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C. Bacci, R. Baldini-Celio, G. Capon, C. Mencuccini, G. P. Murtas, G. Penso, G. Salvini, M. Spinetti, B. Stella and A. Zallo: MULTI-HADRONIC CROSS SECTIONS FROM e^+e^- ANNIHILATION AT ADONE IN THE ENERGY RANGE 1.3 - 3.0 GeV.

(Presented at the XVI International Conference on High Energy Physics, Batavia, Chicago, 1972)

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SUMMARY. -

With an apparatus slightly improved respect to the previous one[1] we have studied multihadronic production at the Adone e^+e^- storage ring at a center of mass energy of 3 GeV. The total cross section and the cross sections for reactions $e^+e^- \rightarrow 2\pi^{\pm} + n\pi^0$ and $e^+e^- \rightarrow (a\pi^{\pm} + n\pi^0)$, $a \geq 4$, have been measured, assuming that the particles are pions, and making use of a pure phase space momentum distribution.

Some new data at total c.m. energies below 3 GeV are also reported.

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1. - INTRODUCTION. -

We have studied the reactions

(1) $e^+e^- \longrightarrow$ multihadronic production

at the maximum energy of Adone, which is 3 GeV in the center of mass. New data have been obtained also, with more limited statistics, at a center of mass energy of 1300, 1650 and 1980 MeV.

Our results may be summarized as follows :

- There is a relatively abundant multiple hadronic production at 3 GeV. These events have three or more hadrons in the final state, and neutral pions are present in a large percentage of the cases.
- The total cross section is $\sigma_T = (33 \pm 17) \times 10^{-33}$ cm^2 that is ~ 3 times the total cross section for mu pair production at 3 GeV.
- The new data at lower energies confirm the multihadronic production at all energies.

We give in the following some experimental details and consider some possible interpretations. The apparatus (Fig. 1) is sub-

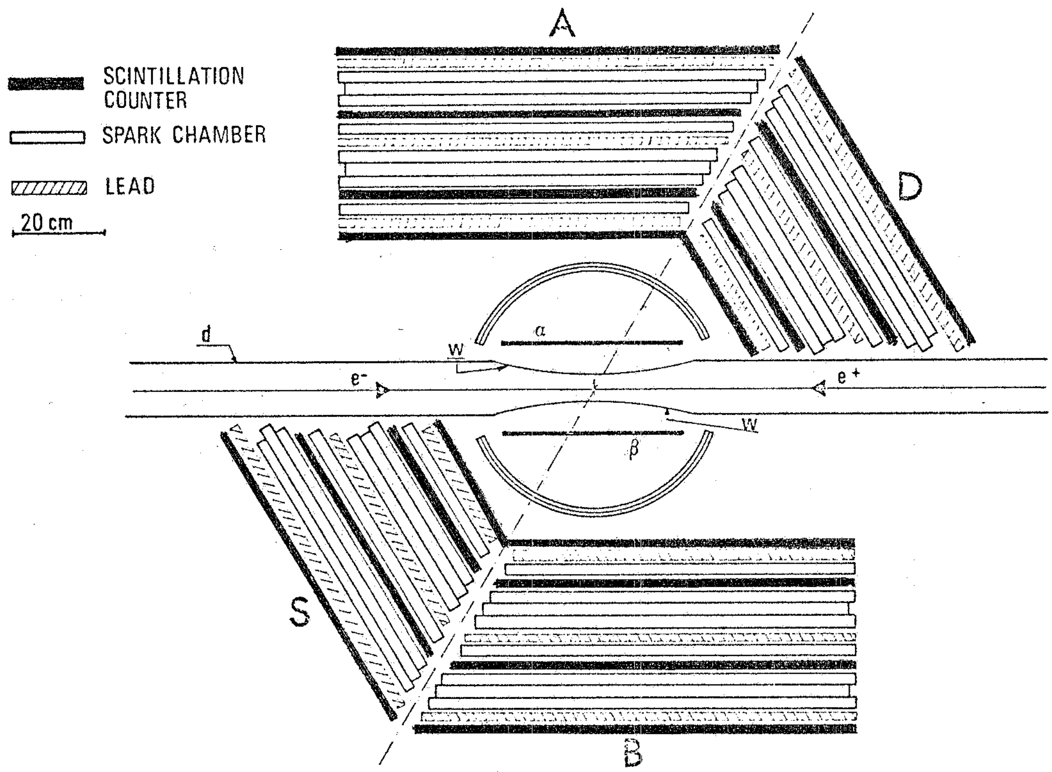

FIG. 1 - Experimental apparatus: front view from Adone center.

stantially equal to the one described in previous papers[1]. It mainly consists of four blocks (A, B, D, S) of scintillation counters, lead converters and spark chambers, above and below the target area, and covers about 0.25 x 4π solid angle. It may detect charged particles with efficiency close to one and γ-rays with an energy dependent efficiency which is typically 80% for an energy $E_\gamma \gtrsim 250$ MeV[2]. A pion (kaon) must have at least 95 MeV (145 MeV) kinetic energy in order to trigger the electronics, and at least 55 MeV (95 MeV) to give a recognizable track in the spark chambers.

The apparatus was triggered whenever at least three tracks or showers had been detected in three of the four blocks A, B, D, S and counters α or β gave a signal (Fig. 1); i.e. one of the particles had to be charged.

2. - DATA HANDLING AND RESULTS AT 3 GeV TOTAL C.M. ENERGY.

Using this trigger we have obtained 63 multiple hadronic events at 3 GeV in the c.m., with a total integrated luminosity of about 125×10^{33} cm^{-2}. These events, as usual in our case, have been distributed in cathegories c (see Table I) according to the number of showers

TABLE I

Distribution of events according to the number of tracks and showers detected at 3 GeV total c.m. energy. T means charged tracks and S neutral shower so that for instance 2T3S means events with 2 charged particles and 3 neutral showers detected. The 63 events correspond to a total luminosity of about 125×10^{33} cm^{-2}.

Cathegory	1T2S	2T1S	2T2S	2T3S	3T	3T1S	3T2S	4T	1T3S	1T4,5S	4T1,2S	5T0,1S
Number of events	5	19	7	2	13	6	1	5	2	0	2	1
												(Tot. 63)

and tracks observed. The luminosity has been measured by using as a monitor the scattering $e^+ + e^- \to e^+ + e^-$ at small momentum transfer[3]. The values of the luminosity are consistent until now with our contemporary results on the less frequent reaction $e^+ + e^- \to \gamma + \gamma$.

By using known arguments,[1] we assume in the following that the multiple events we discuss here are of hadronic nature, with the particles directly produced being pions or kaons. We also assumed that the well known one-photon annihilation channel is the source of these processes.

The other possible sources of multiple events must be considered at 3 GeV with some more attention than at lower energies. In fact the number of events from gamma gamma interactions[4] (that is reaction $e^+ + e^- \longrightarrow e^+ + e^- + \text{hadrons}$) having the necessary configuration to be observed in our spark chambers may become at 3 GeV a not negligible percentage of our results. However, this percentage should not exceed **10 %** in case we assume plausible values for the decay into two gammas of the mesons with C = +1 and even spin. We did not introduce yet any correction for this possible γ-γ channel. We have certainly observed a few events with electrons directly produced, which could be explained by gamma-gamma interactions and which are being analyzed by us.

In order to measure the cross section for multiple hadronic production of 3 GeV c. m. we have assumed that the more relevant processes which contribute to our events may be the following :

(2) $e^+e^- \longrightarrow \pi^+ + \pi^- + n\pi^o$ with $1 \leq n \leq 6$

(3a) $e^+e^- \longrightarrow a\pi^{\pm} + n\pi^o$ with $4 \leq a+n \leq 8$; $a = 4, 6, 8$

(3b) $e^+e^- \longrightarrow 10\ \pi^{\pm}$.

This corresponds to the assumption that disregarding processes with more than 8-10 pions or with kaons does not affect appreciably our final results on the total cross section. This hypothesis sounds to us reasonable, but cannot be strictly demonstrated by our present results.

The cross section at a given energy for the different processes (2), (3) may be in principle obtained, as we already did in previous publications[1], by a system of relations of the type

$$N_c = L_t \, \Sigma_i \, \sigma_i \, \varepsilon_{ic} \qquad (4)$$

where N_c is the total number of the events belonging to the cathegory c of Table I. By L_t we indicate the total luminosity. The cross sections σ_i are those related to the processes listed in (2), (3a), (3b). ε_{ic} is the detection efficiency for events of cathegory c coming from reaction i. In order not to have in the system of equations (4) more unknown quantities than equations, we have grouped together some cross sections (for instance $\sigma(2\pi^{\pm} + 3\pi^o)$ and $\sigma(2\pi^{\pm} + 4\pi^o)$) which from our Montecarlo calculations appear to have similar efficiencies. The efficiencies we have used have been evaluated under the hypothesis of pure invariant phase space momentum distribution.

Following a standard procedure[1] we have looked for the best solution to the relations (4) under the condition that all the σ_i's should be positive or zero. Because of the poor statistics each cross section has a very large error. It seems, however, possible to give a somewhat more reliable value for the sum of the cross sections :

(5) $\sigma(2\pi^{\pm} + n\pi^{0})$ = sum of the cross sections for processes (2)

(6) $\sigma(\geq 4\pi^{\pm})$ = sum of the cross sections for processes (3a) and (3b)

$$\sigma_T = \sigma(2\pi^{\pm} + n\pi^{0}) + \sigma(\geq 4\pi^{\pm})$$ = total cross sections for processes (1).

These cross sections are reported in Table II and shown in Figures 2, 3 and 4.

TABLE II

Total and partial cross sections at different c. m. energies, for processes (1) $e^{+}+e^{-} \rightarrow$ multihadronic production. By σ_T we indicate the total cross section for processes (1). By $\sigma(2\pi^{\pm} + n\pi^{0})$ and $\sigma(\geq 4\pi^{\pm})$ we indicate reactions (2) and (3) respectively. The values for $\sigma(2\pi^{\pm} + n\pi^{0})$ and $\sigma(\geq 4\pi^{\pm})$ average our old and new results.

<table>
<tr><th>Total c. m. energy 2E (GeV)</th><th>σ_T (10^{-33} cm^2)</th><th>$\sigma(2\pi^{\pm} + n\pi^{0})$ (10^{-33} cm^2)</th><th>$\sigma(\geq 4\pi^{\pm})$ (10^{-33} cm^2)</th></tr>
<tr><td>3.0</td><td>33 ± 17</td><td>14 ± 12</td><td>19 ± 7</td></tr>
<tr><td>2.4</td><td>34 ± 12 (±9)</td><td>27 ± 14 (±7)</td><td>7 ± 5 (±2)</td></tr>
<tr><td>2.1</td><td>17 ± 4 (±4)</td><td>8.5 ± 4 (±2)</td><td>8.5 ± 3 (±2)</td></tr>
<tr><td>1.98</td><td>30 ± 14</td><td rowspan="2">15 ± 7</td><td rowspan="2">7 ± 3</td></tr>
<tr><td>1.90</td><td>15.5 ± 4 (±4)</td></tr>
<tr><td>1.65</td><td>36 ± 12</td><td>19 ± 7</td><td>17 ± 7</td></tr>
<tr><td>1.45</td><td>55 ± 15 (±14)</td><td rowspan="2">21 ± 10</td><td rowspan="2">28 ± 12</td></tr>
<tr><td>1.35</td><td>45 ± 23</td></tr>
</table>

The errors indicated contain the pure statistical uncertainty and a reasonable estimate of the width of our possible systematic errors, as due to various sources : uncertainties on the evaluation of the nuclear interactions of the charged particles, on the detection efficiency of the low energy photons, and on the value of the total integrated luminosity.

The total cross section results to be $\sigma_T = (33 \pm 17) \times 10^{-33}$ cm^2, and this must be considered an high value, even if not completely unexpected after previous indications[1, 5] at 2.4 GeV.

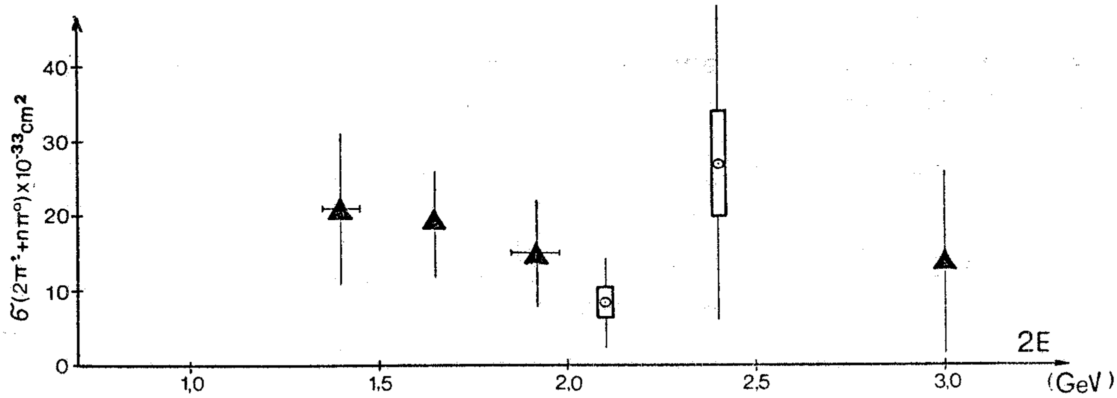

FIG. 2 - Results on $\sigma(2\pi^{\pm} + n\pi^{0})$ as a function of 2E, total energy in the c. m. system. The circle points come from our previous work(1) and the rectangles including them give a reasonable estimate for possible sistematic errors. The triangle points come from our more recent data after a preliminary analysis.

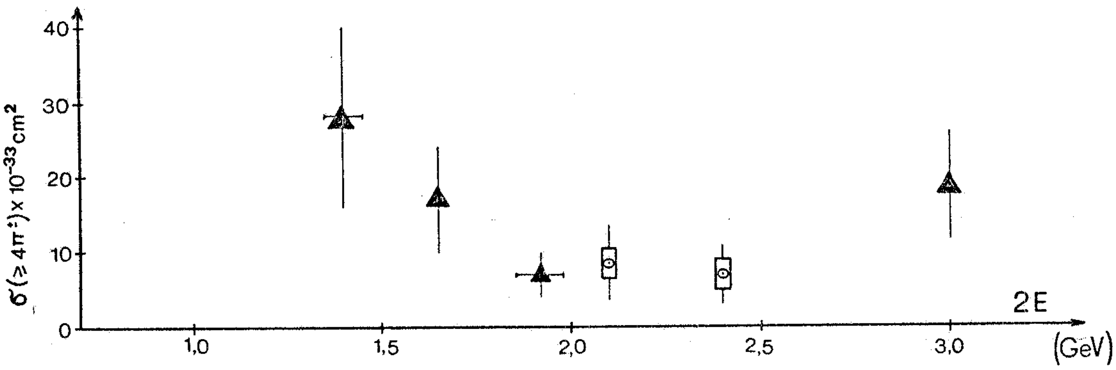

FIG. 3 - Results on $\sigma(\geq 4\pi^{\pm})$ as a function of 2E, total energy in c. m. system. The symbols have the same meaning than in Fig. 2.

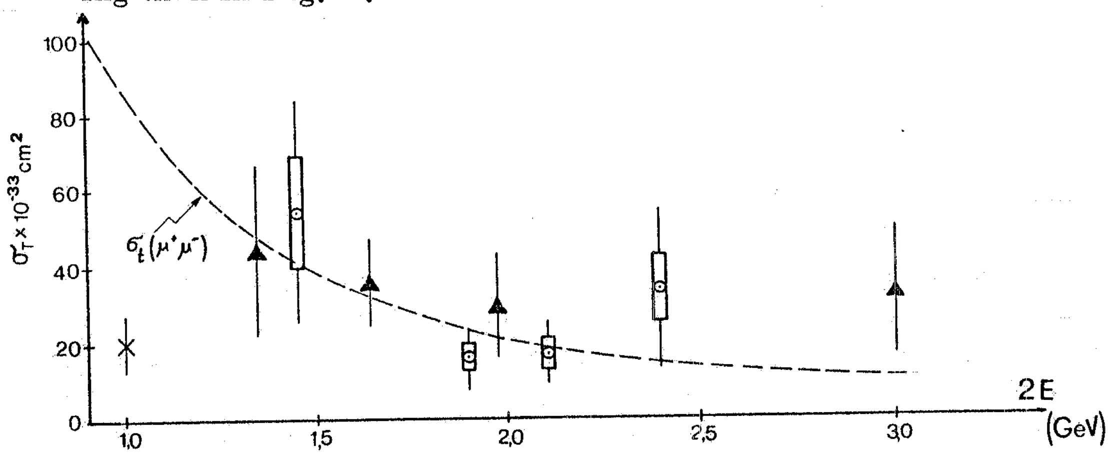

FIG. 4 - Results on the total cross section σ_T, as a function of 2E. The symbols have the same meaning than in Fig. 2. We have added at 2E = 1 GeV the point from ACO. The dashed line indicates the total cross section for the process $e^+e^- \longrightarrow \mu^+\mu^-$.

The value of the cross sections for reactions (3a), (3b) results to be $\sigma(\geq 4\pi^{\pm}) = (19 \pm 7) \times 10^{-33}\ cm^2$. Our pictures tend to show the presence of events with a multiplicity higher than at lower energies. The value of $\sigma(2\pi^{\pm} + n\pi^{o})$ is more uncertain, and from the first analysis of equations (4) we got the value $\sigma(2\pi^{\pm} + n\pi^{o}) = (14 \pm 12) \times 10^{-33}\ cm^2$. We are analyzing the angular distributions of the events with two tracks and one or two showers in order to reduce the uncertainty of this cross section.

3. - RESULTS AT LOWER ENERGIES. -

During the first part of this year, before starting the measurements at 3 GeV, we have taken measurements for multihadronic processes at lower energies. The procedure has been strictly the same already described in our quoted paper(1). The old and new results for the total cross section σ_T at different energies are reported in Fig. 2, 3, 4 and in Table II together with the new results at 3 GeV.

We have again devided our total cross section in the two cathegories $\sigma(2\pi^{\pm} + n\pi^{o})$ and $\sigma(\geq 4\pi^{\pm})$. The statistics are really too small and we have added together the new and old results by regrouping the closest energies.

4. - SOME REMARKS ON OUR VALUES OF σ_T AS FUNCTIONS OF ENERGY. -

We did not examine yet the partial cross sections in order to derive some conclusions, so we discuss here only the total cross section for hadronic production as a function of the c.m. energy, as reported in Fig. 4.

The relevant fact is that the cross sections at 2.4 and 3 GeV appear to be remarkably high. One immediate value for a comparison may be the cross section for muon pair (that is fermion pair) production, which follows rather strictly the 1/s law. As we see in Fig. 4, our values for hadronic production at the highest energies seem to be definitely higher than $(\mu^+\mu^-)$. It will be very interesting to see if the cross section for multiple hadronic production remains high at all energies between 2.4 and 3 GeV. This will help to distinguish between a resonant behaviour and the general hadronic production as connected to the problematic which arose with deep inelastic scattering(6, 7). The models connected with the deep inelastic (jet and statistical models) predict a value $\sigma_T(\text{hadrons}) \simeq \sigma(e^+e^- \to \mu^+\mu^-)$. In the simplest quark model case we should have(7)

$$\sigma_T(e^+e^- \to \text{hadrons}) \simeq 2/3\, \sigma(e^+e^- \to \mu^+\mu^-).$$

This last case seems to be excluded by our recent data. A more recent model by Gell-Mann[8] predicts rather $\sigma_T \simeq 2\,\sigma(\mu^+\mu^-)$. This last case remains possible.

Work is in progress to increase the statistics and to make a detailed kinematical analysis of our events. A new experimental apparatus is under construction.

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We are deeply indebted to the Adone staff for having reached a c.m. energy of 3 GeV with a very smooth and continuous operation of the machine.

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