13

Institute of Nuclear Physics

ИЯФ 53-71

V.E.Balakin, G.I.Budker, L.M.Kurdadze, A.P.Onuchin,
E.V.Pakhtusova, S.I.Serednyakov, V.A.Sidorov,
A.N.Skrinsky, A.G.Khabakhpashev

TEST OF QUANTUM ELECTRODYNAMICS BY $e^+e^- \rightarrow \mu^+\mu^-$

Novosibirsk
1971

Institute of Nuclear Physics
Siberian Division of the USSR Academy of Sciences

V.E.Balakin, G.I.Budker, L.M.Kurdadze, A.P.Onuchin,
E.V.Pakhtusova, S.I.Serednyakov, V.A.Sidorov,
A.N.Skrinsky, A.G.Khabakhpashev

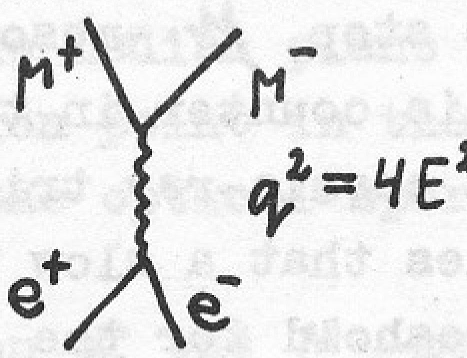
TEST OF QUANTUM ELECTRODYNAMICS BY $e^+e^- \to \mu^+\mu^-$

A b s t r a c t

At 4 values of energy from 1020 up to 1340 MeV the cross-section of the electron-positron annihilation in the μ -meson pair has been measured, the limit of the quantum electrodynamics validity $\Lambda > 3.1$ GeV has been obtained.

In 1969 the experiments on Φ -meson resonance /1/ and 2γ -quantum annihilation /2/ were performed with the electron-positron storage ring VEPP-2 at the energy of 2x510 MeV. In 1970 the same machine was used for investigation of hadronic form factors at 3 energies: 2x590, 2x630 and 2x670 MeV /3/. In all these experiments the events of electron-positron annihilation in the μ -meson pair were detected as well to test quantum electrodynamics at high momentum transfers. The preliminary results of this work were reported at the Kiev conference /4/. Similar experiments at ρ -meson energy were performed in Orsay /5/. At the Kiev conference the preliminary results of similar experiments in Frascati have been reported /6/.

The process considered is described by a single lowest order diagram



The investigation of this process enables to obtain information about the photon propagator behaviour at timelike momentum transfers as well as about the γ-μ interaction vertex.

The working conditions of the machine during the experiments were characterized by the following parameters: the initial currents were 70 mA and 40 mA for electrons and positrons, respectively, the mean lifetime was about 5 hours, the luminosity averaged over the measurement time was $10^{28} cm^{-2} sec^{-1}$.

The luminosity monitoring has been carried out by detecting the double bremsstrahlung events /7/.

The detection system used in the experiments at the energy of 2x510 MeV was described in detail in /1,2/. It consisted of two identical groups of spark chambers covering the solid angle of 2x0,9 steradian near the axis perpendicular to the plane of the orbit. Each group included the coordinate, "shower" and "range" chambers, the total thickness of each group matter being 170 g/cm^2.

For vetoing cosmic rays the detection system was covered by the scintillation counter of dimensions 160x160 cm^2. Before it the lead 220 g/cm^2 thick was placed to stop μ -mesons investigated. The switching of this counter in the anticoincidence channel reduced the cosmic-ray triggering rate by a factor of 50. Besides that a slow coincidence circuit was used with a threshold for the anticoincidence counter channel equal to 0.01 of the average pulse height. This information led to reducing of the cosmic background by a factor of 5.

The additional reducing of the cosmic background by a factor of 4 was achieved by the synchronization of the detection system triggering with the r.f. phase of the storage ring resonator.

The geometrical scheme of the apparatus used in the experiment on the hadronic form-factor investigation is shown in Fig.1. It differs from the previous experiments by the substitution of the wire spark chambers for the optical coordinate spark chambers. Besides that the water Cerenkov counters were placed between the scintillation counters.

From each side of the interaction point three wire spark chambers with ferrite-core memory were placed each chamber having two coordinate planes /8/. The wire chambers operated on-line with the computer "Minsk-22" /9/ all the information was simultaneously recorded on the magnetic tape. The wire chambers were used to determine geometrical characteristics of the events. For events having the upper and lower tracks intersecting in the median plane of the storage ring and the intersection point in the beam region the photographs from the optical spark chambers were scanned.

The selection of the μ -meson events was made by the following criteria:

1) The spacial non-collinearity angle between the higher and the lower tracks is $\Delta\omega < 5^{\circ}$. For the events of the experiment on 2γ -quantum annihilation /2/ where the lead plates inside the coordinate chamber caused notable multiple scattering . $\Delta\omega < 10^{\circ}$.

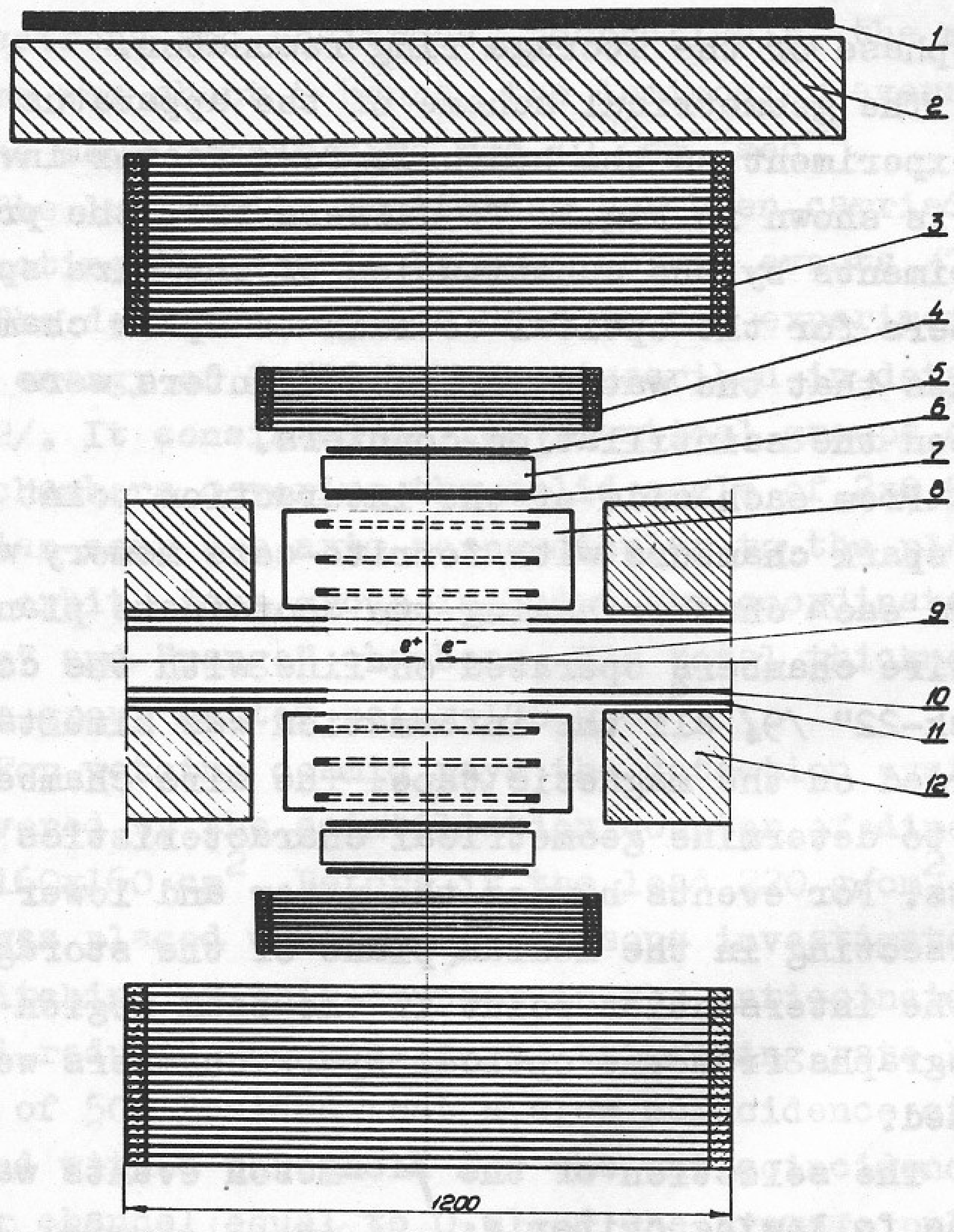


Fig.1. General experimental set-up: 1-anticoincidence scintillation counter; 2-lead; 3-optical "range" spark chamber; 4-optical "shower" spark chamber; 5,7- scintillation counters; 6-water Cerenkov counter; 8-coordinate wire spark chambers; 9-interaction region; 10 and 11-inner and outer vacuum chambers, respectively; 12-storage ring magnet.

2) The range of both particles is more than the optical chamber thickness.

In Fig.2 the distribution of the selected events along the radial axis of the median plane is shown. The radial size of the beams was about 5 mm, the interaction point centre was displaced by 15 mm with respect to the apparatus centre. The events chosen for further consideration lie in the region shown by dashed lines.

Two minds of the background measurements were performed: with the beams vertically displaced from each other by a distance of 2 mm and without the beams. In the latter case tne system of synchronization with the r.f.phase was switched off that increased the effective measurement time by a factor of 4. The measurement showed that the background was due to the cosmic rays, therefore its normalization was done by the ratio of the time spent on effect- and background measurements. To reduce the background the restrictions on the solid angle of the system were introduced, the solid angle for the 2x510 MeV experiment being reduced by 10 % and that for three other energies - by 25 %.

The absolute value of the μ -meson-pair production cross-section was calculated with the help of the monitoring process of the elastic electron-positron scattering. The events of this process can be chosen easily due to the clear picture of a shower in the

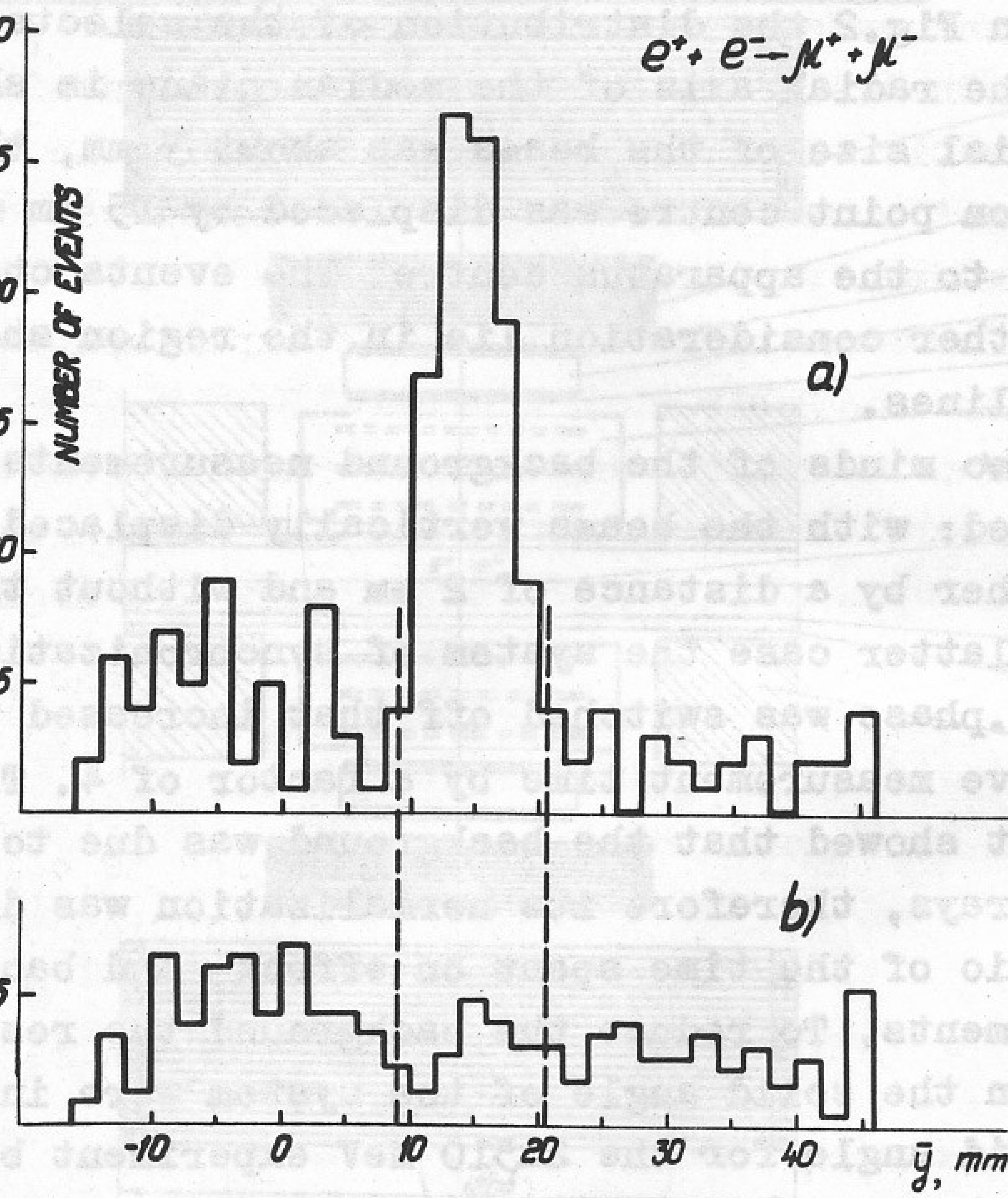


Fig.2. Intersection point distribution of the upper and lower tracks along the radial axis of the median plane for the collinear events with a range corresponding to the μ -mesons, a) - effect, b) - background normalized.

higher and lower spark chambers and they have no background. For monitoring these events were selected by the same geometrical criteria as the μ -meson pairs. The validity of quantum electrodynamics for the elastic electron-positron scattering in the region of momentum transfers considered was checked experimentally /10,11/.

The summary results of the experiments are given in the Table.

The radiative corrections /12,13/ for the calculation of the ratio of the μ -meson events number to that of elastic scattering are highly compensated if the geometrical criteria of the selection are identical. The effect of vacuum polarization /12/ in the region of the Φ -resonance is negligibly small when the averaging over energies is carried out.

To represent the possible distortion of the reaction amplitude by a single parameter the commonplace modification of the form-factor was made

$$|F|^2 = \left(1 \pm \frac{4E^2}{\Lambda^2}\right)^{-2}$$

and using the maximum likelihood method we obtained

$$\Lambda > 3.1 \text{ GeV}$$

with 95 % confidence level. In Fig.3 the experimental values of μ -meson production cross-section are

TABLE

2E, GeV	1.02[1]	1.02[2]	1.18	1.26	1.34
Effect	41	26	17	13	4
Background (normalized)	4.5	7.4	1.9	2.3	0.7
$\mu^+\mu^-$ (background subtracted)	36.5±6.5	18.6±5.4	15.1±4.2	10.7±4.2	3.3±2.0
e^+e^-	322	220	170	112	48

1) Data obtained in the Φ -meson resonance experiment.

2) Data obtained in the 2 γ - quantum annihilation experiment.

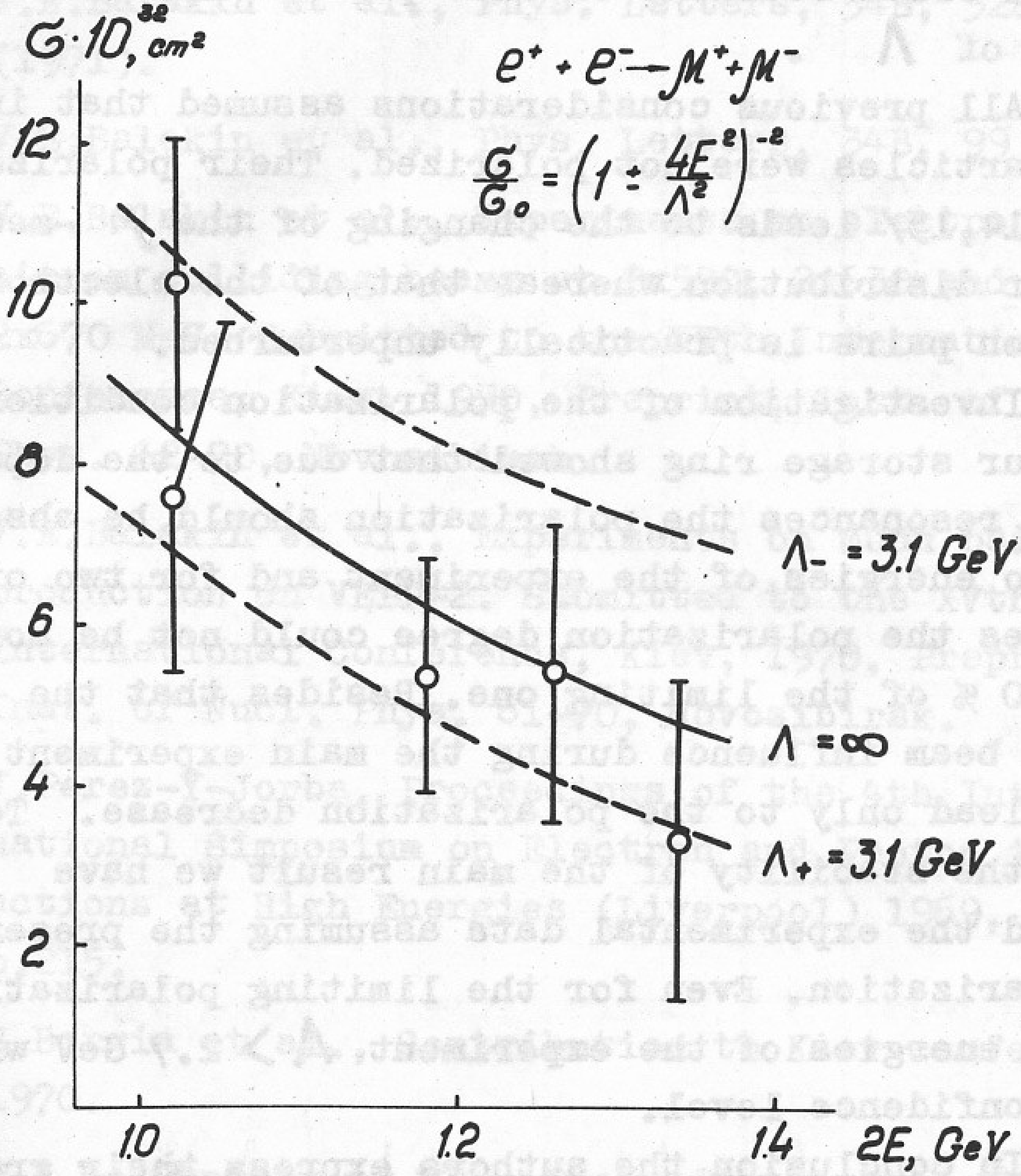


Fig.3. Experimental values of the total μ-meson production cross-section against the energy. The solid and dashed curves give the calculated values of the total cross-sections for three parameters Λ.

plotted as a function of energy as well as the theoretical cross-sections of this process for three values of Λ .

All previous considerations assumed that initial particles were not polarized. Their polarization /14,15/ leads to the changing of the μ -meson angular distribution whereas that of the electron-positron pairs is practically unperturbed.

Investigation of the polarization conditions with our storage ring showed that due to the depolarizing resonances the polarization should be absent for two energies of the experiment and for two other energies the polarization degree could not be more than 60 % of the limiting one. Besides that the second beam influence during the main experiment could lead only to the polarization decrease. To check the stability of the main result we have handled the experimental data assuming the presence of polarization. Even for the limiting polarization at all energies of the experiment $\Lambda > 2.7$ GeV with 95 % confidence level.

In conclusion the authors express their gratitude to V.N.Baier for useful discussions of the results and to the large group of co-workers who took part in data recording and data processing.

R e f e r e n c e s

1. V.E.Balakin et al., Phys. Letters, 34B, 328 (1971).

2. V.E.Balakin et al., Phys. Letters, 34B, 99 (1971).

3. V.E.Balakin et al., Experiments on electron-positron colliding beams at 2x590, 2x630 and 2x670 MeV. Submitted to the XVth International
4. Conference, Kiev, 1970, Preprint, Inst. of Nucl. Phys. 62-70, Novosibirsk.

4. V.E.Balakin et al., Experiments on muon pairs production on VEPP-2. Submitted to the XVth International Conference, Kiev, 1970, Preprint, Inst. of Nucl. Phys. 61-70, Novosibirsk.

5. J.Perez-Y-Jorba. Proceedings of the 4th International Simposium on Electron and Photon interactions at High Energies (Liverpool) 1969, p.215.

6. B.Borgia et al., Contribution to Kiev conference 1970.

7. P.I.Golubnichy et al., Proceedings of the International Symposium on Electron and Positron Storage Rings. Saclay, 1966.
P.I.Golubnichy et al., Atomnaya Energiya, 22, 167, 1967.

8. S.E.Baru et al., Proceedings of Simposium on filmless spark and streamer chambers, Dubna, 1969, p.164.

9. S.E.Baru et al., Proceedings of Symposium on filmless spark and streamer chambers, Dubna, 1969, p.168.

10. J.E.Augustin et al., Proceedings of Symposium on Electron and Photon Interactions, Darsbury, 1969.

11. B.Borgia et al., Phys. Letters, 35B, 340 (1971).

12. G.Altarelli et al., Nuovo Cimento, 47, 113 (1967).

13. S.M.Sukhanov, V.S.Fadin, V.A.Khoze. Doklady AN SSSR, 178, (1968), 822.

14. A.A.Sokolov and I.M.Ternov, Soviet Phys. Doklady 8 (1964) 1203.

15. V.N.Baier, V.N.Katkov. Phys. Letters 25A, 492, 1967.

8. S.E.Baru et al., Proceedings of Simposium on filmless spark and streamer chambers, Dubna, 1969, p.164.

9. S.E.Baru et al., Proceedings of Symposium on filmless spark and streamer chambers, Dubna, 1969, p.168.

10. J.E.Augustin et al., Proceedings of Symposium on Electron and Photon Interactions, Daresbury, 1969.

11. B.Borgia et al., Phys. Letters, 35B, 340 (1971).

12. G.Altarelli et al., Nuovo Cimento, 47, 113 (1969).

13. S.M.Dukhanov, V.S.Fadin, V.A.Khoze. Doklady AN SSSR, 178, (1968), 822.

14. A.A.Sokolov and I.M.Ternov, Soviet Phys. Doklady 8 (1964) 1203.

15. V.N.Baier, V.M.Katkov. Phys. Letters 25A, 492, 1967.

Ответственный за выпуск С.И.Середняков
Подписано к печати 16.8.71. МН02711
Усл. 0,8 печ.л., тираж 200 экз. БЕСПЛАТНО.
Заказ № 53 . ПРЕПРИНТ.
Отпечатано на ротапринте в ИЯФ СО АН СССР.