Transversity measurements at HERMES

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Abstract. Azimuthal single-spin asymmetries (SSA) in semi-inclusive electroproduction of charged pions in deep-inelastic scattering (DIS) of positrons on a transversely polarised hydrogen target are presented. Azimuthal moments for both the Collins and the Sivers mechanism are extracted. In addition the subleading-twist contribution due to the transverse spin component from SSA on a longitudinally polarised hydrogen target is evaluated.

Keywords: transversity distribution, azimuthal single-spin asymmetries (SSA), Collins mechanism, Sivers mechanism, subleading-twist effects in SSA on a longitudinally polarised target
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Recently the HERMES collaboration published first evidence for azimuthal single-spin asymmetries (SSA) in the semi-inclusive production of charged pions on a transversely polarised target [1]. Significant signals for both the Collins and Sivers mechanisms were observed in data recorded during the 2002–2003 running period of the HERMES experiment. Below we present a preliminary analysis of these data combined with additional data taken in the years 2003 and 2004. All data was recorded at a beam energy of 27.6GeV using a transversely nuclear-polarised hydrogen-target internal to the HERA positron storage ring at DESY.

At leading twist, the momentum and spin of the quarks inside the nucleon are described by three parton distribution functions: the well-known momentum distribution $q\left(x,Q^2\right)$, the known helicity distribution $\Delta q\left(x,Q^2\right)$ [2] and the unknown *transversity distribution* $\delta q\left(x,Q^2\right)$ [3, 4, 5, 6]. In the helicity basis, transversity is related to a quark-nucleon forward scattering amplitude involving helicity flip of both nucleon and quark ($N^{\Rightarrow}q^{\leftarrow} \rightarrow N^{\Leftarrow}q^{\rightarrow}$). As it is chiral-odd, transversity cannot be probed in inclusive measurements. At HERMES transversity in conjunction with the chiral-odd Collins fragmentation function [7] is accessible in SSA in semi-inclusive DIS on a transversely polarised target (*Collins mechanism*). The Collins fragmentation function describes the correlation between the transverse polarisation of the struck quark and the transverse momentum $P_{\mathrm{h}\perp}$ of the produced hadron. As it is also odd under naive time reversal (T-odd) it can produce a SSA, i.e. a left-right asymmetry in the momentum distribution of the produced hadrons in the directions transverse to the nucleon spin [8].

The *Sivers mechanism* can also cause a SSA: The T-odd Sivers distribution function [9] describes the correlation between the transverse polarisation of the nucleon and the transverse momentum k_T of the quarks within. A non-zero Sivers mechanism provides a non-zero Compton amplitude involving nucleon helicity flip without quark helicity flip ($N^{\Rightarrow}q^{\leftarrow} \rightarrow N^{\Leftarrow}q^{\leftarrow}$), which must therefore involve orbital angular momentum of the quark inside the nucleon [8, 10].

With a transversely polarised target, the azimuthal angle ϕ_S of the target spin direction in the "$\Uparrow$" state is observable in addition to the azimuthal angle ϕ of the detected hadron. Both azimuthal angles are defined with respect to the lepton scattering plane. The additional degree of freedom ϕ_S, not available with a longitudinally polarised target, results in distinctive signatures: $\sin(\phi+\phi_S)$ for the Collins mechanisms and $\sin(\phi-\phi_S)$ for the Sivers mechanism [11]. Therefore, for all detected charged pions and for each bin in x, z or $P_{h\perp}$ the cross section asymmetry for unpolarised beam (U) and transversely polarised target (T) was determined in the two dimensions ϕ and ϕ_S:

$$A^{\pi^\pm}_{\rm UT}(\phi,\phi_S) = \frac{1}{|P_z|}\frac{N^{\Uparrow}_{\pi^\pm}(\phi,\phi_S) - N^{\Downarrow}_{\pi^\pm}(\phi,\phi_S)}{N^{\Uparrow}_{\pi^\pm}(\phi,\phi_S) - N^{\Downarrow}_{\pi^\pm}(\phi,\phi_S)}.$$

Here $N^{\Uparrow(\Downarrow)}_{\pi^\pm}(\phi,\phi_S)$ represents the semi-inclusive normalised yield in the target spin state "$\Uparrow$ ($\Downarrow$)", and $|P_z| = 0.754 \pm 0.050$ denotes the average degree of the target polarisation.

To avoid cross-contamination, the azimuthal moments for the Collins mechanism $\langle\sin(\phi+\phi_S)\rangle^{\pi^\pm}_{\rm UT}$ and the Sivers mechanism $\langle\sin(\phi-\phi_S)\rangle^{\pi^\pm}_{\rm UT}$ were extracted simultaneously. Recent studies showed that the terms for $\sin\phi_S$ and $\sin(2\phi-\phi_S)$ have to be added in the two-dimensional fit for the asymmetry (the kinematic factors $A(\langle x\rangle,\langle y\rangle)$ and $B(\langle y\rangle)$ are defined in [1]):

$$\begin{aligned} A^{\pi^\pm}_{\rm UT}(\phi,\phi_S) \;=\;& 2\langle\sin(\phi+\phi_S)\rangle^{\pi^\pm}_{\rm UT}\frac{B(\langle y\rangle)}{A(\langle x\rangle,\langle y\rangle)}\sin(\phi+\phi_S) + \\ & 2\langle\sin(\phi-\phi_S)\rangle^{\pi^\pm}_{\rm UT}\sin(\phi-\phi_S) + \\ & 2\langle\sin(2\phi-\phi_S)\rangle^{\pi^\pm}_{\rm UT}\sin(2\phi-\phi_S) + 2\langle\sin\phi_S\rangle^{\pi^\pm}_{\rm UT}\sin\phi_S. \end{aligned}$$

The virtual-photon Collins and Sivers moments as a function of x, z and $P_{h\perp}$ are plotted in figure 1 (see caption for the systematic uncertainties). In addition the simulated fraction of charged pions originating from diffractive vector meson production and decay is shown, to estimate the possible contribution from the poorly known asymmetry of this process. The average values of the kinematic variables in the experimental acceptance are $\langle x\rangle = 0.10$, $\langle y\rangle = 0.53$, $\langle Q^2\rangle = 2.43\,\mathrm{GeV}^2$, $\langle z\rangle = 0.36$, $\langle P_{h\perp}\rangle = 0.40\,\mathrm{GeV}$.

This preliminary result is based on nearly five times more statistics than that in the publication [1] and is consistent with the published result: The average Collins moment is positive for π^+ and negative for π^-. Also, the magnitude of the π^- moment appears to be not smaller than the one for π^+. The averaged Sivers moment is significantly positive for π^+ and implies a non-vanishing orbital angular momentum of the quarks inside the nucleon. For π^- the averaged Sivers moment is consistent with zero.

The extracted Collins and Sivers moments allow the evaluation of the subleading-twist contribution to the previously measured SSA on a longitudinally polarised hydrogen target [13, 14, 15]. These subleading moments $\langle\sin\phi\rangle^q_{\rm UL}$ are due to the longitudinal component of the target spin along the virtual photon direction ("q"). As shown in figure 2 these moments are almost the same as the previously published moments $\langle\sin\phi\rangle^l_{\rm UL}$, where the longitudinal axis was defined along the lepton beam momentum ("l"). However, the maximum contribution of these subleading longitudinal asymmetries to the leading-twist Collins and Sivers moments in figure 1 is 0.004, which is negligible compared to the statistical uncertainty.

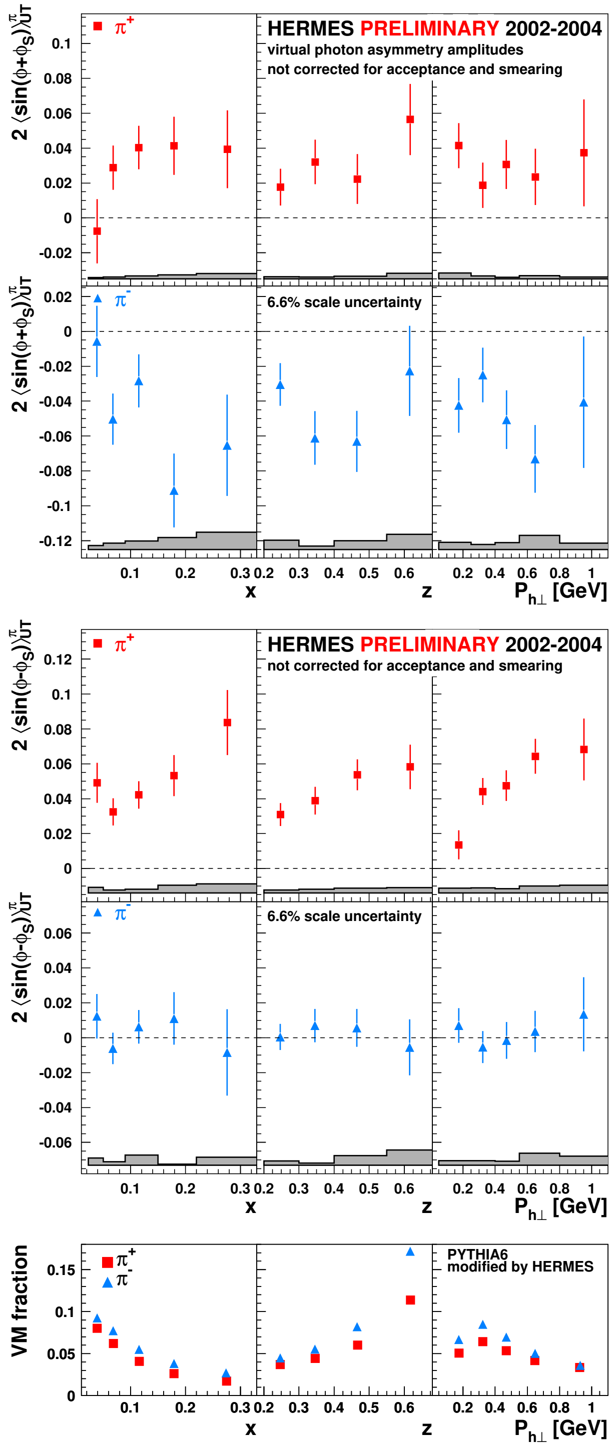

FIGURE 1. Collins moments (upper panel) and Sivers moments (middle panel) for charged pions (as labelled) as a function of x, z and $P_{h\perp}$, multiplied by two to have the possible range ± 1. The error bands represent the maximal systematic uncertainty due to acceptance and detector smearing effects and due to a possible contribution from the $\langle \cos\phi \rangle_{UU}$ moment in the spin-independent cross section. The common overall 6.6% scaling uncertainty is due to the target polarisation uncertainty. The lower panel shows the fraction of charged pions produced in vector meson decay simulated by PHYTHIA6 [12] (tuned for HERMES kinematics).

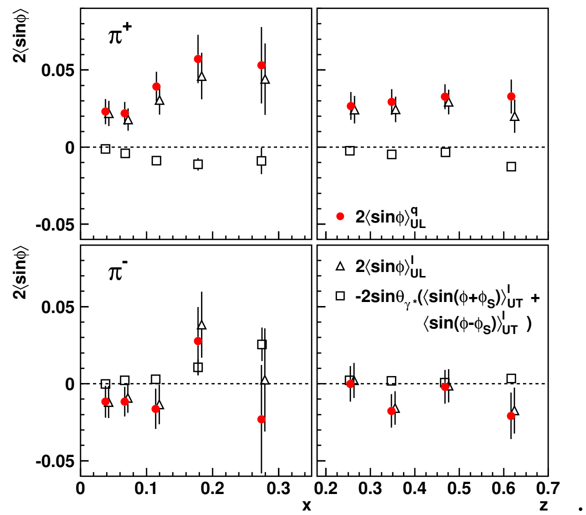

FIGURE 2. The azimuthal moment $\langle\sin\phi\rangle^{q}_{\mathrm{UL}}$ (•, multiplied by two) shows the subleading-twist contribution to the measured asymmetries on a longitudinally polarised hydrogen target for charged pions as a function of x and z. In addition the measured lepton-axis azimuthal moments are plotted (△ and □). There is an overall systematic error of 0.003. The superscript "q" and "l" distinguishes between moments with respect to the photon-axis and lepton-axis taking into account that the measured asymmetries contain contributions from both transverse and longitudinal polarisation components with respect to the virtual photon direction [15].

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