A POSSIBLE EARLY EXPERIMENTAL TEST FOR
A LARGE $\Delta G(x, Q^2)^*$

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Abstract

A proposal that the net spin carried by gluons in a polarized proton may be very large compared to 1/2 has recently received considerable theoretical attention. There exists a unique opportunity to test for this dramatic possibility using an existing experimental setup. We urge the consideration of a precision measurement ($\pm 10 \mu\beta$) of $\Delta \sigma_L^{jet}(p p; p_0, \sqrt{s})$ at $p_0^2 = 5 \text{ GeV}^2$ and $s = 400 \text{ GeV}^2$ using the Fermilab polarized beam facility.

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The longitudinal spin-spin asymmetry in deep-inelastic lepton scattering on polarized protons involves the spin-weighted quark densities. The structure function

\[ g_1^p(x, Q^2) = \frac{1}{2} \sum_i e_i^2 \Delta q_i(x, Q^2) \left[ 1 + \frac{\alpha_s}{\pi} \tau_i(x, Q^2) + \cdots \right] \]  

measures these densities with corrections which are calculable in QCD perturbation theory.\(^1\) In examining these corrections, it is found that the flavor-singlet component of \( g_1^p(x, Q^2) \) receives a contribution from polarized gluons because of the Pontryagen current,\(^2,3\)

\[ K_\mu = \frac{\alpha_s}{2\pi} \epsilon_{\mu \nu \rho \sigma} \text{Tr} \left[ A^\nu \left( F^{\rho \sigma} - \frac{2}{3} A^\rho A^\sigma \right) \right] . \]  

If we define the first moments of parton densities

\[ \langle \Delta q_i \rangle = \int_0^1 dx \Delta q_i(x, Q^2) \]  
\[ \langle \Delta G(Q^2) \rangle = \int_0^1 dx \Delta G(x, Q^2) \]  

in a process-independent factorization prescription, the gluonic current has been shown\(^5\) to modify the contribution to the first moment of \( g_1^p(x, Q^2) \) for each quark flavor to produce an effective density

\[ \langle \Delta \tilde{q}_i \rangle = \langle \Delta q_i \rangle - \frac{\alpha_s(Q^2)}{4\pi} \langle \Delta G(Q^2) \rangle \]  

measured in the experiment.

The form of the Altarelli-Parisi equations insures that \( \langle \Delta q_i \rangle \) and \( \langle \Delta \tilde{q}_i \rangle \) do not evolve with \( Q^2 \) while the \( Q^2 \)-evolution of \( \langle \Delta G(Q^2) \rangle \) in (4) is cancelled by the \( Q^2 \)-dependence of the effective coupling.\(^4\) The moments, (3), can be related to the net contribution of the partons to the proton's spin using the \( J = 1/2 \) sum rule.\(^5\)

\[ \frac{1}{2} = \frac{1}{2} \sum_i \langle \Delta q_i \rangle + \langle \Delta G(Q^2) \rangle + \sum_i \langle L_{si} \rangle \]

\[ \frac{1}{2} = \frac{1}{2} \sum_i \langle \Delta \tilde{q}_i \rangle + \langle \Delta G(Q^2) \rangle \left( 1 + \frac{N_f \alpha_s(Q^2)}{2\pi} \right) + \sum_i \langle L_{si} \rangle . \]
Phenomenological analysis of the recent data from the European Muon Collaboration\textsuperscript{6} has led to speculation that\textsuperscript{3,7}

\[ \left| \frac{N_f(Q_0^2)\alpha_s(Q_0^2)}{2\pi} \langle \Delta G(Q_0^2) \rangle \right|_{Q_0^2=10 \text{ GeV}^2} \cong 1, \tag{6} \]

where \( N_f(Q_0^2) \) is an "effective" number of flavors (assumed to be approximately 2-1/2 or 3). Since \( \alpha_s(Q_0^2) \) is known from other experiments\textsuperscript{8} to be in the range

\[ \alpha_s^{\overline{\text{MS}}}(Q_0^2) \bigg|_{Q_0^2=10 \text{ GeV}^2} \cong 0.25 \pm 0.05 \tag{7} \]

This point of view leads one to consider that the net spin carried by gluons in a polarized proton is very large compared to one. This is a very striking conclusion! The \( J_z = 1/2 \) sum rule, (5), indicates that a large positive value of \( \langle \Delta G(Q^2) \rangle \) must be associated with a comparably large and negative expectation value for the orbital angular momentum carried by the different constituents.

The dramatic possibility that gluons are strongly polarized by the spin of the proton should be checked in other types experiment. Theoretically, the most unambiguous way to test for a significant \( \Delta G(x, Q^2) \) involves the production asymmetry,

\[ a_{LL} \epsilon \sigma(pp \to \gamma X), \]

for large-\( p_T \) direct photons. While the direct photon experiment should be done, it is unlikely that experiments with polarized proton beams and polarized proton targets will have sufficient luminosity in the near future to provide a meaningful result. An experiment which can be performed with the existing polarized proton beam facility at Fermilab\textsuperscript{9} deserves careful consideration.

In Ref. 10, it was pointed out that the measurement of

\[ \Delta \sigma_L^{\text{jet}}(pp; p_0, \sqrt{s}) = \sigma(p^+p^+) \to \text{jet}(p_0)x - \sigma(p^+p^-) \to \text{jet}(p_0)x \tag{8} \]

is sensitive to the underlying spin asymmetries of the fundamental processes in QCD. Incorporating the suggestion that \( \Delta G(x, Q^2) \) is large compared to \( \Delta u(x, Q^2) \) then leads to the conclusion that there exists an accessible kinematic regime where \( \Delta \sigma_L^{\text{jet}}(pp; p_0, \sqrt{s}) \)
is dominated by gluon processes. A numerical estimate of the contribution of polarized gluons to $\Delta \sigma^{\text{jet}}_L$ in the kinematic regime, $\sqrt{s} = 20 \text{ GeV}$, $p_0^2 = 5 \text{ GeV}^2$, gives the value

$$\Delta \sigma^{\text{jet}}_L (pp; p_0, \sqrt{s})\bigg|_{(\Delta G)=6} \approx 26 \mu\text{b.} \quad (9)$$

This can be compared to

$$\Delta \sigma^{\text{jet}}_L (pp; p_0, \sqrt{s})\bigg|_{(\Delta G)=0} \approx 2 \mu\text{b.} \quad (10)$$

The estimate (9) depends on the $x$-distribution assumed for the polarized gluon distribution. The number should therefore be considered only a crude indication of the sensitivity appropriate for an early experimental test of the hypothetical existence of a very large gluon polarization.

Compared to the currently-approved experimental program, a measurement of $\Delta \sigma^{\text{jet}}_L$ with sensitivity $\pm 10 \mu\text{b}$ would require a substantial increase in the running time allotted to polarized protons. The design of the experimental apparatus may also require modification. It is important to consider this type of measurement in terms of a systematic long-range program of spin physics. At larger values of $\sqrt{s}$, the impact of a possible $\Delta G$ on the $\Delta \sigma^{\text{jet}}_L$ is even more dramatic. Estimates at $\sqrt{s} = 100 \text{ GeV}$ give:

$$\Delta \sigma^{\text{jet}}_L (pp; p_0, \sqrt{s})\bigg|_{(\Delta G)=6} \approx 290 \mu\text{b}$$

compared to

$$\Delta \sigma^{\text{jet}}_L (pp; p_0, \sqrt{s})\bigg|_{(\Delta G)=0} \approx 8 \mu\text{b.}$$

REFERENCES


8. See, for example, A. Ali and F. Barreiro, DESY-88-075 and references therein.
