Azimuthal single-spin asymmetries in semi-inclusive deep-inelastic scattering on a transversely polarised hydrogen target

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Abstract. Azimuthal single-spin asymmetries (SSA) in semi-inclusive electroproduction of charged pions and kaons in deep-inelastic scattering of positrons on a transversely polarised hydrogen target were observed. SSA amplitudes for both the Collins and the Sivers mechanism are presented.

Keywords: transversity distribution, azimuthal single-spin asymmetries, Collins mechanism, Sivers mechanism

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In 2005 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 were recorded at a beam energy of 27.6 GeV using a transversely nuclear-polarised hydrogen-target internal to the HERA positron storage ring at DESY. The HERMES dual radiator ring-imaging Čerenkov counter allows full $\pi^\pm$, $K^\pm$, p separation for all selected particle momenta. Therefore, a preliminary analysis of SSA in the electroproduction of charged kaons on a transversely polarised target is also presented.

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 $q(x, Q^2)$, the known helicity distribution $\Delta q(x, Q^2)$ [2] and the unknown *transversity distribution* $\delta q(x, Q^2)$ [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 $P_{h\perp}$ of the hadron produced. 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 $p_{\perp}$ of the quarks within. A non-zero Sivvers 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 about the virtual-photon direction 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 Sivvers 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 :

$$A_{\text{UT}}^{\pi^{\pm}}(\phi, \phi_S) = \frac{1}{|P_z|} \frac{N_{\pi^{\pm}}^{\uparrow(\Downarrow)}(\phi, \phi_S) - N_{\pi^{\pm}}^{\downarrow(\Uparrow)}(\phi, \phi_S)}{N_{\pi^{\pm}}^{\uparrow(\Downarrow)}(\phi, \phi_S) + N_{\pi^{\pm}}^{\downarrow(\Uparrow)}(\phi, \phi_S)}.$$

Here $N_{\pi^{\pm}}^{\uparrow(\Downarrow)}(\phi, \phi_S)$ 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 amplitudes for the Collins mechanism $\langle \sin(\phi + \phi_S) \rangle_{\text{UT}}^{\pi^{\pm}}$ and the Sivvers mechanism $\langle \sin(\phi - \phi_S) \rangle_{\text{UT}}^{\pi^{\pm}}$ 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 least-squares fit for the asymmetry (the kinematic factors $A(\langle y \rangle, \langle R \rangle)$ and $B(\langle y \rangle)$ are defined in [1]):

$$\begin{aligned} A_{\text{UT}}^{\pi^{\pm}}(\phi, \phi_S) = & 2 \langle \sin(\phi + \phi_S) \rangle_{\text{UT}}^{\pi^{\pm}} \frac{B(\langle y \rangle)}{A(\langle y \rangle, \langle R \rangle)} \sin(\phi + \phi_S) + \\ & 2 \langle \sin(\phi - \phi_S) \rangle_{\text{UT}}^{\pi^{\pm}} \sin(\phi - \phi_S) + \\ & 2 \langle \sin(2\phi - \phi_S) \rangle_{\text{UT}}^{\pi^{\pm}} \sin(2\phi - \phi_S) + 2 \langle \sin\phi_S \rangle_{\text{UT}}^{\pi^{\pm}} \sin\phi_S. \end{aligned}$$

In the case of charged pions least squares is a good maximum likelihood estimator. However, in the case of charged kaons because of the limited statistics maximum likelihood fits must be used. Besides the Collins and Sivvers amplitude the likelihood function is also maximised with respect to $\sin(3\phi - \phi_S)$, $\sin(2\phi - \phi_S)$ and $\sin\phi_S$ sine modulations.

In figure 1 the virtual-photon Collins and Sivvers amplitudes as a function of x , z and $P_{h\perp}$ are plotted. The maximum contribution of subleading longitudinal asymmetries to the leading-twist Collins and Sivvers amplitudes in figure 1 is 0.004, which is negligible compared to the statistical uncertainties. In addition the simulated fraction of charged pions originating from diffractive vector meson production and decay is shown, to provide an estimate of the possible contribution from the poorly known asymmetry of this process. The average values of the kinematic variables in the experimental acceptance are $\langle x \rangle = 0.10$, $\langle y \rangle = 0.53$, $\langle Q^2 \rangle = 2.43 \text{ GeV}^2$, $\langle z \rangle = 0.36$, $\langle P_{h\perp} \rangle = 0.40 \text{ GeV}$. These preliminary results are based on nearly five times more statistics than that in the publication [1] and are consistent with the published result:

FIGURE 1. Collins amplitudes (upper panel) and Sivers amplitudes (middle panel) for both charged pions (left column, charge as labelled) and charged kaons (right column, charge as labelled) as a function of x , z and $P_{h\perp}$. The error bands represent the maximal systematic uncertainty due to hadron misidentification, due to acceptance and detector smearing effects and due to a possible contribution from the $\langle \cos\phi \rangle_{UU}$ amplitude 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 (left column) and charged kaons (right column) produced in vector meson decay as simulated by a version of PYTHIA6 [12] tuned for HERMES kinematics.

The average Collins amplitude is positive for π^+ and negative for π^- . Also, the magnitude of the π^- amplitude appears to be comparable or larger than the one for π^+ . One explanation could be a substantial magnitude for the disfavoured Collins fragmentation function with an opposite sign than the favoured Collins fragmentation function. For charged kaons no significant non-zero Collins amplitudes are found. However, the Collins amplitudes for K^+ are consistent to the π^+ amplitudes.

The significantly positive average Sivers amplitudes observed for both π^+ and K^+ imply a non-vanishing orbital angular momentum of the quarks inside the nucleon. For π^- and K^- the averaged Sivers amplitudes are consistent with zero.

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REFERENCES

1. A. Airapetian, et al., *Physical Review Letters*, **94**, 012002 (2005), hep-ex/0408013.
2. A. Airapetian, et al., *Physical Review*, **D71**, 012003 (2005), hep-ex/0407032.
3. J. P. Ralston, and D. E. Soper, *Nuclear Physics*, **B152**, 109 (1979).
4. X. Artru, and M. Mekhfi, *Z. Phys.*, **C45**, 669 (1990).
5. R. L. Jaffe, and X.-D. Ji, *Physical Review Letters*, **67**, 552–555 (1991).
6. J. L. Cortes, B. Pire, and J. P. Ralston, *Z. Phys.*, **C55**, 409–416 (1992).
7. J. C. Collins, *Nuclear Physics*, **B396**, 161–182 (1993), hep-ph/9208213.
8. M. Burkardt, *Physical Review*, **D69**, 057501 (2004), hep-ph/0311013.
9. D. W. Sivers, *Physical Review*, **D41**, 83 (1990).
10. S. J. Brodsky, D. S. Hwang, and I. Schmidt, *Physical Letters*, **B530**, 99–107 (2002), hep-ph/0201296.
11. D. Boer, and P. J. Mulders, *Physical Review*, **D57**, 5780–5786 (1998), hep-ph/9711485.
12. T. Sjöstrand, et al., *Comput. Phys. Commun.*, **135**, 238–259 (2001), hep-ph/0010017.