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STRUCTURE FUNCTIONS OF THE NUCLEON IN THE QUARK–DIQUARK MODEL AND EXTENSION TO FINITE DENSITY

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In this work we use a simple approximation to the relativistic Faddeev description of the nucleon in the framework of the Nambu-Jona-Lasinio (NJL) model. We discuss the flavor dependence of valence quark light-cone momentum distributions, and by comparing with the empirical informations we extract information on the strength of the axial vector diquark correlations. As an extension to finite density, we also discuss the EMC effect in nuclear matter, keeping only the scalar diquark channel in the wave function.

1. Introduction

The investigation of the nucleon structure functions is a very active field of current research [1,2,3]. On the theoretical side, it is not yet possible to directly use QCD for their description, although it is now possible to calculate the first few moments in lattice QCD and discuss the extrapolation to the chiral limit [4]. For a direct description of structure functions, however, effective quark theories, like bag models [5], soliton models [6] and Faddeev descriptions [7], play important roles.

In the first part of this work we will extend our previous calculations of quark light cone (LC) momentum distributions in the nucleon [7], which were based on the relativistic Faddeev equation [8] in the NJL model [9], assuming a simple "static approximation" [10] for the Faddeev kernel. In this approach, the nucleon is described as a bound state of a structured scalar diquark ($J^P = 0^+, T = 0$) and a quark, and pion cloud effects are taken into account perturbatively. Here we wish to investigate the influence of the strength of the correlations in the axial vector (a.v.) diquark channel ($J^P = 1^+, T = 1$) on the flavor dependence of the valence quark distributions, and discuss the consistency with the results based on a study of the static properties of the nucleon [11].

In the second part, we will investigate the medium effects on the nucleon structure functions, that is, the EMC effect in nuclear matter [12]. In a recent work [13], a stable nuclear matter equation of state has been obtained in the NJL model, combining the quark-scalar diquark description of the nucleon with the mean field (Hartree) description of the nuclear matter ground state by using a hybrid model. For the stability of nuclear matter it is essential to incorporate confinement effects phenomenologically so as to avoid unphysical decay thresholds. This has been done by introducing an infrared cut-off, in addition to the usual ultraviolet one, in the proper time regularization scheme [14]. We will present our results for the EMC ratio in nuclear matter based on this equation of state.

2. Calculations and results

The NJL Lagrangian can be characterized by the ratios $r_s = G_s/G_\pi$ and $r_a = G_a/G_\pi$ of the effective coupling constants in the scalar and a.v. diquark channels to the one in the pionic $q\overline{q}$ channel. In the calculation of the structure functions of a free nucleon, we treat r_a as a parameter, reflecting the strength of the correlations in the a.v. diquark channel, and adjust the value of r_s for each r_a so to reproduce the nucleon mass from the pole of the Faddeev equation in the static approximation [7]. We use the constituent quark mass $M = 400$ MeV, and employ the Brodsky-Lepage cut-off scheme [7,15]. The pion cloud effects are treated in the usual convolution formalism. By using the Q^2 evolution in the next-to-leading order [16], the results for the quark LC momentum distributions are evolved from the low energy scale $Q_0^2 = 0.16$ GeV^2 to the scale Q^2 where experimental data [1] and empirical parametrizations [2] are available,

In Fig.1 we show the ratio F_2^n/F_2^p of neutron to proton structure functions for various values of r_a. From the large x behavior we see that for small r_a the flavor dependence of the valence quark distributions is strong, while for large r_a it is weak. Comparing with the re-analyzed data of ref. [17], which are shown by the upper data points in Fig. 1, it seems that the range $0.15 < r_a < 0.3$ is reasonable, which corresponds to the range $0.90 < W_s < 0.98$ for the probability of the scalar diquark channel. (The "probability" is defined here as the contribution to the baryon number.) This conclusion, that a dominant scalar diquark configuration is preferable from the phenomenological point of view, is consistent with the results obtained from the study of the static properties of the nucleon [11,18].

We now discuss the results for the EMC ratio in nuclear matter, which were obtained by calculating the quark LC momentum distributions in a bound nucleon, using the NJL model equation of state of nuclear matter given in ref. [13]. As we men-

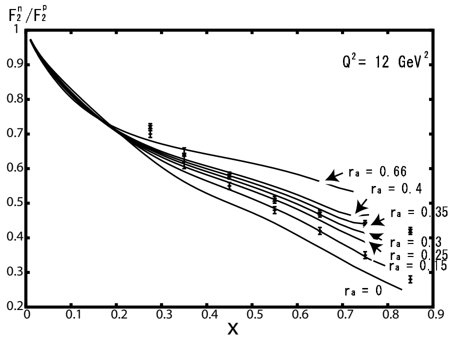

Fig. 1. The ratio of nucleon structure functions F_2^n/F_2^p at $Q^2 = 12$ GeV^2 is shown as a function of the Bjorken variable for various values of r_a. The lower data points are based on the original analysis [1], and the upper ones the re-analyzed data of ref. [17].

tioned above, the stability of the equation of state has been achieved by introducing an infrared cut-off in the proper time regularization scheme. Since this scheme is defined in Euclidean space, we first calculate the moments of the structure functions and then perform the inverse Mellin transformation, which can be done analytically within our model. The equation of state of ref.[13] is also used to calculate the nucleon LC momentum distribution in nuclear matter. The quark LC momentum distributions and structure functions in the medium are then obtained by applying the standard convolution formalism [3]. The EMC ratio in nuclear matter is shown in Fig. 2.

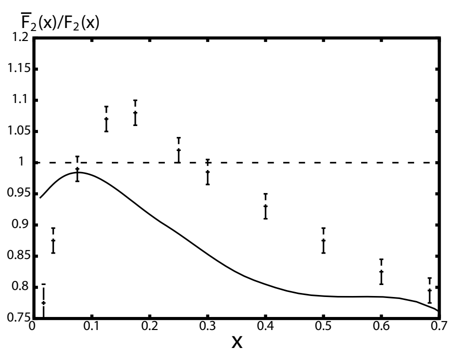

Fig. 2. The ratio of the structure function per nucleon in nuclear matter ($\overline{F}_2$) to the structure function of a free nucleon (F_2) as a function of the Bjorken variable.

The results show that our description can account for the softening of the valence quark distributions. (In terms of the radius for the distribution of baryon charge, our calculation gives an increase of 2% in the medium.) However, the proper time regularization scheme leads to a non-vanishing support of the distribution functions at $x = 1$, although the support vanishes for $x > 1$. For this reason we cannot predict the ratio for $x \to 1$ reliably at the present stage. This point will be improved in a future investigation [19].

3. Summary

In this work we calculated the nucleon structure functions at zero and finite density in the NJL model based on the relativistic Faddeev approach. In order to reproduce the experimental ratio of the neutron to the proton structure functions at zero density, the probability of the a.v. diquark channel should be less than 10%. At finite density our model can explain the softening of the valence quark distributions, corresponding to an increase of the radius associated with the baryon number, but further work has to be done in order to calculate the EMC ratio near the endpoint $x = 1$ reliably.

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