Recent COMPASS results on the gluon polarization

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Abstract. The spin structure of the nucleon is studied in the COMPASS experiment at CERN/SPS, from the collisions of 160 GeV polarized muon beam with a ^{6}LiD target. The data collected from 2002 to 2006 provide an accurate measurement of longitudinal double spin cross-section asymmetries. The latest results on the gluon polarization, accessed from two independent analyses of photon-gluon fusion selected events, are presented. The study of the open-charm production allows to extract the gluon polarization (in LO QCD) from the measurement of the asymmetry, the value obtained being $\Delta g/g = -0.49 \pm 0.27(stat) \pm 0.11(syst)$, at an average $x_g = 0.11\,^{+0.11}_{-0.05}$ and a scale $\langle \mu^2 \rangle = 13$ (GeV/c)^2. An alternative and independent way to study the gluon polarization, by studying the high transverse momentum hadron pairs produced, leads to a value $\Delta g/g = 0.08 \pm 0.10(stat) \pm 0.05(syst)$, at $x_g^{av} = 0.082\,^{+0.041}_{-0.027}$ and $\langle \mu^2 \rangle = 3$ (GeV/c)^2.

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INTRODUCTION

The spin structure of the nucleon is a long-standing subject, as the relative contributions of the quarks and gluons spin and orbital angular momenta, expected to be non-negligible, are not known. The surprisingly small contribution of the quarks spin, measured by the pioneering experiment EMC [1], motivated a whole generation of new polarized Deep Inelastic Scattering experiments. Presently it is known that the quarks spin contribution accounts for only ≈30% of the nucleon spin. The experiments HERMES at DESY, SMC and COMPASS at CERN, and STAR and PHENIX at RHIC address this problem, with a goal of measuring the gluons spin contribution to the nucleon helicity. In COMPASS, the gluon polarization is accessed from the measurement of the longitudinal double spin cross-sections asymmetry, in events with potential sensitivity to the gluon spin. By selecting events where the photon-gluon fusion (PGF) process is significantly enriched, one can probe the gluon helicity in the nucleon.

In COMPASS, two independent analyses study PGF-enriched event samples to obtain the gluon polarization: selecting open-charm events, where D^0 or D^* mesons are produced; or selecting events with hadron pairs produced of large transverse momentum.

COMPASS is a fixed-target experiment, using a naturally polarized μ^+ beam of 160 GeV/c colliding with a longitudinally polarized target of ^{6}LiD, with a total length of 120 cm. This target material allows for an average polarization of ≈ 50%, the fraction of polarizable material (the so-called dilution factor) being 0.4 . Two target cells (three in 2006) are simultaneously polarized in opposite directions, and the polarization orientation is reversed periodically, to minimize systematic errors. The average beam polarization is $\approx -80\%$. The two-stage spectrometer has very good tracking and particle identification capabilities. The experiment is described in detail in [2].

OPEN-CHARM ANALYSIS

In LO QCD approximation, the selection of events with D^0 or D^* mesons produced provides a clean sample of PGF events. The decay channels $D^0 \to K^-\pi^+$ and $D^*(2010)^+ \to D^0\pi^+_{slow} \to K^-\pi^+\pi^+_{slow}$ (and their charge conjugates) are studied, where charged pions and kaons are identified by the Ring Imaging Cherenkov (RICH) detector of the experiment. Eventual misidentification of electrons as π_{slow} is reduced using the RICH electron mass hypothesis. The final samples used in the analysis amount to about 8700 D^* mesons and 37400 D^0 mesons. The D^* sample has a much smaller combinatorial background, due to the small mass difference between D^* and D^0, that makes possible a sharp cut on the D^* mass.

The measured spin asymmetry relates to the gluon polarization, in a given range of x, according to:

$$A_{exp} = \langle\frac{\Delta g}{g}\rangle\, P_t\, P_b\, a_{LL}\, f\, \frac{S}{S+B} + A_B \tag{1}$$

where P_t and P_b are the target and beam polarizations, respectively; f is the dilution factor of the target; and a_{LL} the partonic spin asymmetry of the PGF process, parameterized from Monte-Carlo, using the AROMA generator. The signal (S) and background (B) are evaluated from fits to the invariant mass spectra. An additional term, taking into account the possibility for an asymmetry of the background events is also included. As can be seen, this analysis has only a weak model-dependence, but is statistically limited. The perturbative scale is ensured by the large charm quark mass.

In order to have an optimal statistical gain, the analysis is done with event-weighting. The weight (for signal or background hypotheses) attributed to each event takes into account all the factors that can increase its potential sensitivity to the gluon polarization: the beam polarization, the target dilution factor, the partonic spin asymmetry of $c\bar{c}$ production, and the signal or background purity. Purity of signal and background are parameterized as a function of all the relevant kinematical variables, as well as function of the RICH detector response, from fits to the binned mass spectra.

Having 2 target cells, with 2 possible spin configurations, one obtains 4 equations for signal and another 4 for background, relating the number of signal or background events from some target cell in some spin configuration, to $\langle\Delta g/g\rangle$, the gluon polarization in a given x_g range. This makes a total of 8 equations with 10 unknowns (8 acceptances, $\langle\Delta g/g\rangle$ and A_B). By making the reasonable assumption that variations of the acceptance affect the upstream and the downstream cells in the same way, the set is reduced to 8 unknowns. And with the additional assumption that signal and background events originating from the same cell are affected in the same way by acceptance variations, the number of unknowns reduces to 7. By solving this system of equations one can obtain simultaneously the gluon polarization and the background asymmetry.

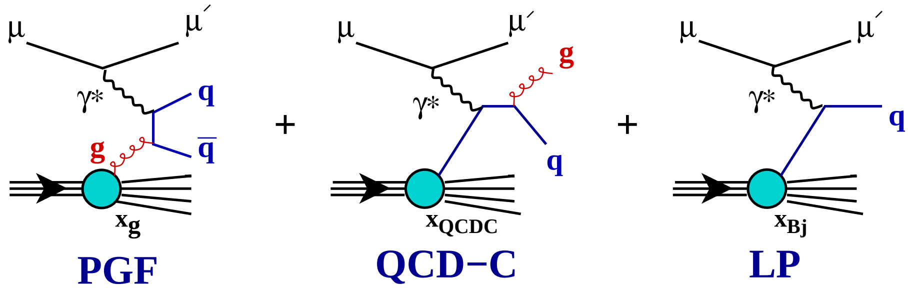

FIGURE 1. Processes contributing to the high p_T hadron pairs sample, at $Q^2 > 1$ (GeV/c)^2.

The data collected from 2002 to 2006 (4 years of data-taking) are analysed with this method, the result being an average gluon polarization $\Delta g/g = -0.49 \pm 0.27(stat) \pm 0.11(syst)$, at an average $x_g = 0.11\,^{+0.11}_{-0.05}$ and a scale $\langle \mu^2 \rangle = 13$ (GeV/c)^2. The background asymmetry is compatible with zero, within errors. Although this analysis makes an optimal use of the statistics available, the statistical error is dominating over systematics. The quadratic sum of all contributions to the systematic error was done separately for each decay channel, the largest (corresponding to D^o) being taken for the final result. The systematics considered include the uncertainty associated to the signal purity parameterization; false asymmetries coming from eventual geometrical asymmetries in the spectrometer itself or in the target cells; and systematics related to the a_{LL} parameterization.

HIGH p_T HADRON PAIRS ANALYSIS

Another way to select PGF events is to require hadron pairs in the final state, each having a high transverse momentum. In this case, both leading and sub-leading hadrons are required to have $p_T > 0.7$ GeV/c. In COMPASS this study is done separately for two different regions of Q^2: the deep inelastic scattering region, at $Q^2 > 1$ (GeV/c)^2; and the quasi-real photo production region, at $Q^2 < 1$ (GeV/c)^2. This latter analysis was published [3] and presented in several conferences [4], thus only its result will be briefly referred to here.

COMPASS data collected between 2002 and 2004 (3 years) are analysed. The DIS cut $Q^2 > 1$ (GeV/c)^2 alone eliminates 90% of the available statistics. The hadrons are required to be positively identified in the hadronic calorimeters of the experiments. The final sample, after selection cuts are applied, amounts to 500 thousand events.

Besides the PGF process, this sample has an important contamination from other processes, that constitute a physics background to be taken into account: QCD-Compton processes (QCDC), and leading order processes (LP). In figure 1 these three processes are presented.

In LO QCD approximation, the measured asymmetry of the high p_T hadron pairs sample can be expressed as:

$$\frac{A_{exp}}{P_b P_t f} \approx R_{PGF}\, a_{LL}^{PGF}\, \frac{\Delta g}{g}(x_g) + R_{QCDC}\, a_{LL}^{QCDC}\, A_1^{LP}(x_{QCDC}) + R_{LP}\, a_{LL}^{LP}\, A_1^{LP}(x_{Bj}) \quad (2)$$

Each of these contributions must be evaluated at the relevant x for the process in question. In this expression, R_i are the fractions of each process with respect to the total; and a^i_{LL} are the partonic asymmetries of each process i. The asymmetry A_1^{LP} is taken from the measured inclusive asymmetry, and is defined as $A_1^{LP} = \frac{\sum_j e_j^2 \Delta q_j}{\sum_j e_j^2 q_j}$, where the index j refers to the quarks flavor. The measured asymmetry of an inclusive sample (where no requirement for high p_T hadrons is done) can be decomposed in a similar way as in equation 2. By combining the two asymmetries, one can write the relation:

$$\frac{\Delta g}{g}(\langle x_g \rangle) = \frac{A_{LL}^{2h}(x_{Bj}) + A^{corr}}{\beta} \tag{3}$$

where β is a function of the R_i and the a^i_{LL}, and the asymmetry A^{corr} is a sum of all the terms contributing to the background. Factors R_i and a^i_{LL}, as well as the partonic momentum fractions x, cannot be determined experimentally, and must be evaluated from Monte-Carlo, thus implying an important model dependence of the analysis. The LEPTO MC generator is used, with the MRST 2004 LO set of parton distribution functions, and JETSET fragmentation. In order to have a good agreement between MC and experimental distributions, mandatory in this analysis, initial and final state radiation is allowed in the generation (the so-called LEPTO parton shower option). This correction accounts for part of the NLO contributions, while the analysis itself is LO, thus leading to a systematic error that is considered in the final result. Additionally, some parameters of the fragmentation were also tuned in the MC.

The fractions R_i of the three sub-processes in each of the two Monte-Carlo samples (high p_T hadron pairs and inclusive) are estimated using a neural network, that parameterizes the probability for each event to be PGF, QCDC or LP.

In the analysis, events are weighted by a factor $w = fDP_b\beta$, with β being function of the R_i and the a^i_{LL}, and D the virtual photon depolarization factor. The final result, averaging the 3 years data results, is $\Delta g/g = 0.08 \pm 0.10(stat) \pm 0.05(syst)$, measured at an average $x_g^{av} = 0.082\,^{+0.041}_{-0.027}$ and at a scale $\langle \mu^2 \rangle = 3$ (GeV/c)^2 (given by the DIS cut).

DISCUSSION AND CONCLUSIONS

The two COMPASS analyses described above result in small values of the gluon polarization, in the limited x_g region of the measurement. They are statistically compatible, and also compatible with the measurement of $\Delta g/g$ obtained from the high p_T hadron pairs analysis in the region $Q^2 < 1$ (GeV/c)^2. The preliminary result of this analysis, using the data collected between 2002 and 2004 is $\Delta g/g = 0.016 \pm 0.058(stat) \pm 0.036(syst)$, measured at $\langle x_g \rangle = 0.085\,^{+0.07}_{-0.04}$ and $\langle \mu^2 \rangle = 3$ (GeV/c)^2 [4].

Figure 2 presents the COMPASS results on the gluon polarization, together with direct measurements from other experiments, SMC [5] and HERMES [6]. The two curves also included correspond to the COMPASS NLO QCD fits to world data, done in the $\overline{MS}$ scheme, at a scale $\mu^2 = 3$ (GeV/c)^2 [7]. Taken together, these results seem to exclude the possibility of a large contribution of the gluon spin to the nucleon helicity.

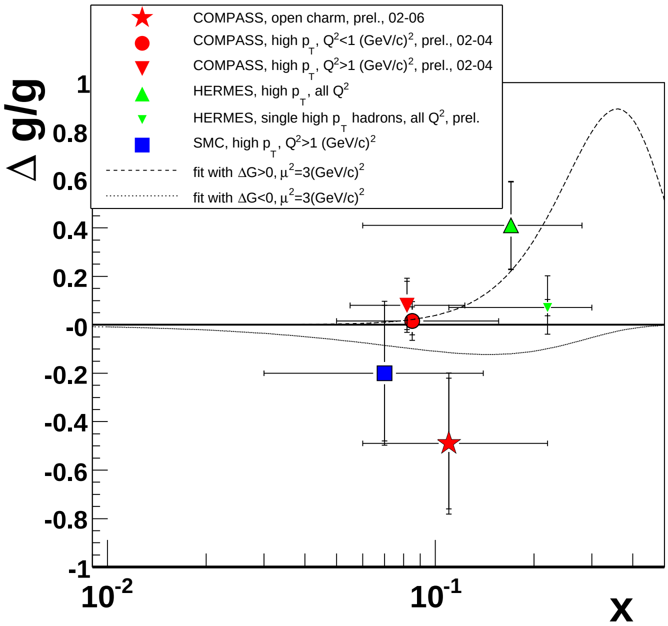

FIGURE 2. Direct measurements of $\Delta g/g$ as a function of x_g, from COMPASS, SMC and HERMES experiments. The curves correspond to NLO QCD fits to world data on structure functions, for the solutions with $\Delta G > 0$ (broken line), and with $\Delta G < 0$ (dashed line).

Both COMPASS analyses discussed here use new methods that optimize the statistical significance of the collected data. The results from COMPASS indicate that $\Delta g/g$ has a small value in the x_g region probed, around 0.1 . In the near future, more data will be analysed, and several improvements to the methods of analysis are presently being studied.

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