

## Preliminary Results from the MINERvA Experiment

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The MINERvA experiment, operating since 2009 in the NuMI neutrino beam line at Fermilab, has collected neutrino and antineutrino scattering data on a variety of nuclear targets. The detector is designed to identify events originating in plastic scintillator, lead, carbon, iron, water, and liquid helium. The goal of the experiment is to measure inclusive and exclusive cross sections for neutrino and antineutrino with much greater precision than previous experiments. We present preliminary kinematic distributions for charged current quasi-elastic scattering and other processes.

*The 2011 Europhysics Conference on High Energy Physics-HEP2011  
Grenoble, Rhône-Alpes*

*July 21-27 2011*

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## 1. Introduction

The discovery of neutrino oscillations from studies of solar and atmospheric neutrino interactions led to the building of extremely intense accelerator-based neutrino beams in order to study the oscillation parameters in detail. These intense neutrino beams provide improved statistical precision of the oscillation parameters, and also enable high precision on neutrino interaction cross sections. The MINERvA experiment was designed to take advantage of the NuMI beamline at Fermilab in order to provide information on those neutrino interactions which limit the systematic errors of oscillation experiments, and also to provide a weak probe of the structure of the nucleon and the nucleus.

The broad energy range of the NuMI neutrino beam will allow MINERvA to study neutrino interactions from about 1 GeV to 20 GeV. The current setting of the beam line is the one used for the MINOS experiment, and has a peak energy of about 3 GeV. The peak energy will be increased to about 8 GeV in 2013 for the NOvA experiment. The combination of lower and higher energy settings will give MINERvA high statistics measurements over a broad range of energies.

The current focus of MINERvA is to understand the various components of both the neutral and charged current cross sections: by designing a fine grained detector with excellent tracking and good hermeticity, exclusive channels can be seen and measured with high precision. By incorporating several different target materials into the detector design, direct comparisons of neutrino interactions as a function of atomic mass can also be made.

## 2. MINERvA Detector

The MINERvA Detector<sup>1</sup> consists of an active tracker volume that is made of scintillator-doped polystyrene read out by wavelength shifting fibers and multi-anode phototubes. The active tracker volume is surrounded on the sides and downstream region by an electromagnetic calorimeter (scintillator/lead layers), followed by hadronic calorimeters (scintillator/steel layers). The MINOS near detector sits 2 m downstream of the MINERvA detector, and provides muon momentum and charge measurements for those muons that leave the MINERvA detector and can be reconstructed in MINOS. The upstream region of the detector contains five layers of passive targets which are composed of varying combinations and thicknesses of iron, lead, and graphite. A liquid water target is planned for the upstream region of the detector. A liquid helium target was installed upstream of the detector in the summer of 2011. The total mass of the detector is about 200 tons, with most of the mass coming from the outer steel calorimeters. The active mass in the tracker region is 8.3 tons, with the fiducial mass significantly less than that. The total number of channels in the detector is 32,448.

## 3. Quasi-Elastic Analysis

The quasi-elastic interaction is one of the simplest charged current neutrino interactions, yet there is currently a discrepancy between lower and higher energy measurements of this

process, as measured by SciBooNE<sup>2</sup> and MiniBooNE<sup>3</sup> at about 0.5-1.5 GeV<sup>2</sup>, and as measured by NOMAD<sup>4</sup> at energies ranging from 6-50 GeV. The two different regimes used different neutrino beamlines, detectors, and analysis techniques, and there are several theories for this discrepancy. MINERvA, with its intermediate energy range of 1-20 GeV and fine-grained detector will be able to provide measurements of this cross section with various final state selections, and should shed light on the source of the discrepancy between low and high energy measurements. The distribution of the square of the four-momentum transferred in the interaction ( $Q^2$ ) also provides input to the nature of the interaction.  $Q^2$  is a more robust variable than neutrino energy to consider in the presence of flux uncertainties, since the  $Q^2$  distribution should change only slowly as a function of incoming neutrino energy.

The analysis presented at this conference uses the earliest data that MINERvA took, which was when the NuMI beamline was providing anti-neutrinos for the MINOS experiment and only the downstream region of the detector was commissioned. The anti-neutrino Quasi-Elastic signature is particularly straightforward: because the final state particles are a neutron and a muon, the analysis need only identify a positively charged muon and the absence of measured energy more than 5 cm from the muon track. Neutrons in the final state may deposit some energy away from the muon but the cut described below takes this into account. Quasi-elastic events are identified simply by the fiducial cuts on the interaction vertex, the requirement of a positively charged muon as tracked by the MINOS detector, and the absence of any extra recoil energy that is away from the muon. The recoil is dependent on the momentum transferred in the event, so a  $Q^2$  dependent cut was made to reduce the non-quasi-elastic background<sup>5</sup> without removing possible signal events.

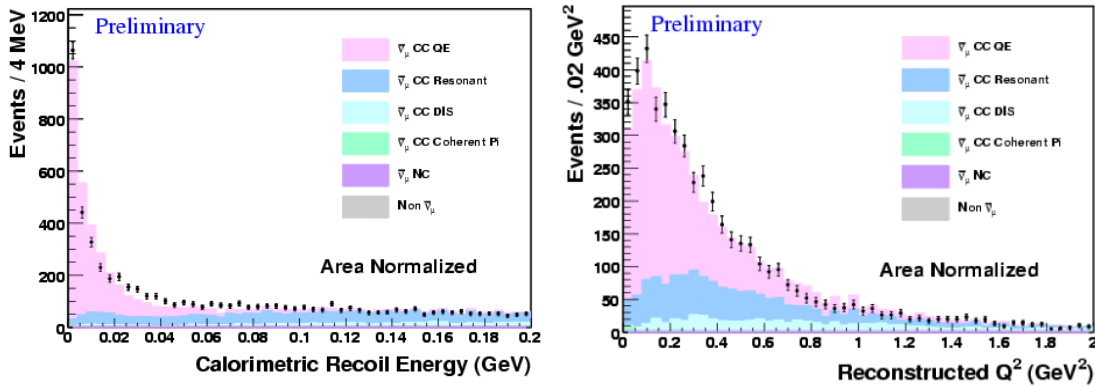


Figure 1 shows (left) the calorimetric recoil energy away from the muon that is located in the charged current event candidates, and (right) the reconstructed  $Q^2$  distribution of the remaining events after a cut on calorimetric energy is made. Both plots are area normalized and only the statistical uncertainties are shown.

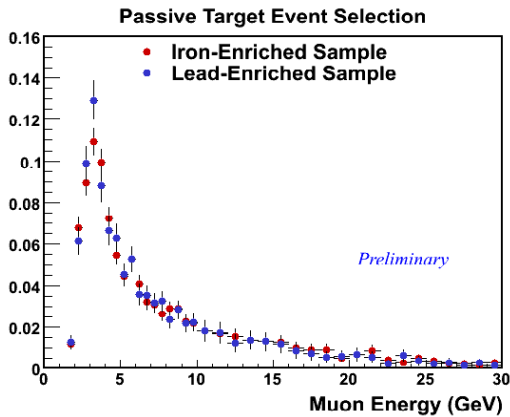
#### 4. Understanding the Neutrino Flux

In order to turn the kinematic distribution shown in the previous section into an absolute cross section measurement, the experiment requires knowledge of the absolute neutrino flux that is incident on the detector. The NuMI beamline is unique among neutrino beams in that it can be tuned to provide fluxes of different neutrino energies<sup>6</sup>. Possible modifications either change the relative position between the target and the focusing horns, or change the current in the

horns. Taking data in different beam tunes allows the study of different regions of the parent pion kinematics. Hadron production models can then be constrained to match the observed distributions. These measurements may test the model using different neutrino interactions, for example, by using both quasi-elastic and inclusive event rates. As of the EPS 2011 conference the experiment had taken data in a total of three different target positions, and two different horn currents for the nominal target position data.

## 5. Nuclear Target Analysis

By taking data simultaneously on several different materials, MINERvA is uniquely suited to probe nuclear effects with a minimum of systematic errors. At the time of the EPS 2011 conference the detector contained targets of graphite, iron, lead and scintillator (CH), and in the fall of 2011 a helium target was commissioned. There are also plans to take data on a water target. The  $\nu_\mu$  charged current (CC) event rates on those targets, assuming  $4 \times 10^{20}$  protons on target (POT) are shown in Table 1.



Target	Fiducial Mass (tons)	$\nu_\mu$ CC event rates/ $4 \times 10^{20}$ POT
Plastic (CH)	6.43	1363k
Helium	0.25	56k
Carbon	0.17	36k
Water	0.39	81k
Iron	0.97	215k
Lead	0.98	228k

Figure 2 shows the muon momentum distribution for neutrino charged current events that are consistent with starting in the most downstream nuclear target of MINERvA, which has regions of both lead and iron. The distributions have been normalized to equal areas. Table 1 shows the event rates expected in different nuclear targets, assuming  $4 \times 10^{20}$  POT accumulated in the current (Low Energy) Configuration.

The first MINERvA study of nuclear effects compares inclusive charged current neutrino event rates as a function of muon energy in carbon, lead and plastic. Figure 2 shows the neutrino charged current event candidates as a function of muon energy for events that are consistent with starting in the most downstream nuclear target<sup>7</sup>, which contains both iron and lead. There is also a small contamination of events originating in the plastic scintillator just downstream of the nuclear target as well. This target represents about a fifth of the lead and iron in the nuclear target region, and the data corresponds to roughly a quarter of the total protons on target planned for the experiment.

## 6. Conclusions

The MINERvA experiment is currently taking data in the NuMI beamline. Installation and commissioning of the full detector was completed in March 2010. As of the EPS 2011 conference the experiment had collected about a third of the low energy beam that was planned,

and there are several different analyses underway, a few of which have been presented here. In the current beamline configuration MINERvA will focus on exclusive final states such as the quasi-elastic channel shown here, and nuclear effects on total and exclusive event rates. When NOvA begins running the NuMI beamline will operate in a higher energy configuration on axis, and in that era MINERvA will be able to focus its efforts on differential cross sections and structure functions on several different nuclear targets.

## 7. 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, including the MINERvA construction project, with the United States Department of Energy. Construction support also was granted by the United States National Science Foundation under NSF Award PHY-0619727 and by the University of Rochester. Support for participating scientists was provided by NSF and DOE (USA) by CAPES and CNPq (Brazil), by CoNaCyT (Mexico), by CONICYT (Chile), by CONCYTEC, DGI-PUCP and IDI-UNI (Peru), and by Latin American Center for Physics (CLAF). Additional support came from Jeffress Memorial Trust (MK), and Research Corporation (EM).

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