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SEARCH FOR NEUTRINO OSCILLATIONS AT LAMPF

R.W. Harper, T.Y. Ling, J.W. Mitchell,
T.A. Romanowski, E.S. Smith, M. Timko,
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R.D. McKeown, K.T. Lesko, E.B. Norman,
R.D. Carlini, J.B. Donahue, G.T. Garvey,
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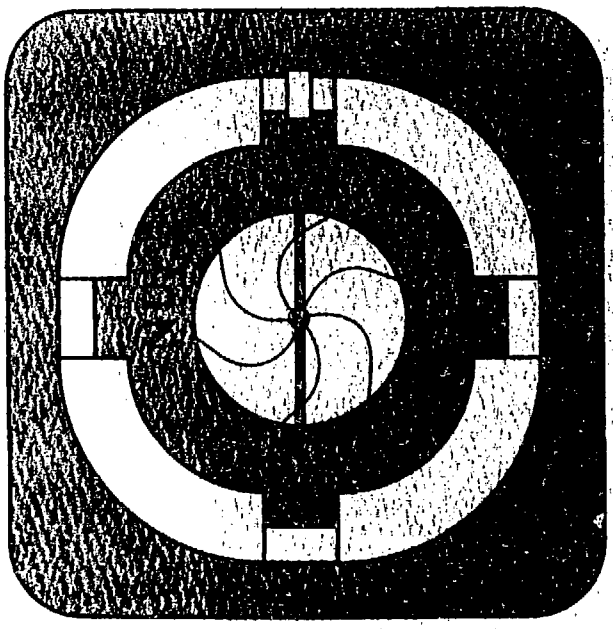

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R.W. Harper, T.Y. Ling, J.W. Mitchell, T.A. Romanowski,
E.S. Smith, M. Timko
Ohio State University, Columbus, OH 43210

S.J. Freedman, J. Napolitano
Argonne National Laboratory, Argonne, IL 60439

B.K. Fujikawa, R.D. McKeown
California Institute of Technology, Pasadena, CA 91125

K.T. Lesko, E.B. Norman
Lawrence Berkeley Laboratory, University of California,
Berkeley, CA 94720

R.D. Carlini, J.B. Donahue, G.T. Garvey, V.D. Sandberg
Los Alamos National Laboratory, Los Alamos, NM 87545

W.C. Choi, A. Fazely, R.L. Imlay, W.J. Metcalf
Lousiana State University, Baton Rough, LA 70803

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W.C. Choi, A. Fazely, R.L. Imlay, W.J. Metcalf
Lousiana State, University, Baton Rouge, LA 70803

Presented by Elton S. Smith

ABSTRACT

The decays of stopped pions in the LAMPF beam stop present a unique opportunity to probe neutrino oscillations in the mass region of $\delta m^2 \sim 0.1 eV^2$ and mixing parameters as low as $\sin^2 2\Theta \sim 10^{-3}$. The appearance of $\bar{\nu}_e$ will be measured with high sensitivity by Experiment 645 during the run cycle that begins in the summer of 1986.

Intermediate-energy proton accelerators provide neutrino sources in the energy range 10-50 MeV, which are ideal for oscillation searches in the mass region $\delta m^2 \sim .1 eV^2$. In addition, the available beams are very intense, allowing the experiments to be sensitive to mixing parameters as low as $\sin^2 2\Theta \sim 10^{-3}$. The distance of the detector from the beam stop (L) and neutrino energy (E_ν) set a typical oscillation scale of $L/E_\nu \sim .6$ m/MeV, a value intermediate to that which can be obtained in reactors and high energy experiments.

The Los Alamos Meson Physics Facility (LAMPF) provides a 670 μA proton beam with a kinetic energy of 800 MeV. The beam is absorbed in a copper beam stop, producing on the average 0.09 pions for every proton.[1] Although both positive and negative pions are produced, π^- quickly fall into atomic orbitals and are absorbed into the nucleus by strong processes. The π^+ come to rest and decay, producing the beam-stop neutrino spectra via the decay sequence $\pi^+ \rightarrow \mu^+\nu_\mu$, $\mu^+ \rightarrow e^+\nu_e\bar{\nu}_\mu$. These decays provide a clean point source of ν_e, $\bar{\nu}_\mu$ and ν_μ.

The LAMPF experiment E-645 is located 24 m from the beam stop at a polar angle of 17^o from the main proton beam. The liquid scintillator detector is the target for the inverse beta decay reaction $\bar{\nu}_e p \rightarrow e^+ n$ which, if seen, would provide a signature for the appearance of $\bar{\nu}_e$. The construction phase of the experiment is complete. Calibration and cosmic-ray background studies are currently under way. The first data run is expected to begin in July of 1986.

The design and construction of the experiment is dictated by the expected backgrounds rather than by the signal of a single isolated positron. Due to the long accelerator duty cycle (~9%), cosmic rays constitute a serious background, since Los Alamos is 2100 m above sea level. The detector will operate inside a tunnel with an overburden of 3000 g/cm^2, enough passive material to eliminate the hadronic component in the cosmic-ray flux (see Figure 1). The estimated integrated muon flux inside the tunnel is 8 kHz. In addition, the central detector is covered by a 4π cylindrical cosmic-ray shield,[2] which contains a 15.2 cm outer layer of liquid scintillator and an inner layer of lead (12.7 cm) and iron (5.1 cm). The outer layer is used to veto charged particles. The passive layer is designed, in particular, to eliminate the background of muons stopping outside the active layer, where an electron from the decay radiates a photon that can pass through the scintillator undetected before it converts inside the shield. To minimize inefficiencies in the

shield, the scintillator fills only three optically isolated sections: the cylinder and one endcap, the bottom and the other endcap. The scintillator is viewed by 360 photomultiplier tubes (EMI 4870-B) to provide ample redundancy.

The central detector has forty layers, each one consisting of a scintillator plane followed by vertical and horizontal proportional drift-chambers (see Figure 2). The liquid scintillator is contained in horizontal lucite tanks ($366 \times 30 \times 3$ cm^3) and viewed at both ends by Hamamatsu R878 phototubes. Particles lose 75% of their energy in the scintillator, the rest is deposited in the lucite and drift tube walls. The drift-chamber planes consist of 45 wires assembled 8.1 cm apart. Drift-time and pulse-height information are recorded for every wire. Nuclei with loosely bound neutrons, e.g. ^{27}Al and ^{13}C, provide a target for ν_e interactions and are a source of background since we are not able to distinguish between electrons and positrons (see Table I). Thus, the drift tubes are constructed of laminated Kraft paper with only a 25-μm aluminum inner layer to shape the electric field.[3] The detector weight is 20 metric tons, of which 2.3 tons is hydrogen.

We must be able to distinguish protons from electrons with high efficiency in order to eliminate knock-on protons produced in fast neutron interactions. The granularity of the detector permits such identification to be made by comparing the particle range to the energy loss measured in the scintillator. An additional selection can be made based on the dE/dx measurement in a single scintillator plane. Using these criteria, protons have been rejected by a factor of 3×10^{-4} in a prototype detector studied in the LAMPF test beam channel. Given the present estimates of neutron backgrounds (~1000/day) in our detector, this rejection is adequate to eliminate knock-on protons with kinetic energies greater than 100 MeV.

The signals from the detector and the shield are digitized with flash ADC's and stored in cyclic memories containing 150 μsec of data. The positron trigger is flagged by hits in three consecutive planes. At this point, data are continued to be read into the memories for 100 μsec, so that when the data are eventually transferred to the computer, only 50 μsec of information is recorded before the event trigger. The history is used to tag any signals that might be associated with the trigger, e.g. a stopping muon. The data recorded after the trigger is needed to help identify the neutron, which would be present if the event was in fact a

$\bar{\nu}_e$ interaction. Mylar sheets painted with natural Gd_2O_3 are located between all scintillator planes. Neutrons from the interaction may thermalize in the scintillator and capture on Gd, which deexcites by emitting 4.5 gamma rays on the average. The detection of these gammas (total energy is 7.9 MeV) provides a neutron signature. The detection efficiency of the neutrons is expected to be about 25%, but depends on requirements imposed on the detection of the resulting gammas.

In Figure 3 we show the expected sensitivity of E-645 to neutrino oscillations. The $\bar{\nu}_e p$ interaction cross section is 11×10^{-41} cm^2.[4] Assuming a positron detection efficiency of 50%, the event rate for maximum oscillation is 47 events/day. Background rates, which limit the sensitivity of the experiment, are hoped to be kept to less than .1 events/day. For comparison, the best published limits are also shown in the figure.[5]

Table I. Backgrounds due to ν_e interactions in the detector.

Target	Mass (tons)	$\sigma(10^{-41}\text{cm}^2)$	Rate/day in Detector (E_ν>35MeV)
^{12}C	15	1.5	<0.01
^{13}C	0.15	< 5	<0.05
^{27}Al	0.2	< 5	<0.03

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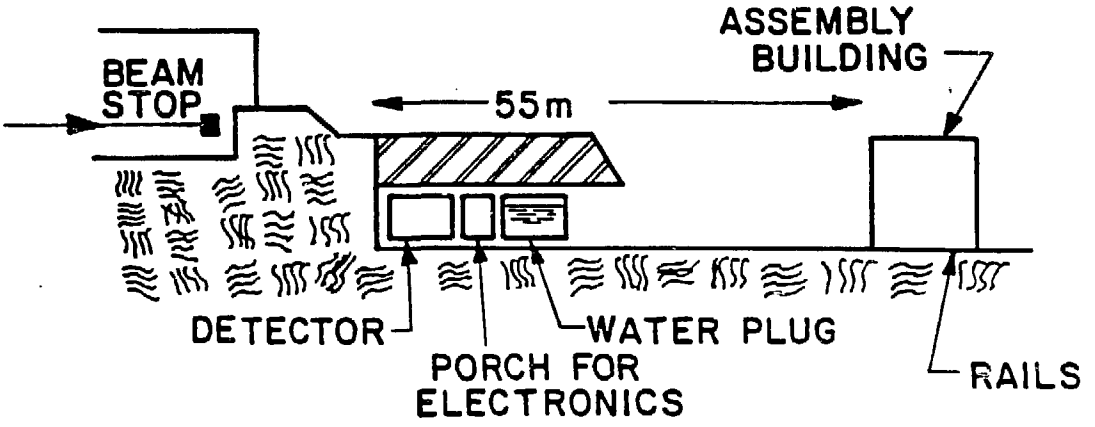
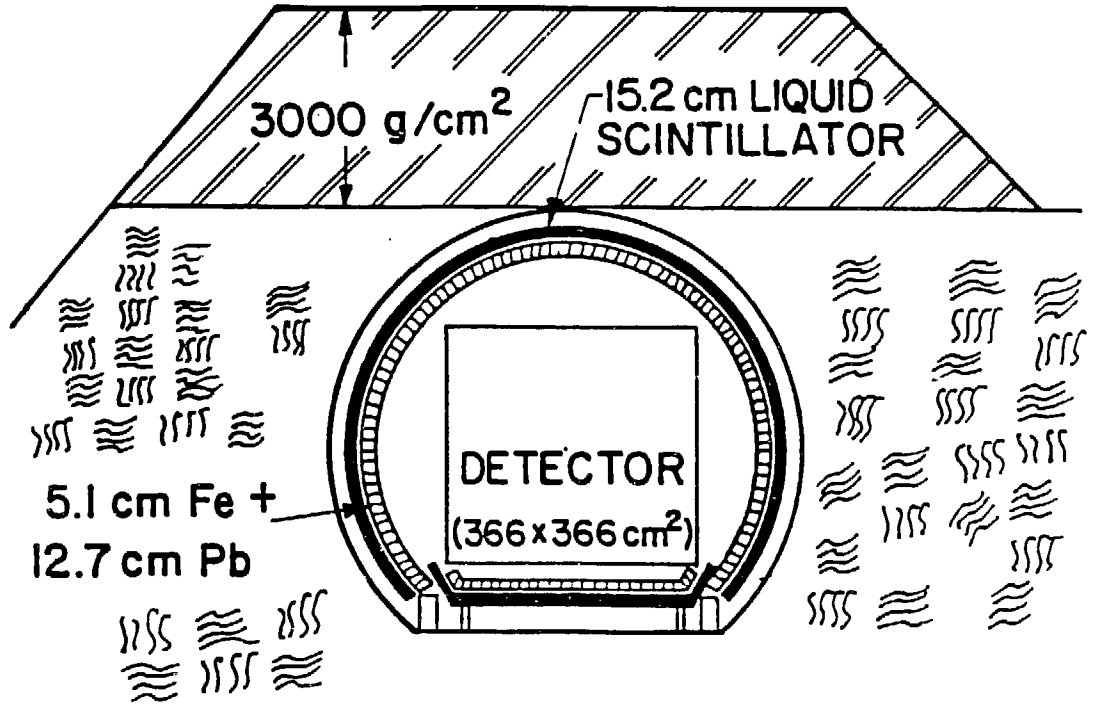


NEUTRINO TUNNEL SIDE VIEW



NEUTRINO TUNNEL FRONT VIEW

Figure 1. Cosmic-ray shielding which includes 3000 g/cm^2 of overburden, an active charged particle veto, and an inner layer of lead and iron.

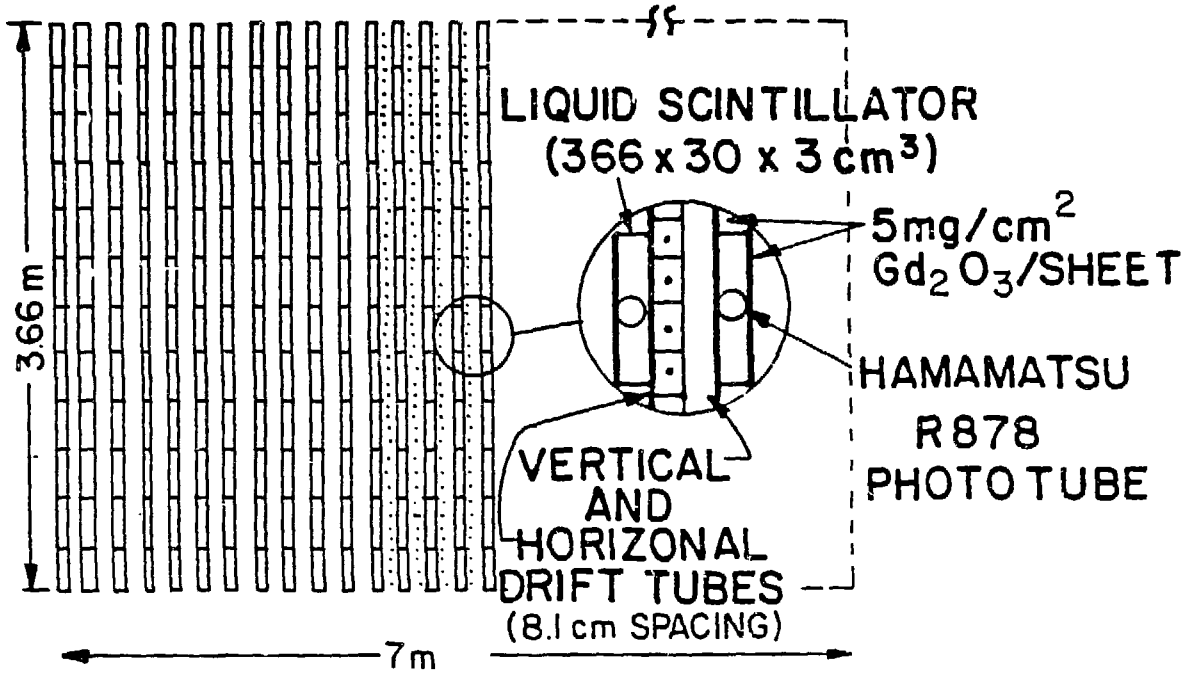


Figure 2. E-645 detector sandwich consisting of forty scintillator and drift-chamber planes.

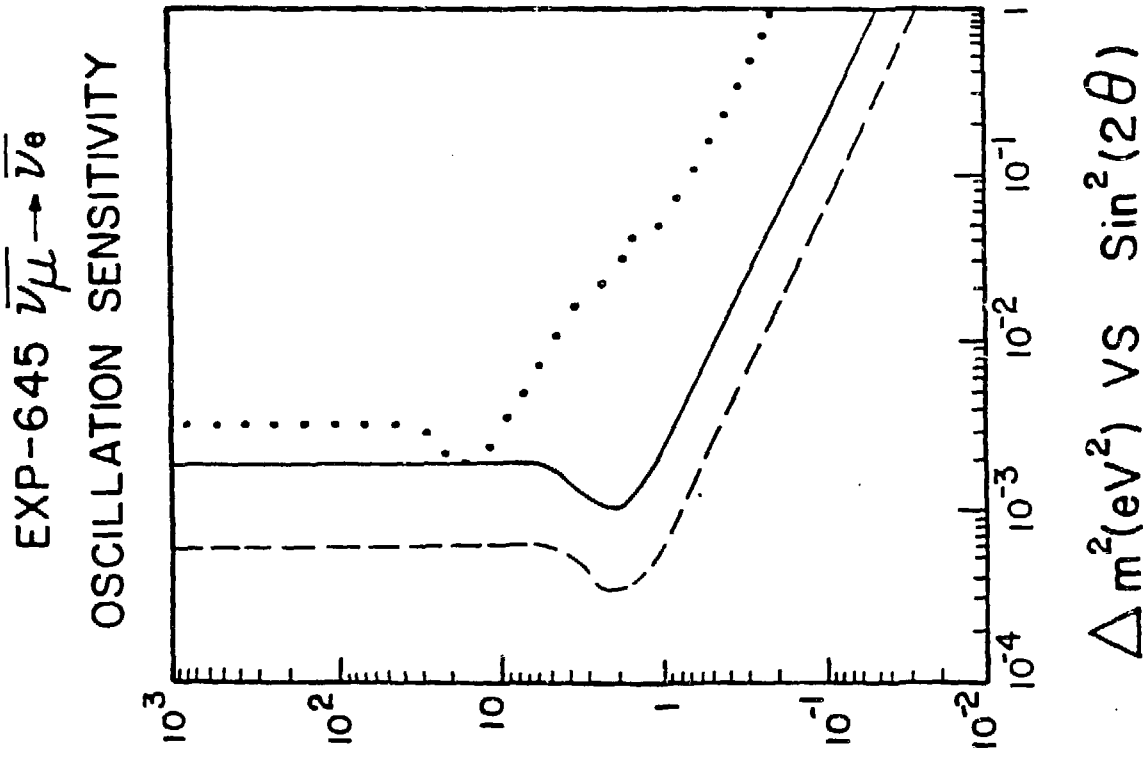


Figure 3. Expected sensitivity of E-645 to neutrino oscillations. The dashed curve assumes the experiment is free of background. The full curve assumes a background rate of .1 events/day. The dotted curve shows current oscillation limits.

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