MUON PAIR PRODUCTION BY e⁺e⁻ ANNIHILATION AT THE 3100 MeV RESONANCE

DASP Collaboration

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We report results for μ pair production in e⁺e⁻ collisions at the 3100 MeV resonance. We find a resonance cross section, integrated over total energy of 1240 ± 140 nb-MeV implying $\Gamma_{\mu\mu}\Gamma_{ee}/\Gamma_{tot} = 0.51 \pm 0.09$ keV. The angular distribution is consistent with $\sim(1 + \cos^2\theta)$. No forward-backward asymmetry is observed.

The production of μ pairs in e⁺e⁻ collisions has been measured at the 3100 MeV resonance [1, 2] using the Double-Arm-Spectrometer (DASP) at the DESY storage ring DORIS. In contrast to our previously reported [3, 4] results on the e⁺e⁻ and neutral decay modes measured in this experiment using the inner detector, the μ pair production was studied with the two magnet arms of DASP.

The storage ring DORIS was run in the 480-bunch mode with electron and positron currents between 120 and 220 mA at a typical luminosity of 2×10^{29} cm⁻² s⁻¹. The beam lifetime was greater than 5 hours. The energy setting of the rings was constantly monitored by a Hall probe and a nuclear magnetic resonance probe measuring the magnetic field in a separate but identical bending magnet powered in series with the ring magnets. Reproducibility of the beam energy at the 3.1 GeV resonance was ~0.2 MeV.

Fig. 1 shows the layout of the double-arm spectrometer. There are two large H-magnets of opposite polarity (maximum magnetic field length 1.8 T·m each) on either side of the interaction point. Part of the return flux flows through iron plates which connect the two magnets on top and bottom. The inner detector [3, 4] is situated between the magnets. A charged particle emitted at the interaction point passes through the following detectors before reaching the magnet gap: a scintillation counter S_0 close to the beam pipe, a second scintillation counter which starts the time of flight measurement, two proportional chambers, (3 planes per chamber, 2 mm wire spacing) a third scintillations counter used for triggering and a wire spark chamber with magnetostrictive readout (2 planes, 1 mm wire spacing). Behind the magnet are 6 wire
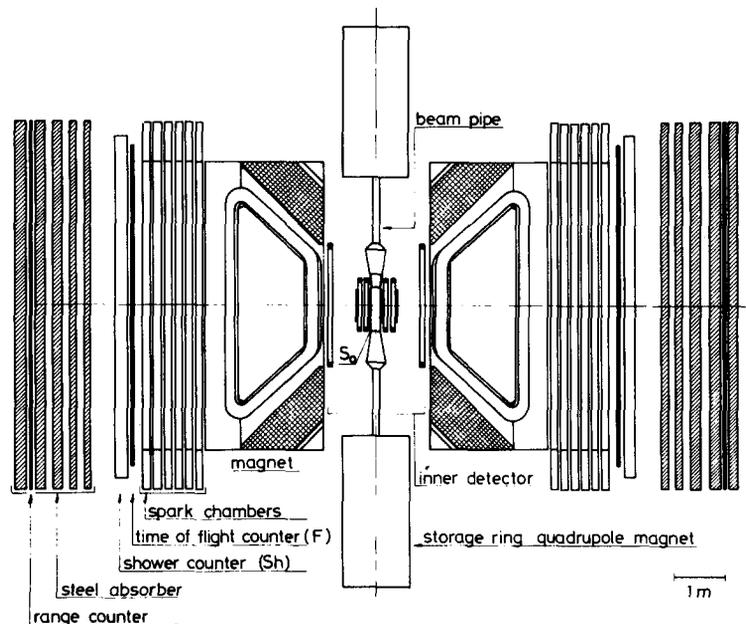
Fig. 1. Schematic view of the Double Arm Spectrometer (DASP) showing the two identical magnetic arms of the apparatus. Most of the inner detector has been omitted from the figure.

spark chambers (2 planes, 1 mm wire spacing, 5.60 by 1.70 m^2 sensitive area), a wall of 31 time of flight counters (F), a wall of 11 shower counters (Sh) (lead scintillator sandwich with 6.2 X$_o$), iron plates with a total thickness of 90 cm and finally a set of 9 scintillation counters ("range" counters). The iron is subdivided into plates of different thickness in order to allow for an optimal choice of iron thickness for pion/muon separation at a given particle momentum. The data were taken with 70 cm of iron corresponding to a minimum muon momentum of ~1 GeV/c.

The useful acceptance of one magnet is 48° to 132° in polar angle and ± 9° in azimuth giving a solid angle of 2 × 0.45 sterad for the two magnets. For the range counters the azimuthal acceptance is the same while the accepted polar angular range for 1.5 GeV/c momenta is 53° to 108° or 72° to 127° depending on the charge of particle and the magnet polarity. This allowed measurement of the angular distribution for μ pair production in the interval $-0.6 < \cos\theta < 0.6$.

A small on-line computer collected event data, and sent them to a central computer for recording on disk and magnetic tape. Event reconstruction was done off-line.

The trigger for production of pairs of charged par-

ticles was defined as the coincidence $(S_o \cdot F \cdot Sh)_{arm1}$ × $(S_o \cdot F \cdot Sh)_{arm2}$. Events satisfying this trigger requirement were collected concurrently with events for other trigger conditions, such as $e^+ e^-$ production in the inner detector [3, 4] and inclusive particle production.

The luminosity was determined from 8-degree Bhabha scattering measured in four identical scintillation-shower counter hodoscopes. The absolute normalization was established from runs outside the resonance region by comparing the large angle Bhabha rate in the inner detector with the prediction of quantum electrodynamics [3].

Data were taken at the 3.1 GeV resonance for an integrated luminosity of 55 nb^{-1}. An additional 19 nb^{-1} were run off the resonance for comparison with QED. The measurements at the resonance were done by frequently stepping over the resonance energy. In order to minimize systematic effects and to increase the accepted range in polar angle the experiment was run with both magnet polarities.

A total of 344 μ-pair events were found in the resonance region (3086.4 to 3093.6 MeV) satisfying the following criteria:

1) the pair trigger was set;
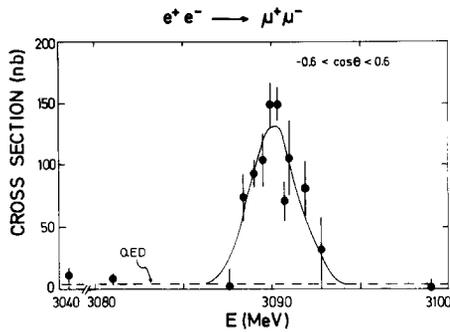
Fig. 2. The energy dependence of the observed cross section for production of collinear muon pairs with $|\cos\theta| < 0.6$ corrected for the azimuthal angular acceptance. Errors are statistical only. The dashed line indicates the prediction of quantum electrodynamics. No correction has been made for radiative effects.

2) at least one range counter fired;

3) the geometrical reconstruction yielded one track in each spectrometer arm of opposite charge.

4) the angular difference between the two tracks was less than 0.15 radians in both projections.

5) the production vertex was within ± 5 cm of the nominal interaction point.

Further cuts on time of flight, track momentum, and vertex position were unnecessary, since their distributions proved that background from cosmic rays and beam gas interactions was already negligible. A study of events where range counters on both, on one or on neither side fired revealed that the contamination of the $\mu^+\mu^-$ sample by hadron-hadron events was completely negligible.

Fig. 2 shows the observed μ pair production cross section for $\cos\theta$ between -0.6 and 0.6 normalized to an azimuthal acceptance of 2π as a function of the total CMS energy E. It has been corrected for inefficiencies of the spectrometer and track reconstruction. The errors shown are only statistical. The expected $\mu^+\mu^-$ production cross section from QED is indicated by the dashed line.

The angular distribution for μ pair production averaged over the resonance region is given in fig. 3. The angle θ is the polar angle between the e^+ and μ^+. The errors given are statistical only. The angular distribution is seen to be consistent with a behaviour $\approx (1 + \cos^2\theta)$ expected for a spin-one state. A fit to $d\sigma/d\Omega = c\,(1 + a\cos^2\theta)$ gives $a = 0.4 \pm 0.6$.
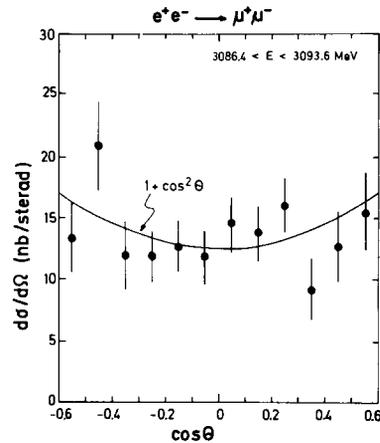

Fig. 3. The angular distribution for $e^+e^- \to \mu^+\mu^-$ for events in the region of the 3.1 GeV resonance. The curve represents the prediction of a $1 + \cos^2\theta$ decay angular distribution. Errors are statistical only. Data corrected for the azimuthal angular acceptance. No correction has been made for radiative effects.

We do not observe any forward-backward asymmetry, the experimental number being

$$\frac{F-B}{F+B} = 0.01 \pm 0.11.$$

This excludes the possibility that the 3.1 GeV resonance is a weak vector boson with pure V-A coupling to leptons and $g_V = g_A$. In this case neglecting the QED contribution the angular distribution would have been of the form $(1 + 2\cos\theta + \cos^2\theta)$ yielding $(F - B)/(F + B) = 0.537$.

The integral over the resonance contribution was obtained by fitting the data to a Gaussian term plus the QED cross section. The integral was then multiplied by 1.39 to correct for radiative processes in the initial state [5]. A behavior of $(1 + \cos^2\theta)$ was assumed in order to extrapolate the polar angular distribution over the full angular range. We find

$$\int \sigma_{\mu\mu}\, dE = 1240 \pm 230 \text{ nb-MeV},$$

which leads to

$$\frac{\Gamma_{\mu\mu}\Gamma_{ee}}{\Gamma_{tot}} = \frac{M^2}{6\pi^2}\int \sigma_{\mu\mu}\, dE = 0.51 \pm 0.09 \text{ keV}.$$

The errors given include statistical effects and uncertainties in the event selection, luminosity, and acceptance.

The width for decay into μ pair is equal, within experimental error to the rate for e^+e^- scattering obtained from the inner detector[‡]:

$$\int \sigma_{e^+e^-} \, dE = 965 \pm 141 \text{ nb-MeV}$$

and

$$\Gamma_{ee}^2/\Gamma_{tot} = 0.41 \pm 0.06 \text{ keV}.$$

We thank all the engineers and technicians of the

[‡] The increase of $\int \sigma_{e^+e^-} \, dE$ over the value given in ref. [3] is due in part to the effect of increased data, and to the fact that the numbers given here include the correction factor 1.39 for radiation effects in the initial state [5], while the published numbers of ref. [3] did not.

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