Neutrino Nucleus Cross Section And Final State Interaction

R. B. Singh[1] & **Jyotsna Singh**[2]
Assistant Professor
Department of Physics,
University of Lucknow, Lucknow, India[1,2]

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ABSTRACT *Neutrino oscillation physics has now entered into an era of precision. As the present and future Neutrino oscillation experiments are aiming to explore new physics, neutrino-nucleus cross section needs to be quantified with utmost precision . The hadron produced in the neutrino-nucleus interaction may re-scatter in the nucleonic medium and this phenomenon can change the charge and multiplicity of the outgoing hadrons (known as final state interaction). A good measurement of these process, which occur inside the nucleonic medium is crucial for the precise determination of neutrino cross section. Neutrino-nucleon cross section are key part of neutrino oscillation analysis.*

Key words: *cross section, interaction, re-scatter, final state interaction.*

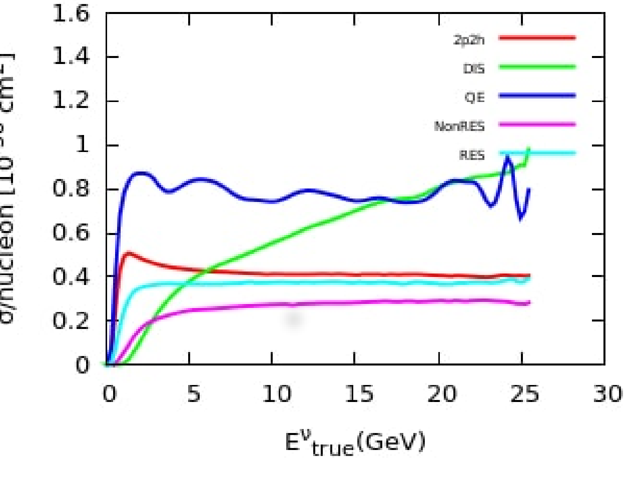
I. Introduction

In order to improve our understanding regarding neutrino and neutrino oscillation, study of neutrino interaction with matter is necessary. The hadron produced in the neutrino nucleon interaction, propagates through the nucleus before it hits the detector and in the meantime it can re-interact inside the nucleus. These re-interactions are called final state interactions (FSI). FSI are governed by strong interactions. The nuclear detectors are huge detectors made of heavy elements hence the nuclear effects or FSI, need to be mentioned while examining the neutrino nucleon cross sections[1][2]. Neutrino's least interactive nature can be correlated with small neutrino cross sections. The neutrino cross section depends upon, the target material, type of interaction (NC or CC) and the energy of the neutrino. The FSI contributes significantly to the systematic errors in the neutrino oscillation measurements. The experimental data analysis is based on the predictions made by Monte Carlo event generators[3]. Several neutrino oscillation experimental data, roughly in 1 GeV energy range can be well justified with Impulse Approximation picture [4].

Monte Carlo codes used by different neutrino oscillation experiments uses inter-nuclear cascade(INC) [5] model to describe FSI. Few Monte Carlo codes are : FLUKA [6], NUANCE [7], NEUT [8], GENIE [9] and GiBUU [10]. Inter-nuclear cascade approach is a semi classical approach in which Pauli blocking, formation time and nucleon correlations are included. Basic idea behind the models of final state interaction in the Monte Carlo is same, only their numerical implementations are different.

II. Related Work

In this work we have used two different M.C. generators, GENIE and GiBUU to include the FSI in our analysis. There are different ways to model FSI, the simplest approach to do this is to approximate the interactions using nuclear scattering data. π^{+} and p scattering data on Fe^{56}. Prediction for other nuclei are made by scaling the cross section according to $A^{1/3}$, A being the atomic mass number.



The GiBBU uses the Boltzmann-Uehling-Uhlenback equation [11] to describe final state interactions. This equation describes the time evolution of phase space density of each particle species, participating in the final state interactions. The particles are coupled through the mean field potential.

In this work we have studied the neutrino nucleon interaction using both generators. These generators are used to study final state interaction and the neutrino interaction csross sections.

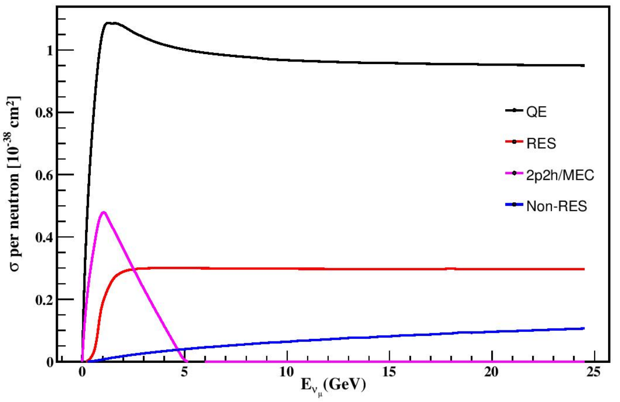


Fig. 1 Neutrino cross section per nucleon as function of neutrino energy (a) Left plot is generated by GENIE (b) Right plot is generated by GiBUU

In the above plot the neutrino-nucleon cross section per nucleon is plotted as function of neutrino energy. Cross section for different interaction processes i.e. 2p2h, DIS, QE, Non Resonance, resonance is plotted using GiBBU and GENIE simulation tools. From the plots we can see the difference in cross sections, estimated by different simulation tools.

III. RESULT

The future and ongoing neutrino beam experiments i.e. MINOS, NoVA, DUNE [12], T2K and K2K have neutrino beam whose energy lie in the energy region of 0.1 GeV to 25 GeV. As these neutrino beam are the secondary decay products, they are not mono-energetic. The wide spread in the energy of neutrino beam demand the accurate cross section measurements in the above energy range. Neutrino nucleon interactions can be classified as QE interactions, Deep inelastic scattering, resonance etc. Different type of interactions dominate at different energies. Generally at lower energies QE interactions is the dominant mode of interaction as we can see in Fig. 1. As the neutrino energy increases many other interaction processes becomes active and their contribution should be added to the total neutrino nucleon interaction. For accurate determination of the neutrino cross section proper understanding of events is essential. By looking at event signatures in the detector we must be able to discriminate between QE and fake QE or QE like events. The proper filtration of QE from QE like events need proper modeling of final state interaction in monte carlo generators. Different generators use different techniques for FSI modeling in the MC generators. This can be visualized in left and right plot of Fig. 1.

IV. Summary and Conclusions

The effect of FSI in the nucleus is complex but large so it needs to be addressed in the neutrino nucleon interactions. In present we depend on hadron nucleus interaction data for mathematical modeling of FSI. Due to FSI, variety of mesons and nucleons come out of the nucleus and their angular and energy response for a given detector is not well understood. In order to incorporate all these effects in the model, experimental data is required for its validation. The experimental data over past few decades collected by different neutrino oscillation experiments have lead us to a better understanding of neutrino nucleon interactions in GeV energy range. The MiniBooNE collaboration [13] reported excess of charge current QE data, which was explained with the help of RFGM, which requires a large increase in the nucleon axial mass in comparison to that obtained from the deutron data. RFGM is capable of assigning some process other than the single nucleon knock out [14] . Complete description of impact of nuclear effects is not possible since in neutrino oscillation experiments deals with large momentum transfer, which makes nonrelativistic approaches impractical. The study of the final state interactions in the determination of neutrino cross section needs to be addressed at priority level as the cross sectional error will effect the determination of neutrino oscillation parameters [15].

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