

NLO QCD result for the gluon polarisation from open-charm D^0 meson production at COMPASS

Krzysztof Kurek, on behalf of the COMPASS Collaboration

The Andrzej Sołtan Institute for Nuclear Studies ,00-681 Warsaw, Poland

E-mail: kurek@fuw.edu.pl

Abstract. One of the main goals of the COMPASS experiment is the measurement of the gluon contribution to the nucleon spin. Among the processes studied by COMPASS, open-charm D^0 meson production seems to be the cleanest channel for probing gluons in the energy range covered by the experiment. The gluon polarisation is related to the measured asymmetry for charmed mesons production via the analyzing power (asymmetry at the partonic level) calculated in the perturbative QCD frame. The analyzing power for the "photon-gluon fusion" process corresponds to a LO QCD approximation. The significant improvement of the statistical precision and the new, final LO result are presented. The NLO QCD corrections to the partonic cross sections (unpolarised and polarized ones) are now also included into the analysis scheme since these higher order contributions are not negligible. The preliminary NLO QCD result on the gluon polarisation based on a set of measured D^0 meson asymmetries in kinematical bins of the D^0 energy and transverse momentum is presented.

1. Introduction

One of the goals of the COMPASS experiment is the direct measurement of the gluon polarisation, important for understanding the spin structure of the nucleon. The experiment is using a 160 GeV polarized muon beam from the SPS at CERN scattered off a polarized ^6LiD target [1]. In LO QCD approximation the only subprocess which probes gluons inside the nucleon is the Photon-Gluon Fusion process (PGF). There are two ways which allow to tag PGF events in the COMPASS experiment: open-charm production where events with reconstructed D^0 mesons (signal events) are used and the production of two hadrons with relatively high- p_T in the final state. The estimate of the gluon polarisation in the open-charm method is much less Monte-Carlo (MC) dependent than in the high- p_T hadron pair method, where the complicated background requires very good MC description of the data. On the other hand the statistical precision in high- p_T hadron pair method is much higher at COMPASS than in the open-charm production. Therefore, to increase statistical precision a weighted method has been used in the open-charm analysis published by COMPASS Collaboration [2, 3]. The estimate of the gluon polarisation from the asymmetry of the signal events requires the knowledge of the so-called analyzing power, a_{LL} , the ratio of polarisation dependent over polarisation averaged partonic level cross sections. In the weighted method a_{LL} as well as the signal strength have to be known on an event-by-event basis. Recently new D^0 decay channels have been included in the COMPASS charm analysis and a Neural Network approach for signal strength estimation has been used. The new, statistically improved result (comparing to the published one) on gluon polarisation is presented in section 2. The published and this new COMPASS result are obtained

using a_{LL} computed in LO QCD approximation. The resolved photon contribution has been verified to be unimportant in the kinematical domain covered by the COMPASS experiment. The so-called intrinsic charm mechanism has also been found to be non-important in the COMPASS kinematical domain (very small Bjorken x).

The NLO QCD corrections to polarisation dependent and polarisation averaged open-charm cross sections are supposed to be non-negligible in the COMPASS kinematical domain. Therefore the open-charm asymmetries in bins of p_T and of D^0 meson energy were also published to allow the use of the COMPASS data in independent analyses. These asymmetries are also weighted but the analyzing power (which is the only place where QCD calculations enter) is not included in the statistical weight. The details can be found in [2]. In the present paper the method of computing the analyzing power in a NLO QCD approximation is presented. The method is based on a LO QCD MC with Parton Shower (PS) switched on allowing to simulate the phase space for NLO processes. There is a part of NLO QCD corrections to muoproduction of open-charm originating from light quark processes, where the emitted gluons produce charm-anticharm quark pairs. These processes contribute to the background because they do not probe gluons inside the nucleon. This introduces a complication into the analysis because the signal defined in COMPASS as observed D^0 mesons is polluted by these higher order processes¹. The proposed method allows easily correct for these unwanted higher order processes contributing to the signal within the analysis scheme used at COMPASS. The paper is organized as follows: in the next section the new result obtained in LO analysis is discussed. The relation between measured asymmetries and the gluon polarisation in NLO QCD approximation is discussed in section 3. The Monte-Carlo approach and the parton shower concept as a phase space simulation tool for NLO QCD processes is discussed in section 4. The NLO QCD result for the gluon polarisation obtained by using the COMPASS published D^0 meson production asymmetries is presented in section 5. A short summary is presented in section 6.

2. New COMPASS result on the gluon polarisation in LO QCD approximation

The main problem in the COMPASS charm analysis is a reduction of the huge combinatorial background that mask the PGF signal, centered on the D^0 mass. To reduce the combinatorial background the COMPASS RICH detector is used to identify Kaons and Pions from the D^0 meson decay. Kinematic cuts are applied on the fraction of virtual photon energy carried by the D^0 : $0.2 < z_{D^0} < 0.85$ and on the angle of the Kaon from the D^0 meson decay in the D^0 center-of-mass, $|\cos(\theta^*)| < 0.65$. The cuts are also important to reduce the contamination from D^0 mesons coming from the struck light quark fragmentation. The combinatorial background can be further removed by studying the so-called D^0 tagged with D^* channel: $D^* \rightarrow D^0 \pi_{slow}$ and $D^0 \rightarrow K\pi$. Recently the additional three low purity D^0 decay channels were included in the analysis: $D^0 \rightarrow K\pi\pi^0$, $D^0 \rightarrow K\pi\pi\pi$ and $D^0 \rightarrow K_{sub}\pi$. The last channel corresponds to candidates without RICH identification for the Kaons (sub-threshold candidates with $p(K) < 9\text{GeV}/c$). The final charm sample used in the presented analysis contains the full deuteron (2002-2006 years of data taking) and proton data (2007). More details of the event selection can be found in [2, 4]. The measured asymmetry is related to the gluon polarisation as follows:

$$A^{exp} = P_b P_t f \frac{S}{S+B} A^{signal} + A^{bgd}, \quad (1)$$

where P_b, P_t and f are the incoming muon polarisation, the target polarisation and the dilution factor, respectively. A combinatorial background asymmetry, A^{bgd} , is extracted together with the signal one, A^{signal} (asymmetry for reconstructed D^0 mesons). $S/(S+B)$ is the signal strength and the asymmetry A^{signal} is directly related to the gluon polarisation $\Delta g/g$, integrated over the

¹ Notice that background taken into account in the COMPASS analysis is a combinatorial background; see also [3]

kinematically accessible region by the COMPASS measurement: $A^{signal} = \langle a_{LL} \rangle \langle \Delta g/g \rangle$. In the weighted method, where a_{LL} is included in the statistical weight, and in LO QCD approximation the extracted signal asymmetry is simply equal to $\langle \Delta g/g \rangle$. The weighted method used in the analysis [3] minimizes the statistical error: $w_S = P_b f a_{LL} \frac{S}{S+B}$ and $w_B = P_b f D \frac{B}{S+B}$ were used as a signal and background weights, where D is a depolarisation factor representing the polarisation transfer from muon to virtual photon. A new method based on a Neural Network approach [5] was used to parameterize the signal strength $S/(S+B)$. Two real data samples were used to as an input to the Neural Network: the so-called good charge combination of the D^0 decay particles sample, a reference to the Pion's charge (gcc, containing signal and background events) and the wrong charge combination particles (wcc) where a wrong charge Pion is selected and which contains only background events. The Neural Network performed a multidimensional comparison between the relevant kinematic variables from both data samples (gcc and wcc), and it was able to distinguish the signal events out from the combinatorial background (inside gcc sample). The method automatically takes into account all correlations between kinematic variables and can be used also for low purity channels, in contrast to the parameterization used in the previous COMPASS analysis [2]. Finally a_{LL} was parameterized with the help on the Neural Network in the same way as it was done in [2].

The new gluon polarisation value, extracted from the measured D^0 meson production asymmetry was found to be $\Delta g/g = -0.08 \pm 0.21 \pm 0.11$ at $\mu^2 \simeq 13(\text{GeV}/c)^2$ and $\langle x_g \rangle \simeq 0.11$. The systematic error is taken conservatively from the previous published analysis. The background asymmetry is compatible with 0.

3. NLO QCD corrections and asymmetry decomposition

In LO QCD approximation PGF is the only process which contributes to the open-charm production. Moreover for the energy range covered by the COMPASS experiment the QCD evolution does not produce a significant fraction of charm sea inside the nucleon so that only the hard part of the cross section is responsible for open-charm production. As it was mentioned above the resolved photon contribution is negligible and intrinsic charm content inside nucleon is also suppressed. It is known that the unpolarised cross section is not precisely described by the LO QCD approximation and NLO QCD corrections are important for the photoproduction of the open-charm [6]. Also the polarisation dependent cross section shows the non-negligible dependence on the QCD approximation used [7]. It was argued that the naive expectation that NLO QCD corrections can be factorized and cancel out at the level of asymmetry is not true. The analyzing power a_{LL} in the NLO QCD approximation is modified taking into account virtual and soft corrections as well as real emission processes (where an extra gluon is emitted in the hard process) in the corresponding polarisation dependent and polarisation averaged partonic cross sections. To guarantee the proper cancellation of the infrared and the soft parts of the cross section the virtual, soft and the real corrections should be added together to obtain the so-called reduced cross section, free of any divergences [6]. In the NLO QCD approach the relation between A^{signal} and the gluon polarisation is modified compared to the LO approach: $A^{signal} = \langle a_{LL} \rangle \langle \Delta g/g \rangle + A^{corr}$, where A^{corr} is the contribution from the light quark NLO processes, mentioned in section 1. This correction has to be subtracted from the measured signal asymmetry at the end while the signal asymmetry extraction procedure from data is the same as in LO approximation. The COMPASS experiment is using a polarized muon beam thus the virtuality of the photon, Q^2 , will never reach the photoproduction limit, where the NLO calculations are available. The average value of Q^2 from charm data sample is $\langle Q^2 \rangle \simeq 0.6(\text{GeV}/c)^2$, and therefore the calculation of a_{LL} in the photoproduction limit is a very good approximation and can be safely used in the COMPASS analysis. The collection of the formulae for polarisation dependent and unpolarised cross sections for the finite Q^2 for the PGF process in the LO QCD approximation can be found in [8]. The NLO QCD corrections for

the $Q^2 = 0$ photoproduction regime are partially listed in [6, 7] while the missing, finite parts are available on request [9]. To compute the analyzing power a_{LL} on an event-by-event basis the knowledge of the kinematics at the parton level is needed. The measurement does not allow to reconstruct kinematical variables at the partonic level as only one produced charmed D^0 meson is reconstructed in each event at COMPASS. Therefore the exact kinematics of the event has to be simulated with the help of Monte-Carlo techniques.²

4. Monte-Carlo approach

As the COMPASS analysis was performed in the LO QCD approximation the LO MC generator AROMA was used to calculate the analyzing power a_{LL} . The COMPASS apparatus was simulated using the GEANT package and produced output was in the form of the real data. The COMPASS reconstruction program was used to reconstruct the simulated events. This procedure allows to take into account all effects related to the real data taking and the simulated event sample after application of all selection criteria [2] were used to compute a_{LL} on an event-by-event basis. The LO QCD approach in the MC is not able to reproduce correctly kinematics of the NLO QCD events unless the parton showers are switched on in the generation. The PS concept has been developed to improve the real data description by the MC and allows to simulate multi-gluon emission. The energy of all gluons emitted in the PS in the event can be considered as a limit of the integration over unobserved gluons associated with the NLO QCD hard, real corrections to the PGF process and to the light quark contribution, A^{corr} . This procedure allows to calculate polarisation dependent and unpolarised cross sections in the LO and the NLO QCD approximation using MC kinematics of the event and theoretical formulae for partonic cross sections from [6, 7]. The calculation of the analyzing power is then straightforward. There is a problem, however, related to the method used: the PS concept is not equivalent to the MC in the NLO QCD approximation. There is still a big discussion how to use LO MC with PS to simulate effectively NLO processes but the subject is difficult and the satisfactory solutions exist only in some cases [10]. Recently a full NLO MC tool for heavy flavour photoproduction, based on HERWIG MC generator has been developed [11]. This NLO MC will be used for a crosscheck of the calculations presented in this paper.

5. Result for the gluon polarisation in the NLO QCD approximation

The gluon polarisation value in NLO QCD approximation, presented here was computed from the published asymmetries by the COMPASS Collaboration. Asymmetries published in [2] are weighted by the weight composed of depolarisation factor and the signal strength $S/(S+B)$. To obtain the gluon polarisation from these asymmetries the analyzing power were calculated in the same kinematical bins in energy and p_T of D^0 mesons as used in the asymmetries determination. To validate the method the gluon polarisation in the LO QCD approximation (AROMA MC generator with PS switched off, COMPASS published asymmetries) was found to be $\Delta G/G = -0.47 \pm 0.23$ in very good agreement with fully weighted COMPASS published result: $\Delta G/G = -0.49 \pm 0.27$. The statistical precision is artificially higher than in the published result because the MC generated pure signal events were used to obtain a_{LL} in the asymmetry kinematical bins. In the fully weighted method a_{LL} obtained from the MC events were parameterized by the Neural Network and this parameterization was used to obtain a_{LL} from the real data. This procedure reduces the MC dependence of the analysis but it increases the statistical error.. The gluon polarisation result obtained in the NLO QCD approximation is: $\Delta G/G = 0.008 \pm 0.25$. It is worth to notice that $\langle x_g \rangle$ at which the gluon polarisation is

² In the ideal case where two charmed particles produced in the final states are reconstructed the LO QCD PGF process could be calculated using measured kinematics of charmed mesons. If unobserved gluons are radiated (NLO QCD corrections to PGF) the kinematics on the partonic level cannot be reconstructed from the heavy system.

probed is dependent on a_{LL} and as a consequence on the QCD approximation. The $\langle x_g \rangle$ for the gluon polarisation estimated in the NLO QCD approximation is above 0.22 while in the LO approximation it is about 0.1. The systematic error for NLO gluon polarisation determination is not yet estimated and therefore only statistical precision is shown here. The new LO QCD result, presented in section 2 corresponds to smaller values of the asymmetries than those ones in the published paper [2]. As $\langle \Delta g/g \rangle$ is proportional to the measured asymmetries the difference between new LO and NLO gluon polarisation determination is expected to be smaller than observed in the case of the published LO result and asymmetries (the NLO light quark correction, A^{corr} , is very small and does not play an important role). The new NLO result is expected as soon as the new set of asymmetries for the open-charm D^0 meson production will be available from the COMPASS Collaboration.

6. Summary

The new result for the gluon polarisation from open-charm D^0 meson production in the LO QCD approximation has been presented. The new value is closer to zero than the previously published result and the statistical error is reduced thanks to the new data samples from low purity D^0 decay channels and due to 2007 proton data included into the analysis. A new method of the signal strength parameterization based on Neural Network approach has been used. The preliminary NLO gluon polarisation result, based on the published asymmetries in the kinematical bins in energy and p_T of D^0 mesons, has been estimated. This NLO result should be compared with the published LO gluon polarisation result (corresponding to the published asymmetries) and the effect of the NLO correction to the analyzing power drives this gluon polarisation value closer to 0. As the new LO result on the gluon polarisation corresponds to smaller values of the asymmetries the influence of the NLO corrections will be smaller in the case of the new analysis. In the light of the obtained results a small value of $\langle \Delta g/g \rangle$ is favored. The results are in a very good agreement with the high- p_T results measured by SMC, HERMES and COMPASS experiments (see e.g. [12]). It is worth to note that the averaged, weighted $\langle x_g \rangle$ is significantly higher for NLO analysis than for LO result. It suggests that also for larger momentum fraction at which gluons are probed the polarisation is close to zero.

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References

- [1] P. Abbon et al., *Nucl. Instr. Meth. A* **577** (2007) 455.
- [2] M. Alekseev et al., *Phys. Lett. B* **676** (2009) 31.
- [3] J. Pretz and J-M Le Goff, *Nucl. Instr. Meth. A* **602** (2009) 594.
- [4] C. Franco, *PoS DIS 2010* 225.
- [5] R. Sulej et al., *Meas. Sci. Tech.* **18** (2007) 2486.
- [6] W. Beenakker, H. Kuijf, W.L. Neerven, J. Smith, *Phys. Rev. D* **40** (1989) 54, J. Smith, W.L. Neerven, *Nucl. Phys. B* **374** (1992) 36.
- [7] I. Bojak and M. Stratmann, *Phys. Lett. B* **433** (1998) 411, *Nucl. Phys. B* **540** (1999) 345, I. Bojak, *PhD thesis*.
- [8] S. Bravar, K. Kurek and R. Windmolders, *Comp. Phys. Comm.* **105** (1997) 42.
- [9] M. Stratmann, private communications.
- [10] D. de Florian, P. Nadolsky, V. Vogelsang, *Berkeley Summer Program on Nucleon Spin Physics* June 1-12, 2009, Private communications. S. Frixione, B.R. Webber, *Cavendish-HEP-08/14*, P. Nason, *hep-ph/0409146v1*.
- [11] T. Toll, *PhD thesis*, <http://www-h1.desy.de/psfiles/theses/h1th-519.pdf>.
- [12] L. Silva, *This proceedings*