COMMENTS ON CAHN AND SIVERS EFFECTS IN SIDIS

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The role of intrinsic \( k_\perp \) in semi-inclusive Deep Inelastic Scattering (SIDIS) processes (\( \ell p \to \ell h X \)) is studied within QCD parton model at leading order. The resulting picture is applied to the description of the weighted single spin asymmetry \( A_{UL}^{\sin(\phi_h-\phi_S)} \) measured by HERMES. It is shown that these data could be described by the Sivers mechanism alone. However, the extracted Sivers functions fail to describe the HERMES data on \( A_{UL}^{\sin(\phi_h-\phi_S)} \).

The role of intrinsic \( k_\perp \) is important in unpolarized SIDIS processes and becomes crucial for the explanation of many single spin effects recently observed and still under active investigation in several ongoing experiments; spin and \( k_\perp \) dependences can couple in parton distributions and fragmentations, giving origin to unexpected effects in polarization observables. One such example is the azimuthal asymmetry observed in the scattering of unpolarized leptons off polarized protons and deuterons.

A recent analysis of SSA in \( p^+ p \to \pi X \) processes, with a separate study of the Sivers and the Collins contributions, has been performed respectively in Refs. 5 and 6, with the conclusion that the Sivers mechanism alone can explain the data, while the Collins mechanism is strongly suppressed.

We consider here the role of parton intrinsic motion in SIDIS processes within the QCD parton model at leading order. The average values of \( k_\perp \) for quarks inside protons, and \( p_\perp \) for final hadrons inside the fragmenting quark jet, are fixed by comparison with data on the dependence of the unpolarized cross section on the azimuthal angle between the leptonic and the hadronic planes and on \( P_T \). Such values are then used to compute the SSA for \( \ell p^+ \to \ell h X \) processes. We concentrate on the Sivers mechanism.

Within the factorization scheme, assuming an independent fragmenta-
The SIDIS cross section for the production of a hadron $h$ in the current fragmentation region with the inclusion of all intrinsic motions can be written as

$$\frac{d^5\sigma}{dx_h dQ^2 dz_h d^2P_T} = \sum_q e_q^2 \int d^2k_\perp f_q(x, k_\perp) \frac{2\pi\alpha^2 s^2 + u^2}{Q^4} \times D^h_q(z, p_\perp) \frac{z}{z_h} \frac{x^2}{x} \langle 1 + \frac{4}{x^2} \frac{k_\perp^2}{Q^2} \rangle^{-1}.$$ 

It is instructive, and often quite accurate, to consider the above equation in the much simpler limit in which only terms of $O(k_\perp/Q)$ are retained. In such a case $x \approx x_B$, $z \approx z_h$ and $p_\perp \approx P_T - z_h k_\perp$. In what follows we assume, both for the parton densities and the fragmentation functions, a factorized Gaussian $k_\perp$ and $p_\perp$ dependence.

In this way the $d^2k_\perp$ integration in Eq. (1) can be performed analytically, with the result, valid up to $O(k_\perp/Q)$:

$$\frac{d^5\sigma}{dx_h dQ^2 dz_h d^2P_T} \approx \sum_q \frac{2\pi\alpha^2 e_q^2}{Q^4} f_q(x_B) D^h_q(z_h) \left[ 1 + \frac{(2 - y)\sqrt{1 - y} \langle k_\perp^2 \rangle z_h P_T}{\langle P_T^2 \rangle Q} \right] \frac{1}{\pi \langle P_T^2 \rangle} e^{-P_T^2/\langle P_T^2 \rangle},$$

where $\langle P_T^2 \rangle = \langle p_\perp^2 \rangle + z_h^2 \langle k_\perp^2 \rangle$. The term proportional to $\cos \phi_h$ describes the Cahn effect.\textsuperscript{1}

By fitting the data\textsuperscript{10} on unpolarized SIDIS we obtain the following values of the parameters: $\langle k_\perp^2 \rangle = 0.25 \text{ (GeV}/c)^2$, $\langle p_\perp^2 \rangle = 0.20 \text{ (GeV}/c)^2$. The results of the fits are shown in Fig. 1.

The unpolarized quark (and gluon) distributions inside a transversely polarized proton can be written as:

$$f_{q/p}(x, \mathbf{k}_\perp) = f_{q/p}(x, k_\perp) + \frac{1}{2} \Delta f_{q/p}(x, k_\perp) S_T \cdot (\hat{P} \times \hat{k}_\perp),$$

Figure 1. Fits to the $\cos \phi_h$ dependence of the cross section and to $d\sigma/dP_T^2$. 

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where $P$ and $S_T$ are respectively the proton momentum and the transverse polarization vector, and $k_{\perp}$ is the parton transverse momentum; transverse refers to the proton direction. Eq. (3) leads to non vanishing SSA, which can be calculated by substituting $f_{q/p}$ by $f_{q/p}^\uparrow$ in Eq. (1). We parameterize, for each light quark flavour $q = u, d$, the Sivers function in the following factorized form: 

$$\Delta N_{q/p}^\uparrow(x, k_{\perp}) = 2N_q(x) h(k_{\perp}) f_{q/p}(x, k_{\perp}),$$

where $N_q(x) = N_q x^{a_q}(1-x)^{b_q}$, $a_q + b_q = 1$, $a_u = 0.1$, $a_d = 0.1$, $b_u = 0.3$, $b_d = 0.3$. The result of the fit is presented in the upper part of Fig. 2.

Having fixed all the parameters we can check the consistency of the model by computing $A_{UL}^\sin \phi$ for kaon and pion production on a deuteron target; our results are given in the lower part of Fig. 2, showing a very good agreement with data.

Looking only at the set of proton HERMES data on $A_{UL}^\sin \phi$ one could conclude that the Sivers mechanism alone can explain such data and that the resulting model works well also for a deuteron target. However, one should not forget that the weighted SSA $A_{UL}^\sin \phi$ can originate from also by the Collins mechanism and higher-twist contributions.

More recently, HERMES data on $A_{UT}^\sin(\phi_h - \phi_S)$ have become available. Such data single out the contribution of the Sivers mechanism alone. Therefore, we have computed $A_{UL}^\sin(\phi_h - \phi_S)$ with the Sivers functions extracted from $A_{UT}^\sin(\phi_h - \phi_S)$, under the assumption that only the Sivers mechanism is responsible for $A_{UL}^\sin \phi$. Our results for $A_{UL}^\sin(\phi_h - \phi_S)$ turn out to be much too large, and with opposite sign, when compared with HERMES data. This definitely shows that the observed $A_{UL}^\sin(\phi_h - \phi_S)$ must receive dominant contributions from higher-twist and/or Collins effects.

A direct extraction of the Sivers functions should be (and has been) performed by first fitting the data on $A_{UT}^\sin(\phi_h - \phi_S)$. One can then check that, in such a case, the contribution of the extracted Sivers functions to $A_{UL}^\sin \phi$ is negligible.

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Hermes data on $A_{UL}^{\sin \phi_h}$ for pion (left) and kaon (right) production in the scattering off a longitudinally polarised proton (upper left) and deuterum (lower part) target. The lines are the results of our calculations, with exact kinematics (solid line) or keeping only terms up to $O(k_L/Q)$ (dashed line). The solid thin line in the upper left part shows the results obtained with approximate kinematics and the use of the LEPTO event generator.

Figure 2.

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