Lepton event rates in neutrino-nucleus DIS

H. Haider*, I. Ruiz Simo†, M. Sajjad Athar* and M. J. Vicente Vacas†

*Department of Physics, Aligarh Muslim University, Aligarh-202 002, India
†Departamento de Física Teórica and IFIC, Centro Mixto Universidad de Valencia-CSIC, Institutos de Investigación de Paterna, E-46071 Valencia, Spain

Abstract. In this work we have studied the nuclear effect in $F_2^A(x)$ and $F_3^A(x)$ weak structure functions and calculated ν-nucleus cross section using them by taking into account Fermi motion, binding energy, pion and rho meson cloud contributions and shadowing and anti-shadowing effects. The numerical calculations have been performed in a local density approximation using relativistic nuclear spectral functions which include nucleon correlations for nuclear matter. The results have been compared with the experimental results of NuTeV and CDHSW collaborations.

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INTRODUCTION

In the intermediate energy region of a few GeV, recently many experiments have come up for studying neutrino events using atmospheric as well as accelerator neutrinos. Several new experiments using various neutrino sources like beta beams, super-beams or neutrinos from factories have been discussed in literature. In most of these experiments nuclear targets are being used. In this ν energy range, contribution to the ν-nucleus cross section comes from quasi-elastic, inelastic as well as deep inelastic processes. Recently in the various neutrino conferences and workshops lots of emphasis has been put to understand the nuclear effects in these reaction channels. For the deep inelastic neutrino-nucleus scattering there are only a few calculations where the dynamical origin of the nuclear medium effect has been studied, and in some theoretical analysis, nuclear medium effect has been phenomenologically described in terms of a few parameters which are determined by fitting the experimental data of charged leptons and neutrino deep inelastic scattering(DIS) from various nuclear targets.
In this paper, we have calculated structure functions F_2^A and F_3^A and the total scattering cross section σ in Iron. These results have been obtained in a theoretical model [1, 2, 3] using spectral function [4] to describe the momentum distribution of nucleons in the nucleus. The spectral function has been calculated using the Lehmann's representation for the relativistic nucleon propagator, nuclear many body theory is then applied to calculate it for an interacting Fermi sea in nuclear matter [1]. A local density approximation is then applied to translate these results to finite nuclei. We have taken the effect of pion and rho meson contributions [1], target mass correction [5], and nuclear shadowing and anti-shadowing effects [6]. In order to examine the dependence of the parton distribution functions (PDFs) on the structure functions, we have used CTEQ [7] and MSTW [8] PDFs. The QCD evolution of the structure functions have also been taken into account using the coefficient functions given in Refs. [9, 10]. Numerical results are compared with the experimental results of NuTeV [11] and CDHSW [12] collaborations, and also these numerical results are compared with the results obtained from the various phenomenological studies [13, 14].

FORMALISM

The expression for the neutrino-nucleon charged current differential cross section, for deep inelastic scattering (DIS), is given by

$$\frac{d^2\sigma^{\nu(\bar\nu)}}{dx\,dy} = \frac{G_F^2 M E_\nu}{\pi(1+Q^2/M_W^2)^2}\Bigg((y^2x+\frac{m_l^2 y}{2E_\nu M})F_1 + \left[(1-\frac{m_l^2}{4E_\nu^2})-(1+\frac{Mx}{2E_\nu})y\right]F_2 \pm \left[xy(1-\frac{y}{2}) - \frac{m_l^2 y}{4E_\nu M}\right]F_3 + \frac{m_l^2(m_l^2+Q^2)}{4E_\nu^2 M^2 x}F_4 - \frac{m_l^2}{E_\nu M}F_5\Bigg) \quad (1)$$

where in F_3 +sign(-sign) is for neutrino(antineutrino), x is the Bjorken variable, $y=\frac{\nu}{E}$, ν and q being the energy and momentum transfer of leptons and $Q^2=-q^2$. F_1 and F_2 are related by the Callan Gross relation leading to only two independent structure functions F_2 and F_3. For the charged current reaction induced by ν_e and ν_μ, F_4 and F_5 are generally omitted since they are suppressed by a factor of at least $m_l^2/2ME_\nu$ relative to the contributions of F_1, F_2 and F_3.

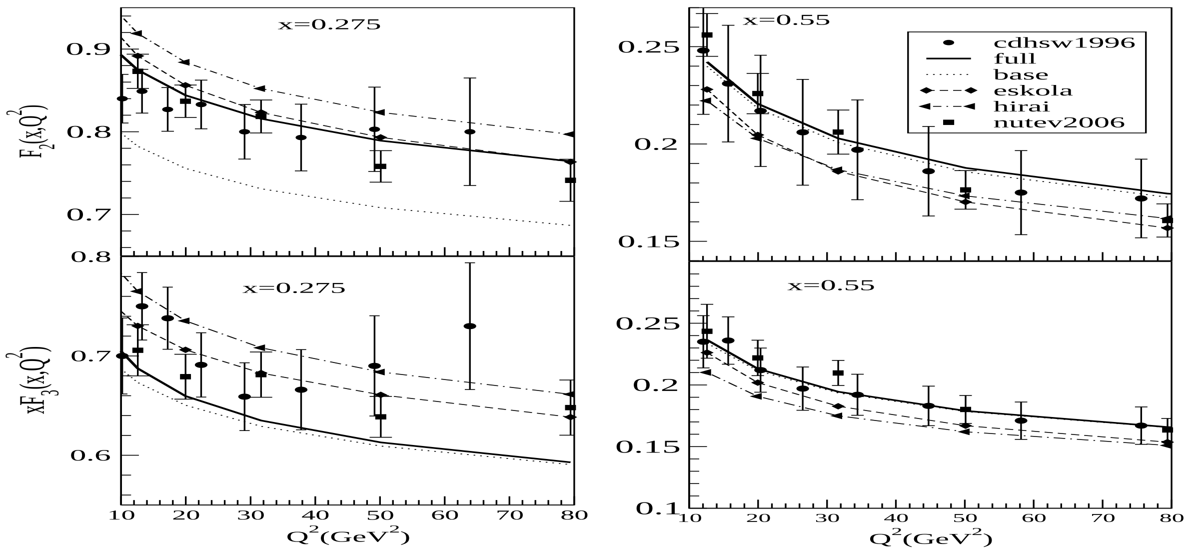

FIGURE 1. Upper panel is for F_2 and lower is for xF_3 structure functions of nucleon in Iron. The dotted and solid curves represent the results from our base and full calculations. Structure function using Hirai(triangles left) [14] and Eskola(diamond) [13] phenomenological fits have also been plotted. NuTeV [11] and CDHSW [12] experimental results are shown respectively by solid squares and circles.

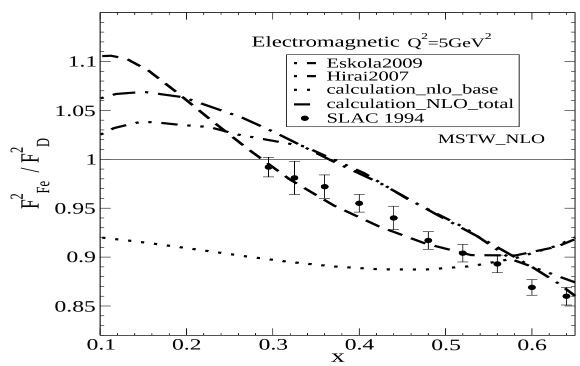

FIGURE 2. F_2^{Fe}/F_2^D as a function of x. Present model is compared to SLAC data [15]. Ratio from base and full calculations are shown by dotted and dashed curves. The dotted-dashed and double dotted-dashed curves represent the phenomenological studies of Eskola et al. [13] and Hirai et al. [14].

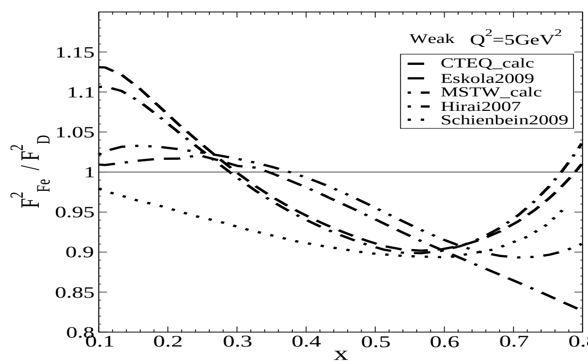

FIGURE 3. F_2^{Fe}/F_2^D as a function of x. The dashed and dotted-dashed curves represent the numerical results obtained in the present model using different PDFs: CTEQ [7] and MSTW [8]. These results have been compared with the results obtained by phenomenological fits of Eskola et al. [13], Hirai et al. [14] and Schienbein et al. [5].

The expressions of F_2 and F_3 structure functions due to nuclear medium effect like Fermi motion and binding energy in the present model are given by [1, 2, 3]

$$F_2^A(x,Q^2) = 4\int d^3r \int \frac{d^3p}{(2\pi)^3}\int_{-\infty}^{\mu} d\omega \; S_h(\omega,\mathbf{p},\rho(\mathbf{r}))\left(\gamma^2 + \frac{6x'^2(\mathbf{p}^2 - p_z^2)}{Q^2}\right) \frac{(1-\gamma\frac{p_z}{M})}{\gamma^2} F_2^N(x',Q^2) \quad (2)$$

$$F_3^A(x,Q^2) = 4\int d^3r \int \frac{d^3p}{(2\pi)^3}\int_{-\infty}^{\mu} d\omega \; S_h(\omega,\mathbf{p},\rho(\mathbf{r}))\frac{p_0\gamma - p_z}{(p_0 - p_z\gamma)\gamma} F_3^N(x',Q^2) \quad (3)$$

where $S_h(\omega,\mathbf{p},\rho(\mathbf{r}))$ is the nuclear spectral function the expression for which is taken from Ref. [4], p=$(M+\omega,\mathbf{p})$, $\gamma = (1+4x^2M^2/Q^2)^{\frac{1}{2}}$, $x = \frac{Q^2}{2Mq^0}$, $\gamma'^2 = 1 + 4x'^2p^2/Q^2$ and $x' = \frac{Q^2}{2p.q}$, F_2^N and F_3^N are free nucleon structure functions. Above expressions of structure functions are our base equations. We have incorporated pion

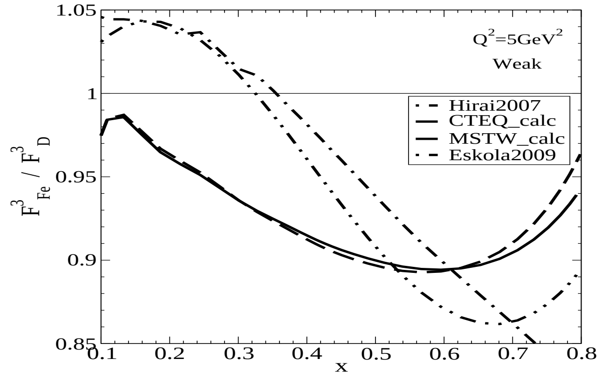

FIGURE 4. F_3^{Fe}/F_3^D as a function of x. The solid and dashed represent the results of our calculation using different PDFs: CTEQ [7] and MSTW [8]. These results are compared with the Eskola et al.(dotted-dashed) [13] and Hirai et al.(double dotted-dashed) [14] phenomenological fits.

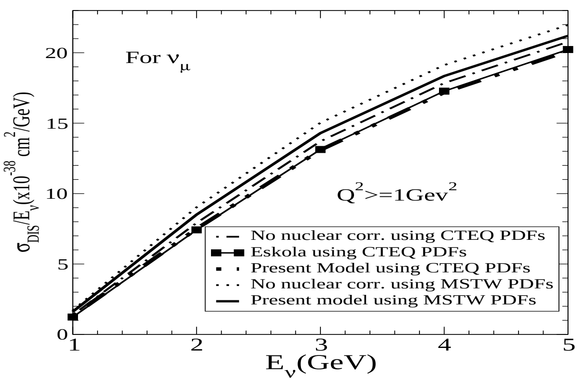

FIGURE 5. σ vs E_ν for Iron target. σ is normalized to $1/E_\nu$. The dotted and dotted dashed curves represent the cross section of DIS using different PDFs: CTEQ [7] and MSTW [8] for the free ν-N reaction. The solid and double dotted-dashed curves represent the respective cross sections with nuclear medium effects. The results using Eskola parameterization [13] have been shown by square-with lines.

and rho cloud contributions following Ref. [1], and shadowing and anti-shadowing effects using the prescription given in Ref. [6], some details of which are given in Ref. [3]. Using Eqns. 2 and 3 in Eq.1 we have calculated the total scattering cross section.

RESULTS AND DISCUSSION

In Fig.1, we have presented the numerical results for the F_2^A and F_3^A structure functions as a function of Q^2 at some values of x and compared them with the experimental results of NuTeV [11] and CDHSW [12] collaborations. Furthermore, these numerical results have been compared with the results obtained from some of the phenomenological studies performed by Eskola et al. [13] and Hirai et al. [14]. These results are presented using our base equation and with full calculations where pion and rho meson contributions and nuclear shadowing and anti-shadowing effects are taken into account. We find that our results using the full calculations agree with the recently measured structure functions by the NuTeV collaboration [11]. We have also obtained the structure function in deuteron using Eq.(60) of Ref. [16]. In Fig. 2, we have obtained the ratio of the structure functions in Iron and Deuteron for electromagnetic case and compared them with the SLAC results [15]. In Figs. 3 and 4, we have obtained this ratio for the neutrino induced weak interaction processes. We find that the F_2 ratios in weak and electromagnetic cases are of similar nature while F_3 is of different nature. In Fig. 5, we present the numerical results for σ vs E_ν in Iron using CTEQ [7] and MSTW [8] PDFs. We have also plotted the results obtained by using Eskola parameterization [13]. By using different PDFs viz. CTEQ [7] and MSTW [8] we find that the results change by about 18% at $E_\nu = 1GeV$ and 8% at $E_\nu = 3GeV$. When we include shadowing and anti-shadowing effects and pion and rho cloud contributions to our base calculations the cross section changes by about 4% at $E_\nu = 1GeV$ and 5% at $E_\nu = 3GeV$. Thus, in the DIS ν-nucleus scattering, the cross section is sensitive to nuclear effects as well as to the PDFs available in the literature and one should consider both effects while predicting the lepton events.

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