

# Double DVCS

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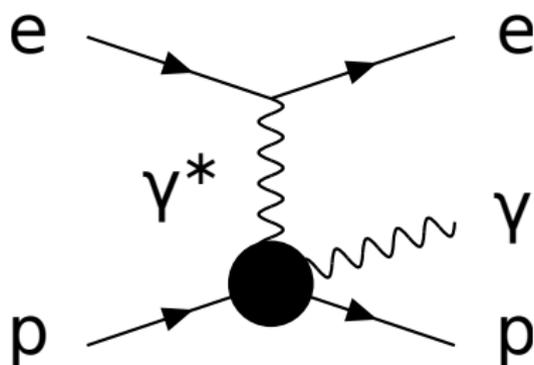
$\mu$ CLAS12 Experiment workshop, March 9, 2026



## DVCS

The simplest and best known process is Deeply Virtual Compton Scattering:

$$ep \rightarrow ep\gamma$$



**Factorization** into **GPDs** and perturbative coefficient function - on the level of **amplitude**.

$$\begin{aligned} \text{DIS :} & \quad \sigma = \text{PDF} \otimes \text{partonic cross section} \\ \text{DVCS :} & \quad \mathcal{M} = \text{GPD} \otimes \text{partonic amplitude} \end{aligned}$$

## GPD definition.

$$\begin{aligned} F^q &= \frac{1}{2} \int \frac{dz^-}{2\pi} e^{ixP^+z^-} \langle p' | \bar{q}(-\frac{1}{2}z) \gamma^+ q(\frac{1}{2}z) | p \rangle \Big|_{z^+=0, \mathbf{z}=0} \\ &= \frac{1}{2P^+} \left[ H^q(x, \xi, t) \bar{u}(p') \gamma^+ u(p) + E^q(x, \xi, t) \bar{u}(p') \frac{i\sigma^{+\alpha} \Delta_\alpha}{2m} u(p) \right], \\ F^g &= \frac{1}{P^+} \int \frac{dz^-}{2\pi} e^{ixP^+z^-} \langle p' | G^{+\mu}(-\frac{1}{2}z) G_{\mu}^+(\frac{1}{2}z) | p \rangle \Big|_{z^+=0, \mathbf{z}=0} \\ &= \frac{1}{2P^+} \left[ H^g(x, \xi, t) \bar{u}(p') \gamma^+ u(p) + E^g(x, \xi, t) \bar{u}(p') \frac{i\sigma^{+\alpha} \Delta_\alpha}{2m} u(p) \right], \end{aligned}$$

► Skeweness:

$$\xi = \frac{-\bar{q}^2}{2\bar{q} \cdot P} \approx \frac{x_B}{2 - x_B}, \quad x_B = \frac{Q^2}{2q \cdot p}$$

momentum transfer between proton initial and final state:

$$\mathbf{t} = (p' - p)^2$$

- Factorization scale dependance,
- Three variables  $x, \xi, t$ .

## GPD - properties,

- ▶ Forward limit:

$$\begin{aligned}H^q(x, 0, 0) &= q(x), & \text{for } x > 0, \\H^q(x, 0, 0) &= -\bar{q}(x), & \text{for } x < 0, \\H^g(x, 0, 0) &= xg(x),\end{aligned}$$

similarly for polarized distributions and PDFs.

- ▶ Reduction to the Dirac and Pauli form factors:

$$\int_{-1}^1 dx H^q(x, \xi, t) = F_1^q(t), \quad \int_{-1}^1 dx E^q(x, \xi, t) = F_2^q(t),$$

- ▶ polynomiality and positivity
- ▶ Ji sum rule:

$$\lim_{t \rightarrow 0} \int_{-1}^1 dx x [H_f(x, \xi, t) + E_f(x, \xi, t)] = 2J_f$$

where  $J_f$  is fraction of the proton spin carried by quark  $f$  (including spin and orbital angular momentum).

## Energy momentum tensor and D-term

- ▶ Gravitational Form Factors:

$$\langle p', s' | \hat{T}_{\mu\nu}^a(x) | p, s \rangle = \bar{u}' \left[ A^a(t) \frac{P_\mu P_\nu}{m} + J^a(t) \frac{i P_{\{\mu} \sigma_{\nu\} \rho} \Delta^\rho}{2m} + \mathbf{D}^a(\mathbf{t}) \frac{\Delta_\mu \Delta_\nu - g_{\mu\nu} \Delta^2}{4m} + m \bar{c}^a(t) g_{\mu\nu} \right] u e^{i(p'-p)x}.$$

- ▶ Form Factor  $\mathbf{D}(\mathbf{t})$  connected to pressure
- ▶ fixed- $t$  dispersion relation for DVCS

$$Re\mathcal{H}(\xi, t) = \Delta(\mathbf{t}) + \text{P.V.} \int_0^1 \frac{1}{\pi} Im\mathcal{H}(x, t) \left( \frac{1}{\xi - x} \mp \frac{1}{\xi + x} \right) dx.$$

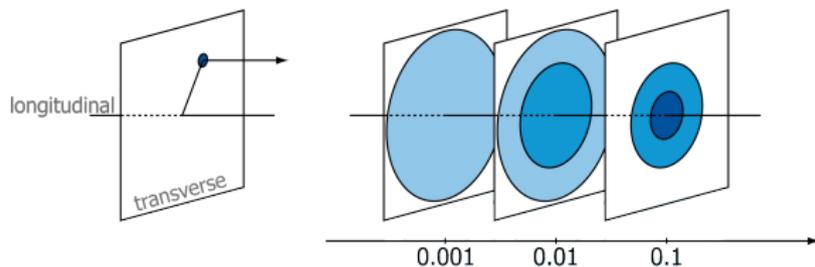
with some approximations:  $\Delta(\mathbf{t}) \sim \sum_q \mathbf{D}^q(\mathbf{t}) + \dots$  First attempts made (Burkert et al, Nature 557 (2018)), but difficult to perform in a model independent way.

## Impact parameter representation

At  $\xi = 0 \quad \Rightarrow \quad -t = \Delta_{\perp}^2 :$

$$H(x, \mathbf{b}_{\perp}) = \int \frac{d^2 \Delta_{\perp}}{(2\pi)^2} e^{-i\mathbf{b}_{\perp} \cdot \Delta_{\perp}} H(x, 0, -\Delta_{\perp})$$

can be interpreted as probability of finding a parton with longitudinal momentum fraction  $x$  at a given  $\mathbf{b}_{\perp}$ .



## DVCS - Coefficient functions and Compton Form Factors

CFFs are the GPD dependent quantities which enter the amplitudes. They are defined through relations:

$$\mathcal{A}^{\mu\nu}(\xi, t) = -e^2 \frac{1}{(P+P')^+} \bar{u}(P') \left[ g_T^{\mu\nu} \left( \mathcal{H}(\xi, t) \gamma^+ + \mathcal{E}(\xi, t) \frac{i\sigma^{+\rho} \Delta_\rho}{2M} \right) + i\epsilon_T^{\mu\nu} \left( \tilde{\mathcal{H}}(\xi, t) \gamma^+ \gamma_5 + \tilde{\mathcal{E}}(\xi, t) \frac{\Delta^+ \gamma_5}{2M} \right) \right] u(P),$$

,where:

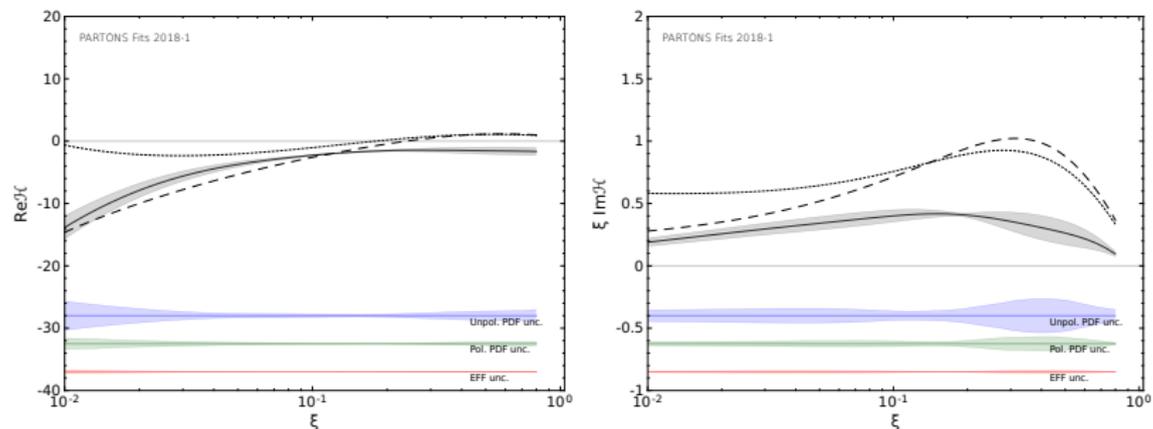
$$\mathcal{H}(\xi, t) = + \int_{-1}^1 dx \left( \sum_q T^q(x, \xi) H^q(x, \xi, t) + T^g(x, \xi) H^g(x, \xi, t) \right)$$

GPDs enter through convolutions! At LO in  $\alpha_S$ :

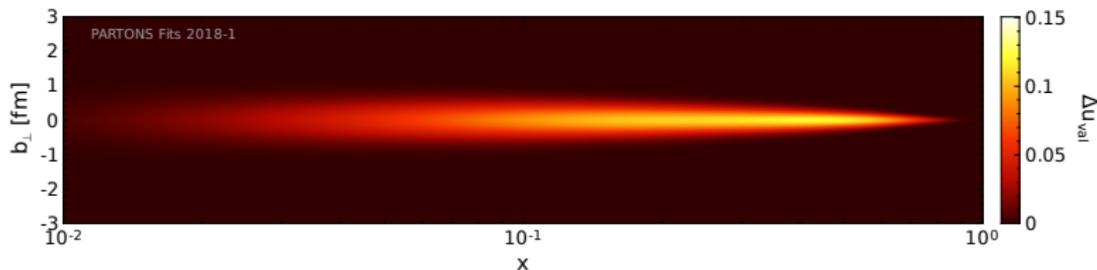
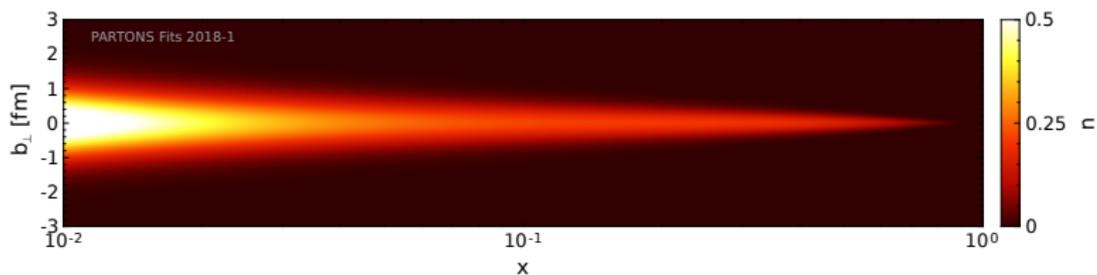
$$^{DVCS} T^q = -e_q^2 \frac{1}{x + \xi - i\epsilon} - (x \rightarrow -x)$$

$$^{DVCS} \text{Re}(\mathcal{H}) \sim P \int \frac{1}{x + \xi} H^q(x, \xi, t), \quad ^{DVCS} \text{Im}(\mathcal{H}) \sim i\pi H^q(\xi, \xi, t)$$

# Compton Form Factors



Real (left) and imaginary (right) parts of the CFF  $\mathcal{H}$  obtained in this work as a function of  $\xi$  at  $t = -0.3 \text{ GeV}^2$  and  $Q^2 = 2 \text{ GeV}^2$ .

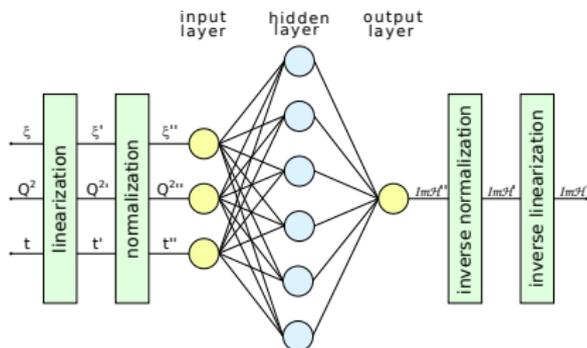


Position of up quarks in an unpolarized proton (upper plot) and longitudinal polarization of those quarks in a longitudinally polarized proton (lower plot) as a function of the longitudinal momentum fraction  $x$ . For the lower plot only the valence contribution is shown.

# Fit with ANN + Genetic algorithm

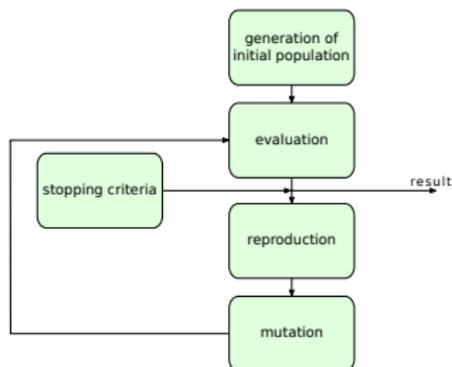
H. Moutarde, P. Sznajder, J. Wagner, Eur.Phys.J. C79 (2019)

## ▶ ANNs

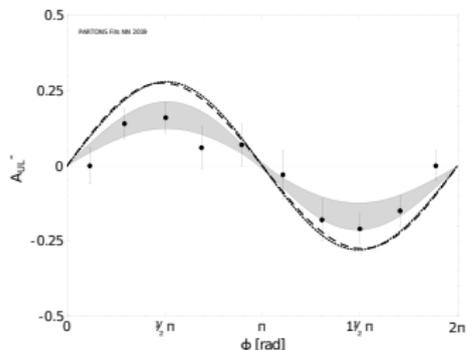
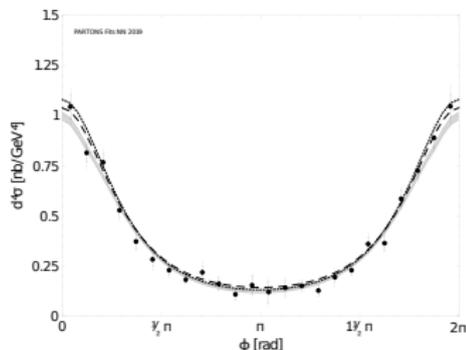


Scheme of a single neural network that is used in this analysis to represent either the real or the imaginary part of a single CFF.

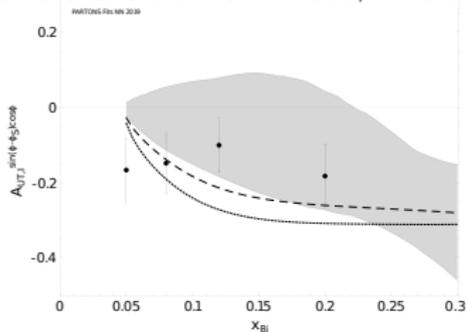
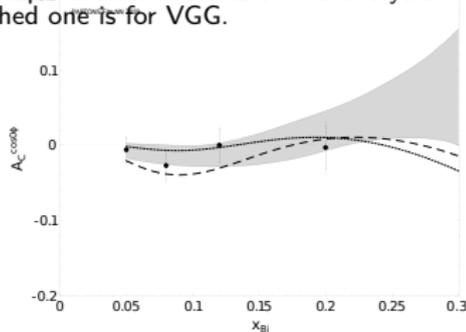
## ▶ Genetic algorithm



# Observables

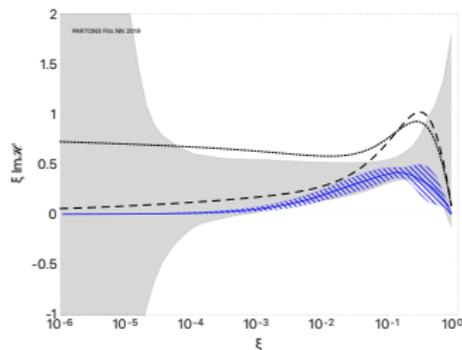
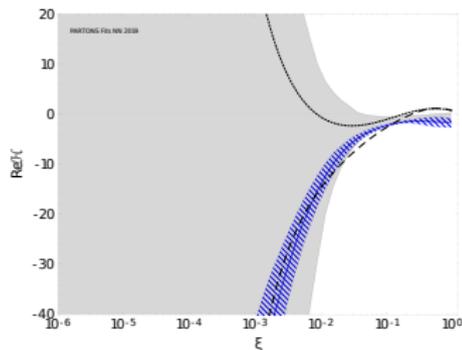


CLAS data for  $d^4\sigma_{UU}^-$  at  $x_{Bj} = 0.244$ ,  $t = -0.15 \text{ GeV}^2$  and  $Q^2 = 1.79 \text{ GeV}^2$  (left) and for  $A_{UL}^-$  at  $x_{Bj} = 0.2569$ ,  $t = -0.23 \text{ GeV}^2$ ,  $Q^2 = 2.019 \text{ GeV}^2$  (right). The gray bands correspond to the results of this analysis. The dotted curve is for the GK GPD model, while the dashed one is for VGG.

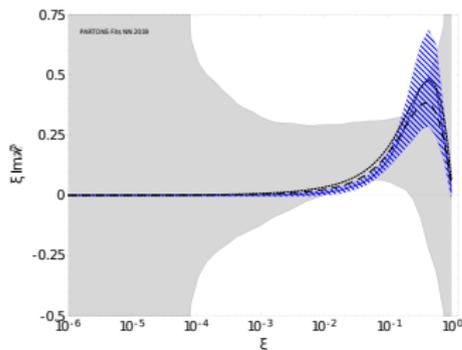
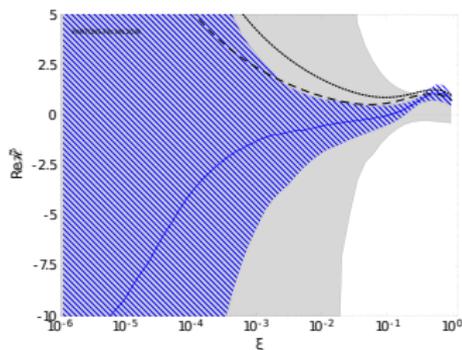


HERMES data for  $A_C^{\cos\phi}$  (left) and  $A_{UT,I}^{\sin(\phi-\phi_S)\cos\phi}$  (right) at  $t = -0.12 \text{ GeV}^2$  and  $Q^2 = 2.5 \text{ GeV}^2$ .

## results for CFFs



Real (left) and imaginary (right) parts of the CFF  $\mathcal{H}$  as a function of  $\xi$  for  $t = -0.3 \text{ GeV}^2$  and  $Q^2 = 2 \text{ GeV}^2$ . The blue solid line surrounded by the blue hatched band denotes the result of our previous analysis.



Real (left) and imaginary (right) parts of the CFF  $\tilde{\mathcal{H}}$  as a function of  $\xi$  for  $t = -0.3 \text{ GeV}^2$  and  $Q^2 = 2 \text{ GeV}^2$ .

## Status of DVCS fits

- ▶ This were just the examples, many other groups:
  - ▶ Kumericki, Muller,
  - ▶ Guidal, Vanderhaeghen, Dupre,
  - ▶ Burkert, Elouadrhiri, Girod
  - ▶ Liuti, Goldstein, Kriesten et al.
  - ▶ GUMP (Guo, Ji, Santiago, Shiells)
  - ▶ Kumericki NN,
- ▶ Most fits still at LO and LT - effectively Compton Form Factors fits
- ▶ higher twist needed, especially for JLab kinematics
- ▶ NLO fits! (first attempts for low- $x$  by Kumerički, Mueller, Lautenschlager recently Marija Čuić, Goran Duplančić , Krešimir Kumerički, Kornelija Passek-K.)
- ▶ Switch from CFFs to GPDs - flexible modelling,
- ▶ Include charm mass effects.
- ▶ More channels needed:

## Other channels

### ► DVCS on neutron

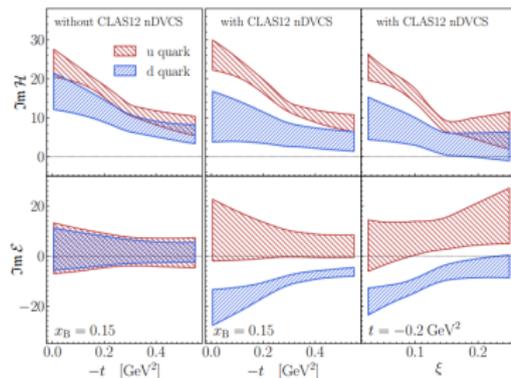
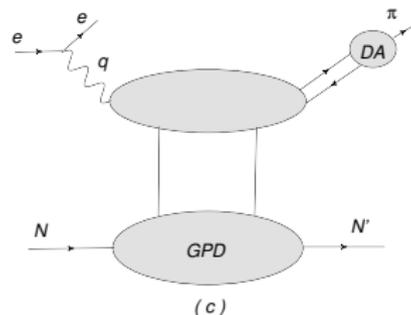


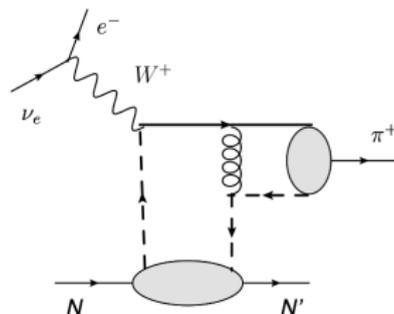
FIG. 6. Extraction of up ( $u$ , coarser shading, red online) and down ( $d$ , finer shading, blue online) quark contributions to  $\Im m\mathcal{H}$  (top) and  $\Im m\mathcal{E}$  (bottom) as a function of  $-t$  (left and middle) and  $\xi$  (right). The leftmost column shows the extraction of the two CFFs without the CLAS12 nDVCS data, which are instead included in the other two columns.

2406.15539 CLAS and Čuić, Kumerički

### ► DVMP



### ► $\nu$ -DVMP



Kopeliovich, Schmidt, Siddikov  
JW, Szymanowski, Pire

## Other channels

### ► Photoproduction of Heavy Vector Mesons:

Ivanov, Schafer, Szymanowski, Krasnikov

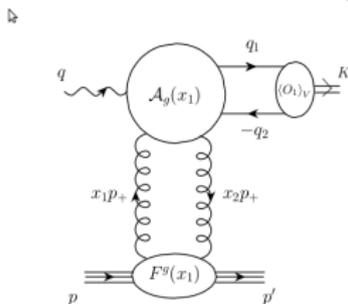
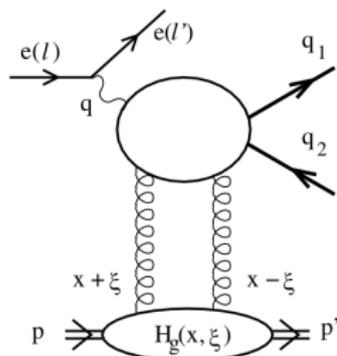


Figure 1: Kinematics of heavy vector meson photoproduction.

### ► 2 jets

Braun, Ivanov

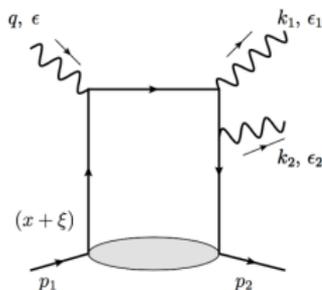


## Other channels

Two particle final states:

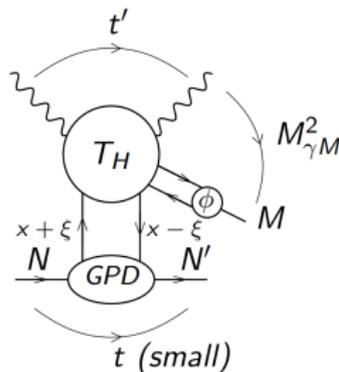
- ▶  $2\gamma$  electro- and photo-production

Grocholski, Pedrak, Pire, Szymanowski, Sznajder, JW



- ▶  $\gamma M$  and  $MN$  pairs:

Duplančić, Saad Nabeebaccus, Passek-Kumerički, Pire, Szymanowski, Wallon



## Limited and enhanced sensitivity

- ▶ Most of those processes (at least at LO) are sensitive only to  $x = \xi$  line
- ▶ Non-invertability (Shadow GPDs and shedding light on them)

Bertone, Dutrioux, Mezrag, Moutarde, Sznajder

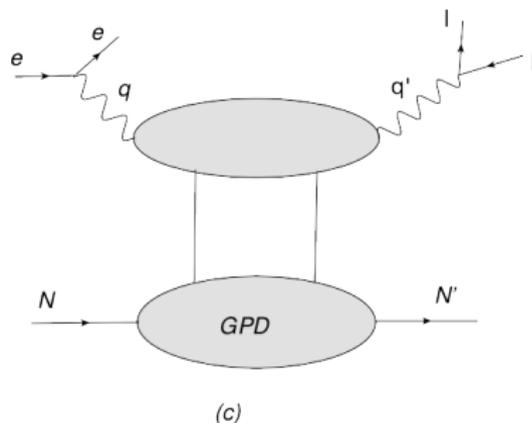
- ▶ Another possible source of information about  $x \neq \xi$  - lattice
- ▶ Other ideas: processes with more particles in the final states.

J.Qiu,Z.Yu

- ▶ Possible problems with factorization in the gluon exchange channel reported recently:

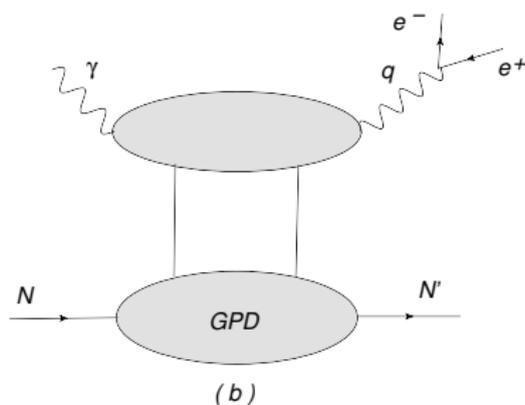
Nabeebaccus, Schönleber, Szymanowski, Wallon - 2311.09146

- ▶ Simplest:



Double Deeply Virtual Compton Scattering (DDVCS):  $\gamma N \rightarrow l^+ l^- N'$

- ▶ Proposed in:
  - Belitsky & Muller, PRL 90, 022001 (2003)
  - Guidal & Vanderhaeghen, PRL 90, 012001 (2003)
  - Belitsky & Muller, PRD 68, 116005 (2003)
- ▶ No problems with factorization.



Timelike Compton Scattering (TCS):  $\gamma N \rightarrow l^+ l^- N'$

Why TCS:

- ▶ universality of the GPDs
- ▶ another source for GPDs (special sensitivity on real part of GPD  $H$ )
- ▶ first step towards DDVCS
- ▶ spacelike-timelike crossing (different analytic structure - cut in  $Q^2$ )

## Spacelike vs Timelike

D.Mueller, B.Pire, L.Szymanowski, J.Wagner, Phys.Rev.D86, 2012.

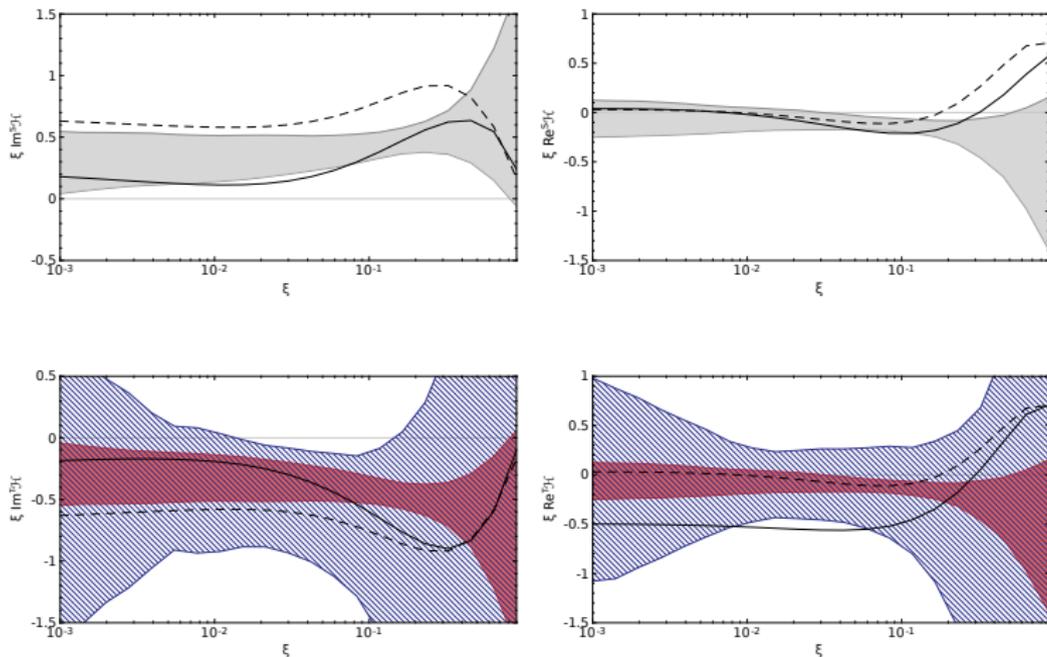
Thanks to simple spacelike-to-timelike relations, we can express the timelike CFFs by the spacelike ones in the following way:

$$\begin{aligned} T\mathcal{H} &\stackrel{\text{LO}}{=} S\mathcal{H}^*, \\ T\tilde{\mathcal{H}} &\stackrel{\text{LO}}{=} -S\tilde{\mathcal{H}}^*, \\ T\mathcal{H} &\stackrel{\text{NLO}}{=} S\mathcal{H}^* - i\pi Q^2 \frac{\partial}{\partial Q^2} S\mathcal{H}^*, \\ T\tilde{\mathcal{H}} &\stackrel{\text{NLO}}{=} -S\tilde{\mathcal{H}}^* + i\pi Q^2 \frac{\partial}{\partial Q^2} S\tilde{\mathcal{H}}^*. \end{aligned}$$

The corresponding relations exist for (anti-)symmetric CFFs  $\mathcal{E}$  ( $\tilde{\mathcal{E}}$ ).

# DVCS vs TCS CFFs

O. Grocholski, H. Moutarde, B. Pire, P. Sznajder, J. Wagner, Eur.Phys.J. C80 (2020)



Imaginary (left) and real (right) part of DVCS (up) and TCS (down) CFF for  $Q^2 = 2 \text{ GeV}^2$  and  $t = -0.3 \text{ GeV}^2$  as a function of  $\xi$ . The shaded red (dashed blue) bands correspond to the data-driven predictions coming from the ANN global fit of DVCS data and they are evaluated using LO (NLO) spacelike-to-timelike relations. The dashed (solid) lines correspond to the GK GPD model evaluated with LO (NLO) coefficient functions.

## Experimental status

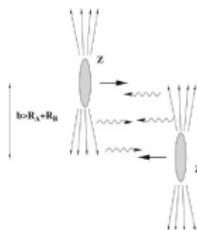
- ▶ First measurement: P. Chatagnon et al. (CLAS), PRL 127, 262501 (2021)

PHYSICAL REVIEW LETTERS 127, 262501 (2021)

### First Measurement of Timelike Compton Scattering

P. Chatagnon<sup>20,\*</sup>, S. Nicolai,<sup>20</sup> S. Stepanyan,<sup>36</sup> M.J. Amarian,<sup>29</sup> G. Angelini,<sup>12</sup> W.R. Armstrong,<sup>1</sup> H. Atac,<sup>35</sup>  
C. Ayerbe Gayoso,<sup>44,†</sup> N.A. Baltzell,<sup>36</sup> L. Barion,<sup>13</sup> M. Bashkanov,<sup>42</sup> M. Battaglieri,<sup>36,15</sup> I. Bedlinskiy,<sup>25</sup> F. Benmokhtar,<sup>7</sup>  
A. Bianconi,<sup>39,19</sup> L. Biondo,<sup>15,18,40</sup> A.S. Biselli,<sup>8</sup> M. Bondi,<sup>15</sup> F. Bossù,<sup>3</sup> S. Boiarinov,<sup>36</sup> W.J. Briscoe,<sup>12</sup> W.K. Brooks,<sup>37,36</sup>

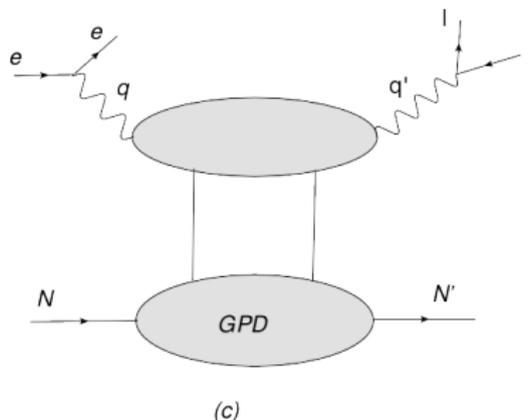
- ▶ TCS has the same final state as  $J/\psi$ , already measured in UPCs! LHCb, CMS, ALICE, AFTER



$$\sigma^{AB} = \int dk_A \frac{dn^A}{dk_A} \sigma^{\gamma B}(W_A(k_A)) + \int dk_B \frac{dn^B}{dk_B} \sigma^{\gamma A}(W_B(k_B))$$

- ▶ Measurement of TCS should also make us **more optimistic** about **DDVCS!**

## Double DVCS



Double Deeply Virtual Compton Scattering (**DDVCS**):  $\gamma^* N \rightarrow l^+ l^- N'$

$$\gamma^*(q_{in})N(p) \rightarrow \gamma^*(q_{out})N'(p')$$

Variables, describing the processes of interest in this generalized Bjorken limit, are the **scaling variable**  $\xi$  and **skewness**  $\eta > 0$ :

$$\xi = -\frac{q_{out}^2 + q_{in}^2}{q_{out}^2 - q_{in}^2} \eta, \quad \eta = \frac{q_{out}^2 - q_{in}^2}{(p + p') \cdot (q_{in} + q_{out})}.$$

- ▶ **DDVCS**:  $q_{in}^2 < 0$ ,  $q_{out}^2 > 0$ ,  $\eta \neq \xi$
- ▶ **DVCS**:  $q_{in}^2 < 0$ ,  $q_{out}^2 = 0$ ,  $\eta = \xi > 0$
- ▶ **TCS**:  $q_{in}^2 = 0$ ,  $q_{out}^2 > 0$ ,  $\eta = -\xi > 0$

## Coefficient functions and Compton Form Factors

CFFs are the GPD dependent quantities which enter the amplitudes. They are defined through relations:

$$\mathcal{A}^{\mu\nu}(\xi, \eta, t) = -e^2 \frac{1}{(P+P')^+} \bar{u}(P') \left[ g_T^{\mu\nu} \left( \mathcal{H}(\xi, \eta, t) \gamma^+ + \mathcal{E}(\xi, \eta, t) \frac{i\sigma^{+\rho} \Delta_\rho}{2M} \right) + i\epsilon_T^{\mu\nu} \left( \tilde{\mathcal{H}}(\xi, \eta, t) \gamma^+ \gamma_5 + \tilde{\mathcal{E}}(\xi, \eta, t) \frac{\Delta^+ \gamma_5}{2M} \right) \right] u(P),$$

,where:

$$\begin{aligned} \mathcal{H}(\xi, \eta, t) &= + \int_{-1}^1 dx \left( \sum_q T^q(x, \xi, \eta) H^q(x, \eta, t) + T^g(x, \xi, \eta) H^g(x, \eta, t) \right) \\ \tilde{\mathcal{H}}(\xi, \eta, t) &= - \int_{-1}^1 dx \left( \sum_q \tilde{T}^q(x, \xi, \eta) \tilde{H}^q(x, \eta, t) + \tilde{T}^g(x, \xi, \eta) \tilde{H}^g(x, \eta, t) \right). \end{aligned}$$

► DVCS vs TCS

$$\begin{aligned} {}^{DVCS}T^q &= -e_q^2 \frac{1}{x+\eta-i\epsilon} - (x \rightarrow -x) = ({}^{TCS}T^q)^* \\ {}^{DVCS}\tilde{T}^q &= -e_q^2 \frac{1}{x+\eta-i\epsilon} + (x \rightarrow -x) = -({}^{TCS}\tilde{T}^q)^* \end{aligned}$$

$${}^{DVCS}Re(\mathcal{H}) \sim P \int \frac{1}{x \pm \eta} H^q(x, \eta, t), \quad {}^{DVCS}Im(\mathcal{H}) \sim i\pi H^q(\pm\eta, \eta, t)$$

► DDVCS

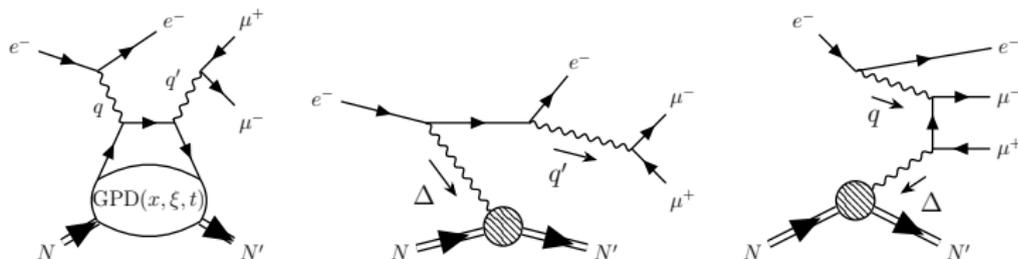
$${}^{DDVCS}T^q = -e_q^2 \frac{1}{x+\xi-i\epsilon} - (x \rightarrow -x)$$

$${}^{DDVCS}Re(\mathcal{H}) \sim P \int \frac{1}{x \pm \xi} H^q(x, \eta, t), \quad {}^{DVCS}Im(\mathcal{H}) \sim i\pi H^q(\pm\xi, \eta, t)$$

## DDVCS - our calculation

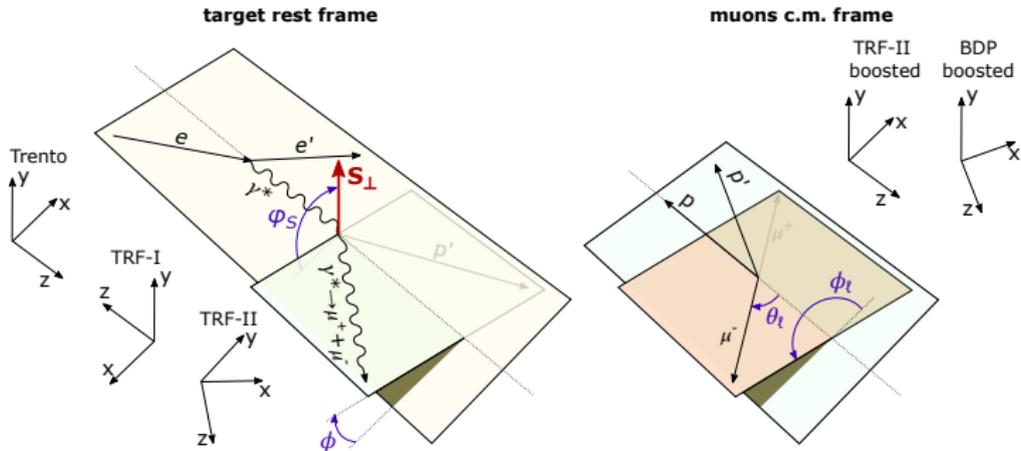
Deja, Martínez-Fernández, Pire, Sznajder, JW, **PRD 107 (2023)**

- ▶ In the view of new experiments, revisiting DDVCS is timely
- ▶ DDVCS is a subprocess in the electroproduction of a lepton pair



(from left to right) DDVCS, BH1, BH2.

- ▶ **Muon** detection crucial
- ▶ New calculation using KS techniques Kleiss & Stirling, Nuclear Physics B262 (1985) 235-262



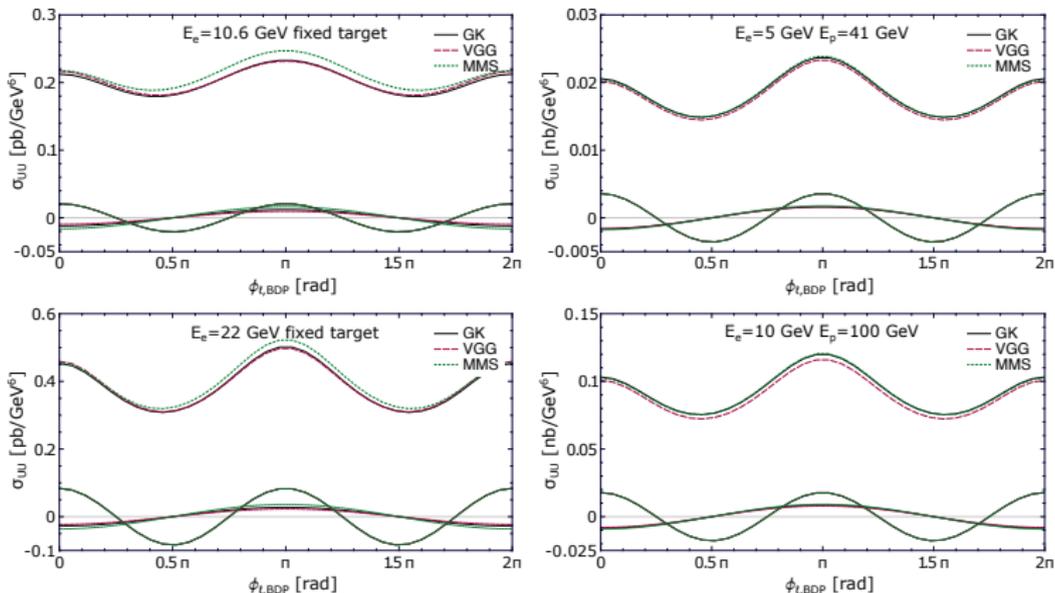
(left) Frame with initial proton at rest and transverse component of target polarisation vector,  $\vec{S}_\perp$ , defined with respect to the incoming virtual photon. (right) Produced lepton pair center of mass frame.

Cross-section:

$$\frac{d^7\sigma}{dx_B dQ^2 dQ'^2 d|t| d\phi d\Omega_\ell} = \frac{\alpha_{\text{em}}^4}{16(2\pi)^3} \frac{x_B y^2}{Q^4 \sqrt{1 + \varepsilon^2}} \left| \frac{\mathcal{M}}{e^4} \right|^2,$$

## Observables: cross-section

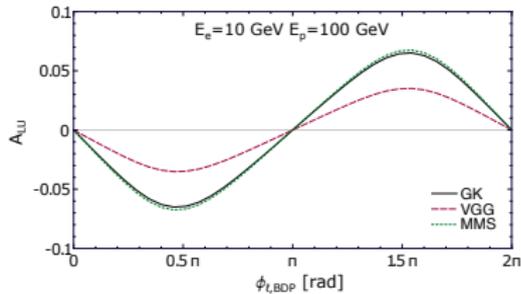
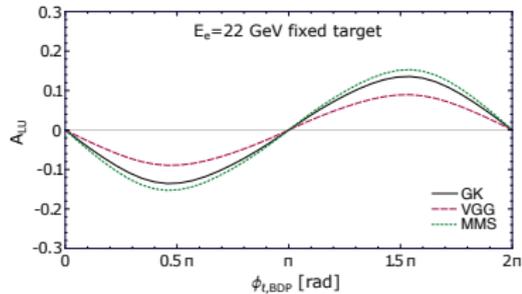
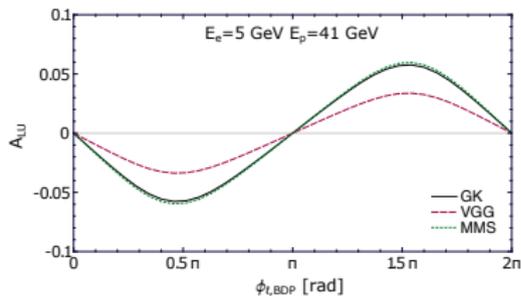
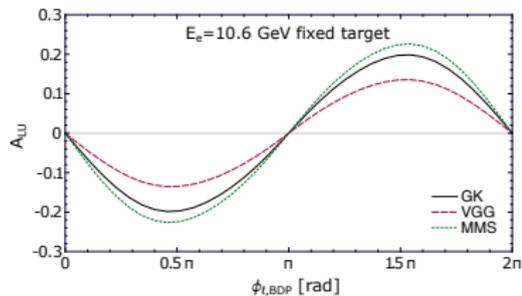
- ▶ We consider  $Q'^2 > Q^2$ : our DDVCS is “more” timelike than spacelike



JLab12, JLab20+		EIC 5x41, EIC 10x100			
Experiment	Beam energies [GeV]	$y$	$ t $ [GeV <sup>2</sup> ]	$Q^2$ [GeV <sup>2</sup> ]	$Q'^2$ [GeV <sup>2</sup> ]
JLab12	$E_e = 10.6, E_p = M$	0.5	0.2	0.6	2.5
JLab20+	$E_e = 22, E_p = M$	0.3	0.2	0.6	2.5
EIC	$E_e = 5, E_p = 41$	0.15	0.1	0.6	2.5
EIC	$E_e = 10, E_p = 100$	0.15	0.1	0.6	2.5



# Observables: beam-spin asymmetry



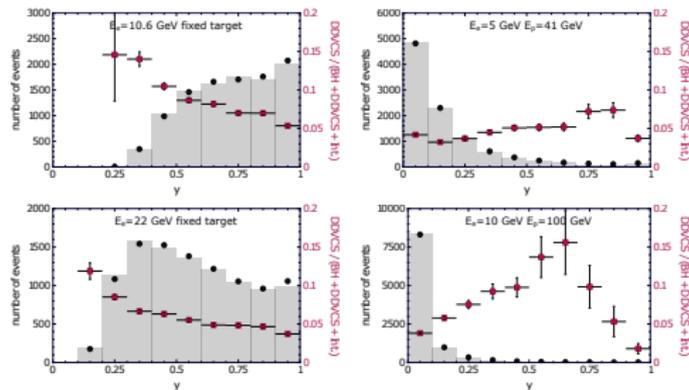
JLab12, JLab20+: up to **15-20%**

EIC 5x41, EIC 10x100: **3-7%**

Experiment	Beam energies [GeV]	$y$	$ t $ [GeV <sup>2</sup> ]	$Q^2$ [GeV <sup>2</sup> ]	$Q'^2$ [GeV <sup>2</sup> ]
JLab12	$E_e = 10.6, E_p = M$	0.5	0.2	0.6	2.5
JLab20+	$E_e = 22, E_p = M$	0.3	0.2	0.6	2.5
EIC	$E_e = 5, E_p = 41$	0.15	0.1	0.6	2.5
EIC	$E_e = 10, E_p = 100$	0.15	0.1	0.6	2.5

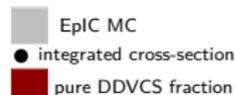


# Monte Carlo study: distribution in $y$



JLab12, JLab20+

EIC 5x41, EIC 10x100



Kinematic cuts:  
 $Q^2 \in (0.15, 5) \text{ GeV}^2$   
 $Q'^2 \in (2.25, 9) \text{ GeV}^2$   
 JLab:  $-t \in (0.1, 0.8) \text{ GeV}^2$   
 EIC:  $-t \in (0.01, 1) \text{ GeV}^2$   
 $\phi, \phi_\ell \in (0.1, 2\pi - 0.1) \text{ rad}$   
 $\theta_\ell \in (\pi/4, 3\pi/4) \text{ rad}$   
 JLab:  $y \in (0.1, 1)$   
 EIC:  $y \in (0.05, 1)$

10000 events/distribution. Neither acceptance nor detectors response are taken into account in this study

Experiment	Beam energies [GeV]	Range of $ t $ [GeV <sup>2</sup> ]	$\sigma _{0 < y < 1}$ [pb]	$\mathcal{L}^{10k} _{0 < y < 1}$ [fb <sup>-1</sup> ]	$y_{\min}$	$\sigma _{y_{\min} < y < 1} / \sigma _{0 < y < 1}$
JLab12	$E_e = 10.6, E_p = M$	(0.1, 0.8)	0.14	70	0.1	1
JLab20+	$E_e = 22, E_p = M$	(0.1, 0.8)	0.46	22	0.1	1
EIC	$E_e = 5, E_p = 41$	(0.05, 1)	3.9	2.6	0.05	0.73
EIC	$E_e = 10, E_p = 100$	(0.05, 1)	4.7	2.1	0.05	0.32



## Summary

- ▶ DDVCS is a theoretically clean channel for accessing GPDs, with no known factorization problems, no other nonperturbative input, generalizing both DVCS and TCS.
- ▶ It provides direct sensitivity to the  $x \neq \xi$  line.
- ▶ Predicted observables are promising at both JLab and the EIC.
- ▶ Muon detection crucial.
- ▶ Recent TCS progress strengthens the case for future DDVCS measurements.