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The Relevance of the Fermilab Neutrino Beam Dump Experiment, E613 to Neutrino Oscillations*

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SUMMARY

A beam dump experiment has been set up at Fermilab to study prompt neutrino production by 400 GeV protons. It is unusual among experiments seeking evidence for neutrino oscillations in that the neutrino path length is short, only 60 m, while the neutrino energies are high, 10 to 200 GeV. The experiment, expected to take data this spring, will be sensitive to oscillations $\nu_e \to \nu_x$ for values of Δm^2 between 200 and 10,000 $(eV)^2$ and $\sin^2 2\alpha \gtrsim 0.2$.

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EXPERIMENTAL PARAMETERS

Figure 1 illustrates the beam dump configuration and the detector, with a compressed longitudinal scale. The proton beam of up to 3×10^{12} protons per pulse is targetted on an assembly containing six interchangeable targets. They are: tungsten of full and 1/3 density, copper of full and 1/2.4 density, and beryllium of full and 1/2 density. Beyond the target is a system of five magnets designed to sweep away most of the produced muons. Beyond the 10 m of magnetized iron an additional 10 m of passive iron is provided to range out muons of below 30 GeV. As there are approximatley 10^{-3} muons produced per beam proton, it is necessary to suppress the produced 3×10^{9} muons by large factors.

The detector, shown in Figure 2, consists of 30 modules of 1.5×3 m^2 area, each containing 86 g/cm^2 of lead in the form of 12 plates separated by liquid scintillator. The modules are separated by 30 crossed pairs of PWC planes. Each event is recorded in both scintillator pulses as digitized from the outputs of the 300 phototubes, and in the pulse heights from the 6000-wire PWC system. Beyond this system is a muon spectrometer containing 5 planes of drift chambers and 3 rectangular iron toroids of 2.4×3.6 m^2 area and totalling 4m length. A veto wall upstream of the detector suppresses spurious events caused by muon interactions in the detector.

RATES

The detector "target" is about 3000 g/cm^2 and subtends angles of up to 40 mr from the proton target with respect to the beam axis. The detector is asymmetric in order to sample high p_T neutrinos. The detector threshold corresponds to about 2.7-6 GeV visible energy, corresponding to an average of about 7 GeV hadron energy.

For a D-pair production cross section of 15 μb/nucleon, we expect one prompt neutrino charged current interaction in the detector (averaged over ν_e, $\bar{\nu}_e$, ν_μ, $\bar{\nu}_\mu$) per 2.5×10^{13} protons incident on the full density tungsten target.

In June, 1980, a short run was taken with lower beam intensity and only a fraction of the detector completed. Analysis of those data produced a sample of 37 ν_μ and $\bar{\nu}_\mu$ charged current events which were distributed in angle and energy and with a production cross section compatible with expectations assuming D-pair production, albeit with very poor statistics. An additional 23 events were collected using the 1/3 density tungsten target, again consistent with expectations but statistically inadequate for any meaningful subtraction.

It is expected that the experiment will resume serious data collection in February, 1980 with the completed detector.

NEUTRINO OSCILLATIONS

Production of charmed hadrons, either D or Λ_c, is expected to lead to nearly equal numbers of ν_e and ν_μ. If it is assumed that ν_μ does not couple significantly to other neutrinos (as suggested by several other experiments), then a study of the ratio of ν_e to ν_μ events may provide a measure of the removal of ν_e from the beam through $\nu_e \rightarrow \nu_\tau$ (or $\nu_e \rightarrow \nu_x$). (Let ν_e and ν_μ be understood here to include both neutrinos and antineutrinos.) The probability that $\nu_e \rightarrow \nu_x$ is given by $P(\nu_e \rightarrow \nu_x) = \sin^2 2\alpha \sin^2 [1.27\ \Delta m^2\ L/E_\nu]$, where $\Delta m^2 = m_x^2 - m_e^2$, and L is the target-detector separation. The ratio ν_e/ν_μ will vary as E_ν changes, so that a plot of this ratio vs. E_ν will show oscillations. The amplitude of the oscillation depends on $\sin^2 2\alpha$; it also would depend on a dilution of ν_e from neutral current events. Studies in a test beam indicate that we can separate about 90% of the neutral current events from ν_e charged current events, based on the large difference between

the longitudinal development of hadron and e.m. cascades.

In Figure 3 the ratio of ν_e charged current events to ν_μ charged current events is given (as "e"/μ) vs. E_ν for two values of assumed Δm^2, 300 and 900 $(eV)^2$ and for $\sin^2 2\alpha$ of 0.4. Values are also noted on the graph for L = 400m with correspondingly lower values of Δm^2; this is a possible future option if indications of neutrino oscillations in the range Δm^2 between 50 and 500 eV should be found.

The sensitive range of this experiment for neutrino oscillations is portrayed on Figure 4. The stippled region indicates the boundary of the $\sin^2 2\alpha$ - Δm^2 space within which this experiment would be sensitive. The left-hand boundary of $\sin^2 2\alpha \approx 0.2$ is determined by the statistical precision of the data; the lower bound in Δm^2 depends in part on statistics and in part on the lower energy limit on E_ν. The upper boundary in Δm^2 depends on the calorimeter resolution and on statistics; for $\Delta m^2 \approx 20{,}000$ $(eV)^2$ the oscillations in ν_e/ν_μ vs E_ν will be very close together except at large E_ν.

Above these values of Δm^2 the effect of oscillations will be to change the average value of ν_e/ν_μ (to 0.8 for $\sin^2 2\alpha = 0.4$ for example), and the stippled vertical bar represents that limit. Of course any beam line or other $\pi \to \mu + \nu_\mu$ contamination in the beam with produce a similar effect, so that conclusions concerning neutrino oscillations based on this average alone must be regarded with suspicion, even from a very careful experiment.

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FIGURE CAPTIONS

Figure 1. Plan view of the experiment from the proton target to the muon spectrometer. Note the compressed longitudinal scale.

Figure 2. Plan view of the detector including inset detail of one detector module and following PWC plane pair. The incident beam axis is offset to be 1/4 of the width of the detector from the west edge (top of this drawing).

Figure 3. Expected ratio of ν_e to ν_μ events vs E_ν for two values of mass difference and $\sin^2 2\alpha = 0.4$. The abscisca is the observed value of $(\nu_e+\bar{\nu}_e)/(\nu_\mu+\bar{\nu}_\mu)$. Numbers in brackets refer to the same graph for a target-detector distance of 400 ft.

Figure 4. Sensitivity of E613 to neutrino oscillations, $\nu_e \to \nu_x$ (or $\nu_e \to \nu_\tau$) in Δm^2 - $\sin^2 2\alpha$ space. It is assumed that ν_μ is not coupled to ν_e or ν_τ.

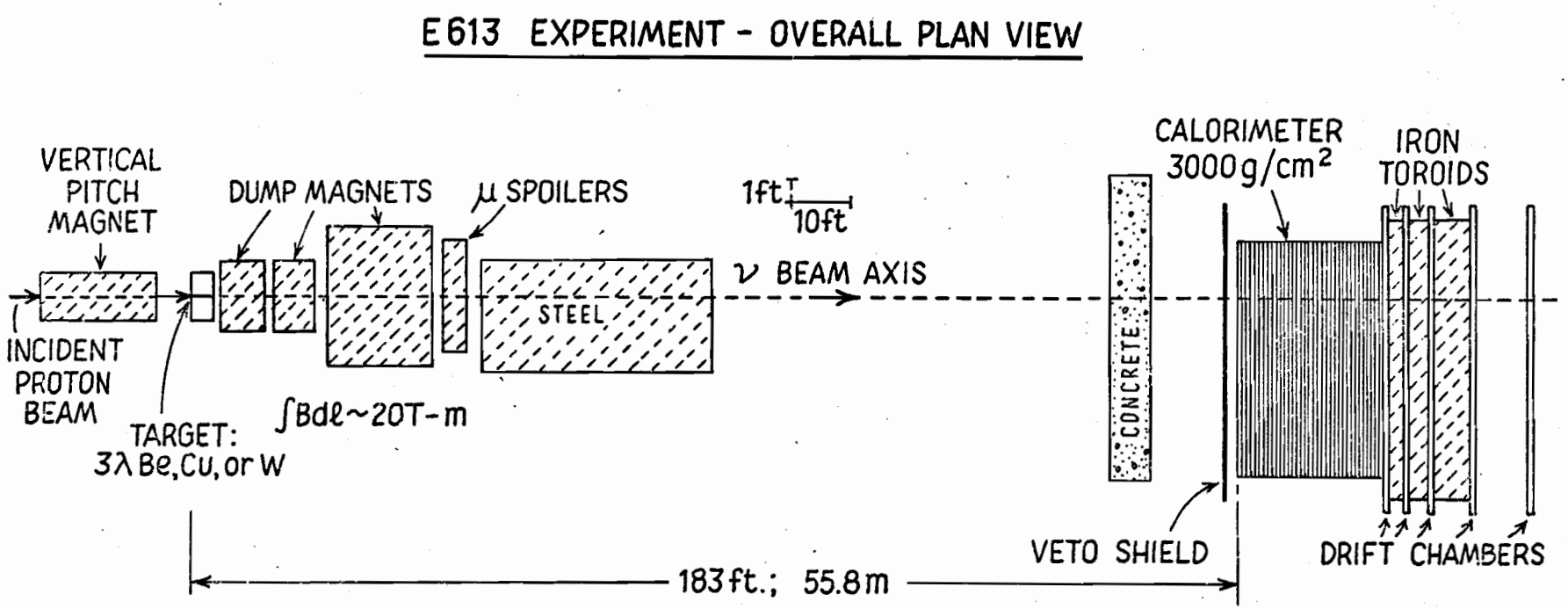

E613 EXPERIMENT - OVERALL PLAN VIEW
VERTICAL PITCH MAGNET
DUMP MAGNETS
μ SPOILERS
1ft
10ft
ν BEAM AXIS
STEEL
CALORIMETER 3000g/cm²
IRON TOROIDS
CONCRETE
INCIDENT PROTON BEAM
TARGET: 3λ Be,Cu,or W
∫Bdℓ~20T-m
VETO SHIELD
DRIFT CHAMBERS
183ft.; 55.8m

Figure 1

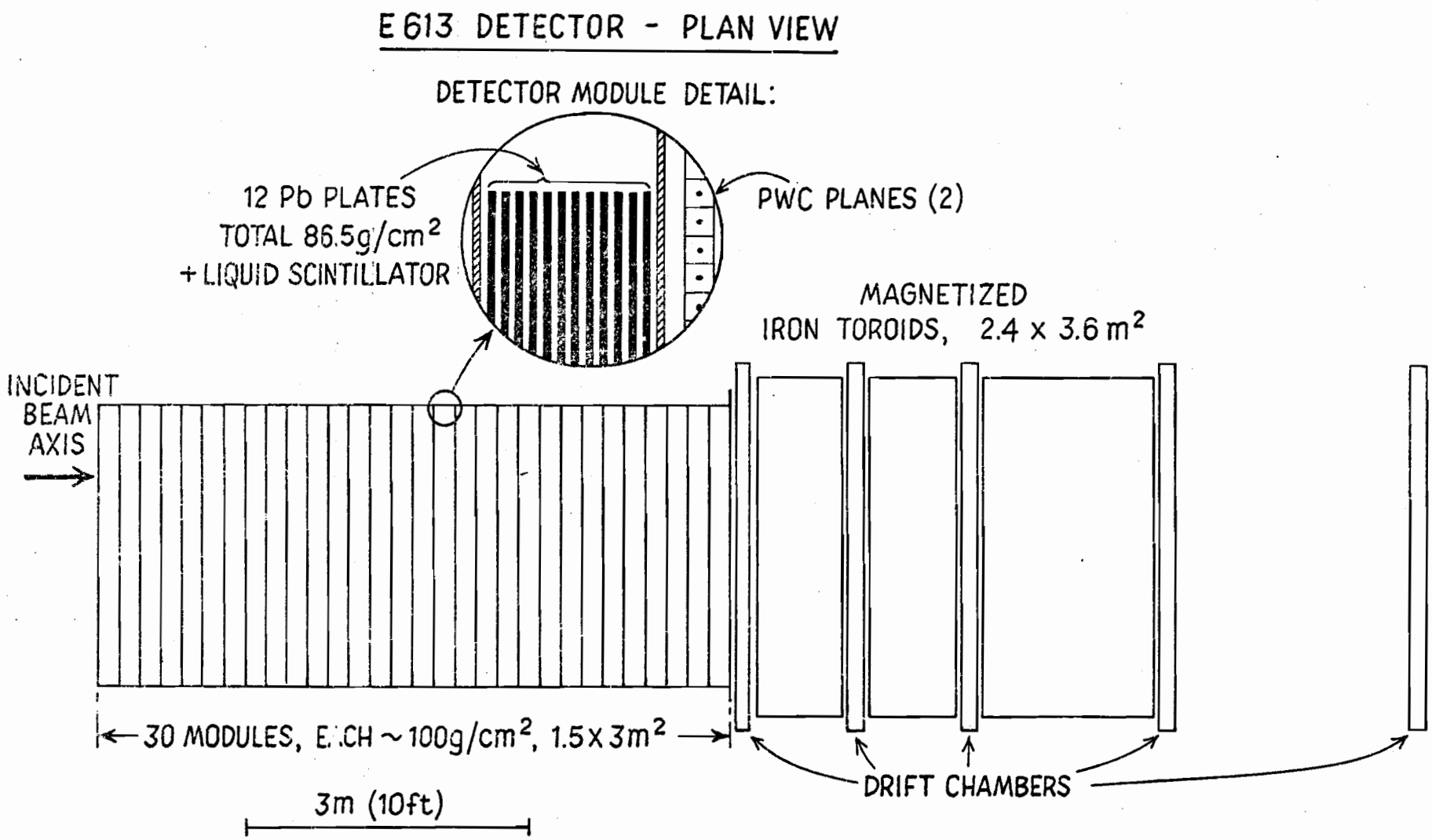
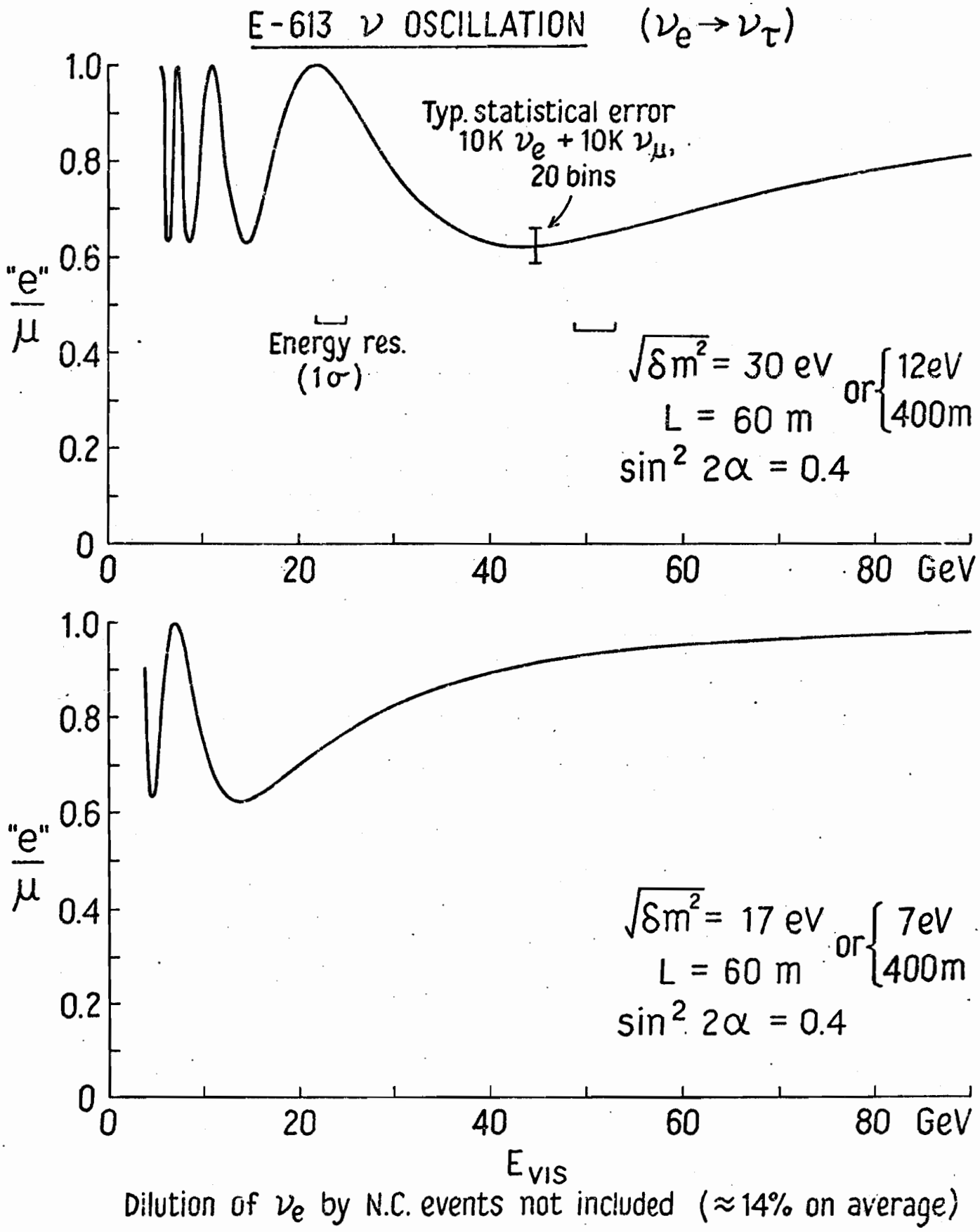

E 613 DETECTOR - PLAN VIEW
DETECTOR MODULE DETAIL:
12 Pb PLATES
TOTAL 86.5g/cm²
+ LIQUID SCINTILLATOR
PWC PLANES (2)
MAGNETIZED
IRON TOROIDS, 2.4 x 3.6 m²
INCIDENT
BEAM
AXIS
30 MODULES, EACH ~100g/cm², 1.5x3m²
3m (10ft)
DRIFT CHAMBERS

Figure 2



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

Figure 3

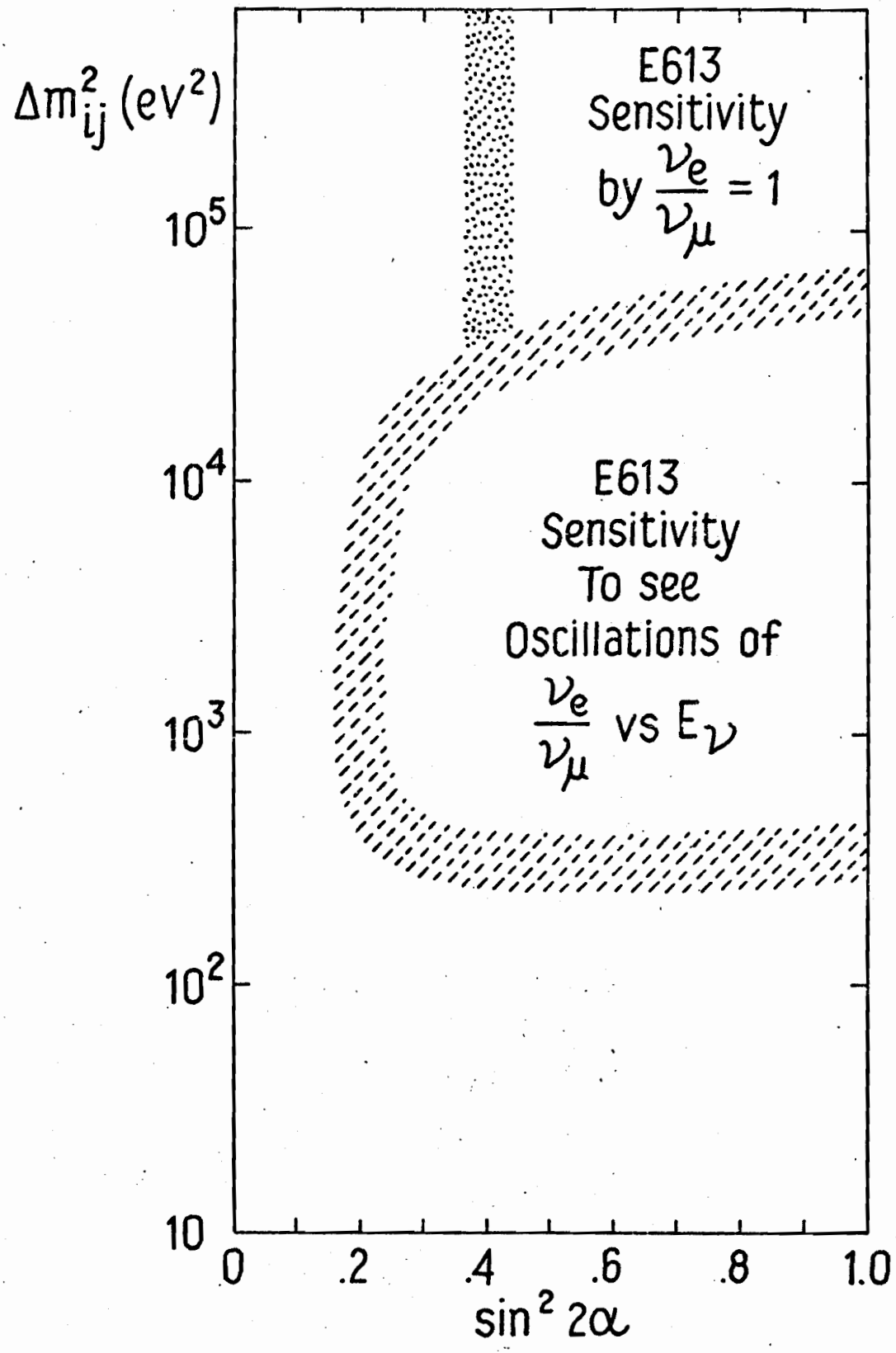

Δm^2_{ij} (ev^2)
10^5
10^4
10^3
10^2
10
0
.2
.4
.6
.8
1.0
$\sin^2 2\alpha$
E613
Sensitivity
by $\frac{\nu_e}{\nu_\mu} = 1$
E613
Sensitivity
To see
Oscillations of
$\frac{\nu_e}{\nu_\mu}$ vs E_ν

Figure 4