

Early-science physics prospects with Deeply Virtual Compton Scattering with ePIC at the EIC

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MENU 2026

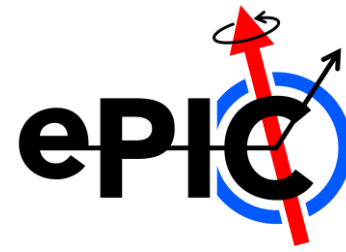
The 17th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon



Image: what ChatGPT
thinks a proton is



This talk

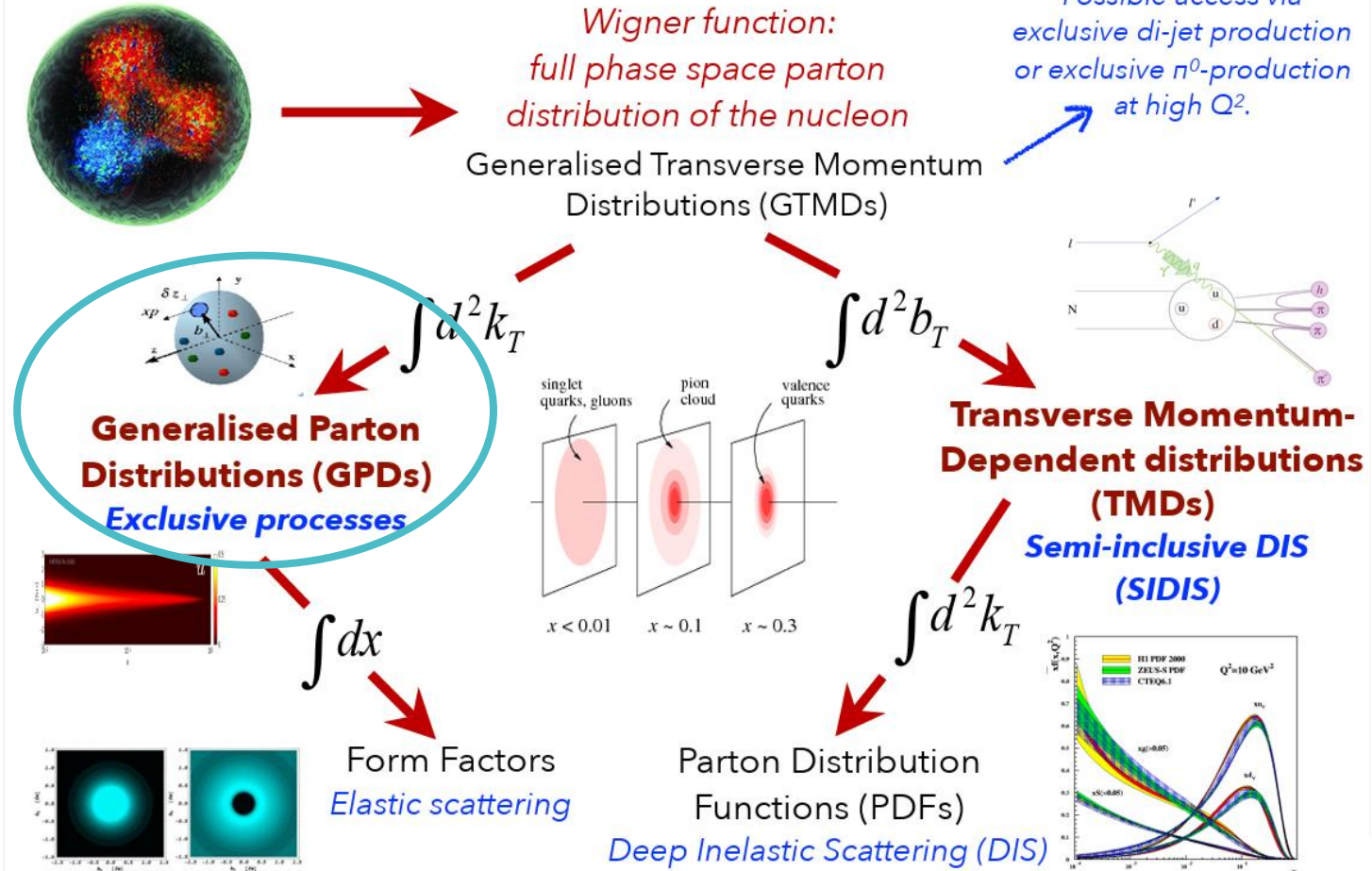


- 3D proton structure
- Deeply Virtual Compton Scattering
 - Previous results
- ePIC and the EIC
 - DVCS within ePIC

3D proton structure

- Understanding the internal structure of the nucleon was part of the 2023 NSAC LRP.
 - How big is the proton?
 - How are quarks distributed?
 - Where does proton spin come from?
- Generalised Parton Distributions
 - Relate transverse position of quarks/gluons to longitudinal momentum.

D. Sokhan, U. of Glasgow

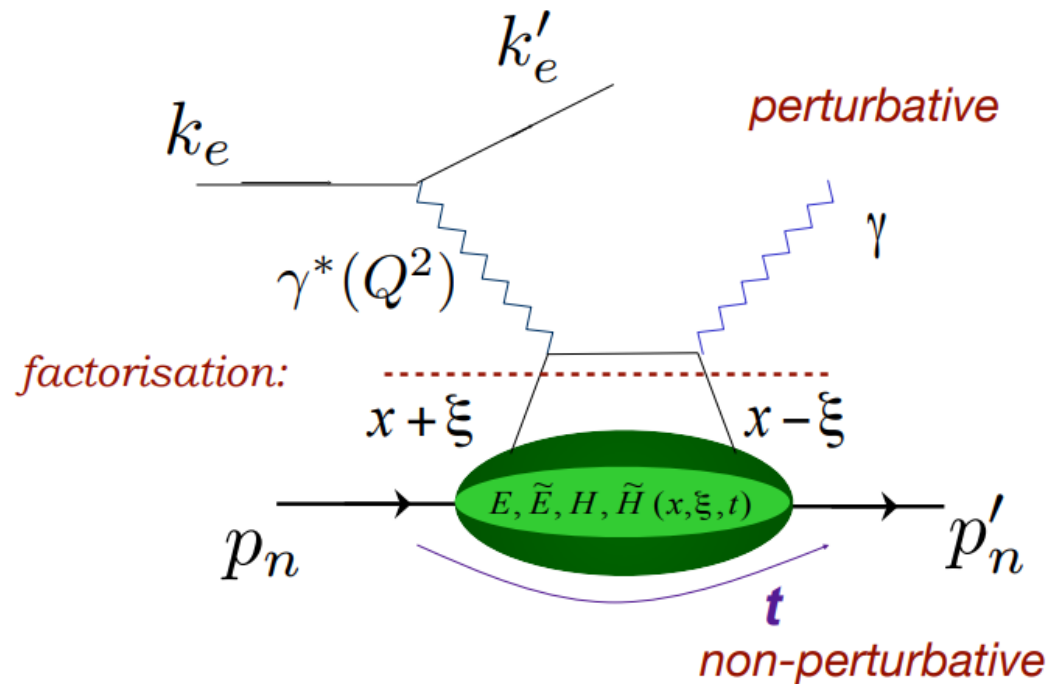


- Distribution of unpolarised quarks:
 - Fourier Transform of GPD H for unpolarised target.
- Proton spin:
 - Ji's Sum Rule
 - Quark OAM given by combination of GPDs
- Many GPD sensitive channels
 - Exclusive π^0 production (Li Xu's talk from Tuesday 20th)
 - Timelike Compton Scattering
 - Deeply Virtual Compton Scattering

Deeply Virtual Compton Scattering

Overview and history of measurements

- $\gamma^* p \rightarrow \gamma p$ process
 - Exclusive production of a real photon
- Experimentally indistinguishable from Bethe-Heitler process (purely EM).

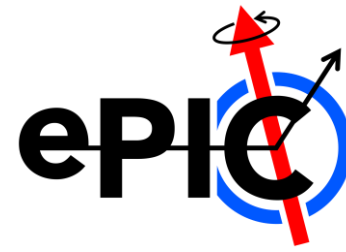


$$\frac{d^4\sigma}{dx_B dy dt d\phi_h} = \frac{\alpha^3 x_B y}{16\pi^2 Q^2 \sqrt{1 + \epsilon^2}} \left| \frac{\mathcal{T}}{e^3} \right|^2$$

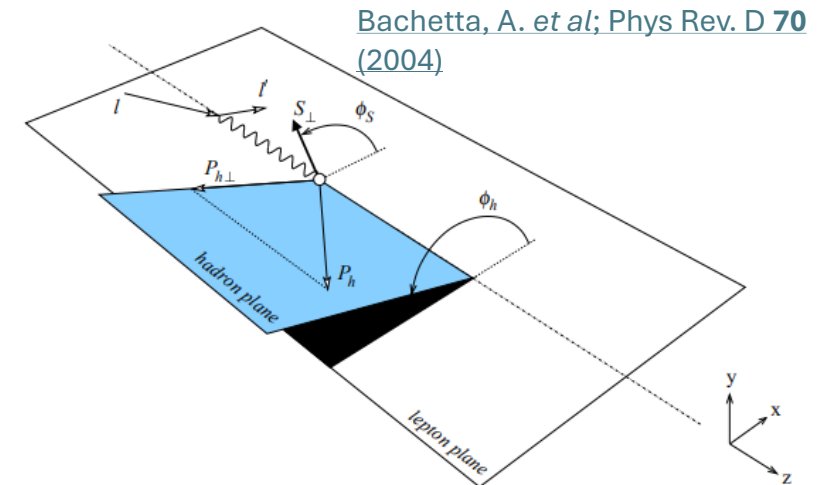
$$\mathcal{T}^2 = |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \mathcal{I}$$

Bethe-Heitler
DVCS
Interference

Getting GPDs from DVCS



- Extract GPD directly components from asymmetries.
- Asymmetry in angular distributions as function of ϕ_h .
 - Angle between “leptonic” and “hadronic” planes of interaction.
- Consider different polarised initial states:
 - Different asymmetries
 - Sensitive to different GPDs



	Proton		
Electron	Unpolarised	Longitudinal	Transverse
Unpolarised	σ	A_{UL}	A_{UT}
Polarised	A_{LU}	A_{LL}	A_{LT}

4 twist-2, chiral-even GPDs: $H, E, \tilde{H}, \tilde{E}$

$$A_{LU,I}^{\sin\phi} \propto \text{Im} \left[F_1 \mathcal{H} + \xi(F_1 + F_2) \tilde{\mathcal{H}} - \frac{t}{4m^2} F_2 \mathcal{E} \right],$$

$$A_{UL,I}^{\sin\phi} \propto \text{Im} \left[\xi(F_1 + F_2) \left(\mathcal{H} + \frac{\xi}{1+\xi} \mathcal{E} \right) + F_1 \tilde{\mathcal{H}} - \xi \left(\frac{\xi}{1+\xi} F_1 + \frac{t}{4M^2} F_2 \right) \tilde{\mathcal{E}} \right],$$

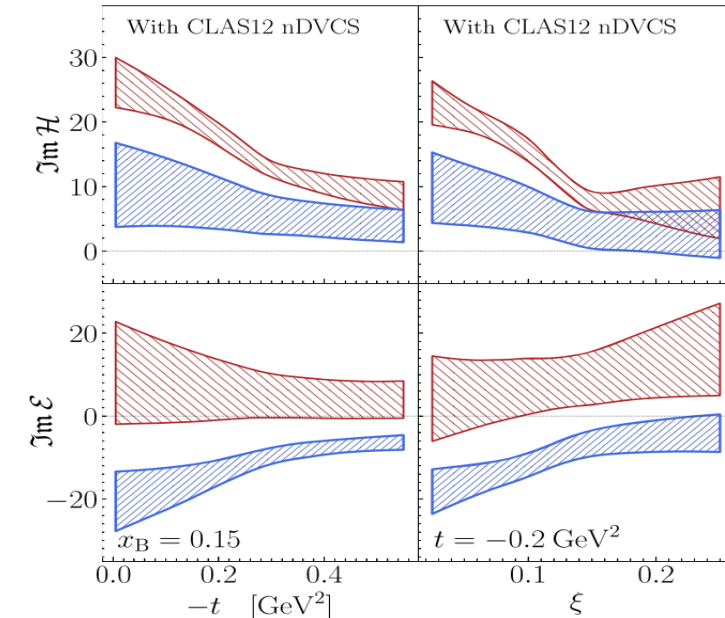
[Kroll, P. et al; Eur. Phys. J. C 73 \(2013\)](#)

	Sum over quark helicities	Difference between quark helicities
Conserve nucleon spin	H	$\tilde{H}$
Flip nucleon spin	E	$\tilde{E}$

Asymmetries can be expressed in terms of real/imaginary part of Compton Form Factors (CFFs).

CFFs $(\mathcal{H}, \mathcal{E}, \tilde{\mathcal{H}}, \tilde{\mathcal{E}})$ = Linear combinations of GPDs $(H, E, \tilde{H}, \tilde{E})$

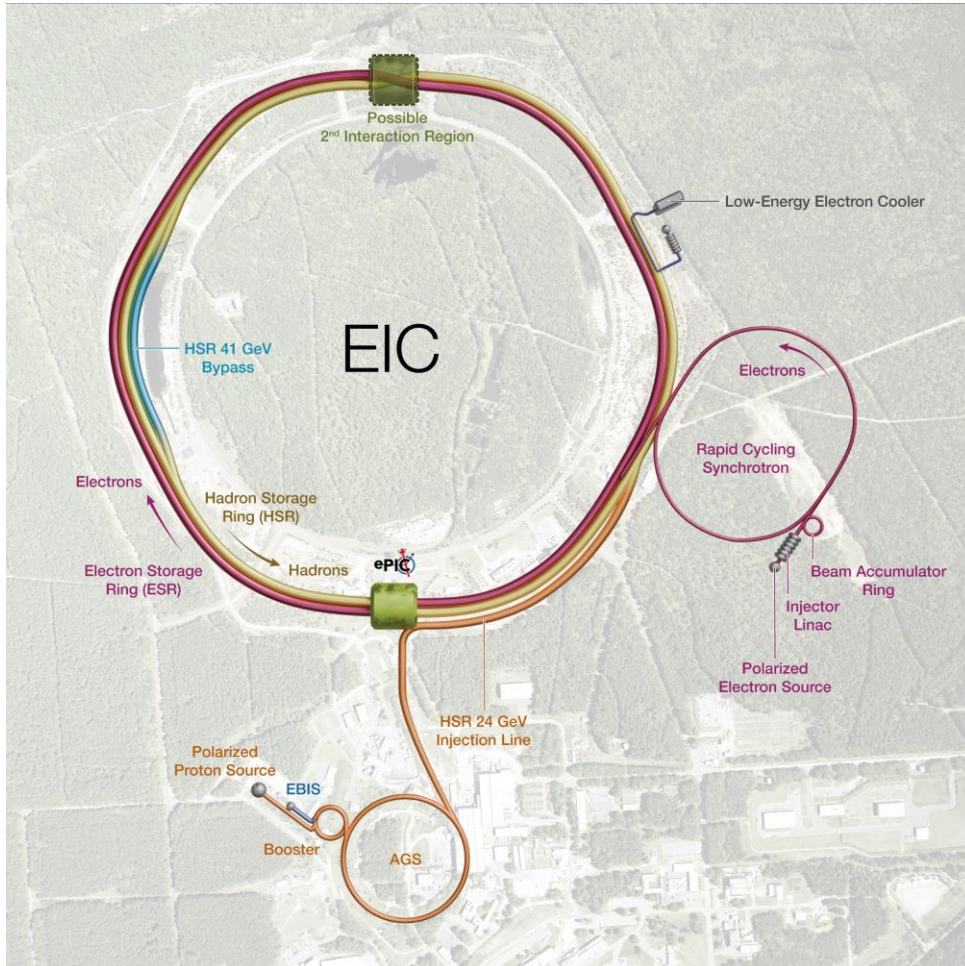
- DVCS has been studied for decades at different facilities.
 - Fixed target (JLab/HERMES/COMPASS)
 - Higher x_B ($\sim 10^{-2}$ - 10^{-1})
 - Polarised lepton beams; target varies on experiment
 - Hall A/Hall C/COMPASS – unpolarised target
 - CLAS – longitudinal proton (and unpolarised neutron!)
 - HERMES – longitudinal and transverse proton data taken
 - Colliding beams (HERA – H1/ZEUS)
 - Lower x_B ($\sim 10^{-4}$ - 10^{-3})
 - No polarised beams used for data taken



[Hobart, A. et al \(CLAS Collaboration\);
Phys. Rev. Lett. **133** \(2024\)](#)

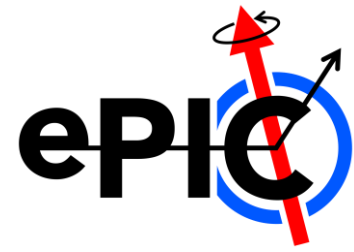
The Electron Ion Collider

And the ePIC experiment

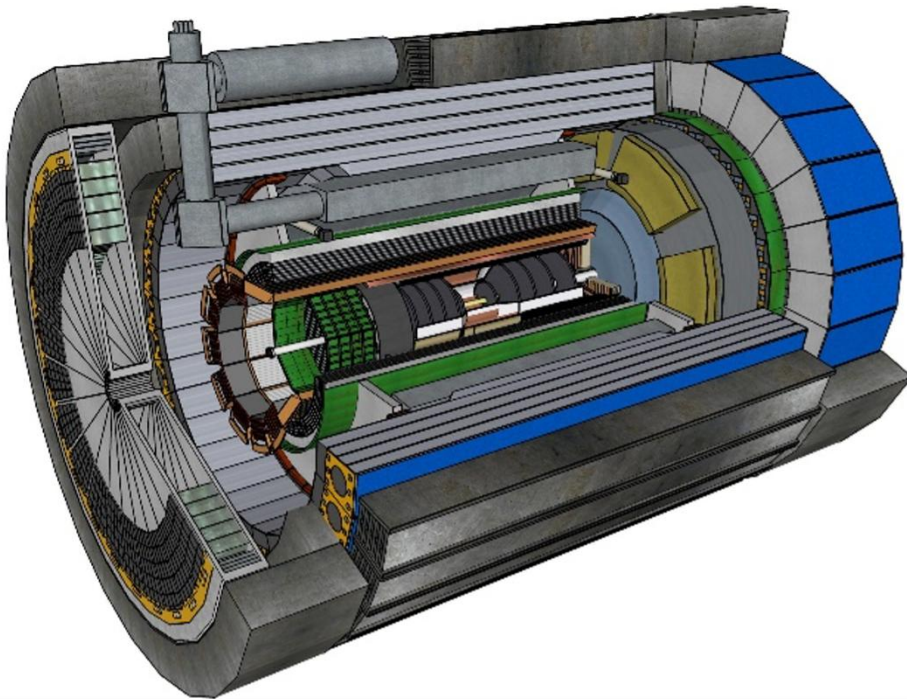


- Proposed collider for Brookhaven National Lab.
 - Polarised electron beam, energy up to 18 GeV
 - New polarised electron source and booster ring to be built.
 - Polarised proton beam, up to 275 GeV
 - Using existing RHIC infrastructure
 - Both longitudinal and transverse polarisation available
 - Polarised light ions (d, He-3) and unpolarised heavier ion species (up to U)
 - Luminosity up to 10^{33} - 10^{34} cm²s⁻¹

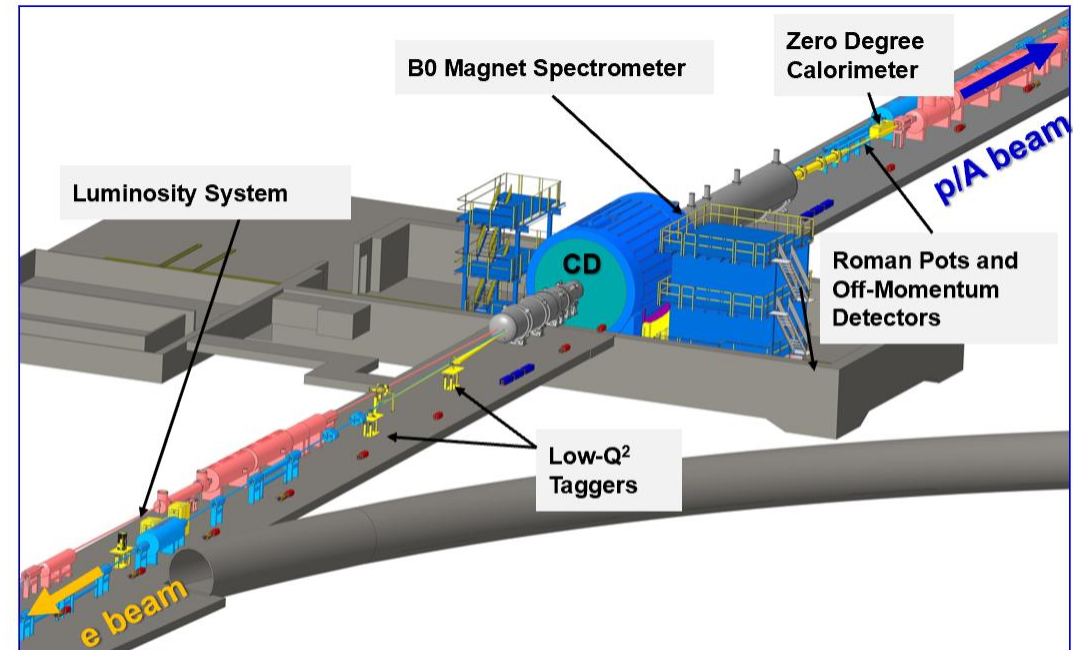
The ePIC detector



More details: [Rongrong Ma's talk from Monday 19th](#)

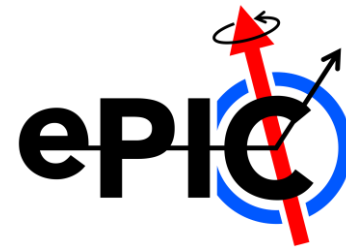


ePIC central barrel – for
electrons and photons

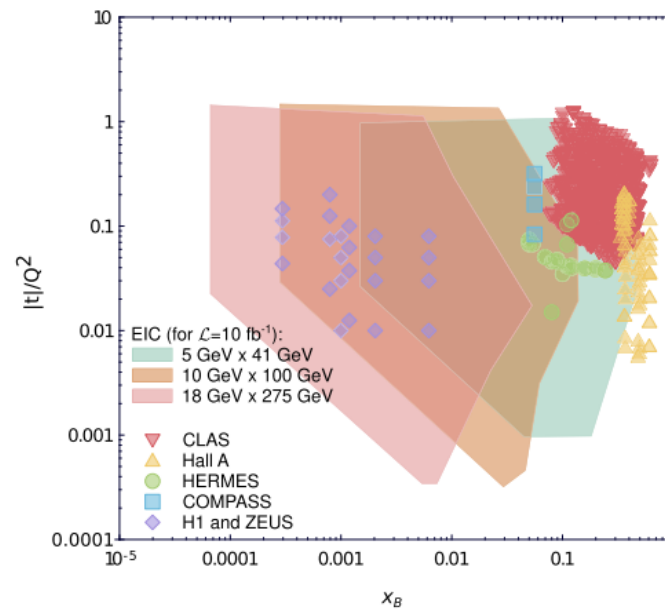
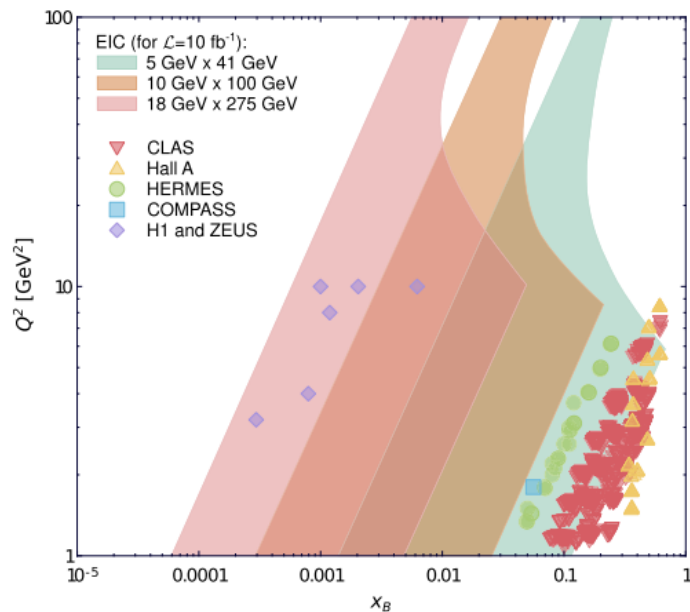


Far forward/backward subsystems – for
scattered protons

Why do DVCS @ EIC?



- Covers phase space between H1/ZEUS and fixed target data.



[Aschenauer, E. C. et al; Phys. Rev. D 112 \(2025\)](#)

Preliminary study of EIC capabilities, using parameterised model of ePIC detector.

Uses 10 fb^{-1} of ep collisions at “standard” EIC energies.

Only considering polarised electron.

- Capable of providing both longitudinal and transverse protons with no change to detector setup.

- Current EIC early science run table

ePIC/EIC Early Science Report

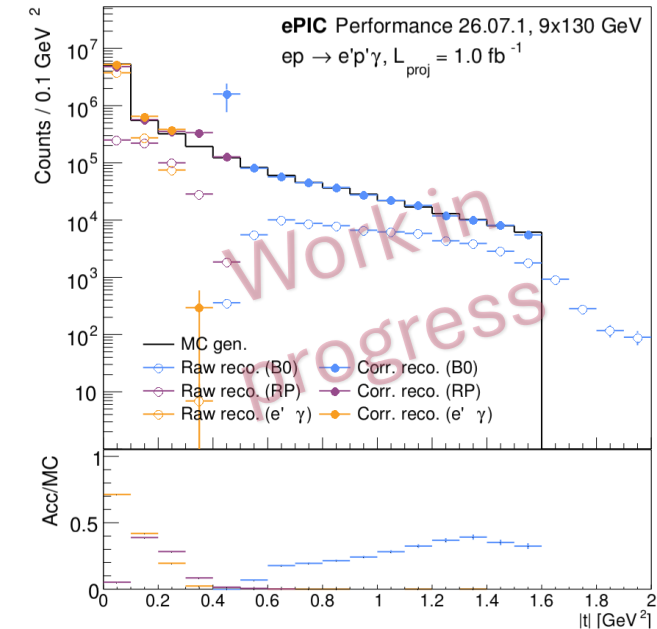
Species	Beam energy (GeV)	Integrated luminosity (fb^{-1})	Electron-beam polarization	Hadron-beam polarization
$e+\text{Ag}$	9×115	1.0	NO	N/A
$e+\text{D}$	9×130	1.5	LONG	NO
$e+p$	9×130	1.0	LONG	TRANS and/or LONG
$e+p$	9×275	2.5	LONG	TRANS and/or LONG
$e+\text{Au}$	9×100	1.0	LONG	N/A
$e+{}^3\text{He}$	9×166	1.5	LONG	TRANS and/or LONG

Electron polarisation
expected to be available by
ep running.

Use ep beams to test
both longitudinal and
transverse protons

- Simulations being performed using [EpIC MC generator](#).
 - Purpose-built generator for GPD-sensitive processes (DVCS/TCS/DVMP).
 - Can run in fixed-target or collider mode.
- Cross-section and GPDs evaluated from models.
 - DVCS events use Goloskokov-Kroll model.
- Simulate full $ep \rightarrow ep\gamma$ process (DVCS + Bethe-Heitler + interference)
 $1 < Q^2 < 100 \text{ GeV}^2$ $10^{-5} < x_B < 0.7$ $0.01 < y < 0.9$
 - Simulations processed in regular ePIC campaigns – **26.07.1** for plots

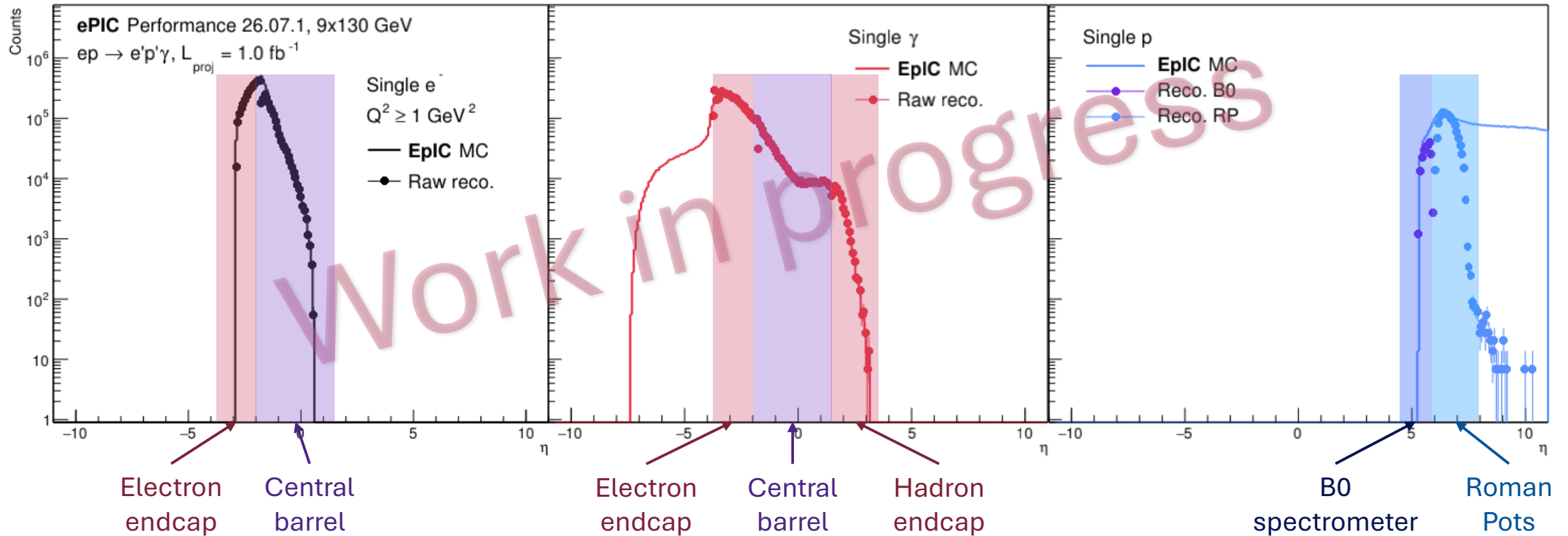
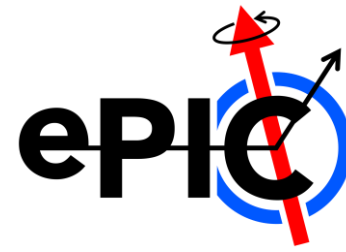
- Reconstruction quality:
 - Electron – calculated $Q^2 \geq 1 \text{ GeV}^2$
 - Proton – track polar angle within expected FF detector
- Full final state exclusivity:
 - Single electron, single far forward proton, single photon
 - No positive tracks in barrel
 - No tracks in OMD/ZDC
- Kinematic cuts:
 - $E_\gamma \geq 1 \text{ GeV}$
 - $15 \text{ GeV} < \Sigma(E-p_z) < 25 \text{ GeV}$
 - $p_{T, \text{miss}} < 0.5 \text{ GeV}$



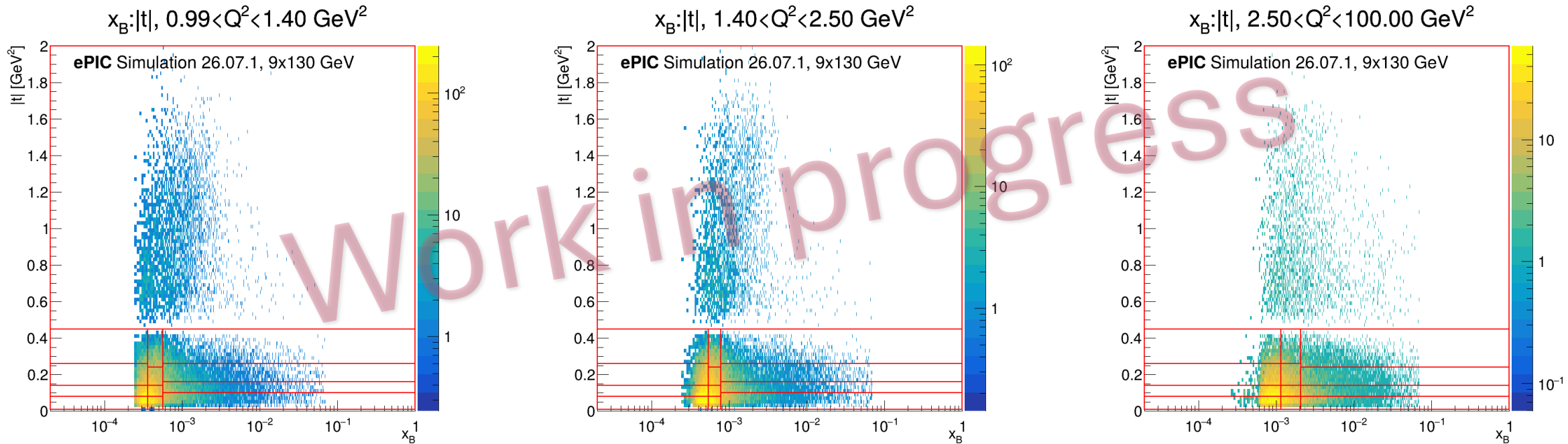
Full efficiency of cuts: **~11%**

- Main drop due to proton reconstruction
 - Single proton: ~22%
 - Full epy final state: ~14%

Detector occupancies

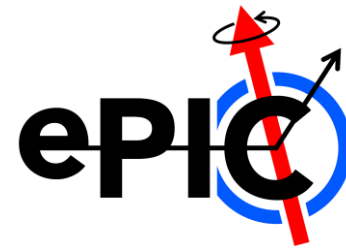


Asymmetries - binning

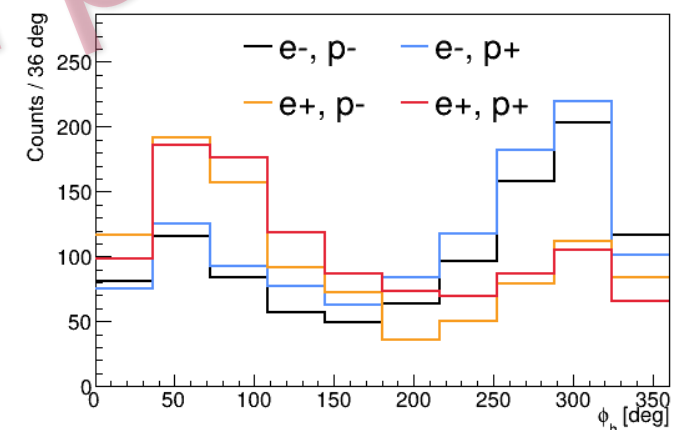
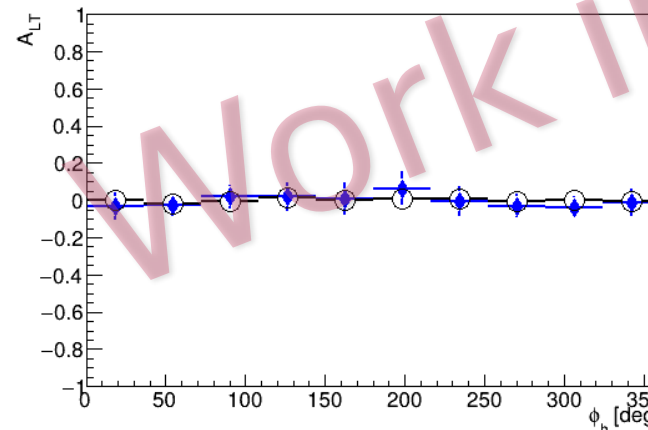
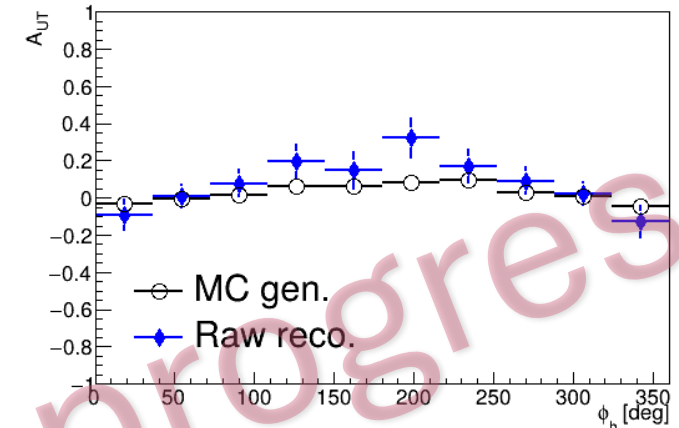
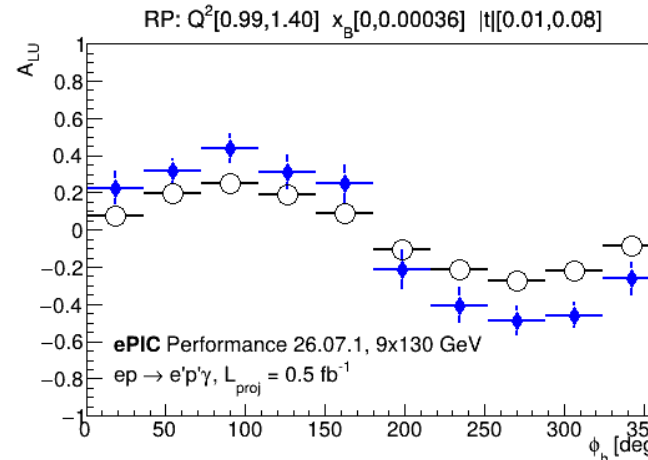


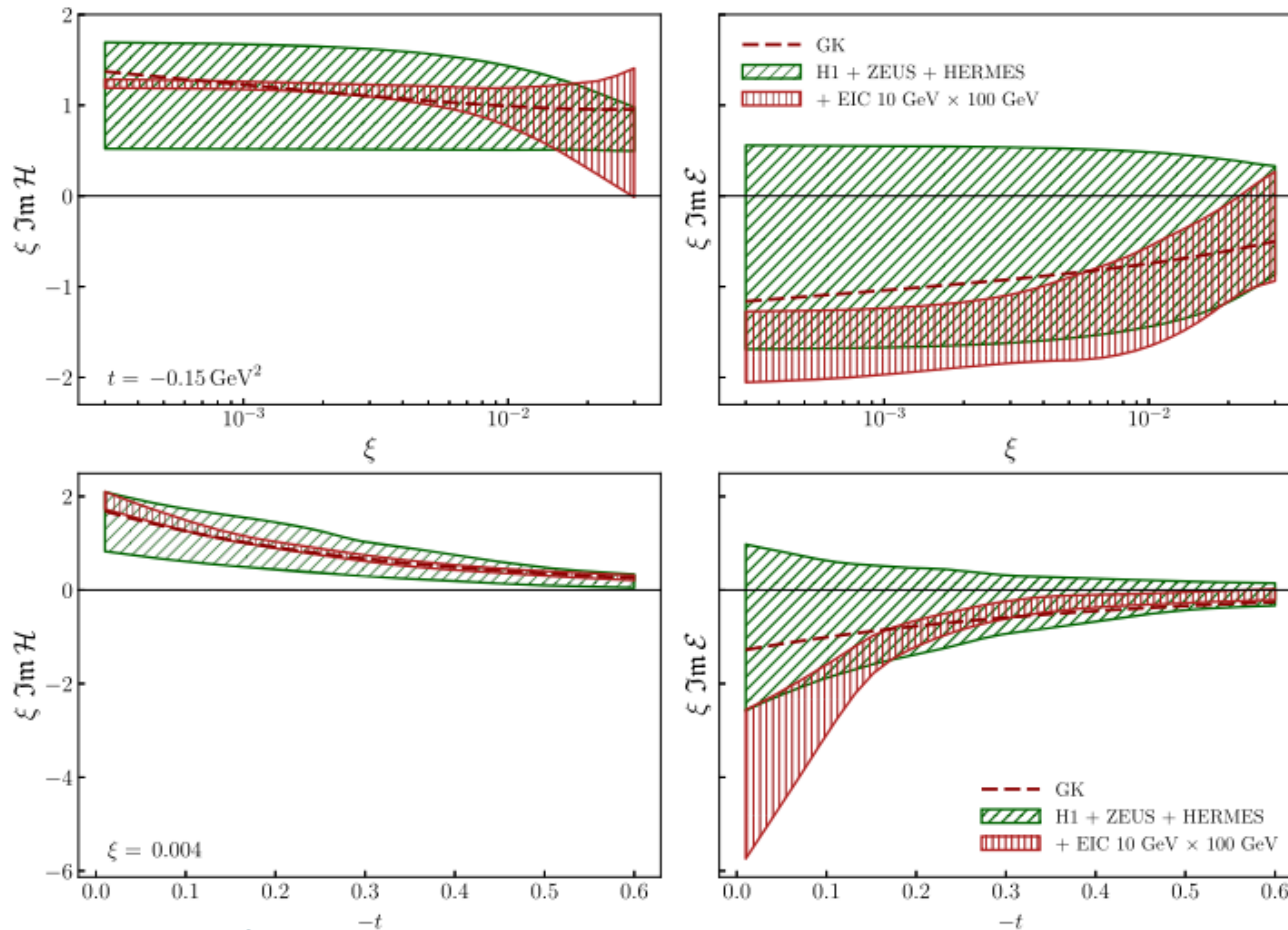
- 3D binning in Q^2 , x_B and $|t|$.
- 3 Q^2 bins; $x_B/|t|$ bins chosen to have similar numbers of events (minimum 1000).

Asymmetries



- Simulated results using projections to 1 fb^{-1} of $9 \times 130 \text{ ep}$ collisions, with longitudinally polarised protons.
 - Assume 50% longitudinal proton, 50% transverse proton
- Values for asymmetry reflect model results.
 - Errors reflect ePIC detector performance.





Aschenauer, E. C. *et al*; Phys. Rev. D 112 (2025)

- Presented plots from study mentioned earlier.
 - Adding 10x100 GeV EIC data to that from H1, ZEUS and HERMES.
- Already shows significant improvement using one possible EIC energy setting.
- Asymmetries from full EIC early science study are currently with theory colleagues.
 - Awaiting results from fitting procedure.

In summary...

- DVCS is an important channel for hadron physics, and the EIC will provide a unique environment in which to study it.
 - Golden channel to extract GPDs, and to answer some of the EIC's key physics questions.
- Polarisation-based asymmetries have never before been extracted within a collider environment.
- The polarised beams available at the EIC will allow for this to be done for the first time.
 - All possible combinations of electron and proton polarisation available.
- **Look forward to preliminary results soon!**

Thank you for listening!

Any questions?

Backup slides

	Proton		
Electron	Unpolarised	Longitudinal	Transverse
Unpolarised	σ	A_{UL}	A_{UT}
Polarised	A_{LU}	A_{LL}	A_{LT}

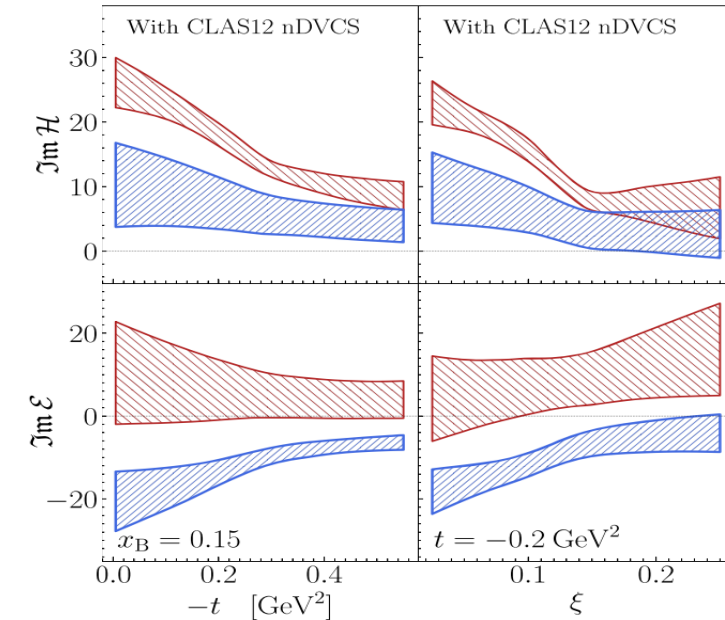
- 4 twist-2, chiral-even GPDs:
 $H, E, \tilde{H}, \tilde{E}$
- H – Conserves helicity of struck nucleon
- E – Struck nucleon helicity flip
- F – Sum over quark helicity states
- $\tilde{F}$ – Difference between quark helicities

$$\begin{aligned}
 A_{LU,I}^{\sin \phi} &\propto \text{Im} \left[F_1 \mathcal{H} + \xi (F_1 + F_2) \tilde{\mathcal{H}} - \frac{t}{4m^2} F_2 \mathcal{E} \right], \\
 A_{UL,I}^{\sin \phi} &\propto \text{Im} \left[\xi (F_1 + F_2) \left(\mathcal{H} + \frac{\xi}{1+\xi} \mathcal{E} \right) + F_1 \tilde{\mathcal{H}} - \xi \left(\frac{\xi}{1+\xi} F_1 + \frac{t}{4M^2} F_2 \right) \tilde{\mathcal{E}} \right], \\
 A_{LL,I}^{\cos \phi} &\propto \text{Re} \left[\xi (F_1 + F_2) \left(\mathcal{H} + \frac{\xi}{1+\xi} \mathcal{E} \right) + F_1 \tilde{\mathcal{H}} - \xi \left(\frac{\xi}{1+\xi} F_1 + \frac{t}{4M^2} F_2 \right) \tilde{\mathcal{E}} \right], \\
 A_{LL,DVCS}^{\cos(0\phi)} &\propto \text{Re} \left[4(1-\xi^2) (\mathcal{H} \tilde{\mathcal{H}}^* + \tilde{\mathcal{H}} \mathcal{H}^*) - 4\xi^2 (\mathcal{H} \tilde{\mathcal{E}}^* + \tilde{\mathcal{E}} \mathcal{H}^* + \tilde{\mathcal{H}} \mathcal{E}^* + \mathcal{E} \tilde{\mathcal{H}}^*) \right. \\
 &\quad \left. - 4\xi \left(\frac{\xi^2}{1+\xi} + \frac{t}{4M^2} \right) (\mathcal{E} \tilde{\mathcal{E}}^* + \tilde{\mathcal{E}} \mathcal{E}^*) \right], \\
 A_{UT,DVCS}^{\sin(\phi-\phi_s)} &\propto \left[\text{Im} (\mathcal{H} \mathcal{E}^*) - \xi \text{Im} (\tilde{\mathcal{H}} \tilde{\mathcal{E}}^*) \right], \\
 A_{UT,I}^{\sin(\phi-\phi_s) \cos \phi} &\propto \text{Im} \left[-\frac{t}{4M^2} (F_2 \mathcal{H} - F_1 \mathcal{E}) + \xi^2 \left(F_1 + \frac{t}{4M^2} F_2 \right) (\mathcal{H} + \mathcal{E}) \right. \\
 &\quad \left. - \xi^2 (F_1 + F_2) \left(\tilde{\mathcal{H}} + \frac{t}{4M^2} \tilde{\mathcal{E}} \right) \right]. \tag{56}
 \end{aligned}$$

Kroll, P. et al; Eur. Phys. J. C **73** (2013)

$\mathcal{F}, \tilde{\mathcal{F}}$ - Linear combinations of GPDs

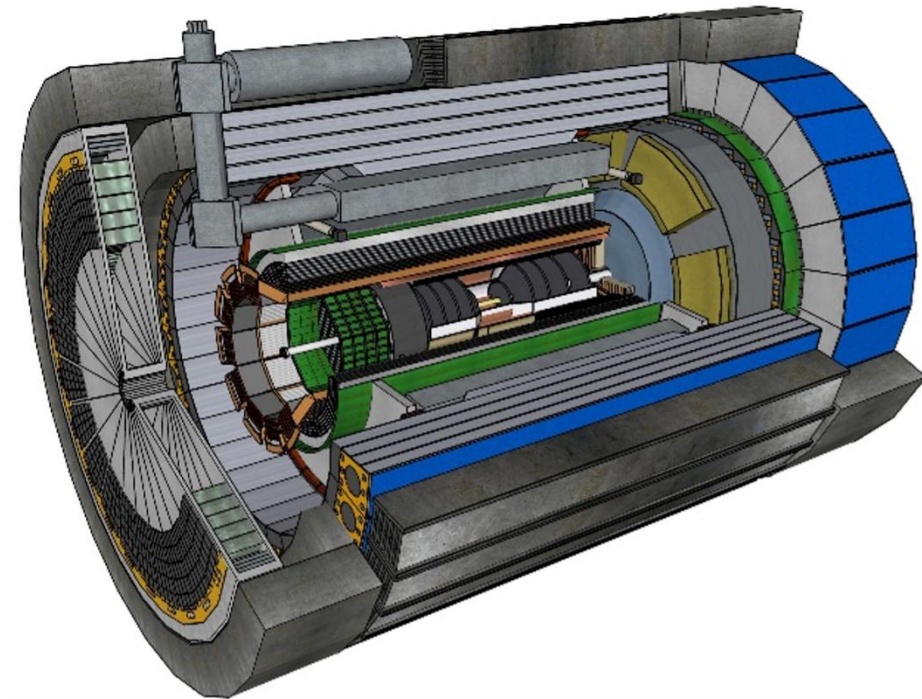
- DVCS has been studied for decades at different facilities.
 - Jefferson Lab (Hall A/Hall C/CLAS)
 - Fixed target $\rightarrow$ high- x (~ 0.1 - 0.6)
 - Polarised electron beam, (CLAS) polarised proton target (longitudinal)
 - HERA (HERMES)
 - Fixed target $\rightarrow$ high- x (but lower than JLab; ~ 0.03 - 0.3)
 - Polarised electron beam, polarised proton beam (longitudinal and transverse)
 - HERA (H1/ZEUS)
 - Colliding beams $\rightarrow$ low- x ($\sim 10^{-4}$ - 10^{-3})
 - No polarised data taken
 - CERN SPS (COMPASS)



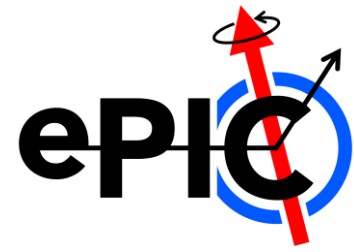
[Hobart, A. et al \(CLAS Collaboration\); Phys. Rev. Lett. **133** \(2024\)](#)

The ePIC detector (1)

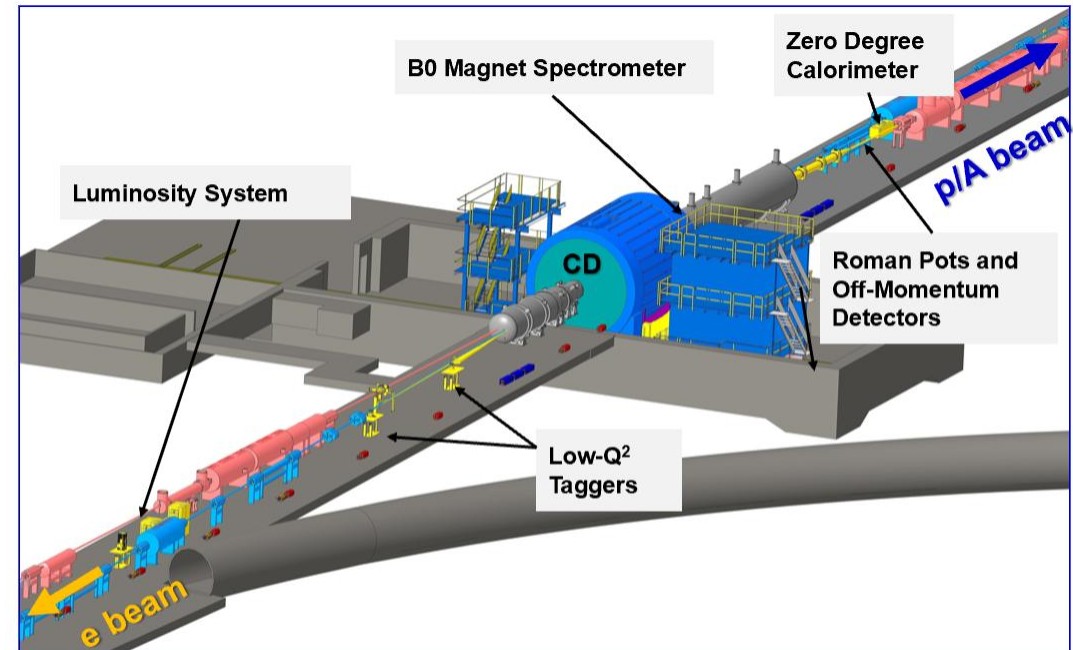
- First detector planned for EIC IP6 (ex-location of STAR detector).
- New 1.7T solenoid magnet.
- Tracking: Si MAPS based on ALICE ITS3 bendable chips.
- PID: multiple systems (TOF/Cherenkov) for $e/\pi/K/p$ discrimination at range of momenta.
- Calorimetry: hadronic and electromagnetic calorimeters to cover most of solid angle.



The ePIC detector (2)



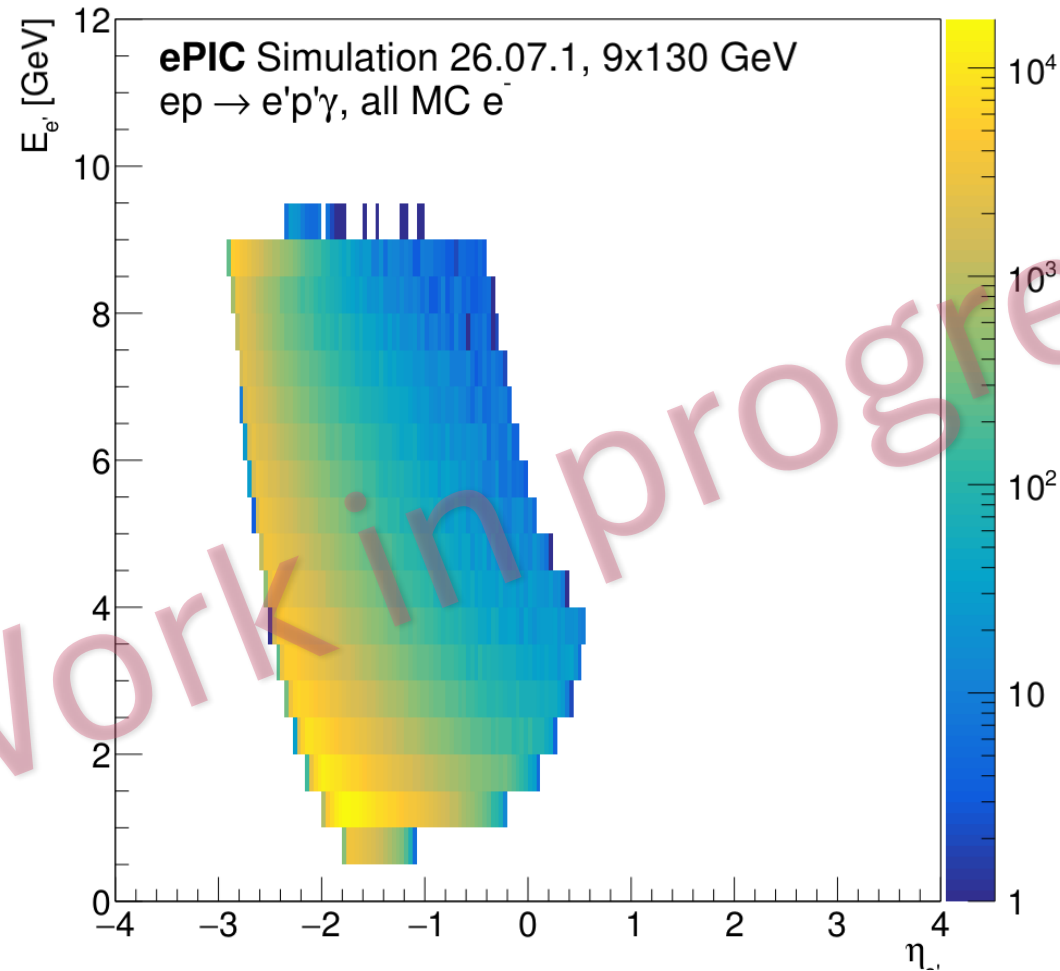
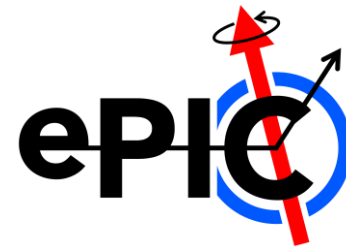
- Many subsystems outside the main ePIC central barrel.
- Far backwards (electron-going)
 - Taggers for low- Q^2 ($\sim 10^{-2}$ - 10^{-3} GeV²) scattered electrons
 - Luminosity monitoring system
- Far forwards (proton-going)
 - B0 spectrometer
 - Roman Pots around proton beam
 - Off-Momentum detectors
 - Zero Degree Calorimeter



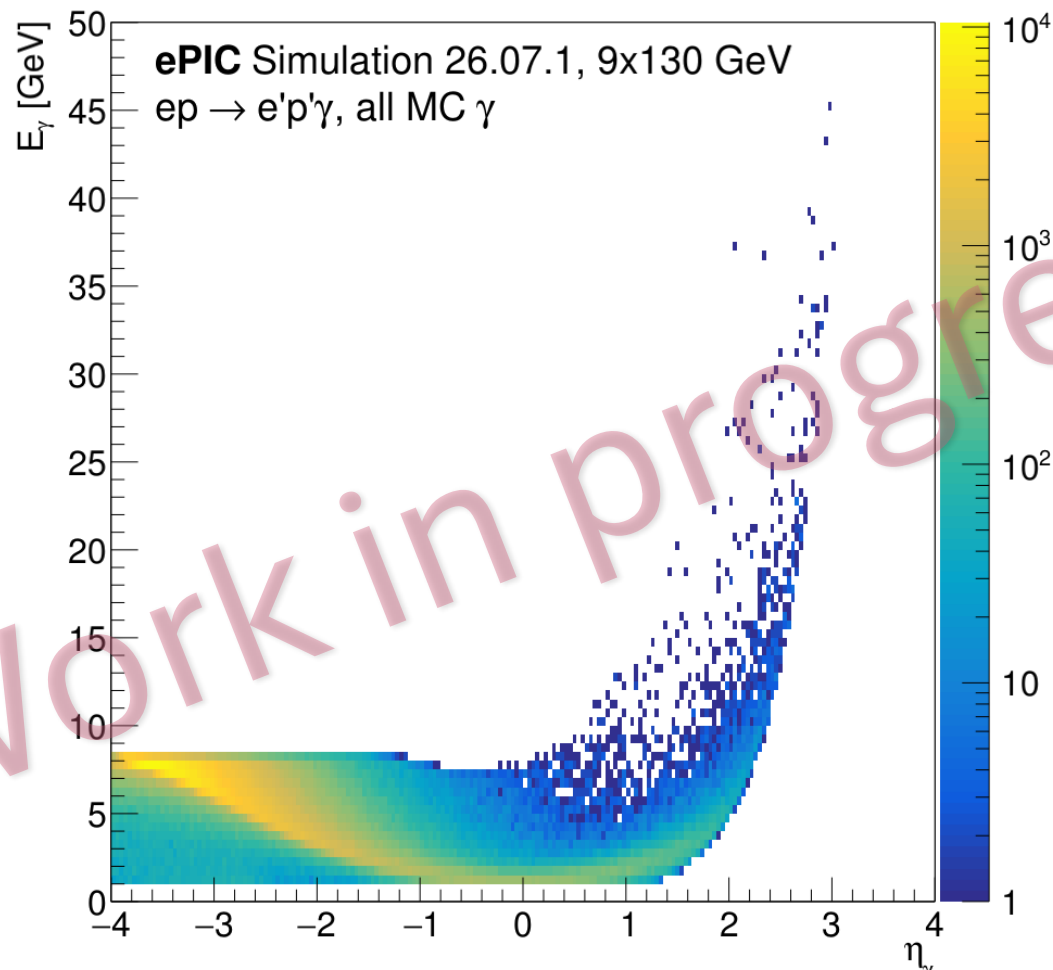
- Based on schedule for EIC commissioning.
- Plan to run ePIC detector during this time.
- Early science ep beams:
 - 1 fb⁻¹ of 9x130 GeV beams (9 GeV electrons on 130 GeV protons)
 - Both longitudinal and transverse polarised protons expected.
 - 2.5 fb⁻¹ of 9x275 GeV
 - Both longitudinal and transverse polarisation .
 - Expected within the first few years of EIC running.

- Events passed through full ePIC software stack:
 - Afterburner – adds 25 mrad crossing angle and beam smearing
 - Geant4-based representation of ePIC detector
 - ElCrecon event reconstruction software package
- Reconstructed particles selected based on kinematic and quality cuts.
- DVCS events selected with further exclusivity cuts.

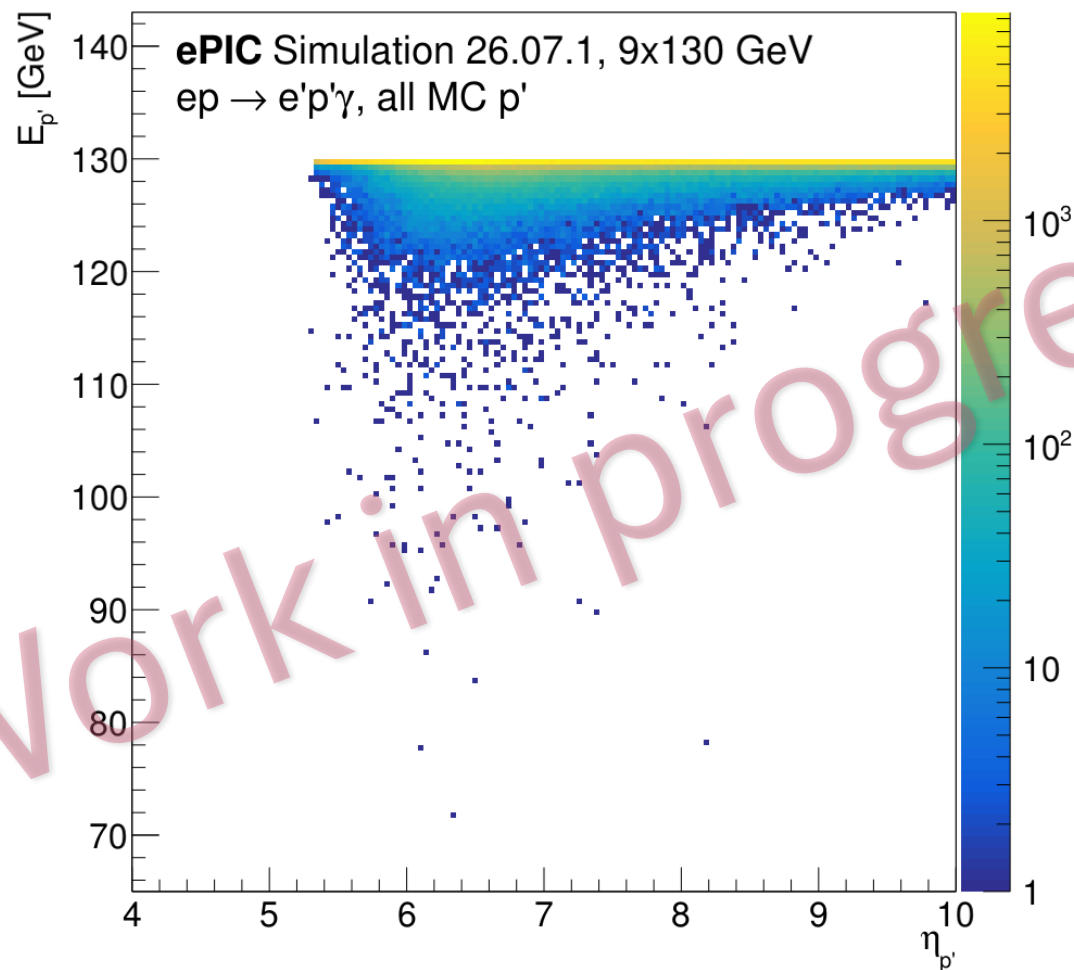
E/η – Generated e'



E/η – Generated γ



E/η – Generated p'



- 3D binning in Q^2 , x_B and $|t|$.
- 3 bins in Q^2 – equal events in each
 - Plot $x_B : |t|$ for each Q^2 bin
- $x/|t|$ bins; philosophy: minimum 1000 events per $Q^2/x/|t|$ bin
 - Most events expected at low- x , low- $|t|$
- High- $|t|$ (B0 region)
 - Project 2D hist. along x for t -range expected for B0 (e.g. 0.45-2 GeV^2 for 9x130)
 - 1 t -bin used
 - Split into maximum number of x -bins with minimum 1000 events (if $N_{\text{ev}} < 2000$, use 1 bin)

Asymmetries – binning scheme (2)



- Low- $|t|$ (RP region) – want 4 t-bins per x_B range
 - Project 2D hist. along t for expected t -range (e.g. 0-0.45 GeV^2 for 9x130)
 - As many x -bins as possible, minimum 4000 events per bin.
 - Excess events go into highest x -bin.
 - Project along x for each chosen x -range.
 - Split t -distribution into 4 equal bins.

- Example: 9x130 GeV ep collisions
- Q^2 : {1., 1.4, 2.5, 100} GeV²
- $x_B/|t|$:

Q2 bin 1 - [0.99 - 1.4] GeV²

(1) High- t (few bins) -

$|t| = \{0.45, 2.\}$

$x = \{0., 1.\}$

(2) Low- t (fine binning) -

$x_B = \{0, 0.00036, 0.00056, 1\}$

$x_B: \{0, 0.00036\} \quad |t| = \{0.01, 0.08, 0.14, 0.26, 0.45\}$

$x_B: \{0.00036, 0.00056\} \quad |t| = \{0.01, 0.08, 0.14, 0.24, 0.45\}$

$x_B: \{0.00056, 1\} \quad |t| = \{0.01, 0.1, 0.16, 0.26, 0.45\}$

Q2 bin 2 - [1.4 - 2.5] GeV²

(1) High- t (few bins) -

$|t| = \{0.45, 2.\}$

$x = \{0., 1.\}$

(2) Low- t (fine binning) -

$x_B = \{0, 0.00054, 0.00078, 1\}$

$x_B: \{0, 0.00054\} \quad |t| = \{0.01, 0.08, 0.14, 0.26, 0.45\}$

$x_B: \{0.00054, 0.00078\} \quad |t| = \{0.01, 0.08, 0.14, 0.24, 0.45\}$

$x_B: \{0.00078, 1\} \quad |t| = \{0.01, 0.1, 0.16, 0.26, 0.45\}$

Q2 bin 3 - [2.5 - 100] GeV²

(1) High- t (few bins) -

$|t| = \{0.45, 2.\}$

$x = \{0., 1.\}$

(2) Low- t (fine binning) -

$x_B = \{0, 0.00114, 0.00208, 1\}$

$x_B: \{0, 0.00114\} \quad |t| = \{0.01, 0.08, 0.14, 0.26, 0.45\}$

$x_B: \{0.00114, 0.00208\} \quad |t| = \{0.01, 0.08, 0.14, 0.26, 0.45\}$

$x_B: \{0.00208, 1\} \quad |t| = \{0.01, 0.08, 0.14, 0.24, 0.45\}$