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E734 Collaboration[1)]

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ABSTRACT

No evidence for $\nu_\mu \rightarrow \nu_e$ oscillations is observed in an experiment in the wide band beam at Brookhaven National Laboratory using the E734 neutrino detector. The 90% confidence level limits obtained are $\sin^2 2\alpha \leq 3.4 \times 10^{-3}$ in the large mass difference limit and $\Delta m^2 \sin 2\alpha < 0.43 eV^2$ in the small mass difference limit.

1. INTRODUCTION

The E734 detector at Brookhaven was constructed by a USA-Japan collaboration[1)] comprised of physicists from BNL, Brown Univ., KEK, Osaka Univ., Univ. of Pennsylvania and SUNY at Stony Brook. The original proposal for this experiment was to measure the elastic scattering of neutrinos on electrons and protons. Since the emphasis in the design was on electron identification and e/γ separation, it is an excellent detector for a $\nu_\mu \rightarrow \nu_e$ oscillation search. The detector is located at the end of the neutrino beam line with a mean distance from the center of the decay tunnel to the center of the detector of 96 meters. Since the wide-band beam peaks at 1 GeV, the L/E_ν is 0.1.

The detector (Fig. 1) is a 175 ton target-calorimeter containing 112 modules followed by a lead-liquid scintillator shower absorber and a magnetic spectrometer. Each module contains a 4m x 4m x 7.5cm plane of liquid scintillator segmented into 16 horizontal cells followed by 4m x 4m x 3.75cm X and Y measuring planes of proportional drift tubes (each plane contains 54 PDT's). The liquid scintillator cells have phototubes on each end and multiple times and a single pulse height can be recorded for each spill. Two times and a single pulse height can be recorded for each PDT tube. Each module is $\approx 1/4$ radiation length and the detector is approximately 90% active. The high segmentation coupled with the timing and pulse height information provides excellent π/p separation, electron identification and photon rejection.

In this experiment the ration of ν_e quasi-elastics ($\nu_e n \rightarrow e^- p$) to ν_μ quasi-elastics ($\nu_\mu n \rightarrow \mu^- p$) is measured as a function of neutrino energy and compared to the calculated ratio. These events, in the low Q^2 region, appear in the detector as single tracks or showers with at most some low energy associated activity at the vertex and are very similar to neutrino elastic scattering events. No excess of electron events was observed[2] and the resultant 90% confidence level limits on $\nu_\mu \rightarrow \nu_e$ are $\sin^2 \alpha \leq 3.4 \times 10^{-3}$ at large Δm^2 and $\Delta m^2 \sin 2\alpha \leq 0.43 eV^2$ at small Δm^2.

2. DATA ANALYSIS

The data for this analysis comes from an exposure of $.9 \times 10^{19}$ POT corresponding to 1.25×10^6 AGS beam bursts. Electron candidates were obtained by processing all bursts through a coarse computer filter program designed to retain events with an electromagnetic shower within 240 mrad of the neutrino beam direction. After scanning by physicists to remove events with additional hadron tracks or significant disconnected energy, a total of 873 events with $\Theta < 240$ mrad and $0.21 < E_e < 5.1 GeV$ remained. The shower energies have a 40% correction for invisible energy and the energy resolution is $\Delta E/E = 0.12/\sqrt{E(GeV)}$. The shower angle was determined from a fit to all shower hits in the PDT cells and the angular resolution was $\Delta\Theta = 30$ mrad.

The major backgrounds in this sample are from $\nu N \pi$ neutral currents, inelastic ν_e scattering ($\nu_e N \pi$) and to a lesser extent $\nu_\mu e \rightarrow \nu_\mu e$ elastic scattering. Backgrounds with a π^+ in the final state were measured by observing the delayed signal from $\pi \rightarrow \mu \rightarrow e$ decay. The shower energy distribution for the events remaining after the π^+ background events were subtracted is shown in Fig. 2a. During the scanning, events with a single shower associated with an upstream energy deposition were collected and used as a control sample of identified photons. The shower energy distribution of these photons is shown in Fig. 2b. The $e^- p$ candidates (Fig. 2a) below $0.9 GeV$ are expected, from calculation and observation, to be mostly photons with a small number of $\nu_\mu e \rightarrow \nu_\mu e$ and very few low energy $\nu_e n \rightarrow e^- p$ because of the 240 mrad restriction. Therefore it is possible to subtract the photon induced events above $0.9 GeV$ in Fig. 2a by normalizing the distributions in Fig. 2a, 2b below $0.9 GeV$. After subtracting events with observed π^+ decays and correcting for the π^+ decay efficiency (40% of candidates), removing π^0's using the observed $p\pi^0$ events (13%) and making small corrections for $eN\pi$ (3%) and $\nu_\mu e \rightarrow \nu_\mu e$ (5.8%), a total of 418 $e^- p$ events remained.

The ν_e events were normalized to a sample ($\approx$ 10% of data) of 1370 $\nu_\mu n \rightarrow \mu^- p$ quasi-elastic events in which one long track left the detector and the other stopped in the detector and was identified by range and ionization as a proton. The background in this sample after acceptance criteria were applied, consisted of charged current single π^+ production (13% of the $\mu^- p$ rate) and a small contribution ($\approx$ 3%) from π^0 and multipion production.

3. RESULTS

The neutrino spectra derived from the measured quasi-elastic samples are shown in Fig. 3 together with the calculated spectra[3)]. The agreement between the observed and calculated ν_μ spectrum in Fig. 3 is a check on the validity of the beam program and of the parameters for π and K production used in it. The agreement between the observed and calculated ν_e spectrum as a function of energy sets limits on possible $\nu_\mu \rightarrow \nu_e$ oscillations. To determine the oscillation limits only the ratio of fluxes is required. This ratio is shown in Fig. 4a and the difference between the measured and calculated ratios as a funtion of neutrino energy is shown in Fig. 4b. Clearly there is no evidence for oscillations. The errors on the data points include a systematic uncertainty of 20% (comprised of equal contributions from the flux calculation and the acceptance calculations). Using the data in the energy range $900 \leq E_\nu(MeV) \leq 2100$, the region in $\Delta m^2 - \sin^2 2\alpha$ space excluded with 90% confidence is shown in Fig. 5. In the large Δm^2 limit $\sin^2 2\alpha \leq 3.4 \times 10^{-3}$ while in the small Δm^2 limit $\Delta m^2 \sin 2\alpha \leq 0.43 eV^2$ at the 90% confidence level.

4. CONCLUSION

The results from this experiment are compared with other results presented at this workshop in Fig. 5. The high statistics and good e/γ separation in this experiment yield the best $\sin^2 2\alpha$ limits for large mass differences while the L/E_ν value of 0.1 restricts the Δm^2 range of the oscillation search to $\geq 0.43 eV^2$. There is no evidence in the E734 data for the excess of electron events reported by the E816 collaboration[4] at this meeting and initially reported by the CERN PS191[5] experiment. The major advantages of the present analysis compared to that in E816 is the use of the simplest (single track) topologies, the ability to identify single photon showers and to measure the incident neutrino fluxes via the observed muon and electron tracks from quasi-elastic events.

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Brookhaven National Laboratory, Brown University, Hiroshima University, National Laboratory for High Energy Physics (KEK), Osaka University, University of Pennsylvania, State University of New York, Stony Brook

2) Ahrens, L.A. et al., Phys. Rev. D 31, 2732 (1985).

3) The beam program used was a CERN wide band beam program (Hydra Applications Library, Nubeam: Neutrino Beam Simulator, C. Visser, CERN, 1979) modified extensively by R. D. Carlini, Los Alamos National Laboratory. The systematics of pion and kaon production used to obtain the curves in Figs. 3 and 4 were based on the semiempirical studies cited in reference 4. The two studies give for K^+/π^+ ratio averaged over all meson momenta from 1 to 14 GeV/c 0.083 (GHR) and 0.089 (SW). The values of the ratio $\Phi(E(\nu_e))/\Phi(E(\nu_\mu))$ at any E_ν between 1 and 5 GeV obtained using the two studies differ by less than 10%. Details of this work on neutrino beams at BNL are published in Phys. Rev. D 34, 75 (1986)

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7) E816 (A Boston Univ., BNL, CERN, Paris Collaboration) Presented at this workshop by P. Astier, LPNHE, Paris.

8) E776 (A Columbia Univ., Univ. of Illinois, Johns Hopkins Univ. collaboration) Presented at this workshop by G. Tzanakos, Columbia Univ.

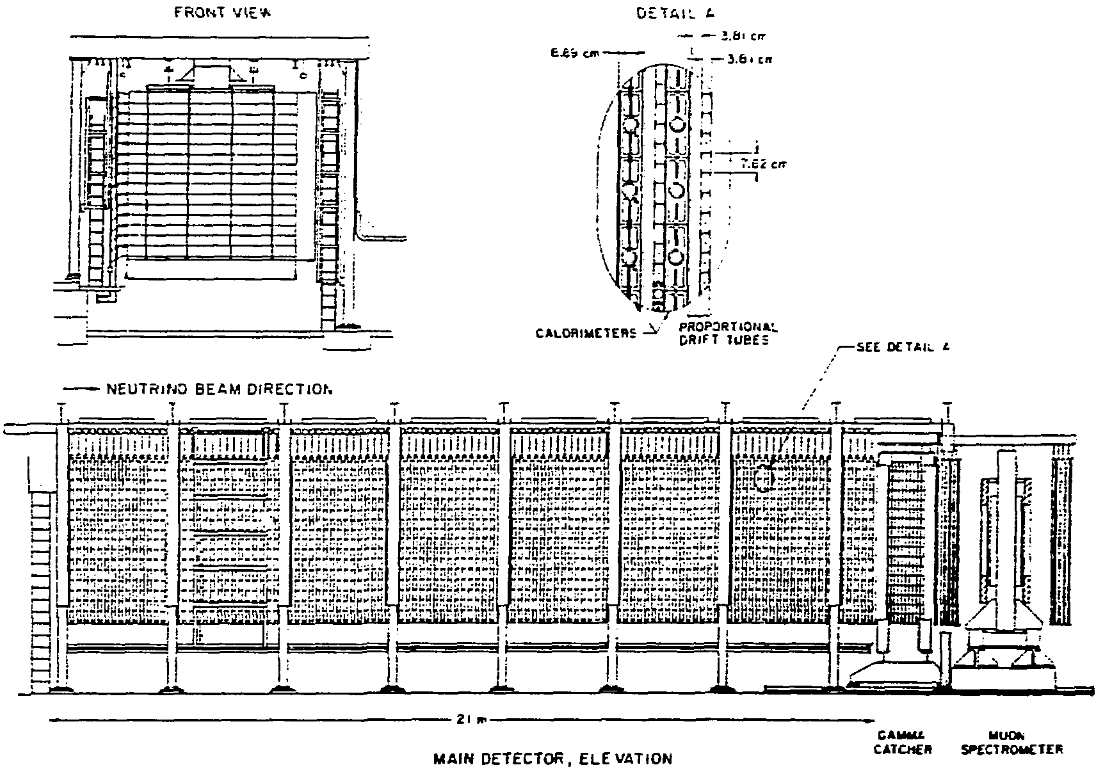

Fig. 1. The E734 detector

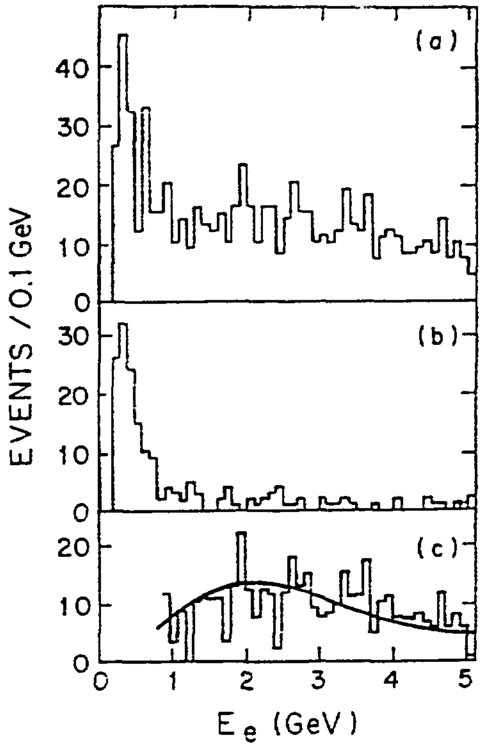

Fig. 2a. Shower energy distribution for all possible $\nu_e n \to e^- p$ candidates; b. Shower energy of photons associated with upstream event vertex; c. The electron energy distribution after all background subtraction.

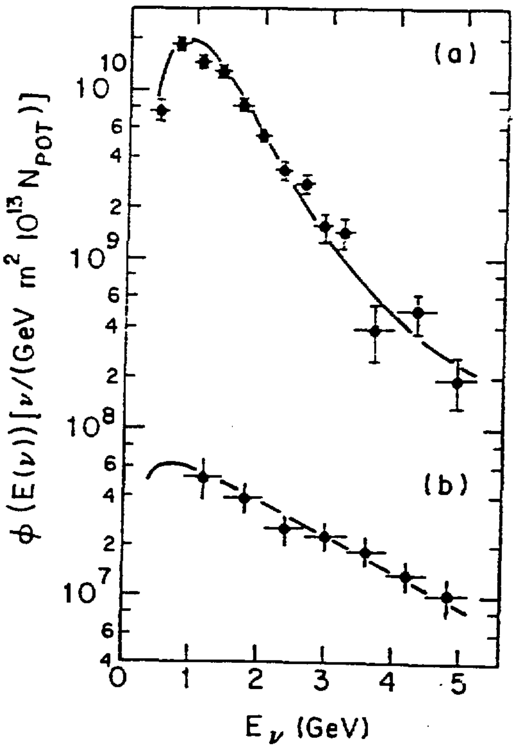

Fig. 3a. ν_μ flux obtained from $\nu_\mu n \to \mu^- p$ events; b. ν_e flux obtained from $\nu_e n \to e^- p$ events. The solid lines are the fluxes calculated from a neutrino beam program.

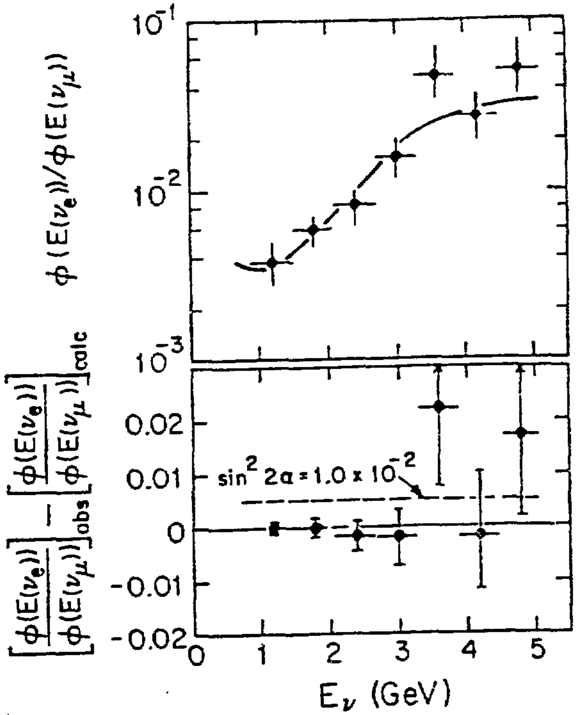

Fig. 4a. Ratio of ν_e/ν_μ flux as a function of E_ν; b. The difference of the calculated and measured ν_e/ν_μ flux ratios as a function of E_ν.

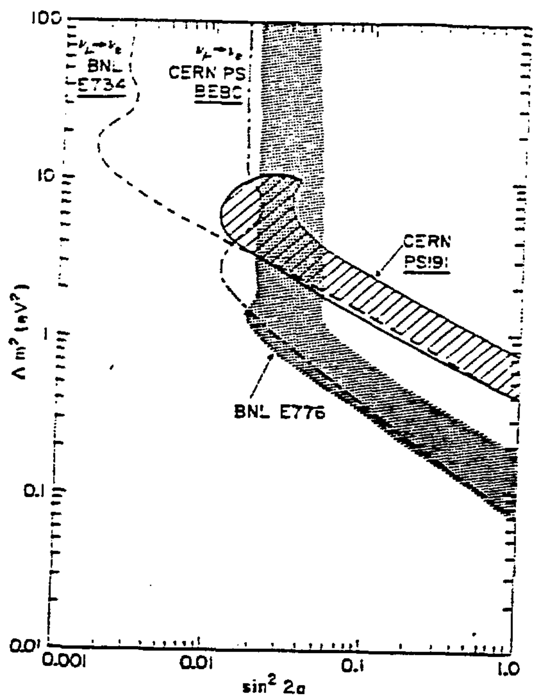

Fig. 5. Experimental results on $\nu_\mu \to \nu_e$ oscillations. Limits from BNL 734 (Ref. 2) and CERN BEBC (Ref. 5). Positive results from CERN PS191 (Ref. 6) which is in agreement with BNL E816 (Ref. 7) results and E776 (Ref. 8). The E776 region is indicative of the allowed region but does not represent a confidence level contour.