Nuclear medium effects in the evalution of GLS and Adler's sum rules

F. Zaidi, H. Haider,* M. Sajjad Athar, and S. K. Singh
Aligarh Muslim University, Aligarh - 202002, INDIA

Neutrino experiments are being performed in the few GeV energy region using nuclear targets. In the region of deep inelastic scattering(DIS), data have been obtained by CCFR and NuTeV collaborations [1, 2] and the plan is to have more precise DIS measurements at MINERνA and the proposed LBNE experiments. In the high energy (anti)neutrino interaction with nuclear target, it is important to study the nuclear medium modification effects on the structure functions $F_2^\nu(x,Q^2)$ and $F_3^\nu(x,Q^2)$. Of much interest is the estimate of the size of the nuclear medium effects on the GLS [3] and Adler's sum rules [4] which have been measured in the past over a wide range of Q^2 [1, 5]. In this paper, we study effects of nuclear medium on the evaluation of sum rules by considering the various effects like binding energy, Fermi motion, nucleon correlation, mesonic degrees of freedom of nuclei, target mass correction and shadowing effects. The details of the model are discussed in Refs. [6, 7].

For an isoscalar target and a symmetric sea, $F_3^N(x)$ structure function is given in terms of valence quarks u_v and d_v which satisfies the Gross-Llewellyn Smith sum rule [3]:

$$\int_0^1 F_3^N(x)dx = 3.$$

and the Adler's sum rule [4] predicts the difference between the quark densities of the neutron and the proton, integrated over x and is given by

$$\int_0^1 \frac{dx}{x}\left[F_2^{\nu(\bar\nu)N}(x) - F_2^{\nu(\bar\nu)N'}(x)\right] = 2; N, N' = p, n$$

*Electronic address: huma.haider8@gmail.com

When these sum rules are evaluated using data from $\nu(\bar\nu)$-A scattering, nuclear medium effects become important, and in the present model [6, 7], the structure functions $F_{2,3}^A(x_A,Q^2)$ are given by

$$F_2^A(x_A,Q^2) = 4\int d^3r\int\frac{d^3p}{(2\pi)^3}\int_{-\infty}^{\mu} d\omega \times S_h(\omega,\mathbf{p},\rho(\mathbf{r}))F'(p,Q^2)F_2^N(x_N,Q^2)$$

In the above expression $F'(p,Q^2) = \frac{\left(1-\gamma\frac{p_z}{M}\right)}{\gamma^2}\left(\gamma'^2 + \frac{6x_N^2(\mathbf{p}^2-p_z^2)}{Q^2}\right)$, $p^0 = M+\omega$, $\gamma'^2 = 1+4x_N^2p^2/Q^2$, $x_N = Q^2/(2p\cdot q)$ and $x_A = \frac{x}{A} = \frac{1}{A}\frac{Q^2}{2Mq_0}$.

Similarly F_3^A nuclear structure function is given by [6]

$$F_3^A(x_A,Q^2) = 4\int d^3r\int\frac{d^3p}{(2\pi)^3}\int_{-\infty}^{\mu} d\omega \times S_h(\omega,\mathbf{p},\rho(\mathbf{r}))F(p,Q^2)F_3^N(x_N,Q^2)$$

where $F(p,Q^2) = \left(\frac{p_0\gamma-p_z}{(p_0-p_z\gamma)\gamma}\right)$, $\gamma = \frac{q_z}{q^0} = \left(1+\frac{4M^2x^2}{Q^2}\right)^{1/2}$.

The GLS sum rule provides a benchmark to test various models used for the calculation of $F_3^A(x,Q^2)$. In the limit of noninteracting nucleons this trivially reproduces the GLS sum rule for free nucleons. The Q^2 dependent nuclear effects in the GLS integral enter through the factor γ and the Q^2 dependence of $F_3^N(x_N,Q^2)$ when it is integrated over x. The Q^2 dependent nuclear corrections to the GLS sum rule are thus linked to the Q^2 dependent perturbative and non-perturbative QCD effects appearing in $F_3^N(x_N,Q^2)$.

In Figs.1 and 2, we present the results for $S_{GLS}^A = \int_0^1 F_3^A(x)dx$ and $S_{Adler}^A = \int_0^1\frac{dx}{x}\left[F_2^{\bar\nu A}(x) - F_2^{\nu A}(x)\right]$(where $A = ^{56}Fe$), using the expressions for $F_{2,3}^A(x_A,Q^2)$. First

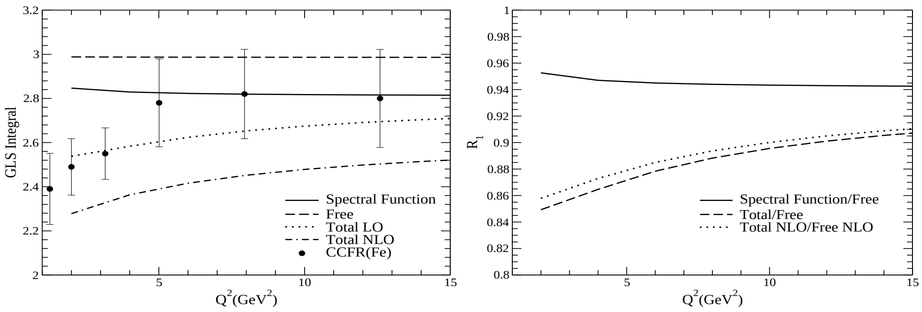

FIG. 1: Gross-Llewellyn Simth sum rule vs Q^2(left panel),$\frac{\int_0^1 [F_3^A(x)/A]dx}{\int_0^1 F_3^N(x)dx}$ vs Q^2(right panel) in iron.

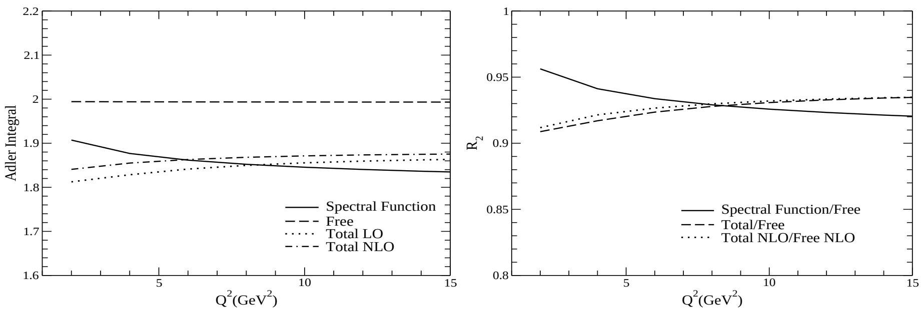

FIG. 2: Adler sum rule vs Q^2(left panel),$\frac{\int_0^1 F_2^A(x)dx}{A\int_0^1 F_2^N(x)dx}$ vs Q^2(right panel) in iron.

we get the results at the leading order(LO) with Spectral Function and Traget Mass Correction. Then we include meson degrees of freedom in case of $F_2^A(x_A, Q^2)$, and shadowing effects in $F_{2,3}^A(x_A, Q^2)$. This we call it as our full prescription(Total) at LO. The final results are obtained when we get the numerical results for the full prescription(Total) at Next-to-Leading Order(NLO). We find that the nuclear medium effects decrease the value of Adler's and GLS integrals for all Q^2. In Fig1(left panel), we have also presented the experimental result of CCFR collaboration [1]. In these figures(right panel), we also show the Ratio $R_1 = \frac{S_{GLS}^A}{A\ S_{GLS}^N}$ and $R_2 = \frac{S_{Adler}^A}{A\ S_{Adler}^N}$ where effect of nuclear medium with the Spectral Function, full presciption at LO and NLO are compared with the free case.

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