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V. Valente and R. Visentin: ANALYSIS OF THE DECAY MODES OF THE
ρ'(1600) MESON.

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An analysis of $\pi^+ \pi^- \pi^+ \pi^-$-events from $e^+ e^-$ annihilation, yields preliminary evidence for the decay scheme $\rho'(1600) \rightarrow \rho^0(760) + \varepsilon^0(850)$. Assuming this decay scheme the ρ'-photon coupling constant $g_{\rho'\gamma} = em^2_{\rho'}/f_{\rho'}$ is evaluated; we found $f^2_{\rho'}/4\pi = 17 \pm 5$.

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The broad peak observed in the energy dependence of the cross section for production of four charged pions in $e^+ e^-$ annihilation[1] has been interpreted[2,3] as preliminary evidence for the existence of a new vector meson resonance, ρ', of mass $m_{\rho'} \sim 1.6$ GeV/c^2, width $\Gamma_{\rho'} \simeq 0.35$ GeV/c^2, having the same quantum numbers of the ρ meson ($J^{PC} = 1^{--}, I^G = 1^+$). Confirming evidence for the ρ' come from recent photoproduction experiments[4,5].

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In this letter we analize the possible final state interactions in the four charged pion system, in order to obtains information about the decay modes of the ρ' meson[6]. As we shall see we find that a relevant decay-mode of the ρ' meson appear to be $\rho' \to \rho^{0} + \varepsilon^{0}$ ($m_{\varepsilon 0}$=0.850 GeV/c^2, $\Gamma_{\varepsilon 0}$=0.3 GeV/c^2).

As discussed in references (1) and (3) we select events in which the four charged pions satisfy the energy-momentum balance, indicating that no other particles are produced and go undetected. The results of the present analysis refer to a total of 18 events, of which 11, previously reported, at 2E=1.6 GeV[1] and 7 new events, at 2E=1.6 GeV, i.e. near the ρ' peak.

Four different production mechanisms have been investigated in order to explain the experimental data:

a) $e^{+}e^{-} \to \pi^{+}\pi^{-}\pi^{+}\pi^{-}$, with the four pions produced according to invariant phase space (IPS);

b) $e^{+}e^{-} \to \rho^{0}\pi^{+}\pi^{-}$, with the $\rho\pi\pi$ system produced according to IPS and subsequent decay $\rho^{0} \to \pi^{+}+\pi^{-}$;

c) $e^{+}e^{-} \to A_{1}^{+} + \pi^{\mp}$ with the subsequent decays: $A_{1}^{\pm} \to \rho^{0} + \pi^{\pm}$, $\rho^{0} \to \pi^{+} + \pi^{-}$;

d) $e^{+}e^{-} \to \rho^{0} + \varepsilon^{0}$ in which ρ^{0} and ε^{0} are produced in S wave and subsequently decay as $\rho^{0} \to \pi^{+} + \pi^{-}$, $\varepsilon^{0} \to \pi^{+} + \pi^{-}$.

The experimental data have been compared with the predictions of the different production mechanisms with the help of a Monte Carlo calculation. This calculation simulates the production of four charged pions according to IPS and simulates the detection of the pions by the apparatus[3]. The different hypothesis b), c) and d) are introduced in the calculation as final state interactions. The matrix elements are charge-symmetrized over the four pions, as we do not distinguish the charge. The resonant states are assumed to be described by Breit-Wigner formulas; their masses and widths are (all in GeV):

$$m_{\rho'} = 0.76, \quad \Gamma_{\rho'} = 0.12, \quad m_{A_1} = 1.07, \quad \Gamma_{A_1} = 0.1, \quad m_{\varepsilon} = 0.85, \quad \Gamma_{\varepsilon} = 0.3.$$

The polarization of the intermediate photon has not been taken into account.

In Fig. 1 the distributions of pion momenta are compared with the predictions of IPS[7]. The systematic deviations of the experimental points from the curves indicates that a pure IPS description is inadequate.

The same indication is also given from the distribution of the invariant mass of pion pairs which is shown in Fig. 2 where the data relative to 2E = 1.5 and 1.6 GeV have been combined. A clear signal in the ρ^{0}-region is observed above the IPS distribution.
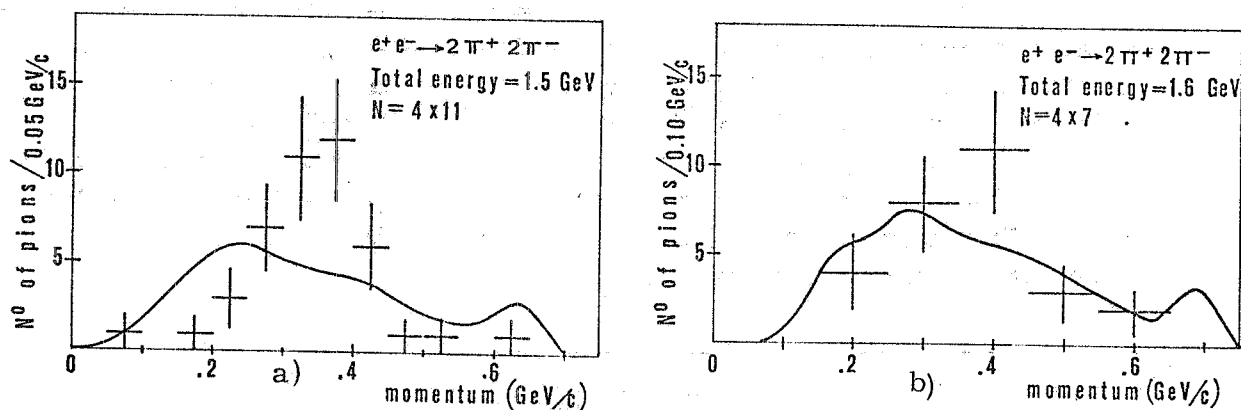
FIG. 1 - Momentum distributions of pions produced in the reac_
tion $e^+e^- \rightarrow \pi^+ + \pi^- \pi^+ \pi^-$. The solid curves are those expected
assuming an invariant phase space (IPS) production mechanism.
Distributions refer to: a) 11 events at 1.5 GeV; b) 7 events at
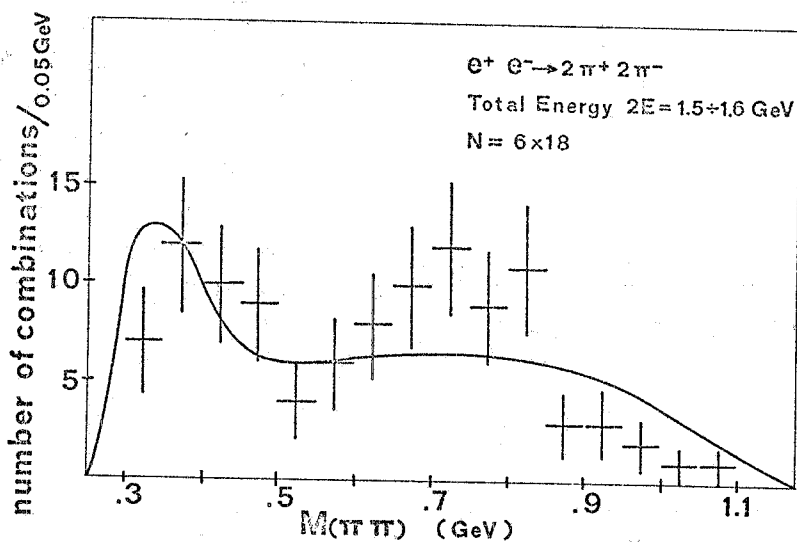1.6 GeV (total energy).

FIG. 2 - Two-pion invariant mass distribution
$M(\pi\pi)$. There are six combinations per event
since the apparatus does not distinguish the char_
ge of the particles. The solid curve is the norma_
lized IPS distribution.

   In order to distinguish among the hypothesis b),c) and d), all in-volving the production of a ϱ°, we must analize the invariant mass of the remaining pion pair. So we examine the scatter plot of the inva-riant mass of a pion pair, $M(\pi_1\pi_2)$, vs the invariant mass of the remai-ning pair, $M(\pi_3\pi_4)$. If this plot is devided into three bands, marked A, B and C in Fig. 3, it is apparent that the three bands are not equally populated. Table I shows the comparison of the experimental populations in A,B,C with the predictions from the models calculated by means of the above mentionated MonteCarlo.
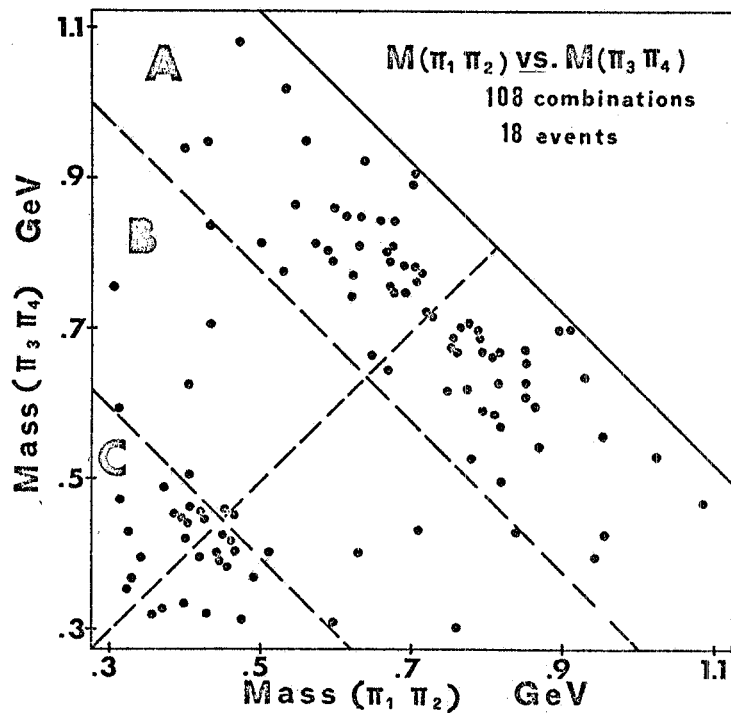

FIG. 3 - Scatter plot of the invariant mass of a pion pair, $M(\pi_1\pi_2)$, vs the invariant mass of the remaining pair, $M(\pi_3\pi_4)$. Each event contributes with siw combinations of which only three are indi-pendent.

TABLE I

	Experiment	$\varrho^{\circ}\pi^+\pi^-$	$A_1^{\pm}\pi^{\mp}$	$\varrho^{\circ}\varepsilon^{\circ}$	
Number of points in A	68 ± 11.5	44	44	68	
Number of points in B	14 ± 5.2	59	57	25	
Number of points in C	26 ± 7.2	5	7	15	
χ^2		88	80	7	

The final entry in the Table I gives the χ^2 for the fit of the data to the various predictions. It is readily apparent that the fit to $\varrho^0 \varepsilon^0$ is greatly preferred.

The same conclusion can be reached on the basis of the following observation. Due to the particular configuration of the experimental set--up[8] and the trigger requirements[3], a 4-prong event can be detected only in two geometrical configurations: i) two particles in each telescope, configuration 2/2; ii) one particle in one telescope and the other three in the opposite one, configuration 1/3. Experimentally we have found only 1 event of type ii) out of a total of 18 events, as expected for the production mechanism involving the $\varrho^0 \varepsilon^0$ intermediate state (see Table II).

<u>TABLE II</u>

Fraction of events in the configuration 1/3	Experiment	IPS	$\varrho^0 \pi^+ \pi^-$	$A_1^\pm \pi^\mp$	$\varrho^0 \varepsilon^0$
	0.06 ± 0.06	0.45	0.61	0.62	0.08

The small percentage of configurations 1/3 in the case of $\varrho^0 \varepsilon^0$ production is easily understood on the basis of simple kinematical conside rations, taking into account the small velocities of the ϱ^0 and $\varepsilon^0 (\beta \sim 0.05)$[10] and the small angular acceptance of the two opposite telescopes $(\pm 37^0)$.

The preceeding analysis leads to the conclusion that the process $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$ in the neighboorhound of 2E=1.6 GeV is compatible with a 100% $\varrho^0 \varepsilon^0$ intermediate state. Under this assumption we have derived, using experimental data previously reported[1,3], the values of the cross section reported in Fig. 4. It should be pointed out that the experimental energy dependence of the cross section is quite different from the one expected (dotted curve in Fig. 4) if the $\varrho^0 \varepsilon^0$-state were reached through a ϱ^0-tail (i.e.: $e^+e^- \rightarrow (\varrho^0)^x \rightarrow \varrho^0 \varepsilon^0 \rightarrow \pi^+\pi^-\pi^+\pi^-$). On the contrary there is good agreement with the energy dependence pre dicted in ref. (2) (full curves in Fig. 4) under the hypothesis of ϱ' produc tion.

If the ϱ' does decay into $\varrho^0 \varepsilon^0$ system, than isospin conservation implies that $\sigma(e^+e^- \rightarrow \varrho^0 \varepsilon^0 \rightarrow \pi^+\pi^-\pi^0\pi^0) = 0.5 \ \sigma(e^+e^- \rightarrow \varrho^0 \varepsilon^0 \rightarrow \pi^+\pi^-\pi^+\pi^-)$. This allows one to derive the coupling constant of the ϱ' meson to the photon $(g_{\varrho'\gamma} \equiv em_{\varrho'}^2/f_{\varrho'})$ following the procedure of ref. (3). The result of this calculation is

$$\frac{f_{\varrho'}^2}{4\pi} = 17 \pm 5$$

6.

In calculating this value we have taken in account that the decay mode $\varrho' \to \pi^+\pi^-$ is higly depressed[4,5,11]. This means that the only final states with $G^\pm$ parity available for the ϱ' decay are $\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^-\pi^0\pi^0$.
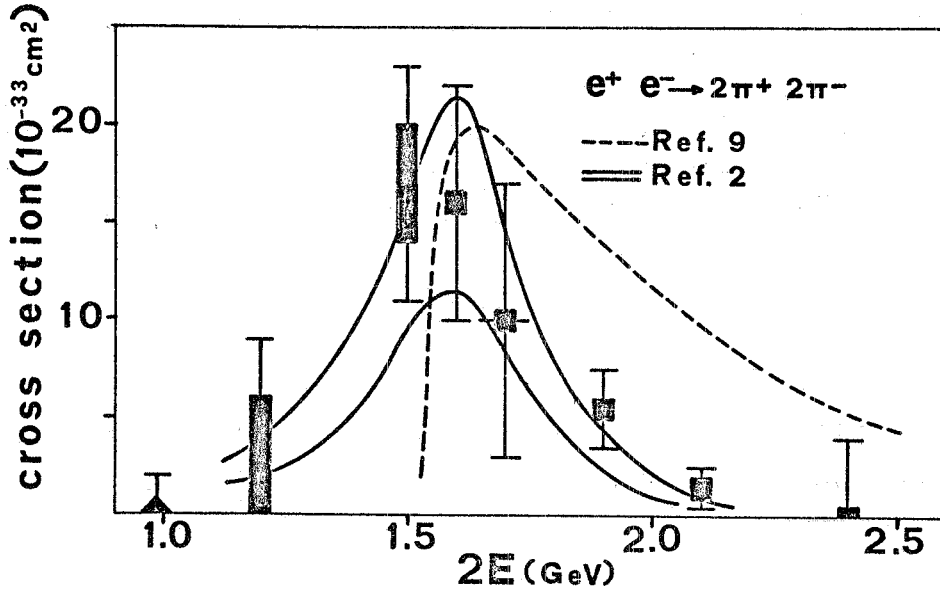

FIG. 4 - Energy dependence of the cross section for process $e^+e^- \to \varrho^0\varepsilon^0 \to \pi^+\pi^-\pi^+\pi^-$. The curves are taken from ref. (2) (═══) and ref. (9) (- - - -). The dotted curve taken from ref. (9) corresponds to that with the steepest energy dependence for $2E > 1.6$ GeV.

We have assumed that also the final state $\pi^+\pi^-\pi^0\pi^0$ is reached through $\varrho^0\varepsilon^0$, i.e. we have neglected a possible $\omega\pi^0$ intermediate state.

If we assume for $\omega\pi^0$ the same contribution that for $\varrho^0\varepsilon^0$, i.e.

$$\frac{\Gamma_{\varrho' \to \omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0}}{\Gamma_{\varrho' \to \varrho^0\varepsilon^0 \to \pi^+\pi^-\pi^0\pi^0}} = 1$$

we obtain

$$\frac{f_{\varrho'}^2}{4\pi} = 13 \pm 5.$$

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(6) - The results of this analysis have been presented in a preliminary version at the XVI Internat. Conf. on High Energy Physics, Batavia, Chicago, (1972).

(7) - The severe angular limitations, the energy cut-off and the trigger requirements of the apparatus modify, of course, the distributions predicted from IPS for an ideal case. These modifications are responsible for the peculiar shape of the curves of Fig. 1.

(8) - We remember here that it consist of two identical telescopes located on opposite sides of the straight section of the Adone machine, in the horizontal plane. For details see ref. (3).

(9) - G. Kramer and T. F. Walsh, Desy Report 72/46 (1972).

(10) - Because of this small velocities, the minimum angle of the decay products of ϱ^{o} or ε^{o} is as large as $\sim 130^{o}$.

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