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STATUS OF THE MINOS EXPERIMENT

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The MINOS experiment is designed to search for neutrino oscillations. A neutrino beam from Fermilab is observed by the Near and Far detectors, separated by 735km. A comparison of the observed neutrino events at the two locations allows a measurement of the oscillation parameters to be made. Commissioning of the Near detector is underway and the Far detector is collecting cosmic ray and atmospheric neutrino data. Analysis of the atmospheric neutrino events has begun and neutrino, antineutrino event separation has been achieved. Data collection with the NuMI beam will begin in December 2004.

1. Introduction

The MINOS (**M**ain **I**njector **N**eutrino **O**scillation **S**earch) experiment[1] is a two detector, long baseline neutrino oscillation study. A neutrino beam created at Fermilab will be sampled first by the Near Detector, on-site at Fermilab, and then by the Far Detector, 735 km away in the Soudan Underground Laboratory in Minnesota. Comparing the relative fractions of neutrino flavors observed at the two locations allows a measurement of the oscillation parameters to be made.

2. The Beam and Detectors

The NuMI (**Ne**utrinos from the **M**ain **I**njector) beam is produced at Fermilab by firing 120 GeV protons from the Main Injector at a graphite target. The resulting secondary particles are focussed by two parabolic magnetic horns and are then allowed to decay along a 675 m evacuated pipe to produce neutrinos. The resulting neutrino beam is predominantly ν_μ with $\sim$1% ν_e . The relative positions of the horns and target are adjustable such that three different beam spectra are possible. MINOS will begin data taking with the low energy beam, which peaks at $\sim$3 GeV.

The MINOS detectors are fine grained tracking calorimeters consisting of alternating layers of inch thick steel and 1 cm thick plastic scintillator. Each scintillator layer is transversely segmented into 4.1 cm wide strips. Scintillation light is collected via wavelength shifting fibers and read out by photomultiplier tubes (PMTs). The detector design gives a resolution of $\sim 23\%/\sqrt{E}$ for electromagnetic showers and $\sim 55\%/\sqrt{E}$ for hadronic showers, where E is measured in GeV. The Near and Far

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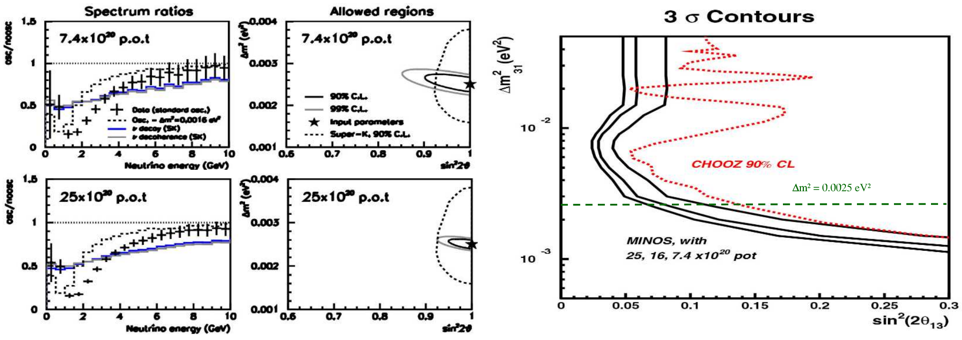


(a) (b)

Fig. 1. (a) The ν_μ disappearance signal in MINOS for $\Delta m^2 = 2.5 \times 10^{-3} eV^2$ and $sin^2 2\theta = 1.0$ for $7.4, 25.0 \times 10^{20}$ POT. The left hand plots show the ratio of the oscillated to unoscillated Far Detector spectrum and the right hand plots show the 90%,99% confidence limits on the determination of the oscillation parameters. Recent limits from SuperKamiokande are also shown. (b) The ν_e appearance discovery limits in MINOS at different values of Δm^2_{31} and different POT.

detectors are both magnetized with a current carrying coil producing an average field of 1.5 T in the fiducial volume, allowing a measure of muon momentum from curvature in addition to that from range.

The 980 t Near Detector is located 1 km downstream of the NuMI target and observes a relatively high rate of beam neutrinos, $\sim$5 interactions during each 10μs spill for the low energy beam. At this location, the neutrino beam spot is only 50 cm wide, so only every fifth plane of a total of 282 is fully instrumented.

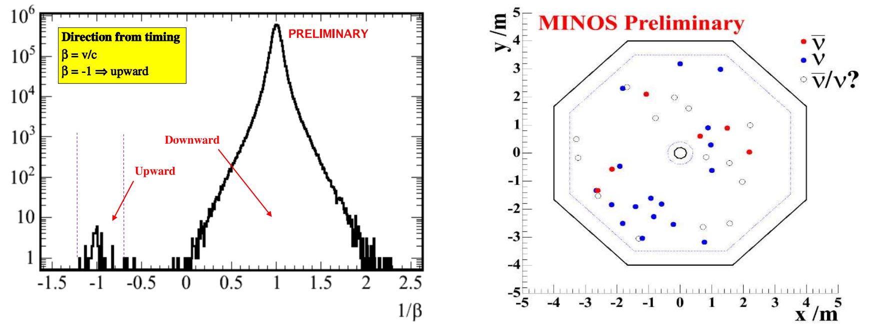
The Far Detector is 5.4 kt in mass and consists of 484 octagonal planes, 8 m in diameter. The detector readout electronics is simplified by multiplexing eight fibers to each PMT channel. A double layer veto shield assembled from scintillator modules was deployed to reduce the cosmic ray muon background in atmospheric neutrino studies.

3. MINOS Physics Reach

MINOS will measure the atmospheric oscillation parameters with unprecedented precision by measuring ν_μ disappearance. MINOS can also potentially improve the CHOOZ θ_{13} limit through $\nu_\mu \rightarrow \nu_e$ appearance studies. Figure 3(a) illustrates MINOS's ability to measure the ν_μ disappearance oscillation parameters in the region of parameter space suggested by the SuperKamiokande experiment[2]. Figure 3(b) shows the 3σ discovery limits for ν_e appearance at difference values of Δm^2_{31} and for different numbers of protons on target, (POT).

4. Atmospheric Neutrino Analyses

Preliminary analysis of the atmospheric neutrino data has been undertaken. The upward-going muon analysis makes use of neutrinos which enter on the far side of



(a) (b)

Fig. 2. (a) $1/\beta$ distribution for muons in the MINOS Far detector. (b) The distribution of contained event vertices on the face of the Far detector. Muon charge determination allows some events to be reliably identified as neutrino or antineutrino.

the Earth and interact in the rock beneath the detector. The resulting upward-going muons which intercept the detector are then separated from the downward going cosmic ray muon background using track timing. Figure 4(a) shows the $1/\beta$ distribution for muons in the Far detector. 48 upward events have been identified.

The contained event analysis looks at neutrino interactions within the detector which produce fully contained muon tracks. The major background to these events are high angle cosmic ray muons which enter the detector between the steel layers, then scatter to produce neutrino-like event topologies. To significantly reduce this background, only events with no hits in the veto shield are used in the analysis. 37 candidate events have been found. Figure 4(b) shows the vertices of the events and highlights the charge identification: of the 37 events, 6 were antineutrinos, 17 were neutrinos and 14 could not be reliably identified.

5. Conclusions

The NuMI beam installation is progressing well, and first protons on target are expected December 2004. The Near detector is being commissioned at FNAL and the Far detector has been collecting cosmic ray and atmospheric neutrino data for over a year. MINOS has observed upward going muons in the Far detector and made the first ever direct observation of separated atmospheric neutrino and antineutrino events.

References

1. Fermilab Proposal P875, February, 1995. “The MINOS Technical Design Report”, NuMI-L-337.
2. E. Kearns, “Atmospheric Neutrino Results from Super-K,” 21st International Conference On Neutrino Physics And Astrophysics, Paris, 2004.