GLUON POLARISATION MEASUREMENT AT COMPASS

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The determination of the gluon helicity contribution, $\Delta G/G$, to the nucleon spin is one of the main goals in the COMPASS spin physics program. The polarisation of gluons carrying a fraction x_G of the nucleon momentum is obtained from the cross-section asymmetry of the photon-gluon fusion reaction in the scattering of polarised 160 GeV muons on a polarised deuteron target. The analysed data have been collected by the COMPASS experiment at CERN in the years 2002-2004. Two approaches have been used for direct $\Delta G/G$ measurements: the "open charm" method and the "high p_T hadron pairs" one. The results of QCD fits on all g_1 data, which provide two solutions with the gluon spin distribution function ΔG positive or negative, are also presented. Our measurements show that the helicity contribution of gluons at $x_G \sim 0.1$ is small and is in agreement with the results of the g_1 global QCD analysis fits.

Keywords: deep-inelastic scattering; nucleon spin; gluon polarisation.

1. Introduction

Since 1988, when the EMC experiment found out that only a small fraction of the nucleon spin is carried by the quarks, $\Delta\Sigma = 12 \pm 9 \pm 14\%$ [1], the origin of the spin of the nucleon is an intriguing puzzle. The discrepancy between this measurement and an expectation following from the relativistic quark models, which predict that 60% of the nucleon spin should come from the intrinsic spin of quark and anti-quark constituents, was named as "spin-crises". Then the EMC result has been confirmed by a series of deep inelastic scattering experiments at CERN, SLAC and DESY, giving, on average, a contribution from the quarks $\Delta\Sigma$ to the nucleon spin equal to $20 - 30\%$.

As the spin 1/2 of the nucleon can be decomposed as $1/2 = 1/2\Delta\Sigma + \Delta G + L_{q+g}$ one can conclude that the remaining contributions to the nucleon spin must come from the gluons spin ΔG, and(or) from quark and gluon orbital angular momenta L_{q+g}.

The measurement of the gluon polarisation is important for two reasons. From one side as a component of the sum rule of the total angular momentum of the nucleon. From another side as a possible solution of the "spin-crisis" and violation of the Ellis-Jaffe sum rule [2] if ΔG is sufficiently big (of order of 3).

2. The COMPASS experiment and ΔG measurement

The COMPASS experiment is a fixed target experiment at CERN studying the spin structure of the nucleon via deep inelastic polarised muon-nucleon scattering. The 160 GeV polarised muon beam from SPS, with 2×10^8 muons per 4.8 s spill and a polarisation of $P_B \simeq 76\%$ is scattered off a polarised deuteron target. The target material, ^{6}LiD, has been chosen for its high dilution factor (fraction of polarised nucleons $f \simeq 40\%$). To reduce false asymmetries, two 60 cm long target cells are polarised in opposite directions to $P_T \simeq 50\%$. The target polarization is reversed once every 8 hours. The COMPASS spectrometer consists of a two stage spectrometer for large and small angle tracking, with precise momentum measurement, particle identification by RICH and hadronic, electromagnetic calorimeters as well [3].

Direct measurements of $\Delta G/G$ have been performed via the photon-gluon fusion $\gamma^* g \to q\overline{q}$ process (PGF) which is shown schematically in Fig. 1.

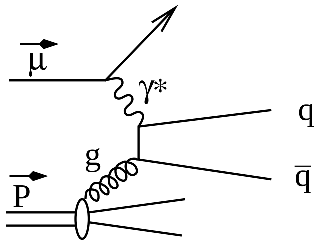

Fig. 1. The photon-gluon fusion diagram.

Two approaches have been used to tag PGF: the "open charm" method and the "high p_T hadron pairs" one. The last method, especially in the low Q^2 region, provides high statistics but suffers from the physics background and, hence, from the model dependence of its description. On the contrary the open charm leptoproduction method is clean, free from physics background but statistically limited. The analyses of open charm events and of the hadron pairs in the low virtuality domain ($Q^2 < 1\ (GeV/c)^2$) have been performed using the 2002-2004 data. The other analysis based on the hadrons pairs in the high Q^2 region ($Q^2 > 1\ (GeV/c)^2$) has been done on the 2002-2003 data. The analysis of the 2004 data is in progress.

3. $\frac{\Delta G}{G}$ from open charm

The cleanest way to tag the PGF reaction is the $\gamma^* g \to c\overline{c}$ process because the presence of c quarks inside the nucleon is negligibly small. The created $c\overline{c}$ pairs predominantly fragment into vector and pseudoscalar charmed-non-strange mesons in the following proportions $D^*(2010)^{\pm}$:$D^*(2007)^0$:$D^{\pm}$:D^0 = 3:3:1:1. All neutral and 68% of charged vector mesons decay into the pseudoscalar D^0 meson and the $\pi^{\pm}$, π^0 mesons or γ:

$$D^*(2007)^0 \to D^0\pi^0, \quad D^*(2007)^0 \to D^0\gamma,$$
$$D^*(2010)^{\pm} \to D^0\pi^{\pm}.$$

Therefore the D^0 mesons are produced more copiously than other weakly decaying D species.

The open charm analysis of 2002-2004 data is based on the charged two-prong Cabibbo favoured $D^0 \to K\pi$ decay channel with the branching ratio equals $(3.80 \pm 0.09) \times 10^{-2}$.

The separation of the primary and secondary D^0 meson decay vertices is impossible due to multiple scattering in the thick polarised target, so the efficient particle identification with the RICH, even in low-multiplicity D^0 decay modes, is crucial in such analysis. The constrain on mass difference $\Delta M = M_{D^*} - M_{D^0}$ (so-called "D^* tag") was used for the effective combinatorial background suppression. In each event with D^0 candidate the soft charged π-meson was searched for in order to detect the possible decay chain $D^*(2010)^{\pm} \to D^0\pi^{\pm}$. Finally two D^0 samples were obtained without (Fig. 2) and with (Fig. 3) "D^* tag".

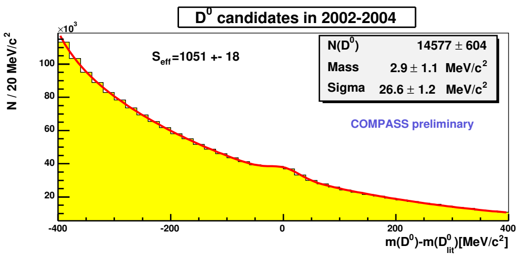

Fig. 2. Invariant mass distributions of the $D^0 \to K\pi$ candidates without D^* tag. The effective signal is given by $S_{eff} = S/(1 + B/S)$ where S and B denote D^0 signal and combinatorial background, respectively. These two values were calculated in the $\pm 2\sigma$ mass interval around D^0 peak which was fitted with a Gaussian function.

The gluon polarisation is related to the measured experimental asymmetry A_{exp} as follows: $A_{exp} = P_B P_T f a_{LL} \frac{S_{eff}}{S} \frac{\Delta G}{G}$, where

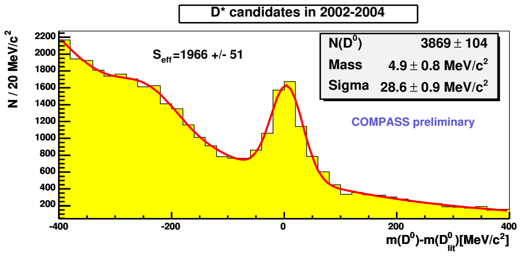

Fig. 3. Invariant mass distributions of the $D^0 \to K\pi$ candidates with D^* tag.

the parameters f, P_B, P_T and their values were discussed in the Sec. 2. The analysing power a_{LL} has to be determined from a Monte Carlo simulation, as the kinematics of the PGF event is not fully known because only one of the two charmed mesons is reconstructed. A parametrisation of a_{LL} was found with a neural network trained on a Monte Carlo sample generated by the AROMA generator and reconstructed as for the real data. Combining all 2002-2004 data a preliminary value of $\frac{\Delta G}{G} = -0.57 \pm 0.41(stat)$ at $x_G \simeq 0.15$ is obtained at a scale of $\mu^2 \simeq 13\ (GeV/c)^2$ [5]. The systematic uncertainty is under the study. The estimations show that the main contributions come from the false asymmetries and from the neural network parametrisation. The systematic error is expected to be smaller than the statistical one.

4. $\frac{\Delta G}{G}$ from high p_T hadron pairs

The PGF events with light quarks $\gamma^* g \to q\overline{q}$ have been tagged [4] by high p_T hadron pairs: $p_T > 0.7\ GeV/c$ and $p_{T1}^2 + p_{T2}^2 > 2.5\ (GeV/c)^2$. The data at Q^2 below or above 1 $(GeV/c)^2$ are treated separately, since the physical background depends on the Q^2 value. This approach relies on good agreement between data and Monte Carlo. For $Q^2 > 1\ (GeV/c)^2$ a Monte Carlo with LEPTO generator was used and for $Q^2 < 1\ (GeV/c)^2$ the PYTHIA one. $\Delta G/G$ is extracted from the measured experimental asymmetry $A_{exp} = P_B P_T f(R_{PGF} a_{LL} \frac{\Delta G}{G} + A_{bkg})$ where R_{PGF} is the fraction of PGF events and A_{bkg} the asymmetry from the different background processes.

4.1. $Q^2 > 1\ (GeV/c)^2$ *analysis*

For the high Q^2 sample ($\sim$ 10% of the high p_T hadron pairs statistics) the most important background contributions come from QCD Compton scattering (QCD-C) and the leading order (LO) processes. The analysis is done in the region $x_{Bjorken} < 0.05$ where A_1^d is small and A_{bkg} contribution vanishes. At the same time, QCD-C and LO processes are still important for R_{PGF} determination. The fraction of PGF events R_{PGF} is found to be about 34%.

The result from 2002-2003 data analysis $\frac{\Delta G}{G} = 0.06 \pm 0.31(stat) \pm 0.06(syst)$ was obtained at $x_G \simeq 0.13$ for $\mu^2 \simeq 3\ (GeV/c)^2$ [5]. The main systematic uncertainty comes from the false asymmetries.

4.2. $Q^2 < 1\ (GeV/c)^2$ *analysis*

For the low Q^2 sample ($\sim$ 90% of the high p_T hadron pairs statistics) there are additional background contributions due to resolved photon processes and vector meson production. About 50% of the events is attributed to the resolved photon processes. The R_{PGF} is found to be about 30%.

The result of 2002-2004 data analysis $\frac{\Delta G}{G} = 0.016 \pm 0.058(stat) \pm 0.055(syst)$ was obtained at $x_G \simeq 0.085$ for $\mu^2 \simeq 3\ (GeV/c)^2$ [6]. The systematic error from the Monte Carlo simulation is the dominant one. Another important contributions to the systematic error are related to unknown polarised distribution functions in the photon and to the false asymmetries.

The COMPASS results are summarised in Fig. 4 and compared to previous measurements of SMC [7] and HERMES [8] experiments. The set of all measurements indicates that ΔG is small around $x_G \sim 0.1$.

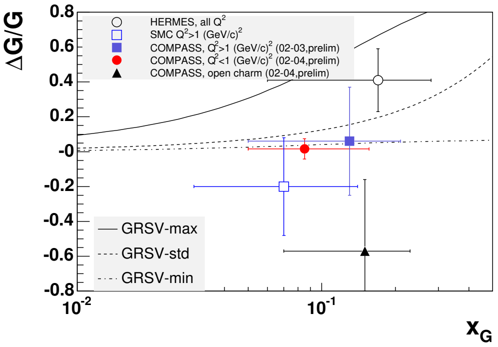

Fig. 4. Various measurements of $\Delta G/G$ compared to three NLO GRSV parameterisations at $\mu^2 = 3\ (GeV/c)^2$ for $\Delta G = 2.5$ 0.6 and 0.2. The scale for the experimental points is about 3 $(GeV/c)^2$ except for the open charm point where it is 13 $(GeV/c)^2$. The errors are statistical only.

5. QCD analysis of g_1

The results of QCD analysis [9] in the next to leading order (NLO) on all g_1 deep inelastic scattering data, including the new COMPASS results, provide two solutions with the gluon spin distribution function ΔG positive or negative which describe the data equally well. Although the gluon distributions strongly differ in the two fits, in both cases, at $Q^2 = 3\,(\mathrm{GeV}/c)^2$ the first moment of ΔG is found to be small and of the order of $0.2 - 0.3$ in absolute value.

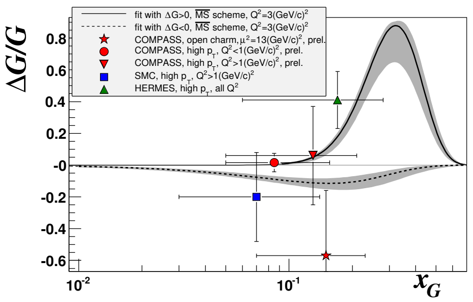

Fig. 5. Distribution of the gluon polarisation $\Delta G(x_G)/G(x_G)$ at $\mathrm{Q}^2 = 3\ (\mathrm{GeV}/c)^2$ for the fits with $\Delta G > 0$ and $\Delta G < 0$. The error bands correspond to the statistical error on $\Delta G(x_G)$ at a given x_G.

In Fig. 5 the direct measurements of $\Delta G/G$ are shown with the distributions of $\Delta G(x_G)/G(x_G)$ derived from the QCD fits. The measured SMC point [7] is too imprecise to discriminate between positive or negative ΔG. The HERMES value [8] is positive and 2σ away from zero. Most precise COMPASS measurement from the high p_T hadron pairs ($Q^2 < 1\ (GeV/c)^2$) analysis is almost on the $\Delta G > 0$ curve but is only 1.6σ away from the $\Delta G < 0$ one, so that no preference for any of the curves can be given so far.

6. Conclusion and outlook

In summary, three different COMPASS analyses performed on data taken in 2002-2004 indicate a small value of ΔG. At the same time, the QCD analysis of g_1 also indicates a small value of the first moment of ΔG. These results are the probable signature of predominant role of angular orbital momentum in nucleon spin decomposition in the frame of parton model and perturbative QCD.

The data taking continues in 2006 with an improved spectrometer. About 20% reducton of the statistical errors is expected.

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