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# COMPASS results on the gluon polarisation in the nucleon

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**Abstract.** Two measurements of the gluon polarisation, $\Delta G$, inside the nucleon, performed by the COMPASS experiment, are presented. The described methods differ in the tagging of the Photon Gluon Fusion process, which is sensitive to $\Delta G/G$; the first uses the detection of charmed mesons, while the second one – high-$p_T$ hadron pairs in the final state.The obtained preliminary results are $\Delta\ G/G\ =\ -0.39\ \pm\ 0.24$ (stat.) $\pm\ 0.11$ (sys.) at $< x_g >\ \approx\ 0.1$ for the open-charm analysis and $\Delta\ G/G\ =\ 0.08\ \pm\ 0.10$ (stat.) $\pm\ 0.05$ (sys.) at $< x_g >\ \approx\ 0.08$ for high-$p_T$ case in the regime $Q^2\ >\ 1\ (GeV/c)^2$.

## 1 Introduction

In the QCD frame the longitudinal spin sum rule:

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z \qquad (1)$$

connects the nucleon spin with the integral of local QCD operators which gives the contributions of quarks and gluons to the nucleon spin. The right hand side terms give respectively the quark contribution, $\Delta\Sigma$, the gluon contribution, $\Delta G$, and the orbital angular momenta of the quarks and gluons, $L_z$. The value of $\Delta\Sigma$ was first determined by the EMC collaboration [1]. Their result - much below the expectations - triggered "the spin crisis". A series of experiments at CERN, DESY and SLAC were founded to investigate the nucleon spin. All the results indicate the small value of $\Delta\Sigma$. The recent COMPASS result extracted from the NLO QCD fit to $g_1$ structure function gives $\Delta\Sigma = 0.30 \pm 0.01$(stat.) $\pm$ 0.02(evol.) [2]. Therefore direct measurements of the gluon and quark helicities are strongly needed. COMPASS aims to measure the gluon contribution to the spin, $\Delta G/G$.

The COMPASS experiment is located at CERN SPS muon beam line which delivers highly energetic (160 GeV) positive muons, naturally polarised. The muons are scattered on the polarised target built from $^6$LiD. The target is divided into 2 (3 in the year 2006) oppositely polarised cells to cancel the systematic effects of the acceptance and of the incident muon flux. The two-staged spectrometer, 50 m long, is equipped with dipole magnets, tracking planes of different type (GEMs, Straws, Micromegas and others) and particle identification devices as RICH, calorimeters and muon filters. For more details concerning the COMPASS setup *c.f.* [3]
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## 2 Determination of $\Delta G/G$

The identification of the Photon Gluon Fusion (PGF) events in polarised lepton-nucleon scattering together with the counting rates measured for different polarisation states allows to

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access in a direct way the fraction of the nucleon spin carried by the gluons. In this process a photon emitted by an incoming lepton interacts with a gluon creating a $q\overline{q}$ pair. Depending on the created quark flavour, two types of PGF can be considered. If a pair of light quarks is created (u, d, s), hadrons with high transverse momenta[1] are studied. If a $c\bar{c}$ pair was created, charmed mesons, reconstructed from their decay products, are analyzed. Since the spin effects are extremely small, the double spin asymmetry is measured:

$$A^{exp} = \frac{N^{\uparrow\Downarrow} - N^{\uparrow\Uparrow}}{N^{\uparrow\Downarrow} + N^{\uparrow\Uparrow}}. \quad (2)$$

N stands for the number of interactions in a given cell, and the arrows indicate the orientation of beam and cell polarisation which can be parallel or antiparallel. The charm channel is a very clean tool tagging PGF due to the fact that the intrinsic charm content in the COMPASS kinematics is suppressed. The charm contribution in the fragmentation process and interactions with resolved photons are also negligible. The perturbative scale is ensured by the charm quark mass. Thus in the LO approximation of QCD, PGF is the only process which contributes to the signal. The difficulty of the measurement relies on the fact that charmed mesons have to be reconstructed on the combinatorial basis[2]. Also, NLO effects may be important for this channel. High-$p_T$ analysis can be studied in two regimes, depending on the scale: $Q^2 < 1$ (GeV/$c$)$^2$ and $Q^2 > 1$ (GeV/$c$)$^2$. In the first case, the perturbative scale is provided by the high transverse momenta of the hadrons in the final state, whereas in latter by $Q^2$ itself. I will focus on the regime of high $Q^2$ in this contribution while the results obtained for small $Q^2$ can be found in [4]. The primary advantage of this channel is its larger statistics in comparison to the open-charm one. The main disadvantage is the presence of background processes which contribute to the final sample. The strong dependence of the high-$p_T$ analysis on the Monte Carlo simulations makes the results model-dependent.

## 2.1 The open-charm method

### 2.1.1 Gluon polarisation extraction

In the LO approximation of the perturbative QCD the experimental asymmetry for charmed meson production can be decomposed into:

$$A^{exp} = P_b P_t f a_{LL} \frac{S}{S+B} \frac{\Delta g}{g} + A^{bgd}. \quad (3)$$

The quantities $P_b$, $P_t$ and $f$ are the beam polarisation ($\sim 80\%$), the target polarisation ($\sim 50\%$) and the target dilution factor ($\approx$ 0.4 for $^6$LiD), respectively. The analyzing power, $a_{LL}$, is the partonic cross-section asymmetry for the process $\mu g \to \mu' c\bar{c}$, (S/S + B) is a fraction of the signal in the final sample (signal purity), $\Delta g/g$ – gluon polarisation, integrated over the kinematically accessible region and $A^{bgd}$ – background asymmetry. The beam polarisation is parametrised as a function of the energy on the basis of the full simulation of the beam from the production target and its value is calculated for each event independently. $P_t$ is measured via NMR signals and the averaged value over about one hour of data taking is used. The dilution factor contains together with the ratio of polarised to unpolarised nucleons in the target also the ratio of cross-sections, which depends on the DIS kinematics and therefore is also calculable on the event-by-event basis. The term $a_{LL}$ is not accessible in the direct measurements and it has to be determined from Monte Carlo simulations (the AROMA generator is used for this purpose). The analyzing power is parameterised in the further analysis using neural networks ([5]) which allows to evaluate its value for real data on the event-by-event basis. Finally, the signal purity (S/S+B) is parameterised from data as a function of many variables characterising the events

[1] transverse with respect to the virtual photon direction.

[2] Due to multiple Coulomb scattering of the charged particles in the target, the spatial resolution does not allow for separation of the production and decay vertices.

| sample | $\langle \Delta g/g \rangle_x$ |
|---|---|
| $D^*$ and $D^0$ channels | $-0.47 \pm 0.27$ (stat.) $\pm 0.11$ (sys.) |
| $D^*$ channel with additional $\pi^0$ | $-0.15 \pm 0.63$ (stat.) |
| $D^*$ channel with RICH–subtreshold kaons | $+0.57 \pm 1.02$ (stat.) |

**Table 1.** Gluon polarisation results for the open-charm data collected in 2002 – 2006.

like the reconstructed $D^0$ mass, the $D^0$ transverse momentum or the RICH likelihoods. To extract $\Delta$ g/g in more efficient way the events collected in the different cells are not counted directly but weighted. Each event is weighted twice: with the signal ($w_S = f P_b a_{LL} S/S+B$) and with the background ($w_B = f P_b D B/S+B$)[3] weight. This approach allows simultaneous extraction of the signal and background asymmetries and yields a smaller statistical error compared to the the classical side-band subtraction method [6].

### 2.1.2 Data selection

Charmed quarks fragment mainly into D mesons which subsequently decay. Identification of charmed mesons decay products provides an access to the PGF. There are two main channels studied in COMPASS: $D^0 \rightarrow K^- \pi^+$ (COMPASS golden channel, called later $D^0$ sample) and $D^{*+} \rightarrow D^0 \pi^+_{slow} \rightarrow K^- \pi^+ \pi^+_{slow}$ (called later $D^*$ sample) and their charge conjugates. The main criteria of events selection are: the presence of incoming and outgoing muons in the primary vertex (PV), the PV within the target cell and at least two (or three in case of $D^*$ sample) charged tracks outgoing from the PV. To reduce combinatorial background only identified particles are used. The identification procedure is based on the RICH likelihoods and removes from the sample events with kaon and pion momenta below 9.1 GeV/$c$ and 2.5 GeV/$c$, respectively. For the $D^*$ sample there are two additional conditions: the cut on the invariant mass difference: 3.2 MeV/$c^2$ $< M_{K\pi\pi_{slow}}$ - $M_{K\pi}$ - $M_\pi <$ 8.9 MeV/$c^2$ and electron rejection which is applied to the $\pi_{slow}$ tracks. The final data samples collected in 2002 – 2006 contain about 37400 $D^0$ and 8700 $D^*$ events and they are presented in Fig. 1. In April 2009 two new channels contributing to the $D^*$ sample were added: 3-body $D^0$ decay channel with additional $\pi^0$ in the final state (seen as a wide bump on the left from the central peak for $D^*$ sample in Fig. 1) and $D^*$ events with kaons with momenta below the threshold for a positive RICH identification (but above the threshold for pions), which are identified by the lack of an associated Cherenkov ring in the RICH.

### 2.1.3 Results

The gluon polarisation from the open charm analysis obtained for the standard channels studied in COMPASS, published in [7], as well the preliminary results for the new events are collected in Table 1. The weighted mean of all these results leads to the preliminary value of the gluon polarisation for 2002 – 2006 data:

$$\langle \frac{\Delta g}{g} \rangle_x - 0.39 \pm 0.24 \,(\text{stat.}) \pm 0.11 \,(\text{sys.}) \qquad (4)$$

at $< x_g >= 0.11^{+0.11}_{-0.05}$ and the scale $< \mu^2 >= 13$ (GeV/$c$)$^2$. The major contributions to the systematical error are listed in Table 2.

[3] Depolarisation factor D is accounting for the polarisation transfer from the lepton to the virtual photon.

| source | $\delta(\langle\Delta g/g\rangle_x)D^0(D^*)$ | source | $\delta(\langle\Delta g/g\rangle_x)D^0(D^*)$ |
|---|---|---|---|
| false asymmetry | 0.05(0.05) | $P_b$ | 0.025 |
| S/(S+B) | 0.07(0.01) | $P_t$ | 0.025 |
| $a_{LL}$ | 0.05(0.03) | f | 0.025 |
| Total: 0.11(0.07) | | | |

**Table 2.** Major contributions to the systematical error for the open-charm result.

## 2.2 The high-$p_T$ method for $Q^2 > 1$ (GeV/$c$)$^2$

### 2.2.1 Gluon polarisation extraction

If we consider light quarks production in DIS, than in the lowest order of QCD, apart from the interesting PGF process, there are other mechanisms of photon-parton interactions which have to be taken into account. The background processes are: the Leading Process (LP) where $\gamma^*$ interacts with a quark from the nucleon and the QCD-Compton (QCD-C) process with an extra gluon emission. The resolved photon processes are assumed to be negligible. Thus the full formula for the double hadron asymmetry, $A^{2h}$, reads:

$$A^{2h} = \frac{A^{exp}}{P_t P_b f} \sim \frac{\Delta g}{g}(x_g) a_{LL}^{PGF} R_{PGF} + A_1^{LO}(x_{Bj}) D R_{LP} + A_1^{LO}(x_c) a_{LL}^{QCDC} R_{QCDC} \qquad (5)$$

where $R_i$ is a fraction of the subprocess $i$ in the final sample and $a_{LL}^i$ – the corresponding analyzing power; $D$ – the depolarisation factor defined in 2.1.1 and $A_1^{LO}$ – the ratio of the quark polarised and quark unpolarised distributions: $\sum e_i^2 \Delta q_i / \sum e_i^2 q_i$. Combination of Eq. 5 with the similar decomposition for inclusive asymmetry allows to extract gluon polarisation. The full formula on $\Delta g/g$ contains many factors which have to be taken from MC simulations, in particular all $R_i$ and $a_{LL}^i$, calculated separately for inclusive and high-$p_T$ samples. The weighting method for $\Delta g/g$ extraction is used analogous with the open-charm analysis.

### 2.2.2 Data selection

Apart from the standard COMPASS events selection concerning the primary vertex, the most important cut is related to transverse momenta of two fastest hadrons: $p_T > 0.7$ GeV/$c$. This requirement substantially reduces fraction of the LP in the final sample. Hadrons originating at the LP may obtain its transverse momenta from the fragmentation or from the intrinsic transverse momentum of the struck quark, therefore small $p_T$ are expected for them. Additional cut on the fraction of the photon energy is used to remove regions with low sensitivity to $\Delta$ g or regions strongly affected by radiative effects: $0.1 < y < 0.9$. The high-$p_T$ sample collected in the years 2002 – 2004 contains about 500k events.

### 2.2.3 Monte Carlo studies

As $\Delta g/g$ extraction is based on the quantities obtained from the simulations, a good agreement between data and MC is crucial. For the regime $Q^2 > 1$ (GeV/$c$)$^2$ the LEPTO generator is used with the special COMPASS tuning. The tuning is related to the transverse momenta of the quark inside the nucleon, $k_T$, and parameters of the fragmentation function which were adjusted to fit the COMPASS kinematics. Additionally, some part of the higher orders effects present in data is taken into account in the MC by switching on gluon radiations in the initial and final state[4]. Lot of effort was put into obtaining reasonable description of data by MC. The agreement between data and simulations for some inclusive ($x_{Bj}$, y, $Q^2$) and exclusive ($p_{T_1}$, $p_{T_2}$) variables, as well the impact of the COMPASS tuning in comparison to the default settings for $\Sigma(p_T)^2$, are shown in Figures 2 and 3.

[4] The disagreement between this approach and the LO formula used for gluon polarisation calculation is estimated in the systematical error.

| source | $\delta(\langle \Delta g/g \rangle_x)$ |
|---|---|
| NN | 0.006 |
| MC | 0.040 |
| f$P_b P_t$ | 0.006 |
| false asymmetry | 0.011 |
| $A_1$ | 0.008 |
| formula | 0.013 |
| Total | 0.045 |

**Table 3.** Major contributions to the systematical error for the high-$p_T$ result.

### 2.2.4 Results

The preliminary result on the gluon polarisation for high transverse momenta hadron pairs in the region of $Q^2 > 1$ (GeV/$c$)$^2$ obtained for 2002 – 2004 data is:

$$\langle \frac{\Delta g}{g} \rangle_x = 0.08 \pm 0.10\,(\text{stat.}) \pm 0.05\,(\text{sys.}). \qquad (6)$$

It was obtained for $< x_g > = 0.082^{+0.041}_{-0.027}$ and the hard scale $< \mu^2 > = 3$ (GeV/c)$^2$. Table 3 contains major contributions to the systematical uncertainty which is highly dominated by Monte Carlo studies.

## 3 Summary and Outlook

The COMPASS direct measurements of the gluon polarisation indicate a small value of $\Delta g/g$, compatible with 0 at $< x_g > \approx 0.1$. In Fig. 3 the direct results are compared to parameterisations of $\Delta g/g$ obtained in the COMPASS NLO fit to the world $g_1$ data.

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**Fig. 1.** Invariant mass distributions of the reconstructed $K\pi$ pairs. On the left: D$^0$ sample ($D^0 \rightarrow K\pi$). On the right: D$^*$ sample ($D^* \rightarrow D^0\pi_{slow} \rightarrow K\pi\pi_{slow}$).

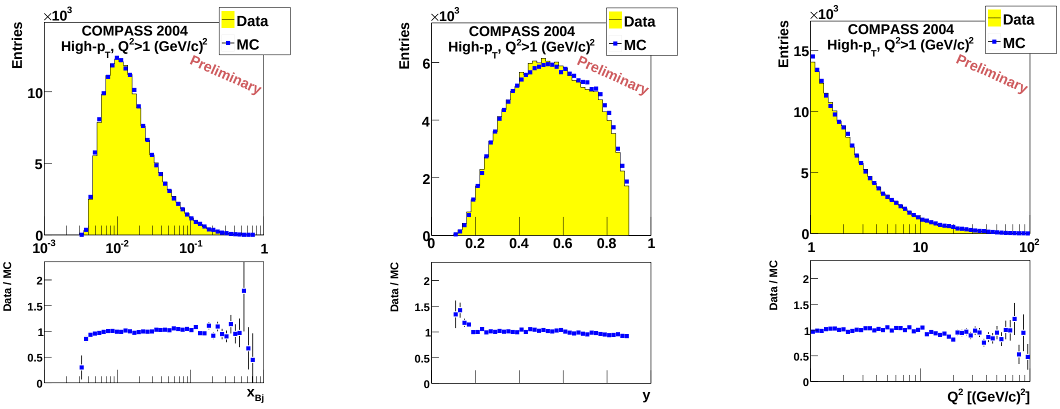


**Fig. 2.** Comparison of inclusive variables x$_{Bj}$, y and Q$^2$ between data and MC simulations.

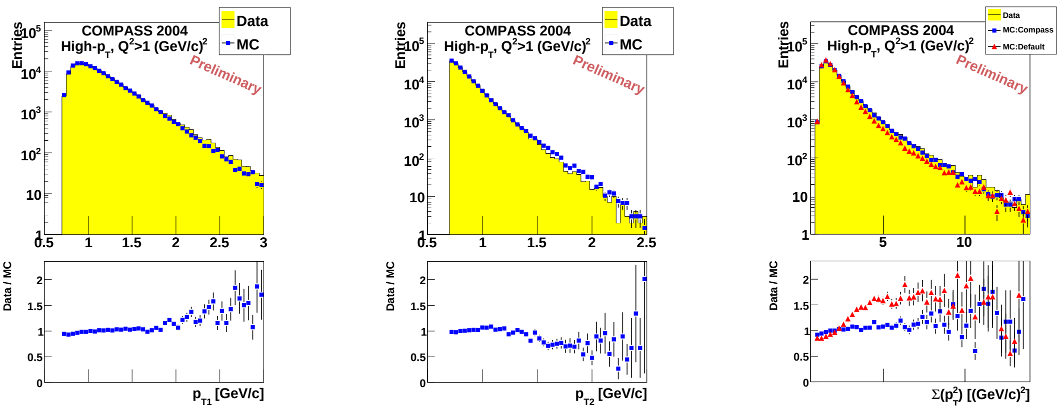


**Fig. 3.** Comparison of exclusive variables p$_{T_i}$ and $\Sigma(p_T)^2$ between data and MC simulations.

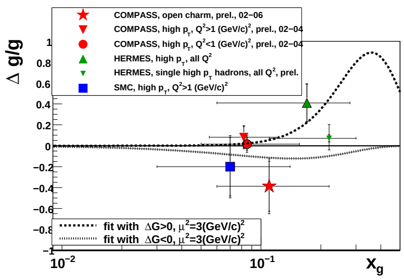


**Fig. 4.** Gluon polarisation obtained from NLO QCD analysis (curves) and from measurements (points).