Nuclear medium effects in the evaluation of Callan Gross relation

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JLab has recently measured $F_1(x)$ and $F_2(x)$ structure functions separately as well as studied the difference $F_2(x)-2xF_1(x)$ (Callan-Gross relation) using electron-nucleus deep inelastic scattering(DIS) in the energy region of $2-6$ GeV of the electron beam [1]. Theoretically, it is important to understand nuclear medium effects for a fundamental process $eN \to eX$(N is the nucleon and X is jet of hadrons) taking place with a nucleon bound inside the nucleus. Generally, nuclear medium effects in the DIS region are understood due to shadowing and antishadowing effects [2, 3], mesonic cloud contributions [4], Fermi motion and binding energy etc. In the present paper we have studied nuclear medium effects in microscopic model using relativistic nucleon spectral function to describe nucleon momentum distribution. The Fermi motion, binding energy effect and nucleon-nucleon correlations are taken into account using spectral functions. The spectral functions that describe energy and momentum distribution of nucleon is obtained by using the Lehmann's representation for the relativistic nucleon propagator and nuclear many body theory is used to calculate it for an interacting Fermi sea in nuclear matter. A local density approximation is then applied to translate these results to a finite nucleus. We have taken into account pion and rho mesons cloud contributions which are found to have important contribution in the intermediate region of Bjorken variable x [4]. Furthermore, shadowing and antishadowing effects are also taken into account using phenomenological model of Kulagin and Petti [5]. Numerical evaluation have been performed both at the leading order(LO) and next-to-leading order(NLO).

The expressions for the nuclear structure functions $F_1^A(x)$ and $F_2^A(x)$ in the present model are obtained as

$$F^A_{1\ N}(x_A,Q^2) = 2\sum_{\tau=p,n} AM\int d^3r\int\frac{d^3p}{(2\pi)^3}\frac{M}{E(\mathbf{p})}$$
$$\int_{-\infty}^{\mu} dp_0 S_h^\tau(p_0,\mathbf{p},\rho^\tau(r))\ \left[\frac{F_1^\tau(x_N,Q^2)}{M}\right.$$
$$\left.+\frac{1}{M^2}{p_x}^2\frac{F_2^\tau(x_N,Q^2)}{\nu}\right]. \quad (1)$$

$$F^A_{2\ N}(x,Q^2) = 2\sum_{\tau=p,n}\int d^3r\int\frac{d^3p}{(2\pi)^3}\frac{M}{E(\mathbf{p})}$$
$$\times\ \int_{-\infty}^{\mu} dp_0 S_h^\tau(p_0,\mathbf{p},\rho^\tau(r))\times\left[\frac{Q^2}{q_z^2}\left(\frac{|\mathbf{p}|^2\ -\ p_z^2}{2M^2}\right)\right.$$
$$\left.+\frac{(p_0\ -\ p_z\ \gamma)^2}{M^2}\left(\frac{p_z\ Q^2}{(p_0\ -\ p_z\ \gamma)q_0q_z}\ +\ 1\right)^2\right]$$
$$\frac{M}{p_0\ -\ p_z\ \gamma}\ F_2^\tau(x,Q^2), \quad (2)$$

where $\gamma=\frac{q^z}{q^0}$, M is the nucleon mass, p_z is the nucleon's momentum along the z-axis and S_h is the hole spectral function. Since in the laboratory frame the target nucleus is at rest, i.e. $\mathbf{p_A}=0, x_A=\frac{Q^2}{2M_A\ q_0}$ and for the nucleons that are moving inside the nucleus $x_N=\frac{Q^2}{2(p_0q_0-p_zq_z)}$. Since structure functions of nucleon can be written in terms of the parton distribution functions(PDFs), therefore, we used CTEQ PDFs [6] for nucleon and PDFs given by Gluck et al. [7] for pion and rho mesons. For details please see Ref. [8, 9].

In this work we have performed the calculations using Eq.1 and Eq.2 for nuclear targets like ^{12}C, ^{56}Fe. To show the nuclear dependence of structure functions, we have compared the results obtained for free nucleon target to the results obtained for nuclear targets.

In Fig.1, we have shown the results of $F_2(x)$ and $2xF_1(x)$ at LO and NLO for ^{12}C(left-panel) and ^{56}Fe(right-panel) nuclei. It may

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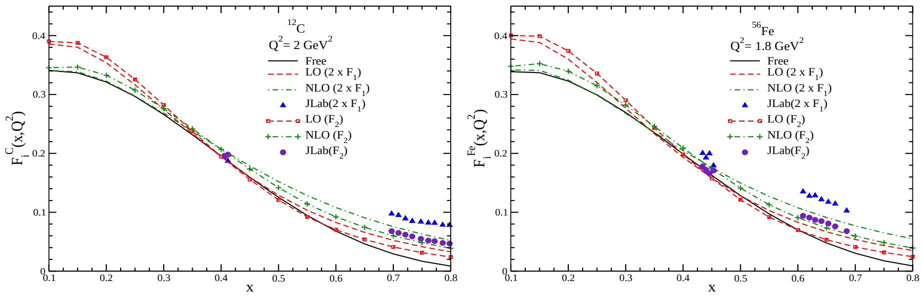

FIG. 1: Results of $F_2(x,Q^2)$ and $2xF_1(x,Q^2)$ for ^{12}C and ^{56}Fe are shown at different Q^2 for LO and NLO. Results are also compared with the JLab [1] exprimental data.

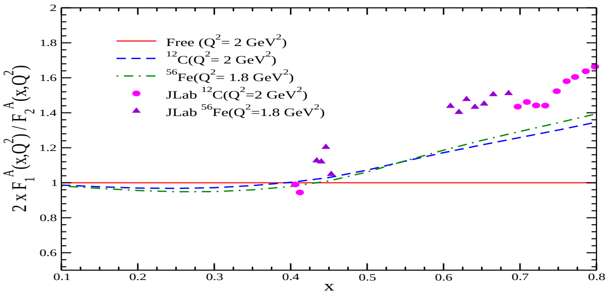

FIG. 2: Deviation of Callan-Gross relation in nuclear medium for ^{12}C and ^{56}Fe at different Q^2 for NLO. Results are also compared with the JLab [1] exprimental data.

be noticed that there is significant difference between $F_2(x)$ and $2xF_1(x)$, e.g. in ^{12}C nucleus at $x = 0.2$ it is around 3% and 15% at $x = 0.6$. When we compared the results obtained at NLO to the results at LO then it is found that there is reduction from LO values and it increases with the increase in x. This difference is more pronounced for heavier nuclear targets. We have also compared our results with the JLab experimental data [1]. We find that the numerical results are in good agreement with the experimental data.

In Fig.2, we have shown the results for the ratio of structure functions $\frac{F_2(x)}{2xF_1(x)}$ for free nucleon and for nuclear targets at NLO. It is noticeable that for free nucleon case this ratio is unity while for the case of bound nucleons it is different from unity at the mid values of x. We have also compared the numerical results with the JLab experimental data and found them in good agreement. Hence, it may be concluded that there is a deviation of Callan-Gross relation in a nucleus when nuclear medium effects are taken into account.

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