Why better theoretical models are needed to understand nuclear medium effect in the DIS region ?

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In the case of lepton scattering processes induced by charged leptons and (anti)neutrino on nucleons and nuclei, the inclusive cross sections at low energies are expressed in terms of structure functions corresponding to excitations of various resonances like Δ, N^*, etc., lying in the first or higher resonance region depending on the center of mass (CM) energy W of the final hadrons. On the other hand, at high energies and Q^2, the inclusive cross sections are expressed in terms of the structure functions corresponding to the Deep Inelastic Scattering(DIS) processes. The DIS region is understood to be the kinematic region with the center of mass energy W $\geq$ 2.0 GeV and $Q^2 \geq$ 1.0 GeV^2.

Charged lepton induced processes in the DIS region are being used to probe quark and gluon structures of nucleons and nuclei. Since the first result from EMC experiment at CERN showing that nuclear effects in the DIS region are non-negligible, efforts are continuously going on to improve our understanding of the nuclear medium effects. Generally the nuclear medium effects in the DIS region are expressed as the ratio of cross sections of lepton(l)-nucleus(A) scattering to lepton(l)-deuteron(D) scattering.

Recently JLab [1] has performed experiments using continuous electron beam facility with energies in the range of approximately 2 – 6 GeV, and precise measurements have been performed for the structure functions $F_1^N(x,Q^2)$, $F_2^N(x,Q^2)$, longitudinal structure function $F_L(x,Q^2)$ extending to low $Q^2(< 5GeV^2)$ using several nuclear targets like ^{12}C, ^{27}Al, ^{56}Fe, ^{64}Cu, ^{119}Sn, etc. The modification of structure functions in nuclear medium has also been studied earlier by NMC, JLab, SLAC, BCDMS, etc. collaborations, in some of these nuclear targets as well as a few other nuclear targets like ^{108}Ag, ^{197}Au, ^{208}Pb, etc. JLab also plans to upgrade electron beam energy to 12 GeV and perform the experiments using several nuclear targets. JLab experiment has observed that Bloom-Gilman duality to work even at $Q^2 \sim 1GeV^2$ or may be less than $1GeV^2$, which means that resonance structure function averaged over the scaling variable is almost equal to the deep inelastic structure function. In the weak sector, several experiments are going on to study neutrino oscillation physics and some of them like MINERνA [2] and DUNE [3] are specially designed to precisely measure neutrino and antineutrino cross sections in the DIS region on some nuclear targets.

Since most of these experiments are being performed using nuclear targets, therefore, it becomes essential to understand nuclear medium effects(NME) in the deep inelastic scattering region both in electromagnetic(EM) as well as weak(Weak) interaction processes. The differential and total scattering cross sections are expressed in terms of $F_{iA}^{EM}(x,Q^2)$, $i = 1-2$ $(A = nucleus)$ structure functions for EM processes and for weak interaction induced processes in terms of $F_{jA}^{Weak}(x,Q^2)$, $j = 1-3$, structure functions. There are two different approaches to understand nuclear medium correction in the DIS region, one is a phenomenological approach and the other is a theoretical approach. In the phenomenological analysis there are few approaches for determining nuclear PDFs. In most PDF analyses, the nuclear correction factors were taken from lepton-nucleus and p-nucleus scattering data, some of them also include Drell-Yan data as well as (anti)neutrino-nucleus scattering data. Most of the studies like of Eskola et al. and de Florian et al. do not find a difference in the nuclear correction factor obtained using $l^\pm - A$ and $\nu/\bar{\nu} - A$ scattering data. However, recent studies by CTEQ-Grenoble-Karlsruhe collaboration (nCTEQ) have shown that the nuclear correction factor is different in electromagnetic and weak interactions.

The several Monte Carlo generators being used for predicting neutrino event rates, do not differentiate between inelastic interactions and deep inelastic interactions, calling everything beyond the delta resonance region simply DIS. There is increasing awareness that shallow inelastic scattering(SIS) and DIS interactions can give significant backgrounds and contributions to the systematics in neutrino oscillation experiments. In future the experimental data in the energy range of 1 – 3 GeV from MINERνA [2], DUNE [3], NOνA [4] are expected which will have significant contributions from the resonance as well as DIS region. Neutrino scattering can also play an important role in extraction of PDFs since only neutrinos via the weak-interaction can resolve the flavor of the nucleon's constituents: ν interacts with d, s, $\bar{u}$ and $\bar{c}$ while the $\bar{\nu}$ interacts with u, c, $\bar{d}$ and $\bar{s}$. Understanding the physics in this kinematic region is therefore important.

There have been few recent developments in the theory of DIS particularly in the weak sector. Kulagin and Petti [5] have performed some studies and the other is done by us at Aligarh [6]-[9]. We have studied NME arising due to the Fermi motion, binding energy, nucleon correlations, mesonic contributions and shadowing effects, in the structure functions, using a many body field theoretical approach. The calculations are performed in a local density approximation using a relativistic nucleon spectral function. The details are given in Ref. [6]-[9].

In this conference, I will present the current understanding of NME in EM and Weak sectors and the challenges ahead at both the theoretical as well as at the experimental levels.

References

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