THE GLUON SPIN ASYMMETRY AS A LINK TO ∆G AND ORBITAL ANGULAR MOMENTUM

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The fundamental program in high energy spin physics focuses on the spin structure of the nucleon. The gluon and orbital angular momentum components of the nucleon spin are virtually unknown. The $J_z = \frac{1}{2}$ sum rule involves the integrated parton densities and can be used to extract information on the orbital angular momentum and its evolution. To avoid any bias on a model of $\Delta G$, we assume that the gluon asymmetry, $A = \Delta G / G$, can be used to extract $\Delta G$ over a reasonable kinematic region. Combining the results for $\Delta G$ with the evolution equations, we can determine a theoretical expression for the orbital angular momentum and its evolution.

1. Introduction

The $J_z = \frac{1}{2}$ sum rule involves the integrated densities.

$$J_z = \frac{1}{2} \Delta \Sigma + \Delta G + (L_z)_q + (L_z)_G,$$

where $\Delta \Sigma$ is the total spin carried by all quarks, $\Delta G$ the spin carried by gluons and $(L_z)_q$ and $(L_z)_G$ the orbital angular momenta of the quarks and gluons respectively. Recent DIS experiments have narrowed the quark spin contribution ($\Delta \Sigma$) to within a reasonable degree. However, the gluon and orbital angular momentum components of the nucleon spin are virtually unknown. The purpose of this work is to estimate the gluon density through use of the asymmetry $A = \Delta G / G$ and, with the evolution equations, determine a theoretical expression for the orbital angular momentum.

There are numerous models for the polarized quark distributions, most of which are in agreement with the polarized DIS data. We have chosen to use the model of Gordon, et. al.\(^1\), which separates the valence and sea flavors and builds in an asymmetry of the quark and antiquark distributions. These polarized distributions depend upon the corresponding unpolarized
distributions. To investigate the effects of a range of polarized PDFs, both CTEQ5² and MRST2001³ unpolarized distributions are used. For the distributions considered, the x-dependence of the quark spin content is identical above x=0.10, but varies considerably for smaller x. Similarly, the different models for the unpolarized glue lead to a few percent differences in the gluon asymmetry and the x dependent values of Lz at small-x.

Our present knowledge of the polarized flavor distributions comes mostly from polarized deep-inelastic-scattering (PDIS). The up and down quark polarizations are fairly well established, but the strange and charm quark distributions are less known. Since these heavier quarks do not contribute more than a few percent to the proton spin, the overall quark spin, ∆Σ is known to within a few percent. Most of the accepted values lie well within the range 0.20 – 0.35. The integrated polarized gluon distribution is virtually unknown, with estimates from almost zero to somewhat large values, around 2.0. This work consists of two parts. The first is to extract information about ∆G from the polarized gluon asymmetry, A = ∆G/G. This minimizes the bias of constructing an arbitrary model of ∆G. The assumptions of the asymmetry are based upon sound theoretical grounds and are directly verifiable by present experiments at DESY and RHIC at BNL. From the asymmetry and knowledge of the unpolarized gluon distributions (extracted from CTEQ and MRST to investigate the variation) we can extract the necessary information about ∆G. Coupled with the Jz = 1/2 sum rule, we can then infer information about Lz and its evolution in Q2.

2. Asymmetry Model for ∆G and Lz

Experiments are underway and planned to measure both ∆G and the polarized gluon asymmetry, A = ∆G/G. To construct a theoretical model of the asymmetry, we assume that it has a scale independent part, A0 plus a small piece that vanishes at some large scale so that ∆G can be written as ∆G = A0 · G + Gε. The scale invariant A0 is calculable and is independent of theoretical models of ∆G. The second term is scale invariant and is interpreted as the difference between the measured polarized gluon distribution and that predicted by the calculated A0 combined with measurement of the unpolarized gluon density. Experimental results can be correlated by measuring the asymmetry, A in a limited kinematic range of x for a fixed Q2 (at HERMES and RHIC). The invariance of A0 and Gε can then be used to extract ∆G over an expanded kinematic region. Combining this with the extraction of ∆G in polarized pp collisions at RHIC can enhance
the correlations of these experimental results. Thus, the model for $A$ can be readily verified in separate sets of experiments.

We can write the asymmetry as

$$A(x, t) = A_0(x) + \epsilon(x, t) \equiv \Delta G/G$$  \hfill (2)

where $t \equiv \ln[(\alpha_s(Q_0^2)/(\alpha_s(Q^2))]$. Then, $\Delta G$ can be written in terms of the calculated asymmetry $A_0(x)$ and a difference term. The calculable part can be found by taking the $t$-derivative of $A_0(x)$:

$$\frac{dA_0(x)}{dt} = \frac{\Delta G}{dt} - A_0 \cdot \frac{dG}{dt} = 0$$  \hfill (3)

to a first approximation. Then $\frac{d\Delta G}{dt}$ and $\frac{d\epsilon}{dt}$ are calculated using the evolution equations. The result is a simple polynomial in $x$. The quantity $\epsilon(x, t) \cdot G(x, t)$ is scale-invariant at some large scale so $\frac{d\epsilon}{dt}$ is also calculable. From the counting rules, we bound $\epsilon(x, t)$ by $\epsilon(x, t) \leq c(t) \cdot x(1 - x)$. We require $\epsilon(x, t)$ to be decreasing at some scale, since $\epsilon(x, t) \cdot G(x, t)$ is scale invariant. Then, the form for $\epsilon(x, t = 0) = x(1 - x)^n$, where $n$ is the power of $(1 - x)$ in $G(x)$ and we assume that $c(t) \equiv 1$. Then, the calculation of $L_z$ and its evolution involves using the $J_z = \frac{1}{2}$ sum rule and the DGLAP evolution equations.

$$L_z = \frac{1}{2} - \frac{\Sigma}{2} - (A_0 + \epsilon) \cdot G. $$  \hfill (4)

From its derivative with respect to $t$ and the evolution equations, the evolution of $L_z$ is

$$\frac{dL_z}{dt} = -[\Delta P_{qq} \otimes \Delta q + \Delta P_{qG} \otimes (A_0 \cdot G)]/2 - A_0[P_{Gq} \otimes q + P_{GG} \otimes G].$$  \hfill (5)

3. Results and Experimental Verification

A plot of the $L_z(x)$ is shown in figure 1. Differences in the MRS and CTEQ based distributions can be seen at small-$x$. The evolved $L_z$ for the CTEQ based model is also shown in the figure as a dotted line. The evolution to 100 GeV is not that significant at leading order.

The model of the gluon asymmetry $A$ can be tested by three separate experiments at DESY (HERA), BNL (RHIC) and CERN (COMPASS). First, $\Delta G$ can be measured via prompt photon production or jet production. These processes yield the largest asymmetries for the size of $\Delta G^4$. Also measurement of $\Delta G/G$ in at least a small kinematic range of $x$ and $Q^2$ will test this model. The corresponding predictions for the orbital angular momentum $L_z$ and its evolution can be measured via deeply-virtual Compton Scattering (DVCS) and vector-meson scattering.
We have proposed a way to calculate the orbital angular momentum and its evolution through use of the gluon asymmetry, $A = \Delta G/G$. Experiments are outlined here to test the various assumptions and results obtained in this model.

![Figure 1. Orbital angular momentum versus x generated by MRS (lines) and CTEQ (crosses) distributions and evolved to $Q^2 = 100 \text{ GeV}^2$ squared (dashes).](image)

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**References**

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