On the Role of Higher Twist in Polarized Deep Inelastic Scattering

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The higher twist corrections $h^N(x)/Q^2$ to the spin dependent proton and neutron g_1 structure functions are extracted in a model independent way from experimental data on $g_1^N(x,Q^2)$ and found to be non-negligible. It is shown that the NLO QCD polarized parton densities determined from the data on g_1, including higher twist effects, are in good agreement with those found earlier from our analysis of the data on g_1/F_1 and A_1 where higher twist effects are negligible. On the contrary, the LO QCD polarized parton densities obtained from the data on g_1, including higher twist, differ significantly from our previous results.

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I. INTRODUCTION

Spurred on by the famous EMC experiment [1] at CERN in 1987, there has been a huge growth of interest in *polarized* DIS experiments which yield more refined information about the partonic structure of the nucleon, *i.e.*, how the nucleon spin is divided up among its constituents, quarks and gluons. Many experiments have been carried out at SLAC, CERN and DESY to measure the longitudinal ($A_\parallel$) and transverse ($A_\perp$) asymmetries and to extract from them the photon-nucleon asymmetries $A_1(x,Q^2)$ and $A_2(x,Q^2)$ as well as the nucleon spin-dependent structure functions $g_1(x,Q^2)$ and $g_2(x,Q^2)$. Many theoretical analyses of the world data on A_1 and g_1 based on leading (LO) and next-to-leading order (NLO) calculations in perturbative QCD have been performed in order to test the spin properties of QCD and extract from the data the polarized parton densities [33]. It was demonstrated that the polarized DIS data are in an excellent agreement with the pQCD predictions for $A_1^N(x,Q^2)$ and $g_1^N(x,Q^2)$. What also follows from these analyses is that the limited kinematic range and the precision of the present generation of inclusive DIS experiments are enough to determine with a good accuracy only the polarized parton densities $(\Delta u+\Delta\bar{u})(x,Q^2)$ and $(\Delta d+\Delta\bar{d})(x,Q^2)$. The polarized strange sea density $(\Delta s+\Delta\bar{s})(x,Q^2)$ as well as the polarized gluon density $\Delta G(x,Q^2)$ are still weakly constrained, especially ΔG. The non-strange polarized sea-quark densities $\Delta\bar{u}$ and $\Delta\bar{d}$ cannot be determined, even in principle, from the inclusive DIS experiments alone without additional assumptions.

There is, however, an important difference between the kinematic regions of the unpolarized and polarized data sets. While in the unpolarized case we can cut the low Q^2 and W^2 data in order to eliminate the less known non-perturbative higher twist effects, it is impossible to perform such a procedure for the present data on the spin-dependent structure functions without loosing too much information. This is especially the case for the HERMES, SLAC and Jefferson Lab experiments. So, to extract the polarized parton densities from the experimental data on $g_1^N(x,Q^2)$ the higher twist corrections have to be included in the data fits. Note that the polarized parton densities in QCD are related to the leading-twist expression of g_1.

It was shown [3–5] that to avoid this problem and to determine polarized parton densities less sensitive to higher twist effects it is better to analyze data on $A_1(\sim g_1/F_1)$ using for the g_1 and F_1 structure functions their *leading twist* (LT) expressions. It is found that if for $(g_1)_{\rm LT}$ an NLO approximation is used, the "effective higher twist" corrections to A_1, extracted from the data, are negligible and consistent with zero within the errors, which means that the higher twists corrections (HT) to g_1 and F_1 approximately cancel in the ratio g_1/F_1, or more precisely, $(g_1)_{\rm HT}/(g_1)_{\rm LT} \approx (F_1)_{\rm HT}/(F_1)_{\rm LT}$.

In this paper we present a detailed study of the higher twist contributions $h^N(x)/Q^2$ to the nucleon structure function $g_1^N(x,Q^2)$. The quantities $h^N(x)$ have been extracted from the data in a *model independent* way. The role of higher twists in the determination of the polarized parton densities is discussed.

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II. CONNECTION BETWEEN THEORY AND EXPERIMENT

The nucleon spin-dependent structure function $g_1^N(x,Q^2)$ is a linear combination of the asymmetries $A_\parallel^N$ and $A_\perp^N$ (or the related virtual photon-nucleon asymmetries A_1^N and A_2^N) measured with the target polarized longitudinally or perpendicular to the lepton beam, respectively. The most direct way to confront the QCD predictions to the data is a fit to data on the ratio of the structure functions, g_1^N/F_1^N. Such data have been directly presented by SLAC/E143 and SLAC/E155 experiments [6]. Most of the Collaborations, however, have presented data on the asymmetry A_1^N which, in practice, are data on $A_\parallel^N/D$. The photon-nucleon asymmetry A_1^N and the ratio g_1^N/F_1^N are related to the measured longitudinal asymmetry $A_\parallel^N$ by

$$A_1^N = \frac{A_\parallel^N}{D} - \eta A_2^N, \qquad (1)$$

$$(1+\gamma^2)\frac{g_1^N}{F_1^N} = \frac{A_\parallel^N}{D} + (\gamma-\eta)A_2^N, \qquad (2)$$

where D denotes the photon depolarization factor, η and γ are kinematic factors. η is proportional to γ and γ is given by

$$\gamma^2 = \frac{4M_N^2x^2}{Q^2}\ . \qquad (3)$$

In (3) $\mathrm{M_N}$ is the nucleon mass. It should be noted that in the SLAC and HERMES kinematic regions γ^2 cannot be neglected on LHS of (2).

The magnitude of A_2^N has been measured by SMC, SLAC/E143 and SLAC/E155 and found to be small [2, 7]. Then to a good approximation its contribution to the RHS of Eqs. (1) and (2) can be neglected and A_1^N and g_1^N/F_1^N can be expressed as

$$A_1^N \cong \frac{A_\parallel^N}{D}\ , \qquad (4)$$

$$(1+\gamma^2)\frac{g_1^N}{F_1^N} \cong \frac{A_\parallel^N}{D}\ . \qquad (5)$$

It is important to note that due to the additional small factor $(\gamma-\eta)$ in (2) the ratio g_1^N/F_1^N is better approximated by the measured asymmetry $A_\parallel^N$ (Eq. (5)) than the virtual photon-nucleon asymmetry A_1^N (Eq. (4)).

Using (4) and (5) we reach the well known relation

$$A_1^N(x,Q^2) \cong (1+\gamma^2)\frac{g_1^N(x,Q^2)}{F_1^N(x,Q^2)} \qquad (6)$$

usually used in the literature. However, as was already mentioned, we have to keep in mind that the presented experimental values on A_1^N [1, 8] neglecting A_2, $''A_1^N(x,Q^2)''_{exp}$, are really the experimental values of $A_\parallel^N(x,Q^2)/D$ and that the latter quantity is very well approximated by $(1+\gamma^2)g_1^N/F_1^N$.

Using the relation between the unpolarized structure function $F_1(x,Q^2)$ and the usually extracted from unpolarized DIS experiments $F_2(x,Q^2)$ and $R(x,Q^2)$

$$2xF_1^N = F_2^N(1+\gamma^2)/(1+R^N) \qquad (N=p,n,d) \qquad (7)$$

Eq. (6) can be rewritten as

$$A_1^N(x,Q^2) \cong \frac{g_1^N(x,Q^2)}{F_2^N(x,Q^2)}2x[1+R^N(x,Q^2)]\ . \qquad (8)$$

Up to now, two approaches have been mainly used to extract the polarized parton densities (PPD) from the world polarized DIS data. According to the first [4, 5] the leading twist LO/NLO QCD expressions for the structure functions g_1^N and F_1^N have been used in (6) in order to confront the data

$$\left[\frac{g_1(x,Q^2)}{F_1(x,Q^2)}\right]_{exp} \Leftrightarrow \frac{g_1(x,Q^2)_{\rm LT}}{F_1(x,Q^2)_{\rm LT}}\ ,$$
$$A_1(x,Q^2)_{exp} \Leftrightarrow (1+\gamma^2)\frac{g_1(x,Q^2)_{\rm LT}}{F_1(x,Q^2)_{\rm LT}}\ . \qquad (9)$$

In (9) we have dropped the nucleon target label N. It was shown [3–5] that in this case the extracted from the data “effective” HT corrections $h^{A_1}(x)$ to A_1

$$A_1(x,Q^2) = (1+\gamma^2)\frac{g_1(x,Q^2)_{\rm LT}}{F_1(x,Q^2)_{\rm LT}} + \frac{h^{A_1}(x)}{Q^2} \qquad (10)$$

are negligible and consistent with zero within the errors, $h^{A_1}(x)\approx 0$ (see Fig. 1). What follows from this result is that the higher twist corrections to g_1 and F_1 compensate each other in the ratio g_1/F_1 and the PPD extracted this way are less sensitive to higher twist effects. We stress again that the polarized parton densities in QCD are related only to the leading-twist part of g_1.

According to the second approach [9, 10], g_1/F_1 and A_1 data have been fitted using phenomenological parametrizations of the experimental data for $F_2(x,Q^2)$ and $R(x,Q^2)$

$$\left[\frac{g_1(x,Q^2)}{F_1(x,Q^2)}\right]_{exp} \Leftrightarrow \frac{g_1(x,Q^2)_{\rm LT}}{F_2(x,Q^2)_{exp}}2x\frac{[1+R(x,Q^2)_{exp}]}{(1+\gamma^2)}\ ,$$
$$A_1(x,Q^2)_{exp} \Leftrightarrow \frac{g_1(x,Q^2)_{\rm LT}}{F_2(x,Q^2)_{exp}}2x[1+R(x,Q^2)_{exp}]\ . \qquad (11)$$

Note that such a procedure is equivalent to a fit to $(g_1)_{exp}$, but it is in principle better than the fit to the g_1 data themselves actually presented by the experimental groups. The point is that most of the experimental data on g_1 have been extracted from the A_1 and g_1/F_1 data using the additional assumption that the ratio g_1/F_1 does not depend on Q^2. Also, different experimental groups have used *different* parametrizations for F_2 and R.

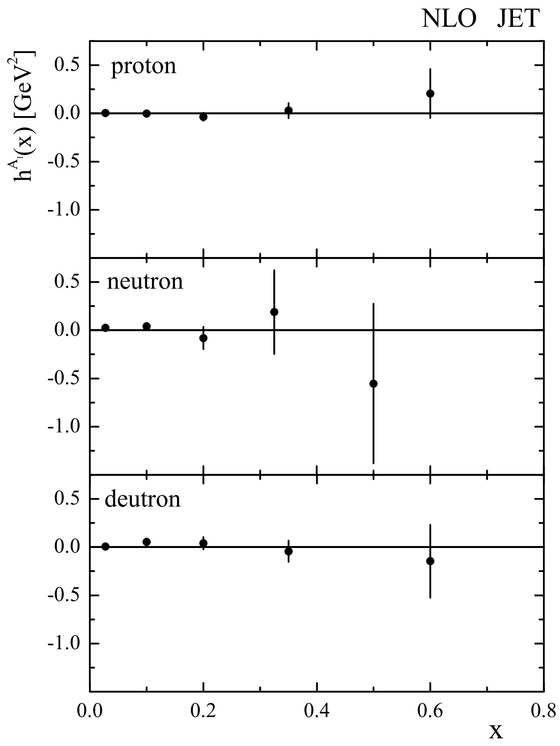

FIG. 1: Effective higher twist contribution $h^{A_1}(x)$ to the spin asymmetry $A_1^N(x,Q^2)$ extracted from the data. Compared to our 1999 result (Fig. 4 [3] and Fig. 1 [5]) we present here the results of a new analysis including in the data set the SLAC/155 proton data not available at that time.

In the analyses [11, 12] a procedure has been used which is somehow a mixture between the two methods above, but bearing in mind the sensitivity of the results to higher twist effects it is analogous to the second one. In these fits the leading twist expression for F_2 instead of its experimental values has been used

$$\left[\frac{g_1(x,Q^2)}{F_1(x,Q^2)}\right]_{exp} \Leftrightarrow \frac{g_1(x,Q^2)_{\rm LT}}{F_2(x,Q^2)_{\rm LT}}2x\frac{[1+R(x,Q^2)_{exp}]}{(1+\gamma^2)}\ ,$$
$$A_1(x,Q^2)_{exp} \Leftrightarrow \frac{g_1(x,Q^2)_{\rm LT}}{F_2(x,Q^2)_{\rm LT}}2x[1+R(x,Q^2)_{exp}]\ . \tag{12}$$

It was shown by GRSV [4] that if the second approach (11) is applied to the data (F_2 and R are taken from experiment) allowing at the same time "effective higher twist" contribution $h^{A_1}(x)/Q^2$ to the RHS of (11), $h^{A_1}(x)$ is found to be sizeable and important in the fit. In other words, bearing in mind that a lot of data on A_1 and g_1/F_1 are at small Q^2 special attention must be paid to higher twist corrections to the structure function g_1. To extract correctly the polarized parton densities from the g_1 data these corrections have to be included into data fits. Note that a QCD fit to the data in this case, keeping in $g_1(x,Q^2)_{QCD}$ only the leading-twist expression, leads to some "effective" parton densities which involve in themselves the HT effects and therefore, are not quite correct.

III. HIGHER TWIST EFFECTS IN $g_1(x,Q^2)$

The usual pQCD expression for the nucleon structure function $g_1^p(x,Q^2)$, in terms of polarized quark and gluon densities, arises from the contribution of the leading twist ($\tau = 2$) QCD operators and in NLO has the form (a similar formula holds for g_1^n):

$$g_1^p(x,Q^2)_{\rm pQCD} = \frac{1}{2}\sum_q^{N_f} e_q^2[(\Delta q+\Delta\bar{q})\otimes(1+\frac{\alpha_s(Q^2)}{2\pi}\delta C_q) + \frac{\alpha_s(Q^2)}{2\pi}\Delta G\otimes\frac{\delta C_G}{N_f}], \tag{13}$$

where $\Delta q(x,Q^2), \Delta\bar{q}(x,Q^2)$ and $\Delta G(x,Q^2)$ are quark, anti-quark and gluon polarized densities in the proton, which evolve in Q^2 according to the spin-dependent NLO DGLAP equations. $\delta C(x)_{q,G}$ are the NLO spin-dependent Wilson coefficient functions and the symbol $\otimes$ denotes the usual convolution in Bjorken x space. $\rm N_f$ is the number of active flavors. In LO QCD the coefficients $\delta C(x)_q$ and $\delta C(x)_G$ vanish and the polarized parton densities in (13) evolve in Q^2 according to the spin-dependent LO DGLAP equations.

It is well known that at NLO and beyond, the parton densities as well as the Wilson coefficient functions become dependent on the renormalization (or factorization) scheme employed [34]. Two often used schemes are the $\overline{\rm MS}$ and the JET schemes. Both the NLO polarized coefficient functions [13] and the NLO polarized splitting functions (anomalous dimensions) [14] needed for the calculation of $g_1(x,Q^2)$ in the $\overline{\rm MS}$ scheme are well known at present. The corresponding expressions for these quantities in the JET scheme can be found in [15].

However, there are other contributions to g_1, arising from QCD operators of higher twist (HT), namely $\tau \geq 3$, which are related to multi-parton correlations in the nucleon. It can be shown that these give rise to contributions to $g_1^N(x,Q^2)$ that decrease like inverse powers of Q^2. The leading term has the form $h^N(x,Q^2)/Q^2$, where $h^N(x,Q^2)$ could have a slow, logarithmic dependence on Q^2.

In the kinematic regime where such terms might be relevant it is important for consistency to realise that the QCD expression (13) is derived under the assumption that $Q^2 >> M_N^2$. There will thus be *purely kinematic* corrections to (13), which involve a power series in M_N^2/Q^2 with small coefficients. The leading term of these so-called target mass corrections (TMC) therefore has a Q^2 behavior similar to the genuine HT terms, but it is not a dynamical HT effect.

In view of this we shall write

$$g_1(x,Q^2) = g_1(x,Q^2)_{\rm LT} + g_1(x,Q^2)_{\rm HT}\ , \qquad (14)$$

where we have dropped the nucleon target label N. In (14)

$$g_1(x,Q^2)_{\rm LT} = g_1(x,Q^2)_{\rm pQCD} + h^{\rm TMC}(x,Q^2)/Q^2\ , \quad (15)$$

where $h^{\rm TMC}(x,Q^2)$ is exactly calculable [16, 17] and

$$g_1(x,Q^2)_{\rm HT} = h(x,Q^2)/Q^2\ . \qquad (16)$$

As mentioned above, $h(x,Q^2)$ denotes the dynamical higher twist power corrections to g_1 which represent the multi-parton correlations in the target. The latter are non-perturbative effects and their calculation is model dependent (see, e.g., [18] and references therein). That is why a *model independent* extraction of the dynamical higher twists $h(x)$ from the experimental data is important not only for a better determination of the polarized parton densities but also because it would lead to interesting tests of the non-perturbative QCD regime.

IV. METHOD OF ANALYSIS

In this Section we will briefly describe the method of our analysis of the data on inclusive polarized DIS taking into account the higher twist corrections to the nucleon structure function $g_1^N(x,Q^2)$. In our fit to the data we have used the following expressions for g_1/F_1 and A_1:

$$\begin{aligned}
\left[\frac{g_1^N(x,Q^2)}{F_1^N(x,Q^2)}\right]_{exp} &\Leftrightarrow \frac{g_1^N(x,Q^2)_{\rm LT} + h^N(x)/Q^2}{F_2^N(x,Q^2)_{exp}} 2x \frac{[1+R(x,Q^2)_{exp}]}{(1+\gamma^2)}\ ,\\
A_1^N(x,Q^2)_{exp} &\Leftrightarrow \frac{g_1^N(x,Q^2)_{\rm LT} + h^N(x)/Q^2}{F_2^N(x,Q^2)_{exp}} 2x[1+R(x,Q^2)_{exp}]\ . \qquad (17)
\end{aligned}$$

where $g_1^N(x,Q^2)_{\rm LT}$ is given by the leading twist expression (15). In (17) $h^N(x)$ are a measure of the dynamical higher twists. In our analysis their Q^2 dependence is neglected. It is small and the accuracy of the present data does not allow to determine it. For the unpolarized structure functions $F_2^N(x,Q^2)_{exp}$ and $R(x,Q^2)_{exp}$ we have used the NMC parametrization [19] and the SLAC parametrization $\rm R_{1998}$ [20], respectively.

As in our previous analysis [5], for the input LO and NLO polarized parton densities at $Q_0^2 = 1\ GeV^2$ we have adopted a simple parametrization

$$\begin{aligned}
x\Delta u_v(x,Q_0^2) &= \eta_u A_u x^{a_u} x u_v(x,Q_0^2),\\
x\Delta d_v(x,Q_0^2) &= \eta_d A_d x^{a_d} x d_v(x,Q_0^2),\\
x\Delta s(x,Q_0^2) &= \eta_s A_s x^{a_s} x s(x,Q_0^2),\\
x\Delta G(x,Q_0^2) &= \eta_g A_g x^{a_g} x G(x,Q_0^2), \qquad (18)
\end{aligned}$$

where on RHS of (18) we have used the MRST98 (central gluon) [21] and MRST99 (central gluon) [22] parametrizations for the LO and NLO($\overline{\rm MS}$) unpolarized densities, respectively. The number of active flavors is $\rm N_f = 3$. The normalization factors A_i in (18) are fixed such that η_i are the first moments of the polarized densities. To fit better the data in LO QCD, an additional factor $(1+\gamma_v x)$ on RHS is used for the valence quarks. Bearing in mind that the light quark sea densities $\Delta\bar{u}$ and $\Delta\bar{d}$ cannot be, in principle, determined from the present inclusive data (in the absence of polararized charge current neutrino experiments) we have adopted the convention of a flavor symmetric sea

$$\Delta u_{sea} = \Delta\bar{u} = \Delta d_{sea} = \Delta\bar{d} = \Delta s = \Delta\bar{s}. \qquad (19)$$

The first moments of the valence quark densities η_u and η_d are constrained by the sum rules

$$a_3 = g_A = \rm F + D = 1.2670\ \pm\ 0.0035\ \ [23], \qquad (20)$$

$$a_8 = \rm 3F - D = 0.585\ \pm\ 0.025\ \ [11], \qquad (21)$$

where a_3 and a_8 are non-singlet combinations of the first moments of the polarized parton densities corresponding to $3^{\rm rd}$ and $8^{\rm th}$ components of the axial vector Cabibbo current

$$a_3 = (\Delta u + \Delta\bar{u})(Q^2) - (\Delta d + \Delta\bar{d})(Q^2)\ , \qquad (22)$$

$$a_8 = (\Delta u + \Delta\bar{u})(Q^2) + (\Delta d + \Delta\bar{d})(Q^2) - 2(\Delta s + \Delta\bar{s})(Q^2)\ . \qquad (23)$$

The sum rule (20) reflects isospin SU(2) symmetry, whereas (21) is a consequence of the $SU(3)_f$ flavor symmetry treatment of the hyperon β-decays. While the isospin symmetry is not in doubt, there is some question about the accuracy of assuming $SU(3)_f$ in analyzing hyperon β-decays. We have previously studied the sensitivity of the polarized parton densities to the deviation of a_8 from its SU(3) flavor symmetric value (0.58). The results are given in [24]. In this analysis we will use for a_8 its SU(3) symmetric value (21).

In our past papers we have used the Jacobi polynomial method to yield the structure functions $g_1^N(x,Q^2)_{\rm LT}$ from their Mellin moments in n space. The details of this procedure are given in [25]. But the accuracy of this method is limited in the low x region, $x<0.01$, so we have now used the inverse Mellin-transformation method (see, e.g., [26]) which reconstructs very precisely $g_1^N(x,Q^2)_{\rm LT}$ from its moments in the whole x region. We have repeated our fits without including HT corrections in order to compare to our previous results [5] obtained by the Jacobi polynomial method. We have found very good agreement between the results obtained by both methods. The reason is that the present kinematic x region of the polarized DIS data coincides with the domain where the Jocobi polynomial method works well. Also, the difference between the structure functions calculated by Jacobi and inverse Mellin-transformation methods is much smaller than the accuracy achieved in the present polarized DIS experiments. Nevertheless, bearing in mind its universality and, in particular, its applicability to the semi-inclusive DIS processes, we have decided to use the inverse Mellin-transformation approach in this analysis.

The unknown higher twists $h^N(x)$ in (17) have been extracted from the data following the method used in [27] and [28] for the higher twist corrections to the unpolarized structure functions F_2 and xF_3, respectively [35]. The measured x region has been split into 5 bins and to any x-bin two parameters $h_i^{(p)}$ and $h_i^{(n)}$ have been attached. We have found that for a deutron the relation $h_i^{(d)}=0.925(h_i^{(p)}+h_i^{(n)})/2$ is a good approximation. So, to the parameters connected with the input PPD (18) we add the parameters $h_i^{(p)}$ and $h_i^{(n)}$, $(i=1,2,..,5)$.

All free parameters

$$\{\ a_u,\ a_d,\ a_s,\ a_g,\ \eta_s,\ \eta_g\ (\gamma_u,\ \gamma_d);\ h_i^{(p)},\ h_i^{(n)}\ \} \qquad (24)$$

have been determined from the best fit to g_1/F_1 and A_1 data using (17), i.e., effectively by fitting $(g_1)_{exp}$. Note that in the calculations of $g_1(x,Q^2)_{\rm LT}$ we have used for the strong coupling constant $\alpha_s(Q^2)$ the same procedure as in our previous paper [5] (see the details in LSS2001 FORTRAN code at http://durpdg.dur.ac.uk/HEPDATA/PDF).

V. RESULTS

In this section we present the numerical results of our fits to the world data on g_1/F_1 [6] and A_1 [1, 8]. The data used (185 experimental points) cover the following kinematic region:

$$0.005\le x\le 0.75, \qquad 1<Q^2\le 58\ GeV^2\ . \qquad (25)$$

The total (statistical and systematic) errors are taken into account. The systematic errors are added quadratically.

We prefer to discuss the results of the NLO analysis in the JET (or so-called chirally invariant) factorization scheme [30]. In this scheme the first moment of singlet $\Delta\Sigma(Q^2)$, as well as the strange sea polarization $(\Delta s+\Delta\bar{s})(Q^2)$, are Q^2 *independent* quantities. Then, it is meaningful to directly interpret $\Delta\Sigma$ as the contribution of the quark spins to the nucleon spin and to compare its value obtained from the DIS region with the predictions of the different (constituent, chiral, etc.) quark models at low Q^2. Later we will briefly comment on the scheme dependence effects on the results of the analysis.

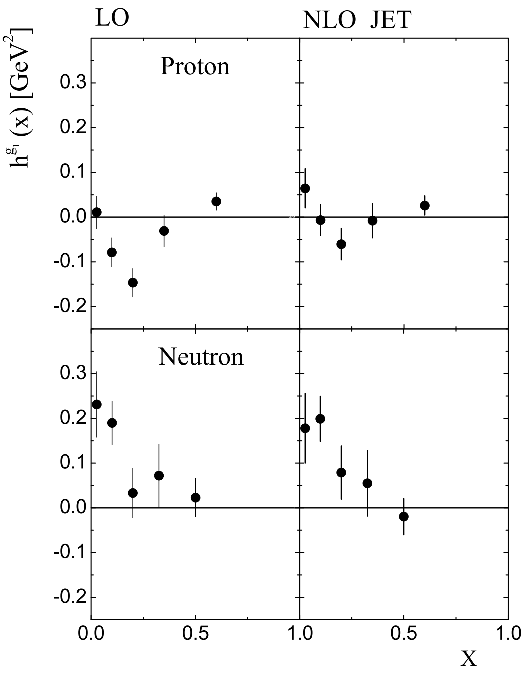

FIG. 2: Higher twist corrections to the proton and neutron g_1 structure functions extracted from the data on g_1 in a case of LO and NLO QCD approximation for $g_1(x,Q^2)_{\rm LT}$.

A. Higher twist effects

The numerical results of our fits to the data are summarized in Tables I and II. As seen from the values of χ^2 per degree of freedom $\chi^2_{\rm DF}$ in Table I, a very good description of the data is achieved. The best LO and NLO(JET) fits correspond to $\chi^2_{\rm DF,LO}=0.892$ and to $\chi^2_{\rm DF,NLO}=0.858$. We have found that the fit to the data is significantly improved, especially in the LO case, when the higher twist corrections to g_1^N are included in the analysis (see Table II). In contrast to the case when the HT corrections to g_1 are not taken into account in the fits, the value of $\chi^2_{\rm LO}$(HT) is very close to that of $\chi^2_{\rm NLO}$(HT), which is an indication that the tail of the neglected higher order logarithmic corrections to g_1 resemble a power behavior of order $\mathcal{O}(1/Q^2)$ [31]. A similar behavior of χ^2 has been observed in the QCD analysis of the unpolarized structure function $xF_3(x,Q^2)$ in [28].

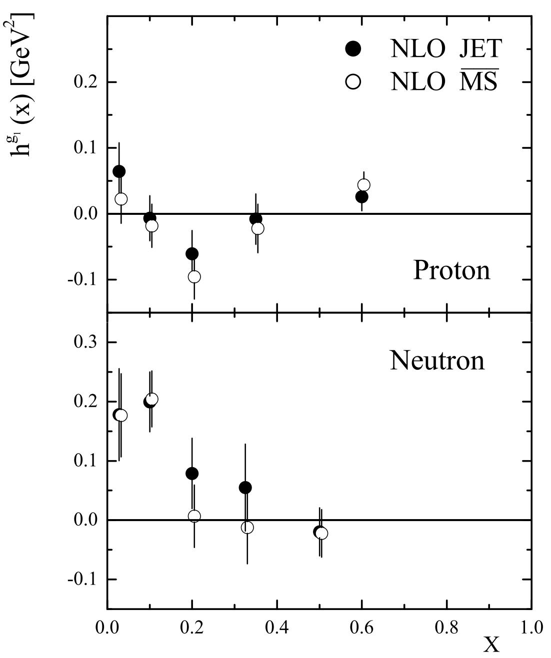

FIG. 3: Higher twist corrections to the proton and neutron g_1 structure functions extracted from the data when the leading twist calculations of $g_1(x,Q^2)_{\rm NLO}$ are performed in different factorization schemes.

The extracted higher twist corrections to the proton and neutron spin structure functions, $h^p(x)$ and $h^n(x)$, are shown in Fig. 2. As seen from Fig. 2 the corrections for the proton and neutron have a different shape. While $h^p(x)$ changes sign in the LO as well in the NLO case, $h^n(x)$ is non-negative in the measured x region in both cases. One can see also that the HT corrections to the proton structure function g_1^p appear to be smaller when for $(g_1)_{\rm LT}$ the NLO approximation is used. In Fig. 3 we demonstrate how the choice of the factorization scheme for the perturbative calculation of $(g_1)_{\rm LT}$ influences the higher twists results. The results are presented for the JET and $\overline{\rm MS}$ schemes. It is seen that the HT corrections to g_1 in both cases coincide within the errors. The small deference between the central values could be considered as an estimation of the NNLO effects in $(g_1)_{\rm LT}$ [36].

B. NLO polarized parton densities

Let us discuss now the polarized parton densities extracted from the data in the presence of the HT corrections to g_1. We will call this set of parton densities PD($g_1^{\rm LT}+$HT). In Fig. 4 we compare the NLO(JET) polarized PD($g_1^{\rm NLO}+$HT) with those obtained in our analysis [5] where we performed fits to the data according to (9). We will call the latter PD($g_1^{\rm NLO}/F_1^{\rm NLO}$). As seen from Fig. 4 the two sets of polarized parton densities are very close to each other. This is a good illustration of the fact that a fit to the data on $A_1(\sim g_1/F_1)$ using for the g_1 and F_1 structure functions their NLO leading twist expressions ($\chi^2_{\rm DF,NLO}=0.859$) is equivalent to a fit to the g_1 data taking into account the higher twist corrections to g_1 ($\chi^2_{\rm DF,NLO}=0.858$). In other words, this analysis confirms once more that the higher twist corrections to g_1 and F_1 approximately cancel in the ratio g_1/F_1.

TABLE I: Parameters of the LO and NLO(JET) input parton densities at $Q^2 = 1\ GeV^2$ as obtained from the best fits to the world g_1/F_1 and A_1^N data including the HT corrections to g_1. The errors shown are total (statistical and systematic). Note that the TMC are included in $(g_1)_{\rm LT}$.

Fit	$(g_1)_{LO}+h(x)/Q^2$	$(g_1)_{NLO}+h(x)/Q^2$
DF	185 - 16	185 - 16
χ^2	150.7	145.0
χ^2/DF	0.892	0.858
η_u	0.926^a	0.926^a
a_u	0.000 ± 0.002	0.312 ± 0.048
γ_u	1.556 ± 0.261	0^a
η_d	- 0.341^a	-0.341^a
a_d	0.000 ± 0.005	0.000 ± 0.049
γ_d	2.808 ± 1.249	0^a
η_s	- 0.072 ± 0.008	- 0.045 ± 0.007
a_s	0.601 ± 0.064	1.583 ± 0.434
η_g	0.803^a	0.803 ± 0.244
a_g	0.376^a	0.376 ± 0.503
x_i	$h^p(x_i)$ $[GeV^2]$	
0.028	0.013 ± 0.036	0.064 ± 0.044
0.100	- 0.076 ± 0.032	- 0.007 ± 0.034
0.200	- 0.145 ± 0.032	- 0.060 ± 0.035
0.350	- 0.030 ± 0.035	- 0.008 ± 0.038
0.600	0.035 ± 0.019	0.026 ± 0.021
x_i	$h^n(x_i)$ $[GeV^2]$	
0.028	0.234 ± 0.073	0.178 ± 0.078
0.100	0.192 ± 0.048	0.199 ± 0.050
0.200	0.035 ± 0.056	0.079 ± 0.059
0.325	0.072 ± 0.071	0.055 ± 0.073
0.500	0.023 ± 0.043	- 0.020 ± 0.040

[a]The parameter is fixed.

TABLE II: The values of χ^2 for the LO and NLO QCD fits without HT included compared to those when the HT corrections to g_1 are taken into account. The TMC are included in $(g_1)_{\rm LT}$.

Fit	LO(HT=0)	NLO(HT=0)	LO+HT	NLO+HT
χ^2	244.5	218.8	150.9	145.0
DF	185 - 16	185 - 6	185 - 16	185 - 6
χ^2/DF	1.36	1.22	0.893	0.858

C. LO polarized parton densities

Let us turn now to the LO polarized parton densities. In LO QCD $\Delta G(x,Q^2)$ does not contribute directly

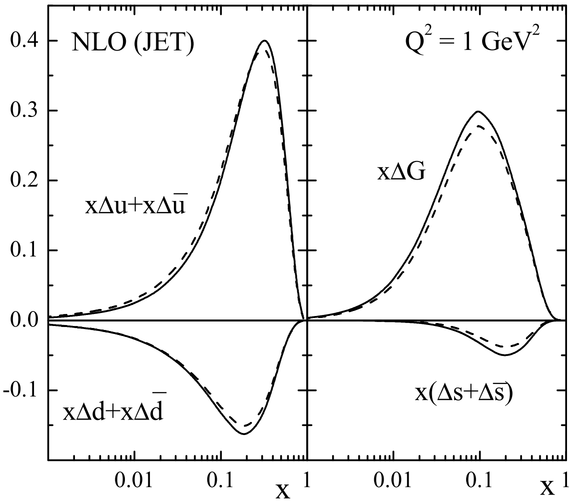

FIG. 4: NLO(JET) polarized parton densities PD($g_1^{\rm NLO}$+HT) (solid curves) compared to PD($g_1^{\rm NLO}/F_1^{\rm NLO}$) (dashed curves) at $Q^2 = 1\ GeV^2$ (see the text).

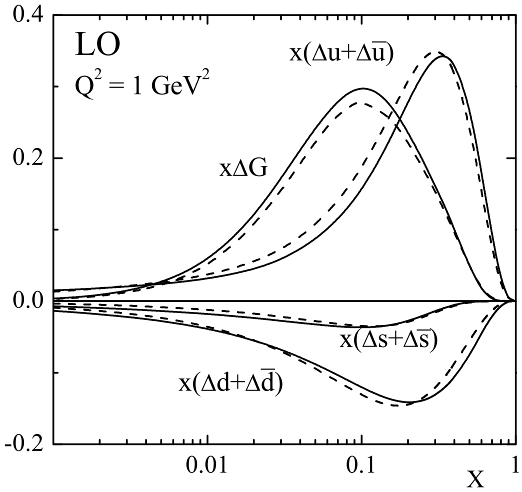

FIG. 5: LO polarized parton densities PD($g_1^{\rm LO}$ + HT) (solid curves) compared to PD($g_1^{\rm LO}/F_1^{\rm LO}$) (dashed curves) at $Q^2 = 1\ GeV^2$ (see the text).

to g_1 and the gluons cannot be determined from DIS data alone. For this reason the LO fit to the data was performed using for the input polarized gluon density $\Delta G(x, Q_0^2)$ the one extracted in the NLO fit to the data:

$$\Delta G(x, Q_0^2)_{\rm LO} = \Delta G(x, Q_0^2)_{\rm NLO(JET)}\ . \qquad (26)$$

It is important to note that in the polarized case the LO approximation has some peculiarities compared to the unpolarized one. As a consequence of the gluon axial anomaly, the difference between NLO anti-quark po-

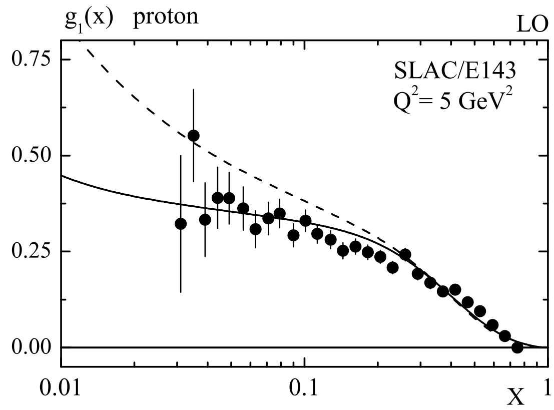

FIG. 6: Comparison of the proton structure function $g_1^{\rm LO}$ calculated using the polarized parton densities PD($g_1^{\rm LO}$ + HT) (solid curve) and PD($g_1^{\rm LO}/F_1^{\rm LO}$) (dashed curve) with SLAC/E143 proton data.

larizations $\Delta\bar{q}_i$ in different factorization schemes can be quite large, comparable in magnitude to the $\Delta\bar{q}_i$ themselves (see, e.g., [5]). In this case the leading order will be a bad approximation, at least for the polarized sea-quark densities. Also, bearing in mind that in polarized DIS most of the data points are at low Q^2, lower than the usual cuts in the analyses of unpolarized data ($Q^2 \geq 4-5\ GeV^2$), the NLO corrections to all polarized parton densities are large in this region and it is better to take them into account. Nevertheless, the LO polarized parton densities may be useful for some practical purposes; e.g., for preliminary estimations of the cross sections in future polarized experiments, etc. They are also needed for comparison with those extracted from semi-inclusive DIS data [32], where the NLO QCD analysis is still very complicated. The extracted LO polarized parton densities PD($g_1^{\rm LO} + HT$) are shown in Fig. 5. Also shown in Fig. 5 are the LO polarized PD($g_1^{\rm LO}/F_1^{\rm LO}$) obtained in our analysis [5]. In contrast to the NLO case, the two sets of LO polarized densities are significantly different. As a result we obtain different theoretical curves for g_1 (see Fig. 6). To illustrate how these curves fit the data, the SLAC/E143 experimental proton data at $Q^2 = 5\ GeV^2$ are also shown. As seen from Fig. 6, the proton structure function $g_1^p(x, Q^2)_{LO}$ calculated using the LO polarized PD($g_1^{\rm LO}/F_1^{\rm LO}$) does not agree with the data for $x < 0.25$. Note that at the same time the ratio $g_1^{\rm LO}/F_1^{\rm LO}$ fits the world data on g_1/F_1 and A_1 quite well in the measured (x, Q^2) region ($\chi^2_{\rm DF} = 0.921$) [5]. The main reason for this peculiarity is that the LO approximations for the unpolarized structure functions $F_2(x, Q^2)$ and $F_1(x, Q^2)$ (or $R(x, Q^2)$) presented in the literature are not self consistent. The unpolarized parton densities in leading order QCD (more correctly in leading logarithmic approximation LLA) are usually extracted including in the data set of the analysis only the experimental data on F_2 and ignoring the data on R (or F1). Remember that in LLA of QCD the structure functions satisfy the Callan-Gross relation $2xF_1(x,Q^2) = F_2(x,Q^2)$ which leads to $R = 4M^2x/Q^2$. However, the experimental data on F_2 and R do not satisfy these relations in a large kinematic region. They are approximately satisfied only at large x and/or large Q^2. At small x and Q^2 the experimental values of F_2 are larger than those of $2xF_1$ by up to 30%. That is why the extracted sets of LO unpolarized parton densities (MRST, CTEQ, etc.) are not quite consistent. While they fit well the data on F_2, they badly fail to describe the $R(F_1)$ data in the region of small x and Q^2. One way to improve the situation would be to perform a LO QCD fit including in the data set the $R(F_1)$ data too. Also, if the data at low Q^2, lower than the usual cuts ($Q^2 \geq 4-5\ GeV^2$), are included in the analysis, the higher twist corrections to F_2 and F_1 should be taken into account.

VI. CONCLUSION

We have analyzed the world data on inclusive polarized deep inelastic lepton-nucleon scattering in leading and next-to-leading order of QCD including in the analysis the higher twist $h^N(x)/Q^2$ and the target mass corrections to the nucleon spin structure function $g_1^N(x,Q^2)$. We have found that the fit to the data on g_1 is essentially improved, especially in the LO case, when the higher twist terms are included in the analysis. The x-dependence of the higher twists $h^N(x)$ have been extracted from the data in a model independent way. It is shown that the size of their contribution to g_1 is not negligible and their shape depends on the target: $h^p(x)$ changes sign while $h^n(x)$ is a non-negative function in the measured x region.

We have found that the polarized parton densities depend on whether the higher twist terms are or are not included in the analysis of g_1. Moreover, the NLO polarized parton densities extracted from the g_1 data in the presence of higher twist terms are in good agreement with those determined by our previous fits [5] to the data on g_1/F_1 and A_1 using for the structure functions g_1 and F_1 only their *leading* twist expressions in NLO QCD. This observation confirms once more that the higher twist corrections to g_1/F_1 and A_1 are negligible so that in the analysis of g_1/F_1 and A_1 data it is enough to account only for the leading twist of the structure functions g_1 and F_1. On the other hand, in fits to the g_1 data themselves the higher twist contribution to g_1 must be taken into account. The latter is especially important for the LO QCD analysis of the inclusive and semi-inclusive DIS data.

Acknowledgments

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[33] Note that the theoretical analyses have been mainly concentrated on the $A_1(g_1)$ data because the measurements of the quantities $A_2(g_2)$ are much less accurate with the exception of the very recent data of E155 Collaboration at SLAC [2]. Another reason is that the theoretical treatment of g_2 is much more complicated.
[34] Of course, physical quantities such as the virtual photon-nucleon asymmetry $A_1(x, Q^2)$ and the polarized structure function $g_1(x, Q^2)$ are independent of choice of the factorization convention.
[35] Note that the moments of the g_1 higher twists have been studied in the SLAC/E143 paper [6] as well as in [17, 29].
[36] In [10] the HT terms have been discussed using for them two phenomenological parametrizations. The authors conclude that they do not find a significant higher twist contribution to g_1 in an NLO treatment of $(g_1)_{\rm LT}$. On other hand, studying the higher twist effects in the moments of g_1, it was shown in [17] that while the first moment of higher twist is quite small, the higher order moments are relevant at $Q^2 \sim$ few GeV^2.