The MINERvA Experiment - A Status Report

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Abstract. MINERvA (Main INjector ExpeRiment v-A) is a few-GeV neutrino-nucleus scattering experiment, stationed in the high intensity NuMI (Neutrinos at the Main Injector) beam line at Fermilab. It has been taking data since November 2009 and completed construction in March 2010. MINERvA aims to make precision measurements of low energy neutrino interactions, both in support of neutrino oscillation experiments and as a pure weak probe of the nuclear medium. For this, the experiment employs a fine-grained, high-resolution detector. The active target region is composed of plastic scintillator. There are additional nuclear targets of helium, carbon, iron, lead and water placed upstream of the fully active region. These targets will be used for measuring the A-dependence of nuclear effects in neutrino scattering. We present our preliminary results, from analyses probing the nuclear effects on charged current events in the iron, lead and plastic of the detector to results from analyses studying charged current quasi-elastic scattering on the active plastic target using both neutrinos and anti-neutrinos.

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INTRODUCTION

Neutrino cross-section uncertainties are an important systematic for precision measurements of oscillation parameters (e.g. CP violation) in the neutrino sector. Oscillation measurements use dense nuclear targets for achieving high statistics, thus necessitating a thorough understanding of neutrino-induced interactions in nuclear media. The interaction probabilities of neutrinos with matter are an important input for measurements involving neutrinos as probes for studying their oscillation, matter effects, nuclear effects, etc. Quasi-elastic interactions provide clear signals for neutrino oscillation measurements because of the simple approximate determination of the neutrino energy based on the outgoing muon angle and momentum. However, distributions of observables ($E_{\text{lepton}}$, $\theta_{\text{lepton}}$) can be modified by the nucleus. Searches for CP violation will involve single-percent level measurements of oscillation probabilities, both for neutrinos and anti-neutrinos [1]. Hence interaction uncertainties can affect CP sensitivity.

Neutrinos provide a weak-force probe of nucleon structure and provide complementary information when compared to charged lepton scattering. The ability of neutrinos and antineutrinos to “taste” different flavors of quarks can help isolate parton distribution functions. Nuclear effects like the EMC effect have been studied in detail via electron scattering experiments. However, nuclear effects using neutrinos as a probe have not been studied with high statistics samples. With further theoretical input we may disentangle a challenging mix of multiple nuclear effects e.g. np-nh [2, 3, 6] and Final State Interactions (FSI).
**CHARGED CURRENT (CC) INCLUSIVE ANALYSES**

Charged current (CC) inclusive analyses $\nu_\mu + N \rightarrow \mu^- + X$ provide the basis for understanding other event topologies in the detector. They serve as references when comparing their kinematic and physics distributions to those from more exclusive topologies. This is pertinent for understanding reconstruction quality, detector performance, efficiency and acceptance effects, etc.

The event selection criteria requires the primary muon track originating in the MINERvA detector [4] and entering the MINOS detector [5]. The track should be reconstructed well and matched between both detectors. The interaction vertex is required to be reconstructed inside the fiducial volume of the detector. The recoil in the event, other tracks and showers, is denoted by $X$.

Kinematic distributions obtained from CC events originating in the scintillator tracker region of the detector show good agreement between data and Monte Carlo, given the current large systematic uncertainties on the neutrino flux. This indicates quality reconstruction, calibration and well-understood detector performance.

**Cross-section Ratios for the Nuclear Targets with Neutrinos**

The goal of the first analysis to measure nuclear effects aims to measure interaction cross section ratios between the passive carbon, iron, and lead targets. The event selection criteria are similar to those of the CC Inclusive analysis on scintillator (above). The reconstructed event vertex should be consistent with the nuclear target. The first (current) version of this analysis measures ratios of the target cross sections on iron and lead to corresponding "control" targets of a similar mass and shape of scintillator, for purposes of cancelling the flux and acceptance systematics. Events that actually originate in the scintillator plane downstream of the passive nuclear target are estimated using data from the control targets.

Figure 1 shows (left) the uncertainties on the signal events for the iron target and (right) those on the double ratio of lead to iron targets, each normalized by control targets. The total error is reduced from 20% to 5% by this double ratio technique. This is very promising and future versions of this analysis will estimate the cross-section ratios for the various nuclear targets.

**CHARGED CURRENT QUASI-ELASTIC (CCQE) ANALYSES**

Charged-current quasi-elastic (CCQE) scattering is the dominant signal channel in next generation of oscillation experiments. The channels are defined by $\nu_\mu + n \rightarrow \mu^- + p$ and $\bar{\nu}_\mu + p \rightarrow \mu^+ + n$ for neutrinos and anti-neutrinos, respectively.
FIGURE 1. We compare the sources of uncertainty on the nuclear target cross-section measurement between a single target (left) and a ratio of two targets (right). Note the different vertical scales.

CCQE Interactions in the Tracker Region with Anti-neutrinos

The event selection criteria requires the following:

1. A primary anti-muon track originating in MINERνA and entering MINOS. The track should be reconstructed well and matched between both detectors.
2. An interaction vertex inside the fiducial tracker region of the detector as configured between November 2009 and March 2010 (fiducial mass = 2.6 tons).
3. No more than one shower-like activity region, since the final neutron might interact.
4. An upper limit on allowable recoil energy over 10 cm away from vertex region as a function of $Q^2$, to select more CCQE-like events.
5. A reconstructed neutrino energy less than 10 GeV.

The background estimation technique for this analysis used sidebands of events with high recoil energy to constrain backgrounds to the low recoil CCQE events for different bins in $Q^2$.

Figure 2 shows the resulting flux-integrated differential cross-section in $Q^2$ as a function of generator level $Q^2$, compared to NuWro, a generator [7] with several different physics models. The data points depict the statistical and systematic uncertainties. In Figure 3 (left) we show a data-Monte Carlo comparison of the event rate ($dN/dQ^2$) vs. $Q^2$ in two different energy bins before background subtraction.

CCQE Interactions in the Tracker Region with Neutrinos

The complimentary analysis of CCQE interactions that involve a neutrino in the initial state is also underway at present and will soon yield cross-section results. The proton
FIGURE 2. A comparison of MINERνA data to the NuWro Event Generator [7] under several different physics models. The effective MEC model is from [8].

FIGURE 3. A comparison of the CCQE event rate as a function of $Q^2$ for low and high energy (left) anti-neutrino and (right) neutrino events.

produced in the final state is more likely to interact, hence the event selection allows for as many as two shower-like activity regions. The fiducial tracker region for this analysis corresponded to the detector after construction was complete (5.4 tons). Figure 3 (right) shows the data-Monte Carlo comparison of the event rate $(dN/dQ^2)$ vs. $Q^2$ in the same two energy bins as was shown above, prior to background subtraction.
CONCLUSIONS

The MINERvA experiment is making significant progress towards its first cross section results. At this conference the first extracted differential cross sections of antineutrino charged current quasi-elastic scattering were shown, with comparisons to different physics models. The current uncertainties in the cross section result are too large to allow discrimination between models. However, with the addition of the remaining statistics that were collected and improvements on the flux uncertainties this will provide strong constraints. The neutrino quasi-elastic event sample was shown to already have significant statistics (1/4 of the total exposure was shown), and again the resulting cross sections on the full data set will give unique insight into this process in a new energy regime. MINERvA’s nuclear target analysis technique was demonstrated to have systematic errors on cross section ratios at only the 5% level for neutrinos above 2 GeV. With the additional statistics of the full exposure and the analysis of all of the passive targets, statistical uncertainties are expected to be close to the systematic uncertainties. Future work will include exclusive final state analyses containing pions, as well as eventual extraction of structure functions on several different nuclei.

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