Transversity and Collins Fragmentation Functions:
Towards a New Global Analysis

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A new, preliminary global analysis of the experimental data on azimuthal asymmetries in SIDIS from HERMES and COMPASS collaborations, and in $e^+e^- \to h_1h_2X$ processes from the BELLE collaboration, is performed. The new data allow for a more precise determination of the Collins fragmentation function and of the transversity distribution function for $u$ and $d$ quarks, in comparison with the results of our previous analysis. Estimates for the single spin asymmetry $A_{UT}^{\sin(\phi_S+\phi_T)}$ at JLab and COMPASS, operating on a transversely polarized proton target, are presented.

The transversity distribution function, usually denoted as $h_1$ or $\Delta_T q$, together with the unpolarized distribution functions $q$ and the helicity distributions $\Delta q$, contain basic information about the spin structure of nucleons.

SIDIS processes represent a testing ground for the transversity distribution where this chiral-odd function couples to another chiral-odd quantity, the Collins fragmentation function \([1]\), giving rise to an azimuthal asymmetry, the so-called Collins asymmetry. Another azimuthal asymmetry produced in the $e^+e^- \to h_1h_2X$ process \([2]\) results from a convolution of two Collins fragmentation functions for quarks and antiquarks.

The first global analysis of data on azimuthal asymmetries in SIDIS and in $e^+e^-$ annihilations, resulting in the first extraction of the transversity distribution and the Collins fragmentation function, was presented in Ref. \([3]\). Recently, much higher statistics data on the $A_{UT}^{\sin(\phi_S+\phi_T)}$ azimuthal asymmetries for SIDIS have become available: in Ref. \([4]\) the HERMES Collaboration have presented pion and kaon azimuthal asymmetries; in Ref. \([5]\) the COMPASS Collaboration have presented their measurements for separated charged pion and kaon asymmetries; the BELLE collaboration have issued new high precision data of the Collins asymmetry in $e^+e^-$ annihilation \([6]\). It is therefore timely to reconsider the results of Ref. \([3]\) using the new data in order to improve our knowledge of the Collins fragmentation function and of the transversity distribution.

We assume the usual parameterization of unpolarized distribution and fragmentation functions \([3]\): $f_{q/p}(x,k_\perp) = f_{q/p}(x) \frac{e^{-k_\perp^2/(\langle k_\perp^2 \rangle)}}{\pi \langle k_\perp^2 \rangle}$, $D_{h/q}(z,p_\perp) = D_{h/q}(z) \frac{e^{-p_\perp^2/(\langle p_\perp^2 \rangle)}}{\pi \langle p_\perp^2 \rangle}$, with the values of $\langle k_\perp^2 \rangle$ and $\langle p_\perp^2 \rangle$ fixed to the values found in Ref. \([7]\) by analysing unpolarized SIDIS: $\langle k_\perp^2 \rangle = 0.25$ (GeV/c)$^2$, $\langle p_\perp^2 \rangle = 0.20$ (GeV/c)$^2$. Integrated parton distribution and

*Talk presented by A. Prokudin at the XVI International Workshop on Deep-Inelastic Scattering and Related Subjects, DIS 2008, London

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Asymmetry data and the predictions for the BELLE A defined as $\Delta q$ taken with some care. The consequences of fitting $Q^{-}$HERMES and COMPASS. Our large improvements our determination of the transversity distribution and Collins FFs, as can be seen from this preliminary analysis, we conclude that the inclusion of the new data sets [4, 5, 6] improves our determination of the transversity distribution and Collins FFs, as can be seen from Table 1.

Table 1: Best values of the free parameters for the $u$ and $d$ transversity distribution functions and for the favoured and unfavoured Collins fragmentation functions. We obtain $\chi^2$/d.o.f. = 1.3. Notice that the errors generated by MINUIT are strongly correlated, and should not be taken at face value. The significant fluctuations in our results are shown by the shaded areas in Figs. 2 and 3.

\begin{tabular}{|c|c|c|}
\hline
\$N_u^\pm$ & 0.79 ± 0.11 & $N_d^\pm$ = -1.00 ± 0.15 \\
\$N_{lu}^\pm$ & 0.43 ± 0.05 & $N_{ld}^\pm$ = -1.00 ± 0.17 \\
\$M_h^\pm$ & 0.91 ± 0.46 (GeV/c)$^2$ & \\
\hline
\end{tabular}

As in our previous analysis [3] we adopt the following parameterizations for the transversity distribution, $\Delta_T q(x, k_\perp)$, and the Collins FF, $\Delta^N D_{h/q^1}(z, p_\perp)$:

\begin{align}
\Delta_T q(x, k_\perp) &= \frac{1}{2} N^q_T (x) [f_{q/p}(x) + \Delta q(x)] \frac{e^{-k_\perp^2/(q_\perp^2)}}{\pi \langle k_\perp^2 \rangle_T}, \\
\Delta^N D_{h/q^1}(z, p_\perp) &= 2 N^q_c (z) D_{h/q}(z) h(p_\perp) \frac{e^{-p_\perp^2/(p_\perp^2)}}{\pi \langle p_\perp^2 \rangle}.
\end{align}

with

\begin{align}
N^q_T (x) &= N^u_T x^\alpha (1-x)^\beta \frac{(\alpha + \beta)(\alpha + \beta + 1)}{\alpha^\alpha \beta^\beta}, \\
N^q_c (z) &= N^u_c z^\gamma (1-z)^\delta \frac{(\gamma + \delta)(\gamma + \delta + 1)}{\gamma^\gamma \delta^\delta}, \\
h(p_\perp) &= \sqrt{2e} \frac{p_\perp}{M_h} e^{-p_\perp^2/M_h^2},
\end{align}

and $-1 \leq N^u_T \leq 1$, $-1 \leq N^u_c \leq 1$. We assume $\langle k_\perp^2 \rangle_T = \langle k_\perp^2 \rangle$. The helicity distribution $\Delta q(x)$ is taken from Ref. [10].

Table 1 contains the results of the best fit to the new data sets, Refs. [4, 5, 6]. In Fig. 1, our present results for the transversity distribution and the Collins fragmentation function are compared to those of our previous extraction, Ref. [3]. Fig. 2 shows the fits to the HERMES [4] and COMPASS [5] data, while Fig. 3 shows the fit to the BELLE $A_{12}$ asymmetry data and the predictions for the BELLE $A_0$ asymmetry [6] (notice that we do not include the $A_0$ data in the fit, as the two sets of BELLE data are not independent; the consequences of fitting $A_0$ instead of $A_{12}$ are presently under investigation).

Finally, in Fig. 4, we show our estimates for COMPASS and JLab experiments operating on proton target. Notice that JLab results will give important information on the range of large $x$ values, which is left basically unconstrained by the present SIDIS data from HERMES and COMPASS. Our large $-x$ estimates are based on an extrapolation of the transversity distribution function into an unexplored region of $x$, and consequently must be taken with some care.

The first $x$-moments of the transversity distribution – related to the tensor charge, and defined as $\Delta_T q \equiv \int_0^1 dx \Delta_T q(x)$ – are found to be $\Delta_T u = 0.59^{+0.14}_{-0.13}$, $\Delta_T d = -0.20^{+0.05}_{-0.07}$ at $Q^2 = 0.8$ GeV$^2$.

From this preliminary analysis, we conclude that the inclusion of the new data sets [4, 5, 6] improves our determination of the transversity distribution and Collins FFs, as can be seen.
by the reduced size of the present uncertainty bands (Fig. 1), and enables us to give more precise predictions for forthcoming experiments (see Fig. 4). The new distributions are compatible with the extraction of Ref. [3] and close to some model predictions for the transversity distribution (see for example Ref. [11]).

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Figure 1: Left panel: the transversity distribution functions for $u$ and $d$ flavours as determined by our global fit; we also show the Soffer bound (highest or lowest lines) and the (wider) bands of our previous extraction [3]. Right panel: favoured and unfavoured Collins fragmentation functions as determined by our global fit; we also show the positivity bound and the (wider) bands as obtained in Ref. [3].

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Figure 2: Fits of HERMES [4] and COMPASS [5] data. The shaded area corresponds to the uncertainty in the parameter values, see Ref. [3].

Figure 3: Left panel: fit of the BELLE [6] data on the $A_{12}$ asymmetry ($\cos(\varphi_1 + \varphi_2)$ method). Right panel: predictions for the $A_0$ BELLE asymmetry ($\cos(2 \varphi_0)$ method).

Figure 4: Estimates of the single spin asymmetry $A_{UT}^{\sin(\phi_\perp + \phi_A)}$ for COMPASS (left panel) and JLab (right panel) operating with proton target.

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