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THE eμ EVENTS PRODUCED IN $e^+ - e^-$ ANNIHILATION*

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This paper is a summary of a talk presented at this Conference. It is nothing more than a picture book of the properties of the eμ events which are produced in $e^+ - e^-$ annihilation. A full discussion of these properties appears in Ref. 1, and an early discussion in Ref. 2. The evidence for the events is given in Refs. 2, 3, and 4.

The eμ events discovered in the data produced at SPEAR by the SLAC-LBL magnetic detector collaboration[3] have the form

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

They are found by studying all events with only 2 tracks visible in the detector, with total charge 0 and with no photons. To strengthen the identification[2,3] of one track as an e and the other as a μ, each track is required to have a momentum greater than 0.65 GeV/c and the event is required to be non-coplanar with respect to the e^+e^- beams by at least 20°. These requirements, particularly the lower momentum limits, affect the distributions to be discussed later. 86 events, including a calculated background[2,3] of 22 ± 5 events, have been in the energy range $3.8 \leqslant \sqrt{s} \leqslant 7.8$ GeV. Here $\sqrt{s} = E_{cm}$ is the total energy of the incident e^+e^- beams.

The observed cross section corrected for background is shown in Fig. 1. Due to the incomplete acceptance of the detector, and the angle and momentum cuts used to select events, the true cross section is 3 to 12 times larger -- the factor depending upon the production mechanism. To further discuss the eμ events we use the natural hypothesis that the e and μ are the decay products of a pair of unknown (U) particles produced in pairs:

$$e^+ + e^- \rightarrow U^+ + U^- \qquad (2)$$

Figure 1 shows that the mass of the U, M_U, is of the order of, or less than, 2 GeV/c^2.

Figures 2, 3, 4 present some of the properties of the e and μ. The collinearity angle between

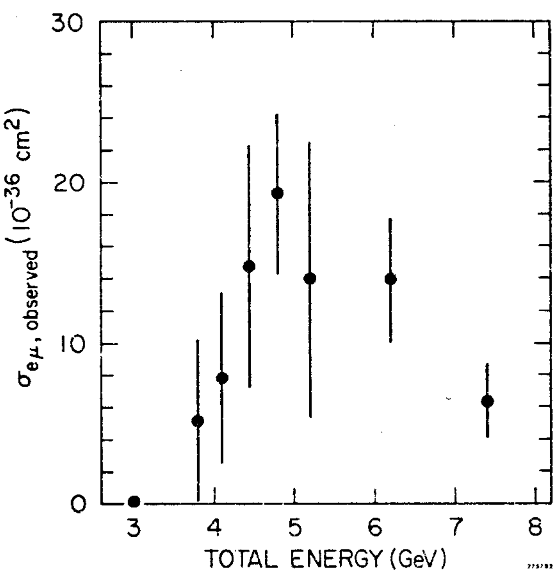

Fig. 1. The observed eμ cross section.

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the e and the μ, θ_{coll}, is defined by

$$\cos\theta_{coll} = -\underset{\sim}{p}_e \cdot \underset{\sim}{p}_\mu / (|\underset{\sim}{p}_e|\ |\underset{\sim}{p}_\mu|)$$

To present the momentum distribution of the e or μ independent of E_{cm} we define

$$\rho = (p - 0.65)/p_{max} - 0.65) \qquad (3)$$

where p is the magnitude of the e or μ momentum in GeV/c and p_{max} depends upon M_U.

We consider here two alternate hypothesis[5] for the nature of the U:

(a) The U is a boson B. A charmed meson[6] or an elementary bosons are examples. The e and μ come from the purely leptonic decays[5]: $B^- \to e^- + \bar{\nu}_e$, $B^+ \to e^+ + \nu_e$, $B^- \to \mu^- + \bar{\nu}_\mu$, $B^+ \to \mu^+ + \nu_\mu$. The dotted curves in Figs. 2, 3, 4 are for

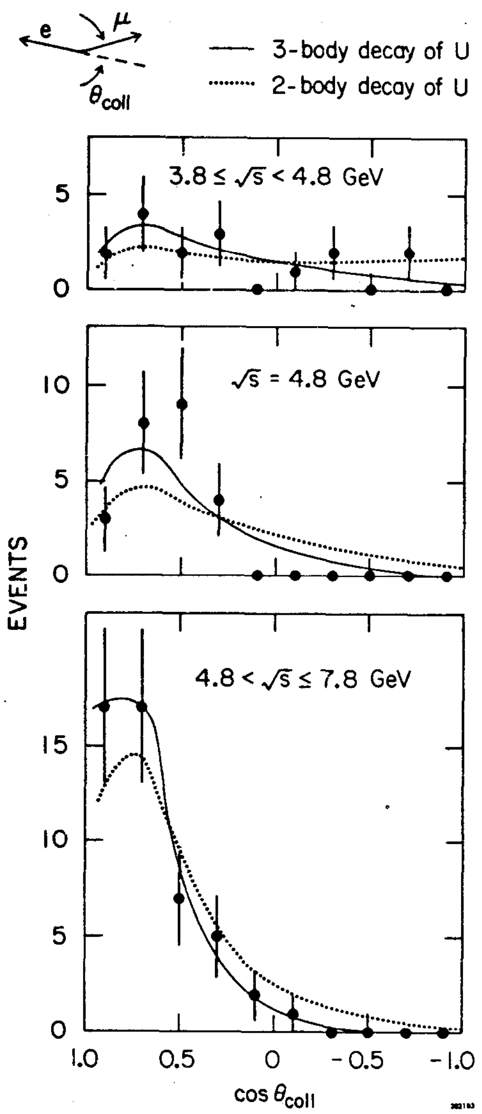

Fig. 2. Distribution in θ_{coll}.

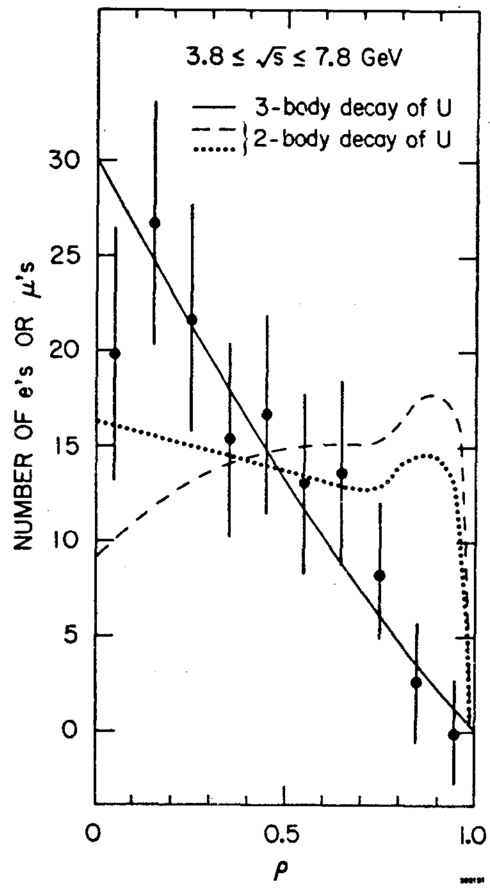

Fig. 3. Distribution in ρ for all $\sqrt{s}$.

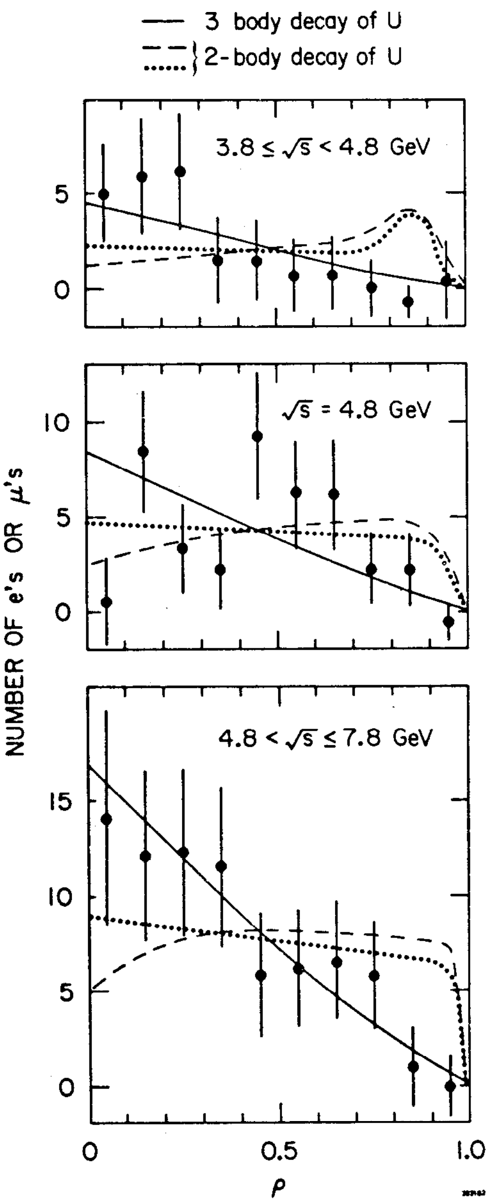

Fig. 4. Distribution in ρ.

this hypothesis with $M_B = 1.9$ GeV/c^2, and no spin-spin correlation between the B^+ and B^-.

(b) The U is a heavy lepton[7] ℓ having the decay modes $\ell^- \to \nu_\ell + e^- + \bar{\nu}_e$, $\ell^+ \to \bar{\nu}_\ell + e^+ + \nu_e$, $\ell^- \to \nu_\ell + \mu^- + \bar{\nu}_\mu$, $\ell^+ \to \bar{\nu}_\ell + \mu^+ + \nu_\mu$. The solid curves in Figs. 2, 3, 4 are for this hypothesis with M_ℓ = 1.8 GeV/c^2, a V-A current between the ℓ and ν_ℓ, and zero mass for the ν_ℓ. Also spin-spin correlation between the ℓ^+ and ℓ^- are ignored. These two hypotheses were chosen to illustrate the characteristic similarities and differences between a 2-body decay and a 3-body decay. And the masses are examples which seem to fit the angle and momentum distributions. But masses in the range of 1.6 to 2.0 GeV/c^2 are acceptable. Particularly in the 4.8 GeV data the 2-body hypothesis has difficulty in explaining the small number of large θ_{coll} events. Reduction of M_U can cure this, but then problems arise[1] with the momentum distribution of the e and μ. An alternative cure requires strong spin-spin correlation between the mesons[2]. A 3-body decay mode obviously fits the cos θ_{coll} distributions in a more natural manner.

The same observation holds for the momentum distributions as shown in Figs. 3 and 4. We see that the 2-body decay mode usually predicts too many large ρ, that is large **p**, points. Only at 4.8 GeV are the 2-body and 3-body hypotheses equally applicable. Finally, if one distorts the theoretical θ_{coll} distribution for a 2-body decay to fit the experimental θ_{coll} distribution, one obtains a slightly worse fit to the ρ distributions. This is the dashed curves in Figs. 3 and 4.

To summarize our knowledge of the eμ events I will paraphrase Gary Feldman's summary of these events at the 1975 Lepton-Photon Conference[4].

1. We know the following:
   a. Anomalous eμ events exist.
   b. The data are not consistent with all the events coming from 2-body decays.

   c. We know of nothing which is inconsistent with the hypothesis that the events come from the 3-body decay of a U particle. In particular the 3-body decay could be the purely leptonic decay of a sequential heavy lepton.

2. We still have to answer the following questions.
   a. Is a heavy lepton completely consistent with the data?
   b. Is any other hypothesis consistent with the data?
   c. Is more than one thing going on? That is, are there several mechanisms producing $e\mu$ events?

REFERENCES

1. M.L. Perl, lecture presented at the 1975 SLAC Summer Institute on Particle Physics, (to be published in the proceedings of that Institute).
2. M.L. Perl, SLAC-PUB-1592 (to be published in Proceedings of the Canadian Institute of Particle Physics Summer School, McGill University, 1975).
3. M.L. Perl et al., SLAC-PUB-1626, submitted to Phys. Rev. Letters.
4. G.J. Feldman, Proceedings of the 1975 International Symposium on Lepton and Photon Interactions at High Energies (SLAC, 1975).
5. We do not have the space here to discuss other hypotheses such as semi-leptonic decay modes.
6. M.K. Gaillard, B.W. Lee, and J.L. Rosner, Rev. Mod. Phys. 47, 277 (1975); M.B. Einhorn and C. Quigg, FNAL report number FERMI-LAB-Pub-75/21-THY.
7. A review as of October, 1974 on heavy lepton theories and searches is M.L. Perl and P. Rapidis, SLAC-PUB-1496 (1974) (unpublished); see also: J.D. Bjorken and C.H. Llewellyn Smith, Phys. Rev. D7, 88 (1973); Y.S. Tsai, Phys. Rev. D4, 2821 (1971).