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СО АН СССР

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A b s t r a c t

The reaction $e^+e^- \to 4\pi$ has been studied at the storage ring VEPP-2M at the c.m. energy from threshold up to 1.34 GeV, at the energy above 1.2 GeV the cross-sections of the processes $e^+e^- \to \pi^+\pi^- 2\pi^0, 2\pi^+ 2\pi^-$ exceed considerably those predicted by vector dominance with $\rho(776)$.

In 1975-1976 experiments devoted to the study of e^+e^- annihilation into hadrons have been performed at the storage ring VEPP-2M using the detector "OLYA" /1,2/. This work deals with the events of the process $e^+e^- \to 4\pi$ observed in these experiments at the c.m. energy 0.77÷1.34 GeV. The detailed description of the detector is presented elsewhere /3/. Its solid angle is 0.65 x 4π steradian, the triggering threshhold for pions is 45 MeV. The integrated luminosity in the experiments was about 370 $n\beta^{-1}$. Preliminary results of this work have been reported at the Tbilisi Conference /2/.

To study multihadronic production events with three or four tracks coming from one point in the interaction region were selected as well as those with two tracks and two photons. An event was considered as that with a photon if a signal in sandwich counters of the quadrant without tracks has been detected. To suppress the background due to radiative processes the acoplanarity angle was required to be larger than 15°. In order to avoid systematical uncertainties due to inefficiency of the chambers only events with a number of tracks in one quadrant not larger than one were considered. The energy range was divided in the 20 MeV intervals (excluding the regions near ω - and Φ - mesons). In Table 1 the energy distribution of selected events is presented as well as integrated luminosities calculated by the number of events of elastic e^+e^- scattering at large angles. The background measured without beams or with the beam collision in another interaction region was negligible.

The pulse height spectra in sandwiches are consistent with the hadronic origin of the particles. As the detection threshold for $K^{\pm}$ - mesons was 65 MeV, while the maximum energy was 670 MeV, the detected particles could not be kaons, i.e. events of the multipionic reactions were observed:

$$e^+e^- \to n\pi^+ n\pi^- m\pi^\circ, \qquad (1)$$

where $n \geqslant 1,\ m \geqslant 0,\ 2n+m \geqslant 3$. During data processing multiplicities higher than 5 were not considered. The

T a b l e 1

E, MeV	L, nb^{-1}	$N_{2T+2\gamma}$	N_{3T}	N_{4T}
383-395	9.2	7I	II	0
395-405	8.0	7	4	0
405-4I5	8.4	I0	4	0
4I5-425	8.3	6	2	0
425-435	8.I	I	2	0
435-445	8.5	7	3	0
445-455	7.7	4	2	0
455-465	7.2	I	I	0
465-475	6.9	5	4	I
475-485	9.2	4	2	I
485-495	6.9	3	2	0
495-505	7.I	7	5	0
505-520	I9.3	67	I5	I
520-530	I0.5	6	3	2
530-540	45.I	45	28	7
540-550	5I.8	70	40	5
550-560	46.5	57	30	I0
560-570	38.8	56	35	9
570-580	36.3	40	40	8
580-590	9.3	I5	I4	2
590-600	9.4	II	II	2
600-6I0	9.3	I8	I6	4
6I0-620	I0.0	I5	I9	4
620-630	9.3	2I	20	4
630-640	I0.6	25	20	5
640-650	9.4	I3	23	4
650-660	4.2	6	I0	6
660-670	4.7	8	I2	5
Total	368.2	599	378	80

smallness of the cross-sections corresponding to production of six and more pions was confirmed by the absence of events with 5 or more tracks.

The detection efficiencies for each class of experimental events and different reactions (1) were calculated by the detailed Monte-Carlo simulation of the reaction kinematics and interaction of the final particles with the detector material /4/. The energy dependence of the detection efficiencies is slight, so in Table 2 we present their values averaged over energy.

Because of Dalitz decays of π^0's and conversion of γ's in front of coordinate chambers the processes $e^+e^- \to \pi^+\pi^-\pi^0$ and $e^+e^- \to \pi^+\pi^-2\pi^0$ can also contribute to events with 3 or 4 tracks, thus simulating production of four charged pions. However, in the energy region higher than the φ - meson mass most four- track events are due to the process $e^+e^- \to 2\pi^+2\pi^-$. To prove this the method of kinematical reconstruction of four- track events has been applied, allowing determination of particle energies by their angles. For an event with four charged pions produced such reconstruction is in principle impossible only in the case when all particles lie in one plane. Finite angular resolution and multiple scattering always distort the event geometry, thereby increasing the probability of non-reconstruction. The calculation shows that for true four-particle events the ratio of the number of nonreconstructed events to that reconstructed is much less than unity, while for simulating events it is much larger (see Table 2). In the region 2E > 1.04 GeV 6 four- track events of 77 detected are nonreconstructed, i.e. the ratio above is $N_4^-/N_4^+ = 0.08 \pm 0.04$ in statistical consistence with the calculated value for $e^+e^- \to 2\pi^+2\pi^-$.

Another important parameter sensitive to the production mechanism is the ratio of events with 4 and 3 tracks. The calculation gives for $e^+e^- \to 2\pi^+2\pi^-$ $N_4/N_3 \sim 0.5$, while for, simulating reactions N_4/N_3 is much lower (see Table 2). In the experiment for 2E > 1.04 GeV $N_4/N_3 = 0.24 \pm 0.03$, T a b l e 2

Detection efficiencies, %

Process	2T+2γ	3T	4T	N_4/N_3	N_4^-/N_4^+
$\rho\pi^+\pi^-$	0.08±0.03	11.73±0.42	6.79±0.32	0.58±0.03	0.05±0.01
$2\pi^+2\pi^-$	0.07±0.03	10.94±0.44	4.02±0.27	0.37±0.02	0.03±0.01
$\omega\pi^0$	4.54±0.24	0.82±0.10	0.04±0.02	0.05±0.03	1.67±0.86
$\rho\pi^0\pi^0$	5.32±0.37	0.89±0.15	0.02±0.02	0.03±0.03	4.40±2.20
$\pi^+\pi^-\pi^0$	1.06±0.07	0.29±0.04	0.01±0.01	0.04±0.03	1.50±0.68
$2\pi^+2\pi^-\pi^0$	1.30±0.41	8.03±1.02	3.63±0.69	0.45±0.10	0.87±0.33

while for 2E > 1.04 GeV only 3 four-track events have been observed compared to 57 three-track events, i.e. N_4/N_3 is notably lower. This indicates clearly that mechanisms of three- and four- track events are different in these two energy regions. Qualitatively these data can be interpreted in the following manner: at the c.m. energy below the Φ - meson three- track events are due to the process $e^+e^- \to \pi^+\pi^-\pi^0$, whereas at higher energies two reactions ($e^+e^- \to \pi^+\pi^- 2\pi^0$, $2\pi^+2\pi^-$) give contribution.

Analysis of angular distributions shows that in the $\pi^+\pi^-2\pi^0$ channel the intermediate $\omega\pi$ - mechanism dominates. The distribution in invariant masses of pion pairs obtained after kinematical reconstruction doesn't allow to choose between the $\rho\pi\pi$ and L I P S (Lorentz - invariant phase space) intermediate mechanisms because of the limited statistics. However, recent experimental data of Frascati showed that at the c.m. energy higher than 1.5 GeV the $\rho\pi\pi$ mechanism is important in the channel $e^+e^- \to 2\pi^+2\pi^-$ /5/. It is natural to assume that the situation is the same in our energy region.

To find the cross sections the following set of equations should be solved in each energy interval:

$$N_i = L \sum_k \sigma_k \varepsilon_{ik}, \qquad (2)$$

where N_i is the number of events in i-th experimental class, L is the integrated luminosity, ε_{ik} is the detection efficiency of events in i-th class for the process with the cross section σ_k. The set (2) is overconstrained, its coefficients are known with some inaccuracy. Therefore to solve it the maximum likehood method has been applied. As the ratios between different detection efficiencies for the processes $e^+e^- \to \pi^+\pi^- 2\pi^0$ and $e^+e^- \to \pi^+\pi^-\pi^0$ are close to each other the set (2) doesn't allow to find them separately with good accuracy. On the other hand in this energy region the reaction $e^+e^- \to \pi^+\pi^-\pi^0$ was already studied experimentally and its cross section is governed by the contribution of interfering ω - and Φ - mesons /3,6,7/. Near

ϕ - meson the contribution of $e^+e^- \to \phi \to K_S K_L$ must be also taken into account. The calculation shows that for our selection criteria radiative processes like $e^+e^- \to \rho(\omega, \phi) + \gamma$ ("return to the resonance") are unimportant. Thus, three unknown parameters must be determined from (2): cross sections of the processes $e^+e^- \to \pi^+\pi^- 2\pi^0$, $2\pi^+ 2\pi^-$, $2\pi^+ 2\pi^- \pi^0$.

The results obtained after the solution of (2) are shown in Figs. 1 and 2. These multihadronic channels have been also studied in Orsay /8-10/, Frascati /5, 11-13/ and Novosibirsk /14/. Shown in the figures are the latest data of each laboratory.

The cross section of the reaction $e^+e^- \to \pi^+\pi^- 2\pi^0$ presented in Fig. 1 at the energy higher than 1.2 GeV exceeds considerably predictions of the vector dominance model (VDM) with one ρ (776) shown by a solid curve /15,16/. As noted in /17/, the best description both of this channel and $e^+e^- \to \pi^+\pi^-$ is achieved if ρ'(1250) is introduced. Besides that another resonances definitely exist in this energy region (ρ'(1600) or even ρ'(1533) and ρ'(1690) according to /9/) and their influence must be also taken into account, which is not simple from the theoretical point of view. We conclude that further efforts, both experimental and theoretical, are needed in this channel, especially in the c.m. energy region higher than 1.4 GeV.

The cross section of the reaction $e^+e^- \to 2\pi^+ 2\pi^-$ shown in Fig. 2 exceeds the VDM predictions (the solid curve). Its energy dependence is clearly resonant, however data of DCI and ADONE differ in the energy range 1.4÷1.6 GeV, making the determination of resonance parameters rather difficult. It should be also noted that during such determination the contribution of ρ (776) is essential. One more comment is in order. As shown in /18/, interference of different mechanisms due to identical pions and a large ρ - meson width results in the energy dependence of the ratio $\sigma(e^+e^- \to \rho\pi^+\pi^-)/\sigma(e^+e^- \to \rho\pi^0\pi^0)$. In the energy region under consideration it is close to 3, rather than 2, as is usually assumed. This fact is also important for precise determination

of resonance parameters in this energy region.

The cross section of the reaction $e^+e^- \to 2\pi^+ 2\pi^- \pi^0$ obtained by solving (2) is small and consistent with zero. Its value at the maximum energy of the experiment is

$$\sigma_{e^+e^- \to 2\pi^+ 2\pi^- \pi^0} = 2.0^{+2.2}_{-1.9} \text{ nb} .$$

From the absence of events with 5 or 6 tracks the following upper limit has been obtained for the cross section of the reaction $e^+e^- \to 3\pi^+ 3\pi^-$ at 2E > 1.3 GeV

$$\sigma_{e^+e^- \to 6\pi^\pm} < 2.6 \text{ nb}$$

at 90% confidence level.

Thus, in the explored energy region from the threshold up to 1.34 GeV production of four pions dominates. In Fig.3 the energy dependence of $R^{I=1}$ is shown (the contribution of $e^+e^- \to \pi^+\pi^-$ was also taken into account /19/). It can be seen that already in this region of rather small c.m. energy $R^{I=1}$ is greater than 1 and approaches its asymptotic value predicted by the quark model.

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Figure Captions

Fig. 1. Cross section of the reaction $e^+e^- \to \pi^+\pi^-2\pi^0$, solid curve is the prediction of VDM with ρ (776), points- experimental results:

- ▲ - Orsay, M2N/8/, M3N/9/;
- ■ - Frascati, $\gamma\gamma$ 2/5/;
- × - Frascati, $\mu\pi$ /12/;
- ● - this experiment.

Fig. 2. Cross section of the reaction $e^+e^- \to 2\pi^+2\pi^-$, solid curve is the prediction of VDM with ρ (776), points - experimental results:

- ▲ - Orsay, M2N/8/, M3N/9/;
- ▼ - Orsay, DM1 /10/;
- ■ - Frascati, $\gamma\gamma$ 2 /5/;
- × - Frascati, $\mu\pi$ /12/;
- ● - this experiment.

Fig. 3. Energy dependence of $R^{I=1}$:

- ▲ - Orsay (ACO),
- × - Orsay (DCI),
- ■ - Novosibirsk (VEPP2),
- ● - Novosibirsk (VEPP-2M).

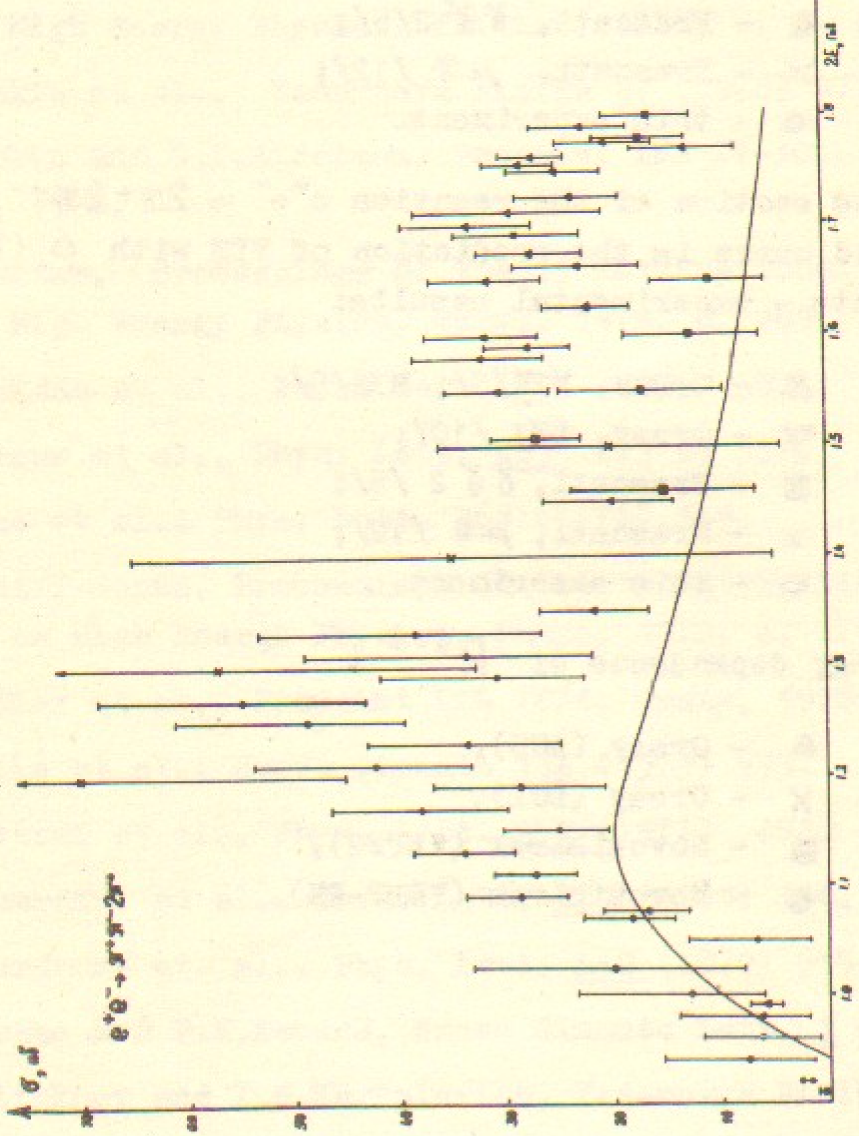

Fig. 1.

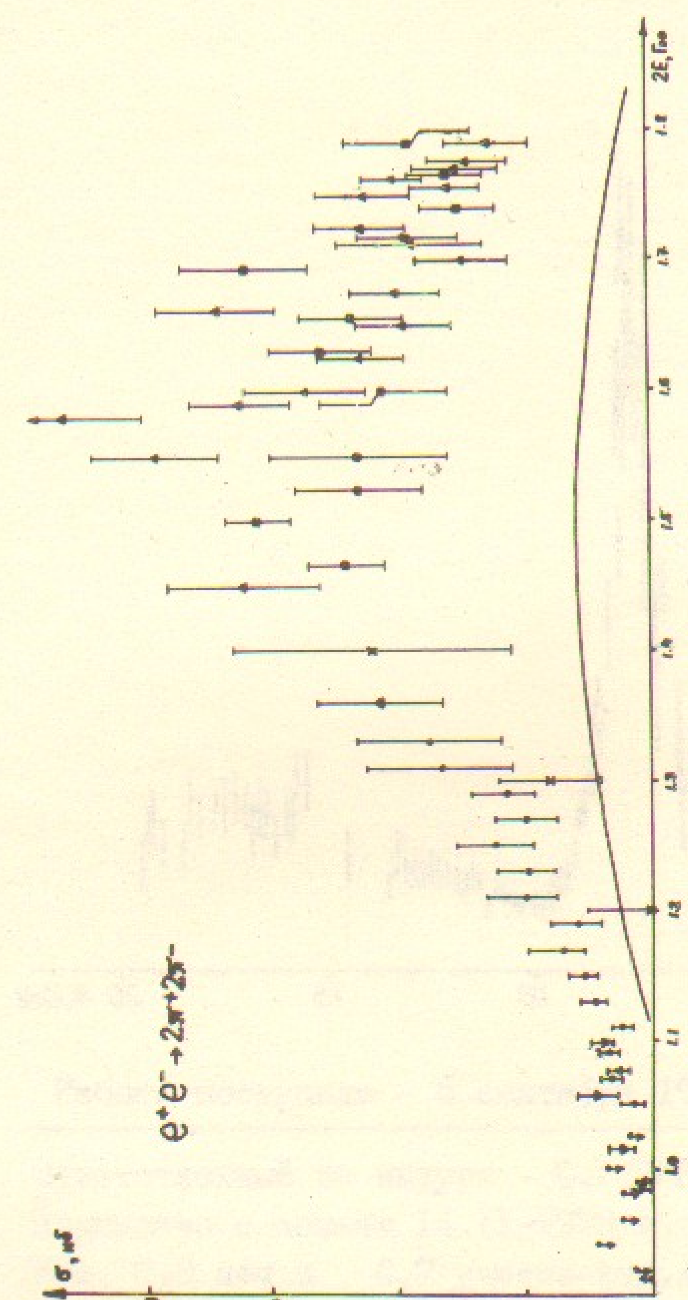

Fig. 2.

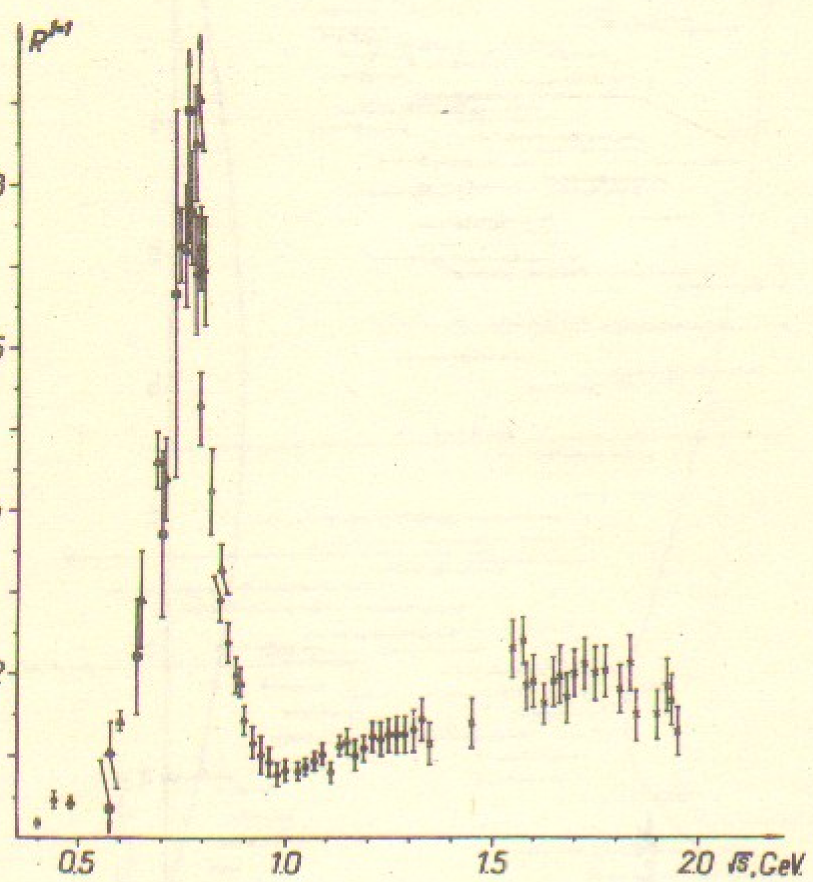

Fig. 3.

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