Measurement on $\pi^+\pi^-\pi^0\pi^0$, $\pi^+\pi^-\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$, $\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$ Production Cross-Sections in e^+e^- Annihilation at (1.45÷1.80) GeV c.m. Energy.

B. ESPOSITO, A. MARINI, G. PIANO-MORTARI (*) and F. RONGA

Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Frascati - Frascati, Italia

M. NIGRO and L. PESCARA

Istituto di Fisica dell'Università - Padova, Italia
Istituto Nazionale di Fisica Nucleare, Sezione di Padova - Padova, Italia

R. BERNABEI, S. d'ANGELO, P. MONACELLI, M. MORICCA
L. PAOLUZI, R. SANTONICO and F. SEBASTIANI

Istituto di Fisica dell'Università - Roma, Italia
Istituto Nazionale di Fisica Nucleare, Sezione di Roma - Roma, Italia

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We present here the measured total cross-section for the reactions

$$e^+e^- \to \begin{cases} \pi^+\pi^-\pi^0\pi^0 , \\ \pi^+\pi^-\pi^+\pi^-\pi^0 , \\ \pi^+\pi^-\pi^+\pi^-\pi^0\pi^0 , \\ \pi^+\pi^-\pi^+\pi^-\pi^+\pi^- , \end{cases} \tag{1}$$

and cross-section values for positive and negative G-parity states in the total c.m. energy range (1.45÷1.80) GeV. The final results, coming from kinematically reconstructed events, on the exclusive channels $e^+e^- \to \pi^+\pi^-\pi^0$ and $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ in the same energy region have been already published ([1]). The $R_{\geqslant 3} = \sum_i \sigma_i(\geqslant 3\pi)/\sigma(e^+e^- \to \mu^+\mu^-)$ values in the same energy region were also published ([2]).

(*) Presently at CERN, Geneva, Switzerland.
([1]) B. ESPOSITO, A. MARTINI, F. RONGA, P. PATTERI, M. NIGRO, L. PESCARA, R. BERNABEI, S. D'ANGELO, P. MONACELLI, M. MORICCA, L. PAOLUZI, R. SANTONICO and F. SEBASTIANI: *Lett. Nuovo Cimento*, **28**, 195 (1980).
([2]) B. ESPOSITO, A. MARINI, G. PIANO-MORTARI, F. RONGA, S. PATTERI, M. NIGRO, L. PESCARA, R. BERNABEI, S. D'ANGELO, P. MONACELLI, M. MORICCA, L. PAOLUZI, R. SANTONICO and F. SEBASTIANI: *Lett. Nuovo Cimento*, **30**, 65 (1981).

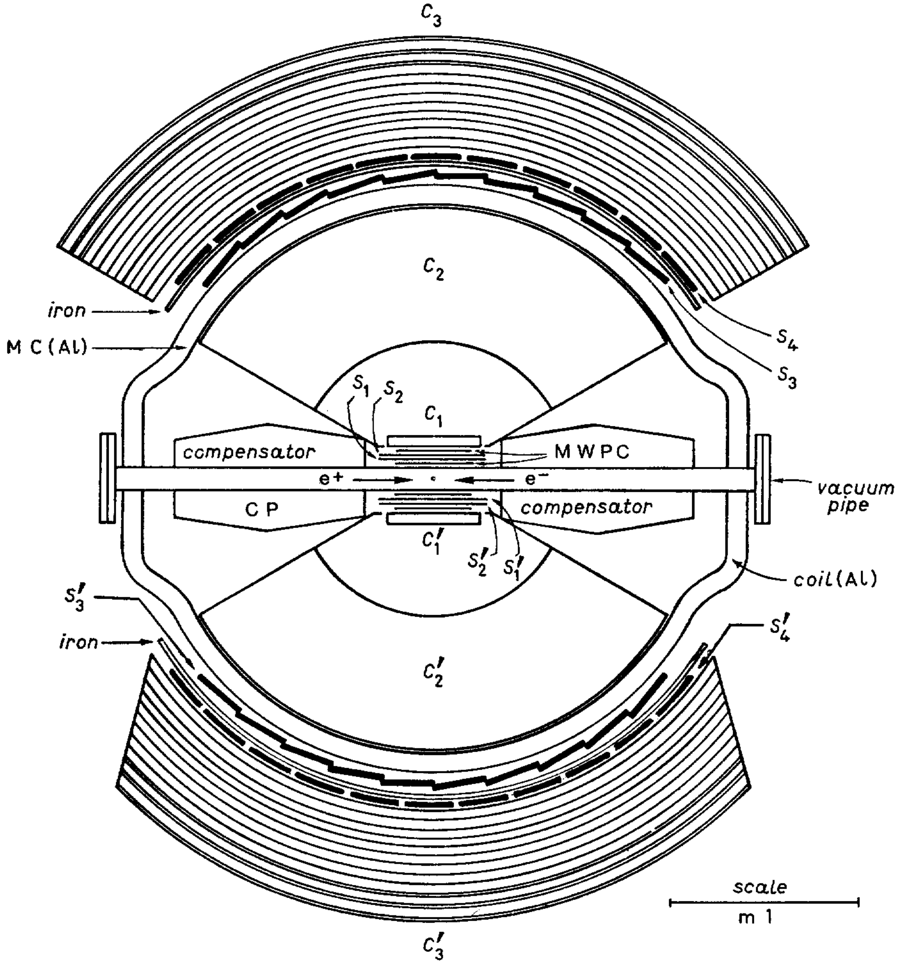

Fig. 1. – Vertical section of the experimental apparatus: C_1C_1' are narrow-gap spark chambers; C_2C_2' wide-gap cylindrical spark chambers for momentum analysis; C_3C_3' thick-plate spark chambers for particle identification; MWPC multiwire proportional chambers; S_1, S_2, ..., S_4' scintillation counters.

TABLE I. – MEA *detector main characteristics.*

Magnetic field	2.0 KG, perpendicular to e^+e^- beams
Solid-angle acceptance	$\Delta\Omega_C = 0.33\times 4\pi$ sr, for triggering and for momentum measurements at beam energies $E_e = 0.75$ GeV $\Delta\Omega_N = 0.27\times 4\pi$ sr, for γ conversion, particle interaction, range measurements
Trigger requirements	Two charged particles penetrate the upper and lower part of the detector (pion kinetic energies of at least 110 and 130 MeV)
Single-track momentum resolution	$\Delta p/p = \pm\,0.05$ at 500 MeV/c (corresponding angular resolution: $\Delta\varphi = \pm\,1.2$ and $\Delta\theta = \pm\,0.08$)

The experiment has been performed at Adone, the Frascati e^+e^- storage ring, with the MEA magnetic detector (fig. 1). The experimental set-up has been described in detail elsewhere (3); the main characteristics are summarized in table I together with the trigger requirements.

The multihadron events were selected by requiring at least two charged tracks. The following criteria were applied in the selection (4,5): the acoplanarity angle of the track pairs and the e^+e^- beams and the noncolinearity angle of the track pairs are required to be $\geqslant 10°$; the reconstructed vertex point of the event must originate in the e^+e^- interaction region and the timing was required to correspond to the bunch-bunch collision time.

The results are referred to a total integrated luminosity $\mathscr{L} = 271.2\,(\text{nb}^{-1})$, as measured by wide-angle Bhabha scattering in the apparatus. The events were selected into different categories, according to the number of observed tracks and γ-rays. The partial cross-sections for different final states were evaluated solving for each energy, by a standard likelihood method, the system

$$\frac{n_K}{\mathscr{L}} = \sum_i \varepsilon_{Ki}\sigma_i\,, \tag{2}$$

where n_K is the number of events belonging to the K-th category, $\mathscr{L}$ the collected luminosity, ε_{Ki} the efficiency for detecting the i-th reaction in the K-th configuration and σ_i the cross-section of each final state. The detection efficiencies ε_{Ki} were obtained by the Monte Carlo method, by assuming that only pions are produced with a phase-space momentum distribution.

TABLE II. – *Calculated detection trigger efficienceis.*

W (MeV)	ε $\pi^+\pi^-\pi^0\pi^0$ (%)	ε $\pi^+\pi^-\pi^+\pi^-\pi^0$ (%)	ε $\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$ (%)	ε $\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$ (%)
1500	2.5	6.1	2.6	8.1
1750	3.1	11.1	6.5	10.5

In table II we give the trigger efficiencies of our apparatus for the different final states; these efficiencies vary smoothly with energy. Furthermore, we assume a maximum multiplicity of six pions and we do not take into account colinear pair production. Solving the system of eqs. (2), we have imposed the relation

$$\sigma(e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0) = 2\sigma(e^+e^- \to \pi^+\pi^-\pi^0\pi^0\pi^0)\,,$$

which derives from isospin considerations.

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TABLE III. – Column 1: total c.m. energy interval in which data have been binned; column 2: mean c.m. energy value of the corresponding interval ΔW; column 3: in integrated luminosity; columns 4-6: cross-sections of the reactions considered; columns 7-8: cross-sections for negative (σ^-) and positive (σ^+) G-parity final states.

ΔW (MeV)	$\langle W \rangle$ (MeV)	$\mathscr{L}$ (nb^{-1})	$\sigma(\pi^+\pi^-\pi^0\pi^0)$ (nb)	$\sigma(\pi^+\pi^-\pi^+\pi^-\pi^0)$ (nb)	$\sigma(\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0)$ (nb)	σ^+ (nb)	σ^- (nb)
1450÷1475	1462	33.1	15.4±1.5	2.0±0.9	4.1±2.2	39.5±3.2	7.2±2.6
1475÷1525	1503	96.1	24.9±6.0	4.0±0.9	9.0±1.3	59.9±6.2	12.0±1.6
1525÷1625	1577	33.2	28.0±2.5	4.0±3.6	9.0±3.8	62.0±4.9	12.0±5.9
1625÷1675	1653	26.2	25.0±6.4	4.0±3.3	8.0±5.2	59.0±8.7	18.0±4.3
1675÷1725	1697	34.6	26.1±3.4	4.0±1.1	10.0±3.6	52.1±5.4	13.0±1.9
1725÷1775	1748	26.4	24.0±2.0	4.0±1.1	10.0±5.0	52.0±5.9	11.0±3.5
1775÷1800	1788	21.6	26.0±7.0	3.9±1.1	6.9±4.2	50.8±8.6	9.9±2.9

The quoted errors are statistical only as obtained by solving the system (2).

For the reaction $e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$ we obtained a cross-section $\leqslant 2$ nb in the explored energy range. In table III we report our results on total cross-section for the other reactions (1).

Figure 2*a*) shows the present results on the cross-section of the reaction $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$ together with those obtained by other experiments (4-10).

In fig. 2*b*) we report the weighted mean of the experimental values of the cross-section, in the energy range (1.1÷2.0) GeV, binned in 50 MeV steps. In the same figure are also shown the contributions from the $\rho(1550)$ (dashed line)—evaluated according to $\sigma(\pi^+\pi^-\pi^0\pi^0) = \frac{1}{2}\sigma(\pi^+\pi^-\pi^+\pi^-)$ from the values (1) of the cross-section of the reaction $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$— (*) and the ρ-tail (solid line)—as evaluated by ALTUKOV and KHRIPLOVICH and quoted in ref. (10).

When we subtract incoherently these contributions from experimental values, as shown in fig. 2*c*), we obtain a clear bump near 1300 MeV, compatible with the existence of the $\rho(1250)$, firstly seen in e^+e^- annihilations by CONVERSI *et al.* (11)

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(*) The $\frac{1}{2}$ factor is derived from naive considerations on isospin conservation, giving

$$\sigma(\rho^0\pi^0\pi^0)/\sigma(\rho^0\pi^+\pi^-) = \tfrac{1}{2}\,.$$

This factor indeed may be smaller, expecially at lower energies, as indicated by S. I. EIDELMAN: *Ž. Èksp. Teor. Fiz. Pis'ma Red.*, **26**, 563 (1977) (quoted in ref. (10)).

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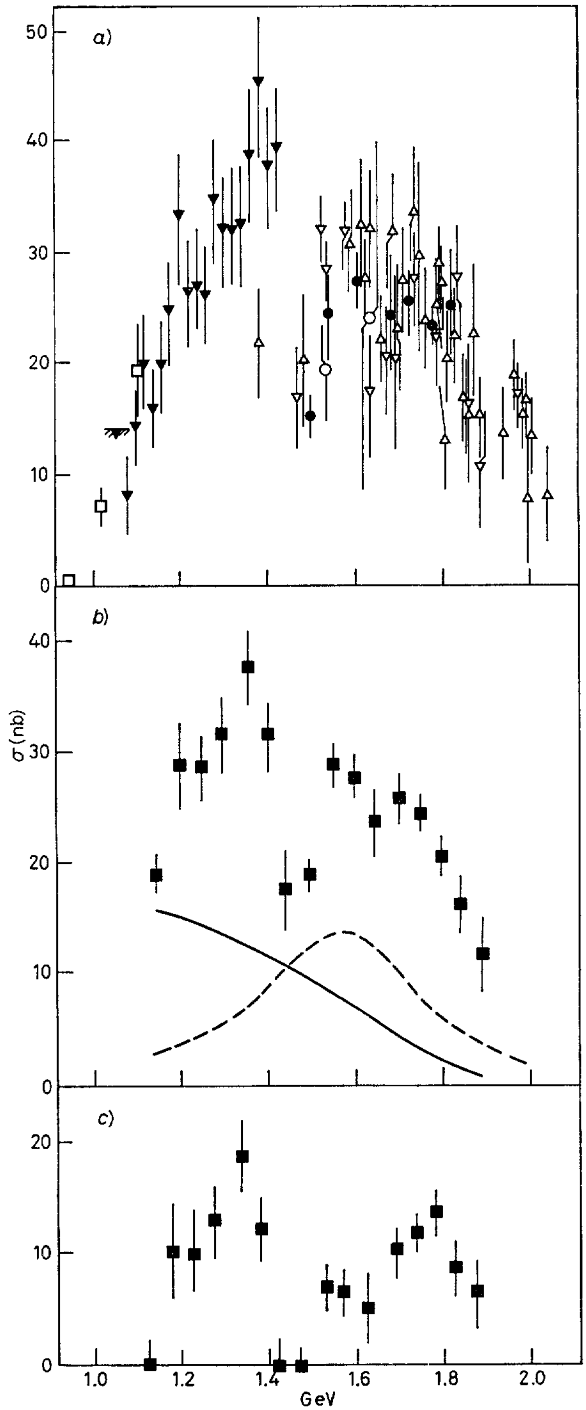

Fig. 2. – *a*) Present results and previous ones on cross-section for the reaction $e^+e^- \to \pi^+\pi^-2\pi^0$; *b*) weighted mean of the experimental values of the cross-section binned in 50 MeV steps from (1.1 ÷ 2.0) GeV, together with ρ(1550) (dashed line) and ρ-tail (solid line) contributions; *c*) weighted mean of the experimental values of the cross-section when the above contributions were incoherently subtracted. ○ present results, ● Adone-Mea (4,5), ▽A done-γγ2 (6), □ ACO-M2N (9), ▼ VEPP 2*M*-OLYA (10), △ DCI-M3N (7,8), ■ weighted mean values.

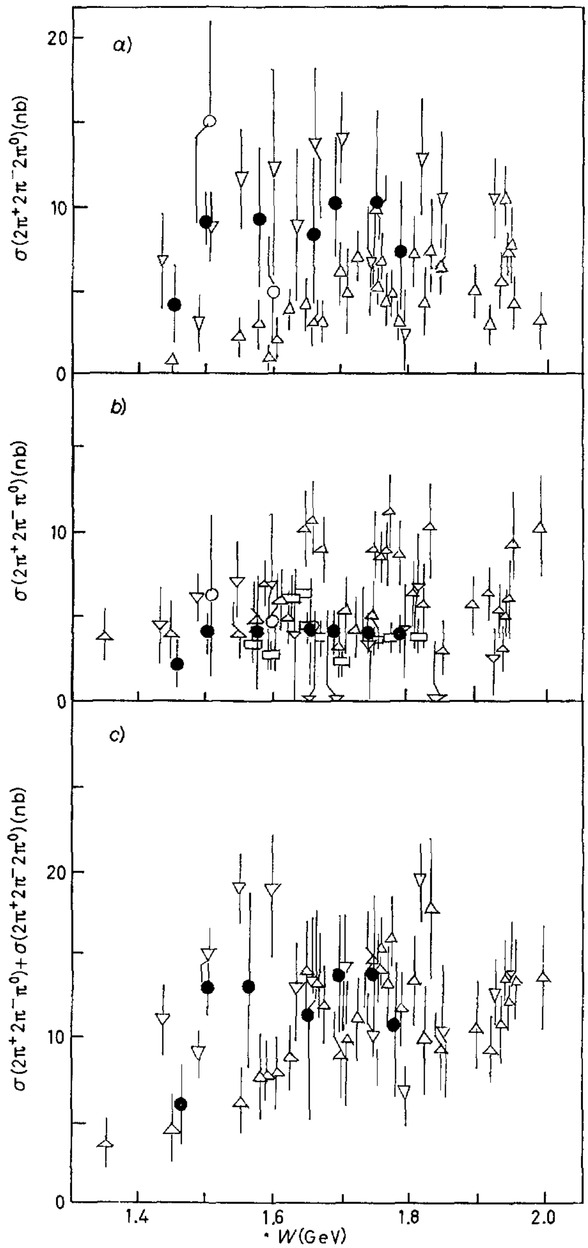

Fig. 3. – Present results and previous ones on total cross-section for reactions *a*) $e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0$, *b*) $e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$, *c*) sum of the cross-sections $\sigma(2\pi^+2\pi^-\pi^0) + \sigma(2\pi^+2\pi^-2\pi^0)$. • present results, ○ Adone-Mea (4,5), ▽ Adone-γγ2 (6), △ DCI-M3N (7,8), □ DCI-DM1 (13).

($M = 1250$ MeV, $\Gamma = 150$ MeV) and recently observed by BARTALUCCI *et al.* [12] ($M = (1266 \pm 5)$ MeV, $\Gamma = (110 \pm 35)$ MeV) in electroproduction and by ASTON *et al.* [13] and by BARBER *et al.* [14] in photoproduction. A more detailed analysis of these data is very involving owing to the presence of different resonant states and the reciprocal interference.

In fig. 3 we report the results for cross-sections of the reactions

$$e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0,\ \pi^+\pi^-\pi^+\pi^-\pi^0\pi^0\,,$$

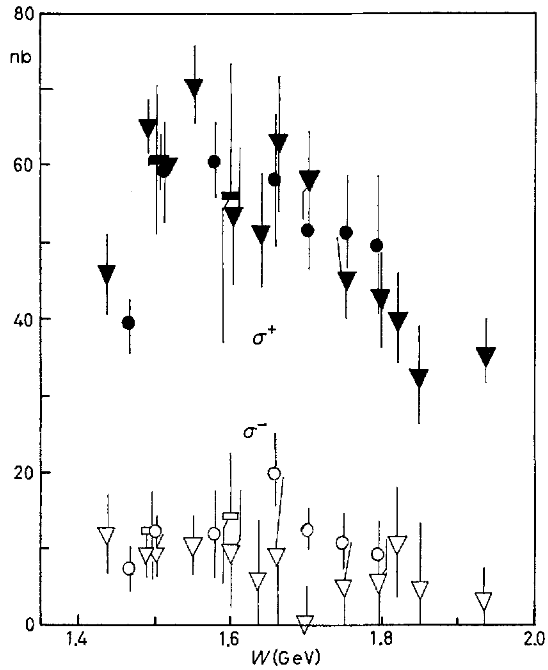

Fig. 4. – Present results and previous ones on cross-sections for production of final states with positive (σ^+) and negative (σ^-) G-parity. •, ○ Present results; ■, □ MEA-Adone [4,5]; ▼, ▽ $\gamma\gamma$2-Adone [6].

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together with those obtained by other experiments [1,4-8,15]. As also fig. 3c) shows, our data are compatible within the errors with previous one.

Finally in table III and fig. 4 we present the total cross-sections for even (σ^+) and odd (σ^-) number of produced pions, corresponding to positive and negative G-parity states, respectively, together with those of other experiments [4-6]. In the whole energy range σ^+ is definitely larger than σ^-, as expected. Furthermore, the enhancement of σ^+ around 1.55 GeV reflects the $\rho(1550)$ production.

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