$\Delta G(x)$ from high p_t hadrons in DIS at a polarised HERA

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Abstract

We investigate the possibility to identify photon-gluon fusion (PGF) events in polarised deep inelastic ep scattering, assuming the kinematics of the HERA collider, by a pair of charged high p_t particles. In a Monte Carlo study we find possible selection criteria and show the expected measurable asymmetries. We discuss the sensitivity to $\Delta G(x)$ and compare the result to the one obtained using di-jets to tag PGF events.

1 Introduction

The extraction of the polarized gluon density ΔG is one of the future key measurements in polarized physics. For the polarized HERA collider several methods have been proposed to measure ΔG [1], the most promising one being the measurement of the di-jet asymmetry in deep inelastic scattering events [2]. In this paper we present a new method to access the polarized gluon density at HERA, using two charged particles with high transverse momentum p_t, instead of jets. This analysis follows closely the one proposed for the COMPASS [3] experiment at CERN, detailed in ref. [4]. The technique to extract the (unpolarized) gluon density from high p_t hadrons has already been successfully applied at HERA, albeit based on one single high momentum charged track and for photoproduction data [5].

The method is very similar to the one using di-jet events to extract ΔG. The aim is to isolate subprocesses which are sensitive to the gluon at the Born level. Fig. 1 shows that this is the case for the Leading Order (LO) photon gluon fusion process (PGF). In case of high partonic p_t the two quarks will emerge as observable jets. These jets can be detected either calorimetrically, as exploited in [2] or can be tagged via particles with high transverse momentum in the $\gamma^* p$ centre of mass system (CMS), as studied here. The present experiments at the HERA collider are equipped with excellent tracking detectors in the photon fragmentation and central region, where most of the jets are expected. Hence we will use charged particles (tracks) for the high p_t hadrons to tag the PGF process.

In this exploratory study for HERA we are guided by the analysis of the di-jet events, and impose similar criteria to select the PGF process. Since in LO the two partons are produced with opposite p_t, two charged hadrons with approximately opposite azimuthal angles ϕ in the $\gamma^* p$ CMS will be required. The background in LO results mainly from the QCD-Compton process (QCDC), see Fig. 1. For events with no hard QCD matrix element, namely 'quark parton

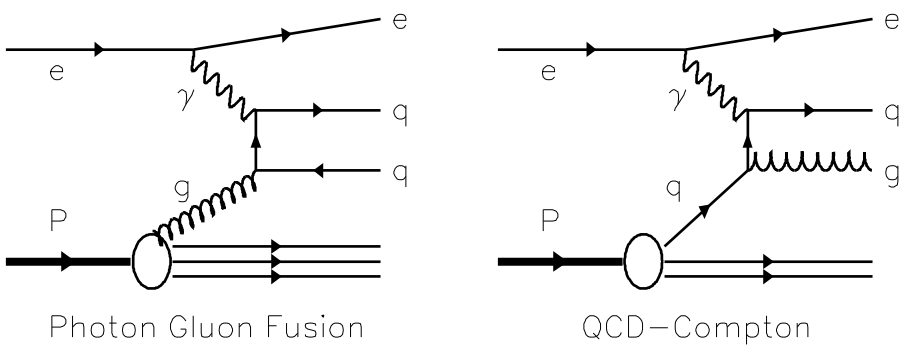

Figure 1: Feynman diagrams for the di-jet cross sections at LO, the Photon-Gluon Fusion (PGF) process (left) and the QCD-Compton process (QCDC) (right).

model (QPM)' events, the p_t of the hadrons only comes from fragmentation and intrinsic k_t of the partons in the proton. Hence this background is expected to be strongly suppressed if two particles with a p_t above 1-2 GeV are required.

We make a full Monte Carlo simulation of the signal and background processes, include hadronization and higher order effects via parton showers. Starting from three different sets of polarised gluon distributions, shown in Fig. 2, we check the sensitivity of the measurements and extract $\Delta G(x)$. These distributions are the Gehrmann-Stirling (GS) sets A and C [6], which result from a QCD analysis of g_1 data, and the instanton-gluon distribution [7]. The latter results from a calculation of the polarised parton distribution in the Instanton Liquid Model [8]. The distributions differ substantially and are purposely selected to demonstrate how poorly $\Delta G(x)$ is constrained by the present polarised data. For the unpolarised parton density functions the parametrizations of Glück, Reya and Vogt in LO were used [9].

2 Analysis method and expected asymmetries

To estimate the sensitivity of high-p_t track events to ΔG a study very similar to the one using di-jet events [2] was performed. The Monte Carlo program PEPSI 6.5 [10, 11] was used and the kinematic range in Q^2 and y was taken to be: $5 < Q^2 < 100$ GeV^2 and $0.3 < y < 0.85$. PEPSI includes, apart from the polarized cross sections at LO, hadronization and (unpolarized) parton showers for higher order effects. The $z - s$ scheme was used to regulate the divergencies of the matrix elements [12, 13].

For this analysis the acceptance of the H1 detector [14] is assumed. Tracks are detected in either the forward or central tracking chambers. The acceptance for tracks in pseudorapidity η in the laboratory frame amounts to the range: $-1.5 < \eta < 2.5$. Events were selected if two tracks were found inside this η-range each with a $p_t > 1.5$ GeV. The difference in the azimuthal

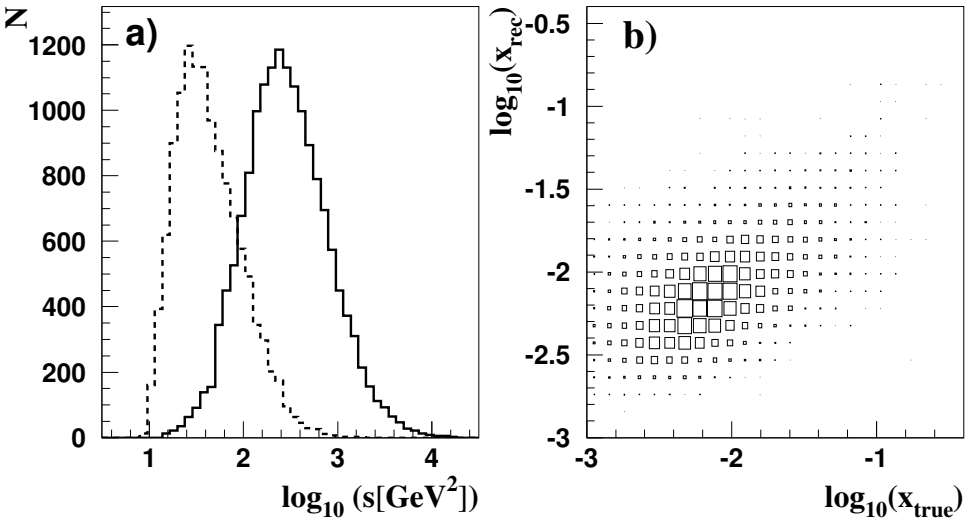

Figure 2: a) The true s_{ij} distribution of the selected events (full line) and the s_{ij} reconstructed from the two tracks (dashed line). b) The reconstructed x_g of high p_t track events versus the true x_g of the event. For the reconstructed x_g a p_t-dependent correction has been applied (see text).

angle ϕ between the two tracks should be within $180 \pm 60°$ and the difference in pseudorapidity should be $|\eta_{track1} - \eta_{track2}| < 2$. In case the two highest p_t tracks of the event do not fulfil these criteria, it was checked whether a third track with $p_t > 1.5$ GeV was present, which does fit the criteria. In the following the convention will be that for the two selected tracks with $p_t(1)$ and $p_t(2)$ we have: $p_t(1) > p_t(2)$. With these cuts and the parton distributions as given above the selected sample contains about 85% PGF events and 15% QCDC events. The QPM background is less than a percent. Events samples with a higher p_t cutoff were studied as well, but the gain in purity and kinematic variable reconstruction (see below) was outweighted by the loss in statistics.

A difference compared to the di-jet analysis is the reconstruction of the kinematics of the events. In the di-jet case an attempt is made to reconstruct the kinematics of the original parton. Thus, the invariant mass squared of the two jets is close to and well correlated with the true invariant mass of the hard subprocess. Here, where only two tracks opposite in azimuth are considered, the invariant mass squared $s_{ij}^{rec} = (P_1 + P_2)^2$, with $P_{1(2)}$ being the four-momentum of track 1(2), is always much smaller than the true value of s_{ij}. This is shown in Fig. 2a. There is an offset between true and reconstructed s_{ij}, but they are correlated. The correlation for $x_g = x(1 + s_{ij}/Q^2)$ reconstructed from the tracks and the true value is shown in Fig. 2b. Here x is the Bjorken-x variable, and x_g is the momentum fraction of the proton carried by the gluon for the PGF process. The offset observed in Fig. 2a due to the incomplete s_{ij} reconstruction is already corrected for in Fig. 2b. This was done by comparing the ratio of true x_g and x_g^{rec} in bins of $p_t(2)$. A polynominal was fitted to $\log_{10}(x_g^{rec})/\log_{10}(x_g) = a_2 p_t^2(2) + a_1 p_t(2) + a_0$ and the right side of this expression was used as a multiplicative correction factor to x_g^{rec}. The coefficients used were: $a_0 = 0.855, a_1 = -0.052, a_2 = 0.0018$. Values of x_g^{rec} presented in this paper are always corrected with this factor. It can be seen that the correlation is already rather good with

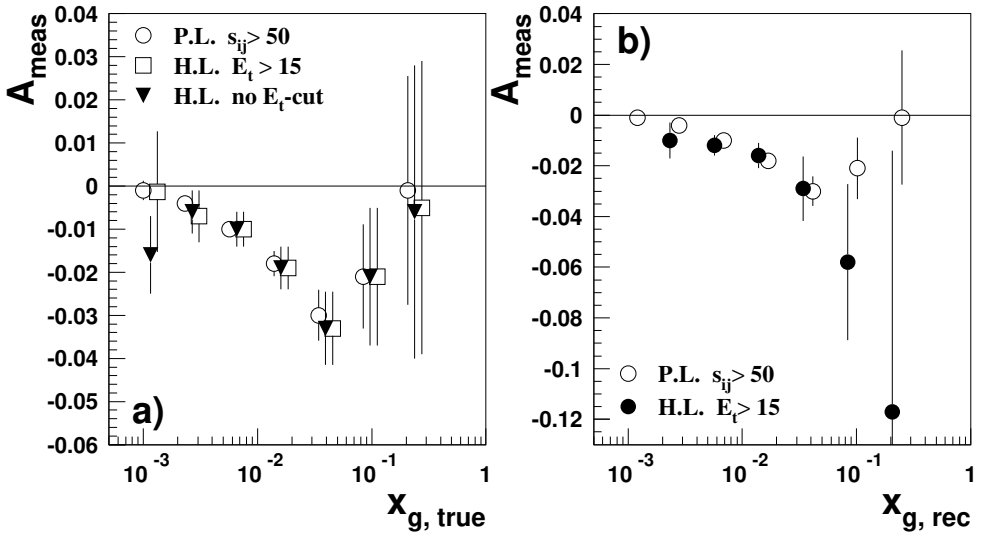

Figure 3: a) Measured asymmetries for high-p_t track events, as a function of the true x_g. Asymmetries on the parton level (P.L.) are compared with the hadron level (H.L.) for different selection cuts. b) The measured asymmetry on hadron level versus the reconstructed x_g. For comparison the same parton level points of a) are shown again. The assumed luminosity is 200 pb^{-1}.

this simple correction factor. A more sophisticated analysis, e.g. using a real unfolding method, where bin-to-bin correlations are fully taken into account, can be performed when real data have been collected, and even better results can be expected.

With the cuts detailed and used so far, the sample contains still a considerable amount, about 23%, of events with $s_{ij} < 100$ GeV^2 for which NLO corrections could be potentially large (based on the experience with the di-jets). An additional criterium is used to reduce this fraction. One possibility is to increase the p_t-requirement for the tracks. Raising it from 1.5 GeV to 2 GeV decreases the fraction of events with $s_{ij} < 100$ GeV^2 to about 10%, but the total number of events is decreased by more than 40%. A better possibility seems to be to check the total transverse energy ΣE_t deposited in the calorimeter (i.e. with $|\eta| < 2.8$ in the laboratory frame) for the event. Requiring $\Sigma E_t > 15$ GeV reduces the fraction of low-s_{ij} events to about 10%, but removes only about 25% of the total statistics. For $\Sigma E_t > 20$ GeV a reduction of low-s_{ij} events to 5% can be obtained, while keeping 55% of the original statistics. The latter number is comparable to the result with the cut of $p_t > 2$ GeV. We decide here for a cut on $\Sigma E_t > 15$ GeV as a reasonable compromise between statistics and low-s_{ij} contamination.

The final event sample contains about 80,000 events/100 pb^{-1}. The measurable asymmetries A_{meas} for the final event sample are shown in Fig. 3. A_{meas} is defined as in [2]:

$$A_{meas} = \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}} = P_e P_p D A_{2tracks} \tag{1}$$

The quantities $N^{\uparrow\downarrow}$ ($N^{\uparrow\uparrow}$) are the total number of observed events with two high p_t tracks ($N^{\uparrow\downarrow} = N^{\uparrow\downarrow}_{PGF} + N^{\uparrow\downarrow}_{QCDC}$) with proton and electron spin antiparallel (parallel) to each other. $A_{2tracks}$ is the true physical asymmetry and on parton level the same as $A_{di\text{-}jet}$ of ref. [2]. The depolarisation factor D is given by $D = (y(2-y))/(y^2 + 2(1-y)(1+R))$, where R is the ratio of longitudinal to transverse $\gamma^* p$ cross section.

Figure 3a shows the asymmetries plotted versus the true x_g of the event. The error bars correspond to an integrated luminosity of 200 pb^{-1}. The assumed polarised gluon distribution is gluon set A of Gehrmann and Stirling [6]. Compared are the asymmetries on hadron level with and without the cut of $\Sigma E_t > 15$ GeV. The asymmetries are not changing significantly and the statistical errors for the low x_g bins are slightly increased after the cut has been applied. Both asymmetries can also be compared to the asymmetry expected on parton level, where only kinematical selection cuts were applied plus a cut on the true $s_{ij} > 50$ GeV^2. The asymmetries on parton and hadron level agree very well, the statistical errors however increase when applying the selection on hadron level. In order to check that the asymmetry that can be related to ΔG we show in Fig. 3b the asymmetry plotted as a function of the reconstructed x_g. The parton level asymmetry is exactly the same as in a), i.e. plotted versus the true x_g. Hence, also for reconstructed quantities an asymmetry is observed, not too different in size from the one at the parton level.

The QCDC background is less than 15% in all bins except the two highest x_g bins where, with increasing x_g, the background increases to 30% and 50% respectively. The $\Delta q/q$ distributions are however expected to be known with a precision of better than 10% at the time of this measurement, and can be subtracted. The background in the high x_g region could be also further suppressed selecting hadrons with opposite charge or with strangeness, as demonstrated in [4].

3 Extraction of ΔG

The study of the extraction of $\Delta G/G$ and $x\Delta G$ follows very closely the procedure described in [2]. We simulate 350 pb^{-1} of events with GS-A as input gluon density. This would in a real measurement correspond to the Monte Carlo generation of events and will therefore be called the 'MC-set' here. Assuming that for each x-bin $\Delta G/G$ and the background corrected asymmetry A_{corr} are related to each other by a simple factor F_i:

$$\left(\frac{\Delta G}{G}\right)_i = F_i \cdot A_{corr,\,i},$$

where i indicates the x-bin, we compute these factors using the MC-set. ($A_{corr} = \frac{N^{\uparrow\downarrow}_{PGF} - N^{\uparrow\uparrow}_{PGF}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}}$.) The factors F_i were then multiplied with the asymmetry A_{corr} which corresponds to the measured asymmetry on hadron level in Fig. 3b. Three 'data sets' are considered: the standard one based on gluon set A, and two additional samples with gluon set C [6] and the instanton induced gluon density [7] respectively. All of these data sets correspond to a luminosity of 200 pb^{-1}. They were used to compute the asymmetries which were then multiplied with the same factors F_i calculated with gluon set A. The results are shown in Figs. 4a - 4c. It can be seen here that within the statistical accuracy the input distributions (solid lines) $\Delta G/G$ are properly extracted in all cases. A discrimination between different polarised gluon sets is thus possible. Figures 4d - 4f show the same result presented for the theoretically more interesting quantity $x\Delta G$. The error bars are scaled errors of the left column, i.e. no uncertainty was assigned to G which is expected to be known to better than 5% at the time of this measurement [15].

The polarised gluon distributions used for the three data samples (see Fig. 4) differ substantially but are all compatible with the present polarized data, stressing the need for direct measurements of $\Delta G(x)$. The GS-A and GS-C distribution show a similar small x behaviour, but differ considerably in the region around $x \sim 0.1$. The GS-C distribution is negative for this

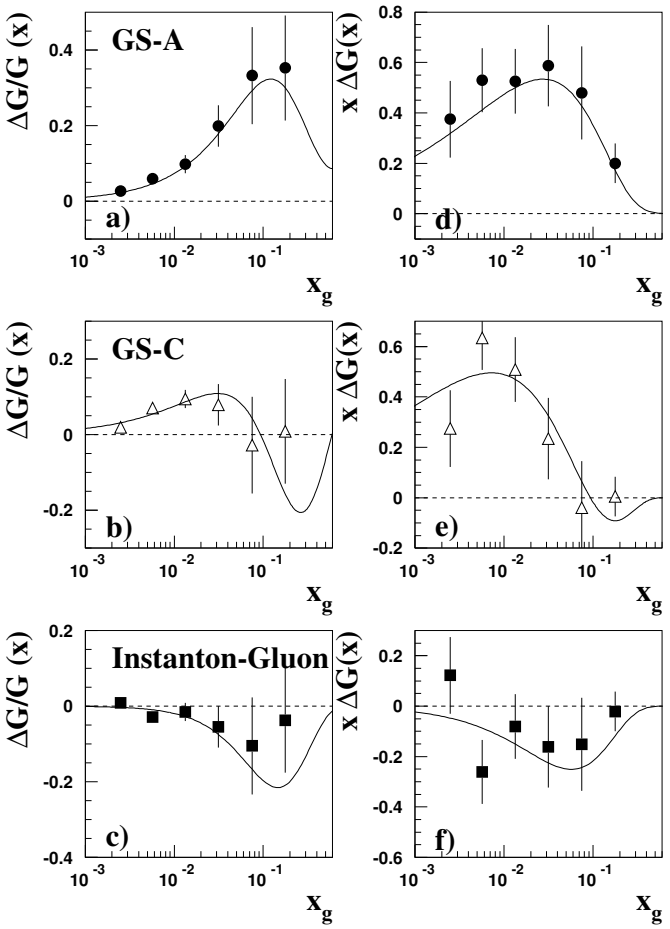

Figure 4: For a luminosity of 200 pb^{-1} the sensitivity to extract $\Delta G/G$ (a-c) and $x\Delta G$ (d-f) is shown for different polarised gluon densities (see text).

x region. The instanton-gluon is quite different from the GS sets. It remains negative over the full x range. The latter gluon is used in combination with the GS-A quark distributions for the study in this paper.

The sensitivity to the shape of $\Delta G/G$ and $x\Delta G$ for an integrated luminosity of 500 pb^{-1} is shown in Fig. 5. The statistical errors for the x points are shown on the curves for $\Delta G/G$ (a-c) and $x\Delta G$ (d-f), showing the separation power of this measurement.

The statistics is similar to the case when di-jet event are selected [2], in fact overall the track sample contains about 15% more events than the di-jet sample. However the events are differently distributed in the x_g-bins. In this analysis we obtain more events at low x_g than in the di-jet case but less events at very high x_g. This is reflected in the statistical errors. The access to lower s_{ij} values allows to explore the extraction of the polarised gluon distribution at lower x_g values, compared to the di-jet method. Due to the presently as yet unknown higher order corrections for the small s_{ij} region, which could be potentially large, we have not pursued this further in this study. The rather big error in the highest x_g bin can probably reduced with a more sophisticated reconstruction method. With the simple correction method used in this analysis most events originating from this bin are smeared into the second high x_g bin.

Comparing the di-jet [2] and the 2-track sample event-by-event we find that about 40% of the 2-track events are also selected in the di-jet analysis. Thus a rather large fraction of the statistics is uncorrelated, i.e. we add statistically new and independent information to the di-jet

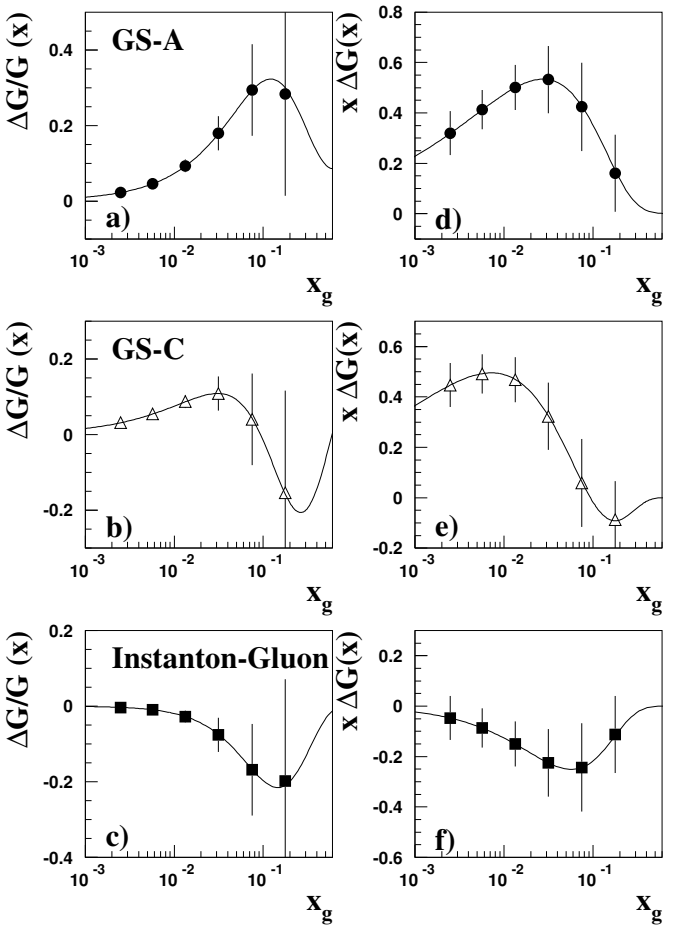

Figure 5: Sensitivity to $\Delta G/G$ (a-c) and $x\Delta G$ (d-f) for a luminosity of 500 pb^{-1}.

results. In addition the systematic errors for this measurement are partially different. This method is not sensitive to the calibration of the hadronic calorimeter and does not depend on a jet definition. One of the potentially most important systematics for this measurement is connected with the fragmentation functions. Therefore the analysis was repeated using the somewhat extreme independent fragmentation scheme instead of the LUND string fragmentation scheme [16] in PEPSI. The results were found to be in good agreement with each other, showing that the result is not too sensitive to details of these functions.

4 Conclusion

The use of two high p_t particles to extract the polarised gluon density at a polarised HERA has been studied. It has been found to have a similar potential to measure ΔG in the range $0.002 < x_g < 0.2$ as the di-jet measurement, with the additional possibility to reach even lower x_g values, if more sophisticated unfolding techniques can be used. At high x_g the precision of the di-jet method remains superior, though. Both methods are subject to different systematics and can therefore be considered as complementary.

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