

# Exclusive Physics update

EIC UK Discussion  
30/06/22

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Daria Sokhan (CEA Saclay/UoG)

On behalf of many participants of ECCE and ATHENA proto-collaborations  
and working groups...

# Overview of Activities

- Heavy UK-based involvement in exclusive, diffractive and tagging physics working groups of **ATHENA and ECCE** during proposal preparations
  - **Co-convenorship**
  - Leading **several reactions/studies**
- Exclusive reactions:
  - **Complete measurements**
    - Scattered lepton, scattered nucleon/nuclei (intact or dissociated), any other particle produced in reaction
    - Acceptance, resolutions, PID → phase space, kinematic binning, background reduction
    - **Far forward** instrumentation for tagging
    - Far backwards may be relevant for some studies
- Physics WG aims:
  - **Study detector capabilities exclusive reaction reconstructions**
  - **Check can address key EIC scientific goals** laid out in EIC White Paper, 2018 NAS report on EIC Science, EIC YR
    - **Origin of nucleon spin**
    - **3D structure of nucleons and nuclei**
    - **Gluon structure of nuclei**
    - **Origin of hadron mass**
    - Any science beyond this?

# Overview of Activities



## ATHENA

*Exclusive, Diffractive and Tagging  
Working Group Co-Convenors:*

S. Fazio (Calabria)

S. Klein (Berkeley)

**D. Sokhan (Saclay/UoG)**

*UK based participants: D. Glazier, K.  
Gates (UoG)*



## ECCE

*Exclusive Working Group Co-Convenors:*

J. Roche (Ohio)

**R. Montgomery (UoG)**

*UK based participants: D. Glazier, K.  
Gates, G. Penman (UoG), S. Fegan (York)*

(Diffractive/Tagging was separate group,  
but joined together towards end and for  
final publication)



# ATHENA Activities

Following ATHENA slides provided by D. Sokhan  
(thank you)

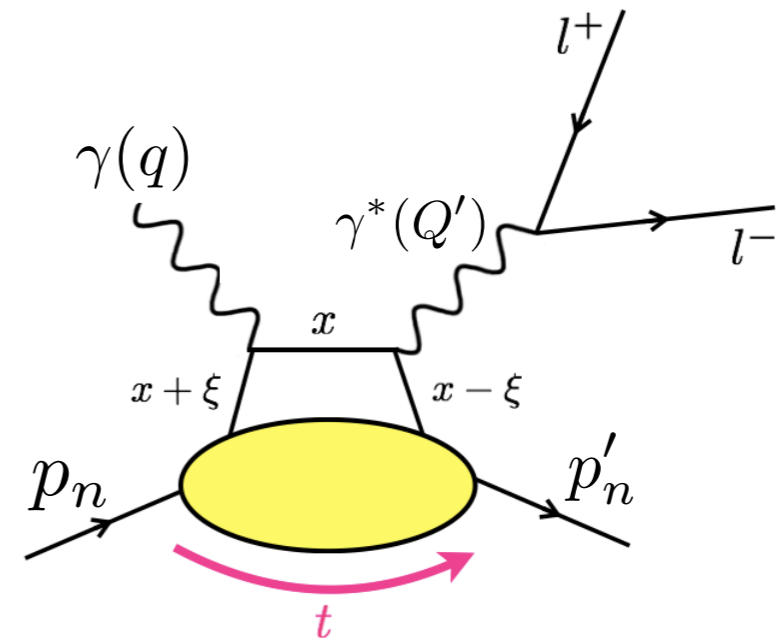
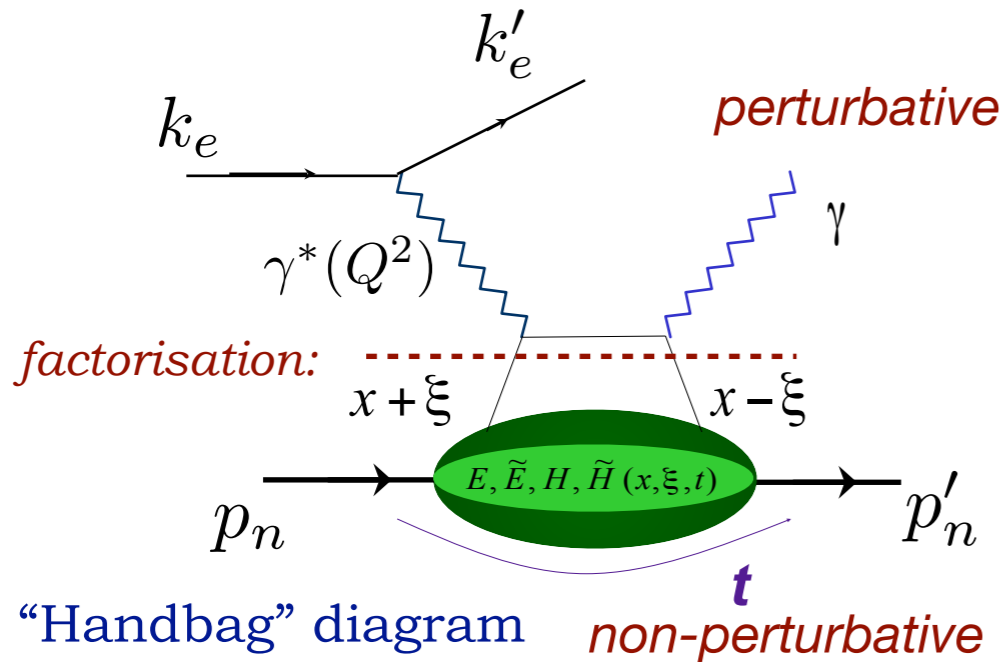


# ATHENA Exclusive/Diffractive/Tagging WG Activities

- Reactions **in final proposal**:
  - DVCS in ep (EpIC) (*S. Fazio/Calabria*)
  - TCS in ep (EpIC) (*D. Sokhan, Saclay/UoG, K. Gates/UoG*)
  - $\Upsilon(1S, 2S, 3S)$  in ep (eSTARlight) (*S. Klein, Y.Ji/LBNL*)
  - $\phi$  in eAu (SARTRE, BeAGLE) (*K. Tu, T. Ullrich, Z. Xu/BNL*)
  
- Reactions in supplementary proposal material (in back up):
  - DVCS in ed (EpIC) (*S. Fazio/Calabria, K. Tu/BNL*)
  - Backward production of  $\omega \rightarrow \pi^0 \gamma$  (eSTARlight) (*Z. Sweger, S. Klein/BNL*)
  - $X, Y, \Psi(2S)$  in ep  $\rightarrow J/\Psi \pi^+ \pi^- p$  (elSpectro generator) (*D. Glazier/UoG, J. Stevens/W&M*)



# DVCS and TCS



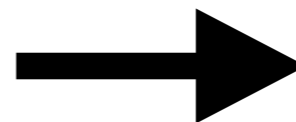
- High  $Q^2$ , low  $t$  → access 4 parton helicity-conserving chiral-even GPDs
- → nucleon spin and 3D structure!
- Experimentally, measure DVCS, BH and INT



$$d\sigma \propto |T_{DVCS}|^2 + |T_{BH}|^2 + T_{BH}T_{DVCS}^* + T_{DVCS}T_{BH}^*$$

- Observables parameterised in CFF: complex functions; Re parts integrals of GPD over  $x$  and Im parts are GPDs at  $x = \pm\xi$

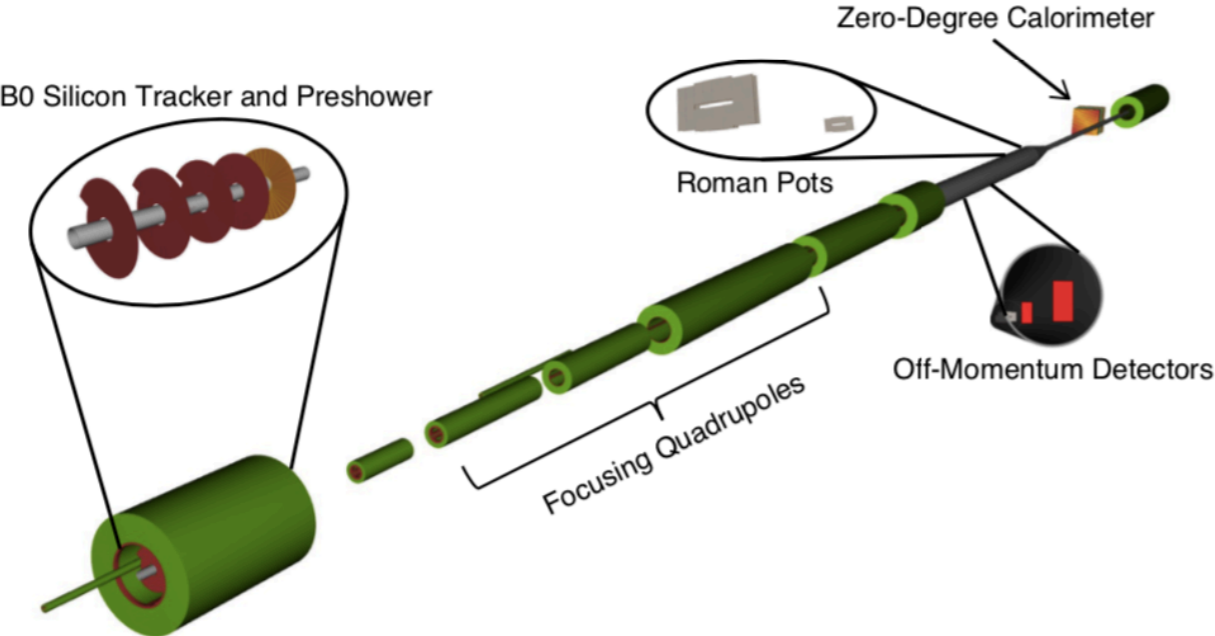
- Real photon interacts with target nucleon, releases virtual photon which decays to  $l^+l^-$
- Time reversal process of DVCS
- Parameterised in terms of same CFF (complex conjugates) - complimentary
- Verification of GPD universality
- Sensitivity to pressure distribution



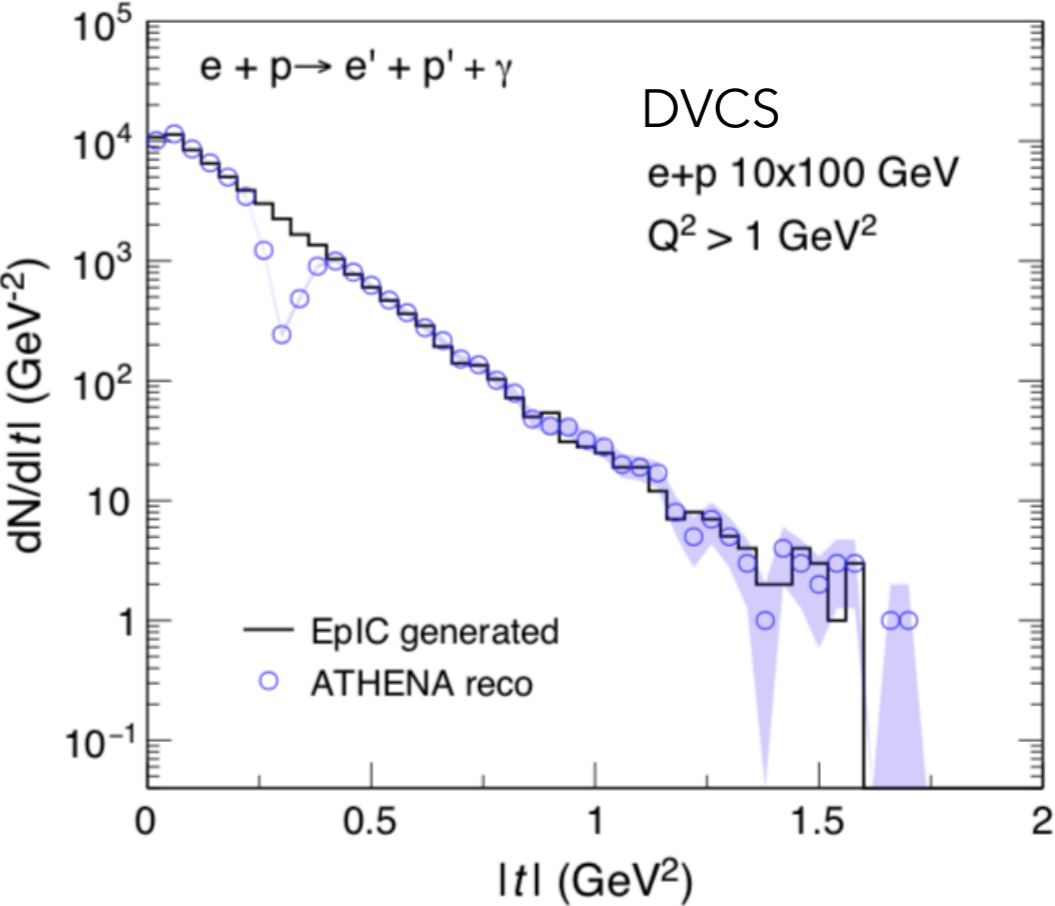
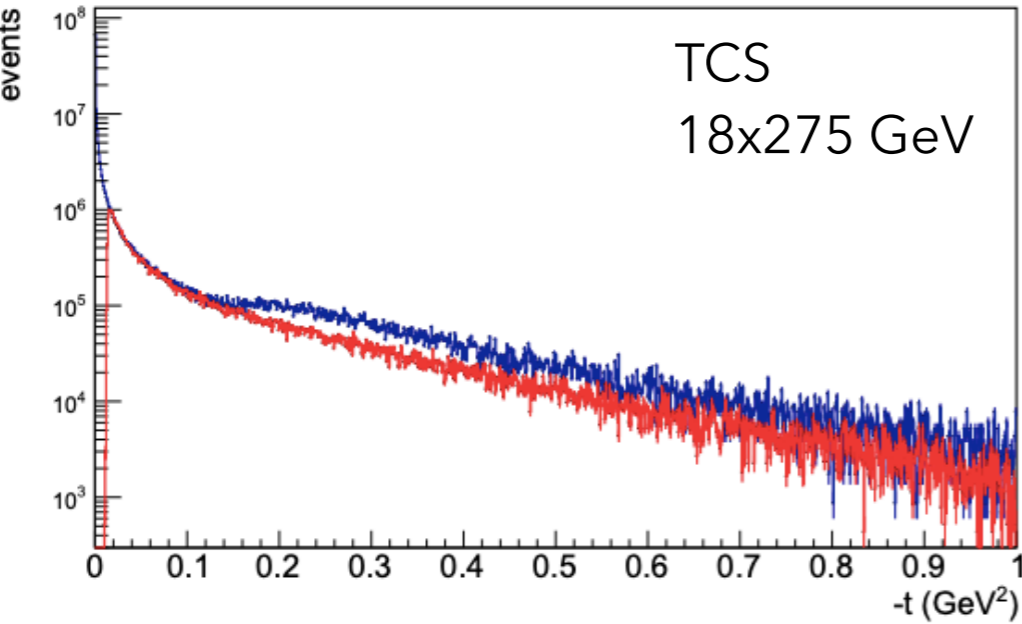
- Nucleon tomography
- Nucleon spin



# Recoil Protons in DVCS and TCS

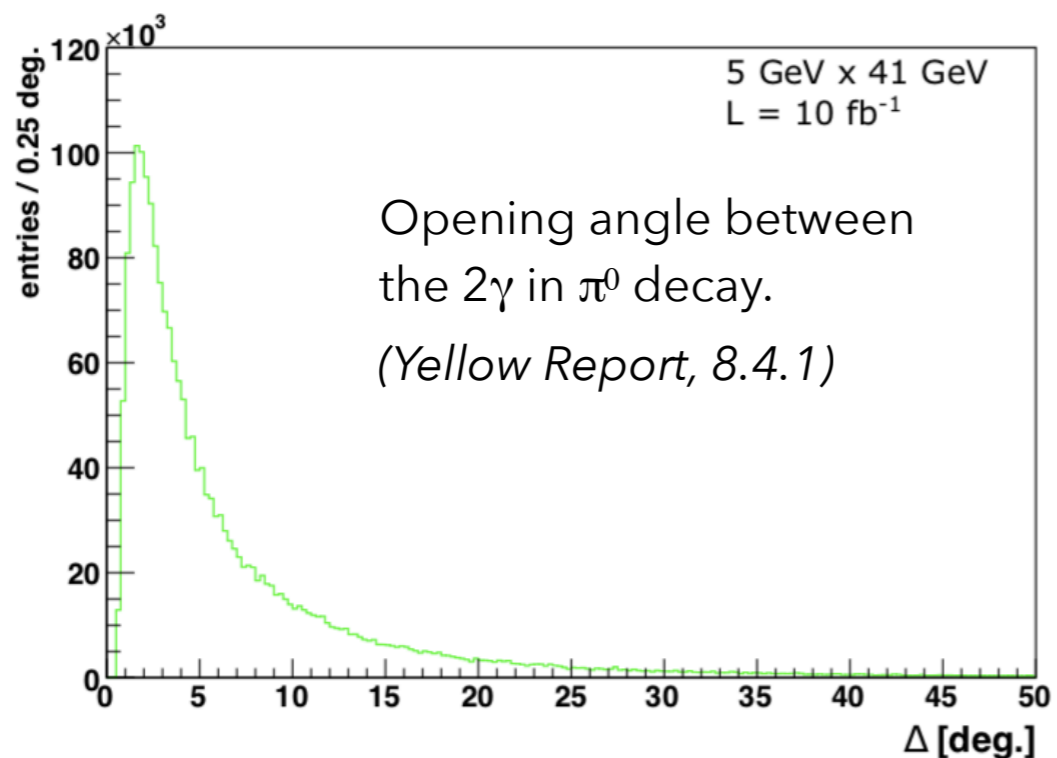
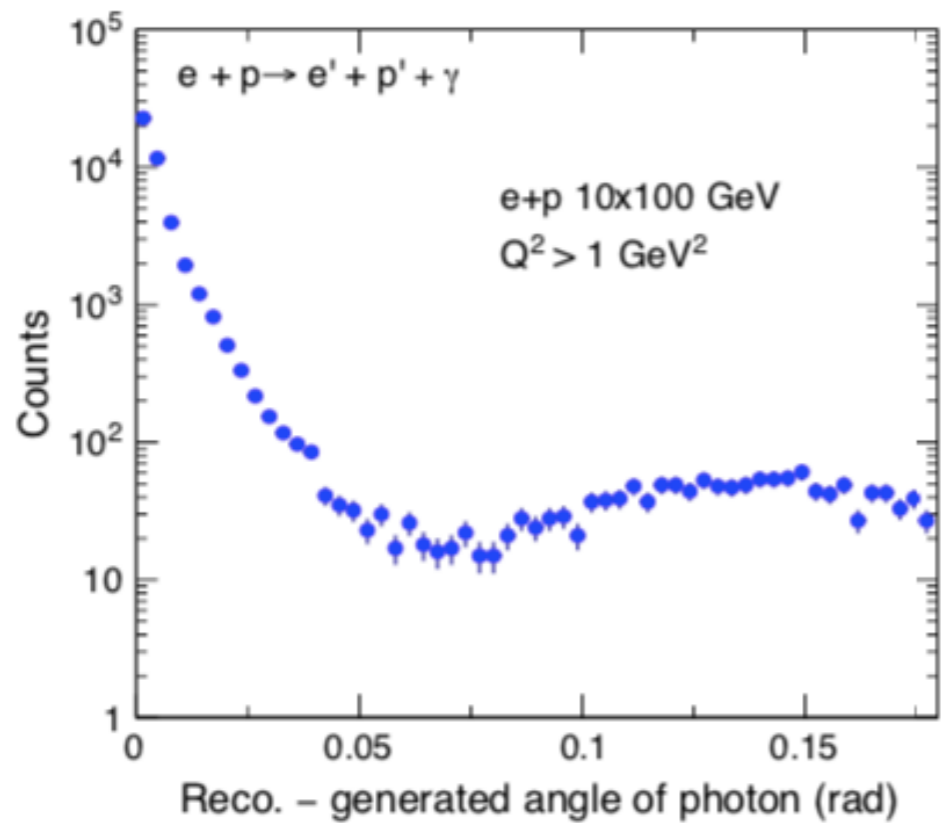


- Access to small  $t$ , and wide range of  $t$  crucial in many exclusive reactions
- $t = (p_{N'} - p_N)^2$
- $0.3 < |t| < 1.6 \text{ GeV}^2$
- $|t|$  reconstructed by scattered protons in far forward instrumentation
- RP for smallest  $t$
- B0 for highest





# Central Detector in DVCS



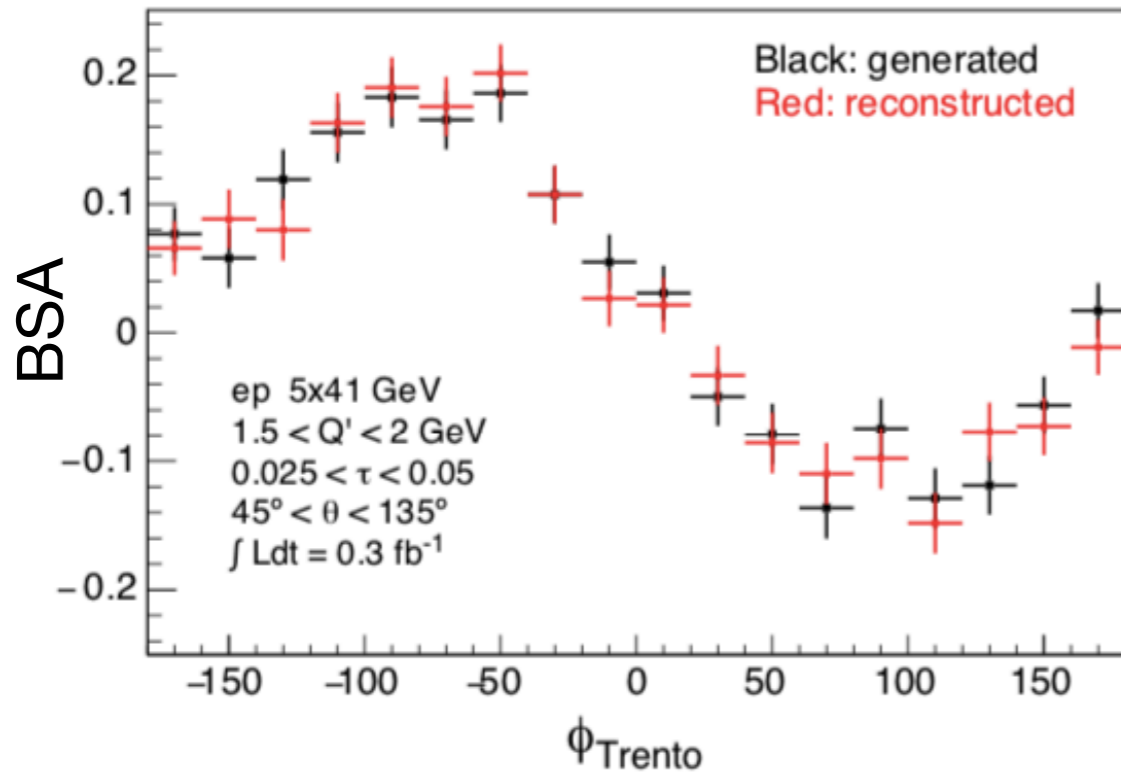
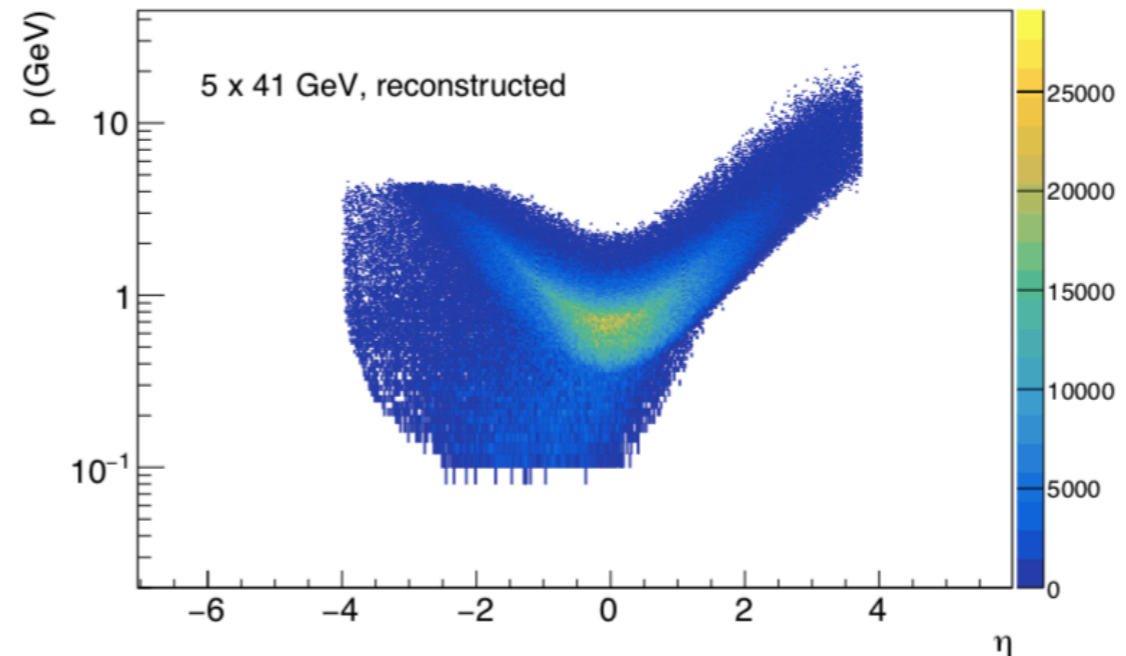
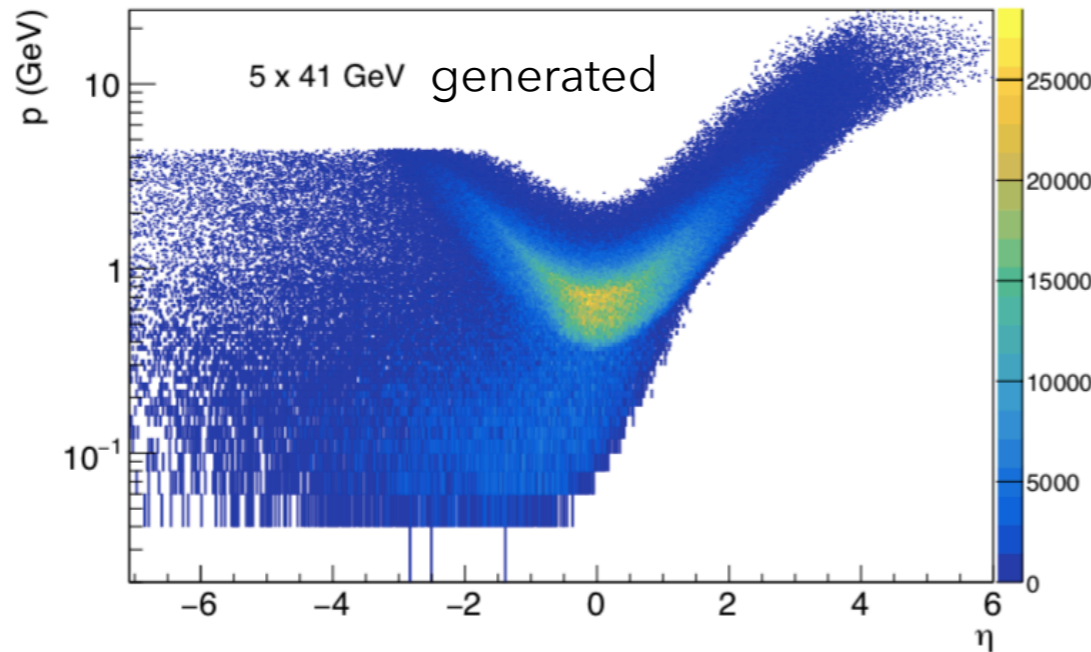
- DVCS real photon detected in ECAL
- Biggest background comes from mesons (eg  $\pi^0$ ) decaying into 2 photon pairs
- Challenging to suppress
- Studied for DVCS ep
- Difference between generated and reconstructed DVCS photon mainly  $< 0.17 \text{ mrad}$  (1 deg), which is typically smallest opening angle for  $\pi^0$  decay





# Central Detector in TCS and BSA

Plots: D. Sokhan  
Saclay/UoG

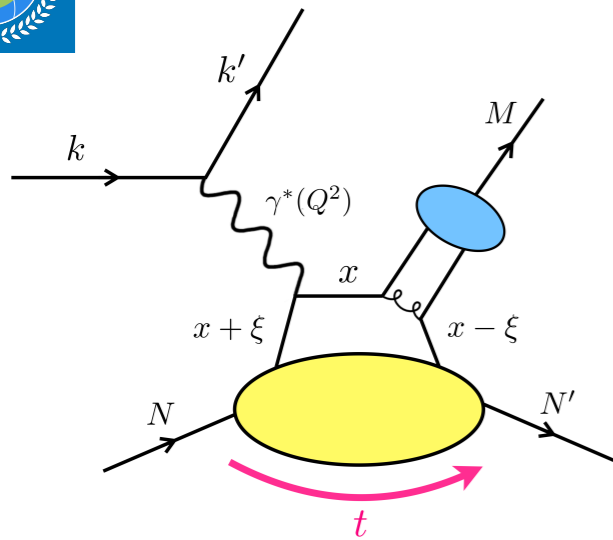


Photon polarisation BSA  
(Access to  $\text{Im}(H)$ )

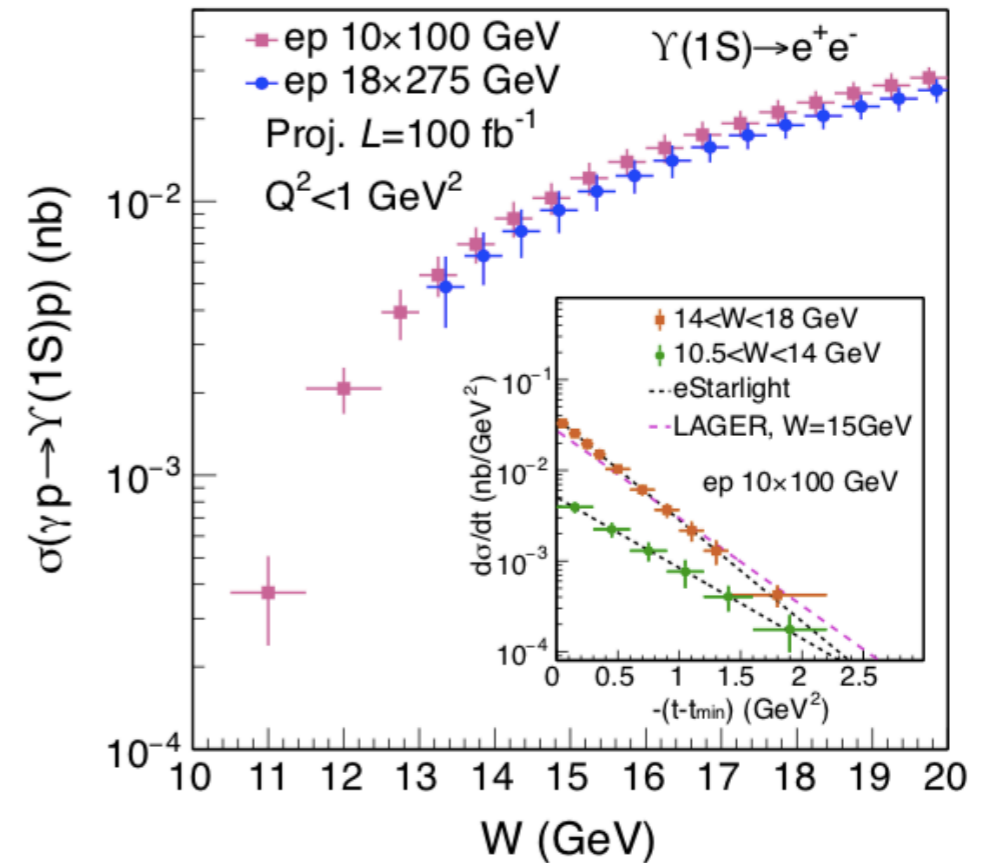
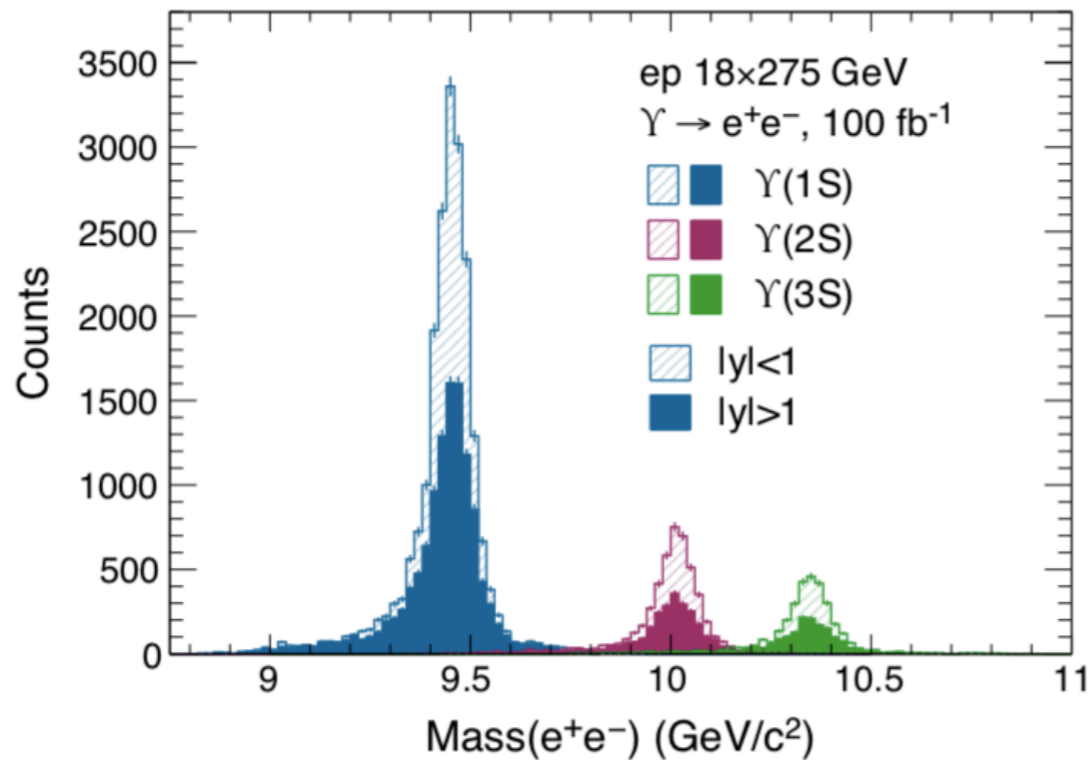
- $e^+e^-$  needs excellent acceptance in central detector
- $e'$  reconstructed through missing mass and momentum (low  $Q^2$  tagger would only help in sub-set of phase space)
- TCS factor 100 less than main background (BH)  
- cross-sections difficult to measure
- Asymmetries - access Re and Im parts of GPDs
- BSA extracted from studies



# GPDs via Meson-Production in ep



- Hard exclusive electro-production of vector mesons (e.g.  $J/\Psi, \Upsilon$ )
  - Access gluon GPDs (multi-dimensional imaging)

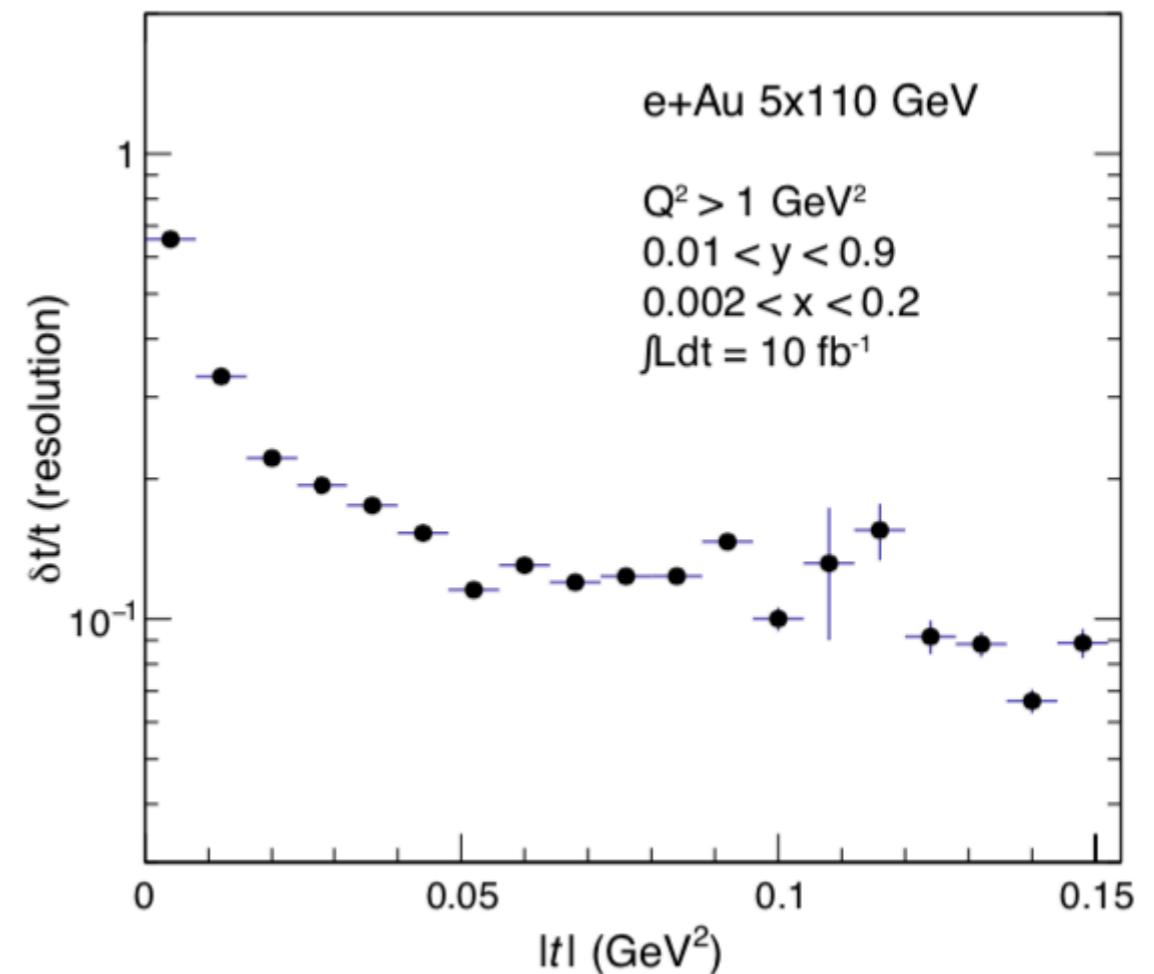
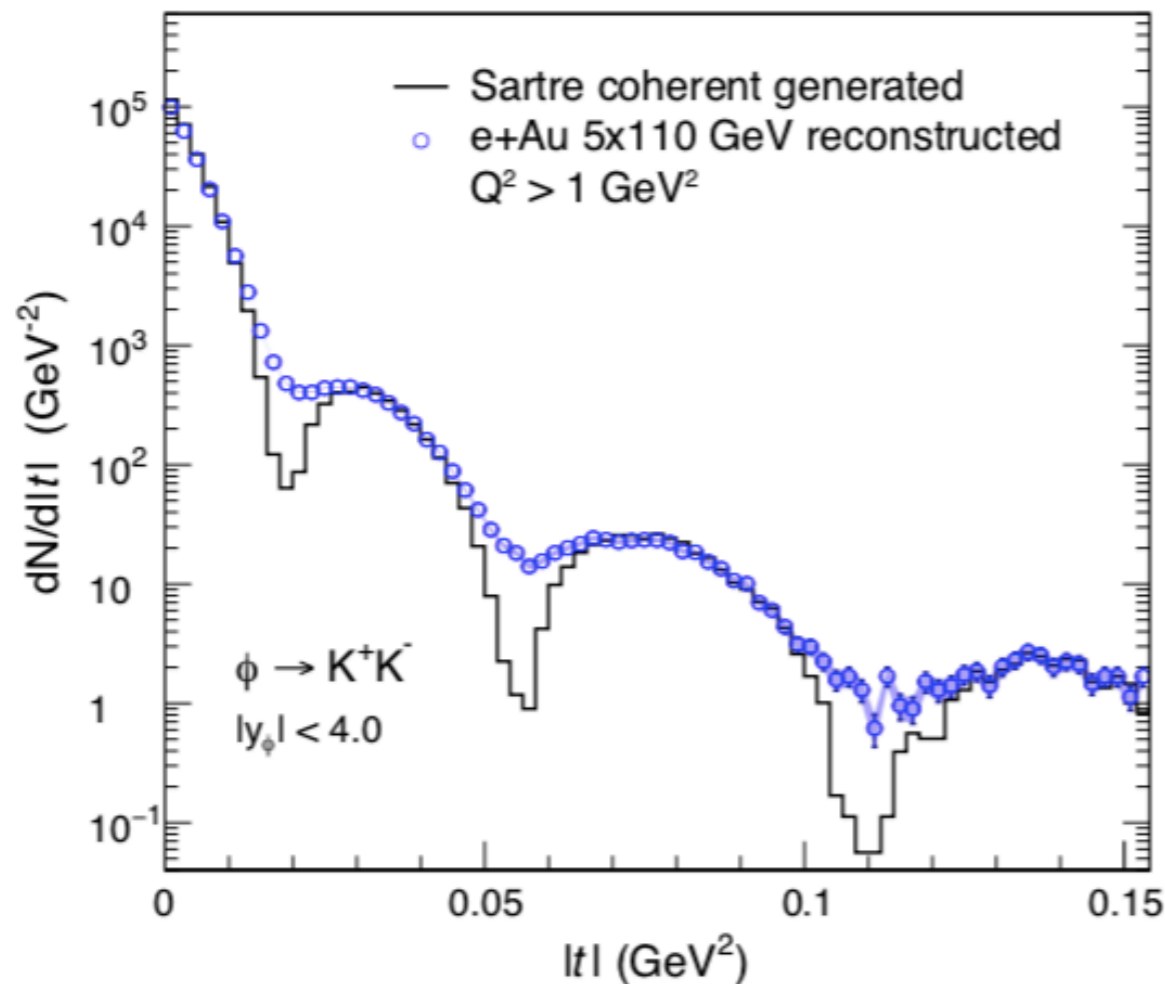


- Upsilon Production in ATHENA
- Good mass resolution to separate three states
- Projected uncertainty of total and differential x-sec of near threshold  $Y$  photoproduction ( $Q^2 < 1 \text{ GeV}^2$ ) and electroproduction ( $Q^2 > 1 \text{ GeV}^2$ )



# Coherent VM production in eA

- Access to gluon distributions in nuclei and gluon saturation effects
- Challenge for detector: reconstruct  $t$  from leptons/mesons in central detector (not from nuclei in far forward region)
- **$t$ -resolution is needed to resolve minima**
- Suppression of incoherent background using far forward region as veto for nuclear break up





# ECCE Activities

- Exclusive WG studies in final proposal:
  - DVCS in ep (MILOU3D) (*I. Korover/MIT, J. Roche/Ohio*)
  - DVMP in ep, J/ψ electroproduction (IAger) (*N. Santiesteban/MIT, S. Fegan/York*)
- Exclusive WG studies in supplementary material:
  - TCS in ep (EpIC) (*K. Gates/UoG, D. Sokhan/Saclay/UoG*)
  - DVCS in eA (<sup>4</sup>He) (Topeg) (*G. Penman/UoG, R. Montgomery/UoG*)
  - DVMP in eA (Au, Pb), Φ electroproduction (SARTRE, BeAGLE) (*J. Frantz/Ohio*)

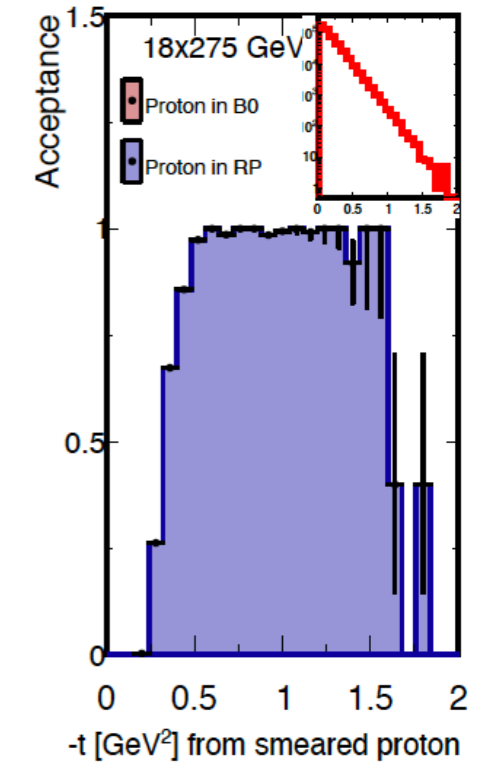
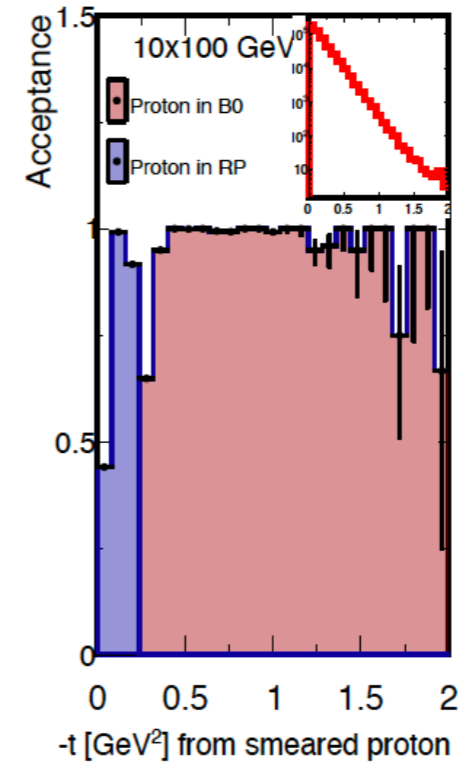
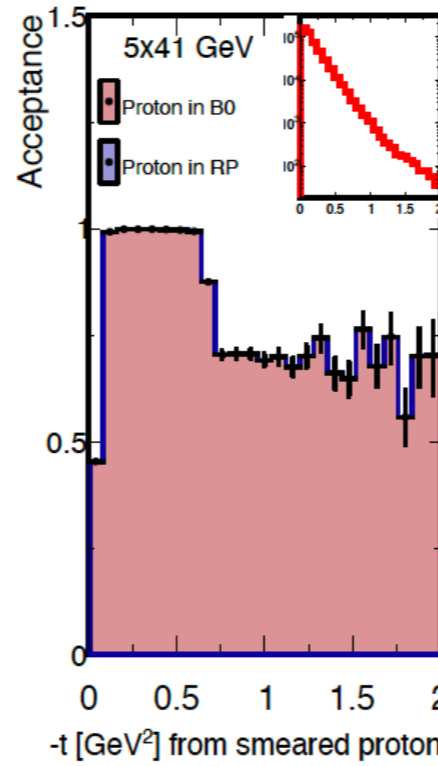
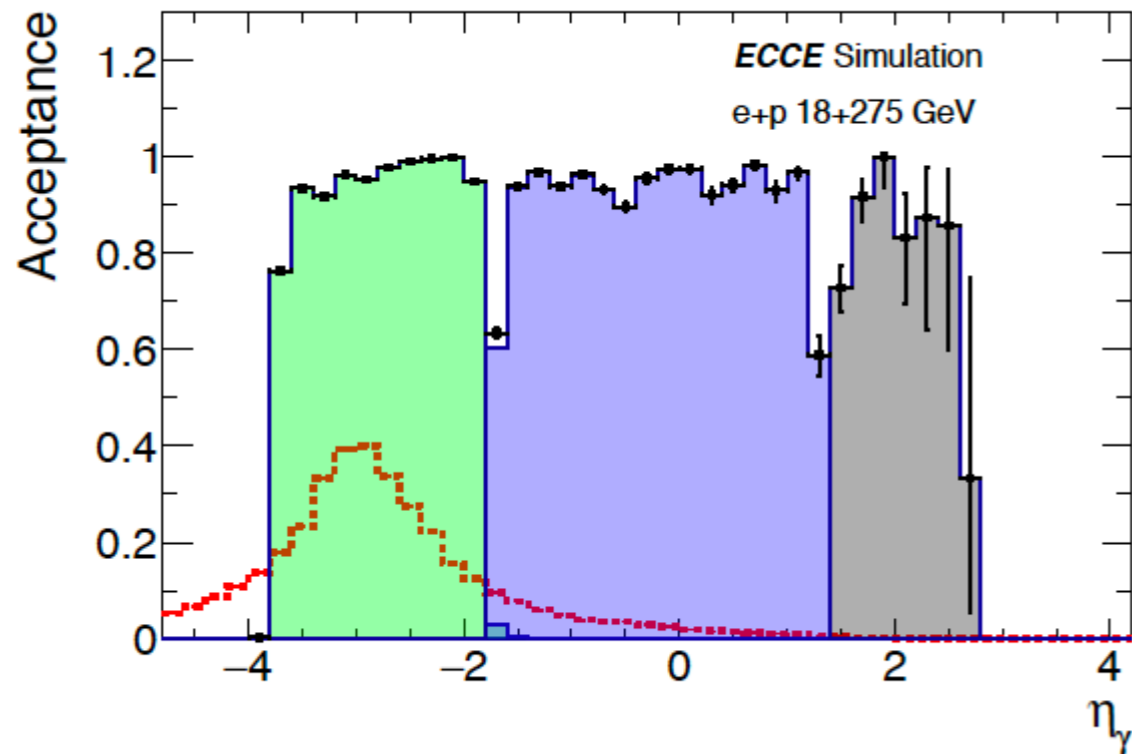
Stand alone relevant analysis notes, studied separately and included in ECCE proposal:

- XYZ Spectroscopy (eISpectro) - (*D. Glazier/UoG*)
- Near threshold J/ψ production (eSTARlight), later addition on nucleon mass topic (*X. Li, W. Zha/Hefei, China*)
- Diffractive WG studies (strong overlap in FF implementation):
  - Pion form factor; pion structure function; neutron spin structure  $A_{n_1}$  (double tagged e<sup>3</sup>He DIS); diffractive J/ψ production in eA (Zr)
  - Results not reported on here
- Exclusive and diffractive/tagging WG eventually joined forces
- Writing paper combining both WG results, plus XYZ spectroscopy



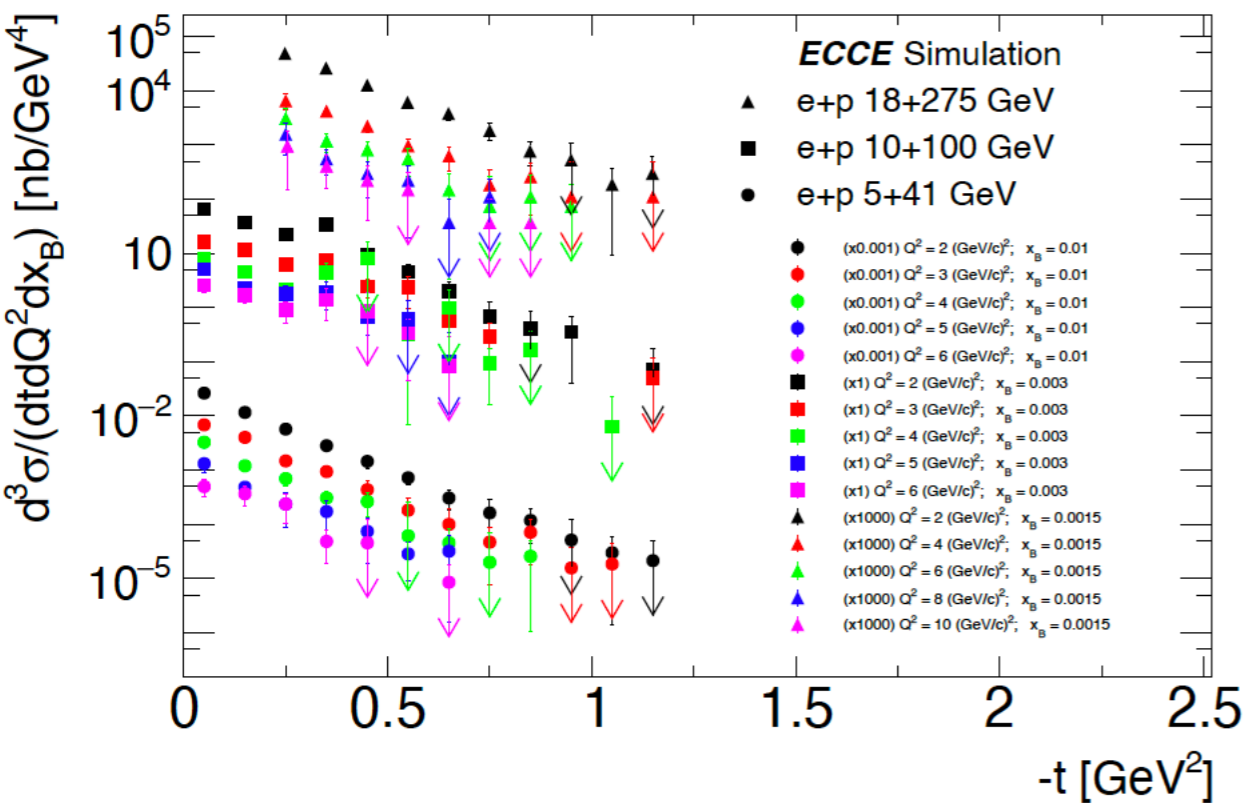
# DVCS in ep

Plots: I. Korover

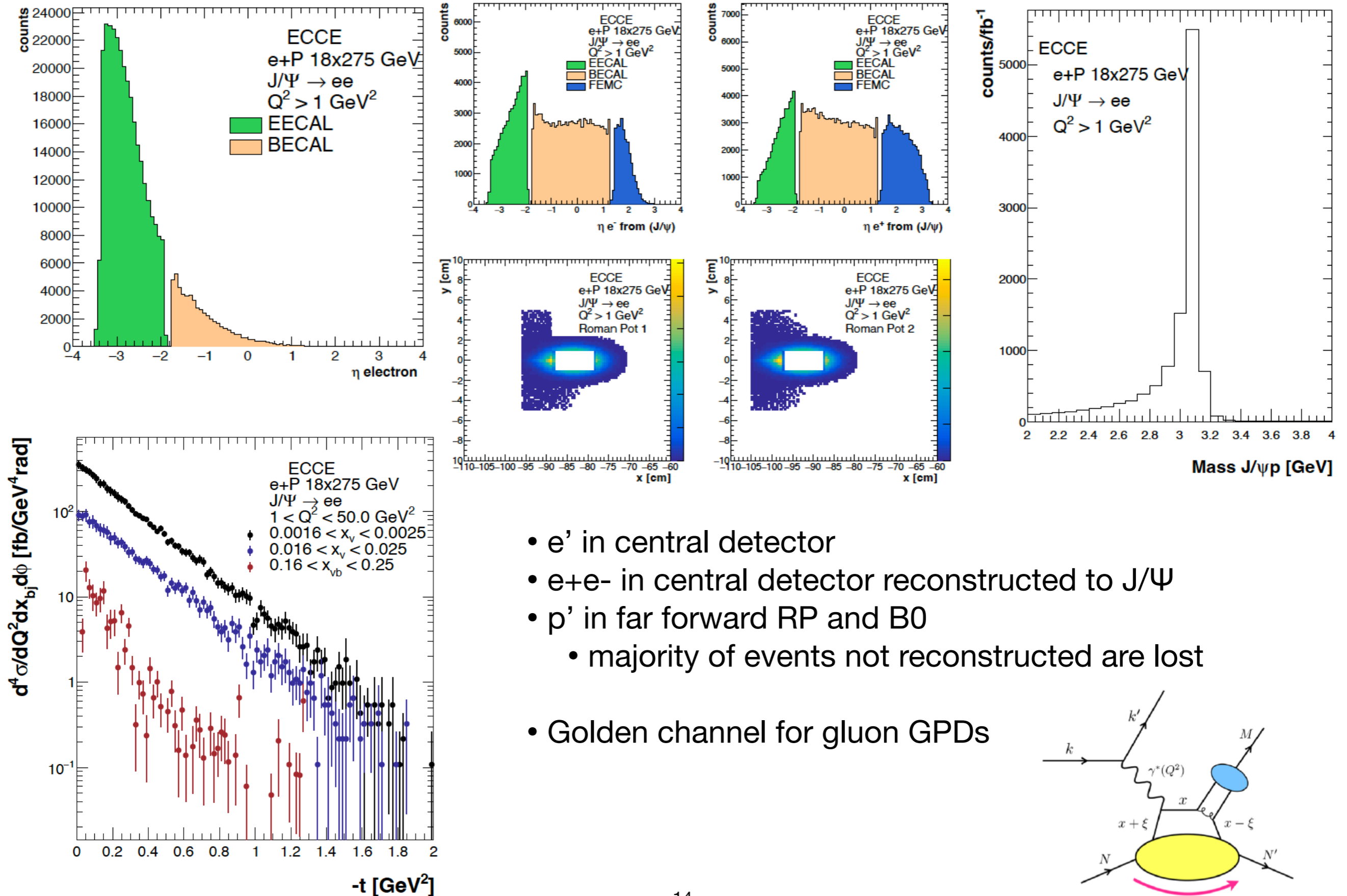


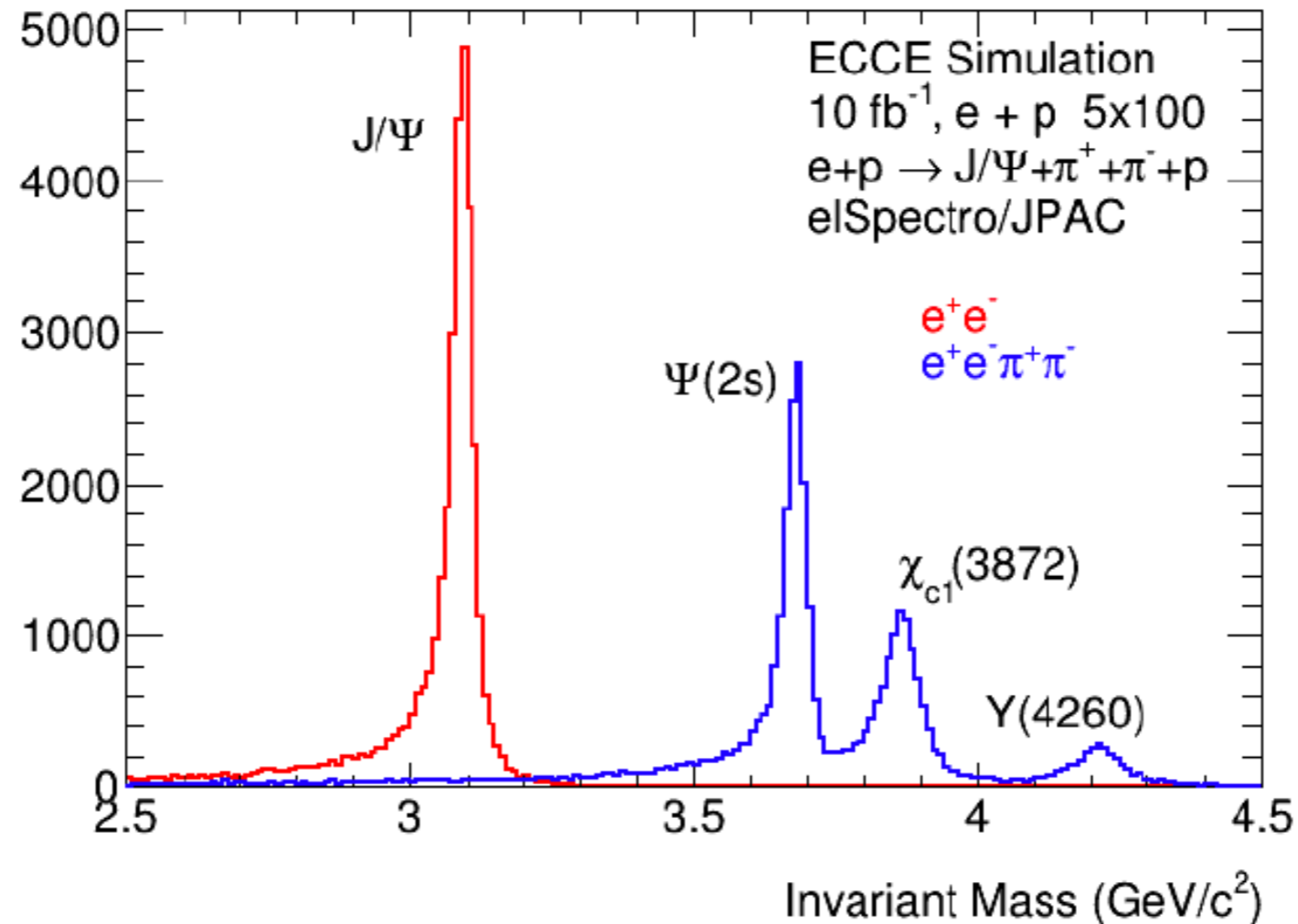
- Photon acceptance in backwards, barrel and forward ECALs

- Proton acceptance in B0 and RP (far forward detectors)



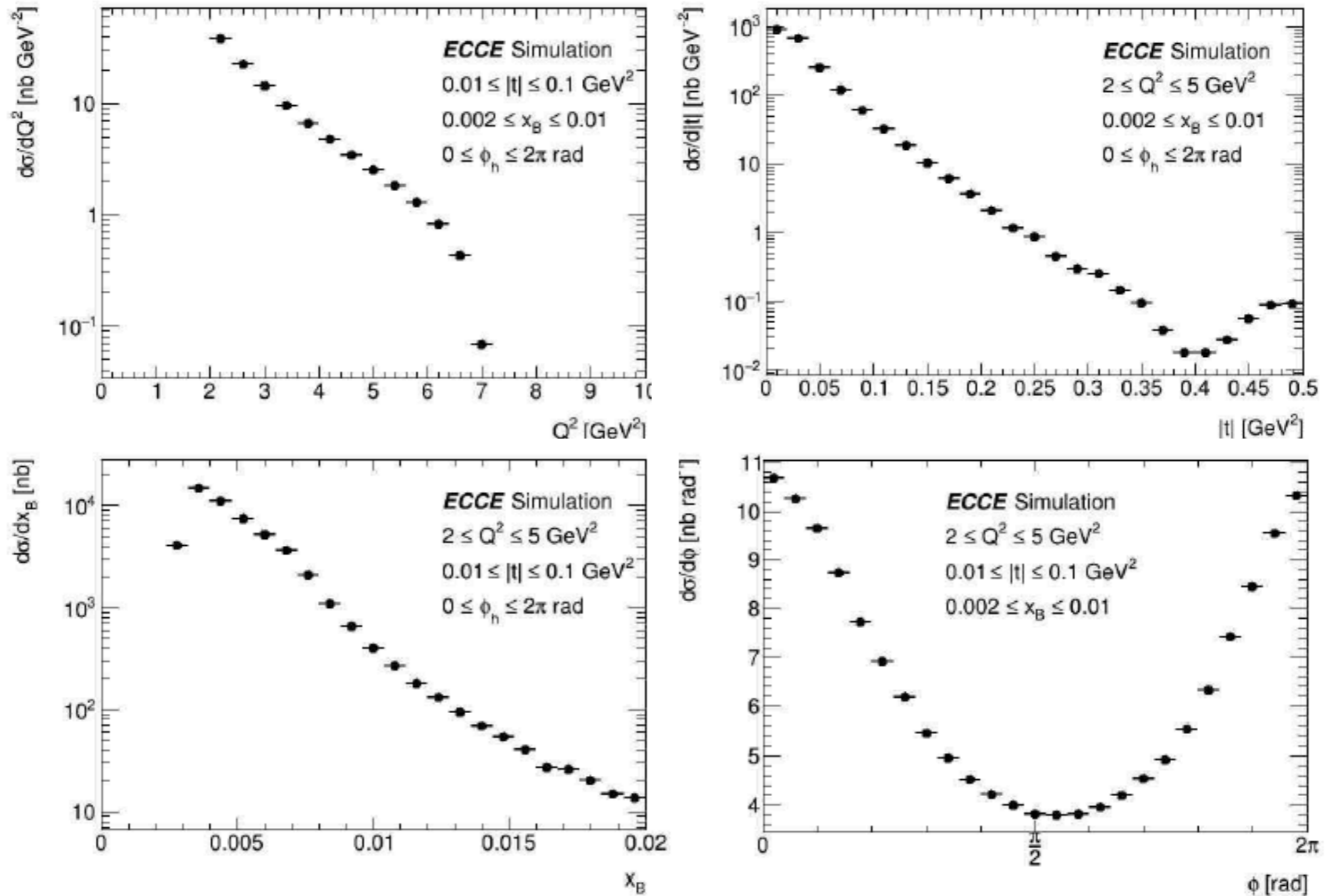
- Practically hermetic coverage for photons
- Excellent coverage for protons (small -t)
- Left: diff x-sec against -t, in bins of  $Q^2$  and  $x_B$  for integrated luminosity  $10\text{fb}^{-1}$
- → multi-dimensional binning possible
- Included in proposal as golden channel for quark GPDs:
  - nucleon spin; 3D structure of nucleon





- XYZ Spectroscopy, spectroscopy of mesons with charm quarks (D. Glazier, UoG, J. Stevens W&M)
- New XYZ states have unexpectedly narrow widths inconsistent with quark model predictions
- Above reconstructed invariant masses obtained with D. Glazier elSpectro generator
- Resolution sufficient to separate states
- Some kinematics and decays may benefit from low  $Q^2$  tagger

## Coherent DVCS $e^4\text{He}$ (5GeV x 164GeV)

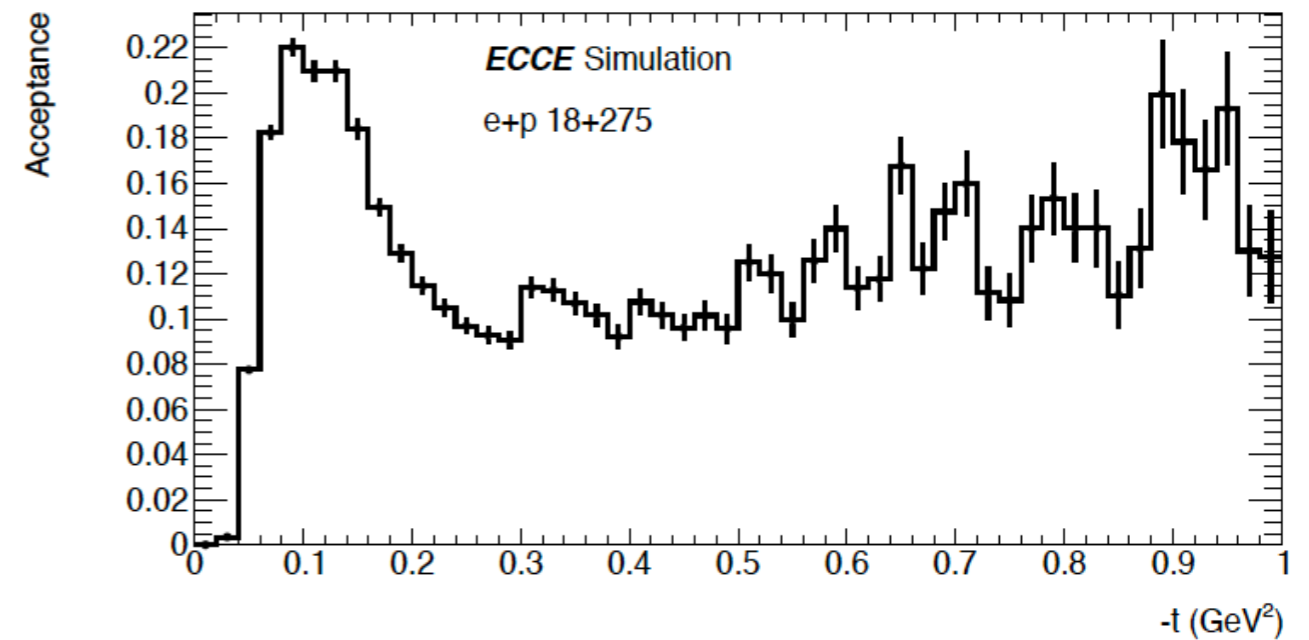
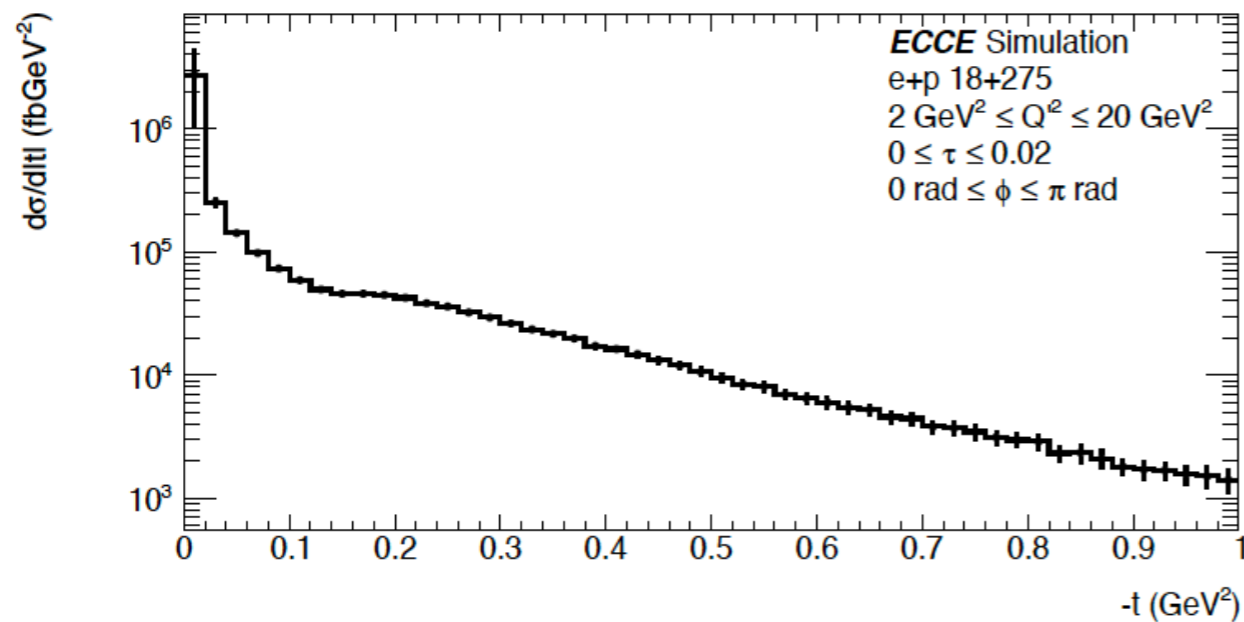
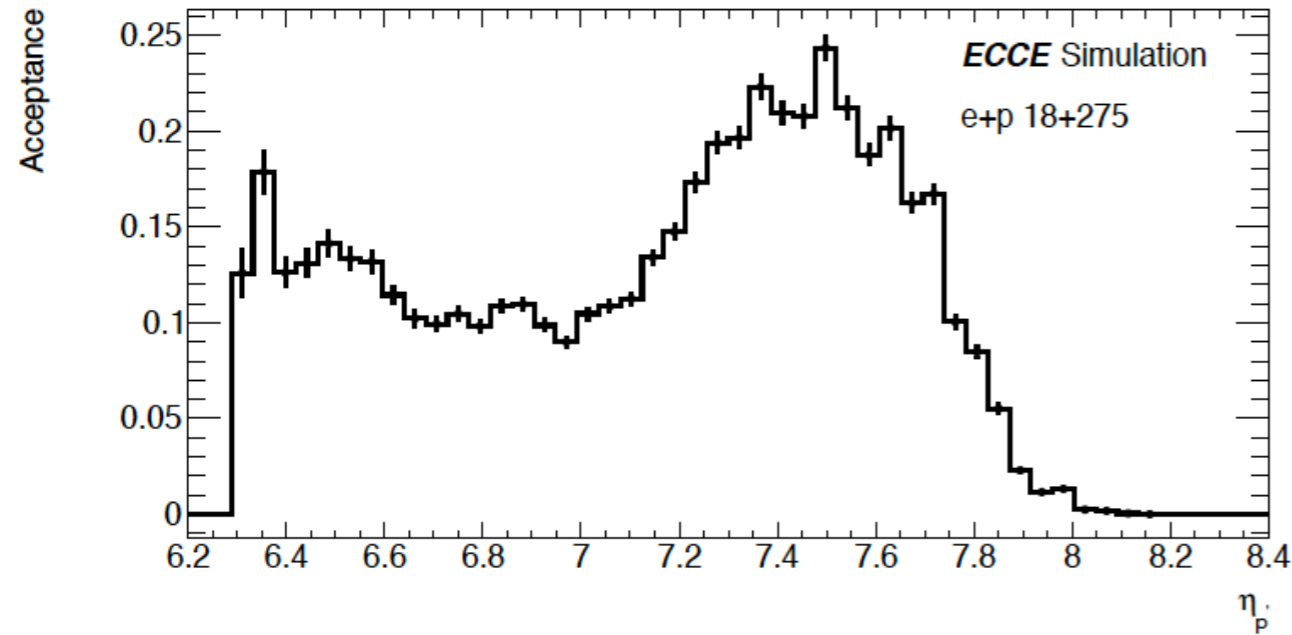


- GPDs, EMC effect, coherent vs incoherent DVCS studies
- $e'$  and real photon detected in central detector ECALs
- **Acceptance of  $\text{He}'$  ions in forward direction crucial**
- Optimisation of far forward beam line acceptance settings (high acceptance setting) yielded  $\sim 68\%$  event acceptance



## TCS ep (18GeV x 275GeV)

- $p'$  in far forward region crucial for accessing  $-t$  range
- Different fractions of events in RP and B0 depending on energy setting
- Central detector for  $e^+e^-$
- $e'$  reconstructed



# Current Activities

- EIC Detector 1 proto-collaboration working towards CD2 (improving performance baseline)
- ATHENA and ECCE WG joined forces → Exclusive, Diffractive, Tagging Working Group
- Maintain UK-based leadership:
  - **Co-convenors:** S. Klein (LBNL); **R. Montgomery (UoG)**; A. Schmidt (GWU); **D. Sokhan (Saclay/UoG)**
- Previous **UK-based participants still leading studies within WG**
  - e.g. XYZ spectroscopy (D. Glazier/UoG); TCS (D.Sokhan/Saclay/UoG; PhD students in DVCS eA and TCS...
- Working towards:
  - cross-checking/resolving discrepancies between previous ATHENA/ECCE studies
  - expanding studies (e.g. backgrounds/other reactions...)
  - **benchmarking golden channel observables from exclusive reactions against a developing detector design**

# Summary

- Broad range of exclusive topics studied for **ATHENA and ECCE** proposals
  - **UK activities and leadership: co-convenor roles and studies of different reactions**
  - **Both groups working on publications to summarising results**
- Now, previous WG joined forces to form **EIC Detector 1 Exclusive, Diffractive and Tagging Working Group**
  - **UK activities and leadership: co-convenor roles and studies of different reactions**
- **Anyone interested welcome to join**
  - Meet fortnightly, Mondays at 5pm (UK time zone), on Zoom (next meeting 11/6/22)
  - Mailing list: <https://lists.bnl.gov/mailman/listinfo/eic-projdet-excldiff-l>
  - Contact [rachel.montgomery@glasgow.ac.uk](mailto:rachel.montgomery@glasgow.ac.uk) or [daria@jlab.org](mailto:daria@jlab.org) for more info...