The MINERνA Experiment

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Abstract. The MINERνA experiment is a dedicated cross-section experiment whose aim is to measure neutrino cross sections for inclusive and exclusive final states on several nuclei. The detector is fully commissioned and began running in March 2010. As a dedicated cross-section experiment, MINERνA has a particular need to know the incident neutrino flux: both the absolute level and the energy dependence. In these proceedings we describe the MINERνA detector, give an update on the experimental status, and discuss the means to determine the neutrino flux.

Keywords: Neutrino mass and mixing,
PACS: 14.60Pq

INTRODUCTION

The MINERνA experiment was proposed to improve our knowledge of neutrino-nucleus cross sections. Although the field of neutrino oscillation physics is making significant advances in the determination of the neutrino mass and mixing matrices, the specific processes that provide the signal and background channels for oscillation experiments are often poorly measured, and there are inconsistent results from various experiments. Furthermore, an important feature of oscillation experiments is the requirement that oscillation probabilities be measured for several neutrino energies. This feature requires a robust model of the relationship between the initial neutrino energy as it enters the detector and the final visible energy in that detector. The model must incorporate the effects of the final state particles interacting inside the nucleus where they were created. Such interactions are currently very poorly constrained by neutrino data.

Previous neutrino cross section experiments were plagued by low statistics and by significant uncertainties on the incoming neutrino flux. Current data, from SciBooNE[1], MiniBooNE[2] and NOMAD [3], have high statistical precision yet show inconsistent results between the low and high energy regimes.

MINERνA is designed to significantly improve our understanding of neutrino interactions. The detector is placed in the NuMI Near Detector Hall, which has the highest neutrino flux in the world. This will provide excellent statistical precision even for MINERνA's modest detector size. The flexibility of the NuMI beamline means that MINERνA should be able to achieve new precision on the flux determination through an approach which involves making neutrino measurements in several different neutrino beam configurations.

In the following section we describe the NuMI beamline that makes this experiment possible, as well as the techniques MINERνA plans to use to measure the NuMI flux. We will describe the MINERνA detector itself, followed by a description of the current detector performance and run plan.

NUMI NEUTRINO BEAMLINE

Neutrinos are produced in the NuMI beamline [4] by focusing 120 GeV protons from Fermilab's Main Injector on a graphite target to produce charged pions and kaons. Those mesons are focused by a two-horn system, which is followed by a 675m long helium-filled decay pipe. A hadron absorber is located at the end of the decay pipe to stop protons which did not interact and the produced hadron showers. A monitoring system for hadrons is located upstream and for muons is located downstream of the absorber, which enable additional beamline measurements. The beamline normally accepts a proton power of roughly 310 kW, and accumulates 3-4×10^{20} protons on target (POT) per year.

The unique design of the NuMI beamline gives MINERνA the ability to change the incident neutrino flux by significantly modifying the focusing geometry in a matter of days. By increasing the relative distance between the production target and the first focusing horn, the longitudinal momentum distribution of pions that are best focused by the horns increases. Figure 1 shows three different transverse and longitudinal momentum distributions for the focused pions in three different beamline configurations.

An alternate (and less unique) way to modify the incident neutrino flux is to change the currents in the horns. By reducing the current, the transverse momentum distribution of pions that are best focused by the horn system is reduced.

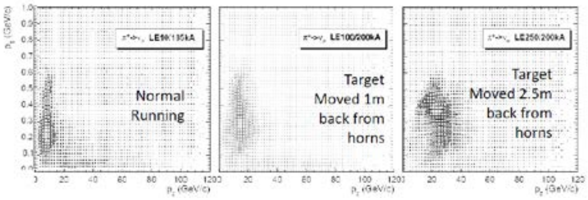

FIGURE 1. Transverse and longitudinal distributions of the focused pions for three different beamline geometries that are accessible in NuMI.

MINERνA plans to take neutrino data in at least five different configurations to determine if the energy dependence of the quasi-elastic cross-section measured in each configuration remains constant. This ensures that the hadron production model that predicts the flux is robust. The absolute flux level is constrained by comparing the total number of inclusive charged current events collected to a prediction that is anchored to the well-measured total cross section at high energies. This run plan is expected to require a total of 0.9 × 10^{20} POT, of which a sixth had been collected at the time of the NuFact10 conference.

Another way to test the model of hadron production is to look at the responses of the muon monitors, which sample muons produced coincident with the neutrinos. Because the muon monitors measure only the total muon rates after different amounts of shielding, they provide a less stringent constraint on the flux model than the neutrino spectrum. However, because the muon rates per spill are extremely high, a much larger set of magnet currents can be sampled because each current setting requires only a minute or two. At the time of the NuFact10 conference, there were data taken for a broad range of horn currents, for two different target positions.

THE MINERνA DETECTOR

The MINERνA detector consists of roughly 8.3 tons of fine-grained scintillator that is surrounded by some 170 tons of both lead-scintillator (electromagnetic) and steel-scintillator (hadronic) calorimetry to ensure event containment. The central detector has a fiducial mass of approximately 3 tons and is about 170 cm in diameter and 260 cm long.

The base element of the detector is a triangular-shaped scintillator strip with a 3.3 cm base and 1.7 cm height. The readout is done via a wave-length shifting fiber into a 64 anode PMT. The strips are in nested rows so that as a track passes through a plane there are usually two strips that scintillate. The light sharing between neighboring scintillator strips is then used to achieve better than 3.5 mm position resolution for tracks normal to the plane. The strips are formed into hexagonal-shaped scintillator planes oriented either vertically or ±60 degrees from the vertical to allow for stereo tracking. The light levels on the strips are high enough to be used for particle identification for tracks that range out in the MINERνA scintillator planes.

The side electromagnetic (EM) calorimeter consists of 2 mm thick lead collars that cover the outer edges of each scintillator plane. The outer hadronic calorimeter is instrumented using rectangular scintillator bars located in slots cut into the steel. The downstream EM calorimetry consists of 20 alternating planes of 1.7 cm thick scintillator planes and 2 mm thick lead, and the downstream hadronic calorimetry consists of 20 alternating planes of 1.7 cm thick scintillator planes and 2.54 cm thick steel. The entire MINERνA detector sits in front of the MINOS Near Detector which serves as a muon spectrometer [5].

Upstream of the central detector are solid planes of lead, iron, and carbon that serve as different targets for the neutrino beam. The geometry of those targets is designed so that acceptance differences between the different kinds of nuclei are minimized. In this way the nuclear effects can be measured with a minimized systematic bias. The experiment is also in the process of building two liquid targets: a water target, which will be inserted into the upstream nuclear target region, and a cryogenic helium target placed upstream of the current detector. A veto system upstream of the helium target will be installed to remove backgrounds from muons entering the front of the detector.

The event samples will be unprecedented for such a fine-grained detector. Of the 9 million events expected to occur in the scintillator, about 800 thousand will be quasi-elastic events. Another 1.7

million events will be resonance production, with the remaining events filling in the gap between resonance production and deep inelastic scattering. These statistics correspond to an exposure of 4×10^{20} POT in low energy running and 12×10^{20} POT in medium energy running. Because of the detector's fine granularity the experiment will be able to map out not only the total cross sections for these different channels, but also differential distributions so that the underlying dynamics can be understood. In addition to the events in the central scintillator tracker region, there are significant statistics in the nuclear target regions, as shown in Table 1.

TABLE 1. MINERνA nuclear targets and associated Charged Current (CC) event statistics in 4×10^{20} POT in low energy running and 12×10^{20} POT in medium energy running (acceptance not included).

Target	Fiducial Mass (tons)	CC Events (million)
Scintillator	3	9
Helium	0.2	0.6
C (graphite)	0.15	0.4
Iron	0.7	2.0
Lead	0.85	2.5
Water	0.3	0.9

RUN PLAN AND DETECTOR PERFORMANCE

Because the NuMI beamline was already operating during detector construction, the first 55% of the MINERνA detector started taking data in November 2009 while the remaining 45% of the detector was being built. During this time the NuMI beamline was running in anti-neutrino mode, and MINERνA accumulated roughly 0.8×10^{20} protons on target, half of which was with steel and lead nuclear targets in the beam. Installation of the full detector was completed in March, 2010 as running in the neutrino mode began. Between March and this writing a total of 1.32×10^{20} POT have been accumulated in neutrino mode, or about 25% of the total planned Low Energy exposure. Part of preparing for NOvA involves a long shutdown to upgrade the NuMI beamline and Main Injector, and after that shutdown MINERνA will run concurrent with NOvA with an expected exposure of 12×10^{20} POT in the Medium Energy neutrino mode.

The detector is functioning well and event displays show clear detached vertices and stopping ionization losses. Particle identification algorithms already show promise of distinguishing protons from pions and muons, and software development to do complete event reconstruction in this complex geometry is progressing rapidly. Figure 2 shows three event displays of one of three tracking views from events originating in the nuclear targets.

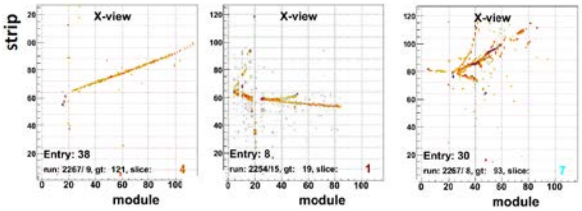

FIGURE 2. Three different neutrino interactions that are nuclear target candidates, for one of three tracking views.

CONCLUSIONS

The MINERνA experiment is now running and has completed 25% of its full Low Energy run. There are various techniques planned for understanding the flux, including taking neutrino data at several different beam configurations. The experiment has gotten a first glimpse of two of the six configurations, and completed four horn current scans.

Because of its exclusive final state reconstruction capabilities MINERνA can provide the much needed input for current and future oscillation experiments. The inclusive final state measurements and comparisons of nuclear effects across as many states as possible will provide new insights into neutrino-nucleus scattering.

ACKNOWLEDGEMENTS

This work was supported by the Fermi National Accelerator Laboratory, which is operated by the Fermi Research Alliance, LLC, under contract No. DE-AC02-07CH11359

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