SINGLE SPIN ASYMMETRIES IN SEMI-INCLUSIVE DIS AT HERMES*

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The new high statistics deuterium data set of HERMES shows significant semi-inclusive single spin asymmetries of identified pions and kaons. The asymmetries observed on the deuterium target differ from those measured on the proton target. The appearance of non-zero single spin asymmetries can be explained in terms of a non-zero transversity distribution combined with a non-zero Collins fragmentation function. However, the detailed interpretation of the data is model dependent as it turns out that the asymmetries are dominated by higher-twist effects. HERMES data that are currently being taken on a transversely polarized target will allow for a model-independent extraction of the transversity distribution.

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1. New structure and fragmentation functions

In 1996, Mulders and Tangerman performed a complete tree-level analysis of the Semi-Inclusive Deep-Inelastic Scattering (SIDIS) cross-section, taking into consideration all measurable spin-degrees of freedom in the initial and final state [1]. Their work identified a series of 8 structure functions of the proton at leading twist, along with an analogous set of 8 fragmentation functions. Each of these functions describes qualitatively different information about 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 on integration over intrinsic quark transverse momentum k_{T}.

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The remaining functions are all implicitly dependent on intrinsic quark transverse momentum, which is necessarily related to the unknown orbital angular momentum of quarks in the nucleon.

The new leading twist transversity function $h_1(x)$ represents the transverse spin distribution of quarks in a proton polarized transversely to the virtual photon. It is not identical to the longitudinal quark distribution in a longitudinally polarized target ($h_1(x) \not\equiv g_1(x)$) due to the fact that boost and rotation operators do not commute.

The Mulders decomposition of the full polarized SIDIS cross-section reveals how experiments may access these new structure and fragmentation functions: by measuring *azimuthal moments* of the measured final-state hadron in polarized SIDIS.

2. The HERMES experiment

The HERMES experiment [2] has been taking data at the HERA accelerator in Hamburg, Germany since 1995. HERMES scatters longitudinally polarized electron and positron beams of 27.6 GeV from polarized gas targets internal to the beam vacuum. Pure atomic H, D, and ^{3}He have been used (as well as a variety of unpolarized nuclear targets). Featuring polarized beams and targets and an open-geometry spectrometer with good particle identification (PID), HERMES is well suited to a study of the spin-dependent azimuthal moments of the SIDIS cross-section. The PID capabilities of the experiment were significantly enhanced in 1998 when the former threshold Čerenkov detector (used to identify pions above a momentum of 4 GeV) was upgraded to a Ring Imaging system (RICH). This new detector provides full separation between charged pions, kaons, and protons over essentially the entire momentum range of the experiment.

In September 2000 HERMES completed its first phase of data taking, on longitudinally-polarized targets. The 1998-2000 period was particularly successful, yielding a very large data set (8 million DIS events) from polarized deuterium. HERMES is now entering its second running phase which will continue until 2006. A cornerstone of this period will be measurements from transversely-polarized targets, with the specific goal of exploring the transversity structure function.

3. HERMES measurements of $A_{\mathrm{UL}}(\phi)$

HERMES has measured the azimuthal distribution of charged [3] and neutral [4] pions in the scattering of "unpolarized" (*i.e.* spin averaged) positrons from a longitudinally polarized hydrogen target. The measured quantity is the following Single-Spin Asymmetry (SSA):

$$A_{\rm UL}(\phi) = \frac{1}{P_{\rm T}} \frac{N^-(\phi) - N^+(\phi)}{N^-(\phi) + N^+(\phi)}\,. \tag{1}$$

Here $P_{\rm T}$ is the target polarization and ϕ is the azimuthal angle of the measured final-state hadron, around the virtual photon direction, and relative to the lepton scattering plane. The symbols N^+ and N^- represent the pion yields in each of the two target spin orientations.

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 also analyzed and found to be consistent with zero in all cases. The mean Q^2 of these measurements is around 1.6 GeV.

At "zeroth-order" in complexity, the moment $A_{\rm UL}^{\sin\phi}$ is related to the product of transversity $h_1(x)$ and the Collins fragmentation function $H_1^{\perp}(z)$. Figure 1 shows the dependence of $A_{\rm UL}^{\sin\phi}$ on the Bjorken scaling variable x, the energy fraction $z \equiv E_h/\nu$ of the pion, and its transverse momentum $p_{\rm T}$ relative to the virtual photon direction. The dependences well match the qualitative predictions of Collins [5] who predicted that the effect should peak in the valence region $x \simeq 0.3$, should rise with $p_{\rm T}$ up to a maximum at some hadronic scale 0.3–0.9 GeV, and should be larger for π^+ than π^- production.

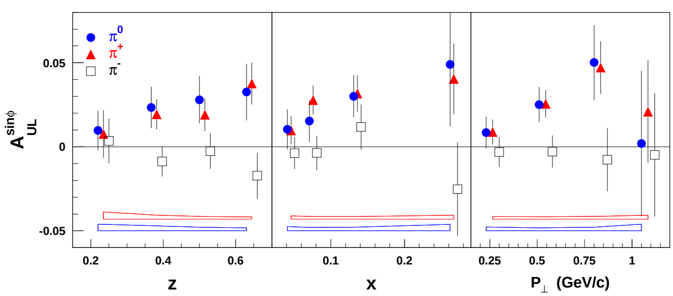

Fig. 1. Kinematic dependences of $A_{\rm UL}^{\sin\phi}$ measured from a hydrogen target.

The reason for this latter expectation can be shown by a simple calculation. It is reasonable to guess that the transverse quark polarization ($\delta q \equiv h_1^q$) is similar to the longitudinal quark polarization ($\Delta q \equiv g_1^q$) in the sense $\delta d/\delta u \approx \Delta d/\Delta u \approx -1/2$. One may also estimate that the favored and disfavored Collins fragmentation functions have a similar ratio as in the unpolarized case ($\eta \equiv D_d^{\pi^+}/D_u^{\pi^+} \approx (1-z)/(1+z) \approx 1/3$), one arrives at these simple estimates:

$$A_p^{\pi^+} \approx \frac{4\,\delta u + \eta\,\delta d}{4\,u + \eta\,d} \approx \frac{\delta u}{u}, \quad A_p^{\pi^0} \approx \frac{4\,\delta u + \,\delta d}{4\,u + d} \lesssim \frac{\delta u}{u}, \quad A_p^{\pi^-} \approx \frac{4\eta\,\delta u + \,\delta d}{4\eta\,u + d} \approx 0\,. \tag{2}$$

The π^+ and π^0 tags enhance the dominance of scattering from u-quarks, making those asymmetries almost entirely proportional to the positive u quark polarization. For π^- production, the favored fragmentation function enhances the contribution from the oppositely polarized d-quarks, leading to a smaller net asymmetry. The expectation that the π^+ and π^0 asymmetries are of similar magnitude is also supported by the data.

3.1. New results on deuterium

HERMES has recently completed an analysis of A_{UL} from the deuterium-target data collected in the years 1998 to 2000. In Fig. 2 preliminary results are presented for the asymmetry moment $A_{\mathrm{UL}}^{\sin\phi}$ for charged pion production. A rough calculation of the type given in Eq. (2) leads to the expectation that $A_{\mathrm{UL}}^{\sin\phi}$ should be roughly the same for π^+ , π^- , and π^0 production from deuterium, and should be about half as large as for π^+ production from hydrogen. These qualitative expectations are indeed borne out by the data. Spin-azimuthal asymmetries for charged kaon production have also been measured for the first time, as shown in the right-hand panel of Fig. 2. Just like the pion moments, the kaon moments are positive and increase with the scaling variable x.

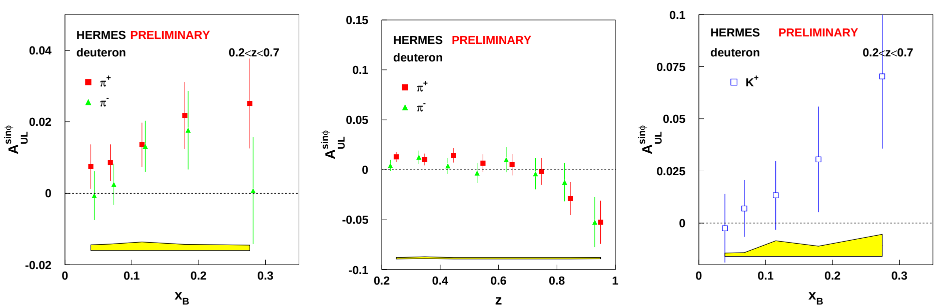

Fig. 2. HERMES preliminary results on the azimuthal asymmetry moment $A_{\mathrm{UL}}^{\sin\phi}$ for charged pion (left panel) and kaon (right panel) production from a deuterium target as function of the Bjorken scaling variable x. The central panel shows the pion moment as a function of the hadron energy fraction z. The strong drop at large z ($z > 0.7$) is related to effects in exclusive pion production.

3.2. Interpretation and future

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 $A_{\mathrm{UL}}(\phi)$ asymmetry. In the theoretical decomposition, the longitudinal and transverse components of the target polarization are measured with respect to the virtual photon direction, not the lepton beam axis. The $A_{\mathrm{UL}}^{\sin\phi}$ analyzing power (subscripts in experimental convention) thus contains a mixture of the cross-section moments $\langle\sin\phi\rangle_{\mathrm{UL}}$ and $\langle\sin\phi\rangle_{\mathrm{UT}}$ (theoretical convention). The $\langle\sin\phi\rangle_{\mathrm{UT}}$ moment is directly proportional to the product of transversity and the Collins function. However the present HEMRES measurement is most directly related to $\langle\sin\phi\rangle_{\mathrm{UL}}$, which is much more complex: it is subleading in Q, and contains the interaction-dependent twist-3 functions $\tilde{h}_L$ and $\tilde{H}$. In addition an as-yet-unknown distribution function $h_{1L}^{\perp}(x)$ makes an appearance.

A variety of theoretical calculations have been performed to address the HERMES measurements of $A_{\mathrm{UL}}(\phi)$ [6–9]. A recently uncovered pair of sign errors in the analyses of the HERMES and DELPHI data [10] modified some of the results. Nevertheless, all calculations agree that $A_{\mathrm{UL}}^{\sin\phi}$ is dominated by higher-twist effects, due to the longitudinal target polarization.

For a better understanding of transversity, the next step is clear: high precision SIDIS data on a transversely-polarized target are required. Accordingly, HERMES has already changed to a transverse-target configuration. A precise measurement of $A_{\mathrm{UT}}(\phi)$, sensitive at leading twist to the product of $h_1(x)$ and $H_1^{\perp}(z)$, will form a cornerstone of new HERMES runs that started in 2002.

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