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TMD measurements at COMPASS

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Summary. — In this contribution an overview of recent COMPASS results for transverse spin dependent azimuthal asymmetries in one- and two-hadron production is given. This includes the results on the third parton distribution function (PDF) h_1 defined in collinear QCD, the so-called "Transversity" which can be measured in combination with either the Collins fragmentation function or the interference fragmentation function (IFF). Taking into account the transverse momentum $\vec{k}_T$ of the quarks, more PDFs can be defined, which are transverse momentum dependent (TMD), like the Sivers function which describes an unpolarized quark in a transversely polarized nucleon. The transverse spin of the nucleon, the quark spin and its $\vec{k}_T$ give rise to 8 asymmetries in the semi-inclusive deep inelastic scattering (SIDIS) cross-section, among them are 4 leading-twist and 4 higher-twist. The latest COMPASS results of these data taken on a transversely polarized proton target (NH_3) and with a 160 GeV/c muon beam in the year 2010 are presented and compared to the corresponding results from HERMES and recent model predictions.

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1. – Collins and Sivers asymmetries

The Collins asymmetry A^P_{Coll} is the amplitude of the $\sin(\Phi_h + \Phi_S + \pi)$ modulation, divided by the target dilution factor f, the target polarization P_T and the spin transfer coefficient D_{nn}. The angle Φ_h is the azimuthal angle of the hadron and Φ_S the azimuthal angle of the nucleon spin both in the lepton-nucleon frame; UT means unpolarized beam and transversely polarized target. The Sivers asymmetry A^P_{Siv} is the amplitude of the $\sin(\Phi_h - \Phi_S)$ modulation divided by the target dilution factor f and the target polarization P_T. It gives the convolution of the Sivers function and the usual fragmentation function. Various COMPASS results on Collins and Sivers asymmetries on deuteron [1]

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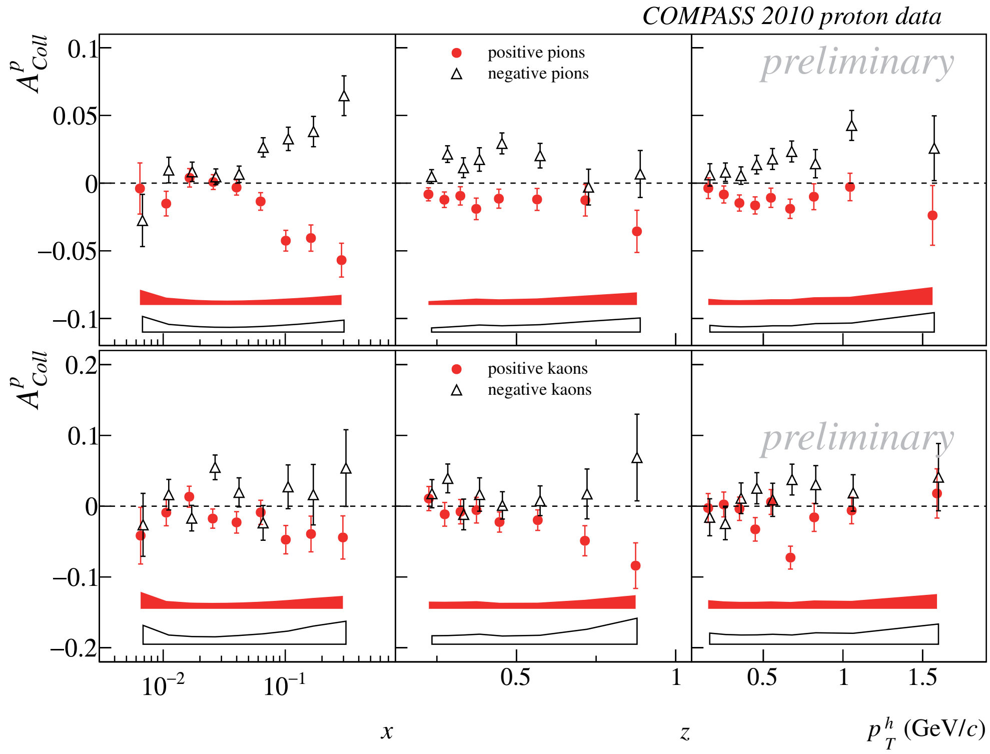

Fig. 1. – The 2010 proton data Collins asymmetries of pions (top) and kaons (bottom), positively (closed circles) and negatively (open triangles) charged.

and proton targets [2] are already published, most recently the Collins [3] and Sivers [4] asymmetries from unidentified hadrons, which are different from zero. In this latest analysis [5] the outgoing hadrons were identified using the RICH detector which allows to separate charged pions and kaons in the momentum range from 2.7 GeV/c for pions and from 9.7 GeV/c for kaons up to 50 GeV/c. The Collins asymmetry for charged pions and kaons [5] as a function of x, z and p_T^h is shown in fig. 1, top. The pion signal is compatible with zero for $x < 0.032$, while at larger x it is clearly different from zero, with an opposite sign for positive and negative pions and in good agreement, both in sign and in magnitude, with the results of unidentified hadrons and the HERMES results [6]. With its larger statistical uncertainty the Collins asymmetry of kaons (fig. 1, bottom) indicates some non-zero behavior in the high x and z regions. The Sivers asymmetry [5] does not show the kind of mirrored asymmetry for the different pion charges as in the Collins case, since for negative pions it is compatible with zero with some indication for small negative values until the second highest x bin. While for the positive pions the Sivers asymmetry is positive down to very low x values, thereby smaller than measured by HERMES [7] and not as pronounced as for positive kaons. In the region $x > 0.032$ this effect was recently investigated and is explained by a Q^2 dependence of the Sivers TMD [8]. This so-called TMD evolution can also explain the differences of the Sivers asymmetry of positive kaons, where HERMES measured larger amplitudes compared to COMPASS, hence for both the values are clearly positive.

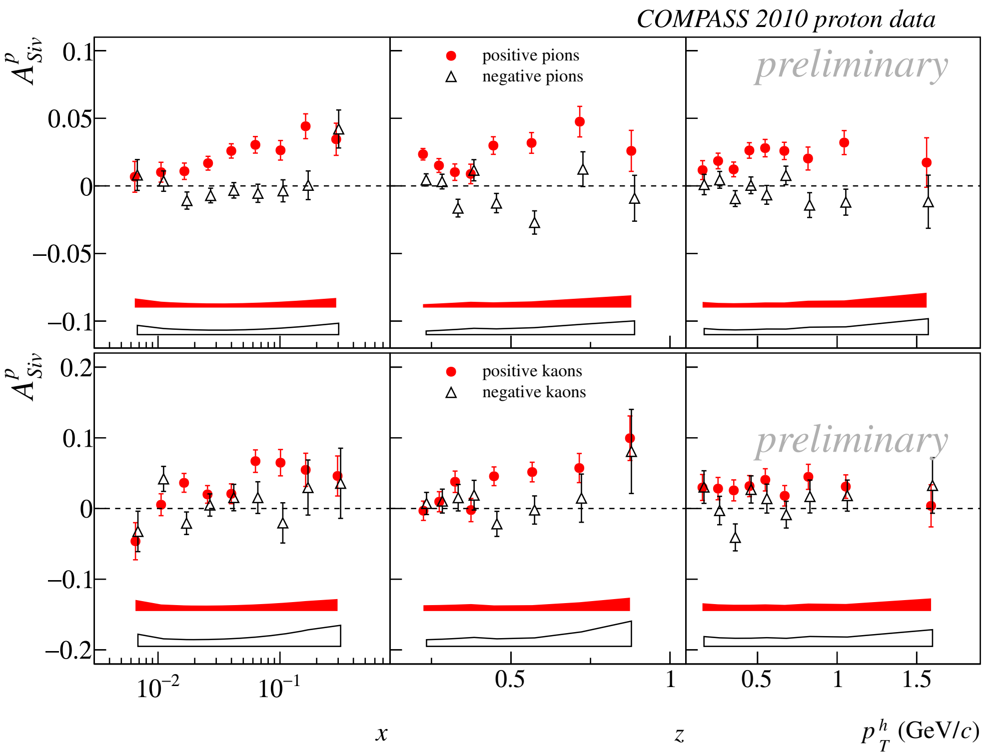

Fig. 2. – The 2010 proton data Sivers asymmetries of pions (top) and kaons (bottom), positively (closed circles) and negatively (open triangles) charged.

2. – The six "Beyond Collins and Sivers" asymmetries

Apart from the Collins and Sivers asymmetries, the target transverse spin dependent part of the SIDIS cross-section [9, 8] contains 6 more asymmetries. They are also well defined in terms of the QCD parton model as leading-twist, like Collins and Sivers, or higher-twist. Three of these asymmetries depend on the (longitudinal) beam polarization are double spin asymmetries. The asymmetries arise from the modulations in terms of ϕ_h and/or ϕ_S: $A_{LT}^{\cos(\phi_S)}$, $A_{LT}^{\cos(2\phi_h-\phi_S)}$, $A_{UT}^{\sin(2\phi_h-\phi_S)}$, $A_{UT}^{\sin(3\phi_h-\phi_S)}$, $A_{LT}^{\cos(\phi_h-\phi_S)}$ and $A_{UT}^{\sin(\phi_S)}$. For the presented results these 6 amplitudes [10] are extracted from the data together with A_{UT}^{Coll} and A_{UT}^{Siv} within a single multidimensional unbinned likelihood fit; therefore the whole data selection and analysis procedure is congruent to the recent published Collins and Sivers data. Concerning the first 4 asymmetries of all charged hadrons shown in fig. 3, namely $A_{LT}^{\cos(\phi_S)}$, $A_{LT}^{\cos(2\phi_h-\phi_S)}$, $A_{UT}^{\sin(2\phi_h-\phi_S)}$ and $A_{UT}^{\sin(3\phi_h-\phi_S)}$, there is no evidence of a non-zero amplitude within the statistical uncertainties. On the other hand the leading-twist $A_{LT}^{\cos(\phi_h-\phi_S)}$ double spin asymmetrie and the higher-twist $A_{UT}^{\sin(\phi_S)}$ single spin asymmetrie are found to have a clear non-zero trend within the statistical uncertainties, for the latter with different signs for different hadron charge. This observation of 4 modulations being compatible with zero, whereas $A_{LT}^{\cos(\phi_h-\phi_S)}$ and $A_{UT}^{\sin(\phi_S)}$ showing a clear signal has also been made by the HERMES Collaboration [11].

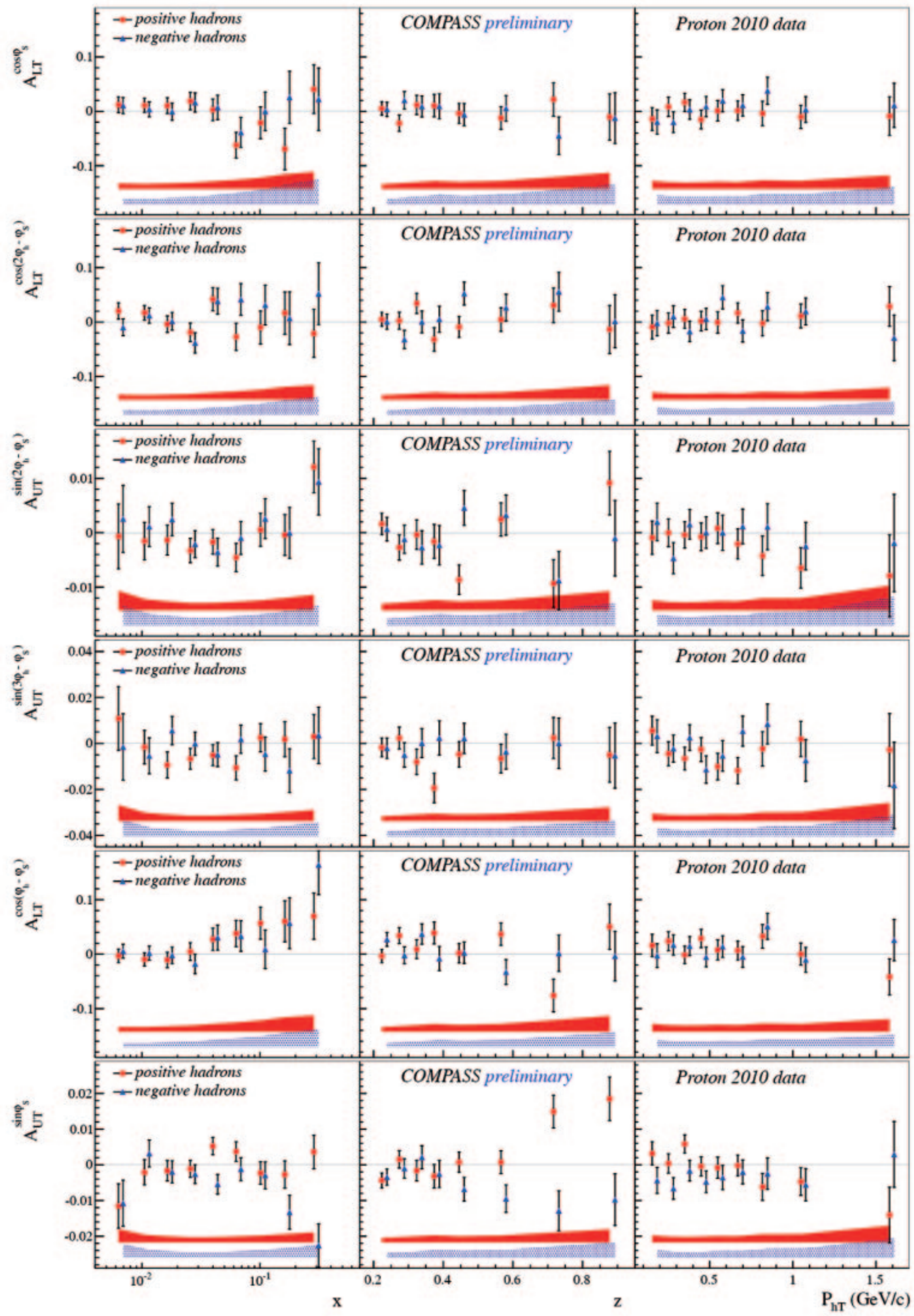

Fig. 3. – The six "beyond Collins and Sivers" transverse spin asymmetries extracted from 2010 proton data: $A_{LT}^{\cos(\phi_S)}$, $A_{LT}^{\cos(2\phi_h-\phi_S)}$, $A_{UT}^{\sin(2\phi_h-\phi_S)}$, $A_{UT}^{\sin(3\phi_h-\phi_S)}$, $A_{LT}^{\cos(\phi_h-\phi_S)}$ and $A_{UT}^{\sin(\phi_S)}$ (from top to bottom) of positively (circles) and negatively (triangles) charged hadrons.

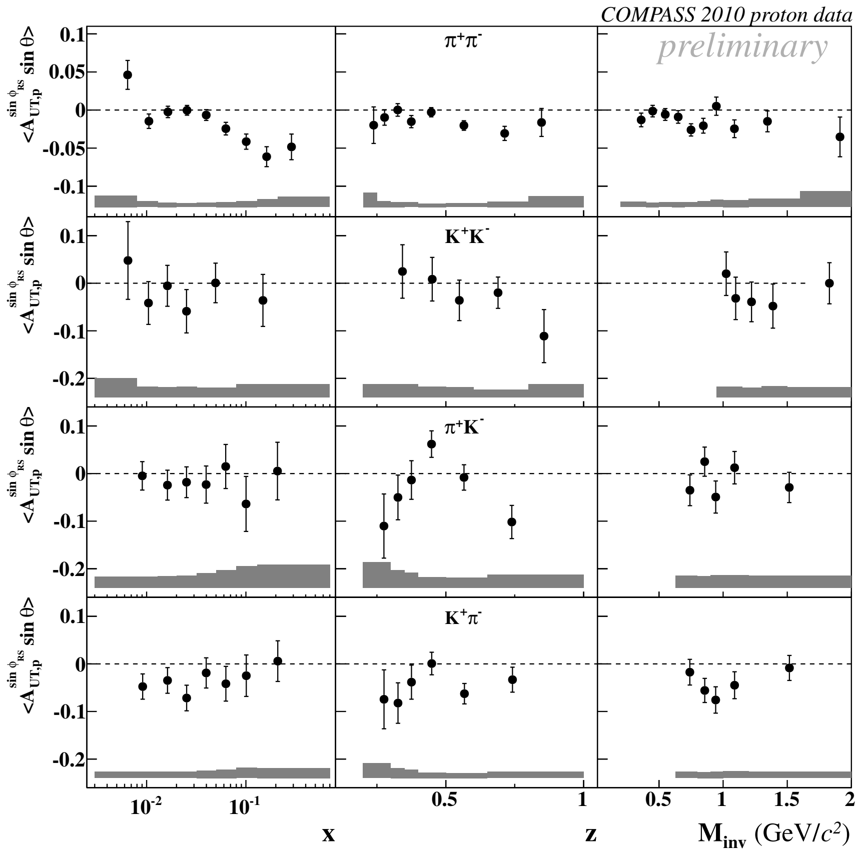

Fig. 4. – The identified two-hadron asymmetries extracted from 2010 proton data: $\pi^+\pi^-$, K^+K^-, π^+K^- and $K^+\pi^-$ pairs (top to bottom).

3. – Two-hadron asymmetries

An alternative way to access the h_1 PDF is its combination with the IFF in two-hadron production. A first measurement of the asymmetry of h^+h^- pairs from a polarized deuteron target was already performed by COMPASS in the years 2002-04 [12]. The results of the two independent measurements of the two-hadron asymmetries on a proton target in 2007 [12] and 2010 are in very good agreement. As described in sect. **1** particle identification can be used to determine the composition of the h^+h^- pairs in terms of pions and kaons. The results [13] for the possible combinations $\pi^+\pi^-$, K^+K^-, π^+K^- and $K^+\pi^-$ are shown in fig. 4. The pion pair asymmetries show a clear signal up to -6% in x, the z dependence is compatible with a constant and for M_{inv} a peak around the ρ^0 mass is found. Exclusively produced ρ^0 mesons were already excluded by a dedicated cut. In contrast the kaon pairs with their large statistical uncertainties show asymmetries compatible with zero, while an indication of a negative mean value in M_{inv} as large as for pion pairs is given. The asymmetries of π^+K^- pairs *vs.* x and *vs.* M_{inv} are mostly compatible with zero, but there might be a possible z-dependence. Negative mean values for all three dependences are measured for the $K^+\pi^-$ pairs. The $\pi^+\pi^-$ asymmetry was also measured by the HERMES experiment [14]. The overall agreement

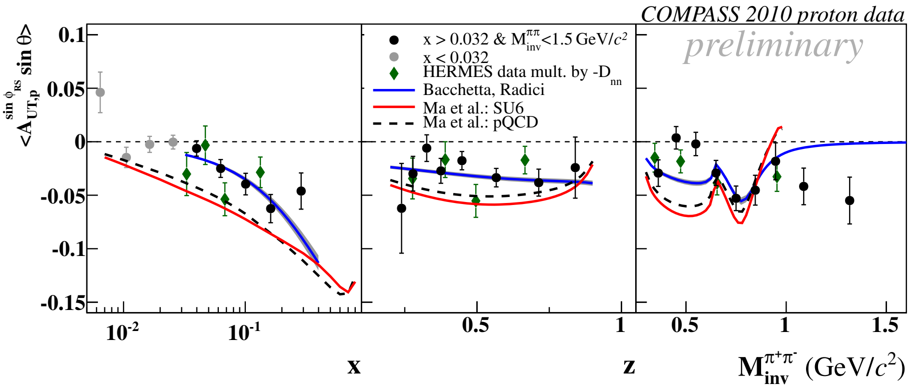

Fig. 5. – The $\pi^+\pi^-$-pair asymmetries for $x > 0.032$ extracted from 2010 proton data in comparison with HERMES data of ref. [14] and model predictions of refs. [15, 16].

between these two experiments is good within the uncertainties (fig. 4) bearing in mind the larger kinematic range of COMPASS. This is an interesting result, particularly due to the different $\langle Q^2 \rangle$ values in the valence region for the two experiments. The available model predictions by Bacchetta *et al.* [15] and Ma *et al.* [16] show a good confirmation of the trend in x and z, as well as for the peak around the ρ^0 mass, see fig. 5. A recent extraction of h_1 via the two-hadron IFF can be found in [17].

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