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ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

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НОВОСИБИРСК

AN EXPERIMENT ON MEASUREMENT
OF TWO-PHOTON WIDTH OF THE η' AND A_2*)

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ABSTRACT

Results are presented of a measurement of the two-photon width of the η' and A_2 at the storage ring VEPP-4 with the detector MD-1. Tagging of at least one scattered electron was required. The following results have been obtained :

$$\Gamma_{\eta'\to\gamma\gamma}=4.6\pm1.1\pm0.9\ \text{keV},$$

$$\Gamma_{A_2\to\gamma\gamma}=1.05\pm0.24\pm0.23\ \text{keV},$$

*) Submitted to the International Symposium on Lepton and Photon Interactions at High Energy, Hamburg, July 1987.

Study of C-even resonance formation in photon-photon interactions has become a classic field of research at e^+e^- storage rings. Recently several experiments on measurement of the two-photon width of the η' and A_2 have been performed [7-18] and its results are collected in the table in the end of the text.

In this preprint we present a study of the processes :

$$ee\to ee\eta' \quad (1)$$
$$\quad \eta'\to\rho\gamma$$
$$\quad\quad \rho\to\pi^+\pi^-$$

$$ee\to eeA_2 \quad (2)$$
$$\quad A_2\to\rho^\pm\pi^\pm$$
$$\quad\quad \rho^\pm\to\pi^\pm\pi^0$$
$$\quad\quad\quad \pi^0\to\gamma\gamma$$

The experiment was performed in 1984—1985 at the storage ring VEPP-4 with the detector MD-1 [1] in the center-of-mass energy range 7.2—10.4 GeV, the integrated luminosity was 20.3 pb^{-1}.

The specific feature of this experiment is detection of at least one scattered electron emitted from the interaction point at almost zero angles. The magnetic field in the detector MD-1 is transverse to the orbit plane of the storage ring and equals to 12 kG at the beam energy of 5 GeV. On both sides of the main magnet the additional magnets with the same field direction are installed. This allows detection of the scattered electrons emitted from the interaction region even at zero angles in the energy range $0.5<E/E_0<0.85$, where E_0 is the beam energy.

The layout of the detector MD-1 is shown in Fig. 1. Charged particles are detected by coordinate proportional chambers. Coordinate system is covered by 24 scintillation counters. Photons are detected in shower-range proportional chambers compiled in 14 separate units. Each unit consists of 10 chambers alternating with 13 mm thick stainless steel plates. Gaseous Cherenkov counters filled with ethelene at a pressure of 25 atm ($\gamma_{thr}=5$) serve for particle identification.

In the trigger firing of at least one scintillation counter and two shower-range units situated on both side from beam axis were required. In each unit at least two chambers measuring different coordinates must be fired. To reject the background from bremsstrahlung and other processes with small transverse momenta the strip with the width of ± 10 cm near the orbit plane in a shower-range chamber was switched off from trigger. The background was additionally suppressed by a factor of two by considering in detail a topology of events during on-line analysis. The selected events were recorded with the frequency 3 Hz at the luminosity $3 \cdot 10^{30}$ cm^{-2} s^{-1}. The detection efficiencies of the η' and A_2 were 20% and 35% respectively.

To study the reactions (1) and (2) events with two oppositely-charged particles with momenta $0.1-2.5$ GeV/c, at least one tagged electron and 1 or 2 photons were selected. Both tracks were required to arise from a fiducial cylinder around the interaction point with the length ± 100 mm along beam axis and radius 30 mm. To reject the background from cosmic rays a cut on the acollinearity angle $\Delta\Omega > 15°$ was imposed.

The following cuts were used to reduce the background from reactions of the type $ee \to eeLL\gamma$, $ee \to LL\gamma$ ($L=e$, μ, π, γ is a primary photon or produced on vacuum chamber or spurious) as well as from non-resonant hadron continuum:

a) the total energy deposition in shower-range chambers is less than 50% of that produced by electron of beam energy;
b) the angle between photon and any charged particle $> 8°$;
c) the transverse momentum of $\pi\pi$-system < 600 MeV, its invariant mass < 1200 MeV;
d) at least one charged particle is not identified as electron by shower-range chambers and Cherenkov counters;
e) no more than 2 scintillation counters fired outside the trajectories of charged particles;
f) the angle between photon and the direction to the cluster produced by charged particle in shower-range chambers $> 8°$;

g) the angle of photon relative to the beam plane $|\theta_z| > 3°$.

The events left after this cuts were kinematically reconstructed under the assumption that a final state is $ee\pi\pi\gamma$. The energy of photon and second (not detected) scattered electron were obtained from equations of energy-momentum conservation. The angle of undetected electron was assumed to be zero. Two extra equations were used for improvement of accuracy of particle parameters by means of procedure of kinematic reconstruction described in [2]. The events were rejected if the confidence level for the fit was less 5%.

When two photons were in the event, as it is in the decay of A_2, the photon with better fit was taken. In fact we take in consideration the photon which is more complanar to $\pi\pi$-system. Ignoring of the second photon in analysis leads to some broadening of spectrum of the A_2 and shift to lower masses, but resonance structure conserves.

The detection efficiency was determined by the Monte-Carlo simulation of two-photon formation of the η' and A_2. The method of equivalent photons in the most precise formulation was used [4]. The passage of particles through detector was simulated taking into account all principal processes by means of universal program UNIMOD developed at INP [3].

The decay $\eta' \to \rho\gamma$ was generated according to the distribution over the invariant mass of $\pi\pi$-system ($m_{\pi\pi}$) and the angle θ^* between pion and photon in cms ρ [5]:

$$\frac{d^2\Gamma}{dm_{\pi\pi}\, d\Omega^*} \propto \frac{(m_{\eta'}^2 - m_{\pi\pi}^2)^3 \cdot (m_{\pi\pi}^2 - 4m_\pi^2)^{3/2}}{(m_\rho^2 - m_{\pi\pi}^2)^2 + \Gamma_\rho^2 m_\rho^2} \sin^2\theta^*,$$

The decay $A_2 \to \rho\pi$ was simulated under assumption that A_2 is produced in pure helicity 2 state [5, 6]. The interference between $\rho^+\pi^-$ and $\rho^-\pi^+$ decay modes was taken into consideration, so that

$$|M(A_2 \to \pi^+\pi^-\pi^0)|^2 = |M(A_2 \to \rho^+\pi^- \to \pi^+\pi^-\pi^0) BW(\rho^+) + M(A_2 \to \rho^-\pi^+ \to \pi^+\pi^-\pi^0) BW(\rho^-)|^2,$$

where $BW = \dfrac{m_\rho \sqrt{\Gamma_\rho}}{m_\rho^2 - m_{\pi\pi}^2 - i m_\rho \Gamma_\rho}$ is a relativistic Breit—Wigner amplitude. For A_2 helicity ± 2 state

$$M(A_2 \to \rho\pi) \propto \pm i |\vec{k}_\rho| \cdot |\vec{p}_\pi| \sin\theta_\rho \sin\theta_\pi e^{\pm 2i\varphi_\rho} \cdot [\cos\varphi_\pi \pm i \cos\theta_\rho \sin\varphi_\pi],$$

where θ_ρ, φ_ρ are the angles of the ρ in cms $\gamma\gamma$, z-axis along photon direction, θ_π, φ_π are the angles of the π-mesons in spiral system of the ρ, φ_π measured from the plane defined by directions of the ρ and $\gamma\gamma$.

In calculation of the efficiency of the scattered electrons tagging system the radiation corrections connected with emission of real photons was taken into account. An estimation of efficiency decrease due to this phenomenon ($\sim 10\%$) we have obtained from experimental data on reactions $ee \to eeXX$ ($X=e$, μ, π) by comparing the measured energy of scattered electron and deduced from momenta of produced particles. In about 90% of events the measured energy of scattered electron coincides with predicted one within measurement accuracy.

In Fig. 2 the spectrum of $\pi\pi\gamma$ invariant masses is presented with the additional cut $500 < m_{\pi\pi} < 1000$ (MeV). This spectrum we use for the A_2 analysis.

In Fig. 3 $\pi\pi\gamma$ invariant mass spectrum is shown with some additional cuts stressing η' and noticeably decreasing the background level:

a) $450 < m_{\pi\pi} < 900$ (MeV);

b) $|\Delta\varphi_{(\pi\pi)\gamma}| < 30°$, where $\Delta\varphi_{(\pi\pi)\gamma}$ — acomplanarity angle between $\pi\pi$-system and photon;

c) $|\Delta\varphi_{\pi\pi}| < 115°$, where $\Delta\varphi_{\pi\pi}$ — acomplanarity angle between π-mesons;

d) there is only one photon in the event.

The solid lines are fits to the data, dashed curves show contributions of resonances and background. For the fit we have used resonance curves of the η' and A_2 from the simulation and third degree polynom with 4 free parameters for the background. Masses of the η' and A_2 were free. As results of the fit for the data of Fig. 2 the following numbers of the η' and A_2 and fitted masses were obtained:

$$m_{\eta'} = 966 \pm 15 \text{ MeV}, \quad m_{A_2} = 1317 \pm 30 \text{ MeV},$$

$$N_{\eta'} = 26.5 \pm 7.5, \quad N_{A_2} = 45.8 \pm 10.6,$$

for the data of Fig. 3 we have obtained

$$m_{\eta'} = 955 \pm 14 \text{ MeV}, \quad m_{A_2} = 1290 \pm 40 \text{ MeV},$$

$$N_{\eta'} = 24.2 \pm 5.6, \quad N_{A_2} = 24.8 \pm 9.4,$$

From comparison with simulation we have obtained for the data of Fig. 2

$$\Gamma_{\eta' \to \gamma\gamma} = 4.1 \pm 1.2 \text{ keV}, \quad \Gamma_{A_2 \to \gamma\gamma} = 1.05 \pm 0.24 \text{ keV},$$

for the data of Fig. 3

$$\Gamma_{\eta' \to \gamma\gamma} = 4.6 \pm 1.1 \text{ keV}, \quad \Gamma_{A_2 \to \gamma\gamma} = 1.06 \pm 0.40 \text{ keV},$$

The corrections connected with non zero masses of colliding photons are negligible (less than 1%) in our case as soon as average mass of virtual photon $\langle -q^2 \rangle \leqslant 0.001$ GeV^2. After all cuts the detection efficiency for reactions under study are 0.7% for the η', 1.5% for the A_2, where the detection efficiency of scattered electrons 55% is included.

The estimates of systematic errors are presented in the table.

Source of systematic error	η'	A_2
Uncertainty of background shape	10%	15%
Trigger efficiency	3%	3%
Luminosity	2%	2%
Branching	5%	3%
Detection efficiency of central detector	10%	10%
Detection efficiency of tagging system	5%	5%
Statistical error of simulation	12%	10%
Total systematic error	20%	22%

Finally, our measurement gives the following two photon width of the η' and A_2 mesons

$$\Gamma_{\eta' \to \gamma\gamma} = 4.6 \pm 1.1 \pm 0.9 \text{ keV},$$

$$\Gamma_{A_2 \to \gamma\gamma} = 1.05 \pm 0.24 \pm 0.23 \text{ keV},$$

These results are in good agreement with other experiments:

$\Gamma_{\eta'\to\gamma\gamma}$	Decay mode	Experiment	Ref
$5.8\pm1.1\pm1.2$	$\rho\gamma$	MARK II(1979)	7
$5.0\pm0.5\pm0.9$	$\rho\gamma$	JADE (1982)	8
$6.2\pm1.1\pm0.8$	$\rho\gamma$	CELLO (1982)	9
$3.8\pm0.3\pm0.4$	$\rho\gamma$	PLUTO (1984)	10
$5.1\pm0.4\pm0.7$	$\rho\gamma$	TASSO (1984)	11
$4.0\pm1.0\pm0.4$	$\gamma\gamma$	JADE (1985)	12
$4.5\pm0.3\pm0.7$	$\rho\gamma$	TPC/2 (1986)	13
$4.6\pm1.1\pm0.9$ (prelim)	$\rho\gamma$	MD-1 (1987)	this exp

$\Gamma_{\eta'\to\gamma\gamma}$	Decay mode	Experiment	Ref
$0.77\pm0.18\pm0.27$	$\eta\pi$	CR.BALL(1982)	14
$0.81\pm0.19\pm0.27$	$\rho\pi$	CELLO (1982)	9
$0.84\pm0.07\pm0.15$	$\rho\pi$	JADE (1983)	15
$1.06\pm0.18\pm0.19$	$\rho\pi$	PLUTO (1984)	16
$1.14\pm0.20\pm0.26$	$\eta\pi$	CR.BALL(1985)	17
$0.90\pm0.27\pm0.16$	$\rho\pi$	TASSO (1986)	18
$1.05\pm0.24\pm0.23$ (prelim)	$\rho\pi$	MD-1 (1987)	this exp

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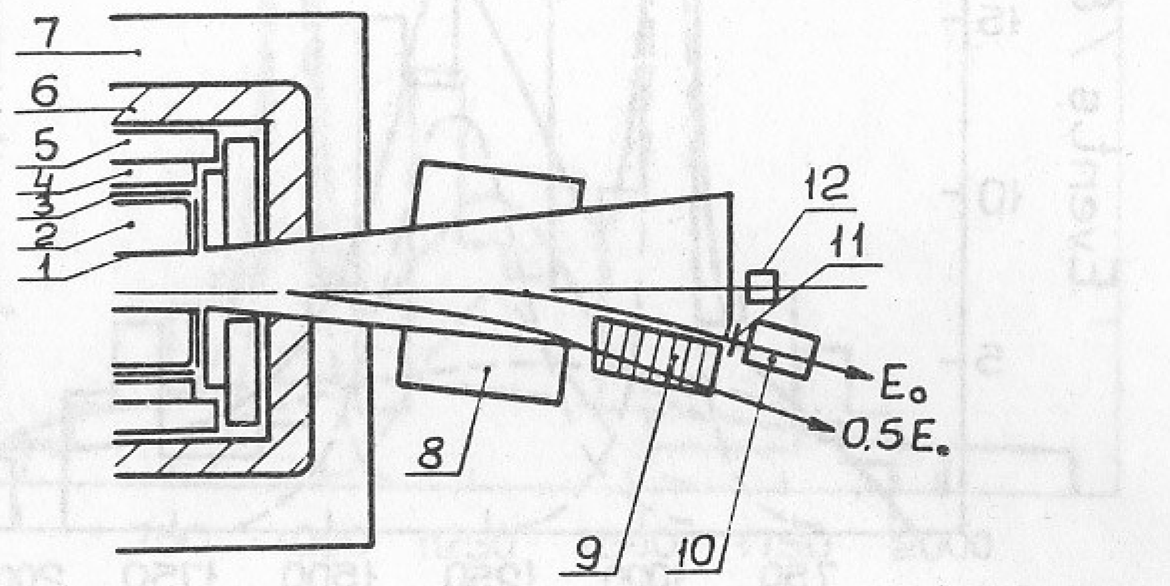

Fig. 1. Detector MD-1.
1 — vacuum chamber; *2* — coordinate chambers; *3* — scintillation counters; *4* — gaseous Cherenkov counters; *5* — shower-range chambers; *6* — magnet winding; *7* — magnet yoke; *8* — bending magnet; *9* — scattered electron tagging system; *10* — lens; *11* — luminosity monitor.

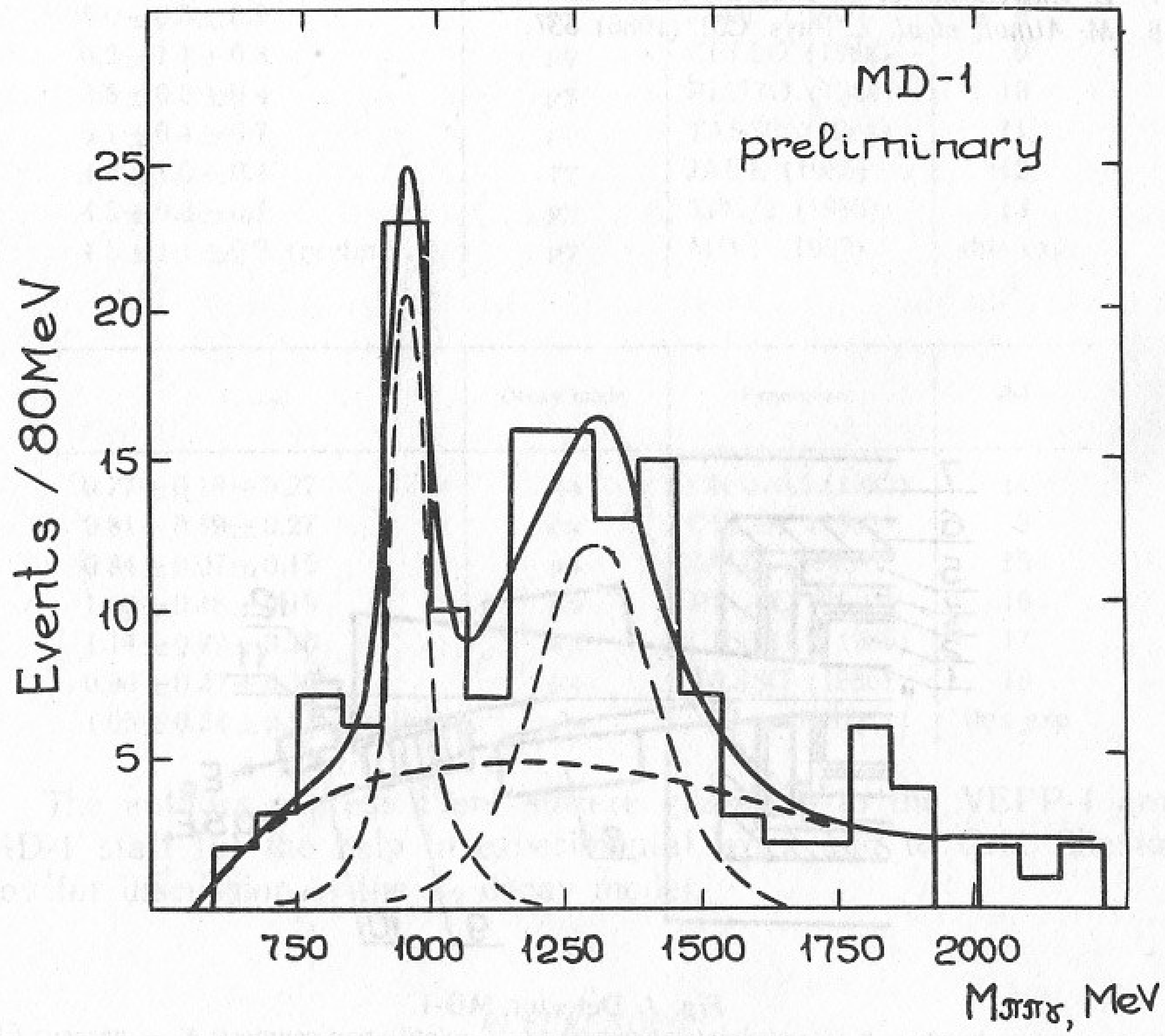

Fig. 2. ππγ invariant mass distribution. Solid line shows the fit, dashed curves show resonances and background contributions.

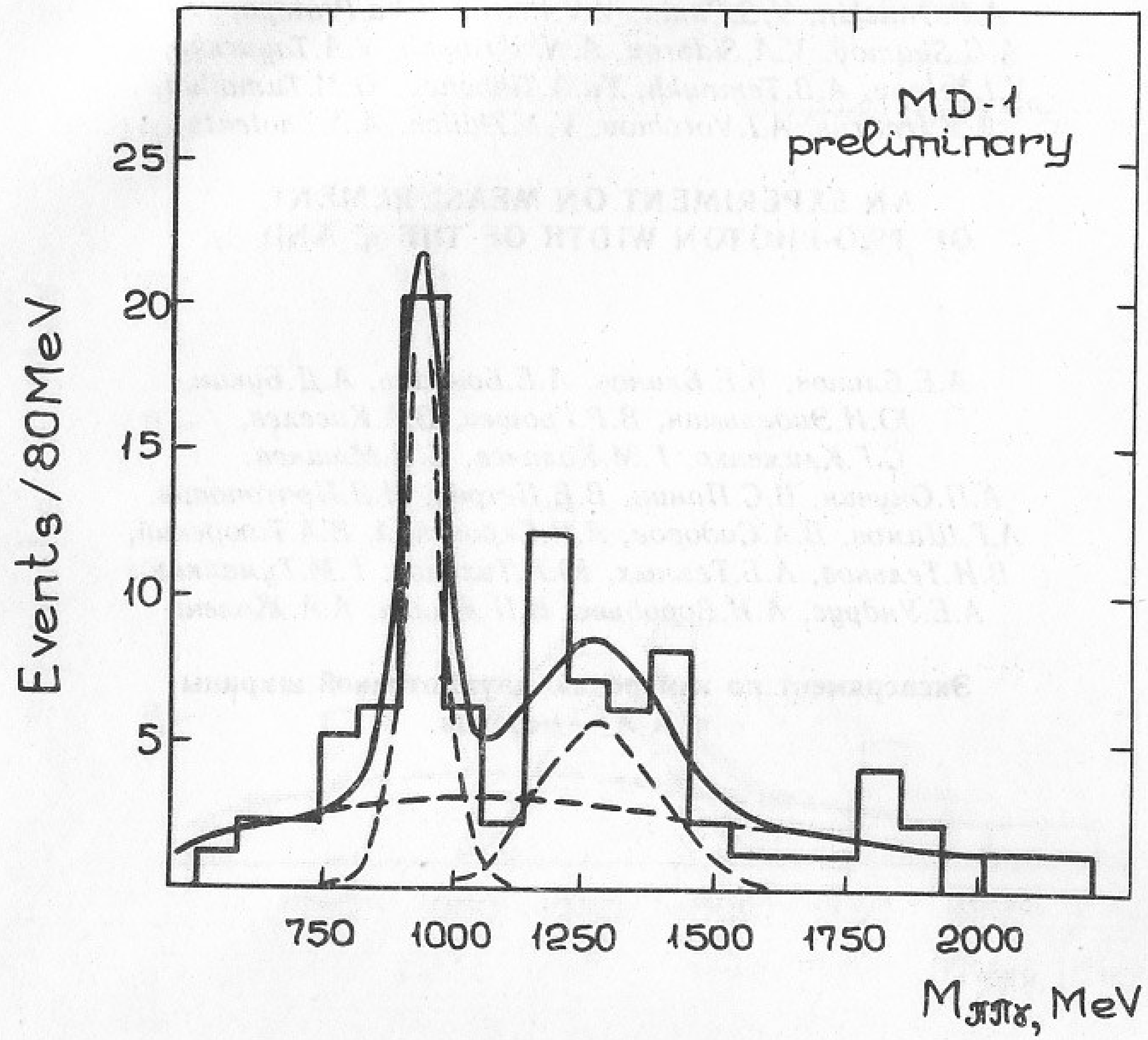

Fig. 3. ππγ invariant mass distribution after cuts stressing the η′ Solid line shows the fit, dashed curves show resonances and background contributions.

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