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Prompt Production of Neutrinos by 400 GeV Protons on Tungsten: First Results From Fermilab E613

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Presented by B. Roe

ABSTRACT

Data from Experiment E613, a Fermilab experiment to study prompt neutrino production, are now being analyzed. The experiment was specifically designed to study neutrinos from the decay of charmed (or other massive) particles. The detector, an 80 metric ton (fiducial volume) lead-scintillator calorimeter, is approximately 60 m from the target. As a result, the angular acceptance extends up to 40 mrad. We have run with a full density tungsten and 1/3 density tungsten target. We report on a sample of 938 neutrino 1μ events. If we parameterize the $D\bar{D}$ production cross-section as proportional to $(1-|x|)^3 e^{-2p_\perp}$ we find that our prompt neutrino 1μ events if interpreted as due to to $D\bar{D}$ production imply $\sigma_{D\bar{D}} = 17.2\pm3.2$ (stat.) $\pm$ 3.4 (sys) μb. For E_ν greater than 25 GeV, the $\bar{\nu}$ flux/ν flux = .8±.35 and the $\bar{\nu}$ flux is 2.9σ from 0.

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We report on the production of prompt neutrinos by 400 GeV protons incident on a tungsten beam dump target. Figure 1 shows the basic layout of the experiment. A 150 ton calorimeter detector is located 60 meters from the target. A beam dump of 11 m of magnetized iron followed by 11 m of passive iron shields the detector. Strongly interacting particles are absorbed and most muons are ranged out or bent away from the calorimeter by the magnetic field. A residual flux of about 3×10^5 muons per typical beam pulse of 2×10^{12} protons was measured at the front of the detector.

The detector, shown schematically in Fig. 2, consists of a 150 ton calorimeter made up of 30 modules. Each module contains 12 teflon-coated lead plates 6.3 mm thick, to give a total of 14.4 rad. lengths, 0.5 hadron absorption length, and 106 gm/cm^2 per module. Light from the liquid scintillator surrounding the plates is detected by 10 photomultiplier tubes per module. Each module is followed by two PWC planes one with horizontal and one with vertical wires on 2.54 cm centers. (See inset to Figure 2.) These are operated in a proportional mode with analog readouts of the pulse height. The PWC's have a wire-to-wire gain uniformity of 10% without software corrections and the readout is linear for showers with as many as 100 particles per wire. The calorimeter is followed by a muon spectrometer with drift chambers and solid iron magnets. For a trigger we require pulses of sufficient amplitude from appropriate calorimeter phototubes as described later and no pulse from the triple wall of veto counters in front of the detector. The beam was operated in the slow extraction mode with a spill time of about 1 s, corresponding to a live-time fraction for the apparatus of about 70%.

The transverse dimensions of the sensitive region are 3 m wide by 1.5 m high. Beam center is 0.75 meters from one side horizontally and centered vertically. The horizontal asymmetry allows us to record neutrino interactions out to a 40 mr production angle.

A set of six calorimeter modules was calibrated in a test beam to determine the energy scale. The calorimeter energy response was found to be quite linear and to have a resolution

$\sigma/E = .55/\sqrt{E}$ (GeV) for hadrons and

$.27/\sqrt{E}$ (GeV) for electrons

To form a trigger the signals from the modules are summed in 24 overlapping groups of 8 longitudinally and 2 vertically. The signals on the two sides are kept separate. Pulse height requirements are then imposed on the summed signals. (See Figure 3) This together with light attenuation in the liquid scintillator results in a trigger threshold which varies with position in a known and calibrated manner. The threshold varies between 5 and 12 GeV (equivalent hadronic energy) for most of the detector. The variation of the average threshold as a function of incoming neutrino angle (θ_ν) is very weak. The effective threshold for 50% acceptance averages around 6 GeV as shown in Figure 4.

In the spring 1981 run 1.87×10^{17} protons on target were obtained. The effective exposure after correcting for live time, bad spills etc. was a little over half this value. The triggering rate was about 30 per pulse. Because of the long spill it was important to understand the background due to cosmic rays. Therefore for each 1 second spill with beam another 1 second spill was taken with beam off. We recorded about 1000 triggers per good neutrino event. About one third of the background was due to cosmic ray triggers and the rest largely due to showers coming from muon interactions in the floor or roof blocks and impinging on the apparatus.

Because of their unambiguous signature in the detector, muon neutrino charged current events have been studied initially. Comparison of two

independent analysis methods indicates that, within the fiducial volume, we have 92% efficiency for keeping events in which the muon goes through the drift chambers. Our fiducial volume boundaries are 6" in from the lead plate edges. We include only events starting in modules 3 through 25.

The results presented here are based upon about 80% of the muon neutrino charged current data from our run with the tungsten target. The raw distribution of 1μ event energies is shown in Figure 5 for ν's and $\bar{\nu}$'s. Table I details the present event sample.

The raw spatial distributions are shown in Figure 6. Note that the events cluster about beam center. Since the beam is pitched up by a magnet just ahead of the target, the distribution of events at the calorimeter from neutrinos in the target should be 25 cm higher than that from background produced further upstream.

We must correct the distributions for the threshold effects and for the probability of a muon passing through the toroids. These effects distort the observed Bjorken x and y distributions. However, the distributions are known and the distortions calculable although further refinements in understanding biases are required. Figures 7-9 indicates that the data are in reasonable agreement with the predicted shape.

Some of the muon neutrino events are due to neutrinos from pions and kaons that decay before absorption in the target. We have determined this fraction by using tungsten targets of two different densities and extrapolating to infinite density. About 21% of our tungsten running was done with a segmented tungsten target whose average density was one-third the normal density of tungsten. We note that because we detect events over a large solid angle our correction is expected to be smaller than that for the CERN CDHS group. This is because the pion decay neutrinos are concentrated at smaller angles than the prompt neutrinos and because we use a tungsten target which has a higher atomic weight and a higher density than the CERN copper target.

In a prompt neutrino experiment control of upstream background is essential. We continually monitored upstream scraping by a series of monitors around the beam pipe. These were calibrated by introducing known amounts of materials in the beam. The background was estimated from these monitors to be less than 1% of the non-prompt signal inherent in our high density tungsten target. Material just upstream of the target (SWICS, SEM, etc) introduced a larger but calculable background of 8.3% of the non-prompt high density tungsten value. A correction averaging around 15% was introduced by hadrons punching through the three absorption length targets into the essentially infinite iron and copper stop in back of the target. The net effect of these corrections on the extrapolation is to reduce the effective density ratio of the two targets from 3 to about 2.5, as shown in Figure 10. In Figure 10 these corrections are ignored in extrapolation A and included in extrapolation B.

In order to determine the prompt cross-section as a function of energy and angle, we have divided the events into bins of energy and angle and done the extrapolation on a bin-by-bin basis using background corrections as a function of energy.

The energy and angular dependence of the neutrino events are shown in Figures 11 through 15. If we assume that the major production mode is via $D\bar{D}$ production we can go further. We assume the cross-section is proportional to $A^{1.0}$. (We hope to test this hypothesis by using copper and beryllium targets. In the present run 14% of the data was with copper targets.) The semi-leptonic branching ratio is taken as the mean of the D° and D^+ branching ratios obtained from e^+e^- data, i.e. 16.4±2.4%. We parameterize the $D\bar{D}$ cross-section as

$$E \frac{d^3\sigma}{dp^3} \propto (1-|x|)^n \, e^{-ap_\perp}$$

where x is Feynman x. We assume that the protons cascade in the target with an average elasticity (ε) of 2/3 and that the charm cross-section varies as s^k. The CERN BEBC group[1] used k=.5. J Leveille[2] suggests k=1.3 is a more appropriate value.

The results for n, a, σ are then:

n	a	ε	k	σ_{-DD} (μb)	stat. error	syst. error
3	2	.67	.5	15.6	± 3.1	± 3.1 (BEBC model)
3	2	.67	1.3	17.2	± 3.4	± 3.4
4	2	.67	1.3	21.4	± 4.3	± 4.3
3	1.6	.67	1.3	18.6	± 3.7	± 3.7
3	2	.3	1.3	24.4	± 4.9	± 4.9

The BEBC group has obtained a value of σ_{-DD} (n=3, a=2, k=0.5) of 30±10μb from $\nu_\mu+\bar{\nu}_\mu$ and 17±10μb from $\nu_e+\bar{\nu}_e$ events[1]. The CHARM group reported (n=4, a=2, no cascading) 19±6 μb.[3].

The E613 data was separated into μ^+ and μ^- events. From the relative event rates the ratio R of $\bar{\nu}_\mu/\nu_\mu$ fluxes was derived. We find that for E_ν > 25 GeV, R=.8±.35. The ν flux is 2.9σ from 0. R is expected to be one if if the flux is dominated by neutrinos from DD production while DY_c production should give R<1. Unlike the CDHS result summarized by G. Conforto at this conference we do have positive evidence for a $\bar{\nu}$ signal.

References:

1. P. Fritze et al. Phys. Lett 96B (1980).
2. J. Leveille, private communication.
3. M. Jonker et al. Phys. Lett. 96B, 435 (1980).

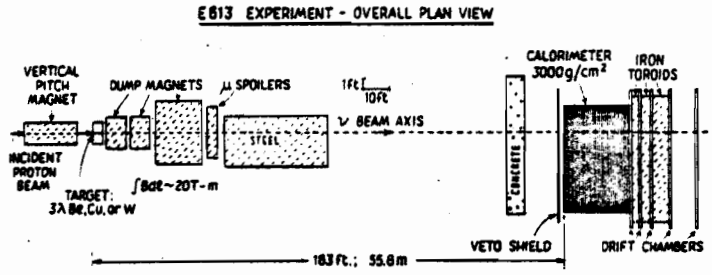

Figure 1. Layout of Fermilab Beam Experiment E613.

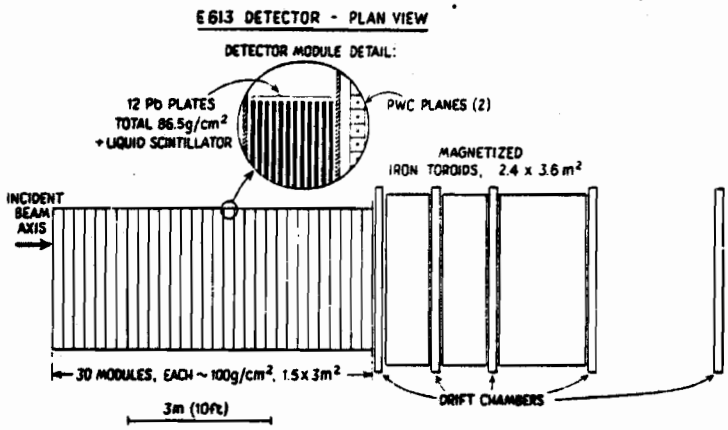

Figure 2. Fermilab E613 Calorimeter.

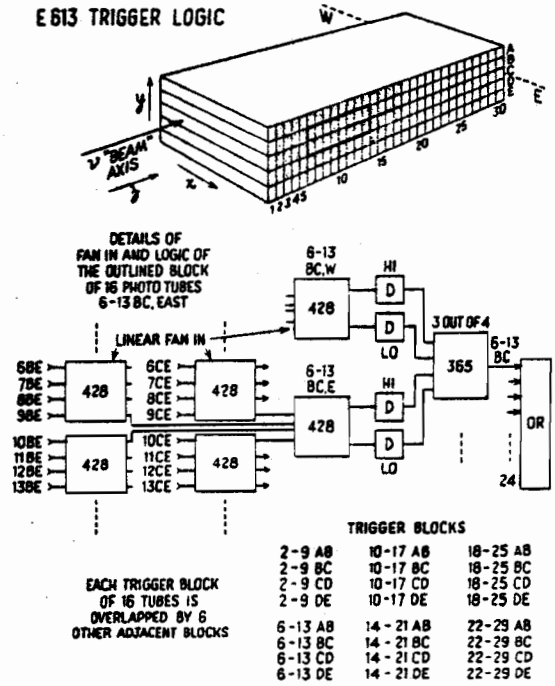

Figure 3. Fermilab E613 Neutrino Interaction Energy Trigger.

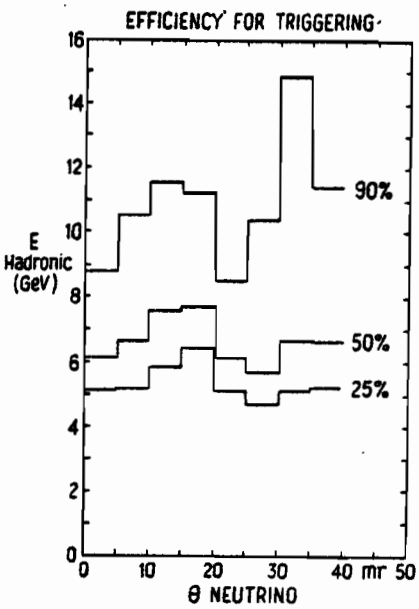

Figure 4. Variation of Threshold with Neutrino Angle.

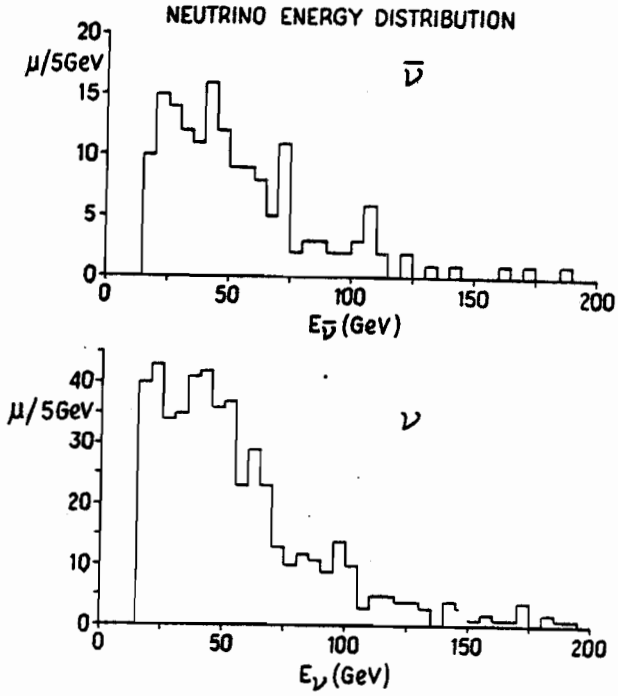

Figure 5. Raw Energy Distribution of 1μ Events.

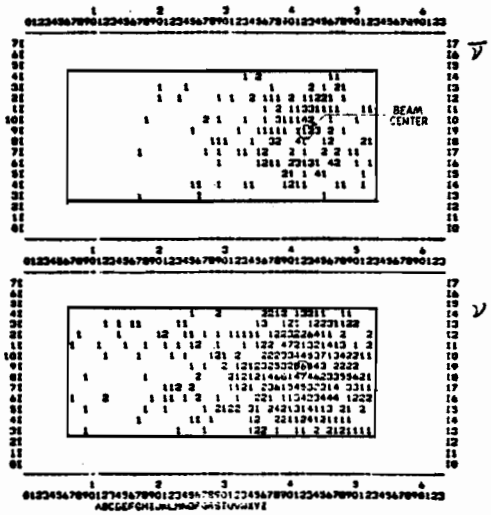

Figure 6. Raw Spatial Distribution of 1μ Events in the Calorimeter.

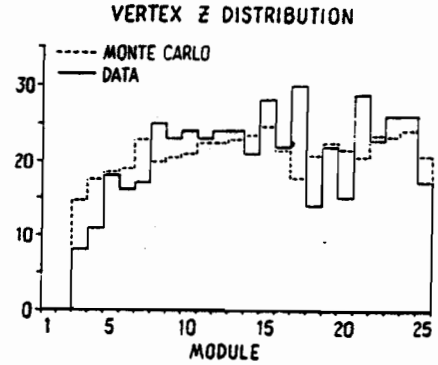

Figure 7. Distribution of Events as a Function of Module Number (Z distribution).

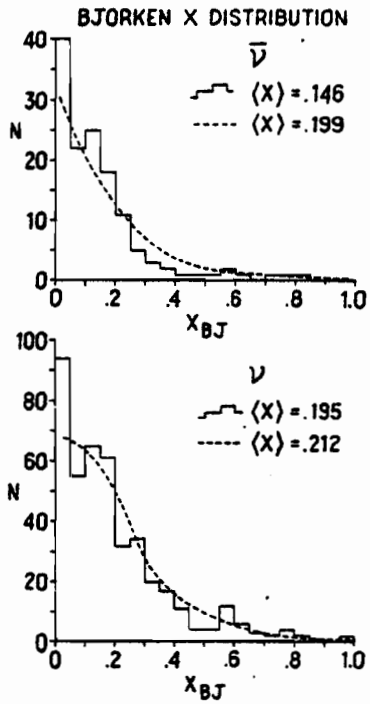

Figure 8. Raw Bjorken x Distribution of 1μ Events.

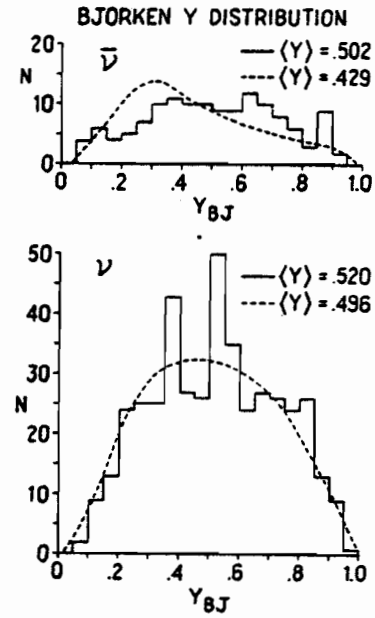

Figure 9. Raw Bjorken y Distribution of 1μ Events.

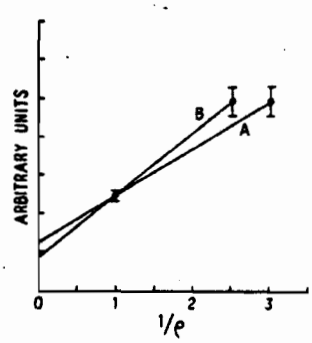

Figure 10. Overall Extrapolation of Neutrino Plus Anti-neutrino Events to an Infinite Density Target.

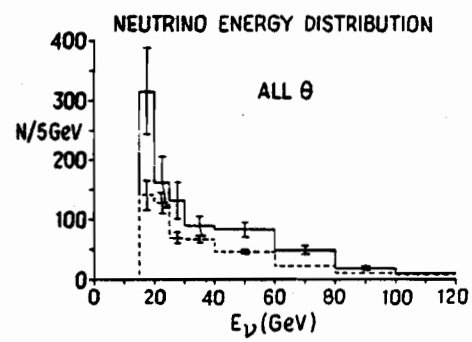

Figure 11. Energy Distribution of all 1μ Events for Full and One-third Density W Targets.

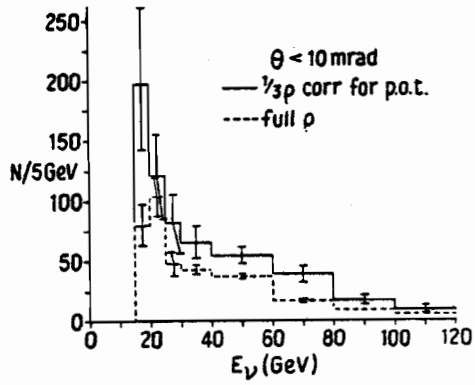

Figure 12. Energy Distribution of 1μ Events for Full and One-third Density W Targets.

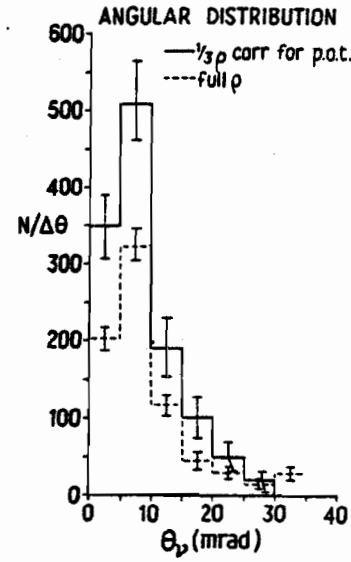

Figure 13. Angular Distribution of 1μ Events With E>15 GeV for Full and One-third Density W Targets.

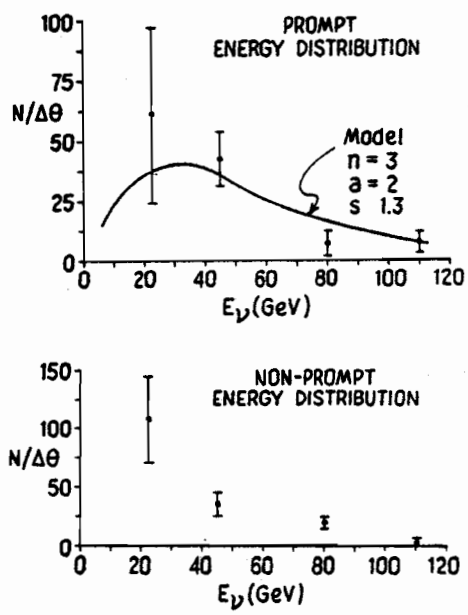

Figure 14. Energy Distribution of Weighted 1μ Prompt and Non-Prompt Neutrino Events.

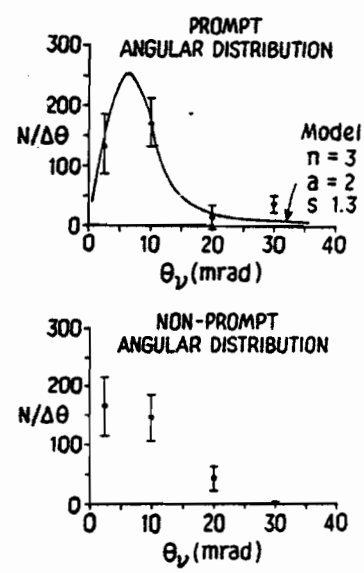

Figure 15. The Angular Distribution of Prompt and Non-prompt Neutrino Events.