# Hadronic Cross-Section in e⁺e⁻ Annihilation from 1.45 to 1.80 GeV.

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We present experimental results on the total cross-section for the reaction

(1)                                  e⁺e⁻ → hadrons
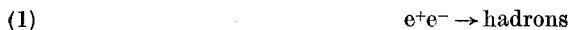
measured with the MEA apparatus at Adone storage ring in the total c.m. energy range
$W = (1.45 \div 1.80)$ GeV.

Results on the cross-sections of some peculiar channels have already been published [1-3].

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The experimental set-up, described in detail elsewhere ([4]), consists of a solenoid (radius 1 m, magnetic field 2 kG) with the axis perpendicular to the $e^+e^-$ beam direction which allows momentum measurement ($\Delta p/p = \pm 0.1$ at $p = 1$ GeV/c) through cylindrically shaped wide-gap spark chambers with thin transparent electrodes (0.15 radiation lengths) and a system of scintillation counters used for triggering and time-of-flight measurements (time-of-flight base 1 m, $= 0.7$ ns). Outside of the coils we utilize a set of heavy-plate narrow-gap spark chambers interleaved with lead and iron plates (8 radiation lengths, 0.8 collision lengths) for particle identification.

To trigger the apparatus two charged particles must penetrate the upper and lower halves of the detector, requiring a kinetic energy of at least 110 MeV, if pions.

The following criteria were applied in the selection ([1,2]): the noncoplanarity angle of the track pairs and the $e^+e^-$ beams and the noncolinearity angle of the track pairs were required to be $> 10°$; the reconstructed vertex point of the event should originate in the $e^+e^-$ interaction region and the event was required to be in time with the bunch-bunch collision.

The results, presented here, are relative to 1090 events, corresponding to a total integrated luminosity $\mathscr{L} = 262.8$ nb$^{-1}$, as measured by wide-angle Bhabha scattering in the apparatus. The data were selected from different categories, according to the number of observed tracks and $\gamma$-rays. The partial exclusive cross-sections for different pion production final states were evaluated by solving for each energy, by a standard likelihood method, the system

$$(2) \qquad \frac{n_k}{\mathscr{L}} = \sum_i \varepsilon_{ki} \sigma_i \,,$$

where $n_k$ is the number of events belonging to th $k$-th categories, $\mathscr{L}$ the collected luminosity, $\sigma_i$ the cross-section of each final state and $\varepsilon_{ki}$ the efficiency for detecting the $i$-th reaction in the $k$-th configuration. The detection efficiencies $\varepsilon_{ki}$ were obtained by Monte Carlo method, assuming that only pions are produced with a phase-space momentum distribution. We assume besides a minimum and maximum multiplicity of three and six pions, respectively: i.e. the two-body final states $e^+e^- \to \pi^+\pi^-$, $K^+K^-$ have not been considered.

In solving the system of eq. (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.

Our results, given in terms of

$$R_{\geqslant 3} = \sum_i \sigma_i(\geqslant 3\pi)/\sigma(e^+e^- \to \mu^+\mu^-)$$

are presented in table I and shown in fig. 1.

([4])   W. W. ASH, D. C. CHENG, B. ESPOSITO, F. FELICETTI, A. MARINI, H. OGREN, F. PERUZZI, M. PICCOLO, F. RONGA, F. SACERDOTI, L. TRASATTI, G. T. ZORN, B. BARTOLI, B. COLUZZI, A. NIGRO, V. SILVESTRINI, F. VANOLI, D. BISELLO, A. MULACHIÉ, M. NIGRO, L. PESCARA, R. SANTANGELO, E. SCHIAVUTA, D. SCANNICCHIO, P. MONACELLI, L. PAOLUZI, G. PIANO-MORTARI and F. SEBASTIANI: *Nucl. Instrum. Methods*, **148**, 431 (1978).

TABLE I.

| $W$ (MeV) | $R_{\geqslant 3}$ | $\langle n_c \rangle$ | $\langle n_0 \rangle$ | $\mathscr{L}$ (nb⁻¹) |
|---|---|---|---|---|
| 1450 ÷ 1475 | 1.68 ± 0.08 | 3.15 ± 0.11 | 1.16 ± 0.06 | 32.0 |
| 1475 ÷ 1500 | 1.98 ± 0.10 | 3.05 ± 0.22 | 1.17 ± 0.14 | 38.6 |
| 1500 ÷ 1525 | 2.23 ± 0.04 | 3.12 ± 0.06 | 1.22 ± 0.06 | 58.4 |
| 1525 ÷ 1550 | 2.41 ± 0.08 | 3.11 ± 0.20 | 1.24 ± 0.14 | 8.9 |
| 1550 ÷ 1575 | 2.30 ± 0.10 | 3.04 ± 0.20 | 1.20 ± 0.16 | 8.6 |
| 1575 ÷ 1600 | 1.98 ± 0.10 | 3.24 ± 0.18 | 1.15 ± 0.09 | 9.3 |
| 1600 ÷ 1625 | 2.07 ± 0.10 | 3.25 ± 0.20 | 1.10 ± 0.14 | 6.3 |
| 1625 ÷ 1650 | 2.04 ± 0.11 | 3.17 ± 0.22 | 1.11 ± 0.11 | 9.9 |
| 1650 ÷ 1675 | 2.43 ± 0.10 | 3.18 ± 0.24 | 1.16 ± 0.10 | 17.2 |
| 1675 ÷ 1700 | 2.31 ± 0.07 | 3.00 ± 0.16 | 1.26 ± 0.08 | 11.3 |
| 1700 ÷ 1725 | 2.21 ± 0.07 | 3.00 ± 0.16 | 1.34 ± 0.07 | 13.2 |
| 1725 ÷ 1750 | 2.13 ± 0.12 | 2.99 ± 0.40 | 1.64 ± 0.20 | 15.0 |
| 1750 ÷ 1775 | 2.07 ± 0.09 | 3.00 ± 0.18 | 1.37 ± 0.09 | 11.4 |
| 1775 ÷ 1800 | 2.06 ± 0.15 | 2.99 ± 0.40 | 1.34 ± 0.21 | 21.6 |

Column 1: total c.m. energy interval on which data have been taken.
Column 2: $R_{\geqslant 3}$ values.
Column 3: $\langle n_c \rangle$ average charged multiplicity.
Column 4: $\langle n_0 \rangle$ average neutral multiplicity.
Column 5: integrated luminosity.
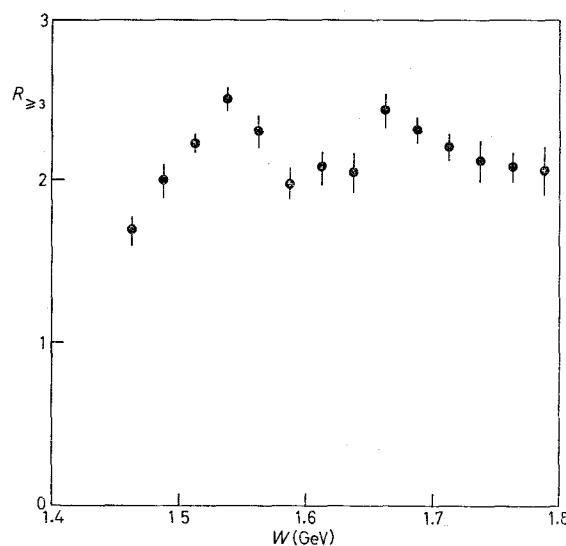


Fig. 1.
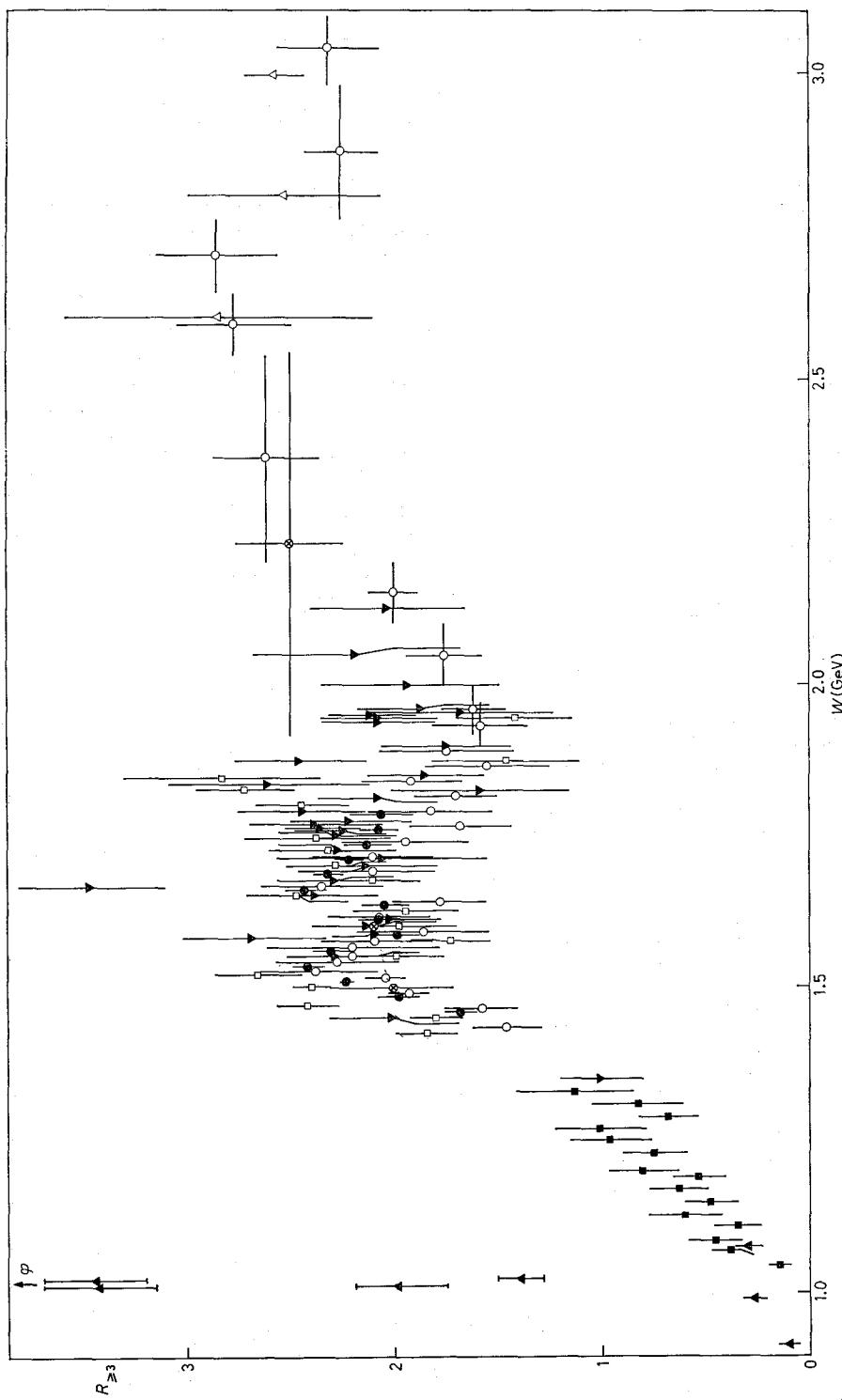
Fig. 2. – ● present experiment, ⊛ Adone-Meₐ ([²,⁷]), ○ Adone-γγ² ([⁸]), □ Adone-B̄B̄ ([⁹]), ▲ ACO-M3M ([⁹]), ▼ DCI-M3N ([¹⁰]), ■ VEPP-2M ([⁵]), ◁ SLAL-LBL ([¹¹]).

The computed cross-sections are clearly model dependent, but Monte Carlo simulations using different models for the dominant channels or assuming kaon production mainly due to the reaction $e^+e^- \to K^*K$ lead to an uncertainty on the $R_{\geqslant 3}$ lower than 15% (*). The quoted errors are statistical only as obtained by solving system (2).

In fig. 2 our data are plotted together with the others already published [1,2,5-11] in the Adone energy region.

The procedure adopted allows one to deduce the charged $\langle n_c \rangle$ and neutral $\langle n_0 \rangle$ multiplicity. The values of $\langle n_c \rangle$ and $\langle n_0 \rangle$ are given in the last two columns in table I and plotted in fig. 3. The solid line in fig. 3a is the best fit of data above 2 GeV from ref. [8]. The straight line in fig. 3b represents the fit to all the $\langle n_0 \rangle$ values reported

$$\langle n_0 \rangle = (1.46 \pm 0.15) \ln W - (0.52 \pm 0.08).$$

Figures 2 and 3 show that our results are in quite good agreement with those already published and summarize moreover all the work done at Adone with the second-generation apparatus ($\gamma\gamma2$, MEA, BB) on the multihadron cross-section.

In the whole energy range $W = (1.0 \div 3.1)$ GeV; the behaviour of $R_{\geqslant 3}$ evidentiates the principal features of the dynamic of the multihadron process.

After a sharp rise between 1.0 and 1.5 GeV, the maximum around 1.6 GeV reflects the existence of the resonant channel $e^+e^- \to \rho(1550)\pi^+\pi^- \to \pi^+\pi^-\pi^+\pi^-$ [2,3,12-14]. The more complicate -and not so clear—structure in the energy region (1.65 ÷ 1.95) GeV indicates the contribution, at the production amplitude, of some observed radial excitation of the $\omega$ and $\varphi$ mesons [3,15-19,22].

(*) The contriubtion coming from possible final states at the production threshold– not accepted by the trigger requirements were not taken into account.

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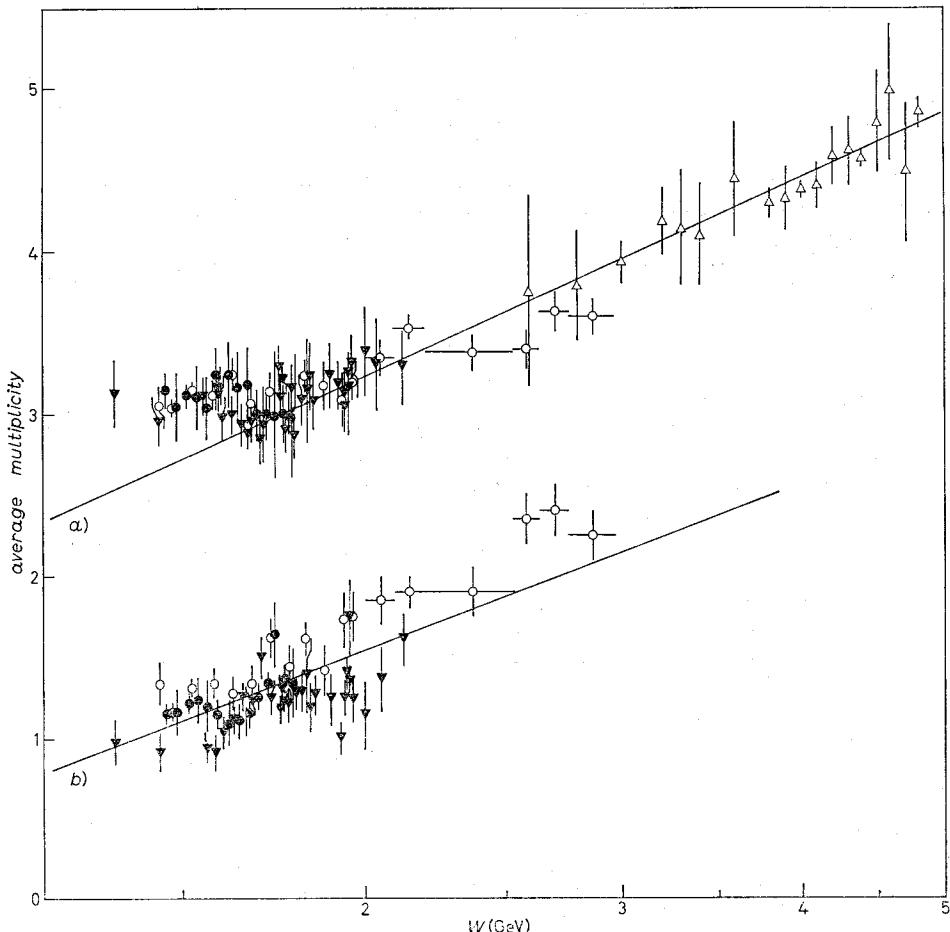
Fig. 3. – • present experiment, ○ Adone-γγ2 [8], ▼ DCI-M3N [10], △ SLAC-LBL [11].

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The step of $R_{\geqslant 3}$ between 2.0 and 2.5 GeV can be interpreted as the full opening of the strange quantum number [7,20-22]. The plateau value $R_{\geqslant 3} \simeq 2.5$ in the $W = (2.5 \div 3.1)$ GeV region is consistent with the quark model prediction.

We conclude stressing that higher-luminosity experiments—with $4\pi$-solid-angle apparatus—are needed to investigate in more detail the contribution of resonant exclusive channels.

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