ANOMALOUS MUON PRODUCTION IN e^+e^- ANNIHILATIONS AS EVIDENCE FOR HEAVY LEPTONS

PLUTO-Collaboration

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We have measured inclusive muon production in e^+e^- annihilation for CMS energies between 3.6 and 5.0 GeV. Above 4 GeV the cross section cannot be explained by conventional sources like higher order QED processes or inclusive production of the J/ψ (3.1). It is, however, compatible with the pair production of heavy particles of a mass of about 1.9 GeV/c^2. Spin assignment and decay parameters are investigated.

Several experiments have reported anomalous lepton signals in e^+e^- annihilation as evidence for the existence of heavy leptons [1, 2] and of charmed particles [3, 4]. In this and the following letter we present new evidence for the production of heavy leptons, and derive some of their major decay properties.

Inclusive muon spectra were measured at CMS energies $\sqrt{s}$ between 3.6 and 5.0 GeV with the magnetic detector PLUTO at the e^+e^- storage ring DORIS at DESY [5]. Muons were identified by range, they had to penetrate 68 cm of iron on average. The probability of misidentifying hadrons as muons was measured as (2.8 ± 0.7)%. A description of the detector and the muon identification has been given in a previous publication [6].

For the present analysis only muons with momentum $p > 1$ GeV, and with $|\cos\theta| \leqslant 0.752$ (θ = angle between track and beam) were used. With this angular cut the solid angle for muon detection is 43% of 4π.

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The events had to contain at least one extra charged particle with $p > 0.2$ GeV and $|\cos\theta| < 0.87$. The event sample was divided into twoprongs (one extra track + any number of photons) and multiprongs. The two classes contain different contributions from conventional processes.

The main conventional sources of twoprong events are the QED processes (1) $e^+e^- \to \mu^+\mu^-$, (2) $e^+e^- \to \mu^+\mu^-\gamma$, and (3) $e^+e^- \to \mu^+\mu^-\gamma\gamma$. Reactions (1) and part of (2) were removed by requiring an acoplanarity angle of $>10°$. The contribution of (2) was further reduced by a cut in the squared missing mass. Because of changing kinematical resolution this cut varied between 1.4 GeV^2 at $\sqrt{s}$ = 3.6 GeV and 2.7 GeV^2 at $\sqrt{s}$ = 5 GeV. The efficiency of this cut was checked with a 60% subsample of type (2) events in which the photon converted in the detector. Fig. 1 shows the squared missing mass of this sample for an intermediate energy range. For the shaded events, the position of the converted photon is compatible with the direction of the missing momentum. From the number of events leaking beyond the

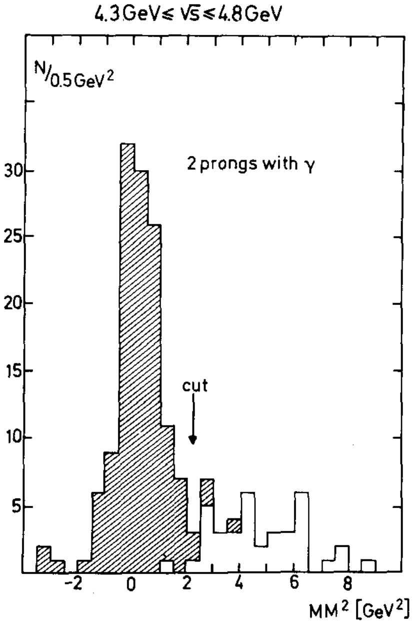

Fig. 1. Square of missing mass for twoprong events with one converted photon. For the shaded events the photon conversion point is consistent with the missing momentum direction.

cut (arrow in fig. 1) the small remaining contamination with type (2) events was determined and subtracted. Reaction (3) cannot be separated by kinematical cuts. Its contribution has been calculated [7] for the acceptance of this experiment and subtracted. It amounts to less than 7% of the remaining muon signal at all energies. The contamination with misidentified hadrons, typically 15%, was also subtracted.

In case of the multiprongs, the misidentified hadrons constitute the main background source. Contributions of $e^+e^- \to e^+e^- + \mu^+\mu^-$ were calculated and found to be small [7]. The contribution of $e^+e^- \to J/\psi\,(3.1) + X$ with subsequent decay $J/\psi \to \mu^+\mu^-$ was eliminated by a cut in the invariant two-particle mass. These events have been discussed in a previous publication [6].

A summary of the elimination procedure is given in table 1. The final twoprong cross section shows a threshold behaviour with a clear signal above 4 GeV, being consistent with zero at 3.6 GeV. The multiprong cross section is also different from zero, but statistically less significant. Both are in good agreement with earlier measurements [2].

Fig. 2 shows the muon spectra of the twoprongs for three different CMS energies. The cross section has been corrected for trigger and detector acceptance, assuming isotropy, but not for losses due to the missing mass cut ‡. The measured spectra show the triangular upper end characteristics of the 3-body decay of a moving object, and are incompatible with the rect-

‡ The loss due to the missing mass cut is model dependent. On the basis of the observed distributions it is estimated to be about 10%. All branching ratios given below are corrected for this loss.

Table 1
Separation of the anomalous muon signal. Event numbers and cross sections refer to muon momenta >1 GeV/*c*. Cross sections are corrected for trigger and detector acceptance. Hadron punchthrough and, for twoprongs also QED, is subtracted.

CMS energy	3.6	4.0–4.3	4.3–4.8	5.0	GeV
Integr. Luminosity	613	1660	2037	1384	nb^{-1}
Twoprongs with missing mass cut					
Events	7	53	109	111	
Hadron punchthrough	3	12	17	12	
$\sigma(\mu\mu\gamma\gamma)$	6	7	7	7	pb
$\sigma_{anomalous}(\mu)$	18 ± 16	74 ± 17	139 ± 19	223 ± 25	pb
Multiprongs					
Events	18	53	130	134	
Hadron punchthrough	16	63	82	62	
$\sigma_{anomalous}(\mu)$	8 ± 25	−15 ± 26	57 ± 29	129 ± 36	pb

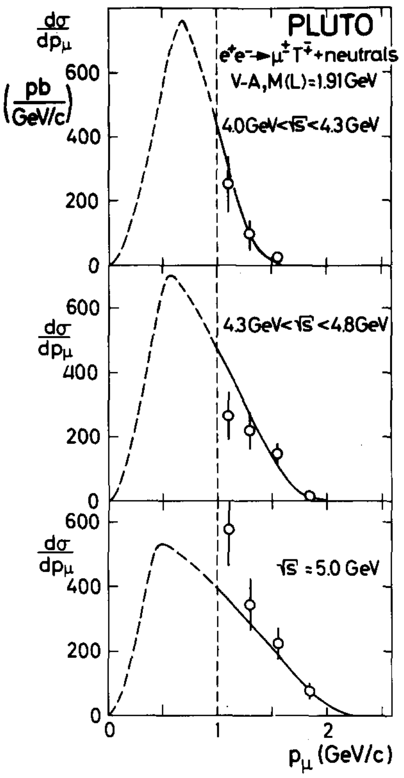

Fig. 2. Muon momentum distribution of twoprong ($\mu^\pm$ + charged track $T^\mp$ + neutrals) events for three different CMS energies. Cross sections corrected for trigger and detector acceptance, punchthrough and QED subtracted. The curves show a fit as described in the text, with V−A decay and $M(\nu_L) = 0$.

angular shape expected from a twobody decay. The velocity of the decaying particle increases with energy, as indicated by the shift of the spectra. In fact, all momentum distributions are consistent with the pair production and decay of a particle of about 1.9 GeV/c^2 mass into one muon, its associated neutrino, and a third particle of low mass. We remark that this third particle cannot be a π^0 or η meson because of the measured low mean photon multiplicity of less than 0.7 per (anomalous) twoprong event. Further evidence against photons and hadrons accompanying the decays will be presented in the following letter [8].

In order to arrive at quantitative conclusions, we investigate the hypothesis that the observed muons originate from the production of a pair of pointlike new particles ($L^\pm$) with subsequent 3-body decay of one:

$$e^+e^- \longrightarrow L^\pm \; L^\mp, \quad L^\mp \longrightarrow \mu^\mp \nu_\mu + \text{"}\nu_L\text{"}, \quad L^\pm \longrightarrow \text{1-prong + neutrals} \qquad (1)$$

The measured twoprong cross section is proportional to the QED production cross section ‡ and to the product of the branching ratios BR(1-prong)·BR(μ). A two-parameter fit determines this product and, from the shape and the $\sqrt{s}$ dependence of the spectra, the mass M(L). The results of the fit depend strongly on the assumed spin of the L, and also on the type of the L decay (V± A) which influences the extrapolation to the unobserved low momentum part of the spectra (see fig. 2). For spin 0 and 1/2 we obtain the following parameters (masses in GeV/c^2):

Spin	Decay	$M(\nu_L)$	M(L)
0	~$K_{\ell 3}$	0	1.67 ± 0.08
1/2	V + A	0	1.79 ± 0.07
1/2	V − A	0	1.91 ± 0.03
1/2	V − A	0.5	1.72 ± 0.09

BR(1-prong)·BR(μ)	χ^2(9 D.F.)
1.35 ± 0.29	6.5
0.136 ± 0.019	15.1
0.109 ± 0.012	10.3
0.130 ± 0.017	22.5

The first three choices all give acceptable fits, thus supporting the hypothesis of the pair production and 3-body decay. The spin 0 assignment (Higgs boson?) can be ruled out, however, because (due to the small QED cross section) it leads to a singular branching ratio, BR(μ) ≈ 100%. As a consequence, we should have found 22 ± 5 anomalous $\mu^+\mu^-$ pairs, in contrast to only 6 observed. We will therefore consider spin 0, although not completely excluded, highly improbable, and try to narrow down the decay of a spin 1/2 particle The large χ^2 of the last fit excludes the possibility that we observe the decay of a new baryon into neutron + μ^+ + ν. Therefore, the assumption of a heavy lepton [1, 9] appears to be the most convincing one. The V − A decay assignment is favoured by the data, independent of a possible small mass $M(\nu_L)$, but V + A cannot be excluded [10].

‡ $\sigma_{QED} = \sigma_{\mu\mu} \cdot (3\beta - \beta^3)/2$ for spin 1/2, and $= \sigma_{\mu\mu} \cdot \beta^3/4$ for spin 0, with β = velocity of the L, and $\sigma_{\mu\mu}$ = 87 nb/s (s in GeV²).

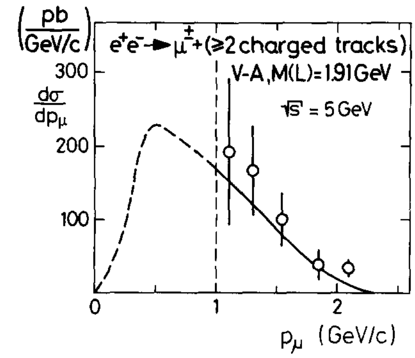

Fig. 3. Muon momentum distribution of multiprong events for $\sqrt{s}$ = 5 GeV. Cross sections corrected for trigger and detector acceptance, punchthrough subtracted. The curve shows a fit to the data of *all* CMS energies (V – A, $M(\nu_L)$ = 0).

The muon spectrum of the multiprongs at $\sqrt{s}$ = 5 GeV is shown in fig. 3. Within its larger errors it is consistent with the twoprong signal, and argues for a common source of both classes. Comparing the two, we obtain the branching ratios for L decays into 1-prongs and multiprongs as:

BR(1-prong) = 0.70 ± 0.10 and

BR(multiprong) = 0.30 ± 0.10 .

This leads to the L branching ratio into muons:

$$\mathrm{BR}(\mu) = \begin{cases} 0.15 \pm 0.03 & \text{for V}-\text{A, or} \\ 0.19 \pm 0.04 & \text{for V}+\text{A decay .} \end{cases}$$

The quoted errors of the branching ratios are purely statistical. We estimate the systematic uncertainties to amount to ±20%.

All branching ratios are in reasonable agreement with theoretical expectations for the decay of a sequential heavy lepton [9]. We cannot experimentally exclude, however, the possibility that our multiprongs contain some contributions from the decay of charmed mesons. In that case BR(1-prong) will come out somewhat higher, and BR(μ) correspondingly lower.

In conclusion, our measured twoprong (μ + 1-prong) events present new evidence for the pair production of heavy particles of about 1.9 GeV/c^2 mass with subsequent 3-body decay. The origin from pointlike spin 0 particles can be ruled out as highly improbable. The low number of multiprongs and of associated photons excludes charmed meson decays like $D^\pm \to K_L^0 (+\pi^0) + \mu^\pm + \nu$ and $F^\pm \to \eta + \mu^\pm + \nu$ as the source of the twoprong events. The origin from the decay of new baryons into neutron + $\mu^\pm$ + ν can also be ruled out. The only consistent description (known at present) has to assume the pair production of heavy leptons. The mass is calculated under two different assumptions about the decay structure. Several branching ratios are determined. They agree as well with earlier experimental results [1] as with theoretical expectations for sequential heavy leptons [9]. More evidence based on the study of $\mu^\pm e^\mp$ pairs will be presented in the following letter.

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References

[1] M.L. Perl et al., Phys. Rev. Lett. 35 (1975) 1489; M.L. Perl et al., Phys. Lett. 63B (1976) 466.
[2] H. Cavalli-Sforza et al., Phys. Rev. Lett. 36 (1976) 558; G.J. Feldman et al., Phys. Rev. Lett. 38 (1977) 117.
[3] W. Braunschweig et al., Phys. Lett. 63B (1976) 471.
[4] J. Burmester et al., Phys. Lett 64B (1976) 369.
[5] Preliminary data have been presented by H. Meyer in Proceedings of the Orbis Scientiae (Coral Gables Conference 1977), DESY 77/19 and by V. Blobel in Proceedings of the XII Rencontre de Moriond (Flaine 1977), edited by Tran Tranh Van, R.M.I.E.M. Orsay.
[6] J. Burmester et al., DESY 77/17 (1977), and Phys. Letters 67B (1977) 367.
[7] F. Gutbrod and Z. Rek, private communication to be published. We are greatly indebted to these authors for performing calculations specific to our detector acceptance
[8] J. Burmester et al., DESY 77/25 and Phys. Lett. 68B (1977) 301.
[9] Y.S. Tsai, Phys. Rev. D4 (1971) 2821.
[10] K. Fujikawa, N. Kawamoto, Phys. Rev. D14 (1976) 59.