A NEXT-TO-LEADING ORDER QCD ANALYSIS OF THE SPIN STRUCTURE FUNCTION g_1 OF THE NUCLEON

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A next-to-leading order QCD analysis of the spin structure function g_1 is performed using SMC data and other presently available data. We present results for the first moments of the proton, deuteron and neutron structure functions, and determine singlet and non-singlet polarized parton distributions. We also test the Bjorken sum rule and find agreement with the theoretical prediction at the level of 10%.

Polarized deep inelastic scattering experiments [1,2] measure the spin structure function g_1. Its first moment $\Gamma_1 = \int_0^1 g_1(x)dx$ provides the axial singlet matrix element $a_0 = a_u + a_d + a_s$ which one may interpret as the contribution $\Delta\Sigma$ of the spin of the quarks to the spin of the nucleon. Experimentally a_0 is found to be smaller than the QPM expectation $\Delta\Sigma \approx 0.6$. This was advertised as the "spin crisis". In QCD, however, $\Delta\Sigma$ is a scheme dependent quantity and the relation between a_0 and $\Delta\Sigma$ depends on the chosen factorisation scheme. In the $\overline{MS}$ scheme $a_0 = \Delta\Sigma$ indeed, while in the AB scheme [3] a_0 receives a gluonic contribution through the axial anomaly of QCD, $a_0 = \Delta\Sigma_{AB} - \frac{n_f \alpha_s}{2\pi}\Delta g$, where Δg is the contribution of the spin of the qluons to the spin of the nucleon. The AB scheme is designed in such a way that $\Delta\Sigma_{AB}$ is independent of Q^2. We may then consider that $\Delta\Sigma_{AB}$ is the intrinsic contribution of the quark, the one that can be compared to the QPM expectation. If Δg is large enough the low value of a_0 could be compatible with the QPM expectation for $\Delta\Sigma$.

A next-to-leading order QCD analysis of g_1 was performed [4] using SMC final data [1] together with data from EMC, SLAC and HERMES [2]. The polarised parton distributions in the AB scheme are parametrised at an initial $Q^2 = 1$ GeV^2, as $\Delta f(x, Q^2) = N\ \eta_f\ x^{\alpha_f}(1-x)^{\beta_f}(1 + a_f\ x)$ where Δf denotes the singlet $\Delta\Sigma$, the non-singlet Δq_{NS}, or the gluon Δg distributions, and $N(\alpha, \beta, a)$ is a normalisation factor such that the parameter η is the integral of the corresponding parton distribution. The normalisation of the non-singlet quark densities $\eta_{NS}^{p,n}$ are fixed using the neutron and hyperon β decay constants and assuming SU(3) flavour symmetry: $\eta_{NS}^{p,n} = (\pm)\frac{3}{4}\frac{g_A}{g_V} + \frac{1}{4}a_8$. We set $\beta_g = 4$ according to QCD counting rules and $a_{NS} = a_g = 0$.

The initial parton distributions are evolved to the Q^2 of the data points using the DGLAP equations, and they are convoluted with the coefficient functions to give $g_1 = \frac{<e^2>}{2}[C_q^S \otimes \Delta\Sigma + 2n_f C_g^S \otimes \Delta g + C_q^{NS} \otimes \Delta q_{NS}]$. A χ^2 is computed from the difference between this calculated g_1 and the measured g_1; it is minimised by changing the initial parton distribution parameters. Two programmes were used, programme 1 was provided by Ball, Forte and Ridolfi [3] while programme 2 was developed within SMC [4]. They give similar fits as illustrated in Fig. 1 and a good description of the data, with χ^2 of 127 and 120 for 125 d.o.f. Programme 1 was used in the rest of the analysis. Fig. 2 presents the resulting parton distributions at the initial Q^2. The theoretical error comes mainly from the sensitivity to the renormalisation and factorisation scales, which is estimated by varying the two scales independently in the range $[0.5Q^2 - 2Q^2]$.

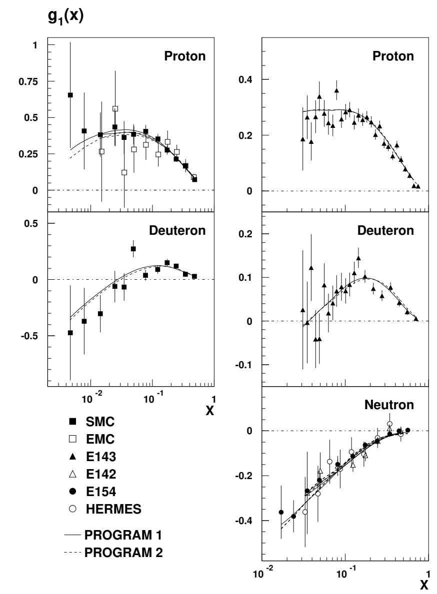

Figure 1: *Data on g_1 from CERN experiments (left) SLAC and DESY experiments (right) at their measured Q^2 together with the two QCD fits.*

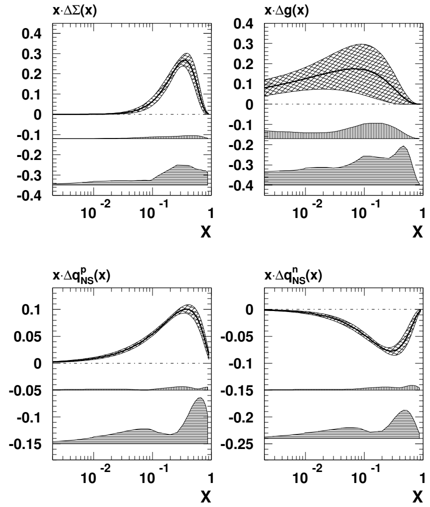

Figure 2: *Polarised parton distribution functions at $Q_i^2 = 1$ GeV^2. Their statistical uncertainty as obtained from the QCD fit is shown by a band with crossed hatch. The experimental systematic uncertainty is indicated by the vertically hatched band, and the theoretical uncertainty by the horizontally hatched band.*

We use all available data in the kinematic region $Q^2 \geq 1$ GeV^2, $x \geq 0.003$ to evaluate $\Gamma_1 = \int_0^1 g_1(x)dx$ at a fixed $Q_0^2 = 5$ GeV^2. Starting from

$g_1(x,Q^2)$ at the measured x and Q^2 we obtain g_1 at a fixed Q_0^2 as: $g_1(x,Q_0^2) = g_1(x,Q^2) + [g_1^{fit}(x,Q_0^2) - g_1^{fit}(x,Q^2)]$. To estimate the contributions to the first moments from the unmeasured low x ($x < 0.003$) and high x ($x > 0.8$) regions, we integrate over g_1^{fit} calculated at $Q^2 = 5$ GeV^2. We obtain $\Gamma_1^p = 0.121 \pm 0.003 \pm 0.005 \pm 0.017$, $\Gamma_1^d = 0.021 \pm 0.004 \pm 0.003 \pm 0.016$, and $\Gamma_1^n = -0.075 \pm 0.007 \pm 0.005 \pm 0.019$. We note that the error on the low x extrapolation covers the result which would be obtained with a Regge like extrapolation.

The integral η_g is the gluon contribution to the spin of the nucleon, we find $\Delta g = 0.99\ ^{+1.17}_{-0.31}\ (sta)\ ^{+0.42}_{-0.22}\ (sys)\ ^{+1.43}_{-0.45}\ (th)$ at $Q^2 = 1$ GeV^2. The uncertainties are very large and points to the need of a direct measurement of Δg in processes where the gluon is involved in the leading order, like the photon gluon fusion process. For the axial singlet matrix element we find $a_0 = 0.19 \pm 0.05(stat) \pm 0.04(syst)$, which means that the Ellis-Jaffe sum rules are violated. The QCD analysis provides directly $\Delta\Sigma_{AB} = 0.38^{+0.03}_{-0.03}{}^{+0.03}_{-0.02}{}^{+0.03}_{-0.05} = 0.38^{+0.05}_{-0.07}$. This is larger than a_0 but still significantly smaller than the QPM expectation.

The Bjorken sum rule cannot be tested directly from the previous estimations of Γ_1 because they were obtained with a QCD analysis which includes the constraint $\eta_{NS}^p - \eta_{NS}^n = \frac{3}{2}\frac{g_A}{g_V}$. This constraint had to be released and the fit redone, giving at $Q^2 = 5$ GeV^2:

$$\Gamma_1^p - \Gamma_1^n = 0.174\ ^{+0.005}_{-0.005}\ ^{+0.011}_{-0.009}\ ^{+0.021}_{-0.006} = 0.174\ ^{+0.024}_{-0.012}\ ,$$

which is in excellent agreement with the theoretical prediction $\Gamma_1^p - \Gamma_1^n = 0.181 \pm 0.003$ at the same Q_0^2.

References

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