Nucleon structure functions with kinematic and dynamic higher twist effects

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Recently lots of emphasis have been put to precisely measure the parameters of neutrino mixing matrix (i.e. PMNS matrix). The next goals of neutrino physics community are to observe CP violation in the leptonic sector and fix the hierarchy problem. For this, long baseline experiments like NOvA, T2KK and DUNE are planned. Since neutrino experiments are using nuclear targets, therefore, it is also important to understand nucleon dynamics in the nuclear medium which are estimated to contribute $20-25\%$ uncertainty in the systematics. Experimentally, EMC type of measurements are going on at MINERvA using neutrino/antineutrino beam with several nuclear targets like ^{12}C, ^{16}O, etc. Most of the neutrino experiments are being performed in the intermediate energy region (1-5 GeV) and it has been estimated that for this energy range significant number of events will contribute from the deep inelastic scattering (DIS) and the duality region [1]. In literature, the precise limits for the cut-off of duality region and the onset of DIS region are not well defined, for example, MINERvA is taking the kinematical limits of $W > 2\ GeV$ and $Q^2 \geq 1\ GeV^2$ for the safe DIS region. Therefore, it becomes important to develop a better theoretical understanding in the intermediate energy region. Phenomenologically, in the case of DIS process the nuclear medium effects for the electromagnetic and weak interactions are taken to be the same by the group of Paukkunen and Salgado while nCTEQ group found them to be different. Since for weak interaction both the vector and axial vector currents contribute unlike the case of electromagnetic interaction, therefore, the nuclear medium effects in the case of weak interaction should be different than the electromagnetic interaction. Hence, it is required to properly understand the free nucleon structure functions before moving to their modifications in the nuclear medium.

In this paper, we study the free nucleon structure functions for the lepton-nucleon DIS process, in the wide range of x and $Q^2 \geq 1\ GeV^2$. The numerical evolution have been performed at next-to-the leading order (NLO) independently for $F_1(x,Q^2)$ and $F_2(x,Q^2)$, i.e. without using the Callan-Gross relation ($2xF_1(x) = F_2(x)$). The nucleon structure functions have been evaluated with the target mass correction (TMC) effect incorporated by using the operator product expansion approach and the dynamic higher twist (HT) effect which is included using the renormalon method. The effects of TMC and HT are important in the kinematic region of high x and moderate Q^2. In this way, we have obtained the results for the ratio of longitudinal to transverse structure functions, i.e. $R(x,Q^2) = \frac{F_L(x,Q^2)}{2xF_1(x,Q^2)}$ and compared them with the results of most widely used phenomenological parameterization given by Whitlow et al. [2] as well as with the available experimental data [2, 3]. Furthermore, we have also discussed the effect of different cuts on the center of mass (COM) energy W.

Formalism

The DIS scattering cross section is generally, written in terms of the nucleon structure functions as follows

$$\frac{d^2\sigma}{dx\,dy} \propto \Big[F_1(x,Q^2) \times x\,y^2 + F_2(x,Q^2) \times \left(1 - y - \frac{x\,y\,M}{2\,E}\right) + F_3(x,Q^2) \times y\left(1 - \frac{y}{2}\right)\Big] \quad (1)$$

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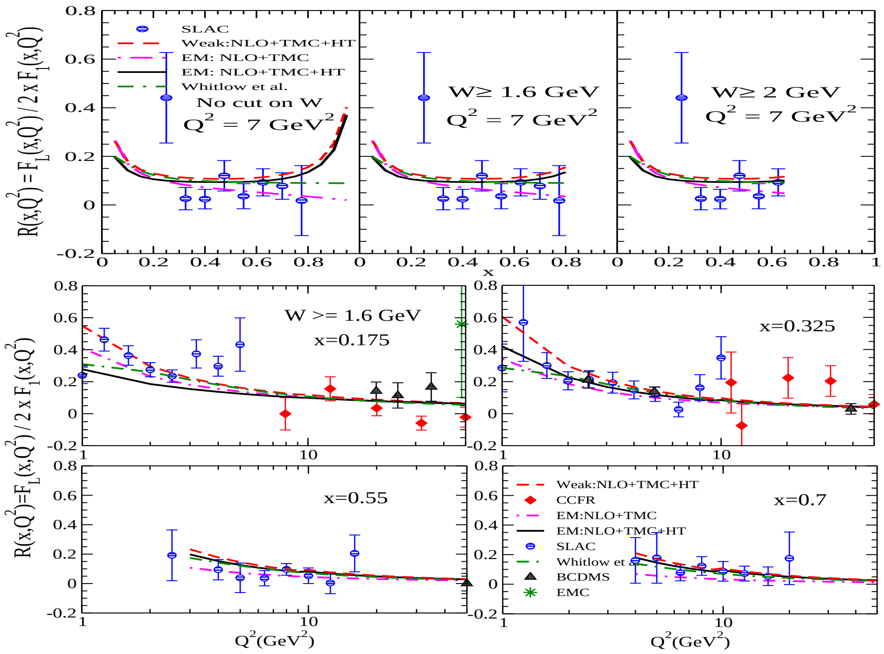

FIG. 1: Results for the ratio $R(x, Q^2) = \frac{F_L(x,Q^2)}{2xF_1(x,Q^2)}$ **(i) Top panel:** vs x at $Q^2 = 7\ GeV^2$ and **(ii) Bottom panel:** vs Q^2 at fix values of x, for the free nucleon target. The results are compared with the available experimental data [2, 3] and the phenomenological parameterization of Whitlow et al. [2].

In Eq. (1), x, y, M and E are respectively, the Bjorken variable, inelasticity, target nucleon mass and the energy of the incoming beam. $F_3(x, Q^2)$ is the parity violating structure function that will play role only in the case of weak interaction. The nucleon structure functions $F_1(x, Q^2)$ is purely transverse in nature, however, $F_2(x, Q^2)$ has contribution from both the transverse and longitudinal components. Therefore, the longitudinal structure function is defined as

$$F_L(x, Q^2) = \left(1 + \frac{4M^2x^2}{Q^2}\right) F_2(x, Q^2) - 2xF_1(x, Q^2),$$

and the ratio $R(x, Q^2)$ is given by

$$R(x, Q^2) = \frac{\sigma_L}{\sigma_T} = \frac{F_L(x,Q^2)}{2xF_1(x,Q^2)}$$

Using the above expression, we have obtained the results for two cases: (**i**) without applying any cut on COM energy (W) and (**ii**) by applying a cut of $W \geq 1.6\,GeV$ and $W \geq 2\,GeV$.

Results and Discussion

In Fig. 1 (top panel), we have shown the results for the ratio $R(x, Q^2)$ vs x at $Q^2 = 7\ GeV^2$ and in Fig. 1 (bottom panel) the results are presented in the wide range of x and Q^2, for the lepton-nucleon deep inelastic scattering processes. We find that the results for the ratio obtained in the case of electromagnetic interaction is different than what has been found out for weak interaction. The numerical results are compared with the experimental data of SLAC, BCDMS, EMC and CCFR [2, 3] as well as with the phenomenological parameterization of Whitlow et al. [2]. We plan to perform the numerical calculations for different nuclear targets and will present the results in the conference.

References

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