Revisiting DDVCS for phenomenological studies

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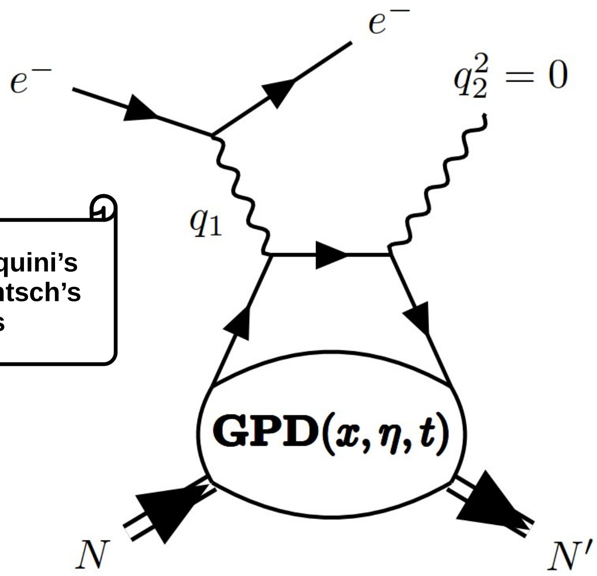
Improving PDF's **1D** picture

- In the late '90s, Ji, Müller and Radyushkin introduced Generalized Parton Distributions (GPDs) through Deeply Virtual Compton Scattering (DVCS) process

- **The point is to study the conversion of a virtual photon into a real one instead of DIS (where xsec is factorized via PDFs)**

cf. Dr. Pasquini's and Dr. Jentsch's talks



$$t = \Delta^2 = (p_2 - p_1)^2, \quad \eta = -\frac{q\Delta}{pq},$$

$$q = \frac{q_1 + q_2}{2}, \quad p = p_1 + p_2$$

DVCS at JLab:
https://doi.org/10.1103/PhysRevC.92.055202

DVCS = exclusive process = factoriz. in amplitude

Sketch of DVCS amplitude (LO)

$$\begin{aligned}\mathcal{A}_{\mathrm{DVCS}} &\sim \int_{-1}^{1} dx\, \frac{1}{x-\eta+i0} \mathrm{GPD}(x,\eta,t) + \cdots \\ &= \mathrm{PV}\left(\int_{-1}^{1} dx \frac{1}{x-\eta} \mathrm{GPD}(x,\eta,t)\right) - \int_{-1}^{1} dx\; i\pi\delta(x-\eta)\mathrm{GPD}(x,\eta,t) + \cdots\end{aligned}$$

So we can measure GPDs at $x = \eta$ only, i.e., we can access $\mathrm{GPD}(\eta,\eta,t)$

Dispersion relation: real part can be computed in terms of the imaginary one

$$\Re e\mathcal{A}(\eta,t) = \mathrm{PV}\left(\int_{-1}^{1} d\eta' \frac{\Im m\mathcal{A}(\eta',t)}{\eta'-\eta}\right) + D(t)$$

GPD definition: 3D distribution

$$\mathrm{GPD}(x,\eta,t) = \frac{1}{2}\int \frac{dz^+}{2\pi} e^{ixp^- z^+} \langle P'|\bar{q}_f(-z/2)\gamma^+ \mathcal{W}[-z/2, z/2] q_f(z/2)|P\rangle\Big|_{z_\perp = z^- = 0}$$

Measurement of the variation in proton’s longitudinal momentum

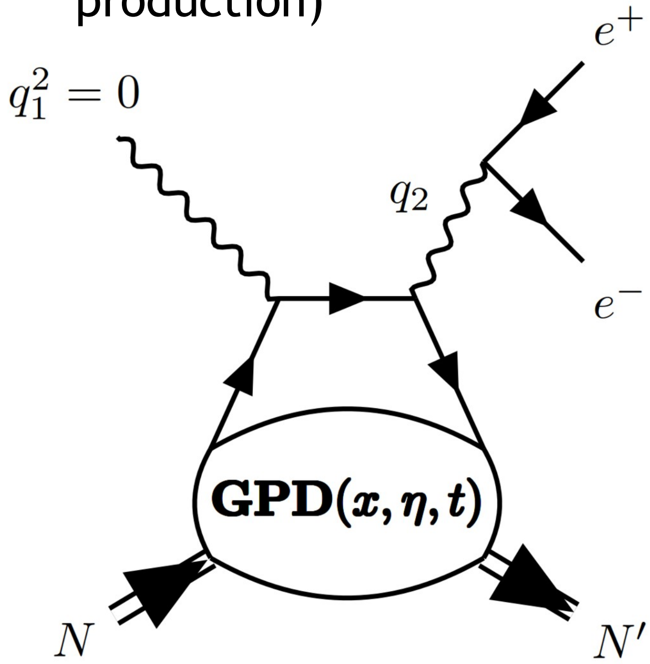
Mandelstam variable

Nucleon tomography via Fourier transform in the plane transverse to proton motion

Other "golden channels" for GPDs

(but experimentally more challenging)

- TCS or timelike Compton scattering
- Counterpart of DVCS
- A real photon transforms into a virtual one (lepton photo-production)



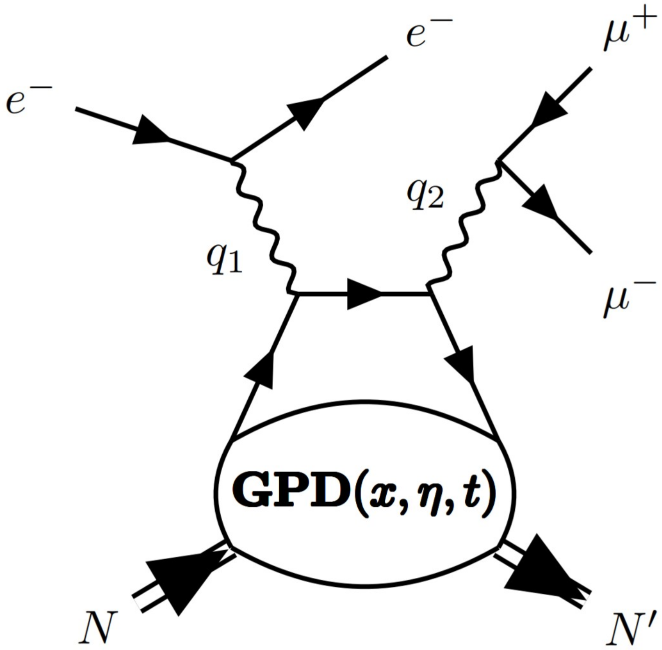
1st measurement of TCS:
https://doi.org/10.1103/PhysRevLett.127.262501

**cf.
Dr. Pasquini's
talks**

Other “golden channels” for GPDs

(but experimentally more challenging)

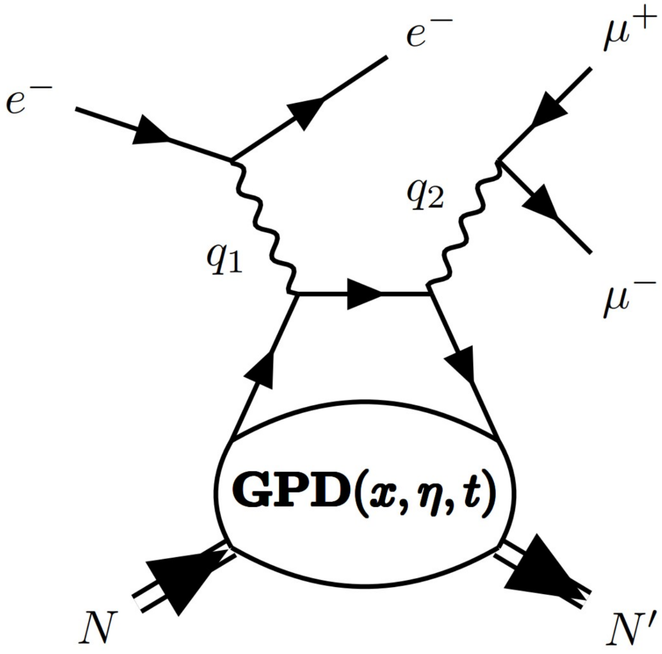
- DDVCS or double DVCS
- 2 virtual photons: spacelike (incoming) and timelike (outgoing)
- **DDVCS: we want to study its feasibility at JLab12 and EIC**



Other “golden channels” for GPDs

(but experimentally more challenging)

- DDVCS or double DVCS
- 2 virtual photons: spacelike (incoming) and timelike (outgoing)
- **Allows to measure GPDs for x ≠ ±η**



Sketch of DDVCS amplitude (LO)

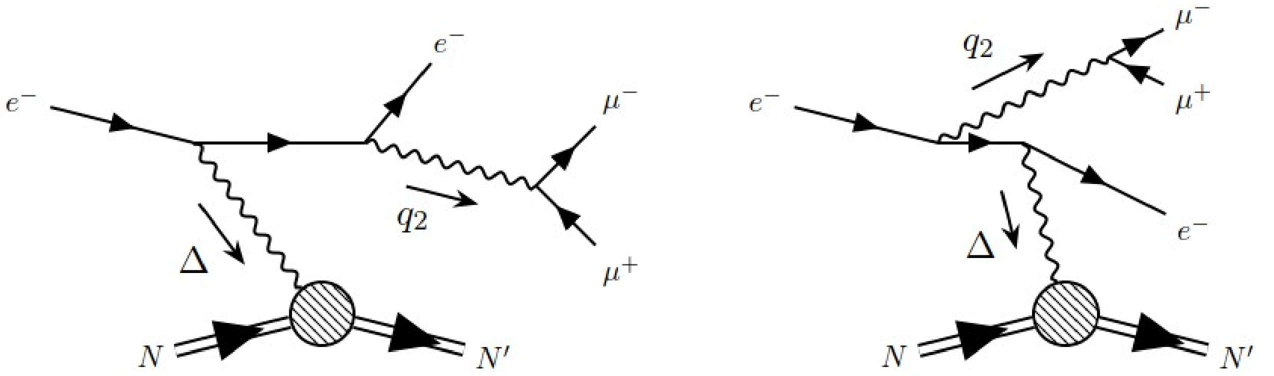
$$\mathcal{A}_{\mathrm{DDVCS}} \sim \int_{-1}^{1} dx\, \frac{1}{x-\xi+i0} \mathrm{GPD}(x,\eta,t) + \cdots$$
$$= \mathrm{PV}\left(\int_{-1}^{1} dx \frac{1}{x-\xi} \mathrm{GPD}(x,\eta,t)\right) - \int_{-1}^{1} dx\; i\pi\delta(x-\xi)\mathrm{GPD}(x,\eta,t) + \cdots$$

So now we can access $\mathrm{GPD}(\xi,\eta,t)$

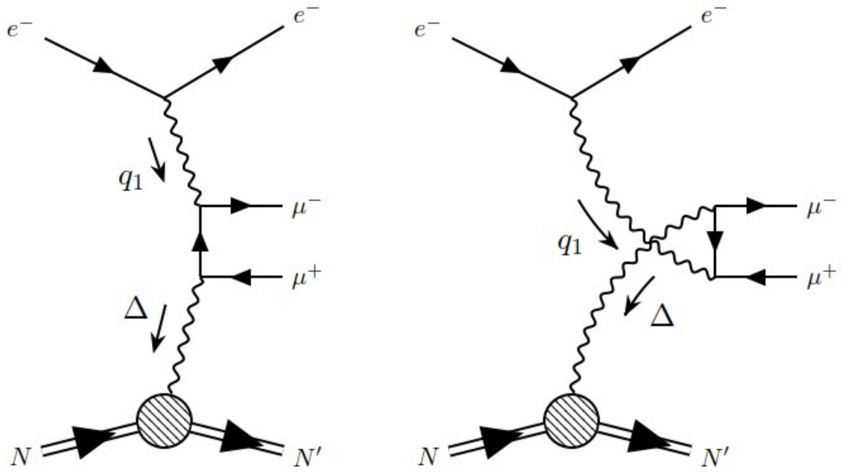
$$\xi = \frac{-q^2}{pq}$$

Not only VCS but also **BH (pure QED)**

BH1 + BH1-crossed =



BH2 + BH2-crossed =



Kleiss and Stirling methods: the basics

- Xsec of DDVCS was already obtained in https://doi.org/10.1103/PhysRevLett.90.012001

- We rederive formulae in a way more suitable for phenomenology: Kleiss & Stirling's spinor techniques (KS)
- **The idea of KS**: compute amplitudes, not the modulus squared of them
- Transform spinor products into new scalars *s* and *t* **(prevents the use of traces of Dirac gamma matrices)**:

$$s(p_1,p_2) := \bar{u}_+(p_1)u_-(p_2) = -s(p_2,p_1)$$

$$t(p_1,p_2) := \bar{u}_-(p_1)u_+(p_2) = [s(p_2,p_1)]^*$$

$$s(p_1,p_2) = (p_1^y + ip_1^z)\sqrt{\frac{p_2^0 - p_2^x}{p_1^0 - p_1^x}} - (p_2 \leftrightarrow p_1)$$

KS' paper: https://doi.org/10.1016/0550-3213(85)90285-8

Specialized softwares used in this study

- PARTONS platform: open-source C++ program
  - Contains several GPD models
  - Leading twist… but higher twist corrections will be included in near future
  - Useful for theorists and experimentalists
  - Provides xsecs, Compton Form Factors, etc
  - DVCS, TCS and DVMP are already included

PARtonic Tomography Of Nucleon Software

To download and for tutorials

http://partons.cea.fr

For detail description of architecture see:

Eur. Phys. J. C78 (2018), 478

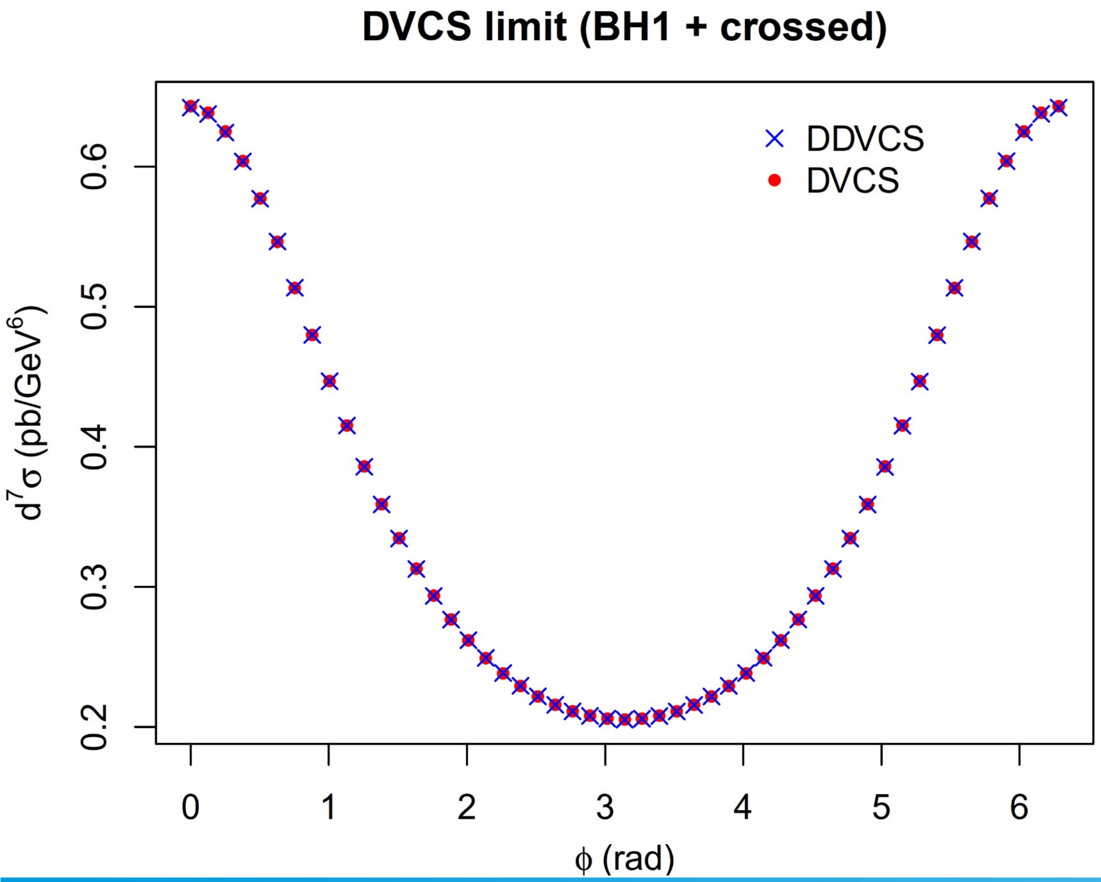
Specialized softwares used in this study

- EpIC Monte Carlo event generator in C++
  - Uses PARTONS framework
  - Includes radiative corrections
  - Generates the kinematic configurations following the probability distributions given by PARTONS
  - DVCS, TCS and DVMP are already included

Access EpIC via GitHub:
https://github.com/pawelsznajder/epic

Detail description and architecture:
arXiv:2205.01762 [hep-ph]

Preliminary results: DVCS & TCS limits of DDVCS



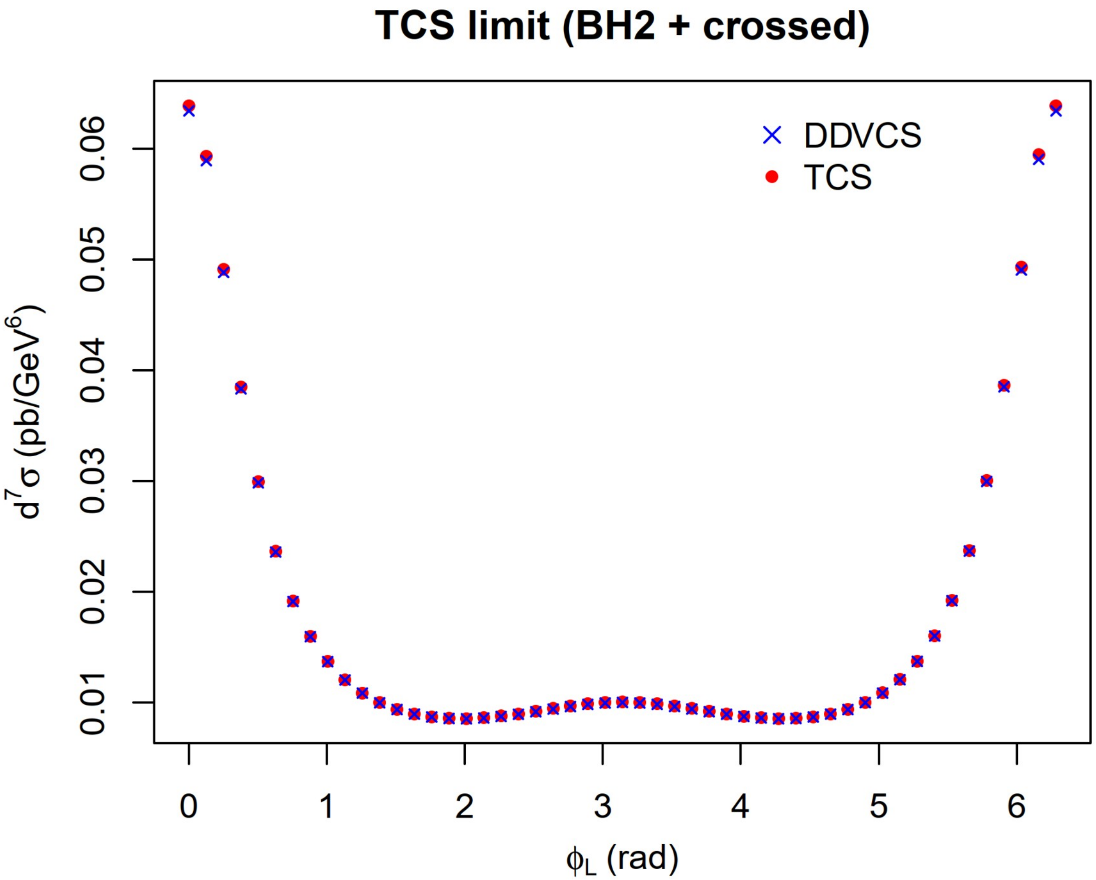
$x_B = 0.04$, $t = -0.1$, $-q_1^2 = 10$, $q_2^2 \approx 0.001$,
$E_{beam} = 160$
(energy units: GeV)

DVCS formulae:

https://doi.org/10.1016/S0550-3213%2802%2900144-X

https://doi.org/10.48550/arXiv.1212.6674

Preliminary results: DVCS & TCS limits of DDVCS



$x_B = 2\cdot10^{-4}$, $t = -0.5$, $-q_1^2 = 2\cdot10^{-3}$, $q_2^2 = 1$, $E_{beam} = 12$
(energy units: GeV)

TCS formulae:
https://doi.org/10.1007/s100520200917

Summary

- We reviewed GPDs through DVCS, TCS and DDVCS.
- We understood the importance of DDVCS: measurement of GPDs for $x \neq \eta$ (at LO).
- KS methods were introduced as a powerful tool to compute Feynman diagrams and xsecs avoiding traces of Dirac gamma matrices.
- It was shown that the calculation done via KS formalism (for BH contribution) produces the right xsecs in the DVCS and TCS limits of DDVCS.
- PARTONS platform and EpIC Monte Carlo generator were introduced as the softwares used for the phenomenological study. Their advantages were discussed.