Abstract

The measurement of transverse spin effects in semi-inclusive deep-inelastic scattering is an important part of the COMPASS physics program. From the analysis of the 2002-2004 data, new results for the transverse target spin asymmetry of $z$-ordered identified pion and kaon pairs are presented [1]. In addition, a first result for the transverse target spin asymmetry of exclusively produced $^0$ mesons on the deuteron is shown.

1 Introduction

Single spin asymmetries in semi-inclusive deep-inelastic scattering on transversely polarized nucleon targets have been under intensive experimental and theoretical investigation over the past few years [2, 3, 4]. 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 $T_q(x)$, the transverse distribution $L, T$. Additionally, they give insight into the parton transverse mom entum distribution and angular mom entum $[7]$.

COMPASS exploited three different "quark polarimeters" to access transversity: For hadron production in deep-inelastic scattering the azimuthal asymmetry of the produced hadrons was measured. This asymmetry gives access to transversity by the Collins mechanism. Another probe to access transversity is the interference fragmentation function in the production of hadron pairs $[5, 6]$. Finally, for the production of baryons the transverse spin of quarks is transferred to the transverse lambda polarization, which is determined experimentally.

In hard exclusive production of $^0$ mesons on a transversely polarized target, a different aspect of the spin structure of the nucleon can be probed. Since few years it is well established that hard meson production is a very good candidate to study the universal generalized parton distributions (GPDs) $[10, 11, 12]$. These distributions describe in the most complete way the nucleon structure and encode fundamental information in particular about the angular mom entum carried by partons and about their spatial distribution.

At the COMPASS experiment at CERN all channels mentioned above have been studied. The following part will focus on two new results, the Collins asymmetry for $z$-ordered hadron pairs and the target spin asymmetry for exclusively produced $^0$ mesons.

2 Two-hadron asymmetry

At leading twist, the fragmentation function $(FF)$ of a polarized quark into a pair of hadrons is expected to be of the form

$$FF = D^h_q (z; M_h^2) + H_1 (z; M_h^2) \sin \frac{\cos \theta}{\rho}$$

where $M_h$ is the invariant mom entum of the hadron pair and $z = z_1 + z_2$ is the fraction of available energy carried by the two hadrons. $D^h_q (z; M_h^2)$ is the unpolarized fragmentation function into two hadrons. The angles and $\rho$ are de ned according to Ref. $[13]$. $\rho = \rho + \sin \theta$ is the sum of the azimuthal angle $\rho$ of a plane containing the two hadrons and the azimuthal angle $\theta$ of
target spin vector with respect to the lepton scattering plane, is the polar angle of the first hadron in the two-hadron center-of-mass frame with respect to the direction of the sum of the hadron momenta. In the $p_T$ bin, the acceptance for $Z$ peak is close to $0.2$ with $< \sin < 0.95$. The following results are obtained by integrating over $\sin \theta$. The number of hadron pairs in a bin of $x$, $z$, or $M_h$, is given by

$$N_{(RS)} = N_0 (1 + \frac{\sin \theta}{R_S^2})$$

where $\theta$ refers to the transverse target spin orientation and $N_0$ is the mean number of detected hadron pairs averaged over $\sin \theta$. From the angular distribution of the hadron pairs, one can thus measure the asymmetry $A_{RS}$:

$$A_{RS} = \frac{1}{N_{P:T}} \frac{q_1^T z^T}{q_1^T} \frac{\sigma_{h_2}^T}{\sigma_{h_1}^T}$$

where $\sigma_{h_2}^T$ is the target dilution factor, $P_T$ the target polarization, and $D$ the depolarization factor given by $D = (1 + y - 1 + y^2)/2$, where $y$ is the fractional energy transfer of the lepton.

The measured asymmetry can be factored into a convolution of the transverse distribution $\tau q(x)$ of the quarks of the two hadrons and the interference fragmentation $H_1^L(Z; M_1^2)$:

$$A_{RS} = \frac{\sigma_{h_2}^T}{\sigma_{h_1}^T} \frac{\tau q(x)}{\tau q(x)} H_1^L(Z; M_1^2)$$

summed over all quark flavors $q$.

3 Event selection

The data discussed here have been taken in the years 2003 to 2004 at the COMPASS experiment at CERN. It scatters a 160 GeV $^4$He beam on a transversely polarized solid state $^6$LiD target. The scattered muons and the produced hadrons are detected in a 50 m long, large-acceptance forward spectrometer with excellent particle identification capabilities. A large scale Ring Imaging Cherenkov (RICH) detector is used to distinguish pions, kaons and protons.

The event selection was done in the same way as in the previous analysis of the Collins and Sivers asymmetries for single hadrons. For the selection of the DIS event sample, kinematic cuts of the squared four-momentum transfer $Q^2 > 1$ (GeV/c$^2$), the hadronic invariant mass $W > 5$ GeV/c$^2$, and the fractional energy transfer of the muon $0.1 < y < 0.9$ were applied.

$H$ hadron pairs originating from the primary vertex are selected. The hadrons are separated into $\pi$ and $K$ pairs. A selection cut of $z_{1+2} > 0.1$ suppresses hadrons from the target fragmentation. The two leading hadrons have been selected according to their fractional energy, taking the first hadron as the most energetic one. A cut on the sum $z = z_1 + z_2 < 0.9$ rejects exclusively produced $\pi$ and $K$ mesons.

By combining data from both target cells as well as from sub-periods with opposite target polarization in a double ratio product described in detail in Ref. [2], the acceptance function of the spectrometer cancels out and the azimuthal asymmetry $A_{RS}(x; z; M_h^2)$ is extracted from the data. In various studies, it was shown that systematic effects of the measurement are considerably smaller than the statistical uncertainty of the data.

4 Results

In figure 4 the results for the target single spin asymmetry $A_{RS}$ for leading $z$-ordered and $K$ pairs are shown. The asymmetries are plotted as a function of the hadron pair invariant mass $M_{inv}$. The measured asymmetries are small and compatible with zero within the statistical precision of the data points. They do not show a significant dependence on the kinematic variables $M_{inv}$ or $x$ and $z$, respectively.
5 Discussion

In several theoretical models, predictions have been made for the measured asymmetries $A_{RS}(x;z;M^2_\text{inv})$ for pions or unidenti ed hadrons on a deuteron target [11,12]. The expected values of the asymmetry are generally small and below 1%. The small signal is attributed in these calculations to a partial cancellation of the asymmetries originating from scattering on up and down quarks of the proton and neutron in the isoscalar deuteron target. In 2007, COMPASS is taking data with a transversely polarized proton target, where the asymmetries are expected to be larger [3,4]. Together with the deuteron data presented here, a separation of the asymmetries originating from up and down quarks shall then become possible.

6 Exclusive $0^+$ production

Hard meson production has been shown to be one possible way to access generalized parton distributions. Here we have studied the exclusive production of $0^+$ mesons on a transversely polarized deuteron target [13].

The analysis is based on the complete COMPASS transverse data set from 2002-2004. For the selection of DIS events, the same cuts as described in section 2 have been applied. To select exclusive $0^+$, a missing energy cut of $2.5 \text{ GeV} < E_{\text{miss}} < 2.5 \text{ GeV}$ has been applied. $0^+$ mesons have been selected in a invariant mass window of $300 \text{ MeV}$ around the $0^+$ mass. A cut on the squared transverse momentum $p_{T}^2$ of the $0^+$ meson in the range between $0.01$ and $0.5 \text{ GeV}/c^2$ has been applied, where the lower limit ensures an accurate measurement of the azimuthal angle and the upper limit suppresses non-exclusive background. In total 270k $0^+$ mesons have been reconstructed. The selected data sample contains $0^+$ produced incoherently and coherently on the deuteron target as well.

An azimuthal asymmetry $A_{\text{az}}$ has been

Figure 1: Asymmetries $A_{RS}$ for identical leading pairs with opposite (top) and equal (second) charge, for identical $K^+$ pairs with opposite (third) and equal positive (fourth) and negative charge (bottom panel) versus $M_{\text{inv}}^2$. Photon 2007
determined with respect to the angle \( \phi = s \), where \( s \) is the azimuthal angle of the meson with respect to the lepton scattering plane. The transverse target spin asymmetry has been calculated from the measured asymmetry \( A_{UT}^{\sin} \):

\[
A_{UT}^{\sin} = \frac{1}{f} A_{UT}^{\sin} \]

where \( f = 0.38 \) is the dilution factor and \( P_T \) the mean target polarization.

Results for the asymmetry \( A_{UT} \) as a function of the transferred four momentum above threshold \( t_0 \), of \( x \) and of the fractional photon energy transfer are shown in figure 2.

7 Discussion of \( ^0 \) results

For longitudinal virtual photons, factorization of the exclusive vector meson production cross section into a hard part sensitive to GPDs and a quark entanglement function has been shown [16]. The cross sections for transversely polarized photons was shown to be suppressed by \( 1 = Q^2 \) compared to the longitudinal one. For the COMPASS kinematics in this analysis, the mean \( < Q^2 > \approx 2 \text{ GeV}^2 \), which gives a ratio of \( T = 1 \). Further studies will aim in a separation of the longitudinal and transverse part of the cross section using the angular distribution of the decay products [12].

The current data taking at COMPASS with a transversely polarized N H3 target will provide the possibility to study exclusive meson production on the proton as well.

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