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LAMPF E645/CURRENT STATUS

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Abstract

Experiment E645 at LAMPF is a search for $\bar{\nu}_{\nu}\to\bar{\nu}_{e}$ oscillations using the proton beamstop as a neutrino source. The apparatus is a 20-ton neutrino detector and a cosmic-ray anticoincidence shield ≃26 m from the beamstop. No evidence for neutrino oscillations was found in the first year of data taking. The experiment is described and the limits on neutrino oscillation parameters from the data collected during 1987 are presented.

Pion factories are copious sources of low energy neutrinos. At the Los Alamos Meson Physics Facility (LAMPF), the proton beamstop is a source of neutrinos produced in the decay of stopped pions and muons. The beamstop source is presently used by E645, a search for neutrino oscillations, being carried out by a collaboration between Argonne National Laboratory, California Institute of Technology, Lawrence Berkeley Laboratory, LAMPF, Louisiana State University, and the Ohio State University.[1]

After passing through production targets, the remaining ≃700-μA of the LAMPF proton beam is degraded to ≃750 MeV before it is absorbed in a water cooled copper beam dump. Charged pions produced in the beamstop are thermalized in a tiny fraction of their decay time. Nearly all of the negatively

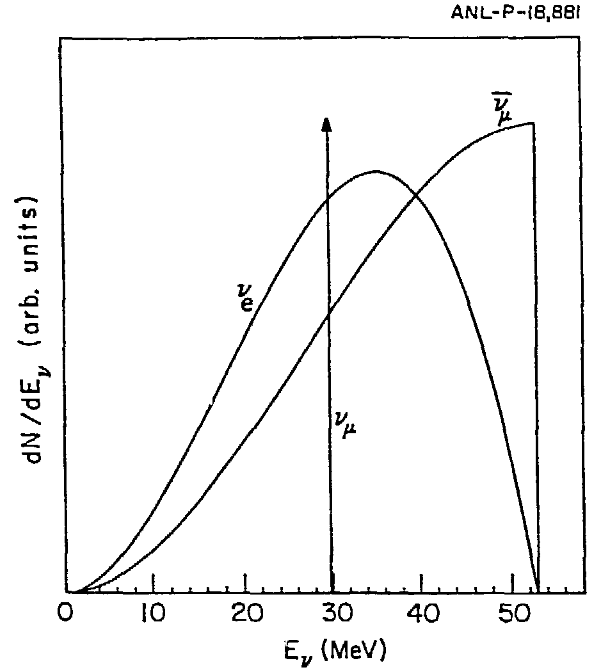

Fig. 1 The energy spectra of the three types of neutrinos produced after stopping π^+ decay in the LAMPF beamstop.

charged pions are captured by copper nuclei but most of the positive pions decay at rest, in the sequence, $\pi^+ \to \mu^+ + \nu_\mu$ followed by $\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$. The beamstop neutrino energy spectrum is shown in Fig. 1. The $\bar{\nu}_e$ contamination from negative pions that manage to evade capture is less than 10^{-3} of the $\bar{\nu}_\mu$ flux. The results of experimental measurements of the positive pion flux from protons, in this energy range, extrapolated to the LAMPF beamstop configuration indicate that there are about 0.09 π^+ decays per incident proton.[2] Taking this and the LAMPF duty cycle into account indicates that the beamstop is an isotropic neutrino source with intensity $\simeq 1.6 \times 10^{18}$ day^{-1} for three neutrino types, ν_e, ν_μ, and $\bar{\nu}_\mu$, all with energies below 52.8 MeV.

E645 is a straightforward appearance experiment. The experimental signal is a detected $\bar{\nu}_e$ which could appear from the transformation of one of the neutrino types produced in the beamstop. Since there is yet no clear indication that neutrinos oscillate it is convenient to compare experimental sensitivities in terms of a simple two neutrino mixing scheme, thus avoiding the complication of more complicated mixing possibilities. In the standard scenario, one expects that a $\bar{\nu}_e$ appears from an initial state of $\bar{\nu}_\mu$ with probability given by:

$$P(\bar{\nu}_\mu \to \bar{\nu}_e) = \sin^2 2\theta \ \sin^2(1.27\ \Delta m^2\ L/E) \ ,$$

where $\Delta m^2 = |m_1^2 - m_2^2|$ is the difference in the squares of the neutrino eigenstate masses in eV^2, θ is the standard two component mixing angle, L is the distance from the source to the detector in meters, and E is the neutrino energy in MeV.

Appearance experiments with low backgrounds have sensitivity to small θ while the sensitivity to Δm^2 is dominated by the particular value of L/E. E645 is comparable in sensitivity to experiments at the Brookhaven AGS and the CERN PS which search for a ν_e appearance in a more energetic ν_μ beam using detectors farther from the source. In contrast to the CERN and BNL experiments, however, E645 is concerned with antineutrinos. These experiments are equivalent only in the context of simple models of neutrino oscillations which incorporate CP invariance.

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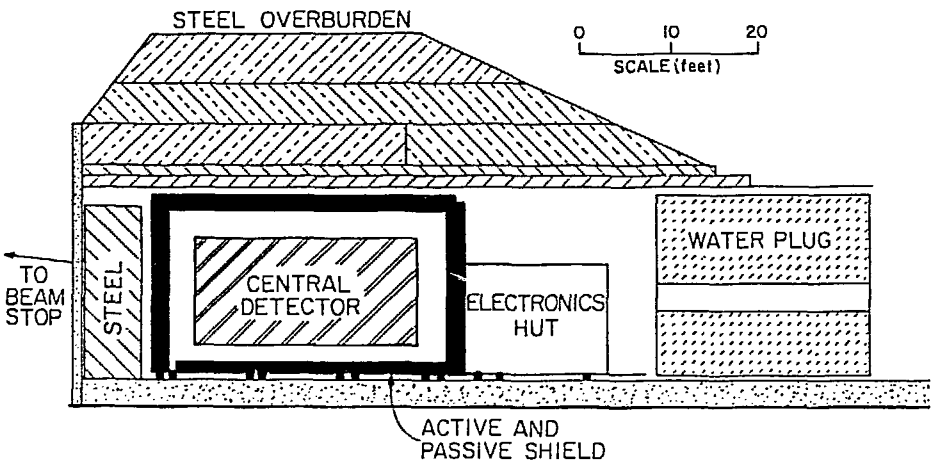

Fig. 2 The experimental arrangement. The neutrino detector and the concentric active and passive shield are housed in a tunnel under 2500 g/cm^2 of overburden 26 m from the LAMPF beamstop. LAMPF itself is about 2200 m above sea level.

The experimental arrangement is shown schematically in Fig. 2. The heart of the experiment is a twenty ton tracking detector. The primary experimental signal for a $\bar{\nu}_e$ is a detected positron from inverse beta decay ($\bar{\nu}_e+p\rightarrow n+e^+$) on the protons contained within the detector itself. The neutrino detector is divided into 40 vertical modules, each consisting of a layer of 12 liquid scintillation counters and two layers of 45 proportional drift tubes (PDT), one vertical and the other horizontal. Scintillation counters are constructed of 0.4-cm wall extruded acrylic tanks 3×30×370 cm with a photomultiplier at each end. The tanks are filled with a mineral oil based scintillation liquid containing about 15% pseudocumene. The detector is incapable of distinguishing electrons from positrons and special care is taken to avoid materials which have a large cross sections for beam ν_e induced charged current reactions. Materials with odd neutron nuclei, like ^{27}Al, are avoided. The PDT's, for example, are constructed of laminated paper with only a very thin aluminum conductive coating.[3] The PDT cross sectional area is 3.8×7.6 cm; they are capable of tracking resolution of better than 1-cm, but the high resolution from drift timing is not used in obtaining the results discussed here. The scintillation counters measure both total energy and differential energy loss (dE/dx) and the combination (along with dE/dx information from the PDT's) is used in identifying positrons in a background of neutron induced recoil proton tracks. A minimum ionizing particle at normal incidence loses about 9 Mev in each module. Each scintillator layer is covered with a plastic sheet painted with a gadolinia (Gd_2O_3) which is used to detect the neutron remnants of inverse beta decay. Neutrons which thermalize within the detector volume have a sizeable probability of capturing on the gadolinium and being identified by a delayed γ-ray signals in scintillation counters. Requiring of a delayed coincidence reduces the overall detector efficiency by nearly a factor of five, but this feature of the experiment is a valuable recourse if an unexplained beam excess signal were to be found. The active detector volume contains about 2.3 tons of proton target.

The LAMPF duty cycle, typically ≃0.5-msec pulses at 120 Hz, is poor for neutrino experiments, and cosmic ray rejection becomes a challenging problem. An unrecognized muon decay can imitate the sought for $\bar{\nu}_e$ appearance signal and muon rejection must be nearly flawless. The active cosmic ray shield is a nearly continuous 15 cm thick cylindrical liquid scintillator tank surrounding the central detector.[4] The liquid scintillator in the shield is coupled 360 hemispherical phototubes, each 13 cm in diameter. A cosmic-ray muon loses about 30 MeV in the shield and the scintillation light pulse is typically seen by many phototubes leading to high rejection efficiency and low sensitivity to background from environmental radioactivity. A concentric passive shield consisting of 13-cm of lead and 5-cm of steel is placed just inside the active shield to suppress spurious events from muon decay bremsstrahlung photons. Neutral cosmic ray particles are suppressed by putting the entire apparatus inside a tunnel under 2500 gm/cm^2 of steel and earth overburden.

The experimental trigger is simultaneous hits in three out of four consecutive central detector scintillation planes. Under typical running conditions the cosmic rays would trigger the apparatus at about 1.6×10^3 Hz, but this rate is reduced to 0.5 Hz with the hardware shield veto turned on. The remaining triggers are approximately equally divided between muons which evade the on-line veto, recoil protons from cosmic ray neutrons, and electrons from stopped muon decay.

Signals from all the phototubes and PDT's are shaped, amplified, and digitized in flash ADC's every 80 nsec for the detector and every 150 nsec for the shield. The results are stored in individual memories and a 160 μsec long "event history" is read out with each on-line trigger. The "history" begins 53-μsec before the triggering event. Later, stringent off-line cuts are applied to the data in these event histories to eliminate various backgrounds. The off-line analysis makes more selective cuts on the signal in the shield and the detector eliminating the residue of muon triggers. The event history is used to find the initiating muon for events triggered by the decay of stopped muon. Proton triggers are primarily rejected by particle identification conditions. The detector is calibrated and monitored with cosmic-ray muons. Stopping muons are particularly valuable for studying the detector response since the electron from muon beta-decay approximates the experimental signal.

The experiment took data for approximately six months in 1987 corresponding to 5100 C of protons on the beamstop. The data from about 1.3×10^6 triggers were written to tape. About 3% of the events remain after imposing simple cuts to eliminate triggers from cosmic-ray muons.

A particle identification cut and more stringent cuts to eliminate unusual cosmic-ray events reduced the event sample to 20 events in the beam on gate and 27 events in the ≃3.5 times longer beam off gate. We are left with a beam excess of 12.3±4.7 events. The overall efficiency for detecting electron above threshold (≃25 MeV) is about 42% from the off-line analysis. The observed beam excess is consistent with the estimated event rate from: (1) beam associated neutrons that get through the beamstop shielding; (2) muons produced by the small number of high energy ν_μ's that come from pions which decay in flight; and (3) charged current processes initiated by ν_e's from the stop (in particular, the reactions $^{12}C(\nu_e,e^-)^{12}N$, $e^-(\nu_e,\nu_e)e^-$, $^{13}C(\nu_e,e^-)^{13}N$, $^{16}O(\nu_e,e^-)^{16}F$, and $^{27}Al(\nu_e,e^-)^{27}Si$). The largest source of beam associated background are the $^{13}C(\nu_e,e^-)^{13}N$ and $e^-(\nu_e,\nu_e)e^-$ reactions. In the end, the observed rate is consistent with the expected background and we find no evidence for neutrino oscillations.[5] Figure 3 shows the resulting ($\bar{\nu}_\mu \to \bar{\nu}_e$) exclusion plots along with the limits from ($\nu_\mu \to \nu_e$) searches at BNL and CERN. One of these experiments (PS191) is in conflict with the present null result in the context of two-state mixing.

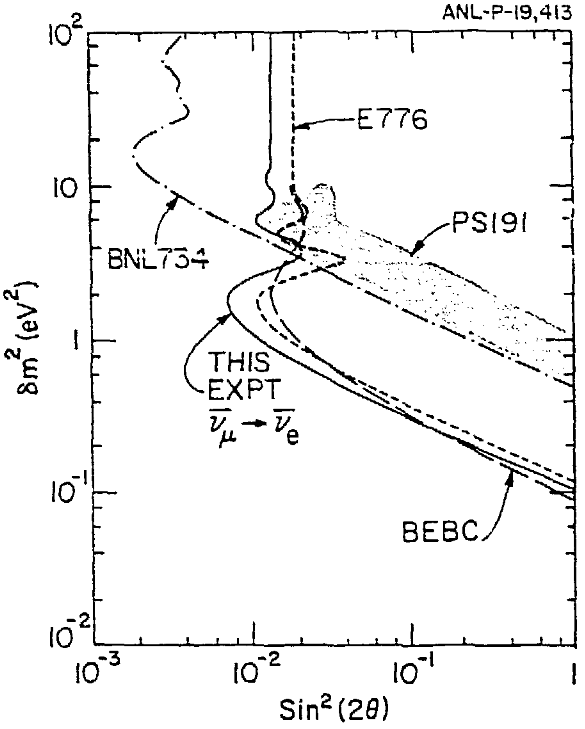

Fig. 3 The neutrino oscillation exclusion limits (90% cl) from E645 and comparable experiments at BNL and CERN. The shaded region (1σ) corresponds to the positive indication from one experiment, CERN PS 191. All experiments, except the present work are $\nu_\mu \to \nu_e$ appearance experiments. See Refs. 5 and 6.

The experiment ran for a second year in 1988 and the data analysis is now being completed. An additional year of data-taking will be accomplished when LAMPF runs in 1989, so we can anticipate the experimental sensitivity to increase in the near future.

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