# Measurement of the Gluon Polarization of the Nucleon at COMPASS

Davide Reggiani (on behalf of the COMPASS Collaboration)

European Organization for Nuclear Research, CERN
1211 Geneva 23, Switzerland

## Abstract

The determination of the gluon polarization $\Delta G/G$ represents one of the main goals of the COMPASS Collaboration at CERN. This quantity is experimentally accessible by selecting photon gluon fusion (PGF) events in the scattering of a polarized 160 GeV muon beam off a polarized $^6$LiD target. At COMPASS the PGF mechanism is tagged by means of three different channels: charmed meson production and high-$p_T$ hadron pairs in either electro-production ($Q^2 > 1\,\mathrm{GeV}^2$) or quasi-real photo-production ($Q^2 < 1\,\mathrm{GeV}^2$). The status of the different analyses and the $\Delta G/G$ results obtained from the 2002-04 data samples are presented. The most precise measurement comes from the hight-$p_T$ quasi-real photo-production, yielding a small gluon polarization.

## 1 Introduction

Over the last twenty years, the spin structure of the nucleon has been investigated by several deep inelastic scattering (DIS) experiments at CERN, SLAC and DESY. After the first results by the EMC Collaboration [2], reporting a negligible contribution from the quarks spin $\Delta\Sigma$, recent precision measurements indicate that around 30 % of the nucleon spin comes from this source. Therefore, the remaining fraction must be due to the gluon spin $\Delta G$ as well as the orbital angular momenta of quarks and gluons $L_Z^{q,g}$:

$$S_z^N = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z^{q,g} \qquad (1)$$

At COMPASS, the measurement of the gluon polarization $\Delta G/G$ is accomplished by tagging the photon gluon fusion (PGF) process ($\gamma^* g \to q\bar{q}$) in polarized lepton-nucleon scattering and extracting the helicity asymmetry of the PGF cross section. The fraction of PGF events in the data sample is enhanced by selection of two different data subsets: open charm events, yielding a clean but statistically poor sample, and high transverse momentum hadron pairs, offering much larger statistics at the cost of introducing physics background.

## 2 The COMPASS experiment

COMPASS is a fixed target DIS experiment located at the M2 beam line of the CERN SPS facility. The 160 GeV naturally polarized ($\langle P_{\mathrm{B}}\rangle = 80 \pm 4\,\%$) $\mu^+$ beam scatters off a longitudinally polarized solid state target filled with $^6$LiD material. The target is composed by two oppositely polarized ($\langle P_{\mathrm{t}}\rangle = 50.0 \pm 2.5\,\%$) cells whose spin directions are reversed every eight hours in order to cancel out acceptance effects in the asymmetry calculation. This configuration makes the measurement flux independent.
The helicity asymmetry $A_{||}$ is determined from the raw counting rate asymmetry $A_{raw}$ between the two target cells:

$$A_{\|} = \frac{1}{P_{\mathrm{B}} P_t f} A_{raw} = = \frac{1}{2P_{\mathrm{B}} P_t f}\left[\frac{N_u^{\leftrightarrows} - N_d^{\leftleftarrows}}{N_u^{\leftrightarrows} + N_d^{\leftleftarrows}} + \frac{N_d^{\leftrightarrows} - N_u^{\leftleftarrows}}{N_d^{\leftrightarrows} + N_u^{\leftleftarrows}}\right] \qquad (2)$$

where $f \approx 0.4$ is the fraction of polarizable target material and $N_{u(d)}^{\leftrightarrows(\leftleftarrows)}$ is the number of events observed by the upstream ($u$) or downstream ($d$) target cell when its spin orientation is antiparallel ($\Rightarrow$) or parallel with respect to the one of the beam ($\leftarrow$).
COMPASS employs a two stages spectrometer provided with more than 300 tracking planes and PID detectors. A detailed description of the COMPASS experiment can be found in [3].
The results presented in this contribution were obtained analyzing data collected during the 2002, 2003 and 2004 COMPASS runs.

## 3 Gluon polarization from open charm

The PGF process is the main source for the production of charm quarks in DIS. On the other hand, the intrinsic charm content of the nucleon as well as charm quark production during fragmentation can be neglected. Thus, open charm represents a clean method to select PGF events in the data sample. Charm quarks hadronize into $D^0$ or $D^{*\pm}$ decaying then into pions and kaons: $D^0 \to K^{\mp}\pi^{\pm}$ (b.r. 3.8 %), $D^{*\pm} \to D^0\pi^{\pm}_{soft}$.
Due to the thick solid state target employed by COMPASS, a separation of production and decay vertex of the charmed meson can not be performed. Therefore, the reconstruction of the meson kinematics is carried out on a combinatorial basis. Background suppression is obtained by applying cuts on particle identification (kaon hypothesis for one charged track detected by the Ring Imaging CHerenkov), on the fraction of energy from the virtual photon carried by the meson ($z > 0.25$ for $D^0$, $z > 0.2$ for $D^*$) and on the angle between the meson flight direction and the kaon momentum in the c.m.s. of the decaying $D^0$ ($D^*$) meson ($|\cos\theta^*_K| < 0.5$ for $D^0$, $|\cos\theta^*_K| < 0.85$ for $D^*$). In addition, due to the small mass difference between $D^0$ and $D^*$, the background of the $D^*$ channel can be very much reduced by cutting on the mass difference $3.1\,\mathrm{MeV} < M_{K\pi\pi} - M_{K\pi} - M_\pi < 9.1\,\mathrm{MeV}$, where $M_{K\pi\pi}$ is the mass of the $D^*$ candidate and $M_{K\pi}$ the mass of the $D^0$ candidate (cf. Fig. 1).
The extraction of $\Delta G/G$ from the raw asymmetry can be obtained by:

$$\frac{\Delta G}{G} = \frac{1}{f P_B P_t a_{LL}^{PGF}} \frac{S+B}{S} A_{raw} \qquad (3)$$

where $\frac{S}{S+B}$ is the signal purity of the event sample determined from a fit to mass spectra as shown in Fig. 1. In order to take into account the correlation between $\frac{S}{S+B}$ and $a_{LL}^{PGF}$, the fit is performed in 5 bins (3 for $D^0$) of the variable $f P_b a_{LL}^{PGF}$.
The analysing power $a_{LL}^{PGF}$ depends upon the kinematical variables of the hard subprocess. Since only one of the two mesons is reconstructed, the experimental data do not contain enough information for a direct determination of $a_{LL}^{PGF}$. Thus, an event sample produced with the AROMA MC generator [4]

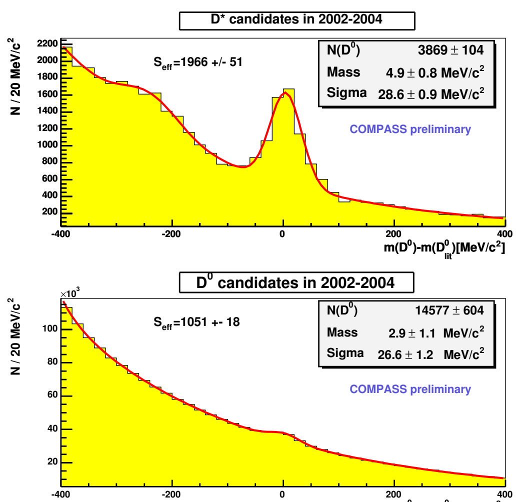


Figure 1: $K$ $\pi$ mass spectra for $D^*$ tagged events (upper plot) and the sample without $D^*$ tag. $S_{eff} = S^2/(B+S)$ is the effective signal.

was used to train a neural network and obtain a parametrization of $a_{LL}^{PGF}$ based on measured quantities.

The open charm analysis of the 2002-2004 data set yielded a preliminary result of

$$\left\langle \frac{\Delta G}{G} \right\rangle = -0.57 \pm 0.41(stat) \pm 0.17(syst) \quad (4)$$

with $\langle x_g \rangle = 0.15$ (RMS 0.08) at hard scale $\mu^2 = 13\,\mathrm{GeV}^2$. The systematic uncertainty is dominated by false asymmetries and by the choice of the fit function for the signal purity.

# 4 Gluon polarization from high-$p_T$ hadron pairs

Another way to increase the fraction of PGF events in the data sample is to look for those cases when two hadrons with large transverse momentum are produced: $\gamma^* g \to q\bar{q} \to h^+ h^-$, with $p_{T,1}, p_{T,2} > 0.7\,\mathrm{GeV}$ and $p_{T,1}^2 + p_{T,2}^2 > 2.5\,\mathrm{GeV}^2$. The target fragmentation region is suppressed by cuts at $x_F$, $z_h > 0.1$, $z_h$ being the energy fraction of the virtual photon taken up by the hadron.

After this selection, the PGF signal is still diluted by background processes like leading DIS and QCD Compton and, in case of low $Q^2$ events, resolved photon processes. Thus, the measured asymmetry can be written as the sum of different contributions:

$$\frac{A_{||}}{D} = R_{PGF} \left\langle \frac{a_{LL}^{PGF}}{D} \right\rangle \frac{\Delta G}{G} + A_{bgd} \quad (5)$$

where $R_{PGF} = \sigma^{PGF}/\sigma^{tot}$ and $a_{LL}^{PGF}$ come from Monte-Carlo simulations. The factor $D$ describes the polarization transfer from the muon to the virtual photon and depends on the photon kinematics.

## 4.1 $\Delta G/G$ at $Q^2 > 1\,\mathrm{GeV}^2$

High-$p_T$ hadron pairs in electro-production are selected by cutting at $Q^2 > 1\,\mathrm{GeV}^2$. So far this analysis has been performed on the 2002 and 2003 data sets. Analysis of data taken in 2004 is ongoing.

In order to exclude the contribution from the leading order DIS and QCD Compton asymmetries, the kinematical region $x < 0.05$ is chosen, where $A_1^d \approx 0$ [5]. After applying this selection criteria, a total of 28 thousands events are left, from which the preliminary asymmetry $A_{||}/D = -0.015 \pm 0.080(stat) \pm 0.013(syst)$ is calculated. The main contributions to the systematic error are coming from fake asymmetries and the uncertainties on the target and beam polarizations as well as the dilution ($f$) and depolarization ($D$) factors.

The estimation of analyzing power and ratio of PGF events is performed by means of a Monte-Carlo simulation based on LEPTO, a generator particularly suited for this $Q^2$ regime. After a careful tuning of the MC fragmentation parameters, a very good agreement with COMPASS data can be reached and the preliminary values $a_{LL}^{PGF}/D = -0.75 \pm 0.05$ and $R_{PGF} = 0.34 \pm 0.07$ extracted. Radiative corrections are taken into account by using RADGEN.

Plugging all these figures in equation 5, one obtains for the gluon polarization the preliminary result $\Delta G/G = 0.06 \pm 0.31(stat) \pm 0.06(syst)$ at $x_g = 0.13$ (RMS 0.08) and hard scale $\langle \mu^2 \rangle = 2.4\,\mathrm{GeV}^2$.

## 4.2 $\Delta G/G$ at $Q^2 < 1\,\mathrm{GeV}^2$

The selection of high-$p_T$ hadron pairs in quasi-real photo-production is achieved by choosing events with $Q^2 < 1\,\mathrm{GeV}^2$. At COMPASS, this sample corresponds approximately to 90 %, in terms of data, of the whole $Q^2$ range, yielding therefore a very large statistics. A total amount of 500 thousands events can be extracted from the 2002 - 2004 runs, with a corresponding measured preliminary asymmetry $A_{||}/D = 0.004 \pm 0.013(stat) \pm 0.003(syst)$.

The Monte-Carlo simulation makes use of PYTHIA, a generator optimized for lepton-nucleon interactions with low virtuality.

Both direct (PGF, QCD Compton and leading DIS) and resolved photon processes are generated. In the latter processes the target nucleon interacts with a parton coming from either a $q\bar{q}$ pair or a vector meson into which the virtual photon has fluctuated. In this $Q^2$ regime, resolved photon processes represent some 50 % of the high-$p_T$ sample and thus can not be neglected. In the direct processes, the dominant role is played by PGF (31 %), followed by QCD Compton (11 %), while leading DIS gives a negligible contribution. The comparison between reconstructed Monte-Carlo events and real data shows a good agreement in all relevant variables.

The Monte-Carlo simulation uses as imput parameters the polarizations of $u$, $d$ and $s$ quarks in the deuteron to provide values of the analyzing power for each subprocess. However, since the polarized parton distribution functions (PDFs) of the virtual photon have not been measured yet and the polarized distributions of quarks and gluons in $\gamma^*$ can not be fully calculated in the frame of QCD, only limits of the polarized PDFs from the unpolarized case with the so-called *maximal* and *minimal scenarios* [6] can be determined. The gluon polarizations extracted by applying these two scenarios are then averaged obtaining a preliminary result of $\Delta G/G = 0.016 \pm 0.058(stat) \pm 0.014(exp.syst) \pm 0.052(MC.syst) \pm 0.013(photon)$, at $\langle x_g \rangle = 0.085$ and hard scale $\langle \mu^2 \rangle = 3\,\mathrm{GeV}^2$. The details of this analysis can be found in [9].

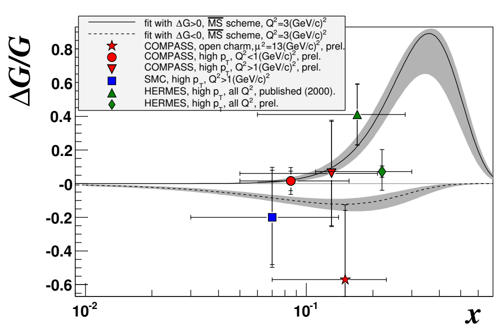


Figure 2: COMPASS measurements of $\Delta G/G$ compared with results from SMC [7] and HERMES [8] as well as NLO QCD fits (bands).

## 5 Summary

The results from three independent analyses of COMPASS data taken between 2002 and 2004 have been presented. A comparison between COMPASS and other existing results is shown in Fig. 2 along with QCD fits from [10]. In the present situation, curves corresponding to small values of $\Delta G$ are favored by the data points. The analysis of COMPASS 2006 and 2007 runs will allow for a further clarification of the spin puzzle.

## 6 Acknowledgments

I thank my COMPASS colleagues, in particular S. Koblitz and K. Kurek, for helping me in selecting the material. I gratefully acknowledge CERN for the financial support.

## References

[1] Slides: `http://indico.cern.ch/materialDisplay.py?contribId=5&sessionId=34&materialId=slides&confId=3841`

[2] J. Ashman *et al.*, Phys. Lett. B **206** (1988) 364.

[3] COMPASS, Nucl. Instrum. and Meth. A, **577** (2007) 455-518.

[4] G. Ingelman *et al.*, AROMA 2.2, Comput. Phys. Commun. **101** (1997) 135.

[5] E.S. Ageev *et al.*, Phys. Lett. B **612** (2005) 154.

[6] M. Gluck, E. Reya and C. Sieg, Eur. Phys. J. **C 20** (2001) 271-281.

[7] B. Adeva *et al.*, Phys. Rev. **D 70** (2004) 012002.

[8] A. Airapetian *et al.*, Phys. Rev. Lett. **84** (2000) 2584.

[9] COMPASS, Phys. Lett. B 633 (2006) 25-32.

[10] COMPASS, Phys. Lett. B **647** (2007) 8.