Status of the MINOS Experiment

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MINOS is designed to explore the neutrino oscillation parameter space favored by the SuperKamiokande Experiment. Presented is a description of MINOS and the status of the effort at this time.

1. Introduction

MINOS(Main Injector Neutrino Oscillation Search)[1] will combine large neutrino pathlength with the high-rate Fermilab NuMI beam to explore the Super-K signal region of ν_μ oscillations parameter space and distinguish between ν_τ, ν_e, and ν_s flavor modes. Recent Super-K results[2] have narrowed the 90% confidence region for $\nu_\mu \to \nu_\tau$ oscillations to $1.5 \times 10^{-3} < \Delta m^2 < 5 \times 10^{-3}$, for high mixing($\sin^2 2\theta > 0.88$).

MINOS uses two massive coarse-grained iron-scintillator spectrometers, one close to the neutrino source (near detector), to observe the unoscillated beam, and a second detector ~730 km away in the SOUDAN iron mine in Minnesota (far detector), giving MINOS a low Δm^2 reach. Figure 1 shows the path of the NuMI neutrino beam produced from the Fermilab main injector.

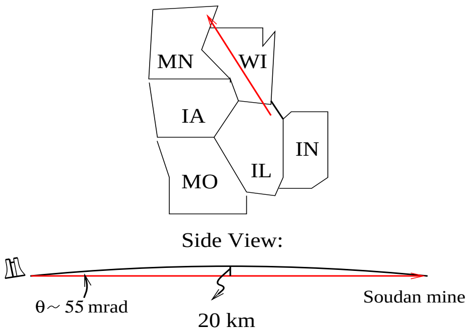

Figure 1. Sketch of the path of the MINOS neutrino beam produced at the Fermilab main injector. The beam is aimed at the far detector in the Soudan mine ~730 km away in Minnesota.

2. Neutrino Beams

The NuMI neutrino beam is produced from π and K decay in a 725 m decay pipe beginning just downstream of a double horn focusing system. The proton flux used to generate the π's and K's, will be 5×10^{13} ppp(at 120 GeV) with a rep rate of 1.9sec. Single turn extraction will be used resulting in a pulse width of about 8μsec. The beam will be composed primarily of ν_μ's (with about 2% ν_e component for low energy beam). By adjusting the target and horn separations the mean momentum of secondaries accepted by the focusing system can be tuned allowing for three different beam options as shown in Figure 2. MINOS will start running with the low energy configuration which is the most sensitive to oscillations in the region favored by Super-K($\Delta m^2 < 5 \times 10^{-3}$).

3. Detectors

The near detector(ND) serves both as a monitor of the neutrino beam and also as a reference detector, greatly reducing the dependence on detector Monte Carlos and the calibration requirements. The near and far detectors are designed to be as nearly identical as possible, thus they share the basic detector element, 4 cm wide by 1 cm thick scintillator strips up to 8 m in length. Light is collected and extracted to photodetection

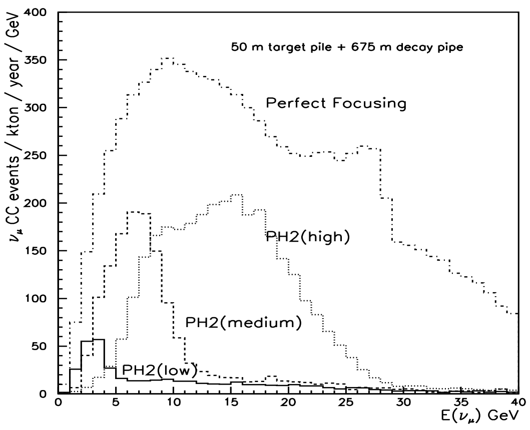

Figure 2. Beam spectra at the far detector for the three beam configurations of MINOS normalized to 1 Kton year. Perfect focusing assumes all secondary charged particles(correct sign) focused into a pencil beam with no divergence.

devices (16 pixel Hamamatsu M16 PMT's) using 1.2 mm diameter wavelength shifting fibers glued into an extruded groove traversing the length of the strip. Active detector planes are composed of scintillator strips assembled side-by-side into modules of 20 strips (some are 28), encased in aluminum boxes for support. Active detector planes are sandwiched between 2.54 cm thick steel plates.

The 980 ton near detector is "squashed" octagonal in shape, approximately 3.9 m high and 4.4 m wide. An off-center coil penetration is positioned so that the central part of the neutrino beam is 1.4 m away. The field in the magnetized iron in both near and far detectors is ~1.3 Tesla.

Along the beam direction the near detector consists of four regions: Veto, Target, Shower Section, and Muon Spectrometer. Each is comprised of identical detector elements, 2.54 cm thick steel plates and planes of 1 cm thick scintillator strips, differ only in functionality and readout granularity. Neutrino interactions occurring in the fully instrumented 1.0 m target section can be compared directly with interactions occurring in the far detector. The 1.5 m fully instrumented shower section following the target is needed to contain showers produced in the interaction and has sufficient longitudinal depth to distinguish between events containing a muon track and NC events. The muon spectrometer section, (with every fifth scintillator plane instrumented - 3.8 m × 3.8 m), measures muon momenta, allowing for reconstruction of neutrino energy in charged current interactions. The muon spectrometer is therefore crucial in measuring beam flux information.

The first three sections are instrumented in a transverse region centered on the beam of approximately 2.8 m × 2.8 m, for four planes and 3.8 m × 3.8 m every fifth plane. This dimension was chosen in order to measure the neutrino spectrum out to 1 m from the axis and necessary to contain hadronic showers (transverse size ≈0.5 m) generated by interacting neutrinos.

The MINOS far detector(FD) will be located in a new Soudan mine cavern ~1/2 mile underground, accessible only through a narrow (approximately 2 m × 2 m) vertical shaft. The 5.4 kton octagonal detector, 8 m × 8 m in width, will be fully instrumented and composed entirely of units (486 in total) of alternating scintillator-steel planes. The 2 m wide scintillator detector modules, will be constructed in several above ground locations and transported down the shaft for final assembly into full-sized planes underground. Welding of steel plates into full-sized planes must also take place underground in the MINOS cavern.

4. MINOS Physics

Neutrino oscillations will result in an alteration of the neutrino energy spectrum and the ν_μ charged current event rate at the MINOS iron-scintillator-toroid far detector. The most sensitive and robust oscillations test in MINOS is the NC/CC ratio test. This test compares the ratio of ν_μ charged current (CC) to neutral current (NC) interactions in the near detector to that in the far detector. ν_μ CC events can be distinguished on a statistical basis from NC events by their length in the detector, due to the presence of a final state muon. NC events (short events) can be efficiently selected with a maximum event length cut while events containing a muon track (long events) are rejected by this cut.

The near/far CC rate test, also sensitive to either oscillation mode, searches for depletion of CC events at the far detector This test, together with the energy spectrum for CC events at the far detector can be used to measure the oscillation parameters. The rate is related to $\sin^2 2\alpha$ and the shape of the energy spectrum provides a measure of Δm^2.

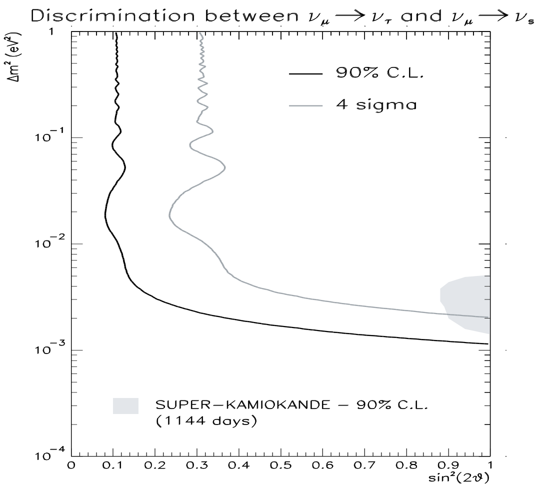

Figure 3. 90% confidence limit and 4-σ contours for MINOS sensitivity to discriminate between $\nu_\mu \rightarrow \nu_\tau$ and $\nu_\mu \rightarrow \nu_{sterile}$, assuming a 10 Kton year run with the low energy beam configuration.

An important measurement is the determination of neutrino flavors involved in the oscillations. In general, the oscillation pattern may involve a combination of $\nu_\mu \rightarrow \nu_\tau$, $\nu_\mu \rightarrow \nu_e$ and $\nu_\mu \rightarrow \nu_{sterile}$ transitions. Because the Super-K experiment sees no anomalous behavior in ν_e interactions and the reactor experiment CHOOZ[3] sees no $\overline{\nu_e}$ depletion consistent with $\Delta m^2 > 10^{-3}\mathrm{eV}^2$, the oscillations are likely to be $\nu_\mu \rightarrow \nu_\tau$, $\nu_\mu \rightarrow \nu_{sterile}$ or some combination of both. In the MINOS experiment, for the low energy beam, the former oscillation mode would deplete ν_μ CC interactions, but would leave the NC interaction rate unaltered. The latter mode would reduce both NC and CC interaction rates. If Δm^2 is sufficiently high, ($> 10^{-3}eV^2$), $\nu_\mu \rightarrow \nu_\tau$ can be distinguished from $\nu_\mu \rightarrow \nu_s$, statistically by comparing the ν_μ CC to total NC rate as shown in figure 3.

5. Schedule

MINOS far hall excavation at the Soudan mine began in March and should be completed by the end of this year. Scintillator module production will commence this Fall. Detector installation in the far hall is scheduled to begin early in 2001 with the first supermodule to be completed in Fall of 2002. At Fermilab the target shaft has been dug and boring of the beam tunnel is about to begin. Installation of beamline components is due to begin in October of 2002. With the completion of detector installation and the start of system commissioning in July 2003, data taking should start in the Fall of 2003 in the low energy beam configuration.

REFERENCES

1. MINOS Institutions: Argonne National Lab.,Univ. of Athens, Brookhaven National Lab.,CalTech, Univ. of Chicago, Dubna JINR, Elmhurst College, Fermilab, Harvard Univ., IHEP Beijing, IHEP Protvino, Indiana Univ., ITEP Moscow, James Madison Univ., Lebedev Physical Institute, Lawrence Livermore Lab., Univ. College London, Univ. of Minnesota, Northwestern Univ., Oxford Univ., Univ. of Pittsburgh, Rutherford Appleton Lab., Univ. of S. Carolina, Stanford Univ., Univ. of Sussex, Texas A&M, Univ. of Texas at Austin, Tufts Univ., Western Washington Univ., and Univ. of Wisconsin.
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