{\prime}(.) = v_j/n$. Analysis of homogeneity of individual RV pairs and their large $M >> 1$ sequences remains a critical data handling procedure.
A method for evaluating homogeneity of random vectors $v(.)$ and $v^{\prime}(.)$ pregrouped in peaks with several fixed components $v_j(.)$ of multimodal distributions of functionals $ID(v(.))$ is proposed [1]. $ID(v(.))_m = a_0 v_{0.m} + a_1 v_{1.m} + \ldots + a_l v_{l,m}$, where $a = (a_0, \ldots, a_l)$ - is a defined vector $[1,2]$.
The method is based on an analysis of the $\rho\left(\mu(v, \ldots, S)_m, \mu(v, \ldots, S)\right)_q$ metric of the phase trajectory projections of the complex functions of the empirical central moments of RV of fractional orders $S > 1$
$\mu(v(.), S) = \frac{1}{1-n} \sum_{j=1}^{n}\left(k_j - \bar{k}\right)^s = \mathrm{Re}\left(\mu(v, S) + i\mathrm{Im}(\mu(v, S)\right), \quad i^2 = -1$

| m, q | $\nu_m$ | $P\left(\nu_m\right)$ | $\rho(, m)$ | $\rho(, m)$ |
|---|---|---|---|---|
| 1 | 6031 | 0.0006 | 0.013 | 0.0087 |
| 2 | 5131 | 0.0043 | 0.0092 | 0.0046 |
| 3 | 4231 | 0.0123 | 0.0048 | 0 |
| 4 | 3331 | 0.0193 | 0 | 0.0048 |
| 5 | 2431 | 0.0169 | 0.0047 | 0.0092 |
| 6 | 1531 | 0.0079 | 0.0094 | 0.013 |
| 7 | 0631 | 0.0015 | 0.016 | 0.018 |

Contrary to [2] the proposed method takes into account besides the imaginary one also the real component $\mathrm{Re}(\mu(v, S))$ of the momentum function $\mu(v, S)$. In particular, for RV, forming one of peaks in distributions $M(ID(v(.)))$ at $\bar{k} = 1.176\ldots; n = 10$ probabilities of their realization $P(v(.))$ and values of metrics $\rho(.)$ are $S_{\max} = 4.9\rho(m = 3, m) \quad \rho(m = 4, m)$ at $S_0 = 1$.

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# Section 2. Experimental and theoretical studies of nuclear reactions

## TEST SETUP FOR REGISTRATION OF COINCIDENT SIGNALS FROM REACTIONS WITH THE EMISSION OF CHARGED PARTICLES AND NEUTRONS ON THE RADEX CHANNEL

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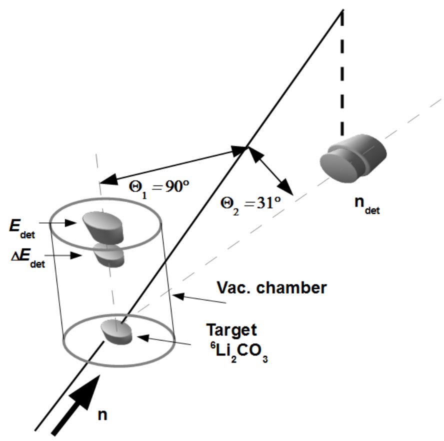
The neutron beam of the RADEX channel of the INR RAS is used by us to study few-nucleon reactions caused by neutrons with an energy of $10 - 100$ MeV. The registration in the coincidence of neutrons and charged particles, their identification and energy determination are necessary for study such reactions. For the preliminary test measurements, the reaction $n +^6 \mathrm{Li} \to \alpha + d + n$ with the registration of secondary alpha particles and neutrons was chosen.
The kinematic simulation according to the technique described in [1] showed that it’s possible to register alpha particles and neutrons on opposite sides of the beam axis at angles of $\sim 90^\circ$ and $\sim 30^\circ$ respectively. Test measurements can be considered successful if there are peaks in the energy spectrum of alpha particles corresponding to the breakup of the ground and excited states of the $^6$Li nucleus in coincidence with the neutron signal. To test the possibility of registration in the coincidence of charged particles and neutrons a prototype of the setup was created (fig. 1). The setup prototype includes a small vacuum scattering chamber with an installed $^6\mathrm{Li_2CO_3}$ target and an $\Delta E - E$ telescope of silicon. A neutron detector based on an organic scintillator makes it possible to distinguish signals from neutrons and gamma quanta by the pulse shape. To measure the neutron energy by time-of-flight the fast $\Delta E - E$ signals of the telescope are used as start impulse. The setup was tested on the neutron beam of the RADEX channel. The obtained experimental data are currently being processed. It’s assumed that the use of the second arm for the registration of charged particles and a thin target will make it possible to significantly expand the program of investigated few-nucleon reactions on the neutron beam of the RADEX channel. It will also be possible to reconstruct the complete kinematics of such reactions with the separation of background and investigated reactions.

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# EXCLUSIVE STUDY OF PRE-EQUILIBRIUM EMISSION OF ALPHA PARTICLES IN ALPHA INDUCED REACTIONS AT MODERATE EXCITATION ENERGY

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During the past few decades, the mechanism of pre-compound (PCN) emission has been a topic of fundamental interest in α-particle induced reactions at low and intermediate energies. Earlier many of the theoretical and experimental studies have triggered the observation of such phenomenon at relatively higher energies. Recent studies showing the observations of PCN emission even at low incident energies where evaporation process dominates, have renewed interest to carry out further research in the aforesaid reaction mechanism [1-4]. In the present work excitation functions for (α,n) and (α,αxn) reaction channels for light, medium and heavy mass targets e.g., $^{55}$Mn, $^{89}$Y and $^{169}$Tm have been analysed with the available reaction model codes ALICE91 [5], PACE4 [6], EMPIRE3.2 [7], Talys1.95 [8] and COMPLET [9]. All these models have been extensively employed to optimize global set of input parameters available with in the codes for reproduction of experimental data available in literature for the said targets.

From the present study it is observed that for (α,n) channels all the model codes satisfactorily reproduced the experimental excitation functions for optimized set of input parameters while the shallowness of dips (valleys) in the experimental excitation functions of the reactions (α,αxn) clearly indicates that the alpha particle might be emitted in the pre-equilibrium phase. The emission of an alpha particle in the pre-equilibrium phase is not included in the other nuclear models except COMPLET. This is the reason for steep valleys in the theoretical curves obtained via other codes as opposed to the shallow dips observed in the experimental excitation functions. The alpha particle emission is treated as an evaporation process in the codes, while COMPLET model gives a better agreement, giving a shallow valley region indicating the inclusion of pre-equilibrium alpha emission in the model.

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# FEATURES OF DATA PROCESSING OF AN EXPERIMENT ON STUDYING PROTON-PROTON CORRELATIONS IN THE d + $^1$H → p + p + n REACTION

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A value of a neutron-neutron scattering length was obtained in different experiments. It can be observed that there is a difference in values of a neutron-neutron scattering length ann (in the range from −16 to −22 fm). In [1] it was suggested that such difference may be explained by influence of 3*N*-forces. It can be assumed that *pp* scattering length (or energy of $^1S_0$ virtual state) extracted in the $d$ + $^1$H → $n + p + p$ reaction will be influenced by 3*N*-forces and will differ from the value obtained in the experiment on the scattering of a proton on a hydrogen target. To test the assumption, INR RAS is currently carrying out work on the study of the $d$ + $^1$H → $n + p + p$ reaction.
Kinematic modeling was carried out according to technique developed at INR RAS. The possibility of extracting Epp and $a_{pp}$ from an experimental energy spectrum of protons was shown. Parameters of the experimental setup for studying this reaction were determined. A scheme of the setup is presented in [2].
It should be noticed that there are two peaks in the modeling energy spectrum of protons. In our investigation protons are detected at an angle close to an angle of departure of the *NN*-system. In reactions with a formation and a breakup of a virtual *NN*-state a "breakup" particle can fly out in the center of mass system either forward (~ 0°) or backward (~ 180°). Only such particles from *NN*-state breakup can fly into the detector. The presence of two peaks in the energy spectrum of protons is explained by that fact. Difference between values of energies in the spectrum depends on energy of the virtual *NN*-state. With an increase of $E_{pp}$ value distance between peaks in the energy spectrum of protons increases. Consequently, analysis of experimental energy spectrum of protons allows determining the value of the virtual singlet *pp*-state energy with some accuracy. Δ*E*-*E*-telescope is used for obtaining experimental energy spectrum. It can be noticed that there is complex dependence of energy losses of protons formed in the reaction $d$ + $^1$H → $p + p + n$ in the detecting Δ*E*–*E* system. Modeling showed that in spite of this fact two peaks are also present in the energy spectrum of proton losses in the *E*-detector.
The energy spectrum of protons corresponding to the $d$ + $^1$H → $p + p + n$ reaction can be obtained as a result of processing experimental data. It is possible to compare experimental and simulated energy spectra of protons with usage minimum $\chi^2$ estimation method. This method permits to establish to which value of virtual singlet *pp*-state energy specific experimental spectrum corresponds. In the work modeling was carried out with various options for settings of detectors and an information collection system.
Determining neutron energy from the time of flight requires a fast start signal from the Δ*E*-*E*-telescope. Parameters of this telescope, in particular, depend on a value of the lower threshold of signal registration. It determines the possible ranges of energies of detected particles, requirements for background conditions and permissible loads of the information collection system. Choice of the threshold value for registration of proton energy by the *E*-detector was made from analysis of simulation results. It corresponds to possibility of determining time intervals that set optimal ratio of effect and background events.

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# REGISTRATION OF $\gamma$-QUANTA FOR DETECTION $^{12}$B AND $^{12}$N - ACTIVITIES PRODUCED AT THE PULSED ELECTRON ACCELERATOR IN REACTIONS $^{13}C(\gamma, p)$; $^{14}N(\gamma, 2p)$; $^{14}N(\gamma, 2n)$

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Study of cross-sections and yields of photonuclear reactions with production of $^{12}$B($T_{1/2}$ ≃ 20.2 ms) and $^{12}$N($T_{1/2}$ ≃ 11.0 ms) is interesting both for development of ideas about nuclear reactions with nuclei-products near the boundaries of stability to nucleon-emission, and for detection of hidden explosives and drugs (see, e.g., [1]) with registration of $^{12}$B- and $^{12}$N- activities.

In [2, 3] we considered characteristic features of emission of γ- quanta, electrons and positrons from targets at decays of produced in them $^{12}$B and $^{12}$N.

In [4] for reactions $^{13}$C(γ, *p*), $^{14}$N(γ, 2*p*), $^{14}$N(γ, 2*n*), we gave analysis of known experimental and model-calculated data (including our own calculated by the widely used models of nuclear reactions). It was shown that new yield measurements are necessary for these reactions because estimated discrepancies of data are on the level of at least one order of magnitude. In [5] there were considered two variants of such experiments with measuring activities of $^{12}$B and $^{12}$N with registration of emitted β- particles or γ- quanta.

In the present work we considered measuring of $^{12}$B- and $^{12}$N- activities at pulsed electron accelerator based on registration of emitted from the target γ- quanta by two NaI-spectrometers (100 mm × ∅150 mm) with usage of the controlled dividers of power supply for the photomultiplier tubes of both scintillation spectrometers [6].

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# POSSIBILITY FOR SEPARATION A SHORT-LIVED COMPONENT ($T_{1/2}$ ~ 1 ms) IN TOTAL QUANTITY OF DELAYED NEUTRONS FROM PHOTOFISSION OF $^{238}$U AT REGISTRATION BETWEEN ELECTRON LINAC PULSES

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At fission of actinide nuclei, fast neutrons are produced, mostly "prompt" neutrons (PN) but also (~2%) "delayed" neutrons (DN with different half-lives $T_{1/2}$). Usually for convenience DN are separated on 6–8 groups according to $T_{1/2}$-values at about 0.2 s < $T_{1/2}$ < 56 s (see, e.g., [1]). But there are some indications about need to search short-lived DN with $T_{1/2}$ down to ~1 ms (see, e.g., [2]).

In our previous works [3–5] we tried to find such short-lived DN-components in time intervals between pulses of linear electron accelerator LUE-8-5 of the INR RAS [6] at the energy of incident electrons $E_e \approx 10$ MeV, duration of each beam pulse ≈3 μs, and their repetition rates (50–300) s$^{-1}$. As we showed in [4] in such conditions after about 7 min of irradiation by beam with stable parameters, flux of all DN with 0.2 s < $T_{1/2}$ < 56 s will be almost constant at an aggregated saturation level (except for some statistical fluctuations). Under these conditions the sought-for short-lived component of DN will give an addition to this level which will decrease exponentially with increasing of $t$ – time after beam pulse (from $t = t_0$ – start of each measuring interval).

In the present work we considered possibility for separation a short-lived component with $T_{1/2}$ = 1 ms from total quantity of DN from photofission of $^{238}$U in dependence as on characteristics of delayed neutrons, namely, $a_i$ – the relative part of the $i$-th group of delayed neutrons, as on characteristics of used registration process: value of $t_0$ and level of accumulated "statistics".

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# REGISTRATION OF DELAED NEUTRONS FROM PHOTOFISSION OF $^{238}$U BY THE SCINTILLATION SPECTROMETER AND DISTORTIONS IN REGISTERED SPECTRA

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In our previous works [1–3] we measured spectra of delayed neutrons (DN) from photofission of $^{238}$U and searched short-lived components in these DN (with half-lives $T_{1/2}$ down to ~1 ms) in time intervals between pulses of linear electron accelerator at the energy of incident on metal U-target electrons $E_e \approx 10$ MeV. Fast neutrons were registered by scintillation stilbene (50 mm × ∅50 mm) spectrometer with discrimination of background γ-quanta using differences in shapes of scintillation pulses. This spectrometer has Pb-shielding (~5 cm-thick). To avoid negative influence on the used scintillation detector from background of γ-quanta and neutrons, produced by beam pulses, the controlled divider of power supply for the photomultiplier tube of the scintillation detector [4] was used (especially for short-lived groups). More details are in [1–4] and in the references therein.

In the present work we considered distortions in registered spectra of DN using Monte Carlo simulation for transport of DN by codes LOENT and SHIELD [5–7] taking into account first of all interactions of DN with atomic nuclei of Pb-shielding for stilbene spectrometer.

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# CLUSTERING AND MICROSCOPICALLY SEPARATED STATES FORMATION IN FISSION POTENTIAL ENERGY CALCULATIONS

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Potential Energy calculations are the basis for static and dynamic studies of the nuclear fission process. Calculation of surface, nuclear, Coulomb, rotational functionals, curvature, congruence, and Wigner energy functionals was recently presented for a wide variety of nuclear shape parameterizations [1].
Current approaches typically aim to achieve a theoretical description of the potential energies and shapes of a fissioning system along the conventional fission valleys. In contrast, we study the whole potential energy surface using a realistic mean field and flexible shape parameterization [2], with the aim of treating specific areas of surface related to the new cluster structure formation. To achieve this, we conducted calculations of the regions of maximum energy, saddle points and partly ridges separating the various passes to fission.
Nucleon localization relative to the cluster formation has been studied based on the realistic mean field calculations [3]. Rearrangement of nucleons gives rise to decentralized dynamics in a fissile system in terms of nucleon degrees of freedom.
Decentralized model approach is suggested with the aim of finding specific requirements needed for the new cluster state formation. Clustering could be simulated as a dynamics of neighboring particles. This type of dynamics occurs when particles can autonomously adapt to their environment. There are many examples in nature where adaptability arises from simple decentralized processes [4].

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# CROSS SECTION MEASUREMENT OF THE $^{13}C(\alpha,n_0)^{16}O$ REACTION IN THE 2-6.2 MEV $\alpha$-PARTICLE ENERGY RANGE

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The $^{13}C(\alpha,n)$ $^{16}O$ reaction cross section plays an important role as the background source in the geoneutrinos measurements and as the source of neutrons for the s-process in nuclear nucleosynthesis. The cross section for its reverse reaction is important for the number of practical applications, including the design of the nuclear power plants, the assessment of helium accumulation in structural materials, and dosimetry. The sets of experimental data on this reaction cross section, as well as the evaluation given in different libraries, differ significantly (20-50%) from each other. The report presents the results of measurements performed by the time-of-flight method on a tandem accelerator at IPPE JSC. The thickness and characteristics of the $^{13}C$ target, as well as the state of the target during measurements, were determined by ion beam analysis methods. The analysis of the influence of multiply scattered neutrons on the measurement results is carried out. The experimental data obtained are compared with the results of other authors and with the evaluated cross sections from the nuclear data libraries.

# SPECIFIC FEATURES OF THE $^{6}$He AND $^{6}$Li NUCLEI IN INTERACTION WITH $\alpha$-PARTICLES

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In recent years, the study of light weakly bound nuclei has not become less interesting due to the development of both experimental facilities and theoretical approaches. The nucleus $^{9}$Be having Borromean structure was the subject of study on its manifestation of cluster in direct nuclear reactions [1]. In particular, it was found that in the $^{9}$Be($d$,$\alpha$)$^{7}$Li nuclear reaction the $^{5}$He heavy cluster is transferred mainly simultaneously, and the contribution of its sequential transfer is an order of magnitude lower. The importance of taking into account the mechanism of sequential transfer of the $n$–$p$ system was revealed. Based on these observations, it was concluded that the $^{9}$Be nucleus may have cluster structure.
There is a need further broaden the theoretical research method, supposed in Ref. [1], with the nuclei $^{6}$He and $^{6}$Li. The experimental data on elastic scattering of $\alpha$-particles by $^{6}$He and $^{6}$Li demonstrate significant growth of cross section at backward angles. Such kind of behaviour is characterized by contribution of the elastic transfer channel [2, 3].
The study of this work is based on the three body wave function using the Gaussian basis [4]. It worth to note that the three body model excludes the Pauli forbidden states by means of the method of orthogonalizing pseudo-potentials [5]. The analysis based on the CRC calculations shows that the major contribution to the elastic transfer cross section is resulted from the di-nucleon transfer channel, whereas the sequential transfer is one order of magnitude lower.

# STUDIES OF THE REACTIONS $^{9}$Be$(,d)$ AND $^{9}$Be$(,)$ IN THE ENERGY RANGE OF 300-1400 KEV

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At present, at low astrophysical energies there is experimental information on the cross sections of the reactions $^{9}$Be$(,d_0)$ and $^{9}$Be$(,_0)$ obtained by different authors [1-14]. Nevertheless, as shown in the review [15], the extrapolation of the S-factors of these reactions to zero energy has a large uncertainty (the difference is up to 10 times). This is partly due to the many resonances present at low energies. For reliable extrapolation of experimental data, for example, by the R-matrix method, it is very important to have accurate experimental data in the regions of the maxima and minima of the available resonances. Obtaining these data for the region $E_{p,\ lab.}$= 300 - 1400 keV the present work that has been carried out at the electrostatic tandem accelerator UKP-2-1 of the Institute of Nuclear Physics (Almaty) is devoted. The Be film of natural isotopic composition ($^{9}$Be ~ 100%) was used as a target. Detailed description of the accelerator and experimental methods can be found in [16, 17] and in their references.
The measurement of the differential cross sections of the reactions $^{9}$Be(p,d$_0$) and $^{9}$Be$(,_0)$ at the range of angles $\theta_{lab.}$ = 200 - 1650 with a step of 100 at $E_{p,\ lab.}$ = 400, 600, 940, 1050, 1200, 1300 and 1400 keV have been carried out with an error of about 15%. We also measured the excitation functions of these processes for the angles $\theta_{lab.}$ = 700 and 1600 in the energy range $E_{p,\ lab.}$ = 300 - 1400 keV with a step of 10 - 20 keV. Within the limits of error, the results of the present experiment coincided with the literature data in the overlapping areas.

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# MICROSCOPIC ANALYSIS OF ELASTIC SCATTERING OF ONE-PROTON HALO NUCLEUS $^{17}$F ON DIFFERENT MASS TARGETS

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An analysis of cross sections of elastic scattering of $^{17}$F on $^{12}$C, $^{14}$N, $^{58}$Ni, and $^{208}$Pb nuclei at energy 170 MeV and on $^{208}$Pb at various energies is carried out by using the microscopic optical potentials (OPs). The proton and neutron density distributions of the exotic nucleus $^{17}$F are computed in the framework of microscopic models. The real part of the OP is calculated by a corresponding folding procedure accounting for the anti-symmetrization effects, while the imaginary part is obtained on the base of the high-energy approximation [1]. In the hybrid model of the optical potential developed and explored in our previous works [2,3] the only free parameters are the depths of the real and imaginary parts of the OPs obtained by fitting the experimental data. A good agreement of the theoretical results with the available experimental data is achieved pointing out clearly to a peripheral character of the scattering.

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# REACTION CROSS SECTIONS FOR $^{10,11,12}$Be BEAM IONS ON $^{28}$Si, $^{59}$Co, $^{181}$Ta TARGETS

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Total reaction cross section ($\sigma_R$) values for interaction $^{10,11,12}$Be cocktail beam particles with $^{28}$Si, $^{59}$Co, $^{181}$Ta target nuclei in the energy range 12–48 A·MeV are presented. Experimental method of direct measuring of $\sigma_R$ is based on detection of prompt n, γ radiation by 12 CsI(Tl) detectors γ-spectrometer [1] was used. A comparison of the two methods for calculating the total cross sections of reactions will be presented. The first technique involves the use of averaged multiplicity. The second technique takes into account the experimental values of the registration efficiency of gamma radiation for various multiplicity of the spectrometer detectors [2].

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# TIME-DEPENDENT DESCRIPTION OF REACTIONS WITH WEAKLY BOUND NUCLEI $^{11}$Li, $^{11}$Be

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Numerical solution of the time-dependent Schrödinger equation [1-3] is used for studying the dynamics of breakup reaction and nucleon transfer at energies above the Coulomb barrier. The spin-orbit interaction is taken into account [2]. The evolution of the wave functions for an outer weakly bound two neutrons of $^{11}$Li nucleus and one neutron of $^{11}$Be in collisions with $^{28}$Si and $^{48}$Ti [3] nuclei is studied (see Fig. 1). The cross sections for the stripping of the outer nucleon due to transfer and breakup are calculated.

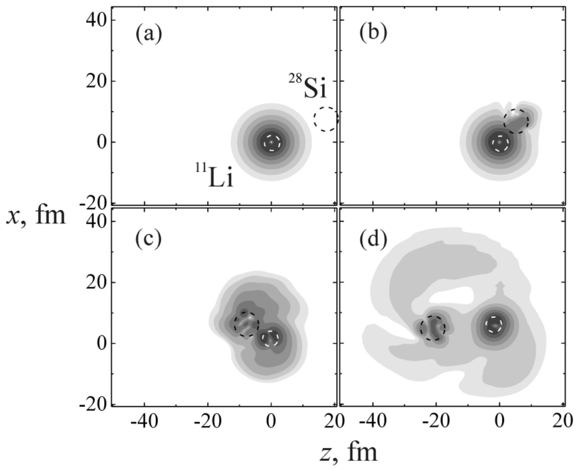


Figure 1: Evolution of the probability density for the outer neutrons of $^{11}$Li with initial state $1p_{1/2}$ in collision $^{11}$Li + $^{28}$Si for $E_{\text{c.m.}}$= 79 MeV, along with impact parameter $b = 7$ fm in a reference system moving relative to the laboratory system with a constant velocity equal to that of a projectile at a fairly large distance from the target nucleus. The course of time corresponds to the panel locations (a), (b), (c), (d). Greyscale gradation in the logarithmic scale is used. The radii of the circles correspond to those of nuclear cores of 2.4 fm and 3.8 fm respectively.

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# ELASTIC HAPRON SCATTERING ON THE $^{7}$Be NUCLEUS AT INTERMEDIATE ENERGIES

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The study of the scattering of hadrons with nuclei is a key element of the theory of the atomic nucleus and nuclear reactions. This is a test that allows one to investigate both the structure of the nucleus and the nuclear interaction. The best studied both experimentally and theoretically is the scattering of protons. For example, a large cycle of studies on the structure of light exotic nuclei by means of scattering of intermediate-energy protons was carried out by the GSI-PNPI collaboration (Germany-Russia). The experiments were carried out on a GSI radioactive beam (Darmstadt, Germany) in inverse kinematics, at an energy of 0.7 GeV / nucleon, in the range of momentum transfers $0.002 \le |t| \le 0.05$ (GeV/c)$^2$. The same scientific collaboration recently carried out a similar new and very important experiment [1] for $^{7}$Be and $^{8}$B nuclei.

The choice of these nuclei as the object of research is not accidental. These nuclei are associated with the currently most discussed nuclear physics application - nuclear astrophysics. The 8B nucleus is formed on the Sun as a result of the $^{7}$Be (p, γ) $^{8}$B reaction and emits a high-energy neutrino, which can be experienced in ground-based experiments. The proton capture rate in 7Be strongly depends on the structure of $^{8}$B. The size of $^{8}$B and the shape of the proton density distribution at large distances determine the rate of proton capture and can be used in theoretical calculations of the solar neutrino flux. Therefore, a comprehensive study of the structure of these nuclei in different ways, and primarily through hadron scattering, is an important task.

In this work, we carry out a theoretical analysis of small-angle scattering of 0.7 GeV hadrons by a $^{7}$Be nucleus within the framework of Glauber's diffraction theory. The external parameters of Glauber's theory are the wave function of the target nucleus and the elementary amplitudes of the interaction of an incident particle with nucleons and nucleon clusters of the nucleus. We describe the internal state of the $^{7}$Be nucleus in a dynamic two-cluster (α-τ) model with forbidden states. This wave function describes well the main characteristics of both the ground and low-excited states of the nucleus under study. The next external parameter of Glauber's theory is the elementary amplitudes of hadron-nucleon and hadron-cluster scattering. They are usually parameterized for the energy region of interest from independent experimental data. In our problem, the α-particle is considered structureless and for it in the scientific literature there are parameters of elementary amplitudes, while there are no parameters for hadron-τ scattering. Therefore, the interaction of an incident proton and mesons with a τ-cluster is expressed through interactions with individual nucleons entering this cluster.

Within the framework of the diffraction theory, we obtained here an expression for the matrix elements of elastic p$^{7}$Be- and π$^{7}$Be scattering. The wave function of the target nucleus is expanded in Gaussian, so all the integrals in the matrix element are taken analytically. This greatly improves the accuracy of the calculation. We will not present the expression for the matrix element itself because of its cumbersomeness. The calculations performed on the scattering of protons are in good agreement with the experimental data. Unfortunately, experimental data are available only for small proton scattering angles. We carried out theoretical calculations up to scattering angles of 40 °, taking into account single and double scattering. A similar calculation of the cross section was also performed for the scattering of π-mesons. A comparative analysis of the obtained results is made.

This work was carried out within the framework of the scientific project AR08855589.

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# STUDIES OF ISOMERIC STATES OF NUCLEI ON THE PROTON BEAM OF THE PHASOTRON AND ELECTRON BEAM OF THE LINAC-200 ACCELERATORS AT JINR USING THE $^{209}$Bi, $^{238}$U, $^{165}$Ho TARGETS

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The experiments in the framework of the project "Energy and Transmutation" were carried out with the use of the Phasotron and LINAC-200 accelerators at JINR. The samples were placed in the neutron fields produced by the interaction of the proton beam with the lead target or in the bremsstrahlung radiation fields, which were produced in the lead converters irradiated with the electron beams. Gamma spectra of the activated samples were measured using HPGe detectors. The measurement times were from a few minutes to several hours. The yields of the nuclei and their half-life times were studied. Gamma spectra were measured using HPGe detectors on the spectrometric complex at YASNAPP-LNP and LHEP JINR.

- The bismuth and lead residual nuclei in the $^{209}$Bi target as the results of (γ, xn) reactions were identified to A =199.
- In the (γ, f) fission and (n, γ) capture reactions, when using the $^{238}$U target, more than 30 nuclei of fragments were identified and the fission curve was obtained (see the report of the conference).
- In the irradiation of $^{165}$Ho in the field of the bremsstrahlung radiation with an energy of 100 MeV, the decay of the nuclei and their isomeric states were observed to A = 156.

In the result of the experiments on the bremsstrahlung radiation, we observed all the isomeric states in the nuclei of the Holmium with A = 155 ÷ 165 [1, 2, 3].

The decay of some nuclei of the holmium and their isomers are shown in Figure 1.

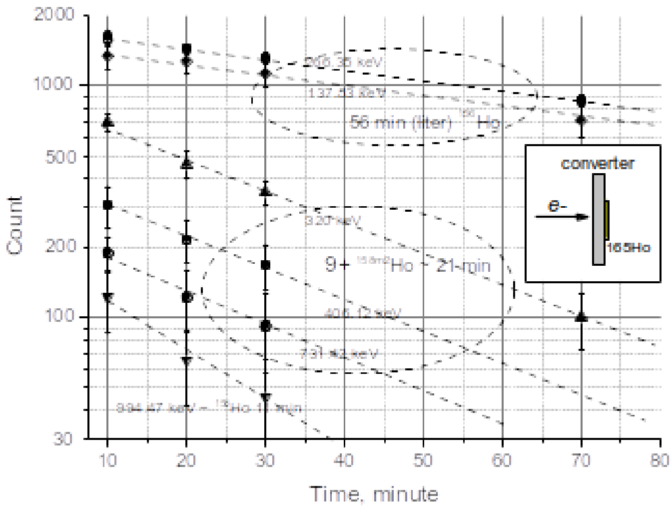


Figure 1: The decay of the holmium nuclei.

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# THE FIRST EXPERIMENTS AT E = 180 MEV ON THE ELECTRON BEAM OF THE LINAC-200 ACCELERATOR TO DETERMINE ISOMERS OF BISMUTH AND LEAD

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In the framework of the "Energy + Transmutation" [1] project, the experiments have been carried out at the LINAC-200 accelerator of JINR. The $^{209}$Bi samples were irradiated in the field of bremsstrahlung radiation by the 180 MeV electrons. The bismuth was used as a converter to obtain the bremsstrahlung radiation, Figure 1.

The gamma spectra of the $^{209}$Bi activated samples were studied using HPGe detectors in a range from 40 to 3000 keV on the spectrometric complex at YASNAPP-LNP and LHEP JINR. The identification of the nuclei and their yields obtained in the $^{209}$Bi sample as a result of the irradiation and were carried out under the periods of the half-life time and the ratio of the intensities of the gamma rays in the spectra as well as compared the results with literary data on the study of $^{209}$Bi (γ, xn) reactions [2]. The yields of the bismuth nuclei obtained in (γ, xn) reactions at the electron energies E = 60 and 180 MeV are shown in Figure 1.

The yield of the isotopes with A = 202 for E = 180 MeV is up to more than ten times compared with the yield at E = 60 MeV, which makes it possible to effectively study the isomers and structure of the bismuth nuclei and lead with masses of A from 199 to 203.

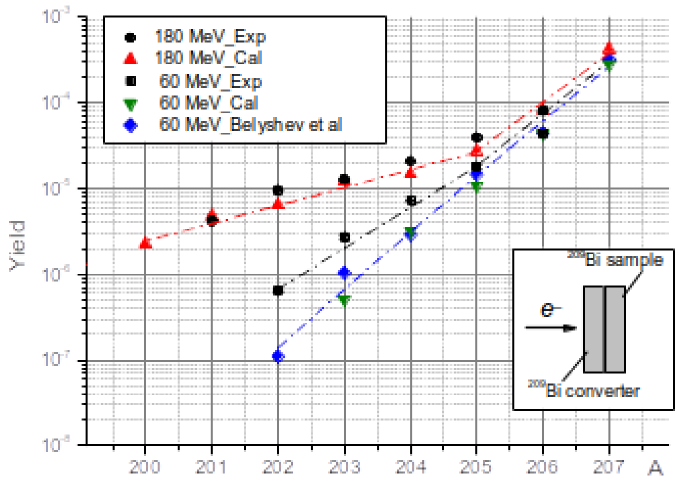


Figure 1: The relative yields of the (γ, xn) reactions in $^{209}$Bi.

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# SPIN-CORRELATION EXPERIMENT FOR INVESTIGATING DD REACTIONS IN PNPI

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After Leemann et al. [1] experimentally demonstrated that the thermonuclear reaction cross section of $^3He(d,p)^4He$ could be increased by a factor of 1.5 by using polarized reactants, theorists [2] showed that the same effect could be achieved with other reactions, in particular, in $^2H(d,p)^3H$ and $^2H(d,n)^3He$. The usage of polarized particles could lead to improvements of future thermonuclear reactors. However, there are no experiments performed with both polarized deuterons at energy below 100 keV due to its complexity and high cost. Low cross-sections and cosmic background are the biggest issues of the experiment.
PNPI Gatchina (Russia) in collaboration with Forschungszentrum Juelich (Germany) and INFN University of Ferrara (Italy) have been carring out the first low-energy spin-correlation experiment POLFUSION [3] with both reactants polarized. Two polarized beam sources have been brought to Gatchina from KVI (Groningen, Netherlands) and University of Ferrara with necessary improvements [4]. The $4\pi$ detector system to measure the angular distributions of the fusion products has been developed by PNPI. It consists of 576 silicon PIN photodiodes arranged in a cubic structure.
POLFUSION sets the goal to measure vector and tensor analyzing powers, spin correlation coefficients, quintet state suppression factor of dd reactions with various combinations of polarization directions. The results will allow to solve the discrepancy between different theoretical predictions. The experimental setup is described. Results of the test-run in 2020 are presented. Details of future plans are discussed.

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# POTENTIALS FOR $\alpha$+$^{116,122,124}$SN ELASTIC SCATTERING

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The present work reports the analyses of the experimental angular distributions of $\alpha+^{116,122,124}$Sn elastic scattering in terms of the non-monotonic (NM) and modified single-folded (MSF) potentials. These two types of optical model (OM) potentials have enjoyed success in explaining the $\alpha$-induced elastic scattering and non-elastic processes on several targets [1-4]. The NM potential is a complex potential having a soft repulsive core in its real part which has its root in the energy-density functional (EDF) theory of Brueckner, Coon and Dabrowski (BCD) [5]. The MSF potential, on the other hand, is a semi-microscopic single-folded potential [4] based on the combined distributions of $\alpha$-like clusters and unclustered nucleons in the target. Empirically adjusted imaginary potentials are used in conjunction with the real potential to reproduce the experimental $\alpha+^{116,122,124}$Sn elastic scattering data. Two sets of real NM potentials have been found through the analysis using the unshifted and shifted repulsive cores respectively termed as Set-1 and Set-2 potentials. The volume integral per nucleon pair for the real part of the Set-1 and Set-2 potentials has been found to be ~100 MeV.fm$^3$ which is normally expected for the NM potential. The closeness of the fits to the data using the real potential with unshifted repulsive core and with shifted repulsive core suggests that the effect of the potential shape in the central region of the target is not that significant in determining the cross-sections and the scattering is dominated by the nuclear potential at the surface of the target nuclei. The MSF potential, without any renormalization, satisfactorily describes the $\alpha+^{116,122,124}$Sn elastic scattering data for the energies considered herein. The number of nucleons making ⍺-like clusters is deduced as $4A_\alpha = 88$ for all the three isotopes of Sn, while the number of unclustered nucleons has been found as $A_N =$ 28, 34, and 36 for $^{116}$Sn, $^{122}$Sn, and $^{124}$Sn respectively in the time-average picture.

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# POSSIBILITY OF IDENTIFYING THE VIRTUAL COMPONENT IN SCISSION NEUTRONS

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Experimental measurements of angular and energy distributions of fission neutrons $n(\theta, E)$ per fission event were carried out in [1-4] assuming that $n(\theta, E) = n_{ev}(\theta, E) + n_{sc}(\theta, E)$, where $E$ is asymptotic kinetic energy of a neutron, $\theta$ is angle between the directions of the outgoing neutrons and the light fission fragment, $n_{ev}(\theta, E)$ is number of prompt neutrons evaporated from light and heavy fission fragment, $n_{sc}(\theta, E)$ is number of scission neutrons. These measurements corresponded to the cases of spontaneous fission of the $^{252}$Cf nucleus and thermal neutron-induced fission of $^{233}$U, $^{235}$U and $^{239}$Pu target nuclei. Also, in these papers a theoretical calculation of the prompt neutron distributions $n_{ev}(\theta, E)$ was carried out. The value $B(\theta, E) = \frac{n(\theta,E)}{n_{ev}(\theta,E)} = 1 + \frac{n_{sc}(\theta,E)}{n_{ev}(\theta,E)}$ was further constructed, and it can be used to calculate $n_{sc}(\theta, E)$ by the formula
$n_{sc}(\theta, E) = \frac{(B(\theta,E)-1)n(\theta,E)}{B(\theta,E)}$.
Unfortunately, the approaches used for calculations $n_{sc}(\theta, E)$ require a certain adjustment, since at definite angles $\theta$ they lead to $B(\theta, E) < 1$, which corresponds to $n_{sc}(\theta, E) < 0$,which is impossible due to the positive definition of $n_{sc}(\theta, E)$.

In the present paper, for all studied nuclei, the appearance of a peak for $n_{sc}(\theta, E)$ in the vicinity of the angle $\theta = 90°$ for $50° \leq \theta \leq 125°$ is demonstrated, which is a direct indication of the emission of scission neutrons from the neck of a compound fissile nucleus. At the same time the energy spectrum $n_{sc}(\theta, E)$ in the specified range of angles corresponds to the energies of neutrons lying in the range of $0 \leq E \leq 1$ MeV. Since these neutrons are emitted from neutron states of a compound fissile nucleus corresponding to binding energies about (- 6) MeV, so the appearance of these neutrons in continuous spectrum states with positive energies $0 \leq E \leq 1$ MeV and emission angles in the vicinity of the angle $\theta = 90°$ can be explained [5] by considering the emission of these neutrons from the neck of a compound fissile nucleus analogously to the light particle emission in ternary nuclear fission.

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# STUDY OF REACTIONS WITH PROTON EMISSION AT $E_{MAX}$ = 20 MEV ON NATURAL AND ENRICHED HAFNIUM TARGETS

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The study of the cross-sections and yields for the population of high-spin isomeric states in reactions with the charged particles emission makes it possible to get information on the exciting levels' structure in the continuous and discrete regions of excitation as well as on the mechanisms of the nuclear reaction occurrence. Therefore, our work aims to investigate the production yields of Lu-(179m+g) and Lu-178m in reactions with bremsstrahlung gamma quanta for energies in the giant dipole resonance region.

The weighted average yields were measured by the activation method using γ-quanta bremsstrahlung for electrons with the 20 MeV maximum energy on targets of natural metallic hafnium and enriched hafnium Hf-180 in powdery form.

The spectra of irradiated targets were measured by the Canberra and Ortec HPGe spectrometers with the (15-40)% detection efficiency compared to the 3'×3" NaI (Tl) detector. The spectrometers' energy resolution was 1.8–2.0 keV on the Co-60 1332 keV γ-line.

The gamma transitions from the Lu-(179m+g) and Lu-178m decays are reliably distinguished in the studied spectra.

The Lu-179m+g weighted average population yield was measured for the (γ, p)-reaction on Hf-180, and Lu-178m weighted average population yield was measured for the (γ, p)-reaction on natural hafnium at the 20 MeV maximum value of the γ-ray bremsstrahlung for the first time.

The following values of the weighted average yields were obtained: for $^{180}$Hf(γ, p)$^{179m+g}$Lu-reaction 185(49) µbn, for $^{179}$Hf (γ, p) $178m$Lu -reaction 12.7 (21) µbn.

We stated the dominance of non-statistical processes as a modeling result within the framework of the TALYS-1.9 program code. The obtained data are discussed.

This research was performed according to the Development program of the Interdisciplinary Scientific and Educational School of Lomonosov Moscow State University «Photonic and Quantum technologies. Digital medicine».

# DETERMINATION OF PHOTONEUTRON PRODUCTION FROM DIFFERENT TARGETS IRRADIATED BY ELECTRON BEAM

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This research focused on photoneutron production determination using two different photoneutron converters BeO, $D_2O$. Experiment was carried out on a linear electron accelerator [1] in A. Alikhanyan National Laboratory in Yerevan, Armenia. A set of targets was irradiated by 70MeV electron beam. Reaction rates were determined as a result of investigations. Besides experimental results, a number of simulations were also conducted using MCNP software [2] to determine reaction rates and they were compared with ones obtained from the experiment.

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# STUDY OF THE EXCITED STATES OF $^{46}$Ti AND $^{45}$Ti NUCLEI IN THE $^{45}$Sc + $^{3}$He REACTION AT A $^{3}$He BEAM ENERGY OF 29 MEV

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The angular distributions for the emission of deuterons in the $^{45}$Sc($^{3}$He,d)$^{46}$Ti reaction were measured; based on the change in the energy of deuterons, we determined the cross sections for population of the ground and excited states of the $^{46}$Ti nuclei formed in this reaction at energy 29 MeV of the $^{3}$He bombarding particles. The measured angular distributions for the excited states of the $^{46}$Ti nuclei were compared with the data obtained for this reaction at energy 37.7 MeV of $^{3}$He [1].

Comparison of the angular distributions for the ground and excited states of $^{46}$Ti with DWBA calculations carried out in [1] showed that when protons are stripped from $^{3}$He, transfer of angular momenta 3 and 1 occurs, which corresponds to population of the shells $1f_{7/2}$ and $2p_{3/2}$, respectively. The rearrangement of nucleons in the unoccupied shells $1f_{7/2}$ and $2p_{3/2}$ leads to excitation of both collective and particle-hole states with different angular momenta. The energy spectra of $^{46}$Ti obtained in the experiment were analyzed within the framework of the cluster model of the di-nuclear system [2].

In the case of charge exchange reactions $^{45}$Sc($^{3}$He,t)$^{45}$Ti, we also observed a number of excited states of the $^{45}$Ti nucleus [3]. None of the studied excited states in $^{45}$Ti exhibit a pronounced collective structure.

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# INVESTIGATION OF $(d, d)$ AND $(d, t)$ REACTIONS ON $^{11}$B NUCLEI AT ENERGY OF 14.5 MeV

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The differential cross sections of elastic and inelastic scattering of deuterons on $^{11}$B nuclei with excitation of low-lying states of 0.0 MeV ($3/2^-$), 4.445 MeV ($5/2^-$) and 6.74 MeV ($7/2^-$), as well as the reaction (d,t) with transitions to the ground ($0^+$) and excited states with energies of 0.718 MeV ($1^+$), 1.74 MeV ($0^+$, T = 1), and 2.15 MeV ($1^+$) have been measured at an energy of 14.5 MeV. From the scattering analysis, the optical potentials of the $^{11}$B + d system were found, with which a good description of the experimental sections of elastic and inelastic scattering in the full range of angles was obtained, and the value of the quadrupole strain parameter $\beta_2$ = 0.80 ± 0.2 was extracted in accordance with the results obtained from scattering of protons, $\alpha$ particles and $^3$He.
Assuming a direct neutron capture mechanism in reaction (d, t), it is possible to describe fairly well the angular distributions for transitions to the ground ($0^+$) and excited states with energies of 0.718 MeV ($1^+$), 1.74 MeV ($0^+$, T = 1), and 2.15 MeV ($1^+$) $^{10}$B nucleus. Spectroscopic amplitudes extracted from the analysis are consistent with the theoretical predictions of the shell model. The possible contribution to the reaction of the exchange mechanism of the transfer of the heavy $^8$Be cluster in the reaction $^{11}$B (d,$^{10}$B) t, which is physically indistinguishable from the reaction (d, t), is estimated. It was shown that both single-stage (with $^8$Be transfer) and two-stage (with sequential transfer of $\alpha$-particles) mechanisms do not play a significant role at a deuteron energy of 14.5 MeV.

# ASTROPHYSICAL S-FACTOR $S_{1\,16}$ EVALUATION USING ANCS $^{17}$F→$^{16}$O+P FROM ANALYSIS OF THE $^{16}$O($^{10}$B,$^{9}$BE)$^{17}$F REACTION

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Knowledge of the asymptotic normalization coefficients (ANC) for the resulting single-particle bound configurations in the final nucleus (or nuclear vertex constants which differ only by a multiplier from ANCs) [1], plays a crucial role in the calculations of direct nuclear-astrophysical processes of radiative capture [2].
Particularly, to extrapolate the astrophysical S factor $S_{1\,16}(E)$ of the $^{16}$O(p,γ)$^{17}$F reaction, which plays an important role in cold CNO cycle of hydrogen burning, it is required to know the corresponding ANCs for $^{16}$O+p→$^{17}$F. These values can be conveniently and reliably extracted from the analysis of nucleon transfer in reactions with heavy ions at near-barrier energies.
The differential cross sections (DCS) of the reaction $^{16}$O($^{10}$B,$^{9}$Be)$^{17}$F measured at $^{10}$B ions beam of the C-200P cyclotron of the Heavy Ion Laboratory (University of Warsaw) with the energy $E_{10B}$=41.3 MeV have been analyzed using the modified DWBA method [3,4]. Domination of the peripheral proton transferring was found to both proton bound states in $^{17}$F nucleus and the ANC for bound $^{17}$F→$^{16}$O+p configurations were extracted for the ground (5/2+) and first excited (E*=0.495 MeV, ½+) states. At that the squared ANC $(C_{^{10}B\to{}^{9}Be+p})^2$ [5] was used as the DCS of the reaction should be normalized by the product of the ANCs squares $(C_{^{10}B\to{}^{9}Be+p})^2\times(C_{^{17}F\to{}^{16}O+p})^2$.
Since the reaction 16O(p,γ)17F occurs through the direct radiative capture of protons at energies below $E_p$ = 2.5 MeV (lab), the modified two body potential approach [6] was used to calculate the astrophysical S-factor $S_{1\,16}$. The obtained value of total $S_{1\,16}(0)$ within the margin of error consistent with the value obtained in [7].

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# RADIATIVE CAPTURE IN THE $^{4}$HE + $^{2}$H SYSTEM IN THE FRAMEWORK OF A MICROSCOPIC APPROACH

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The nuclear $^{4}$He + $^{2}$H system is of great importance to nuclear astrophysics. Radiative capture proceeding in this system is responsible for production of the $^{6}$Li nuclei during the primordial nucleosynthesis. In this work, the $^{4}$He + $^{2}$H radiative capture is considered from the microscopic viewpoint within a developed approach [1, 2] based on clustering aspects of nuclear structure and dynamics and formalism of expansions over the oscillator basis. The cross section in terms of the astrophysical $S$ factor for the reaction are calculated. The low-energy dependence of the astrophysical $S$ factor serves as a source of information useful for the so-called second "lithium puzzle". A comparison of the calculated results with experimental data is performed.

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# CREATION OF RADIOACTIVE C-14 UNDER THUNDERSTORM ATMOSPHERIC FLASHES

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The occurrence of lightning is preceded by the fast development of electron avalanche in electric fields with strengthof about ~ 300 kV/m [1]. The growth of avalanche in number of relativistic electrons ensures an energetic terrestrial gamma-ray bursts, that can ensure the photonuclear reactions on atmospheric isotopes (with significant cross sections for hard photons $E_\gamma$ =20-60 MeV ) in the main neutron production channels ($^{14}\mathrm{N}(\gamma,n)^{13}\mathrm{N}$, $^{16}\mathrm{O}(\gamma,n)^{15}\mathrm{O}$, $^{40}\mathrm{Ar}(\gamma,n)^{39}\mathrm{Ar}$). In turn the knowing of the neutron flux allows to evaluate the generation of radiocarbon $^{14}\mathrm{N}(n,p)^{14}\mathrm{C}$, and another isotopes in the reactions $^{40}\mathrm{Ar}(n,\gamma)^{41}\mathrm{Ar}$, $^{14}\mathrm{N}(n,a)^{11}\mathrm{B}$, $^{14}\mathrm{N}(n,\gamma)^{15}\mathrm{N}$ [2,3].
It was proposed the spherical-layer-model for calculation of radiocarbon C-14 (knowledge of which creation is exclusively important for radiochronology) and other isotope production in the air under thunderstorms. The simulation were realized at the several altitudes of the lower part of the atmosphere at the altitudes: 1, 3, 5, 7, 10, 13 and 15 km. Decrease of the atmospheric densities at increase of the altitude is critical for electron avalanche evolution and is included in the model. It was obtained that yield of radiocarbon C-14 cannot compete not only with it cosmogenic production (but it also significantly lower compare to the yield from Sun irradiation) that allows to take off the problematic and discussed question on it significant yield to the total production in the Earth atmosphere (~ 472 g-mole/year) under thunderstorms.
An unimportance of thunderstorm $^{14}$C yield is agreed with increase of radiocarbon in tree rings in the time distance AD 774–775 at intensive Sun activity [4].

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# 6LI(D,P0)7LI, 6LI(D,P1)7LI*(0.478 MEV), 6LI(D,P2)7LI*(4.63 MEV), 6LI(D,P4)7LI* (7.46 MEV) REACTION CROSS SECTION

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Upgraded evaluation of integral cross sections of 6Li(d,p0), 6Li(d,p1), 6Li(d,p2), 6Li(d,p4) reactions was obtained in our SaBa (SarovBase) library due to appearance of new experimental data. Data were derived from the results of our experimental studies of 6Li+d reaction channels at 4 to 10 MeV deuteron energy Ed [2]. The reliability of the obtained data was confirmed by the fact that the sum of the 6Li(d,p0) and 6Li(d,p1) reactions integral cross sections was approximately equal to the sum of the integral cross sections of the 6Li(d,n0) and 6Li(d,n1) corresponding mirror reactions [3] at the energy points within this interval. Cross sections of the other dp-reactions where tritons are produced are shown in fig.1. These cross sections were also taken into account when 6Li(d,xt) reaction cross sections had been obtained. Data were supplemented at 10.7 and 12.1 MeV energy by 6Li(d,n2), 6Li(d,n4) reaction cross sections [10] which are mirror reactions for 6Li(d,p2) and 6Li(d,p4) reactions, respectively.

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# STUDY OF FUSION, TRANSFER, AND BREAKUP REACTIONS WITH WEAKLY BOUND NUCLEI 6,8HE

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Fusion cross sections $\sigma_{\mathrm{fus}}$ for the strongly bound nucleus $^{4}$He and the weakly bound nuclei $^{6,8}$He have differences in the width of the main maximum of the barrier distribution function $D(E) = d^2\left(E\sigma_{\mathrm{fus}}\right)/dE^2$ [1] near the Coulomb barrier (see Fig. 1). It indicates the differences in the mechanisms of interaction of these projectiles with target nuclei. These differences are the result of correlation between the relative motion of nuclei and their internal degrees of freedom. For simplicity, we use the model of discretization of barrier distributions and multi-dimensional potential barriers. We assume that the cross sections for fusion and transfer channels may be represented as combinations of the cross sections for the finite numbers of one-dimensional radial Coulomb barriers $V_i(r)$ with weights $w_i$ determined by fitting of experimental barrier distribution functions and fusion cross sections. Numerical solution of the time-dependent Schrödinger equation [2] and the coupled channel method [3] are used to investigate the dynamics of transfer and breakup reactions of $^{6,8}$He nuclei in the interaction with $^{197}$Au, $^{208}$Pb nuclei at energies near and above the Coulomb barrier and to calculate the cross sections of these reactions.

# DECAY BRANCHING RATIO OF MAIN AND EXCITED STATES OF $^{11}$B NUCLEUS PRODUCED BY NEUTRON FROM 1 TO 6 MEV

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Decay branching ratio of main and excited state of $^{11}$B in the interaction of neutron and $^{10}$B in energy between 1 and 6 MeV is studied. The experiment is performed at the photoneutron source of the Institute for Nuclear Research of Russian Academy of Sciences. Neutron detector based on the $^{10}$B-layer which served as both target and cathode of wire chamber for detecting secondary nucleus ionization losses is used [1]. Trigger of neutron lower than 0.5 MeV energy is suppressed by both cadmium filter and high threshold setting.
Branching ratio of $n +^{11}\mathrm{B} \rightarrow^{7}\mathrm{Li} +^{4}\mathrm{He}$ and $n +^{11}\mathrm{B} \rightarrow^{7}\mathrm{Li} +^{4}\mathrm{He} + \gamma$ reactions is determined using pulse height spectra and correlation from two detector gap signals together with $^{7}$Li and $^{4}$He ionization loss simulation taking into account kinematics of each reaction.

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# A SYSTEMATIC STUDY OF EXCITATION FUNCTIONS OF VARIOUS EVAPORATION RESIDUES IN HEAVY ION REACTIONS AT MODERATE EXCITATION ENERGY: INCOMPLETE FUSION VS COMPLETE FUSION

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Study of heavy ion induced reactions with special reference incomplete fusion (ICF) and complete fusion (CF) process has been a subject of paramount interest of nuclear physicists working on heavy ion (HI) nuclear reactions at low and intermediate energies [1–4]. Measurement and analysis of excitation functions of various evaporation residues populated in nuclear reactions induced by heavy ions (HIs) occurring at near and above barrier energies provides inimitably sensitive probes of the actual reaction dynamics mostly associated in heavy ion interactions. Present work is an attempt to exclusively measure and study the excitation functions (EFs) of evaporation residues populated in 12C+159Tb system at energies ≈ 4.5 − 6.5 MeV/nucleon. The stacked foil activation technique followed by offline $\gamma$ − ray spectroscopy
with a high-resolution HPGe detector has been employed. The experimentally measured excitation functions are compared with the theoretical predictions obtained from statistical model code PACE-4 [5]. For xn and/or pxn channels, the experimentally measured excitation functions are found to be in good agreement with theoretical predications. However, in case of $\alpha$ emitting-channels, the measured EFs had significantly more production cross-section values than PACE-4 predicated values, which may be credited to the incomplete fusion (ICF) of the projectile with the target nucleus. The coupled channel (CC) calculations are also performed using a modified version of the code CCFULL [6] for the present system. CC calculation performed using the code CCFULL do not take into account the coupling to unbound or continuum state and hence the breakup of the incident projectile is not considered into account. The experimental data have been compared to the result of CC calculation. A good description of the experimentally measured CF cross section data can be obtained by multiplying the CC calculation, by a factor of 0.89. Thus, it can be concluded that experimentally measured CF cross sections for 12C+159Tb system have been suppressed by 11% in comparison to value predicted by CC calculations performed by using the code CCFULL.

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# ALPHA DECAY OF POLONIUM ISOTOPES USING DIFFERENT CHOICES OF ASSAULT FREQUENCY

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The alpha (α) emission is one of the prominent ground state decay mechanism, which is used as investigating tool to understand the relative stability of a nuclear isotopes. In last few decades, many experimental and theoretical attempts were made to understand the cluster-core interplay of radioactive nuclei. The preformed cluster model (PCM) [1,2] have successfully explored α-particle and other ground state decay modes in recent years. In this methodology, cluster is supposed to be preformed inside the mother nucleus and the preformation probability of decaying fragment serves as an important tool to investigate the half-life and the decay constant. The relative stability of a nucleus depends on the decay constant which is the product of three factors such as assault frequency (ν0), penetration probability (P) and the preformation probability (P0). In this work, we have used the classical and quantum mechanical assault frequency in reference to [3]. Classically, it is considered that alpha particle move back and forth inside the nucleus. In the quantum mechanical approach the alpha particle is considered to be vibrating near the surface of parent nucleus, under the influence of harmonic oscillator potential. A comparative study is carried out for the alpha decay of Polonium (Po) isotopes (having mass AP=188-218) within the framework of PCM. The fragmentation potential, preformation probability and penetration probability of considered Po isotopes are investigated. The relevant role of proton (Z) and neutron (N) magic shell closures of the daughter nuclei is worked out. The PCM calculated α-decay half-lives are calculated using both assault frequency approaches and compared with the available experimental data [4].

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# NON-STATISTICAL NATURE OF FRAGMENTS' SPIN DISTRIBUTIONS IN BINARY NUCLEAR FISSION

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Since for spontaneous and low-energy induced fission, compound fissile nuclei and primary fission fragments in the vicinity of the scission point are in cold nonequilibrium states [1], when constructing the spin distributions of these fragments, it is necessary to take into account [2,3] only zero transverse bending- and wriggling-vibrations of the indicated fissile nuclei. Expressing the normalized distribution function of $W\left(\mathbf{J_1},\mathbf{J_2}\right)$ fission fragments over spins $\mathbf{J_1}$ and $\mathbf{J_2}$ in terms of the product of the squared moduli of the wave functions of zero bending- and wriggling-vibrations, one can obtain [4]:

$$W\left(\mathbf{J_1},\mathbf{J_2}\right)=\frac{4J_1J_2}{\pi C_bC_w}\exp\left[-\frac{1}{2}\left(\frac{1}{C_b}+\frac{1}{C_w}\right)\left(J_1^2+J_2^2\right)+\left(\frac{1}{C_b}-\frac{1}{C_w}\right)J_1J_2\cos\phi\right], \quad (1)$$

where $\phi\,(0\leq\phi\leq 2\pi)$ is the angle between the two-dimensional spin vectors of fragments $\mathbf{J_1}$ and $\mathbf{J_2}$ lying in plane $XY$. By integrating in (1) over variables $J_2$ and $\phi$, one can obtain [4] the normalized distribution of spin $J_1$ of the first fission fragment and estimate the average value $\bar{J}_1$ of spin $J_1$:

$$W(J_1)=\frac{4J_1}{C_b+C_w}\exp\left[-\frac{2J_1^2}{C_b+C_w}\right], \bar{J}_1=\int\limits_0^\infty J_1W(J_1)dJ_1=\frac{1}{2}\sqrt{\frac{\pi}{2}}(C_b+C_w)^{1/2}. \quad (2)$$

For a fissile nucleus $^{236}$U at values [4] of parameters $M_w=1.6\cdot 10^6\mathrm{MeV}\cdot\mathrm{Fm}^2\cdot\mathrm{s}^2$; $M_b=2.0\cdot 10^6\mathrm{MeV}\cdot\mathrm{Fm}^2\cdot\mathrm{s}^2$; $K_w=295\mathrm{MeV}\cdot\mathrm{rad}^{-2}$; $K_b=52\mathrm{MeV}\cdot\mathrm{rad}^{-2}$; $\hbar\omega_w=2.3\mathrm{MeV}$; $\hbar\omega_b=0.9\mathrm{MeV}$; $C_w=132\hbar^2$ and $C_b=57\hbar^2$, it follows that the energies of vibrational quanta $\hbar\omega_w$ and coefficients $C_w$ for wriggling-vibrations turn out to be noticeably larger than those for bending-vibrations. This means that the main contribution to $\bar{J}_1$ (2) comes from wriggling vibrations. Then the calculated value $\bar{J}_1=8.6$ correlates well with the experimental [5] average values of the spins of fission fragments $\bar{J}_1=$ 7–9.

This means that the spin distribution of fission fragments is determined with a good degree of accuracy by taking into account zero wriggling and bending vibrations of a composite fissile system. This confirms the assumption [6] about the inequality of the statistical Gibbs distribution with temperature $T$ for the spin distribution of fragments, which is used in [1].

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# ALPHA PARTICLES EMISSION IN FAST NEUTRONS PROCESSES ON 143ND NUCLEUS

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Nuclear reactions induced by fast neutrons starting from 0.5 MeV up to 25 MeV followed by alpha particles emission were investigated. Cross sections, angular correlations and related asymmetry effects were evaluated with Talys [1] and own computer codes. Contribution to the cross section of nuclear reaction mechanisms like direct, compound and pre-equilibrium together with discrete and continuum states of residual nuclei were determined. Theoretical evaluations are compared with existing experimental data. Further, parameters of nuclear potential in the incident and emergent channels are obtained. Using cross-section and angular correlation theoretical Talys data, forward-backward effects are obtained for different incident neutron energies and target dimensions. The Simulated forward-backward asymmetry coefficient is much lower than the experimentally measured effect [2]. The difference can be explained by the presence of other emergent channels including alpha particles and not by the existece of so-called non-statistical effects suggested in [2].
The present work was realized in the frame of the fast neutrons scientific program from FLNP JINR Dubna.

# ANALYSIS OF NEUTRON-INDUCED FISSION CROSS-SECTIONS OF PB ISOTOPES NEAR THE CLOSED NEUTRON SHELL

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We analised the fission cross-section of Pb-204, Pb-206, Pb-207 and Pb-208 nuclei at neutron energies varied from 30 MeV up to 180 MeV. Experimental data were obtained from [1]. The main parameters influence the calculated fission cross-sections are the height of the fission barrier and the level density at the top of the barrier. The height of the barriers are determined by the shell corrections which are different for different near magic Pb-208 nuclei. We determine the barrier heights fitting the experimental cross-sections with TALYS code calculations. An example of experimental fission cross-section for Pb-207 nucleus is shown on Fig.1. The solid line on the figure is the result of the TALYS calculation. Difference of the obtained barriers with liquid drop model barrier heights or Sierk model heights [2] give the size of the shell correction of the fissioning nuclear at the deformation on the top of the barrier.
The auther is grateful to A.N. Smirnov for stimulating interest in the problem.

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# SEPARATION EFFICIENCY AND SEPARATION TIME OF MASS SEPARATOR MASHA MEASURED FOR RADON AND MERCURY ISOTOPES

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The discovery of the Super Heavy Elements (SHE) with atomic number Z=113-118 as well as new neutron excess isotopes of the elements with Z=104-112 was one of the outstanding scientific results of the last decades. These high priority experiments were carried out on the cyclotron U400 of the FLNR (JINR, Dubna, Russia). The synthesis of the new super heavy elements stimulated works on the development of methods of their identification by means of the technique called Isotope Production On-Line (ISOL). Thereto, in the FLNR there was designed and put into commissioning the mass separator MASHA - Mass Analyzer of Super Heavy Atoms. The uniqueness of this mass spectrometer consists in ability to measure "on line" the masses of the synthesized isotopes of the super heavy elements simultaneously with detection of their alpha decays and spontaneous fission.
The main characteristics of MASHA setup is the separation efficiency and separation time. To determine these parameters two experiments by using the complete fusion reactions $^{40}$Ar+$^{144}$Sm and $^{40}$Ar+$^{166}$Er, $E_{\mathrm{beam}}$ = 5-7 MeV/n, were carried out. The experiments were carried out at the U400M cyclotron of the FLNR, JINR (Dubna). In the first experiment, the absolute cross sections of evaporation residua (radon and mercury isotopes) were obtained. In addition the absolute cross sections for p(xn) and $\alpha$(xn) reactions were also measured. The method of moving absorber made of ultra-thin aluminum foils (0.8 $\mu$m), where the reaction products were stopped, was used. The alpha decay of synthesized isotopes was detected by using silicon detectors. Energy resolution of alpha-radioactive isotopes was ~ 100 keV. Time moving of aluminum absorbers between two extreme positions was 0.3 s. The using of beam interruption method allowed to measure half-life of synthesized nuclei. As a result, the method allowed reliable identification of reaction products. In the second experiment, the excitation functions of the same reactions were measured with upgraded mass separator MASHA including the modernization of rotating target assembly, solid hot catcher, ECR-ion source, beam diagnostics and DAQ system. To register the products of nuclear reactions, a multi-strip silicon detector was installed in the focal plane of the mass separator.
By direct comparison of these results, the separation efficiency and separation time of evaporation residua were determined.

# NEW PHOTONEUTRON REACTION CROSS SECTIONS FOR PB ISOTOPES

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The total photoneutron yield reaction cross sections ⊠(⊠,xn) = ⊠(⊠,1n) + 2⊠(⊠,2n) + 3⊠ (⊠,3n)+… for $^{208}$Pb were obtained in experiments carried out using bremsstrahlung, quasimonoenergetic annihilation photons (Livermore (USA) [1] and Saclay (France) [2], and tagged photons [3]. Available data were evaluated using the method of reduction – the special treatment for converting different experiments data into the form for the monochromatic photon effective spectrum [4]. The comparison of data forces one to conclude that all cross sections under discussion agree to each other with exception of Livermore one having a significantly lover value. Using the experimental-theoretical method and the objective physical criteria of data reliability partial reactions (⊠,1n), (⊠,2n), and (⊠,3n) cross sections were evaluated [5] using the Saclay [2] cross section ⊠exp(⊠,xn). It was shown that significant differences between Saclay and Livermore, as well as between evaluated and Livermore, data are the results of the loss notable amount of neutrons from the reaction (⊠,1n). Data for total and partial reactions for $^{206,207}$Pb were obtained only at Livermore in the same experiment as for $^{208}$Pb [1]. Because similar to the situation for 208Pb the values of both ⊠exp(⊠,xn) cross sections are noticeably smaller in comparison with the once theoretically calculated in the frame of the Combined PhotoNucleon Reaction Model (CPNRM) [6] both ⊠exp(⊠,xn) for $^{206,207}$Pb were normalized to the ⊠theor(⊠,xn) with the factors 1.21 ($^{207}$Pb) and 1.13 ($^{206}$Pb). With those normalized ⊠exp(⊠,xn) the reliable cross sections for (⊠,1n), (⊠,2n), and (⊠,3n) reactions were evaluated using experimental-theoretical method. It was obtained that new evaluated cross sections are noticeably different from the experimental once. It was shown that in analogy to the situation for 208Pb such kind differences in the cases of $^{206,207}$Pb could be explained only by the loss many neutrons from the reactions (⊠,1n).

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# CHARACTERISTICS OF HEAVY-ION FRAGMENTATION REACTIONS AT FERMI ENERGIES

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Heavy-ion-induced projectile fragmentation reactions at Fermi energies are of general interest as a means to investigate the properties of nuclei far from the valley of stability and for various applications. It is thus of importance to understand in detail the production mechanism. Here we treat such reactions in a microscopic approach, which consists of three steps: initialization of ground states of the colliding nuclei, dynamical evolution until the freeze-out point where the primary fragments can be identified, and de-excitation of these primary hot fragments. For the dynamical evolution we use a Boltzmann-Vlasov-type transport code, and for the de-excitation a statistical multi-fragmentation description. Here we further introduce realistic, stable initializations of the colliding nuclei, which are important to control and determine the excitation energies of the nuclei and fragments. We apply this approach to collisions of light projectile nuclei, and calculate isotope distributions and velocity spectra of the produced isotopes. In particular, the velocity spectra are shown to contain much information on the reaction mechanism.

# STUDY OF (Γ, P)-REACTIONS ON TUNGSTEN ISOTOPES

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The study of the cross-sections and yields of (γ,p)-reactions allows one to obtain information on the structure of excited levels in the continuous and discrete regions of excitation and the mechanisms of the nuclear reactions' occurrence. Our work aims to study the yields of Ta-185,183,182 in reactions with the proton emission for irradiated targets by the bremsstrahlung gamma quanta with energies in the region of giant dipole resonance.
The study of the weighted average yields was carried out by the activation method on a bremsstrahlung γ-beam for electrons with the 20 MeV maximum energy on natural tungsten targets.
The spectra of irradiated targets were measured on Canberra and Ortec HPGe gamma spectrometers with the (15-40)% detection efficiency compared to the 3'×3' NaI(Tl) detector. The energy resolution of the spectrometers was 1.8–2.0 keV on the Co-60 1332 keV γ-lines.
The gamma transitions from the Ta-185,183,182 decay are reliably distinguished in the spectra.
The weighted average yields of the reactions 186W(γ,p)185Ta, 184W(γ,p)183Ta, and 183W(γ,p)182Ta have been measured on natural tungsten targets at the 20 MeV maximum energy of bremsstrahlung photons for the first time.
The following values of the weighted average yields were obtained: for 186W(γ,p)185Ta-reaction 0.70(7) mbn, for 184W(γ,p)183Ta-reaction 1.8(3) mbn, and for 183W(γ,p)182Ta-reaction 3.9(13) mbn. We can state the dominance of non-statistical processes as a modeling result within the TALYS-1.9 program code framework. The theoretical weighted average yields were significantly lower than the experimental values. The obtained data are discussed.

# PRODUCTION CROSS SECTIONS OF MERCURY AND RADON ISOTOPES IN COMPLETE FUSION REACTIONS WITH $^{36,40}$Ar AND $^{40,48}$Ca PROJECTILES

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The complete fusion - excitation functions of *xn*-evaporation channels of the reactions $^{144}$Sm(40Ar, *xn*)$^{184-x}$Hg, $^{148}$Sm($^{36}$Ar, *xn*)$^{184-x}$Hg, $^{144}$Nd($^{40}$Ca, *xn*)$^{184-x}$Hg, $^{142}$Nd($^{48}$Ca, *xn*)$^{190-x}$Hg, and $^{166}$Er($^{40}$Ar, *xn*)$^{206-x}$Rn have been measured by using the catcher foil method [1]. A modified version this technique was applied allowing to measure decay properties of α-radioactive nuclides with half-lives ≥ 0.1 s. The beam interruption method was used for the isotope identification. The influence of the beam energy spread at its passing through absorbing foils and the target layer on the excitation functions has been taken in account using the Gold deconvolution method [2]. The measured excitation functions have been compared with theoretically calculated with the coupled-channel model [3,4]. The influence of both the target and projectile nucleus deformations on the final *xn*-evaporation channel cross sections has been analyzed.

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# STUDY OF PHOTONUCLEAR REACTIONS WITH THE CHARGED PARTICLES EMISSION FOR THE ZIRCONIUM-89 PRODUCTION

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Zirconium-89, with a half-life of 3.3 days, is one of the most promising radioisotopes for nuclear imaging based on monoclonal antibodies (Immuno-PET). Immuno-PET studies require that the half-life of the diagnostic radioactive isotope coincide with the biological half-life of the carriers (monoclonal antibodies), which exceeds 24 hours and averages 2-6 days. Thus, the half-life of $^{89}$Zr ideally matches the half-life of antibodies, and the average positron energy of 395 keV allows for high-resolution PET images.
Currently, the production of Zr-89 is carried out mainly in reactions with protons and deuterons. Accelerators of these particles are complex and expensive to maintain. A promising method for obtaining zirconium-89 is the use of widespread and economic electron accelerators.
However, it is tough to obtain the required radionuclide from the $^{90}$Zr(γ, n)$^{89}$Zr reaction. It is difficult to isolate the Zr-89 from an irradiated zirconium matrix. Therefore, we have carried out studies of reactions with the emission of alpha particles. We studied (γ, αn) and (γ, α)-reactions on natural molybdenum, molybdenum enriched in the $^{94}$Mo isotope, natural zirconium, and natural niobium.
The experimental weighted average yields of the reactions under study at the boundary energy of bremsstrahlung gamma quanta of 20 MeV are as follows:
$^{90}$Zr(γ,αn)$^{85}$Sr: 0.030 ± 0.015 mbn
$^{96}$Zr(γ,αn)$^{91}$Sr: 0.15 ± 0.05 mbn
$^{93}$Nb(γ,αn)$^{88}$Mo: 1.16 ± 0.12 mbn
$^{93N}$b(γ,αn)$^{88}$Mo: 0.97 ± 0.10 mbn
$^{94}$Mo(γ,αn)$^{89}$Zr: 1.04 ± 0.09 mbn
$^{100}$Mo(γ,αn)$^{95}$Zr: 0.03 ± 0.01 mbn
$^{99}$Mo(γ,α)$^{88}$Zr: 0.081 ± 0.009 mbn
The obtained data are discussed.
The reported study was funded by RFBR according to the research project 20-315-90124.

# DATA ANALYSIS FROM CATCHER FOIL EXPERIMENT FOR CROSS SECTIONS MESUREMENT OF 40Ar + 144Sm REACTION

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Cross sections from the complete fusion reaction of $^{40}$Ar + $^{144}$Sm were measured by the catcher foil method [1] (on the U400M cyclotron at the Flerov Laboratory of Nuclear Reactions). The catchers were made out of five aluminum foils (0.8 μm thick) stacked downstream from the target. The experiment was carried out in repetitive short cycles (10 s). The foils were periodically moved from the beam position to the detector position. Data from the detector were analyzed to obtain α-spectra of implanted isotopes. A new method of data analysis was proposed in the work taking into account TRIM [2],[3] and Geant4 [4]Monte-Carlo simulations for alpha spectra, PACE4 [5]fusion-evaporation code for residual nuclei energy distribution, Couple channel method calculation [6] for theoretical cross sections and SRIM [3] evaluation of produced isotopes stopping ranges. Using this method the 1pxn, 2pxn and 1αxn complete-fusion excitation functions are presented.

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# $^{238}$U IN THE NEUTRON FIELD AND THE BREMSSTRAHLUNG RADIATION FIELD ON THE BEAMS OF PROTONS AND ELECTRONS OF THE ACCELERATORS AT JINR: CALCULATIONS AND EXPERIMENTS

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In the framework of the “Energy and Transmutation of RAW” collaboration [1], the experiments were carried out at the accelerators: Nuclotron, Phasotron and LINAC of JINR and have studied deeply nuclear inelastic processes using gamma spectroscopy techniques and HPGe detector.

The neutron fields on the proton beam were created using the lead and uranium targets. The field of the secondary bremsstrahlung radiation during the irradiation of the samples on the electron beams was obtained with the use of the lead (or bismuth) converter. The gamma spectra were measured and studied with the HPGe detectors on the spectrometric complex at YASNAPP-LNP and LHEP JINR.

As the result of the study, the yields of the products of the secondary reactions: (n, f), (γ, f) – fission reactions in the $^{238}$U samples; (γ, xn) – photonuclear reactions in the $^{238}$U, $^{209}$Bi samples and also (n, γ) for all the samples.

For the theoretical interpretation of the studied reaction, the simulation programs were used: FLUKA, GEANT4 and MCNP. As the result of simulating, the calculations were made: the distribution of neutrons emitted from the lead targets by energies and coordinates on the proton beam (figure 1); the distribution of the secondary bremsstrahlung radiation (and the secondary neutrons) on the electron beam produced using the Pb or $^{209}$Bi converters; the quantitative results of the (n, f) fission reaction products on the proton beams in the $^{238}$U samples; the quantitative results of the photonuclear reaction products (n, γ)on the electron beams in the $^{238}$U and $^{209}$Bi samples.

The calculation estimates of the yields of the capture and fission products in the reactions on the actinide nuclei were made at the energy of the incident charged particles with E > 1 GeV.

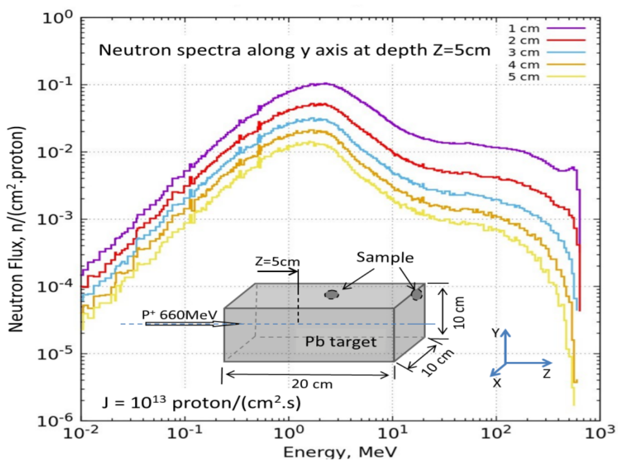


Figure 1: The distribution of the neutron emitted from the lead target on the proton beam with E = 660 MeV.

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# $^{237}$Np, $^{239}$Pu ACTINIDES IN THE NEUTRON FIELD OF THE “QUINTA” URANIUM TARGET

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The study of the production of actinides in the neutron field of the “Quinta” uranium target was carried out within the framework of the “Energy - Transmutation” project at the accelerators of JINR: Nuclotron and Phasotron.

The purpose of this work is to compare the yields of capture and fission reactions at various energies of the charged particles in a range from 1 to 20 GeV, determine their relation [3] for the residual nuclei in the $^{237}$Np sample and compare with the ratio in the $^{239}$Pu sample.

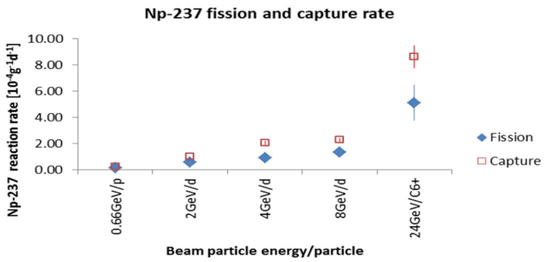


Figure 1: The fission and capture yields for $^{237}$Np

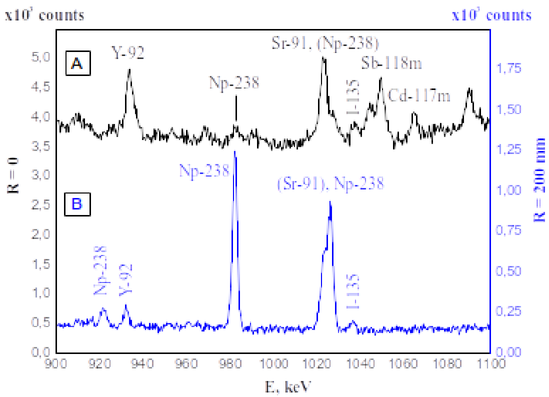


Figure 2: Comparison of gamma spectra of $^{23}$7Np samples, irradiated with the proton beam (A) and the secondary neutrons (B) at the distance of 200 mm from the proton beam in the “Quinta” uranium target.

The studies were carried out using HPGe detectors on the spectrometric complex at YASNAPP-LNP and LHEP JINR. The reliability of the studies is confirmed by the presence of the gamma transition with energy 984.5 keV and 1028.5 keV arising in the presence of the neutron capture with the $^{237}$Np nucleus in the “B” gamma spectra (Fig 2).

To interpret the results obtained in Figure 1, the report discusses the possibility of the cumulative data from the experiments on multifragmentation [1].

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# ADVANCES IN MODELING OF FAST NEUTRON INDUCED FISSION ON $^{232}$Th

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Nuclear data obtained in the neutron induced fission of 232 Thorium are of a great importance for advanced fast reactors based on Th fuel cycle. Fission cross sections, mass and charge distributions, prompt emission in fission including neutron multiplicities, yields of some isotopes of interest, and associated uncertainties were obtained. This paper presents the theoretical predictions and the first results on $^{232}$Th(n,f) by applying Talys and an author's computer code for modelling of nuclear reaction mechanisms. Uncertainties induced by nuclear data were quantified using preliminary, energy-dependent relative covariance matrices evaluated with ENDF nuclear data and processed for the studied fission process. Theoretical evaluations obtained are compared with existing experimental data. The present researches on $^{232}$Th(n,f) reaction are realized in the frame of nuclear data program running at JINR basic facilities IREN and MT-25 Microtron.

# HIDDEN VARIABLES IN ANGULAR CORRELATIONS OF THE PARTICLES EMITTED IN FISSION

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The hidden-variables (HV) theory was once put forward by opponents of the probabilistic interpretation of the wave function (EPR paradox). It was assumed that the state of the system could be predicted with a less uncertainty than this is admitted by the Heisenberg uncertainty principle, if one knew additional, that is HV. This theory is rejected by the community. However, examples can be given of how HV suddenly appear, for example, in modern simulations of the angular distributions of gamma quanta or neutrons emitted from fission fragments. This happens if one considers the spin of each fragment to have a definite direction in the plane perpendicular to the fission axis, and then averages over the directions of the spin in the azimuthal plane. In this way, the well-known phenomenon of the alignment of the spins of fragments in a plane perpendicular to the fission axis might be erroneously treated. Then the supposed direction of the fragment's spin appears as a HV. Contrary, in a consecutive quantum-mechanical approach, the state of the fragment is characterized by two quantum numbers: the spin and its projection onto the quantization axis z, which is along the fission axis. Then the alignment of the fragments merely means that the projection of their spins onto this axis is close to zero. And in the general case of incomplete alignment, it is necessary to use the density matrix.
A comparative analysis of experiments [1,2] on studying the (n, f), on one hand, and (n, n), on the other hand, angular correlations in fission is carried out, based on the model proposed by muonic conversion in fragments of prompt fission of 238U with negative muons. Their fundamental difference is shown in the sense of the information that can be inferred from them. To show this explicitly, and for the purpose of testing the experimental method, I propose an experimental check of the empirical relation between the alignment and polarization parameters, respectively:
$A_{nJ}$ = 2 $A_{nf}$.
Among the other examples of use of HV, I point out the use of the immeasurable parameter ξ in the method of specific differences for the elimination of the Bohr—Weisskopf effect in the study of the hyperfine splitting in heavy ions of $^{209}$Bi [3].

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# SPONTANEOUS AND INDUCED TERNARY AND QUATERNARY FISSION AS A VIRTUAL PROCESSES

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In experimental papers [1, 2] the yields, angular and energy distributions of the pairs of light third and fourth particles, such as $\alpha$-particles pair $(\alpha_1, \alpha_2)$, were obtained for the spontaneous quaternary fission of the nuclei $^{252}$Cf, $^{248}$Cm and for the induced by thermal neutrons quaternary fission of compound nuclei $^{234}$U, $^{236}$U. Using the theoretical concepts [3-5] of ternary and quaternary fission as virtual processes [6], we consider spontaneous quaternary fission from the ground states of even-even actinides [1,2] with the sequential emission of two $\alpha$-particles from nuclei A and (A-4) with the formation of the intermediate nuclei $(A-4)$ and $(A-8)$ in the virtual states, and the subsequent binary fission of the residual fissile nucleus $(A-8)$ into light and heavy fission fragments. Induced quaternary fission occur from the excited states of compound nucleus $A$, which is formed when the neutron is captured by the target nucleus, and after that the process goes in the same way as in analogous spontaneous fission. These $\alpha$-particles, in contrast to the $\alpha$-particles that fly out in the sub-barrier $\alpha$-decay from ground states of the studied nuclei $A$ and $(A-4)$, when the energies $Q^A_{\alpha_1}$ and $Q^{(A-4)}_{\alpha_2}$ of this decays are close to $4-6$ MeV, are long-ranged, since their asymptotic kinetic energies $T_{\alpha_1} \approx 16$ MeV and $T_{\alpha_2} \approx 13$ MeV, are markedly larger than energy values $Q^A_{\alpha_1}$ and $Q^{(A-4)}_{\alpha_2}$.

The quaternary fission yield $N^A_{\alpha\alpha f}$ normalized to the yield of the binary fission of the nucleus $A$ for spontaneous fission using the formula [4] for the virtual quaternary fission width of nucleus $A$ can be presented as

$$N^A_{\alpha\alpha f} = \frac{1}{(2\pi)^2} \int\int \frac{(\Gamma^A_{\alpha_1})^{(0)}(T_{\alpha_1})(\Gamma^{(A-4)}_{\alpha_2})^{(0)}(T_{\alpha_2})(\Gamma^{(A-8)}_f)^{(0)}}{(Q^A_{\alpha_1}-T_{\alpha_1})^2(Q^{(A-4)}_{\alpha_2}-T_{\alpha_2})^2(\Gamma^A_f)^{(0)}} dT_{\alpha_1} dT_{\alpha_2}, \quad (1)$$

where index (0) denotes to the configuration of fissile nuclei, corresponding to the appearance of two deformed fission prefragments, connected by the neck; $(\Gamma^A_{\alpha_1})^{(0)}$ and $(\Gamma^{(A-4)}_{\alpha_2})^{(0)}$ are the width of the $\alpha$-emission from the fissile nucleus neck. In (1) the ratio of the binary fission widths $(\Gamma^A_f)^{(0)}/(\Gamma^{(A-8)}_f)^{(0)} \approx 1$. In the case of the induced quaternary fission the energy $Q^A_\alpha$ should be replaced by $Q^A_\alpha + B_n$, where $B_n$ is neutron binding energy in compound nucleus A. Using Gamov formulae for $(\Gamma^A_{\alpha_1})^{(0)}$ and $(\Gamma^{(A-4)}_{\alpha_2})^{(0)}$ , taking into account the fact that the probabilities of formation of the $\alpha_1$ and $\alpha_2$ particles are close to each other and the neck radius $r^A_{neck}$ before the emission of $\alpha_1$-particle does not differ from the neck radius $r^{(A-4)}_{neck}$ before the emission of the second $\alpha_2$-particle, the specified estimation of the yield $N_{\alpha\alpha f}$ for spontaneousand induced quaternary can be derived.

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# Section 3. Modern nuclear physics methods and technologies

## EFFICIENCY STUDY OF THE ECAL DETECTOR OF THE HADES EXPERIMENT

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The High Acceptance DiElectron Spectrometer (HADES) is a fixed target experiment which explores the properties of hadronic matter in collisions of pions, protons and nuclei at beam energies 1-2 AGeV. Currently the HADES experiment operates at the SIS18 accelerator in GSI, Darmstadt. When the SIS100 accelerator is built, HADES will be the first experiment in FAIR Phase-0 project.
In order to extend capabilities of HADES in measurements of hyperons and neutral mesons, the new electromagnetic calorimeter ECal was built. In March 2019 the ECal detector was used for the first time in measurements of Ag+Ag collisions at beam energies 1.58 and 1.23 AGeV. The calibration of ECal was done using electrons and positrons emitted in collisions. Their identification and measurement of momentum was carried out by the RICH, MDC and RPC detectors.
This talk describes the procedure of the ECal efficiency determination with usage of machine learning.

# SIMULATION OF TOF PERFORMANCE OF ECAL MPD/NICA

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A cylindrical electromagnetic calorimeter with a length of 6 m and an inner (outer) diameter of 3.45 (4.6) m, composed of 38400 trapezoidal towers with a base of 4x4 cm2 and a length of 40 cm, is created to operate as part of the MPD detector of the NICA project. "Shashlyk" technology was used for tower development with 210 alternating layers of lead and a scintillator 0.3 and 1.5 mm thick, pierced with 16 wavelength-shifting fibers to collect light on a silicon photomultiplier. Calorimeters of this type can provide subnanosecond time resolution that can be used for neutron identification, background suppression, and separation of hadron and electromagnetic showers. Because of the complexity of the light collection process, the time response simulation of a calorimeter presents significant difficulties. In full, this task comes down to obtaining the distribution of energy release in scintillators, converting it into photons of blue light, collecting these photons on wavelength-shifting fibers, converting and capturing green photons in fibers, transporting them to a multipixel APD, shaping its output signal and registering with digital electronics. The current status of the simulation program is discussed, as well as the results of time measurements on the manufactured calorimeter modules using electron beam. This work was supported by the RFBR grant no. 18-02-40054.

# GEANT4 STUDY FOR GEOMETRY OF QUARTZ FIBER LUMINOMETER AT CMS HL-LHC

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In particle physics experiments one of the most important parameter is the large center of mass energy available for the production of new effects. The higher energies achived by accelerators is not the only parameters for new physics but also the number of useful interactions (events) is very important parameter to be measured and it is called luminosity which is proportional to events per second and the cross section of the interaction. The aim of this study is to perform Geant4 simulations for geometry of combination of tungsten quartz fiber luminometer to be used for the CMS experiment in HL-LHC era.

# NEW TECHNOLOGIES FOR THE VERTEX DETECTORS AT THE NICA COLLIDER EXPERIMENTS

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In modern high energy physics and elementary particle physics experimental research, one of the important problems is connected with the study of the yields of the hadrons containing heavy quarks. These hadrons practically do not interact (low interaction cross sections) with the nuclear medium and, therefore can provide undistorted information about the states of nuclear matter arising in the relativistic nuclei collision processes. Thus, an effective registration of strange and charmed particles by the experimental setup in the nucleus-nucleus collisions at the NICA collider plays a key role in the analysis of possible nuclear matter evolution and its phase transitions mechanisms. In addition, at relatively low energies of the colliding nuclei at the NICA collider ($\sqrt{s_{NN}}$ = 4 - 11 GeV) [1], it becomes possible to study inside the nuclei the different clusters of dense nuclear matter [2].

The number of secondary particles produced in central collisions of relativistic ions can reach several thousand in the energy range of the NICA collider. For precise registration of these events we need the vertex detector systems, which allow reconstructing the tracks of primary charged particles and products of their decays. These detector systems should provide the ability to reconstruct the decay vertices of short-lived multi-strange and charmed hadrons with high spatial resolution at minimum material budget. Therefore, the leading high energy and elementary particle physics experiments: ALICE, ATLAS, CMS at the Large Hadron Collider (LHC), STAR at the Relativistic Heavy Ion Collider (RHIC) are using now the silicon pixel sensors as the main element of the whole tracking system [3].

In present overview the technologies for the vertex detectors at the NICA collider experiments together with new ultra-light radiation-transparent carbon fiber support structures as basic elements for these detectors and CMOS monolithic active pixel sensors are discussed. To investigate the efficiency and main characteristics of the proposed carbon fiber support structures and pixel sensors, the comprehensive studies with gamma, beta sources, with cosmic rays and also with different cooling systems were carried out.

Acknowledgments: the reported study was supported by RFBR, research project No. 18-02-40075.

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# STUDY OF PERFORMANCE OF FAST BEAM-BEAM COLLISION MONITOR SYSTEM WITH MC SIMULATIONS AND MACHINE LEARNING METHODS

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New experiments are being planned at the NICA collider beams aimed to explore the properties of high-density baryonic matter formed in heavy-ion collisions with energies up to $\sqrt{s_{NN}} = 11$ GeV. With the aim of selecting the collision events of interest, it was proposed in [1] to develop a fast beam-beam collision monitor (FBBC) system, which would be capable to determine the time and space of each ion-ion collision.
In this report, we consider a system of 6 segmented ring-shaped detectors based on the microchannel plates (MCP) placed in the vacuum of the beam-pipe at some distance along the beam-line on both sides from the center of the experimental facility. Intrinsic high timing characteristics of MCPs (signal duration below 1 ns) allow to consider the required functionality of the FBBC for monitoring the luminosity of collisions and to provide the event selection, precise event timing information, determination of the event interaction point, and suppression of the beam-gas interaction events.
MC simulations of the beam-beam collisions monitoring system were performed within the DQGSM[2] event generator. Taking into account the information about the multiplicity of registered charged particles and their time-of-flight, the position of the interaction point and multiplicity/centrality in the event were estimated. To perform such estimations, different machine learning methods were used. It is shown that the monitoring system and machine learning algorithms can provide an interaction point position within the acceptance of the experiment with the precision of about $\pm 1.6$ cm at least; also the ability of the system to distinguish peripheral and central collisions is discussed.

This work is supported by the RFBR grant №18-02-40097/19.

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# THE USE OF THE PSA METHOD IN THE INTERPRETATION OF THE BEHAVIOR OF CURVES ON THE △E-E DIAGRAMS FOR TELESCOPE OF THE Si - DETECTORS.

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PSA method (pulse shaping analyze) widely used in nuclear physics experiments and radiation detection [1]. This method was first proposed in 1963 (S. Barlini), but is still being developed by many scientists. A wide variety of pulse features have been extracted to realize this method. Many ways to implement the PSA method have been proposed, mainly to determine the type of particle (for example, the charge integration method, the charge balance parameter method that have been widely used in n/$\gamma$ discrimination into PSA). Concerning the use of silicon detectors, for example, in the 1970 opportunity was found to discriminate the proton and the alpha particles by rise time of the pulse and so more.
This article proposes a variant of the PSA method and a specific area of its application. The operation of the method is demonstrated on the information obtained in the study of the reaction $d + {}^2\mathrm{H} \rightarrow p + p + n + n$, that was performed using deuteron beam with energy of 15 MeV at the SINP MSU. The measurement system mainly consisted of a set of ORTEC totally depleted silicon surface barrier detector (25, 300, 400 $\mu$m), a Canberra 2003BT pre-amplifier (or ORTEC H242A, 142A) and a CAEN DT5742 and 5720 digitizer. EJ301 detectors was registered neutrons in the other arm of setup. The preamplifiers used had fast signal outputs. These signals are required for the TOF system to function and are obtained by processing of the main signals.
Waveforms of all signals were digitized by digitizers. For each event from the silicon telescope, its position on the $\Delta E$–$E$ diagram was analyzed depending on the duration of the leading, trailing edges and the amplitude of the fast signal.
It was shown that taking into account the shape of a fast signal in the form of edge durations makes it possible to unambiguously determine whether an event belongs to the forward or reverse course of the curves on the $\Delta E$–$E$ diagram. In the case of intense spots on such curves, this helps in the analysis of experimental information. This is necessary in the case of using silicon telescopes consisting of several detectors located in the air. Especially interesting has the dependence of the trailing edge of the signal on the fact of the passage of the particle through the detector.

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# LUMINOSITY DETERMINATION WITH ALICE AT THE LHC

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Cross section measurements in hadronic collisions are crucial to the physics program of ALICE. These measurements require a precise knowledge of the luminosity delivered by the LHC. Luminosity determination in ALICE is based on the measurement of visible cross sections in dedicated calibration sessions, the van der Meer (vdM) scans. By combining information from the ALICE detectors and the LHC instrumentation, a per cent level of precision on luminosity can be achieved. This contribution presents a review of the ALICE luminosity determination methodology and results during the LHC Run 2. In particular, new results will be presented for pp collisions at $\sqrt{s}$ = 13 TeV and for Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. The latter include a measurement of the inelastic hadronic interaction cross section.

# TOWARDS MAPS BASED INNER TRACKING SYSTEM OF NICA MPD.

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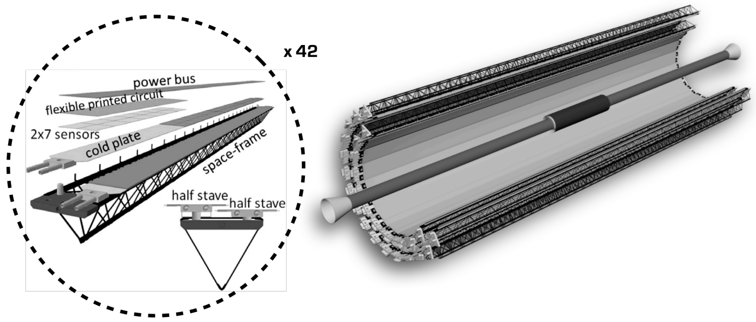
The Multipurpose Detector (MPD) of the NICA complex at JINR will include an Inner Tracking System (ITS) which is a vertex detector meant to complement the Time Projection Chamber of the MPD for the precise tracking, momentum determination and vertex reconstruction for hyperons ($\Lambda$, $\Xi$, $\Omega$) and D-mesons. It will be placed inside the bore of the TPC and it will be composed of 5 layers of silicon Monolithic Active Pixel Sensors (MAPS) grouped in two barrels, with 3 layers on the inner barrel and 2 layers on the outer barrel (Fig. 1), with a spatial resolution of less that 5 $\mu$m and a material budget of less than 0.8%$X_0$. The project is a collaboration between Russian and Chinese institutions lead by the JINR and the Central China Normal University, respectively. The production and assembly of the detector will be shared by both countries, while the mechanics will be designed and manufactured completely at JINR and the readout electronics will be developed and produced in China. The project foresees the construction of the outer barrel on a first stage (2022/2023) based on the same MAPS technology used for the outer barrel of the ALICE-ITS2 [1] currently under commissioning at CERN as the first MAPS-only large area ($\sim$ 10 m$^2$) detector. These are 15 mm x 30 mm x 100 $\mu$m silicon sensors (from TowerJazz 180 nm CMOS technology) with 1024 x 512 pixels. The addition of the inner barrel is programmed for a second stage (2025/2026) with the intention of building it based on 280 mm-long and 30 $\mu$m-thick bent sensors currently under R&D by the ALICE-ITS3 project at CERN [2]. Nevertheless, the use of the current ALICE-ITS2 inner barrel technology (15 mm x 30 mm x 50 $\mu$m) is considered as a backup plan. Figure 1 shows a cut of the MPD-ITS geometry along with a breakdown of one of the 42 Stave structures that compose the outer barrel. Each one of this Staves is segmented into two identical structures (Half Staves) where 2 rows of 7 MAPS are attached to a Flexible Printed Circuit to conform a structure called Hybrid Integrated Circuit (HIC) and 7 of this HICs are glued to a multilayer composite graphite plate with embedded cooling pipes (Cold Plate). According to the current MPDRoot-based simulation results [3, 4] of the MPD tracking system (ITS + TPC) for central Au + Au collisions at $\sqrt{S_{NN}}$= 9 GeV, on the initial stage with only 2 layers (outer barrel) and a beam pipe dimeter of 64 mm the signal extraction of reconstructed hyperons from the invariant mass spectrum of their decay products would be performed with an efficiency of 0.2% which is enough for assessing the identification ability of the system at debugging stage. On the other hand, only with the setup of a 5-layers ITS plus the TPC and a beam pipe diameter of 40 mm would it be possible to achieve a reliable detection efficiency of about 1% for both multi-strange and charmed particles.

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# READOUT ELECTRONICS OF THE SILICON TRACKING SYSTEM OF THE BM@N EXPERIMENT AT NICA

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BM@N experiment at NICA in Dubna is currently being upgraded for the study of dense nuclear matter in heavy-ion collisions. One of the major upgrades is a new hybrid tracking system consisting of large-area Silicon Tracking System (STS) and seven GEM planes. The STS contains four tracking stations equipped with double-sided micro-strip silicon sensors of CBM-type. To collect data from 600 000 channels, a state-of-art data acquisition system (DAQ) based on the STS-XYTER ASIC and supporting the GBT data transmission protocol is being developed and tested. The standalone, initially self-triggered STS data acquisition system must be able to operate on a trigger and be integrated into the global DAQ of the BM@N experiment. Front-end electronics, electrical connections, data concentrator and architecture of data processing board are described in the report. The results of testing of a pilot version of the readout chain are presented.
Work is supported by RFBR 18-02-40047 grant.

# CATHODE STRIP CHAMBERS FOR THE OUTER TRACKER OF THE BM@N EXPERIMENT

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Baryonic Matter at Nuclotron (BM@N) is a fixed target experiment at the NICA accelerator complex (JINR) aiming at studies of nuclear matter in relativistic heavy ion collisions. The outer tracking system for the BM@N heavy ion beam program is based on Cathode Strip Chambers. The outer tracker will be installed downstream the analyzing magnet to precise parameters of tracks, obtained in central tracking system and to find corresponding hits in time-of-flight systems. The full configuration of the CSC tracking system will include four CSC of the size 1129×1065 $mm^2$ and two CSC of the size 2190×1453 $mm^2$. First Nuclotron beam test of the 1129×1065 $mm^2$ CSC was performed in beams of C, Ar and Kr ions in March 2018: the chamber was installed in front of time-of-flight detectors to check its performance as outer tracker for heavy ions. The structure of the BM@N CSC detectors and the results of the study of their characteristics are presented. The full configuration of the CSC tracking system is shortly reviewed.

# SCINTILLATION DETECTOR PROTOTYPES FOR BEAM-BEAM COUNTER AT NICA SPD

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The Beam Beam Counter of the Spin Physics Detector at NICA is proposed for local polarimetry and luminosity monitoring. The main option of the Beam Beam Counter is the scintillation tiles with SiPM readout. The work presents the results for studies the scintillation detector prototypes using two developed options of the front-end electronics. The estimation of time resolution using the time-walk correction procedure, as well as the coordinate scanning are discussed.

# CALIBRATION AND PERFORMANCES OF THE ELECTROMAGNETIC CALORIMETER AT MPD/NICA.

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The electromagnetic calorimeter (ECal) is an integral part of the MPD experiment and designed to measure the energy and coordinates of photons and electrons as a manifestations of the nuclear matter properties. ECAL has a segmented structure and consists of 2.400 modules, everyone has 16 cells (towers). Each tower is assembled from 210 layers, which is a set of alternating lead and scintillation plates pierced with wavelength shifting fibers to transport light to photodetectors [1]. Mass production of calorimetric modules was launched last year. At the present time, more than 300 modules of various types have been produced. The calorimeter modules are tested and calibrated in two directions: on the stand at JINR using cosmic rays and on the electron beam of S-25R «Pakhra» of the Lebedev Physics Institute [2]. This report presents the methods and results of calibration and testing of the selected ECal modules. The simulation programs for beam and cosmic tests were developed [3]. Last experimental results in comparison with simulated data are presented and discussed.
This work was supported by RFBR grant no. 18-02-40079.

Keyword: Multi-Purpose Detector, electromagnetic calorimeter (ECal), «Pakhra» synchrotron, calibration, cosmic rays, nuclaer matter properties

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# PARTICLE IDENTIFICATION METHODS IN THE BM@N EXPERIMENT

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The BM@N (Baryonic Matter at the Nuclotron) is a fixed target experiment at the NICA (Nuclotron-based Ion Collider fAcility). The first physics runs were carried out with the collection of experimental data in 2018. One of the important problems of the experiment is particles identification. This paper discusses the implemented identification algorithms based on the separation of charged particles by time of flight. The implemented methods were planned to be applied to experimental and Monte Carlo data. However, the experimental data are noisy, therefore, before applying identification methods to them, the filtering procedures described in this work were carried out. The paper also describes the implemented algorithm for calculating the efficiency of stations. It is used in order to determine how much better the Monte Carlo data than the experimental ones. After adding in the Monte Carlo data effects that make them more similar to the results obtained in the experiment, the identification method was applied to them. The results of the effectiveness of the method, obtained by testing it on modified Monte Carlo data, are presented in this work. This work is supported by Russian Foundation for Basic Research grant 18-02-40104 mega.

# DIRECTIONAL SENSITIVITY INVESTIGATION OF TWO COORDINATE NEUTRON DETECTOR BASED ON $^{10}$B LAYER AND WIRE CHAMBER

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The directional sensitivity of two coordinate neutron detector based on 3-$\mu$ m $^{10}$B layer and a wire chamber was studied [1]. In the experiment, the detection of scattered neutrons by the detector was found to be suppressed in comparison with the data from the helium-3 tube counter in the experimental area.
A simulation shows that this phenomena can be explained by two factors acting simultaneously: a neutron flux strong absorption in the $^{10}$B layer which falling at a large angle to the detector plane and the fact that secondary nucleus energy of $^{4}$He or $^{7}$Li is not enough to exceed the energy threshold if nucleus outgoes from the depth of the $^{10}$B layer.

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# OSIRIS – AN ONLINE SCINTILLATOR RADIOPURITY MONITORING PRE-DETECTOR OF JUNO

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JUNO is a 20 kt liquid scintillator detector under construction in Jiangmen, China, whose primary goal is to determine the neutrino mass hierarchy. Its construction is expected to be finished in 2022. To meet the stringent requirements on the radiopurity of the liquid scintillator, $10^{-16}$ g/g of $^{238}$U and $^{232}$Th, the OSIRIS (Online Scintillator Internal Radioactivity Investigation System) pre-detector has been designed to monitor the liquid scintillator during the several months of filling the large volume of JUNO. The OSIRIS design has been optimized for sensitivity for the $^{238}$U/$^{232}$Th decay rates via the tagging of the respective $^{214}$Bi -$^{214}$Po and $^{212}$Bi-$^{212}$Po coincidence decays in the $^{238}$U/$^{232}$Th decay chains. OSIRIS will be equipped with 76 20-inch PMTs. There are 64 of them observing the inner detector, which contains the 18-tons liquid scintillator target, surrounded by water. The remaining 12 PMTs are installed in the water Cherenkov veto detector, which surrounds the inner detector that is optically separated. This poster will show the design of several subsystems as well as the sensitivity of OSIRIS to the $^{238}$U/$^{232}$Th, $^{14}$C and $^{210}$Po contaminations of the liquid scintillator.

# FAST AND THERMAL NEUTRON SCATTERING AND ABSORPTION BY STRUCTURAL MATERIALS OF NEUTRON DETECTORS

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It is important to choose structural materials for its parts when creating neutron detector. We demonstrate advantages of gas detector over other detector types and we consider advantages and disadvantages of isotopes $^3$He, $^7$Li and $^1$0B as converting. Difference between the operation of gas-filled detectors and detectors based on solid layer is also considered. Scattering of neutrons distortion measured neutron field and their flux from source. Activation of nuclei by structural materials, in particular, metals, leads to detector excitation in the absence of neutrons. Neutron absorption reduces their flux.

We propose the using of aluminum and silicon as structural materials. We propose the using glass and ceramic based on $Al_2O_3$ as insulators. They have a small scattering, absorption and activation cross-section and do not give long-lived isotopes. The converter choice of $^3$He, $^7$Li or $^1$0B is determined by neutron energy range and background conditions of gamma quanta and other particles.

# FOCAL PLANE DETECTOR SYSTEM OF THE MAVR SPECTROMETER

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The modern development of experimental technology makes it possible to create facilities and carry out measurements using the method of labeled atoms (registration of each event). This is especially important when working both on primary beams of heavy ions and on beams of radioactive nuclei. For this reason, it is advisable to use precision position-sensitive detectors that allow extracting maximum information about the characteristics of the beam itself, as well as about the products of their reactions. In this regard, preference is given to the creation of wide-aperture multivariate facilities. One of such installations is the multi-detector system of a high-resolution magnetic analyzer (MAVR, FLNR, JINR), which allows registering and identifying the products of nuclear reactions by charge Q, atomic number Z and mass A with an accuracy of one by mass and charge.
The detector is located in the focal plane of the spectrometer and consists of two modules. First one is an ionization chamber with a Frisch grid, a segmented anode and two single-wire proportional position counters. Second one is a scintillation unit for registering long-range particles located directly behind the ionization chamber. A detailed description of the ionization chamber is given in [2].

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# METHOD FOR RECORDING LOW-ENERGY TRANSITIONS THAT OCCUR DURING THE DECAY OF SUPERHEAVY ELEMENTS IN THE FOCAL PLANE OF A MAGNETIC SPECTROMETER (MAVR)

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At the MAVR installation In the focal plane, it is supposed to measure the correlation of alpha particles in coincidence with the cold core of the super-heavy element residue. The focal plane allows simultaneous detection of alpha particles with a certain energy in coincidence with the cold core residue, which are focused in different places of the focal plane, but at the same magnetic field value.It is assumed that the heavy residue remains unexcited and has a low energy of the order of ~ 30 MeV. The core of the residue is ejected in the forward direction along with the alpha particles. The report will present the possibility of registering alpha particles with a certain energy when they coincide with the cold core residue in the gas-filled version of the MAVR installation. To implement this task, the assembly of position-sensitive strip Si-detectors and semiconductor CdZnTe detectors will be used. A special feature of the proposed method is the registration of low-energy transitions resulting from the decays of superheavy elements.

# IDREAM DETECTOR AT KALININ NPP: STATUS AND PROSPECTS

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At present, various neutrino applications are widely discussed through the community. One such topic is the use of neutrinos for nuclear nonproliferation and reactor monitoring. Industrial detector of reactor antineutrinos for monitoring (IDREAM) is the prototype detector, developed for antineutrinos registration from the reactor core through the inverse beta decay process. Neutrino target is 1 ton of liquid scintillator based on linear alkylbenzene doped with gadolinium. The detector has been installed at Kalinin nuclear power plant (Russia), 19 m from the reactor core. The IDREAM data taking is ongoing since spring 2021. In this talk the concepts and schemes of the experiment will be presented. The results of gamma and neutron background measurements at the detector's location, as well as efficiency estimation of the IDREAM radiation shielding will be discussed.

# THE PENNING TRAP WITH THE COMBINED FUNCTIONS OF PURIFICATION AND MEASUREMEN

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A Penning trap is a powerful device for measuring properties of ions and subatomic particles. Presently it can reach the highest accuracy in the determination of the mass of a nuclide. The typical Penning-trap system for on-line mass measurements requires two dedicated traps. The first trap – preparation trap (PT) – serves for the purification and cooling of the captured ions via the conventional mass selective buffer-gas cooling technique. The second trap – measurement trap (MT) – which, in combination with the downstream MCP detector, serves for the determination of the ion’s cyclotron frequency and, therefore, its mass.

Such a configuration alows mass measurements with uncertainties of a few keV on medium-heavy nuclides with half-lives down to about a few hundred milliseconds. However, when captured, the ions are no longer well centered in the trap, acquiring coherent axial and magnetron motions, what in turn introduces additional systematic shifts in the measurement of eigenfrequencies and, thus, the systematic error of the measured mass. This effect is one of the limitations in the final precision for the PI-ICR detection technique[1]. For the sake of mass measurements of short-lived nuclides the issue can be circumvented by combining the features of both the PT and MT in a single ‘hybrid’ trap.

In the hybrid trap the buffer gas can be injected in the trap region in a pulsed manner using a fast piezo valve. In this way, the pressure in the trap volume is built up only for the cooling phase. After that, the valve is closed, allowing the buffer gas to be pumped out, and when the pressure drop is sufficient, finally the frequency measurement takes place. Besides the reduction of the systematic effects, such hybrid system lowers the overall cost of the apparatus, because it requires only one standard superconducting magnet instead of two or a special single magnet with two regions of highly homogeneous magnetic field.

This work presents the design of the proposed ‘hybrid’ Penning trap system, estimation of its capabilities, and its relevance to the future PITRAP project – the Penning-trap mass spectrometer at the PIK reactor in Gatchina[2].

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# BACKGROUND REDUCTION IN PULSED GAMMA BEAM EXPERIMENTS USING SEGMENTED GERMANIUM DETECTORS

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The Extreme Light Infrastructure-Nuclear Physics (ELI-NP) project is one of the most prestigious research infrastructures in the world due to its unique state-of-the art equipment, the facility will deliver the most brilliant high-energy gamma beams in the world, with unprecedented bandwidth and spectral density[1]. The multi-detector array (ELIADE – ELI-NP Array of DEtectors) is the gamma-ray spectrometer for Nuclear Resonance Fluorescence experiments (both for fundamental research and applications). It is made of eight segmented high-purity Ge clover detectors and 4 large LaBr3 scintillator detectors. The array is the able to detect with high efficiency gamma rays of energies up to several MeV in the presence of the radiation background produced by a gamma beam. Gamma-ray transition energies and angular distributions can be measured with high accuracy[2].
In order to reduce gamma-contamination from the gamma beam in the recorded spectra, the Clover detectors will be surrounded by a passive lead shield. The quality of spectra will be also improved by applying the active Anti-Compton Shield (ACS). The ACS consists of a back-catcher made of CsI crystals plus front and side shield made of BGO crystals. Based on the performed studies, a reliable Geant4 model of ELIADE array including active anti-Compton shields has been developed. It will be presented the Geant4 simulations for the Clover HPGe crystals, CsI and BGO detectors. In this study, the simulations were validated using measurements with standard calibration sources, the estimated impact of ACS to gamma-ray spectra recorded by ELIADE is discussed. The model will help to design NRF experiments for forthcoming experimental campaigns at ELI-NP using gamma beams from 2023.

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# CLUSTER OF PHOSWICH Γ-DETECTORS FOR “MULTI” FACILITY

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The array of 8 CeBr3–NaI(Tl) phoswich detectors coupled to 6-12 CsI(Tl) MULTI 4π γ-spectrometer (Fig.1 Left) of MULTI [1-3] setup was designed at FLNR JINR for studying reaction cross sections with neutron-rich nuclei [4, 5]. The array of 9 CeBr3–NaI(Tl) phoswich detectors (Fig.1 Right) can be used as PARIS cluster [6] for study of β-decay process accompanied by γ-rays from high-lying collective Giant Dipole Resonances (GDR) and low-lying collective Pygmy Dipole Resonances (PDR) from the daughter nuclei.

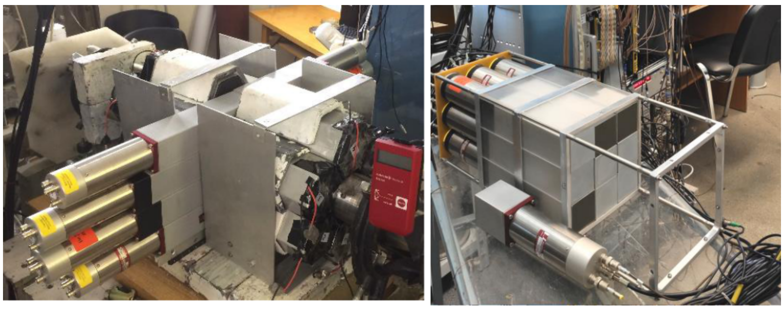

Figure 1: (Left) 8 phoswich detectors coupled to 12 CsI(Tl) 4π γ-spectrometer. (Right) Cluster of 9 phoswich detectors.

The cluster of 9 phoswich detectors has been tested with neutrons and γ-rays at various γ-ray energies using radioactive sources. The investigation results of the response functions of phoswich detectors to γ-radiation at the low energy range (efficiency, pick efficiency, Compton-suppression coefficient, etc.) in depending on the detector-source distance and γ-ray energy are presented. The measurements were carried-out within γ-tagged method. The experimental results are compared with GEANT4 calculations. The complex scintillation waveforms of phoswich detectors have been investigated both the digital (Mesytec Digital Pulse Processor MDPP-16) and analog (Mesytec MADC-32, MQDC-32) electronics [7].
Two-dimensional waveform analysis of phoswich pulses based on the digital electronics were compared to the analog discrimination methods. Both approaches allow to separate clearly the CeBr3 and NaI(Tl) scintillation components of phoswich detectors.

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# BACKGROUND SUPPRESSION IN THE MEASUREMENT OF REACTIONS USING THE NEUTRON TAGGING TECHNIQUE ON THE NG-150 NEUTRON GENERATOR

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Precision experimental data on the differential cross sections for the interaction of fast neutrons with nuclei are in demand in both applied and fundamental research.

In 70-90 years these reactions were intensively studied, especially in the range of neutron energies $E_n$=$13 - 15\mathrm{MeV}$, obtained by the reaction $\mathrm{T} + \mathrm{d} \rightarrow \mathrm{n} + \alpha$. However, the errors in determining the cross sections using the $\Delta \mathrm{E} - \mathrm{E}$ method were $\sim 15 - 20\%$, which are largely due to the significant value of background events in such experiments [1]. The main sources of background events are the reactions $^{28}\mathrm{S(n,p)}^{28}\mathrm{Al}, ^{28}\mathrm{Si(n,d)}^{27}\mathrm{Al}$ and detector into the telescope and the use of triple coincidences significantly reduces the probability of random coincidences from reactions occurring in each of the detectors. However, the registration of the reaction products that occurred in the first detector $\Delta \mathrm{E}$ (with a flight forward) or in the final E-detector of the telescope (with a flight backward) leads to real triple coincidences that form the background. To suppress it, we used the tagged neutron technique [2]. The principle of background suppression is illustrated in Fig. 1. Alpha particles arising from the interaction of a deuteron beam with a tritium-containing target are recorded at a backward angle by a semiconductor detector $\mathrm{E}_a$ in a certain solid angle $\Omega_a$. In this case, a beam of neutrons labeled by registration of alpha particles flies forward in a corresponding solid angle $\Omega_\mathrm{n}$. The target under study is installed in an evacuated chamber on the axis of this beam. A telescope consisting of Si detectors $\Delta \mathrm{E}_1, \Delta \mathrm{E}_2$ and E can be installed at the required angles $\theta$ relative to the tagged neutron beam. In this case, the camera with the target and the telescope is obviously in the flux of fast (including untagged) neutrons generated in the tritium target of the neutron generator, so that background reactions occur in the target, and in all detectors and constructive elements (see neutron trajectories 1 and 2 in the figure).

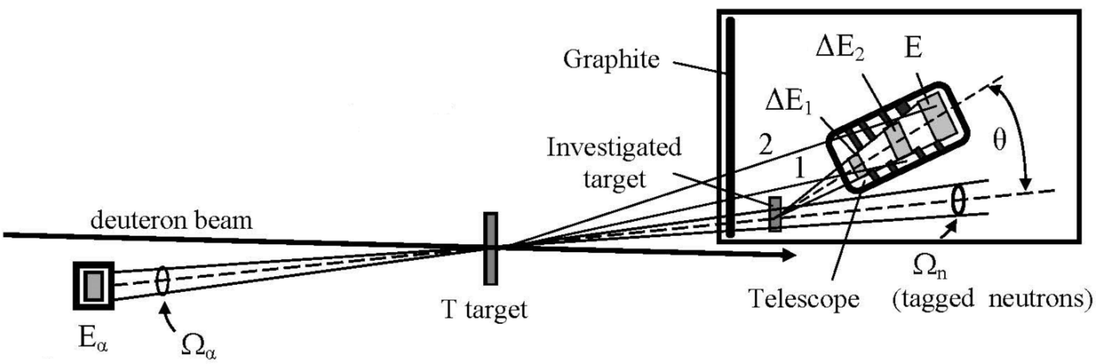


Figure 1: Measurement scheme with background suppression.

The degree of background suppression was experimentally estimated by measuring the background twodimensional $\Delta \mathrm{E2} - \mathrm{E}-$ spectra (in the absence of the target under study) on the NG-150 neutron generator of the INP AS RUz. The acquisition of events was controlled by a pulse coincidence signal from all four detectors (neutron tagging mode), and a pulse coincidence signal from only three telescope detectors. The telescope consisted of detectors with thicknesses

$W_{\Delta E1} = 60\mu m$,$W_{\Delta E2} = 75\mu m$ and $W_E = 1200\mu m$. According to preliminary estimates, seeding by background events in the kinematically allowed registration region decreased several times when the tagged neutron mode was switched on.

If the registration of coinciding events in the telescope is allowed by the signal from the detector $E\alpha$, then all the reaction products arising outside the region of intersection of the tagged neutron beam with the target under study will not be registered. Of course, the reaction of background events will not be realized for small values of the angle θ, when the telescope aperture overlaps with the tagged neutron beam.

It is planned to use such a measurement mode to study reactions (n, d) on a number of light nuclei in order to obtain spectroscopic information necessary for nuclear astrophysical calculations.

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# ELIGANT $^{3}$HE LONG NEUTRON COUNTER FOR (A, XN) AND (A, XP) REACTION STUDIES

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α-induced neutron reactions can result in a neutron yield important for fabrication/storage of nuclear reactor fuel and low background neutron applications. α-emitters in the actinide mass region have different half-lives and thus represent a steady and long-term α-flux [1, 2]. The neutron production yield of (α,xn) reactions vary rapidly in response to the incident α energy and should be accordingly considered by safeguards at nuclear power/enrichment plants; for low background measurements (α,xn) reactions is the source of background events. The underlying experimental cross-section of these (α,xn) reactions become one the main source of uncertainty in the safeguard calculations and the background estimations. Since F compounds of U and Pu are ubiquitous in the nuclear fuel cycle in the project it is proposed to study the 19F(α,xn) reaction to resolve the discrepancy in the available cross section tables. Additional to neutron rates, data on neutron spectra and neutron angular distributions are the important observable. Thus, the mean neutron energy from (α, n) is necessary to estimate a proper shielding for storage/production of reactor fuel. Using the neutron angular anisotropy information it is possible to determine dynamically the ratio of (α, n) rate to spontaneous fission for coincidence counting applications.

This kind of experiments can be fulfilled by using a long ($^{3}$He) neutron counter such as the ELIGANT-TN (ELI-NP) array [3]. Beside high efficiency it provides an opportunity to measure neutron angular correlations and also can give a hint on the energy of the incident neutron beams (using the ring-to-ring technique). If the response of ELIGANT to mono-energetic neutrons is calibrated the mean energy of the detected neutrons can be derived.

In the talk it is presented the ELIGANT detector and constructed to measure parameters (α, xn), (p, xn) and (γ, n) reactions. The project to calibrate ELIGANT using isotropic mono-energetic sources produced in resonant and non-resonant (α, n), (p, n) reactions is discussed. Future experiments, in the astrophysics interest, using a gamma to be provided at ELI-NP are highlighted.

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# WHY DO WE NEED THE FORMULA FOR THE ENERGY RESOLUTION OF A SCINTILLATION SPECTROMETER WITH SEVERAL PHOTODETECTORS?

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Now, there are many works on the theory of scintillation spectrometers, which offer different formulae for the energy resolution of scintillation spectrometers, sometimes contradicting each other. The terms included in the formulae for the energy resolution differ not only in their names but also in the physical meaning of the processes they take into account. The main drawback of all existing theories of scintillation spectrometers is the possibility of introducing various terms into the formula for the energy resolution without giving specific formulae for their relationship with the characteristics of the detector. This approach is not only wrong but also counterproductive, since it does not allow comparing the results obtained by different scientific groups. In this paper, based on the microscopic theory of scintillation spectrometers with several photodetectors, the shortcomings of existing theories are analyzed. It is shown that only the formulas of the microscopic theory for arbitrary moments of the signal distribution function at the outputs of a scintillation spectrometer with several photodetectors can serve as a standard theory of scintillation spectrometers, and will be a reliable basis for linking theoretical and experimental research in the field of physics of scintillation detectors.

# PROTON POLARIMETER FOR THE EXPERIMENTS AT THE NUCLOTRON

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The polarimeter upgrade program at the Nuclotron for the experiments at the internal target are presented. This polarimeter is intended for measurements of the proton and deuteron polarisation. The simulation of the pd-elastic and pp-elastic scattering for 500 - 1000 MeV proton energy are performed. The results of the first test of the new detectors are presented.

# ANALYZING POWER IN QUASI-ELASTIC PROTON-PROTON SCATTERING AT THE BEAM ENERGIES OF 200-650 MEV/NUCLEON

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Analyzing power of the quasi-elastic proton-proton scattering was obtained using a polarized deuteron beam and a polyethylene target at the Nuclotron Internal Target Station. The selection of useful events was performed using time and amplitude information from scintillation counters. The asymmetry on hydrogen was obtained by the carbon background subtraction. The analyzing power values were obtained at the beam energies of 200-650 MeV/nucleon and were compared with the predictions of the partial-wave analysis. The obtained values show the possibility of the deuteron beam vector polarization determination using this method.

# NEW MECHANIC AND COOLING SYSTEMS FOR THE SILICONE DETECTORS USED IN HIGH ENERGY PHYSICS EXPERIMENTS

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A key role for charged particles tracking in modern high energy physics experiments, belongs to the central vertex detectors surrounding the interaction point. With these detectors, it can be possible to investigate heavy-flavour particle (registering of the particles containing c and b quarks) physics and investigate the space-time evolution of strongly interacting matter so-called quark-gluon plasma. To achieve these goals, it is important to improve the spatial resolution of primary and secondary vertices and to decrease a registration threshold for transverse momenta of charged particles. Therefore, the new pixel detectors with minimum material budget (to reduce the multiple scattering effects) and efficient mechanic and cooling systems should be used for tracking charged particles.
In the present work, the ideas, developments and studies of mechanic and cooling systems for novel vertex detectors based on silicon pixel sensors have been presented. The obtained results can be used in both high-luminosity collider experiments and for some high-technology medical applications.
The reported study was supported by RFBR, research project No. 18-02-40075.

# COMPLEX ESTIMATION OF THE PROPORTIONAL CHAMBER CATHODE SURFACE CONDITION AFTER WORK AT LARGE HADRON COLLIDER EXPERIMENT

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In the report the complex study of the multiware proportional chamber cathodes surface that had worked under continuous radiation exposure conditions at Large Hadron Collider (LHC) experiment was performed. At the areas where the spontaneous self-supporting electron emission effect (Malter-effect – ME) was observed and where there was no effect, the cathode surface was investigated. For the first time the detector cathode surface was studied with the help of a set of methods including nuclear-scanning microscopy, atomic-scanning microscopy, Raman spectrometry and Roentgen-phase analysis. An essential difference at cathode surface structure at the regions with or without ME was detected. Possible mechanisms inducing this electron emission effect are discussed.

# NEURAL NETWORK APPLICATION TO EVENT-WISE ESTIMATES OF THE IMPACT PARAMETER

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Evaluation of the impact parameter in a single event is crucial for correct and efficient data processing in collision-based nuclear and particle physics experiments. Real-time estimates of the impact parameter allows experimentalists to preselect the most informative events at the data acquisition stage, before any processing. Here we consider a number of model setups to check whether a neural network can evaluate the impact parameter from the spacial and time-of-flight data collected in real time by a set of inexpensive microchannel plate ring detectors.
We evaluate several detector geometries, including the geometries considered for SPD detector [1] at NICA, and several neural network architectures.

We have shown that even low spacial resolution detectors in realistic geometry would make it possible to separate low — less than 6 fm — impact parameter events from other collisions with 84% probability.
The analysis of the full $4\pi$ geometry would rise the probability of the low impact parameter collision identification to 97%. Appropriate usage of the time of flight information is crucial to obtain these results. Without time information the quality of identification of low impact parameter events does not exceed 64%, with especially high contamination from high — greater than 12 fm — impact parameters.

The presented computational experiments prove application of neural network techniques for direct impact parameter evaluation useful for future experimental setups.

This work is partially supported by Russian Foundation for Basic Research grants 18-02-40104 mega and 18-02-40097 mega.

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# CATALYSTS OF RADIO-CHEMICAL REACTIONS, CONNECTION WITH THE CONCEPTS OF THE ORIGIN OF PETROLEUM ON EARTH

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The catalytic properties of zeolites have been known since the late fifties of the twentieth century. Zeolites are crystalline substances with developed porosity. A number of work was devoted to formation and transformation of petroleum hydrocarbons in porous system [1-3]. The theory of the abiogenic deep origin of hydrocarbons recognizes that the petroleum is a primordial material of deep origin [Kutcherov, Krayushkin 2010]. The experimental results confirming the possibility of synthesis of natural gas from inorganic compounds under the upper mantle conditions were published in [Kutcherov et al.,2010]. Both donors of carbon (carbon itself, carbonates, CO2 ) and hydrogen( water, hydroxyl group of minerals) are present in the asphenosphere in sufficient amounts. Thermodynamically favourable reaction environment (reducing conditions) could be created by a presence of FeO. The presence of several present of FeO in basical and ultra-basical rocks of asthenosphere is documented [3]. It has been shown the reactions of the formation of petroleum’s aromatics in presence of bentonite clay [2].
In this presented research, bentonite clay from Alpoid deposit, Azerbaijan was proposed as a catalyst for radiation-induced isomerization of petroleum hydrocarbons at low doses of gamma-radiation. Natural clays, which are a low-cost and scarce natural resource, are nontoxic to the ecosystem.
The raw bentonite clay sample used in these experiments has nanostructured composition with particle size in the range of 55≤ d [nm] ≤ 175 nm [2]. In the present work, the influence of gamma-irradiation ($^{60}$Co) on physicochemical parameters (“crystallinity”, specific surface, cation exchange capacity, main layer charge) of clay minerals were investigated. The influence of gamma-irradiation on the physicochemical properties is generally weak at law doses. A reduction of lattice iron during irradiation could be measured, which causes decreasing values of cation exchange capacity (CEC) and main layer charge of the smectites. A weak loss of “crystallinity” of bentonite could be observed. The regulation of active sites and adsorption properties, as well as the topology of support surfaces, allows a potential predictive design of novel catalysts for transformation of hydrocarbons. The main purposes of the study were set, which are discovering the role of catalyst for transformation maximum energy to the system. Hydrocarbons adsorbed on mineral solid of high surface area. The catalytic conversion of hydrocarbons of petroleum occurring on contact with irradiated solids. The main essence of radiocatalytic processes is transferring the unbalanced charges formed by absorbed ionizing radiation energy on the surface of the catalyst to the system.

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# CAPABILITIES OF PROBE EMISSION MÖSSBAUER SPECTROSCOPY FOR STUDIES ON POST-EFFECTS OF CRITICAL RADIATION EXPOSURE IN TANTALUM

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By the use of $^{57}$Co impurity atoms as structure-sensitive physico-chemical probes and X-ray Diffraction method, post-effects of critical radiation-induced effects have been studied that resulted from irradiation of metal tantalum with charged particles.
The small (less than 0.2 μm) thickness of surface layers of samples doped with $^{57}$Co atoms enabled the direct radiation damage of Ta crystal lattice by proton beams to be excluded (the number of displaced atoms being negligibly low, of less than 0.1 vacancies/ion), as well as the consequences of irradiation of the metal by their “own” Ta atoms to be studied (the number of the displaced atoms being 3900 vacancies/ion), these atoms having been knocked out of the crystal lattice during target bombardments.
The experimental data obtained by both Emission Mössbauer Spectroscopy and X-ray Diffraction methods have shown that irradiation of metal with heavy ions (atoms of Ta) is accompanied by disordering of the metal surface layers: by the formation of thermal- and displacement spikes in metal Ta.

# THE DEVELOPMENT OF NUCLEAR SECURITY CULTURE IN THE REPUBLIC OF BELARUS IN 2020-2021

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Nuclear security culture is an essential means for nuclear security enhancement. It contributes to the ability of personnel to effectively mitigate potential threats to nuclear and radioactive material by promoting appropriate attitude and behavior that result in personnel adopting a more rigorous and prudent approach to their nuclear security responsibilities. Within organizations that have a strong nuclear security culture it is less likely that personnel will commit a malicious act, either due to their belief that nuclear security is important or to the deterrence factor of vigilance and professional adherence to nuclear security practices.

This paper is a continuation of the «Advanced Nuclear Security Program at The Joint Institute for Power and Nuclear Research – Sosny» [1] which reflects the process of nuclear security culture implementation and strengthening. The authors touched upon the development of nuclear security culture in the Republic of Belarus in 2020-2021. This time coincides with the period of the first unit of Belarusian Nuclear Power Plant in Ostovets commissioning on the one hand, and with the spread of COVID-19 on the other.

The role of nuclear security culture has increased as reflected in a number of regulations approved 2020:

• Requirements and rules for ensuring nuclear and radiation safety «General provisions for nuclear power plants safety insurance» [2]

• Requirements and rules for ensuring nuclear and radiation safety «Safety when handling ionizing radiation sources. General provisions.» [3]

Role, functions and requirements for nuclear security culture are set forth not only for Belarusian nuclear power plant [2], but also for organizations operating ionizing radiation sources [3].

Presently, we all are living in a time of COVID-19 spread. Sanitary standards establishment has made corrections to organization of activities necessary for development and strengthening of nuclear security culture in organizations.

The paper presents the approach and lists the activities organized by the Scientific Institution "JIPNR - Sosny" to improve nuclear security culture.

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# CARBON NANOMATERIALS APPLICATION FOR ISOL-METHOD OF HEAVY ION FUSION REACTION PRODUCTS

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The experiment directed to the study of a new carbon nanomaterials application was performed on the U-400M heavy ion beam at MASHA facility, FLNR, JINR. In the present speech a new technical improvements will be discussed such as usage of thin carbon nanotubes paper (thickness 6.4 mg/cm2) and graphene (thickness 1.1 mg/cm2) in the hot solid catcher block unit. The main goal of the experiment was to determine radiation resistance of these materials for ISOL method. Previous experimental researches performed with polygraphene structure, which represents a thermally expanded graphite hot catcher, showed an incompatibility with high intensity beams [1]. Measurements via new carbon nanomaterials showed also decreasing of the separation time for mercury in reaction 144Sm(40Ar, xn)184-xHg. Thus, it became possible to gain statistics and to analyze 6n-evaporation channel decays (178Hg) with the T1/2=0.266 s at the focal plane of data acquisition system. Early separation time measurements performed by beam interruption method [2] showed average separation time for mercury 1.8±0.3 s. The improvements of ISOL method application allow synthesizing new products at the beam intensities up to 0.5 p⊠A and even more for the Super Heavy Element factory perspective in FLNR, JINR. Consequently, the experiment with carbon nanotubes paper demonstrated perspectives for the fusion reaction products separation at MASHA facility due to its radiation resistance and shorter response time.

# NEUTRON FLUX ESTIMATION IN THE SPALATION EXPERIMENT AT THE PNPI SYNCHROTRON

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The synchrotron, as a source of neutrons, has a number of advantages, in particular, the presence of a starting time mark. The high energy spectrum, up to energies of 1 GeV may be an advantage for measuring the cross-section of reactions with neutrons. The application of the PNPI synchrotron in the splice mode is described in detail in the article [1]. In this work, the experiment was conducted simultaneously with the experiment on GNEIS.
To estimate the neutron spectrum, several identical containers with a moderator and thin stainless foils were used as monitors. Three tanks measuring 200x300x400 mm with a volume of 24 liters were placed under the synchrotron chamber against the proton motion (to reduce the influence of the scattered proton beam on the experimental results) starting from the plumbum target. Else two containers were placed in the transverse direction. In the lower part of the containers, foils were fixed. After the irradiation, the activity was determined from the gamma spectra of the samples and the fluence was found by the formula:

$$Fluence = \frac{IM_N e^{\frac{\ln 2}{T_{\frac{1}{2}}} t_{lag}}}{\text{mk}\sigma N_A(1 - e^{\frac{\ln 2}{T_{\frac{1}{2}}} t_{exp}})}$$

I is the partial activity of the isotope in the monitor, $M_N$ is the mass of the nucleus of the parent isotope in atomic mass units, $T_{1/2}$ – the half-life of the daughter isotope, $t_{lag}$ – the measurement delay time after the synchrotron stops, $t_{exp}$ – the time of irradiation of the sample in the neutron flux, m—the mass of the sample, k – the product of the content of the corresponding element and the percentage of the parent isotope in it, σ – the cross section of the reaction of the parent nucleus + neutron, NA – the number of Avogadro-neutron fields. The results of the experiment were compared with the numerical experiment. The coincidence of the real experiment and the numerical one can be considered satisfactory. The flux for the sample that registered the most “soft” spectrum was about $10^8$ neutrons per second per $cm^2$.

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# NEUTRON-PHYSICAL CHARACTERISTICS ESTIMATION OF THE SUBCRITICAL ASSEMBLY "YALINA-THERMAL" WITHIN THE PHYSICAL BIRTH-AND-DEATH MODEL

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An analytical approach based on the birth-and-death model for description of the neutron and neutron-multiplying medium interaction process is presented in this work. It is called physical birth-and-death model [1]. Mathematical expressions of the multiplying medium main characteristics, reactivity ρ and average particles number at the time M(t), are given. These characteristics are estimated within obtained expressions for the subcritical assembly "Yalina-Thermal" with uranium fuel $^{235}$U of 10% enrichment [2].

The physical birth-and-death model is a special case of the probability birth-and-death model (BDM). Neutron and neutron- multiplying medium interaction processes in a thermal nuclear reactor core were considered with linear growth approximation of the birth-and-death model in the E.A. Rudak works [3]. The radioactive particles decay processes properties within the framework of Poisson and binomial distributions were studied with BDM. The equations and fundamental curves describing multiplying medium parameters of the point thermal reactor example were analyzed by this model too. Nuclear assembly core is considered as ensemble of thermal point-reactors within birth and death model. This approach makes it possible to obtain the average values of the parameters that describe state of the system as a whole. The model is purely mathematical and operates intensities of birth (λ) and death (μ) concepts, but is not directly connected with the neutron multiplying medium parameters. Physical characteristics accounting is the next stage in the BDM development.

YALINA-Thermal is a subcritical assembly. It has been constructed at Joint Institute for Power and Nuclear Research – Sosny, Minsk, Belarus. The assembly together with the highly intensity neutron generator are used for neutrons static and dynamic properties research of accelerator-driven systems.

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# IMPLEMENTATION OF HIGH-PERFORMANCE COMPUTING TECHNOLOGIES IN THE BMNROOT FRAMEWORK

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The purpose of the BM@N experiment at NICA accelerator complex in Joint institute for Nuclear Research (Dubna, Russia) is study of heavy-ion collisions with fixed targets. Successful study requires efficient algorithms of event reconstruction and particle identification using data from the detector subsystems of the facility as well as its efficient and high-performance software implementation in the BmnRoot package. Development and study of such algorithms, their software implementation and optimization of the existing software components of the BmnRoot are subjects of the report. Implementation of simulation and reconstruction algorithms for hybrid computing systems are also discussed.

The study was supported by RFBR grant № 18-02-40104 mega.

# STUDY OF FALLOUTS IN THE BOTTOM SEDIMENTS OF CHERNOBYL NUCLEAR POWER PLANT COOLING POND

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This work reports studies of fuel fallouts from bottom sediments of the Chernobyl NPP cooling pond. We took samples to a 30 cm depth at cooling pond different locations for gamma spectrometrical and radiochemical study. The measurement results show that over 80% of the radionuclide activity is located at a depth of 10-20 cm. The Am-241 activity is 6-8% compared to Cs-137, while in usual Chernobyl fuel fallouts, this value is 2-3%. The Sr-90 activity is 40-50% compared to Cs-137 in studied samples. The fixed activities Eu-155 and Eu-154 allow us to determine the burnout of fuel depositions in cooling pond bottom sediments. Activation radionuclides Co-60 and Nb-94 were detected in studied samples. Analysis of the Co-60 and Nb-94 ratios showed that, most likely, these are fallouts from the first accident explosion of the 4th unit of the Chernobyl nuclear power plant. Precipitation at a depth of 0-10 cm is mainly associated with the deposition of aerosol fallout in subsequent years. Radionuclide ratios in the cooling pond bottom sediments at the 10-20 cm depth correlate with radionuclide ratios in soils near the Shelter after the installation of Second Confinement. The fallout of the cooling pond also contains a component associated with the fallout in the post-variance period. Moreover, its vertical migration correlates with the vertical migration of aerosol fallout in 30-km zone Chernobyl NPP soils. The following results show the studied radioisotope activities at a depth of 10-15 cm: Am-241 684 Bq/sample, Am-243 1.6 Bq/sample, Eu-154 28.5 Bq/sample, Eu-155 4.31 Bq/sample, Cs-137 10260 Bq/sample, Nb-94 2.0 Bq/sample, Co-60 1.75 Bq/sample, Sr-90 4500 Bq/sample. The obtained results are discussed. Acknowledgments: The reported study was funded by RFBR, project number 19-05-50095.

# THE STUDY OF NUCLEUS REACTIONS IN GUNESHLI PETROLEUM BY EPR METHOD

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Crude oil is naturally occurring oil generated by geological and geochemical processes. Each type of crude oil or petroleum product has unique characteristics or properties [1]. These properties influence how petroleum will behave when it is exposed by gamma-rays with and without catalyst. The process of crude oil's hydrocarbon's radiolysis is complicated [2]. Over the past decade, it has been achieved a new level in understanding of the most important processes' mechanisms of hydrocarbon conversion.

The aim of this study was to investigate the changes of hydrocarbon generation on the surface of the catalyst, irradiated with gamma rays. The raw bentonite sample used in these experiments has nanostructured composition [2]. Due to such a structure, the applied catalyst supports maximum energy transfer to the system. One of the primary objectives of this research work is increasing the efficiency of transformation of adsorbed beam energy in solid phase to the system and improvement of formation of branched hydrocarbons in petroleum. The changes taking place in raw bentonite, under ionizing radiation, can be interpreted as involving the creation of a structure with radiation defects. It has been investigated the dynamics of dose–dependent changes in the amount of izostructural hydrocarbons and the main reason change of its form under radiation are the configuration, distortion of n-hydrocarbon structure of crude oil, the conformation, transformation and reorientation of some sections of petroleum molecules and weakening of intermodular interaction. By using the method of EPR spectroscopy has been discussed possible mechanism of radio-catalytic reaction for conversion of n-alkanes to branched hydrocarbons at low dose irradiation.

The crude oil samples were irradiated with gamma radiation from the $^{60}$Co isotope under static conditions, within vacuum sealed quartz tubes at room temperature. The dose rate was 10.5 Rad/sec. Electron Paramagnetic Resonance (EPR) is used to study metal centers and radicals involved in chemical processes. Structural insights from the chemical structure to intermolecular interactions are obtained from EPR techniques ("Bruker" EMX MicroX) at room temperature. Parameters for signal measurement: microwave frequency 9.87 GHz, modulation frequency 100 kHz, modulation amplitude 5 G, sweep width 100G, measuring range 100 G.

Taking into account that EPR is a non-destructive method and there is no need for sample preparation, it demonstrates that EPR can be used for the on-line monitoring or even for the EPR logging to follow the influence of thermal or radio-catalytic treatment of heavy crude oil.

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# Section 4. Relativistic nuclear physics, elementary particle physics and high-energy physics

## CMS STANDARD MODEL RESULTS

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The Large Hadron Collider (LHC) has completed in 2018 its second working phase and the experiments have collected data sets of proton–proton collisions at center-of-mass energies of 13 TeV with an integrated luminosity of about 140 $\mathrm{fb}^{-1}$ . This report reviews the status of standard model measurements with the CMS experiment at the LHC.

# SEARCH FOR THE CHIRAL MAGNETIC WAVE USING THE ALICE DETECTOR IN PB–PB COLLISIONS AT $\sqrt{S_{\mathrm{NN}}} = 5.02$ TEV

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In heavy-ion collisions, a strong magnetic field ($\sim 10^{15}$ T) is expected to be created, which together with the presence of a non-zero electric and axial charge density, can lead to vector and axial currents in the produced system called the Chiral Magnetic Effect (CME) and Chiral Separation Effect (CSE), respectively. Their coupling gives rise to a collective excitation in the quark-gluon plasma (QGP) called the Chiral Magnetic Wave (CMW), causing a charge-dependent elliptic flow, $v_2$. As a result, the normalized difference of $v_2$ of positive and negative charges, ($\Delta v_{2_{\mathrm{Norm}}}$), may exhibit a positive slope as a function of the asymmetry ($A_{\mathrm{ch}}$) in the number of positively and negatively charged particles in an event. However, non-CMW mechanisms like Local Charge Conservation (LCC) can also lead to a similar dependence of $v_{2_{\mathrm{Norm}}}$ on $A_{\mathrm{ch}}$. A similar measurement with $v_3$ can probe the effect of LCC as we expect it not to be affected by the CMW.

In this talk, we present ALICE measurement of $v_2$, $\Delta v_{2_{\mathrm{Norm}}}$, $v_3$ and $\Delta v_{3_{\mathrm{Norm}}}$ of charged hadrons in $0.2 < p_{\mathrm{T}} < 1.0$~GeV/$c$ and pions in $0.2 < p_{\mathrm{T}} < 0.5$~GeV/$c$ as a function of $A_{\mathrm{ch}}$ in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. The slope parameters corresponding to $v_{2_{\mathrm{Norm}}}$ and $v_{3_{\mathrm{Norm}}}$ versus $A_{\mathrm{ch}}$ are measured as a function of collision centrality to search for the CMW phenomena at LHC energies. We will also compare the ALICE results with those from the CMS experiment and lower collision energy STAR experiment and also with different model predictions.

# INVESTIGATION OF THE DP-BREAKUP REACTION AT INTERMEDIATE ENERGIES AT NUCLOTRON

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The studies of nuclear reactions involving deuterons play an important role in the understanding of the structure of the nucleons and the dynamics of nuclear interactions. The study of processes involving the deuteron helps to solve many actual relativistic problems of nuclear physics, such as nucleon-nucleon interaction at high energies, the structure of light nuclei at small inter-nucleon distances and the production of baryon resonances. At the present, a lot of data on the deuteron are accumulated by using electron and hadron beams [1-3].

Investigation of the deuteron-proton breakup reaction is one of the tools for studying the nature of 3NF and relativistic effects. The dp-breakup measurements have been carried out at the internal target station [4] at the Nuclotron at the Veksler and Baldin Laboratory of High Energy Physics of Joint Institute for Nuclear Research in the framework of DSS project. The energy calibration of the $\Delta E - E$ detector has been performed at 300, 400,and 500 MeV. The goal is to obtain results in the form of kinematical curve (S - curve) of the experimental data obtained at the kinetic energy of the deuteron beam of 300 MeV. The results of particular configurations obtained at 300 Mev of deuteron energy will be presented.

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# DESCRIPTION OF THE SPECTRA OF CUMULATIVE PROTONS, PIONS AND PHOTONS IN COLLISIONS OF HEAVY IONS WITH INTERMEDIATE ENERGY BASED ON THE HYDRODYNAMIC APPROACH

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On the basis of the hydrodynamic approach with a nonequilibrium equation of state [1-3], collisions with a beryllium target of $^{12}C$ nuclei at energies of 0.3-3.2 GeV per nucleon, studied at the ITEP accelerator, with the emission of protons [4], pions [5] and photons [6] are considered. Experimental proton spectra contain a high-energy cumulative part, as well as a soft part, to which fragmentation contributes. We were able to describe the cumulative part of the proton spectrum [2] within the framework of the nonequilibrium hydrodynamic approach, taking into account the nuclear viscosity and the correction for the microcanonical distribution [2] and to supplement the calculations with the proton contribution based on the statistical mechanism of fragmentation in the soft region of the spectrum [3]. Distinguishing the compression stage, the expansion stage, and the spread stage with the formation of secondary particles, we described the experimental inclusive double differential cross sections for the emission of pions at an energy of 3.2 GeV per nucleon for carbon nuclei [5], which were presented recently, as well as the emission of hard photons [6], presented earlier.In our approach, the description of the cumulative spectra of secondary particles is achieved due to the isolation and hydrodynamic evolution of local heating - hot spot in the overlap region of colliding heavy ions. We also considered the emission of protons and pions for various nuclei at the energies of the SIS accelerator (GSI). Agreement with the experimental data is achieved without introducing fitting parameters, and can be extended to the energy range of the NICA accelerator complex under construction in Dubna.

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# STUDY OF SPECTATOR CHARGE DISTRIBUTIONS IN THE HADES EXPERIMENT FOR AG+AG@1.58AGEV AND AU+AU@1.23AGEV

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Fragments charge has been measured with the forward hodoscope (FWall) in the HADES experiment for Ag+Ag@1.58AGeV and Au+Au@1.23AGeV. First results on the nuclei fragments description with the framework of the DCM-QGSM-SMM model and comparison with the experimental data will be presented. The description of the fragments within the model is a crucial task to determine the collision centrality and geometrical properties of the nucleus-nucleus collision.

# A POSSIBILITY TO REGISTER ASSOCIATED PAIR PRODUCTION OF HADRONS AND LIGHT NUCLEI IN A KINEMATICALLY FORBIDDEN REGION IN AA-INTERACTIONS ON THE FODS DOUBLE ARM SPECTROMETER AT THE U-70 ACCELERATOR COMPLEX (THE MONTE CARLO SIMULATION)

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The possibility to register the associated pair production of hadrons and light nuclei in a kinematically forbidden region in AA-interactions on the FODS double arm spectrometer at the U-70 accelerator complex (Protvino) is analyzed. The value of ion beam energy is 20.5 GeV/nucleon ($\sqrt{s_{NN}}$=6.3 GeV). The mode of measurements with one arm makes it possible to study production of hadrons and nuclei in forward direction at zero angle for values of Feynman variable reaching x=2.5. Here we analyze a variant with activationof both arms. The arms are installed asymmetrically at angles of 128.9 mrad and -268.9 mrad relatively to propagation of the ion beam for South and North arms respectively. This gives ability to register processes with emission of the secondary nucleons and nuclei into forward and backward hemispheres in the center of mass. The purpose of such an experiment is to explicitly reveal the cases of binary interactions, showing the cluster structure of nucleus.
This work was supported by the grant from the Russian Foundation for Basic Research Ho.19-02-00278.

# COMBINANT ANALYSIS OF MULTIPLICITY DISTRIBUTIONS IN P+P INTERACTIONS IN MULTIPOMERON EXCHANGE MODEL

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Studies of multiplicity fluctuations and the shape of multiplicity distributions (e.g. the KNO scaling) are among the basic components of relativistic nuclear physics. Combinants being the linear combinations of ratios of probabilities, as well as widely used cumulants, are quantities that characterize a distribution. Recently it was found that combinants obtained from multiplicity distributions in p+p interactions at LHC collision energies exhibit an oscillatory behavior that is not reproduced by the standard statistical distributions such as negative binomial.

Modified multipomeron exchange model [1-4] successfully reproduces the general features of $p+p$ and $p+\overline{p}$ collisions such as energy dependence of charged multiplicity (Nch), transverse momentum <pt> as well as the experimentally observed transition from negative to positive <pt> - Nch correlation. In this paper, we test whether the oscillating nature of combinants is present in the model, argue the importance of precise measurements of events with zero multiplicity, and introduce a modification to the combinants definition in order to deal with truncated distributions.

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# NEW EFFECTS IN THE MONTE CARLO MODEL OF PP, PA AND AA COLLISIONS WITH STRING FUSION

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A further development of Monte Carlo model of pp, pA and AA collisions with string fusion [1-3] is made for a more detailed description of the multiple hadron production both in small and large transverse momentum areas.
An effective dipole partonic cascade was implemented, taking into account the Lorenz invariance of the observed values. Thus, a single parameter will remain in the model dependent on the energy of the collision. Running coupling constant is taken into account, which allows one to more correctly describe the hard collisions. Short-range correlations of transverse momentum in the string fragmentation is implemented. The model parameters tuning is made and predictions of the model are compared with experimental data.
This work is supported by the SPbSU grant ID:75252518

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# CORRELATION OF CUMULATIVE PARTICLE PRODUCTION WITH STRANGE AND HEAVY-FLAVOR PARTICLE YIELDS IN THE STRING FUSION MODEL

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The possible correlation between the yield of strange and heavy-flavour particles and the emission of particles in the region outside pN-kinematics (the so-called cumulative region) in pA collisions is studied. The particle production in the cumulative area is considered as a trigger, confirming participation in the process of a dense few-nucleon cluster. From the modern point of view this cold dense nuclear matter clusters (fluctons), intrinsically presented in nuclei, could be regarded as multiquark bags. For the description of particle production from such objects, the scheme based on the evaluation of the diagram near thresholds is applied.
In present work, using the string fusion model, we analyze the fragmentation of the nuclear cluster residue after the emission of a particle in cumulative region. Previous studies show that the diagrams are dominant, in which all rest quarks of the cluster (the donors, compensating the momentum of the fast cumulative quark) must interact with the projectile. At the same time these donor quarks belong to a shrunk configuration in transverse plane of the reaction. As a consequence the strings formed in the interactions of all remnant quarks of the cluster with the projectile occur strongly overlapped in the impact parameter plane, what leads to the enhanced yield of strange and charm particles due to sting fusion processes. Along with the standard Schwinger-based version of a string fragmentation we consider also the modified version characterized by the thermal-like spectra. In this model the additional increase of the strange and heavy-flavour particle production is observed. Basing on this picture we calculate the strength of the correlation between the yield of particles in the backward cumulative hemisphere and the magnitude of additional forward strange and charm particles production in relativistic pA collisions. The possibility of experimental observation of the given phenomenon in fixed target experiments is also discussed.
The work was supported by the RFBR grant 18-02-40075.

# STRONGLY INTENSE OBSERVABLES AS A TOOL FOR STUDYING CLUSTERS OF QUARK-GLUON STRINGS IN RELATIVISTIC HADRONIC INTERACTIONS

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The using of strongly intensive observables are considered as a way to suppress the contribution of trivial "volume" fluctuations in experimental studies of the correlation and fluctuation phenomena [1]. In this regard, we study the properties of the strongly intensive variable characterizing correlations between the number of particles produced in two observation windows separated by a rapidity interval in pp interactions at LHC energies in the model with quark-gluon strings (color flux tubes) as sources [2,3].

It is shown that in the version of model with independent identical strings this variable really depends only on the individual characteristics of a string and is independent of both the mean number of strings and its fluctuation, which reflects its strongly intensive character.

In the version of the model when the string fusion processes are taken into account, and a formation of string clusters of a few different types takes place, it was found that the observable is proved to be equal to a weighted average of its values for different string clusters, with weight factors, depending on details of the collision - its energy and centrality [4].

The analytical calculations are supplemented by the MC simulations permitting to take into account the experimental conditions of pp collisions at LHC energies. We perform the MC simulations of string distributions in the impact parameter plane and take into account the string fusion processes, leading to the formation of string clusters, using a finite lattice (a grid) in the impact parameter plane [4,5].

As a result, the dependences of this variable both on the width of the observation windows and on the value of the gap between them were calculated for several initial energies. Analyzing these dependencies we see that in pp collisions at LHC energies the string fusion effects have a significant impact on the behavior of this observable and their role is increasing with the initial energy and centrality of collisions. In particular, we found that the increase of this variable with initial energy and collision centrality takes place due to the growth of the portion of the dense string clusters in string configurations arising in pp interactions.

We show that the comparison of our model results with the preliminary experimental values of the strongly intensive variable obtained by the analysis of the ALICE data on pp collisions enables to extract information on the parameters characterizing clusters with different numbers of merged strings, in particular, to find their two-particle correlation functions and the average multiplicity of charged particles from cluster decays [5].

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# STUDY OF MULTIPLICITY AND TRANSVERSE MOMENTUM FLUCTUATIONS IN THE MONTE-CARLO MODEL OF INTERACTING QUARK-GLUON STRINGS

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In the search for the critical point of strongly interacting matter one of the key methods is the study of the event-by-event fluctuations of different event observables. One important aspect of this research is an accurate definition of the initial conditions event-wise. Namely, the influence of the trivial fluctuations, such as those of the system volume should be eliminated in the studied quantities or well-controlled in the experiment. From the phenomenological point of view, one can address this question in the two-stage string model of particle production, whose results can act as a baseline to estimate the non-critical background of fluctuations. In this work we develop and use Monte-Carlo model of interacting quark-gluon strings of the finite length in rapidity space to determine the influence of the string fusion on the final fluctuation measures [1]. On the other hand, the model results in comparison to the experimental data can guide us in the study of the particle production sources and their interactions.
This work is supported by the RFBR research project no. 18-02-40097.

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# ACCESSING THE GENUINE THREE-BARYON INTERACTIONS VIA FEMTOSCOPIC STUDIES IN PP COLLISIONS AT $\sqrt{S}$ = 13 TEV WITH ALICE

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The femtoscopic studies done by the ALICE Collaboration provided results with unprecedented precision for the short-range strong interactions between different hadron pairs. The next challenge is the development of the three-particle femtoscopy which will deliver the first ever direct measurement of genuine three-body forces. Such results would be a crucial input for the low-energy QCD and neutron star studies. In particular, the momentum correlation of p–p–p triplets can provide information about genuine three-nucleon forces while the p–p–$\Lambda$ interaction is a necessary piece to understand if the production of $\Lambda$ hyperons occurs in neutron stars.
In this talk, the first study of p–p–p and p–p–$\Lambda$ correlations will be presented. The results were obtained using high-multiplicity pp collisions at $\sqrt{s}$ = 13 TeV measured by ALICE at the LHC. The measured three-body correlation functions include both three- and two-particle interactions. The cumulant method was applied to subtract lower-order contributions and infer directly on the genuine three-body forces. The two-particle contributions were estimated both experimentally by applying mixed-event technique, and mathematically by projecting known two-body correlation functions on the three-body systems. The measured p–p–p and p–p–$\Lambda$ correlation functions and the corresponding cumulants will be shown.

# ANGULAR CORRELATIONS OF PARTICLE YIELD RATIOS

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Measurements of fluctuations allow one to study phase transitions and other collective phenomena in systems formed in high-energy hadronic collisions.
In this report, we will discuss properties of a recently proposed fluctuation observable, namely, the correlation coefficient between ratios of identified particle yields measured in two angular acceptance windows. With such an observable it is possible, for instance, to study the correlation between relative strangeness yield in separated rapidity intervals, which should be sensitive to the density of the fireball formed in A–A collisions. These correlations are also sensitive to various short-range effects, in particular, they are affected by spin statistics. We will show predictions from several models of pp and A–A collisions that include known effects, and these calculations will serve as baselines for the future measurements with this observable in real experimental data.

# MULTIPLICITY DEPENDENCE OF PION-EMITTING SOURCE SIZE IN P+AU AND D+AU COLLISIONS AT $\sqrt{S_{NN}}$=200 GEV IN STAR EXPERIMENT

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Femtoscopy is a tool to measure the spatial and temporal characteristics of a system produced after a collision of two nuclei happened. Currently, it is not possible to directly measure these properties of the system, however, femtoscopy rely on a different approach to accomplish this task, it uses momentum correlations of particle pairs. Those correlations originate from quantum statistics and final state interactions of identical particles. By measuring a relative momentum distribution of two identical particles it becomes possible to extract the femtoscopic radii. The femtoscopic radii as a function of event multiplicity or a pair transverse momentum provide the information about dynamics of the system. It is also important to understand how the system size would change for different collision species.

In this work, we present the charged pion femtoscopy for p+Au and d+Au collisions at $\sqrt{s_{NN}}$=200 GeV taken in the STAR experiment. Emitting-source radius dependence on the event multiplicity and transverse momentum of the pion pairs will be discussed.

# STUDY OF NEUTRAL AND CHARGED PIONS FLUCTUATIONS WITH ALICE EXPERIMENT

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Fluctuations of relative yield of neutral and charged pions are expected to be sensitive to the creation of quark-gluon matter, pion Bose-condensate or chiral phase transition, which may take place in AA, pA or even pp collisions. Quantitatively, such fluctuations can be estimated using the variable $\nu_{dyn}$ which, by its construction, reduces or completely removed most of the collisional bias, such as impact parameter fluctuations or fluctuations from the finite number of particles within the detector acceptance. In this report we will present the results of the analysis of fluctuations of charged and neutral pions using the dynamic variable $\nu_{dyn}$ in Monte-Carlo simulation of pp, pA and AA collisions at an energy of 5.02 TeV in the ALICE experiment. We will demonstrate that photons measured in the PHOS calorimeter do reproduce fluctuations of parent pions after correcting for the probability of registering one or two decay photons. We will discuss contributions of resonance decays and ways to reduce related contribution to $\nu_{dyn}$. Possible relations to recent ALICE results on charged and neutral kaon fluctuations in Pb-Pb collisions will be addressed.

# GENERATING FUNCTION FOR NUCLEUS-NUCLEUS SCATTERING AMPLITUDES IN GLAUBER THEORY

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A new approach to deal with the scattering amplitudes in Glauber theory is proposed. It relies on the use of generating function, that has been explicitly found. The main advantage of the method is in a relatively simple analytical form that allows to carry out calculations in the all interaction orders of the Glauber theory. Until now the only way to do it without additional approximations is Monte Carlo calculations.

As an example we apply our method to $^{12}C$ – $^{12}C$ scattering at the energy 950 MeV per nucleon for which there exist the experimental data. The proposed generating function is appropriate for any pairs of colliding nucleus regardless their atomic weight.

# HADRONIC RESONANCES AS PROBES OF THE LATE HADRONIC PHASE IN HEAVY-ION COLLISIONS AT NICA ENERGIES

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The short-lived hadronic resonances are used to study the properties of the hot and dense medium produced in relativistic heavy-ion collisions. Due to their short lifetimes, the resonance yields and peak shapes measured in the hadronic channels are sensitive to rescattering and regeneration effects in the hadronic phase. Besides, the resonances with different strangeness content and baryonic numbers probe the strangeness enhancement phenomenon and hadronization mechanisms in the low-to-intermediate transverse momentum range. In the MPD experiment at NICA, the resonance production will be measured in heavy-ion collisions at $\sqrt{s_{NN}}$ = 4-11 GeV, in the range of energies where extensive measurements of resonances are not experimentally available.
In this contribution, we report on the expected modifications of the resonance yields and line shapes in heavy-ion collisions at NICA energies estimated using general-purpose event generators. Results of feasibility studies for reconstruction of resonances in the MPD detector will be presented with a focus on reconstruction of $K*(892)^{\pm}$, $\Sigma(1385)^{\pm}$ and $\Xi(1530)^{0}$, which have weakly decaying daughters. The results are presented and discussed as a function of collision energy and centrality.

# ULTRA-PERIPHERAL PHYSICS WITH ATLAS

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This talk gives an overview of the latest ultra-peripheral physics measurements performed with the ATLAS detector at the LHC. These include differential measurements of the exclusive di-muon production cross-section, which are crucial for setting constraints on the initial photon spectrum for all UPC measurements at the LHC; measurements of light-by-light scattering, which result in an observation of this elusive Standard Model process and set competitive limits on the parameter space for axion-like particles; measurements of electromagnetic di-muon production in non-UPC Pb+Pb collisions, which are sensitive to the structure of the initial EM fields and possibly EM content of the created Quark-Gluon Plasma; and measurements of collective behavior in high-multiplicity photo-nuclear collisions.

# CHEMICAL POTENTIAL EFFECT ON DUAL PHOTON RADIATION IN RELATIVISTIC HEAVY ION COLLISION

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The electromagnetic probes are one of the unique probe which determine the state of quark gluon plasma (QGP). These are only the signal which travel through the whole space-time volume due to weak interaction from surrounding medium. With theoretical quasiparticle model, we found that production rate increases with increase the chemical potential values. By including the chemical potential, the behavior of the system of QGP changes drastically due to the interaction among the particles. We plot the dual photon spectrum with respect to mass at suitable high temperature and finite chemical potential incorporating the quark mass value. This quark mass depends on both temperature and chemical potential which enhance the production rate of dual photon. Thus, the results are important in the investigation of quark gluon plasma at RHIC and LHC.

# NON-EQUILIBRIUM HYDRODYNAMIC APPROACH AND COLLISION OF ATOMIC NUCLEI IN APPROXIMATION OF THE KORTEVEG-DE VRIES SOLITONS

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The main purpose of the study of heavy ion collisions is to study the equation of state of nuclear matter (EOS - equation of state). Along with molecular dynamics and the Vlasov dynamic equation, nuclear hydrodynamics is an effective method for describing the interaction of heavy ions at medium and intermediate energies. In our works [1-3], it was shown that local thermodynamic equilibrium in the process of heavy ion collisions is not established immediately, since the nonequilibrium component of the distribution function is important at the compression stage, which leads to the formation of a collisionless shock wave.

In this work, we used a kinetic equation to find the nucleon distribution function, which is solved together with the hydrodynamic equations, and at low energies leads to the equations of long-range hydrodynamics. Within the framework of the hydrodynamic approach, an analytical solution of the equations in the soliton approximation for the collision of nuclear slab layers is found. The compression stage, the expansion stage, and the fragmentation stage are considered in the framework of a single formula for layers with energies of the order of ten MeV per nucleon. This reduction of solutions of the hydrodynamic equations to the solution of two Korteweg - de Vries equations, as far as we know, has not been previously considered and is of independent interest for a wide range of applied problems.

As a result, we were convinced that the introduction of dispersion in the effective forces and in the pressure does not violate the idea of a hot spot formation. The introduction of additional dimensions will not fundamentally break this representation. The nonequilibrium equation of state, which is part of the hydrodynamic equations, allows us to describe the experimental energy spectra of secondary particles formed in collisions of heavy ions of intermediate energies better [2-3] than the equation of state corresponding to traditional hydrodynamics, which initially assumes the establishment of local thermodynamic equilibrium.

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# JET SUBSTRUCTURE MEASUREMENTS WITH ALICE

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Jet substructure measurements, based on the distribution of constituents within a jet, are able to probe specific regions of QCD radiation phase space for jet showers in vacuum. This powerful capability provides new opportunities to study fragmentation patterns of parton showers in vacuum and the dynamics of jet quenching in heavy-ion collisions.

The ALICE experiment has unique capabilities for jet substructure measurements, due to its high-precision tracking system and focus on jets with low transverse momenta. The excellent tracking of the ALICE detector also allows the study of jet substructure in the heavy-flavour sector by tagging jets with fully reconstructed charm hadrons. Heavy-flavour jets are declustered to trace all branchings of the charm quark and to reveal mass dependence of the shape and structure of the parton shower due to the dead-cone effect.

In this talk, we report several new jet substructure measurements in pp and Pb–Pb collisions by the ALICE Collaboration. These include the first fully corrected inclusive measurements of the groomed jet momentum fraction, $z_{\mathrm{g}}$, and the groomed jet radius, $\theta_{\mathrm{g}} \equiv R_{\mathrm{g}}/R$, as well as the $N$-subjettiness distribution and the fragmentation distribution of reclustered subjets. We also report on the measurement of several groomed substructure observables of heavy-flavour jets in pp collisions, fragmentation functions and the new measurements of the radial distributions of $\mathrm{D}^0$ mesons or $\Lambda_{\mathrm{c}}^{+}$ baryons in jets. The measurements will be compared to theoretical calculations and provide new constraints on the physics underlying parton fragmentation and jet quenching.

# HARD PROBES OF HEAVY ION COLLISIONS WITH ATLAS

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This talk gives an overview of the latest hard process measurements in heavy ion collision systems with the ATLAS detector at the LHC, utilizing the high statistics 5.02 TeV Pb+Pb data collected in 2018. These include multiple measurements of jet production and structure, which probe the dynamics of the hot, dense Quark-Gluon Plasma formed in relativistic nucleus-nucleus collisions; measurements of electroweak boson production to constrain the modifications of nuclear parton densities and test the Glauber model and binary scaling picture of heavy ion collisions; and measurements of quarkonia and heavy flavor production to probe the QGP medium properties. A particular focus of the measurements is the systematic comparison of fully unfolded data to state of the art theoretical models.

# GLOBAL POLARIZATION OF Ξ HYPERONS IN AU+AU COLLISIONS IN THE STAR EXPERIMENT

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The hot dense matter produced in non-central heavy-ion collisions possess a large initial orbital angular momentum. This initial orbital angular momentum leads to global polarization of hadrons produced after hadronization, which could be measured via CP-violating weak decays of hyperons. The STAR experiment observed non-zero $\Lambda$ global polarization. Large amount of new data provided opportunities to measure multistrange hyperon polarization. It could be important input for hydrodynamic studies of system.
It this talk, we will report results of $\Xi$ hyperon global polarization ($P_{\Xi^- + \overline{\Xi}^+}$) measurement for Au+Au collisions at $\sqrt{s_{NN}}$ = 27, 54.4 GeV and 200 GeV.

# COLLECTIVE DYNAMICS OF HEAVY ION COLLISIONS IN ATLAS

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This talk gives an overview of the latest measurements of collective behavior in a variety of collision systems with the ATLAS detector at the LHC, including pp collisions at 13 TeV, Xe+Xe collisions at 5.44 TeV, and Pb+Pb collisions at 5.02 TeV. These include measurements of vn-[pT] correlations in Xe+Xe and Pb+Pb, which carry important information about the initial-state geometry of the Quark-Gluon Plasma and can potentially shed light on any quadrupole deformation in the Xe nucleus; measurements of flow decorrelations differential in rapidity, which probe the longitudinal structure of the colliding system; and measurements of the sensitivity of collective behavior in pp collisions to the presence of jets, which seek to distinguish the role that semi-hard processes play in the origin of these phenomena in small systems. These measurements furthermore provide stringent tests of the theoretical understanding of the initial state in heavy ion collisions.

# PRODUCTION OF K*(892)0 MESONS IN SMALL COLLISION SYSTEMS AT PHENIX EXPERIMENT

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The investigation of nuclear matter effects in relativistic ion collisions, especially quark-gluon plasma (QGP) ones, is one of the main goals of PHENIX experiment [1]. To study the dynamics of collisions at high energies, strange hadron production is considered as a significant tool. Due to its strange quark content, the $K^{*0}$ meson is a good probe for the investigation of such QGP effects as strangeness enhancement and flavor dependence of partonic energy loss [2]. New results of the PHENIX experiment on hadron production and elliptic flow in small collision systems suggested the possibility of QGP formation in such systems [3]. Thus, the measurement of $K^{*0}$ mesons production in small collision systems allows to investigate aspects of QGP formation depending on the collision system size. We have performed analyses of $K^{*0}$ meson production in wide set of small systems such as p+Al, p+Au, and $^3$He+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV.

In this talk, we present invariant transverse momentum ($p_T$) spectra and nuclear modification factors ($R_{AB}$) of $K^{*0}$ meson as a function of $p_T$ measured in p+Al and p/$^3$He+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Nuclear modification factors of K*0 meson in p+Al and p/d/$^3$He+Au collisions are in a good agreement at $p_T$ < 2 GeV/*c whereas at intermediate-pT range (2 GeV/*c* < $p_T$ < 5 GeV/*c*) a hint of ordering is observed. $R_{AB}$ values for $K^{*0}$, $\varphi$, and $\pi^0$ mesons fall on the same curve in all centrality bins in favor of strangeness enhancement effect absence.

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# ENERGY AND MASS DEPENDENCIES FOR THE CHARACTERISTICS OF $P_T$ REGIONS OBSERVED AT LHC ENERGIES

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The $p_T$ distributions of the $K^0$- and $\phi$ - mesons produced in the $pp$ collisions at $\sqrt{s} = 2.76$ $TeV$ have been analyzed by fitting them using the exponential function. It was observed that the distributions contain several $p_T$ regions similar to the cases with the charged particles, $\pi^0$- and $\eta$-mesons produced in the same events. These regions could be characterized using three variables: the length of the region $L_K^c$ and free fitting parameters $a_K^c$ and $b_K^c$. It was observed that the values of the parameters as a function of energy grouped around certain lines and there are jump-like changes. These observations together with the effect of existing the several $p_T$ regions can say on discrete energy dependencies for the $L_K^c$ , $a_K^c$ and $b_K^c$. The lengths of the regions increase with the mass of the particles.This increase gets stronger with energy. The mass dependencies of the parameters $a_K^c$ and $b_K^c$ show a regime change at a mass $\simeq 500MeV/c^2$. According to the phenomenology of string theory, these results could be explained by two processes occurring simultaneously: string hadronization and string breaking. In the experiment we can only measure the spectrum of the hadronized particles, since we cannot access the spectrum of the strings themselves. The string breaking effect could be a signal of string formations and the reason behind the observation of several $p_T$ regions and the jump-like changes for the characteristics of the regions.

# INVESTIGATION OF LIGHT FLAVOR PARTICLE PRODUCTION AT THE MPD EXPERIMENT

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Precise study of heavy ion collisions in the energy range $\sqrt{s_{NN}}$ = 4 - 11 GeV is one of the key features of the NICA complex which is currently under construction at JINR (Dubna). Current experimental results in this area suggest this energy region as the most interesting to study the QCD phase diagram and search for phase transition and possible Critical Point. The MPD experiment at NICA will perform Bi+Bi collisions with $5 * 10^{25}$ luminosity for the first physics runs and will switch to Au+Au collisions with higher luminosity in later runs allowing us to collect high statistics for comprehend analysis.
We present recent results on light flavor particle production, centrality determination and nuclear modification factor at the energy range $\sqrt{s_{NN}}$ = 7.7 − 11 GeV. Charged pion and kaon production in different centrality regions is calculated for several MC models. Nuclear modification factor $R_{CP}$ and pion to kaon ratios are presented.
We discuss measurements that will be performed on the first experimental data of the MPD experiment.

# MEASUREMENT OF CHARGED HADRON PRODUCTION IN RELATIVISTIC ION COLLISION SYSTEMS

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Measurement of charged hadron production in relativistic ion collision systems is one of the main methods to study hadronization of quark gluon plasma (QGP) - a state of matter, which is thought to consist of asymptotically free quarks and gluons [1]. According to QCD calculations, conditions in small collision systems are not sufficient for QGP formation, but flow studies in the PHENIX experiment established the evidence of possible QGP formation in such systems [2]. Therefore, investigation of charged hadron production in small collision systems is important to distinguish cold nuclear matter effects and possible QGP effects.

Theoretical calculations of charged hadron production in small collision systems can be provided by Angantyr model in Pythia8 [3], which is generalized the formalism for pp collisions to an event generator for nuclei collisions and consequently considers only cold nuclear matter effects. Therefore this model can serve as an effective tool for studying non-collective background to observables sensitive to collective behavior.

This talk will present PHENIX results on identified hadron production in small collision systems. Nuclear modification factors and ratios of identified charged hadrons ($\pi^{\pm}$, $K^{\pm}$, $p$ and $\bar{p}$) as a function of $p_T$ and centrality measured in p+Al and $^3$He+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV will be presented. Comparison of obtained experimental data with theoretical predictions based on the Angantyr model in Pythia8 will be discussed.

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# SOFT-QCD STUDIES IN ALICE: FOCUS ON FORWARD PARTICLE MULTIPLICITIES AND THE UNDERLYING EVENT

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It is well-established that high-multiplicity pp and p–Pb collisions exhibit a collective-like behaviour and signatures, like the strangeness enhancement and the ridge behaviors, that were commonly attributed to the formation of the Quark-Gluon Plasma. These processes, which are typically described by phenomenological models and soft QCD measurements, provide important constraints on the model parameters. Thus, the study of system size dependence of particle production and characterisation of underlying events is crucial.

We present measurements of charged and neutral particle production in the forward rapidity range (-3.4 < $\eta$ < 5.0 and 2.3 < $\eta$ < 3.9) exploiting the full coverage of the ALICE detector at forward rapidities. The evolution of the width of the pseudorapidity density distribution with centrality is shown and a lower bound on the Bjorken energy density for different collision systems is extracted. We also present results obtained using Underlying Event (UE) techniques, allowing the measurement of the average number density in the Toward, Transverse, and Away regions with respect to the leading trigger particle. For the first time at the LHC, an analysis, based on UE measurements, is applied also to p-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV to test the similarities between pp and p-Pb collisions. The charged particle multiplicity in the Transverse UE-dominated region, $N_{\mathrm{TS}}$, is used as a multiplicity estimator to study particle production mechanisms in pp, p-Pb and Pb-Pb collisions at the same center-of-mass energy. Finally, the UE studies are used to search for jet-like modification by subtracting the UE contributions measured in the Transverse region from the Toward and the Away regions. The results are compared with predictions from QCD-inspired Monte Carlo event generators with different particle-production mechanisms and initial conditions.

# MULTIDIMENSIONAL SPINORS AND DIRAC EQUATION IN THE THEORY OF SUPERALGEBRAIC SPINORS

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The theory of superalgebraic spinors [1] - [6] is an extension of the theory of algebraic spinors [7]. It is a modern version of algebraic quantum field theory. The main difference of this theory from other versions of quantum field theory is that the field operators in it are the superposition of Grassmann densities in momentum space and their derivatives. In this case, gamma operators (algebraic analogs of Dirac gamma matrices) are constructed from the Grassmann densities and their derivatives. In this approach, we have proved that in the case of a four-dimensional spacetime, in addition to the five gamma operators corresponding to the Dirac gamma matrices, there are two more gamma operators (Clifford vectors). The generator of rotation in the plane of these vectors is the operator of the electric charge, and the electromagnetic field is the connection in the spinor bundle [4]. We have constructed explicitly the spinor vacuum state vector and inversion operators P, T and C [6] - [7]. We have proved that the vacuum is symmetrical with respect to the P, CT and CPT inversions. But the operators T and C transform the vacuum into an alternative one and therefore cannot be operators of the exact symmetry of the spinors [6] - [7].

This paper discusses the extension of the theory to more than four dimensions. Such a generalization is nontrivial, since in this case the classification of representations of the Lorentz group is fundamentally different from the four-dimensional case, and the spinor cannot be considered the representation (1/2, 0), and the antispinor, the representation (0, 1/2). Moreover, for an odd number of dimensions, the automorphisms of Clifford algebras are not internal. Therefore, the theory of spinor bundles is considered only for even-dimensional spaces. The use of the superalgebraic spinor formalism allows us to solve these problems.

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# ON THE POSSIBILITIES OF USING THE BASIC PRINCIPLES OF QUANTUM FIELD THEORY FOR MODELING THE INTERACTION OF NEUTRINOS WITH A STRONGLY INHOMOGENEOUS MEDIUM

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Recently, much attention has been paid to the effects of interaction of quantised fields with macro-objects. This area of research is important for the development of both theoretical and experimental physics, and there is every reason to believe that their results will find many scientific and technical applications. Here, to construct the models necessary for theoretical research, the Symanzik approach can be used, which was initially proposed for the description of quantum field systems with inhomogeneous space-time [1]. It was developed to describe the effects of the interaction of fields of quantum electrodynamics (QED) with two-dimensional materials. The requirements of locality, renormalisability and gauge invariance impose essential restrictions on the admissible form of the modified Lagrangian. To describe in the framework of a unified model all the effects of interaction of a homogeneous and isotropic material plane with QED fields, in the most general case, no more than nine additional dimensionless constants are sufficient [2-9].

It is proposed to apply the Symanzik approach to modeling the processes of neutrino propagation in a strongly inhomogeneous medium, taking into account the possibility of calculating the characteristics of the oscillation regime [10-12]. Scattering of neutrinos on a homogeneous isotropic plane is considered as a simple example. The analysis of the influence of their collisions with the plane on the oscillation processes is carried out.

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# THEORETICAL LIMITATIONS OF AMPLITUDES AND THEIR DECISIVE INFLUENCE ON THE PARAMETERS OF RESONANCES

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Recent years have shown how important a role in resonance spectroscopy is played by theoretical limits imposed on amplitudes. They are unitarity and crossing symmetry. Generally, it is about the analysis of the analytical structure of complex amplitudes, which are so important that, for example, they eliminate long-existing ambiguities in experimental data and dramatically change the resonance parameters. These changes strongly affect the interpretation of the resonance structure, which is crucial in searching for e.g. exotic states, so important in testing the Standard Model. These searches are the main or one of the main lines of research carried out by, for example, the GlueX, Compass and Nica projects. There is no doubt now that the decisive conclusions about these important and sometimes key topics come from theoretical analysis - much more accurate and demanding than even the data from a well-conducted and analyzed experiment. This indicates a new and often accepted, even by definition, conservative collective Particle Data Group, method of analyzing experimentally determined data and amplitudes and drawing very often revolutionary but certain conclusions so very important today for the evaluation of effects beyond the Standard Model. The presentation will show the greatest achievements of the above-mentioned methods for mesons to about 2 GeV and prospects for their further development. As an example, the results of $f_0(500)$, $\rho(1450)$ and $K^*(800)$ resonance analyzes [1,2,3] will be presented. The presentation will also encourage all physicists - experimentalists and theorists to use the presented methods and to abandon the long-known e.g. isobar models violating unitarity. Modern physics (especially after the discovery of Higgs) and its requirements, force us to apply the above-mentioned methods and undoubtedly represent the future of physics.

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# DYNAMIC STRONG MAGNETIC FIELD FOR QUARK GLUON PLASMA EQUATION OF STATE

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We study the equation of state of quark gluon plasma (QGP) with dynamic strong and intense magnetic field. This magnetic field is expected to be generate due to the collisions of massive nuclei at relativistic heavy ion collider and large hadron collider. To get a deeper understanding of QGP physical picture, we use a quasi-particle model with various initial condition. The calculation results with quasi-particle model are found to be significant not only in the presence of static magnetic field but also provide significant contribution for dynamic magnetic field. We compare results with and without dynamic magnetic field. The results of QGP equation of state with dynamic magnetic field give deeper insights in QGP. Therefore, the current investigation of the QGP equation of state give unique insights into the development of heavy ion collisions, early universe and various other properties of quark matter under extreme conditions. The model work is thus useful for theoreticians and experimentalists to understand QGP better.

# LARGE RAPIDITY GAP EVENTS IN PROTON-NUCLEUS COLLISIONS AT LHC ENERGIES

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Role of photon-exchange in proton-nucleus collisions with forward large rapidity gaps at LHC energies is discussed. Relative contributions via gamma- and pomeron- exchanges for forward large rapidity gap events in proton-lead collisions are estimated. The obtained results compared with recent preliminary CMS data at LHC.

# THEORY OF HOLOGRAPHIC MODELS FOR LINEAR REGGE TRAJECTORIES AND ITS APPLICATIONS

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In our work we systematized various holographic models and relations between them. We started by constructing the most general theory that has a quadratic in fields, holographic 5D action violating the Poincaré invariance along the fifth coordinate, but which still produces linear Regge mass spectrum. This setup shows that a solvable Soft-Wall (SW) model with linear spectrum can have two $z$-dependent terms in the five-dimensional mass. However, as we demonstrated both these contributions can be reformulated as modifications of the AdS background.

After briefly reviewing our holographic framework outlined above, we discuss various phenomenological applications and properties of holographic models. In particular, we consider the vector two-point correlation function and pion form factor. In both cases we highlight the differences between the results produced by various SW models. In the case of pion form factor we compare our results with experimental data and show that the $\mathrm{SW}^-$ model is remarkably successful in describing both mass spectra and pion form factor data with the universal value of the intercept, while the $\mathrm{SW}^+$ model doesn't have this property. This is especially interesting considering that the $\mathrm{SW}^-$ model reproduces Vector Meson Dominance concept.

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# INFLUENCE OF CHIRAL IMBALANCE ON COLOR SUPERCONDUCTIVITY PHENOMENON

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Phase structure of quark matter with chiral and isospin imbalance is considered in the framework of effective models. There has been considered as two color as well as three color QCD. It was shown that chiral imbalance has several rather peculiar properties such as being universal catalyzer, i. e. it catalyzes all the considered symmetry breaking patterns in the system, including the diquark condensation phenomenon (color superconductivity). Duality properties found earlier have been considered in this case.

Part of the talk is based on [1-5].

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# EFFECTIVE MODELS OF HADRONS IN QUANTUM FIELD THEORY ON THE LIGHT FRONT

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A possibility to obtain the spectrum of mesons (as quark-antiquark states) in effective model of Quantum Chromodynamics on the Light Front (LF) is considered. We use the effective Hamiltonian on the LF having the quark fields interracting with the zero modes of gluon fields. This effective Hamiltonian includes these terms in such a way that one can get quark-antiquark bound states. We chose these terms using arguments connected with the investigation of the limit transition to canonical formulation on the LF from the usual one, and also some semiphenomenological assumptions.

# A LIGHT-FRONT ADS/QCD QUARK-DIQUARK NUCLEON MODEL IN PROTON-PROTON AND HEAVY-ION COLLISIONS

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This work discusses a phenomenological quark-diquark nucleon model based on light-front soft-wall AdS/QCD holography able to be used in particle collision simulations.
The light-front holography has predicted two particle bound state wave function inside nucleons which can not be derived simply from a picture of valence quarks, namely diquarks [1]. In this framework, from the construction of phenomenological diquark Parton Distribution Functions based on light-front QCD and soft-wall AdS/QCD [2, 3] matched to data from NNPDF2.3 QCD+QED NNLO [4, 5]; as well as, due to consequences of the color gauge $SU(3)_c$ in QCD, we have armed a nucleon model and implemented it into the PYTHIA simulation package.
The quark-diquark nucleon model contains both scalar (isoscalar-scalar diquark singlet) state and axial-vector (isoscalar-vector diquark and isovector-vector diquark) state as participating in hard-scattering process alongside quarks and gluons in particle collisions.

Thanks to the hadronization machinery already existing in PYTHIA, we were able to to compare the model in the proton-to-pion ratio in proton-proton collisions at transverse momentum region $0 \leq p_T \leq 20$ GeV at $\sqrt{s} = 13$ TeV with default PYTHIA processes and experimental data from ALICE experiment [6]. The quark-diquark model shows an enhancement of baryon production in the region $2 \leq p_T \leq 4$ GeV, being in better agreement with experimental data than default PYTHIA models, which only consider quarks and gluons in hard processes.
On the side of heavy-ions, we compared the quark-diquark nucleon model to data from PHENIX experiment in HeAu collisions at $\sqrt{s} = 200$ GeV [7], obtaining a better agreement in the $p/\pi^+$ ratio than the default models in PYTHIA in the region $0 \leq p_T \leq 3$ GeV.
In general terms, as expected from a quark-diquark nucleon model with interacting valence diquarks in hard-processes, the studied systems of collisions showed a subtle increase of production of proton over pions not observed in models without diquark hard-processes. It is proposed to generalize and use the model in phenomena where diquark degrees of freedom may play a role.

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# CLUSTER FORMATION IN SPECTATOR MATTER IN COLLISIONS OF RELATIVISTIC NUCLEI

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Nucleons which escape interactions with nucleons of the collision partner in collisions of relativistic nuclei move forward and form spectator matter. Reliable models describing the properties of spectator matter are of particular interest for modeling the response of forward calorimeters in experiments at NICA [1,2] and at the LHC [3]. In ultracentral collisions of nuclei a fireball with a large volume is formed, and residual spectator matter has a characteristic shape of a narrow crescent. In contrast to more peripheral collisions, the loss of cohesion between very few spectator nucleons can be expected and the spectator system does not reach thermal equilibrium. It can also happen in collisions of light nuclei like $^{16}$O. However, traditional abrasion-ablation models consider spectator matter only as a single excited nuclear system in full equilibrium with its subsequent decays.
In order to improve the description of spectator matter we have developed an advanced algorithm of the prefragment clusterization based on the construction of a minimum spanning tree (MST). The algorithm is implemented into the AAMCC model [4,5] to calculate the yields of spectator fragments taking into account all secondary decays. The developed MST clustering is based on the Kruskal algorithm [5] and takes into account the expansion of excited spectator matter by considering the correlation [7,8] between the matter density and its excitation energy.
With AAMCC model supplemented by the MST clustering we study the properties of spectators in ultracentral $^{208}$Pb—$^{208}$Pb collisions. In the absence of the MST clustering the number of free spectator nucleons is overestimated, while the agreement with data is restored with MST. Our approach allows us to describe better the data on fragmentation of $^{16}$O in nuclear emulsions [8,9]. However, due to neglecting alpha-clustering in initial $^{16}$O nuclei in the present version of the model the fractions of events with two and three alpha-particles are underestimated. AAMCC-MST model can be used to predict the production of spectator fragments in $^{16}$O—$^{16}$O collisions at the LHC in future runs [10].
The work has been carried out with financial support of the Russian Fund for Basic Research within the project 18-02-40035-mega.

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# ML APPROACH FOR CENTRALITY DETERMINATION IN XE+CSI COLLISION AT 4.0 AGEV AT THE BM@N EXPERIMENT

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The first experiment at the upgraded BM@N on the study of particle production in Xe+CsI at 4.0 AGeV collisions is planned at the beginning of 2022. To measure the centrality of nucleus collisions in this reaction the new forward hadron calorimeter FHCal will be used. The performance of new upgraded forward hadron calorimeter with transverse and longitudinal segmentations is shown. Results of applying the ML methods for the centrality determination with FHCal at simulated data of Xe+CsI collisions at 4.0 AGeV are discussed.
This work was supported by the Russian Foundation of Basic Research (RFBR) Grants №18-02-40081.

# SPECTATOR MATTER IN COLLISIONS OF RELATIVISTIC DEFORMED NUCLEI

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Density distributions of many nuclei in their ground states are not spherically symmetric and are described by modified Woods–Saxon distributions using spherical harmonics [1]. Collisions of deformed $^{129}$Xe, $^{197}$Au and $^{238}$U nuclei were studied, in particular, in the ALICE experiment at the LHC [2] and in the STAR experiment at RHIC [3]. I was shown [4], that collision events with different initial orientations of deformed nuclei lead to different azimuthal distributions of multiplicities and transverse momenta of produced particles. It is also expected that by the comparison of experimental results with theoretical predictions the adequacy of the shape parametrization can be evaluated [5]. As shown [6,7], the detection of non-interacting spectator neutrons in forward Zero Degree Calorimeters helps to distinguish central $^{238}$U–$^{238}$U collisions with different initial orientations.

In the present work we use our Abrasion–Ablation Monte Carlo for Colliders (AAMCC) model [8,9] to calculate various characteristics of spectator matter in $^{238}$U–$^{238}$U collisions at RHIC. The modeling of each collision event consists of several stages. Firstly, the size and shape of spectator prefragments from both colliding nuclei are defined using Glauber Monte Carlo model. Secondly, the excitation energy of spectator prefragments is calculated. Thirdly, the minimum spanning tree (MST) clustering algorithm is applied to both prefragments to define secondary clusters. Finally, cluster decays are simulated with SMM, Fermi Break-up and evaporation models from Geant4 toolkit. In addition to spectator neutrons considered in Ref.[6,7], we also model the production of spectator protons and nuclear fragments.

We show that the yields of spectator nucleons and their forward-backward asymmetry strongly depend on the relative initial orientation of colliding $^{238}$U nuclei. As found, the widest and the narrowest distributions of the nucleon asymmetry are observed in side-side and tip-body collisions, respectively. On the one hand, body-tip collisions result in the largest (body side) and smallest (tip side) numbers of spectator nucleons. On the other hand, tip-tip and body-body collisions result in similar distributions of both observables. We also study the dependence of the multiplicity of spectator nucleons on the quadrupole deformation parameter $\beta_2$ of $^{238}$U. As found, larger $\beta_2$ leads to a higher multiplicity of spectator nucleons in tip-body $^{238}$U–$^{238}$U collisions. This makes it possible to use experiments on nucleus-nucleus collisions at relativistic energies to explore nuclear deformation.

The work has been carried out with the financial support of the Russian Fund for Basic Research within the project 18-02-40035-mega.

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# METHODS FOR CENTRALITY DETERMINATION IN HEAVY-ION COLLISIONS WITH THE CBM EXPERIMENT

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Centrality is an important concept in a study of strongly interacting matter created in a heavy-ion collision whose evolution depends on its initial geometry. Experimentally collisions can be characterized by the measured multiplicities or energy of produced particles at midrapidity or spectator fragments emitted in the forward rapidity region. Relation between collision geometry and experimentally measured multiplicities is commonly evaluated within the Monte-Carlo Glauber approach.

We will present methods for centrality determination in heavy-ion collisions with the Compressed Baryonic Matter (CBM) experiment at the future Facility for Antiproton and Ion Research (FAIR). The multiplicity of charged hadrons is provided by the CBM silicon tracking system (STS) and connected to collision geometry parameters using the Monte-Carlo Glauber model. The energy of spectator fragments is estimated with the CBM projectile spectator detector (PSD). We will discuss possibilities to determine centrality using the PSD and Monte-Carlo Glauber model.

# FEASIBILITY STUDIES OF TAU-LEPTON ANOMALOUS MAGNETIC MOMENT MEASUREMENTS WITH ULTRA-PERIPHERAL COLLISIONS AT THE LHC

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Ultra-peripheral heavy-ion collisions provide a unique opportunity to study two-photon induced processes. The production of tau lepton pairs in the process $\mathrm{Pb{+}Pb} \rightarrow \mathrm{Pb{+}Pb{+}}\tau^{+}\tau^{-}$ at the LHC is particularly interesting since its cross section is sensitive to poorly known electromagnetic moments of the $\tau$-lepton. Possible deviations of the anomalous magnetic moment $a_{\tau} = (g-2)/2$ of the $\tau$-lepton from the Standard Model predictions may indicate the presence of effects beyond the Standard Model, such as contributions of supersymmetric particles or composite nature of the $\tau$-lepton. In this contribution, the prospects of exclusive ditau cross section measurements in ultra-peripheral Pb-Pb collisions at the LHC will be discussed and projections for possible $a_{\tau}$ limits will be presented.

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# PROBING THE GLUON HELICITY DISTRIBUTION AT SPD

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Since the results the from European Muon Collaboration (EMC) indicated that the combined quarks and anti-quarks account for only about one-quarter of the proton spin, theories and experiments have been trying to understand and measure the contributions from other sources. Gluons have been of particular interest in the last couple of decades. Spin asymmetry measurements from proton-proton collisions sensitive to gluons are the prime channels to access this information. After years of suggested models predicting a variety of gluon spin contributions, RHIC results helped constrain the gluon helicity PDF in the last decade. The proposed Spin Physics Detector (SPD) at the NICA facility in JINR, Dubna will be an excellent laboratory to probe various gluon spin distributions inside protons and deuterons. In particular, double helicity asymmetry measurements at SPD will be sensitive to the gluon helicity distributions and will make signicant contributions to constrain the uncertainties in the large momentum fraction (Bjorken $x$) region ($0.3 \leq x \leq 0.5$).

# THE IDENTIFICATION CAPABILITY OF THE INNER TRACKING SYSTEM FOR THE DETECTION OF D-MESONS AT THE NICA/MPD

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The yields of charmed particles are the important observables sensitive to critical phenomena in QCD-matter at high baryon density. Highly efficient registration of such short-lived products of nuclear interactions using the Inner Tracking System (ITS) of Multi-Purpose Detector (MPD) based on Monolithic Active Pixel Sensors will play a key role in the charm production analysis.
The identification capability of the ITS has been studied during the Monte Carlo simulation, when reconstructing the decays of $D^0$, $D^+$ and $D_s^+$, produced in central Au+Au collisions at NICA energies. Results of D-meson reconstruction using Kalman Filter and Vector Finder tracking methods are compared.
The reported study was supported by RFBR research project No. 18-02-40119 and No. 18-02-40075

# PROSPECTS OF PHOTON CONVERSION MEASUREMENTS IN THE FUTURE MPD EXPERIMENT AT NICA

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The future MPD experiment at the NICA collider is aimed to study hot and dense matter created in heavy ion collisions at center-of-mass energies from 4 to 11 GeV. Measurements of photon spectra via reconstruction of electron-positron pairs from photon conversions provide a unique opportunity to probe the temperature of the produced medium and study $\pi^0$ and eta meson yields down to low transverse momenta. In this contribution, feasibility of photon conversion measurements with the MPD experiment will be discussed. A proposal to increase the photon conversion probability with a dedicated retractable converter will be presented and the prospects to probe the material budget of the experiment with converted photons will be evaluated.

This work was funded by RFBR according to the research project No.18-02-40045.

# PERFORMANCE EVALUATION OF THE STAGE-I INNER TRACKING SYSTEM FOR HYPERON RECONSTRUCTION AT MPD/NICA

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The upgrade program of the Multi-Purpose Detector (MPD) experiment at the Nuclotron-Based Ion Collider Facility (NICA) complex considers assembly and installation of an Inner Tracking System (ITS) made of Monolitic Active Pixel Sensors (MAPSs) between the beam pipe and the Time Projection Chamber (TPC). It is expected that the new detector will enhance the experimental potential for reconstruction of short-lived particles — in particular, open-charm hadrons.

The new detector is planned to be built in two stages. At the first stage, two outermost layers will be installed. In the talk, results of a Monte Carlo study of the performance of this configuration for reconstruction of (multi)strange hyperons will be presented.

# A MONTE CARLO SIMULATION OF THE BM@N DETECTOR PERFORMANCE FOR STRANGENESS PRODUCTION STUDIES IN HEAVY-ION INTERACTIONS

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In a few months, the accelerator complex of the Booster and Nuclotron at JINR (Dubna) will be ready to accelerate heavy ions. At the same time, the Baryonic Matter at Nuclotron (BM@N) experimental setup is completing its configuration to investigate relativistic heavy-ion beam interactions with fixed targets.

One of the most important experimental tasks of the BM@N physics program is determination of the equation of state of the high-density baryonic matter. This task can accomplished via measurements of the (multi)strange hyperon excitation function, i.e. hyperon yields at different energies.

In the talk, the results of the Monte Carlo simulation of the BM@N detector performance for studying strangeness production in heavy-ion interactions will be presented.

# QUARK-GLUON PLASMA IS APPEARED IN COLLISIONS OF MEDIUM NUCLEI AT HIGHER ENERGIES THAN IN HEAVY ION INTERACTIONS

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Recently the NA61/SHINE collaboration has published new experimental data on Pi- meson production in Ar-40+Sc-45 interactions at projectile nucleus laboratory momenta 13, 19, 30, 40, 75 and 150 GeV/c/N. The data are analyzed in Epos LHC, Epos 1.99 and Geant4 FTF models. The data were obtained for 0 - 5 % centrality interactions. In order to imitate the centrality selection we choose impact parameters intervals 0 - 2.5, 0 - 2.9, and 0 - 3.1 fm for the pointed models, correspondently, normalizing model results on experimental data at 19*A GeV/c. In the case, the model results are in agreement with each other and experimental data at momenta below 75*A GeV. At higher energies, only Epos LHC gives satisfactorily results. Epos 1.99 and Geant4 FTF model essentially underestimate the data. Two last models are pure hadronic models. The Epos LHC considers collective hadronization which simulates QGP effects. Earlier, irregularities in particle production were observed in heavy ion collisions at energies above 20*A GeV/c (NA49 analysis).

# Z-SCALING AND SEARCH FOR SIGNATURES OF PHASE TRANSITION IN NUCLEAR MATTER

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The concepts of "scaling" and "universality" have been developed to study critical phenomena. Scaling implies that systems near a critical point (CP) exhibit self-similarity and are invariant with respect to scale transformations. The universality of their behavior lies in the fact that vastly different systems behave in a similar way near the respective CP.

We present some results of analysis of hadron production in $p+p$ and $A+A$ collisions obtained in the framework of $z$-scaling in searching for signatures of a phase transition in nuclear matter. This approach is one of the methods allowing systematic analysis of experimental data on inclusive cross sections over a wide range of the collision energies, multiplicity densities, transverse momenta, and angles of various particles. The concept of the $z$-scaling is based on the principles of self-similarity, locality and fractality reflecting general features of particle interactions. The self-similarity variable $z$ is a function of the momentum fractions $x_1$ and $x_2$ of the colliding objects carried by interacting hadron constituents and depends on the fractions $y_a$ and $y_b$ of the scattered and recoil constituents carried by the inclusive particle and its recoil counterpart. The scaling function $\psi(z)$ is expressed via inclusive cross-section, multiplicity density and three model parameters. Structure of the colliding objects and fragmentation processes is characterized by the structural and fragmentation fractal dimensions $\delta$ and $\epsilon$, respectively. The produced medium is described by a "specific heat" $c$. The function $\psi(z)$ reveals energy, multiplicity, angular and flavor independence found in analyses of inclusive spectra measured at the ISR, SPS, Tevatron, RHIC and LHC. A microscopic scenario of hadron production in terms of constituent momentum fractions and recoil mass of produced system is developed. The constituent energy loss as a function of energy and centrality of collision and transverse momentum of inclusive particle is estimated in the $z$-scaling approach. Discontinuity of the model parameters - the fractal and fragmentation dimensions and "heat capacity" - are discussed from the point of view of the search for a phase transitions in the nuclear matter.

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# COLD SUPERDENSE BARYONIC COMPONENT OF NUCLEAR MATTER

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Started in the late 1950s at DLNP JINR pioneering experimental studies of proton scattering on nuclei allowed D.I. Blokhintsev assumed the presence in nuclei a lower mass nucleus in a compressed state, i.e. the presence of a cold strongly compressed component in ordinary nuclear matter. The search and study of two- and three-nucleon systems in nuclei continued at DLNP JINR and ITEP (Moscow) and beyond. The investigations were carried out in the kinematic region, outside the kinematics of the nucleon-nucleon interaction. In the future, the processes in this kinematic region were called cumulative processes.

In this report is presented the results of the cumulative processes study outside of the nuclear fragmentation region and with production of particles with the transverse momentum greater than 1 GeV/c. These experiments were carried out with proton and carbon nuclei beams by the IHEP(Protvino) accelerator complex. The data were takeout using the SPIN set up – single-arm magnetic spectrometer. The obtained data showed that the processes of direct knock-out of deuteron and tritium nuclei with momentum up to 6.5 GeV/c are observed. This confirms the presence of deuterons and tritium in the nuclear matter in a highly compressed state, in other words, existing of the cold superdense baryonic component.

# CORRELATION IN $^{8}BE$ NUCLEI FORMATION AND $\alpha$-PARTICLE MULTIPLICITIES IN FRAGMENTATION OF RELATIVISTIC NUCLEI

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In the events of peripheral dissociation of relativistic nuclei in the nuclear track emulsion, it is possible to study the emerging ensembles of He and H nuclei, including those from decays of the unstable $^{8}$Be and $^{9}$B nuclei, as well as the Hoyle state. These extremely short-lived states are identified by invariant masses calculated from the angles in $2\alpha$-pairs, $2\alpha p$- and $3\alpha$-triplets in the approximation of conservation of momentum per nucleon of the primary nucleus. In the same approach, it is possible to search for more complex states. Correlation between the formation of $^{8}$Be nuclei and the multiplicity of accompanying $\alpha$-particles in the dissociation of relativistic $^{16}$O, $^{22}$Ne, $^{28}$Si, and $^{197}$Au nuclei are investigated. On this basis, estimates of such a correlation are presented for the unstable $^{9}$B nucleus and the Hoyle state. An enhancement in the $^{8}$Be contribution to dissociation with the $\alpha$-particle multiplicity is found. It is shown that decays of $^{9}$B nuclei and Hoyle states follow the same trend.

# QUASI-ELASTIC KNCKOUT OF NUCLEON FROM THE SHORT-RANGE NN CORRELATION AND RESCATTERINGS IN THE REACTION 12C+P→10A+ PP+N

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Short-range correlated (SRC) NN pairs play an important role in structure of atomic nuclei and are studied using mainly electron beams [1]. A new step was done at BM@N in JINR [2] where the reaction $^{12}$C+p→$^{10}$A+pp+N is studied using the $^{12}$C beam at energy of 4 GeV/nucleon in inverse kinematics providing interaction with the hydrogen target to probe the SRC pairs in the $^{12}$C. In theoretical analysis [3] of the SRC effects in this reaction is used a properly modified approach developed earlier (see Ref. [4] and references therein) to describe the quasi-elastic knock-out of fast deuterons from the light nuclei $^{12}$C and $^{7,6}$Li by protons in the reactions (p,pd) and (p,nd) [5]. Elementary sub-processes in the (p,Nd) were the backward quasi-elastic scattering of the proton on the two-nucleon clusters p{pn}→pd and p{nn}→nd at the proton beam energy 670 MeV. As in Ref. [4], the spectroscopic amplitudes for NN-pairs in the ground state of the $^{12}$C nucleus are calculated here within the translation-invariant shell model (TISM) with mixing configurations. Factorization of the two-nucleon momentum distribution over the internal $n_{rel}$ ($q_{rel}$) and the c.m.s. $n_{cm}$ ($k_{c.m.}$) momenta is assumed and for $n_{rel}$ ($q_{rel}$) the squared deuteron (or singlet deuteron) wave function the CD Bonn NN-interaction potential is used. Relativistic effects in the sub-process p+{NN}→p+N+N of quasi-elastic knockout of nucleon from the SRC pair are taken into account in the light-front dynamics [6]. We found that the c.m. distribution of the deuteron clusters obtained within the TISM and used in [4], [5] to describe the (p,Nd) data [4] has to be modified considerably [6] to describe the kc.m. distribution of the SCR NN pairs measured in the electron data [7]. The ratio of the spin-singlet to spin-triplet pairs {pp}s/{pn}t is calculated and found to be in agreement with existing data. Here the initial and final state interaction effects are estimated within the eikonal approximation using the Glauber model for the N-$^{10}$A scattering. The one-loop approximation with elastic N-$^{10}$A rescatterings is applied and the effect is found to be moderate.
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# EXPERIMENTAL STUDY OF THE E+E- -> N ANTI-N PROCESS AT THE VEPP-2000 E+E- COLLIDER WITH THE SND DETECTOR

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The $e^+e^- \to n\bar{n}$ cross section has been measured in the experiment at the VEPP-2000 $e^+e^-$ collider with the SND detector. The technique of the time measurements in the multichannel NaI(Tl) electromagnetic calorimeter is used to select n anti-n events. The value of the measured cross section from the threshold up to 2 GeV varies from 0.6 to 0.4 nanobarn. The effective neutron timelike form factor is derived from the measured cross section and compared with the proton form factor. The ratio |GE|/|GM| of the neutron electric and magnetic form factor is obtained from the measured angular distribution and found to be close to 1.

# THERMAL MULTIFRAGMENTATION IN C + AU INTERACTIONS AT 22 GEV INCIDENT ENERGIES

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The analysis of charge distribution (Fig. 1) of intermediate mass fragments (IMF) was performed for interaction of 22 GeV carbon projectiles with a gold terget. The main behavior of charge distribution is well described by a power low with a power function exponent equal to $2.16 \pm 0.03$. The power law distribution follows from the classical droplet Fisher model [1], which predicts this behavior of the liquid droplet sizes with the power function exponent equal to 2-3 at the critical point. Experimental data are well described by a combined model INC [2] + SMM [3].

The relative angle correlation of IMF has been studied for $^{12}$C + Au collisions at 22 GeV. Strong suppression at small relative angles is observed caused by Coulomb repulsion of fragments. The time scale for IMF emission is estimated by comparison the measured correlation function to that obtained by the multi-body Coulomb trajectory calculations with time as a parameter. The analysis has been done on an event-by-event basis. The mean decay time of fragmenting system is found to be less than $59 \pm 10$ fm/$c$.

This work was performed at the Dubna Nuclotron with the $4\pi$ detector array FASA. Calculations were performed using HybriLIT platform of LIT JINR. The research was supported by Grant No. **19-02-00499 A** from Russian Foundation for Basic Research.

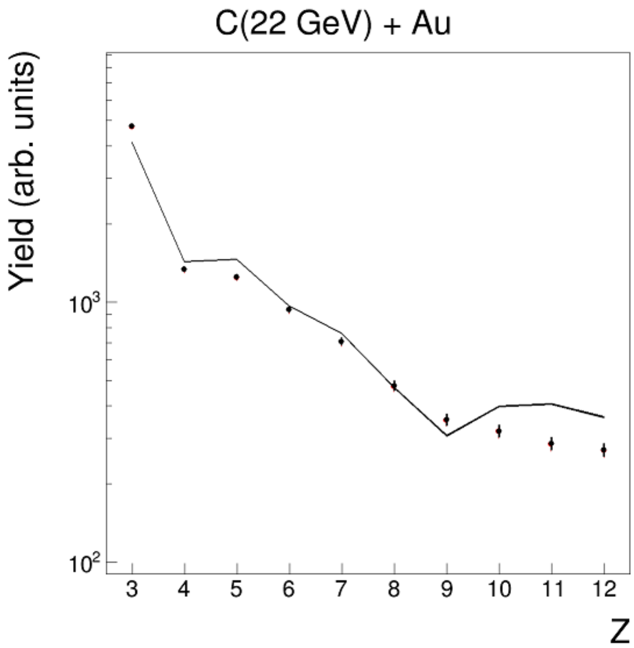


Figure 1: Charge distribution of IMF produced in C + Au collisions at 22 GeV. Points - experimental data. Solid line - INC + SMM calculations.

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# SHORT RANGE CORRELATIONS INVESTIGATED BY DSS COLLABORATION IN DEUTERON INVOLVED REACTIONS

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Investigation of the reactions of deuteron elastic scattering and deuteron breakup are interesting from the point of view of nucleon-nucleon (NN) and three nucleon (3N) correlations, special attention is paid to short distances with high transferred momenta. The Deuteron Spin Structure (DSS) collaboration revealed a strong sensitivity to the spin structure of short-range isoscalar NN correlations, this has been observed for elastic dp scattering in deuteron analyzing powers. Spin structure of np short-range correlations was found earlier in the inclusive reaction of Ayy's tensor analyzing power at JINR synchrophasotron. The analysis was performed at different energies in wide areas of fraction of longitudinal xF and the transverse momenta pT of proton. Ayy demonstrates dependence on at least these two internal variables, but the approach used could not describe the data. Effective cross section and analyzing powers of the elastic dp process are obtained and partially processed in the energy range 200 - 2000 MeV. The most interesting energy region we plan to pass through with a step of only 50 MeV. The results are compared with a relativistic model of multiple scattering. The deuteron breakup reaction in the region of hundreds of MeV have rich phase space, by scanning, angular and energetic we can learn more about short-range correlations of nucleons or e.g. on non - nucleonic degrees of freedom depending on the selected part of the phase space. A large influence of relativistic effects was observed in the reaction d (n, np) n at 200 MeV in the configuration where one arm was fixed and the other scanned the angular interval. Contribution from relativistic effects can reach up to 60%. Deuteron - proton breakup reaction is investigated in the energy range 300 - 500 MeV in specific areas of the phase space, where the influence of short-range correlations and in some cases also relativistic effects should be remarkable.

# A MULTIHARMONIC/LARGE-ORDER FLOW CUMULANT ANALYSIS FOR RELATIVISTIC HEAVY-ION COLLISIONS

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In the past years, significant progress has happened in high-energy nuclear physics models. A more robust and quantitative picture has replaced the qualitative descriptions of heavy nuclei collisions in the earlier days, enabling us to have a clearer picture of different stages of a heavy-ion collision. These models typically have $O(10)$ free parameters that are tuned by Bayesian analysis in recent years. To better understand the free parameter values, it is essential to experimentally probe their phase space by observables, each containing independent information of the model.
In this presentation, our focus is on anisotropic flow observables. We introduce a method to extract anisotropic flow cumulant systematically. Employing a Monte Carlo simulation tuned by Bayesian analysis results, we predict the value of some abandoned low-order flow harmonic cumulants with significant signals that have not been measured at the LHC. Moreover, we introduce a new method to extract the linear and nonlinear hydrodynamic response coefficients based on our multiharmonic cumulant study. Besides, this systematic study enables us to propose a genuine three-particle correlation function for the first time. This observable is a summation of all third-order flow harmonic cumulants of all harmonics. The large-order flow cumulant ($v_n\{2k\}$ with large $k$) contains a unique piece of information about the underlying flow distribution. In particular, we discuss the relation between the nonvanishing Lee-Yang zero phase and large-order flow cumulant ratios at ultra-central, ultra-peripheral, large, and small collision systems.

Based on:

1. S. F. Taghavi, (2020), arXiv:2005.04742 [nucl-th] (will be appeared in Eur.Phys.J.C)

# THE EFFECT OF DIFFERENT CENTRALITY DETERMINATION ON THE ELLIPTIC FLOW MEASUREMENTS

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One of the methods for studying the transport properties of QCD matter at extreme temperatures and energy densities is the study of anisotropic flow. The precise definition of centrality is an important task since directed and elliptic flow coefficients are dependent on centrality. Two methods of centrality determination were considered to study the effect of different centrality determination on the elliptic flow measurements. The first method is based on the Glauber model, and the second is based on inverse Bayes' theorem together with the geometric properties of the collision. Comparison of elliptic flow with centrality determination methods based on both charged particle multiplicity in TPC and the energy deposited in the forward calorimeters FHCal will be presented.

# RELATIVE ELLIPTIC FLOW FLUCTUATIONS AT NICA ENERGY REGIME

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The main aim of the MPD experiment at the future collider NICA is to study the strongly interacting matter created in the heavy-ion collisions at center-of-mass energies $\sqrt{s_{NN}}$ = 4-11 GeV. The azimuthal anisotropy is a key observable in such collisions as its sensitivity to the transport properties and equation of state of the created matter. The relative elliptic flow fluctuations are of intense interest since they can be used as a probe for the initial conditions using the ratio of cumulants $v_2\{4\}/v_2\{2\}$. State-of-the-art models of heavy-ion collisions: UrQMD, AMPT, and vHLLE+UrQMD are employed for the study of relative elliptic flow fluctuations at the NICA energy regime.

# CBM PERFORMANCE FOR THE MEASUREMENT OF $\Lambda$ HYPERON’S DIRECTED FLOW IN AU+AU COLLISIONS AT FAIR SIS-100 ENERGIES

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The main goal of the CBM experiment is to study highly compressed baryonic matter produced in collisions of heavy ions. The SIS-100 accelerator at FAIR will give a possibility to investigate the QCD matter at temperatures up to about 120 MeV and net baryon densities 5-6 times the normal nuclear density. Hyperons produced during the dense phase of a heavy-ion collision provide information about the equation of state of the QCD matter. The measurement of their anisotropic flow is important for understanding the dynamics and evolution of the QCD matter created in the collision. We will present the status of the performance studies for $\Lambda$ hyperon directed flow measurement with the CBM experiment at FAIR. $\Lambda$ hyperons decay within the CBM detector volume and are reconstructed via their decay topology. The Particle-Finder Simple package, which provides an interface to the Kalman Filter Particle (KFParticle) mathematics, is used to reconstruct $\Lambda \rightarrow p + \pi^-$ decay kinematics and to optimize criteria for $\Lambda$ hyperon candidate selection. Directed flow of $\Lambda$ hyperons calculated using different flow measurement techniques is studied as a function of rapidity, transverse momentum and collision centrality. The effects on flow measurement due to non-uniformity of the CBM detector response in the azimuthal angle, transverse momentum and rapidity are corrected using the QnTools analysis package.

# ANISOTROPIC FLOW AT ENERGIES $\sqrt{S_{NN}}$=2-11 GEV

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Multi-Purpose Detector (MPD) experiment at NICA collider has the potential for discoveries in the area of QCD phase diagram with high net baryon densities and moderate temperatures. Anisotropic transverse flow is one of the key observables to study the properties of matter created in heavy-ion collisions. The directed and elliptic flow were studied at the beam energy range $\sqrt{s_{NN}}$=2-11 GeV corresponding to HADES (SIS18), BMN (Nuclotron), and MPD (NICA) experiments. Comparison of the existing experimental data with different heavy-ion event generators is employed to provide a useful tool for feasibility studies at the MPD experiment.

# STUDY OF THE BEAM ENERGY DEPENDENCE OF ANISOTROPIC FLOW IN RELATIVISTIC HEAVY ION COLLISIONS USING SCALING RELATIONS.

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Anisotropic flow measurements of produced particles in relativistic heavy-ion collisions play an essential role in the studies of transport properties of the strongly interacting metter.
In this work we provide the results of the most comprehensive systematic study of the beam energy dependence of anisotropic flow based on existing data and discuss them using different scaling relationsfor azimuthal anisotropy.

# REVIEW ON CHARMONIUM NUCLEAR MODIFICATION FACTOR AND FLOW COEFFICIENTS IN PB-PB AND P-PB COLLISIONS WITH ALICE

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The quark-gluon plasma (QGP) is a strongly-interacting deconfined state of matter produced in ultra-relativistic heavy-ion collisions. In order to study the QCD matter and its evolution, quarkonia, bound states of a heavy quark and antiquark pair, are preferred tools as they are sensitive to the first stages of the collision and to the evolution of the created system. The study of the quarkonia relies on various observables, two of which will be presented: the nuclear modification factor and the flow.

Measuring nuclear modification factors in large collision systems gives information regarding QGP effects on quarkonium production.

Measurements of the azimuthal anisotropies (expressed as elliptic and triangular flows, $v_2$ and $v_3$ respectively) shed light on collective behaviors of the particles within this hot and dense medium. Measuring azimuthal anisotropies for these hard probes gives us information regarding their own production mechanisms, and the formation of the QGP.

In this contribution, we review the results from the ALICE collaboration regarding the charmonium nuclear modification factor and flow. The $R_{\mathrm{PbPb}}$ and $R_{\mathrm{pPb}}$ as a function of $p_{\mathrm{T}}$, rapidity and centrality will be presented.
Concerning the flow, we review ALICE measurements for Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV in which the $J/\psi$ exhibits a significant non-zero $v_2$ in a wide centrality and $p_{\mathrm{T}}$ range as well as a significant non-zero $v_3$. In the p-Pb system, which is typically used as a standard candle for cold nuclear matter effects in Pb-Pb, $J/\psi$ does display a non-zero $v_2$ for $3 < p_{\mathrm{T}} < 6$ GeV/c whose magnitude is even comparable to the one from Pb-Pb collisions. The smallest hadronic system pp is being investigated in view of production and prospects for measurements of flow are discussed.

# SCALING OF COLLECTIVE FLOW OF CHARGED AND IDENTIFIED HADRONS IN AU+AU COLLISIONS AT $\sqrt{S_{NN}} = 11.5 - 62.4$ GEV FROM THE STAR EXPERIMENT

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Heavy-ion collisions create matter which is characterized by high temperature and energy density, called Quark-Gluon Plasma (QGP). Azimuthal anisotropy of produced particles is sensitive to the transport properties of QGP (the equation of state, speed of sound and specific shear viscosity) and may provide information about initial state of the collision. In this work, we report results for elliptic ($v_2$) and triangular ($v_3$) flow of charged and identified hadrons ($\pi^{\pm}, K^{\pm}, p, \bar{p}$) in Au+Au collisions at $\sqrt{s_{NN}}$ = 11.5, 14.5, 19.6, 27, 39 and 62.4 GeV from the STAR experiment at RHIC. Measurements of the collective flow coefficients $v_2$ and $v_3$ are presented as a function of particle transverse momenta ($p_T$) and collision centrality. In addition the number of constituent quark scaling will be presented for these energies.

# PROTON DIRECTED FLOW RELATIVE TO THE SPECTATOR PLANE IN AG+AG COLLISIONS AT 1.23A AND 1.58A GEV WITH HADES

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We report a new measurement of proton directed flow $v_1$ relative to the spectator plane for Ag+Ag collisions at the beam energies of 1.23A and 1.58A GeV recorded by the HADES experiment at GSI. The projectile spectator plane is estimated using signals of the charged fragments registered with the HADES forward hodoscope. Directed flow is presented differentially as a function of transverse momentum and rapidity in different centrality classes. The slope of $v_1$ at midrapidity, $dv_1/dy$, is reported as a function of centrality and collision energy. The new results extend the existing data available from the previous HADES measurements of directed flow in Au+Au collisions at the beam energy of 1.23A GeV. Sensitivity of the directed flow to the initial angular momentum and connection with the measurement of the lambda hyperon directed flow and global polarization are discussed.

# PERFORMANCE OF THE CBM EXPERIMENT AT FAIR FOR MEASUREMENT OF CHARGED HADRON ANISOTROPIC FLOW

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The Compressed Baryonic Matter experiment (CBM) at FAIR aims to study the area of the QCD phase diagram at high net baryon densities and moderate temperatures using collisions of heavy ions at center-of-mass energies of a few GeV per nucleon. Anisotropic transverse flow is among the key observables to study the properties of matter created in such collisions. The CBM performance for charged hadron anisotropic flow measurements is studied with Monte-Carlo simulations using gold ions at SIS-100 energies with lab momentum up to 12A GeV/c employing different heavy-ion event generators. Various combinations of CBM detector subsystems are used to investigate the possible systematic biases in flow measurement and to study the effects of detector azimuthal non-uniformity. The resulting performance of CBM for flow measurements is demonstrated for different harmonics of identified charged hadron anisotropic flow as a function of rapidity and transverse momentum in different centrality classes.

# PROBING OF EXOTICS STRUCTURE IN HADRON AND HEAVY ION COLLISIONS

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The spectroscopy of charmonium-like mesons with masses above the $2m_D$ open charm threshold has been full of surprises and remains poorly understood [1]. The currently most compelling theoretical descriptions of the mysterious XYZ mesons attribute them to hybrid structure with a tightly bound $c\bar{c}$ diquark [2] or $cq\overline{(cq)}$ tetraquark core [3 - 5] that strongly couples to S-wave $D\overline{D}$ molecular like structures. In this picture, the production of a XYZ states in high energy hadron collisions and its decays into light hadron plus charmonum final states proceed via the core component of the meson, while decays to pairs of open-charmed mesons proceed via the $D\overline{D}$ component.
These ideas have been applied with some success to the XYZ states [2], where a detailed calculation finds a $c\bar{c}$ core component that is only above 5% of the time with the $D\overline{D}$ component (mostly $D^0\overline{D^0}$) accounting for the rest. In this picture these states are compose of three rather disparate components: a small charmonium-like $c\bar{c}$ core with $r_{rms} < 1$ fm, a larger $D^+D^-$ component with $r_{rms} = \hbar/(2\mu^+B^+)^{1/2} \approx 1.5$ fm and a dominant component $D^0D^0$ with a huge, $r_{rms} = \hbar/(2\mu^0B^0)^{1/2} > 9$ fm spatial extent. Here $\mu^+(\mu^0)$ and $B^+(B^0)$ denote the reduced mass for the $D^+D^-$ ($D^0\overline{D^0}$) system and the relevant binding energy |m_D + m_D - M_X(3872)| (B+ = 8.2 MeV, B0 < 0.3 MeV). The different amplitudes and spatial distributions of the $D^+D^-$ and $D^0D^0$ components ensure that the X(3872) is not an isospin eigenstate. Instead it is mostly I = 0, but has a significant (~ 25 %) I = 1 component.
In the hybrid scheme, XYZ mesons are produced in high energy proton-nuclei collisions via its compact ($r_{rms} < 1$ fm) charmonium-like structure and this rapidity mixes in a time (t ~ $\hbar/\delta M$) into a huge and fragile, mostly D0D0, molecular-like structure. δM is the difference between the XYZ meson mass and that of the nearest cc\bar mass pole core state, which we take to be that of the χc1(2P) pure charmonium state which is expected to lie about 20 ~ 30 MeV above M_X(3872) [6, 7]. In this case, the mixing time, cτ_mix 5 ~ 10 fm, is much shorter than the lifetime of X(3872) which is cτ_X(3872) > 150 fm [8].
The experiments with proton-proton and proton-nuclei collisions with √S_pN up to 26 Gev and luminosity up to 10^32 cm^-2s^-1 planned at NICA may be well suited to test this picture for the X(3872) and other XYZ mesons. In near threshold production experiments in the √S_pN ≈ 8 GeV energy range, XYZ mesons can be produced with typical kinetic energies of a few hundred MeV (i.e. with γβ ≈ 0.3). In the case of X(3872), its decay length will be greater than 50 fm while the distance scale for the cc\bar → D0D*0 transition would be 2 ~ 3 fm. Since the survival probability of an r_rms ~ 9 fm "molecular" inside nuclear matter should be very small, XYZ meson production on a nuclear target with r_rms ~ 5 fm or more (A ~ 60 or larger) should be strongly quenched. Thus, if the hybrid picture is correct, the atomic number dependence of XYZ production at fixed √S_pN should have a dramatically different behavior than that of the ψ', which is long lived compact charmonium state.
The current experimental status of XYZ mesons together with hidden charm tetraquark candidates and present simulations what we might expect from A-dependence of XYZ mesons in proton-proton and proton-nuclei collisions are summarized.

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# ATLAS RESULTS ON CHARMONIUM PRODUCTION

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Recent results of the ATLAS experiment on charmonium production in proton-proton at 8 and 13 TeV collisions will be presented. The measurement of the associated production of the J/psi meson and a gauge boson, including the separation of single and double parton scattering components, will be discussed. The measurement of J/psi and psi(2S) differential cross sections will be reported as obtained on the whole Run 2 dataset.

# OVERVIEW ON HEAVY-FLAVOUR RESULTS FROM THE ALICE EXPERIMENT

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Heavy-flavour quarks (charm and beauty) are excellent probes for the study of the properties of the quark-gluon plasma (QGP), a colour-deconfined medium produced in ultra-relativistic heavy-ion collisions. Being produced on shorter time scales than the typical QGP formation time and having negligible thermal production and in-medium annihilation rates, heavy quarks experience the full QGP evolution, interacting with its partonic constituents while traversing it and losing energy through radiative and collisional processes. Measurements of their final-state hadrons provide thus fundamental information on these partonic interactions.

The study of heavy-flavour hadrons in proton-proton and proton-nucleus collisions allows us to obtain a reference for probing QGP effects on heavy quarks, as well as to test perturbative QCD calculations at the LHC energies and study cold-nuclear-matter effects. The study of charm baryon production in proton-proton collisions is particularly relevant for investigating charm-quark hadronisation mechanisms, as recent measurements have demonstrated the breaking of the universality of heavy-quark fragmentation fractions among different collision systems.

The ALICE experiment can profit of excellent tracking, vertexing and particle identification performance to reconstruct heavy-flavour hadrons from hadronic and semileptonic decay channels at central rapidity, as well as electrons and muons produced from heavy-flavour hadron decays at central and forward rapidity, respectively.

Recent highlights from ALICE heavy-flavour measurements in pp, p-Pb and Pb-Pb collision systems will be presented. In particular, the prompt and non-prompt D-meson production cross sections, and baryon-over-meson production ratios for various charmed hadrons in pp collisions will be discussed. A selection of recent results in p-Pb and Pb-Pb collision systems, including measurements of nuclear modification factor and elliptic-flow coefficient, will also be shown. These observables will be compared to predictions from several models implementing different descriptions of the in-medium charm-quark interactions.

# AN IMPROVED SELECTION OPTIMIZATION METHOD USED FOR THE MEASUREMENT OF ZZ PRODUCTION UNDER CONDITIONS OF ATLAS EXPERIMENT DURING LHC RUN LL.

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The production of a pair of Z-bosons in the llυυ channel (l = e, μ) is studied with the conditions of proton-proton collisions at a centre-of-mass energy of 13 TeV. The generation of signal and background events is performed using the MadGraph5_aMC@NLO Monte Carlo event generator. The Pythia8 and Delphes3 frameworks are used for event showering, hadronization, and detector response simulation.
This report describes an improved cut-based optimization method to maximize signal significance, where signal significance is considered as a multivariate function of the optimized variables.
The described method makes it possible to find the best combination of cuts for kinematic variables corresponding to the best signal/background ratio. An additional option of the method is the ability to find cuts that satisfy various conditions, such as a limit on the number of minimum signal events.

# ESTIMATION OF ELECTRON-TO-PHOTON MISIDENTIFICATION RATE IN Z(NN)Γ MEASUREMENTS FOR CONDITIONS OF ATLAS EXPERIMENT DURING RUN II

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Z-peak tag-n-probe method was widely used for estimation of electron-to-photon misidentification rate for photon-oriented studies in Run I and in early Run II pp-collisions data. The increased luminosity and energy of collisions in Run II requires an improvement of the existing method, especially it is necessary for a description of underlying background spectra in the Z boson mass region of tag-n-probe mass distribution. This study presents the improved ways of tag-n-probe mass spectra fit in order to estimate a pure number of tag-n-probe events originating from the Z boson. Two approaches are considered. The first fit with exponential polynomial functions does not include the Z peak itself. And the second one includes the Z peak, which is described by a Voigtian function. Comparison of e-to-γ misidentification rate estimation with two approaches is presented. The study is done for photons selected in Z(νν)γ measurements, which use 139 $fb^{-1}$ of data collected by the ATLAS experiment during full Run II at LHC.

# MEASUREMENT OF THE ANTINUCLEI INELASTIC CROSS SECTIONS WITH ALICE AND IMPLICATIONS FOR INDIRECT DARK MATTER SEARCHES

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The measurement of the flux of low-energy cosmic antinuclei may reveal the existence of exotic processes such as dark matter annihilation, since the production rate of these ions through ordinary collisions between cosmic rays and the interstellar matter is very low. However, the lack of experimental data at low energies, where both the antinuclei production and inelastic cross sections are poorly known, prevents precise predictions of antinuclei fluxes near Earth.
In ultra-relativistic pp, p-Pb and Pb-Pb collisions at the CERN LHC, matter and antimatter are produced in almost equal abundances at midrapidity. This allows the study of the production cross sections of (anti)nuclei with high precision as well as the measurement of the absorption process of (anti)nuclei in the detector materials.

In this talk, the first results on the absorption cross sections of antideuterons and (anti-)^{3}He in the ALICE detector materials are presented and the implications of these results for indirect Dark Matter searches near Earth are discussed.

# CMS SUSY AND EXOTICA RESULTS

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The search for new physics such as supersymmetry (SUSY) and other beyond-the-standard-model physics is a major goal of the LHC physics program. The talk will cover the most recent results of SUSY and Exotica searches using 137 $fb^{-1}$ data collected in 2016-2018 with the CMS detector at the LHC.

# CMS TOP RESULTS

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As the heaviest known fundamental particle, the top quark has taken a central role in the study of fundamental interactions. Production of top quarks in pairs provides an important probe of strong interactions. The top quark mass is a key fundamental parameter which places a valuable constraint on the Higgs boson mass and electroweak symmetry breaking. Observations of the relative rates and kinematics of top quark final states constrain potential new physics. Top quarks are involved in many beyond standard model (BSM) physics. Due to comparatively higher statistics than Tevatron, CMS has been able to and continuously doing precise measurements on top-quark properties for thorough scrutiny of standard model (SM) and search for new physics. This talk will be focused on the different measurements done on Top quark on CMS.

# DARK MATTER THROUGH THE HIGGS PORTAL AT THE LHC

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A broad class of theoretical scenarios called "the Higgs-portal models" describes the interaction of dark matter with the "usual" matter only through the Higgs sector. From an experimental point of view, the models provide an interesting intersection of several directions in the search for new physics, namely, the study of non-standard properties of the observed Higgs boson, the search for new Higgs states from the extended Higgs sector and the search for new particles - candidates for dark matter. The talk presents the recent results of the CMS collaboration on this topic.

# COMBINED HIGGS BOSON MEASUREMENTS AND THEIR INTERPRETATIONS IN EFFECTIVE FIELD THEORIES AND NEW PHYSICS MODELS WITH THE ATLAS EXPERIMENT

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Combining measurements of many production and decay channels of the observed Higgs boson allows for the highest possible measurement precision for the properties of the Higgs boson and its interactions. These combined measurements are interpreted in various ways; specific scenarios of physics beyond the Standard Model are tested, as well as a generic extension in the framework of the Standard Model Effective Field Theory. The latest highlight results of these measurements and their interpretations performed by the ATLAS Collaboration will be discussed.

# SEARCHES FOR HEAVY HIGGS BOSONS IN THE FRAMEWORK OF 2HDM MODEL

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Difficulties associated with the multiplicity of particle production in proton collisions at the LHC and with theoretical description of hadronization lead to assumptions about a new physics in studying the angles of escape and energy of jets. Problems of such physics are connected with the vacuum properties related to the hierarchy problem. The explanation of difficulties of Standard Model (SM) is realized within the theories beyond SM, one of which is Supersymmetry (SUSY). The most promising SUSY model is 2-Higgs-Doublet Model (2HDM) [1]. In the framework of 2HDM model we presented the searches for heavy neutral and charged Higgs bosons, which are performed through the calculations of production cross sections using MadGraph5aMC@NLO program [2] with ansatz of Yukawa coupling and the restricted parameter space connected with LHC Run 2 data [3, 4]. The searches for heavy resonances are performed over the mass range 0.1–1 TeV for the $pp \to At\bar{b}$, $pp \to H^+b\bar{t}$ , $pp \to H^+t\bar{t}$ , $pp \to HHZ$ decay modes. The presented data demonstrate the jump in the production cross section of $H^+b\bar{t}$ and $HHZ$ production processes in the mass range of 100-200 GeV and 100-300 GeV accordingly at energy of 14 TeV.

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# SEARCHES FOR LOW- AND HIGH-MASS HIGGS-LIKE RESONANCES WITH THE ATLAS DETECTOR

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Several theories beyond the Standard Model predict the existence of new particles decaying into pairs of gauge bosons. These states generally have masses larger than that of the Higgs boson, while some theories predict resonances with masses smaller than it. The latest ATLAS results on searches for such resonances in final states with leptons and photons based on pp collision data collected at 13 TeV will be presented.

# HIGGS BOSON MEASUREMENTS IN COUPLINGS TO QUARKS AND LEPTONS WITH THE ATLAS EXPERIMENT

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Testing the Yukawa couplings of the Higgs boson to quarks and leptons is important to understand the origin of fermion masses. The talk presents several new measurements in Higgs boson decays to two bottom quarks or two tau leptons, searches for Higgs boson decays to two charm quarks or two muons, as well as indirect constraints of the charm-Yukawa coupling. The production of Higgs bosons in association with top quarks will also be discussed. These analyses are based on pp collision data collected at 13 TeV.

# HIGGS BOSON MEASUREMENTS IN ITS DECAYS INTO BOSONS WITH THE ATLAS EXPERIMENT

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With the full LHC Run 2 pp collision dataset collected at 13 TeV, very detailed measurements of Higgs boson properties can be performed using its decays into bosons. This talk presents measurements of Higgs boson properties using decays into bosons and their combination with fermionic decays, including production mode cross sections and simplified template cross sections, as well as their interpretations.

# CMS HIGGS RESULTS

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The Higgs boson within the Standard Model (SM) has been discovered by the ATLAS and CMS experiments in 2012. However analyzing a larger volume of LHC dataset collected by the CMS detector from 2016 to 2018 at a higher center of mass energy ($\sqrt{s}$ = 13 TeV) is expected to shed more light on the Higgs boson properties and would improve the related measurement sensitivity. Few comprehensive analysis on the Higgs decaying to different standard model particles(including all possible Higgs production modes) using the Run 2 dataset of $137\text{fb}^{-1}$, recorded by the CMS experiment would be presented here. The sensitivity of the analyses are improved by categorizing the events based on different Higgs production mechanisms: Gluon-Gluon fusion (GGH), Vector Boson Fusion (VBF), Vector Boson associated production (VH) and top quark associated production (ttH, tH). Combining all production modes, the latest Higgs boson signal strength measured in $H \rightarrow \gamma\gamma$ decay channel is to be $1.02^{+0.11}_{-0.09}$ with respect to the corresponding SM predictions. Also the measurements of other properties like standard model signal strength modifiers, production cross sections, and its couplings to other Standard Model particles will also be presented.

# Section 5. Neutrino physics and astrophysics

## INVESTIGATION OF DOUBLE BETA DECAY OF $^{150}$ND TO EXCITED STATES OF $^{150}$SM IN NEMO-3

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Results of NEMO-3 experiment for double beta decay of $^{150}$Nd to the $0_1^+$ and $2_1^+$ excited states of $^{150}$Sm are reported. The data recorded during 5.25 y with 36.6 g of the isotope $^{150}$Nd was used in the analysis. For the first time the signal of 2νββ transition to the $0_1^+$ excited state is detected with statistical significance exceeding 5 sigma. The half-life is measured to be $T_{1/2}^{2\nu\beta\beta}(0_{gs}^+ \to 0_1^+) = \left[1.11^{+0.19}_{-0.14}\ (\text{stat})^{+0.17}_{-0.15}\ (\text{syst})\right] \times 10^{20}$ y. Limits on $2\nu\beta\beta$ decay to $2_1^+$ level and on $0\nu\beta\beta$ decay to $0_1^+$ and $2_1^+$ levels of $^{150}$Sm are estimated since no evidence was found for the signal of corresponding transitions.

# STRATEGY AND DATA ANALYSIS FOR THE DISCOVERY OF CNO SOLAR NEUTRINO BY BOREXINO

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Borexino is a large liquid scintillator experiment designed for real-time detection of low-energy solar neutrinos. It is located at the underground INFN Laboratori Nazionali del Gran Sasso, in Italy. During more than ten years of data collection, it has measured all the neutrino fluxes produced in the proton-proton-chain, i.e. the main fusion process accounting for ~99% of the energy production of the Sun. Recently, Borexino provided the first observation of solar neutrinos emitted from the Carbon-Nitrogen-Oxygen (CNO) fusion cycle. The key difficulty of this measurement is represented by the 210Bi contaminating liquid scintillator, whose spectral shape is very similar to the one induced by CNO neutrinos. The only way to break this correlation is to determine the 210Bi rate independently and to constrain it in the multivariate fit. Such strategy relies on the connection between the 210Bi and the $\alpha$-decays of its daughter 210Po, that can be identified on an event-by-event basis via pulse shape discrimination techniques. To suppress convective motions introducing non-equilibrium 210Po in the fiducial volume of the analysis, it was necessary to thermally stabilise the detector.

The purpose of this presentation is to provide a description of the detector thermal stabilisation process, the 210Bi constraint determination, and the analysis strategy adopted to extract the interaction rate of CNO neutrinos.

# HEAVY NEUTRINOS AT FUTURE LINEAR E+E-COLLIDERS

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Neutrinos are probably the most mysterious particles of the Standard Model. The mass hierarchy and oscillations, as well as the nature of their antiparticles, are currently being studied in experiments around the world. Moreover, in many models of the New Physics, baryon asymmetry or dark matter density in the universe are explained by introducing new species of neutrinos. Among others, heavy neutrinos of the Dirac or Majorana nature were proposed to solve problems persistent in the Standard Model. Such neutrinos with masses above the EW scale could be produced at future linear e+e- colliders, like the Compact LInear Collider (CLIC) or the International Linear Collider (ILC).

We studied the possibility of observing production and decays of heavy neutrinos in qql final state at the ILC running at 500 GeV and 1 TeV and the CLIC running at 3 TeV. The analysis is based on the WHIZARD event generation and fast simulation of the detector response with DELPHES. Dirac and Majorana neutrinos with masses from 200 GeV to 3.2 TeV are considered. Estimated limits on the production cross sections and on the neutrino-lepton coupling are compared with the current limits coming from the LHC running at 13 TeV, as well as the expected future limits from hadron colliders. Impact of the gamma-induced backgrounds on the experimental sensitivity is also discussed. According to our results, future linear colliders like ILC and CLIC have sensitivities to couplings orders of magnitude smaller than current and future limits from the LHC.

# ESTIMATION OF SOLAR NEUTRINO BACKGROUND IN THE EXPERIMENT GERDA

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The work evaluates the background induced by solar neutrinos into the experiment GERDA, that was organized to search for neutrinoless double beta decay of Ge-76 nucleus. A feature of this background is its fundamental inevitability, which imposes restrictions on the sensitivity of the entire experimental setup. To calculate the cross section for the solar neutrinos capture by Ge-76 nuclei, the self-consistent theory of finite Fermi systems was taken into account. There carried out the decomposition of the charge-exchange reaction spectrum for Ge-76 nucleus. It is shown in the work that considering Gamow-Teller resonances (GGTR and pygmy resonances) increases the total capture cross section by 25 to 50%. Finally a Monte Carlo simulation of the beta decay for the formed As-76 nucleus was performed. A verdict was made on the effect of the solar neutrino background in GERDA experiment and the next-generation experiment LEGEND.

# AT THE INTERSECTION BETWEEN MACHINE LEARNING AND NUCLEAR ASTROPHYSICS: A CGAN FRAMEWORK FOR HELIUM REACTION MODELING

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While the field of nuclear astrophysics has recently been a burgeoning area of study and research, there is still a significant portion of information regarding the topic that is not known to science. In particular, while certain foundations of the subject area seem plausible, there is not currently any proof that helium fusion is a key component that drives nuclear astrophysics. In this work, we take an innovative approach by training generative adversarial networks (GANs), which are a machine learning-based algorithm, to model the progression of helium reactions. The cGAN architecture is utilized. We hope that this work will provide insights into the underpinnings of nuclear astrophysics by providing an automated environment for its study.

# PROSPECTS OF THE NEUTRINO-4 EXPERIMENT ON THE SEARCH FOR STERILE NEUTRINO

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The Neutrino-4 collaboration plans to improve existing detector and to create new neutrino laboratory at reactor SM-3.
Equipment for the new neutrino laboratory at the SM-3 reactor is being prepared for implementation. Main part of the improving is new scintillator with higher gadolinium concentration and doped with DIN for pulse shape discrimination ability increase. Thus, a new detector larger volume will improve the accuracy of measuring the flux of reactor antineutrinos by 3.1 times.
After starting the PIK reactor at full power, the experiment will continue in Gatchina. For this, a preliminary design of another detector and a project for its placement on the PIK reactor are already being developed.

# THE POSSIBLE EXPERIMENT FOR SEARCH OF STERILE NEUTRINOS

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An advance in solution of the sterile neutrino search can be reached by creation of the intensive $\bar{\nu}_e$-source with well known hard spectrum. The most intensive artificial antineutrino sources used for neutrino experiments are the nuclear reactors. The resulting reactor $\bar{\nu}_e$-flux is the complicated additive function of fluxes: from fission fragments; from $\beta$-decay of heavy nuclei. In spite of the doubtless superiority in flux value the antineutrino reactor spectra (formed by main fuel isotopes are characterized by large uncertainties in the total $\bar{\nu}_e$-spectrum (4 $\div$ 6)\% -precision at energy up to ~ 6 MeV) that lead to very serious problems in interpretation of neutrino oscillation results [1,2].
The creation of intensive source of well definite hard spectrum can be solved by the scheme of continuous circulation of $^8$Li produced in $(n, \gamma)$-capture on the $^7$Li activation close the reactor active zone. The created $^8$Li-isotope is pumped continuously in the elongated channel loop which includes the large reservoir and remote $\bar{\nu}_e$-detector. The scheme allows the unique possibility to produce the variable and controlled hardness of the total $\bar{\nu}_e$-spectrum [3].
For the scheme (3+1) with three active and one sterile neutrinos the probability of $\bar{\nu}_e$-source of existence at distance $L(m)$ from the source is given by two flavor model $P = 1 - \sin^2(2\Theta) \times [1.27\Delta m^2_{41}(L(\mathrm{m})/\mathrm{E(MeV)}]$, $\Theta$ - angle of mixing; $\sin^2(2\Theta) = 4|U_{i4}|^2(1 - |U_{i4}|^2)$; $U_{i4}$ - element of mixing matrix for active neutrino flavor
$i = e, \mu, \tau$; $\Delta m^2_{41}(\mathrm{eV}^2)$ - maximum squared-mass difference between sterile and active neutrinos (i.e., $|\Delta m^2_{41} \gg |\Delta m^2_{31}| \gg |\Delta m^2_{21}|$ [4,5].
It was obtained the dependencies of cross section for ($\bar{\nu}_e,\ p$)-reaction from the hardness $H$ that allows to simulate the expected number of events for oscillation experiment. The simulation fully confirmed the reality to ensure the hard spectrum in the space not far from the reservoir. It was obtained the dependences of count errors (in the total spectrum) on detector position for the specified geometry and operation regime [3, 5]. The results also demonstrates an important advantage of the hard lithium spectrum at increase the threshold of registration –large decrease of the expected errors (below 1.5%) in case of increase of the threshold from 3 MeV to 6 MeV.

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# MONTE CARLO SIMULATION OF NEUTRINO-4 EXPERIMENT

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Monte Carlo simulation of the multi-section reactor antineutrino detector of the Neutrino-4 experiment is carried out. The scintillation-type detector is based on the inverse beta-decay reaction. The current experiment at the SM-3 reactor (Dimitrovgrad, Russia) and the future experiment at the PIK reactor (Gatchina, Russia) are considered. As a result of the simulation, the distributions of photomultiplier signals from the positron and the neutron are obtained. The efficiency of the detector depending on the signal recording thresholds is calculated. The simulated spectrum was obtained and compared with the experimental one. Monte Carlo simulation of results expected with employing of spectral independent method of data analysis is done taking into account geometric configuration of the antineutrino source and detector including the sectioning. Also, the simulation of the experiment taking into account the background conditions observed in the experiment and the energy dependence of the energy resolution of the detector is presented.

# SEARCH FOR HEAVY STERILE NEUTRINOS IN $\beta$-DECAY OF $^{144}$PR NUCLEI

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The discovery of solar and atmospheric neutrino oscillations means that at least two from three neutrino mass states are nonzero. The obtained oscillation parameters together with the constraints on the sum of light neutrinos masses obtained from the Planck telescope data limit the most severe mass state of the known types of neutrinos ($\nu_e, \nu_\mu, \nu_\tau$) up to 70 meV. Heavier sterile neutrinos appear in many extensions of the Standard Model, additionally, they are well-motivated candidates for the role of dark matter particles.
In this work the search for sign of massive neutrinos in the measured spectra of electrons from decays of $^{144}$Ce – $^{144}$Pr nuclei have been performed. The $^{144}$Ce – $^{144}$Pr electron antineutrino source is one of the most suitable for studying neutrino oscillations into a sterile state with a mass of about 1 eV. The decay schemes for $^{144}$Ce – $^{144}$Pr allow to test the possibility of emission in these β-transitions of heavy neutrinos with masses from several keV to 3 MeV. The range of possible investigated masses is determined by the resolution of the $\beta$-spectrometer and end-point energy of $^{144}$Pr $\beta$-decay [1].
The energies of $\beta$-transitions in the $^{144}$Ce and $^{144}$Pr nuclei are 319 keV and 2998 keV, respectively. For the case of heavy neutrino emission, the resulting spectrum $S(E) = (1-|U_{eH}|^2)B(E, 0) + |U_{eH}|^2 B(E, m_{\nu H})$ is the sum of two $\beta$-spectra $B(E, m)$ with the end-point energy $E_0$ and neutrino masses $m = 0$ and $m = m_{\nu H}$. All 6 most intense $\beta$-transitions to the excited states of daughter nuclei were taken into account in analysis.
The measurements were performed with the original $\beta$-spectrometer with $4\pi$-geometry consisting of two Si (Li) -detectors with a sensitive region thickness of more than 8 mm, which exceeds the range of 3 MeV electrons [2,3]. The measured spectrum, containing $1.5 \times 10^9$ events, was fitted in the energy range (250 - 3030) keV with an acceptable value $\chi^2$ = 1.04 (P-value is 0.014) for the case $m_{\nu H}$ = 0. For different neutrino masses $m_{\nu H}$, the values of emitting probability $|U_{eH}|^2$ were determined by searching for the minimum of $\chi^2$. As a result, for neutrinos with a mass $m_{\nu H}$ in the range (100–2200) keV, new upper bounds on the mixing parameter are set at the level $|U_{eH}|^2 \leq (0.1\text{–}3.0) \times 10^{-3}$ for 90% C.L., which are in 2-3 times stronger than obtained ones in previous experiments.
The work was supported by the Russian Foundation for Basic Research (projects 19-02- 00097) and Russian Science Foundation (project 21-12-00063).

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# INTERPRETATION OF THE XENON1T EXCESS IN THE DECAYING STERILE NEUTRINO MODEL

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The observed excess of electronic recoil events in the XENON1T experiment with energies from 1 to 7 keV [1] is considered in the framework of the phenomenological model with three active and three sterile neutrinos [2]. Assuming sterile neutrinos with appropriate masses in the several keVs domain to be decaying [3], it becomes possible to interpret the observed energy spectrum of electronic recoil events. Using this approach allows one to predict several peaks in the energy range of 1 - 7 keV for electronic recoil events owing to dark photons and photons emitted in this energy range [4, 5]. To study oscillations with decaying sterile neutrinos analytical expressions are obtained for transition and surviving probabilities for different neutrino flavors and the graphs of these probabilities are presented at some test values of model parameters.

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# SHAKE AS THE PREDETERMINING MECHANISM OF THE NEUTRINOLESS DOUBLE ELECTRONIC CAPTURE

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The process of double neutrinoless e-capture is of great interest as a test of the Majorana nature of neutrino This process is traditionally considered as a resonance one, since not a single particle is emitted as a result of the nuclear transformation [1]. In contrast, we performed calculations of the probability of shake off and shake up, with the ionization or excitation of the electron shell during the nuclear transformation. $^{164}$Er nucleus is one of the main candidates for discovering the neutrinoless mode of the process [2]. As a result, the contribution of the new mechanism turns out to be three times stronger than that of the traditional resonance mechanism [3]. It rapidly increases with the increasing resonance defect, thus becoming the main mechanism of the double neutrinoless electron capture. One can conclude that account of the shake mechanism generally increases the decay rate by an order of magnitude. Therefore, the double neutrinoless e-capture appears not to be a resonance process at all. This considerably increases the chance for successful experimental research of the process.

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# RESONANCE STRUCTURE OF NEUTRINO CAPTURE CROSS SECTION BY 100MO NUCLEI

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The work presents calculations of the solar neutrino capture cross-section σ(Eν) by 100Mo nuclei. In calculations experimental data on strength function S(E), received in charge-exchange reactions (3He, t) [1, 2] were used. Within the framework of the self-consistent theory of finite Fermi systems, the charge-exchange strength function S(E) for this nucleus is calculated. The influence of the resonance structure of the strength function S(E) on the calculated cross section for the capture of solar neutrinos was investigated. The influence of the Gamow-Teller [3], analog [4] and pygmy resonances [5] is taken into account, and the contributions of each resonance to the cross section for the capture of solar neutrinos σ(Eν) by the 100Mo nucleus was distinguished. The question of changing the neutrino capture cross section due to taking into account the effect of neutron emission from the daughter nucleus is considered. The contribution of all components of the solar neutrino spectrum is calculated. It was noted that the capture of solar neutrinos by the 100Mo nucleus is a background process in the study of double beta decay of this nucleus.

The work is partial supported by the grant of the Department of Neutrino Processes of the National Research Center "Kurchatov Institute".

# BETA-DECAY RATE IS AN IMPORTANT FACTOR OF THE R-PROCESS HEAVY NUCLEI FORMATION.

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More than the half of all nuclei heavier iron in nature are formed in the nucleosynthesis, supported by rapid neutron capture process, and the region where it has occurred lies close to neutron drip-line [1]. The nucleosynthesis rate of heavy nuclei in the r-process is defined both by the astrophysical scenario and beta-decay rates of heavy nuclei involved. Under speeding up or slowing down the nucleosynthesis wave movement into the region of more heavier nuclei, the trajectory of the r-process is changed as well as the position of the third peak on the abundance curve of heavy nuclei [2], that is pointing out on the complicated influence of the beta-decay model on nucleosynthesis.
Using the results of heavy nuclei abundances calculations in the r-process in the scenario of neutron stars merger the sensitivity of the results on input data was determined. The influence of different theoretical models of beta-decay on abundances of heavy nuclei was investigated.
In the nucleosynthesis calculations global beta-decay half-lives predictions based on different microscopic models [3, 4, 5] have been used. The calculations have confirmed the strong beta-decay model influence on heavy nuclei nucleosynthesis process. Comparison of the results have shown that dependence of average nucleosynthesis rate value on existed theoretical models of beta-decay is weak. But even the moderate change of the rate leads to the shift of platinum peak position in comparison with observations and strong discrepancy in abundances. All these results have shown that for reliable predictions of heavy nuclear abundances the more prominent microscopic models [6] are needed.

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# SOME CORRECTIONS TO FERMI-FUNCTIONS AND NEUTRINO CAPTURE CROSS-SECTIONS

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Neutrino capture cross-section, which depend on the incident-neutrino energy $E_\nu$, has the form:
$\sigma(E_\nu) = \frac{(G_F g_A)^2}{\pi c^3 \hbar^4} \int_0^{W-Q} W p_e F(Z,A,W) S(x) dx$
where $S(E)$ is the charge-exchange strength function, $G_F/(\hbar c)^3 = 1.1663787(6) \times 10^{-5}\ GeV^{-2}$ is the weak coupling constant, $g_A = -1.2723$ is the axial-vector constant and $F(Z,A,W)$ is the Fermi-function, which takes into account the Coulomb interaction between beta-particle and the daughter nucleus. The change in the Fermi-function is practically proportional to the change in the cross-section. Since the founding work of Fermi [1] which presented the Fermi-function for point-like nucleus there have been many works describing corrections to the Fermi-function including finite nuclear size, charge distribution, screening etc. One can see a good review of different types of them in [2].

In this work we present the influence of finite nuclear size, screening etc. corrections to the Fermi-function and consequently to cross-section as an example of the $^{127}$I [3]. Particular attention is paid to the dependence of Fermi-function on the nuclear charge radius $R_C$ . Recent experimental results of isotopic dependence of the charge radii for K, Cu, Sn together with theoretical calculations based on the self-consistent theory of finite Fermi-systems with the Fayans density functional was taken into account [4], [5].

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# NUCLEAR INELASTIC SCATTERING EFFECT IN SPECTRA OF NEUTRINOS AT WEAK COUPLING REGIME

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Effect of inelastic nuclear scattering in magnetized hot and dense matter in neutrino spectra relevant for supernovae, neutron star mergers, proto-neutron stars is considered. At finite temperature neutrino exhibits exo- and endoenergetic scattering on nuclear species due to the neutral-current Gamow-Teller interaction component. The kinetic equation for neutrino transport at decoupling regime is derived from an analysis of energy transfer cross sections [1] due to additional noticeable mechanisms of energy exchange. The energy transfer coefficient is shown to change from positive to negative value at neutrino energy increasing four times the matter temperature. Such a property results in focusing neutrino energy.

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# SELF-CONSISTENT CALCULATIONS OF SOLAR CNO NEUTRINO CAPTURE-RATES FOR 115IN.

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The first direct detection of the neutrinos from carbon-nitrogen-oxygen (CNO) fusion cycle in the Sun has been announced recently by the BOREXINO Collaboration [1]. An estimate of possible “CNO-like” events induced by geo-antineutrino from 40K decay in the Hydride model of the Earth has been done in [2]. This has revived attention to the additional experimental prospects given by improved 115In detector system (LENS Project [3]).
In the report, the CNO neutrino capture rates for 115In are calculated within a revised self-consistent approach to the charge-exchange excitations of odd-A nuclei [4]. It includes new version of the Fayans functional DF3-a fitted to the spin-orbit splitting data for 105 nuclei [5]. The β-decay strength function is calculated within continuum Quasiparticle Random Phase (pnQRPA) approximation including the Gamow-Teller and first-forbidden transitions [6].

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# FISSION FRAGMENTS DISTRIBUTION AND HEAVY NUCLEI NUCLEOSYNTHESIS

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The discovery of neutron star merger process and simultaneous observation of heavy elements registered for the first time [1] confirms the theoretical findings that neutron star merger scenario for the close binary is the main site for the r-process passing.
As it was shown for the first time in numerical calculations of the r-process [2], the fission in such a scenario became one of the main reaction channel for the heavy nuclei formation due to involvement of fission products into the r-process as secondary seed nuclei. More than that in such a scenario, leading to the initial conditions with big ratio of free neutrons to seeds, the role of fission products mass distribution became very important for the creation of second peak on the abundance curve. From the other hand the agreement of predicted abundances of second peak heavy nuclei with observations is the test for theoretical models of fission fragment mass distribution.
In the present report the influence of fission fragment mass distribution models and their parameters on the nucleosynthesis results of heavy nuclei in neutron-rich matter of jets, formed as a result of neutron stars merger, are discussed. We considered the fission fragment mass distributions, based on the FFDn [3] and KT-M [4] models, and have researched the dependence of predicted value of chemical elements abundances on the fission fragments mass distribution models used.
It was shown that fission fragments mass distribution models, with parameterization leading to mainly symmetrical fission gives better agreement with abundances observations for the second peak. Besides that the theoretical peak position coincides with observable one only for models, in which fission neutrons were taking into account. And the number of fission neutrons in these models for the neutron rich nuclei should be in times more than in fission of experimentally known nuclei. Under formation of heavy elements in the r-process the contribution of triple fission to the addition to binary one was also evaluated [5,6].

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# SENSITIVITY OF LIQUID ARGON DARK MATTER SEARCH EXPERIMENTS TO CORE-COLLAPSE SUPERNOVA NEUTRINOS.

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Future liquid-argon DarkSide-20k and ARGO detectors, designed for direct dark matter search, will be sensitive also to core-collapse supernova neutrinos, via coherent elastic neutrino-nucleus scattering. Thanks to the low-energy threshold of ~0.5~keVnr achievable via the ionization channel, DarkSide-20k and ARGO have the potential to discover supernova bursts throughout our galaxy and up to the Small Magellanic Cloud, with sensitivity also to the neutronization burst. The accuracies in the reconstruction of the average and total neutrino energy in the different phases of the supernova burst, as well as its time profile, taking into account the expected background and the detector response, are reviewed.

# Section 6. Plasma physics and thermonuclear fusion.

## PLASMA SHIELDING EFFECTS ON NUCLEAR SPECTRA: 18NE APPLICATION

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In this study, for the first time, in particular to astrophysics and fusion studies, how atomic nuclei embedded in the plasma environment are affected by plasma are systematically analysed. The related interactions in plasma environments considered as Debye and quantum plasma are depicted by more general exponential cosine screened Coulomb (MGECSC) potential. The plasma effects on the change of nuclear energy levels are probed through computations performed within the nuclear shell-model framework. For this purpose, the single-particle energy (spe) values to be used in the calculations are obtained by considering the modified Woods-Saxon (WS) potential due to shielding effect of plasma environment. As the modification in question is executed on Coulomb interaction term in WS potential, the computations are carried out for 18Ne nucleus which has two valence protons. Under the influence of the plasma, it is confirmed that the spe's change within certain limit value ranges. When considering the nuclear shell-model for the related computing, it is clear that this change leads to an obvious shifting in the energies of the nuclear states. It is observed that proton spe values are sensitive to Plasma shielding effect, and shielding effect has a significant potent on the ground-state and excited energy states of the nucleus. In particular, the ground-state binding energies are determined to be extremely sensitive to the plasma shielding parameters Plasma environments affect the proton spe and ground state energy (gse) in the same way.

# ON THE POSSIBILITY OF OBSERVING THE STIMULATED DE-EXCITATION OF THE NUCLEAR ISOMER 186MRE IN THE PLASMA OF Z-PINCH AT THE ANGARA-5-1 FACILITY

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In ref. [1] a laser plasma with an electron temperature Θe ~ 1 keV, a lifetime of about 0.3 ns and a mass of ~ 1 μg was obtained from metallic rhenium containing isomeric nuclei of the 186mRe (T1/2, m = 2·105 y). In such a plasma, there was observed stimulated de-excitation of isomeric 186mRe nuclei with a probability Pstim ~ 10 − 7, which was determined after a laser shot by the degree of disequilibrium between the decay of the isomers and the 186Re nuclei in the ground state (T1/2, g = 91 h).

The probability Pstim is proportional to the plasma lifetime, and to enhance the effect, it was proposed in ref. [2] to use instead of laser plasma an electric discharge plasma with the 186mRe isomeric nuclei, the lifetime of which increases up to ~ 10 ns while maintaining the temperature Θe ~ 1 keV. Such a plasma can be obtained in high-current Z-pinches at the Angara-5-1 facility at the JSC TRINITY. The plasma is formed during the implosion of a two-cascade cylindrical multi-wire assembly (liner) when a current pulse of ~ 4 MA passes through it, with a voltage of 1 MV and a duration of ~ 100 ns [3]. The outer cascade with a diameter of 12 mm with mass of ~ 300 μg/cm per unit liner length is composed of aluminum wires, the inner cascade with a diameter of 6 mm and a linear mass of ~ 20 μg/cm is composed of tungsten wires with a diameter of 6 μm. The material of the pinch plasma is mainly deposited at the ends of the discharge gap 16 mm long, from where a sample can be taken to determine the probability Pstim according to the method of ref. [1]. For the experiments, a technique was developed for introducing the 186mRe isomer into the liner by electrodeposition of a rhenium layer about 0.5 μm thick onto tungsten wires. The mass of rhenium in the liner will be ~ 10 μg. Thus, in the plasma of the Angara-5-1 facility, the amount of the 186mRe isomer can be an order of magnitude higher than in the laser plasma of the experiment [1], and the probability Pstim can be two orders of magnitude higher. All this shows that the proposed experiments at Angara-5-1 facility are promising.

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# Section 7. Synchrotron and neutron studies and infrastructure for their implementation

## DEVELOPMENT OF THE HIGH-BRIGHTNESS HEC-2 COLD NEUTRON SOURCE AT THE REACTOR PIK

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The main goal of the created cold neutron source on horizontal experimental channel HEC-2 of reactor PIK is to obtain the maximal neutron brightness. There are two main possibilities for using two different material as a main body in the thermalisation chamber of the source: the liquid deuterium or the parahydrogen. When using optimal size and form of the chambers they give nearly equal brightnesses of the source. There are different pro and contra for using each of this options. Here we made the comparison of these two possibilities within neutron physical calculations.
Liquid deuterium as well as liquid hydrogen may present in two spin state in the mixtures: para- and ortho- states. Inelastic cross-section of para- and ortho- deuterium are similar but for hydrogen they are strongly different at energies smaller then 1 meV. For this reason the optimal form of the maximal brightness deuterium and hydrogen chambers will be strongly different. They will also have different heat loads. The brightness of the sources depends also on the position of the chambers in the heavy water reflector toward the reactor core. We made the optimization calculation of the form and the position of the liquid deuterium chamber to provide the maximal brightness of it and compare the obtained brightness and heat load with the brightness and heat load of the parahydrogen chamber of optimal size placed in the same position.

# ADVANCED COLD NEUTRON SOURCE FOR HEC-3 AT THE REACTOR PIK (STATUS & PERFORMANCES)

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Several cold neutron sources (CNS) are planned to be built at the reactor PIK. Two of them are planned to be mainly used for condensed matter physics. They will produce cold neutrons in the horizontal experimental channels HEC-3 and HEC-2 with highest brightness. Neutron source for the channel
HEC-3 will be mounted in the vertical vacuum tube placed in the heavy water reactor reflector [1]. The chamber of spherical form filled with liquid deuterium will be placed into the tube. The operation temperature of the deuterium is in the range of 21 − 25 K, and the volume of it is about 24.6 liters. The chamber has a displacer of special form to increase the neutron brightness of the source. The CNS will be operated in two modes: the normal mode with the chamber filled with liquid deuterium and the standby mode without deuterium. In both cases the released heat in the chamber will be removed with the special helium loop. Heat load in the chamber and in the other elements of the source placed in the vertical tube was calculated using MCNP code and the full computer model of the reactor. It includes prompt neutron and gamma heat releases as well as heat release from the decay gamma radiation from the reactor core as well as from the activation products of the reactor and CNS constructional materials. Also, the impact of the β-decay radiation was included. Tritium production in the deuterium was evaluated as well as the activity of the deuterium along the reactor operation.
There is also a special neutron reflector in the tube between the chamber and a heat exchanger. The purpose of the reflector is to increase the brightness of the source as well as to reduce the activation of constructional materials in the upper part of the CNS.
The neutron guide system of CNS HEC-3 is also described as well as setups in the experimental hall and in the hall of horizontal channels which are planning to use these cold neutrons.

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# Section 8. Nuclear medicine

## 3D VISUALIZATION OF RADIOTRACERS FOR SPECT IMAGING USING A TIMEPIX DETECTOR WITH A CODED APERTURE

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The report contains a description of the SPECT system based on the Timepix detector with a coding aperture developed at DLNP JINR. Using a semiconductor pixeled detector with CdTe sensor and Timepix readout chip allows conduct research using multinuclide radiopharmaceuticals with high energy and submillimeter spatial resolution for laboratory animals. Are given the main characteristics of the resulting system, examples are shown 2D and 3D images obtained with calibration phantoms. Is being discussed possible development of the system, including changing the field of view and spatial resolution, as well as the ability to create on the basis SPECT / CT scanner installations. The characteristics of the installation are compared with commercial counterparts.

# ENHANCED PRODUCTION CROSS SECTIONS OF $^{123,124,126,128}$I VIA INCOMPLETE FUSION REACTIONS: SCOPE IN NUCLEAR MEDICINE

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It has been a constant research endeavor to find new ways of producing radionuclides for diagnostic and therapeutic purposes in nuclear medicine. The research area has ever grown due to technological developments and facilities like heavy-ion accelerators. The iodine isotopes e.g., $^{131}$I has been widely used as a radiotracer for thyroid-related diseases. This neutron-rich isotope ($^{131}$I) is produced using a reactor. Although often difficult to procure locally, but it can be transported easily because of its long lifetime ($\tau_{1/2}$= 8.04 d). Another isotope $^{123}$I produced using cyclotron, is also utilized in recent times. The suitable $\gamma$-ray energy (E$_\gamma$) region is 100-600 keV which is high enough to be sufficiently penetrating through the medium of the human body, and can be fully absorbed in the detector. These two isotopes of iodine – $^{131}$I emitting the photon of energy 364 keV and $^{123}$I of energy 159 keV – qualify the requirement.

We investigated the production of four isotopes of iodine $^{123,124,126,128}$I via incomplete fusion reactions (ICF) by bombarding the beams of $^{10,11}$B (60-78 MeV) on $^{122,124}$Sn foils using the 14-UD Pelletron accelerator at the Tata Institute of Fundamental Research, Mumbai, India. The experimental results for our initial experiment $^{11}$B+$^{122}$Sn were presented [1] in the conference NN2012. Later, we utilized the same experimental procedure for the other reactions as well. Our purpose was two-fold. Firstly, to measure the cross sections of all the long-lived (minutes to days) reaction products using the off-line γ-ray spectrometry. The main products (Cesium nuclei) of the complete fusion reactions (CF) were produced with high cross sections as expected, and were in the good agreement with the statistical model code PACE4 [2] predictions. Secondly, our main objective was to identify all the ICF products – with enhanced cross sections over the PACE4 predictions – and understand the reaction mechanism. Special attention was paid to iodine isotopes because of their relevance in nuclear medicine. Our results turned out to be quite promising. All the iodine isotopes produced through ICF (α-channels) – $^{123}$I ($\tau_{1/2}$= 13.2 h, E$_\gamma$=159 keV), $^{124}$I ($\tau_{1/2}$= 4.2 d, E$_\gamma$=603 keV), $^{126}$I ($\tau_{1/2}$= 12.9 d, E$_\gamma$=389 keV), and $^{128}$I ($\tau_{1/2}$= 25 m, E$_\gamma$=443 keV) – were suitable radiotracers because of long lifetimes and $\gamma$-ray energies. Moreover, through the process of ICF reactions their cross sections were an order of magnitude higher than the expected CF process.

Earlier works on ICF reactions in literature were carried out at high beam energies, and the sum rule model (original-SRM) [3] was quite successful in explaining the observed results. However, the original-SRM underestimated the ICF cross sections at our utilized low beam energies. We therefore made modification in the model mainly to incorporate the energy dependence in the definition of critical angular momentum. Using our modified-SRM, we found a significant improvement in predicting the enhancement in the cross sections. The present work has much potential in nuclear medicine, as it can improve the accessibility of many iodine isotopes for the better scope in their utilization and circulation.

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# STUDY OF DOSE-ENHANCING AGENTS ON BREMSSTRAHLUNG PHOTONS FROM SL75-5MT MEDICAL ACCELERATOR

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Contrast-enhanced radiotherapy allows to enhance the radiation dose absorbed by the tumor when using the hard elements (I, Gd, Au, Bi, etc.) for a photon absorption [1]. The dose-enhancing agents have a better absorption capacity, than biological tissues and thus sparing the surrounding healthy cells. In [2], an increase dose absorbed by iodinated water (for 50 mg/ml iodine concentrations) was obtained at using bremsstrahlung photons generated by the clinical linear electron accelerator SL75-5MT. Normally, dose-enhancing agent concentrations employ up to 15 mg/ml.

In our work, we investigated the possibility of using metal-organic composites containing dose-increasing agents to increase the absorption of SL75-5MT bremsstrahlung photons. The present study aims to assess feasibility of using of the metal-organic composites SL75-5MT bremsstrahlung photons to increase radiation absorbed by [3]. The linear accelerator 0.5-4.5 MeV photons (80% of total flux and 2 Gray/min absorbed dose) created secondary X-rays and electrons in the dose-enhancing metallic agents of the metal-organic composites. This is enhanced the radiation dose absorbed by the tumor. The dose absorbed by tissue-equivalent phantom with metallic agents (Cd, Au, W, Bi, Pb) was measured by PTW MULTIDOS dosimetry with clinical ionization chambers. In addition, a gamma radiation from the phantom were measured using BDMG-08R gamma detectors. For Au, Bi, Pb dose-enhancing agents the absorbed dose increased by 10-20%. The significant increase in the absorbed dose (> 50%) was observed from d(γ,n)p reaction when using deuterated water instead of tissue-equivalent phantom. Therefore, it is possible to employing deuterated water for photon energy spectra of SL75-5MT clinical accelerator in order to reach a therapeutically significant effect.

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# STUDY OF DOSE TRANSMISSION IN A MULTILEAF COLLIMATOR ON A VARIAN HALCYON ACCELERATOR

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The study of dose transmission is a vital topic because the number of patients who have developed delayed radiation injuries increases every year [2,3].

Recently commissioned linear accelerator Varian Halcyon V1.0 (Varian Medical Systems, Palo Alto, Calif., USA) without collimation shutters is now gaining popularity in oncology clinics. The Halcyon MLC System features the stacked and staggered dual-layer multileaf collimator. The primary and secondary collimators are fixed; there is no flattering filter [1, 4].

This study aims to measure dose transmission from a Varian Halcyon multileaf collimator experimentally. Our experiments were carried out on the Varian Halcyon linear accelerator with a boundary photon energy of 6 MeV:

1. Investigation of the effect of field size on dose transmission. IMRT plans were created to irradiate the phantom with different sized fields in the treatment planning system Eclipse. The dose profile was measured with an IC Profiler SunNuclear array detector. A water-equivalent Solid Water GAMMEX phantom was used. The data obtained were used to plot the beam profiles. All received doses were normalized to a absorbed dose in a 10 × 10 cm2 reference field at a depth of 10 cm.

2. Measurement of dose transmission at a small field size. In this experiment, a plan was created to irradiate the 3D Scanner SunNuclear water phantom. The multileaf collimator was positioned to create a rectangular beam size 1x2 cm2. The SNC125c ionization chamber was used. The experiment showed that despite the fact that in all experiments, the same dose of 200 monitor units was applied, the dose transmission becomes larger with increasing field size. At a distance of 16 cm from the central axis, doses of 0.003, 0.012, 0.029, 0.052, 0.092, 0.128 Gy are observed for fields with sizes 5x5, 10x10, 15x15, 20x20, 25x25 cm2, respectively. The results of the current study are essential for understanding how field size affects dose transmission.

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# DEVELOPMENT OF NEW METHODS FOR MEDICAL RADIONUCLIDE PRODUCTION FOR RADIOISOTOPE COMPLEX AT NRC “KI” - PNPI

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At NRC “KI” - PNPI (National Research Center “Kurchatov Institute” - Petersburg Nuclear Physics Institute) the cyclotron C-80 capable of producing 40–80 MeV proton beam with a current of 100 $\mu$A has been constructed. One of the main goals of C-80 is production of a wide spectrum of medical radionuclides for diagnostics and therapy. A special beam line will be erected as well for the treatment of malignant eye diseases. Currently a project is being worked out for the construction of radioisotope complex with three target stations at the beam of C-80. The peculiarity of the proposed facility is the use of the mass-separator with the target-ion source device as one of the target stations for on-line, or semi on-line production of a high purity separated medical radionuclides. The radionuclides planned to be produced are $^{64,67}$Cu, $^{68}$Ge, $^{82}$Sr, $^{111}$In, $^{123,124}$I, $^{223,224}$Ra, $^{225}$Ac and others, believed to be promising for diagnostics and therapy. Presently new thermal methods for selective production of radionuclide pointed out are being developed. The general idea is to use the difference in volatility of atoms of the needed radionuclide and target material when it is heated in a high vacuum at definite temperature. The results of a new high temperature method utilization for separation of $^{67}$Cu, $^{82}$Sr from irradiated target materials have been presented. Also the results of experiments for the production of radioisotopes $^{223,224}$Ra and $^{225}$Ac by the mass-separator method are discussed. It is important to emphasize that the method of “dry” thermal separation allows the subsequent use of the mass-separator method for further purification of the targeted radionuclides.

# STUDY OF THE DISTORTION OF IMAGES OF MRI SCANNERS

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MRI has now become the preferred choice in many clinical trials due to its superior ability to distinguish one tissue type from another. However, the likelihood of geometric distortion (distortion) present in MR images limits the use of MRI in some areas where high accuracy is required.

The main sources of geometric distortion from MRI equipment are inhomogeneity in the main magnet, nonlinearity of gradient fields and eddy currents associated with switching gradient coils [1]. The amount of geometrical distortion due to field inhomogeneity depends on the magnitude of the field used. For example, at a field value of 1.5 T, a 1% drop in the field value will lead to a distortion of 1 mm. The magnitude of the gradient nonlinear distortion usually reaches 4–6 mm [2].

The objective of the study is to quantify geometric distortions by analyzing MR images of a special phantom, obtained on MRI scanners with different magnetic field strengths, and subsequent data processing.

Comparison of the obtained data from the tomograph and the true data of the phantom is one of the methods for measuring distortion. The study of images will allow to deduce the patterns of distortions, as well as algorithms to overcome these distortions in the future.

Correction of geometric distortions in MR images is often performed as a post-processing stage and consists in finding functions that relate the coordinates of the space of the distorted image and the undistorted space.

The result of the work is the values of the deviation of the points of the phantom on the MR image from the real position. Approximate dependences of the deviation from the distance to the isocenter of the coil are obtained.

Based on the data obtained, it is planned to develop a set of corrective functions for the most popular MRI scanners used in Russia in the future. The results of the study can be used to overcome the uncertainties associated with geometric distortions, which will allow more efficient use of MRI in radiation oncology.

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# CONE BEAM COMPUTED TOMOGRAPHY RESEARCH ON LEKSELL GAMMA KNIFE ICON.

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The new model of the Leksell Gamma Knife Icon (LOL Icon) is equipped with additional features for fractionated radiation with masked fixation of the patient's head, namely, a cone-beam computed tomography (CBCT). LGK Icon allows to perform CBCT for frame-based radiosurgical treatment as well. This is not a mandatory stage, but it can be an alternative method of defining stereotactic space and could be used as an independent check of the patient's positioning before radiosurgery.

The purpose of this work was to assess differences between frame-based and Cone Beam Computed Tomography (CBCT) defined stereotactic space and to identify predictors of the observed findings.

Differences between frame-based and CBCT-defined stereotactic space after image coregistration were reviewed for 529 patients. Treatment planning system reported the information about the shifts in XYZ coordinates of the center of the stereotactic space (ie, coordinate x = 100 mm, y = 100 mm, z = 100 mm) defined by the frame, and the maximum shot displacement (MSD) in mm. We collected the potential predictors of the differences. 19 factors were investigated. We used multiple linear regression to evaluate associations with the increased differences.

Rotational and translational shifts greater than 1 degree and 1 mm, respectively, were observed in 2.6% of patients. At the same time, a decrease in tumor coverage of more than 5% was detected in 8.3% of cases. It was revealed that the higher fiducial errors (both mean and maximum), greater weight of the patient, lower Karnofsky Performance Scale (KPS) were predictors of increased rotational, translational shifts and the MSD.

# CALCULATION OF DOSES FROM SECONDARY NEUTRONS DURING OPERATING MEDICAL LINAC

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For cancer treatment medical linear accelerators are applied to be using for creation of electron beams and bremsstrahlung radiation. When a beam of bremsstrahlung photons with energies above 8 MeV interacts with the structural elements of the accelerator, photonuclear reactions occur, as a result of which secondary particles, mainly neutrons, are formed. This radiation may cause an additional dose load on the patient, as well as unacceptable conditions for the work of personnel.

The contribution of photoneutron radiation to the dose in the treatment room is not evaluated and is not taken into account in modern planning systems. Secondary particles pose a serious radiobiological hazard. The relatively small contribution of photoneutrons to the radiation flux leads to a great increase of the dose in the irradiated tissues, which is unacceptable in the oncology treatment.

To estimate the contribution of secondary particles to the dose, the head of a medical linac is modeled. The model is verified based on the depth dose distribution in water. As a result of the work, the spectra of secondary neutrons were obtained, their average energy was estimated, and the contribution of photoneutron radiation to the dose was calculated.

# THE USE OF ANNIHILATION PHOTONS AS A METHOD FOR DOSE DISTRIBUTION CONTROL IN PHOTON BEAM RADIATION THERAPY

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Radiation therapy plays a significant role in the treatment of cancer. In recent years, radiation therapy techniques have begun to be introduced, which make it possible to control the position of the tumor directly during the irradiation process, reducing the procedure time and minimizing the negative impact on the patient. An example of combining diagnostics and radiation therapy is the “Tomotherapy” device, in which a beam of ionizing radiation is directed at a tumor with the highest accuracy, and an integrated computer tomograph determines the shape, size and position of the tumor in a matter of seconds before the start of the session.
The paper proposes a method that can become a way to assess the dose distribution in the patient’s body during irradiation. The method uses the ideology on which PET tomography is based and is based on the registration of annihilation photons. The creation of electron-positron pairs is one of the processes that occurs when photons with an energy of more than 1.22 MeV interact with matter. The resulting positrons then annihilate with the formation of photons. By registering such photons, it is possible to obtain information that, after appropriate processing, will lead to a conclusion about the dose distribution.
To study the proposed method, a computer experiment was carried out using the GEANT4 package, based on the Monte Carlo method. Within the framework of the work performed, the correlation between the distribution of the absorbed dose of photon and positron radiation and the distribution of positron annihilation sites was estimated, and the energy spectra of bremsstrahlung and annihilation photons were analyzed.
As a result, the depth distributions of the absorbed dose and the number of annihilations were obtained, and a recalculation function was obtained, which makes it possible to obtain the depth distribution of the absorbed dose from the distribution of the number of annihilations.
The data obtained are discussed.

The research was carried out with the support of the Interdisciplinary Scientific and Educational School of Moscow University “Photonic and Quantum Technologies. Digital Medicine”.

# CALCULATION OF SPECIFIC ABSORBED FRACTIONS IN BODY USING MONTE-CARLO SIMULATIONS

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We calculated specific absorbed fractions (SAF) to estimate absorbed doses in the breast tissue of adult female. Reference adult female phantom was used as a model of the body. An in-house program was written to convert the phantom to the format suitable for Monte-Carlo simulations.
SAF from monoenergetic radiation were calculated. They were adjusted to masses of organs and tissues that include the mass of blood. Adjusted SAF were compared to SAF published by International Commission on Radiological Protection (ICRP) to verify the model.
S-values (unit doses per nuclear transformation) from Iodine-131 in thyroid were derived from SAF. These values were compared to [1] as an additional verification. Because of comparatively low energy the radiation from Iodine-131 is attenuated by tissues of the body. S-values to small organs and tissues and organs and tissues that are distant from thyroid have high uncertainty caused by Monte-Carlo method even using high number of histories.
One of the most challenging problem is calculation of dose from radionuclides distributed over the body. When simple source is simulated, it is considered that radionuclide is distributed uniformly over the source region. However tissues of body have various densities and the radionuclide has various mass activity in them. A new algorithm was proposed in [2] to calculate SAF from radionuclide distributed in the whole body. The algorithm requires the statistical weight of source particles to be equal to the density of corresponding tissues in gram per cubic centimeter. Electron and photon radiation should be treated differently. Electrons which are emitted from bone tissue are not taken into account. Difficulties of implementation of this approach are discussed in this talk.

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# MODEL ANALYSIS OF DOSE DISTRIBUTION IN A BONE IMPLANT DURING RADIATION STERILIZATION

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Relevance of this work is defined by constantly increasing need of practical medicine in plastic material for carrying out restorative surgical interventions in traumatology, orthopedics, maxillofacial, military field surgery and other fields [1]. The most important part of the process of obtaining an effective plastic material is sterilization. The innovative development of perspective radiation and combined technologies of bone implants sterilization [2] is associated with the necessity to achieve optimal radiation treatment regimes that ensure destruction of pathogens while minimizing the dose load. The latter is caused by the existence of dose-dependent changes in the structure of the bone tissue, decrease in the osteoinductive and osteoconductive characteristics of implants. It is particularly important to provide the most accurate and objective information on the value of integral absorbed dose during radiation sterilization of bone fragment as we;; as on its spatial distribution in the sample as it is associated with the specialties of bone tissue architectonics and with the existence of developed system of intraosseous spaces in it [3]. To solve this problem, in addition to computational methods and direct measurements with the use of film dosimeters, model consideration of the effect of radiation exposure on the bone fragment with the help of program software GEANT4 was applied. Parameters of the real experiment were used as the initial configuration [2]. The calculation results show that the Monte Carlo simulation with the use of the GEANT4 package allows to obtain estimates of the deep dose distribution in the bone material considering certain parameters of the radiation exposure process. These parameters include the size of the irradiated object, the geometry of the exposure process and the energy characteristics of the radiation source. Furthermore, it also allows developing practical recommendations on its optimization. A comparison of various kinds of radiation technologies demonstrates the differences in the conditions of the implementation of processing. For instance, for gamma radiation the object can be motionless but requires greater exposure time and intensity; whereas fast electron-beam is characterized by their greatest effect coming onto the surface. Therefore, it is necessary for the sample to be rotated or turned over to obtain uniform radiation. Along with technical difficulties, it is also required to consider different cost-effectiveness of these techniques. Despite the fact that sterilization using electron-beam takes the less part in the market volume, such optimization creates condition for expanding its usage in bioimplantology. This research has been supported by the Interdisciplinary Scientific and Educational School of Moscow University «Photonic and Quantum technologies. Digital medicine».

# INFLUENCE OF A COMPLEX SHAPE OF AN OBJECT ON UNIFORMITY OF DOSE DISTRIBUTION

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Observance of the uniformity of the dose distribution over the volume of the irradiated object is an urgent task in the field of sterilization of medical devices. Under-irradiation can lead to the non-sterility of the processed object. Over-irradiated leads to unwanted chemical changes in the object.

Most medical devices have a complex shape, so this must be taken into account when selecting the physical and technical processing parameters.

The purpose of the study was to calculate the absorbed dose distribution uniformity throughout the volume of the balloon complex shape and to evaluate the effect of the shape of its bottom on the degree of uniformity of irradiation.

Dose distribution uniformity over the irradiated complex geometry object volume was calculated with the computer simulation using the Geant4 toolkit. Complex geometry object in the model of Geant4 corresponded to the real prototypes of aluminum cylinders with thermal water. The total height of the balloon was 15.5 cm, of which 4.5 cm was occupied by a cavity with water. The radius of the balloon was 2.5 cm, the wall thickness was 0.5 mm.

During the simulation, the object was irradiated by electrons with 9.5 MeV (according to the operating mode of the accelerator of the radiation sterilization center) from two opposite sides along the vertical direction parallel to the cylinder axis. Simulation of ordinary cylinders forms balloons irradiation under the same conditions was also carried out for comparison. The volume of the balloon was divided into virtual layers in the height and the radial direction by a cylindrical grid with a constant pitch. The data on the absorbed dose, obtained for each virtual volume, was used to calculate the uniformity of the distribution of the absorbed dose depth in the volume of the cylinders. The evaluation criterion was the ratio of the minimum dose value to the maximum dose value in the cross-section of a cylindrical phantom.

The study showed a large irradiation irregularity in both object shapes. It was confirmed that the complex shape of the balloon's bottom has no significant effect on uniformity. For the balloon of a complex shape, the irregularity was 5.27, while for ordinary cylinders object this value was 5.25. The absence of significant corrections of a complex shape in the dose profile makes it possible to model an object with a cylinder or to calculate distributions analytically.

This research has been supported by the Interdisciplinary Scientific and Educational School of Moscow University «Photonic and Quantum technologies. Digital medicine».

# Poster session

## THE APPLICATION OF GAMMA-SPECTROMETRY WITH A GERMANIUM DETECTOR FOR OIL AND ORE GEOLOGY.

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The use of the gamma spectroscopy method for measuring the value of the indicator of the ratio of the activities of uranium and thorium A (U) / A (Th) makes it possible to estimate quantitatively the manifestations of various geological processes from the accumulation of thorium and uranium in the ore content to the formation of reservoirs favorable for the accumulation of hydrocarbons, and also to determine the position of the wells relative to the supply faults.
We present the results of research on the example of the Timan-Pechora oil and gas province.
The method is based on measurements of the ratio of the intensities of gamma lines 351.9 keV (for uranium) and 238.6 keV (for thorium) in the decay of daughter nuclides 214Pb and 212Pb. Based on the values of the experimental indicator A (U) / A (Th), a comparative analysis of rocks, oils and formation waters is possible.
also established by an independent geochemical method.
Another methodological approach used in this work consists in recalculating the values of the activities of uranium and thorium into values generally accepted for geochemical studies - into weight indicators (ppm) of the content of uranium and thorium in the rock.
Analysis of the calculated values of the U and Th contents in conjunction with the A (U) / A (Th) values makes it possible to evaluate in quantitative characteristics the manifestations of various geological processes from the accumulation of thorium and uranium in the ore content.

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# ЭФФЕКТИВНОЕ ДЕЙСТВИЕ ЛИПАТОВА И ИЕРАРХИЯ БАЛИЦКОГО

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Эффективное действие Липатова, введенное в [1], является хорошо согласованной с экспериментом теорией сильного взаимодействия в пределе Редже. Наш подход формализма эффективного действия представляет вариант квантовой хромодинамики для теории полей Редже. В ней мы строим теорию возмущений, основанную на знании классических решений уравнений движения и петлевого вклада в эффективное действие. В работах [2,3] нами были получены решения классического глюонного поля для уравнений движения в виде разложения по степеням константы связи. В дальнейшем взаимодействии с действием мы используем подстановку вместо глюонного поля сумму состоящую из полученного классического решения, асимптотического глюонного поля [4] и флуктуации. В [5] мы рассматриваем действие с флуктуациями с точностью до порядка их квадрата, мы взяли функциональный интеграл от производящего функционала введя этим новое действие содержащие вклад вида Ln(1+GM), которое содержит в себе вклады одно-петлевой точности для дальнейших расчетов вершин. В дальнейшем, удержав больше степеней флуктуаций, мы сможем масштабировать петлевую точность. На основании этой работы в [6] мы получили соответствия между корреляторами реджеонных полей и операторов линий Вильсона. Это позволило ввести иерархию корреляторов реджеонных полей, которая обеспечивает расчеты унитарных поправок к амплитудам. Результат [6] позволил заключить о эффекте реджеизации этой вершины. Другими словами, вклад этой вершины с одно-петлевой поправкой представим в виде древесного результата, умноженного на экспоненту от удвоенной траектории. Дальнейшее применении этих аналитических методов можно будет сравнить с результатами [7], получаемыми численными методами. В [8] мы показываем, как корреляторы могут быть получены непосредственно из эффективного действия Липатова. Это полезный инструмент для дальнейших пертурбативных вычислений, связанных с уравнением БК.

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# METHOD FOR RECONSTRUCTION THE SPECTRA OF SHORT-RANGE CHARGED PARTICLES IN STOPPED Π⊠-MESON SBSORPTION BY NUCLEI

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The possibilities of using a monitor system [1] based on semiconductor Si detectors (SCD) for reconstructing the spectra of short-range charged particles in experiments to study the mechanisms of stopped negative pion absorption by nuclei [2] are considered.

The method is based on the possibility of measuring the stopping depth of a pion in a thick (~ 100 μg/cm2) target by the amount of energy loss in monitor Si detectors. The characteristics of the system are considered and the method of their measurement is proposed. Various methods of reconstructing the spectra of short-range particles from thick targets are analyzed and their applicability in both inclusive and correlation measurements with the registration of pairs of charged particles for coincidence is demonstrated.

The use of this approach makes it possible to increase the efficiency of research by combining the maximum statistical data security with the advantages of experiments on thin (~20 μg/cm2) targets.

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# DISTRIBUTION OF SECONDARY PARTICLES IN DEPENDENCE ON TRANSVERSE MOMENTUM IN HIGH ENERGY COLLISIONS OF PROTONS AND SIGNALS OF DARK MATTER IN THE SPECTRA OF PHOTONS

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Developing a statistical model of multiple particle production based on [1-3], an algorithm is proposed for finding the transverse momentum distribution Λ- hyperons formed in pp collisions at energies $\sqrt{s}$ of 53, 200, 900 and 7000 GeV [4]. The calculated spectra of hyperons are consistent with experimental data and calculations using the quark-gluon string model [5]

Analyzing, following [6], the experimental data [7] on the spectra of soft photons depending on the transverse momentum, in this work it is proposed to interpret the hardening of the spectrum [7] as a manifestation of the contribution of a new X17 boson particle with a mass of about 17 MeV, which is a candidate for the role of particles of dark matter. An algorithm for finding the mass of the X17 boson based on the tube model is proposed. The interpretation of experimental data on the spectra of soft photons with the help of new particles - bosons X17 and X38 [8] was proposed. They can form massive dark matter objects in astrophysics. The presence of the boson mass X17, equal to 17 MeV, and X38, equal to 38 MeV, is substantiated, proceeding from the electromagnetic tube when combining two-dimensional $QCD_2$ and $QED_2$.

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# KINEMATIC APPROACH FOR NUCLEI COALESCENCE IN TRANSPORT MODELS

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Transport approach [1,2] for nucleus-nucleus collisions description is widely used and underlies many popular Monte Carlo event generators, such as SMASH [3] and UrQMD [4]. Unfortunately, the mechanisms of nucleus fragmentation and coalescence are not taken into account by the transport approach based models. In final states, nucleus fragments (such as spectators or made by coalescence light nuclei) are presented as many individual protons and neutrons. It leads to significant overestimation of particle multiplicity in the regions of large pseudorapidity ($|\eta| > 3.5$) (Fig. 1).

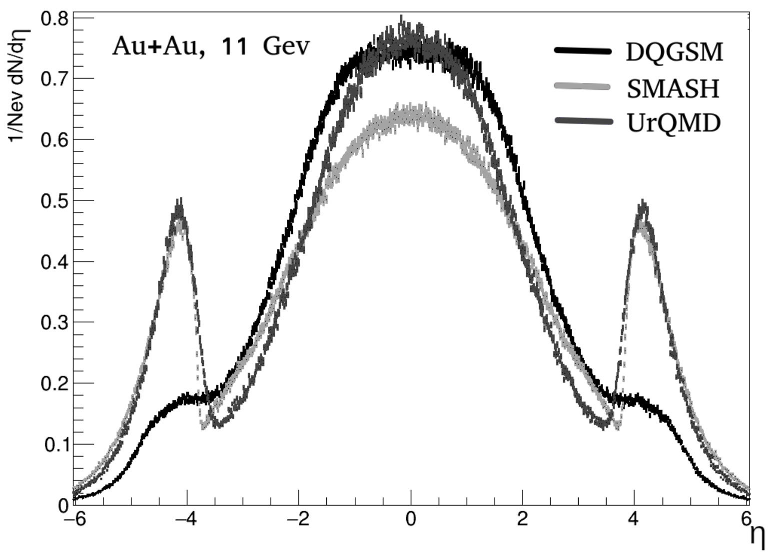


Figure 1: Pseudorapidity distribution of charged particles

To solve this problem, the kinematic approach for nuclei coalescence was developed. The main idea of the approach is to interpret a bulk of nearly spaced nucleons with close velocities as a single nucleus. The predictions of the approach within the transport models are compared with non-transport models predictions and experimental data. The obtained results are discussed.

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# COMPARISON OF SOME CHARACTERISTICS OF CHARGED PIONS IN P$^{12}$C AND N$^{12}$C COLLISIONS AT 4.2 GEV/C

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The new experimental data on various characteristics of the secondary charged pions produced in n$^{12}$C collisions at 4.2 GeV/c are presented. A comparative analysis of the average multiplicities and various kinematic characteristics of the charged pions produced in n$^{12}$C and p$^{12}$C collisions at 4.2 GeV/c is made. The experimental data are compared systematically with the predictions of the modified FRITIOF model.

**1. Introduction**

This work is a continuation of a series of the papers [1, 2] andis devoted to the comparative analysis of various characteristics of the charged pionsproduced in p$^{12}$C and n$^{12}$C collisions at 4.2 GeV/c. The experimental data are compared with the results of Monte Carlo calculations in the framework of the modified version of the FRITIOF model [3, 4].

**2. Experimental results and their discussion**

Table 1 shows the experimental data on the average multiplicities of charged pions (the mean number of the charged pions per one inelastic collision event)produced in p$^{12}$C and n$^{12}$C collisions at 4.2 GeV/c.

From Table 1 one can see that the average multiplicity of negative (positive) pions coincides with the average multiplicity of positive (negative) pions in p$^{12}$C and n$^{12}$C collisions, respectively. This result is obvious from the isotopic invariance of the strong interactions considered by us. However, as seen from Table 1, the model overestimates the average multiplicities in comparison with the experimental data by approximately 10%, both for negative and positive pions.

| Quantity | Type of collision | | | |
|---|---|---|---|---|
| | $p^{12}$C | | $n^{12}$C | |
| | Experiment | Model | Experiment | Model |
| $<n(\pi^-)>$ | 0.36±0.02 | 0.40±0.01 | 0.64±0.02 | 0.70±0.01 |
| $<n(\pi^+)>$ | 0.63±0.02 | 0.71±0.01 | 0.37±0.02 | 0.39±0.01 |
| $\Delta R$ | 0.27 ± 0.03 | 0.31 ± 0.01 | 0.27 ± 0.03 | 0.31 ± 0.01 |

Figure 1: Table 1. Average multiplicities of $\pi^-$ and $\pi^+$ mesons, as well as their absolute differences DR in the experiment and in the modified FRITIOF model in p12C and n12C collisions at 4.2 GeV/c

In order to determine the contribution of inelastic charge exchange reactions of the initial neutron (proton) to the formation of negative (positive) pions, let us consider the difference in the average multiplicities of the negative (positive) and positive (negative) pions in $n^{12}C$ ($p^{12}C$) collisions (see the last line of Table 1).

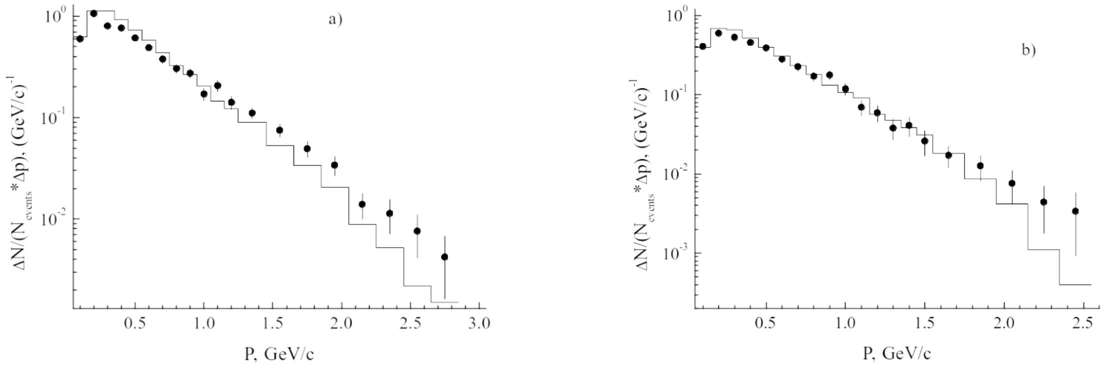


Figure 2: The normalized total momentum distributions of the negative (a) and positive (b) pions in $n^{12}C$ collisions at 4.2 GeV/c. Histograms – the calculations within the framework of the modified FRITIOF model.

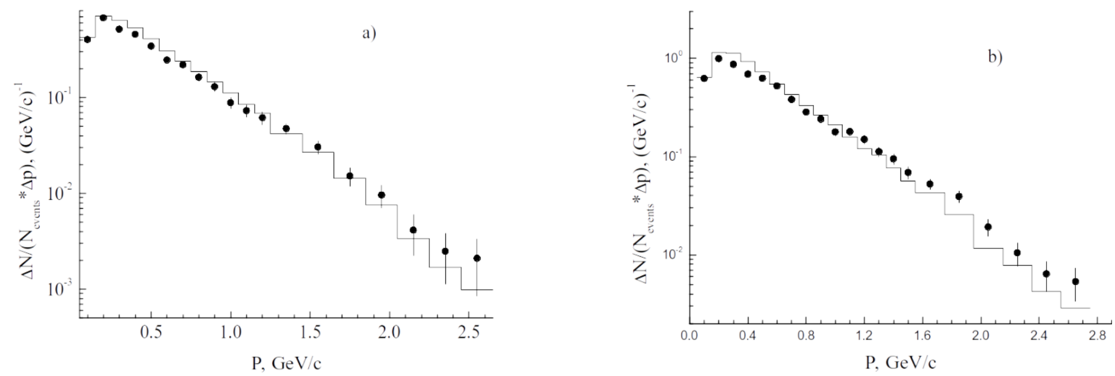


Figure 3: 2.The normalized total momentum distributions of the negative (a) and positive (b) pions in $n^{12}C$ collisions. Histograms – the calculations within the framework of the modified FRITIOF model.

Figs. 1 and 2 show the total momentum distributions of $\pi^-$ (a) and $\pi^+$ (b) mesons in $n^{12}C$ (Fig. 1) and $p^{12}C$ (Fig. 2) collisions at 4.2 GeV/c, normalized by the total number of inelastic events (Nevents) and the width of the momentum interval (DP). The corresponding distributions calculated using the modified FRITIOF model are shown as histograms for comparison.

Figs. 1 and 2 show also that the calculated momentum spectra of the charged pions for both $\pi^-$ (a) and $\pi^+$ (b) mesons are single-modal ones and there are no deviations from the general smooth behavior of the spectra with increasing the momentum [5]. The theoretical data exceed the experimental ones for both $\pi^-$ (a) and $\pi^+$ (b) mesons for both types of collisions in the momentum range of p ≤ 1 GeV/c. The model describes well the shape of the experimental momentum distributions of the negative (positive) pions in $n^{12}C$ ($p^{12}C$) collisions in the range 1 ≤ p ≤ 2 GeV/c. Regarding the high momentum tail of the momentum distributions (p $\geq$ 1 GeV/c), the model systematically underestimates the experimental data for the negative (positive) pions in $n^{12}C$ ($p^{12}C$) collisions.

**3. Conclusions**

We have presented the new experimental data on various characteristics of the secondary charged pions produced in $n^{12}C$ collisions at 4.2 GeV/c. We have also performed a comparative analysis of the average multiplicities and various kinematic characteristics of the charged pionsproduced in $n^{12}C$ and $p^{12}C$ collisions at 4.2 GeV/c. Experimental data were compared systematically with thecalculationsusing the modified FRITIOF model.

It is shown that in $n^{12}C$ ($p^{12}C$) collisions at 4.2 GeV/c around half of the negative (positive) pions are produced due to inelastic charge exchange reaction (conversion) of the initial neutron (proton) into proton (neutron) and the negative (positive) pion.

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# EMISSION OF TWO GAMMA RAY PHOTON FROM QAURK-GLUON PLASMA WITH CHEMICAL POTENTIAL

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We work on the electromagnetic probes as gamma ray photon using phenomenological model. The model is based on quasi-particles in which finite quark mass is dependent on temperature as well as chemical potential under extreme condition of hot and dense quark matter. The production rate of two photons are found to be enhance with chemical potential with suitable initial conditions at RHIC and LHC. Our results are compared with earlier theoretical work. Therefore, these signatures are unique and considered as a clean probe for the detection of quark gluon plasma in the field of high energy physics.

# EARLY UNIVERSE EXPANSION OF QUARK GLUON PLASMA WITH QUASI-PARTICLE APPROACH

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We study the expansion of early universe using quasi-particle approach. In order to determine the accurate time evolution of the thermodynamic parameters in the early universe of quark gluon plasma (QGP), we solve the Friedmann equation. The calculation results provide us the time variation of the energy density and also the time evolution of temperature in the early universe using finite quark mass value. The results shown in figures show the time evolution of early universe which also help to calculate other thermodynamic observables. Finally, these new findings about this state of matter using quasi-particle approach could be interesting in the relativistic heavy ion collisions and in QGP-Hadron phase transition.

# RECONSTRUCTION OF THE ELECTRON SPECTRUM FROM DEPTH DOSE DISTRIBUTION WITH THE MODIFIED TIKHONOV REGULARIZATION

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Radiation technologies are widely used in various fields of science and medicine. Usually, electron accelerators are utilized as radiation sources. It is necessary to control the energy spectrum of the emitted electrons because it significantly affects the result of exposure to the electron beam. Measuring spectra directly is a difficult and non-trivial task that requires specialized equipment. Thus, it seems to be natural to look for alternative methods of obtaining the energy spectrum of an electron beam.

One of these methods is to reconstruct the beam spectrum from the depth dose distribution. The corresponding inverse problem is usually posed in the form of the Fredholm equation of the first kind. This problem is ill-posed and requires regularization. Usually, Tikhonov regularization a classic zero-order stabilizer is used [1]. However, for beams whose spectra have narrow peaks, this method does not give a satisfactory result. The reconstructed spectrum is excessively smoothed in the region of the peak, and outside the region of the peak, the spectrum is not sufficiently smoothed, and nonphysical oscillations are practically untouched [2]. Increasing the order of the stabilizer does not improve the results, since the peaks also have relatively large derivatives, and, therefore, are subjected to excessive smoothing once again. Thus, the classical regularization method requires modification. The paper proposes a modification of the Tikhonov regularization method, which provides a solution to this problem. The modification consists in introducing nonnegative weight functions into zero and first order stabilizers.

The result of the work was a numerical matrix method for solving a regularized problem. Various types of weighting functions were considered. It was found that the spectra reconstructed with weights having a negative power-law dependence reconstruct spectrum more accurately the position of the spectrum peak and its width.

This research has been supported by the Interdisciplinary Scientific and Educational School of Moscow University «Photonic and Quantum technologies. Digital medicine».

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# ABOUT LEPTONS IN THEORY OF SPACE-TIME FILM

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Nonlinear field model of extremal space-time film is considered [1-3]. Its space-localized solution in toroidal coordinates with periodic dependence on time is investigated. In particular, we consider the field configuration having a form of the twisted lightlike soliton moving along the singular ring of the coordinate system. The solutions in the form of twisted lightlike solitons was considered in the work [1]. As was shown in this work, the subclass of such solitons can be conformed to real photons. In the present talk, we consider approximate time-periodic toroidal solutions. The approximate solutions are represented in the form of finite Fourier sums on the circular wave phase and the polar toroidal coordinate. The dependence of the solution on the radial toroidal coordinate is approximated by a fractional-rational function from the exponent of the coordinate. The phase of the circular wave is linearly dependent both on time and the azimuthal toroidal coordinate. The obtained solutions have the electrical charge and finite energy and angular momentum or spin. The question as to the relation these solutions to leptons is considered.

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# IDENTIFICATION OF CENTRAL EVENTS IN NUCLEUS-NUCLEUS COLLISIONS BY MACHINE LEARNING ALGORITHMS

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Estimation of centrality is one of the key steps in any analysis sensitive to initial stages of nucleus-nucleus collisions. In fixed target experiments typically one can use forward detectors to measure energy of nucleon spectators as a proxy for centrality estimator. Precision of this determination in limited by the detector resolution and losses of particles on a way from an interaction point to the detector.

In this contribution we present results of application of machine learning algorithms for centrality determination in Ar+Sc collisions at SPS collision energies based on EPOS model. For this goal realistic simulations of the response of the Projectile Spectator Detector (forward hadronic calorimeter) of the NA61/SHINE experiment was used. Modular structure of detector in transverse plane allows us to use energy depositions in different modules as features for the symbolic regression, decision trees and the convolutional neural network.

This work is supported by the Russian Science Foundation under grant 17-72-20045. We thank to the support and help from all the members of the CERN NA61/SHINE Collaboration.

# EXTENDED MULTIPOMERON EXCHANGE MODEL FOR PP, PA AND AA COLLISIONS

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A new generalization of the multipomeron exchange model [1-7] is proposed that provides a reasonable description of processes of pp, pA, and AA collisions. The main feature of this model is that the effect of string collectivity is accounted for by a given parameter associated with a change in string tension due to the fusion process. In a new approach, special attention is paid to the production in AA collisions of the hadrons containing strange quarks, which is generally considered as a signal of the formation of quark-gluon plasma. Besides the higher yield of strangness, increasing string tension results in a specific class of events with a large multiplicity and facilitates in the string fragmentation process creation of particles containing c-quark. This mechanism can be considered as an additional source of charm production [5].

The parameters of the model are fixed according to the dependence of the transverse momentum on the multiplicity in $pp$ and $p\bar{p}$ collisions in a wide energy range (from ISR to LHC). In addition, the yields of multistrange and charmed particles are obtained as a function of the charged multiplicity for Pb-Pb collisions at LHC energy, and the predictions of the model are compared with experimental data.

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# TRANSVERSE SPHEROCITY DEPENDENCE OF ELLIPTIC FLOW AND APPLICATION OF MACHINE LEARNING TOOLS IN HEAVY-ION COLLISIONS AT THE LHC USING AMPT MODEL

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Recently, event shape observables such as transverse spherocity ($S_0$), has been studied successfully in small collision systems at the LHC as a tool to separate jetty and isotropic events. In our work, we have performed an extensive study of charged particles' azimuthal anisotropy in heavy-ion collisions as a function of $S_0$ for the first time using a multi-phase transport (AMPT) model. We have used the two-particle correlation (2PC) method to estimate the elliptic flow ($v_2$) for different centrality classes in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV for high-$S_0$, $S_0$-integrated and low-$S_0$ events. We found that transverse spherocity successfully differentiates heavy-ion collisions' event topology based on their geometrical shapes {\em i.e.} high and low values of spherocity ($S_0$). The high-$S_0$ events are found to have nearly zero elliptic flow while the low-$S_0$ events contribute significantly to elliptic flow of spherocity-integrated events. It was found that the number of constituent quark scaling of elliptic flow is strongly violated in events with low-$S_0$ compared to $S_0$-integrated events. In the absence of experimental explorations in this direction, we implement a machine learning based regression method to estimate $S_0$ distributions in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV by training the model with experimentally available event properties. This method works well as a good agreement between the simulated true values and the predicted values from the ML-model is observed.

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# DIFFRACTION PROCESSES IN ELASTIC SCATTERING OF 16-O BY MEDIUM NUCLEI

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As one of the methods for the experimental detection of the multicluster structure of atomic nuclei, the authors proposed a method for expanding the experimental angular distributions of differential cross sections for elastic diffraction scattering into multicluster components [1-2]. Within the framework of the diffraction theory and under the assumption of total absorption inside the interaction sphere, the authors obtained expansions of the total amplitudes of the angular distributions of the differential cross sections for elastic scattering of 16-O, in particular, on 28-Si at energies of 20.83 MeV [3] and 240 MeV [4].

The experimental data are described within the framework of the theory of diffraction scattering as a superposition of wave functions on an absolutely black nucleus and on its absolutely black substructures (for example, alpha clusters) [2]. Figures 1 and 2 show the fitting results. Satisfactory agreement is seen between the theoretical curves and experimental data. In Figure 1, there is a discrepancy with theory in the range of back angles from 160 to 177 degrees. This is due to the limited applicability of this model, which, within the framework of this paradigm, does not take into account other nuclear phenomena. Thus, the interaction of 16-O ion beams with 28-Si revealed clumps of nuclear matter with characteristic radii of 1 fm and 0.5 fm. The analysis of the differential cross sections for elastic scattering of 16-O already at 40-Ca by this method has shown itself to be unsatisfactory, which speaks in favor of the "dissolution" of clusters in the mean nucleon field of the nucleus.

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# NUCLEON DENSITY PROFILES AND NUCLEUS-NUCLEUS INTERACTION POTENTIAL

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One of the standard methods to construct the internuclear potential is the folding procedure. Consequently, the characteristics of the Coulomb barrier obtained by this procedure turn out to be sensitive to both the parametrization of the nucleon-nucleon interaction and the quality of the description of the nucleons distribution in nuclei [1,2]. In this report, the calculations are carried out for spherical even-even nuclei with $Z, N \geq 8$. Required nucleon density distribution is chosen as a Fermi-distribution. Special attention is paid to the correction of charge radius. The approximation most accurately describing experimental data is applied [3]. The dependency of the potential barrier localization from both diffuseness and half-density radius is considered. Gained nucleon density Fermi-distributions are compared with those obtained in Skyrme-Hartree-Fock approach.

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# STRUCTURE OF LEVELS AND ELECTROMAGNETIC TRANSITION RATES IN ODD-ODD NUCLEI CLOSE TO DOUBLY-MAGIC NEUTRON DEFICIENT $^{100}$SN

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In our previous papers, we extensively studied odd-odd nuclei adjacent to doubly magical stable nuclide $^{208}$Pb, as well as to also doubly magical neutron excess $^{132}$Sn. To date, some experimental information has emerged also about the properties of such nuclei in the vicinity of an extremely neutron deficient and also doubly magical $^{100}$Sn. In our calculations of odd-odd nuclei close to $^{100}$Sn, we applied random phase approximation and multi-particle shell model, both based on the phenomenological nuclear potential [1] and effective two-body interaction [2], which parameters were defined by us before. The subject of our interest were $^{98}_{49}\mathrm{In}_{49}$, $^{100}_{49}\mathrm{In}_{51}$, $^{98}_{47}\mathrm{Ag}_{51}$ and $^{94}_{45}\mathrm{Rh}_{49}$. In these nuclei we determined energy spectra and $E2, M1$ transition rates. Effective transition operators were also defined by us before [3], and they successfully described $E2$ and $M1$ transitions in nuclei close to $^{208}$Pb and $^{132}$Sn. In particular, the values of proton and neutron effective charges were $e_p = 1.6|e|$ and $e_n = 0.9|e|$. In our case, the value of $e_p \approx 1.6|e|$ was also obtained by us by using the experimental $T_{1/2}$ values of the $8^+_1 \to 6^+_1$ and $6^+_1 \to 4^+_1$ transitions in $^{98}_{48}\mathrm{Cd}_{50}$ [4], as well as our RPA calculation for these cases. However, the energy of an analogous $6^+_1 \to 4^+_1$ transition and its half-life in $^{102}_{50}\mathrm{Sn}_{52}$ are known with great uncertainty [4, 5] and thus the value of neutron effective charge in nuclei close to$^{100}$Sn is also very uncertain [5]: $e_n = 2.3(+0.6-0.2)|e|$. Such a large value of neutron effective charge is a subject of discussions. Here, we defined the values of $e_p$ and $e_n$ from the joint description of the $4^+_1 \to 6^+_1(gr.st.)$ and $2^+_1 \to 4^+_1(gr.st.)$ transitions in $^{98}$Ag and $^{94}$Rh. The result is $e_p \approx 1.6$ and $e_n \approx 2.8$. Mention that the obtained by us value of $e_n$ agrees with the experimental results [6, 7], considered together with theoretical calculations performed by us for the $6^+_1 \to 4^+_1$ transition in $^{102}$Sn [2].

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# STUDY OF GROUND STATES OF 13,14C, 13,14N, 14O NUCLEI BY FEYNMAN’S CONTINUAL INTEGRALS

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The ground states of $^{13,14}$C, $^{13,14}$N, $^{14}$O nuclei were studied in two complementary few-body models. In first model the studied isotopes were considered as cluster nuclei with following configurations: $^{13}$C ($3\alpha + n$ ), $^{14}$C ($3\alpha + 2n$), $^{13}$N ($3\alpha + p$), $^{14}$N ($3\alpha + n + p$), $^{14}$O ($3\alpha + 2p$). In second model the studied isotopes were considered as systems consisting from nuclear core $^{12}$C and one or two valence nucleons. The wave functions and energies of these few-body systems were calculated by Feynman’s continual integrals method in Euclidean time [1–3]. The algorithm of parallel calculations was implemented in C++ programming language using NVIDIA CUDA technology [4]. Calculations were performed on the NVIDIA Tesla K40 accelerator installed within the heterogeneous cluster of the Laboratory of Information Technologies, Joint Institute for Nuclear Research, Dubna [5]. Results of the few-body model were compared with results of the shell model of deformed nuclei [6, 7].

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# CALCULATIONS OF THE OCTOPOLE DEFORMATION OF RADIUM AND THORIUM ISOTOPES IN THE HARTREE-FOCK-BOGOLYUBOV APPROXIMATION WITH SKYRME FORCES

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In the Hartree-Fock-Bogolyubov (HFB) approximation, assuming the axial symmetry of nuclei with Skyrme forces (SkM* and SLy4), we calculated the properties of Ra and Th isotopes with A = 218 – 230. These isotopes are currently intensively studied for the presence of octupole deformation in them. In addition, HFB calculations of the properties of Ra and Th isotopes were carried out in the vicinity of the neutron drip line with A = 280 – 290. We used the computer code HFBTHO v2.00d [1] in our calculations. Pairing of nucleons in nuclei is described by density-dependent zero-range pairing forces with different sets of pairing force constants. In the calculations, we used the constrained conditions on the parameters of the quadrupole $_2$ and octupole $_3$ deformations of nuclei and refining calculations without the constrained conditions in the vicinity of the minimum of the dependence of the total nuclear energy $E(_2, _3)$ on $_2$ and $_3$. It is shown that for the considered isotopes Ra and Th, the value of $_3$ nuclei strongly depends on the choice of the parameters of the nucleon pairing force. The preferred values of the constants of the pairing forces of neutrons and protons for the considered isotopes Ra and Th were selected from a comparison of the calculated values of the proton and neutron energy gaps with their values calculated from the even-odd differences in the masses of neighboring nuclei. The increase in the pairing strength leads to a decrease or complete disappearance of $_2$ and $_3$ in the considered isotopes Ra and Th.

# ALPHA DECAY CHARACTERISTICS OF SUPERHEAVY ELEMENTS

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Superheavy elements are of great interest from the point of view of fundamental nuclear physics. The most important task of this direction is not only the discovery of new elements, but also the synthesis of the maximum number of isotopes of each element, which makes it possible to consider the change in the physical properties of heavy nuclei both with a change in the number of protons and with an increase in the number of neutrons. An important feature of the region of superheavy nuclei is the predominant decay with the emission of an alpha particle. This feature is at the heart of modern methods for registration of new elements, so prediction of the alpha decay characteristics of unknown elements is very important [1].

The alpha decay energy of an unknown nucleus can be obtained by evaluating the binding energies of the corresponding nuclei. Successful phenomenological approach application to binding energy predictions for nuclei with a proton number $Z$ up to 106 based on the residual np-interaction formula was demonstrated in our previous work [2]. The report presents the further development of the approach. The prediction method is expanded by taking into account experimental alpha decay energy. This modification made it possible to overcome the limitations and carry out calculations in the field of heavier nuclei. New results obtained using the latest experimental data compilation AME2020 [3]. Comparison with other model predictions is presented.

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# COLLISIONAL QUENCHING OF THE PIONIC HELIUM LONG-LIVED STATES

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About 60 years ago G. Condo [1] suggested a possible existence of long-lived states of pionic and kaonic helium atoms ($\pi^-\mathrm{He}^+$ and $K^-\mathrm{He}^+$) in order to explain that a some fraction (about 2%) of the negative mesons decays after the stopping in the helium target, contrary to the hydrogen target.
A direct experimental evidence of the similar states was obtained by the observation of the time spectra of the products of $K^-$ decay and of the products of $K^-$ and $\pi^-$ nuclear absorptions. The discovery of the similar metastable states of antiprotonic helium [2] opened a whole new area of the study that bring an extensive information on the exotic atoms and fundamental antiproton characteristics [3,4].
Recently laser-induced transition in pionic helium was observed for the first time [5]. A possibility of the further precision laser spectroscopy of this system depends, in particular, on the stability of the states against the quenching by collisions with the medium atoms. We consider Stark transitions between the highly excited states in the collisions
$(\pi^-\mathrm{He}^+)^*_{nL} + \mathrm{He} \to (\pi^-\mathrm{He}^+)^*_{nL'} + \mathrm{He} \quad (L' \neq L)$,
which can be expected as the most probable due to a small difference of the inner initial and final energies.
The cross sections and transition rates are calculated by solving the close coupling equations involving the different $L$ at a fixed $n$. In order to obtain an interaction between the colliding systems we calculate the Potential Energy Surface (PES) of the three electrons in the field of three heavy particles (two $\alpha$-particles and $\pi^-$). (Similar PES calculations were done in the paper [6], however no results for the potential were published.)

Dependencies of the Stark transition cross sections on the quantum numbers of the states and on the initial kinetic energy will be presented in the talk.

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# THE INFORMATION SYSTEM MASCA FOR CALCULATION AND GRAPHICAL REPRESENTATION OF ATOMIC MASSES, BINDING ENERGIES OF NUCLEI, ENERGIES OF SEPARATIONS AND NUCLEAR DECAYS, ENERGY THRESHOLDS OF NUCLEAR REACTIONS

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The database MASCA contains the evaluated atomic mass values of AME 2020 [1]. The program-interface to it allows getting the recommended values of atomic mass and nuclear binding energy for a given nuclide, as well as the calculated values of the energies of the main nuclear decays; the energies of proton and neutron separations; nuclear pairing energies; energy thresholds of nuclear reactions caused by protons, neutrons, deuterons, gamma quanta, etc. The covariance matrix is used to calculate the uncertainties of the derived quantities.

For the selected group of nuclides and the selected mass characteristics, a table of their values and a graphical representation of their changes for any of the three parameters $A$, $Z$, $N$ can be got [2]. The resulting tables and graphs can be saved and used in applications. The database MASCA and the program-interface to it have passed state registration [3] and are free distributed on request.

Using databases of different years under the same shell, AME 2012, AME 2016 and AME 2020, allows us to compare them quantitatively and study the dynamics of our knowledge in this area.

The information system MASCA can be used for educational purposes when studying the basics of nuclear physics.

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# THE ALIGNMENT OF THE $^{16}O(3^-$; 6.131 MEV) NUCLEUS FORMED IN SOME NUCLEAR REACTIONS AT $E_X \approx 7.5$ MEV/NUCLEON

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Experimental and calculated the $F_2(\theta_y)$ and $F_4(\theta_y)$ alignment angular dependences of the $^{16}O$ nucleus in the excited state $3^-$ (6.131 MeV), formed in the reactions $^{16}O(\alpha,\alpha)^{16}O$, $^{14}N(\alpha,d)^{16}O$, $^{15}N(\alpha,t)^{16}O$ and $^{19}F(p,\alpha)^{16}O$ at energies $E_\alpha = 30.3$ MeV and $E_p = 7.5$ MeV are presented. The orientation parameters $F_k$ ($k = 1,\ldots,2J, |F_k| \leq 1$) are polynomials in the mean values of the powers $\langle J_z \rangle$ and are included in the expression for the interaction energy of nuclei with an electromagnetic field [1]. The parameter of the dipole orientation $F_1$ is called polarization, and the quadrupole $F_2$ is the alignment of the nuclei. Since the method of angular correlations used in this work makes it possible to experimentally determine only even components, we consider the parameters of the quadrupole $F_2$ and hexadecapole $F_4$ orientations. In the case of an isotropic spin distribution, the alignment is zero. The maximum value of the parameters is achieved at the maximum value of the spin projection $M = J$ onto the quantization axis:

$$F_2 = \frac{2J+1}{\sqrt{5}}\sqrt{\frac{(J+1)(2J+3)}{J(2J-1)}}T_{20},\ F_4 = \frac{2J+1}{6}\sqrt{\frac{(2J+3)(2J+2)(2J+4)(2J+5)}{J(J-1)(2J-1)(2J-3)}}T_{40},\ T_{k0} = \frac{1}{2J+1}\frac{\rho_{k0}(\theta_y)}{\rho_{00}(\theta_y)},$$

where $\rho_{k0}(\theta_y)$ is the spin tensor component of the nucleus density matrix.
Experimental information was obtained on the basis of previously retrieved [2-5] spin-tensors $\rho_{kK}(\theta_y)$ density matrices of the $^{16}O$ nucleus ($3^-$; 6.131 MeV) by measuring of the angular particle-gamma correlations.
The experimental orientation parameters are compared with the calculated ones under the assumption of the mechanisms of stripping or pickup a nucleon cluster by the coupled channel method (FRESCO code [6]) and a compound nucleus (TALYS code [7]). The features of the behavior of the orientation parameters of the $^{16}O$ nucleus ($3^-$; 6.131 MeV) formed in various reactions are discussed and compared.

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# PROTON SPECTRA IN HE PROTON-PROTON COLLISIONS RECALCULATED TO LABORATORY SYSTEM: THE SPECIFICS THAT ARE REPRODUCED IN SPECTRA OF ASTROPHYSICAL PROTONS, GAMMA AND NEUTRINO.

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Production, collision, and decay of matter in space, I think, are responsible for the forming of particle spectra that are measured in cosmic rays and astrophysics. Protons, nuclei, and dark matter are the known form of matter. If we understand how a proton produces protons in the collision with another proton ( or antiproton), we can predict the form of the spectra of secondary elementary particles that we measure in astrophysical experiments. In such a way, the nature of dark matter becomes clearer.

LHC experiments are ready to provide us with the proton spectra at the extremely high energy of the collision. The deal is only to convert this spectrum into the laboratory system. In this paper, it was shown that spectra of neutrino and cosmic protons reproduce altogether the form of proton production spectrum at the single collision of the initial proton of extremely high energy. The gamma spectrum does not show such specifics, because it is initiated by pion production.

# INVESTIGATION OF HEAVY-ION FUSION REACTION WITH FORMATION OF MEDIUM MASS NUCLEI AT LOW ENERGIES

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In low-energy nuclear reaction physics the interactions of 12C, 16O nuclei play an important role at the studies of the stellar nucleosynthesis. The low interaction energies (which are relevant for the processes occurring in the stars) lead to significant difficulties in describing the fusion reaction mechanism for these nuclei. The main problem in this case connected with the resonance structure [1] of studied nuclei and the lowering of the reaction cross section due to the hindrance effect [2]. In this work, the recently proposed approaches [3] were used to describe resonances in the framework of the potential model. The decrease of the cross-section due to hindrance effect was taken into account and the results for possible position of the astrophysical S-factor maximum were obtained using the R-matrix approach with account for the resonances.

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# STUDY OF FOUR-NEUTRON CORRELATIONS IN CLUSTER DECAY OF $^{12}$BE HIGHLY-EXITED STATES ON RADEX CHANNEL

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Kinematic simulation of simultaneous four-neutron emission at $\alpha$-cluster decay of $^{12}$Be$^*$ highly-exited states has been considered in $^{13}$C$(n, 2p)^{12}$Be$^*$ reaction on RADEX cascade neutron. The cluster decay fragments should have specific energy and angular correlations reflecting strong spatial correlations of "valence" nucleons orbiting in the decay nucleus [1]. The study of characteristics of cluster decay channels is extremely important for studying the cluster properties of various nuclear states [2]. Calculations using the antisymmetric model of molecular dynamics revealed the α-cluster structure of the isotopes Be, B, and C [3]. In $^{12}$Be highly-exited states the possibility the formation of $^8$Be-cluster and a $4n$-correlated cluster with a radius of $\leq$ 3 fm in a nuclear field $\geq$ 3 MeV or as a resonance with an energy of 2 MeV in the continuous spectrum [4]. Excitation of the highly-exited $\alpha$-cluster states in $^{12}$Be is possible when a proton pair is quasi-elastically knocked out of $^{13}$C at an angle of $\sim 15°$ by a cascade neutron with an energy of $\geq$ 40 MeV or in an $n - p$ charge exchange reaction followed by rescattering by a proton at an energy $\leq$ 100 MeV. In the work a two-stage kinematic simulation of the process of formation and escape of $4n$-correlated cluster in $^{13}$C$(n, 2p2\alpha)4n$ reaction was carried out. At the first stage, the $^{13}$C$(n, 2p)^{12}$Be$^*$ reaction was considered with excitation of double analog state of $^{12}$C (Fig. 1a). At the second stage, subsequent $\alpha$-cluster decay of $^{12}$Be$^*$ on $4n$-correlated cluster and $^8$Be or $\alpha$-particles was considered.
Estimated parameter of the pulsed source of cascade neutrons at an energy of 40-100 MeV is $10^{13}$ n/s. Calculations show that of two-proton registration from the formation of an excited state of $^{12}$Be$^*$ is possible in a narrow cone. The decay of the $\alpha$-cluster excited state of $^8$Be $+ 4n$ should be recorded at the widest solid angle. The registration of 4-particle coincidence must suppress the background (Fig. 1b).

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# EXPERIMENT FOR DETERMINING NP-SCATTERING LENGTH IN THE N + D → (NP) + N REACTION

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In the INR RAS experimental studies of nucleon-nucleon and three-nucleon interactions and effects of charge symmetry breaking are carried out [1, 2]. A test experiment to determine the *np*-scattering singlet length ($a_{np}$) on the neutron beam of the RADEX channel of the INR RAS was carried out. The experiment purpose is to determine anp in the reaction *n + d ⟶ (np) + n* and search for the influence of three-nucleon forces (3*NF*). The influence of 3*NF* can be manifested in the difference between the $a_{np}$ value obtained in the reaction with three particles in the final state and the value obtained in the forward *np*-scattering.
The experiment was carried out at low neutron energies of 10±2 MeV using a $C_6D_6$ scintillator as an active deuterated target. The experiment consists in the registration of a recoil neutron and a neutron from the breakup of the *np*-system as well as the fact of registration of a breakup proton in a deuterated target.
The energy of the neutron beam, the energy and emission angle of the proton are recovered from the kinematics of the reaction *n + d ⟶ n + p + n*. The relative energy of the np-system is calculated for each event and then the dependence of the reaction yield on the relative energy is plotted. The experimental dependence is compared with the simulation results which depend on the *np*-scattering length.
The test experiment showed that it's possible to determine the value of $a_{np}$ and to compare this value with the value obtained in the forward *np*-scattering at sufficient statistics.

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# PROBING ISOSCALING TO DETERMINE THE NUCLEAR TEMPERATURE IN LOW-ENERGY FISSION

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We examined the bulk of available yields of fission fragments from $Z$=28 to $Z$=67 verifying the applicability of isoscaling for low-energy fission. The phenomenon of isoscaling indicates the statistical distribution of the energy, released during the fission process, among the corresponding fission fragments. This behavior has been already discovered in special cases of fission processes as described in previous studies (from the first work [1] to the latest one [2]). In this connection, the yields ($Y_1$,$Y_2$) of specific isotopes with ($N$, $Z$), produced in two similar fission reactions, are related by the following equation:

$$\frac{Y_2}{Y_1} = C \cdot exp(\alpha \cdot N + \beta \cdot Z),$$

where $C$ is a normalisation constant.

The isoscaling parameters ($\alpha$ and $\beta$) were obtained by fits applied to the ratios of fission fragment yields available for 4 different energy classes of low-energy fission processes compiled in ENDF/B-VII.1 data library for fissioning nuclei with atomic numbers from 90 (Th) to 100 (Fm) [3]. The isoscaling parameters are related to the nuclear temperature, the mass and the atomic numbers of the nuclei, undergoing fission, and the symmetry energy coefficient $C_{sym}$. The last magnitude is well known from fits of experimental binding energies achieved within the liquid drop model [4]. The value $C_{sym}$ = 23 MeV, adopted therefrom, is used to evaluate nuclear temperatures which are in rather good agreement with corresponding values obtained by other approaches such as the isotope thermometry [5].

This new approach to extract the nuclear temperature in low-energy fission is described in details.

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# ANALYSIS FOR 6LI+12C ELASTIC SCATTERING USING DIFFERENT POTENTIALS

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Experimental angular distributions for the elastic scattering of 6Li projectile on a 12C target have been reanalyzed in the energy range 4.5- 60 MeV. The projectile-target optical potential was calculated phenomenologically with optical model (OM) of Woods-Saxon (WS) potential shape for real and imaginary parts and semi-microscopically using both of double folding approach based on energy dependent São Paulo potential (SPP) and double-folding cluster (DFC) potential. The generated cluster folding potentials is based on the (α-d) structure of 6Li.The theoretical calculations using the different concerned potentials reproduce fairly well the experimental data in the whole energy range.

# PRELIMINARY RESULTS OF THE STUDY OF GAMMA-RAY TRANSITIONS IN 11C AND 11B NUCLEI IN 9BE(3HE,NΓ)11C AND 9BE(3HE,PΓ)11B REACTIONS

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Excitation functions of gamma-transition in nuclei produced in reactions involving the 3He and 9Be ions are required to reconstruct distributions of fast 3He ions in thermonuclear plasma using gamma-ray spectrometry methods [1]. The distribution of fast ions can be obtained in two following ways: analyzing the gamma-line intensities measured by a gamma-spectrometer and analyzing the shape of the gamma-line broadened by the Doppler effect. The latter method also requires precise semiconductor spectrometers to be used in the measurements. The 3He minority ions are applied to the so-called three-ion ion-cyclotron radiofrequency (ICRF) scenario of tokamak plasma heating [2]. 3He ions accelerated to the MeV-energy range were observed in JET plasma [3]. The obtained data presented in this work will be applied for the analysis of the plasma heating regimes at JET and future facilities such as ITER.
Excitation functions of gamma-transition in 11C и 11B nuclei produced in reactions involving the 3He and 9Be ions were measured on the Cyclotron of Ioffe Institute in the energy range from 1.5 to 6 MeV. A target consisted of beryllium, deposited on a 0.5-mm-thick tantalum substrate, was used in the measurements. The thickness of beryllium is 212 μg/cm2. Gamma radiation was measured by two HPGe spectrometers with a relative efficiency of 49% and 56%. In the first measurements, the line shapes of 6.9-MeV gamma-transition from the 9Be(3He,nγ)11C reaction and 8.92-MeV transition from the 9Be(3He,pγ)11B reaction were obtained at the energy of 3He of 2.57 MeV [4]. In the present work, angular distributions of 2.0-, 4.32- and 6.9-MeV gamma-transitions from the 9Be(3He,nγ)11C reaction and 2.12-, 7.29- and 8.92-MeV transitions from the 9Be(3He,pγ)11B reaction were measured. Furthermore, based on the 7.29- and 8.92-MeV gamma-line shape analysis, the angular distribution of the proton emission upon the population of the corresponding excitation levels of the 11B nucleus was obtained, as well as the angular distribution of the neutron emission upon the population of the 6.9-MeV level of the 11C nucleus. In this work, the preliminary results of measurements of partial cross-sections and angular distributions of gamma quanta, protons and neutrons are presented at different energies of the 3He beam.

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# STUDY OF THE REACTION BASED ON THE SCATTERING OF DEUTERONS BY A $^{9}$BE NUCLEUS AT AN ENERGY OF 23 MEV

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The experiment $^{9}$Be(d,d')$^{9}$Be at E(d) = 23 MeV was carried out at the HI-13 tandem accelerator, China Institute of Atomic Energy (CIAE), Beijing. Two different method of detection were used: Q3D spectrometer at forward angles and strip detectors (ΔE-E) at medium and large angles. Differential cross sections were obtained for the following excited states: g.s, 2.43, 2.78, 3.05, 3.82, 4.7, 5.59, 6.38, 6.76 and 7.94 MeV. The theoretical analysis of the obtained experimental data was carried out using the DWBA and MDM methods. The conclusion was made about the formation of bands in the $^{9}$Be.

# INVESTIGATION OF CONTINUOS SPECTRA OF LIGHT CHARGED PARTICLES EMITTED IN PROTON INDUCED REACTION ON 103RH NUCLEUS AT 22 MEV ENERGY

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The development of the new generation of nuclear energy systems with a high level of safety (Accelerator Driven System), consisting of a proton accelerator, the neutron production target and sub critical reactor are deployed in many countries. In creating such devices for correct modeling of the neutron flux the data on the spectral composition and angular distributions of secondary protons and light charged particles produced by primary proton beam are required.
Continuous energy spectra of protons, deuterons and alphas emitted from reactions initiated by proton of 22 MeV on rhodium nucleus were measured on isochronous cyclotron U-150M of Institute of Nuclear Physics (Kazakhstan). For registration two telescopes of detectors were used. One of them consisted of silicon detector of 100 micron thickness and CsI(Tl) detector of 2.5 cm thickness (for protons and deuterons), and another consisted of 50 micron and 2 mm silicon detectors (for alphas). The self-supporting foil of Rh with thickness of 3 mkm was used in these experiments.
The energy calibration of a spectrometer was carried out on kinematics of levels of residual nuclei in the reaction 12C(p,xp) and protons of recoil. The whole systematic error was less than 10 % and the statistical uncertainty was less than 8 %.
The analysis of the experimental results has been conducted in the Griffin exciton model [1] of the preequilibrium decay of nuclei. The code Talys, which describes the emission of particles with mass numbers from 1 to 4, has been used in our theoretical calculations. A satisfying agreement between experimental and calculated values in the energy region corresponded to the pre-equilibrium mechanism has been achieved.

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# THE EFFECT OF SOIL DEPTH ON THE RADIATION ABSORPTION PARAMETERS OF SOIL SAMPLES

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The aim of this study is to theoretically investigate radiation absorption parameters of six soil samples which have various depth as 0-10 cm, 10-30 cm, 30-50 cm, 50-70 cm, 70-100 cm and 100-200 cm. For this purpose, mainly used radiation absorption paramaters which are linear attenuation coefficient (LAC), mass attenuation coefficients (MAC), half value layer (HVL), tenth value layer (TVL), mean free path (MFP), radiation protection efficiency (RPE), transmission factor (TF), effective atomic number (Zeff) and effective electron density (Neff) of soils were determined using Photon Shielding and Dosimetry (Phy-X/PSD) software [1] in energy range from 0.015 MeV to 15 MeV. LACs, MACs and RPEs reduce with increment of photon enegy whereas HVLs, TVLs, MFPs and TFs rise with increment of the photon energy. Variation of Zeff as function of energy indicate similar behavior to variation of Neff as a function of energy. As a result, radiation absorption parameters of soil samples change dependence on the soil depth, density of soil samples and elemental contents of the of the soil samples.

Keywords: Radiation absorption parameters, Phy-X/PSD software, Soil depth

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# MODELING OF CHERENKOV RADIATION IN SEMI-CLASSICAL APPROACH

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Cherenkov radiation detection is being used in the most experimental physics installations and, therefore, the detailed modeling to construct and study its properties is required. The methods of calculations in the time-spatial representation in the semiclassical approach were developed in [1-3] to simulate the electromagnetic field energy change in the passage of the primary particle and the secondary particles through the medium.

A separate consideration of the formation of the current density vector and the field excited by this current was considered in [4] in a semiclassical approach to modeling the electromagnetic field flux density in the optical range. At the first stage, the current density vectors of each charged particle are calculated using the GEANT4 simulation package. Secondly, the components and the energy of the electromagnetic field are calculated in the spatial-temporal representation by the formulas of classical electrodynamics.
The present results summarize the results obtained for the gas, liquid and solid states of the substance. The calculations were performed using data parallelization.
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# DISTRIBUTION COEFFICIENTS OF ELEMENTS IN THE SYSTEM OF CATION EXCHANGE RESIN - SELENOUS ACID

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Enriched selenium used in low-background experiments [1] is expediently purified using ion exchange. This work is devoted to the study of the sorption of a number of traditional radioactive impurities in solutions of selenous acid on a cation exchange resin. The radioactive indicators Ra-223, Ac-225 and U-230 were obtained from a proton-irradiated thorium target [2]. The radionuclide Th-234 was isolated from the U-238, and the Co-60 and Cs-137 (a chemical analog of potassium) were of commercial origin. The distribution coefficients (KD) of a same of elements at the Dowex 50W×8 cation exchange resin in selenous acid solutions are shown in the figure 1.

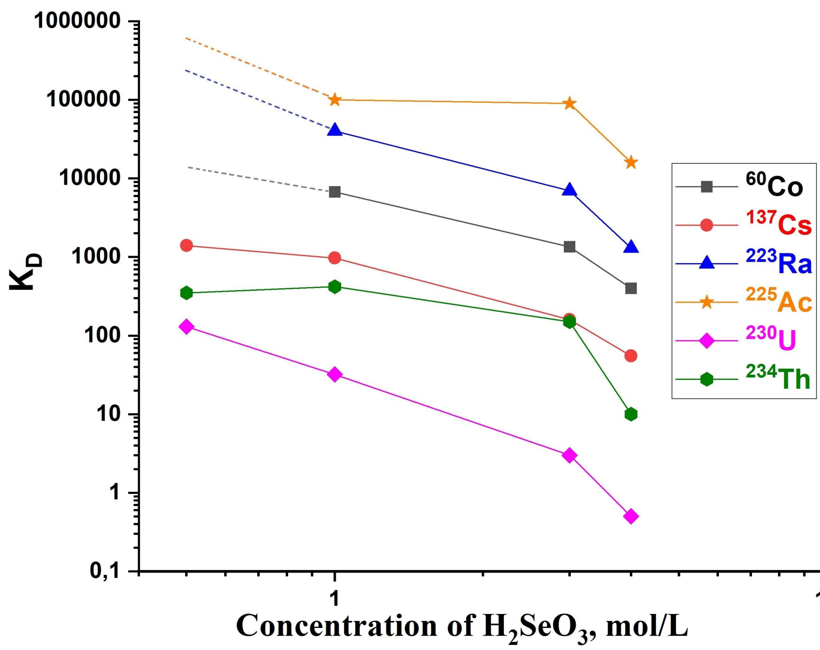


Figure 1: The distribution coefficients of a same of elements at the Dowex 50W×8 (200-400 mesh) in selenous acid solutions.

As can be seen from Figure 1 that the KD values of elements decrease with an increase of the concentration of selenous acid. It is also seen that selenium can be effectively purified from the impurities on the cation exchange resin. In addition, it should be noted that uranium and thorium can be selectively separated from a wide range of elements in this system. These results are in good agreement with the hypothesis that for the studied metals in such solutions there is a significant interaction with the neutral form of selenous acid.

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# THE INTRINSIC ENERGY RESOLUTION OF A SCINTILLATION DETECTOR

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At present, the intrinsic energy resolution of a scintillation detector is understood by many authors differently. The terms of existing formulae for the energy resolution, on which the intrinsic energy resolution of the scintillation detector is determined, differ not only in their names, but also in the physical meaning of the processes they take into account. The main drawback of all existing theories of scintillation spectrometers is the unjustified introduction of various terms in the formula for the energy resolution, without their connection with the specific characteristics of the scintillation detector, which does not allow correct determining the intrinsic energy resolution of a scintillation detector. The intrinsic energy resolution of a scintillation detector should correctly be defined as the irreducible limit that can be reached when all the parameters of the detector reach their limit values and their fluctuations are absent. Based on the microscopic standard theory of scintillation detectors, it is shown that the intrinsic energy resolution is determined by the nonlinearity of the light output, and the fluctuations in the number of electron-hole pairs.

# STUDIES OF RADIONUCLIDE CONCENTRATIONS IN THE SEDIMENT SAMPLES FROM THE ST. PETERSBURG RIVERS

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The study of environmental pollution processes is one of the geoecology’s key activities last decades. These studies are covered almost all components of the natural landscape. However, the most interesting results can be obtained during the study of the sediments samples taken from the different water objects. One of the fundamental issues in these investigations is to determine the age of the sediments formation and the rate of its accumulation in the last 100-150 years. To solve this task, the method with identification of non-equilibrium $^{210}$Pb radionuclide is widely used, but its accuracy depends on the hydrodynamic regime and on the level of lead contamination. To avoid these problems. One can use the method with the registration of $^{137}$Cs radionuclide and identification of its concentration in the sediment samples. The accumulation of $^{137}$Cs on territory of Russian Federation is associated with the beginning of the atmospheric nuclear weapons tests since 1949. The highest intensity of these tests was in 1958 and 1963. In 1963 all atmospheric, space and under water nuclear weapons tests were forbidden, but underground tests were remained and the accumulation of radionuclides in natural objects was continued. In 1986, from Chernobyl nuclear power plant accident, the concentration of $^{137}$Cs in the landscape components of western part former USSR territory has increased.

In this work with using the method of $^{137}$Cs identification, the age and rate of cesium accumulation in three columns of sediment samples from the Olkhovka, Karpovka and Chernaya Rechka (rivers of St. Petersburg) have been obtained. The column thickness ranges were from 38 to 63 cm. The sediments consisted of sandy-clayey silts and was contaminated with oil hydrocarbons and heavy metals. The samples were taken in range of 3-6 cm. For precise measurements of activity of the radionuclides which was detected in the samples at low concentrations, a spectrometric complex based on a High Purity Germanium detector was used together with a specially developed efficiency calibration procedure. Detailed analysis of the obtained data allowed us to identify the concentration of $^{137}$Cs in the samples and made the conclusion about this radionuclide accumulation into the sediments.

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# PROPERTIES AND COMPOSITION OF NATURAL QUARTZITES AFTER THE IRRADIATION BY GAMMA RADIATION

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The most reliable and long-term isolation of radioactive waste can be ensured by their burial in stable deep geological formations. The main factors which provide the stability of the geological formation during deep immobilization are absorbed by the protective container.

The natural quartzite was from the Ovruch deposit from the Ukrainian crystal shield. These natural quartzites were irradiated with converted gamma quanta for 12 years on an LUE with E = 12 MeV, I = 450 μA, the maximum absorbed dose D = 35 million Gy. The element's content of the samples irradiated by bremsstrahlung from the linear accelerator electron with an energy of 23 MeV and the current 500 μA was determined. Activation of samples carried out on air. The determination of an element's content in samples was performed by gamma spectrometer method on Ge(Li)-detector with the volume of 50 cubic cm and a resolution of 3.2 eV at 1332 keV line. To reduce the influence of the background, the detector is equipped with three-layer Pb-Cu-Al protection. The element's content in the samples was constant Si (33%), Al, Fe, Mn, Ca, Ti, Mg, and Na (from 0.7 to 0.05%).

The IR-spectroscopy and crystal-optical investigation were used for obtained information about the composition of the natural quartzite and identify not only the molecular species present in its but also the crystalline form. After irradiation, the grains of quartz, which consist of quartzite, have a smoky color and sometimes lose their transparency due to the formation of accumulation of impurities and inclusions, which are formed as a result of radiation-stimulated diffusion.

After irradiation, the grains of quartz, which makeup quartzite, acquire a smoky color and sometimes lose their transparency due to the formation of accumulation of impurities and inclusions, which are formed as a result of radiation stimulated diffusion. There is not visible cracking or amorphization of the quartz.

It is noted that irradiation with quartzite quanta for such a long period contributes to the formation of a more perfect crystal structure of this mineral.

The investigated quartzites are highly resistant to radiation exposure and can be used as a natural geological environment for the long-term storage of radioactive waste.

# ULTRA-LIGHTWEIGHT MATERIALS AND COOLING SYSTEMS FOR THE NEW DETECTOR COMPLEXES WITH THE HIGHEST RADIATION TRANSPARENCY

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In high energy physic experiments the new detector complexes with large granularity and the highest radiation transparency should be used for tracking of charged particles, providing minimal distortions due to the multiple scattering effects. In this case the minimum material budget is required for all materials have to be used within the sensitive area of the detective volume. This means that all parts of the detector complexes: sensors, microcables, support structures and cooling system must contain a minimum amounts of low-Z materials.
Therefore, the Ultra-lightweight carbon support structures with the gaseous cooling system for thin large area coordinate sensitive silicon pixel sensors were proposed.
For such support structures and cooling system the results of investigations of their main parameters are presented and discussed.

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# TPC STATUS OF MPD/NICA

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In frame of the JINR scientific program on study dense baryonic matter a new accelerator complex the Nuclotron-based Ion Collider fAcility (NICA) is under realization at the Joint Institute for Nuclear Research (Dubna, Russia) 1. Two interaction points are foreseen at NICA for two detectors. One of these detectors, the Multi-Purpose Detector (MPD), is optimized for investigations of heavy-ion collisions [2].
The MPD - 4π detector is a spectrometer capable of detecting charged hadrons, electrons, and photons produced by heavy ion collisions at high luminosity in the energy range of the NICA collider.
The Time-Projection Chamber (TPC) is the main tracking device in the MPD central barrel for 3-dimensional tracking charge particles and particle identification [3-5].
In the poster report presents current status of the basic design parameters of the TPC and the basic TPC configuration, and also status of something its systems.

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# HIGH GAIN MCPS WITH MONOLAYERS OF $AL_2O_3$ FOR FAST BEAM-BEAM COLLISIONS MONITOR AT NICA

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Tuning of the beam-beam collisions and fast, event-by-event monitoring are essential both to achieve the high luminosity of colliders and to provide in the experiment the event selection, precise event timing information, determination of the event interaction point and the reaction plane, suppression of the beam-gas interaction events. To meet the challenges of the fast monitoring of the high-intensity beam-beam collisions at NICA at JINR, the compact MCP-based Fast Beam-Beam Collisions (FBBC) detector was proposed in [1]. The FBBC concept is based on the application of the Micro Channel Plates (MCPs) as a detector of charged particles produced in the collisions of the beams. The main characteristic features of the MCPs are very short ($\sim$ 1ns) signals and high intrinsic gain ($\sim 10^6$). It is a well known fact that high precision accuracy for timing requires both sharp rise-time of signals and mitigation of the effects of large spread of signal amplitudes. This could be achieved by a careful optimization of signal readout and by the increase of the MCPs intrinsic gain. The paper presents the results of experiments to improve the technology for creating a new class of MCPs with higher gain by application of the additional monolayers of aluminum oxide ($Al_2O_3$). In particular, the original method of deposition on the MCP surface of monolayers of aluminum oxide is proposed which is based on the Atomic Layer Deposition (ALD) technique [2]. This approach allows to increase the amplitude of the signals from the MCP detector by a factor of up to a factor of ~1.5. Technology features are briefly described and results of tests are discussed.

This work was supported in part by the Russian Foundation for Basic Re-search (RFBR), project No.18-02-40097.

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# NUCLEAR FRAGMENTS RECONSTRUCTION IN C-P REACTIONS IN THE SRC SETUP OF THE BM@N EXPERIMENT.

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The Short Range Correlation (SRC) program is the extension of the BM@N (Baryonic Matter at Nuclotron) experiment. It studies interactions of carbon beam with a liquid-hydrogen target. The data analysis in the SRC experiment requires a comparison of experimental data with Monte-Carlo information. Due to various reason the procedure of simulation doesn't reproduce the experiment in some details. In the report the steps made to solve this problem are presented. Firstly, the influence of signal thresholds and variance of electron avalanche radius in Gas Electron Multipliers (GEM) on hit residuals and cluster width in GEMs were investigated in order to make the Monte Carlo data more realistic. The simulation chain was also modified by adding Beam Counters (BC). It allows us to determine the total outgoing charge of event and distinguish the fragments obtained in the MC procedure. All changes were made according to the experimental data. Algorithm of the vertex finder was improved in reconstruction of experimental cases, so the interactions on the target construction are excluded from experimental data during analysis.

The study was supported by RFBR according to the research project № 18-02-40104 mega.

# RESEARCH, DEVELOPMENT, AND TEST THE MONITORING SYSTEM PROTOTYPE OF THE ELECTROMAGNETIC CALORIMETER FOR MPD EXPERIMENT.

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The Multi-purpose Detector (MPD) is being created to study the properties of hot and dense nuclear matter at the interaction point of heavy ions beams at the NICA complex. The electromagnetic calorimeter in the new experimental setup is designed to identify photons and electrons by measuring their energy and coordinates, as well as separating them from hadrons. For the stable operation of 38400 calorimeter channels, the prototype of the LED monitoring system with fiber-optic light distribution was created. In this talk, we have presented the results of the study and test of this monitoring system.

# ADVANCED TECHNOLOGIES OF RADIATION TRANSPARENT SUPPORT STRUCTURES FOR NOVEL THIN SILICON DETECTORS.

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The current developments in the field of very thin large area coordinate sensitive Si detectors for precise tracking of short-lived charged particles in future high-energy physics experiments requires the state-of-the-art solutions for systems of cooling, mechanics and engineering. This task represents a strong challenge due to contradictive demands of high thermo- and mechanical stability of the large ultra thin silicon sensors arrays (of many square meters) vs. minimal weight of low-Z materials of all services in the sensitive region [1].
In the giving report we present the conceptual ideas and results of developments of technology for production of several configurations of extremely lightweight carbon fiber structures for large area, thin (~20 um), silicon sensors. A very promising option of cylinder geometry bent thin silicon coordinate sensitive detectors, that is being considered by ALICE [2] for the innermost sensitive tracking layers, could be also beneficial for other collider experiments (for MPD or SPD experiments at the NICA collider) due to the obvious gain in accuracy of determination of secondary vertices of short-lived particles.
Results obtained in the present work in the mechanical tests of the produced extra lightweight carbon fiber mechanical support structures show the limits of deformation under the forces relevant to bending of silicon sensors. Technology for manufacturing of new configurations of carbon fiber structure is discussed. It is shown that these technologies are capable to ensure a high level of thermo-mechanical stability with enough the minimum of matter applied in the sensitive area of novel generation of extra-low-material-budget Si-Vertex Detectors for future experiments at CERN and JINR.

This work is supported by the SPbSU grant ID:75252518

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# SIC NUCLEAR RADIATION DETECTORS FOR DETECTION OF HEAVY IONS

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In the last decade, silicon carbide (SiC) has obtained increasing interest in the field of radiation detectors due to achievement of a high purity level in the crystal structure and considerable thickness (> 100 μm) in the epitaxial layer. SiC is very perspective material for fabrication radiation-tolerant electronics, high-temperature electronics as well as for nuclear radiation detectors of ionizing radiation for working in harsh environments. SiC is mostly investigated for its physical properties, e.g.: the band gap energy of the polytype 4H-SiC is 3.26 eV, the mean energy of electron-hole pair creation is 7.78 eV, the electron saturation drift velocity is 2x107 cm/s and the breakdown voltage is 2x106 V/cm at room temperature. Detectors based on high quality epitaxial layer of 4H-SiC show a high radiation hardness, good spectroscopic resolution and can operated at room and also at elevated temperatures (~300℃) [1,2].
Our detector structures [3] were prepared on a 25 μm or 50 μm thick nitrogen-doped 4HSiC layer (donor doping ~ l x 1014 cm-3) grown by the liquid phase epitaxy on a 4” SiC wafer (donor doping ~ 2 x 1018 cm-3, thickness 350 μm). Circular Schottky contact (diameter 3.0 mm) to 4H-SiC layer (Ni/Au with thicknesses 10/30 nm) was formed through a contact metal mask, while full area contact (Ti/Pt/Au with thicknesses 10/30/90 nm) was evaporated on the other side (substrate).
Electrical characteristic of prepared SiC detectors were measured using Keithley measuring complex, which consisted of 4200A-SCS Parameter Analyzer, 2657A High Power System and CVIV Multi-Switch. Current-voltage and capacity-voltage (C-V) measurements were performed up to 300 V. The reverse breakdown voltage exceeded 300 V and the reverse current was below 10 pA. From C-V measurements the depletion thickness and doping concentration profile were calculated. Spectroscopic parameters were measured with alpha sources 226Ra and 238Pu and FWHM of SiC detectors varied round of 20 keV for 5.5 MeV α-particles energy.
SiC detectors were used in experiments at the IC-100 cyclotron of the Joint Institute for Nuclear Research in Dubna. We studied the effect, which is known in the literature as Pulse Height Defect [4], as well as the degradation of these detectors under impact of the high-energetic beam of heavy ions of Xenon. Prepared SiC detectors shown good energy resolution and high radiation resistance and can be used for long-term monitoring of heavy ion beams.

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# CHARACTERISTICS OF SIC DETECTORS AFTER NEUTRON IRRADIATION

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The results of an investigation of silicon carbide (SiC) detectors when irradiated with neutrons are presented. SiC detectors were manufactured on the basis of the epitaxial layer of 4H-SiC n-type conductivity [1, 2]. The thickness of n-type epitaxial layer was 25 µm. Schottky barrier contacts with a diameter of 3.0 mm were made by vacuum evaporation of a double layer of Ni and Au 10 and 20 nm thick. The initial energy resolution of detectors was < 25 keV for α-particles (E = 5.5 MeV).
The radiation resistance of SiC detectors was studied experimentally by analyzing their characteristics before and after neutron irradiation with integral fluxes of 5.1 ⊠1013 and 5.4 ⊠1014 n/cm2 in the energy range of 0.001⊠14 MeV. The irradiation was carried out at the pulse reactor IBR-2M (JINR, Dubna).
The α-source 226Ra (E = 4.8, 5.5, 6.0, 7.7 MeV) that was used for calibration and control of spectrometric characteristics of SiC detectors. It is shown that after neutron irradiation, significant degradation was observed: the reverse current increased by more than two and ten times; the peaks from the alpha particles shifted towards smaller channels and became much wider; the charge collection efficiency (CCE) decreased from 100% to 98%, and 70% (operating voltage 300 V) at the neutron irradiation fluence of 5.1x10^13 and 5.4x10^14 n/cm2, respectively. Although the degradation exists, the SiC detectors successfully survive intense neutron radiation and show better radiation resistance than silicon detectors.

# DEGRADATION OF SI-BASED DETECTORS PARAMETERS UNDER LONG-TERM IRRADIATION BY $^{252}$CF FISSION PRODUCTS AT ROOM AND LIQUID NITROGEN TEMPERATURES

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A compact calibration neutron source is highly required for a number of current and future nuclear and astrophysical experiments [1, 2]. An appropriate solution could be considered in a combination of $^{252}$Cf radionuclide source which undergoes $\alpha$-decay and spontaneous fission with a branching ratio of 97:3, whereas each spontaneous fission event liberates also a number of fast neutrons, with a semiconductor detector that detects the fission fragments and provides a time reference of the neutron production. However, performance of such neutron source could be considerably limited by the radiation defects formed in the semiconductor detector during the operation since the incoming fission fragments and $\alpha$-particles would create the atomic displacement damage in the crystal lattice of the semiconductor [3].

This work will present the investigation results of Si-based detectors operating parameters degradation under irradiation with fission products of the $^{252}$Cf nuclide. The irradiation of the detectors was performed at room and liquid nitrogen temperatures using the experimental setup specially designed for the simultaneous measurement of fission fragments spectrum and the determination of operational signs of the detector degradation (a decrease in the energy resolution, shift of the peaks positions, an increase in the reverse current, etc.). As a result of irradiation with 1-5×$10^8$ of fission fragments, a gradual shift of the energy positions of the fission fragments bumps towards the lower energies (i.e. the progressing pulse height defect [4]) was observed which proceeds nearly linear with the irradiation dose. Therefore, we were able to estimate the maximal exposure the detector could sustain before "degradation", which was considered to occur when the $\alpha$-peak and the bump of the heavier fission fragments overlap. Preliminary results indicate that the investigated detectors can sustain exposure of up to 8×$10^8$ of fission fragments. More details about the obtained experimental results will be presented at the Conference.

The reported study was funded by RFBR, project number 20-02-00571.

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# APPLICATION OF NUCLEAR SPECTROSCOPY METHODS FOR ANALYTICAL SUPPORT AND CORRECTION OF THE EXPERIMENT ON LIQUID EXTRACTION OF TPE AND REE

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In August last year, the Radium Institute (ROSATOM) conducted an experiment on the extraction of transplutonium and lanthanides. In the experiment, a system consisting of centrifugal extractors was used, similar to the work [1]. To monitor the extraction of transplutonium elements, we used the estimation of the volume activity of solutions using gamma spectra from various stages of extractors, underwater and outgoing lines, and bypasses. As a result of the measurements, the flows were adjusted. The experiment was carried out according to a scheme similar to that described in [1]: the classical PUREX process consisting of extraction, re-extraction and washing. Extraction was carried out with 30% TBF, diluted with C13, from an aqueous nitric acid solution. The purpose of such experiments is usually to select nitric acid concentrations and organic and aqueous phase fluxes for these model solutions, including transplutonium elements(TPE) and rare earths (REE). The final results of the experiment are the distribution of the concentrations of elements in the stages of extractors. For the analysis of concentrations, the volume activities of solutions are found, the concentration is calculated by the formula: $n = \left|\frac{\mathrm{dN}}{\mathrm{dt}}\right| \bullet \frac{1}{V} \bullet \frac{T_{\frac{1}{2}}}{ln2} \bullet \frac{M}{N_A}$, where $n$ is concentration of TPE in solution, $\frac{\mathrm{dN}}{\mathrm{dt}}$ is activity of sample, $V$ is volume of sample, $T_{\frac{1}{2}}$ is half-life TPE, $M$ is its molar mass, $N_A$ is Avogadro constant.

At the disposal of the organizers of the experiment, the following capabilities were available : a gamma-ray spectrometer with a semiconductor detector (HPGE), which has a high resolution, but low recording efficiency in the required energy range of X-ray and gamma radiation (10–100 keV) and a scintillation spectrometer with a large crystal and a well, which has a high efficiency and low energy resolution, as well as an alpha spectrometer.

Since the experiment was carried out on model solutions, and did not assume the presence of other gamma emitters other than 241Am, it was not assumed that in the gamma spectra it would be necessary to separate closely lying lines from various elements (isotopes), so a scintillation method was proposed for registration, both for monitoring during the experiment and for the final calculation of concentrations. The use of an alpha spectrometer was not considered due to the lengthy sample preparation.

For activity calibration, calibrated solutions and simulations in the PHITS neutron transport program were used.

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# REAL TIME FAST NEUTRON FLUX MONITORING WITH DIAMOND RADIATION DETECTOR

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Currently, devices that include electrophysical sources of neutron radiation, or, as they are also called, neutron generators, are widely used in applied research. Neutron radiation in these devices is obtained through the implementation of nuclear reactions such as d (d, 3He) n or d (t, 4He) n. Currently, generators based on sealed gas-filled neutron tubes (GFT) are becoming more and more widespread in the field of practical application.
In this work, an experimental study was carried out of the possibility of using diamond radiation detectors to control some characteristics of neutron generators operating on the basis of a nuclear reaction of the type (d, t). The possibility of using detectors of this type for real-time monitoring of the neutron flux density for generators based on GFT is shown. With the averaging time of readings from the detector on the order of 5 seconds, the value of the neutron flux leaving the generator target in the full solid angle can be determined with an accuracy of 4% at a flux value of the order of 1E + 8 neutrons per second. In the course of measurements, the impact of polarization on the stability of the detector was also assessed [1]
The use of a diamond radiation detector for generators neutron yield monitoring allows obtaining more accurate and timely information due to the low sensitivity of the detector to gamma radiation and the small size of the sensitive part. The signal from gamma quanta of any energy in energy equivalent from this detector does not exceed a level of the order of 400 keV. [2]. The small size of the sensitive part of the detector makes it possible to achieve the maximum ratio between the number of primary and scattered neutrons falling into it, when located as close to the source as possible.
Also, in the work, a model of the experiment was created using the Geant4 tool package. The value of flux attenuation coefficient of fast neutrons passing through the structural elements of the installation is obtained. The fraction of scattered neutrons falling into the sensitive volume of the detector is estimated.

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# STUDY OF THE GR-280 REACTOR GRAPHITE SURFACE STRUCTURE IN THE VIEW OF PERSPECTIVE ION-PLASMA DEACTIVATION TECHNOLOGY

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Today’s searches of effective technology to deactivate irradiated reactor graphite are very acute due to the large volumes of accumulated irradiated graphite in the world (about 100 thousand tons) and the challenging problem of uranium-graphite reactors decommissioning period. It is also well known that 14C isotope makes the greatest contribution to the irradiated graphite residual activity from RBMK reactors which are now on the way of out-of-operation stage. The problem is that 14C isotope suffers beta-decay with long lifetime ~ 5700 years and is dangerous when entering into biological food chains. It is also known that 14C isotope is mainly produced during operation of RBMK reactors as a result of neutron absorption by nitrogen atoms from a helium-nitrogen gas cooling mixture. In this way 14C atoms are precipitated from the gas and accumulated on the surface of reactor graphite pile. Another channel of 14C formation and accumulation is due to nitrogen intercalation and migration in between graphene-graphene layers of graphite, where nitrogen atoms are activated by neutrons. Predominantly surface localization of 14C in the irradiated reactor graphite was confirmed in [1-2].

We are developing ion-plasma deactivation technology [3] of irradiated reactor graphite, which provides sputtering of the reactor graphite surface of a given thickness by micro-plasma discharge in inert gas (argon) at high pressure up to atmospheric one. The deposition of the sputtered layer, including radioactive atoms, is carried out on the cooled collector plate with control of the discharge operating parameters (current, voltage, pressure, etc.). So, graphite surface structure data are of great importance for the development of effective technology for the irradiated graphite deactivation.

We experimentally studied the surface of the pure reactor graphite (GR-280) non-irradiated samples by SEM with X-ray microanalysis and BET-porosimetry. It was obtained that the values of the specific surface area of GR-280 reactor graphite are near to 2.1 m2 / g; pore volume ~ 0.004 cm3 / g, pore radius ~19.4 A. Based on these data, the surface layer depth of reactor graphite enriched by 14C isotope was estimated around 420 nm, this result is also consistent with the data from [1,2]. A number of another atomic species were observed by SEM X-ray microanalysis spectra in contrary to declared bulk atomic content of GR-280. It is important for a choice of graphite surface temperature and exposure duration under plasma treatment, as this temperature may vary in the range of 600-1800 K depending on the processing conditions and the input power level [4].

Plasma technology described [1] can also be used to decontaminate the surfaces of metal structures of nuclear power plants, is patented in our collaboration with Concern Rosenergoatom JSC and Rosatom and also is suitable for Fukushima NPPs accident dismantling efforts.

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# STUDY OF FISSION FRAGMENT'S BRAKE-UP AT PASSING THROUGH SOLID-STATE FOILS USING TIMEPIX3 PIXEL DETECTORS (INVESTIGATION PROJECT)

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The goal of the project is to investigate the new effect consisting in fission fragment's brake-up while passing the solid-state foil. According to the previous experiments [1-3], it is expected that masses of some brake-up residuals correspond to magic nuclei such as $^{128,132}Sn$ and $^{144}Ba$. The project aims to detect in coincidence all the products of fragment's brake-up using the Timepix3 pixel detector. It permits simultaneous determination of (x, y) coordinates of the detected products with $\mu$m resolution as well as their energy and time-of-flight. Measurements of angular and energy correlations of the products are performed in FLNR (JINR) with thin source of $^{252}Cf(sf)$. Special software for searching for multibody decays were worked out and applied for processing of the experimental data already obtained. First results and problems arisen of using Timepix3 detectors will be reported.

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# RADIOCHEMICAL METHOD OF INCREASING THE ACCURACY OF MEASURING THE RADIUM CONTENT IN URANIUM ORE

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Gamma-spectrometric methods for measuring the content of radium-226 using a photopeak with an energy of 186 keV are well known. However, according to the complete decay scheme of radium-226, this gamma-ray photopeak accompanies the alpha decay of radium to radon with a low quantum yield for decay of 5.4%. An increase in the measurement error on a semiconductor gamma spectrometer is also due to the low detector efficiency of 30%. A method is proposed for increasing the accuracy of measuring radium-226 in ore weighed portions by the radiochemical method. A sample of ore with a known mass is infused in a sealed vessel with water. In 12 days, the secular equilibrium between radium and radon-222 is practically achieved, when their activities coincide. Also, according to the decay scheme of radium, radon undergoes 3 alpha decays and 2 beta decays into daughter products to polonium-210 with a half-life of 22.5 years. Water with radon dissolved in it and its five decay products is drained, the solution is mixed with a scintillator according to a standard technique and measured on a Hidex SL-300 liquid scintillation spectrometer. The measurement efficiency here is 100%, every alpha and beta decay is recorded. Measurements are repeated every day. For 4 days, activity is halved, since the half-life of radon is 3.8 days. After 30 days, the activity of polonium-210, a decay product of radon with a half-life of 22.5 years, remains. The total initial alpha-beta activity of the solution is divided by five and the true activity of radon is obtained, equal to the activity of the weighed portion of radium in an aqueous solution, and subsequent calculations are used to calculate the specific activity of radium in the ore. Thus, by taking into account the total alpha-beta activity of short-lived daughter decay products of radon-222, the threshold value for detecting radon activity in an aqueous solution decreases 5 times and the sensitivity of the method increases 5 times compared to traditional measurement methods (1), when only one alpha decay of radon.

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# A LIBRARY LEAST SQUARE APPROACH IN THE PROMPT-GAMMA NEUTRON ACTIVATION ANALYSIS (PGNAA) PROCESS IN BULK COAL SAMPLES

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Application possibility of Library Least Square (LLS) approach in Prompt-Gamma Neutron Activation (PGNA) technique in bulk coal samples elemental analysis is investigated this work. 14 MeV neutrons were produced by a neutron generator via the T(d,n)4He reaction. A polyethylene block as a neutron moderator. The prompt gamma ray spectra from five different powders of pure compounds (namely Ca(OH)2, Fe2O3, NaCl, SiO2 and TiO2) and, afterwards, several powder-mixtures of various composition were measured by a LaBr3(Ce) gamma detection system. The gamma detection system data was streamed directly to the computer, event-by-event. The experiment simulation was performed using GEANT4 instruments.
Simulation and experimental data were loaded into the algorithm based on LLS which sent out a volume coefficient for each component of a powder-mixture investigated. The results were compared in order to optimize GEANT4 model up to the most efficient version.
As an optimization process output, the simplest decision to increase results' accuracy was to remove a steel framework and a moderator from the experimental setup simulation. The reason was significant amount of iron, carbon and hydrogen located rather close to the sample and the scintillator what usually caused neutralization of needed characteristic radiation peaks in samples' spectra. Since a GEANT4 toolkit provides an opportunity to divide gamma rays spectra into neutron capture gamma-radiation (NCGR) spectrum and inelastic scattering gamma-radiation (ISGR) spectrum. The optimized model was used to obtain the reasonable results of an elemental analysis carried out for various model mixtures.
A set of remarkable functional dependences were derived using processed model data. Firstly, error dependence of an initial amount of a component was derived. The larger initial volumetric coefficient of a component is the lower measure of inaccuracy is.
Secondly, to show that a way of spectra calibration is rather important within PGNAA elemental analysis, a series of calculations were carried out using some particular results. The data contained different sets of components' volume coefficients which were obtained using various combinations of spectra displacements along the energy axis. The bigger is displacement of a component spectrum relative to other compounds' spectra, the larger is a value of ratio error. To make a conclusion, a list of recommendations was established in order to increase effectiveness of the PGNAA technique of elemental analysis:
• Providing an experimental detector responses library for pure compounds is advisable.
• There must be no massive objects made of high-density materials relatively close to the sample and a detector.
• A pulsed neutron generator is necessary to fix an impulse duration (in order to divide NCGR and ISGR spectra).
• A preferable energy range of detector's response is from 0.1 to 8.0 MeV.
• Spectra calibration should be carried out thoroughly (a pair of close characteristic radiation peaks must not be further than 15-30 keV from each other)
• The larger initial amount of a component in a mixture is, the more accurate the results of applying the LLS algorithm are.

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# TRANSMISSION EFFICIENCY OF ISOTROPICALLY EMITTED NUCLEAR DECAY AND REACTION PRODUCTS FROM THE RADIOACTIVE SOURCE

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The successful study and detection of radioactive nuclei, produced in nuclear reactions or transformations inside the body of a target source, is not solely dependent upon their high rates of production, but also from the high efficiency of transmission of the produced recoils through the target's material. There exists an interest of correctly estimating the transmission efficiency of alpha-, beta-particles and fission products from a fissile target, produced by thermal neutron irradiation, for the purposes of nuclear spectroscopic studies of the exotic nuclei[1,2]. All of these cases will share the same mathematical derivation for the transmission efficiency formula as regardless of the means of production, nuclear transformation or thermal neutron fission reaction, the recoil products will have isotropic angular distribution from any center of production inside the radioactive source. By simply using software like the SRIM/TRIM program one can reconstruct the spatial distribution of thermalized ions in a given medium and estimate from it the transmission efficiency through the medium, generated only from a monoenergetic unidirectional beam of charged particles, which is emitted from a single point source[3,4].

In this work we will provide the derivation of the spatial distribution and transmission efficiency formulas in the more general case of monoenergetic isotropic beam of charged particles from a realistic (3D) source.

First of all in this work we present the mathematical derivation of the formula of spatial distribution of thermalized nuclear reaction products inside the target source material, emitted isotropically from a single radioactive point source, which represents the simplest case of a presence of a single radioactive atom inside the whole target material. Then the spatial distribution from a single radioactive point source is being generalized to a more realistic case of spatial distribution from a three dimensional radioactive target source, which represents the case of a realistic radioactive target, in which every atom is a potential radioactive point source. From this result then the transmission efficiency of nuclear reaction products emitted isotropically from a realistic three dimensional radioactive source is being calculated and compared in the general cases of rectangular, cylindrical and spherical target source geometry.

The results obtained will be useful in planning projects with the study of exotic nuclides, for example, the PITRAP project at the "Kurchatov Institute".

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# EJ-276 BASED NEUTRON SPECTROMETER WITH NEUTRON-GAMMA PULSE SHAPE DISCRIMINATION MAXIMUM LOAD EXPERIMENTAL ESTIMATION

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The work is devoted to the EJ-276 plastic scintillator based neutron spectrometer with pulse shape discrimination (PSD) capability experimental development [1]. A DT neutron generator was used as a radiation source. The PSD method is carried out using a CAEN DT5730B digitizer.
An experiment was carried The maximum neutron flux density at which the spectrometric channel is capable to separate neutron and gamma radiation was measured. The experiment consisted of response spectra at different neutron fluxes measurements sets, while the distance from the neutron generator target to detector R was 10 ± 1 cm.
PSD value parameter characterizes a neutron-gamma discrimination. The PSD quality is characterized by the FoM parameter. FoM ≥ 1.27 is the criterion for positive PSD result [2].
Thus, the neutron flux density φ in the detector, at which PSD separation is carried out, is not less than 1*10E6 n*s-1 *cm-2. At higher flux densities, the neutron radiation component is suppressed, which is associated with a large number of overlaps of pulses arriving at the data processing unit.The scintillator segmentation and more accurate processing of overlays can be used to increase the flux density processed by the spectrometer.
This result allows identifying the scope of developed device practical application, in particular, in the field of medical physics, accelerator and reactor technology, in the field of radiation resistance.

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# VALIDATION OF ENDF/B-7.1 NUCLEAR LIBRARY ON CALCULATIONS OF PIK-04 CRITICAL EXPERIMENTS

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The serial of critical experiments of circle geometry were performed in 70th of the last century at Petersburg Nuclear Physics Institute of the Russian Academy of Science [1,2]. The reactor PIK fuel elements of reduced length were used. Along these experiments the size of the inner water trap were varied. The geometry and the nuclear content of the fuel element were carefully measured.
The goal of this work is to validate using of the ENDF/B-7.1 nuclear data library on these experiments. At the moment the older library ENDF/B-6.0 is used for reactor PIK safety calculations. Unfortunately the bias in calculation using this two libraries of the reactor $k_{eff}$ is significant. Especially it is concern the $^{235}$U isotope. Doing the criticality calculation of these experiments can give us the possibility without additional complications of the whole reactor to validate the using of the new library.
The calculations were performed using MCNP and SCALE codes. The using of TSUNAMI module of the SCALE code make the opportunity to validate the PIK-04 critical experiments and made sensitivity calculations for the whole set of the nuclear reactions for all nuclei used in the experiment. With the help of the ICSBEP world base of criticality experiments we made trending analysis on different parameters. Also TSUFFER module gives us the idea of possible modification of nuclear data reaction libraries of elements used in the experiment.

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# SPATIAL DISTRIBUTIONS OF RADON ISOTOPES IN THE TIEN SHAN (ALMATY REGION) FOOTHILL REGIONS AND IN THE NEVA LOWLAND (ST PETERSBURG REGION)

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The territory of the Republic of Kazakhstan is characterized by a complicated radiation situation due to the active development of extractable natural resources (coal, non-ferrous metals and uranium), the geological features of the certain areas of ground surface, seismically activity and the highlands in the southern regions. In this context, radioactive gases and their decay products formed in uranium and thorium (natural radioactivity) decay chains have a big influence on the common radiation background. These radioactive elements, from the depths of the lithosphere, come into the surface atmospheric layer. Then, such radionuclides entered to the human body by the breathing processes and it is a main case for the human internal exposure. The exposure level is determined by the radionuclide mixture of the inhaled air which depends on a number of factors. The key role in this mixture is played by the radon isotopes and their decay products. There were discovered more than 30 radon isotopes, but only four of them are formed in nature: 222-Rn, 220-Rn, 219-Rn, 218-Rn, and only two isotopes: 222-Rn, 220-Rn are responsible for approximately 50% of the average annual effective dose of internal human exposure [1].

The natural radiation background in the regions of the Republic of Kazakhstan has average value approximately 3.1 mSv / year [2], and the total dose from natural and industry radioactive sources in average per person is about 4 mSv / year. This is in 1.5 times higher than the average dose accepted in the world for the human society [2]. In this case it has to be interesting to study of the radon isotopes spatial distribution in the foothill regions of the Tien Shan, located in the Almaty region. Because the tectonic faults and the mountain rocks are the additional sources of the radon emanations. On the other hand, there is an additional interest to compare the experimental data obtained in mountainous areas with the data of the radon distribution obtained in the Neva lowland at zero height above mean sea level (St. Petersburg region). An additional interest for the study of the radon formation processes is connected with the development of new buildings (in big and rapid growth cities) with the increased energy efficiency [3].

In present work the new data on spatial distribution of radon isotopes were obtained for the foothills of the Tien Shan (Almaty region) at different heights above mean sea level: from 600 to 2500 meters. Finally, the radon isotopes distribution map with the corresponding values of its concentration has been plotted. Similar experimental investigations were carried out in the Neva lowland area (St. Petersburg region). All the measurements were done at the altitude above the sea level which did not exceed 50 m. Based on the obtained values of radon concentration it was made the conclusion about spatial distribution of the radon isotopes in this region.

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# SENSITIVITY OF R-PROCESS SIMULATION TO CHOICE OF THE MASS MODEL

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Astrophysical r-process is considered to be the main source of neutron-rich isotopes beyond the iron peak and, therefore, poses a great interest to modern nuclear physics. It takes place in stellar medium at temperatures above 1 GK and very high densities that can be reached in extreme scenarios,such as supernova explosions or neutron star and black hole collisions. Computer simulations of the r-process depend on a very large number of nuclear parameters.

In this study we have calculated r-process nucleosynthesis using numeric model [1], based on the SkyNet library [2], and obtained final mass distributions of r-process products at the temperature of 1.2 GK. One of the most important parameters that impacts neutron capture rates in r-process are masses of participating nuclei, especially in the little-studied exotic isotope regions of the nuclide chart. Sensitivity of the calculation to different nuclear mass models has been studied by substitution of complete astrophysical neutron capture rate libraries, that were used during the calculation. Several reaction rate libraries with different parameters were obtained via TALYS package [3] and their results were compared to each other in the interval $A = 60 \div 220$.

Calculations were performed using the macro-microscopic models FRDM [4] and WS4 [6], the Skyrme interaction-based HFB mass model [5], and the new mass evaluation based on local mass relations [7]. Calculated r-process yields illustrate the differences of the considered mass models.

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# PRECISION MEASUREMENTS OF $^{144}$CE - $^{144}$PR BETA-SPECTRA WITH SI(LI)-SPECTROMETER

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The discovery of solar and atmospheric neutrino oscillations means that at least two of three neutrino mass states are nonzero. The oscillation parameters and the Planck telescopeconstraints on the sum of light neutrinomasses limit the most severe mass state of the three known types of neutrinos ($\nu_e, \nu_\mu, \nu_\tau$) to 70MeV. Heavier sterile neutrinos appear in many SM extensions, they are well-motivated candidates for the role of dark matter particles. This work is devoted to the search for manifestations of massive neutrinos in the $\beta$-spectra of $^{144}\mathrm{Ce}$ – $^{144}\mathrm{Pr}$ nuclei. The $^{144}\mathrm{Ce}$ – $^{144}\mathrm{Pr}$ electron antineutrino source is one of the most suitable for studying neutrino oscillations into a sterile state with a mass of about 1 eV. The $^{144}\mathrm{Ce}$ – $^{144}\mathrm{Pr}$ decay schemes allow to test the emission of neutrinos with masses from several keV to 3 MeV. The range of possible investigated masses is determined by the resolution of the β-spectrometer and the end-point energy of $^{144}\mathrm{Pr}\beta$-decay [1].
We used an original $\beta$-spectrometer with $4\pi$-geometry [2], consisting of two Si(Li) -detectors with a sensitive volume thickness 8 mm, that exceeds the range of 3 MeV electrons. The $4\pi\beta$ total absorption spectrometer allows direct measurement of $\beta$-spectra, which does not require corrections of the response function due to backscattering of electrons from the surface of the crystal. The measured spectrum, containing $1.5 \times 10^9$ events, was fitted in the energy range (250 - 3030) keV. The upper limits on the mixing parameter $|U_{eH}|^2$ were determined in a standard way from the profile of the dependence $\chi^2(|U_{eH}|^2)$. As a result, for neutrinos with a mass $m_{\nu H}$ in the range (100–2200) keV, new upper limits were set at the level $|U_{eH}|^2 \leq (0.1{-}3.0) \times 10^{-3}$ for 90% C.L., which are 2-3 times more stringent than those obtained in previous experiments.
The work was supported by the Russian Science Foundation: grant RFBR pos. 19-02- 00097 and grant RSF pos. 20-02-00571.

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# STUDY OF THE SILVERING PROCESS OF ANCIENT ROMAN COINS USING NUCLEAR-PHYSICAL METHODS AND COMPLEMENTARY TECHNIQUES

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Monetary system in ancient time was a challenging task, influenced by economic crisis, availability of metal sources and monetary reforms. In particular, the Ag content of the currency minted for about sixty years by the Antoninii emperors reflected the economic health or crisis of the Roman Empire. At the beginning, the Antoninianus denomination was a silver-rich coin (up to 80% of Ag), but gradually was devalued becoming a bronze coin with a very low content of silver (about 2–3% of Ag).

Two of ancient Roman silver coins (one of them was mint as barbarian imitations of roman coin), dating back between III-IV Centure AD have been characterized. We used a set of modern micro- and non-invasive analytical techniques: Focused Ion Beam-Field Emission Scanning Electron Microscopy-Energy Dispersive X-ray Microanalysis (FIB-FESEM-EDXM), Scanning Electron Microscopy (SEM-EDX), Micro-X-ray Fluorescent analysis (μXRF), Synchrotron- and Neutron-based Computer Tomography (CT), Synchrotron-based X-ray Diffraction (XRD), Neutron Radiation Analysis (NRA) that offers the most advantageous means of obtaining access to the bulk composition and other complementary methods.

The results revealed that a complex Ag-Cu and Ag-Cu-Pb-Sn alloys were used. The use of alloys was common in the flourishing years of the Roman Empire. In the prosperous periods, Romans produced Ag-Cu alloys with relatively high silver content for the manufacture of both the external layers and inner nucleus of coins. This study also revealed that, although surface silvering processes were applied in different periods of crisis under the reign of Antoninii, even during crisis, Romans produced Antoninianus of high quality. It possible, moreover, a first attempt to improve the silvering procedure using Hg-Ag amalgam has been identified, because Hg was detected in the upper silver layer of coins.

# PROTON-CAPTURE MEASUREMENTS ON STORED RADIOACTIVE IONS FOR THE P-PROCESS NUCLEOSYNTHESIS

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Highly-charged stable or radioactive ions can be stored and cooled in a heavy-ion storage ring offering unrivaled capabilities for precision studies of the atomic and nuclear structure, and for astrophysics [1]. We have employed the unique feature of the Experimental Storage Ring (ESR) facility at GSI to address astrophysically relevant reactions for explosive nucleosynthesis, in particular for the poorly understood production of the rare p-nuclei.

After the successful campaign for (p,γ) measurements on stored stable beams [2-3], within the framework of the experimental program at GSI in 2020 and 2021, the (p, γ) reaction cross-sections have been successfully measured at 10MeV/u, 7 MeV/u and 6 MeV/u beam energies using a radioactive ion beam for the first time, namely 118 Te beam with 6 days half-life. Using a Double Sided Silicon Strip Detector (DSSSD), introduced directly into the Ultra High Vacuum environment of the storage ring, the proton-capture reaction products have been detected. With the application of the newly developed "elimination of the Rutherford elastic scattering" (ERASE) technique the sensitivity for the proton-capture products is maximized.

In this contribution, the experimental method for precision studies of the proton-capture will be introduced with the highlight on the working principle of the ERASE background suppression technique. In addition, preliminary experimental results from the 118 Te(p,γ) 119 I reaction measurement will be discussed in detail.

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# STUDY EXCITATION OF ISOMERIC STATES IN (Γ,N) AND (N,2N) REACTIONS ON 82SE, 81BR AND 90ZR

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This work presents work results of investigation of the isomeric yield ratios Ym/Yg of the 82Se(γ,n)81m,gSe, 82Se(n,2n)81m,gSe, 81Br(⊠,n)80m,gBr, 81Br(n,2n)80m,gBr, 90Zr(γ,n)89m,gZr and 90Zr(n,2n)89m,gZr reactions. The isomeric yield ratios were measured by the induced radioactivity method. Samples of natural Se, Br and Zr have been irradiated in the bremsstrahlung beam of the betatron SB-50 in the energy range of 10⊠35 MeV with energy step of 1 MeV. For 14 MeV neutron irradiation we used the NG-150 neutron generator.

# NEW SET OF OPTICAL PARAMETERS FOR NEUTRON SCATTERING ON $^{12}$C NUCLEI

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The project TANGRA is devoted to study of nuclear reactions induced by 14.1-MeV tagged neutrons. Several measurements of $\gamma$-quanta angular distributions were conducted, including the experiment with carbon sample [1]. At the moment it is planned to measure angular distributions of the neutrons scattered on carbon, the results will require model description. An optical model [2] will be used in the analysis of experimental data.

Optical potentials are often used with other methods: the coupled-channel approach (CC) can be used with various nuclear deformations and approaches to handle excited states of the nucleus. In our case, an oblate shape was adopted for $^{12}$C, and the first excited state at 4.44 MeV ($2_1^+$) was considered rotational in CC, as it was proposed in some works. The estimation of $^{12}$C deformation is somewhat ambiguous, the quadrupole deformation parameter $\beta_2$, apparently, depend on type and energy of the probing particle used [3].

To determine the correct optical parameters and $\beta_2$ for $^{12}$C, we developed a specially designed ROOT library, which can iteratively run TALYS [4] calculations and process their results. The potential parameters were obtained by minimizing the deviation of the differential cross sections for elastic and inelastic neutron scattering calculated in TALYS from the experimental data.

The obtained optical potential was used to calculate integral and differential cross sections of the most probable processes occurring in the interaction of 14.1 MeV neutron with $^{12}$C nucleus. The calculated values were compared with experimental data.

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# ANALYSIS OF PRODUCTION OF FORWARD-ANGLE FRAGMENTS IN THE 22NE +BE/TA(40 MEV/NUCLEON)NUCLEAR REACTIONS.

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The velocity, charge, and isotopic distributions of the products of nuclear reactions by 22Ne +Be/Ta (40 MeV/nucleon) were obtained at COMBAS fragment separator at the U400M Research Facility in JINR. The results of velocity spectra analytical parametrization and isotopic ratios are presented. Velocity distributions are parametrized as consisting of three terms: direct Gaussian-like component representing direct component, second Gaussian-like component at smaller energies having the dissipative nature and exponential component corresponding to velocity attenuation at smaller velocities. The results are compared with model predictions. The discussion of the different mechanisms involved in these types of the reactions is given.

# EXCITATION OF ISOMERIC STATES IN (Γ, N), (N, 2N) AND (N, Γ) REACTIONS ON 120,122,128,130TE NUCLEI

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The isomeric ratios in reactions of the (γ, n), (n, 2n) AND (n, γ) types on 120,122,128,130Te nuclei in the energy range of 10-35 MeV have been studied by the method of induced activity. Samples of natural Sm have been irradiated in the bremsstrahlung beam of the betatron SB-50 of National University of Uzbekistan in the energy range of 10�35 MeV with energy step of 1 MeV

# SPECTROSCOPIC FACTOR FOR $^{25}$MG→$^{24}$MG+N THROUGH THE "EXPERIMENTAL" ANC FROM ANALYSIS OF THE PERIPHERAL TRANSFER REACTIONS.

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A possibility of determining the spectroscopic factor (SF) for the $^{25}$Mg→$^{24}$Mg+n configuration is demonstrated by a method that significantly reduces its dependence on the model geometric parameters of the bound-state potential. In this method, to exclude the strong dependence of results on the single-particle potential parameters the additional information about the asymptotic normalization coefficient (ANC), $C^2_{exp}$ for $^{25}$Mg→$^{24}$Mg+n [1] is introduced into the DWBA analysis. ANC value is extracted from the analysis within the framework of the MDWBA method (see [2] and references therein) of the reaction $^{24}$Mg(d,n)$^{25}$Mg at $E_d$ =13.6 [3] and 14.5 MeV [1].
Studying the behavior of the test functions R(b) which is a criterion of reaction peripherality [2] in the region of the main maximum of the angular distributions at both energies indicates a strong non-peripherality of the neutron transfer process in this reaction. Here b is the one-particle normalization coefficient, that determines the amplitude of the tail of the one-particle wave function of the neutron in the nucleus $^{25}$Mg. So, owning to the MDWBA conception, one can't extract the correct value of ANC for the configuration {$^{25}$Mg=$^{24}$Mg+n} from the MDWBA analysis. But, one can obtain the SF Z24Mg+n value if the geometry parameters of the neutron bound state potential are known (or known the single particle ANC b).
With that, owing to the established value of the ANC of this configuration from the analysis of the peripheral reaction $^{25}$Mg(d,t)$^{24}$Mg, it is possible to establish the value of the spectroscopic factor from the DWBA analysis with the additional restriction on b value. As shown in [2], the square of ANC is uniquely related to the SF Z by the relation C2 = Zb2, and the SF value for the bound state $^{25}$Mg→$^{24}$Mg+n can be obtained which is equal to . In this case, the uncertainty of its value, associated with the ambiguity of the choice of the geometrical parameters of the nuclear potential of the bound state $^{24}$Mg + n, turns out to be significantly minimized.

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# ЦИФРОВАЯ ЭЛЕКТРОНИКА 2.0 ДЛЯ ПОСТРОЕНИЯ ПОЛНОСТЬЮ ОЦИФРОВАННЫХ СИСТЕМ СБОРА И ОБРАБОТКИ ДАННЫХ

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Построение цифровых схем для обработки и управления экспериментальными установками за 15 лет с тех пор, как CAEN выпустил на рынок первые диджитайзеры стало, по сути, стандартом. За прошедшие десятилетия сотни средних и крупных экспериментов в мире были выполнены на основе продвигавшейся CAEN парадигмой цифрового подхода. Это и эксперименты по исследованию тёмной энергии, гамма-сферы, построенные за эти годы во многих странах мира, эксперименты по нейтринным осцилляциям, эксперименты на различных токамаках, ядерных реакторах, астрофизика, исследования ядерных распадов и многое-многое другое.

Растущие сложность экспериментов приводят к появлению всё новых требований к цифровой электронике. Они уже не ограничиваются роста скоростей оцифровки, или ростом скорости передачи и обработки данных. Растущие объёмы данных делают всё более и более заманчивой идею не переносить данные на компьютер, а обрабатывать их прямо на железе, непосредственно во время сбора данных. Проблемой тут встаёт либо невозможность изменять встроенную в ПЛИС прошивку, либо требования к написанию сложного низкоуровнего кода для работы с ПЛИС.

Мы рады представить научному сообществу 2-е поколение DIGITIZERS 2.0, которое решает все стоящие перед современным научным сообществом задачи.

- Больше скорости оцифровки
- Большая битность сигнала
- Большие объёмы памяти
- Большие скорости передачи данных
- Большая плотность каналов
- Возможность легко изменять прошивки ПЛИС и обрабатывать данные на самом диджитайзере.

# INVESTIGATION OF PLUTONIUM NITRIC ACID SOLUTIONS WITH UNKNOWN ISOTOPIC COMPOSITION BY ALPHA AND GAMMA SPECTROSCOPY

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In the laboratory for the reprocessing of spent nuclear fuel (SNF, Radium Institute) a solutions of $^{238}$Pu - $^{239}$Pu with unknown concentration and relation of nuclides were studied. The research was carried out both on the laboratory equipment and the equipment of the metrological service of the Radium Institute. For alpha spectroscopy we used an ionization chamber and a PIPS detector, for gamma spectroscopy NaI and HPGe detectors were used. At last to compare the results we carried a gravimetric analysis.

This study allowed us to make sure that in the solution of $^{238}$Pu - $^{239}$Pu also $^{240}$Pu and $^{241}$Am present in valuable quantities. The relative concentration for each isotope was calculated twice: by alpha-particle spectroscopy (the fitting of experimental alpha-particle spectra was done with Gaussian and two left-sided tails peak shape) and with HPGe gamma measurements. The measurement results correspond to each other with a good agreement.

Also the metrological service suggests a number of recommendations about the preparation of counting samples in the SNF laboratory.

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# DELAYED EMISSION OF ELECTRONS IN A PHOTOMULTIPLIER.

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Using an autocorrelation delayed coincidence spectrometer [1], two types of time correlation of noise pulses associated with the photocathode and photomultiplier dynodes have been established. The time distributions of pulses from noise and external light sources in photomultiplier tubes XP2020, XP2232B, XP1021, FEU-85, FEU-87, FEU-93, FEU-130, R7600U-200 have been studied. For some types of photomultipliers, the presence of an exponential time component in the nanosecond range has been established

# NEW TIME PICK-OFF ALGORITHM FOR TIME-OF-FLIGHT MEASUREMENTS WITH PIN DIODES

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Use of PIN diodes in spectrometry of low heavy ions poses some methodological challenges. One of them is correctly accounting for the so-called plasma delay effect (PDE) which is due to generation of plasma in a heavy ion track in the PIN diode. The PDE prevents precise measurements of a particle's time-of-flight (TOF). In this presentation, we discuss new algorithm of time pick-off when using Si PIN diodes for measuring time-of-flight of heavy ions. The algorithm implies that the signal is split into two parts: the first part is approximated with a parabola which vertex coincides with the start of the signal and lies on the averaged baseline; and the second part is approximated by smoothing spline function. The proposed algorithm was experimentally verified with data acquired using two time-of-flight spectrometers, one with 252Cf source and another one, installed at IC-100 accelerator (FLNR, JINR). The results demonstrate that the developed algorithm allows obtaining unbiased fission fragment's mass for the wide range of ion's masses and energies, and thus provides a reliable "true" pick-off time for PIN diodes when used as time detectors.

# MONITORING, ALARM AND CONTROL SYSTEM FOR THE ELIADE γ-RAY SPECTROMETER

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ELIADE (ELI-NP Array of Detectors) is the γ-ray spectrometer which will be used for Nuclear Resonance Fluorescence (NRF) studies at ELI-NP. The array consists of 8 High Purity Germanium detectors and 4 $LaBr_3$ detectors. This configuration is used in order to optimize efficiency for a large range of γ-ray energies: from a few hundred keV to several MeV.
The highly efficient monitoring system (MACE- Monitoring, Alarm and Control for ELIADE), which uses feedback control, has been developed to constantly read-out the status of the detectors. The monitoring parameters are the high voltage, leakage current and the temperature for the crystals of the detectors, the valves of the cooling system and the room temperature.
The temperature monitoring is done using PT100 and cRio, a system which works through the use of EPICS and Python. The information which is being read out is inserted into a database which is developed using the InfluxDB language.
The high voltage and leakage current monitoring is done using the CAEN SY4527 High-Voltage Source, from where data is extracted using Python and EPICS. Then, the final data is inserted into an InfluxDB database.
Grafana is a monitoring and analytics platform that works with every database, in our case InfluxDB being used. It allows us to plot data from the database, and with real time insertion, thanks to a continuously running Python script, real time data can be plotted. Grafana works in the form of a server which can be accessed through browser from any PC in the local area network.
Along monitoring, MACE has 3 modes of alarms. The passive one consists of ping notifications using Telegram in the form of a text message. The yellow one is set to notify the responsible persons in case of an emergency, when the temperature of a crystal is increased above certain threshold. It consists of a telegram call and, in parallel, a sim-call, if the network crashes. The last one is the red alarm, which represents the worst case scenario. Its role is to shut down the high voltage from the CAEN HV Source, so the detectors do not overheat, resulting in the damaging of the crystals.
As a conclusion, MACE allows prompt an timely alerting of the scientists on the status of ELIADE and different problems it can experience. At the last stage if the problem is not solved MACE reassures shutting down the high voltage in the automatic mode. Therefore, MACE allows safe and long-term, non-stop operation of the ELIADE array

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# THE LEVEL OF THE URANIUM, RADIUM, AND OTHERS RADIONUCLIDES CONCENTRATION IN OBJECTS OF ENVIRONMENT AND BIOOBJECTS IN POWERFUL INDUSTRIAL CENTER

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The problem of actinides and radionuclides migration, distribution, and concentration process in objects of environment and bioobjects stay of one of the importance and actual. There are the samples of drinking water, soil, roots, and the leaf of hydrophyte "Pistia stratiotes", the teeth of patients (72) with odontogenic inflammatory diseases, and patients' kidney stones (54) with urolithiasis treated. The samples were taken from Kharkiv's region. The determination of actinides and radionuclides content in samples was performed by gamma spectrometer method on Ge(Li)-detector with the volume of 50 cubic cm and resolution of 3.2 keV at 1332 keV line. To reduce the influence of background the detector is equipped with three-layer Pb-Cu-Al protection. Samples irradiated by bremsstrahlung from the linear accelerator electron with energy 23 MeV and current 500 micro A. Activation of samples carried out on air, the temperature of samples in the course of the activation didn't exceed 40 degrees C. The more significant error is for 238U (line 186 keV is equal sums of the line from 226Ra + 235U). The errors of measurements were from 7 to 25%. The limit of detection elements for photoactivation analysis was 100-0.1 ppm. The 235U and 226Ra in the nuclear reaction were calculated with help of the program complex PENELOPA. In addition to gamma activation analysis, there was the method of IR-spectroscopy (the spectral range 4000…400 cm-1 regions) and crystal-optical investigation for determination of different chemical components, crystalline form, classification kidney stones, etc. in biological samples.

The whole samples contained 235,238U and 226Ra. In drinking water, there are these actinides 1.2 - 1.8 ppm Bk/cubic dm. The actinides content in various types of soil has differences. There are radionuclides content in hydrophyte 40K, 131I, 7Be, 228Ac, 212,214Pb, 137Cs, 235U, 226Ra. It has been found that the accumulation of 226Ra, 212,214Pb, 214Bi in the teeth with odontogenic pathology is 15…40 times higher than in the teeth of patients with the same pathology in other countries. For the samples of teeth and kidney stones, 235U content was from 1 to 100 ppb.

The detected actinides and radionuclides confirm the influence of technogenic pollution of the ecosystem, as well as their geochemical mobility and biogenic migration.

# INVESTIGATION OF THE EFFECT OF FIXATION DEVICES ON DOSE DELIVERY IN RADIATION THERAPY OF HEAD TUMORS.

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The main goal of radiation therapy is to irradiate the target with a given dose while maximizing the protection of healthy tissues and organs. According to the theoretical data from radiobiology and the ICRU recommendations, to achieve the maximum results of radiation therapy, dose delivery with an accuracy of 3-5% is required [1]. The dosimetric effect of devices external to the patient is a complex combination: an increase in the dose to the skin, a decrease in the dose in a tumor, and a change in the dose distribution [2]. Despite the fact that the use of dosimetry protocols (TRS-398, TRS-483) and modern dose calculation algorithms can significantly reduce the uncertainty in dose delivery, the presence of immobilization devices is usually overlooked in treatment planning.
We studied the effect of immobilization devices on the dose in the skin layer and the average dose in the target during RT of head tumors. In the Eclipse treatment planning system, VMAT irradiation of target (ball of radius R = 3 cm) was simulated in the CIRS STEEV patient's head phantom with the inclusion of the following Q-fix fixation devices in the phantom model: headrest, thermoplastic mask (U-shaped mask support, thermoplastic part of the mask ), base plate ACCUFIX. The PTW 3D Semiflex ionization chamber (measuring volume 0.07 cm3) for measuring the average dose in the target was positioned in the geometric center of the target. Parameters such as the speed of the accelerator gantry, the speed of movement of the multi-leaf collimator blades and their position, dose rate and beam energy remained unchanged for all dosimetric irradiation plans. The therapeutic table was taken into account in all cases; when analyzing the irradiation plans, the dose distributions were normalized to 1. The experiment on measuring the average dose in the volume of the ionization chamber was carried out on a linear medical accelerator TRUEBEAM (Varian).
The simulation results showed that the failure to take into account fixing devices in dosimetric planning (not including fixing devices in the patient model) can lead to an underestimation of the average, maximum, minimum dose in the target and target coverage by 1.3%, 0.8%, 1.4 % and 1.3%, respectively. The use of a 1.6 mm U-shaped thermoplastic Q-fix mask as a fixing device increases the dose in the cutaneous 1.1% (the thickness of the skin layer according to the recommendations of RTOG 1021 [3] is a layer of 5 mm from the edge of the phantom). The simulation results are in good agreement (less than 0.2%(+-0.03%) discrepancy) with the measurements of the average dose in the target. The results obtained show the need to take into account the immobilization device when planning radiation therapy, since the errors caused by their absence in the model are comparable to the allowable limits.
This research has been supported by the Interdisciplinary Scientific and Educational School of Moscow University «Photonic and Quantum technologies. Digital medicine»

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# ESTIMATION OF SOME ADVANTAGES OF GADOLINIUM IN NCT

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Neutron Capture Therapy (NCT) is a radiotherapeutic technique still in experimental phase, that exploits the high thermal-neutron cross section of gadolinium isotopes and the ability to selectively accumulate in tumor cells such isotopes chemically bound to suitable tumor-seeking compound [1]. 157Gd (σth = 255000 b) has been considered too, owing to the Auger-electron-induced DNA damages. In the reaction of 157Gd with thermal neutrons, prompt gamma rays of various energies are emitted. The disadvantage of GdNCT over BNCT is just the long-range gammas emitted by 157Gd reactions that deliver dose also far from the reaction position, with damage to healthy tissue. In this work, Monte Carlo (MC) calculations concerning radiation transport and gamma dose distribution in a cubic water phantom with 14 cm side were carried out. MCNPX has been used to run simulations about neutron fluence and gamma dose in various configurations. Calculations were performed 157Gd. Considering that suggested concentrations in tumor tissue are 100 ppm for 157Gd and that the conventional carrier selectivity is around 3.5, for calculations suitable concentrations of the two isotopes in the water phantom were taken. The following simulations were performed: (i) water phantom (in order to evaluate fluence and gamma dose coming from epithermal neutron thermalization in water, as reference data); (ii) water phantom containing 28.6 ppm of 157Gd; (iv) water phantom containing 14.3 ppm of 157Gd. Results show that 28.6 ppm of 157Gd reduce significantly the thermal neutron fluence and increase substantially the gamma dose. The simulation with 157Gd (in the halved amounts) shows lower reduction of thermal neutron fluence and lower gamma dose; moreover, it highlights a more advantageous condition because it joins an acceptable gamma dose in healthy tissue to the ability to perform Gadolinium imaging. No drastic changes have been found by introducing volumes with limited extension containing 100 ppm of 157Gd .

The problem of the high absorbed dose in healthy tissue could be overcome by using, a Gd pharmaceutical with very high tumor-to-tissue uptake ratio. For additional investigation of above mentioned effects we developed and carried out experimental study with use of Magnelec, a paramagnetic contrast agent for magnetic resonance imaging. For this study we developed new model for analysis in vitro, using survival slices of glial tumours of human brain [2]. Preliminary results revealed that despite of low flux density at absorbed doses 5,10-20 Gy about 10-20% of tumor cells died 24 hours after irradiation. Dosimetry calculations are complex owing to the multiplicity of secondary radiation emitted during Gd reactions:electrons and photons with many possible energies and then many different ranges in tissue [3].

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# TOPOLOGY OF DISTRIBUTION OF NATURAL RADIOACTIVITY ON THE SURFACE OF THE HUMAN BODY

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The main share of oncological diseases of the lungs and bronchi is caused by radon isotopes and their daughter decay products [1], therefore, the study of radiation damage to biological objects from radon isotopes 219Rn, 220Rn, 222Rn and their decay products is an urgent task. In Kazakhstan, lung cancer is in second place (10.4%) among oncological diseases.

The aim of this work was to study the distribution of natural alpha, gamma and beta background over the surface of the human body as an indicator of cancer risk and cancer incidence. A method of measuring the topology of distribution over biological objects and the human body of local zones of background radiation using modern electronic radiometers was developed: RKS-01A-SOLO, RKS-01B-SOLO and RKS-01G-SOLO. The distribution of alpha, gamma, and beta activity over the human body was measured in a room with the lowest background by scanning along and across the body at the closest possible distance from it. Measurements were taken at the following control points: head-4, thyroid-3, left-1.9 and right side of the chest-2.1, stomach-1 and legs-0.

According to the results (Figure 1) of measurements of the radioactivity of the control points of the human body, it can be seen that the greatest background is found in the region of the thyroid gland and in the region of the brain. These results confirm the previously known facts [2] that the accumulation of radioactivity in the human body is concentrated in adipose tissues, as well as in muscle tissue accumulations. The well-known pattern of an increase in the natural radiation background with the age of a person is associated with the effect of accumulation of radioactivity due to long-lived radionuclides. The same pattern in medicine is diagnosed as an increase in diseases in the corresponding localizations. This pattern will be investigated in the future in the pool of age categories of the population due to the fact that the risk of cancer morbidity increases with age, as well as in cancer patients in the corresponding medical institutions.

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# ION CHANNELS AND NUCLEAR PORE CHANNEL GATING

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Abstract
Calcium, sodium, potassium, zinc, magnesium etc & all other ion channels carry vital biological functions with respective signaling playing great role in plasma, heart beats, dopamine & many other functions either directly by particle, ions or by their waves. There are three main types of ion channels, i.e., voltage-gated, extracellular ligand-gated, and intracellular ligand-gated along with two groups of miscellaneous ion channels. Ion channels facilitate passive movement of ions across biological membranes and are essential for life. Ion-channel engineering approaches help elucidate structure-function mechanisms of proteins. Engineered ion channels are important tools for probing and manipulating cell biology. Voltage-gated channels respond to perturbations in cell membrane potential, and are highly selective for a specific ion, i.e., Na+, K+, Ca2+, and Cl-, Others are Ligand-Gated Ion Channels (LGIC),'Cys-Loop" LGIC, Ionotropic Glutamate Receptors., P2X Receptors. .Mechano-Sensitive Ion Channels. Their ions &ion channels enable the flow of electrical signals through the body.
Nuclear envelope (NE) cisternal Ca2+ and cytosolic ATP are required for nuclear-pore-complex-(NPC-) mediated transport of DNAs, RNAs, transcription factors and other large molecules. Isolated cardiomyocyte nuclei, capable of macromolecular transport (MMT), have intrinsic NPC ion channel behavior.Ca2+ and IP3 waves may convert the NE into an effective Ca2+ barrier and, consequently, affect the regulation of gene activity and expression through their feedback on MMT and NPCC gating. Thus, [Ca2+] NE regulation by intracellular messengers is an effective mechanism for synchronizing gene activity and expression to the cellular rhythm. We found that calcium ion channels & some other ion channels play great roles in all biological activities & require great investigations in field of nuclear medicines as most of diseases are caused by abnormal functions of ions & ion-channels in lives. Behind biology is physics or nuclear physics & all require simultaneous quite clear definitions in this respect.

# GENERATION OF RADIATION EFFECTS FROM HIGH-ENERGY GAMMA QUANTA DURING IRRADIATION OF BIOLOGICAL OBJECTS AT THE MEDICAL LINEAR ACCELERATOR ELEKTA AXESSE

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The study of X-ray-induced mutations The white gene is becoming one of the main test objects in the study of the problem of direct and reverse mutation of its alleles under the action of X-ray radiation [1], and later under the action of neutrons and γ-radiation [2] on such biological objects as Drosophila melanogaster. Moreover, at present, Drosophila is used as a model object in the study of the influence of various environmental factors, such as high and low temperatures, the inclusion of active oxygen in the metabolism, nutritional characteristics and diabetes mellitus on longevity and fertility [3-4]. The work [5] studied the number and frequency of mutations in the white gene induced by different doses of reactor neutrons (E = 0.85 MeV) with doses from 2.5 Gy to 20 Gy, as well as by 60-Co γ-radiation with doses up to 60 Gy. In various works, gamma-ray irradiation of the studied biological objects is mainly carried out with energies up to 3 MeV. In this work, experiments have been carried out to study mutations of the radiation effect on the capabilities of new generations of Drosophila melanogaster by beams of gamma quanta with energies of 10 and 15 MeV. The radiation doses were 2 Gy, 10 Gy and 20 Gy. The electron accelerator Elekta Axesse of the Sunkar Cancer Center (Almaty, Republic of Kazakhstan) was used as a source of gamma quanta. The technique of irradiation of biological objects was tested by measuring the experimental linear absorption coefficients of 6 MeV gamma quanta obtained at this linear accelerator for elements B, C, O, S, Fe, Ba [6].

As a result of the experiments, the types of induced mutations, the dependence of the mutagenic effect on the dose were determined, and the significance of genetic effects for various energies of gamma quanta was estimated. This made it possible to develop a methodology and perform experiments on irradiation of Drosophila melanogaster to study the influence of hard gamma radiation and the occurrence of radiation effects and mutations in this energy range.

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# INFLUENCE OF HIGH-ENERGY PROTON AND GAMMA-RADIATION ON DNA STRUCTURE IN SOLUTION

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The use of a specific technique and type of radiation in radiotherapy of tumors is determined by various factors: the localization of the tumor in the body, its oxygenation, the stage of the disease, the availability of the technique for the patient, etc. The study of damage in the DNA structure under the influence of different types of radiation and with varying irradiation conditions provide important information for improving the methods of radiation therapy. This work compares the damage in the DNA structure under the action of $^{60}Co$ $\gamma$-radiation (used in the gamma knife therapeutic device) and 1 GeV protons (at synchrocyclotron of the St. Petersburg Institute of Nuclear Physics Research Center "Kurchatov Institute" SC-1000, since 1975 there has been a medical center for stereotactic proton therapy). These two types of radiation have the same value of LET = 0.3 keV/$\mu m$.
Disturbances in the DNA structure were studied by spectrophotometric melting. The parameters of the helix-coil transition in the irradiated macromolecule are influenced by various types of radiation damage. Single- and double-strand breaks, destruction, modification, and release of nucleobases lead to destabilization of the secondary structure and lower the melting temperature of DNA (Tm), while interstrand cross-links increase Tm [1].
Melting curves of DNA irradiated with doses of 0-100 Gy were obtained at ionic strengths of solutions of 5 mM and 150 mM $NaCl$, as well as at a total ionic strength of 5 mM = 3 mM $Na^+$ + 2 mM $Mg^{2+}$. The absorption spectra of DNA solutions were measured at $25^oC$, $95^oC$, as well as after melting and rapid (within 10 min) cooling to $25^oC$. From these data, the helix-coil transition interval, Tm, the DNA molar extinction coefficient, the hyperchromic effect, and the degree of DNA renaturation after melting upon rapid cooling were determined. Proton and $\gamma$-irradiation cause a broadening of the melting interval, which indicates an increase in the heterogeneity of the DNA structure, i.e. the appearance in the DNA chain of regions that differ sufficiently in thermal stability. For DNA irradiated in 150 mM $NaCl$ solutions with proton and $\gamma$-radiation, several maxima are observed in the differential melting curves. Under these conditions, it is possible to assume the formation of cross-links (both between two complementary strands and between DNA regions distant along the chain) as a result of irradiation. In 0.15M $NaCl$ solutions, the secondary structure of DNA is more resistant to radiation than in 5mM $NaCl$ solutions. It was found that proton irradiation causes a smaller drop in DNA Tm than $\gamma$-irradiation in a 0.15M $NaCl$ solution at doses of 0–100 Gy and in a 5 mM $NaCl$ solution at doses of 70-100 Gy. For the DNA irradiated with protons at doses of 10 and 20 Gy, an abnormally large hyperchromic effect was recorded, exceeding the value measured for native DNA. The data obtained allow us to conclude that under proton irradiation, clustered damage are formed in the DNA structure – slowly repairable or unrepairable sites, while under $\gamma$-irradiation, isolated DNA lesions appear, which can be quickly and efficiently repaired in the cell [2]. Thus, irradiation with high-energy protons has a greater lethal effect on the cell than $\gamma$-irradiation.

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# SIMULATION OF PROMPT GAMMA IMAGING IN HADRON THERAPY

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Hadron therapy is efficient method of cancer treatment due to phenomenon of the Bragg peak which cause precise localization of the dose absorbed by biological tissues [1, 2]. It improves quality of life of a patient minimizing action of therapeutic beam on healthy part of body. Transversal scattering of the beam is less than that for other kinds of radiotherapy.

Hadron therapy has some shortcomings. It is highly sensitive to unavoidable errors of preparing the treatment plan and its realization. Influence of some kinds of errors or uncertainties cannot be accounted in simulation or theoretic considerations. So experimental or “online” techniques are absolutely required to control the hadron therapy treatment process and especially stopping region of protons or carbon ions from the therapeutic beam [3]. Positron emission and computer tomography methods may be used to control the treatment process. Prompt Gamma Imaging (PGI) method is relatively new and perspective technique, which may be very efficient. Our study consider dependence of the beam parameter, Bragg peak localization and distribution parameters of secondary particles in the PGI method. Reference points of distribution are defined which may be used to define Bragg peak position. Proton and carbon ions have been considered. FLUKA and GEANT4 packages are used for simulation.

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# SIMULATIONS EXAMINE PERFORMANCE OF PURE BORON, BORON CARBIDE, HIGH-DENSITY CARBON AND BORON NITRIDE ABLATORS—THE MATERIAL

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The performance of pure boron, boron carbide, high-density carbon and boron nitride ablators—the material that surrounds a fusion fuel and couples with the laser or hohlraum radiation in an experiment—in the polar direct drive exploding pusher (PDXP) platform. The platform uses the polar direct drive configuration to drive high ion temperatures in a room-temperature capsule and has potential applications for plasma physics studies and as a neutron source. Our simulations predict that the platform is not amenable to the electron-ion coupling measurements due to a lack of implosion symmetry, these alternate materials do enable better coupling between the lasers and capsule, we can test those predicted impacts on future neutron source experiments.
Examining the improvement in coupling because it could help improve the yield of the polar direct drive neutron sources, and ultimately provide data on the validity of laser modeling for direct drive simulations. Inertial confinement fusion simulation code developers implement more advanced models for electron-ion coupling, and modeling the direct drive implosions have been closely coupled with that code development. One of the main goals has been to create ignition in deuterium-tritium plasma in the laboratory. The design of these experiments relies heavily on computer models that are based on an understanding and assumptions about the behavior of these hot plasmas. In these experiments, ions are heated more rapidly than the electrons via a very strong laser-generated shock. Intended to use time resolved spectroscopy, which is a measure of how much light is being emitted from the plasma at a specific frequency, in order to measure the temperatures of both the ions and the electrons as a function of time during the experiment. Electron-ion coupling is a parameter that describes how ions and electrons exchange energy in plasma. The PDXP platform was developed to study electron-ion equilibration but ended up being an ideal neutron source for several other campaigns. The great advantage of this platform is that it is simple —spherical shell filled with fuel—and allows multiple diagnostics from any ports to take data and produces high neutron yield. This research did a theoretical study of performance (neutron yield) versus composition of the shell materials and its thickness.Based on these models predicting a particularly useful improvement in performance, like higher yield, or the model predicting a large change in a measured quantity, like the trajectory of the imploding capsule or the temperature of the nuclear burn, we can execute to test if the calculation was indeed successful at predicting the change in performance.

## STRONTIUM ISOTOPE EVIDENCES

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Four outstanding multiple burials were discovered near Eulau, Germany. The 4,600-year-old graves contained groups of adults and children buried facing each other. Skeletal and artifactual evidence and the simultaneous interment of the individuals suggest the supposed families fell victim to a violent event. In a multidisciplinary approach, archaeological, anthropological, geochemical (radiogenic isotopes), and molecular genetics methods were applied to these unique burials. Using autosomal, mitochondrial, and Y-chromosomal markers, it was identified genetic kinship among the individuals. A direct child-parent relationship was detected in one burial, providing the oldest molecular genetic evidence of a nuclear family. Strontium isotope analyses point to different origins for males and children versus females. It tells insight into a Late Stone Age society, which appears to have been exogamous and patrilocal, and in which genetic kinship seems to be a focal point of social organization.
Cotton (Gossypium sp.), a plant of tropical and sub-tropical origin, appeared at several sites on the Arabian Peninsula at the end of the 1st mill. BCE -beginning of the 1st mill. CE. Its spread into this nonnative, arid environment is emblematic of the trade dynamics that took place at this pivotal point in human history. Due to its geographical location, the Arabian Peninsula is connected to both the Indian and African trading spheres, making it complex to reconstruct the trans-continental trajectories of plant diffusion into and across Arabia in Antiquity. Key questions remain pertaining to: provenance, i.e. are plant remains of local or imported origin and the precise timing of cotton arrival and spread. The ancient site of Mleiha, located in modern-day United Arab Emirates, is a rare and significant case where rich archaeobotanical remains dating to the Late Pre-Islamic period (2nd–3rd c. CE), including cotton seeds and fabrics, have been preserved in a burned-down fortified building. To better understand the initial trade & production of cotton in this region, strontium isotopes of leached, charred cotton remains are used as a powerful tracer and the results indicate that the earliest cotton finds did not originate from the Oman Peninsula, but were more likely sourced from further afield, with the north-western coast of India being an isotopically compatible provenance. Identifying the presence of such imported cotton textiles and seeds in southeastern Arabia is significant as it is representative of the early diffusion of the crop in the region, later to be grown extensively in local oases.