ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

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SEARCH FOR RARE PROCESSES WITH THE NEUTRAL DETECTOR AT THE VEPP-2M COLLIDER

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ABSTRACT

New results of the experiments with the Neutral detector are presented. The cross section of the process $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ in the threshold region has been measured. For the first time the decay mode $\omega \to \pi^0 e^+e^-$ has been observed with a branching ratio of

$$B(\omega \to \pi^0 e^+ e^-) = (0.6 \pm 0.2) \cdot 10^{-3}.$$

The upper limit for the branchings of rare decay modes of vector mesons were placed at 90% c.l.:

$$B(\rho \to \pi^+\pi^-\pi^0\pi^0) < 4 \cdot 10^{-5},$$
$$B(\Phi \to \pi^0 \eta\gamma) < 2.5 \cdot 10^{-3}.$$

From the reaction $e^+e^- \to \rho,\ \omega \to \pi^+\pi^-\pi^0$ the upper limits have been placed for the amplitude of electromagnetic $\rho - \omega$-mixing and the branching ratio:

$$|\delta| < 2.1 \text{ MeV}, \quad B(\rho \to \pi^+\pi^-\pi^0) < 5.8 \cdot 10^{-4}.$$

Upper limits for the leptonic widths of C-even resonances were obtained:

$$\Gamma(\eta' \to e^+e^-) < 0.06 \text{ eV},$$
$$\Gamma(f_0(975) \to e^+e^-) < 8.4 \text{ eV},$$
$$\Gamma(f_2(1270) \to e^+e^-) < 1.7 \text{ eV},$$
$$\Gamma(f_0(1300) \to e^+e^-) < 20 \text{ eV},$$
$$\Gamma(a_0(980) \to e^+e^-)\, B(a_0(980) \to \pi^0\eta) < 1.5 \text{ eV},$$
$$\Gamma(a(1320) \to e^+e^-) < 25 \text{ eV}.$$

Another measurement of this contribution was done in Ref. [7] using the decay mode $\omega\rightarrow\pi^0\gamma$. Study of the energy dependence of the cross section (1) will clarify the problem of the other intermediate states like $\rho\varepsilon$ or $a_1\pi$ which have not yet been explicitly selected.

We present here the results for the energy region 0.85—1.005 GeV in which the integrated luminosity of 1.7 pb^{-1} was collected. The selection criteria were the same as in [6] and required events with two charged particles and four or more photons coming from two π^0-mesons. Energy-momentum balance was also required.

287 events have been found after these cuts. The $\pi^+\pi^-\pi^0$-mass at $2E>0.95$ GeV is shown in Fig. 1. A peak at the ω-meson mass gives evidence for the $\omega\pi^0$-intermediate state.

The total cross section σ_T was obtained from the expression $\sigma_{vis}=\sigma_T\cdot\varepsilon\cdot b$ where σ_{vis} is the visible cross section, ε is the detection efficiency obtained from Monte Carlo [8] and equal to $(4.4\pm0.3)\,\%$ for the $\omega\pi^0$-model at $2E=1$ GeV, b is the radiative correction which in the threshold region changes from 0.85 to 0.90. A systematic uncertainty due to the simulation of pion interaction with the detector material is estimated to be 10%.

The main background process in this energy range is

$$e^+e^-\rightarrow\pi^+\pi^-\pi^0 \qquad (3)$$

with a cross section of 30 nb at 1 GeV [9]. Due to spurios showers caused by nuclear interactions of pions or fluctuations of the development of photon showers the events of this process can be detected

tained $g_{\rho\omega\pi}=18.5\pm0.6$ GeV^{-1}.

under the selection criteria above with the probability of $1.5\cdot10^{-3}$. Its contribution to the detection cross section has been calculated.

In Fig. 2 and Table 1 the energy dependence of the total cross section is shown. Also presented are the results from our experiment at higher energies [6] as well as data from M2N group at ACO [2] and OLYA [3]. A solid line is the cross section of the process (2) calculated in the vector dominance model taking into account $\rho(770)$ and $\rho'(1600)$ with the coupling constants $g_{\rho\omega\pi}=16.6$ GeV^{-1} $g_{\rho'\omega\pi}=2.0$ GeV^{-1} (formula (10) of Ref. [7]). Fitting the data at $2E<1$ GeV and assuming the $\omega\pi^0$ only, we ob-

The results obtained give evidence for the significant contribution of the $\omega\pi^0$-intermediate state in the threshold region. From Fig. 2 it follows that the cross section starts rising at the threshold

Table 1

Cross Section of the Process $e^+e^-\rightarrow\pi^+\pi^-\pi^0\pi^0$ Near Threshold

(* —experimental points from Ref. [6])

$2E$, MeV	$\sigma_{\pi^+\pi^-\pi^0\pi^0}$, nb	$2E$, MeV	$\sigma_{\pi^+\pi^-\pi^0\pi^0}$, nb
425.	$0.3+0.8-0.3$	482.5	$7.4+3.7-2.6$
430.	$1.7+1.2-0.7$	485.	$2.6+2.6-1.4$
435.	$0.6+0.9-0.4$	487.5	$5.4+2.9-2.0$
440.	$0.6+0.9-0.4$	490.	$6.8+1.9-1.5$
445.	$0.9+0.9-0.5$	492.5	$13.1+4.3-3.3$
450.	$0.9+0.9-0.5$	495.	$4.8+3.3-2.1$
455.	$0.0+0.4$	497.5	$12.5+4.3-3.3$
460.	$2.1+1.5-0.9$	500.	11.0 ± 1.7
470.	$1.5+1.2-0.7$	502.5	$10.8+4.4-3.2$
472.5	$4.6+4.5-2.5$	505.*	9.1 ± 1.3
475.	$2.1+2.1-1.2$	520.*	13.6 ± 1.8
477.5	5.6 ± 0.7	530.*	11.9 ± 1.9
480.	5.2 ± 0.7		

of $\omega\pi^0$ production. However its value is greater than the estimated contribution of the reaction (2). The excess is about 50% at 1 GeV indicating that other mechanisms contribute.

2. SEARCH FOR THE DECAY MODE $\rho\rightarrow\pi^+\pi^-\pi^0\pi^0$

The visible cross section of the process (1) becomes lower than that of the background process (3) at $2E<0.9$ GeV. However at $2E\simeq m_\rho$ one could expect the increase of the cross section due to a strong interaction decay

$$e^+e^-\rightarrow\rho\rightarrow\pi^+\pi^-\pi^0\pi^0. \qquad (4)$$

In the $\omega\pi^0$-model the decay probability is suppressed due to the small phase space of the intermediate state with one massive particle. As a result the calculated value of the branching ratio in the vector dominance model is $B(\rho\rightarrow\pi^+\pi^-\pi^0\pi^0)=6\cdot10^{-6}$ [10] despite the large coupling constant $g_{\rho\omega\pi}$.

To search for the decay (4) experimental data from the energy range $2E$ from 660 up to 900 MeV corresponding to the integrated luminosity of 4 pb^{-1} have been used. Events were selected with two charged particles and two π^0-mesons and energy-momentum balance. The detection efficiency for the process (4) in the $\omega\pi^0$-model changes from 1 to 4% in our energy range.

The visible cross section of the selected events shown in Fig. 3*a* is determined by the main background process

$$e^+e^-\to\rho\pi\to\pi^+\pi^-\pi^0, \qquad (5)$$

which has a total cross section of 1.5 μb in the maximum of the ω-meson and the detection efficiency of $3.6\cdot10^{-4}$. The fit of the energy dependence of the data took into account the contributions of (4) and (5). The cross section of (4) was written as

$$\sigma(e^+e^-\to\rho\to\pi^+\pi^-\pi^0\pi^0)=\sigma_0\frac{m_\rho^2\,\Gamma_\rho^2}{(s-m_\rho^2)^2+m_\rho^2\,\Gamma_\rho^2}\cdot\frac{F(s)}{F(m_\rho^2)}, \qquad (6)$$

where $s=4E^2$, σ_0 is the cross section at $s=m_\rho^2$, $F(s)$ is a factor taking into account the $\omega\pi^0$ phase space. The background process (5) was also described by the Breit—Wigner curve taking into account ω—Φ-interference and $\rho\pi$-intermediate state. Radiative corrections were applied. The obtained value of the ω-meson width agrees with our result [11], but the cross section in the ω-meson maximum is by a factor 1.5 higher than earlier. This circumstance is presumably due to the large systematic uncertainty in the detection efficiency of the process (5) when it is detected as a four-particle process.

The visible cross section of the process (4) can be found as a difference between the total detection cross section and the contribution of (5). This difference is shown in Fig. 3*b*. Also shown is the expected energy dependence of (4) which is a rapidly growing function of energy (6). Besides the processes (4) and (5) other physical processes (e.g. QED processes) as well as background (cosmic particles, beam-gas) can contribute which was not taken into account in the fit. As a result an upper limit for the cross section (4) is obtained: $\sigma_0<0.04$ nb. The corresponding upper limit for the branching ratio $B(\rho\to\pi^+\pi^-\pi^0\pi^0)=\sigma_0/\sigma_\rho$ where $\sigma_\rho=1.1$ μb is the cross section of ρ-meson production, is

$$B(\rho\to\pi^+\pi^-\pi^0\pi^0)<4\cdot10^{-5} \quad \text{or} \quad \Gamma(\rho\to\pi^+\pi^-\pi^0\pi^0)<6\,\text{keV} \qquad (7)$$

at 90% c.l. for the $\omega\pi^0$-intermediate state.

The best previous limit for the branching ratio was $2\cdot10^{-4}$ [3].

3. SEARCH FOR THE DECAY MODE $\rho\to\pi^+\pi^-\pi^0$

The ρ—ω-mixing manifests itself in the ρ- and ω-meson *G*-parity violating decays. It has been earlier observed in the $\omega\to\pi^+\pi^-$ decay. Its branching ratio is [12]

$$B(\omega\to\pi^+\pi^-)=1.7\pm0.2\%\,. \qquad (8)$$

A similar decay $\rho\to\pi^+\pi^-\pi^0$ has not been observed yet. A model-dependent upper limit for its branching ratio is [13]

$$B(\rho\to\pi^+\pi^-\pi^0)<1.5\%\,. \qquad (9)$$

In the model of electromagnetic ρ—ω-mixing [14] transitions are described by a complex mixing parameter $\varepsilon=2i\delta/\Gamma_\rho$, where δ is a real transition amplitude. Both probabilities $\omega\to\pi^+\pi^-$ and $\rho\to\pi^+\pi^-\pi^0$ can be expressed in terms of δ. Predictions of the model for the $\omega\to\pi^+\pi^-$ decay probability are consistent with the experimental value (8). The calculation taking into account the area under the resonance curve yields for the probability $\rho\to\pi^+\pi^-\pi^0$ the value of about $7\cdot10^{-4}$. Recently in Ref. [15] it was claimed that from J/Ψ-decays this probability is 10^{-2} in contrast with [14].

The aim of this work is to study ρ—ω-interference in the reaction

$$e^+e^-\to\rho,\,\omega\to\pi^+\pi^-\pi^0. \qquad (10)$$

Detection of the process $\rho\to\pi^+\pi^-\pi^0$ is rather complicated since it manifests itself as a small distortion of the narrow ω-meson resonance curve in the channel $\omega\to\pi^+\pi^-\pi^0$. The total cross section of the process (10) taking into account ρ—ω-interference [14] and the Φ-meson contribution has the form

$$\sigma_{\pi^+\pi^-\pi^0}(s)=|A_\omega\cdot(1+A_\rho)+A_\Phi\,e^{i\theta_\Phi}|^2\cdot(1+\delta_R),$$

$$A_V=\frac{m_V\Gamma_V\cdot\sqrt{\sigma_V\cdot F(s)/F(m_V^2)}}{m_V^2-s-i\sqrt{s}\,\Gamma_\rho}, \qquad V\equiv\omega,\varphi, \qquad (11)$$

$$A_\rho=\sqrt{\frac{\Gamma_{\rho ee}}{\Gamma_{\omega ee}}}\cdot\frac{2|\delta|\,e^{i\theta_\rho}\,m_\omega}{m_\rho-s-i\sqrt{s}\,\Gamma_\rho},$$

where σ_V is a cross section of the resonance in its peak, θ_ρ are resonance phases, $\Gamma_{\rho ee}$, $\Gamma_{\omega ee}$ are their electron widths, $F(s)$ is a $\rho\pi$ phase space [16], δ_R is a radiative correction.

To select $\pi^+\pi^-\pi^0$-events experimental data in the energy range

660—950 MeV corresponding to the integrated luminosity of 4.1 pb^{-1} have been used. Events were analyzed which had two charged particles and two photons. The background contribution is mainly due to the processes

$$e^+e^- \to e^+e^-\gamma\gamma, \quad (12)$$

$$e^+e^- \to \pi^+\pi^-\gamma. \quad (13)$$

These processes have been studied in our energy range in Refs [17, 18]. The process (13) can imitate the decay under study because of the showers splitting and nuclear interactions of pions. To suppress the background contribution it was required that a minimal angle between the particles in the plane perpendicular to the beams be greater than 30°, while the acollinearity angle in this plane be greater than 20°. Energy-momentum balance was also required. To this end kinematical reconstruction of the events was performed under the assumption that charged particles were pions [1]. To suppress the events due to the process (12) e/π-separation was applied according to Ref. [19]. The detection efficiency for the processes (10), (13) and the cross section of the process (12) were determined from the Monte Carlo [8].

In Fig. 4 we present the visible cross section of the selected events which was approximated by the formula

$$\sigma_{vis}(s) = \sigma_{\pi^+\pi^-\pi^0}(s)\cdot\varepsilon_1(s) + \sigma_{\pi^+\pi^-\gamma}(s)\cdot\varepsilon_2(s) + \sigma_{QED}(s), \quad (14)$$

where $\sigma_{\pi^+\pi^-\pi^0}$, $\sigma_{\pi^+\pi^-\gamma}$ are the total cross sections, ε_1, ε_2 are corresponding detection efficiencies, σ_{QED} is the visible cross section of the process (12). The values of Φ-meson parameters as well as m_ρ, Γ_ρ, $\Gamma_{\rho ee}$, $\Gamma_{\omega ee}$ were taken from the table [12]. For θ_ρ zero value was used which is close to the prediction of [14] and is consistent with the experimental value $5.0\pm6.3°$ [20]. δ, σ_ω, Γ_ω were determined by the maximum likelihood method taking into account the uncertainties in the values of ε_1, ε_2 and σ_{QED}. The values of σ_ω, Γ_ω obtained are consistent with our previous results from the ω-meson study [11]. The energy dependence of the cross section (10) is in good agreement with the formula (11). Since our value for $|\delta|$ differs from zero insignificantly, an upper limit for this quantity is placed: $|\delta| < 2.1$ MeV at 90% c.l. The main uncertainty in the determination of δ is statistical one. In order to estimate the systematic error data analysis was performed with another set of selection criteria, without e/π-separation and restrictions on the $\gamma\gamma$-invariant mass

and besides that, using two-quantum annihilation instead of elastic e^+e^--scattering for the overall normalization. Such an analysis showed that the systematic uncertainty is not greater than 25% of the statistical one.

The upper limit for the quantity $B(\rho\to\pi^+\pi^-\pi^0)$ obtained is close to the value measured earlier in the decay $\omega\to\pi^+\pi^-$. In the model [14] the following upper limit can be obtained using the formula $B \simeq 0.75\cdot 4|\delta|^2/\Gamma_\rho^2$ *)

$$B(\rho\to\pi^+\pi^-\pi^0) < 5.8\cdot10^{-4}, \quad (15)$$

which is close to a theoretically expected value $7\cdot10^{-4}$.

4. OBSERVATION OF THE DECAY $\omega\to\pi^0e^+e^-$

By studying the process $\omega\to\pi^0e^+e^-$ one can obtain information on the $\omega-\pi$-transition structure. The corresponding diagram is shown in Fig. 5. Quantitavely the electromagnetic structure of the vertex of the $\omega-\pi^0$-transition is described by the transition form factor $F_{\omega\pi}(q^2)$ depending on the squared momentum q^2 of the virtual photon. At the present time data on the $F_{\omega\pi}(q^2)$ behaviour exist from two experiments: study of the process $e^+e^-\to\omega\pi^0$ by the Neutral detector in the energy range $q^2 = 1\div2$ GeV^2 [7] and investigation of the decay $\omega\to\pi^0\mu^+\mu^-$ in the region $q^2 = 0\div0.4$ GeV^2 by the LEPTON-G group [21]. Behaviour of the form factor in the region $q^2 = 1\div2$ GeV^2 is well described by the extended vector dominance with $\rho'(1600)$. If $\rho'(1600)$ is taken into account, one obtains correct values for the widths $\omega\to\pi^0\gamma$ and $\omega\to\pi^+\pi^-\pi^0$. However, the form factor in the region $q^2 = 0.2\div0.4$ GeV^2 extracted from the $\omega\to\pi^0\mu^+\mu^-$ is not consistent with the extended vector dominance at the values of parameters obtained in [7]. Other theoretical models listed in Ref. [22], can't account for the existing experimental data. Thus behaviour of $F_{\omega\pi}(q^2)$ requires further experimental and theoretical investigation.

In this work for the first time the decay mode $\omega\to\pi^0e^+e^-$ has been observed and its branching ratio measured. $8.6\cdot10^5$ decays of the ω-meson were detected in the energy range 770—800 MeV corresponding to the integrated luminosity of 1.2 pb^{-1}. For a search

*) G. N. Shestakov, private communication.

for the process

$$e^+e^-\to\omega\to\pi^0e^+e^- \qquad (16)$$

the following cuts were imposed:

1) an event has two photon showers and one or two showers from the charged particles,
2) there are two tracks in the cylindrical chambers with an azimuthal angle between them greater than 3°,
3) an azimuthal angle between the any charged particle and neutral particles is greater than 30°,
4) there is energy-momentum balance,
5) a shower from the more energetic charged particle deposits energy in three or more NaI(Tl) layers,
6) the two photon invariant mass is in the range 85—185 MeV, i.e. close to the π^0-meson mass,
7) the total energy of the photon pair is greater than 300 MeV.

The second condition allows suppression of the background due to the decay mode $\omega\to\pi^0\gamma$ with the photon conversion in the vacuum chamber. Third and fourth cuts suppress the beam background, as well as that due to the cosmic particles and the process $e^+e^-\to e^+e^-\gamma$ which can imitate the final state $e^+e^-\gamma\gamma$ because of the shower fluctuations. The contribution of the decay $e^+e^-\to\omega\to\pi^0\gamma$, $\pi^0\to\gamma e^+e^-$ was determined from Monte Carlo and was less than one event.

The following processes can also contribute to the background:

$$e^+e^-\to e^+e^-\gamma\gamma \text{ (QED)}, \qquad (17)$$

$$e^+e^-\to\omega\to\pi^+\pi^-\pi^0 \qquad (18)$$

In Fig. 6*a*—6*c* we present two-dimensional distributions over the azimuthal angle between the charged particles and the photon pair energy obtained from the Monte Carlo of the processes (16—18). The main part of the events of the process (16) is inside the peak due to the small azimuthal angle between the tracks and the photon pair energy of $E_{\gamma\gamma}=403$ MeV which corresponds to the smallest recoil mass of the π^0-meson. Fig. 6*d* presents the same distribution in the experiment. It has a peak giving evidence for the process (16). In Fig. 7 we present an experimental distribution over the azimuthal angle between the tracks for events with the $E_{\gamma\gamma}$ from 340 to 460 MeV. This distribution was fitted by a sum of the contributions due to (16) and (18) (Fig. 7). The contribution of (17) de-

termined from Monte Carlo was 3 events and further ignored. The number of events due to (16) was $43\pm10\pm10$, where the first error is statistical and the second one is systematic, associated with model dependence of the background subtraction. The probability of the difference from zero is 98.5%. From the detection efficiency of 8.5% obtained for (16) from Monte Carlo the branching ratio is

$$B(\omega\to\pi^0e^+e^-)=(0.6\pm0.2)\cdot10^{-3}, \qquad (19)$$

consistent with the calculated value of $0.87\cdot10^{-3}$ [22].

Information on the transition form factor can be obtained from the recoil spectra of π^0-mesons. That requires greater statistics and further background suppression.

5. SEARCH FOR THE DECAY MODE $\Phi\to\pi^0\eta\gamma$

In this work we continue a search for rare radiative decays of the Φ-meson started in Ref. [23]. One of the most interesting processes of this series is the decay

$$\Phi\to\pi^0\eta\gamma, \qquad (20)$$

which can be caused by different mechanisms. In the model of vector dominance the calculation of the branching ratio for the decay $\Phi\to\rho\pi$, $\rho\to\eta\gamma$ yields $0.8\cdot10^{-5}$, whereas $\Phi\to a_0(980)\gamma$, $a_0(980)\to\pi^0\eta$—$2\cdot10^{-4}$**). Completely new mechanisms can not be excluded.

To look for this process five-photon events with the energy-momentum balance and only one π^0-meson were selected. For such events a spectrum of the invariant masses for two photons with the largest energy of the three not included into π^0-meson was constructed (Fig. 8*a*). The observed spectrum is determined mainly by the background process $\Phi\to\eta\gamma$, $\eta\to3\pi^0$. If one subtracts its calculated contribution (Fig. 8*b*), the remaining spectrum is accounted for by the process $\Phi\to K_SK_L$, $K_S\to2\pi^0$ and possesses besides that a small peak at the η-meson mass. This peak can give evidence for the existence of the decay (20).

To determine the number of events of this process the distribution obtained was fitted by a sum of the peak due to the decay mode

**) N.N.Achasov, private communication.

(20) and a smooth curve describing the background. As a result the statistical significance of the observed peak is about two standard deviations. This allowes to establish only upper limit for the number of the events of the reaction (20). Using this limit and the detection efficiency of $\sim 1\%$ the following upper limit for branching ratio is placed:

$$B(\Phi \to \pi^0 \eta\gamma) < 2.5 \cdot 10^{-3} \text{ at } 90\% \text{ c.l.} \qquad (21)$$

which is by one order of magnitude larger than the calculated value. Further investigation of this decay mode is of great interest. If such a decay really exists and its branching is about 10^{-3}, then it can not be determined by any known mechanism.

6. LEPTONIC WIDTH OF THE η'-MESON

η'-mesons can be directly produced in e^+e^--collisions via a two-photon intermediate state (see the diagram of Fig. 9). The probability of the process $\eta' \to e^+e^-$ can be expressed in terms of a two-photon width of the η'-meson. In the limiting case when both photons are on the mass shell, this probability equals $6.8 \cdot 10^{-10}$ [22]. However the form factor of the η'-meson transition into two photons can enhance this probability by an order of magnitude. Therefore the value of the leptonic width can clarify the form factor structure.

Using the Neutral detector we have made an attempt to measure the η'-meson leptonic width. To this end the energy range from 955.5 to 959.5 MeV was scanned with a step of 0.5 MeV, the integrated luminosity of 534 nb^{-1} was collected.

The direct production of the η'-meson can be reliably identified using the following reaction:

$$e^+e^- \to \eta' \to \pi^+\pi^-\eta \qquad (22)$$
$$\hookrightarrow \gamma\gamma$$

The branching ratio of this decay of η'-meson is relatively large, the number of final particles is small and the final state has following characteristic features: the two photon mass equals the η-meson mass, the minimium angle between the photons is about 134°, the maximum energy of π-mesons is less than 300 MeV, so that they stop in the first NaI(Tl) layer. The most probable origin of background is that of the reactions $e^+e^- \to \omega$, $\Phi \to \pi^+\pi^-\pi^0$ and $e^+e^- \to \omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$ [6].

Events were selected with two charged particles and two photons. For best angular accuracy photons must fire the shower chambers, charged particles must stop in the first NaI(Tl) layer. Since pions do not deposit their energy in the calorimeter completely, the total energy deposition must not exceed $1.6 \cdot E$. It was also required that an angle between the charged particles in the plane perpendicular to the beam axis be greater than 5°, while the spatial angle between the photons — greater than 120°. Events thus selected were subject to kinematical fit [1] on the assumption that charged particles are pions. For events satisfying energy-momentum balance after kinematic fit the two-photon masses were calculated. The events with $450 < m_{\gamma\gamma} < 600$ MeV were selected. The detection efficiency was calculated by Monte Carlo and was equal to 1% with respect to all the η'-meson decays.

No events satisfying all selection criteria were found. To calculate an upper limit for the leptonic width of the η'-meson we took into account deformation of the resonance curve by radiative corrections and the beam energy spread (0.38 MeV) comparable to the total width. The following limit was obtained:

$$B(\eta' \to e^+e^-) < 2.1 \cdot 10^{-7} \text{ or } \Gamma(\eta' \to e^+e^-) < 0.06 \text{ eV} \qquad (23)$$

at 90% c.l. This value is by three orders of magnitude larger than a unitary limit and does not contradict to any of the existing models of the form factor.

7. UPPER LIMITS FOR THE LEPTONIC WIDTHS OF $f_0(975)$-, $f_2(1270)$-, $f_0(1300)$-, $a_0(980)$-, $a_2(1320)$- MESONS

Similar to the η'-meson, scalar and tensor C-even resonances can be produced in e^+e^--collisions via a two-photon intermediate state (Fig. 9). Two-photon widths of $f_2(1270)$-, $a_0(980)$-, $a_2(1320)$-mesons were recently measured [26]. In the unitary limit (intermediate photons on the mass shell) one can estimate their leptonic width. For tensor mesons it must be by a factor α^2 less than a two-photon width and equals ~ 0.01 eV for the $a_2(1320)$-meson and ~ 0.03 eV for $f_2(1270)$-meson [27]. For scalar mesons estimation is similar to that in Ref. [28], where a pseudoscalar matrix element is replaced by a scalar one. One must also take into account the additional helicity suppression by a factor of $(m_e/m_s)^2$ where m_e and m_s

are the masses of the scalar meson and electron. This gives for $a_0(980)$-meson the value of $4\cdot 10^{-6}$ eV. A gain of about 10 can be achieved if one takes into account the form factor of the transition of the C-even state into two photons. The integrated luminosity of 19 pb^{-1} was collected by the Neutral detector in the energy range from 0.5 to 1.4 GeV. Using these data we have placed upper limits on the leptonic widths of $f_0(975)$-, $f_2(1275)$-, $f_0(1300)$-, $a_0(980)$-, $a_2(1320)$-mesons in the following reactions:

$$e^+e^-\rightarrow f_0(975), f_2(1270), f_0(1300)\rightarrow \pi^0\pi^0, \quad (24)$$

$$e^+e^-\rightarrow a_0(980), a_2(1320)\rightarrow \pi^0\eta, \quad (25)$$

with four photons in the final state. Background comes from the processes:

$$e^+e^-\rightarrow \gamma\gamma\gamma, \quad (26)$$

$$e^+e^-\rightarrow \gamma\gamma\gamma\gamma, \quad (27)$$

$$e^+e^-\rightarrow \omega\pi^0\rightarrow \pi^0\pi^0\gamma, \quad (28)$$

$$e^+e^-\rightarrow \omega, \Phi\rightarrow \text{neutral particles}. \quad (29)$$

Events of (26) can imitate the effect when a broad shower in the calorimeter is accepted as two particles. The process (27) is a usual process of QED. The multiphoton events of the processes (28) and (29) may also imitate the effect when some of the photon merge together or escape detection.

Events with four photons in the calorimetr had to fire the shower chambers. Energy deposit in each shower had to exceed 20 MeV, a space angle between any two photons had to exceed 20°. In the decay of a pion with an energy of 700 MeV the minimum angle between the photons is about 22°, thus this restriction did not influence the selection. For each event two photon can be combined into two pairs by three possible combinations. For each pair its invariant mass was calculated. In Fig. 10 we show two-dimensional distributions over the lower $m_{\gamma\gamma}^{low}$ and higher $m_{\gamma\gamma}^{high}$ masses. Each event in the figure gives three entries. For intermediate states of $\pi^0\pi^0$ ($\pi^0\eta$) obtained by Monte Carlo simulation of the decay of C-even resonances (Fig. 10*a*, *b*, *e*, *f*, *g*) one sees clustering of events at $m_{\gamma\gamma}^{low}=m_{\pi^0}$, $m_{\gamma\gamma}^{high}=m_{\pi^0}(m_\eta)$ all other points in the figure are a combinatorial background. For the process (27) all the points populate uniformly the kinematically allowed region (Fig. 10*d*). The

reaction (28) is characteristic of the larger density in the band at $m_{\gamma\gamma}^{low}=m_{\pi^0}$ (Fig. 10*c*). The same distribution is observed for experimental events at $2E>1$ GeV (Fig. 10*k*, *l*). Here the contribution of the process (28) is more significant. At $2E<1$ GeV the indicated regions possess no singularities (Figs. 10*i*, *j*). Intermediate $\pi^0\pi^0$-states were selected by imposing the cuts: $90<m_{\gamma\gamma}^{low}<180$ MeV and $90<m_{\gamma\gamma}^{high}<180$ MeV. For $\pi^0\eta$-states similarly $90<m_{\gamma\gamma}^{low}<180$ MeV and $500<m_{\gamma\gamma}^{high}<600$ MeV. The corresponding visible cross sections are presented in Figs. 11*a*, *b*. Peaks at the masses of ω- and Φ-mesons are due to the background processes (29). Also observed is the rise of the cross section at $2E>1$ GeV caused by a threshold rise of the cross section of the process (28). The visible cross section for the $\pi^0\pi^0$ and $\pi^0\eta$ final states was approximated by the formula

$$\sigma_{vis}(s)=\sum_R \sigma_R+\sigma_{\omega\pi^0}, \quad (30)$$

where the cross section $\sigma_{\omega\pi^0}$ was taken from Ref. [25] with the corresponding detection efficiency. Contributions of the C-even resonances as well as that of the background (29) σ_R are parametrized in the Breit—Wigner approximation without interference. For all the resonances but ω and Φ energy dependence of the width was neglected. The leptonic widths of the resonances and amplitudes of the ω- and Φ-mesons were free parameters. The detection efficiency determined from Monte Carlo varied from 2 to 4% for different resonances. For other parameters their table values were taken [12]. From the experimental data for the $\pi^0\pi^0$-states the following limitations for the leptonic widths were placed:

$$\Gamma(f_0(975)\rightarrow e^+e^-)<8.4\ \text{eV},$$
$$\Gamma(f_2(1270)\rightarrow e^+e^-)<1.7\ \text{eV}, \quad (31)$$
$$\Gamma(f_0(1300)\rightarrow e^+e^-)<20\ \text{eV at } 90\%\ \text{c.l.}$$

Similarly for the $\pi^0\eta$-state

$$\Gamma(a_0(980)\rightarrow e^+e^-)B(a_0(980)\rightarrow \pi^0\eta)<1.5\ \text{eV},$$
$$\Gamma(a_2(1320)\rightarrow e^+e^-)<25\ \text{eV}. \quad (32)$$

The limits obtained are two orders of magnitude higher than the unitary limits for tensor mesons and six orders higher for scalar ones.

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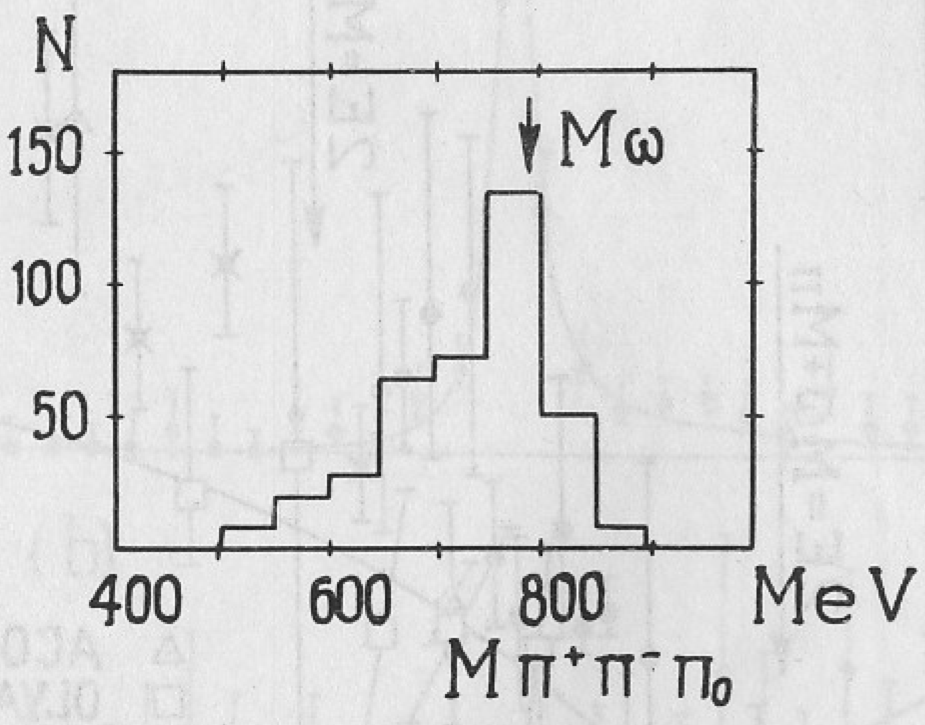


Fig. 1. Mass spectrum of the $\pi^+\pi^-\pi^0$-system for selected events of the process (1). The peak at the ω-meson mass gives evidence for a significant contribution of the process (2).

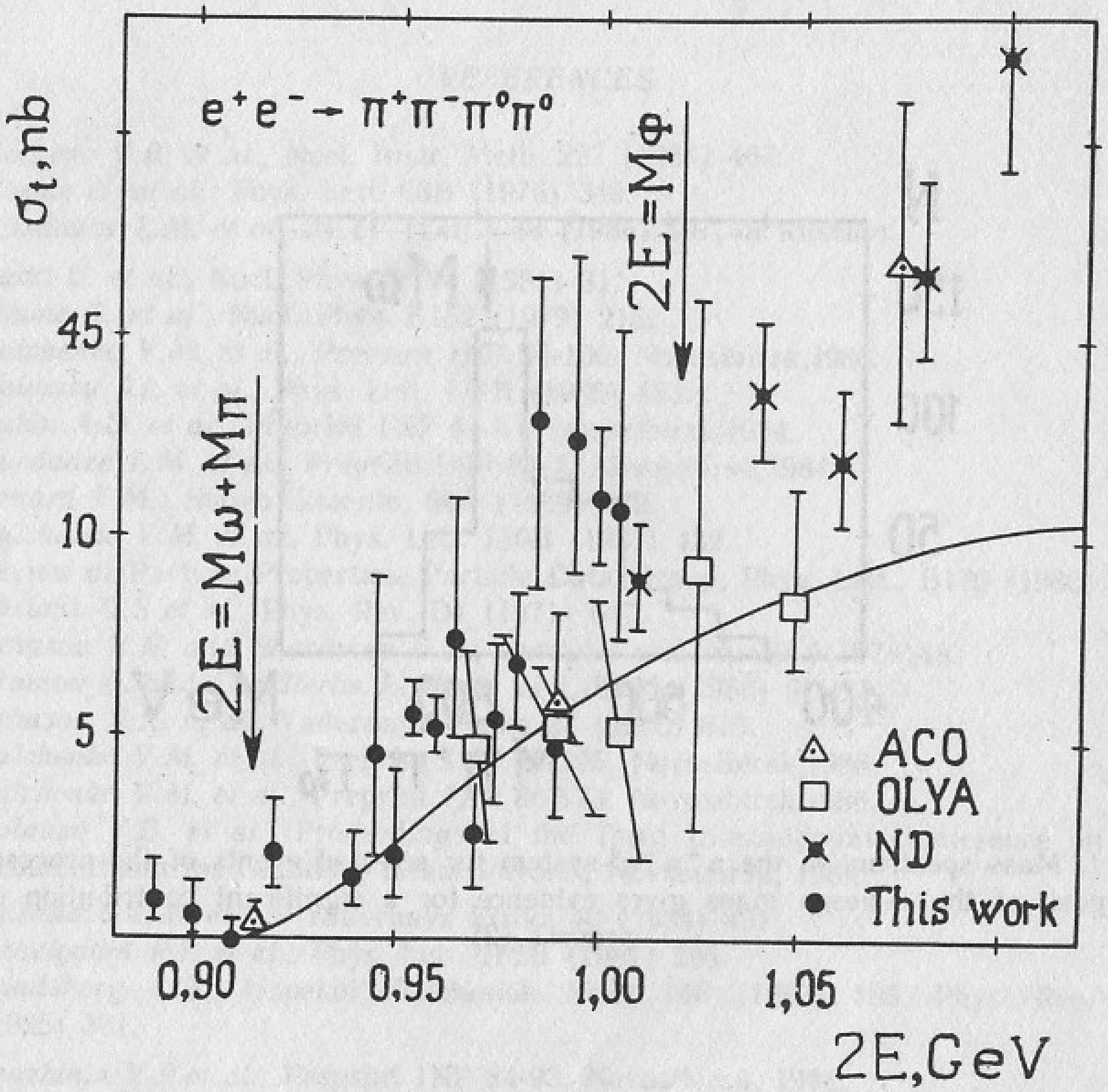


Fig. 2. Total cross section of the reaction (1). A solid line is the calculated contribution of the process (2) according to [7].

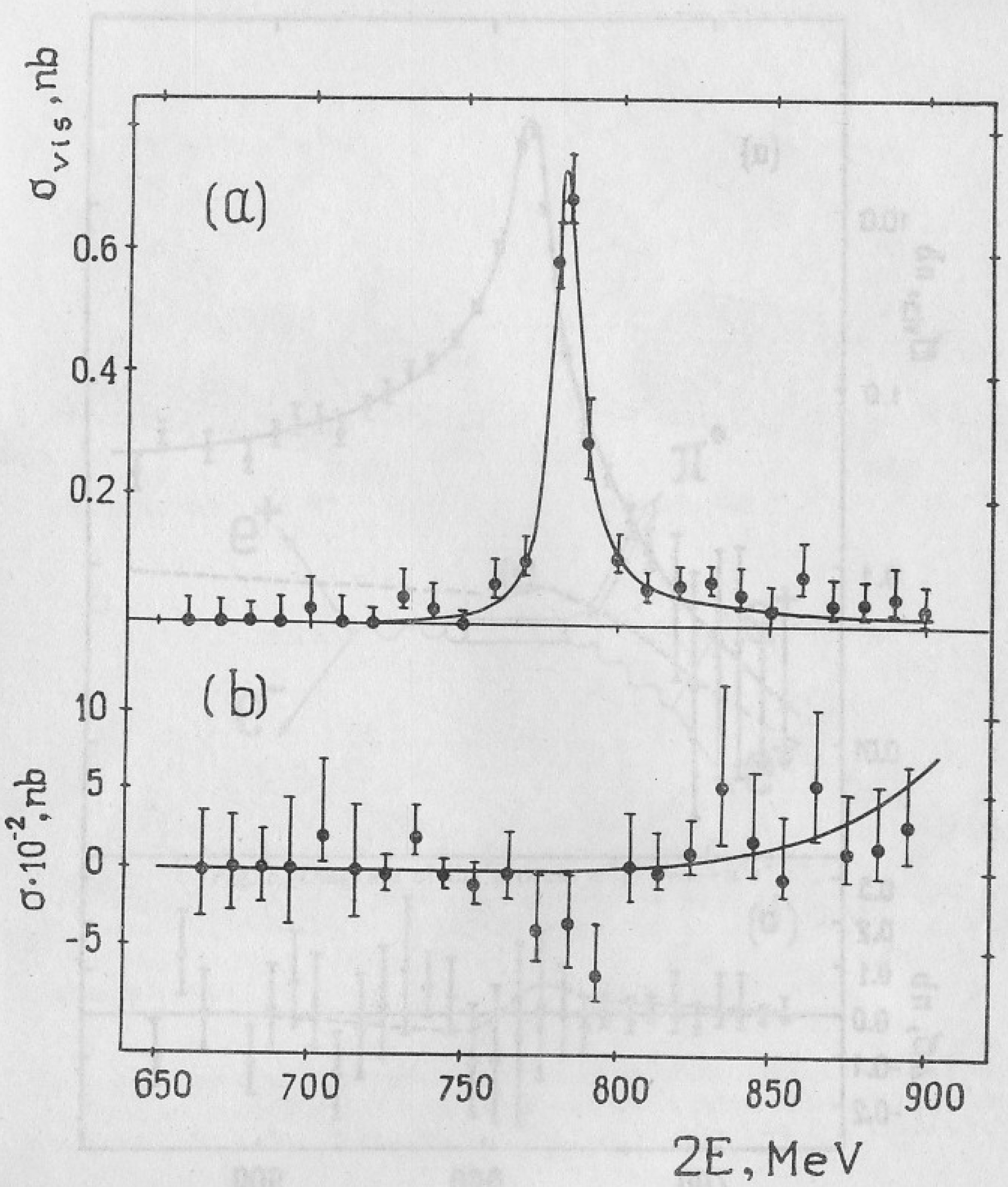


Fig. 3. The visible cross section of the process $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$: *a*—experiment, a solid line is an optimal curve for the process (3), *b*—is the difference between the experimental visible cross section (Fig. 3*a*) and the optimal contribution from the process (3), a solid line corresponds to the limiting value of the process (4) contribution at 90% c.l.

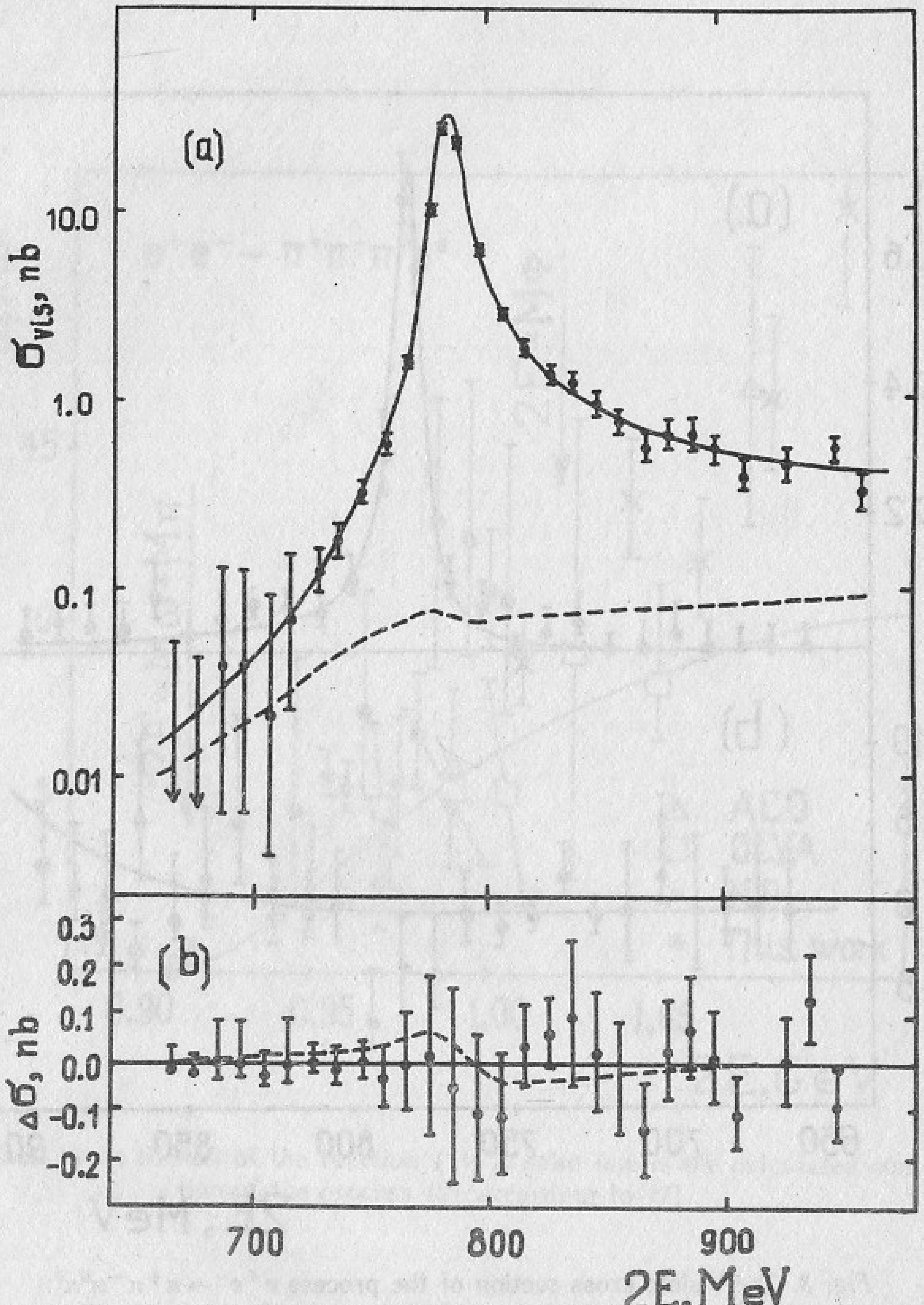


Fig. 4. a — the visible cross section for selected events, a solid line is the optimal curve, a dashed line is the contribution of the process (13), the visible cross section of the process (12) is less than $3 \cdot 10^{-3}$ nb. b — the difference between the visible cross section and the optimal curve. The dashed line corresponds to the upper limit of the contribution of the decay $\rho \to \pi^+\pi^-\pi^0$ at 90% c.l.

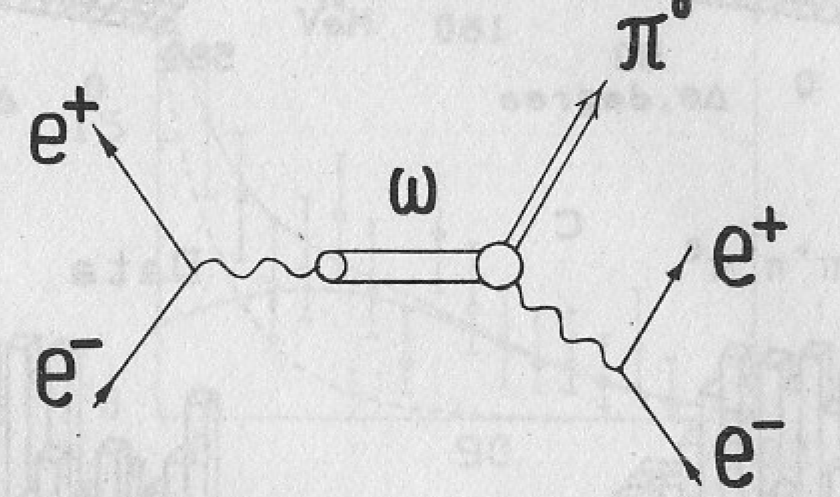


Fig. 5. Diagram of the process $e^+e^- \to \omega \to \pi^0 e^+ e^-$.

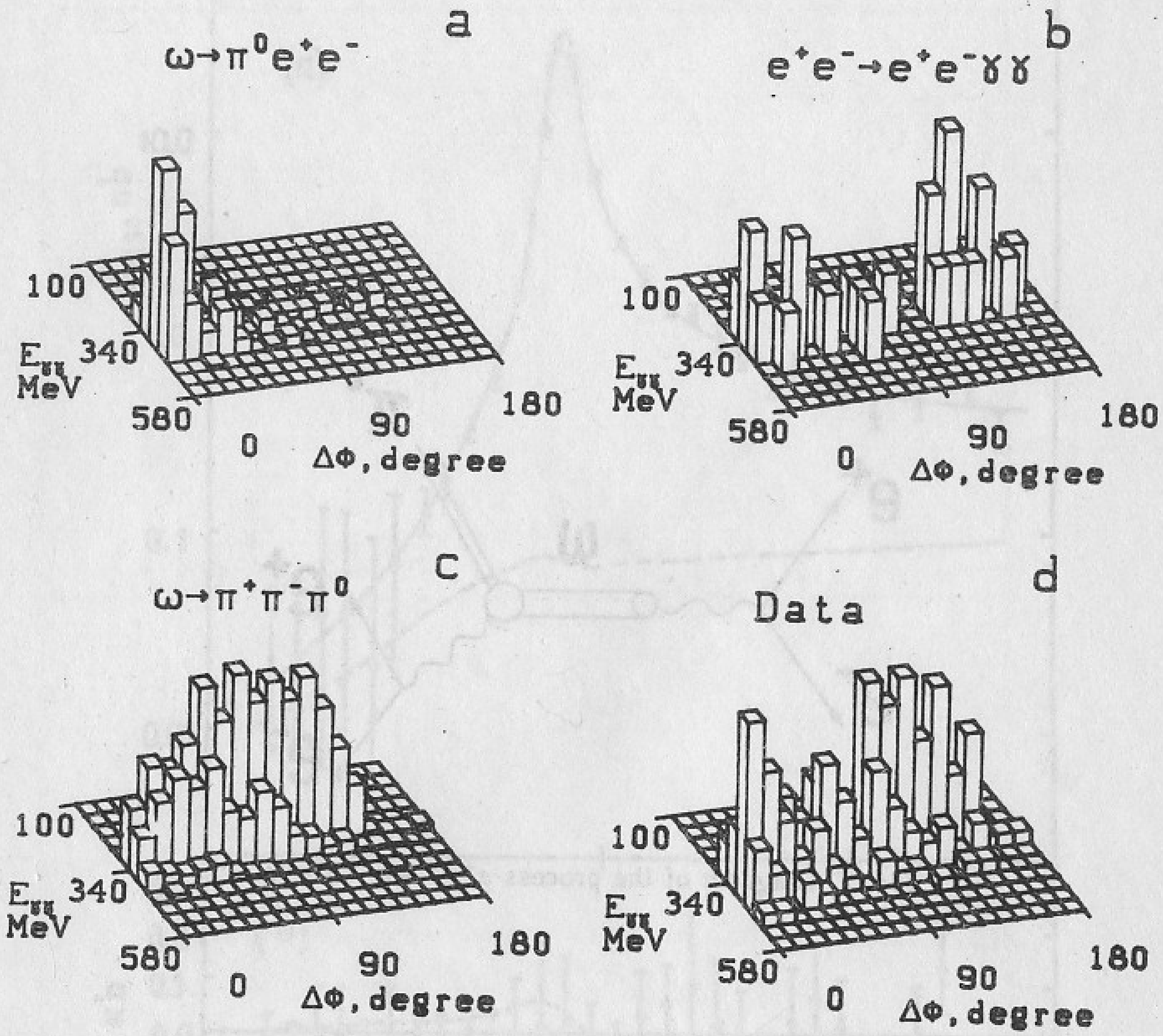


Fig. 6. Two-dimensional distribution over the azimuthal angle between charged particles $\Delta\varphi$ and the total energy of the photon pair $E_{\gamma\gamma}$ for simulation of the processes: $a - e^+e^- \to \omega \to \pi^0 e^+e^-$; $b - e^+e^- \to e^+e^-\gamma\gamma$; $c - e^+e^- \to \omega \to \pi^+\pi^-\pi^0$ and d — for experimental events.

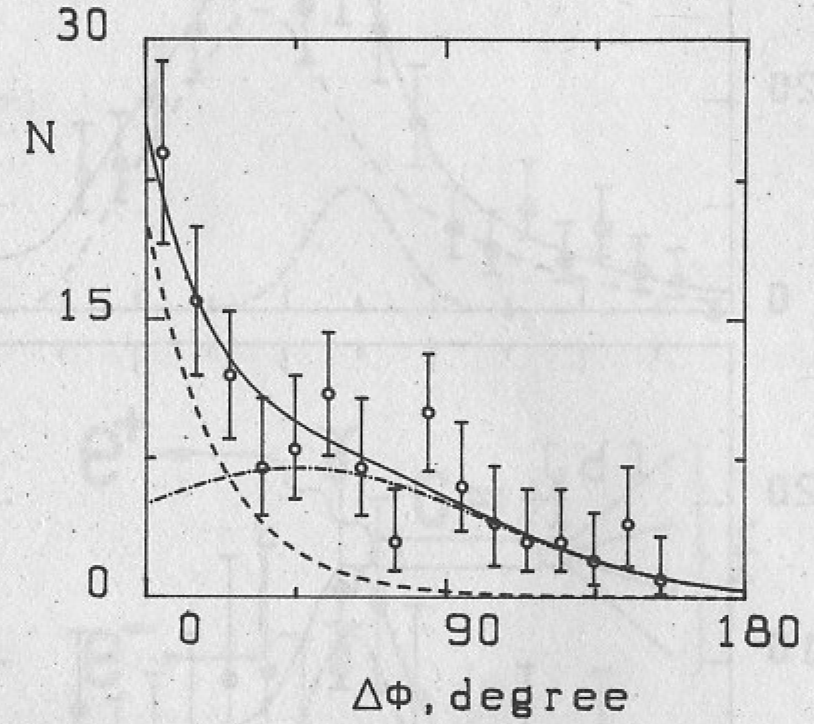


Fig. 7. Distribution over the azimuthal angle between charged particles for experimental events with the total energy of the photon pair from 340 to 460 MeV. A dashed line shows the contribution of the process $e^+e^- \to \omega \to \pi^0 e^+e^-$, a dashed-dotted line $e^+e^- \to \omega \to \pi^+\pi^-\pi^0$, and a solid line is their sum.

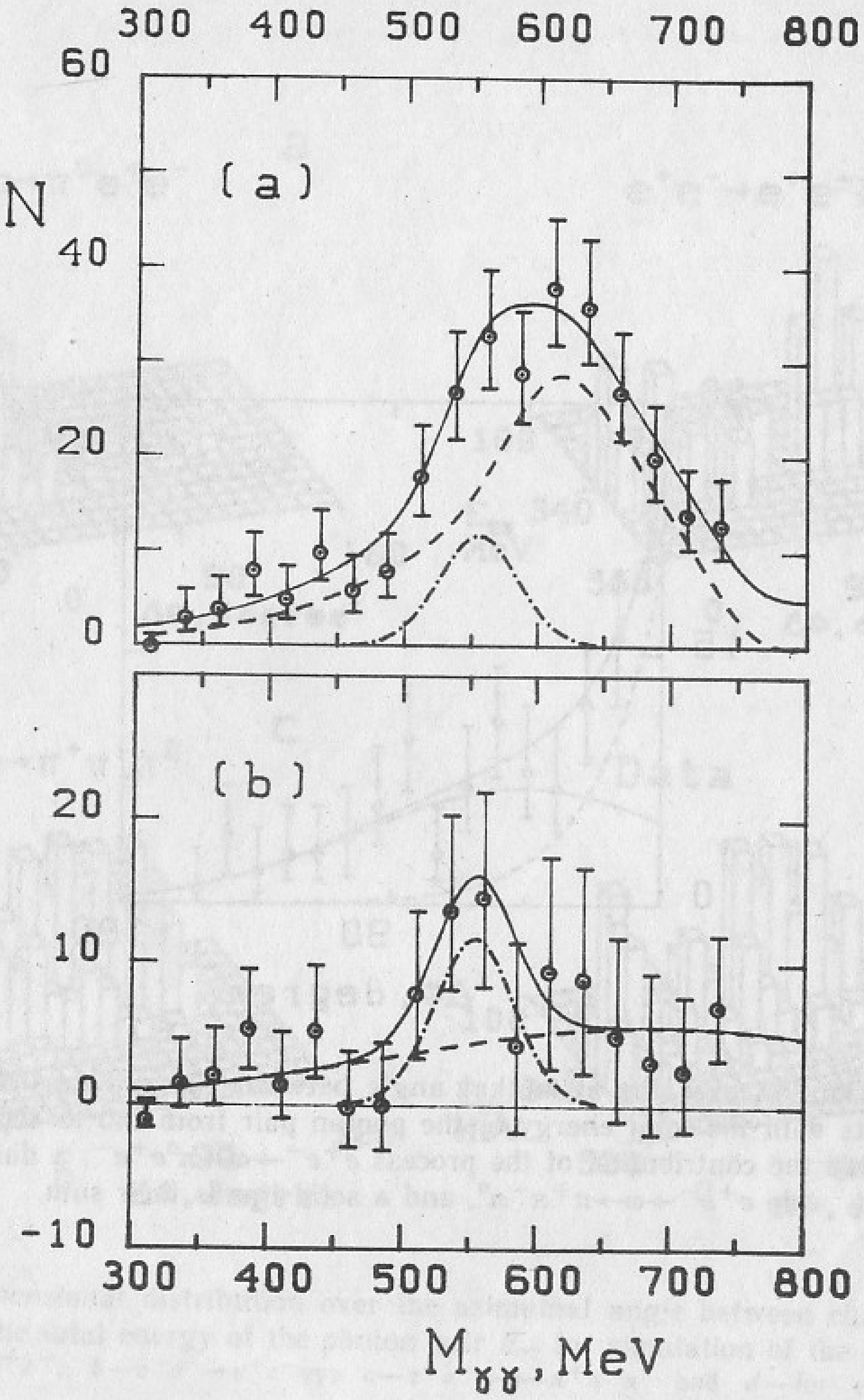


Fig. 8. Masses of two photons with the highest energy of three in experimental $\pi^0\gamma\gamma$-events. A solid line is an optimal curve, a dashed-dotted line is simulation of the decay $\Phi\to\pi^0\eta\gamma$:

a—all events, a dashed line is the contribution of the decay $\Phi\to\eta\gamma$; *b*—the contribution of the decay $\Phi\to\eta\gamma$ is subtracted. A dashed line is the background approximation.

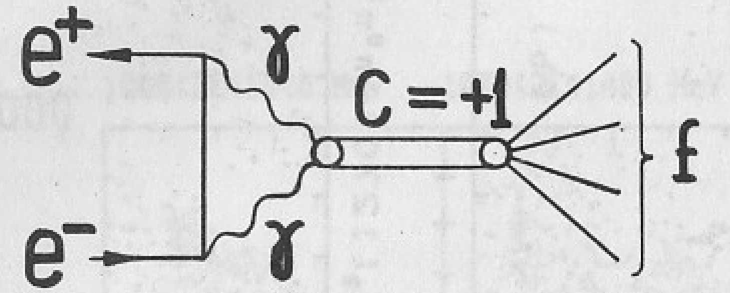
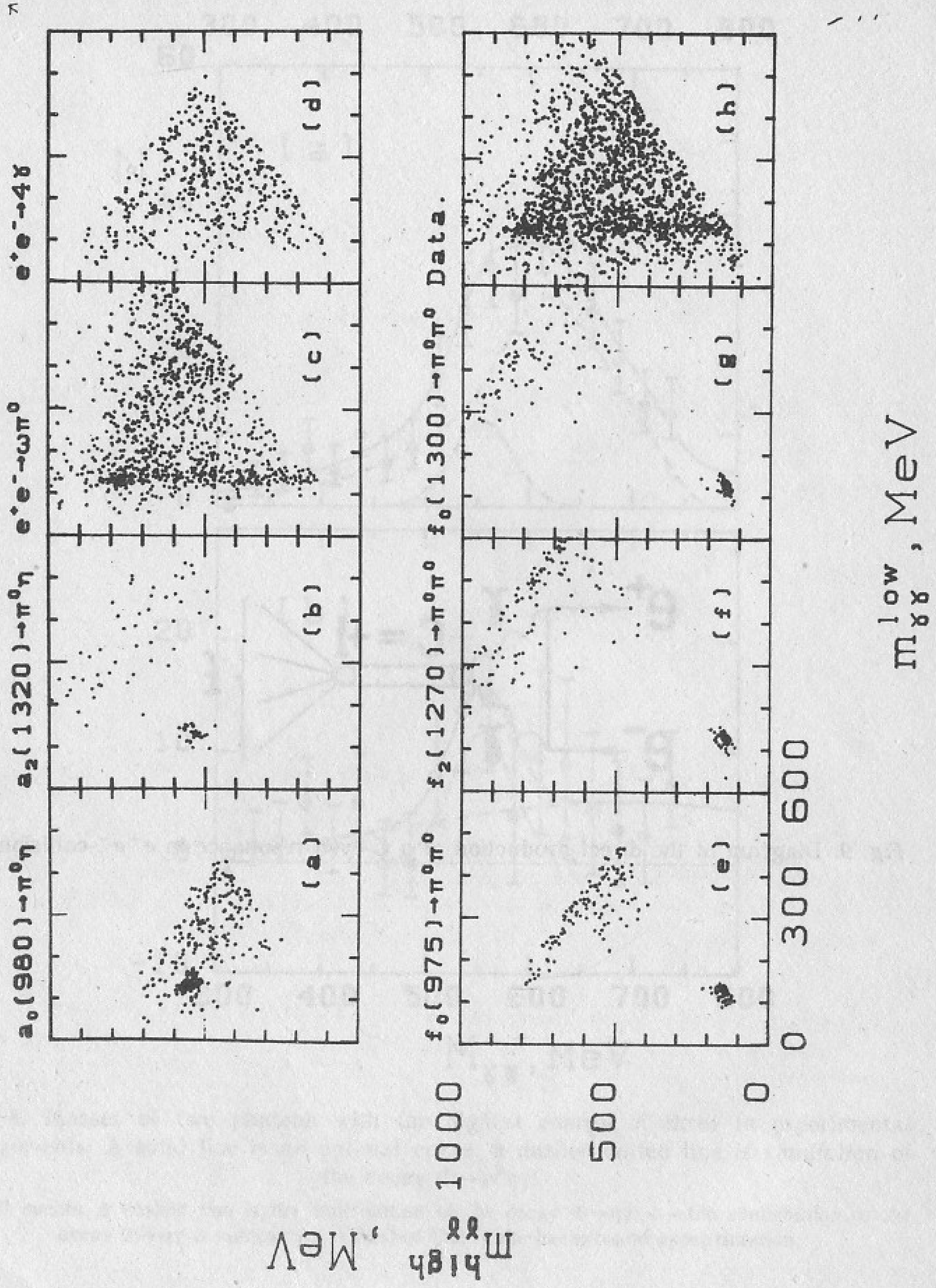


Fig. 9. Diagram of the direct production of a C-even resonance in e^+e^--collisions.



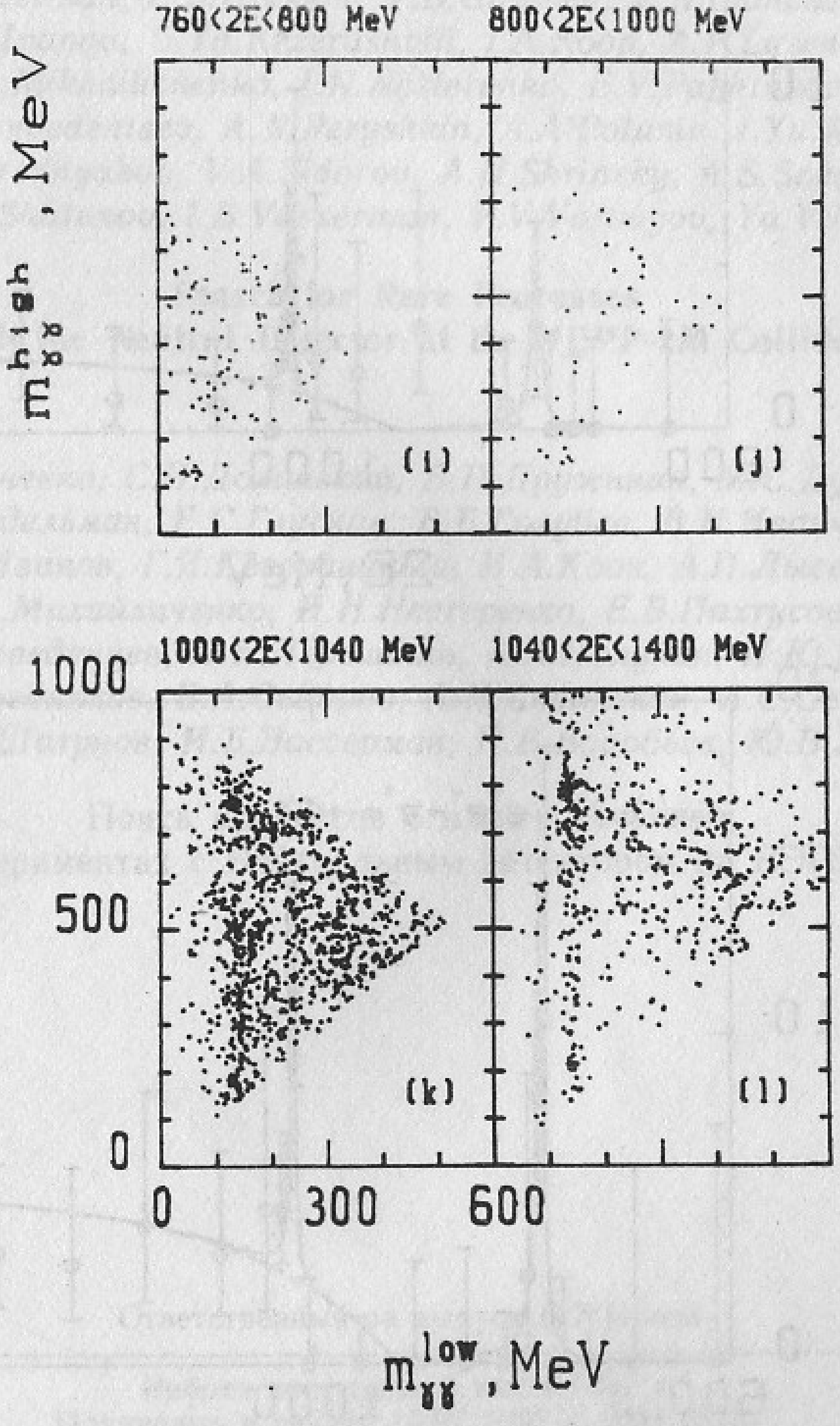


Fig. 10. Two-dimensional distribution over the lower and higher invariant masses of photon pairs for events with four photons (each event gives three entries). $a-g$ — simulation of the processes (24),(25) and possible background reactions (27),(28); h — all experimental data; $i-l$ — experimental data in different energy ranges.

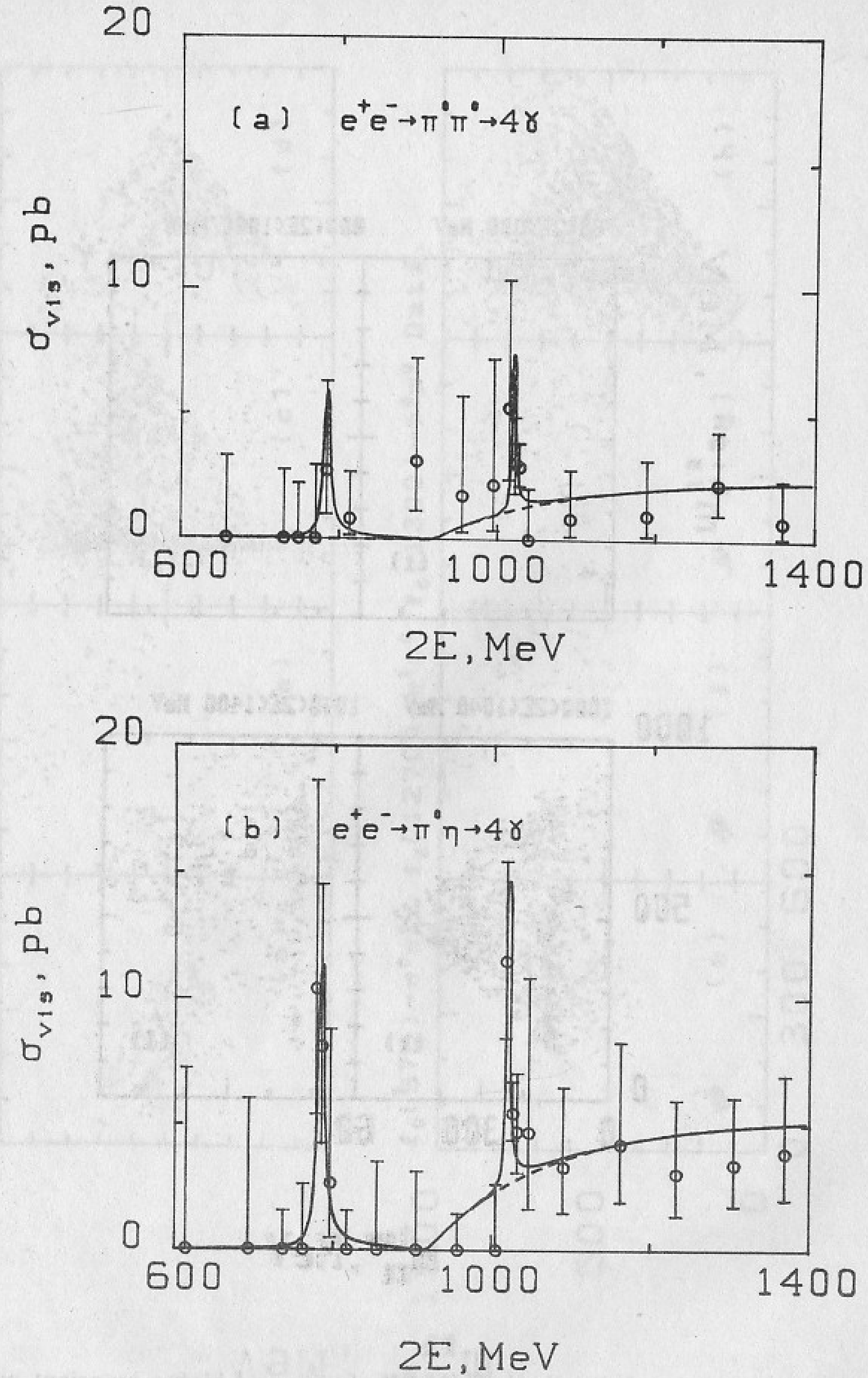


Fig. 11. Visible cross sections for the events with four photons after selection over the masses of intermediate states: $a-\pi^0\pi^0$, $b-\pi^0\eta$. A solid curve is the total visible cross section, a dashed line shows the contribution of the process (28).

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Search for Rare Processes with the Neutral Detector at the VEPP-2M Collider

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Поиск процессов с малым сечением в экспериментах с Нейтральным детектором на ВЭПП-2М

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