Deeply Virtual Compton Scattering – Analysis updates

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Exclusive, Diffractive and Tagging PWG meeting
27/07/26

This presentation

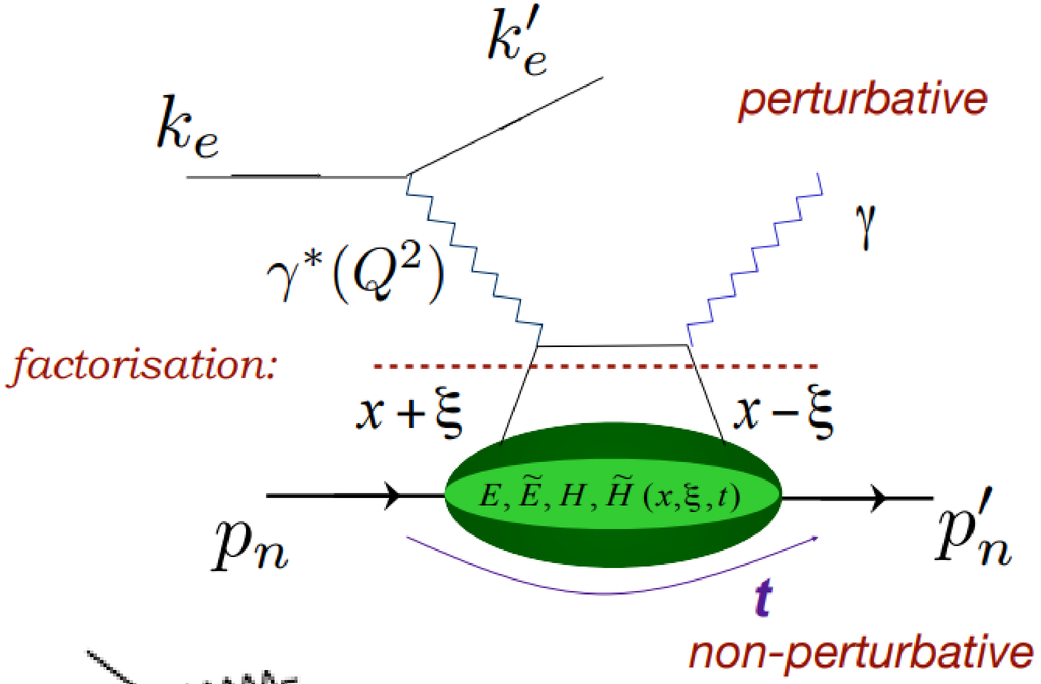
- Overview of DVCS simulation studies
- Update to 3D binning scheme

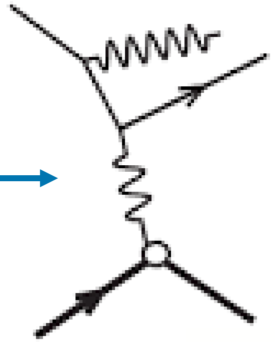
Deeply Virtual Compton Scattering

Deeply Virtual Compton Scattering

- Electroproduction of a single photon off a hadron target.
  - $ep \rightarrow e'p'\gamma$
  - Simplest inelastic channel the EIC can study.
  - Easiest channel for probing GPDs.

- The cross-section for this process is related to its matrix element, $|\mathcal{T}|^2$.
  - $|\mathcal{T}|^2 = |\mathcal{T}_{DVCS}|^2 + |\mathcal{T}_{BH}|^2 + \mathcal{I}$
  - $\mathcal{I}$ is an interference term.
  - Bethe-Heitler: purely EM process, which does not probe partonic content.





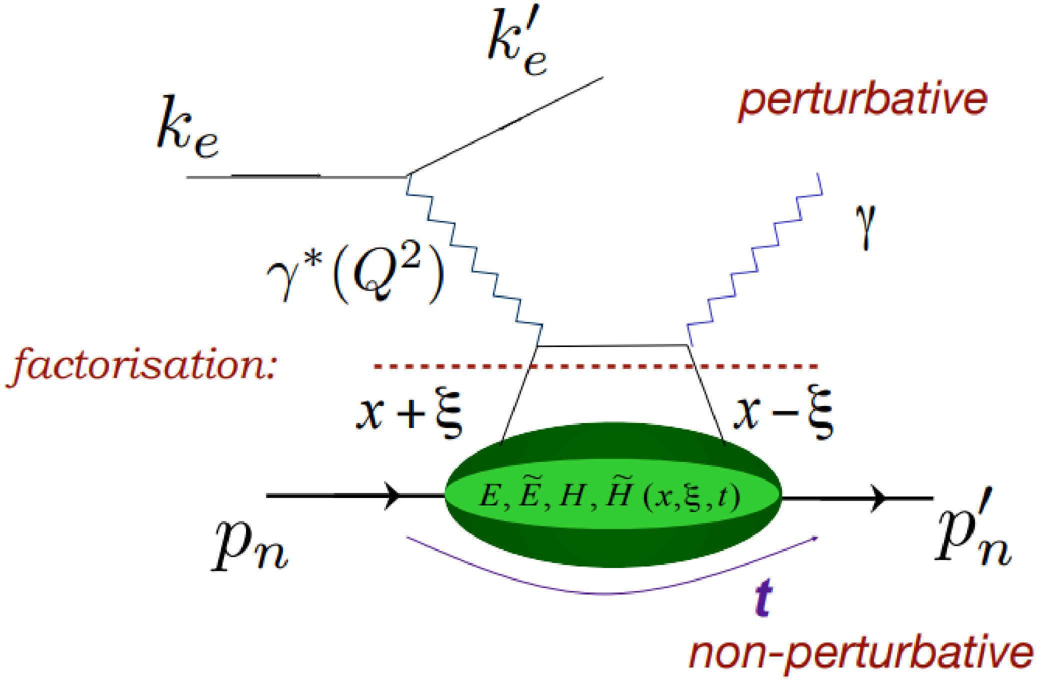
Deeply Virtual Compton Scattering

- Default kinematics:
  - $e(k) + p(p) \to e'(k') + p'(p') + \gamma$

$$Q^2 = -q^2 = -(k-k')^2 \qquad x = \frac{Q^2}{2q.p}$$

$$y = \frac{q.p}{k.p} \qquad \xi = \frac{x}{2-x} \approx \frac{x}{2}$$

$$t = (p-p')^2$$



- Other formulae exist, using other combinations of reconstructed quantities, if needed (e.g. see InclusiveKinematics branches in EICrecon trees).

DVCS simulations

Simulation details - current

- Current analysis efforts on EpIC v1.1.6 samples detailed previously.
  - Unpolarized protons, longitudinally polarized electrons
  - Full DVCS+BH+int. process
  - ~1/5 expected luminosity from early science beams

- New samples have been generated for 26.07.1 campaign (9 GeV electron beam).
  - EpIC v1.1.8
  - All possible combinations of electron (long.) and proton (long./trans.) polarizations
  - Kinematics as for EpIC v1.1.6 sample; full early science lumi

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DVCS in 26.07.1 campaign has been run
Analysis yet to be processed

3D binning

3D binning

- Initial binning based off 2025 EIC DVCS paper.
  - 8 Q^2 bins, 11 x_B bins, 14 $|t|$ bins
  - Constant bin edges

- Plenty of statistics at low Q^2 and low x_B, but this drops off quickly.
  - No bins with decent stats from protons in B0 (at high-t).

- Want to redo binning scheme to equalise statistics.

New scheme - philosophy

- Want to try and get at least ~1000 events in each 3D bin.
  - Get ~10% of generated events passing all fully-exclusive cuts.
  - ONLY considering fully-exclusive events for asymmetries (for now).
- Keep events from protons in B0 separate from those in Roman Pots for binning.
- Focus binning on areas away from likely BH kinematics.
  - Bethe-Heitler events have singularity at $\phi \sim 0/2\pi$
  - When filling histograms, weight by $\sin^2\phi$ to avoid bias towards BH events
- Process uses 1D Q^2 histogram and 2D x_B:$|t|$ histograms for each Q^2 range

New scheme - process

1) Divide Q^2 range into 3
   - Equal number of events in each.
2) For each bin in Q^2, do the following:
   i. For protons in B0 (high-t), use only 1 t-bin (base “high-t” cutoff from gap in t-coverage).
      - If N_{ev} < ~2000, use 1 x bin. Otherwise, split to get ~1000 events per bin in x.
   ii. For protons in RP, process is more involved.
      - Project 2D histo along x_B
      - Split into bins of ~4000 entries
      - For each bin in x_B, project 2D histo along $|t|$
      - Split into 4 equal bins

New scheme – results (10x130, old DVCS sample)

- 3 Q^2 bins: {1., 1.4, 2.5, 100} GeV^2
- High-t: 1 bin for each Q^2 range
  - x_B: {0, 1}; |t|: {0.45, 2.} GeV^2
- Low-t: typically, 3/4 x_B bins, 4 |t| bins per x_B
  - |t| bin edges relatively consistent (v. slight variations between x/Q^2 bins – details in backup): ~ {0, 0.1, 0.15, 0.25, 2.} GeV^2
  - x_B bins – trend to higher x with higher Q^2
    - Low-Q^2: x_B – {0, 3.2e-4, 4.6e-4, 1}
    - Mid-Q^2: x_B – {0, 4.6e-4, 6e-4, 1}
    - High-Q^2: x_B – {0, 9.4e-4, 1.44e-3, 2.54e-3, 1}

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- Low-t: typically, 3/4
  - |t| bin ed ... ins –

Effect of binning not yet tested
Will need to be redone for new samples

...4, 1}
..., 9.4e-4, 1.44e-3, 2.54e-3, 1}

Concluding remarks

Next steps

- Process for 3D binning now in place.
- Preliminary bins decided for old (26.02.0 - 26.04.1) dataset.
  - Still yet to check effect of binning scheme – complex to implement!

- 26.07.1 campaign run a.o. 27th July (email from Sakib @ 08:10 EST) with full combinations of polarization states.
  - Again, yet to check this – will be done as soon as possible.

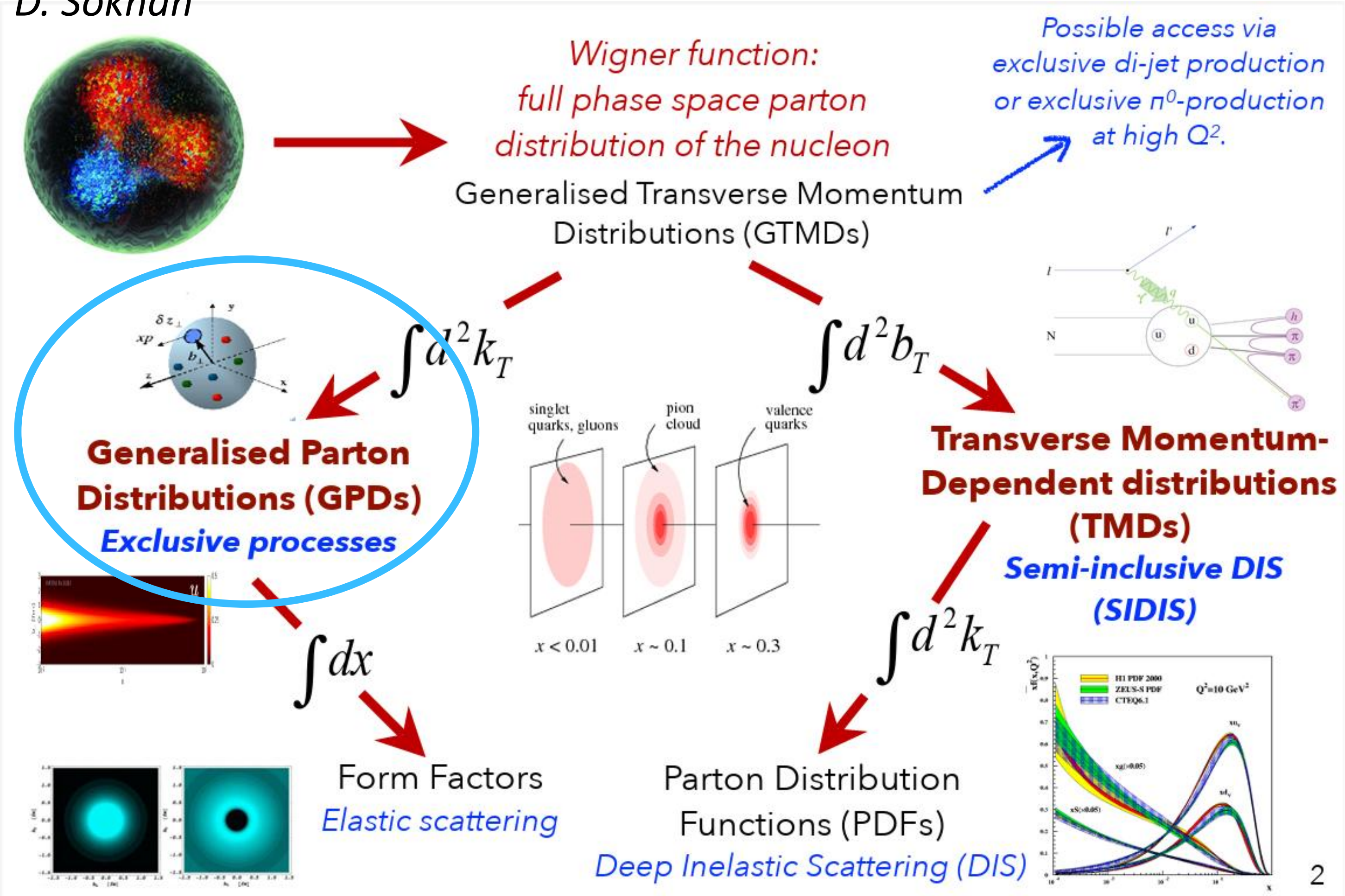
Thank you for listening!

Any questions?

Backup

Nucleon structure

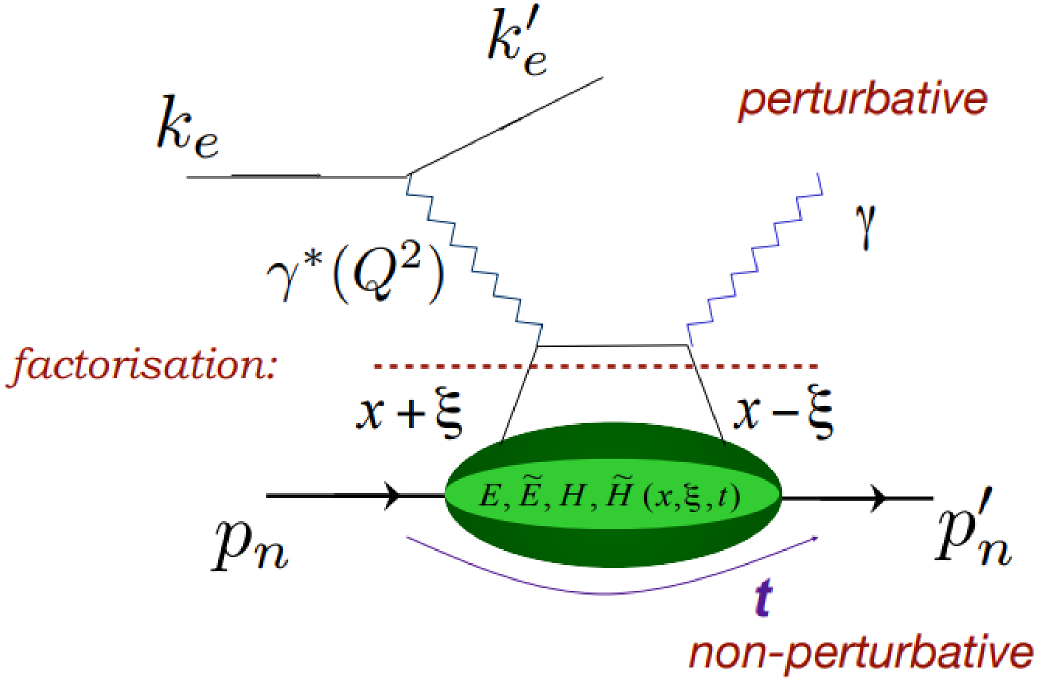
D. Sokhan



- Nucleon structure can be described within multiple dimensions by a large number of different functions.
  - GTMDs – full 5D phase space distributions.
  - PDFs – 1D as function of parton momentum.
  - Form factors – 1D as function of transverse distance from centre.
- GPDs relate the transverse position of partons to their longitudinal momentum fraction.

Deeply Virtual Compton Scattering

- DVCS amplitude can be parameterized in terms of Compton Form Factors (CFFs).
  - Experimentally accessible!
  - Access 4 quark GPDs: H_q, $\widetilde{H}_q$, E_q, $\tilde{E}_q$.
  - Note: does not access GPDs directly, but linear combinations of GPDs.
- $Re\ \mathcal{F}_q(\xi,t) \propto \int_0^1 [F_q(x,\xi,t) - F_q(-x,\xi,t)]dx$
- $Im\ \mathcal{F}_q(\xi,t) \propto [F_q(\xi,\xi,t) - F_q(-\xi,\xi,t)]$
- Different combinations of (un)polarised beam and target are sensitive to different combinations of CFFs.



Extract CFFs from asymmetries between different beam polarisation states!

Why DVCS @ ePIC?

- Amongst the EIC's physics goals are:
  - Probing the 3D structure of nucleons.
  - Solving the mystery of proton spin.

- For an unpolarised target, the distribution of unpolarised quarks is the Fourier transform of the GPD H_q.

$$q(x, b_\perp) = \int \frac{d^2\Delta_\perp}{(2\pi)^2} e^{-ib_\perp\Delta_\perp} H_q(x, 0, t = -\Delta_\perp{}^2)$$

Why DVCS @ ePIC?

- Amongst the EIC's physics goals are:
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  - Solving the mystery of proton spin.

- By Ji's Sum Rule, quark angular momentum can be given by a combination of GPDs.

$$J = \frac{1}{2}\int_{-1}^{1} x dx [H(x,\xi,t=0) + E(x,\xi,t=0)]$$

Why DVCS @ ePIC?

- The final state of the DVCS reaction will utilise many of the subsystems present in ePIC and provide useful probes of their resolutions.
  - The scattered proton will only be deflected by a small angle and will end up in the far forward region.
    - Tests B0 spectrometer and Roman Pots.
  - The scattered electron will be detected in the central barrel or (mostly) the backward endcap.
    - Test of trackers, PID detectors and calorimeters almost everywhere in the barrel (just not hadron endcap/planes).
  - The scattered photon will be detected in the backward endcap.
    - Very clean test of EEEMCAL resolution.

Full binning

- Q^2 bins: {1., 1.4, 2.5, 100} GeV^2
- All Q^2 ranges – 1 x_B bin for B0 protons (x_B: {0, 1}; |t|: {0.45, 2.} GeV^2)
- Q^2 {1, 1.4} GeV^2
  - x_B: {0, 0.00032, 0.00046, 1}
  - |t|: {{0, 0.08, 0.14, 0.28, 2};
    {0, 0.08, 0.14, 0.26, 2};
    {0, 0.1, 0.16, 0.26, 2}} GeV^2
- Q^2 {1.4, 2.5} GeV^2
  - x_B: {0, 0.00046, 0.0006, 1}
  - |t|: {{0, 0.08, 0.14, 0.26, 2};
    {0, 0.08, 0.14, 0.26, 2};
    {0, 0.1, 0.14, 0.24, 2}} GeV^2
- Q^2 {2.5, 100} GeV^2
  - x_B: {0, 0.00094, 0.00144, 0.00254, 1}
  - |t|: {{0, 0.08, 0.14, 0.26, 2};
    {0, 0.08, 0.14, 0.26, 2};
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    {0, 0.1, 0.14, 0.24, 2}} GeV^2