Sivers distribution functions and the latest SIDIS data

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Abstract. We present an extraction of the Sivers distribution functions from the most recent experimental data of the HERMES and COMPASS experiments, assuming a negligible contribution of sea quark Sivers functions.

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In Ref. [1], we presented an extraction of the Sivers distribution functions based on a fit of SIDIS experimental data from the HERMES [2] and COMPASS [3, 4] collaborations. Data from HERMES [2] presented an unexpectedly large $A_{UT}^{\sin(\phi_h-\phi_S)}$ asymmetry for K^+ production, about twice as much as the analogous asymmetry for π^+. Such a large asymmetry suggested an important role of the sea Sivers functions. Our analysis confirmed this expectation finding a large contribution of the $\bar{s}$-Sivers function.

Since then, new experimental results have become available: the COMPASS collaboration has released new SIDIS data off a proton target, showing a clear Sivers asymmetry [5]; a new HERMES data analysis, based on a much larger statistics, while confirming the previous pion data, softens the enhanced peak in the K^+ Sivers azimuthal moment [6]. These new data prompted us to perform a new analysis. Here we present a preliminary phenomenological fit of COMPASS [3, 4] and HERMES [6] data including only u and d valence quarks in order to see if the new data can be described consistently without any contribution of the sea Sivers functions.

The SIDIS transverse single spin asymmetry (SSA) $A_{UT}^{\sin(\phi_h-\phi_S)}$ measured by HERMES and COMPASS, in the $\gamma^* - p$ c.m. frame and at order $k_\perp/Q$, is given by [7, 8, 9]:

$$A_{UT}^{\sin(\phi_h-\phi_S)} = \frac{\sum_q \int d\phi_S d\phi_h d^2\boldsymbol{k}_\perp \Delta^N f_{q/p^\uparrow}(x,k_\perp) \sin(\varphi-\phi_S) \frac{d\hat{\sigma}^{\ell q\to\ell q}}{dQ^2} D_q^h(z,p_\perp) \sin(\phi_h-\phi_S)}{\sum_q \int d\phi_S d\phi_h d^2\boldsymbol{k}_\perp f_{q/p}(x,k_\perp) \frac{d\hat{\sigma}^{\ell q\to\ell q}}{dQ^2} D_q^h(z,p_\perp)} \cdot \tag{1}$$

where ϕ_S and ϕ_h are the azimuthal angles identifying the directions of the proton spin $\boldsymbol{S}$ and of the momentum of the outgoing hadron h respectively w.r.t. the lepton plane, while φ defines the direction of the incoming (and outgoing) quark transverse momentum,

$\boldsymbol{k}_\perp = k_\perp(\cos\varphi, \sin\varphi, 0)$; $\frac{d\hat{\sigma}^{\ell q\to\ell q}}{dQ^2}$ is the unpolarized cross section for the elementary scattering $\ell q \to \ell q$; $D_q^h(z, p_\perp)$ is the fragmentation function describing the hadronization of the final quark q into the detected hadron h with momentum $\boldsymbol{P}_h$; h carries, with respect to the fragmenting quark, a light-cone momentum fraction z and a transverse momentum $\boldsymbol{p}_\perp$. Finally $\Delta^N f_{q/p^\uparrow}(x, k_\perp)$ is the Sivers distribution function [10]:

$$\Delta^N f_{q/p^\uparrow}(x, k_\perp) = -\frac{2k_\perp}{m_p} f_{1T}^\perp(x, k_\perp)\,. \tag{2}$$

The Sivers function is parameterized in terms of the unpolarized distribution function, as in Ref. [7], in the following factorized form:

$$\Delta^N f_{q/p^\uparrow}(x, k_\perp) = 2\,\mathcal{N}_q(x)\,h(k_\perp)\,f_{q/p}(x, k_\perp)\,, \tag{3}$$

with

$$\mathcal{N}_q(x) = N_q x^{\alpha_q}(1-x)^{\beta_q}\frac{(\alpha_q+\beta_q)^{(\alpha_q+\beta_q)}}{\alpha_q^{\alpha_q}\beta_q^{\beta_q}}\,, \qquad \text{and} \qquad h(k_\perp) = \sqrt{2e}\,\frac{k_\perp}{M_1}\,e^{-k_\perp^2/M_1^2}\,, \tag{4}$$

where N_q, α_q, β_q and M_1 (GeV/c) are free parameters to be determined by fitting the experimental data. We adopt a Gaussian factorization for the unpolarized distribution and fragmentation functions with the Gaussian widths $\langle k_\perp^2\rangle$ and $\langle p_\perp^2\rangle$ fixed to the values found in Ref. [8] by analysing the Cahn effect in unpolarized SIDIS: $\langle k_\perp^2\rangle = 0.25\ (\mathrm{GeV}/c)^2$ and $\langle p_\perp^2\rangle = 0.20\ (\mathrm{GeV}/c)^2$. For the unpolarized, $k_\perp$-integrated distribution and fragmentation functions we use the GRV98 [11] and DSS [12] sets. We best fit the HERMES proton and COMPASS deuteron data from Refs. [3, 6] (209 points) including only Sivers functions for u and d quarks, corresponding to seven free parameters, shown in table 1. The results we obtain are rather satisfactory, with a χ^2_{dof} of about 1.06. They are shown in Figs. 1, 2. The corresponding Sivers functions are plotted in the right panel of Fig. 3. Such results are similar to those obtained in Ref. [7] The gray band in Figs. 1, 2, 3 represents the statistical error of the fitting procedure, calculated as in Ref. [1]. As shown in the left panels of Figs. 1 and 2, pions data are well described by our fit. The new HERMES data on kaon production can be described reasonably well without any sea Sivers functions contribution, although their inclusion in the fit procedure can slightly improve the χ^2_{dof} [13]. In the left panel of Fig. 3 we show our predictions for the Sivers asymmetry at COMPASS kinematics on a proton target. Although apparently we overestimate the positive charged hadron asymmetry, COMPASS proton data are affected by a scale error of ± 0.01, not shown in the figure, so that our predictions are still compatible with them. Figs. 4 and 5 show the uncertainties of the fit parameters. They are obtained following the procedure of Ref. [1]. We generate randomly new sets of parameters, then we collect the sets giving a variation of χ^2 with respect to the minimum corresponding to a 95.45% confidence level. The figures show the $\Delta\chi^2$ as a function of each parameter. Some of the parameters are correlated. The strongest correlation is between N_u and M_1^2, as it is shown in the most right panel of Fig. 5. It is interesting to notice that the M_1 parameter, which fixes the Gaussian width of the Sivers function (i.e. its distribution in $k_\perp$) is rather well constrained and turns out to be between one half and two thirds of the unpolarized distribution function width.

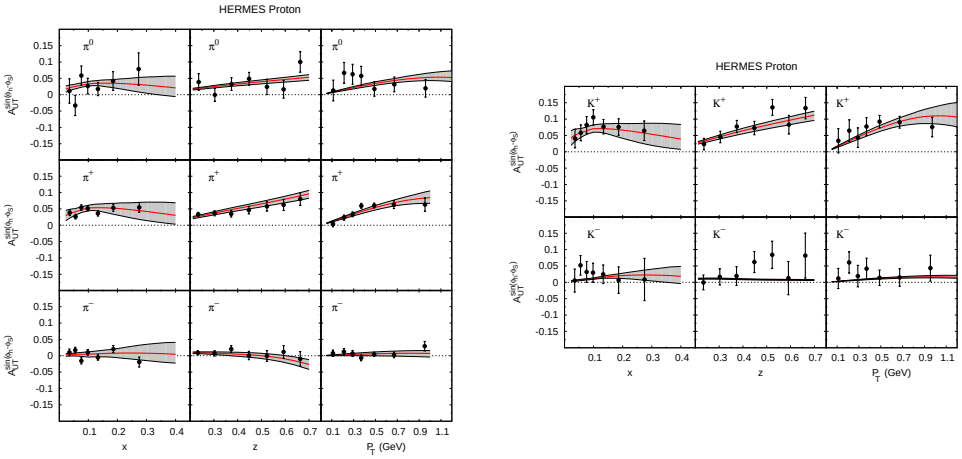

FIGURE 1. Fit of HERMES data [6] for pion (left panel) and kaon production (right panel).

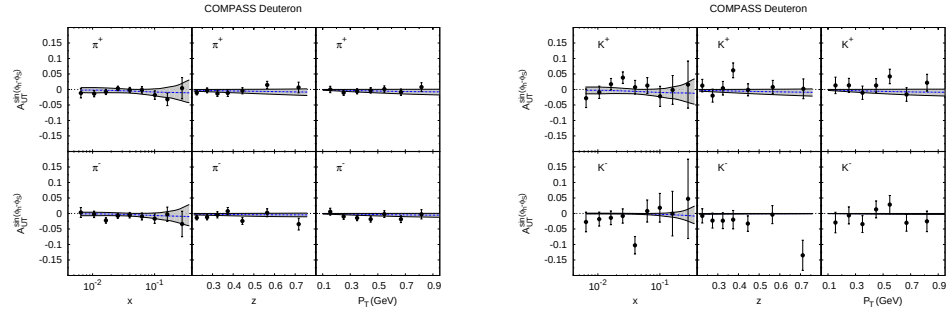

FIGURE 2. Fit of COMPASS deuteron data [3] for pion (left panel) and kaon production (right panel).

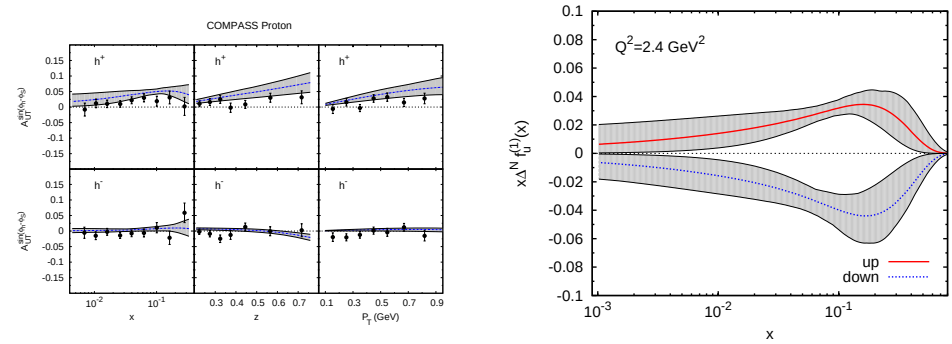

FIGURE 3. In the left panel we compare our predictions on proton target for charged hadrons with the data released by the COMPASS collaboration [5]. The errors on the data are the statical and systematic errors added in quadrature. The right panel shows the first moment of the Sivers functions extracted from the fitting procedure.

TABLE 1. χ^2 and best values of the parameters.

$\chi^2/dof = 1.06$		
$N_u = 0.40$	$\alpha_u = 0.35$	$\beta_u = 0.26$
$N_d = -0.97$	$\alpha_d = 0.44$	$\beta_d = 0.90$
$M_1^2 = 0.19\ \mathrm{GeV}^2$		

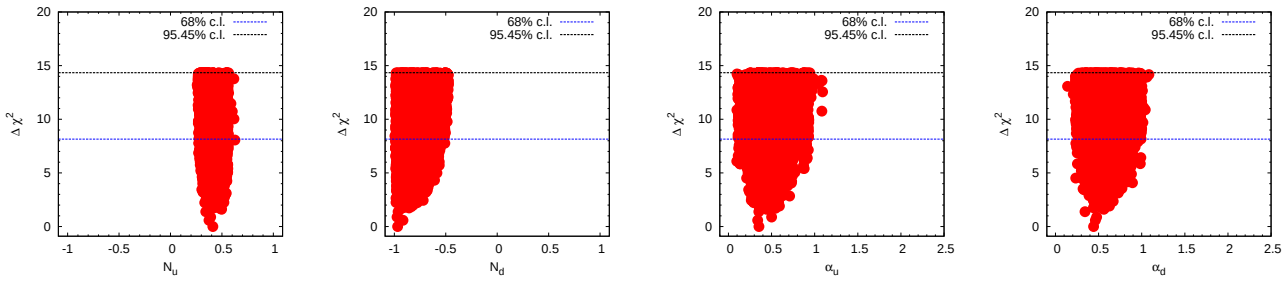

FIGURE 4. From left to right: $\Delta\chi^2$ as a function of N_u, N_d, α_u and α_d.

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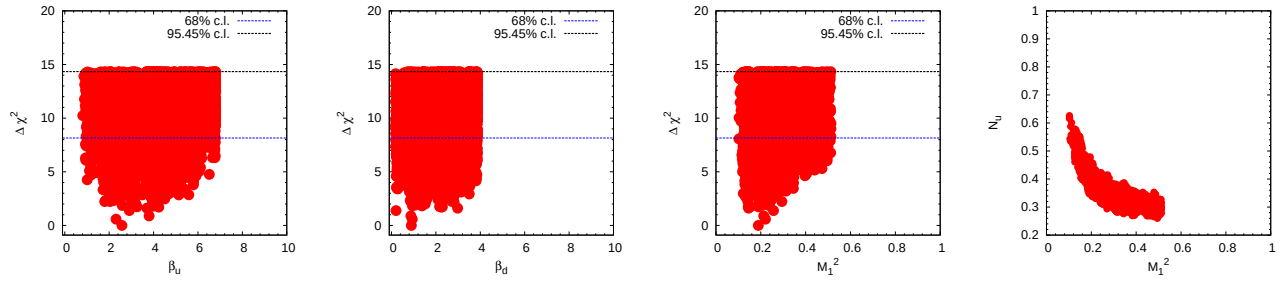

FIGURE 5. From left to right: $\Delta\chi^2$ as a function of β_u, β_d, M_1^2 and correlation between M_1^2 and N_u.