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Status and goals of the MINOS experiment

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1. Introduction

MINOS [1] is a two detector neutrino oscillation experiment positioned in the NuMI line, a recently commissioned long-baseline neutrino beam at Fermilab. A 980 ton Near Detector is installed at 1.04 km from the neutrino target. A 5400 ton Far Detector has been assembled in the Soudan mine, in northern Minnesota, at about 700 m below surface, and at a distance of 735 km from the neutrino target.

MINOS is a precision neutrino oscillation experiment at the atmospheric Δm^2 scale, whose main goals are:

1. verification of the dominant $\nu_\mu \rightarrow \nu_\tau$ oscillation through a detailed measurement of the characteristic oscillation energy dependence of ν_μ charged current (CC) events in the Far Detector, with a corresponding measurement of the atmospheric Δm^2 at the 10% level;
2. provide high statistics discrimination against unconventional explanations, i.e. ν decay, extra dimensions, decoherence, …;
3. search for the sub-dominant $\nu_\mu \rightarrow \nu_e$ oscillation;
4. measurement of atmospheric neutrino events with $\nu/\bar{\nu}$ identification, MINOS being the first large underground detector with a magnetic field.

2. Neutrinos at the Fermilab Main Injector

NuMI [2] is an acronym that stands for Neutrinos at the Main Injector. The Main Injector, a rapid cycling (up to 204 GeV/c/s) proton synchrotron at 120 GeV/c, is fed by up to 6 proton batches, of 5×10^{12} protons each, from the 8.9 GeV/c Fermilab Booster.

The 120 GeV/c primary proton beam, single turn extracted from the Main Injector in about 10 μs, is transported by a large acceptance primary proton line over a distance of 350 m, brought to a pitch angle of 58 mrad in order to point to the neutrino Far Detector, and focused onto a water-cooled graphite target. Design values of the NuMI line are 4×10^{13} protons/pulse (ppp) every 1.9 s, corresponding to a power of 0.4 MW.

The graphite target, of 2 interaction lengths, is followed by two water-cooled, parabolic aluminum horns, pulsed with up to 200 kA, providing a 1/r toroidal field that has a maximum of 30 kG. The focused particles are allowed to decay in a 675 m long decay pipe of 1 m radius, evacuated down to 0.4 Torr. A water-cooled aluminum beam absorber is positioned at the end of the decay pipe.

High rate ionization chambers [3] are used to monitor the beam immediately upstream of the absorber (Hadron monitor) and in 3 successive alcoves downstream of the absorber (Muon monitors).

A novel feature of the NuMI line is the possibility to tune the energy of the resulting neutrino beam by changing the distance between the two horns up to ~ 40 m and, most importantly, by having a motorized target carrier that allows for 2.5 m of target motion in beam direction.

Predicted charged current event spectra in the Far Detector for three different neutrino energy configurations, Low, pseudo-Medium and pseudo-High energy beams, are shown in Figure 1. The pseudo-Medium and pseudo-High energy configurations are obtained by retracting the target from the Low energy position by 1.0 m and 2.5 m, respectively, without adjusting the second horn position.

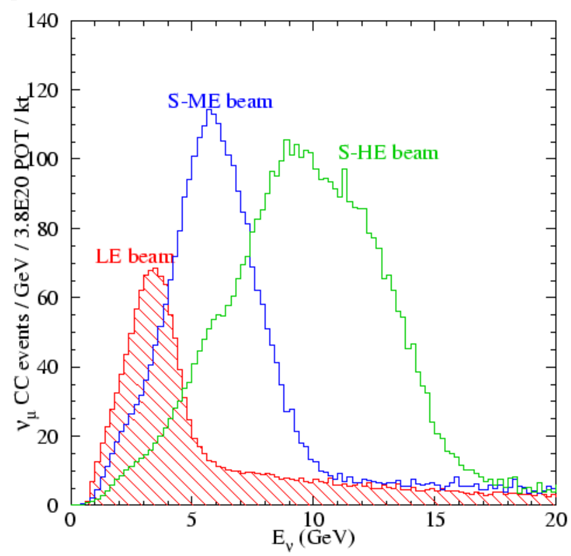

Figure 1: CC event spectra in the Far Detector for Low, pseudo-Medium and pseudo-High energy beams.

3. The detectors

The Near and Far neutrino detectors are ‘identical’ in all of their important features. They are tracking calorimeters made of interleaved planes of 2.54 cm thick steel plates and solid scintillator detectors, segmented in 1 cm thick and 4.1 cm wide scintillator strips. Strips in alternating planes are oriented at ±45° to the vertical, thereby providing views of the events in two orthogonal planes. The scintillation light is collected by wavelength shifting fibers embedded in the scintillator strips and then transmitted through clear optical fibers to multi-anode photomultiplier tubes. The detectors are magnetized to an average value of 1.5 T.

The Near Detector electronics allows measurement of charge in each 19 ns RF bucket to separate multiple events in a same beam spill.

4. MINOS startup and data taking

Commissioning of the primary proton line started on December 2004, with beam successfully extracted on the first pulse from the Main Injector and hitting the center of the Hadron monitor detector on the 10^{th} pulse, thus proving the proton beam to be aligned within ~ 30 μrad of the GPS-surveyed line to the Far Detector.

The commissioning of the neutrino line resumed in January 2005, when the first neutrino interactions were observed in the MINOS Near Detector.

MINOS data taking began in the middle of March, at a beam intensity of 1×10^{13} ppp. Since then intensity has been steadily growing up to 2×10^{13} ppp at the time of NuFact05, with cycle repetition rates of 0.25-0.5 Hz. Data taking was suspended during the month of April to fix a problem with a water leak in the target and resumed again in May.

Near Detector neutrino energy distributions have been collected both in Low energy beam mode (the default running condition) and, in order to understand the systematic of neutrino production and detector response, also in pseudo-Medium and pseudo-High energy configurations.

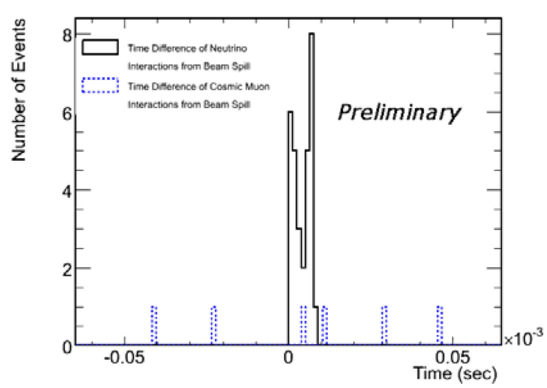

Figure 2: Time difference between Far Detector events and beam signals, for neutrino candidates (solid line) and cosmic events (dashed line).

The pseudo-High energy period has provided enough interactions in the Far Detector to check for the time difference between neutrino candidates in the Far Detector and the beam-synchronized signal (see Figure 2). Neutrino beam candidates, selected by visual scanning, are all within a 10 μs time interval, as expected from the spill length.

5. Conclusions

At the time of NuFact05 MINOS has accumulated ~ 0.8×10^{19} pot in the Low energy configuration. By the end of 2005 we foresee to collect 1×10^{20} pot corresponding, in case of no oscillations, to ~ 180 ν_μ CC reconstructed events in the Far Detector fiducial volume in a 1-10 GeV energy range. The expected MINOS sensitivity for 1×10^{20} pot is shown in Figure 3.

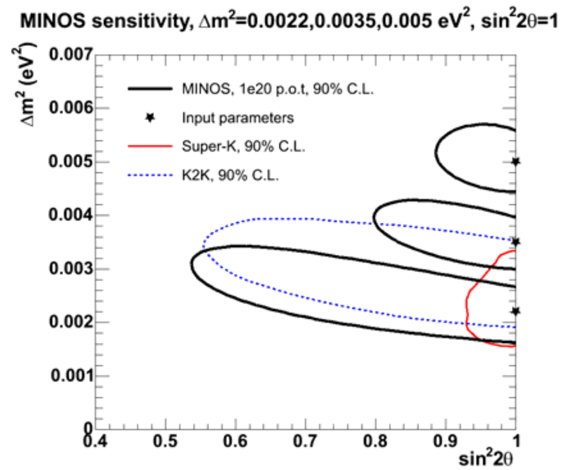

Figure 3: MINOS sensitivity for 1×10^{20} pot. Allowed regions for Super-Kamiokande [4] and K2K [5] experiments are shown.

During a five year period, MINOS expects to collect ~ 16×10^{20} pot, which allows a measurement of the atmospheric Δm^2 at the 10% level, together with a good sensitivity for unconventional explanations. The search for the sub-dominant $\nu_\mu \rightarrow \nu_e$ oscillation has a 3 σ sensitivity for non-zero values of θ_{13}, if this is within a factor 2 of the CHOOZ [6] limit.

References

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[3] D. Indurthy *et al.*, *Ion Chamber Arrays for the NuMI Beam at Fermilab*, FERMILAB-CONF-05-108-AD, e-Print Archive: physics/0506193

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[5] L. Ludovici for the K2K Coll., in these proceedings.

[6] M. Apollonio *et al.*, Phys. Lett. **B420** (1998) 397 and Phys. Lett. **B466** (1999) 415.