Further Studies of Prompt Neutrinos with the E-613 Detector

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SUMMARY

We propose to improve and enlarge the E-613 detector to make a finer grained detector more suitable for τ-neutrino physics and for studying neutrino oscillations. Details of the design of the detector will depend on our experience in E-613, further Monte Carlo studies, and possibly tests of a prototype with beam. At present we contemplate a detector which would have twice the mass of the present one with proportional readout of approx. 20,000 wires compared to $\approx$ 6500 at present. With the increased detector mass and a factor of five increase in average intensity we expect $\sim 2 \times 10^5$ prompt neutrino events and $\sim 2 \times 10^3$ $\nu_\tau \rightarrow \tau$ events with subsequent decay of the $\tau^\pm$ to $\mu^\pm + \nu_\tau + \nu_\mu$. Running could be at energies from 200 to 1000 GeV.

THE PRESENT DETECTOR

The E-613 detector, shown in Fig. 1, consists of 30 lead-scintillator calorimeter modules, each 5 ft. high by 10 ft. wide with a mass of 5 metric tons. Each module is viewed by 10 photomultiplier tubes. After each module are two planes of proportional wire chambers with pulse height readout. One plane of each pair of PWC's has wires horizontal; the other has wires vertical. The wires are on 1" centers. By fitting energy deposition profiles we can effectively interpolate between wires and obtain a resolution for tracking the energy deposition which is considerably better than the wire spacing. The calorimeter is followed by a muon spectrometer made up of solid iron toroids with drift chambers to track the muons.

The calorimeter is shielded by a 2' thick heavy concrete roof upon which cosmic ray veto counters are located.

The present beam dump is shown in Fig. 2. A notable feature is the pitching magnet just ahead of the target. This magnet aims the proton beam upward so that at the detector the prompt neutrino flux is centered about 12" above the nominal Meson Lab beam height. Thus neutrino events from background sources upstream of the pitching magnet will be distinguishable from neutrinos produced in the target by their spatial distribution alone. This feature of the experiment will provide a crucial test of the origin of our events which is especially important in searching for possible neutrino oscillations.

PROPOSED MODIFICATIONS

We propose to enlarge the present detector to approx. twice the present mass. The added elements will be of low Z material and have much finer grained sampling of the energy deposition. This will greatly improve the resolution in missing $P_\perp$ which is vital in distinguishing tau neutrinos from ordinary neutrinos.[1,2]

The most economical and convenient choice of a low Z material for the detector seems to be ordinary concrete (appropriately reinforced with steel or aluminum). A possible configuration for the enlarged detector is shown in Fig. 3. Each of the 15 cells would consist of two of the lead-scintillator modules from the present detector preceeded by 8 slabs of concrete; each slab will be 4" thick and a single PWC plane would follow each concrete slab. The PWC planes would be alternately x and y with a total of 180 planes, three times as many as in the present array.

One advantage of interspersing new detector elements with the present lead-scintillator modules is that no new triggering elements would be required.

ν_τ SEARCH

Our rate estimates are based on an assumed proton flux of 5×10^{12}/pulse on a hevimet target with prompt ν production

cross sections from the CERN beam dump experiments.[3] We assume an A^1 production cross section to extrapolate from the copper target used at CERN to tungsten (hevimet). Cross sections for ν_τ production and $\tau \to \mu + \nu_\mu + \nu_\tau$ branching ratios are taken from C. Albright et al.[2]

With 5×10^{12} protons incident at 400 GeV we estimate $\sim$ 0.5 prompt ν events with $E_{vis} > 10$ GeV per spill. At 5000 spills per day and 100 days of running, this is 2.5×10^5 total prompt ν events. Albright et al.[2] estimate that the $(\nu_\tau + \bar{\nu}_\tau)$event rate with the τ subsequently decaying into a μ is $\sim$ 1% of the prompt ν rate, so this corresponds to $\sim$2500 useful ν_τ events. Even after the cuts prescribed by Schrock et al. to isolate the ν_τ events, we can expect several hundred events.

Comparable rates could be expected with a 1000 GeV beam. The increased ν fluxes would roughly compensate the lower repetition rate.[4]

An important advantage of our detector in searching for the tau neutrino is the large solid angle it subtends. At larger angles and higher E_ν the ratio of ν_τ to $(\nu_\mu + \nu_e)$ increases significantly [Table I]. This should serve as an important check that we are actually observing ν_τ's.

Our own Monte Carlo studies of the Albright-Schrock technique indicate that with the angular resolution for hadron showers anticipated for the CHARM and E-594 detectors the rejection of background from ν_μ events is

only about 20:1. We are continuing to investigate various detector configurations to find the optimum choice. Possible further cuts on the data to enhance the ν_τ signal are also being studied. There is also the possibility that $\nu_e \rightarrow \nu_\tau$ oscillations might dramatically enhance the ν_τ signal.

NEUTRINO OSCILLATIONS

The three groups taking part in the beam dump experiment carried out at CERN in the spring of 1979 have all reported values for the ratio

$$R = \frac{\text{Number of prompt electron events}}{\text{Number of prompt muon events}}$$

which are substantially smaller than unity. The presently available determinations of R are the following

BEBC[3]	$R = 0.49 \pm 0.17$
CHARM[3]	$R = 0.59 \pm 0.22$
CDHS[5]	$R = 0.62 \pm 0.13$

from which the combined value $R = 0.574 \pm 0.096$ can be derived.

If the prompt neutrinos come from decays of charmed particles we would expect R=1. No convincing explanation for this discrepancy exists at present. The possibility that it may be due to oscillations of ν_e's into ν_τ's (or perhaps even other kinds of neutrinos so far unsuspected)

has been suggested in Reference 6. This explanation requires mixing angles α of about 20° and values of $\delta m = \sqrt{|m_3^2 - m_1^2|} \gtrsim 7$ eV which are not excluded by any experimental observation available at present.

V. Barger et al.[7] have also reanalyzed the situation regarding possible neutrino oscillations. They do not consider the CERN beam dump results. They conclude that the reactor, deep mine, and accelerator data are consistent with ν oscillations with $\delta m \gtrsim 0.1$ eV. One of their "solutions" corresponds to a $\delta m \sim 3$ eV; however, they seem to favor the solutions with smaller δm which are not consistent with the CERN beam dump results.[6] In view of the uncertainty in the experimental situation, there seems to be no justification for eliminating the possibility of ν oscillations with $\delta m \gg 1$ eV. [Cosmological arguments suggest that $m_{\nu_\tau} \lesssim 50$ eV. This limit is inferred from the density of the universe which is subject to large uncertainties.]

The subject of neutrino oscillations is currently in a state of such rapid evolution that these remarks should serve primarily as a reminder that neutrino oscillations are a topic of lively interest, and that any experiment which may significantly clarify this situation is of considerable importance.[9]

Maximum sensitivity to ν oscillations occurs when $E_\nu/L \sim (\delta m)^2$ where L is the distance between the neutrino source and detector and E_ν is the neutrino energy. Thus our detector with $L \approx 60$ m would be sensitive to larger δm than the CERN detectors.

If $\nu_e \rightarrow \nu_\tau$ transitions do occur, the ratio of electron neutrino to muon neutrino events will vary with E_ν in a characteristic way. The approximate expected behavior of $R \equiv$ (events with e)/(events with μ) is shown in Fig. 4 for $\sin^2 2\alpha = 0.4$, $\delta m = 17$ eV and $L = 60$ m.

Fortunately the M2 beam line is flexible enough to allow the proton beam to be targetted farther from our detector to vary L. If, for example, the proton beam is targetted on the steel collimator blocks on the Meson Lab target train and aimed at our apparatus, $L \cong 500$ m. Increasing the proton beam intensity will partially offset the decreased solid angle subtended by our detector. For $L = 500$ m the curve in Fig. 4 is appropriate for $\delta m \cong 5.9$ eV. It may also be possible to target at an intermediate location along the M2 line if it proves desirable to explore $60 < L < 500$ m.

If the effect observed in the CERN experiment is of spurious origin, it is most likely due to the decay of pions either produced by the scraping of the primary beam somewhere upstream of the target or leaking out of the

dump target itself. In either case placing the detector as close to the target as possible is an advantage since the signal due to prompt neutrinos increases roughly as the square of the inverse of the distance between the target and the detector, while the background due to the pion decays is almost independent of the distance. The pitching magnet just ahead of our target provides a strong check on the origin of the events since neutrino events from the target will have a distribution centered over a foot above those from pion decays upstream.

OTHER PHYSICS

In E-613 we plan to make detailed studies of prompt ν production as a function of proton energy, atomic weight of the target, neutrino energy, and neutrino angle. We would, of course, wish to continue these studies up to 1000 GeV. At higher energies it may become possible to distinguish the contribution to prompt ν production from the decay of particles with naked beauty on the basis of the wider angular distribution these neutrinos would have. This argues for a close in detector capable of being moved to larger angles (i.e. - similar in concept to the E-613 detector).

There is also the distinct possibility that E-613 will uncover some new phenomena which we would want to follow up at higher energies. We can only speculate about such

possibilities at present. In general, however, more massive particles are produced with broader angular distributions and decay with broader angular distributions. This is another strong argument for a detector which subtends a large solid angle.

We are also investigating the possibility of studying ν_e-e elastic scattering. The background from ν_e neutral current events poses serious problems, and it is not clear whether any practical electronic detector could provide sufficient rejection.

RUNNING CONDITIONS AND OTHER CONSIDERATIONS

Since this experiment is likely to be running when 1000 GeV external proton beams are beginning to be available, it is important to discuss how readily we can run at Tevatron energies. As previously noted, event rates will be roughly the same. It will take more magnetized iron in the beam dump to deflect the higher energy muons. This can be easily provided by adding another beam dump magnet to the present train, thus moving the target a few meters upstream. Some restacking and augmentation of the iron and concrete shield would also be necessary. We emphasize, however, that much of the physics, the ν_τ search and neutrino oscillations in particular, can be pursued with 400 GeV beam.

T.E. Toohig[8] has discussed the question of targetting 10^{13} protons/minute at 1 TeV onto a beam dump in the Meson Detector Bldg. He also discusses operation with 10^{13} protons/pulse at 400 GeV. He concludes that it is reasonable to target up to 10^{13} protons/pulse in the building if the muons are deflected vertically and personnel are kept out of areas like the catwalk downstream of the dump. Thus we anticipate no serious problems in increasing the intensity from the 10^{12} protons/pulse envisioned for E-613 to 5×10^{12} protons/pulse.

We propose that the costs of augmenting the detectors be borne by the experimenters and costs of enlarging the wonder building, modifying the beam dump, and rigging be borne by the laboratory.

We believe that upgrading the M2 beam dump to 1000 GeV and improving the E-613 detector is by far the most cost effective approach to future beam dump experiments at Fermilab. However, our group would not reject the possibility of relocating the E-613 detector in the Neutrino Laboratory We emphasize that any "new physics" is likely to be most conspicuous at relatively large angles and $P_{\perp}$. Thus any new neutrino facility should not preclude a study of large angle phenomena.

REFERENCES

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3. H. Wachsmuth, Proc. of the Int'l. Symposium on Lepton and Photon Interactions at High Energies, Fermilab, August, 1979.
4. S. Mori, Fermilab Tech. Memo TM-848, 2251.0, Jan. 24, 1979.
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7. V. Barger, K. Whisnant, D. Cline, and R. Phillips, Univ. of Wisconsin Rep't. COO-881-135, Feb. 1980.
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9. A recent preprint by F. Reines et al. indicates positive evidence for ν oscillations from reactor data which correspond to a $\delta m \gtrsim 0.6$ eV. Rumors of new results from the ITEP group measuring the spectrum from H^3 beta decay suggest a ν_e mass ~ 17 eV.

TABLE I - ν_τ and $(\nu_\mu+\nu_e)$ Fluxes, 1000 GeV

[From S. Mori, TM-848]

E_ν (GeV)	0-2 mr		4-6 mr		8-10 mr	
	$\nu_\tau+\bar{\nu}_\tau$ Flux*	$\frac{\nu_\mu+\nu_e}{\nu_\tau}$ †	$\nu_\tau+\bar{\nu}_\tau$ Flux*	$\frac{\nu_\mu+\nu_e}{\nu_\tau}$ †	$\nu_\tau+\bar{\nu}_\tau$ Flux*	$\frac{\nu_\mu+\nu_e}{\nu_\tau}$ †
50	1.5×10^3	15	15.6×10^3	17	6.4×10^3	32
100	9.4	32	4.0	48	1.9	19
150	4.4	48	2.5	22	0.51	9.0
200	2.9	38	1.2	11	0.11	4.1
250	2.0	26	0.43	7	0.02	—
300	1.3	14	0.13	—	—	—

* $\nu_\tau+\bar{\nu}_\tau$ from F decay, $(\mathrm{GeV}^{-1}\text{-}\mathrm{m}^{-2})/10^{13}$ protons. Averaged over 2 mr radial bin.

† Includes $\nu+\bar{\nu}$. $\nu_\mu+\nu_e$ from D decay. ν_τ from F-decay

FIGURE CAPTIONS

1. The existing E-613 detector
2. E-613 target and beam dump.
3. Possible configuration of enlarged detector. One of 15 cells is shown.
4. Representative behavior of the ratio of events with electrons to events with muons vs. E_{vis}, the energy deposited in the detector. These curves are scaled from those in Ref. 6. For L fixed, an increase in δm causes the curve to shift to higher energies. Doubling δm, for example, will cause a quadrupling of the energy scale.

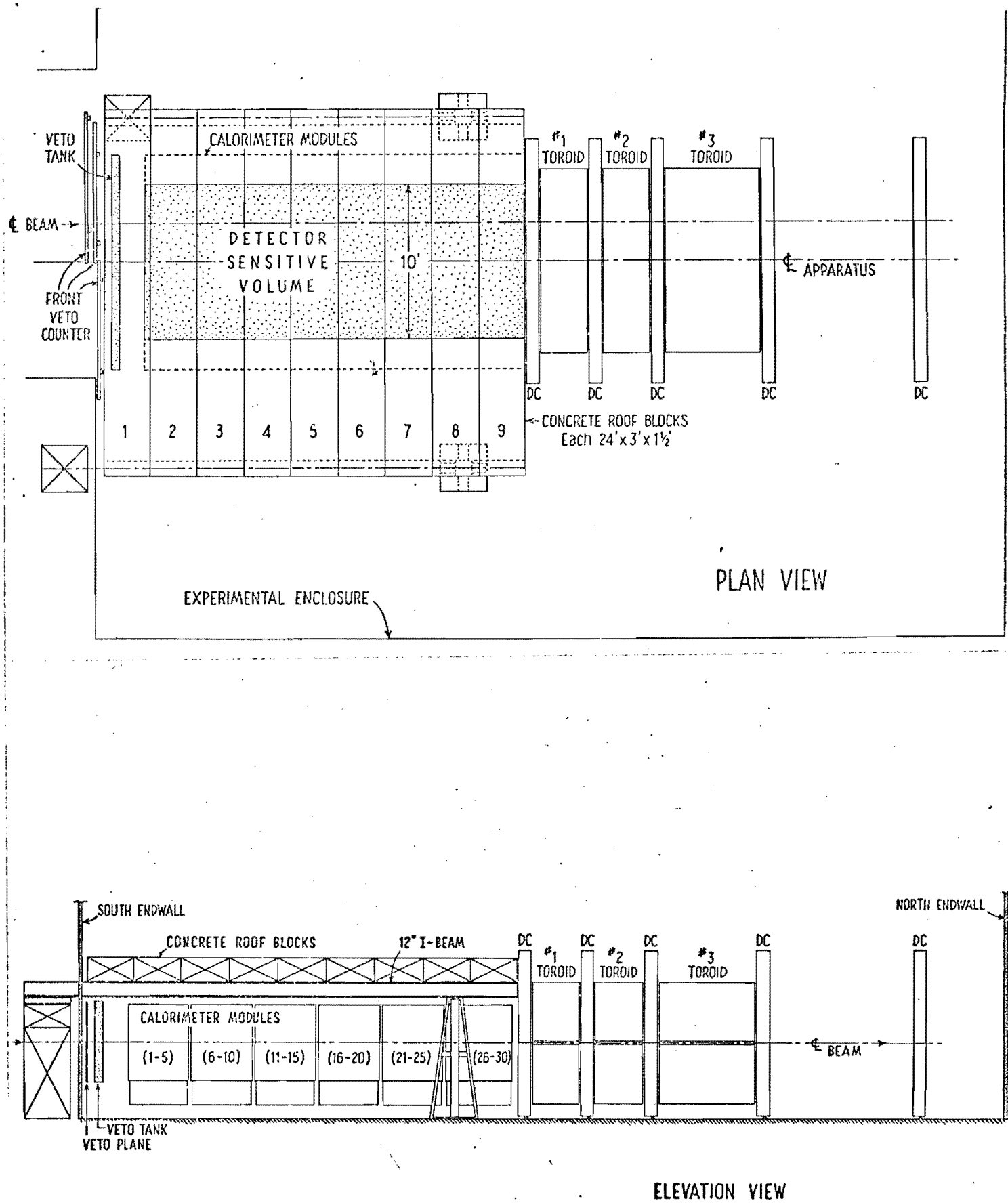
VETO TANK
CALORIMETER MODULES
#1 TOROID
#2 TOROID
#3 TOROID
℄ BEAM
DETECTOR SENSITIVE VOLUME
10'
℄ APPARATUS
FRONT VETO COUNTER
DC
DC
DC
DC
DC
1
2
3
4
5
6
7
8
9
CONCRETE ROOF BLOCKS Each 24'x3'x1½'
PLAN VIEW
EXPERIMENTAL ENCLOSURE
SOUTH ENDWALL
NORTH ENDWALL
CONCRETE ROOF BLOCKS
12" I-BEAM
DC
#1 TOROID
DC
#2 TOROID
DC
#3 TOROID
DC
DC
CALORIMETER MODULES
(1-5)
(6-10)
(11-15)
(16-20)
(21-25)
(26-30)
℄ BEAM
VETO TANK
VETO PLANE
ELEVATION VIEW

FIGURE 1

E 613 TARGET AND DUMP MAGNETS

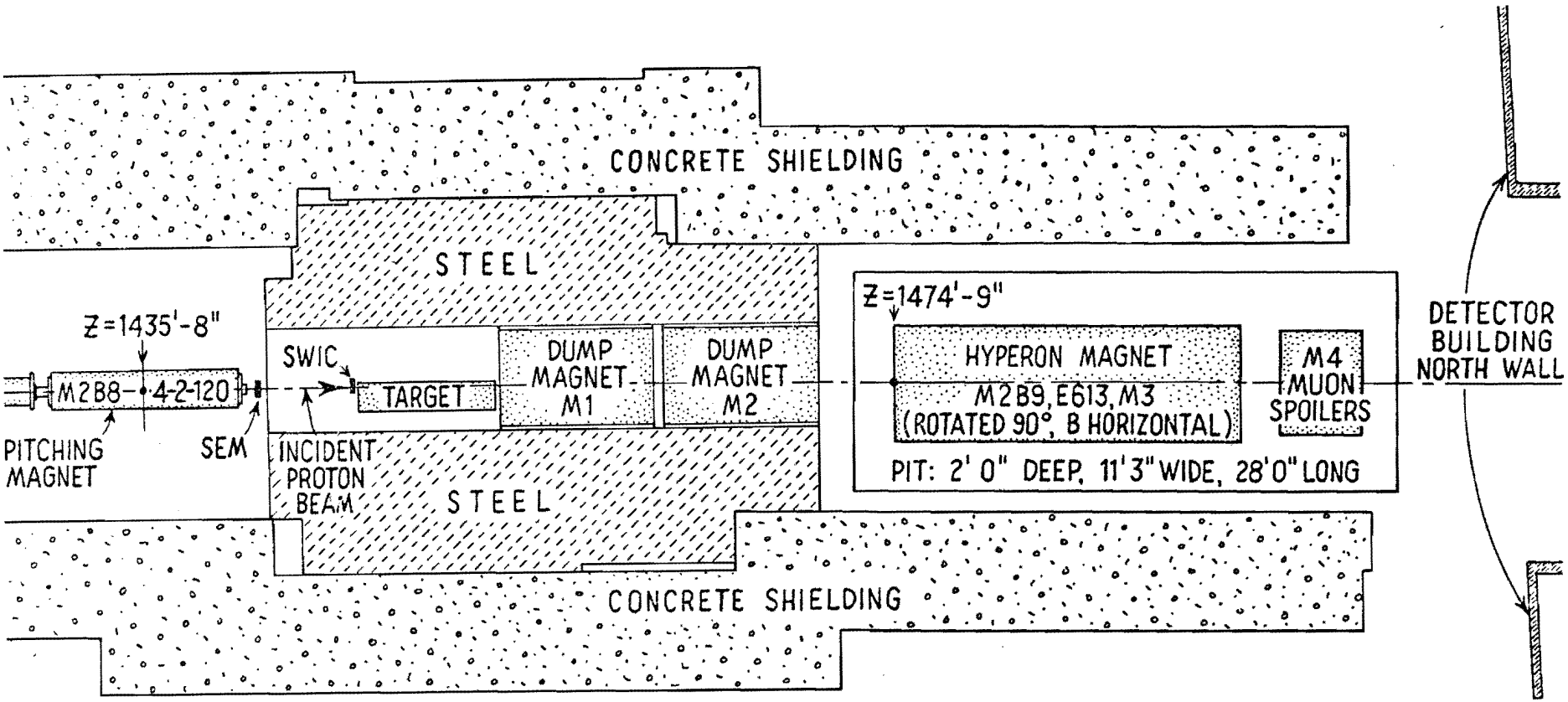

FIGURE 2

ONE OF 15 CELLS OF PROPOSED DETECTOR

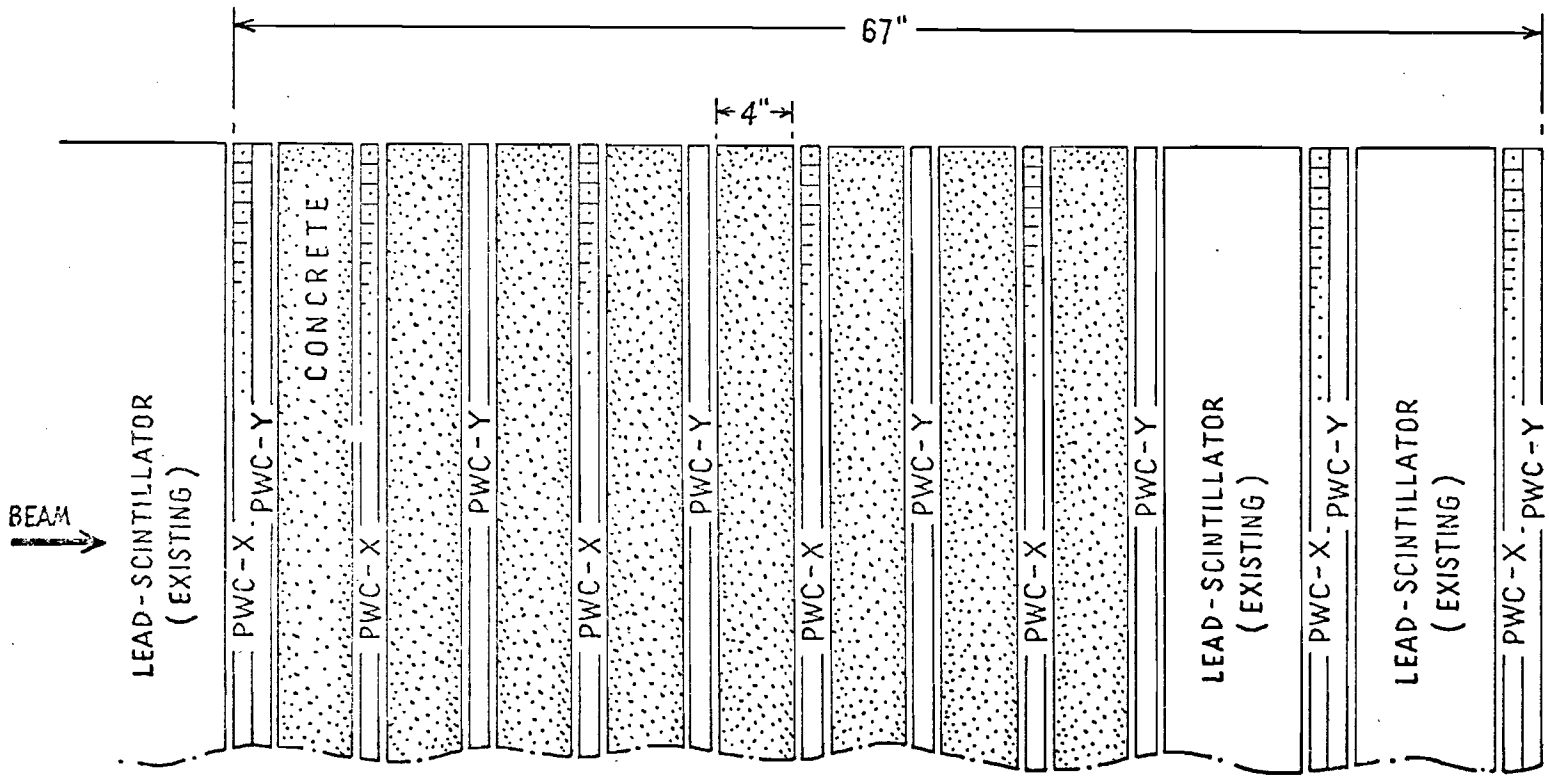

FIGURE 3

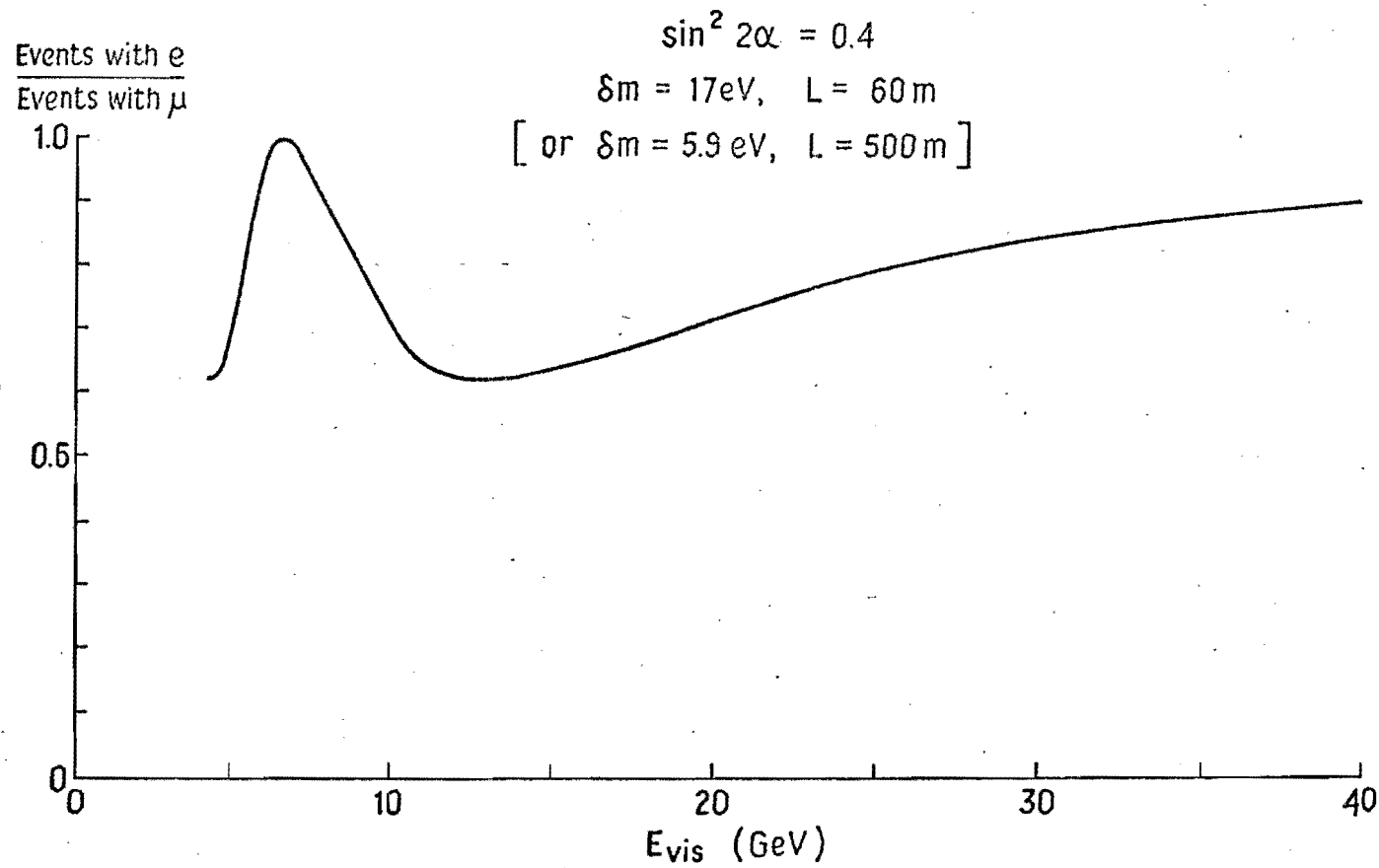
sin² 2α = 0.4
δm = 17eV, L = 60 m
[or δm = 5.9 eV, L = 500 m]
Events with e / Events with μ
1.0
0.6
0
0
10
20
30
40
E_vis (GeV)

FIGURE 4