Backward Hadronic Calorimeter

Status and plans

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nHCal DSC-TC meeting 25.2.2025

THE OHIO STATE UNIVERSITY

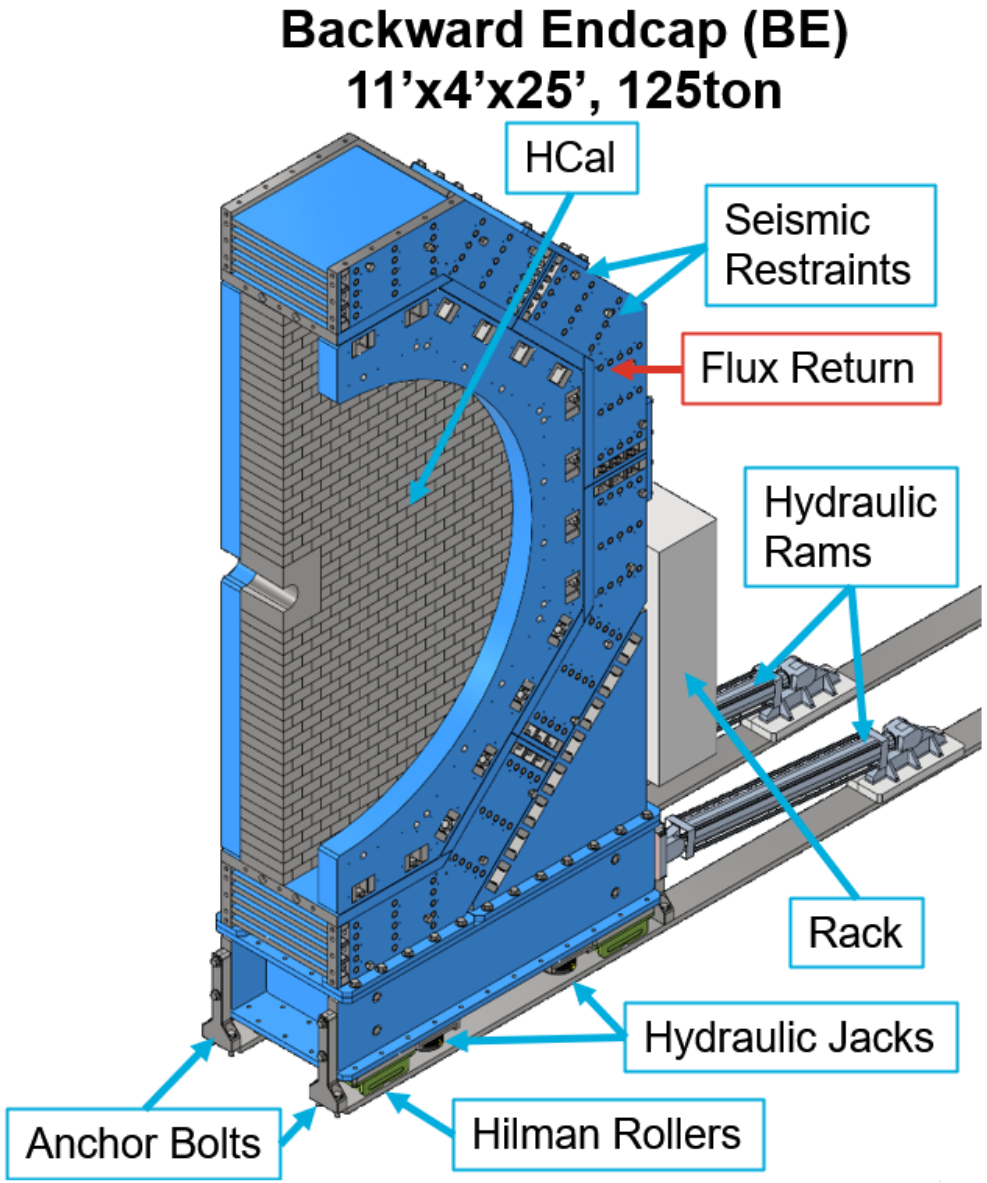
Outline

Status

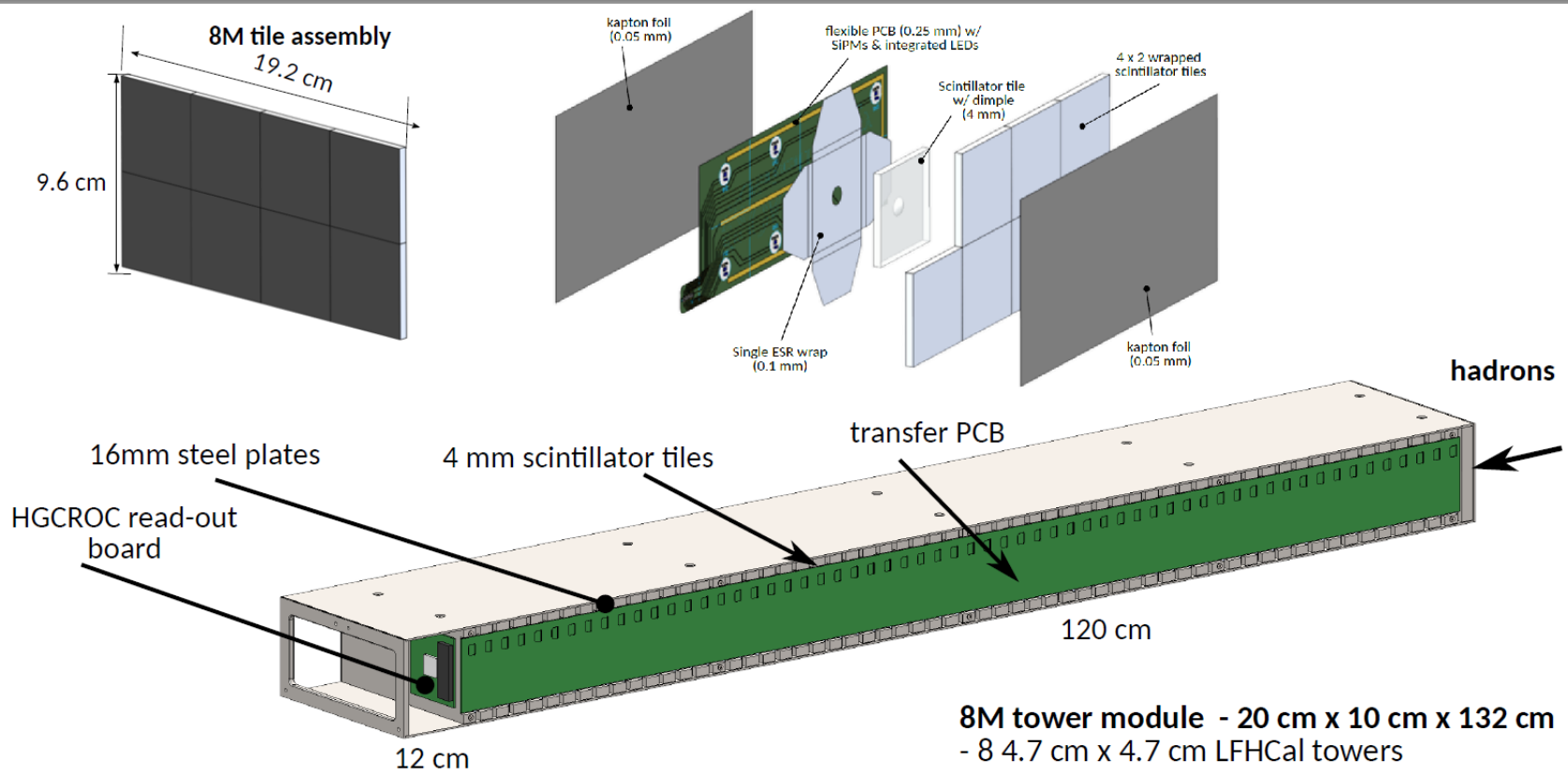
- Basic pre-TDR completed
  - **Zenodo v1:** `https://doi.org/10.5281/zenodo.14328280`
  - **Review of v1:** `https://docs.google.com/spreadsheets/d/1mineH2breuoVui-uZm1ZYSraRquLjM9oOY4w2ASdvtA/edit?usp=sharing`
  - **Repositories located here:** `https://github.com/orgs/OSUNuclearPhysics/repositories`
  - No review yet, only small text corrections
  - Would be good for experts to look at it

Baseline design

- Global design prepared by project enginneers
- Acceptance
  - Front geometry limit: $-4.03 < \eta < -1.18$
  - Back geometry limit: $-4.14 < \eta < -1.27$
  - Clusters: $-3.95 < \eta < -1.25$
  - MC particles showering in nHCal(with hits): $-4.16 < \eta < -1.16$

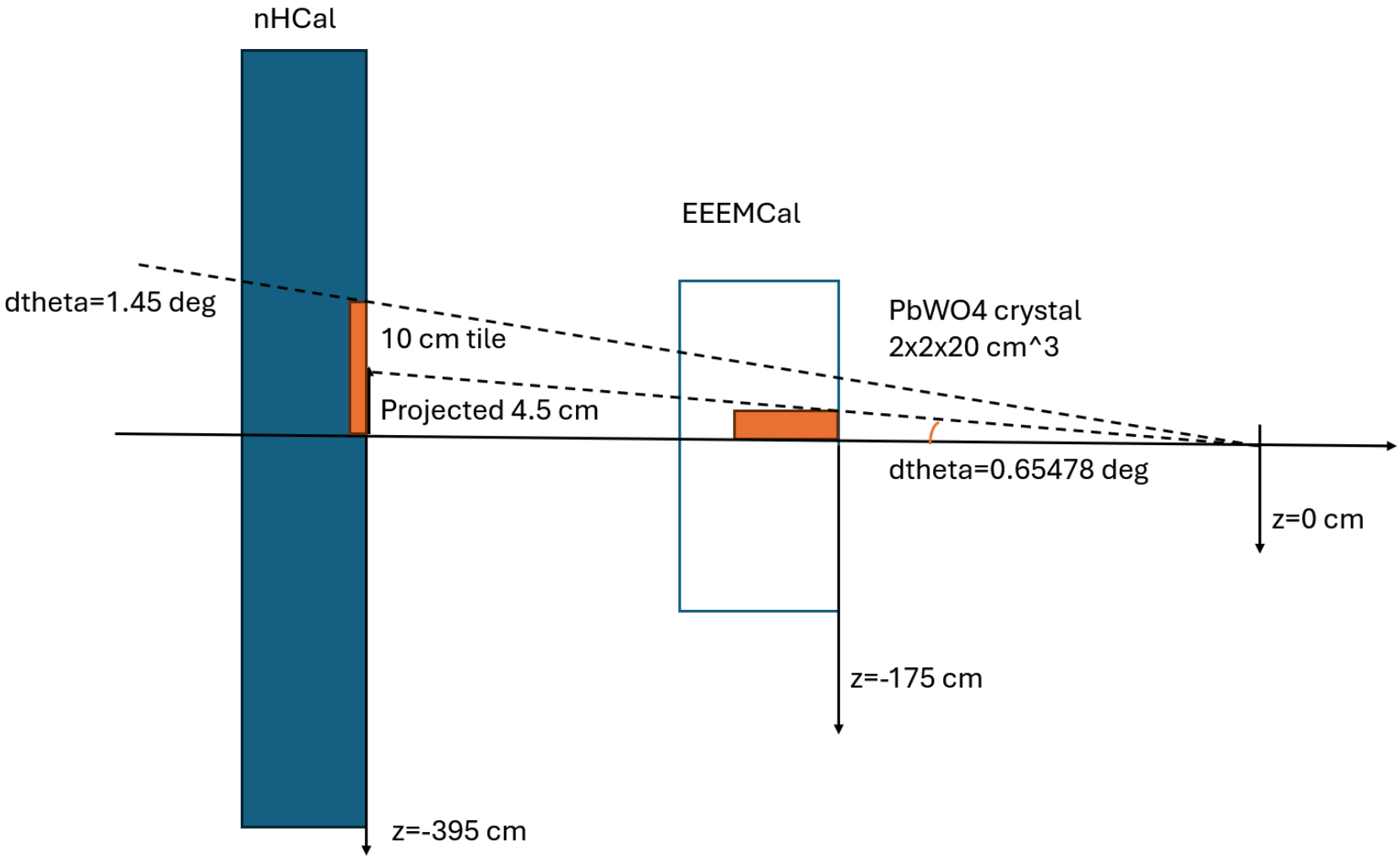


Geometry



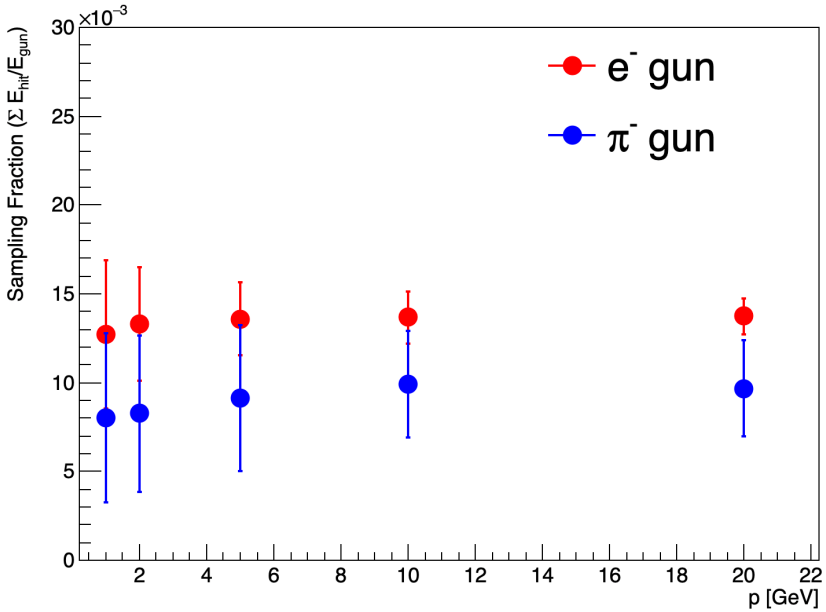
- 10 layers with total thickness 45 cm, $2.4\lambda_0$
  - 4 mm plastic scintillator
  - 4 cm steel absorber plates
- 10 $\mathrm{cm} \times 10\ \mathrm{cm}$ tiles now implemented, but can simply use
- 5 $\mathrm{cm} \times 5\ \mathrm{cm}$ for cost saving
- Similar to LFHCAL module designs: `https://indico.bnl.gov/event/25021/`
  - Direct: `https://indico.bnl.gov/event/25021/attachments/57749/99174/8M%20Tower%20Assem_Combined_Oct1.pdf`
- Produce our own module? Most likely. Alternatively, reuse and modify LFHCAL module.

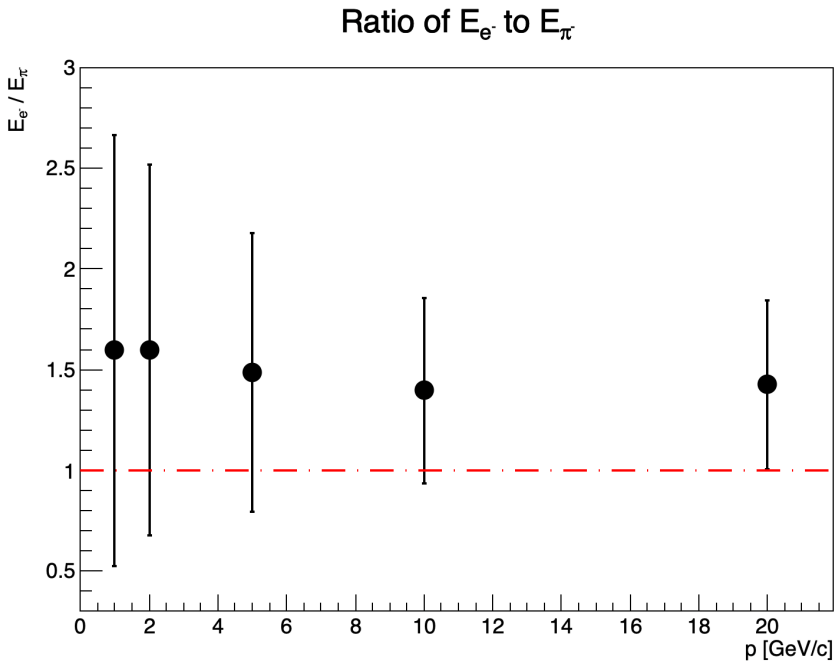
Integration with EMcal



- $5\,\mathrm{cm} \times 5\,\mathrm{cm}$ tiles are a lower limit
- Due to larger transverse size of hadronic showers, even $10\,\mathrm{cm} \times 10\,\mathrm{cm}$ tiles are good enough

Sampling fraction

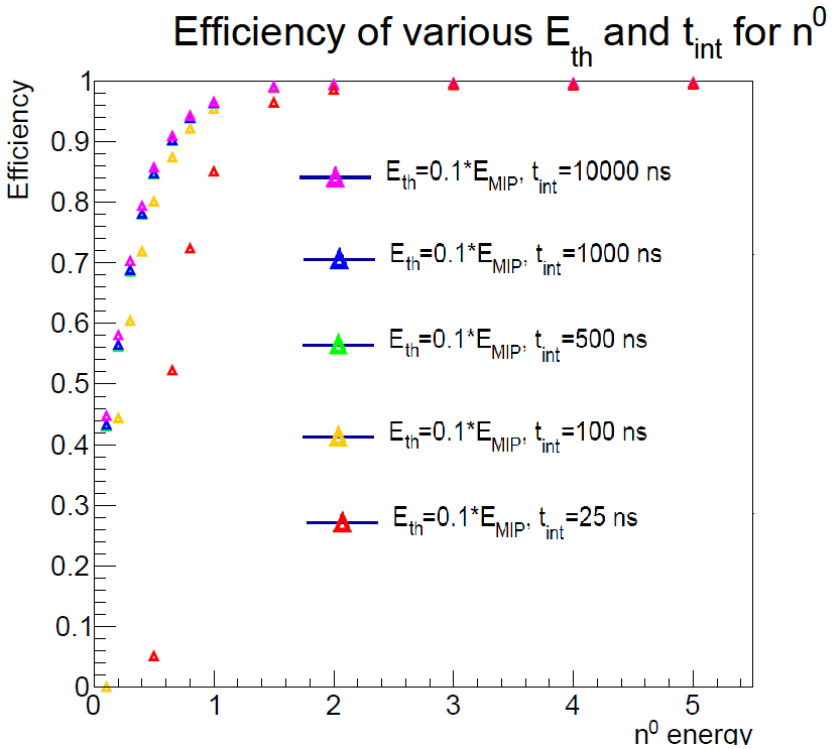




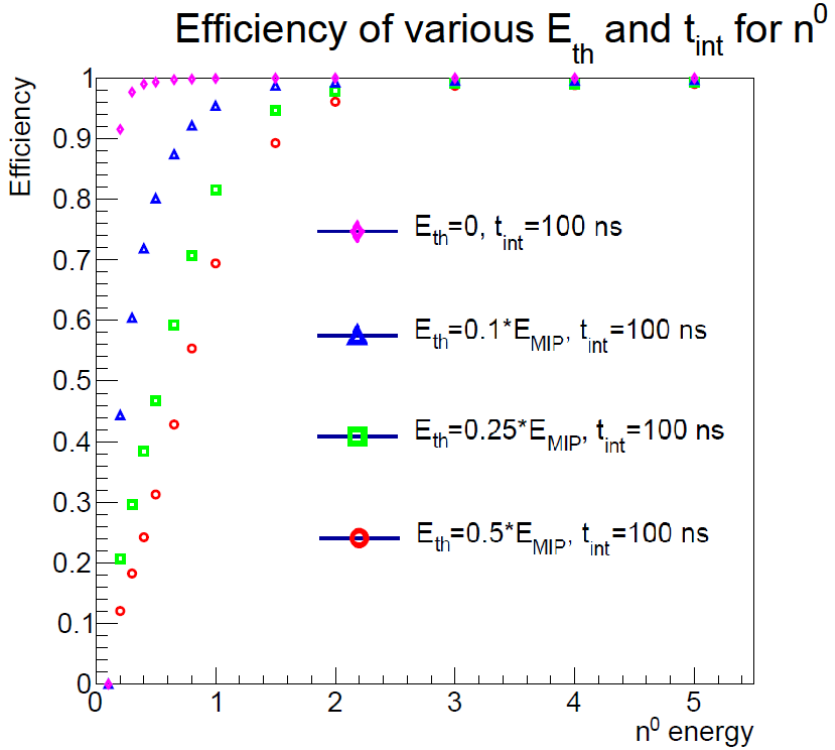
- Sampling fraction 0.95% for pions, but needs to be revisited
  - Used pion energy instead of energy deposits as a reference
- $e/h \approx 1$ ratio suggests compensation
- May need more frequent sampling to better measure low energy neutrons eg. below $E_k = 1\,\mathrm{GeV}$

Neutron detection efficiency

Integration time dependence



Threshold dependence

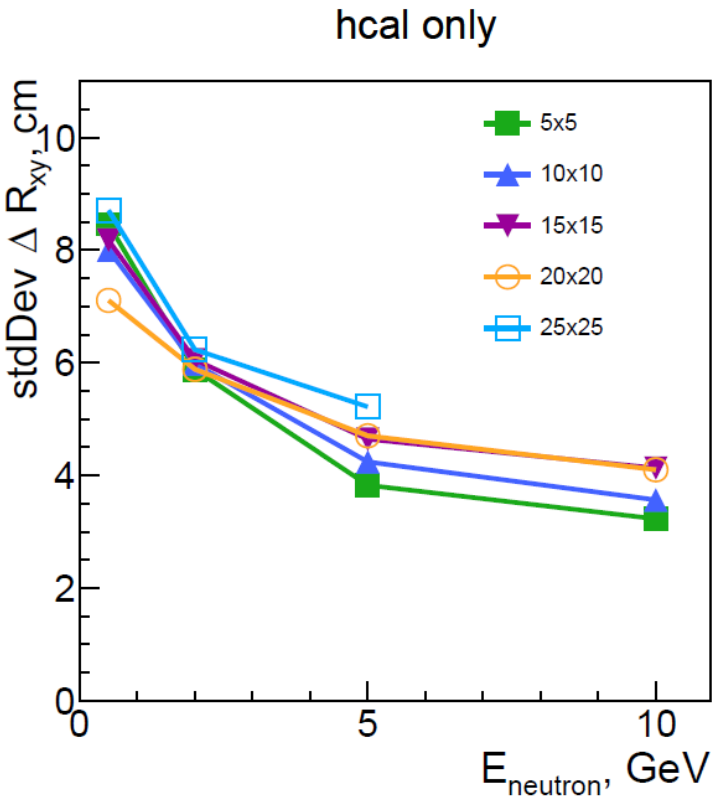


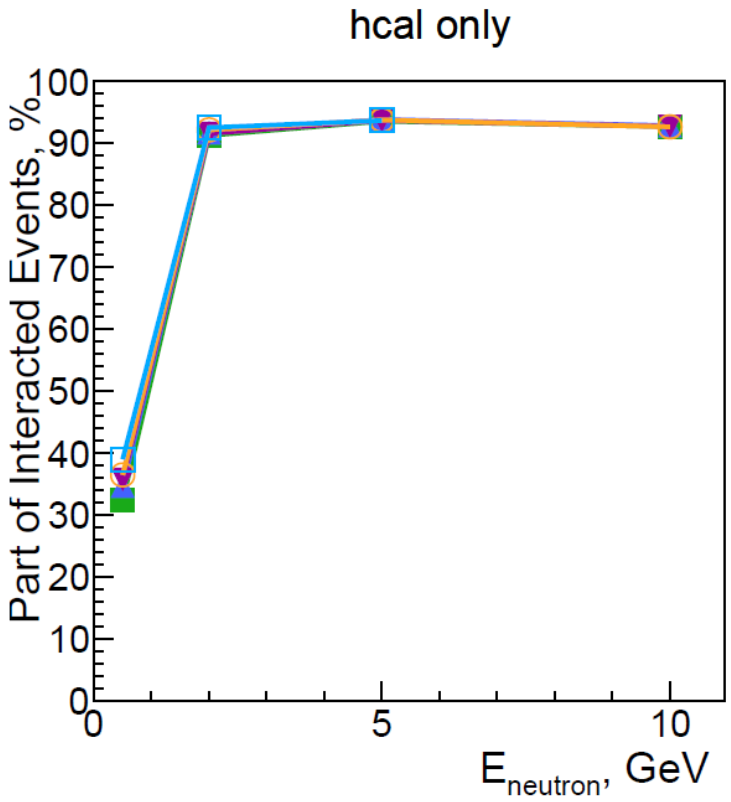
Sam Corey, OSU

- Efficiency of requiring a hit with a sum of hit contributions energy integrated up to t_{int} and passing a threshold E_{th}, $t_0 = 0$
- Checked with simulation only - no digitization
- E_{MIP} is 0.75 MeV per layer
- E_{th} has the biggest impact
- 100 ns is good enough, but lower energy neutrons may need longer times
- 60% efficiency for $E = 300\,\mathrm{MeV}$ neutrons $E_{th} = 0.1 \times E_{MIP} = 75\,\mathrm{keV}$ and 100 ns

Single particle position resolution study

Alexandr Prozorov, CTU

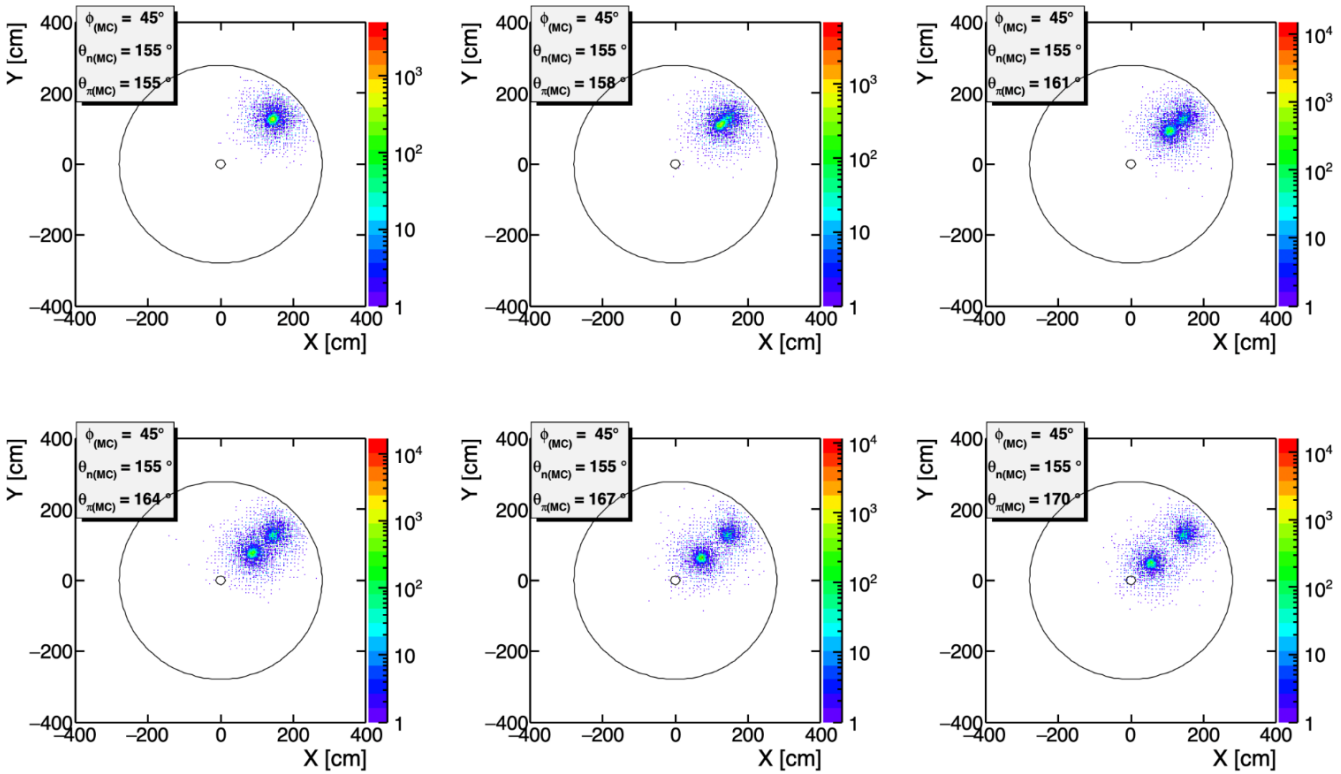




- Shoot single neutrons and compare ideal projections to RECO clusters
- Vary energy and tile size to obtain scaling
- Even large tiles up to 25 cm seem to be OK
- Need track projections and cluster matching in realistic DIS events - next steps

2-particle resolution study

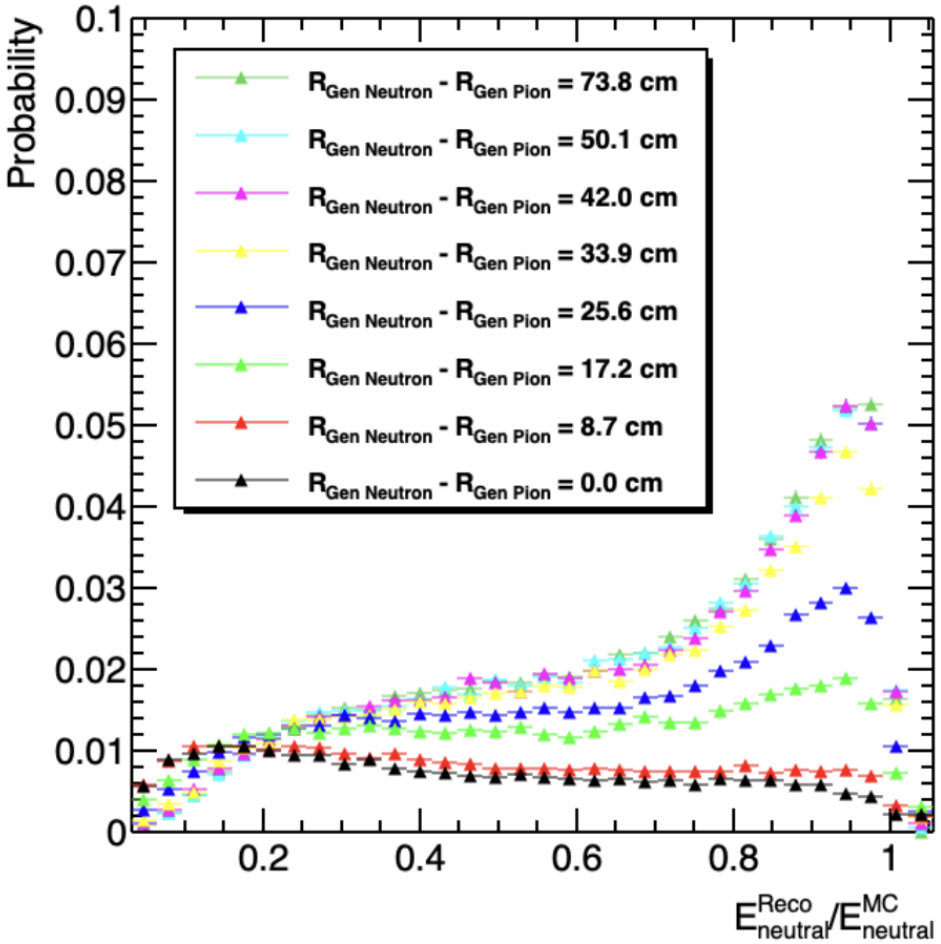
Subhadip, Pal



- Shoot single neutrons and pions at different distances
- Vary energy and tile size to obtain scaling
- Even large tiles up to 25 cm seem to be OK
- Need track projections and cluster matching in realistic DIS events - next steps
- **This is a workaround for a full study with track-cluster matching, ideally need support from Reconstruction Software group to get it working and tested**

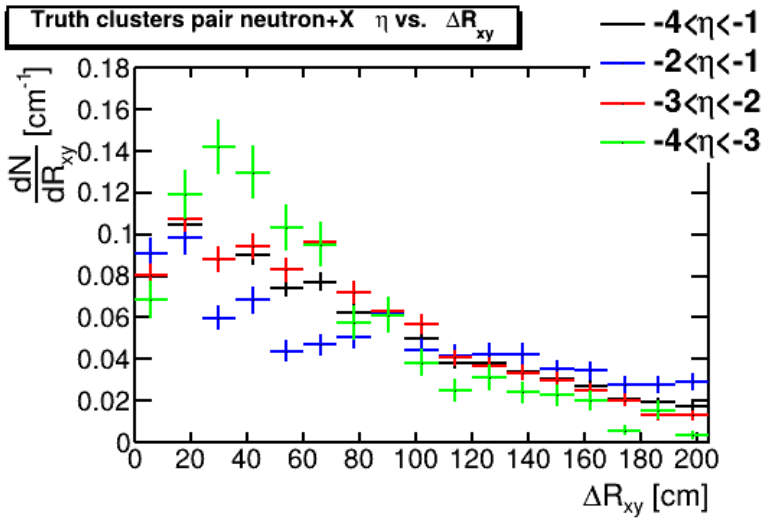
2-particle resolution study

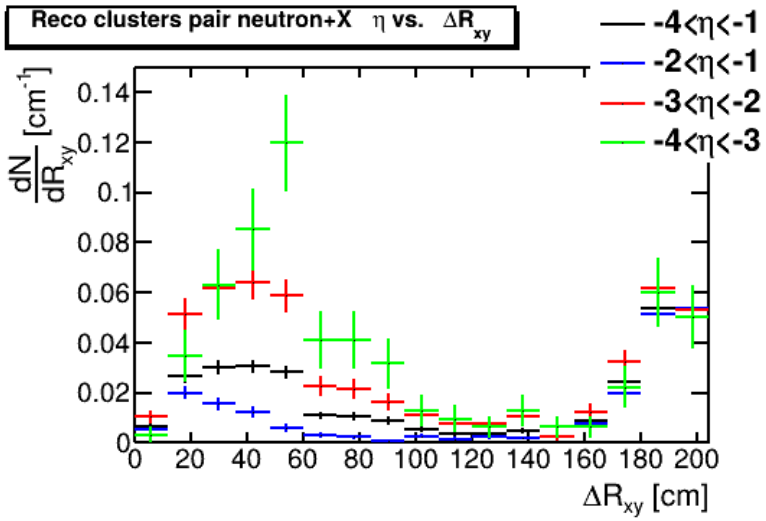
Subhadip, Pal



- Shoot neutrons and pions at different distances
- Merging appears to start at 33.9 cm
- Distance of 25.6 cm seem to be separable
- Need track projections and cluster matching in realistic DIS events - next steps

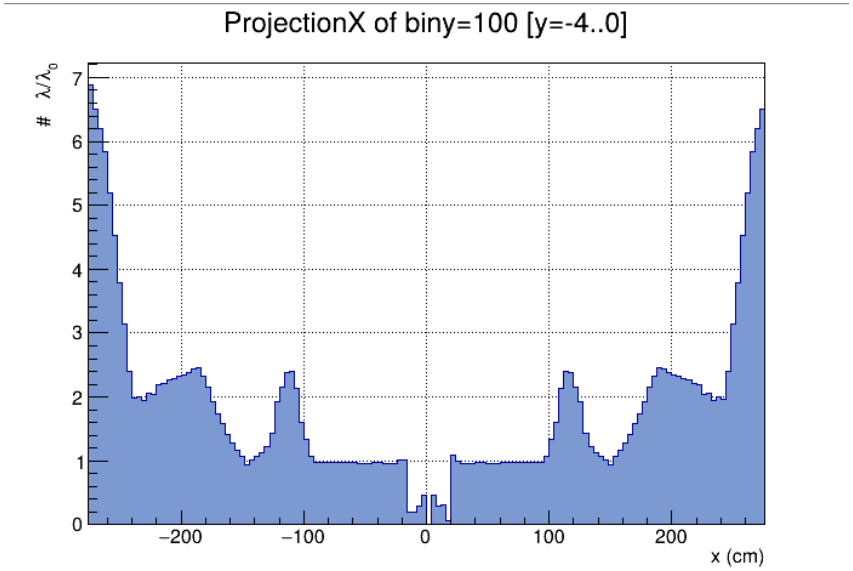
Cluster distances in diffractive dijet events

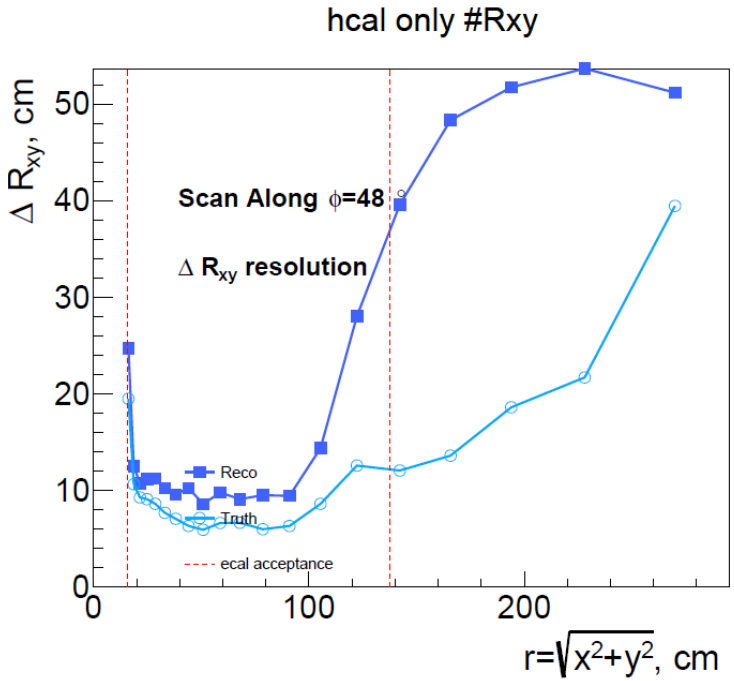




- Neutron cluster vs. charged cluster separation
- 22% of MC clusters are within 30 cm
- 5% within 30 cm of all reconstructed due to merging
- 0.7% of charged MC particles are within 30 cm from a neutron

High material impact on shower reco





full epic

- Investigate impact in more details
  - Basic distributions, hits etc. vs. radial distance
  - Check the true stop vertex of MCparticle
- Try to determine optimal clustering parameters
- If needed revisit position resolution study with full geometry

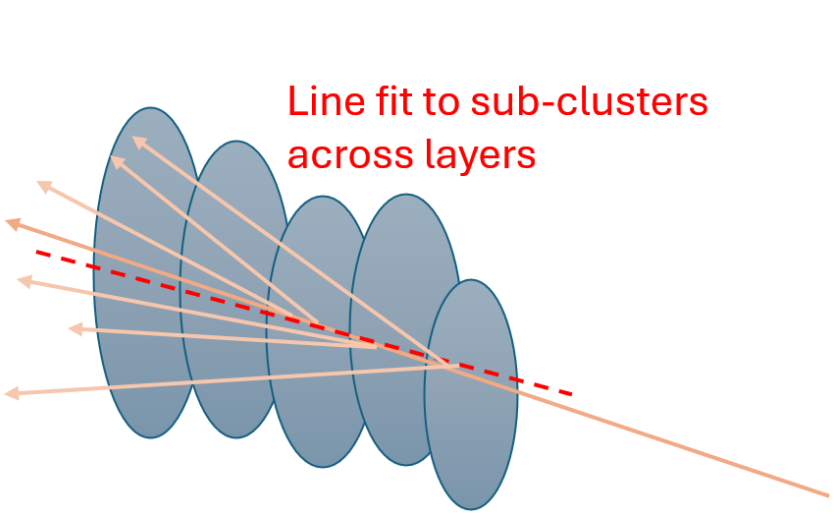
Summary

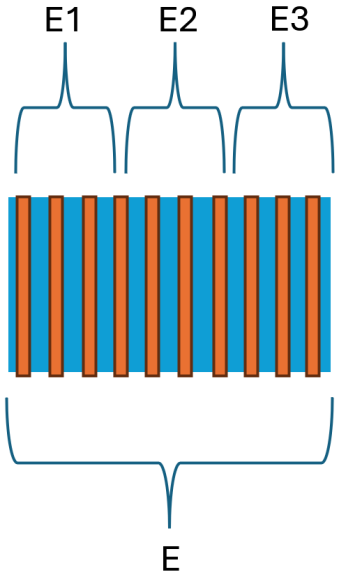
Conclusions

- Presented status
- Prepared a list of tasks in a separate document

BACKUP

Position resolution improvement





1. Check if using max energy deposit in the first layer improves position resolution
2. Do 3D clustering
   - Store subclusters for every layer
   - Code for BIC from Sylvester: `https://eicweb.phy.anl.gov/EIC/juggler/-/blob/main/JugReco/src/components/ImagingClusterReco.cpp`
   - Fit a line through the clusters across the layers (and compare to a reco track)
3. Independent vs. integrated readout from layers
   - Affects 3D clustering etc.
   - If removed, most likely no effect on energy resolution
   - Can reduce channels by up to factor of 10
   - Any suggestions about which quantity may decide that?

Shower reconstruction with machine learning

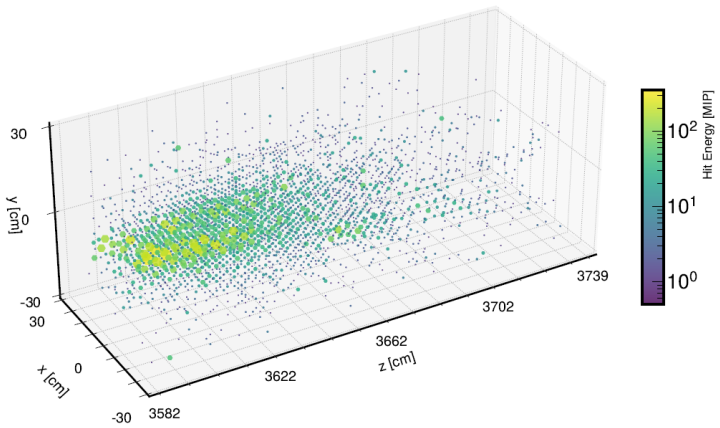
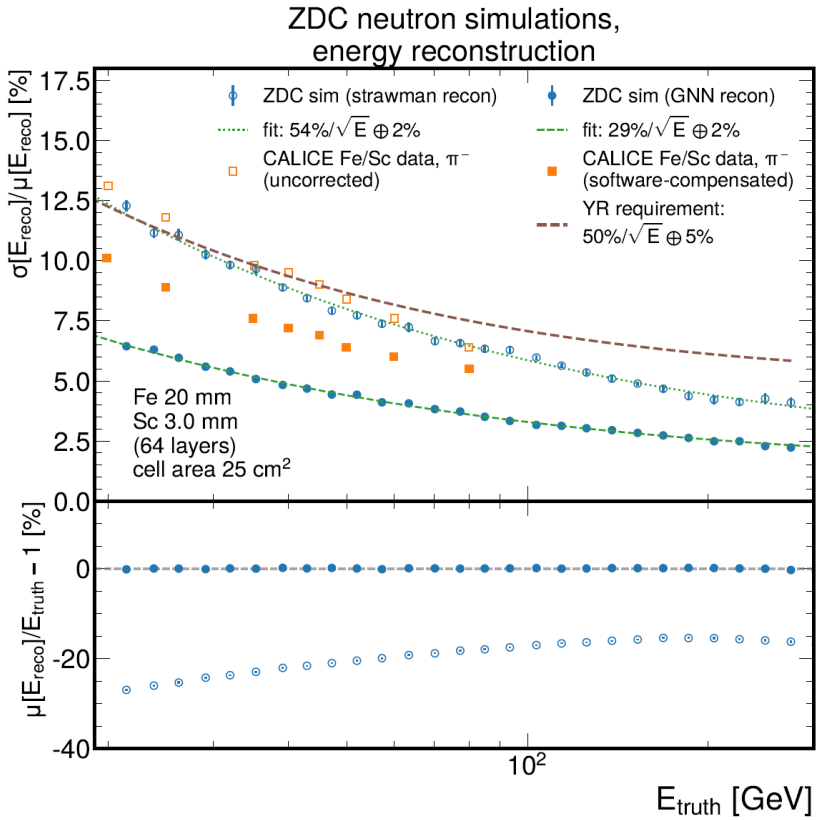
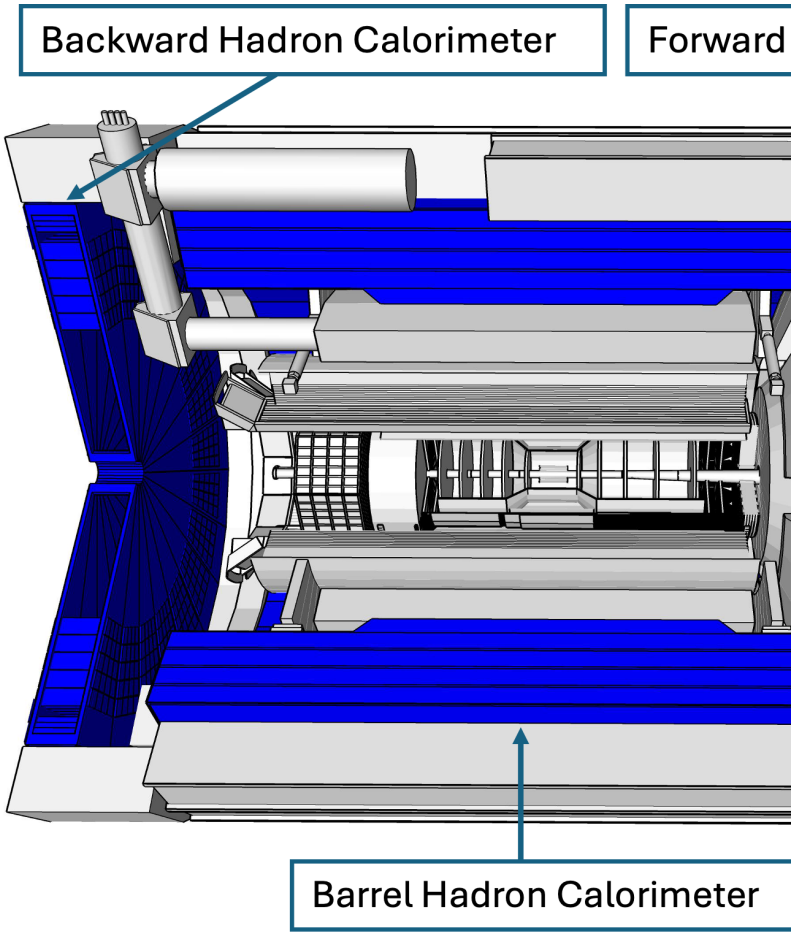


Figure 7: Examples of 4 reconstructed 3D shower shapes in the ZDC for events with 1 neutron ($N_n = 1$), 2 neutrons ($N_n = 2$), 4 neutrons ($N_n = 4$), and 9 neutrons ($N_n = 9$). The color code represents hit energy in terms of E_{MIP}. The marker size is displayed proportionally to hit energy for display purposes.



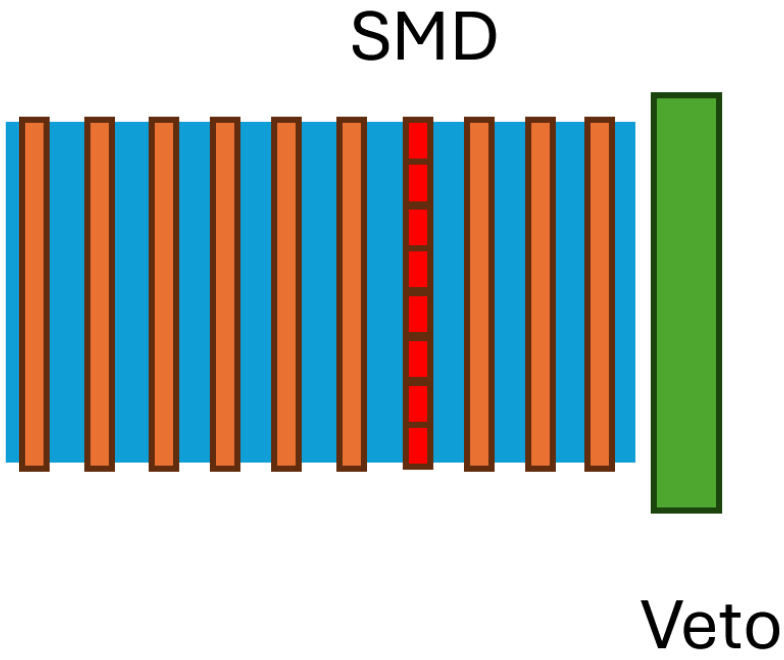
- Potential to use machine learning to improve shower reconstruction
- Studies done by LFHCAL Insert/ZDC group (UC Riverside)
  - Applied Graph Neural Networks (GNN): `https://arxiv.org/abs/2406.12877`
  - [Nucl.Instrum.Meth.A 1047 (2023) 167866]
- Revisit later

Detector thickness in z



1. Can we extend from 45 cm in z to eg. 70 cm?
   - Limited by oculus and room for electronics
   - Increases cost - estimate?
   - Improves energy resolution - quantify?
   - Other benefits?

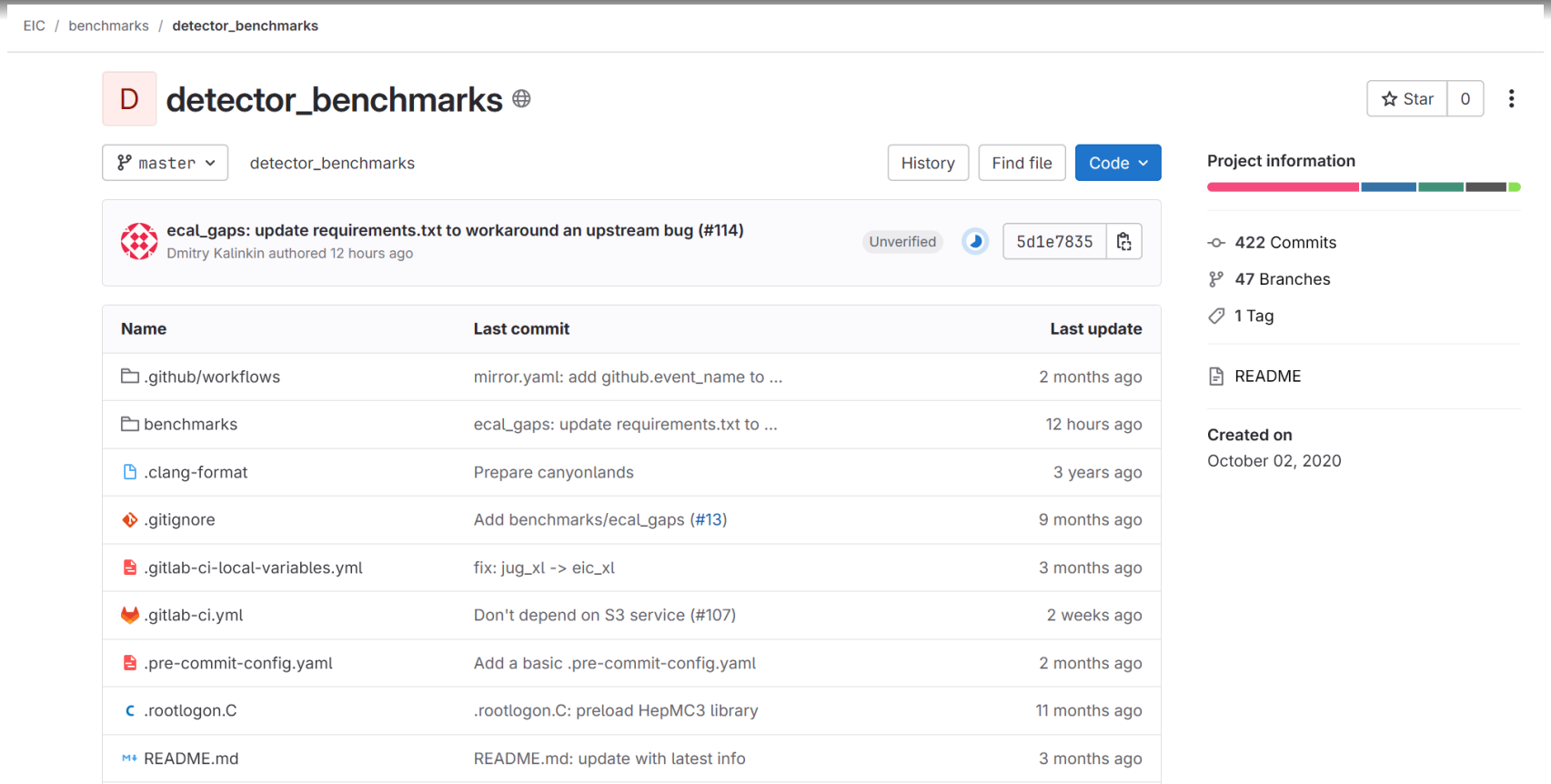
Additional charged veto and SMD layer



1. Investigate if adding extra scintillator layer as a charged veto helps isolate neutral showers
2. This extra layer needs to be thicker eg. $2\,\mathrm{cm}$ to leave enough signal
3. Can have better granularity than standard tiles

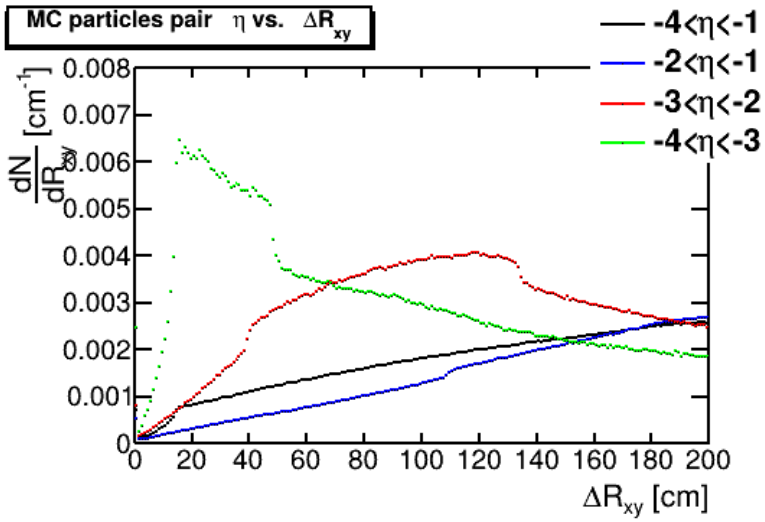
1. Revisit option of adding an SMD layer with high position resolution
2. Initially no plans to reuse STAR EEMC SMDs, because of too low light yield
   - `https://wiki.bnl.gov/athena/images/6/60/ATHENA_bnHCal_Notes_v1.pdf`
3. Similar idea to KLM
4. Another option to use smaller tiles

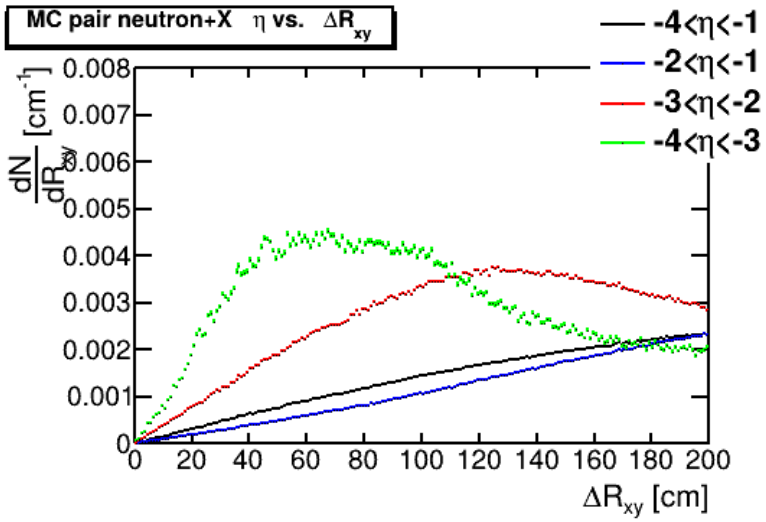
Benchmarks for CD/CI



- Develop benchamrks for CD/CI
- `https://eicweb.phy.anl.gov/EIC/benchmarks/detector_benchmarks`
- `https://indico.jlab.org/event/420/contributions/8307/attachments/6911/9434/20210504-Automated_workflows.pdf`
- Useful for automated checks: hit distributions, acceptance etc.
- Ideal task for bachelor and undergraduate students
- Submitted a thesis proposal at Warsaw University of Technology
  - May be piked up by a student around February-March 2025

MC particle projection distances in diffractive dijet events





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- 0.7% of charged MC particles are within 30 cm from a neutron