Gluon Polarisation Measurements @ COMPASS

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Abstract. 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 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 in the COMPASS experiment, where a 160 GeV/c naturally polarised muon beam, impinging on a polarised nucleon fixed target 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 divided, for the first time, into three statistically independent measurements at LO. The result from open charm analysis is obtained at LO and NLO. In both analyses a new weighted method based on a neural network approach is used.

1. The Nucleon Spin

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 [1, 2, 3, 4, 5]. 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.

2. Gluon Polarisation Measurements

The spin dependent effects are measured experimentally using the helicity asymmetry $A_{\mathrm{LL}}^{\mathrm{exp}}$ defined as $\frac{\sigma^{\overleftarrow{\Leftarrow}} - \sigma^{\overleftarrow{\Rightarrow}}}{\sigma^{\overleftarrow{\Leftarrow}} + \sigma^{\overleftarrow{\Rightarrow}}}$ where ($\overleftarrow{\Leftarrow}$) and ($\overleftarrow{\Rightarrow}$) 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 was taken in the COMPASS experiment [6]. The gluon polarisation can be measured 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.

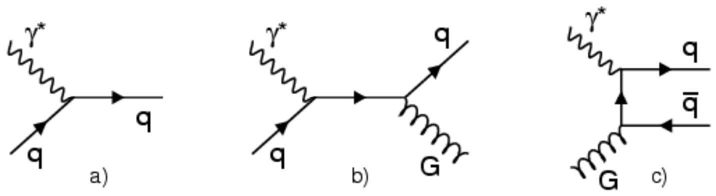


Figure 1: DIS Feynman diagrams for $\gamma^\star N$ scattering: a) virtual photo-absorption (LP), b) gluon radiation (QCD Compton) and c) photon-gluon fusion (PGF).

2.1. High p_T

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. 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:

$$A_{\rm LL}^{2h}(x_{Bj}) = R_{\rm PGF}\, a_{\rm LL}^{\rm PGF}\frac{\Delta G}{G}(x_G) + R_{\rm LP}\, D\, A_1^{\rm LO}(x_{Bj}) + R_{\rm QCDC}\, a_{\rm LL}^{\rm QCDC} A_1^{\rm LO}(x_C)\ . \quad (1)$$

The process fractions are represented by R_i, i referring to the different processes. $a_{\rm LL}^i$ 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. The virtual photon asymmetry $A_1^{\rm LO}$ is defined as $A_1^{\rm LO} \equiv \frac{\sum_i e_i^2 \Delta q_i}{\sum_i e_i^2 q_i}$. A similar equation to (1) can be written to express the inclusive asymmetry of a data sample, $A_{\rm LL}^{incl}$. Using (1) for the high p_T hadron pair sample and the above mentioned equation for the inclusive sample the final expression to extract the gluon polarisation is obtained:

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

This formula corresponds to the spin helicity asymmetry $A_{\rm LL}^{2h}$, measured directly from data, plus a correcting asymmetry $A^{\rm corr}$ involving mainly the virtual photo-absorption and the gluon radiation processes. The λ factor relates the partonic asymmetries and the fractions of the involving processes. During the data selection process it is not possible to identify the process that originated each event, neither to access its partonic variables. Therefore the partonic asymmetries and the process fractions need to be estimated using a dedicated and well tuned Monte Carlo (MC) simulation. The quality of the simulation is illustrated by the comparison of the distributions for three variables in the presented at the conference slides. In the high p_T analysis a Bayesian Neural Network (NN) [7] approach was used. The purpose of such approach is to assign a event probability for each process involved: LP, QCD Compton and PGF. These probabilities represent the process fractions in (1). Also the NN is used to provide the partonic asymmetries and x_C and x_G variables. The gluon polarisation is calculated in an event by event basis using an optimal weight which improves the figure of merit.

Details about the high p_T analysis, for $Q^2 > 1$ (GeV/c)^2, can be found in [8]. A similar analysis was performed for the $Q^2 < 1$ (GeV/c)^2 data, which contains $\sim 90\%$ of the whole Q^2 range. 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 already mentioned three intervening processes the inclusion of photon structure processes in the MC simulation needs to be accomplished. Details of this analysis can be found in [9].

2.2. Open Charm

For the open charm analysis the spin helicity asymmetries are calculated using a 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. Applying a set of kinematic cuts the combinatorial background originated from process in which the virtual photon strikes a parton inside the nucleon is reduced. In addition the backgroun is suppressed by selecting the $D^\star \to D^0\pi_{slow}$ channel. Doing in this way three channels were included in the final analysis: $D^0 \to K\pi$, $D^0 \to K\pi\pi^0$ and $D^0 \to K\pi\pi\pi$. The data used in this analysis are deuteron data collected from 2002 to 2006 and proton data collected in 2007.

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

$$N_t = \alpha(S+B)\left[1+\beta\left(a_{\rm LL}\frac{S}{S+B}\frac{\Delta G}{G} + D\frac{B}{S+B}A^{\rm bg}\right)\right] \ . \tag{3}$$

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. $\frac{A(B)}{S+B}$ is the signal (background) significance. $A^{\rm bg}$ is the asymmetry of the background. Taking into account all the possible muon target spin configurations and the unknown variables a set of equations is derived from the expression (3). This equation set is solved by χ^2 minimisation. As in high p_T analysis, the gluon polarisation calculation is performed event by event with an appropriate weight. Still to solve this equation system the partonic asymmetry $a_{\rm LL}$ and the signal significance $\frac{S}{S+B}$ must be estimated for every event. To compute the partonic asymmetry $a_{\rm LL}$ a dedicated MC simulation is used. A NN approach is designed to parametrise the partonic asymmetry and the signal significance $\frac{S}{S+B}$ as a function of the kinematics. The latter represents the event probability for having D^0 particles. Details about this analysis can be found in [10]. A NLO QCD analysis was also performed. Into the analysing power NLO QCD virtual and gluon bremstrahlung corrections were included to the PGF process, as well as background processes.

3. Results

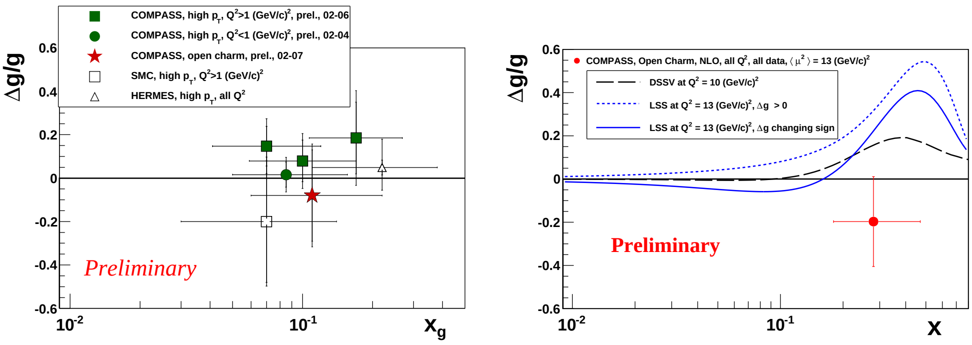
The preliminary results on gluon polarisation using the high p_T ($Q^2 < 1$ and $Q^2 > 1$ (GeV/c)^2, LO QCD order) and open charm (LO and NLO QCD order) analyses are now presented. The $\Delta G/G$ value obtained in high p_T analysis, for

$Q^2 > 1$ $(\text{GeV}/c)^2$, 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 measurement is presented in three statistically independent points, in table 1. The same result for $Q^2 < 1$ $(\text{GeV}/c)^2$ is $\Delta G/G = 0.016 \pm 0.058_{stat} \pm 0.055_{sys}$.

Table 1: Gluon polarisation results in bins of x_G.

	1^{st} Bin	2^{nd} Bin	3^{rd} 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}	$0.07^{+0.05}_{-0.03}$	$0.10^{+0.07}_{-0.04}$	$0.17^{+0.10}_{-0.06}$

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 $\langle \mu^2 \rangle = 3.4$ $(\text{GeV}/c)^2$, while the ones from open charm mesons were evaluated at a hard scale of $\langle \mu^2 \rangle = 13$ $(\text{GeV}/c)^2$. All the gluon polarisation results of the COMPASS Collaboration are summarised in figure 2 together with the SMC and HERMES results.



(a) LO QCD (b) NLO QCD

Figure 2: Gluon polarisation results: (a) LO QCD order results, (b) NLO QCD order results.

More details can be found on the conference slides (`http://www.nuclear.kth.se/NCNP2011/Presentation_files/L.Silva.pdf`).

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