Understanding DIS Region using CC $\bar{\nu} - A$ scattering on C, Fe and Pb at MINERvA energies

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Introduction

Worldwide efforts are being made to understand (anti)neutrinos. Recent results from some of the neutrino oscillation experiments hint that CP is being violated in the weak sector and neutrinos follow the normal mass hierarchy [1]. For the precise measurements of the oscillation parameters, we require high statistics measurements with systematic uncertainties constrained to a few percent level. Next generation experiments like DUNE and HyperK aim to precisely measure δ_{CP}, which require the systematic uncertainties from the neutrino cross sections to be at 2-3% level. For the precise knowledge (anti)neutrino-nucleon and (anti)neutrino-nucleus cross sections, we require better theoretical as well as experimental studies. This thesis comprise of two parts: (I) The experimental study of $\bar{\nu}_\mu - A$ cross sections in the deep inelastic scattering (DIS) region, performed at MINERνA, Fermilab, USA and (II) the theoretical study of $\nu_l(\bar{\nu}_l) - N$ and $\nu_l(\bar{\nu}_l) - A$ $(l = \mu, \tau)$ cross sections in the DIS region [2, 3].

$\bar{\nu}_\mu$ DIS analysis at MINERvA

Main INjector ExpeRiment for $\nu - A$ (MINERνA) was a hexagonal cylindrical shaped (anti)neutrino detector, designed to perform self contained, high statistics, precise measurements of (anti)neutrino cross sections on a variety of nuclear targets (C, Fe, Pb and CH). The (anti)neutrino beam used by MINERνA was generated by the Neutrinos from the Main Injector (NuMI) beamline at Fermilab. The MINERvA detector comprised of active scintillation modules interleaved with passive nuclear targets, a main fiducial tracker region entirely made of scintillator followed by the electromagnetic and hadronic calorimeters. Muon momentum and charge were measured by the MINOS near detector, which was located 2 meters downstream of the MINERνA detector.

We have studied the charge-current antineutrino DIS process, $\bar{\nu}_\mu + A \to \mu^+ + X$, which contributes significantly to the medium energy antineutrino flux of MINERvA ($\langle E_{\bar{\nu}_\mu} \rangle \sim 6\ GeV$). We select all the charged current antineutrino events reconstructed in a given material or target with the following kinematic constrains: Muon energy between 2-50 GeV, outgoing muon angle $< 17^o$ with respect to the beam, four momentum transfer squared $Q^2 > 1GeV^2$ and center of mass energy $W > 2GeV$.

The antineutrino interactions have been simulated using the GENIE version 2.12.6, with some additional weights [4] like: a non-resonant pion weight, obtained using the reanalysis of the deuterium bubble chamber data, a 2p-2h weight, simulated using Valencia model and a random phase approximation weight, taken into account using the Valencia model.

More details on analysis procedure shall be presented in the symposium. We shall present the results for the $\bar{\nu}_\mu - A$ DIS cross sections on carbon, hydrocarbon, iron and lead as well as the cross section ratios in C/CH, Fe/CH and Pb/CH.

Theoretical work at Aligarh

Tau neutrino is the least studied standard model particle. In the past the experiments like DONUT, NOMAD, OPERA, etc., have observed some of the tau neutrino events but they are very limited in statistics, however the next generation neutrino experiments like DUNE, SHiP, DsTau, FASERν, etc., are plan-

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ning to observe a high statistics of tau neutrino events. In the literature there are various theoretical calculations of $\nu_\tau - N$ cross sections but there are significant uncertainties in these results. In this work we have studied the $\nu_\tau(\bar{\nu}_\tau)-$N DIS processes by taking into account various perturbative and nonperturbative QCD effects, like the evolution of parton distribution functions at next to leading order (NLO) and the target mass correction (TMC) as well as the higher twist (HT) effects [2]. We have also compared the different results from the literature and highlighted the need of better understanding of these cross sections even at the free nucleon level.

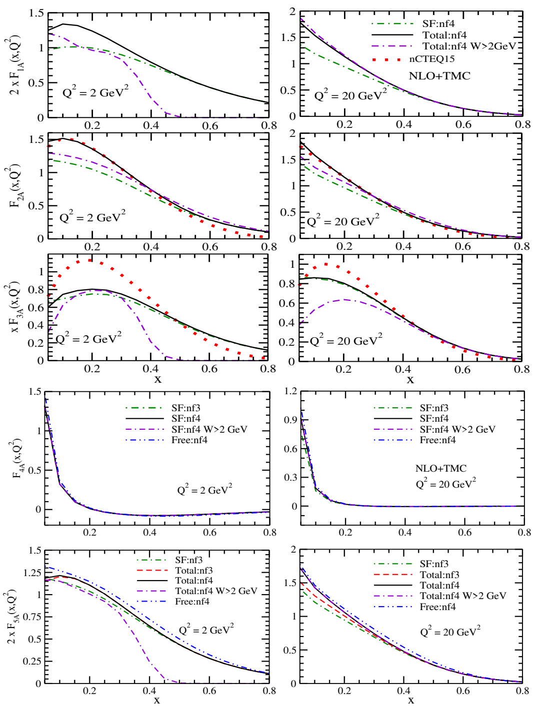

FIG. 1: $F_{iA}(x,Q^2)$;$(i=1-5)$(top to bottom) vs x at NLO using MMHT PDFs parameterization with TMC effect in the four flavor scheme. The results with only the spectral function (SF) as well as with full model(Total) are shown.

We have also obtained the results for $\nu_\tau/\bar{\nu}_\tau-^{40}Ar$ DIS cross sections, where the numerical calculations have been performed using a microscopic field theoretical model. We have incorporated the effects like binding energy, Fermi motion and nucleon correlations using hole spectral function. Associated with each nucleon bound inside the nucleus there are virtual mesons and because of the strong attractive nature of the nucleon-nucleon interaction, the probability of a $W-$boson interaction with the mesonic cloud becomes high. Thus the contributions of the pion and rho meson clouds have also been considered. For detailed formalism for $\nu_\tau/\bar{\nu}_\tau-N$ and $\nu_\tau/\bar{\nu}_\tau-A$ cross sections one may refer to [2, 3].

In Fig. 1, the results for the nuclear structure functions $F_{iA}(x,Q^2)$ $(i=1-5$ from the top to bottom) vs x are shown for different Q^2, at NLO with TMC effect. The results are obtained with and without a $W > 2.0GeV$ cut. The results presented here are relevant to understand the nuclear medium modifications, dependence on the kinematic variables such as x, Q^2 and W. $F_4(x,Q^2)$ and $2xF_5(x,Q^2)$ are the two additional structure functions which only contribute to the charged current $\nu_\tau/\bar{\nu}_\tau-N$ and $\nu_\tau/\bar{\nu}_\tau-A$ scattering cross sections due to $m_\tau \neq 0$, while their contributions become negligible in ν_e or ν_μ induced processes. More details on these results would be presented in the symposium.

Conclusion

We shall report the first direct measurement of nuclear effects in DIS region using antineutrino. These results would be helpful for the upcoming DUNE experiment.

This is the first theoretical study of $\nu_\tau/\bar{\nu}_\tau-A$ DIS cross sections. These results would be helpful in simulating the tau neutrino events in the future experiments dedicated to study tau neutrino events.

References

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