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Neutrino Beam data in the MINOS (Main Injector Neutrino Oscillation Search) experiment

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A new accelerator neutrino beam (NUMI) has been built at Fermilab. This beam is directed to the 5.4 kt MINOS detector placed 735 km away in the Soudan mine in northern Minnesota. We expect to measure the atmospheric oscillation parameters (Δm^2 and $\sin^2(2\theta)$) with a precision of about 10% with this experiment. The NUMI beamline started operation in January 2005.

1. Introduction

A new neutrino beamline, known as NuMI (Neutrinos at the Main Injector) has been built at Fermilab. At its design intensity, 4×10^{13} protons per pulse with 120 GeV/c momentum from the Main Injector strike a one meter long segmented graphite target every 1.9 seconds. The secondary mesons are collected by a two-horn focusing system and directed toward the Soudan Iron Mine in Minnesota, 735 km away, at an angle of 58 mrad into the ground. The mesons, most of which are charged pions, are sign selected to be positive by the horn system and allowed to decay in a 675 meter long and 2 m diameter evacuated decay tunnel.

The MINOS experiment has two detectors, the near detector and the far detector, to compare the unoscillated neutrinos with a sample which has traveled far enough to exhibit significant oscillations, based on the "atmospheric" value of Δm^2. The detectors are described in detail in these proceedings.[1]

The first event in the far detector from a Fermilab neutrino was observed in March 2005. Soon after that, a water leak developed in the target, but after the target was drained, this problem has not reappeared. An "energy scan" took place, with a variety of target configurations to compare near detector measurements with predictions from the beam Monte Carlo. These include running with a Medium Energy beam (pME) and a High Energy beam (pHE) which gives the largest statistics.[2] After the energy scan, MINOS will take data in its "Low Energy" (LE) configuration.[3]. Before the NuMI program started, the Fermilab Main Injector ran with only one batch of protons for $\bar{p}$ production for the Tevatron. With NuMI, it runs with six batches. The Main Injector has to share beam between the NuMI program and $\bar{p}$ production for the Tevatron program. So far, the initial goals for multi-batch running with the Fermilab Main Injector and for spill repetition rates have been achieved.

Currently, the 120 GeV Fermilab Main Injector is operating in two modes. In "NuMI" mode, there are 6 Booster batches extracted to NuMI. This mode is possible during the one hour $\bar{p}$ shots to the Fermilab Recycler. Work is in progress to also provide "NuMI" mode running during shots to the Tevatron. In "mixed" mode, there are two fast extractions within one millisecond. One batch goes to the anti-proton target, consisting of either a single Booster batch, or the merging of two Booster batches from a process called "slip-stacking". The remaining five batches go to the NuMI target, following the firing of the NuMI kicker. As of June 13, 2005, the Main Injector has exceeded 1×10^{19} protons delivered to the NuMI target, with 6×10^{18} in the LE configuration. Work is in progress to continue to reduce possible sources of beam loss, and increase efficiencies regarding beam sharing between the Tevatron and NuMI programs.

2. Sensitivity to Oscillations

The design intensity of the experiment is to accumulate 7.4 $\times$ 10^{20} protons on target with two years at full intensity. During this first calendar year of operation, we expect to accumulate 1.0×10^{20} protons. We expect the data for this period to be analyzed promptly so that we can specify the target position for subsequent running so to achieve optimal sensitivity. Figure 1 shows the energy distribution that we expect to measure in our far detector, compared to the no-oscillation expectation, for three possible values of Δm^2. The expectation is measured in our near detector. Figure 3 shows the oscillation sensitivity for these values of Δm^2 assuming maximal mixing, along with recently reported parameter space plots from K2K and Super-Kamiokande. The sensitivity for $\Delta m^2 = 2.5 \times 10^{-3} eV^2$ is shown in Figure 2. Other sensitivity plots for the full experiment are shown in References [4] and [5]. Our run plan now calls for 16-25 $\times$ 10^{20} protons on target, and we are working closely with Fermilab beam physicists to be able to achieve this goal.

MINOS is also sensitive to $\nu_\mu \rightarrow \nu_e$ oscillations.[4] Such oscillations might be expected in the MINOS experiment depending on the value of the yet-to-be-measured parameter θ_{13}. The best current limit on θ_{13} comes from the Chooz experiment[6], and MINOS is the only currently running experiment which might be able to find a non-zero value of θ_{13}.

3. Summary

The MINOS experiment, which was first proposed in 1994,[3] is now beginning to take data. In addition to a strong program of measuring oscillations in a neutrino beam, MINOS is also studying atmospheric neutrinos ([7], [8]) and cosmic rays [9]).

4. Acknowledgments

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References

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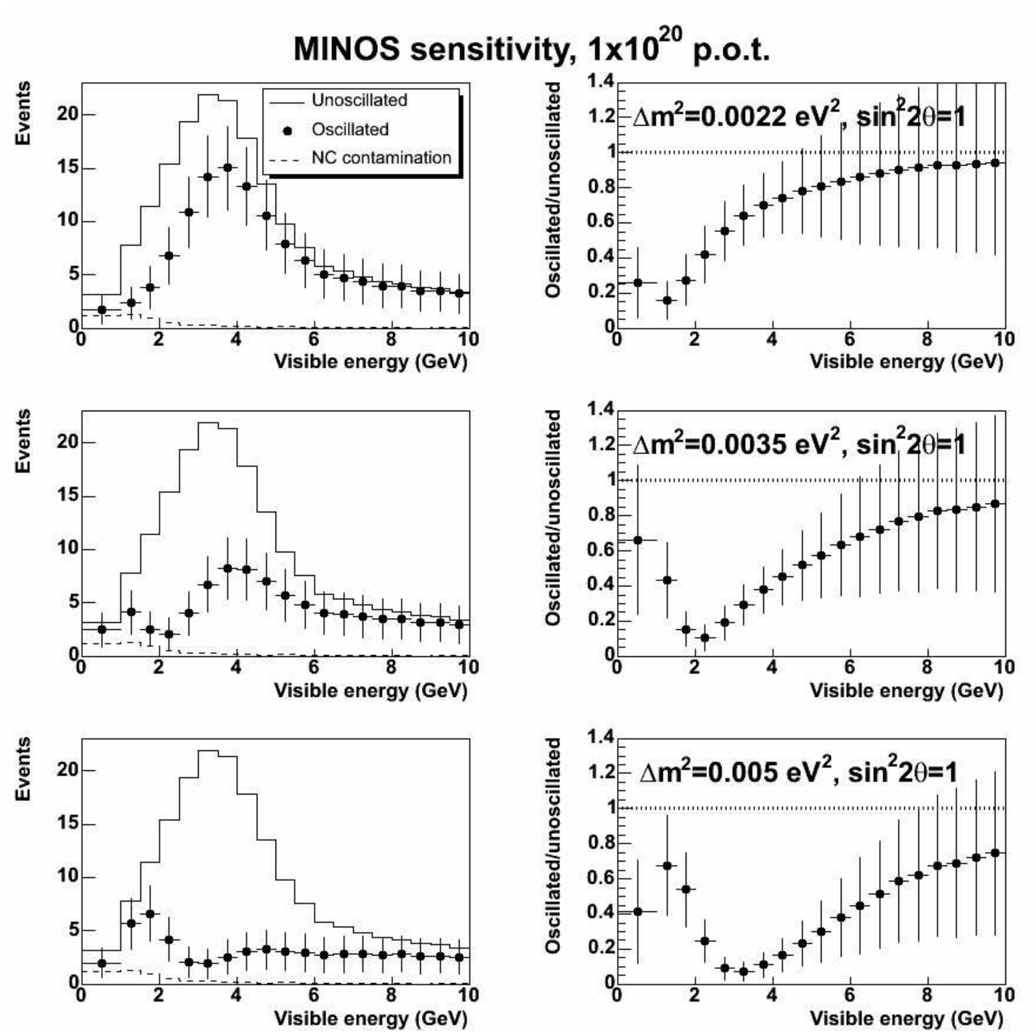

Figure 1. Expected charged current visible energy distributions with and without oscillations in the MINOS far detector for our first year of running and for three values of Δm^2 at maximal mixing. The neutral current background is also shown on the left. The ratio is shown on the right.

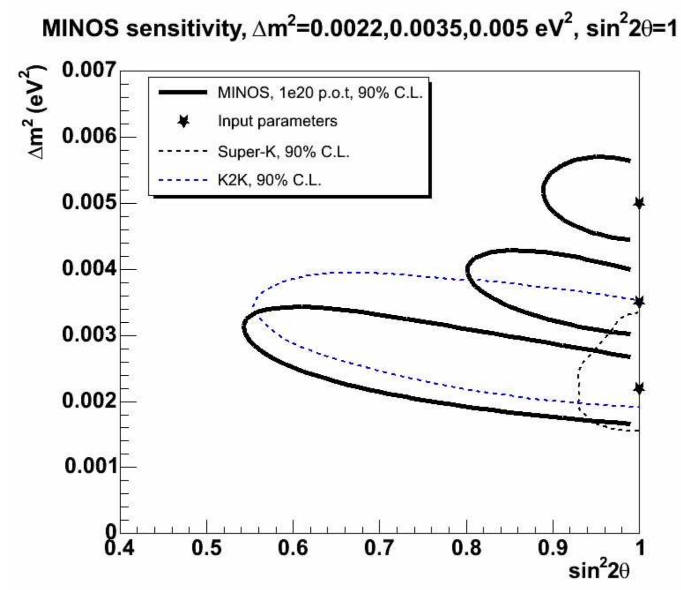

Figure 2. Parameter space sensitivity for MINOS's first year for maximal mixing and three values of Δm^2. Also shown are recent reported measurements from K2K and Super-Kamiokande.

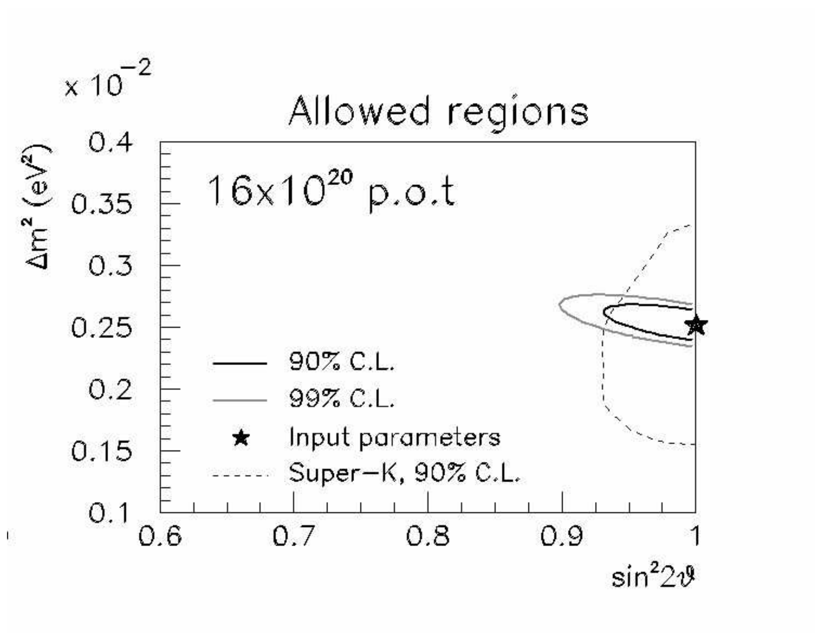

Figure 3. Parameter space sensitivity for MINOS with 16 $\times 10^{20}$ protons on target for maximal mixing and $\Delta m^2 = 2.5 \times 10^{-3} eV^2$.