Fermi National Accelerator Laboratory

FERMILAB-Pub-77/113-EXP
7410.310

(Submitted to Phys. Rev. Lett.)

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S. Mori, A. Benvenuti, F. Bobisut, D. Cline, P. Cooper,
M. Heagy, R. Imlay, M. E. Johnson, T. Y. Ling, R. Lundy,
A. K. Mann, P. McIntyre, D. D. Reeder, J. Rich,
R. Stefanski and D. R. Winn

Fermi National Accelerator Laboratory
P. O. Box 500, Batavia, Illinois 60510

Department of Physics, Harvard University
Cambridge, Massachusetts 02138

Department of Physics, University of Pennsylvania
Philadelphia, Pennsylvania 19104

Department of Physics, Rutgers University
New Brunswick, New Jersey 08903

Department of Physics, University of Wisconsin
Madison, Wisconsin 53706

December 1977

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S. Mori, A. Benvenuti,[+] F. Bobisut,[++] D. Cline, P. Cooper,
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Fermilab
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Department of Physics
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Philadelphia, Pennsylvania 19104

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Rutgers Unversity
New Brunswick, New Jersey 08903

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University of Wisconsin
Madison, Wisconsin 53706

ABSTRACT

Confidence levels against the hypothesis that the trimuon events observed with the Neuland detector at Fermilab were induced by new kinds of neutrinos associated with short-lived particles were estimated to be 99.9 %, 99 %, and 85 %, respectively for the trimuon events in the three categories in which the momentum of the lowest energy muon is greater than 5, 10, and 20 GeV/c.

Trimuon events which were observed in interactions from high energy neutrino beams have been well established experimentally. Origins of the trimuon phenomena have not been understood, particularly for very energetic trimuon events.[1,2,3] In this paper we estimate the probability that observed trimuon events were induced by one or more new kinds of neutrinos (or antineutrinos) associated with postulated short-lived particles which were produced in the high energy proton-nucleus interactions. We divide trimuon events into three categories in which the momentum of the lowest energy muon (P_μ^{min}) for each event is greater than 5, 10, and 20 GeV/c because events in the three categories may originate from qualitatively different processes.

Trimuon events[1,2] observed by the Neuland detector at Fermilab were acquired in several neutrino and antineutrino beams: (1) a quadrupole triplet beam[4], (2) a sign-selected bare target (SSBT) neutrino beam and (3) an SSBT antineutrino beam.[5] Trimuon events in each category and numbers of protons are summarized in Table I. The incident proton energy was 400 GeV.

Ordinary neutrino and antineutrino fluxes from pion and kaon decay are quite different for the three beams. In contract, flux distributions of neutrinos from a source that is short-lived relative to pions and kaons should be nearly identical for the three beams since the short-lived particles decay immediately after the proton-nucleus interaction takes place. In the following analysis we assume that

all the trimuon events in each category from the quadrupole triplet and SSBT neutrino runs were induced by the neutrinos from the short-lived source, and estimate the numbers of trimuon events expected in the SSBT antineutrino run. We estimate confidence levels against the assumption made in the first step.

Figure 1 shows the schematic diagrams of the two SSBT beams. The primary proton beam was incident on a target of one interaction length of alumina (Al_2O_3). After the target the protons were dumped in the beam stopper at the end of the decay pipe for the neutrino beam and the beam dump in the SSBT train for the antineutrino beam. The beam dump is a 3 m long aluminum block. The beam stopper consists of a 3 m thick aluminum block followed by a 3 m thick steel block. The incident angles of the proton beams at the dumps with respect to the neutrino beam line were 0 mrad and 3.4 mrad as indicated in Fig. 1. The quadrupole triplet train focussed charged pions and kaons produced at the target with conventional quadrupole magnets. The primary proton beam was dumped at the end of the decay pipe at 0 mrad as in the case of the SSBT neutrino beam. The quadrupole triplet beam contained both neutrinos and antineutrinos essentially without any sign selection. The neutrino and antineutrino fluxes of the quadrupole triplet beam were roughly twice those for the SSBT neutrino and antineutrino beams.

The trigger arrangement, trigger dead time, efficiency of the trigger system, and event scanning criteria for the quadrupole triplet data were substantially different from the values for the SSBT neutrino and antineutrino data. Table I gives the dead times and relative triggering efficiencies for the three runs. The overall corrected detection efficiency for the trimuon events with $P_{\mu}^{min} > 5$ GeV/c, however, is approximately the same for the three runs. The total numbers of 400 GeV protons on the target and numbers of protons after the corrections are made for the trigger efficiency and dead time are given in Table I.

The relative yield of the short-lived particles at the primary target (one interaction length) and the dump, were respectively 63% and 37%. Corrections for the solid angle of the Neuland detector were assumed to be inversely proportional to the square of the distance between the detector and the incident proton absorber. Then the relative flux contributions of the neutrinos associated with the short-lived particles were 0.63, 0.37, and 0.70 (= 0.37 x 1.9) for the target, the beam dump of the antineutrino beam, and the beam stopper of the quadrupole triplet and SSBT neutrino beams, respectively. (See Fig. 1(a).)

Table II presents the numbers of protons with and without the additional correction for solid angle and the number of trimuon events in each of the three categories for the neutrino (quadrupole triplet and SSBT neutrino) and SSBT antineutrino runs.

The anticipated trimuon event rates and observed rates for the SSBT antineutrino run are given in Table III with statistical errors only. Confidence levels against the hypothesis that all the trimuon events were induced by the neutrinos (or antineutrinos) associated with the short-lived particles are respectively 99.9%, 99%, and 85% for the three categories of P_{μ}^{min} greater than 5, 10, and 20 GeV/c.

The angular acceptance of the Neuland detector is about ±1 mrad along the ordinary neutrino beam line. If the angular distribution of the flux from the short-lived source is much narrower than 3.4 mrad with respect to the incident proton direction, the 37% of the primary protons which interacted in the SSBT beam dump for the antineutrino run do not yield any flux at the Neuland detector. In this case the solid angle correction made earlier for the neutrino run should also be reduced, and therefore, the confidence levels given in Table III do not change significantly. The present limits are dominated by the statistical uncertainty due to the small number of trimuon events in the neutrino run. The new quadrupole triplet run which is currently under way will provide many more trimuon events. Perhaps further classification of trimuon events will be also feasible.

In conclusion, it is unlikely that the majority of the trimuon events observed with the Neuland detector were induced by new kinds of neutrinos associated with short-lived particles.

This work was supported in part by the Department of Energy and the National Science Foundation.

References and Footnotes

+ Now at INFN and Istituti di Fisica, Università di Bologna, Bologna, Italy.

++ Visitor at the University of Pennsylvania, on leave from Istituto di Fisica dell' Università, Padova, Italy.

+++ Now at Ohio State University, Columbus, Ohio 43210

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Beam	Quad Triplet	SSBT Neutrino	SSBT Antineutrino
Total numbers of trimuon events observed	6	6	1
Trimuon events			
$p_\mu^{min} > 5$ GeV/c	5	3	0
$p_\mu^{min} > 10$ GeV/c	4	1	0
$p_\mu^{min} > 20$ GeV/c	1	1	0
Total numbers of protons on the target (400 GeV)	1.12×10^{18}	0.41×10^{18}	2.55×10^{18}
Relative efficiency of the trigger system	0.6	1.0	0.88
Dead time	14 %	19 %	16 %
Corrected numbers of protons	0.58×10^{18}	0.33×10^{18}	1.88×10^{18}

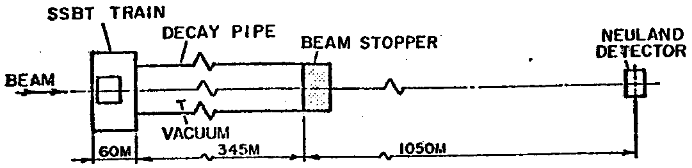
Table I. Trimuon events detected by the Neuland detector at Fermilab, total numbers of protons, relative efficiency of the trigger system, dead time, and corrected numbers of protons for the quadrupole triplet, SSBT neutrino and SSBT antineutrino runs

Beam	Neutrino	Antineutrino
Total numbers of protons after corrections made for trigger efficiency and dead time	0.91×10^{18}	1.88×10^{18}
Relative solid angle correction	1.33	1.00
Relative numbers of protons after corrections made for trigger efficiency, dead time and solid angle	0.64	1.00
Numbers of trimuon events		
$P_\mu^{min} > 5$ GeV/c	8	0
$P_\mu^{min} > 10$ GeV/c	5	0
$P_\mu^{min} > 20$ GeV/c	2	0

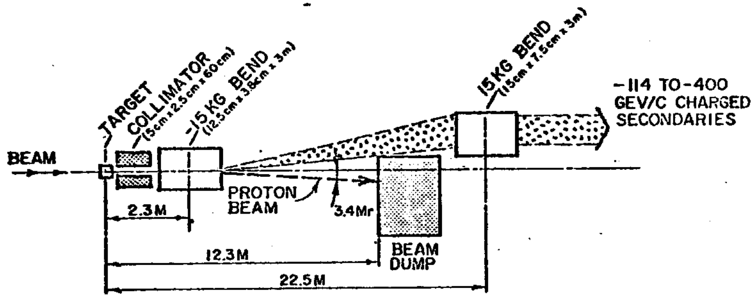
Table II. Corrected numbers of protons, solid angle corrections, relative numbers of protons after all the corrections are made, and trimuon events for the neutrino (quadrupole triplet and SSBT neutrino) and SSBT antineutrino runs.

Categories	Anticipated trimuon event rates	Observed trimuon events	Confidence levels
$P_\mu^{min} > 5$ GeV/c	12.5 ± 4.4	0	99.9 %
$P_\mu^{min} > 10$ GeV/c	7.8 ± 3.5	0	99 %
$P_\mu^{min} > 20$ GeV/c	3.1 ± 2.2	0	85 %

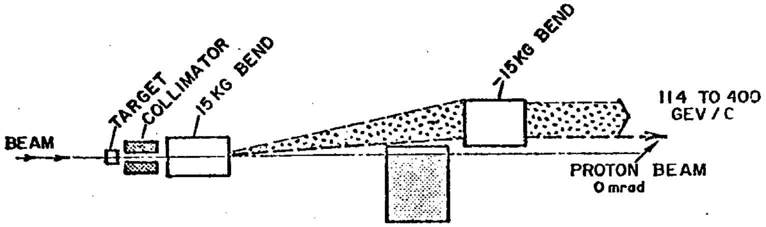
Table III. Anticipated trimuon event rates and observed trimuon events for the SSBT antineutrino run, and confidence levels against the hypothesis of the short-lived sources for the three categories of trimuon events. The confidence levels are calculated using binomial statistics.



(a) THE SSBT TRAIN, DECAY PIPE, BEAM STOPPER, & NEULAND DETECTOR



(b) THE SIGN SELECTED BARE TARGET ANTI-NEUTRINO BEAM



(c) THE SIGN SELECTED BARE TARGET NEUTRINO BEAM

Fig. 1. (a) The sign-selected bare target train (SSBT), the decay pipe, the dump, and the Neuland detector. (b) The SSBT antineutrino beam. About one-third of the incident proton beam strikes the beam dump with an angle of 3.4 mrad. (c) the SSBT neutrino beam. The incident proton beam travels parallel to the ordinary neutrino beam axis before being dumped in the beam stopper at the end of the decay pipe.