Partonic Nuclear Effects in MINERvA

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Measurements of the Deep Inelastic Scattering (DIS) neutrino cross-section ratios between Carbon, Iron, and Lead to Scintillator are presented by the MINERvA collaboration. These flux-integrated cross-section ratios are presented as a function of the Bjorken scaling variable x, and as a function of neutrino energy. Events in this sample span the neutrino-energy range of 5-50 GeV. Data is low relative to the GENIE prediction in the nuclear shadowing region, $x < 0.1$. These results have been published and can be found in Reference [2]. Future measurements using a $\langle 6 \rangle$ GeV neutrino beam will also be discussed.

1 Introduction

Deep Inelastic Lepton Scattering describes the interaction between a lepton and a nucleon with that has a larger amount of energy transfer than either quasi-elastic or resonance events. Charged lepton scattering experiments have been testing the quark-parton model for several decades and have found intriguing deviations from the expected behavior [4]. Neutrino DIS measurements present experimental challenges, such as the unknown a priori energy of the incoming lepton. Thus the incoming neutrino energy must be determined by reconstructing the outgoing particles from the interaction. The traditional variables used to describe the kinematics of the interaction are as follows. The hadronic invariant mass of the event, denoted as W, is calculated as follows:

$$W^2 = M_N^2 + 2M_N E_{had} - Q^2 \tag{1}$$

Where M_N is the mass of the struck nucleon, and E_{had} is the hadronic energy of the final state. The squared four-momentum transfer between the lepton and the nucleus is:

$$Q^2 = 4E_\nu E_\mu sin^2 \frac{\theta_\mu}{2} \tag{2}$$

And finally the Bjorken scaling variable x, calculated by:

$$x = \frac{Q^2}{2M_N E_{had}} \tag{3}$$

Measurements of charged lepton scattering cross section ratios between heavy (Pb, Fe, Ca) to light (D_2) nuclei have shown x dependent nuclear effects that can be separated into four distinct regions. The nuclear shadowing region with $x < 0.1$ is characterized by a reduction in the ratio below 1.0 of heavy to light nuclei due to hadronic fluctuations that result in destructive interference of multiple coherent scattering. The anti-shadowing region with $0.1 < x < 0.3$ is characterized by an increase in the ratio above 1.0. The "EMC" region with $0.3 < x < 0.65$ is characterized by an unexplained dip in the ratio. And finally, the Fermi motion region with $x > 0.65$ shows a dramatic increase in the ratio due to the upper limit on x for the nucleus being $x < A$, rather than $x < 1$ for a nucleon.

2 The MINERvA Detector

The MINERvA experiment is a dedicated neutrino cross section experiment located in the Neutrinos in the Main Injector (NuMI) beamline at Fermilab. It consists of a hexagonal fine grained scintillator tracking core, with planes arranged in three orientations for unambiguous three dimensional track reconstruction. Electromagnetic and hadronic calorimeter regions wrap around the central core and cover the downstream end of the detector. The most upstream component of the detectors consists of several solid passive nuclear targets of Carbon, Iron, and Lead, with active tracking modules in between. Diagrams of the detector and the nuclear target region can be seen in figures 1 and 2. More details can be found in Reference [1].

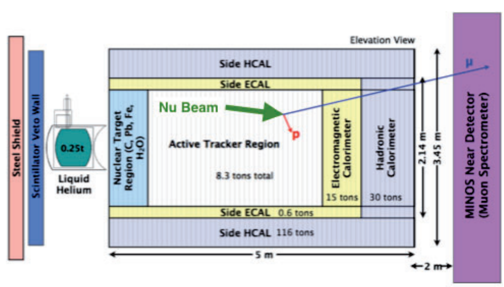

Figure 1 – The MINERvA Detector. The front of the MINOS near detector is also shown.

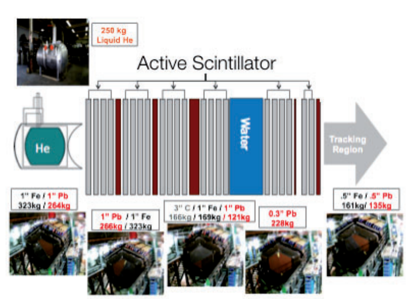

Figure 2 – A zoomed in view of the nuclear target region. Photos of the individual targets are shown, as well as their arrangements between scintillator modules. The nuclear target region sits at the most upstream end of the MINERvA Detector.

3 Analysis and Results

The signal for this analysis is events that have a $Q^2 \geq 1\text{GeV}^2$ and a $W \geq 2$ GeV, and neutrino energies ranging from 5-50 GeV. The neutrino energy is measured by adding together the energy of the muon measured in the MINOS near detector (see figure 1) and the hadronic energy in the event, measured calorimetrically. Differences in the acceptance between the different targets and the tracker region are calculated using a GEANT4 simulation. Background events are divided into two kinematic categories, those with $W > 2$ GeV^2 and $Q^2 < 1$ GeV, and those with $W < 2$ GeV^2 and $Q^2 > 1$ GeV. The normalizations of these two regions are fit simultaneously. Background events originating from neighboring scintillator planes are also subtracted from the nuclear target samples. Further information about the background subtraction methods and acceptance calculations can be found in reference [2].

The resulting ratios of A/CH are shown in figure 3. For comparison, the simulation in 3 represents the GENIE simulation [3] which tunes x dependent nuclear effects for every nucleus to electron scattering data on iron. The x range of 0.3-0.75 shows good agreement with the simulation in all targets. The largest disagreements to the simulation are seen at low x ($x < 0.2$), which are consistent with the nuclear shadowing expected with the axial-vector current.

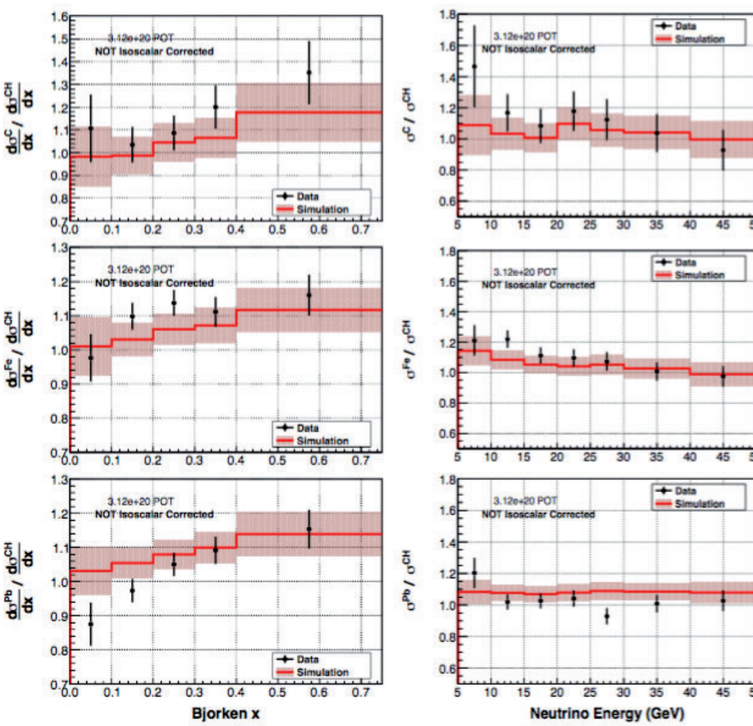

Figure 3 – Red histogram displays GENIE simulation results. Black points represent MINERvA data.

4 Potential for DIS in Higher Energy Beam

In 2013, the NuMI beamline tuning was changed so that the average neutrino energy moved from $\langle 3.5 \rangle$ GeV to $\langle 6 \rangle$ GeV. This increased the flux and the average interaction cross section, since the cross section increases with the neutrino energy. Additionally, since DIS is the dominant interaction process for neutrino energies greater than 5 GeV, the percentage of events that are DIS increases. The DIS ratio analysis in the higher energy beam will be systematics limited, with a statistical error of less than 10% over all Bjorken-x values.

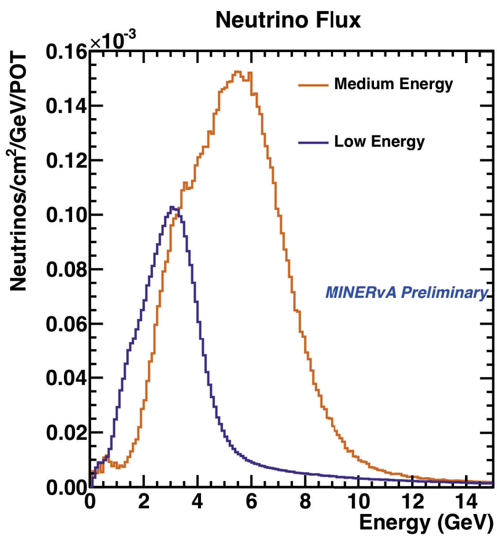

Figure 4 – Comparisons of the flux between the lower energy beam, peak energy 3.5 GeV, and the medium energy beam, peak energy 6 GeV.

5 Conclusions

MINERvA is the first experiment able to do precision measurements to study neutrino DIS on multiple nuclear targets simultaneously. MINERvA is currently taking data in the $\langle 6 \rangle$ GeV neutrino energy beam, and further results will be forthcoming.

Acknowledgments

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