Laboratori Nazionali di Frascati

LNF-73/18

F. Ceradini, M. Conversi, S. D'Angelo, L. Paoluzzi, R. Santonico, K. Ekstrand, M. Grilli, E. Iarocci, P. Spillantini, V. Valente, R. Visentin and M. Nigro:

ANALYSIS OF THE DECAY MODES OF THE ρ'(1600) MESON

Phys. Letters 43B, 341 (1973).

ANALYSIS OF THE DECAY MODES OF THE $\rho'(1600)$ MESON

F. CERADINI, M. CONVERSI, S.D'ANGELO, L. PAOLUZI, R. SANTONICO,
Istituto di Fisica dell'Università di Roma and Istituto Nazionale di Fisica Nucleare, Sezione di Roma, Italy

K. EKSTRAND, M. GRILLI, E. IAROCCI, P. SPILLANTINI, V. VALENTE, R. VISENTIN,
Laboratori Nazionali del C.N.E.N., Frascati, Roma, Italy

and

M. NIGRO
Istituto di Fisica dell'Università di Padova and Instituto Nazionale di Fisica Nucleare, Sezione di Padova, Italy

Received 28 December 1972

An analysis of $\pi^+\pi^-\pi^+\pi^-$ events from e^+e^- annihilation yields preliminary evidence for the decay scheme $\rho'(1600) \to \rho^0(760) + \epsilon^0(800)$. Assuming this decay scheme the coupling constant of the ρ' meson to the photon is evaluated.

The broad peak observed with the Frascati e^+e^- storage ring, Adone, 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 $m_{\rho'} \approx 1.6$ GeV/c^2, width $\Gamma_{\rho'} \approx 0.35$ GeV/c^2, having the same quantum numbers of the ρ meson ($J^{PC} = 1^{--}$, $I^G = 1^+$). We stress that since this result comes directly from the analysis of well identified four-charged pion final states [1, 3], identification of the ρ' quantum numbers is unambiguous†. This is not the case in general for the photoproduction experiments [4, 5] which, however, gave confirming evidence for the existence of the ρ' meson††.

In this letter we analyse the possible final state interactions in the four charged pion system, in order to obtain information about the decay modes of the ρ' meson†††. As we shall see, we find that a relevant decay-mode of the ρ' meson appears to be $\rho' \to \rho^0 + \epsilon^0$ ($m_{\epsilon^0} = 0.8$ GeV/c^2, $\Gamma_{\epsilon^0} = 0.3$ GeV/c^2).

As discussed in refs. [1, 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 23 events, of which 11, previously reported, at $2E = 1.5$ GeV [1] and 12 new events: 7 obtained at $2E = 1.6$ GeV and 5 at $2E = 1.7$ GeV.

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 the two pions in a relative S-wave state, the ρ^0 undergoing the subsequent decay $\rho^0 \to \pi^+\pi^-$;

c) $e^+e^- \to A_1^{\pm}\pi^{\mp}$ with the subsequent decays: $A_1^{\pm} \to \rho^0\pi^{\pm}$, $\rho^0 \to \pi^+\pi^-$;

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

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

† In our opinion this point has not been made clear in ref. [5], due also to a misleading bibliographic quotation. A letter on this matter had been sent to Professor Ballam on July 20, 1972, after the presentation of the results by Smadjá et al. [6].

†† Actually a four pion enhancement in the process $\gamma p \to p 2\pi^+ 2\pi^-$ was first observed in the experiment by Liu et al., ref. [4].

††† The results of this analysis have been reported in a preliminary version, see ref. [7].

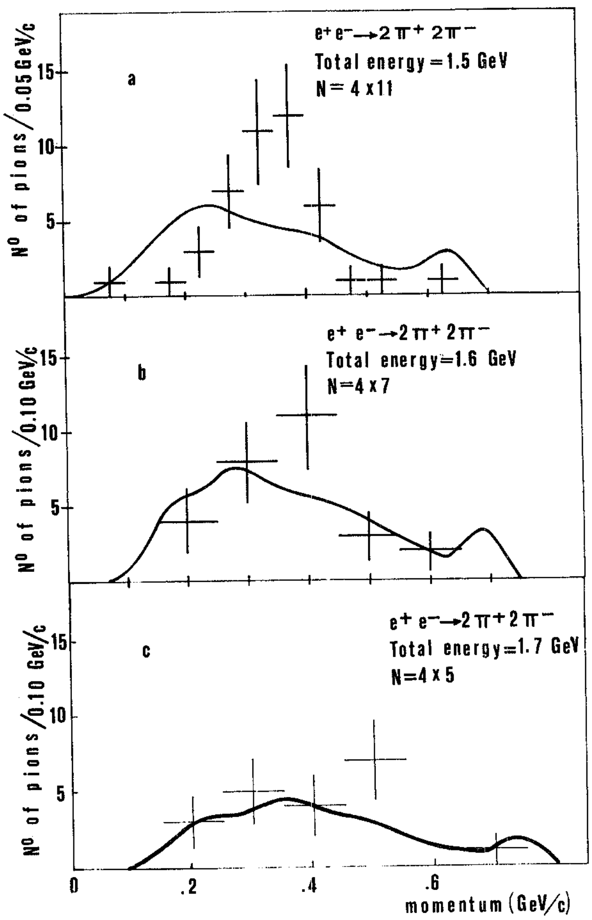

Fig. 1. Momentum distribution of pions produced in the reaction $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$. The solid curves are those expected assuming an invariant phase space (IPS) production mechanism. Distributions refer to: a) 11 events at 1.5 GeV; b) 7 events at 1.6 GeV; c) 5 events at 1.7 GeV total energy.

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):

$$m_\rho = 0.76, \quad \Gamma_\rho = 0.12, \quad m_{A_1} = 1.07, \quad \Gamma_{A_1} = 0.1,$$

$$m_\epsilon = 0.8, \quad \Gamma_\epsilon = 0.3.$$

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

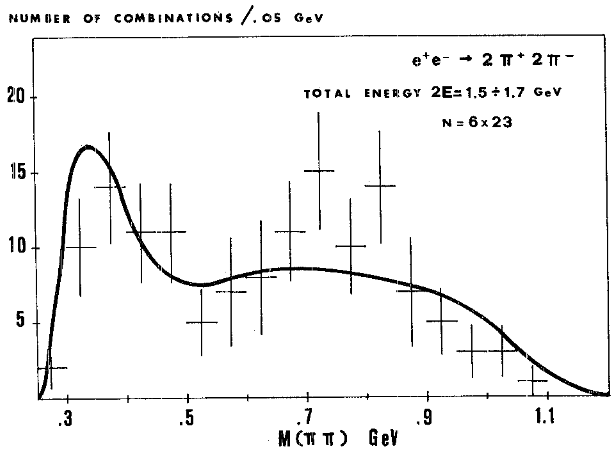

Fig. 2. Two-pion invariant mass distribution $M(\pi\pi)$. There are six combinations per event since the apparatus does not distinguish the charge of the particles. The solid curve is the normalized IPS distribution.

In fig. 1 the distributions of pion momenta are compared with the predictions of IPS. 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 of the peculiar shape of the curves of fig. 1. 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 all three energies have been combined. A clear signal in the ρ^0-region is observed above the IPS distribution.

In order to distinguish among the hypothesis b), c) and d), all involving the production of a ρ^0, we must analyse the invariant mass of the remaining pion pair. So we examine the scatter plot of the invariant mass of a pion pair, $M(\pi_1\pi_2)$, versus the invariant mass of the remaining pair, $M(\pi_3\pi_4)$. If this plot is divided into five bands, marked 1 to 5 in fig. 3, it is apparent that the five bands are not equally populated. In table 1 the experimental population densities are compared with those predicted from the models treated by means of the Monte Carlo calculation, as mentioned above.

‡The apparatus has been described in detail elsewhere [3]. We recall here that it consists of two identical counter-spark chamber telescopes located on opposite sides at one of the straight sections of Adone, in the horizontal plane.

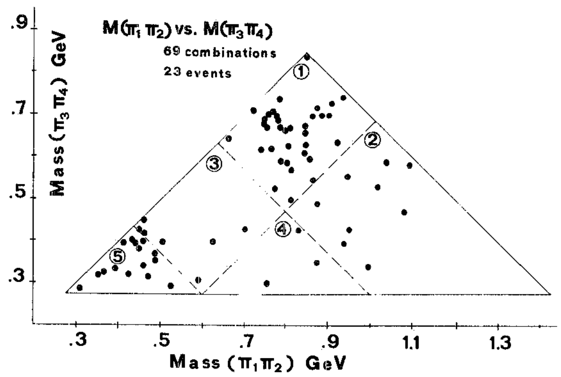

Fig. 3. Scatter plot of the invariant mass of a pion pair, $M(\pi_1\pi_2)$, versus the invariant mass of the remaining pair, $M(\pi_3\pi_4)$. Each event contributes with six combinations of which only three are independent.

The final entry in table 1 gives the χ^2 for the fit of the data to the various predictions. It is readily apparent that the fit to $\rho^o\epsilon^o$ is greatly preferred. Direct evidence for this conclusion can be seen immediately in fig. 3, if one takes into account that the points falling in band 1 are essentially due to a quasi-two-body reaction in which a pair of slow nearly-equal-mass particles is produced, just as in the process $e^+e^- \to \rho^o\epsilon^o$ at $2E = \sim 1.6$ GeV.

A different approach leading to the same conclusion can be based on the following argument. Due to the particular configuration of the experimental set-up 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 2 events of type ii) out of a total of 23 events. As seen in table 2 the observed fraction of configurations 1/3 is just as expected for a $\rho^o\epsilon^o$ intermediate state. The small percentage of configurations 1/3 in the case of $\rho^o\epsilon^o$ production is easily understood on the basis of simple kinematical considerations, taking into account the small velocities of the ρ^o and ϵ^o ($\beta \approx 0.05$)‡ and the small angular acceptance of the two opposite telescopes (±37°).

The preceding analysis leads to the conclusion that the process $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ in the neighbourhood of $2E = 1.6$ GeV is compatible with a 100% $\rho^o\epsilon^o$ intermediate state. Under this assumption we have de-

‡Because of these small velocities, the minimum angle of the decay products of ρ^o or ϵ^o is as large as ≈ 130°.

Table 1

Comparison between experimental and expected values of population densities in five bands of the scatter plot (fig.3). Experimental values agree only with the values expected assuming production mechanism d), i.e.: $e^+e^- \to \rho^o\epsilon^o \to 2\pi^+2\pi^-$.

Band	Exp.	$\rho^o\pi^+\pi^-$	$A_1^{\pm}\pi^{\mp}$	$\rho^o\epsilon^o$
1	35 ± 5.9	18	21	34
2	9 ± 3	18	15	10
3	7 ± 2.6	11	12	9
4	3 ± 1.7	16	15	6
5	15 ± 3.9	6	6	10
χ^2		80	65	5

Table 2

Comparison between experimental and expected fractions of configurations in which one particle of a 4-prong event is in one telescope, and the other three are in the opposite telescope. Again the experimental value agrees only with that expected assuming production mechanism d).

Experiment	IPS	$\rho^o\pi^+\pi^-$	$A_1^{\pm}\pi^{\mp}$	$\rho^o\epsilon^o$
0.09 ± 0.06	0.45	0.61	0.62	0.08

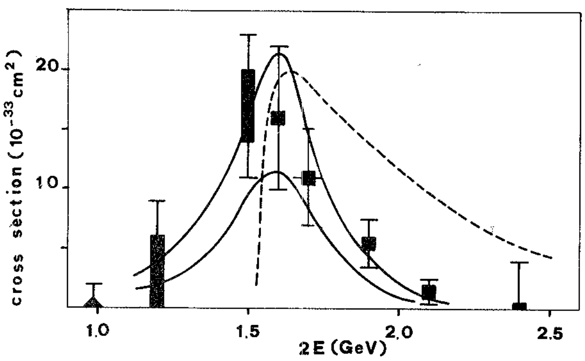

Fig. 4. Energy dependence of the cross section for process $e^+e^- \to \rho^o\epsilon^o \to \pi^+\pi^-\pi^+\pi^-$. The curves are taken from ref. [2] (══) and ref. [8] (----). The dotted curve taken from ref. [8] corresponds to that with the steepest energy dependence for $2E > 1.6$ GeV.

rived 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 $\rho^o\epsilon^o$-state were reached through a ρ^o-tail, i.e.: $e^+e^- \to (\rho^o)^* \to \rho^o\epsilon^o \to \pi^+\pi^-\pi^+\pi^-$. On the contrary there is good agreement with the energy dependence predicted in ref. [2] (full curves in fig. 4) under the hypothesis of ρ' production.

If the ρ' does decay into a $\rho^o\epsilon^o$ system, then isospin conservation implies that $\sigma(e^+e^-\to\rho^o\epsilon^o\to\pi^+\pi^-\pi^o\pi^o) = 0.5\ \sigma(e^+e^-\to\rho^o\epsilon^o\to\pi^+\pi^-\pi^+\pi^-)$. Since the $\rho' \to \pi^+\pi^-$ decay mode is highly depressed [4,5,9] we can derive the coupling constant of the ρ' meson to the photon ($g_{\rho'\gamma} \equiv e\, m^2_{\rho'}/f_{\rho'}$) under two extreme hypotheses: i) if a possible contribution from a $\omega\pi^o$ system to the $\pi^+\pi^-\pi^o\pi^o$ final states is neglected, we obtain $f^2_{\rho'}/4\pi = 17 \pm 5$; ii) if, on the other hand, the $\omega\pi^o$ system is assumed to be produced at the same rate as the $\rho^o\epsilon^o$ system in the $\pi^+\pi^-\pi^o\pi^o$ states, then we obtain $f^2_{\rho'}/4\pi = 13 \pm 5$.

References

[1] G. Barbarino et al., Lett. Nuovo Cim. 3 (1972) 689.
[2] A. Bramon and M. Greco, Lett. Nuovo Cim. 3 (1972) 693.
[3] B. Borgia et al., Frascati Report LNF-72/71 (1972); Nuovo Cim., to be published.
[4] F.F. Liu, Nucl. Phys. B47 (1972) 1.
[5] H.H. Bingham et al., Phys. Lett. 41B (1972) 635. In this experiment a linearly polarized γ beam has been used, and identification of the ρ' quantum numbers became therefore possible.
[6] G. Smadja et al., 3rd Intern. Conf. on Experimental meson spectroscopy, Philadelphia, April 1972.
[7] XVI Intern. Conf. on High energy physics, Batavia, Chicago, September 1972;
Frascati Report LNF 72/90, October 1972.
[8] G. Kramer and T.F. Walsh, Desy Report 72/46 (1972).
[9] F. Ceradini et al., Congresso Nazionale di Fisica, Cagliari, 1972.