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Nuclear medium effects in $F_{2A}^{EM}(x, Q^2)$ and $F_{2A}^{Weak}(x, Q^2)$ structure functions

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Abstract

Recent phenomenological analysis of experimental data on DIS processes induced by charged leptons and neutrinos/antineutrinos beams on nuclear targets by CTEQ collaboration has confirmed the observation of CCFR and NuTeV collaborations, that weak structure function $F_{2A}^{Weak}(x, Q^2)$ is different from electromagnetic structure function $F_{2A}^{EM}(x, Q^2)$ in a nucleus like iron, specially in the region of low x and Q^2. In view of this observation we have made a study of nuclear medium effects on $F_{2A}^{Weak}(x, Q^2)$ and $F_{2A}^{EM}(x, Q^2)$ for a wide range of x and Q^2 using a microscopic nuclear model. We have considered Fermi motion, binding energy, nucleon correlations, mesonic contributions from pion and rho mesons and shadowing effects to incorporate nuclear medium effects. The calculations are performed in a local density approximation using a relativistic nucleon spectral function which includes nucleon correlations. The numerical results in the case of iron nucleus are compared with the experimental data.

Keywords: Nuclear medium effects; Structure functions; Electromagnetic interaction; Weak interaction

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1. Introduction

The Deep Inelastic Scattering (DIS) processes induced by charged leptons and neutrinos/antineutrinos on nucleons and nuclear targets are important tools to study the quark parton structure of free nucleons and the nucleons when they are bound in a nucleus. The first observation of EMC effect in the DIS of muon [1] from iron target and using electron beam with various nuclear targets at SLAC [2], discovered that the quark parton distribution of free nucleons are considerably modified when they are bound in a nucleus. Subsequent DIS experiments performed on many nuclear targets with charged leptons [3–12] and neutrinos/antineutrinos [13–23] have confirmed the initial results of EMC effect. These experiments make measurements of DIS cross sections which are theoretically expressed in terms of nucleon structure functions. The structure functions are determined by making Rosenbluth-like separations of the measured cross section. The electromagnetic DIS cross section induced by charged leptons are given in terms of two structure functions $F_i^{EM}(x, Q^2)$ $(i = 1, 2)$, while the weak DIS cross section induced by neutrinos/antineutrinos are given in terms of three structure functions $F_i^{Weak}(x, Q^2)$ $(i = 1, 2, 3)$, where x is the Bjorken scaling variable given by $x = \frac{Q^2}{2M\nu}$; Q^2, ν and M being the four momentum transfer square, the energy transfer $(\nu = E_l - E_l')$ to the target and nucleon mass, respectively [24]. In the kinematic region of Bjorken scaling of large ν and Q^2, the structure functions $F_1(x, Q^2)$ and $F_2(x, Q^2)$ are related by the Callan–Gross relation [25]. Therefore, in this kinematic region, the electromagnetic DIS cross sections are expressed in terms of only one structure function chosen to be $F_2^{EM}(x, Q^2)$ and the weak DIS cross sections are given in terms of two structure functions $F_2^{Weak}(x, Q^2)$ and $F_3^{Weak}(x, Q^2)$. The DIS experiments induced by charged leptons have been done using nuclear targets in the entire region of mass number from light nuclei to heavy nuclei, while the weak DIS experiments induced by neutrinos/antineutrinos have been done mainly on medium and heavy nuclei [18–23]. Therefore, it is very important to study the nuclear medium effects in the cross section and the structure functions determined from these DIS experiments in order to understand the structure functions of free nucleons and their modifications in nuclear medium.

Considerable theoretical and experimental efforts have been devoted to understand the nuclear medium effects on the structure function $F_{2A}(x, Q^2)$ in electromagnetic and weak interactions as they play dominant role in determining the cross sections. A precise knowledge of nuclear medium effects in $F_{2A}^{EM,Weak}(x, Q^2)$ can give information about the higher twist effects in the quark–parton distributions of both valence quarks and sea quarks in the free nucleon as well as their modifications in the nuclear medium in contrast to $F_{3A}^{Weak}(x, Q^2)$ which is sensitive only to the valence quarks. Consequently a comparative study of $F_{2A}^{EM,Weak}(x, Q^2)$ and $F_{3A}^{Weak}(x, Q^2)$ gives very useful information about the properties of sea quarks and their modifications in nuclear medium.

JLab is using high luminosity electron beams to make cross section measurements with several nuclear targets, which have resulted in obtaining wealth of new information on the structure functions $F_{1A}^{EM}(x, Q^2)$ and $F_{2A}^{EM}(x, Q^2)$ with good precision [10]. Furthermore, the future plan is to perform these measurements using high energy electron beam of 12 GeV in wide range of x and Q^2. In the weak sector, several experiments are going on to study neutrino oscillation physics and some of them like MINERvA [15,16] and DUNE [26] are specially designed to precisely measure neutrino and antineutrino cross sections in the DIS region on some nuclear targets like carbon, oxygen, argon, iron and lead. The presently available data on electromagnetic nuclear