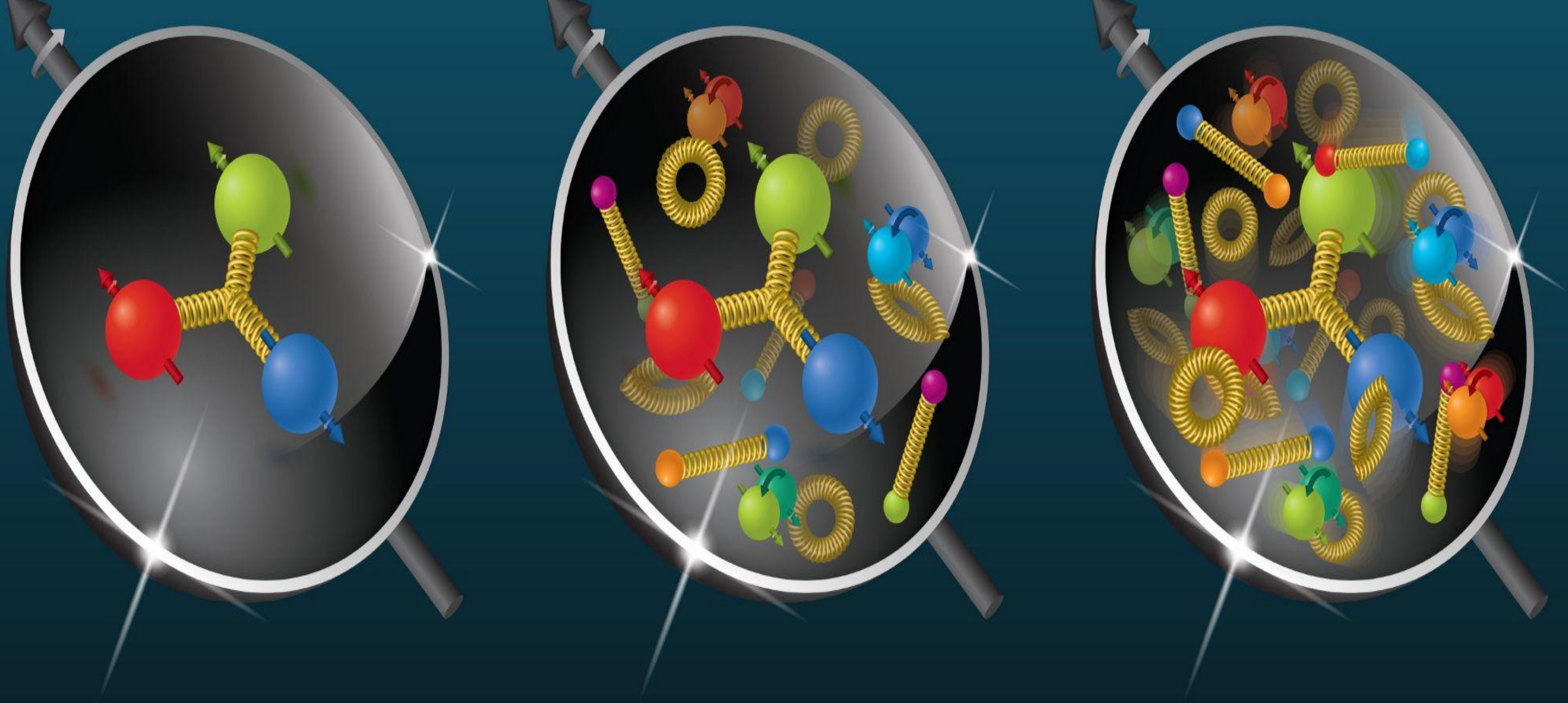
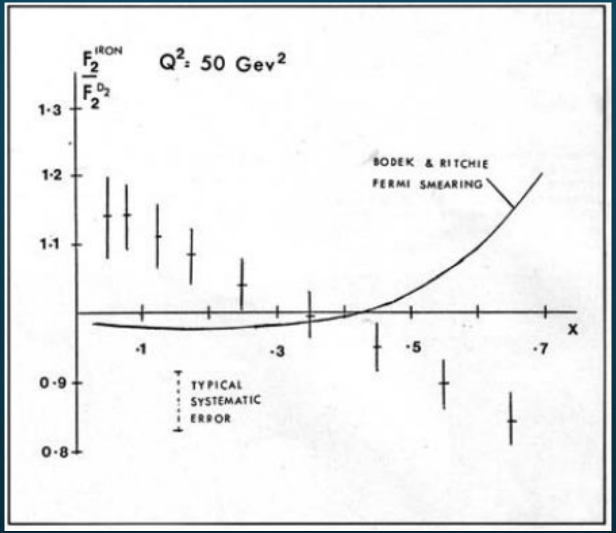
# DVCS of $^4$He at the EIC



G Penman EIC UG/ECW 25.07.2022

# History of DVCS and DIS

- Measurements of $F_2^{Fe}/F_2^{D2}$ in DIS at CERN, 1982
- Binding Energy of Nucleus << Typical momentum transfer
- Expect almost constant plot with minor corrections
- Instead, see clear downward gradient!
- Dubbed: ‘EMC Effect’




EMC Data, CERN Courier 1982.

https://cds.cern.ch/record/1734943/files/vol53-issue4-p035-e.pdf

# DVCS of $^4$He

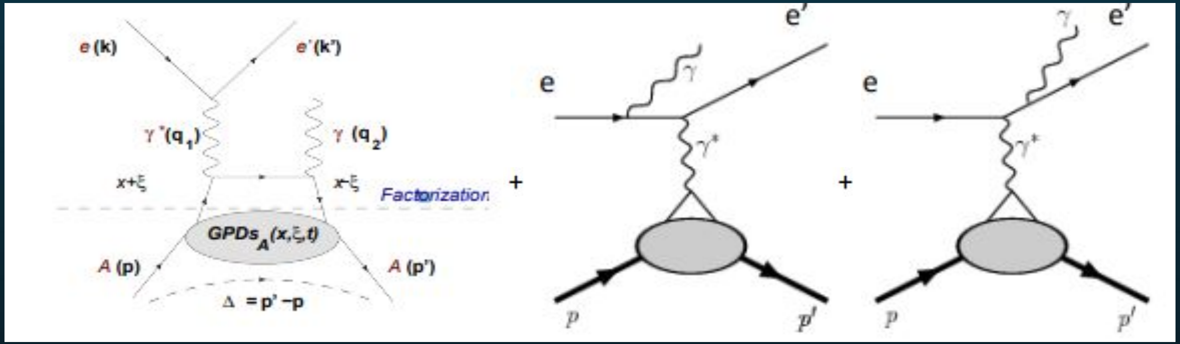
- Process which can give understanding of EMC effect, and tomographic view of nucleons.
- Pure DVCS reaction illustrated by 'Handbag Mechanism'.
- At leading twist order full picture DVCS + Bethe-Heitler:

$Q^2 = -q^2 = -(k' - k)^2$, the virtuality of $\gamma^*$

$x_B = Q^2/2M\nu$

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

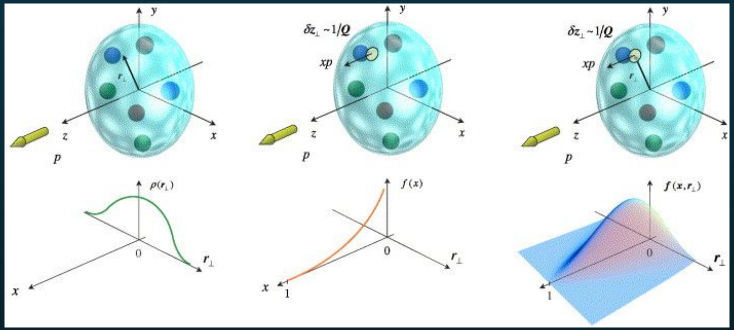
$\phi_h$ = angle between leptonic and hadronic scattering planes.

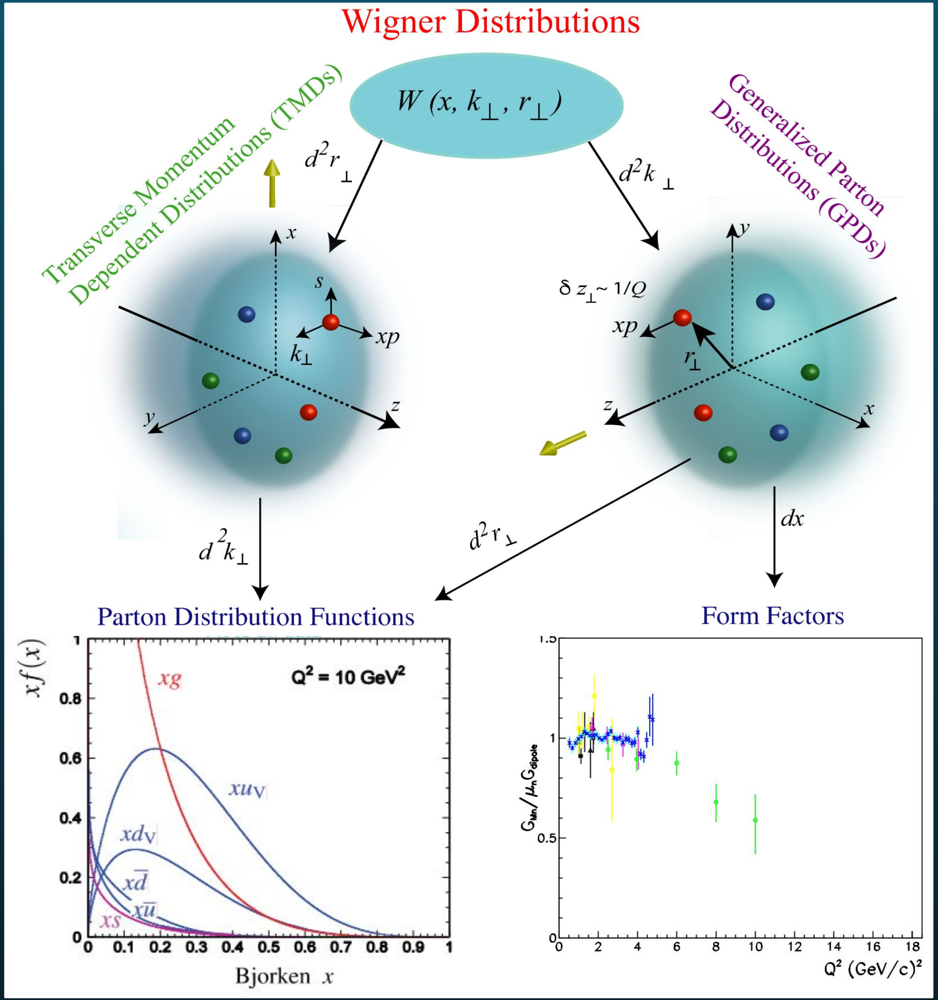



Handbag approximation of coherent DVCS of $^4$He
https://arxiv.org/pdf/1910.07458.pdf

# Generalized Parton Distributions

- FFs describe 1D transverse distribution, PDFs describe 1D longitudinal momentum, but no correlation!
- GPDs directly correlate longitudinal momentum and transverse position of partons.



# Generalized Parton Distributions

- DVCS / TCS allow access to 1+2D GPDs through CFFS.
- Many ep studies and experiments so far.
- Recent publication of 12 GeV e-p results, en (e`,d) approved at PAC50
- However only current e-$^{4}$He data from CLAS6!

$$H_q(x,\xi,t) \quad E_q(x,\xi,t)$$
$$\tilde{H}_q(x,\xi,t) \quad \tilde{E}_q(x,\xi,t)$$

Combine differently depending on polarization of beam and target (BSA, ITSA, BITSA, tTSA).

Only 1 Chiral even GPD needed to parameterize structure of spinless nuclei:

$$H_A(x,\xi,t)$$

# DVCS-eA at EIC with ECCE

**The (DVCS) Orsay-Perugia Event Generator : TOPEG**

https://gitlab.in2p3.fr/dupre/nopeg

- Raphael Dupre, Sara Fucini

DVCS-eA events generated using Goloskokov-Kroll GPD parameterisation: https://doi.org/10.1140/epjc/s2005-02298-5

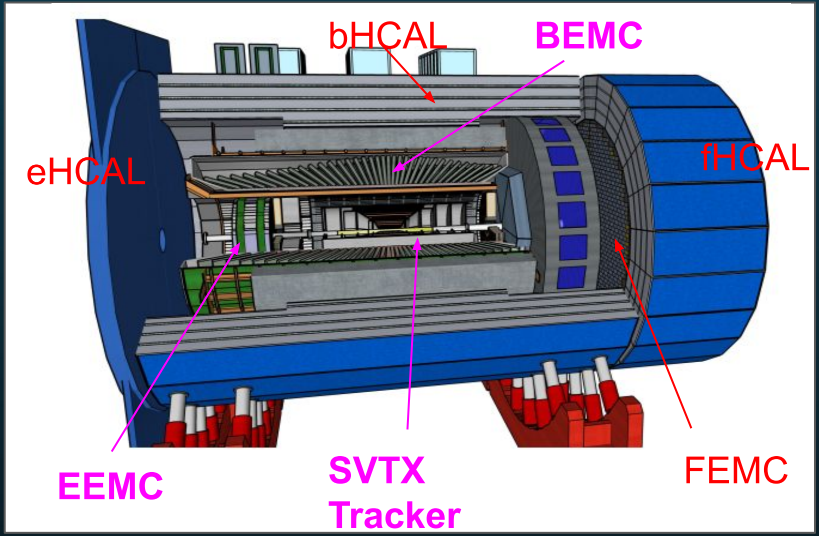
and Fucini helicity model: https://arxiv.org/pdf/2008.11437.pdf

Neglects real part of H GPD to optimize CPU time.

Fun4All (F4A) Software Stack:

Full Geant4 simulation with complete ECCE detector implementation.

https://github.com/ECCE-EIC/macros



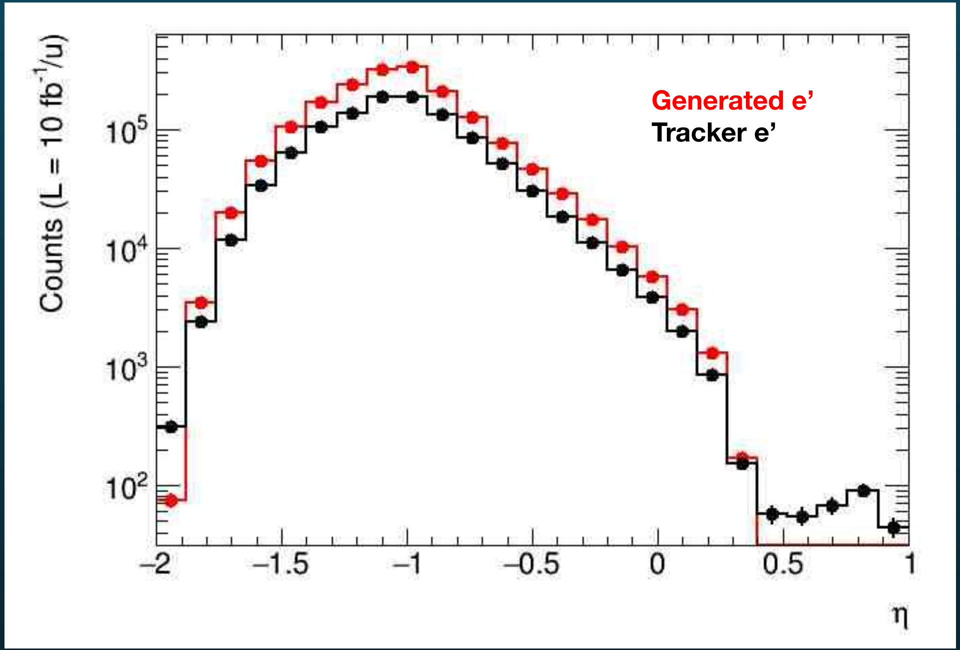
# Electron Selection: Internal Tracker

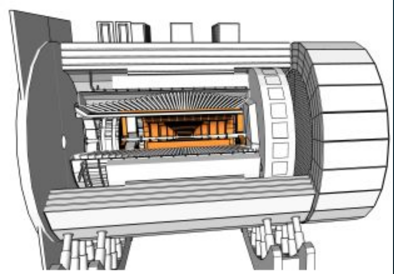
F4A outputs 'containers' (c++ classes containing objects that represent hits in each detector, and variables, momentum energy etc).

Truth Container includes all info input to simulation before detector effects.

To select electron we choose number of tracks in internal Si tracker == 1.

Resulting acceptance 883608 / 1M = 88.3%



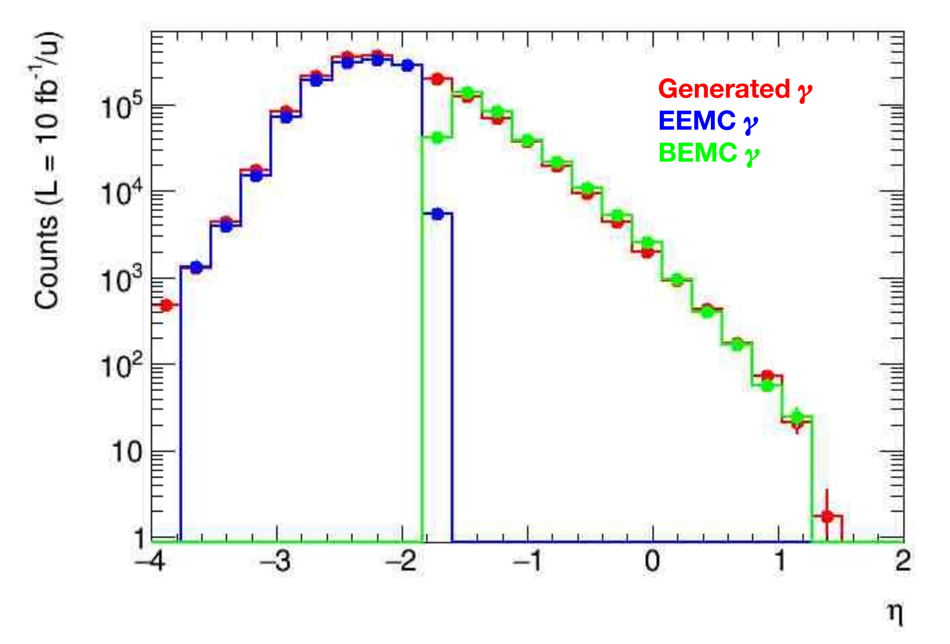



# Photon Selection: Calorimeters

nElectronTracks == 1
&&
nCalorimeterHits > 0
&&
Calorimeter photon with max energy per event per cluster: Pmax
&&
Pmax > 250 MeV

EEMC (blue): 668757
BEMC (green): 192606
-> 861363/ $10^6$ = 86.1%

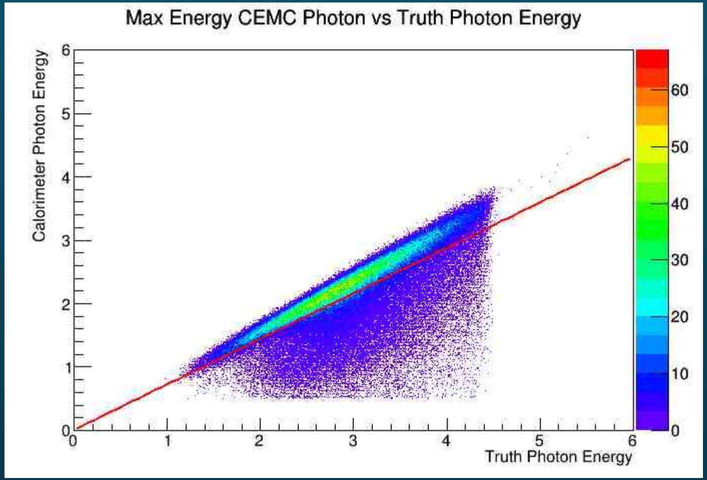
Currently all photon hits detected in EEMC or BEMC.

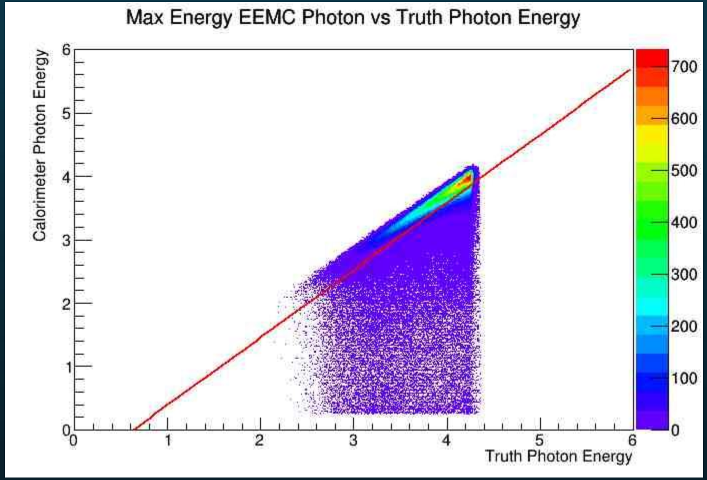


# Photon Selection: Calorimeters

Calibration:

- ❖ Fit Pmax to Truth energy for calibration coefficients.
- ❖ Done separately for CEMC and EEMC responses.
- ❖ Calibrated photon energy mean increases +.72 GeV.



# Helium Selection: Far Forward Detectors

- Layer 1 ID = 1
- Layer 2 ID = 4294967297
- Layer 3 ID = 8589934593
- Layer 4 ID = 12884901889

Other hits with tiny z-momenta values are clearly not Helium Hits!

Select Helium with Hit ID equal to the 4 numbers.

Intrinsic Geant4 Tracking integers - the basis of tracking algorithm!

Layer 1 Hit

Layer 2 Hit

Layer 3 Hit

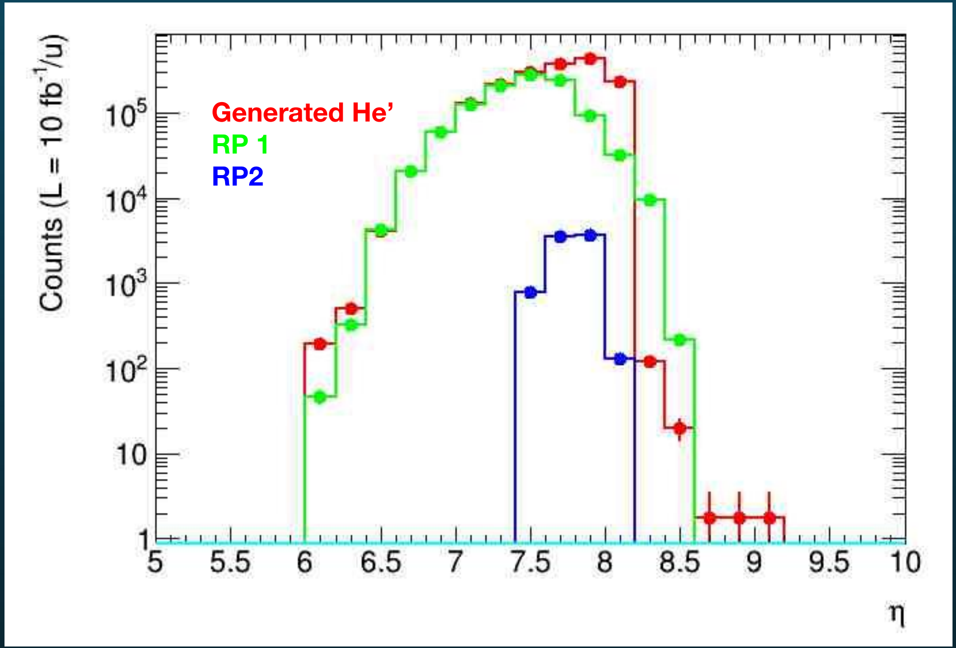
Layer 4 Hit

<u>Hit, Px, Py, Pz, x, y,  z</u>

```
 Event filled, next
 event = 3947
B0 hit id: 1 -4.24336 -4.24336 163.572 -15.2652 -0.0784237 591.95
B0 hit id: 2 -0.000779096 -0.000779096 0.000613575 -15.2667 -0.07843 592.008
B0 hit id: 4294967297 -4.29247 -4.29247 163.568 -15.8913 -0.0808451 615.95
B0 hit id: 8589934593 -4.34099 -4.34099 163.566 -16.5245 -0.0832892 639.95
B0 hit id: 8589934594 -0.000653522 -0.000653522 0.00223425 -16.5259 -0.0832945 640.002
B0 hit id: 8589934595 0.000658633 0.000658633 -0.000891056 -14.8743 3.06838 640.05
B0 hit id: 8589934596 -0.000226966 -0.000226966 0.000655253 -16.0391 3.51019 639.95
B0 hit id: 12884901889 -4.39428 -4.39428 163.561 -17.1656 -0.0860088 663.95
```

# Helium Selection: Far Forward Detectors

- No FF momentum reconstruction - use truth values with 1% smearing.
- 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 $\eta$ bins (i.e. non-physical acceptance). Postulate detector + simulation effects + bin migration phenomena.
- Overall ion acceptance 8% -> 60% with 'high acceptance ' beam parameterisation.

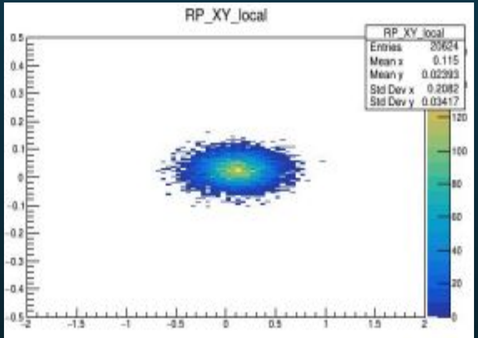


# Beam Parameterisations

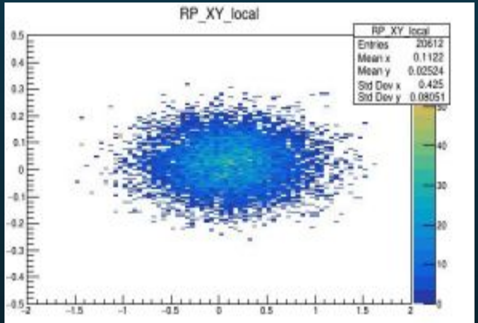
High Divergence (HD) setting used in detector proposal.

High Acceptance Setting (HA) improves results in DVCS eA channel

HA results reported in ECCE EDT publication.




High Acceptance Setting




High Divergence Setting (proposal)

10$\sigma$ cut on roman pot based on beam spot width:

<u>Hi Acceptance</u>

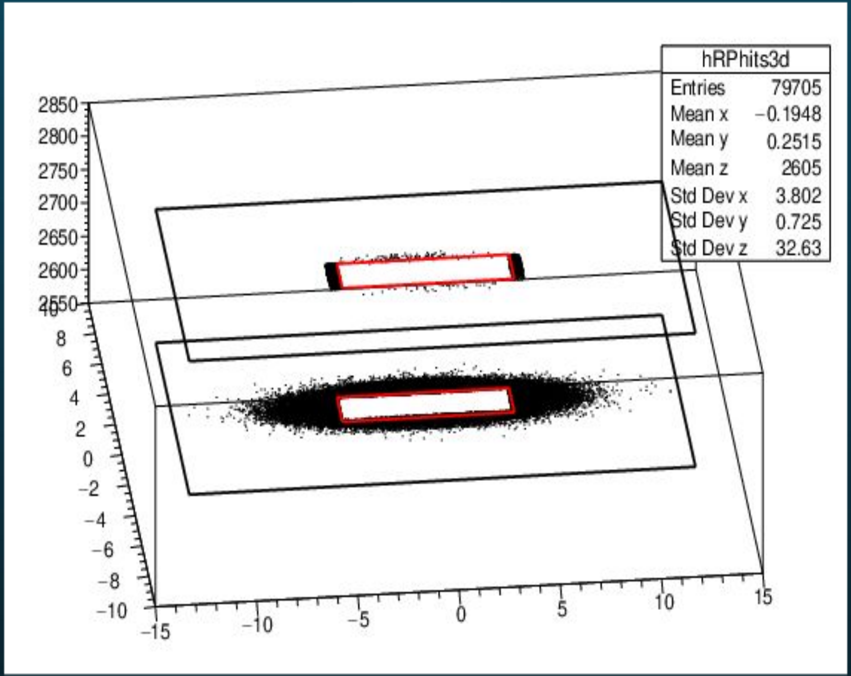
- xcut = 2.082 cm
- ycut = 0.3417 cm

<u>Hi Divergence</u>

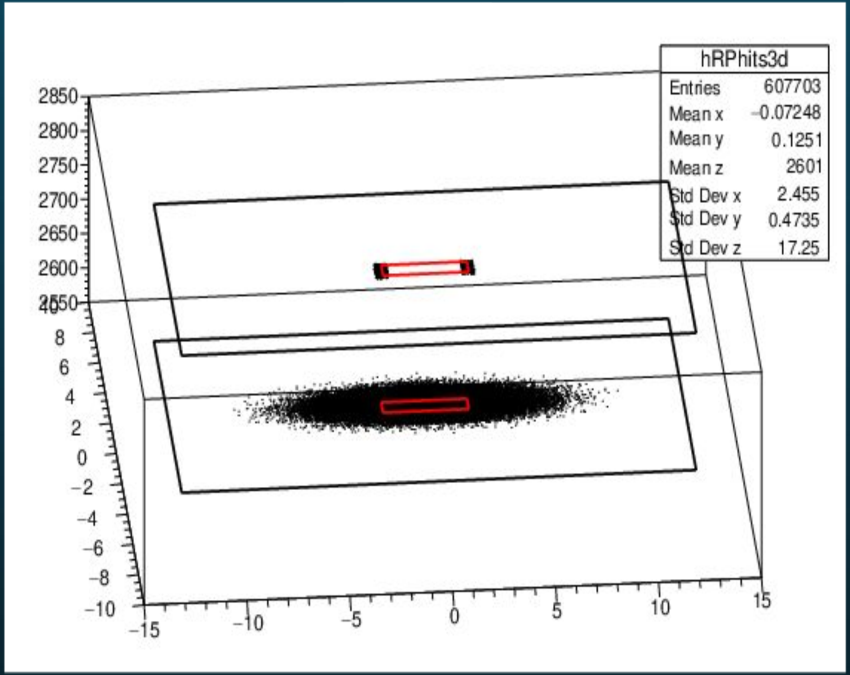
- xcut = 4.25 cm
- ycut = 0.8041 cm

# Beam Parameterisations - RP Occupancy

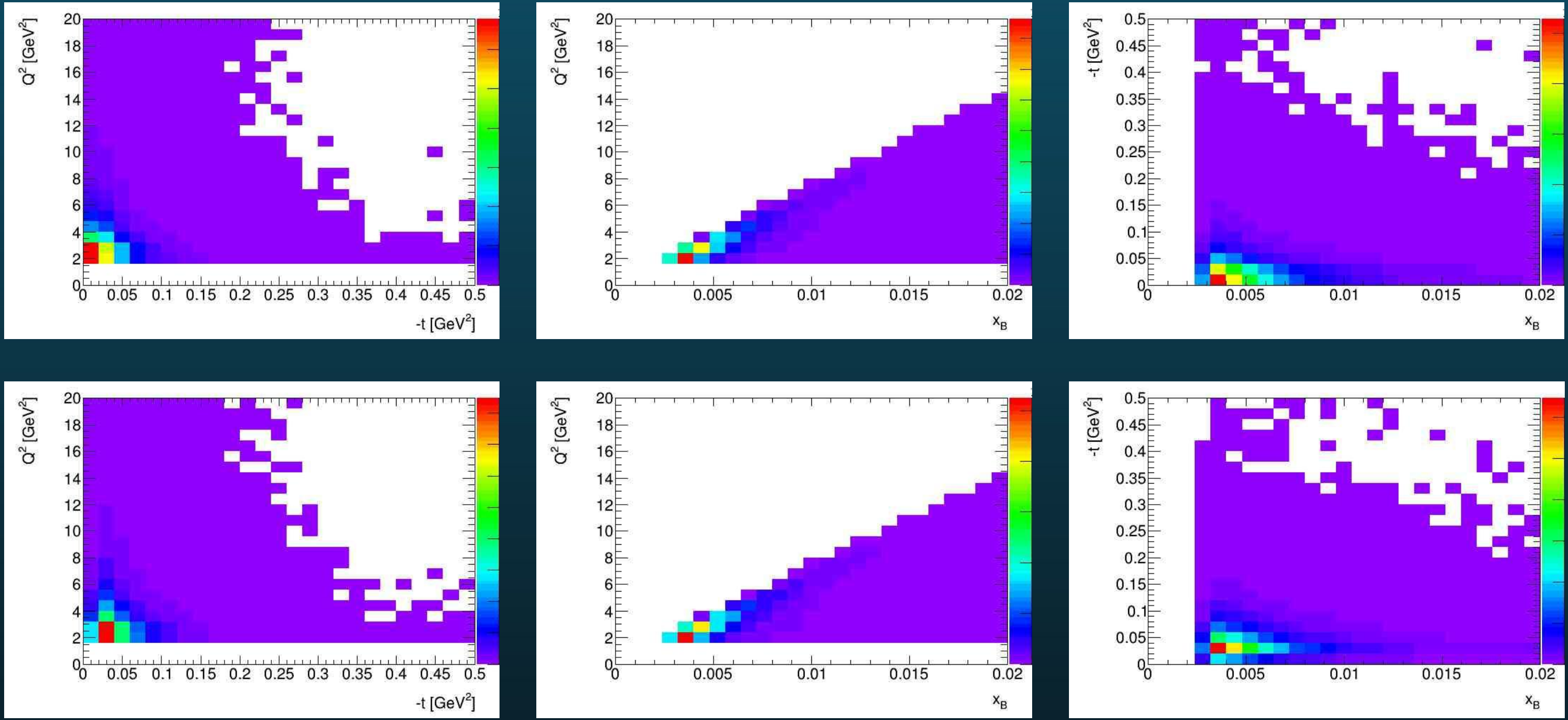
**High Divergence**



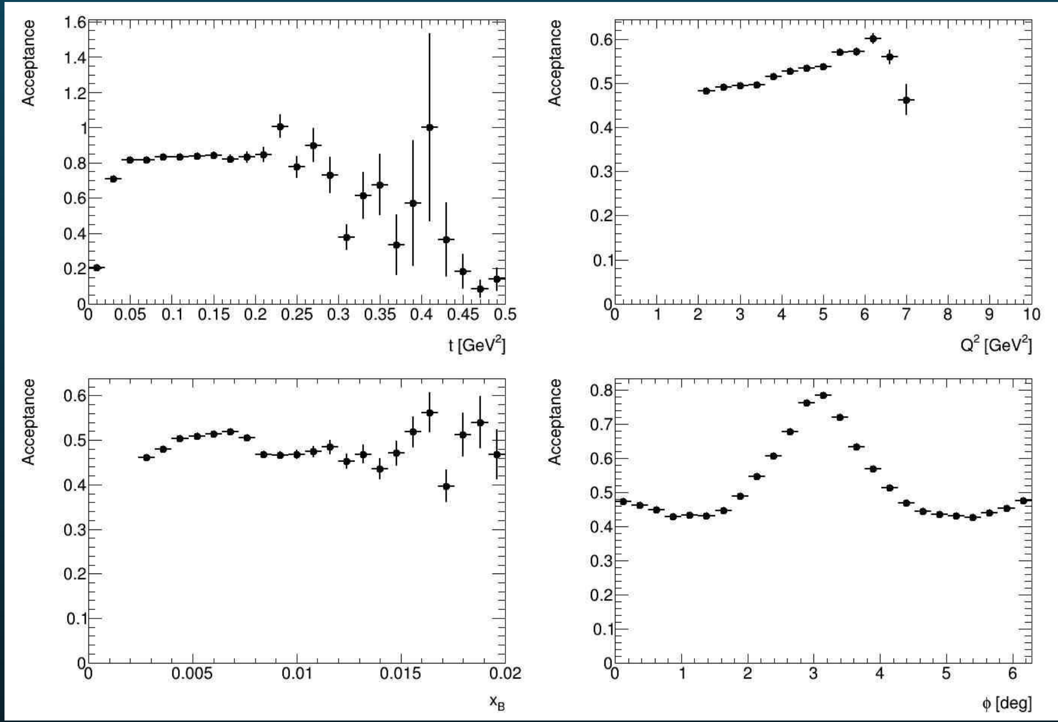

**High Acceptance**



# 2D Phase Space Coverage (Gen / Reconstructed)



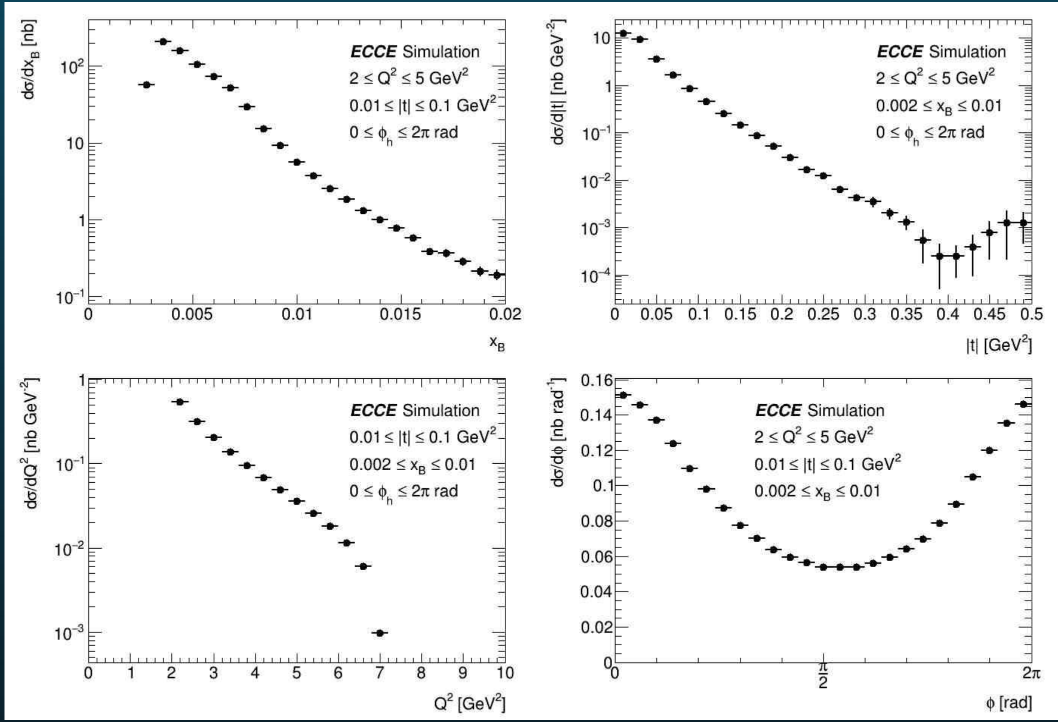
# Detector Acceptance for Physics Quantities (5x41/u)




***ECCE***
**$2.0 \leq Q^2 \leq 5.0$ GeV$^2$**
**$0.002 \leq x_B \leq 0.01$**
**$0.01 \leq -t \leq 0.1$ GeV$^2$**
**$0 \leq \phi \leq 2\pi$**

**$\sigma$ = 0.71 nb**
**(MC Integral)**

# Differential Cross Section Measurements (5x41/u)




$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} = \frac{1}{L\Delta\Omega}(N \pm \sqrt{N})$$

- $N$ is the number of counts in the bin
- $L$ is the integrated luminosity
- $\Delta\Omega$ is the multi-dimensional bin size:

$$\Delta\Omega = \Delta Q^2 \Delta x_B \Delta t \Delta\phi$$

# Future Work

- ❖ Asymmetry study
- ❖ Begin to look at files in new software framework for Detector-1
- ❖ 10x100 GeV/u and 18x137 GeV/u kinematics studied
- ❖ Continue optimization of generator and integrated cross section extraction

# Conclusions

- ❖ DVCS Interesting and powerful process for extracting 3D images of nucleons.
- ❖ EIC will be a fantastic tool for probing at new energies
- ❖ ECCE (Now Det1) detector (IP6) High Acceptance implementation ~60% acceptance in exclusive channel - large improvement on initial study!

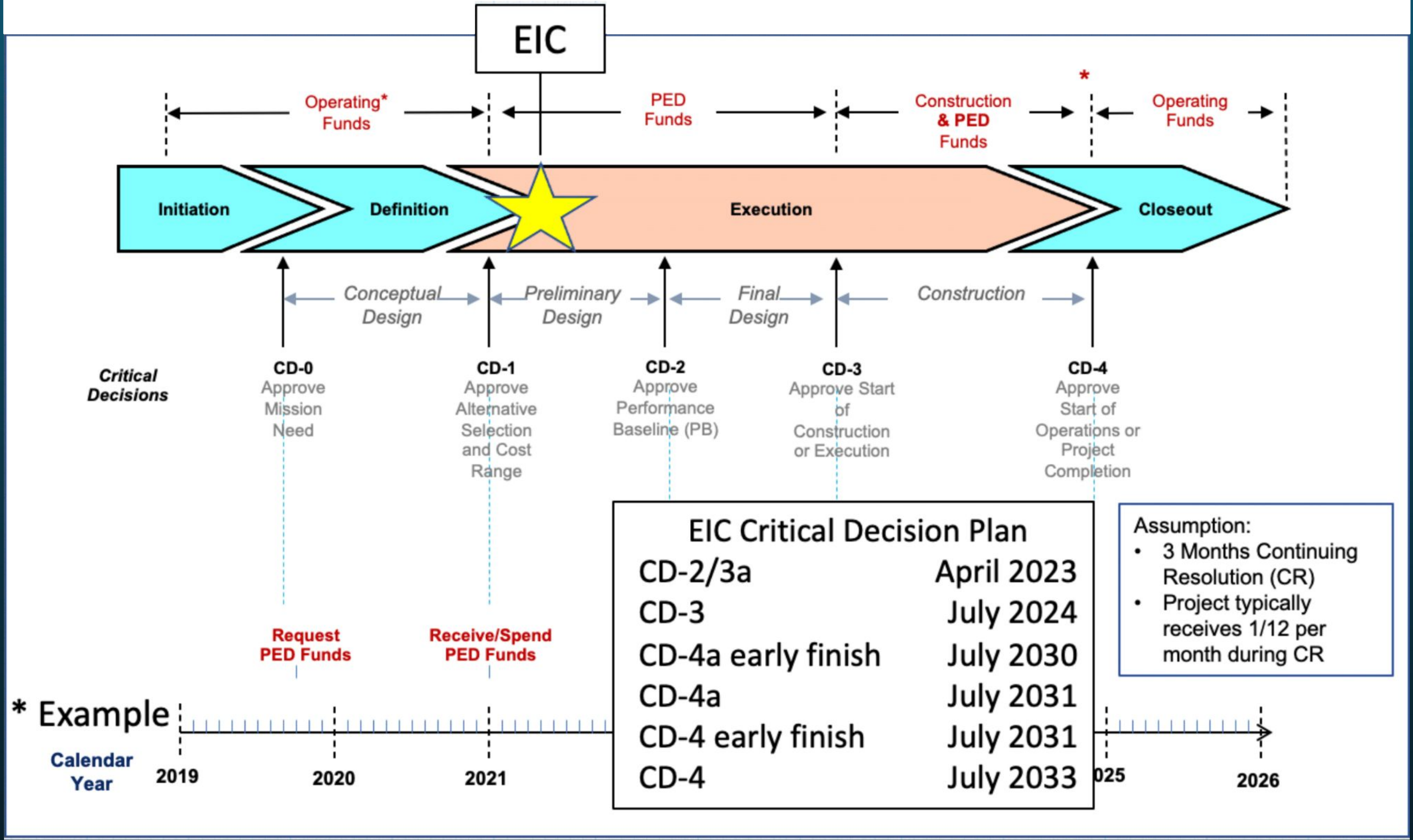
Special thanks to PhD supervisor (and WG convenor) R. Montgomery; all of the EDT working group; EICUG/ECW organisers and convenors; staff and colleagues within EIC.

# Thank You For Listening!

# References

1. CERN Courier 1982. https://cds.cern.ch/record/1734943/files/vol53-issue4-p035-e.pdf
2. C. Munoz. https://indico.cern.ch/event/180678/contributions/304829/attachments/240727/337060/Munoz.pdf
   https://indico.cern.ch/event/686555/contributions/2960213/attachments/1681076/2700798/talk.pdf
3. EIC White Paper https://arxiv.org/abs/1212.1701
4. I. Korover. https://indico.bnl.gov/event/11463/contributions/52412/attachments/36426/59854/eic_ecce_final_1.pdf
5. ECCE https://www.ecce-eic.org/_files/ugd/2b2c77_5fd1cff0c2f04337ac67d4675985f208.pdf
6. S. Fucini. https://arxiv.org/pdf/1910.07458.pdf
7. F. Bock. https://github.com/FriederikeBock/AnalysisSoftwareEIC
8. ECCE-EIC https://github.com/ECCE-EIC/ecce-detectors/tree/master/FastPID
9. F. Georges https://www.jlab.org/hugs/archive/Schedule2016/seminar/15_Slides_Frederic_Georges.pdf

# Backup




Example EIC Critical Decision Timeline

**EIC Project POC**
Rolf Ent (JLab)

**ECCE Steering Committee**
Or Hen (MIT)
Tanja Horn (CUA)
John Lajoie (ISU)

**Institutional Board**

**Computing Team**
Cristiano Fanelli (MIT)
David Lawrence (JLab)

**Diversity, Equity and Inclusion**
Narbe Kalantarians (VUU, co-chair)
Christine Nattrass (UTK, co-chair)
Simonetta Liuti (UVA)
Elena Long (UNH)

## Computing Working Groups:

- Artificial Intelligence
  **William Phelps (CNU/JLab)**
- Computing and Software
  **Joe Osborn (ORNL)**

**Detector Team**
Doug Higinbotham (JLab)
Ken Read (ORNL)

**Physics Benchmarks Team**
Carlos Munoz-Camacho (IJCLab-Orsay)
Rosi Reed (Lehigh U.)

**Editorial Team**
Tom Cormier (ORNL)
Richard Milner (MIT)
Peter Steinberg (BNL)

## Detector Working Groups:

- IP8/Equipment Re-use
  **John Haggerty (BNL)**
- Far Forward/Far Backward*
  **Michael Murray (KU), Yuji Goto (RIKEN), Igor Korover (MIT)**
- Tracking
  **Xuan Li (LANL), Nilanga Liyanage (UVA)**
- Calorimetry
  **Friederike Bock (ORNL), Yongsun Kim (Sejong U.)**
- Particle ID
  **Greg Kalicy (CUA), Xiaochun He (GSU)**
- Magnetic Field
  **Paul Brindza (JLab), Renuka Rajput-Ghoshal (JLab)**
- DAQ/Electronics/Readout
  **Chris Cuevas (JLab), Martin Purschke (BNL)**

***Alex Jentsch, Yulia Furletova**
(far-forward/backward POC)

## Physics Working Groups:

- Simulations
  **Cameron Dean (LANL), Jin Huang (BNL)**
- Inclusive Processes
  **Tyler Kutz (MIT), Claire Gwenlan (Oxford)**
- Semi-Inclusive
  **Ralf Seidl (RIKEN), Charlotte Van Hulse (Orsay)**
- Exclusive
  **Rachel Montgomery (Glasgow), Julie Roche (OU)**
- Diffractive and Tagging
  **Wenliang Li (W&M), Axel Schmidt (GWU)**
- Jets and Heavy Flavor
  **Cheuk-Ping Wong (LANL), Wangmei Zha (USTC)**
- BSM and Precision Electroweak
  **Sonny Mantry (UNG), Xiaochao Zheng (UVa)**

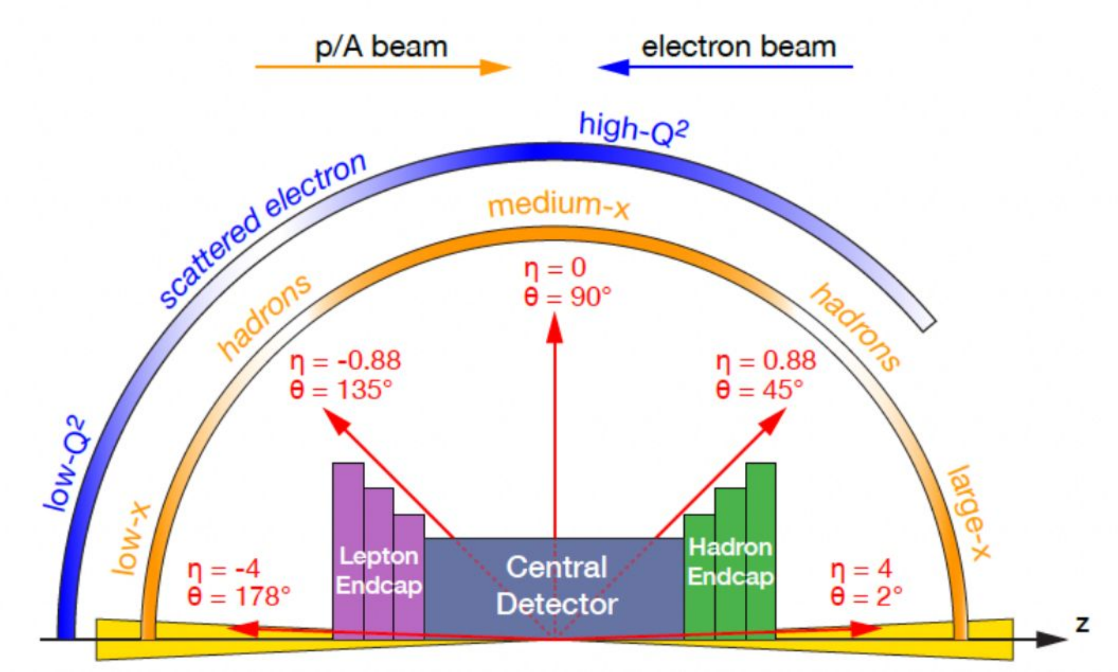
## Editorial Working Groups:

- Proposal Editing, Verification and Version Control
- Costing and Management

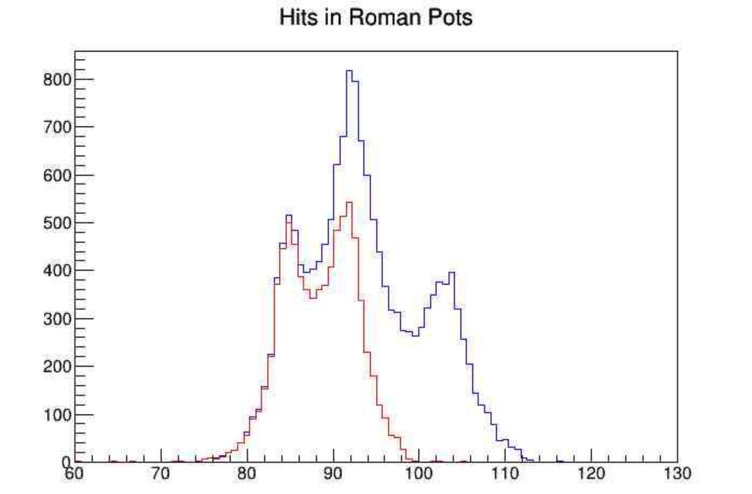


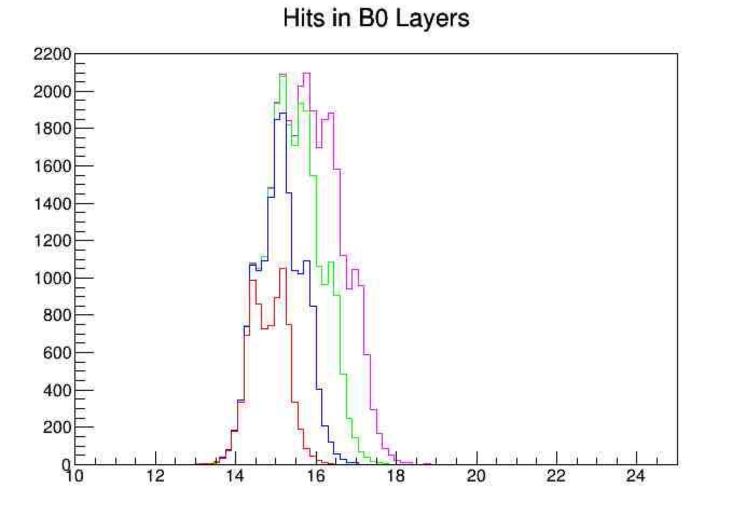
ECCE Consortium Overview[4]

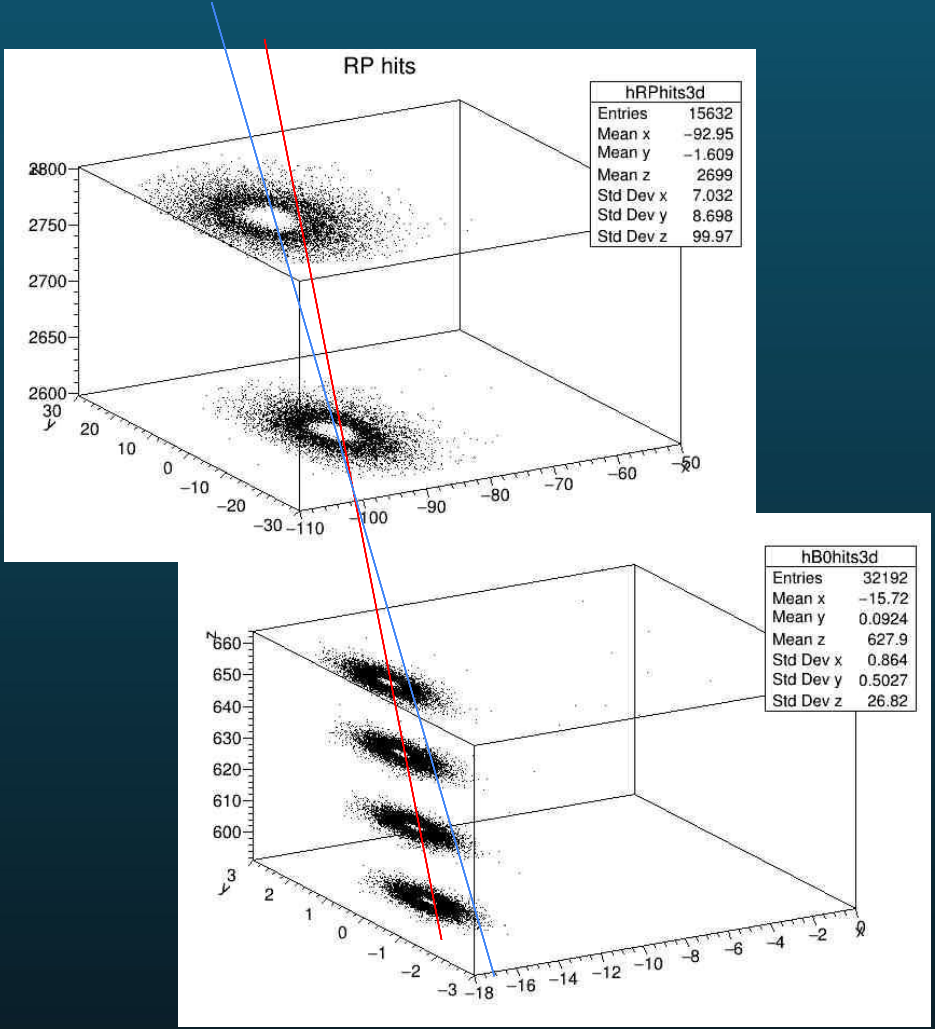
# More ECCE Details[4]




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


Hits in Roman Pots
800
700
600
500
400
300
200
100
0
60
70
80
90
100
110
120
130


Hits in B0 Layers
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
10
12
14
16
18
20
22
24


RP hits
hRPhits3d
Entries 15632
Mean x −92.95
Mean y −1.609
Mean z 2699
Std Dev x 7.032
Std Dev y 8.698
Std Dev z 99.97
2800
2750
2700
2650
2600
y
30
20
10
0
−10
−20
−30
−110
−100
−90
−80
−70
−60
−50
x
hB0hits3d
Entries 32192
Mean x −15.72
Mean y 0.0924
Mean z 627.9
Std Dev x 0.864
Std Dev y 0.5027
Std Dev z 26.82
z
660
650
640
630
620
610
600
y
3
2
1
0
−1
−2
−3
−18
−16
−14
−12
−10
−8
−6
−4
−2
0
x

# Track Resolution