HIGHER TWIST EFFECTS IN POLARIZED DIS *

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The size of higher twist corrections to the spin proton and neutron $g_1$ structure functions and their role in determining the polarized parton densities in the nucleon is discussed.

1. Introduction

The study of the quark-hadron duality phenomena\textsuperscript{1} using the present much more precise data for the polarized and unpolarized structure functions is in a progress\textsuperscript{2}. The better understanding of the non-perturbative higher twist effects is important for this analysis, especially in the polarized case, where the investigations are in the very beginning.

In this talk we will discuss both, the size of the higher twist effects in polarized DIS as well as their role in the determination of the polarized parton densities (PPDs) in the nucleon using different approaches of QCD fits to the data.

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2. QCD Treatment of the $g_1$ Structure Function

In QCD the spin structure function $g_1$ can be written in the following form ($Q^2 >> \Lambda^2$):

$$ g_1(x, Q^2) = g_1(x, Q^2)_{\text{LT}} + g_1(x, Q^2)_{\text{HT}}, \quad (1) $$

where "LT" denotes the leading twist ($\tau = 2$) contribution to $g_1$, while "HT" denotes the contribution to $g_1$ arising from QCD operators of higher twist, namely $\tau \geq 3$. In Eq. (1) (the nucleon target label $N$ is dropped)

$$ g_1(x, Q^2)_{\text{LT}} = g_1(x, Q^2)_{\text{pQCD}} + h_{\text{TMC}}(x, Q^2)/Q^2 + O(1/Q^4), \quad (2) $$

where $h_{\text{TMC}}(x, Q^2)$ are the calculable kinematic target mass corrections, which effectively belong to the LT term. $g_1(x, Q^2)_{\text{pQCD}}$ is the well known (logarithmic in $Q^2$) pQCD expression and in NLO has the form

$$ g_1(x, Q^2)_{\text{pQCD}} = \frac{1}{2} \sum_{q=1}^{N_f} \epsilon_q^2 (\Delta q + \Delta \bar{q}) \otimes (1 + \frac{\alpha_s(Q^2)}{2\pi} \delta C_q + \frac{\alpha_s(Q^2)}{2\pi} \Delta G \otimes \delta C_G), \quad (3) $$

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. $N_f$ is the number of active flavors.

In Eq. (1)

$$ g_1(x, Q^2)_{\text{HT}} = h(x, Q^2)/Q^2 + O(1/Q^4), \quad (4) $$

where $h(x, Q^2)$ are the dynamical higher twist ($\tau = 3$ and $\tau = 4$) corrections to $g_1$, which are related to multi-parton correlations in the nucleon. The latter are non-perturbative effects and cannot be calculated without using models. That is why a model independent extraction of the dynamical higher twists $h(x, Q^2)$ 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 and, in particular, of the quark-hadron duality.

One of the features of polarized DIS is that a lot of the present data are in the preasymptotic region ($Q^2 \sim 1 - 5 \text{ GeV}^2, 4 \text{ GeV}^2 < W^2 < 10 \text{ GeV}^2$). While in the unpolarized case we can cut the low $Q^2$ and $W^2$ data in order to minimize the less known higher twist effects, it is impossible to perform such a procedure for the present data on the spin-dependent structure functions without losing too much information. This is especially
the case for the HERMES, SLAC and Jefferson Lab experiments. So, to confront correctly the QCD predictions with the experimental data and to determine the polarized parton densities special attention must be paid to the non-perturbative higher twist (powers in $1/Q^2$) corrections to the nucleon structure functions.

3. Higher Twists and Their Role in Determining PPDs

We have used two approaches to extract the polarized parton densities from the world polarized DIS data. According to the first the leading twist LO/NLO QCD expressions for the structure functions $g_1$ and $F_1$ have been used in order to confront the data on spin asymmetry $A_1(\approx g_1/F_1)$ and $g_1/F_1$. We have shown that in this case the extracted from the world data ‘effective’ HT corrections $h_{g_1/F_1}(x)$ to the ratio $g_1/F_1$ are negligible and consistent with zero within the errors, i.e. $h_{g_1/F_1}(x) \approx 0$, when for $(g_1)_{LT}$ and $(F_1)_{LT}$ their NLO QCD approximations are used. (Note that in QCD the unpolarized structure function $F_1$ takes the same form as $g_1$ in (1), namely $F_1 = (F_1)_{LT} + (F_1)_{HT}$. What follows from this result is that the higher twist corrections to $g_1$ and $F_1$ approximately compensate each other in the ratio $g_1/F_1$ and the NLO PPDs extracted this way are less sensitive to higher twist effects. This is not true in the LO case (see our discussion in Ref. 7). The set of polarized parton densities extracted this way is referred to as PD($g_1^{NLO}/F_1^{NLO}$).

According to the second approach, the $g_1/F_1$ and $A_1$ data have been fitted using phenomenological parametrizations of the experimental data for the unpolarized structure function $F_2(x, Q^2)$ and the ratio $R(x, Q^2)$ of the longitudinal to transverse $\gamma N$ cross-sections (i.e. $F_1$ is replaced by its expression in terms of usually extracted from unpolarized DIS experiments $F_2$ and $R$). Note that such a procedure is equivalent to a fit to $(g_1)_{exp}$, but it is more consistent than the fit to the $g_1$ data themselves actually presented by the experimental groups because here the $g_1$ data are extracted in the same way for all of the data sets. In this case the HT corrections to $g_1$ cannot be compensated because the HT corrections to $F_1(F_2$ and $R)$ are absorbed in the phenomenological parametrizations of the data on $F_2$ and $R$. Therefore, to extract correctly the polarized parton densities from the $g_1$ data, the HT corrections (4) to $g_1$ have to be taken into account. So,
according to this approach we have used the following expression for the ratio \( g_1/F_1 \):

\[
\left[ \frac{g_1^N(x, Q^2)}{F_1^N(x, Q^2)} \right]_{\text{exp}} \Leftrightarrow \frac{g_1^N(x, Q^2)_{\text{LT}} + h^N(x)/Q^2}{F_1^N(x, Q^2)_{\text{exp}}},
\]

where \( g_1^N(x, Q^2)_{\text{LT}} \) (N=p, n, d) is given by the leading twist expression (3) in LO/NLO approximation including the target mass corrections. In (6) \( h^N(x) \) are the dynamical \( \tau = 3 \) and \( \tau = 4 \) HT corrections which are extracted in a model independent way. 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. The set of PPDs extracted according to this approach is referred to as PD\((g_1^{LT} + HT)\). The details of our recent analysis using the present available data on polarized DIS are given in 8.

The extracted higher twist corrections to the proton and neutron spin structure functions, \( h^p(x) \) and \( h^n(x) \), are shown in Fig. 1. As seen from Fig. 1 the size of the HT corrections is not negligible and their shape depends on the target. In Fig. 1 our previous results on the higher twist corrections to \( g_1 \) (before the JLab Hall A data were available) are also presented. As seen from Fig. 1, thanks to the very precise JLab Hall A data at large \( x \) the higher twist corrections to the neutron spin structure function are now much better determined in this region. In Fig. 1 our parametrizations of the values of higher twists for the proton and neutron targets

![Figure 1. Higher twist corrections to the proton and neutron \( g_1 \) structure functions extracted from the data on \( g_1 \) in NLO(\( \overline{\text{MS}} \)) QCD approximation for \( g_1(x, Q^2)_{\text{LT}} \). The parametrization (7) of the higher twist values is also shown.](image.png)
\[ h^p(x) = 0.0465 \frac{0.1913}{\sqrt{\pi/2}} \exp[-2((x - 0.2087)/0.2122)^2] \]

\[ h^n(x) = 0.0119 + \frac{0.2420}{\sqrt{\pi/2}} \exp[-2((x - 0.0783)/0.1186)^2] \]  

(7)

are also shown. These should be helpful in a calculation of the nucleon structure function \( g_1 \) for any \( x \) and moderate \( Q^2 \) in the experimental region, where the higher twist corrections are not negligible. The impact of the very recent COMPASS data\(^1\) on the values of higher twist corrections is negligible. The new values are in a good agreement with the old ones\(^2\).

The values of the higher twist corrections to the proton and neutron \( g_1 \) structure functions extracted in a model independent way from polarized DIS data are in agreement with the QCD sum rule estimates\(^3\) as well as with the instanton model predictions\(^4\) but disagree with the renormalon calculations\(^5\). About the size of the HT corrections extracted from the resonance region see the discussion in the Fantoni’s talk at this Workshop.

In Fig. 2 we compare the NLO(MS) polarized parton densities PD(\( g_1^{LT} + \) HT) (solid curves) together with their error bands compared to PD(\( g_1^{NLO}/F_1^{NLO} \)) (dashed curves) at \( Q^2 = 4 \text{ GeV}^2 \).
HT) with PD\( (g_1^{\text{NLO}}/F_1^{\text{NLO}}) \). As seen from Fig. 2 the two sets of PPDs are very close to each other, especially for \( u \) and \( d \) quarks. This is a good illustration of the fact that a fit to the \( g_1 \) data taking into account the higher twist corrections to \( g_1 \) \( (\chi^2_{\text{DF},\text{NLO}} = 0.872) \) is equivalent to a fit of the data on \( A_1(\sim g_1/F_1) \) and \( g_1/F_1 \) using for the \( g_1 \) and \( F_1 \) structure functions their NLO leading twist expressions \( (\chi^2_{\text{DF},\text{NLO}} = 0.874) \). In other words, this fact confirms once more that the HT corrections to \( g_1 \) and \( F_1 \) approximately cancel in the ratio \( g_1/F_1 \). Nevertheless, we consider that the set of the polarized parton densities PD\( (g_1^{\text{LT}} + \text{HT}) \) is preferable because using them and simultaneously extracted higher twist corrections to \( g_1 \), the spin structure function \( g_1 \) can be correctly calculated in the preasymptotic \( (Q^2, W^2) \) region too.

In conclusion, the higher twist effects in polarized DIS have been studied. It was shown that the size of the HT corrections to the spin structure function \( g_1 \) is not negligible and their shape depends on the target. It was also demonstrated that their role is important for the correct determination of the polarized parton densities.

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