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MEASUREMENT OF THE REACTION $e^+e^- \to \eta\pi^+\pi^-$ IN THE CENTER OF MASS ENERGY INTERVAL 1350–2400 MeV

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The $e^+e^- \to \eta\pi^+\pi^-$ reaction has been measured in the center of mass energy interval 1350–2400 MeV by the magnetic detector DM2 at the Orsay storage ring DCI. Under the hypothesis of only one large resonance the cross section is not fit in a satisfactory way. The branching ratio $\tau^- \to \eta\pi^-\pi^0\nu_\tau = (0.13 \pm 0.02)\%$ is deduced via CVC from the above measurement.

1. Introduction

This paper reports on a new measurement of the reaction

$$e^+e^- \to \eta\pi^+\pi^- , \quad (1)$$

performed by the DM2 experiment at the Orsay storage ring DCI in the center of mass energy interval 1350–2400 MeV.

Interest in this reaction has been recently renewed by the claim [1] that the ρ' (1600) may consist of two overlapping resonances. Indeed the e^+e^- annihilation into 2π, 4π and $\rho\eta$, the relative photoproduction data, the $\pi\pi$ scattering and $\pi^- p \to \eta\pi^+\pi^- n$ charge exchange phase shifts do not fit very well under the hypothesis of only one large resonance. The interpretation of most of the above measures is not free from modeling uncertainties. In particular the 4π channel may involve different decay modes, like $\rho(770)\pi\pi$ and/or $a_1\pi$, which are not easy to disentangle, and resonances may have different interference patterns in each mode. Conversely, the $\rho\eta$ channel, which has been measured with large uncertainties in the past [2], is a genuine two-body decay and it can add cleaner information in order to understand the ρ' (1600) nature.

Furthermore the present inclusive measurement [3] of the one-prong τ branching ratio is $\sim 6\%$ higher than the sum of the separate available exclusive channels. The proposed solution to this discrepancy [4] involves τ decays containing the η meson. A large branching fraction for the decay

$$\tau^- \to \eta\pi^-\pi^0\nu_\tau \quad (2)$$

has been measured [5], although not confirmed [6] later. The anomalous decay $\tau^- \to \eta\pi^-\nu_\tau$ has also been invoked [7], yet not confirmed [8]. It has been proposed [9] to use reaction (1) to predict a value for the decay (2) via CVC.

The present measurement is relative to a collected luminosity of 1814 nb^{-1}, evaluated by means of large-angle Bhabha events, with an estimated ±5% systematic error.

The magnetic detector DM2 [10] has been described in details elsewhere. It consists mainly of a system of drift and proportional chambers inside a 2m large, 3m long, 5 kG solenoidal magnet. The solid angle for detecting charged particles is $0.87\times 4\pi$ sr, and the momentum resolution is 3.5% at $P_t = 1$ GeV/c. The magnet is surrounded by a shower detector made of lead, streamer tubes [11] and scintillator counters. The coordinates in the r–ϕ view are measured looking at the streamer tube hits, and the one along the beam direction by means of a helix wound on each pair of tubes. In this way, the r–ϕ and z coordinates are associated unambiguously. The solid angle for detection of neutral particles is $0.67\times 4\pi$ sr and the average resolution on photon directions [12] is 10 mr.

2. Event selection

The reaction $e^+e^- \to \eta\pi^+\pi^-$ has been studied in three η decay modes:

(i) $\eta\to\gamma\gamma$ (BR=38.9%).

From the sample of events with total charge zero, two charged tracks coming from the primary vertex and two detected photons, a first selection has been made requiring that the coplanarity angle between the charged total momentum P and the plane of the photons be less than 200 mr, and the projection of P onto the same plane be inside the photons convex angle. Events have been finally subjected to a 2C kinematical fit. The $\gamma\gamma$ invariant mass for events with $\chi^2 \leqslant 10$ is reported in fig. 1. This distribution has been fit to two gaussian curves and a polynomial background. The main source of background is expected to come from $\pi^+\pi^-\pi^0\pi^0$ events, where only the hard decay photons have been detected. In the whole CM energy interval the $\eta\pi^+\pi^-$ candidates are 134±14 over a background of ≈35 events.

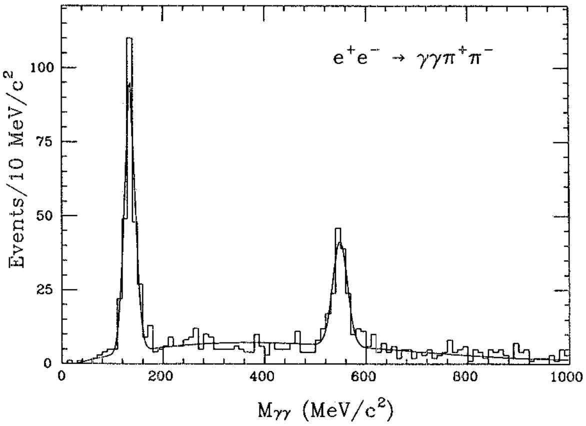

Fig. 1. Invariant $\gamma\gamma$ mass after kinematical fit.

(ii) $\eta\to\pi^+\pi^-\pi^0$ (BR=23.7%)

$\eta\to\pi^+\pi^-\gamma$ (BR=4.9%) .

The events, selected in the sample with four charged tracks coming from the primary vertex with zero total charge and two photons, have been analyzed with the same criteria as above. To increase the statistics the sample with only one photon was also considered. In absence of a kinematical fit the missing photon parameters have been calculated and further requirements have been imposed: the $\gamma\gamma$ invariant mass must be less than 250 MeV/c^2 and the missing photon momentum must be less than 100 MeV/c or outside the shower detector solid angle. In this selection, events coming from the decay $\eta\to\pi^+\pi^-\gamma$ have been recovered too. In order to improve the η mass measurement in this sample a cut on the quantity P_s^2 [#1] has been used: events with $P_s^2 \leqslant 2000$ (MeV/$c)^2$ have been assigned to the $\pi^+\pi^-\gamma$ category. The $\pi^+\pi^-\pi^0$ (γ) invariant mass distribution for the selected events (fig. 2a) gives clear evidence for η and ω signals. In fig. 2b the $\pi^+\pi^-\pi^0$ (γ) mass combination closest to the η mass is shown. The η peak, defined by fitting the data to a gaussian plus a polynomial background, contains 94±13 candidate events over a background of ≈38 events.

For each topology and energy interval the back-

[#1] P_s^2 is the quantity $P_m^2 \sin^2(\theta/2)$, usually considered in J/ψ radiative decays. Here P_m is the missing momentum and θ the angle between P_m, and the reconstructed photon direction.

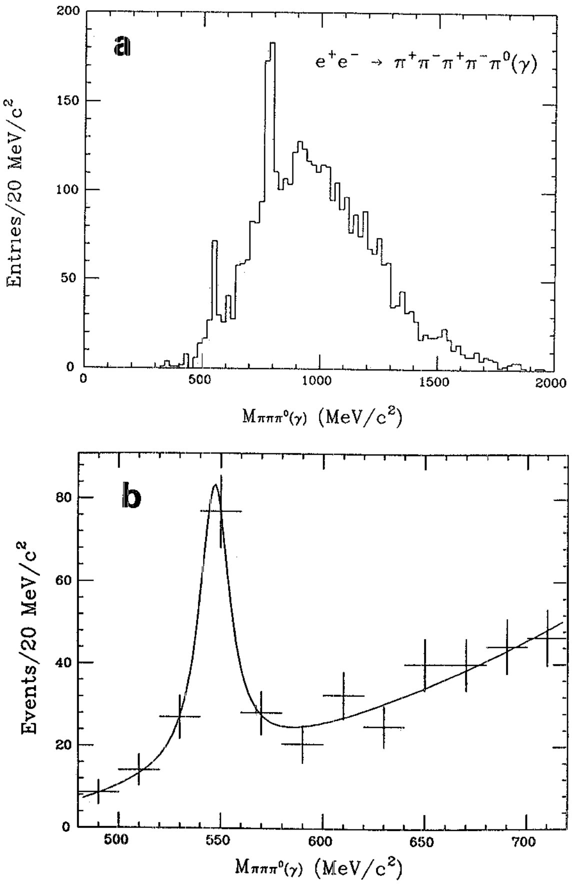

Fig. 2. Invariant mass $\pi^+\pi^-\pi^0$ (γ) after kinematical fit. In (a) all combinations are shown (4 in each event), in (b) only the combination closest to the η mass.

ground has been evaluated using η peak side bins and subtracted.

3. Results

Charge conjugation constrains the $\pi^+\pi^-$ pair in front of the η to have the ρ^0 quantum numbers. The experimental evidence for ρ^0 production is shown in fig. 3, where the $\pi^+\pi^-$ invariant mass distribution is histogrammed. In fig. 4 the π^+ angular distribution with respect to the $\pi^+\pi^-$ system direction in its center of mass is shown, and corresponds to the distribution expected for a vector meson decay, i.e. $d\sigma/d\Omega^* \propto \sin^2\theta^*_\pi$.

The average detection efficiencies for the reaction

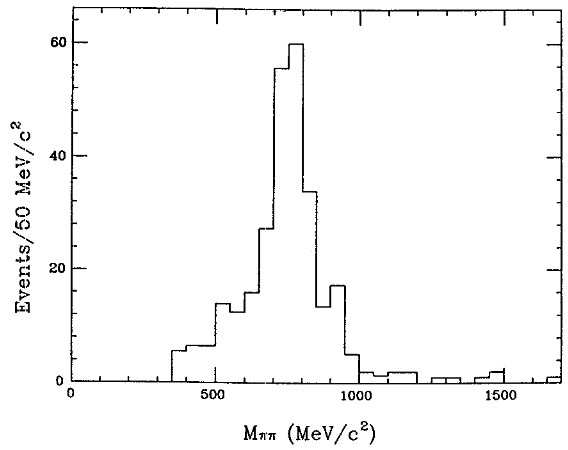

Fig. 3. Invariant $\pi^+\pi^-$ mass in front of the η.

$$e^+e^- \to \rho\eta\,, \qquad (3)$$

are 0.15, 0.13 and 0.10 for $\eta\to\gamma\gamma$, $\eta\to\pi^+\pi^-\pi^0$ and $\eta\to\pi^+\pi^-\gamma$, respectively. The efficiencies vary almost linearly with the energy within $\pm 13\%$ in the whole energy interval. On the basis of the selected events in the $\eta\to\gamma\gamma$ mode, the number of events expected in the $\eta\to\pi^+\pi^-\pi^0$ plus $\eta\to\pi^+\pi^-\gamma$ mode is 82 ± 9, in good agreement with the 94 ± 13 selected ones. Therefore a weighted mean of the cross sections from the three analyzed η decay modes has been computed, according to their relative branching ratios.

Radiative corrections, evaluated in the peaking ap-

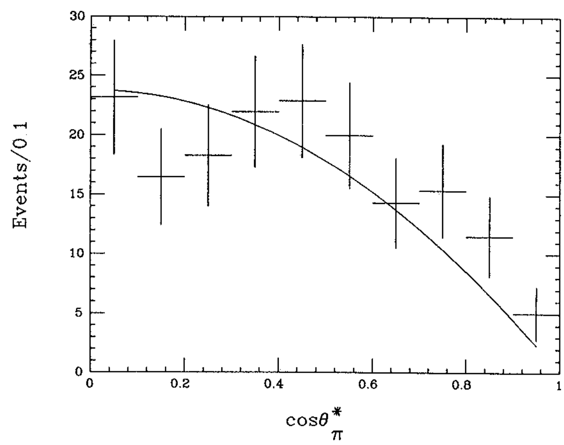

Fig. 4. Angular distribution of the π with respect to the ρ direction in the ρ center of mass. The solid line is a fit to $\sin^2\theta^*_\pi$.

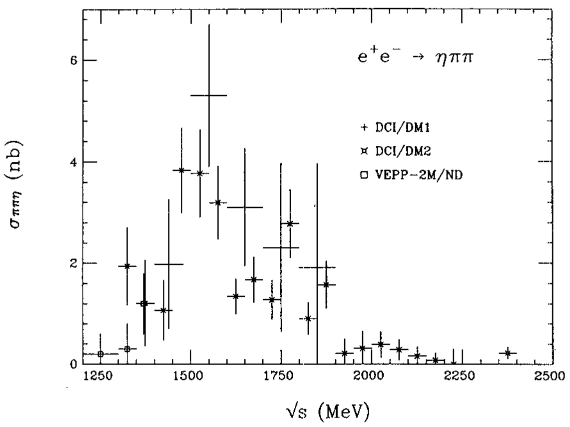

Fig. 5. Cross section $e^+e^-\to\eta\pi^+\pi^-$ as a function of the center-of-mass energy.

proximation, have been taken into account in the detection efficiencies.

The total cross section for reaction (1) is shown in fig. 5 together with the previous [2] results and the values are reported in table 1 [#2]. It should be noticed that the contribution from $e^+e^-\to\omega\eta(\omega\to\pi^+\pi^-)$ is expected negligible in this energy interval. In fact the $BR(\omega\to\pi^+\pi^-)$ is very small and the $e^+e^-\to\omega\eta$ cross section is expected to be much smaller than the $e^+e^-\to\rho\eta$ as the $I=0$ cross sections respect to the $I=1$ ones.

4. Discussion

In fig. 6 (dashed line) the DM2 cross section has been fit to a relativistic Breit–Wigner function (first line in table 2) using the $\rho'(1600)$ parameters as obtained [#3] from the $e^+e^-\to\pi^+\pi^-\pi^+\pi^-$ cross section. The total width is assumed to vary with the energy according to a homographic attenuation [14,15]:

[#2] At energies just below the J/ψ peak, assuming

$$\sigma(e^+e^-\to\rho\eta)=\frac{BR(J/\Psi\to\rho\eta)}{BR(J/\Psi\to\mu^+\mu^-)}\sigma(e^+e^-\to\mu^+\mu^-)$$

a further point can be calculated as

$$\sigma(e^+e^-\to\rho\eta)=(0.025\pm0.006)\ \text{nb}$$

using for $BR(J/\Psi\to\rho\eta)$ the value from ref. [13].

[#3] Preliminary DM2 results are in good agreement with ref. [14].

Table 1
$e^+e^-\to\eta\pi^+\pi^-$ cross section.

$\sqrt{s}$ (MeV)	$\eta\to\gamma\gamma$ events (background)	$\eta\to\pi^+\pi^+\pi^-\pi^0(\gamma)$ events (background)	Luminosity (nb^{-1})	σ(nb)
1350	6 (2)	4 (0)	51.6	1.94±0.77
1350–1400	2 (1)	2 (0)	27.9	1.21±0.85
1400–1450	7 (3)	5 (4)	72.5	1.07±0.60
1450–1500	15 (1)	11 (2)	69.6	3.83±0.84
1500–1550	15 (2)	13 (3)	66.7	3.77±0.86
1550–1600	18 (3)	12 (3)	83.8	3.19±0.72
1600–1650	20 (5)	19 (6)	192.3	1.34±0.34
1650–1700	12 (4)	21 (4)	118.0	1.67±0.44
1700–1750	24 (4)	6 (5)	137.1	1.27±0.39
1750–1800	12 (1)	9 (1)	67.2	2.77±0.68
1800–1850	9 (2)	8 (3)	124.9	0.90±0.32
1850–1900	12 (1)	5 (2)	83.8	1.57±0.47
1900–1950	3 (1)	2 (1)	76.5	0.21±0.28
1950–2000	2 (0)	0 (1)	46.7	0.31±0.34
2000–2050	3 (1)	6 (2)	90.9	0.38±0.25
2050–2100	3 (1)	3 (1)	103.8	0.28±0.20
2100–2150	2 (1)	2 (1)	92.6	0.16±0.18
2150–2200	1 (1)	2 (0)	91.7	0.08±0.14
2200–2250	0 (0)	0 (0)	56.8	<0.17 (CL 68%)
2400	3 (1)	3 (0)	160.7	0.22±0.11

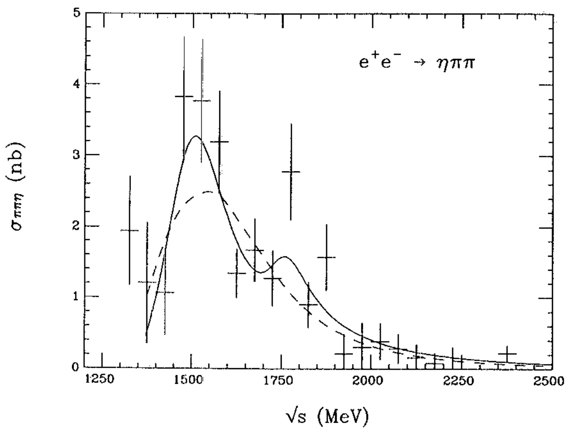

Fig. 6. Fit of the $\eta\pi^+\pi^-$ total cross section. The dashed line corresponds to the fit with just one resonance, the solid line to the fit described in the text.

$$\Gamma(w)=\frac{\phi(w)/w^2}{A+B(\phi(w)/w^2)},$$

where $\phi(w)$ is the $\rho\pi\pi$ phase space. This empirical rule reproduces well the fit behaviour at threshold and at high energies. A similar rule is assumed for the $\rho\eta$ partial width:

$$\Gamma_{\rho\eta}=\frac{(P_\eta/w)^{2L+1}}{C+D(P_\eta/w)^{2L+1}},$$

taking into account the $\rho\eta$ angular momentum $L=1$, C and D being free parameters. The $\rho'(1600)$ fit gives:

$\Gamma_{ee}\mathrm{BR}(\rho'(1600)\to\rho\eta)=(176\pm58)$ eV

with a poor confidence level. Similar results (second line in table 2) are obtained using current PDG [16] values for the $\rho'(1600)$ parameters. The addition of a ρ^0 tail does not change these conclusions.

A better confidence level (third line in table 2) is achieved with two fully interfering Breit–Wigners, fig. 6 (solid line). The parameters of these resonances are in fair agreement with the values reported in ref. [1].

Finally the τ branching ratio for $\tau^-\to\eta\pi^-\pi^0\nu_\tau$ can be calculated from the $e^+e^-\to\eta\pi^+\pi^-$ cross section, according to CVC:

$$\frac{\Gamma(\tau^-\to\eta\pi^-\pi^0\nu_\tau)}{\Gamma(\tau^-\to e^-\bar{\nu}_e\nu_\tau)}=2\cos^2\theta_C$$

$$\times\int_0^1 dx(1-x)^2(1+2x)\,\frac{\sigma(e^+e^-\to\eta\pi^+\pi^-)}{\sigma_\mu},$$

where $x=s/m_\tau^2$ and $\sigma_\mu=4\pi\alpha^2/3s$.

Using for the $\mathrm{BR}(\tau^-\to e^-\bar{\nu}_e\nu_\tau)$ the value from PDG [16] we obtain: $\mathrm{BR}(\tau^-\to\eta\pi^-\pi^0\nu_\tau)=(0.13\pm0.02)\%$. This result disagrees with the measured value [5] of $(4.2\pm1.6)\%$ and can be compared to the most recent [6] upper limit of 0.9% at the 95% CL.

5. Conclusions

The $e^+e^-\to\eta\pi^+\pi^-$ cross section is not well fit under the hypothesis of only one large resonance with the $\rho'(1600)$ parameters. A fit with two Breit–Wigners gives better results. However, the statistics collected by the DM2 experiment is still insufficient to resolve clearly the structure appearing between 1.5–2.0 GeV.

The branching ratio $\mathrm{BR}(\tau_-\to\eta\pi^-\pi^0\nu_\tau)=(0.13\pm0.02)\%$ has been deduced via CVC from this measurement.

Table 2
Fit of the $\eta\pi^+\pi^-$ excitation curve. The three different fits are described in the text.

M_1 (GeV/c^2)	Γ_1^{tot} (GeV)	BR·Γ_{ee} (eV)	M_2 (GeV/c^2)	Γ_2^{tot} (GeV)	BR·Γ_{ee} (eV)	CL %
1.57 [14]	0.51 [14]	176±58	–	–	–	2
1.59 [16]	0.26 [16]	104±62	–	–	–	0.1
1.47±0.02	0.23±0.03	91±19	1.74±0.02	0.15±0.03	7±3	35

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