Eur Phys J C **33**, s01, s834–s836 (2004)
Digital Object Identifier (DOI) 10.1140/epjcd/s2003-03-911-8

EPJ C direct
electronic only

Status and prospects of the MINOS experiment

Peter Shanahan[a]

Fermilab - MS220, P.O. Box 500, Batavia, IL 60510 USA

Received: 2 December 2003 / Accepted: 12 December 2003 /
Published Online: 18 December 2003 – © Springer-Verlag / Società Italiana di Fisica 2003

Abstract. The MINOS experiment aims to conduct precision measurements of neutrino oscillation properties. Commissioning will start in early 2005, with two detectors separated by a baseline of 735km, and a beam of primarily ν_μ.

1 Introduction

The MINOS (Main Injector Neutrino Oscillation Search) experiment will study neutrino oscillations using a beam composed primarily of ν_μ, and two detectors separated by a baseline of 735 km. The neutrino beam will be produced at the Fermilab Main Injector, and will have a tuneable energy spectrum. Comparison of neutrino interaction rates and spectra in the Near Detector at Fermilab and the Far Detector in the Soudan Mine in the US state of Minnesota will be used to extract oscillation properties. The principle aim is to confirm the oscillation hypothesis of the atmospheric neutrino effect, and make a precision measurement of Δm^2 in ν_μ disappearance. MINOS also expects to improve the current limits on $\nu_\mu \to \nu_e$, and will have a unique sensitivity to differences in the oscillations of atmospheric ν_μ and $\bar{\nu_\mu}$.

2 The NuMI beam

The NuMI (Neutrinos at the Main Injector) beam starts with the extraction of 120 GeV/c protons from the Fermilab Main Injector onto a graphite target. Two magnetic horns focus the resulting hadrons in the direction of the detectors, at a downward angle of 3.3°. The relative positions of the target and horns can be modified to yield a variety of neutrino spectra by changing the selection of hadron momenta. The hadrons drift through a 675 m evacuated decay vessel, which ends with a 4.7 m long water-cooled Fe and Al absorber. Another 330 m of rock before the Near Detector hall ranges out the remaining muons.

As of Oct. 2003, the major construction of the underground complex at Fermilab has been completed, and installation of beam components has begun.

Figure 1 shows the interaction neutrino energy spectrum at the Far Detector, for 3 different sets of the target and horn positions. Based on the Super-Kamiokande value for Δm^2, MINOS will start data taking with the Low Energy beam configuration.

3 MINOS detectors

The MINOS detectors [1] are tracking calorimeters, composed of 2.54 cm thick planes of iron and 1 cm thick planes of plastic scintillator, with a 5.9 cm pitch. The scintillator is segmented into 4.1 cm wide strips, which are read out by wavelength shifting fiber, into multi-anode PMTs.

The Far Detector, located in the Soudan mine with an overburden of 2090 mwe, is composed of a total of 485 planes of iron and scintillator, grouped into 2 approximately equal “super-modules” with at total mass of 5.4 kt. The planes are 8 m wide (face-to-face) octogons. The iron is magnetized to an average field of 1.3 T by a water-cooled coil running the length of each super-module.

The first and second super-modules were completed in August 2002, and June 2003, respectively. Collection of cosmic-ray and atmospheric neutrino data for each super-module has been in progress since shortly after the completion of each.

The 282 planes of the 980 t Near Detector have a “squashed-octogon” shape, 3.8 m tall by 4.8 m wide, with the magnet coil offset from the center of the detector. This allows significantly less iron to be used, while ensuring a fiducial region transverse to the beam axis with a magnetic field very close to that of the average in the Far Detector. Although the fiducial region is a small fraction of the detector, the high neutrino flux will insure sufficient statistics.

All components for the Near Detector have been fabricated, and installation is expected to start in early 2004. Commissioning with beam neutrinos will start in early 2005.

---

[a] on behalf of the MINOS collaboration

4 Physics program

4.1 Atmospheric neutrinos

MINOS is unique in that it is the only large, underground detector with a magnetic field. This allows the differentiation of μ^- and μ^+, and therefore charged current interactions of ν_μ and $\bar{\nu_\mu}$. A comparison of atmospheric oscillation properties for the two would be a test of CPT symmetry in neutrino masses and mixing. Upward-going muons, identified by timing, select a clean set of charged current muon neutrino interactions occuring in the rock beneath the detector. A veto shield above and to the sides the detector is used to improve the rejection of the 1 Hz total rate of incoming cosmic ray muons, in the selection of atmospheric neutrino interactions occuring within the detector. The currently analyzed set of upgoing muons, for a 136 day exposure of super-module 1, is shown in Fig. 2. This corresponds to approximately 1/5 of the exposure for the entire detector during 1 year.

4.2 Beam neutrinos

The principle objective of beam running is to make precision measurements of the oscillation parameters in ν_μ disappearance. The ν_μ charged current event spectrum in the Near Detector will be used to predict the spectrum in the Far Detector in the absence of oscillations. The ratio of the observed and predicted Far Detector interaction spectra will yield the oscillation parameters.

The two detectors differ in several respects. The most significant is that while the Far Detector sees effectively a point source of neutrinos, the Near Detector sees a source of substantial extent on the 500 m scale of the distance from the decay volume. The non-oscillated event spectra in the two detectors are therefore different. The potential systematic uncertainty due to this effect will be ameliorated by improved understanding of hadron production that is expected from the upcoming MIPP experiment at Fermilab. Constraints will also come from comparisons of Near and Far Neutral Current interaction spectra. The electronics used to read out the two detectors are also different. This, and other calibration issues, are addressed by a special $1\ m \times 1\ m \times 60$ plane calibration detector, which has taken data in charged particle test beam at CERN.

Figure 3 shows an example of the MINOS reach in ν_μ disappearance, for $\Delta m^2 = 2.0 \times 10^{-3}\ eV^2$ and maximal mixing. The three rows of plots are for different integrated numbers of protons on target, highlighted in a 5 year run plan recently submitted by the MINOS collaboration. The left column shows the expected ratio of observed and predicted interaction spectra in the Far Detector, with the hypothesis of oscillations with $\Delta m^2 = 1.4 \times 10^{-3}\ eV^2$, and the neutrino decoherence hypothesis [2]. The right column shows the expected confidence level contours in Δm^2 and $\sin^2(2\theta)$. With 7.4×10^{20} protons on target, the precision of Δm^2 will already be greatly improved over the Super-Kamiokande result.

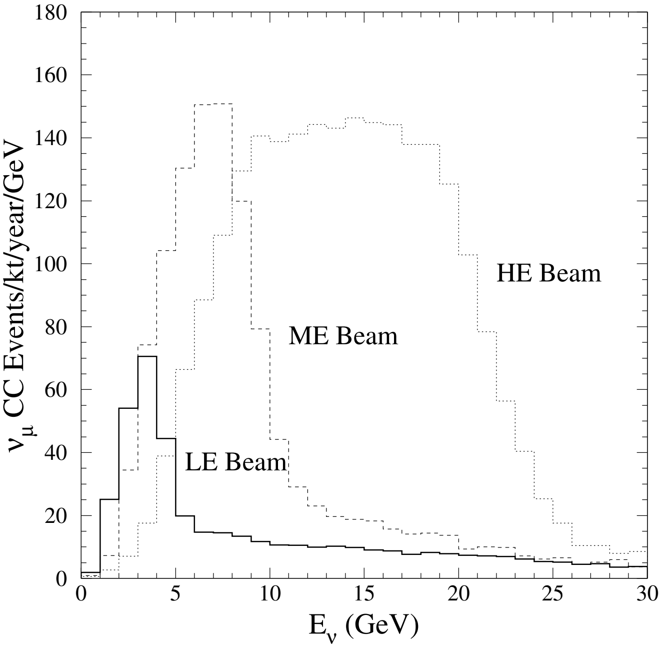

Fig. 1. Expected ν_μ Charged Current interaction spectra in the Far Detector, without oscillations, for 3 settings of the target and horn separations. (The "year" in the ordinate label is equivalent to 4×10^{20} protons on the NuMI target. MINOS hopes to achieve 2.5×10^{20} protons on target during the 1st year of running)

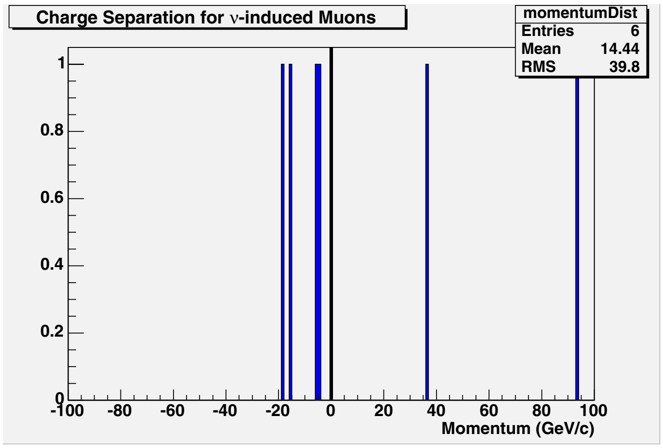

Fig. 2. Charge-signed momentum distribution for upgoing muons observed in the MINOS Far Detector

MINOS also expects to improve the $\sin^2(2\theta_{13})$ limit beyond the current Chooz bound, in $\nu_\mu \to \nu_e$. Intrinsic beam ν_e will represent a substantial backround to this measurement. Current estimates of the expected systematic uncertainty on this background indicate a 3σ discovery potential for $\sin^2(2\theta_{13})$ about a factor of 2 below than the current Chooz bound [4].

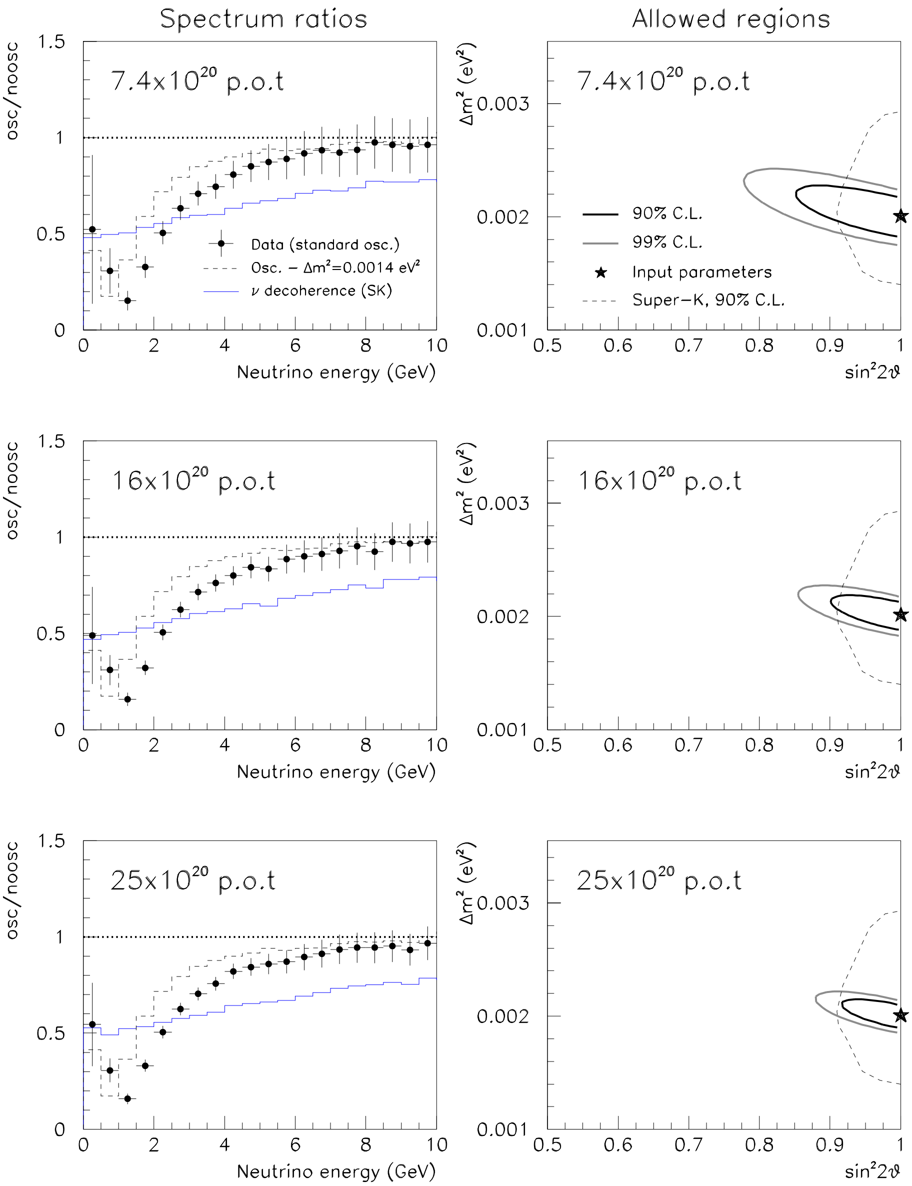

Fig. 3. Expected ratios of observed and predicted Far Detector ν_μ Charged Current interaction spectra *(left)*, and expected sensitivity in $\sin^2(2\theta)$ and Δm^2 *(right)*, for 3 different total fluxes of protons on the NuMI target. The input parameters are the central value of the recent Super-Kamiokande result [3]

5 Conclusions

The MINOS experiment will start data taking with the NuMI neutrino beam in early 2005. The study of ν_μ disappearance is expected to yield a significant improvement in the accuracy of the atmospheric neutrino mass splitting, Δm^2. Improvement in also expected in the current limits of $\sin^2(2\theta_{13})$, in ν_e appearance. Atmospheric neutrino data taking already in progress will permit a test of CPT symmetry in the atmospheric neutrino mixing effect.

References

1. C. Smith: Eur. Phys. J. C, (2003) (Proceedings of the Detector and Data Handling session of this conference)
2. G.L Fogli, E. Lisi, A. Marrone, and D. Montanino: Phys. Rev. D **67**, 093006 (2003)
3. Y. Hayato: Eur. Phys. J. C, (2003) (Proceedings of the Neutrino Oscillation session of this conference)
4. M. Apollonio et al.: Eur. Phys. J. C **27**, 331 (2003)