Measurement of the Gluon Polarization in the Nucleon at COMPASS

J. Pretz[a]
on behalf of the COMPASS collaboration

[a]Physikalisches Institut, Universität Bonn, Nußallee 12, 53115 Bonn, Germany

COMPASS (**CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy) is a fixed target experiment at CERN studying nucleon spin structure in polarized deep inelastic muon nucleon scattering and hadron spectroscopy using hadron beams.

The main goal of the COMPASS spin physics program is the measurement of the helicity contribution of gluons to the nucleon spin, ΔG. Experimentally this quantity is mainly accessible via two processes in polarized deep inelastic scattering: The first one is the production of hadron pairs with large transverse momentum. The second one is open charm production which provides the cleanest and most direct measurement. The first method has a higher statistical accuracy but larger systematic uncertainties due to contributing background processes.

Recent results of the COMPASS collaboration, indicating a small value for ΔG, obtained with the two methods will be presented.

1. Introduction

Relativistic quark models predict that the quark helicities contribute approximately 75% to the nucleon spin. Results from deep inelastic scattering (DIS) indicate a much smaller value of $\Delta\Sigma = 20 - 30\%$. The difference could be explained by a large helicity contribution of gluons, $\Delta G = 2 - 3$, to the nucleon spin [1].

In this document ΔG always denotes the first moment of the gluon helicity distribution, $\Delta g(x)$, i.e. $\Delta G \equiv \int_0^1 \Delta g(x)\mathrm{d}x$. The momentum fraction of the gluon is denoted by x.

The data presented were taken in the years $2002-2006$ with a 160 GeV polarized muon beam on a longitudinally polarized ^{6}LiD target. A more detailed description of the experimental setup can be found in [2].

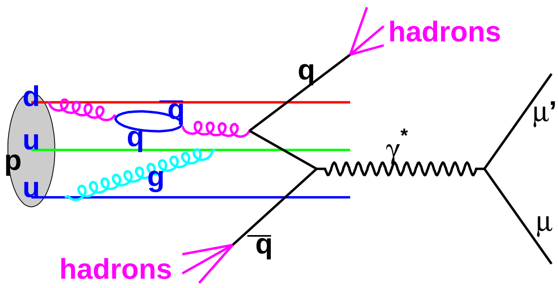

Figure 1. Deep inelastic μ-proton event with the photon-gluon-fusion process as the underlying partonic subprocess.

2. Ways to measure $\Delta g(x)$

Information about gluons inside the proton can be obtained in semi-inclusive deep inelastic scattering ($\mu + N \rightarrow \mu' +$selected hadrons$+ X$) by selecting hadronic final states signaling the participation of a gluon in the underlying partonic subprocess. Fig. 1 shows a deep inelastic event in the proton-photon CMS where the underlying partonic subprocess is photon-gluon-fusion (PGF). Experimentally this process can be tagged by the presence of a hadron pair with large transverse momentum (typically $p_T > 0.7$ GeV) with respect to the virtual photon axis or by the observation of charmed particles in the final state.

To get access to the gluon helicity distribution, $\Delta g(x)$, one has, in both methods (high p_T and open charm), to measure a double spin asymmetry A^{raw} with a longitudinally polarized beam and target. This asymmetry is related to the polarization of gluons in the nucleon, $\Delta g/g$, in the following way:

$$A^{raw} = \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}}$$
$$= P_B \, P_T \, f \; a_{LL} \frac{\sigma_{PGF}}{\sigma_{PGF} + \sigma_{bgd}} \left\langle \frac{\Delta g}{g} \right\rangle + A^{bgd} \quad (1)$$

The meaning of the variables in eq. (1) and their approximate numerical values are given in Tab. 1. Since the gluon momentum fraction x cannot be calculated from the event kinematics, one measures a gluon polarization $\langle \Delta g/g \rangle$ averaged over a certain range in x. To extract $\langle \Delta g/g \rangle$ from A^{raw} the various quantities in eq. 1 have to be known.

Whereas some of the these (P_B, P_T, f) are the same in both methods, some are different. The asymmetry of the partonic photon-gluon-fusion process, a_{LL}, is for example negative for light quarks and varies from positive to negative values as a function of the photon-gluon center-of-mass energy for heavy quarks. For both methods a_{LL} is determined event by event by a neural network. Another important difference is that for the high p_T method the signal purity, $\sigma_{PGF}/(\sigma_{PGF} + \sigma_{bgd})$, has to be estimated from Monte Carlo generators (PYTHIA for $Q^2 < 1\text{GeV}^2$ and LEPTO for $Q^2 > 1\text{GeV}^2$), whereas in the open charm method it can be measured from the background in the invariant mass spectrum of the observed charmed mesons. This reduces the model dependence of the result. Both methods will be described in more detail in the following.

2.1. The high p_T method

COMPASS analyzes the samples with the virtual photon momentum transfer Q^2 separately for $Q^2 < 1\text{GeV}^2$ and $Q^2 > 1\text{GeV}^2$. This document concentrates on the more recent analysis of the sample with $Q^2 > 1\text{GeV}^2$. Hadron pairs with a transverse momentum $p_T > 0.7$ GeV are selected. Further cuts are applied on the Feynman variable $x_F > 0$ (to select hadrons from the current fragmentation region) and on the sum of the momentum fraction of the two hadrons $z_1 + z_2 < 0.95$ (to exclude exclusive events).

Unfortunately, with this event selection other processes, like QCD-Compton (QCDC) and leading order (LO) contribute to the cross section. A neural network (NN) was used to classify every event into one of three classes (PGF, QCDC and LO). The neural network uses as input variables the Bjorken variable, x_{Bj}, the four momentum transfer, Q^2, as well as the longitudinal and transverse momenta of the two hadrons. The neural network has two outputs because the sum of the probabilities to belong to one of the three subprocesses is 1. To train the neural network the LEPTO event generator was used. The output of the NN is used to determine the signal purity $\sigma_{PGF}/(\sigma_{PGF} + \sigma_{bgd})$.

In order to trust the result, a good MC description of the data is mandatory. Fig. 2 shows a data/MC comparison of the transverse momentum of the hadron with the largest p_T. Agreement on the same level was also observed for other variables.

To minimize the statistical error, $\langle \Delta g/g \rangle$ is not extracted using event rates as suggested by eq. 1 but every event is weighted by its statistical significance which is essentially given by the product of all factors in front of $\langle \Delta g/g \rangle$ in eq. 1. A^{bgd} is determined from the inclusive asymmetry A_1. The preliminary result is

$$\left\langle \frac{\Delta g}{g} \right\rangle = 0.08 \pm 0.10(\text{stat.}) \pm 0.05(\text{sys.})\,.$$

This analysis probes the gluon helicity distribution at an average momentum fraction $< x >= 0.082^{+0.041}_{-0.027}$ and a scale $\mu^2 = 3\text{GeV}^2$. The main contribution to the systematic error comes from the MC description of the data.

2.2. The open charm production method

A much cleaner tag of the photon-gluon-fusion process is the observation of charmed particles in the final state. Because of the small intrinsic charm contribution in the proton and the low probability to produce charm quarks in the fragmentation process, charm quarks are almost exclusively produced via the photon-gluon-fusion process. Experimentally, one detects D^0 and D^{*+} mesons and their anti-particles via their respective decays in $K^- + \pi^+$ and $D^0 + \pi^+_{slow} \rightarrow K^- + \pi^+ + \pi^+_{slow}$. Fig. 3 shows the invariant mass spectra of $K\pi$ pairs for the D^0 and the D^* sample, respectively. The D^* sample is much cleaner due

Table 1
Explanation of the variables used in eq 1.

	high p_T pairs	open-charm
$N^{\uparrow\downarrow}(N^{\uparrow\uparrow})$	number of events with antiparallel (parallel) spin of beam and target	
P_B	beam polarization ≈ -0.8	
P_T	target polarization ≈ 0.5	
f	dilution factor ≈ 0.4 for ^{6}LiD target	
a_{LL}	asymmetry of partonic process $\vec{\mu}+\vec{g}\to q+\bar{q}$	
	≈ -0.5	-0.5 to 0.6
$\frac{\sigma_{PGF}}{\sigma_{PGF}+\sigma_{bgd}}$	fraction of photon-gluon-fusion processes (signal purity)	
	0.3	$0.5(D^*)$ 0.1 (D^0)
source of background	Compton, Leading Ord.	combinatorial background
determination of bgd	LEPTO/PYTHIA MC	from D^* (D^0) mass spectrum
A^{bgd}	background asymmetry	
	from incl. A_1	determined simultaneously

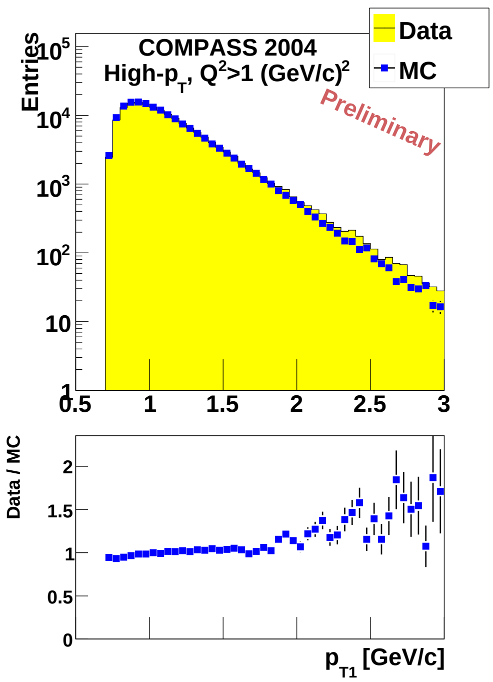

Figure 2. Data/MC comparison of the transverse momentum of the hadron with the largest p_T.

to the additional requirement of a slow pion. The signal purity is obtained from these spectra and one does not rely, as in the high p_T method, on a MC generator to estimate it. This reduces the model dependence of the result. To make optimal use of the events, the signal purity is not only determined as a function of the mass but also as a function of 10 other kinematical variables and the response of the Ring Imaging Cherenkov Counter used to identify particles. The analysis is done independently for the D^0 and D^* samples. As in the high p_T analysis, events are weighted with their statistical significance. In addition $\langle\Delta g/g\rangle$ and the background asymmetry A_B of the combinatorial background in the invariant mass spectrum are extracted simultaneously in a statistically optimal way, leading to a higher figure of merit than the classical side band subtraction method. The preliminary result is

$$\left\langle \frac{\Delta g}{g} \right\rangle = -0.49 \pm 0.27(\text{stat.}) \pm 0.11(\text{sys.})$$

at $< x >= 0.11^{+0.11}_{-0.06}$ and a scale $\mu = 13\,\text{GeV}^2$. The largest contribution to the systematic error comes from the parameterization of the signal purity in the case of the D^0 sample and possible experimental false asymmetries in the D^* sample. Note that these contributions can be lowered with more statistics.

3. Comparison with other results

Fig. 4 shows the results for $\Delta g/g$ obtained by COMPASS together with results from other ex-

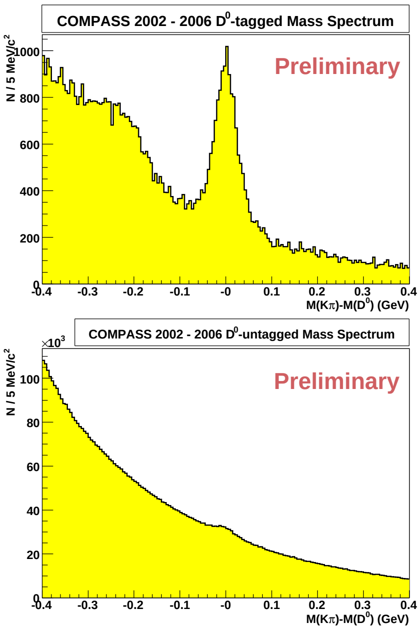

Figure 3. Invariant mass distributions of the $K\pi$ pairs of the D^* (upper) and the D^0 sample (lower).

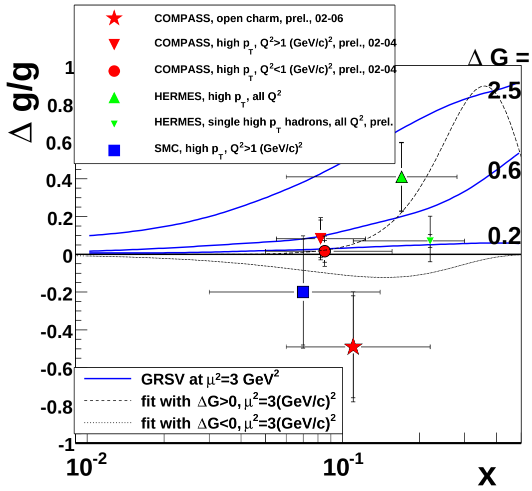

Figure 4. Comparison of the $\Delta g/g$ measurements from open charm and high p_T hadron production by COMPASS, SMC [4] and HERMES [5] as a function of x. Horizontal bars mark the range in x for each measurement, vertical ones give the statistical precision and the total errors (if available). The open charm measurement is at a scale of about 13 GeV^2, other measurements and curves at 3 GeV^2. The broken (black) curves display parameterizations from a NLO QCD analysis by COMPASS [6]. The solid (blue) curves are a parameterizations [3] with a first moment $\Delta G = \int_0^1 \Delta g(x) \mathrm{d}x = 0.2, 0.6, 2.5$.

periments and various parameterizations. The results clearly favor a small value of $\Delta g/g$ at $x \approx 0.1$ and exclude first moments of $\Delta G = 2 - 3$.

4. Summary and Outlook

COMPASS recently presented two new measurements of the gluon helicity contribution to the nucleon at a gluon momentum fraction of $x \approx 0.1$. Both measurements favor small values of the first moment of the gluon helicity distribution, ΔG, in consistency with other measurements. Scenarios with large first moments of $\Delta G = 2 - 3$ proposed to solve the nucleon spin puzzle are excluded. Note that a helicity contribution of $\Delta G = 1/2$, i. e. the gluon carrying 100% of the nucleon spin, is still not excluded by the data.

For the high p_T method, the data taken in 2006 are not yet analyzed. Adding this will further reduce the statistical error. In addition COMPASS took data in 2007 on a polarized NH_3 which are not yet included in either of the analyses presented here.

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