3D Imaging of Nucleons and Nuclei with ECCE at the Future EIC

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On Behalf of the ECCE Consortium

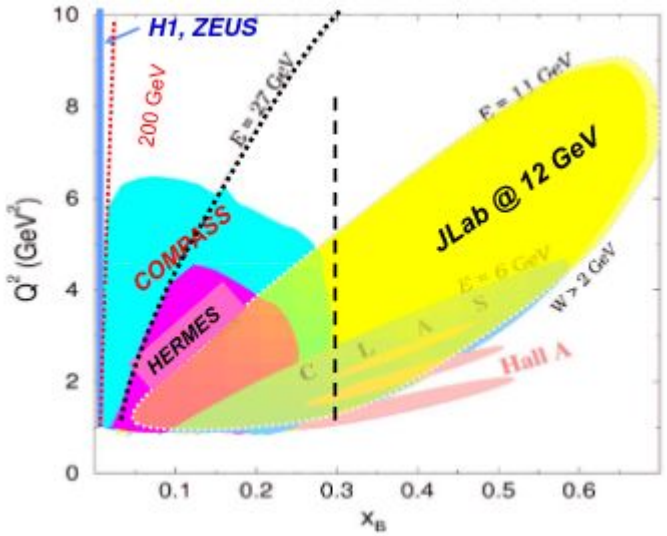
University of Glasgow

ECCE

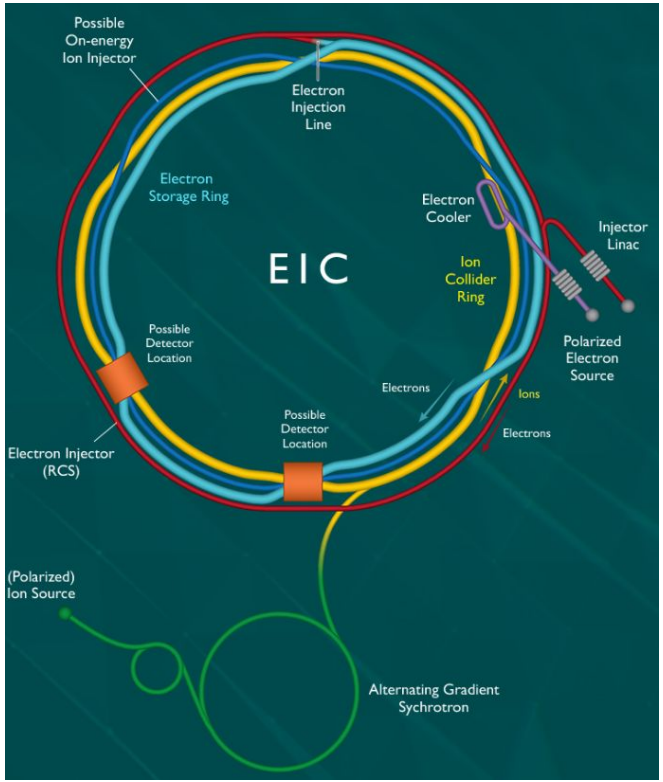
Electron Ion Collider

Upgrading existing RHIC and adding electron accelerator

Probing novel/extreme regions of phase space:



Kinematic complementarity at different locations[1]



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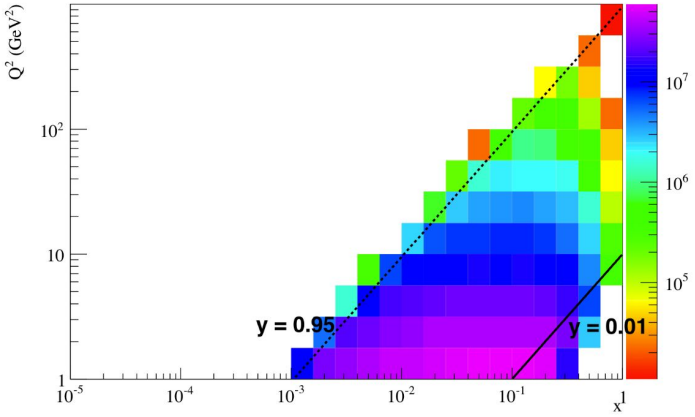
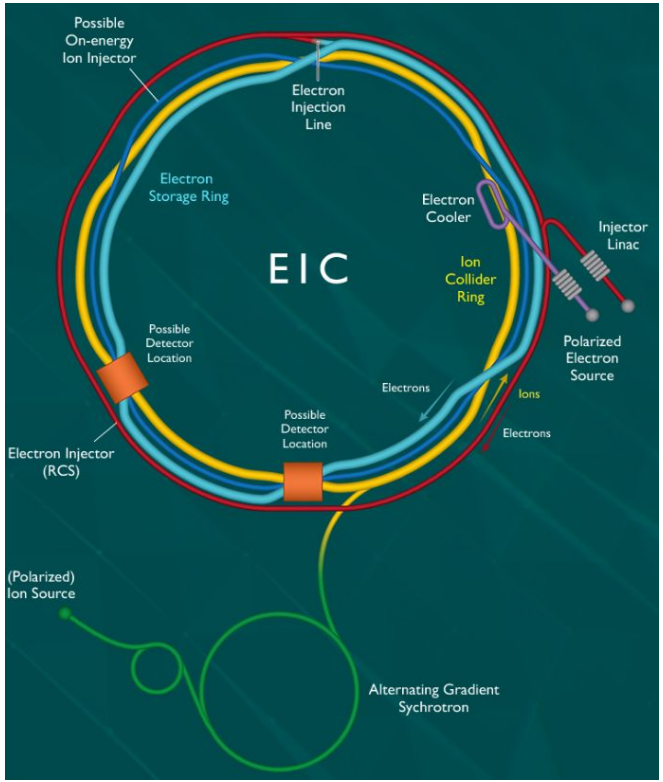
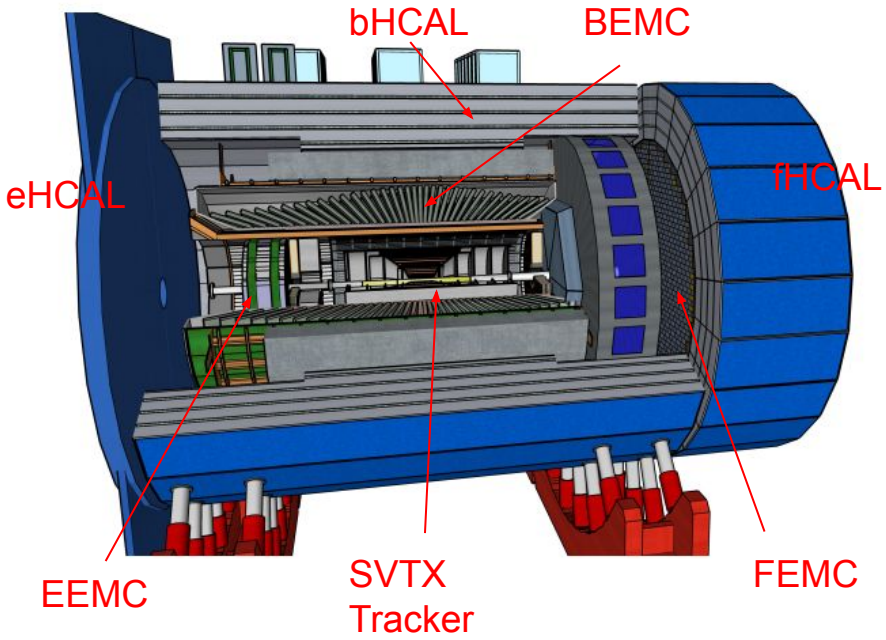
Probing novel/extreme regions of phase space:



Kinematic Coverage of EIC (5x50 GeV^2)[2]



EIC Comprehensive Chromodynamics Experiment (ECCE)



EIC Detector Proposal Call:

- ECCE, ATHENA, CORE

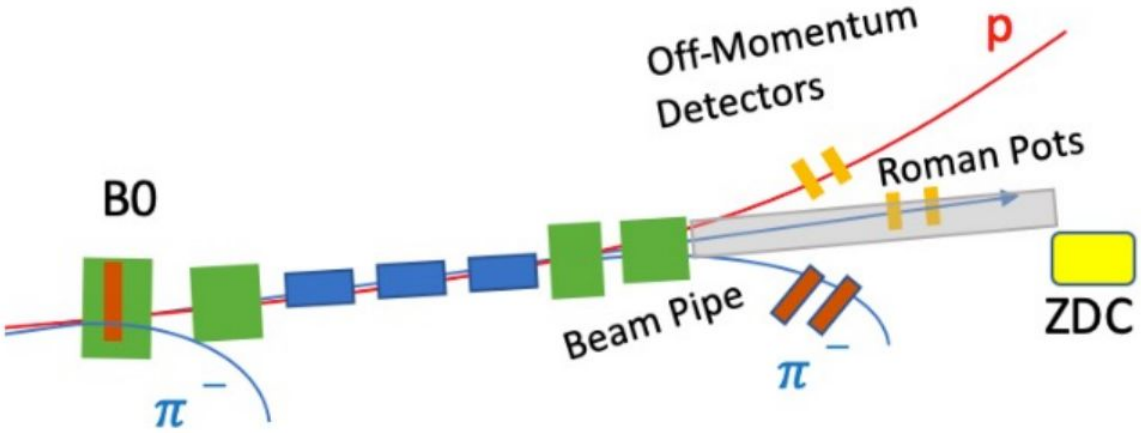
ECCE recommended as reference design.

Detector with intricate calorimetry and internal tracking

1.4 T Babar magnet

Full Geant4 Detector Responses in Fun4All (F4A)

Far Forward Region[3]



Forward detection particularly crucial in exclusive measurements - need to measure the proton/ion!

For many studies, the B0 and/or Roman Pots are the critical forward detection regions.

Different beam parameterisations have been created in the simulation to maximise acceptance in these regions.

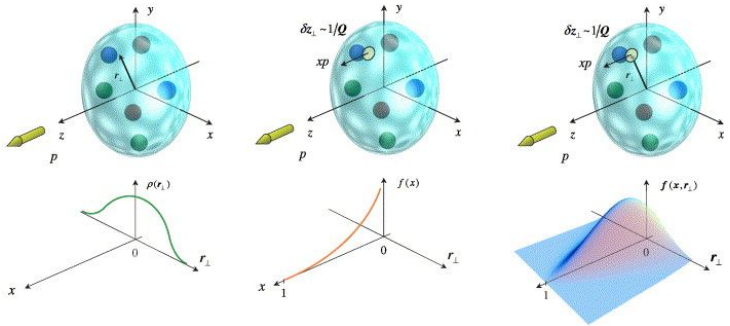
Exclusive, Diffractive and Tagging WG

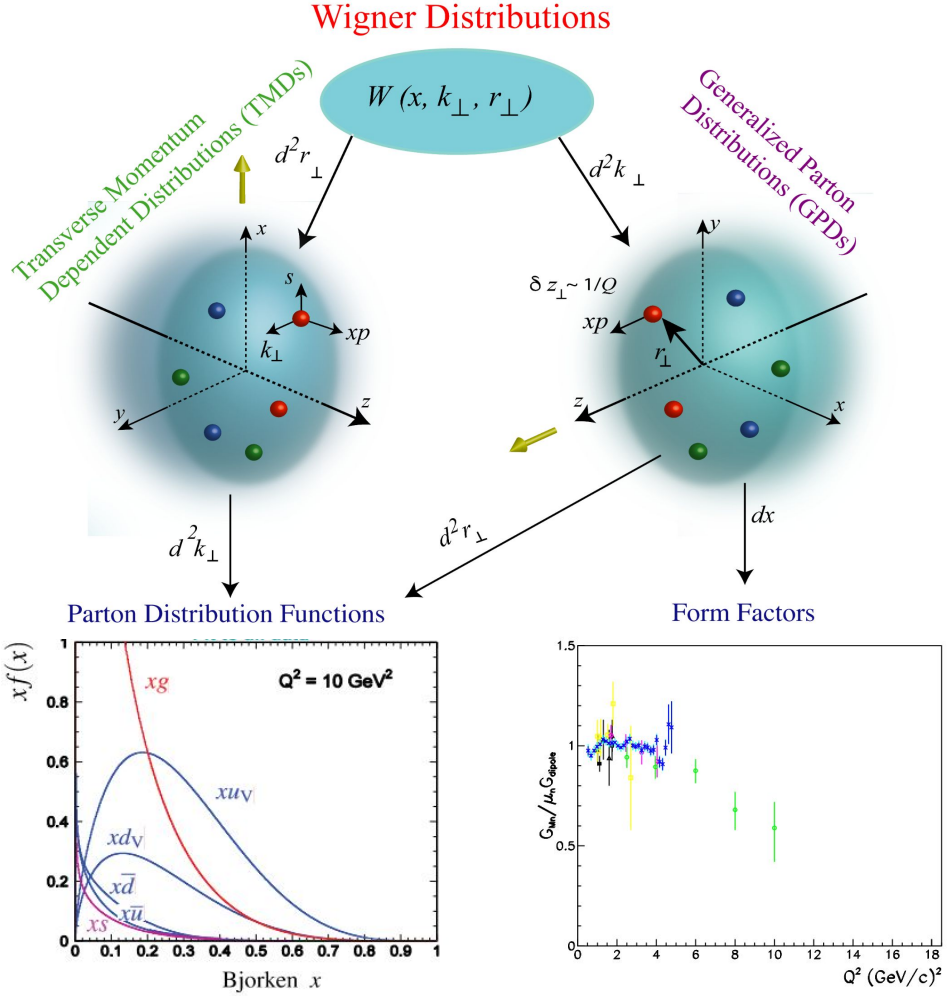
Channel	Generator	Kinematics
DVCS ep	MILOU3D	5x41, 10x100, 18x275
DVCS eA (e-He4)	TOPEG	5x41/u
TCS	EPIC	5x41, 18x275
DVMP ep	LAGER	18x275
DVMP eA (e-Pb)	Sartre + BeAGLE	18x108.4/u
Diffractive J/Psi (e-Zr90)	Sartre + BeAGLE	18x108.4/u + 18x122/u (Bg)
Pion FF* & SF	DEMP + EIC_mesonMC	5x41, 5x100*, 10x100, 18x275
Double Tagged e-He3	DJANGOH	5x41/u, 18x166/u
XYZ Spectroscopy	elspectro	5x41, 5x100, 10x100, 18x275
Y Photo and Electroproduction	eSTARlight	-
u-Channel DVCS	-	-

- Exclusive (Blue) and Diff Tagg (red) WGs worked closely together.
- Now a joint WG.
- Today I will focus on exclusive reactions
- Exclusive reactions provide typically clean final states which are efficient probes in 3D nucleon structure.

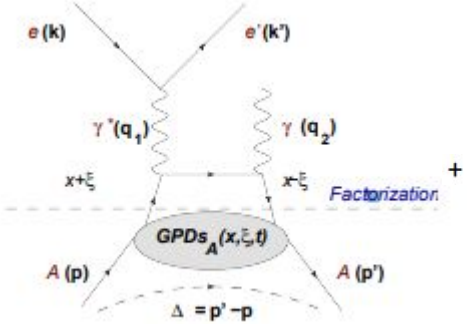
Hard Exclusive Processes and 3D Imaging

- Elastic scattering gives FFs for 1D longitudinal but we also need transverse to build 3D
- DVCS / TCS allows access to GPDs (and CFFs)
- Diffractive / vector meson sensitive to gluon contribution

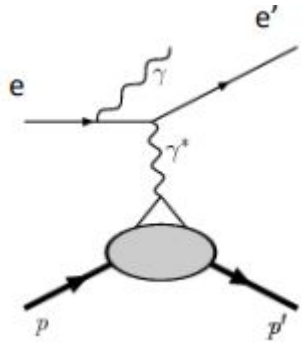


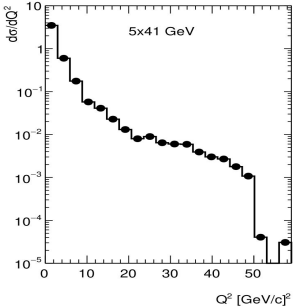


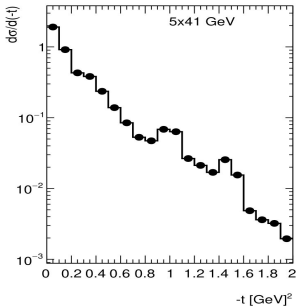
DVCS ep

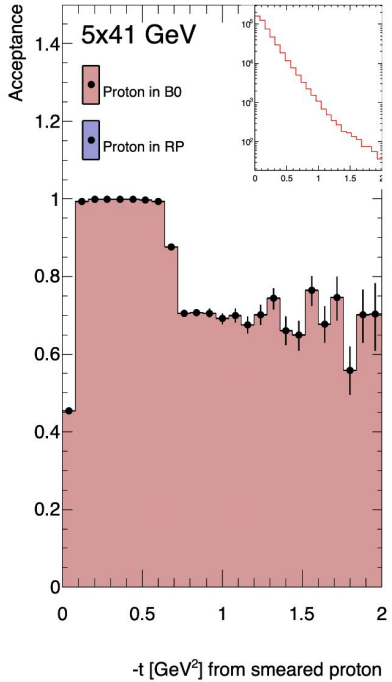

e (k)
e' (k')
γ*(q1)
γ (q2)
x+ξ
x-ξ
Factorization
GPDs_A(x,ξ,t)
A (p)
A (p')
Δ = p' − p

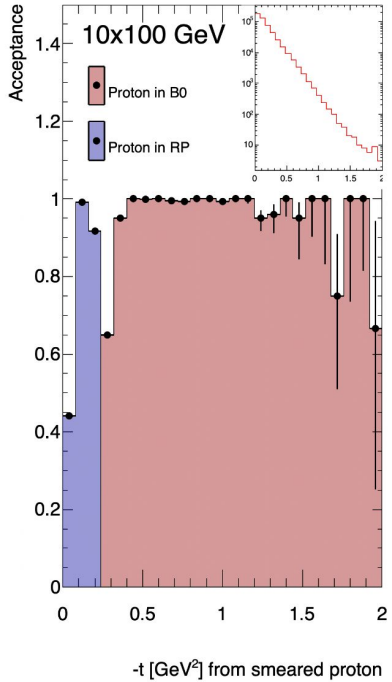
+

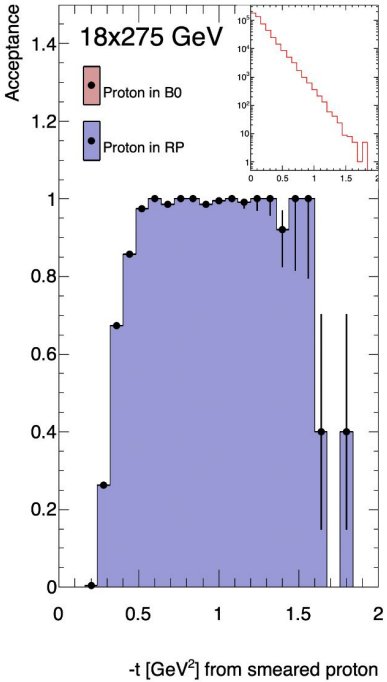

e
e'
γ
γ*
p
p'

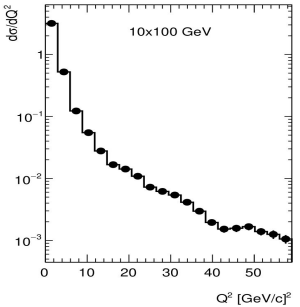

5x41 GeV
dσ/dQ²
Q² [GeV/c]²

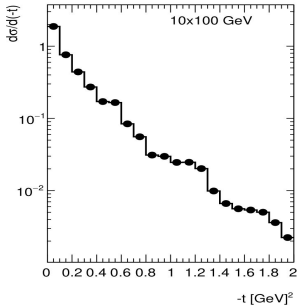

5x41 GeV
dσ/d(-t)
-t [GeV]²

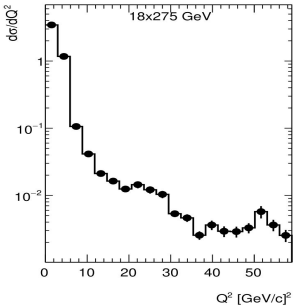

5x41 GeV
Proton in B0
Proton in RP
Acceptance
-t [GeV²] from smeared proton

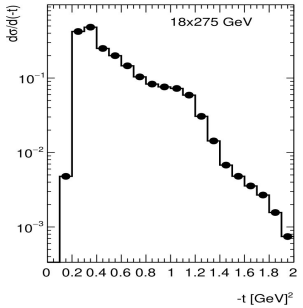

10x100 GeV
Proton in B0
Proton in RP
Acceptance
-t [GeV²] from smeared proton


18x275 GeV
Proton in B0
Proton in RP
Acceptance
-t [GeV²] from smeared proton

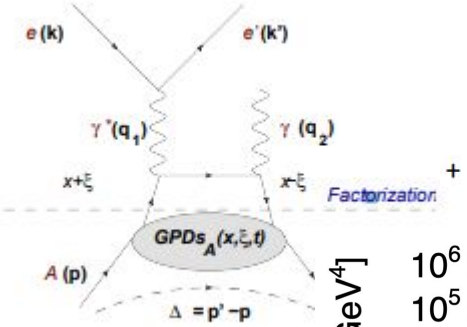

10x100 GeV
dσ/dQ²
Q² [GeV/c]²


10x100 GeV
dσ/d(-t)
-t [GeV]²

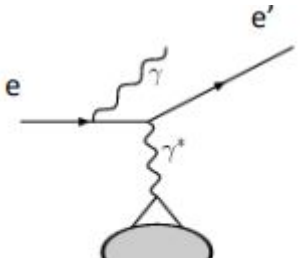

18x275 GeV
dσ/dQ²
Q² [GeV/c]²

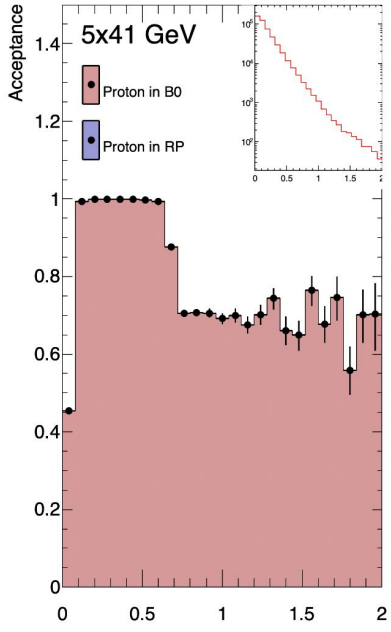

18x275 GeV
dσ/d(-t)
-t [GeV]²

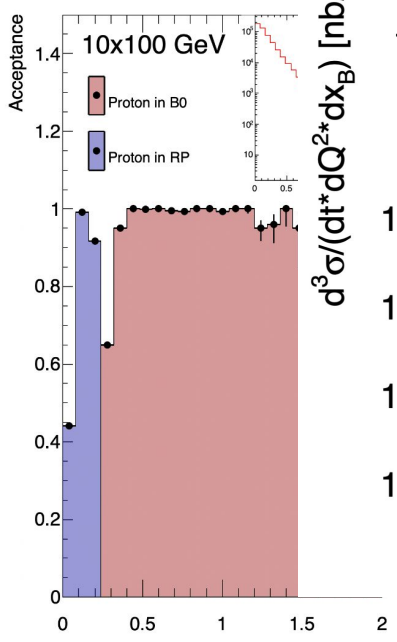
DVCS ep

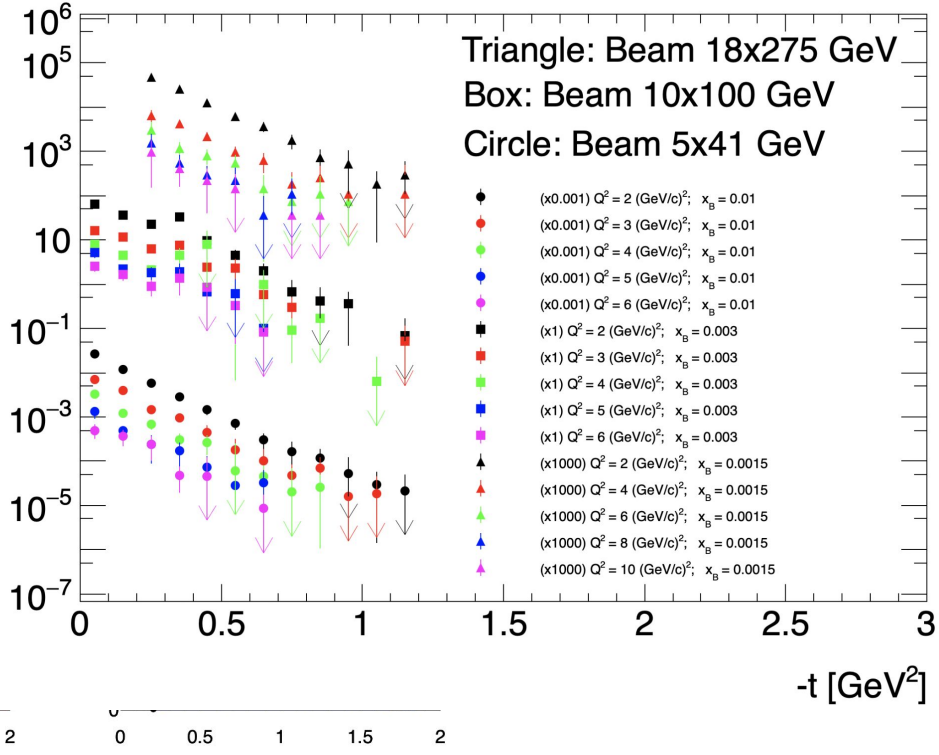

e (k)
e' (k')
γ*(q1)
γ (q2)
x+ξ
x-ξ
GPDs_A(x,ξ,t)
A (p)
Δ = p' − p
Factorization

+

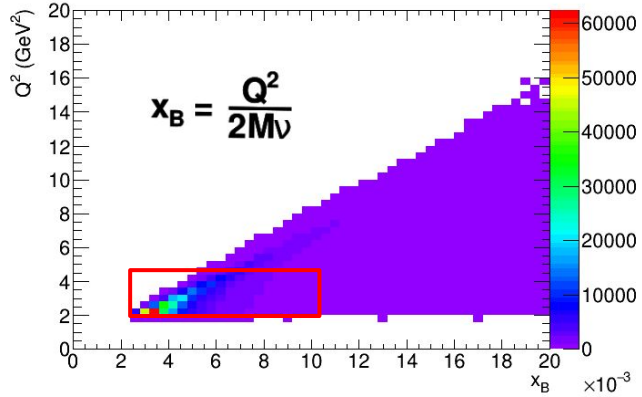

e
e'
γ
γ*

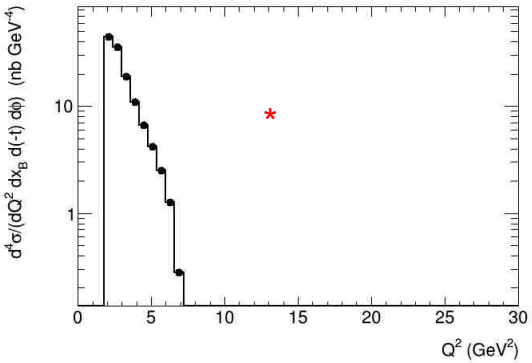

5x41 GeV
Proton in B0
Proton in RP
Acceptance
-t [GeV²] from smeared proton

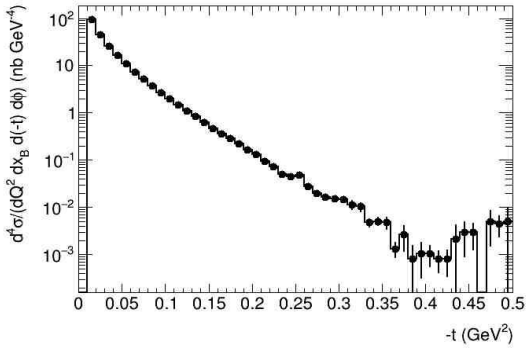

10x100 GeV
Proton in B0
Proton in RP
Acceptance
-t [GeV²] from smeared proton

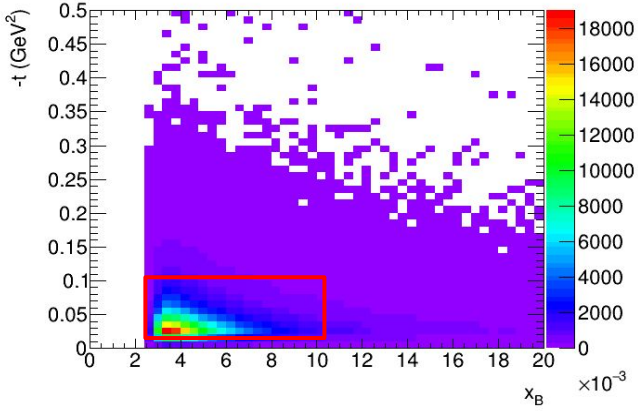

Triangle: Beam 18x275 GeV
Box: Beam 10x100 GeV
Circle: Beam 5x41 GeV
d³σ/(dt*dQ²*dx_B) [nb/GeV⁴]
-t [GeV²]
(x0.001) Q² = 2 (GeV/c)²; x_B = 0.01
(x0.001) Q² = 3 (GeV/c)²; x_B = 0.01
(x0.001) Q² = 4 (GeV/c)²; x_B = 0.01
(x0.001) Q² = 5 (GeV/c)²; x_B = 0.01
(x0.001) Q² = 6 (GeV/c)²; x_B = 0.01
(x1) Q² = 2 (GeV/c)²; x_B = 0.003
(x1) Q² = 3 (GeV/c)²; x_B = 0.003
(x1) Q² = 4 (GeV/c)²; x_B = 0.003
(x1) Q² = 5 (GeV/c)²; x_B = 0.003
(x1) Q² = 6 (GeV/c)²; x_B = 0.003
(x1000) Q² = 2 (GeV/c)²; x_B = 0.0015
(x1000) Q² = 4 (GeV/c)²; x_B = 0.0015
(x1000) Q² = 6 (GeV/c)²; x_B = 0.0015
(x1000) Q² = 8 (GeV/c)²; x_B = 0.0015
(x1000) Q² = 10 (GeV/c)²; x_B = 0.0015

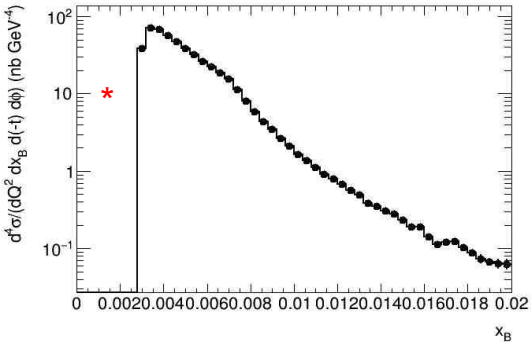
DVCS e-He^4 (5x41/u GeV)

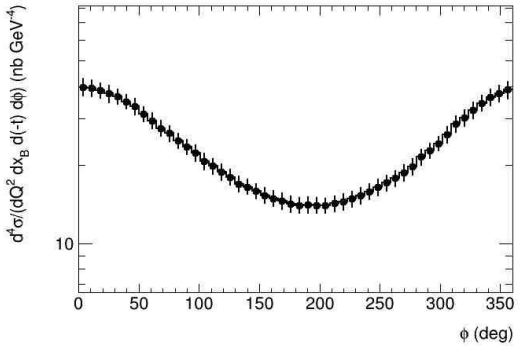










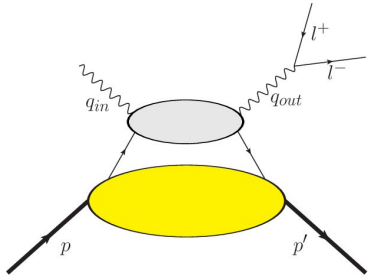


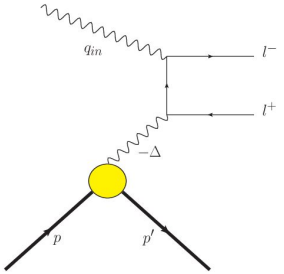
TCS ep

Inverse process of DVCS. Both sensitive to quark GPDs

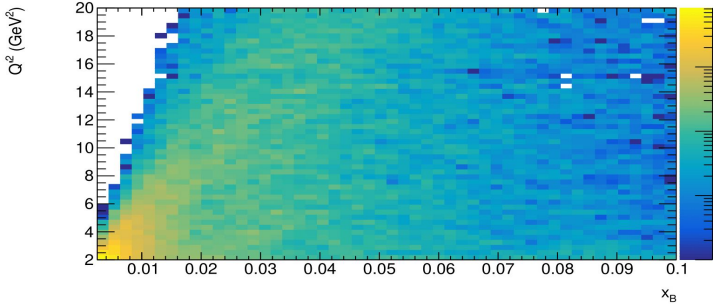
Also allows access to compton form factors (CFF) -> Each CFF related to a GPD.

Reconstruction in higher energy kinematic yields less statistics (in this beam parameterisation) Due to lower RP occupancy

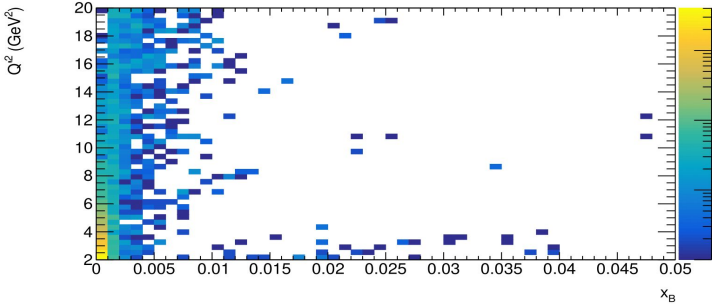


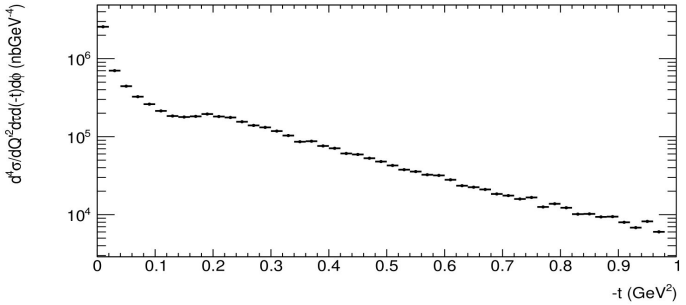


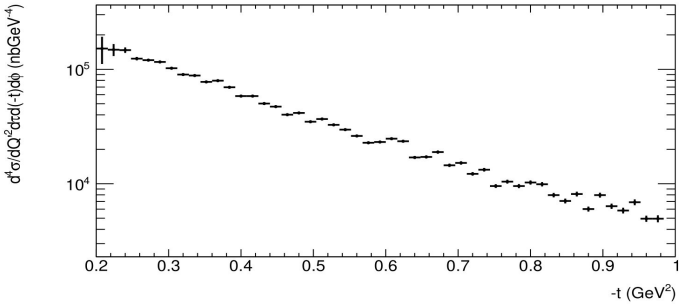
5x41



18x275





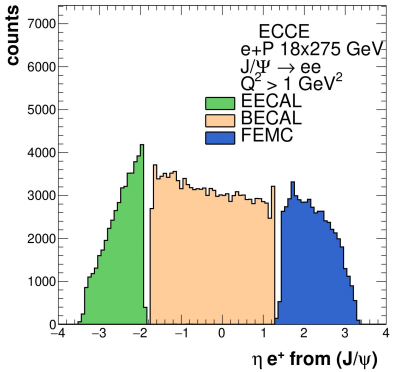


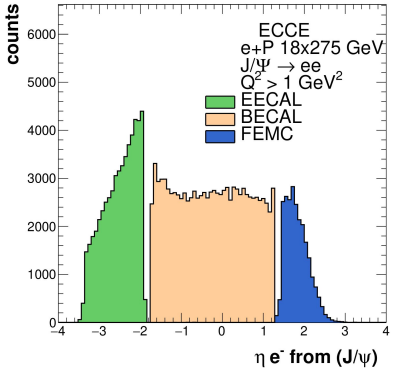
DVMP ep

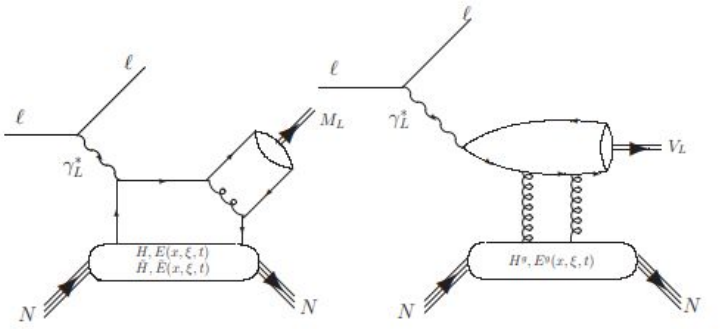
Access to gluon 2D spatial and 1D longitudinal momentum in nucleon.

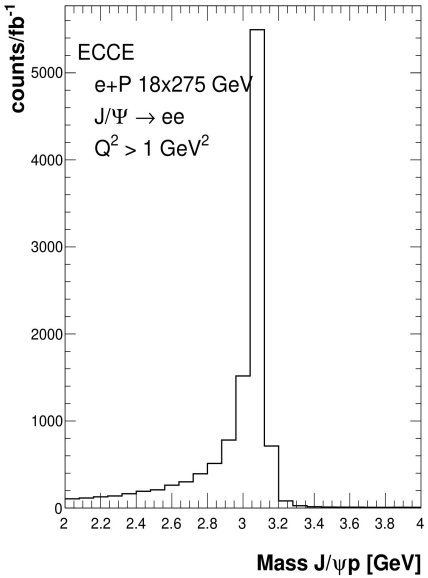
Lepton pair detected across η spectrum by multiple calorimeters.

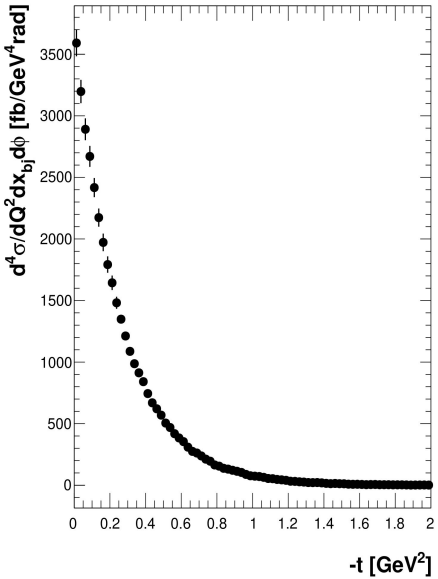
- Can construct J/psi missing mass spectrum











DVMP e-Pb^{207}

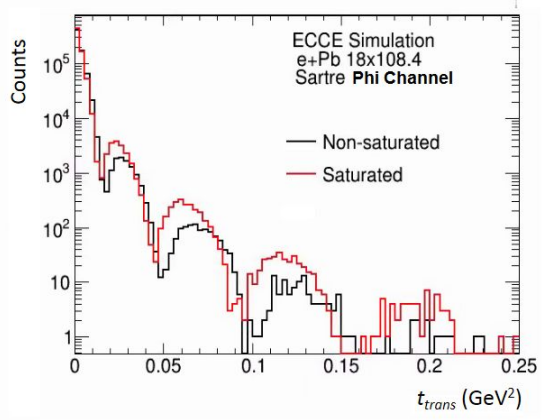
Study of vector meson final state allows exploration of saturation

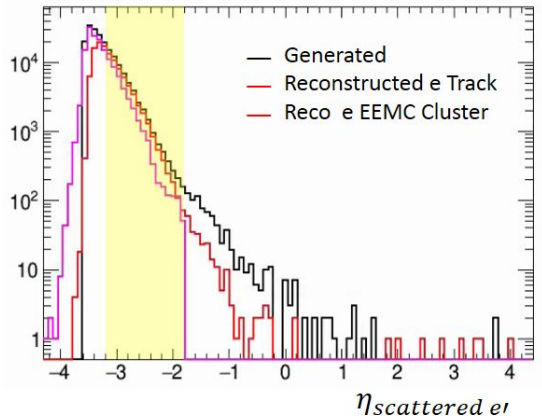
Larger mesons like ϕ more sensitive to saturation effects

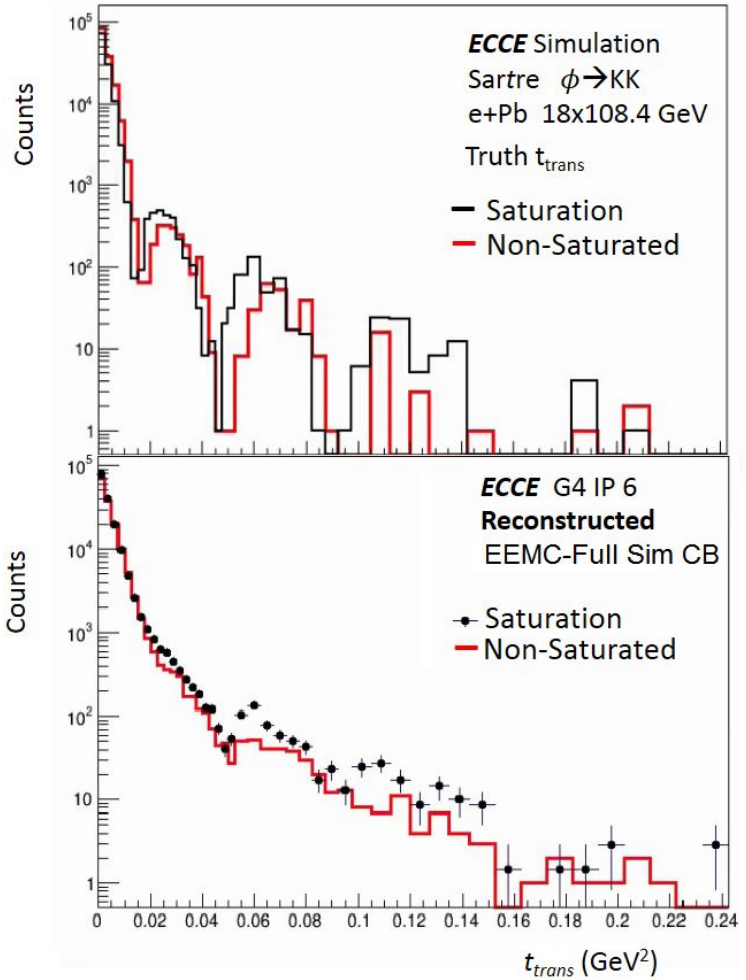
Expect shift in -t with saturation included.

Background Rejection + Calorimetry

- ➢ Begin to resolve diffractive minima in saturated spectrum!







Next Steps / Further Work

WGs writing up results into publications.

ECCE, ATHENA, CORE merger of WGs

Continue to benchmark physics as detector design evolves

Background studies

Specifically in exclusive WG: IP8, asymmetry studies, different kinematics, testing of beam parameterisations in simulation (HA v HD)

Conclusions

- Pre and Post proposal work on ECCE showing promising results in probing EIC phase space in a wide variety of physics channels
- ECCE now ref design for det 1 at EIC
- EIC has critical decision 1
  - expect physics on timescale of 10 years.
- Exclusive Diffractive and Tagging group very happy with physics results so far
  - Continue to benchmark + new kinematics
  - Results not covered today in publication (to come)!

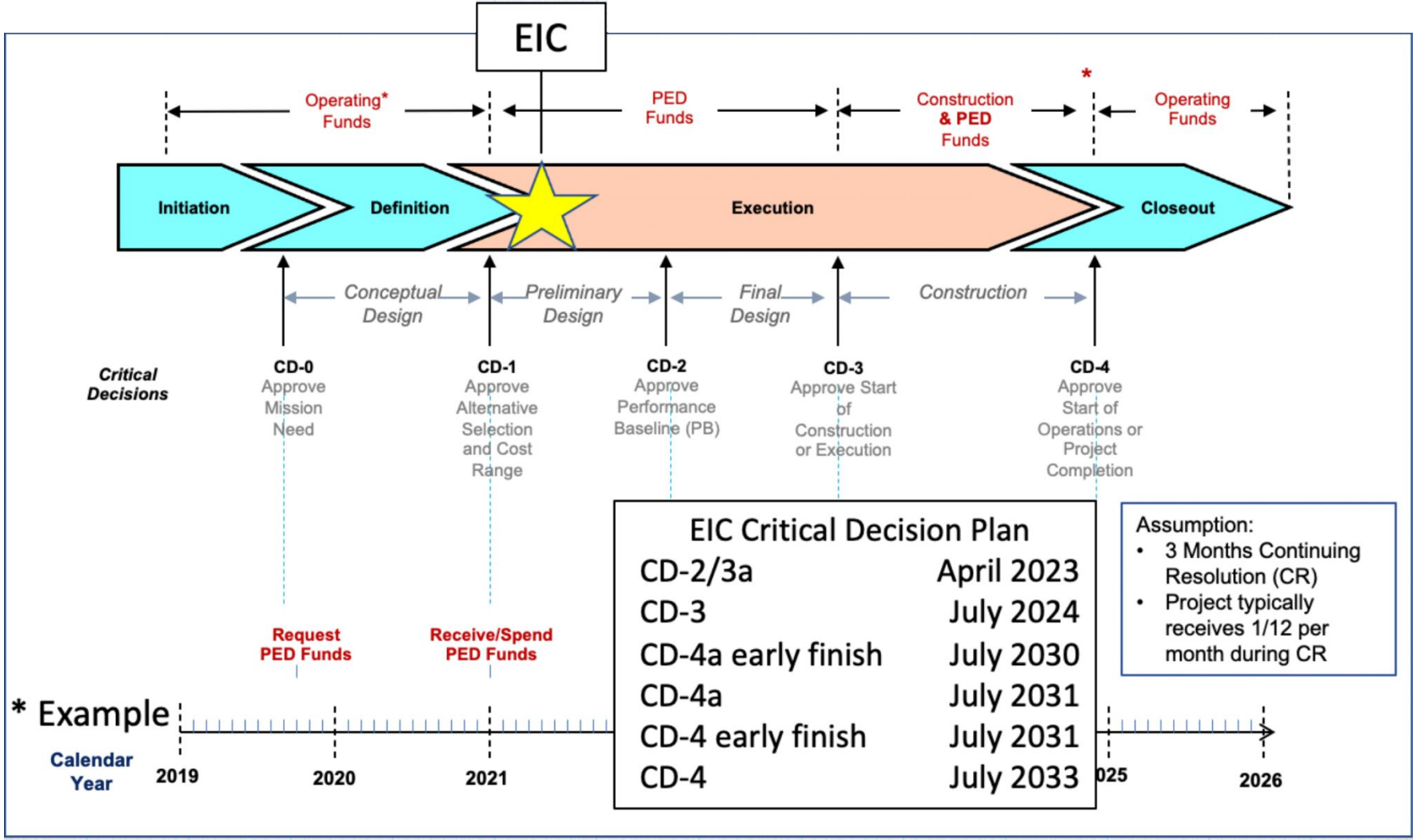
References and Acknowledgments

1. C. Munoz. https://indico.cern.ch/event/180678/contributions/304829/attachments/240727/337060/Munoz.pdf
2. BNL https://wiki.bnl.gov/eic/index.php/DIS_Kinematics
3. I. Korover. https://indico.bnl.gov/event/11463/contributions/52412/attachments/36426/59854/eic_ecce_final_1.pdf
4. ECCE https://www.ecce-eic.org/_files/ugd/2b2c77_5fd1cff0c2f04337ac67d4675985f208.pdf

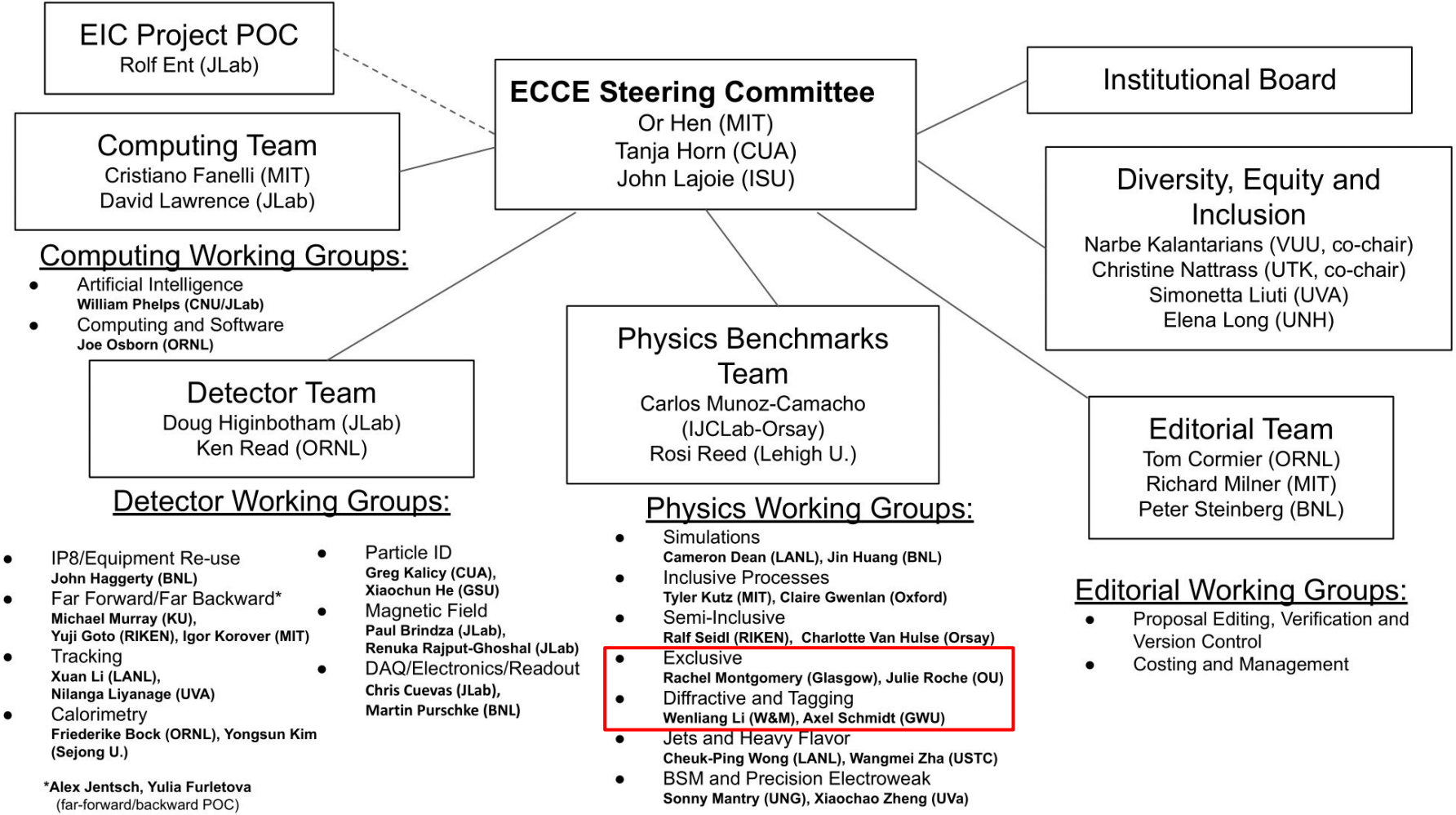
Special thanks to PhD supervisor (and WG convenor) R. Montgomery; all of the EDT working group; DIS organisers and convenors; staff and colleagues within ECCE.

Thank You For Listening!

Backup



Example EIC Critical Decision Timeline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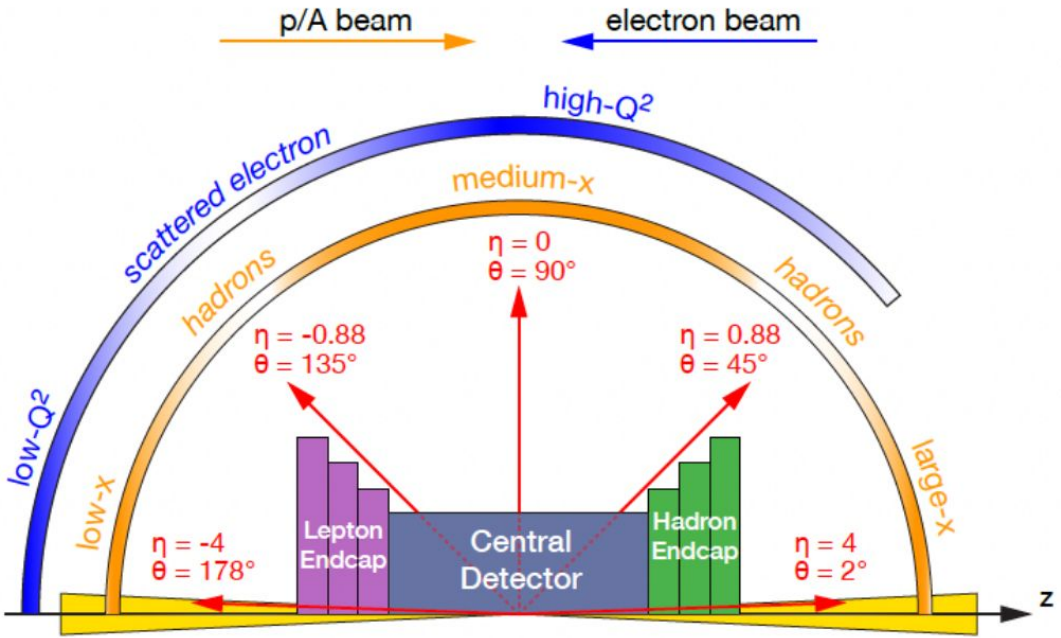
Proposal Editing, Verification and Version Control
Costing and Management

More ECCE Details[4]

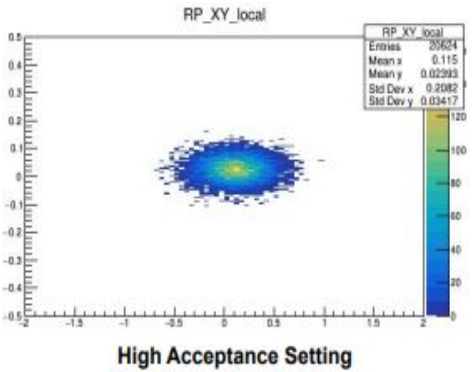


Detector	Proposed technology
Zero-Degree Calorimeter (ZDC)	EMcal: Crystal (PbWO4) + W/Si (based on ALICE-FoCal-E) Hcal: Pb/Si + Pb/Sci (Shashlik or Spaghetti) (+ AC-LGAD?)
Roman Pot (RP)	AC-LGADs
Off-Momentum Detectors (OMD)	AC-LGADs
B0 spectrometer	Tracker: MAPS or AC-LGADs EMcal (PbWO4) or preshower?
Low-Q^2 tagger	Tracker: AC-LGADS EMcal: Crystal (PbWO4)

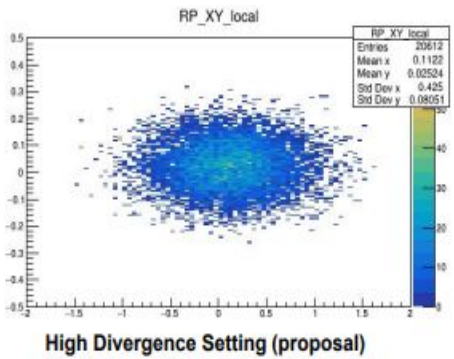
Beam Parameterisations

High Divergence (HD) setting used in detector proposal.

High Acceptance Setting (HA) improves results in some channels (e.g DVCS-eA).



High Acceptance Setting



High Divergence Setting (proposal)

10σ cut on roman pot based on beam spot width:

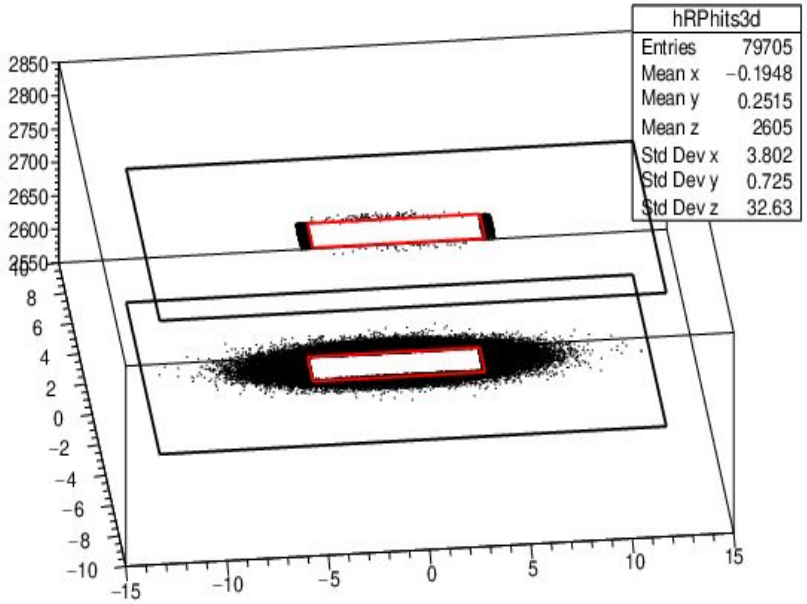
<u>Hi Acceptance</u>

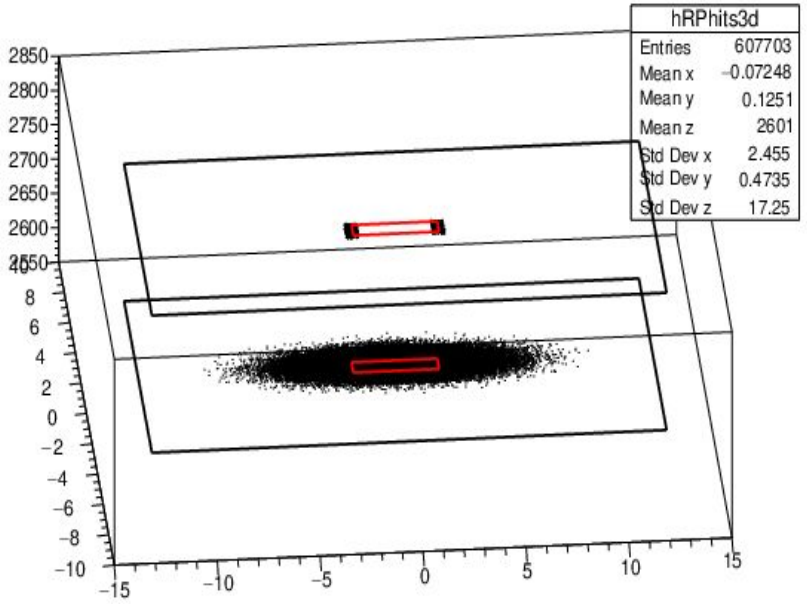
- xcut = 2.082 cm
- ycut = 0.3417 cm

<u>Hi Divergence</u>

- xcut = 4.25 cm
- ycut = 0.8041 cm

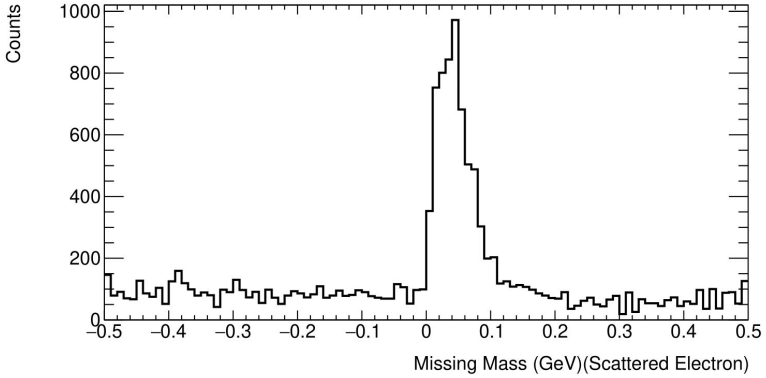
Beam Parameterisations - RP Occupancy

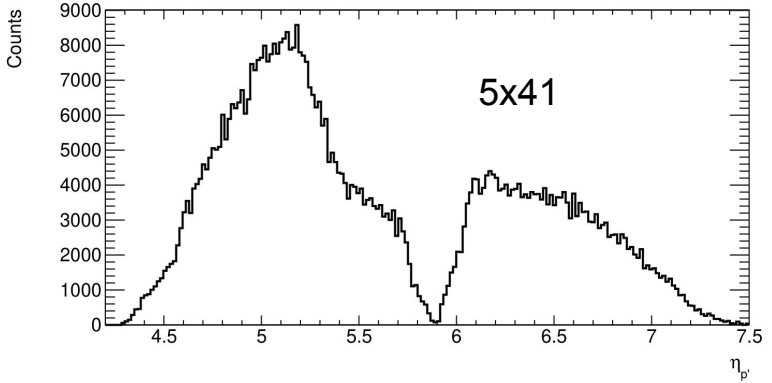


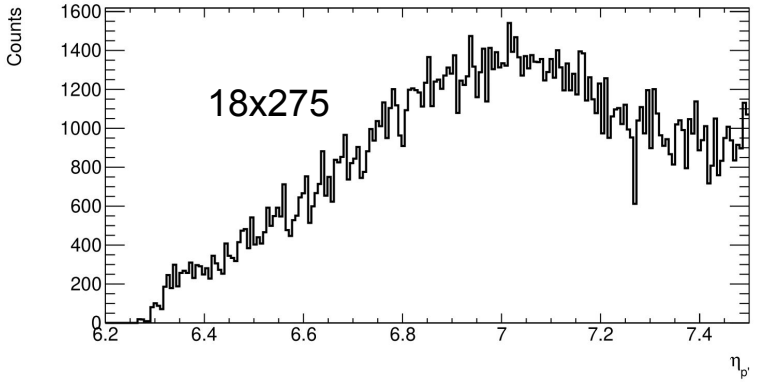


Backup Plots

TCS



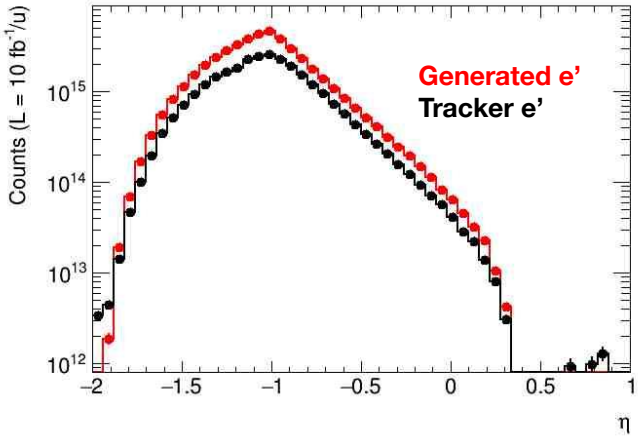




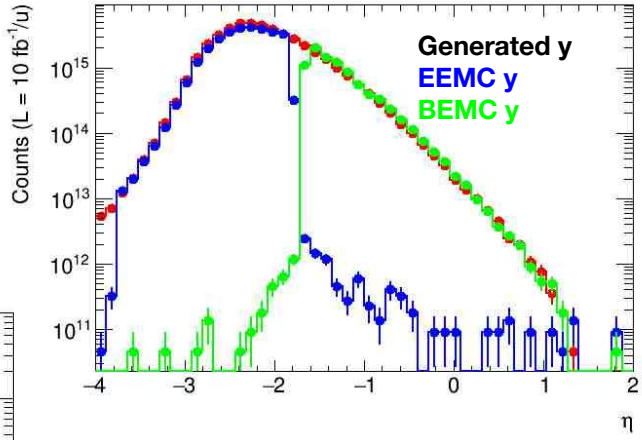
Preliminary look at new parameterisation*

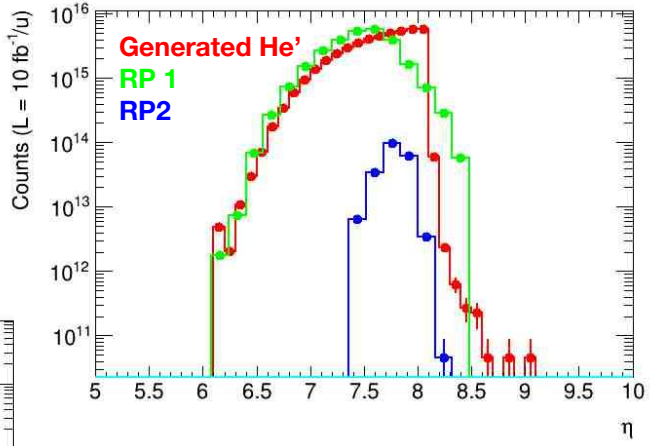
Backup Plots

- “Tails” in calorimeter photon distributions are in part a result of the selection process in clusters.
- However can still observe different ranges of eta for each calorimeter.
- No photons/leptons in fEMC (expected)



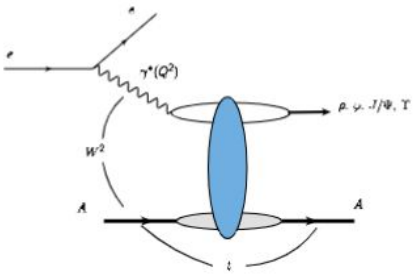
DVCS eA

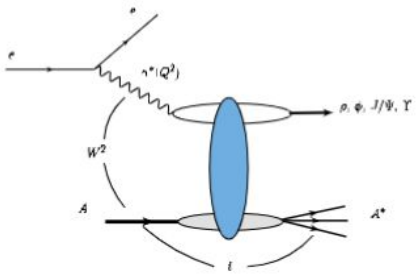




- Second roman pot catches small subset of particles which miss the first. Acceptance in $6 \leqslant \eta \leqslant 8.5$
- Observe spillover of events in higher η bins (i.e. non-physical acceptance). Postulate detector + simulation effects + bin migration phenomena.
- Overall ion acceptance 8% -> 60% with ‘high acceptance ‘ beam parameterisation.

Diffractive J/psi (e-Pb^{207})

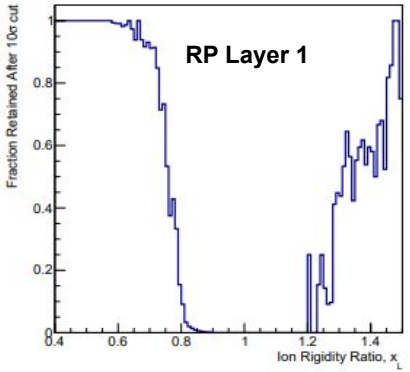


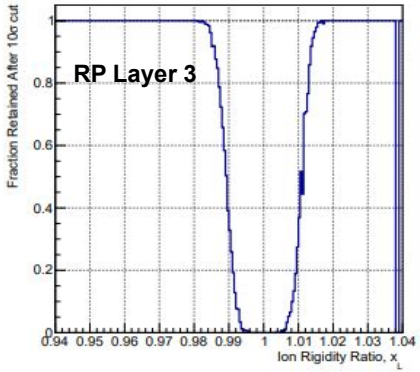


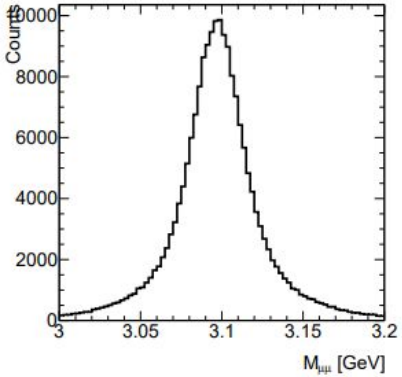
Less sensitive to saturation effects due to smaller wavefunction

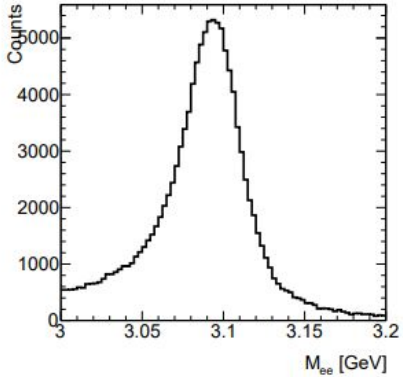
Detection of Rigid Ions highly improved with second interaction region

Missing mass reconstruction using different lepton pairs in fair agreement.

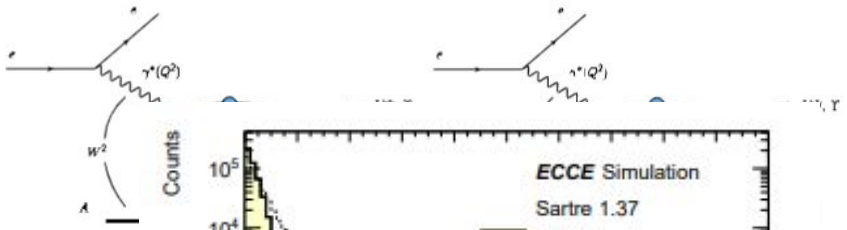








Diffractive J/psi (e-Pb^{207})



Less sensitive to saturation effects due to smaller wavefunction

Detection of Rigid Ions highly improved with second interaction region

Missing mass reconstruction using different lepton pairs in fair agreement.

- Begin to resolve diffractive minima when moving from tracker to calorimeter.