Neutrino Deep Inelastic Scattering with the MINERνA Experiment

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The MINERνA experiment, located in the NuMI beam at Fermilab, is in a position to significantly add to the world knowledge of DIS. Current neutrino DIS data contains poorly understood nuclear effects. In order to investigate these nuclear effects, MINERνA has installed nuclear targets of C, Fe and Pb in the same beam to measure the Fe/C and Pb/C ratios of DIS cross sections. While many uncertainties due to neutrino flux will cancel out in these ratios, MINERνA has developed three independent studies to better measure and constrain neutrino flux for total cross section measurements. MINERνA has begun a charged current inclusive neutrino analysis, which will serve as a basis as a more complete DIS analysis.

1 Motivation

Data from neutrino deep inelastic scattering (DIS) experiments are very helpful in forming a complete set of parton distribution functions, or pdfs. Neutrino DIS measurements probe a complementary set of quark flavors from those probed in charged lepton DIS interactions. Unfortunately, anomalies in current charged lepton and neutrino DIS datasets prevent the creation of global pdfs. For example, recent analysis from CTEQ suggests the nuclear effects in neutrino-nuclear deep inelastic scattering seen by the NuTeV experiment may be quite different in magnitude and shape from charged lepton DIS [1]. However, the NuTeV result is a statistics limited sample, and only engaged one type of nucleus. High statistics, multi-Z neutrino DIS measurements are needed to resolve this apparent discrepancy, paving the way for the full characterization of pdfs. MINERνA will provide these high statistic neutrino DIS measurements, across a wide range of targets.

2 Beamline Description and Flux Measurement

The NuMI neutrino beam, located at Fermi National Accelerator Laboratory in Batavia, IL, is one of the world's most intense source of accelerator neutrinos. The two experiments located in the NuMI beam line are MINERνA and MINOS. NuMI produces neutrinos by colliding 120 GeV protons with a thin graphite target. Two magnetic horns are used to sign-select positive or negative mesons from the p-C collisions. The horns and target are mounted on rails,

*http://minerva.fnal.gov/

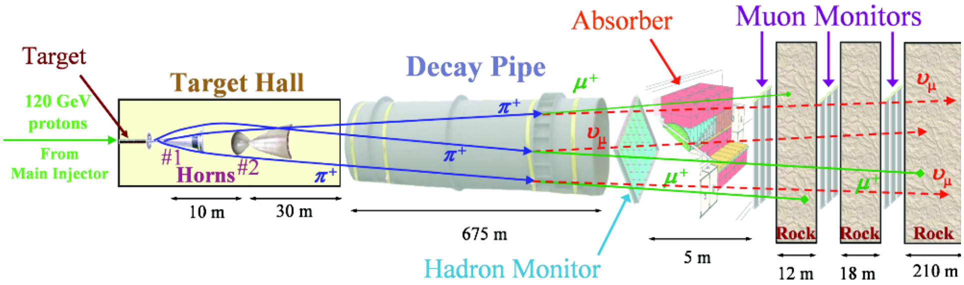

Figure 1: Diagram of the MINERνA beamline, showing the muon monitors and moveable magnetic horns.

allowing the experiments to select varying momentum ranges of the resulting mesons and their daughter neutrinos. The mesons are allowed to decay into ν (positive mesons) and $\overline{\nu}$ (negative mesons) in the decay pipe. The decay pipe terminates in a hadron absorber, allowing only muons and neutrinos to continue toward the detectors. The remaining muons are stopped by 240 m of rock located between the hadron absorber and the MINERνA detector hall.

Measuring the neutrino flux is vitally important for all of MINERνA's physics goals. The largest flux uncertainty arises from uncertainties in hadron production models of p-C collisions in the NuMI target. External hadron production data is used to reduce this uncertainty. Hadron production data from the NA49 experiment is used to re-weight the MINERνA Monte Carlo depending on the parent meson of the neutrino. The NA49 experiment used a similarly sized target and a proton beam of similar energy as NuMI. However, there is a proposal for MINERνA to conduct a dedicated hadron production experiment using the exact beam energy and target as NuMI. This work would be carried out with the SHINE collaboration at CERN.

MINERνA takes dedicated special runs with varying target positions and horn currents to constrain the neutrino flux. The resulting spectrum of neutrino events in the MINERνA main detector is used to fit a parametrized Monte Carlo of hadron production in the NuMI target. This procedure is repeated using data from the muon monitors interspersed in the 240 m of rock between the end of the decay pipe and the MINERνA detector hall. This gives the MINERνA experiment three handles on the measurement and constraint of the neutrino flux.

3 Detector and Performance

The MINERνA detector consists of a fine-grained scintillating tracking detector with position resolution of 3.00 mm. This design allows for excellent capability in reconstructing muons from DIS events. The tracking detector is followed by electromagnetic and hadron calorimeters with sufficient mass to contain final state hadron showers. Upstream of the tracker region are solid nuclear targets of graphite, iron and lead. In addition, MINERνA has installed a cryogenic liquid helium target as well as a liquid water target. The ensemble of nuclear targets exposed to the same neutrino beam will allow MINERνA to make the world's first systematic measurement of nuclear effects in neutrino scattering across a wide range of Z.

A DIS analysis in MINERνA will rely on accurate measurements of muon energy and angle, as well as final state hadron energy. Muon reconstruction in MINERνA currently relies on using the MINOS near detector to measure the final state energy and momentum of muons exiting

MINERνA. The final state muon track is matched to a track in MINERνA. The efficiency of this process is approximately 93%. Additional energy is added to the muon based on the material in the detector, until a production energy and angle is determined.

Hadronic energy in MINERνA is computed via calorimetry. Visible energy deposited in the detector is divided into muon and recoil energy. The visible recoil energy is weighted depending on the amount of passive material proximate to the event. The resolution of this process is determined using Monte Carlo. Energy deposited in the detector is compared to generated neutrino energy for neutral current events. This process determines the resolution of the calorimetric measurement for each bin of generated energy. The recoil energy is then fitted to a standard calorimetry resolution function (see Figure 2). Hadronic reconstruction in MINERνA will also be cross calibrated using data from a dedicated test beam experiment.

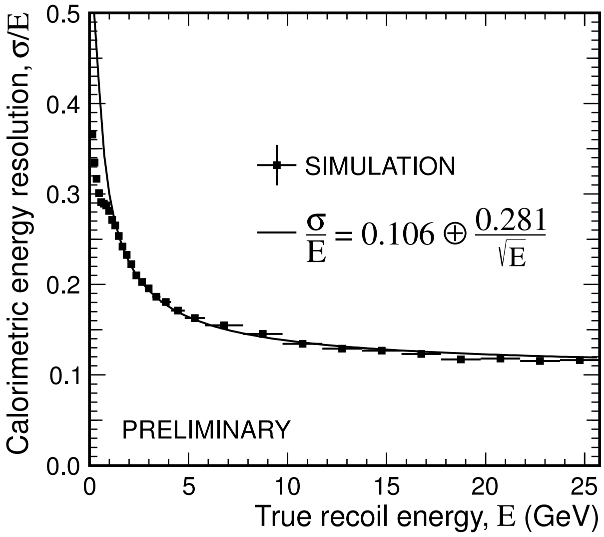

Figure 2: Calorimetric energy resolution vs. true recoil energy. The solid curve is the parametrized fit to the points.

4 Charged-Current Inclusive Analysis

The first step in a full DIS analysis is a charged current inclusive analysis. In this analysis, neutrino events are selected based on the location of the event vertex in the tracker region of the detector. The vertex must be inside a fiducial area of a 85 cm apothem hexagon. Outgoing muons from this vertex are then matched to tracks in the MINOS near detector, where their final state energy and momentum are measured. The number of CC inclusive events per POT recorded is plotted in Figure 3 for the neutrino exposure.

A DIS analysis will be derived from the inclusive analysis. Kinematic cuts will be placed on the events of $Q^2 > 1\,\mathrm{GeV}^2$ and $W > 2\,\mathrm{GeV}$. Events will also be restricted to the iron and lead regions of the nuclear targets. These samples will be compared to event rates in the tracker region of the detector in order to compute ratios of events. Likewise, the ratio of events from iron to lead will be measured by dividing the iron to plastic ratio by the lead to plastic ratio. This method allows the measurement of nuclear effects independent of flux uncertainties and MINOS acceptance effects.

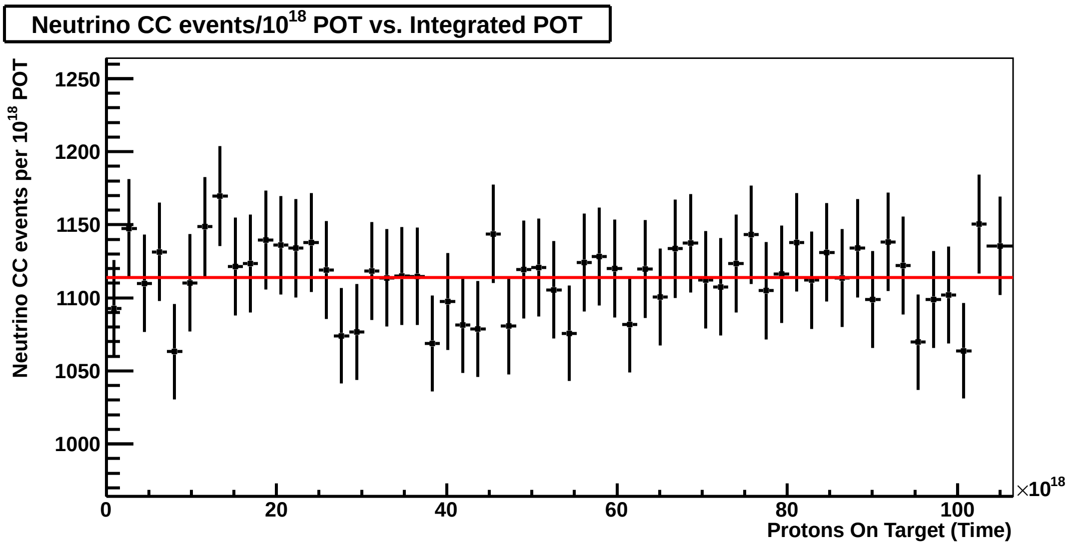

Figure 3: Number of CC Inclusive events vs. POT recorded by MINERνA.

5 Conclusion

The MINERνA collaboration has just completed collection of its low energy data set, and will soon be releasing results for a number of analyses. Using the reconstruction and flux measurements discussed in this note, a DIS analysis will be conducted in the near future based on the CC inclusive analysis. This DIS analysis will be complete but preliminary, and will lay a foundation for a more comprehensive analysis using the medium energy beam sample.

References

[1] K. Kovarik *et al.* Phys. Rev. Lett. **106** (2011) 122301, `arXiv:1012.0286 [hep-ph]`.