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QCD ANALYSIS OF THE SEMI-INCLUSIVE HERMES AND COMPASS DATA

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The first moments of polarized valence PDFs, responsible for the respective contributions to the nucleon spin, are extracted in NLO QCD from the data of COMPASS and HERMES Collaborations on the semi-inclusive difference asymmetries. To this end, the new method of QCD analysis (alternative to the usual global fit analysis) is applied. Using the obtained results on valence PDFs, the first moments of polarized sea PDFs are reconstructed. They occur surprisingly small: compatible with zeros within the errors.

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The first moments of polarized parton distribution functions (PDFs), which directly compose the nucleon spin together with the orbital parton momenta, are of crucial importance for solution of the proton spin puzzle, attracting great both theoretical and experimental efforts during many years. Nowadays, there is a huge growth of interest to the semi-inclusive DIS (SIDIS) experiments with longitudinally polarized beam and target such as SMC [1], HERMES [2], COMPASS [3]. It is of importance that namely SIDIS experiments allow us to find the sea and valence contributions to the nucleon spin in separation. In this short letter we focus on this important task. To this end, we apply the new method of the QCD analysis of the polarized SIDIS data elaborated in [4–7]. First, we will extract the valence contributions to the proton spin (first moments of the polarized valence PDFs) from the combined SIDIS data on pion production of COMPASS and HERMES Collaborations. Then, using these results, sum rules, and well-known purely inclusive data on Γ_{1d}, we will estimate the sea contributions to the spin of proton.

The procedure of direct extraction in NLO QCD of nth moments of the valence PDFs from the measured difference asymmetries is described in [4, 6, 7] in detail. The key equations allowing one to find from the data on the difference

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asymmetries $A_{p,d}^{\pi^+-\pi^-}$ the nth moments $\Delta'_n q \equiv \int_a^b dx\, x^{n-1} q(x)$ of valence PDFs truncated to the accessible for measurement x region (a, b) look as

$$\begin{aligned}\Delta'_n u_V &\simeq \frac{1}{5}\frac{\mathcal{A}_p^{(n)} + \mathcal{A}_d^{(n)}}{L_{(n)1} - L_{(n)2}},\\ \Delta'_n d_V &\simeq \frac{1}{5}\frac{4\mathcal{A}_d^{(n)} - \mathcal{A}_p^{(n)}}{L_{(n)1} - L_{(n)2}},\end{aligned} \tag{1}$$

where all notations are almost the same as in [6] (see (9)–(16)) in [6]). The only difference is that we rewrite equation for the quantities $\mathcal{A}_{p,d}^{(n)}$ entering (1) in more convenient form* (compare with (16) in [6]):

$$\mathcal{A}_p^{(n)} = \sum_{i=1}^{N_{\rm bins}} (1+R)^{-1} A_p^{\pi^+-\pi^-}(\langle x_i \rangle)\Big|_Z \int_{x_{i-1}}^{x_i} dx\, x^{n-1}(4u_V - d_V)(x)\times \\ \times \int_Z^1 dz_h \left[1 + \otimes \frac{\alpha_s}{2\pi} C_{qq}^2 \otimes\right](D_1 - D_2), \tag{2}$$

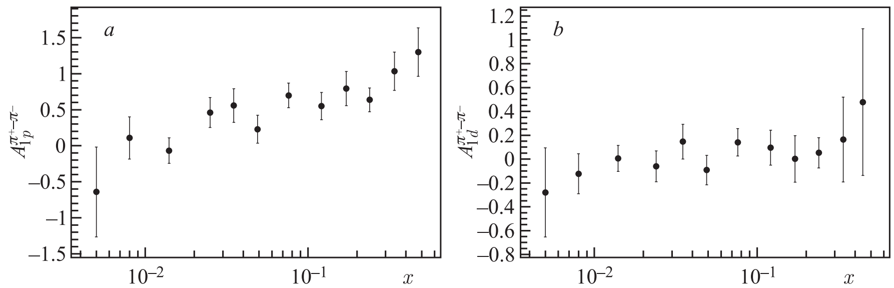
and analogously for $\mathcal{A}_d^{(n)}$ with the replacements $(1+R)^{-1} \to (1+R)^{-1}\times (1-1.5\omega_D)^{-1}$ and $(4u_V - d_V) \to (u_V + d_V)$.

Both COMPASS [9, 10] and HERMES [2] Collaborations published the data only on asymmetries $A_{p,d}^{\pi^\pm}$, while the published data on the pion difference asymmetries $A_{p,d}^{\pi^+-\pi^-}$ is still absent (see the Figure). That is why, the special procedure was applied in [6] to construct asymmetries $A_{p,d}^{\pi^+-\pi^-}$ from the HERMES data on pion production, and we repeat here this procedure for the COMPASS case. Namely, in each ith bin the pion difference asymmetries can be rewritten as

$$A^{\pi^+-\pi^-}(x_i) = \frac{R_i^\pm}{R_i^\pm - 1} A^{\pi^+}(x_i) - \frac{1}{R_i^\pm - 1} A^{\pi^-}(x_i), \tag{3}$$

where the quantity $R_i^\pm$ is just the ratio of unpolarized cross sections for π^+ and π^- production: $R_i^\pm = \sigma_{\rm unpol}^{\pi^+}(x_i)/\sigma_{\rm unpol}^{\pi^-}(x_i) = N_i^{\pi^+}/N_i^{\pi^-}$. As was argued in [6], this relative quantity is very well reproduced by the LEPTO generator of unpolarized events [11], which gives a good description of the fragmentation processes. So, we again use here the LEPTO generator to this end.

*This form allows one to explicitly account for the corrections due to the factor $R = \sigma_L/\sigma_T$ and the deuteron D-state contribution $\omega_D = 0.05 \pm 0.01$ (see, for example, discussion around (10) in [8] and references therein).



The pion difference asymmetries $A_{1p}^{\pi^+-\pi^-}$ and $A_{1d}^{\pi^+-\pi^-}$ at $Q^2 = 10$ GeV^2, constructed with Eq. (3) from the COMPASS data on $A_{p,d}^{\pi^\pm}$ in the region $0.004 < x < 0.7$ and HERMES data on $A_{p,d}^{\pi^\pm}$ in the region $0.2 < x < 0.6$ (last three bins of HERMES)

Let us now discuss the question of Q^2 dependence of asymmetries and its influence on the final results. The point is that both DIS and SIDIS asymmetries very weekly depend on Q^2 (see, for instance, Fig. 5 in [12]), so that the approximation

$$A(x_i, Q_i^2) \simeq A(x_i, Q_0^2) \tag{4}$$

is commonly used (see, for example, [1, 2, 10]) for analysis of the DIS and SIDIS asymmetries. Nevertheless, for more comprehensive analysis, it is useful to account for the corrections caused by the weak Q^2 dependence of the difference asymmetries, i.e., to estimate the shifts

$$\delta_i A_{p,d}^{\pi^+-\pi^-} = A_{p,d}^{\pi^+-\pi^-}(x_i, Q_0^2) - A_{p,d}^{\pi^+-\pi^-}(x_i, Q_i^2) \tag{5}$$

in the difference asymmetries and their influence on the moments of the valence PDFs. To this end, we approximate r.h.s of (5) by the respective difference of «theoretical» asymmetries calculated with substitution of two new parameterizations [8, 13] on polarized PDFs (elaborated with application of both DIS and SIDIS data) to the theoretical expressions in NLO QCD for the difference asymmetries (see the respective equations in [4, 6]) and then average* the obtained results on $\delta_i A_{p,d}^{\pi^+-\pi^-}$. Adding the calculated in this way $\delta_i A_{p,d}^{\pi^+-\pi^-}$ to the initial experimental asymmetries $A_{p,d}^{\pi^+-\pi^-}(x_i, Q_i^2)$, we estimate the evolved from Q_i^2 to Q_0^2 asymmetries $A_{p,d}^{\pi^+-\pi^-}(x_i, Q_0^2)|_{\rm evol}$. Using the obtained in such a way evolved asymmetries, we extract the respective corrected moments of the valence PDFs

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*Notice that the shifts in asymmetries as well as in the final results on the moments of valence PDFs obtained with two applied parameterizations differ very insignificantly from each other.

$\Delta'_n q_V|_{\rm corr}$. Then we compare the corrected moments $\Delta'_n q_V|_{\rm corr}$ with the respective moments $\Delta'_n q_V$ from the previous section (obtained without corrections due to evolution) and calculate the respective shifts $\delta(\Delta'_n q_V) = \Delta'_n q_V|_{\rm corr} - \Delta'_n q_V$ and the relative quantities $\delta(\Delta'_n q_V)/\Delta'_n q_V$. Of importance is the optimal choice of the common for evolved asymmetries scale Q_0^2, allowing one to reduce as much as possible the shifts in the results due to evolution. Our experience shows that for combined analysis of COMPASS and HERMES data (see below) the optimal choice is close to $Q_0^2 = 10$ GeV^2.

We perform the combined analysis of COMPASS [9, 10] and HERMES [2] data on pion production with both proton and deuteron targets. COMPASS Collaboration published their data in the Bjorken x range $0.004 < x < 0.7$ and $0.004 < x < 0.3$ for proton and deuteron targets, respectively, while the HERMES data $A_{p,d}^{\pi^\pm}$ were presented in the range $0.023 < x < 0.6$ for both targets. Inclusion of HERMES data into the analysis is especially important because COMPASS data in the region $0.3 < x < 0.7$ for deuteron target is still absent. Besides, application of the combined data allows us to increase the available statistics, and therefore to decrease the errors.

The statistical addition of asymmetries $A_{p,d}^{\pi^\pm}$ and their errors is performed in accordance with the standard formulas

$$A_N^h|_{\rm averaged} = \frac{A_N^h|_{\exp 1}/(\delta A_N^h|_{\exp 1})^2 + A_N^h|_{\exp 2}/(\delta A_N^h|_{\exp 2})^2}{1/(\delta A_N^h|_{\exp 1})^2 + 1/(\delta A_N^h|_{\exp 2})^2}, \quad (6)$$

$$(\delta A_N^h|_{\rm averaged})^2 = \frac{1}{1/(\delta A_N^h|_{\exp 1})^2 + 1/(\delta A_N^h|_{\exp 2})^2}. \quad (7)$$

However, this is the case only for the last three bins of COMPASS and HERMES experiments we deal with (after proper extrapolation* of HERMES data in the last bin from 0.6 to 0.7 upper x value). Besides, notice that for the last two bins the COMPASS published SIDIS data for deuteron target is still absent. That is why it is of especial importance to include in the analysis of COMPASS data the HERMES data in the region $0.2 < x < 0.6$ (last three bins of HERMES). The respective results are presented in Table 1.

In Table 1, we present the results obtained both with and without corrections due to weak Q^2 dependence of asymmetries. One can see that the difference is not too significant (the relative corrections $\delta(\Delta'_n q_V)/\Delta'_n q_V$ take the small values).

Thus, we estimated in NLO QCD the contributions of valence quarks (first moments of polarized valence PDFs) to the nucleon spin. Let us now find the respective contributions of light sea quarks.

*Our experience shows that such an extrapolation leads to negligible change in the final result, irrespective of the choice of the extrapolation procedure.

Table 1. **Four first moments of polarized valence PDFs truncated to the region $0.004 < x < 0.7$ are presented at $Q^2 = 10$ GeV^2. The moments are obtained as a result of NLO QCD analysis of the combined data on $A_{p,d}^{\pi^+-\pi^-}$, constructed with (3) from the COMPASS data on $A_{p,d}^{\pi^\pm}$ in the region $0.004 < x < 0.7$ and HERMES data on $A_{p,d}^{\pi^\pm}$ in the region $0.2 < x < 0.6$ (last three bins of HERMES). Capital letters A and B correspond to the application of AKK08 and DSS parameterizations for FFs, respectively. Rome numbers I and II correspond to the moments uncorrected and corrected due to evolution, respectively. Besides, the relative corrections $\delta_r(\Delta'_n q_V) \equiv \delta(\Delta'_n q_V)/\Delta'_n q_V$ for moments caused by evolution are presented here**

n	$\mathrm{A_I}$	$\mathrm{A_{II}}$	$\delta_r(\Delta'_n u_V)$, %	$\mathrm{B_I}$	$\mathrm{B_{II}}$	$\delta_r(\Delta'_n u_V)$, %
1	0.731 ± 0.087	0.695 ± 0.087	-3.8	0.693 ± 0.084	0.713 ± 0.084	2.8
2	0.166 ± 0.024	0.167 ± 0.024	0.8	0.155 ± 0.024	0.158 ± 0.024	1.6
3	0.055 ± 0.010	0.055 ± 0.010	1.3	0.052 ± 0.010	0.052 ± 0.010	1.8
4	0.022 ± 0.005	0.022 ± 0.005	1.5	0.021 ± 0.005	0.021 ± 0.005	2.0

n	$\mathrm{A_I}$	$\mathrm{A_{II}}$	$\delta_r(\Delta'_n d_V)$, %	$\mathrm{B_I}$	$\mathrm{B_{II}}$	$\delta_r(\Delta'_n d_V)$, %
1	-0.519 ± 0.162	-0.524 ± 0.162	0.9	-0.473 ± 0.157	-0.481 ± 0.157	1.7
2	-0.100 ± 0.054	-0.102 ± 0.054	1.8	-0.090 ± 0.051	-0.092 ± 0.051	2.7
3	-0.029 ± 0.023	-0.030 ± 0.023	2.5	-0.026 ± 0.022	-0.027 ± 0.022	3.7
4	-0.011 ± 0.011	-0.011 ± 0.011	3.1	-0.010 ± 0.010	-0.010 ± 0.010	4.4

Table 2. **First moments of polarized sea PDFs truncated to the region $0.004 < x < 0.7$ are presented at $Q^2 = 10$ GeV^2, as well as their sums and differences. The moments are obtained with application of Eq. (8), where DSSV parameterization is used to estimate $(\Delta'_1 q + \Delta'_1 \bar{q})|_{\text{parameter}}$, while the first moments of valence PDFs are taken from Table 1 (only HERMES data from last three bins are applied). Capital letters A and B correspond to the application of AKK08 and DSS parameterizations for FFs, respectively. Rome numbers I and II correspond to the moments uncorrected and corrected due to evolution, respectively**

	$\mathrm{A_I}$	$\mathrm{A_{II}}$	$\mathrm{B_I}$	$\mathrm{B_{II}}$
$\Delta'_1\bar{u}$	0.018 ± 0.044	0.036 ± 0.044	0.037 ± 0.042	0.027 ± 0.042
$\Delta'_1\bar{d}$	0.065 ± 0.081	0.067 ± 0.081	0.042 ± 0.079	0.046 ± 0.079
$\Delta'_1\bar{u} + \Delta_1\bar{d}$	0.082 ± 0.092	0.102 ± 0.092	0.078 ± 0.089	0.072 ± 0.089
$\Delta'_1\bar{u} - \Delta_1\bar{d}$	-0.047 ± 0.092	-0.032 ± 0.092	-0.005 ± 0.089	-0.019 ± 0.089

Within this procedure one first of all uses some NLO QCD parameterization on the polarized PDFs to estimate the quantities $\Delta'_1 q + \Delta'_1 \bar{q}$ $(q = u, d)$. Since the sums $\Delta q(x) + \Delta\bar{q}(x)$ $(q = u, d)$ are well fitted by the reached purely inclusive DIS data (these quantities are considered as relatively well known and practically are the same for the different modern parameterizations), it is not especially important which parameterization one applies for this purpose (here we use the most popular and widely cited DSSV [13] parameterization). Then, having in his disposal both $(\Delta'_1 q + \Delta'_1 \bar{q})|_{\text{parameter}}$ $(q = u, d)$ and (see Table 2) $\Delta'_1 q_V$ $(q = u, d)$ quantities, one easily gets the truncated first moments of sea u and d quarks, applying the obvious relation

$$\Delta'_1 \bar{q} = \frac{1}{2}((\Delta'_1 q + \Delta'_1 \bar{q})|_{\text{parameter}} - \Delta'_1 q_V). \tag{8}$$

The received in such a way first moments $\Delta'_1\bar{u}$, $\Delta'_1\bar{d}$, as well as their differences and sums, are presented in Table 2. Looking at this table one can draw the conclusion that irrespective of the procedure used in the SIDIS data analysis the first moments of sea PDFs are consistent with zero within the errors.

CONCLUSION

The pion difference asymmetries are constructed by combining the SIDIS data of COMPASS and HERMES on pion production. The new direct (free of any fitting procedures) method of QCD analysis is applied to these asymmetries. As a result, the valence contributions to the nucleon spin (first moments of polarized valence PDFs) are found in NLO QCD. Using these results on valence PDFs, the contributions of light sea quarks to the nucleon spin are estimated. They occur surprisingly small: compatible with zeros within the errors.

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