Longitudinal semi-inclusive double-spin asymmetries at HERMES

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DOI: `http://dx.doi.org/10.3204/DESY-PROC-2012-02/117`

Final results are reported on the semi-inclusive double-spin asymmetries A_{LL} for charged hadrons and identified charged pions and kaons measured at HERMES longitudinally polarized hydrogen and deuterium targets and the longitudinally polarized 27.6 GeV HERA lepton beam. The kinematic dependences of the azimuthal $cos\phi$ moments of A_{LL} simultaneously on Bjorken-x, the hadron energy fraction z and hadron transverse momentum $p_{h\perp}$ are explored. The x, z and $p_{h\perp}$ dependencies of $A_{LL}^{cos\phi}$ asymmetry were found to be small, no dependence on the kinematic variables was observed.

1 Introduction

Longitudinal double-spin asymmetries in polarized deep inelastic scattering (DIS) have since many years provided a window to study the spin-structure of the nucleon by HERMES [1] and other experimental collaborations. At fixed beam energy, the inclusive virtual-photon nucleon asymmetry A_1 is defined in terms of the photoabsorption cross section in the two possible virtual-photon-nucleon spin configurations and is a function of only two kinematic variables:

$$A_1(x, Q^2) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}(x, Q^2) \ , \qquad (1)$$

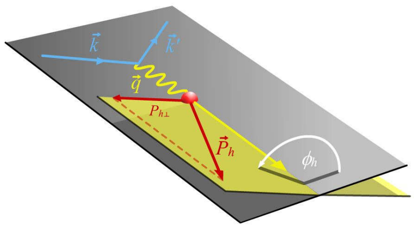

Figure 1: $p_{h\perp}$ and $\phi = \phi_h$ defined for SIDIS

where x is the Bjorken scaling variable and -Q^2 is the squared four-momentum transfer of the virtual photon Q^2. In leading order QCD, one can express this asymmetry as the ration of the charge-weighted sums of polarization-dependent to polarization-independent quark densities:

$$A_1(x, Q^2) \sim \frac{\sum_q \Delta q(x, Q^2)}{\sum_q e_q^2 q(x, Q^2)} \ . \qquad (2)$$

In semi-inclusive DIS (SIDIS), the measurement of a final state hadron in conjunction with the scattered lepton provides additional information about the flavor-dependence of the parton structure and about the fragmentation process through which these hadrons are produced. The presence of the hadron provides us with three additional possible kinematic degrees of freedom, for which we will use z, the fraction of the virtual photon's momentum carried by the hadron, $p_{h\perp}$, the transverse momentum of the hadron with respect to the virtual photon direction, and ϕ, the azimuthal angle between the hadron production plane and the lepton sattering plane, depicted in Fig. 1.

The semi-inclusive asymmetry, A_1^h can then be expressed

$$A_1^h(x, Q^2, z_h, p_{h\perp}, \phi) = \frac{\sigma_{1/2}^h - \sigma_{3/2}^h}{\sigma_{1/2}^h + \sigma_{3/2}^h}(x, Q^2, z_h, p_{h\perp}, \phi) \ , \tag{3}$$

where h represent the hadron observed.

The decision to present the kinematic dependences is motivated be several factors. First, the additional kinematic dimensions contain information that could be used to extract information otherwise unavailable when semi-inclusive parameters, sensitive specifically to the fragmentation process, are integrated over. For example, the two sources of transverse momentum, the parton distribution related intrinsic $k_\perp$ and fragmentation related $p_\perp$ combine to make the $p_{h\perp}$ dependence of the asymmetry. A multidimensional dataset potentially provides additional leverage for disentangling these individual contributions as x for example resides exclusively in the parton densities and z in the fragmentation function. It is also increasingly clear that empirical results should be made available with as few model assumptions and model-related kinematic requirements as are reasonable in order to accommodate the broadest possible range of theoretical models and assumptions. Finally, the growing interest in unintegrated cross sections reminds us that providing fuller kinematic dependence only may simplity theoretical interpretation.

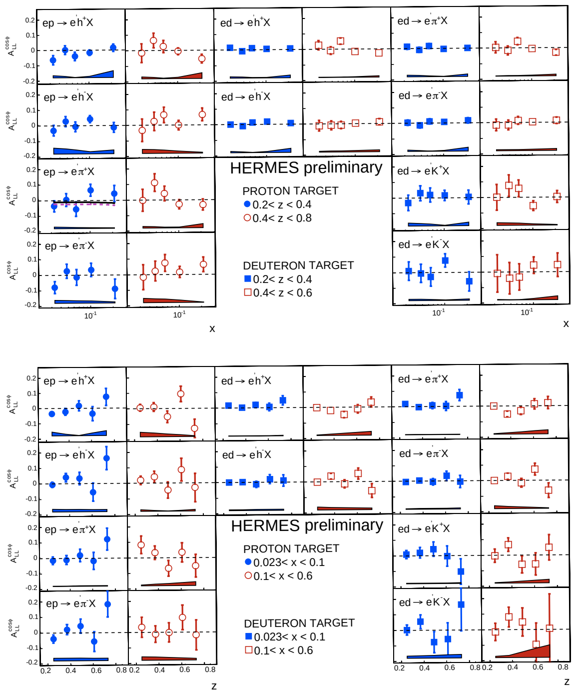

Figure 2: The asymmetries $A_{p,d}^{\cos\phi}$ as a function of x (top) in two z slices and z in two x slices (bottom) for positively and negatively charged hadrons, pions and kaons.

2 Measurement of asymmetries

The data presented here were collected using the HERMES spectrometer [2] at the HERA storage ring during the years 1996-2000. A longitudinally polarized lepton (electron or positron) beam was scattered off a longitudinally polarized hydrogen (H) or deuterium (D) gas target.

The polarization of the target was flipped approximately every 60(90) seconds foe H(D) to provide yields in both spin states and to reduce systematic uncertainties related to the stability of the experimental setup. The asymmetries are computed using the same procedure presented in prior papers on longitudinally polarized SIDIS asymmetries [3]. The Born lepton-nucleon asymmetry is constructed as follows:

$$A_{||}^{B} = \frac{C_{\phi_h}}{f_D}\Big[\frac{L^{\overset{\rightarrow}{\Rightarrow}} N^{\overset{\rightarrow}{\Leftarrow}}_{(h)} - L^{\overset{\rightarrow}{\Leftarrow}} N^{\overset{\rightarrow}{\Rightarrow}}_{(h)}}{L_P^{\overset{\rightarrow}{\Rightarrow}} N^{\overset{\rightarrow}{\Leftarrow}}_{(h)} + L_P^{\overset{\rightarrow}{\Leftarrow}} N^{\overset{\rightarrow}{\Rightarrow}}_{(h)}}\Big]_B \ , \tag{4}$$

where $N^{\overset{\rightarrow}{\Leftarrow}}_{(h)}$ represent yields (hadron h tagged for SIDIS samples) containing events which meet the kinematic requirements and $L^{\overset{\rightarrow}{\Rightarrow}(\overset{\rightarrow}{\Leftarrow})}$ and $L_P^{\overset{\rightarrow}{\Rightarrow}(\overset{\rightarrow}{\Leftarrow})}$ represent the luminosity and the polarization weighted luminosity in the parallel (antiparallel) beam-target helicity configuration. The square brackets, $[]_B$, indicate that the experimental asymmetry is corrected to Born level, i.e. unfolded for radiative and detector smearing, using Born and smeared Monte Carlo simulations according to the essentially model-independent procedure described in [3]. The factor f_D represents the dilution of the polarization the nucleon with respect to that of deuterium the nucleus.

The factor C_ϕ is a correction applied to the semi-inclusive asymmetries that compensates for the influence of the spectrometer acceptance in the implicit integration over kinematic variables in the semi-inclusive yields. It is primarily the azimuthal integral (over ϕ), which combines a non-uniform acceptance with azimuthal modulations in the unpolarized yield which are contained in the denominator of the semi-incusive asymmetries. Such modulations are produced, for example, by the Cahn Effect [4]. In practice, the measured asymmetry that we measure, $\tilde{\mathrm{A}}$, involves a convolution with an acceptance function $\xi(\phi)$:

$$\tilde{A}_1^h(x, Q^2, z, p_{h\perp}) = \frac{\int d\phi \Delta\sigma^h(x, Q^2, z, p_{h\perp}, \phi)\xi(\phi)}{\int d\phi \sigma^h(x, Q^2, z, p_{h\perp}, \phi)\xi(\phi)}. \tag{5}$$

The ϕ modulation of the SIDIS cross section can be decomposed into $\cos(\phi)$ and $\cos(2\phi)$ moments as follows:

$$\begin{aligned} \frac{d\sigma}{dx\ dQ^2\ dz\ dp_{h\perp}\ d\phi} \quad &\propto \quad \sigma_{UU}(x, Q^2, z, p_{h\perp}) + \\ &+\ \sigma_{UU}^{\cos(\phi)}(x, Q^2, z, p_{h\perp})\ \cos(\phi) + \sigma_{UU}^{\cos(2\phi)}(x, Q^2, z, p_{h\perp})\ \cos(2\phi) + \\ &+ P_B\ P_T\Big[\sigma_{LL}(x, Q^2, z, p_{h\perp}) + \\ &+\ \sigma_{LL}^{\cos(\phi)}(x, Q^2, z, p_{h\perp})\ \cos(\phi) + \sigma_{LL}^{\cos(2\phi)}(x, Q^2, z, p_{h\perp})\ \cos(2\phi)\Big]. \end{aligned} \tag{6}$$

The subscript UU of the first three coefficient functions denotes unpolarized beam and unpolarized target, whilethe subscript LL denotes longitudinally polarized beam and longitudinally polarized target. P_b and P_t represent the longitudinal polarizations of beam and target – which are zero in the unpolarized case.

In order to correct for this effect in the unpolarized denominator of the asymmetry, a recent parameterization of the azimuthal modulation measured by HERMES [5] was used. This parameterization was produced by unfolding unpolarized semi-inclusive yields in all five kinematic degrees of freedom simultaneously. The unfolding was conducted in 5000 $(5x \times 4y \times 5z \times 5p_{h\perp} \times 12\phi)$ bins, correcting the unpolarized yields to 4π and avoiding any integration over the detector acceptance.

The unpolarized correction factor C_ϕ is formed by taking the ratio of two Monte Carlo asymmetries, A_1^h, where one contains no azimuthal cross-section dependence and the other is computed in acceptance and weighted event-by-event by the parameterized azimuthal modulation to reproduce the effect with the non-uniform azimuthal acceptance.

3 Result

Also the polarization-dependent numerator of the asymmetry is also subject to possible azimuthal modulations, i.e. the ϕ dependence σ_{LL} of Equation (5) , that can enter the cross section at subleading-twist [5]. Sizeble subleading twist effects have in fact been observed in the asymmetries A_{UL} [7], which accentuates the need to proceed with some caution. As statistics are limited in the longitudinally double-spin dataset for a complete five-parameter kinematic unfolding, a full parameterization of polarization dependent modulations is currently not possible, preventing a correction similar to that described for the unpolarized azimuthal acceptance. In order to address this, $A_{||}$ was unfolded simultaneously in $x-z$, $x-p_{h\perp}$, $z-x$ and ϕ and the $A_{LL}^{cos\phi}$ moments were found to be small. These moments are shown in Fig. 2 as a function of x in two z slices (top panel) and as a function of z in two x slices (bottom panel) and in Fig. 3 as a function of $p_{h\perp}$ in two x slices for charged hadrons and identified charged pions and kaons. No statistically significant dependence on the kinematic variables has been observed

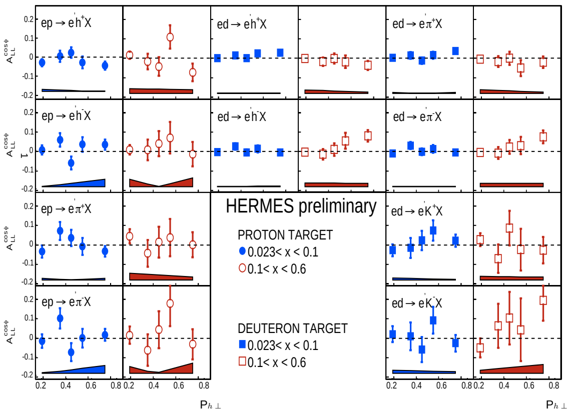

Figure 3: The asymmetries $A_{p,d}^{\cos\phi}$ as a function of $p_{h\perp}$ in two x slices for positively and negatively charged hadrons, pions and kaons.

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