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 where 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 distribution $f_1^q(x) = q_q^+(x) + q_q^-(x)$ if the nucleon and its quark content are unpolarised, the helicity distribution $g_1^q(x) = q_q^+(x) - q_q^-(x)$ in the case of longitudinal polarizations and the transversity distribution $h_1^q(x) = q_q^{\uparrow\uparrow}(x) - q_q^{\uparrow\downarrow}(x)$ [1] respectively in the transvers case. $\uparrow\uparrow$ means quark spin parallel and $\uparrow\downarrow$ antiparallel to the spin of the nucleon. The transversity function is chiral-odd and therefore is not 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 one 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].

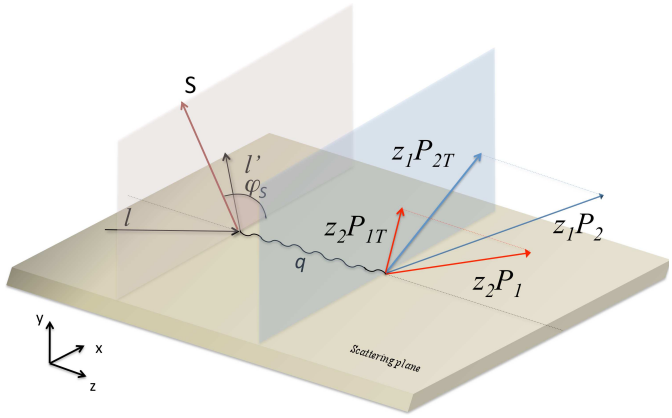

Fig. 1. – Schema of $lN^{\uparrow} \to l'hh$. $\mathbf{p_{1,T}}$ and $\mathbf{p_{2,T}}$ are the components of hadron momenta perpendicular to $\mathbf{q}$.

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]:

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

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 $\Phi_{RS} = \sin(\Phi_R + \Phi_S - \pi)$ [6].

$$\frac{\mathrm{d}^7\sigma}{\mathrm{d}\cos\theta\ \mathrm{d}M_h^2\ \mathrm{d}\Phi_R\ \mathrm{d}z\ \mathrm{d}x\ \mathrm{d}y\ \mathrm{d}\Phi_S} = \frac{\alpha^2}{2\pi Q^2 y}\Big((1-y+\frac{y^2}{2})\sum\nolimits_q e_q^2 f_1^q(x)D_{1,q}(z,M_h^2,\cos\theta) + (1-y)S_\perp\sum\nolimits_q e_q^2\frac{|\mathbf{p_1}-\mathbf{p_2}|}{2M_h}\sin(\Phi_{RS})\sin(\theta)h_1^q(x)H_{1,q}^{\sphericalangle}(z,M_h^2,\cos\theta)\Big). \tag{2}$$

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

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

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

In the description of the data selection we focus on the analysis 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 $Q^2 > 1\,(\mathrm{GeV}/c)^2$, the fractional energy transfer of the muon $0.1 < y < 0.9$ and the hadronic invariant mass $W > 5\,\mathrm{GeV}/c^2$ were applied. The hadron pair sample requires more selection w.r.t. to the one-hadron asymmetry analysis [3], of which the requirement for a vertex with 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 $x_\mathrm{F} > 0.1$, 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 $E_{miss} > 3\,\mathrm{GeV}$, 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 $|\mathbf{R_T}| > 0.07\,\mathrm{GeV}/c$, 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 2002-04 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 this data also a sample with identified hadrons is available (not shown here). The asymmetries of all hadron pairs are determined by the asymmetries of $\pi^+\pi^-$-pairs. The statistics of the sample including kaons is smaller and again the asymmetries are compatible with zero.

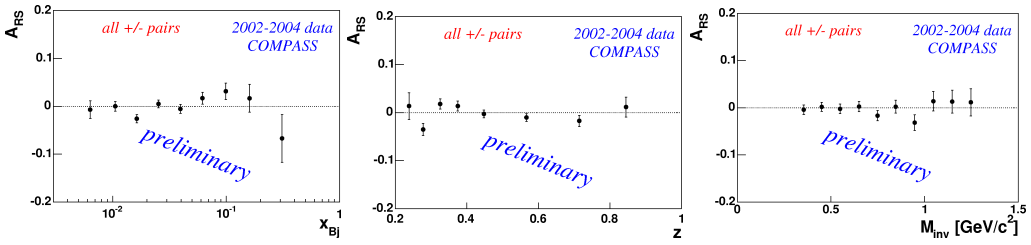

Fig. 2. – 2002-2004 deuteron two-hadron asymmetries of h^+h^--pairs from [8]

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 intererence FF $H_{1,q}^{\sphericalangle}$. A first extraction of the transversity with 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.

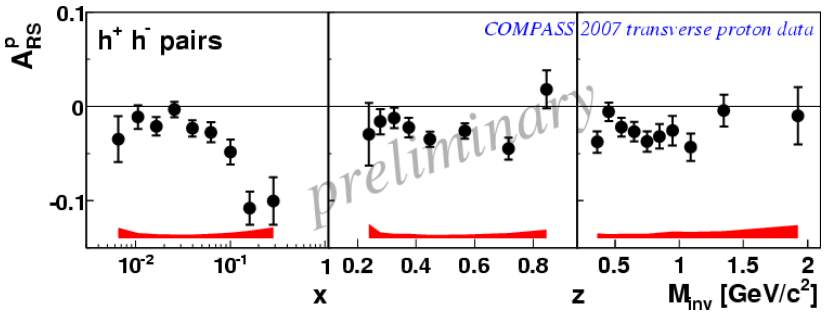

Fig. 3. – 2007 proton two-hadron asymmetries of h^+h^--pairs from ref. [9]

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 with higher precision. 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.

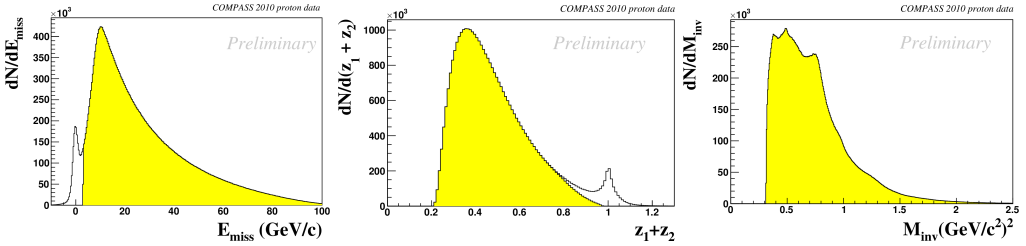

Fig. 4. – Missing energy E_{miss} for hadron pairs (left), $z_{sum} = z_1 + z_2$ (middle) and invariant mass M_{inv}-distribution (right). The final data sample after all cuts is shown in yellow.

This independent measurement of the two-hadron asymmetry by COMPASS 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 systematical 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 comparsion 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] and multiplied by -1 due to an additional phase π in the angle definition of Φ_{RS} in the

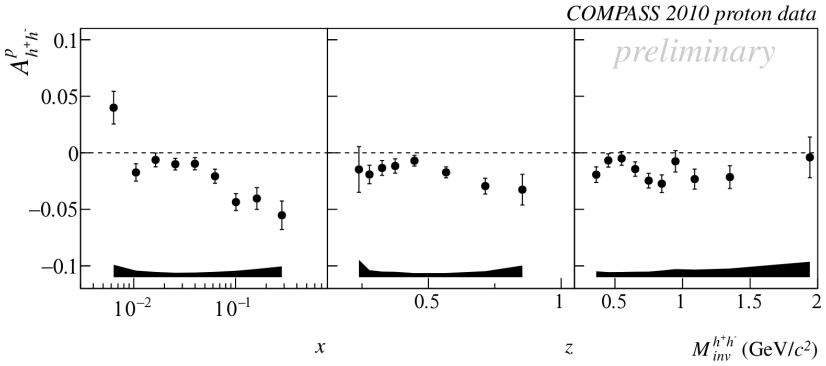

Fig. 5. – 2010 proton data two-hadron asymmetries of h^+h^--pairs

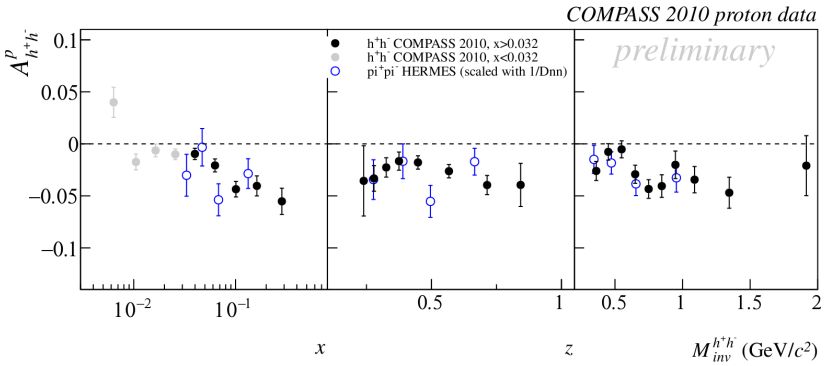

Fig. 6. – 2010 proton data in comparison with HERMES data [11, 12, 13]

COMPASS analysis. HERMES published lepton-nucleon asymmetries, while COMPASS calculates photon-nucleon asymmetries. 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 in the signal window for the two experiments. The prediction for the two-hadron asymmetry from the model of Bachetta and collaborators [14] were scaled with this factor of about -3 to undo the adaptation made to fit the HERMES data [16]. This is shown in fig. 7, 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. While the agreement between model predictions of ref. [15] (not shown here) and the data is in general poorer.

6. – Conclusions & Outlook

Now a large set of COMPASS two-hadron data on a transversely polarized target 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 pre-

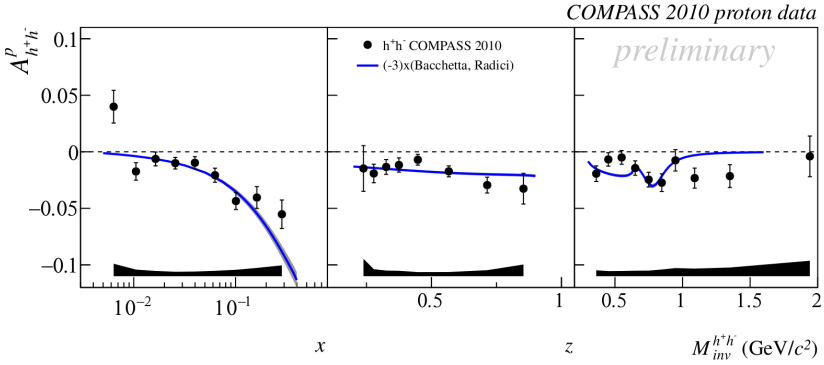

Fig. 7. – 2010 proton data in comparison with model predictions from refs. [14, 16]

vious 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 extracting the asymmetries for identified hadron pairs, containing $\pi^+\pi^-$ and also charged kaons.

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