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Overview of recent HERMES results

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Abstract. An overview of more recent and important results from the HERMES experiment is presented in this paper. HERMES 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 structure of the nucleon. Amongst them are the semi-inclusive deep-inelastic scattering measurements of azimuthal modulations sensitive to the leading-twist transverse momentum distributions and the distributions sensitive to convolutions of the twist-2 and twist-3 distribution and fragmentation functions. They all provide information on the three-momentum-dependent quark distributions. Knowledge about the quark distribution as a function of longitudinal momentum and transverse position in impact-parameter space can be accessed, e.g., through exclusive vector−meson leptoproduction. Particularly, the measurement of spin-density-matrix elements on an unpolarized hydrogen target and the measurement of azimuthal modulations on transversely polarized hydrogen target for the ω−meson production are described in this paper. The results of the measurement of ratios of helicity amplitudes for the ρ^0−meson leptoproduction on transversely polarized hydrogen target are also presented.

1. Introduction

The HERMES experiment at DESY collected the data from 1995 until 2007 using the 27.6 GeV HERA electron or positron beams. In the analysis of data presented here, longitudinally polarized leptons were scattered off longitudinally, transversely or an unpolarized hydrogen targets, and 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 (ring-imaging Cherenkov detector from 1998). Hadron identification was performed by Cherenkov detectors, allowing the discrimination of pions, kaons and 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 this section.

Data collected on longitudinally and transversely polarized hydrogen targets are used to extract the Spin-Density-Matrix Elements (SDMEs) and the amplitudes of the single-spin asymmetry of the cross section respectively in hard exclusive leptoproduction of $\omega-$ mesons. They provide information on the sign of $\pi\omega$ transition form factor. The measurement of amplitudes of azimuthal sine modulations is presented in section 3.

The results from the analysis of the ratios of helicity amplitudes in hard exclusive leptoproduction of ρ^0- mesons on transversely polarized hydrogen target are summarized in section 4.

2. Single- and double-spin asymmetries measured in semi-inclusive DIS off an unpolarized and transversely polarized hydrogen target

Semi-inclusive DIS off a transversely polarized target (T) allows to access the single- and double-spin asymmetry amplitudes with characteristic angular modulations. Two angles appear in the description of the cross section of this process: angle ϕ (below also denoted by $\sin\phi_h$), 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 fine 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- and double-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 $A_{LU}^{\sin\phi_h}$, which is sensitive to convolutions of twist-2 distribution (fragmentation) functions with twist-3 fragmentation (distribution) functions. HERMES published the results of the single-spin asymmetry A_{LU} for charged and neutral pions as a function of x, z and $P_{h\perp}$ [5]. The HERMES preliminary results of the asymmetry amplitudes $A_{LU}^{\sin\phi_h}$ extracted from data on unpolarized hydrogen and deuterium targets for charged pions and kaons are shown in figure 3 as a function of x, z and $P_{h\perp}$. In order to present a direct relation to the corresponding structure functions the asymmetry amplitudes $A_{LU}^{\sin\phi_h}$ are plotted taking into account the ratio of longitudinal and transverse photon flux ϵ. As an example, the multidimensional extraction of these asymmetry amplitudes for positive pions in projections of x, z and $P_{h\perp}$ in four bins for each of the kinematic variables are shown in figure 4.

In figure 5 the HERMES preliminary results on the x, z and $P_{h\perp}$ dependencies of the asymmetry amplitudes $A_{LU}^{\sin\phi}$ extracted from data on unpolarized protons for π^+ and π^- mesons are compared with those obtained by the CLAS Collaboration at Jefferson Lab [6]. 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 6 the HERMES preliminary results of the 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 ^6LiD target obtained by COMPASS Collaboration at CERN [7]. For the isoscaler targets a consistent behavior is observed.

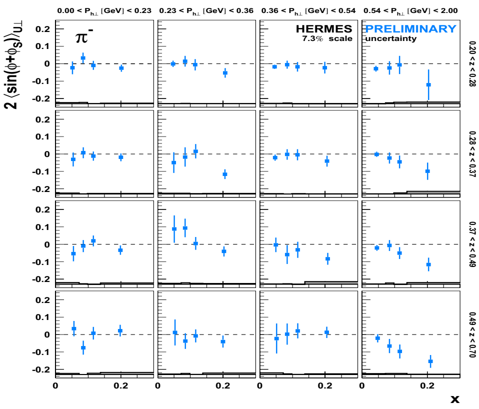

Figure 1. The HERMES preliminary results of Collins amplitudes for π^- vs. x for four bins in $P_{h\perp}$ and z.

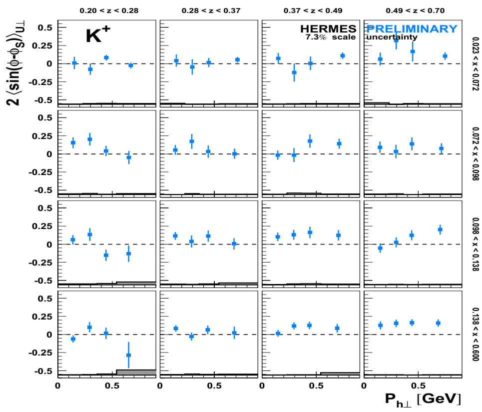

Figure 2. The HERMES preliminary results of Sivers amplitudes for K^+ vs. $P_{h\perp}$ for four bins in z and x.

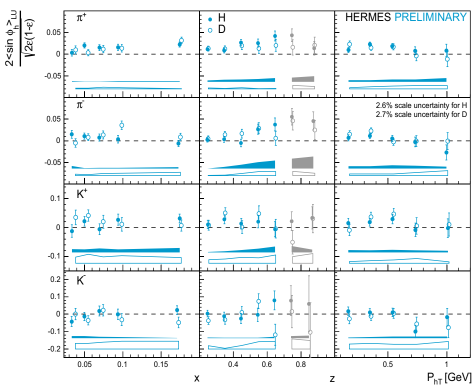

Figure 3. The HERMES preliminary results of $A_{LU}^{\sin\phi_h}$ amplitudes for charged pions and kaons extracted from data on unpolarized hydrogen (H) and deuterium (D) targets.

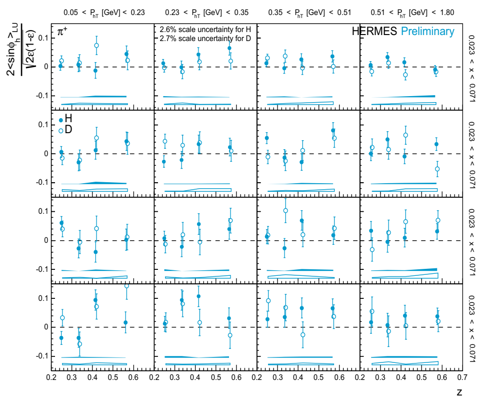

Figure 4. The HERMES preliminary results of the multidimensional extraction of $A_{LU}^{\sin\phi_h}$ amplitudes for π^+ mesons from data on unpolarized hydrogen (H) and deuterium (D) targets.

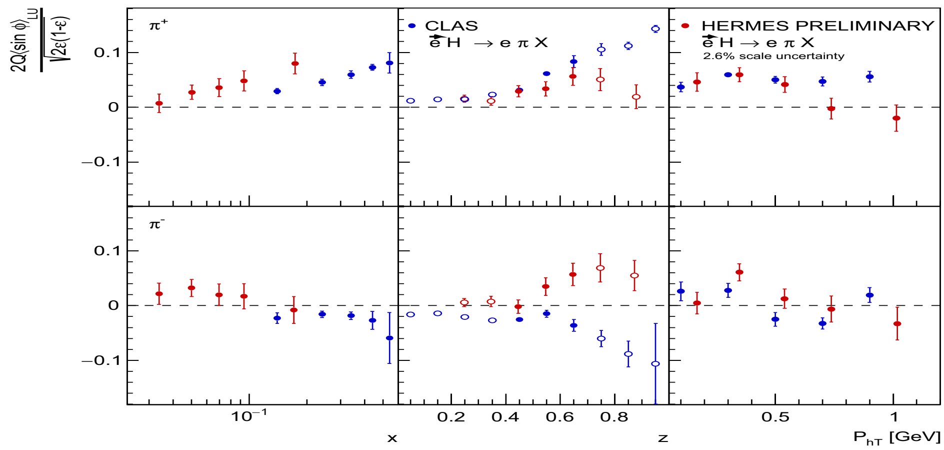

Figure 5. The HERMES preliminary results of $A_{LU}^{\sin\phi}$ amplitudes extracted from data on unpolarized protons for π^+ and π^- mesons compared with those from CLAS [6].

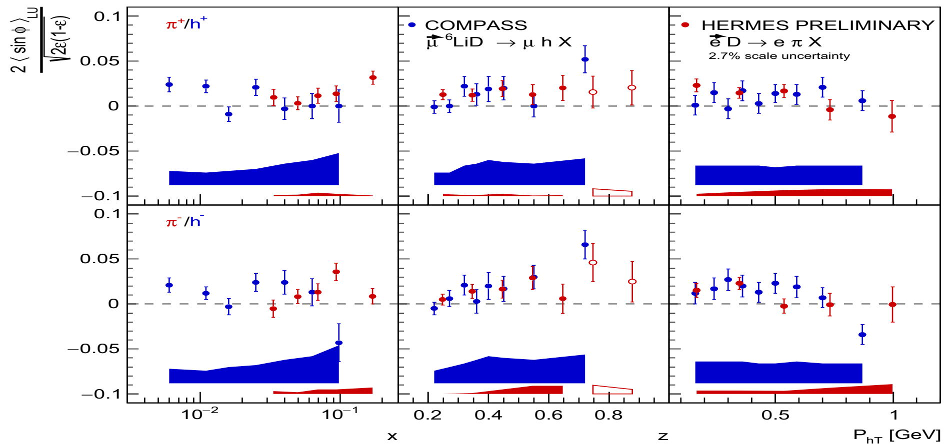

Figure 6. The HERMES preliminary results of $A_{LU}^{\sin\phi}$ amplitudes extracted from data on unpolarized deuterons for π^+ and π^- mesons compared with those from COMPASS [7].

3. Exclusive $\omega-$meson leptoproduction

Hard exclusive leptoproduction of $\omega-$mesons has been studied with the HERMES spectrometer by scattering longitudinally polarized positron and electron beams on unpolarized hydrogen and deuterium targets or on transversely polarized hydrogen target in the kinematic region $Q^2 > 1.0\,\mathrm{GeV}^2, 3.0\,\mathrm{GeV} < \mathrm{W} < 6.3\,\mathrm{GeV}, \mathrm{and} -\mathrm{t}' < 0.2\,\mathrm{GeV}^2$. Here, Q^2 represents the negative square of the virtual-photon four-momentum, W is the invariant mass of the photon-nucleon system and $-t'$ is the smallest kinematically allowed value of the momentum transfer to the target. Using an unbinned maximum likelihood method, 15 unpolarized and 8 polarized SDMEs are extracted from unpolarized hydrogen and deuterium data [8]. From the analysis of transversely polarized hydrogen data the amplitudes of five sine modulations of the single-spin asymmetry of the cross section with respect to the transverse proton polarization are measured [9], the Q^2 and $-t'$ dependence of which are shown in figure 7. They are determined in the entire kinematic region (open squares) as well as for two bins in photon virtuality and momentum transfer to the nucleon (full circles). The inner error bars represent the statistical uncertainties, while the outer ones indicate the statistical and systematic uncertainties added in quadrature. The results receive an additional 8.2% scale uncertainty corresponding to the target-polarization uncertainty. These results are compared to a phenomenological model that includes the pion pole contribution [10]. As can be seen the data favor, within this model, a positive $\pi\omega$ transition form factor (red curves), the sign of which was not possible to determine from the measurements of SDMEs. Also, a separation of asymmetry amplitudes into longitudinal and transverse components is performed (not shown here).

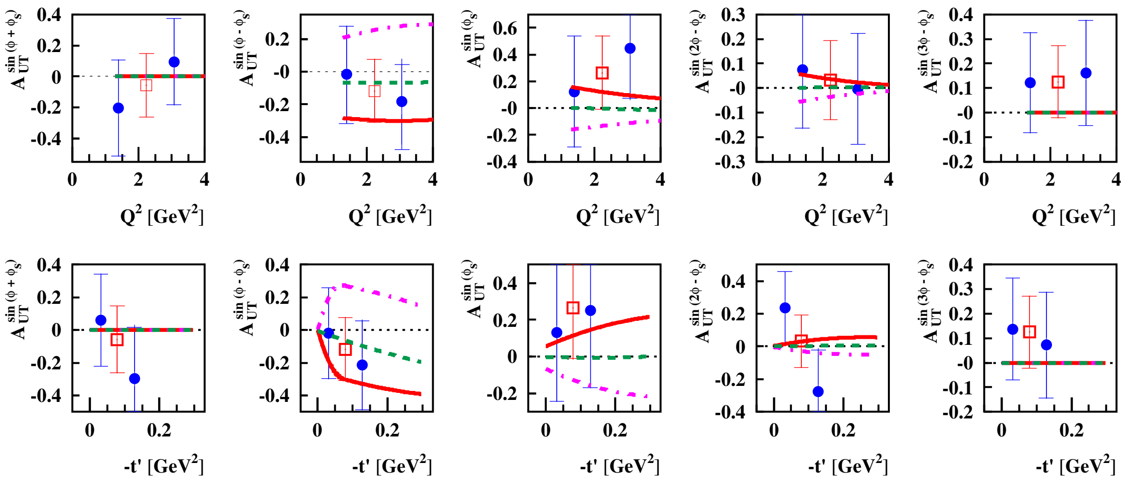

Figure 7. The amplitudes describing the strength of the sine modulations of the cross section for hard exclusive $\omega-$meson leptoproduction.

4. Ratios of the helicity amplitudes in exclusive ρ^0-meson leptoproduction

Hard exclusive leptoproduction of ρ^0-mesons has been studied by the HERMES experiment in scattering longitudinally polarized positron and electron beams on unpolarized, longitudinally or transversely polarized hydrogen targets [11-14]. The results of the analysis of SDMEs on unpolarized and transversely polarized hydrogen target were published in Ref. [11] and Ref. [12], respectively. The results of the ρ^0 helicity amplitudes extracted from transversely polarized hydrogen data were published first in Ref. [13] and updated in Ref. [14]. In the latter case, the ρ^0-mesons were detected by the HERMES spectrometer in the kinematic region of $1.0\,\mathrm{GeV}^2 < \mathrm{Q}^2 < 7.0\,\mathrm{GeV}^2, 3.0\,\mathrm{GeV} < \mathrm{W} < 6.3\,\mathrm{GeV}, \mathrm{and} -\mathrm{t}' < 0.4\,\mathrm{GeV}^2$. Using an unbinned maximum-likelihood fit method 25 parameters are extracted, which determine the real and imaginary parts of the ratios of several helicity amplitudes. (The denominator of these ratios is the dominant nucleon-helicity-non-flip amplitude $F_{0\frac{1}{2}0\frac{1}{2}}$).

The results of the ρ^0 helicity amplitude ratios obtained from the 25-parameter fit is presented in figure 8. Also the results from a previous analysis [12] are plotted in the figure. Furthermore, 71 ρ^0 SDMEs are determined from the 25 parameters (see Figs. 4-6 of Ref [14]), compared to the 53 elements directly determined in earlier analyses [11-13].

All amplitude ratios are compared with those from the phenomenological model that takes into account the contribution from pion exchange [10], and they are found to be in good agreement for most of the helicity amplitude ratios with a few exception (see Fig. 6. of Ref [14]). Within the model, the data favor a positive sign for the $\pi - \rho$ transition form factor.

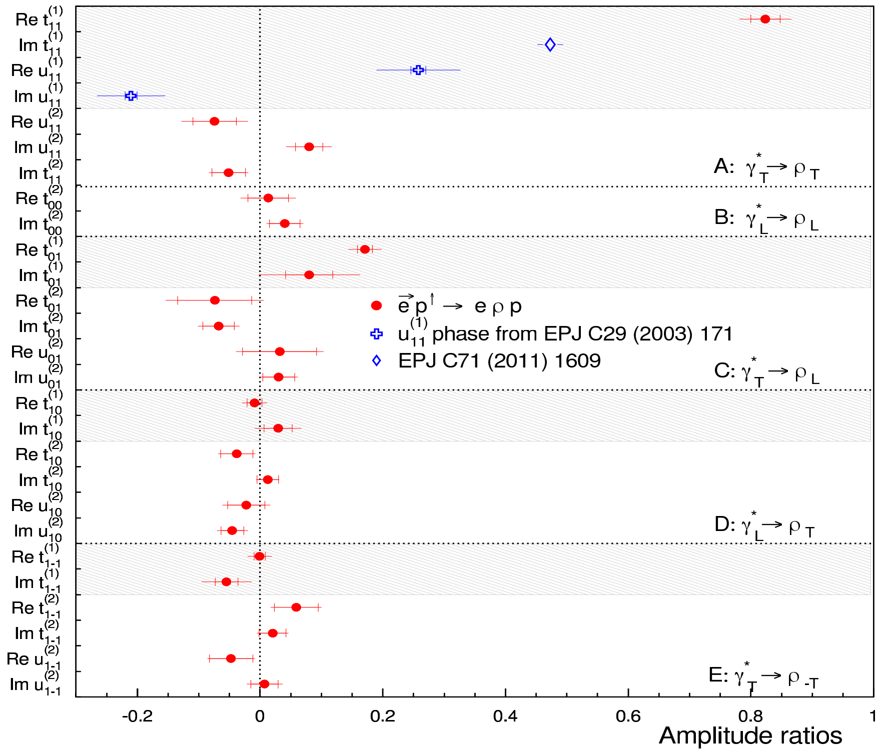

Figure 8. The summary plot of ratios of the helicity amplitudes for hard exclusive ρ^0−meson leptoproduction measured at HERMES [14].

Acknowledgments

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