FERMILAB TEVATRON PROPOSAL
STUDY OF NEUTRINO OSCILLATIONS AND SEARCH FOR THE TAU NEUTRINO

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I. Outline of Proposal

Summary of Techniques Proposed

To expose the Fermilab 15-Foot Bubble Chamber filled with D_2, with a solid Ar or Ne calorimeter, to the Tevatron Beam Dump neutrino beam with active muon shield. A run of 2.5×10^{18} protons is requested, with the existing or an improved EMI. High-resolution optics will be useful, if available.

Predicted Rates

$\nu_e \rightarrow e^- + x$	730
$\bar{\nu}_e \rightarrow e^+ + x$	290
$\nu\tau$ or $\bar{\nu}_\tau \rightarrow \tau^\pm + x$	300
$\nu\mu \rightarrow \mu^- + x$	1100
$\bar{\nu}\mu \rightarrow \mu^+ + x$	440
Neutral Current	880

Physics Goals

A. The active Tevatron Beam Dump allows a beam of 200 to 250m length. The prompt electron neutrino event rate will peak between 100 and 200 GeV. Thus, $\frac{\ell}{E} \sim 10^{-3}$, a smaller value than in any other experiment, allowing oscillations to be seen directly with $\delta m^2 \sim 500$ to 10^3 eV^2.

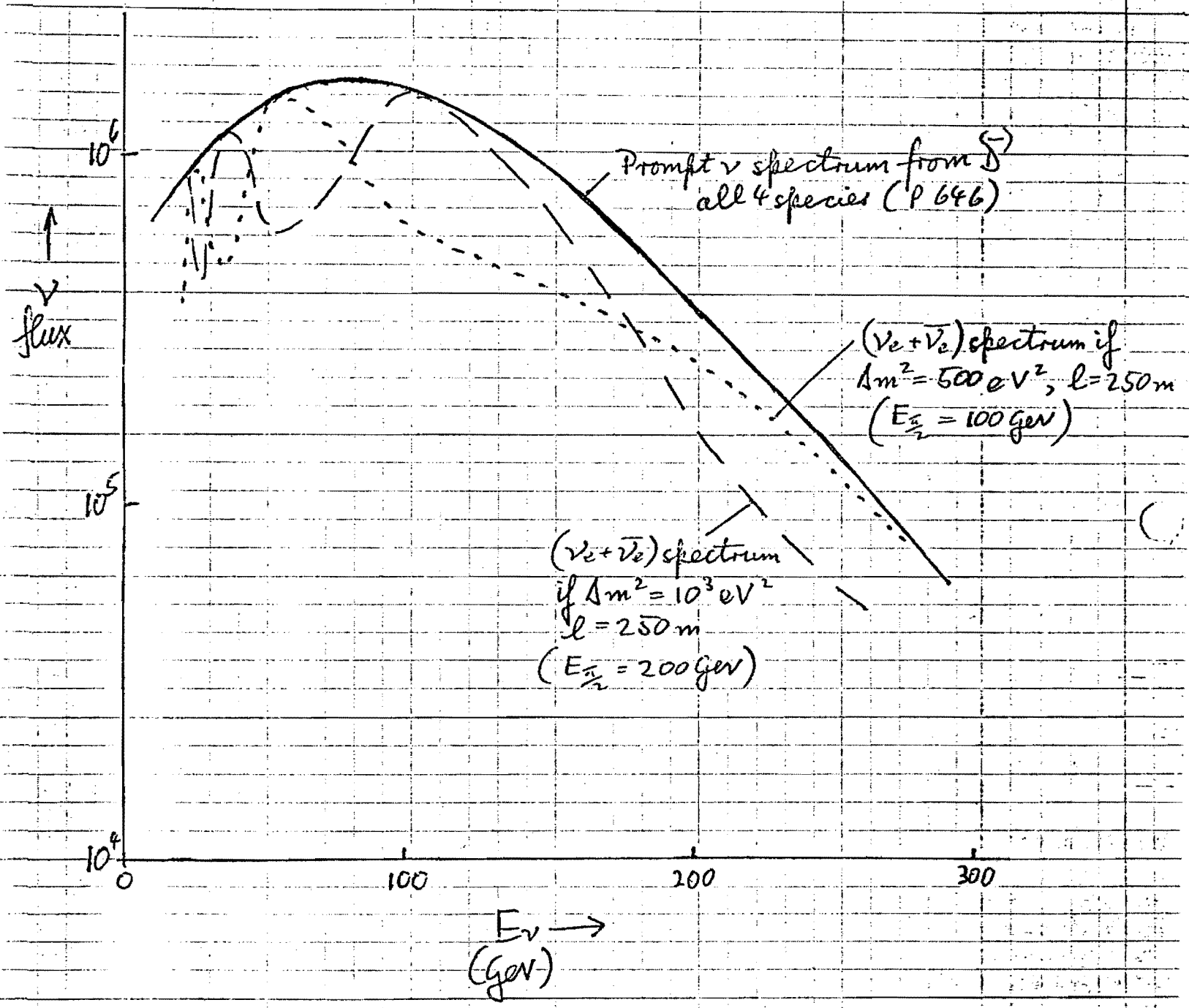
B. With deuterium in the 15-Ft. Chamber and a calorimeter, electron neutrino events can be measured with better than ± 15% of energy resolution up to the highest Tevatron energies. This could not be done with neon-hydrogen where electron measurement becomes increasingly unreliable above 20 GeV.

C. The combination of the Beam Dump and the calorimeter will allow us to see oscillations directly in the ν_e spectrum, if the value of $\sin^2 2\theta$ is as large as other experiments suggest (See Figure 1).

2. 300 τ events will be well measured and may be separated from the non-exotic back ground either by kinematics or by seeing the τ decay. $\tau^{\pm} \rightarrow e^{\pm}$ events will be particularly interesting.

3. Other topics include ν_e/ν_μ universality, investigation of prompt ν production by comparison of the spectra of all species, search for new phenomena(heavy leptons etc.), neutral current studies(especially ν_e neutral current rates).

Figure 1



N.B. i) Event rates $\propto l$ to spectrum $\times E_\nu$ ∴ most between 50 & 200 GeV

ii) $E_{\frac{\pi}{2}} = \frac{2.54 \times \Delta m^2 \times l}{\pi}$ is energy at which modulation is maximal, given Δm^2 & l.

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ADDENDUM TO PROPOSAL 700

A Beam Dump Experiment to Study ν_τ and ν_e with Deuterium and an Internal Calorimeter in the 15' Bubble Chamber*

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INTRODUCTION

The active Tevatron beam-dump together with a deuterium filling and a calorimeter in the 15' chamber will allow us to identify a significant number of tau-neutrino events (if the production rate for ν_τ is as predicted). It will also give a unique opportunity to identify and construct a clean sample of electron neutrino events and to investigate the neutral current coupling of electron neutrinos. This proposal was first submitted in outline in March 1981 with emphasis on the possibility of observing neutrino oscillation effects. New limits on electron-neutrino disappearances now make it unlikely that such clear effects could be seen[(1)] but there remain important studies for which the technique is ideally adapted.

A. Calorimeter Development

The present status of tests on solid argon and solid neon calorimeters is reviewed in the accompanying addendum to P651. Tests on a prototype calorimeter are now taking place at CERN and preliminary results will be available by the beginning of April 1982.

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B. Physics Programme, Revised

1. Predicted event-rates for 2.5×10^{18} protons (2)

$\nu_e \rightarrow e^- + X$	730
$\bar{\nu}_e \rightarrow e^+ + X$	290
ν_τ or $\bar{\nu}_\tau \rightarrow \tau^\pm + X$	220
$\nu_\mu \rightarrow \mu^- + X$	1100
$\bar{\nu}_\mu \rightarrow \mu^+ + X$	440
Neutral current	940

2. τ-Neutrino Physics

The statistics expected in deuterium are, of course, lower than those in the neon-hydrogen experiment (P646) or in the small freon chamber (P636). The direct observation of τ tracks using high resolution optics or holography will not be significantly hampered by heavy liquids. But the majority of the τ decays will not be directly resolved in any of the proposed experiments and it will be necessary to use final-state kinematics to identify them. It is here that deuterium gives a distinct advantage, especially over heavy freon (P636). The UCL and Ecole Polytechnique groups can still remember the difficulties involved in a 1962 experiment (T11) with CF_3Br in a chamber at CERN which was very similar to the one proposed for P636. With only a 3.5 GeV/c beam the final-state interactions made events extremely difficult to measure. Recent experience in E 546 has shown that it is very difficult to get reliable information on fast forward states in Neon-hydrogen because of the interactions of fast hadrons.

With deuterium in the chamber the charged hadrons from τ + X final states will be measured more accurately than in a heavy liquid. And the calorimeter will give much better measurement of both the energy and direction of neutrals. We will therefore be in a much stronger position to carry out the Albright, Schrock and Smith programme of

tests on charged current candidates (both μ and e events) in which the direction and magnitude of the missing transverse momentum is used to select $\tau \to \ell\nu\bar{\nu}$ [3]. We can also expect to be able to reconstruct the fast A_1 ($\to \pi^{\pm}\pi^{+}\pi^{-}$)and $\rho(\to \pi^{\pm}\pi^{0})$ from τ decays. These four decay modes ($\tau \to \mu\nu\nu, e\nu\nu, A_1,\nu$ and $\rho\nu$) account for approximately 65% of all τ decays.

3. Electron Neutrino Physics

The predicted prompt electron neutrino spectrum was given by P646 (see fig.2 of P700), assuming only D, $\bar{D}$ decay. The peak of the spectrum is at about 90 GeV, with a significant flux up to 200 GeV. When the energy-dependence of the cross-section is folded in it is clear that the bulk of the ν_e interactions will be above 50 GeV and the majority of the associated electrons will be between 30 GeV and 150 GeV.

Heavy liquid experiments in neon-hydrogen have had considerable difficulty in measuring electron tracks above 20 GeV.Using deuterium, with its long radiation length, we will be able to measure the sign of electrons over the whole anticipated energy range. The calorimeter will give a precise energy measurement ($\sim \pm 13\%/\sqrt{E}$) and will have enough longitudinal segmentation to reject pions with much better than 500 to 1 efficiency. There are, of course, very few pions above 30 GeV anyway.

This unique combination of electron identification and measurement, together with a beam in which ν_e events form almost 30% of the total, means that it will be possible to reconstruct a significant sample of ν_e and $\bar{\nu}_e$ charged current events. Because of the calorimeter and the simple target these events will be well reconstructed with accurate values for E_ν, x, y etc. and, in many cases, a knowledge of whether the interaction was on a proton or a neutron. It will therefore be possible to check the universality of electron-neutrino charged-current couplings by comparing the cross sections and structure functions with those for muon-neutrinos.

If the data are consistent with charged-current universality, and in

particular with a linear increase of cross-section for electron neutrinos, then the prompt spectra for ν_e, $\bar{\nu}_e$, ν_μ and $\bar{\nu}_\mu$ can be compared and the simple D, $\bar{D}$ production model may need to be revised by the addition of F and charmed hyperon contributions to the ν_e and ν_μ flux.

The most fundamental measurement which might be made for electron-neutrinos is to estimate their neutral current couplings. The NC/CC ratio for muons has been thoroughly studied over the last few years[4] so if approximately 1500 muon charged current ν_μ events are seen we expect approximately 520 ± 30 NC events from ν_μ and $\bar{\nu}_\mu$. The remaining 420 NC candidates which are expected will mostly be electron-neutrino events with a small tau-neutrino NC addition (∿ 80 events). But there are two complicating factors:-

a) Many of the charged-current τ events will look like neutral currents

b) The beam-dump beam will be dirty. There will be a large number of neutron stars which may simulate NC events.

In order to measure the electron neutrino NC rate to ∿ ±20% it will be necessary to keep these two sources of error down to ∿ ±15% of the 340 expected electron-neutrino NC events, i.e. uncertainties of less than ± 50 events due to each of a) and b). For the τ background, and to estimate the τ NC contribution, it will be necessary to calculate the number of τ charged current events to ∿ ±20%. The accuracy of this calculation will depend upon our success in identifying the τ events by kinematic tests such as the Albright, Schrock and Smith technique (see above and (3)).

The neutron background may be harder to defeat unless an upstream IPF is provided for the 15' bubble chamber. With such an IPF any timeslot in the calorimeter with an NC candidate is rejected if there is a simultaneous hit in the upstream detector, just outside the chamber body. Most fast neutrons are accompanied by a muon or other charged particles from the production point in the shield or the chamber coil. This technique is now being used in BEBC.

The neutral-current couplings of electron neutrinos remain almost

completely unchecked parameters in the phenomenology of electroweak couplings[4]. This is a test which the standard model has yet to undergo. We believe it could be done in our proposed experiment if an upstream IPF is provided.

C. Improvements to the 15' Neutrino Facility

In the accompanying addendum to P651 and in ref.5 we mention a list of improvements which could be made. The general arguments apply to this experiment as well, but we wish to stress two particular points:-

1) The beam dump will need its own system of counters to monitor the flux and the penetration pattern of background muons. Some subset of this information should be recorded on an event by event basis, perhaps by adding to the 15' EMI. record.

2) This experiment would be improved by the addition of an upstream IPF to veto the neutron background to neutral current events. The argument is even stronger here than it is for P651.

References

1. WA24 results; reported by M. Tyndel, ν '81 Hawaii,Vol.II p.34 and Erriquez et al, Phys.Letts. 102B, 73 (1981)

2. Event rates taken from P646, scaled to a deuterium filling and confirmed by M.Peters, ν '81 Hawaii,Vol.II p.228

3. Albright, Schrock and Smith, Phys.Rev. D 20 2177 (1979)

4. See review by Büsser, ν '81 Hawaii, Vol.I p.328.

5. D.J.Miller, "The 15' Bubble Chamber's E.M.I.", Fermilab Neutrino Note No.68 (April 1981): and "Future of E.M.I. for 15' Bubble Chamber", Neutrino Note No.66 (August 1981).