MINOS: Design & Detectors

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Abstract

MINOS is a 735 km long-baseline neutrino oscillation experiment from Fermilab (IL, USA) to the Soudan mine (MN, USA). The experiment measures ν_μ a various energies from Fermilab's NuMI beam. The near and far detectors are almost identical steel–scintillator sandwich tracking calorimeters. MINOS has been running in atmospheric mode since 2003 and in beam mode since February 2005. MINOS is designed to make precision measurements of the neutrino oscillation parameters in the atmospheric sector whilst also being able to improve the current limit on reactor sector oscillations. Several stages of calibration have to be performed to achieve this.

1 Overview

The Main Injector Neutrino Oscillation Search is a long baseline experiment using muon neutrinos from Fermilab's NuMI beam [1]. The experiment consists of two identical, magnetised, tracking calorimeter detectors: a near detector, 1 km from the target, at Fermilab (IL, USA); and a far detector at Soudan (MN, USA), 735 km from the target. The experiment has already measured atmospheric neutrinos since 2003 at the far detector, and the beam–phase of the experiment started in February 2005.

2 Beam, Beamline and Protons

120 GeV protons from Fermilab's Main Injector are fired at a graphite target, producing pions and kaons. These intermediate particles are focused by magnetic horns and decay into (mainly) ν_μ along the 675 m decay tunnel. The total distance from the target to the near detector is 1.0 km, an absorber covers much of the intervening distance to decrease the muon flux at the near detector. The magnetic horns can be moved to low, medium and high energy configurations, so the neutrino energy spectrum can be tuned to physics requirements.

The first neutrinos to MINOS from the NuMI beam were sent in January 2005, and the first beam neutrino events were seen at the near detector in January and then at the far detector in March. Apart from 3 weeks of beam shut-off in March and April due to a cooling water leak in the target, the beam has been running reliably since. The intensity of the protons fired at the target had reached $2.1\text{x}10^{13}$ per pulse by July, with a beam pulse every 3 s. The beam-line has been tested with up to $2.5\text{x}10^{13}$ protons per pulse in February, and this is the intensity goal with pulses every 2 s by the end of 2005. With this proton intensity, MINOS expects to see $1.1\text{x}10^{4}$ neutrino interactions at the near detector every day.

3 Detectors

The detectors consist of 6 cm composite planes of 1 in thick steel, 1 cm thick solid scintillator [2] and an air gap (for mechanical reasons). The scintillator is divided up into 4.1 cm wide strips and alternating planes have these strips oriented orthogonal to each other at 45° to vertical: this gives MINOS three-dimensional resolution. Light is collected from the scintillator using wavelength-shifting optical fibres running in a groove along the scintillator strips, and these are read out by multi-anode photomultiplier tubes [3].

The near detector has a total mass of 0.96 kT and is 282 planes long. The detector has a 1.5 T magnetic field centred away from the beam axis. Every 5th plane in the detector is fully instrumented (96 strips across). In the front 120 planes, the calorimeter section, the intervening planes are partially instrumented (64 strips across). This section is used for measuring shower energies. The back 160 planes constitute the spectrometer section, and there is no read-out between fully instrumented planes. This back section is used to measure high energy muon momenta by curvature in the magnetic field.

The far detector has 485 planes with 192 strips in each plane, it is 8 m across and 31 m long, with a fiducial mass of 5.4 kT. There is a 1.5 T magnetic field running through the centre of the detector which allows it to measure the charge-sign of charged-current atmospheric neutrino events. These can be distinguished from stopping cosmic muons using timing and a veto shield covering the top of the detector. The detector has an angular resolution of 1° and has already measured 10^7 through-going cosmic muon events since it commenced data-taking in 2003. It has detected the shadow of the moon in the direction spectrum of muons >20 GeV, and the first oscillation results from atmospheric neutrinos will be announced soon.

4 Calibration

Calibration is performed in MINOS by a series of corrections for different effects. The first link in the calibration chain is on-board electronics calibration with charge injection. Then PMT gain and "gain drift" calibrations are performed with a light injection system [4]. Once the read out is calibrated, the response of each strip in the detector is normalised with cosmic ray muons. Then the inter-detector calibration is perfomed using muons that stop in each detector, to ensure the same part of the Bethe-Bloch curve is measured at each detector. Absolute calibration is carried out using Monte Carlo simulations and a special calibration detector to characterise the response to different particles at different energies.

The MINOS detectors are designed to be calibrated to 2% relative and 5% absolute uncertainty in order for systematic errors to be less than statistical errors after 3 years of NuMI beam running. This is an important aspect of MINOS, since MINOS will compare the energy scales at the near and far detectors in order to extract the atmospheric neutrino oscillation parameters to 10% precision.

References

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