GRSV Parton Densities Revisited

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An updated next-to-leading order (NLO) QCD analysis of all presently available longitudinally polarized deep-inelastic scattering (DIS) data is presented in the framework of the radiative parton model.

1. INTRODUCTION

Many new or improved measurements of the spin asymmetry

$$A_1(x,Q^2) \simeq \frac{g_1(x,Q^2)}{F_2(x,Q^2)/[2x(1+R(x,Q^2))]}, \qquad (1)$$

$R = F_L/2xF_1$, in longitudinally polarized DIS off various different targets (p, n, d) have become available in the past two years: E142, E143, and SMC have presented their final data sets [1], and new results from HERMES, E154, and E155 have been reported recently [2]. Since none of these measurements were included in our original NLO QCD analysis [3], it seems to be appropriate to reanalyse these data[2] within the framework of [3].

In NLO the polarized structure function g_1 in (1) reads (suppressing all x and Q^2 dependence)

$$g_1 = \frac{1}{2}\sum_{q=u,d,s} e_q^2 \left[(\Delta q + \Delta\bar{q}) \otimes \left(1+\frac{\alpha_s}{2\pi}\Delta C_q\right) + \frac{\alpha_s}{2\pi}\Delta g \otimes \Delta C_g\right] , \qquad (2)$$

where $\Delta C_{q,g}$ are the spin-dependent Wilson coefficients and the symbol $\otimes$ denotes the usual convolution in x space. From (2) it is obvious that inclusive DIS data [1, 2] can reveal only information on $\Delta q + \Delta\bar{q}$ but neither on Δq *and* $\Delta\bar{q}$ nor on Δg, which enters (2) only as an $\mathcal{O}(\alpha_s)$ correction. Thus one can either stick to a comprehensive analysis of polarized DIS [4, 5] or one has to impose certain *assumptions* about the flavor decomposition in order to be able to estimate processes other than DIS for upcoming experiments like RHIC. As in [3], and other more recent QCD analyses [6, 7], we follow the latter option.

2. DETAILS OF THE GRSV ANALYSIS

Due to the lack of space we shall be rather brief and concentrate only on the most important changes since [3]. The limited amount of data demands a reasonably simple, but flexible enough ansatz for the polarized densities such as

$$\Delta f(x,\mu^2) = N_f x^{\alpha_f}(1-x)^{\beta_f} f(x,\mu^2) , \qquad (3)$$

with $f = u, \bar{u}, d, \bar{d}, s, \bar{s}, g$. Note that in [3] we actually used $f = u_v, d_v$ in (3) instead of u and d, however the positivity constraint

$$\left|\Delta f(x,Q^2)\right| \leq f(x,Q^2) , \qquad (4)$$

which we want to exploit in our analysis, does not necessarily hold for the valence densities. Of course, the bound (4) is strictly valid only in LO and is subject to NLO corrections [8] because the Δf become unphysical, scheme-dependent objects in NLO. However the corrections are not very pronounced, in particular at large x [8], the only region where (4) imposes some restrictions in practice. We therefore use (4) also in NLO.

To further simplify (3) we *assume* that $\Delta\bar{q} = \Delta\bar{u} = \Delta\bar{d}$, fix $N_{u,d}$ by the relations between the first moments of the non-singlet combinations $\Delta q_{3,8}$ and the F and D values (using the updated value for $|g_A/g_V| = 1.2670 \pm 0.0035$ [9]), and take $\Delta s = \Delta\bar{s} = \lambda\Delta\bar{q}$. In the latter relation we *choose* $\lambda = 1$ ($SU(3)_f$ symmetric sea), but similarly agreeable fits are obtained, e.g., for $\lambda = 1/2$ (see also [7]), as well as by using an independent x shape for Δs, reflecting the above mentioned uncertainty in the flavor separation.

For the unpolarized distributions f in (3) and (4) we use the updated GRV densities [10] and

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[2]The E155 proton data are still preliminary and hence not included in our analysis.

also adopt their values for the input scale μ ($\approx 0.6\,\mathrm{GeV}$ in NLO) and $\alpha_s(M_z^2) = 0.114$. Note that in [10] the RG equation for α_s is now solved exactly instead of using the approximative NLO formula (see, e.g., [9]), which is more appropriate at low Q^2 where many of the polarized data lie.

To fix the remaining parameters in (3) we perform fits to the directly measured spin asymmetry (1) in LO *and* NLO, which is mandatory if one wants to adopt these distributions in a consistent analysis of the perturbative stability of polarized processes. Also most MC programs only contain LO matrix elements, and hence LO densities are more appropriate. Apart from the above outlined 'standard scenario' fit, equally good fits can be performed in a 'valence scenario' (see [3]) which is based on the assumption [11] that the F, D values fix only the valence parts of $\Delta q_{3,8}$. The main feature of such a model is the possibility to describe the data with a vanishing strange sea. Due to the lack of space we do not pursue this scenario here and restrict ourselves in what follows to the results obtained in the NLO ($\overline{\mathrm{MS}}$) 'standard scenario' framework.

3. RESULTS

A comparison of our new NLO fit with the available $A_1(x, Q^2)$ data [1, 2] and with our previous analysis [3] is presented in Fig. 1. The total χ^2 values of the new and old fits are 147.4 and 183, respectively, for 185 data points and adding statistical and systematical errors in quadrature. As can be seen, sizeable differences appear only in case of the neutron asymmetry, which leaves its footprint also in the individual parton densities Δf shown in Fig. 2. Since the neutron data mainly probe Δd, the most prominent changes are observed here.

The differences in the sea and in Δg only reflect the fact that they are constrained to a much lesser extent by the data than u and d. In particular Δg remains to be hardly constrained at all, which is not surprising due to the lack of any direct information on Δg so far. Therefore we show in Fig. 2 also the results of two other fits, which are based on additional constraints on Δg. For the '$\Delta g = 0$' fit we start from a vanishing gluon input in (3),

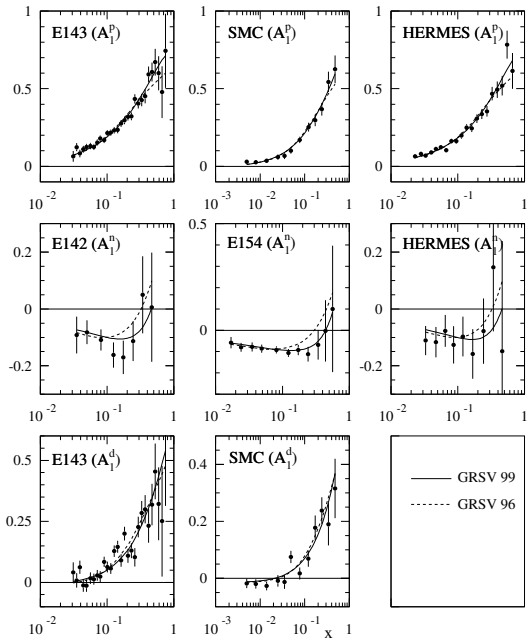

Figure 1. Comparison of our reanalysed NLO results for $A_1(x, Q^2)$ (solid lines) with available data sets (not shown, but included in the fit: E155 (deuteron) and the old EMC and SLAC data) and with our previous analysis [3] (dashed lines).

and the 'static Δg' is chosen in such a way that its first moment becomes independent of Q^2. This can be achieved by setting $d\Delta g(Q^2)/d\ln Q^2 = 0$ and yields in LO $\Delta g \simeq -\Delta\Sigma/2$ (see [12]), where $\Delta\Sigma$ is the total helicity carried by quarks (the relation is only subject to a small NLO correction). Both gluons give also excellent fits to the available data and do not affect the results for u and d (see Fig. 2). In fact we can obtain fits without any significant change in χ^2 for $\Delta g(\mu^2)$ in the range -0.3...0.6 (our best fit has 0.28, corresponding to $\Delta g(10\,\mathrm{GeV}^2) \simeq 0.9$). The uncertainty in Δg is compatible to the one found in [5], although our gluons extend also to slightly negative first moments. It is interesting to observe that for our best fit gluon the spin of the nucleon

$$S_z = \frac{1}{2} = \frac{1}{2}\Delta\Sigma(Q^2) + \Delta g(Q^2) + L_z(Q^2) \qquad (5)$$

is dominantly carried by quarks and gluons at our

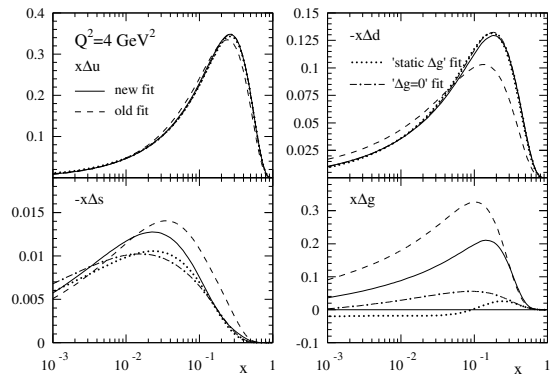

Figure 2. The polarized NLO $\overline{\rm MS}$ densities at $Q^2 = 4\,{\rm GeV}^2$ as obtained in the new and old [3] GRSV analyses. Also shown are the distributions obtained in two other fits employing additional constraints on Δg (see text). In all fits shown we have chosen a flavor symmetric sea.

input scale μ, and only during the Q^2 evolution a large negative $L_z(Q^2)$ is being built up in order to compensate for the strong rise of $\Delta g(Q^2)$, see Fig. 5 in [12]. For the 'static Δg' the situation is completely different: by construction the quark and gluon contributions to (5) cancel each other implying that for *all* values of Q^2 the spin is entirely of angular momentum origin, contrary to what is intuitively expected.

Inevitably the large uncertainty in Δg implies that the small x behaviour of g_1 is completely uncertain and not predictable (see Fig. 3 in [12]), which translates also into a large theoretical error from the $x \to 0$ extrapolation when calculating first moments of g_1. Taking our best fit we obtain $\Gamma_1^p = 0.133$ and $\Gamma_1^n = -0.624$ at $Q^2 = 10\,{\rm GeV}^2$ in agreement with a recent SMC QCD analysis [5].

The two challenging questions concerning polarized parton densities are still Δg and the flavor decomposition. Recent semi-inclusive DIS results [13] may help to unravel the latter, but major progress, in particular on Δg, can be only expected from RHIC. A realization of the optional upgrade of HERA to a polarized collider would be also very helpful to gain more insight into the spin structure of the nucleon *and* the photon, with the latter being completely unmeasured so far.

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