EVIDENCE FOR HEAVY LEPTONS FROM ANOMALOUS μe PRODUCTION IN e^+e^- ANNIHILATION

PLUTO-Collaboration

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Events of the type $e^+e^- \to \mu^\pm + e^\mp$ + "nothing" have been observed in the magnetic detector PLUTO at the storage ring DORIS at DESY. The data support the hypothesis of the pair production of heavy leptons, and allow to determine decay parameters. Decay rates into muons and electrons are equal within error, and argue for a new lepton number of the heavy lepton.

In order to verify the interpretation of the anomalous muon events reported in the preceding letter [1], we have investigated specific final states. Events containing one muon and one electron are of particular importance [2], because they discriminate best between the origin from pairs of sequential heavy leptons [3], which produce only undetectable neutrinos in addition, and other sources like the production and semileptonic decays of charmed mesons. μe events have earlier been found and interpreted as originating from the decay of heavy leptons [2]. We have observed μe + "nothing" events which are rather free of background, and which add new information to the interpretation.

Data taking and the selection of anomalous muon events has been described in the preceding letter. Electrons are identified by the showers they produce in two lead converters, 0.44 and 1.7 R.L. thick, which are inserted in between the cylindrical proportional chambers of PLUTO. Electron identification is possible in 55% of 4π. The efficiency has been determined from converted photons and from $e^+e^-\gamma$-events. It rises smoothly from 20% at 300 MeV to a roughly constant level of 80% above 700 MeV. The probability for misidentifying a hadron as electron has been determined from purely hadronic decays of the J/ψ (3.1) resonances as $3.5 \pm 0.7\%$. The lead converters as well as the material of the beam pipe and track detector also constitute an efficient photon converter. The photon detection efficiency is about 80% for $|\cos\theta| < 0.55$, and drops to $\approx 50\%$ at $|\cos\theta| = 0.87$ (θ = angle between momentum vector and beam).

The results of the μe search are displayed in table 1. Between 4 and 5 GeV CMS energy 23 events μe + "nothing" were found, (9 $\mu^\pm e^-$, no $\mu^\pm e^\pm$). 2 ± 0.5 events are estimated as faked by misidentified hadrons, leaving 21 ± 5 genuine μe events. No such events were observed at 3.6 GeV. The μe cross section is shown in fig. 1, together with that of the inclusive twoprong and multiprong events [1]. All three show a similar

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Table 1
Cross sections are given for muon momenta >1 GeV/c, and have been corrected for trigger and detector acceptance, and, if applicable, for electron and photon detection efficiency. Hadron punchthrough and QED have been subtracted.

CMS-energy	3.6	4.0–4.3	4.3–4.8	5.0	4.0–5.0	GeV
Int. Luminosity	613	1660	2037	1384	5081	nb^{-1}
$e^+e^- \to e^{\pm}\mu^{\mp}$ + nothing						
Events	0	3	9	11	23	
Hadr. background	0	0.4	0.9	0.6	1.9	
Cross section	<30	13± 8	32 ± 12	61 ± 19	33 ± 8	pb
$e^+e^- \to \mu^+\mu^-$ + nothing						
Events	0	0	1	5	6	
Hadr. background	0	0.1	0.2	0.2	0.4	
Cross section	<29	<11	3 ± 4	27 ± 12	8 ± 4	pb
$e^+e^- \to \mu^{\pm}e^{\mp} + n\cdot\gamma$						
Events	0	0	0	4	4	
Hadr. background	0.1	0.34	0.76	1.0	2.1	
Cross section					5 ± 5	pb
$e^+e^- \to \mu^{\pm}e^{\mp}$ + ($\geqslant 1$ charged track)						
Events	0	0	2	5	7	
Background	0.0	1.6	3.0	3.7	8.3	
Cross section					−2 ± 3	pb

threshold behaviour and, in addition, consistent distributions of the muon momenta. We therefore conclude that the μe events originate from decays of the same heavy lepton L (mass M(L) = 1.9 GeV/c^2 in case of V−A decay, 1.8 GeV/c^2 for V + A, see [1]) as the inclusive muons.

Comparing the cross sections for μe + "nothing" and inclusive muons [1] we obtain the branching ratio into electrons

$$\mathrm{BR(e)} = \begin{cases} 0.14 \pm 0.04 & (\mathrm{V-A}) \\ 0.13 \pm 0.04 & (\mathrm{V+A}) \end{cases}$$

Within errors this value is equal to our measured BR(μ) [1]. Equality of both is predicted for the decays of a "sequential" heavy lepton with a new lepton quantum number, being associated with a neutrino different from the known ν_e and ν_μ. For paraleptons [4] on the other hand which have the same lepton number as the electron (or μ) of opposite charge, one expects a ratio BR(e)/BR(μ) = 2 (or 0.5). Our result

$$\mathrm{BR(e)/BR(\mu)} = \begin{cases} 0.92 \pm 0.37 & (\mathrm{V-A}) \\ 0.67 \pm 0.28 & (\mathrm{V+A}) \end{cases}$$

is compatible with a new lepton number and excludes the "paraelectron" assignment.

We have observed 6 events of the type $\mu^+ + \mu^-$ + "nothing" with large missing mass, consistent with the number expected from heavy lepton decays.

A consistency check is given by the electron momentum spectrum as shown in fig. 2. The solid curve is calculated from V−A 3-body decay as above, the electron detection efficiency, and the distribution of the CMS energies. The measured spectrum agrees with this curve, and is incompatible with the electron spectrum expected [5] and measured [6] in the decay of charmed mesons.

The μe events are characterized by a high missing mass ($MM^2 > 3$ GeV^2 for 20 out of 23 events) and a large missing energy, typically more than half of the available CMS energy. We have investigated whether this energy is carried away by charged particles or pho-

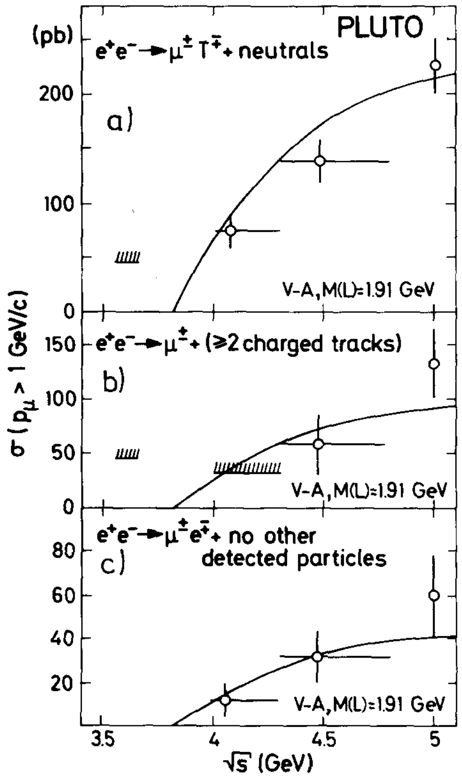

Fig. 1. CMS energy dependence of muon cross sections: 1a): inclusive twoprongs (muon + charged track ($T^\pm$) + neutrals) [1], 1b): inclusive multiprongs, and 1c): exclusive μe events. Cross sections are given for muon momenta > 1 GeV, and have been corrected for trigger and detector acceptance, and for hadron punchthrough. 1a) has also been corrected for QED, 1c) for electron detection efficiency. The solid curves are calculated for V – A decay with M(L) = 1.91 GeV/c^2, $M(\nu_L) = 0$.

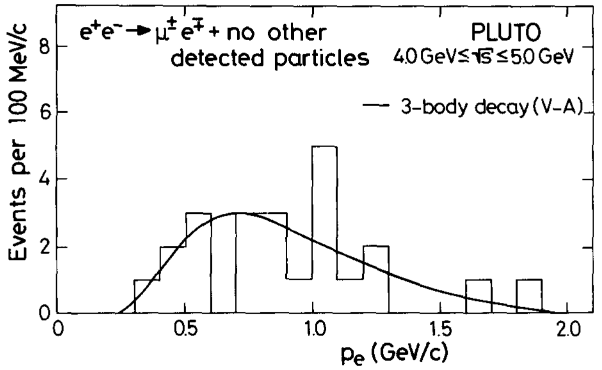

Fig. 2. Electron momentum spectrum. Corrections and parameters of the curve like in fig. 1c). Note that the detection efficiency distorts the lower part of the spectrum.

tons which escaped detection. Because of the large solid angle and high photon conversion efficiency we should then find a large number of μe events in which photons or extra charged particles are detected. Table 1 shows, however, that the number of such events is consistent with the estimated background.

We can convert the cross sections of table 1 into branching ratios for hypothetical L decay modes, assuming that they produce roughly the same electron and muon momentum spectra as the μe + "nothing" events, and obtain as upper limits (90% C.L.):

BR(e + charged p.) + BR(μ + charged p.) < 4% ,

BR(e + photons) + BR(μ + photons) < 12%.

The small number of μe events with associated particles or photons provide a strong argument against the possibility that the μe + "zero" events are simulated by semi-leptonic decays of charmed particles. The most pessimistic assumption would be the decay scheme $D\bar{D} \to K^0 e\nu_e, K^0 \mu\nu_\mu$, because of the high escape probability for the associated particles, namely 25% via $K^0_L K^0_L$ pairs, plus about 2% due to the limited detection efficiency for the K^0_S decay product. In this case we would have observed almost three times as many μe events *with* additional tracks or converted photons than without, in contrast to the data. We therefore conclude that no more than 9% of our μe events could be due to this assumed production scheme (90% C.L.). Other conceivable schemes which partly contain K^{0*}, π^0, or η particles instead of the K^0, lead to a lower escape probability in our detector and therefore to a still lower limit for the sum of all charm contributions. This low limit for charm contribution to our μe + "nothing" events is naturally explained by the soft muon spectrum characteristics of semi-leptonic charm decays [5, 6]. In conclusion, the observed μe events are fully compatible with the pair production and subsequent 3-body decays of heavy leptons. The origin from the semileptonic decay of charmed mesons can be ruled out. Using the branching ratio into muons as determined from the inclusive muon production [1], we obtain the branching ratio of the heavy lepton into electrons. Both branching ratios are equal within error: as expected for the decay of a "sequential" heavy lepton with a new lepton number.

References

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