PROCEEDINGS OF SCIENCE

Spin, TMDs and DVCS at COMPASS

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The main objective of the COMPASS muon physics program is the study of the nucleon spin. COMPASS has accumulated data during 5 years using the CERN SPS 160 GeV polarized muon beam and a longitudinally or transversely polarized deuteron (^{6}LiD) or proton (NH_3) target.

We present here results obtained on the gluon helicity from double spin asymmetries of cross-sections for two different channel, open charm production and high transverse momentum hadron pairs, both proceeding through the photon–gluon fusion process. Results show a gluon helicity compatible with zero in the measured range, $x\sim0.1$, constraining the total integral of ΔG below ~0.3 in absolute value. The consequence for the total nucleon spin decomposition is shown. The longitudinal spin structure functions of the proton g_1^p and of the deuteron g_1^d were measured in parallel as well as the quark helicities for the various flavours.

On the transversity side, the results obtained with a proton target for the Collins and Sivers asymmetries are presented for positive and negative hadrons as a function of several variables: x, z and p_T. The Collins asymmetry, sensitive to the transverse spin structure $h_1(x)$, shows a large signal at high x for both hadron charges. The Sivers asymmetry shows a positive signal for positively charged hadrons, smaller than observed by HERMES, however in a slightly different kinematic range.

Finally, we briefly present plans for the future COMPASS-II experiment which include two new topics: Exclusive reactions DVCS and DVMP using a muon beam and a hydrogen target in view of a transverse imaging of the nucleon, as well as polarized Drell-Yan measurements using a pion beam and a polarized NH_3 target to study transverse momentum dependent distributions.

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1.Longitudinal Spin

The nucleon spin can be decomposed into contributions from quarks, gluons and orbital angular momentum as ½ = ½ ΔΣ + ΔG + Lz. Predictions from the naive quark parton model as well as from a QCD approach neglecting the strange quark polarization lead to a large polarization of the quarks, *i.e.* ΔΣ=0.6. On the contrary, measurements from the last decades show that a_0, the singlet axial matrix element related to ΔΣ, is small, ~0.3. In fact, in some QCD schemes, *e.g.* the AB scheme, $a_0 = \Delta\Sigma - (3\alpha_s/2\pi)\Delta G$. Thus a large value of ΔG could help restoring ΔΣ ~0.6. This fact, together with the ½ nucleon spin sum rule, motivated the direct measurements of ΔG. This can be performed via the double spin asymmetry of cross sections for the photon gluon fusion (PGF) process, searched for in two channels: the 'open charm' one, with the production of D° mesons, and the 'high p_T hadron pair' channel, where two outgoing quarks hadronize with high transverse momentum. Fig.1 shows all direct measurements of the gluon polarization

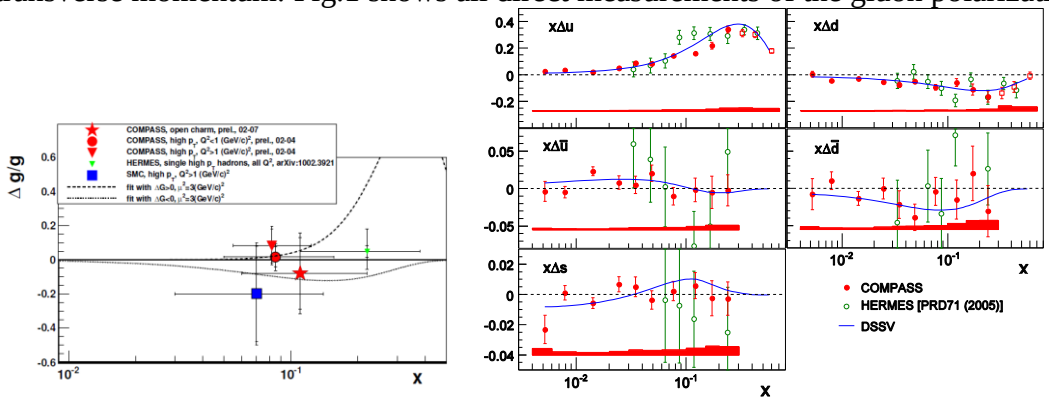

Figure 1: *Left:* Gluon polarization ΔG/G(x); results from COMPASS open charm (star) and high p_T hadrons (large triangle and circle), HERMES (small triangle) and SMC (square) with two QCD fits to g_1. *Right*: Helicity quark distributions xΔq(x) from COMPASS (closed points) and HERMES (open points) and NLO QCD fit of DSSV.

ΔG/G(x). COMPASS results [1] from the open charm (star) and high p_T hadron (large triangle and circle) channels are shown together with HERMES (small triangle) and SMC (square) results. The results probe *x* values around ~0.1-0.2, and are all compatible with zero in this kinematic range. The curves describe the two solutions, one positive and one negative, from the COMPASS QCD fits to the g_1 world data, with resulting first moments of ΔG of the order of 0.2-0.3 in absolute value. From all experimental results, including RHIC spin data, one concludes on a first moment of ΔG smaller than ~0.35. The consequence for the possible decomposition of the ½ nucleon spin on its constituents is summarized in the Table 1, where three scenarios with minimal, zero and maximal ΔG at a scale of 3 $(GeV/c)^2$ are shown.

TABLE 1). Three possible scenarios for the nucleon spin decomposition

	1/2ΔΣ	ΔG	Lz
Scen.1, ΔG max <0	0.15	0.35	0.
Scen.2 ΔG=0	0.15	0.	0.35
Scen.3, ΔG max >0	0.15	-0.35	0.70

Data on deep inelastic scattering μp → μX (DIS) are used to extract the spin structure functions of the proton [2] and deuteron g_1^p and g_1^d (Fig.2). Global QCD fits at NLO of world data on g_1 provide the quark and gluon helicity distributions $\Delta q(x,Q^2)$ and $\Delta G(x,Q^2)$. Semi inclusive DIS (SIDIS) events where an additional hadron tags the flavor of the struck quark are used to extract at LO helicity quark distributions for all flavors. This provides a wider picture of the nucleon spin, however requiring an additional input, COMPASS results [3] obtained using the quark fragmentation functions (FFs) from DSS are shown in Fig.1 *right*, together with HERMES results.

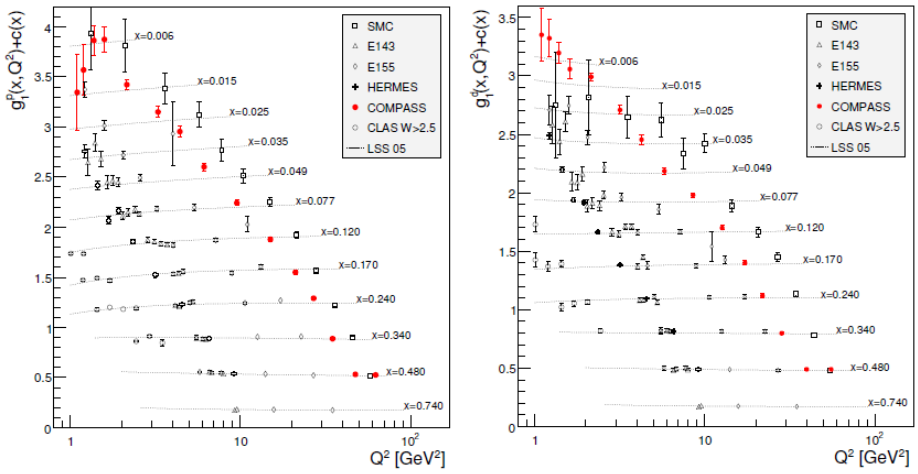

FIGURE 2: Spin structure function of the proton (left) and deuteron (right) *vs* Q^2, for various *x*.

2. Transverse Spin

Three structure functions are necessary to describe the nucleon at leading twist: $F_1(x)$, $g_1(x)$ and $h_1(x)$. The latter is linked to the distribution of transversely polarized partons. It can be accessed in SIDIS with a transversely polarized target, when coupled to an adequate FF. The azimuthal asymmetry of hadrons, the 'Collins' asymmetry, is sensitive to $h_1(x)$. COMPASS has published the asymmetries measured with a deuteron target, which are compatible with zero. In Fig.4 *left*, the results [4] obtained with a transversely polarized proton target are shown for positively and negatively charged hadrons. The data extend towards ten times lower *x* than HERMES. A combined analysis of COMPASS deuteron, HERMES proton and BELLE FF data concludes that $\Delta_T u(x)$ is positive and $\Delta_T d(x)$ negative, and both smaller than helicity distributions.

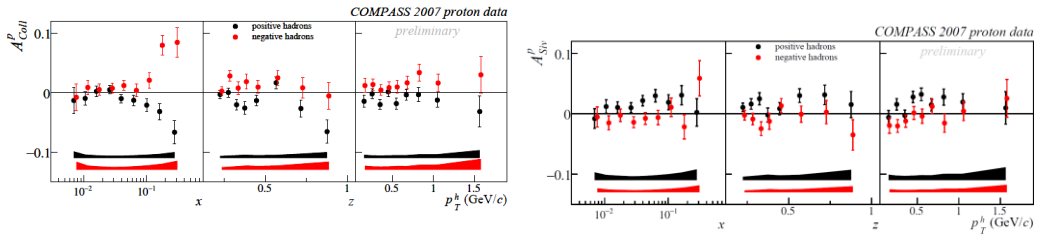

FIGURE 4. Collins (left) and Sivers (right) asymmetries on proton *vs* *x*, *z* and p_T, for positive and negative hadrons.

Simultaneously, another independent azimuthal asymmetry is measured, the 'Sivers' asymmetry, which is sensitive to the correlation between the nucleon spin and the

transverse momentum of quarks. COMPASS results on the deuteron are compatible with zero, while the results on the proton, shown in Fig.4 *right*, present a slight signal at high *x* for positively charged hadrons. The present signal is smaller than the one seen by HERMES, however in a slightly different kinematical range. Combined analyses of COMPASS deuteron and HERMES proton data provide the Sivers functions for the various quark flavours. Other azimuthal asymmetries, not shown here, are measured simultaneously. When analyzed in global fits, they should impose constraints on the transverse momentum dependent (TMD) distributions.

3.COMPASS-II

In the future COMPAS-II experimental programme, foreseen for 2012 onwards, two new sectors will be studied: the transverse imaging of the nucleon via exclusive processes, and the TMD distributions via polarized Drell-Yan reactions.

3.3Transverse imaging via exclusive processes: DVCS and DVMP

Generalized parton distributions (GPDs) provide a unified description of form factors and parton distribution functions, and a transverse imaging of the nucleon. Several observables sensitive to GPDs will be measured. They are accessible through exclusives processes like the deep virtual Compton scattering ($\mu p \rightarrow \mu p \gamma$ DVCS) or the deep virtual meson production (DVMP). The measurement of the 'Beam Charge and Spin' asymmetry obtained in the interference of the DVCS and the Bethe-Heitler (BH) processes, will cover the *x* range between 0.01 and 0.1, *i.e.* intermediate between the DESY and JLab ranges. A short test run was done in 2009 to study the feasibility of the experiment, by studying events with exclusive production of photons. The data sign the presence of DVCS events, as expected at high *x*.

3.2 TMD distributions via polarized Drell-Yan

Using the high energy pion beam in conjunction with the transversely polarized proton target (NH_3) and detecting Drell-Yan (DY) events via muon pairs, COMPASS-II will be able to measure asymmetries sensitive to various TMDs, like the Sivers and Boer-Mulders ones. These data will provide a test of the factorization approach: the sign of the Sivers function is expected to be opposite in the DY and SIDIS reactions and this has never been tested experimentally yet. A first short test run, realized in 2009 to study the feasibility of such a measurement, provided the invariant mass spectrum of the dimuon. A two year measurement of an azimuthal asymmetry sensitive to the Sivers function is foreseen at COMPASS-II.

References

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