Anomalous Muon Production in $e^+e^-$ Annihilation
as Evidence for Heavy Leptons

by
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Abstract

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 (1s). 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 and of charmed particles. 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 between 3.6 and 5.0 GeV with the magnetic detector PLUTO at the e+e- storage ring PONIS at DESY. Muons were identified by range, they had to penetrate 65 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.

For the present analysis only muons with momentum p > 1 GeV, and with |cosθ| < 0.792 (θ = angle between track and beam) were used. With this angular cut the solid angle for muon detection is 4.5% of 4π. The events had to contain at least one extra charged particle with p > 0.2 GeV and |cosθ| < 0.87. The event sample was divided into two-prongs (one extra track + any number of photons) and multijprongs. The two classes contain different contributions from conventional processes.

The main conventional sources of two-prong events are the QED processes (1) e+e- → μ+μ-, (2) e+e- → μ+μγ, and (3) e+e- → μ+μγγ. Reaction (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 √s = 3.6 GeV and 2.7 GeV^2 at √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 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 multiprong, the misidentified hadrons constitute the main source. Contributions of \(e^+e^- \rightarrow e^+e^- + \mu^+\mu^-\) were calculated and found to be negligible \(^7\). The contribution of \(e^+e^- \rightarrow J/\psi (3.1) + X\) with subsequent decay \(J/\psi \rightarrow \mu^+\mu^-\) 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 I. The final two-prong 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 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 characteristic of the 3-body decay of a moving object, and are incompatible with the rectangular shape expected from a two-body 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 two muons, its associated neutrino, and a third particle of low mass. We remark that this third particle cannot be a \(\pi^0\) or \(\rho^0\) because of the measured low mean photon multiplicity of less than 0.7 per (anomalous) two-prong 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:

\[
e^+e^- \rightarrow L^+ L^- p^+p^- \rightarrow \mu^+\mu^- \rightarrow 1\text{-prong neutrals}
\]

The measured two-prong cross section is proportional to the QED production cross section \(^9\) and to the product of the branching ratios \(BR(1\text{-prong}) \cdot BR(p)\). A two-parameter fit determines this product and, from the shape and the \(p_T\) 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 \((V^\pm A)\) which influences the extrapolation to the unobserved low momentum part of the spectra (see fig. 3). For spin 0 and 1/2 we obtain the following parameters (masses in GeV/c\(^2\)):

<table>
<thead>
<tr>
<th>Spin</th>
<th>Decay</th>
<th>(M(p))</th>
<th>(M(L))</th>
<th>(BR(1\text{-prong}) \cdot BR(p))</th>
<th>(\chi^2/9\text{ D.F.})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(\nu\bar{\nu})</td>
<td>0</td>
<td>1.67(2.08)</td>
<td>1.35 (2.02)</td>
<td>6.5</td>
</tr>
<tr>
<td>1/2</td>
<td>(\pi^\pm)</td>
<td>0</td>
<td>1.79(2.07)</td>
<td>0.136 (2.019)</td>
<td>15.1</td>
</tr>
<tr>
<td>1/2</td>
<td>(V^\pm)</td>
<td>0</td>
<td>1.91(2.03)</td>
<td>0.109 (2.012)</td>
<td>10.3</td>
</tr>
<tr>
<td>1/2</td>
<td>(V^\mp)</td>
<td>0.5</td>
<td>1.72(2.09)</td>
<td>0.130 (2.017)</td>
<td>22.5</td>
</tr>
</tbody>
</table>

The first three choices all give acceptable fits, thus supporting the hypothesis of the pair production and 3-body decay. The spin 0 assignment \((Higgs \ \text{boson?})\) can be ruled out, however, because (due to the small QED cross section) it leads to a singular branching ratio, \(BR(p) = 100\%\). As a consequence, we have found 22 \(\pm 5\) 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 velocity of the \(L\) and \(\sigma_{\text{BR}} = 0.39(38-6^3)/2\) for spin 1/2, and \(\sigma_{\text{BR}} = 0.39/4\) for spin 0, with \(s = \text{velocity of the } L\), and \(\sigma_{\text{BR}} = 57\ nb/s \ (s \text{ in GeV}^2)\).
decay of a spin 1/2 particle. The large $\chi^2$ of the last fit excludes the possibility that we observe the decay of a new baryon into neutron + $p^+ + \nu$. Therefore, the assumption of a heavy lepton $\psi$ appears to be the most convincing one. The $V-A$ decay assignment is favoured by the data, independent of a possible small mass $M(\psi)$, but $V-A$ cannot be excluded [9].

The muon spectrum of the multiprong events at $\sqrt{s} = 5$ GeV is shown in fig. 5. Within its larger errors it is consistent with the two-prong 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 multiprong events:

\[ BR(1\text{-prong}) = 0.70 \pm 0.10 \quad \text{and} \quad BR(\text{multiprong}) = 0.30 \pm 0.10. \]

This leads to the $L$ branching ratio into muons:

\[ BR(\mu) = \begin{cases} 
0.17 \pm 0.07 & \text{for } V-A, \text{ or} \\
0.19 \pm 0.04 & \text{for } V-A \text{ decay.}
\end{cases} \]

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

All branching ratios are in reasonable agreement with theoretical expectations for the decay of a sequential heavy lepton [10]. We cannot experimentally exclude, however, the possibility that our multiprong events contain some contributions from the decay of charmed mesons. In that case $BR(1\text{-prong})$ will come out somewhat higher, and $BR(\mu)$ correspondingly lower.

In conclusion, our measured two-prong ($p + 1\text{-prong}$) 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 multi-prongs and of associated photons excludes charmed meson decays like `$c^- + K^0(\pi^0) + p^+ + \nu$' and `$c^- + \pi^+ + p^+ + \nu$' as the source of the two-prong events. The origin from the decay of new baryons into neutron + $p^+ + \nu$ 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 [11] as with theoretical expectations for sequential heavy leptons [9]. More evidence based on the study of $p^\pm + \pi^\mp$ pairs will be presented in the following letter.

Acknowledgements

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5. Preliminary data have been presented by H. Meyer in Proceedings of
   the Orbis Scientiae (Coral Gables Conference 1977), DESY 77/19
   and by Y. Blobel in Proceedings of the XII Rencontres de Moriond
   (Plaine 1977), edited by Tran Thanh Van, R.M.I.R.M. DESY.

6. J. Burmester et al., DESY 77/17 (1977), and Phys. Letters
   to be published.

7. F. Gütbrod and Z. Rek, private communication to be published.
   We are greatly indebted to these authors for performing calculations
   specific to our detector acceptance.


9. Y. S. Tsai, Phys. Rev. D 6 (1971) 2821


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 two-pronged also QED, is
subtracted.

<table>
<thead>
<tr>
<th>CMS energy</th>
<th>3.6</th>
<th>4.0-4.3</th>
<th>4.3-4.8</th>
<th>5.0</th>
<th>GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Int. Luminosity</td>
<td>613</td>
<td>1660</td>
<td>2037</td>
<td>1384</td>
<td>nb^{-1}</td>
</tr>
</tbody>
</table>

Two-pronged with
missing mass cut

<table>
<thead>
<tr>
<th>Events</th>
<th>Hadron punchthrough</th>
<th>$\sigma_{\mu\mu\gamma\gamma}$</th>
<th>$\sigma_{\text{anomalous}}(\mu)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>3</td>
<td>6</td>
<td>18.16</td>
</tr>
<tr>
<td>53</td>
<td>12</td>
<td>7</td>
<td>74.17</td>
</tr>
<tr>
<td>109</td>
<td>17</td>
<td>7</td>
<td>130.19</td>
</tr>
<tr>
<td>111</td>
<td>12</td>
<td>7</td>
<td>223.25</td>
</tr>
</tbody>
</table>

Multi-pronged

<table>
<thead>
<tr>
<th>Events</th>
<th>Hadron punchthrough</th>
<th>$\sigma_{\text{anomalous}}(\mu)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>6</td>
<td>8.25</td>
</tr>
<tr>
<td>55</td>
<td>82</td>
<td>-15.26</td>
</tr>
<tr>
<td>130</td>
<td>62</td>
<td>37.29</td>
</tr>
<tr>
<td>134</td>
<td></td>
<td>129.36</td>
</tr>
</tbody>
</table>
Figure Captions

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

2. Muon momentum distribution of two-prong ($p^+ +$ charged track $\gamma^\pm +$ 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 $N (\gamma L) = 0$.

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, $M (\gamma L) = 0$).