PROCEEDINGS OF SCIENCE

Extraction of Transversity and Collins functions

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We present a global re-analysis of recent experimental data on azimuthal asymmetries in semi-inclusive deep inelastic scattering, from the HERMES and COMPASS Collaborations, and in $e^+e^- \to h_1 h_2 X$ processes, from the Belle Collaboration. The transversity distribution and the Collins functions are extracted simultaneously, in a revised analysis which also takes into account a new parameterization of the unknown functions.

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1. SIDIS and e^+e^- scattering

The transversity distribution and the Collins fragmentation function can be studied in Semi Inclusive Deep Inelastic Scattering (SIDIS) processes by considering the $\sin(\phi_h + \phi_S)$ moment of the A_{UT} asymmetry:

$$A_{UT}^{\sin(\phi_h+\phi_S)} \propto \frac{\Delta_T q(x,k_\perp) \otimes d(\Delta\hat{\sigma}) \otimes \Delta^N D_{h/q^\uparrow}(z,p_\perp)}{f_{q/p}(x,k_\perp) \otimes d\hat{\sigma} \otimes D_{h/q}(z,p_\perp)}\,, \tag{1.1}$$

where $\mathbf{k}_\perp$ and $\mathbf{p}_\perp \simeq \mathbf{P}_T - z\,\mathbf{k}_\perp$ denote, respectively, the partonic transverse momentum in the distribution function and the hadronic transverse momentum in the fragmentation function, while $\mathbf{P}_T$ denotes the hadron transverse momentum in the γ^*P reference frame; $\Delta_T q(x,k_\perp)$ is the transversity function; $\Delta^N D_{h/q^\uparrow}(z,p_\perp) = (2\,p_\perp/z m_h)\, H_1^{\perp q}(z,p_\perp)$ is the Collins function; $d\hat{\sigma}$ and $d(\Delta\hat{\sigma})$ are respectively the partonic unpolarized and spin transfer cross sections.

The extraction of transversity requires the knowledge of the Collins function. Independent information on the Collins function can be obtained in unpolarized e^+e^- processes, by looking at the azimuthal correlations of hadrons produced in opposite jets [1]. Two methods are currently adopted in the experimental analysis (for further details and definitions see Refs. [1 – 3]):
i) the "$\cos(\varphi_1 + \varphi_2)$ method" in the Collins-Soper frame. Here, the jet thrust axis defines the $\hat{z}$ direction while the $e^+e^- \to q\bar{q}$ scattering defines the $\widehat{xz}$ plane; φ_1 and φ_2 are the azimuthal angles of the two hadrons around the thrust axis (the corresponding asymmetry will be denoted by "A_{12}");
ii) the "$\cos(2\varphi_0)$ method" in the Gottfried-Jackson frame ("A_0" asymmetry). One of the produced hadrons (h_2) identifies the $\hat{z}$ direction and the $\widehat{xz}$ plane is determined by the lepton and the h_2 directions. The other hadron, h_1, forms an azimuthal angle φ_0 with respect to the $\widehat{xz}$ plane.

Moreover, to eliminate false asymmetries, it is useful to consider the ratio of unlike-sign ($\pi^+\pi^-$ + $\pi^-\pi^+$) to like-sign ($\pi^+\pi^+$ + $\pi^-\pi^-$) or to charged ($\pi^+\pi^+$ + $\pi^+\pi^-$ + $\pi^-\pi^+$ + $\pi^-\pi^-$) pion pair production, denoted respectively with indices U, L and C.

In our analysis we adopt a simplified Gaussian and factorized parameterization of the TMDs. In particular for the unpolarized parton distribution and fragmentation functions (FFs) we use:

$$f_{q/p}(x,k_\perp) = f_{q/p}(x)\,\frac{e^{-k_\perp^2/\langle k_\perp^2\rangle}}{\pi\langle k_\perp^2\rangle}\,, \qquad D_{h/q}(z,p_\perp) = D_{h/q}(z)\,\frac{e^{-p_\perp^2/\langle p_\perp^2\rangle}}{\pi\langle p_\perp^2\rangle}\,, \tag{1.2}$$

with $\langle k_\perp^2\rangle$ and $\langle p_\perp^2\rangle$ fixed to the values extracted in Ref. [4]. For the integrated parton distribution and fragmentation functions, $f_{q/p}(x)$ and $D_{h/q}(z)$, we use the GRV98LO [5] and DSS sets [6].

For the transversity distribution, $\Delta_T q(x,k_\perp)$, and the Collins fragmentation function, $\Delta^N D_{h/q^\uparrow}(z,p_\perp)$, we adopt the following "standard" parameterizations [3]:

$$\Delta_T q(x,k_\perp) = \frac{1}{2}\,\mathcal{N}_q^T(x)\,[f_{q/p}(x) + \Delta q(x)]\,\frac{e^{-k_\perp^2/\langle k_\perp^2\rangle_T}}{\pi\langle k_\perp^2\rangle_T}\,, \tag{1.3}$$

$$\Delta^N D_{h/q^\uparrow}(z,p_\perp) = 2\,\mathcal{N}_q^C(z)\,D_{h/q}(z)\,h(p_\perp)\,\frac{e^{-p_\perp^2/\langle p_\perp^2\rangle}}{\pi\langle p_\perp^2\rangle}\,, \tag{1.4}$$

with

$$\mathcal{N}_q^T(x) = N_q^T\,x^\alpha(1-x)^\beta\,\frac{(\alpha+\beta)^{(\alpha+\beta)}}{\alpha^\alpha\beta^\beta}\,, \tag{1.5}$$

$$\mathcal{N}_q^C(z) = N_q^C\, z^\gamma (1-z)^\delta \,\frac{(\gamma+\delta)^{(\gamma+\delta)}}{\gamma^\gamma \delta^\delta}\,, \qquad h(p_\perp) = \sqrt{2e}\,\frac{p_\perp}{M_h}\, e^{-p_\perp^2/M_h^2}\,, \tag{1.6}$$

and $-1 \le N_q^T \le 1$, $-1 \le N_q^C \le 1$. We assume $\langle k_\perp^2\rangle_T = \langle k_\perp^2\rangle$. The combination $[f_{q/p}(x)+\Delta q(x)]$, where $\Delta q(x)$ is the helicity distribution, is evolved in Q^2 according to Ref. [7]. Notice that with these choices both the transversity and the Collins function automatically fulfill their proper positivity bounds. For the Collins FF, $\Delta^N D_{h/q^\uparrow}$, as its scale dependence is unknown, we assume the same Q^2 evolution as for the unpolarized FF, $D_{h/q}(z)$. In order to limit the number of parameters we have introduced in our fit favoured and disfavoured fragmentation functions instead of fully flavor dependent FFs; for further details, see Eqs. (30-31) of Ref. [8].

In Ref. [8] we started by repeating the fitting procedure reported in Refs. [3, 9], using the same "standard" parameterization, Eqs. (1.2)–(1.6), but including all the most recent SIDIS data on $A_{UT}^{\sin(\phi_h+\phi_S)}$ from COMPASS [10] and HERMES [11] Collaborations, and the corrected Belle data [12] on A_{12}^{UL} and A_{12}^{UC}. We obtained remarkably good fits, with a $\chi^2_{\rm d.o.f}$ of 0.80 (first line of Table 1) consistent with those found in our previous extractions. However, we noticed that the description of A_0 Belle data (not included in the fit) was not satisfactory. Thus, we performed another global fit based on the SIDIS and A_0 Belle data, and then computed the A_{12} values. The second line of Table 1 shows that, although this time A_0^{UL} and A_0^{UC} data are fitted, their corresponding χ^2 values remain large. This has induced us to explore a different functional shape for the parameterization of $\mathcal{N}_q^C(z)$, Eq. (1.6):

$$\mathcal{N}_q^C(z) = N_q^C\, z\,[(1-a-b)+a\,z+b\,z^2]\,, \tag{1.7}$$

with the subfix $q = \text{fav},\text{dis}$, and $-1 \le N_q^C \le 1$; a and b are flavour independent. For this parameterization, the positivity bound is not automatically fulfilled but has been checked *a posteriori*.

We have then repeated the previous fitting procedure with this new parameterization. Fitting the combined SIDIS, A_{12}^{UL} and A_{12}^{UC} Belle data, we obtain that the resulting best fits are very close to those obtained with the standard parameterization, see for instance the corresponding χ^2's in Table 1. The situation is different when fitting the SIDIS data together with A_0^{UL} and A_0^{UC}; in such a case the polynomial parameterization allows a better best fit. Moreover, a reasonable agreement can also be achieved between the data and the computed values of A_{12}^{UL} and A_{12}^{UC}, as shown by the χ^2 values in Table 1. Our newly extracted transversity and Collins functions are shown in Figs. 1 and 2: in the left panels we show $x\,\Delta_T q(x) = x\,h_{1q}(x)$, for u and d quarks, while in the right panels we plot:

$$z\Delta^N D_{h/q^\uparrow}(z) = z\int d^2\mathbf{p}_\perp \Delta^N D_{h/q^\uparrow}(z,p_\perp) = z\int d^2\mathbf{p}_\perp \frac{2p_\perp}{z m_h} H_1^{\perp q}(z,p_\perp) = 4zH_1^{\perp(1/2)q}(z)\,, \tag{1.8}$$

for $h = \pi^\pm$ and $q = u$. The tables containing the corresponding parameters of the best fits can be found in Ref. [8].

When comparing the results of Fig. 1 and 2, one notices a sizeable difference in the favoured (u/π^+) Collins function, and less evident differences in the transversity distributions. This differences reflect the fact that the A_{12} and A_0 data sets seem to exhibit a different trend. While the A_{12} set can be described equally well by both the parameterizations, the A_0 data seems to prefer the polynomial parameterization, which allows for larger asymmetries at larger z_h values.

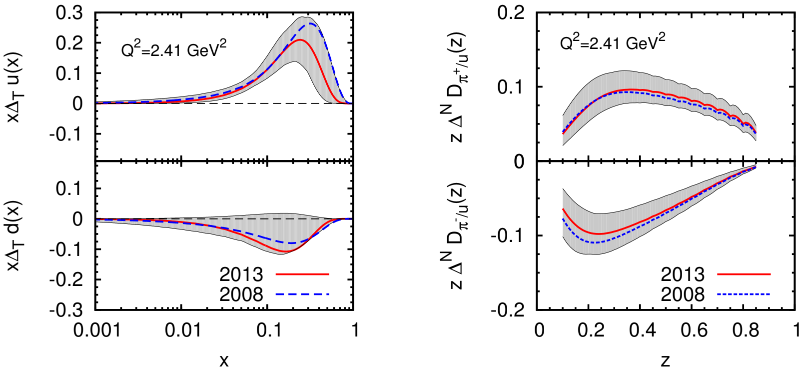

Figure 1: Transversity and Collins functions (solid red lines) obtained from our best fit of SIDIS data on $A_{UT}^{\sin(\phi_h+\phi_S)}$ and e^+e^- data on A_{12}, adopting the standard parameterization. The dashed blue lines show the same quantities as obtained in Ref. [9] using the data then available on $A_{UT}^{\sin(\phi_h+\phi_S)}$ and A_{12}^{UL}.

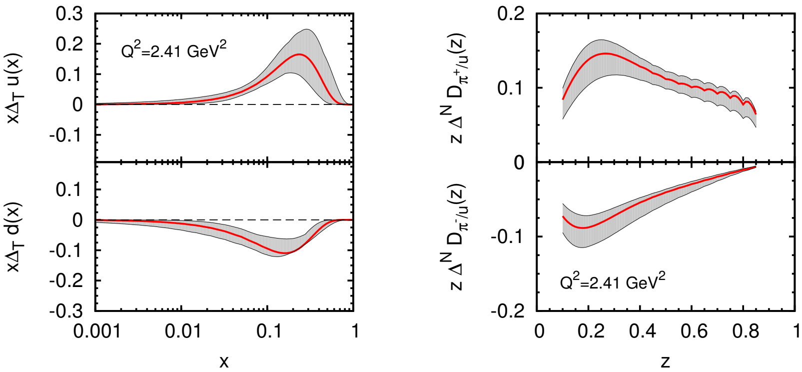

Figure 2: Transversity and Collins functions (solid red lines) obtained from our best fit of SIDIS data on $A_{UT}^{\sin(\phi_h+\phi_S)}$ and e^+e^- data on A_0, adopting the polynomial parameterization.

Further information on the Collins function will be provided by the BaBar Collaboration. In Ref. [8] we used our extracted Collins functions, based on Belle data, to give predictions for the forthcoming BaBar data on A_{12} and A_0.

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	FIT DATA 178 points	SIDIS 146 points	A_{12}^{UL} 16 points	A_{12}^{UC} 16 points	A_0^{UL} 16 points	A_0^{UC} 16 points
Standard Parameterization $\chi^2_{\text{d.o.f}} = 0.80$	$\chi^2_{\text{tot}} = 135$	$\chi^2 = 123$	$\chi^2 = 7$	$\chi^2 = 5$	$\chi^2 = 44$ NO FIT	$\chi^2 = 39$ NO FIT
Standard Parameterization $\chi^2_{\text{d.o.f}} = 1.12$	$\chi^2_{\text{tot}} = 190$	$\chi^2 = 125$	$\chi^2 = 20$ NO FIT	$\chi^2 = 12$ NO FIT	$\chi^2 = 35$	$\chi^2 = 30$
Polynomial Parameterization $\chi^2_{\text{d.o.f}} = 0.81$	$\chi^2_{\text{.tot}} = 136$	$\chi^2 = 123$	$\chi^2 = 8$	$\chi^2 = 5$	$\chi^2 = 45$ NO FIT	$\chi^2 = 39$ NO FIT
Polynomial Parameterization $\chi^2_{\text{d.o.f}} = 1.01$	$\chi^2_{\text{tot}} = 171$	$\chi^2 = 141$	$\chi^2 = 44$ NO FIT	$\chi^2 = 27$ NO FIT	$\chi^2 = 15$	$\chi^2 = 15$

Table 1: Summary of the χ^2 values obtained in our fits.

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