THE PROMPT NEUTRINO EXPERIMENT E-613*

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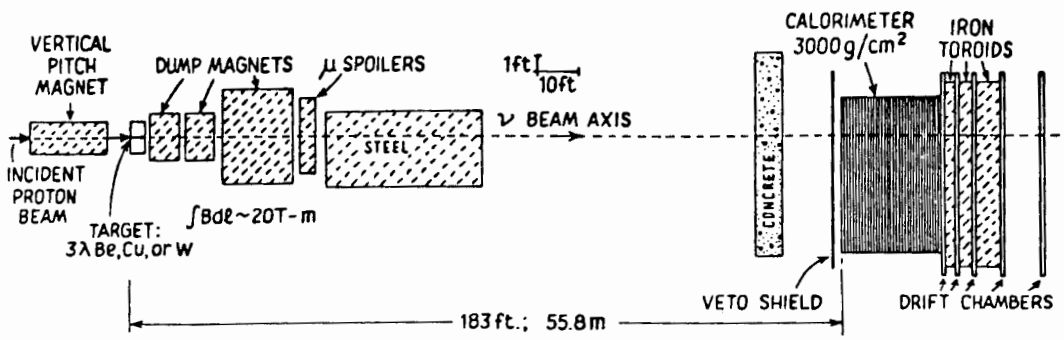
At the end of the M2 beam in the Meson Laboratory is a dump. But before calling the EPA or bringing your trash, be assured that it was designed and constructed for a very precious commodity, the 400-GeV proton beam. The proton beam deposits all its energy in the dump in the course of which all varieties of particles are produced. The high density of the dump causes particles such as pions and kaons to interact before they decay into neutrinos and muons. However, for more exotic and massive particles such as charmed mesons and baryons the reverse is true, i.e., they decay before interacting. The study of the neutrinos produced by these "prompt" decays is the objective of E-613 and provides a window to look exclusively at new particles such as charm.

The experiment was constructed and installed in the summer of 1980 and about 1.6×10^{17} protons were dumped on a tungsten target last spring. Preliminary results based on these data will be discussed. A second run this spring will yield about twice the initial data.

The figure below shows a schematic diagram of the experimental arrangement. The detector which records the interaction



E-613 beam dump experimental arrangement.

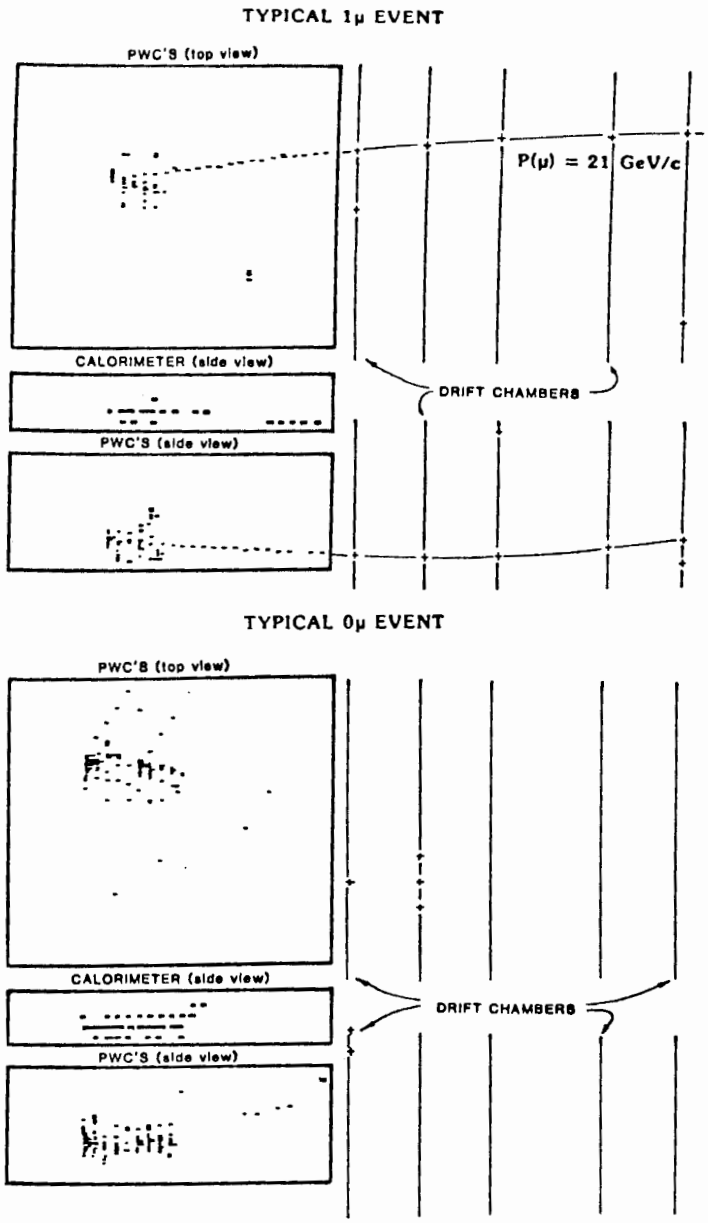
*This experiment is a collaboration of groups from Fermilab, National Institute for Nuclear Physics at Florence, Italy, the University of Michigan, Ohio State University, and the University of Wisconsin. The members are R. C. Ball, S. Childress, C. T. Coffin, G. Conforto, M. B. Crisler, M. E. Duffy, G. K. Fanourakis, H. R. Gustafson, J. S. Hoftun, L. W. Jones, T. Y. Ling, M. J. Longo, R. J. Loveless, D. D. Reeder, T. J. Roberts, B. P. Roe, T. A. Romanowski, D. L. Schumann, E. S. Smith, J. T. Volk, and E. Wang.

of the neutrinos is of relatively conventional design. The calorimeter is an active target in which the hadronic and electromagnetic cascades from the neutrino interaction are sampled by scintillators and photomultipliers. Muons which may be produced are measured using drift chambers and magnetized iron toroids. A novel feature of this detector compared to others is the use of lead in the calorimeter. The difference in energy deposition of hadron induced showers and electron (or photon) induced showers characteristic of a lead calorimeter is used to separate ν_e induced events from neutral current interactions.

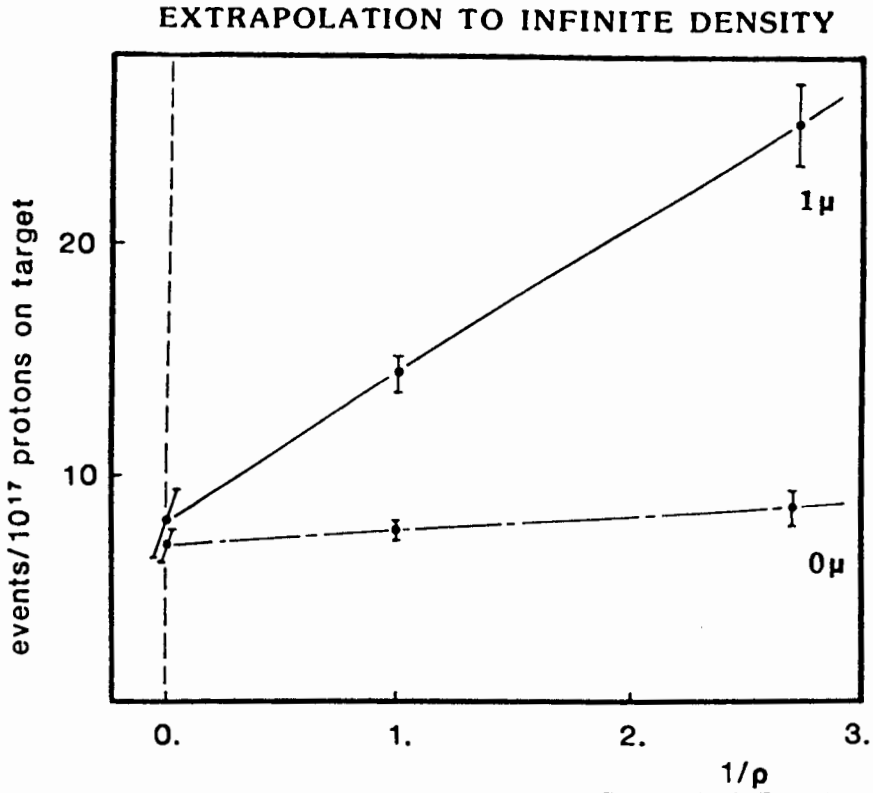
The most innovative feature of this experiment is the scheme used to reduce the large muon flux from the target to more manageable values at the detector. In conventional neutrino experiments extensive shielding is required in which the muons lose energy largely by ionization. The 1 km earth and iron shield in the Neutrino Laboratory is an example of this type. But a very large detector (3-4 m diameter) located one kilometer from the target will subtend a few milliradians only. This limitation on angular acceptance is removed if the detector is brought much closer to the target. In E-613 the distance from target to detector is 56 m which results in an angular acceptance to about 35-40 milliradians. This is achieved by using an active shield composed of several dipole magnets of solid iron (dump magnets). These dump magnets deflect negatively charged muons up (positives-down) so that they miss the detector and pass relatively harmlessly by. The $4\text{-}5\times10^{12}$ protons which are dumped each spill produce a few 10^9 muons. This muon flux is reduced by 4 orders of magnitude by the active shield. The detector is protected from the remaining muon flux by the scintillator anti-counter (veto counter).

The recording of the data was triggered by an energy deposition in the calorimeter exceeding a minimumn value ($\sim$7 GeV). The computer reconstruction of a typical event is shown on the next page. However, the bulk of the recorded events are not neutrino induced but caused by cosmic rays or particles leaking from the roof or the floor which are produced by the muons passing by above and below the detector. An initial selection is done using a computer program and the final sample is chosen by examination of the computer reconstruction. About 1600 events with the neutrino energy greater than 20 GeV were found in this preliminary analysis.

The dump target is of finite density of course so that the neutrinos due to decay of ordinary long-lived particles although reduced have not been eliminated. But by extrapolating the event rate in targets of different density to that value which would be observed in a physically impossible target of infinite density the true prompt neutrino event rate can be determined. This technique is shown in the figure on page 12 in which the event rates for various categories of events are shown. The rates for prompt neutrino events which have been so determined are underneath the figure.



Typical 1μ and 0μ events.



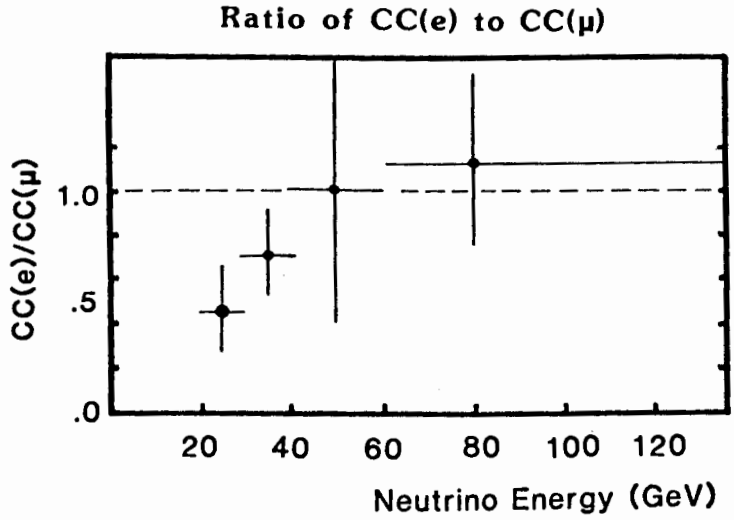
Type (E > 20 GeV)	Corrected Events 10^{16} protons on target
ν_μ(cc)	62±14
$\bar{\nu}_\mu$(cc)	19±8
muonless events (0μ)	79±8
ν_μ neutral currents (E_h > 20 GeV)	10±2

The ratio of $\bar{\nu}_\mu$ flux/ν_μ flux is found to be 0.65±0.30. The most naive expectation is that the charmed particles are produced in pairs, e.g. $D\bar{D}$, so that the ratio $\bar{\nu}_\mu/\nu_\mu$ would be 1. However, the D^+ and D^0 appear to have different lifetimes and thus different semileptonic branching ratios. Thus if the production of D^+ is unequal to D^- the ratio could deviate from 1. Similarly, the associated production of $\Lambda_c^+ \bar{D}$ could also produce a ratio unequal to one.

In order to infer the production cross section of charmed or other short-lived particles a model-dependent calculation must be performed. We assume the dependence on Feynman X_F and transverse momentum to be

$$E\frac{d^3\sigma}{dxdp^2} \;\alpha\; \begin{cases} (1 - X_F)^n e^{-bp} & \text{Model I} \\ (1 - X_F)^n e^{-bm} & \text{Model II} \end{cases}$$

muon and electron masses is negligible. The results from the earlier beam dump experiments at CERN indicated the possibility that this ratio was different from 1. For neutrino energy greater than 20 GeV our result is $\nu_e/\nu_\mu = 0.78 \pm 0.19$ (statistical error only). However, the systematic effects are most important near the lower energy boundary. The variation of this ratio with neutrino energy is shown in the figure. One sees that for energies in excess of 30 GeV the ratio is one, albeit with an uncomfortably large error.



In summary, the results of a preliminary analysis of the data obtained in E-613 have broken new ground in the study of hadronic production of charmed particles. They appear to contradict some of the results obtained in the pioneering experiments at CERN but the final analysis is not complete. These data, extended and augmented by this spring's running, will provide the definitive description of the hadronic production of particles producing "prompt" neutrinos.

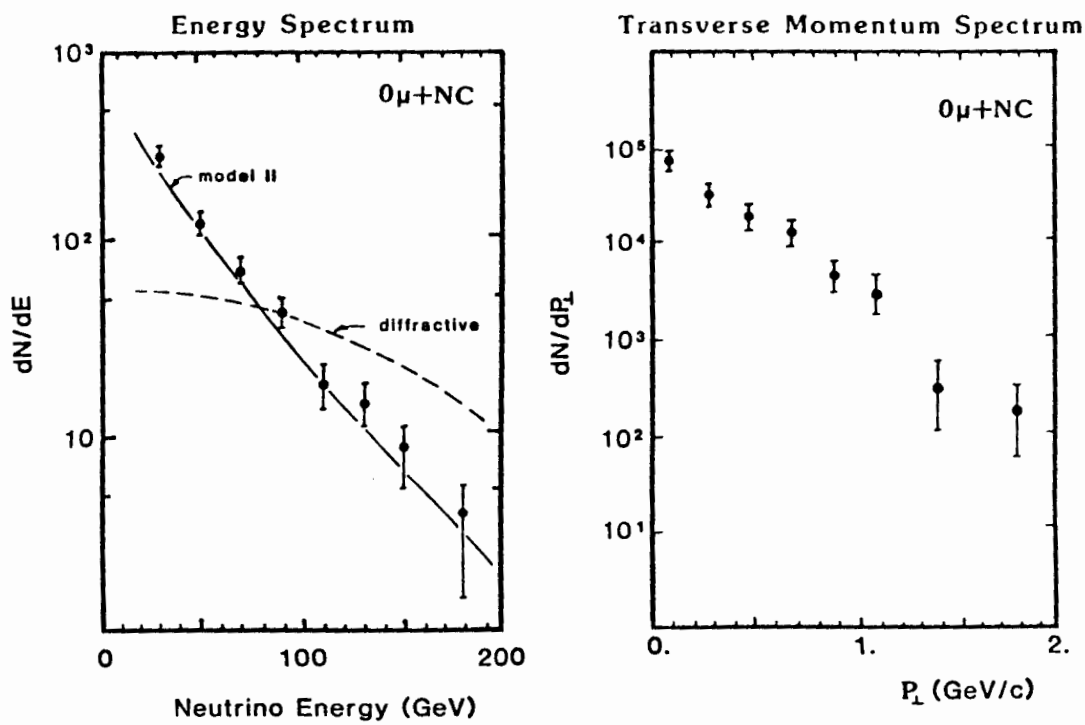
We wish to acknowledge the invaluable help provided by all branches of the Laboratory in achieving the successful completion of E-613. In particular, we wish to thank members of the Meson Laboratory for the superb support they afforded us.

with a couple of additional assumptions the cross section for $D\bar{D}$ production is

Model		$\sigma_{D\bar{D}}$ (μb)
I	n = 3 b = 2	18±3
II	n = 5 b = 3.45	30±6

So one can easily see that the value of $\sigma_{D\bar{D}}$ is quite dependent on the particular model chosen and that these systematic uncertainties outweigh the statistical error shown.

The energy distribution and transverse momentum distribution of the muonless events are shown in the accompanying figures. If the charmed particles are produced diffractively as appears to be the case at the ISR at CERN, then the energy distribution would be more nearly constant. A model calculation is shown in the figure.



We can infer with the usual necessary assumptions from the energy distribution that the diffractive production of $\Lambda_c\bar{D}$ is less than 3% of the centrally produced $D\bar{D}$.

Another quantity of interest is the ratio of ν_e to ν_μ which should be unity for massive particles where the difference in