The MINERνA Detector

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Abstract. MINERνA (Main INjector Experiment for ν-A) is a dedicated neutrino-nucleus scattering experiment at Fermilab. It uses a fine-grained fully active detector to make precision measurements of neutrino and antineutrino interactions on a variety of different nuclear targets (plastic scintillator, C, Fe, Pb, He and H2O) for energies up to few GeV. An overview of the experiment and a description of the detector are presented.

Keywords: neutrino detector, neutrino scattering, MINERvA, FERMILAB

INTRODUCTION

To study oscillation parameters in detail, present long baseline neutrino oscillation experiments make use of high-Z detector material such as carbon, oxygen or iron in order to maximize interaction rates. However, to correctly interpret the data, it is necessary to well understand nuclear effects in neutrino interactions. Detailed knowledge of inclusive and exclusive neutrino-nucleus cross sections and final state interactions within the target nucleus are important for determining the incoming neutrino energy and separating backgrounds from oscillation signal events.

Extremely intense accelerator-based neutrino beams used in oscillation experiments also enable high precision measurements on neutrino interaction cross-sections. The MINERνA experiment, using the high intensity NuMI neutrino beam, will measure the inclusive and exclusive cross sections for neutrinos and anti-neutrinos with much greater precision than previous experiments. In addition, using its high resolution detector, MINERνA will be the first experiment to study the A-dependence of neutrino reactions on a variety of nuclei such as helium, carbon, water, iron and lead. This will improve our knowledge on neutrino interactions which limit the systematic errors of oscillation experiments and allow us to study the structure of the nucleon and the nucleus using a unique weak probe. Such knowledge is important not only for neutrino physics but for the nuclear physics as well. The MINERνA collaboration consists of approximately 80 particle, nuclear and theoretical physicists from 24 institutions located in 8 countries

THE MINERνA EXPERIMENT

MINERνA (Main INjector Experiment for ν-A) [1] is a dedicated neutrino-nucleus scattering experiment that uses the NuMI high-intensity neutrino beam at FERMILAB. NuMI (Neutrinos at the Main Injector) [2, 3] is a tertiary neutrino beam resulting from decays of pions and kaons secondaries produced by colliding 120 GeV energy protons against a water-cooled graphite target. Protons come from the Main Injector accelerator in $\sim$10 μs long spills at a frequency of $\sim$0.5 Hz. On average, $\sim$35E12 protons on target (POT) are used in each spill. After the collision, the resulting positively charged secondaries particles, pions and kaons, are focused by two magnetic horns into a 695 m long decay pipe to produce mostly ν_μs. The remaining protons and particles which have not decayed are stopped in an hadron absorber. Muon monitors placed downstream of the absorber measure the profile of muons from hadron decay and monitors the beam direction and intensity. The beam's energy distribution can be tuned by changing the relative position of the target with respect to the magnetic horns. An $\bar{\nu}_\mu$ beam can also be obtained by reversing the current in the magnetic horns in order to focus negative particles (π^-s and K^-s) instead of positive ones (π^+s and K^+s). The broad energy range of the NuMI beam allows MINERνA to study $\bar{\nu}_\mu$ and $\bar{\nu}_\mu$ interactions from about 1 GeV to 20 GeV.

In order to make cross-section measurements, we need to understand and simulate the NuMI beam line to calculate the neutrino flux at the MINERνA detector [4]. This simulation is done with GEANT4, and data from the NA49 experiment at CERN is used to constrain the simulation of the hadron production at the NuMI target. The result of this simulation is shown in the left side of figure 1 and the current uncertainties are also summarized in [4]. In the future,

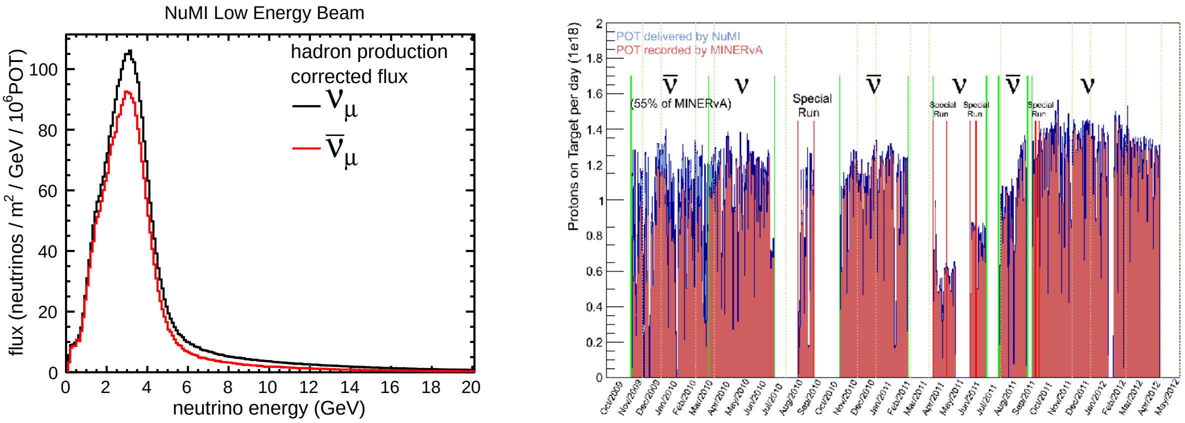

FIGURE 1. NuMI's neutrino and anti-neutrino flux prediction at the MINERνA detector (left). Protons on target delivered to the NuMI beamline during its low-energy configuration period. The live time of the MINERνA detector during this period was 97.2% (right).

to improve the flux simulation, the MINERνA collaboration plans to:

- Analyze MINERνA's data during periods of different NuMI beam configurations.
- Use new hadron production data (NA61 experiment at CERN).
- Use in-situ measurement from muon flux via muon monitors.

MINERνA'S DATA COLLECTION

MINERνA has taken data using the NuMI beam in its low-energy configuration (LE) with a peak energy of ~3 GeV. In a first stage, a partially constructed detector took data in anti-neutrino mode between November 2009 and March 2010. Then, the full detector took data from March 2010 to April 2012 switching between low-energy neutrino and anti-neutrino modes and different NuMI's horn current and target position configurations, known as *special runs*, to study the neutrino flux. The total exposure was of 3.98E12 POT taken with a LE ν_μ beam, 1.7E12 POT with a LE $\bar{\nu}_\mu$ beam and 0.49E20 POT of *special runs*. The POT collected during this period, as well as the different configuration used, are showed in right side of figure 1.

MINERνA is now getting ready to be exposed at NuMI's medium-energy configuration (ME) beam, with a peak energy of ~8 GeV. This new exposure is planned to start in the summer 2013.

THE MINERνA DETECTOR

The MINERνA detector consits of an inner tracker volume made of active plastic scintillator surrounded by electromagnetic and hadronic calorimeters and a set of passive nuclear targets. An schematic view of the MINERνA detector is shown in figure 2.

The detector was built using 120 modules stacked along the beam direction. The modules are hexagonal in shape with an inner portion surrounded by an outer steel support frame. This frame is 56 cm wide and partially instrumented with scintillator and serves as a hadronic calorimeter. The content of the inner portion depends on the part of the detector the module is located: the tracker, calorimeters or nuclear targets.

Modules in the tracker region contain two layers of finely segmented scintillator planes in three posible orientations, 0° (vertical) and ±60°, to allow three dimensional track reconstruction. Each plane is composed of 127 strips of extruded polystyrene scintillator that are triangular in cross section (17.0 mm height × 33.4 mm base). The triangular shape ensures energy deposition in two strips per plane for most particle paths, improving the position resolution of the reconstruction. A 1.2 mm diameter green wavelength shifting fiber down the middle of each strip guides the generated light to a single pixel of a 64 anode PMT. Downstream the tracker, in the calorimeters region, 10 modules contain two additional lead sheets that are each 2 mm thick to provide electromagnetic calorimetry, and in the last 20

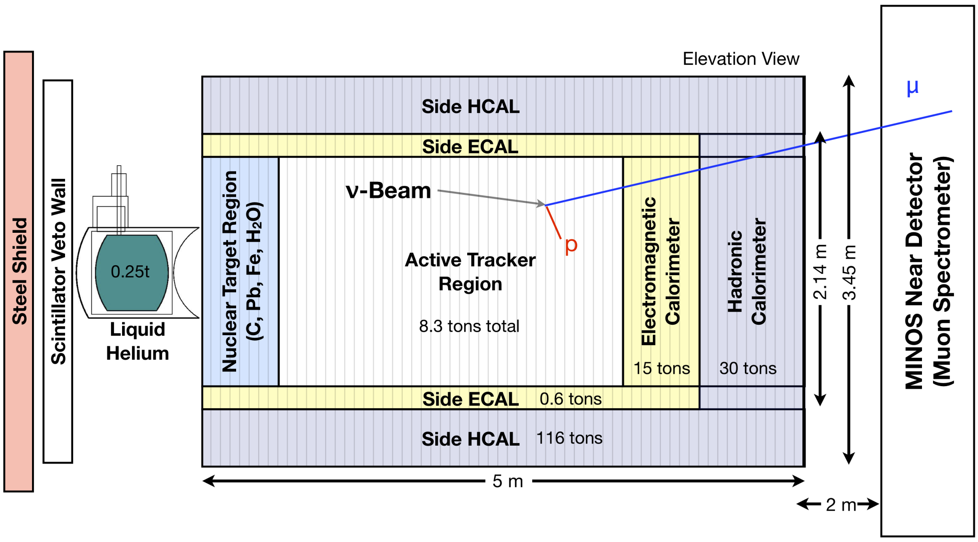

FIGURE 2. Schematic section view of the MINERνA detector. The beam enters from the left at a downward angle of about 3 degrees. The nuclear targets are located at the front of the detector followed by a fully-active, finely-segmented scintillator region. The electromagnetic and hadronic calorimeter portions of the detector are indicated

TABLE 1. Nuclear target masses and expected event rates in the MINERνA detector.

Target	Fiducial Mass*	ν_μ CC Events in 1.0E20 POT
Polystyrene Scintillator	6.43 tons	340k
Helium	0.25 tons	14k
Carbon	0.17 tons	9.0k
Water	0.39 tons	20k
Iron	0.97 tons	54k
Lead	0.98 tons	57k

* within a 90 cm cylinder.

modules one plane of scintillator per module has been replaced by a 1 inch thick steel plate to serve as a hadronic calorimeter. The nuclear targets region is upstream the tracker and involves five layers of pasive absorbers which are composed of varying combinations and thicknesses of iron, lead, graphite and water interspersed with active scintillator. A cryogenic liquid helium target was also installed upstream this region. The MINOS near detector sits 2 m downstream of MINERνA and provides momentum and charge measurements for those muons that leave MINERνA and enters the MINOS near detector. The total mass of the detector is about 200 tons, with most of the mass coming from the outer steel calorimeters. Table 1 shows the masses and the expected event rate of each nuclear material within a 90 cm radius cylinder along the axis of the detector. The total number of channels in the detector is 32,448.

DETECTOR PERFORMANCE

Most of the current analyses in the MINERνA experiment [5, 6, 7, 8] rely on the muon's energy and charge reconstruction using the MINOS near detector [1]. We have measured the efficiency to track and match a muon already

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[1] Muons that do not reach MINOS can also be analyzed, but no charge measurement is possible. MINERνA has presented at this conference, its first analysis in which final-state muons which do not reach MINOS are used [6]

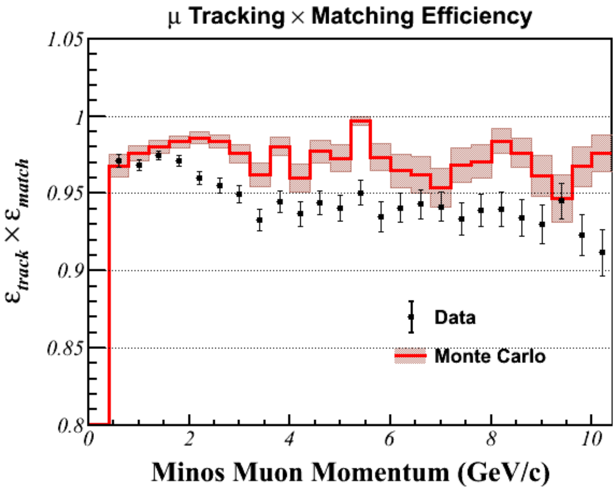

FIGURE 3. Tracking × MINOS matching efficiency of muons reconstructed in the MINOS near detector with origin in MINERνA's tracker region. The method consist of selecting muon tracks in MINOS that point back to MINERνA and then trying to find a track in MINERνA that matches the selected MINOS one.

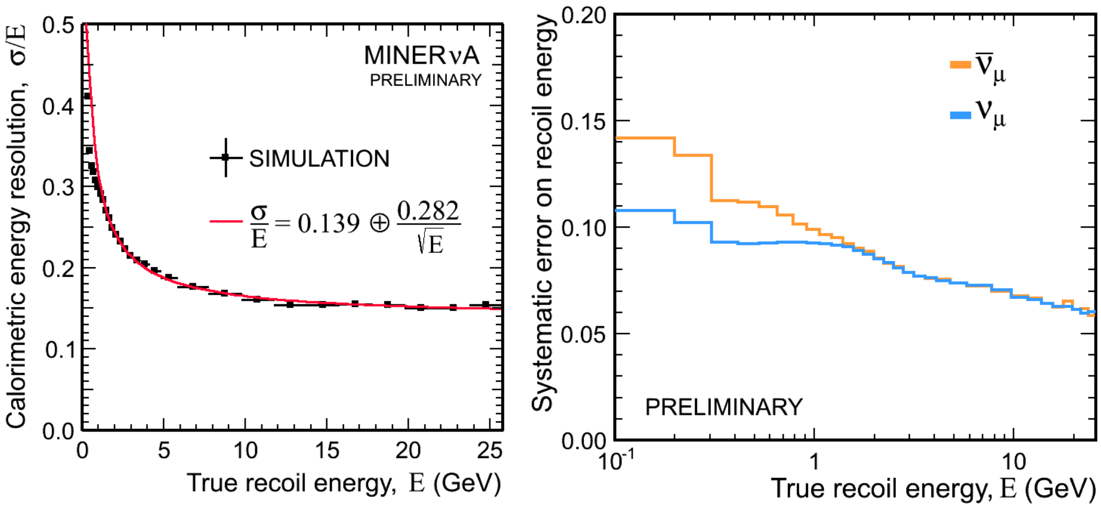

FIGURE 4. Calorimetric energy resolution as a function of true recoil energy (left). Systematic error on the calorimetric reconstruction of the recoil energy which is a convolution of single particle response uncertainties: mesons, 5%; electromagnetic ($e^{\pm}$,γ), 3%; protons, 10% and neutrons, 15%.

reconstructed in the MINOS near detector. This efficiency is > 90% and can be seen in figure 3 as a function of the measured momentum in the MINOS near detector. The principal sources of failures that decrease this efficiency are big showers obscuring the muon track, pile-up of events and detector's dead time. The Monte Carlo simulation has been overlaid with data to include the last two of these effects. The remaining difference between the data and Monte Carlo is being studied and has been taken into account as a systematic error in all the analyses.

The purpose of the fully-active, fine-grained detector design for MINERνA is to enable the identification of particular exclusive final states and to achieve excellent position and energy resolution when reconstructing neutrino interactions. To achieve these goals, a detailed chain of energy calibration steps are carried out for all data [9]. In particular, MINERνA's ability to measure calorimetric energy is shown in figure 4.

Furthermore, the NuMI beamline supplies a useful in situ calibration sample: neutrinos undergoing charged-current interactions in the rock surrounding the detector hall create muons which can enter the detector. Since the beginning

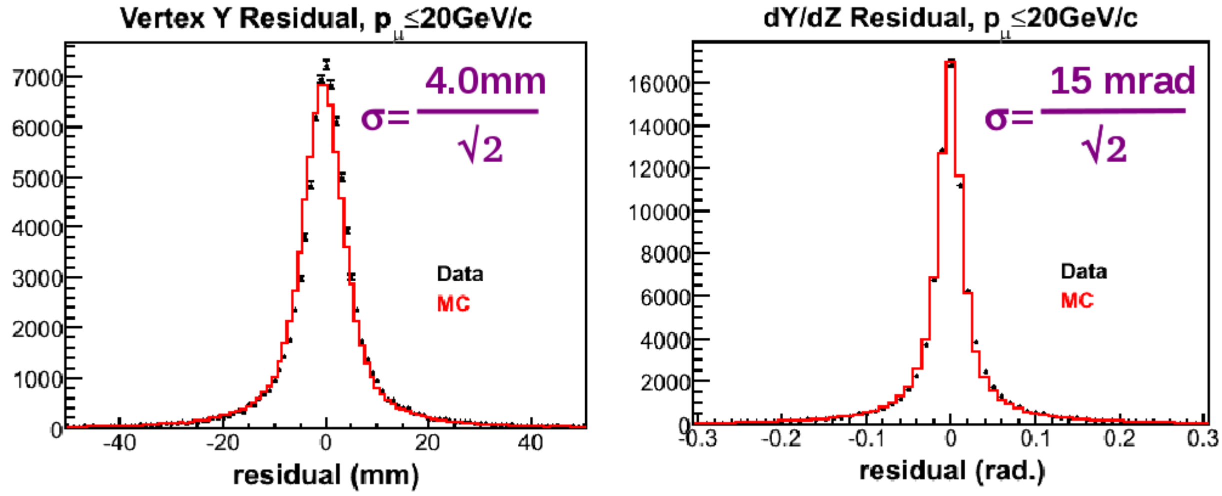

FIGURE 5. Track resolutions using "rock muons": Vertex (left) and track slope (right) residuals from split-rock muon tracks in tracker region.

of data-taking, well over 1 million of these "rock muons" have passed through MINERνA. This "rock muon" sample has been used to measure vertex and track slope residuals by breaking the "rock muon" track in two, re-run over each half the track fitting routine and compare the resulting new values. The result of this procedure can be seen in figure 5.

CONCLUSIONS

MINERνA has all its low-energy beam data and is very busy analyzing it. At the same time, MINERνA is getting ready to start running in a higher energy beam run in the summer 2013. Finally, the detector is working well and meeting its design specifications.

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