Interaction of neutrinos with matter in low and intermediate energy region

K. Saraswat[1], V. Kumar[2],* P. Shukla[2], and V. Singh[1]

[1] *Department of Physics, Banaras Hindu University, Varanasi-221005, INDIA. and*
[2] *Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA*

Introduction

There are compelling evidences for oscillations of neutrinos which are caused by nonzero neutrino masses and neutrino mixing [1]. The 3-neutrino mixing in vacuum can be parameterized in terms of three mixing angles θ_{12}, θ_{23}, θ_{13} and a CP phase δ. Thus, the neutrino oscillations are determined in terms of these parameters as well as two mass squared differences Δm^2_{21} and Δm^2_{32}. The neutrinos generated in the upper atmosphere are the best candidates to study the phenomena of neutrino oscillations considered by many experiments planned worldwide. The flux of atomospheric neutrinos [2] rapidly falls with energy as shown in Figure 1 at the INO site. Typically, the detectors measure recoil muons which are produced by charged current interaction of neutrinos inside the detector medium. Considering the acceptances of the detectors (e.g. ICAL at INO) neutrinos between energy 1 to 3 GeV will form bulk of the signal. The interaction of neutrinos with matter at this energy involves many processes. We study the contributions of these processes for free nucleon as well as nuclei.

Neutrino interaction with matter

Depending on energy, many processes can contribute to neutrino interaction such as elastic scattering, Quasi Elastic Scattering (QES), interaction via Resonance Production (RES) and Deep Inelastic Scattering (DIS).

QES is dominant process in the low and intermediate energy range. The charged current

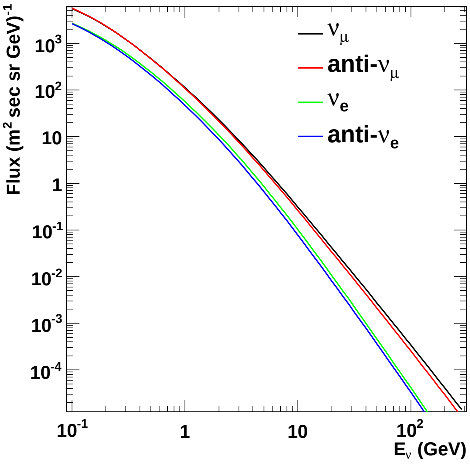

FIG. 1: Atmospheric neutrino flux (at INO site) averaged over zenith angle.

QES process is given by

$$\nu_\mu + n \to \mu^- + p. \qquad (1)$$

We calculate ν-N cross section in nucleon rest frame using Llewellyn Smith model [3]. For nucleus, Pauli Suppression Model is used.

The neutrino can interact with nucleon via a baryonic resonance production. The dominant contribution comes from Δ and is written as

$$\nu_\mu + N \to \mu^- + \Delta \to \mu^- + N + \pi \qquad (2)$$

We calculated RES using Rein-Sehgal model [4]. For nucleus one has to consider coherent resonance production.

In DIS, ν interacts with a quark inside nucleon and the nucleon breaks into other hadronic states X as

$$\nu_\mu + N \to \mu^- + X. \qquad (3)$$

*Electronic address: vineet.salar@gmail.com

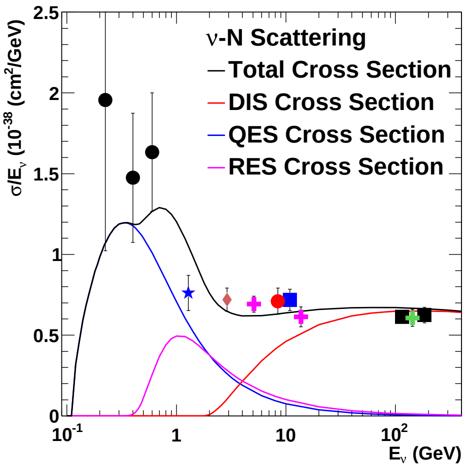

FIG. 2: Charge Current neutrino nucleon cross section as a function of energy.

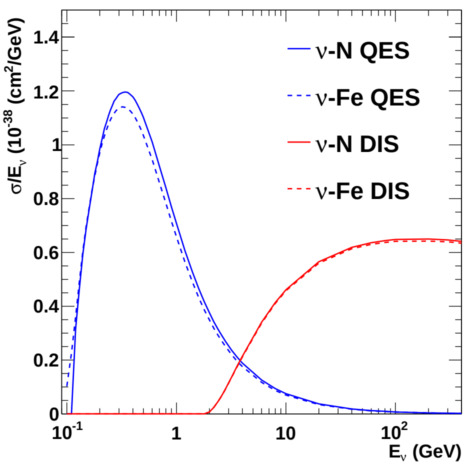

FIG. 3: Charge Current neutrino nucleus (^{56}Fe) cross section as a function of energy.

The ν -N DIS differential cross section can be written in terms of inelasticity y, structure functions (F_1, F_2, F_3) and neutrino energy E_ν [5]. We used latest partonic distribution functions CTEQ6.6 and EPS09 nuclear correction [6] to calculate DIS cross sections.

Results and Discussions

Figure 2 shows charged current neutrino nucleon interactions cross section as a function of energy. All the processes contributing to the cross section are shown by various lines. The contribution of QES peaks at 300 MeV, then decreases slowly with energy and becomes negligible after 20 GeV. DIS is the largest contribution after $\sim$ 4 GeV and beyond 20 GeV the sole contriution comes from DIS. The RES (via Δ) peaks arround 1 GeV. There can be other resonance contributing which have been neglected here. In Figure 3, charged current neutrino interactions cross section with free nucleon is compared to (^{56}Fe) for two processes namely, QES and DIS. The work on calculating resonance cross section considering nucleus as a whole is under progress. The total calculated inclusive cross-section matches well with various experimental data. To get the total cross section arround neutrino energy $\approx$ 1 GeV all competing processes must be taken into account.

Acknowledgement

We thank Prof. Sajjad Athar and Prof. V. M. Datar for many fruitful discussions.

References

[1] Y. Fukuda *et al.* [Super-Kamiokande Collaboration], Phys. Rev. Lett. **81**, 1562 (1998), [hep-ex/9807003].

[2] M. Honda, T. Kajita, K. Kasahara and S. Midorikawa, Phys. Rev. D **83**, 123001 (2011) [arXiv:1102.2688 [astro-ph.HE]].

[3] C. H. Llewellyn Smith, Phys. Rept. **3**, 261 (1972).

[4] O. Lalakulich and E. A. Paschos, Phys. Rev. D **71**, 074003 (2005), [hep-ph/0501109].

[5] M. Hirai, S. Kumano and K. Saito, AIP Conf. Proc. **1189**, 269 (2009) [arXiv:0909.2329 [hep-ph]].

[6] K. J. Eskola, H. Paukkunen and C. A. Salgado, JHEP **0904**, 065 (2009) [arXiv:0902.4154 [hep-ph]].