Transversity Signal in two Hadron Pair Production in COMPASS

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Measuring single spin asymmetries in semi-inclusive deep-inelastic scattering (SIDIS) on a transversely polarized target gives a handle to investigate the transversity distribution and transverse momentum dependent distribution functions. In the years 2002, 2003 and 2004 COMPASS took data with a transversely polarized deuteron target and in the year 2007 with a proton target. Three channels for accessing transversity have been analysed. Azimuthal asymmetries in the production of hadron pairs, involving the polarized two hadron interference fragmentation function [1], azimuthal asymmetries in the production of single hadrons, involving the Collins fragmentation function and polarization measurements of spin-$\frac{1}{2}\hbar$ particles like Λ-Hyperons via their self analyzing weak decay [2]. In the following we will focus on new preliminary results from the analysis of two hadron pair asymmetries measured with the proton target.

1 Introduction

Single spin asymmetries in semi-inclusive deep-inelastic scattering (SIDIS) off transversely polarized nucleon targets have been under intense experimental investigation over the past few years [3, 4, 5, 6] They provide new insights into QCD and the nucleon structure. For instance, they allow the determination of the third yet unknown leading-twist quark distribution function $\Delta_T q(x)$, the so-called transversity distribution [7, 8]. It is defined as the difference in the number density of quarks with momentum fraction x with their transverse spin parallel to the nucleon spin and their transverse spin anti-parallel to the nucleon spin (transverse w.r.t the virtual photon direction). A rather new probe measuring the transversity distribution is the measurement of two hadron production [9, 10], introducing the chiral odd polarized two hadron interference fragmentation function (FF) $H_1^{\sphericalangle}(z, M_{h^+h^-}^2)$ [8, 7, 11].

2 Polarized two hadron interference fragmentation function

The chiral-odd transversity distribution $\Delta_T q(x)$ can be measured in combination with the chiral-odd polarized two hadron interference FF $H_1^{\sphericalangle}(z, M_{h^+h^-}^2)$ in SIDIS. The fragmentation of a transversely polarized quark into two unpolarized hadrons leads to an azimuthal modulation in $\Phi_{RS} = \phi_R + \phi_S - \pi$ in the SIDIS cross section. Here ϕ_S is the azimuthal angle, measured around the direction of the virtual photon $\hat{q}$, between the spin of the initial quark $\vec{S}$ and the scattering plane, defined by $\hat{q}$ and the incoming muon $\vec{\ell}$

$$\cos\phi_S = \frac{(\hat{q}\times\vec{\ell})}{|\hat{q}\times\vec{\ell}|} \cdot \frac{(\hat{q}\times\vec{S})}{|\hat{q}\times\vec{S}|}, \qquad \sin\phi_S = \frac{(\vec{\ell}\times\vec{S})\cdot\hat{q}}{|\hat{q}\times\vec{\ell}||\hat{q}\times\vec{S}|},$$

and ϕ_R is the azimuthal angle between $\vec{R}_T$ and the scattering plane

$$\cos\phi_R = \frac{(\hat{q}\times\vec{\ell})}{|\hat{q}\times\vec{\ell}|} \cdot \frac{(\hat{q}\times\vec{R}_T)}{|\hat{q}\times\vec{R}_T|}, \qquad \sin\phi_R = \frac{(\vec{\ell}\times\vec{R}_T)\cdot\hat{q}}{|\hat{q}\times\vec{\ell}||\hat{q}\times\vec{R}_T|}.$$
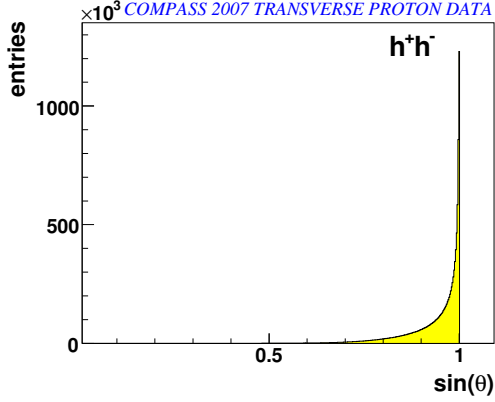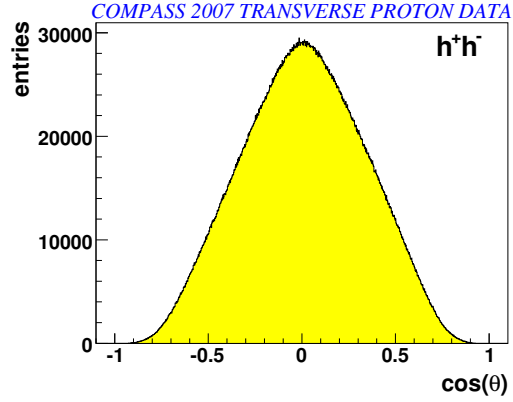
Figure 1: $\sin\theta$ distribution

Figure 2: $\cos\theta$ distribution

In which $\vec{R}_T$ is the transverse component of $\vec{R}$ defined as:

$$\vec{R} = (z_2 \cdot \vec{P}_1 - z_1 \cdot \vec{P}_2)/(z_1 + z_2).$$

$\vec{P}_1$ and $\vec{P}_2$ are the momenta in the laboratory frame of h^+ and h^- respectively. This definition of $\vec{R}_T$ is invariant under boosts along the virtual photon direction.

The number of produced oppositely charged hadron pairs $N_{h^+h^-}$ can be written as:

$$N_{h^+h^-} \; \propto \; 1 \pm f \cdot P_T \cdot D_{nn} \cdot A_{RS} \cdot \sin\Phi_{RS} \cdot \sin\theta$$

in which θ is the angle between the momentum vector of h^+ in the center of mass frame of the h^+h^--pair and the momentum vector of the two hadron system. f is the fraction of polarized protons in the target, P_T the target polarization and $D_{nn} = (1-y)/(1-y+y^2/2)$ the depolarization factor.

The measured amplitude A_{RS} is proportional to the product of the transversity distribution and the polarized two hadron interference FF

$$A_{RS} \propto \frac{\sum_q e_q^2 \cdot \Delta_T q(x) \cdot H_1^{\triangleleft}(z, M_{h^+h^-}^2)}{\sum_q e_q^2 \cdot q(x) \cdot D_1(z, M_{h^+h^-}^2)}.$$

The sums run over the quark flavors q, e_q is the charge of the quark and $D_1(z, M_{h^+h^-}^2)$ is the unpolarized two hadron interference FF. The polarized two hadron interference FF can be expanded in the relative partial waves of the hadron pair system, which up to the p-wave level gives [12]:

$$H_1^{\triangleleft} = H_1^{\triangleleft,sp} + \cos\theta H_1^{\triangleleft,pp}.$$

Where $H_1^{\triangleleft,sp}$ is given by the interference of s and p waves, whereas the function $H_1^{\triangleleft,pp}$ originates from the interference of two p waves with different polarization. For this analysis the results are obtained by integrating over θ, because the $\sin\theta$ distribution shown in Fig. 1 is strongly peaked at one and the $\cos\theta$ distribution is symmetric around zero (see Fig. 2).

3 The COMPASS experiment

COMPASS is a fixed target experiment using a beam extracted from CERN SPS accelerator with a wide physics program focused on the nucleon spin structure and on hadron

spectroscopy. COMPASS investigates transversity and the transverse momentum structure of the nucleon in SIDIS. A $160\,\mathrm{GeV}/c$ muon beam is scattered off a transversely polarized hydrogen or deuterium target. The scattered muon and the produced hadrons are detected in a wide-acceptance two-stage detector with excellent particle identification capabilities [13].

4 Data sample and event selection

In 2007 COMPASS took data with a transversely polarized proton target (NH_3). The polarization P_T of the material is $\sim 90\%$ with a dilution factor f of ~ 0.15. The target consists of three cells, where the two outer cells are polarized in one direction and the middle cell is oppositely polarized. To reduce the systematic error the polarization was reversed every four to five days. The new solenoid magnet installed in 2005 increased the angular acceptance of the experiment to the design value of $180\,\mathrm{mrad}$.

The quality and the stability of the data was checked carefully. For the results presented here, the entire data set of 2007 with transversely polarized target was used.

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 consists of all oppositely charged hadron pair combinations originating from the reaction vertex. The hadrons used in the analysis have $z > 0.1$ and $x_F > 0.1$. Both cuts ensure that the hadron is not produced in the target fragmentation. To reject exclusively produced ρ^0-mesons a cut on the sum of the energy fractions of both hadrons was applied $z_1 + z_2 < 0.9$. Finally, in order to have a good definition of the azimuthal angle ϕ_R a cut on $R_T > 0.07\,\mathrm{GeV}/c$ was applied.

After all cuts $11.28 \cdot 10^6$ h^+h^--pairs contribute to the analysis. The resulting invariant mass distribution is shown in Fig. 3. One clearly sees the peaks of the K^0- and ρ^0-meson at around $0.5\,\mathrm{GeV}/c^2$ and $0.77\,\mathrm{GeV}/c^2$ respectively.

To extract the asymmetries an extended unbinned maximum likelihood method was used. The probability function is expressed as

$$P(\phi_R, \phi_S; a, A) = a(\phi_R, \phi_S) \cdot (1 \pm A \cdot \sin\Phi_{RS})$$

In which $a(\phi_R, \phi_S)$ is the COMPASS acceptance. The Likelihood function is given by LH $= (\prod_j P_j) \cdot e^{-\mu}$. In which the product runs over the probabilities of the measured events and μ is the theoretically expected number of events $\mu = \int \mathrm{d}\phi_R \int \mathrm{d}\phi_S\, P(\phi_R, \phi_S; a, A)$. To separate acceptance and spin dependent modulations, two cells (u, d) and two consecutive periods with opposite polarization ($\uparrow\downarrow$) have been coupled. The acceptance is fixed by the assumption that for each target cell the change of acceptance between two consecutive periods is described by a constant.

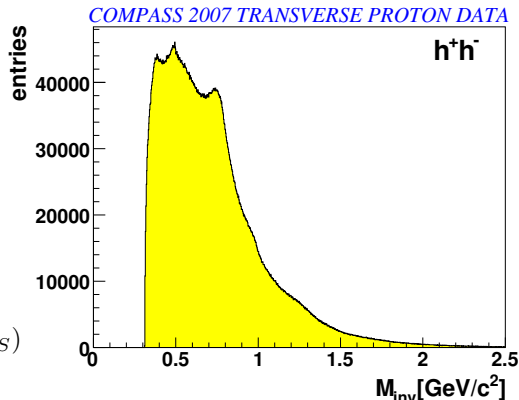$$C_u = \frac{a_u^\uparrow}{a_u^\downarrow}; \; C_d = \frac{a_d^\downarrow}{a_d^\uparrow}$$

Figure 3: Invariant mass distribution

Tests with Monte-Carlo data showed that the functional form of the acceptance function $a(\phi_R, \phi_S)$ has no impact on the result of the physical asymmetry. Therefore it was described by single constants taking care of the different number of events per period and target cells. The results have been checked by several other estimators described in [3].

5 Results

The results as a function of x, z and M_{inv} are shown in Fig. 4. We measure a strong asymmetry in the valence x-region, which implies a non-zero transversity distribution and a non-zero polarized two hadron interference FF $H_1^{\triangleleft}$. In the invariant mass we observe a strong signal around the ρ^0-mass and the asymmetry is negative over the whole mass range. The lines are predictions from Bacchetta and Radici [14], which are based on the transversity distribution from Anselmino et al. [15] and on a fit to HERMES data [16]. One sees that the predictions are a factor of about 3 smaller than our measured asymmetry. To enhance
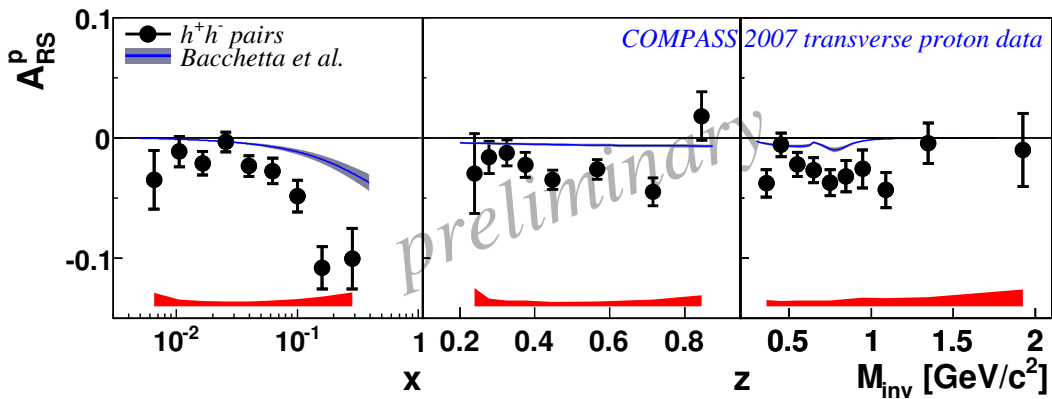

Figure 4: Results, with predictions

the signal binned in z and M_{inv} a cut on $x > 0.032$ was applied. The results are shown in Fig. 5. With respect to Fig. 4 the number of bins in z and M_{inv} was reduced to take care of the lower statistics. The distribution in z becomes rather constant. For M_{inv} the amplitude is enhanced in the region of the ρ^0-mass. Comparing the results with the one published by the HERMES group [10], our measured asymmetry is larger by a factor of about 3. The opposite sign between the two results is due to a different definition of ϕ_{RS}. Again the predictions, which are based on the HERMES data are a factor of about 3 smaller.

6 Summary

For the first time preliminary results for two hadron asymmetries measured at COMPASS in SIDIS on a transversely polarized proton target have been presented. The measured asymmetries are non-zero and negative for $x > 0.032$, which implies that the polarized two hadron interference FF and the transversity distribution are both non-zero. The asymmetry is negative in the whole mass range and seems to be enhanced in the region of the ρ^0 mass. Compared to the results of HERMES our asymmetry is a factor of about 3 larger.
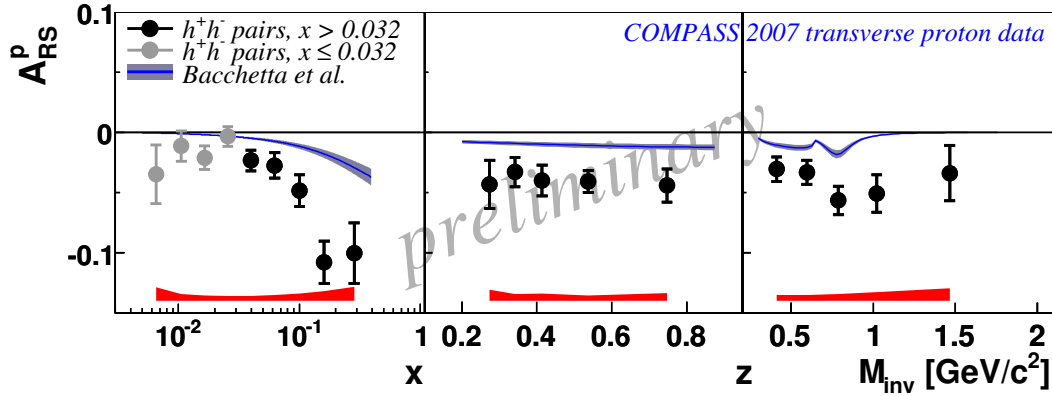
Figure 5: Results $x > 0.032$, with predictions

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