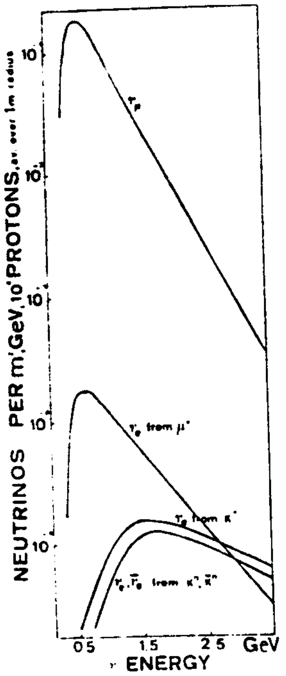

Figure 8) The calculated ν_μ and ν_e spectra in BEBC for 12 GeV protons from the CERN PS.

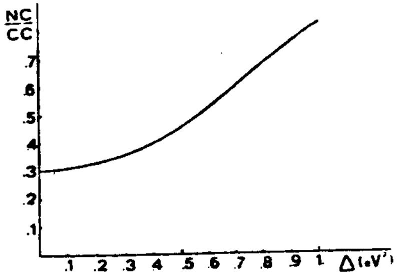

Figure 9) The ratio of neutral current to charged current events as a function of the mass difference squared.

References

1) H. Deden et al., Submitted to Phys. Letters B.
2) Nemethy et al., Los Alamos preprint.
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THE NEUTRINO BEAM DUMP EXPERIMENT AT FERMILAB (E613)

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ABSTRACT

E613, an experiment to study prompt neutrino production, is now set up in the M2 beam line at Fermilab. In contrast to the pioneering ν beam dump experiments at CERN, our experiment was specifically designed to study ν's from the decay of charmed (or other massive) particles. The detector, a 200 ton lead-scintillator calorimeter, is approx. 60 m from the target in comparison to the CERN detectors which were $\simeq$ 900 m. As a result, our event rates will be many times higher and background from non-prompt ν's much lower. Our experiment will be sensitive to $\nu_e \rightarrow$ (?) oscillations if $\delta m^2 \gtrsim$ 100 eV^2. For favorable δm^2 we would be sensitive to $\sin^2 2\alpha \geq 0.1$.

E-613 had a test run last May with approx. half the detector in place and instrumented. We expect to resume detector tuneup and data taking this November. During the test run the muon background in our detector was higher than expected. This problem will be solved by adding more passive shielding ahead of the detector.

The layout of the experiment is shown in Fig. 1. The proton beam is incident from the left on a thick target (tungsten, copper, or beryllium). The pitching magnet just ahead of the target pitches the beam up about 5 mr so that the prompt neutrino events in our detector will be centered well above background ν events from upstream sources. The target is immediately followed by a beam dump consisting of approx. 11 m of magnetized iron and another 11 m of unmagnetized iron.

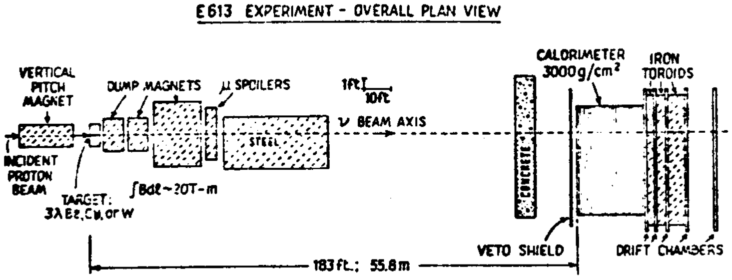


FIGURE 1

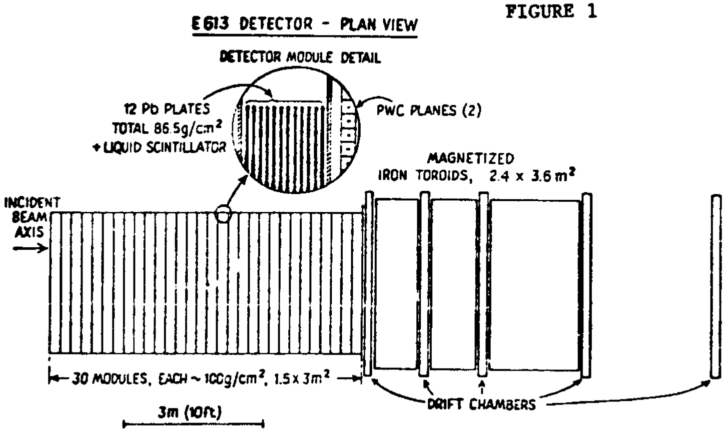


FIGURE 2

The detector, shown schematically in Fig. 2, consists of a 200 ton calorimeter made up of 30 modules. Each module contains 12 teflon-coated lead plates, 6.3 mm thick. Light from the liquid scintillator surrounding the plates is detected by a total of 300 photomultiplier tubes. Each module is followed by two PWC planes, one with horizontal and one with vertical wires on 2.54 cm centers (see inset). These are operated in a proportional mode with analog readouts of the pulse height. The PWC's show no significant variation of pulse height if the angle of the incident track with respect to the wire is varied. Wire-to-wire gain uniformity is ≈ 10% without software corrections, and the readout is linear for showers with as many as ≈ 200 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 and no pulse from the front veto counters or from cosmic ray veto counters mounted over the calorimeter.

Charged current ν_e events can be separated from neutral current events with good efficiency for neutrino energies $\gtrsim$ 10 GeV on the basis of the longitudinal energy deposition profile observed in the calorimeter. In the test run last spring data were taken with a total of ~ 2 × 10^{16} protons on a tungsten target. We expect ≈ 200 prompt ν events from this run. A "typical" event is shown in Fig. 3. With the full calorimeter we expect ~ 1000 ν events per 100 hrs. with 10^{12} protons per pulse and a threshold of approx. 5 GeV.

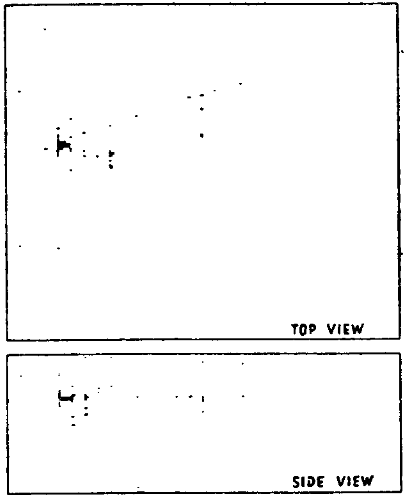
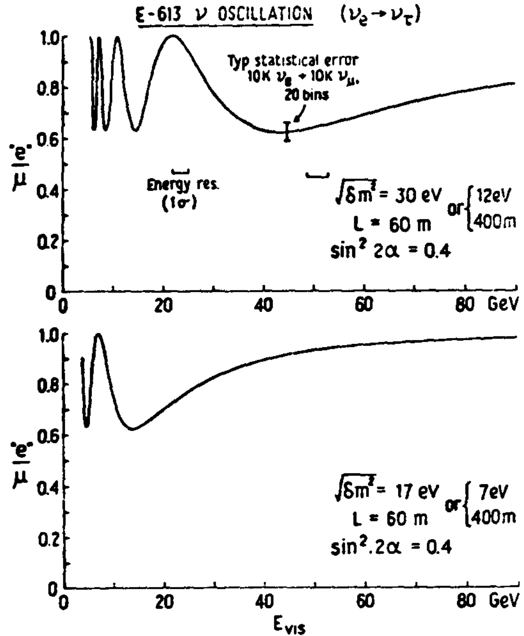


Fig. 3. PWC information from a typical event. Each dash represents a single PWC. The width of the dash is proportional to the log of the pulse height.

Neutrino oscillations such as $\nu_e \rightarrow \nu_\tau$ would show up in our data as a variation of the ratio of electron to muon neutrino events with neutrino energy. Fig. 4 shows examples of the expected behavior of the ν_e/ν_μ ratio as a function of E_{vis}, the energy deposited in the calorimeter, for 2 choices of δm^2. Also shown is a typical statistical error assuming a 10 week run and ≈ 20 energy bins. The expected energy resolutuion is also indicated. Note that if δm^2 is small the oscillations only occur for small E_{vis}. If $\delta m^2 \lesssim 100$ ev^2, the oscillations move below E_{vis} ~ 10 GeV where systematic errors are large and our energy resolution poor. For favorable δm^2 we should be sensitive to $\sin^2 2\alpha \gtrsim 0.1$. We have the possibility of targetting the proton beam farther upstream to give a source to detector spacing L of approx. 400 m. which would make us sensitive to smaller δm^2.

The CERN beam dump experiments[1] suggest δm^2 may be $\gtrsim 100$ eV^2. If the neutrino masses follow the pattern of the charged leptons, $\delta m \sim m(\nu_1)$. The ITEP tritium β decay experiment[2] indicates $m(\nu_e) \approx$ 35 eV. Also astrophysical arguments[3] suggest neutrino masses ~ 30 eV. There is however some negative evidence against large δm^2 unless $\sin^2 2\alpha \ll 1$. The most stringent limit seems to be that from a BEBC experiment with a narrow-band neutrino beam[4], which appears to set limits of $\sin^2 2\alpha \lesssim 0.3$ for δm^2 between about 100 and ~ 300 eV^2.



Dilution of ν_e by N.C. events not included (≈14% on average)

Fig. 4. Expected behavior of e/μ ratio with detected energy in the calorimeter.

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NEUTRINO OSCILLATIONS IN DUMAND

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ABSTRACT

A Monte Carlo simulation of a one-year experiment with a 0.6 km^3 DUMAND Array yields 18,656 expected events with one muon from ν_μ charged-current interactions. It is shown that neutrino oscillations resulting from eigenmass-squared differences in the range .1 to 1000 eV^2 would be detectable as a modulation of the one-muon event rate with zenith angle. Using several proposed models, it is shown that the statistics and measurement precision are adequate to aid in the determination of mass differences and mixing angles and perhaps provide unique information on matter oscillations.

INTRODUCTION

The DUMAND (Deep Underwater Muon and Neutrino Detection) project is a proposal to place a large array of light sensors at a depth of 4-5 km in the ocean off the Hawaiian islands. The detector would be capable of observing the Cerenkov light from high energy muons and hadronic cascades produced by neutrino interactions in the water. The direction of the muon, its energy and the energy of the cascade would be measured. Thus it will be possible to study the properties of neutrino interactions above 500 GeV, using neutrinos produced by cosmic rays hitting the atmosphere, and search for extraterrestrial sources of high energy neutrinos.

Because of the large range in path length for neutrinos passing through the earth, experiments deep underground or underwater offer unique possibilities in the study of neutrino oscillations. This report considers those possibilities for DUMAND. By means of a Monte Carlo simulation, it is shown that the reaction

$$\nu_\mu N \rightarrow \mu X$$

will be modulated by neutrino oscillations of the type which have been recently considered[1,2]. This modulation would be detectable with sufficient statistics and precision to provide important information on the mass difference and mixing matrix elements involved.

In Fig. 1 we define the zenith angles, θ at the detector and θ* at the production point in the atmosphere, and show how the path length L is related to θ. Other Monte Carlos[3] have shown that DUMAND is capable of measuring the muon direction and thus θ, to an accuracy of 10 mr for muons above 1 TeV, so L would be well-determined. In particular, we note the large dynamic range in L, from 20 to 12,000 km, which makes this experiment, and the others proposed for deep mines, a powerful probe of neutrino oscillations.