

# Transverse Spin Physics at COMPASS

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The study of transverse spin effects is part of the scientific program of COMPASS, a fixed target experiment at the CERN SPS. COMPASS investigates the transversity PDFs in semi-inclusive DIS, using a longitudinally polarized muon beam of 160 GeV/c impinging on a transversely polarized target. From 2002 to 2004, data have been collected using a <sup>6</sup>LiD target transversely polarized. Transversity has been measured using different quark polarimeters: the azimuthal distribution of single hadrons, the azimuthal dependence of the plane containing hadron pairs, and the measurement of the transverse polarization of baryons ( $\Lambda$  hyperons). All the asymmetries have been found to be small, and compatible with zero, a result which has been interpreted as a cancellation between the u and d-quark contributions. In 2007 COMPASS has taken data using a NH<sub>3</sub> polarized proton target which will give complementary information on transverse spin effects.

## 1 Introduction

To fully specify the quark structure of the nucleon at twist two level, three parton distribution functions are needed: the well known momentum and helicity distribution  $q(x)$  and  $\Delta q(x)$ , and the transversity distribution  $\Delta_T q(x)$ . This latter describes the probability density of finding transversely polarized quarks in a transversely polarized nucleon, and it is currently receiving a lot of attention, both from the experimental and from the theoretical point of view.

Due to its chiral odd nature, the transversity PDFs must be coupled to another chiral-odd function in order to build an observable. For this reason, transversity cannot be measured in DIS experiments, but only in semi-inclusive DIS experiments (SIDIS), where at least one hadron in the final state is detected. In SIDIS, different channels allow to access transversity: the azimuthal distribution of single hadrons, the azimuthal dependence of hadron pairs and the measurements of the transverse polarization of  $\Lambda$  hyperons. All these channels have been investigated by the COMPASS Collaboration.

COMPASS [2] is a fixed target experiment at the CERN SPS, with a physics program focused on the study of the nucleon spin structure. From 2002 to 2004, COMPASS took data with a longitudinally polarized muon beam of 160 GeV/c and a <sup>6</sup>LiD target. For about the 20% of the time, the target nucleons have been polarized transversely with respect to the beam direction, in order to allow the measurements of transverse spin effects. The <sup>6</sup>LiD material is characterized by a high dilution factor ( $f \sim 0.38$ ), and the polarization values  $P_t$  reached during data taking are around 50%.

## 2 Single spin asymmetries

### 2.1 Collins asymmetries

The transversity PDF can be accessed in single hadron production via the so called Collins effect [3]. In this mechanism, the fragmentation function of transversely polarized quarks

into unpolarized hadrons is composed by two parts, an unpolarized and a polarized one, depending on the quark spin (Collins FF). More precisely, the FF shows an azimuthal dependence with respect to the plane defined by the quark momentum and the quark spin, meaning that the event yield can be written as:

$$N = N_0 \cdot (1 + f \cdot P_t \cdot D_{nn} \cdot A_C \cdot \sin(\phi_C)) \quad (1)$$

where  $f$  and  $P_t$  have been already introduced, and  $D_{nn} = (1 - y)/(1 - y + y^2/2)$  is the transverse spin transfer coefficient from the initial to the struck quark. The Collins angle  $\phi_C$  is defined as  $\phi_h - \phi_{s'}$ , where  $\phi_h$  is the angle of the transverse momentum of the outgoing hadron and  $\phi_{s'} = \pi - \phi_s$  is the azimuthal angle of the struck quark spin ( $\phi_s$  is the azimuthal angle of quark before the hard scattering).  $A_C$  is the Collins asymmetry, proportional to the convolution of the Collins fragmentation function and the transversity distribution:

$$A_C = \frac{\sum_q e_q^2 \Delta_T q(x) \Delta_T^0 D_q^h(z, p_T^2)}{\sum_q e_q^2 q(x) D_q^h(z, p_T^2)} \quad (2)$$

where  $z = E_h/(E_l - E_{l'})$  is the fraction of available energy carried by the hadron, and  $p_T$  is the hadron transverse momentum with respect to the virtual photon direction. Comparing the number of hadrons produced in SIDIS reactions on nucleons polarized transversely in opposite directions, the modulation given by the Collins angle gives access to the asymmetry  $A_C$ .

In order to select DIS events in the data, interaction vertices with one incoming muon, one scattered muon and at least one outgoing hadron have been selected. To select the DIS regime, the photon virtuality  $Q^2$  is taken above 1 (GeV/c)<sup>2</sup>, the fractional energy of the virtual photon  $y$  between 0.1 and 0.9, and the invariant mass of the final hadronic state  $W$  above 5 GeV/c<sup>2</sup>. Moreover, the following cuts on the hadron variables have been applied:  $z > 0.2$  and  $p_T > 0.1$  GeV/c. After all the cuts applied, the total number of positive and negative hadrons is 7 and 8.5·10<sup>6</sup>, respectively.

The Collins asymmetries of unidentified hadrons [5, 6] for the full statistics are shown in Fig. 1, as a function of  $x$ ,  $z$  and  $p_T$ . The asymmetries are small, and compatible with zero within the very good statistical accuracy, which is reaching ~1% in the central  $x$  bins. The systematic errors, investigated with extensive studies, have been found to be well below the statistical precision. A naïve interpretation of the results can be achieved in the parton model: restricting to the valence region, the small asymmetries on deuterium are due to a cancellation between the transversity PDF for the u and d quark. This result is valid even if the Collins FF are opposite in sign and similar in size, as is suggested by the non zero asymmetries on a proton target measured by the HERMES Collaboration [7].

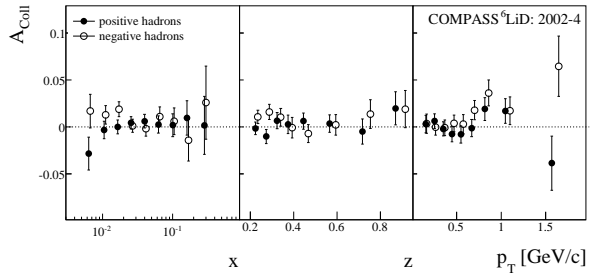


Figure 1: Collins asymmetries for not identified hadrons as a function of  $x$ ,  $z$  and  $p_T$ .

In order to perform a more sophisticated flavor separation analysis, the hadrons in the final state have to be identified. In COMPASS, charged kaons and pions are identified a RICH [4]. Due to the different Cherenkov thresholds, pions and kaons can be identified for momenta larger than  $\sim 3$  GeV/c and 10 GeV/c, respectively, and up to 50 GeV/c, that corresponds to a  $1.5 \sigma$   $\pi$ -K mass separation. Neutral kaons have been selected in the data from the invariant mass of the decay products. After the selection, the invariant mass spectra show a peak at the  $K^0$  mass, with a signal-to-background ratio around 15. The final sample of  $K^0$ s for the analysis has been selected considering a  $\pm 20$  MeV/c<sup>2</sup> mass window around the  $K^0$  mass. The final statistics consists of  $5.2$  and  $4.5 \cdot 10^6$   $\pi^+$  and  $\pi^-$ ,  $0.9$  and  $0.6 \cdot 10^6$   $K^+$  and  $K^-$ , and  $0.25 \cdot 10^6$   $K^0$ .

The results obtained for pions and kaons [8] are presented in Fig. 2. Also here, the asymmetries are small and compatible with zero within the statistical errors.

## 2.2 Sivers asymmetries

The Collins asymmetry is not the only possible single spin asymmetry that can be measured with a transversely polarized target. In the complete SIDIS cross section expression, 8 structure functions depending on the transverse target polarization are present, yielding 8 asymmetries with independent azimuthal modulations. The Sivers asymmetries is the most famous one; it is related to the Sivers PDF, that gives a measurement of the correlation of the intrinsic transverse momentum of an unpolarized quark in a transversely polarized nucleon. Results for the Sivers asymmetries have been provided for unidentified [5, 6] and identified hadrons [8]. The measured Sivers asymmetries are very small and compatible with zero, indicating also in this case a cancellation between the u and d-quark contribution in an isoscalar target.

## 3 Hadron pair asymmetries

Another mechanism sensitive to the transversity PDF is the two hadrons production. The event selection for this analysis is the same as described for the single hadron analysis, apart for the lower cut on the hadron  $z$ , that has been released to 0.1. All the events with at least two hadrons in the final state have been considered, and a cut on the sum of the relative energies,  $z = z_1 + z_2 < 0.9$ , has been applied to remove exclusive production.

As for the Collins mechanism, the fragmentation of a transversely polarized quark into

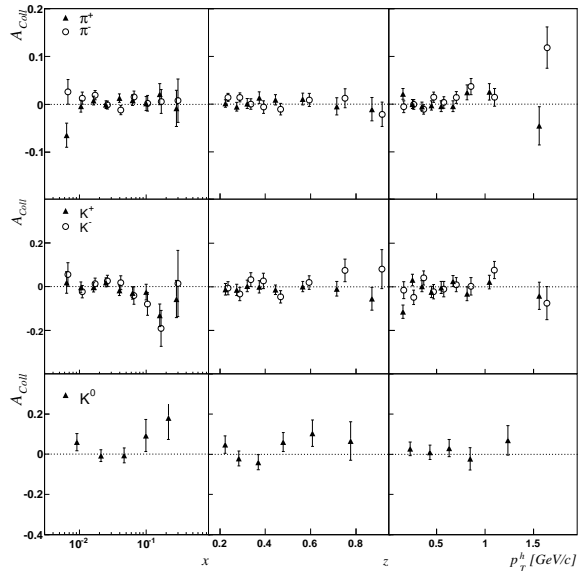


Figure 2: Collins asymmetries for pions and kaons as a function of  $x$ ,  $z$  and  $p_T$ .

a pair of hadrons is expected to depend on an azimuthal angle [9, 10, 11, 12], yielding for the number of events:

$$N = N_0 \cdot (1 + f \cdot P_t \cdot D_{nn} \cdot A_{\phi_{RS}} \cdot \sin(\phi_{RS})) \quad (3)$$

where  $\phi_{RS}$  is defined as  $\phi_R - \phi_{s'}$ ;  $\phi_R$  is the azimuthal angle between the lepton scattering plane and the plane containing the virtual photon momentum  $\mathbf{q}$  and the component  $R_T$  of the relative hadron momentum  $\mathbf{R} = \frac{1}{2}(\mathbf{P}_1 - \mathbf{P}_2)$  which is perpendicular to the summed hadron momentum  $\mathbf{P}_h = \mathbf{P}_1 + \mathbf{P}_2$ . The asymmetry  $A_{\phi_{RS}}$  is proportional to the transversity function convoluted with the fragmentation function describing the two hadrons production,  $H_1^{\perp h}$ :

$$A_{\phi_{RS}} \propto \frac{\sum_q e_q^2 \Delta_T q(x) H_1^{\perp h}(z, M_h^2)}{\sum_q e_q^2 q(x) D_q^h(z, M_h^2)} \quad (4)$$

where  $M_h^2$  is the invariant mass of the hadron pair.

Two different analyses have been performed. In the first one, the hadron pair is composed of a positive and a negative hadron: the hadrons have been identified with the RICH, so that four combinations have been considered:  $\pi^+\pi^-$ ,  $\pi^+K^-$ ,  $K^+\pi^-$ ,  $K^+K^-$ . In the second analysis, the hadrons have been ordered considering the leading and sub-leading hadrons (defined by the corresponding  $z$ ); in this analysis, also combination of hadrons with the same charge are possible, leading to 16 combinations.

All these asymmetries have been measured as a function of  $x$ ,  $z$  and  $M_h$ . No clear indication of a signal different from zero has been obtained from all the measurements.

## 4 Conclusions

In 2002-2004 COMPASS has provided a complete set of measurement of transverse spin effects using a deuterium target. All the measured asymmetries are small and compatible with zero, implying a cancellation between the u and d-quark contribution in a isoscalar target.

## References

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