DVCS on ep Analysis Update

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Exclusive, Diffractive and Tagging PWG meeting

25/08/25

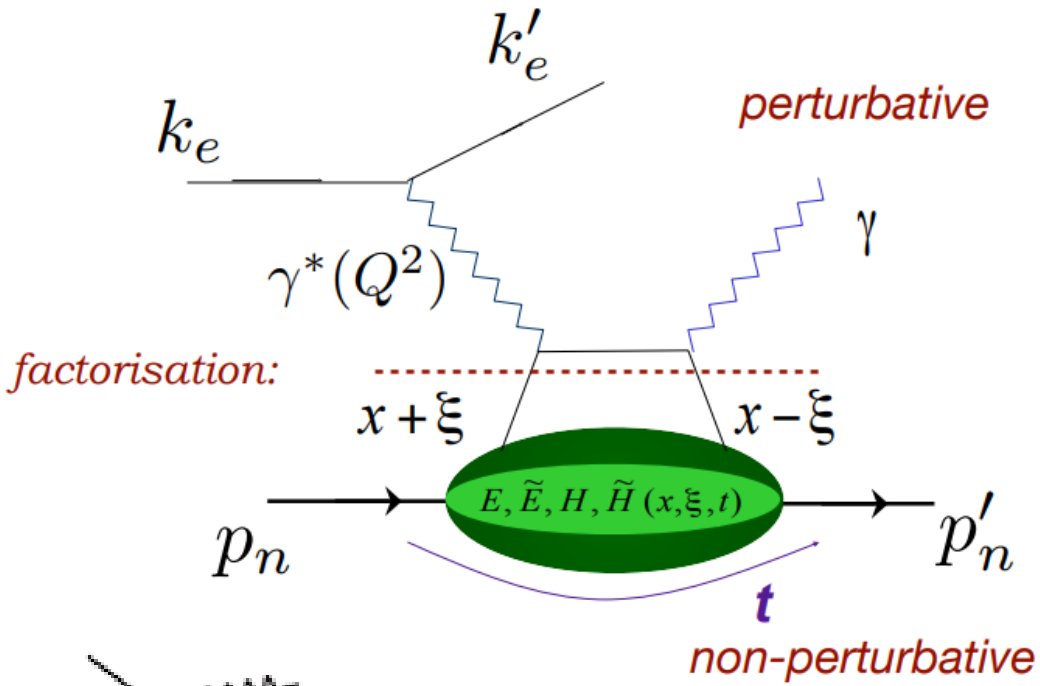
This presentation

- Brief introduction to DVCS and ePIC.
- Updates since last meeting:
  - Analysis note
  - DIS file comparison

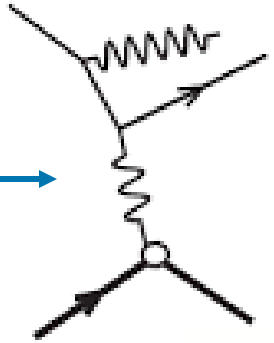
Deeply Virtual Compton Scattering

Deeply Virtual Compton Scattering

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



- Final state $e'p'\gamma$ is not purely DVCS:
  - Also contains Bethe-Heitler contamination and QM interference.
  - Bethe-Heitler: purely EM process, which does not probe partonic content.



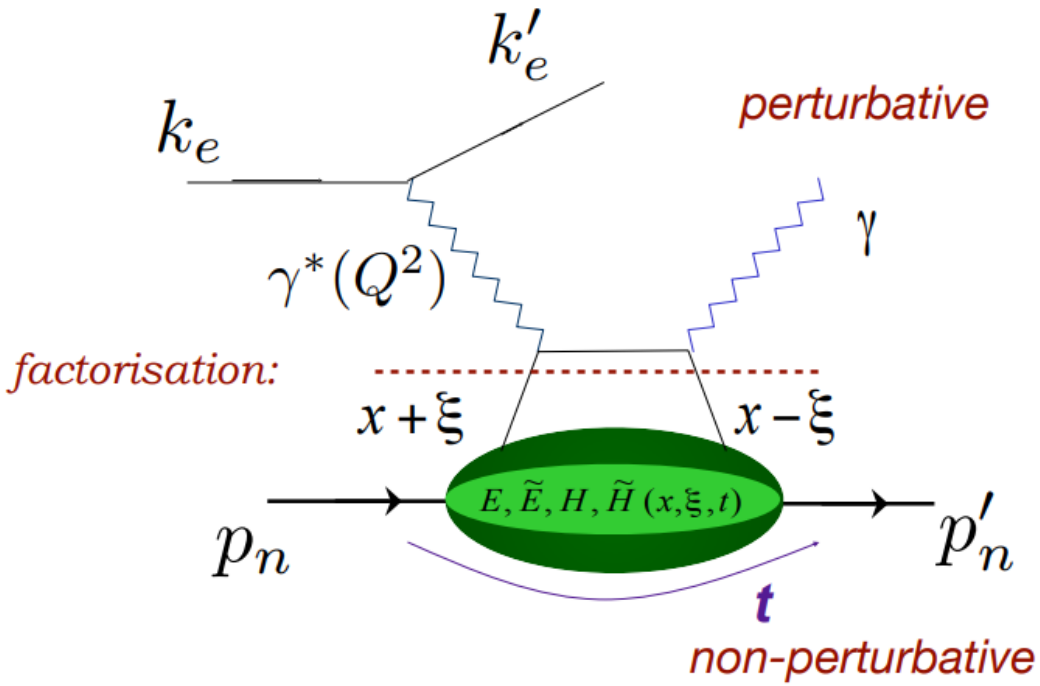
Deeply Virtual Compton Scattering

- Formulae used for this analysis:
  - $e(k) + p(p) \rightarrow e'(k') + p'(p') + \gamma$

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

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

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



- DIS kinematics: electron method
- Mandelstam t: BABE method

Analysis Note

DVCSep analysis note

- Previous skeleton of analysis note has been fleshed out.
  - Only covers 10x130 GeV early science setting for now.

- Still wants a few more citations, but nothing that is unique to just DVCS analysis (EICroot/software stack/etc.)

- Link to view note (also in ExclusiveWG_Paper repo.):
  - https://www.overleaf.com/read/pmsdvtmcztjx#5819b9

DIS physics background study

Comparing to DVCS 10x130 results

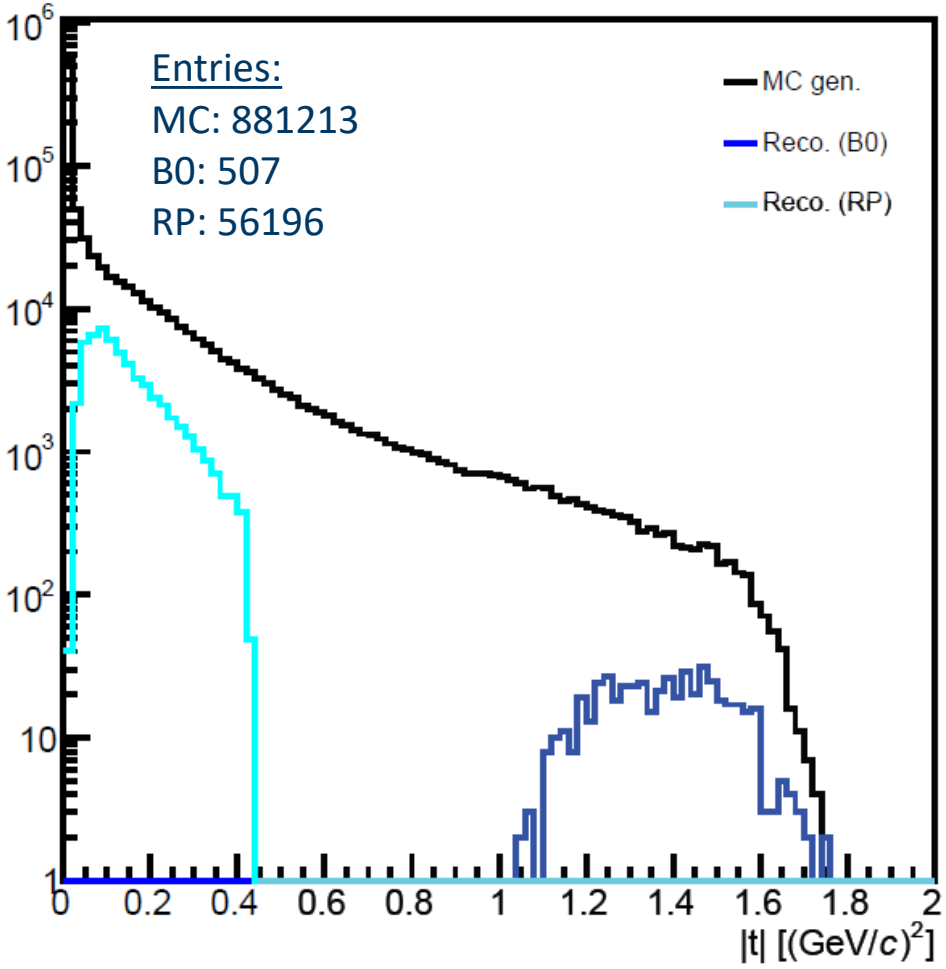
DIS physics background

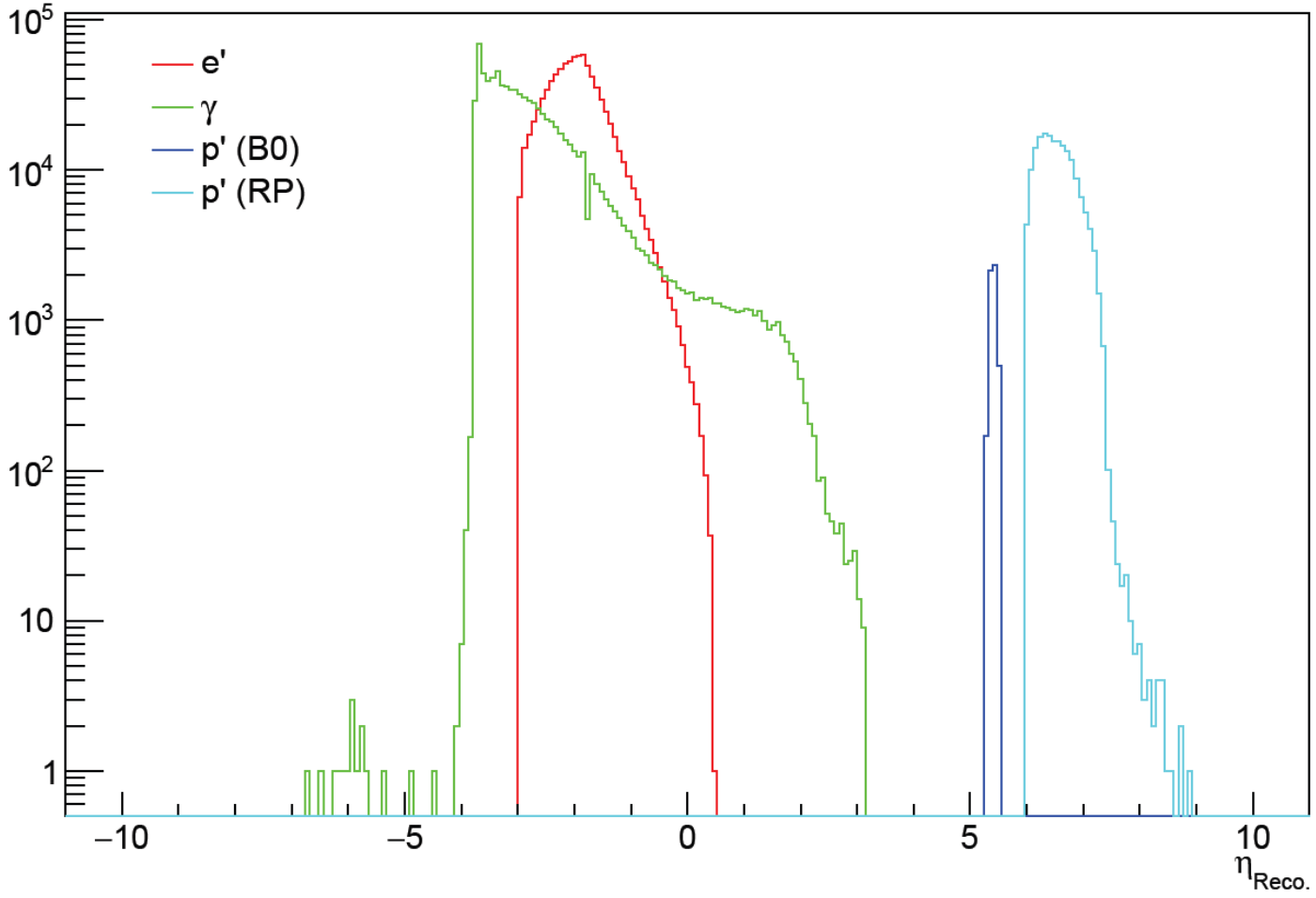
- Using files put onto XRootD.
  - `/volatile/eic/sjdkay/RECO_pythia6_ep_early_science`

- DVCS analysis code run over single combined files.
  - `…/CombinedFiles/DIS_10x130_Q2_1_10_Combined.root`
  - `…/CombinedFiles/DIS_10x130_Q2_10_100_Combined.root`

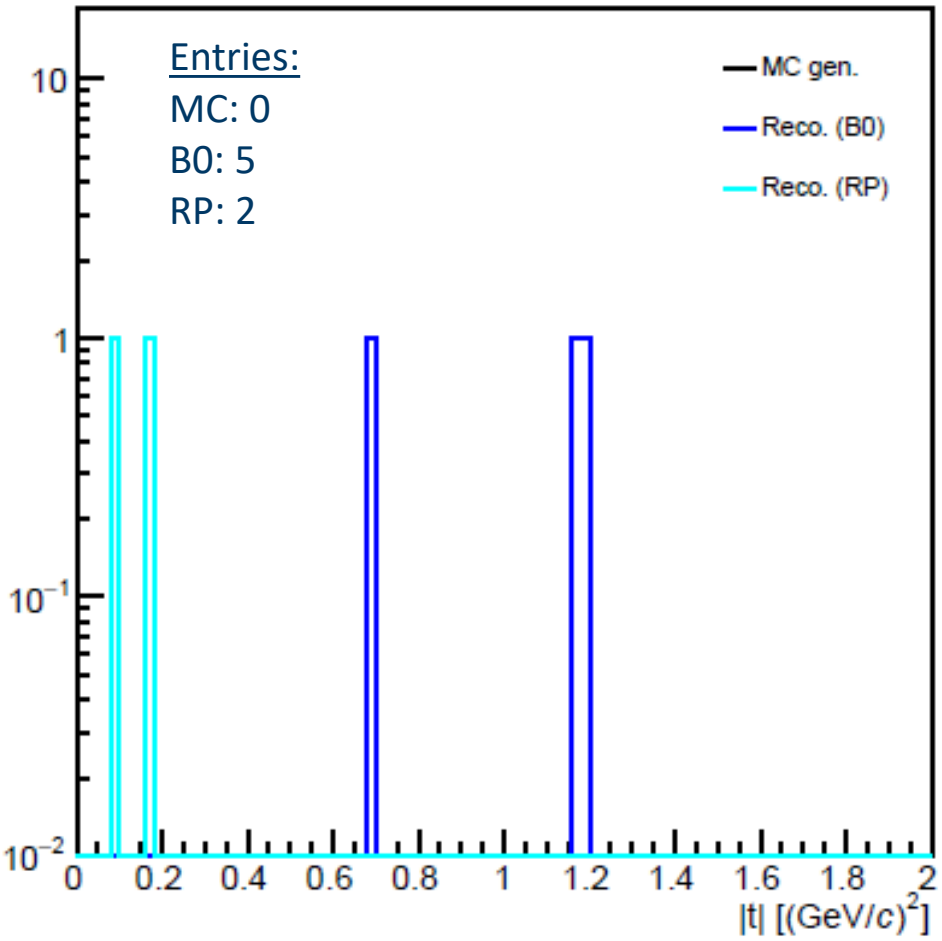
- Cuts used are as for DVCS analysis (unless otherwise stated).
  - Full e'p'γ final state.
  - $Q^2 > 1$ GeV^2, proton track θ cut, $M_{miss}^2 < 1$ GeV^2

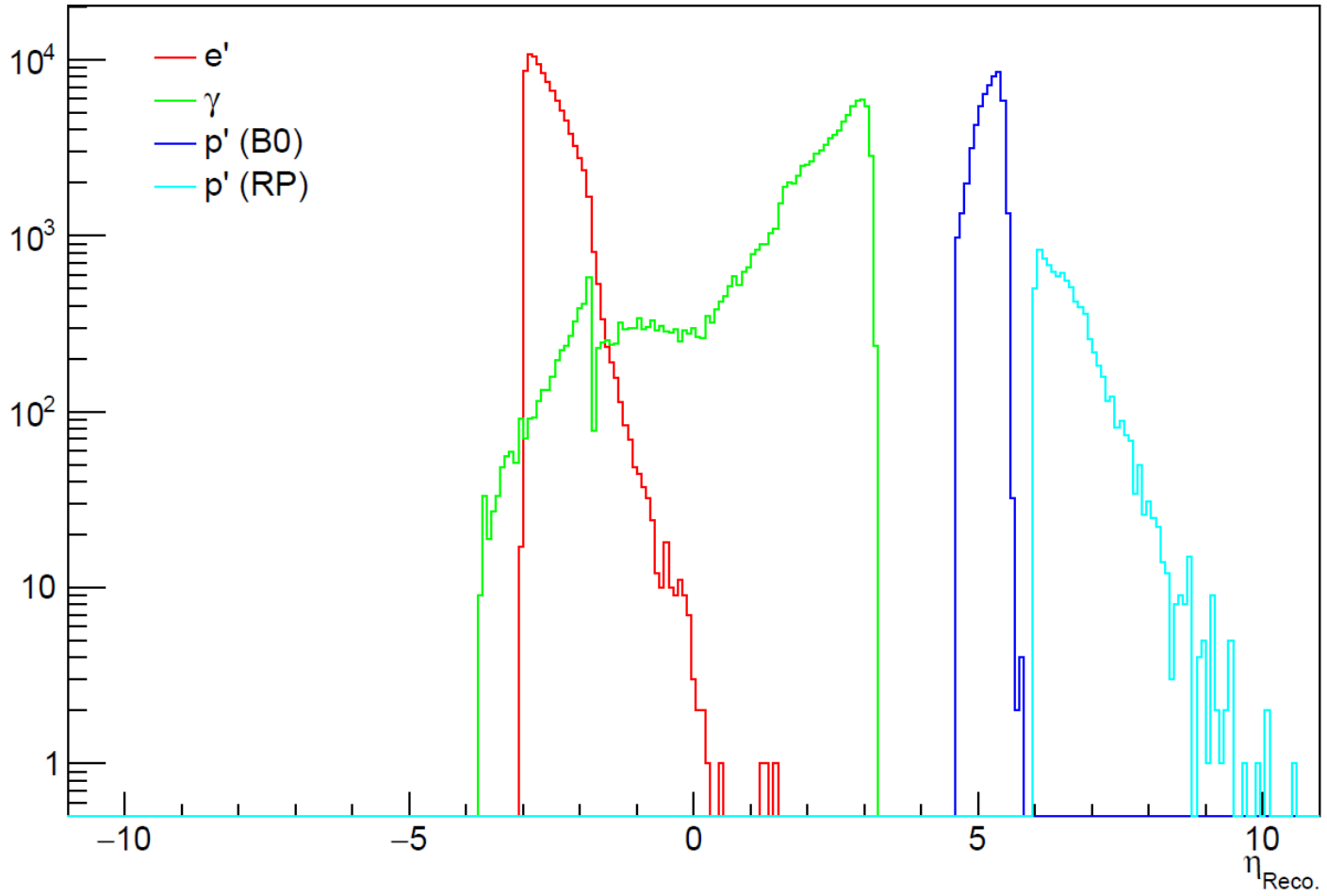
Baseline: DVCS 10x130



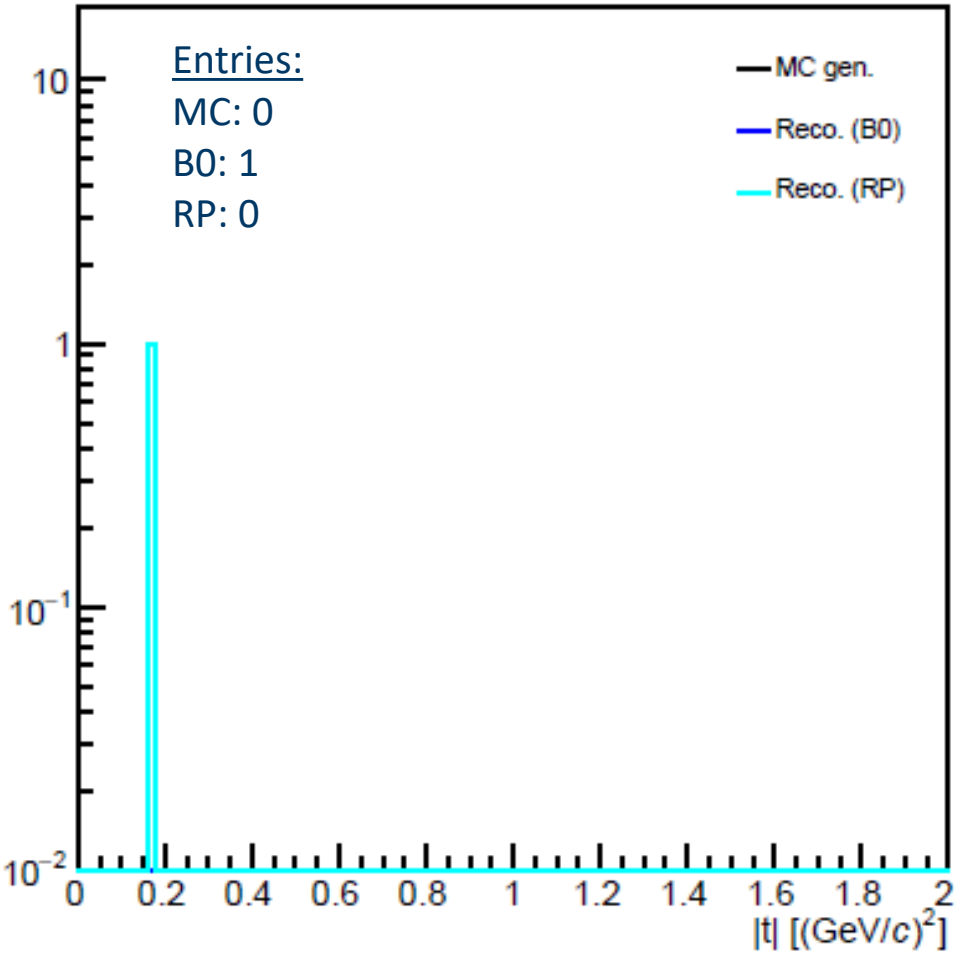


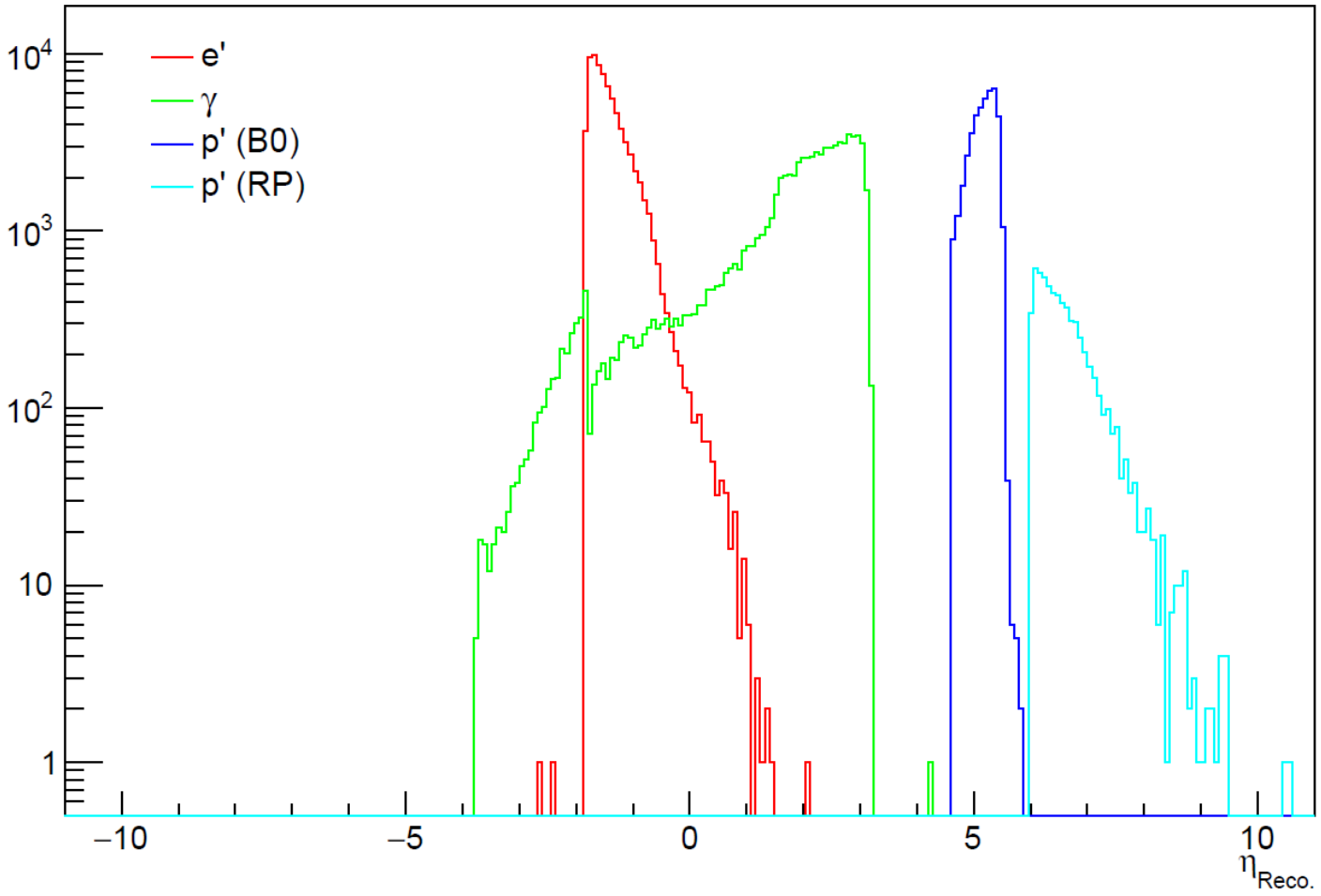
Comparison: DIS $1<Q^2<10$ GeV^2





Comparison: DIS $10<Q^2<100$ GeV^2





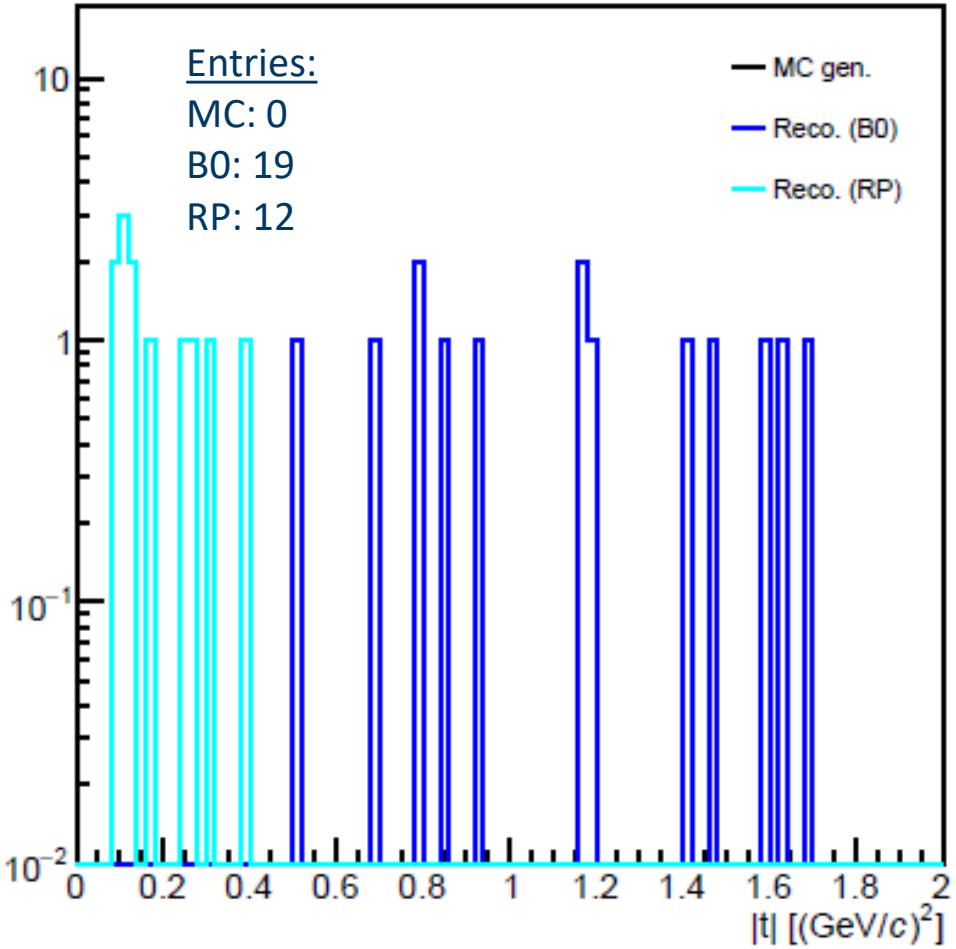
Comments (1)

- Significant reduction in reconstructed “DVCS” events as fraction of total.
  - Seen in both Q^2 ranges.
- Complications arising:
  - Overcounting “protons” from RP track assumption.
  - Default cuts require ONLY ONE of each species in the final state.
    - Valid for real data? Pile-up/noise/material interactions…
  - DIS events will have multiple final state electrons and photons.

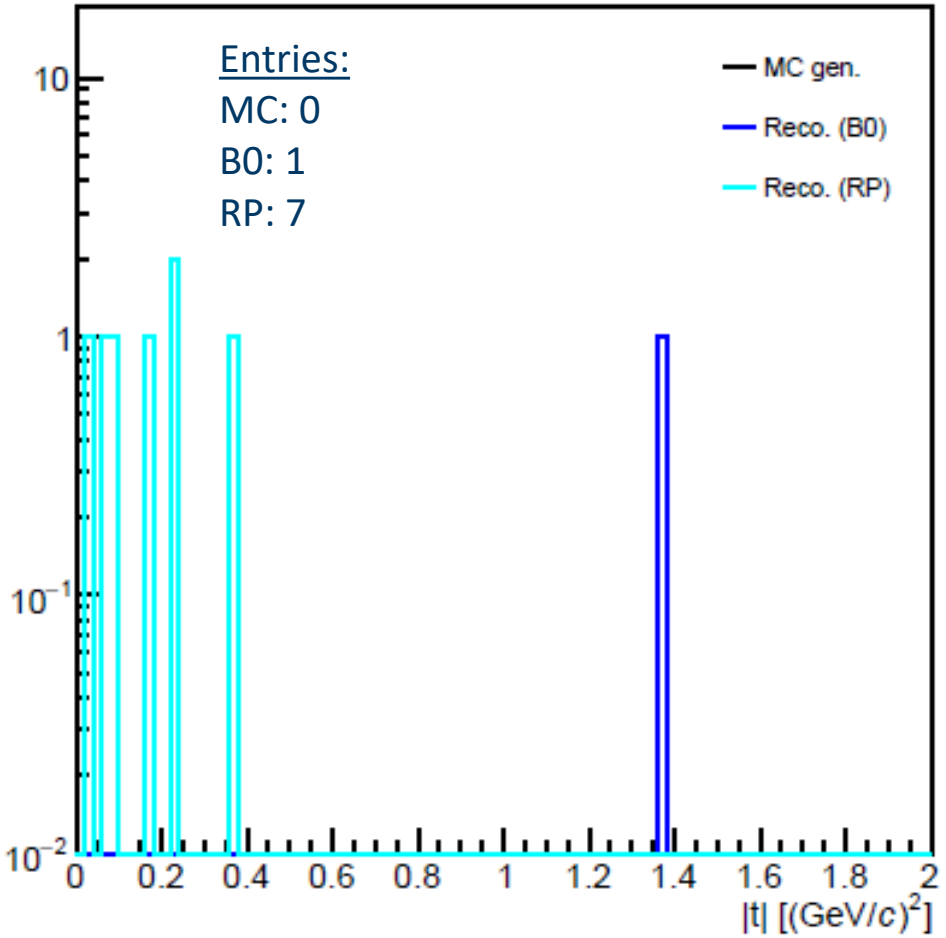
- Try making selection less strict: *at least one* of each species in the final state (calculate *t* from first candidate in particle arrays).

DIS comparison, multiplicity > 0

$1 < Q^2 < 10$



$10 < Q^2 < 100$



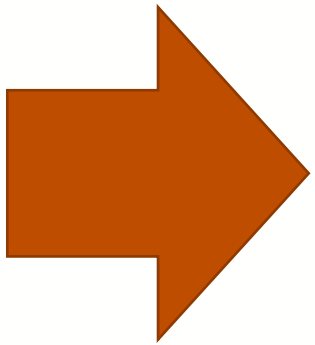
Comments (2)

- Still see low counts of fake DVCS events as fraction of total.
- Main culprit: M_{miss}^2 cut (plots in backup).

- **CAVEAT:** The cross-sections used for the DIS events are orders of magnitude larger than that for the ‘real’ DVCS events.
  - The DIS samples represent significantly lower integrated luminosities than the DVCS sample.

Cross-sections

- DIS (10x130, $1<Q^2<10$ GeV^2)
  - $\sigma_{int} \approx 0.64$ μb
  - (For 500k events) $L_{int} \approx 7.8 \times 10^{-4}$ fb^{-1}
- DIS (10x130, $10<Q^2<100$ GeV^2)
  - $\sigma_{int} \approx 0.047$ μb
  - (For 500k events) $L_{int} \approx 0.016$ fb^{-1}
- DVCS (10x130, $1<Q^2<10$ GeV^2)
  - $\sigma_{int} \approx 2.1$ nb
  - (For 1M events) $L_{int} \approx 0.47$ fb^{-1}



DVCS is factor ~30 higher lumi. than mid-Q^2 DIS.

Factor ~ 600 higher than low-Q^2 DIS!

Conclusions on DIS background

- Inclusive single species plots will get swamped by DIS background without DVCS exclusivity cut.
  - This will reduce rates significantly in DVCS analysis due to B0/RP acceptances.

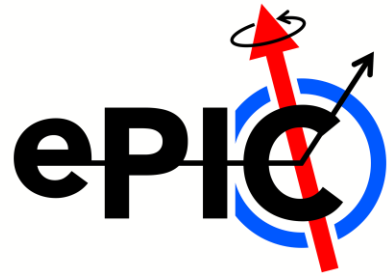
- Exclusive DVCS event kinematic plots are harder to tell.
  - Assuming a constant scaling to the DIS plots → DIS could provide ~10% background to RP events or *dominate* B0 events.
  - Mostly from low Q^2 DIS events.
  - Very hard to gauge effect of increased lumi. from low statistics in DIS plots.

Concluding remarks

Next steps

- Analysis note now ~90% complete (at least first draft).
  - Can take plots from there for early science exclusive paper.
  - If more/different plots are needed: get in contact.

- DIS background to DVCS is hard to judge.
  - Current missing mass cut reduces DIS contamination significantly → but not completely.
  - Very hard to judge effect of increased luminosity with current statistics.
  - Would need to generate ~120M DIS events to match luminosity of DVCS sample.
    - MINIMUM useful DVCS ~200k events → still ~60M DIS events.



Thank you for listening!

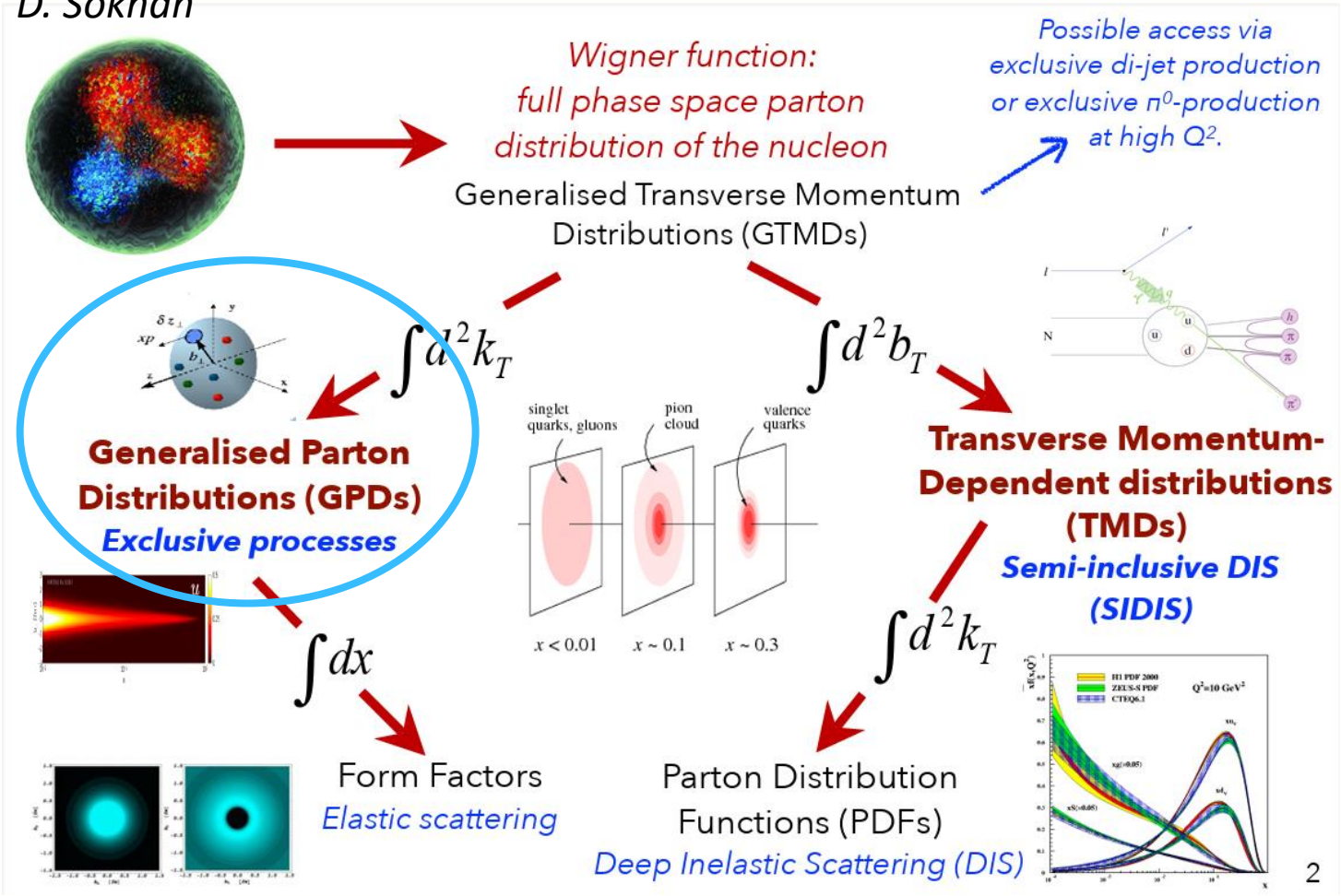
Any questions?

Offline questions? Ping me an email!

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

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  - $ep \to e'p'\gamma$
  - Simplest inelastic channel the EIC can study.
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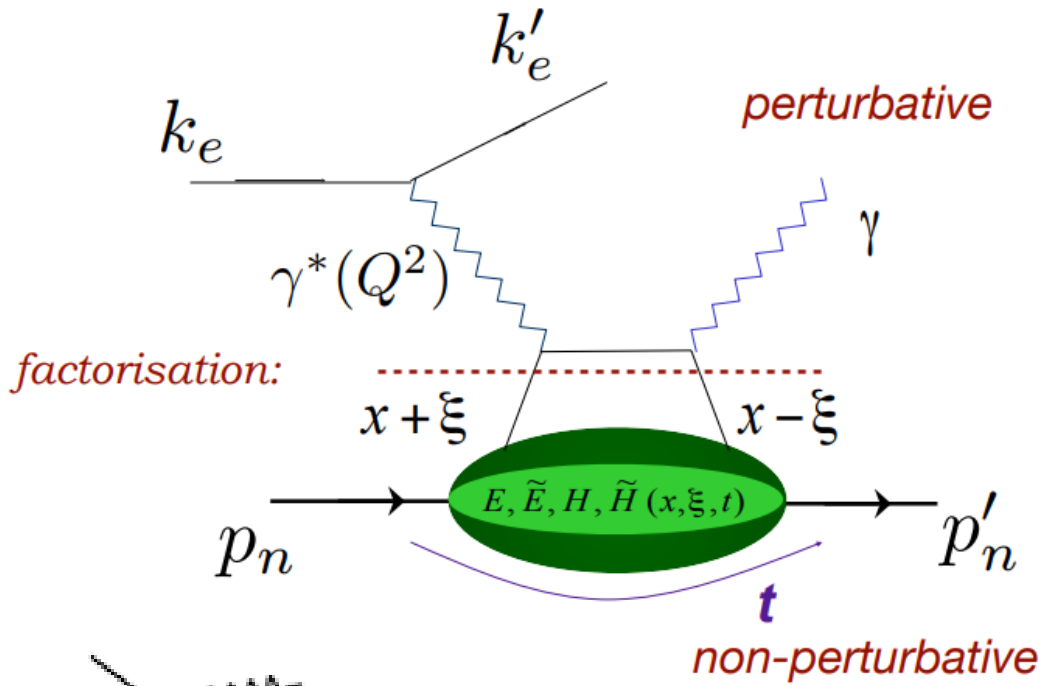
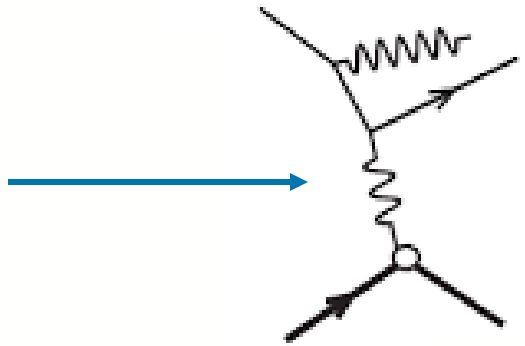
- The cross-section for this process is related to its matrix element, $|\mathcal{T}|^2$.
  - $|\mathcal{T}|^2 = |\mathcal{T}_{DVCS}|^2 + |\mathcal{T}_{BH}|^2 + \mathcal{I}$
  - $\mathcal{I}$ is an interference term.
  - Bethe-Heitler: purely EM process, which does not probe partonic content.





Deeply Virtual Compton Scattering

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

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

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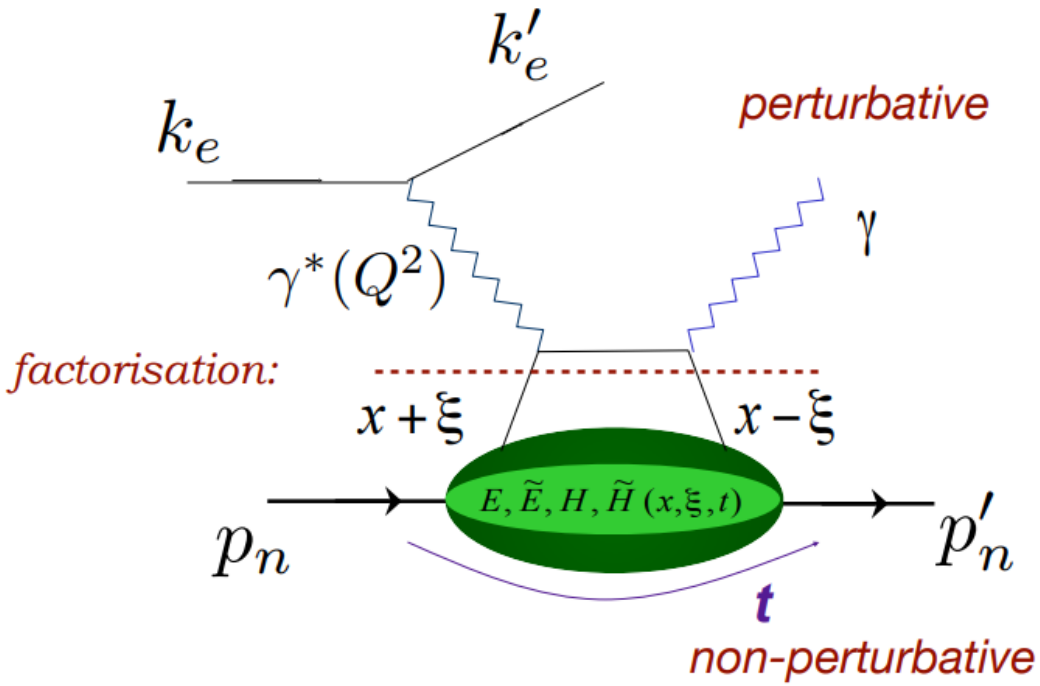
$$t = (p - p')^2$$

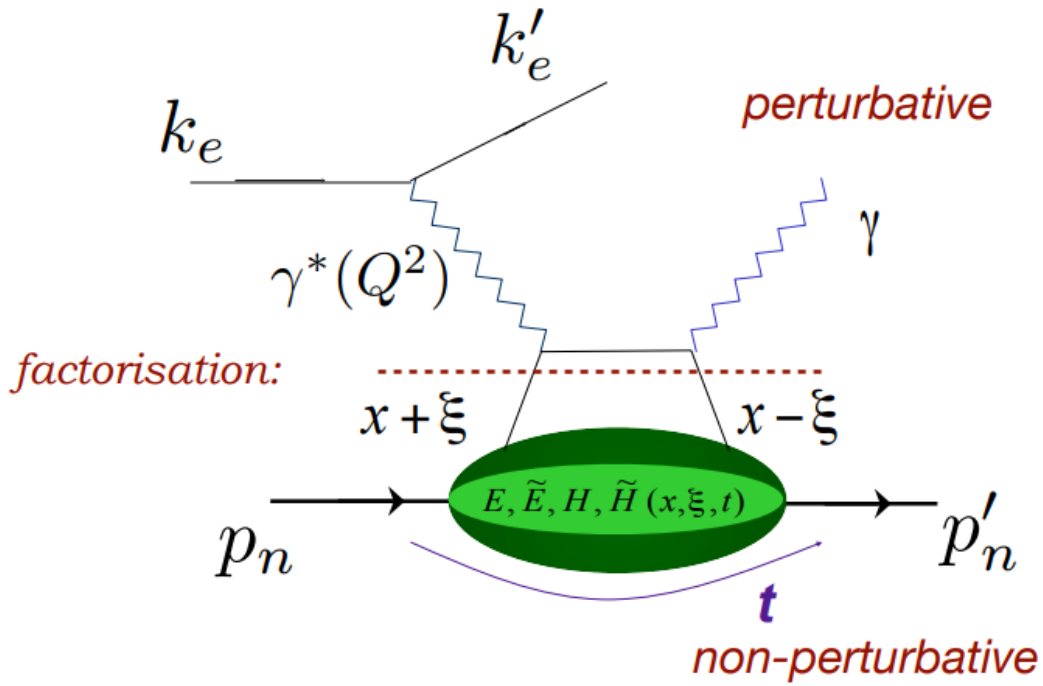


- Other formulae exist, using other combinations of reconstructed quantities, if needed (e.g. see InclusiveKinematics branches in EICrecon trees).

Deeply Virtual Compton Scattering

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

- 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.

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

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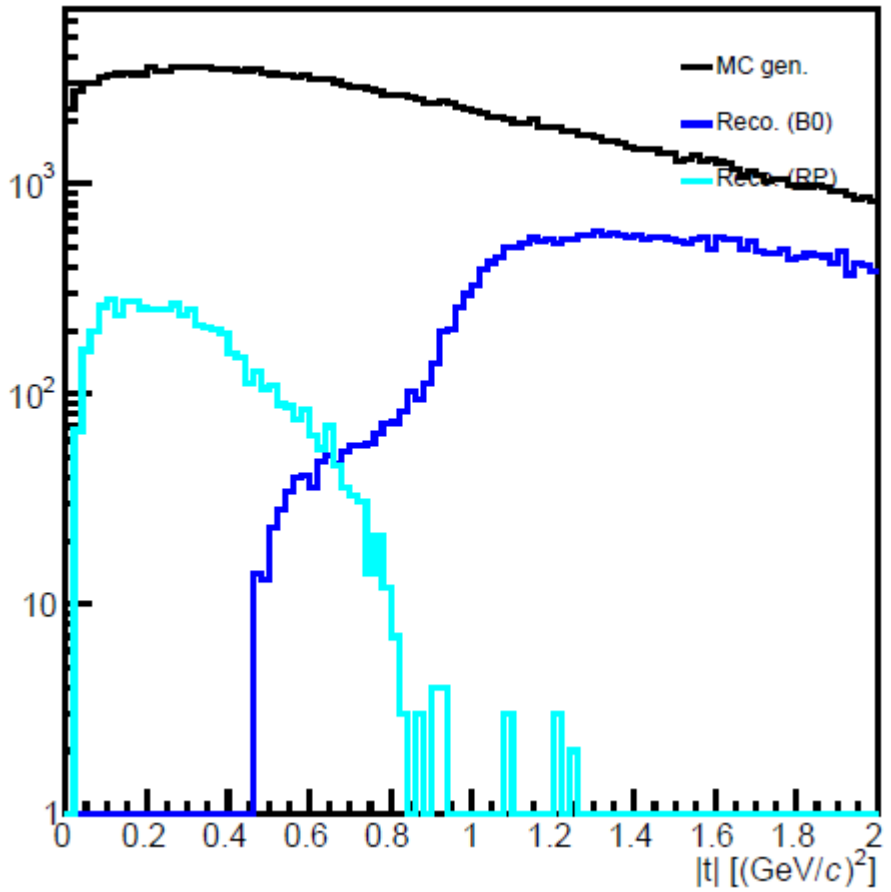
- By Ji's Sum Rule, quark angular momentum can be given by a combination of GPDs.

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

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.

DIS 1-10 GeV^2, no MM2 cut (mult > 0)



DIS 10-100 GeV^2, no MM2 cut (mult > 0)