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MEASUREMENT OF HADRONIC EXCLUSIVE CROSS SECTIONS IN e^+e^- ANNIHILATION FROM 1.42 TO 2.20 GeV

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ABSTRACT

Total cross sections for reactions $e^+e^- \rightarrow \pi^+\pi^-\pi^o$, $\pi^+\pi^- 2\pi^o$, $2\pi^+ 2\pi^-\pi^o$, $2\pi^+ 2\pi^- 2\pi^o$, $3\pi^+ 3\pi^-$ have been measured in the total c.m. energy range 1.42-2.20 GeV. Partial $R = \sigma_{had}/\sigma_{\mu^+\mu^-}$ values for two and four produced charged pions, and cross sections for positive and negative G-parity states are also reported.

* * * * * *

We present experimental results on the total cross section for the reactions

$$e^+e^- \rightarrow \pi^+\pi^-\pi^o \quad (1)$$

$$\pi^+\pi^- 2\pi^o \quad (2)$$

$$2\pi^+ 2\pi^-\pi^o \quad (3)$$

$$2\pi^+ 2\pi^- 2\pi^o \quad (4)$$

$$3\pi^+ 3\pi^- \quad (5)$$

obtained at the e^+e^- Adone storage ring ($\gamma\gamma 2$ experiment) in the total c.m. energy region W = 1.42 - 2.20 GeV, where large multihadron production was observed by the first experiments at Frascati[(1)].

Preliminary results from the present experiment have been previously reported(2), while the final results on reaction $e^+e^- \longrightarrow 2\pi^+ 2\pi^-$ have been already published(3). The experimental set-up and the trigger logic have been described elsewhere(4, 5). Multihadron events have been selected by requiring two charged particles plus at least another particle (track or photon).

We have collected 4009 multihadron events corresponding to a total integrated luminosity of 419 nb^{-1}, measured by wide angle Bhabha scattering in our apparatus. Background events from beam-gas interaction, measured by running the machine with a single beam, turn out to be negligible with our selection criteria.

Following a standard method(3, 5) the multihadron events have been classified in different categories according to the number of observed tracks and photons. The number n_k of events in the k-th category is given by

$$n_k = L \cdot \Sigma_i \, \varepsilon_{ki} \cdot \sigma_i \qquad (6)$$

where L is the integrated luminosity, ε_{ki} is the efficiency for detecting the i-th reaction in the k-th category, and σ_i is the corresponding cross section. ε_{ki} have been evaluated by Monte Carlo method assuming that only pions are produced with an invariant phase space momentum distribution(*). Moreover a minimum (maximum) multiplicity of three (six) pions has been assumed.

For reactions (1)-(5) the calculated detection efficiency given in Table I, turns out to vary smoothly with energy. In solving the system of eqs. (6) by standard maximum likelihood method, the relation

$$\sigma(e^+e^- \longrightarrow 2\pi^+ 2\pi^- \pi^0) = 2\sigma(e^+e^- \longrightarrow \pi^+\pi^- 3\pi^0)$$

which follows from isospin consideration, has been imposed.

<u>TABLE I</u> - Calculated detection efficiency for reactions (1)-(5) at two different energies. The efficiencies vary smoothly with W.

W (GeV)	ε $\pi^+\pi^-\pi^0$ (%)	ε $\pi^+\pi^-2\pi^0$ (%)	ε $2\pi^+2\pi^-\pi^0$ (%)	ε $2\pi^+2\pi^-2\pi^0$ (%)	ε $3\pi^+3\pi^-$ (%)
1.5	9	9	17	13	12
2.0	9	11	25	26	31

(x) The detection efficiency for reaction $e^+e^- \longrightarrow \pi^+\pi^-\pi^0$ varies by $\lesssim 15\%$ if a $\sin^2\theta$ distribution is assumed for the angle between the normal to the $\pi^+\pi^-\pi^0$ plane and the beam line.

In Table II we report our results on total cross sections for reactions (1)-(4). Radiative corrections[6] have been applied only to reaction $e^+e^- \rightarrow \pi^+\pi^- 2\pi^0$ for which lower-energy data are available. The quoted errors are statistical only. As far as reaction $e^+e^- \rightarrow 3\pi^+ 3\pi^-$ is concerned, our limited statistics allows only to infer a cross section $\lesssim$ 2 nb in the explored energy range.

In Fig. 1 we report our results for reactions $e^+e^- \rightarrow \pi^+\pi^-\pi^0$, $2\pi^+2\pi^-\pi^0$, $2\pi^+2\pi^-2\pi^0$ together with those from other experiments[7-10]. For reaction $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ (Fig. 1a) our data are compatible with the existence of a relatively narrow resonance around 1.65 GeV which has been observed in this channel by other experiments[8,9]. This state has been detected[9,10] also in reaction $e^+e^- \rightarrow 2\pi^+ 2\pi^-\pi^0$ (Fig. 1b) but our limited statistics does not allow to confirm its existence in this channel. It should be noted that

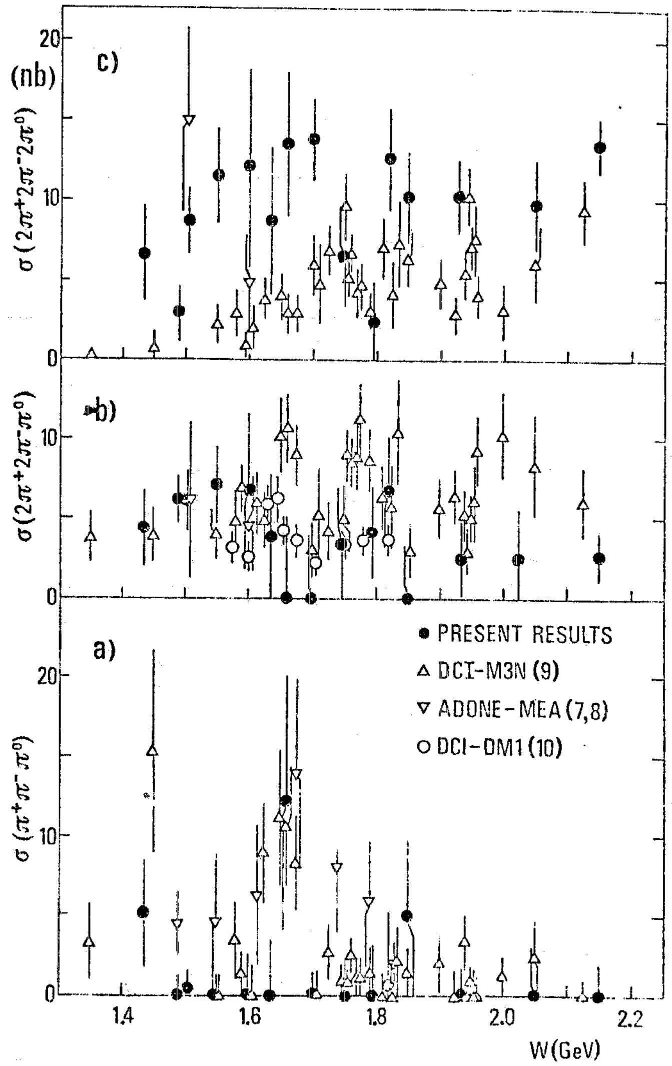

FIG. 1 - Present results and previous ones on total cross sections for reactions: a) $e^+e^- \rightarrow \pi^+\pi^-\pi^0$; b) $e^+e^- \rightarrow 2\pi^+ 2\pi^-\pi^0$; c) $e^+e^- \rightarrow 2\pi^+ 2\pi^- 2\pi^0$. The energy interval corresponding to each point of present experiment is reported in Tab. II.

TABLE II - Column 1 : total c. m. energy interval in which data have been lumped. Column 2 : mean total c. m. energy values of the corresponding interval ΔW. Column 3 : integrated luminosity. Column 4-7 : cross sections for reactions (1)-(4). Column 8-9 : cross sections for negative and positive G-parity final states. Column 10-11 : Partial R values for reactions with respectively two or four produced charged pions.

ΔW (MeV)	<W> (MeV)	L (nb^{-1})	$\sigma_{\pi^+\pi^-\pi^0}$ (nb)	$\sigma_{\pi^+\pi^-2\pi^0}$ (nb)	$\sigma_{2\pi^+2\pi^-\pi^0}$ (nb)	$\sigma_{2\pi^+2\pi^-2\pi^0}$ (nb)	σ^- (nb)	σ^+ (nb)	R_2	R_4
1420-1475	1437	32.9	5.2±3.4	16.7±4.7	4.4±2.4	6.6±2.9	11.7±4.9	45.9±5.6	0.58±0.13	0.74±0.06
1475-1500	1491	62.1	0.0±1.2	31.6±2.7	6.2±1.5	2.9±1.8	9.3±2.6	65.1±3.3	0.90±0.07	0.91±0.04
1500-1525	1505	69.2	0.4±1.1	28.0±3.1	6.1±1.9	8.7±2.1	9.3±3.1	60.7±3.8	0.83±0.07	0.99±0.05
1525-1575	1549	35.4	0.1±1.3	31.2±3.4	7.1±2.4	11.5±3.0	10.3±3.8	70.1±4.7	0.97±0.10	1.13±0.07
1575-1615	1600	14.7	0.0±2.6	16.9±5.8	6.7±4.9	12.1±6.3	10.0±7.8	53.4±8.9	0.60±0.17	1.28±0.14
1615-1650	1633	16.4	0.0±3.6	20.0±4.9	3.9±3.9	8.7±4.6	5.9±6.9	51.1±7.0	0.68±0.19	1.08±0.11
1650-1670	1660	9.4	12.2±8.0	20.1±8.1	0.0±5.0	13.5±4.6	8.9±11.0	62.9±9.5	1.03±0.22	1.37±0.13
1670-1725	1701	21.7	0.0±1.5	27.3±4.4	0.0±4.0	13.8±2.6	0.0±6.2	58.4±5.2	0.92±0.14	1.05±0.09
1725-1775	1752	20.1	0.0±2.4	22.1±4.5	3.4±3.4	6.5±3.2	5.0±5.6	45.4±5.7	0.85±0.17	0.95±0.09
1775-1805	1794	13.2	0.0±3.2	27.1±5.4	4.1±2.8	2.4±2.5	6.1±5.3	42.7±6.0	1.10±0.22	0.74±0.09
1805-1835	1821	20.8	0.6±4.8	16.3±4.9	6.7±3.4	12.6±3.2	10.6±7.0	39.9±5.9	0.78±0.24	1.13±0.09
1835-1875	1851	12.9	4.9±5.0	10.4±5.5	0.1±3.2	10.2±2.9	5.1±6.9	32.5±6.2	0.62±0.29	0.89±0.10
1875-2000	1935	34.2	0.0±1.7	16.9±3.2	2.5±2.3	10.2±2.3	3.6±4.0	35.6±4.0	0.79±0.15	0.95±0.07
2000-2100	2050	15.0	0.0±3.0	16.6±4.0	2.4±3.2	9.7±2.8	3.6±5.7	34.6±5.2	0.88±0.22	0.99±0.11
2100-2200	2150	41.0	0.0±2.0	15.0±2.7	2.7±1.6	13.4±1.7	4.1±3.1	35.1±3.3	0.88±0.16	1.14±0.08
2200-2540	2370	12.0							1.23±0.36	1.16±0.15
2540-2640	2590	11.6							1.30±0.38	1.07±0.14
2640-2760	2700	12.5							0.96±0.20	1.63±0.25
2760-2980	2870	23.1							0.83±0.19	1.09±0.10

in this reaction our results are on the average in good agreement with those from DCI--DM1[10]. Conversely the data from DCI-M3N[9] are, especially at high energy, quite higher than the present ones. This situation appears to be reversed in the reaction $e^+e^- \longrightarrow 2\pi^+ 2\pi^- 2\pi^0$ (Fig. 1c). This effect may be due to systematic errors in photon identification and in evaluation of the photon detection efficiency. In fact the sum of $\sigma(2\pi^+ 2\pi^- \pi^0)$ and $\sigma(2\pi^+ 2\pi^- 2\pi^0)$ cross sections (Fig. 2a), which is less sensitive to photon detection efficiency, turns out to be in better agreement between the two experiments.

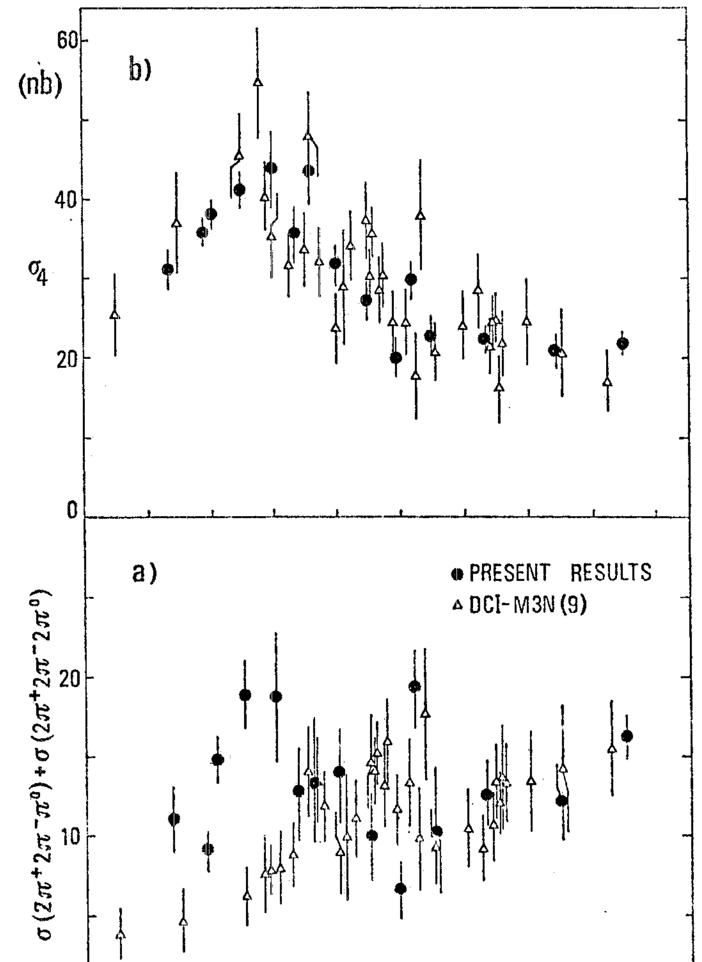

FIG. 2 - Comparison of present results with those from DCI-M3N. a) Sum of the cross sections $\sigma(2\pi^+ 2\pi^- \pi^0) + \sigma(2\pi^+ 2\pi^- 2\pi^0)$. b) Sum of the cross sections of reactions with four produced charged pions $\sigma_4 = \sigma(2\pi^+ 2\pi^-) + \sigma(2\pi^+ 2\pi^- \pi^0) + \sigma(2\pi^+ 2\pi^- 2\pi^0)$. Errors on present data take into account correlations between cross sections due to eq. (6), while for DCI-M3N data, errors have been calculated by summing quadratically the errors on each cross section.

Furthermore if we consider the

$$\sigma_4 = \sigma(2\pi^+ 2\pi^-) + \sigma(2\pi^+ 2\pi^- \pi^0) + \sigma(2\pi^+ 2\pi^- 2\pi^0)$$

cross section (Fig. 2b), which is practically independent on photon detection efficiency, the agreement becomes quite good in the whole energy region. These results support the above-mentioned interpretation of the discrepancies between DCI-M3N data[9] and present ones.

The high cross section value of present data at W = 1.82 GeV in Fig. 2a represents the effect of the resonant state already observed with higher energy resolution[11]. The present data don't allow to single out which is the resonant channel between the reactions $e^+e^- \to 2\pi^+ 2\pi^- \pi^0$ and $e^+e^- \to 2\pi^+ 2\pi^- 2\pi^0$.

Fig. 3 shows present results on reaction $e^+e^- \to \pi^+\pi^- 2\pi^0$ together with those obtained by other experiments[7,9,12,13]. A theoretical model based on vector dominance predicts[14] a cross section due to ϱ tail (curve a of Fig. 3) which is about a factor two lower than the experimental data.

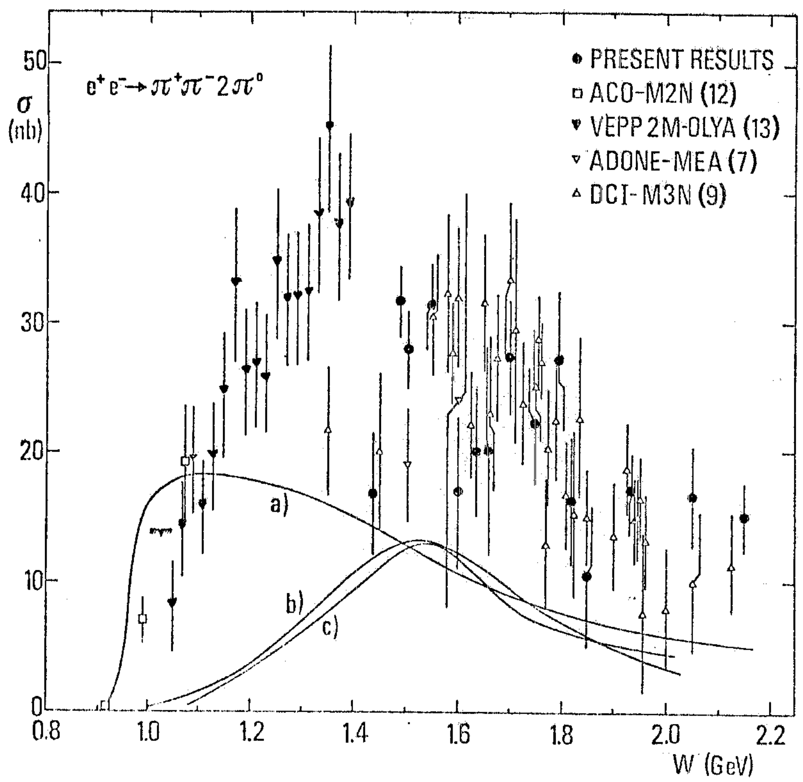

FIG. 3 - Present results and previous ones on cross section for reaction $e^+e^- \to \pi^+\pi^- 2\pi^0$. The energy interval corresponding to each point of present experiment is reported in Table II. Curve a) : vector dominance model prediction (ϱ-tail)[14]. Curve b) : expected contribution from $\varrho'(1600) \to \varrho^0\pi^0\pi^0$ without any non-resonant background[3] in $\sigma(2\pi^+ 2\pi^-)$. Curve c) : same as curve b), but taking into account a non-resonant $e^+e^- \to \pi A_1$ background[15].

Actually a further relevant contribution is expected from the decay $\varrho'(1600) \rightarrow \varrho^o\pi^o\pi^o$. From isospin considerations we have $\Gamma(\varrho' \rightarrow \varrho^o\pi^o\pi^o) = 1/2\ \Gamma(\varrho' \rightarrow \varrho^o\pi^+\pi^-)$. Assuming that between 1.0 and 2.0 GeV the $e^+e^- \rightarrow 2\pi^+ 2\pi^-$ cross section is due only to $\varrho'(1600) \rightarrow \varrho^o\pi^+\pi^-$ without any non-resonant background(3), the $\varrho' \rightarrow \varrho^o\pi^o\pi^o$ contribution is given by curve b (Fig. 3). However if we take into account the presence of a non-resonant πA_1 background in the $e^+e^- \rightarrow 2\pi^+ 2\pi^-$ cross section(15), the corresponding $\sigma(\pi^+\pi^- 2\pi^o)$ prediction is given by curve c (Fig. 3). These theoretical predictions are definitely lower than the experimental cross section, also if ϱ tail and ϱ' contribution are added up. Therefore other contributions, e. g. from an eventual $\varrho'(1600) \rightarrow \omega\pi^o$ decay, should be present.

In Fig. 4 and Table II we report, in a wider energy interval, the $R = \sigma(e^+e^- \rightarrow \text{hadrons})/\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ values for events produced with two (R_2) and four (R_4) charged pions, with or without neutrals. Two body final states (e. g. $e^+e^- \rightarrow \pi^+\pi^-$) are not considered in our analysis and therefore not included in R_2. The agreement with SLAC-LBL results(16) is quite good in the overlapping energy region.

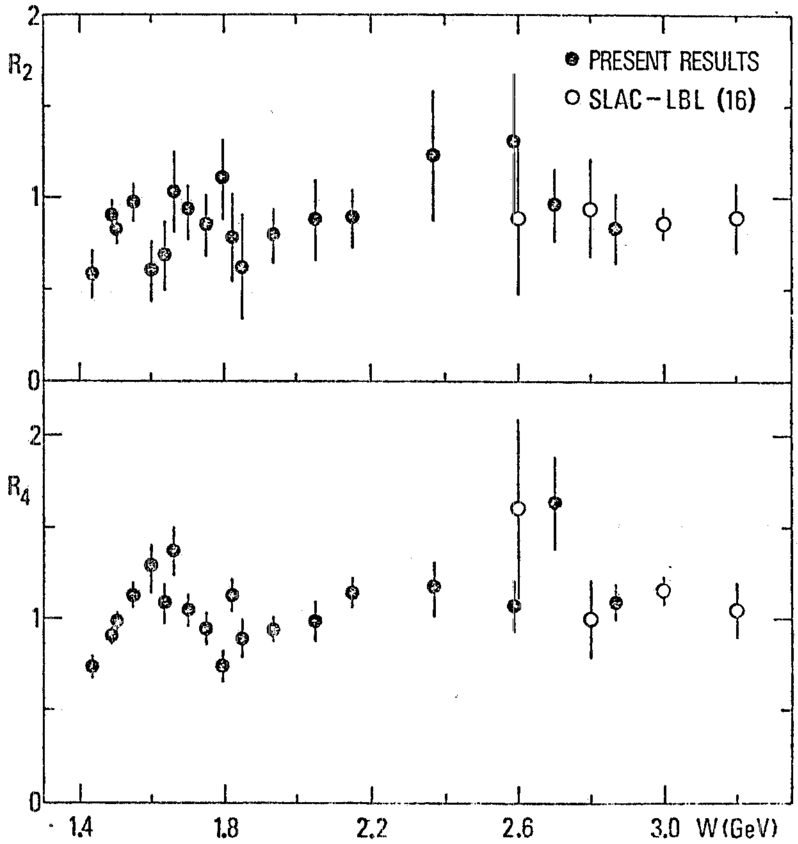

FIG. 4 - Present results and previous ones on R partial values for two (R_2) and four (R_4) produced charged pions versus total c. m. energy W.

Finally we report in Table II and Fig. 5 the total cross sections for even (σ^+) and odd (σ^-) number of produced pions, which correspond respectively to positive and negative G-parity states. Around 1.5-1.6 GeV the σ^+ is dominated by the $\varrho'(1600)$ reso-

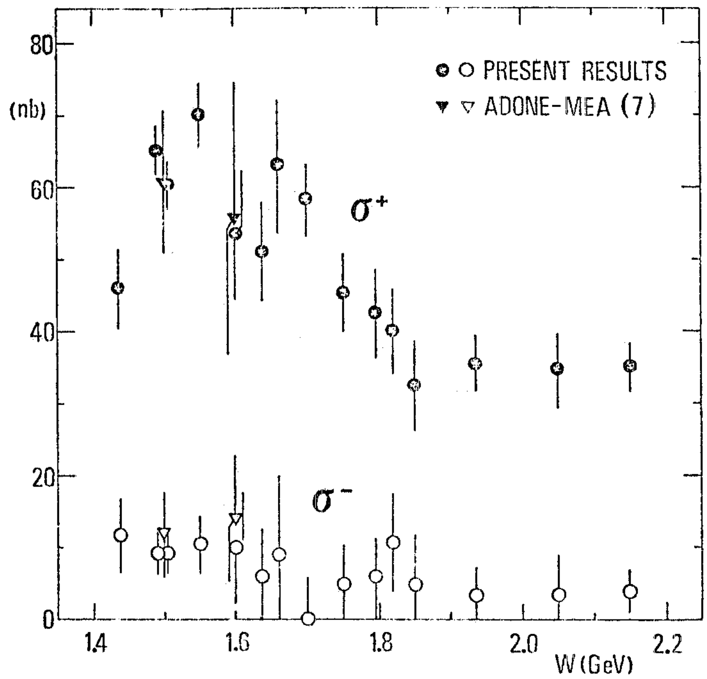

FIG. 5 - Present results and previous ones on cross sections for production of final states with positive (σ^+) and negative (σ^-) G-parity.

nance. In the whole energy range σ^+ is definitely larger than σ^-, as expected. In fact taking into account the quarks composition of the ϱ-like and ω-like states, SU(3) predicts that for asymptotic $\overline{W}$ values, the following relation holds :

$$\frac{M^-}{M^+} = \frac{\int_{W_o}^{\overline{W}} dW\ \sigma^-(W)}{\int_{W_o}^{\overline{W}} dW\ \sigma^+(W)} = \frac{|Q_u + Q_d|^2}{|Q_u - Q_d|^2} = \frac{1}{9}$$

where $Q_{u,d}$ is the quark charge.

In order to compare our results with this theoretical expectation we report in Fig. 6 the ratio M^-/M^+ calculated from present results, with W_o = 1.42 GeV. The agreement with the predicted asymptotic value is quite good.

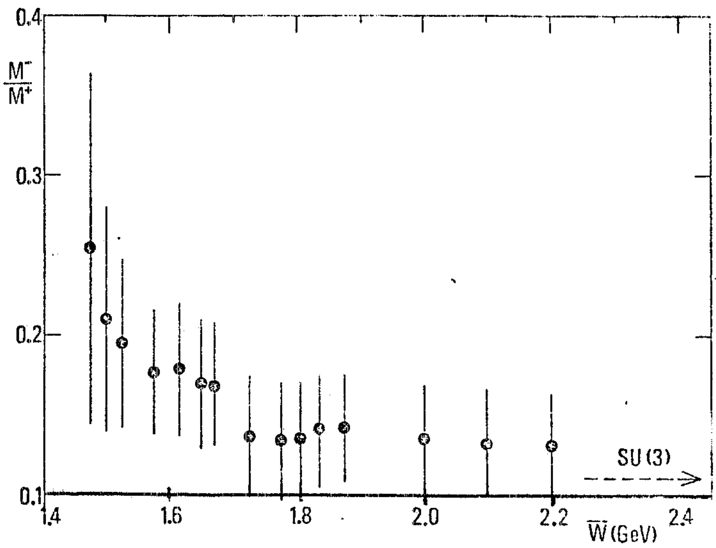

FIG. 6 - Ratio of the zeroth momentum of the negative and positive G-parity cross sections.

REFERENCES.

(1) - B. Bartoli et al., Phys. Letters 36B, 598 (1971); C. Bacci et al., Phys. Letters 38B, 551 (1972); G. Barbarino et al., Lett. Nuovo Cimento 3, 689 (1972); B. Bartoli et al., Phys. Rev. D6, 2374 (1972); F. Ceradini et al., Phys. Letters 43B, 341 (1973); C. Bacci et al., Phys. Letters 44B, 533 (1973); M. Grilli et al., Nuovo Cimento 13A, 593 (1973); M. Conversi et al., Phys. Letters 52B, 493 (1974).

(2) - G. P. Murtas, Proceedings of the 19th Intern. Conf. on High Energy Physics, Tokyo 1978, p. 269; R. Baldini-Celio, Proceedings of the Intern. Conf. on High Energy Physics, Geneva 1979, p. 350; M. Spinetti, Proceedings of the Intern. Symp. on Lepton and Photon Interaction at High Energies, Batavia 1979, p. 506.

(3) - C. Bacci et al., Phys. Letters 95B, 139 (1980).

(4) - R. Baldini-Celio et al., Lett. Nuovo Cimento 11, 711 (1974); C. Bacci et al., Lett. Nuovo Cimento 12, 269 (1975); R. Baldini-Celio et al., Phys. Letters 64B, 356 (1976); C. Bacci et al., Phys. Letters 71B, 227 (1977); R. Baldini-Celio et al., Phys. Letters 78B, 167 (1978); R. Baldini-Celio et al., Lett. Nuovo Cimento 24, 324 (1979).

(5) - C. Bacci et al., Phys. Letters 68B, 234 (1979).

(6) - G. Pancheri, Nuovo Cimento 60, 321 (1969); G. Bonneau and F. Martin, Nuclear Phys. B27, 381 (1971); M. Greco, G. Pancheri-Srivastava and Y. Srivastava, Nuclear Phys. B101, 234 (1975);

(7) - B. Esposito et al., Lett. Nuovo Cimento 19, 21 (1977); 25, 5 (1979).

(8) - B. Esposito et al., Lett. Nuovo Cimento 28, 195 (1980).

(9) - G. Cosme et al., Nuclear Phys. B152, 215 (1979); C. Paulot, Thesis, Orsay Report LAL 79/14 (1979).

(10) - B. Delcourt, Proceedings of the Intern. Symp. on Lepton and Photon Interactions at High Energies, Batavia 1979, p. 499.

(11) - B. Esposito et al., Phys. Letters 68B, 389 (1977); C. Bacci et al., Phys. Letters 68B, 393 (1977); G. Barbiellini et al., Phys. Letters 68B, 397 (1977).

(12) - G. Cosme et al., Phys. Letters 63B, 349 (1976).

(13) - V. A. Sidorov, Proceedings of the Intern. Symp. on Lepton and Photon Interactions at High Energies, Batavia 1979, p. 490.

(14) - J. Layssac and F. M. Renard, Nuovo Cimento 6A, 134 (1971).

(15) - G. Penso and T. N. Truong, Phys. Letters 95B, 143 (1980); Nuclear Phys., to be published.

(16) - J. L. Siegrist, SLAC-Report No. 225 (1979).