

Transverse spin dependent azimuthal asymmetries at COMPASS

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Abstract. In the semi-inclusive deep inelastic scattering of polarized leptons on a transversely polarized target eight target transverse spin-dependent azimuthal modulations are allowed. In the QCD parton model half of these asymmetries can be interpreted within the leading order approach and the other four are twist-three contributions. The first two leading twist asymmetries extracted by HERMES and COMPASS experiments are related: one to the transversity distribution and the Collins effect, the other to the Sivers distribution function. These results triggered a lot of interest in the past few years and allowed the first extractions of the transversity and the Sivers distribution functions of nucleon. The remaining six asymmetries were obtained by the COMPASS experiment using a 160 GeV/c longitudinally polarized muon beam and transversely polarized deuteron and proton targets. Here we review preliminary results from COMPASS proton data of 2007.

1. Introduction

Using standard SIDIS notations transverse spin S_T dependent part of the general, model-independent cross-section of lepton-hadron SIDIS processes can be written in the following way [1], [2]:

$$\begin{aligned}
 \frac{d\sigma}{dx dy d\psi dz d\phi_h dP_{hT}^2} &= \frac{\alpha^2}{xyQ^2} \frac{y^2}{2(1-\varepsilon)} \left(1 + \frac{\gamma^2}{2x}\right) \left\{ \dots \right. & (1) \\
 &+ |\mathbf{S}_T| \left[\sin(\phi_h - \phi_S) \left(F_{UT,T}^{\sin(\phi_h - \phi_S)} + \varepsilon F_{UT,L}^{\sin(\phi_h - \phi_S)} \right) + \varepsilon \sin(\phi_h + \phi_S) F_{UT}^{\sin(\phi_h + \phi_S)} \right. \\
 &+ \left. \varepsilon \sin(3\phi_h - \phi_S) F_{UT}^{\sin(3\phi_h - \phi_S)} + \sqrt{2\varepsilon(1+\varepsilon)} \left(\sin\phi_S F_{UT}^{\sin\phi_S} + \sin(2\phi_h - \phi_S) F_{UT}^{\sin(2\phi_h - \phi_S)} \right) \right] \\
 &+ |\mathbf{S}_T| P_l \left[\sqrt{1-\varepsilon^2} \cos(\phi_h - \phi_S) F_{LT}^{\cos(\phi_h - \phi_S)} + \sqrt{2\varepsilon(1-\varepsilon)} \cos\phi_S F_{LT}^{\cos\phi_S} \right. \\
 &+ \left. \left. \sqrt{2\varepsilon(1-\varepsilon)} \cos(2\phi_h - \phi_S) F_{LT}^{\cos(2\phi_h - \phi_S)} \right] \right\}, \quad \text{where } \varepsilon = \frac{1-y-\frac{1}{4}\gamma^2 y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2 y^2}, \quad \gamma = \frac{2Mx}{Q}
 \end{aligned}$$

This expression contains eight azimuthal modulations in the ϕ_h and ϕ_S (azimuthal angles of the produced hadron and of the nucleon spin correspondingly). Each modulation leads to

an asymmetry described by the associated structure function F depending on x , Q^2 , z and P_{hT} . The superscript of the structure function indicates the corresponding modulation, the first and the second subscripts - the respective ("U"-unpolarized,"L"-longitudinal and "T"-transverse) polarization of beam and target and the third subscript specifies the polarization of the virtual photon. The eight Transverse Spin Asymmetries (TSA) linked to the azimuthal modulations are defined as the ratios of the corresponding structure functions to the unpolarized one $A_{BT}^{w_i(\phi_h, \phi_s)} \equiv F_{BT}^{w_i(\phi_h, \phi_s)} / F_{UU,T}$ where $B = L$ or $B = U$ indicates the beam polarization. As one can see, there are five Single-Spin Asymmetries (SSA), which depend only on S_T and three Double-Spin Asymmetries (DSA), both S_T and P_l (beam polarization) dependent. In the QCD parton model approach four of the eight TSAs have Leading Order (LO) interpretation and are described by the convolutions of Transverse Momentum Dependent (TMD) twist-two distribution functions (DFs) and fragmentation functions(FFs):

$$\begin{aligned} A_{UT}^{\sin(\phi_h - \phi_s)} &\propto f_{1T}^{\perp q} \otimes D_{1q}^h, & A_{UT}^{\sin(\phi_h + \phi_s)} &\propto h_1^q \otimes H_{1q}^{\perp h}, \\ A_{LT}^{\cos(\phi_h - \phi_s)} &\propto g_{1T}^q \otimes D_{1q}^h, & A_{UT}^{\sin(3\phi_h - \phi_s)} &\propto h_{1T}^{\perp q} \otimes H_{1q}^{\perp h} \end{aligned} \quad (2)$$

Here the first two are Collins and Sivers asymmetries, which have been extracted from HERMES experimental data collected on proton target [3, 4] and COMPASS deuteron [5, 6, 7] and proton [8] data. These measurements triggered a strong phenomenological and theoretical interest and, for example, allowed the first extraction of the Sivers DF and combined with the BELLE data [9, 10] - of the transversity function and Collins FF [11, 12, 13].

The other two $A_{LT}^{\cos(\phi_h - \phi_s)}$ and $A_{UT}^{\sin(3\phi_h - \phi_s)}$ LO TSAs can be used for extraction of g_{1T}^q (worm-gear) and $h_{1T}^{\perp q}$ (pretzelosity) DFs correspondingly. There are different model-based calculations of these asymmetries made for COMPASS kinematics, in this article we refer, for instance, to the following ones: $A_{LT}^{\cos(\phi_h - \phi_s)}$ DSA calculated using "Kotzinian-Mulders" model [14, 15], and predictions for both $A_{LT}^{\cos(\phi_h - \phi_s)}$ and $A_{UT}^{\sin(3\phi_h - \phi_s)}$ based on light-cone constituent quark models [16, 17] and quark-diquark model [18].

The remaining four asymmetries are higher-twist effects, though they can be interpreted as twist-two Cahn kinematic corrections to spin effects on the transversely polarized nucleon [1]:

$$\begin{aligned} A_{UT}^{\sin(\phi_s)} &\propto \frac{M}{Q} (h_1^q \otimes H_{1q}^{\perp h} + f_{1T}^{\perp q} \otimes D_{1q}^h), & A_{UT}^{\sin(2\phi_h - \phi_s)} &\propto \frac{M}{Q} (h_{1T}^{\perp q} \otimes H_{1q}^{\perp h} + f_{1T}^{\perp q} \otimes D_{1q}^h) \\ A_{LT}^{\cos(\phi_s)} &\propto \frac{M}{Q} (g_{1T}^q \otimes D_{1q}^h), & A_{LT}^{\cos(2\phi_h - \phi_s)} &\propto \frac{M}{Q} (g_{1T}^q \otimes D_{1q}^h). \end{aligned} \quad (3)$$

For instance, such an approach was used in [18], in order to evaluate these TSAs basing on the quark-diquark model.

Both LO $A_{LT}^{\cos(\phi_h - \phi_s)}$ and $A_{UT}^{\sin(3\phi_h - \phi_s)}$ as well as the other four $A_{UT}^{\sin(\phi_s)}$, $A_{UT}^{\sin(2\phi_h - \phi_s)}$, $A_{LT}^{\cos(\phi_s)}$ and $A_{LT}^{\cos(2\phi_h - \phi_s)}$ "higher-twist" asymmetries have been extracted from COMPASS deuteron data [19, 20] together with the measurement of Collins and Sivers effects completing the whole "deuteron"-set of eight allowed in SIDIS TSAs. Now in the next section we present our preliminary results for all six "beyond Collins and Sivers" TSAs from COMPASS proton data.

2. Results

In COMPASS transverse $A_{UT}^{\sin(3\phi_h - \phi_s)}$, $A_{UT}^{\sin(\phi_s)}$ and $A_{UT}^{\sin(2\phi_h - \phi_s)}$ SSAs and $A_{LT}^{\cos(\phi_h - \phi_s)}$, $A_{LT}^{\cos(\phi_s)}$ and $A_{LT}^{\cos(2\phi_h - \phi_s)}$ DSAs were extracted for positive and negative hadron production in SIDIS of high energy muons on transversely polarized protons. The data were collected in 2007 using 160

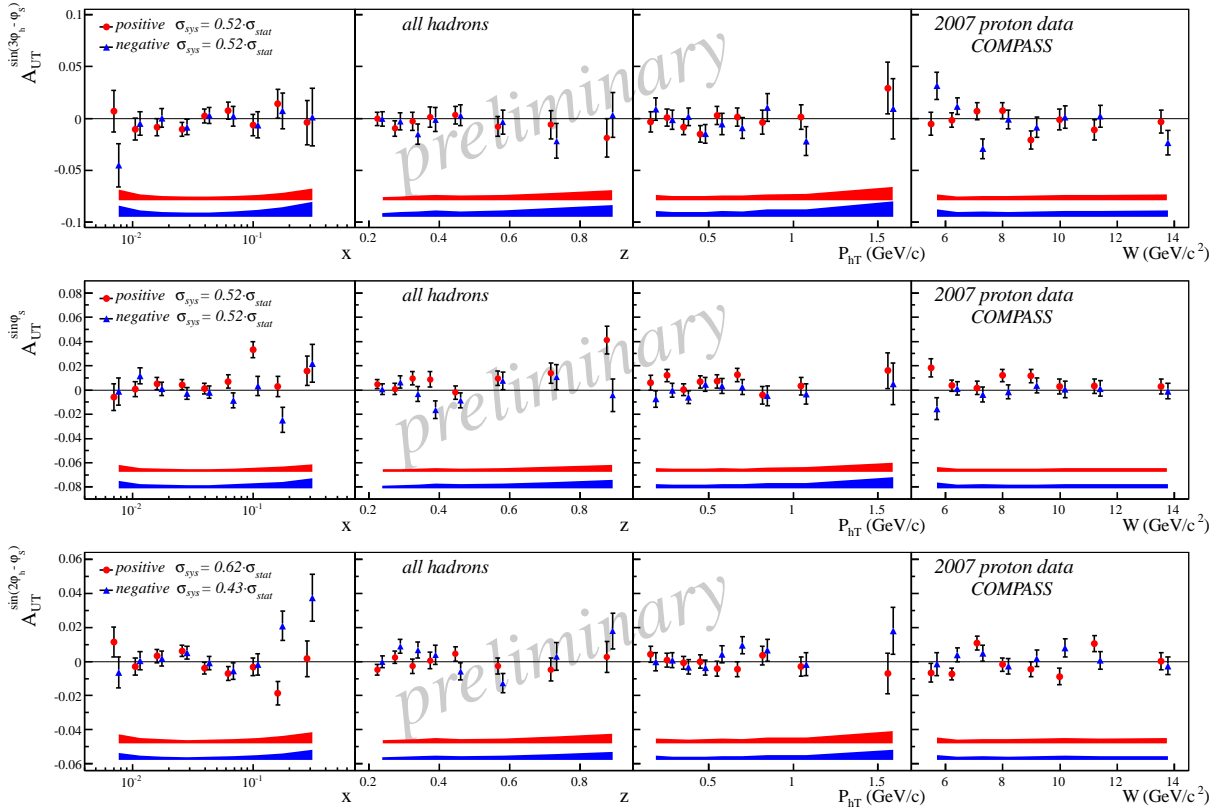


Figure 1. $A_{UT}^{\sin(3\phi_h - \phi_s)}$, $A_{UT}^{\sin\phi_s}$ and $A_{UT}^{\sin(2\phi_h - \phi_s)}$ asymmetries for positive (red circles) and negative (blue triangles) hadrons vs. x , z , P_{hT} and W . Systematic uncertainties are shown by the correspondingly colored bands.

GeV/c longitudinally polarized muon beam and NH_3 transversely polarized three-cell target. The neighboring target cells were polarized oppositely which allowed simultaneous collection of data with both spin polarizations. In order to minimize the acceptance effects after each 4-5 days polarization was reversed in all three cells.

The kinematic cuts applied in the analysis are the following ones: $Q^2 > 1$ (GeV/c)², $W > 5$ GeV, $0.1 < y < 0.9$, $P_{hT} > 0.1$ GeV/c and $z > 0.2$.

The estimator used for the evaluation of the raw asymmetries is based on an extended unbinned maximum likelihood method and as well as the whole analysis procedure is exactly the same as the one applied for already published Collins and Sivers asymmetries on proton. Detailed description of COMPASS spectrometer and analysis methods can be found in: [21, 5, 6, 7, 8, 19]

In Figs. 1 - 2 we present six TSAs extracted from COMPASS 2007 data collected on a proton target. The asymmetries for positive and negative hadrons are plotted as a function of x , z , P_{hT} and W . The systematic uncertainties have been estimated separately for each asymmetry for positive and negative hadrons and are given by the bands. Next, Figs. 3 - 4 show the x -dependence of the calculated for COMPASS kinematical region asymmetries from [15], [17] and [18] together with the COMPASS measured values. In Fig. 3 we show only SSAs for positive and negative hadrons, while Fig. 4 is dedicated to DSAs. One can see that at maximum UT asymmetries are predicted to be of order of 1 – 2% and LTs around 5 – 10% and that the theoretical curves basically stay within the error bands showing an agreement with COMPASS measurements at this level of the statistical accuracy. Yet, improved precision is needed for definitive conclusions and further analysis.

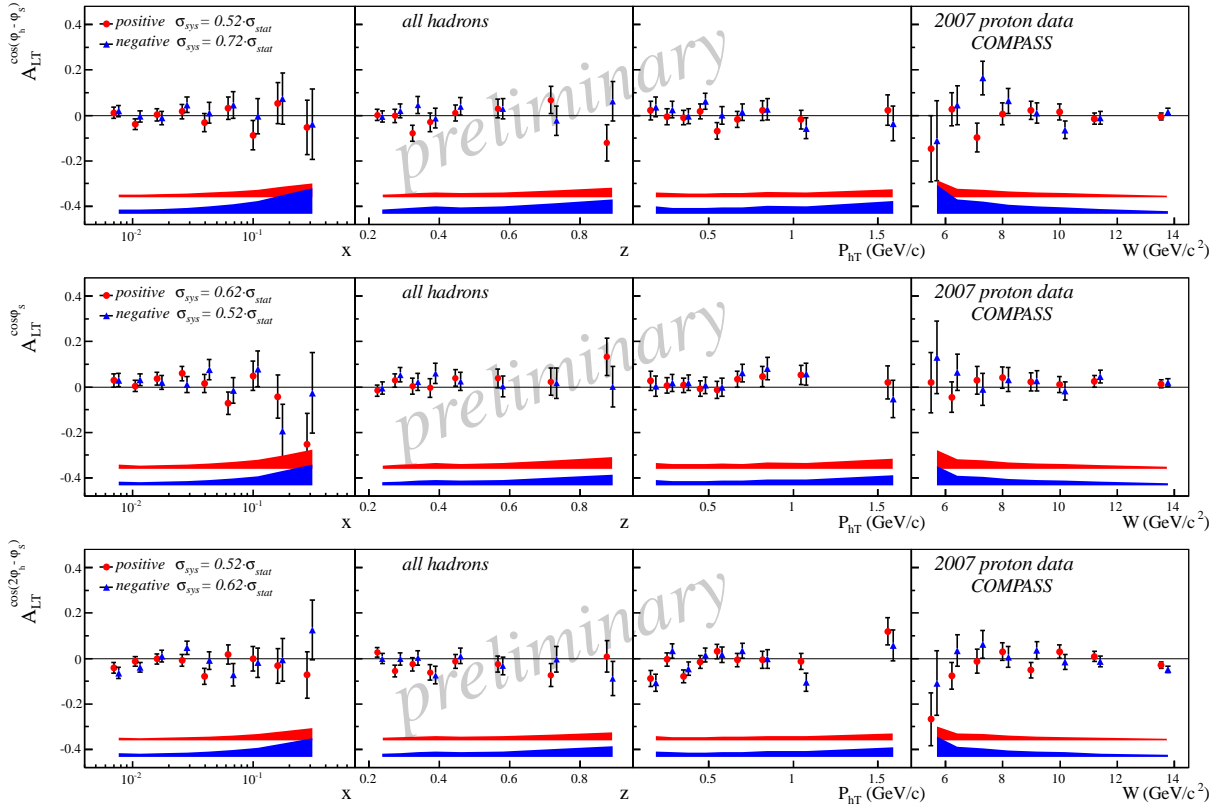


Figure 2. $A_{LT}^{\cos(\phi_h-\phi_s)}$, $A_{LT}^{\cos\phi_s}$ and $A_{LT}^{\cos(2\phi_h-\phi_s)}$ asymmetries for positive (red circles) and negative (blue triangles) hadrons vs. x , z , P_{hT} and W . Systematic uncertainties are shown by the correspondingly colored bands.

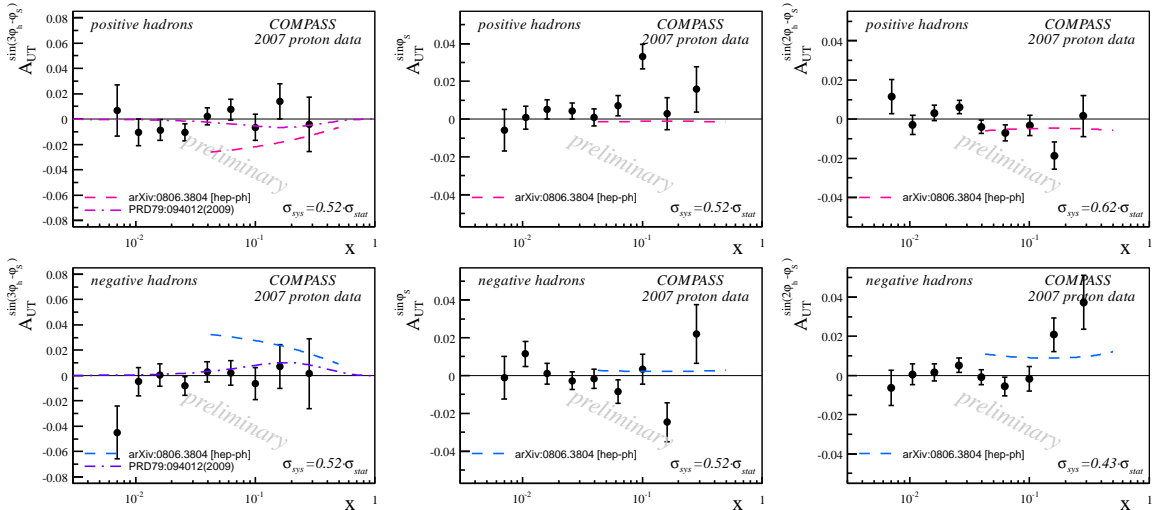


Figure 3. $A_{UT}^{\sin(3\phi_h-\phi_s)}$, $A_{UT}^{\sin\phi_s}$, $A_{UT}^{\sin(2\phi_h-\phi_s)}$ asymmetries for h^+ (top) and h^- (bottom) vs. x . compared with the predictions from: [17] (dot-dashed) and [18] (dashed).

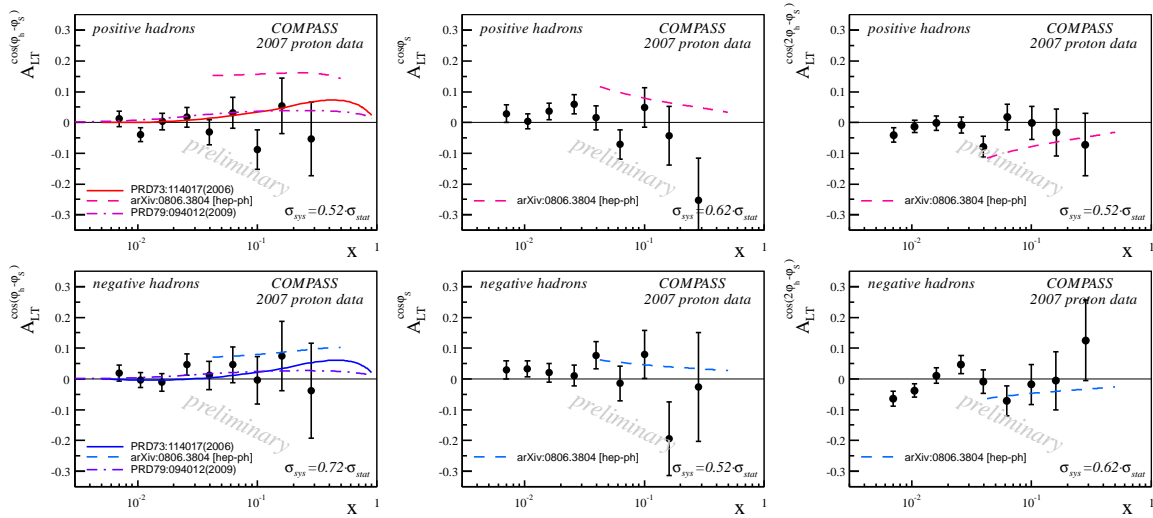


Figure 4. $A_{LT}^{\cos(\phi_h - \phi_s)}$, $A_{LT}^{\cos\phi_s}$, $A_{LT}^{\cos(2\phi_h - \phi_s)}$, asymmetries for h^+ (top) and h^- (bottom) vs. x . compared with the predictions from: [15] (solid), [17] (dot-dashed) and [18] (dashed).

3. Conclusions

We have presented preliminary results for six new target transverse spin dependent asymmetries extracted from COMPASS 2007 data collected on a proton target. These measurement together with the published Collins and Sivers TSAs on proton and with our deuteron measurements complete the whole set of eight azimuthal asymmetries allowed in SIDIS and give another access to the studies of TMD DFs and FFs. Obviously, presented comparison plots for different theory predictions show that the statistical accuracy has yet to be enhanced to draw some decisive conclusions. However, in 2010 COMPASS collected a new large sample of data with transversely polarized proton target, and we look forward to significantly improve the precision of our results.

4. References

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