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A NEUTRINO-INDUCED FOUR LEPTON EVENT

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Abstract

We report observation of a neutrino-induced event with two electrons, one positron, one positively charged muon, a neutral K meson, and seven gammas in an experiment performed in the FNAL 15-ft. Bubble Chamber with a 47% atomic mixture of neon in hydrogen. Estimated experimental electron backgrounds are $\sim 10^{-4}$ per track. At present we have no plausible interpretation of this event.

In a partial scan of events produced by neutrinos and anti-neutrinos we have found an event with two electrons, one positron, one positively charged energetic muon, one neutral K meson and seven gammas. Previous experiments have reported one four-muon event and many trimuon events.[1] Several bubble chamber experiments have reported muon-electron events produced by neutrinos.[2] This is the first reported example of tri-electron production by neutrinos and the first multi-lepton event in which the details of the accompanying hadron shower can be identified.

The event was recorded using the Fermilab 15-ft. Bubble Chamber and a two-plane External Muon Identifier (EMI)[3], which were exposed to a beam of neutrinos and antineutrinos. The chamber was filled with a 47% atomic mixture of neon in hydrogen for which the radiation length is 54 cm and the pion absorption length is 1.9 m. The target mass within the fiducial volume was 9 metric tons.

The neutrinos were produced by a 400 GeV proton beam incident on a beryllium oxide target. The resultant mesons were focused using the FNAL quadrupole triplet beam, which enhances the fraction of neutrino flux at high energy.[4] The average ratio of the flux of antineutrinos to that of neutrinos is 0.30[5].

The event is pictured in Fig. 1 together with a magnified view of the vertex region showing the $K^o_S \rightarrow \pi^+\pi^-$ decay, which occurs 1.7 cm from the vertex. The electromagnetic processes which signify the electron identification are as follows: 1) trident production (TR); 2) non-visible change in curvature due to bremsstrahlung with electron pair which points tangent to a track but not to a vertex (NVB + EP); and 3) visible change of curvature due to bremsstrahlung which may or may not have an accompanying electron pair (VB + EP). In addition to these electron signatures, each electron spirals at the end of its track. Table I presents the measured momenta and energies of the tracks and the identifying signatures. Some of the invariant mass combinations are also noted.

Except for three short stubs, presumably protons from fragmentation of the neon nucleus, there are no charged tracks leaving the vertex other than the four leptons. Each electron originates at the vertex. Seven gammas from the vertex convert within the fiducial volume; other gamma conversions are bremsstrahlung from the direct electrons. Six gammas can be interpreted as three π° produced at the vertex.

The muon track was extrapolated through 9 absorption lengths and was recorded in the two-plane EMI. One chamber in each plane has a good match to the extrapolated track. There are no other hits in either chamber within 1 μsec. of the muon signal. The probability that this muon comes from pion decay is .004.

Among the background processes which can simulate direct electron production are Compton scattering, internal conversion of photons and decay of charged K mesons by the K_{e3} mode. Since the invariant masses of the e^+e^- pairs exceed 0.8 GeV/c[6], the Dalitz decay of a π° or η° meson can be ruled out. The probability that there is a Dalitz decay followed by a large angle electron scattering is $<10^{-8}$ per event. The probability that any one electron originates as a Compton electron within one cm is $\lesssim 10^{-4}$ per event and as an asymmetric Dalitz pair whose partner is undetected ($E \lesssim 3$ MeV) is $\lesssim 0.4 \times 10^{-4}$ per event. Similarly the probability that any one electron is produced by K_{e3} decay is $\lesssim 3.3 \times 10^{-4}$ per kaon. Therefore, the interpretation of the event as an ordinary interaction or a dilepton interaction with the additional electrons produced by these background processes can be discarded. The estimated probabilities of various specific examples of this interpretation are $<10^{-9}$ per $\nu(\bar{\nu})$ interaction.

This event appears to be a charged current antineutrino interaction. The μ^+ has the largest momentum of all the tracks and has a characteristically large momentum transverse to the ν direction, $p_\perp(\mu^+) = 1.67 \pm .06$ GeV/c (see figure 2). The missing momentum transverse to the neutrino direction is $0.34 \pm .11$ GeV/c. If we assume the event is an inelastic antineutrino interaction we can compute the scaling variables and other kinematic quantities. The results are presented in Table II.

The entire sample should contain 20,000 ν charged current events and 2500 $\bar{\nu}$ events, but only ten percent have been examined. Assuming no additional events are found we set an upper limit based on the full sample at the 90% confidence level of $16. \times 10^{-4}$ $(2. \times 10^{-4})$ for this process with respect to charged current antineutrino (neutrino) interactions.

Possible interpretations of the event and estimated rate per antineutrino charged current interaction are listed below.

1) Production of the charmed F meson with $K\bar{K}$.[7]

$$\bar{\nu}_\mu + N \rightarrow \mu^+ + F^- + K\bar{K} + X, \quad F^- \rightarrow \phi e^- \nu, \quad \phi \rightarrow e^+ e^-$$

Assuming a 1% rate of F production, a branching ratio into $\phi e \nu$ of 15%, and the rate of associated production of 20%, we estimate the rate to be 10^{-7}.

2) Charm production with inclusive vector meson production

$$\bar{\nu}_\mu + N \rightarrow \mu^+ + D + V + X, \quad D \rightarrow K e \nu, \quad V \rightarrow e^+ e^-$$

Assuming the rate of inclusive vector meson production is 5%, we estimate the rate to be 10^{-7}.

3) Trilepton production with associated $K\bar{K}$ production.

$$\bar{\nu}_\mu + N \rightarrow \mu^+ e^+ e^- + K\bar{K} + X, \quad \bar{K} \rightarrow e^- \pi^\circ \nu$$

Assuming the rate of trilepton production above 30 GeV is 10^{-4} and that the electron comes from K decay, Compton scattering or asymmetric Dalitz decay, we estimate the rate to be 10^{-7}.

4) Charm production with a radiative e^+e^- pair. The large invariant mass of the pair makes this interpretation improbable. The estimated rate is 10^{-8}.

Other hypotheses such as heavy lepton production, new quark production, background processes, etc. are estimated to have comparable or smaller rates in consideration of the limited value of W^2 and other kinematic characteristics.

In conclusion, we have observed one example of neutrino-induced four lepton production in an incomplete analysis of an exposure obtained using a neon-hydrogen bubble chamber. We have no compelling interpretation of the origin of the event.

We acknowledge the efforts of the FNAL 15-ft. Bubble Chamber staff. We also thank the staffs at the various laboratories for their assistance in constructing EMI chambers and for scanning and measuring our data.

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6. If no bremsstrahlung corrections are made to the electrons, the minimum invariant mass of any e^+e^- pair is 0.66 ± .04 GeV.

7. The invariant masses reported in ref. 1 for the four muon event are also consistent with this interpretation.

FIGURE CAPTIONS

Fig. 1 The neutrino-induced event with two electrons, one positron, one muon, a $K_s \rightarrow \pi^+\pi^-$ decay, and multiple gammas. The insert provides a magnified view of the vertex showing the leptons originating at the vertex and the K_s° decay.

Fig. 2 Momenta transverse to neutrino direction. The dotted line shows the missing transverse momentum excluding proton stubs.

Table I. Momenta of tracks from the vertex, electron identification signatures, and invariant mass combinations. The neutrino is incident along the x-axis. Bremsstrahlung corrections are included for the electron tracks.

Table II. Summary of neutrino scaling variables.

TABLE 1

Track	P_x	P_y	P_z	E	Signatures
1. μ^+	21.68±.43	1.54±.06	.65 ±.02	21.74±.44	EMI (2 planes)
2. e^+	1.95±.18	.32±.03	-.46 ±.05	2.03±.18	TR, NVB + EP, TR, VB + EP, VB + EP
3. e^-	.74±.06	-.48±.05	-.24 ±.03	.91±.08	TR, NVB + EP, VB
4. e^-	2.27±.20	-.26±.03	.08 ±.01	2.29±.21	NVB + EP, VB + EP
5. K^o_S	1.95±.04	-.35±.02	.31 ±.02	2.06±.04	3C Kinematic fit $\chi^2 = 1.6$
6. γ_1	.04±.004	-.23±.02	.12 ±.01	.26±.03	
7. γ_2	.10±.01	.07±.01	.004±.001	.12±.01	
8. γ_3	.54±.05	-.03±.005	.01 ±.002	.54±.05	
9. γ_4	.16±.01	-.17±.02	.08 ±.01	.25±.02	
10. γ_5	.08±.01	-.02±.003	-.04 ±.004	.09±.01	
11. γ_6	1.60±.14	-.20±.02	-.20 ±.02	1.62±.15	
12. γ_7	.005±.001	.04±.005	-.06 ±.01	.07±.01	
13. proton	.33±.07	.02±.01	.32 ±.07	1.05±.04	
14. proton	.21±.05	-.17±.05	-.12 ±.13	.98±.003	
15. proton	-.09±.01	.12±.01	.08 ±.01	.95±.001	

Invariant Masses

$m_{234} = 1.15 \pm .08$	$m_{2345} = 2.19 \pm .10$	$m(\gamma_5\gamma_6) = .13 \pm .02$
$m_{23} = .96 \pm .07$	$m_{25} = 1.24 \pm .05$	$m(\gamma_3\gamma_6) = .15 \pm .02$
$m_{24} = .82 \pm .05$	$m_{35} = .98 \pm .05$	$m(\gamma_4\gamma_5) = .13 \pm .02$
$m_{34} = .79 \pm .08$	$m_{45} = .78 \pm .05$	$m(\gamma_1\gamma_4) = .14 \pm .02$
$m_{15} = 2.49 \pm .05$	$m_{1234} = 4.09 \pm .10$	$m(K^o\gamma_5\gamma_6) = .89 \pm .03$
	$m_{all} = 7.46 \pm .06$*	

*Excluding proton stubs

Table II

E_{vis} = 32.0

y_{vis} = .32

x_{vis} = .21

v = .068±.004

$W^2_o = (\Sigma_{vis}E_h)^2 - (\Sigma_{vis}p_h)^2$ = 14.3±1.1

$W^2_{vis} = 2mE_{vis}y(1-x_{vis}) + m^2$ = 16.0

Q^2_{vis} = 4.11

Missing transverse momentum = .34±.11

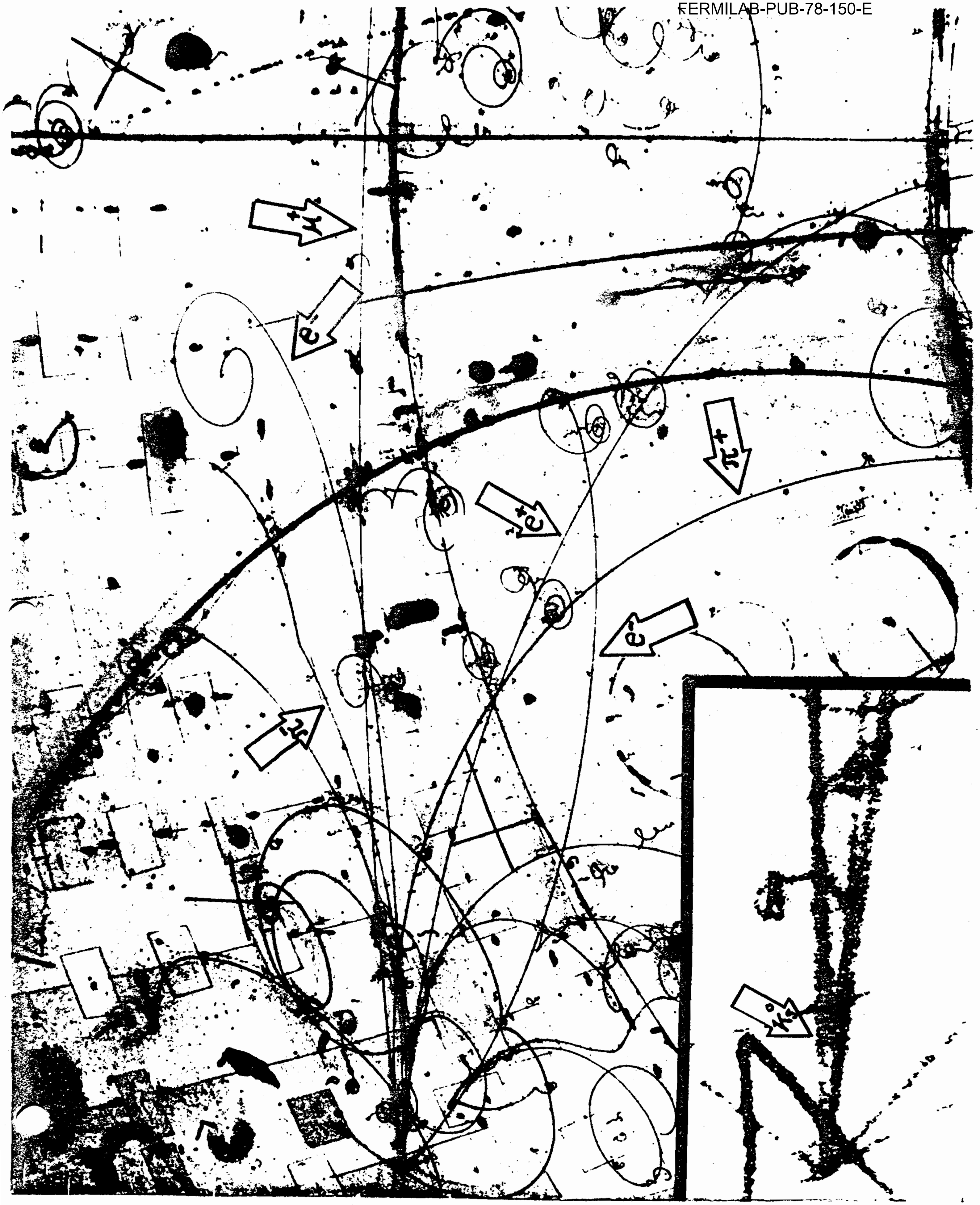

Fig. 1

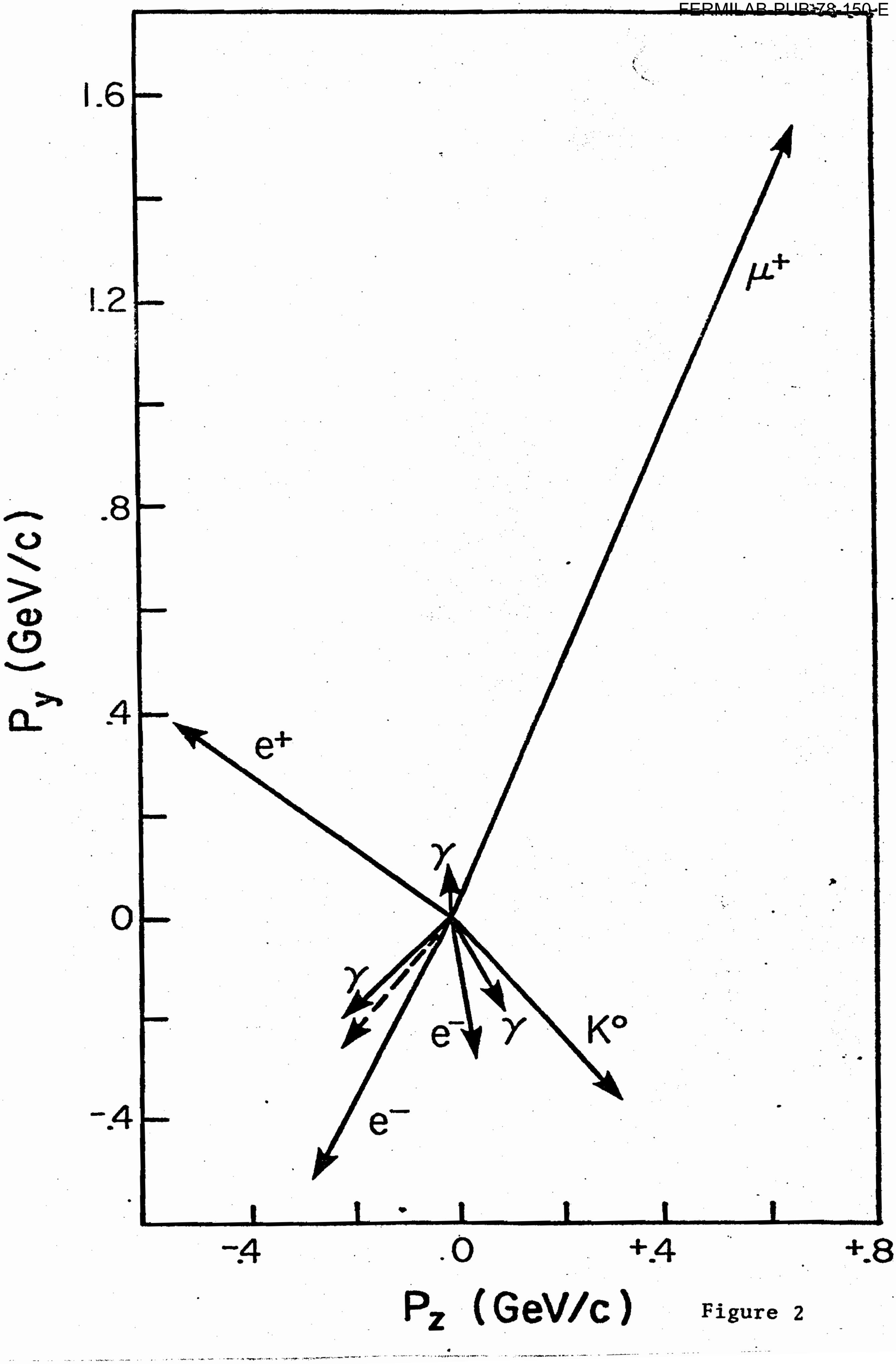

Figure 2