Spin Physics with COMPASS

Eric Weise
On behalf of the COMPASS collaboration

Physikalisches Institut, Universität Freiburg, Germany

COMPASS is a fixed target experiment at CERN studying nucleon spin structure in polarised 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 the gluons to the nucleon spin, ΔG. This quantity is accessible via the photon-gluon-fusion process which can be selected by open charm production or production of hadron pairs with large transverse momenta. The spin physics program of COMPASS includes also measurements with a transversely polarised target. These allow to measure the transverse structure function.

COMPASS has up to now succesfully finished three runs with a muon beam of 160 GeV and a longitudinally polarised ^{6}LiD target in the years 2002, 2003 and 2004. An overview of the physics addressed by the muon program, with an emphasis on the $\Delta G/G$ measurement will be presented. The status of the analysis of the high p_T hadron pairs, open charm, longitudinal and transverse asymmetries will be reviewed.

1 Introduction: The Nucleon Spin

In an intuitive picture the spin of the nucleon is carried by its valence quarks. The analysis of axial matrix elements of weak baryon decays shows, that this contribution is reduced to about 60% if the sea quarks are assumed to be unpolarised. But the deep inelastic scattering (DIS) experiments (EMC/SMC, SLAC, HERMES) revealed that the contribution of the quarks to the nucleon spin is even smaller with only 30%, and a strange quark contribution consistent with zero [1]. However the interpretation of DIS results is not without ambiguity if the helicity contribution of the gluons to the nucleon spin is sizable. Therefore the measurement of the gluon polarisation, $\Delta G/G$ is of basic interest and this measurement is presently the main goal of the COMPASS experiment [2].

2 The COMPASS Experiment

COMPASS is a fixed-target experiment located at the muon beam-line M2 of the CERN-SPS accelerator. The muon beam energy is currently 160 GeV. The beam intensity is about 2×10^8 muons per spill of 4.8 s every 16.8 s with a polarization of about 76%. The target is a two-cell solid-state ^{6}LiD target, polarised by Dynamic Nuclear Polarisation up to 54% and with a dilution factor of about 40%. Our luminosity is $\sim 5 \times 10^{32}\,\mathrm{cm}^{-2} s^{-1}$.

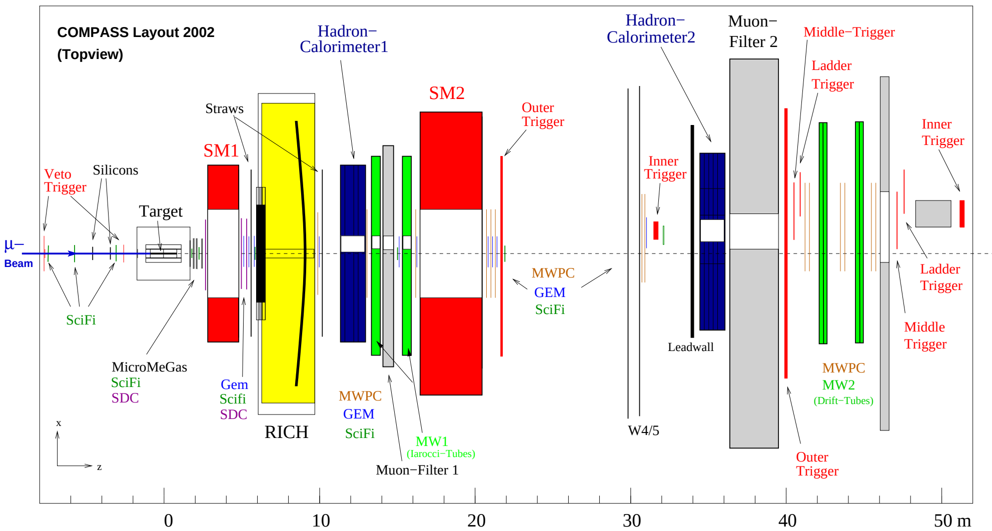

Fig. 1. Schematic view of the COMPASS experiment

COMPASS uses a two-stage forward spectrometer [3], shown in Fig. 2. Both stages consist of a bending magnet with tracking stations in front and behind it, particle identification provided by calorimeters, a Ring Imaging Cherenkov Counter (RICH) in the first stage, and an iron absorber for muon identification. The magnets have a bending power of 1.1 Tm and 4.4 Tm. The RICH provides a $K-\pi$ separation up to 40 GeV/c. The overall combined acceptance of the spectrometer and the presently used SMC target magnet is 70 mrad in polar angle, full acceptance in azimuth. Tracking is provided by different types of detectors. The beam region is covered by scintillating fibre hodoscopes and silicon detectors. Small angle tracking is provided by Micromeagas, Gas Electron Multipliers (GEMs) and Multi Wire Proportional Chambers (MWPCs). For large angle tracking, large conventional Drift Chambers ($120 \times 120\text{cm}^2$) and drift tube chambers (straws, 320×240 cm^2) are used.

3 COMPASS Physics Programme: Nucleon Spin Structure

The main goal of the COMPASS experiment at present is the measurement of the gluon polarisation $\Delta G/G$. In addition to this we have a broad spectrum of measurements using the muon beam: especially the measurement of the inclusive asymmetry A_1^d and the transversity distribution.

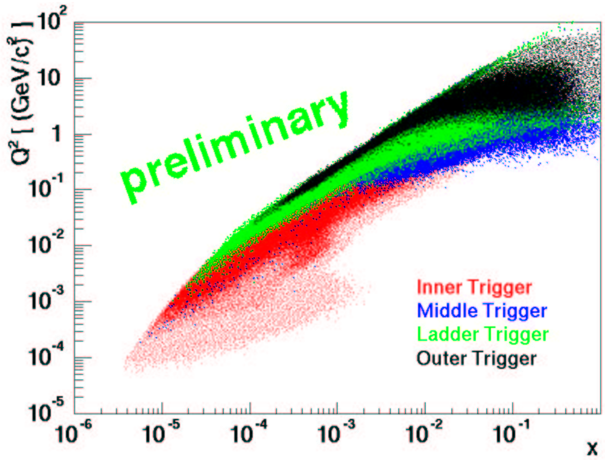

Fig. 2. Kinematic range of COMPASS of the 2002 year's data: 570×10^6 events with an incoming and a scattered muon; 29×10^6 inclusive events with $Q^2 > 1\mathrm{GeV}^2$

3.1 The Inclusive Asymmetry A_1^d and g_1

Experimentally we gain access to spin effects in DIS by measurements of asymmetries. Counting the DIS events with parallel and anti-parallel beam and target polarisation, $N^{\uparrow\uparrow}$ and $N^{\uparrow\downarrow}$, we gain access to the spin structure function $g_1(x, Q^2)$.

$$\frac{1}{D\,P_{\text{beam}}\,f\,P_{\text{target}}}\,\frac{N^{\uparrow\downarrow}-N^{\uparrow\uparrow}}{N^{\uparrow\downarrow}+N^{\uparrow\uparrow}} \quad = \quad A_1^{\gamma^* N\to X} \quad \approx \quad \frac{g_1(x,Q^2)}{F_1(x,Q^2)}$$

with D: depolarisation factor, $P_{\text{beam}}, P_{\text{target}}$: beam- and target polarisation, f: dilution factor and $F_1(x, Q^2)$ is the spin-independant structure function.

The inclusive asymmetry (Fig. 3.) A_1^d was derived from the first year of data taking 2002. Since then, we have collected four times more statistics. The analysis of the data from 2003 and 2004 is under way.
The large uncertainty of A_1^d for $x > 0.04$ originates from limited kinmatical aceptance of COMPASS, which was designed to access small Q^2 and small x. In 2003 we have upgraded our trigger to access larger Q^2 and larger x.

3.2 Measurement of $\Delta G/G$

COMPASS has in principle three ways to approach $\Delta G/G$: QCD analysis, open-charm production and high-p_T hadron production.

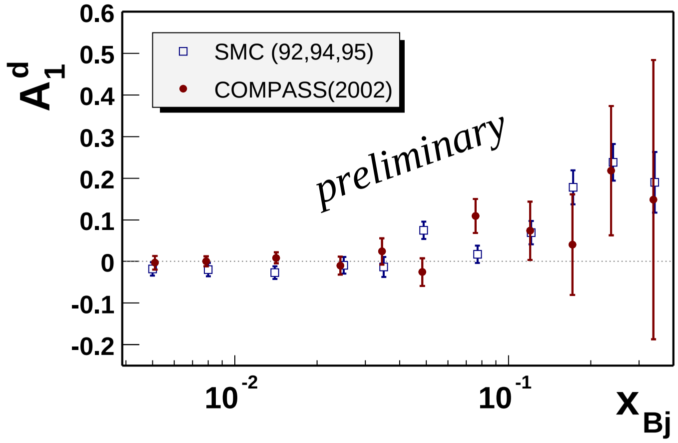

Fig. 3. Inclusive asymmetry A_1^d from the first year of data taking 2002

3.3 QCD analysis

Up to now most of the experiments focused on *inclusive* deep inelastic scattering where only the scattered lepton is observed in the final state $(l + N \to l' + X)$. This allows to derive ΔG from a fit of $g_1(x, Q^2)$ to polarised DIS data [4]. In the quark parton model, including non-pertubative QCD extensions, the spin structure function g_1 can be expressed by

$$g_1(x, Q^2) = \frac{\langle e^2 \rangle}{2} \left(C^{NS} \otimes \Delta q_{NS} + C^S \otimes \Delta\Sigma + C^G \otimes \Delta G \right)$$

with $\langle e^2 \rangle = \sum_{i=1}^{n_f} e_i^2 / n_f$, Δq_{NS}: the non-singlet quark distributions and $\Delta\Sigma$: the helicity contribution of the quarks. COMPASS will substantly improve the existing world data on $g_1(x, Q^2)$ at small x and small Q^2, which is quite sparsely populated.

3.4 open charm production

COMPASS has further the possibility to observe part of the hadronic final state: $l + N \to l' + hadrons + X$. This so called semi-inclusive process allows a deeper insight into the structure of the nucleon. Tagging the hadron, which orginated from the scattering process, permits to identify the struck parton. A gluon participating in a deep-inelastic process via the photon-gluon fusion $(\gamma^* + g \to q + \bar{q})$ (Fig. 4.) can therefore be identified by its hadronic final state.

In the case the produced quarks are charm quarks the process can be tagged by the observation of charmed hadrons. Since there is no intrinsic charm quark

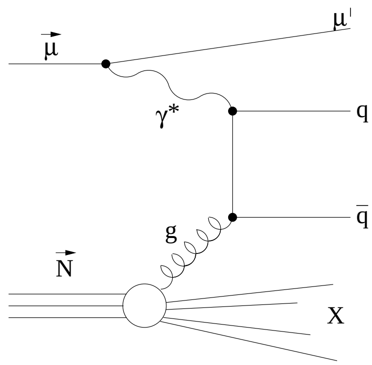

Fig. 4. The photon-gluon fusion process. The incident muon and the target nucleon are polarised.

in the proton and the production of charm quarks in the fragmentation process is suppressed, the observation of a charmed hadron clearly tags the photon-gluon fusion process. On average 1.2 D^0 or $\bar{D}^0$ are produced in the fragmentation of the photon-gluon fusion process. The D^0 can be detected via several decay channels. The most promising one is $D^0 \to K^- + \pi^+$. It is possible to suppress background by looking for an additional soft pion π_s. Using this method of D^*-tagging, we identified the D^0 mesons (Fig. 5) from the $D^* \to D^0 + \pi_s$ decay. To measure the gluon polarisation $\Delta G/G$ one has to measure the double spin asymmetry of PGF events with nucleon and lepton spin parallel and anti-parallel.

3.5 high-p_T hadron production

In case the produced quarks are light quarks, the PGF process can be tagged by a pair of hadrons with large transverse momenta. This high-p_T method is less clean due to concurrent backgrounds, like the QCD compton processes ($\gamma^* + q \to q + g$) and "resolved" photon contributions which also leads to the creation of hadrons with large transverse momenta. From the 2002 data we extracted an asymmetry in production of hadron pairs with high transverse momenta of

$$A^{\gamma^* d} = -0.065 \pm 0.036_{(\mathrm{stat.})} \pm 0.010_{(\mathrm{syst.})}$$

Up to now the systematic error contains only studies on false asymmetries due to target and spectrometer effects. To deduce the gluon polarisation $\Delta G/G$ from this asymmetry, it is necessary to determine the fraction of PGF events and the analyzing power of the PGF process using Monte Carlo.

The statistical errors we anticipate from the open charm production events and the high p_T hadron events for the years 2002 to 2004 data taking are shown in Fig. 6.

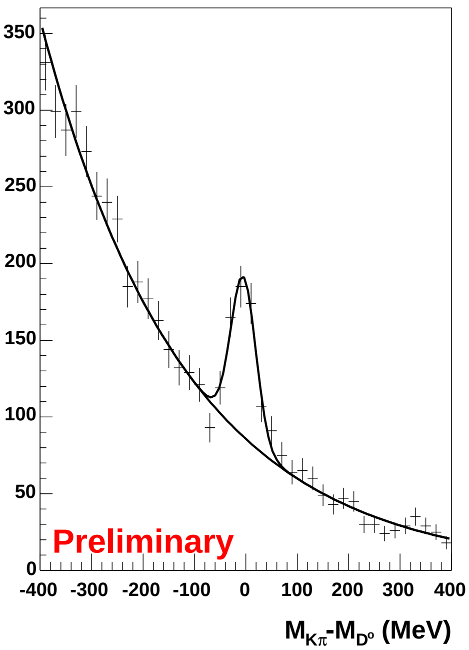

Fig. 5. Mass difference of the K-π system and the D^0 mass. The plot contains about 80% of the 2002 year's data.

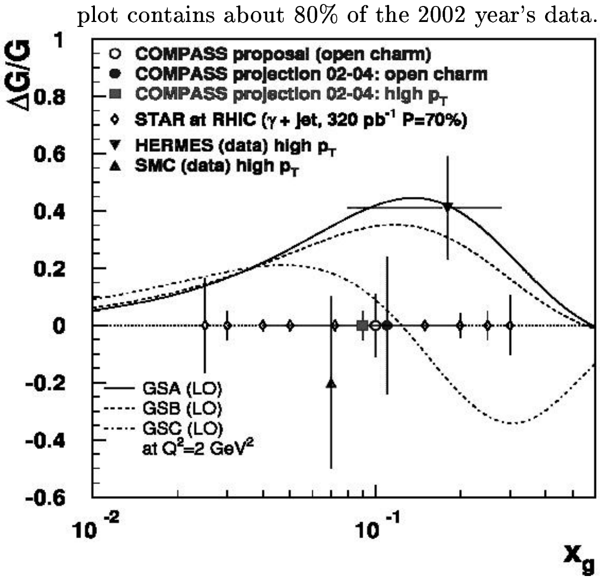

Fig. 6. Projected error on $\Delta G/G$ based on 2002, 2003 and 2004 data samples

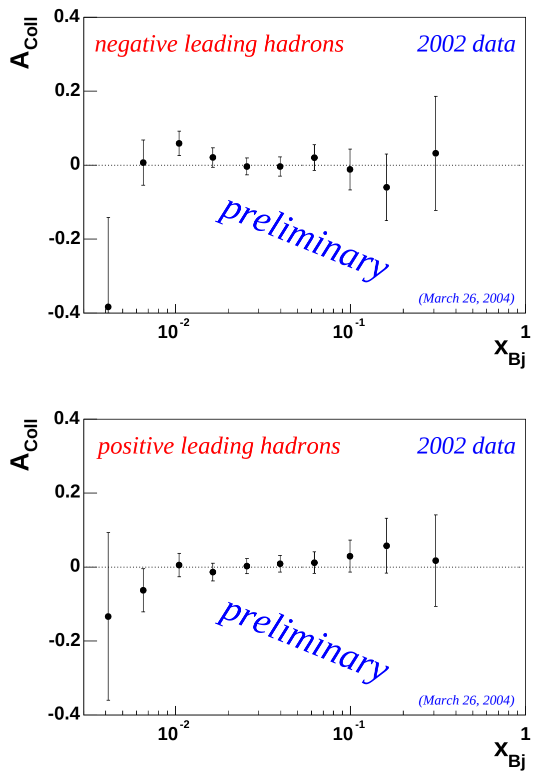

Fig. 7. Collins asymmetry for negative and positive leading hadrons as a function of x

3.6 Transversity

To completely describe the quark state of the nucleon at twist-two level, three distribution functions are neccessary: the momentum distribution of the partons $q(x)$, the helicity distribution $\Delta q(x)$ and the transverse spin distribution $\Delta_T q(x)$, which are all of equal importance.

The transverse distribution $\Delta_T q(x)$ are difficult to measure, as they are chirally-odd and therefore absent in inclusive DIS. They can be accessed by measuring the single spin asymmetries (SSA) in semi-incusive DIS on transversely polarised nucleons, in which a hadron is detected in the final state.

From the SSA, Collins-asymmetry [5] A_{Coll} can be extracted, which is a combined effect of $\Delta_T q(x)$ and the spin dependant "Collins" fragmentation function

$\Delta_T^0 D_q^h(z, p_\perp^2)$. It appears as a $\sin\phi_C$-shaped modulation of the distribution of the azimuthal angle ϕ_C of the produced hadron relative to the spin direction of the target nucleon:

$$A_{\mathrm{Coll}} = \frac{A_{UT}^{(\sin\phi_C)}}{D_{\mathrm{NN}}\, f\, P} \propto \frac{\sum_q e^2\, \Delta_T q(x)\, \Delta_T^0 D_q^h(z, p_\perp^2)}{\sum_q e^2\, q(x)\, D_q^h(z, p_\perp^2)}$$

with D_{NN}: polarisation transfer to the virtual photon, f: dilution factor and P: target polarisation

In 2002, 1.6×10^6 DIS events on a transversely polarised ^{6}LiD target have been collected. In the hope to enhance the asymmetry signal, analysis has been focussed on leading hadrons in the final state (about 80% are pions), with a required momentum fraction $z > 0.25$. Preliminary Collins-asymmmetries as a function of x are shown in Fig. 7.

4 Outlook

Meanwhile the 2003 data is partly analyzed. And a first, preliminary COMPASS result on $\Delta G/G$ from high p_T-hadron production with a cut on $Q^2 > 1\mathrm{GeV}^2$ was obtained: $\Delta G/G = 0.06 \pm 0.31_{(\mathrm{stat.})} \pm 0.06_{(\mathrm{syst.})}$. The statistics will be nearly doubled, when the 2004 year's data will be added.

In 2005 COMPASS will be upgraded to fit the needs of the hadron spectroscopy program. This program, which will start after 2006, will use π-, K- and p-beams, and will concentrate on Primakoff reactions (polarisibility of π, K), glueballs, hybrid- and charmed hadrons (a pilot run with a hadron beam took place end of 2004). In parallel, additional statistics will be collected on spin physics, mainly $\Delta G/G$ up to 2010, and generalised parton distributions may be adressed in some mid-term future.

References

[1] K.Ackerstaff et all., Phys. Lett. B **464** (1999) 123

[2] COMPASS proposal, CERN/SPSLC 96-14, SPSLC/P297, 1996

[3] G.K. Mallot, Nucl. Instr. Meth. **A518** (2004) 121

[4] J. Blümlein & H.Böttcher, Nucl. Phys. B **636** (2002) 225

[5] J. Collins, Nucl. Phys. B **396** (1993) 161