Charged current deep inelastic scattering of muon neutrino with Iron nuclei

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Introduction

Neutrinos in the upper atmosphere are the best tools to study the neutrino oscillations. Neutrinos with energies between 1 to 3GeV which form bulk of the signal in the detector are suitable for the above purpose. Neutrino in this range can interact with matter by many processes such as quasi elastic scattering (QES), resonance pion production (RES) and deep inelastic scattering (DIS). All three processes contribute in the scattering if the neutrino energy is ~1 GeV. At high neutrino energy, DIS dominates over all the processes. Deep inelastic scattering (DIS) is an experimental tool to study the properties of the hadronic matter. In this process, leptons collide with hadronic matter at high energy and large numbers of particles emerge in the final state. There are three scattering processes of a neutrino with a nucleon:

- Elastic Scattering – In this process, ν interacts with nucleon (*N*) by neutral current. The type of nucleon remains same after scattering.

$$\nu_\mu + N \rightarrow \nu_\mu + N$$

- Quasi-Elastic Scattering – In this scattering process, ν interacts with nucleon by charged current. A corresponding lepton is produced and the nucleon *n(p)* changes to *p(n)*.

$$\nu_\mu + n \rightarrow \mu^- + p$$

- Deep-Inelastic Scattering – In this scattering process, ν interacts with nucleon producing a corresponding lepton. Here the nucleon changes to another hadronic state *X*.

$$\nu_\mu + N \rightarrow \mu^- + X$$

In this article, we study the DIS process for the free nucleon as well as iron nuclei.

The model of neutrino - nucleon / nucleus Deep Inelastic Scattering

In DIS, neutrino (ν_μ) interacts with a quark inside the nucleon (N) and the nucleon breaks into other hadronic states X as $\nu_\mu(k) + N(p) \rightarrow \mu^-(k') + X(P')$. Here k and k′ are the 4-momentum of the incoming neutrino and outgoing muon, respectively. p is the 4-momentum of nucleon and P′ is the 4-momentum of the hadronic states.

The differential cross section for ν_μ–N DIS is given by

$$\frac{d^2\sigma^{\nu(\bar{\nu})}}{dxdy} = \frac{G_F^2 M_N E_\nu}{\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 \left[F_1 xy^2 + F_2\left(1-y-\frac{M_N xy}{2E_\nu}\right) \pm F_3 xy\left(1-\frac{y}{2}\right)\right].$$

Where ± indicates + for neutrino and − for antineutrino, G_F is the Fermi coupling constant, M_N is the mass of nucleon, E_μ is the incoming neutrino energy, and M_w is the mass of W boson. Here Q^2 is given by $Q^2 = -q^2 = (k - k')^2$, x is the Bjorken scaling variable i.e. $x = Q^2/(2P\cdot q)$ and y is the inelasticity, which is equal to $[P \cdot q / (P \cdot k)]$. F_1, F_2 and F_3 are the dimensionless structure functions [1].

We calculate the differential cross section by expressing the structure functions in terms of Parton Distribution Functions (PDFs). PDFs are derived from fitting DIS and related hard scattering data using parameterization at low Q^2 ranging between 1 - 7 $(\mathrm{GeV/c})^2$ and evolving these to higher Q^2. These PDFs are presented as grids in $x - Q^2$. In the qPDFs calculation, LHAPDF 5.8.8 (CT10) [2] is used and to calculate the modifications of the PDFs inside the nucleus, the EPS09 [3] sets are used. LHAPDF (The Les Houches Accord PDFs) provides C++ code to these PDFs with interpolation grid build into the PDFLIB. We use EPS09 to obtain NLO and LO Nuclear Partonic Distribution Functions (nPDFs) and the corresponding error sets. When PDFs evaluate at the Nachtman variable (ξ) [4] rather than the Bjorken variables x, the target mass correction (TMC) is implemented in the qPDFs. The Nachtman variable is defined as

$$\xi = \frac{2x}{1+\sqrt{1+\frac{4M_N^2 x^2}{Q^2}}}.$$

Result and discussion

Figure 1 shows the differential cross-section (1/E$_\mu$) (dσ / dx . dy) per unit neutrino energy for the neutrino-neutron and neutrino-iron DIS as a function of inelasticity y neutrino energy E$_\mu$= 35 GeV and x = 0.015. We observed that the neutrino-iron DIS cross section is less than the neutrino-nucleon cross-section due to the nuclear effects such as shadowing and anti-shadowing.

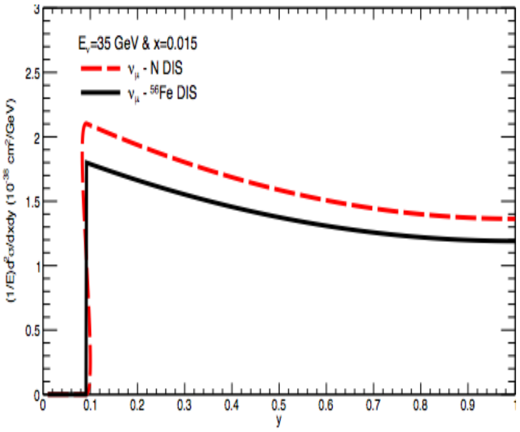

Fig. 1: ν_μ-*N* and ν_μ-^{56}*Fe* charged current differential scattering cross section per unit neutrino energy vs. inelasticity *y.*

The Target Mass Correction (TMC) can be taken into account when the parton distribution functions evaluate at Nachtman variable ξ [2] rather than Bjorken variable *x*. Figure 2 shows the total cross section (σ/E$_\mu$) of neutrino-iron DIS with and without TMC per unit neutrino energy as a function of neutrino energy E$_\mu$.

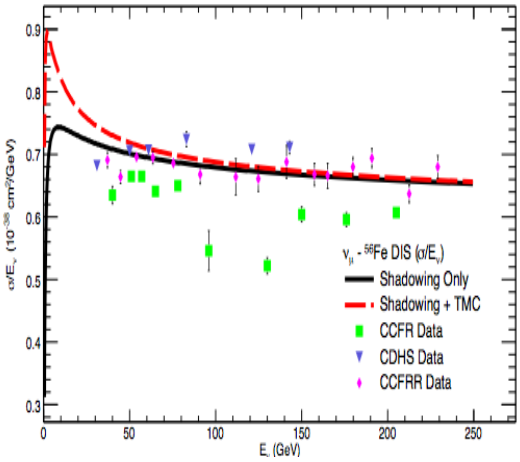

Fig. 2: ν_μ–^{56}*Fe* charged current differential scattering cross section with and without TMC per unit neutrino energy vs. inelasticity *y* compared to CCFR and CDHSW data.

Total cross section for ν - *N* and ν - *A* case is obtained by integrating the respective differential cross sections over the Bjorken variable *x* (0 → 1) and inelasticity *y* (0 → 1). Figure 2 also shows the total cross section with and without TMC per unit neutrino energy vs. neutrino energy. The calculations are compared to the measurements of CCFR, CCFRR and CDHSW experiments. We observed that our calculation describes the experimental data.

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