Proc. 24th International Spin Symposium (SPIN2021)
JPS Conf. Proc. **37**, 020106 (2022)
https://doi.org/10.7566/JPSCP.37.020106

Overview of HERMES results on longitudinal spin asymmetries

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(Received January 13, 2022)

The HERMES experiment 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, for which the HERMES dual-radiator ring-imaging Cherenkov counter provided final-hadron identification between 2 GeV to 15 GeV for pions, kaons, and (anti)protons.
In this contribution, longitudinal single- and double-spin asymmetries in SIDIS will be presented. The azimuthally uniform double-spin asymmetries using longitudinally polarized nucleons constrain the flavor 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 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-flavor 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 polarizations. 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 scattered off longitudinally or unpolarized hydrogen targets, and longitudinally or unpolarized deuterium targets. 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).

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 2. The dependence of the asymmetries on hadron transverse momentum and azimuthal

angle extends the sensitivity to the flavour 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 also presented in this section.

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 presented in section 3.

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

HERMES published the results of longitudinal double-spin asymmetries for charged pions and kaons produced in semi-inclusive DIS of electrons and positrons on hydrogen and deuterium targets, based on the full HERMES data set [1]. Although the analysis has much in common with those in prior HERMES publications (see, e.g., Refs. [2,3]), several changes are made, which increase statistical precision and reduce the systematic uncertainties.

In a typical experimental situation with the target-polarization orientation along the lepton beam direction, the asymmetry $A^h_{||,N}$ is computed from event yields in different beam- and target-polarization configurations using the procedure presented, e.g., in Refs [2,3]. The resulting x dependence of the asymmetries $A^h_{||,N}$ is presented for hydrogen and deuterium targets in figure 1. The asymmetries extracted were found to be essentially identical to those in prior HERMES analyses [2].

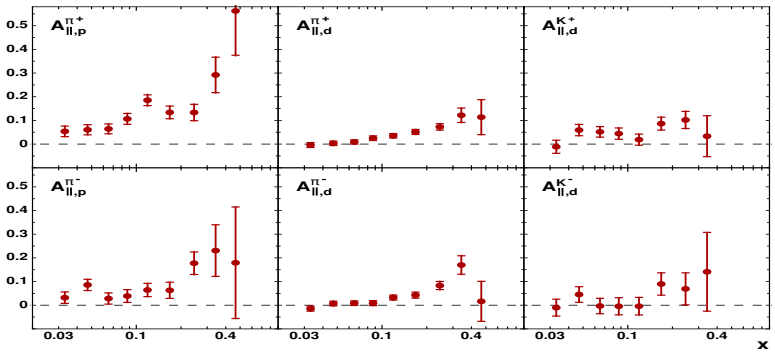

Fig. 1. The longitudinal double-spin asymmetries $A^h_{||,N}$ as a function of x with $N = p, d$ denoting the target nucleus and $h = \pi^+, K^+$ the final-state hadron detected.

In the framework of the two-dimensional analysis, the z-dependence of longitudinal double-spin asymmetries for the three x slices is shown in figure 2, while the $P_{h\perp}$-dependence in figure 3. 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 [4,5] and weak dependences reported by the CLAS collaboration [6].

Azimuthal moments of asymmetries $A^h_{||,N}$ are potentially sensitive to unique combinations of distribution and fragmentation functions. In figure 4 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 $\cos 2\phi$ asym-

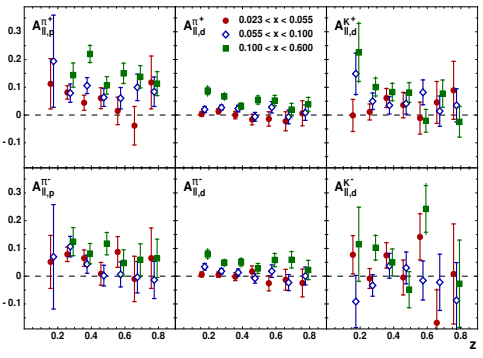

Fig. 2. The longitudinal double-spin asymmetries $A^h_{||,N}$ as a function of z in three different x ranges.

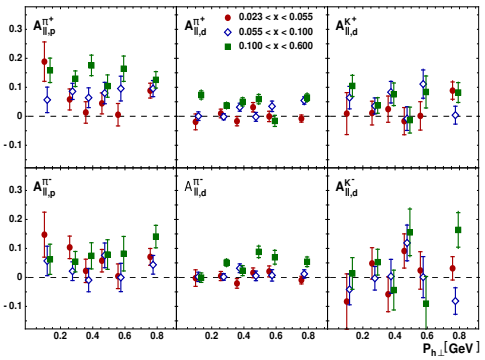

Fig. 3. The longitudinal double-spin asymmetries $A^h_{||,N}$ as a function of $P_{h\perp}$ in three different x ranges.

metry can be expected because in the one-photon-exchange approximation there is no such contribution to the cross section.

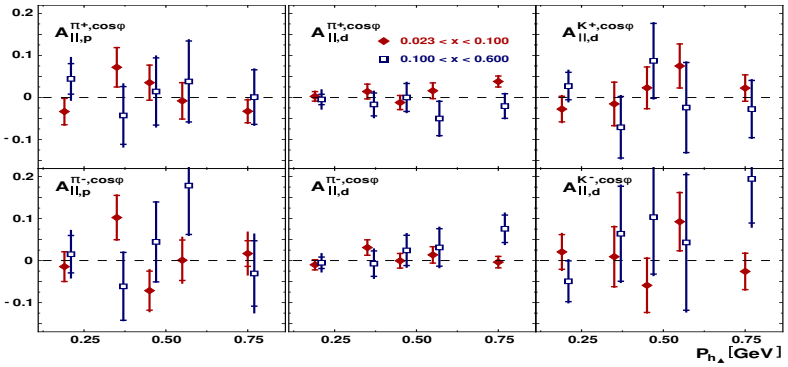

Fig. 4. $A^{h\cos\phi}_{||}(P_{h\perp})$ in two x ranges for charged pions (and kaons) from protons (deuterons).

The hadron charge-difference asymmetry $A_1^{h^+-h^-}$ provides additional spin-structure information, where the asymmetry A_1^h is defined in the virtual-photon-nucleon system and related to the asymmetry $A^h_{||,N}$ by kinematic factors (e.g., degree of polarization transfer), and corrections for target-polarization components transverse to the virtual photon as detailed in Ref. [1]. The difference asymmetries for pions from the hydrogen target and pions, kaons, and undifferentiated hadrons from the deuterium target are shown in figure 5, together with results from the COMPASS Collaboration for unidentified hadrons from a ^{6}LiD target [7]. 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 [8]. 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 6 alongside

the same quantities computed from the previous HERMES purity extraction [2]. 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 leading-twist factorization hypothesis.

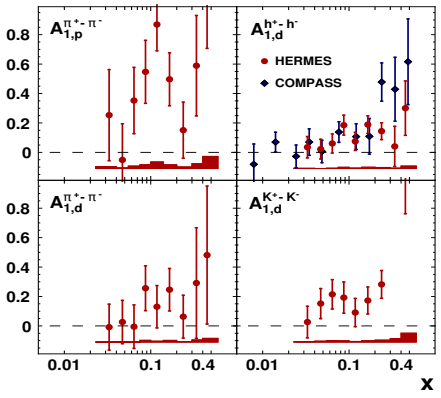

Fig. 5. Hadron charge-difference asymmetries for pions from the hydrogen target and pions, kaons, and all hadrons from the deuterium target.

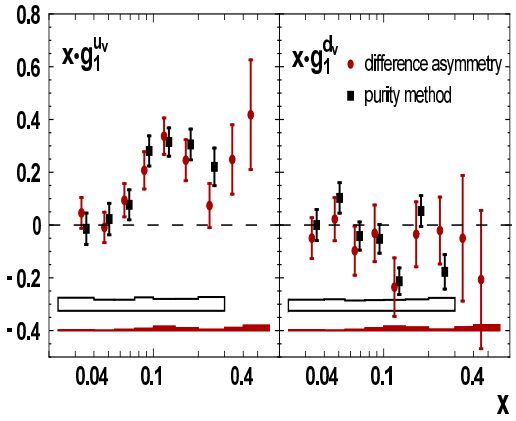

Fig. 6. Helicity distributions for valence quarks computed using pion charge-difference asymmetries.

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

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. In Ref. [9], HERMES extracted the single-spin asymmetry amplitude $A_{LU}^{\sin\phi}$ for charged pions, kaons as well as (anti-)protons from data on unpolarized hydrogen and deuterium targets. The usage of these two targets and final-state hadrons is interesting, because it offers different sensitivity to the valence-quark flavors. This measurement supersedes the former HERMES analysis for charged pions based on a smaller data sample [10].

In figure 7 the HERMES results on the x, z and $P_{h\perp}$ dependences of the asymmetry amplitudes $A_{LU}^{Q,\sin\phi}$ are extracted from the same data set of events on unpolarized protons for π^+ and π^- mesons, but scaled by the photon virtuality Q for a more direct comparison with similarly defined asymmetries obtained by the CLAS Collaboration at Jefferson Lab [10]. The 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 8 the HERMES results of the beam-helicity asymmetry amplitudes extracted from unpolarized deuteron data for charged pions are compared with similar results for muon production of charged hadrons in SIDIS from a ^{6}LiD target obtained by the COMPASS Collaboration at CERN [12]. For the isoscaler targets a consistent behavior is observed.

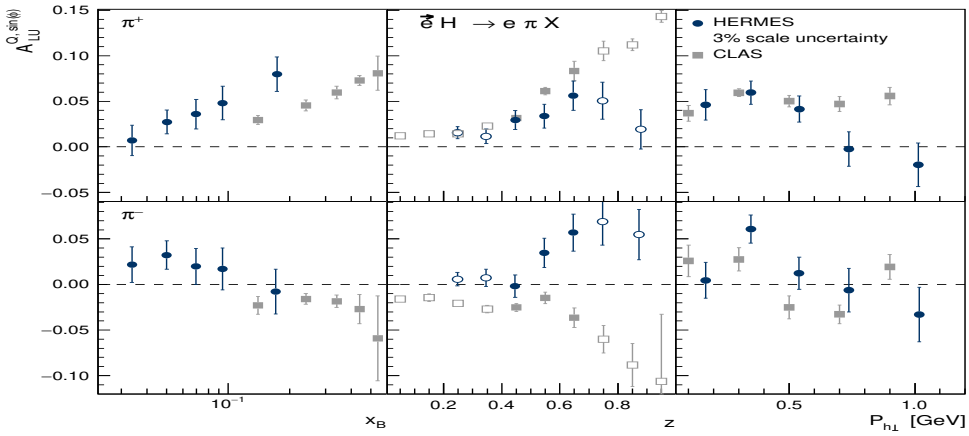

Fig. 7. The HERMES results of the scaled beam-helicity asymmetry amplitudes, $A_{LU}^{Q,\sin\phi}$, extracted from data on unpolarized protons for π^+ and π^- mesons compared with those from CLAS [10].

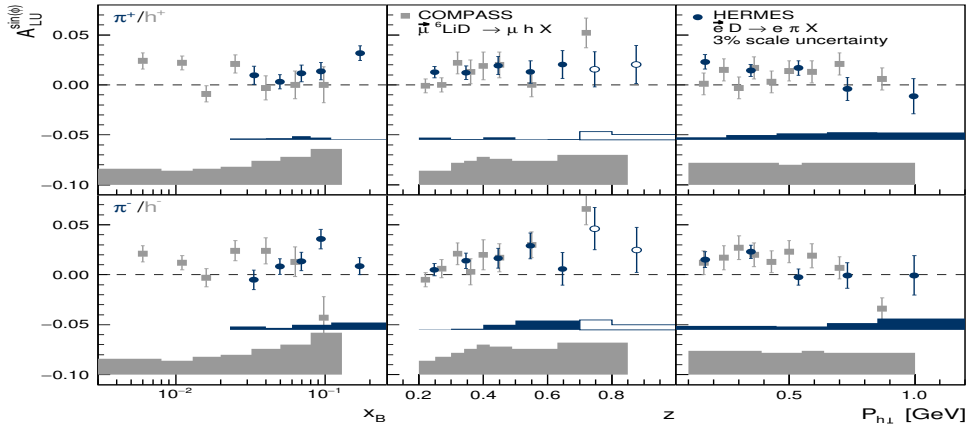

Fig. 8. The HERMES results of the beam-helicity asymmetry amplitudes, $A_{LU}^{\sin\phi}$, extracted from data on unpolarized deuterons for π^+ and π^- mesons compared with those from COMPASS [11].

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