SINGLE SPIN AZIMUTHAL ASYMMETRIES

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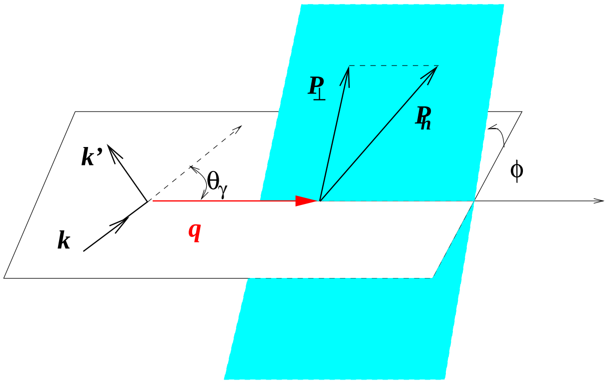
Single spin azimuthal asymmetries for pion electroproduction in deep inelastic scattering using a *longitudinally* polarised hydrogen target have been observed in the HERMES experiment. For semi-inclusive pion production a significant target spin asymmetry of the distribution in the azimuthal angle ϕ has been measured for π^+. The corresponding analysing power in the $\sin\phi$ moment of the cross section is of the order of 2 %. First and preliminary results for exclusive pion electroproduction have been presented. Significant large single spin azimuthal asymmetries in the exclusive channel have been observed for π^+ and π^0. In case of π^+ the sign of the asymmetry is opposite to the asymmetry measured in semi-inclusive pion production.

1 Introduction

The leading twist description of the nucleon involves three types of parton distribution functions, the unpolarised distribution function f_1, the longitudinal spin distribution function g_1 and the still unmeasured transverse spin distribution function h_1. At higher twist level other parton distribution functions appear [1]. The transversity function h_1 belongs to the class of chiral-odd structure functions and is therefore not observable in inclusive deep inelastic scattering experiments. To access this distribution function it must be combined with some other chiral-odd structure. Such a measurement is possible for example in polarised proton proton scattering or in semi-inclusive lepton hadron scattering where only the lepton *or* the target hadron is polarised. In the latter case the chiral-odd structure is found in the quark to a hadron fragmentation process (the Collins fragmentation function). An observable single spin dependence is predicted [2] to appear in the dependence of the cross section for pion electroproduction on the angle between the spin axis of a *transversely* polarised target and the plane defined by the virtual photon momentum and the momentum of the pion (the Collins angle). In the case of semi-inclusive pion production from a *longitudinally* polarised nucleon the Collins angle is the azimuthal angle ϕ of the pion around the virtual photon direction, with respect to the lepton scattering plane (see Fig. 1). Recent theoretical studies [1,3] have shown how each chiral-odd spin distribution function coupled with the chiral-odd fragmentation function gives rise to a specific single spin dependent moment of the pion yield distribution in ϕ.
Large single spin azimuthal asymmetries for a *transverse* polarisation of the target nucleon have been predicted [4,5] to occur in exclusive electroproduction of pseudoscalar mesons. The recently developed formalism of skewed parton distribution functions (SPD) made the treatment of hard exclusive electroproduction of mesons in the framework of pertubative QCD possible. In 1997 the factorisation theorem for this process was proven [6].

2 Semi-inclusive pion production and single spin azimuthal asymmetries

The kinematics of the process are illustrated in Fig. 1, where the scaling variables are defined. Here k and k' are the 4-momenta and E and E' the laboratory energies of the incoming and outgoing leptons. P and $P_{\rm h}$ are the 4-momenta of the target proton and the produced hadron, q is the 4-momentum transfer with $q^2 = -Q^2$, and $W^2 = 2M\nu + M^2 - Q^2$ is the invariant mass of the photon-proton system. E_π is the pion laboratory energy and M the proton mass. The transverse momentum $P_\perp$ of the pion is defined with respect to the virtual photon direction.



$$
\begin{aligned}
\nu &= \frac{P\cdot q}{M} &\overset{\text{lab}}{=}& \; E - E' \\
x &= \frac{Q^2}{2P\cdot q} &\overset{\text{lab}}{=}& \; \frac{Q^2}{2M\nu} \\
y &= \frac{P\cdot q}{P\cdot k} &\overset{\text{lab}}{=}& \; \frac{E-E'}{E} \\
z &= \frac{P\cdot P_{\rm h}}{P\cdot q} &\overset{\text{lab}}{=}& \; \frac{E_\pi}{\nu}
\end{aligned}
$$

Figure 1: Kinematics for pion electroproduction in the deep inelastic scattering process $e\,N \to e'\,\pi\,X$.

The data were recorded during the 1996 and 1997 running periods of the HERMES experiment using a nuclear polarised hydrogen internal gas target in the 27.6 GeV HERA polarised positron storage ring at DESY. The respective polarisations were 0.86 ± 0.04 and 0.55 ± 0.02. The spectrometers particle identification capabilities [7] provides charged pion identification in the energy range 4.5 GeV $< E_\pi <$ 14.0 GeV. A cut on the transverse pion momentum $P_\perp > 50$ GeV was applied. Kinematic requirements on the scattered positron used for this analysis were $Q^2 > 1$ GeV^2, $W^2 > 4$ GeV^2 and $y < 0.85$.
For semi-inclusive pion production in the kinematic range $0.2 < z < 0.7$, various contributions to the ϕ dependent single spin asymmetry were isolated by extracting moments $A^{\rm W}_{\rm UL(LU)}$ of the cross section weighted by corresponding ϕ dependent functions W(ϕ) for a longitudinally polarised target (beam). For π^+ production a significant $\sin\phi$ moment of the distribution has been observed, which was evaluated as

$$
A^{\sin\phi}_{\rm UL} = \frac{\frac{L^+}{L^+_{\rm P}} \int_0^{2\pi} \sin\phi \; {\rm d}N_+ \; - \; \frac{L^-}{L^-_{\rm P}} \int_0^{2\pi} \sin\phi \; {\rm d}N_-}{\frac{1}{2}\left[\int_0^{2\pi} {\rm d}N_+ \; + \; \int_0^{2\pi} {\rm d}N_-\right]} \,. \tag{1}
$$

Here $\pm$ refer to the target spin state, $L^\pm$ are the dead-time corrected luminosities, and $L^\pm_{\rm P}$ luminosities weighted by the absolute value of the average target polarisation. The values of $A^{\sin 2\phi}_{\rm UL}$ and $A^{\sin\phi}_{\rm LU}$ were found to be consistent with zero within errors for π^+ and π^-. In Fig. 2 the measured asymmetries for π^+ and π^- are shown as function of Bjorken x and as function of the pion transverse momentum $P_\perp$. The average values for these asymmetries are 0.022 ± 0.005 (stat.) $\pm\, 0.003$ (syst.) for π^+ and -0.005 ± 0.008 (stat.) $\pm\, 0.004$ (syst.) for π^- [8]. The difference between π^+ and π^- can be interpreted in terms of favoured and unfavoured Collins fragmentation functions [9] showing a flavour dependence as strong as for chiral-even fragmentation functions. The increase of $A^{sin\phi}_{\rm UL}$ for π^+ with x suggests that single spin asymmetries are associated with valence quark contributions [10,11]. The increase of the asymmetry with $P_\perp$ up to ~ 0.8 GeV can be related to the dominant role of intrinsic quark transverse momentum when $P_\perp$ remains below a typical hadronic mass ($\sim$ 1 GeV) [12].

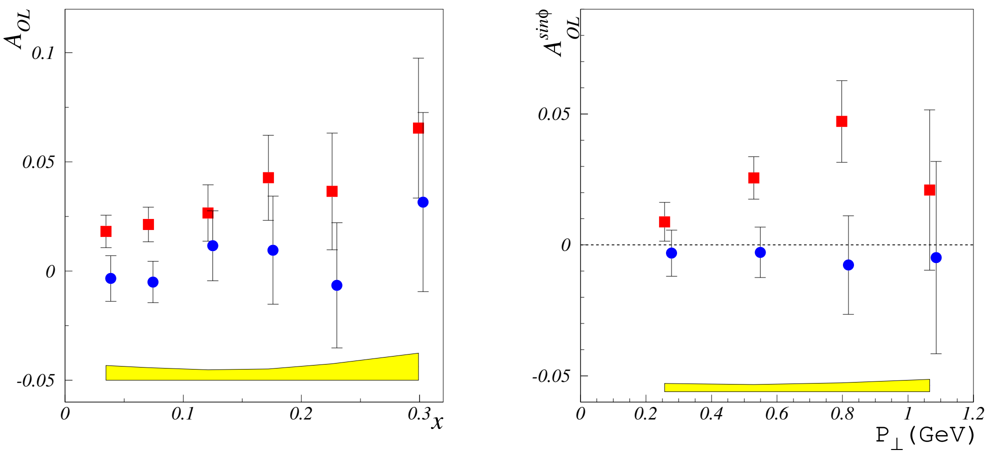


Figure 2: $A_{\mathrm{UL}}^{sin\phi}$ for π^+ (squares) and for π^- (circles) from semi-inclusive production as a function of Bjorken x (left) and of the pion transverse momentum (right). Error bars show the statistical the bands the systematic uncertainties.

3 Exclusive pion electroproduction and single spin azimuthal asymmetries

The same data set has been analysed to investigate exclusive electroproduction of pions. Again, charged pions were identified in the energy range of 4.5 GeV $< E_\pi <$ 14.0 GeV. Neutral pion identification was provided by the detection of the γ-clusters from the two-photon π^0 decay in the electromagnetic calorimeter. The invariant undetected squared missing mass M_X^2 and the squared momentum transfered to the nucleon t were computed from the lepton and pion kinematics as $M_X^2 = (P + q - P_{\mathrm{h}})^2$ and $t = (q - P_{\mathrm{h}})^2$. Kinematic requirements on the scattered positron were the same as given before. Furthermore a cut on $-t > 0.5$ was applied and only one pion track in addition to the positron track was allowed. Background contributions to the reaction $ep \to e'\pi^+ n$ from semi-inclusively produced π^+ were treated using the measured π^- yield which was normalised to the π^+ yield by a factor of 1.4, obtained from the comparison of both spectra in the region of missing mass > 2 GeV. After subtracting the π^- yield from the π^+ yield a clear π^+ signal around the nucleon mass was observed as presented in Fig. 3. Within the current experimental setup a missing mass resolution of 0.25 GeV was obtained from data for values of M_X around the nucleon mass in agreement with Monte Carlo estimates.

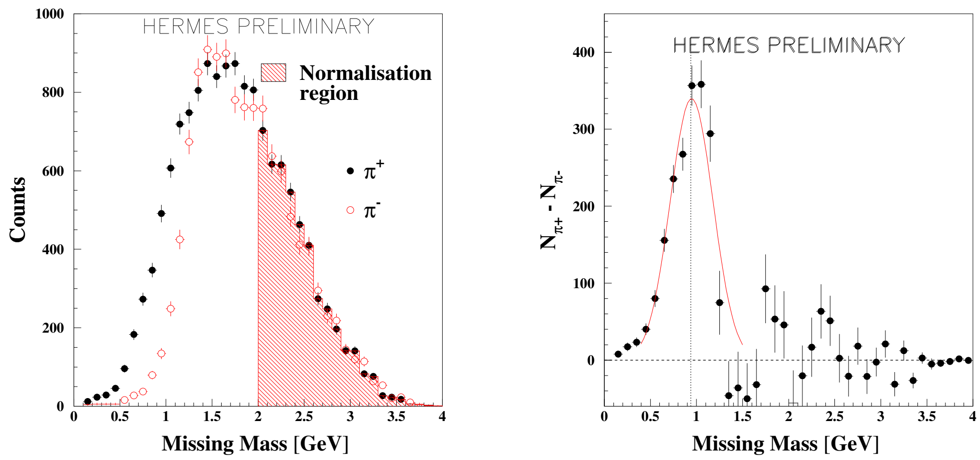


Figure 3: Measured π^+ and π^- yield as function of missing mass (left). Right figure shows the difference of π^+ and normalised π^- yield versus missing mass resulting in a clear peak around the nucleon mass indicated by the line.

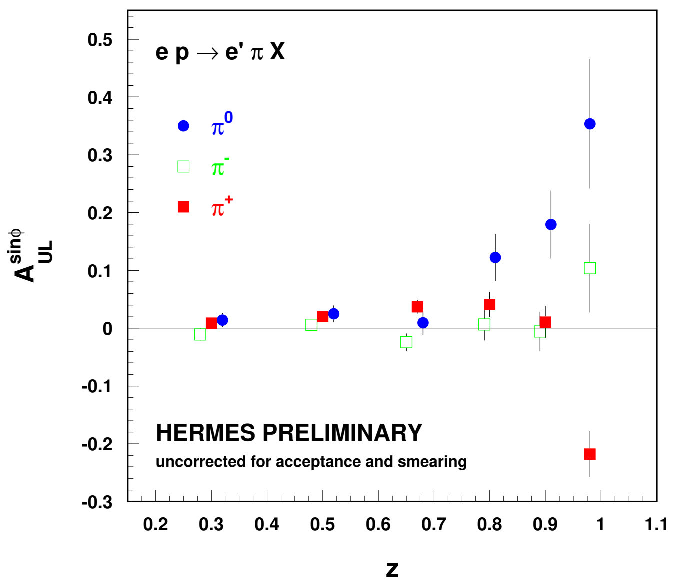


Figure 4: $A_{\mathrm{UL}}^{sin\phi}$ for pion electroproduction as function of z. Only statistical errors are shown.

The $\sin\phi$ moments of the single spin azimuthal asymmetries for π^0, π^+ and π^- were evaluated according to Eq. (1) using the polarised data and rejecting the cut on t and the single pion track requirement. Results are presented in Fig. 4 as function of z in the kinematic range $0.2 < z < 1.0$. No corrections for smearing due to detector resolution and for the spectrometer acceptance were applied. The first three data points correspond for π^+ and π^- to the results for semi-inclusive single spin asymmetries previously described. In the exclusive region of high z and low missing mass (nucleon missing mass corresponds to $z \approx 0.98$) $A_{\mathrm{UL}}^{sin\phi}$ shows a large variation for π^0 and π^+ while the value for π^- is consistent with zero within errors over the whole z-range. In case of π^+ the sign of $A_{\mathrm{UL}}^{sin\phi}$ in the exclusive region is opposite to that in the non-exclusive region.

4 Summary

Single spin azimuthal asymmetries of pions produced in deep inelastic positron scattering on a longitudinally polarised hydrogen target have been measured. For semi-inclusive pion production a significant azimuthal asymmetry was observed for π^+ showing a x and $P_\perp$ dependent behaviour in agreement with expectations from the Collins fragmentation model. The appearance of this single spin asymmetry can be interpreted as an effect of of chiral-odd spin distribution functions coupled with a chiral-odd fragmentation function.
First and preliminary results from investigations of exclusive pion production give clear evidence of the exclusive process $ep \to e'\pi^+ n$. The single spin asymmetries evaluated over the whole kinematic range in z show large values for π^0 and π^+ at high z. In this region a sign of the π^+ azimuthal asymmetry opposite to that in the semi-inclusive region and opposite to predictions made for a transversely polarised target has been observed.

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