DVCS & TCS IN NEW HELICITY AMPLITUDES FORMALISM

HIGH INTENSITY PHOTON SOURCE WORKSHOP
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Outline

1. Motivation
2. Helicity Amplitudes Formalism for DVCS and TCS
3. Importance of studies twist three contributions to DVCS and TCS: universality
4. Implementation in experimental analyses
5. Conclusions
1. MOTIVATION
DVCS was proposed as an avenue to access GPDs in experiments by Ji in 1997
Several papers were written, after that, on the formalism for the deeply virtual exclusive electroproduction cross section.

On the analysis of lepton scattering on longitudinally or transversely polarized protons

Received: 7 March 2005 / 
Published online: 24 May 2005 – © Springer-Verlag / Società Italiana di Fisica 2005
The most complete treatment is the work by BKM*

Theory of deeply virtual Compton scattering on the nucleon

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All extractions of leading order GPDs from experiment have been carried out following the BKM formalism

*complemented by several more recent papers
However…

In the past few years new developments have arisen, triggered by the quest for partonic **Orbital Angular Momentum**, and involving both Generalized Transverse Momentum Distributions (GTMDs) and twist three GPDs.
These developments, in turn, point at the importance of understanding QCD at the amplitude level

- Single Spin Asymmetries (SSA) as correlations of quark/proton spin and intrinsic transverse momentum/momentum transfer

- Through SSA explore how FSI/ISI probe underlying non-perturbative dynamics: from orbital motion and spin correlations to mechanisms for generating quark-antiquark pairs from flux tube ➔ dynamical symmetry breaking and confinement properties of the theory

- This physics involves orbital motion and it is not about “hand waving” models!
PT transformation

Forward case: Sivers function (J. Collins, 2002)

PT:
\[ \langle P, S | \overline{\psi}(0)\gamma^+\psi(z) | P, S \rangle = \langle P, -S | \overline{\psi}(0)\gamma^+\psi(z) | P, -S \rangle \]

\[ f_{1T}^{\perp,SIDIS} = M_+ - M_- = 0 \]

\[ M_+^v - M_-^v = 0 \]

\[ f_{1T}^{\perp,DY} = M_+^v - M_-^v \]
Off forward case: GTMD $F_{14}$

PT:

$$\langle P - \Delta, S \mid \bar{\psi}(0) \gamma^+ U(v, z) \psi(z) \mid P, S \rangle = \langle P, -S \mid \bar{\psi}(0) \gamma^+ U(-v, z) \psi(z) \mid P - \Delta, -S \rangle$$

$L_{\pm}^{\nu, \Delta}$

$L_{-}^{-\nu, -\Delta}$

$L_{+}^{\nu, \Delta} - L_{-}^{-\nu, -\Delta} = 0$

$$(k_{T} \times \Delta_{T}) F_{14}^{\text{SIDIS}} = L_{+}^{\nu, \Delta} - L_{-}^{-\nu, -\Delta} = (k_{T} \times \Delta_{T}) F_{14}^{\text{DY}} = L_{+}^{-\nu, \Delta} - L_{+}^{-\nu, \Delta}$$
large effect from lattice (M. Engelhardt, arXiv:1701.01536)

\[ u-d \text{ quarks} \]
\[ m_\pi = 518 \text{ MeV} \]
\[ \hat{\bar{\zeta}} = 0.39 \]

PRD, arXiv:1111.4249

insight into non-perturbative aspects of QCD associated with dynamical chiral symmetry breaking and confinement
Generalized LIR for straight gauge link (no FSI)

Obtained by studying in detail the $k_T$ structure of GTMDs and twist 3 GPDs for a straight gauge link (Ji’s definition)

1. $L_q^z \frac{d}{dx} \int d^2 k_T \frac{k_T^2}{M^2} F_{14} = \tilde{E}_{2T} + H + E$

   $k_T$ moment of a GTMD

   twist 3 GPD

2. $L_q^z S_q^z \frac{d}{dx} \int d^2 k_T \frac{k_T^2}{M^2} G_{11} = - \left( 2\tilde{H}_{2T} + E_2' + \tilde{H} \right)$

The formalism of BKM does not allow us to include this physics in a straightforward way.

Additional practical problem: in BKM it is hard to disentangle the $Q^2$ dependence of the various terms beyond $O(M^2/Q^2, t/Q^2)$ type approximations.
It is timely, in view of the upcoming experiments, to have a formalism that includes in a natural way the recent developments in the cross section of polarized deeply virtual exclusive processes:

- Polarized DVCS
- DVCS with Recoil Polarization
- Timelike Compton Scattering (TCS)
- Double DVCS (DDVCS)
- More exclusive processes leading to the measurement of GTMDs

The formalism we present is based on the helicity amplitudes decomposition of the cross section, and it is more suitable for a direct use in experimental analyses/MCs.
2. HELICITY AMPLITUDES FORMALISM
Dustin Keller & U.Va. Polarized Target Group

Experiment

Pheno

Theory

Abha Rajan
Gary Goldstein
Osvaldo Gonzalez Hernandez
Deeply Virtual Exclusive Photoproduction

\[
\frac{d^5 \sigma}{dx_{Bj} dQ^2 dt d\phi d\phi_S} = \frac{\alpha^3}{16\pi^2 (s - M^2)^2 \sqrt{1 + \gamma^2}} |T|^2 ,
\]

\[
T(k, p, k', q', p') = T_{DVCS}(k, p, k', q', p') + T_{BH}(k, p, k', q', p'),
\]
We extended to GPDs the formalism used in the forward case (SIDIS)

\[ \frac{d^4\sigma}{dx_Bdyd\phi dt} = \Gamma \left\{ F_{UU,T} + \epsilon F_{UU,L} + \epsilon \cos 2\phi F_{UU}^{\cos 2\phi} + \sqrt{2\epsilon(\epsilon + 1)} \cos \phi F_{UU}^{\cos \phi} + h \sqrt{2\epsilon(1 - \epsilon) \sin \phi F_{LU}^{\sin \phi}} \right\} \\
+ S_{||} \left[ \sqrt{2\epsilon(\epsilon + 1)} \sin \phi F_{UL}^{\sin \phi} + \epsilon \sin 2\phi F_{UL}^{\sin 2\phi} + h \left( \sqrt{1 - \epsilon^2} F_{LL} + \sqrt{2\epsilon(1 - \epsilon) \cos \phi F_{LL}^{\cos \phi}} \right) \right] \\
+ S_{\perp} \left[ \sin(\phi - \phi_S) \left( F_{UT,T}^{\sin(\phi - \phi_S)} + \epsilon F_{UT,L}^{\sin(\phi - \phi_S)} \right) + \epsilon \left( \sin(\phi + \phi_S) F_{UT}^{\sin(\phi + \phi_S)} + \sin(3\phi - \phi_S) F_{UT}^{\sin(3\phi - \phi_S)} \right) \right] \\
+ \sqrt{2\epsilon(1 + \epsilon)} \left( \sin \phi_S F_{UT}^{\sin \phi_S} + \sin(2\phi - \phi_S) F_{UT}^{\sin(2\phi - \phi_S)} \right) \\
+ S_{\perp} h \left[ \sqrt{1 - \epsilon^2} \cos(\phi - \phi_S) F_{LT}^{\cos(\phi - \phi_S)} + \sqrt{2\epsilon(1 - \epsilon)} \left( \cos \phi_S F_{LT}^{\cos \phi_S} + \cos(2\phi - \phi_S) F_{LT}^{\cos(2\phi - \phi_S)} \right) \right] \right\} 

\text{SIDIS cross section} \\
\text{unpolarized target} \\
\text{longitudinally polarized target} \\
\text{transv. polarized}
Angle between hadron and lepton planes

\[ F_{UUU}^{\cos \phi} \]

Beam polarization

Target polarization
Virtual Compton scattering off protons at moderately large momentum transfer

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Received 13 July 1995; revised 28 December 1995
Interpretation in terms of structure functions, example

\[ F_{UU}^{\cos \phi_h} = \frac{2M}{Q} C \left[ \hat{h} \cdot k_T \left( x h H_1^\perp + \frac{M_h}{M} f_1 \tilde{D}^\perp \right) - \hat{h} \cdot p_T \left( x f_1 \perp D_1 + \frac{M_h}{M} h_1^\perp \tilde{H} \right) \right] \]

n.p. \( Q^2 \) dependence

Kinematical factor

Structure functions (twist 2 \( \times \) twist 3)

Convolution over transverse momenta
Extension to DVCS

\[
\gamma^* p \to \gamma(M) p'
\]

\[
q' = q + \Delta, \Lambda_{\gamma}'
\]

\[
k' = k - \Delta, \lambda'
\]

\[
P' = P - \Delta, \Lambda'
\]

\[
\sigma = \sigma^{UU} + h \sigma^{LU} + S_{||} \sigma^{UL} + S_{||} h \sigma^{LL} + S_T \sigma^{UT} + S_T h \sigma^{LT}
\]

\[
\sigma^{UU} = \frac{\Gamma}{2} \sum_{h,\Lambda} \sum_{\Lambda',\Lambda_{\gamma}} \left(T_{DVCS,\Lambda\Lambda'}^{h\Lambda_{\gamma}}\right)^* T_{DVCS,\Lambda\Lambda'}^{h\Lambda_{\gamma}}
\]

example
BASIC MODULE (based on helicity amplitudes)

\[
\sum_{\Lambda', \Lambda} \left( T_{DVCS, \Lambda \Lambda'}^{h'\Lambda' \gamma} \right)^* T_{DVCS, \Lambda \Lambda'}^{h\Lambda' \gamma} =
\]

\[
\frac{1}{Q^2} \frac{1}{1 - \epsilon} \left\{ (F_{\Lambda+}^{11} + F_{\Lambda-}^{11} + F_{\Lambda+}^{-1-1} + F_{\Lambda-}^{-1-1}) + \epsilon (F_{\Lambda+}^{00} + F_{\Lambda-}^{00}) \right\}
\]

\[
+ 2\sqrt{\epsilon(1 + \epsilon)} \text{Re} \left( -F_{\Lambda+}^{01} - F_{\Lambda-}^{01} + F_{\Lambda+}^{0-1} + F_{\Lambda-}^{0-1} \right) + 2\epsilon \text{Re} \left( F_{\Lambda+}^{1-1} + F_{\Lambda-}^{1-1} \right)
\]
Initial and final proton helicities

Virtual Photon helicities

\[ F_{\Lambda \Lambda' \gamma^* \gamma^*}^{\Lambda(1) \Lambda(2)} = \sum_{\Lambda \gamma'} \left( f_{\Lambda \Lambda' \gamma^* \gamma'}^{\Lambda(1) \Lambda \gamma'} \right)^* f_{\Lambda \Lambda' \gamma^* \gamma'}^{\Lambda(2) \Lambda \gamma'} \]

Helicity amplitudes
The unpolarized cross section: example

\[ \sigma^{UU} = \frac{\Gamma}{Q^2(1-\epsilon)} \left[ F_{UU,T} + \epsilon F_{UU,L} + \epsilon \cos 2\phi F_{UU}^{\cos 2\phi} + \sqrt{\epsilon(\epsilon + 1)} \cos \phi F_{UU}^{\cos \phi} \right] \]

\[ F_{UU,T} = 2(F_{++}^{11} + F_{+-}^{11} + F_{-+}^{11} + F_{--}^{11}), \]
\[ F_{UU,L} = 2F_{++}^{00} \]
\[ F_{UU}^{\cos \phi} = \text{Re} \left[ F_{++}^{01} + F_{--}^{01} \right] \]
\[ F_{UU}^{\cos 2\phi} = \text{Re} \left[ F_{++}^{1-1} + F_{+-}^{1-1} + F_{-+}^{1-1} + F_{--}^{1-1} \right] \]

Twist 2
Twist 4
Twist 3
Photon helicity flip: transverse gluons
Phase dependence

\[ f \rightarrow e^{i\left[\Lambda_{\gamma^*} - \Lambda_{\gamma'} - (\Lambda - \Lambda')\right]} \phi \]

The phase is determined entirely by the virtual photon helicity which can be different for the amplitude and its conjugate.
Interpretation in terms of GPDs

\[
A_{++,++} = \sqrt{1 - \xi^2} \left( \frac{H + \HH}{2} - \frac{\xi^2}{1 - \xi} \frac{E + \EE}{2} \right)
\]

\[
A_{+-,+-} = \sqrt{1 - \xi^2} \left( \frac{H - \HH}{2} - \frac{\xi^2}{1 - \xi} \frac{E - \EE}{2} \right)
\]

\[
A_{++,+-} = -\frac{\Delta_1 + i\Delta_2}{t_0 - t} \frac{t_0 - t}{2M} \frac{E - \xi\EE}{2}
\]

\[
A_{-+,++} = \frac{\Delta_1 - i\Delta_2}{t_0 - t} \frac{t_0 - t}{2M} \frac{E + \xi\EE}{2}
\]

\[
f^{11}_{++} = \sqrt{1 - \xi^2} \left( H + \HH - \frac{\xi^2}{1 - \xi^2} (E + \EE) \right)
\]

\[
f^{11}_{--} = \sqrt{1 - \xi^2} \left( H - \HH - \frac{\xi^2}{1 - \xi^2} (E - \EE) \right)
\]

\[
f^{11}_{+-} = e^{-i\phi} \frac{\sqrt{t_0 - t}}{2M} (E + \xi\EE)
\]

\[
f^{11}_{-+} = -e^{i\phi} \frac{\sqrt{t_0 - t}}{2M} (E - \xi\EE)
\]
\begin{align*}
F^{11}_{++} &= (1 - \xi^2) |\mathcal{H} + \tilde{\mathcal{H}}|^2 - \xi^2 \left[ (\mathcal{H}^* + \tilde{\mathcal{H}})^* (\mathcal{E} + \tilde{\mathcal{E}}) + (\mathcal{H} + \tilde{\mathcal{H}})(\mathcal{E}^* + \tilde{\mathcal{E}}^*) \right] \\
F^{11}_{--} &= (1 - \xi^2) |\mathcal{H} - \tilde{\mathcal{H}}|^2 - \xi^2 \left[ (\mathcal{H}^* - \tilde{\mathcal{H}})^* (\mathcal{E} - \tilde{\mathcal{E}}) + (\mathcal{H} - \tilde{\mathcal{H}})(\mathcal{E}^* - \tilde{\mathcal{E}}^*) \right] \\
F^{11}_{+-} &= \frac{t_0 - t}{4M^2} |\mathcal{E} + \xi\tilde{\mathcal{E}}|^2 \\
F^{11}_{-+} &= \frac{t_0 - t}{4M^2} |\mathcal{E} - \xi\tilde{\mathcal{E}}|^2
\end{align*}
Twist 3

\[ f_{\Lambda\Lambda'}^{01} = g_{-+}^{01} \otimes A_{\Lambda' +, \Lambda -} + g_{+-}^{01} \otimes A_{\Lambda' +, \Lambda -} + g_{+* -}^{01} \otimes A_{\Lambda' -, \Lambda +} + g_{+* -}^{01} \otimes A_{\Lambda' -, \Lambda +} \]

“Bad” component (exchanged gluon flips the quark chirality)
We connect the tw 3 amps DVCS formalism with the TMD, GPD, GTMD comprehensive parametrization in Meissner Metz and Schlegel, JHEP08 (2009)

Example

\[ A_{+-,+++} = \frac{1}{2} \left( \tilde{E}_{2T} - \bar{E}_{2T} + \tilde{E}'_{2T} + \bar{E}'_{2T} \right) \]

\[ A_{+-*,+++} = \frac{1}{2} \left( -\tilde{E}_{2T} + \bar{E}_{2T} + \tilde{E}'_{2T} + \bar{E}'_{2T} \right) \]

Spin Orbit interaction

Orbital angular momentum
DVCS: bilinears of tw 2 and tw 3 CFFs

\[ F_{++}^{01} = \mathcal{P} \left[ \mathcal{H}^* (\bar{\mathcal{E}}_{2T} - \bar{\mathcal{E}}_{2T} + \ldots), \ldots \right] \]

Preliminary extraction from experiment using Wandzura Wilczek approximation

BH Amplitude

\[ T_{BH,\Lambda,\Lambda'}(k, p, k', q', p') = \frac{1}{\Delta^2} \sum_{\tilde{\Lambda}_\gamma} B_{h,\Lambda,\Lambda'}(k, k', q') J_{\Lambda\Lambda'}(p, p'), \]

**Lepton part**

\[ \bar{u}(k', h) \left[ \gamma^\mu (k' + q') \gamma^\nu \frac{1}{(k' + q')^2} + \gamma^\nu (k - q') \gamma^\mu \frac{1}{(k - q')^2} \right] u(k, h) \epsilon_{\mu,\Lambda,\gamma}^*(q') \epsilon_{\nu,\tilde{\Lambda},\gamma}^*(\Delta) / \Delta^2 \]

\[ = L_{\text{h}}^{\mu,\nu} \epsilon_{\mu,\Lambda,\gamma}^*(q') \epsilon_{\nu,\tilde{\Lambda},\gamma}^*(\Delta) = B_{h,\Lambda,\Lambda'}. \]  

(10)

**Hadron part**

\[ \overline{U}(p', \Lambda') \Gamma \nu U(p, \Lambda) = \overline{U}(p', \Lambda') \left[ (F_1(-\Delta^2) + F_2(-\Delta^2)) \gamma^\nu - \frac{(p + p')^\nu}{2M} F_2(-\Delta^2) \right] U(p, \Lambda), \]
The BH term can be calculated exactly (QED+ proton form factors) 

\[
\hat{B}_{h,\Lambda'}^{(1)} = \left\{ \frac{\gamma^2 y^2 + 4y - 4}{y-1} \left( \frac{x_B M_p}{4\gamma^2} \right) \left( 2h \left( \tilde{\Lambda}_\gamma \cos (\theta') - \cos (\theta) \Lambda'_\gamma \right) \right) + \gamma^2 \sqrt{\gamma^2 + 1} + \left( \tilde{\Lambda}_\gamma \Lambda'_\gamma (\gamma^2 \cos (\theta) \cos (\theta') - 2 \sin (\theta) \sin (\theta')) - \gamma^2 \right) \frac{(y - 2)}{(\gamma^2 + 1) y} \right\} \\
+ \cos (\phi) \left\{ \left( \frac{x_B M_p}{2\gamma} \right) \Lambda'_\gamma \left[ \tilde{\Lambda}_\gamma \left( \frac{4\sqrt{1 - y}}{(\gamma^2 + 1) \sqrt{1 - y}} + \sin (\theta + \theta') \right) \frac{y}{(\gamma^2 + 1) \sqrt{1 - y}} - \right.ight. \\
\left. \cos (\theta) \sin (\theta') \frac{(1 - \gamma^2) y}{(\gamma^2 + 1) \sqrt{1 - y}} + 2h \sin (\theta) \frac{(2 - y)}{(\gamma^2 + 1) \sqrt{1 - y}} \right] \right\} \\
- \cos (2\phi) \left\{ \sqrt{\frac{\gamma^2 y^2 + 4y - 4}{y - 1}} \left( \frac{x_B M_p}{4} \right) \left( 1 + \tilde{\Lambda}_\gamma \cos (\theta) \Lambda'_\gamma \cos (\theta') \right) \frac{(2 - y)}{(\gamma^2 + 1) y} + \right. \\
\left. 2h \left( \tilde{\Lambda}_\gamma \cos (\theta') + \cos (\theta) \Lambda'_\gamma \right) \frac{1}{\sqrt{\gamma^2 + 1}} \right\} \\
+ \sin (\phi) \left\{ i \left( \frac{x_B M_p}{2\gamma} \right) \left( \tilde{\Lambda}_\gamma \sin (\theta') \frac{\left( \gamma^2 y^2 + 4y - 4 \right)}{(\gamma^2 + 1) \sqrt{1 - y} y} - \right. \right. \\
\left. 2h \tilde{\Lambda}_\gamma \Lambda'_\gamma \sin (\theta) \cos (\theta') \frac{(y - 2)}{\sqrt{\gamma^2 + 1} \sqrt{1 - y}} + \Lambda'_\gamma \sin (\theta) \frac{(y - 2)^2}{(\gamma^2 + 1) \sqrt{1 - y} y} \right\} \\
- \sin (2\phi) \left\{ \sqrt{\frac{\gamma^2 y^2 + 4y - 4}{y - 1}} \left( \frac{x_B M_p}{4} \right) \left( i2h \left( 1 + \tilde{\Lambda}_\gamma \cos (\theta) \Lambda'_\gamma \cos (\theta') \right) \frac{1}{\sqrt{\gamma^2 + 1}} + \right. \right. \\
\left. \left( \tilde{\Lambda}_\gamma \cos (\theta') + \cos (\theta) \Lambda'_\gamma \right) \frac{(2 - y)}{(\gamma^2 + 1) y} \right\} \right. \\
\text{(3)}
\]
BH-DVCS interference

\[ I = \left( T_{BH, \Lambda\Lambda'}^{h\Lambda'\gamma} \ast T_{DVCS, \Lambda\Lambda'}^{h\Lambda'\gamma} + T_{DVCS, \Lambda\Lambda'}^{h\Lambda'\gamma} \ast T_{BH, \Lambda\Lambda'}^{h\Lambda'\gamma} \right) \]
Phase dependence allowing us to separate out tw 2 from tw 3 terms comes entirely from here.

The rest is a “contamination” that we calculate exactly.
3. IMPORTANCE OF DVCS AND TCS COMPARISON
All the formalism shown above is extended straightforwardly to TCS

In TCS there are important differences:

• one can use the linearly polarized photons to measure the asymmetries sensitive to the polarized GPDs (Goritschnig, Pire, Wagner, PRD 2014) …

• NLO weighs more

• etc….

… but we don’t want to use TCS as an ancillary process to DVCS!
An argument that cannot be refused...

Universality/process dependence of parton distributions

- $\infty,0$ to $-\infty,0$
- $0,0$ to $\infty,0$
- $z_T$ to $z_T$

Graph showing:
- $u-d$ quarks
- $m_\pi = 518$ MeV
- $\hat{\zeta} = 0.39$
\[ F_{1,4} = \int \frac{d^2 l}{(2\pi)^2} \frac{e_c^2 g_s^2 M^2 2P^+(1 - x)^2 \left(1 + \frac{l_T}{k_T} \cos \phi_l \right)}{2x(l_T^2 + m_g^2)((k - l)^2 - M^2)^2((k - \Delta)^2 - M^2)^2} \]
Two additional processes: DVCS and TCS twist three contributions

Extracting twist 3 GPDs from these processes will allow us to zoom into aspects of the “sign change”
4. IMPLEMENTATION IN EXPERIMENTAL ANALYSES
Implementation in experimental analysis

• We provide (Dustin) with all the necessary terms that are necessary to extract any given observable (for example we focused on the unpolarized cross section)

• We run the MC with model GPDs to validate the procedure by verifying that the initial model corresponds to the output

• We have a tool that can be both tested with other models and used with real data to constrain the models parameters and to obtain GPD shapes
A variety of GPD models
• Extracting GPD from increasingly precise sets of data will involve elements of Information Theory (see D. Ireland, analysis of pseudoscalar meson photoproduction PRD82 2010)


• From the structure functions of DIS

\[ f(x, Q_o^2) = A_{q,g} x^{-\alpha_{q,g}} (1 - x)^{\beta_{q,g}} F(x, c_{q,g}, d_{q,g}, \ldots) \]

to the Compton Form Factors of DVCS, DVMP, TCS, …

\[ H_{q_v}(x, \xi, t; Q_o^2) = \]
\[ H_{\bar{q}}(x, \xi, t; Q_o^2) = \]
\[ H_g(x, \xi, t; Q_o^2) = \]
Covariant Scattering Matrix/spectator model

\( k = \text{quark, anti-quark} \) (flavor separation from combination of \( \Lambda_x = 0,1 \))

\( k = \text{gluon} \)

\( P, \Lambda \)

\( k, \lambda \)

\( k_x, \Lambda_x = 0,1 \)

\( P, \Lambda \)

\( k, \lambda \)

\( k_x, \Lambda_x = 1/2,3/2 \)
Quark GPDs (with Hessian error not shown)

$x_{Bj} = 0.13$

$Q^2 = 1.1 \text{ GeV}^2$

$0.1 < -t < 1.1 \text{ GeV}^2$
Valence quarks parameters constrained by polynomiality

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$H$</th>
<th>$E$</th>
<th>$\tilde{H}$</th>
<th>$\tilde{E}$</th>
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<td>$\alpha'_u$</td>
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<td>$2.811 \pm 0.765$</td>
<td>$1.543 \pm 0.296$</td>
<td>$5.130 \pm 0.101$</td>
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<td>$0.620 \pm 0.0725$</td>
<td>$0.863 \pm 0.482$</td>
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<td>-0.966</td>
</tr>
<tr>
<td>$\chi^2$</td>
<td>0.822</td>
<td>0.688</td>
<td>0.110</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Gluons in DGLAP region using smooth $t$ dependence of gluon form factor from QCD sum rules (Braun et al., PLB 1993)
One can measure the spin orbit term as a twist 3 spin orbit correlation in $^4$He!
Conclusions

- A wealth of physics studies on QCD at the amplitude level can be extracted from the comparison of DVCS and TCS.
- We presented an helicity based formalism for deeply virtual exclusive electron proton scattering processes.
- This formalism allows us to interpret the DVCS cross section twist three GPDs contribution in a clear way, because it organizes the spurious $Q^2$ dependence from both the BH contamination and from kinematical terms.
- It also allows us to connect to experiment directly (analyses using data are on their way).
- Complete results for TCS are on their way.
\[ \frac{d}{dx} \int d^2 k T \frac{k^2 T}{M^2} F_{14} = \tilde{E}_{2T} + H + E \]