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ABSTRACT - The cross section for the reaction $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ has been measured at the e^+e^- storage ring Adone, in the total c. m. energy range 1.42 - 2.20 GeV. The peak and the following descent of the $\varrho'(1600)$ resonance is observed. Using also lower energy data, and assuming that only one resonant amplitude contributes to the observed cross section, the parameters of the $\varrho'(1600)$ are deduced.

We present experimental results on the cross section for the reaction:

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

obtained at the e^+e^- storage ring Adone ($\gamma\gamma 2$ experiment) in the total c. m. energy range W = = 1.42 - 2.20 GeV. In this energy region the existence of a broad resonance (the so-called $\varrho'(1600)$ state) in channel (1) was established by the first experiments[1] at Adone.

Preliminary results from present experiment have been already reported[2]. The experimental set up has been described elsewhere[3-5]. The trigger logic requires at least two charged particles, one in the upper part and one in the lower part of the apparatus, with a kinetic energy of at least 120 MeV for pions (190 MeV for kaons). If also photons convert in the apparatus, this limit can be as low as 35 (60) MeV. Multihadron events were selected by requiring that in addition to the two triggering particles also another particle (track or photon) was present. This selection criterion practically rejects all the background events due to beam-gass interaction, as checked by running the machine with a single beam.

In these conditions we have collected in the above-mentioned energy range 2955 multihadron events, corresponding to a total integrated luminosity of 312 nb^{-1}, measured by wide angle Bhabha scattering in our apparatus. In order to extract from these data the cross section for exclusive channels and in particular for reaction (1), we divide the multihadron events in different categories according to the number of observed tracks and photons. The number n_k of events in the k-th category is then related to the cross sections σ_i for the different exclusive channels by the relation[4,5]:

$$n_k = L \Sigma_i \varepsilon_{ki} \sigma_i \quad (2)$$

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TABLE I - Column 1 : Total c.m. energy interval on which data have been lumped. Column 2 : Mean total c.m. energy values of the corresponding interval ΔW. Column 3 : Cross section for reaction $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$. Column 4 : Integrated luminosity.

ΔW (MeV)	W (MeV)	σ (nb)	L (nb^{-1})
1419 - 1475	1456	22.6 ± 4.1	17.0
1475 - 1500	1491	30.6 ± 2.3	34.8
1500 - 1525	1507	23.4 ± 2.8	32.7
1525 - 1575	1546	26.3 ± 3.5	12.5
1575 - 1615	1600	24.4 ± 3.5	14.7
1615 - 1650	1633	22.4 ± 2.9	12.4
1650 - 1670	1660	29.3 ± 4.1	9.4
1670 - 1725	1701	17.3 ± 2.2	21.7
1725 - 1775	1752	16.8 ± 2.4	20.1
1775 - 1805	1794	13.2 ± 2.5	13.2
1805 - 1835	1821	10.1 ± 2.1	20.8
1835 - 1875	1851	11.9 ± 2.3	12.9
1875 - 2000	1935	8.2 ± 1.4	34.2
2000 - 2100	2050	8.3 ± 2.1	15.0
2100 - 2200	2150	5.3 ± 1.3	41.0

ε_{ki} being the efficiency for detecting the i-th reaction in the k-th category, and L being the integrated luminosity. In evaluating ε_{ki} by Monte Carlo method, we assume that only pions are produced with an invariant phase space distribution. Furthermore we assume a minimum and a maximum multiplicity of three and six pions respectively. The relation $\sigma(e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0) = 2\sigma(e^+e^- \to \pi^+\pi^-\pi^0\pi^0\pi^0)$ coming from isospin consideration, has been imposed.

For reaction (1) the calculated overall detection efficiency varies smoothly from $\sim 17\%$ at W = 1.5 GeV to $\sim 22\%$ at W = 2 GeV. Furthermore this detection efficiency is practically unchanged if the decay scheme $\varrho'(1600) \to \varrho^0\pi^+\pi^- \to \pi^+\pi^-\pi^+\pi^-$ is assumed, as suggested by different experiments(6, 7). It should be noted that the maximum likelihood method used for resolving the system (2) introduces correlations between the obtained σ_i values. Nevertheless the cross section for reaction (1) is the less sensitive ($< 10\%$) to this effect.

In Table I we report our results on cross section for reaction (1). The quoted errors are statistical only. Radiative corrections(8) have been applied. In Fig. 1 these results are reported together with those obtained by other experiments ; they give on the whole a clear signal for the $\varrho'(1600)$ resonance. The peak value of the cross section (around 25-30 nb) indicates that this channel is one of the main contributions to the observed structure(5) in R around 1.6 GeV.

In a small energy region around 1.5 GeV an additional set of data was collected with a modified(5, 9) apparatus. An independent analysis of these data gives us an estimation of possible systematic errors (e.g. on scanning procedure and efficiency calculation). In this energy region the average cross section for reaction (1) obtained with the original (modified) apparatus is 26.2 ± 1.5 (21.8 ± 1.4) nb, which is consistent with a previously estimated(5) systematic error of 15%.

Throughout our data analysis we have assumed that all the detected charged particles in multihadron final states are pions, disregarding the possible presence of kaons. In fact the processes $e^+e^- \to K^+K^-\pi^+\pi^-$, $K^0_S K^\pm \pi^\mp$, $K^0_S K^{*0}$ can simulate reaction (1) in our apparatus. More precisely taking into account experimental results on kaons production below(5, 10) and above(7, 10) 1.55 GeV, the systematic error on cross section for process (1) due to non identification of kaons is negligeable at ~ 1.5 GeV and < 2 nb above 1.6 GeV.

In Fig. 2 present results are reported together with lower energy measurements from Orsay(11, 12) and Novosibirsk(13). To obtain the $\varrho'(1600$ parameters we have fitted these data assuming that only one resonant amplitude is responsible for the observed cross section behaviour.

In particular we disregard both the possible existence(14) of a $\varrho'(1250)$ and of a non resonating background. Therefore the experimental results are fitted with a pure Breit-Wigner formula

$$\sigma(e^+e^- \to \pi^+\pi^-\pi^+\pi^-) = \frac{12}{W^2} \frac{M^2 \Gamma_e B(\pi^+\pi^-\pi^+\pi^-) \Gamma(W)}{(W^2 - M^2)^2 + M^2 \Gamma^2(W)} \quad (3)$$

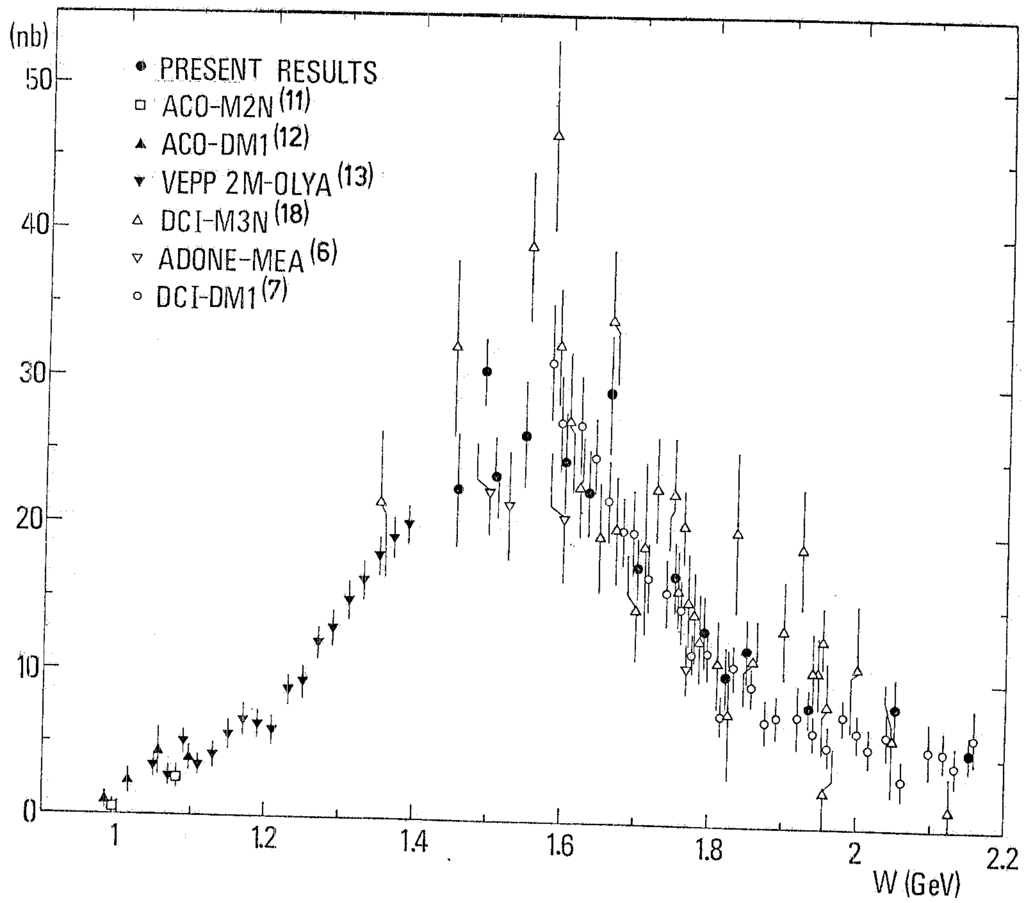

FIG. 1 - Cross section for $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$. Present results are reported together with previous ones.

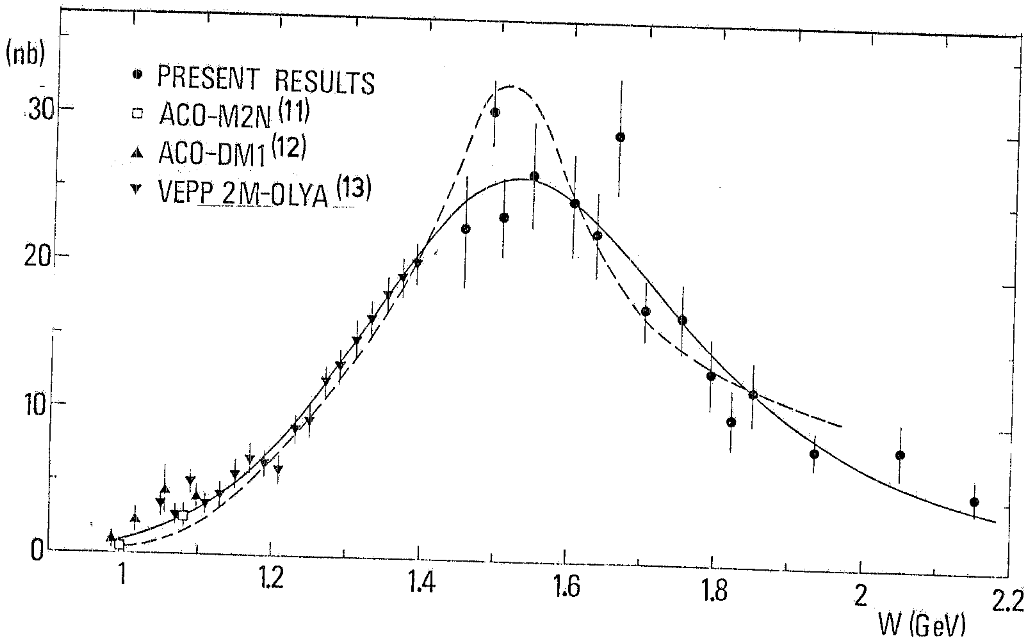

FIG. 2 - Cross section for $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$. Present results are reported together with lower energy ones. Solid line represents the fit by a pure Breit-Wigner formula (see text). Dashed line is a fit according to Ref. (17).

where M is the mass, Γ_e is the leptonic width, $\Gamma(W)$ is the total width of the $\varrho'(1600)$ resonance and $B(\pi^+\pi^-\pi^+\pi^-)$ is the branching ratio for the decay $\varrho' \to \pi^+\pi^-\pi^+\pi^-$. If the $\varrho'(1600)$ decays only through a $\varrho\pi\pi$ intermediate state as suggested by different experiment(6, 7), then from isospin consideration one should have $B(\pi^+\pi^-\pi^+\pi^-) = 2/3$.

For the total width $\Gamma(W)$ we assume the following empirical energy dependence which gives the correct threshold behaviour

$$\Gamma(W) = \frac{\Phi(W)/W^2}{a + b\,\Phi(W)/W^2}$$

where $\Phi(W)$ is the Lorentz Invariant Phase Space for the decay $\varrho' \to \varrho^0\pi^+\pi^-$, a and b being free parameters of the fit. The best fit $(\chi^2/n_D = 40/35)$ obtained with these formulae is reported in Fig. 2 (solid line). The corresponding values of the $\varrho'(1600)$ parameters are:

$$M = 1666 \pm 39 \text{ MeV}; \quad \Gamma(M) = 700 \pm 160 \text{ MeV}; \quad \Gamma_e B(\pi^+\pi^-\pi^+\pi^-) = 2.83 \pm 0.42 \text{ keV}.$$

The maximum in the cross section occurs at an energy $W_{peak} \simeq 1530$ MeV, while the total width (FWHM) of the fitting curve is $\simeq 530$ MeV. As expected these values are different from M and $\Gamma(M)$ because $\Gamma(W)$ is energy dependent. These values are not in disagreement with those obtained in photoproduction experiments(15) for the same $\pi^+\pi^-\pi^+\pi^-$ final state. It should be noted however that in $\pi^+\pi^-$ photoproduction a resonance around 1600 MeV has also been observed(15), but with a much lower width (230 - 280 MeV). This fact can be explained either assuming that the observed $\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^-$ resonances are different objects, or that not only one (resonant) amplitude contributes to the $\pi^+\pi^-\pi^+\pi^-$ cross section.

It has been pointed out(16) that a non-resonant background due to the reaction $e^+e^- \to A_1^{\pm}\pi^{\mp} \to \varrho^0\pi^+\pi^-$ should be present at these energies. Therefore a fit(17) to the experimental cross section for reaction (1) has been done (dashed line of Fig. 2), which takes into account a "$\varrho'(1600)$" resonance, a $A_1\pi$ non-resonant background and their interference. The corresponding ϱ' parameters deduced from this fit ($M \simeq 1.5$ GeV; $\Gamma \simeq 0.23$ GeV; $\Gamma_e B(\pi^+\pi^-\pi^+\pi^-) = 0.4$ keV) are not immediately comparable to those coming from the present pure Breit-Wigner formula, because of the different theoretical approach which is discussed in Ref. (17). Nevertheless this fit achieves a substantially better consistency between the $\varrho'(1600)$ total width, observed in $\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^-$ final states.

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