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ON THE POSSIBLE EXISTENCE OF A VECTOR MESON $\rho'(1250)$

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By combining new results obtained at C.M. energies of 1.2 and 1.3 GeV with previous data obtained at lower energies from the e^+e^- annihilation process $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$, we get an indication in favour of the existence of a new vector meson of the ρ type, $\rho'(1250)$, the first daughter of the ρ in the predictions of the Veneziano model. Further results on the annihilation process $e^+e^- \to \rho''(1600) \to \pi^+\pi^-\pi^+\pi^-$ are also presented.

The existence of vector mesons heavier than the well-established ρ, ω and φ mesons is predicted by the Veneziano and other Regge models [1]. The results of recent experiments on e^+e^- annihilation [2–4] and on meson photoproduction [5, 6] may be interpreted in terms of a new vector meson of the ρ type, having a mass of approximatively [2–6] 1.6 GeV and a width of 350 MeV. Such a meson [‡1] will be called here ρ'', for it fits into the Veneziano spectrum as the second daughter of the $\rho(760)$, with a mass close to that of the $J^P = 3^-$ g-meson. The first daughter of the ρ should be a $\rho'(\sim 1250)$.

The problem of the possible existence of the ρ' meson, which has been discussed on theoretical grounds by various authors [8–10] is discussed in the present letter on an experimental basis; specifically on the basis of a few points of the excitation curve for the process

$$e^+e^- \to \pi^+\pi^-\pi^0\pi^0 \,. \qquad (1)$$

Points of such a curve, as obtained with the Frascati storage ring, Adone, are given for total c.m. energies ($E_+ + E_- = 2E = \sqrt{s}$) from 1.2 GeV to 2.1 GeV. New data are available for each of the energies from 1.2 GeV to 1.7 GeV, yielding improved statistics with respect to the data previously published [3].

The apparatus, which has been described in detail elsewhere [3, 11], consisted essentially of two counter track-chamber telescopes, covering about 1/4 of the total solid angle around the collision region of the e^+ and e^- bunches [‡2]. Simultaneously with the multihadron events the two telescopes also recorded the two-body events discussed elsewhere [12–14], cosmic rays being efficiently rejected by means of a time-of-flight technique [15]. In the same straight section of Adone a monitoring system [16] measured the machine luminosity and a counter tagging system [17] was used to record directly two-photon annihilation processes [18].

The events that can be assigned to reaction (1) appear in the apparatus as "2T-events" [3], i.e. events in which two charged particles are detected with an acoplanarity angle $\Delta\phi > 10°$. $\Delta\phi$ is defined as the angle between two planes each of which contains one of the two tracks and the beam direction. The numbers of 2T-events recorded at six different energies are reported in table 1 together with the time-integrated luminosities, L. For reasons which will become clear in a while we give also, in this table, the numbers of 3T-, 4T-, 5T-, 6T-events in the combinations $N_{3T} + N_{4T}$ and $N_{5T} + N_{6T}$. Of course the recorded numbers

‡1 Up to now indicated in the literature [2–7] as $\rho'(1600)$.
‡2 At the energies involved in the present investigation the bunches have a length of about ± 15 cm and transverse dimensions in the mm region.

table 1

Numbers of multihadron events recorded in various configurations at six different energies. Data are corrected for a small background due to beam-gas interactions [3].

$2E$ (GeV)	L (nb^{-1})	N_{2T} ($\Delta\phi \geq 10°$)	$N_{3T}+N_{4T}$	$N_{5T}+N_{6T}$
1.2	5.1	11	3	0
1.3	5.8	15	8	0
1.4	11.0	29	35	0
1.5	27.0	51	85	1
1.9	43.5	42	45	1
2.1	90.0	83	90	3

of 2T-events, N_{2T}, contain in general not only events from process (1) but also events from the reaction $e^+e^- \to \pi^+\pi^-\pi^0$ and events with higher multiplicity final states. However we known [19] that [‡3] $\sigma(\pi^+\pi^-\pi^0) \ll \sigma(\pi^+\pi^-\pi^0\pi^0)$ and that $\sigma(e^+e^- \to >6$ pions) can be neglected at the energies involved. On the other hand, on the basis of previous e^+e^- annihilation data [3, 19] we shall assume that events (such as $e^+e^- \to \pi^+\pi^-\pi^0\pi^0\pi^0$) characterized by a neutral multiplicity in excess of their charged multiplicity, are very rare. Finally, since no event with more than four tracks has been observed at energies smaller than 1.5 GeV, we shall neglect also the contribution from events with six charged pions. Therefore only the reactions $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$, $\pi^+\pi^-\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$, are assumed to contribute the recorded number N_{2T} of 2T-events in addition to reaction (1).

These reactions are recorded as 2T-, 3T-, 4T-events with efficiencies ϵ_2, ϵ_3, ϵ_4, computed by a Monte-Carlo simulation of the experiment. We point out that the ratio $\epsilon_2/(\epsilon_3+\epsilon_4)$ is essentially the same, at a given energy, for all reactions (see table 2). This allows one to evaluate in a simple way the contributions of these reactions to be subtracted to N_{2T}.

In table 3 for each energy we give the number N_2 obtained from N_{2T} after subtraction of these contributions. All the uncertainties deriving from the statistics and the subtraction procedure are taken into account in the indicated errors.

The final state $\pi^+\pi^-\pi^0\pi^0$ can be contributed by the $\rho''(1600)$, via neutral decay of the ϵ^0 meson, i.e.: $e^+e^- \to \rho'' \to \rho^0\epsilon^0 \to \pi^+\pi^-\pi^0\pi^0$. This contribution can be calculated from the measured values of the cross section of process

$$e^+e^- \to \rho''(1600) \to \rho^0(760)\epsilon^0(800) \to \pi^+\pi^-\pi^+\pi^- , \qquad (2)$$

assuming $\sigma(\pi^+\pi^-\pi^0\pi^0) = \frac{1}{2}\sigma(\pi^+\pi^-\pi^+\pi^-)$ as required by isospin conservation in reaction (2). The energy dependence of the cross section of process (2), as obtained on the basis of all our results collected up to now, is shown in fig. 1. From a best fit of a Breit–Wigner curve to the experimental points, we obtain for the assumed ρ'' vector meson, the new and more accurate values $m_{\rho''} = (1550 \pm 60)$ MeV/c^2 and $\Gamma_{\rho''} = (360 \pm 100)$MeV/$c^2$, which agree with our previous results [2–4].

In table 3 that part of N_2 which comes from the $\rho''(1600)$ meson, is indicated as $N(\rho'')$. The numbers $N(\rho'')$ are promptly computed using the experimental values of the cross section of processes (2) (see fig. 1) and the values

‡3 This assumption can be omitted without affecting the important conclusion (see below) that the cross section $\sigma(e^+e^- \to \pi^+\pi^- + \text{neutrals})$ in the region 1.2 – 1.3 GeV has comparatively large values.

Table 2

Ratios between the detection efficiencies defined in the text. In order to improve the statistical accuracy, the data have been combined for pairs of contiguous energies having the average values reported in the first column of the table. (The procedure is correct because the ratios do not depend critically on E [3]).

Total energy $2E$ (GeV)	Ratios $\epsilon_2/(\epsilon_3+\epsilon_4)$ computed assuming final state $\pi^+\pi^-\pi^+\pi^-$ from a) $\rho^0\epsilon^0$	$\pi^+\pi^-\pi^+\pi^-$ with IPS	$2\pi^+2\pi^-\pi^0$ with IPS	$2\pi^+2\pi^-2\pi^0$ with IPS
1.25	0.44 ± 0.02	0.47 ± 0.02	0.50 ± 0.02	0.49 ± 0.03
1.45	0.35 ± 0.03	0.39 ± 0.02	0.43 ± 0.03	0.38 ± 0.04
2.00	0.53 ± 0.05	0.43 ± 0.02	0.50 ± 0.04	0.42 ± 0.03

a) The choice of this particular channel is based on the conclusions of ref. [4].

Table 3

Derivation of the cross section of the process $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ assuming for the final state pions a phase space distribution. The detection efficiency $\epsilon^{(IPS)}$ is computed under this assumption by a Montecarlo simulation of the experiment [3]. The input data are the corrected numbers of 2T-events ($N(\rho'')$ is the $\rho''(1600)$ contribution computed using the experimental values of $\sigma(e^+e^- \to \rho'' \to \rho^0\epsilon^0 \to \pi^+\pi^-\pi^+\pi^-)$ and the detection efficiency $\epsilon_2^* \equiv \epsilon(\rho'' \to \rho^0\epsilon^0 \to \pi^+\pi^-\pi^0\pi^0)$.

$2E$ (GeV)	N_2	ϵ_2^* (%)	$N(\rho'')$	$n_2 = N_2 - N(\rho'')$	L (nb^{-1})	$\epsilon^{(IPS)}$ (%)	$\sigma_{IPS}(\pi^+\pi^-\pi^0\pi^0) = n_2/L \cdot \epsilon^{(IPS)}$ (nb)
1.2	9.6 ± 3.4	8.3 ± 0.6	0	9.6 ± 3.4	5.1	2.7 ± 0.2	70 ± 25
1.3	11.4 ± 3.9	8.4 ± 0.6	1.8 ± 1.3	9.6 ± 4.1	5.8	2.9 ± 0.2	57 ± 24
1.4	13.5 ± 6.0	5.2 ± 0.5	6.0 ± 2.3	7.5 ± 6.4	11.0	2.0 ± 0.2	35 ± 30
1.5	18.6 ± 8.0	4.4 ± 0.5	8.3 ± 3.0	10.3 ± 8.5	27.0	1.9 ± 0.2	20 ± 16
1.9	21.5 ± 6.9	1.5 ± 0.2	2.0 ± 0.5	19.5 ± 7.0	43.5	1.5 ± 0.1	30 ± 11
2.1	43.0 ± 9.7	1.1 ± 0.2	1.0 ± 0.5	42.0 ± 9.7	90.0	1.8 ± 0.1	26 ± 6

of the efficiency $\epsilon_2^* \equiv \epsilon(\rho'' \to \rho^0\epsilon^0 \to \pi^+\pi^-\pi^0\pi^0)$ reported in table 3. The remaining events, $n_2 = N_2 - N(\rho'')$, represents therefore, at each energy, the number of events due to $\pi^+\pi^-\pi^0\pi^0$ final states without the ρ'' contribution. In the last column of the table we give the corresponding values of the cross section $\sigma_{IPS}(\pi^+\pi^-\pi^0\pi^0) = n_2/L \cdot \epsilon^{(IPS)}$, where L is the time-integrated luminosity and the detection efficiency $\epsilon^{(IPS)}$ has been computed assuming that the final state $\pi^+\pi^-\pi^0\pi^0$ has a phase space distribution. The results are presented in fig. 2, together with other results obtained on well identified $\pi^+\pi^-\pi^0\pi^0$ states with ACO at lower energies [21].

The cross-section is seen to rise rapidly with increasing the total energy $2E$ from 1.0 to 1.2 GeV, reaching a value of ~ 70 nb at this latter energy value. We have tested explicitly to which extent this result depends on the assumption that the final state,

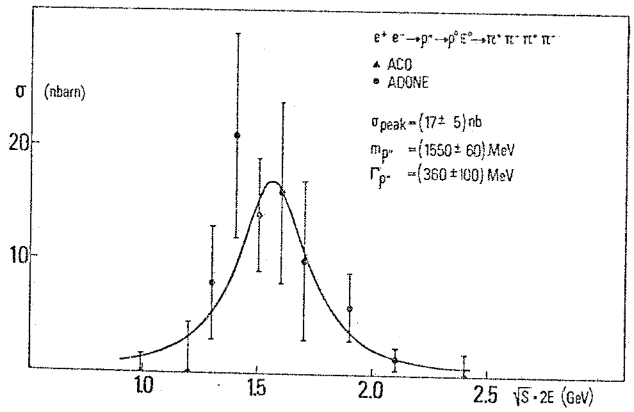

Fig. 1. Energy dependence of the cross section of the process $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ as obtained by combining "old" [3] and "new" data collected with the apparatus of the "$\mu\pi$-group" at Adone. These results ase essentially based on the recorded numbers of 4T-events kinematically reconstructed and on the corresponding detection efficiencies, computed by a Montecarlo simulation of the experiment [3]. The upper limit at $2E = 0.99$ GeV (68% c.l.) comes from ACO. The curve is a best fit of a Breit–Wigner function to the experimental points.

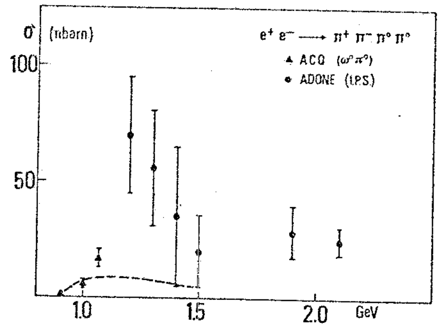

Fig. 2. Energy dependence of the cross section of the process $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$. The points from ADONE are computed assuming a pure phase space distribution after subtraction of the $\rho''(1600) \to \rho^0\epsilon^0 \to \pi^+\pi^-\pi^0\pi^0$ resonant contribution. (The correction is negligeable at 1.2 GeV and has a maximum value of ~ 25% at 1.5 GeV). The points from ACO, obtained with a nearly 4π-detector which allows unambiguous identification of the final states, show a clear threshold effect at the $\omega^0\pi^0$ mass [21]. The dotted curve represents the theoretical expectation of this effect assuming only the contribution from the ρ^0 meson [23]. Already the point at $2E = 1.076$ GeV is seen to be nearly two standard deviations above what expected.

$\pi^+\pi^-\pi^o\pi^o$, has a phase space distribution. Assuming for instance that this final state is reached via quasi-two body intermediate processes, such as $e^+e^- \to \omega^o\pi^o$ and $e^+e^- \to A^\pm\pi^\mp$, we have found that the cross sections are essentially unchanged, within the errors, for $2E \leqslant 1.3$ GeV. On the other hand, for $2E > 1.3$ GeV, they are critically dependent on the assumed production mechanism. For this reason in the following we shall discuss only the results relative to the energy region $2E \leqslant 1.3$ GeV which can be derived from the experiment without ambiguity. We point out, incidentally, that our values of the cross section $\sigma(e^+e^- \to \pi^+\pi^-\pi^o\pi^o)$ are consistent with those obtained at Novosibirsk [22] around $2E = 1.25$ GeV for the multihadron total cross section (essentially $\sigma(e^+e^- \to 4$ pions)).

The fast rise we have just pointed out in the cross section $\sigma(e^+e^- \to \pi^+\pi^-\pi^o\pi^o)$ between ~ 1.0 and 1.2 GeV (see fig. 2), can hardly be interpreted in terms of a threshold effect. As a matter of fact a similar effect, should have, but has not been observed (see fig. 1), in the same energy interval, for the final state $\pi^+\pi^-\pi^+\pi^-$, if due to intermediate states such as $A_1\pi$, $\rho^o\epsilon^o$, $\rho^o\pi\pi$, ... On the other hand, the threshold effect due to the $\omega^o\pi^o$ intermediate state, clearly identified by the Orsay group [21] in the energy region $\sim 0.9 - 1.1$ GeV, seems to be largely unable, in the current theoretical schemes [23], to account for the large values of $\sigma(e^+e^- \to \pi^+\pi^-\pi^o\pi^o)$ found for $2E \geqslant 1.1$ GeV (see fig. 2).

Thus a possible and "simple" interpretation of the results under discussion, can be given in terms of the production of a resonant state (ρ'), with a mass in the range 1.2 – 1.3 GeV. Such a resonance could be responsible (i) for the enhancement recently found, at 1.24 GeV, in the mass spectrum of the ($\pi^+\pi^-$ +neutral) system peripherally produced in high energy γp interactions [24]; (ii) for the signal observed at a mass of ~ 1.25 GeV for the $\omega^o\pi^o$-system produced by $p\bar{p}$ annihilation at rest [25]. (iii) For the indication of a structure observed by one group at Adone [26] for the electromagnetic form factor of the pion in the time-like region, in the energy region 1.2 – 1.3 GeV.

In order to evaluate the $\gamma-\rho'(1250)$ coupling constant ($f^2_{\rho'}/4\pi$) we have carried out a best fit through the values of the cross section $\sigma(\pi^+\pi^-\pi^o\pi^o)$ measured for $2E \leqslant 1.3$ GeV, assuming contributions from both ρ and ρ' mesons. By taking [25] $m_{\rho'} = 1.25$ GeV and $\Gamma_{\rho'} = 150$ MeV, and $g^2_{\rho\omega\pi} = 325$ GeV^{-2} for the $\rho\omega\pi$ coupling constant [21], the best fit yields

$\sigma_{peak}(\pi^+\pi^-\pi^o\pi^o) = (120 \pm 40)$ nb and $\varphi = (1.2 \pm 0.2)$ rad $= \sim (70 \pm 10)^o$ for the peak value of the cross section and, respectively, for the relative phase between the ρ and ρ' amplitudes. Assuming furthermore that the $\rho' \to \omega^o\pi^o$ is the dominant decay mode of the ρ' meson [24] we then find

$$f^2_{\rho'}/4\pi = 7 \pm 2 .$$

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