Nucleon Spin Distributions From Recent SMC, SLAC and DESY Data

Gordon P. Ramsey\(^1,2\) and Mehrdad Goshtasbpour\(^3,4\)

\(^1\) Loyola University of Chicago, Chicago, IL 60626, USA
\(^2\) Argonne National Laboratory, IL 60439, USA
\(^3\) Shahid Beheshti University, Tehran, Iran
\(^4\) Institute for Physics and Mathematics, Tehran, Iran

ABSTRACT

We have extracted polarized nucleon distributions from recent data at CERN, SLAC and DESY. The flavor-dependent valence and sea quark spin distributions are determined for each experiment. The up and down distributions are comparable, but the strange sea contribution determined from different experiments do not agree, even including higher order corrections. Only experiments sensitive to the polarized gluon and sea will reconcile these differences.

Recently, the Spin Muon Collaboration (SMC) group from CERN\(^1\) and the experimental groups from SLAC\(^2\) measured \(A_1\) and \(g_1\) to low \(x\) in deep-inelastic lepton-hadron scattering (DIS) For the proton, neutron and deuteron. They have improved statistics and minimized the systematic errors. The measurement of \(g_{1p,n,d}^p\) provides a means by which we can extract the polarized quark contributions to proton spin. We have done a detailed flavor dependent analysis including the QCD corrections and the gluon anomaly. We use data from each experiment and the sum rules to extract the spin information.

The polarized valence quark distributions are obtained from the unpolarized ones by starting with a modified 3-quark model.\(^3\) The free parameter is adjusted to satisfy the Bjorken sum rule (BSR).\(^4\) Using our values \(\langle \Delta u_\nu \rangle = 1.00 \pm 0.01\) and \(\langle \Delta d_\nu \rangle = -0.26 \pm 0.01\), both the BSR and magnetic moment ratio \(\mu_p/\mu_n\) are satisfied. Thus, the spin contribution from valence quarks equals 0.74 ± 0.02. Errors arise from \(g_A/g_V\) data and differences in the unpolarized distributions.

The SU(6) symmetry of the sea is broken by assuming that the polarization of the heavier strange quarks is suppressed. The sea distributions are then related by:

\[
\Delta \bar{u}(x) = \Delta u(x) = \Delta \bar{d}(x) = \Delta d(x) = [1 + \epsilon] \Delta s(x) = [1 + \epsilon] \Delta s(x),
\]

where \(\epsilon\) is a measure of the increased difficulty in polarizing the strange quarks.

The integrated polarized structure function, \(I^{p(n)} \equiv \int_0^1 g_1^{p(n)}(x) \, dx\), is related to the polarized quark distributions by

\[
I^{p(n)} = \frac{1}{18} (1 - \alpha_s^{corr}) \left\{ [4(1) \Delta u_{tot} + 1(4) \Delta d_{tot} + (\Delta s_{tot})] \right\}.
\]

where \(\alpha_s^{corr}\), has been calculated to \(O(\alpha_s^4)\). The higher twist corrections\(^6\) are negligible at the \(Q^2\) values of the data. Additional constraints are provided by the axial-vector current operators, \(A_3, A_8\) and \(A_0\).
The BSR is a fundamental test of QCD. In terms of the polarized distributions and equation (1), the BSR can be reduced to:

\[ I^p - I^n = \frac{1}{6} \int_0^1 \left[ \Delta u_v(x, Q^2) - \Delta d_v(x, Q^2) \right] dx = \frac{A_2}{6} (1 - \alpha_s^\text{corr}), \quad (3) \]

with \( I^d = \int_0^1 g_1^d(x) dx = \frac{1}{2} [I^p + I^n] (1 - \frac{3}{2} \omega_D) \), where \( \omega_D \) is the probability that the deuteron will be in a D-state. The BSR is used to extract an effective \( I_0 \), determined by hyperon decay, is given by:

\[ A_8 = \langle \Delta u_v + \Delta d_v + \Delta u_s + \Delta d_s + \Delta \bar{u} + \Delta \bar{d} - 2\Delta s - 2\Delta \bar{s} \rangle \approx 0.58 \pm 0.02. \quad (4) \]

\( A_0 \) is related to the total spin carried by the quarks in the proton. It can be written in terms of the non-zero axial currents as:

\[ A_0 = 9(1 - \alpha_s^\text{corr})^{-1} \int_0^1 g_1^p(x) dx - \frac{1}{4} A_8 - \frac{3}{4} A_3 = \langle \Delta q_{\text{tot}} \rangle - \Gamma. \quad (5) \]

The model of \( \Delta G \) that is used has a determines the effective quark distributions through the gluon axial anomaly,\(^7\) which has the general form: \( \Gamma(Q^2) = \frac{\alpha_s(Q^2)}{2\pi} \int_0^1 \Delta G(x, Q^2) dx \). Each quark flavor is modified by \( \Gamma \). We have used two models for \( \Delta G \): (1) \( \Delta G = xG \) and (2) \( \Delta G = 0 \). We believe that present data imply that \( \Delta G \) is limited at low \( Q^2 \).

The orbital angular momentum of the constituents, \( L_z \), can be found from: \( L_z = \frac{1}{2} = \frac{1}{2} \langle \Delta q_v \rangle + \frac{1}{2} \langle \Delta S \rangle + \langle \Delta G \rangle + L_z \). Although this does not provide a constraint on either \( \Delta q_{\text{tot}} \) or \( \Delta G \), it gives an estimate of the angular momentum component to proton spin.

Equations (1) through (5) are used to extract the flavor dependent information on the contributions to the proton spin. Results are given in Table I. The E154 and HERMES data are preliminary, as reported in this symposium.

**Table I: Integrated Polarized Distributions:**

\[ \Delta G = xG \ (\text{above line}), \ \Delta G = 0 \ (\text{below line}) \]

| Quantity      | \( SMC(I^p) \) | \( SMC(I^d) \) | \( E154(I^n) \) | \( E143(I^d) \) | \( \text{HERMES} \ (I^n) \) |
|---------------|----------------|----------------|----------------|----------------|------------------|
| \( < \Delta u >_{\text{tot}} \) | 0.85 | 0.82 | 0.87 | 0.87 | 0.90 |
| \( < \Delta d >_{\text{tot}} \) | -0.42 | -0.43 | -0.39 | -0.40 | -0.36 |
| \( < \Delta s >_{\text{tot}} \) | -0.07 | -0.10 | -0.04 | -0.06 | -0.02 |
| \( I^p \) | 0.136 | 0.129 | 0.134 | 0.131 | 0.135 |
| \( L_z \) | -0.14 | -0.11 | -0.18 | -0.15 | -0.22 |
| \( < \Delta q >_{\text{tot}} \) | 0.36 | 0.29 | 0.45 | 0.41 | 0.52 |

| Quantity      | \( \text{SMC} \) | \( E154 \) | \( E143 \) | \( \text{HERMES} \) |
|---------------|----------------|------------|------------|------------------|
| \( < \Delta u >_{\text{tot}} \) | .83 | .80 | .85 | .84 | .88 |
| \( < \Delta d >_{\text{tot}} \) | -.44 | -.45 | -.41 | -.43 | -.39 |
| \( < \Delta s >_{\text{tot}} \) | -.09 | -.12 | -.07 | -.08 | -.04 |
| \( < \Delta q >_{\text{tot}} \) | .30 | .23 | .37 | .33 | .45 |
| \( L_z \) | .35 | .39 | .32 | .35 | .28 |
From the results in Table I, we can draw the following conclusions:

1. The naive quark model is not sufficient to explain the proton’s spin characteristics, since the total quark contribution to proton spin falls between about $\frac{1}{4}$ and $\frac{1}{2}$. The uncertainties due to data and the choice of $\Delta G$ are comparable.

2. The up and down total contributions to proton spin all agree to within a few percent. Most data, including that of the proton and deuteron, imply a larger polarized sea with the strange sea polarized greater than the positivity bound. The strange sea contribution is the most uncertain of all the flavors. Higher twist corrections do not reconcile these differences.

3. This analysis is consistent with a small anomaly correction. Specifically, a larger anomaly term from a greater $\Delta G$ implies that the strange sea would be positively polarized, while the other flavors are negatively polarized. Since there is no obvious mechanism that allows selective polarization of different flavors, we conclude that these data imply that $\Delta G$ is of small to moderate size.

4. The orbital angular momentum extracted from data is rather small, but could be positive or negative, depending on the size of the polarized gluon distribution.

5. The extracted value for $I^p$ is comparable for all the data and well within experimental uncertainties. This indicates the validity of the BSR.

These experiments along with theoretical progress in calculating higher order QCD corrections, have allowed us to narrow the range of the spin contributions for each flavor. They have probed to smaller $x$ values, while decreasing the statistical and systematic errors. The main differences are the strange sea spin content and the size of $\Delta G$. There are a number of technologically feasible experiments that would supply more information about these distributions. Detailed summaries can be found in reference 9.

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