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TITLE: $\nu_\mu C^{12} \rightarrow \mu^- X$ Cross Section and $\nu_\mu - \nu_e$ Oscillation Using the Decay-in-Flight Source at Line-E of LAMPF

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$\nu_\mu C^{12} \rightarrow \mu^- X$ Cross Section and $\nu_\mu \dashrightarrow \nu_e$ Oscillation

Using the Decay-in-Flight Source at Line-E of LAMPF

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Abstract

This paper describes an experiment to measure the $\nu_\mu C^{12} \rightarrow \mu^- X$ cross section and to detect $\nu_\mu \dashrightarrow \nu_e$ oscillations. A test run was completed last year. The detector has been calibrated and backgrounds are under study. The sensitivity of the experiment is estimated for the 1985 LAMPF run cycle to be $\pm$ 20% for the cross section measurement and the 90% confidence level limits for the neutrino oscillation experiment are $\sin^2 2\Theta < 10^{-3}$ and $\Delta m^2 < 10^{-1} eV^2$.

I. Introduction

This experiment will provide the first cross section measurement of ν_μ on a nucleus in the low energy range, with about 10% of the interactions going to a specific nuclear final state. The cross section measurement will provide new data on nuclear effects in the weak charged-current interaction. The cross section measurement is also important to interpret certain underground laboratory experiments. The experience gained from such a measurement will be useful in future detector design for use in the LAMPF Neutrino Facility[1].

Recently the search for neutrino oscillations has become popular. The reason for this is interest is based on fundamental experimental and theoretical questions such as

where are the missing solar neutrinos?
if quarks mix why not leptons?
do neutrinos have mass?

The presence of neutrino oscillations could answer these questions. This experiment will provide competitive limits on the oscillation of neutrinos.

II. The Decay-in-Flight Neutrino Source at Line-E

The layout of Line-E is shown in Fig. 1. Briefly, the decay-in-flight neutrino source consists of a pyrolitic graphite target, a 12m pion decay channel, a tungsten beam stop, 7m of iron shielding, and an additional 1m of concrete shielding. The neutrino detector lies about 20m from the target. In January 1983 Line-E was authorized to run with 20μA of protons. In October of 1984 20μA of protons were sent through Line-E. In 1985 we intend to ask for authorization up to 200μA. Also planned is a pion focusing horn which will increase the neutrino flux by a factor of 10.

III. Physics

A. Cross Section Measurement

The cross section for $\nu_\mu C^{12} \rightarrow \mu^- N^{12}$ will be measured. There are three physics processes of interest that we will use to identify the above final state. These processes occur over three easily separated time intervals. The muon signal from a charged-current interaction in the detector will arrive tens of nsecs after the protons hit the target. This 50nsec time interval is called the "prompt interval." The muon will decay and the decay electron will be detected in the "muon interval" which lasts for 20μsec after the prompt interval. Finally the N^{12} will beta-decay with a lifetime of 10 msec and the 40 msec interval after the muon interval is called the "N^{12} interval." The presence of all three signals in the same general location in the detector unambiguously identifies this event type. We will also look for the more prevalent type of events $\nu_\mu C^{12} \rightarrow \mu^- X$. Here the signals observed are the same as above but without the final beta-decay.

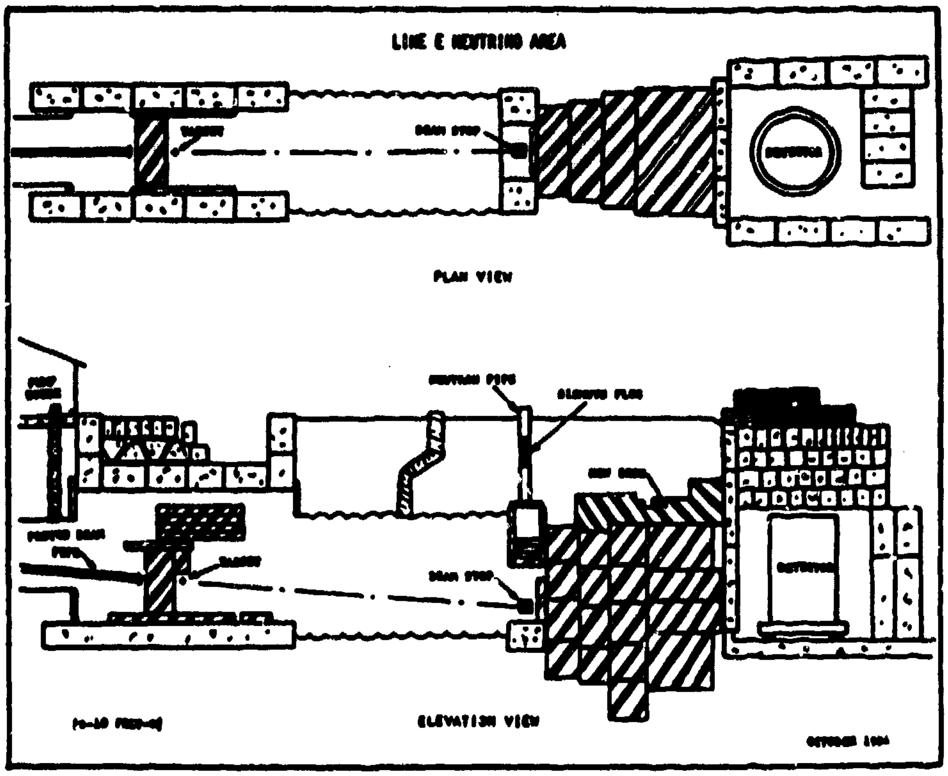

Fig. 1 -- Top: Plan view of Line-E and the E-764 detector. Bottom: Elevation view of Line-E and the E-764 detector.

B. Neutrino Oscillations

If muon neutrinos oscillate into electron neutrinos and the electron interacts via a weak-charged-current interaction then the signal for the reaction is simply a "prompt" (as defined above) high energy (>100MeV) electron.

IV. The Detector

The central detector consists of a cylinder housing 26 "honeycomb" modules filled with liquid scintillator (ND306) corresponding to a fiducial mass of 4.5 tons. The central detector is 214cm high and has a radius of 80cm. Each module is roughly 30cm x 30cm x 214cm. A 9" phototube looks into each end of each module. Outside the central detector is an inner veto which consists of 2.5 tons of liquid scintillator. The light signals are detected by eight 2" phototubes. Surrounding the inner veto is a layer of Pb shot corresponding to about 5 radiation lengths. Outside the Pb absorber is an outer veto which surrounds the central-inner veto assembly except at the bottom. For calibration purposes an array of 14-180cm long by 15cm wide hodoscopes surround the outer veto.

V. Calibration

Calibration of the central detector modules was done using cosmic rays. Cosmic ray muons passing through the detector can form a coincidence between hodoscope counters on opposite sides of the detector. Such "through" muons lie on a well-defined trajectory and their energy loss through the honeycomb modules is calibrated using the well-known energy loss rate for minimum ionizing particles. An energy spectrum for a typical module is shown in Fig. 2. Figure 3 shows the electron spectrum from the decay of muons in the detector. Timing of the modules is also done with cosmic rays along a well-defined hodoscope pair trajectory. The muon lifetime is shown in Fig. 4. Figure 5 shows the decay of a cosmic ray muon in the central detector. The arrival time of the signals at each phototube is used to measure the longitudinal position of a particle in the module as well as the particle's arrival time in the module.

VI. Estimates of Backgrounds

Running with 20μA of proton current will yield about ten charged-current interactions/day of which about one will be to the specific nuclear final state. For neutrino oscillations, if all ν_μ change to ν_e, we expect at least three times the above event rate. A muon decay signal or an energy cut of 100 MeV for the prompt signal should eliminate all beam associated backgrounds. The ultimate sensitivity of the experiment is therefore limited by the cosmic ray background. The estimate of the cosmic ray background includes contributions from charged particles that fail to trigger the veto system and from the neutral component of

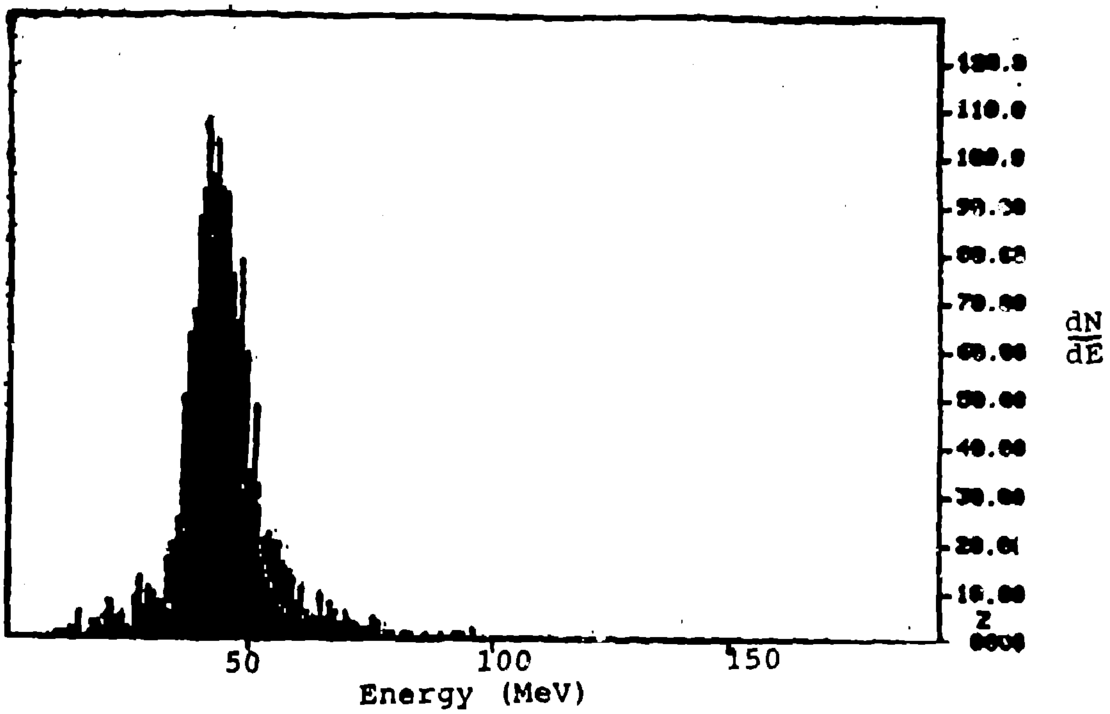

Fig. 2 -- Energy spectrum (prompt interval) for a typical module using cosmic ray muons on a well-defined trajectory. The module is about 30cm across and the average energy lost in the module is 46Mev with a resolution of ±20%.

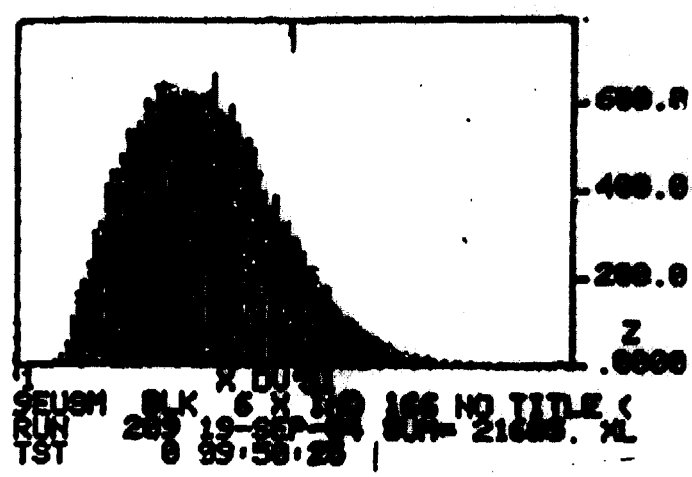

Fig. 3 -- The energy spectrum for the muon decay interval. This is the well-known Michel energy spectrum from muon decay. The spectrum is smeared by the resolution of the detector.

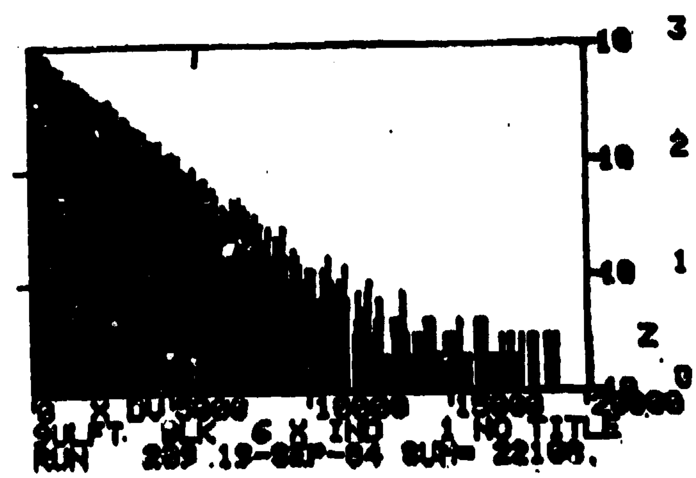

Fig. 4 -- The arrival time of a particle in the muon interval. The time spectrum gives a lifetime of about 2μsec consistent with the muon decay time.

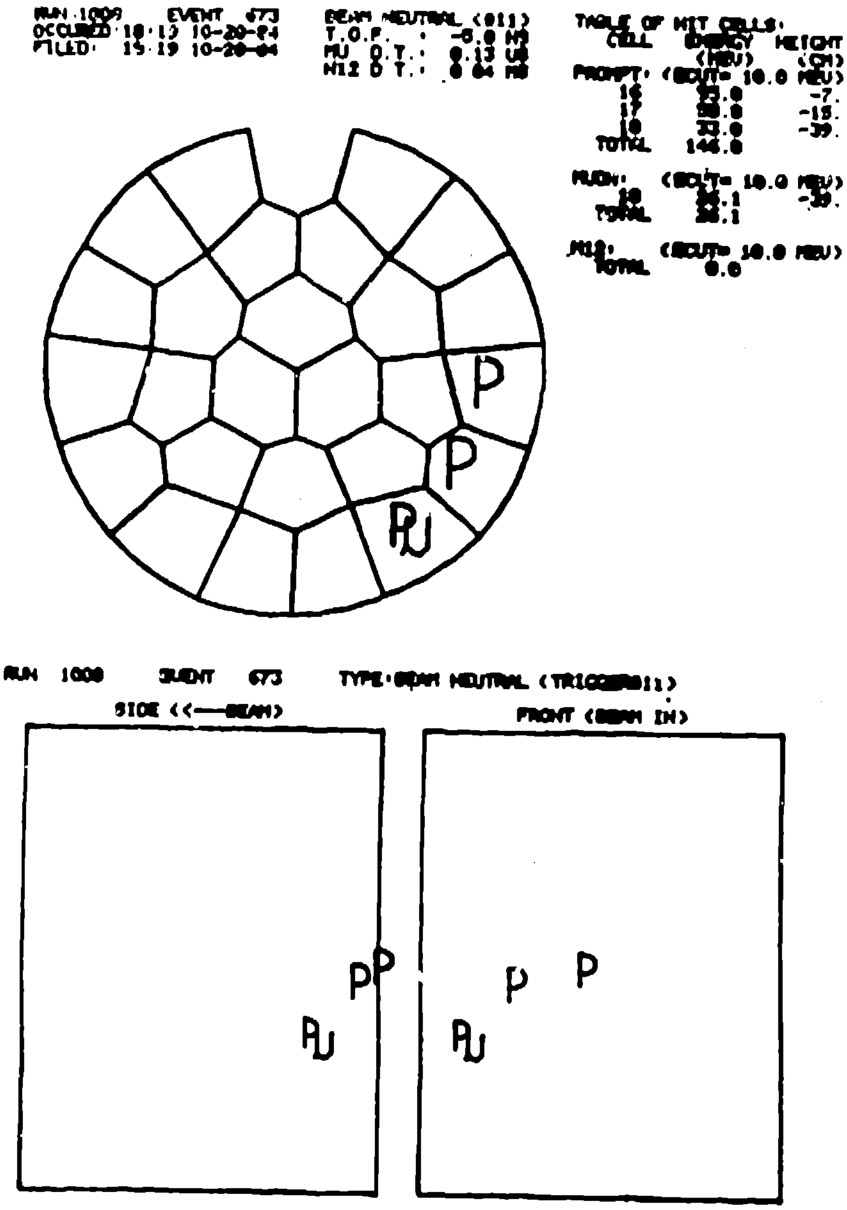

Figure 5 - Example of a cosmic ray muon that decayed in the detector. The "P" means that the module was triggered during the prompt interval (see main text for definition of time intervals). The "U" means that the module triggered during the muon decay interval. If there had been information in the N interval then a "N" would appear in the appropriate module.The size of the letter is related (logarithmically) to the energy deposited in the module. The table on the right shows the energy deposited per module and per time interval. In this event the prompt muon deposited 146 MeV, the decay electron deposited 26 MeV, and the muon decay time was 0.1 μsec.

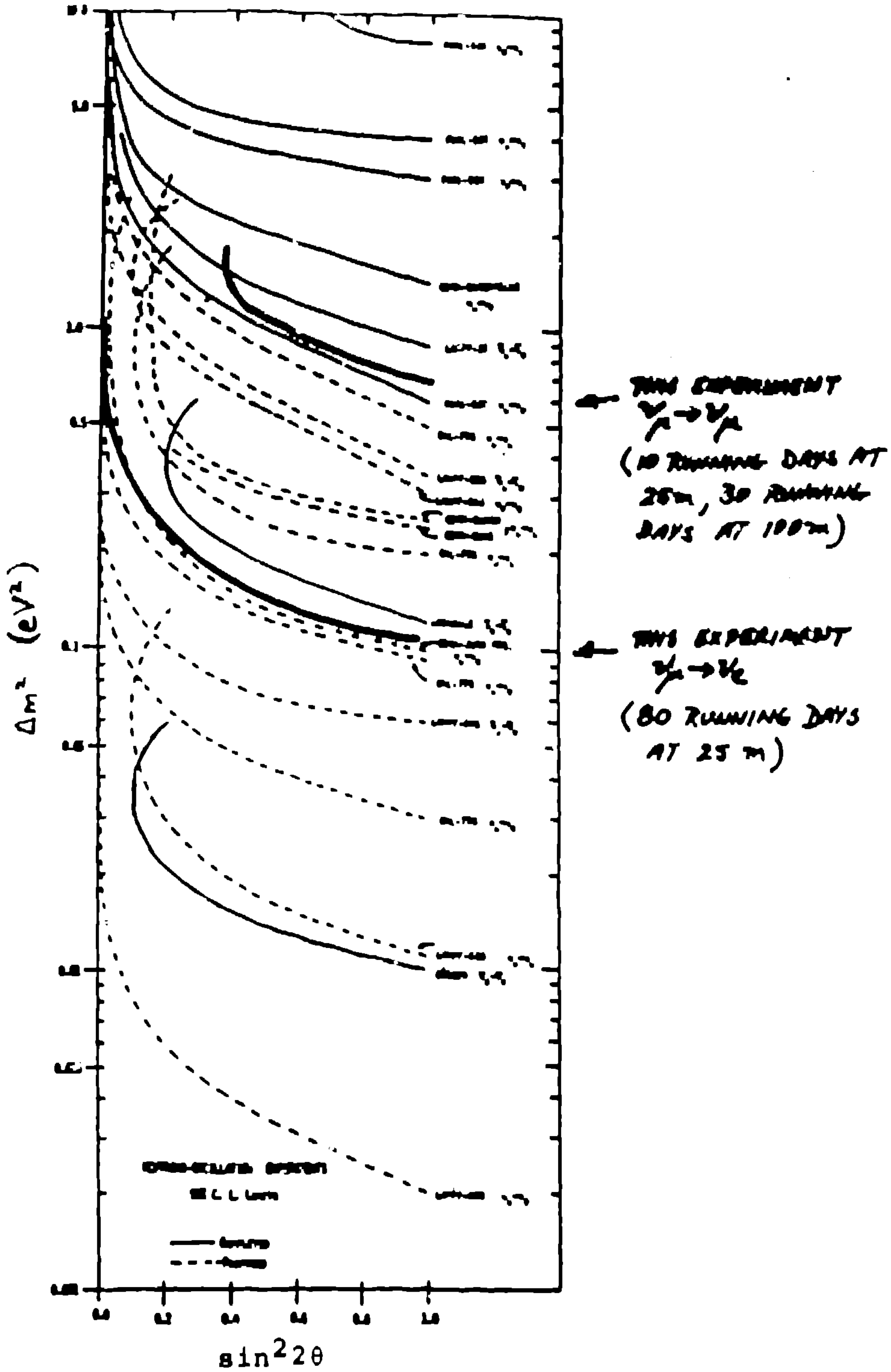

Figure 6 -- Δm^2 versus $\sin^2 2\Theta$ for various completed (solid curve), proposed (dashed curve) experiments. The present experiment is the dark solid curve.

cosmic ray showers. The rate we measured is .016 events/day for charged particles that fail the veto system and .020 events/day for the neutral cosmic rays for a total of .036 backgrounds events/day.

Based on data taken during the 1984 running cycle we plan to implement some of the following upgrades in order to reduce beam associated backgrounds.

* 1) additional shielding
* 2) beam pulse timing cut
* 3) particle range cut
4) pulse shape discrimination

* = partially implemented and ready by Spring '85

VII. Estimated Experimental Precision

The cross section measurement will be limited to a precision of about ±20% with the major contribution to the systematic error coming from the flux normalization. With 20μA of proton current and 30 days of running time we can set limits on neutrino oscillations of

$$\sin^2 2\Theta < 10^{-3}$$

$$\Delta m^2 < 10^{-1} eV^2$$

at the 90% confidence level. Figure 6 shows a plot of Δm^2 versus $\sin^2 2\Theta$ for various neutrino oscillation experiments including the present one. As can be seen from the plot this experiment is competitive among current experiments.

VIII. Conclusions

The Line-E decay-in-flight neutrino source at LAMPF achieved its authorized limit of 20μA of proton current. The E764 detector has been calibrated using cosmic rays. Upgrades to the experiment are partially implemented at present and improvements will continue until the Spring 1985 running cycle begins. In 1985 we expect to measure the $\nu_\mu C^{12} \rightarrow \mu^- N^{12}$ cross section to ±20% limited by the flux normalization. Also we expect to put limits on the oscillation of neutrinos $\nu_\mu \rightarrow \nu_e$ namely,

$$\sin^2 2\Theta < 10^{-3}$$

$$\Delta m^2 < 10^{-1} eV^2.$$

References

1. "Proposal to the U.S. Department of Energy for a National Facility to Provide a High Intensity Neutrino Source," Los Alamos National Laboratory, June, 1982.