Recent gluon polarization results from COMPASS

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One of the main goals of the COMPASS experiment at CERN is the measurement of the gluon polarization in the nucleon, ΔG, by scattering of 160 GeV/c polarized muons on a polarized ^{6}LiD target. This quantity is experimentally accessible via the photon-gluon fusion process, tagged either by charmed mesons production or by high p_T hadron pairs production. The status of these two analyses is presented. Preliminary results obtained from the 2002/03 data samples on the D^0 and the $D^{*\pm}$ channels are shown. The high p_T hadron pairs, produced at $Q^2 \lessgtr 1$ (GeV/c)^2, were also analysed, and the measured $\Delta G/G$ values are presented here.

1. Introduction

The origin of the observed spin of the nucleon $\hbar/2$ is a subject of study since several decades, investigated at CERN, SLAC and DESY in deep inelastic scattering (DIS) experiments. The contribution from the quarks spin $\Delta\Sigma$ to the spin of the proton was shown to be small by the EMC experiment [1]. According to the present results, it amounts to only 20 to 30% of the total spin of the nucleon. This is in contrast with the expectation from a naïve quark-parton model of a 60% contribution coming from quarks. Thus, the remaining contributions must come from the gluons spin ΔG, as well as from quark and gluon orbital angular momenta $L_Z^{q,g}$:

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \langle L_Z^{q,g} \rangle \tag{1}$$

Among other goals, COMPASS aims at measuring the contribution from the gluon spin ΔG, by tagging the photon-gluon fusion (PGF) process in polarized lepton-nucleon scattering, and measuring the helicity asymmetry of the PGF cross-section ($\gamma^* g \to q\bar{q}$). The fraction of PGF events in the data sample can be enhanced by selecting either open charm events or hadron pairs with high transverse momentum. The first method provides a clean but low statistics sample, while the latter has much more statistics but is more difficult to analyse, due to the physics background contributions to the asymmetry that have to be taken into account.

2. The COMPASS experiment

COMPASS is a fixed target experiment [2], located at the M2 beam line of the CERN SPS. The naturally polarized μ^+ beam with 160 GeV/c momentum interacts in a long solid-state target longitudinally polarized. The beam has an average polarization $P_b = -76 \pm 5\%$, and its momentum is measured accurately by beam detectors placed upstream from the target. The ^{6}LiD target consists of two cylindrical cells each 60 cm long and 3 cm in diameter, spaced by 10 cm, to allow for flux cancellation. The target cells are oppositely polarized, using the dynamic nuclear polarization method. Their spin is rotated every 8 hours, to ensure that acceptance variations cancel out in the asymmetry calculation. The average target polarization is $P_t = 50.0 \pm 2.5\%$. The measured helicity asymmetry $A_\parallel$ is determined from the raw asymmetry A_{raw}, the counting rate difference between the two target cells:

$$\begin{aligned} A_\parallel &= \frac{1}{P_b P_t f} A_{raw} = \\ &= \frac{1}{2 P_b P_t f} \left[\frac{N_1^{\overset{\leftarrow}{\Rightarrow}} - N_2^{\overset{\leftarrow}{\Leftarrow}}}{N_1^{\overset{\leftarrow}{\Rightarrow}} + N_2^{\overset{\leftarrow}{\Leftarrow}}} + \frac{N_2^{\overset{\leftarrow}{\Rightarrow}} - N_1^{\overset{\leftarrow}{\Leftarrow}}}{N_2^{\overset{\leftarrow}{\Rightarrow}} + N_1^{\overset{\leftarrow}{\Leftarrow}}} \right] \end{aligned} \tag{2}$$

where f is the fraction of polarizable material in the target ($f \approx 0.4$); and N is the number of events observed from each of the target cells $(1, 2)$, with the arrows showing the relative spin orientation of the muons in the beam ($^{\leftarrow}$, not changing), and the nucleus in the target ($^{\Rightarrow}$ or $^{\Leftarrow}$, rotated every height hours).

A two-stage spectrometer allows to reconstruct the scattered muon and the hadron tracks, in a broad momentum and angular ranges. Particle identification is performed with hadron and electromagnetic calorimeters, as well as a large ring imaging Cherenkov (RICH) detector. The trigger system provides efficient tagging down to $Q^2 = 0.002$ GeV^2. The data here presented were taken in the running periods of 2002 and 2003.

3. Gluon polarization from open charm production

PGF can be tagged by selecting the semi-inclusive events where $c\bar{c}$ pairs are produced. The charm quarks hadronize eventually into a D^0 or a $D^{*\pm}$ particle. These open charm mesons are identified in the experiment via their decay products, by requiring particle identification in the RICH: $D^0 \to K^{\mp}\pi^{\pm}$, $D^{*\pm} \to D^0\pi^{\pm}_{soft}$. The event selection requires the charm particle decay products to be associated with the primary vertex, as well as an incoming and a scattered muon.

The asymmetry in the open charm production relates to the gluon polarization $\Delta G/G$, according to:

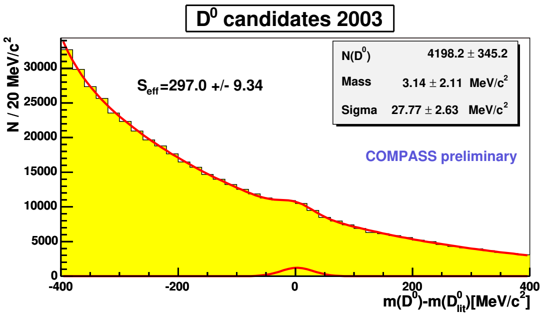
$$\begin{aligned} A^{PGF} &= \frac{\int d\hat{s}\ \Delta\sigma^{PGF}(\hat{s})\ \Delta G(x_g, \hat{s})}{\int d\hat{s}\ \sigma^{PGF}(\hat{s})\ G(x_g, \hat{s})} \\ &\approx \langle a_{LL}^{PGF} \rangle\ \frac{\Delta G}{G} \end{aligned} \tag{3}$$

where $\hat{s} = m^2_{c\bar{c}}$, and a_{LL}^{PGF} is the helicity asymmetry of the $\mu g \to \mu' c\bar{c}$ cross-section, the so-called analyzing power.

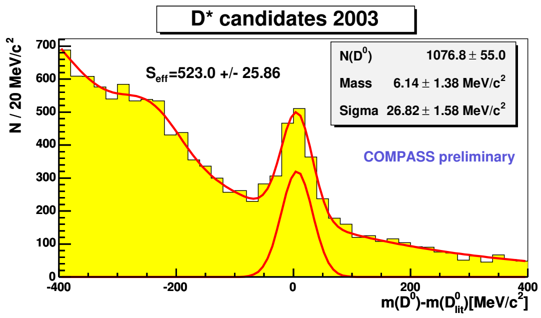
Figure 1 shows the invariant mass spectra, from the 2003 data sample. D^0 and D^* candidates are fitted using a gaussian for the signal peak and a decreasing exponential for the combinatorial background coming from uncorrelated kaons and pions. In (b) an additional gaussian is used to describe the background bump on the left-hand side of the D^0 peak, originating from $D^0 \to K^-\pi^+\pi^0$ decays, which were not taken into account in the analysis. The effective signal is calculated in the peak positions, $S_{eff} = S^2/(S+B)$.

The experimental raw asymmetry is calculated from the events in a mass window around the D^0 peak. $\Delta G/G$ is obtained according to:

$$\frac{\Delta G}{G} = \frac{1}{f\ P_b\ a_{LL}^{PGF}\ P_t}\ \frac{S+B}{S}\ A_{Raw} \tag{4}$$



(a)



(b)

Figure 1. Invariant mass spectra of D^0 (a) and D^0 tagged by D^* (b), from the 2003 data sample.

The analyzing power of the PGF process a_{LL}^{PGF} depends on both the photon and the gluon kinematics. Since in the data typically only one charmed meson is reconstructed per event, a_{LL}^{PGF} cannot be computed exactly on an event-by-event basis, and has to be estimated from Monte-Carlo. The Monte-Carlo signal is produced using the AROMA generator [3]. The generated events are passed in a GEANT simulation of the spectrometer, and reconstructed as for real data. The analyzing power a_{LL}^{PGF} calculated in POLDIS [4] is parameterized as a function of the hadronic variables p_T and z_D (z_D being the fraction of energy of the γ^* taken by the D meson), and the event variable y. The average gluon momentum fraction x_g is estimated from Monte-Carlo to be $\langle x_g \rangle = 0.15$, with an RMS of 0.08 . With all these ingredients, one obtains for the gluon polarization $\Delta G/G(x_g = 0.15) = -1.08 \pm 0.73(stat.)$. The systematic uncertainty coming from fake asymmetries is smaller than the present statistical error. Figure 2 shows the gluon polarization from D^0 and $D^{*\pm}$, for the two data taking periods, and the averaged result.

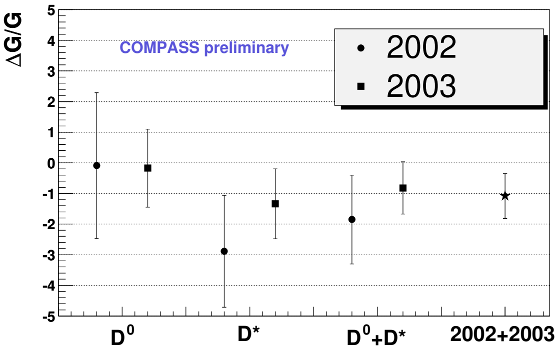


Figure 2. $\Delta G/G$ obtained from the analyses of D^0 and D^0 tagged from $D^{*\pm}$ events, for 2002 and 2003 data.

4. Gluon polarization from high-p_T hadron pairs

Another possibility to increase the fraction of PGF events in the data sample is to select those where two hadrons, noted h_1 and h_2, with high transverse momentum are produced: $p_T^{h_{1,2}} > 0.7$ GeV/c and $(p_T^{h_1})^2 + (p_T^{h_2})^2 > 2.5$ (GeV/c)^2. To enlarge the contribution from the current fragmentation region, cuts at $x_F > 0.1$ and $z_h > 0.1$ (where z_h is the fraction of energy of the γ^* taken by the hadron) are applied.

Besides the PGF process, other physics contributions have to be taken into account: QCD Compton and leading DIS process dilute the signal we are interested in. For events of low photon virtualities, an additional contribution from resolved photon processes has to be considered. The measured asymmetry $A_\parallel/D$ results from the sum of all these contributions:

$$\frac{A_\parallel}{D} = R_{PGF} \, \langle \frac{a_{LL}^{PGF}}{D} \rangle \, \frac{\Delta G}{G} + \\ + \; Background \; asymmetry \qquad (5)$$

where $R_{PGF} = \sigma^{PGF}/\sigma^{total}$ and a_{LL}^{PGF}/D are estimated from Monte-Carlo. The reason to calculate $A_\parallel/D$ is that by weighting the events with the depolarization factor $D(y)$ one minimizes the statistical error on the asymmetry [5].

4.1. $\Delta G/G$ at $Q^2 > 1$ GeV^2

An analysis of high-p_T hadron pairs, with a cut at $Q^2 > 1$ GeV^2 is performed, using the LEPTO generator. The contribution from the three processes, PGF, QCD Compton and leading DIS process, have to be considered in this analysis. The kinematical region $x_{Bj} < 0.05$ is selected, since in this region the asymmetry A_1^d is measured to be very small ($A_1^d \approx 0$) [6]. In equation 5, the contributions of QCD Compton and leading DIS process are multiplied by a very small factor A_1, and thus can be neglected, in this kinematical region.

After selection cuts, the high-p_T sample amounts to 28 thousand events, from where the asymmetry is measured to be $A_\parallel/D = -0.015 \pm 0.080(stat) \pm 0.013(syst)$. The systematic error includes the contribution from fake asymmetries and the uncertainties in the target and beam polarizations, on the dilution factor f and on the depolarization factor.

A Monte-Carlo simulation using the LEPTO generator is performed, with a modified set of fragmentation parameters [7] and including radiative corrections (RADGEN), from where R_{PGF} and a_{LL}^{PGF}/D are estimated. The average gluon momentum fraction is calculated from Monte-Carlo to be $\langle x_g \rangle = 0.13$ with an RMS of 0.08 . Using equation 5, one obtains for the gluon polarization $\Delta G/G(x_g = 0.13) = 0.06 \pm 0.31(stat) \pm 0.06(syst)$, where the systematic error includes the contribution from QCD Compton and leading process DIS.

4.2. $\Delta G/G$ at $Q^2 < 1$ GeV^2

Approximately 90% of the events registered in the experiment have $Q^2 < 1$ GeV^2. The statistical accuracy being very good, the knowledge of the *background asymmetry* contributions becomes crucial for this analysis. The measured asymmetry is $A_\parallel/D = 0.002 \pm 0.019(stat) \pm 0.003(syst)$.

The Monte-Carlo simulation uses PYTHIA, since this event generator provides a model for the lepton-nucleon interactions at low Q^2. Direct (PGF, QCD Compton and leading DIS process) and resolved processes are generated. While at $Q^2 < 1$ GeV^2 the resolved processes constitute 50% of the high-p_T sample, this contribution is only $\approx$ 10% at $Q^2 > 1$ GeV^2, and it is negligible for $Q^2 > 2$ GeV^2. In the resolved processes the virtual photon does not take part in the hard partonic interaction, but fluctuates into a vector-meson. The interaction occurs between a parton extracted from this vector-meson and a parton from the nucleon – if it is a gluon, the process is sensitive to the gluon polarization, contributing to the signal. This analysis requires a factorization between the hard and soft parts of the interaction, hence the dependence on a hard scale μ^2, provided in this analysis by the transverse momentum of the partons involved in the interaction. Those Monte-Carlo events where no hard scale can be found are classified as *low p_T*. Figure 3 shows the relative contribution of the physics subprocesses to the Monte-Carlo high-p_T sample. The fraction of PGF events is seen to be $R_{PGF} = 0.31$.

The generated events are passed through a simulation of the spectrometer and reconstructed using the same procedures as for real data. The Monte-Carlo distributions obtained show a good agreement with real data in all the relevant variables.

The analyzing power of each subprocess is calculated in pQCD at leading order [8]. The polarizations of the u, d and s quarks in the deuteron are calculated using the unpolarized parton distribution functions (PDFs) from GRV98, and the polarized PDFs from GRSV2000 [9], at leading order. Nevertheless the polarizations of the quarks and gluons in the virtual photon are unknown, since the polarized PDFs of the γ^* have not yet been measured. From theoretical considerations, the unpolarized case provides limits on the values of the polarized PDFs that can be used to overcome this problem, the so-called *maximal* and *minimal scenarios* [10]. The gluon polarization obtained in each of these scenarios is $\Delta G/G|_{min} = 0.016 \pm 0.068(stat) \pm 0.011(exp.syst) \pm 0.018(MC\ syst)$; and $\Delta G/G|_{max} = 0.031 \pm 0.089(stat) \pm 0.014(exp.syst) \pm 0.052(MC\ syst)$. The average gluon momentum fraction is estimated from Monte-Carlo to be $\langle x_g \rangle = 0.095$. The hard scale is also obtained from Monte-Carlo as $\langle \mu^2 \rangle = 3$ GeV^2.

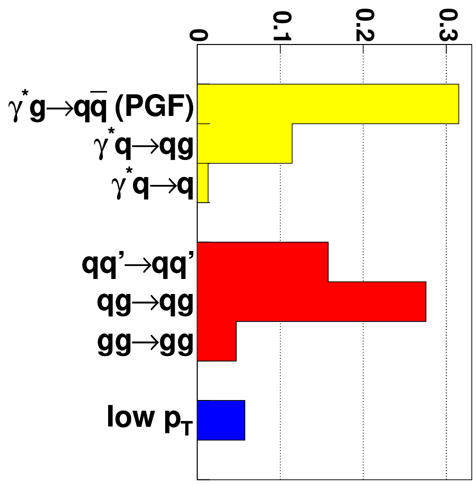


Figure 3. Relative contributions of each PYTHIA subprocess: direct processes (top), resolved photon processes (middle) and low p_T scattering (bottom).

Figure 4 shows this result, together with the one obtained in the $Q^2 > 1$ GeV^2 analysis presented above. The values of $\Delta G/G$ as a function of x_g published by the SMC [7] and the HERMES [11] collaborations are also shown, for comparison. In this figure, the horizontal bars on each point represent the accessed range in x_g. Good

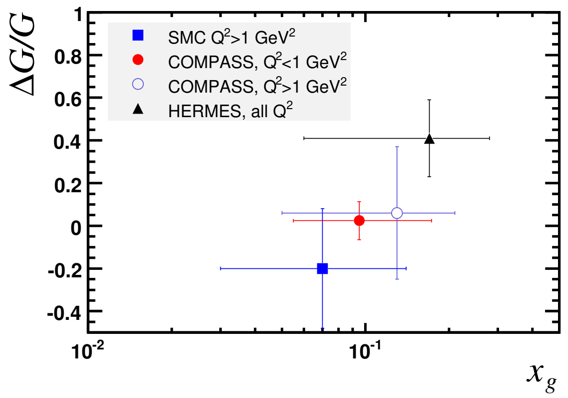


Figure 4. $\Delta G/G$ measurements from high-p_T analyses of COMPASS data, as compared to the SMC [7] and HERMES [11] results.

compatibility is observed between the COMPASS measurements and the SMC one, obtained from an analysis of high-p_T events at $Q^2 > 1$ GeV^2. These results show that the gluon polarization is compatible with zero, while the HERMES result suggests positive polarization. This latter analysis is mostly at low Q^2, but the resolved processes contribution to the asymmetry is neglected.

5. Conclusion

The results from three independent analyses of COMPASS data taken in 2002 and 2003 are presented, leading to estimations of the gluon polarization in the deuteron. $\Delta G/G$ is accessed via the photon gluon fusion process, by selecting open charm events, or events with two hadrons of large transverse momentum. The results from the study of the D^0 and $D^{*\pm}$ channels have a much smaller model dependence, being simpler to interpret, but suffer from low statistics. $\Delta G/G$ obtained from this open charm analysis is $\Delta G/G(x_g = 0.15) = -1.08 \pm 0.73(stat)$. The selection of high-$p_T$ hadron pairs, on the contrary, has large statistics, but several physics contributions other than PGF have to be estimated from Monte-Carlo, thus introducing strong model dependence. Restraining the analysis to the DIS region ($Q^2 > 1$ GeV^2), one obtains $\Delta G/G(x_g = 0.13) = 0.006 \pm 0.31(stat) \pm 0.06(syst)$, where the statistical error is still dominating the result. From the analysis of the photo-production region ($Q^2 < 1$ GeV^2), where most of the COMPASS data lays, the average gluon polarization is $\Delta G/G(x_g = 0.095, \mu^2 = 3\ GeV^2) = 0.024 \pm 0.089(stat) \pm 0.057(syst)$. This result indicates that either the gluon polarization is very small, or it has to cross zero around $x_g = 0.1$.

The COMPASS data taken in 2004 amounts to as much statistics as the two previous years taken together. Besides the increase in the raw data, an additional increase in the number of open-charm events is to be expected, from the study of other possible decay channels. COMPASS will continue its physics program, and resume data taking with polarized muon beam in 2006.

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