COLLINS EFFECT AND SSA FOR HERMES AND COMPASS EXPERIMENTS *

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Predictions are made for single spin azimuthal asymmetries (SSA)due to the Collins effect in pion production from semi-inclusive deeply inelastic scattering off transversely and longitudinally polarized targets for the HERMES and COMPASS experiments. The SSA A_{UT} from the *transversely* polarized proton target are found to be about 20% for positive and neutral pions both at HERMES and COMPASS. For a *longitudinally* polarized target for COMPASS $A_{UL}^{\sin\phi} \sim 1\%$ and $A_{UL}^{\sin 2\phi} \sim 3\%$.

Introduction. Noticeable SSA $A_{UL}^{\sin\phi}$ have been observed by the HERMES collaboration in pion and kaon electro-production in semi-inclusive deep-inelastic scattering (SIDIS) of an unpolarized lepton beam off a longitudinally polarized proton or deuteron target [1, 2, 3, 4]. Assuming factorization these single spin asymmetries can be explained by the Collins and Sivers effect in terms of so far unexplored distribution and fragmentation functions, namely the nucleon chirally odd twist-2 transversity distribution h_1^a and twist-3 distribution functions h_L^a and the Collins fragmentation function $H_1^{\perp a}$ or the chirally even Sivers distribution function $f_{1T}^{\perp a}$

Reasonable descriptions of the HERMES data using different assumptions and models were given in Refs. [5, 6, 7] in terms of the Collins effect only.

In this talk I will give predicts of the SSA due to the Collins effect from a transversely polarized target for the kinematics of the HERMES and COMPASS experiments.

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Collins effect contribution to A_{UT}. In the HERMES and COMPASS experiments the cross sections $\sigma_N^{\uparrow\downarrow}$ for the process $lN^{\uparrow\downarrow} \to l'hX$ will be measured at the transversely with respect to the beam polarized target. With ϕ (ϕ_S) denoting the azimuthal angles between the hadron production plane (the nucleon spin) and the lepton scattering plane the observables of interest are defined as

$$A_{UT}^{\sin(\phi+\phi_S)}(x) = \frac{2}{|S_T|}\frac{\langle\sin(\phi+\phi_s)\rangle^\uparrow - \langle\sin(\phi+\phi_s)\rangle^\downarrow}{\langle 1\rangle^\uparrow + \langle 1\rangle^\downarrow} \,. \tag{1}$$

The expressions for the differential cross sections entering the asymmetry in Eqs. (1) was derived in [8, 9] assuming factorization. In order to deconvolve the transverse momenta in $A_{UT}^{\sin(\phi+\phi_S)}$ in Eq. (1) we assume the distributions of transverse momenta in the unintegrated distribution and fragmentation functions to be Gaussian. Under this assumption one obtains

$$A_{UT}^{\sin(\phi+\phi_s)}(x) = a_{\rm G}\, B_T(x)\,\frac{\sum_a e_a^2\, x\, h_1^a(x)\,\langle H_1^{\perp a}\rangle}{\sum_b e_b^2\, x\, f_1^b(x)\,\langle D_1^b\rangle}\,, \tag{2}$$

where $B_T(x)$ and $a_{\rm G}$ are defined as

$$B_T(x) = \frac{2\int {\rm d}y\,(1-y)\,\sin\Theta_S/Q^4}{\int {\rm d}y\,(1-y+y^2/2)\,/Q^4}\,,\quad a_{\rm G} = \frac{1}{2\langle z\rangle\sqrt{1+\langle z^2\rangle\langle P_{\rm N\perp}^2\rangle/\langle P_{h\perp}^2\rangle}}\,, \tag{3}$$

where $\langle P_{\rm N\perp}^2\rangle$ and $\langle P_{h\perp}^2\rangle/\langle z^2\rangle$ are the mean transverse momentum squares characterizing the Gaussian distributions of transverse momenta in the unintegrated distribution and fragmentation function.

Transversity and Collins PFF. In order to estimate the azimuthal asymmetry, Eqs. (1) one has to know h_1^a and $H_1^{\perp a}$. For the former we shall use the predictions of the chiral quark-soliton model (χQSM) [10], and for the latter our analysis of the HERMES data from Ref. [6][1].

The χQSM is an effective relativistic quantum field-theoretical model with explicit quark degrees of freedom, in which twist-2 nucleon distribution functions can unambiguously be defined and evaluated at a low renormalization point of about (600 − 700) MeV. The χQSM has been derived from the instanton model of the QCD vacuum [12] and has been shown to describe well numerous static nucleonic observables without adjustable parameters. The field-theoretical nature of the model is crucial to ensure the theoretical consistency

[1] Actually, in that analysis the Sivers function was neglected, which has later been shown to be theoretically consistent and phenomenologically justified [11].

of the approach: the quark and antiquark distribution functions computed in the model satisfy all general QCD requirements.

The results of the model agree for the distribution functions $f_1^a(x)$, $g_1^a(x)$ and $g_T^a(x)$ within (10 - 30)% with phenomenological information. This encourages confidence that the model describes the nucleon transversity distribution function $h_1^a(x)$ [10] with a similar accuracy. Also in this approach one can justifiably approximate $h_L^a(x)$ by its twist-2 ("Wandzura-Wilczek" like) term $h_L^a(x) = 2x\int_x^1 \mathrm{d}x'\, h_1^a(x')/x'^2$. Moreover, T-odd distribution functions vanish in the χQSM [13].

For Collins fragmentation functions a strong suppression of the unfavoured with respect to the favoured has been assumed. In Ref. [6] information on $H_1^\perp$ was gained from the HERMES data on the $A_{UL}^{\sin\phi}$ asymmetry in π^+ and π^0 production [2, 3]. For that the transverse momentum distributions were assumed to be Gaussian and the parton distribution functions h_1^a and h_L^a were taken from the χQSM. For the analyzing power the value was found

$$\langle H_1^\perp\rangle/\langle D_1\rangle = (13.8 \pm 2.8)\% \tag{4}$$

at $\langle z\rangle = 0.4$ and $\langle Q^2\rangle = 2.5\ \mathrm{GeV}^2$ [6]. This asymmetry was also measured using the DELPHI data collection and a value $|\langle H_1^\perp\rangle/\langle D_1\rangle| = (12.5 \pm 1.4)\%$ for $\langle z\rangle \simeq 0.4$ at a scale of M_Z^2 was reported [14].

A_{UT} asymmetries for HERMES. The beam in the HERMES experiment has an energy of $E_{\mathrm{beam}} = 26.7\,\mathrm{GeV}$. We assume the cuts implicit in the integrations in Eq. (3) to be the same as in the longitudinal target polarization experiments: $1\,\mathrm{GeV}^2 < Q^2 < 15\,\mathrm{GeV}^2$, $2\,\mathrm{GeV} < W$, $0.2 < y < 0.85$, $0.023 < x < 0.4$ and $0.2 < z < 0.7$ with $\langle z\rangle = 0.4$, and $\langle P_{h\perp}\rangle = 0.4$ GeV. The predictions for $A_{UT}^{\sin(\phi+\phi_S)}$ for the transversely polarized proton and deuterium target are shown in Figs. 1a and 1b, respectively.

This demonstrate that $A_{UT}^{\sin(\phi+\phi_S)}$ is sizeable, roughly 20% for positive and neutral pions for the proton target and about 10% for all pions for the deuteron target. Comparing this result with the $A_{UL}^{\sin\phi}$ asymmetries $\sim (2-4)\%$ we see that $A_{UT}^{\sin(\phi+\phi_S)}$ asymmetry can clearly be observed.

For negative pions from a proton, however, there might be additional sizeable corrections due to unfavoured flavour fragmentation.

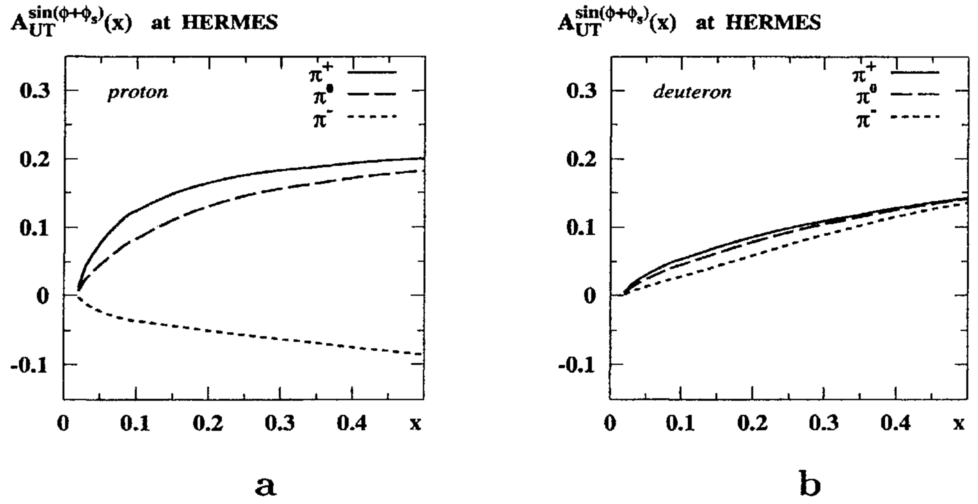

Figure 1: Predictions for azimuthal asymmetries $A_{UT}^{\sin(\phi+\phi_S)}(x)$ in SIDIS pion productions from transversely polarized proton (a) and deuteron (b) targets for kinematics of the HERMES experiment.

COMPASS experiment. The beam energy available at COMPASS is $E_{\text{beam}} = 160\,\text{GeV}$ For the kinematic cuts we shall take: $2\,\text{GeV}^2 < Q^2 < 50\,\text{GeV}^2$, $15\,\text{GeV}^2 < W^2 < 300\,\text{GeV}^2$, $0.05 < y < 0.9$, $x < 0.4$ and evaluate the distribution functions at $Q^2 = 10\,\text{GeV}^2$. We take $\langle P_{h\perp}\rangle \approx 0.4$ GeV and $\langle z\rangle \approx 0.4$. The latter means that we can use for $\langle H_1^\perp\rangle/\langle D_1\rangle$ the result in Eq. (4) assuming that the ratio $\langle H_1^\perp\rangle/\langle D_1\rangle$ is only weakly scale dependent in the range of scales relevant in the HERMES and COMPASS experiments. The estimate of $A_{UT}^{\sin(\phi+\phi_S)}$ obtained in this way is shown in Fig. 2a.

It shows that $A_{UT}^{\sin(\phi+\phi_S)}$ can be up to $\mathcal{O}(20\%)$ at COMPASS energies, i.e. as large as at HERMES. This is not unexpected since this asymmetry is twist-2 (in the sense that it is not power suppressed).

About 80% of the beam time the target polarization in the COMPASS experiment will be longitudinal. This will allow to measure the longitudinal target spin asymmetries $A_{UL}^{\sin\phi}$ and $A_{UL}^{\sin 2\phi}$. The estimates for these asymmetries in our approach are shown in Figs. 2b and 2c. Clearly, the longitudinal target spin asymmetries are much smaller than the transverse target spin asymmetry $A_{UT}^{\sin(\phi+\phi_S)}$, however, the larger statistics could help to resolve them. The $A_{UL}^{\sin 2\phi}(x)$ asymmetry is of particular interest since it is one of the "independent observables" which could provide further insights on transversity distribution.

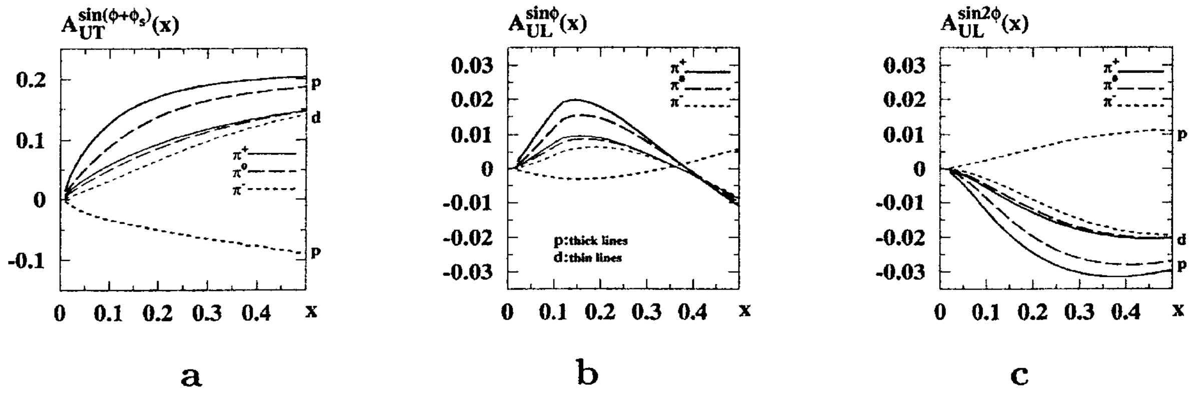

Figure 2: **a.** Prediction of the SSA $A_{UT}^{\sin(\phi+\phi_S)}(x)$ in SIDIS pion production from a transversely polarized proton and deuteron target for the kinematics of the COMPASS experiment. Predictions of the SSA $A_{UL}^{\sin\phi}(x)$ (**b**) and $A_{UL}^{\sin 2\phi}(x)$ (**c**) from a longitudinally polarized target for the kinematics of the COMPASS experiment.

Sivers azimuthal asymmetries. Actually, our approach would imply the vanishing of $A_{UT}^{\sin(\phi-\phi_S)}(x)$ asymmetry, which is due to the Sivers effect [9] and will be measured at HERMES and COMPASS simultaneously with $A_{UT}^{\sin(\phi+\phi_S)}(x)$. However, this cannot be taken literally as a prediction for the following reason. The chiral quark-soliton model was derived from the instanton vacuum model as the leading order in terms of the instanton packing fraction $\frac{\rho}{R} \sim \frac{1}{3}$ (ρ and R are respectively the average size and separation of instantons in Euclidean space time). In this order the T-odd distribution functions vanish [13].

In higher orders the Sivers function can be well non-zero and all one can conclude at this stage is that the Sivers functions is suppressed with respect to the T-even. However, considering that $H_1^\perp(z)$ is much smaller than $D_1(z)$, cf. Eq. (4), it is questionable whether such a suppression could be sufficient such that in physical cross sections the Collins effect $\propto h_1^a(x)H_1^\perp(z)$ is dominant over the Sivers effect $\propto f_{1T}^\perp(x)D_1(z)$.

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