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Gluon polarization in nucleon

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ABSTRACT

In the context of the so-called valon model, we calculate $\frac{\delta g}{g}$ and show that although it is small and compatible with the measured values, the gluon contribution to the spin of nucleon can be sizable. The smallness of $\frac{\delta g}{g}$ in the measured kinematical region should not be interpreted as δg being small. In fact, δg itself at small x, and the first moment of the polarized gluon distribution in the nucleon, $\Delta g(Q^2)$, are large.

1. Introduction

The decomposition of nucleon spin in terms of its constituents has been an active topic both from theoretical and experimental point of views. It is established that the quark contribution, $\Delta\Sigma$, to the nucleon spin is a small fraction of the nucleon spin. Other sources that might contribute to the nucleon spin come from gluon spin and the overall orbital angular momentum of the partons. Thus, one can write the following spin sum rule for a nucleon:

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + L_{q,g} \tag{1}$$

where $\Delta\Sigma$ is the quarks and anti-quarks contribution to the nucleon spin, Δg is the gluon contribution and $L_{q,g}$ represents the overall orbital angular momentum contribution of the partons.

In deep inelastic scattering, the gluon spin content of the nucleon can be calculated from the Q^2 dependence of the polarized structure function g_1. Experimentally, it is possible to use semi-inclusive deep inelastic scattering processes to measure $\frac{\delta g}{g}$ from helicity asymmetry in photon–gluon fusion, $\gamma^* g \to q\bar{q}$ process. The COMPASS collaboration [1] has used this method and find a rather small value for $\frac{\delta g}{g} = 0.024 \pm 0.080 \pm 0.057$. The smallness of $\frac{\delta g}{g}$ cannot by itself rule out the possibility of a large value for the first moment, Δg, of the gluon polarization. In fact, when the singlet axial matrix element a_0 was found to be much smaller than the contribution expected from quark–parton model, it was suggested that the deference could be accounted for by a large contribution from the gluon spin: $\Delta\Sigma = a_0 - N_f \frac{\alpha_s}{2\pi}\Delta g$. This would require a value of $\Delta g \sim 3$ at $Q^2 = 3$ GeV^2 in order to obtain the expected value of $\Delta\Sigma$. Moreover, Altarelli and Ross [2] and Efremov et al. [3] have shown that polarized gluon makes a scaling contribution to the first moment of the polarized structure function, g_1, which means that it must be large at higher momentum scales.

The total quark spin contribution $\Delta\Sigma$ to the nucleon spin is fairly well determined and gives a value around 0.4. There is no direct determination of orbital angular momentum component, and one is not expected in the near future. In contrast to $\Delta\Sigma$, knowledge about gluon polarization is limited. The existing and the emerging data on $\frac{\delta g(x,Q^2)}{g(x,Q^2)}$ cannot rule out the negative and/or zero polarization for gluon, including a possible sign change. There are mainly three method to access gluon polarization:

(1) polarized deep inelastic scattering, in which one would parameterize quark and gluon densities and fit them to the data on polarized structure function $g_1(x, Q^2)$. Gluon enters into the analysis through the Q^2 evolution, but the limited range of Q^2 leads to not so precise determination of $\delta g(x)$. Recent data suggest that global fits with positive, negative, zero, and sign changing $\delta g(x)$ provide equally good agreement.
(2) Using $c\bar{c}$ production in semi-inclusive deep inelastic processes by γ–g fusion.
(3) via single particle production in polarized p–p collision.

In this Letter we determine the gluon polarization in the polarized proton using the so called *valon* model, as described below.

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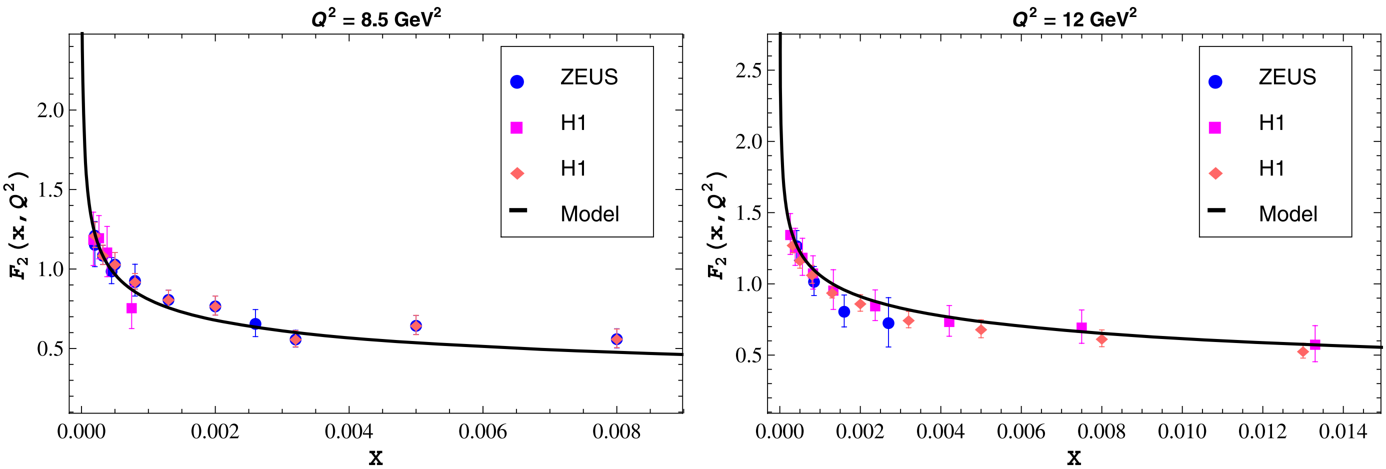

Fig. 1. Unpolarized structure function of proton, F_2^p at $Q^2 = 8.5$ and 12 GeV^2. Data points are from [10,11].

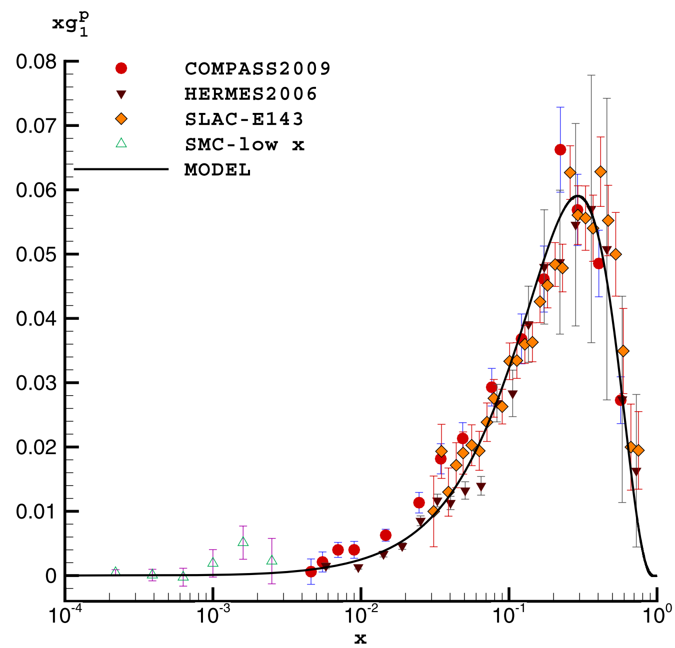

Fig. 2. Polarized structure function of proton, xg_1^p, as a function of x. Solid curve is the model results at $Q^2 = 5$ GeV^2. The data points are from Refs. [12–17].

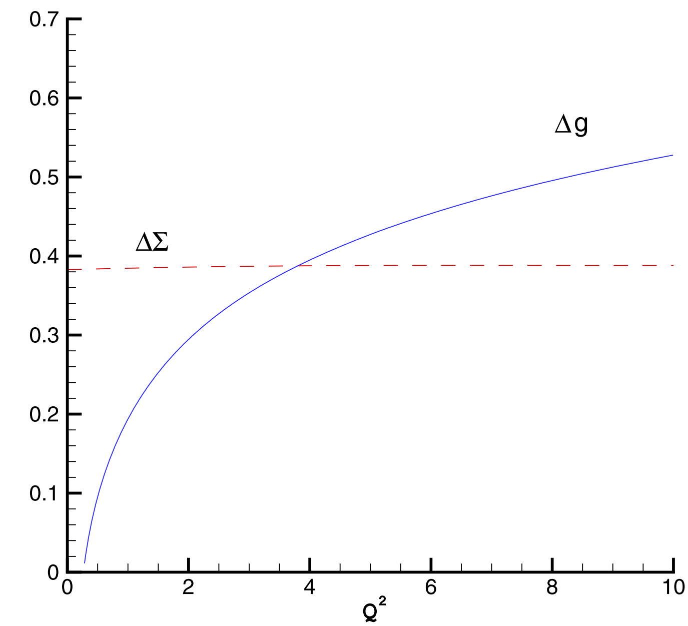

Fig. 3. First moments of polarized quark, $\Delta\Sigma$, and gluon, Δg, in the proton as a function of Q^2.

2. The valon model description of nucleon

Deep inelastic scattering reveals that the nucleon has a complicated internal structure. Other strongly interacting particles also exhibit similar structure. However, under certain conditions, hadrons behave as consisting of three (or two) constituents. Therefore, it seems to make sense to decompose a nucleon into three constituent quarks called U and D. We identify them as *valons*. A valon has its own internal structure, consisting of a valence quark and a host of $q\bar{q}$ pairs and gluons. The structure of a valon emerges from the dressing of a valence quark with $q\bar{q}$ pairs and gluons in perturbative QCD. We take the view that when a nucleon is probed with high Q^2 it is the internal structure of the valon that is resolved. The valon concept was first developed by R.C. Hwa [4], and in Refs. [5–7] it was utilized to calculate unpolarized structure functions of a number of hadrons. This representation is also used to calculate the polarized structure of nucleon. The details can be found in [8,9].

We have worked in $\overline{MS}$ scheme with $\Lambda_{QCD} = 0.22$ GeV and $Q_0^2 = 0.283$ GeV^2. The polarized and unpolarized structure of a valon is calculated in the framework of Next-to-Leading order in QCD. Then, the polarized (unpolarized) structure function of the nucleon is obtained by the convolution of the valon structure with the valon distribution in the hosting nucleon:

$$g_1^h(x, Q^2) = \sum_{valon} \int_x^1 \frac{dy}{y} \delta G_{valon}^h(y) g_1^{valon}\left(\frac{x}{y}, Q^2\right) \tag{2}$$

where $\delta G_{valon}^h(y)$ is the helicity distribution of the valon in the hosting hadron and $g_1^{valon}(\frac{x}{y}, Q^2)$ is the polarized structure function of the valon. A similar relation can also be written for the unpolarized structure function, F_2. We maintain the results of Ref. [8] for the polarized structure function, but re-analyze the unpolarized case. This is necessary in order to arrive at a consistent conclusion on $\frac{\delta g}{g}$. In the moment space the initial densities for both polarized and unpolarized densities of the partons in a valon are taken to be as follows,