$\Delta G$ from correlated high-$p_T$ hadron pairs in polarized $l-N$ scattering

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Abstract. We propose to access the gluon polarization $\Delta G$ by measuring the cross section spin-asymmetry in semi-inclusive polarized lepton–nucleon scattering. The photon-gluon fusion sub-process will be tagged by detecting high-$p_T$ correlated hadron pairs in the forward hemisphere. Selecting oppositely charged kaon pairs will allow to suppress the background coming from gluon radiation.

Polarized deep inelastic scattering (DIS) experiments have shown that the quark spins account for only a rather small fraction of the nucleon spin [1], thus implying an appreciable contribution either from gluon spins, or possibly from orbital angular momentum. Competing explanations exist for this result, in which the polarized glue $\Delta G$ or negatively polarized strange quarks $\Delta s$ lower the quark contribution to the nucleon spin. One way to solve this puzzle is to measure $\Delta G$ directly by studying, for example, polarized semi-inclusive processes, where the gluons enter in the initial state of the hard scattering sub-processes at lowest order in $\alpha_s$.

Favorable conditions to perform such studies are given, for example, in heavy flavor production which proceeds via photon-gluon fusion (PGF), and in the reaction, $\gamma^* + N \rightarrow 2$ high-$p_T$ jets $+ X$, which goes via PGF (Fig. 1c) with a non negligible background from gluon radiation (Fig. 1b). The latter would require the detection of two jets with large transverse momenta ($p_T (\text{jet}) > 5 \text{ GeV/c}$); at moderate energies of fixed target experiments the identification of jets is not well defined.

Alternatively to the direct jet reconstruction we propose to look for two correlated high-$p_T$ hadrons $h_1$ and $h_2$ in the forward hemisphere ($x_F > 0$) with $p_T(h_1) > p_{T,\text{min}}$ and $h_2$ opposite in azimuth to $h_1$ with $p_T(h_2) > p_{T,\text{min}}$. The measured cross section spin-asymmetry for $h_1 + h_2$ production can be related to the gluon polarization $\Delta G$. The idea is based on the observation that hadron transverse momentum spectra get significant contributions from the first order QCD diagrams already at relatively low values of $p_{T}$ ($p_T > 1 \text{ GeV/c}$) [2]. In events with an underlying $2 \rightarrow 2$ hard scattering QCD sub-process (Fig. 1b
FIGURE 1. Lowest order Feynman diagrams for DIS $\gamma^* N$ scattering: a) virtual photo-absorption, b) gluon radiation (Compton diagram), c) photon-gluon fusion (PGF).

$qg$-event and Fig. 1c $q\bar{q}$-event) the two outgoing partons will fragment to two high-$p_T$ hadrons with $x_F > 0$ and, on average, larger transverse momenta than hadrons produced in events with a leading order QED sub-process (Fig. 1a $q$-event). From the numerical analysis based on Monte Carlo studies a $p_{T,min} > 1.0 - 1.5$ GeV/$c$ is found to be sufficiently large to suppress almost completely the QED sub-process and to tag effectively the PGF process. A more detailed discussion will be presented elsewhere [3].

The parton distribution functions (PDF) are probed in $qg$- and $q\bar{q}$-events at a momentum fraction $\eta = (\hat{s}+Q^2)/2ME_{\gamma^*} = x_{Bj}(\hat{s}/Q^2+1)$, where $\hat{s}$ is the c.m. energy of the hard sub-process and $E_{\gamma^*}$ the energy of the virtual photon. In fixed target experiments the lepton energies are between $100 - 500$ GeV, which corresponds a c.m. energy of $\sqrt{\hat{s}} = 15 - 30$ GeV for the $\gamma^* - N$ system. To have reasonably large values of $\hat{s}$, one can probe the PDF only above $\eta \sim 0.05$ ($\langle \eta \rangle \sim 0.1$). As far as the spin of the nucleon is concerned, this appears to be the most interesting region, since the largest contribution to $\Delta G$ is expected to come from that region [4]. The proposed method will probe the PDF at a scale around $10$ GeV$^2$.

The following selection criteria are found to enhance the contributions of the $q\bar{q}$- and $qg$-events to the correlated hadron pair production cross section and to suppress almost completely the contribution of the $q$-events.

A – $p_T$ cut: There should be two hadrons in the event with $p_T > 1.0 - 1.5$ GeV/$c$. The $p_T$ cut will depend also on the final event yields and a higher $p_T$ cut is preferable.

B – $x_F$ cut: To avoid fragmentation effects from the target remnant only hadrons produced in the forward hemisphere ($x_F > 0$) should be considered. We also require $z > 0.1$ for each hadron.

C – $\Delta \phi$ cut: The two hadrons should be found opposite in azimuth, such that $150^\circ < \Delta \phi < 210^\circ$.

D – mass cut: To avoid the divergences in the QCD matrix elements in addition to the $p_T$ cut, we require the invariant mass of the hadron pair $m(h_1,h_2)$ to exceed 2 or 3 GeV/$c^2$ ($\hat{s} > m^2(h_1,h_2)$). A higher mass cut is preferable.

Two competing processes of the same order in $\alpha_s$ contribute to the cross section; however only the PGF is of interest for the extraction of $\Delta G$, while the
FIGURE 2. Contributions of different sub-processes to the cross section: (a) no cuts, (b) opposite charged hadron pairs, (c) opposite charged kaon pairs \((p_T > 1 \text{ GeV}/c \text{ and } m(h_1,h_2) > 3 \text{ GeV}/c^2)\). The dashed line shows the effect of the asymmetric \(x_F\) cut. The event yields are normalized to \(10^6\) generated events.

Compton diagram acts as a background. Around \(\eta \sim 0.1\) most of the Compton background comes from scattering off \(u\) quarks. The relative contribution of the PGF over the Compton diagram can be further enhanced from the following considerations.

**E – oppositely charged hadrons:** Fragmenting partons in \(q\bar{q}\)-events have opposite charges and favored fragmentation will lead to opposite charged hadrons in contrast to \(qg\)-events, where the gluon fragments with equal probability to positive and negative hadrons.

**F – \(K^+K^-\) pairs:** The production of strange hadrons in fragmentation is quite suppressed compared to non-strange hadrons, unless there is already an \(s\) quark in the initial state. This effect is parametrized with a strangeness suppression factor \(\gamma_s\), which presently ranges between 0.2 and 0.3. The production of a high \(p_T\) correlated kaon pair will be strongly suppressed, unless there is already a fragmenting \(s\bar{s}\) pair which can be produced via the PGF only.

**G – asymmetric \(x_F\) cut:** The Compton process in the partonic c.m. is peaked in the backward direction, while the PGF has a symmetric distribution. In the hadronic c.m. the first process will generate faster positive hadrons, because of the favored fragmentation of \(u\) quarks to positive hadrons. Thus by requiring additionally \(x_F^+ < x_F^-\) the relative contribution of the PGF can be further enhanced.

We have performed a numerical analysis in the kinematical conditions of the COMPASS experiment [5] with a 200 GeV/c \(\mu^+\) beam incident on a deuteron (iso-scalar) target and the following kinematical requirements: \(0.5 < y_{Bj} < 0.9\), \(W^2 > 200 \text{ GeV}^2/c^2\), and \(Q^2 > 1 \text{ GeV}^2\). A slightly modified version of the LEPTO [6] event generator has been used with the GRV94LO unpolarized parton densities.
FIGURE 3. left: Gluon $\eta$ spectra for $q\bar{q}$-events (dashed line) and quark $\eta$ spectra for $qg$-events (dotted line) for accepted high-$p_T$ hadron pairs. The full line is the sum of the two. right: Correlation between the generated and the reconstructed parton momentum fraction $\eta$.

Figures 2b and 2c show the relative suppression of the $q$-events for oppositely charged hadron and kaon pairs, respectively, with $p_T > 1.0$ GeV/$c$ and $m(h_1, h_2) > 3$ GeV/$c^2$ compared to Fig. 2a where no selections on the final hadronic state have been applied. The fraction of $q$-events in the selected samples is about $5\%$. Let’s define $R = \sigma^{PGF}/\sigma^{Compt}$; $R \gtrsim 1$ for the selected hadron pairs and $R \gtrsim 2$ for the kaon pairs. The reduction factor for the hadron pairs is $\sim 1.5 \times 10^{-3}$ and for the kaon pairs is $\sim 0.8 \times 10^{-4}$.

Including the photo-production $Q^2 \rightarrow 0$ limit will significantly increase the event yields. The relevant scales are set by $\hat{s}$ and/or $p_T^*$ and are around $10$ GeV$^2$, and the possible contribution from non-pointlike photons is expected to be very small. We estimate the total non-diffractive cross section for producing such correlated hadron pairs to be around $150 \pm 50$ nb, by extrapolating from the DIS cross section to $Q^2 \rightarrow 0$ using a dipole form factor with a mass parameter of $10$ GeV$^2$ set by the hard process scale.

Figure 3 shows the $\eta$ distribution for the accepted hadron pairs. Also shown is the correlation between the generated and the reconstructed $\eta$ using the kinematics of the two selected hadrons only. The $\eta$ distribution is peaked around 0.1, and above $\eta \sim 0.15 - 0.20$ the $qg$-events dominate over the $q\bar{q}$-events. The gluon $\eta$ region accessible via the hadron pairs with a 200 GeV beam ranges from $\eta \sim 0.04$ to $\sim 0.2$. The correlation in $\eta$ allows to study $\Delta G_G(\eta)$ and further suppress the Compton background.

The cross section spin-asymmetry $A^{IN\rightarrow h_1h_2}_{LL}$ can be approximated over a small phase space as
\[ A_{\gamma N \rightarrow h^+h^-}^{\Delta G/G} \sim \langle \hat{a}_{\gamma N}^{\gamma^*G \rightarrow q\bar{q}} \rangle \frac{\Delta G}{G} \frac{R}{1 + R} + \langle \hat{a}_{\gamma N}^{\gamma^*q \rightarrow qG} \rangle \frac{\Delta u}{u} \frac{1}{1 + R}. \]  \tag{1}

The \( \langle \hat{a}_{LL} \rangle \)'s are the scattering asymmetries at partonic level. The small contribution to \( A_{\gamma N \rightarrow h^1h^2}^{\Delta G/G} \) from \( q \)-events has been neglected. In order to extract \( \Delta G/G \) from (1) the quark polarizations \( \Delta q/q \) and the ratio \( R \) must be known. The first can be taken from other measurements, while the latter can be estimated with an event generator. Since \( \langle \hat{a}_{\gamma N}^{\gamma^*G \rightarrow q\bar{q}} \rangle \sim -1 \) and \( \langle \hat{a}_{\gamma N}^{\gamma^*q \rightarrow qG} \rangle \sim +0.5 \) the contribution of the Compton sub-process to the asymmetry is further suppressed.

Using the polarized parton densities of [4], we have estimated a value for the photon nucleon asymmetry \( A_{\gamma N \rightarrow h^+h^-}^{\Delta G/G} \) of about \(-12\%\), and a value for \( A_{\gamma N \rightarrow K^+K^-}^{\Delta G/G} \) of about \(-20\%\) around \( \eta \sim 0.1 \). Note that these asymmetries have opposite sign compared to the polarized open charm muoproduction asymmetry [5].

In a high luminosity fixed target experiment like COMPASS [5], integrated luminosities \( L \) of 1 – 2 fb\(^{-1}\) can be easily achieved in one year. With \( L = 2 \) fb\(^{-1}\) and a cross section of 150 nb, about 60 k \( K^+K^- \) pairs with \( p_T > 1 \) GeV/c and \( m(K^+, K^-) > 2 \) GeV/c\(^2\), and about 80 k \( h^+h^- \) pairs with \( p_T > 1.5 \) GeV/c and \( m(h^+, h^-) > 3 \) GeV/c\(^2\) can be collected in one year of data taking. With a beam polarization of \( \sim 80\% \) and an effective target polarization of \( \sim 25\% \) per nucleon, these event samples will give a statistical precision of about 2 – 3 \% for both \( A_{\gamma N \rightarrow h^+h^-}^{\Delta G/G} \) and \( A_{\gamma N \rightarrow K^+K^-}^{\Delta G/G} \).

We have estimated a statistical precision on \( \Delta G/G \) of about 5 \% for kaon pairs and of about 8 \% for hadron pairs. The precision on the extraction of \( \Delta G/G \) is mostly affected by the Compton background subtraction, which is larger in the \( h^+h^- \) channel compared to the \( K^+K^- \) one. Combining both channels might yield a better determination of \( \Delta G/G \) because of the different backgrounds involved, while the gluon densities remain the same. The asymmetric \( x_F \) cut has not been used for these estimates. Adding this cut will reduce the systematic uncertainty in the background subtraction.

REFERENCES

1. EM Collaboration, J. Ashman et al., Nucl. Phys. B 328, 1 (1989).
2. E665 Collaboration, M.R. Adams et al., Phys. Rev. D 48, 5057 (1993); EM Collaboration, M. Arneodo et al., Z. Phys. C 36, 527 (1987).
3. A. Bravar et al., work in preparation.
4. T. Gehrmann and W.J. Stirling, Phys. Rev. D 53, 6100 (1996).
5. The COMPASS Collaboration, COMPASS Proposal, CERN/SPSLC 96-14, SPSC/P297, March 1996; A. Bravar, these proceedings.
6. G. Ingelman, A. Edin, and J. Rathsman, Comp. Phys. Comm. 101, 108 (1997).