Azimuthal Asymmetries in Meson Electroproduction at HERMES

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Abstract. The measurement of single-spin azimuthal asymmetries for pseudoscalar meson production in semi-inclusive deep-inelastic scattering of 27.6 GeV electrons off a longitudinally polarised hydrogen and deuterium target is reported by the HERMES experiment. A significant target-spin asymmetry amplitude in the azimuthal distribution of charged and neutral pions and positively charged kaons relative to the lepton scattering plane has been observed. The dependence on the relevant kinematic variables which are the Bjorken variable x, the meson fractional energy z and the meson transverse momentum $P_\perp$ has been investigated as well. The results are compared to predictions of model calculations which are base on a fragmentation function that varies with the transverse polarisation of the struck quark. In addition, data from the measurement of a single beam-spin azimuthal asymmetry in the electroproduction of positive pions in semi-inclusive and semi-exclusive deep-inelastic scattering will be presented.

INTRODUCTION

Polarized deep-inelastic lepton scattering has been the main experimental basis for our understanding of the spin structure of the nucleon for decades. In addition to inclusive and semi-inclusive measurements, recently single-spin azimuthal asymmetries in semi-inclusive scattering have been recognized as a powerful tool to access further information about the spin structure of the nucleon. A complete tree-level analysis of the semi-inclusive deep inelastic scattering (SIDIS) cross section [1] identifies a series of 8 distribution functions of the nucleon at leading twist along with an analogous set of 8 fragmentation functions. Each of these function describes qualitatively different information about the hadronic structure and formation. The functions $f_1(x)$, $g_1(x)$ and $h_1(x)$ have a special property: they are the only distribution functions which survive at leading twist integration over the intrinsic quark transverse momentum. The new leading twist distribution function $h_1(x)$, the so-called transversity or helicity-*flip* distribution, represents the transverse spin distribution of quarks in a nucleon polarized transversely to the virtual photon in the infinite momentum frame [2]. The afromentioned decomposition of the full polarized SIDIS cross section reveals how experiments may access the new distribution and fragmentation functions: by measuring moments of the azimuthal asymmetries in SIDIS.

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TARGET-SPIN AZIMUTHAL ASYMMETRIES

HERMES has measured the azimuthal distribution of charged and neutral pions and of K^+ in the scattering of unpolarized (spin averaged) positrons from longitudinally polarized hydrogen [3] and deuterium targets. The target-spin cross section asymmetry A_{UL} for an unpolarized beam (U) and a longitudinally polarized target (L) was evaluated as

$$A_{\mathrm{UL}}(\phi) = \frac{1}{|P_{\mathrm{L}}|} \cdot \frac{N^{\rightarrow}(\phi)/L^{\rightarrow} - N^{\leftarrow}(\phi)/L^{\leftarrow}}{N^{\rightarrow}(\phi)/L^{\rightarrow} + N^{\leftarrow}(\phi)/L^{\leftarrow}}, \tag{1}$$

were $N^{\rightarrow(\leftarrow)}$ is the number of pions or kaons detected at angle ϕ for the target-spin antiparallel (parallel) to the beam momentum, $L^{\rightarrow(\leftarrow)}$ the respective dead-time corrected luminosities and P_{L} the mean longitudinal target polarization.

Here ϕ is the azimuthal angle of the meson around the virtual photon direction, with respect to the lepton scattering plane. For the hydrogen target, the measured asymmetries show a significant $\sin\phi$ moment in the case of π^+ and π^0 production, while no ϕ-dependence is seen in π^- production. The $\sin 2\phi$ moments of the asymmetries were found to be consistent with zero in all cases. The new data from a deuterium target are shown in Fig. 1, integrated over the experimental acceptance in the kinematic variables x, $P_\perp$, z, y and Q^2. In Fig. 1, fits of the functions $f_1(\phi) = P_0 + P_1 \sin\phi$ and $f_2(\phi) = P_0 + P_1 \sin\phi + P_2 \sin 2\phi$ are shown, where all coefficients P_0 are compatible with zero. The $\sin\phi$ and $\sin 2\phi$ amplitudes P_1 and P_2 represent the analyzing powers $A_{\mathrm{UL}}^{\sin\phi}$ and $A_{\mathrm{UL}}^{\sin 2\phi}$ of the cross section asymmetry. The analyzing powers $A_{\mathrm{UL}}^{\sin\phi}$ have been studied as a function of x, $P_\perp$ and z and are shown in Fig. 2 together with the asymmetries from the proton target. The results for the two different targets show a similar behaviour in their kinematic dependences on x and z, but not $P_\perp$. The monotonic increase of $A_{\mathrm{UL}}^{\sin\phi}$ with
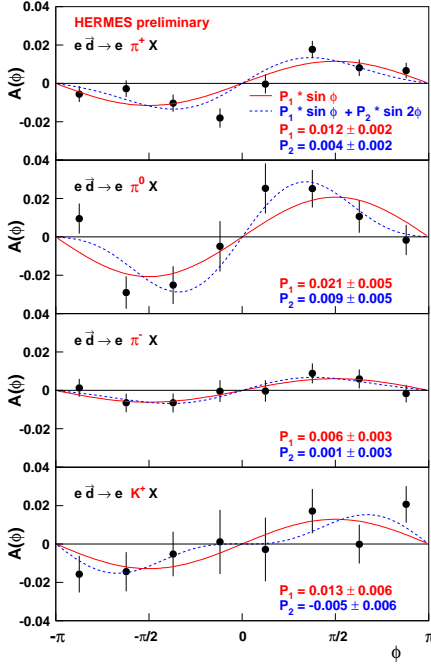
1: Cross section asymmetries $A_{\mathrm{UL}}(\phi)$ for π^+, π^-, π^0 and K^+. The error bars give the statistical uncertainty.

increasing x for all mesons suggests that single-spin asymmetries are associated with valence quark contributions. Two mechanisms have been proposed to explain the measured single-spin asymmetries. One is the combination of chiral-odd transversity-related dis-
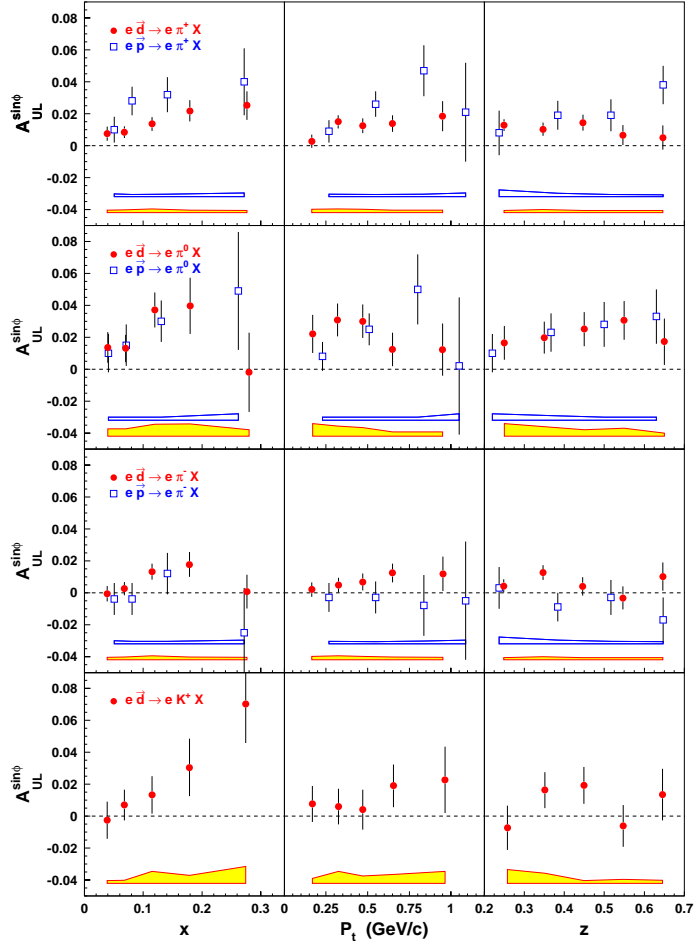
FIGURE 2. $A_{UL}^{\sin\phi}$ for semi-inclusive π^+, π^0, π^- and K^+ production on a deuterium *(filled circles)* and a proton *(open squares)* target as function of x, $P_\perp$ and z. The error bars give the statistical uncertainty, the bands give the systematic uncertainties for the deuteron *(filled band)* and for the proton measurement *(white band)*.

tribution functions and chiral-odd fragmentation functions such as the Collins fragmentation function $H_1^\perp$ [4]. The other one is a final-state interaction of the outgoing meson with the target remnant (Sivers Effect) [5, 6]. No calculations are available for the latter scenario to compare with data. Recent publications [7, 8] have reported transversity-related model calculations of $A_{UL}^{\sin\phi}$ for scattering of positrons off a longitudinally polarized deuterium target within the kinematic range of the HERMES experiment. As an input, the transversity distributions calculated in the chiral quark soliton model (χQSM) [8], in the SU(6) quark spectator diquark model [7] and in a perturbative QCD model [7] have been used.
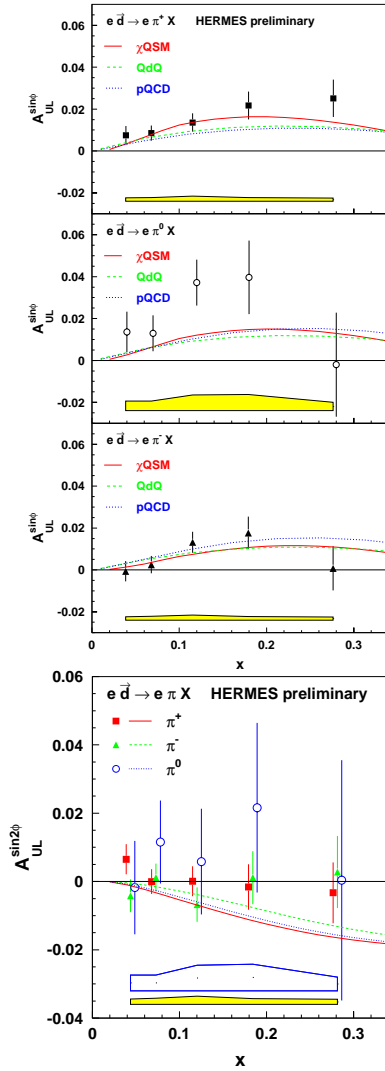
3: Comparison of $A_{UL}^{\sin\phi}$ and $A_{UL}^{\sin2\phi}$ with predictions from model calculations (see text).
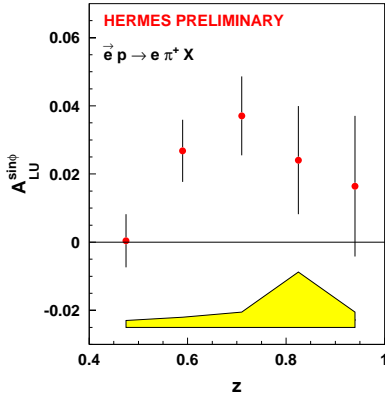
The results of some model calculations for pions are displayed in Fig. 3 together with the experimental data. The model predictions that are shown here describe the data fairly well at least for charged pions. In Fig. 3 also the dependence of $A_{UL}^{\sin2\phi}$ on x is shown. Integrated over the measured x-range, it is compatible with zero for all mesons. Also shown are results from χQSM calculations [8]. According to this model, a deviation of the analyzing power from zero originates from effects of twist-3 distribution functions calculated by Wandzura-Wilczek type relations from the twist-2 transversity distribution function. However, as can be seen from the lower panel of Fig. 3, the data do not follow the prediction of negative analyzing power.

For a more sophisticated interpretation of the data one must consider in detail which terms in the SIDIS cross-section of ref. [1] contribute to the $A_{UL}(\phi)$ asymmetry. In the theoretical decomposition, the longitudinal and transverse components of the target polarization are measured with respect to the virtual photon direction, not to the lepton beam axis. The analyzing power $A_{UL}^{\sin\phi}$ thus contains a mixture of the cross section moments $\langle\sin\phi\rangle_{UL}$ and $\langle\sin\phi\rangle_{UT}$ (theoretical convention). The $\langle\sin\phi\rangle_{UT}$ moment is directly proportional to the product of transversity and Collins fragmentation function. However, the present HERMES measurements are most directly related to $\langle\sin\phi\rangle_{UL}$, which is more complex as it is subleading in Q and contains interaction-dependent twist-3 functions. All theoretical calculations adressing the HERMES measurements of $A_{UL}(\phi)$ agree that $A_{UL}^{\sin\phi}$ is dominated by higher-twist effects due to the longitudinal target polarization.

HERMES begun already measurements with a transversely polarized target. A precise measurement of $A_{UT}(\phi)$, sensitive at leading twist to the product of $h_1(x)$ and $H_1^{\perp}(z)$, will form a cornerstone of the new HERMES Run-II [9] that started in 2002. Moreover, by scattering on a transversely polarized target, it will be possible to distinguish the Collins and Sivers mechanism through their different dependence on the angle ϕ_S between the transverse target polarization vector and the lepton scattering plane.

BEAM-SPIN AZIMUTHAL ASYMMETRIES

At higher twist, in addition to $f_1(x)$, $g_1(x)$ and $h_1(x)$, other distribution functions survive integration over the intrinsic quark transverse momentum in the tree-level analysis of the SIDIS cross section of Ref. [1]. At twist-3 level these additional functions are the chiral-even polarized distribution function $g_T(x)$ and two chiral-odd distribution functions, the polarized one $h_L(x)$ and the unpolarised distribution function $e(x)$. The combination of the latter distribution function and the Collins fragmentation function gives rise to a beam-spin azimuthal asymmetry

$$A_{\text{LU}}(\phi) = \frac{1}{|P_{\text{B}}|} \cdot \frac{N^{\rightarrow}(\phi)/L^{\rightarrow} - N^{\leftarrow}(\phi)/L^{\leftarrow}}{N^{\rightarrow}(\phi)/L^{\rightarrow} + N^{\leftarrow}(\phi)/L^{\leftarrow}}, \qquad (2)$$

4: $A_{\text{LU}}^{\sin\phi}$ for π^+ electroproduction on a proton target.

where now $N^{\rightarrow(\leftarrow)}(\phi)$ is the number of pions at azimuthal angle ϕ for opposite beam helicity states, $L^{\rightarrow(\leftarrow)}$ the respective dead-time corrected luminosities and P_{B} the mean beam polarization. A significant beam-spin azimuthal asymmetry was reported recently by Jefferson Lab's CLAS collaboration [10]. HERMES has measured the analyzing power $A_{\text{LU}}^{\sin\phi}$ for π^+ production from scattering longitudinal polarized positrons from an unpolarized (spin averaged) hydrogen target. The asymmetry shows a significant dependence on z, as displayed in Fig. 4. The beam-spin asymmetry provides a complementary tool to access information about the Collins fragmentation.

REFERENCES

1. P.J. Mulders and R.D. Tangermann, *Nucl. Phys.* B **461**, 197 (1996).
2. For a recent review see V. Barone, A. Drago, and P. G. Ratcliffe, *Phys. Rept.* **359**, 1-168 (2001).
3. A. Airapetian et al., HERMES collaboration, *Phys. Rev. Lett.* **84**, 4047 (2000), *Phys. Rev.* D **64**, 097101 (2001).
4. J. Collins, *Nucl. Phys.* B **396**, 161 (1993).
5. S. Brodsky, D. Hwang and I. Schmidt, *Phys. Lett.* B **530**, 99 (2002).
6. X. Ji and F. Yuan, hep-ph/0206057.
7. B. Ma, I. Schmidt, and J. Yang, hep-ph/0209114, accepted by Phys. Rev. D.
8. A.V. Efremov, K. Goeke, P. Schweitzer, hep-ph/0112166, Eur. Phys. J. C **in press**, (2002).
9. D. Hasch, Contribution to this Symposium.
10. H. Avakian, Contribution to this Symposium.