Fermi National Accelerator Laboratory

FERMILAB-Pub-76/81-EXP
7300.045

(Submitted to Phys. Rev.)

SEARCH FOR μe EVENTS IN ANTINEUTRINO-NUCLEON INTERACTIONS

J. P. Berge, F. A. DiBianca, H. Emans, R. Hanft, C. Kochowski,
F. A. Nezrick, W. G. Scott, W. Smart, and W. Venus
Fermi National Accelerator Laboratory, Batavia, Illinois 60510 USA

and

V. V. Ammosov, A. G. Denisov, P. F. Ermolov, V. A. Gapienko,
V. I. Kljukhin, V. I. Koreshev, A. I. Mukhin, P. V. Pitukhin,
Y. G. Rjabov, E. A. Slobodyuk, and V. I. Sirotenko
Institute of High Energy Physics, Serpukhov, USSR

and

V. I. Efremenko, P. A. Gorichev, V. S. Kaftanov, V. D. Khovansky,
G. K. Kliger, V. Z. Kolganov, S. P. Krutchinin, M. A. Kubantsev,
S. V. Mironov, A. N. Rosanov, and V. G. Shevchenko
Institute of Theoretical and Experimental Physics, Moscow, USSR

and

C. T. Coffin, R. N. Diamond, H. French, W. Louis, B. P. Roe,
A. A. Seidl, and D. Sinclair
University of Michigan, Ann Arbor, Michigan 48104 USA

October 1976

SEARCH FOR μe EVENTS IN ANTINEUTRINO-NUCLEON INTERACTIONS

J. P. Berge, F. A. DiBianca, H. Emans,[†] R. Hanft, C. Kochowski,[‡]
F. A. Nezrick, W. G. Scott, W. Smart, and W. Venus*
Fermi National Accelerator Laboratory,
Batavia, Illinois 60510, USA

and

V. V. Ammosov, A. G. Denisov, P. F. Ermolov, V. A. Gapienko,
V. I. Kljukhin, V. I. Koreshev, A. I. Mukhin, P. V. Pitukhin,
Y. G. Rjabov, E. A. Slobodyuk, and V. I. Sirotenko
Institute of High Energy Physics
Serpukhov, USSR

and

V. I. Efremenko, P. A. Gorichev, V. S. Kaftanov, V. D. Khovansky,
G. K. Kliger, V. Z. Kolganov, S. P. Krutchinin, M. A. Kubantsev,
S. V. Mironov, A. N. Rosanov, V. G. Shevchenko
Institute of Theoretical and Experimental Physics,
Moscow, USSR

and

C. T. Coffin, R. N. Diamond, H. French, W.Louis, B. P. Roe,
A. A. Seidl, and D. Sinclair
University of Michigan
Ann Arbor, Michigan 48104, USA

ABSTRACT

A search for μe events produced in an antineutrino hydrogen-neon experiment using the Fermilab 15-foot bubble chamber is reported. Based on a single candidate the 90% confidence upper limit for the relative yield of μ^+e^- events is 0.5% of all charged current events with antineutrino energy greater than 10 GeV.

---

*Visitor from the Rutherford High Energy Laboratory, Chilton, Didcot, Berkshire, England.

[†] Visitor from the University of Bonn, Bonn, Germany.

[‡] Visitor from the CEN, Saclay.

Recently evidence has been reported for neutrino induced events with both a positron and a negative muon in the final state. At high energy these events are reported to occur at a level of ~1% of all neutrino interactions. There is evidence that the rate of strange particle production in these events is anomalously high. The existence of these events cannot be explained in terms of the properties of known particles and interactions.[1,2]

This letter reports on a search for similar events produced in an antineutrino beam. The data are based on an exposure of 7[illegible],400 pictures obtained using the Fermilab 15-foot bubble chamber filled with a hydrogen neon mixture containing 21 atomic percent of neon. The density of this mixture is 0.3 gms cm^{-3} and the average gamma conversion length is 140 cms.

The chamber was exposed to a broad-band double horn focused antineutrino beam. An absorptive plug downstream of the target was used to suppress the neutrino contamination to less than 4% of the flux. The proton energy was 300 GeV and the mean proton intensity was $0.8 - 0.9 \times 10^{13}$ protons/pulse.

The external muon identifier (EMI) was used in this experiment. The EMI consists of approximately 600 gms cms^{-2} of zinc absorber together with the magnet coils inside the vacuum vessel of the bubble chamber followed by 23 m^2 of multiwire proportional chambers.[3] Muon candidates seen in the bubble chamber are extrapolated to the EMI in an attempt to match them with fitted coordinates in the proportional chambers.[4] For low momentum muons both EMI geometric acceptance and background problems are important; therefore only tracks with an acceptable match in the EMI and with momentum greater than 4 GeV/c are considered as identified muons.

The film was divided equally among the four laboratories and scanned for neutral induced events with visible momentum along the beam direction, p_x, greater than about 1 GeV/c. Events consisting of a single charged track only were not included in the scan. A total of about 3000 events were found.

Events with $p_x > 7.5$ GeV/c in a fiducial volume of 21 m^3 were examined by physicists searching for evidence of electrons or positrons at the primary vertex. Each track was examined carefully over its entire length. Any track which spiralled smoothly to a point in the liquid or which had any visual indication of catastrophic energy loss - bremstrahlung (sudden curvature changes and/or converted pairs), tridents, large δ-rays, or annihilation (in the case of positrons) - was considered an electron or positron candidate. Each electron or positron candidate was measured and fitted over its entire length to find evidence of radiative energy loss. Electron or positron candidates which showed definite evidence of energy loss inconsistent with any other mass assignment were considered as identified.

In order to measure the detection efficiency for electrons produced with the same spatial distribution as the events in the bubble chamber, physicists examined both tracks of each electron-positron pair produced within 20 cms of the primary vertex of an event. Each track was examined to see whether it would have been classified as an electron or positron candidate using the same criteria as were used for tracks from the primary vertex. Figure 1 shows the measured electron detection efficiency as a function of the electron energy E_e. This efficiency decreases with increasing E_e to an approximately constant value $\eta = 0.70 \pm 0.08$ for $E_e >$ 800 MeV.

As the electron energy decreases the number of expected background events becomes large as discussed below. Therefore events with electrons or positrons at the interaction vertex with $E_e <$ 200 MeV are not considered further. After removing electron-positron pairs 12 events have an electron or positron apparently originating at the interaction ver·ex. These events are listed in Table I. The energies E_e are determined from curvature measurements corrected where appropriate for detected bremstrahlung.

Five events have all tracks other than the electron or positron identified as hadrons in the bubble chamber. Only events 5 and 8 have a muon identified by the EMI and are considered as μe candidates. Event 11 has a 4 GeV/c K_s^o; no other event shows any evidence for a strange particle.

In order to assess the significance of the two μe candidates consider the following backgrounds:

1) Electron neutrinos and antineutrinos are expected to be present in the beam at about the 1% level. Events 3 through 7 and 9 through 12 in Table I have leading electrons or positrons and are very likely to be ν_e or $\bar{\nu}_e$ induced events. A ν_e or $\bar{\nu}_e$ event can simulate

a μe event when a hadron is misidentified as a muon by the EMI. The probability that a hadron is misidentified as a muon by the EMI is estimated to be ~3%. With the assumption that all the events in Table I are ν_e or $\bar{\nu}_e$ induced, this background is estimated to be ~.03 μ^+e^+ and ~.15 μ^+e^- events.

2) The film quality is such that a close in Compton electron vertex (within about 2 cm of the interaction vertex) may not be resolved. This background has been estimated from the measured gamma spectrum. Fig. 2 shows the expected number of charged current events with close in Compton electrons with $E_e > E_{min}$.

3) Events with asymmetric gamma conversions within 2 cm of the primary vertex or asymmetric Dalitz pairs having an undetected electron or positron, apparently have a single positron or electron at the interaction vertex. With the assumption that electrons or positrons with $E_e < 5$ MeV are always undetected the expected number of such events has been estimated from the observed spectrum of Dalitz pairs and close in pairs and is shown in Fig. 2. As E_e decreases below 200 MeV the background from both sources 2) and 3) increases rapidly.

4) Small angle K_{e3} decays are estimated from the observed number of K_s^o decays and decay kinematics to contribute 0.02 e^- and 0.04 e^+ background events.

Event 5 is the only μ^+e^+ candidate. In addition to the μ^+ and the e^+ in this event there are two negative hadrons. Interpreted as a $\bar{\nu}_\mu$ charged current event the estimated antineutrino energy[5] $E_{\bar{\nu}}$ is 64 GeV, and the estimates for the scaling variables[6] are x = 0.001 and y = 0.86. However the presence of a high energy leading e^+ suggests that this event may be a $\bar{\nu}_e$ event with a positive hadron misidentified as a muon even though the expected number of such events is only ~0.03.

Event 8 is the only μ^+e^- candidate. Events of the type μ^+e^- are of the particular interest because the lepton configuration is charge conjugate to the configuration μ^-e^+ observed in neutrino interactions as reported in references 1 and 2. In addition to the μ^+ and the e^- there are 4 positive hadrons and 2 negative hadrons in this event. Interpreted as a $\bar{\nu}_\mu$ event the estimates for the antineutrino energy and the scaling variables are given by $E_{\bar{\nu}}$ = 36 GeV, x = 0.066 and y = 0.51. The combined background from all sources 1 - 4 considered above for $E_e >$ 1.2 GeV is 0.2 ± 0.2 events. In fact for this particular event there is a small track of unknown sign at the interaction vertex which could be a positron with energy $\lesssim$2 MeV which would indicate that the electron is part of a very asymmetric Dalitz pair. The electron track overlaps 4 other tracks at the interaction vertex and it cannot be excluded that it is due to a Compton electron. The event is not considered compelling evidence for $\bar{\nu}_\mu$ induced μ^+e^- events.

Table II shows the upper limit at 90% confidence for the yields of μ^+e^- and μ^+e^+ events relative to all antineutrino charged current events based on a single candidate in each case. The upper limit on the relative yield of μe events with associated neutral strange particles detected via charged decay modes (V^o) is also given based on zero candidates. The number of charged current events has been corrected for missing single track events.[7] No correction has been applied for EMI acceptance; the assumption is made that the EMI acceptance for μe events is the same as for all other charged current antineutrino events. The upper limits have been corrected for the electron detection efficiency $\eta = 0.70$. The upper limits are applicable for electrons with energies $E_e > 200$ MeV and for muons with energy above 4 GeV.

We wish to thank the Hawaii and Berkeley groups for their assistance in operating the EMI and for making available to us their EMI programs. We also wish to thank the members of the Neutrino Laboratory at Fermilab and the scanning, measuring and secretarial staffs at our respective laboratories for their contribution to this experiment.

REFERENCES

[1] H. Deden et al., Phys. Lett. 56B 361 (1975).

[2] J. Von Krogh et al., Phys. Rev. Lett. 36 710 (1976).

[3] R. J. Cence et al., University of Hawaii Report UH 511 217 76: Lawrence Berkeley Laboratory Report LBL-4816 (to be published in Nuclear Instruments and Methods).

[4] In this experiment a muon is considered to be identified by the EMI if the muon confidence level for the match is greater than 4% and if the hadron confidence level is less than 10%.

[5] The antineutrino energy $E_{\bar{\nu}}$ is estimated for individual events using an average correction for neutral energy loss characteristic of the total event sample.

[6] The scaling variables are defined by $x = Q^2/2m\nu$ and $y = \nu/E_{\bar{\nu}}$ where Q^2 is the square of the 4 momentum transfer, ν is the energy transfer to the hadrons in the lab system, and m is mass of the proton.

[7] The missing single track events are expected to be largely confined to the region of small y. The number of missing events is estimated assuming a y-distribution of the form $dN/dy = (1 + y + y^2/2) - By(1 - y/2)$ with $B = 0.8$ (see for example: W. G. Scott, Vanderbilt Conference; AIP Conference proceedings 30; Particle Searches and Discoveries 1976; Edited by R. S. Panvini) and extrapolating to $y = 0$. The correction is 14% for $E_{\bar{\nu}} > 10$ GeV and less at higher energies.

TABLE I

LIST OF EVENTS WITH SINGLE ELECTRONS OR POSITRONS WITH E_e > 200 MeV

Event Number	P_x	E_e	EMI Muon	V^o
1.	26 GeV/c	1.4 ± 0.1 GeV e^+	None	None
2.	8 GeV/c	2.0 ± 0.1 GeV e^+	None*	None
3.	21 GeV/c	12 ± 2 GeV e^+	None	None
4.	33 GeV/c	32 ± 7 GeV e^+	None*	None
5.	54 GeV/c	35 ± 5 GeV e^+	8.7 GeV μ^+	None
6.	56 GeV/c	56 ± 13 GeV e^+	None*	None
7.	68 GeV/c	67 ± 10 GeV e^+	None*	None
8.	32 GeV/c	1.2 ± .01 GeV e^-	17.3 GeV μ^+	None
9.	10 GeV/c	6.3 ± 0.4 GeV e^-	None	None
10.	42 GeV/c	31 ± 8 GeV e^-	None	None
11.	55 GeV/c	37 ± 12 GeV e^-	None	4 GeV/c K_s^o
12.	153 GeV/c	130 ± 40 GeV e^-	None*	None

*All secondaries identified as hadrons in the bubble chamber.

TABLE II

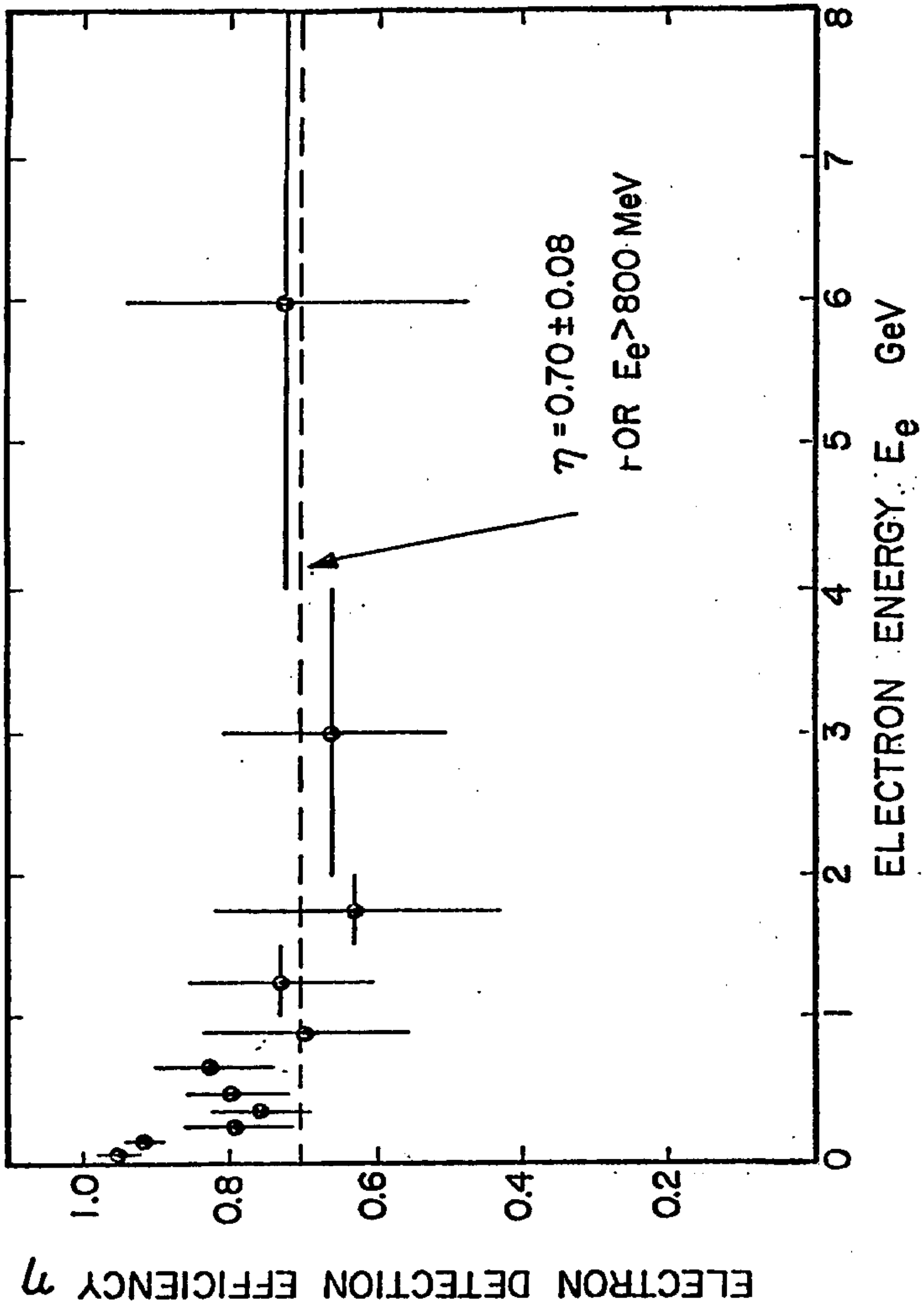
UPPER LIMITS FOR ANTINEUTRINO INDUCED μe EVENTS AS A FUNCTION OF ENERGY (90% CONFIDENCE LEVEL)

$E_{\bar{\nu}}$	CHARGED CURRENT EVENTS	$\sigma(\mu^+e^-)/\sigma(\mu^+X)$	$\sigma(\mu^+e^+)/\sigma(\mu^+X)$	$\sigma(\mu e V^0)/\sigma(\mu^+X)$
>10 GeV	1120	0.5%	0.5%	0.3%
>20 GeV	630	0.9%	0.9%	0.5%
>30 GeV	330	1.7%	1.7%	1.0%
>40 GeV	160	2.1%	3.[illegible]%	2.1%

FIGURE CAPTIONS

Figure 1: The electron detection efficiency η determined from a study of electron positron pairs plotted as a function of electron energy E_e.

Figure 2: The expected number of background events with $E_e > E_{min}$ due to close in Compton electrons and due to asymmetric Dalitz pairs and close in pairs.



$\eta = 0.70 \pm 0.08$
FOR $E_e > 800$ MeV
ELECTRON ENERGY E_e GeV
ELECTRON DETECTION EFFICIENCY η
0
1
2
3
4
5
6
7
8
1.0
0.8
0.6
0.4
0.2

Fig. 1

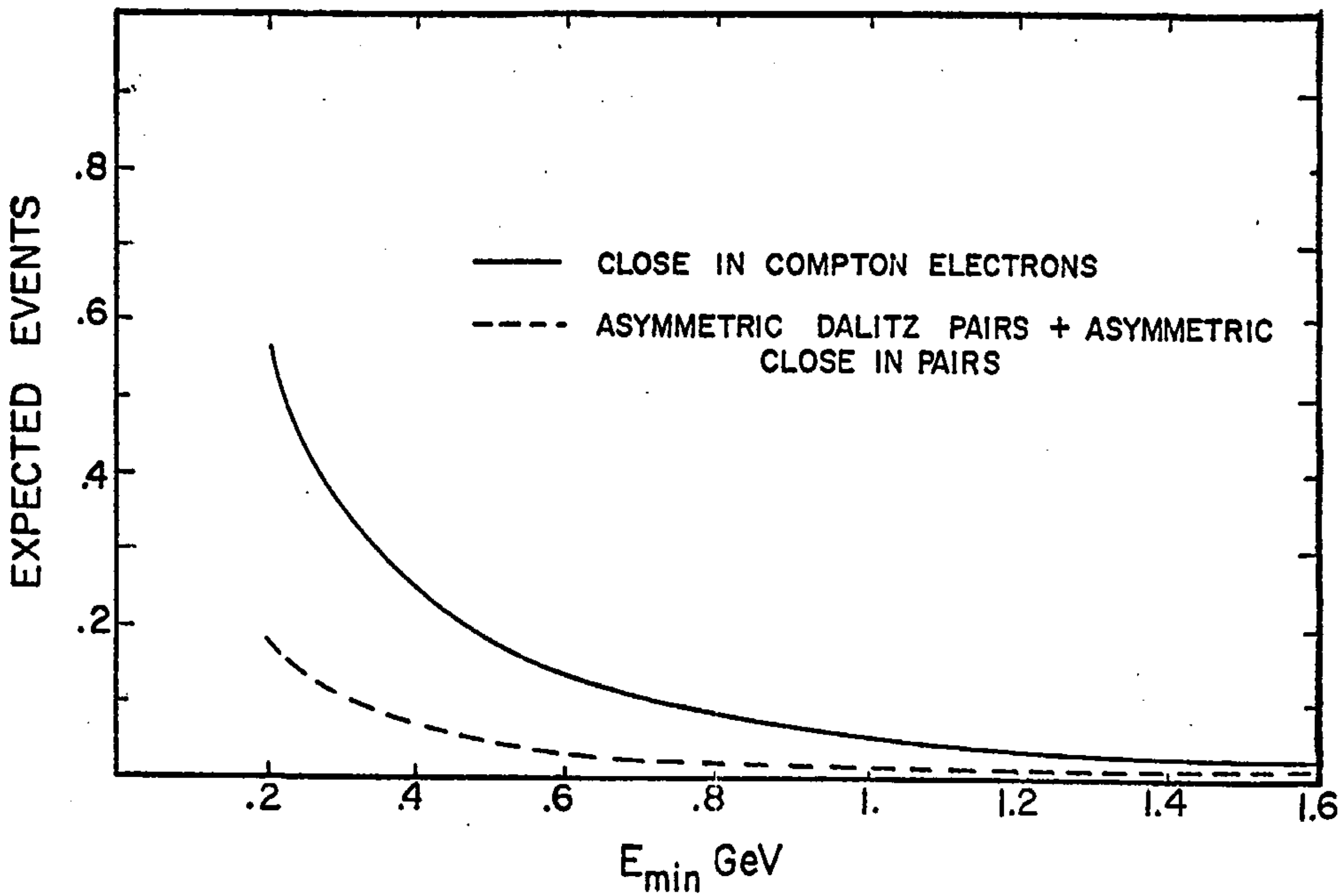

EXPECTED EVENTS
.8
.6
.4
.2
CLOSE IN COMPTON ELECTRONS
ASYMMETRIC DALITZ PAIRS + ASYMMETRIC CLOSE IN PAIRS
.2
.4
.6
.8
1.
1.2
1.4
1.6
E_min GeV

Fig. 2