Nuclear effects in $\bar{\nu}_\mu - A$ DIS at MINERνA

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Introduction

MINERνA is a dedicated $\nu_\mu/\bar{\nu}_\mu$ scattering experiment in the NuMI beamline at Fermilab [1]. We present preliminary results for $\bar{\nu}_\mu$ charged-current (CC) deep inelastic scattering (DIS) cross sections on carbon, iron, lead and scintillator (CH) using fine grained MINERνA detector exposed to a $\bar{\nu}_\mu$ beam at $\langle E_{\bar{\nu}} \rangle \sim 6$ GeV. CC $\bar{\nu}_\mu$ DIS is characterized by a final state with a μ^+ and a hadronic shower. The events analyzed have muon energy $2 < E_\mu < 50$ GeV and lepton scattering angle (θ_μ) less than 17° with respect to the beam. We extract total cross sections as a function of antineutrino energy and flux-integrated differential cross sections with respect to the Bjorken scaling variable x. The ultimate aim of this study is to extract the cross section ratios in C, Fe and Pb to CH, which provide the first high-statistics direct measurement of the nuclear medium effects in DIS region using antineutrinos.

The MINERνA detector

MINERνA's medium energy (ME) run took data from 2012 to 2019. The detector has been dismantled, but data analyses are still in progress. MINERνA detector was made up of 120 hexagonal modules of four types: active tracking, passive nuclear target, electromagnetic calorimeter (ECAL) and hadronic calorimeter (HCAL) [1]. In the most upstream part of MINERνA, there were five passive targets, each separated by four scintillating modules. Target 4 had Pb; targets 1, 2, and 5 had Fe and Pb; target 3 had C, Fe, and Pb. Downstream of the passive target region, there was a fully active tracking region. The target and tracker regions were surrounded by ECAL and HCAL. The magnetized MINOS near detector, located 2 m downstream of the MINERνA detector, was used to measure the charge and momentum of the outgoing muon.

Analysis strategy

E_μ, θ_μ, and the recoil energy E_{had} are primarily measured in MINERνA. For the DIS analyses we use kinematic selections based on the square of four momentum transferred $Q^2 (= 4E_\nu E_\mu \sin^2 \frac{\theta_\mu}{2})$ and the invariant mass of hadronic system $W (= M_N^2 + 2M_N E_{had} - Q^2)$, where the reconstructed neutrino energy $E_\nu = E_\mu + E_{had}$. DIS signal is defined as $Q^2 > 1.0 GeV^2$ and $W > 2.0 GeV$.

Detector limitations lead to two main backgrounds. The first one, known as the physics background (BKG) is due to smearing low-W and Q^2 events upward into the DIS region and the second one, known as plastic BKG is due to events misreconstructed in the passive nuclear target modules although originated in the scintillating modules surrounding the targets. The rate of these events is estimated by scaling the Monte Carlo (MC) simulation to agree with data in two physics sidebands, ($Q^2 \geq 1.0 GeV^2$, $1.3 \leq W \leq 1.8 GeV$; $Q^2 < 0.8 GeV^2$, $W \geq 2.0 GeV$) and two plastic sidebands, (upstream and downstream). The data in these regions are then used to tune BKG templates. MC BKGs tuned by the scaling factors serve as the data BKGs. Finally, the BKG constrained by data and simulation is subtracted bin by bin from reconstructed data and simulation events, respectively.

So far, the event distributions are in terms of the reconstructed variables while we need information in terms of true variables. We use unfolding to remove the effect of the detector limitations from the measurement. For this purpose we construct the unfolding matrix M_{ij} (which shows the mapping between reconstructed and true bins) and use Bayesian unfolding approach [2], which reduces any bias

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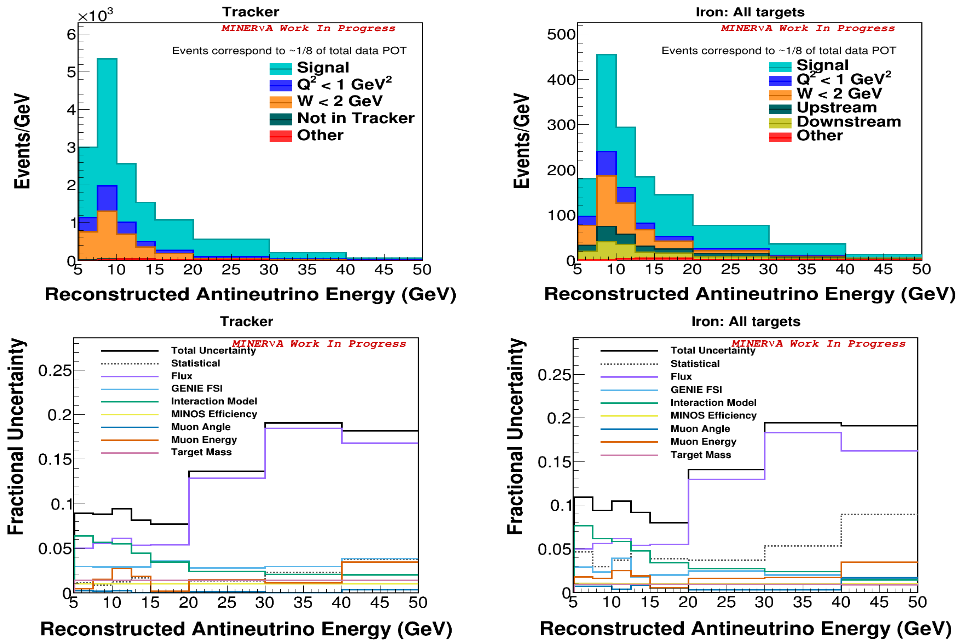

FIG. 1: (Top panel): Signal and background categorization vs $E_{\bar{\nu}}$ in CH (left) and Fe (right). (Bottom panel): Breakdown of systematic uncertainties in simulated $E_{\bar{\nu}}$ distribution in CH (left) and Fe (right)

in the unfolded distributions to a few-percent level.

To extract cross-sections we divide unfolded distributions by the overall efficiency, flux, and the number of targets. Efficiency/acceptance correction is used to recover the true signal distribution. True signal distributions are generated using MC to extract the efficiencies. The nuclear target region is upstream of the fully active tracking region which leads to better muon acceptance in tracker than in passive targets.

Results and discussion

In the present study we use events exposed to $\sim 1.53 \times 10^{20}$ protons on target (POT), which is ~1/8 of the total data available at MINERνA in the ME mode. In Fig.1(top panel), we show reconstructed DIS signal and backgrounds in simulation for CH (left) and Fe (right). In the tracker region physics BG dominantly contributes and we explicitly show the low-W and low-Q^2 events. On the other hand we additionally have plastic BKGs in the passive target region as discussed above. Signal purities are around 64% in CH and 54% in Fe. In total we have ~33% physics BKG in CH, and ~17% physics and ~28% plastic BKGs in Fe. In Fig.1(bottom panel), we show the sources of systematic uncertainties in the simulated distributions in CH (left) and Fe (right). We expect that the statistical uncertainty to be reduced once we include the entire antineutrino beam exposure and most of the flux uncertainty shall get cancelled out when we extract the cross sections ratios. We extract $\frac{d\sigma^A}{dx}$ vs x and σ^A vs $E_{\bar{\nu}}$ (for A=C,Fe,Pb,CH) and extract the cross section ratios in C, Fe and Pb to CH. This analysis will eventually improve our understanding of hadron dynamics in the nuclear medium.

Acknowledgments

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References

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