



Gluon polarization in nucleon

Abolfazl Shahveh^a, Fatemeh Taghavi-Shahri^b, Firooz Arash^{a,*}

^a Physics Department, Tafresh University, Tafresh, Iran

^b School of Particles and Accelerators, Institute for Research in Fundamental Sciences (IPM) P.O. Box 19395-5531, Tehran, Iran

ARTICLE INFO

Article history:

Received 11 April 2010

Received in revised form 6 June 2010

Accepted 7 June 2010

Available online 11 June 2010

Editor: W. Haxton

Keywords:

Nucleon spin

Gluon polarization

QCD

Valon model

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.

© 2010 Elsevier B.V. All rights reserved.

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:

$$\frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta g + L_{q,g} \quad (1)$$

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, $\gamma^* g \rightarrow q \bar{q}$ 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 difference 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 $Q^2 = 3 \text{ GeV}^2$ 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 methods 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.

* Corresponding author.

E-mail address: farash@cic.aut.ac.ir (F. Arash).

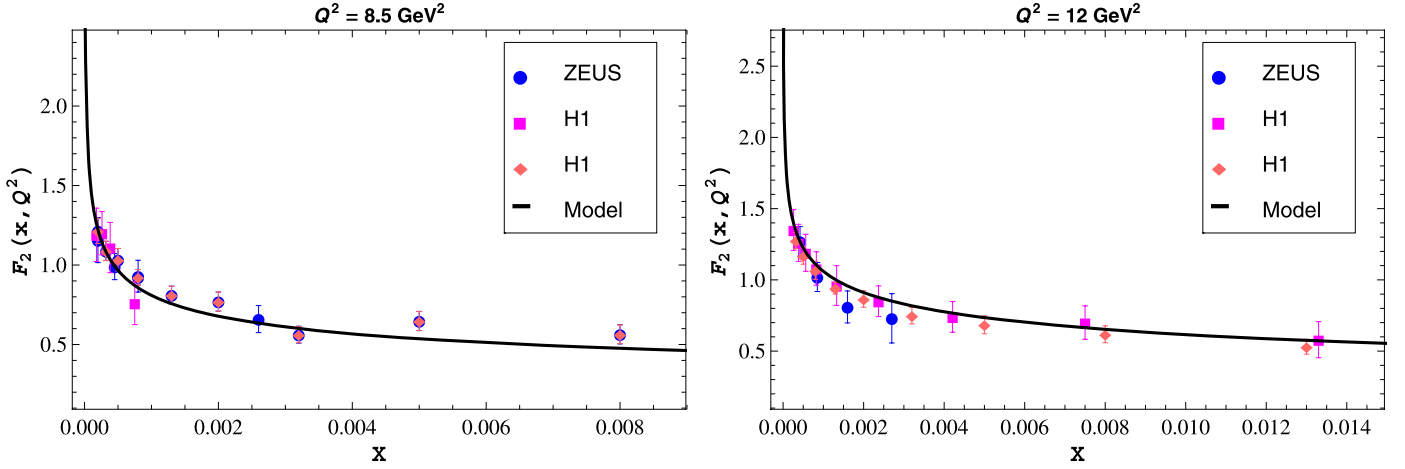


Fig. 1. Unpolarized structure function of proton, F_2^p at $Q^2 = 8.5$ and 12 GeV^2 . Data points are from [10,11].

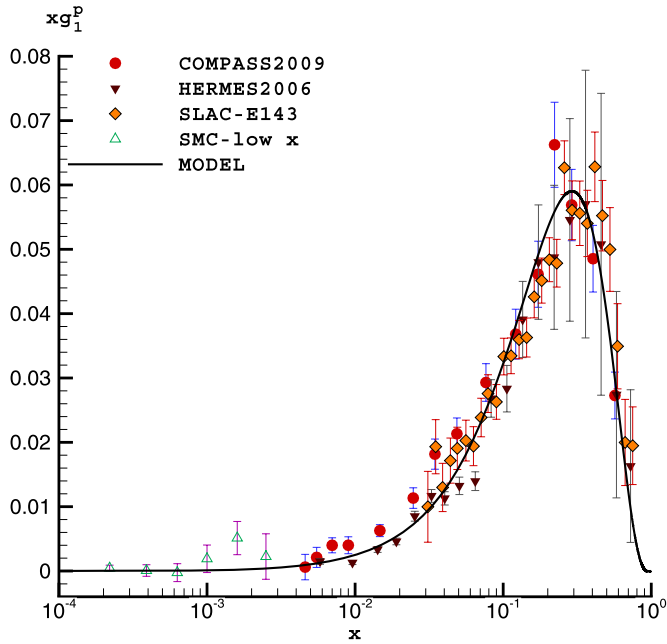


Fig. 2. Polarized structure function of proton, xg_1^p , as a function of x . Solid curve is the model results at $Q^2 = 5 \text{ GeV}^2$. The data points are from Refs. [12–17].

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].

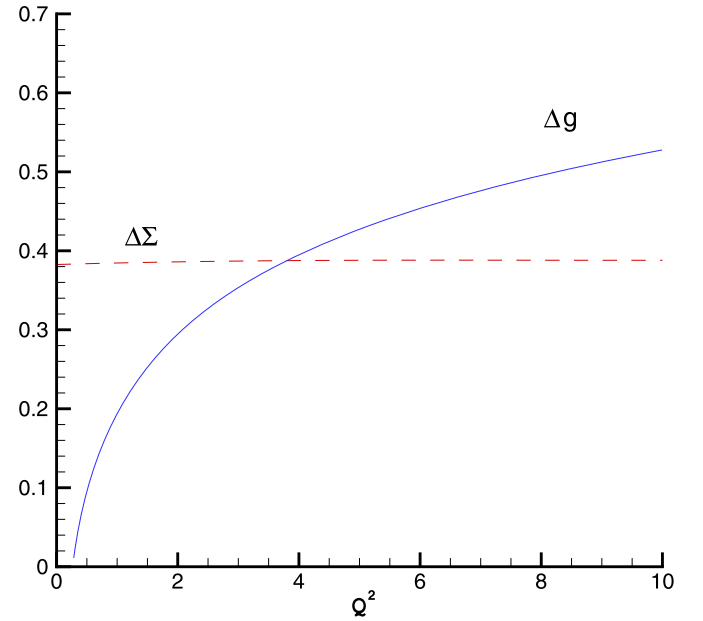


Fig. 3. First moments of polarized quark, $\Delta\Sigma$, and gluon, Δg , in the proton as a function of Q^2 .

We have worked in $\overline{\text{MS}}$ scheme with $\Lambda_{\text{QCD}} = 0.22 \text{ GeV}$ and $Q_0^2 = 0.283 \text{ GeV}^2$. 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:

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

where $\delta G_{\text{valon}}^h(y)$ is the helicity distribution of the valon in the hosting hadron and $g_1^{\text{valon}}(\frac{x}{y}, Q^2)$ 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,

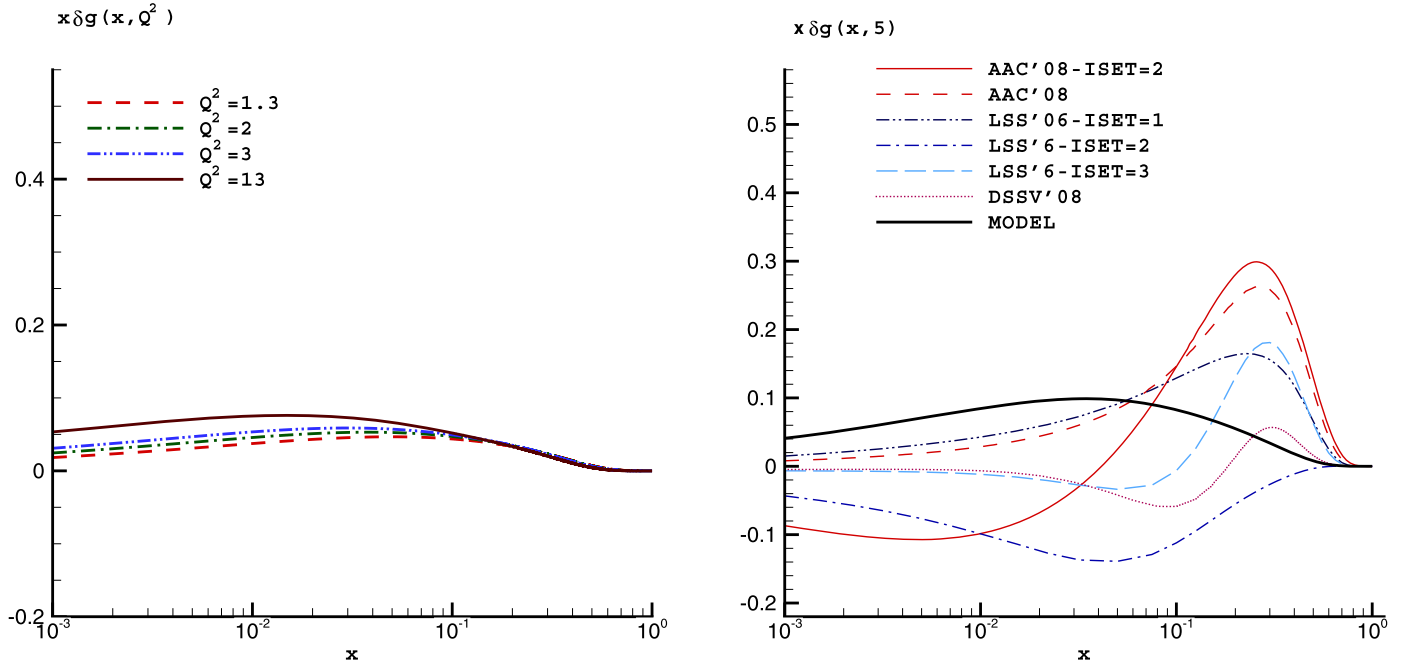


Fig. 4. Left: Polarized gluon distribution function, $x\delta g(x, Q^2)$, for some values of Q^2 . Right: Comparison of the results of the present model and global fits from Refs. [22–24] at a single value of $Q^2 = 5 \text{ GeV}^2$.

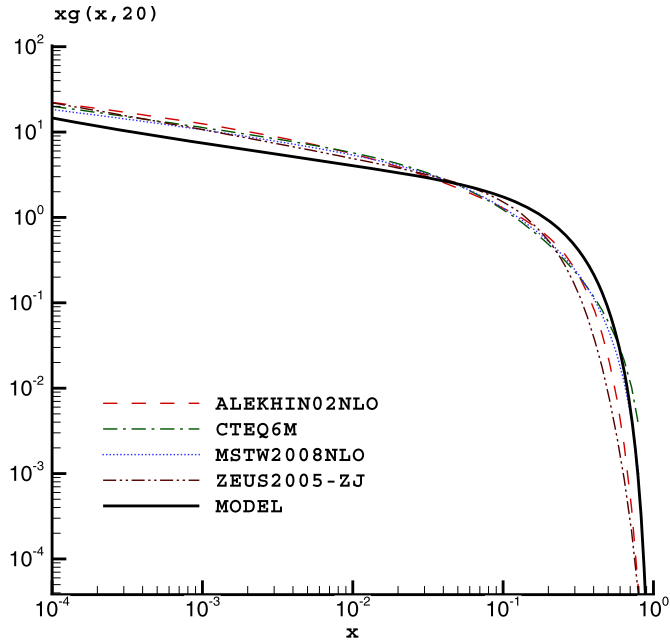


Fig. 5. The model result for the unpolarized gluon distribution, $xg(x)$, at $Q^2 = 20 \text{ GeV}^2$. Also shown are the results from the global fits.

$$\begin{pmatrix} \delta q^n(Q_0^2) \\ \delta g^n(Q_0^2) \end{pmatrix} = \begin{pmatrix} q^n(Q_0^2) \\ g^n(Q_0^2) \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}. \quad (3)$$

The above initial densities mean that if Q^2 is small enough, at some point we may identify $g_1^{\text{valon}}(\frac{x}{y}, Q^2)$ and $f_2^{\text{valon}}(\frac{x}{y}, Q^2)$ as $\delta(z-1)$, for the reason that we cannot resolve its internal structure at such Q^2 value. Here $f_2^{\text{valon}}(\frac{x}{y}, Q^2)$ is the unpolarized structure function of the valon.

In Fig. 1 a sample of results for the unpolarized structure function, F_2 , is presented. The data points are from [10,11]. Similar results are also obtained at different kinematics [5].

Fig. 2 shows the polarized structure function of proton, xg_1^p , obtained from the model, along with the available data from various experiments [12–17]. It is important to note that our analysis does not rely on any kind of data fitting. The structure of a valon is obtained simply from QCD processes via DGLAP evolution [18–20]. Our main concern here is to determine the polarized and unpolarized gluon distributions and hence, the ratio $\frac{\delta g(x, Q^2)}{g(x, Q^2)}$. The gluon is a component of the singlet sector of the evolution kernel. Their moments are given as

$$\begin{pmatrix} \delta M_S(n, Q^2) \\ \delta M_G(n, Q^2) \end{pmatrix} = \left\{ \mathbf{L}^{-(\frac{2}{\beta_0})\delta \hat{P}^{(0)n}} + \frac{\alpha_s(Q^2)}{2\pi} \hat{\mathbf{U}} \mathbf{L}^{-(\frac{2}{\beta_0})\delta \hat{P}^{(0)n}} - \frac{\alpha_s(Q_0^2)}{2\pi} \mathbf{L}^{-(\frac{2}{\beta_0})\delta \hat{P}^{(0)n}} \hat{\mathbf{U}} \right\} \begin{pmatrix} 1 \\ 0 \end{pmatrix} \quad (4)$$

where $\mathbf{L} \equiv \alpha_s(Q^2)/\alpha_s(Q_0^2)$, and $\delta \hat{P}^{(0)n}$ is 2×2 singlet matrix of splitting functions, given by

$$\delta \hat{P}^{(0)n} = \begin{pmatrix} \delta P_{qq}^{(0)n} & 2f\delta P_{qg}^{(0)n} \\ \delta P_{gq}^{(0)n} & \delta P_{gg}^{(0)n} \end{pmatrix}, \quad (5)$$

$\delta P_{lm}^{(0)n}$ are the n th moments of the polarized splitting functions and \mathbf{U} accounts for the 2-loop contributions as an extension to the leading order. The explicit forms of these functions are given in [21] in the next-to-leading order. Now it is straightforward to calculate the moments of the polarized partons inside a valon at any Q^2 value. They are given in Ref. [8]. The densities are obtained by an usual inverse Mellin transformation. To obtain the polarized parton distributions in a hadron, one needs to convolute the results with the valon distribution in the hadron. In Fig. 3 the first moments of the polarized partons in the proton are shown as a function of Q^2 . In spite of the fact that we have started with $\Delta g = 0$ at the starting scale, it grows rapidly with increasing Q^2 . This behavior of gluon polarization can be related to the positive sign of the pertinent anomalous dimension $\delta\gamma_{gg}^{(0)1}$. The positivity of the anomalous dimension dictates that the polarized quark preferably to radiate a gluon with helicity parallel to the quark po-

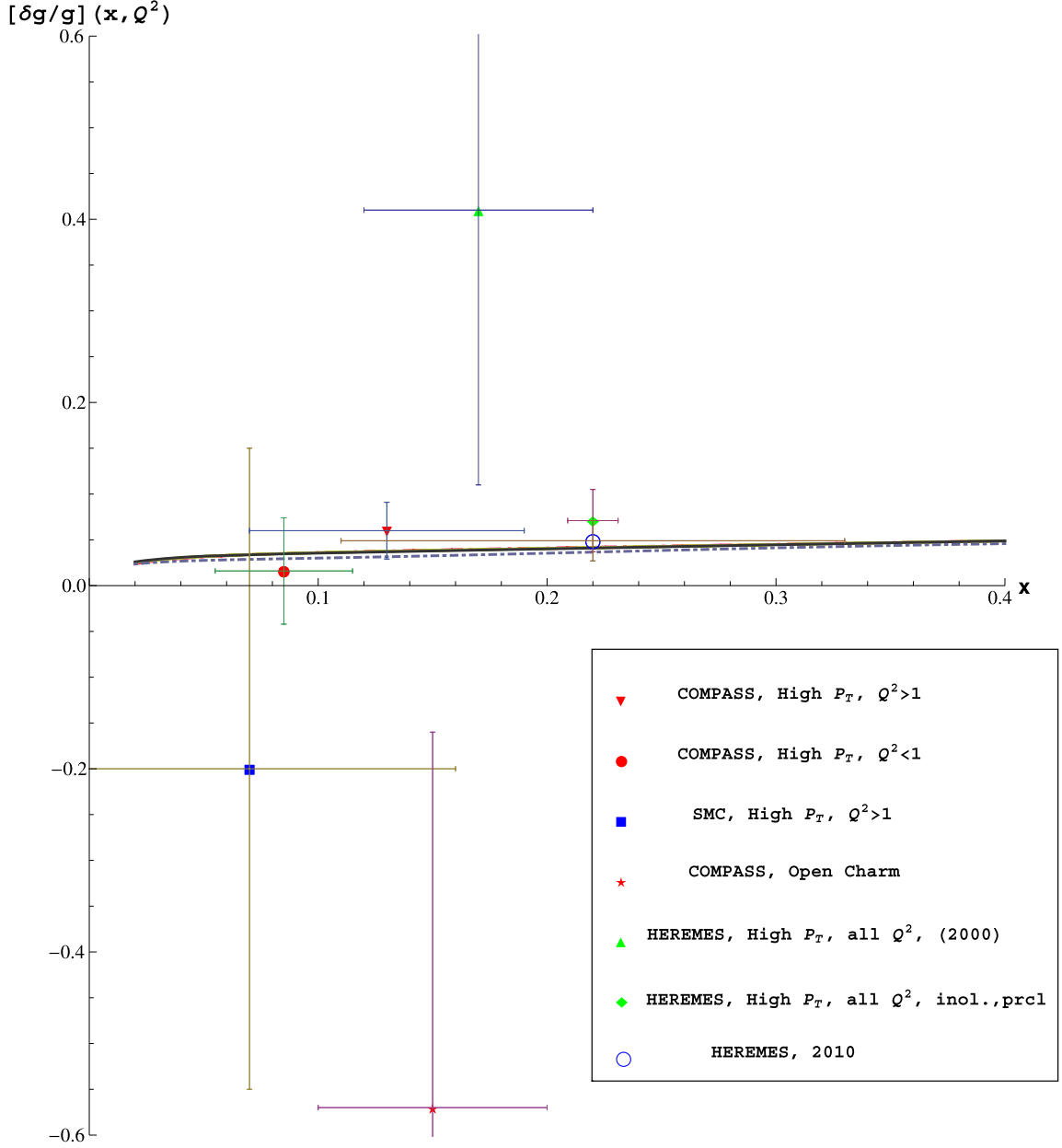


Fig. 6. The ratio $\frac{\delta g(x, Q^2)}{g(x, Q^2)}$ calculated in the valon model and compared with the exist experimental data. The apparent wide band in the figure is actually seven closely packed curves corresponding to the seven values of Q^2 s at which the data point are measured. The data are from Refs. [29–35].

larization. Since the net quark spin in a valon is positive, it follows that perturbatively radiated gluon from quarks must have $\Delta g > 0$. We also note that the growth rate of Δg is especially fast for the relatively low Q^2 . In order to satisfy the sum rule in Eq. (1) it requires that the orbital angular momentum component to be negative and decreasing as Q^2 increases [9].

Figs. 1 and 2 demonstrate that the model can accommodate the experimental data on structure functions fairly accurately. The calculated polarized gluon distributions, $x\delta g(x, Q^2)$, are shown in Fig. 4 as a function of x for several values of Q^2 . We have also shown the results at $Q^2 = 5 \text{ GeV}^2$ and compared it with the global fits from [22–24]. The unpolarized gluon distribution is also shown in Fig. 5 and is compared with the results obtained from various global fits [25–28].

Our results for the sea quark polarization is consistent with zero, and yield a positive value for the first moment of gluon,

$\Delta g(Q^2)$, which increases with Q^2 reaching a value of around 0.5 at $Q^2 = 10 \text{ GeV}^2$ as can be seen from Fig. 3.

It is now straight forward to calculate the ratio $\frac{\delta g(x)}{g(x)}$ in the proton. This ratio is calculated and shown in Fig. 6. The calculation is done for the proton at each value of Q^2 corresponding to the experimental kinematics. This allows us to make a meaningful comparison of our results with the experimental data. The apparent wide band in the figure is actually seven closely packed curves corresponding to the seven individual values of Q^2 s at which the data are measured. Apparently, HERMES high p_T (2000) [29] and COMPASS open charm data disagree with our results. However, these two data points are the least accurate ones with very large error bars. In contrast, our results are in good agreement with the remaining experimental points, including the very recent one from HERMES and COMPASS [29–35].

3. Conclusion

We calculated gluon polarization in a polarized proton in the valon model and compared it with the existing data, including the most recent one from HERMES collaboration [30]. Since the experimental data are obtained at different Q^2 values, the calculations are also carried out at the corresponding Q^2 , individually. It is evident from the results that the polarized valon model of nucleon not only agrees with the existing data on g_1 but also provides a clear resolution for the spin problem. We maintain the view that $\Delta g(Q^2)$ is positive and increases with Q^2 . The growth of $\Delta g(Q^2)$ in part is compensated by a negative and large orbital angular momentum, $L_{q,g}$. Although, we have not calculated L_q and L_g individually, but the overall $L_{q,g}$ is given in [8].

This suggests that even if $\delta g(x, Q^2)$ maybe small at relatively large x , but the first moment of gluon polarization in the proton is sizable. In fact, $\delta g(x, Q^2)$ is quiet large at small x .

Acknowledgements

We would like to thank Professor Mauro Anselmino and Professor Jacques Soffer for their critical reading of the manuscript and for their useful suggestions.

References

- [1] E.S. Ageev, et al., Phys. Lett. B 633 (2006) 25, hep-ex/0511028.
- [2] G. Altarelli, G.G. Ross, Phys. Lett. B 212 (1988) 391.
- [3] A.V. Efremov, J. Soffer, O.V. Teryaev, Nucl. Phys. B 346 (1990) 97.
- [4] R.C. Hwa, Phys. Rev. D 22 (1980) 759.
- [5] F. Arash, A.N. Khorramian, Phys. Rev. C 67 (2003) 045201.
- [6] F. Arash, Phys. Lett. B 557 (2003) 38.
- [7] F. Arash, Phys. Rev. D 679 (2004) 054024.
- [8] F. Arash, F. Taghavi-Shahri, JHEP 0707 (2007) 071.
- [9] F. Arash, F. Taghavi-Shahri, Phys. Lett. B 668 (2008) 193.
- [10] H1 Collaboration, C. Adloff, et al., Nucl. Phys. B 493 (1997) 3; H1 Collaboration, T. Ahmed, et al., Nucl. Phys. B 439 (1995) 471.
- [11] ZEUS Collaboration, M. Adamus, et al., Phys. Lett. B 407 (1997) 432.
- [12] HERMES Collaboration, A. Airapetian, et al., Phys. Rev. D 75 (2007) 012007.
- [13] HERMES Collaboration, A. Airapetian, et al., Phys. Lett. B 666 (2008) 446.
- [14] COMPASS Collaboration, A. Korzenev, arXiv:0704.3600 [hep-ex]; V.Yv. Alexakhin, et al., Phys. Lett. B 674 (2007) 8.
- [15] COMPASS Collaboration, M. Alekseev, et al., Phys. Lett. B 680 (2009) 217; COMPASS Collaboration, M. Alekseev, et al., arXiv:1001.4654v1 [hep-ex].
- [16] SMC Collaboration, B. Adeva, et al., Phys. Rev. D 58 (1998) 112001; SMC Collaboration, B. Adeva, et al., Phys. Rev. D 60 (1999) 072004.
- [17] E143 Collaboration, K. Abe, et al., Phys. Rev. Lett. 75 (1995) 1; E143 Collaboration, K. Abe, et al., Phys. Rev. D 58 (1998) 112003.
- [18] G. Altarelli, G. Parisi, Nucl. Phys. B 126 (1997) 298; G. Altarelli, Phys. Rep. 81 (1981).
- [19] V. Gribov, L. Lipatov, S. J. Nucl. Phys. 15 (1972) 438.
- [20] Y.L. Dokshitzer, Sov. Phys. JETP 46 (1977) 641.
- [21] Bodo Lampe, Ewald Reya, Phys. Rep. 332 (2000) 1.
- [22] AAC08, Asymmetry Analysis Collaboration, M. Hirai, S. Kumano, Nucl. Phys. B 813 (2009) 106.
- [23] LSS'06, E. Leader, A.V. Sidorov, D.B. Stamenov, Phys. Rev. D 73 (2006) 034023.
- [24] DSSV'08, D. de Florian, R. Sassot, M. Stratmann, W. Vogelsang, Phys. Rev. Lett. 101 (2008) 072001.
- [25] S. Alekhin, Phys. Rev. D 68 (2003) 014002.
- [26] MSTW08, A.D. Martin, W.J. Stirling, R.S. Thorne, G. Watt, Eur. Phys. J. C 64 (2009) 653.
- [27] CTEQ6M, J. Pumplin, D.R. Stump, J. Huston, H.L. Lai, P. Nadolsky, W.K. Tung, JHEP 0207 (2002) 012.
- [28] ZEUS Collaboration, S. Chekanov, et al., Eur. Phys. J. C 42 (2005) 1.
- [29] HERMES Collaboration, A. Airapetian, et al., Phys. Rev. Lett. 84 (2000) 2584, hep-ex/9907020.
- [30] HERMES Collaboration, A. Airapetian, et al., arXiv:1002.3921v1 [hep-ex].
- [31] P. Liebing, Can the gluon polarization in the nucleon be extracted from HERMES data on single high-pT hadrons?, PhD thesis, University at Hamburg (2004).
- [32] Spin Muon (SMC) Collaboration, B. Adeva, et al., Phys. Rev. D 70 (2004) 012002, hep-ex/0402010.
- [33] COMPASS Collaboration, E.S. Ageev, et al., Phys. Lett. B 633 (2006).
- [34] COMPASS Collaboration, E.S. Ageev, et al., Nucl. Phys. B 765 (2007) 31.
- [35] S. Koblitz, arXiv:0707.0175 [hep-ex], 2007.