TOTAL CROSS SECTION FOR HADRON PRODUCTION BY e^+e^--ANNIHILATION AT CENTER OF MASS ENERGIES BETWEEN 3.6 AND 5.2 GeV

DASP Collaboration

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The total cross section for e^+e^- annihilation into hadronic final states between 3.6 and 5.2 GeV was measured by the nonmagnetic inner detector of DASP, which has similar trigger and detection efficiencies for photons and charged particles. The measured difference in $R = \sigma_{had}/\sigma_{\mu\mu}$ between 3.6 GeV and 5.2 GeV is $\Delta R = 2.1 \pm 0.3$. We observe three peaks at cm energies of 4.04, 4.16 and 4.417 GeV, the parameters of which, when interpreted as resonances, are given.

The nonmagnetic inner detector of the double arm spectrometer DASP was used to determine the total hadronic cross section for e^+e^--annihilation from a series of measurements performed at center of mass energies between 3.6 and 5.2 GeV. Previously the total cross section has been measured in this energy range by two experiments [1,2] with a precision of 10–15%. The two experiments agree on the general dependence of the cross section but show differences in detail which amount to as much as 30%. It need not be stressed that a precise knowledge of this cross section is of fundamental importance.

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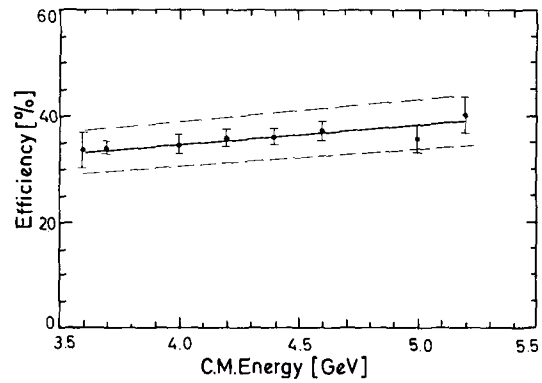

Fig. 1. Detection efficiency versus energy. The straight line interpolation of the experimental data points is indicated together with the estimated error band of ±12%.

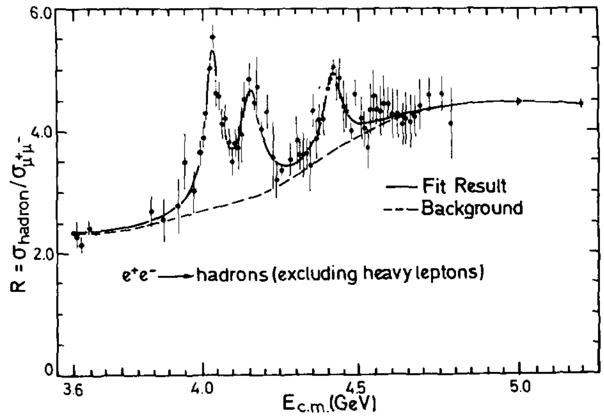

Fig. 2. The ratio $R = \sigma_{hadron}/\sigma_{\mu^+\mu^-}$ without heavy lepton production versus energy. Only statistical errors are indicated. The fit to the data described in the text is indicated and separately the nonresonant background term.

The technique of detection used in the present experiment differs considerably from that of refs. [1] and [2]. We use a nonmagnetic detector which has similar trigger and detection efficiencies for photons and charged particles, whereas the previous experiments triggered mainly on charged particles. Furthermore we determine the detection efficiency of the apparatus to a large extent directly by analysing inclusive particle production measured with the magnetic spectrometer arms of DASP, rather than computing it from a model. Our experiment will therefore have different systematic uncertainties.

The inner detector is mounted between the two magnetic arms of DASP. A detailed description of it can be found in ref. [3]. It is azimuthally divided into eight sectors, six of which consist of scintillation counters, proportional chambers, lead scintillator sandwiches and tube chambers, and the remaining two, facing the magnet aperture, have only scintillation counters and proportional chambers. Each of the six sandwich sectors is split perpendicular to the beam line at the interaction point into two segments. A coincidence sensitive to minimum ionizing particles as well as photons is formed between the various counters of a segment. For a multihadron event trigger at least three of the 12 segments must have fired plus one of the 22 scintillation counters surrounding the beam pipe. To fire a segment a minimum ionizing particle must deposit at least 40 MeV. The trigger efficiency for photons (charged pions) is 95% (86%) for momenta above 400 MeV/c and decreases slowly at lower momenta (63% (50%) at 200 MeV/c and 22% (0%) at 100 MeV/c). The sensitive trigger region covers a solid angle of 57% of 4π, however tracks are recorded over a larger solid angle, 62% for photons and 76% of 4π for charged particles.

Data were collected for a total integrated luminosity of 7500 nb^{-1}, which was determined from small angle Bhabha scattering measured by four identical hodoscopes. The small angle rates are in good agreement with e^+e^-, $\mu^+\mu^-$ production measured by the magnetic part of the detector. The uncertainties of the luminosity measurement are estimated to be less than 5%.

The events were scanned by a computer program for charged tracks as well as "tracks" originating from photon or electron induced showers. To separate hadronic annihilation events from beam gas and cosmic ray background as well as electromagnetic proeesses the following selection criteria were applied.

(a) There are three or more tracks (where photons are also counted as tracks).

(b) At least two tracks have hits in more than 5 of the proportional or tube chamber planes and point within ± 10 cm to the interaction point. (There are 12 or 15 planes depending on the sector, but only 6 proportional chamber planes in front of each of the magnet gaps.)

(c) No two tracks are collinear to within 9°.

(d) There is at most one showering charged track.

(e) Not all tracks lie in only the forward or backwarc

Table 1
Resonance parameters of the best fit described in the text and shown in fig. 2. The errors include statistical effects, the uncertainties of the detection efficiency, and some coarse estimate of interference between the resonance amplitudes.

Mass (MeV)	Γ_{tot} (MeV)	$\Gamma_{e^+e^-}$ (keV)
4040±10	52±10	0.75±0.15
4159±20	78±20	0.77±0.23
4417±10	66±15	0.49±0.13

hemisphere measured along the beam direction.

Events selected by these criteria are almost free of beam gas or cosmic ray background. From the time of flight measured between the outermost scintillation counters of the inner detector we estimate the background due to cosmic ray events to be less than 2%. The beam gas background is estimated from the measured distribution of vertex points. A vertex is determined by a three dimensional fit to all tracks. The vertex distribution shows a clear peak at the interaction point. From the events distributed along the beam line the beam gas background was found to be 3–5% and subtracted from the data.

The background due to higher-order electromagnetic processes ($e^+e^- \to L^+L^-\gamma$, $e^+e^- \to e^+e^-L^+L^-$, where L stands for electron or muon) and $e^+e^- \to e^+e^-$ + hadrons should mainly show up in the three track events, which were found to account for only 5.5%–8.5% of the hadronic events. Less than 1% showed two charged and one photon track. Searching in our data sample at 5.0 and 5.2 GeV for three electron events (from the reaction $e^+e^- \to e^+e^-e^+e^-$) 19 candidates were found compared to 14000 multihadron events. These 19 candidates were rejected by selection criterion (d), however. Other two photon processes can be safely neglected since their cross section is small compared to $e^+e^- \to e^+e^-L^+L^-$ [4].

The largest correction to be made was for the detection efficiency, which is about 40% per hadronic event. To determine this efficiency, use was made of the fact that the inclusive trigger of the magnetic spectrometer arms of DASP described in ref. [5] works in parallel and independent of the trigger used in the present experiment. Therefore hadronic annihilation events, which are identified as inclusive events by the outer detector (N_{tot}^{incl}) have a subsample ($N_{multihadron}^{incl}$),

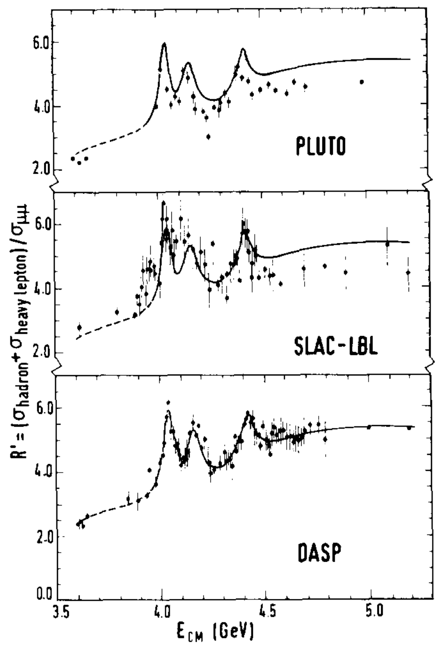

Fig. 3. The data on $R' = (\sigma_{hadron} + \sigma_{heavy\ lepton})/\sigma_{\mu^+\mu^-}$ together with the results of the SLAC–LBL and PLUTO groups. The heavy lepton contribution plus the fitted curve of fig. 2 is, for comparison, drawn in each data set. Our data are insufficient to resolve structure between 3.70 and 4.0 GeV.

which also fulfills the trigger conditions and software cuts mentioned in the beginning. The efficiency in first approximation is determined by the number of events in this subsample normalized to the total inclusive events

$$\epsilon_{exp}^{incl} = (N_{multihadron}^{incl}/N_{tot}^{incl})_{exp} . \quad (1)$$

The experimentally determined efficiency must be corrected for the fact that we consider only events with a charged pion or kaon pointing into the magnetic part of the detector. For this an extensive Monte Carlo program was set up, which closely simulated the detector. Final states containing pions, kaons and nucleons were generated to reproduce the inclusive data of ref. [5] and charged particle multiplicities of ref. [6]. The production of charmed mesons including its semileptonic decays and pair production of the sequential heavy lepton τ with a mass of 1.8 GeV was taken into account for $E_{cm} > 3.6$ GeV. The various decays of the heavy lepton were chosen according to refs. [7,8]. The

Monte Carlo results, which are in reasonable agreement with the various measured distributions were used to determine the correction to ϵ_{exp}^{incl}. Considering only final states which fulfill the inclusive trigger condition we calculate in analogy to eq. (1) ϵ_{MC}^{incl}, which agrees to within 10% with ϵ_{exp}^{incl}. Taking all final states we determine the Monte Carlo efficiency of the inner detector,

$$\epsilon_{MC} = (N_{multihadron}/N_{tot})_{MC} \; . \tag{2}$$

The calculation yields an ϵ_{MC} for heavy lepton events, which is about three times less than ϵ_{MC} for real hadronic events. Since the heavy lepton production should not be counted in the total hadronic cross section we subtract the small heavy lepton contribution (< 10%) from the uncorrected data and consider only real hadronic events for eq. (2), hence we restrict ourselves to real hadron production. The experimental efficiency of the inner detector can than be written as

$$\epsilon_{exp} = \epsilon_{exp}^{incl} \cdot (\epsilon_{MC}/\epsilon_{MC}^{incl}) \; . \tag{3}$$

The ratio in the brackets amounts to only about 1.07. This value was found to be insensitive to the specific parameters of hadron production such as jet versus phase-space production or charged and neutral multiplicities. ϵ_{exp} is shown in fig. 1 as a function of E_{cm}. Since ϵ_{MC} is smoothly varying with energy even at charm threshold, we averaged over wider energy bins in order to reduce the statistical errors. The final efficiency correction was done with a straight line interpolation of the experimental data. This line is also shown in fig. 1 together with its estimated uncertainties of about 12%. Radiative corrections were applied following the procedure of Bonneau and Martin [9] taking into account that the detection efficiency decreases with increasing photon energy. The corrections ranged from −6% (3.6 GeV) to +13% (4.04 GeV).

The hadronic annihilation cross section normalized to the $\mu^+\mu^-$ cross section is shown in fig. 2. Only statistical errors are indicated. The additional normalization uncertainty is estimated to about 15%. The difference in R between 5.2 GeV and 3.6 GeV is ΔR = 2.1 ± 0.3. We observe three peaks centered around 4.04 GeV, 4.16 GeV and 4.42 GeV. The data are insufficient to resolve structure between 3.70 and 4.0 GeV [1,10,11]. If the three peaks are assumed to be resonances and if the simplifying assumption is made that the cross section can be described by an incoherent sum of Breit–Wigner resonances σ_r^i and a nonresonant background σ_b, we find resonance parameters listed in table 1. More precisely:

$$\sigma_r^i = \frac{3\pi}{s} \cdot \frac{\Gamma^i_{e^+e^-} \cdot \Gamma^i_{tot}}{(\sqrt{s} - M_r^i)^2 + (\Gamma^i_{tot}/2)^2} \; , \tag{4}$$

$$\sigma_b = \sigma(3.6) \cdot \frac{(3.6\,\mathrm{GeV})^2}{s} + \sum_{k=1}^{6} A_k \cdot \beta_k^3 \cdot F^2/s \; , \tag{5}$$

where k = 1 to 6 indicates the $D\bar{D}$, $D\bar{D}^*$, $D^*\bar{D}^*$, $F\bar{F}$, $F\bar{F}^*$ and $F^*\bar{F}^*$ threshold respectively; A_k are free parameters; β_k is the velocity of the relevant particles and F is a form factor chosen as $F = (1 - s/(3.1)^2)^{-1}$ [12] [‡1].

The charmed meson masses have been taken from refs. [10,13]. The best fit curve yielding the parameters of table 1 is indicated in fig. 2 together with its background term only. Adding the Breit–Wigner amplitudes coherently we obtained slightly different results. The errors quoted in table 1 include this effect in addition to the statistical ones and the uncertainties of the detection efficiency.

In fig. 3 we compare our data with the results of the SLAC–LBL collaboration and the PLUTO group. Since these groups did not separate the heavy lepton contribution, we added in fig. 3 the heavy lepton cross section to our data shown in fig. 2. Our data agree with those of PLUTO reasonably well in shape but exceed their cross sections by about half a unit in R above 4 GeV. In magnitude our data are in closer agreement with those of SLAC–LBL but show some differences in the finer details of the energy dependence. For instance the 4.16 structure is not resolved in the SLAC–LBL data. Furthermore, while the two experiments agree on the position of the 4.41 structure, its total width measured by SLAC–LBL is smaller than ours (Γ = 33 ± 10 MeV compared to 66 ± 15 MeV). Despite of these discrepancies, the differences observed between the three experiments are within the systematic errors quoted.

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[‡1] This form factor ansatz is certainly oversimplified. See Gottfried [13].

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