ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

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НОВОСИБИРСК

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Abstract

The experiment on the study of the process $e^+e^- \to e^+e^- + e^+e^-$ has been performed at storage ring VEPP-4 with the detector MD-1. The average value of an invariant mass of detected events was 2 MeV. Such small invariant masses became attainable due to the transverse magnetic field of the detector MD-1. The experiment was performed at the beam energy 2 x 1.8 GeV. The main background process is the e^+e^- pairs production by synchrotron radiation photons on electrons of the colliding beam. The contribution of this background is calculated to be 10%. The experimental results are in agreement with quantum electrodynamics calculations.

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1. Introduction

An interest to two-photon processes (Fig. 1a), as a mechanism of a particle production, occured in the beginning of the 30-th after the discovery of the positron by Andersen. In 1934 the cross-section of e^+e^- pair production via $\gamma\gamma$ mechanism in the collision of two charged particles was calculated by L.D.Landau and E.M.Lifshitz /1/

$$\sigma = \frac{28}{27\pi} \cdot (Z_1 \cdot Z_2)^2 \alpha^2 r_0^2 \ln^3 \frac{S}{M_1 M_2}$$

The process $ee \to ee+ee$ was observed for the first time in 1969 /2/ at the storage ring VEPP-2. During the data handling of ψ-meson experiment some events have been found that were not connected with ψ-meson. From the analysis it was determined, that these events could be ascribed to the process of two-photon production of e^+e^- pair. This process was observed also in the experiment, carried out at the storage ring VEPP-2 in 1970 with another detector and in other energy region /3/. Later in Frascaty at the storage ring ADONE the two-photon production of e^+e^- and $\mu^+\mu^-$-pairs was also studied /4/.

In the beginning of the 70-th a large number of theoretical papers appeared, where two-photon processes were studied in detail. The bibliography of these papers is given in reviews /5÷8/.

A new series of experiments on study of the two-photon lepton pairs productions at electron-positron storage rings started in the end of 70-th. The experiments at the storage rings DCI with detector DM-1 /9/, at SPEAR with detector MARK-II /10/, at PETRA with detectors PLUTO /11/, TASSO /12/, MARK J /13/, CELLO /14/ were performed. A review of these experiments is given in Ref. /8/.

A great number of experiments on the two-photon production of lepton pairs is due to the fact that these processes have large cross-sections, can be easily identified and calculated with necessary precision. The study of these processes is also of a great importance because due to their large cross-sections they represent the main background to many other processes. An agreement between experiment and calculation gives one a confidence in a procedure of data taking. When such measurements are carried out in a new kinematical region, they represent also a test of the quantum electrodynamics. The peculiar feature of our experiment is the magnetic field of MD-1 that is transverse to the plane of the beam orbit. The transverse field allows to detect and measure the momenta of particles outgoing even at zero angle. A detection of the produced particles at the small angles and with small momenta in the process under study means the detection of events with the small invariant masses, i.e. from the region of the main part of the production cross-section. In this experiment events with an average invariant mass of 2 MeV were detected. For the comparison at the detector DM-1 /9/ the minimum mass of the detected pair was 80 MeV, at the detector PLUTO - /11/ 800 MeV.

The main background process* in this experiment is the production of electron-positron pair by the synchrotron radiation photons on the electrons of the colliding beam $\gamma + e \to e + ee$. The counting rate of this process grows more rapidly with the increase of the beam energy than for the main one. At the beam energy of 5 GeV both counting rates are equal. For this experiment the beam energy was chosen equal to 1.8 GeV where the contribution of background process is about 10%.

2. The effective cross-section

The main contribution to the production of e^+e^- pair in two-photon process comes from the diagram of type A, shown in Fig. 1. The calculation of the total cross-section, taking into account the main diagrams with power accuracy on the energy, was done in Ref. /16/

$$\sigma = \frac{\alpha^2 r_0^2}{\pi}\left(1.03L^3 - 6.6L^2 - 11.7L + 104\right),$$

where $L = \ln(S/m_e^2)$.

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* A.E.Blinov et al., to be published.

This cross-section grows with increasing of the beam energy. At the energy $E = 1.8$ GeV it is equal $5 \cdot 10^{-27}$ cm^{-2}.

The contribution to the total cross section of the bremsstrahlung diagrams was calculated in Ref. /17/. At the beam energy of 1.8 GeV this contribution is 0.3%. Numerically small (-0.1%) contribution at this energy comes from the account of an identity in the final state /7/.

The differential cross section over the invariant mass of produced pair is given by the following expression /16/:

$$\frac{d\sigma}{dW} = \frac{16\alpha^2 r_0^2}{3\pi} \cdot \frac{m_e}{W^3} \cdot \ln^3\frac{S}{W^2}\left[2\ln\frac{W}{m_e} - 1\right].$$

One can see, that the main contribution to the cross-section comes from the low invariant mass region. The convenient expression for the invariant mass of produced pair is

$$W^2 = 2m_e^2 + 2\left(E_3E_4 - |\vec{P}_3|\cdot|\vec{P}_4|\cdot\cos\widehat{\vec{P}_3\vec{P}_4}\right),$$

where E_3, E_4 and $\vec{P}_3, \vec{P}_4$ - are the energies and momenta of the produced particles. From this follows, that low invariant masses mean small relative angles or small energies of produced particles.

To calculate the visible cross-section we used the programs, developed by Smith and Vermaseren /18/. These programs generate events with weights. Using the Neumann method, as usually, we obtained events with unit weights. The main problem here is the low efficiency of the method due to singularities of the differential cross-section. Using the simple kinematical cuts in /18/ we increased the efficiency of generation by factor 10.

The simulation of the detector response for events under consideration was done with the help of the general purpose simulation program for the experiments at e^+e^- colliding beams /19,20/ developed in our Institute. The complex geometry of the detector, electromagnetic showers, as well as low efficiency of events generation, all this produce a need in a lot of computer time. About 100 hours of ES 1061 CPU time were necessary to obtain the statistics of about 300 events.

3. Apparatus

The experiment was carried out at the storage ring VEPP-4 with the detector MD-1 /15/. The magnetic field of the detector is transverse to the orbit plane. Bending angle in the detector is 16 degrees. The strength of the magnetic field during the experiment was 5.4 kG. A lay-out of the detector is shown in Fig. 2. In the trigger and in the analysis the coordinate chambers and scintillation counters were used. For trigger it was required the firing of one or more scintillation counters and several coordinate chambers from both sides of the beam.

The vacuum chamber of the storage ring in the interaction region is a cylinder with radius of 40 cm and length of 1 m. The thickness of matter along particle trajectory form the interaction point to coordinate chambers is $0.085 X_o$.

For the detection of charged particles and measurement of their momenta the system of 38 proportional chambers with maximum size 0.9×0.9 m^2 was used. The anode wires step of chambers measuring a momentum is 2 mm, for the chambers measuring vertical coordinate - 4 mm. The total number of electronics channels is 12,000.

For the luminosity measurement the process of double bremsstrahlung was used. The photons were detected both in electron and in positron directions with NaI(Tl) counters, situated in 10 m from the interaction region. The counting rate at luminosity $4 \cdot 10^{27}$ cm^{-2} sec^{-1} was ~ 0.4 Hz. The uncertainty of the luminosity measurements was estimated to be $\pm 5\%$. This error is due mainly to inaccuracies in the knowledge of photons detection threshold.

4. Experiment

The experiment was performed in May 1984. During the experiment the parameters of the storage ring VEPP-4 were as follows: the energy $E = 1.8$ GeV, currents $I^{\pm} = 0.4$ mA, the average luminosity $L = 4 \cdot 10^{27} \text{cm}^{-2} \text{sec}^{-1}$. The luminosity was limited by the collisions effects, which did not permit to have electron and positron currents greater than 0.5 mA. A part of the time the experiment was carried out with separated beams to measure background conditions. In general 227,000 events were recorded on the magnetic tape when head-on collisions ("effect") and 41,000 when beams were separated ("background"). The ratio of recording time of "effect" to that of "background" was about 5.5. The integrated luminosity of 440 μb^{-1} was collected.

5. The data processing

Selection of the events was performed using spatial characteristics of charged particles, detected in the coordinate system. First of all, we required two charged particles to be detected from the interaction region of the sizes: 400 mm along the beam axis, 220 mm in the orbit plane and 100 mm in the vertical direction. After this selection 3,400 events in "effect" runs and 392 events in "background" runs remained.

Then a point on the beam axis, nearest to the track of each particle, was found, and the distance from the center of interaction region to this point was determined. The distribution over this parameter is shown in Fig. 3 for "effect" and "background" runs. The background distribution is normalized by the same total time as "effect" runs. The events with the distances more than 150 mm were rejected. The number of events remained was 1,300 events and 2 for "effect" and "background" runs respectively.

For the further analysis the events where both particles reached the walls of the volume containing the coordinate chambers were selected. This cut rejected events with the particles making more than one turn in the coordinate system. To avoid the edge effect the events with at least one particle passing close than 10 mm from the chamber edges were also rejected. Furthermore we required one or more scintillation counters to be fired at least on the one particle track. As a result 587 evnts in "effect" runs and zero events in "background" runs was remained. A typical event picture is presented in Fig. 4.

6. The comparison of the experimental data with Q E D expectations

In Fig. 5 the distribution over a momentum of particles in selected events is shown. The average momenta for the experimental and for the Monte Carlo simulated events are respectively: $\overline{P}_{exp.} = (55.6 \pm 0.4)$ MeV, $\overline{P}_{MC} = (56.7 \pm 0.4)$ MeV.

For particles with so small momenta the interaction with the beam pipe causes a displacement of reconstructed vertex of an event with respect to the real one. The contribution to this of the energy losses is of the same order of magnitude as of the multiple scattering. Thus, the corrections to the particle momenta due the energy losses have not been done. In Fig. 6 the distribution over the distance R between the emission points in a plane, transversal to the direction of magnetic field is presented. Emission point of each particle in an event is a crossing point of a straight line between the centers of the circules and each circle itself. The parameter $R > 0$ if circles do not intercept each other, otherwise it's negative. In the same figure the distribution for simulated events is also shown. The agreement between the experimental and simulated distributions is good: $P(\chi^2) = 30\%$.

Along the particle path before the scintillation counters there are 30 mm stainless steel walls of container of coordinate chambers. The probability for the particle hit scintillation counter is $(12.1 \pm 1.3)\%$ for the experiment and $(11.8 \pm 2.4)\%$ for the simulation. A good agreement between these values, as well as agreement of the data in Fig. 6, gives a good evidence, that the detected particles are the electrons.

In Fig. 7 the distribution over absolute value of the sum particle momenta projected on the plane transverse to the beam direction is shown. The average values of $P_\perp$ are (8.2 ± 0.2) MeV for experiment and (7.4 ± 0.3) MeV for simulation.

In Fig. 8 the distribution over the angle θ between the emission direction of particle and the beam is shown. The dashed line presents the distribution for original particles from the simulation, the empty points - results of Monte Carlo calculations, dark circles experimental results. The distribution of particles is peaked at small angles. Half of the particles have $\theta < 0.8°$. For such small angles the multiple scattering in the wall of the beam pipe considerably changes the angular distribution. The experimental data are in good agreement with the calculation: $P(\chi^2) = 40\%$.

In Fig. 9 the distributions over the visible invariant mass for experimental and simulated events are presented. The distribution without interaction of the particles with the beam pipe is shown in the same figure by the dashed line. The mean value for this distribution is equal to 2.1 MeV. One can see, that the width of the distributions for experiment and Monte Carlo simulation taking an interaction with the beam pipe into account is mainly due to the detector resolution. The average reconstructed masses for the measurement and simulation are respectively: $\overline{W}^{exp.}_{vis} = (5.7 \pm 0.3)$ MeV and $\overline{W}^{MC}_{vis} = (5.7 \pm 0.2)$ MeV.

To compare the experimental and Monte Carlo values of the visible cross-sections it is necessary to take into account the efficiencies of the chambers. The loss of efficiency for chambers is due to some dead electronic channels and the primary ionization and gas amplication fluctuations. The efficiencies of the chambers, not included in the trigger, were determined from th experimental data. For the trigger chambers they were determined by number of the dead electronic channels taking into account the probability of their hitting in experimental events. This procedure was checked using the chambers which were not included in the trigger. The average efficiency for chambers with 4 mm step was $(97.3 \pm 0.3)\%$. The correction factor, due to the chamber inefficiency, was 1.19 ± 0.02.

So, the experimental visible cross-section is equal to $\sigma_{exp} = (1.61 \pm 0.12)\,\mu b$. The error comes from: luminosity measurement - 5%, statistics - 4%, correction on the chamber inefficiencies - 2%.

The calculated visible cross-section for the process $e\,e \to e\,e + e\,e$ is equal to (1.58±0.15) μb.

According to ref. /7/ the radiative corrections for this process are less than 0.5%.

Besides it is necessary to take into account the contribution from the background process of e^+e^- pair production by the synchrotron radiation on colliding beam. By Monte Carlo calculation the visible cross-section of this process is found to be equal to (0.24±0.06) μb.

The calculated Monte Carlo visible cross-section is σ_{MC} = (1.82±0.16) μb in good agreement with the measured one.

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References

1. L.D.Landau, E.M.Lifshitz, Sov. Phys. 6(1934)244;
2. V.E.Balakin et al., Phys. Lett., 34B(1971)663;
3. V.E.Balakin et al., Yader. Phys., 16(1972)729;
4. C.Bacci et al., Nuovo Chim. Lett., 3(1972)709;
   G.Barbillini et al., Phys. Rev. Lett., 32(1974)385;
5. V.M.Budnev et al., Phys. Rep., 15(1975)181;
6. H.Terazawa, Rev. Mod. Phys., 45(1973)615;
7. V.N.Baier et al., Phys. Rep., 78(1981)295;
8. H.Kolanoski, Springer tracts in mod. phys. vol.105, Springer verlag (1984);
9. A.Courau et al., Phys. Lett., 84B(1979)145;
   A.Courau et al., Phys. Lett., 96B(1980)402;
10. A.Roussarie et al., Phys. Lett., 105B(1981)304;
11. PLUTO collaboration, Ch.Werger et al., Phys. Lett., 94B(1980)254;
12. TASSO collaboration, R.Brandelike et al., Z. Phys., C10(1981)177;
13. MARK J collaboration, B.Adeva et al., Phys. Rev. Lett., 48(1982)721;
14. CELLO collaboration, H.-J.Behrend et al., Phys. Lett., 126B(1983)384;
15. Major detectors in elementary particle physics, LBL-91 supplement, UC-37, 1983;
    S.E.Baru et al., Preprint INP 83-39, Novosibirsk 1983;
16. E.A.Kuraev and L.N.Lipator, Yadern. Phys. 16(1972)1060;
    V.N.Baier and V.S.Fadin, ZhETF, 6(1971)476.
17. E.A.Kuraev and L.N.Lipatov, Yadern. Phys. 20(1974)112;
18. J.Smith, J.A.M.Vermaseren, G.Grammer, Phys. Rev., D15(1977) 3280;
    J.A.M.Vermaseren et al., Phys. Rev., D19(1979)137;
    J.A.M.Vermaseren, Proceedings of the Intern. workshop on

$\gamma\gamma$-collisions,
Amiens, Ed.G.Chcochard end P.Kesler, Lecture notes in physics vol. 134, Springer verlag (1980);

19. A.E.Blinov et al., Preprint INP 82-93, Novosibirsk 1982;

20. A.D.Bukin et al., Preprint INP 84-33, Novosibirsk 1984.

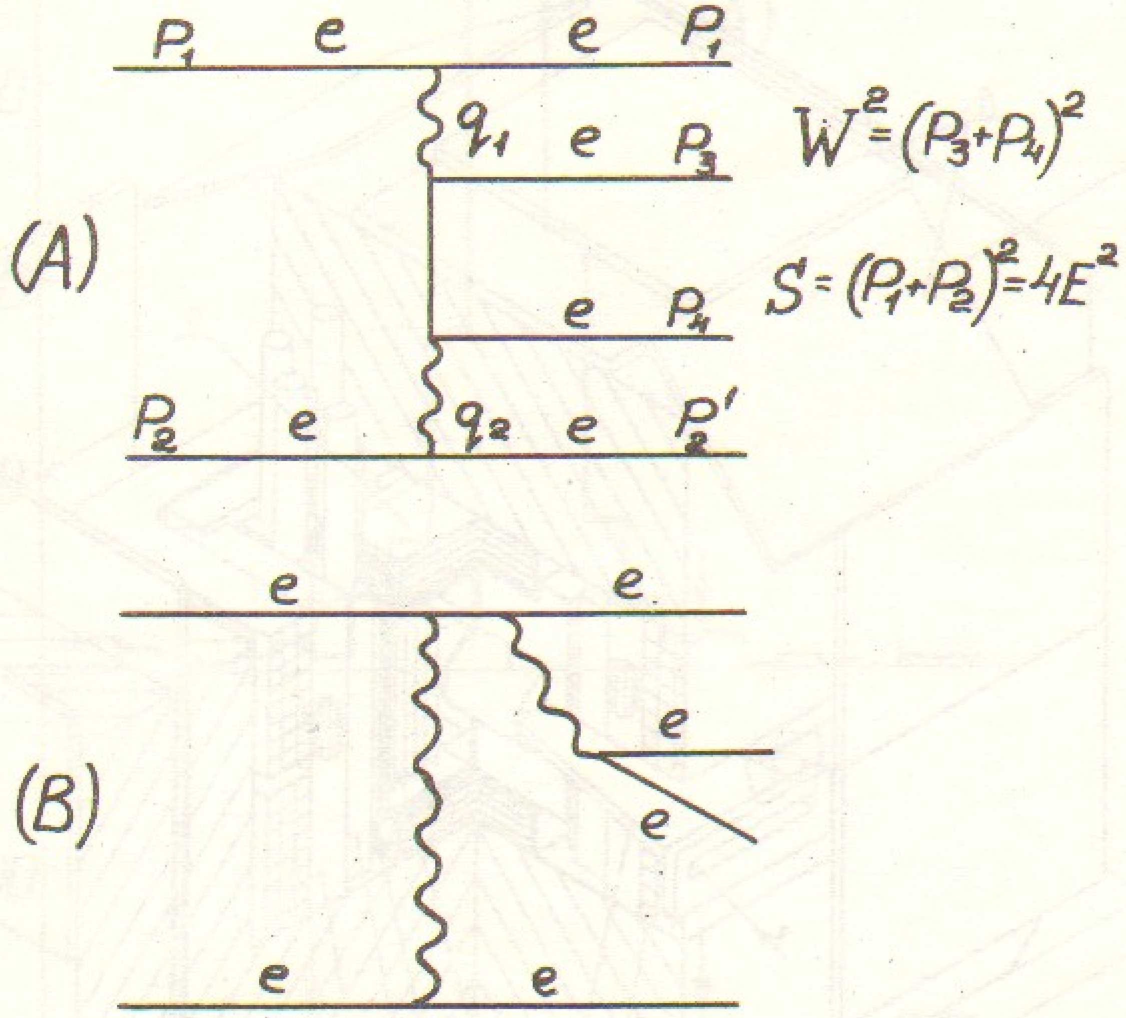

Fig. 1. Diagrams for reaction $e^+e^- \longrightarrow e^+e^- + e^+e^-$:
(A) - the two-photon graph,
(B) - the bremsstrahlung type graph.

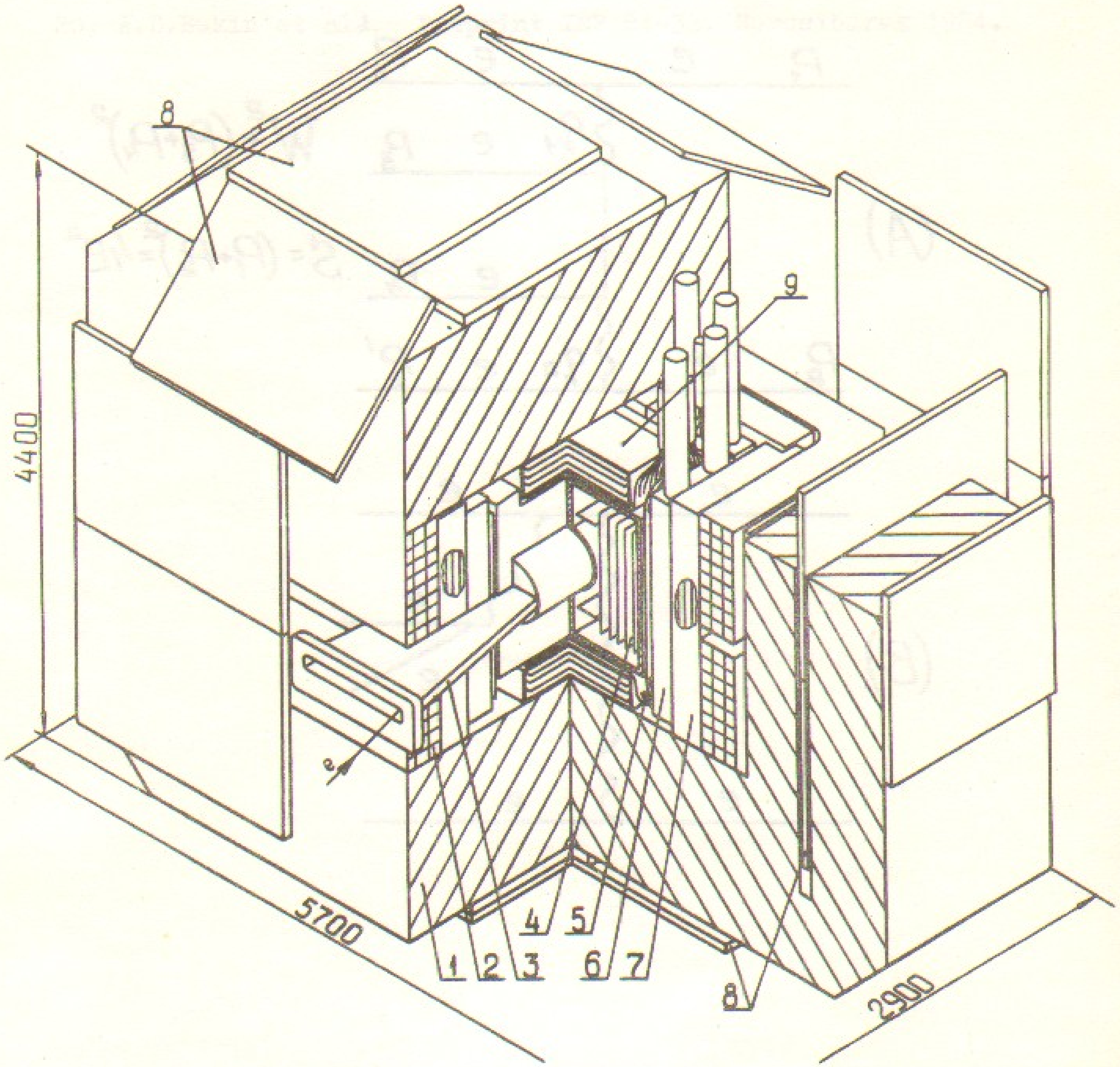

Fig. 2. Detector MD-1:
1 - magnet yoke, 2 - copper winding, 3 - beam pipe,
4 - coordinate chambers, 5 - scintillation counters,
6 - gas Cherenkov counters, 7,9 - shower-range
chambers, 8 - muon chambers.

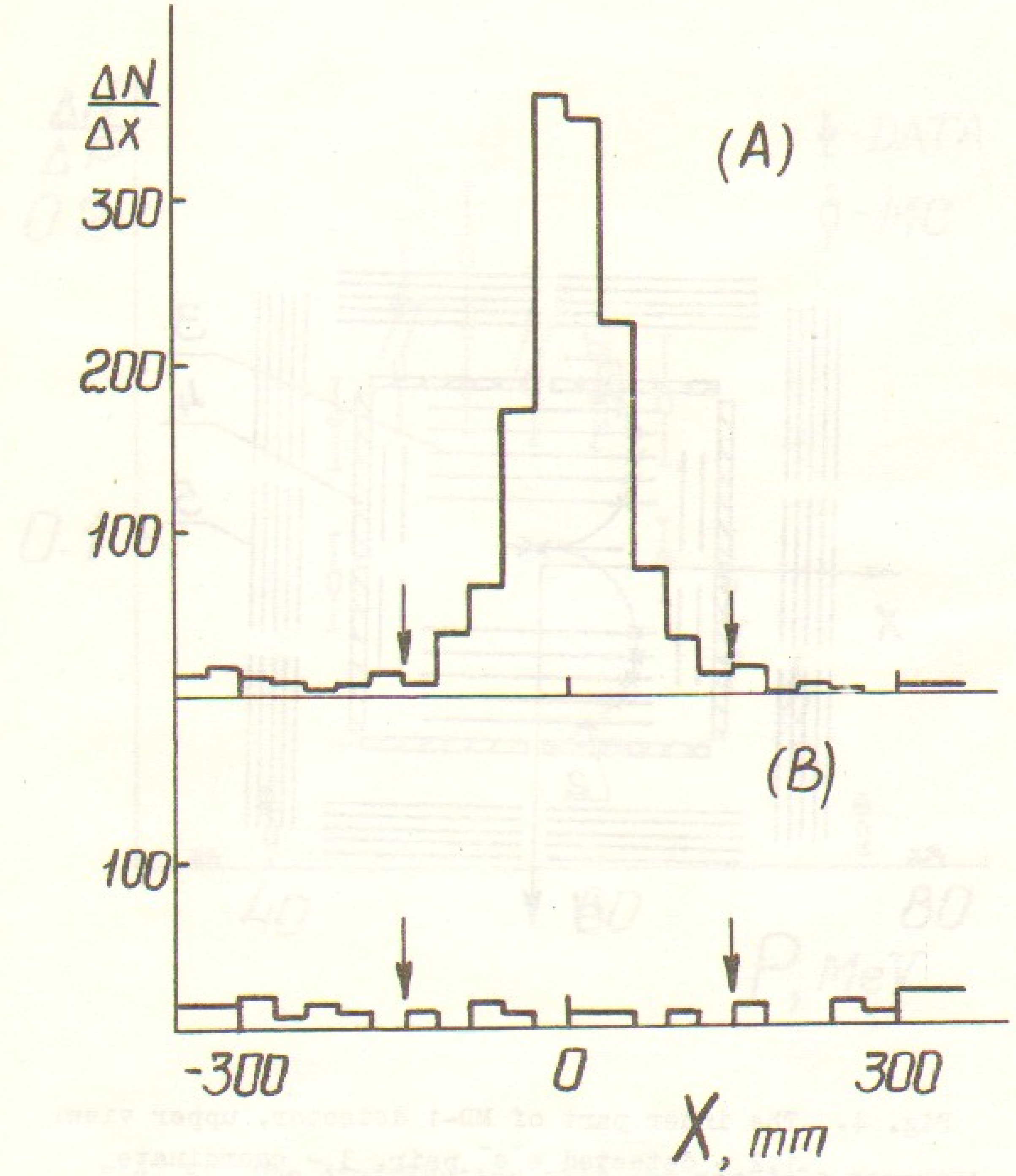

Fig. 3. The distribution over the distance from the centre of interaction region to the point on the beam axis nearest to the particle track.
(A) - for "effect" runs, (B) - for "background" runs.
The "background" distribution is normalized by the same time as "effect" runs.

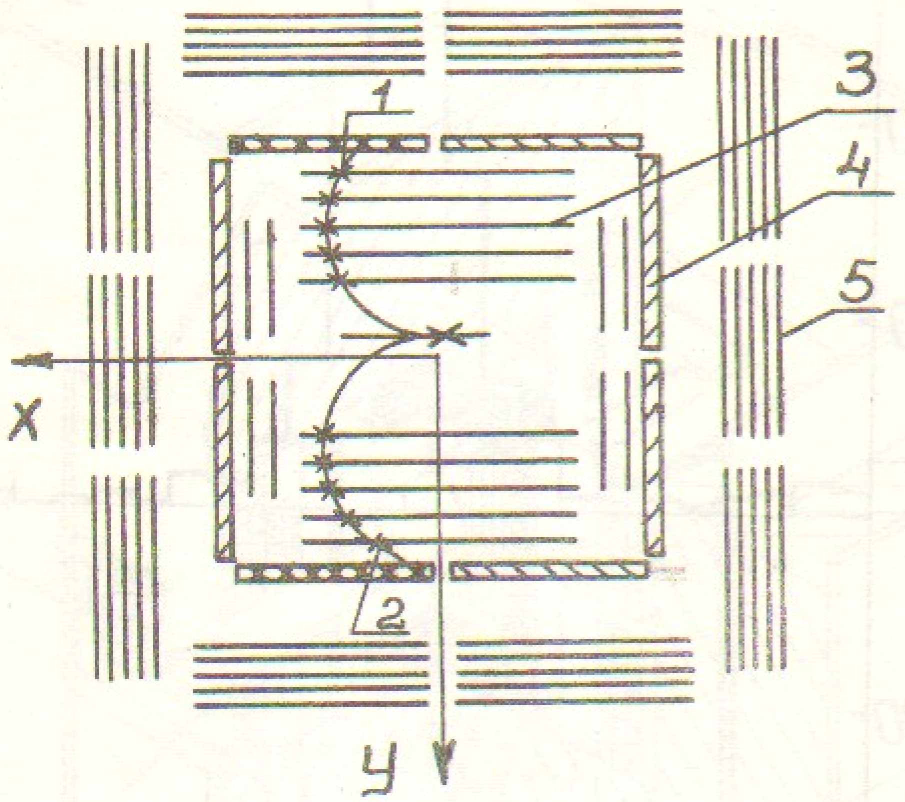

Fig. 4. The inner part of MD-1 detector, upper view: 1,2 - detected e^+e^- pair, 3 - coordinate chambers, 4 - scintillation counters, 5 - shower-range chambers.

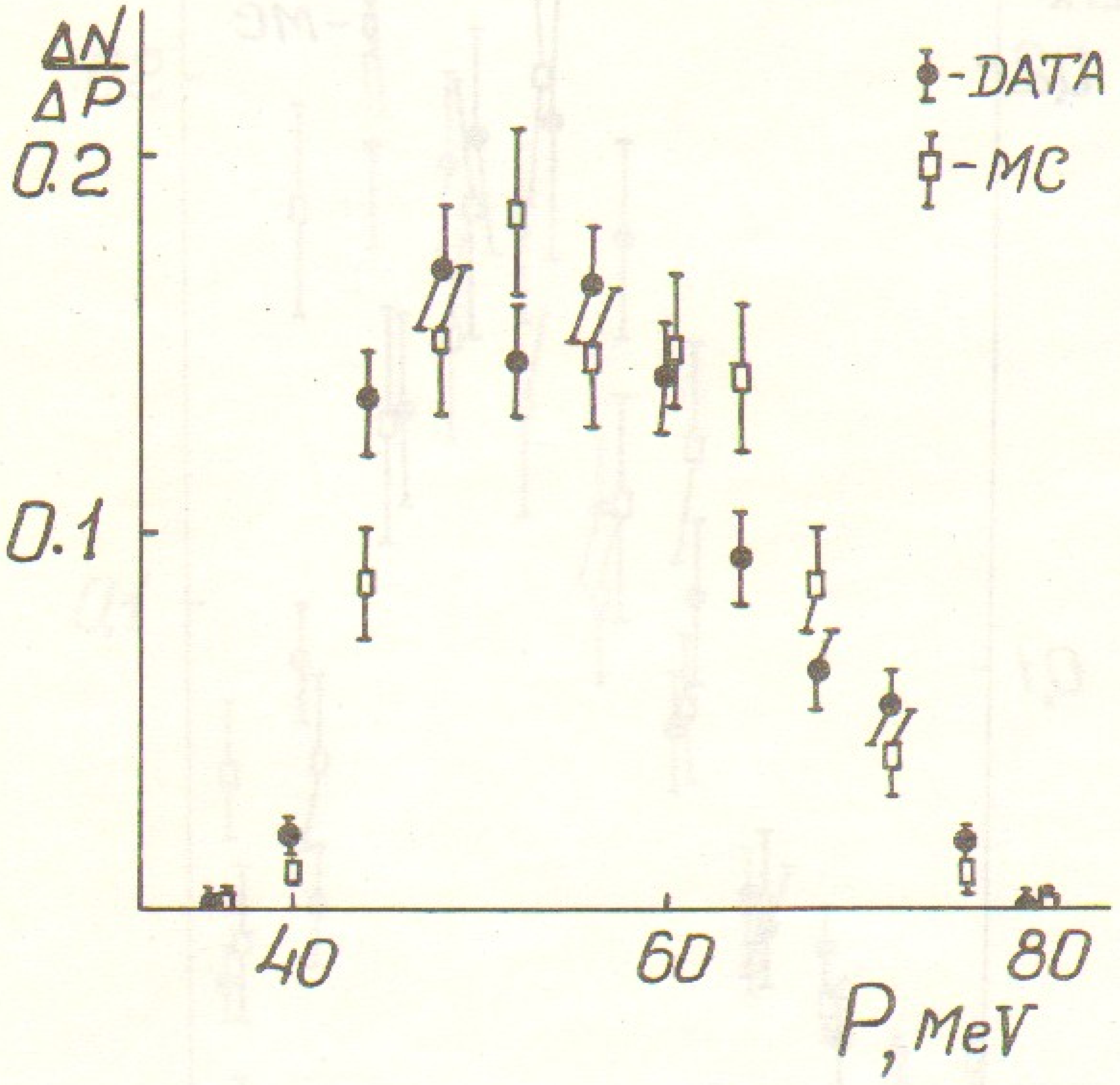

Fig. 5. The distribution over the particle momenta:

● - experiment,

□ - simulation.

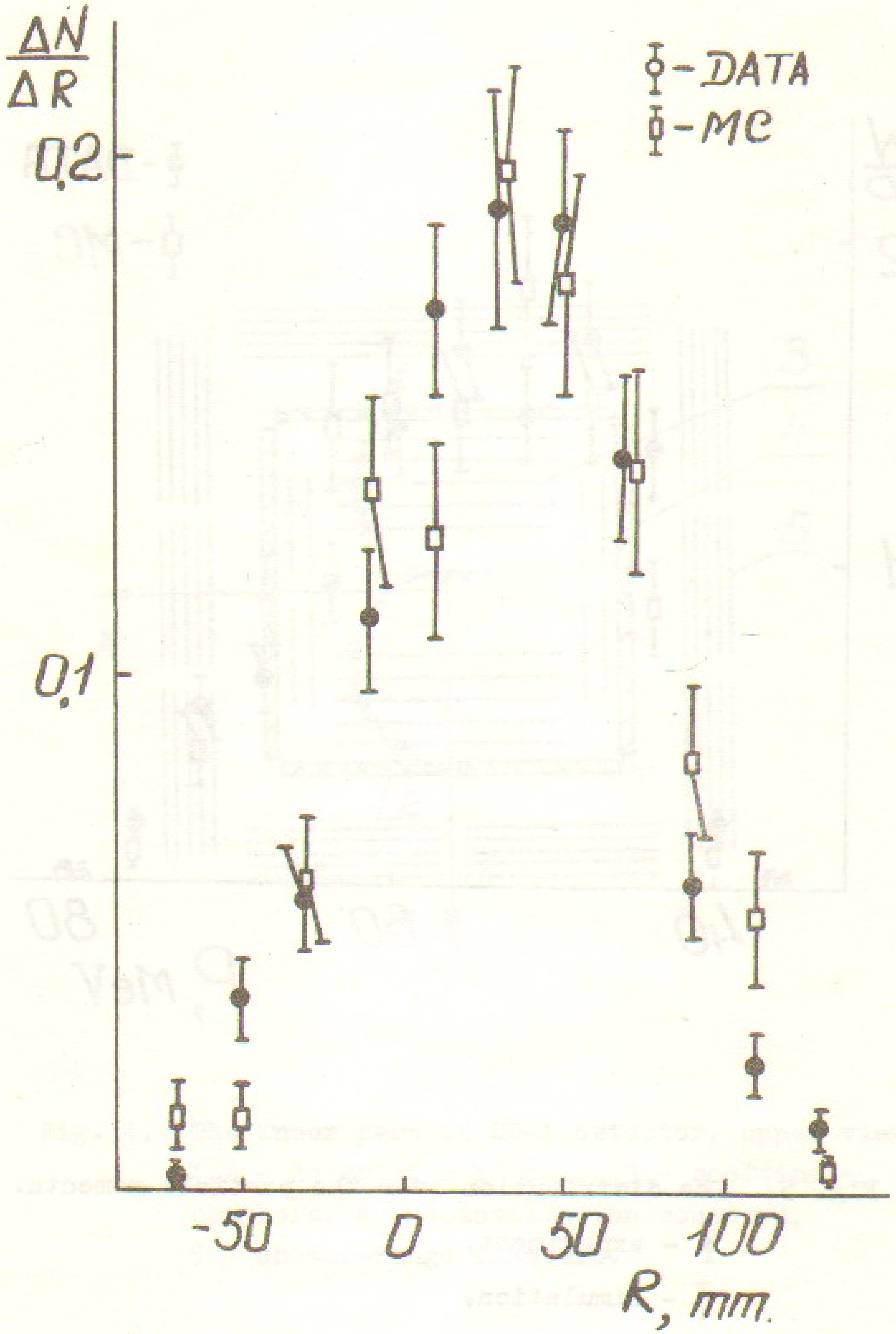

Fig. 6. Distribution over the distance between the particle emission points:

● - experiment,

□ - simulation.

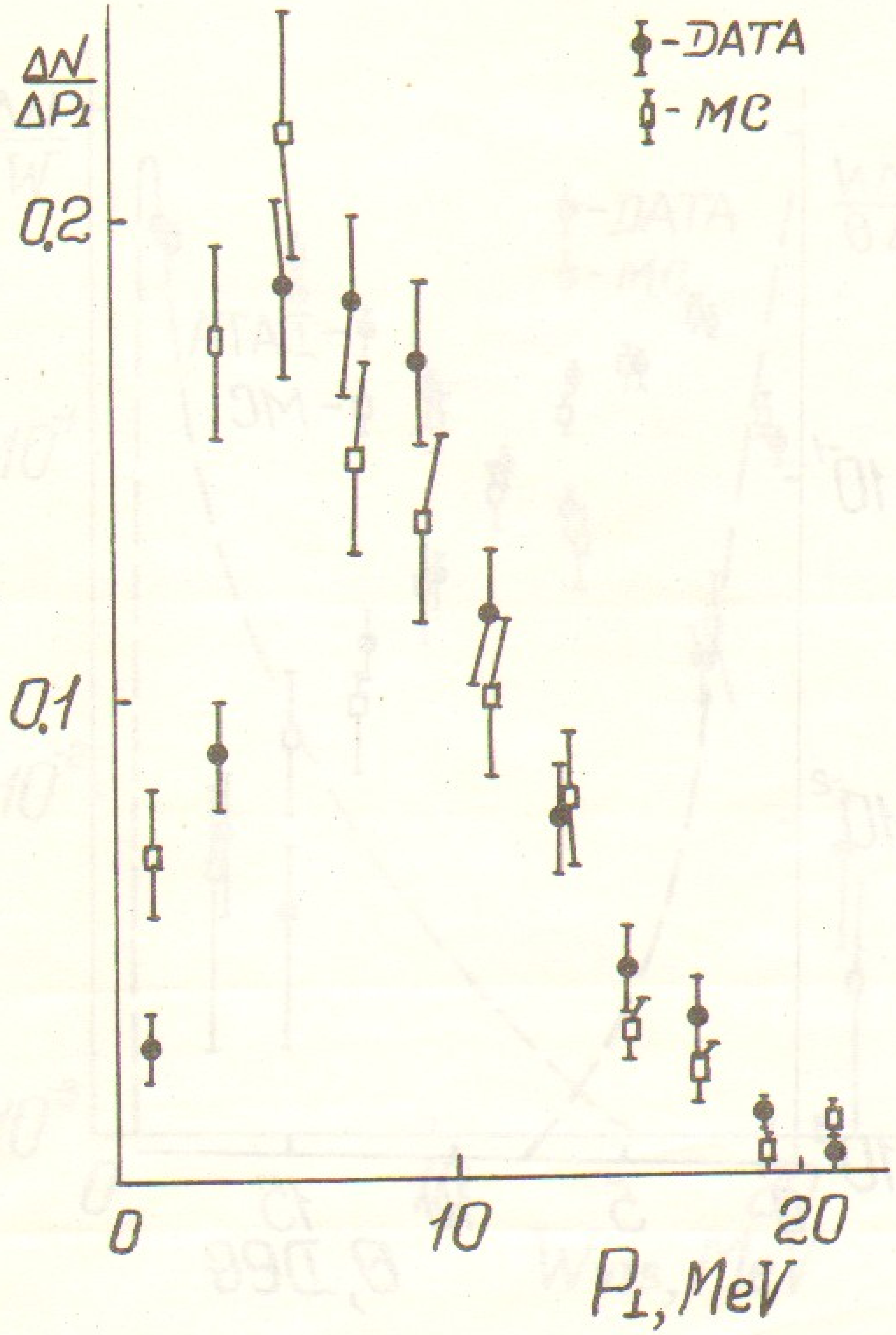

Fig. 7. The distribution over total transverse momentum in the event:

● - experiment,

□ - simulation.

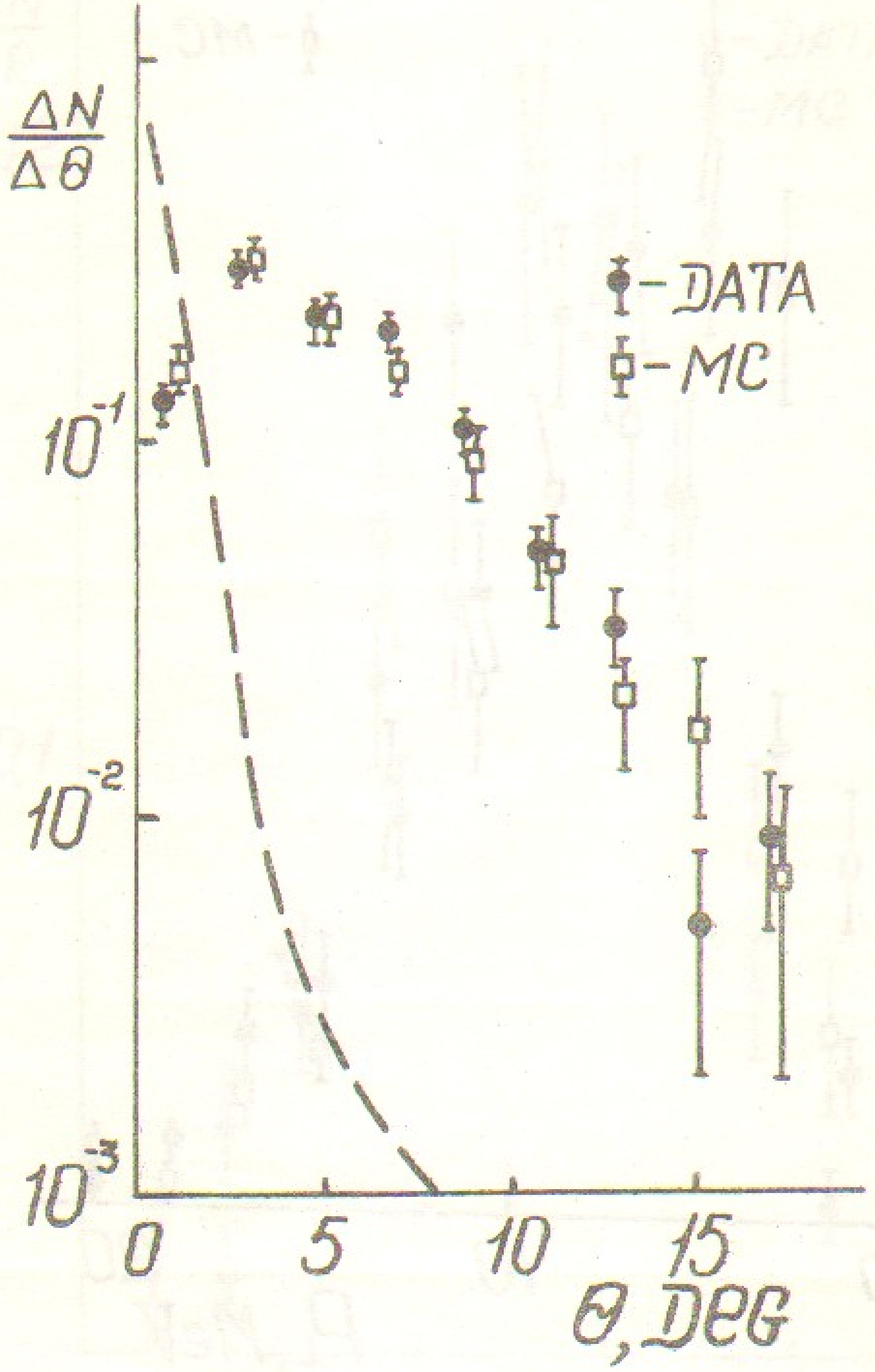

Fig. 8. The distribution over the angle θ between the direction of the particle emission and the beam:

● - experiment,

□ - simulation.

The dashed line shows the expected distribution without interaction of the particles with the beam pipe.

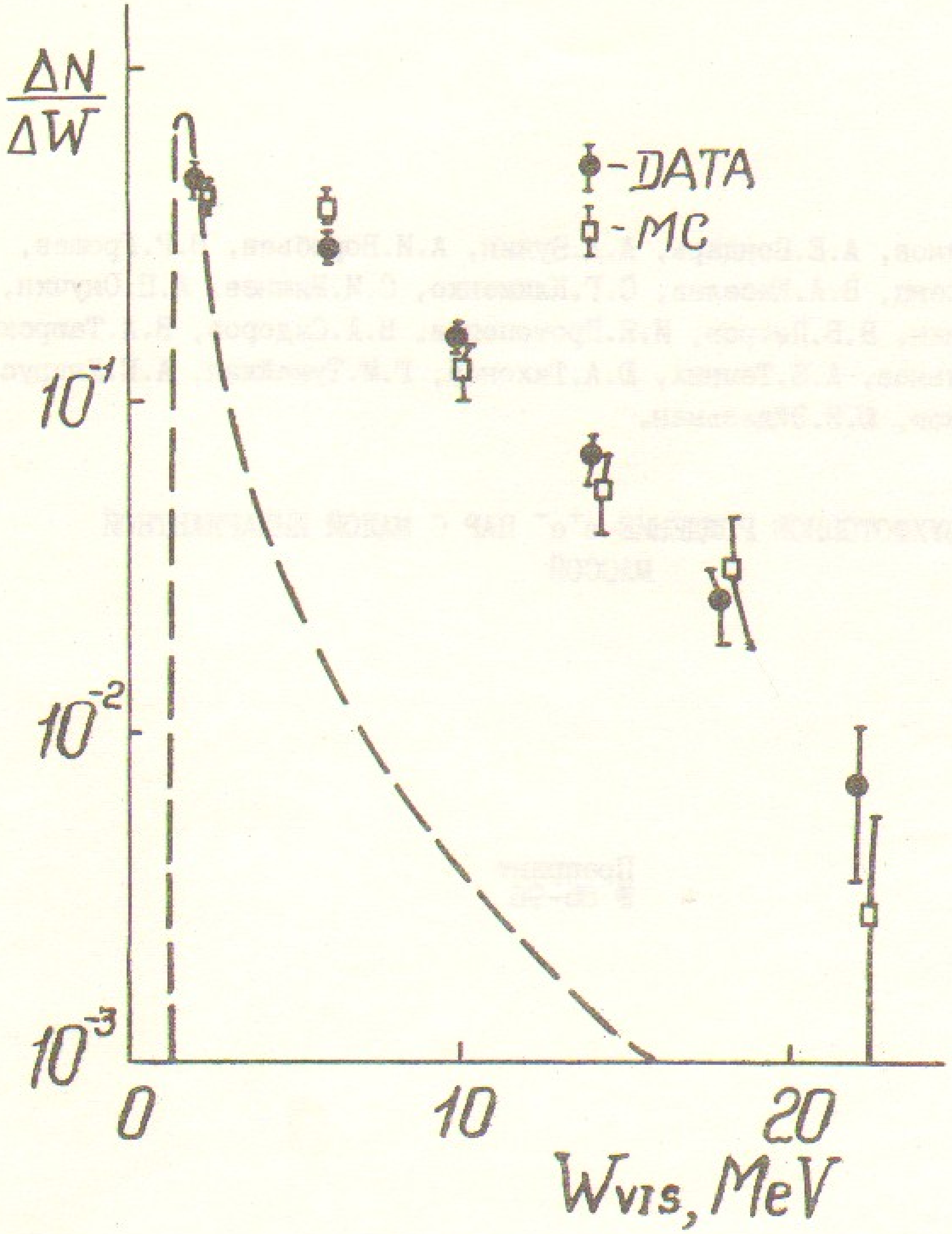

Fig. 9. The distribution over the visible invariant mass of the detected pair:

● - experiment,

□ - simulation.

The dashed line shows the expected distribution without interaction of the particles with the beam pipe.

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ДВУХФОТОННОЕ РОЖДЕНИЕ e^+e^- ПАР С МАЛОЙ ИНВАРИАНТНОЙ МАССОЙ

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