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A.N.Skrinsky

ACCELERATOR AND DETECTOR PROSPECTS OF ELEMENTARY PARTICLE PHYSICS

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INTRODUCTION

The progress in accelerator physics and techniques is one of the most important conditions for development in nuclear physics and physics of elementary particles. In the work presented here, the content of which corresponds in its major part to the report delivered at the XI International Conference on high energy physics /1/, I will try to consider briefly the shifts in the accelerator and, partly, in the field of instrumentation, which were most significant in facilitating the progress of elementary particle physics in recent years and will be in the near future.

First of all, let me make only two remarks general now both for the accelerators and detectors. The solution of problems of elementary particle physics, which become more and more complicated, forces to shift to a larger scale for all the systems, both for accelerators and detectors. This shift, in particular, becomes accessible because of a wide use of the module principle for construction of systems with maximum homogeneity of modules. This permits making systems significantly cheaper, prolonging their life time and reliability.

Of the same importance is the profound and versatile use of the stormy developing electronics and especially computers. In the modern systems of high energy physics the computer devices became as widely spread and necessary as magnets and counters. They serve the functions of continuous collecting the data on the installations and the processes, system control and data processing.

In section I, general questions are considered which connected with the most important physical and technical developments in the field of accelerators: exploration of the widely used method of colliding beams, development of the beam cooling techniques, preparation for the wide use of superconductive systems, the commencement of the superlinac developments.

In section II the most essential progressive changes are briefly reviewed occurring in the field of systems for detection of the final products of reactions under study and experimental data processing.

Section III is devoted to evaluation of modern possibilities for the high energy particle beam generation as the primarily accelerated and secondary particles; and an attempt is made to estimate the more distant prospects in this direction. Especial attention is paid to production of high quality beams--pure, ultimately intense, with the possibly lower emittance, desirably polarized.

In section IV the prospects are considered for creation of a system with colliding beams with possibly wide range of particles including those polarized and ultimately monochromatic. It is emphasized the possibility of achieving sufficient luminosity with participation of stable and unstable particles.

Sections V and VI are of especially certain character connected with the development of superlinacs which initiated by Prof. A.M.Budker and developing in INP (Novosibirsk) during the last decade.

In section V, the so-called proton klystron is described enabling to use the modern and future proton accelerators at ultimately high energies for generation of pure intense beams of particles with a total (and even higher) energy which generation has not yet visible in other ways. The purpose of this section is to stimulate the main proton centers to the development of the concrete projects.

Finally, in section VI, the project is described, which is under development at INP, of the installation with linear electron-positron colliding beams (VLEPP) which, if realized in the whole scale, will enable one to achieve the electron-positron interaction energy up to 1 TeV.

Note, that the presence of these two special sections in the paper has naturally led to expansion of the INP papers given in References.

I. Progress in Accelerator Physics and techniques

I. The greatest event in the area under consideration is the exploration of the colliding beam method (the summary of the development and its prospects are considered in /2/). Colliding beam experiments starting with electron-electron beams in Stanford and Novosibirsk, electron-positron in Novosibirsk, Orsay and Frascati and proton-proton at CERN became one of the main sources of fundamental information in elementary particle physics, and their significance will only increase in future. Below we shall have a special detailed discussion of colliding beams.

2. It is well-known how important for implementation of electron-positron colliding beams was the existence of radiation cooling for light particles even at low energies. Radiation cooling enabled one to stack intense positron beams, to compress transverse dimensions of e^+e^- colliding beams down to small sizes (to a few microns even now) and to maintain the beams compressed despite strong perturbations of particle motion caused by the field of encountered beam, and correspondingly to achieve high luminosity.

Cooling will be of the same fundamental importance also for implementation of the proton-antiproton colliding beam experiments, cooling of heavy particle beams became accessible after development of electron cooling in Novosibirsk /3,4/ and stochastic cooling at CERN /5/. These two methods complement each other substantially in their possibilities. Stochastic cooling is especially effective for beams of low density with large emittance (i.e. at small 6 - dimensional phase density). Electron cooling is the most effective particularly for getting low-temperature ("narrow") beams of heavy charged particles (protons, antiprotons, ions). It is not excluded that cooling with the circulating electron beam will turn out to be useful for suppressing the diffusional beam cross-section growing with time of proton-antiproton colliding beams at high energies. Let me note that at energies $\geqslant$ 10 TeV an important and positive role will be played by radiation cooling for increasing luminosity of proton-antiproton colliding beams.

The use of ionization cooling /4 b/ can open up very interesting possibilities in getting intense muon beams of high energy including implementation of muon colliding beams of sufficiently high luminosity (see below).

2.1. Continuous cooling of the particle beam in a storage ring gives an important possibility for carrying out experiments with superthin internal targets /6/ wherein diffusional growing of the beam size (because of multiple scattering on the target substance and due to fluctuations of ionization losses) is suppressed by intensive cooling. Thus, fine "spectrometric" experiments become possible with ultimate high luminosity which is only determined by the injector productivity and the cross-section for single-scattered particle loss on the target substance, that is impossible to achieve in the ordinary set-up of experiments. Experiments of this kind - electro-excitation of nuclei - for a few years are being performed on electron storage ring VEPP-2 /6/.

Another application of the superthin target mode of operation is generation of secondary beams with good tagging (of kind of the generated particle and its momentum) using registration of accompanying particles. Such a mode gives 100% duty cycle, the relative intensity of the secondary beam is determined by the ratio of the interaction cross-section in use and the total cross-section, beam emittance is only determined by properties of the process used for generation and by the size of the continuously cooled primary circulating beam at the interaction section; weakening the flux of secondary particles due to absorption in the target is naturally absent.

2.2. Similar set up of experiments with continuous cooling is reasonable even under conditions when the target cannot practically be made so dense that the life-time of a particle in the storage ring would be determined by the collision with target and not by residual gas in the vacuum chamber (another possible restriction for an intensity increase are the restrictions on the stored current value). Consequently in this case, though, the luminosity does not achieve its ultimate value but the great gain is conserved compared to the single pass of the beam through the same target and also there is a possibility to operate with a very stable beam of high quality.

Such a situation is characteristic for experiments with the polarized gas-targets which nowadays permit one to have even for hydrogen or deuterium up to 10^{12} atom/cm^2 only, which corresponds to average vacuum in a storage ring better than 10^{-9} Tor. Naturally, the most interesting work with a polarized target is in a storage ring with polarized beams.

Another interesting example of this kind can become the target of free neutrons which is especially promising for detailed study of $\bar{p}n$ interaction at low and medium energies /4/.

3. Nowadays we are at the stage when important improvements for accelerator field are under implementation.

First of all, a wide use of superconductivity has started. The use of superconducting magnetic system even now permits increasing the maximum guiding field from 20 kG to 45 kG (using Nb, Ti alloys) and correspondingly gaining energy for proton and antiproton beams (at a given scale of accelerator facility). There is a possibility to reach 100 kG in the near future (the use of Nb, Sn alloys). An important fact is the significant reduction in energy consumption, which is the gain being especially high for the storage ring mode of operation.

I would like to draw attention to the fact that at small fields up to 20 kG (with ferromagnetic formation of a magnetic field in the storage ring or slow accelerator) the use of superconducting coils permits construction of extremely miniature magnet systems (design works of the High Energy Laboratory, JINR, Dubna).

However, superconducting magnet systems should still demonstrate long operability with the intense beams which are planned for most projects; that longevity requires a special care.

The use of high magnetic guide field enables one to increase the energy of heavy particle beams, but this way is closed for electrons and positrons because of excessive increase of synchrotron radiation losses. However, the use of superconductive magnetic structures turns out to be efficient for reaching higher luminosity for electron-positron colliding beams at low and average energies /2/ and also for producing generating structures for various applications of synchrotron radiation.

The use of superconductive resonators in RF accelerating structures, which have already been used in RF separators for beams of secondary particles, will be essential for accelerator progress. Up to now it is not clear whether an increase of accelerating gradient of these systems higher than 5 or 10 MeV/m will be achieved, but, at any rate, such systems will permit increasing noticeably (by 1.5-2 times) the energy of cyclic electron-positron storage rings /7,8/.

4. A sharp increase in acceleration rate in linear accelerating structures (up to 100 MeV/m and maybe somewhat higher) one can achieve in a pulsed mode (with normal conductivity of resonators). Such accelerators could be called superlinacs. The problem of achieving an appropriate surface strength with respect to high voltage break-down as well as the problem of developing accelerating structures for relativistic particles with minimum overvoltage, one can consider as solved in principle /9, 10/. The basis of possible progress in this field is the development of pulsed short-wave generators of a fundamentally new level of pulsed power (order of gigawatt). Two directions in the development of "RF-pumping" systems seem to be most promising.

One of these directions is connected with the fast progress in the technology of high power pulsed relativistic electron beams /9/. Already now when solving the controlled fusion problems the pulsed power of electron beams of a few gigawatts is achieved for durations of the order of a microsecond, with transformation of a substantial part of the beam energy into the energy of the RF electromagnetic field. The present day task is to make these generators more efficient, more sensitive in control over the amplitude and phase and to develop them for the regime of comparatively high repetition rates.

Another direction /11/ is connected with the fact that modern big proton accelerators (not even mentioning future accelerators) have an energy stored in the beam of millions joules, good properties of high energy proton beams (small energy spread – only tens of MeV at an energy 500 GeV – and a small emittance) permit rather easily (with the help of a bending modulator) to cause the deep bunching along the beam with the required wave length of the order of one centimeter. With such an ultrarelativistic beam passing through the corresponding diaphragmed waveguide one can effectively transmit the energy of a proton beam in the electromagnetic field of this linear accelerating structure with an accelerating rate up to 100 GeV/km. Let us call such a mode of operation the proton klystron mode (see section V). By injecting ultrarelativistic particles to be accelerated after the exciting proton bunch one can obtain a wide range of particles of high energies.

In such a way it is possible to transfer nearly full energy of the basic proton accelerator to accelerating particles with the beam intensity up being of substantial part of the initial beam intensity. By lengthening accelerating structure and exciting consecutive sections with various proton superbunches one can proportionally raise an energy of accelerating particles with corresponding loss in their mean intensity.

II. Progress in Detector Field*

1. The progress in detector systems is very strongly connected to the permanent revolution in electronics. Namely the "electronics revolution" enables one to create modern fast track devices and to handle the large flows of information. The very rough upper estimation of information on an individual event in a big detector (10^7 resolvable elements of space x 10^2 resolvable time moments x 10^2 resolvable values of amplitudes = 10^{11} resolvable elements) shows that the number of elements is very large, so that computer image of an event is quite informative - or as it is said sometimes now - - is quite pictorial. As a rule, thousands of these events should be registered in a second i.e. the full information flows are very large.

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* References in this section are mainly made to the papers presented to the XX International Conference on High Energy Physics.

Therefore, development of everfaster processors is very important. Apparently the "Fast-bus system" developed at Brookhaven is the record one which provides the processing rate up to Gigabit per second /12/. But even this rate is insufficient for the purpose of processing the full information flow if the information considered as totally uncorrelated and of equal importance.

The separation of taking and processing information is of great significance, as well as the use for this purpose of the more perfect programmable microprocessors, that enables to record and further to use for analysis only potentially interesting information. There could be several levels of decision on the further more detailed recording and processing the information and even several levels of triggering of the detector devices.

2. The detector systems used now happen to be huge in their size. Especially large are neutrino detectors /13/ and the multikiloton detectors for the study of proton stability /14/.

But of extreme importance is also the line of the microdetectors development when for achieving necessary information the ultimately high spatial, time and amplitude resolutions are used (either one kind or combined). The International Symposium in Italy (September, 1980) was specially devoted to microdetectors.

3. Let us consider now the progress and prospects in some certain detecting techniques.

The discharge track devices are improving. Revolution in electronics enables one to use the finer properties of electric discharge in various media. Already now the spatial resolution in a liquid-argon chamber is $\sigma_x = 8\ \mu m$ /15/, in a gas chamber - 20 μm /16/ and the time resolution achieved $\sigma_t = 20$ pikoseconds /17/.

One can confidently predict that further improvement and miniaturization of electronic components (as well as their lower cost) and, may be, the use of integrated sensitive and electronics processing components will further facilitate the progress in track detectors.

4. It is quite promising the direction of "active targets" with a fast (electronic) information reading which is direct outgrowth of the bubble chambers and high pressure gas chambers /18/. One of the versions of such a target is a set of fine semiconductor counters /19/ with a longitudinal resolution 10 μm, designed, in particular, for measuring the life-time of D-mesons generated in the substance of the target itself. Possibilities of this device are expanded especially with the add of the transverse resolution for each counter (the prototype of the device is already manufactured providing transverse resolution $\sigma_x = 10\ \mu m$).

But with the use of technological means of modern microelectronics - thin silicon plates production, ion implantation, molecular epitaxy, laser and in not too distant future X - ray lithography with the use of synchrotron radiation of electron storage rings, the use of integrated circuits in production of the whole channel with up to transport of information into processor - the prospects open up for the real revolution in the whole this field.

The latter note is valid also for the system of information read-out, optical, in particular, for the detectors of any kind.

5. Quite interesting possibilities appear when using the thin-wire scintillation hodoscopes /20/. Good results obtained for information read-out when using the avalanche photodiodes and microchannel electron multipliers. It looks realistic today to have hodoscopes with the spatial resolution up to 100 μm, the length along filaments of 1 m and event rate up to 10^7 Hz.

6. Interesting prospects open up for small bubble chambers at operation with very small bubbles /21/ - the resolution already achieved is of 10 μm. Especially attractive in this case is the use of holographic information taking which enables one (maintaining the same resolution) to increase sharply the image optical depth (a 10 cm image depth is already achieved). The main efforts in this case are put on the further information processing. Note, as the studies of Nuclear Physics Institute (Leningrad) has shown, the holographic way

of information reading is apparently feasible for streamer chambers. Actually, for holographical detection in the real detectors it is reasonable to tend for using the filmless way of taking information, i.e. microchannel multiplying plates, the large area semiconductor counters with the necessary spatial resolution and perhaps some other techniques.

7. Note, the hybrid emulsion and rapid-cycle bubble chambers with the counter aiming the interesting events and adding high time resolution are still of interest, especially for operation with very high multiplicities and complex unknown events.

In particular, the hybrid bubble chambers can be adequate to the work with linear electron-positron colliding beams at super high energies /9/ when at an average repetition rate of tens Hz the luminosity at a single interaction should be very high.

8. In conclusion of the detector section let me note the quite extensively developing methods of direct measurements (or at least estimates) of relativistic γ-factors of particles under study. With the energy growth this problem becomes more and more complicated and important. Among these methods I would mark the gas Čerenkov counters (especially those with measurements of Čerenkov radiation image ring/29/), detectors of transition radiation /23/, the use of relativistic dependence of ionization loss (at high energies in gases), radiation at channeling in monocrystals, which is most successfully applicable for positive particles, and the synchrotron radiation. For various cases the optimal methods can be different and sometimes optimal may be their combination. Some methods, for instance, channeling radiation, is mostly applicable for tagging the secondary particles falling down the target when directions of their motion are sufficiently collinear.

III. Generation Possibilities of Elementary Particle Beams

Let us consider now the possibilities for generation high quality beams of a possibly wide set of particles both the primarily accelerated and secondary. The progress in this direction determines to a significant extent the development of elementary particle physics.

Among the characteristics of beams significant from the point of view of elementary particle physics, energy and intensity have obvious importance. An increase in the energy of projectile particles leads to an increase in reaction energy for fundamental processes under study. In ultrarelativistic case this energy increases as $\sqrt{E}$ in the experiments with stationary target and as E in colliding beams. An increase in intensity makes possible both the observation of more rare processes and higher accuracy of experimental data, which frequently supplies qualitatively new information of fundamental importance. As a bright illustration of the latter may serve the discovery in laser experiments of the parity violation in atomic transitions and, consequently, the discovery of electron-nucleon weak interaction due to neutral currents /24/.

In addition to an energy and intensity, the following qualities of beams are of a very great importance: smallness of their emittance, monochromaticity and optimum of their time structure. The smallness of emittance permits minimizing the transversal size of interaction region between particles of a beam and the substance of the target, which improves, say, momentum analysis of reaction product. Concerning the time structure of the beams it's worth mentioning that sometimes it's beneficial to have the shortest intense bunches separated by long particle free periods for helping to avoid, for example, homogeneous cosmic background, for the use of primarily triggered detectors like bubble chambers, and for separation over the velocities; in other cases it is beneficial to have the beams, continuously distributed in time, loading optimally the detecting electronics and getting the possibility to "tag" each interesting particle by the products accompanying its production.

In recent years, obtaining polarized beams has become more and more important. The opinion accepted earlier that spin effects, for strong interactions at any rate, become weaker and weaker at higher energy turned out to be absolutely incorrect. More than that, one can say that it is impossible to develop the quantitative theory of elementary particles without experimental study of the spin properties.

Let us consider now, very schematically, the possibilities of generation of the beams of all known stable enough particles. The secondary beam generation is often the multi-step and complex process. And at many stages the use of super-thin target mode with a suitable cooling could be effective.

1. Protons. The proton accelerators continue to grow in energy and intensity being the basis for the great class of experiments including colliding beam experiments.

Already now the energies up to 500 GeV accessible; too distant future the DOUBLER at I TeV will be put into operation in not; the UNK project at 3 TeV /25/ is under way. The subject of consideration of ICFA (International Committee of Future Accelerators), 1979 was an accelerator at energy 20 TeV.

Modern intensity of proton beams of the highest energy is 10^{13} p/sec; further increase of their intensity is connected with a solution of a problem of further sharp improvement in the "beam hygiene", which is of particular importance for accelerators using superconductivity, that is used in every project for proton accelerators at super high energy. The use of superlinacs with the proton klystrons opens up interesting possibilities for getting protons of higher energies using existing and future facilities.

The record intensities for medium energies belong to meson factories (up to 10^{16} p/sec). Further increase in intensity will be in progress with the growth in power of RF generators and solution of radiation problems.

In the field of lower energies the electrostatic tandem generators are distinguished for the excellent beam properties. However, many corresponding experiments, e.g. spectrometric ones appear to be feasible (and without sharp energy limit) with the help of the proton storage rings with electron cooling in the super-thin target operation mode /4/.

Obtaining polarized proton beams is connected with the design of sufficiently enough intense sources of polarized protons and, in the case of cyclic accelerators at high energies, with overcoming the depolarizing effects of spin resonances. The experience of Argonne laboratory has shown experimentally the possibility (and high usefulness) of acceleration of polarized protons up to rather high energies.

New possibilities are already seen now for filling cyclic proton accelerators with polarized particles up to the total intensity of the given accelerator. The main way is the use of the proton polarized H^--beams, which may have nearly the same intensity as that of polarized H^+-beams, and the use of charge exchange injection into the accelerator, that enables one to increase by several orders of magnitude the current circulating in the accelerator compared to the current of the H^--source /26/. Additional increase in injection multiplicity and improvement in the stored beam emittance one can achieve by introducing electron cooling during the injection process. Only for meson factories are there yet no possibilities for the intensity of polarized proton beams to approach the intensities of ordinary beams.

Acceleration up to very high energies in cyclic accelerators is accompanied by numerous spin resonances. This question was thoroughly studied theoretically and ways were found for overcoming the determinal effect of resonances, including producing magnetic structures which eliminate these resonances completely /27/.

The problem of producing polarized protons of high energies after initial charge-exchange stacking in a booster is especially simplified with use of superlinacs, in particular, with the use of proton klystrons /11/.

Since presently there are no pure polarized targets of condensed substance, an especially important role could be played by the experiments in storage rings with an internal totally polarized gas target which enables one to operate with nearly pure initial spin states. One should pay attention that even longitudinal polarization of a coasting beam near the target can be made stable /28/ for achieving initial states with the given helicities.

2. Nuclei. "Relativistic nuclear physics"/29/ turned out to be more interesting than it was expected earlier ("porridge on porridge"). Such experiments give both ideas on supercompressed nuclear substance and supply data on fundamental interactions (study of "cumulative" inclusive processes). Already nowadays accelerated uranium nuclei are obtained with energy up to 10 MeV/nucleon and 10^9 U/s and nuclei to carbon with 5 GeV/nucleon energy and up to 10^7 C/s intensity (the latter is in the High Energy Physics Laboratory, JINS, Dubna). An implementation of projects is under way which sharply raise the ceiling of available energies and intensities. In some cases coherent methods of acceleration could be used, including "smokotron" devices.

This table represents the expected maximum parameters (energy and intensity) of the nuclear beams for one of the biggest projects VENUS (Berkeley):

Table 1.	1 GeV/nucleon	20 GeV/nucleon
Ne	$0.8 \cdot 10^{12}$	$1.2 \cdot 10^{11}$
Kr	$2 \cdot 10^{11}$	$3 \cdot 10^{10}$
U	$0.7 \cdot 10^{11}$	$1 \cdot 10^{10}$

This project also envisages an operation in colliding beam mode.

Obtaining beams of polarized deuterons of high energies is even simpler than in the case of protons (because of smallness of the deuteron anomalous magnetic moment).

Note, that **with** the necessity of stacking beams of heavy ions and especially of conserving them compressed for a long time, the most reasonable is the use of cooling by proton beam which, in its turn, is cooled by electron beam ("proton cooling" /4/.

3. Neutrons. Neutron fluxes with an energy up to tens of MeV are produced mainly with nuclear reactors (including pulsed reactors) and with deuteron and proton accelerators. For monochromatization of reaction energy the velocity separators and the time-of-flight techniques of detection are used.

I cannot help but drawing attention to the fact that it is a very attractive possibility for the energy range from tens eV to hundreds keV to use very powerful and highly collimated synchrotron radiation from electron storage rings at an energy $\geqslant$ 10 GeV (with the quantum energy above 1.6 MeV) irradiating a beryllium target. Small transverse dimensions of the effective neutron source (achievable dimensions are down to 10 μm x1 mm), short pulse (fractions of nanosecond) and a very low duty factor ($\geqslant 10^{-5}$) at high average intensity (up to 10^{14} n/s) provide by many orders of magnitude better conditions for the study of neutron reactions using the time-of-flight technique. In the lower part of the mentioned energy range the small transverse dimensions of the source make very effective the use of Bragg's monochromatization with the use of bent crystals, and also make effective obtaining polarized neutrons with the help of magnetized mirrors.

At higher energies an interesting pulsed source of neutrons can be obtained at meson factories with the use of charge-exchange ($H^- \to H^+$, $D^- \to D^+$) stacking of accelerated protons or deuterons in a cyclic storage ring, and using their possibly fast drop onto the target.

At energies $\geqslant$ 100 MeV an optimum way for obtaining quite monochromatic and well directed neutrons is the use of the decay reaction for accelerated deuterons with required energy pe nucleon. In the superthin target mode an intensity for well collimated and quite monochromatic neutron flux can be achieved close to that for the deuterons and also good tagging with the remaining proton of the same energy. The use of polarized deuterons enables one to have neutrons with a good degree of polarization.

The use of charge-exchange reaction $pZ \to n(Z+1)$ permits doubling energy for neutrons obtained at a given cyclic accelerator but the beam quality in this case is worse. The cross-section of elastic charge-exchange falls down rapidly with proton energy growth ($\sigma_{ex} \approx 2 E_{GeV}^{-2}$ mb, $\sigma_{ex}/\sigma_{tot} \approx 0.04 E_{GeV}^{-2}$) and at energies higher than tens of GeV one has to use the reaction $pp \to n\pi^+p$ with the useful cross-section of 0.2 mb having with proton accelerators up to 0.5% efficiency of transforming of protons to neutrons.

4. Antiprotons. Development of electron and stochastic cooling techniques gives the possibility of obtaining the high intensity, absolutely pure, monochromatic and small-emittance antiproton beams. The first projects of antiproton storage rings under implementation and under preparation /30-34/ will give $(1\div5)\cdot10^7$ $\bar{p}$/s. In the first experiments at CERN the sufficient stacking rate is achieved /31/. Nowdays the ways are visible for an increase in efficiency up to 10^9 $\bar{p}$/s /4,33,34/.

The stacking will be performed at an energy $0.5\div5$ GeV. The antiprotons can be decelerated to very low energies and accelerated up to highest energies available for proton accelerators /4,35/ (or even higher when using proton klystrons). Of special interest are the studies with antiprotons at low energies with continuous electron cooling in obtaining intense and long-life protonium fluxes - $p\bar{p}$-electromagnetically-bound states/4,35/.

When using (continuously cooled with electrons) antiproton beams, which interact with a longitudinally polarized hydrogen gas target at the storage ring section with stable longitudinal polarization of the circulating beam, one can achieve polarized antiproton beams with intensity up to 10% of the intensity of the initial antiprotons /4/ with their subsequent acceleration (or deceleration) up (or down) to the energy required.

5. Antideuterons. With the same storage rings being designed for obtaining antiprotons one can get absolutely pure beams of antideuterons with intensity only by 3-4 orders of magnitude lower than that for antiprotons /4/. At these low intensities the use of stochastic cooling in the stacking system becomes optimal enabling to cool beams with a large energy spread and emittance just at an energy of the deuteron production. Such beams can turn out to be interesting for the study of nuclear states consisting of nucleons and two antinucleons.

6. Antineutrons. At energies up to tens of GeV the most profitable is to obtain antineutrons due to elastic charge-exchange reaction $\bar{p}p \rightarrow \bar{n}n$ (the cross-section at high energies is about $\sigma_{ex} = 15/E^{-2}_{GeV}\ mb$) with tagging, if possible, by the remaining neutron of low energy. The intensity of antineutrons will be up to $\sigma_{ex}/\sigma_{tot} \approx E^{-2}_{GeV}$ of the system efficiency for antiprotons. The use of polarized antiprotons will apparently enable obtaining the beams of polarized antineutrons with an intensity one more order of magnitude lower additionally (because of losses during antiproton polarization).

At still higher energies one has to get antineutrons in the reaction $\bar{p}p \rightarrow \bar{n}\pi^-p$ with cross-section of fractions of mb having worsened quality of the resulting beam (even with tagging). The antineutron intensity can reach a fraction of a percent of the antiproton intensity.

The antineutron beam of an excellent quality, intensity up to 10^{-3} that of the antiprotons and with ideal tagging by the remaining $\bar{p}$ can be obtained by the decay of the stored and accelerated antideuterons.

7. Pions. The generation of charged pion beams is the most explored field among the secondary particle beams production at high energies. Here, I would like to draw attention only to the tempting prospects for obtaining pure, rather monochromatic and well-collimated pion beams by their acceleration in superlinacs with acceleration rate higher than $2m_\pi c/\tau_\pi = 0.4\ MeV/cm$; in this case, the most natural is the use of a proton klystron /11/. When using optimal conversion systems, for each ten protons with energy $\geqslant$ 100 GeV we can have one positive and one negative pions with an energy of a few GeV which are fit for further acceleration. In order to decrease the number of muons accompanying the beam of accelerated pions one should tend maximum acceleration rate.

Let me note here that at energies above hundreds GeV the number of events with full cross-section induced by neutral pions in a condensed target becomes substantial. So, at initial proton energy of 1 TeV with intensity 10^{13} p/s more than 10^5 events will be caused by neutral pions having average flight length of 20 μm. But, of course, the problem of identification of these events is extremely difficult.

8. Kaons. Unfortunately, for acceleration of charged kaons the accelerating gradients higher than 3 MeV/cm are requi-

red; that is still out of reality. There is some hope to achieve such gradients using special modification of a proton klystron where all the protons should be compressed into one (or several, with long distances in-between) bunch about 1 cm long and injected into a special linear wave-guide structure /36/ (see section V). In this case, inside the bunch a very strong longitudinal electric field shall appear, decelerating the protons of the bunch. Consequently, negative particles traveling with protons together inside the bunch shall be accelerated. So, the scheme gives possibility, in very principle, to accelerate K^-. Neutral kaons , if necessary, could be produced using charge exchange or charge loss reaction of accelerated K^- with a target. The development and design of enough damage-resistant systems of such kind is, of course, a task for future.

But present day an optimum method for setting up kaon-beams production at high energies may turn out to be the use of the thin target mode (and at energies and intensities enabling effective cooling - the superthin target mode) at proton storage ring with the best available tagging (correspondingly with very complicated trigger). Since the total cross-section for generation of every kind of kaons in p-p reactions is large (fractions of mb), there are many kaons generated on this target. Naturally, for making more pure experiment one will have to use the whole set of the charge, momentum, velocity and gamma-factor selection techniques, and, while recording products of KN reaction, one should most carefully take into account the quantum numbers of particles produced.

9. Hyperons. A new circumstance at superhigh energies is the long life-time for hyperons. Even at 100 GeV the long-lived hyperons live for tens of meters distances. Nevertheless, for separation of initial beam from the beam of produced negative and neutral hyperons (or positive of significantly deviated momentum) one should use strong magnetic fields, but this problem becomes easier linearly with energy growth. All the rest said on carrying out experiments with kaons remains valid even in this case (inclusive cross-sections, in particular, are of the same order).

10. Antihyperons. At not very high energies (rather to hundreds of GeV) the use of elastic charge-exchange reactions $\bar{p}p \to \bar{Y} Y$ ($\sigma_{ex} / \sigma_{tot} \approx 10^{-2}/E^2_{GeV}$) with tagging using by-product hyperons (being nearly at rest) in the (super) thin target mode in antiproton storage ring seems to be the optimum for obtaining antihyperon beams. Apparently, antihyperons produced in such a process by polarized antiprotons will preserve a noticeable polarization level.

At higher energies one will have to proceed in the same way as in the case of hyperons; the inclusive cross-section for antihyperons production in pp collisions is only one order of magnitude lower than that for hyperons.

11. Electrons. Electron accelerators and storage rings play a very essential role both in experiments on elementary particle physics and in various applications (in particular, for generation of synchrotron radiation).

The record in electron accelerators belongs to SLAC; the available energy there is in excess of 30 GeV and in the near future will attain 50 GeV at intensity up to 10^{14} e^-/s. Both electrons and positrons of higher energies are obtained presently on proton accelerators due to the process $pZ \to \pi^0 X; \pi^0 \to 2\gamma;$ $\gamma Z \to e^+e^- Z$. Nowadays it is possible to obtain electron beams of quite good quality with energy up to 300 GeV at intensity up to 10^8 $e^\pm/s$ (separation with synchrotron radiation, for example, /37/).

A sharp increase in intensity (up to 10^{13} $e^\pm/s$) of electron beams with energy of hundreds GeV will be feasible after construction superlinacs for linear electron-positron colliding beams (see 9.3).

Intensities of polarized electron beams have reached 10^{11} e^-/s at SLAC. Intense polarized circulating beams are obtained due to radiative polarization in storage rings /38-42/. Using intense circularly-polarized radiation (e.g. laser beam) travelling against electron beam it is possible to achieve much higher polarization rate of circulating electrons (and positrons) /43,44/.

At energies above 100 GeV with the use of a single pass through magnetic fields of hundreds kG one can get satisfactory level of polarization $e^\pm$ by using synchrotron radiation dependence on the spin orientation of irradiating particles with respect to magnetic field /45/.

12. Positrons. In the energy range of electron accelerators the presently available intensity of positron beams of about full energy achieves 1% intensity of electron intensity at worse quality of the beam. The use of intermediate storage rings with radiation cooling can essentially improve the quality of positron beams and increase their intensity.

Producing beams of polarized positrons in experiments still was necessarily connected with radiative polarization in storage rings.

At energies higher than 100 GeV, as mentioned above, possibilities for positron beams, including polarized beams, are the same as those for electrons.

13. Photons. Intensities and energies of beams of γ-quanta obtained as bremsstrahlung at electron accelerators and also as a result of decay of neutral pions at proton ones are quite high. However, an important problem is beam separation and energy tagging for quanta hitting the targets. The latter is especially complicated for proton accelerators, and even so complicated that first of all one has to obtain $e^\pm$ beams of known energy and only after that following the ordinary procedure of measuring the energy of remaining $e^\pm$ an energy of the bremsstrahlung quantum can be tagged. The same technique of tagging energies of photons obtained on internal (superthin) targets is also convenient for obtaining intense fluxes of gamma-quanta in electron storage rings.

Interesting prospects in obtaining intense, monochromatic and, at the same time, appropriately polarized beams of gamma-quanta of high energies is an inverse Compton-effect on electrons travelling in cyclic storage rings at high energies.

For obtaining such quanta with energy E one should have electrons with energy E and polarized photons with energy higher than $(m_e c^2)^2/E$. Under these conditions, zero-angle scattered photons will have full energy E (almost independently on the initial photon energy). At the scattering angles larger than $m_e c^2/E$ the photon energy will be much lower. So, for effective monochromatization of quanta flux one needs to find out their propagation direction to interaction points with a target, and electron beam should have as small angular spread as possible. In addition, it is useful to use tagging the quantum energy by measuring energy of electron remained after photon scattering.

Inside an angle $m_e c^2/E$ photons will have an energy E with a spread $\Delta E/E = \frac{(mc^2)^2}{E\,E_\gamma}$, where E_γ is an energy of initial photons. In this angle the fraction of the full flux of scattered photons of the order $(\ln \frac{E}{\Delta E})$ is concentrated.

At energies up to 50 GeV, as primary photons, it is reasonable to employ synchrotron radiation from the special irradiator-undulators. In this case, one should ensure the electron interactions only with photons moving inside an angle $1/\gamma$ (γ is relativistic factor of electrons irradiating in undulator). Irradiating particles can travel either in the same storage ring (e^+e^- colliding beams) or in a special storage ring at a substantially lower energy.

Some interesting possibilities can arise when using radiation scattering of mirrorless short-wave lasers based on powerfull electron beams /46/. At energies higher than 50 GeV one can use photons of short-wave lasers of usual type.

An intensity of such beams of gamma-quanta corresponds to energy transfer of all stored electrons to these quanta with the life-time due to this process of thousands seconds (up to $10^8 \gamma$/s) with the use of synchrotron radiation as a primary one. With appropriate lasers available the intensity of high energy γ-quanta can be sharply increased.

Especially intense fluxes of γ-quanta can be produced at installations of VLEPP-type (see sect. VI).

For quanta of low energies (up to a few MeV; in future - up to 20 MeV) the installations record in intensity (and especially in brightness) are electron storage rings at high energies 10-100 GeV (see also /47/).

At energies of tens and hundreds of MeV some interesting prospects open up when using radiation at electron channeled motion in monocrystals /48,49/. Intensities of such well collimated beams can be of ten times higher than bremsstrahlung radiation of electron beams at the same part of spectrum.

14. Muons. In order to have very pure, high energy and most intense muon beams with a very small emittance and good monochromaticity it is reasonable to proceed as follows /50,11,4,5/:

a) to produce as many as possible pions with energy of 1 GeV on the target, with strong focusing, in nuclear cascade using the proton beams of energy $\gtrsim$ 100 GeV;

b) to let pions decay in the possibly stronger focusing channel;

c) to cool muons (with ionization cooling) in a special ring with targets placed at the sections with a very strong focusing;

d) to accelerate muons up to required energy in the short-pulse cyclic accelerator or (better) in a superlinac.

The intensity of the muon beam can reach up to 10% of the intensity of the basic proton synchrotron (with use of the proton klystron mode).

In order to get polarized muon beams of high energy it seems to be most reasonable to use monochromatic pion beams accelerated in a superlinac by injecting them into a special ring with strong magnetic field (pulsed or superconducting). The structure of the ring should be designed in the way to have dynamically stable longitudinal polarization /28/ of circulating muons (at injection energy, at any rate) equal in both long straight sections, which occupy, say, $^3/4$ of the circumference of the ring). The muons produced in the forward hemisphere in pion rest frame will have momentum quite close to the pion momentum and nearly equal laboratory helicity; muons of inverse helicity (moving backward in rest frame of the pions) deviate strongly over the momentum and can easily be removed from the ring. Polarization of the produced muon beams can be quite high (approaching the ratio of straight sections length to the circumference).

15. Neutrinos. The beams of muon neutrinos of high energies, well-directed and of useful intensity of a few percent of the intensity of the basic proton synchrotron, can be obtained with beams of accelerated pions. In order to decrease the neutrino beam diameter near the detecting facilities, which are located behind shielding of required thickness, it is profitable to perform the pion decay in a special storage ring with relatively long straight sections.

Both muon and electron neutrinos of the same intensity can be obtained in the track of this kind by injecting into the track the accelerated cooled muons. The properties of neutrino beams in this case could be much better than in the usual $K^{\pm}$ - decay approach.

Thus, a combination: "superlinac - special race-track" can be a multipurpose installation.

As to the beams of ν_τ - neutrinos connected with a heavy lepton, it might turn out that their main source will be decay of τ - leptons from $\tau^{\pm}$ - pairs produced by γ - quanta on the target nuclei /51/. γ - quanta can be obtained both with the help of proton and electron beams of high energy. More specifically one can evaluate the flux of τ - neutrinos from electrons. In a thick target the number of produced pairs will be of about $(m_e/m_\tau)^2 = 10^{-7}$ with respect to the number of incident electrons. Since at sufficiently high energy the nuclei form-factor does not influence on cross-section of τ -pairs generation (see section VI.9).

Quality of neutrino beam produced by protons will hardly be higher.

It is not excluded, that in a 100% duty cycle mode it would be possible to design the trigger system on τ - lepton and similar events production, for facilitating selection of events caused by ν_τ in neutrino target.

IV. Colliding Beams

Colliding beam experiments became the main supplier of fundamental data in physics of elementary particles. Many electron-positron storage rings are in operation now (see

Table 2 and Figure 1). Certainly, the colliding beams experiments are essentially needed at the highest energies.

1. However, the e^+e^- colliding beams shall necessarily be developed and advanced not only at the highest energies. In particular, this necessity is connected with the fact, the detailed study of quark-gluon systems in the field of low and intermediate energies is of primary importance at present since it permits quantitative study of quantum chromodynamic effects, in particular, connected with the asymptotic freedom to confinement transition. Such studies are especially suitable for electron-positron colliding beams, but to this end a sharp increase in luminosity of installations is required. The possibility and usefulness of this were proved by experience of VEPP-2M designed specifically for increased luminosity and, correspondingly, yielding increased accuracy of experimental data in the energy range up to $\sqrt{S}$ = 1.5 GeV. Even now the possibilities are seen for making installations with luminosity up to 10^{33} $cm^{-2}s^{-1}$ at full energy of 4-5 GeV.

Other directions in improvement of electron-positron installations also promise to give important results. The possibility to work with polarized beams is very useful. In addition to sharp increase in absolute accuracy of measurements of produced particle masses /52,53/ (see Table 3), even the experiments with transversely polarized colliding beams help in understanding the spins of produced final and intermediate states. Implementation of experiments with longitudinally polarized beams permits obtaining qualitatively new information on the spin dependence of strong interactions, and to study weak interactions, for instance, of b-quarks in the region of Υ-mesons and decay properties of heavy leptons. Note that in many cases it is enough to have at the interaction point only one beam polarized longitudinally.

The possible sharp increase (higher than one order of magnitude) in monochromaticity of electron-positron reactions opens up interesting possibilities /54/. So, one can proportionally raise the fraction of resonance reactions, that is of special importance for Υ-mesons, and to study the inner structure of Ψ-mesons (even for the purpose of proving that

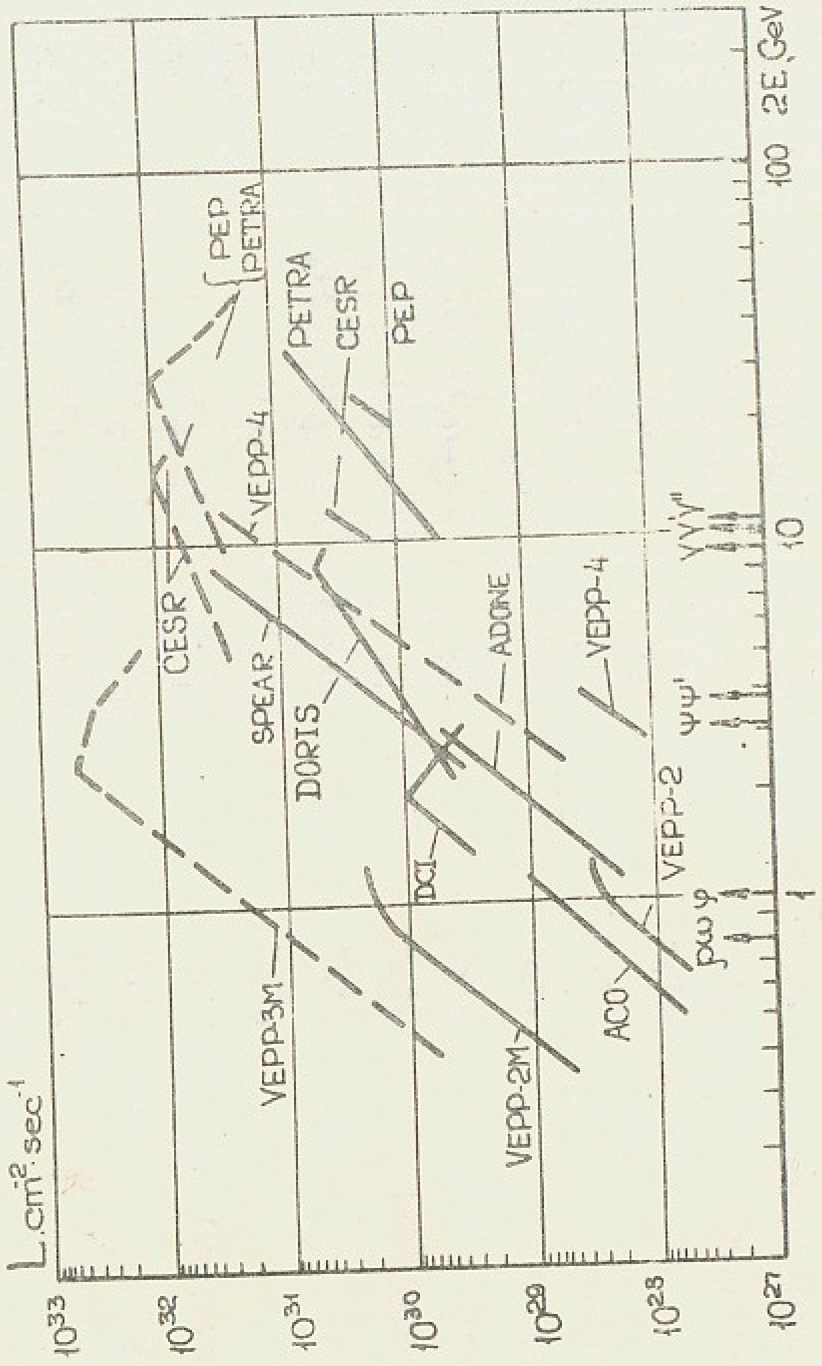

Fig. 1. Achieved (solid line) and design (dashed line) luminosity for e^+e^- storage rings.

Table 2

Storage ring laboratory	Particles	(GeV)	Lmax($cm^{-2}sec^{-1}$)	Start	
VEP-1 (Novosibirsk)	e^-e^-	0,32	$5\cdot10^{27}$	1965	Stopped
Stanford storage rings	e^-e^-	1	$2\cdot10^{28}$	1965	Stopped
VEPP-2 (Novosibirsk)	e^+e^-	1,4	$3\cdot10^{28}$	1966	Stopped
ACO (ORSAY)	e^+e^-	1,1	$1\cdot10^{29}$	1967	Stopped
ADONE (Frascati)	e^+e^-	3	$6\cdot10^{29}$	1970	
CEA (Cambridge)	e^+e^-	4	$3\cdot10^{28}$	1971	Stopped
SPEAR (Stanford)	e^+e^-	8,2	$2\cdot10^{31}$	1972	
VEPP-2M (Novosibirsk)	e^+e^-	1,4	$5\cdot10^{30}$	1974	
DORIS (Hamburg)	e^+e^-	10(11)	$1\cdot10^{30}(10^{31})$	1974	
DCI (ORSAY)	e^+e^-	4	$1\cdot10^{30}$	1976	
VEPP-4 (Novosibirsk)	e^+e^-	11	$1\cdot10^{30}$	1979	
PETRA (Hamburg)	e^+e^-	38	$2\cdot10^{31}(10^{32})$	1979	
CESR (Cornell)	e^+e^-	11(16)	$2\cdot10^{30}(10^{32})$	1979	
PEP (Stanford)	e^+e^-	30(36)	$0.7\cdot10^{31}(10^{32})$	1980	

Table 3

Particle	Mass, MeV	
	High Precision Measurement*	Old World Average
$K^\pm$ K^o	493.670±0.029	493.668±0.018
Φ	1019.54±0.12 1019.52±0.13	1019.62±0.24
Ψ	3096.93±0.09	3097.1±0.9
Ψ'	3686.00±0.10	3685.3±1.2

* High precision measurements have been performed at VEPP-2M and VEPP-4 using the resonance depolarization method of the absolute energy calibration.

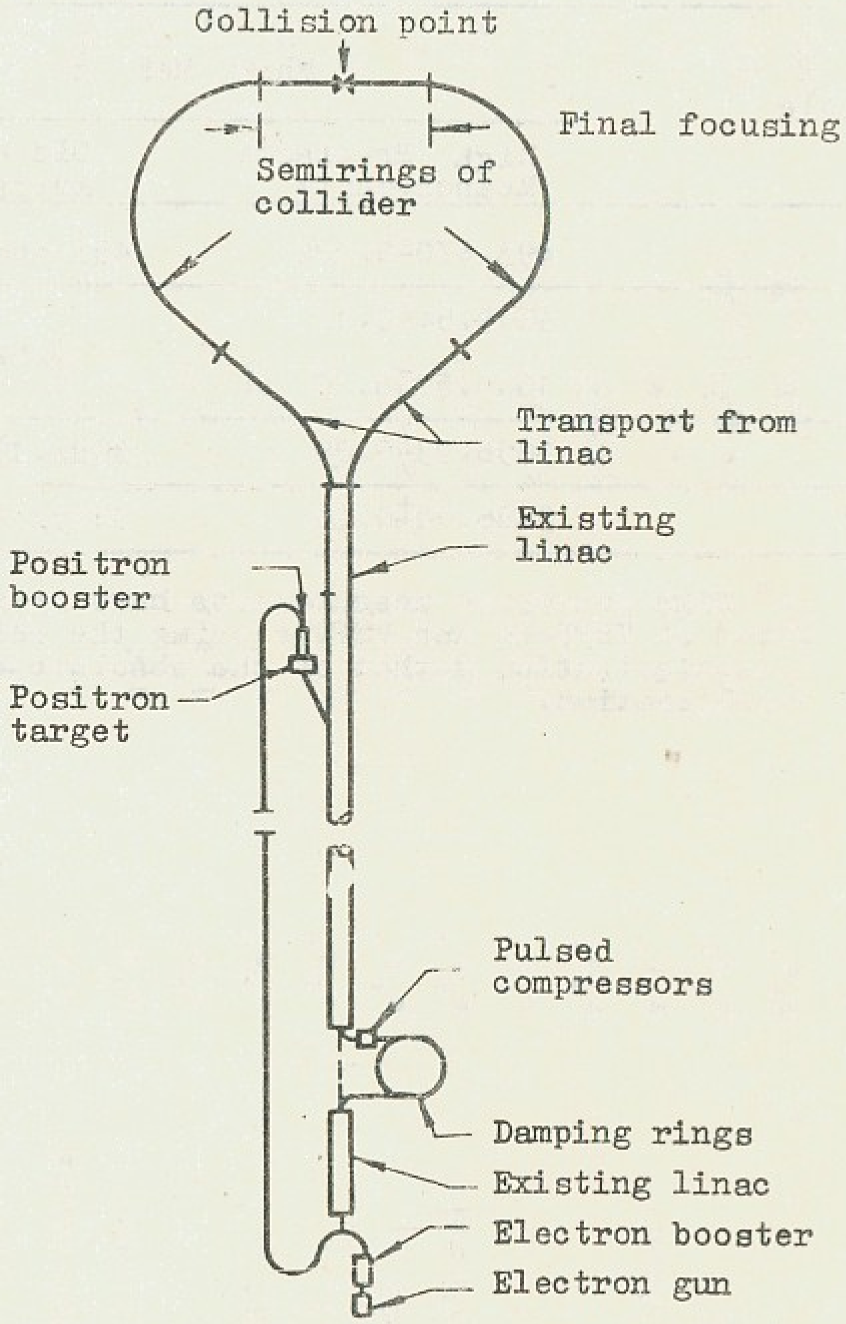

Fig. 2. General layout of the SLAC Linear Collider.

it does not exist). Note, that even higher monochromaticity can be achieved with $p\bar{p}$ - colliding beams under continuous electron cooling /4/.

2. But the main trend in the field of electron-positron colliding beams remains the tendency to higher energies, which is a task of fundamental importance.

Already now the total energies up to $\sqrt{S}$ = 40 GeV become accessible (PETRA, PEP). An intensive development of the LEP project is under way (first stage-up to $\sqrt{S}$ = 100 GeV, second - - up to 250 GeV), the project of the new storage ring at Cornell and also the HERA project enables, in principle, obtaining e^+e^- energies up to 100 GeV (see Table 4). Note, that at these high energies in cyclic storage rings (despite the overlapping of spin resonances) implementation of e^+e^- polarized colliding beams is feasible /55/. The new and interesting is the SLC project of quasilinear single-pass e^+e^- colliding beams at SLAC /56/ (Fig. 2) at an energy up to $\sqrt{S}$ = 100 - 140 GeV.

Further increase in energy of electron-positron colliding beams in cyclic storage rings (now conventional) is almost unrealistic because of the catastrophic rise in energy loss by synchrotron radiation that forces enlarge the installation both in dimensions and power consumption as the square of energy. Therefore, the main direction in development becomes linear colliding beams /9/.

In the plans for linear colliders at super high energies even from the initial stage the possibilities are considered of using long superconducting structures with recuperation of accelerated particle energy and of using pulsed superlinacs /57/. Several projects of linear e^+e^- superconducting colliders are being developed now - Cornell, CERN, Hamburg /58-60/. The collider project VLEPP based on superlinacs is being developed in Novosibirsk /9,10,61,62/ (see section VI).

3. The first proton colliding beam facility (ISR) has been operating at CERN since 1971. Its maximum energy is 2x33 GeV, the maximum number of stored particles is up to 10^{14} in each beam, ultimate luminosity is $0.7\cdot10^{32}cm^{-2}s^{-1}$. During this period a number of various experiments have been conducted which

Table 4

Project/ Laboratory	Particles	$\sqrt{S}$ (GeV)	L($cm^{-2}s^{-1}$)	Start
LEP (CERN)	e^+e^-	Ist 100 IIst 250	10^{32}	1986(?)
New Cornell Ring	e^+e^-	100	$3\cdot10^{31}$	1986(?)
Stanford Single-pass Collider	e^+e^-	100	$1\cdot10^{30}$	1985(?)
VLEPP (Novosibirsk)	e^+e^-	Ist 300 IIst 1000	$1\cdot10^{32}$ $1\cdot10^{32}$	1989(?)

provided valuable information.

Construction of the big superconducting storage rings is being carried out at Brookhaven proton-proton colliding beams at energy $\sqrt{S}$ = 800 GeV - ISABELLE - with very high design luminosity ($10^{33}cm^{-2}s^{-1}$). Implementation of proton-proton experiments on the Main Ring-Doubler facility is under consideration at Fermilab at an energy $\sqrt{S}$ = 1100 GeV (300 GeV on 1000 GeV). Proton-proton colliding beams are envisaged in the accelerating facility at Serpukhov (UNK) at an energy up to 2x3 TeV. So, we see, colliding beam energies will increase rather rapidly (see Table 5). But experimental feasibility of reactions, now of intense interest, with energy 0,1 megajoul in elementary interaction (beloved 10^{15} GeV in rest frame!) - is the question for not so near future.

Experiments with deuteron-deuteron beams have been carried out on the storage ring ISR for a few years and recently performed first experiments with colliding α -particles. There is a project for producing heavy ion colliding beams at the same storage ring.

4. First installations are put into operation with proton--antiproton colliding beams. The installation ISR and proton synchrotron SPS(CERN) were modified for the mode of $p\bar{p}$ colliding beams /30,31/. An energy up to S = 600 GeV was achieved at SPS. The luminosity $1\cdot10^{27}cm^{-2}s^{-1}$ achieved at both of these installations (1981) enabled to carry out experiments with cross--sections of ordinary nuclear interactions. An extensive work is undertaken on increasing the luminosity.

Next will be comissioning of the $p\bar{p}$ installation at an energy up to $\sqrt{S}$ = 2000 GeV based on the superconducting proton synchrotron Doubler (Tevatron, Phase I) being built at Fermilab /32/. The $p\bar{p}$ project is designed for UNK (Novosibirsk-Serpukhov) at the energy up to $\sqrt{S}$ = 6 TeV /33,34/.

In the first years after announcing the first proton-antiproton colliding beam project (1966 VAPP-NAP, Novosibirsk /63,64/) the proton-antiproton experiments at maximum accessible energy were considered by many physicists as an exceedingly complicated addition to proton-proton experiments at the same

Table 5

Project/ Laboratory	Particles	$\sqrt{s}$ (GeV)	L($cm^{-2}s^{-1}$)	Start
ISR(CERN)	pp	62	$0.7 \cdot 10^{32}$	1971
ISABELLA (Brookhaven)	pp	800	$2 \cdot 10^{32} (1 \cdot 10^{33})$	1986
Main Ring/Doubler (Fermilab)	pp	1,100		
UNK (Serpukhov)	pp	6,000		
ISR(CERN)	$p\bar{p}$	62		1981
SPS(CERN)	$p\bar{p}$	600	$\geqslant 1 \cdot 10^{30}$	1981
Tevatron, Phase I (Fermilab)	$p\bar{p}$	2,000	$\geqslant 1 \cdot 10^{30}$	1984
UNK (Serpukhov-Novosibirsk)	$p\bar{p}$	6,000	$3 \cdot 10^{30}$	1990
Pentavac (Fermilab)	$p\bar{p}$	10,000		
HERA(Hamburg)	$e^{\pm}p$	300 (30e ↔ 800p)	$4 \cdot 10^{31}$	1988
CHEER(Fermilab)	$e^{-}p$	200 (10e ↔ 1,000p)	$5 \cdot 10^{31}$	1985(?)
TRISTAN (KEK)	$e^{-}p$	170 (25e ↔ 300p)	$1 \cdot 10^{31}$	1988

energies. Even then, of course, it was evident that this addition is rather important.

In addition to the necessity of verification of fundamental theorem of the equality of $p\bar{p}$ total cross-sections two classes of experiment are assumed which are specific namely to $p\bar{p}$ colliding beams: first, the study of hadron annihilation, second, the study of two-particle charge-exchange reactions, i.e., reactions with conservation of baryon charge of each colliding particle. The annihilation cross-section apparently decreases only inversely as the energy of the colliding beams and even at an energy 2x1000 GeV the cross-section will be of the order 10^{-30} cm^2. So, the main problem will be separation of annihilation processes from the vast majority of "the events of the total cross-section". At the same time, the cross-section of the process like

$$p\bar{p} \to \Lambda\bar{\Lambda}$$

decreases (in the energy region presently known) as E^{-4} and only with a luminosity of the order $10^{32} cm^{-2} s^{-1}$ one can manage to get some data about these processes at energies above 100 GeV.

In recent years the attitude toward proton-antiproton colliding beams has changed greatly. The quark model is acquiring more and more dynamical content and more and more "public opinion" is inclined to consider hadrons as consisting of quarks interacting as point-like particles. Accordingly, processes with very large momentum transfer will occur through the interaction of quarks, the components of the colliding hadrons (Drell-Yan processes). Here proton-proton collisions give quark-quark reactions, while proton-antiproton collisions give quark-antiquark reactions. In this sense one can say that in experiments in colliding proton-antiproton beams it is possible to obtain the same fundamental information as in colliding electron-positron beams of the same luminosity and with an energy of the order of one-sixth of the energy of the baryons. Similarly, proton-proton colliding beams are equivalent to electron-electron collisions. Of course, for strongly interacting particles such as protons and antiprotons we cannot say that they consist only of quarks of one "polarity". However, according to contemporary neutrino data the content of antiquarks in a proton is about 5% (this is also the estimate of the content of quarks in the antiproton). Therefore quark-antiquark interactions are dominant in proton-antiproton collisions, and quark-quark interactions provide only a small admixture. For proton-proton collisions the ratio will be the reverse. In addition, the average energy of quark-antiquark reactions in proton-proton collisions will be substantially lower than in proton-antiproton collisions. So, for example, quite interesting interactions will take place at $p\bar{p}$ colliding beams with cross-section of $10^{-34} cm^2$ and energy of hundreds GeV:

$$\begin{matrix} p\bar{p} \\ p\bar{p} \end{matrix} \to \begin{pmatrix} u\bar{u} \\ d\bar{d} \end{pmatrix} + X$$

Note, (see sect. III) that it is feasible to obtain proton-proton polarized beams with full luminosity and also the proton-antiproton beam with luminosity one order of magnitude lower than that for unpolarized, including experiments with given helicities of interacting particles.

Some interesting possibilities will open up when cooling high energy colliding $p\bar{p}$ beams with circulating electron beams /4,65-67/. At very low equilibrium dimensions of colliding particles a possibility opens up to measure precisely differential cross-section of $p\bar{p}$ elastic scattering at the angles of effective interference of strong and Coulomb interactions. Such measurements, in particular, enable to give the information about behaviour of proton-antiproton total cross-section at energies by the order of magnitude higher than the energy of $p\bar{p}$ collisions under study.

5. A few words about the "strategy" of advancing to the ultimately-high energies. One can distinguish (quite conditionally) three stages of exploring new regions at energies of hundreds GeV and higher.

In the first stage only interactions of any point-like objects (nowadays - leptons, quarks) should be accessible which enable one to produce as large as possible momentum transfer both in scattering and in production of massive objects (space- and time-like momentum transfers). In the first stage it is not too important for which pairs it will be done. The question of primary importance is the question of having beams available for the first stage experiments. Colliding beams of particles and antiparticles seem to give more experimental information as the systems having less restrictions for generation of new massive objects. From this point of view, the most advantageous variant for the experiments will be proton-antiproton colliding beems.

Of course, when we are talking here and below about the study of fundamental interactions of different objects, it is just a way to classify the experiments over the initial states. Each certain class of experiments will also provide vast additional information on other interactions.

To the second stage one can refer the experiments which cover interactions of all fundamental particles i.e. the study of lepton-lepton, lepton-antilepton, quark-lepton, quark-antilepton, quark-quark and quark-antiquark interactions. In this case, the choice of concrete particles is still determined by that which is the most realistic to realize.

These problems will apparently be solved soon in the following colliding beam experiments:

a) lepton-lepton and lepton-antilepton - $e^- + e^-$ and $e^- + e^+$ (also γe and $\gamma\gamma$ at installations of the VLEPP type);

b) lepton-quark and antilepton-quark - $e^- + p$ and $e^+ + p$; the experiments of this kind are already planned at installations at superhigh energies which are being built and designed /68-71/ (see Table 5);

c) quark- and antiquark interactions will primarily be studied in pp and $p\bar{p}$ experiments.

In the next stage it will apparently be important to obtain as complete as possible set pairs of fundamental particles in the initial state. And finally, for advance in understanding of fundamental interactions at ultimate high energies it will become necessary to study the collisions of all elementary particles and, apparently, nuclei.

6. In this connection, it is worth paying attention that many of those experiments which now seem exotic and unrealistic will

become available in the not too distant future.

So, quite soon after exploring proton-antiproton colliding beams deuteron-antideuteron experiments will become accessible (for the study of neutron-antineutron interactions): for the effectiveness of stacking antideuterons is only four orders of magnitude lower than that for antiprotons, so the luminosity of the order 10^{27} $cm^{-2}s^{-1}$ will be achieved immediately and one should not wait too long for progress in this field.

With time, colliding beam experiments with unstable particles will become accessible (see sect. V).

V. On Proton Klystron

1. As already mentioned above some interesting prospects are opened up with the use of large cyclic proton accelerators as storages of big energies in the form well suitable for its transformation into electromagnetic excitation energy of linear accelerating structure /11/. The energy stored in proton beams in accelerators SPS and Main Ring achieved now of 3 MJ and much higher energies and intensities are planned to achieve. One can only talk of proton (not electron) cyclic accelerators since only here RF power is transmitted to the beam and not used for compensation of synchrotron radiation losses. Note, when using superconducting magnetic and RF systems the transformation factor for mains power into proton beam power can be comparatively high.

The stored energy of 3 MJ is enough for excitation of accelerating structure with a wave length, for example, 5 cm with acceleration rate 100 MeV/m of 50 km long which enables one to accelerate the various charged particles ($p^{\pm}$, , $\mu^{\pm}$, $\pi^{\pm}$) up to an energy of 5 TeV. I'd like to emphasize that the particle energy of a basic accelerator can be much lower in this case. As much as half of the energy stored in the basic accelerator beam can be, in principle, transmitted to the accelerated particles. However, the energy of accelerated particles will be, in this limiting case, much lower than that

achievable in the scheme chosen.

RF pumping power can attain (even with no longitudinal compression of the exciting proton beam) 100 GW in today's accelerators; longitudinal compression makes it possible to increase additionally this value.

2. Let us now consider the question how to make the proton beam with a large stored energy to be capable to transmit this energy to a linear accelerating structure, i.e. to the correctly chosen diaphragmed wave guide.

First of all, the proton beam, homogeneous in time, should be transformed into a density-modulated one with the wavelength required (of the order of 1 cm). It is desirable that the current amplitude of the needed harmonic I_{λ} be close to its maximum, i.e. $I_{\lambda} \approx 2I_0$ where I_0 is a average proton current prior to modulation. Such a modulation can be performed in two stages. First, the homogeneous beam is modulated over its energy during its passage through the accelerating structure. This structure is excited at a wavelength required and provides the proton beam energy modulation substantially exceeding the energy spread of the primary proton beam in SPS (this spread is less than 50 MeV). In order to improve the further bunching, modulation on higher harmonics is useful to add. It seems most reasonable to carry out a subsequent transformation of energy modulation to density modulation for ultrarelativistic particles, which are high energy protons, with a bending modulator. With a correct choice of the bending radius and modulator focusing structure, the path length will depend on proton energy (in "normal" case the path length increases with energy and, hence, the lower energy protons leave behind the higher energy protons during the turn). If the rotation is interrupted at the moment when the proton of all energies are arranged on the same azimuth (note that this occurs within one wavelength and with an accuracy of up to the energy spread of the beam and an approaching degree of the effective energy modulation to the skew one), the outgoing (from the modulator) beam will contain as much as possible current harmonic. After this procedure the proton beam is directed to the corresponding linear accelerating structure with the needed magnetic quadrupole focusing to keep protons within the holes of the wave guide diaphragms. No further relative longitudinal shifts of ultrarelativistic particles occur when the latter are moving along the straight line.

Either a special magnetic track through which the emitted proton beam passes after energy modulation or the ring of a basic proton accelerator may be used as a bending modulator. In the second case, a linear accelerator (its energy of the order of 100 MeV) can be located in one of the straight sections of the basic cyclic accelerator, outside the operating aperture. As soon as the acceleration cycle is completed, the beam is "thrown" through this modulating linac, and the necessary beam density modulation appears in the bending part during the further beam motion.

3. Let such a density-modulated beam of ultrarelativistic particles pass through the linear accelerating structure with wavelength λ which corresponds to the first harmonic of modulation. In this structure, a high-frequency field will be excited, which decelerates the protons transmitting their energy to the electromagnetic field. At first, the amplitude of this field E_o will increase proportionally to the total proton charge eN flowing through a given cross section:

$$E_o \approx 10^{2}\frac{eN}{\lambda^2} = 1,5\cdot 10^{-11}\frac{N}{\lambda^2_{cm}}\left[\frac{MV}{cm}\right].$$

This increase goes on up to the proper damping time in the system τ_d, which is proportional to $\lambda^{3/2}$, and, for λ = 1 cm, equals to 20 nsec for a copper wave guide. If the period of flowing the proton current is much larger than τ_d, then the electric field amplitude is established proportional to the average proton current I in the structure:

$$E_o = 2IR \approx 3\frac{I_A}{\sqrt{\lambda_{cm}}}\left[\frac{MV}{cm}\right]$$

In the above formula R is a unit length impedance of the structure, I_A is the proton current in ampers; an additional electron load because of cold emission under the action of highly excited electric field is assumed to be still negligibly small.

A direct use of the proton beam produced by the present-day record accelerators makes it possible to obtain an equilibrium field amplitude of about 0.6 MV/cm in the structure with λ = 1 cm (for about 20 sec rotation time in such accelerators). Already comparatively insignificant prebunching of the proton beam will allow one to generate, in the accelerating structure, an effective field of up to 1,5 MV/cm, which is maximum with respect to the electric strength of the surface; the total time of existence of this field will be proportionally less than that obtained without such a bunching. Passing any relativistic particles together with the exciting proton beam in accelerating phase (for a given sign of particle charge) one can accelerate them with a rate of 60-150 GeV/km, correspondingly.

This method enables the particles to be accelerated up to an energy close to the peak energy of a basic accelerator. In this case, the highest intensity of accelerated beam will constitute about 10% of that of the basic accelerator (monochromaticity is of the order of one percent).

If the initial beam is divided into several bunches long enough and each of them is transmitted (with correct shift in time) through the linear accelerating structures in series, each providing almost full deceleration of the initial beam, it is possible to make the accelerated particles pass, in sequence, through all these structures. Note that the energy of accelerated particles is proportionally increased as compared to that of basic accelerator. The limiting intensity of the accelerated particle beam will, of course, be proportionally lower.

The necessary time redistribution of particular parts of the exciting beam - both the worked out and "fresh" bunches have to reach simultaneously each new section - may be performed according to various schemes. From the logical point of view, the simplest thing is to install, in the tunnel of the basic accelerator, the additional pulsed magnetic small-aperture tracks at full energy, which have somewhat different revolution periods for particles with a given momentum, and then to let each bunch, which occupies the corresponding part of the accelerator circumference, in its track. When all bunches coincide with respect to the azimuthal position, it is necessary, after the short-wave density modulation of each bunch, to let them in and to direct to the corresponding sections of linear accelerating structure. The same procedure may be performed by using long delays in channels, though additional tunnels will be needed for this case.

4. In order to confine the particles of the exciting and accelerated beams in the holes of the diaphragmed wave guide of accelerating structure, strong enough focusing is necessary; moreover, the stability of transverse oscillations of particles with very different momenta should be simultaneously provided. Estimations show that in case of the optimal quadrupole focusing for the accelerated particles with a momentum of a few GeV, the beams of modern proton accelerators will pass almost without losses even for centimeter-range wave guides.

The other problem associated with the passage, through the same structure, of ultrarelativistic particles with sharply different γ -factors and, hence, with a somewhat different velocities is to provide a correct relative phasing of these particles. To eliminate the consequences of gradual lag of the particles with lower velocity, it is necessary, after each section of length $\frac{1}{2}\lambda\gamma^2_{min}$, to separate the exciting and accelerated beams and to delay one beam relatively to the other approximately by $\frac{3}{4}\lambda$, due to the difference in the path lengths, to the following accelerating section input. Such a method makes it possible to clean the accelerated beam from the particles with different masses.

5. As has already been mentioned, the rate of energy increase of the order of 100 MeV/m in linear accelerators enables one to accelerate also unstable but comparatively long-lived particles, i.e. muons and charged pions. However, for charged kaons to be accelerated, the acceleration rate should be above 300 MeV/m. Such gradients are likely to cause the complete shunting of the structure by the cold-emission electrons and, correspondingly, such a field cannot be generated by a gradual increase of the energy stored in the wave guide.

An interesting possibility of obtaining the gradients of a necessary level on the basis of a proton klystron is suggested in Ref. /36/. If one collects the number N of protons,

which are formally required to obtain the needed gradient in one short bunch of the same length as diaphragm spacing of an accelerating wave guide, then a maximum decelerating field of approximately the same magnitude will be achieved within the proton bunch :

$$E_{max} \approx 10^{-12}\frac{N}{a^2 cm}\left[\frac{\text{MB}}{cm}\right]$$

where a is the diaphragm spacing of the wave guide and the diameter of their holes.

In terms of the eigen modes of a wave guide, one can say that a single bunch excites simultaneously several (azimuthally-symmetric) harmonics which amplitudes are added within the length of the exciting bunch. The electric field strength on the surface of the diaphragms achieves, though for a very short time, the same magnitude as that in the centre of the bunch. Therefore, a high shunting current is found to appear, but there is no time for this current to influence significantly the magnitude of decelerating field inside the bunch. One should take care only for that the residual electromagnetic field excited by the bunch should not release its energy on the diaphragm surfaces. To do this, the diaphragms may be open from the outer side, and a strongly absorbing material, instead of the outer coaxial of a wave guide, is placed at a large distance from the diaphragms.

The method described above allows one to accelerate much shorter bunches of opposite sign inside the bunch of exciting particles (i.e. negative particles inside the proton bunch). To attain the rate of acceleration of the order of 300 MeV/m, that is a necessary minimum for acceleration of negative kaons, one needs to form the half-centimeter bunches of ultrarelativistic protons, 10^{12} protons per bunch. In big proton accelerators mentioned, such a number of protons occupies $3\cdot10^{-3}$ of the accelerator circumference (with the bunching factor taken into account), that equals approximately 20 meters. When obtaining the needed bunch with the help of purely longitudinal compression, an energy spread available in the accelerator should increase at least to 200 GeV (from 50 MeV) (almost 50% of the full proton energy). Such a procedure is likely to be almost unrealizable from the technical point of view.

Feasibility of the method can be simplified, if one can use the smallness of the transverse emittance of a proton beam, and can increase the linear density of the beam by adding, in the transverse direction, particular parts of the proton beam which is initially elongated along the whole circumference of the basic accelerator. This may be performed, for example, by extraction of the beam part from the accelerator with its subsequent re-injection with necessary delay, using additional tracks (see section V.3). A multiple compression of such a kind will be somewhat less expensive, if the facility already has two rings at full energy (Main Ring-Doubler, ISABELLE, UNK).

6. Let us now consider in more detail the potentialities of the acceleration version described in section V.

If the conditions mentioned above are satisfied, acceleration of stable charged particles (if from the very beginning their velocity is close to the velocity of light) presents no difficulties irrespective of a particle kind. Of interest are also an increase of proton energy (with injection of a portion of primary protons in the accelerating phase of RF voltage), electron and positron acceleration without any limitations connected to a catastrophic growth of synchrotron radiation characteristic for cyclic accelerators (during linear acceleration the losses which are due to noncoherent radiation are negligibly small). Of special interest is the acceleration of polarized particles of all kinds since during linear acceleration the depolarizing effects can be made very small.

Accelerators on based on the proton klystrons can be most interesting for acceleration of unstable particles. The required acceleration rate $\frac{dE}{ds}\big|_0$ from E_i to E_f with a decrease in the number of particles in the accelerated beam, caused by decay, from N_i to N_f is given by a formula

$$\frac{dE}{ds} = \frac{mc}{\tau_0} \cdot \frac{\ln(E_f/E_i)}{\ln(N_i/N_f)}$$

where m, τ_0 - are the mass and lifetime of particles in the rest frame.

The value $\frac{mc}{\tau_0}$ is 1.6 keV/cm for muons and 0.18 MeV/cm for pions. Hence, a linear accelerator with an energy increase rate of about 1 MeV/cm provides the acceleration both for muons and pions, with small intensity losses, up to the ultimate energies.

As has already been said, prior to acceleration the muon beam is reasonable to cool by ionization cooling, and then, before injection into a linear accelerator, the muons should be bunched, with a bending modulator, within the phases close to the maxima of accelerating voltage. The bunching of pion beams being injected into a superlinac is desirable to perform by bunching the high-quality primary proton beam used for pion generation.

Kaon acceleration in the method under discussion can only be carried out with the help of the method described in section V.5.

7. The use of superlinacs with proton klystrons enables one, in principle, to perform most of colliding beam experiments described in section IV on the basis of the existing high-energy proton accelerators and those being constructed and designed.

For production of $\pi^+\pi^-$-colliding beams, the pions, after their acceleration in a superlinac, should be injected into a magnetic track with the highest (to increase the number of collisions for the lifetime) value of a magnetic field. In this case, the ultimate average luminosity $L_\Sigma^{\pi\pi}$ will be equal to

$$L_\Sigma^{\pi\pi} = \frac{\xi N_p}{e} \cdot \frac{N_\pi}{}$$

where ξ is the efficiency of the proton-pion conversion, $\dot{N}_p$ is the number of protons produced by a basic accelerator per second, N_π is the number of pions in one superbunch, ℓ_t^{eff} is the effective length of the optimized conversion target, ℓ_π is the length of the superbunch in the magnetic track and, simultaneously, the value of beta-function at the collision point, p_π is the pion momentum after conversion, p is the momentum of accelerated pions, H is the value of magnetic field in the track in which the collisions occur; τ_π is the pion rest frame lifetime.

If one takes that $\dot{N}_p = 10^{13}$ p/s, $N_\pi = 10^{11}$, $\xi = 10^{-1}$, $p = 5$ GeV/s, $p_\pi = 500$ GeV/s, $H = 100$ kG, $\ell_t^{eff} = 1$ cm, $\ell_\pi = \ell_\mu$, then one obtains the ultimate luminosity

$$L_\Sigma^{\pi\pi} = 3\cdot 10^{27}\ \text{cm}^{-2}\text{s}^{-1},$$

that is, in principle, sufficient for experiments on the study of fundamental properties of the pion-pion strong interaction.

With the use of the same system for the pion-proton experiments with substitution of positive pions for protons, the ultimate average luminosity is

$$L_\xi^{\pi p} = L_\Sigma \cdot \frac{\dot{N}_p'}{N_\pi}$$

With the number of particles in one proton bunch $N_p = 10^{12}$ and with the same remaining parameters, this gives

$$L_\Sigma^{\pi p} = 3\cdot 10^{28}\ \text{cm}^{-2}\text{s}^{-1}$$

If one uses the system under consideration for the muon-muon experiments with colliding beams in which the muon beams are cooled by ionization (under the condition that in collision the normalized muon emittance is conserved to be equal to their emittance directly after the ultimate ionization cooling), then the ultimate average luminosity will be equal to

$$L_\Sigma = \frac{\xi \dot{N}_p}{\ell_c}\cdot\frac{N_\mu}{\ell_\mu}\cdot\frac{p}{2m_e c}\cdot\frac{eH\tau_n}{2\pi m_\mu c},$$

where ℓ_c is the ionization-cooling target length, which is equal to the value of the cooler beta-function in the target region, m_e is an electron mass. Assuming that $\ell_c = 1$ cm and $\ell_\mu = 5$ cm (the remaining parameters are the same), one obtains the following estimate of the ultimate luminosity

$$L_\Sigma = 3\cdot 10^{31}\ \text{cm}^{-2}\text{s}^{-1}$$

The superlinacs, which are excited by proton klystrons, can be used also in the linear electron-positron colliding beams experiments. With the use of the approach and the estimates described in section VI, the ultimate e^+e^- luminosity, for the "standard" productivity of a proton accelerator $\dot{N}_p = 10^{13}$ p/s, will be equal to

$$L_\Sigma = 10^{31}\ \text{cm}^{-2}\text{s}^{-1}$$

Even such a luminosity is of interest, in addition, the proton synchrotron efficiency will further grow.

VI. The VLEPP-Project

Finally, I would like to talk, in more details, on the VLEPP project which has been more than once reported at the conferences and meetings but still is not yet known enough to the physics community.

1. First, a few historical remarks. In the Novosibirsk report at the International Seminar on the Prospects in High Energy Physics in Morges (Switzerland, 1971) /57/ it is said the following:

"May be, the most interesting thing in high energy physics is lepton-lepton interactions on highest possible energies. ...

The one way to study these reactions in a hundred GeV region is to build two ordinary linear accelerators*) with highest possible power in the beams and to learn the way to compress transversal beam dimensions down to about 10 microns and to achieve the same accuracy in beam control. In successful case, having 10 megawatts in the beams, it should be possible to have $10^{31}\text{cm}^{-2}\text{sec}^{-1}$ luminosity.

Another way for e^+e^-, e^-e^- reactions will appear after success in superconducting linear accelerators. In this case, it is possible not to have large active power in the beam and after acceleration to decelerate it in the second half of accelerating structure. In this case, you do not spend the RF power and have in the middle point the maximum reaction energy. It is very difficult to estimate more or less definitely the luminosity in this case, but it seems that it can be more (and even much more), than in the first case".

As is seen from the quotation we were more optimistic with respect to the prospects of superconducting linear colliding

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*) Note that analogous scheme for electron-positron colliding beams at low energies, as we have learned later, was first considered by U. Tigner in 1965 /72/.

beams. But further success in producing and operation of electron-positron colliding beams with transversal dimensions of a few microns at the collision point (VEPP-2M) and also same difficulties in achievement of high acceleration rate in superconducting structures which make the super high energy linear accelerators too cumbersome, forced us to concentrate our efforts on the development of electron-positron linear colliding beams on the basis of pulsed linear accelerators with a maximum acceleration rate.

As a result, at the International Seminar on "Problems of High Energy Physics and Controlled Thermonuclear Fusion", which was held in Novosibirsk, in 1978, devoted to the 60th anniversary of academician A.M.Budkers birth who, unfortunately, could not live till this anniversary, we could present the first rather detailed project of electron-positron colliding beams at a reaction energy 200-500 GeV - the VLEPP-project, which was then reported at many conferences and meetings /9/.

Let us consider briefly this project in the way we can see it now.

2. As already said, the general idea of the VLEPP project consists in the use of two accelerators that "fire" at each other the bunches of electrons and positrons. In such a way the idea looks like quite a trivial, but the analysis of the possibilities of modern linear accelerators shows that their parameters do not satisfy by several orders of magnitude the requirements for a sufficiently high luminosity (one has to have very intense bunches at extremely small emittance), for the power consumption and dimensions of a device.

The luminosity of such a device can be estimated as:

$$L = \frac{N^2}{4\pi\sigma_x\sigma_z} \cdot f ,$$

where N is the number of particles in each of the colliding single bunches, $4\pi\sigma_x\sigma_z$ is the effective area of the beam cross-section at the collision point, f is the acceleration repetition rate.

In order to achieve the satisfactory power consumption the linear accelerator should be operated at a repetition rate of 10-100 Hz. Both by the same reasons and because of the growth of complication in the "high current" problems the number of accelerating particles can not be much higher than 10^{12} particles in a bunch. Therefore, for achieving the required luminosity of the order of 10^{32} cm^{-2}s^{-1} the cross section area in the point of collision should be very small - of the order of a few square microns. Correspondingly, the beam emittance (for the case of a round cross section) even with optimal focusing and the bunch length l only 1 cm, one should make an exceedingly small, of the order of

$$\Omega/\pi = \frac{S}{l_e} = 10^{-8}\,cm\ rad.$$

Both the obtaining of intense bunches of such a small emittance and its maintaining during acceleration are extremely complicated problems but we managed to show that they are solvable.

For acceleration of $2\cdot10^{12}$ particles up to 100 GeV one should introduce into beams an energy of 30kJ the total energy stored in the accelerating structure should not be lower than 150 kJ. It should be transferred to the accelerating structure from the SHF-generators in times shorter than the damping time of electromagnetic field in accelerating structure which is about $2\cdot10^{-7}$ s at the wave length λ = 5 cm. Thus, the total energy of the SHF generators should be of 10^{12} W and, assuming that 1 generator for 1 GeV section of accelerator is used, the power of a single generator should then be of 5 GW that is by two orders of magnitude over the record power for commercially available generators at a wave length of 10 cm.

Though, the progress in development of powerful electron beams gives the real basis for the solution of this problem in the not-too-distant future.

The desire to have the shortest possible accelerator length and also, the intention to simplify the solution of the problem for keeping the beam emittance small during acceleration, force us to shift to the superlinacs with acceleration rate of 100 MeV/m. The analysis and experimental studies have shown that this problem is also solvable /9, 10/.

The task of creating VLEPP, thus, consists in creating linear accelerators with an acceleration rate of 100 MeV/m that is capable of accelerating the 1 cm single bunches of electrons and positrons with 10^{12} particles in each bunch with a very small beam emittance and sufficiently monochromatic at the exit, and in creating the high-efficient and finely tunable over amplitude and phase SHF generators at a wave length of 5 cm and a pulse power of a few gigawatts with the pulse duration of 0.5 μs and the repetition rate of tens of Hz. It is very desirable to have a possibility to work with the polarized electron-positron colliding beams.

3. The general layout of the facility may be represented as follows (Fig. 3). Two superlinacs at an energy, say, of 100 GeV and 1 km long each, fed by high-power SHF sources installed about 10 m apart, "fire" at each other the 1 cm long (with 10^{12} particles in each) single bunches of polarized electrons and positrons with a repetition rate of order of 10 Hz. Following the collision at the collision point, the bunches are slightly deflected by a pulsed field into a small angle analysing system enabling measurements of the energy spectrum of the colliding particles. From the analyzer the bunch enters a special conversion system - the long helical magnetic undulator. Passing through the system the particles irradiate of 1% of their energy as the circularly polarized photons with an energy of 10 MeV /62/. The remained polarized beam is slightly deflected and directed, for example, into the special halls for carrying out the experiments with the stationary polarized targets and the emitted photons reach the converter. The longitudinally polarized particles with the charge sign required generated on the target (only the upper part of the spectrum is collected) are accelerated at high acceleration rate up to an energy of 1 GeV. After the acceleration the particle polarization is transformed into the transverse (vertical) polarization, the bunch length is increased by an order of magnitude and the particles are injected into a special cyclic synchrotron radiation cooler where the beam emittance goes down to the very small value required (which is not so easy to be reached for 10^{12} particles in a bunch). After full cooling the

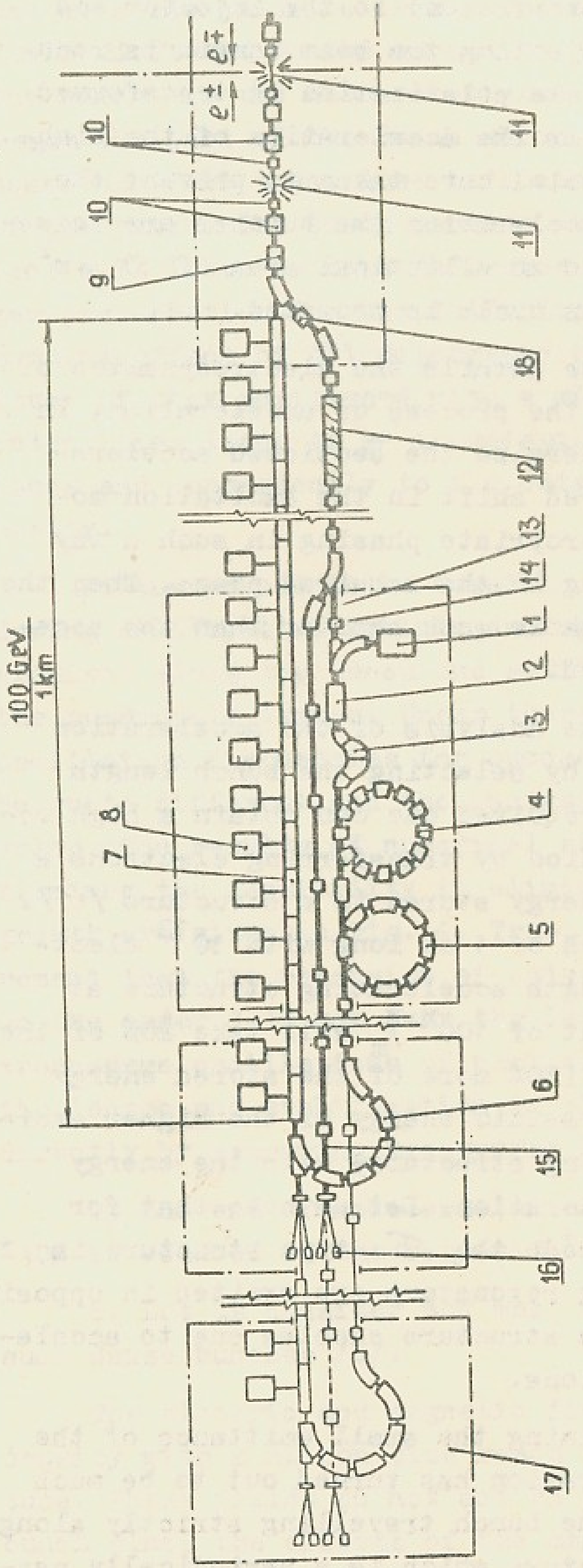


Fig. 3.

1. INITIAL INJECTOR
2. INTERMEDIATE ACCELERATOR
3. DEBUNCHER
4. STORAGE RING
5. COOLER -INJECTOR
6. BUNCHER
7. ACCELERATING SECTIONS
8. SHF SOURCE
9. PULSE DEFLECTOR
10. FOCUSING LENSES
11. COLLISION POINTS
12. HELICAL ONDULATOR
13. THE BEAM OF γ-QUANTA
14. CONVERSION TARGET
15. RESIDUAL ELECTRON BEAM
16. ELECTRON (POSITRON) BEAM EXPERIMENTS WITH STATIONARY TARGET
17. THE SECOND STEP
18. SPECTROMETER

beam is transported (without aberration) to the injector end of the superlinac. Prior to injection the beam length is reduced down to 1 cm and the particle polarization is transformed into that required. Then follows the acceleration of the highest possible gradient with special care taken to prevent the beam emittance growth. Upon acceleration the bunches are focussed at the collision point into an elliptical area of 10 μm^2 and after that the acceleration cycle is repeated.

4. Let us consider in some details the electrodynamics of the accelerator structure and the process of acceleration. In our case the SHF generators energize the sectioned accelerating structure with the required shift in the excitation moments of each section with appropriate phasing in such a way to make the beam always passing in the required phase. Then the accelerating bunch whose length is much shorter than the accelerator wave length is injected.

A nontrivial result of the analysis of the acceleration process lies in the fact that by selecting the bunch length with the number of particles required one can obtain a high monochromaticity after acceleration by transferring electrons a significant fraction of the energy stored in a structure /6 /. So, the ultrarelativistic bunch of 1 cm long with 10^{12} electrons passing the 5 cm wave length accelerating structure at effective acceleration gradient of $100^{MeV}/_{m}$ will take 20% of the electromagnetic energy stored (20% more of the stored energy will be transformed into a parasitic energy of the higher excitation modes of the accelerating structure) with the energy spread being of 1% after acceleration. Let us note that for operation in a stored-energy mode the π -type structure is optimal where two neighbouring resonators are excited in opposite phases. In addition, such a structure enables one to accelerate particles in both directions.

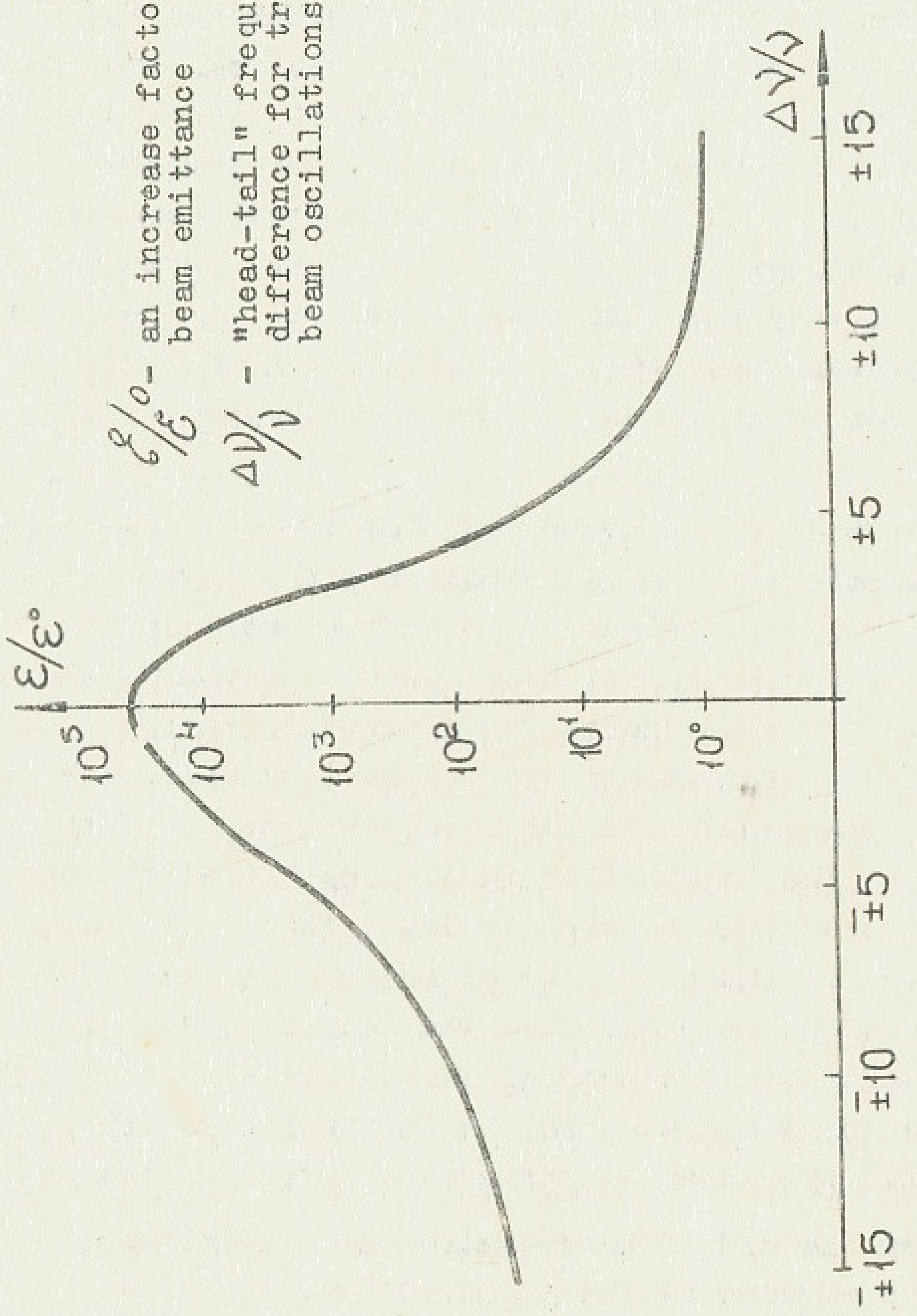
5. The problem of maintaining the small emittance of the beam in the process of acceleration has turned out to be much more complicated /61/. When the bunch travelling strictly along the axis of accelerating structure which is a periodically narrowing waveguide, the particles do not practically feel the transverse forces from the total RF field. At deflection from the axis the particle irradiates a nonsymmetric mode which field diffracted on the waveguide diaphragm steadily reaches the bunch. In the ultrarelativistic case this field cannot reach the part of the bunch which generated the field but it makes the full transverse influence on all the succeeding parts of the bunch. The bunch portion which experienced such an effect will later be more deflected from the axis causing stronger perturbation for the following portions of the bunch. The summing effect of all diaphragms of accelerating structure (even if they positioned with a micron accuracy) at necessary intensities leads to ar inadmissible growth of the beam emittance and consequently to the catastrophic reduction of luminosity.

It turned out to be possible to overcome this problem during acceleration by introducing the high particle energy gradient along the bunch and sufficiently strong focusing with the quadrupole lenses. Under these conditions the transverse oscillation frequencies for succeeding parts of the bunch will be quite different and the instability described will not develop. The results of numerical simulation of this effect confirmimng the feasibility in elimination of the beam emittance growth are given in Fig. 4. True, this fact imposes the requirement that the precision of adjustment for focusing lenses be on the order 1-10 mcm over the length of the order of the transverse oscillations of particles. The final adjustment of the lenses and stabilization in their position will be done directly by measuring transverse motion of the bunches.

By the end of acceleration an initial energy spread of ±10% is reduced to the required ±1%.

6. Let us consider now what happens during collisions of such dense bunches /6/.

The electric and magnetic fields of the bunches of high density with a micron size reach the megagauss order of magnitude. These fields do not act on particles of "their own" bunch since the effects of the magnetic and electric fields are mutually compensated. At the same time, for the colliding particles the effects of the electric and magnetic fields are added and the maximum effective field is equal to the doubled



$\varepsilon/\varepsilon^0$ - an increase factor for a beam emittance

$\Delta\nu/\nu$ - "head-tail" frequency difference for transverse beam oscillations

Fig. 4.

value:

$$|H_{eff}| = |H| + |E| = \frac{4N_e}{\ell_e(\sigma_x+\sigma_z)},$$

where σ_x σ_z are the transverse half-dimensions of a beam at the collision point, ℓ_e is the bunch length.

Let us consider briefly three aspects of the effects of these fields. The first, in this field the particle radiates the synchrotron radiation with the length of the total energy loss being quite small under considered conditions:

$$\ell_{rad} = \frac{mc^2}{r_e^2\gamma H_{eff}^2}.$$

The reaction energy spread will correspond to the energy spread in the bunch

$$\frac{\Delta E}{E} = \pm\frac{2r_e^2 N^2\gamma}{\ell_e(\sigma_x+\sigma_z)^2}.$$

As a result, instead of collisions of the monochromatic electron-positron bunches, in case of $\sigma_x=\sigma_z$ one gets the full spectrum of e^+e^- reactions energy and additionally a number of γe and $\gamma\gamma$ collisions. Because of this fact one has to change to flat bunches with the same cross section area for maintaining the luminosity. As we have seen before, the fields in flat beams are reduced proportionally with the growth of the bunch width.

The second. The colliding beams fields of opposite sign particles makes the strong focusing influence resulting in a few Z -oscillations of the bunch particles during collision time. At the head-on head collisions the effective dimensions do not change for the bunches with the smooth density distribution over various directions (even there is a slight compression) that has been shown with the numerical simulation for a self-consistent collision. Let us note, that the effect mentioned decreases sharply the attainable luminosity of e^-e^- and e^+e^+ colliding beams (defocusing).

The third important effect of the colliding bunch coherent fields is their influence on the spin behaviour for the polarized colliding beams. Because of the anomalous magnetic momentum at too large angles of the transverse oscillations of particles in the field of a colliding bunch the spin rotation with respect to the particle velocity leads to the full depolarization of electrons and positrons in the process of collision. The admissible angles in the beam are the following:

$$\theta_{all} \approx \frac{1}{3}\,\frac{g_0}{g'\gamma} = \frac{0.15}{E_{GeV}}.$$

To satisfy the condition it is necessary to have (for longitudinal polarization):

$$\frac{\gamma N \sigma_z}{l_e(\sigma_x+\sigma_z)} \leq 0.6\ 10^{17}\,cm^{-1}.$$

(x - motion);

(z - motion).

The shift to the flat beams solves this problem too.

A decrease in one of the bunch dimensions down to such a small value, though, requires the quadratic decrease in the beam emittance along this direction. If this requirement happens to be very hard to satisfy one can shift to a four-bunch variant of collisions - the electron and positron bunches travelling from each side. If the bunches moving from each side are superimposed before they reach the collision point, their coherent fields are mutually compensated (within the accuracy that the bunches are equal and they are superimposed perfectly). Therefore, all the collisional effects are attenuated and their detrimental effect becomes insignificant. In this case, because of the single collision of the bunches, the instabilities which appear at DCI during a four-bunch mode of operation will not develop. It is logically the simplest way to obtain four bunches with four separate accelerators, but it is also possible to perform the simultaneous acceleration of the electron and positron bunches in the same accelerating structure with a shift in between by a half of the wave length and subsequent delay of the first bunch after acceleration.

It is quite possible that the use of the compensating bunch mode will enable one to raise significantly the VLEPP luminosity. Let us note that for this mode of operation a half of the total luminosity will be gained from e^+e^- reactions and the second half is divided equally between e^-e^- and e^+e^+ collisions. The disadvantage of such mode of operation is that one

cannot measure the charge asymmetry of the process under study.

7. It is understood recently that additional extension of the reaction spectra is feasible on VLEPP /73/. The laser technology is nearing the stage allowing the creation of high-efficient photon targets (of small cross section, at any rate) which because of the backward Compton scattering will enable one just prior the collision to transform the main part of electrons and/or positrons into γ -quanta with an energy close to the full energy of accelerated particles. Therefore, the possibility appears for realization of the real photon-photon colliding beams at super-high energies.

Let us consider briefly the main problems connected with the realization of these experiments drawing attention only to these aspects which are intrinsic to the VLEPP operation in this specific mode.

At an energy of primary photons be of $(mc^2)^2/E$ (so much the more-higher) the photons of nearly full energy E will be emitted at an angle $1/\gamma$ with respect to the direction of the scattering electron. If the effective length of the primary photon pulse is smaller than the length of electron bunch l_e and the light beam is focussed down to the diffraction limit with area λl_e, where λ is the primary photon wave length, and this area is still larger the electron beam area at this place, then for achieving the conversion efficiency $\varkappa$ the total energy of the photon pulse is equal to:

$$E_{\Sigma}^{phot} \approx \frac{2\varkappa m c^2 l_e}{\alpha\, r_e}$$

The most promising version of generation of such photon pulses is the use of the coherent radiation in the appropriate undulators of the self-bunched electron beams of the VLEPP device (mirrorless electron laser) /74/, since these beams will have a very high local density, very small emittance and small local energy spread, and the radiation spectrum in the appropriate undulators at electron energy of a few GeV will be in the required range.

The parameters of the high energy electron beams remained after their passage through the laser targets should ensure regeneration of electrons for succeeding cycles.

The angular spread (at a given point) of electrons on VLEPP out of the collision point is much smaller than $1/\gamma$, therefore, if the photon target is placed in the converting flux not far from the collision at a distance L_0 the useful photons with an energy E will form the spot with an area $\pi (L_0/\gamma)^2$. Between the photon targets and the collision point one should introduce the moderate magnetic field in order to shift apart the electron beams at the collision point by the value larger than the electron spot size (from this view point it is convenient to operate just in the electron-electron mode). For this purpose, in particular, L_0 should be sufficiently large. In this case, the γ-quanta only of full energy will effectively interact with an ultimate luminosity of the order

$$L_\Sigma^{\gamma\gamma} = \frac{N_\gamma^2}{S_{eff}^{\gamma}} \cdot f = \frac{\varkappa^2 N_e^2 \gamma^2 f}{2\pi L_0}$$

The energy spread for $\gamma\gamma$ reactions will be of 10% in this conditions. If necessary, the reaction monochromaticity can be improved by the use of the shorter wave lasers (with the proportional increase of the laser pulse energy).

If only one electron beam is converted into photons, one can obtain $e\gamma$ colliding beams of nearly full energy with the even smaller energy spread and the luminosity about

$$L_{e\gamma} = \frac{N_e N_\gamma}{S_{eff}^{\gamma}} \cdot f = \frac{\varkappa N_e^2 \gamma^2 f}{\pi L_0^2}$$

Note, that if the conditions for e^+e^- collisions in the operation mode without compensation need to be chosen in such a way to have not too high fields in the bunches, in the case of $\gamma\gamma$ and $e\gamma$ collisions there is no such a limit and the luminosity, in principle, could be even higher.

For an energy of 10 J in the laser pulse one can hope for (already at 2x100 GeV) to achieve on VLEPP rather monochromatic colliding beams of $\gamma\gamma$ and $e\gamma$ with the respective luminosities:

$$L_{\gamma\gamma} \geqslant 3\cdot 10^{30}\ \text{cm}^{-2}\text{s}^{-1};$$

$$L_{e\gamma} \geqslant 1\cdot 10^{31}\ \text{cm}^{-2}\text{s}^{-1}.$$

Let us note that obtaining luminosity for the photon-photon collisions of the same order of magnitude as for electron-positron (or electron) colliding beams is accessible only on installations with single collisions of bunches of charged particles. The storage rings have no such possibilities.

The study of $\gamma\gamma$ and $e\gamma$ collisions with helicities of colliding particles being arbitrary chosen (due to the appropriate selection of the laser beam polarization) may become an important extention in possibilities of VLEPP.

With respect to the main body of events with generation of hadrons, $\gamma\gamma$ collisions are similar to the hadron-hadron collisions of the same energy and $e\gamma$ reactions will contribute information similar to that supplied by the deep inelastic e p reactions.

In this case, the total cross section of hadron generation in $\gamma\gamma$ collisions will apparently be very large - of order 0.3 mcb. The main body of these events will yield hadrons flying at small angles with respect to the photon direction and, therefore, will hardly be accessible for studying, though, in principle, with the help of magnetic field one can separate the initial γ-beams and the charged hadrons generated.

More promising seems to be the study of electromagnetic generation of the quark (and antiquark) jets. For all kinds of quarks with masses much lower than the photon energy the cross sections for the jet generation are the same (proportional to their squared charges). This is the radical advantage of the photon-photon collisions compared to pp and $p\bar{p}$ colliding beams in which the quark content results in the generation of jets with the d, $\bar{d}$, u, $\bar{u}$ - quarks. In addition, $\gamma\gamma$ collisions give effectively the gluon jets also. The partial cross section of these processes at energies of hundreds of GeV is of order 10^{-35} cm^2 and therefore is in principle accessible for studying on VLEPP.

In the region of electro-weak interaction especially interesting is the study of reactions

$$\gamma\gamma \longrightarrow W^+W^-$$

The cross section of this process is of the order $10^{-34}\,\mathrm{cm}^2$ and in the first approximation does not fall down with energy growth (differing, for example, from $e^+e^- \rightarrow W^+W^-$). The study of this process supplies the information of the unknown by now γW^+W^- -interaction (anomalous magnetic momentum of W, form-factor W, etc.).

The same interaction can be studied in the reaction

$$\gamma e^{\pm} \longrightarrow W^{\pm}\nu ,$$

which cross section is of the same level, but the threshold is lower. The feature of this reaction is that the generated W is single that enables one to study clearly the decay properties of these bosons. In addition, the dependence of the $e\nu W$ interaction on the electron helicity is very clear.

8. Let us consider some features of the experimentation on the VLEPP facility.

The VLEPP machine differs from the conventional colliding beam systems by that the bunch interactions in VLEPP are very rare - of tens times per second - at a high total luminosity at one collision. The circumstance makes difficult the separation of events as well as elimination of the background reactions.

The most principal limitation of the useful luminosity per one collision of the bunches is that the total cross section of electrodynamic processes of the kind

$$e^+e^- \rightarrow e^+e^- + X$$

grows rapidly with the decrease in momentum transferred to X. Consequently, every collision of bunches and every interesting event are accompanied by a large number of charged particles and photons with energies much lower than the total energy of initial particles. Therefore, special measures should be taken including, for example, installing the absorbing substance in front of the detector, introducing the longitudinal magnetic field, avoiding the registration of the small angle particles, developing the special version of a trigger, etc., for ensuring

the detection, separation and analysis of the events of interest. The probability of superposition for two interesting in current experiment events one can make negligibly small by the appropriate decrease in luminosity maintaining the high rate of statistics gathering for these events.

Another source of the background are the photons of synchrotron radiation accompanying a collision, which are generated in the coherent field of the counting bunch. These fields as mentioned above are to be made sufficiently small in order to achieve the average synchrotron radiation energy loss not higher than, say, 1%. In this case, each electron and positron radiate a few photons which can interact with the counter-flying photons and electrons. The main background processes of this origin are the generation of electron and muon pairs. The background can be suppressed with the means mentioned above. With the use of a four-beam mode of operation with compensation for coherent fields this source of the background can be practically eliminated.

Some other kinds of background of more "technical" origin can occur. So, together with the bunch of electrons having in the device under consideration the exceedingly small mean-square dimensions, some strongly deflected particles can travel, which can appear, for example, because of a single scattering on the nuclei of residual gas in the cooler ring (the beam "halo"). The interaction of such particles with a substance in the detector region results in producing the total energy showers. Therefore, a very high level of the "beam hygiene" is needed including high vacuum both in the storage ring and linac and also installing the special diaphragms far from the collision point.

Another source of the technical background can become the presence in the detector region of products of interaction between the beam-beam synchrotron radiation quanta with a substance of the vacuum chamber, lenses, etc. It forces to take care for the place of striking the substance by photons should be far enough from the collision point. In this case, the moment for the background particles entering the detector will be much delayed with respect to the particles under study. In addition, the solid angle and consequently the total number of secondary particles that reach the detector can be sharply decreased with the help of collimation. The background of this origin vanishes naturally in a four-beam mode of operation.

Thus, we have seen that the study (an inclusive, at any rate) of events producing the electrons, muons and photons with an energy which is substantial fraction of the initial particle energy will not cause much difficulties. This type of processes includes those as the two-particle reactions (electrodynamical, weak and mixed) and generation of intermediate bosons. It will also not be of principal difficulty the study of reactions producing the hadron jets which carry a considerable fraction of the initial particle energy. At the same time, the study of all interesting processes will require the solution of the very complicated background problems.

Let us note that the physical background during studying $e\gamma$ and $\gamma\gamma$ reactions on VLEPP will be substantially lower.

The pulsed character of the VLEPP luminosity, the high resulting multiplicity of the majority of the most interesting processes as well as a number of quite low-energy background particles forces to develop quite special detecting systems especially in their internal, "geometric", track part. It is not excluded that one of the possible solutions can become the use of the hybrid rapid cycle bubble chambers with electronic indication.

Let us emphasize that the VLEPP average luminosity can be distributed between several separate experiments. In this case, in any certain cycle the only one collision point is switched on; the succession of switching can be arbitrarily given.

9. Let us remind that VLEPP can be used in the regime parallel to the colliding beam regime as an accelerator supplying 10^{13} appropriately polarized electrons and positrons per second with full energy E, as well, supplying the laser conversion, as the source of polarized γ-quanta of nearly full energy with the satisfactory monochromaticity and intensity of order 10^{12} s^{-1} for experiments with the stationary targets.

Let us also remind that by striking the target with the electron and especially with the photon beams of VLEPP one can obtain quite intense and well collimated fluxes of any kind of high energy neutrinos. It is of special interest that these fluxes enriched heavily with ν_τ neutrinos from τ-lepton decays (and, if they exist, the neutrinos from heavier leptons). In this case, the flux can reach $10^6 \nu_\tau$/s in the angle $M c^2/E$ with the energy of the order 1/4E.

In the special experimental mode one can obtain the polarized electrons, positrons and photons of doubled energy by making $e^\pm$ pass succeedingly both linacs (in this case the sections of the second linac should be excited with a time shift opposite to the normal shift in time).

If the VLEPP machine is added with the intense sources of charged pions and cooled muons, it can be also used for their acceleration.

10. Finally, let us give the list of the main parameters of the VLEPP project.

	I stage	Full project
Energy	2 x 150 GeV	2 x 500 GeV
Length	2 x 1.5 km	2 x 5 km
Total luminosity	$10^{32} cm^{-2} s^{-1}$	
Collision points	5	
Repetition frequency	10 Hz	
Number of particles in a bunch	10^{12}	
Average beam power	2 x 250 kW	2 x 900 kW
Pulse power of SHF sources	1000 GW	4000 GW
Total consumption of power from the mains	15 MW	40 MW

Conclusion

The seventies are characterized by a stormy development of elementary particle physics. The dominant factor was the sharp extension of experimental possibilities. The forthcoming decade opens up even more breathtaking prospects (if only external factors will not deform the character of science development).

The more and more serious character is acquired by application of developments, techniques and the phenomena primarily explored in high energy physics in the other fields of science and technology. Important examples of such a kind are the radiation technology and first of all the radiative chemical one, the use of modern detection systems and data processing techniques which commenced to be used, for example, in medical treatment, and various applications of synchrotron radiation generated by electron storage rings. This circumstance should facilitate the further attention to development of high energy physics.

In conclusion, I would like to express the deep gratitude to many of my colleagues at the Institute of Nuclear Physics (Novosibirsk) and also to our colleagues from the Institute of Theoretical and Experimental Physics (Moscow), Institute of Mathematics (Novosibirsk), Leningrad Institute of Nuclear Physics, Stanford Linear Accelerator Centre, Madison University, Fermilab, Cornell University, CERN, DESY, whose numerous useful discussions facilitate to form the attitudes and approaches presented in this review.

References

I. Skrinsky A.N.: "Accelerator and Instrumentation Prospects of Elementary Particle Physics"; Proceedings of the XX International High Energy Physics Conference, Madison, 1980.

2. Skrinsky A.N.: "Colliding beams - present and future"; IY National Accelerator Meeting Dubna, 1978; Preprint INP 79-12, Novosibirsk, 1979.

3. Budker G.I.: Atomnaya Energiya, 22, 346, 1976.
G.I.Budker, N.S.Dikansky, V.I.Kudelainen, I.N.Meshkov, V.V.Parkhomchuk, D.V.Pestrikov, A.N.Skrinsky, B.N.Sukhina: Particle Accelerators, v. 7, p. 197 (1976).
Dikansky N.S., Kononov V.I., Kudelainen V.I., Meshkov I.N., Parkhomchuk V.V., Pestrikov D.V., Skrinsky A.N., Sukhina B.N.: "A study of fast electron cooling", Proceedings of IV National Accelerator Meeting, Dubna, 1978, v. 1, p. 99.

4.a) Budker G.I., Skrinsky A.N.: "Electron Cooling and New Possibilities of Elementary Particle Physics", UPhN, 124, v. 4, 1978.

Budker G.I., Dikansky N.S., Meshkov I.N., Parkhomchuk V.V., Pestrikov D.V., Skrinsky A.N.: "Proceedings of the XVIII International Conference on Elementary Particle Physics", Tbilisi, 1976;
Dikansky N.S., Meshkov I.N., Skrinsky A.N.: Nature, 1978, v. 276 (5690) p. 769.

b) Parkhomchuk V.V., Skrinsky A.N.: "Methods of Cooling Charged Particle Beams", ECHAYA, v. 12, issue 3; Moscow, 1981.

5. Van der Meer: "On Stochastic Cooling"; CERN Intern. Report, CERN, Intern. Report, CERN/ISR-PO/12-31, 1972.
D.Möhl, G.Petrucci, T.Thorndahl, S. Van der Meer: Physics Report, 58, (1980), 73.

6. Belyaev S.T., Budker G.I., Popov S.G.: "The Possibility of Using Storage Rings with Internal Thin Target"; Proceedings of the III International Conference on High Energy Physics and Nuclear Structure", 1970.
Voitsekhovsky B.B., Nikolenko D.M., Popov S.G., Toporkov D.K.: Pisma v JETP, 29, 105-109, 1979.

7. MacDaniel B.: "New Cornell e^+e^- Project"; Proceedings of the XX Intern. High Energy Physics Conference, Madison, 1980.

8. Schnell W., Picasso E.: "LEP Project"; Proceedings of the XX Intern. High Energy Physics Conference, Madison, 1980.

9. Balakin V.E., Budker G.I., Skrinsky A.N.,: "On a possibility of Creation the Electron Positron Colliding Beams at Super High Energies", "Problems of High Energy Physics and Thermonuclear Fusion". Nauka, 1981; VI National Accelerator Meeting, Dubna, 1978.
Balakin V.E., Budker G.I., Skrinsky A.N.: "Feasibility of creating a superhigh energy colliding electron-positron beam facility", Preprint INP 78-101, 1978.
Balakin V.E., Skrinsky A.N.: "A Superhigh Energy Colliding Electron-Positron Facility (VLEPP)", ICFA-II Proceedings, 1980.

10. Balakin V.E., Brezhnev O.N., Novokhatsky A.V., Semenov Yu.I.: "Accelerating Structure of Linear Electron Positron Colliding Beam Project (VLEPP)" Proceedings of VI National Accelerator Meeting, Dubna, 1979;
Preprint INP 79-83, Novosibirsk 1979.

11. Perevedentsev E.A., Skrinsky A.N. "On Possibility of Using Intense Beams of Large Proton Accelerators for Excitation of Linear Accelerating Structures". Proceedings of VI National Accelerator Meeting, Dubna, 1978.
Preprint INP 79-80, Novosibirsk, 1979; ICFA-II Proceedings, 1979.

12. Leipuner L.B. et al.: "First Experience with Fastbus System at Brookhaven"; Proceedings of the XX Intern. Conference on High Energy Physics, Madison, 1980.

13. Cortez B. et al.: "A Sensitive Search for the Time Evolution of an Electron Neutrino Beam", XX Intern. High Energy Conference, Madison, 1980 (contributed paper).

14. Blandino J., Camerini U., Cline D., et al.: "A Decay Mode Independent Search for Baryon Decay Using a Large Volume Cherenkov Detector"; XX Intern. High Energy Physics Conference, Madison, 1980 (contributed paper).

15. Dieters K., Donat A., Lanius K., et al.: "Test of a Liquid Argon Multistrip Ionization Chamber"; XX Intern. High Energy Physics Conference, Madison, 1980 (contributed paper).

16. Bondar A.E. et al.: Proceedings of the III Intern. Meeting on Proportional and Drift Chambers, Dubna, 1978, p. 184.

17. Pestov Yu., Fedotovich G.: "Fast Spark Counter with Localized Discharge"; Preprint INP 77-78, Novosibirsk, 1977.

18. Vorobyov A.A. et al.
Nucl. Instr. Methods, 119, (1974) 509.
Burg. J. et al.: "Measurements of the Total -He and -He Cross-Sections"; Proceedings of the XX Intern. High Energy Physics Conference, Madison, 1980.

19. Albine E. et al.: "A Live Target for Measuring the Lifetime of Charmed Particles"; Proceedings of the XX Intern. High Energy Physics Conference, Madison, 1980 (contributed paper).

20. Potter D. et al.: "Two New Triggerable Track Chamber - - Target"; XX Intern. High Energy Physics Conference, Madison, 1980 (contributed paper).

21. Dykes M., et al.: "Test of High Resolution Small Bubble Chamber"; XX Intern. High Energy Physics Conference, Madison, 1980 (contributed paper);
Montanet L.: "Holographic Photography of Bubble Chamber Tracks"; Proceedings of the XX Intern. High Energy Physics Conference, Madison, 1980.

22. Gilmore R.S., Leith D.W., Williams S.H. "Development of High Gain Multigap Avalanche Detectors for Cherenkov Ring Imaging"; XX Intern. High Energy Physics Conference, Madison, 1980 (contributed paper).

23. Astabatyan R.A., Lorikyan M.P., Manukyan E.A., Markaryan K.Zh.: "On Some Possibilities of Extraction of Local Ionization"; XX Intern. High Energy Physics Conference, Madison, 1980 (contributed paper).

24. Barkov L.M., Zolotorev M.S.: "Parity Violation in Atomic Transitions"; Physics Letters, 85B, 308, 1979.

25. Soloviev L.D.: "The IHEP Accelerator Storage Complex Status Report". Proc. XX Intern. High Energy Physics Conference, Madison, 1980.

26. Belchenko Yu.I., Budker G.I., Derevyankin G.E., "High Current Proton Beams in Novosibirsk"; Proceedings of X International Conference on High Energy Accelerators, Serpukhov, 1977, v. 1, p. 287.

27. Derbenev Ya.S., Kondratenko A.M.: "Acceleration of Polarized Protons in Cyclic Accelerators"; Proceedings of X International Conference on High Energy Accelerators, Serpukhov, v. 2, 1977, DAN, 223, 830, 1975.

28. Derbenev Ya.S., Kondratenko A.M., Skrinsky A.N.: "Spin Motion in Storage Rings with Arbitrary Field"; Preprint INP 2-70, Novosibirsk, 1970, DAN, 192, 1255, 1970.

29. Baldin A.M.: "Multibaryon Interactions at Relativistic Energies"; Progress in Particle and Nuclear Physics, v. 4; pp. 95-132, 1980.

30. "CERN SPS Used as $p\bar{p}$ Collider"; Proceedings of the Workshop on Producing High Energy Proton-Antiproton Collisions, Berkeley, 1978.

31. S. van der Meer: "Stochastic Cooling in the CERN Antiproton Accumulator"; 1981 Particle Accelerator Conference, Washington D.C.

32. "Tevatron Used as $p\bar{p}$ Collider"; Proceedings of the Workshop on Producing High Energy Proton-Antiproton Collisions, Berkeley, 1978.
"Tevatron: Phase-I", Fermilab, 1980.
Young S.: "$p\bar{p}$ in Fermilab"; Proceedings of the XX Intern. High Energy Physics Conference, Madison, 1980.

33. Vsevolojskaya T.A., Grishanov Ya.S., Derbenev Ya.S., Dikansky N.S., Meshkov I.N., Parkhomchuk V.V., Pestrikov D.V., Sil'vestrov G.I., Skrinsky A.N. "Antiproton Source for UNK"; Preprint INP, 80-182, Novosibirsk, 1980.

34. Vsevolojskaya T.A., Grishanov B.I., Derbenev Ya.S., Dikansky N.S., Meshkov I.N., Parkhomchuk V.V., Pestrikov D.V., Silvestrov G.I., Skrinsky A.N., Balbekov V.I., Guriev G.G., Drojjin A.I., Miznikov K.P., Fedotov Yu.S., Yarba V.A.: "Proton Antiproton Colliding Beams with UNK"; Proceedingd of VII National Accelerator Meeting, Dubna, 1980.

35. "Design Study of a Facility for Experiments with Low Energy Antiprotons"; CERN/PS/DL, 80-7, 1980.

36. Balakin V.E., Novokhatsky A.V., "The Method of Accelerating the Electrons with a Maximum High Gradient by a Proton Beam", Preprint INP 79-86, Novosibirsk, 1979.

37. Guiragossian Z., Rand R. "A 300 GeV High Quality Electron and Pion Beam at the New Generation of Proton Accelerators"; The San-Francisko Particle Accelerator Conference, 1973.

38. Baier V.N., UPhN, 105, 441 (1971).

39. Serednyakov S.I., Skrinsky A.N., Tumaikin G.M., Shatunov Yu.M.: JETP, 71, 2025 (1976).

40. Serednyakov S.I., Sidorov V.A., Skrinsky A.N., Tumaikin G.M., Shatunov Yu.M.; Phys. Lett., 66B, 102, 1977.

41. Derbenev Ya.S., Kondratenko A.M., Serednyakov S.I., Skrinsky A.N., Tumaikin G.M., Shatunov Yu.M.; Particle Accelerators, 8, 115, 1978.

42. Derbenev Ya.S., Kondratenko A.M., Serednyakov S.I., Skrinsky A.N., Tumaikin G.M., Shatunov Yu.M., Particle Accelerators, 10, 177, 1980.

43. Derbenev Ya.S., Kondratenko A.M., Saldin E.L., Nucl. Instr. Meth., 165, 15-19, 1979.

44. Derbenev Ya.S., Kondratenko A.M., Saldin E.L., Nucl. Instr. & Method., 165, 201-208, 1979.

45. Baier V.N., Katkov V.M., Strakhovenko V.M., Phys. Lett., 70B, 83, 1977.

46. Kondratenko A.M., Saldin E.L.: "Generation of Coherent Radiation by a Relativistic Electron Beam in an Undulator"; Preprint INP, 79-48, Novosibirsk, 1979.

47. Alferov D.F., Bashmakov Yu.A., Bessonov E.G., Govorkov B.B.: "Irradiation of Polarized Quasimonochromatic γ-Quanta", Preprint PhIAN, N 83, 1977.

48. Kumakhov M.A., Phys. Lett., 57A, 17, 1976.

49. Baier V.N., Katkov V.M., Strakhovenko V.M., Phys. Lett. 73A, 44, 1979.

50. Budker G.I., Proceedings of the Intern. Conference on High Energy Physics, Kiev, 1970.

51. Perl M.L.: "Heavy Lepton Phenomenology"; SLAC-PUB-2219, 1978.

52. Bukin A.D., Kurdadze L.M., Serednyakov S.I., Sidorov V.A., Skrinsky A.N., Shatunov Yu.M., Shwarts B.A., Eidelman S.I.: "φ - meson: ω - φ Interference and Precision Measurements of Mass φ- Resonance"; Yadernaya Fizika, v. 27, p. 1978.

53. Zholentz A.A., Kurdadze L.M., Lelchuk M.Yu., Mishnev S.I., Nikitin S.A., Pakhtusova E.V., Petrov V.V., Protopopov I.Ya., Saldin E.L., Sidorov V.A., Skrinsky A.N., Tumaikin G.M., Chilingarov A.G., Shatunov Yu.M., Shwartz B.A., Eidelman S.I. and Eidelman Yu.L.: "High Precision Measurement of the ψ-and ψ'-meson Masses"; Preprint INP, 80-156, Novosibirsk, 1980, Physics letters, vol. 96B, No. 1,2, 1980.

54. Zholents A.A., Protopopov I.Ya., Skrinsky A.N.: "Monochromatization of Energy of Particle Interaction in Storage Rings"; VI National Accelerator Meeting, Dubna, 1978.

55. Derbenev Ya.S., Kondratenko A.M., Skrinsky A.N.: "Radiative Polarization at Ultrahigh Energies", Particle Accelerators, v. 9, p. 247, 1979.

56. Richter B. et al.: "The SLAC Single-Pass Collider"; Proceedings of XI Intern. Conference on High Energy Accelerators, CERN, 1980.

57. Skrinsky A.N.: "Colliding Beams in Novosibirsk"; Intern. Seminar on Perspectives in High Energy Physics, Morges, Switz., 1971; CERN/D.Ph. 11/YGC/, 21.9.1971.

58. Tigner M., Private Communication.

59. Amaldi U.: "A possible scheme to obtain e^+e^- collisions at energies of hundreds of GeV"; Phys. Lett., 61B, p. 313, 1976.

60. Gerke H., Steffen K.: "Note on a 45-100 GeV "Electron Swing" Colliding Beam Accelerators", Int. Rep., DESY PET-79/04, Hamburg, 1979.

61. Balakin V.E., Koop I.A., Novokhatsky A.V., Skrinsky A.N., Smirnov V.P.: "Beam Dynamica at VLEPP (electron positron linear colliding beams)"; Proceedings of VI National Accelerator Meeting, Dubna, 1978.

62. Balakin V.E., Mikhailichenko A.A.: "The Conversion System for Obtaining High Polarized Electrons and Positrons", Preprint INP 79-85, Novosibirsk, 1979.

63. Budker G.I., Skrinsky A.N.: "Electron Cooling and Proton Antiproton Colliding Beams"; Orsay Symposium on Colliding Beams, 1966.

64. VAPP-NAP Group Report: "Proton-Antiproton Colliding Beams"; Proc. VIII Intern. Conf. on High Energy Accelerators; Geneva, CERN, 1971.

65. Rubbia C.: "Relativistic Electron Cooling to Increase the Luminosity of the $p\bar{p}$ Collider"; Workshop on Cooling of High Energy Beams, Madison, 1978.

66. Skrinsky A.N.: "On High Energy Electron Cooling"; Workshop on Cooling of High Energy Beams, Madison, 1978.

67. Derbenev Ya.S., Skrinsky A.N.: "On High Energy Electron Cooling"; Preprint INP, 79-87, Novosibirsk, 1979; Proceedings of National Accelerator Meeting, Dubna, 1980.

68. Wiik B.H.: "HERA-Electron-Proton Colliding Beam Facility at DESY"; Proc. XX Intern. High Energy Physics Conf., Madison, 1980.

69. Nishikawa T. "TRISTAN - the Japanese Electron-Proton Colliding Beam Project"; Proc. XX Intern. High Energy Phsics Conf., Madison, 1980.

70. "CHEER-Canadian Electron-Proton Project"; Proc. XX Intern. High Energy Physics Conference, Madison, 1980.

71. Wilson E. et al.: "Electron-Proton Colliding Beams at Fermilab"; Proc. XX Intern. High Energy Physics Conference, Madison, 1980.

72. Tigner M.: Nuovo Cimento, 37, 3, 1965.

73. Ginzburg I.F., Kotkin G.L., Serbo V.G., Telnov V.I.: "On Possibility to Obtain Colliding - and - beams with High Energy and Luminosity Using Accelerators of VLEPP Type"; Preprint INP, 81-50, Novosibirsk, 1981.

74. Kondratenko A.M., Pakhtusova E.V., Salin E.L.: "The use of Free Electron Laser for Generation of High Energy Photon Colliding Beams on VLEPP"; Preprint INP, 81-85, Novosibirsk, 1981.

А.Н.Скринский

УСКОРИТЕЛЬНЫЕ И ДЕТЕКТОРНЫЕ ПЕРСПЕКТИВЫ ФИЗИКИ ЭЛЕМЕНТАРНЫХ ЧАСТИЦ

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