Overview of recent HERMES results

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Abstract. The HERMES experiment has collected a wealth of data using the 27.6 GeV polarized HERA lepton beam and various polarized and unpolarized gaseous targets. This allows for a series of unique measurements of observables sensitive to the multidimensional (spin) structure of the nucleon, in particular semi-inclusive deep-inelastic scattering (SIDIS) measurements.

In this contribution, transverse single-spin asymmetry, longitudinal single- and double-spin asymmetries in SIDIS will be presented. The azimuthally uniform double-spin asymmetries using longitudinally polarized nucleons constrain the flavour dependence of the quark-spin contribution to the nucleon spin. For a first time, such asymmetries are explored differential in three dimensions in Bjorken-x and the in the hadron kinematics z and $P_{h\perp}$ (which respectively represent the energy fraction and transverse momentum of the final-state hadron) simultaneously. This approach increases the quark-flavour sensitivity and allows to probe the transverse-momentum dependence of the helicity distribution. The measurement of hadron charge-difference asymmetries allows, under certain simplifying assumptions, the direct extraction of valence quark polarisations.

The azimuthal modulation of this double-spin as well as of the single-(beam)spin asymmetry probe novel quark-gluon-quark correlations through twist-3 distribution and fragmentation functions. Also here, asymmetries are explored in several dimensions. Furthermore, in case of the beam-spin asymmetry, results for electro-produced protons and antiprotons have become available. The beam-spin asymmetries for pions are compared to similar measurements for pions at CLAS and unidentified hadrons at COMPASS.

1. Introduction

The HERMES experiment at DESY collected data from 1995 until 2007 using the 27.6 GeV longitudinally polarized electron or positron beams of the HERA storage ring. In the analysis of data presented here, polarized leptons were scattered off transversely, longitudinally or unpolarized hydrogen targets, and longitudinally or unpolarized deuterium target. The scattered lepton and particles produced in the reaction were detected by a forward spectrometer. The lepton-hadron separation was performed using a transition-radiation detector, a scintillator preshower counter, an electromagnetic calorimeter and a threshold gas Cherenkov counter (dual-radiator ring-imaging Cherenkov detector from 1998, which provided final-hadron identification between 2 GeV to 15 GeV for pions, kaons, and (anti)protons).

The analysis of the azimuthal distribution of hadrons in semi-inclusive deep-inelastic scattering (DIS) of leptons off a transversely polarized hydrogen target provides access to the Sivers distribution [1] and Collins fragmentation [2] functions. The former describes the distribution of unpolarized quarks in a transversely polarized nucleon, correlating quark transverse momentum with the nucleon's transverse spin, while the latter describes the fragmentation of a transversely polarized quark into an unpolarized hadron. The selected results sensitive to these two quantities are presented in section 2. The results from the recent analysis of amplitudes of the single-spin asymmetry in semi-inclusive DIS leptoproduction of hadrons in case of collision of a longitudinally polarized lepton beam with an unpolarized target are also presented in that section.

Data collected on longitudinally polarized hydrogen and deuterium targets are used to extract the amplitudes of the double-spin asymmetry for charged pions and kaons in semi-inclusive DIS of longitudinally polarized electrons and positrons. The results are presented in section 3. The dependence of the asymmetries on hadron transverse momentum and azimuthal angle extends the sensitivity to the flavor structure of the nucleon beyond the distribution functions accessible in the collinear framework. The measurement of the hadron charge-difference asymmetry, which under certain model assumptions provides access to the helicity distributions of valence quarks, is presented in the same section.

2. Single-spin asymmetries measured in semi-inclusive DIS

Semi-inclusive DIS off a transversely polarized target (T) allows to access the single-spin asymmetry amplitudes with characteristic angular modulations. Two angles appear in the description of the cross section of this process: angle ϕ, defined as the angle between the lepton-scattering and the hadron-production planes, and ϕ_S, being the azimuthal angle of the transverse component of the target-spin vector about the virtual photon direction with respect to the lepton scattering plane. Each of the azimuthal amplitudes corresponds to convolutions of different distribution and fragmentation functions. Two of them, proportional to the $\sin(\phi - \phi_S)$ and $\sin(\phi+\phi_S)$ modulations respectively, are interpreted as the convolutions of the Sivers distribution function [1] and the spin-independent fragmentation function and transversity and the Collins fragmentation function [2]. The HERMES results on the Sivers and Collins amplitudes for charged and neutral pions and for charged kaons as a function of x, z and $P_{h\perp}$ were published in Ref. [3] and Ref. [4], respectively. Here, x represents the Bjorken scaling variable, z denotes the fractional hadron energy with respect to the virtual photon energy in the target rest frame, and $P_{h\perp}$ the magnitude of the transverse momentum of the final-state hadron.

Moreover, the finely binned three-dimensional (x, z, $P_{h\perp}$) extraction of various azimuthal amplitudes for charged pions, kaons and protons is possible from HERMES data. This allows to constrain global fits to the experimental measurements in a more profound way. As an example, the HERMES preliminary results of the Collins amplitudes for negative pions vs. x extracted for four $P_{h\perp}$ and z bins are presented in figure 1, showing an increase of the amplitudes with x at large $P_{h\perp}$, and the Sivers amplitudes for positive kaons vs. $P_{h\perp}$ for four z and x bins are presented in figure 2. Note that the values of Sivers amplitudes are larger for positive kaons than for π^+ (not shown here). The three-dimensional extraction of all possible single-spin asymmetry amplitudes sensitive to different combination of distribution and fragmentation functions are also available (not shown here).

In case of longitudinal beam (L) and unpolarized target (U) only target spin-independent parts can contribute to the asymmetry. Here, the structure function of interest is related to the asymmetry amplitude $A_{LU}^{\sin\phi}$, which is sensitive to convolutions of twist-2 distribution (fragmentation) functions with twist-3 fragmentation (distribution) functions. HERMES extracted the single-spin asymmetry amplitude $A_{LU}^{\sin\phi}$ for charged pions and kaons, as well as for (anti-)protons from data on unpolarized hydrogen and deuterium targets [5]. The usage of these two targets is interesting, because it offers different sensitivity to the valence-quark flavors. This measurement supersedes the former HERMES analysis for charged pions [6].

In figure 3 the HERMES results on the x, z, and $P_{h\perp}$ dependences of the virtual-photon asymmetry amplitudes $A_{LU}^{Q,\sin\phi}$ extracted from data on unpolarized protons for π^+ and π^- mesons are compared with those obtained by the CLAS Collaboration at Jefferson Lab [7]. The

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different behavior of asymmetry amplitudes for the two data sets observed for negative pions in z projection is probably due to the sensitivity of the Collins $e(x)$ term to different x-range probed in these experiments. In figure 4 the HERMES results of the virtual-photon asymmetry amplitudes extracted from unpolarized deuteron data for charged pions are compared to similar results for muoproduction of charged hadrons in SIDIS from a ^{6}LiD target obtained by COMPASS at CERN [8]. For the isoscaler targets a consistent behavior is observed.

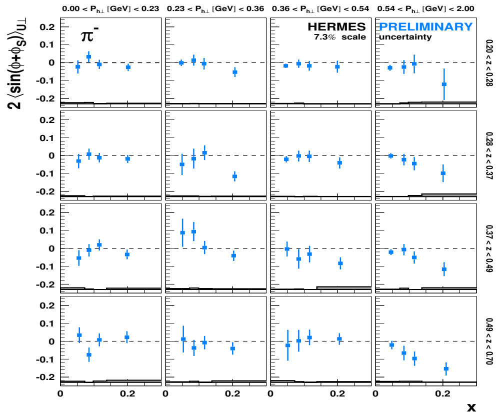

Figure 1. Preliminary HERMES results of Collins amplitudes for π^- vs. x for four bins in $P_{h\perp}$ and z.

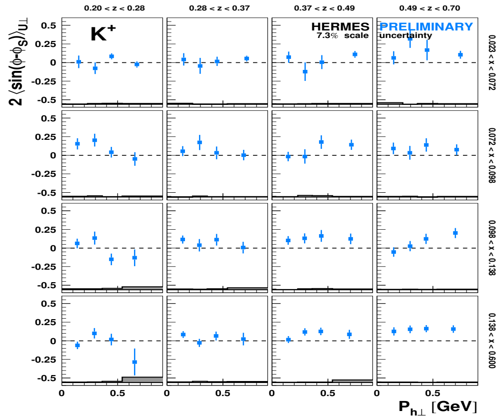

Figure 2. Preliminary HERMES results of Sivers amplitudes for K^+ vs. $P_{h\perp}$ for four bins in z and x.

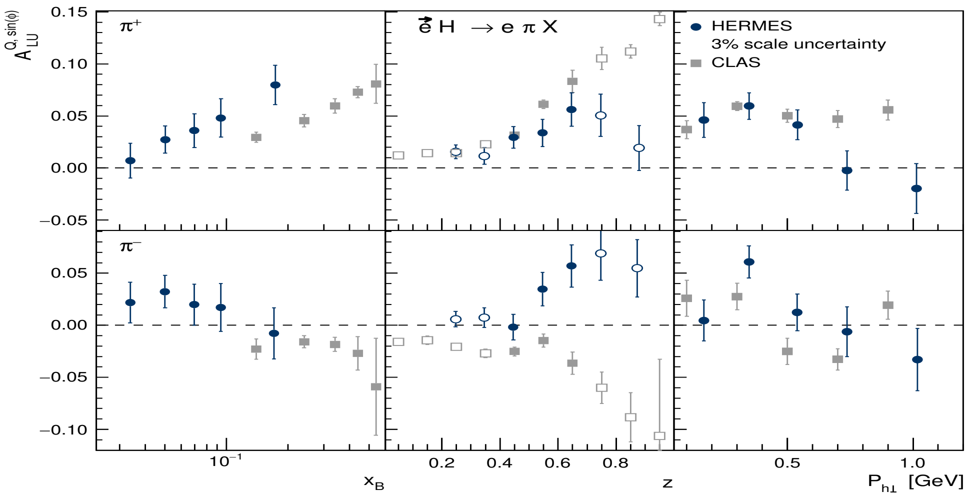

Figure 3. HERMES results [5] of virtual-photon asymmetry amplitudes $A_{LU}^{Q,\sin\phi}$ extracted from data on unpolarized protons for π^+ and π^- mesons compared to those from CLAS [7].

3. Longitudinal double-spin asymmetries measured in semi-inclusive DIS

HERMES published new results of longitudinal double-spin asymmetries A_{LL} for charged pions and kaons produced in semi-inclusive DIS of electrons and positrons on hydrogen and deuterium

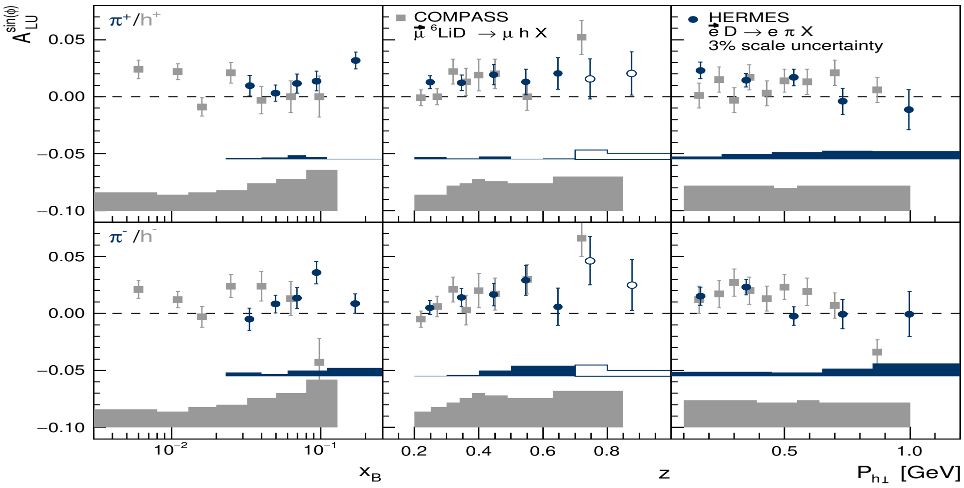

Figure 4. HERMES results [5] of virtual-photon asymmetry amplitudes $A_{LU}^{\sin\phi}$ extracted from data on unpolarized deuterons for π^+ and π^- mesons compared to those from COMPASS [8].

targets, based on the full HERMES data set [9]. Although the analysis has much in common with those in prior HERMES publications (see, e.g., Refs. [10, 11]), several changes were made, which increase statistical precision and reduce the systematic uncertainties.

The resulting x dependence of the asymmetries $A_{||,N}^h$ is presented for hydrogen and deuterium targets in figure 5. The asymmetries extracted were found to be essentially identical to those in prior HERMES analyses [10].

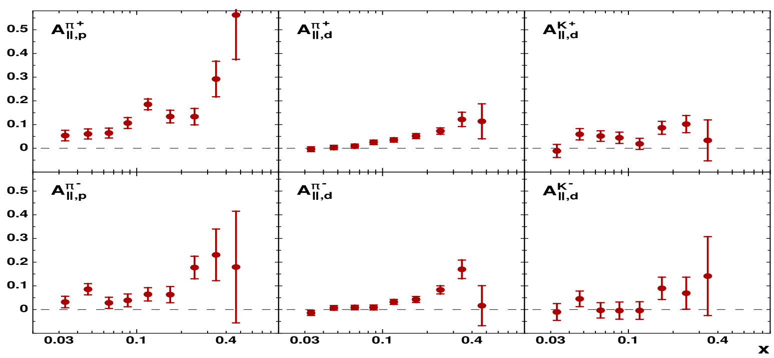

Figure 5. The longitudinal double-spin asymmetries $A_{||,N}^h$ as a function of x with $N = p, d$ denoting the target nucleus and $h = \pi^+, K^+$ the final-state hadron detected [9].

In the framework of two-dimensional analysis, the z-dependence of longitudinal double-spin asymmetries for the three x slices is shown in figure 6, while the $P_{h\perp}$-dependence in figure 7. No strong dependence on z or $P_{h\perp}$ is visible, in agreement with results by the COMPASS collaboration for charged-hadron production from longitudinally polarized deuterons [12, 13] and weak dependences reported by the CLAS collaboration [14]. Furthermore, for the first time $A_{||,N}^h$ has been analyzed binned in three kinematic variables simultaneously allowing a more detailed

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analysis of the correlations between quark-flavor dependences of the helicity distribution and the fragmentation process beyond the collinear framework.

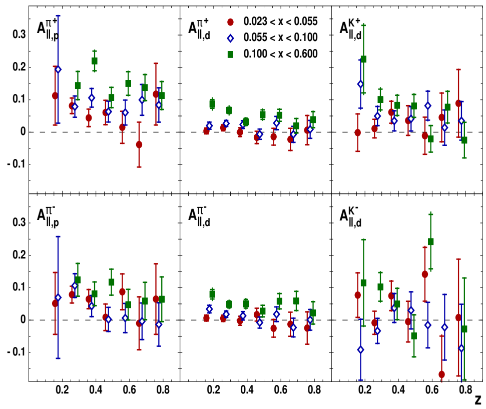

Figure 6. The longitudinal double-spin asymmetries $A^h_{||,N}$ as a function of z in three different x ranges [9].

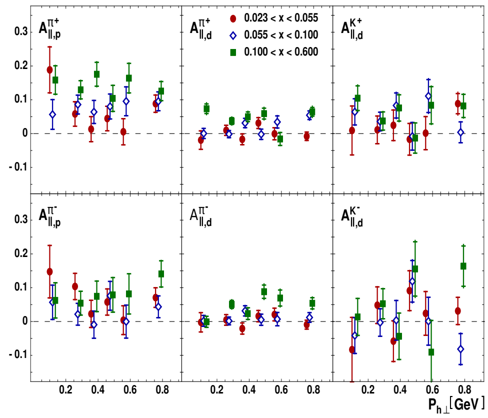

Figure 7. The longitudinal double-spin asymmetries $A^h_{||,N}$ as a function of $P_{h\perp}$ in three different x ranges [9].

Azimuthal moments of $A^h_{||,N}$ are potentially sensitive to unique combinations of distribution and fragmentation functions. In figure 8 the $P_{h\perp}$ projections of the $\cos\phi$ moments for charged pions for both hydrogen and deuterium targets, as well as for charged kaons in case of a deuterium target are presented. The $\cos\phi$ moments, as well as the $\cos 2\phi$ moments not shown here, are found to be consistent with zero. A vanishing $\cos 2\phi$ asymmetry can be expected because in the one-photon-exchange approximation there is no $A^{h\cos 2\phi}_{LL}$ contribution to the cross section.

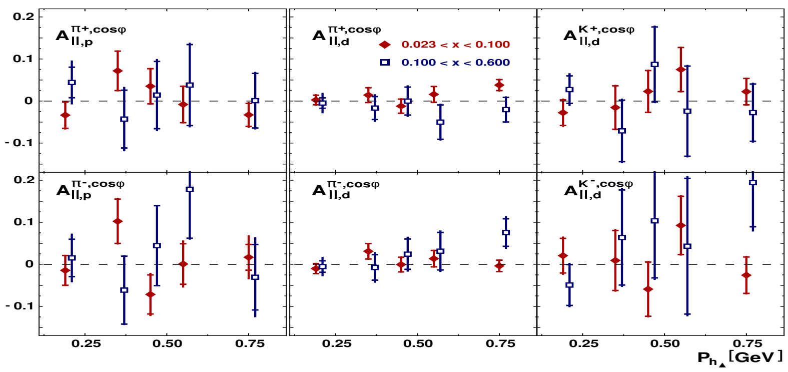

Figure 8. $A^{h\cos\phi}_{||}(P_{h\perp})$ in two x ranges for charged pions (and kaons) from protons (deuterons).

The hadron charge-difference asymmetry $A^{h^+-h^-}_1$ provides complementary spin-structure information. The difference asymmetries for pions from the hydrogen target and pions, kaons, and undifferentiated hadrons from the deuterium target are shown in figure 9, together with results from COMPASS for unidentified hadrons from a ^{6}LiD target [15]. As a result of the larger difference between yields of charged kaons (despite the smaller sample size) compared to that of the charged pions the uncertainties for the kaon asymmetry are considerably smaller than those on the pion asymmetry. Under the assumption of leading-order, leading-twist QCD, and charge-conjugation symmetry of the fragmentation functions, the asymmetry $A_1^{h^+-h^-}$ on the deuterium target corresponds to a certain combination of parton distribution [16]. Assuming in addition isospin symmetry in fragmentation, one can deduce the helicity distributions of valence quarks from the charge-difference asymmetries. Valence-quark helicity densities from this analysis are presented in figure 10 alongside the same quantities computed from the previous HERMES purity extraction [10]. Finally, the consistency of results from both methods, and the lack of dependence on hadron type for the charge-difference asymmetries suggest that there is no significant deviation from the factorization hypothesis.

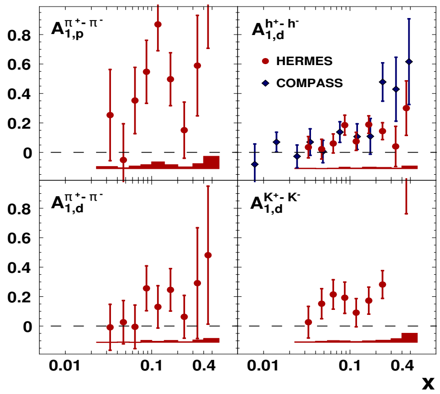

Figure 9. Hadron charge-difference asymmetries for pions from the hydrogen target and pions, kaons, and all hadrons from the deuterium target.

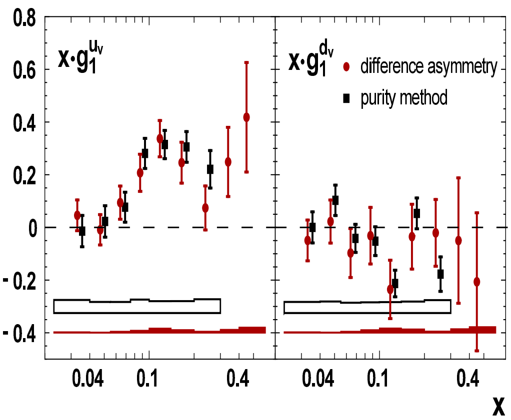

Figure 10. Helicity distributions for valence quarks computed using pion charge-difference asymmetries.

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