RESULTS FROM THE COMPASS EXPERIMENT AT CERN

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On behalf of the COMPASS collaboration

COMPASS has accumulated so far 3 years of data, using the 160 GeV polarized muon beam from CERN and a polarized deuterium target to study the spin structure of the nucleon. The most precise determination of the gluon polarization is obtained at x_g=0.085 and a QCD scale μ^2=3 GeV^2, from the high p_T hadron pair channel at $Q^2 < 1$ GeV^2; the value $\Delta G/G = 0.016 \pm 0.058 \pm 0.055$ is compatible with zero. Two other determinations are also shown, one using data at $Q^2>1$, and the other, data from the production of charmed D^0 mesons. New data on the spin structure function g_1 and results from a NLO QCD global analysis are presented A measurement of the Collins asymmetry on deuterium, linked to the transversely polarized parton distributions, is shown. Finally, major upgrades of the spectrometer are launched in view of the 2006 run.

1. The nucleon spin and the COMPASS experiment

The main objective of the COMPASS muon physics program is the study of the nucleon spin, and in particular the measurement of the gluon polarization $\Delta G/G$ and of the quark spin distributions, longitudinal and transverse. The decomposition of the nucleon spin among its constituents, quarks, gluons and orbital angular momentum respectively can be written as $½ = ½\ \Delta\Sigma + \Delta G + L_z$. Predictions from the naïve quark parton model (QPM), and using a QCD approach (and neglecting strange quark polarization) lead to a large polarization of the quarks, *i.e.* $\Delta\Sigma$=0.60 for QCD. On the contrary, measurements from the last decades show that a_0, the singlet axial matrix element related to $\Delta\Sigma$, is small, ~0.25. In fact, $a_0 = \Delta\Sigma$ in the QPM, but in QCD for certain schemes, $a_0 = \Delta\Sigma - (3\alpha_s/2\pi)\ \Delta G$. Thus a large value of ΔG could help restoring $\Delta\Sigma$ ~0.6. COMPASS performs a direct measurement of $\Delta G(x)$. This requires polarized beam and target, and the measurement of spin asymmetries of a process sensitive to the gluon distribution in the nucleon. The 160 GeV polarized muon beam from CERN, with 2.10^8 muons per 4.8s spill and a polarization of 80% is scattered on a polarized deuteron target. The target material, ^{6}LiD, has been chosen its high dilution factor (fraction of polarized nucleons ~ 50%). To reduce false asymmetries, two 60 cm long target cells are polarized in opposite directions to about 50%. The target polarization is reversed once every 8 hours when polarized longitudinally, and once every week when polarized transversely. The COMPASS spectrometer is a two stage spectrometer for large and small angle tracking, with precise momentum measurement and particle identification [1]. Data were taken during 3 years from 2002 to 2004.

2. Inclusive measurements and NLO QCD analysis

2.1. *Spin structure function g_1^d and QCD analysis*

Using data taken with the longitudinally polarized target, the A_1^d spin asymmetry from inclusive DIS $\mu d \rightarrow \mu X$ events (Q^2>1GeV^2) is measured, and the corresponding spin-dependent structure function g_1^d is extracted. Fig.1 shows COMPASS results (closed points) [2,3] compared to SMC results. The COMPASS data are much more precise at Q^2>1 for 0.004<x<0.03, an important region for low x extrapolation. The data taken in 2004, with higher statistics at high x, will soon be added. The results on g_1^d were included in a global NLO QCD analysis of world data (full curve in Fig.2). The analysis assumes an initial parameterization of the polarized parton distributions and takes into account the pQCD evolution equations. Preliminary values obtained for ΔΣ and ΔG (integrals) are:

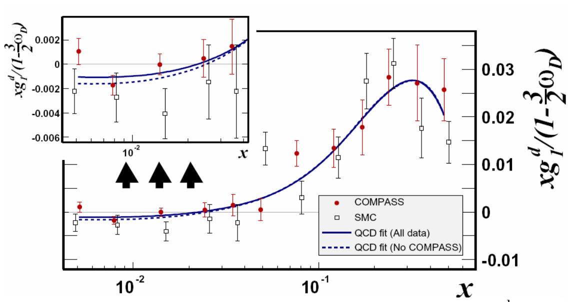


Figure 1. The longitudinal spin structure function xg_1^d as a function of x (2002-2003 data[3])

$$\mathbf{\Delta\Sigma = 0.25 \pm 0.02} \qquad \text{and} \qquad \mathbf{\Delta G = 0.4 \pm 0.2}$$

The statistical error obtained by the fit, decreased from 0.03 to 0.02 for ΔΣ by including COMPASS 2002-2003 data. A much larger uncertainty associated to the choice of the initial parameterization is expected especially for ΔG. Since g_1 world data cover only two decades in x and Q^2, ΔG is poorly constrained.

2.2. *Longitudinal spin asymmetry A_1^d at low Q^2*

The COMPASS domain extends to even lower x and Q^2 (Fig.2) than shown in **2.1**. New results obtained for the longitudinal spin asymmetry A_1^d at Q^2<1

GeV^2 are shown in Fig.3 [2], in full blue circles (published data at $Q^2>1$ [3] in red). COMPASS explores x values ten times smaller than SMC, with error bars already a magnitude smaller. Additional data, taken in 2004, are still to come.

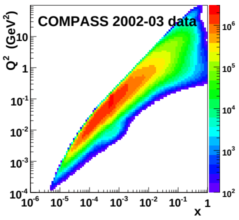


Figure 2. x-Q^2 range

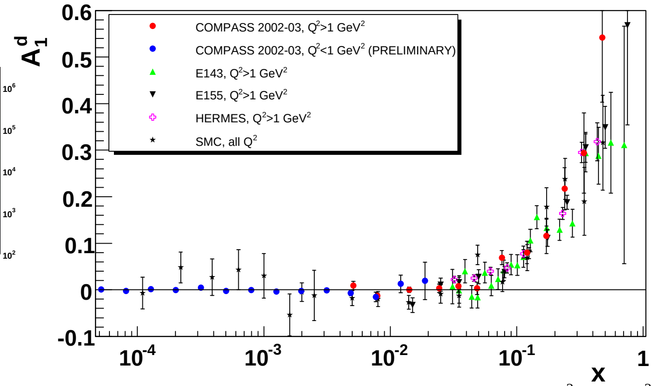


Figure 3 . The A_1^d longitudinal spin asymmetry versus x. New COMPASS results at $Q^2<1$ GeV^2 and low x ($5\ 10^{-5}<x<0.02$) : full points in blue. 2002-2003 data

3. Measuring the gluon polarization directly

A direct measurement of the gluon polarization is performed via the spin asymmetry of photon gluon fusion (PGF) events (Fig.4). Two channels are studied, the *'open charm'* channel where the outgoing quarks are c and $\bar{c}$, and the *'high transverse momentum (p_T) hadron pair'* channel (light quarks). The theory for the *open charm* channel is well established, but the statistics is low. On the contrary, for the '*high p_T*' channel, there are competing processes which cannot be separated experimentally, but the statistics is high.

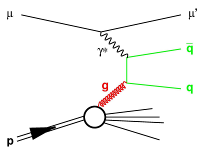


Figure 4. The photon gluon fusion diagram $\gamma^*g \rightarrow q\bar{q}$

3.1. *Open charm channel ($\gamma^*g \rightarrow c\bar{c}$)*

The presence of the outgoing $c\bar{c}$ quark pair from the PGF process is signed by the production of a charmed D^0 meson which can decay into a $K\pi$ pair. There is basically no contamination from other physics channels. The QCD scale is

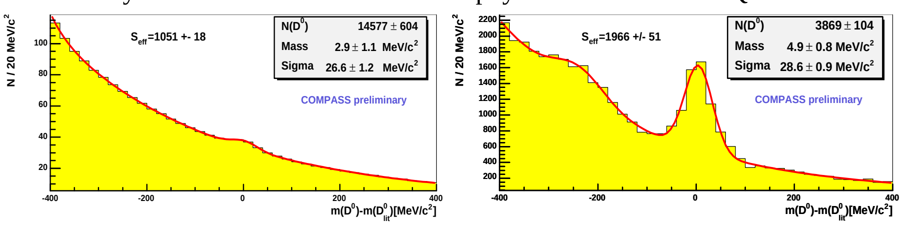


Figure5. $M(K\pi)$ - $M(D^0)$ for untagged D^0 (left) , and 'tagged' D^0 (right): $D^* \rightarrow D^0$

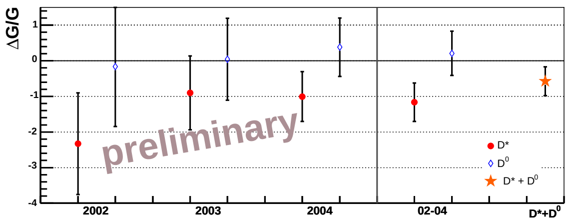


Figure 6 ΔG/G (charm channel) vs year, and averaged.

given by the mass of the charm quark. D^0s are also identified by tagging D* mesons which decay into D^0 and a soft π. Fig. 5 shows the invariant mass distribution of the Kπ pair for the untagged D^0s, and for the D^0s tagged by a D*. In the latter case where a soft π is required, the background is much reduced. The gluon polarization is extracted using the measured spin asymmetry and the analyzing power of the PGF process calculated at leading order. The preliminary results[4] obtained for ΔG/G are shown in Fig.6 as a function of the year and averaged over the 3 years, both for the untagged D^0s (open points) and the tagged one (labeled as D*, closed points). Finally, the average over the 2 channels is

ΔG/G (charm) = 0.57 ± 0.41 (stat).

The systematic error is smaller than the statistical one. On average, the fraction of the momentum taken by the gluon is $\langle x_g \rangle = 0.15$ and the QCD scale $\langle \mu^2 \rangle = 13$ $(GeV/c)^2$.

3.2. *High p_T hadron pair channel*

When the outgoing quark and antiquark of the PGF event are light quarks, the process is identified by the production of two hadrons at high transverse momentum p_T. Data at Q^2 below or above $1 (GeV/c)^2$ are treated separately, since the physical background depends on the Q^2 value.

Data at $Q^2>1$ (GeV/c)^2: a Monte Carlo with the LEPTO generator is used to calculate the fraction of events of all processes involved (PGF, leading order scattering and QCD Compton,…) , and the mean value of corresponding analyzing powers. About 1/3 of the events are PGF events. The preliminary result [4] using 2002-2003 data is

ΔG/G (high p_T $Q^2>1$) **= 0.06 ± 0.31** (stat) ± **0.06** (syst) .

The value is compatible with zero. It is obtained at $\langle x_g \rangle = 0.13$ and $\langle \mu^2 \rangle \sim 3$ $(GeV/c)^2$. The physical background is well understood, and gives a negligible contribution to the asymmetry. More data, from the 2004 run will come soon.

Data at $Q^2<1$ (GeV/c)^2 (see [5] for 2002-2003 data): The sample of data at $Q^2<1$ $(GeV/c)^2$ is 10 times larger than the one at $Q^2>1 (GeV/c)^2$. The PYTHIA generator, adapted to this kinematical range, shows that in the total, there are about 1/3 of PGF events and 1/2 of events where the photon is ‘resolved’, giving rise to several additional processes sensitive to polarized parton distributions in the nucleon, but also to polarized parton distributions in the photon. In the end, the contributions of these processes to the asymmetry appear to be small. For the part of the polarized parton distributions in the photon which are not known, the bounds given by the unpolarized distribution are used. The preliminary result [4] obtained from the 2002-2004 data is

$$\mathbf{\Delta G/G} \text{ (high } p_T\ Q^2<1) \ \mathbf{= 0.016 \pm 0.058} \text{ (stat) } \pm \mathbf{0.055} \text{ (syst)}$$

The above value, measured at $<x_g>$ = 0.085 and $<\mu^2>$= 13(GeV/c)^2 is compatible with zero. So far, this result is the most precise one for the direct measurement of ΔG/G. In Fig.7 the two '*high* p_T' points from COMPASS (Q^2 <1, full red circle; Q^2 >1, full square) and the *charm* result (black triangle), are compared to the previous '*high* p_T' data from SMC (Q^2>1) and HERMES (all Q^2). Note that the μ^2 QCD scale is not identical for all data. The 3 curves are QCD NLO fits to g_1, giving integrals of ΔG = 0.2, 0.6 and 2.4 respectively, at μ^2 = 3 (GeV/C)^2. For this given shape COMPASS data exclude large values for the integral of ΔG. Note that recent RHIC Spin results on A_{LL} (π^0 or jet production) [6] also favor also a small ΔG.

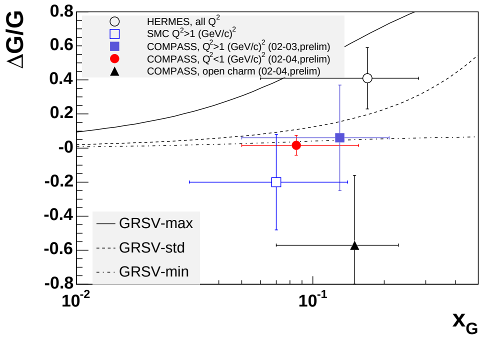


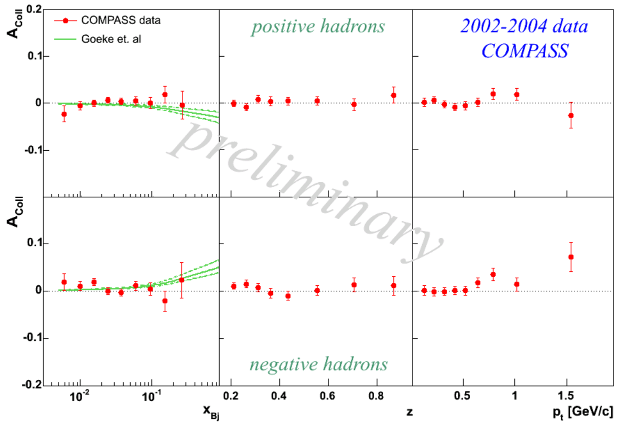
Figure 7. ΔG/G vs x_g. New COMPASS measurements (high p_T low Q^2=full red point, high Q^2=full blue square, charm= triangle) compared to existing data and QCD fits to g_1.

4. Transversity

4.1. *Collins Asymmetry*

Three structure functions are necessary to describe the nucleon at leading twist: $F_2(x)$, $g_1(x)$ and $h_1(x)$. The latter is linked to the distribution of transversely polarized partons. It cannot be measured in DIS, but it can be accessed in semi-inclusive DIS with a transversely polarized target, when coupled to an adequate fragmentation function (see [7&8] for more details).

The azimuthal asymmetry of single hadrons, the 'Collins' asymmetry, is sensitive to $h_1(x)$. In Fig.8, the new COMPASS results obtained with a transversely polarized deuteron target from 2002-2004 data, are shown as a function of *x*, *z* and p_T, both for positive and negative hadrons. Results are compatible with zero. This might be due to a cancellation between p and n.



These data, with error bars about 3 times smaller than in our previous publication[8], agree with a model[9] describing HERMES p data [10] and first asymmetries related to fragmentation functions from Belle (see [6]).

Figure 8. Collins asymmetry on deuteron vs x, z and p_T; positive(up) and negative(down) hadrons

4.2. *'Two hadron' asymmetry*

Another way to access the transversity is to use the 'two hadron' azimuthal asymmetry [7]. Results on deuteron are shown in Fig.9. They are also compatible with zero, and thus compatible with the above Collins asymmetry measurements. Another attempt to measure the transversity is also done via the production of Λs [11] although with much less statistics.

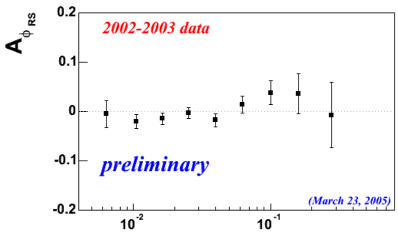


Figure 9. Two hadron asymmetry on deuteron

4.3. *Sivers asymmmetry*

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 the quarks. Results on the deuteron [7] are shown again versus x, z and p_T (Fig.10). Results are compatible with zero and agree with a model [12] which describes also HERMES p data [10]. A cancellation between p and n can explain the "zero" value for the deuteron.

Data with a transversely polarized proton target will be taken in the future.

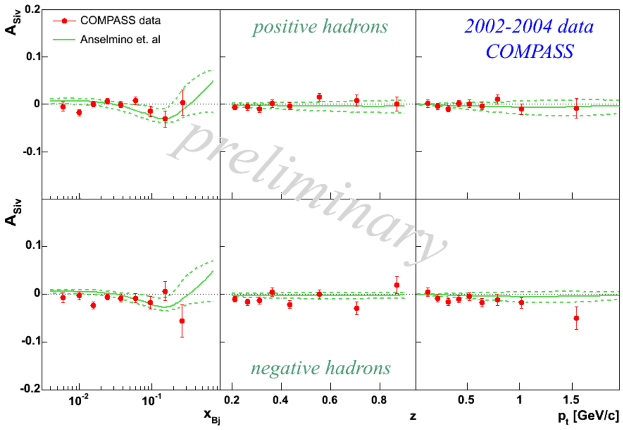


Figure 10. Sivers asymmetry on d vs *x*, *z* and p_T, for positive (up) and negative (down) hadrons.

4. Other measurements

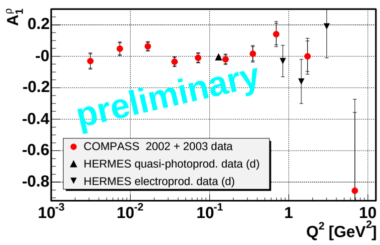


Figure 11.ρ^0 longitudinal spin asymmetry

Several other measurements are performed in COMPASS and included in separate contributions to this conference. All results on $\Lambda(\bar{\Lambda})$ physics (longitudinal Λ polarization, Λ production from transversely polarized target, spontaneous transverse hyperon production) can be found in [11]. Studies on ρ^0 production are given in [13]. Note that the ρ^0 longitudinal spin asymmetry is found to be compatible with 0 at low Q^2 (Fig.11). Finally, the future prospects for COMPASS are described in [14].

5. Spectrometer upgrades

Major upgrades have been launched to increase the figure of merit of the experiment for the measurement of $\Delta G/G$ via the open charm channel, to increase the acceptance and to make the whole apparatus suited for higher rates (beam and trigger), as well as to face the challenges of data taking with a hadron beam.

Figure 12. The new large acceptance target magnet

- The new large acceptance 2.5T superconducting target magnet (Fig.12) will increase the acceptance from 70 to 180 mrad.
- A new microwave cavity allowing a 3-cell target should reduce by an order of magnitude the false asymmetries, by doing simultaneously measurements with two different combinations of target spin as illustrated in Fig.13.

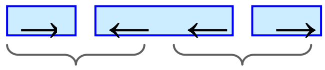


Figure 13. Measurements with the 3-cell target

- To increase the purity and the efficiency in particle identification, and also to allow for higher beam intensities, a major upgrade of the RICH is done: the central part will be equipped with multi anode photo multipliers for fast photon detection, while the CsI photon detectors of the outer part will be equipped with new fast electronics (60000 channels).
- Finally, large area trackers are being built to cope for the enlarged acceptance.

Altogether, more than a factor 2 in the figure of merit of the experiment (*charm* channel) is expected. In addition this will allow COMPASS to run with higher intensities in the coming years.

6. Conclusion and outlook

After three years of running, many new results have been obtained in COMPASS, among which the precise determination of the gluon polarization $\Delta G/G$ at x_g~0.1 from the *high* p_T channel. Sivers and Collins asymmetry have been measured on the deuteron and found compatible with zero in a broad kinematical range. In the future, more statistics will be taken, including data with a polarized proton target. Major upgrades of the spectrometer will improve the figure of merit of the experiment, especially for $\Delta G/G$ from the *charm* channel.

References

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