CONF-79-107-E
F-0613

FERMILAB-CONF-79-107-E

613

UM HE 79-34

PROMPT NEUTRINO AND AXION EXPERIMENTS AT FERMILAB*

B.P. ROE, H.R. GUSTAFSON, L.W. JONES, and M.J. LONGO

University of Michigan
Department of Physics
Ann Arbor, Michigan 48109

Paper presented at the X International Symposium on Multiparticle Dynamics

Goa, India
September, 1979
(to be published)

*Supported by the U.S. National Science Foundation

RECEIVED
OCT 31 1979
DIRECTORS OFFICE
FERMILAB

PROMPT NEUTRINO AND AXION EXPERIMENTS AT FERMILAB*

L.W. JONES, B.P. ROE, H.R. GUSTAFSON, and M.J. LONGO
University of Michigan
Ann Arbor, Michigan 48109

Abstract A test experiment has been carried out at Fermilab to explore the feasibility of prompt neutrino detection with close target-detector separations. A small (4 ton) iron-scintillator calorimeter was located 22 m from a tungsten beam-dump target with 10^{11} protons of 400 GeV per pulse incident. A prompt neutrino signal was detected at a level of marginal statistical significance ($\sim 1\frac{1}{2}\,\sigma$). If interpreted as resulting from D meson decay, the data correspond to a D-production cross section of 40-80 μb for reasonable production models. The same data may also be interpreted in terms of axion production; using current theoretical models, they establish a limit on the axion mass of > 25 MeV. Our group is now building a new, larger prompt neutrino experiment in collaboration with physicists from the University of Wisconsin and Ohio State University. This experiment will employ a lead scintillator calorimeter of 3000 g cm^{-2} together with proportional chambers and a muon spectrometer and is designed to collect 10^4 prompt neutrino events from a variety of targets.

Introduction Results from beam dump experiments at CERN[1] have indicated a source of prompt neutrinos produced by 400 GeV protons on dense targets, and D-pair production and subsequent semileptonic decay has been suggested as the mechanism. We have performed a simple experiment at Fermilab with the M2 diffracted

*Work supported by the U.S. National Science Foundation

proton beam in the Meson Laboratory which yields new information on the kinematic distribution of prompt neutrinos and which provides evidence for their origin from decays of charmed particles. An essential difference between this experiment and the CERN experiments lay in the solid angles subtended by the detectors: at CERN the detectors were about 850 m from the proton target and subtended ± 1.5 - 2 mr, whereas our detector was only 22 m from the target and subtended 12-15 mr.

Experimental Details The detector was a 4-ton calorimeter consisting of 30 plates of iron each 61 x 61 cm^2 x 3.9 cm, separated by scintillation counters of equal area[2]. The diffracted proton beam of about 10^{11} protons per pulse was incident on a 45 cm tungsten target followed by 5.5 m of iron magnetized to 2.1 T (which served as a solid iron spectrometer for a separate dimuon experiment). An additional 5.7 m of unmagnetized iron lay just ahead of the detector. Useful data were collected for a very limited time, corresponding to 2 x 10^{15} protons on the target. The beam for this experiment was about 5% of the proton beam incident on the primary beryllium target for the Meson Laboratory, and possible neutrino background could come from this target or from scraping of the diffracted beam on collimators or other beam elements. The beam dump target was 440 m from the primary target, and the detector was 13 m to one side of the extrapolated primary proton direction. The muon flux at the detector was a measure of background neutrino sources, and a 30 x 30 cm^2 muon scintillation counter telescope was incorporated with the detector. During data collection, a muon flux of about

5000 muons per 10^{11} protons on the beam dump target were counted. In order to prevent these muons from simulating neutrino interactions, an anticoincidence shield of six large scintillators was mounted ahead of the detector. A seventh counter of 60 x 120 cm^2 was mounted above the detector to serve as a cosmic ray shield.

Besides the "data" runs, the equipment was operated at reduced intensity on the dump target to evaluate upstream neutrino background and, with the accelerator off, to evaluate cosmic ray background.

Separate pulse heights and times were digitized from each of the 4 calorimeter phototubes, as well as pulse heights from the veto counters and the event time relative to the accelerator r.f. signal. The calorimeter had a measured resolution for 20-40 GeV hadrons of $\sigma = (73/\sqrt{E})\%$. The event recording threshold was set at 10 GeV; events were selected in the analysis only with $E \geq 20$ GeV. The energy, timing, and relative pulse height cuts eliminated 97% of the recorded, triggered events from the analysis. During data collection the summed anticoincidence rate was about 5×10^6 per one second beam pulse, which limited the system live time to only 22%.

The cosmic ray veto counter would also veto a fraction of neutrino events if a secondary particle penetrated upward through the calorimeter into the veto counter. This effect was calibrated in a hadron beam and was determined to correspond to a 38 ± 8% of events.

<u>Results</u> The results from the data run, the background runs, and the cosmic ray run are summarized in Table 1 below.

Table 1

PROMPT NEUTRINO AND BACKGROUND DATA

	Data	Background	Cosmic Ray
Protons per pulse on dump target	1.4×10^{11}	$\sim 10^{10}$	0
Total protons, corrected for dead time	4.3×10^{14}	3×10^{13}	0
Intensity on Meson target (protons per pulse)	2×10^{12}	2×10^{12}	0
Muon counts	87.8×10^{6}	29.3×10^{6}	
Events	11	7	77
Events minus cosmic ray background	10.1 ± 3.1	6.4 ± 3.6	
Events minus background	4.7 ± 3.9		
Net events corrected for self veto	7.5 ± 6.2		

The cosmic ray background was subtracted by normalizing to equal live times. The background due to upstream neutrino sources was more ambiguous; in Table 1 the assumption was made that muons counted in the muon telescope were proportional to upstream neutrinos and were thus a reliable measure of background. Other background assumptions result in a smaller estimated background and a larger net signal. Thus if the beam on the primary meson target is responsible for a part of the background, and if associated muons are swept away, a lower net background may be derived. Here we adopt a conservative assumption, leading to a lower prompt neutrino signal with larger errors. (In an earlier

conference paper[3] we reported a signal of 10.0 ± 5.5 events, based on a different set of background assumptions.)

In addition to the large statistical uncertainty and the uncertainty in the background subtraction prescription, there is an additional ± 50% uncertainty from the combination of fiducial volume uncertainty, self veto efficiency uncertainty, and uncertainty in the energy cut due to the calorimeter energy calibration uncertainty.

Interpretation In order to interpret our results in terms of D production a large number of assumptions are necessary. With these assumptions, Monte Carlo calculations may be carried out to provide values against which the data may be compared to deduce a production cross section. We adopted the following assumptions:

(1) All prompt neutrinos are from D-meson production

(2) The production cross section varies as $A^{1.0}$ of the target nucleus.

(3) Equal numbers of D^+, D^-, D°, $\overline{D}^\circ$ are produced.

(4) The branching ratio of all D's to neutrinos (semileptonic decays) is 20%.

(5) There are equal numbers of ν_e, $\overline{\nu}_e$, ν_μ, and $\overline{\nu}_\mu$.

(6) A target efficiency factor of 1.12 was included to account for production from degraded protons. This was estimated from the excitation function for ψ production.

(7) Interactions of neutrinos in the calorimeter were determined by published charged and neutral current cross sections.

(8) The production of D pairs followed an x and p_t dependence similar to proton production of ψ/J particles. Here several different parameterizations were used including

(a) $E\, d^3\sigma/dp^3 \propto (1 - |x|)^n\, e^{-bp_t}$, and

(b) $d^2\sigma/dx\, dp_t^2 \propto e^{-}(a|x| + bp_t)$.

Different reasonable models gave similar results to ± 10%. In what follows we will use the calculation (a) with n = 4 and $b = 1.6\ (\mathrm{GeV}/c)^{-1}$.

With these various assumptions, our signal of 7.5 events with $E_{vis} > 20$ GeV for 4.3×10^{14} incident protons yields a D pair production cross section ∿ 55 μb per nucleon.

The same Monte Carlo program and other assumptions applied to the published CERN BEBC ν_e events at 0° yields $\sigma = 50$ μb for D pair production. This differs from their published figure[1] primarily through the assumption (2) of $\sigma \propto A^{1.0}$ in our calculation. A summary of various D search experiments is given in Table II below.[4]

Table 2

CHARM SEARCHES AT 400 GeV

Experiment	Deduced $D\bar{D}$	(μb/nucleon)
This experiment	∿ 55	(20-100)
BEBC[1] (our analysis)	50 ± 20	
CDHS[1,4]	∿ 15	
Gargamelle[1,4]	50 ± 20	
Cal. Tech. - Stanford (prompt μ)[4]	∿ 40	
Niu et al.[4]	∿ 40	(2 events)
Ditzler et al.	< 100	($\bar{D}°$ only)
Coremans-Bertrand et al.	< 1.5	

Only the Coremans-Bertrand et al. emulsion data are inconsistent with other positive evidence.

Axions Theoretical models for high energy interactions have suggested the existence of a light boson, the axion. This experiment sets new limits to the axion mass. Since axion production is a semiweak process we assume production cross sections $\sigma \propto A^{1.0}$, and in view of the assumed low mass (<< 100 MeV) intra-target cascading increases the effectiveness of each incident proton by a factor ~ 3. We have assumed $d^3\sigma/dp_t^2 \propto e(-6\ m_t)$ with $m_t^2 = p_t^2 + 0.1\ m_\pi^2$, and $d\sigma/dy$ = constant for $-2.5 < y < +2.5$. If our entire signal (10 events) is due to axions, we find

$$\sigma_{prod.} \times \sigma_{int.} \leq 2 \times 10^{-66}\ e^{-7.3 \times 10^{-8}/\gamma\tau}\ cm^4$$

where τ is the decay lifetime of the axion. Ellis and Gaillard give a theoretical lower limit[6]

$$\sigma_{prod.} \times \sigma_{int.} \geq 9 \times 10^{-66}\ cm^4,$$

and Weinberg further relates the axion mass to lifetime.[7] Our data are compatible with the production-interaction predictions of theory only if $\tau/m_a << 4 \times 10^{-9}$ sec/GeV.

From Weinberg this leads to a limit on axion mass of $m_a > 25$ MeV. It may be noted that this new limit is a consequence of the short target-detector separation compared with other axion search experiment.

New Experiment A new prompt neutrino experiment is under construction at Fermilab involving the authors together with collaborators from the University of Wisconsin and Ohio State University[8]. It involves a neutrino target composed of 30 lead-scintillator modules each of 100 g/cm^2 thickness and

150 x 300 cm^2 area. These are separated by PWC planes with 1 in. wire spacing and followed by a muon spectrometer employing 3.2 m of magnetized iron and 5 drift chamber planes. A magnetized iron beam dump shield should permit 10^{12} protons per pulse on the target without excessive muon flux through the detector. A 45 cm concrete roof and veto counters will reduce cosmic ray triggers. Several targets (Be, Cu, W) will be used to evaluate the A-dependence and density dependence of prompt neutrino production.

Particular emphasis will be placed on high p_t neutrinos, and the initial configuration of the detector will be sensitive to production angles $\lesssim$ 38 mr. Flexibility is being incorporated into the experiment to permit later access to larger angles.

Acknowledgments One of us (LWJ) would like to acknowledge the hospitality of the Tata Institute of Fundamental Research during the preparation of this paper.

References

1. P. Alibran et al., Phys. Lett. 74B, 134 (1978); T. Hansl et al., Phys. Lett. 74B, 139 (1978); P.C. Bosetti et al., Phys. Lett. 74B, 143 (1978).
2. L.W. Jones et al., Nucl. Inst. and Methods 118, 431 (1974).
3. B.P. Roe et al., p. 246, Cosmic Rays and Particle Physics, Bartol Conference 1978, A.I.P. Conference Proceedings No. 49 (1979).
4. See papers in the Symposium on Charm Production in Cosmic Rays and Particle Physics, Bartol Conference 1978, A.I.P. Conference Proceedings No. 49 (1979).

5. W.R. Ditzler et al., Phys. Lett. 71B, 451 (1977).

6. J. Ellis and M.K. Gaillard, Phys. Lett. 74B, 374 (1978).

7. S. Weinberg, Phys. Rev. Lett. 40, 223 (1978).

8. Fermilab experiment E 613, B.P. Roe et al.