COMPASS results on gluon polarisation

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One of the missing keys in the present understanding of the spin structure of the nucleon is the contribution from the gluons: the so-called gluon polarisation. This quantity can be determined in DIS through the Photon-Gluon Fusion (PGF) process, in which two analysis methods may be used: (i) identifying open charm events or (ii) selecting events with high-p_T hadrons. The data used in the present work were collected by the COMPASS experiment, where a naturally polarised muon beam of 160 GeV, impinging on a polarised nucleon fixed target, is used. In the analyses a new weighted method based on a neural network approach is used. Preliminary results for the gluon polarisation from high-p_T and open charm analyses are presented. The gluon polarisation result for high-p_T hadrons is presented for $Q^2 < 1$ and $Q^2 > 1$ $(\text{GeV}/c)^2$ regimes and divided, for the first time, into 3 statistically independent bins at LO ($Q^2 > 1$ $(\text{GeV}/c)^2$). The result from open charm analysis is obtained at LO and NLO.

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1. Gluon Polarisation Measurements

The nucleon spin sum rule can be written in a heuristic way as: $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{q,g}$, where $\Delta\Sigma$ and ΔG are the quark and gluon contributions to the nucleon spin, respectively, and $L_{q,g}$ is the parton orbital angular momentum. In the late 80's it was announced and confirmed from several experiments that the contribution carried by the quarks is $\sim 1/3$ of the nucleon spin . The purpose of this work is to estimate the gluon polarisation $\Delta G/G$, which is deeply related with the gluon contribution to the nucleon spin.

The spin dependent effects are measured experimentally using the helicity asymmetry $A_{\mathrm{LL}}^{\mathrm{exp}}$ defined as $\frac{\sigma^{\Leftarrow}-\sigma^{\Leftrightarrow}}{\sigma^{\Leftarrow}+\sigma^{\Leftrightarrow}}$ where ($\Leftarrow$) and ($\Leftrightarrow$) refer to the parallel and anti-parallel spin helicity configuration of the beam lepton ($\leftarrow$) with respect to the target nucleon ($\Leftarrow$ or $\Rightarrow$). The data for the present analyses were collected in the COMPASS experiment [1]. The gluon polarisation can be accessed via the Photon-Gluon Fusion (PGF) process, depicted in Figure 1 c), which allows to probe the spin of the gluon inside the nucleon. The PGF process may be selected using two analysis methods: (i) selecting high-p_T hadron events, or (ii) selecting events containing open charm mesons.
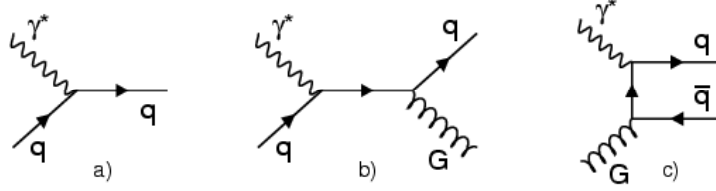

Figure 1: DIS Feynman diagrams for $\gamma^\star N$ scattering: a) virtual photo-absorption (LP), b) gluon radiation (QCD Compton) and c) photon-gluon fusion (PGF).

In the high-p_T analysis the spin helicity asymmetry is calculated by selecting events containing high-p_T hadron pairs above 0.7 and 0.4 GeV/c, respectively for the highest and the second highest p_T hadron with respect the virtual photon direction. A cut on $Q^2 > 1$ (GeV/c)^2 was also applied in order to select DIS events. Two other processes compete with the PGF process in LO QCD approximation, namely the virtual photo-absorption leading order process (LP) and the gluon radiation (QCD Compton) process, illustrated in Figure 1. The spin helicity asymmetry for the high-p_T hadron pair data sample can thus be schematically written as:

$$A_{\mathrm{LL}}^{2h}(x_{Bj}) = R_{\mathrm{PGF}}\, a_{\mathrm{LL}}^{\mathrm{PGF}}\frac{\Delta G}{G}(x_G) + R_{\mathrm{LP}}\, D A_1^{\mathrm{LO}}(x_{Bj}) + R_{\mathrm{QCDC}}\, a_{\mathrm{LL}}^{\mathrm{QCDC}} A_1^{\mathrm{LO}}(x_C) . \qquad (1.1)$$

Where x_{Bj}, x_C and x_G are the momentum fractions carried by the struck parton for each of the aforementioned processes. The process fractions are represented by R_i, i referring to the different processes. a_{LL}^i represents the partonic cross section asymmetries, $\Delta\hat{\sigma}^i/\hat{\sigma}^i$, also known as analysing power. The depolarisation factor D is the fraction of the muon beam polarisation transferred to the virtual photon. A_1^{LO} is the virtual photon asymmetry. A similar eq. to (1.1) can be written to express the inclusive asymmetry of a data sample, A_{LL}^{incl}. Using eq. (1.1) for the high-p_T hadron pair sample and the same equation but for an inclusive sample, the final expression to extract the gluon polarisation is obtained:

$$\frac{\Delta G}{G}(x_G^{av}) = \frac{A_{\mathrm{LL}}^{2h}(x_{Bj}) + A^{\mathrm{corr}}}{\lambda} . \qquad (1.2)$$

This formula corresponds to the spin helicity asymmetry A_{LL}^{2h}, measured directly from data, with a term A^{corr} that accounts for the contributions from the other two processes. The λ factor relates the partonic asymmetries and the fractions of the involved processes. The partonic asymmetries and the process fractions need to be estimated using a dedicated and well tuned Monte Carlo (MC) simulation. A bayesian Neural Network (NN) [2] approach was used. The purpose of such approach is to assign an event probability for each process involved, represented by the process fractions in eq. (1.1). The NN is also used to provide the partonic asymmetries and x_C and x_G variables. Details about the high-p_T analysis, for $Q^2 > 1$ (GeV/c)^2, can be found in [3]. A similar analysis was performed for the $Q^2 < 1$ (GeV/c)^2 data. This separation is due to the physical processes contained in the two Q^2 regimes. The $Q^2 < 1$ (GeV/c)^2 regime represents the quasi-real photon, in such conditions the photon may exhibit some inner structure. Therefore beside the three already mentioned processes the photon structure processes need to be included in the MC simulation. Details of this analysis can be found in [4].

The spin helicity asymmetries related to the open charm process are calculated using data with D^0 mesons in the final state. These events are selected from their decaying products, *i.e.* $K\pi$ pairs. To achieve this selection a good particle identification is required. The combinatorial background originated from processes, in which the virtual photon strikes a parton inside the nucleon, is reduced by applying a set of kinematic cuts. In addition the background is even more suppressed by tagging the D^0 candidates with a parent $D^\star$ using the $D^\star \to D^0\pi_{slow}$ channel. In this way three additional channels were included in the final analysis, D^0 to $K_{sub}\pi$, $K\pi\pi^0$ and $K\pi\pi\pi$. The former includes kaon candidates not identified by the RICH detector [1].

The number of events with D^0 particles in the final state is related to the gluon polarisation as shown by this expression:

$$N_t = \alpha(S+B)\left[1 + \beta\left(a_{LL}\frac{S}{S+B}\frac{\Delta G}{G} + D\frac{B}{S+B}A^{bg}\right)\right].$$ (1.3)

The subscript t on the number of events corresponds to the possible muon target spin configurations. The α factor contains the acceptance, muon flux and number of nucleons and β the beam and target polarisations and dilution factor. S and B represent the number of signal and background events taken under the invariant mass spectrum peak. $\frac{S(B)}{S+B}$ is the signal (background) purity. A^{bg} is the asymmetry of the combinatorial background. Taking into account all the possible muon target spin configurations a set of equations is derived from eq. (1.3). Still, to solve this system of equations the partonic asymmetry a_{LL} and the signal purity $\frac{S}{S+B}$ must be estimated. To compute the partonic asymmetry a_{LL} a dedicated MC simulation is used. A NN approach is designed to parametrise the partonic asymmetry and the signal significance $\frac{S}{S+B}$. Details about this analysis can be found in [5]. A NLO QCD analysis was also performed, these corrections were included into the analysing power.

2. Results

The preliminary results on gluon polarisation using the high-p_T ($Q^2 < 1$ and $Q^2 > 1$ (GeV/c)^2, LO QCD order) and open charm (LO and NLO QCD order) analyses are now presented. The $\Delta G/G$ value obtained in high-p_T analysis, for $Q^2 > 1$ (GeV/c)^2, averaged at $x_g = 0.09^{+0.08}_{-0.04}$ was

found to be equal to $\Delta G/G = 0.125 \pm 0.060_{stat} \pm 0.063_{sys}$. This data was separated in three statistically independent points, in Table 1. The same result for $Q^2 < 1$ $(GeV/c)^2$ is $\Delta G/G = 0.016 \pm 0.058_{stat} \pm 0.055_{sys}$.

	1st Bin	2nd Bin	3rd Bin
$\Delta G/G$	$0.147 \pm 0.091 \pm 0.088$	$0.079 \pm 0.096 \pm 0.082$	$0.185 \pm 0.165 \pm 0.143$
x_G^{av}	$0.07^{+0.05}_{-0.03}$	$0.10^{+0.07}_{-0.04}$	$0.17^{+0.10}_{-0.06}$

Table 1: Gluon polarisation results in bins of x_G.

The gluon polarisation value for the open charm analysis was found as $\Delta G/G = -0.08 \pm 0.21_{stat} \pm 0.08_{sys}$ averaged at $x_G = 0.11^{+0.11}_{-0.05}$ for LO QCD order and $\Delta G/G_{NLO} = -0.20 \pm 0.21_{stat} \pm 0.08_{sys}$ averaged at $x_G = 0.28^{+0.19}_{-0.10}$ at NLO QCD order. The gluon polarisation values from high-p_T hadrons are measured at a hard scale of $\langle \mu^2 \rangle = 3.4$ $(GeV/c)^2$, while the ones from open charm mesons were evaluated at a hard scale of $\langle \mu^2 \rangle = 13$ $(GeV/c)^2$. All the gluon polarisation results of the COMPASS Collaboration are summarised in Figure 2 together with the SMC and HERMES results.
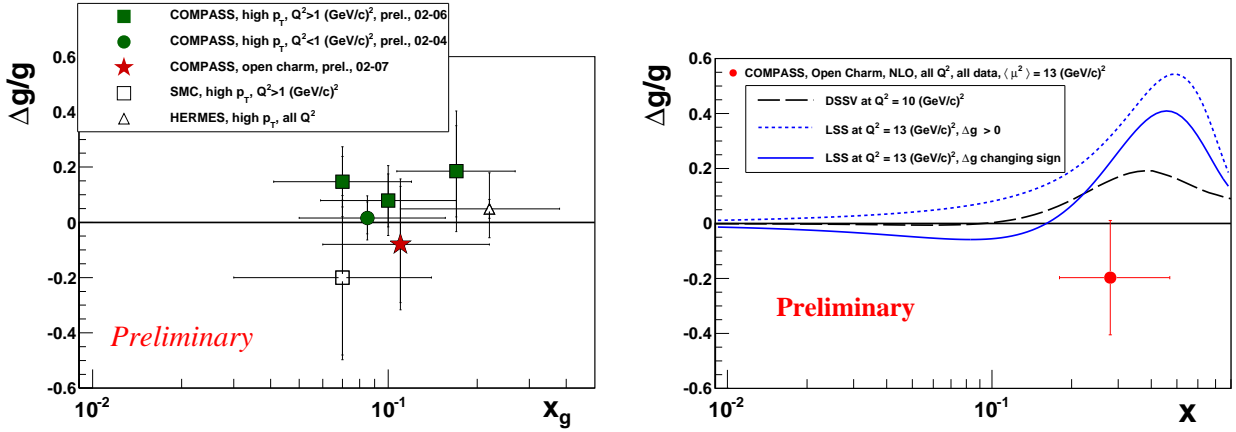

Figure 2: Gluon polarisation results: LO QCD order results (left side plot), NLO QCD order results (right side plot).

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