COMPASS - Status and Perspectives

Jörg Pretz
Physikalisches Institut, Universität Bonn
on behalf of the COMPASS collaboration

Abstract

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 polarised deep inelastic muon nucleon scattering and hadron spectroscopy using hadron beams [1]. This talk discusses the physics objectives of the muon beam program and gives a status report of the experiment.

1 Introduction: The Nucleon Spin Puzzle

In an intuitive picture the spin of the nucleon is completely 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. It came as a big surprise when deep inelastic scattering (DIS) experiments revealed that the contribution of the quarks to the nucleon spin is even smaller and only 20-30% with a negative strange quark contribution of about -10%. However the interpretation of DIS results is not without ambiguity if the helicity contribution of the gluons to the nucleon spin is large. One of the most interesting open questions in understanding the spin structure of the nucleon is therefore the size of the helicity contribution of gluons, ΔG.

2 The Spin Physics Program

The main goal of the COMPASS experiment is the measurement of the helicity contribution of gluons in the nucleon spin, ΔG. Other measurements discussed in this paper are:

- A flavor decomposition of the quark helicity contributions, $\Delta u_V(x), \Delta d_V(x), \Delta s(x), \dots$,
- the transverse spin distribution functions $\Delta_T q(x)$.

Up to now most of the experiments focused on inclusive deep inelastic scattering where only the scattered lepton is observed in the final state ($l+N \rightarrow l' + X$). Common to all measurements mentioned above is the observation of part of the hadronic final state:

$$l + N \rightarrow l' + \textbf{hadrons} + X$$

This so called semi-inclusive process allows a deeper insight in the structure of the nucleon, since it allows us to tag the parton participating in a deep inelastic process. The observation of a π^+ for instance indicates that a u or a $\bar{d}$-quark was struck in the nucleon. The observation of a strange particle indicates that an s-quark participated in the scattering process.

In the following the variables Q^2, x and y have their usual meaning: four momentum transfer, Bjorken variable and the fraction of the beam energy carried by the virtual photon in the target rest frame. z denotes the fraction of the virtual photon energy carried by a hadron in the target rest frame.

2.1 The measurement of ΔG

Tagging of a gluon is more complicated since the photon doesn't couple directly to the gluon. The gluon can participate in a deep inelastic process via the photon-gluon fusion process ($\gamma^* + g \rightarrow c + \bar{c}$). In the hadronic final state the process manifests itself by the observation of charmed hadrons. This is illustrated in Fig. 1. Since there is no intrinsic charm quark in the proton and

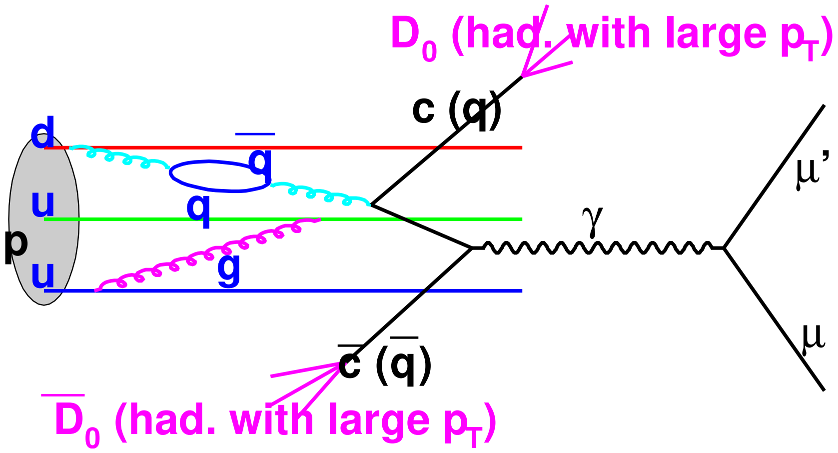

Figure 1: Deep inelastic scattering with a photon gluon fusion process as partonic subprocess.

the production of charm quarks in the fragmentation process is suppressed, the observation of a charmed hadron clearly tags the gluon. On average 1.1 D^0 or $\bar{D}^0$ are produced in the fragmentation of the partonic process $\gamma^* + g \rightarrow c + \bar{c}$. The D^0's can be detected via several decay channels. The most promising one is $D^0 \rightarrow K^- + \pi^+$.

In a leading order process where the photon is directly absorbed by a quark ($\gamma^* + q \rightarrow q$), hadrons are mainly produced along the axis of the virtual photon. In a photon gluon fusion process where light quarks are produced ($\gamma^* + q \rightarrow q + \bar{q}$) the observation of a hadron pair with large transverse momentum, p_T, with respect to the virtual photon tags a gluon as well. This tagging is less clean due to concurrent background processes like the QCD compton ($\gamma^* + q \rightarrow q + g$) which also leads to the creation of hadrons with large transverse momenta.

To allow an interpretation of the data in perturbative QCD the scale in the partonic process has to be larger than ≈ 1 GeV^2. For inclusive processes this scale is simply given by the virtuality of the photon, Q^2. Therefore inclusive experiments focused mainly on the kinematic region $Q^2 > 1$GeV^2. In the two processes to measure ΔG the scale is given by $4m_c^2$ and p_T^2, respectively. Therefore one can exploit the full statistics down to $Q^2 \approx 0$. Since low Q^2 correlates with small scattering angles this is an experimentally challenging task.

Up to now only the tagging of the gluon was discussed. To measure its helicity distribution one has to measure the double spin asymmetry

$$A^{exp} = \frac{N^{\uparrow\downarrow}-N^{\uparrow\uparrow}}{N^{\uparrow\downarrow}+N^{\uparrow\uparrow}} = P_t P_b f D \frac{\int_{4m_c^2}^{2MEy} \Delta\sigma(s)^{\gamma g \to c\bar{c}} \Delta G(\eta, s) ds}{\int_{4m_c^2}^{2MEy} \sigma(s)^{\gamma g \to c\bar{c}} G(\eta, s) ds} . \qquad (1)$$

In this equation $N^{\uparrow\uparrow}(N^{\uparrow\downarrow})$ is the number of events with nucleon and lepton spin parallel (anti-parallel). Events stand for a DIS scattering process with charmed hadron in the final state. $G(\eta, s)$ is the (known) unpolarised gluon distribution function which depends, as $\Delta G(\eta, s)$, on the momentum fraction η and the scale s. $\Delta\sigma(s)^{\gamma g \to c\bar{c}}$ ($\sigma(s)^{\gamma g \to c\bar{c}}$) are the polarised (unpolarised) cross sections of the partonic subprocess. The experimental asymmetry is diluted by the target polarisation, P_t, the beam polarisation, P_b, the dilution factor, f, which is defined as the fraction of polarisable material in the target and the depolarisation factor, D, which describes the polarisation transfer from the lepton to the virtual photon. A^{exp} is of the order of 2-3%.

A similar expression holds for the method with high p_T hadron pairs. But as mentioned above several background processes contribute to the asymmetry as well. They can be computed and subtracted. This leads to a larger systematic error compared to the method with charmed mesons.

2.2 The measurement of $\Delta q(x)$

The measurement of $\Delta q(x)$ can be performed in parallel to the measurement of ΔG. i.e. with longitudinal beam and target polarisation.

The double spin asymmetries of hadrons is a linear combination of all quark helicity distributions:

$$A^h(x, z) = P_t P_b f D \frac{\sum_q e_q^2 \Delta q(x) D_q^h(z)}{\sum_q e_q^2 q(x) D_q^h(z)} \quad q = u, d, s, \bar{u}, \bar{d}, \bar{s}$$

where $q(x)$ are the unpolarised quark distributions and $D_q^h(z)$ the fragmentation functions. Both are known. Thus measuring asymmetries for different hadrons one obtains a system of linear equations which can be solved for the $\Delta q(x)$'s.

2.3 The measurement of $\Delta_T q(x)$

The transverse quark distribution can be accessed via single spin asymmetries when only the target is polarised perpendicular to the beam momentum. The asymmetry considered in this case is

$$A_T^h = \frac{N^{\uparrow}(\Phi_S) - N^{\downarrow}(\Phi_S + \pi)}{N^{\uparrow}(\Phi_S) + N^{\downarrow}(\Phi_S + \pi)} = D_{NN}|P_t|f \frac{\sum_q e_q^2 \Delta_T q(x) \Delta_T D_q^h(z)}{e_q^2 \Delta q(x) D_q^h(z)} \sin(\Phi_H + \Phi_S) \ . \quad (2)$$

$N^{\uparrow}(N^{\downarrow})$ is the number of events with target spin pointing upwards (downwards). Φ_H and Φ_S are the azimuthal angle of the leading hadron and the target spin with respect to the lepton scattering plane. $D_{NN}(y)$ is a depolarisation factor.

3 The COMPASS Experiment

The requirements for the measurements discussed above are

- a polarised high energy lepton beam
- a polarised target
- a spectrometer with particle identification and a large acceptance down to $Q^2 \approx 0$

The COMPASS experiment fulfils these requirements. COMPASS is a fixed target experiment located at the muon beam-line of the CERN-SPS accelerator.

The muon beam energy can be varied between 100 and 200 GeV. The muons originating from a parity violating π-decay are naturally polarised to $P_b \approx -80\%$. The beam intensity is about 2×10^8 muons per spill of 5 s every 14.4 s.

The target is a two cell solid state target polarised by Dynamic Nuclear Polarisation. NH_3 will be used as a proton target. The dilution factor is $f \approx 3/(3 + 14) = 0.17$. ^{6}LiD serves as a deuteron target. In ^{6}LiD the lithium can be considered as ^{4}He + D so that the dilution factor f is 50%. With 60 cm long target cells the nominal luminosity is $5 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

COMPASS uses a two stage forward spectrometer, shown in Fig. 2. Both stages consist of a bending magnet and particle identification provided by an electro-magnetic and a hadronic calorimeter, a Ring Imaging Cherenkov Counter (RICH) and an iron absorber to identify muons. The magnets have a bending power of 1 Tm (5 Tm). The two RICHs provide a $K - \pi$ separation in the momentum range 3-50 GeV and 20-120 GeV, respectively for the two stages. The overall acceptance of the spectrometer is ± 200 mrad and 1-200 GeV. Tracking is provided by different types of detectors. The beam region is covered by scintillating fiber hodoscopes and silicon detectors. Small area tracking is provided by Micromeagas, Gas Electron Multipliers (GEMs) and MWPCs. For large area tracking drift chambers with a size up to 320×240 cm^2 are used.

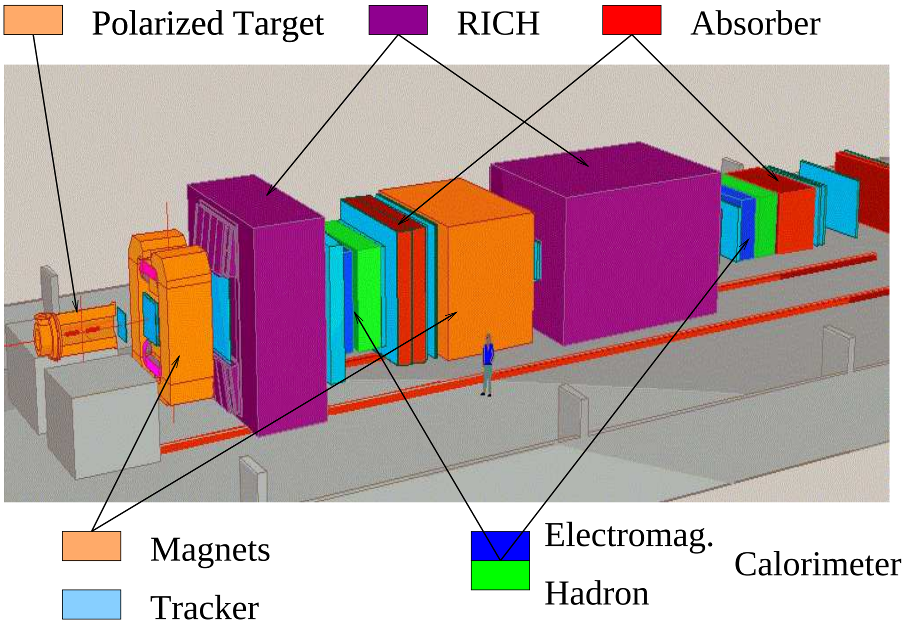

Figure 2: The COMPASS experiment

Among the detectors mentioned above the second RICH and the electromagnetic calorimeters are not yet installed. Their presence is not essential for the measurements discussed here.

Coincidences between two hodoscope planes at different positions along the beam serve as a trigger for the scattered muon. Compared to previous experiments the kinematic range is extended to very low Q^2. This corresponds to a small scattering angle of the muon so that the trigger hodoscopes have to be positioned close to the beam region. To trigger efficiently on these DIS events, a certain energy deposition in the hadron calorimeters is demanded in addition to the coincidence in the two hodoscope planes.

3.1 The 2002 Data Taking

After an engineering run in 2001 COMPASS had its first physics run in 2002. Out of the 100 days of beam time, 76 days could be used to take physics data. The other 24 days were needed for setup and tuning. 80% of the physics data were taken with a longitudinal polarised target the rest with a transversely polarised target. In total 300 TByte of data were collected.

The performances of a few components of the experiment will be discussed. Fig. 3 shows the measurement of the target polarisation as a function of time for the 10 NMR coils, 5 in each target cells. To cancel systematic effects the two target halves are polarised oppositely. The build up time of the polarisation is approximately two days. During the 2002 run target polarisation of about 50% were routinely reached.

In Fig. 4 the reconstructed vertex position along the beam direction is shown. One clearly distinguishes the two target halves. The reduced number of reconstructed vertices in the upstream target half is explained by the absorption of hadrons in the target material. Hadrons are mandatory to find the vertex position since the data is dominated by events where the scattering angle of the muon is small.

Fig. 5 shows the Cherenkov angle measured in the RICH vs. the particle momentum determined by the tracking detectors. Besides the electron and pion ridges a kaon ridge is clearly visible.

3.2 Error Estimates from the 2002 data

In the following statistical error estimates are given for the three physics topics discussed in section 2.

For the measurement of ΔG we anticipated a statistical error of $\delta\Delta G/G = 0.3$ from the method with high p_T hadron pairs. The following cuts were applied to reduce the background:

- $p_T > 0.7\mathrm{GeV}^2$,

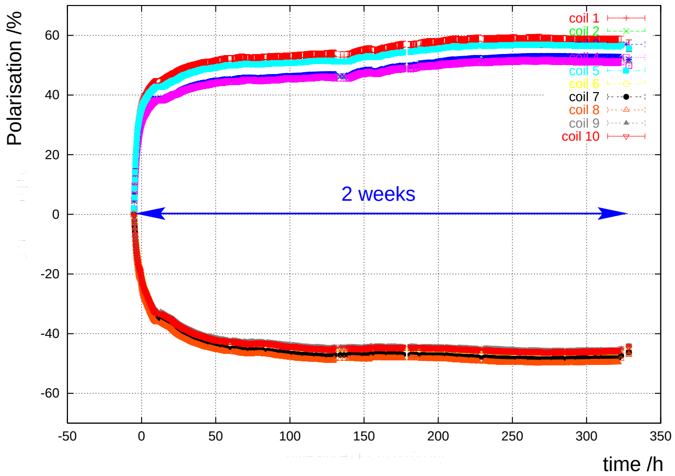

Figure 3: The target polarisation as a function of time measured with 10 NMR coils.

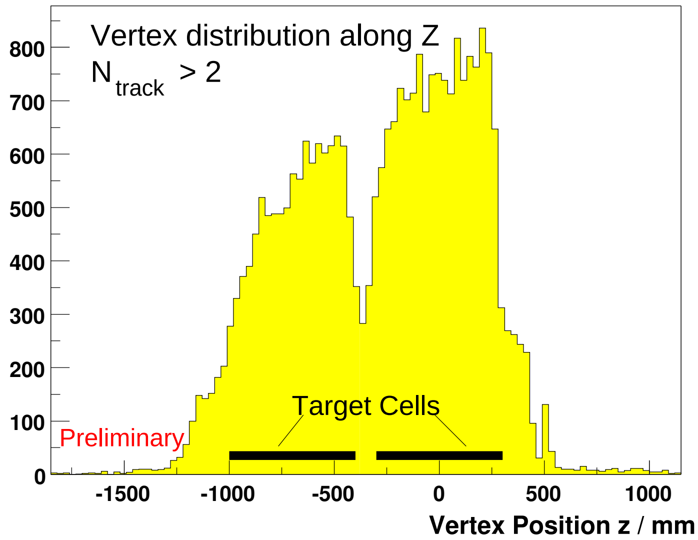

Figure 4: Vertex distribution along the beam direction.

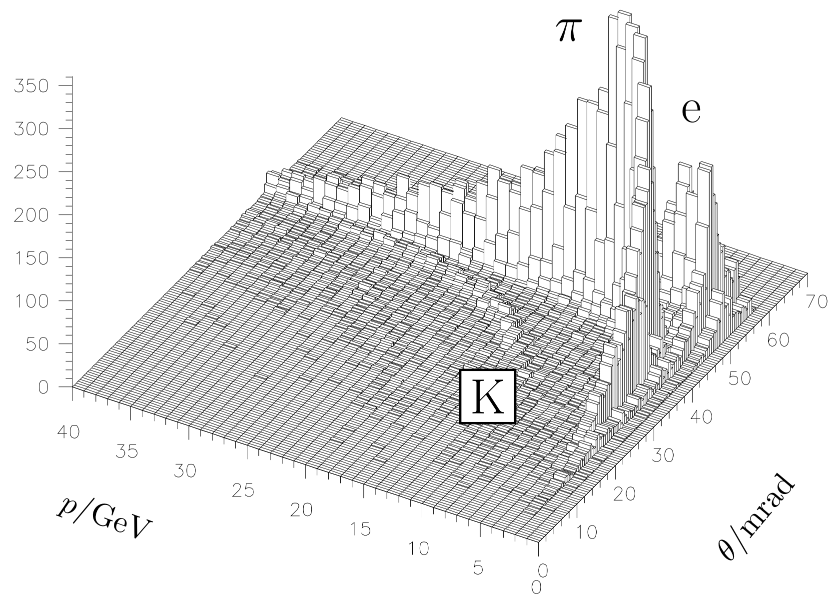

Figure 5: The Cherenkov angle, θ, measured with the RICH vs. the particle momentum, p, determined by tracking.

- $p_{1,T}^2 + p_{2,T}^2 > 2.5 \mathrm{GeV}^2$,
- $Q^2 > 1$ GeV^2.

Figs. 6 shows the statistical error estimates on Δs. The inclusive asymmetry and asymmetries from positive, negative hadrons, K^+, K^- and K_s entered this estimate. Cuts on $Q^2 > 1$ GeV^2 and $z > 0.2$ were imposed.

Finally, Fig. 7 shows an error estimate for the transverse polarised quark distributions $\Delta_T q(x)$. The asymmetry A_{UT} shown is a linear combination of the $\Delta_T q(x)$'s:

$$A_{UT} = \frac{\sum_q e_q^2 \Delta_T q(x) \Delta_t D_q^h(z)}{e_q^2 \Delta q(x) D_q^h(z)} \ .$$

The curve is a model prediction from Efremov.

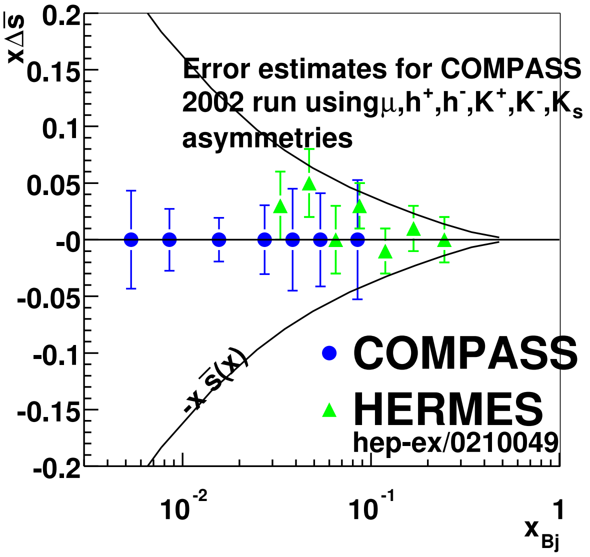

Figure 6: The estimated statistical error on Δs.

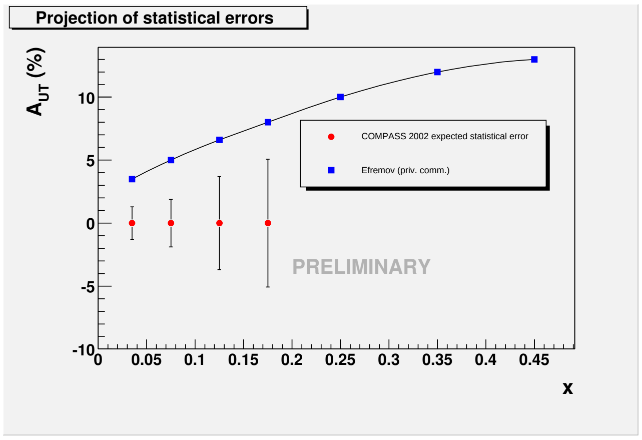

Figure 7: The estimated statistical error on $A_{UT} = \frac{\sum_q e_q^2 \Delta_T q(x) \Delta_t D_q^h(z)}{e_q^2 \Delta q(x) D_q^h(z)}$.

4 The Future

The next steps are the production of the full 2002 data set and the reconstruction of D^0's. The 2003 run started in May. Another run with a muon beam is scheduled for 2004 as well as a first short hadron run. COMPASS plans to continue running after the SPS shutdown in 2005.

References

1. COMPASS proposal, CERN/SPSLC 96-14,SPSLC/P297, 1996