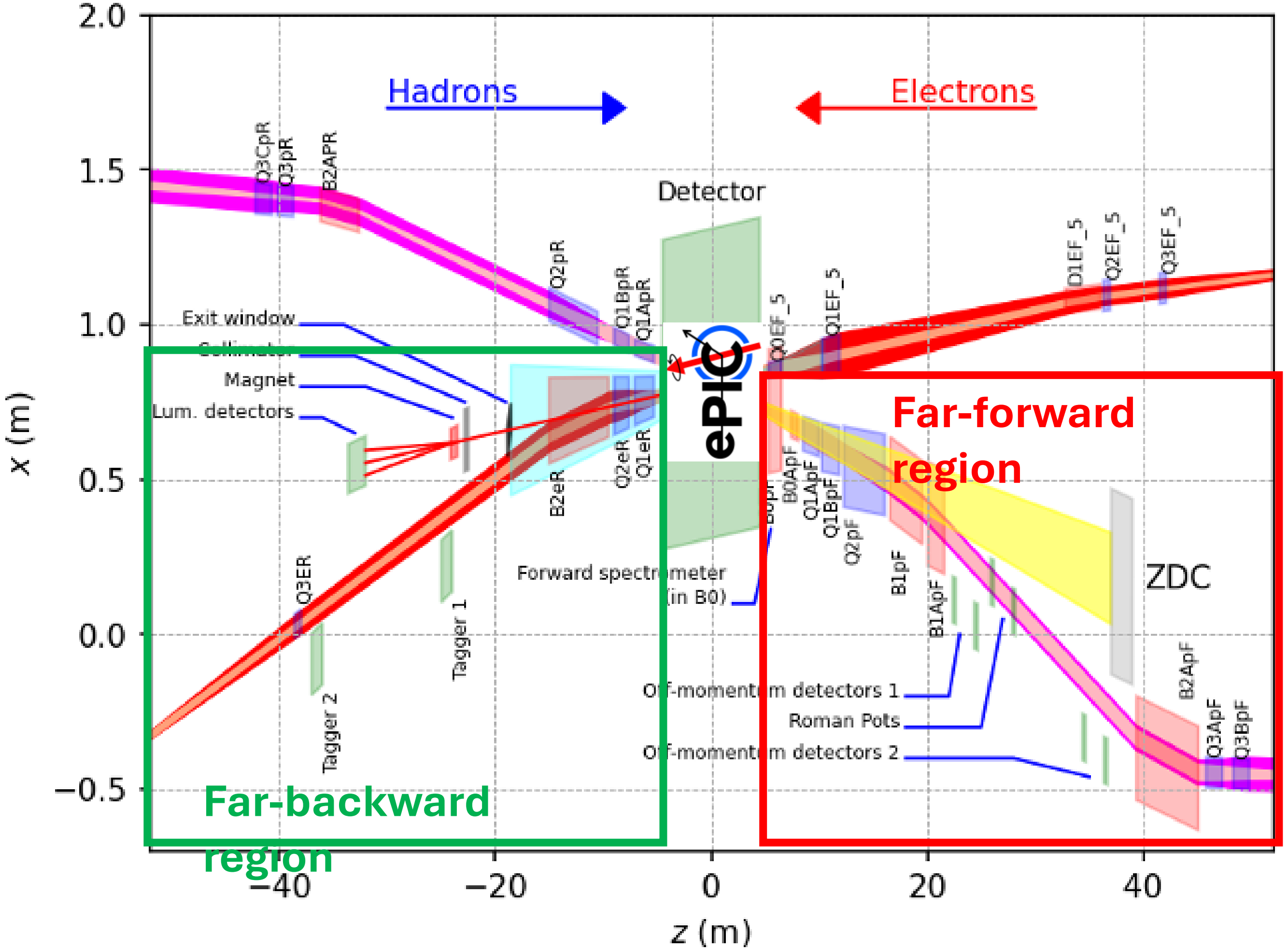
Single-neutron and DEMP studies in ePIC

Barak Schmookler

EIC Interaction Region (IR)

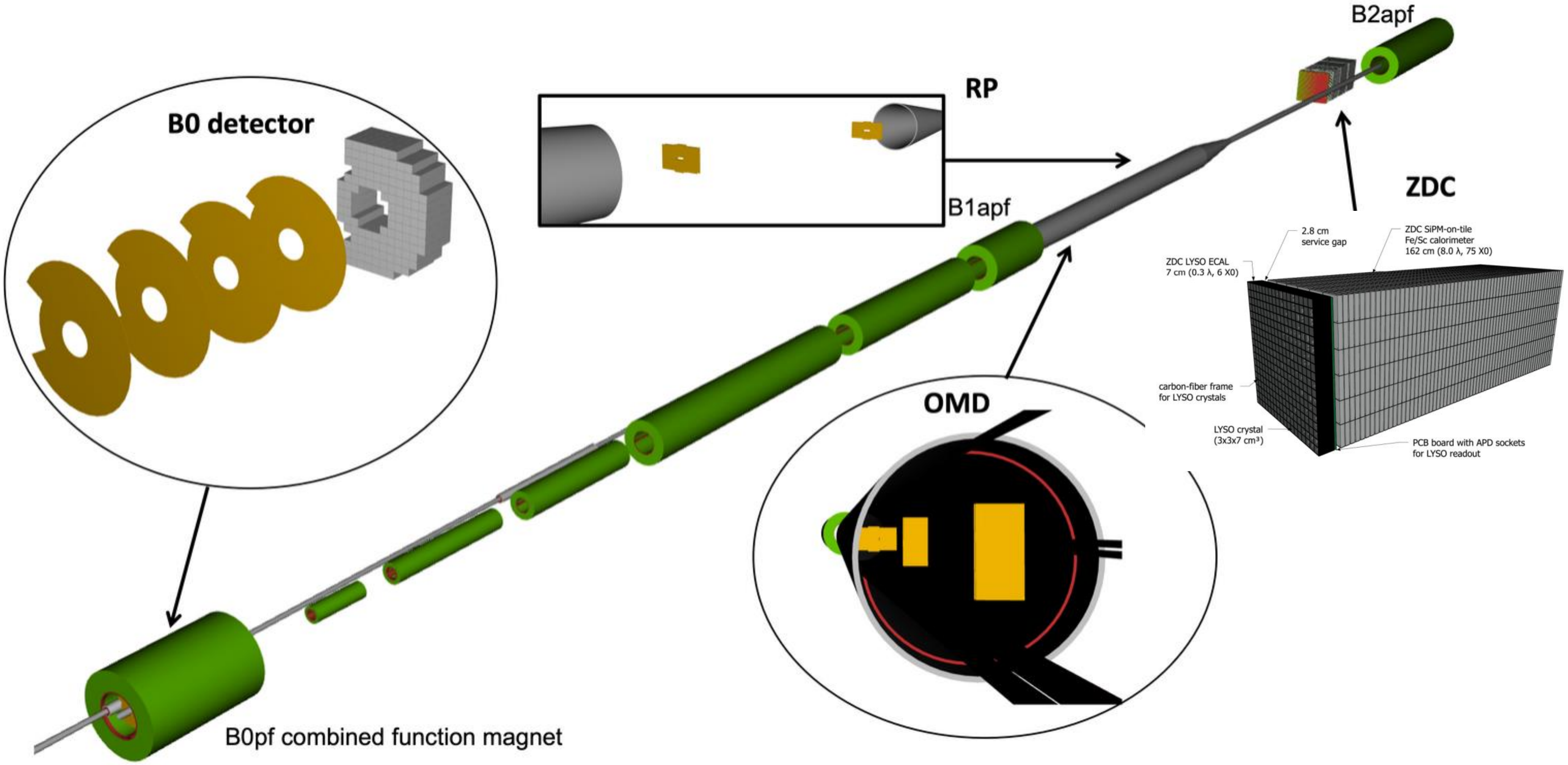


IR design is critical for EIC science

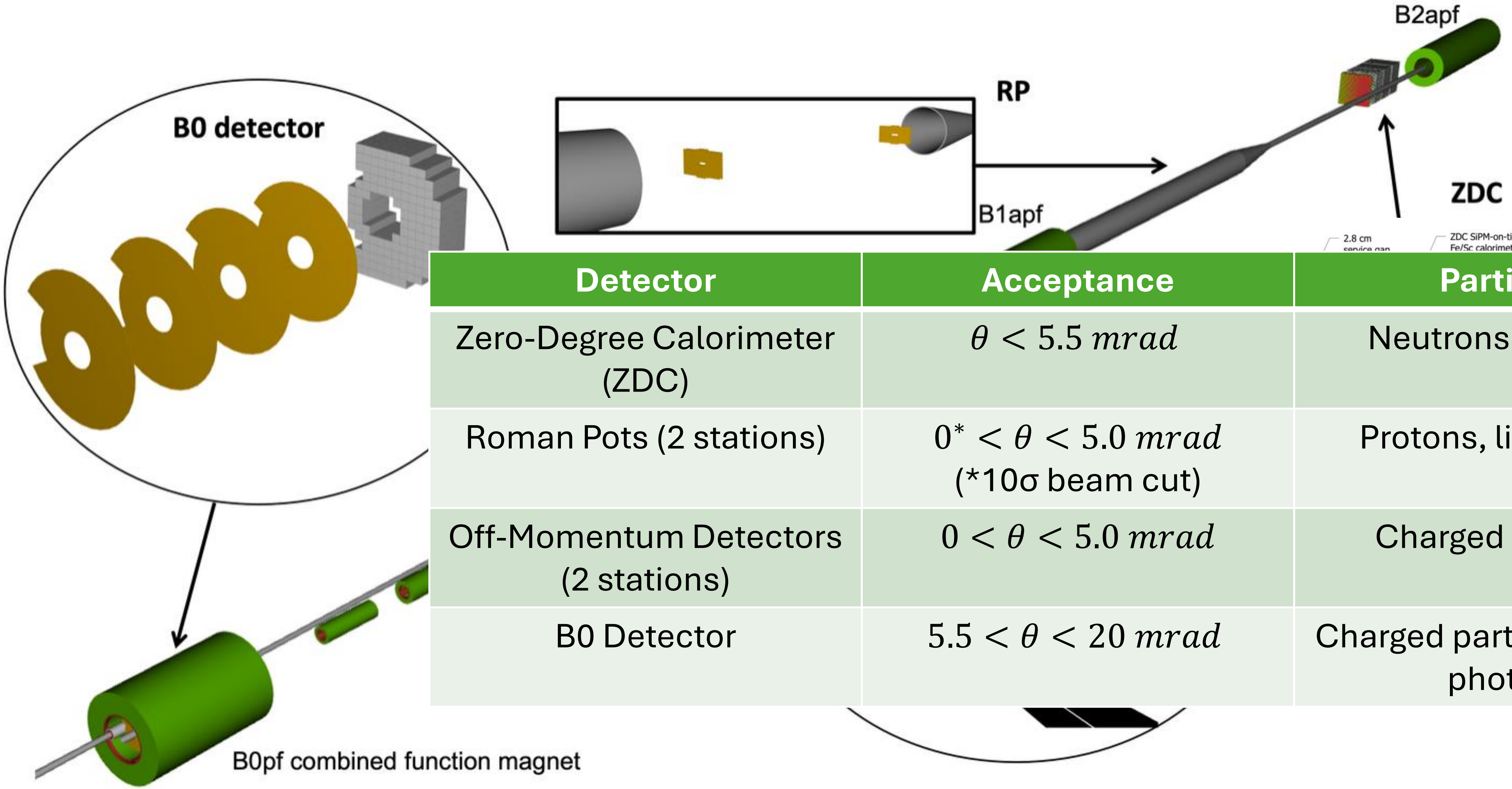
Far-forward region: Many physics channels require the tagging of charged and neutral particles scattered at very small angles to the incoming proton/ion beam. Detectors in this region are the B0, Off-Momentum detectors, Roman Pot detectors, and Zero-Degree calorimeter.

Far-backward region: Measurement of the absolute and relative luminosity, as well as tagging of low-Q^2 electrons. The detectors in this region are the Direct Photon detector, the Pair Spectrometer, and the Low Q^2 taggers.

Far-forward region in ePIC

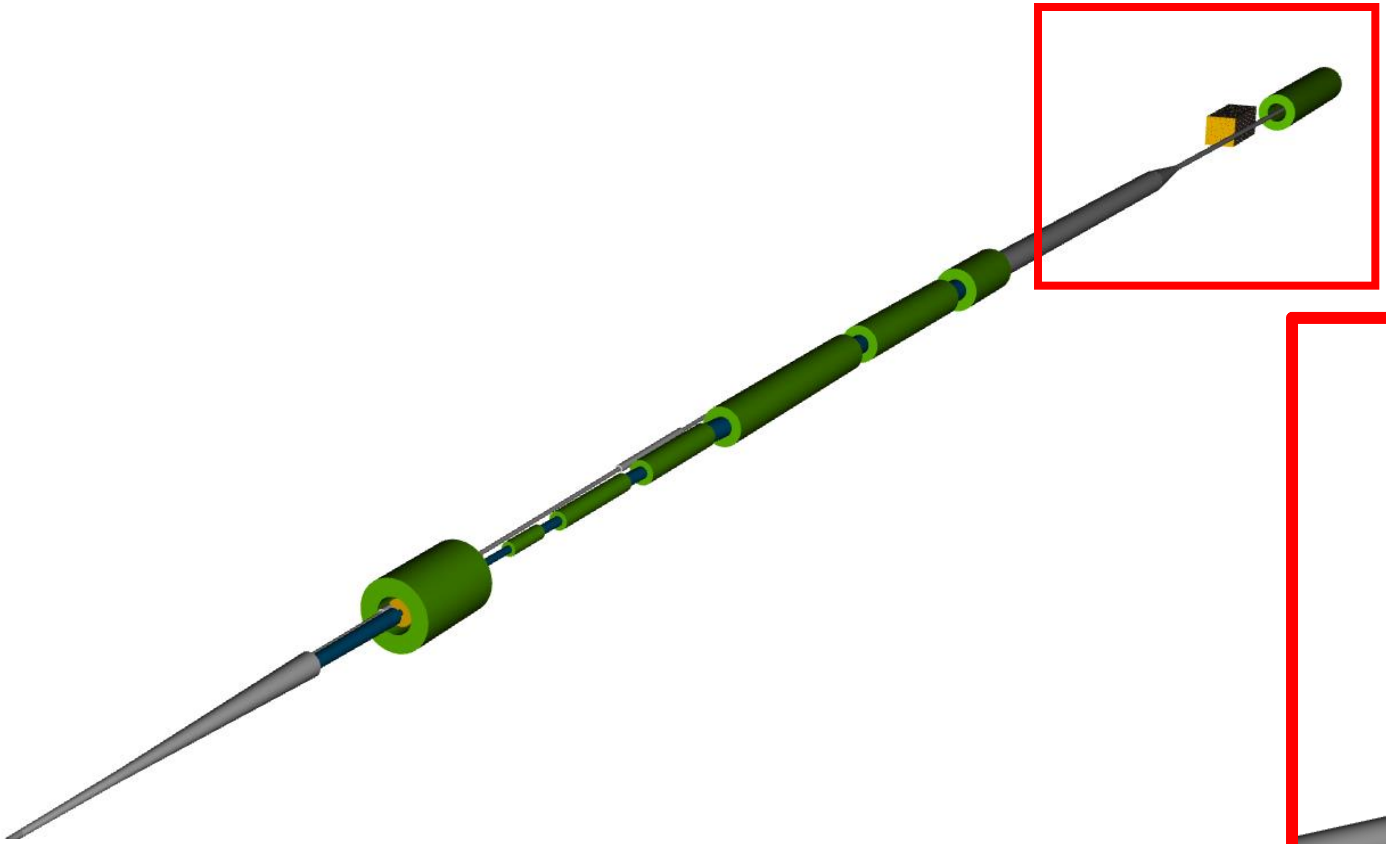


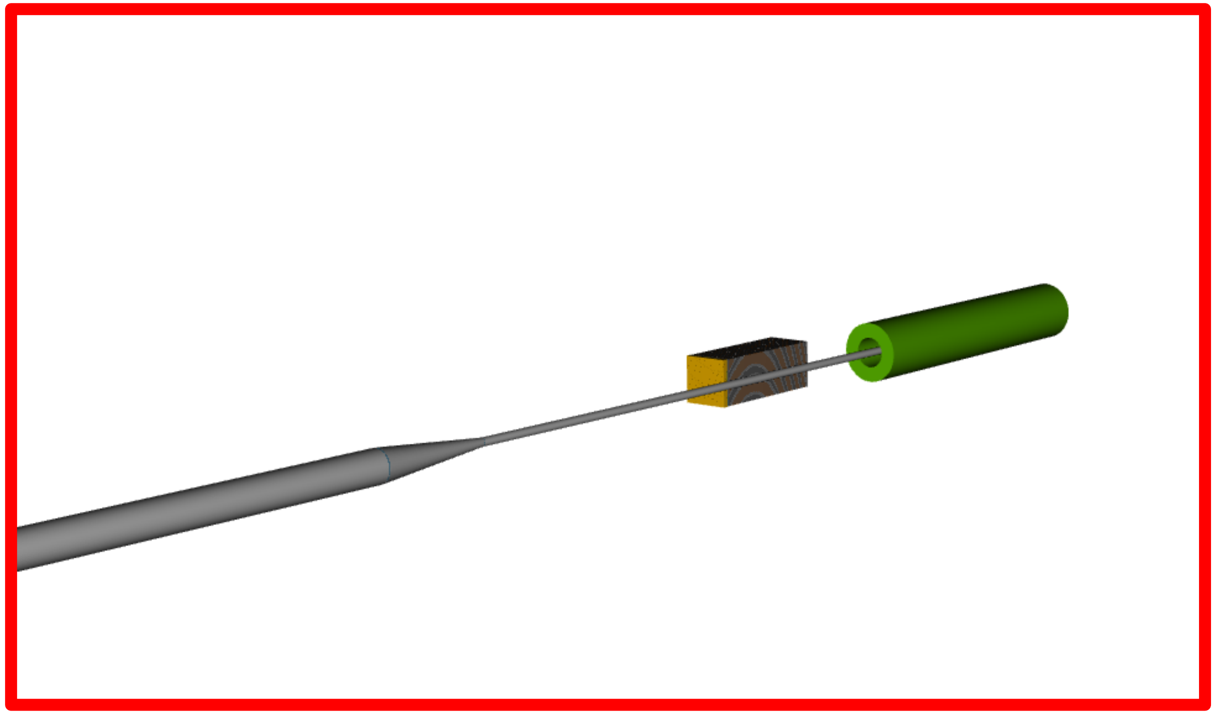
Far-forward region in ePIC



Detector	Acceptance	Particles
Zero-Degree Calorimeter (ZDC)	$\theta < 5.5\ mrad$	Neutrons, photons
Roman Pots (2 stations)	$0^* < \theta < 5.0\ mrad$ (*10σ beam cut)	Protons, light nuclei
Off-Momentum Detectors (2 stations)	$0 < \theta < 5.0\ mrad$	Charged particles
B0 Detector	$5.5 < \theta < 20\ mrad$	Charged particles, tagged photons

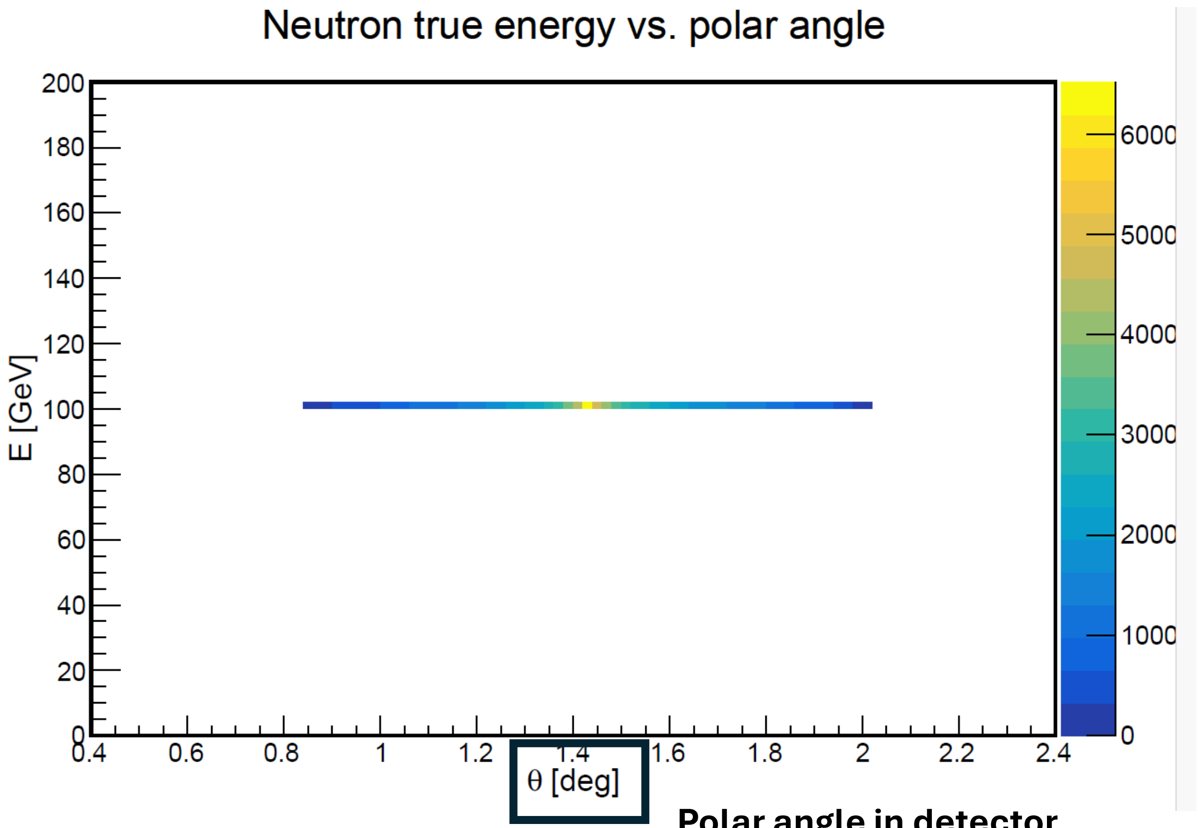
Full far-forward region in Geant4





Single-neutron simulation

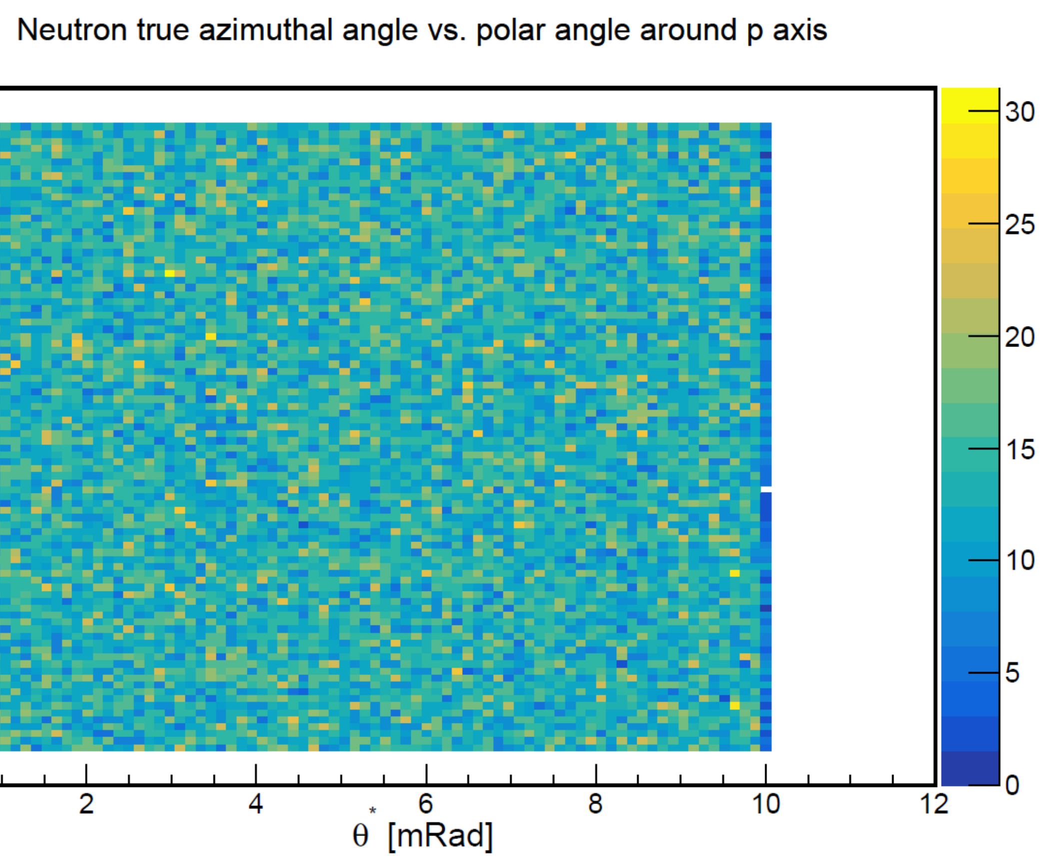
- 100k neutrons using official ePIC simulation with full geometry (DD4Hep) and reconstruction (EICRecon).
- Kinematics:
  - 100 GeV (or 40 GeV)
  - θ = [0,10] mRad w.r.t. proton beam direction
  - ϕ = [0,2π] Rad w.r.t proton beam direction



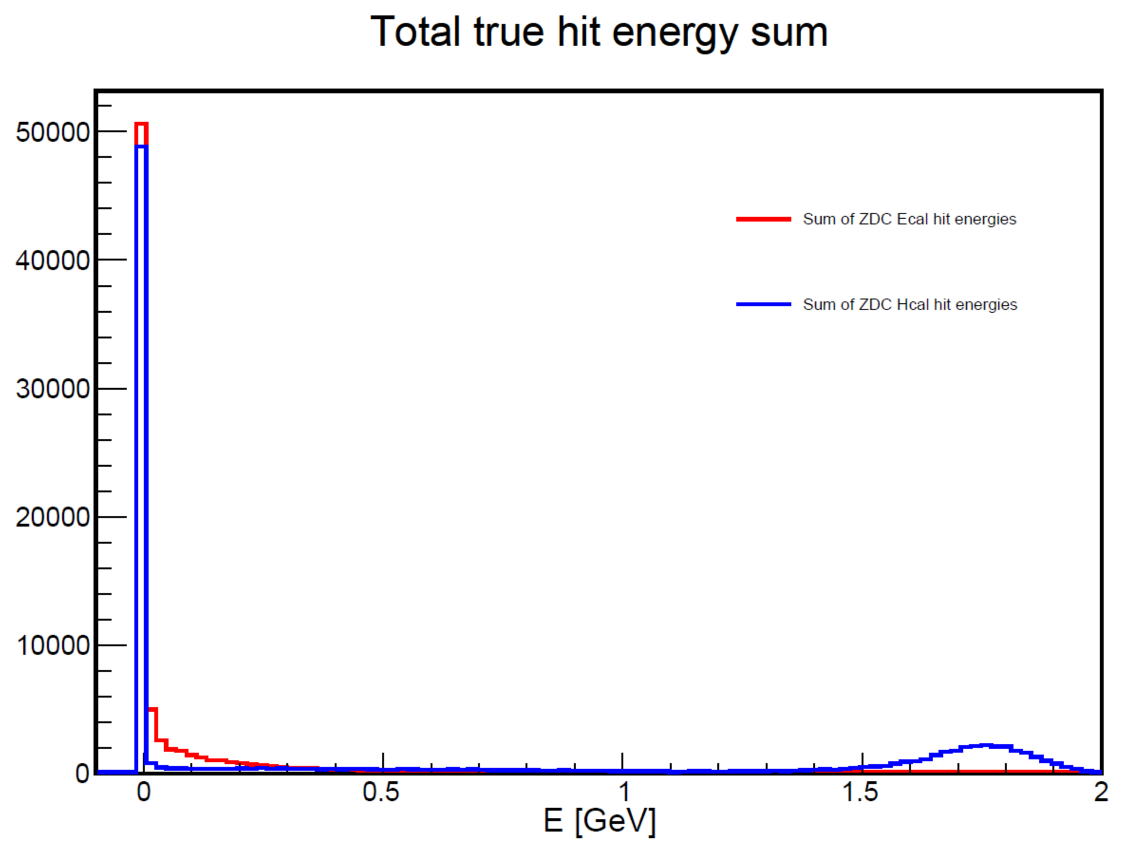
Polar angle in detector coordinates (z axis is anti-parallel to electron beam direction).

Single-neutron simulation – Geant-level response

All generated neutrons

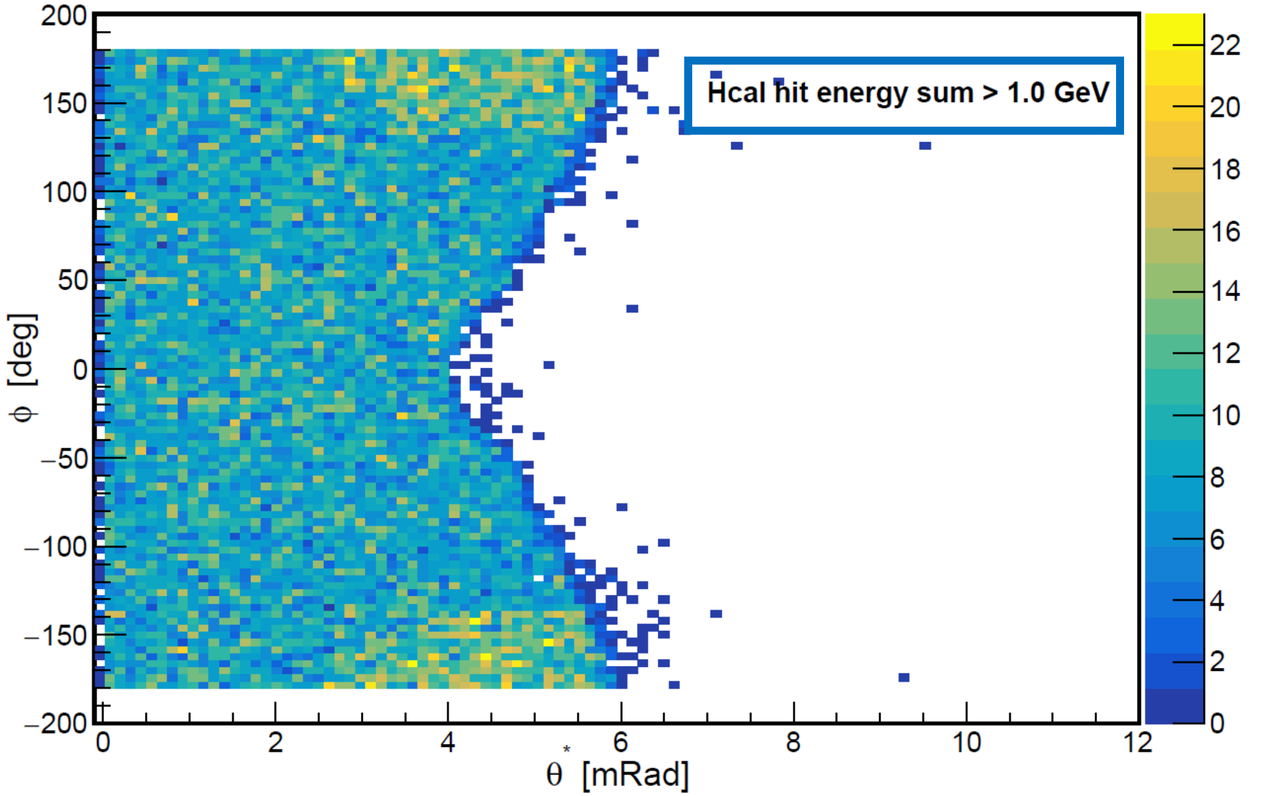


Total Energy deposited in active area

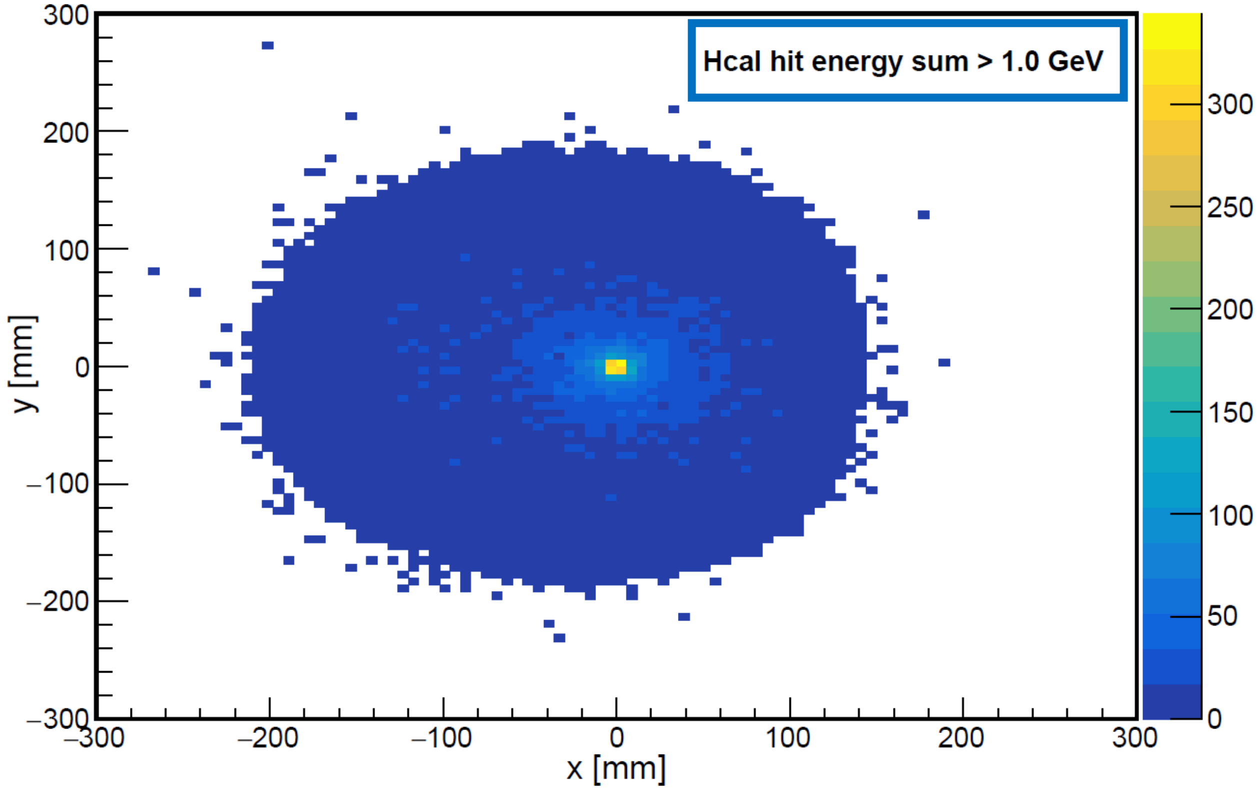


Single-neutron simulation – Geant-level response

Neutron true azimuthal angle vs. polar angle around p axis



Neutron local hit position at ZDC HCal front face

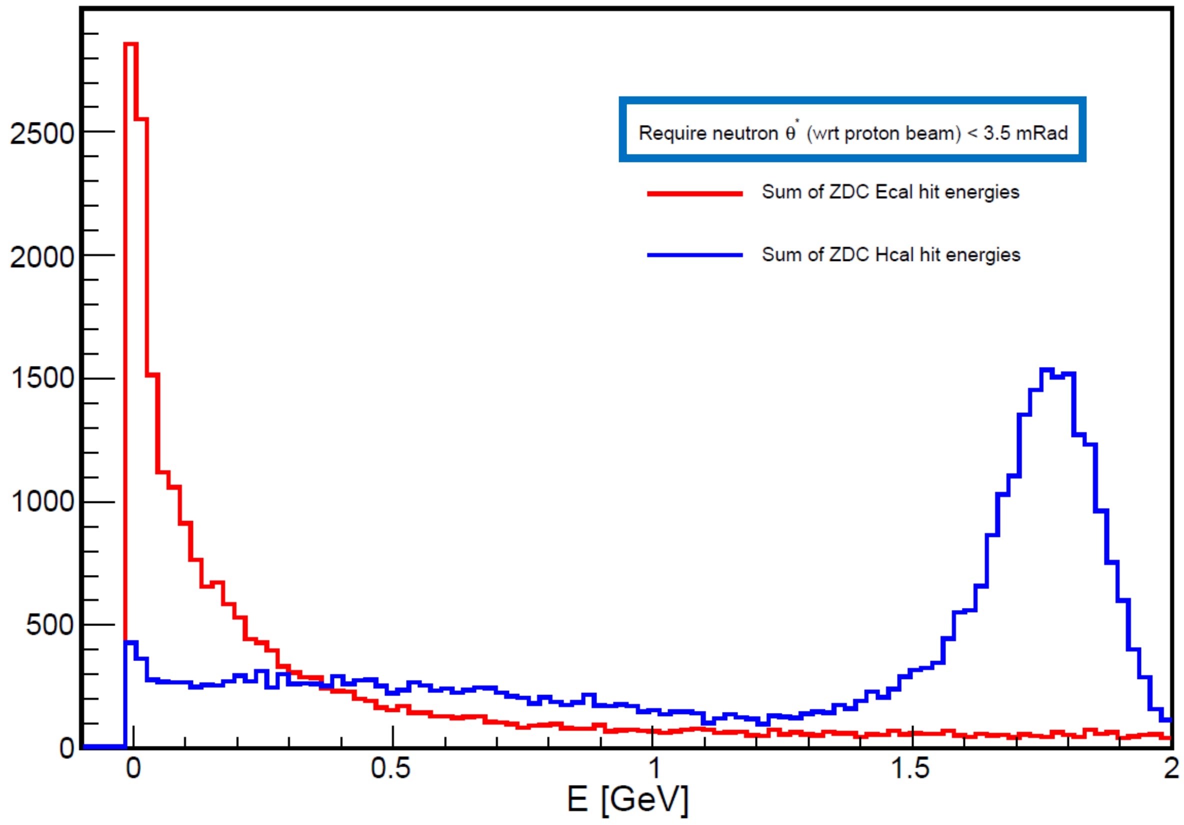


ZDC extends out to ±300 mm (~8.4 mRads at the front face). We see a sharp cutoff in the acceptance with some asymmetry in x. This is due to two magnets near the B0 detector.

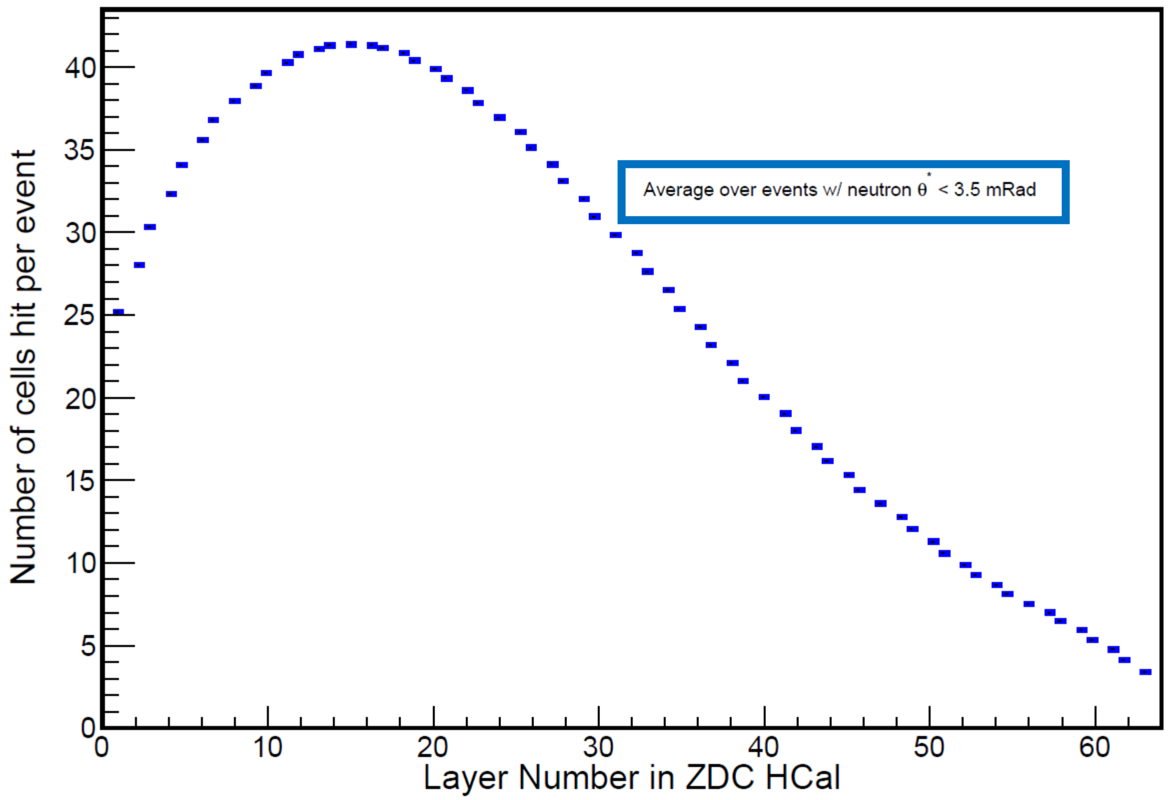
An update is to the beamline is coming, which will add an exit window for the neutrals that go towards the ZDC. The acceptance will then be uniform, but again with a hard edge around 5 mRad.

Single-neutron simulation – Geant-level response

Total true hit energy sum

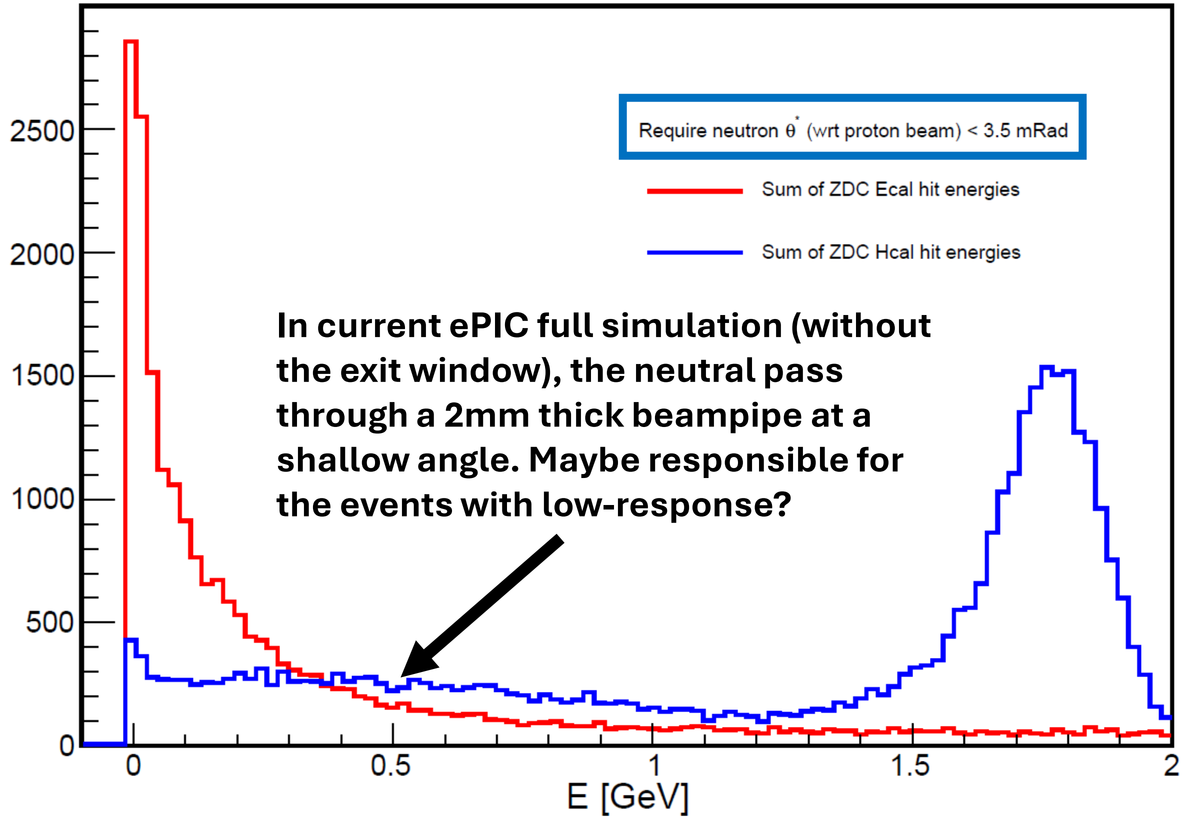


Cells w/ non-zero energy deposit

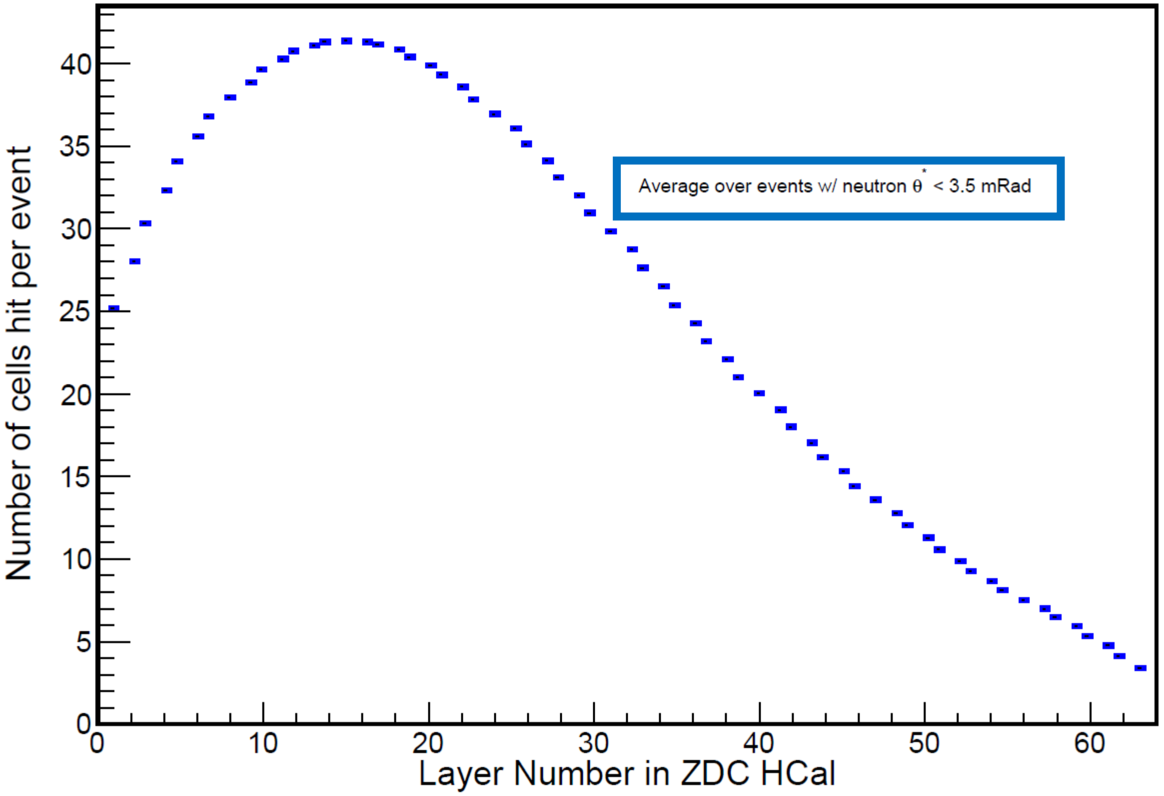


Single-neutron simulation – Geant-level response

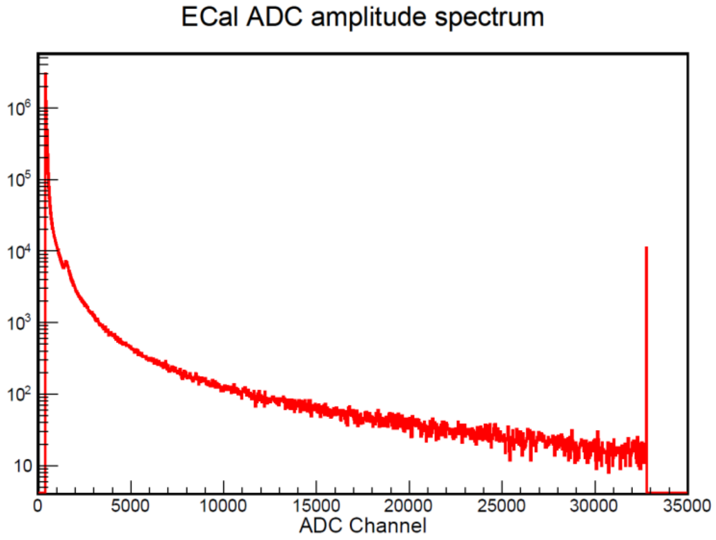
Total true hit energy sum

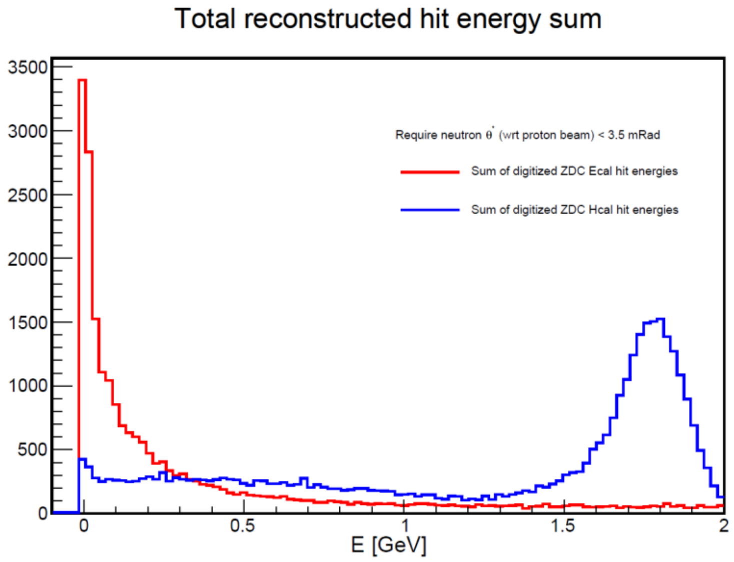


Cells w/ non-zero energy deposit

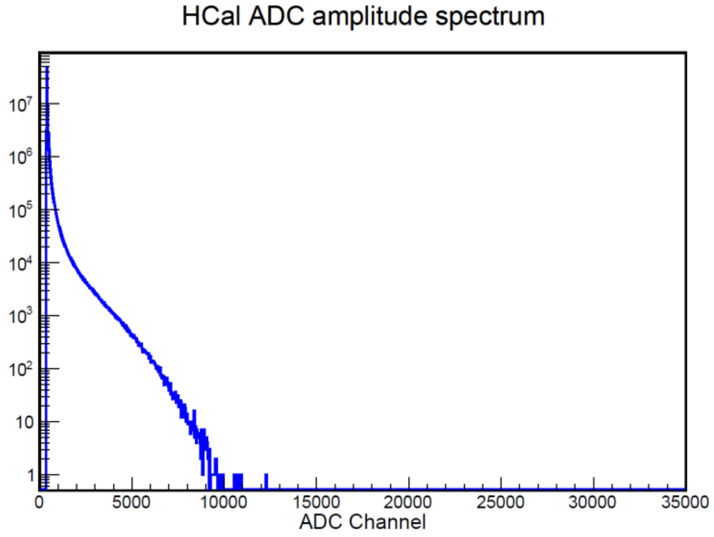


Single-neutron simulation – Reconstruction-level



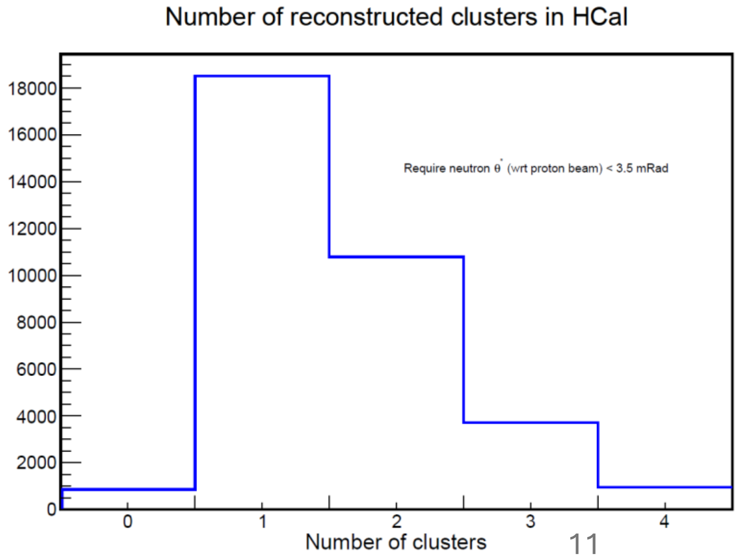


LYSO Ecal ADC saturates. Need to adjust in simulation.



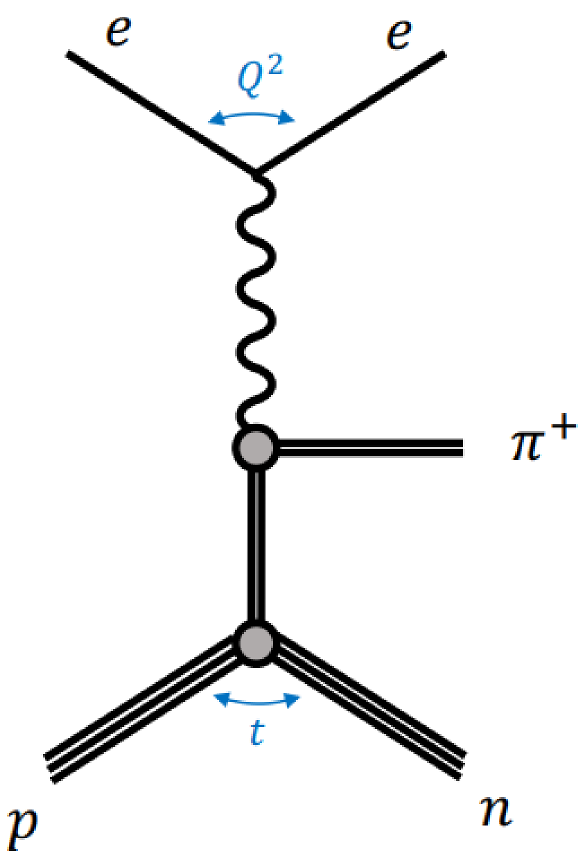
Hcal ADC shows no saturation, but can adjust gain to cover entire dynamic range.

Default Island clustering on sub-cells. Should tune and/or update to imaging clustering.



Deep **E**xclusive **M**eson **P**roduction (**DEMP**)

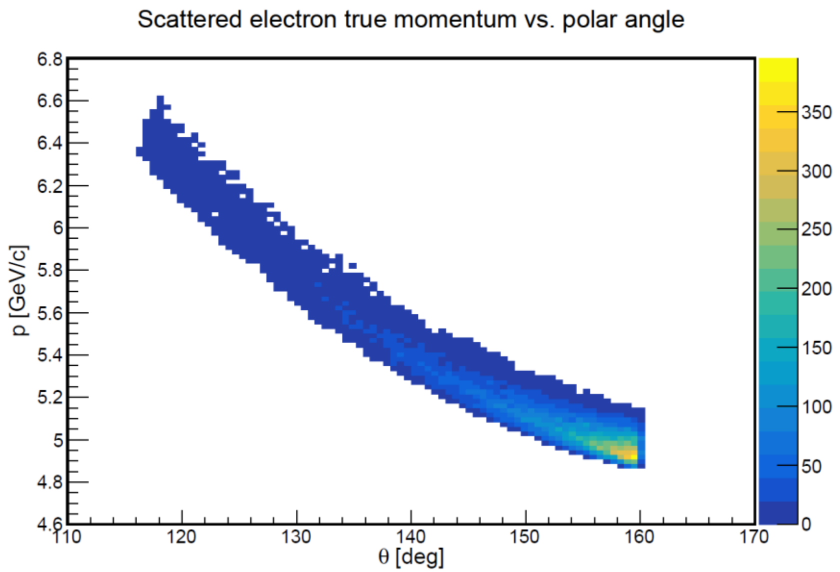
$e^- + p^+ \rightarrow e^- + pi^+ + n$

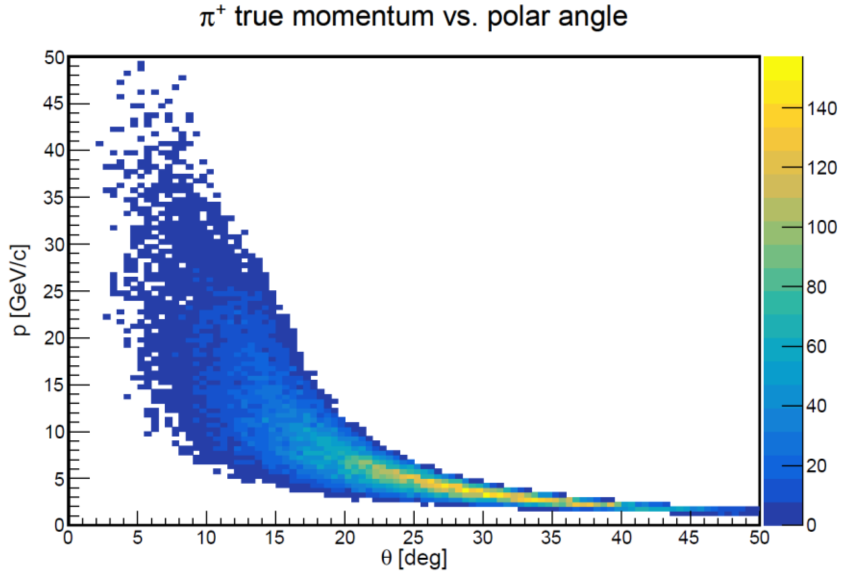


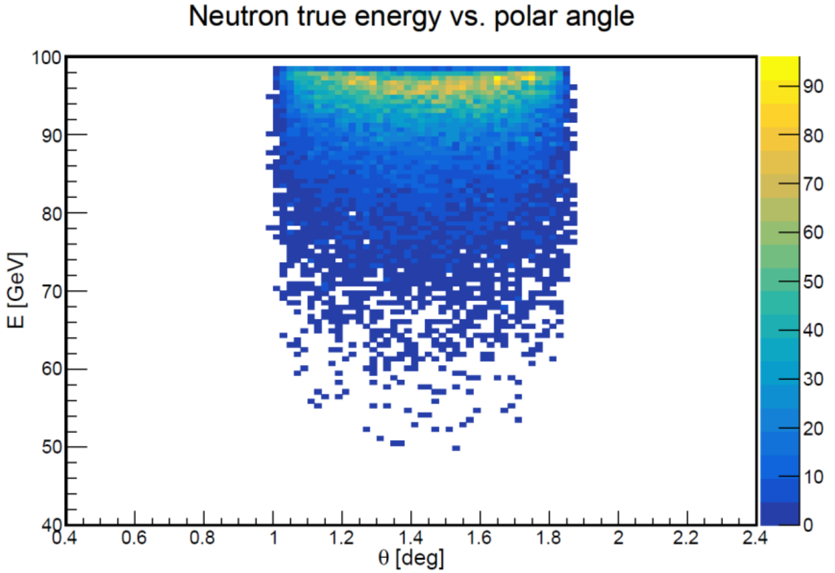
1. Simple 3-particle final state. Electron and positive pion go into the main detector. The neutron goes into the ZDC.
2. Good reconstruction of the neutron angle may be needed for accurate **t** reconstruction.
3. Generated events from the *DEMPgen* event generator exist on S3 in HepMC3 format. These events have the IP6 crossing angle and beam smearing effects already applied

Results with DEMP simulation – truth level

5x100 GeV – 30k events simulated



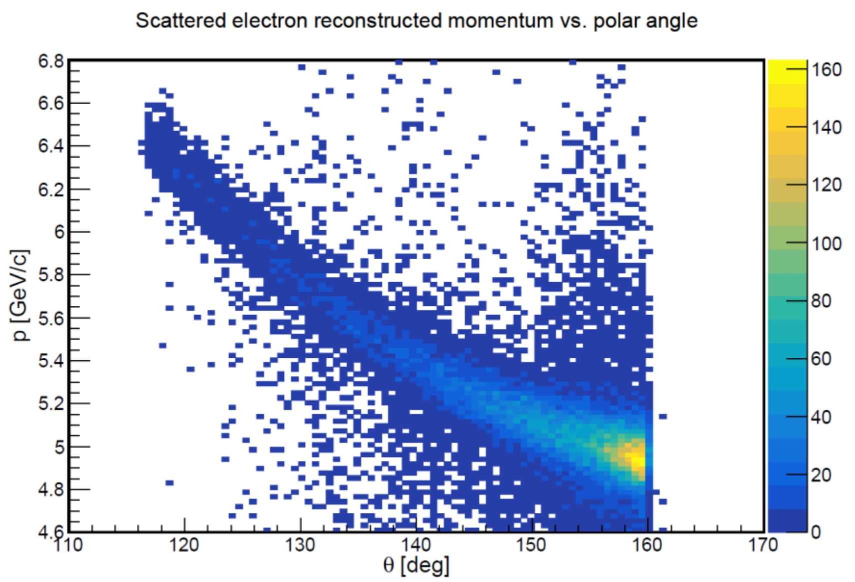


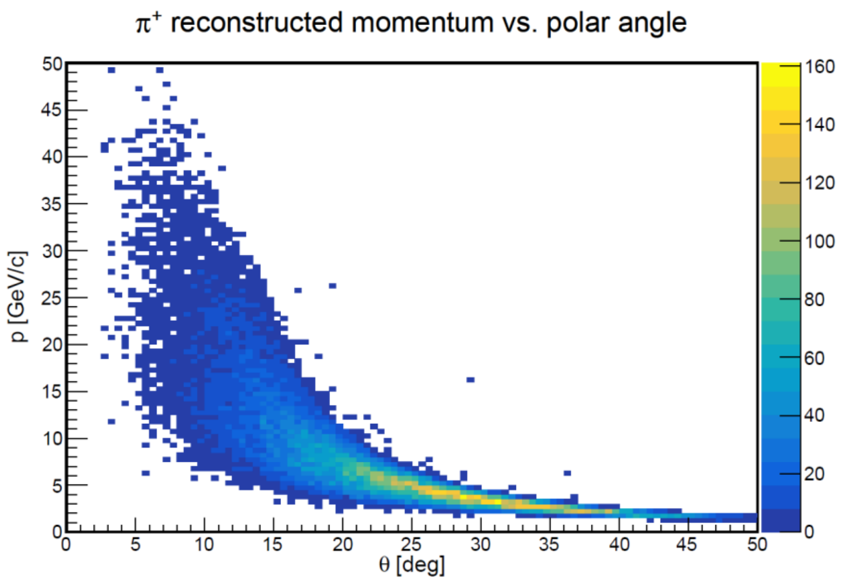


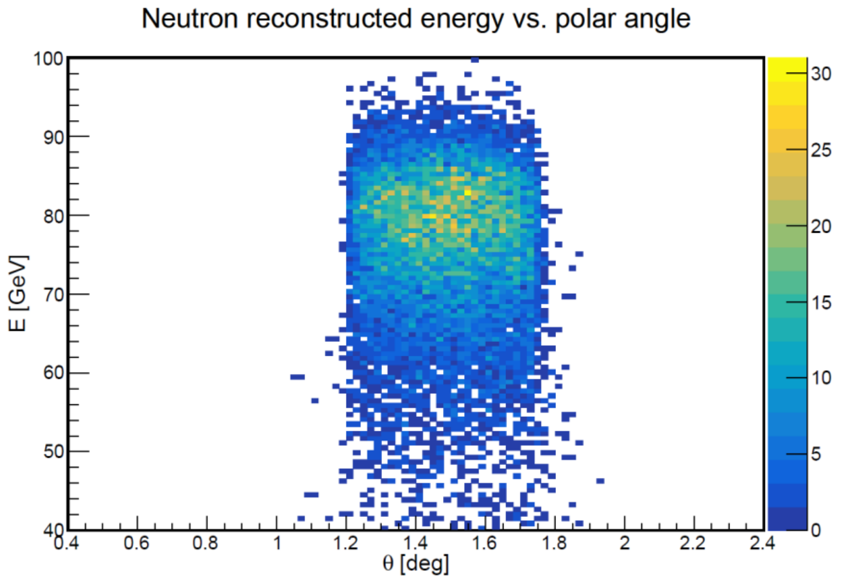
Neutron centered around 25 mRad (1.4 degrees), which is the proton beam direction

Results with DEMP simulation – reconstructed level

5x100 GeV – 30k events simulated





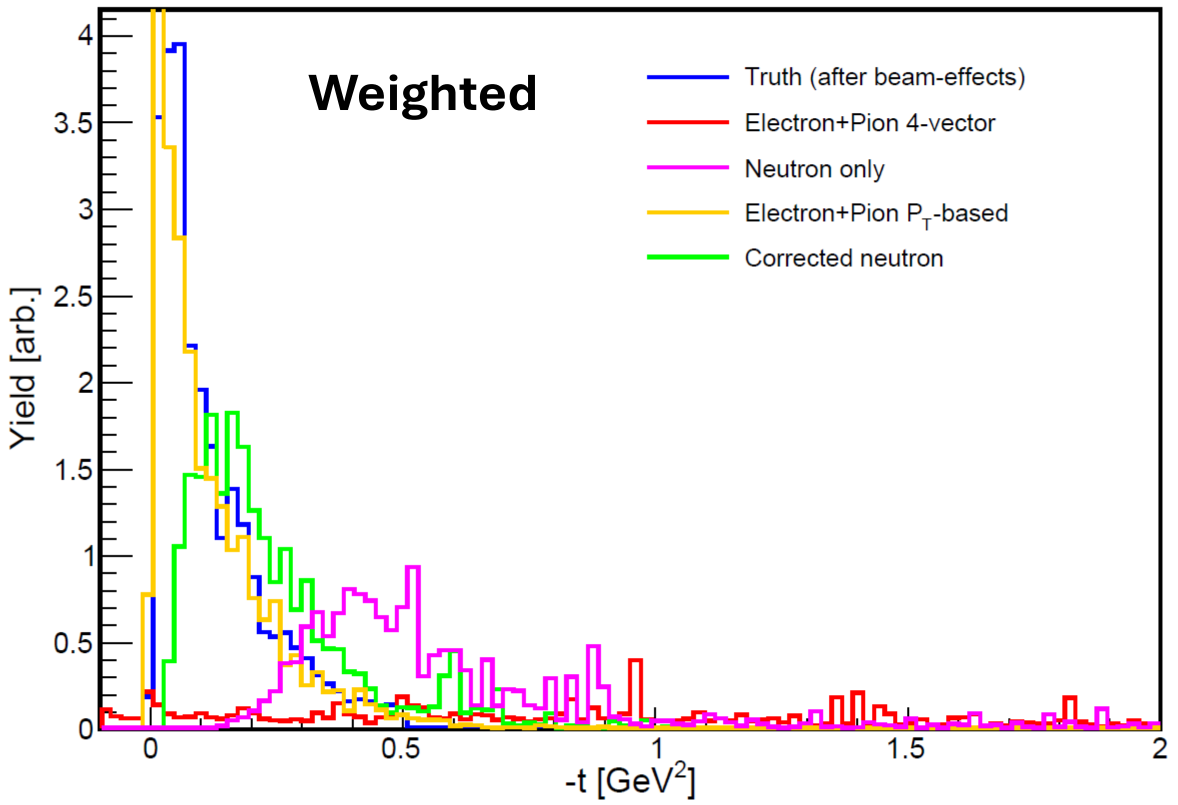


Electron and pion are reconstructed using the central detector tracker (i.e. ReconstructedChargedParticles)

The neutron is reconstructed in the ZDC using the HEXPLIT algorithm (https://arxiv.org/pdf/2308.06939.pdf) and Island clustering.

t reconstruction

5x100 GeV – 30k events simulated



Corrected neutron method from ECCE (here):

$$p_{miss} = p_e + p_p - p_{e'} - p_\pi$$

$$p_e = (0,0,-5,5) \text{ GeV/c}$$

$$p_p = 100 \times (\sin(\theta_{cross}), 0, \cos(\theta_{cross}), 1) \text{ GeV/c}$$

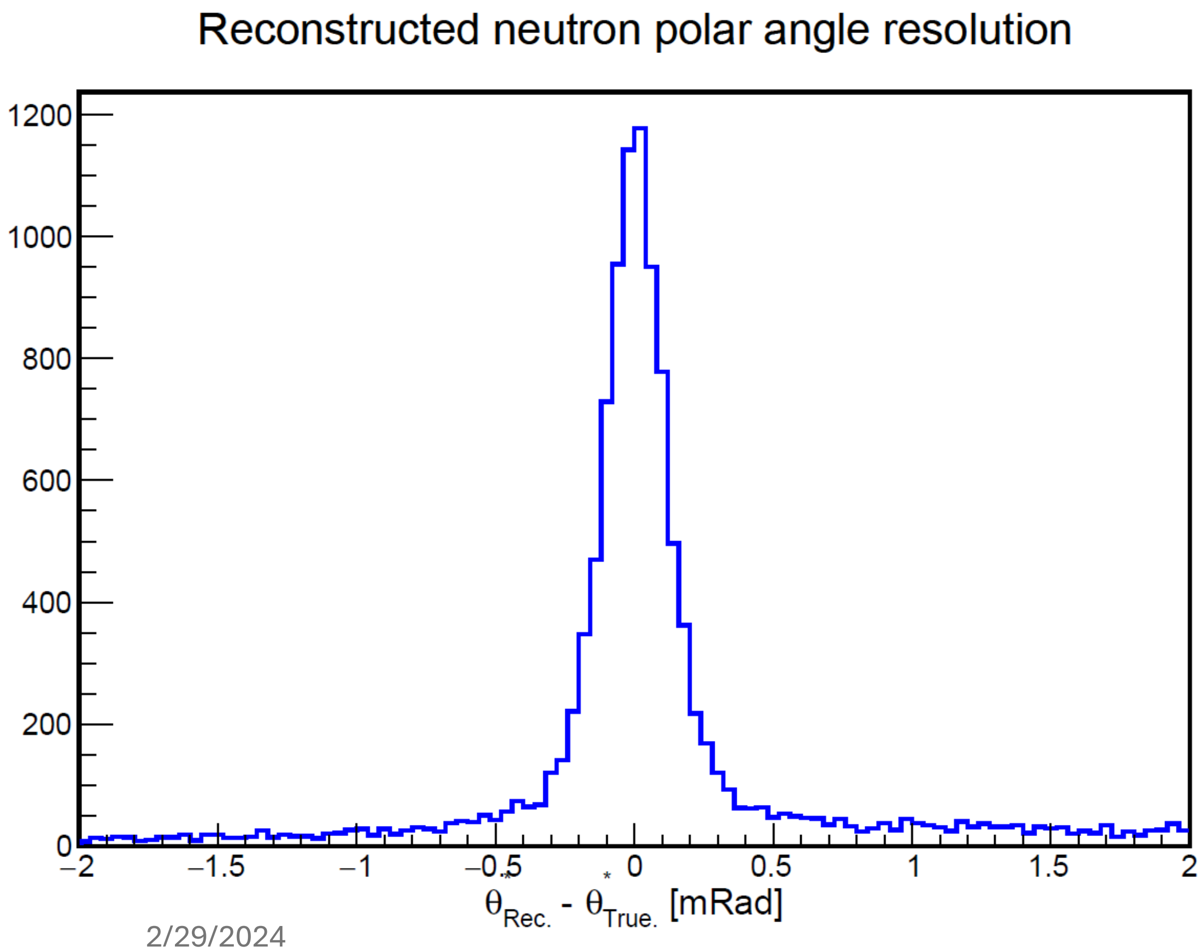
Replace the angles in p_{miss} by the reconstructed neutron angles and set the mass of the 4-momentum to the neutron mass → p_{neut}^{opt}

$$t = (p_p - p_{neut}^{opt})^2$$

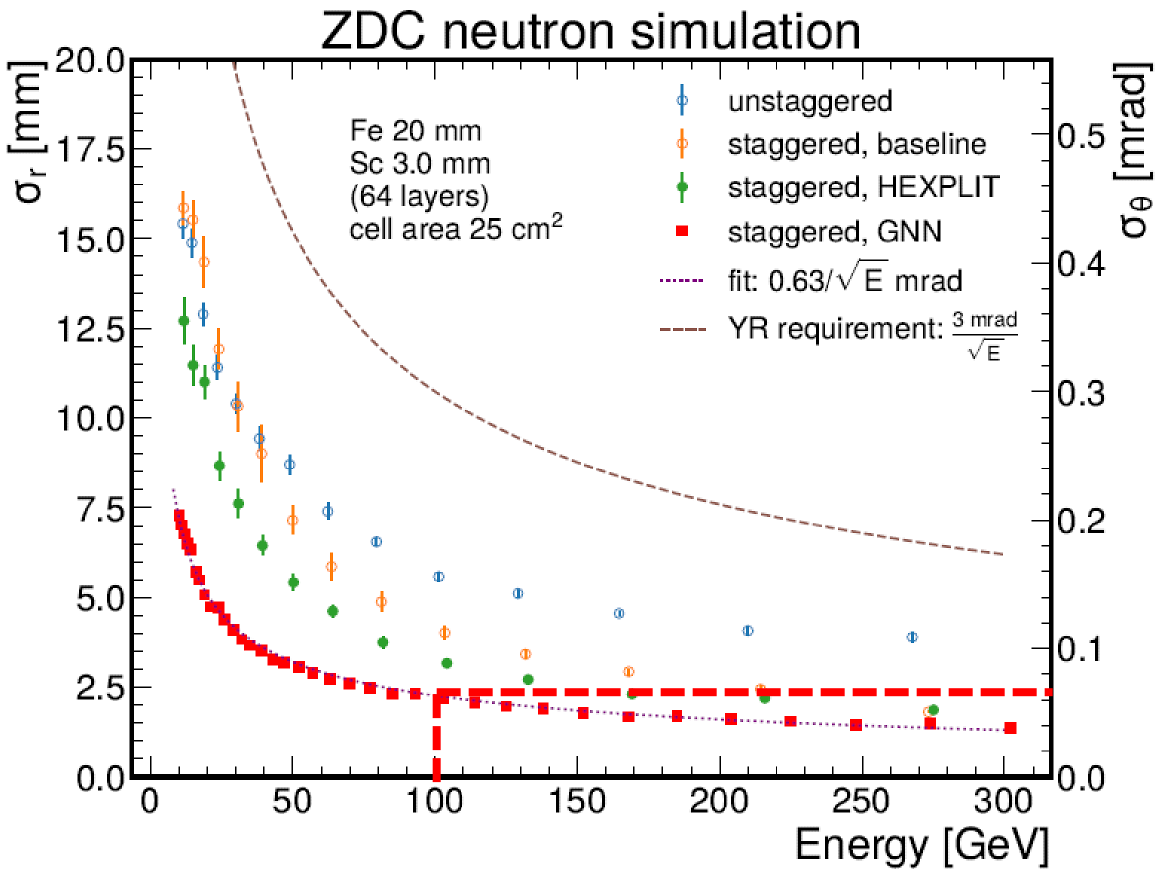
Some conceptual similarity to method L in On the Calculation of t in Diffractive VM production and DVCS

t reconstruction in this method depends on reconstructed neutron angles

From cluster reconstruction in ePIC full simulation for ~100 GeV neutrons.



From standalone simulation with GNN. (Assumes one particle.)



Summary / next steps

- We have performed some single-neutron and DEMP studies using the full ePIC simulation framework.
- Next steps for single-particle simulation:
  1. Repeat studies once updated far-forward beampipe (with exit window) is ready.
  2. Adjust ADC parameters as needed.
  3. Tune cluster algorithm and/or modify the one that is used. Look at cluster splitting and cluster angle reconstruction.
- Next steps for DEMP simulation
  1. Need updated DEMPgen files to be uploaded to S3, since these are the only files that can be used for the TDR plots (and physics benchmarks).
  2. Understand weighting normalization.