

COMPASS Results on Collins and Sivers Asymmetries

Andrea Bressan¹

(on behalf of the COMPASS collaboration)

1- Department of Physics, University of Trieste and Trieste Section of INFN,
via Valerio 2, 34127, Trieste, Italy

In the list of the main items studied by the CERN COMPASS experiment there are the transverse spin and momentum effects visible in the azimuthal distributions of hadrons produced in the deep inelastic scattering. In the years 2002-2004 COMPASS has collected data with a ⁶LiD target with the polarization oriented transversely with respect to the muon beam direction for about 20% of the running time; in 2007, COMPASS has used for the first time a proton NH₃ target with the data taking time equally shared between longitudinal and transverse polarization of the target. After reviewing the results obtained with the deuteron, the new results for the Collins and Sivers asymmetries of the proton will be presented.

1 Introduction

The study of transverse spin and momentum effects of the nucleon have started significantly later than the longitudinal case, mainly since there was a prejudice that transverse spin is small or irrelevant for ultra-relativistic particles, or, at least in hard reactions. The large single-spin asymmetries in pion production from the interaction of a transversely polarized 200 GeV protons on a liquid H₂ target first reported by the Fermilab E704 collaboration [2] (and today confirmed at higher energies by the RHIC experiments) were not understood but believed to be a tail of low-energy phenomena. During the nineties both the experimental and the theoretical progress allowed to better spot the relevance of transverse spin and momentum effects for a deeper understanding of the nucleon structure. As a consequence, at that time several new experiments (HERMES at DESY, COMPASS at CERN, the RHIC experiments at BNL) were proposed; since that, the activity in the field is continuously growing, both theoretically and experimentally, giving a more and more complete picture. It is now well established that to fully specify the quark structure of the nucleon at the twist-two level, the transversity distributions $\Delta_T q(x)$ have to be added to the unpolarised distributions $q(x)$ and the helicity distributions $\Delta q(x)$. The transversity PDF's give the probability that the quark spins are aligned parallel or antiparallel to the spin of a transversely polarised nucleon. They are difficult to measure, since they are chirally odd and need to be coupled to a chirally odd partner. In particular, they cannot be measured in inclusive deep-inelastic scattering (DIS). In hadron colliders (or with hadronic beams) they can be measured looking at the Drell-Yan processes as proposed by the RHIC experiments [3] for transversely polarized protons on proton scattering and by GSI experiments [4] with hard polarised proton anti-proton scattering. They can also be measured in semi-inclusive DIS (SIDIS) of leptons on transversely polarised nucleons in which final state hadrons are also detected. To access the transversity PDF in SIDIS, one has to measure the quark polarisation, i.e. to use the so-called 'quark polarimetry'. Different techniques have been proposed in so far. Three of them are presently used in COMPASS, namely:

- measurement of the single-spin asymmetries (SSA) in the azimuthal distribution of the final state hadrons (the so-called Collins asymmetry);

- measurement of the polarisation of final state hyperons (the so-called Λ polarimetry);
- measurement of the SSA in the azimuthal distribution of the plane containing the final state hadron pairs (the so-called two-hadron asymmetry);

In this contribution the results obtained by COMPASS with the first two methods will be given while the results obtained with the last of the three polarimeters is presented in [5].

The Collins asymmetry A_{Coll} , is due to the combined effect of $\Delta_T q$ and the chiral-odd Collins fragmentation function $\Delta_T^0 D_q^h$, which describes the spin-dependent part of the hadronization of a transversely polarized quark into a hadron with transverse momentum p_T^h . At leading order, the Collins mechanism [9] leads to a modulation in the azimuthal distribution of the produced hadrons given by:

$$N(\Phi_C) = \alpha \cdot N_0 (1 + A_{\text{Coll}} \cdot P_T \cdot f \cdot D_{NN} \sin \Phi_C),$$

where α contains the apparatus efficiency and acceptance, P_T is the target polarization, D_{NN} is the spin transfer coefficient and f is the fraction of polarizable nucleons in the target; $\Phi_C = \phi_h - \phi_{S'} = \phi_h + \phi_S - \pi$ is the Collins angle, with ϕ_h the hadron azimuthal angle, $\phi_{S'}$ the final azimuthal angle of the quark spin and ϕ_S the azimuthal angle of the nucleon spin in the $\gamma - N$ system. Finally

$$A_{\text{Coll}} = \frac{\sum_q e_q^2 \cdot \Delta_T q(x) \cdot \Delta_T^0 D_q^h(z, p_T^h)}{\sum_q e_q^2 \cdot q(x) \cdot D_q^h(z, p_T^h)}$$

is the Collins asymmetry.

Another way to access transversity is by measuring the transverse Λ and $\bar{\Lambda}$ polarization in the reaction $\mu N^\uparrow \rightarrow \mu \Lambda^\uparrow X$. If the struck quark fragments into a Λ hyperon in this reaction, the corresponding polarization is given by:

$$P_\Lambda = f P_T D_{NN}(y) \frac{\sum_q e_q^2 \cdot \Delta_T q(x) \cdot \Delta_T D_q^\Lambda(z)}{\sum_q e_q^2 \cdot q(x) \cdot D_q^\Lambda(z)}$$

where the T-axis for the measurement of the polarization is given by the polarization vector of the struck quark. In this case the transversity distributions appear coupled to the chiral-odd part of the Λ fragmentation functions $\Delta_T D_q^\Lambda(z)$, which are so far completely unknown.

Another important aspect under study in this field is the role of the quark intrinsic transverse momentum and the connection with the spin for the description of the nucleon structure. The transverse momentum dependent (TMD) distribution functions (PDF) and fragmentation functions (FF) are today considered an important ingredient in the structure of the nucleon. The SIDIS cross-section in one-photon exchange approximation contains eight TMD PDF, three of which survive upon integration over the transverse momenta. Some of these TMD distributions can be extracted in SIDIS looking at the azimuthal distributions of the final state hadrons. This is particularly true for the so-called Sivers asymmetry, which is, together with the Collins asymmetry, presently the most studied. Through the Sivers asymmetry it is possible to access the Sivers PDF, which takes into account a possible deformation in the distribution of the quark intrinsic transverse momentum in a transversely polarised nucleon. Particularly interesting is also the so called Boer-Mulders function and the COMPASS efforts to access it are described in [6]. Measuring SIDIS on a transversely

polarized target allows the Collins and the Sivers effects to be disentangled. The Sivers asymmetry can be written as:

$$A_{\text{Siv}} = \frac{\sum_q e_q^2 \cdot \Delta_0^T q(x, p_T^h) \cdot D_q^h(z)}{\sum_q e_q^2 \cdot q(x) \cdot D_q^h(z)}$$

with a modulation expressed in terms of the Sivers angle $\Phi_S = \phi_h - \phi_S$. Since in this case the unpolarized fragmentation functions are known, the measurement of the Sivers asymmetry for both positive and negative produced hadrons allows a direct extraction of the Sivers functions, if the measured asymmetry are different from zero, while a zero result for an isoscalar target like the ${}^6\text{LiD}$ used in COMPASS can come both from a vanishing Sivers function or from a cancellation between u and d quark contributions.

2 The COMPASS experiment

The COMPASS experiment has been set up at the CERN SPS M2 beam line. It combines high rate beams with a modern two stage magnetic spectrometer[7].

Both stages are equipped with tracking devices covering the full acceptance, with e.m. and hadronic calorimetry and muon identification via filtering through thick absorbers. In the first stage a RICH detector is also installed, allowing the identification of charged hadrons up to 50 GeV. Detectors, electronics and data acquisition system are able to handle beam rates up to 10^8 muons/s. The triggering system and the tracking system of COMPASS have been designed to stand the associated rate of secondaries, and use state-of-the-art detectors. Also, fast front-end electronics, multi-buffering, and a large and fast storage of events are essential.

COMPASS has collected data with a 160 GeV positive muon beam impinging on a polarized solid target. The beam is naturally polarized by the π -decay mechanism, and the beam polarization is estimated to be $\sim 80\%$ with a $\pm 5\%$ relative error. The beam intensity is 2×10^8 muons per spill.

Up to 2004 COMPASS has used the polarized target system of the SMC experiment, which allows for two oppositely polarized target cells, 60 cm long each. The PT magnet can provide both a solenoid field (2.5 T), to hold the longitudinal (with respect to the beam direction) polarization, and a dipole field (0.5 T), needed for adiabatic spin rotation and for holding the transverse polarization. In 2006 the installation of a new PT magnet, with an increased inner bore radius matching the full acceptance of the spectrometer (180 mrad), was performed.

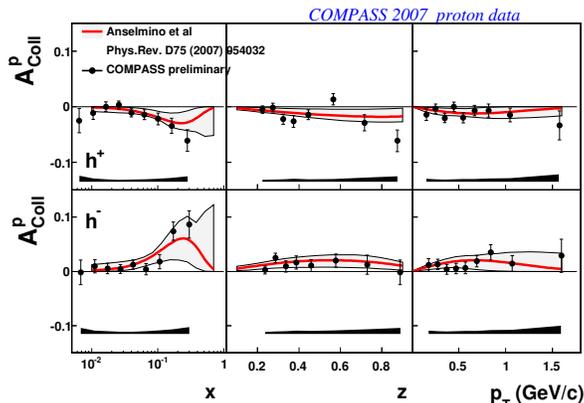


Figure 1: Collins asymmetry for positive (upper row) and negative (lower row) hadrons as a function of x , z and p_T for the proton 2007 data.

Up to 2006 the experiment has used ${}^6\text{LiD}$ as deuteron target because its favorable dilution factor of $\simeq 0.4$, particularly important for the measurement of $\Delta G/G$. In 2007 an ammonia NH_3 target has been used as proton target. Moreover, the target material has been distributed in three cells, with a length of 30 cm for the outer cells and 60 cm for the inner one. In this case the outer cells have the same orientation of the polarization, opposite to the central one. Polarizations of 50% and 90% have been reached, respectively for the two target materials.

3 Analysis and Results

The event selection requires standard DIS cuts, i.e. $Q^2 > 1$ $(\text{GeV}/c)^2$, mass of the final hadronic state $W > 5$ GeV/c^2 , $0.1 < y < 0.9$, and the detection of at least one hadron in the final state. For the detected hadrons it is also required that:

- the fraction of the virtual photon energy carried is $z = E_h/E_\gamma > 0.2$ to select hadrons from the current fragmentation region;
- $p_T > 0.1$ GeV/c (where p_T is the hadron transverse momentum with respect to the virtual photon direction) for a better determination of the azimuthal angle ϕ_h .

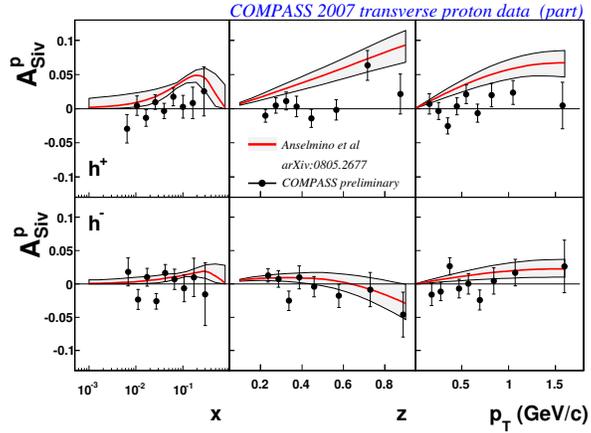


Figure 2: Siverson asymmetry for positive (upper row) and negative (lower row) hadrons as a function of x , z and p_T for the proton 2007 data.

The asymmetries have been calculated as a function of x , z and p_T for positive and negative hadrons respectively. Both the resulting Collins and Siverson asymmetries from the whole deuteron data turned out to be small and compatible with zero [11] (a trend that is also shown by the identified hadron results [12]), a result which was interpreted as a cancellation between the contribution of the u and d quarks, for the isoscalar deuteron target. The new results for the proton NH_3 target are shown in Fig. 1 for the Collins asymmetries and in Fig. 2 for the Siverson asymmetries, together with the prediction from [13, 14], based on the global analysis of the HERMES proton data, COMPASS deuteron data and BELLE e^+e^- data for Collins and on the HERMES proton data and COMPASS deuteron data for Siverson. Collins asymmetries as a function of x are small, compatible with zero, up to $x \sim 0.05$, while in the last points a signal appears, and the asymmetries increases up to 10% with opposite sign for the positive (upper row) and negative (lower row). The trend is in good agreement with what observed by HERMES [15]. At variance the Siverson asymmetries are small and compatible with zero over the full x range and for both positive and negative hadrons; in this case the compatibility with HERMES results is fine for negative hadrons but is marginal, if

any, for positive hadrons. The origin of the disagreement, needs to be understood [16] and will be an interesting issue for the near future.

In Fig. 3 the measured transverse Λ and $\bar{\Lambda}$ polarizations are shown as a function of x . The result is statistically compatible with zero, over the full range, and this may come both from the relatively low- x region sampled, or by the fact that most of the statistics comes from a region with $z_\Lambda < 0.4$, where $\Delta_T D_q^\Lambda$ may be small.

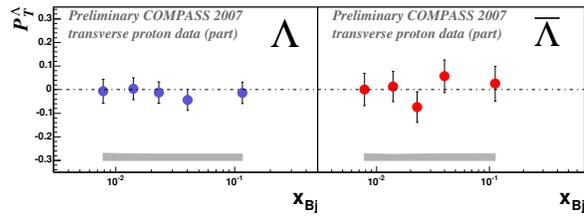


Figure 3: Transverse Λ and $\bar{\Lambda}$ polarization as a function of x for part of the 2007 proton data.

References

- [1] Slides:
<http://indico.cern.ch/contributionDisplay.py?contribId=309&sessionId=4&confId=53294>
- [2] The E704 Collaboration, D. L. Adams *et al.*, Phys. Lett. **B264** (1991) 462.
- [3] G. Bunce *et al.*, Part. World 3 (1993) 1.
- [4] The ASSIA Collaboration, M. Maggiora, SPIN PRAHA 2005, Czech J. Phys. 56 (2006) C75.
- [5] H. Wollny, “Transversity signal in two hadrons production at COMPASS”, these proceedings.
- [6] A. Bressan, “Azimuthal asymmetries in SIDIS off unpolarized targets at COMPASS”, these proceedings.
- [7] The COMPASS Collaboration, P. Abbon *et al.*, Nucl. Instrum. Meth. **A577** (2007) 455.
- [8] E. Albrecht *et al.*, Nucl. Instrum. Meth. **A553** (2005) 215 and P. Abbon *et al.*, Nucl. Instrum. Meth. **A595** (2008) 23.
- [9] J. C. Collins, Nucl. Phys. **B396** (1993) 161.
- [10] D.W. Sivers, Phys. Rev. **D41** (1991) 83.
- [11] The COMPASS Collaboration, E.S. Ageev *et al.*, Nucl. Phys. **B765** (2007) 31.
- [12] The COMPASS Collaboration, M. Alekseev *et al.* Phys. Lett. **B673** (2009) 127.
- [13] M. Anselmino *et al.*, Phys. Rev. **D75** (2007) 954032.
- [14] M. Anselmino *et al.*, Eur. Phys. J. **A39** (2009) 89.
- [15] M. Diefenthaler *et al.*, arXiv:0706.2242 (2007), published in ‘Munich 2007, Deep-inelastic scattering’ 579-582.
- [16] W. Vogelsang, to appear in the proceeding of International Conference on Particles And Nuclei (PANIC08), 9-14 of November, 2008 in Eilat, Israel.