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QCD ANALYSIS OF DIS AND SIDIS DATA

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The combined analysis of polarized DIS and SIDIS data is performed in NLO QCD using two alternative procedures: standard fitting procedure and the recently developed direct new method. The results from two methods are compared. The especial attention is paid to the light sea and strange PDFs.

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Since the observation of the famous spin crisis in 1987, one of the most intriguing and still unsolved problems of the modern high-energy physics is the nucleon spin puzzle. The key component of this problem, which attracted the great both theoretical and experimental efforts for many years, is the finding of the polarized parton distribution functions (PDFs) in nucleon.

The basic process which enables us to solve these problems is the process of semi-inclusive DIS (SIDIS). However, until recently the quality of the polarized SIDIS data was rather poor, so that its inclusion in the analysis did not help us to solve the main task of SIDIS measurements: to extract the polarized sea and valence PDFs of all active flavors. Only in 2004, the first polarized SIDIS data with the identification of produced hadrons (pions and kaons) were published [1]. These data were included in the global QCD analysis in [2]. Recently, the new data on the SIDIS asymmetries $A_d^{\pi^\pm}, A_d^{K^\pm}$ were published [3] by the COMPASS collaboration. It is of importance that these data cover the most important and badly investigated low x region. In this paper we include these data in the new global QCD analysis of all existing polarized DIS and SIDIS data. The elaborated parametrization on the polarized PDFs in some essential points differs from the parametrization of [4] (see below).

We tried to be as close as possible to our previous NLO QCD analysis of pure inclusive DIS data [5]. Namely, we parametrize the singlet $\Delta\Sigma$ and two nonsinglet Δq_3, Δq_8 combinations at the initial scale $Q_0^2 = 1$ GeV^2 in the common form (which is used also for ΔG and $\Delta\bar{u}$, $\Delta\bar{d}$ distributions)

$$\Delta q = \eta \frac{x^\alpha (1-x)^\beta (1 + \gamma x + \delta\sqrt{x})}{\int_0^1 x^\alpha (1-x)^\beta (1 + \gamma x + \delta\sqrt{x})\, dx}. \tag{1}$$

Then, the quantities $\Delta u + \Delta\bar{u}$, $\Delta d + \Delta\bar{d}$, $\Delta s = \Delta\bar{s}$ are determined as: $\Delta u + \Delta\bar{u} = (1/6)(3\Delta q_3 + \Delta q_8 + 2\Delta\Sigma)$, $\Delta d + \Delta\bar{d} = (1/6)(3\Delta q_3 - \Delta q_8 + 2\Delta\Sigma)$, $\Delta s = \Delta\bar{s} = (1/6)(\Delta\Sigma - \Delta q_8)$. Further, to properly describe the SIDIS data we, besides $\Delta\Sigma$, Δq_3, and Δq_8, parametrize the sea PDFs of u and d flavors. For the DIS sector we introduced the additional factors $\gamma_{\Delta q_3} x$, $\gamma_{\Delta q_8} x$ for Δq_3 and Δq_8 to provide the better flexibility of the parametrizations required by the inclusion of SIDIS data. Besides, we introduce the additional factors $\delta_{\Delta q_8}\sqrt{x}$ for Δq_8 and $\gamma_{\Delta G} x$ for ΔG to provide the possibility of sign-changing scenarios for Δs and ΔG, respectively.

We analyze the inclusive A_1 and semi-inclusive A_1^h asymmetries. We work in $\overline{\mathrm{MS}}$ factorization scheme.

For our analysis we collected all accessible in literature polarized DIS and SIDIS data. We include the inclusive proton, deutron, and neutron data by SMC, E143, E155, E154, COMPASS, HERMES, CLAS. The semi-inclusive data are collected by SMC, HERMES, and COMPASS. We include also the latest COMPASS data from [3]. In total, we have 232 points for the inclusive polarized DIS and 202 points for semi-inclusive polarized DIS. For 16 fit parameters $\chi_0^2|_{\mathrm{inclus}} = 188.4$ and $\chi_0^2|_{\mathrm{semi\text{-}inclus}} = 194.8$ for DIS and SIDIS data, while $\chi_0^2|_{\mathrm{tot}} = 383.9$ for the full set of data (434 points). Thus, one can conclude that the fit quality is quite good: $\chi_0^2/\mathrm{dof} \simeq 0.84$. The optimal values of our fit parameters are presented in Table 1. The first moments of PDFs together with their uncertainties are presented in Table 2. We calculate the uncertainties for two options: $\Delta\chi^2 = 1$ (standard) and $\Delta\chi^2 = 18.065$ (more reliable).

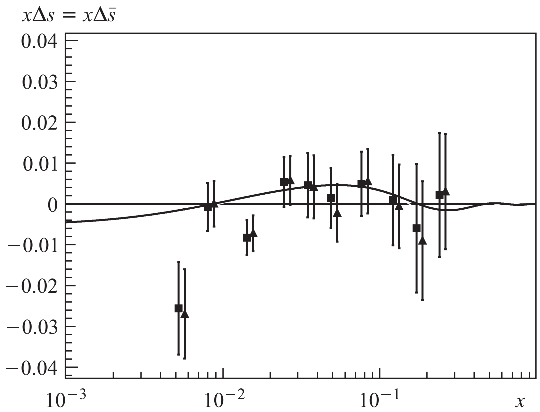
Let us now discuss the obtained parametrization. First, the results on the first moments $\Delta_1\Sigma \equiv \eta_{\Delta\Sigma}$ and $\Delta_1 G \equiv \eta_{\Delta G}$ are very close to the respective results (scenario with $\Delta G < 0$) obtained in [5] in the case of pure inclusive DIS. This is not surprise since $\Delta\Sigma$ is well fixed already by DIS data. What concerns the polarized strangeness in nucleon, looking at the Figure we see that our Δs distribution possesses the sign-changing Δs scenario, as well as the same distribution in [4]. However, while within parametrization [4] Δs changes the sign one time, within our parametrization Δs changes the sign twice. It seems that this distinction occurs due to the inclusion of the latest COMPASS semi-inclusive data [3], which allow one to better fix Δs shape. This is illustrative to compare the NLO results on Δs obtained here with the respective results of direct Δs extraction in LO by COMPASS (see the Figure). We see very similar Δs behavior in both the cases. Such a behaviour of Δs is of extreme importance since after the appearance of the first results on Δs extraction from SIDIS data performed by HERMES [1], we met the puzzle with the positive Δs in the middle x HERMES region $0.023 < x < 0.6$, while the total moment $\Delta_1 s$ definitely should be negative in accordance with the sum rule for Δq_8. To satisfy this requirement, $\Delta s(x)$ should possess the compensating negative behavior in the unaccessible for HERMES low x region $0 < x < 0.023$, i.e., the

Table 1. **Optimal values of the global fit parameters at the initial scale $Q_0^2 = 1$ GeV^2**

Parameters	$\Delta\Sigma$	Δq_3	Δq_8	ΔG	$\Delta\bar{u}$	$\Delta\bar{d}$
α	1.02	–0.63	–0.79	0.90	–0.35	0.28
β	3.38	3.14	$=\beta_{\Delta_{q_3}}$	$=\beta_{\Delta\bar{u}}$	15.0 (fix)	$=\beta_{\Delta\bar{u}}$
γ	0.0 (fix)	23.91	36.84	–5.67	0.0 (fix)	0.0 (fix)
δ	0.0 (fix)	0.0 (fix)	–13.74	0.0 (fixed)	0.0 (fix)	0.0 (fix)
η	0.38	1.27	0.62	–0.18	0.07	–0.08

Table 2. **Estimations of the first moments of polarized PDFs and their uncertainties for two options of $\Delta\chi^2$ choice**

Quantities	$\Delta\chi^2 = 1$	$\Delta\chi^2 = 18.065$
$\Delta\Sigma$	$0.3846^{+0.0050}_{-0.0122}$	$0.3846^{+0.0342}_{-0.0389}$
$\Delta u + \Delta\bar{u}$	$0.8640^{+0.0028}_{-0.0049}$	$0.8640^{+0.0114}_{-0.0084}$
$\Delta d + \Delta\bar{d}$	$-0.4020^{+0.0028}_{-0.0048}$	$-0.4020^{+0.0115}_{-0.0130}$
$\Delta s = \Delta\bar{s}$	$-0.0387^{+0.0014}_{-0.0024}$	$-0.038738^{+0.0061}_{-0.0065}$
ΔG	$-0.1828^{+0.0720}_{-0.1090}$	$-0.1828^{+0.1693}_{-0.2831}$
$\Delta\bar{u}$	$0.0672^{+0.0263}_{-0.0270}$	$0.0672^{+0.06483}_{-0.0737}$
$\Delta\bar{d}$	$-0.0792^{+0.0191}_{-0.0238}$	$-0.0792^{+0.0795}_{-0.0830}$



Obtained NLO parametrization on Δs (solid line) in comparison with the COMPASS results [3] obtained in LO QCD (points with error bars), $Q^2 = 3$ GeV^2

sign-changing scenario for Δs should be realized. We hope forthcoming kaon data from COMPASS will allow to answer definitely: should Δs change sign only once or it should change it twice? Further, comparing the central values of the first moments of $\Delta\bar{u}$ and $\Delta\bar{d}$ with [4] we find that they are different, which is of extreme importance. We point that recently, analyzing the SIDIS data on $h^{\pm}$ production, COMPASS obtained rather surprising result [6] that the sum $[\Delta_1\bar{u} + \Delta_1\bar{d}](Q^2 = 10\ \text{GeV}^2)$ is just zero within the errors:

$$[\Delta_1\bar{u} + \Delta_1\bar{d}]_{\text{COMPASS}} = 0.0 \pm 0.04 \pm 0.03. \tag{2}$$

This result was confirmed in the subsequent COMPASS paper [3], where sum $\Delta\bar{u}(x, Q^2 = 3\ \text{GeV}^2) + \Delta\bar{d}(x, Q^2 = 3\ \text{GeV}^2)$ of the local PDFs was extracted from the measured asymmetries $A_{1d}, A_{1d}^{\pi^{\pm}}, A_{1d}^{K^{\pm}}$ in the region $0.004 < x < 0.3$ (see Fig. 4 in [3]) and occurs to be about zero in the whole this region (the central values occur in both positive and negative vicinities of zero). Thus, at least in the leading order (COMPASS analysis) the sum $\Delta\bar{u}(x) + \Delta\bar{d}(x)$ is about zero in the region $3 < Q^2 < 10\ \text{GeV}^2$, which sheds new light on our understanding of polarized light quark sea. Namely, the sea is extremely asymmetric ($\Delta\bar{u} \simeq -\Delta\bar{d}$), on the contrary to the assumption of symmetric sea scenario $\Delta\bar{u}(x, Q_0^2) = \Delta\bar{d}(x, Q_0^2)$, applied in practically all the existing parametrizations based on the pure inclusive DIS data analysis. Our analysis shows that the sum $\Delta\bar{u}+\Delta\bar{d}$ is very small quantity in NLO QCD, too: $[\Delta_1\bar{u} + \Delta_1\bar{d}](Q^2 = 1\ \text{GeV}^2) = -0.01^{+0.01}_{-0.02}$, while DSSV produces -0.08 for this quantity. Thus, this question should be carefully checked.

Now we proceed to the alternative analysis. It is well known that the standard fitting procedure has important disadvantages. Main of them is arbitrariness in the functional form of initial distributions which can cause the essential difference on the results of analysis and, at the same time, the corresponding uncertainty is not calculable. Thus, it is very important to develop the alternative procedure, free of such problems. Such a procedure was developed in a sequel of papers [7]. Here we apply it to the same set of data as in the described above standard fitting analysis. Within the procedure [7] we instead of complicated system of integro-differential equations (in standard procedure) solve the simple algebraic system on the first truncated moments of the PDFs $\Delta_1' q$ in the region available for measurements:

$$\begin{cases} \mathcal{A}_p^{\pi^+} \simeq \sum_{q,\bar{q}} \Delta_1' q\, L_q^{\pi^+}, \\ \dots\dots\dots\dots\dots\dots\dots\dots\,, \\ \dots\dots\dots\dots\dots\dots\dots\dots\,, \\ \mathcal{A}_d^{K^-} \simeq \sum_{q,\bar{q}} \Delta_1' q\, L_q^{K^-}, \end{cases} \tag{3}$$

where

$$\mathcal{A}_p^h = \sum_{i=1}^{N_{\text{bins}}} A_{1p}^h(\langle x_i \rangle) \int_{x_i}^{x_{i+1}} dx\, F_1^h(x), \tag{4}$$

$$L_q^h \equiv \int\limits_Z^1 dz_h \Big[D_q^h(z_h) + \frac{\alpha_s}{2\pi} \int\limits_{z_h}^1 \frac{dz'}{z'} \Delta_1 C_{qq}(z') D_q^h\left(\frac{z_h}{z'}\right) + \\ + \Delta_1 C_{gq}(z') D_g^h \left(\frac{z_h}{z'}\right)\Big], \quad (5)$$

$$\Delta_1 C_{qq(gq)(z)} \equiv \int\limits_0^1 dx\, \Delta C_{qq(gq)}(x, z). \quad (6)$$

The core system of equations which allow one to extract all five quark distributions Δu, $\Delta\bar{u}$, Δd, $\Delta\bar{d}$, $\Delta s = \Delta\bar{s}$ should contain asymmetries $A^{\pi^\pm}_{p(d)}$, $A^{K^\pm}_{p(d)}$. That is why for a moment we extracted the moments only in the HERMES region $0.023 < x < 0.6$. The results are presented in Table 3, where to save space for the fitting procedure we present only the uncertainties for $\Delta\chi^2 = 18.065$ option. As is seen from this Table the results obtained within two procedures occur in good agreement. This confirmes the validity of the performed analysis. The only difference in central values occurs for strangeness. Nevertheless, the results for strangeness obtained with both the methods are in agreement within the errors. One can hope that the expected in the nearest future new COMPASS data on kaon asymmetries will essentially decrease the undeterminateness on polarized strangeness.

Table 3. **Comparison of results on the extracted in NLO first moments obtained within two analysis procedures.** $Q^2 = 10$ **GeV**^{2}

PDF	Direct method	Fitting procedure
$\Delta_1' u$	0.594 ± 0.027	$0.589^{+0.033}_{-0.046}$
$\Delta_1' d$	–0.242 ± 0.036	$-0.241^{0.0467}_{0.0426}$
$\Delta_1' \bar{u}$	0.036 ± 0.027	$0.037^{+0.046}_{-0.034}$
$\Delta_1' \bar{d}$	–0.078 ± 0.037	$-0.060^{+0.060}_{-0.069}$
$\Delta_1' s = \Delta_1' \bar{s}$	0.009 ± 0.016	$0.003^{+0.025}_{-0.009}$

In conclusion, the new combined analysis of polarized DIS and SIDIS data in NLO QCD is presented. The impact of modern SIDIS data on polarized PDFs is studied, which is of especial importance for the light sea quark PDFs and strangeness in nucleon. The results were obtained within two alternative analysis procedures: the standard fitting procedure and the recently developed direct procedure. The obtained results occur in the excellent agreement with each other, that confirms the correctness of the performed analysis. The obtained results are in agreement with the latest direct leading order COMPASS analysis of SIDIS asymmetries [3] as well as with the recent global fit analysis in NLO

QCD of [4], where the SIDIS data were also applied. Nevertheless, there are also some distinctions concerning, first of all, the polarized quark sea peculiarities. At the same time, it is clearly demonstrated within two analysis procedures that the present quality of SIDIS data is still not sufficient to make the eventual conclusions about the quantities influenced mainly by SIDIS.

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