First measurement of interference fragmentation on a transversely polarized hydrogen target

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Abstract. The HERMES experiment has measured for the first time single target-spin asymmetries in semi-inclusive two-pion production using a transversely polarized hydrogen target. These asymmetries are related to the product of two unknowns, the transversity distribution function and the interference fragmentation function. In the invariant mass range 0.51 GeV $< M_{\pi^+\pi^-} <$ 0.97 GeV the measured asymmetry deviates significantly from zero, indicating that two-pion semi-inclusive deep-inelastic scattering can be used to probe transversity.

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INTRODUCTION

An important missing piece in our understanding of the spin structure of the nucleon is the transversity distribution $h_1(x)$. It is the only one of the three leading-twist quark distribution functions, $f_1(x)$, $g_1(x)$ and $h_1(x)$, that so-far remains unmeasured. The function $h_1(x)$ describes the distribution of transversely polarized quarks in a transversely polarized nucleon. It is quite difficult to measure $h_1(x)$, since it is a chiral-odd function, which can only be probed in combination with another chiral-odd function. This can be done in semi-inclusive DIS, where the second chiral-odd object is a fragmentation function, describing the fragmentation of the struck quark into one or more final-state hadrons.

HERMES is one of the pioneering experiments on this subject. The structure function $h_1(x)$ is probed by measuring various single-spin asymmetries. First, a longitudinally polarized target [1] was used and more recently a transversely polarized target was used [2]. In these experiments, single spin asymmetries (SSA's) were only measured for *single-hadron* semi-inclusive DIS (SIDIS). However, already in 1993 Collins et al. [3] and in 1998 Jaffe et al. [4] suggested to study transversity in two-hadron SIDIS. Although this comes at the expense of a larger statistical uncertainty, there is a good reason for looking at SSA's in two-hadron SIDIS: the measured SSA's relate directly to the product of $h_1(x)$ and the fragmentation function, whereas in single-hadron SIDIS this product is convoluted with the transverse momentum of the hadron. Also measuring SSA's in two-hadron SIDIS provides an independent method of measuring $h_1(x)$, since it involves a different fragmentation function as compared to single-hadron SIDIS.

In order to finally extract the structure function $h_1(x)$, one needs to know the value of the involved fragmentation function. Although this function is also still unknown, it can be cleanly measured in e^+e^- experiments, such as Belle and Babar.

SINGLE SPIN ASYMMETRY

The transversity distribution can be accessed experimentally by measuring the single target-spin asymmetry, defined as:

$$A_{UT}(\phi_{R\perp},\phi_S,\theta)=\frac{1}{|S_T|}\frac{N^{\uparrow}(\phi_{R\perp},\phi_S,\theta)/N^{\uparrow}_{\rm DIS}-N^{\downarrow}(\phi_{R\perp},\phi_S,\theta)/N^{\downarrow}_{\rm DIS}}{N^{\uparrow}(\phi_{R\perp},\phi_S,\theta)/N^{\uparrow}_{\rm DIS}+N^{\downarrow}(\phi_{R\perp},\phi_S,\theta)/N^{\downarrow}_{\rm DIS}}=\frac{\sigma_{UT}}{\sigma_{UU}}, \tag{1}$$

where UT refers to Unpolarized beam and Transversely polarized target. The asymmetry is evaluated as a function of the angles $\phi_{R\perp}$, ϕ_S and θ which are defined in Fig. 1[1]. The azimuthal angle ϕ_S represents the spin direction of the target "↑" state and $N^{\uparrow(\downarrow)}(\phi_{R\perp},\phi_S,\theta)$ is the number of semi-inclusive $\pi^+\pi^-$-pairs in the target ↑(↓) spin state. These numbers are normalized to the corresponding number of DIS events, $N^{\uparrow}_{\rm DIS}$ and $N^{\downarrow}_{DIS}$, respectively. The quantity $|S_T|$ indicates the average target polarization. The asymmetry is equal to the ratio of σ_{UT} and σ_{UU}, which are the polarized and unpolarized cross sections, respectively. According to Bacchetta et al. [6] σ_{UT} can be written at leading-twist[2] as:

$$\begin{aligned}\sigma_{UT} \;=\; & -\sum_q \frac{\alpha^2 e_q^2}{2\pi Q^2 y}(1-y)|\vec{S}_\perp|\frac{|\vec{R}|}{M_{\pi\pi}}\sin(\phi_{R\perp}+\phi_S)\sin\theta\, h_{1,q}(x)\\ & \times\left[H_{1,q}^{\sphericalangle,sp}(z,M_{\pi\pi}^2)+\cos\theta H_{1,q}^{\sphericalangle,pp}(z,M_{\pi\pi}^2)\right]\end{aligned} \tag{2}$$

where $|\vec{R}|=\frac{1}{2}\sqrt{M_{\pi\pi}^2-4M_\pi^2}$ with $M_{\pi\pi}$ the invariant mass of the pion pair, M_π the pion mass and x, y and z the standard scaling variables used in semi-inclusive DIS. The transversity distribution $h_1(x)$ couples to a combination of two-hadron interference fragmentation functions, $H_1^{\sphericalangle,sp}$ and $H_1^{\sphericalangle,pp}$. These functions describe the interference between different production channels of the pion pair; $H_1^{\sphericalangle,sp}$ relates to the interference between s- and p-wave states and $H_1^{\sphericalangle,pp}$ to the interference between two p-wave states.

A two-dimensional fit function of the form

$$f(\phi_{R\perp}+\phi_S,\theta)=p_0+p_1\sin(\phi_{R\perp}+\phi_S)\sin\theta \tag{3}$$

was used to extract from the measured asymmetry the part related to the product $h_1H_1^{\sphericalangle,sp}$, where $p_1\equiv A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta}$.

RESULTS

The present results are based on data taken in the period from 2002 until 2004 using a transversely polarized hydrogen target in the HERMES experiment at DESY. The average target polarization, $|S_T|$, was 75.4 ± 5.0 %.

[1] The angle definitions are consistent with the "Trento Conventions" [5].
[2] See [6] for the sub-leading twist expression.

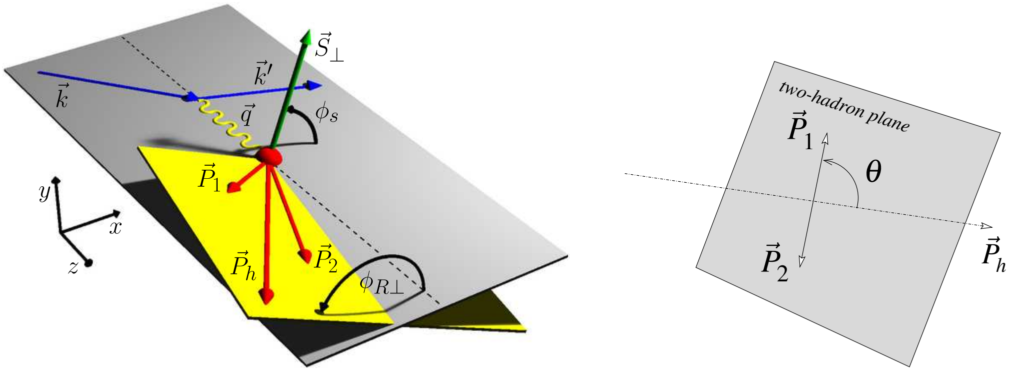

FIGURE 1. Left: kinematic planes, where $\phi_{R\perp}$ is the angle between the plane spanned by the incident ($\vec{k}$) and scattered lepton ($\vec{k}'$) and the plane spanned by the two detected pions $\vec{P}_1$ (π^+) and $\vec{P}_2$ (π^-) with $\vec{P}_h \equiv \vec{P}_1 + \vec{P}_2$. Right: description of the polar angle θ, in the center-of-mass frame of the two pions. The vector $\vec{P}_h$ is evaluated in the hadronic center-of-mass system.

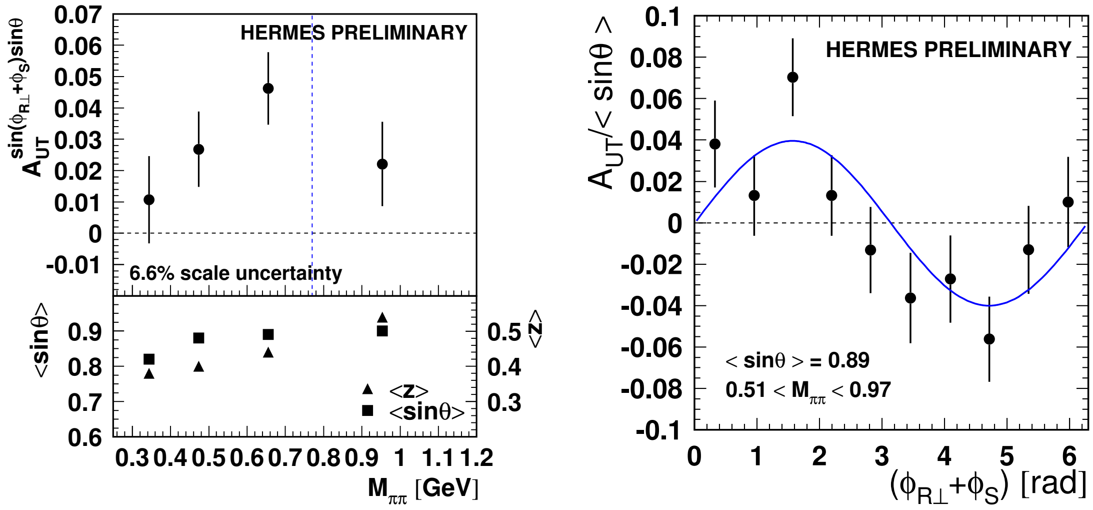

FIGURE 2. On the left the asymmetry $A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta}$ is shown versus the invariant mass of the $\pi^+\pi^-$-pair (using mass binning, with the bin boundaries at 0.25, 0.40, 0.55, 0.77, 2.0 GeV) and on the right the asymmetry A_{UT} divided by the average <$\sin\theta$> is shown versus the angle combination $(\phi_{R\perp}+\phi_S)$.

In the left plot of Fig. 2 the data for $A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta}$ are shown versus the invariant mass of the $\pi^+\pi^-$-pair. The asymmetry is clearly positive over the entire invariant mass range and largest in the region of the ρ^0 mass. The corresponding invariant mass distribution is shown in the left plot of Fig. 3. Whereas the results on SSA's in two-hadron fragmentation using a *longitudinally* polarized deuterium target [8] gave a hint of a sign change of the asymmetry at the ρ^0 mass (770 GeV) as predicted in [4], the new results presented here are clearly inconsistent with such behavior.

In the right plot of Fig. 2 the raw asymmetry is shown in bins of $\phi_{R\perp}+\phi_S$, integrated over the invariant mass range 0.51 GeV $< M_{\pi\pi} <$ 0.97 GeV. This plot shows that a clear $\sin(\phi_{R\perp}+\phi_S)$ behavior is present in the data. The plot includes a curve resulting from

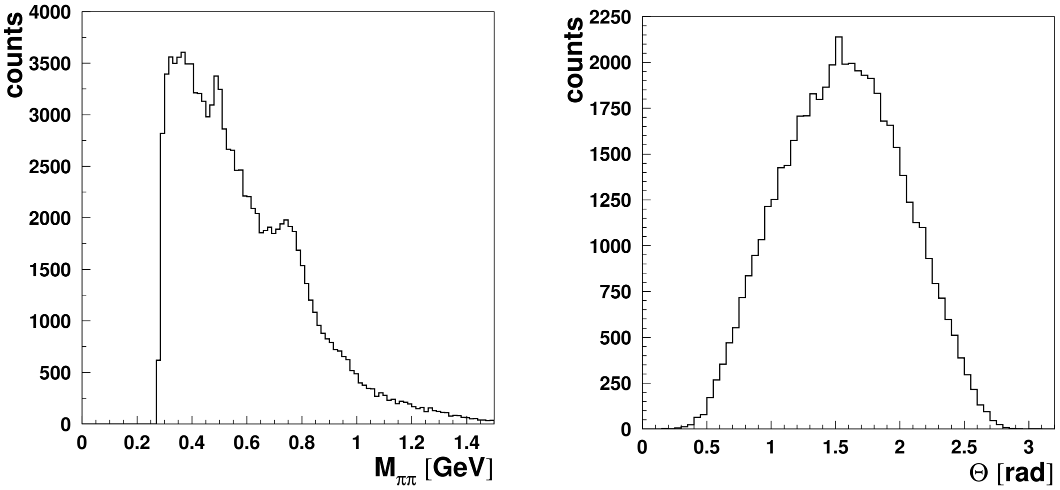

FIGURE 3. The left plot shows the distribution of the invariant mass of the $\pi^+\pi^-$-pairs and the right plot shows the distribution of the angle θ (for the invariant mass range 0.51 GeV $< M_{\pi\pi} <$ 0.97 GeV.

fitting the data with $f(\phi_{R\perp}+\phi_S) = p_0 + p_1 \sin(\phi_{R\perp}+\phi_S)$, where $p_1 \equiv A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta} =$ 0.040 ± 0.009 (stat) $\pm$ 0.003 (syst). Due to the peaked shape of the θ-distribution (right plot in Fig. 3) the asymmetry is mostly evaluated around $\theta = \frac{\pi}{2}$. Therefore the value of $A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta}$ is insensitive to whether one uses this one-dimensional fit function, integrating over θ, or a two-dimensional one, like eq. 3.

Data taking with a transversely polarized hydrogen target will continue until November 2005 after which the analysis of the full data sample is expected to lead to a decrease of the uncertainty on the asymmetry with approximately a factor of $\sqrt{2}$. Further steps in the analysis include looking at the part of the asymmetry coupling to $H_1^{\triangleleft,pp}$ and studying the x and z dependence of the asymmetries.

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