Charged current $\nu_\tau -^{16} O$ scattering in the DIS region

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1. Introduction

This is the first theoretical study to understand nuclear medium effects in the charged current ν_τ induced deep inelastic scattering (DIS) cross sections off oxygen (^{16}O) target. This work is relevant for the atmospheric neutrino experiments like HyperK and IceCube, as well as to the $\nu_\mu \to \nu_\tau$ appearance experiments using accelerator sources. $\tau-$lepton production has been reported by various experimental collaborations such as OPERA, DONUT, SuperK, IceCube, etc., however, the reported events are with low statistics. Some promising future experiments like SHiP, DUNE, DsTau, FASERν are aiming to study $\nu_\tau-$physics. Therefore, theoretical understanding of ν_τ interaction off free nucleon and nuclear targets become important. Recently, we have performed a theoretical study of $\nu_\tau - N$ charged current DIS process by incorporating the higher order perturbative and nonperturbative QCD corrections [1]. Since all the neutrino experiments are being performed using nuclear targets where nuclear medium effects become important, therefore, in this work, we have studied $\nu_\tau-^{16}$O DIS cross section. The numerical calculations have been performed using a microscopic field theoretical model, where the nuclear medium effects like binding energy, Fermi motion and nucleon correlations are included through the hole spectral function. Further the mesonic contribution is taken into account and shadowing effect is included following the Glauber-Gribov multiple scattering theory. For details please see Ref. [2].

2. Formalism

The differential scattering cross section for $\nu_l(k) +^{16} O(p) \to l^-(k') + X(p');\ (l = e, \mu, \tau)$ is written as [3]:

$$\begin{aligned}\frac{d^2\sigma_A}{dxdy} &= \kappa\Big\{\Big[y^2x + \frac{m_l^2 y}{2E_\nu M_N}\Big]F_{1A}(x,Q^2) + F_{2A}(x,Q^2)\\ &\times \Big[\Big(1-\frac{m_l^2}{4E_\nu^2}\Big) - \Big(1+\frac{M_N x}{2E_\nu}\Big)y\Big] \pm F_{3A}(x,Q^2)\\ &\times \Big[xy\Big(1-\frac{y}{2}\Big) - \frac{m_l^2 y}{4E_\nu M_N}\Big] + F_{4A}(x,Q^2)\\ &\times \frac{m_l^2(m_l^2+Q^2)}{4E_\nu^2 M_N^2 x} - \frac{m_l^2}{E_\nu M_N}F_{5A}(x,Q^2)\Big\}, \quad (1)\end{aligned}$$

where $F_{iA}(x,Q^2);\ i = 1-5$ are the dimensionless nuclear structure functions, $\kappa = \frac{G_F^2 M_N E_\nu}{\pi(1+\frac{Q^2}{M_W^2})^2}$ and the symbols have their usual meanings [3]. For $\tau-$lepton production, the contributions from $F_{4A}(x,Q^2)$ and $F_{5A}(x,Q^2)$ are non-negligible. The expressions for $F_{iA}(x,Q^2)$ are obtained independently at the nuclear level and are given in terms of the hole spectral function (S_h) as [2]

$$\begin{aligned}F_{iA,N}(x_A,Q^2) &= 4\int d^3r \int \frac{d^3p}{(2\pi)^3}\,\frac{M_N}{E_N(\mathbf{p})}\\ &\times \int_{-\infty}^{\mu} dp^0\ S_h(p^0,\mathbf{p},\rho(r))\ \times f_{iN}(x,Q^2), \quad (2)\end{aligned}$$

where μ is chemical potential, $\rho(r)$ is the nuclear charge density and $i = 1-5$ [2]. $f_{iN}(x,Q^2);\ (i=1-5)$ are expressed in terms of the dimensionless nucleon structure functions $F_{iN}(x_N,Q^2);\ (i=1-5)$ which are evaluated by using the MMHT nucleonic PDFs parameterization in the four flavor (u, d, s and c) MSbar scheme assuming the Callan-Gross and Albright-Jarlskog relations to be valid at the leading order. In the present calculations, the charm quark is treated to be massive. The expressions for $f_{iN}(x,Q^2);\ (i = 1-3)$ and the other details of the numerical calculations would be presented in the symposium. The results obtained with spectral function only have been labeled here as 'SF' and the results with full model, i.e. having contributions from mesonic cloud and shadowing effect are

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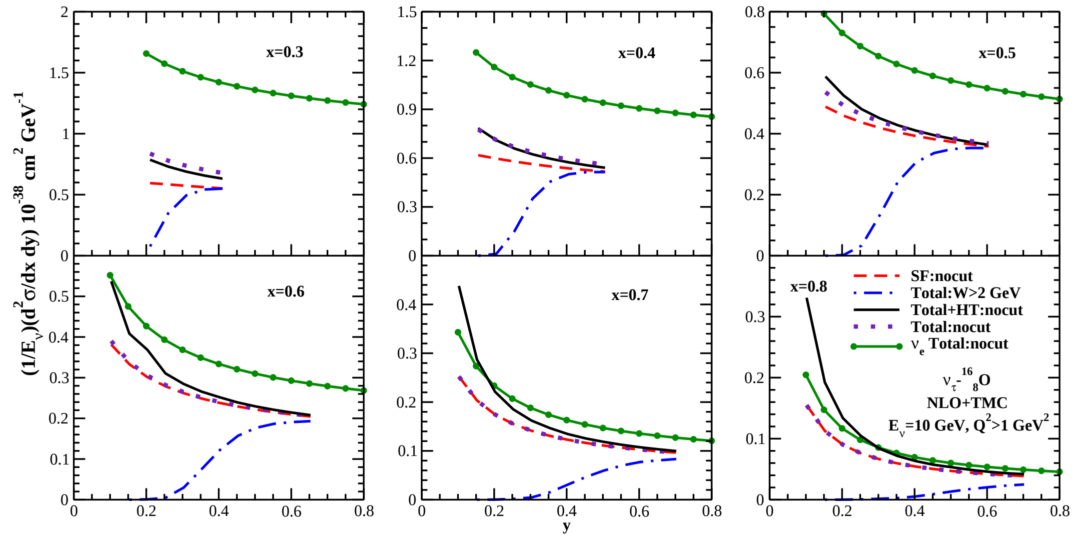

FIG. 1: Differential cross section for $\nu_\tau{-}^{16}$O at $E_\nu = 10$ GeV are shown. Results are obtained at NLO by using MMHT PDFs parameterization and incorporating the TMC, HT and massive charm effects.

labeled as 'Total'. All the results are obtained by incorporating the TMC effect and keeping $Q^2 > 1$ GeV^2.

3. Results and Discussion

The results for the differential scattering cross sections for $\nu_\tau{-}^{16}$O are shown in Fig. 1 at $E_\nu = 10$ GeV. We find that the results obtained with the full model are $\approx 40\%(7\%)$ higher than the results with the spectral function only at $x = 0.3(0.5)$ and $y = 0.2$ which become $\approx 23\%(4\%)$ for $y = 0.4$. This enhancement is due to the mesonic contributions which is significant for $x < 0.6$ and becomes negligible for $x > 0.6$. Furthermore, we have observed that the effect of massive charm quark is negligible in the present case (not shown here explicitly). When higher twist corrections is included along with TMC effect, the differential cross sections gets slightly reduced at low $x(< 0.5)$ while with the increase in $x(\geq 0.5)$ there is an enhancement especially in the region of low y. Moreover, due to the effect of center of mass energy cut ($W > 2$ GeV) we have observed a reduction in the results of scattering cross section which is about 90% at $x = 0.3$ and 99% at $x = 0.5$ for $y = 0.2$ while it reduce to 20% at $x = 0.3$ and 24% at $x = 0.5$ for $y = 0.4$. We have also compared the results of differential cross sections obtained for $\nu_\tau{-}^{16}$O and $\nu_e{-}^{16}$O DIS processes in order to quantify the lepton mass effect. From the figure, one may notice that $\tau-$lepton cross sections are significantly less as compared to the electron production cross section which is due to the contribution coming from $F_{4A}(x, Q^2)$ and $F_{5A}(x, Q^2)$ to the scattering cross sections. Quantitatively this difference is $\approx 50\%$ at $x = 0.3$ and 32% at $x = 0.5$ for $y = 0.2$. However, for $0.7 \leq x \leq 0.8$ and $y \leq 0.3$, tau lepton events get enhanced as compared to electron production events mainly due to the effect of HT corrections. Present results will be discussed in detail in the forthcoming symposium.

References

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