Single hadron transverse spin asymmetries from COMPASS

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Abstract

Transverse spin physics is an important part of the scientific programme of the COMPASS experiment at CERN. The analysis of the data taken with the target polarized orthogonally to the 160 GeV/c muon beam momentum has allowed to measure for the first time the Collins and Sivers asymmetries of the deuteron. Both for the positive and the negative hadrons produced in semi-inclusive DIS the measured asymmetries are small and, within errors, compatible with zero. New results for $\pi^{\pm}$ ans $K^{\pm}$ are presented here.

PACS: 13.60.-r, 13.88.+e, 14.20.Dh, 14.65.-q

Key words: transverse spin effects, parton distribution functions, semi-inclusive deep inelastic scattering

The COMPASS experiment has measured for the first time single hadron transverse spin asymmetries in DIS of high energy muons on deuterons, scattering the 160 GeV/c muon beam at the CERN SPS on a transversely polarised ^{6}LiD taget. In such processes the measurable asymmetry A_{Coll} ("Collins asymmetry") is due to the combined effect of the transversity distribution function (DF) $\Delta_T q(x)$ and another chirally-odd function, $\Delta_T^0 D_q^h$, which describes the spin dependent part of the hadronization of a transversely polarized quark q in a hadron h. At leading order A_{Coll} can be written as

$$A_{Coll} = \frac{\sum_q e_q^2 \cdot \Delta_T q \cdot \Delta_T^0 D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^h} \tag{1}$$

where e_q is the quark charge. The quantities $\Delta_T^0 D_q^h$ can be obtained by investigating the fragmentation of a polarised quark q into a hadron h, f.i. in $e^+e^- \rightarrow$ hadrons.

A different mechanism has also been suggested in the past as a possible cause of a spin asymmetry in the cross-section of SIDIS between leptons and transversely polarised nucleons. Allowing for an intrinsic k_T dependence of the quark distribution in a nucleon, a left-right asymmetry could be induced in such a distribution by the transverse nucleon polarisation, thus causing an asymmetry A_{Siv} (the "Sivers asymmetry") in the quark fragmentation hadron with

*Presented at 17th International Spin Physics Symposium (SPIN06), 2-7 October 2006, Kyoto, Japan, Proceedings to be published from AIP, American Institute of Physics.

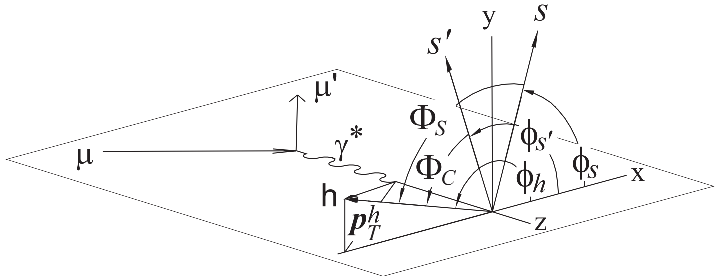

Figure 1: Definition of the Collins and Sivers angles.

respect to the nucleon polarisation.

$$A_{Siv} = \frac{\sum_q e_q^2 \cdot \Delta_0^T q \cdot D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^h} \quad (2)$$

The asymmetries A_{Coll} and A_{Siv} can be extracted separately from semi-inclusive hadron production in DIS scattering on transversely polarised nucleons by measuring a $\sin\Phi_C$ or $\sin\Phi_S$ modulation in the azimuthal distributions of the hadrons, where $\Phi_C = \phi_h + \phi_S - \pi$ and $\Phi_S = \phi_h - \phi_S$ (see Fig. 1 for the definition of the reference system).

The COMPASS experiment is described in these Proceedings [1] and in more detail in Ref. [2]. About 20% of the total beam-time in 2002, 2003 and 2004 was devoted to the run with the transversely polarised deuteron target. The kinematic cuts $Q^2 > 1$ (GeV/c)^2, $W > 5$ GeV/c^2 and $0.1 < y < 0.9$ were applied to the data, where Q^2 is the photon virtuality, W the mass of the hadronic state, and y the fractional energy of the virtual photon. The energy fraction of the hadron, z, was required to be larger than 0.2 for the "all hadron" sample, and 0.25 for the "leading hadron" sample. After all the analysis cuts the total number of DIS events was about $10{\cdot}10^6$.

The resulting Collins and Sivers asymmetries for "all" and "leading" hadrons from the 2002, 2003, and 2004 data are final. They have already been accepted for publication [2], and are shown in [1]. The preliminary results for the $\pi^\pm$ and $K^\pm$ asymmetries are plotted against the kinematic variables x, z and p_T in Fig. 2 for "leading" $\pi^\pm$ and in Fig. 3 for "leading" $K^\pm$. They refer to the 2003 and 2004 data, and correspond to $6.2 \cdot 10^6$ and $1.1 \cdot 10^6$ events for π's and K's respectively. Full points correspond to the positively charged hadrons and open points correspond to the negatively charged hadrons. Only statistical errors are shown: systematic errors have been shown to be considerably smaller than statistical ones.

As apparent from Fig. 2 and 3, all the measured asymmetries are small, if any, and compatible with zero. This trend already characterised the published data of the 2002 run [3], and is confirmed by the new data with considerably improved precision.

An analysis of the results on the deuteron can be done only in conjunction with corresponding proton data, which up to now have been measured only by the HERMES Collaboration [4]. Within the statistical accuracy of the HERMES 2002-2004 data on protons and our 2002 data on deuterons, a few global analysis aiming at the extraction of the Sivers functions and of the transversity distributions have already been performed, and the observed phenomena can be described in a unified scheme [5].

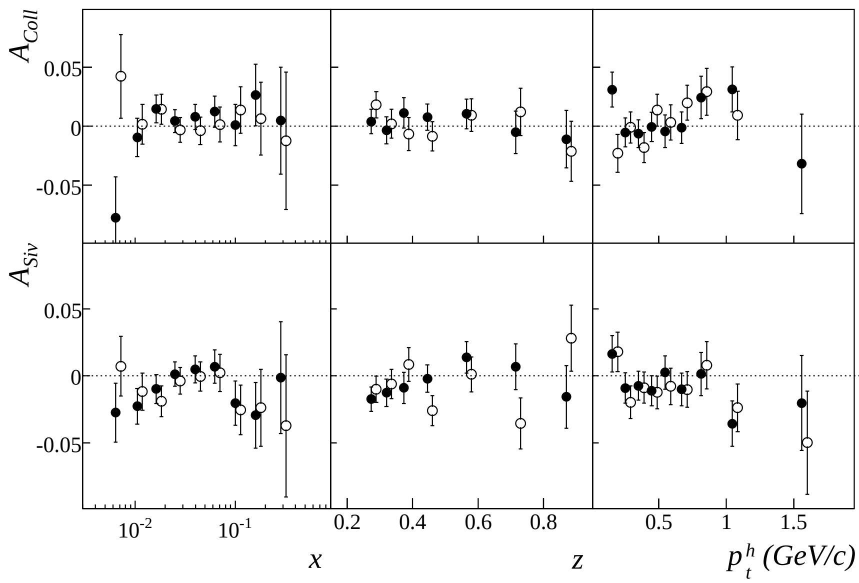

Figure 2: Preliminary results for Collins asymmetry (top) and Sivers asymmetry (bottom) against x, z and p_T^h for "leading" π^+ (full circles) and "leading" π^- (open circles) from 2003 and 2004 data.

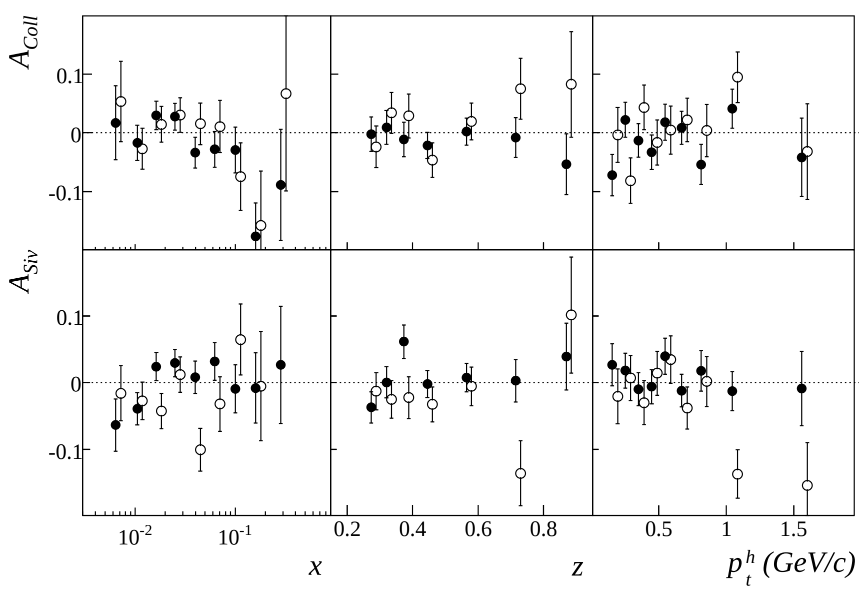

Figure 3: Preliminary results for Collins asymmetry (top) and Sivers asymmetry (bottom) against x, z and p_T^h for "leading" K^+ (full circles) and "leading" K^- (open circles) from 2003 and 2004 data.

Independently from the model calculations, I'd like to stress that we are witnessing the discovery of new phenomena. The measured non zero Collins asymmetry on the proton has provided convincing evidence that both the transversity distribution $\Delta_T u(x)$ and the Collins mechanism $\Delta_T^0 D_u^h(z)$ are not zero (the present HERMES data has allowed to extract only the leading contribution to the proton transverse asymmetry, that is the u quark contribution). Independent evidence that the Collins mechanism is a real measurable effect has come from the recent analysis of the BELLE Collaboration [6]. Furthermore, the HERMES data on a proton target have provided convincing evidence that the Sivers mechanism is also at work.

In the following, naive expectations are given for the pion asymmetries, which are valid also for the non-identified hadrons, since about 80% of them are pions. Formulas (1) and (2) simplify considerably by neglecting the sea contribution and considering only the valence x-region, i.e. the region where the HERMES and COMPASS data overlap, and the HERMES data show non-zero values. Assuming: $D_u^{\pi^+} = D_d^{\pi^-} = D_1$, $D_d^{\pi^+} = D_u^{\pi^-} = D_2$, $\Delta_T^0 D_u^{\pi^+} = \Delta_T^0 D_d^{\pi^-} = \Delta_T^0 D_1$, $\Delta_T^0 D_d^{\pi^+} = \Delta_T^0 D_u^{\pi^-} = \Delta_T^0 D_2$, and using Eq. (1), one gets for a deuteron target

$$A_{Coll}^{d,\pi^+} \simeq \frac{\Delta_T u_v + \Delta_T d_v}{u_v + d_v} \frac{4\Delta_T^0 D_1 + \Delta_T^0 D_2}{4D_1 + D_2}\,, \quad A_{Coll}^{d,\pi^-} \simeq \frac{\Delta_T u_v + \Delta_T d_v}{u_v + d_v} \frac{\Delta_T^0 D_1 + 4\Delta_T^0 D_2}{D_1 + 4D_2}\,. \qquad (3)$$

The fragmentation term is known to be different from zero (and HERMES data suggest that $\Delta_T^0 D_1 \simeq -\Delta_T^0 D_2$), therefore the smallness of both the π^+ and π^- Collins asymmetries we have measured on the deuteron is a first indication that $\Delta_T u_v \simeq -\Delta_T d_v$. One has to stress that in so far the model calculations which have analysed our partial results from the 2002 data were not able to constrain the transversity of the d-quark, but this should be possible now, with our new precise data.

Also for the Sivers asymmetry it is useful to consider the expressions one obtains for the pions. Again, the simplified analysis neglects the sea contribution, and is restricted to the valence region. For a deuteron target the Sivers asymmetries can be written as

$$A_{Siv}^{d,\pi^+} \simeq \frac{\Delta_0^T u_v + \Delta_0^T d_v}{u_v + d_v}\,, \quad A_{Siv}^{d,\pi^-} \simeq \frac{\Delta_0^T u_v + \Delta_0^T d_v}{u_v + d_v} \qquad (4)$$

which implies $A_{Siv}^{d,\pi^+} \simeq A_{Siv}^{d,\pi^-}$. The approximatively zero Sivers asymmetries for positive and negative hadrons observed in COMPASS require $\Delta_0^T d_v \simeq -\Delta_0^T u_v$, a relation which is also obtained in some models, and which anyhow has a simple physical interpretation if the Sivers distortion of the PDF of the nucleon is associated with the orbital angular momentum of the u and d quarks, whose sum almost vanishes in the deuteron. As a matter of fact, if we accept that in the deuteron the contributions of the u and the d quark should cancel, the smallness of the Sivers asymmetry for positive and negative hadrons on the deuteron can be interpreted as evidence for the absence of gluon orbital angular momentum in the nucleon, as suggested in Ref. [7].

References

[1] A. Magnon, "Overview of COMPASS", these Proceedings.

[2] E.S. Ageev et al. [COMPASS Collaboration], *Nucl. Phys. B*, in press, CERN-PH-EP-2006-031, hep-ex/0610068.

[3] V. Yu. Alexakhin et al. [COMPASS Collaboration], *Phys. Rev. Lett.* **94** 202002, (2005).

[4] A. Airapetian et al. [HERMES Collaboration], *Phys. Rev. Lett.* **94**, 012002 (2005). M. Diefenthaler [HERMES Collaboration], arXiv:hep-ex/0507013.

[5] W. Vogelsang and F. Yuan, *Phys. Rev. D* **72**, 054028 (2005). A. Efremov et al., *Phys. Rev. D* **73** (2006) 094025. M. Anselmino et al., Proceedings of the Int. Workshop on Transverse Polarization Phenomena in Hard Processes (Transversity 2005), World Scientific, 2006.

[6] K. Abe et al. [Belle Collaboration], *Phys. Rev. Lett.* **96**, 232002 (2006). A. Ogawa et al., arXiv:hep-ex/0607014. R. Seidl, "Spin dependent fragmentation function analysis at Belle", these Proceedings.

[7] S. J. Brodsky and S. Gardner, *Phys. Lett. B* **641**, 440 (2006).