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Nuclear medium effects in structure functions of nucleon at moderate Q^2

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Abstract

Recent experiments performed on inclusive electron scattering from nuclear targets have measured the nucleon electromagnetic structure functions $F_1(x, Q^2)$, $F_2(x, Q^2)$ and $F_L(x, Q^2)$ in ^{12}C, ^{27}Al, ^{56}Fe and ^{64}Cu nuclei. The measurements have been done in the energy region of $1\ \text{GeV}^2 < W^2 < 4\ \text{GeV}^2$ and Q^2 region of $0.5\ \text{GeV}^2 < Q^2 < 4.5\ \text{GeV}^2$. We have calculated nuclear medium effects in these structure functions arising due to the Fermi motion, binding energy, nucleon correlations, mesonic contributions from pion and rho mesons and shadowing effects. The calculations are performed in a local density approximation using a relativistic nucleon spectral function which includes nucleon correlations. The numerical results are compared with the recent experimental data from JLab and also with some earlier experiments.

Keywords: Deep inelastic scattering; Structure function; Nuclear medium effect; Local density approximation

1. Introduction

Charged lepton induced processes in the deep inelastic scattering region are used to probe quark and gluon structures of nucleons and nuclei. The inclusive lepton scattering from nucleon and nuclear targets is an important tool to study the nucleon structure and its modification in

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nuclear medium. The early results from the experiments performed at SLAC in the kinematic region of high energy transfer (ν) and high momentum transfer (Q^2) corresponding to Deep Inelastic Scattering (DIS) exhibited remarkable phenomenon of Bjorken scaling [1]. In Bjorken scaling, the nucleon structure functions in the asymptotic region of very high Q^2 are found to be independent of Q^2 and depend only upon single dimensionless variable $x(=\frac{Q^2}{2M\nu})$ instead of otherwise independent variables Q^2 and ν. This Q^2 independence of nucleon structure functions led to the first evidence that nucleons consist of structureless constituents identified as quarks and gluons. Furthermore, the lepton–nucleon cross sections were found to be incoherent sum of elastic lepton scattering cross section from these structureless constituents confirming the asymptotic freedom predicted by QCD. At lower values of Q^2 and x, the nucleon structure functions exhibit Q^2 dependence which is attributed to the violation of Bjorken scaling due to higher twist correction in QCD [2–4]. These higher twist corrections arise due to quark–quark and quark–gluon interactions in the nucleon which play an important role when we move to lower Q^2 from the asymptotic region in Q^2. The nucleon structure functions in the scaling region of high Q^2, and their Q^2 evolution to lower Q^2 region are described rather well using the methods of perturbative QCD and evolution equation of DGLAP [5].

In the case of deep inelastic lepton scattering from nuclear targets, the nuclear structure functions per nucleon are found to be quite different from the nucleon structure functions as discovered by the EMC effect first observed at CERN [6] and confirmed by many experiments thereafter [7–30]. These modifications in the nucleon structure function are due to the nuclear medium effects like Fermi motion, binding energy, nucleon correlations, mesonic contributions, etc. These are in addition to higher twist effects in QCD for nucleons and mesons in nuclear medium [31–33].

The nuclear medium effects in the DIS region are divided into four parts which are broadly identified in terms of Bjorken scaling variable x. These are (i) the shadowing effect which is effective in the low values of $x(< 0.1)$. It has been found that in this region $R(=\frac{\sigma^A}{\sigma^D})$ gets suppressed, and the suppression increases with the increase in the nucleon number A, (ii) the anti-shadowing effect which is effective in the region $0.1 < x < 0.3$, where there is slight enhancement in the ratio R which has been found to be independent of the nucleon number A. Shadowing and anti-shadowing effects are attributed respectively due to the constructive and destructive interference of amplitudes arising from the multiple scattering of quarks inside the nucleus, (iii) the EMC effect which is a large suppression in a wide range of x $(0.3 < x < 0.8)$, and is broadly understood as due to the modification of nucleon structure functions in nuclei, and (iv) the binding energy and the Fermi motion effect which is effective for $x > 0.8$ and this arises due to the fact that the nucleons in a nucleus are moving with an average momentum $p \leq p_F$, where p_F is the Fermi momentum.

In the DIS region, phenomenologically [34–38] as well as theoretically [39–73] various attempts have been made to understand the nuclear medium effects. Phenomenologically the studies have been made to obtain a nuclear correction factor by doing the analysis of the experimental data on charged lepton–nucleus scattering, (anti)neutrino nucleus scattering, pion–nucleus scattering, proton–nucleus scattering, Drell–Yan processes, etc. Theoretically many models have been proposed to study these effects on the basis of nuclear binding, nuclear medium modification including short range correlations in nuclei [39–63], pion excess in nuclei [41,43,48,64–66], multi-quark clusters [67–69], dynamical rescaling [70,71], nuclear shadowing [72,73], etc. In spite of these efforts a comprehensive understanding of the nuclear modifications of nucleon structure functions valid for the entire region of x is still lacking [44–47].