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NEUTRINO INTERACTIONS WITH $e^+\mu^-$ AND MULTIPLE K^0's*

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Collaboration[1)]

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ABSTRACT

A scan for directly produced positrons in 5,000 neutrino interactions in the Neon (21%) - Hydrogen filled bubble chamber at Fermilab has yielded 15 events, 9 of which have μ^-'s identified in the external muon identifier. On correcting for detection efficiency one obtains $\frac{\sigma(e^+\mu^-)}{\sigma(\mu^-)} \sim 1 \times 10^{-2}$ for $E_{e^+} > .8$ GeV and $E_\nu > 5$ GeV. The kaon multiplicity is unexpectedly high. Eleven of the events have one or more Vees and three have two or more. Among the 11 events are two clear Λ's and two ambiguous K^0/Λ. There are four events with identifiable charged kaons. A 16^{th} e^+ event (⑨) is a definite $\bar{\nu}_e$. From this information one concludes that the kaon multiplicity is $2 \pm .6$ K^0's and 2 ± 1 $K^\pm$'s per interaction. From the observation $\langle p_{\mu^-}\rangle / \langle p_{e^+}\rangle = 6.6$, one concludes that the e^+'s are probably not uniquely from heavy lepton decay. From a variety of analyses involving the e^+ and/or K^0's one learns that the mass of the hadron (C) that produces the e^+'s is greater than 1.6 GeV. By determining the fraction of normal charged current (CC) events that have $K^0_S \to \pi^+\pi^-$ we are able to compare this fraction with the fraction of CC events that have $e^+\mu^-$ $(K^0_S \to \pi^+\pi^-)$ to establish a conservative lower limit to the semileptonic branching ratio,

$$\frac{C \to (e^+ \text{ and } \mu^+)\,\nu}{C \to \text{all}} > 0.33\,(1 \pm .42)\ ,$$

provided that the same number of K^0_S exist in the nonleptonic decays as in the semileptonic ones, and that the phase space for μ^+ and e^+ are nearly equal. There is no compelling evidence for an energy threshold and there is a hint of some neutral current events among the e^+ events.

CONTENTS

I. INTRODUCTION

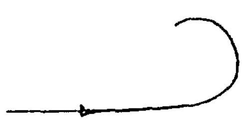
The 15-foot Ne(21%)-H hybrid [2] bubble chamber system at Fermilab has been used to examine the hadronic state of neutrino events that have a well identified positron and a possible negative muon. This experiment [3] was motivated by the evidence for dimuons in one percent of the charged current (CC) neutrino interactions above 35 GeV in the HPWF experiment [4] and by the ψ discovery [5] and the possibility that this narrow resonance might be a bound state of the charmed quark-anticharmed quark ($c\bar{c}$) system. The dileptons could then be produced by the semileptonic decay of charmed mesons ($c\bar{u}$, $c\bar{d}$ or $c\bar{s}$) together with the μ^- of the CC event.

In what we believe to be an unbiased scan for directly produced positrons (or electrons) in a sample of 5,000 neutrino interactions we have found 15 $e^+\mu^-$ candidates with a surprisingly large number of K^0's. Seven of them have unambiguous $K^0_S \to \pi^+\pi^-$ decays in them. The visible energy of these events ranges from 15 GeV to 100 GeV and although the fraction of events when corrected for detection efficiency is close to the HPWF [4] value of one percent there is no clear evidence for an energy threshold.

II. POSITRON DETECTION

The 15-foot bubble chamber is approximately a sphere of 1.9 meters radius. The liquid mixture of the Ne (21% atomic) and H has a radiation length of 1.1 meters. The positrons are identified by their electromagnetic interaction as shown topologically in the following diagrams

"VB" = Visible Energy Loss by Bremsstrahlung



"VC" + ("PR" = e^+e^- Pair)

"NVB + PR" = Non Visible Energy Loss by Bremsstrahlung + e^+e^- Pair

TRIDENT

The overall detection efficiency as measured by observing these processes for tracks of e^+e^- pairs is 0.48 ± 0.07 and is nearly independent of positron energy above 0.8 GeV. It decreases below that energy. For rate determination we ignore events with positrons of energy below 0.8 GeV. Two of the 15 events are of this type.

Any positron candidate that is consistent with being the positive branch of a π^0 Dalitz pair *) is rejected as a directly produced positron. We believe that only 5% of the real events are rejected by this criterion.

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*) Namely, that the $M_{e^+ \text{"}e^-\text{"}} < 140$ MeV/c^2 .

III. MUON IDENTIFICATION (EMI)

External to the bubble chamber and shielded from the volume of the chamber by a wall of absorber is located a "plane" of 24 multiwire proportional Chambers (MWPC, 1 m^2 each). All non-interacting tracks are considered as potential muons and their trajectories are extrapolated through the absorbers and to the MWPC. Any MWPC encoding that falls within the 2 standard deviation "multiple scattering circle" certifies the track as a likely muon candidate. If, furthermore, the track carries the highest transverse momentum with respect to the neutrino direction it is considered as a very likely muon. Three of the events whose tracks had this property missed the EMI. For normal (CC) events the geometrical efficiency of the EMI was 85%. Furthermore, three events (7), (8), and (16) are doubtful muon candidates. Figs. 6a,b summarize the EMI confidence levels for those events where the μ^- candidate strikes the EMI. C_μ is the probability that a muon gives a worse match and C_h is the probability that a hadron gives a better match. Muons are flat in C_μ for any momentum, hadrons are flat in C_h for any momentum, but not vice versa. Even though events (7), (8), and (16) are not likely μ^- candidates they have been treated here as though they were CC events. (16) is a likely $\bar{\nu}_e$ but not (7) or (8). More will be said of events (7) and (8) in section V.5.

IV. RESULTS

Table I summarizes the results of the scan in which 5,000 $\pm$ 300 neutrino events with $\Sigma p_x > 5$ GeV/c (x is the neutrino direction) were found. The beam intensity with $\sim 5 \times 10^{12}$ 300-GeV protons per pulse striking a 1 interaction-length Al target (followed by the 2-horn focusing system) was such as to produce an event every eight pictures. The first two columns of this table tell how the leptons were identified.

IV.1. Rate and Background

The 13 $e^+\mu^-$ candidates with $E_{e^+} > .8$ GeV were observed in this sample of neutrino interactions, 90% of which we estimate were CC events. Taking account of the 48% e^+ detection efficiency and the 5% Dalitz pair loss-factor, one calculates the $e^+\mu^- / \mu^-_{total}$ production ratio to be

$$e^+\mu^- / \mu^-_{total} = \frac{(\text{number of } e^+ \text{ events, } E_{e^+} > .8 \text{ GeV})(\text{Dalitz Pair loss-factor})}{(\text{number of } \mu^- \text{ events})(e^+ \text{ detection efficiency for } E_{e^+} > .8 \text{ GeV})}$$

$$= \frac{(13 \pm 3.6)(1.05 \pm .05)}{(5000)(.9)(.48 \pm .07)}$$

$$= 0.63\ (1 \pm .33) \times 10^{-2}\ .$$

This number must be corrected for possible backgrounds and for the loss of events whose positrons have momenta less than 0.8 GeV. The greatest uncertainty occurs for this latter phenomenon because it is model dependent. Let f be the fraction of the e^+ spectrum, that is above 0.8 GeV. It could be as small as 1/2. The background which will be summarized shortly could account for less than one event and, in light of the much greater uncertainty of the energy cut loss, is ignored here. The final "corrected" ratio is,

$$\boxed{(e^+\mu^- / \mu^-_{total})_{corr} \approx f^{-1}\ 0.63(1 \pm .33) \times 10^{-2}}.$$

Backgrounds can be summarized as follows:

1. Asymmetric Dalitz pairs.

$$\nu_\mu N \to \mu^- \pi^o X$$
$$\quad \hookrightarrow \gamma e^+ e^- (E_{e^-} < 5 \text{ MeV})$$

< 0.7 events

2. $\nu_\mu N \to \mu^- K^+ X$

$\quad \hookrightarrow e^+_{collinear}$ (π^0 with missing PPS) ν_e

$< .0\,3$ events

3. $\bar{\nu}_e N \to e^+ X$

$= 0.5$ events for all E_{e^+}/E_{vis}

$< 6 \times 10^{-2}$ events for $E_{e^+}/E_{vis} < 0.5$

We expect 23 $\nu_e N \to e^- X$ events and find 29. Figure 1 summarizes the E_{e^-} distribution for these events one of which has a μ^+ candidate.

Event (9) is very likely a $\bar{\nu}_e$ because there is no muon candidate and the e^+ is very energetic (low y).

Event (16) is also a likely $\bar{\nu}_e$ but has been treated as one of the $e^+\mu^-$ events.

4. $K^o_L \to e^+ \pi^- \nu$ decay close to the primary vertex.

$< 1.7 \times 10^{-2}$ events.

Total background: < 1 event

IV.2. The K^o Phenomenon

The third column of Table 1 reveals the following details of the 15 $e^+\mu^-$ events,

7 have $K^o_S \to \pi^+\pi^-$

2 have $K^o_S \to \pi^+\pi^-$ or $\Lambda \to p\pi^-$ (ambiguous)

2 have $\Lambda \to p\pi^-$ which might be secondaries from $\bar{K}^o$ N interactions within the nucleus

4 have no Vees.

On the basis of the 7 unambiguous $K^0_S \to \pi^+\pi^-$ alone one predicts 23 ± 9 K^0 produced in these 15 $e^+\mu^-$ events ; consequently, per $e^+\mu^-$ event,

$$<N_{K^0}> = \frac{7 \times (3.3)^*}{15} = 1.54 \pm 0.58$$

based on unambiguous $K^0_S \to \pi^+\pi^-$.

Adding into the sample of $K^0_S \to \pi^+\pi^-$ the 2 ambiguous K^0/Λ ;

$$<N_{K^0}> = \frac{9 \times 3.3}{15} = 2.0 \pm 0.6$$

Total K Multiplicity

By assuming that $<N_{K^\pm}> = <N_{K^0}>$ (ie charge symmetry) we obtain for the total K multiplicity per $e^+\mu^-$ event,

$$\boxed{<N_{K^0_\pm}> = 4.0 \pm 1.2}$$

As an indication of internal consistency with the hypothesis of the production of 2 K^0's and 2 $K^\pm$ per $e^+\mu^-$ event, the following tabulation compares what we should expect with what we observe

	K^0_S		K^0_L		Λ via $\bar{K}^0$ Int in neon nucleus	Events with no Vees	$K^\pm$	
	+ −	0 0	Decay	Int			Decay	Int+Λ
Observe	9	2	2	2(I→Λ)	2 + 2 amb	4	2	1 or 2
Expect if $N_{K^0}=N_{K^\pm}=2$	9.3	1.8	1.2	1.6(I→Λ)	~ 1 or 2	4.7	[illegible]	2

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* This factor is 3.3 rather than 3 because we estimate a 10 % loss of $K^0_S \to \pi^+\pi^-$ because they decay too close to the vertex. The factor of 3 takes account of the $K^0_S \to \pi^+\pi^-$ branching ratio of 2/3 and that half the K^0's are K^0_S.

V. POSSIBLE ORIGINS OF THE PHENOMENON

V.1. Heavy Leptons or Charmed Particles ?

Table 11 summarizes the kinematic quantities of the $e^+\mu^-$ events. The momenta of the leptons and strange particles are given in the first 6 columns and the usual deep inelastic kinematic variables for the "visible" quantities are given in the last five. Fig 2a is a plot of Q^2_{vis} vs ν_{vis}. Figs 2b shows the x_{vis} and y_{vis} distributions.

The ratio of the mean μ^- and e^+ momenta,

$$\langle P_{\mu^-}\rangle / \langle P_{e^+}\rangle = 6.6,$$

according to the Pais and Treiman[6] analysis suggests that the positrons do not originate uniquely from heavy lepton decay. They seem more likely to be associated with the semileptonic decay of a charmed hadron system. Their association with K^0's would suggest the primary origin to be charmed meson decay. The $e^+\Lambda$ events could indicate charmed baryon decay. However, some of the Λ's are expected to be from the $\bar{K}^0 N$ interactions in the Ne nucleus.

V.2. Mass and Momentum Correlations

Table III gives various correlations including the invariant mass of the positron and the strange particle(s). An indicator of the mass of the decaying object is the component of the positron's momentum normal to μ-ν plane. (Here the normal to the plane is defined as $\hat{n} = \vec{\mu} \times \vec{\nu} / |\vec{\mu} \times \vec{\nu}|$). The average value of $\langle |p^{e^+}_{\hat{n}}| \rangle$ for the 15 $e^+\mu$ events is 0.23 GeV/c. Fig 3 shows this distribution and compares it with normal hadrons in CC events. Fig 4 is a similar distribution for the K^0's. Neither e^+'s nor K^0's differ in this respect from normal hadrons.

If we are observing the 2 and 3 body purely leptonic decays of the objects suggested by Pati and Salam[7] their effective masses must be considerably smaller than 2 GeV/c in order to produce positrons with as low a value of $\langle p^{e^+}_{\hat{n}} \rangle$ as 0.23 GeV. If on the other hand they decayed into leptons + hadrons their effective mass could be higher and be consistent with our data. Various charmed meson models can be constructed [8] that lead to mass estimates of the charmed meson. However, the mass determination is very sensitive to whether one is observing 3-body or 4-body semileptonic decay. Generally, the $|p_{\hat{n}}^{e^+}|$ distribution for 3-body decay suggests that ,

$$\boxed{m_{charm} > 1.6 \text{ GeV}}$$

Possible "O-C" determination of the charmed Meson Mass

If there were enough data one might search for a subset of events in which all particles except the hypothetical semi-leptonic decay neutrino would be visible. One could calculate the missing neutrino momentum via O-C analysis. Even though Fermi motion of the target nucleon smears the $e^+K^o\nu$ mass, one might determine the mass from the central value of this distribution. We tried this analysis, on one candidate of this type (4). It gave the following values of $m(e^+K^o\nu)$ for different values of Fermi momentum.

$(P_x)_{Fermi}$ (GeV/c)	$m_{e^+\bar{K}^o\nu}$ (GeV)
-.1	2.36
0	1.84
.1	1.30

V.3. Semi leptonic Branching Ratio (lower limit)

The production and decay of charmed hadrons could proceed as follows,

$$\nu N \rightarrow \mu^- C + nK's + X$$
$$C \rightarrow e^+(\nu) + mK's \quad \text{(semileptonic)}$$
$$C \rightarrow \text{hadrons} + m'K's \quad \text{(non leptonic)}$$

If one assumes m = m' it is possible to set some approximate limits on the semileptonic branching ratio by comparing the fraction of CC events that have $K_s^o \rightarrow \pi^+\pi^-$, $4.7\ (1 \pm .18) \times 10^{-2}$, (scaled up by the ratio of the number of e^+ events seen to the number of them that have $K_s^o \rightarrow \pi^+\pi^-$) to the fraction of CC events that have semi-leptonic e^+ events (f^{-1} $0.63\ (1 \pm .33) \times 10^{-2}$).

1. The lowest possible lower limit

The branching ratio $\frac{C \to e^+}{C \to \text{total}}$ can be made smallest by making the denominator largest by assuming that all the $K^0_s \to \pi^+\pi^-$ seen in CC events are from C decay (a rather unreasonable assumption considering that there are an equal number of Λ's seen in the same sample of data that determined the $(K^0_s \to \pi^+\pi^-)/\mu^-$ total $= 4.7 \times 10^{-2}$, which suggests some of the K^0_s are from normal associated production). However, the spirit of the present estimate is to make this branching ratio lower limit as small as possible. Therefore,

$$BR\left(\frac{C \to e^+}{C \to \text{all}}\right) > \frac{(e^+\mu^-/\mu^-\text{tot})_{corr}}{\left(\frac{\text{number of } e^+ \text{ events}}{\text{number of } e^+ \text{ events with } K^0_s \to \pi^+\pi^-}\right)\left(\frac{K^0_s \to \pi^+\pi^-}{\mu^- \text{ tot}}\right)}$$

where earlier we had determined,

$$(e^+\mu^-/\mu^-\text{tot})_{corr} = f^{-1}\ \frac{(\text{number of } e^+ \text{events})(\text{Dalitz Pair loss-factor})}{(\text{number of } \mu^- \text{ events})(e^+ \text{ detection efficiency})}$$

f is the fraction of the e^+ spectrum above .8 GeV.

Thus,

$$BR\left(\frac{C \to e^+}{C \to \text{all}}\right) > \frac{f^{-1}(\text{number of } e^+ \text{ events with } K^0_s \to \pi^+\pi^-)(\text{Dalitz Factor})}{(\text{number of } \mu^- \text{ events})(e^+ \text{ det eff})(K^0_s \to \pi^+\pi^-/\mu^- \text{ total})}$$

If we use the sample of 13 e^+ events with $E_{e^+} > 0.8$ GeV and take all $K^0_s \to \pi^+\pi^-$ among them, namely 8. This ratio becomes :

$$\underset{(\text{lowest poss})}{BR}\left(\frac{C \to e^+}{C \to \text{all}}\right) > 0.083\ (1 \pm .42),$$

where the fractional error of 0.42 comes mostly from the statistical error on the 8 e^+ events with $K^0_s \to \pi^+\pi^-$. Note that we have set f = 1 in order to make this limit as low as possible.

2. Still a conservative lower limit

If instead of the extreme assumption that all $K^0_s \to \pi^+\pi^-$ come from C decay one were to assume that half of them did, one would still be conservative in light of the evidence for normal associated production of $K_s^o \to \pi^+\pi^-$. This doubles the previous value,

$$BR_{\text{conservative}} \left(\frac{C \to e^+}{C \to all}\right) > 0.17 \ (1 \pm .42).$$

Finally, if one assumes that e^+ and μ^+ phase spaces are nearly equal then the total semileptonic branching ratio lower limit becomes,

$$\boxed{BR_{\text{conservative}} \left(\frac{C \to e^+ \text{ or } \mu^+}{C \to all}\right) > 0.33 \ (1 \pm .42)}$$

(provided that m = m').

The fractional error is dominated by the statistical uncertainty of the number of observed $K_s^o \to \pi^+\pi^-$ in our 15 (13 with $E_{e^+} >$ .6 GeV) e^+ events.

In fact, one should realize that the whole K^o phenomenon, based upon the $K_s^o \to \pi^+\pi^-$ events alone, is statistically uncertain. We might recall that the first four e^+ events we reported on at the Irvine Conference (7 Dec. 1975) each had an unambiguous $K_s^o \to \pi^+\pi^-$. Since then only five more (two of them ambiguous) have been found in eleven additional e^+ events.

There is an old proverb that says, "Truth is the daughter of time."

V.4. Possible Threshold of the Phenomenon

Figure 5 displays the distribution of energy, E_ν, of the 15 $e^+\mu^-$ events together with that for normal CC events. Both shapes are consistent with each other. This is also illustrated as follows :

E_ν (GeV)	Normal 1 μ^- (CC)	μ^-e^+
> 50	18 %	21 %
> 40	25 %	28 %
> 30	37 %	42 %

There is no compelling evidence for a threshold.

V.5. Possible Neutral Current Events

There are two or three events among the 15 e^{+} for which the EMI information favors a hadron hypothesis over the muon one (#'s ⑦, ⑤, ⑯). There is a possibility of EMI inefficiency although we do not expect it at this level. Our intent is to study the EMI performance during the times these events occurred for evidence of possible malfunction. One of the three events, ⑯, could be an $\bar{\nu}_e \rightarrow e^{+}$ event but the others are not likely $\bar{\nu}_e$'s.

VI. Summary

VI.1. There are 15 $e^{+}\mu^{-}$ events in $5000 \pm 300\nu$ interactions with $\Sigma p_x > 5$ GeV/c

VI.2. The best estimate of the rate is $(e^{+}\mu^{-}/\mu^{-} \text{ total})_{corr} = f^{-1}0.6(1\pm.33) \times 10^{-2}$ where f could be as small as $\frac{1}{2}$.

VI.3. The K^{o} multiplicity at production is,

$$\langle N_{K^o}\rangle = 2.0 \pm 0.6$$

and if $\langle N_{K^o}\rangle = \langle N_{K^\pm}\rangle$,

the total K multiplicity is

$$\langle N_{K^{o}_{\pm}}\rangle = 4.0 \pm 1.2$$

There is internal consistency with 2 K^{o} and 2 $K^{\pm}$ produced per event.

VI.4. The ratio, $\langle P_{\mu^-}\rangle/\langle P_{e^+}\rangle = 6.6$, is evidence that the $e^{+}\mu^{-}$ events are semileptonic decays of hadrons in CC neutrino interactions, and not uniquely heavy lepton decays.

VI.5. The e^{+}'s are not likely to come from the purely leptonic 2 or 3 body decay of the > 2 GeV objects of Pati and Salam.

VI.6. From the positron transverse momentum distribution one finds the mass of the charmed meson to be greater than 1.6 GeV.

VI.7. The semileptonic branching ratio is likely to be,

$$\frac{C \rightarrow e^{+} \text{ or } \mu^{+}}{C \rightarrow \text{total}} > 0.33 \; (1 \pm .42)$$

VI.8. There is no compelling evidence for a threshold for the $e^{+}\mu^{-}$ events.

VI.9. There is a hint that two of the events might be neutral current ones (but not $\bar{\nu}_e$'s).

VII. Acknowledgements

We wish to thank the scanning and measuring staff of our institutions for the outstanding work they did in this experiment. They worked with very difficult events where great care had to be used to achieve high electron and positron detection efficiency.

Furthermore, we wish to pay tribute to the Fermilab staff for developing the accelerator, the neutrino facility, and in particular the 15-foot bubble chamber. The fact that our institutions were able to participate in such an important neutrino experiment using the equipment built by others demonstrates a remarkable laboratory policy. Our thanks goes to R.R. Wilson for such a policy and our great indebtedness goes in particular to the Fermilab bubble chamber group for what it has meant to them.

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Table 1. Topology of the events.

ID#	How e^+ Ident.	μ^- Ident.	K^o_s	K^o_L	$K^\pm$	$\pi^\pm$	$L^\pm$ $I^\pm$ $S^\pm$
①	1NVB+PR 1VB+PR	EMI	+ −			$1S^-$	$2L^+5I^+1S$ $1L^-$
②	1NVB+PR 2VB+PR	Geom. Miss of EMI	+ −				$2I^+$ $2I^-$
③	2(VB+PR) ANNIH+PR	EMI	+ −				1γ
④	1DELTA 1VB 1TRID	Geom. Miss $L^+(2.8)$ in EMI	+ −				$2L^+$ $1L^-1I^-2\gamma=\pi^o$
⑤	1(VB+PR) 1NVB+C $\delta(-2)$ at VTX	EMI	+ −,00	1d		1^+d	$2L^+2I^+$ $2L^+1I^-$
⑥	1NVB+C 1NVB+PR 1NVB+C?	EMI	+ −	1d		1^-d	$2I^-$ $1L^-$
⑦	1NVB+CPR 1VB+CPR	EMI Says Prob Had	Λ			1^+d	$1L^+$ $1L^-$
⑧	1VB+PR	SHWR+no EMI	Λ				$1L^+1I^+$ $1I^-$
$\bar{\nu}_e$ ⑨	4NVB+PR	All Part Interact or Stop					$1I^-,1S^+=P$

Table 1. Topology of the events. (Continued)

ID#	How e^+ Ident.	μ^- Ident.	K^o_s	K^o_L	$K^\pm$	$\pi^\pm$	$L^\pm$ $I^\pm$ $S^\pm$
(10)	1VB+PR	Geom. Miss EMI		$1I \to \Lambda$ $1I \to K^o_{3\pi^o}$	1^-d		$1L^+$ $1L^-$
(11)	1NVB+PR 1VB KINK or VB	EMI	+ −	$1I \to \Lambda$,1n		$3I^+$ $1I^- 1^-$(K)	$2L^+$,6γ
(12)	1VB+PR	EMI	00				$1L^+$ $1L^- 3\gamma$
(13)	1NVB+PR 1VB+PR	EMI	+ − or Λ				$1I^+$ $1I^o 1\gamma$
(14)	2(VB+PR)	EMI			1^+d		$1L^+ 2I^+ 1\gamma$(DZ) $3L^-$ 3γ
(15)	1NVB+PR 1VB+PR	EMI	+ − or Λ				$1I^+ 1S^+$=P $1L^-$ 1γ
($\bar{\nu}_e$) (16)	1TRID	EMI Says Prob Had					$1S^+$=P $1I^-$ γ

NVB	Non Visible Brems	γ	$e^\pm$ Pair from Prim VTX	CH	Charge Exchange
VB	Visible Brems	L	Leaving Track	DZ	Dalitz Pair
TRID	$e^\pm$ Pair on e^+ Track	I	Interacting Track		
PR	Electron-Position Pair	S	Stopping Track		
C	Compton Electron	d	Decay		
n	Neutron				

Table 2. Lepton and strange particle kinematics.

ID#	E_{vis}	Momenta					Visible				
		μ^-	e^+	K^o_s	K^o_L	$K^\pm$	Q^2	ν	x	y	W^2
①	33	14	1.6	6.1			0.13	18	0.004	0.56	35
②	12	3.4	1.1	3.1			1.6	8.1	0.10	0.71	15
③	26	21.8	2.2	1.6			6.2	3.1	0.9	0.12	1.7
④	28	9.3	5.2	5.8			7.2	18	0.21	0.66	28
⑤	98	58	2.1	+ - 00 4.4,	2.1		0.21	39	0.003	0.41	75
⑥	24	15	0.4	2.2	3.3		5.5	7.8	0.37	0.34	10
⑦	15	SS (2.0)	5.6	1.2Λ			0.16	12	0.007	0.86	24
⑧	29	(5.4)	0.64	11Λ			1.0	23	0.024	0.81	43
$\bar{\nu}_e$ ⑨	17	None	14				0.33	4.5	0.039	0.24	9
⑩	20	(0.80)	3.9		3.6 4.6	0.6	16	18	0.49	0.96	18
⑪	97	SS 9.3	5.7	38	1.0		9.4	87	0.058	0.90	154
⑫	21	14.1	1.3	00 1.1			1.2	5.7	0.11	0.29	10

Table 2. Lepton and strange particle kinematics. (Continued)

ID#	E_{vis}	Momenta					Visible				
		μ^-	e^+	K_S^o	K_L^o	$K^\pm$	Q^2	ν	x	y	W^2
(13)	30	26.2	1.4	1.6 or Λ			2.7	2.9	0.49	0.10	3.6
(14)	61	SS 17.9	4.0			+ 0.25	0.70	42.0	0.009	0.70	78.0
(15)	42	33.6	0.80	1.5 or Λ			3.8	7.3	0.29	0.17	10.0
($\bar{\nu}_e$) (16)	11	(3.3)	5.6				1.4	6.6	0.11	0.66	12.0

SS "Same Side" Muon
( ) Doubtful Muon

Table 3. Mass, momentum correlations ⊥ to $\vec{\nu}_{inc}$.

ID#	M_{e^+K}	Positron $P^e_{\hat{n}}$	Positron $P^e_{\hat{\mu}}$	Positron $\lvert\vec{P}^e_\perp\rvert$	Strange $P^K_{\hat{n}}$	Strange $\vec{P}^K_{\hat{\mu}}$	Strange $\lvert\vec{P}^K_\perp\rvert$	Event Total $P^{Miss}_{\hat{n}}$	Event Total $P^{Miss}_{\hat{\mu}}$	Event Total $\lvert\vec{P}^{Miss}_\perp\rvert$
①	0.70	−0.018	−0.006	0.019	−0.552	0.776	0.952	1.897	0.512	1.964
②	0.81	−0.051	−0.040	0.065	0.277	−0.924	0.965	−0.170	0.234	0.289
③	1.04	−0.321	−0.503	0.597	0.180	−0.862	0.881	0.108	−0.951	0.957
④	0.70	−0.187	−0.499	0.531	−0.279	−0.550	0.617	0.260	0.102	0.279
⑤	0.60 0.69	0.007	−0.256	0.257	−0.089 0.272	−0.205 0.556	0.229 0.619	−0.369	−0.234	0.437
⑥	0.66 0.67	−0.047	0.067	0.081	0.143 0.024	−0.219 −0.573	0.261 0.573	−0.091	−0.807	0.812
⑦	2.6(Λ) (1.5(K))	−0.390	−0.843	0.929	0.320	−0.221	0.389	0.033	−0.581	0.581
⑧	1.3(Λ)	0.085	0.079	0.116	−0.490	0.592	0.769	−0.237	1.320	1.341
$\bar{\nu}_e$ ⑨		0	0.499	0.499				0.0624	−0.227	0.235
⑩	0.85 0.75 1.4K⁻	−0.052	−0.213	0.219	−0.082 −0.371 −0.026	−0.629 −0.391 −0.241	0.634 0.539 0.242	0.407	1.052	1.129
⑪	1.3 2.1	0.054	−0.557	0.580	0.249 0.049	1.296 −0.254	1.320 0.259	−0.019	−1.251	1.252
⑫	1.08	0.379	−0.416	0.562	−0.002	0.327	0.327	−0.740	−0.487	0.886

Table 3. Mass, momentum correlations $\perp$ to $\vec{\nu}_{inc}$. (Continued)

ID#	M_{e^+K}	Positron			Strange			Event Total		
		$P^e_{\hat{n}}$	$P^e_{\hat{\mu}}$	$\lvert\vec{P}^e_\perp\rvert$	$P^K_{\hat{n}}$	$\vec{P}^K_{\hat{\mu}}$	$\lvert\vec{P}^K_\perp\rvert$	$P^{Miss}_{\hat{n}}$	$P^{Miss}_{\hat{\mu}}$	$\lvert\vec{P}^{Miss}_\perp\rvert$
(13)	1.38(K)	-0.397	0.288	0.491	-0.194	-0.925	0.945	0.678	-0.990	1.200
(14)	1.89	-0.334	0.482	0.587	0.210	0.068	0.221	0.062	-0.593	0.596
(15)	0.95K (1.5Λ)	0.420	-0.164	0.451	-0.104	-0.024	0.107	-0.240	-0.814	0.849
($\bar{\nu}_e$) (16)		1.277	-0.409	1.341				-0.721	0.143	0.735

FIGURE CAPTIONS

Fig. 1 The positron and electron energy distributions and their ratios $E_e^{\pm}/E_{vis}$.

Fig. 2a Q^2_{vis} vs ($\nu_{vis} = E_{vis} - E_{\mu^-}$) for the $e^+\mu^-$ events

2b x_{vis} vs y_{vis} distribution for the $e^+\mu^-$ events

Fig. 3 The $|p_{\hat{n}}^{e^+}|$ distribution - $p_{\hat{n}}^{e^+}$ is the e^+ momentum component normal to the μ-ν plane. The dashed curve is for hadrons of normal CC events.

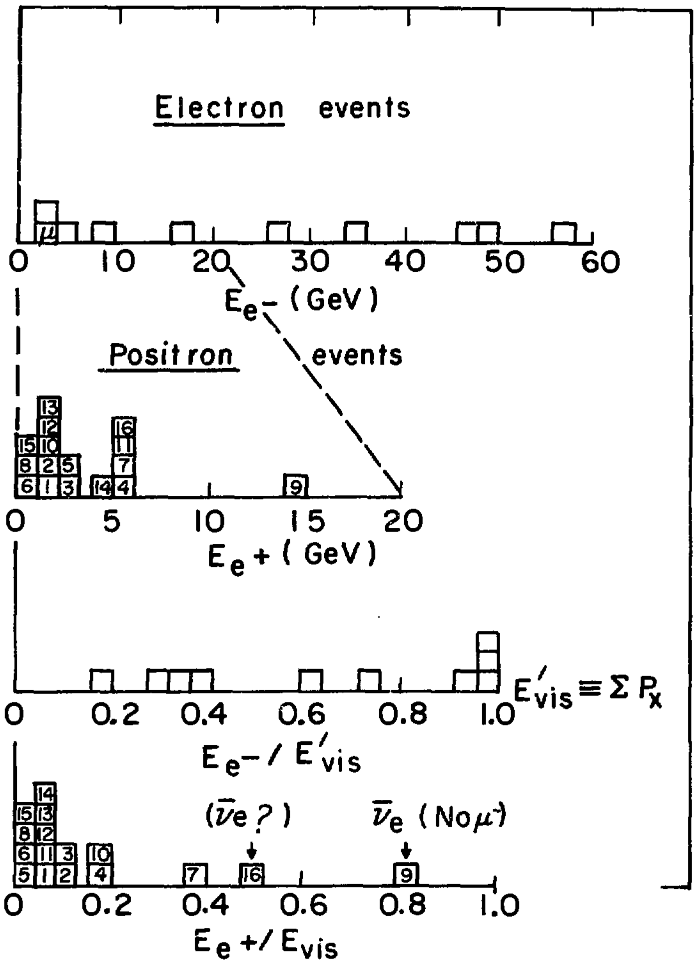
Fig. 4 The $|p_{\hat{n}}^{K}|$ distribution - $p_{\hat{n}}^{K}$ is the strange particles momentum component normal to the μ-ν plane. The dashed curve is for hadrons of normal CC events.

Fig. 5 Neutrino energy distribution for the $e^+\mu^-$ events compared with that for normal CC events.

Fig. 6 Muon identification : EMI confidence level distributions :

a) C_μ is the probability that a muon gives a <u>worse</u> match.

b) C_h is the probability a hadron gives a <u>better</u> match.



XBL768-3347

Fig. 1

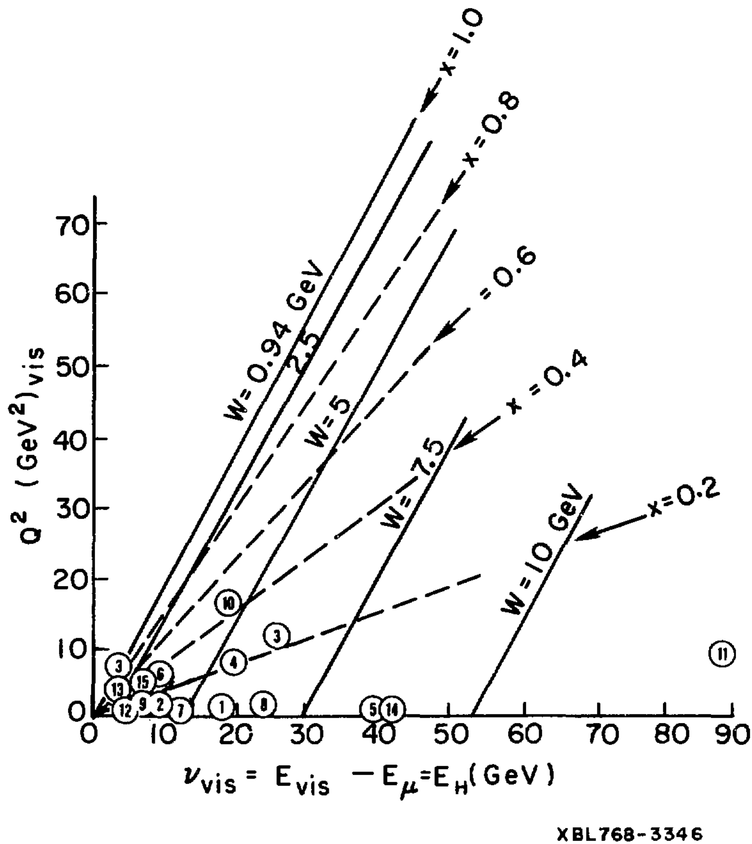
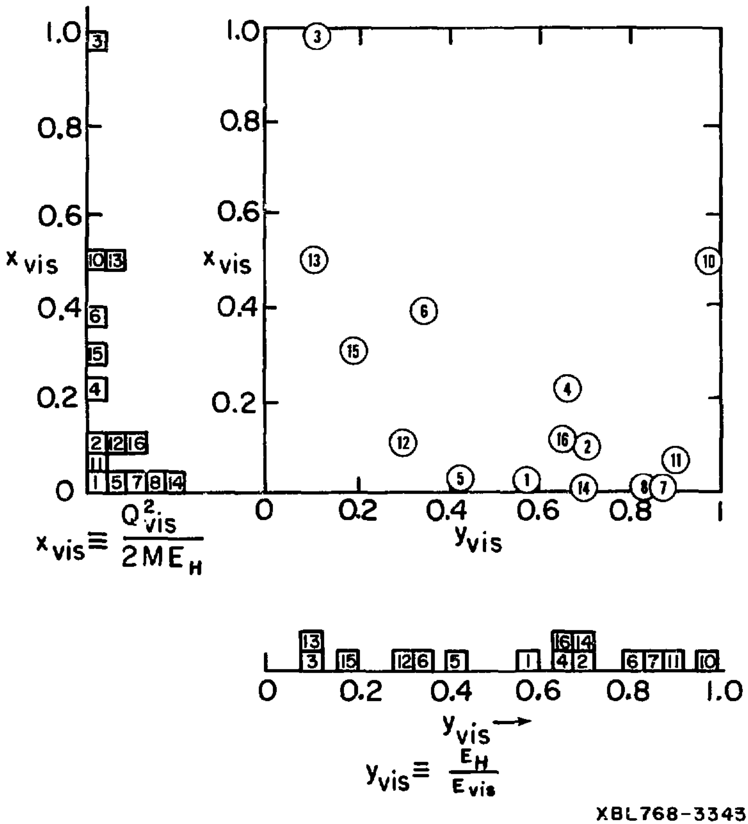
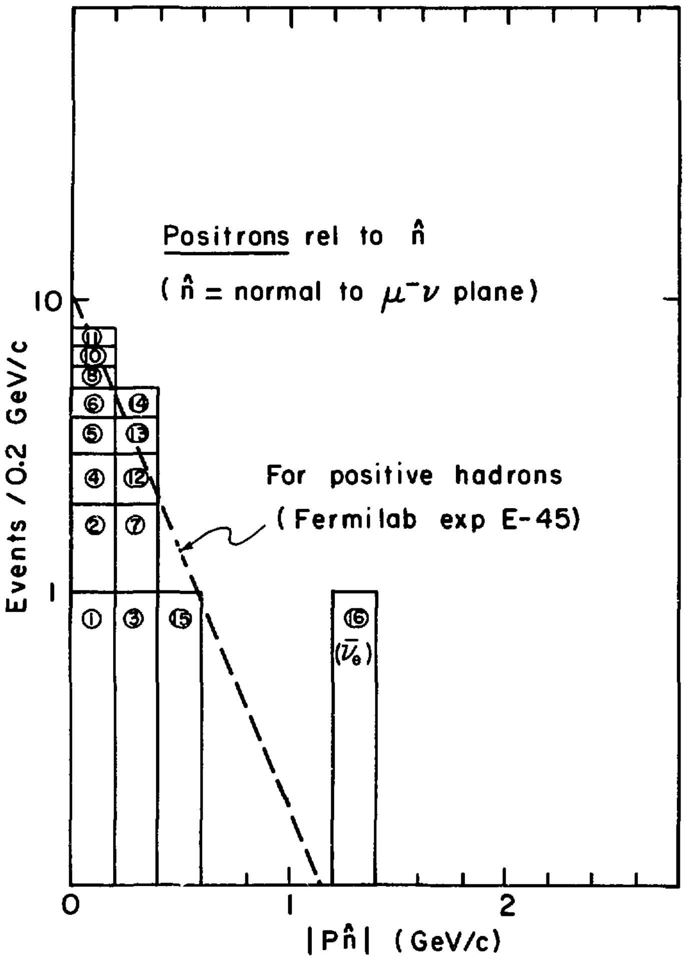

x=1.0
x=0.8
=0.6
x =0.4
x=0.2
W=0.94 GeV
2.5
W=5
W=7.5
W=10 GeV
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
Q² (GeV²)vis
νvis = Evis − Eμ=EH(GeV)
XBL768-3346

Fig. 2a



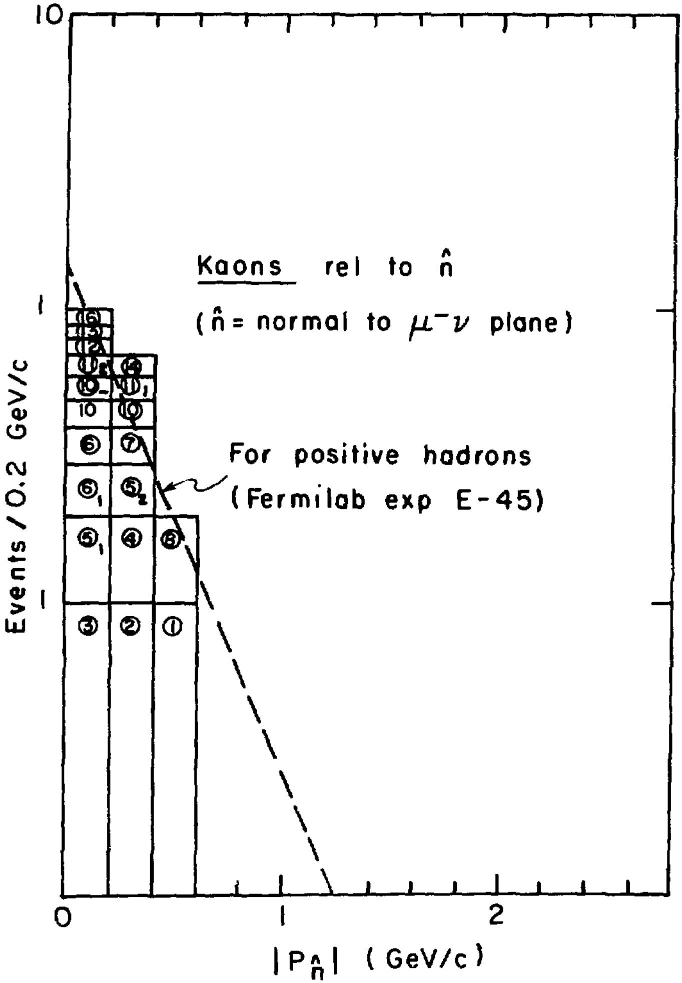
1.0
0.8
0.6
0.4
0.2
0
x_{vis}
$x_{vis} \equiv \frac{Q^2_{vis}}{2ME_H}$
0
0.2
0.4
0.6
0.8
1
y_{vis}
0
0.2
0.4
0.6
0.8
1.0
y_{vis}
$y_{vis} \equiv \frac{E_H}{E_{vis}}$
XBL768-3343

Fig. 2b



XBL768-3344

Fig. 3



XBL768-3345

Fig. 4

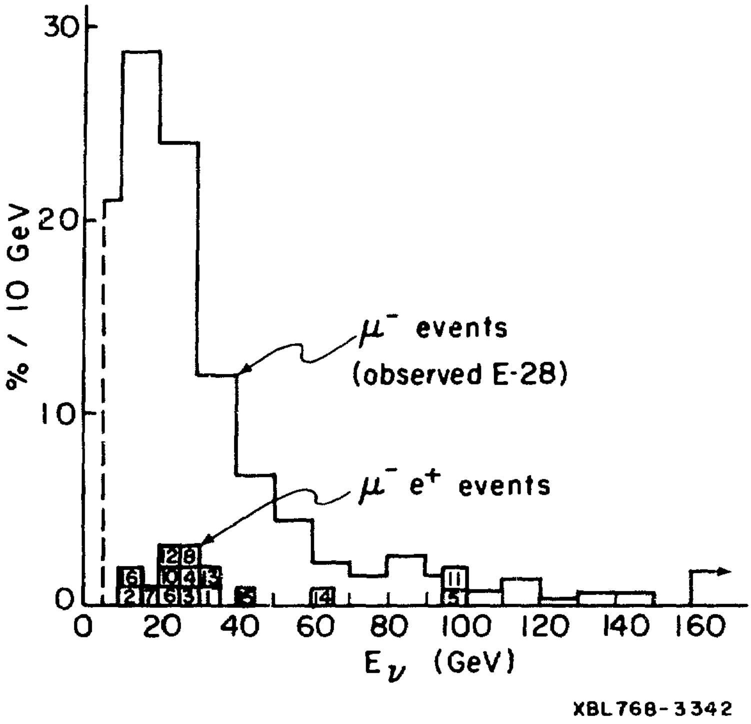

% / 10 GeV
30
20
10
0
μ⁻ events
(observed E-28)
μ⁻ e⁺ events
0
20
40
60
80
100
120
140
160
E ν (GeV)
XBL768-3342

Fig. 5

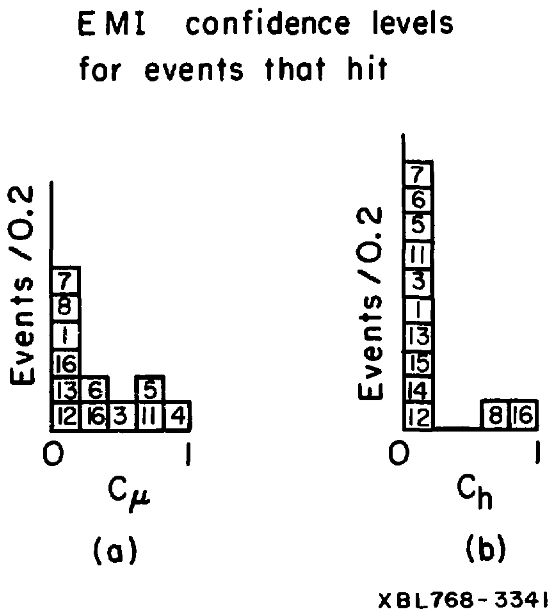

EMI confidence levels
for events that hit
Events /0.2
7
8
1
16
13
6
5
12
16
3
11
4
0
1
C_μ
(a)
Events /0.2
7
6
5
11
3
1
13
15
14
12
8
16
0
1
C_h
(b)
XBL768-3341

Fig. 6