the fiducial decay volume. The corresponding flux for the Kolar Gold Mines experiment is about 8×10^{10} ν_μ (and approximately an equal number of $\bar{\nu}_\mu$) of $E_\nu > 5$ GeV.[4] The energy spectra for the two experiments are shown in Fig. 3. The mean $(\nu_\mu + \bar{\nu}_\mu)$ energy $\langle E\rangle$ (with a cutoff at 5 GeV) is 20 GeV for this experiment, and 7 GeV for Ref. 3.

It is difficult to make a direct quantitative comparison of the Kolar Gold Mines experiment and the experiment described here, because the geometries of the two experiments are very different. In the Kolar experiment the neutrinos are incident from all directions so that the angle of production of a new long-lived penetrating neutral particle would be largely averaged by the detector. Hence the detection efficiency in the experiment does not appear to depend sensitively on either the angle of production or the amount of target material available for neutrino interactions. In the present experiment the neutrino beam is incident from a single, well-defined direction, and therefore the detection efficiency varies appreciably with the assumed angle of production. This leads to the qualitative conclusion that although we cannot definitely rule out the existence of the special class of events observed in the Kolar Gold Mines, we do not in this experiment confirm that result.

De Rújula, Georgi, and Glashow[5] have suggested that the Kolar Gold Mines events might have been produced by a massive neutral lepton L^0 produced by decays of a charged lepton $L^\pm$ which was in turn pair-produced electromagnetically by cosmic rays. Crude model-dependent estimates give $M_{L^0} \sim 2$ GeV/c^2, $\tau_{L^0} \simeq 10^{-15}$ sec. Rate estimates based on this model and applied to our conditions predict that > 500 events should have been observed.

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Evidence for Anomalous Lepton Production in e^+-e^- Annihilation*

M. L. Perl, G. S. Abrams, A. M. Boyarski, M. Breidenbach, D. D. Briggs, F. Bulos, W. Chinowsky,
J. T. Dakin,† G. J. Feldman, C. E. Friedberg, D. Fryberger, G. Goldhaber, G. Hanson,
F. B. Heile, B. Jean-Marie, J. A. Kadyk, R. R. Larsen, A. M. Litke, D. Lüke,‡
B. A. Lulu, V. Lüth, D. Lyon, C. C. Morehouse, J. M. Paterson,
F. M. Pierre,§ T. P. Pun, P. A. Rapidis, B. Richter,
B. Sadoulet, R. F. Schwitters, W. Tanenbaum,
G. H. Trilling, F. Vannucci,‖ J. S. Whitaker,
F. C. Winkelmann, and J. E. Wiss
Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California 94720,
and Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305
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We have found events of the form $e^+ + e^- \to e^\pm + \mu^\mp$ + 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.

We have found 64 events of the form

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

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 Stanford Linear Accelerator Center–Lawrence Berkeley Laboratory (SLAC-

LBL) magnetic detector at the SLAC 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 $l^- \to \nu_l + e^- + \bar{\nu}_e$, $l^+ \to \bar{\nu}_l + e^+ + \nu_e$, $l^- \to \nu_l + \mu^- + \bar{\nu}_\mu$, and $l^+ \to \bar{\nu}_l + \mu^+ + \nu_\mu$ would appear as such events. Another possibility is the pair production of charged bosons with decays $B^- \to e^- + \bar{\nu}_e$, $B^+ \to e^+ + \nu_e$, $B^- \to \mu^- + \bar{\nu}_\mu$, and $B^+ \to \mu^+ + \nu_\mu$. 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.

The momentum-analysis and particle-identifier systems of the SLAC-LBL magnetic detector[8] cover the polar angles $50° \leq \theta \leq 130°$ 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 solely by requiring that the shower-counter pulse height be greater than that of a 0.5-GeV e. Incidently, the e's in the e-μ events thus selected give no signal in the muon chambers; and their shower-counter pulse-height distribution is that expected of electrons. Also the positions of the e's in the shower counters as determined from the relative pulse heights in the photomultiplier tubes at each end of the counters agree within measurement errors with the positions of the e tracks. Hence the e's in the e-μ events are not misidentified combinations of $\mu+\gamma$ or $\pi+\gamma$ in a single shower counter, except possibly for a few events already contained in the background estimates. Muons are identified by two requirements. The μ must be detected in one of the muon chambers after passing through the iron flux return and other material totaling 1.67 absorption lengths for pions. And the shower-counter pulse height 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 9550 three-or-more-prong events and 25 300 two-prong events which include $e^+ + e^- \to e^+ + e^-$ events, $e^+ + e^- \to \mu^+ + \mu^-$ events, two-prong hadronic events, and the e-μ events described here. To study two-prong events we define a coplanarity angle

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

where $\vec{n}_1$, $\vec{n}_2$, and $\vec{n}_{e^+}$ 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 $\theta_{\text{copl}} > 20°$. Making this cut leaves 2493 two-prong events in the 4.8-GeV sample.

To obtain the most reliable e and μ identification[9] we require that each particle have a momentum greater than 0.65 GeV/c. This reduces the 2493 events to the 513 in Table I. The 24 e-μ events with no associated photons, called the signature events, are candidates for Reaction (1). The e-μ events can come conventionally from the two-virtual-photon process[10] $e^+ + e^- \to e^+ + e^- + \mu^+ + \mu^-$. Calculations indicate that this source is negligible, and the absence of e-μ events with charge 2 proves this point since the number of charge-2 e-μ events should equal the number of charge-0 e-μ events from this source.

We determine the background from hadron misidentification or decay by using the 9550 three-or-more-prong events and assuming that every particle called an e or a μ by the detector either was a misidentified hadron or came from the decay of a hadron. We use $P_{h \to l}$ to designate the sum of the probabilities for misidentification or decay causing a hadron h to be called a lepton l. Since the P's are momentum dependent[9] we use all the

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

N_γ / Particles	0	1	>1	0	1	>1
	Total charge = 0			Total charge = ±2		
e-e	40	111	55	0	1	0
e-μ	24	8	8	0	0	3
μ-μ	16	15	6	0	0	0
e-h	20	21	32	2	3	3
μ-h	17	14	31	4	0	5
h-h	14	10	30	10	4	6

e-h, μ-h, and h-h 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 $P_{h\to e}=0.183 \pm 0.007$ and $P_{h\to\mu}=0.198\pm0.007$. Collinear e-e and μ-μ events are used to determine $P_{e\to h} = 0.056\pm0.02$, $P_{e\to\mu}=0.011\pm0.01$, $P_{\mu\to h}=0.08 \pm0.02$, and $P_{\mu\to e}<0.01$.

Using these probabilities and assuming that all e-h and μ-h events in Table I result from particle misidentifications or particle decays, we calculate for column 1 the contamination of the e-μ sample to be 1.0 ± 1.0 event from misidentified e-e,[11] <0.3 event from misidentified μ-μ,[11] and 3.7 ± 0.6 events from h-h in which the hadrons were misidentified or decayed. The total e-μ background is then 4.7 ± 1.2 events.[12,13] The statistical probability of such a number yielding the 24 signature e-μ events is very small. The same analysis applied to columns 2 and 3 of Table I yields 5.6 ± 1.5 e-μ background events for column 2 and 8.6 ± 2.0 e-μ background events for column 3, both consistent with the observed number of e-μ events.

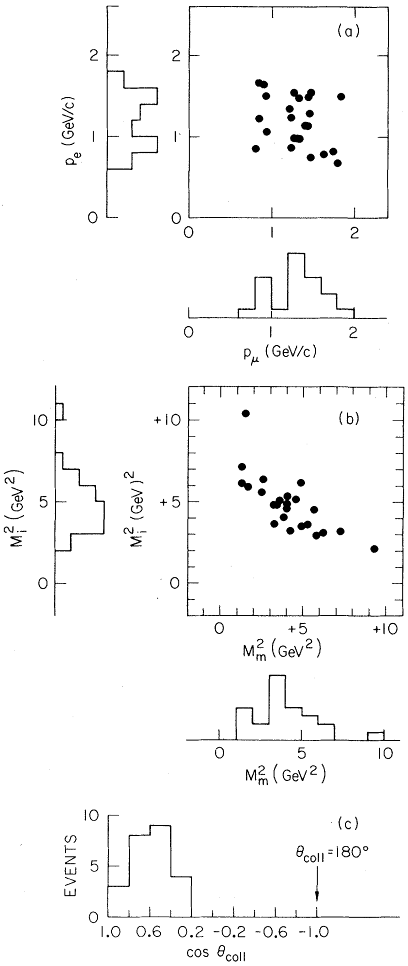

FIG. 1. Distribution for the 4.8-GeV e-μ signature events of (a) momenta of the e (p_e) and μ (p_μ); (b) square of the invariant mass (M_i^2) and square of the missing mass (M_m^2); and (c) $\cos\theta_{coll}$.

Figure 1(a) shows the momentum of the μ versus the momentum of the e for signature events.[14] 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 1(b) shows the square of the invariant e-μ mass (M_i^2) versus the square of the missing mass (M_m^2) recoiling against the e-μ system. To explain Fig. 1(b) at least two particles must escape detection. Figure 1(c) shows the distribution in collinearity angle between the e and μ ($\cos\theta_{coll} = -\vec{p}_e\cdot\vec{p}_\mu/|\vec{p}_e||\vec{p}_\mu|$). 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 *observed* cross section in the range of detector acceptance for signature e-μ events versus center-of-mass energy with the background subtracted at each energy as described above.[9] There are a total of 86 e-μ events summed over all energies, with a calculated background of 22 events.[12] 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 e-μ 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 fac-

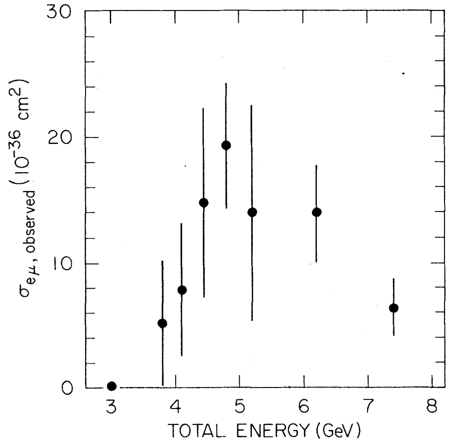

FIG. 2. The *observed* cross section for the signature e-μ events.

tors are largest for low $\sqrt{s}$. Thus, the apparent threshold may not be real.

We conclude that the signature e-μ 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 conventionally lead to an e and a μ in the final state. A possible explanation for these events is the production and decay of a pair of new particles, each having a mass in the range of 1.6 to 2.0 GeV/c^2.

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[*] Work supported by the U. S. Energy Research and Development Administration.

[†] Present address: Department of Physics and Astronomy, University of Massachusetts, Amherst, Mass. 01002.

[‡] Fellow of Deutsche Forschungsgemeinschaft.

[§] Centre d'Etudes Nucléaires de Saclay, Saclay, France.

[‖] Institut de Physique Nucléaire, Orsay, France.

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[11] These contamination calculations do not depend upon the source of the e or μ; anomalous sources lead to overestimates of the contamination.

[12] Using *only* events in column 1 of Table I we find at 4.8 GeV $P_{h\to e}=0.27\pm0.10$, $P_{h\to\mu}=0.23\pm0.09$, and a total e-μ background of 7.9 ± 3.2 events. The same method yields a total e-μ background of 30 ± 6 events summed over all energies. This method of background calculation (Ref. 9) allows the hadron background in the two-prong, zero-photon events to be different from that in other types of events.

[13] Our studies of the two-prong and multiprong events show that there is *no* correlation between the misidentification or decay probabilities; hence the background is calculated using independent probabilities.

[14] Of the 24 events, thirteen are $e^+ + \mu^-$ and eleven are $e^- + \mu^+$

Linear Regge Trajectories for the Psion Family and O(4) Dynamics[*]

Ngee-Pong Chang[†]
Physics Department, City College of the City University of New York, New York, New York 10031

and

C. A. Nelson[‡]
Department of Physics, State University of New York at Binghamton, Binghamton, New York 13901

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The newly discovered psion family can be described by mass-squared linear Regge trajectories. The new J^{PC} assignments are for 2.8 GeV/c^2, 0^{++}, and for the 3.4 region, 2^{++}, 1^{-+}, 0^{++}. All radiative decays are related through a single $S_{\mu\nu}F_{\mu\nu}$ coupling. A good fit is obtained.

With the discovery[1-4] of the psions[5] J/ψ, ψ', P_c, χ, X a new chapter in elementary particle spectroscopy has been opened up. A popular scheme for this new spectroscopy is the charmonium model[6] based on a $c\bar{c}$ bound-state picture where the potential is a mixture of linear potential ("quark confinement") and Coulomb potential ("asymptotic freedom"). The resulting J^{PC} assignments are, in the order of increasing masses, 0^{-+} (2.8), 1^{--} (3.1), 2^{++}, 1^{++}, 0^{++} in the 3.4-GeV mass region, 1^{--} (3.7), and so on.[7]

In this note we report on an alternative to the charmonium spectroscopy, in which 2.8 GeV/c^2 has 0^{++} and in the 3.4-GeV/c^2 mass region the J^{PC} assignments are 2^{++}, 1^{-+}, and 0^{++}. This alternative assignment is based on a study of the dynamics of linear O(4) Regge trajectories. The motivation for our study came principally from the following simple empirical observation: A family of Regge trajectories, linear in M^2, with