New measurements of $\Delta G\,/\,G$ at COMPASS

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One of the main goals of the COMPASS experiment at CERN is the determination of the gluon polarisation in the nucleon, $\Delta G\,/\,G$. It is determined from spin asymmetries in the scattering of polarised muons at $160\,\mathrm{GeV}/c$ on a polarised LiD target. The gluon polarisation is accessed by the selection of photon-gluon fusion events. Such events are tagged either with a charmed meson or a hadron pair with high transverse momenta in the final state. The selection of charmed mesons is based on the reconstruction of decayed $D^\star$ and D^0 mesons in the COMPASS spectrometer. For the high-p_T hadron pairs two independent analyses are performed in the kinematic regimes of DIS ($Q^2 > 1\,(\mathrm{GeV}/c)^2$) and quasi-real photoproduction ($Q^2 < 1\,(\mathrm{GeV}/c)^2$. The results presented in this paper were obtained from the data coming from 2002-2004 for the open charm and the high p_T with $Q^2 < 1\,(\mathrm{GeV}/c)^2$ channels resp. from 2002-2003 for the high p_T with $Q^2 > 1\,(\mathrm{GeV}/c)^2$ channel.

1. Introduction

In the framework of QCD, the spin of the nucleon is composed of the contributions from the quark $\Delta\Sigma$ and the gluon ΔG spin as well as the orbital angular momentum of quarks L_q and gluons L_g: $S_n = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$. The discovery, that the quark contribution $\Delta\Sigma$ is small [1], led to a series of measurements to determine the other spin contributions. Since QCD fits only give weak constraints on ΔG, it has to be measured directly. First investigations were performed by the HERMES [2] and the SMC[3] collaborations using high p_T hadron pairs in the final state. The primary goal of the COMPASS experiment is to perform a precise measurement of $\frac{\Delta G}{G}$ also with a new approach. Therefore charmed meson production is studied, since the selection of charmed mesons in the final state provides an event sample of photon gluon fusion events with no background from other physical processes.

2. The COMPASS Spectrometer

The COMPASS experiment uses a high intensity polarised muon beam on a fixed target. At 160 GeV beam energy the beam muons are naturally polarised to about -0.80. Due to the tertiary nature of the muon beam it has a momentum spread of 3%.
The COMPASS target is a two cell target filled with ^{6}LiD. It is located inside a superconducting solenoid providing a homogeneous longitudinal magnetic field of 2.5 T. The nuclei in the two target cells are polarised to an average polarisation around 50%. Every 8 hours the sign of the solenoid current is inverted and with the change of the magnetic field the orientation of the nucleon spins is also inverted.
The COMPASS detector consists of two spectrometers. The Large Angle Spectrometer is optimised for tracks with angles larger than 30 mrad, while particles leaving the target with smaller angles are reconstructed in the Small Angle Spectrometer. To measure the momenta of charged tracks, both spectrometers contain dipole magnets with an integrated field of 1 Tm for large angles resp. 4.4 Tm for small angles. More than 300 tracking planes insure a stable track reconstruction with a momentum resolution of $\sigma p/p = 0.5\%$ for tracks reaching SAS and $\sigma p/p = 1.2\,\%$ for tracks in LAS.
The first spectrometer is equipped with a Ring Imaging CHerenkov detector (RICH) used for particle identification. It is capable to separate π, K and p in a momentum range from the particles Cherenkov threshold to about 50 GeV. Figure 1 shows the RICH response for these three particles as a function of their momentum. One can

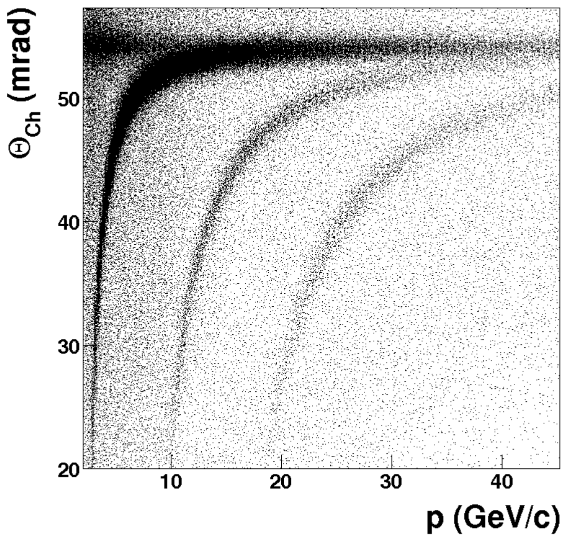

Figure 1. Cherenkov angles measured with RICH-1 vs. particle momenta. The histogram content in the kaon region is multiplied by a factor 30, in the proton region by a factor 150.

see, that kaons can be identified starting from the kaon threshold around 9 GeV.

3. Photon Gluon Fusion

The ΔG measurement at COMPASS is based on the Photon Gluon Fusion (PGF) process. In this process the photon emitted by the incoming muon interacts with a gluon embedded in the nucleon. The interaction occurs via the exchange of a virtual quark, resulting in a $q\bar{q}$ pair in the final state. In COMPASS the study of PGF events in the scattering of a polarised muon beam on a polarised target gives access to the polarised gluon distribution ΔG with the determination of the longitudinal cross section asymmetry $A_{||}$:

$$A_{||} = \frac{\sigma^{\uparrow\Downarrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\uparrow\Downarrow} + \sigma^{\uparrow\Uparrow}} \ ,$$

where $\uparrow$ indicates the spin orientation of the muon and $\Uparrow$ the spin of the nucleon. The experimental asymmetry using event counting rates A_{exp} is

$$A_{exp} = \frac{1}{2}\left(\frac{N_u - N_d}{N_u + N_d} - \frac{N'_u - N'_d}{N'_u + N'_d}\right) \ .$$

In this case the indices u, d denote the target cell in which the interaction was observed. The experimental asymmetry A_{exp} is related to the cross section asymmetry $A_{||}$ by $A_{exp} = P_{beam}\, P_{target}\, f\, \frac{S}{S+B}\, A_{||}$, where the $P_{beam,(target)}$ denote the beam (target) polarisation and f describes the fraction of polarisable material in the target. For ^6LiD this dilution factor is 50%. To ensure the cancellation of the muon flux in the experimental asymmetry the incoming muons are required to cross both target cells. Since the spin orientation of the target material is reversed three times per day, the experimental asymmetry is the mean of the asymmetries calculated for the two different target configurations. The asymmetry from the second configuration, marked with a $'$, has the opposite sign of the first, since its spin configuration is reversed. This procedure reduces effects from acceptance and spectrometer instabilities in the asymmetry determination.
The measured cross section asymmetry is related to the gluon polarisation $\frac{\Delta G}{G}$ via

$$\frac{A_{||}}{D} = \frac{\int d\hat{s}\, \Delta\sigma^{PGF}(\,\hat{s}\,)\, \Delta G(\,x_g,\, \hat{s}\,)}{\int d\hat{s}\, \sigma^{PGF}(\,\hat{s}\,)\, G(\,x_g,\, \hat{s}\,)} \approx < a_{LL} > \frac{\Delta G}{G},$$

where D is the depolarisation factor describing the transfer of the muon polarisation to the virtual photon. The partonic asymmetry for the photon gluon interaction, a_{LL}, depends on the kinematics of a given event and ranges from -1 to 1. It is evaluated for the events sample chosen for the asymmetry calculation.
In COMPASS two different methods are used to select PGF events for the asymmetry determination. The first, so-called open charm method is based on tagging PGF via the production of charm quark pairs which are detected via the decay of D^0 or $D^\star$ mesons. The second approach relies on the selection of hadron pairs with high transverse momenta with respect to the photon direction. The advantage of this method is a much higher statistics as it is not only restricted to charmed quarks in the final state. However PGF is not the only process producing high p_T hadron pairs, resulting in background contributions in the event sample. The treatment of this background requires an evaluation of the

event sample with Monte Carlo generators introducing additional systematic uncertainties.

4. ΔG from open charm channel

The PGF process is the main reaction for the production of charm quarks in DIS. Due to the high charm mass, the intrinsic charm content of the nucleon can be neglected as well as the production of charm quarks during fragmentation. In the independent fragmentation of a $c\bar{c}$ pair most frequently D mesons are produced. On average 1.2 D^0 mesons are produced per each $c\bar{c}$ pair [4].
The D^0 mesons are reconstructed from their $\pi\,K$ decay which has a branching ratio of 3.8 %. The reconstruction is done on the combinatorial basis, since the vertex resolution of the COMPASS spectrometer does not allow a separation of production vertex and decay vertex of the meson. Thus, for each oppositely charged track pair in a given event the invariant mass is calculated using the kaon mass hypothesis for one of the tracks.
To suppress the high combinatorial background several cuts are applied on the track pair. The most important requirement is the RICH particle identification for the kaon candidate. Due to the large charm mass the fraction of energy from the virtual photon that is carried by the meson, z, is expected to be higher for a real charmed meson than for combinatorial background. Therefore a cut of $z > 0.25$ is applied on the D^0 candidates. A third cut to reduce the combinatorial background is applied on the angle between the D^0 flight direction and the K momentum vector in the D^0 rest frame, $|\cos\theta^\star_K| < 0.5$.
With these cuts the ratio of open charm signal events to combinatorial background is still in the order of $1 : 10$. Therefore a second more exclusive channel is also studied: $D^\star \to D^0\pi \to K\,\pi\,\pi$. Due to the small mass difference between $D^\star$ and D^0 combinatorial background can be very much suppressed by a cut of on the mass difference: $3.1\,\mathrm{MeV} < M_{K\pi\pi} - M_{K\pi} - M_\pi < 9.1\,\mathrm{MeV}$. Here, $M_{K\pi\pi}$ denotes the mass of the $D^\star$ candidate and $M_{K\pi}$ the mass of the D^0 candidate. Since this so-called $D^\star$ tag is very effective in the reduction of combinatorial background, the z and the $\cos\theta^\star$ cuts can be relaxed. With $z > 0.2$ and $|\cos\theta^\star| < 0.85$ for $D^\star$ tagged D^0 mesons a signal to background ratio of 1:1 can be obtained (cf. Fig. 2).

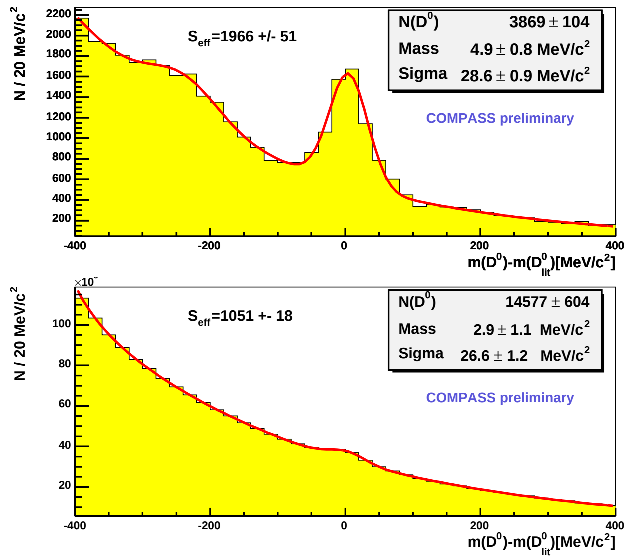

Figure 2. Kπ mass spectra for $D^\star$ tagged events (upper plot) and the sample without $D^\star$ tag ($S_{eff} = S^2\,/\,(B+S)$ is the effective signal)

Since only one of the two mesons is reconstructed, the full kinematics of the PGF process, which is needed for the calculation of a_{LL} is not known for the single event. Thus, a parametrisation based on measured quantities was introduced, providing the best estimation of a_{LL} for each open charm event. The parametrisation was obtained by training a neural network with an event sample generated with the AROMA generator in leading order QCD. For these events the full PGF kinematics were available as well as the reconstructed observables from the D^0 mesons. The correlation between the a_{LL} values coming directly from the generated quantities and the reconstructed a_{LL} from the parametrisation is about 82%.
With the data 2002-2004 the preliminary result for the COMPASS open charm analysis of

$$< \frac{\Delta G}{G} >= -0.57 \pm 0.41(\mathrm{stat})$$

was obtained. For the measured sample the average x_g is 0.15 with RMS 0.08 and the hard scale at which this result was obtained is $13\,\mathrm{GeV}^2$. The systematic uncertainty of this result involving the contribution from resolved photon processes is currently under study.

5. ΔG from two high p_T hadrons

In the second approach, the statistics of the event samples is much larger, but a non-negligible fraction of background events is present in the final sample. The requirement of two hadrons with high transverse momenta relative to the virtual photon direction, is exploiting the fact, that in PGF the $q\bar{q}$ pair is produced back-to-back. The resulting transverse momenta from the produced quarks is transferred to the hadrons during fragmentation. Therefore, the high p_T selection enhances the fraction of PGF events in the sample. For the $\frac{\Delta G}{G}$ determination an evaluation of the fraction of signal events is done using Monte Carlo generators.

In the case of high p_T hadron pairs in DIS ($Q^2 > 1\,\mathrm{GeV}^2$), LEPTO[5] was used, to determine the fraction of PGF events as well as for the evaluation of the a_{LL} of the event sample. For the 2002-2003 data set a value for $\frac{\Delta G}{G}$ of $< \Delta G/G >$ $=$ 0.06 $\pm$ 0.31(stat) $\pm$ 0.06(syst) was obtained for an average x_g of 0.13 (RMS: 0.08) and a hard scale of $3\,\mathrm{GeV}^2$.

About 90% of the high p_T hadron pairs are at $Q^2 < 1\,\mathrm{GeV}^2$. In this kinematic region contribution from resolved photon processes cannot be neglected. For the evaluation of the fraction of PGF events in the selected sample and of a_{LL} a PYTHIA [6] Monte Carlo was used. Since the exact contribution of resolved photon processes is not known, their effect on the $\frac{\Delta G}{G}$ determination was evaluated in the Monte Carlo simulation and embedded in systematic error. For the 2002-2004 data set a result of

$$< \frac{\Delta G}{G} > = 0.016 \pm 0.058(\mathrm{stat}) \pm 0.055(\mathrm{syst})$$

was obtained with an average x_g of $0.095^{+0.08}_{-0.04}$ and a hard scale of $3\,\mathrm{GeV}^2$.

6. Summary

The result for the first $\frac{\Delta G}{G}$ measurement from the open charm channel is presented. This is the most direct measurement of $\frac{\Delta G}{G}$ since it is only weakly based on Monte Carlo. A comparison of the new COMPASS results and other existing results is given in figure 3. The measurements are compared with the parton parametrisations from [7]. The data points give an indication that curves corresponding to small values of ΔG are favourable. With the addition of the data taken in 2006 the statistical precision of the results will be improved.

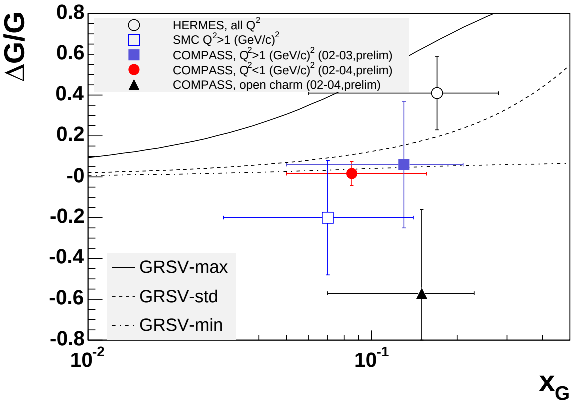

Figure 3. Comparison of the $\frac{\Delta G}{G}$ measurements from COMPASS, SMC[3] and HERMES[2]. The curves show the GRSV2000[7] parametrisations at $3\,\mathrm{GeV}^2$ in the $\overline{\mathrm{MS}}$ scheme for $\int \Delta G(x_G)dx_G =$ 2.5 / 0.62 / 0.16. Note that the open charm point was obtained at a much higher scale.

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