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

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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, the open-charm D0 meson production is the cleanest channel for the gluon polarisation estimation. The gluon polarisation was estimated through the relation between the measured asymmetry for charmed mesons and the analyzing power (asymmetry at the partonic level) from the photon-gluon fusion process, corresponds to a LO QCD approximation. The significant improvement of the statistical precision is also reported in this conference by COMPASS. The NLO QCD corrections to the partonic cross sections (unpolarized and polarized) should be included in the analysis since these higher order contributions are considered to be non-negligible in COMPASS kinematical domain. The treatment of the data in NLO QCD approximation in the COMPASS open-charm analysis is presented. The NLO QCD prediction for the gluon polarisation based on asymmetries for D^0 meson production published by COMPASS, is discussed.

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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 a SPS at CERN scattered off a polarized ^{6}LiD target [1].

In LO QCD approximation the only subprocess which probes gluons inside the nucleon is a 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 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 channel is much less Monte-Carlo (MC) dependent than in the two high-p_T hadrons method, where the complicated background requires very good MC description of the data. On the other hand the statistical precision in high-p_T hadrons method is much higher at COMPASS than in the open charm channel. To increase statistical precision a weighted method has been used in the open-charm analysis, published by COMPASS Collaboration [2, 3].

The analysis has been performed in LO QCD approximation. The resolved photon contribution has been checked to be unimportant in the kinematical domain covered by the COMPASS experiment. The so-called intrinsic charm mechanism has also be found to be non-important in the COMPASS kinematical domain (very small Bjorken x). The estimatie of the gluon polarisation as well as a construction of the statistical weight used in the analysis requires the knowledge of the analyzing power, a_{LL}, the ratio of polarized over unpolarized partonic cross sections and of the signal strength on an event-by-event basis. The analyzing power is calculated in the LO QCD approximation and as a signal identified D^0 mesons (reconstructed from its decays) are used. Recently new open-charm channels have been included in the COMPASS analysis and statistically improved result on gluon polarisation is discussed in this conference [4].

The published and newly presented COMPASS result is obtained in LO QCD approximation while NLO QCD corrections to unpolarized and polarized cross sections are supposed to be non-negligible in the COMPASS kinematical domain. To allow the use of the COMPASS data in independent analyses the open-charm asymmetries in bins in p_T and energy of D^0 meson was published. The asymmetries were weighted but analyzing power (which is the only place where QCD calculations are used) was not included in the weight. The details can be found in COMPASS paper [2].

In this paper the method of computing the analyzing power on an event-by-event basis 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. The proposed approach can be easily applied in the COMPASS analysis scheme, also in the weighted method. There is a part of NLO QCD corrections to muoproduction of open-charm from light quark originating processes, where emitted gluons produce charm-anticharm quark pairs. These processes contribute to the background because they do not probe gluons inside the nucleon. It introduces a complication into the analysis because the signal defined in COMPASS as an observed D^0 meson is polluted by these higher order processes [1]. The proposed method allows to easily correct for these unwanted higher order processes contributing to the signal within the analysis scheme used at COMPASS.

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

The paper is organized as follows: in the next section the relation between measured asymmetries and the gluon polarisation in NLO QCD approximation is discussed. The Monte-Carlo approach with parton shower concept as a phase space simulation tool for NLO QCD processes is presented in section 3. The NLO QCD result for the gluon polarisation obtained by using published D^0 meson asymmetries is presented in section 4.

2. 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 nucleon so the only 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 unpolarized cross section (averaged over spin states) is not precisely described by the LO QCD approximation and NLO QCD corrections are important for the photoproduction of the open-charm [5]. Also the spin-dependent (polarized) cross section shows the important dependence on the QCD approximation used [6]. It was also argued that the naive expectation that NLO QCD corrections can be factorized and cancel out on the level of asymmetry is not true.
The place where the QCD approximation is used is the analyzing power calculation, a_{LL}. The measured asymmetry is related to the gluon polarisation as follows:

$$A^{exp} = P_b P_t f a_{LL} \frac{S}{S+B} A^{signal} + A^{bgd} \tag{2.1}$$

where P_b, P_t and f are beam polarisation, target polarisation and dilution factor, respectively. A combinatorial background asymmetry, A^{bgd}, is extracted together with the signal (reconstructed D^0 mesons). $S/(S+B)$ is a signal purity and A^{signal} is related directly to the gluon polarization $\Delta g/g$, integrated over kinematically accessible region by COMPASS measurement. In the LO QCD approximation and fully weighted method, where a_{LL} is included in the weight, $A^{signal} =< \Delta g/g >$; in the case of published asymmetries (a_{LL} not included in the weight) $A^{signal} =< a_{LL} >< \Delta g/g >$. In the NLO QCD approach there is an extra correction term in the relation between A^{signal} and the gluon polarisation:

$$A^{signal} =< a_{LL} >< \Delta g/g > + A^{corr} \tag{2.2}$$

where A^{corr} is a contribution from the light quark higher order processes, discussed in section 1. The analyzing power a_{LL} in the NLO QCD approximation is also modified, taking into account virtual and soft corrections and real emission processes with an extra gluons emitted (two into three particle kinematics). To guarantee the proper cancellation of the infrared and the soft parts the virtual and the real corrections should be added together (after integration over the unobserved gluon in the final state) to obtain the so-called reduced cross section, free of any divergences [5]. COMPASS is using a polarized muon beam thus the virtuality of the photon, Q^2, will never reach the photoproduction limit. The smallest value of Q^2 allowed by kinematics is proportional to the muon mass. Nevertheless the calculation of a_{LL} in the photoproduction limit is a very good approximation and can be used in the COMPASS analysis. The collection of the formulae for polarized and unpolarized cross sections for the finite Q^2 for PGF process in the LO QCD approximation can be found in [7]. The NLO QCD corrections are partially listed in [5, 6] while the missing, finite parts are available on request [8]. To compute the analyzing power a_{LL} on an event-by-event basis the knowledge of the kinematics on of the parton level is needed. The measurement does not allow to reconstruct kinematical variables on the partonic level as only one produced, charmed D^0 meson is reconstructed in the event at COMPASS. Therefore the exact kinematics of the event has to be simulated with the help of Monte-Carlo techniques.[2]

3. Monte-Carlo approach

As the COMPASS analysis is performed in the LO QCD approximation the LO MC generator AROMA is used to calculate the analyzing power a_{LL}. The COMPASS apparatus is simulated using the GEANT package and produces output is in the form of the real data. Finally the COMPASS reconstruction program is 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] are used to compute the 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 gluon associated with the NLO QCD real corrections to the PGF process and to the light quark contribution, A^{corr} . This procedure allows to calculate polarized and unpolarized cross sections in the LO and the NLO QCD approximation. 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 [9]. To test the correctness of the proposed method based on the LO MC with PS the kinematics of the events with real gluon emission has been generated again using uniformly distributed kinematical variables and then the events were re-weighted by the cross section correctly calculated in the NLO QCD approximation (re-weighted MC method). The re-weighted MC approach cannot be used in the COMPASS analysis scheme because the detector description cannot be included into the simulation but results obtained with AROMA generator and PS and with using the re-weighted MC approach are practically identical justifying the approach based on the PS concept.

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

The gluon polarisation value presented in this paper is computed from the published asymmetries by the COMPASS Collaboration. Asymmetries published in [2] are weighted by the weight

[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.

composed of depolarisation factor and the signal strength $(S/(S+B))$. In the calculations presented here the signal strength is assumed to be one because the MC reproduces signal onlyl (only open charm events are generated). In the re-weighted simple MC simulation, discussed in the previous section, the Peterson fragmentation function fitted to data from BELLE Collaboration was used [10] while for AROMA generation JETSET fragmentation was applied. 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 gluon polarisation result obtained in the NLO QCD approximation is: $\Delta G/G = 0.008 \pm 0.25$ and - to justify the PS concept approach - it is compared with the re-weighted MC result:
$\Delta G/G = 0.005 \pm 0.22$. The good agreement suggests that the result does not strongly dependent on the charm quark fragmentation mechanism. It is worth to notice that $< x_g >$ at which the gluon polarisation is probed is dependent on a_{LL} and as a consequence on the QCD approximation. The $< x_g >$ for the gluon polarisation estimated in the NLO QCD approximation is above 0.22 while in the LO approximation - above 0.1. The NLO QCD gluon polarisation result is much closer to zero comparing to the LO one.

The new LO QCD result, presented in this conference [4] shows much smaller value of asymmetries and in a consequence $< \Delta g/g >$ than in the published paper. As $< \Delta g/g >$ is proportional to the measured asymmetries (the light quark correction in the NLO QCD, A^{corr}, is very small) the effect of the NLO QCD corrections in the a_{LL} for the gluon polarisation estimation is expected to be smaller than presented here and closer to the LO result. The new NLO result is expected as soon as a new set of asymmetries for the open-charm D^0 meson production will be available from the COMPASS Collaboration.

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