И Н С Т И Т У Т
ЯДЕРНОЙ ФИЗИКИ СОАН СССР

И Я Ф 54 - 72

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Observation of Multihadronic Events in $e^+ e^-$ Collisions at the Energy of 1.18 - 1.34 GeV

Новосибирск

1972

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Abstract

Using the electron-positron storage ring VEPP-2 the multipionic events have been observed at the total energy of 1.18 - 1.34 GeV. The experimental cross-section appears to be considerably larger than the sum of cross-sections for the processes $e^+e^- \to \rho\pi$, $\rho\varepsilon$, $\omega\pi$, $A_1\pi$. The data on the total cross-section obtained in the framework of the statistical model with 4 pions are presented.

In 1970 the experiment to investigate the π-meson and K - meson form factors has been performed with the electron - positron storage ring VEPP-2 at three values of the total energy : 2E = 1.18 , 1.26 and 1.34 GeV /1 , 2/. During its data processing the events were discovered in which two non-collinear charged particles had been detected (multiparticle events). The preliminary analysis of these events was submitted to the Kiev Conference /3/. Evidence for multiparticle production at the energy region of 1.6 - 2.0 GeV in Frascati was also reported at the Kiev Conference /4,5/.

After these reports a number of theoretical papers / 6 - 14 / appeared which considered different mechanisms of multiparticle production. In papers / 6 - 8 / the parton and statistical model were discussed, in / 9 / the existence of the new vector meson ρ' with the mass about 1.5 GeV was proposed.

Another type of the processes being widely discussed was that of the double electroproduction

.processes

$$e^+ e^- \to e^+ e^- + e^+ e^- \qquad (1)$$
$$\to e^+ e^- + \mu^+ \mu^-$$
$$\to e^+ e^- + \pi^+ \pi^-$$

(the detailed list of references is given in /10/).

The process of the electron-positron pair electroproduction which was firstly observed in Novosibirsk /15/ can be distinguished from the multihadronic processes by the peculiarities characteristic for electrons passing through the detection system. The contribution of the muon and pion pair electroproduction to the multihadronic events observed was estimated to be negligible.

In papers / 11 - 14 / the quasitwobody processes with the subsequent decay of the resonances produced are considered :

$$e^+ e^- \to \rho\pi \,, \rho\varepsilon \,, \omega\pi \,, A_1\pi \qquad (2)$$

and total cross-sections are calculated in the framework of the vector dominance model. These processes beyond any doubt contribute to the experiment. However , the results of the calculations

are rather uncertain because experimental data on coupling constants are not available. For example, for the $\rho\varepsilon$ -channel estimates of the cross-section in /13/ and /14/ differ by almost two orders, for the $A_1\pi$ -channel different models / 12,13,14 / give the cross-sections differing by a factor of 4 - 10. It should be also mentioned that the existence of the ε - and A_1 - resonances is not well established. Besides that the last experimental data on pion pair production / 1,2,16 / in the region of momentum transfers considered is not consistent with the vector dominance model. Thus these calculations can hardly give the quantitative consistence with the experiment.

Since the Kiev Conference in Frascati the number of detected events became several times greater and the wider energy region was examined /16-19/. In the events with 4 charged pions first evidence for the existence of the ρ'-meson was obtained /20/. Multiparticle events have been also observed in Orsay at the energy of 0.99 GeV/21/. In spite

of the large number of theoretical papers and new experimental data no conclusion on the mechanism of the multiparticle production has been obtained.

In this paper we present the results of the detailed analysis of the multiparticle events observed / 2,3 /. It was already reported / 2,22 / that the part of these events is due to the double electroproduction of the electron-positron pair (1). The remaining multiparticle events are discussed in this paper.

The detection system used in the experiment (Fig. 1) was described in / 1,22,24 /. It consisted of the optical and wire spark chambers, the scintillation counters and the threshold water Cerenkov counters /23/. The chambers and the counters covered an angle of $\pm$ 25° near the vertical direction, the solid angle of the system was 2 x 0,8 steradian. The total matter thickness of the optical chambers was 170 g/cm^2. The triggering threshold of the system was 25 MeV for electrons and 50 MeV for pions. The detection efficiency of the Cerenkov counters was 99 % for electrons; for pions it

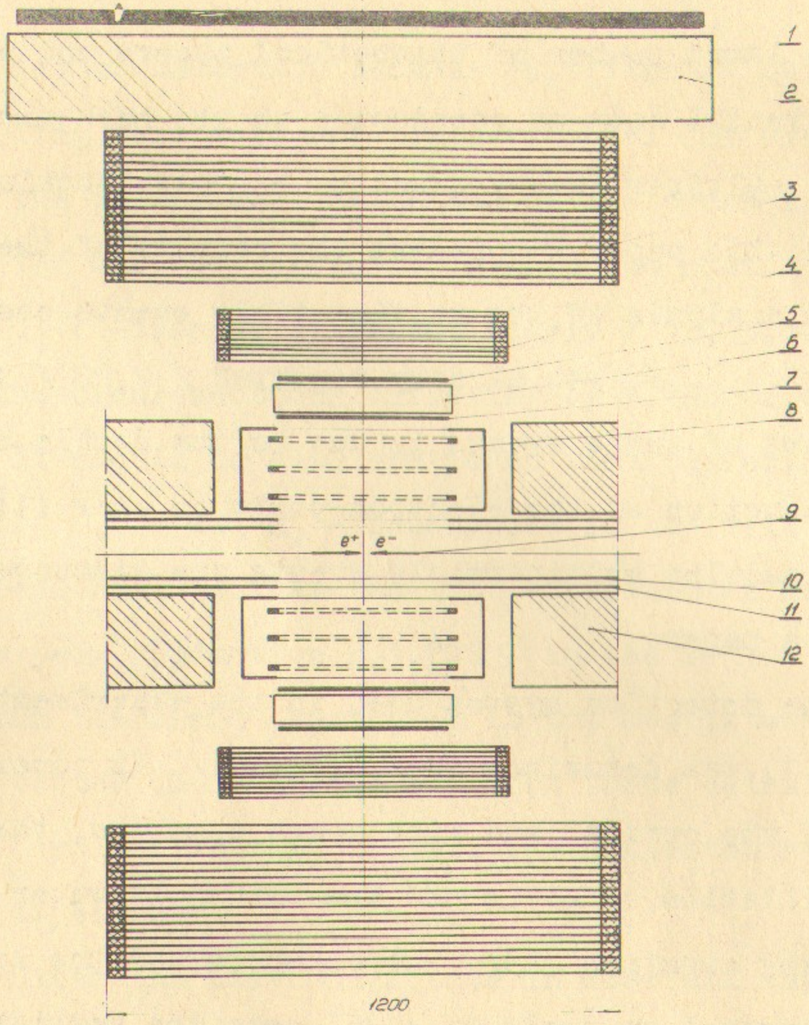


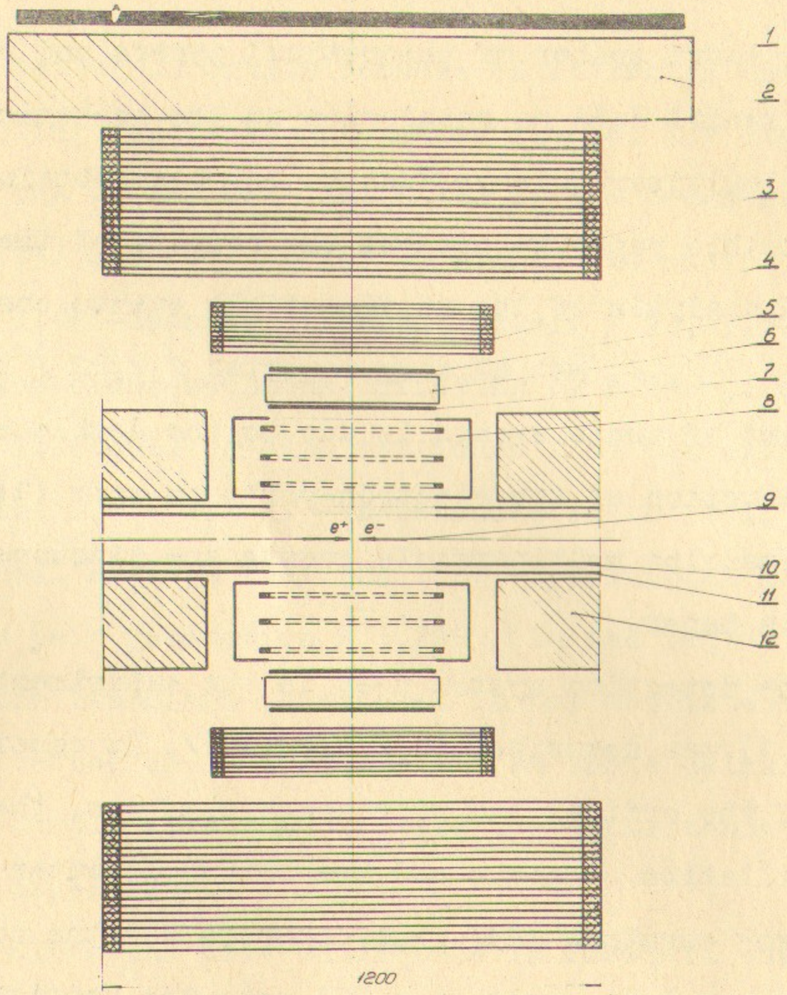
Fig. 1 Geometrical scheme of the experiment.
1- anticoincidence scintillation counter; 2- lead; 3- range spark chamber; 4- shower spark chamber; 5 , 7 - scintillation counters; 6- water Cerenkov counter; 8- coordinate wire spark chambers; 9- interaction region; 10,11 - inner and outer vacuum chambers; 12- storage ring magnet.

was 50 % at the kinetic energy of 80 MeV and 90 % for 120 MeV.

The working conditions of the machine during the experiment were characterized by the following parameters : the initial currents were 70 mA and 40 mA for electrons and positrons , respectively, the mean lifetime of the beams was about 5 hours, the luminosity averaged over the measurement time was 10^{28} cm^{-2} sec^{-1}. The r.m.s. length of the interaction region was 85 mm at 1.26 GeV.

Besides the main measurements-the effect, two kinds of background measurements have been performed : with the beams vertically displaced from each other by a distance of 2 mm (background) and without the beams (cosmic). Background measurements took about 30 % of the total time of the experiment and used the same beam currents. The analysis of the background conditions showed that for the processes considered the main background was due to the beam-residual gas interaction in the vacuum chamber.

All the events detected in the experiment were divided into 2 types according to the spacial non-



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All the events detected in the experiment were divided into 2 types according to the spacial non-

collinearity angle $\Delta\omega$ between the tracks in the upper and the lower chambers : collinear - $\Delta\omega < 5°$ and non-collinear (multiparticle) - $\Delta\omega > 5°$. The collinear events were due to the μ -meson pair production /24/ as well as pair production of the charged pions and kaons / 1,2 /.

During the analysis of the non-collinear events the particle ranges as well as triggering of the Cerenkov counters were taken into account. All the events were divided into 2 types with respect to the particle ranges : "short range" - both particles have a range from 10.5 up to 20 g/cm^2 (from the detection threshold to the shower chamber) and "long range" type including all the remaining events. The ionization range of the "short range" group corresponded for pions to the energy region of 50 - 70 MeV.

The "short range" group events accompanied by the triggerings of both Cerenkov counters were identified as electron-positron pairs due to the double electroproduction process (1). Their analysis is given separately in / 2,22 /. The events probably due to this

process were also found in the range interval 20-30 g/cm^2. These events are not considered in this paper.The estimates showed that in the remaining region there may be one event of the double electroproduction process.

The events without triggerings of the Cerenkov counters had a large background , these events were not taken for the further analysis.

The number of the remaining events in the "long range" group is given in table 1.

Table 1

Energy 2E,GeV	1.18	1.26	1.34	Sum for 3 energies
Luminosity integral 10^{33}cm^{-2}	6.0	5.1	2.4	13.5
Number of events $e^+e^- \to e^+e^-$	239	174	67	480
Multipionic events	5.2±4.4	15.9±5.0	6.8±3.7	27.9±7.6

Three of these events were accompanied by the γ-quantum in the shower chamber. No events were found with 3 charged particles detected.

The multiparticle events detected are in our opini on pionic. The experimental data on particle range and triggerings of the Cerenkov counters are consistent with this statement. These events can not be caused by the charged K-mesons because their energy islower than the threshold of the Cerenkov counters. Besides that at the energy of 1.18 GeV the energy of the non-collinear K-mesons is lower than the detection threshold. All the information concerning triggerings of the Cerenkov counters, particle ranges and the track picture in shower chambers indicates that particles of the detected events are not electrons.

We have compared the experimental data with the theoretical calculations of the processes (2) as well as with the bremschtrahlung processes in which initial electrons return to the ρ - and ϕ -resonances:

$$e^+ e^- \to \rho\gamma \quad , \quad \phi\gamma \qquad (3)$$

Using the Monte-Carlo method we have integrated the differential cross-sections of Altukhov and

Khriplovich /14/ under the experimental conditions for the processes (2). For the processes (3) the differential cross-section was taken from the paper of Baier and Khoze /25/. The calculations took into account the finite size of the interaction region and nuclear absorption of the π -mesons.

In table 2 are given the efficiencies to detect 2 charged pions for the energy of 1.26 GeV and the detection threshold T_π =50 MeV. For comparison we list here the detection efficiencies for the statistical model (matrix element equal to unity). One can see that the results of the statistical model are rather close to those of particular processes with the exception of $\rho\varepsilon$ and $A_1\pi \to \pi^+\pi^-\pi^0$.

The last column gives the expected number of events summed over 3 energies of the experiment.

The theoretical values of the cross-sections of the processes $\rho\gamma$ and $\phi\gamma$ are reliable enough, thus for comparison of the experiment with the processes (2) one can subtract the processes $\rho\gamma$ and $\phi\gamma$ from the experimental one.

TABLE 2

Process	Detection efficiency, % 2E = 1.26 GeV	Expected number of events (sum for 3 energies)
$\rho\varepsilon \to \pi^+\pi^-\pi^+\pi^-$	6.0	1.8
$\to \pi^+\pi^-\pi^0\pi^0$	3.8	
$\rho\pi \to \pi^+\pi^-\pi^0$	0.9	0.7
$\omega\pi \to \pi^+\pi^-\pi^0\pi^0$	1.1	2.2
$A_1\pi \to \pi^+\pi^-\pi^+\pi^-$	4.0	2.4
$\to \pi^+\pi^-\pi^0\pi^0$	0.3	
$\rho\gamma \to \pi^+\pi^-\gamma$	1.4	3.2
$\varphi\gamma \to K_L K_S\gamma$ $\hookrightarrow \pi^+\pi^-$	1.2	0.6
Statistical model $\pi^+\pi^-\pi^+\pi^-$	4.0	
$\pi^+\pi^-\pi^0\pi^0$	0.8	
$\pi^+\pi^-\pi^0$	1.4	

The experimental number of events 24.1± 7.6 thus obtained is in obvious inconsistence with the expected number of events 7.1 for the processes (2). One should note that to calculate the number of events due to the quasitwobody process (2) we used the total cross-sections from the paper of Altukhov and Khriplovich /14/ in which the cross-sections were the largest among those in similar papers/11 - 14/. The exceeding of the experimental data over the calculations apparently indicates that some new effects respensible for multiparticle production exist.

Fig. 2 shows the experimental number of events VS detection threshold. The calculated number of events due to the processes $\rho\gamma$ and $\varphi\gamma$ is subtracted. The calculated number of events of the processes (2) is given by the solid curve. All the experimental values apear to be greater than the calculated ones.

In Fig. 3 the number of events is given for each value of the energy. For convenience the num-

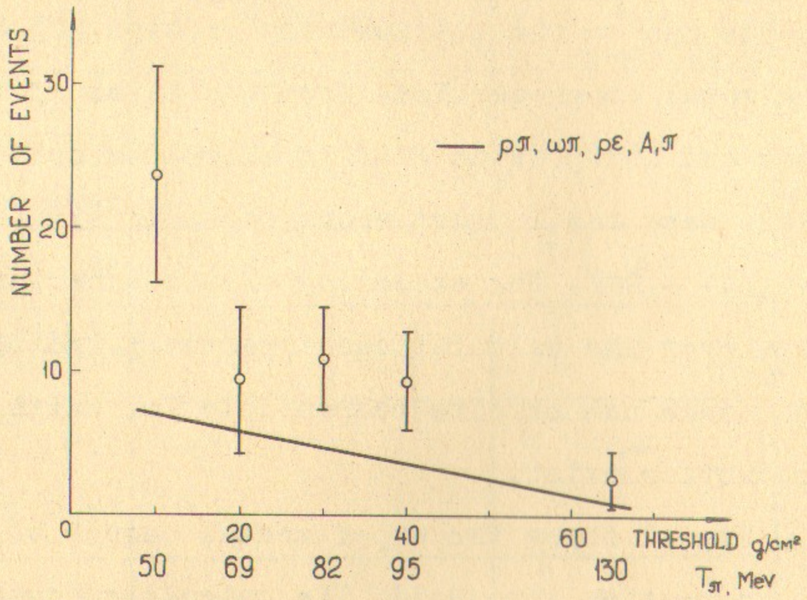

Fig. 2 Distribution of events with respect to the matter thickness passed by both particles. The solid curve gives the results of the calculations for processes $\rho\pi$, $\rho\varepsilon$, $\omega\pi$, $A_1\pi$ with the cross-sections of /14/ The events due to $\rho\gamma$ and $\varphi\gamma$ are subtracted.

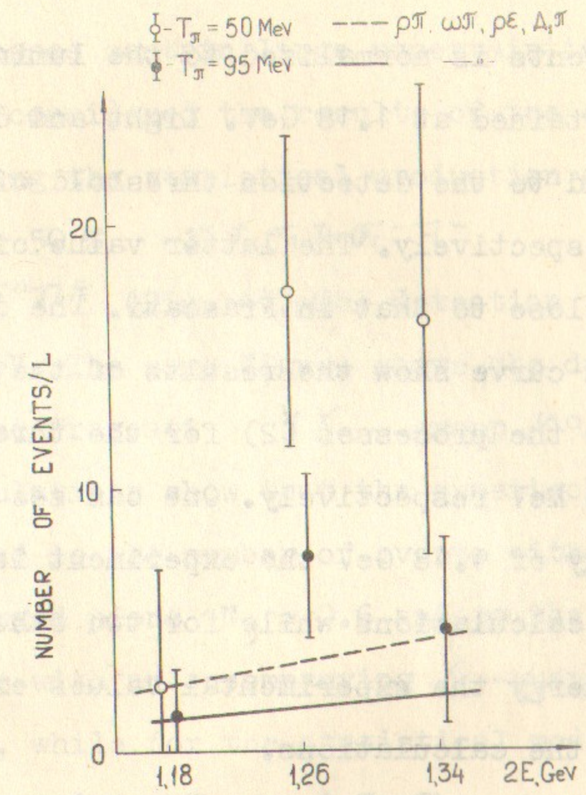

Fig. 3 The number of events normalized to the luminosity integral obtained at 1.18 GeV, $L = 6 \cdot 10^{33}$ cm^2. Light and dark points correspond to the detection threshold of 50 and 95 MeV respectively. The dotted and the solid line show the results of the calculations for processes $\rho\pi$, $\rho\varepsilon$, $\omega\pi$, $A_1\pi$ for the detection threshold of 50 and 95 MeV. The events due to $\rho\gamma$ and $\varphi\gamma$ are subtracted.

ber of events is normalized to the luminosity integral obtained at 1.18 GeV. Light and dark points correspond to the detection threshold of 50 and 95 MeV respectively. The latter value of the threshold is close to that in Frascati. The dashed and the solid curve show the results of the calculations for the processes (2) for the threshold of 50 and 95 MeV respectively. One can see that at the energy of 1.18 GeV the experiment is consistent with the calculations while for two other values of the energy the experimental values exceed these of the calculations.

No peculiarities can be observed in the angular distribution of the detected events, the experimental results do not contradict to the distribution in the statistical model with 4 pions. However it should be mentioned that for rather smooth angular distributions the sensitivity of the experiment to the form of the distribution is weak due to the small solid angle of the detection system.

The calculated cross-sections for the quasi-

twobody processes contain large uncertainties, thus we have considered the results of the experiment assuming the statistical production of 4 final pions : 50 % $\pi^+\pi^+\pi^-\pi^-$ and 50 % $\pi^+\pi^-\pi^0\pi^0$ (Fig. 4). The detection threshold is 95 MeV. The same figure shows the data of Orsay /21/ and Frascati $\gamma\gamma$ - group /19/.

The calculations show that the quasitwobody processes lead to the number of events with 3 detected charged pions $N_3 = 0.6$ and to the number of events with an accompanying γ -quantum $N_{2+\gamma} = 1.3$, while for the statistical model considered $N_3 = 1.3$, $N_{2+\gamma} = 1.7$. The experimental results are $N_3 = 0$, $N_{2+\gamma} = 3$, this does not contradict to both calculations.

On the other hand , the absence of events with 3 charged particles leads to the upper limit of the cross-section of the statistical production of 4 charged pions averaged over 3 values of the energy

$$\sigma\ (\pi^+\pi^-\pi^+\pi^-) < 40 \text{ nbarn}$$

with 95% confidence level.

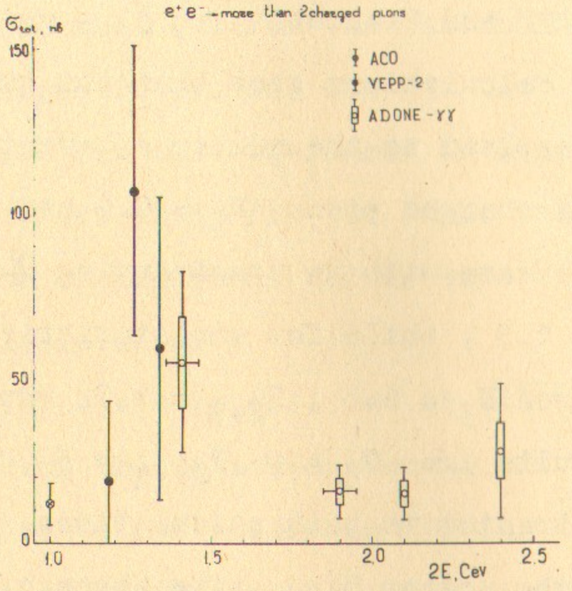

Fig. 4 The total cross-section of the multihadronic processes : ACO - /21/, VEPP-2 - this paper , ADONE - γγ - /19/.

In conclusion the authors are grateful to the large group of co - workers who participated in the preparing of the apparatus, data recording and data handling and to I.B.Khriplovich and A.M.Altukhov for the calculations of the differential cross-sections of the multipionic processes and useful discussions.

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Ответственный за выпуск С.И.Середняков
Подписано к печати 9.08.1972. МН 10468.
Усл. 1,3 печ.л., тираж 200 экз. Бесплатно.
Заказ №54 . ПРЕПРИНТ

Отпечатано на ротапринте в ИЯФ СО АН СССР,вг