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Abstract

Reactions $e^+e^- \to \pi^+\pi^- 2\pi^0$ and $e^+e^- \to 2\pi^+ + 2\pi^-$ have been studied at the c.m. energy below 1.4 GeV. At the energy above 1.2 GeV the cross-section of the reaction $e^+e^- \to \pi^+\pi^- 2\pi^0$ is considerably higher than that predicted by vector dominance with ρ (776). In the cross-section of the reaction $e^+e^- \to 2\pi^+ + 2\pi^-$ the picture characteristic of interference between two resonances ρ (776) and ρ' (1600) has been observed.

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In 1978 an experiment devoted to the study of e^+e^- annihilation into hadrons has been performed at the storage ring VEPP-2M using the detector "OLYA" /1/. The c.m. energy region $0.64 \div 1.4$ GeV was scanned with a step approximately equal to an energy spread in the beam: $\Delta(2E) = 0.5$ MeV at $2E < 1.0$ GeV and $\Delta(2E) = 0.66$ MeV at $2E > 1.0$ GeV. The integrated luminosity in the experiment was $\sim 1500\ nb^{-1}$. In contrast to our previous works /2,3/ the detector "OLYA" was additionally equipped with shower chambers to detect coordinates of γ - quanta and range chambers for selection of μ - mesons. The triggering threshold was 45 MeV for $\pi^{\pm}$ - mesons and 65 MeV for $K^{\pm}$ - mesons, the solid angle of the detector was $0.65 \times 4\pi\ St$.

In this work preliminary results are presented concerning production of four pions in the reactions

$$e^+e^- \to \pi^+\pi^- 2\pi^0 ,$$

$$e^+e^- \to 2\pi^+ 2\pi^-$$

at the energy from 1.01 up to 1.4 GeV. It is known from the previous experiments in Orsay /4-7/, Frascati /8-12/ and Novosibirsk /2,13/ that higher multiplicities are rare below 1.5 GeV.

To study the reaction $e^+e^- \to \pi^+\pi^- 2\pi^0$ the events were selected with two tracks coming from one point in the interaction region and having γ - quanta in shower chambers of the quadrants without tracks. Analysis showed that events with one detected γ - quantum were strongly "contaminated" by the radiative processes like $e^+e^- \to e^+e^-\gamma$. The number of events with four detected γ - quanta was negligibly small. Therefore only events with two tracks and two or three γ - quanta were considered. These events could be caused by the processes $e^+e^- \to \pi^+\pi^-\pi^0$ and $e^+e^- \to \pi^+\pi^- 2\pi^0$. To understand which of the processes dominated, the ratio of the number of events with 3 and 2 γ - quanta was considered. The detailed Monte-Carlo simulation of our experiment showed that for processes with two created π^0 ($\omega\pi^0$, $\rho^0\pi^0\pi^0$)

this ratio is considerably higher than that for the process $e^+e^- \to \pi^+\pi^-\pi^0$ /14/. In Table 1 the results of simulation are compared with the experimental values of the ratio. It is seen that in the φ - meson energy region (1.0 - 1.05 GeV) the experimental value of the ratio is much lower than that predicted for $e^+e^- \to \omega\pi^0, \rho^0\pi^0\pi^0$. The ratio somewhat exceeds the expected value for $e^+e^- \to \pi^+\pi^-\pi^0$ that is probably due to the contribution of $\varphi \to K_S K_L$ decay mode. At the same time at higher energy the experimental fraction of events with 3 γ - quanta increases and is in good agreement with the values calculated for $e^+e^- \to \omega\pi^0$ and $e^+e^- \to \rho^0\pi^0\pi^0$.

Table 1

	Experiment		Simulation		
	1.0-1.05GeV	1.05-1.4GeV	$\pi^+\pi^-\pi^0$	$\omega\pi^0$	$\rho^0\pi^0\pi^0$
$N_{3\gamma}/N_{2\gamma}$	0.13±0.04	0.25±0.02	0.04±0.02	0.27±0.09	0.24±0.08

Another important characteristic sensitive to the production mechanism is a fraction of the events with two γ - quanta in one quadrant. All events with two γ's were divided into two groups: γ's in different quadrants or in one only. Fig.1 presents the ratio $\mathcal{R}$ of the number of events in two groups versus the experimental energy. It can be seen that $\mathcal{R}$ is maximum near the φ - meson and is practically constant at higher energies. It is clear that for $e^+e^- \to \pi^+\pi^-\pi^0$ $\mathcal{R}$ grows with energy as an increase of the π^0 average velocity results in a decrease of the limiting angle between γ's from its decay. The calculated value of $\mathcal{R}$ for $e^+e^- \to \pi^+\pi^-\pi^0$ is shown by a solid curve of Fig. 1. At the energy higher than the φ - meson mass the curve is notably above the experimental points which are in good consistence with the expected value of $\mathcal{R}$ for the process $e^+e^- \to \omega\pi^0$ (the upper shaded area in Fig. 1). The second production mechanism $e^+e^- \to \rho^0\pi^0\pi^0$

predicts $\mathcal{R}$ = 0.18±0.07 (the lower shaded area in Fig. 1) which is well below the average experimental value $\mathcal{R}$ = = 0.53±0.04. This analysis allows to conclude that the majority of the observed events is due to the reaction $e^+e^- \to \pi^+\pi^- 2\pi^0$ proceeding via $\omega\pi^0$ intermediate mechanism.

In Table 2 the selected number of events with two tracks and 2 or 3 γ's is presented for each 10 MeV energy interval. Also shown is the value of the integrated luminosity calculated by the number of events of e^+e^- elastic scattering /15/. The third column gives the cross-section calculated in the assumption of the $\omega\pi^0$ mechanism. The detection efficiency for this process is (5.03±0.56)% independently of the energy. In the energy intervals below 1.1 GeV the φ - meson contribution was taken into account.

To investigate the reaction $e^+e^- \to 2\pi^+ + 2\pi^-$ the events with 3 and 4 tracks have been selected coming from one point in the interaction region without γ - quanta in shower chambers. Figures 2a and 2b show distributions in a transverse coordinate DYM and pointlikeness DELM respectively for selected events with 4 tracks. The arrows indicate experimental cuts.

In Fig. 3 we present the distributions in the sum of pulse neights in sandwich counters calculated for each track of three-track (hystogram) and four-track (points with errors) events.

Note that only events with one track per quadrant were selected for Fig. 3 and each event contributes 3 or 4 times depending on the number of tracks. The distributions for 3-track and 4-track look similar, providing evidence for their common origin. However the experimental ratio of events with 4 and 3 tracks N_4/N_3 = 0.30±0.02 is considezably lower than the predicted value 0.47±0.03 for the process $e^+e^- \to 2\pi^+ + 2\pi^-$ (production in the LIPS model is assumed). Partially this discrepance is due to the fact that the process $e^+e^- \to \omega\pi^0$ has a rather high detection efficiency for 3 tracks caused by Dalitz decays of π^0 or conversion of γ's in front of coordinate chambers (a vacuum chamber with a thickness 0.015 X_0 and

T a b l e 2

E, MeV	$\mathcal{L}$, nb^{-1}	$N_{2\pi+2,3\gamma}$	$\sigma(\pi^+\pi^-2\pi^0)$, nb	$N_{3,4T}$	$\sigma(2\pi^+2\pi^-)$, nb
505-520	29.2	87	<13.8	28	< 2.2
520-530	28.8	23	8.1±3.5	29	3.4±0.8
530-540	31.0	27	14.0±3.7	26	2.7±0.7
540-550	31.8	34	19.4±4.2	41	5.0±0.8
550-560	31.6	25	15.7±3.6	32	3.5±0.7
560-570	30.4	30	19.6±4.2	38	4.2±0.8
570-580	28.5	35	24.4±4.9	47	5.6±1.0
580-590	28.4	47	32.9±6.0	57	6.7±1.1
590-600	34.3	45	26.1±4.9	65	6.4±0.9
600-610	35.0	47	26.7±4.9	60	5.9±0.9
610-620	34.7	45	25.8±4.8	88	8.7±1.0
620-630	36.3	63	34.5±5.8	101	9.3±1.1
630-640	46.4	74	31.7±5.1	163	12.0±1.1
640-650	42.5	68	31.8±5.2	161	13.0±1.2
650-660	43.1	70	32.3±5.3	187	14.9±1.3
660-670	43.2	83	38.2±6.0	207	16.2±1.3
670-680	52.3	118	44.9±6.5	279	17.9±1.3
680-690	49.5	93	37.4±5.7	281	19.2±1.4
690-700	58.6	115	39.0±5.7	349	20.1±1.3
Total	715.6	1129	-	2239	-

the first triggering counter - $0.017X_0$). At the same time the detection efficiency for 4 tracks is very small for $e^+e^-\to\omega\pi^0$, so that the contribution of this process decreases the ratio N_4/N_3 . Table 3 presents the detection efficiencies for the processes $e^+e^-\to 2\pi^+ + 2\pi^-$ (LIPS) and $e^+e^-\to\omega\pi^0$, averaged over energy.

T a b l e 3

	Detection efficiency,%		
	4 tracks	3 tracks	
$2\pi^+ + 2\pi^-$	8.50±0.42	18.16±0.61	0.47±0.03
$\omega\pi^0$	<0.14	0.75±0.22	< 0.19

Some excess of the number of 3-track events over 4-track ones (compared to the expected) remains after subtraction of the contribution of $e^+e^-\to\omega\pi^0$. This excess is probably due to some inefficiency of coordinate chambers when two tracks are in one quadrant. Therefore a part of 4-track events is detected as 3-track events, while the loss of 3-track events due to the inefficiency is small because the probability for two tracks to be in one quadrant is much lower than that for 4-track events. After corrections taking into account this inefficiency the ratio N_4/N_3 =0.43±0.02 which is consistent with simulation.

Note that the inefficiency effect is compensated if one calculates the cross-section of $e^+e^-\to 2\pi^+ + 2\pi^-$ by the total number of 3-track and 4-track events. Table 2 gives this number and corresponding cross-section for each energy interval. The errors cited are statistical only. According to our estimates the inaccuracy of the detection efficiency $e^+e^-\to\omega\pi^0$, as well as corrections for the chamber inefficiency can result in a 15% systematical error of the cross-section.

Assuming that produced particles are pions from the reaction $e^+e^-\to 2\pi^+ + 2\pi^-$ one can perform complete reconstruction of 4-track events, i.e. calculate particle energies by their angles. Then invariant masses of different combinations of pion pairs are obtained (their total number is 6). The corresponding distribution is shown in Fig. 4 for $1.35 < 2E < 1.40$ GeV. One can clearly see the excess of experimental events over the curve (simulation in the LIPS model) in the vicinity of the ρ- meson mass. The excess is ensured statistically: 43 ± 12 events are observed, i.e. 3.5 standard deviation effect. This indicates to the $\rho\pi\pi$ mechanism of $2\pi^+ + 2\pi^-$ production in agreement with recent observations in Frascati at $2E > 1.5$ GeV /16/. One should note that such a ρ - meson signal is observed only at the highest attainable energy. This is not strange if one takes into account strong interference among final states differing by permutations of identical pions /17/. At our energy this effect smears the ρ - meson peak. Besides that we do not distinguish between neutral and charged combinations of pion pairs, therefore two "charged" combinations are added to four "neutral", in which ρ - meson can be seen.

In Fig. 5 the cross-section of the process $e^+e^- \to \pi^+\pi^- 2\pi^0$ is presented. Also shown are the results of experiments at ACO /5/, DCI /6/ and ADONE /20/. No structures are present in the cross-section, it grows with energy and at $2E \gtrsim 1.2$ GeV exceeds considerably the prediction of the vector dominance model based on ρ (776) /18,19/ (a solid curve). The accuracy of this experiment is much higher than that in the previous one /2/, the results being consistent.

It is clear that while discussing whether or not the large value of the cross-section in the region 1.2-1.4 GeV is due to the new resonance (ρ'(1250)) one should take into account a contribution of ρ'(1600). In fact the main mechanism of the decay $\rho' \to 2\pi^+ + 2\pi^-$ is the $\rho\pi^+\pi^-$ one, therefore its isotopic partner $\rho\pi^0\pi^0$ must also contribute to the channel $e^+e^- \to \pi^+\pi^- 2\pi^0$. Simple considerations based on the isospin conservation predict the ratio $\sigma(\rho\pi^+\pi^-)/\sigma(\rho\pi^0\pi^0)$ to be two. However, the interference due to a large ρ - meson width and identical pions leads, as shown in /17/, to the energy dependence of the ratio. It approaches 2 only at

very high energy when ρ - meson is produced with a large momentum, while in the region 1.2-1.6 GeV it is much higher (~ 3). Thus, the contribution of the channel $2\pi^+ + 2\pi^-$ to the channel $\pi^+\pi^- 2\pi^0$ is essentially lower than it is usually assumed. This circumstance was not taken into account in a recent analysis of the experimental situation performed in /20/. Note that in /20/ contributions of ρ (776) and ρ'(1600) were added incoherently. In our opinion this is not true as in the region 1.2 - 1.4 GeV these contributions are of the same order, so that their interference can notably change the energy behaviour of the cross-section.

The conclusion about nonexistence of ρ'(1250) made in /20/ is based essentially on the value of its leptonic width $\Gamma_{\rho' ee} \sim 4$ KeV and, as a result, very large cross-section $\sigma(e^+e^- \to \omega\pi^0) \sim 150$-250 nb in contradiction with the experiment. On the other hand data on ρ'(1250) photoproduction indicate to a much lower value $\Gamma_{\rho' ee} \sim 0.6$ KeV /21/. This value is in line with the work /22/ in which ρ'(1250) with the main decay mode $\omega\pi^0$ is used to describe simultaneously data on $e^+e^- \to \pi^+\pi^-$ and $e^+e^- \to \pi^+\pi^- 2\pi^0$. If one assumes that the excess over the ρ - meson tail is due to ρ'(1250) only, then $\Gamma_{\rho' ee} \sim 0.5$ KeV in consistence with /21,22/. One conclude that it is too early to make final judgements. To describe the whole situation in this energy region one must consider simultaneously all the resonances. This problem seems not very simple from the theoretical point of view. It is clear that experimental separation of different mechanisms ($\omega\pi^0$, $\rho\pi^0\pi^0$, $A_1\pi$ etc.) will considerably improve our understanding of the problem.

In Fig. 6 the cross-section of the reaction $e^+e^- \to 2\pi^+ + 2\pi^-$ is shown. As in the case of $\pi^+\pi^- 2\pi^0$ channel these results are in consistence with our previous experiment /2/, while the accuracy is much better. Also shown are data from ACO /5,7/, DCI /6,23/ and ADONE /20/. The picture indicates at the resonance with a mass about 1.6 GeV. However in the region 1.1-1.2 GeV a kind of a "shoulder" is observed, which can be due to the interference between ρ (776) and ρ'(1600) contributions. A solid curve shown in Fig. 6 is a two-resonance fit ($P(\chi^2)$ = 73%). Although one resonance fit is also possible ($P(\chi^2)$ = 5%) we believe that in this energy range one should take into account the contribution of ρ (776) as well.

In conclusion the authors express their profound gratitude to the whole staff of VEPP-2M for excellent performance of the accelerator and to V.M.Budnev and A.I.Vainshtein for fruitful discussions.

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Figure captions

Fig. 1. The ratio of the number of events with two γ's in one quadrant to that with γ's in two quadrants: points-experiment, solid curve - $e^+e^- \to \pi^+\pi^-\pi^0$ (simulation), dashed areas - $e^+e^- \to \omega\pi^0$ and $e^+e^- \to \rho^0\pi^0\pi^0$ (simulation).

Fig. 2. a) Distribution in a transverse distance from the beam for 4-track events,
b) distribution in a pointlikeness for 4-track events.

Fig. 3. Distribution in a sum of pulse heights in a sandwich counters for each track (hystogram - 3-track events, points - 4-track events). Only events with tracks in different quadrants are selected.

Fig. 4. Distribution in invariant masses of pion pairs, $1.35 < 2E < 1.40$ GeV. Solid curve - prediction of the phase space (LIPS) model.

Fig. 5. Cross-section of the reaction $e^+e^- \to \pi^+\pi^- 2\pi^0$, solid curve $e^+e^- \to \rho \to \omega\pi^0$.

Fig. 6. Cross-section of the reaction $e^+e^- \to 2\pi^+ + 2\pi^-$. Solid curve - two resonance fit (ρ(776) and ρ'(1600)).

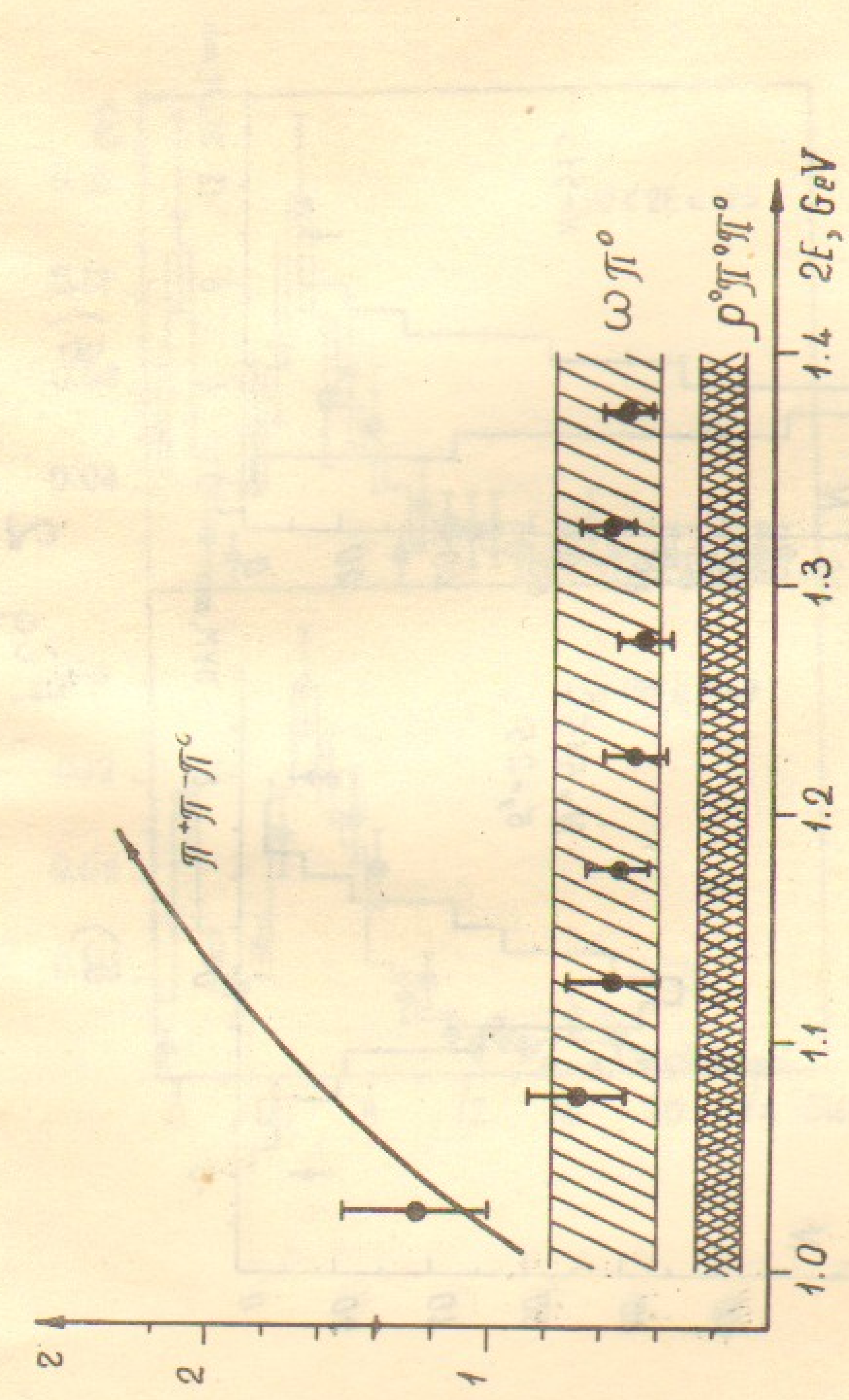

Fig. 1

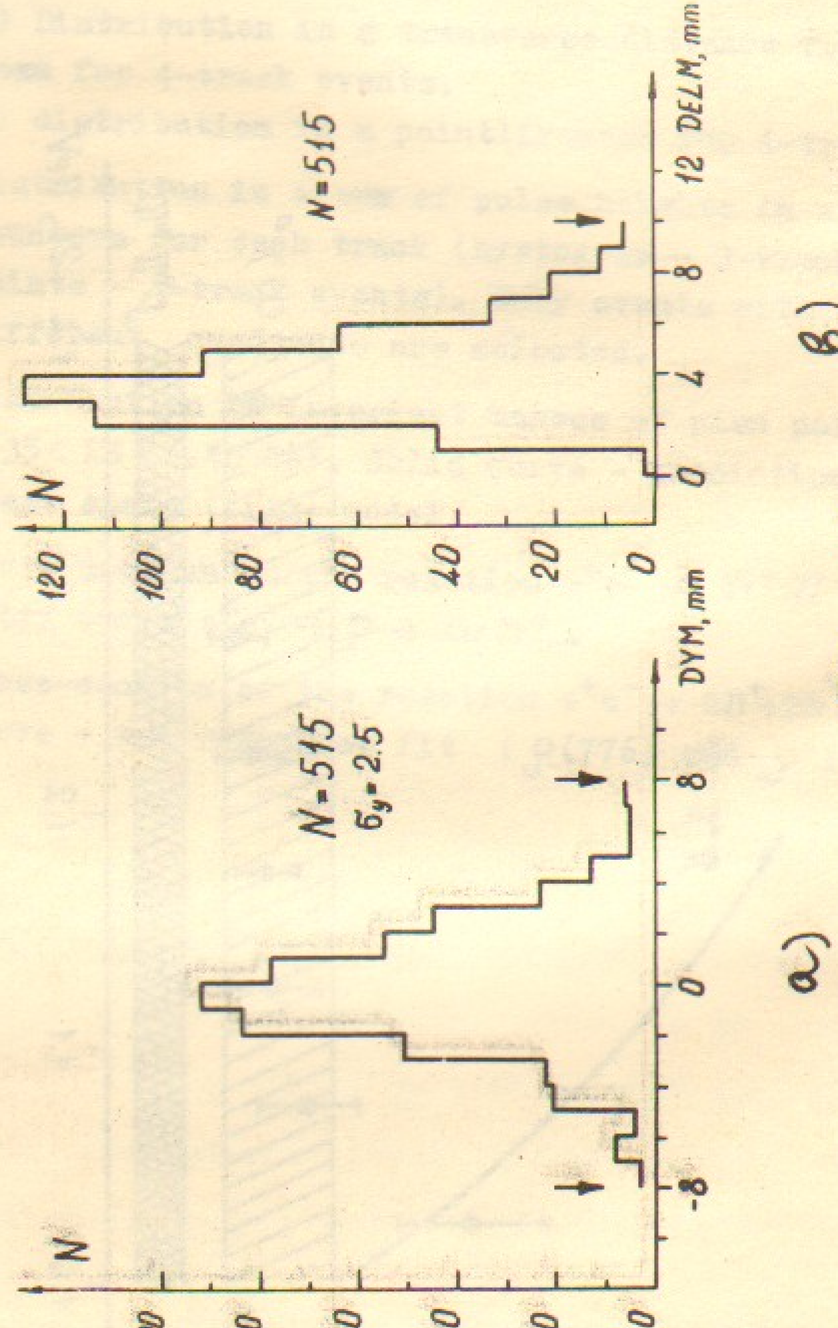
N
DYM, mm
N=515
σ_y=2.5
a)
N
DELM, mm
N=515
б)

Fig. 2

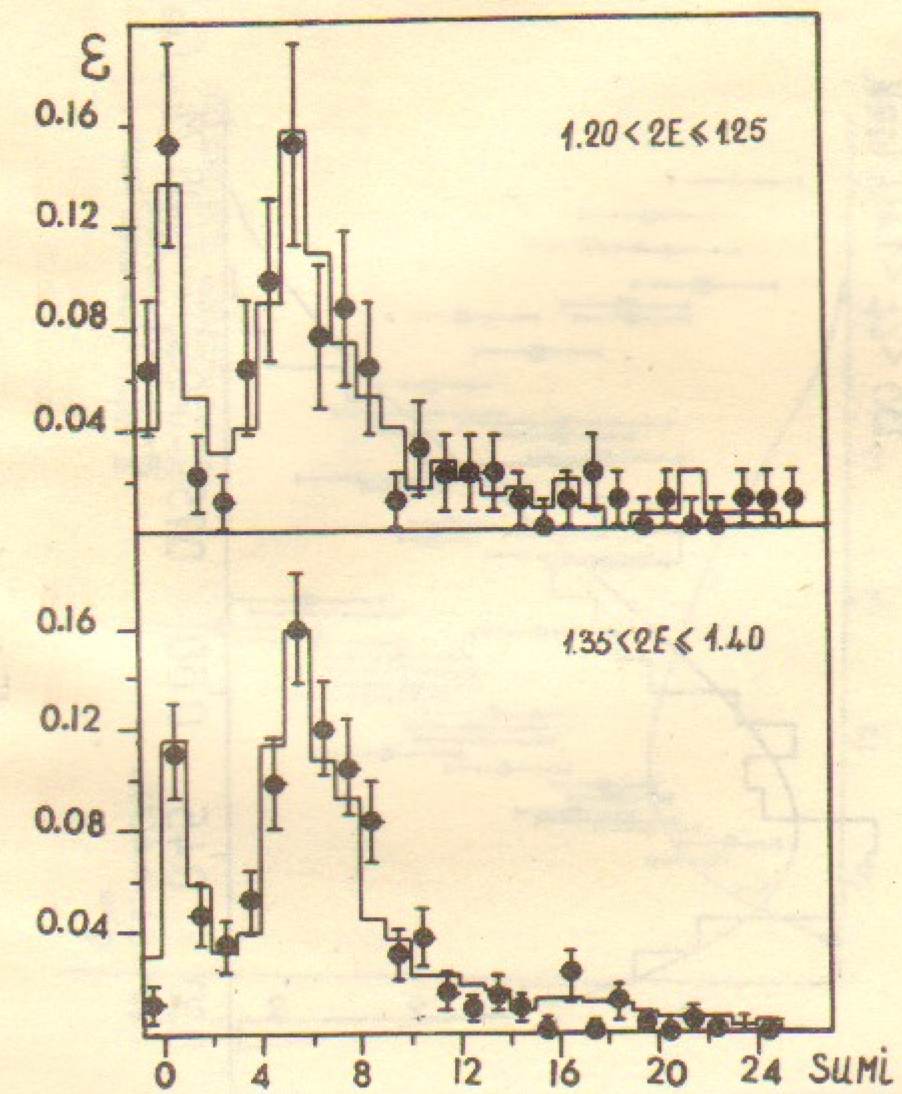
ε
1.20 < 2E ≤ 1.25
1.35 < 2E ≤ 1.40
SUMi

Fig. 3

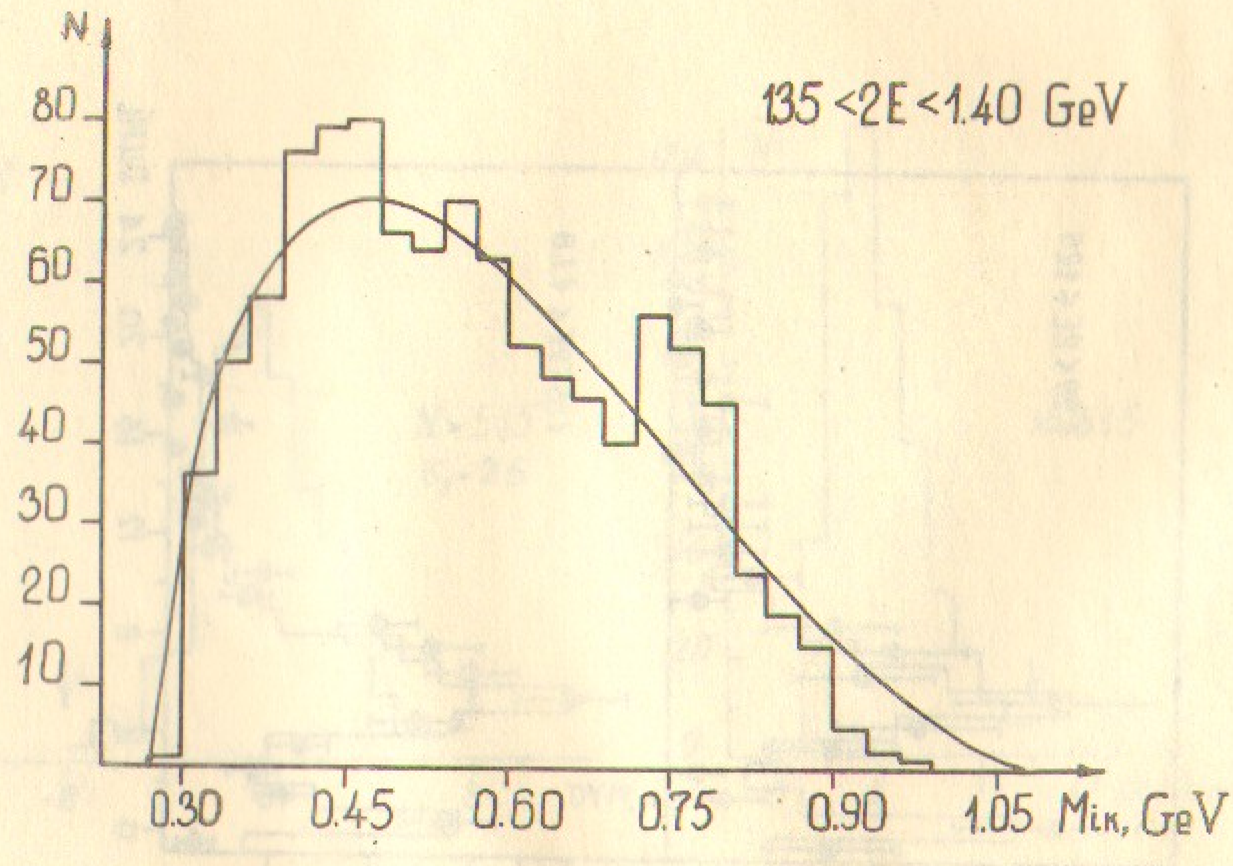
N
80
70
60
50
40
30
20
10
1.35 <2E <1.40 GeV
0.30
0.45
0.60
0.75
0.90
1.05
Mπγ, GeV

Fig. 4

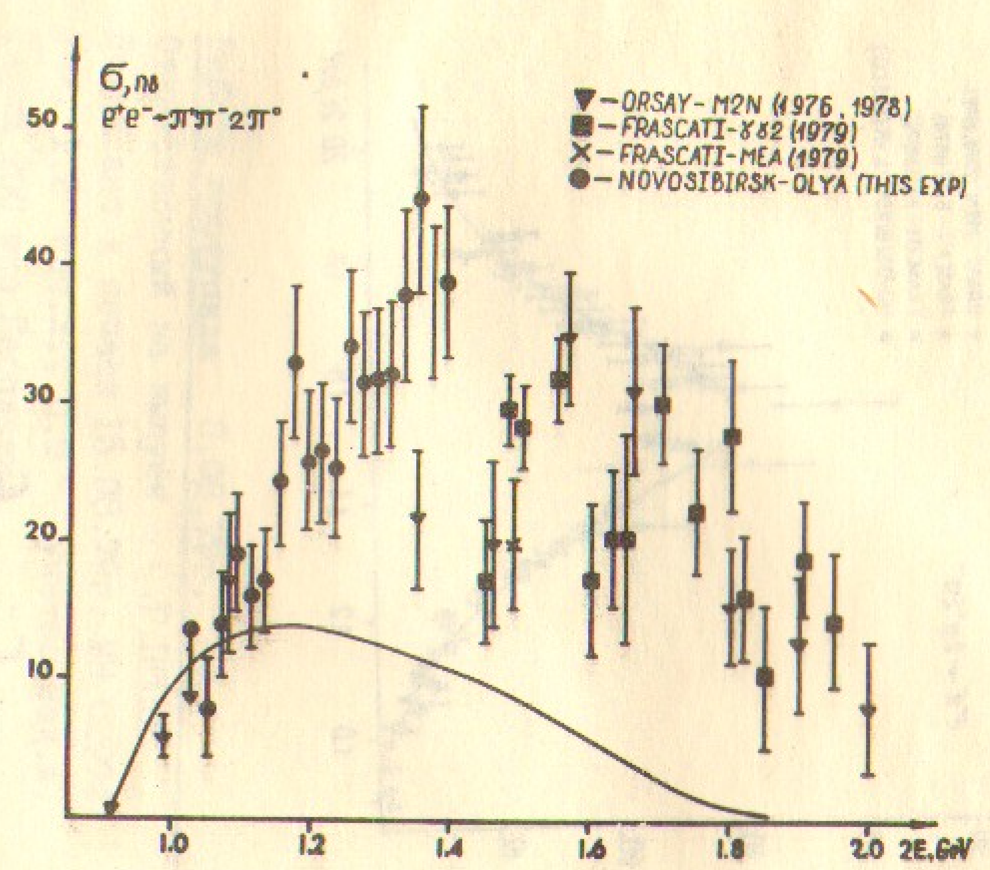
σ, nb
$e^+e^- \to \pi^+\pi^- 2\pi^0$
▼ – ORSAY - M2N (1976, 1978)
■ – FRASCATI - γγ2 (1979)
✕ – FRASCATI - MEA (1979)
● – NOVOSIBIRSK - OLYA (THIS EXP)
50
40
30
20
10
1.0
1.2
1.4
1.6
1.8
2.0
2E, GeV

Fig. 5

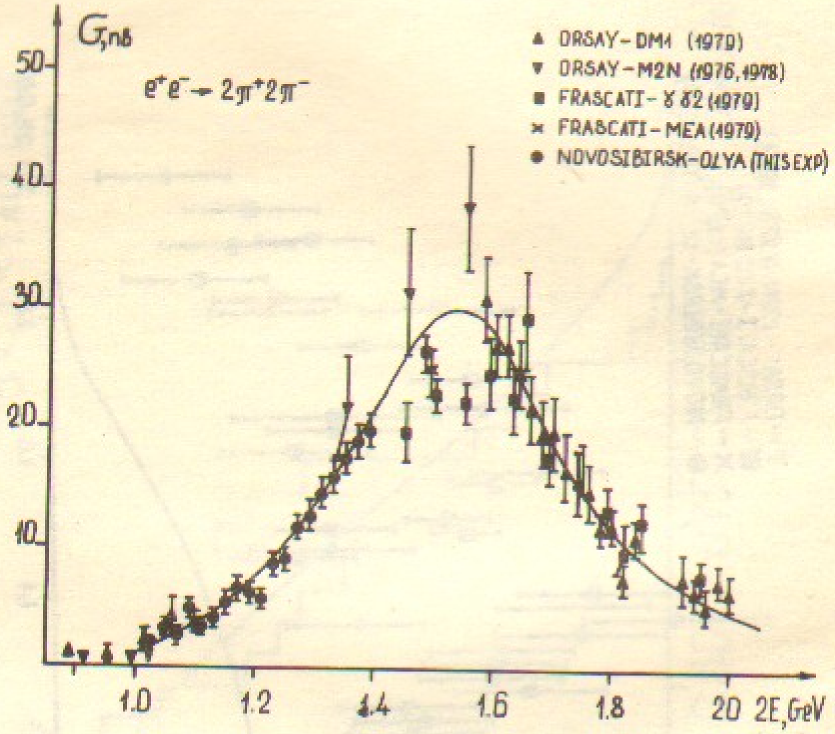

Fig. 6

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