

CHARACTERISTICS OF MUON-ELECTRON EVENTS
PRODUCED IN HIGH ENERGY NEUTRINO INTERACTIONS

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Abstract: The observation of neutrino interactions producing a muon, and an electron among the final state particles implies production of at least one new particle with a new quantum number. Evidence is presented for such events produced using the Fermilab 15' Hydrogen-Neon Bubble chamber and the external muon identifier.

An experiment to study neutrino interactions at high energies was proposed in 1970 to be performed using the Fermilab large bubble chamber filled with a Neon hydrogen mixture. The primary motivation was to search for new phenomena in the unexplored area of high energy neutrino interactions. Since that time additional motivation, if it were necessary, has been provided by the discovery¹ and the confirmation² of dimuon events by the Harvard-Pennsylvania-Wisconsin-Fermilab counter neutrino experiment. These events were interpreted as evidence for production of a particle (Υ) with a new quantum number. Assuming μ -e universality, muon-electron events would also be produced.

The FNAL bubble chamber filled with hydrogen and 20% Neon by volume is uniquely suited to a search for direct electron production, and is complementary to the dimuon experiment. Specifically, there is no π -K decay background, the acceptance is very good, the systematic errors are quite different and the production vertex can be visually examined.

A further improvement in the experimental technique is the External Muon Identifier (EMI). The EMI consists of 24 one meter squared proportional wire chambers located behind the coils and a zinc absorber. A muon is identified as an outgoing track which does not interact in the chamber and is recorded by the EMI at a position consistent with the extrapolation of the track through the absorber as modified by multiple coulomb scattering. Less than 2% of the hadrons would "punch through" the 4-5 absorption lengths and be incorrectly identified as a muon.

Electrons are identified by their electromagnetic interactions characterized by the radiation length of about 1.1 m. The 2.0 m absorption length for hadrons, in addition to fil-

tering muons, provides detection and identification of neutral and strange hadrons (K^+ , K_L^0 , n) with reasonable efficiency. The visible chamber volume permits the detection of neutral strange particles (K_S^0 , Λ) by their characteristic decay " ν ".

The electron detection efficiency was measured by means of external pair production. Using our scanning criteria the efficiency is the ratio of the number of pairs in which both electrons are identified to the number for which only one is identified. The result is that the electron detection efficiency is about 30% and essentially independent of electron energy.

The scanning procedure had two phases. First, professional scanners located neutrino interactions. In the 80,000 pictures obtained in this experiment a candidate for a neutrino interaction occurred once in eight frames on average. Second, each track of each event was examined carefully by a physicist to determine if it could be identified as an electron. It is very important to recognize that this was the only criterion for selecting events.

The events which contained direct electrons were then classified in three categories.

- i. Internal photon conversion (dalitz pairs). An event was placed in this category if it had another identified electron, or if the invariant mass and angle when combined with a non-interacting track of opposite charge was consistent with the dalitz pair hypothesis. Although the latter requirement was necessary to establish the presence of μ -e events it clearly errs in discarding valid events, thus making it difficult to determine the rate of μ e events.

ii. Events which had no negative track consistent with its interpretation as a μ^- . All events in this category have e^- and can be attributed to the ν_e component in the neutrino beam.

iii. The remaining events could be interpreted as producing a μ^- , an e^+ as well as a number of hadrons.

In a partial sample (Sample I) of about 1500 neutrino interactions we found about i) 75 dalitz pairs, ii) 6 e^- events attributed to ν_e and iii) 4 events containing μ^-e^+ .

Since the positron is the most important particle in the selection of these events, backgrounds which involve positrons must be evaluated. The most important of these backgrounds are:

1. An asymmetric Dalitz pair $\pi^0 \rightarrow \gamma + e^+ + e^-$ with the e^- having an energy less than 5 MeV. From the theoretical energy distribution between the e^- and e^+ , and number of observed Dalitz pairs in the sample, this contribution has been estimated as less than than 0.2 events.³
2. $K^+ \rightarrow e^+ + \pi^0 + \nu$: The estimated number of events is less than 0.1, assuming a 2 GeV K^+ decay length of 50cm and the ability to detect kinks with projected angles of greater than 6° on film.
3. $K_L^0 \rightarrow e^+ + \pi^- + \nu$: If this happens close to the vertex (within 1 cm), the tracks are taken as coming from the main vertex: 5×10^{-3} events expected.
4. $K^+ \rightarrow e^+ + \nu$ and $\pi^+ \rightarrow e^+ + \nu$. The contribution from these processes is 5×10^{-4} events.
5. Incoming neutral hadrons simulating ν interactions where a kaon is produced and decays in flight into an electron. This background was evaluated empirically in the same experiment giving rise to an expected background of 2×10^{-3} events.

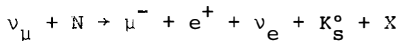
6. $\bar{\nu}_e + N \rightarrow e^+ + (\text{hadrons})$:

From the estimated $\bar{\nu}_e$ flux for this experiment

($\phi_{\bar{\nu}_e} / \phi_{\nu_\mu} \simeq 10^{-3}$) we expect to observe .1 events.

As a check we computed the number of ν_e -interactions ($\nu_e N \rightarrow e^- + \text{hadrons}$) expected to be observed in this sample. This number is 4.8 events, to be compared with the 6 ν_e events found. This results gives credence to the correctness of the $\bar{\nu}_e$ -flux used for background.

Thus we conservatively calculate a total expected background of about 4×10^{-1} events. The probability that the 4 events are due to background is extremely small. We conclude that these positron events are not due to background and represent the first observation of the reaction



Although each of the four events is accompanied by a K_S^0 , I reiterate that neither the scanning criteria nor the background estimate depends on the presence either of the K_S^0 or the muon.

Various kinematic quantities associated with these events are tabulated in Table I. Three additional events found since the analysis of the partial sample was completed are also shown.

Among the notable features of these events are:

1. Six of the seven events have a K_S^0 .

Event 7 has 4 γ 's which have an invariant mass of $0.45 \text{ GeV}/c^2$ and which do not point at the vertex. Event 5 has two neutral K's and possibly a $K^{*0} \rightarrow K^+ \pi^-$. In fact, the average number of neutral K mesons per event is

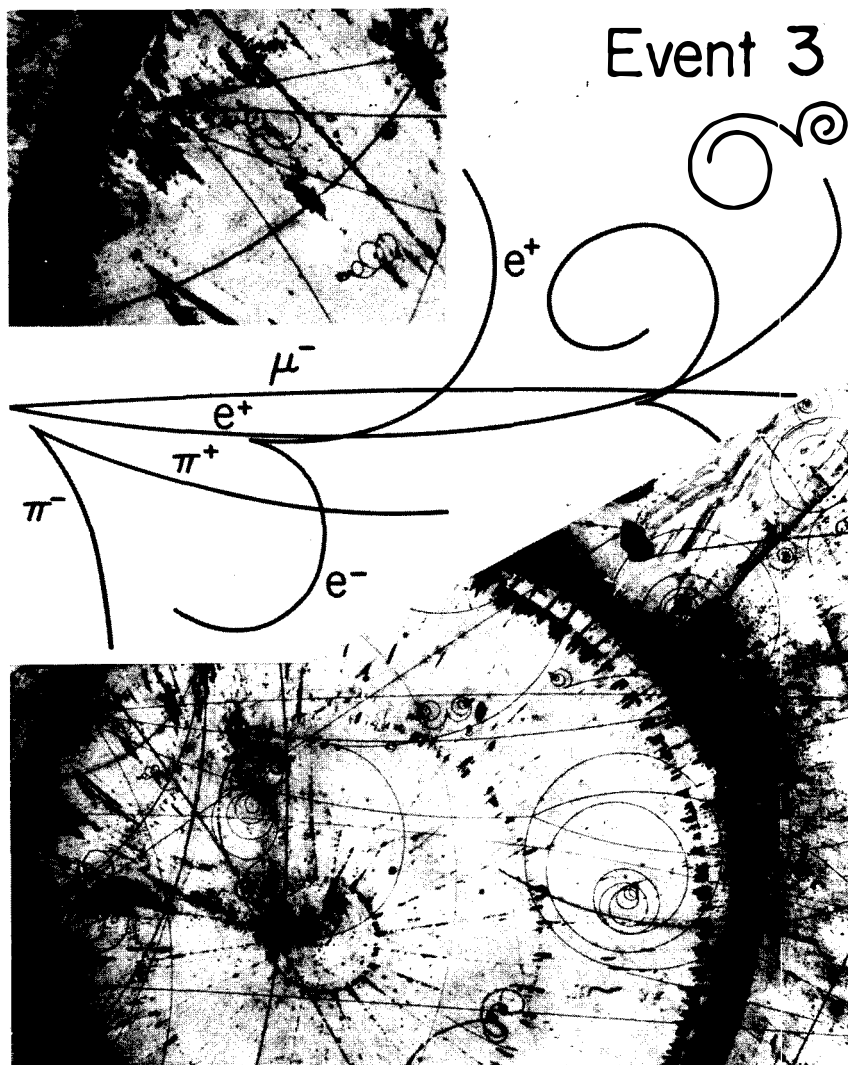
$$\langle N_K \rangle \simeq \frac{1.3}{\epsilon_K} \geq 2 \text{ to } 4$$

Note that no event has a Λ^0 from the primary vertex.

2. Event 3 is particularly notable (Fig. 1) in that

the only particles identified in the final state are the μ^- , the e^+ and the K_S^0 . Lepton conservation implies a ν present in the final state.

Figure 1. The two photos and the diagram are of Event 3. The absence of a low energy electron which could come from an asymmetric pair is illustrated in the enlargement.



3. The ratio of the average muon momentum to the average positron momentum $\langle P_\mu \rangle / \langle P_e \rangle \gtrsim 5$, a result corroborating the dimuon data and exceeding the limit calculated by Pais and Trieman.⁴ From this we infer the events must be the β decay of a hadron with a new quantum number. No evidence for a visible track of this particle is obtained from close inspection of the vertices, from which we can set an upper limit to the lifetime of the new particle as 2×10^{-11} sec.
4. The rate of production of these μe events is difficult to measure precisely. At this time we believe it to be $\sim 1\%$ of all single muon events, a result compatible with the dimuon number.
5. The mass of the new particle is best inferred from the transverse momentum of the electron projected on the normal to the plane formed by the momenta of the incident neutrino and the outgoing muon. Using this quantity the mass is about $2 \text{ GeV}/c^2$.

In summary, we have evidence for the production of at least one new particle which decays via the weak interaction. The production and/or decay appears related to strangeness. At this point it would be folly to prescribe a single explanation (e.g. charm) of these data. The large number of K mesons per event will mislead those who attribute the K's we see to the decay of charmed particles. Therefore I have not given the K_e invariant masses. As the data accumulate there will emerge a clearer picture of the possibly diverse phenomena inherent in neutrino interactions. We are sure the future will be as stimulating as the past.

I. TABLE OF EVENT PARAMETERS

Sample	I				II		
	1	2	3	4	5	6	7
Event Number	1	2	3	4	5	6	7
Total Visible Energy GeV	34.	11.	26.	28.	100.	97.	21
Muon Momentum GeV/c	14.3	3.4	21.9	9.3	9.3	57.5	14.1
EMI Identification	Yes	Miss	Yes	Miss	Yes	Yes	Yes
Electron Momentum GeV/c	1.6	1.1	2.1	5.3	5.6	2.1	1.2
Neutral decaying particles (Vee's)	K_S^0	K_S^0	K_S^0	K_S^0	K_S^0 K_L^0 $K^{*0}?$	K_S^0 K_L^0 K_L^0 K_L^0 $K^0 \rightarrow 2\pi?$	-----
Momentum of K_S^0	6.3	3.1	1.8	5.6	38.	4.	-----
Y (min)	.6	.7	.2	.7	.9	.4	.3
X (max)	.003	.10	.9	.2	.06	.003	.09
W Invariant Mass of Hadrons	6.2	3.8	1.4	5.4	12.7	8.7	3.5
V = XY	.002	.071	.135	.139	.052	.001	.032
Q^2	0.1	1.5	6.5	7.3	9.0	0.2	1.3
Electron momentum transverse to total Hadronic momentum	.4	.7	.4	.7			

References and Footnotes

1. A. Benvenuti, et al., Phys. Rev. Letters 34, 419, 597 (1975), Phys. Rev. Letters 35, 1199 (1975), Phys. Rev. Letters 35, 1203 (1975), Phys. Rev. Letters 35, 1249 (1975).
2. B. Barish, et al., Proceedings of the Paris International Conference on Neutrino Interactions, Ecole Polytechnic, P. 131. B. Barish, Int'l Conference on Lepton and Photon Interactions at High Energy, Stanford University, August 1975.
3. About 10% of the dalitz decay of η^0 mesons would pass the criterion concerning invariant mass of e^+ and negative leaving track. However, these events would contribute <0.5 events to the background.
4. A. Pais, S. B. Treiman, Phys. Rev. Letters 35, 1206 (1975).