COMPASS results on transverse spin dependent azimuthal asymmetries in dihadron production in semi-inclusive deep-inelastic scattering

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The parton distribution function \( h_1^q \) of a transversely polarized quark \( q \) inside a transversely polarized nucleon is chiral odd and therefore not accessible in inclusive deep inelastic scattering. It can be observed however in semi-inclusive deep inelastic scattering (SIDIS) in combination with another chiral odd function like e.g. the dihadron interference fragmentation function (IFF) \( H_{\text{IFF}} \).

Using the polarized \( \mu^+ \) beam of CERN’s M2 beamline COMPASS has been investigating the spin structure of the nucleon using polarized solid-state targets since 2002. In this contribution an overview of COMPASS results for the azimuthal asymmetries in dihadron production is given. This includes the results of all hadron pairs \( h^+ h^- \) on a polarized deuteron target from the data taken in the years 2002 to 2004, as well as the first data set on a transversely polarized proton target taken in the year 2007 and a data set taken on the same target during the year 2010. The COMPASS spectrometer allows a good particle identification, which can be used to determine the composition of the \( h^+ h^- \) pairs in terms of pions and kaons. The results for the possible combinations \( \pi^+ \pi^- \), \( K^+ K^- \), \( \pi^+ K^- \) and \( K^+ \pi^- \), obtained very recently from the 2007 and the 2010 data, will be discussed in detail. Moreover the asymmetries for \( \pi^+ \pi^- \) pairs will be compared to the available model predictions and the corresponding results from HERMES.

XXI International Workshop on Deep-Inelastic Scattering and Related Subject -DIS2013,
22-26 April 2013
Marseilles, France

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1. Framework & data selection

In the SIDIS process $\mu N \rightarrow \mu' h_1 h_2 X$ the incoming lepton is scattered off a transversely polarized quark inside the nucleon via the exchange of a virtual photon. The struck quark hadronizes into at least two unpolarized hadrons. For each oppositely charged hadron pair, the quantity $R$ is defined, i.e. their normalized relative momentum. Figure 1 shows a simplified scheme of this process. In the SIDIS cross section the angle $\phi_R$ between the dihadron plane and the scattering plane and the azimuthal angle of the spin of the initial quark $\phi_S$ appear in an azimuthal modulation as a function of $\phi_{RS} = \phi_R + \phi_S - \pi$ [1, 2]. To select DIS events in general, 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. the single hadron asymmetries analysis [3], of which the requirement for a vertex with at least three outgoing tracks (scattered $\mu^+$ and 2 hadrons) is the most fundamental one. 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 $x_F > 0.1$, to ensure that the hadron is not produced by target fragmentation. Exclusively produced $\rho^0$ mesons are rejected by a cut on the missing energy $E_{\text{miss}} > 3 \text{ GeV}$ of the pair system. This cut is shown in fig. 2 (left) and its consequence is clearly visible as a removal of the exclusivity peak around 1 in the distribution of $z_1 + z_2$ in fig. 2 (center). Finally a cut of $R_T > 0.07 \text{ GeV/c}$ ensures a well defined azimuthal angle $\phi_R$. After all cuts the full statistics on the proton target consists of $45.5 \cdot 10^6 h^+ h^-$ pairs, of which $28.0 \cdot 10^6$ are identified as pion pairs. The deuteron sample consists of $5.8 \cdot 10^6 h^+ h^-$ pairs. In the distribution of the invariant mass $M_{\text{inv}}$ of the pion pairs, shown in fig. 2 (right) the $K^0$, $\rho^0$ and $f_1$ resonances are clearly visible.
2. Deuteron data 2002-04

The dihadron asymmetry of all hadron pairs \( h^+ h^- \) for the data collected in 2002-04 on the deuteron target are consistently small and compatible with zero within the uncertainties (fig. 3 top). Furthermore no specific trend is visible for their dependence on \( x, z \) and \( M_{\text{inv}} \). This result is in line with the COMPASS measurement of the Collins asymmetry on the deuteron, and is interpreted as being due to an almost complete cancellation of the \( u \) and \( d \) quark transversity on the deuteron target [3], which is also predicted by the available models, see refs. [4, 5].

3. Proton data 2007 and 2010

The first measurement of the dihadron asymmetry of \( h^+ h^- \) pairs on a proton target at COMPASS was performed using the data collected in the year 2007. The results as a function of \( x, z \) and \( M_{\text{inv}} \) are shown in the bottom part of fig. 3 and ref. [6]. A large asymmetry up to \(-10\%\) in the valence \( x\)-region was measured. A recent extraction of \( h^p_1 \) including a flavor separation can be found in ref. [7]. As for the \( z \) dependence, no specific trend is visible, while for the invariant mass
Figure 4: Identified dihadron asymmetries from combined 2007 and 2010 proton data: $\pi^+\pi^-$, $K^+K^-$, $\pi^+K^-$ and $K^+\pi^-$ pairs (top to bottom) as a function of $x$, $z$ and $M_{inv}$ (left to right).

Figure 5: $\pi^+\pi^-$ asymmetries from combined 2007 and 2010 proton data in comparison with HERMES data from ref. [8] and model predictions from refs. [4, 5] in the valence region ($x > 0.032$).

a negative signal around the $\rho^0$ mass of $0.770\text{GeV}/c^2$ is observed and the asymmetry is negative over the whole mass range.

All the COMPASS beam time in the year 2010 was dedicated to collect again data on a transversely polarized proton target. The large amount of data collected not only confirmed and improved the $h^+h^-$ results in terms of statistics, but also allowed to expand the possibilities for further analyses. The COMPASS spectrometer allows a very precise particle identification, which can be used to determine the composition of the $h^+h^-$ in terms of pions and kaons. In particular the signal in the
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$x$ valence region ($x > 0.032$) is confirmed, nearly constant with a negative asymmetry in $z$ and the structure in $M_{inv}$ is congruent.

Since the COMPASS spectrometer allows a good charged particle identification, it has been a natural choice to combine these 2 years of data to a final COMPASS result of dihadron asymmetries of identified pairs on a polarized proton target. The results for the possible combinations $\pi^+\pi^-$, $K^+K^-$, $\pi^+K^-$ and $K^+\pi^-$ are shown in fig. 4.

The pion pair asymmetry shows a clear signal up to $-6\%$ in $x$, the $z$ dependence is compatible with a constant and for $M_{inv}$ a pronounced peak around the $\rho^0$ mass is observed. The kaon pairs however with their larger statistical uncertainty show an asymmetry compatible with zero in the $x$ and $z$ dependence, while an indication of a negative value at large $M_{inv}$ is given. The asymmetries of the mixed pairs are mostly compatible with zero, apart from a positive peak around $z = 0.45$ for the $\pi^+K^-$ and a negative peak around $M_{inv} = 0.9\text{GeV}/c^2$ for $K^+\pi^-$. The $\pi^+\pi^-$ asymmetry was also measured by the HERMES experiment [8].

The overall agreement between these two experiments is good within the uncertainties (fig. 5) bearing in mind the larger kinematic 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 valence region for the two experiments.

Both available model predictions by Bacchetta et al. [4] and Ma et al. [5] well reproduce the trend in $x$, as well as the peak around the $\rho^0$ mass, while the agreement in other mass regions and $z$ is in general poorer, see fig. 5.

The COMPASS proton and deuteron data give a clear indication of a non-zero transversity $h_1$ for both $u$ and $d$ quarks, as shown in ref. [7]. With the recent results, of the dihadron asymmetries of identified pairs presented in this proceeding the flavor separation can be further pursued.

References


