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

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COMPASS is a fixed target experiment at CERN where nucleon spin structure and hadron spectroscopy are investigated. An important part of its physics program are the measurements of single spin asymmetries in semi-inclusive deep inelastic scattering on transversely polarized targets. Data on a deuteron target were taken in 2002-2004. After taking the first data on a transversely polarized proton target in 2007, a full year of data taking followed in 2010 to increase precision. In this contribution we present the latest results for the azimuthal asymmetries in two-hadron production which allow to investigate the transversity distribution function coupled to the two-hadron interference fragmentation function.

## 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): the quark distribution $f_1$, the helicity distribution $g_1$ and the transversity distribution $h_1$. The latter is chiral-odd and therefore is not accessible in inclusive deep inelastic scattering (DIS). $h_1$ can be observed in semi-inclusive DIS in combination with another chirally odd function *e.g.* the two-hadron interference fragmentation function (FF) $H_1^{\sphericalangle}$ 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 [1] and the $\Lambda$ polarization. A schema of the reaction $lN^{\uparrow} \to l'hh$ is shown in fig. 1. The incoming lepton (in the COMPASS case a 160 GeV/$c^2$ polarized $\mu^+$), the scattered lepton and the virtual photon $\gamma$ 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 $\mathbf{p_2}$. The angle $\Phi_R$ between the two-hadron plane and the scattering

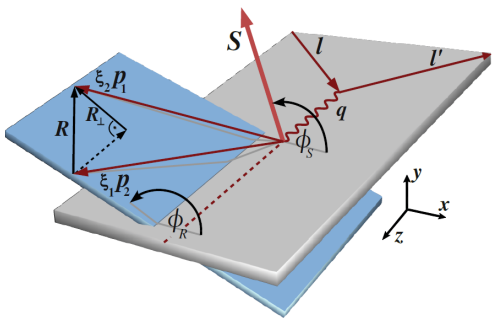


Figure 1: Definition of the azimuthal angles $\Phi_R$ and $\Phi_S$ in two-hadron production, where $l, l', q$ and $p_i$ are the 3-momenta of beam, scattered muon, virtual photon and hadrons.

plane is defined by $\frac{(\mathbf{q}\times\mathbf{l})\cdot\mathbf{R}}{|(\mathbf{q}\times\mathbf{l})\cdot\mathbf{R}|}\arccos\left(\frac{(\mathbf{q}\times\mathbf{l})\cdot(\mathbf{q}\times\mathbf{R})}{|\mathbf{q}\times\mathbf{l}||\mathbf{q}\times\mathbf{R}|}\right)$ [2]. In the SIDIS cross section of a transversely polarized quark into two unpolarized hadrons $\Phi_R$ and the azimuthal angle of the spin of the initial quark $\Phi_S$ appear in an azimuthal modulation as a function of $\Phi_{RS} = \sin(\Phi_R + \Phi_S - \pi)$ [3].

$$\frac{\mathrm{d}^7\sigma}{\mathrm{d}\cos\theta\ \mathrm{d}M_{inv}^2\ \mathrm{d}\Phi_R\ \mathrm{d}z\ \mathrm{d}x\ \mathrm{d}y\ \mathrm{d}\Phi_S} = \frac{\alpha^2}{2\pi Q^2 y}\Big((1-y+\frac{y^2}{2})\sum_q e_q^2 f_1^q(x) D_1(z, M_{inv}^2, \cos\theta) + (1-y)S_\perp \sum_q e_q^2 \frac{|\mathbf{p_1}-\mathbf{p_2}|}{2M_{inv}}\sin(\Phi_{RS})\sin(\theta) h_1^q(x) H_1^{\sphericalangle}(z, M_{inv}^2, \cos\theta)\Big) \ . \tag{1}$$

Accordingly one gets the number of produced pairs $N_{2h}^{\pm}(\Phi_{RS}) = N_{2h}^0(1 \pm f(x,y) P_T D_{NN}(y) A_{2h} \sin\Phi_{RS}\sin\theta)$ , where the asymmetry amplitude $A_{2h}$ can be written as

$$A_{2h} \propto \frac{|\mathbf{p_1}-\mathbf{p_2}|}{2M_{inv}} \frac{\sum_q e_q^2 \cdot h_1^q(x) \cdot H_1^{\sphericalangle}(z, M_{inv}^2, \cos\theta)}{\sum_q e_q^2 \cdot f_1^q(x) \cdot D_1(z, M_{inv}^2, \cos\theta)} \ . \tag{2}$$

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 unpolarized dihadron fragmentation function $D_1$ can be found in ref. [4].

## 2 Data selection

In the description of the data selection we focus on the analysis of the 2010 proton ($NH_3$ target) data, which is very similar to that of the data collected in the previous years. To select DIS events, kinematic cuts on $Q^2 > 1$ GeV/$c^2$, the fractional energy transfer of the muon $0.1 < y < 0.9$ and the hadronic invariant mass $W > 5$ GeV/$c^2$ were applied. The hadron pair sample requires more selection *w.r.t.* the one-hadron asymmetry analysis [1], of which the requirement for a vertex with 3 outgoing tracks (a scattered $\mu^+$ and two hadrons) is essential. All possible combinations of oppositely charged hadron pairs originating from the vertex are taken into account, each of these hadrons has to have a $z > 0.1$ and a $x_F > 0.1$, to exclude products of target fragmentation. Exclusively produced $\rho^0$ mesons are rejected by a cut on the missing energy $E_{miss} > 3$ GeV, which is the Lorentz invariant difference of the energy of the pair system *w.r.t.* the energy of the $\gamma$-nucleon system. Finally a cut of $|\mathbf{R_T}| > 0.07$ 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 $\Phi_R$. After all cuts the 2010 statistics consists of $34.56 \cdot 10^6$ $h^+h^-$-pairs.

## 3 Results from the deuteron and proton data until 2007

The two-hadron asymmetries for the data collected in 2002-04 for the deuteron ($^6$LiD) target are consistently small and compatible with zero within the error bars (fig. 2 upper part). Furthermore no specific trend is visible for their depenence on $x$, $z$ and $M_{inv}$.
The first measurement of a two-hadron asymmetry on a proton target at COMPASS were performed using the data collected in 2007. The results [5] as a function of $x$, $z$ and $M_{inv}$ are shown in the lower part of fig. 2. 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

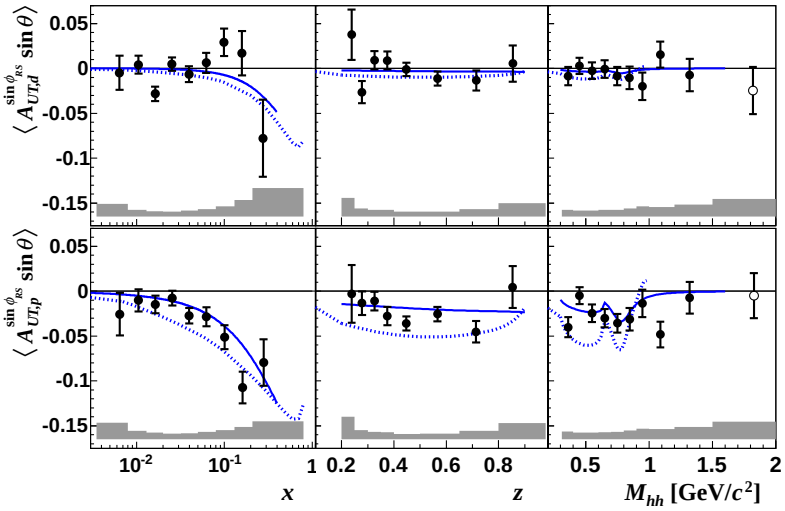


Figure 2: 2002-2004 deuteron (top) and 2007 proton (bottom) two-hadron asymmetries of $h^+h^-$-pairs in comparison with model predictions from refs. [12] (solid lines) and refs. [13] (dotted lines). The systematical uncertainty is given by the error band.

hadron intererence FF $H_1^{\sphericalangle}$. A First extraction of $h_1$ for proton and deuteron targets can be found in ref. [6, 7, 8]. For the $z$-dependence no specific trend is visible, while for the invariant mass a negative signal around the $\rho^0$-mass of 0.77 GeV/$c^2$ is observed and the asymmetry is negative over the whole mass range.

# 4 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, resulting in a gain in statistics of $\approx 3.5$ *w.r.t.* 2007. These two independent measurements of the two-hadron asymmetry by COMPASS are in good agreement. The signal in the $x$ valence region is confirmed. Nearly constant 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 [9]. HERMES published lepton-nucleon asymmetries, while COMPASS calculates photon-nucleon asymmetries. To allow a comparsion with their results for identified $\pi^+\pi^-$-pairs, their released asymmetry values have to be scaled with $\langle 1/D_{nn}\rangle \approx 3$ [10, 11] and multiplied by $-1$ due to an additional phase $\pi$ in the angle definition of $\Phi_{RS}$ in the COMPASS analysis. The overall agreement between HERMES and COMPASS is good within the error bars (fig. 3) 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 valance region for the two experiments. The prediction for the two-hadron asymmetry from the model of Bachetta and collaborators [12] were scaled with this factor of about 3 to undo the adaptation made to fit the HERMES data, the result is shown in fig. 3. 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 Ma *et al.* [13] and the data is in general poorer.

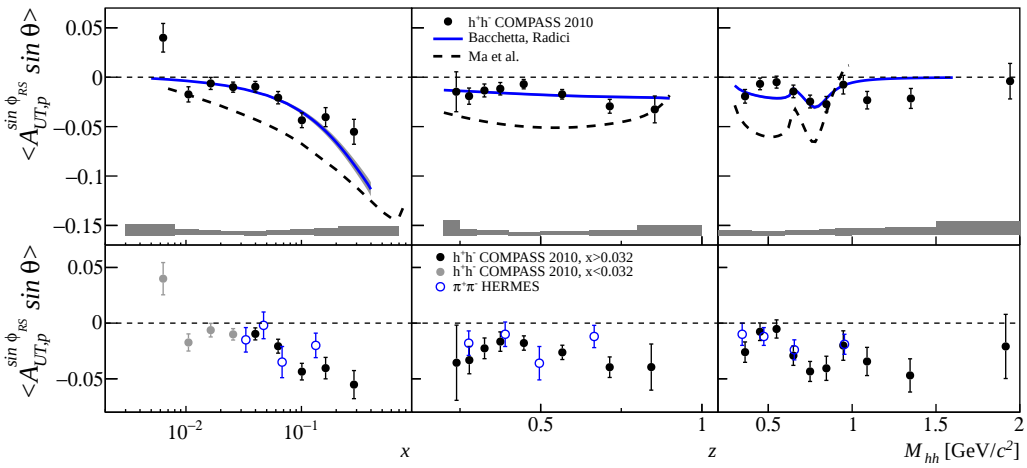


Figure 3: 2010 proton data two-hadron asymmetries of $h^+h^-$-pairs in comparison with model predictions from refs. [12, 13]

# 5 Conclusions & Outlook

Now a large set of COMPASS two-hadron data on a transversely polarized target is available — deuteron data and two independent measurements on the proton. The presented preliminary results from 2010 data are in agreement with the previous COMPASS data, the HERMES data and the available model predictions in particular with the one of Bacchetta and Radici [12]. The small systematic uncertainties and high statistics of the data will allow more studies, in particular in a next step the extraction of the asymmetries for identified pion pairs and also pairs including charged kaons.

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