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COMPASS results on transverse-spin asymmetries in two-hadron production in SIDIS

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Summary. — COMPASS is a fixed-target experiment at the CERN M2 beamline, with a rich physics program in spectroscopy and nucleon structure. The nucleon spin structure is investigated using a 160 GeV/c polarized μ^+ beam and polarized solid state targets. The measurements of single-spin asymmetries in semi-inclusive deep inelastic scattering (SIDIS) on a transversely polarized target are an important part of the COMPASS physics program. A transversely polarized ^{6}LiD (deuteron) target was used in 2002–2004. After taking the first data on a transversely polarized NH_3 (proton) target in 2007, a full year of data taking followed in 2010 to increase precision. In this contribution we present for the first time the results from the 2010 data for the azimuthal asymmetries in two-hadron production which allow to investigate the transversity distribution function coupled to the two-hadron interference fragmentation function (FF).

PACS 13.60.-r – Photon and charged-lepton interactions with hadrons.
PACS 13.88.+e – Polarization in interactions and scattering.
PACS 21.10.Hw – Spin, parity, and isobaric spin.

1. – Theoretical framework

The quark content of the nucleon at twist-two level can be fully characterized in the collinear case by three independent parton distribution functions (PDF) for each quark flavour q: the quark number density $f_1^q(x)$ if the nucleon is unpolarised, the helicity distribution $g_1^q(x) = q_q^+(x) - q_q^-(x)$ in the case of longitudinal polarizations—$q^+(q^-)$ is the density of quarks with spin parallel (antiparallel) to the direction of the nucleon spin— and the transversity distribution $h_1^q(x) = q_q^{\uparrow\uparrow}(x) - q_q^{\uparrow\downarrow}(x)$ [1], respectively, in the transverse case. The notation $\uparrow\uparrow$ means quark spin parallel and $\uparrow\downarrow$ antiparallel to the spin of the nucleon. The transversity function is chiral-odd and therefore is not

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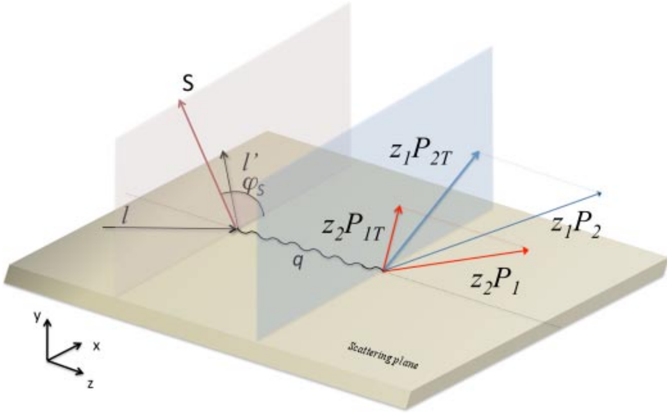

Fig. 1. – Schema of $lN^\uparrow \to l'hh$. $\mathbf{p}_{1,\mathrm{T}}$ and $\mathbf{p}_{2,\mathrm{T}}$ are the components of hadron momenta perpendicular to $\mathbf{q}$.

accessible in inclusive deep inelastic scattering (DIS). $h_1^q(x)$ can be observed in SIDIS in combination with another chirally odd function, *e.g.*, the two-hadron interference fragmentation function $H_{1,q}^{\sphericalangle}$ [2] in two-hadron production, which is the subject of this contribution. Other possible channels which have also been measured at COMPASS are the production of single hadrons using the Collins effect [3] and the Λ polarization [4]. A schema of the reaction $lN^\uparrow \to l'hh$ is shown in fig. 1. The incoming lepton (in the COMPASS case a μ^+), the scattered lepton and the virtual photon γ with their 3-momenta $\mathbf{l}, \mathbf{l}'$ and $\mathbf{q}$ define the scattering plane. $\mathbf{R} = (z_2\mathbf{p}_1 - z_1\mathbf{p}_2)/(z_1 + z_2)$ is the normalized relative hadron momentum with the momenta of the two hadrons $\mathbf{p}_1$ and $\mathbf{p}_2$. Its azimuthal angle is defined by [5]:

(1) $$\Phi_R = \frac{(\mathbf{q}\times\mathbf{l})\cdot\mathbf{R}}{|(\mathbf{q}\times\mathbf{l})\cdot\mathbf{R}|}\arccos\left(\frac{(\mathbf{q}\times\mathbf{l})\cdot(\mathbf{q}\times\mathbf{R})}{|\mathbf{q}\times\mathbf{l}|\,|\mathbf{q}\times\mathbf{R}|}\right).$$

In the SIDIS cross section of a transversely polarized quark into two unpolarized hadrons Φ_R and the azimuthal angle of the spin of the initial quark Φ_S appear in an azimuthal modulation as a function of the angle $\Phi_{RS} = \Phi_R + \Phi_S - \pi$ [6]:

(2) $$\frac{\mathrm{d}^7\sigma}{\mathrm{d}\cos\theta\,\mathrm{d}M_h^2\,\mathrm{d}\Phi_R\,\mathrm{d}z\,\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}\Phi_S} = \frac{\alpha^2}{2\pi Q^2 y}\Bigg(\left(1 - y + \frac{y^2}{2}\right)\sum_q e_q^2 f_1^q(x) D_{1,q}(z, M_h^2, \cos\theta) + (1-y)S_\perp \sum_q e_q^2 \frac{|\mathbf{p}_1 - \mathbf{p}_2|}{2M_h}\sin(\Phi_{RS})\sin(\theta) h_1^q(x) H_{1,q}^{\sphericalangle}(z, M_h^2, \cos\theta)\Bigg).$$

Accordingly the number of produced pairs $N_{2h}^{\pm}$ is given by

(3) $$N_{2h}^{\pm}(\Phi_{RS}) = N_{2h}^0(1 \pm f(x,y) P_T D_{NN}(y) A_{2h} \sin\Phi_{RS}\sin\theta)\,,$$

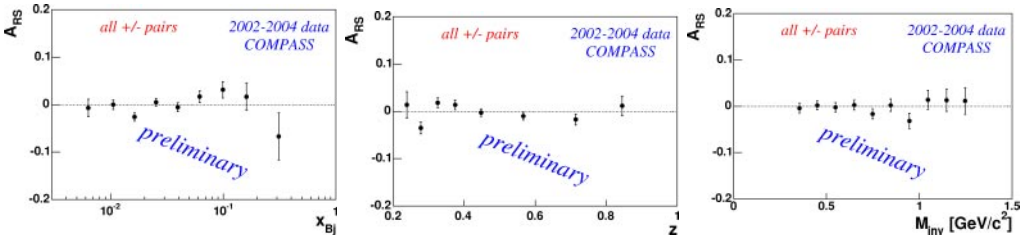

Fig. 2. – 2002–2004 deuteron data two-hadron asymmetries of h^+h^--pairs from [8].

where the asymmetry amplitude A_{2h} can be written as

$$A_{2h} \propto \frac{|\mathbf{p}_1 - \mathbf{p}_2|}{2M_h} \frac{\sum_q e_q^2 \cdot h_1^q(x) \cdot H_{1,q}^{\sphericalangle}(z, M_h^2, \cos\theta)}{\sum_q e_q^2 \cdot f_1^q(x) \cdot D_{1,q}(z, M_h^2, \cos\theta)}. \tag{4}$$

In eq. (3) the $\pm$ signs indicate the spin orientation of the nucleon, $f(x, y)$ gives the fraction of events originating from polarised protons or deuterons relative to all events, P_T the target polarization and $D_{NN}(y) = (1-y)/(1-y+\frac{y^2}{2})$ the transvers spin transfer coefficient. The latest results on the fragmentation function $D_{1,q}$ can be found in ref. [7].

2. – Data selection

The data selection follows the analysis of the single hadron spin asymmetries of the 2010 proton data, which is very similar to that of the data collected in the previous years. To select DIS events, kinematic cuts on the squared four momentum transfer ($Q^2 > 1\,(\text{GeV}/c)^2$), the fractional energy transfer of the muon ($0.1 < y < 0.9$) and the hadronic invariant mass ($W > 5\,\text{GeV}/c^2$) were applied. The hadron pair sample requires more selection w.r.t. to the one-hadron asymmetry analysis [3], in particular the requirement for a vertex with at least 3 outgoing tracks (a scattered μ^+ and two hadrons) is essential. All possible combinations of oppositely charged hadron pairs originating from the vertex are taken into account in the analysis. Each of these hadrons has to have a $z > 0.1$ and a $x_F > 0.1$, to ensure that the hadron is not produced by target fragmentation. Exclusively produced ρ^0-mesons are rejected by a cut on the missing energy $E_{miss} > 3\,\text{GeV}$, which is the Lorentz invariant difference of the energy of the pair system w.r.t. the energy of the gamma-nucleon system (fig. 4 middle). Finally a cut of $|\mathbf{R_T}| > 0.07\,\text{GeV}/c$, which is the absolute value of the component of $\mathbf{R}$ perpendicular to $\mathbf{q}$ ensures a good definition of the azimuthal angle Φ_R. After all cuts the 2010 statistics consists of $34.56 \cdot 10^6\, h^+h^-$-pairs.

3. – Results from the deuteron data

The two-hadron asymmetries for the data collected in 2002–2004 for the deuteron target are consistently small and compatible with zero within the error bars (fig. 2). Furthermore no specific trend is visible for their depenence on x, z and M_{inv}. For these data also a sample with identified hadrons is available (not shown here). The asymmetries of all hadron pairs are driven by the asymmetries of $\pi^+\pi^-$-pairs. The statistics of kaon sample is smaller and again the asymmetries are compatible with zero.

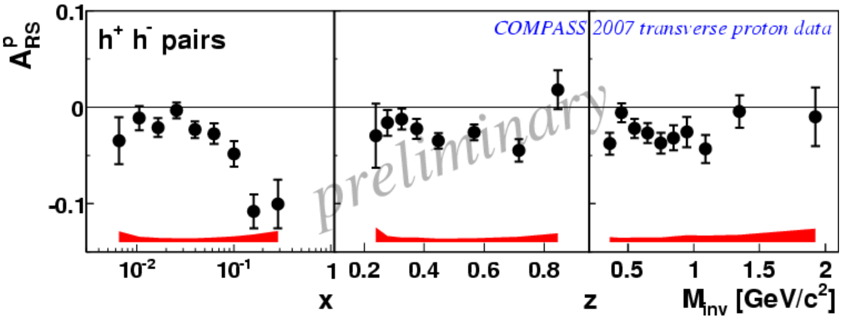

Fig. 3. – 2007 proton data two-hadron asymmetries of h^+h^--pairs from ref. [9].

4. – Results from the proton data: 2007

The first measurement of a two-hadron asymmetry on a proton target at COMPASS where performed using the data collected in 2007. The results as a function of x, z and M_{inv} are shown in fig. 3. A large asymmetry up to 5–10% in the valence x-region has been measured. This implies a non-zero transversity distribution and a non-zero polarized two hadron intererfence FF $H_{1,q}^{\sphericalangle}$. A first extraction of the transversity distribution using these data can be found in ref. [10]. For the z-dependence no specific trend is visible, while for the invariant mass a negative signal around the ρ^0 mass of $0.77\,\mathrm{GeV}/c^2$ is observed and the asymmetry is negative over the whole mass range.

5. – Results from the proton data: 2010

The whole COMPASS beam time in 2010 was dedicated to measure the spin asymmetries on transversely polarized protons. As for the Collins and Sivers asymmetries [3], for the two-hadron sample the final statistics is larger than in 2007, and in this case we gain a factor of 3.5. To reject exclusively produced ρ^0-meson, which form a peak at 1 in the distribution of the sum of the z values of the two hadrons (fig. 4 middle) a cut in the missing energy was applied. In fig. 4 (left) this cut at $E_{miss} > 3\,\mathrm{GeV}$ is shown. The resulting invariant mass distribution is shown in fig. 4 (right). The peaks of the K^0- and the ρ^0-meson are clearly visible around 0.5 and $0.77\,\mathrm{GeV}/c^2$ respectively assuming the pion mass for all hadrons.

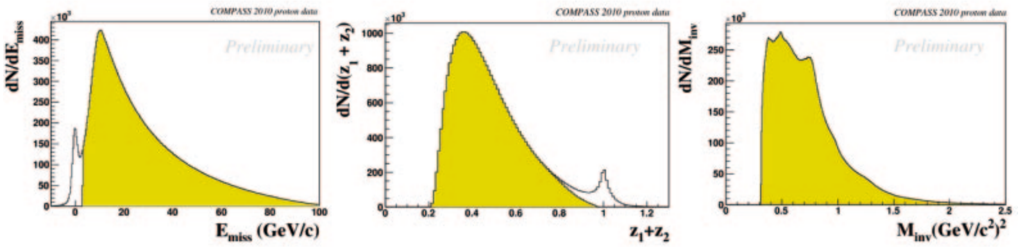

Fig. 4. – Missing energy E_{miss} for hadron pairs (left), $z_{sum} = z_1 + z_2$ (middle) and invariant mass M_{inv}-distribution (right). The final data sample after all cuts is shown in yellow.

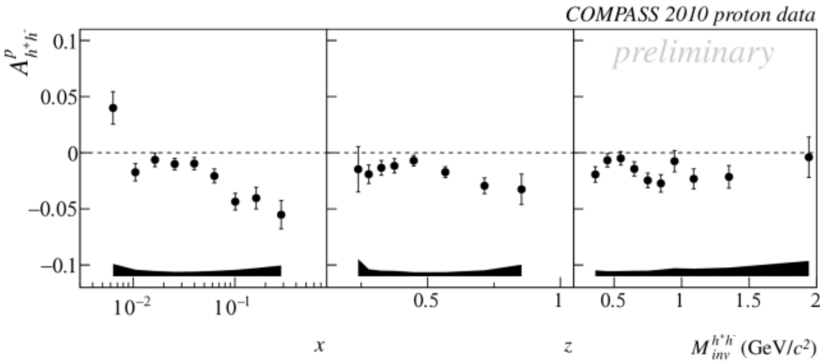

Fig. 5. – 2010 proton data two-hadron asymmetries of h^+h^--pairs.

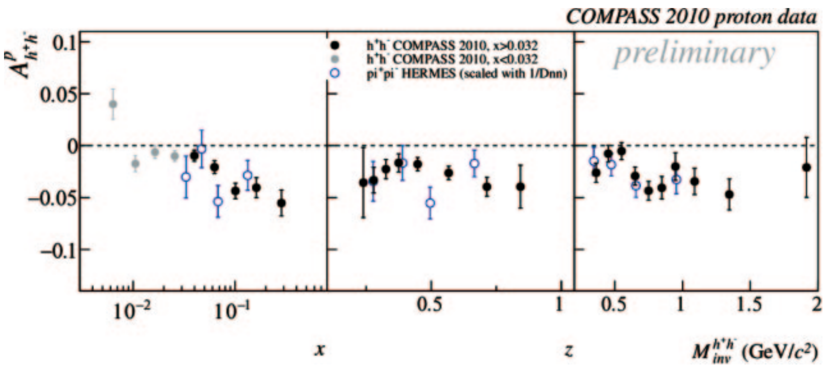

Fig. 6. – 2010 proton data in comparison with HERMES data [11-13].

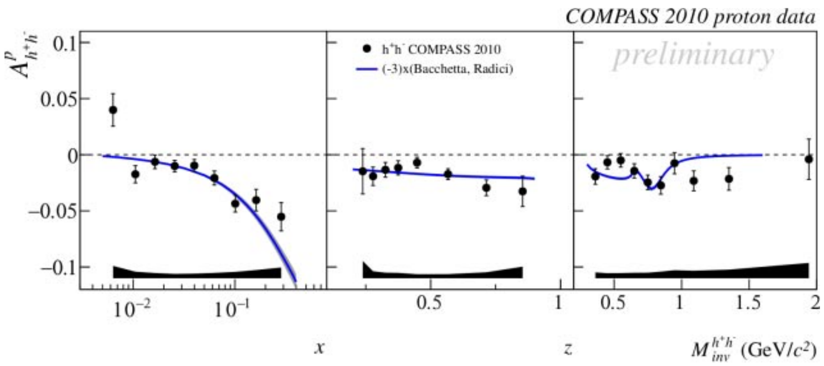

Fig. 7. – 2010 proton data in comparison with model predictions from refs. [14, 15].

This independent measurement of the two-hadron asymmetry on a polarized proton target by COMPASS is shown in fig. 5. It is in good agreement with the results from 2007, with an overall reduction in the statistical error of about a factor of 1.7. The systematic error is given by the error band. The signal in the x valence region is confirmed. A linear trend with a negative asymmetry in z, and the structure in M_{inv} are congruent. The two-hadron asymmetry was also measured by the HERMES experiment [11]. To allow a comparison with their results for identified $\pi^+\pi^-$-pairs, their released asymmetry values have to be scaled with $\langle 1/D_{nn} \rangle \approx 3$ [12, 13] (HERMES published lepton-nucleon asymmetries, while COMPASS calculates photon-nucleon asymmetries) and multiplied by -1 due to an additional phase π in the definition of Φ_{RS} in the COMPASS analysis.

Furthermore the minimum z-cut applied in the COMPASS data rejects contribution of products of a possible target fragmentation. The overall agreement between HERMES and COMPASS is good within the error bars (fig. 6) bearing in mind the larger kinematical range in x and M_{inv} of COMPASS. This is an important result, also because of the different $\langle Q^2 \rangle$ values for the two experiments at large x, where the signal is large. The prediction for the two-hadron asymmetry from the model of Bacchetta and collaborators [14] is shown in fig. 7. Since the prediction was fitted to the HERMES data [15], it has been rescaled by the $1/D_{nn}$ factor. For the x dependence of the asymmetry the agreement is good and the trend is clearly visible, in the cases of z it implies a more linear behavior and for M_{inv} the agreement is fair. On the contrary, the agreement between model predictions of ref. [16] (not shown here) and the data is in general poorer.

6. – Conclusions and outlook

Now a large set of COMPASS two-hadron data on transversely polarized targets is available, consisting of the deuteron data and two independent measurements on the proton. The present preliminary results from 2010 data are in agreement with the previous COMPASS data, the HERMES data and the available model predictions. The small systematic uncertainties and high statistics of the data will allow more studies of these interesting asymmetry. In particular in a next step the asymmetries for identified hadron pairs, containing $\pi^+\pi^-$ and also charged kaons, will be extracted.

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