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SEARCH FOR $\bar{\nu}$ INDUCED μ^+e^- EVENTS*†

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ABSTRACT

We have examined 1200 interactions with visible energies greater than 7.5 GeV produced by an anti-neutrino beam in the Fermilab 15-foot bubble chamber filled with a light neon hydrogen mixture. We have found one event with a μ^+e^- and hadrons in the final state, but with no evidence of strange particle production. This event may be an example of dilepton production by an anti-neutrino interaction, but other interpretations are possible. With 90% confidence, we conclude that the rate for the process $\bar{\nu} + N \rightarrow e^- + \mu^+ +$ hadrons is $\leq .8\%$ of charged current anti-neutrino interactions with visible energy > 7.5 GeV.

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I report here on a search made for μe events in the Fermilab 15-foot chamber exposed to a wide-band, horn-focussed anti-neutrino beam. The liquid in the chamber was a light neon-hydrogen mixture (20 atomic percent neon). The previous talk dealt with a similar search in a neutrino beam. We must begin by expressing our appreciation to the large number of colleagues listed on page one, who are responsible for the collection and analysis of these data. (They should not, however, be held responsible for what I will say today).

The exposure being reported on involves approximately 50,000 pictures. These were divided equally between four laboratories (Fermilab, IHEP-Serpukhov, ITEP-Moscow, and University of Michigan). Before distribution, the film was duplicated so that each participating nation had a complete set of pictures for the entire exposure. The same External Muon Identifier (EMI) referred to in the previous talk was operated during this exposure.

The film was scanned in each of the four laboratories for possible $\bar{\nu}$ (and ν) interactions, each laboratory handling its own share of the film. Events with at least one forward track greater than 1.0 GeV (by template) and no backward track greater than .7 GeV (by template) were selected for measurement. Physicists examined the events and excluded those thought to be due to charged hadrons. All the measured events (~2000) were collected together in a single Data Summary Tape (DST). From this, a sample of 1200 events with visible energy greater than

7.5 GeV was obtained. The visible energy was computed by combining the longitudinal momenta of all prongs, associated V's, electron pairs and neutron stars. It is on these 1200 events that this report is based.

All the film was collected at a single laboratory (Fermilab) and the events were looked at by physicists working in pairs. Each track leaving the primary vertex was followed to its end, and examined for any evidence that it was due to an electron or a positron. The following were taken as an indication of an electron or a positron:

(1) Evidence of bremstrahlung as indicated by a positron-electron pair in a tangential direction to a track.

(2) Production of a trident.

(3) Production of a delta ray with an estimated energy greater than that possible for a muon.

(4) Spiralization to a stop, characteristic of an electron or positron.

(5) An Abnormally large increase in curvature before leaving the chamber.

As a result of this examination, 83 events were selected as having tracks that were possible e^+, e^- or both. These events were examined again by physicists working in pairs and 49, which contained both e^+ and e^- were rejected as being either Dalitz pairs or regular pairs converting very close to the main vertex. Of the remaining 34 events, 9 were obvious single

electron events (5 e^+, 4 e^-). A summary of the characteristics of these 9 events is given in Table I. Of the remaining 25 events, all have been rejected as electron or positron candidates because the orbits of the tracks are compatible with those of higher mass particles (pions or muons). A typical event of this type consists of a pion with a momentum of < 500 MeV, which decays in flight to a muon with no visible kink. After the muon stops, it decays to an electron emitted in the same direction as the stopping muon. Such tracks cannot be distinguished from spiraling electrons by visual inspection. However, by measuring many points along these tracks and reconstructing their orbits, one of us (JPB) was able to sort out, in all cases, the true nature of these tracks. Two events of this type were included in the sample of three μe events reported in Kaftanov's talk at the New York Meeting of the American Physical Society in February of this year. We are now completely certain that these events are not μe events.

Referring now to the events shown in Table I, we see that two of these events have muon candidates identified by the EMI. The condition for such identification is that there must be a "hit" in the EMI close to the predicted location of the supposed muon, such that the probability that the track is a muon is > 4%, and the probability that it is a hadron is < 10%. The actual hadron probability for event (1) is 5%. That is to say, 95% of all hadron tracks heading for the EMI would not produce a "hit" that close to the predicted location of the muon. This fraction,

TABLE I

Roll. Frame (Event)	E_{VIS}	E(e)	$y_{VIS}(\nu_e)$	EMI Muon?	E(μ)	Interpretations other than μe events
72.3036 (1)	31.9 ± .4	1.24 e^- ± .04	.96	yes	17.3 μ^+ ± .3	1. ν_e event with "punch-thru" (unlikely) 2. $\bar{\nu}_\mu$ event with background electron (16%)
67.758 (2)	26.6 ± .5	1.42 e^+ ± .07	.95	no	-	$\bar{\nu}_e$ event
72.4670 (3)	21.0 ± 2.0	12.0 e^+ ± 2.0	.43	no	-	$\bar{\nu}_e$ event
73.246 (4)	41.0 ± 8.0	31.0 e^- ± 8.0	.24	no	-	ν_e event
67.6142 (5)	33.0 ± 7.0	32.0 e^+ ± 7.0	.03	no	-	$\bar{\nu}_e$ event
72.6375 (6)	53.5 ± 5.0	35.0 e^+ ± 5.0	.35	yes	8.7 μ^+ ± .1	$\bar{\nu}_e$ event with "punch-thru" (10%)
67.5957 (7)	55.0 ± 12.0	37.0 e^- ± 12.0	.33	no	-	ν_e event
67.6435 (8)	56.0 ± 13.0	56.0 e^+ ± 13.0	.00	no	-	$\bar{\nu}_e$ event
73.1198 (9)	130. ± 40.	153. e^- ± 40.	.15	no	-	ν_e event

however, covers hadrons of all energies. High energy hadrons are much more likely to produce a "hit" than are low energy hadrons. Indeed, for $\bar{\nu}$ interactions with a visible energy of > 30 GeV, 10% have two "hits" in the EMI. This indicates a "punch-through" rate of about 10% for high energy events.

In the last column of Table I, we have listed possible interpretations for the 5 e^+ and 4 e^- events. As we have said, event (1) could be a ν_e event with a "punch-through" hadron. However, because of the high transverse momentum of the muon candidate relative to the hadron direction (2.4 GeV), we believe this interpretation unlikely. A second possibility is that it is due to one of several background sources which, for electrons with energies greater than 1.2 GeV, have the following rates for our experimental sample.

	Rate
(1) Asymmetric pair ≤ 2 cm from vertex:	.02
(2) Asymmetric Dalitz pair:	.03
(3) K_{e3} decay in flight with kink < 6^o:	<.01
(4) δ - ray	00
(5) Compton scatter ≤ 2 cm from vertex:	.10
Total background for e^- with energy ≥ 1.2 GeV:	.16

A distance of 2 cm from the vertex is justified, because for event (1) the first 2 cm of the electron track is obscured due to the presence of other tracks (see Figure 1). We have checked to see if the electron in event (1) could be a δ-ray produced by one of the other tracks. There is a 1.5 GeV π^- in the event with the correct direction but too low energy to make such a δ-ray. Hence an estimated rate for this process is set equal to zero. Also we have checked to see if the electron in event (1) could be one of a positron-electron pair, either Dalitz pair or close conversion. To do this we calculated the invariant masses obtained by combining the electron with each of the other positive tracks leaving the chamber unidentified. The smallest value of invariant mass so found was 380 MeV. Hence we must reject the hypothesis that the electron is one member of a positron-electron pair whose other member leaves the chamber unidentified.

The other event with a "hit" in the EMI is event (6). This event has an e^+ with an energy of 35 ± 5 GeV. It is extremely unlikely that such a positron is due to any of the background processes described above. A possible explanation, however, is that the event is due to a $\bar{\nu}_e$ interaction with a "punch-through" hadron. This has a probability of ~10%. Indeed, since our total sample contains seven high energy electron events that are surely ν_e or $\bar{\nu}_e$ interactions, having one with a "punch-through" hadron is not too surprising. The transverse momentum of the muon relative to the hadron direction in this event is 0.9.

Before concluding, something should be said about the efficiency of the procedures described in this talk for detecting the electrons and positrons. To estimate this, the physicists involved in the search for e^+ and e^- tracks from the primary vertices also examined tracks from associated γ-pairs

converting within 20 cms of the main vertex (40 cm in the case of tracks with energies > 1 GeV). Table II shows the results of this study.

Table II

Track Energy (GeV)	Number Recognized	Number not Recognized	Total	Efficiency
.1 - .2	96	12	108	.88
.2 - .4	78	22	100	.78
.4 - 1.0	98	26	124	.79
1.0 - 10.0	57	29	86	.66

For tracks above 1 GeV energy, the efficiency is 2/3, and it is this number that is used for the rate estimates which appear below.

With 90% confidence,

$$(1)\quad \frac{\sigma(\bar{\nu} + N \to \mu^+ + e^- + \text{hadrons})}{\sigma(\bar{\nu} + N \to \mu^+ + \text{hadrons})} \leq .008 \text{ for } E_{VIS} > 7.5 \text{ GeV}$$

$$(2)\quad \frac{\sigma(\nu + N \to \mu^- + e^+ + \text{hadrons})}{\sigma(\nu + N \to \mu^- + \text{hadrons})} \leq .035 \text{ for } E_{VIS} > 7.5 \text{ GeV}$$

The second of these estimates is possible because of the 11% event contamination in our sample due to neutrino interactions.