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EVIDENCE FOR ANOMALOUS LEPTON PRODUCTION IN $e^+ - e^-$ ANNIHILATION*

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ABSTRACT

We have found events of the form $e^+ + e^- \rightarrow e^\pm + \mu^\mp$ + missing energy, in which no other charged particles or photons are detected. Most of these events are detected at or above a center-of-mass energy of 4 GeV. The missing energy and missing momentum spectra require that at least two additional particles be produced in each event. We have no conventional explanation for these events.

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We have found 64 events of the form

$$e^{+} + e^{-} \rightarrow e^{\pm} + \mu^{\mp} + \geq 2 \text{ undetected particles} \qquad (1)$$

for which we have no conventional explanation. The undetected particles are charged particles or photons which escape the 2.6π sr solid angle of the detector, or particles very difficult to detect such as neutrons, K_L^0 mesons, or neutrinos. Most of these events are observed at center-of-mass energies at, or above, 4 GeV. These events were found using the SLAC-LBL magnetic detector at the Stanford Linear Accelerator Center colliding beams facility SPEAR.

Events corresponding to (1) are the signature for new types of particles or interactions. For example, pair production of heavy charged leptons[1-4] having the decay modes $\ell^- \rightarrow \nu_\ell + e^- + \bar{\nu}_e$, $\ell^+ \rightarrow \bar{\nu}_\ell + e^+ + \nu_e$, $\ell^- \rightarrow \nu_\ell + \mu^- + \bar{\nu}_\mu$, $\ell^+ \rightarrow \bar{\nu}_\ell + \mu^+ + \nu_\mu$, would appear as such events. Another possibility is the pair production of charged bosons with decays: $B^- \rightarrow e^- + \bar{\nu}_e$, $B^+ \rightarrow e^+ + \nu_e$, $B^- \rightarrow \mu^- + \bar{\nu}_\mu$, $B^+ \rightarrow \mu^+ + \nu_\mu$. Charmed quark theories[5,6] predict such bosons. Intermediate vector bosons which mediate the weak interactions would have similar decay modes, but the mass of such particles (if they exist at all) is probably too large[7] for the energies of this experiment. There are many other possibilities such as higher order weak-interactions, $e^+ + e^- \rightarrow e^+ + \nu_e + \mu^- + \bar{\nu}_\mu$; (calculations give much too small a cross section to fit our observations) neutral leptons ($L^0 \rightarrow e^+ + \mu^- + \bar{\nu}_\mu$ for example), etc.

The momentum analysis and particle identifier systems of the SLAC-LBL magnetic detector[8] cover the polar angles $50^\circ \leq \theta \leq 130^\circ$ and the full 2π azimuthal angle. Electrons, muons and hadrons are identified using a cylindrical array of 24 lead-scintillator shower counters, the 20 cm thick iron flux return of the magnet, and an array of magnetostrictive wire spark chambers situated outside the iron. Electrons are identified by requiring a large pulse height in the shower counters. Muons are identified by two requirements: the μ must be detected in one of the muon chambers and the shower counter pulse of the μ must be small. All other charged particles are called hadrons. The shower counters also detect photons (γ). For γ energies above 200 MeV, the γ detection efficiency is about 95%.

To illustrate the method of searching for events corresponding to reaction (1), we consider our data taken at a total energy ($\sqrt{s}$) of 4.8 GeV. This sample contains 9,550 three-or-more-prong events and a large number of two-prong events which include $e^+e^- \to e^+e^-$ events, $e^+e^- \to \mu^+\mu^-$ events, two-prong hadronic events and the $e\mu$ events described here. To study two-prong events we define a coplanarity angle

$$\cos\,\theta_{copl} = -(\underset{\sim}{n}_1 \times \underset{\sim}{n}_{e^+}) \cdot (\underset{\sim}{n}_2 \times \underset{\sim}{n}_{e^+})/(|\underset{\sim}{n}_1 \times \underset{\sim}{n}_{e^+}|\;|\underset{\sim}{n}_2 \times \underset{\sim}{n}_{e^+}|) \qquad (2)$$

where $\underset{\sim}{n}_1$, $\underset{\sim}{n}_2$, $\underset{\sim}{n}_{e^+}$ are unit vectors along the directions of particles 1, 2, and the e^+ beam. The contamination of events from the reactions $e^+e^- \to e^+e^-$ and $e^+e^- \to \mu^+\mu^-$ is greatly reduced if we require $\theta_{copl} > 20^\circ$. Making this cut leaves 2493 two-prong events in the 4.8 GeV sample.

To penetrate the iron plates of the flux return, a muon must have a momentum greater than about 0.55 GeV/c. Also electrons of less than 0.5 GeV/c momentum will be misidentified as pions more than half the time, since the pulse height of such low momentum electrons in the shower counters is small. Therefore, we require that both momenta be greater than 0.65 GeV/c. This reduces the 2493 events to the 513 in Table I. The 24 eμ events with no associated photons, called the signature events, are candidates for reaction (1). The eμ events can come conventionally from the two-virtual-photon process[9]: $e^+e^- \rightarrow e^+e^- + \mu^+\mu^-$. Calculations indicate that this source is negligible, and the absence of eμ events with charge 2 proves this point since the number of charge 2 eμ should equal the number of charge 0 eμ from this source.

We determine the background from hadron misidentification or decay by using the 9550 three-or-more-prong events assuming every particle called an e or a μ by the detector was either a misidentified hadron or came from the decay of a hadron. We use $P_{h \rightarrow b}$ to designate the sum of the probabilities for misidentification or decay causing a hadron h to be called a lepton b. Since the P's are momentum dependent[10] we use all the eh, μh, and hh events in column 1 of Table I to determine a "hadron" momentum spectrum, and weight the P's accordingly. We obtain the momentum averaged probabilities $P_{h \rightarrow e} = .183 \pm .007$, $P_{h \rightarrow \mu} = .198 \pm .007$. Collinear ee and μμ events are used to determine $P_{e \rightarrow h} = .056 \pm .02$; $P_{e \rightarrow \mu} = .011 \pm .01$; $P_{\mu \rightarrow h} = .08 \pm .02$; $P_{\mu \rightarrow e} < .01$.

Using these probabilities and assuming all eh and μh events in Table I result from particle misidentifications or particle decays, we calculate for column 1 the contamination of the eμ sample to be 1.0 ± 1.0 events from misidentified ee, < 0.3 events from misidentified μμ, and 3.7 ± 0.6 events from hh in which the hadrons were misidentified or decayed. The total eμ background is then 4.7 ± 1.2 events.[11] The statistical probability of such a number yielding the 24 signature eμ events is very small. The same analysis applied to columns 2 and 3 of Table I yields 5.6 ± 1.5 eμ background events for column 2 and 8.6 ± 2.0 eμ background events for column 3, both consistent with the observed number of eμ events.

Figure 1a shows the momentum of the μ versus the momentum of the e for signature events. Both p_μ and p_e extend up to 1.8 GeV/c, their average values being 1.2 and 1.3 GeV/c, respectively. Figure 1b shows the invariant eμ mass squared (M_i^2) versus the missing mass squared (M_m^2) recoiling against the eμ system. To explain Fig. 1b at least two particles must escape detection. Figure 1c shows the distribution in collinearity angle between the e and μ ($\cos\theta_{coll} = -\underset{\sim}{p}_e \cdot \underset{\sim}{p}_\mu / (|\underset{\sim}{p}_e|\,|\underset{\sim}{p}_\mu|)$). The dip near $\cos\theta_{coll} = 1$ is a consequence of the coplanarity cut, however, the absence of events with large θ_{coll} has dynamical significance.

Figure 2 shows the <u>observed</u> cross section in the detector acceptance for signature eμ events versus center-of-mass energy with the background subtracted at each energy as described above.[10] There are a total of 86 eμ events summed over all energies, with a calculated background of 22 events.[11] The corrections to obtain the true cross section for the angle and momentum cuts used here depend on the hypothesis as to the origin of these eμ events and the corrected cross section can be many times larger than the observed cross section. While Fig. 2 shows an apparent threshold at around 4 GeV, the statistics are small and the correction factors are largest for low $\sqrt{s}$. Thus, the apparent threshold may not be real.

We conclude that the signature eμ events cannot be explained either by the production and decay of any presently known particles or as coming from any of the well-understood interactions which can conve lead to an e and a μ in the final state. A possible explanation foı events is the production and decay of a pair of new particles, each ı a mass in the range of 1.6 to 2.0 GeV/c^2.

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10. For further discussion of background estimates and hypothesis tests see M.L. Perl, SLAC-PUB-1592 (to be published in Proceedings of the Canadian Institute of Particle Physics Summer School, McGill University, 1975).
11. Using *only* events in column 1 of Table I we find at 4.8 GeV $P_{h \to e}$ = .27 $\pm$ .10, $P_{h \to \mu}$ = .23 $\pm$ .09, and a total eμ background of 7.9 $\pm$ 3.2 events. The same method yields a total eμ background of 30 $\pm$ 6 events summed over all energies.

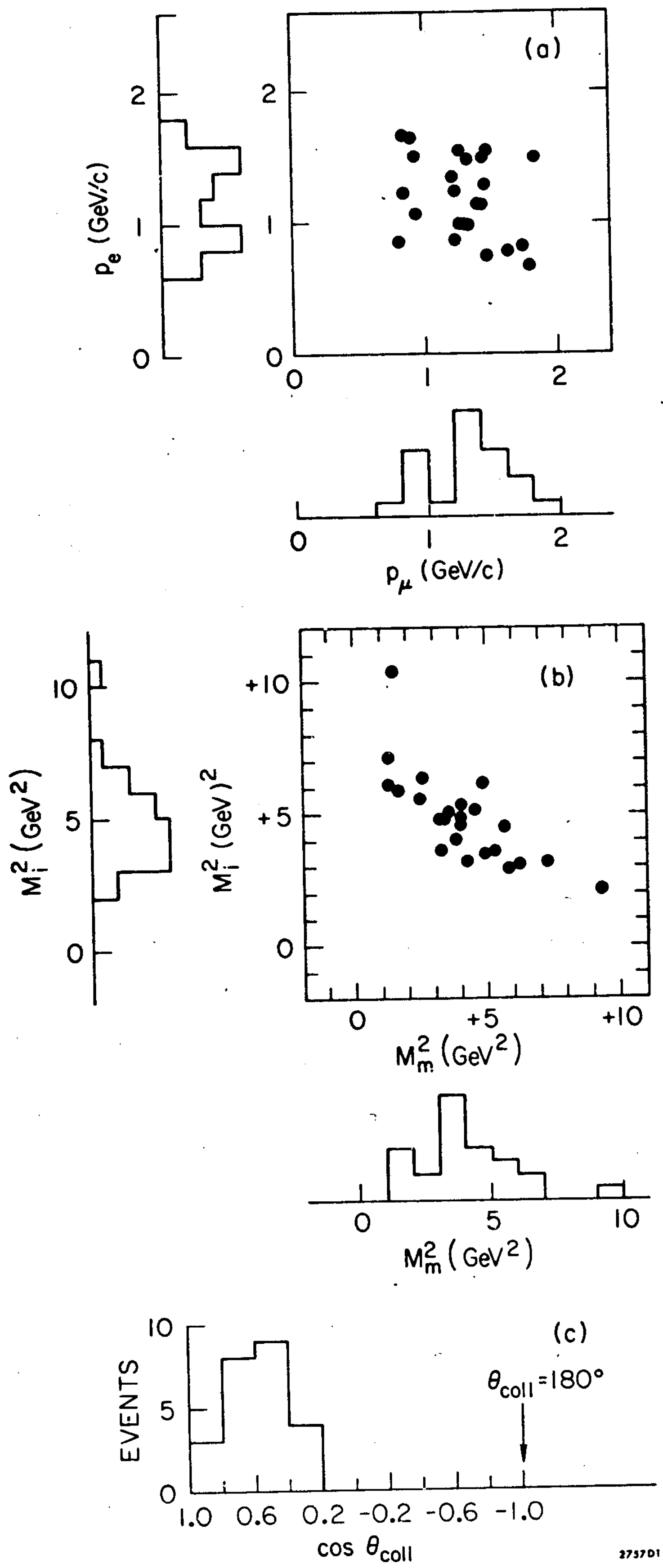
FIGURE CAPTIONS

1. Distribution for the 4.8 GeV eμ signature events of (a) momenta of the e (p_e) and μ (p_μ); (b) Invariant mass squared (M_i^2) and missing mass squared (M_m^2); and (c) cos θ_{coll}.
2. The *observed* cross section for the signature eμ events.

TABLE I

Distribution of 513, two-prong, events, obtained at E_{cm} = 4.8 GeV, which meet the criteria: $|\underset{\sim}{p}_1| > 0.65$ GeV/c, $|\underset{\sim}{p}_2| > 0.65$ GeV/c, $\theta_{copl} > 20^{o}$. Events are classified according to the number of photons detected, total charge, and the nature of the particles. All particles not identified as e or μ are called h for hadron.

	Total Charge = 0			Total Charge = ± 2		
Number Photons =	0	1	> 1	0	1	> 1
ee	40	111	55	0	1	0
eμ	24	8	8	0	0	3
μμ	16	15	6	0	0	0
eh	20	21	32	2	3	3
μh	17	14	31	4	0	5
hh	14	10	30	10	4	6



(a)
2
1
0
p_e (GeV/c)
0
1
2
p_μ (GeV/c)
(b)
+10
+5
0
10
5
M_i^2 (GeV^2)
M_i^2 (GeV)^2
+5
+10
M_m^2 (GeV^2)
M_m^2 (GeV^2)
(c)
EVENTS
θ_{coll}=180°
1.0
0.6
0.2
-0.2
-0.6
-1.0
cos θ_{coll}
2737D1

Fig. 1

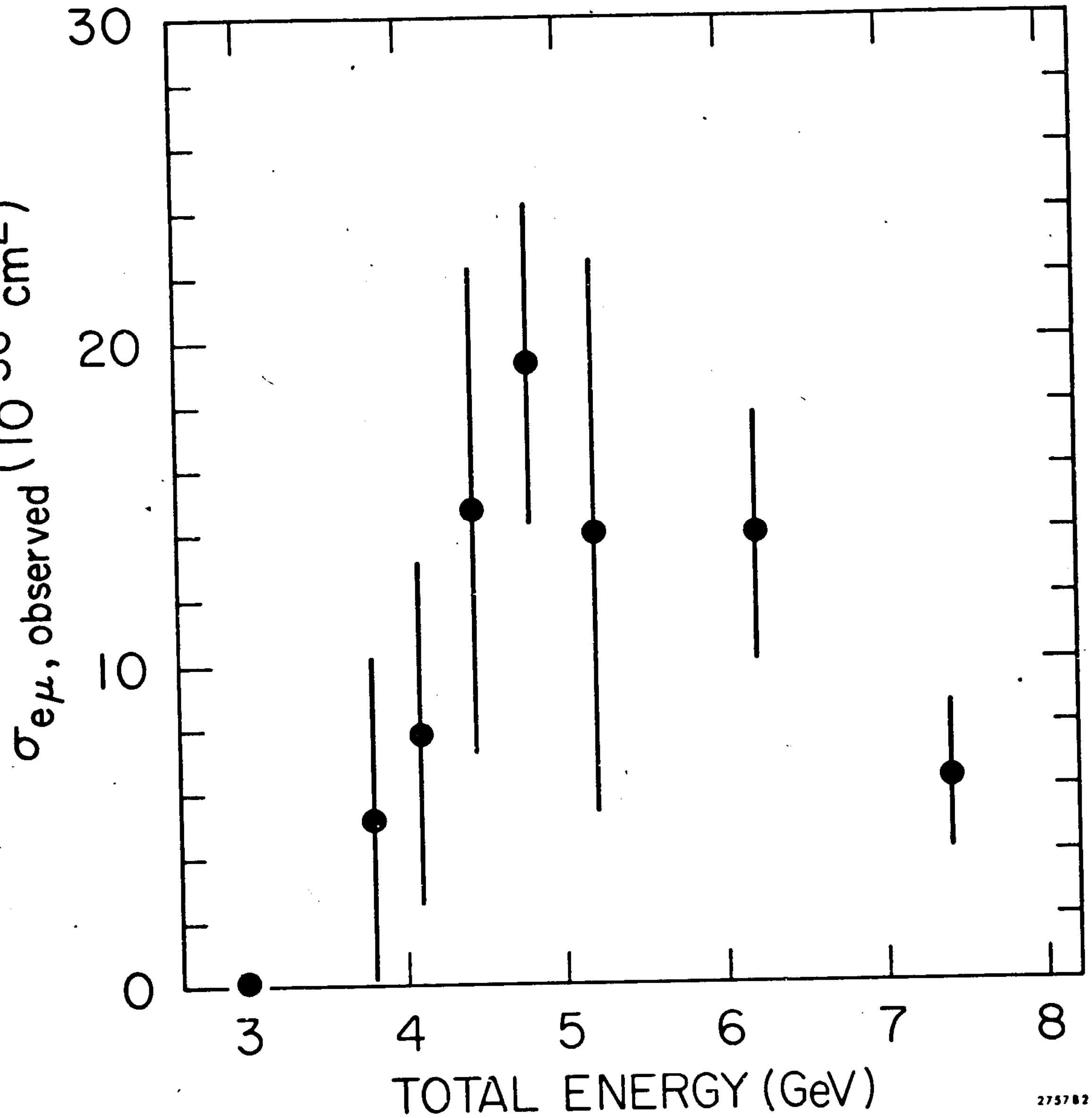

30
20
10
0
3
4
5
6
7
8
$\sigma_{e\mu, \text{observed}}$ (10^{-36} cm^2)
TOTAL ENERGY (GeV)
275782

Fig. 2