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TOTAL CROSS SECTION FOR HADRON PRODUCTION BY e^+e^- ANNIHILATION AT PETRA ENERGIES

by

JADE Collaboration

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Abstract

The cross section for the process $e^+e^- \rightarrow$ multihadrons has been measured at the highest PETRA energies. We measure R (the total cross-section in units of the point-like $e^+e^- \rightarrow \mu^+\mu^-$ cross-section) to be 2.9 ± 0.7, 4.0 ± 0.5, 4.6 ± 0.4 and 4.2 ± 0.6 at $\sqrt{s}$ of 22, 27.7, 30 and 31.6 GeV respectively. The observed average multiplicity, together with existing low energy data, indicate a rapid increase in multiplicity with increasing energy.

In this letter we report the first results(1) on the total hadronic cross-section and charge multiplicity obtained with the JADE detector operating at the e^+e^- storage ring PETRA at DESY. An analysis of the hadron production mechanism and the results on QED reactions will be presented in subsequent letters.

For this experiment, PETRA operated at total C.M. energies $\sqrt{s}$ between 22 and 31.6 GeV. Instantaneous luminosities of up to 2×10^{30} cm^{-2} sec^{-1} were obtained with two bunches of e^+ and two bunches of e^- and currents of about 4 mA per bunch.

Fig. 1 shows a sectional view through the JADE detector. A solenoid coil, 3.5 m long, 2 m in diameter and with a 7 cm thick aluminium conductor, produces a uniform magnetic field of 0.5 Tesla parallel to the beam axis. An array of 24 scintillation counters surrounds the beam pipe and a further array of 42 "time of flight" counters is mounted immediately inside the coil. Inside the magnetic field volume is a cylindrical track detector and outside the main solenoid coil is a cylindrical array of lead glass shower counters which in turn is surrounded by an iron return yoke and by a muon filter.

Two small compensating solenoid coils are placed 13 m apart symmetrically about the interaction point. They cancel the effect of the main field on the e^+ and e^- beams.

The trajectories of charged particles are measured in a special type of high-pressure drift chamber, called the "jet chamber" which has been described elsewhere(2). In the range of polar angle $34^\circ < \theta < 146^\circ$ (measured with respect to the direction of the incident positron), 48 points are measured along each track, whereas for polar angles $\theta < 34^\circ$ and $\theta > 146^\circ$ a reduced number of points is measured. At least 8 points on a track are obtained over a solid angle of 97% of the full sphere. At each point, three coordinates, r, ϕ and z are given by the wire position, the drift time and the charge division measurements. dE/dx information, which is used for particle identification, is also obtained. The double track resolution (which is adjustable) was set to 7.5 mm.

The magnet coil is surrounded by 30 rings of lead glass shower counters covering the angular range $35^0 < \theta < 145^0$. Each ring contains 84 glass wedges (Schott SF5) with an inner surface of 85 x 102 mm^2 and a depth of 300 mm (12.5 X_0). These 2520 barrel shower counters, together with the 192 shower counters mounted inside the magnet on the two end caps of the yoke, cover 90% of the full solid angle and serve to detect and measure the energies of photons and electrons.

It should be noted that the inner parts of the JADE detector (hodoscopes, track detector and the shower counters) have rotational symmetry in the azimuthal angle.

The flux return yoke, including the end caps, forms a rectangular box surrounding the cylindrical part of the detector. It is utilized as one of the layers of the muon filter and is followed by three further layers consisting of iron loaded concrete. The total thickness of absorber amounts to a minimum of 785 g/cm^2 (6 absorption lengths), interspersed with 4 or 5 layers of drift chambers which measure the trajectories of penetrating particles with a coverage of 92% of the full solid angle.

Two small detectors, consisting of an array of scintillation counters, drift chambers and lead glass modules record electrons and positrons close to the beam direction ($35 \leq \theta \leq 75$ mrad). They provide an on-line measurement of the luminosity and tag the two photon processes ($e^+e^- \rightarrow e^+e^-$ + hadrons).

Two types of trigger were used for the multihadron events. The "charged particle trigger" required

1) at least two time of flight counters to have fired,
2) total shower energy (sum of the barrel and end caps) to be more than 1 GeV, and
3) at least one track recognized by hard-wired logic based on the hit pattern of the track detector.

The "shower energy trigger" on the other hand, was based exclusively on the energy measurement of the lead glass counters and required a total energy more than 4 GeV. These two triggers have a considerable overlap since more than 95% of the finally accepted multihadron events satisfy both trigger conditions. The data taking rate with these triggers varied between 1 and 5 counts per second depending on the beam conditions.

Multihadron candidates were selected by off-line analysis using the following criteria:

1) At least 2 tracks passing through a cylindrical fiducial volume of radius 3 cm (r-ϕ) and length $\pm$ 40 cm (beam direction z). This volume was chosen to be considerably larger than the size of the interaction region folded with the resolution. To suppress QED and cosmic ray backgrounds, an acoplanarity condition of $> 10^0$ is required for events with only two tracks.
2) Barrel shower energy greater than 2 GeV at $\sqrt{s}$ = 22 GeV and greater than 3 GeV at higher energies, or both end cap shower energies greater than 0.4 GeV.

A data reduction factor of about 5000 was obtained by applying these selection criteria. Surviving events were scanned by at least two physicists independently and checked for the correctness of pattern recognition and the existence of a vertex. Any backgrounds from cosmic rays or showering e^+e^- or $e^+e^-\gamma$ events were removed and any deficiencies in the pattern recognition were rectified. After these visual checks, a further selection of events with at least 4 tracks was made, in order to reduce the background from $e^+e^- \rightarrow \tau^+\tau^-$. The $\tau^+\tau^-$ background was further minimised by rejecting 4 track events if three of the charged tracks were in an opposite direction to the fourth.

The total visible energy and the longitudinal momentum balance were calculated for these events in the following way:

Total visible energy = $E_{vis} = \sum_i E_i$

Longitudinal momentum balance = $B_L = \sum_i p_i \cos\theta_i / E_{vis}$

where the sums are taken over charged particle and shower energies. Particle masses were neglected when calculating energies. The shower energies include the contributions from charged particles (typically 300 MeV per track). Fig. 2a) shows a correlation plot for momentum balance versus total visible energy for data at $\sqrt{s}$ = 27.7 GeV. A cut of $|B_L| < 0.4$ was applied to reduce the backgrounds from beam-gas and two-photon processes. Fig. 2b) shows the visible energy distribution after this momentum balance cut together with the expected background from the two-photon processes. A further cut of E_{vis} > beam energy, eliminated the remaining beam gas background and reduced the level of two-photon events to about 1%. This amount was verified by Monte-Carlo simulation and subtracted. The residual background from $\tau^+\tau^-$ was estimated to be about 2% and also subtracted.

The efficiencies of the trigger and the off-line selections have been determined by Monte-Carlo simulation using a jet model(3) including u,d,s,c,b flavour production. Radiative corrections were applied following the procedure of Bonneau and Martin(4) where the initial e^+,e^- were allowed to radiate photons up to a maximum energy of k_{max} ($= 0.95 * E_{beam}$) and where the decrease in detector efficiency with increasing radiated and undetected photon energy was also taken into account. The efficiency was calculated to be $\varepsilon = 0.82$ (compared to 0.88 without radiative effects) and the radiative corrections, $1+\delta$, were calculated to be 1.21. The product $\varepsilon * (1+\delta)$, which determines the overall correction, is insensitive to the precise value of k_{max} close to the beam energy. To estimate the systematic error in the efficiency determination, two further jet models were used, one with different decay matrix elements for the heavy mesons(5) and the other including gluon effects(6). The efficiencies obtained from the three different jet models agreed with each other to within 5%.

The luminosity was determined from small angle Bhaba scattering detected by the end cap counters in the angular region $14^o < \theta < 24.5^o$. This luminosity measurement agreed with the result obtained from large angle Bhaba scattering to within 3% and with the result from the small angle luminosity monitor within a similar amount.

It should be pointed out that a longitudinal polarisation $P_{\parallel}$ of the beams, if present, would change the observed cross-section for the production of multihadron events by a factor of $(1-P_{\parallel}^2)$, whereas the measured luminosity would remain practically unaffected. An upper limit on this effect can be obtained from the reactions $e^+e^- \to \gamma\gamma$ and $\to$ large angle e^+e^- which are also affected by longitudinal polarisation(7). The differential cross-section measured by JADE(8) agree with QED at all energies within the statistical error and provide an upper limit (95% C.L.) of $P_{\parallel}^2 \leq 0.15$ at $\sqrt{s}$ = 27.7 and 30 GeV and $P_{\parallel}^2 \leq 0.3$ at $\sqrt{s}$ = 22 and 31.6 GeV.

The values for R ($= \sigma_{tot}/\sigma_{\mu\mu}$) are summarised in Table 1 and plotted in Fig. 3 together with published data(9) (see also ref.(10)). The errors are statistical only. The naïve quark-parton model prediction for R assuming only u,d,s,c and b quarks, is R = 11/3 and this is increased to 3.9 by the inclusion of QCD corrections(11). This value is shown in Fig. 3 for comparison purposes together with the additional contribution from the production of a possible charge 2/3 t-quark. There is no evidence in our data for the production of a new quark flavour with a charge of 2/3.

Charge multipilicities were determined for the multihadron events. Jet-like events with the jet axis at a small angle to the incident beam ($\theta < 40^o$) were excluded in order to avoid possible loss of particles in the beam direction. Any e^+e^- pairs from converted photons were also excluded. The resulting average charge multiplicities are given in Table 1 and are plotted in Fig. 4 together with previously published data(12) (see also G. Wolf ref.(10)). The errors quoted are statistical only whereas systematic errors are estimated to be about 1.5. The selection of events with more than or equal to 4 tracks is expected to result in a negligible bias according to the jet model used. It is interesting to note that the simple power law $n \propto s^{1/4}$ proposed by Fermi(13) provides a fair description of the rise in multiplicity as a function of total C.M. energy.

To summarise, the values for R are observed to be nearly constant over the energy range covered by this experiment. The charged multiplicity rises rapidly with energy and no evidence is found for the production of a new quark flavour with a charge of 2/3.

Acknowledgements

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$\sqrt{s}$	Luminosity nb^{-1}	No. of events	R	$<n_{ch}>$
22 GeV	39	21	2.9 ± 0.7	10.1 ± 0.7
27.7	192	89	4.0 ± 0.5	11.6 ± 0.5
30	438	198	4.6 ± 0.4	11.7 ± 0.5
31.6	132	49	4.2 ± 0.6	10.9 ± 0.6

Average (22 - 31.6 GeV) = 4.14 ± 0.26

Table 1

Hadronic cross sections $R(=\sigma_{tot}/\sigma_{\mu\mu})$ and average charge multilicities $<n_{ch}>$ at the specified C.M. energies $\sqrt{s}$.

Figure captions

Fig. 1. Sectional view of the JADE detector.

Fig. 2. a) Scatter plot of longitudinal momentum balance versus visible energy. b) Projection onto the visible energy axis for |momentum balance| < 0.4

Fig. 3. Ratio of hadronic to $\mu^+\mu^-$ cross-sections - R, as a function of $\sqrt{s}$. The predictions with and without a t quark are also shown.

Fig. 4. The average charge multiplicity as a function of $\sqrt{s}$.

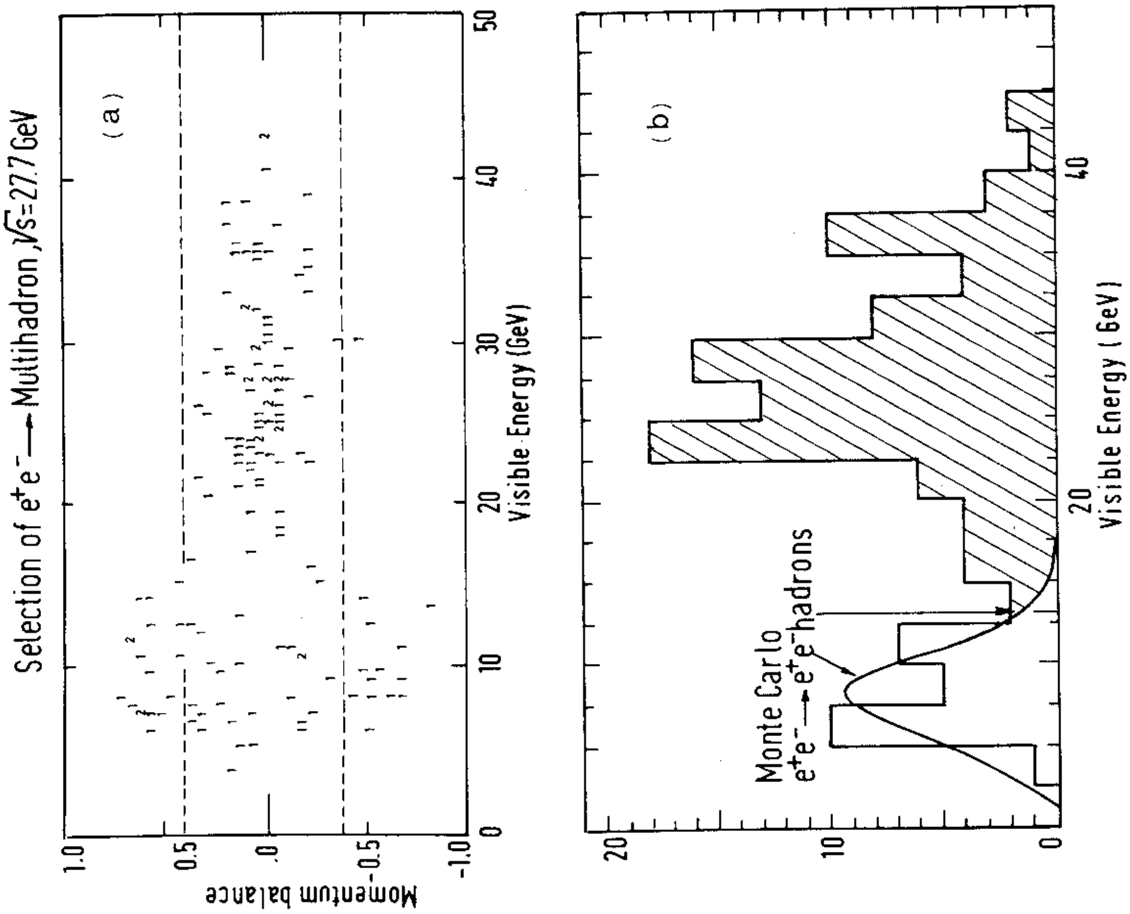

Selection of e+e− ⟶ Multihadron, √s=27.7 GeV
(a)
Momentum balance
1.0
0.5
.0
-0.5
-1.0
Visible Energy (GeV)
0
10
20
30
40
50
(b)
Monte Carlo
e+e− ⟶ e+e−hadrons
20
10
0
Visible Energy (GeV)
20
40

Fig.2

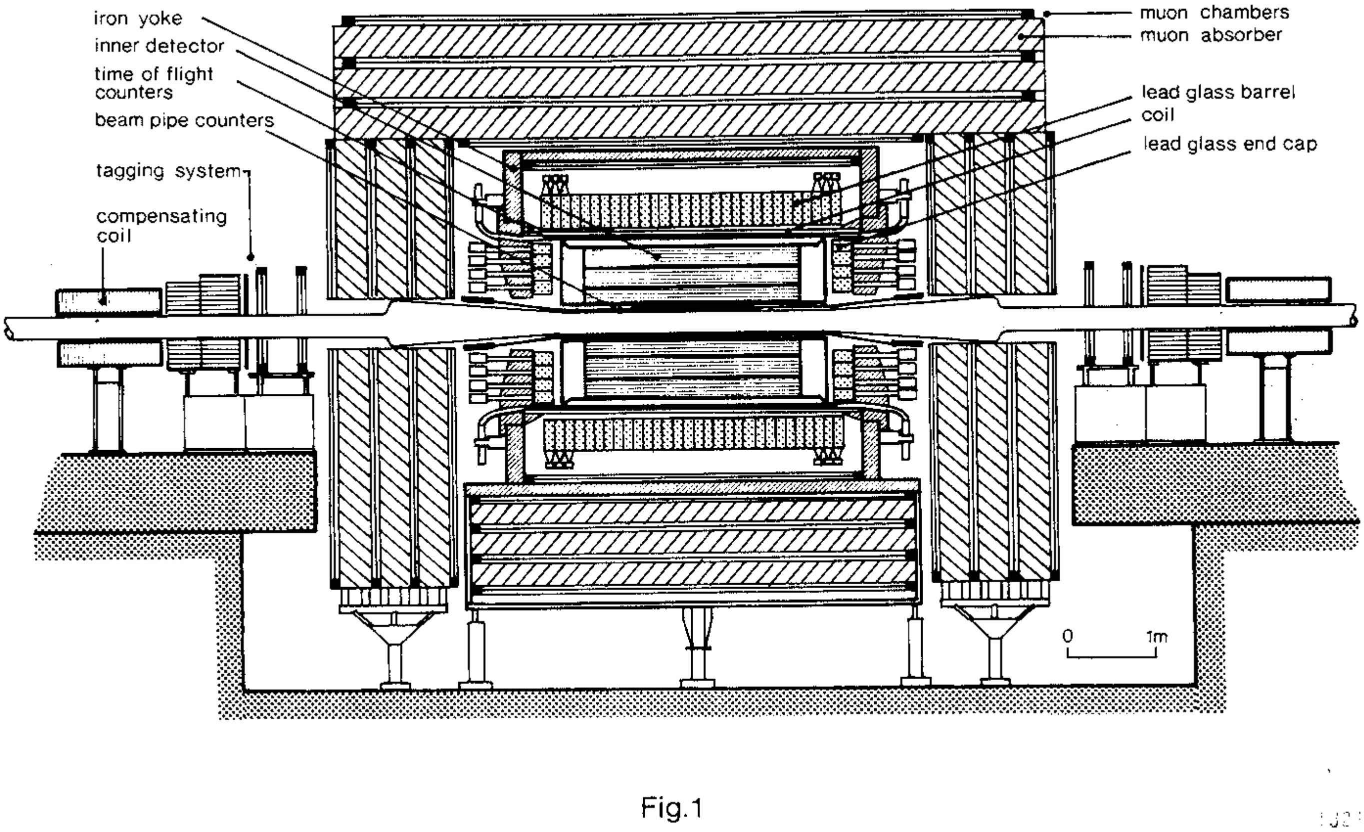
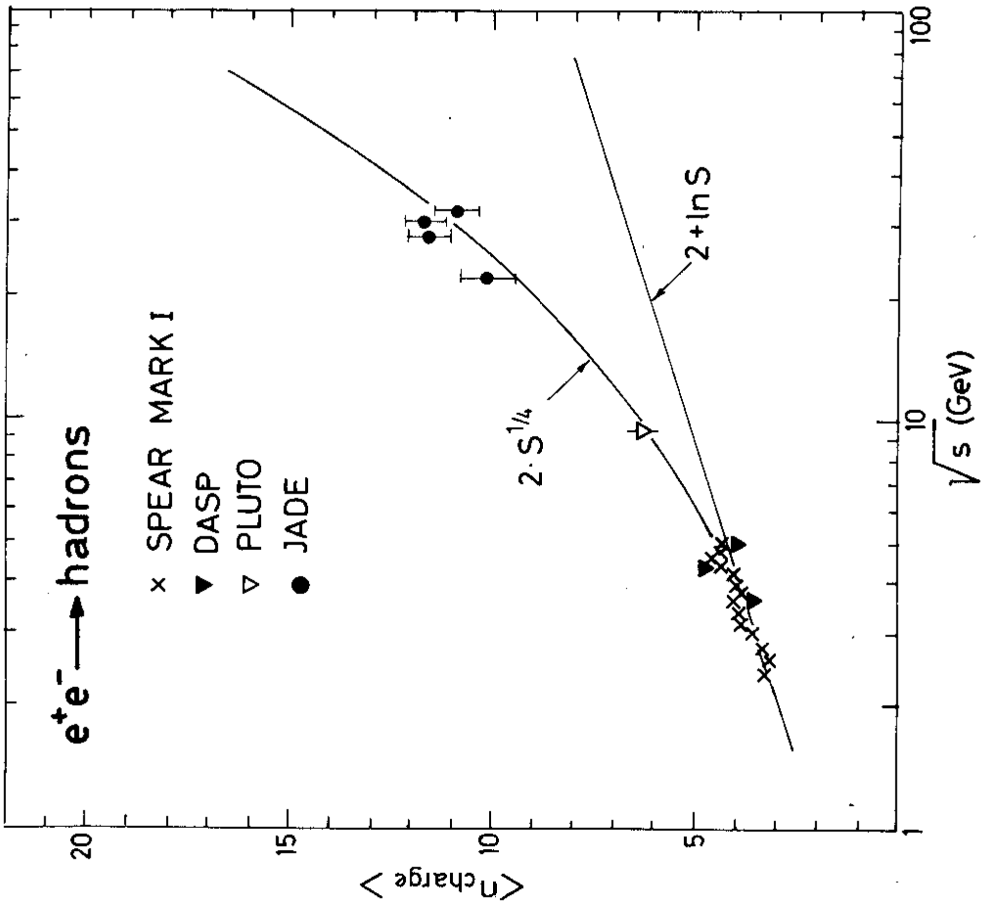
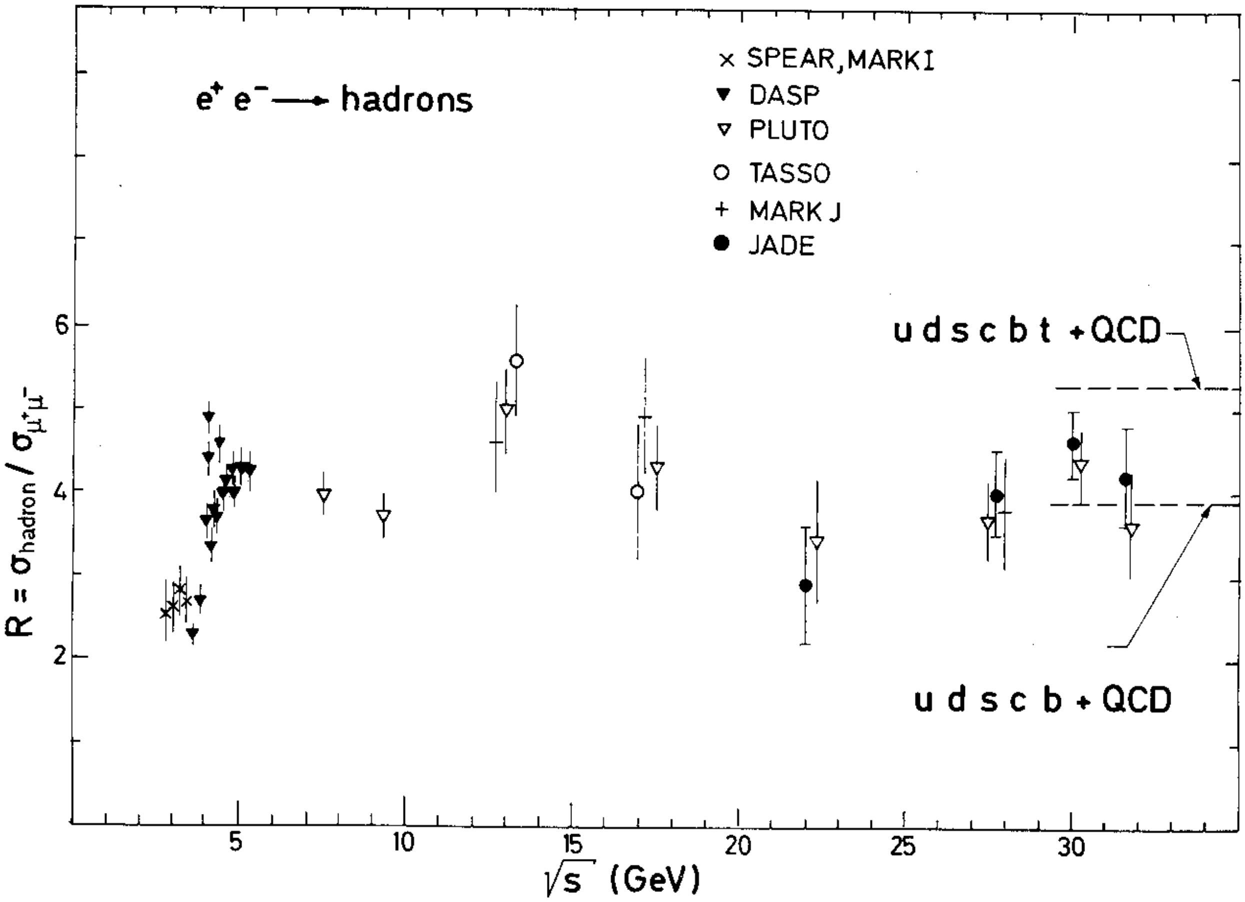

iron yoke
inner detector
time of flight counters
beam pipe counters
tagging system
compensating coil
muon chambers
muon absorber
lead glass barrel
coil
lead glass end cap
0
1m

Fig.1



e+e- ⟶ hadrons
× SPEAR MARK I
▼ DASP
▽ PLUTO
● JADE
2·S^1/4
2+ln S
<n_charge>
20
15
10
5
1
10
100
√s (GeV)

Fig. 4



e+ e- ⟶ hadrons
× SPEAR, MARK I
▼ DASP
▽ PLUTO
○ TASSO
+ MARK J
● JADE
u d s c b t + QCD
u d s c b + QCD
R = σhadron / σμ+μ-
2
4
6
5
10
15
20
25
30
√s (GeV)

Fig. 3