New COMPASS results on Transverse Spin Asymmetries in Hadron Pair Production in DIS

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The COMPASS measurements of the azimuthal asymmetries in the hadron pairs production in DIS on transversely polarised targets are here presented. Results on oppositely charged pion and kaon pairs produced on both deuteron and proton targets are shown. They have been used to update the calculation of the Transversity function which was previously extracted from the asymmetries measured from un-identified hadron pairs. Also a new method for the direct measurement of the integral of Transversity using both COMPASS and BELLE results is presented.

Keywords: nucleon spin structure; transversity; COMPASS; BELLE

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1. Theoretical framework and data selection

The transverse spin distribution h_1^q, often referred to as Transversity and which gives the probability difference of finding a quark q polarised parallel or antiparallel to the spin of a transversely polarised nucleon, is one of the most interesting quantities which describe the spin structure of the quark inside the nucleon. Transversity can be assessed in SIDIS both in single hadron production $l\,N \to l'\,h\,X$, by measuring the Collins asymmetries, and in di-hadron production $l\,N \to l'\,h_1\,h_2\,X$. In this case the amplitudes of the asymmetries on the azimuthal angle $\phi_{RS} = \phi_R + \phi_S - \pi$ are measured, where ϕ_R is the azimuthal angle of the relative transverse momentum of the hadron pair $\boldsymbol{R}$ and ϕ_S is the azimuthal angle of the spin of the initial quark, both calculated with respect to the scattering plane in the $\gamma^* - N$ system. A detailed description of the process can be found in Ref. 1. The amplitude of the asymmetry is calculated in a collinear framework and is given by the product of transversity and the interference fragmentation function, which describes the spin-dependent part of the fragmentation of a transversely polarised quark into a pair of

unpolarised hadrons[2−3] after integration over the azimuthal angle of the total transverse momentum of the pair. These asymmetries are measured at COMPASS using a positive muon beam of 160GeV/c after standard DIS events selection, namely asking the 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 $W > 5\,\text{GeV}/c^2$. 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 fractional energy $z > 0.1$ and a Feynman $x_F > 0.1$, to ensure that the hadrons are not produced in target fragmentation. Exclusively produced ρ mesons are rejected by a cut on the missing energy $E_{miss} > 3\,\text{GeV}$. Finally a cut of $R_T > 0.07\,\text{GeV}/c$ ensures a well defined azimuthal angle ϕ_R.

2.   Results from the 2003-04 deuteron data

The di-hadron asymmetries $A_d^{2\pi}$ of pion-pairs $\pi^+\pi^-$ for the data collected in 2003–2004 on the deuteron target are shown in Fig. 1. They are small and compatible with zero within the uncertainties and no specific trend is visible for their dependence on x, z and the invariant mass of the di-hadron system M_{inv}[4]. This result, in line with previous measurements [6−5], is interpreted as the consequence of a cancellation of the u and d quark contributions to the total Transversity distribution of the deuteron[7−8]. The asymmetries of the other identified pair combinations K^+K^-, π^+K^- and $K^+\pi^-$ are compatible with zero within their uncertainties or give only weak hints of nonzero signals.

3.   Results from the combined 2007/2010 proton data

COMPASS has measured the di-hadron asymmetry on a proton target (NH_3) in 2007 and in 2010, and the combined results for h^+h^- pairs as a function of x, z and M_{inv} are published in Ref. 9. Results on identified hadrons are available and they are shown in Fig. 2. The pion-pair asymmetries $A_p^{2\pi}$ exhibit a strong signal in x, there is no clear trend in the z and some structure can be seen in the asymmetries as function of M_{inv}, in particular at the ρ mass. The asymmetries of the other identified pair combinations K^+K^- and $K^+\pi^-$ give some weak indications of nonzero signals as functions of their invariant masses.

4.   Extraction of Transversity

The complete set of di-hadron asymmetries obtained from the COMPASS data taken on both transversely polarized deuteron and proton targets gives the unique possibility to extract the Transversity distributions $xh_1^q(x)$ of u and d valence quarks separately. This was first done in Ref. 11, using the COMPASS unidentified hadron data and following an original procedure[10] which used only the proton data from COMPASS, only from the 2007 run, and HERMES. Later the procedure was extended to include also the COMPASS deuteron data[12]. Now the ex-
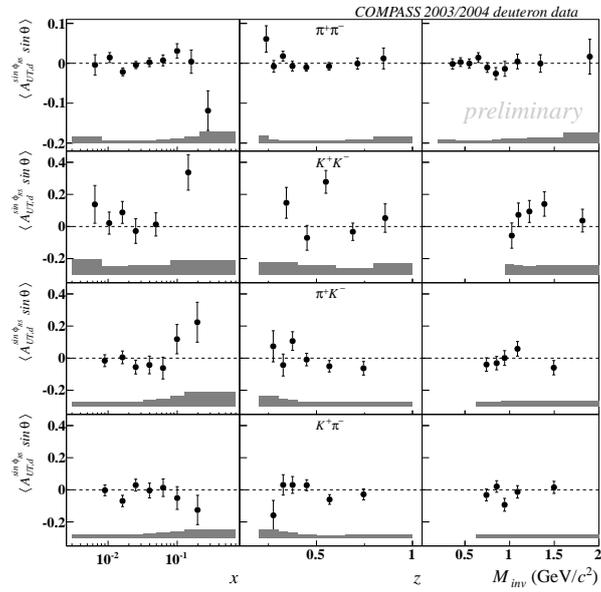
Fig. 1.   The identified di-hadron asymmetries rom the 2003–04 deuteron data.
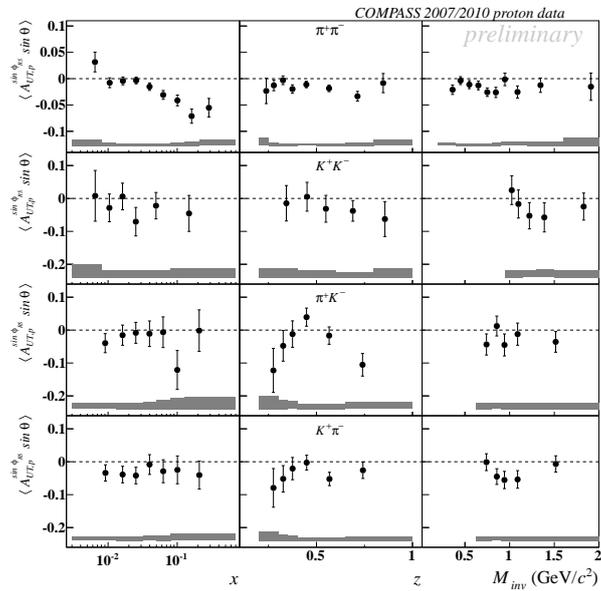

Fig. 2.   The identified di-hadron asymmetries from the combined 2007/2010 proton data.
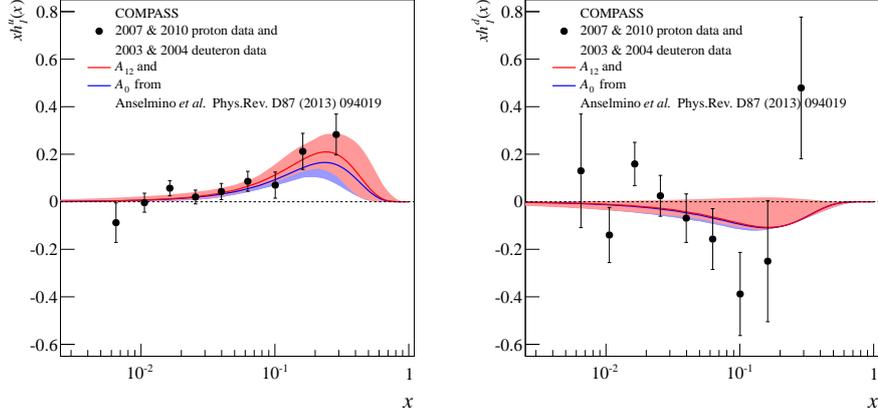
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Fig. 3.   Point-by-point Transversity distributions for u (left) and d (right) valence quarks obtained from this data. They are compared to the corresponding results extracted from the single hadron Collins asymmetries.

traction of $xh_1^u(x)$ and $xh_1^d(x)$ has been updated using the pion-pairs asymmetries measured on the polarized proton target from the 2010 data[4]. The starting points are the linear combinations $xh_{1,p}(x, Q^2) = xh_1^u(x, Q^2) - \frac{1}{4}xh_1^d(x, Q^2)$ and $xh_{1,d}(x, Q^2) = xh_1^u(x, Q^2) + xh_1^d(x, Q^2)$ extracted in Ref. 12. The bin-by-bin ratios between $xh_{1,p/d}$ and the COMPASS di-hadron asymmetries of h^+h^- pairs used as an input in the extraction are then calculated. These ratios contain the information on the unpolarized process as well as on the interference fragmentation function. They are used as conversion factors in order to calculate the point-by-point amplitudes of the Transversity distribution $xh_{1,p}$ with the new $\pi^+\pi^-$ results. The final u and d valence quark Transversity distributions are obtained by solving the system of two linear equations. Figure 3 shows the results for xh_1^u and xh_1^d. A non zero trend at large x values is evident in both distributions with opposite sign for the u and d quarks and the strength of the signal is compatible within the uncertainties. The xh_1^u and xh_1^d distributions of Fig. 3 are also well compatible with the extraction of Ref. 13 carried out using single hadron Collins asymmetries and BELLE e^+e^- results on Collins fragmentation function.

5. A new method for a measurement of the integral of Transversity

An interesting quantity can be calculated by combining the COMPASS asymmetries $A_p^{2\pi}$ extracted as function of z or M_{inv} with the measurements performed by BELLE[14] on the interference fragmentation function (IFF) from the $e^+e^- \rightarrow (\pi^+\pi^-)(\pi^+\pi^-)$ reaction. The di-hadron asymmetry measured on the
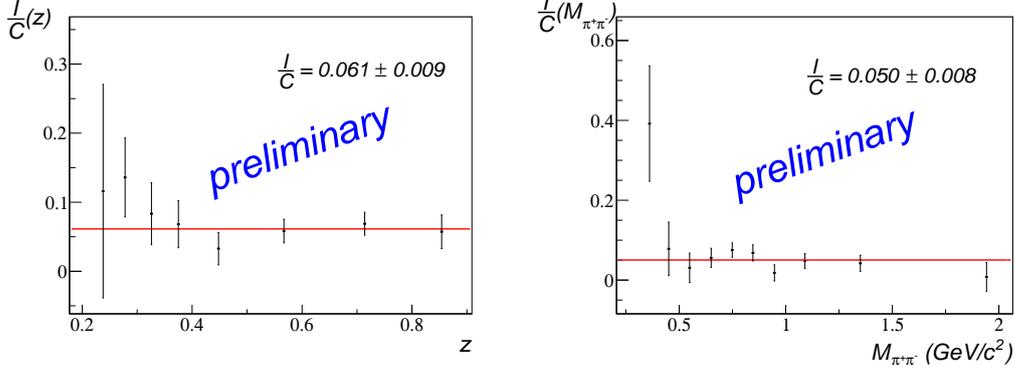
Fig. 4.   Points calculated for $\frac{I}{C}(z)$ (left) and $\frac{I}{C}(M_{inv})$ (right). The average value of $\frac{I}{C}$ is also shown.

transversely polarized proton target in bins of z can be written as

$$A_p^{2\pi}(z) = \frac{I}{C} \cdot \beta(z), \tag{1}$$

where

$$I = \frac{2\pi s \alpha^2}{\langle D_{NN} \rangle} \cdot \int_{\omega_x, \omega_y} dxdy \frac{2(1-y)}{Q^4} [4x h_1^{u-\bar{u}}(x) - x h_1^{d-\bar{d}}(x)], \tag{2}$$

$$C = 2\pi s \alpha^2 \cdot \int_{\omega_x, \omega_y} dxdy \frac{1+(1-y)^2}{Q^4} [4x f_1^{u+\bar{u}}(x) + x f_1^{d+\bar{d}}(x)], \tag{3}$$

being $D_{NN} = \frac{2(1-y)}{1+(1-y)^2}$ and $f_1^{\cdots}$ are the unpolarized PDFs. The usual assumptions on the fragmentation functions (FFs) are made[15] and the Q^2 dependence of the FFs and parton distribution functions (PDFs) is neglected. The term $\beta(z)$ contains only the favored IFF H_f^{2h} and the unpolarized di-hadron FF D_f^{2h}

$$\beta(z) = \frac{\int_{\omega_{M_{inv}}} H_f^{2h}(z, M_{inv}) dM_{inv}}{\int_{\omega_{M_{inv}}} D_f^{2h}(z, M_{inv}) dM_{inv}}. \tag{4}$$

In the same way the asymmetry measured in bins of M_{inv} can be written as

$$A_p^{2\pi}(M_{inv}) = \frac{I}{C} \cdot \beta'(M_{inv}), \tag{5}$$

where

$$\beta'(M_{inv}) = \frac{\int_{\omega_z} H_f^{2h}(z, M_{inv}) dz}{\int_{\omega_z} D_f^{2h}(z, M_{inv}) dz}. \tag{6}$$

 The terms defined in Eq. (4) and (6) can be calculated from the BELLE azimuthal asymmetries $a_{12}(z, M_{inv})$ measured in bins of z and M_{inv} and given in Ref. 14, since the ranges of z and M_{inv} are similar to the ones covered by COMPASS.

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Indeed, using the relations among FFs of Refs. 15–14, it can be written that $\beta(z) = \frac{1}{\sqrt{k}} \cdot \langle a_{12}(z) \rangle_{M_{inv}}$ where $\langle a_{12}(z) \rangle_{M_{inv}}$ is the weighted mean calculated over the bins in M_{inv} and $k = \frac{-5}{8} \frac{s^2}{1+c^2} \cdot a_I$. The angular quantities $\frac{s^2}{1+c^2}$, defined in Ref. 14, are almost independent from z and M_{inv} and a_I is proportional to the asymmetries integrated over the whole z, M_{inv} plane and which value is also given in Ref. 14. The effect of the Q^2 evolution on the ratio H_f^{2h}/D_f^{2h} has been evaluated to be less than 10% in Ref. 15 for the two experiments and the quantities of Eq. (4) and (6) can be replaced by the corresponding ones calculated from the BELLE results. The ratios $\frac{I}{C}(z) = A_p^{2\pi}(z)/\beta(z)$ and $\frac{I}{C}(M_{inv}) = A_p^{2\pi}(M_{inv})/\beta^{'}(M_{inv})$ calculated in this way are shown in Fig. 4. As expected they do not show a depepndence on z or M_{inv}. Thus the ratio I/C can be extracted by fitting with a constant the values $\frac{I}{C}(z)$, picture at the left in Fig.4, or the values $\frac{I}{C}(M_{inv})$, picture at the right in Fig.4. The results obtained are: 0.061 ± 0.009 and 0.050 ± 0.008 from the fits to $\frac{I}{C}(z)$ and to $\frac{I}{C}(M_{inv})$ respectively. Only the statistical errors are taken into account. These are very preliminary results and the evaluation of the final systematic error is still ongoing. It will be interesting to compare our measured value of I/C with the one expected from Eq. (2) and (3) when using known values of f_1^q and the available parametrizations for the transversity function. Moreover results on the di-hadron asymmetries on polarized deuteron will allow to measure the integral of $h_1^{u-\bar{u}}(x)$ and $h_1^{d-\bar{d}}$ separately.

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