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NLO QCD method of SIDIS data analysis

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Abstract

The semi-inclusive deep inelastic scattering (SIDIS) process is considered. It is proposed a theoretical procedure allowing the direct extraction from the SIDIS data of the first moments of the polarized quark distributions in the next to leading (NLO) QCD order. The validity of the procedure is confirmed by the respective simulations. To this end both broken and symmetric sea scenarios are considered. Especial attention is paid to the application of the proposed procedure to such important questions as the symmetry of the light quark polarized sea and the polarized strangeness content in nucleon. In this connection the pecularities and the respective possibilities of the HERMES and COMPASS experiments are studied.

The main points of interests for the modern semi-inclusive deep inelastic scattering (SIDIS) experiments wi longitudinally polarized beam and target are the strange quark, light sea quark and gluon contributions to the nucleon spin (see, for example [1] and references therein). Of special importance is also still open question whether the polarized light quark sea symmetric or not, i.e., if the quantity[1] $\Delta_1\bar{u} - \Delta_1\bar{d}$ is equal to zero or not. At the same time it was shown [2, 3] that to get the reliable results on such the tiny quantities as Δs and $\Delta_1\bar{u} - \Delta_1\bar{d}$ from the data obtained at the relatively small average Q^2 available to modern SIDIS experiments (such as HERMES and COMPASS), one should apply next-to leading order (NLO) QCD analysis. The respective procedure of $\Delta_1 q$ extraction in NLO QCD order have been proposed in ref [4]. In ref. [4] it was shown that the proposed procedure could be successfully applied for the *direct* extraction from the

[1]From now on the notation $\Delta_1 q \equiv \int_0^1 dx \Delta q$ will be used to distinguish the local in Bjorken x polarized quark densities $\Delta q(x)$ and their first moments.

SIDIS data of the quantities $\Delta_1 u_V$, $\Delta_1 d_V$ and, eventually, of the quantity $\Delta_1\bar{u} - \Delta_1\bar{d}$. The respective equations for these quantities look as

$$\Delta_1 u_V = \frac{1}{5}\frac{A_p^{exp} + A_d^{exp}}{L_1 - L_2}; \quad \Delta_1 d_V = \frac{1}{5}\frac{4A_d^{exp} - A_p^{exp}}{L_1 - L_2}. \tag{1}$$

for valence distributions and

$$\Delta_1\bar{u} - \Delta_1\bar{d} = \frac{1}{2}\left|\frac{g_A}{g_V}\right| - \frac{2A_p^{exp} - 3A_d^{exp}}{10(L_1 - L_2)} \tag{2}$$

for the $\Delta_1\bar{u} - \Delta_1\bar{d}$. All the quantities in the r.h.s of these equations contain only already measured unpolarized quark distributions and pion fragmentation functions (favored and unfavored, entering the coefficients L_1 and L_2, respectively), known NLO Wilson coefficients and the so-called "difference asymmetries" (see, for example, [1, 4, 5]) for the pion production on the proton and deutron targets , $A_p^{\pi^+-\pi^-}$ and $A_d^{\pi^+-\pi^-}$, entering the quantities A_p^{exp} and A_d^{exp}. Thus, these difference asymmetries are the only unknown input which should be measured to find the quantities $\Delta_1 u_V$, $\Delta_1 d_V$ and $\Delta_1\bar{u} - \Delta_1\bar{d}$ using Eqs. (1) and (2).

In the paper [4] it was performed the detailed analysis on the possibility to correctly extract in NLO QCD order of the quantities $\Delta_1 u_V$, $\Delta_1 d_V$ and $\Delta_1\bar{u} - \Delta_1\bar{d}$ in the real conditions of the HERMES and COMPASS experiments. Special attention was paid to the such important questions as the statistical errors on the difference asymmetries[2] and to the uncertainties caused by the low x_B regions unavailable to HERMES and COMPASS. First of all, the performed in [4] analysis confirms that the proposed NLO QCD extraction procedure meets the main requirement: to reconstruct the quark moments in the accessible to measurement x_B region. On the other hand, it was shown that even with the rather overestimated low x_B uncertainties given in [4], one can conclude that the question is $\Delta_1\bar{u} - \Delta_1\bar{d}$ equal to zero or not could be answered even with the HERMES kinematics in the case of strongly asymmetric polarized sea. In any case, the situation is much better with the available to COMPASS x_B region.

[2]At first sight it could seem that the difference asymmetries suffer from the much larger errors in comparison with the usual asymmetries because of the difference of π^+ and π^- counting rates presents in denominator. However, fortunately, for the proton and deutron target it is not the case because on these targets (on the contrary to the neutron target) π^+ production essentially exceeds π^- production. As a consequence, the statistical errors occur quite acceptable [4].

At present COMPASS experiment uses only the polarized deutron target in the muon part ot its program. Besides, it is obvious that the statistic of semi-inclusive events with pion production is much higher than the respective statistics of kaon production (one registrates about 90% pions among all semi-inclusive events). So, it is of interest to see could we extract so important quantity as polarized strangeness in nucleon using only pion production on the deutron target. To this end we will use so-called "sum asymmetries" (see, for example, [5] and references therein) $A_d^{h+\bar{h}}(x,Q^2) = \int_{0.2}^1 dz_h (g_1^{N/h+} g_1^{N/\bar{h}}) / \int_{0.2}^1 dz_h (F_1^{N/h} + F_1^{N/\bar{h}})$ and also the $SU_f(3)$ sum rule $a_8 = F + D$. Then, operating quite analoguously to the case of difference asymmetries [4], after some simple algebra one obtains the following NLO QCD equation for the quantity $\Delta_1 s + \Delta_1 \bar{s}$ we are interesting in:

$$(\Delta_1 s + \Delta_1 \bar{s})_{NLO} = \frac{A_{exp(d)}^{\pi^+ + \pi^-} - 5\,(3F - D)\left(L_1^{[qq]} + L_2^{[qq]} + 2L_g^{[gq]}\right)}{10\left(L_1^{[qq]} + L_2^{[qq]}\right) + 4L_s^{[qq]} + 24L_g^{[gq]}} \qquad (3)$$

$$A_{exp(d)}^{\pi^+ + \pi^-} \equiv \int_0^1 dx\ A_d^{\pi^+ + \pi^-} \int_{0.2}^1 dz_h \left(F_{1d}^{N/h^+} + F_{1d}^{N/h^-}\right)$$

$$L_q^{[qq]\,h}(Q^2) \equiv \int_{0.2}^1 dz_h \left[D_q^h(z_h, Q^2) + \frac{\alpha_s}{2\pi}\int_{z_h}^1 \frac{dz'}{z'}\ \Delta_1 C_{qq}(z') D_q^h(\frac{z_h}{z'}, Q^2)\right]$$

$$L_g^{[gq]\,h}(Q^2) \equiv \frac{\alpha_s}{2\pi}\int_{0.2}^1 dz_h \frac{dz'}{z'}\,\Delta_1 C_{gq}(z')\, D_g^h(\frac{z_h}{z'}, Q^2)$$

where $\Delta_1 C(z)_{qq,gq} \equiv \int_0^1 dx\ \delta C_{qq,gq}(x,z)$ are the first moments of the NLO Wilson coefficients which can be found in [6] and the fragmentation functions $D_1 \equiv D_u^{\pi^+} = D_{\bar{u}}^{\pi^-} = D_{\bar{d}}^{\pi^+} = D_d^{\pi^-}$ (favored), $D_2 \equiv D_d^{\pi^+} = D_{\bar{d}}^{\pi^-} = D_u^{\pi^-} = D_{\bar{u}}^{\pi^+}$ (unfavored), $D_s \equiv D_s^{\pi^+} = D_s^{\pi^-} = D_{\bar{s}}^{\pi^+} = D_{\bar{s}}^{\pi^-}$ (unfavored) can be found in ref. [7]. To understand is it possible to correctly extract the quantity $\Delta_1 s + \Delta_1 \bar{s}$ using proposed NLO QCD procedure, we, just as before [4], perform the simulations using the polarized event generator PEPSI. The all simulation conditions exactly correspond to the COMPASS kinematics (see [4] for details). It is obvious that to be valid, the extraction procedure, being applied to the simulated asymmetries should yield results maximally close to the ones obtained directly from the parametrization entering the generator as an input.

Comparing the upper and the lower parts of the Table 1, one can see that the results of $\Delta_1 s + \Delta_1 \bar{s}$ reconstruction in the accessible x_B region for both input parametrizations (broken and symmetric sea scenarios) are in a good agreement[3] with the respective integrals over the same x_B region (COMPASS region) of the respective parametrizations. Thus, the performed analysis confirms that the proposed NLO QCD extraction procedure can be applied to reconstruct the quantity $\Delta_1 s + \Delta_1 \bar{s}$ we are interested in.

Table 1: The upper part presents the results on $\Delta_1 s + \Delta_1 \bar{s}$ obtained from integration of GRSV2000NLO parametrization (symmetric sea I and broken sea II scenario). The lower part presents the results on $\Delta_1 s + \Delta_1 \bar{s}$ extracted from the simulated sum asymmetries applying the proposed NLO procdeure with parametrizations I and II entering the generator as an input.

x_{Bj}	Q^2	$[\Delta_1 s + \Delta_1 \bar{s}]_{\rm I}$	$[\Delta_1 s + \Delta_1 \bar{s}]_{\rm II}$
$0.0001 < x_{Bj} < 0.99$	$7.45\,\mathrm{GeV}^2$	-0.119	0.002
$0.003 < x_{Bj} < 0.7$	$7.45\,\mathrm{GeV}^2$	-0.088	0.008
$0.003 < x_{Bj} < 0.7$	$7.45\,\mathrm{GeV}^2$	-0.10 ± 0.01	0.01 ± 0.01

Let us now apply the proposed procedure to the real data[4] of HERMES on asymmetries $A_{p,d}$, $A^{\pi^\pm}_{p,d}$ [8]. The proposed procedure in this case allows to obtain the simple expressions for the NLO quantities $\Delta_1 u$, $\Delta_1 d$ and $\Delta_1 \bar{q} \equiv \Delta_1 \bar{u} = ..$ via the quantities $A_{(exp)p,d}$, $A^{\pi^\pm}_{(exp)p,d}$ which contain only already measured unpolarized quark distributions, fragmentation functions[5], known NLO Wilson coefficients and the measured asymmetries $A_{p,d}$, $A^{\pi^\pm}_{p,d}$. Certainly, one could choose only three equations (containing any three of six measured asymmetries) to obtain the minimal nondegenerate system which can be directly solved with respect to NLO quanitities $\Delta_1 u$, $\Delta_1 d$ and $\Delta_1 \bar{q}$. However, to increase the precision of extraction, we, as usual, use the fitting procedure where we inlcude all six available quantities $A_{(exp)p,d}$, $A^{\pi^\pm}_{(exp)p,d}$ entering the constructed χ^2.

[3]From the Table 1 one can see that the truncated moments (input and extracted respectively) are in a good agreement with each other, and, besides, they are quite close to the "exact answer" - second line in the Table 1. Let us stress, however, that it is certainly necessary to properly estimate low x_B uncertainties (see, for example, [4]) to do the eventual conclusion on the polarized strangeness content in nucleon.

[4]Since the kaon fragmentation functions are stil poorly known, while here we mainly would like to check the validity of the metod itself (irrespectively to this problem), we will consider here the most simple case of the pion production with the assumption $\Delta_1 \bar{u} = \Delta_1 \bar{d} = \Delta_1 s = \Delta_1 \bar{s} \equiv \Delta_1 \bar{q}$. The application of the method to the kaon asymmetries is now in preparation.

[5]The paremetrization for the framentation functions from ref. [7] is used for both testing with PEPSI[12] and reconstruction from the real HERMES data

First of all, we again perform the testing of our method using the GRSV2000(NLO) parametrization as an input. Comparing the upper and the lower parts of the Table 2, one can see that the results of $\Delta_1 u$, $\Delta_1 d$ and $\Delta_1 \bar{q}$ reconstruction are in a good agreement with the input parametrization. Thus, the performed testing shows that our procedure can be applied to $\Delta_1 u$, $\Delta_1 d$ and $\Delta_1 \bar{q}$ reconstruction.

Table 2: The upper part presents the results on $\Delta_1 u$, $\Delta_1 d$ and $\Delta_1 \bar{q}$ obtained from integration of GRSV2000NLO parametrization (symmetric sea scenario). The lower part presents the respective results extracted from the simulated asymmetries applying the proposed NLO procdeure with GRSV2000NLO parametrization entering the generator as an input.

x_B region	$\Delta_1 u$	$\Delta_1 d$	$\Delta_1 \bar{q}$
$0.023 < x_B < 0.6$	0.724	-0.302	-0.026
$0.023 < x_B < 0.6$	0.702±0.020	-0.274±0.025	-0.027±0.013

Let us now perform NLO extraction of $\Delta_1 u$, $\Delta_1 d$ and $\Delta_1 \bar{q}$ from the real HERMES data [8] on $A_{p,d}, A^{\pi^\pm}_{p,d}$. It is of importance that the unpolarized quark densities entering the quantities $A_{(exp)p,d}, A^{\pi^\pm}_{(exp),d}$ are obtained from the structure functions. Thus, dealing with the real data one should first express SIDIS structure function F_1^h (entering the quantities $A_{(exp)}$) via F_2^h: $F_2^h = 2xF_1^h(1 + R(x, Q^2))$ and then use pQCD NLO expressions for F_2^h via the respective unpolarized quark densities and Wilson coefficients [6]. The respective results are presented in the Table 3. It is instructive to compare the results of Table 3 with the respective integrals of two latest NLO parametrizations [9]; see Table 4. It is seen that the results are in a good agreement within the errors.

Table 3: The results on NLO exctracted $\Delta_1 u$, $\Delta_1 d$ and $\Delta_1 \bar{q}$ from the HERMES data on asymmetries $A_{p,d}, A^{\pi^\pm}_{p,d}$.

$\Delta_1 u$	$\Delta_1 d$	$\Delta_1 \bar{q}$
0.624±0.063	-0.355±0.070	0.016±0.038

Thus, the performed analysis argues that the proposed procedure is acceptable for extraction of $\Delta_1 q$ in the next-to-leading QCD order.

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Table 4: The results on $\Delta_1 u$, $\Delta_1 d$ and $\Delta_1 \bar{q}$ obtained from the respective integrals of parametrizations AAC2003 and BB.

Parametrization	$\Delta_1 u$	$\Delta_1 d$	$\Delta_1 \bar{q}$
AAC2003	0.691	-0.293	-0.034
BB	0.667	-0.274	-0.024

vokhizhin, E. Kuraev, A. Maggiora, A. Nagaytsev, A. Olshevsky, G. Piragino, G. Pontecorvo, J. Pretz, I. Savin and O. Teryaev, for fruitful discussions.

References

[1] COMPASS collaboration (G. Baum et al.), "COMPASS: A proposal for a common muon and proton apparatus for structure and spectroscopy", CERN-SPSLC-96-14 (1996).

[2] E. Leader, D.B. Stamenov, Phys. Rev. **D67** (2003) 037503

[3] A.N. Sissakian, O.Yu. Shevchenko and O.N. Ivanov, Phys. Rev. **D 68** (2003) 031502(R).

[4] A.N. Sissakian, O.Yu. Shevchenko and O.N. Ivanov, Phys. Rev. **D 70** (2004) 074032.

[5] E. Christova and E. Leader, Nucl. Phys **B 607** (2001) 369.

[6] D. de Florian and R. Sassot, Phys. Rev. **D 62** (2000) 094025.

[7] S. Kretzer, Phys.Rev. **D 62** (2000) 054001.

[8] HERMES collaboration (A. Airapetian et al.), DESY-04-107, Jul 2004, hep-ex/0407032.

[9] Asymmetry Analysis Collaboration (M. Hirai et al), Phys. Rev. **D 69** (2004) 054021 (AAC2003);
J. Blumlein, H. Bottcher Nucl.Phys. **B636** (2002) 225.

[10] EMC collaboration (J, Ashman et al.), Z. Phys. **C 52** (1991) 361

[11] M. Gluck, E. Reya, M. Stratmann, W. Vogelsang, Phys.Rev. **D 63** (2001) 094005.

[12] L. Mankiewicz, A. Schafer, M. Veltri, Comput. Phys. Commun.**71** (1992) 305-318.