Structure functions of free and in-medium nucleons

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Abstract. Spin-dependent quark light-cone momentum distributions are calculated for a nucleon in the nuclear medium. We utilize a modified NJL model where the nucleon is described as a composite quark-diquark state. Scalar and vector mean fields are incorporated in the nuclear medium and these fields couple to the confined quarks in the nucleon. The effect of these fields on the spin-dependent distributions is investigated. Our results for the "spin-dependent EMC effect" are also discussed.

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INTRODUCTION

In this paper we determine the valence spin-dependent quark light-cone momentum distributions in a nuclear medium. The theoretical investigation of medium modifications to spin-dependent parton distributions (see *e.g.* [1, 2, 3, 4]) has not experienced the same level of activity as their spin-independent counterparts. However, it is crucial to investigate these effects as they go to the very heart of our understanding of nuclear structure. From a purely practical point of view we need to know how to correctly extract neutron structure functions from nuclear data.

FINITE DENSITY QUARK DISTRIBUTIONS

The spin-dependent light-cone quark distribution per nucleon in a nucleus of mass number A is defined as

$$\Delta f_{q/A}(x_A) = \frac{P_-}{A^2}\int \frac{d\omega^-}{2\pi} e^{iP_- x_A\,\omega^-/A}\langle A,P|\overline{\psi}_q(0)\,\gamma^+\gamma_5\,\psi_q(\omega^-)|A,P\rangle, \tag{1}$$

where ψ_q is the quark field (flavor q) and P^μ the 4-momentum of the nucleus. We evaluate this distribution using the convolution formalism.

In our model, we describe the single nucleon as a bound state of a quark and a scalar diquark in the Nambu-Jona-Lasinio model, and then calculate the nuclear matter equation of state in the mean field approximation. As a result we obtain the mean scalar and vector fields as functions of the baryon density. It is demonstrated in Ref. [5] that given a quark distribution in a free nucleon, the in-medium effect of the scalar

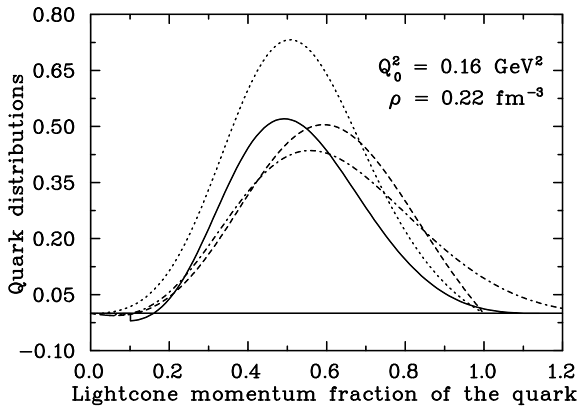

FIGURE 1. All results presented here for the polarized up-quark distribution are at the model scale, $Q_0^2 = 0.16\,\mathrm{GeV}^2$ and each distribution is multiplied by and plotted with respect to the appropriate Bjorken scaling variable. For the meaning of the lines, see text.

field can be included via the effective masses, and after the inclusion of fermi motion via convolution, the effects of the mean vector field can be included via the scale transformation

$$\Delta f_{q/A}(x_A) = \frac{\varepsilon_F}{E_F}\Delta f_{q/A0}\left(\tilde{x}_A = \frac{\varepsilon_F}{E_F}x_A - \frac{V_0}{E_F}\right). \tag{2}$$

Here $\varepsilon_F = \sqrt{p_F^2 + M_N^2} + 3V_0 \equiv E_F + 3V_0$, p_F is the Fermi momentum and V_0 is the zeroth component of the vector field felt by a quark. (The index 0 in Eq.(2) refers to the distribution without the vector field.)

The evaluation of this distribution can be associated with Feynman diagram calculations, see Ref. [6]. The zero density, longitudinally polarized, spin-dependent valence quark distributions, have a term from the "quark diagram", $\Delta f^{(Q)}_{q/N0}$, and the "diquark diagram", $\Delta f^{(D)}_{q/N0}$, and are given by

$$\Delta u_N(x) = \Delta f^{(Q)}_{q/N0} + \frac{1}{2}\Delta f^{(D)}_{q/N0}, \qquad \Delta d_N(x) = \frac{1}{2}\Delta f^{(D)}_{q/N0}, \tag{3}$$

where all quantities involve the free (zero density) masses. Because we include only the scalar diquark channel at this stage we find that $\Delta d_N(x) = 0$. For further details of our calculation and results for the free longitudinally polarized distributions, we refer to Refs. [6, 5].

RESULTS

The results for the finite density spin-dependent up-quark distribution are presented in Fig. 1. The dotted line shows the distribution in a free proton, the dashed line includes the effect of the scalar field, and incorporating Fermi motion via convolution results in the dot-dashed distribution. The effect of the vector field is now simply determined from the scale transformation of Eq. (2), and is indicated by the solid line in Fig. 1.

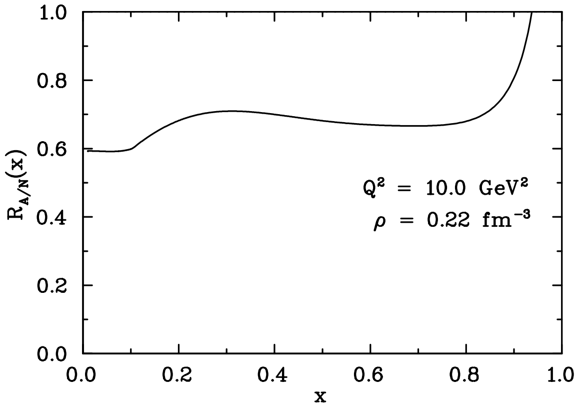

FIGURE 2. Ratio of $\Delta u_A(x_A)$ in the nuclear medium to $\Delta u_N(x)$ in the free proton, at the model saturation density and $Q^2 = 10$ GeV^2.

The curve in Fig. 2 is the ratio of the nuclear and nucleon spin-dependent u-quark distributions

$$R_{A/N}(x) = \frac{\Delta u_A(x_A)}{\Delta u_N(x)} \tag{4}$$

where the relation $x_A = \frac{M_{N0}}{\varepsilon_F} x = 1.02x$ is used to obtain $R_{A/N}(x)$ as a function of x only. (Here $M_{N0} = 940$ MeV is the free nucleon mass.) The ratio exhibits a plateau between $x \simeq 0.4$ to $x \simeq 0.8$ with an average value of about 0.7, and if we compare this to the corresponding result for the spin-independent case (that is, the EMC ratio), we expect that the medium modifications are more significant for the spin-dependent structure functions. For more quantitative conclusions, however, we have to include in addition also the axial vector diquark channel.

CONCLUSION

Nuclear medium modifications to the spin-dependent quark light-cone momentum distributions have been discussed. We find that the medium effects are significant, more so than the spin-independent case, discussed in Ref. [5], where the same formalism was used.

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