Quasi-elastic Neutrino-nucleus Interactions

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Introduction

Study of the neutrino interactions is one of the most exciting recent developments in particle physics. With the discovery of neutrino oscillations, first proposed by Pontecorvo [1], the current neutrino experiments [2] are aiming to make precise measurements of the oscillation parameters. Neutrino oscillations is a quantum mechanical phenomenon which arises since the mass eigenstates (ν_1, ν_2, ν_3) and the flavor eigenstates of neutrinos $(\nu_e, \nu_\mu, \nu_\tau)$ are not identical, due to which there is a flip in their flavor or mass-mixing as these travel large distances. Improving our understanding of neutrino-nucleus interaction cross-sections is crucial to these precision studies of neutrino oscillations. Interactions in the neutrino energy region around 1 GeV are particularly important because of the expected oscillation signal in this energy region in many experiments [3], however, the cross-sections in this region are not very well known. The data analysis needs to consider a large number of nuclear effects that distort the signals and produce new sources of background that are absent in the elementary neutrino-nucleon processes. In this context, it is clearly of interest to have a theoretically well founded and unified framework in which the electroweak interactions with nuclei could be systematically studied. Furthermore, the recent measurements of the cross-sections for several channels [4] provide a serious benchmark to the theoretical models.

Results

In this study, we have investigated the various types of neutrino interactions by looking for muon neutrino interactions with oxygen. Choosing Oxygen as the target is because of its abundance in the atmosphere. The muon neutrinos have also been chosen for being the most abundant amongst the three flavors of neutrinos. The study has been carried out at the energy of around 1 to 2 GeV. We have used the Wroclaw Neutrino event generator, NuWro [5], for simulating the events. This event generator is simple, basic, elaborate and full featured and handles almost all the important processes in neutrino-nucleus interactions. In the present study, the cross-sections for 10,000 such events for all the three processes enabled by NuWro i.e., resonance excited scattering (RES), deep inelastic scattering (DIS) and quasi-elastic (QE) scattering each through charged-current (CC) interactions has been obtained and the corresponding plots are showing the average cross-section per neutrino interaction event for different processes. In this energy region of 1 to 2 GeV, the main reaction mechanisms are quasi-elastic scattering, resonance excited scattering and single pion production through delta excitation [6].

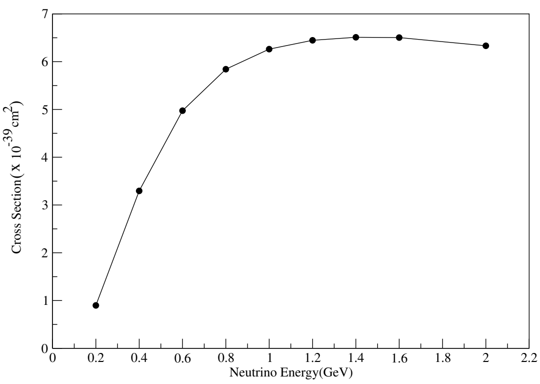

FIG. 1: Quasi-Elastic Charged Current.

The results are much in confirmation with

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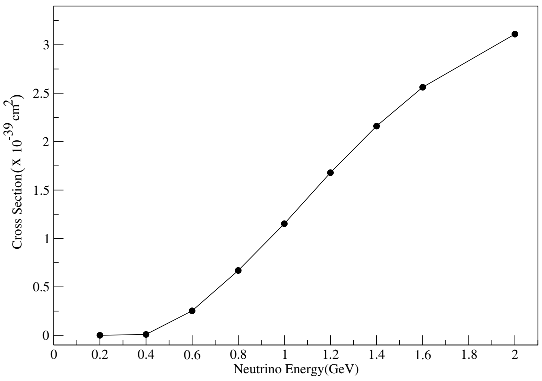

FIG. 2: Resonance Excited Scattering Charged Current.

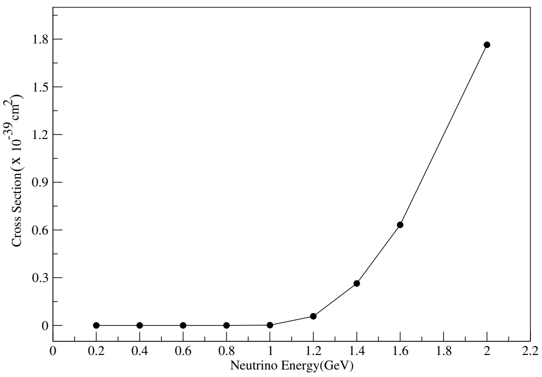

FIG. 3: Deep Inelastic Scattering Charged Current.

the previously established results [7]. One well established fact is that, of the three interaction channels, QE-CC has the largest cross-section and hence one can consistently describe some experimental data. Moreover, the very fact that the predicted cross-sections for QE scattering are very similar for most models [8], these processes have been abundantly studied. However, more sophisticated treatment of the nuclear effects is also necessary to get a detailed agreement with data. For example, the theoretical results are clearly below the data published by MiniBooNE [9]. The discrepancy is large enough to provoke much debate and theoretical attention. This suggests that much of the experimental cross-section can be attributed to processes that are not properly QE, stressing the need of a unified framework dealing with all relevant mechanisms, namely pion production and multi-nucleon excitation. A pion production principal interaction appears to be quasi-elastic if the pion is absorbed in the final state interactions. Depending on cuts, this effect is thought to account for about 10 to 20 percent [10] of quasi-elastic events. Moreover, as the hadrons propagate through nucleus before these can be detected, the interactions of produced pions in the nucleus leads to pions being absorbed or re-scattered, thus reducing the cross-section. Overall, the impact of nuclear effects on observables is considerably significant and there are uncertainties associated with any approach.

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