Recent COMPASS Results on Transverse Physics

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Abstract. The investigation of transverse spin and transverse momentum dependent effects in deep inelastic scattering of muons off nucleons is one of the key physics programs of the COMPASS collaboration at CERN. We have investigated the effects from the data obtained with a polarized proton target. In order to access the transversity distribution function, following channels have been analyzed: The azimuthal distribution of single hadrons, the azimuthal dependence of the plane containing hadron pairs, and the measurement of the transverse polarization of lambda hyperons in the final state. The Sivers distribution function which is one of the transverse momentum dependent functions has been investigated also from the azimuthal distribution of single hadrons. Azimuthal asymmetries in unpolarized deep inelastic scattering give important information on the inner structure of the nucleon to access the so-far unmeasured Boer-Mulders function. We have measured these asymmetries using spin-averaged ^6L_iD.

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THE COMPASS EXPERIMENT

COMPASS is a fixed target experiment at the CERN SPS with a broad physics programme focused on the nucleon spin structure and on hadron spectroscopy. The nucleon spin structure is investigated by observing deep inelastic scattering (DIS) of a high energy muon beam off polarised deuteron and proton targets. These measurements allow to access transverse spin and transverse momentum dependent effects. A 160 GeV muon beam is scattered off a transversely polarized deuteron(^{6}LiD) or proton(NH_3) targets. The scattered muon and the produced hadrons are detected in a wide-acceptance two-stage spectrometer with excellent particle identification capabilities [3]. The target consists of several cells along the beam direction, which are oppositely polarized. The polarization is periodically reversed to reduce systematic effects due to the different acceptance of the cells.

The COMPASS collected data for the deuteron target in the years 2002, 2003, 2004 and 2006, and for the proton target in the recent years 2007 and 2010. Analyzing the data, the Collins and the Sivers assymmetries which allow to access the transversity and the Sivers distribution functions, are obtained and published [4, 5, 6, 7].

In this talk, new preliminary results for the proton target are presented. The results include the Collins and Sivers asymmetries, transverse polarization of Lamda and two-hadron asymmetries. Also, preliminary results for the spin independent azimuthal asymmetries on deuteron are presented. They allow to access the so-far unmeasured Boer-Mulders function.

TRANSVERSITY AND TRANSVERSE MOMENTUM DEPENDENT FUNCTIONS

The quark structure of the nucleon in the collinear approximation or after integration over the intrinsic quark transverse momentum is fully specified at the twist-two level by three parton distribution functions (PDFs) for each quark flavour [1] : the momentum distributions $q(x)$, the helicity distributions $\Delta q(x)$ and the transverse spin distributions $\delta_T q(x)$, where x is the Bjorken variable. The latter distribution, often referred to as transversity is, chiral-odd and thus not directly observable in DIS. Azimuthal asymmetries in semi-inclusive DIS (SIDIS) off transverely polarized targets give important information on the transversity .

The investigation of the transverse momentum dependent(TMD) functions is also important in the study of nucleon structure. Azimuthal asymmetries in unpolarized SIDIS give important information on the TMD functions and allow to access the so-far unmeasured Boer-Mulders function.

Single hadron asymmetries in SIDIS

The transversity could be measured in semi-inclusive lepton nucleon scattering (SIDIS) due to a mechanism involving another chiral-odd function in the hadronisation, known today as the Collins fragmentation function(FF). [2] The mechanism leads to a left-right asymmetry in the distribution of the hadrons produced in the fragmentation of transversely polarized quarks. In this case the measurable Collins asymmetry, A_{Coll}, is proportional to the convolution of the transversity PDF and the Collins FF.

In the case of SIDIS of longitudinally polarized leptons off transversely polarized targets the cross-section contains eight azimuthal modulations which are harmonic functions of linear combinations of the azimuthal angles of the hadron (ϕ_h) and of nucleon spin (ϕ_S) in the $\gamma^\star N$ reference system. Among them, those relevant for the extraction of the transversity and the Sivers functions are the amplitudes ε_C and ε_S of $sin\Phi_C$ and $sin\Phi_S$ modulations, where $\Phi_C = \phi_h + \phi_S - \pi$ and $\Phi_S = \phi_h - \phi_S$ are the Collins and Sivers angles.

From the measurements one obtains the so-called Collins asymmetry $A_{Coll} = \varepsilon_C/(D_{NN} \cdot S_T)$ and the Sivers asymmetry $A_{Siv} = \varepsilon_S/S_T$. The quantity $D_{NN} = (1-y)/(1-y+y^2/2)$ is the transverse spin transfer coefficient from the target quark to the struck quark, y is the fractional energy of the virtual photon, and S_T is the nucleon polarisation. The Sivers asymmetry gives access to the convolution of the Sivers function with the known spin independent FF, and thus allows to extract informations on the Sivers function.

Collins and Sivers asymmetries

The COMPASS has measured the Collins and the Sivers asymmetries on deuteron and proton using a 160 GeV μ^+ beam with a longitudinal polarisation of about 80 %.

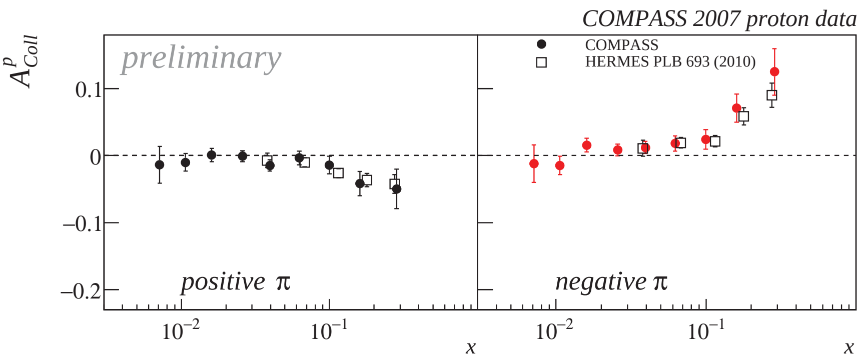

FIGURE 1. Collins asymmetries on proton for positive and negative pions as measured by COMPASS with comparison with the HERMES results.

The deuteron results for charged and identified hadrons from the data collected with the ^{6}LiD target in the years 2002, 2003, and 2004 have already been published [4, 5, 6]. Both the Collins and the Sivers asymmetries turned out to be compatible with zero. That could be explained in terms of cancellation of the u- and the d-quark contributions in a deuteron target.

In 2007 data were collected using a transversely polarised NH_3 target. The 2007 experimental apparatus was similar to the one used in the years 2002-2004. In the data analysis the DIS events have been selected by requiring a photon virtuality $Q^2 > 1(GeV/c)^2$, $0.1 < y < 0.9$, and a mass of the hadronicfinal state $W > 5GeV/c^2$. The charged hadrons used in the extraction of the asymmetries were required to have a relative energy $z > 0.2$ and a transverse momentum with respect to the virtual photon direction $p_T^h > 0.1GeV/c$.

The obtained results for not-identified-hadrons have been already published [7]. The results for Collins asymmetries show, at small x the values are compatible with zero both for positive and negative hadrons. In the valence region, at $x > 0.1$, the Collins asymmetry is definitely different from zero and of opposite sign for positive and negative hadrons.

As for the Collins asymmetry, for positive hadrons, positive value is measured over a wide x range. Comparing with the HERMES data in the overlap region, the asymmetry measured by COMPASS is about a factor of 2 smaller than that observed by HERMES for positive pions. The signal of the Sivers asymmetry for positive hadrons seems to be concentrated at small W, in the region where HERMES measures, and goes to zero at large W, which for large x means large Q^2. Thus our data give an indication for a possible W dependence of the Sivers asymmetry for positive hadrons. For negative hadrons the asymmetry is compatible with zero, slightly negative at small x, and compatible with the HERMES results [10].

The new results for the Collins asymmetry on proton for identified hadrons are shown in FIGURE 1 with a comparison to the HERMES results [8]. The size of the asymmetries measured by COMPASS is very similar to those measured by HERMES and in agreement with the calculations based on the global fit results [9].

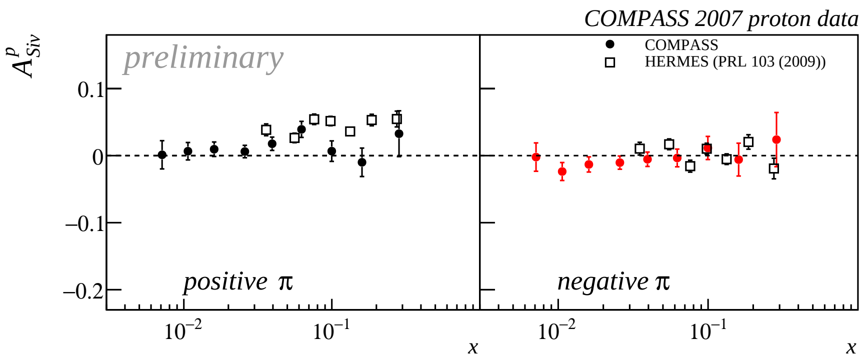

FIGURE 2. Sivers asymmetries on proton for positive and negative pions as measured by COMPASS with comparison with the HERMES results.

The new preliminary results for the Sivers asymmetry on proton for identified hadrons are shown in FIGURE 2 compared with the HERMES results [10]. As can be seen, for negative pions the asymmetry is compatible with zero, and compatible with the HERMES results. For positive pions, no definite conclusion can be given from the COMPASS data due to limited statistics.

Two hadron asymmetries

The transversity can be measured in combination with the polarized two-hadron interference fragmentation function [11, 12, 13, 14] $H_1^{\sphericalangle}(z;M_{inv}^2)$ in SIDIS. M_{inv}^2 is the invariant mass of the h^+h^- pair. The fragmentation of a transversely polarized quark into two unpolarized hadrons leads to an azimuthal modulation in $\Phi_{RS} = \phi_R + \phi_S - \pi$ in the SIDIS cross section. Here ϕ_R is the azimuthal angle between $\vec{R}_T$ and the lepton scattering plane and $\vec{R}_T$ is the transverse component of $\vec{R}$ defined as:

$$\vec{R} = (z_2 \cdot \vec{p}_1 - z_1 \cdot \vec{p}_2)/(z_1 + z_2). \tag{1}$$

$\vec{p}_1$ and $\vec{p}_2$ are the momenta in the laboratory frame of h^+ and h^-, respectively. The number of the hadron pairs N_{hh} can be written as:

$$N_{hh} = N_0 \cdot (1 + f \cdot P_T \cdot D_{nn} \cdot A_{RS} \cdot \sin\Phi_{RS} \sin\theta) \tag{2}$$

Here, θ is the angle between the momentum vector of h^+ in the center of mass frame of the hadron pair and the momentum vector of the hadron pair system.

The measured amplitude A_{RS} is proportional to the product of the transversity and the polarized two-hadron interference fragmentation function

$$A_{RS} \propto \frac{\Sigma_q e_q^2 \cdot \Delta_T q(x) \cdot H_1^{\sphericalangle}(z;M_{inv}^2)}{\Sigma_q e_q^2 \cdot q(x) \cdot D_q^{2h}(z;M_{inv}^2)} \tag{3}$$

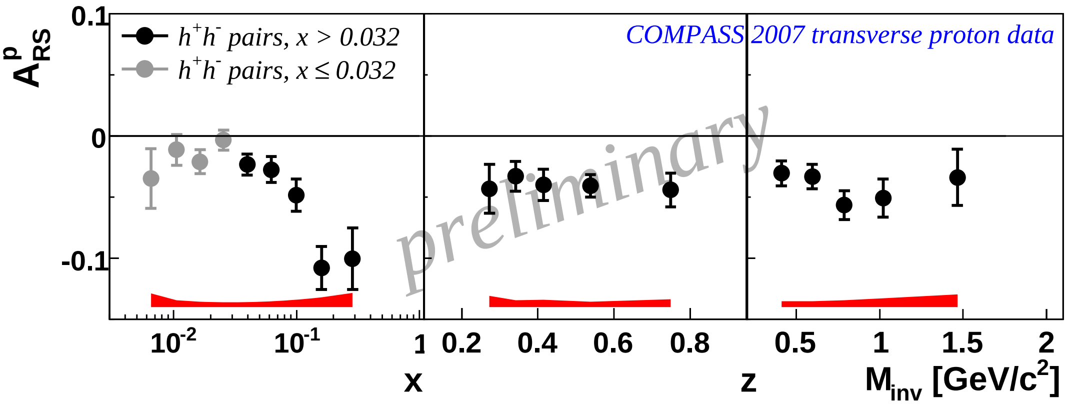

FIGURE 3. Two-hadron asymmetry A_{RS} on proton as a function of x, z and M_{inv}.

$D_q^{2h}(z;M_{inv}^2)$ is the unpolarized two-hadron interferencefragmentation function.

The two-hadron asymmetry on protn is shown in FIGURE 3. A strong asymmetry in the valence x-region is observed, which implies a non-zero transversity and a non-zero polarized two hadron interference fragmentation function In the invariant mass binning one observes a strong signal around the ρ-mass and the asymmetry is negative over the whole mass range.

Transverse Λ polarization

Another way to access transversity is to study Λ and $\overline{\Lambda}$ polarization in SIDIS with a transversely polarized target [15]. The polarization P_T^λ of the produced Λ and $\overline{\Lambda}$-Hyperons is evaluated with respect to the direction of the struck quark spin, via the parity violating decays $\Lambda \to p\pi^-$ and $\overline{\Lambda} \to \overline{p}\pi^+$, respectively. It is in first order proportional to a product of transversity and the fragmentation function $\Delta_T D_q^\Lambda$.

The polarizations of measured with transversely polarized ^{6}LiD and NH_3 targets, respectively, have been evaluated [16, 17]. For both targets the evaluated polarizations are small and compatible with zero within the errors.

Azimuthal asymmetries in unpolarized target

The azimuthal asymmetries which appear in the cross-section of SIDIS off unpolarized targets can give insights on the possible correlation between transverse spin and transverse momentum of the quarks and the information on the TMD distribution functions. The Boer-Mulders function is of special interest among the TMD distribution functions [18]. It describes the transverse parton polarization in an unpolarized hadron.

The SIDIS cross section for longitudinally polarized leptons over unpolarized targets can be expressed [20] as

$$d\sigma = \frac{\alpha^2}{xyQ^2}\frac{(1+(1-y)^2)}{2}\cdot(A_0+\varepsilon_1(y)A^{UU}_{\cos\phi_h}\cos\phi_h+ \\ \varepsilon_2(y)A^{UU}_{\cos 2\phi_h}\cos 2\phi_h+\lambda_l\varepsilon_3(y)A^{UU}_{\sin\phi_h}\sin\phi_h). \quad (4)$$

The angle ϕ_h is the angle between the hadron production plane and the lepton plane, λ_l is the longitudinal polarization of the incident lepton and the quantities ε_i are given by:

$$\varepsilon_1(y) = \frac{2\cdot(2-y)\sqrt{1-y}}{1+(1-y)^2}, \quad \varepsilon_2(y) = \frac{2\cdot(1-y)}{1+(1-y)^2}, \quad \varepsilon_3(y) = \frac{2\cdot y\sqrt{1-y}}{1+(1-y)^2}. \quad (5)$$

In order to obtain these asymmetries the COMPASS data taken with a longitudinally polarized or a transversely polarized ^6LiD target in the year 2004 have been spin averaged. The Boer-Mulders function is expected to contribute to the $\cos\phi_h$ and the $\cos 2\phi_h$ moments as well, together with the Cahn effect [19] which arises from the fact that the kinematics is non-collinear when k_T is taken into account.

The results of the $\cos\phi_h$ asymmetries are shown in FIGUREs 4 and 5. as a function of x, z and p_T .

Large asymmetries up to 15% are found for the $\cos\phi_h$ modulation and asymmetries in the order of 5% for the $\cos 2\phi_h$ modulation. They show strong dependence on x, z and P_T. The trend of the asymmetries for positive and negative hadrons are similar, however, the magnitudes of the two differs significantly.

SUMMARY

The investigation of transverse spin and TMD effects in SIDIS is one of the physics programs of the COMPASS at CERN. Recent results of COMPASS obtained with the data with transversely polarized proton and unpolarized deuteron target are presented. They give important information on the issues related to transversity and TMD distribution functions.

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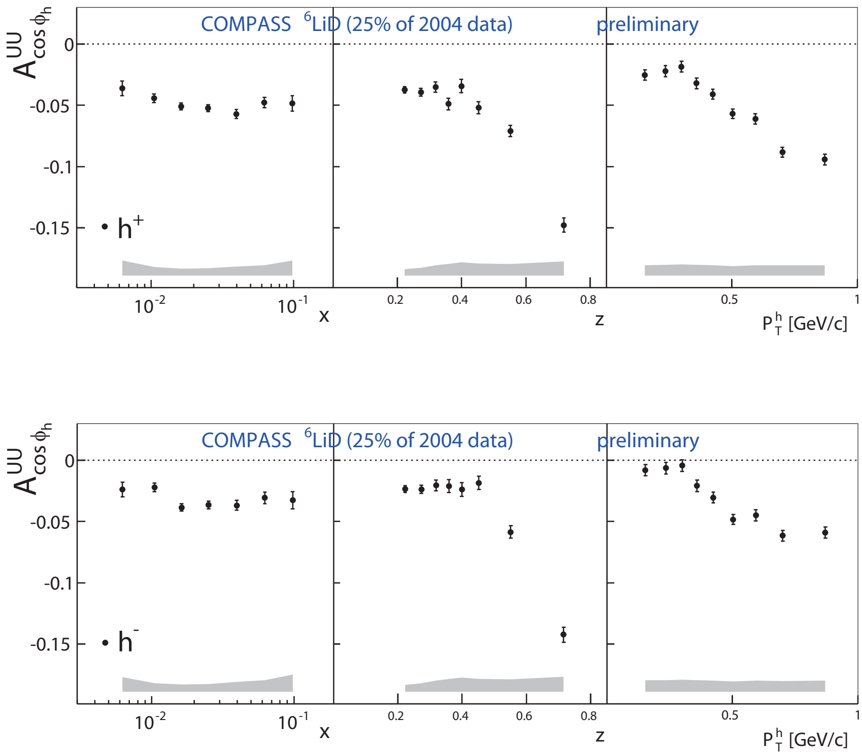

FIGURE 4. The azimuthal asymmetry of SIDIS on unpolarized deuteron target(^{6}LiD) $A^{UU}_{\cos\phi_h}$ for positive(upper row) and negative(lower row) hadrons.

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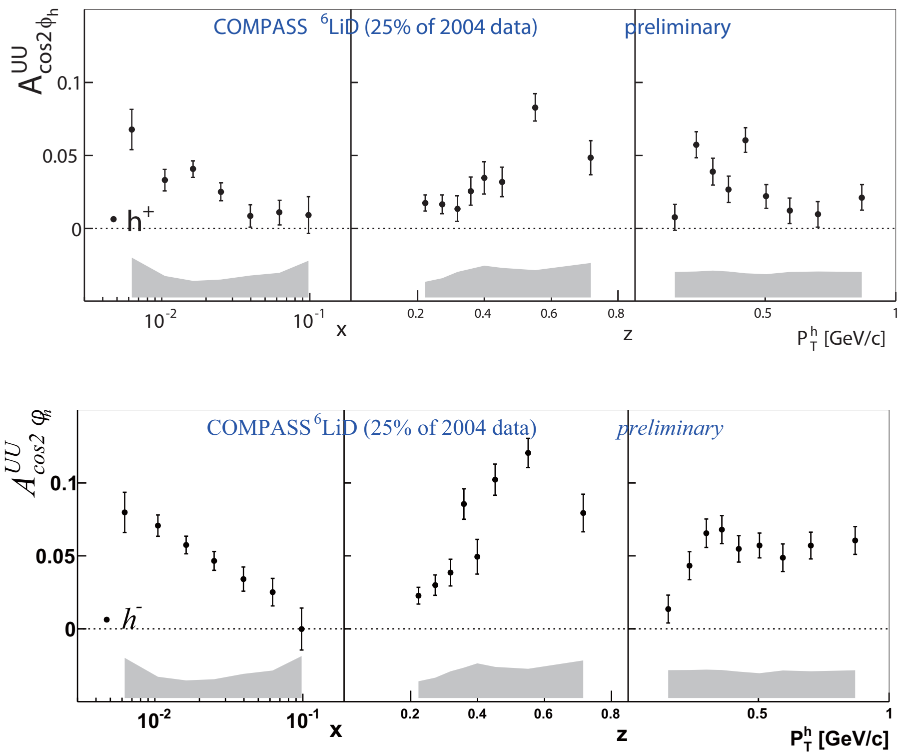

FIGURE 5. The azimuthal asymmetry of SIDIS on unpolarized deuteron target(^{6}LiD) $A^{UU}_{\cos 2\phi_h}$ for positive(upper row) and negative(lower row) hadrons.