The gluonic halo of the nucleons

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Abstract. On the scope of the nonextensive statistical model for the nucleon’s structure function, we propose that gluons may occupy a bigger volume than the quarks, in nucleons. This correction is needed to fit the carry out momentum of each kind of particle. At the end of the work, we notice that the radius was not the only variable to be changed to get the goal of momentum adjustment and the another constraints.

1. Introduction

The use of statistical models to describe the structure function (unpolarized and polarized) of the nucleons was quite common at the end of the eighties and beginning of nineties [1–10]. These model were mainly based in the MIT bag models [11, 12], with some variations. More recently, Trevisan [13] and Trevisan and Mirez [14] proposed models that consider the nonextensive effects on the quarks statistics, for both cases. All these models suppose that the bag has a fixed radius, for the gluons and quarks. After an initial function is obtained, some corrections are needed to fit better the model, such as finite size corrections [9] or the QCD convolutions [3].

2. The model

In the present work, we show a model where the gluons may place in a bigger space than the quarks, since the quarks may emit gluons in all directions and therefore gluons may occupy more volume than the quarks. We notice that from this correction, some features of the model may be improved, such as the total momentum carried by gluon, that under the initial hypothesis of equal radius for quarks and gluons was below the observed values. Therefore, in the proposed model of the nucleon, the quarks have around them a gluonic cloud, the gluonic halo of the nucleons.

In our picture the nucleon (mass $M = 939$ MeV) consists of a gas of massless partons (quarks, antiquarks, gluons) in equilibrium at temperature $T$ in the spherical volume $V$ with radius $R$. Considering the usual sum rules for the proton and some experimental data for the polarized structure function E142 [15], E143 [16], E154 [17,18], SMC [19] and HERMES [20], we have the following set of equations and constraints:

\begin{align}
  n_{u\uparrow} + n_{u\downarrow} - n_{u\uparrow} + n_{u\downarrow} &= 2, \\
  n_{d\uparrow} + n_{d\downarrow} - n_{d\uparrow} + n_{d\downarrow} &= 1,
\end{align}
\[ n_{s\uparrow} + n_{\bar{s}\downarrow} - n_{s\downarrow} - n_{\bar{s}\uparrow} = 0, \]  
\[ n_{u\uparrow} - n_{u\downarrow} + n_{\bar{u}\uparrow} - n_{\bar{u}\downarrow} = \Delta u, \]  
\[ n_{d\uparrow} - n_{d\downarrow} + n_{\bar{d}\uparrow} - n_{\bar{d}\downarrow} = \Delta d, \]  
\[ n_{s\uparrow} - n_{s\downarrow} + n_{s\downarrow} - n_{s\uparrow} = \Delta s, \]  
\[ \sum_{\text{all partons}} (\text{momentum fraction}) = 1, \]

Where the values are \( \Delta u = 0.83 \pm 0.03, \Delta d = -0.43 \pm 0.03, \Delta s = -0.10 \pm 0.03. \)

The parton number density \( \frac{dn^i}{dx} \) in the infinite-momentum frame (IMF) and the density \( \frac{dn}{dE} \) in the nucleon rest frame are related to each other by:

\[ \frac{dn^i}{dx} = \frac{M^2 x^2}{2} \int_{M/2}^{M/2} \frac{dE}{E^2} \frac{dn}{dE}, \]

where the superscript \( i \) refers to the IMF, \( M \) is the nucleon mass and \( E \) is the parton energy. For each particle \( \alpha \), we have:

\[ \frac{dn_\alpha}{dx} = \frac{M^2 x^2 V}{2} \int_{M/2}^{M/2} \frac{g_f_\alpha(E) dE}{2\pi^2}, \]

where \( x \) is the Bjorken variable and \( g \) is the spin-color degeneracy factor. \( V \) is the nucleon volume and \( f_\alpha(E) \) is the probability distribution, which is given by:

\[ f_\alpha(E) = \frac{1}{[1 + (q - 1)\beta(E - \mu_\alpha)]^{1/(q-1)} + 1}, \]

for the case \( (E - \mu_\alpha) > 0 \) and

\[ f_\alpha(E) = \frac{1}{[1 + (1 - q)\beta(E - \mu_\alpha)]^{1/(1-q)} + 1}, \]

The following relations among the chemical potentials are used to solve the system:

\[ \mu_{\bar{u}\downarrow} = -\mu_{u\uparrow}, \]  
\[ \mu_{\bar{d}\uparrow} = -\mu_{d\downarrow}. \]

3. Preliminary Results
In order to fit the variables, two additional constraint are considered, as follow:

(i) The total momentum of quarks is around 0.54 [21].
(ii) The violation of Gottfried sum rule is around 0.118 That is difference

\[ \int_0^1 \bar{d} - \bar{u} \]

in the proton [22].

The Preliminary results are shown in the table below:
Table 1. Some values for the radius of gluons and quarks in the model. As predicted, gluons are bigger than the quarks. Rg and Mg are the gluon radius and momentum, respectively. Rq and Mq are related to the quarks. T is the temperature, and q is the Tsallis variable.

| T(MeV) | q   | Rg(fm) | Rq(fm) | Mg  | Mq  | Gott |
|--------|-----|--------|--------|-----|-----|------|
| 31     | 0.94| 4.58   | 2.8    | 0.43| 0.57| 0.144|
| 32     | 0.94| 4.4    | 2.6    | 0.43| 0.57| 0.122|
| 33     | 0.94| 4.2    | 2.5    | 0.43| 0.58| 0.118|

Therefore we may conclude that, with the used data, the following relation is obtained:

\[
\frac{R_g}{R_q} \approx 1.67
\]

In comparison with the previous result, showed in [13], we notice that the temperature has changed from \( T = 46 \) MeV, with \( q = 0.96 \) and \( R = 1.8 \) fm. The total momentum of the quarks was about 80%. The physical interpretation may be the following: to decrease the quark momentum, the temperature must decrease also, but to keep the same violation of the Gottfried sum rule, the meson cloud must be big.

To consider the gluonic halo may help to understand the mesonic cloud and some interactions in nuclear medium [23]. Therefore, this study should be improved. More recent works, based on lattice QCD [24], obtained the gluon momentum fraction about 30%. Jahan and Choudhury [25] used the self similarity to obtain a relation among the gluon fraction and \( Q^2 \). The possible correlations among the temperature, gluon momentum, the violation of the Gottfried sum rule and the radius is also an interesting subject to be researched.

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