57

ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

G.Ya. Kezerashvili, A.M. Milov
and B.B. Wojtsekhowski

THE GAMMA RAY ENERGY TAGGING SPECTROMETER OF ROKK-2 FACILITY AT VEPP-3 STORAGE RING

PREPRINT 91-118

НОВОСИБИРСК

The Gamma Ray Energy Tagging Spectrometer of ROKK-2 Facility at VEPP-3 Storage Ring

G.Ya. Kezerashvili, A.M. Milov
and B.B. Wojtsekhowski

Budker Institute of Nuclear Physics,
630090, Novosibirsk, USSR

A B S T R A C T

The gamma ray energy tagging spectrometer is described. The storage ring bending magnet was used as an analyzer for the gamma ray tagging spectrometer in the photon energy range from 1.5% up to 14% of the initial beam energy with the drift chambers as a coordinate detector. Factors determine the registration efficiency and the energy resolution of the tagging spectrometer are discussed. The tagging spectrometer energy resolution is measured by using the width of high energy edge of the Compton spectrum. The registration efficiency value consists 95% and the photon energy resolution is 4 MeV.

1. INTRODUCTION

In order to realize the experimental program on nuclear physics of the electromagnetic interactions in intermediate energy range [1] at VEPP-3 storage ring in 1987 was built ROKK-2 facility (Russian abbreviation means Backscattered Compton Gamma Quanta-2) [2]. The experiments carried out at this facility [3, 10-11] were the extension of the research begun by ROKK-1 facility [4-6] at VEPP-4 storage ring at Novosibirsk.

Producing of the gamma ray beam at ROKK-2 is based on the usage of the effects of the Compton Backscattering of the laser photons against the high energy electrons and Bremsstrahlung of the electrons circulating in the storage ring against the residual gas atoms.

Providing of the photonuclear experiments usually requires the knowledge of the gamma ray initial energy in the nuclear interaction. There are two approaches to the monochromatization of the Compton gamma ray beams. The first one is associated with the angle-energy correlation. For the first time it was realized at LADONE facility at Frascati [7]. However it leads to the gamma ray intensity loss because of the collimation of the gamma ray beam. The second approach based on the determination of each gamma ray energy by measurirg of the scattered electron momenta is free of this shortage. It was used on ROKK-1, ROKK-2 facilities and LEGS at Brookheaven [8] and at last time at LADONE [9]. Moreover this approach is well enough for the Bremsstrahlung gamma ray which have no angle-energy correlation.

2. THE TAGGING SPECTROMETER MAIN PARAMETERS

The principle of the gamma ray energy tagging is based on the measuring of the electron deflection in the magnetic field. The electrons lose energy producing gamma rays in scattering against the laser photons or the residual gas atoms.

The scheme of ROKK-2 facility and the main parameters are represented in Fig. 1. The short pulse laser radiation synchronous to the electron bunch passing at the straight

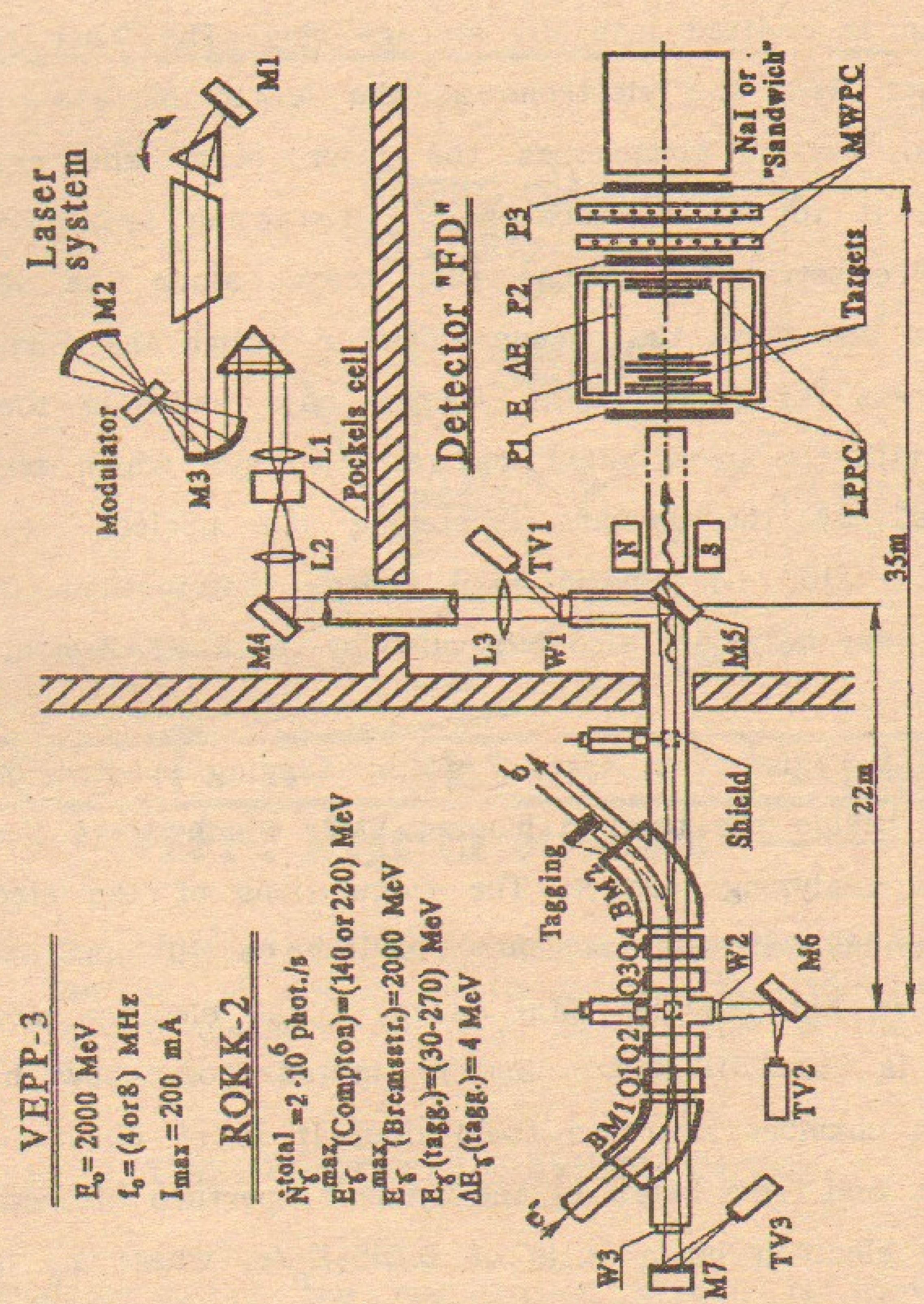

Fig. 1. ROKK-2 facility arrangement. BM are bending magnets, Q are quadrupole lenses, M are optical mirrors, L are optical lenses, W are windows, TV are television cameras, P are scintillating plactics, ΔE and E are colarimeters, MWPC are multiwires proportional chambers, LPPC are low preassure proportional chambers.

section is emitted into the storage ring. The laser photons interact with the electrons at the length of about 2 m. Optical system compresses the laser beam and precisely places it to the electron-photon interaction area. Compton and Bremsstrahlung gamma rays travel along the straight section and leave the vacuum chamber trough the mirror M5 (thickness 0.1 rad. length). Gamma rays irradiate the targets with the investigated materials isotopes which are surrounded by the layout registering the nuclear reactions products [10, 11]. Spatial and energy distributions of the gamma ray beam are also controlled by the ROKK-2 monitoring system.

The registration system of the tagging spectrometer is placed beside the bending magnet BM2, which plays the role of the analyzing magnet. The calculations of the electrons trajectories with the momenta less than equilibrium one are shown in Fig. 2. The total range of the electron momenta losses is (30-270) MeV/c, and is limited from above by the vacuum chamber aperture (bold line) it is of about $0.14 \times \times E_0/c$, and from below by the dynamic aperture (dashed line) of the electron beam it is of $0.015 \cdot E_0/c$, where E_0 is the electron energy in the beam.

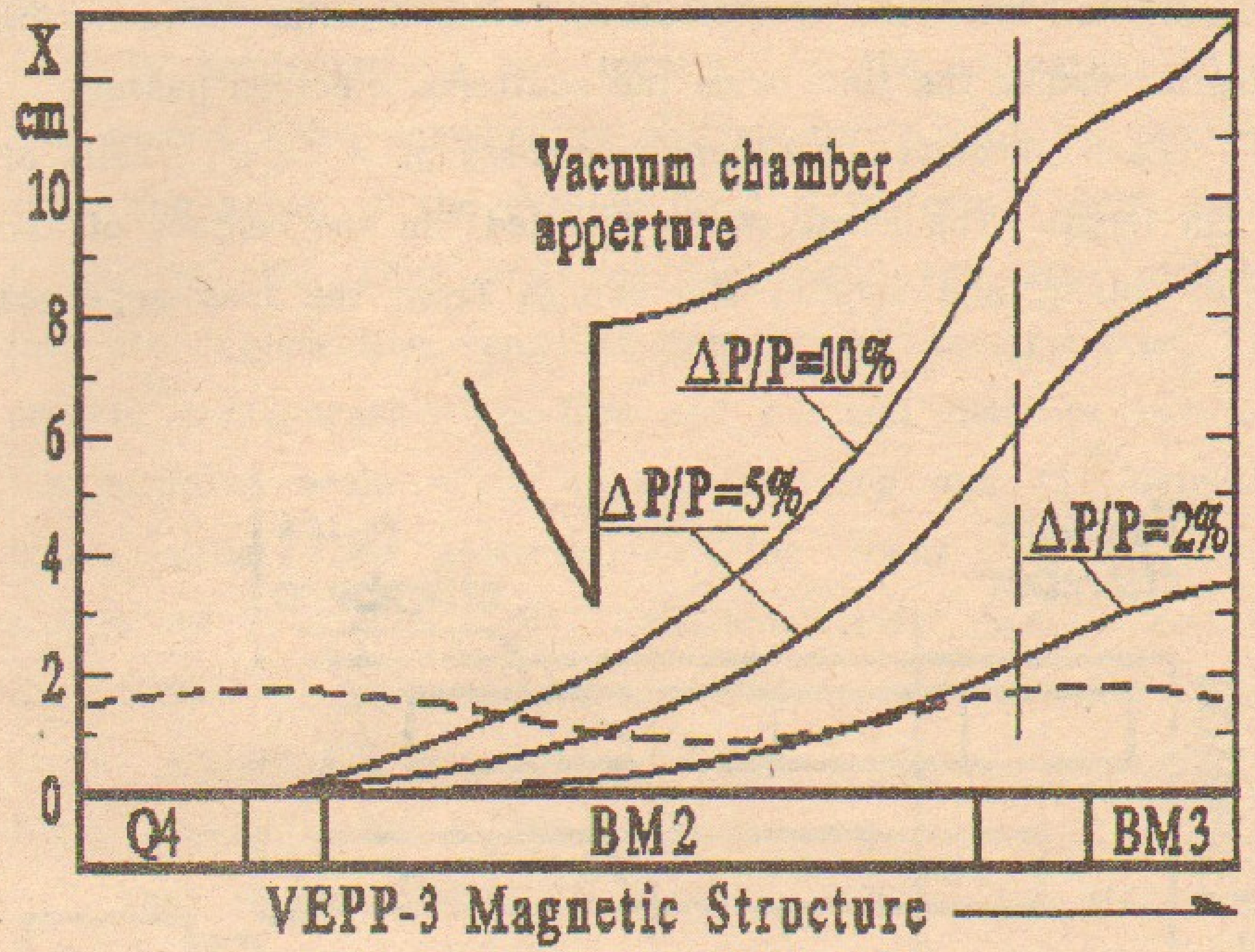

Fig. 2. The electron deflection in the magnetic field as a function of the momenta losses. Bold line is the vacuum chamber aperture, dashed line is the beam dinamical aperture.

3. THE REGISTRATION SYSTEM DESIGN

The design of the registration system is shown in Fig. 3. It consists of two drift chambers and scintillating counter. Drift chambers determine the electron entering coordinate into the registration system. The scintillating counter marks the time when the scattered electron passes.

Each of drift chambers consists of 4 drift cells of 2 cm length. The anode wires situated in the centers of the cells collect and amplify the charge from the ions appeared

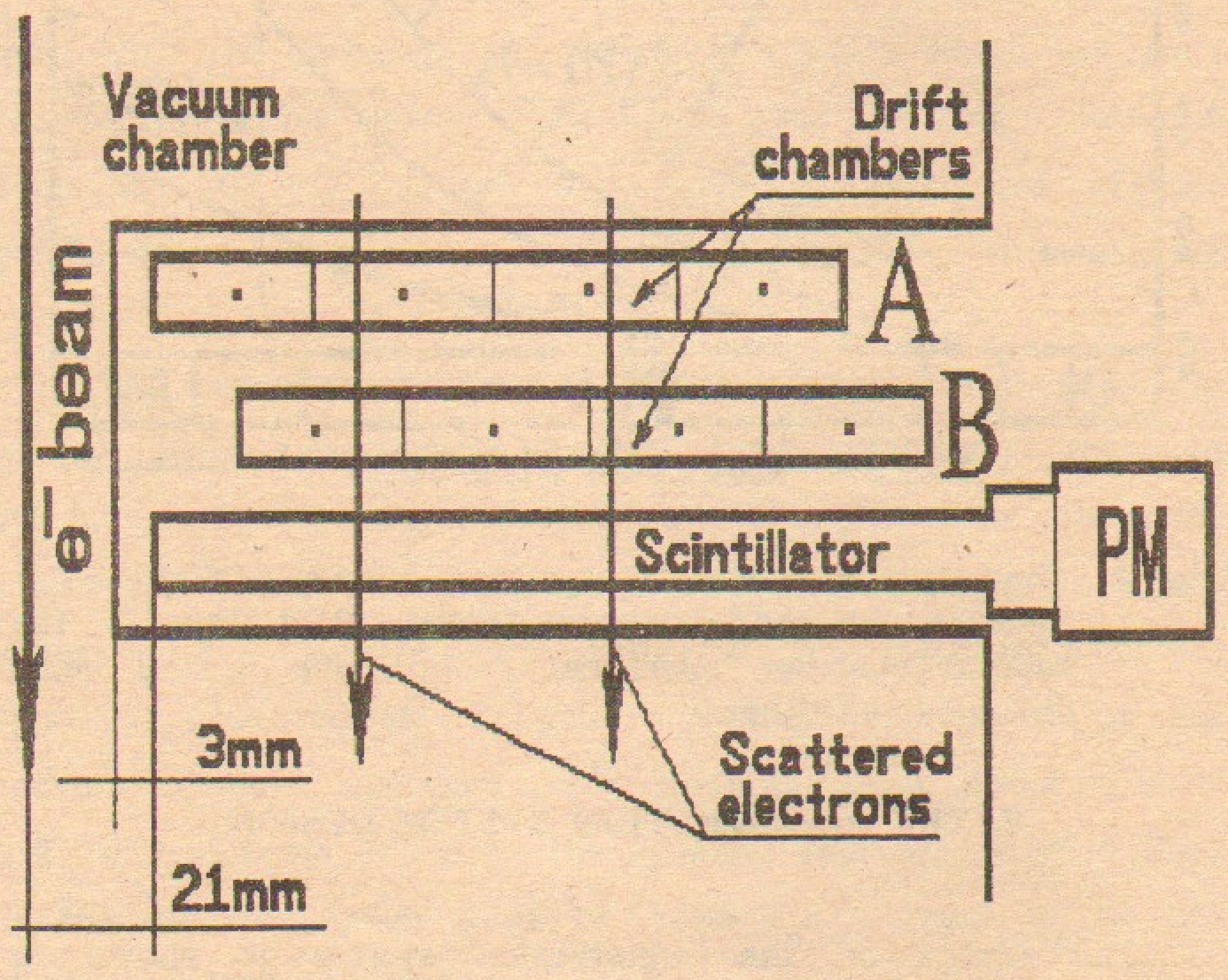

Fig. 3. The design of the registration system.

at the electron entering point. Time than the ions reach the wire is dominated by the location of the ionization point. The second drift chamber is shifted for a half of the cell size. The areas of the overlap of 8 cells form 7 drift gaps. A half of the first and the last cells are also included into the registration range of the tagging spectrometer. The present configuration provides the minimal distance between the electron beam orbit at storage ring and the detector active area. The electron entering point is determined simply by two drift cells. Full ions drift time is 220 ns that permit to separate the electrons come from interactions in two consecutive revolutions of the electron beam (VEPP-3 beam revolution time is 250 ns).

The whole system is placed inside the thin wall stainless box is being a part of the storage ring vacuum chamber and can be moved in the radial direction. The registration system is protected by tungsten plates from sinchrotron radiation rescattered on the walls of the vacuum chamber.

4. DETECTOR OPERATION

A mixture of $Ar+CO_2$ (75/25) is used in the drift chambers. The operable voltage values for the drift cells lyes from +1.6 kV up to +1.9 kV for the anode wire and from -0.88 kV up to -0.55 kV for the cathode ones.

A two-dimensional histogram of the events in two neighbors drift cells is demonstrated in Fig. 4. If the area in the histogram has no bend the drift velocities is constant along the X coordinate of the cell.

Fig. 5 represents the counting rates of the drift cells vs. the electron beam current. One can see that the current dependencies stay linear up to 1.5 MHz per one drift cell.

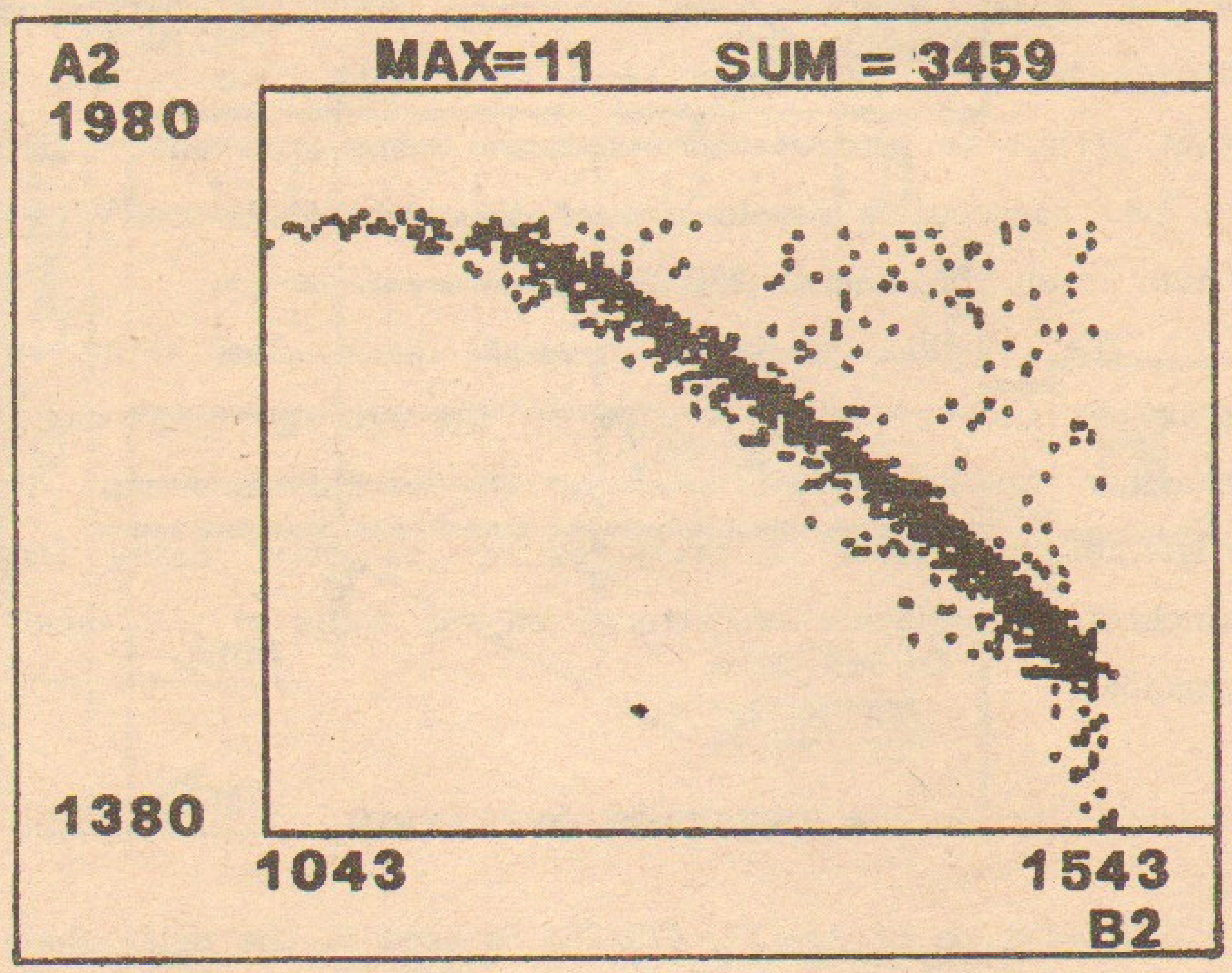

Fig. 4. Two-dimensional times histogram of the events registered by two drift cells A2 and B2 of the same drift gap. A2 drift time is in vertical direction B2 drift time in horizontal.

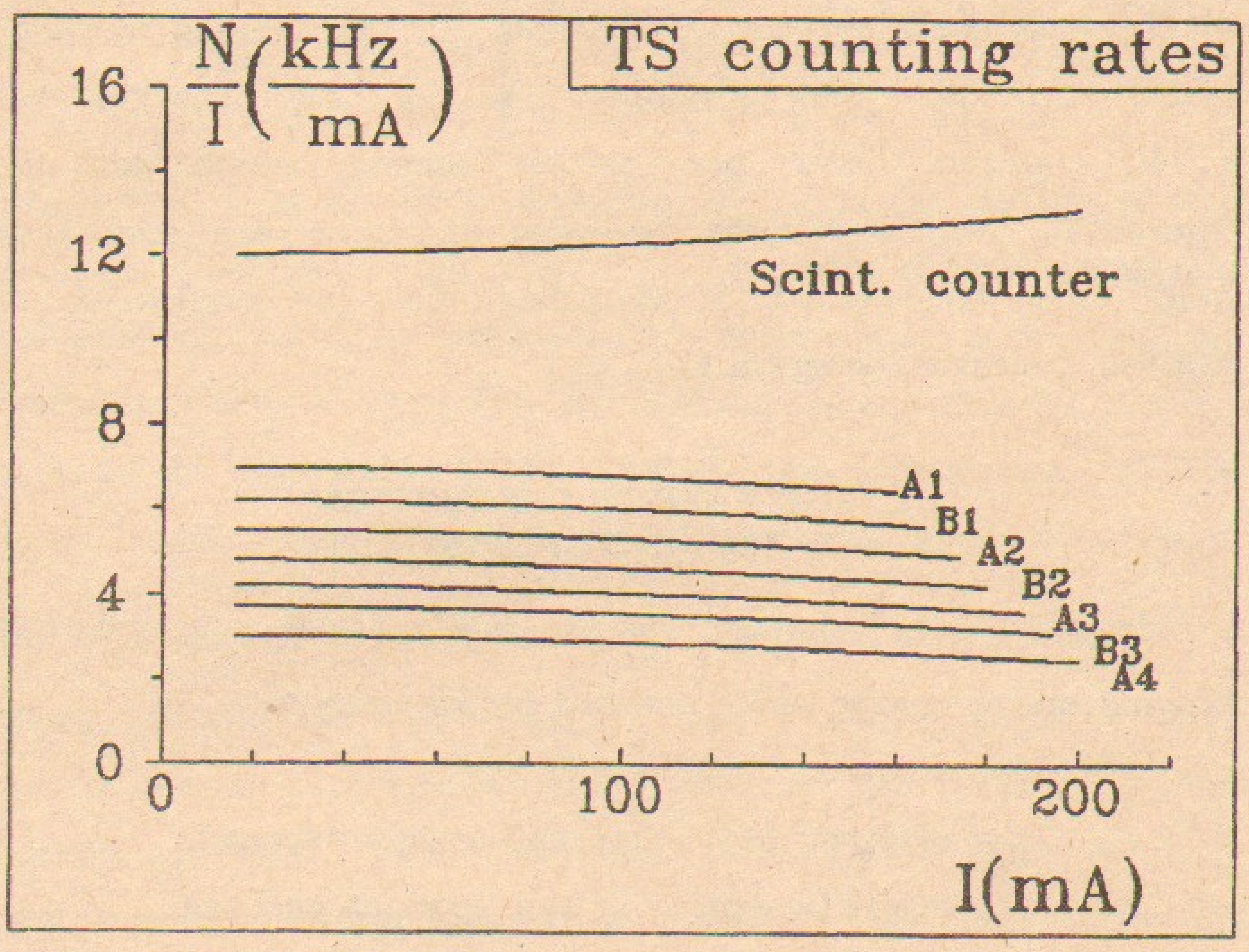

Fig. 5. Drift cells and scintillating counter counting rates as a functions of the electron beam current.

Counting rate of the scintillating counter against the electron beam current equals to the full counting rate of the registration system without events then two or more electrons pass the registration system simultaneously. One can see that the drift cells work with the maximal efficiency at the counting rates less than 1.2 MHz.

The speed of the recording into computer memory depends on the full time of the CAMAC electronics survey. This value is of about $2 \cdot 10^3$ events per second. So the tagging spectrometer provides the possibility to tag the energies of $1.5 \cdot 10^6$ gamma rays per second among which all the interesting events can be recorded if there are less than $2 \cdot 10^3$ ones per second. It is enough for the realization of ROKK-2 research program [1].

5. THE ENERGY RESOLUTION OF THE TAGGING SPECTROMETER

Factors influencing the energy resolution of the tagging spectrometer are discussed below, they are:

i) the electron beam energy spread;

ii) the electron beam size and angular spread;

iii) the magnetic optics in the straight section;

iv) the drift chambers spatial resolution;

v) the electronics time resolution.

a) Transformation of the Compton spectrum.

To measure the energy resolution we restored the Compton spectrum high energy edge by means of tagging spectrometer. It is easy to show that in the first approach the energy spectrum of the Compton gamma rays $\frac{d\sigma_c}{d\omega}$ is transformed due to the energy resolution of the tagging spectrometer $\Delta\omega$ as:

$$\frac{d\sigma'_c}{d\omega} \approx \frac{d\sigma_c}{d\omega} \cdot \frac{1}{2} \left[1 - \mathrm{erf}\left(\frac{\omega - \omega_{max}}{\sqrt{2}\,\Delta\omega} \right) \right] \qquad (1)$$

where erf( ) is an error function, ω_{max} is the energy of the Compton spectrum high edge. The results of the numerical calculations in the interesting kinematical case has no visible deflections from the curve given by equation (1).

It is necessary to note that the parameters of the laser system do not contribute to the measurement accuracy. Introducing parameter $\Lambda = \frac{4 \cdot \gamma \cdot \omega_0}{m \cdot c^2}$ the doubled relative photon energy in the electron rest frame (which equals 0.07 for ROKK-2 conditions) where ω_0 is the initial photon energy, γ, $m \cdot c^2$ are the relativistic factor and electron rest energy respectively one can write. The contribution of all these parameters to the relative resolution of the tagging spectrometer as:

$$\frac{\Delta\omega}{\omega} = \sqrt{\left(\frac{2+\Lambda}{1+\Lambda}\right)^2 \cdot \left(\frac{\Delta\gamma}{\gamma}\right)^2 + \left(\frac{1}{1+\Lambda}\right)^2 \cdot \left(\frac{\Delta\omega_0}{\omega_0}\right)^2 + \left(\frac{\Delta\alpha}{2}\right)^4} \qquad (2)$$

where $\frac{\Delta\gamma}{\gamma}$, $\frac{\Delta\omega_0}{\omega_0}$ are the relative energy spreads at the electron and laser beams respectively, $\Delta\alpha$ is an average value of the angular distribution between initial directions of the photon and electron momenta. For the ROKK-2 parameters $\Delta\alpha$ is determine by an angular distribution in the electron beam. Its value is of about $2 \cdot 10^{-3}$. Taking into account that $\Delta\alpha$ has the next order in eq. 2 than $\frac{\Delta\gamma}{\gamma}$ one can neglect this contribution. Linewidth of the argon laser $\frac{\Delta\omega_0}{\omega_0}$ used at ROKK-2 facility is less than 10^{-6} so one can neglect this parameter too. The values of $\Delta\alpha$ and $\frac{\Delta\omega_0}{\omega_0}$ become significant when the necessity to obtain high power in the light wave requires focusing and time compression of the laser pulses [12]. For the VEPP-3 parameters $\frac{\Delta\omega}{\omega} \approx 2\,\frac{\Delta\gamma}{\gamma}$ it is of about $1.5 \cdot 10^{-3}$. This value is rather small to be taking into account then the gamma ray energy is tagged by the electron momentum measurement.

b) Influence of the magnetic structure parameters.

One of the main factors influence on the accuracy of the electron momenta measurements is the fact that the electron beam has the initial size, angle and energy spreads. Moreover scattered electrons enter the registration system after passing some trajectory in the magnetic field of the storage ring straight section (Fig. 1). Taking into account all of these factors the contribution to the energy resolution as a result of the spread of the points the electrons enter the registration system was calculated as a function of the value of momentum loss and the scattering point in the straight section (Fig. 6). Total alteration

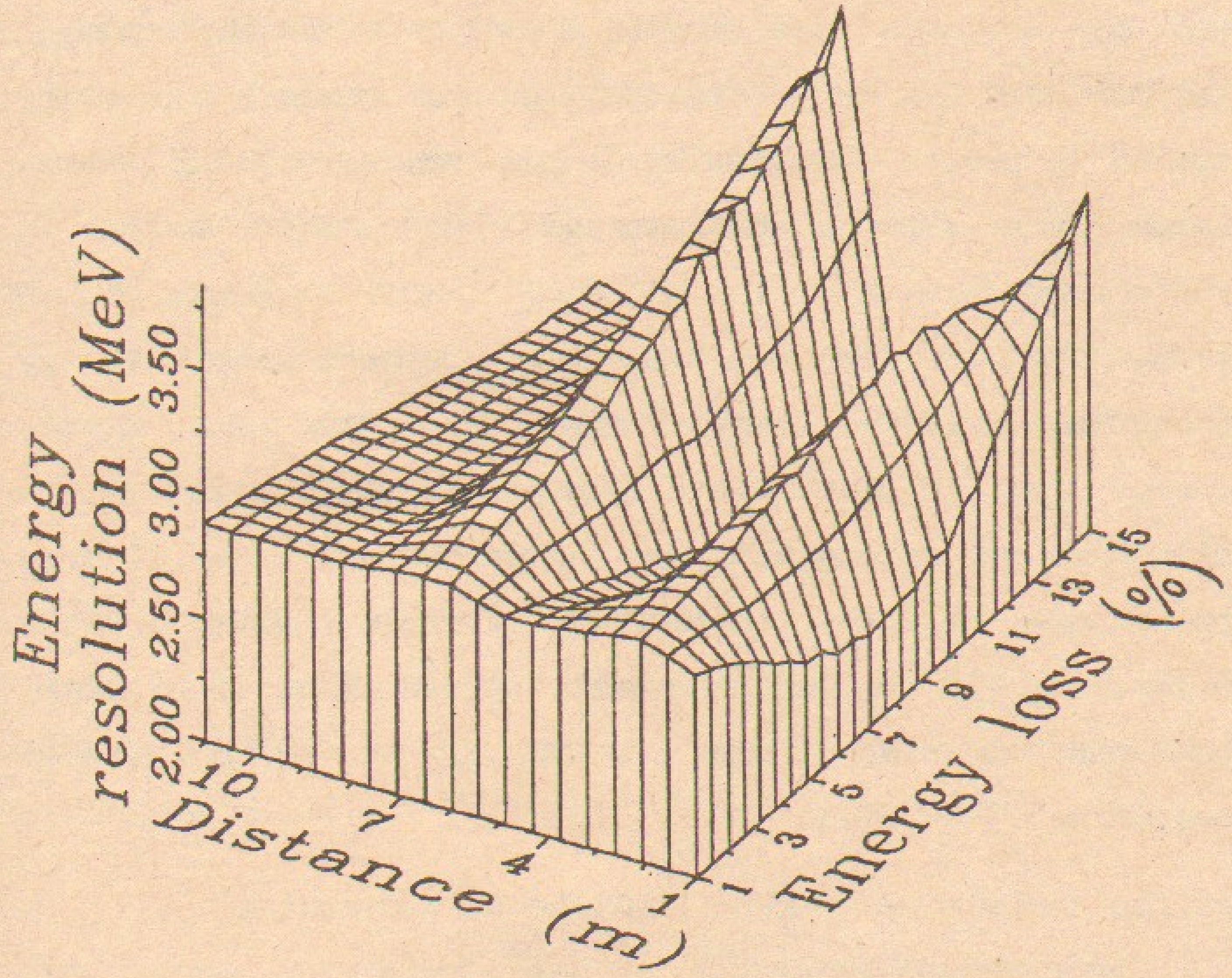

Fig. 6. Electron beam parameters contribution to the energy resolution of the tagging spectrometer as functions of the energy loss value and location of the interaction point inside the storage ring straight section. Tagging spectrometer is in the end of the section.

range of the calculated value is lying between 0.7 mm and 1.27 mm. That carry out a contribution to the energy resolution of the tagging spectrometer of 2 - 3.5 MeV. In Fig. 6 one can see the area in the first part of the straight section (the nearest to the registration system) where the spread is practically constant in the whole range of energy losses. This part of the storage ring straight section in preferable for the arraignment of the electron-photon interaction for the constant tagging spectrometer energy resolution in whole energy range. When the value of the energy loss is small the electron entering points coordinate spread is constant and equals 2.8 MeV (the electron beam size at the registration system position point is 0.95 mm). The average coordinate spread value is of about 1.0 mm that carry out the contribution to the energy resolution $\Delta E \approx 3$ MeV.

c) The registration system instrumental resolution.

Instrumental resolution of the registration system was measured as following. When the deflected electron crosses the registration system (the drift gap and the scintillating counter) drift times sum in two cells of the same gap equals to maximum drift time 220 ns. So the two-dimensional distribution of such events (the axis represent the drift time in the cells) should be located near the line Y = 220[ns] - X.

The experimental distribution is represented in Fig. 4.

Width of the distribution is the spatial resolution of the registration system. It includes also the time jitter of the scintillating counter which must be subtracted. It was measured independently and consists of about 5 ns. The events lying above the area are determined by two electrons passing trough the same gap simultaneously.

Find instrumental time resolution varies from 11 ns for A3 & B3 drift gap up to 14 ns for A1 & B1 one. In the energy scale of the registration system this time jitter equals to 1.3 MeV - 1.7 MeV. So the registration system has an instrumental resolution of about 1.5 MeV.

So one can calculate the energy resolution of the tagging spectrometer. As all the factors have independent reasons we need to take the squared sum of the values. Calculated value of the average tagging spectrometer energy resolution is 3.4 MeV.

6. MEASUREMENTS

To demonstrate the tagging spectrometer operation a part of Bremsstrahlung spectrum measured by the total absorption spectrometer is shown in Fig. 7 curve 1. Curve 2 represents the same part of the spectrum where the events, registered by the tagging spectrometer are subtracted. The registration efficiency of the tagging spectrometer can be

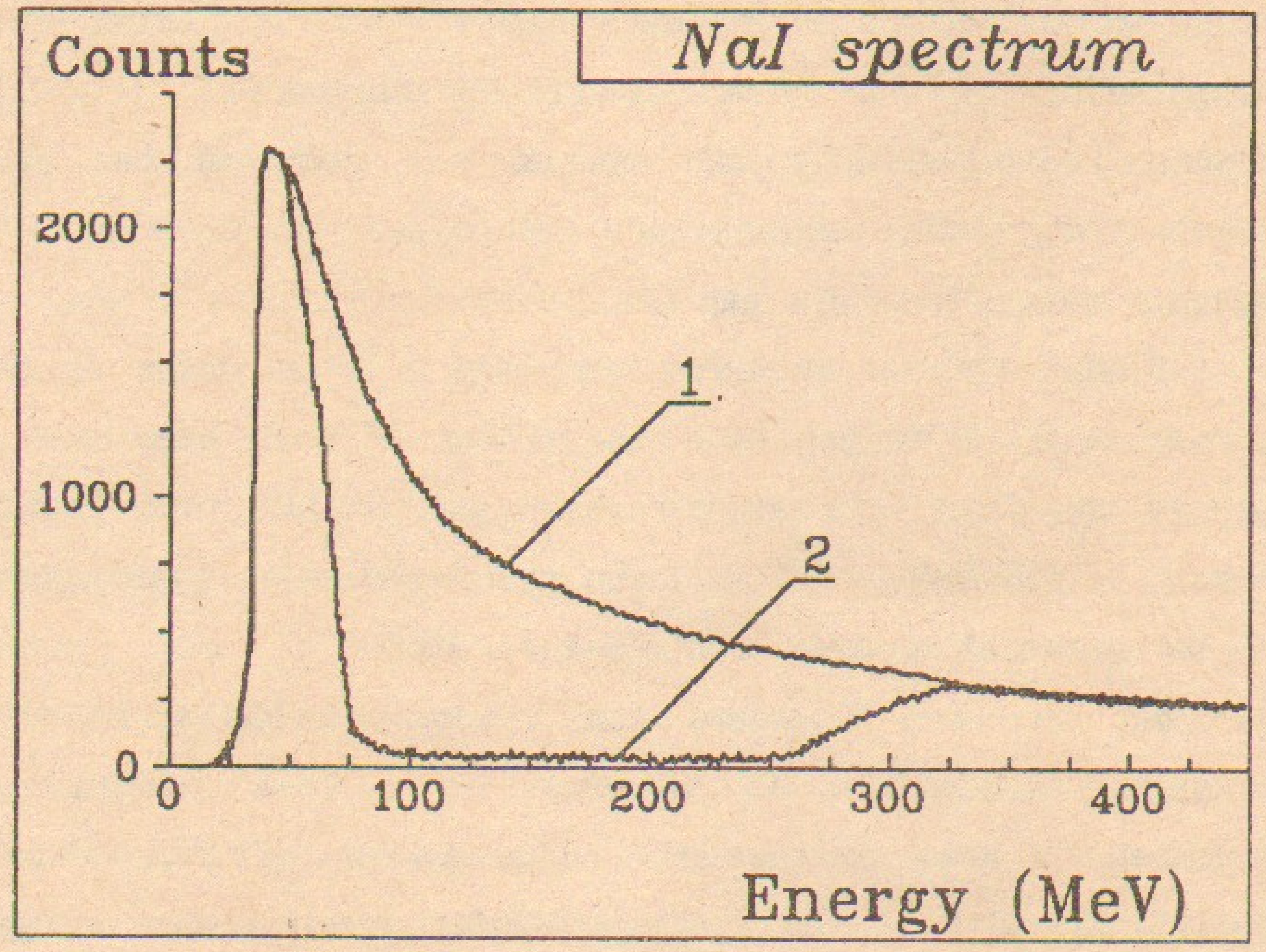

Fig. 7. The part of the Brems. spectrum measured by NaI total absorption spectrometer. Curve 1 is the Brems. spectrum, curve 2 is the same part of the spectrum in anticoincidence with the tagging spectrometer.

calculated dividing number of events in every point of curve 1 by the number of events in the same point of curve 2. Find registration efficiency of the tagging spectrometer is of 95% at low electron beam current at the storage ring. The two-dimensional histogram of the events registered by the tagging spectrometer in horizontal axis and NaI total absorption spectrometer in vertical axis is shown in Fig. 8.

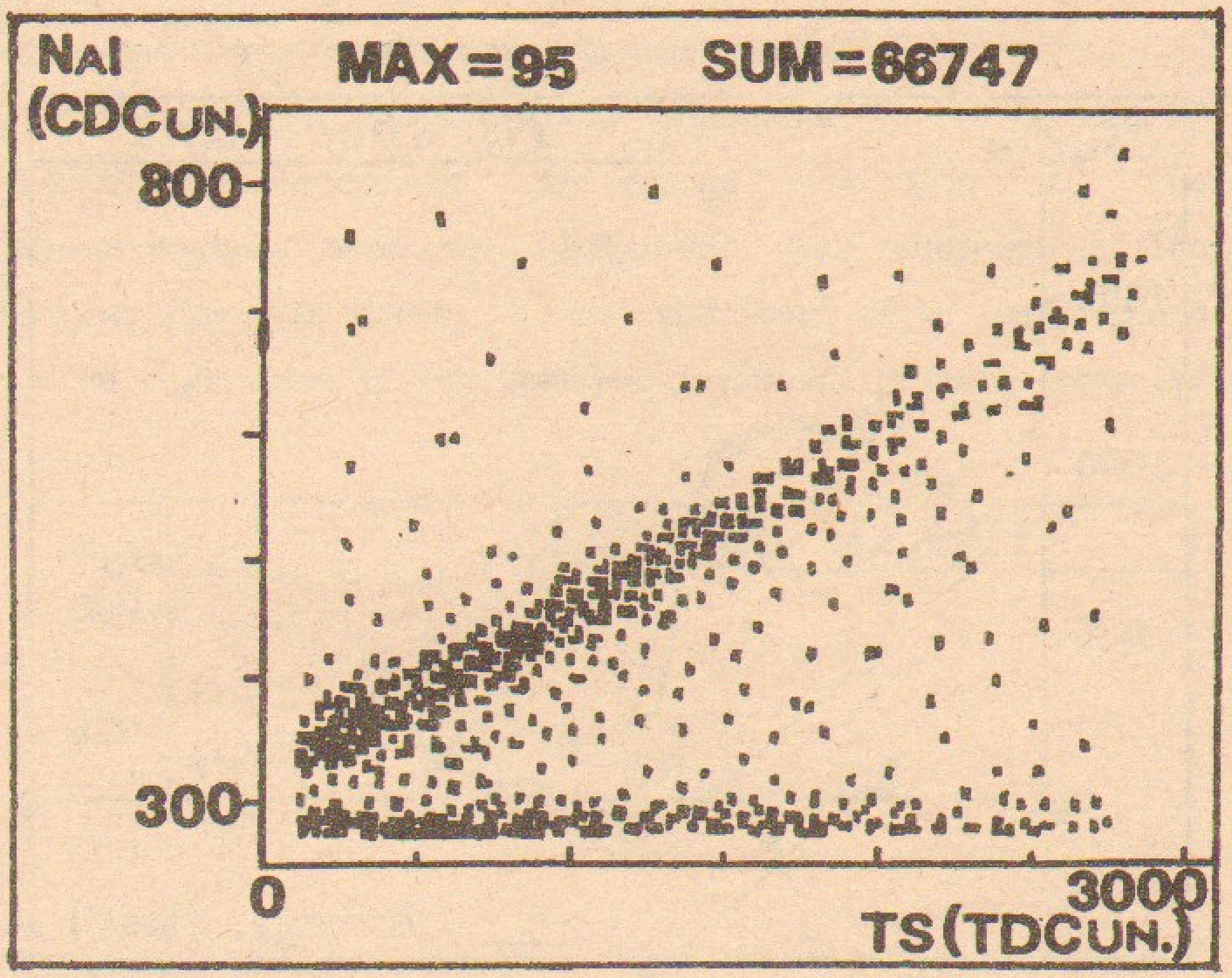

Fig. 8. The gamma ray energy measured by NaI total absorption spectrometer and tagging spectrometer.

The main part of the gamma ray energies is measured equal by the NaI spectrometer and by the tagging spectrometer. The area in the bottom of the figure is a result of the fact that some of the gamma rays do not reach the total absorption spectrometer. The width of the distribution in Fig. 8 is dominated by the NaI spectrometer energy resolution.

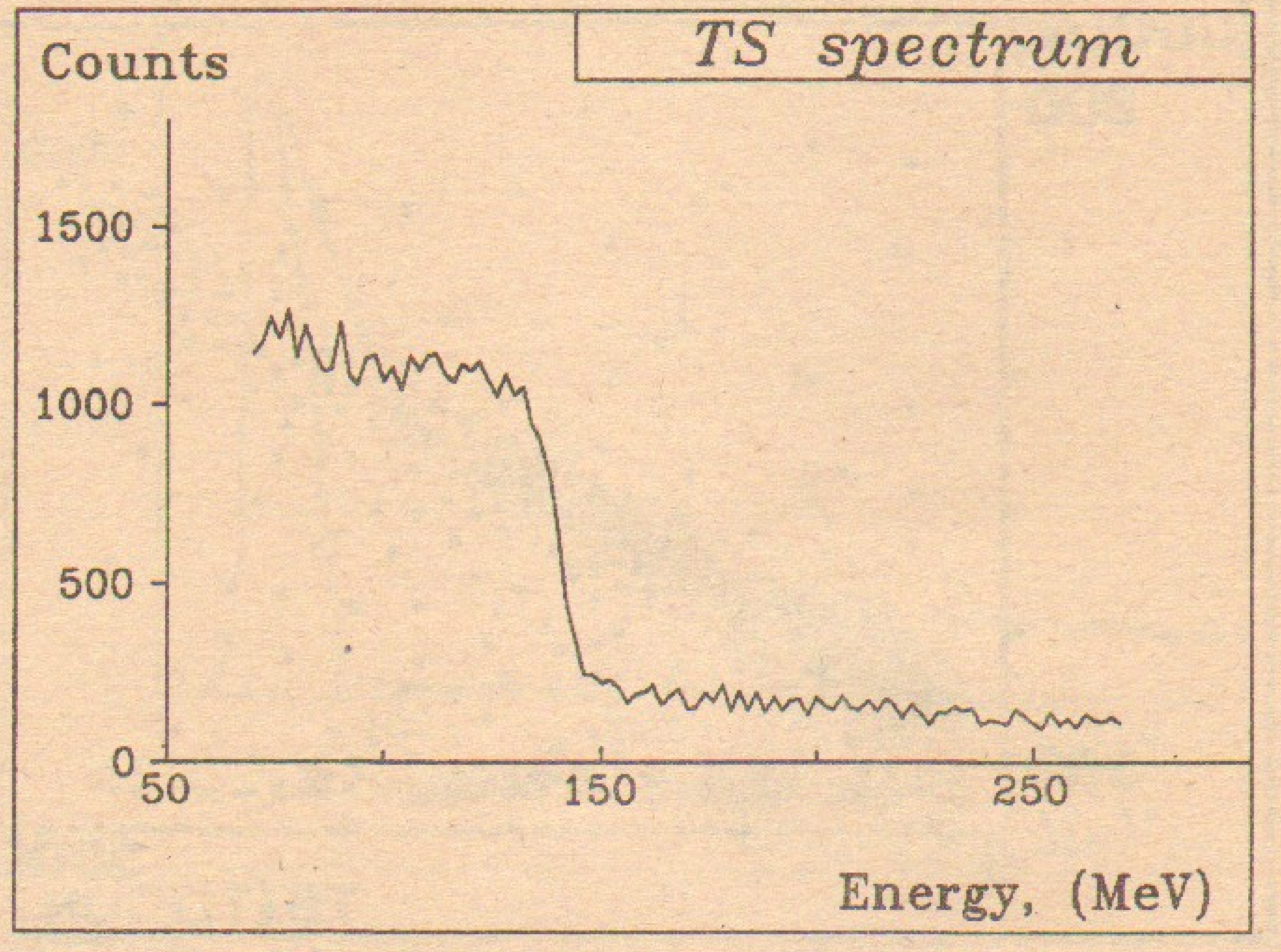

Fig. 9. Compton electrons energy loss spectrum restored by tagging spectrometer.

The Compton electron spectrum restored by the tagging spectrometer is represented in Fig. 9. In detail the high bound of the energy spectrum is shown in Fig. 10. Curve 1 corresponds to the laser initial photon wavelength 488 nm, curve 2 corresponds to the laser initial photon wavelength 514 nm, curve 3 represents part of the Bremsstrahlung spectrum in the energy range of the drift gap measuring. One

can see the resolution of two Compton spectra with 5% differences in the initial photon wavelength.

The energy resolution was determine by the spread of the Compton spectrum high energy edge (Fig. 10). The Bremsstrahlung spectrum background was subtracted. The tangent line was drown in the bend point which corresponds to the edge value of the Compton spectrum. It must cross the

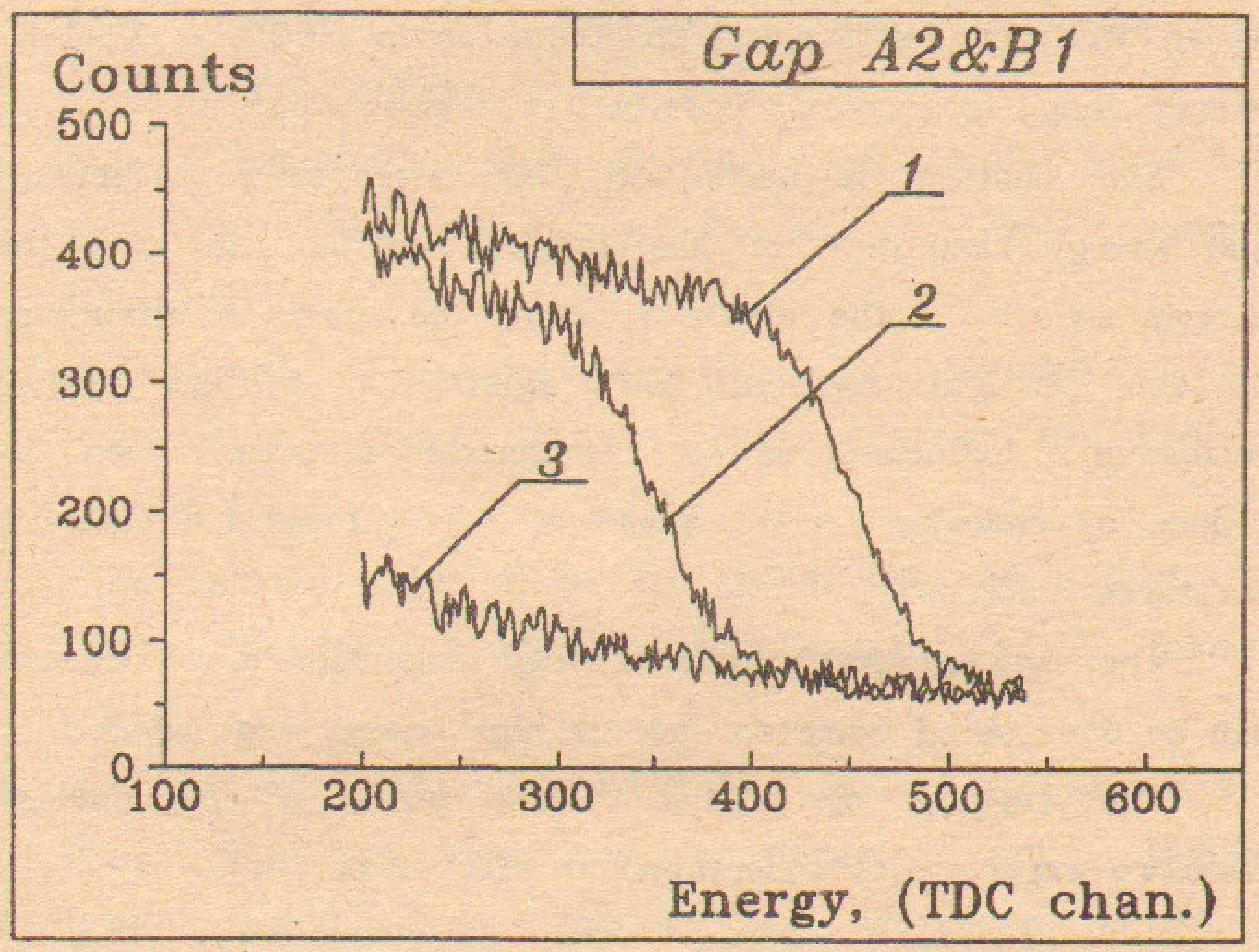

Fig. 10. Measured spectra of the Compton electrons energy loss. Curve 1 corresponds to initial photon wavelength 488 nm, curve 2 to 514 mn, curve 3 to a part of Bremsstrahlung spectrum.

abscissa axes at the distance $2.5 \cdot \Delta\omega_{max}$ from ω_{max}. Find values are: 3.9±1.0 MeV (curve 1); 4.2±1.0 MeV (curve 2). It consists of about 1.7% of the upper edge of the tagging spectrometer energy range. The measurements error of 1.0 MeV has a statistical origin.

7. CONCLUSION

So the usage of the magnetic structure bending magnet as an analyzer for tagging spectrometer in (0.015 - 0.14) E_o energy range is perfectly possible.

The factors influence on the registration efficiency and energy resolution of the tagging spectrometer are the energy spread in the electron beam; the magnetic structure of the straight section; the registration system spatial resolution. Influence of the magnetic structure can be reduce by choosing of the areas of straight section focusing scattered electrons.

The tagging spectrometer energy resolution measurements can be done using Compton spectra high energy edge spread.

The tagging spectrometer was used in the nuclear research experiments undertaken at ROKK-2 facility.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the VEPP-3 machine group for their work during providing of the experiments. We thanks U.G. Ukraintsev for the assistance and D.I. Ivanov, V.G. Nedorezov, A.S. Sudov from the Moscow institute of Nuclear Research for the assistance and useful discussions.

REFERENCES

1. *G.M. Gurevich, G.Ya. Kezerashvili and V.G. Nedorezov.* Preprint INR P-0580, Moscow (1988).
2. *S.A. Belomestnykh, M.M. Brovin, N.A. Vinokurov et al.* Proc. 11th Nat. Conf. on Accelerators, vol.1, Dubna (1989), p.410.
3. *D.I. Ivanov, G.Ya. Kezerashvili, V.V. Muratov et al.* Preprint INR P-686, Moscow (1991); Preprint INR P-687, Moscow (1991).
4. *P.V. Vorobyev, A.A. Kazakov, G.Ya. Kezerashvili et al.* Proc. 8th Nat. Conf. on Accelerators, vol.2, Dubna (1983), p.272.
5. *A.A. Kazakov, G.Ya. Kezerashvili, A.N. Skrinsky et al.* Proc. 9th Nat. Conf. on Accelerators, vol.2, Dubna (1985), p.268; Proc. 2nd Intenat. Workshop on High Energy Spin Physics, Serpukhov (1985), p.140.
6. *A.A. Kazakov, G.Ya. Kezerashvili, L.E. Lazareva et al.* JETP Letters 40, (1984), p.445.

7. *L. Federici, G. Giordano, G. Matone et al.* Nuovo Cimento 59B (1980), p.247; Hadronic Jornal, 4 (1981), p.1295.
8. *C.E. Thorn, G. Giordano, O.C. Kistner et al.* NIM A285 (1989) p.447.
9. *D. Babusci, L. Casano, A. Dangelo et al.* Progress in Particle and Nuclear Physics 24(1989), p.119.
10. *B.M. Alexandrov, D.I. Ivanov, G.Ya. Kezerashvili, et al.* NIM, A288 (1990) p.399.
11. *V.A. Zapevalov, D.I. Ivanov, G.Ya. Kezerashvili, et al.* Prib. and Tekhn. Experim., Sov.J., 1 (1990) p.80.
12. *Ya.T. Grinchishin, M.P. Recalo.* JETP 84(5) (1983), p.1605; Sov. J. Nucl. Phys. 40(7) (1984), p.181.

G.Ya. Kezerashvili, A.M. Milov and B.B. Wojtsekhowski

The Gamma Ray Energy Tagging Spectrometer of Rokk-2 Facility at VEPP-3 Storage Ring

Г.Я. Кезерашвили, А.М. Милов, Б.Б. Войцеховский

Спектрометр мечения гамма-квантов по энергии установки РОКК-2 на накопителе ВЭПП-3

Ответственный за выпуск С.Г. Попов

Работа поступила 29 ноября 1991 г.
Подписано в печать 29.11 1991 г.
Формат бумаги 60×90 1/16 Объем 1,7 печ.л., 1,5 уч.-изд.л.
Тираж 290 экз. Бесплатно. Заказ N 118

Ротапринт ИЯФ СО АН СССР,
Новосибирск, 630090, пр. академика Лаврентьева, 11.