Azimuthal asymmetries from unpolarized data at COMPASS

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Abstract. The investigation of transverse spin and transverse momentum effects in the nucleon is one of the key physics programs of the COMPASS experiment at CERN. COMPASS investigates these effects scattering 160 GeV/c muons off a fixed NH_3 or ^6LiD target. The azimuthal asymmetries which appear in the cross-section of semi-inclusive deep-inelastic scattering on an unpolarized target have been measured. These asymmetries give insight into the intrinsic transverse momentum of the quarks in the nucleon by the Cahn effect and into a possible correlation between transverse momentum and transverse spin. New results for azimuthal asymmetries of single hadrons produced in scattering muons off an unpolarized ^6LiD target are presented.

Keywords: unpolarized deep-inelastic scattering, azimuthal asymmetries, structure functions
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INTRODUCTION

The study of transverse momentum dependent distribution functions was initiated by Ralston and Soper in their study of Drell-Yan processes [1]. In order to understand these effects in a QCD framework, the description of the partonic structure of the nucleon has been extended to include the quark transverse spin and transverse momentum k_T [2]. The SIDIS cross-section in the one-photon exchange approximation contains eight transverse-momentum dependent distribution functions. Some of these can be extracted in SIDIS measuring the azimuthal distribution of the hadrons in the final state [3]. The chiral-odd Boer-Mulders function is of special interest among the transverse-momentum dependent distribution functions [4], since it describes the transverse parton polarization in an unpolarized hadron. The Boer-Mulders function generates azimuthal asymmetries in unpolarized SIDIS, together with the so-called Cahn effect [5], which arises from the fact that the kinematics is non-collinear when k_T is taken into account.

THE COMPASS EXPERIMENT

COMPASS is a fixed target experiment at the CERN SPS accelerator with a wide physics program focused on the nucleon spin structure and on hadron spectroscopy [6]. A 160 GeV muon beam is scattered off a transversely polarized ^{6}LiD target. For this analysis data with opposite target polarization have been spin-averaged, in order to obtain a result for an unpolarized deuteron target. The scattered muon and the produced hadrons are detected in a 50 m long wide-acceptance forward spectrometer with excellent particle identification capabilities [7]. A variety of tracking detectors is used to cope with the different requirements of position accuracy and rate capability at different angles.

UNPOLARIZED AZIMUTHAL ASYMMETRIES IN SIDIS

The cross-section for hadron production in lepton-nucleon SIDIS $\ell N \rightarrow \ell' hX$ for unpolarized targets and an unpolarized or longitudinally polarized beam has the following form [8]:

$$\begin{aligned}\frac{d\sigma}{dxdydzd\phi_h dp_{h,T}^2} &= \frac{\alpha^2}{xyQ^2}\frac{1+(1-y)^2}{2}\cdot \\ &[F_{UU,T}+F_{UU,L}+\varepsilon_1\cos\phi_h F_{UU}^{\cos\phi_h} \\ &+\varepsilon_2\cos(2\phi_h)F_{UU}^{\cos 2\phi_h}+\lambda_\mu\varepsilon_3\sin\phi_h F_{LU}^{\sin\phi_h}]\end{aligned} \tag{1}$$

where α is the fine structure constant. $F_{UU,T}$, $F_{UU,L}$, $F_{UU}^{\cos\phi_h}$, $F_{UU}^{\cos 2\phi_h}$ and $F_{LU}^{\sin\phi_h}$ are structure functions. Their first and second subscripts indicate the beam and target polarization, respectively, and the last subscript denotes, if present, the polarization of the virtual photon. λ_μ is the longitudinal beam polarization and:

$$\begin{aligned}\varepsilon_1 &= \frac{2(2-y)\sqrt{1-y}}{1+(1-y)^2} \\ \varepsilon_2 &= \frac{2(1-y)}{1+(1-y)^2} \\ \varepsilon_3 &= \frac{2y\sqrt{1-y}}{1+(1-y)^2}\end{aligned} \tag{2}$$

are depolarization factors.

The Boer-Mulders parton distribution function contributes to both the $\cos\phi_h$ and the $\cos 2\phi_h$ moments. Another source of $\cos\phi_h$ and the $\cos 2\phi_h$ moments in unpolarized scattering is the so-called Cahn effect [5] which arises from the fact that the kinematics is non collinear when the transverse momentum $k_\perp$ of the quarks is taken into account. Additionally, perturbative gluon radiation, resulting in higher order α_s QCD processes, contributes to the observed $\cos\phi_h$ and the $\cos 2\phi_h$ moments as well. pQCD effects become important for high transverse momenta p_T of the produced hadrons.

In this analysis, data taken with a longitudinally or transversely polarized ^{6}LiD target in the year 2004 has been spin-averaged in order to obtain an unpolarized data sample. To select DIS events, kinematic cuts on the negative 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. A Monte Carlo simulation is used to correct for acceptance effects of the detector. The SIDIS event generation is performed by the LEPTO generator [9], the experimental setup and the particle interactions in the detectors are simulated by the COMPASS Monte Carlo simulation program COMGEANT.

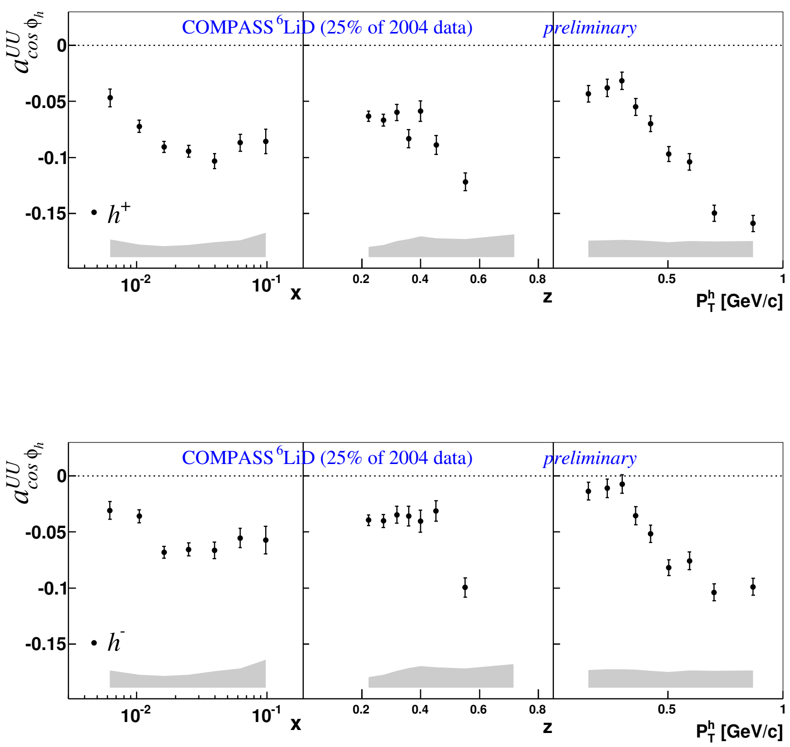

FIGURE 1. $\cos\phi_h$ asymmetries from COMPASS deuteron data for positive (upper panel) and negative (lower panel) hadrons. The bands indicate the size of the systematic uncertainty.

The acceptance of the detector as a function of the azimuthal angle $A(\phi_h)$ is then calculated as the ratio of reconstructed over generated events for each bin of x, z and p_T in which the asymmetries are measured. The measured distribution, corrected for acceptance, is fitted with the following functional form:

$$N(\phi_h) = N_0 \left(1 + A^D_{\cos\phi} \cos\phi_h + A^D_{\cos 2\phi} \cos 2\phi_h + A^D_{\sin\phi} \sin\phi_h\right) \tag{3}$$

The contribution of the acceptance corrections to the systematic error was studied in detail.

The $\sin\phi_h$ asymmetries measured by COMPASS, not shown here, are compatible with zero, at the present level of statistical and systematic errors, over the full range of x, z and p_T covered by the data. The $\cos\phi_h$ asymmetries extracted from COMPASS deuteron data are shown in Fig. 1 for positive (upper panel) and negative (lower panel) hadrons, as a function of x, z and p_T. The bands indicate the size of the systematic error. The asymmetries show the same trend for positive and negative hadrons with slightly larger absolute values for positive hadrons. Values as large as $30-40\%$ are reached in the last point of the z range. Since the Cahn effect does not depend on the hadron charge [5], the difference between positive and negative hadrons gives a hint to a non-zero and flavor dependent Boer-Mulders distribution function. The measured asymmetries have been

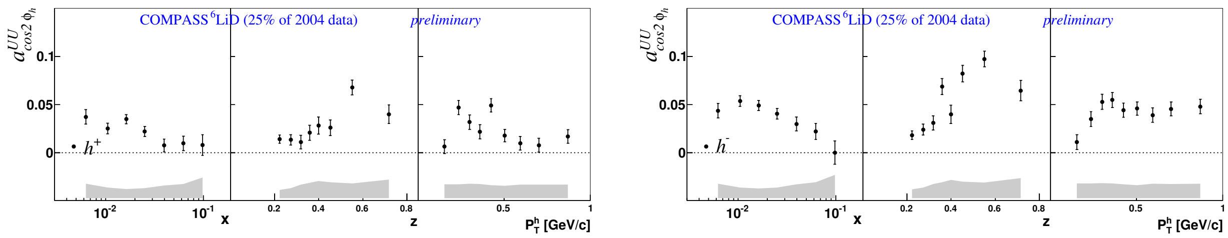

FIGURE 2. $\cos 2\phi_h$ asymmetries from COMPASS deuteron data for positive (left panel) and negative (right panel) hadrons. The bands indicate size of the systematic error.

compared to model calculations, taking into account the Cahn effect for different values of the intrinsic transverse momentum of the quarks k_T [8].

The $\cos 2\phi_h$ asymmetries are shown in Fig. 2. The asymmetries are positive for all hadrons and decrease with increasing x. The asymmetries show a similar trend for positive and negative hadrons with larger absolute values for negative hadrons.

SUMMARY AND OUTLOOK

The measured unpolarized azimuthal asymmetries on a deuteron target show large negative $\cos\phi_h$ moments for positive and for negative hadrons. The asymmetries are larger for positive hadrons than for negative ones. The $\cos 2\phi_h$ moments are all positive and show a decreasing magnitude with increasing values of x.

Acknowledgments

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REFERENCES

1. J.P. Ralston and D.E. Soper, Nucl. Phys. **B 152**, 109 (1979).
2. P.J. Mulders, R.D. Tangerman, Nucl. Phys. **461**, 197 (1997).
3. J.C. Collins *et al.*, Nucl. Phys. **B420**, 565 (1994).
4. D. Boer and P.J. Mulders, Phys. Rev. **D57**, 5780 (1998).
5. R.N. Cahn, Phys. Lett. **B78**, 269 (1978).
6. V.Yu. Alexakhin *et al.* [COMPASS collaboration] Phys. Rev. Lett. **94**, 202002 (2005); E.S. Ageev *et al.* [COMPASS collaboration] Nucl. Phys. **B765**, 31 (2007); M.G. Alekseev *et al.* [COMPASS collaboration], Phys. Lett. **B692** (2010), 240. and M. Alekseev *et al.* [COMPASS collaboration], Eur. Phys. J. **C64** (2009), 171.
7. P. Abbon *et al.* [COMPASS collaboration], NIM **A577**, 455-518 (2007).
8. A. Bacchetta *et al.*, JHEP **0702**, 93 (2007).
9. G. Ingelman, A. Edin and J. Rathsman, Comp.Phys.Commun. **101**, 108 (1997).