Charged Current Neutrino Scattering in MINERvA

R. D. Ransome[a,b]

[a]*Rutgers, The State University of New Jersey*
Piscataway, NJ
[b]*On behalf of the MINERvA collaboration*[1]

Abstract: MINERvA is a neutrino detector in the NuMI beamline of FNAL, with a central fully active scintillator detector and targets of iron, lead, carbon, water, and LHe upstream of the central detection region. MINERvA began operations in late 2009 with a partially compete detector and has been fully operational since early 2010. Data have been taken with both neutrino and anti-neutrino beams. The objective is to measure inclusive and exclusive cross sections for neutrino-nuclear interactions with unprecedented statistics and detail off a wide range of nuclear targets. We will present preliminary results for ratios of Pb/Fe/scintillator inclusive and charged current quasi-elastic scattering kinematic distributions.

Keywords: Neutrino scattering, neutrino quasi-elastic scattering, neutrino cross section
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THE MINERVA EXPERIMENT

MINERvA is a high resolution neutrino cross section experiment in the NuMI beam line at Fermi National Accelerator Laboratory (FNAL) upstream of the MINOS[2] near detector. The goal of the experiment is to measure exclusive and inclusive neutrino cross sections in the energy range of 1-20 GeV on several nuclei with greatly improved precision over previous experiments.

A schematic of the MINERvA detector is shown in Fig. 1. The detector consists of five main regions: the fully active central detector, the upstream nuclear targets, a downstream electromagnetic and hadron calorimeter, and a surrounding electromagnetic and hadron calorimeter.

The central detector serves as both the primary target and the tracking detector. It consists of planes of triangular plastic scintillator strips arranged in three orientations. Each strip is 1.7 cm high and 3.3 cm wide, and is read out via a wavelength shifting fiber. Light sharing between the strips gives a position resolution of approximately 3 mm. The light yield is approximately 5.0 photo-electrons/MeV, giving about 13.5 photo-electrons/plane for minimum ionizing muons.

The downstream electromagnetic calorimeter consists of alternating planes of 2 mm thick Pb and scintillator planes of the same form as in the central detector. The hadron calorimeter is similar, with 2.5 cm planes of steel instead of Pb. The side electromagnetic calorimeter consists of 2 mm thick Pb plates between every other tracking plane in the outer region of the central detector. The side hadron calorimeter consist of planes of steel with scintillator strips embedded.

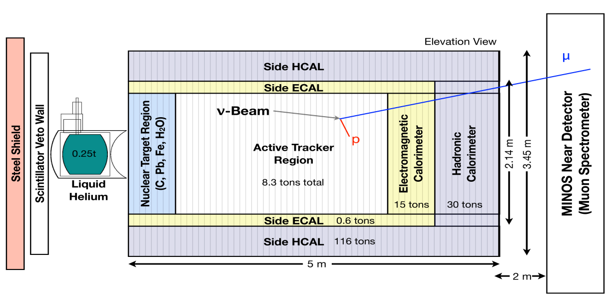

FIGURE 1. Schematic view of the MINERvA detector.

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Upstream of the central detector are planes of passive targets, with two planes 2.5 cm thick of mixed Fe/Pb, one plane with 2.5 cm thick Fe/Pb and 7.5 cm C, a solid plane of Pb 0.75 cm thick, and a mixed plane of Fe/Pb 1.5 cm thick. The mixed Fe/Pb planes are split with part of the plane being iron and part of the plane being lead, such that the total mass is approximately equal. Tracking planes are placed between each plane of passive targets. Planned for fall 2011 are a 15 cm water target to be installed downstream of the Fe/Pb/C target and a tank of liquid ^{4}He about 1 m in diameter will be installed upstream of the main detector. Figure 2 shows a schematic of the nuclear target region along with the placement of carbon, lead, and iron in the various targets.

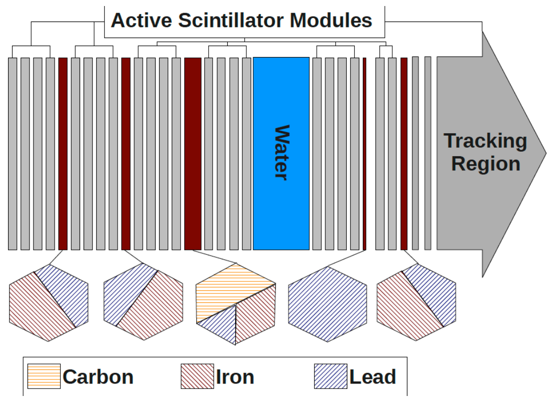

FIGURE 2. Expanded view of the upstream nuclear target region.

Charged current events originating in the central detector are fully contained, except for the muon, for neutrino energies less than about 10 GeV. The MINOS detector gives both muon energy and charge for forward going muons. The threshold energy for a muon to exit MINERvA and be tracked into MINOS is about 2 GeV. There is good angular acceptance for muons with scattering angles below 10 degrees, with acceptance dropping to zero for scatters greater than about 20 degrees. For particles stopping in MINERvA particle identification can be determined from the dE/dX, but there is no charge determination.

MINERvA began operations with about half of the detector installed in October, 2009, and took data with the anti-neutrino beam until March, 2010. Installation of the full detector was completed in March, 2010. Running since that time has been divided between the neutrino mode, anti-neutrino mode, along with a few special settings intended to help determine the neutrino flux. The analysis to date has concentrated on those events which have a muon identified in MINOS. We will discuss here two of the first analyses: the A dependence of the inclusive cross section and quasi-elastic anti-neutrino cross section.

INCLUSIVE NEUTRINO SCATTERING

One of the first measurements we have studied is the nuclear dependence of the inclusive cross section, and in particular the ratio of lead to iron. This requires a precise determination of the actual target nucleus in a given interaction. The transverse resolution of the detector is quite good, and Monte Carlo simulations indicate that fewer than 0.1% of vertices will be tracked to the wrong target. The longitudinal (z) resolution is less precise and depends on the number of final state particles and how far they travel. Because there is no tracking in the Fe/Pb targets, it is not possible to tell if events with a single muon in the final state originated in Pb/Fe target or in the downstream tracking detectors. Monte Carlo studies of the background do indicate that it is substantial. Figure 3 (left) shows a stacked histogram with the true vertex location for events with a vertex determined to be in the iron or immediately upstream or downstream of the iron. Subtraction of those events can be done by determining the event rate in scintillator from the tracking detectors, and is currently underway. Because the acceptance into MINOS of muons from the Pb and Fe targets is not identical, an acceptance correction must be made to make the ratio. This has been checked by taking regions of scintillator with the same areas as the Fe/Pb just downstream of the target, and comparing with Monte Carlo estimates. There is good agreement between data and Monte Carlo, as shown in Fig. 3 (right). Analysis of the data to determine the Pb/Fe inclusive ratio is still underway.

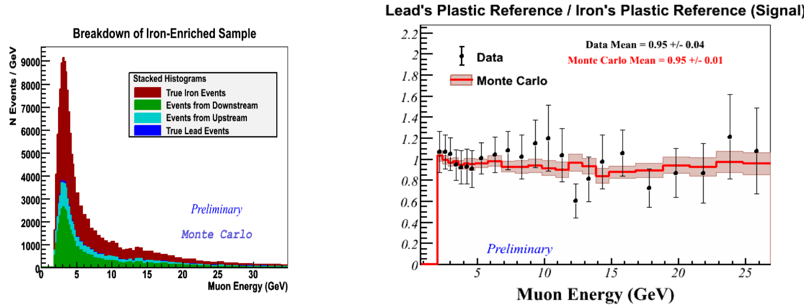

FIGURE 3. Ratio of inclusive muon rates for lead-like and iron-like regions of the active target.

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ANTINEUTRINO QUASI-ELASTIC SCATTERING

Quasi-elastic scattering is the dominant interaction cross section for neutrino energies below one GeV and a significant part of the cross section for energies up to 5 GeV, and gives a nearly constant cross section at higher energies. The quasi-elastic cross section is the best method to determine the Q^2 dependence of the axial form factor of the nucleon. This reaction has gained attention recently because measurements by MiniBooNE[3] and SciBooNE[4] appear to give significantly different values of the axial mass, of about 1.35 GeV, than older and higher energy measurements which average about 1.05 GeV.

We have measured the anti-neutrino quasi-elastic scattering in the first running period with the partial detector. Figure 4 shows the Q^2 distributions with the nominal absolute normalization, and compared to a Monte Carlo simulation of the components of the measured cross section. The preliminary data are in general agreement with an axial mass of 1.05, but appear to give a smaller cross section than predicted with the nominal neutrino flux. However, studies of the absolute neutrino flux, as well as further analysis of the scattering data, are still underway, so we cannot draw any conclusions on the discrepancy at this time.

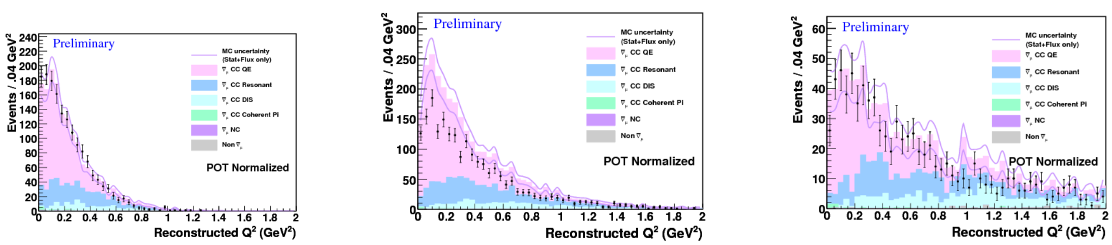

FIGURE 4. Anti-neutrino quasi-elastic scattering events as a function of Q^2, divided by the inferred neutrino energy: left < 3 GeV, middle 3-5 GeV, right 5-10 GeV.

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ACKNOWLEDGEMENTS

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