Conf-911141--3
ANL-HEP-CP-92-03
PDK-498
D.M. Roback
January 20, 1992

SEARCH FOR ATMOSPHERIC NEUTRINO OSCILLATIONS WITH THE SOUDAN2 DETECTOR

ANL-HEP-CP--92-03

DE92 007397

Donald M. Roback
University of Minnesota

INTRODUCTION

Underground proton decay detectors record a sizeable number of atmospheric neutrino-induced events. These neutrinos come primarily from the decay of pions and muons produced in cosmic ray showers in the earth's atmosphere. The expected flux ratio of muon neutrinos to electron neutrinos traversing an underground detector, ν_μ/ν_e, is about 2. The combined effects of detector systematics and nuclear cross section differences between ν_μ and ν_e interactions typically reduce the measured ν_μ/ν_e event ratio to about 1. Over the last decade, both the Kamioka detector in Japan and the IMB detector in the United States have made high-statistics measurements of the atmospheric neutrino event ratio.[1][2] Both groups have presented strong experimental evidence that the underground ν_μ/ν_e event ratio is substantially smaller than predicted. In both cases, a statistically significant deficit of muon neutrino-induced events is measured. The Frejus detector in the Frejus tunnel between France and Italy and the NUSEX detector in the Mount Blanc tunnel have collected fewer events and hence can not decisively confirm or contradict the Kamioka and IMB results.[3][4]

One possible explanation of the muon neutrino deficit is that these neutrinos are undergoing flavor oscillations between their production points in the atmosphere and their interaction points in underground detectors. An MSW effect interpretation of solar neutrino experiments implies[5] a $\nu_e \rightarrow \nu_\mu$ oscillation region in Δm^2-$\sin^2(2\theta)$ space at least two orders of magnitude lower in Δm^2 than the best fit point of the Kamioka result. It is therefore usually assumed that the relevant flavor oscillation for atmospheric muon neutrinos would be $\nu_\mu \rightarrow \nu_\tau$.

The Soudan 2 nucleon decay detector is now approaching completion and collecting data. It will be able to make low-background measurements of atmospheric neutrinos in the next few years to check the possibility that atmospheric neutrinos undergo detectable flavor oscillations.

PHYSICS RESULTS

The Kamioka collaboration has recently presented[1] an analysis of 310 single ring contained events from an exposure of 4.9 fiducial kiloton years. In this sample, the final state electrons have momenta between 30 and 1330 MeV/c and the final state muons have momenta between 200 and 1500 MeV/c. Compared to the prediction of their Monte Carlo they find

$$\frac{\nu_\mu/\nu_{e\,Data}}{\nu_\mu/\nu_{e\,MonteCarlo}} = 0.60 \pm^{0.07}_{0.06} \pm 0.05 \quad (1)$$

* Work supported by the U.S. Department of Energy, Division of High Energy Physics, Contract W-31-109-ENG-38.

This result is supported by a deficit of contained events with a muon decay compared to their Monte Carlo prediction. Defining δ_+/δ_0 as the ratio of contained events with a muon decay signal to contained events without a muon decay signal, Kamioka measures

$$\frac{\delta_+/\delta_{0\,Data}}{\delta_+/\delta_{0\,MonteCarlo}} = 0.61 \pm 0.07 \tag{2}$$

The IMB collaboration has also recently presented[2] an analysis of 507 single ring contained events from an exposure of 7.7 fiducial kiloton years. The final state electrons have momenta between 100 and 1500 MeV/c and the final state muons have momenta between 300 and 1500 MeV/c. From their measurement of the fraction of contained events without a shower in the final state, one can calculate

$$\frac{\nu_\mu/\nu_{e\,Data}}{\nu_\mu/\nu_{e\,MonteCarlo}} = 0.54 \pm 0.08 \tag{3}$$

Frejus neither confirms nor contradicts the above numbers primarily because of poor statistics. With 165 fully and partially contained events from an exposure of 1.56 fiducial kiloton years they measure[3]

$$\frac{\nu_\mu/\nu_{e\,data}}{\nu_\mu/\nu_{e\,MonteCarlo}} = 1.06 \pm .23 \tag{4}$$

though this data sample may be contaminated by cosmic ray muons. When only the fully contained events are used, the Frejus number drops to 0.87$\pm$ .15. These events must have more than 200 MeV visible energy in the final state which translates to momentum thresholds of 200 MeV/c for electrons and about 290 MeV/c for muons. NUSEX obtains a ν_μ/ν_e ratio consistent with their Monte Carlo prediction.[4] This experiment, however, has collected only 50 events, so the statistical errors preclude any definitive conclusion.

Neutrino oscillations can affect not only the flavor composition, as reported by Kamioka and IMB, but also the energy distribution and angular distribution of the underground neutrino flux. At Δm^2 of 3.0 $10^{-3}eV^2$, for example, the oscillation length of atmospheric neutrinos will be comparable to the radius of the earth. Since neutrinos coming through the earth, then, are much more likely to oscillate than those coming only through the atmosphere, the angular distribution will not be flat. Presently, none of the above experiments report angular distributions that deviate from flat.

THE SOUDAN 2 DETECTOR

Soudan 2 is a 930-ton tracking calorimeter which is being constructed in northern Minnesota to search for nucleon decay and to study atmospheric neutrino interactions [6]. The detector consists of finely segmented iron instrumented with drift tubes. For each gas crossing three spatial coordinates and dE/dx are recorded. There is superior neutrino background rejection to nucleon decay because of excellent event-reconstruction capability, particle identification, and muon sign and direction for stopping tracks. Predicted detector performance has been verified using cosmic ray muon tracks and a charged particle test beam calibration[7]. There are also plans to expose a small portion of the Soudan 2 detector to a neutrino test beam if an acceptable beam can be found. The first 688 tons of Soudan 2 are now in steady operation (Dec 1991) with completion of the detector scheduled for late 1992 or early 1993.

The Soudan 2 detector is surrounded on all sides by an active shield, which consists of a 1700 m^2 double layer of proportional counters.[8] When complete this active shield will be greater than 95% efficient at tagging backgrounds of charged particles that originate outside the cavern.

POSSIBLE MEASUREMENTS

1 Measurement of the ν_μ/ν_e ratio

Soudan 2 will be able to measure the atmospheric ν_μ/ν_e event ratio with a systematic error determined independently using data from our charged particle test beam exposure. Statistically, Soudan 2 will measure approximately 140 contained neutrino interactions per fiducial kiloton year. Systematically, Soudan 2 should have smaller uncertainty than Kamioka, IMB, and Frejus. For example, Kamioka estimates[1] the systematic uncertainty in their ν_μ/ν_e measurement to be approximately 9%. This error is based on uncertainties in atmospheric neutrino flux, the detector Monte Carlo, and the analysis. The analysis errors come primarily from track/shower separation and the determination of the number of rings in an event. Soudan 2 has comparable systematic errors in atmospheric neutrino flux and detector Monte Carlo, but our analysis errors are smaller due to our fine-grain detector design and our calibration with a charged particle test beam. Soudan 2 can resolve individual prongs and vertices much better than water Cherenkov detectors because of our fine granularity and our sensitivity to particles of velocity below Cherenkov threshold. Our granularity also allows us to trigger with $>$ 50% efficiency on muons above 200 MeV/c with a muon trigger threshold of 120 MeV/c. The test beam exposure allows us to optimize methods of track/shower separation and particle identification using ionization. A preliminary analysis using test beam data shows that we can differentiate a 236 MeV/c muon from a 236 MeV/c electron at an efficiency of 90%. Similarly, using Monte Carlo data, we can separate tracks from showers of 200 MeV kinetic energy at 90% efficiency. From test beam protons and muons of the same range, we find that proton gas crossings ionize on average 1.6 times more than muon gas crossings.

Figure 1 shows the region of Δm^2-$\sin^2(2\theta)$ space for $\nu_\mu \rightarrow \nu_\tau$ oscillations that is allowed at the 90% CL by the Kamioka ν_μ/ν_e data and the region that is disallowed at the 90% CL by the Frejus ν_μ/ν_e data. Also in fig 1 is our estimate of what limits we can set on $\nu_\mu \rightarrow \nu_\tau$ after 1, 3 and 5 fiducial kiloton years of exposure including only statistical errors.

2 Disappearance experiment using the up/down ratio

Another experiment Soudan 2 will perform is a comparison of contained neutrino events from opposite sides of the earth. Because neutrino flux attenuates as r^{-2} and source area increases as r^2 for a given solid angle, the expected angular distribution in $\cos\theta$ of neutrinos underground is flat. Therefore the total number of upward-going and downward-going neutrino interactions in underground detectors should be the same assuming no $\nu_\mu \rightarrow \nu_\tau$ oscillations and no geomagnetic effects. This experiment takes advantage of having a detector different distances from two nearly identical sources. The short baseline is approximately the 10 km distance from the top of the atmosphere to the detector and the long baseline is approximately the 13000 km diameter of the earth. In order to best approximate two beams of atmospheric neutrinos on opposite sides of the earth, only events that originate in small upward- or downward-pointing cones are used in this experiment. For example, such cones have been chosen in an IMB analysis[9] to be approximately 2.5 sr each. The data sample is therefore decreased by 60% in this case and consequently the statistical error increases.

We are currently calculating the region in Δm^2-$\sin^2(2\theta)$ space that Soudan 2 can rule out with such a measurement.

SUMMARY

The Soudan 2 detector is well suited to check the possibility of the atmospheric neutrino flavor oscillations suggested by the Kamioka and IMB data. We expect to compensate for the advantage those two experiments have in exposure by having smaller systematic errors in Soudan 2. As of Dec 1991, Soudan 2 has 0.83 fiducial kiloton years of exposure. With a few more years of running, we will be able to confirm or contradict the present results which indicate a deficit of atmospheric muon neutrino interactions compared to electron neutrino interactions.

References

[1] Kajita *et al.*, these proceedings.

[2] Dye *et al.*, these proceedings.

[3] Ch. Berger *et al.*, Phys. Lett. **B227** (1989) 489.

[4] M. Aglietta *et al.*, Eurphys. Lett. **8** (1989) 611.

[5] Neutrino Astrophysics, John N. Bahcall, Cambridge University Press, 1989.

[6] D. S. Ayres, "The Soudan 2 Experiment", Proceedings of the 10th Workshop on Grand Unification, Chapel Hill, North Carolina, April 1989.

[7] J. L. Thron, Nucl. Instr. and Methods **A283** (1989) 642.

[8] W. P. Oliver *et al.*, Nucl. Instr. and Methods **A276** (1989) 371.

[9] LoSecco *et al.*, Phys. Rev. Lett. **55**, 2299, (1985)

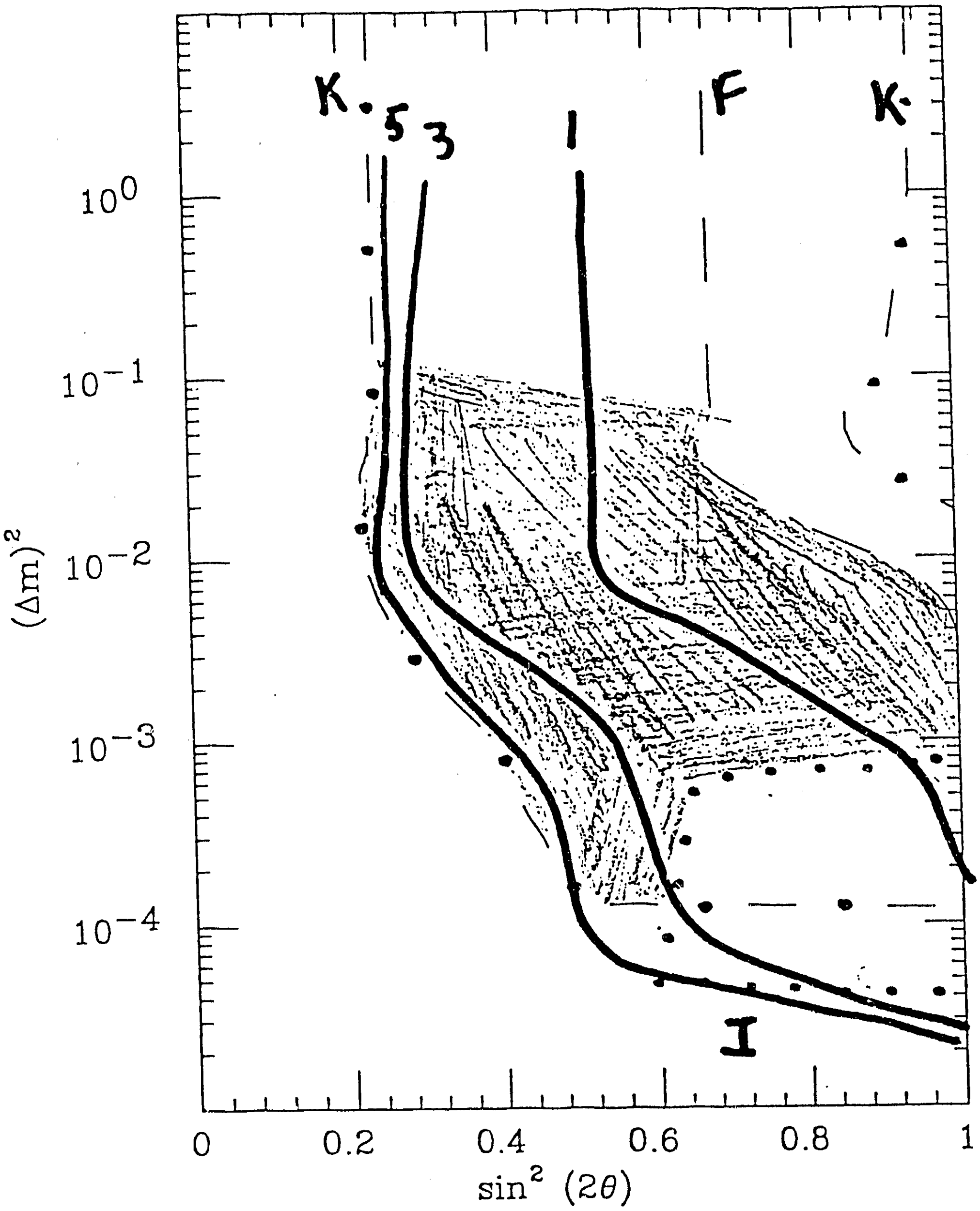

Figure 1. The region of $\nu_\mu \rightarrow \nu_\tau$ parameter space suggested by the 3.4 kt-year Kamioka muon neutrino deficit is between the two dash-dot curves "K" at 90% confidence level. The point shown is the "best fit". The Frejus experiments excludes the area to the right of the dash curve "F" and the IMB up/down ratio excludes the dotted portion labeled "I". The shaded area represents the parameter space allowed by all of these results and by accelerator experiments at 90% confidence level. If the Soudan 2 experiment measures the expected atmospheric neutrino flavor ratio after 1, 3 and 5 kiloton years of exposure, we will be able to exclude area to the right of the curves labelled 1, 3 and 5 respectively.

END

DATE FILMED

3/24/92