ИЯФ

ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

V.P.Druzhinin, V.B.Golubev, V.N.Ivanchenko,
P.M.Ivanov, G.Ya.Kezerashvili, I.A.Koop, A.N.Peryshki
S.I.Serednyakov, Yu.M.Shatunov and V.A.Sidorov

# TEST OF QUANTUM ELECTRODYNAMICS IN THE COMPTON SCATTERING OF QUASIREAL PHOTONS BY ELECTRONS AND POSITRONS AT THE VEPP-2M STORAGE RING



PREPRINT 84—62

НОВОСИБИРСК

ABSTRACT

The results of the experiment with the Neutral Detector at the VEPP-2M storage ring are presented. A process of Compton scattering of quasireal photons by electrons and positrons has been studied in the total energy range of $2E=1000\div1048$ MeV. The visible cross section of the process as well as the angular distributions are in good agreement with the predictions of quantum electrodynamics. The ratio of the visible cross sections for the Compton scattering of quasireal photons by electrons and positrons is equal to $0.99\pm0.02$. The limitations on the cross section of heavy electron production have been found.

The process of Compton scattering of a quasireal photon by a colliding electron was one of the first identified in the experiments with the Neutral Detector [1]. This process was first observed at the ACO storage ring in 1973 [2] with a total number of events less than 20. Later, about 150 events were recorded at ADONE [3]. In our experiment, the number of events is about $10^4$, allowing a detailed study of the reaction. The experiment was carried out at the VEPP-2M electron-positron storage ring [4] in the center of mass energy range $2E=1000\div1048$ MeV. The total integrated luminosity in the experiment is about 1.3 $pb^{-1}$.

A lay-out of the Neutral Detector [5] is shown in Fig.1. The main part of the detector is a shower electromagnetic calorimeter consisting of 168 scintillation counters with NaI(Tl) crystals [6]. Its total weight is equal to 2.6 tons and the minimum thickness along the particle path is 12 radiation lengths. In the centre of the detector there is a tracking system for charged particles composed of three layers of two-coordinate cylindrical proportional chambers [7]. Two layers of proportional «shower» chambers intended to measure the photon angles are installed in the gaps between the NaI(Tl) crystals. To suppress a background caused by cosmic particles, anticoincidence counters are installed outside the detector, separated from NaI(Tl) crystals by an iron absorber 10 cm thick. The total solid angle of the detector is about 65% of $4\pi$. The energy resolution of the detector for electrons and photons is determined by the amount of material between the NaI(Tl) crystals and is about 15% (FWHM) in the 300—500 MeV energy range. The angular resolutions (RMS) for electrons and photons are, respectively, 1.0 and 3.6 degrees for a polar angle and 0.7 and 1.7 degrees for an azimuthal angle.

In the lowest order of QED, the process of Compton scattering of a quasireal photon by a colliding electron is represented by the diagrams in Fig.2. This process is a particular case of single Bremsstrahlung when a virtual photon with the energy comparable with that of the beam is close to the mass shell $(q_\gamma^2 \sim -m^2)$. The kinematics of the process (Fig.3) is rather simple: one of the initial particles is deflected at a small angle $\alpha \sim 1/\gamma$ and remains undetected while another electron and photon are scattered at large angles. Let us refer to this process as virtual Compton scattering (VCS). Its theory in the Weizsacker-Williams approximation was developed in [8], a more detailed formula, which should hold in a broad angular range of the final particles [9,10] can be written in the form:

$$d\sigma^0 = \frac{4\alpha^3}{(2\pi)^2 E^2} F_e \delta(p_1 + p_2 - p_3 - p_4 - k) \frac{d^3 p_3}{2\varepsilon_3} \frac{d^3 p_4}{2\varepsilon_4} \frac{d^3 k}{2\omega}$$

$$F_e = W \frac{ss'(s^2+s'^2) + tt'(t^2+t'^2) + uu'(u^2+u'^2)}{k_1 k_2 k_3 k_4 ss'tt'} \qquad (1)$$

$$s = (p_1+p_2)^2; \quad s' = (p_3+p_4)^2 \quad t = (p_2-p_4)^2; \quad t' = (p_1-p_3)^2$$

$$u = (p_2-p_3)^2; \quad u' = (p_1-p_4)^2; \quad k_n = 2(kp_n)$$

$$W = u(st+s't') + u'(st'+s't) + 2(s'tt' + stt' + ss't' + ss't)$$

where $E$ is the centre of mass energy and $\omega$ is a photon energy. Formula (1) is exact when $(|t|, |t'|, s', k_n) \gg m^2$, however in the VCS case these conditions for $|t|$ or $|t'|$ are not valid and so that the accuracy of the formula (1) does not exceed 5% in the total cross section due to the neglection of the terms of the order of $m^2/E^2$. Specially for the present paper the authors of Ref.10 have obtained the correction (2) taking into account such contributions asymptotically.

$$d\sigma = d\sigma_0(1+\Delta) \qquad (2)$$

$$\Delta = \frac{m^2}{t} \frac{x^2}{1-x+x^2/2} + \frac{m^2}{t'} \frac{y^2}{1-y+y^2/2}; \quad x = \frac{k_3}{s}; \quad y = \frac{k_4}{s};$$

The above formula with this correction has an accuracy of about 2% associated with the contributions of higher orders of QED.

Investigation of VCS allows to check QED at $e^+e^-$ colliding beams in a region, where cross section is determined by behaviour of the electron propagator at large positive $q_e^2$ in contrast to the Bhabha scattering, $\mu^+\mu^-$-production and two-photon annihilation. This region is also of interest for the search of suggested by Low [11] heavy or «excited» electron $e^*$ (HE) decaying into $e+\gamma$. The differential cross section $e^+e^- \to e^+e^{-*}$ [12] is determined by the diagrams in Fig.4 and can be written in the form:

$$d\sigma^- = \frac{\alpha^2\lambda^2}{2sM}\left\{-4u - \frac{s+t}{st}(s^2+t^2+u^2)\right\}\left(1-\frac{M^2}{s}\right)do^+ \qquad (3)$$

$$s = (p_+ + p_-)^2; \quad t = (p_+ - p'_+)^2; \quad u = (p_- - p'_+)^2;$$

where $M$ is a mass of HE and $\lambda$ is a dimensionless coupling constant. The cross section for the heavy positron production ($d\sigma^+$) can be derived from (2) with the help of evident substitutions. As seen from formula (3), the cross section of the process drastically increases with $|t|$ decreasing because of the contribution from the scattering diagram. In this case, just as in VCS, the final electron is deflected at a small angle and escapes detection. Thus the kinematic region of VCS is most suitable for a search for HE, which must reveal itself as a peak in an invariant mass distribution of the $e\gamma$-system. The width of this peak should be equal to an apparatus one, since the eigenwidth of HE is not higher than few KeV by known limitations on the parameter $\lambda$ [12].



One more specific feature of VCS kinematics is the possibility of unambiguous determination by which of initial particles the photon was scattered, i.e. the possibility of direct comparison of the VCS cross section for electron and positron. This provides a test of C-invariance of electromagnetic interactions.

To collect the VCS events from the sample the following selection criteria were applied:

1) the event contains one photon and one charged particle;

2) total energy deposition in the detector exceeds 400 MeV;

3) $\Delta\varphi$—acollinearity of an electron and photon in azimuthal direction is not larger than 15 degrees.

The selected events contain some background of two types: two-gamma annihilation with a conversion of one photon in the material before the tracking system and a background caused by decays $\Phi \to$hadrons. To suppress the background of the first type the events with the acollinearity in the beam plane $\Delta\theta = \pi - \theta_e - \theta$іню— less than 15 degrees were rejected. The background from $\Phi$-meson decays was additionally suppressed using the procedure of $\pi-e$ separation [13], based on the analysis of the energy depositions in NaI(Tl) layers. At a 90% efficiency for electrons, the $\pi$-meson background was suppressed by one order of magnitude and was less than 1% of 10000 selected events.

For comparison of the experiment and theory, the Monte Carlo simulation of VCS was performed using the formulae (1) and (2) and the simulation program [14]. This program after the generation of each event, i.e. determination of the energies and angles of the particles, simulates in detail their propagation through the detector material, taking into account ionisation losses, multiple scattering, development of the electromagnetic showers and real spatial resolution of the tracking chambers. The simulation of HE production with the cross section (3) was also done at several values of HE mass in order to find the detection cross section and the apparatus resolution for an invariant mass of the $e\gamma$ system.

The energy dependence of VCS cross section is shown in Fig.5. The experimental data is in good agreement with expected $1/E^2$ dependence, no bump is observed at the Φ-meson mass. At $2E = 1020$ MeV the visible cross section of VCS is equal to $6.96 \pm 0.15$ nb. The error contains the statistical one (1%) and the systematical uncertainty of the integrated luminosity value estimated to be 2%. The integrated luminosity during the data processing was calculated using the wide angle Bhabha and two-gamma annihilation events in the detector. The theoretical prediction for the cross section, obtained by the Monte Carlo simulation is equal to $6.74 \pm 0.18$ nb . An error here is determined by the simulation statistics (2%) and the contribution of higher orders of QED (about 2%), not taken into account. The ratio of the visible VCS cross section and the theoretical one is $1.03 \pm 0.04$.

Fig. 6 presents the $\Delta\varphi$ distribution of VCS events. Its width is much larger than an apparatus one and is eventually determined by the angular distribution of quasireal photons. The shape of the distribution is well consistent with the QED predictions. The distributions over the polar angles of electrons and photons (Fig.7), which are determined by the VCS dynamics and the detector acceptance are also in good agreement with QED calculations.

The visible cross sections of VCS by electron and positron were compared. The ratio $\sigma(e^+\gamma)/\sigma(e^-\gamma)$ is equal to $0.99 \pm 0.02$, while the angular distributions did not exhibit statistically significant differences, thus confirming the C-invariance of electromagnetic interactions.



Fig.8 shows the distributions over the invariant mass of $e\gamma$-system. A sharp decrease in the low mass region is of purely kinematical nature. It is associated with the impossibility for both final particles to be detected together. An excess of events in maximum mass region, which can imitate the HE production, is in fact connected with the residual background of two-quantum annihilation with conversion of one photon. For this reason, a search for the HE in this experiment is possible only in $500 \div 900$ MeV range of HE mass. Since the experimental distribution is in complete agreement with QED and does not contain any peaks, one can find the upper limit for the parameter $\lambda$, which is determined by the following formula:

$$\lambda^2 < \frac{2\sqrt{N}}{L\sigma^* \varepsilon} \qquad \text{(95\% confidence level)} \qquad (4)$$

Here $N$ is the number of VCS events in the 100 MeV interval of invariant masses that is equal to the apparatus resolution, $\varepsilon$ is the calculated detection efficiency of HE, $L$ is the integrated luminosity, and $\sigma^*$ is the total cross section for HE production with the mass $M$ and $\lambda = 1$. The results are presented in Fig.9. The upper limit on parameter $\lambda$, in $500 \div 900$ MeV HE mass range, obtained in this paper: $\lambda^2 \lesssim 3 \cdot 10^{-5}$ is roughly 5 times smaller than recent results given in [3,15] in this HE mass range.

The authors are indebted to E.A.Kuraev and V.S.Fadin for helpful discussions.

*REFERENCES*

1. *V.M.Aulchenko et al.*, Preprint INP 82-142, Novosibirsk, 1982.
2. *G.Cosme et al.*, Lett. Nuovo Cim. 8(1973)560.
3. *M.Spinetti*, Preprint LNF-79/25(P), 1979.
4. *G.M.Tumaikin*, Proc. of 10 International Conf. on High Energy Accelerators, V.1, p.443, Serpukhov, 1977.
5. *A.D.Bukin et al.*, Preprint INP 83-80, Novosibirsk, 1983.
6. *M.D.Minakov et al.*, Pribory i Tekhnika Experimenta, 4 (1980)58.
7. *V.B.Golubev, A.N.Peryshkin, I.Yu.Redko and S.I.Serednyakov*, Pribory i Tekhnika Experimenta 6(1981)40.
8. *G.Carimalo, P.Kessler and J.Parisi*, Nucl.Phys.B57 (1973) 582.
9. *F.A.Berends, R.Gastmas and T.T.Wu*, Phys. Lett. 103B (1981) 124.
10. *V.N.Baier, V.S.Fadin, V.A.Khoze and E.A.Kuraev*, Phys. Rep. 78(1981)2.
11. *F.E.Low*, Phys. Rev. Lett. 14(1965)238.
12. *G.I.Gakh, E.A.Kuraev and V.S.Panin*, Preprint INP 81-21, Novosibirsk, 1981.
13. *V.B.Golubev, V.P.Druzhinin, V.N.Ivanchenko and S.I.Serednyakov*, 3 International Conf. on Instrumentation for Colliding Beam Physics, Novosibirsk, 1984, March 15-21.
14. *A.D.Bukin and S.I.Eidelman*, Preprint INP 77-101, Novosibirsk, 1977.
15. *A.D.Bukin et al.* Yadernaya Fizika 35(1982)1444.




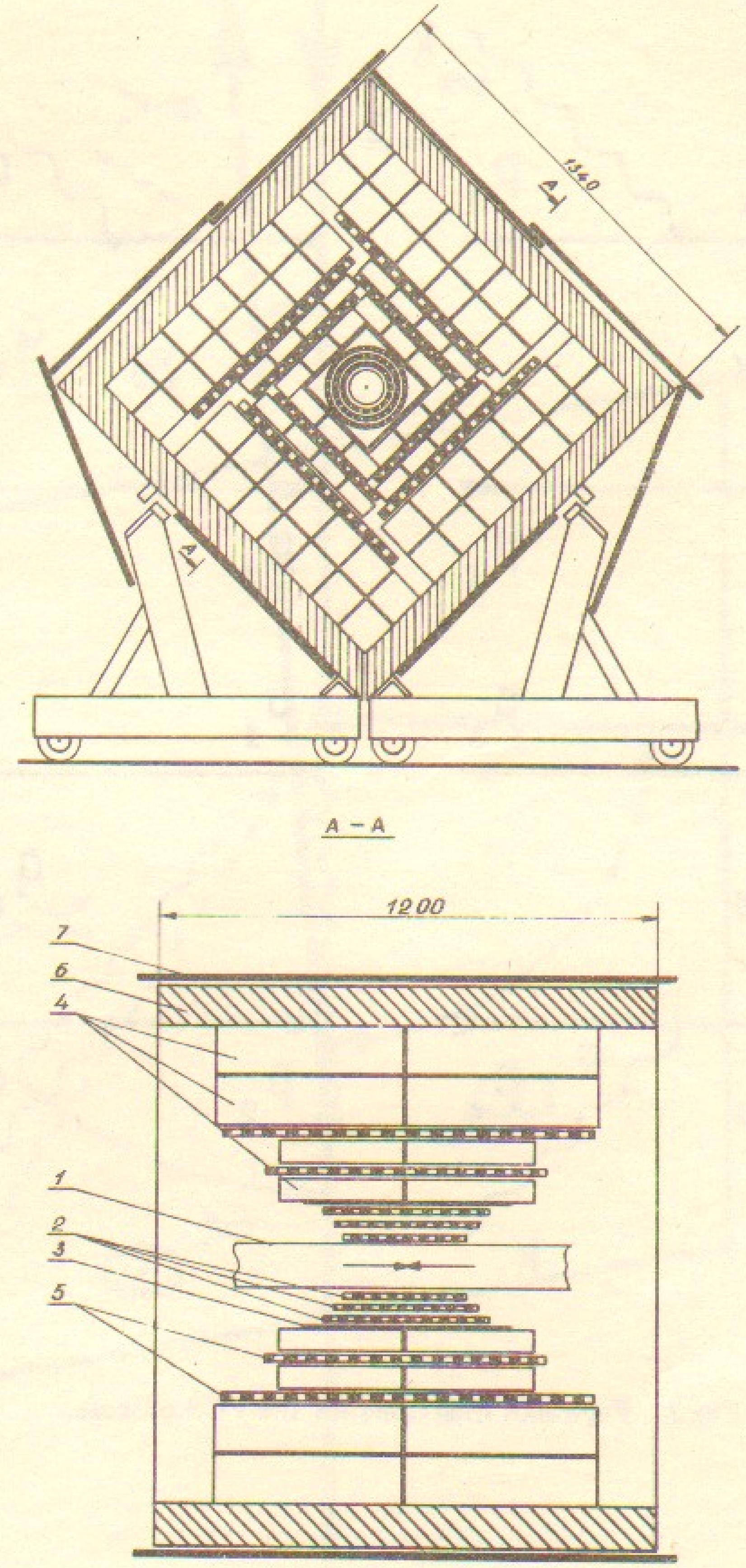


Fig.1. General lay-out of the Neutral Detector: 1—beam pipe of the storage ring; 2—coordinate proportional chambers; 3—scintillation counters; 4—scintillation counters with NaI (Tl) crystals; 5—proportional «shower» chambers; 6—absorber (10 cm Fe); 7—anticoincidence counters.

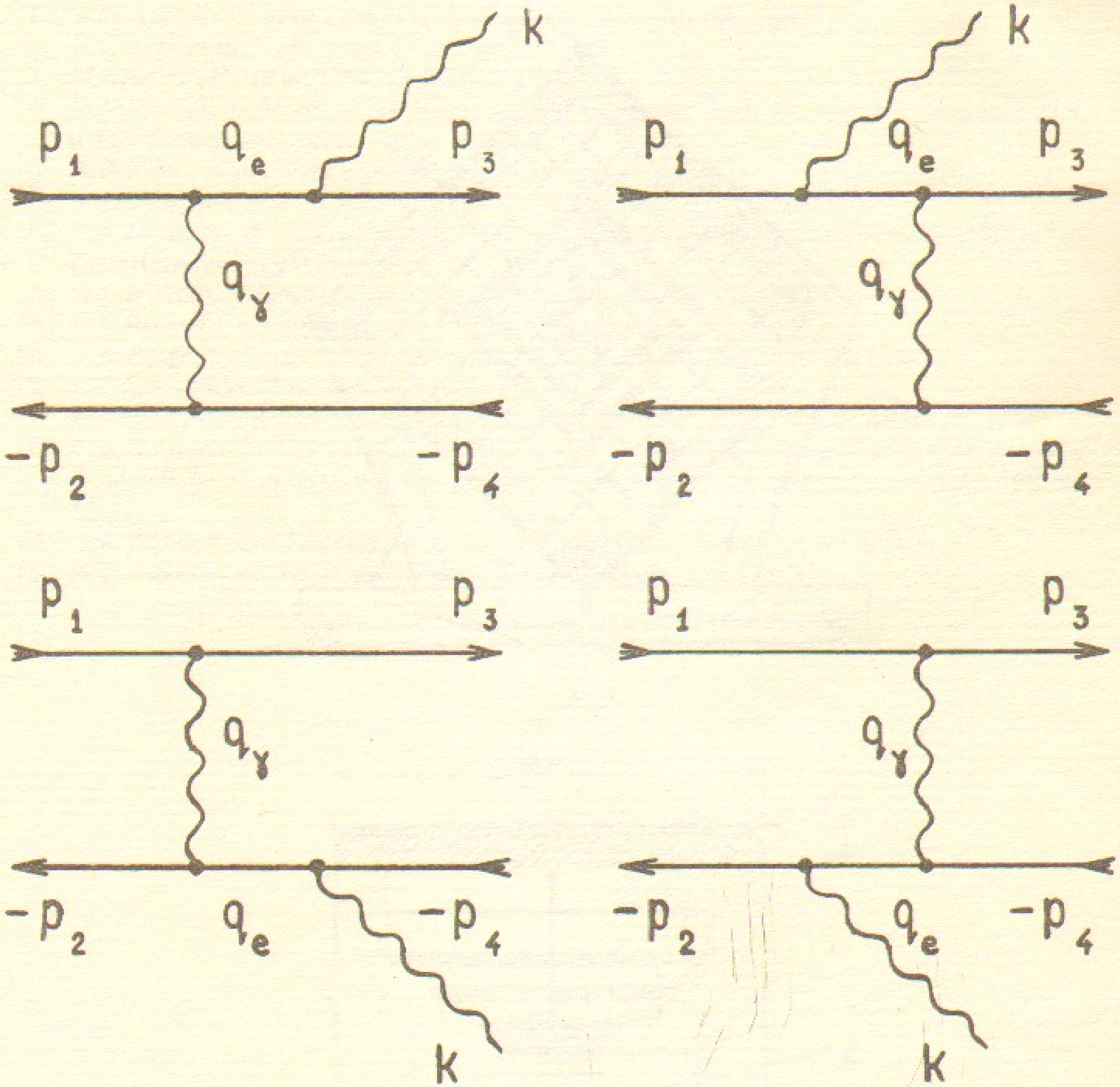


Fig.2. Feynman diagrams for the VCS process.



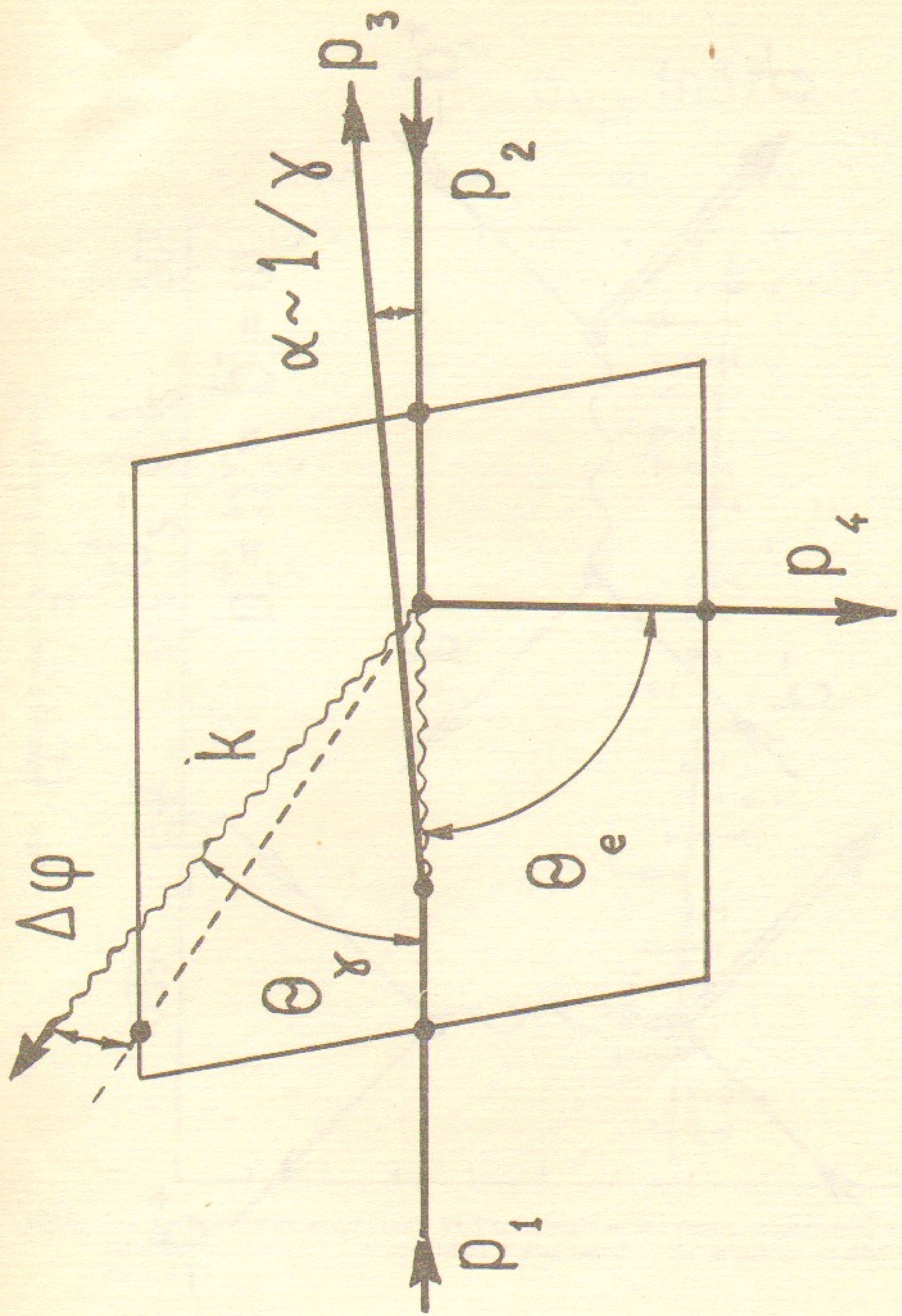


Fig.3. Kinematics of the VCS process.

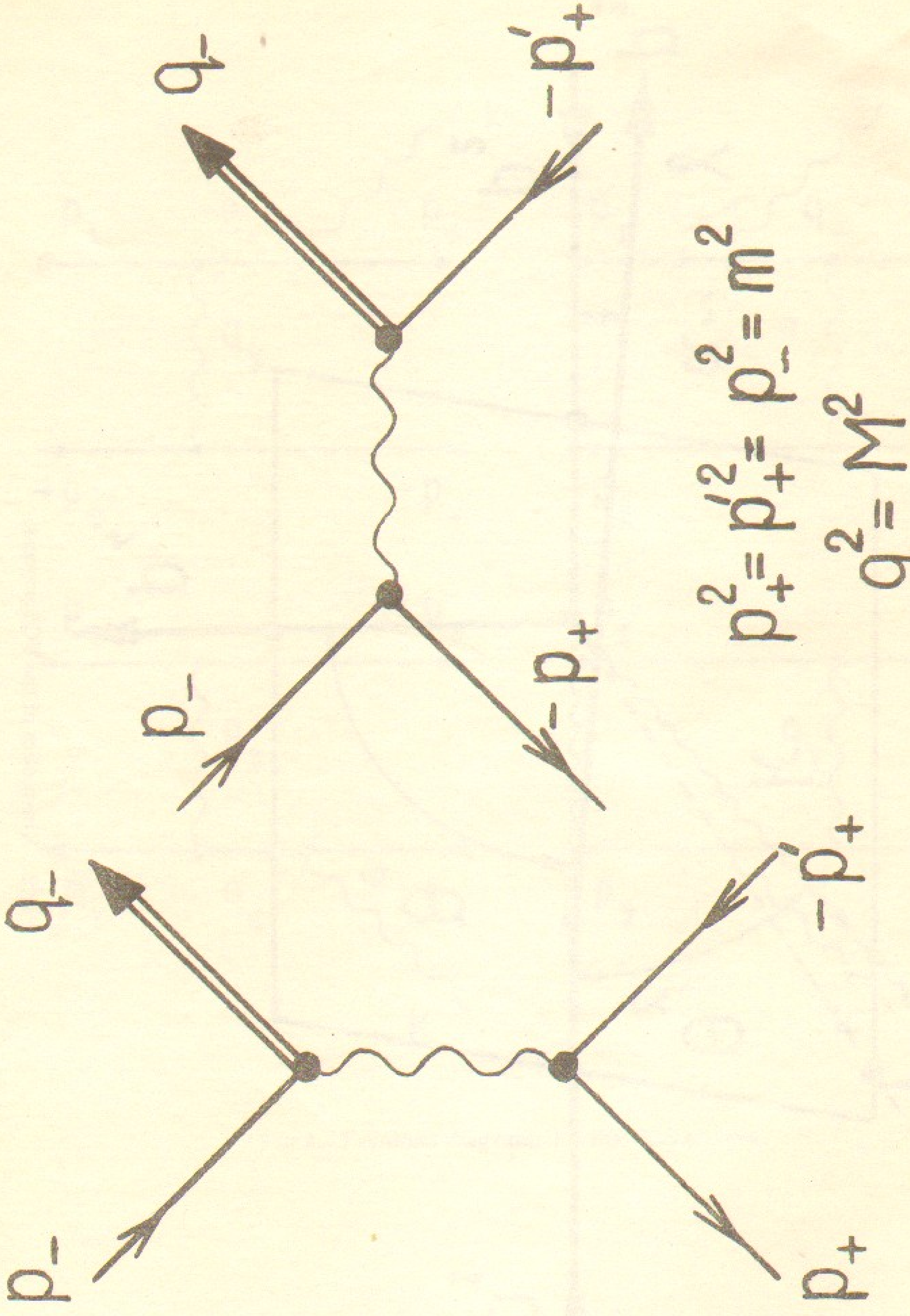


Fig.4. Feynman diagrams for HE production.



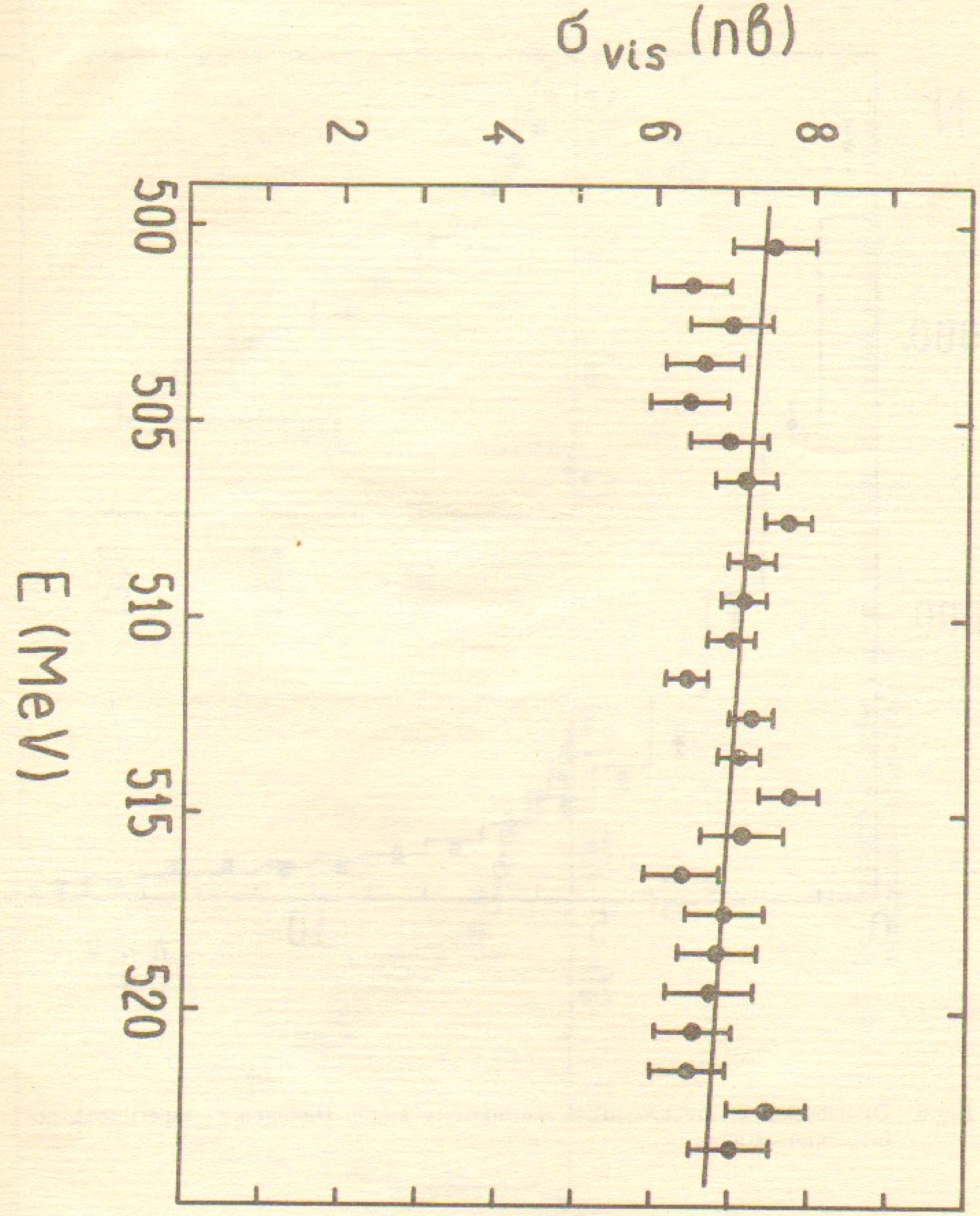


Fig.5. Energy dependence of the visible VCS cross section. The points—experiment, the solid line $\sigma(E) = A/E^2$. The coefficient $A$ was found by the maximum likelihood method.

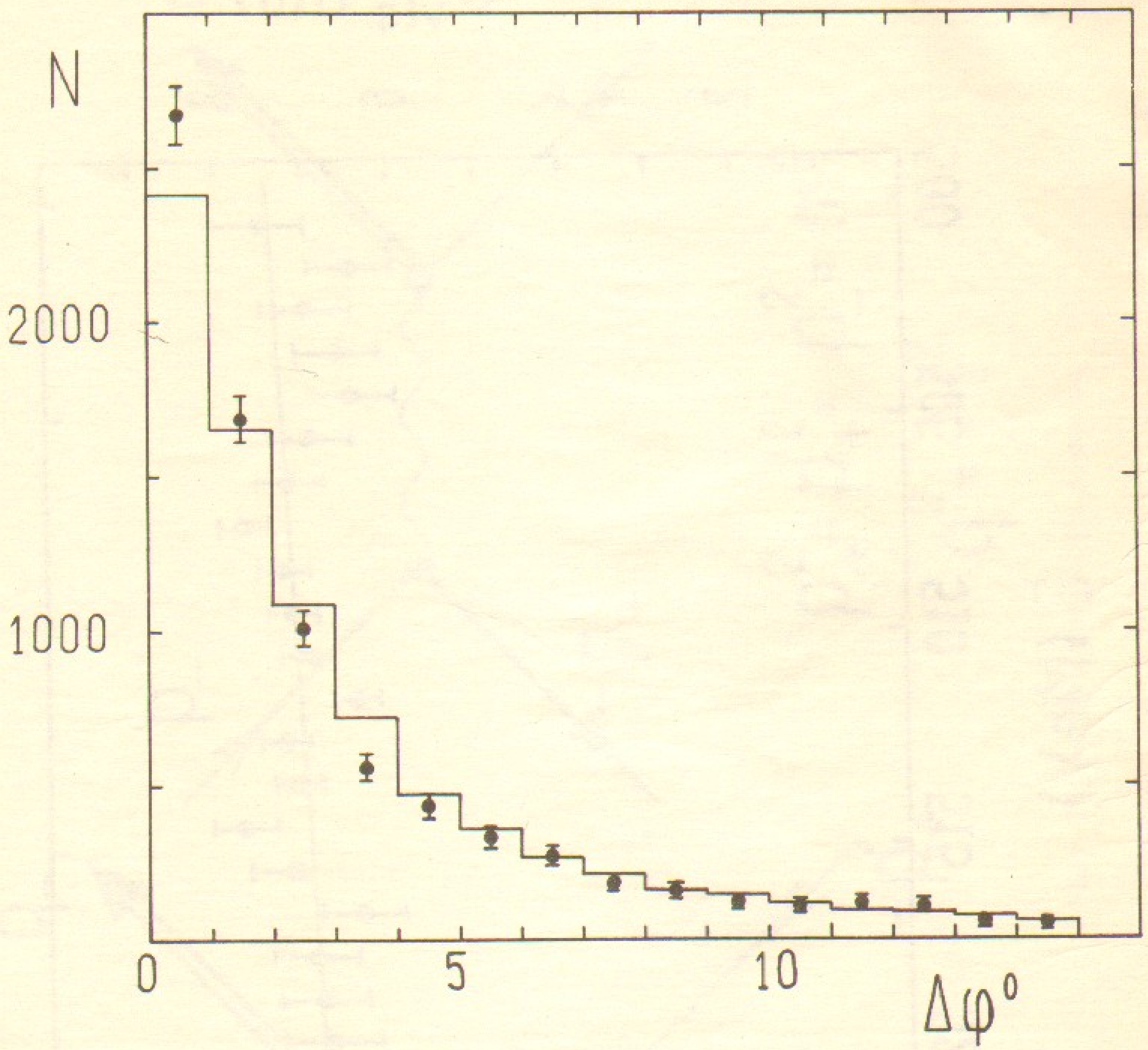


Fig.6. Distribution in the azimuthal acollinearity angle. Histogram—experiment, points—simulation.



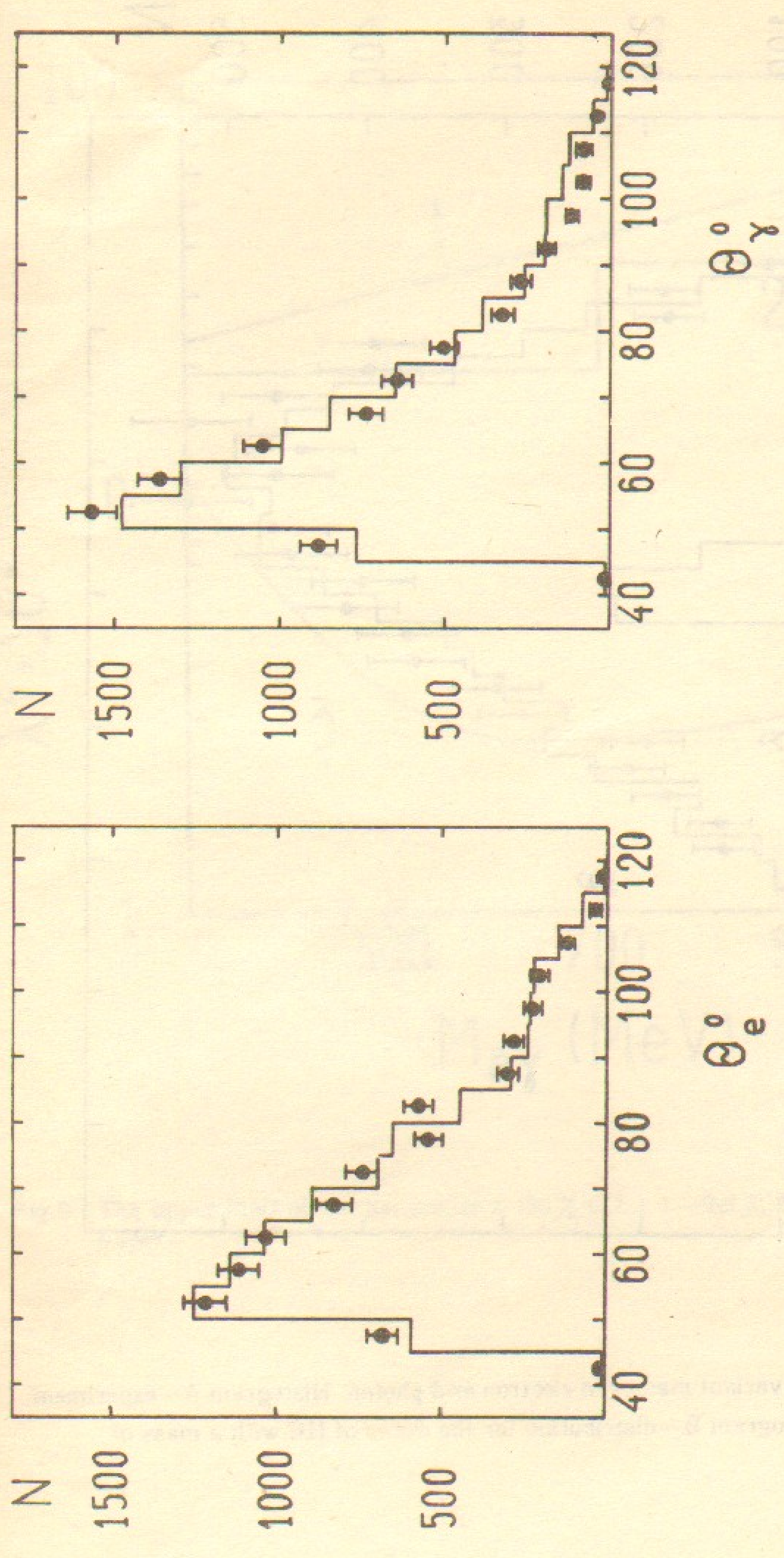


Fig.7. Distribution in the polar angle of an electron and photon. Histogram—experiment, points—simulation.

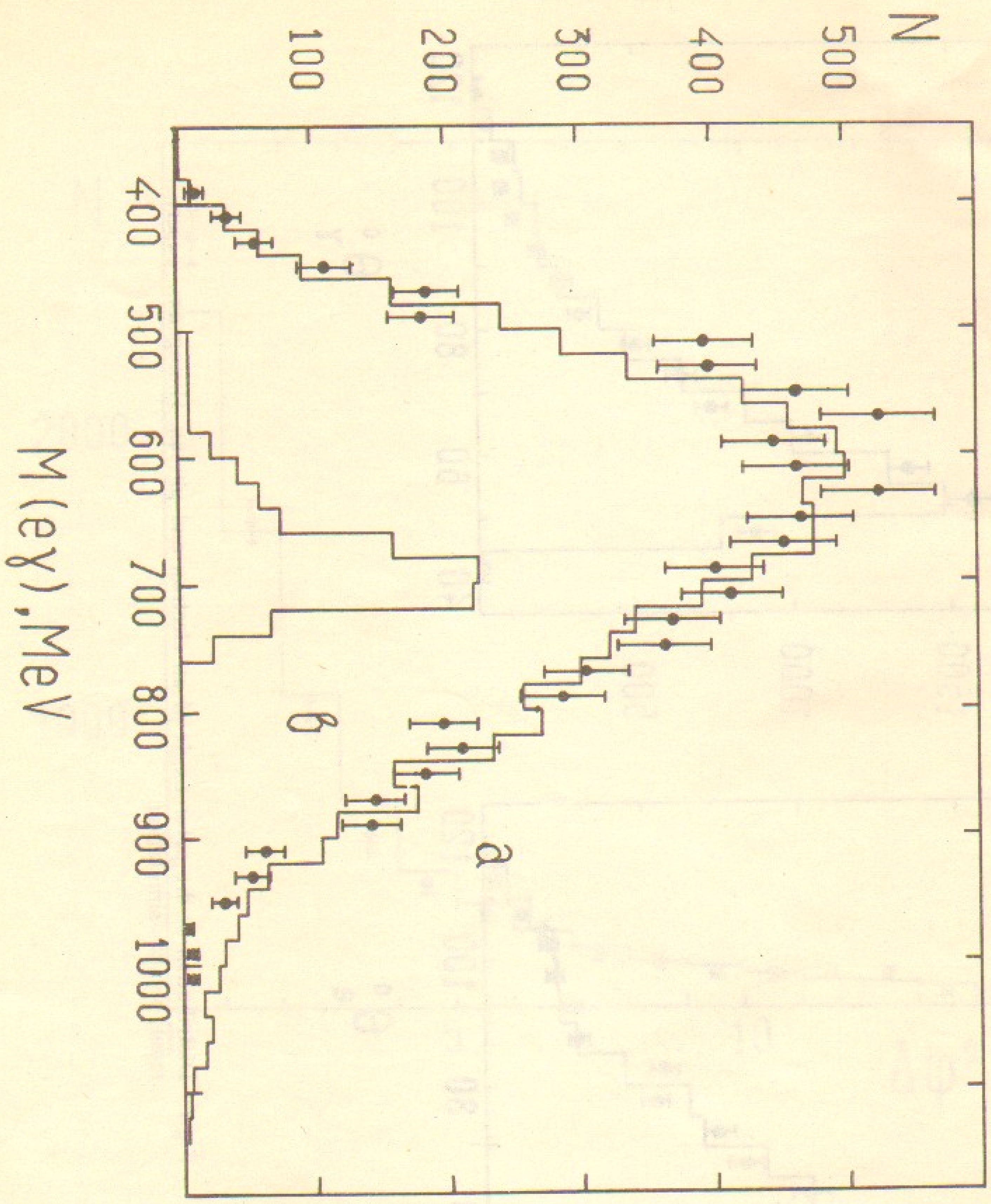


Fig.8 Spectrum of invariant masses of electron and photon. Histogram A—experiment, points simulation, histogram B—distribution for the decay of HE with a mass of 700 MeV (simulation).



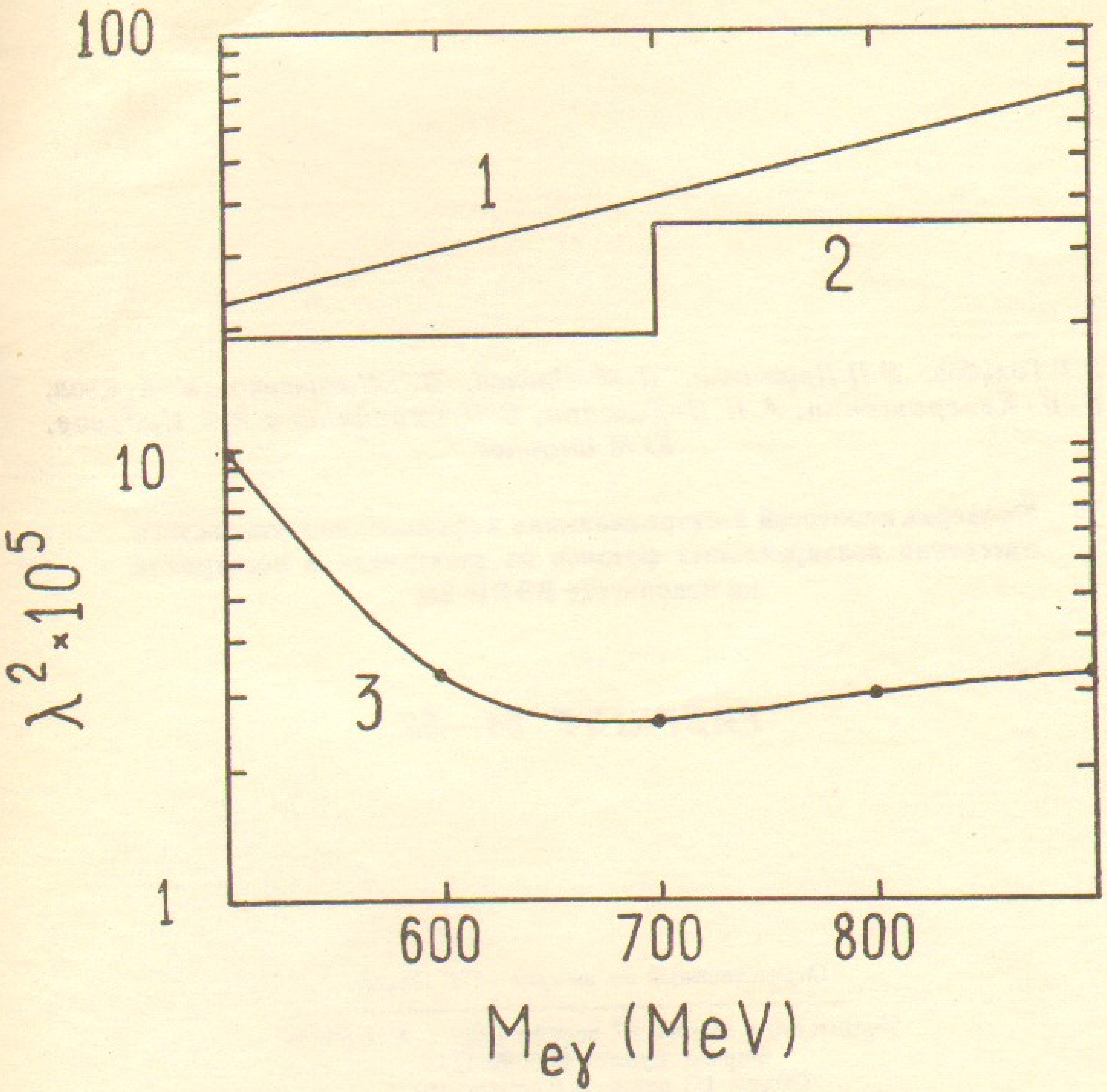


Fig.9. The upper limit of the parameter λ (95% C.L.) 1—Ref.3; 2—Ref.15; 3—present paper.

*В.Б.Голубев, В.П.Дружинин, П·М·Иванов, В.Н.Иванченко, И·А·Кооп, Г·Я·Кезерашвили, А.Н.Перышкин, С.И.Середняков В.А.Сидоров, Ю.М.Шатунов*

**Проверка квантовой электродинамики в процессе комптоновского рассеяния квазиреальных фотонов на электронах и позитронах на накопителе ВЭПП-2М**

***PREPRINT 84—62***

Ответственный за выпуск—С.Г.Попов

Подписано в печать 17 апреля 1984 г. МН 04241
Формат бумаги 60×90 1/16.
Объем 1,3 печ.л., 1,0 учетно-изд.л.
Тираж 290 экз. Бесплатно. Заказ № 62

*Набрано в автоматизированной системе на базе фотонаборного автомата ФА-1000 и ЭВМ «Электроника» и отпечатано на ротапринте Института ядерной физики СО АН СССР,*
*Новосибирск, 630090, пр. академика Лаврентьева, 11*