Overview of Spin Studies at COMPASS

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Abstract. Spin studies at COMPASS are presented. Results on gluon and quark helicities, as well as on transversity are shown. Future plans are summarized.

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LONGITUDINAL SPIN STRUCTURE FUNCTION

One of the main goals of the current experiments studying nucleon spin structure is to determine how the total longitudinal spin projection of the nucleon, 1/2, is distributed among its constituents: quarks, gluons and orbital angular momentum. This is summarized in the equation $1/2 = (1/2)\Delta\Sigma+\Delta G+L_z$, where $\Delta\Sigma$ is the contribution of the spin of all quarks and antiquarks. Old estimations from the naive quark parton model as well as from a QCD approach neglecting strange quark polarization, have predicted a large polarization of the quarks $\Delta\Sigma=0.6$. When EMC first measured a value of $\Delta\Sigma$ compatible with zero in 1987, this led to the nucleon "spin crisis". Extensive measurements during the last decades have shown that the singlet axial matrix element a_0, which is related to $\Delta\Sigma$, is small, of the order of 0.3, but not zero. In some QCD schemes, $a_0 = \Delta\Sigma-(3\alpha_s/2\pi)\Delta G$. Thus a very large value of ΔG, several times the value of the nucleon spin, had been advocated to restore $\Delta\Sigma = 0.6$ when $a_0=0.3$. Today, first results from lattice QCD indicate in the contrary that the valence quark contributions to the nucleon spin could add up to a lower value of $\Delta\Sigma$ (u and d only) compatible with the latest measurements (0.3). They also indicate sizable quark contributions $L_z(u)$ and $L_z(d)$ to the angular momentum L_z however opposite thus canceling in L_z. Not much is known theoretically on ΔG, and in the last 15 years a large experimental effort has been undertaken for its measurement by various collaborations: HERMES at DESY, COMPASS at CERN, STAR and PHENIX at RHIC.

Gluon helicity

The gluon polarization can be determined by three different methods: in polarized lepton nucleon SIDIS reactions, in polarized pp hard collisions (done at RHIC), by choosing channels sensitive to the gluon distribution and measuring spin asymmetry of cross-sections, or through global QCD fits of polarized inclusive DIS data. By using 160 GeV polarized μ beam scattered on polarized nucleons, direct measurements of

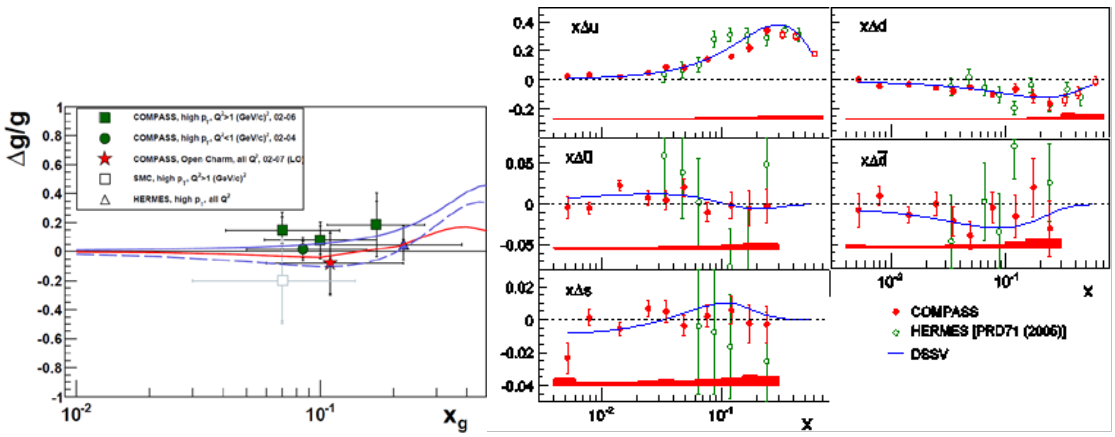

FIGURE 1. ***Left:*** COMPASS results for the gluon polarization $\Delta g/g(x)$ (4 green points from high p_T hadron pairs and red star from open charm channel), with HERMES and SMC results. All points are extracted at leading order (LO) in QCD. The curves are DSSV (lower red line) [3] and LSS (dashed and upper blue lines) [4] QCD fits at LO not including the data. ***Right:*** COMPASS (closed red points) and HERMES (open green points) results for the helicity quark distribution $x\Delta q(x)$ for five flavors compared to the global fit at NLO from DSSV[3].

$\Delta G/G$ are performed at COMPASS via a double spin asymmetry of cross sections for the photon gluon fusion (PGF) process $gg \rightarrow qq$. PGF events are searched for in two channels: the "open charm channel" where a cc pair is produced and a c quark is identified via the production of a D^0 meson, and the "high p_T hadron" channel, where outgoing lighter quarks hadronize into pions, with high transverse momentum p_T . The open charm channel is only accessible at COMPASS thanks to the high energy of the CERN polarized muon beam. It provides a clean signature of the PGF but is a difficult channel requiring counting events with D^0 production over a large combinatorial background of πK pairs, leading to limited statistics. On the contrary, the high p_T channel benefits from high statistics but suffers from competing background processes which have to be simulated and accounted for. Fig.1-*left* shows all existing direct measurements of the gluon polarization $\Delta G/G(x)$ extracted at leading order (LO) in QCD from the measured spin asymmetries. COMPASS results from the open charm (star) [1] and high p_T (squares and circle) [2] channels are shown together with other results. The measurements probe x_g values of the gluon momentum fraction around 0.1 and give results compatible with zero. The curves show parameterizations [3.4] from QCD analyses which do not include these data and which are discussed later.

The third way to determine -indirectly- the gluon contribution to the nucleon spin is to perform a global fit of polarized data, making use of the QCD Q^2 evolution equations which correlate g_1 and ΔG. Data on the longitudinal spin structure function g_1 exist for the proton, deuteron and neutron (^{3}He). They cover three decades in x and three in Q^2 (Fig.2). This is not sufficient to constrain severely enough $\Delta G(x,Q^2)$, however first results from global fits exist. To further constrain the fit, polarized pp data can be added, as in [3]. As a result the polarized gluon distribution is severely constrained in the range $0.05 < x_g < 0.2$. For the future, precise g_1 data taken at COMPASS at 200 GeV incident muon energy will improve the quality of data at low x values.

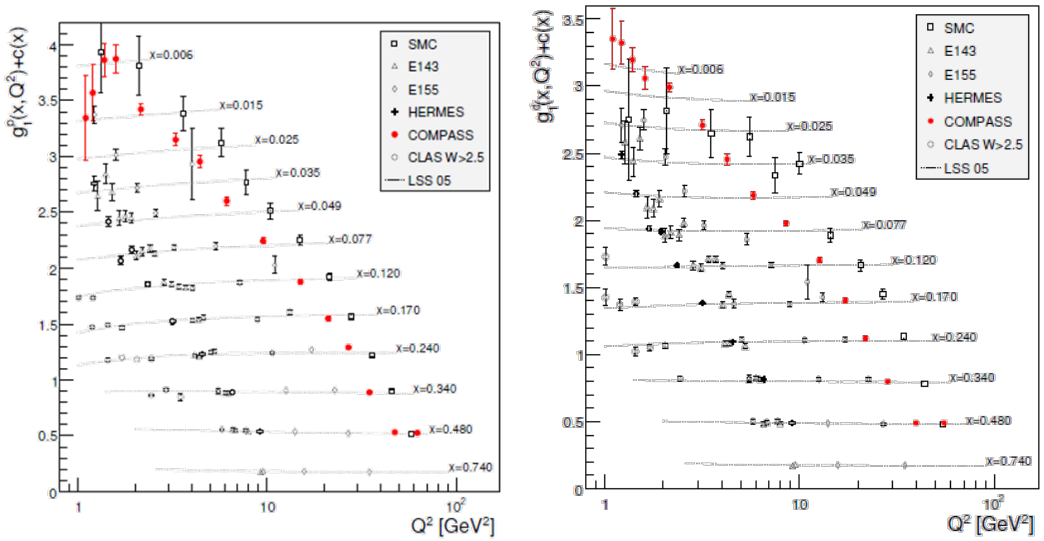

FIGURE 2. World data on longitudinal spin structure function g_1: proton (left) and deuteron (right)

Quark helicities

In parallel to the polarized inclusive DIS measurements, semi inclusive (SIDIS) events where an additional hadron tags the flavor of the struck quark, were recorded both at HERMES and COMPASS. The data from this reaction, $\mu\, p \rightarrow \mu h X$, are used to extract at LO the helicity quark distributions for each quark flavor separately down to x = 0.004. This provides a broader picture of the nucleon spin, however requiring an additional input, the quark fragmentation functions (FF). COMPASS results [5] obtained using FFs from DSS [6] are shown in Fig.1-*Right* together with HERMES results [7] for which FFs are extracted from the same HERMES data. The curve shows the global QCD fit of DSSV [3] at LO. Sea quark polarized distributions are found to be compatible with zero within the statistical errors. Concerning the strange quarks, note that the DSSV fit accommodates both the SIDIS data and the DIS data. The COMPASS and HERMES SIDIS data for $\Delta s(x)$ shown here are compatible with zero in the measured range, while the results from analyses of inclusive DIS data lead to a negative first moment for Δs, suggesting a negative contribution at low x. In the future, the SIDIS sector will benefit from more precise determination of quark FFs, presently the largest source of error on $\Delta s(x)$.

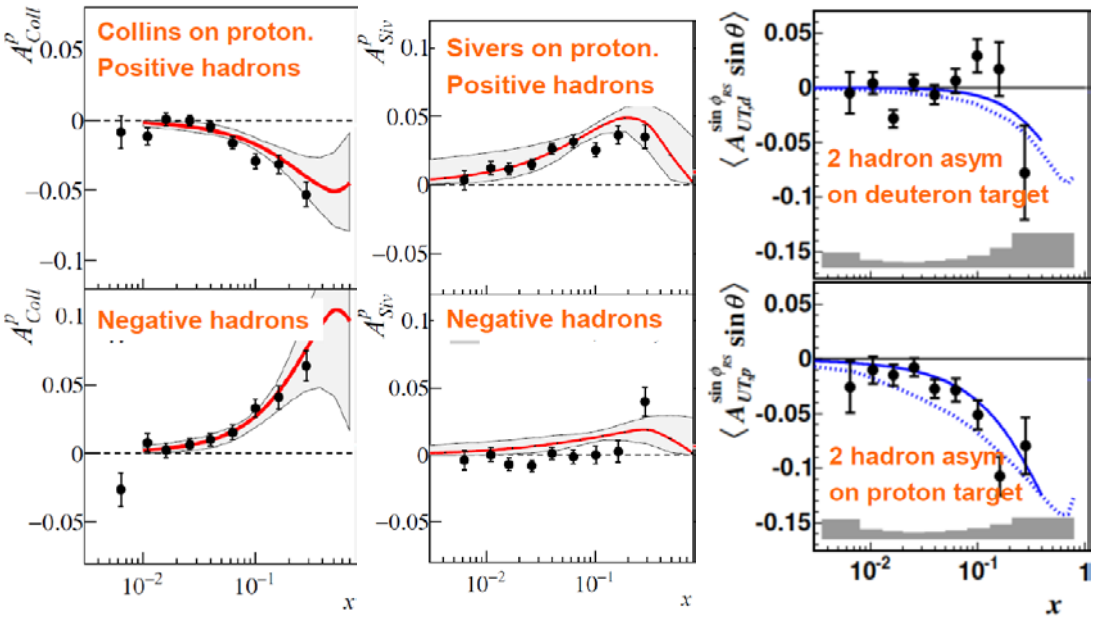

FIGURE 3 ***Left*****:** Collins asymmetry on proton target, for positive *(top)* and negative *(bottom)* hadrons, COMPASS 2007 and 2010 combined data. ***Center:*** Sivers asymmetry, idem. ***Right:*** "Two hadron" asymmetry on deuteron *(top)* and proton *(bottom)* target, 2002-2004 and 2007 data respectively.

TRANSVERSITY

Three structure functions are necessary to describe the nucleon at leading twist: $F_1(x)$, $g_1(x)$ and $h_1(x)$. If one does not integrate over the transverse momentum dependent (TMD) distributions of the partons, more structure functions are needed. $h_1(x)$ is linked to the distribution of transversely polarized partons and can be accessed in SIDIS. The experiment requires a lepton beam, a transversely polarized nucleon target and the detection of an outgoing hadron $l\ p \rightarrow l\ h^{+/-}$. The Collins and Sivers asymmetries as well as other azimuthal asymmetries are measured simultaneously by looking at various modulations of the outgoing angle of the hadron. The Collins asymmetry is sensitive to the correlation between the outgoing hadron direction and the initial quark transverse spin. Thus it can provide a determination of the quark transverse spin distributions $\Delta_T u(x)$ and $\Delta_T d(x)$. The Sivers asymmetry, obtained from a different angular modulation, is sensitive to a TMD that correlates the nucleon spin and the transverse momentum of the parton k_T. Collins and Sivers asymmetries were measured both at HERMES and COMPASS using a transversely polarized proton target, and in addition at COMPASS using a deuteron target. Mainly because of cancelations between u and d quark contributions, the data on deuteron give asymmetries compatible with zero [8] for both Collins and Sivers (not illustrated here). On the contrary signals are observed with the proton target for the Collins asymmetry [9] for all charged hadrons (Fig.3-*Left*) and for the Sivers [10] one for positive hadrons (Fig.3-*Center*, *Top*). In these figures, the full data set of COMPASS is shown combining 2007 and 2010 statistics together. Taken at an average Q^2 about 3-4 times higher than HERMES, the Collins data on the proton [9] are in excellent

agreement with HERMES, but give slightly smaller signal for Sivers[10]. An early global analysis [11] using the first HERMES proton data combined with the COMPASS deuteron data and the BELLE fragmentation function data, led to the extraction of $\Delta_T u(x)$ and $\Delta_T d(x)$. They were shown to be opposite to each other in sign, and smaller in size than the helicity distributions. The extracted u and d Sivers functions are also opposite in sign. More data are needed to disentangle the dependence on the various kinematic variables x, z, p_T separately.

An alternative method to probe quark transverse spin distributions $\Delta_T u(x)$ and $\Delta_T d(x)$ is to study azimuthal asymmetries from hadron pairs. Fig.3-*Right* shows COMPASS results [12] for the "two hadron asymmetry" measured with a deuteron *(top)* and proton *(bottom)* target. Data confirm the signal of transversity at high x. A first direct extraction of transversity [13] at LO was done using HERMES similar data on proton, while COMPASS data existing for both proton and deuteron targets could be used in a similar way [14] to separate u and d contributions.

As a conclusion, it must be noted that there has been major progresses in measurements of transversity and transverse momentum dependent (TMD) distributions. These TMDs constitute a powerful tool to understand the correlations. They are complemented by lattice calculations which start to quantify correlations observed between spin, position and momentum of the partons.

OUTLOOK

From 2014 onwards, two new sectors will be studied at COMPASS: the transverse imaging of the nucleon with the measurement of Generalized Parton Distributions (GPDs) via exclusive processes [15], and the TMD distributions via polarized Drell-Yan reactions. In parallel to the GPD program, high statistics on SIDIS reactions $\mu p \rightarrow \mu' h$ will be recorded both to access several TMDs and to perform a full mapping of pion and kaon multiplicities which will serve as input to global QCD analyses of quark FF on one side and on PDFs on the other one.

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