Backward Hadronic Calorimeter

Work plan and priorities

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The Ohio State University

nHCal DSC meeting 25.3.2025

Outline

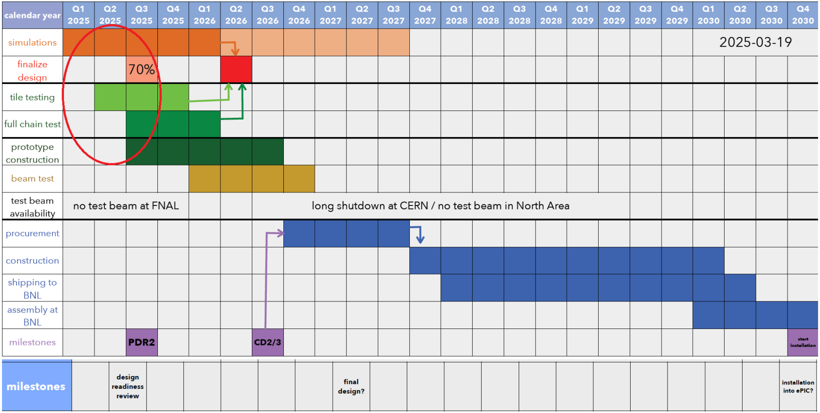
- Official name: **nHCal - Negative Hadronic Calorimeter**
- Started as part of Mobility Project at CTU in Prague - few months in BNL (initially for ATHENA)
- Leadership
  - L. Kosarzewski - Detector Subsystem Leader (DSL)
  - C. Riedl - Detector Subsystem Technical Leader (DSTC)
- Original idea by:
  - Oleg Tsai: `https://wiki.bnl.gov/athena/images/6/60/ATHENA_bnHCal_Notes_v1.pdf`
  - Brian Page, Xiaoxuan Chu, Elke Aschenauer: [Phys. Rev. D 101, 072003 (2020)]
- Cost estimates: 6.5 $\mathrm{M\$}$ (EIC project+in kind contributions)
- Small but growing DSC: OSU, CTU in Prague, UIUC, help from BNL

Main webpage

`https://wiki.bnl.gov/EPIC/index.php?title=Backward_Hcal`

Weekly meetings page (many updates!)

`https://indico.bnl.gov/category/549/`



Plan for Q1-Q2 2025 and part of Q3 2025 before preliminary design review in autumn

Work plan priorities

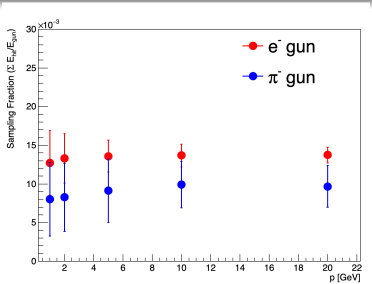
Plan for Q1-Q2 2025 and part of Q3 2025 before preliminary design review in autumn

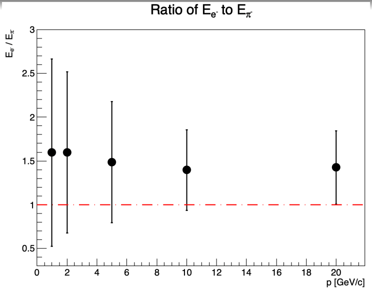
Order	Task	Priority	Progress
1	Determine detector geometry: tile, absorber and overall thickness	high	started
2	Tile tests in different configurations: SiPM on tile, WLS fibers etc.	medium	waiting for tiles
3	Finalize jet/diffractive dijet reconstruction study to optimize the tiles	high	in progress
4	Study of muon track identification with nHCal	medium	in progress
5	Study of K_{L} identification with nHCal	low	started
6	Re-check position resolution study with full ePIC geometry	medium	
7	Investigate shower reconstruction in high material region	medium	
8	Prototype construction - on hold until geometry fixed	medium	
9	Prepare for beam tests	medium	

Work plan link

https://docs.google.com/document/d/1SSqGlWChuWoEM8sNb0CyXTGGEHa-pAdBQc0MXvHJgLw/edit?usp=sharing

1. Geometry optimization: Sampling fraction





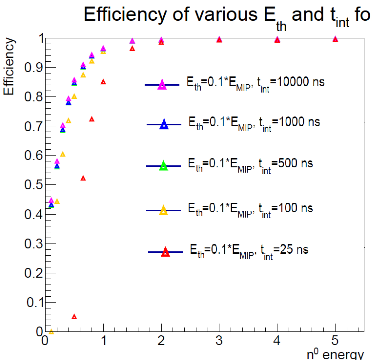
- Check a few different configurations and optimize:
  - e/h response
  - energy resolution
  - neutron detection efficiency
- Baseline: tile thickness 4 mm, steel absorber 4 cm, total 45 cm
- Switch from stainless steel to steel in epic repository (minor effect)
- Sampling fraction 0.95% for pions, 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 $E_k = 1\,\mathrm{GeV}$

More detailed instructions:

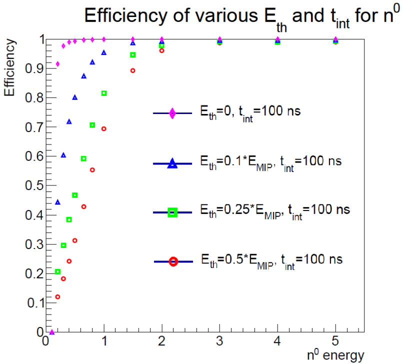
https://docs.google.com/document/d/1p9QSd1E2REgA7cfunoBBrwUadJ3kUskcXm0GAKWCxcE/edit?usp=sharing

Neutron detection efficiency check

Integration time dependence

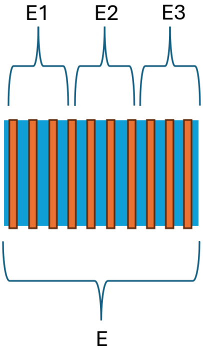


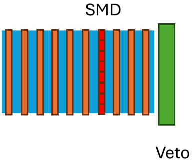
Threshold dependence



Sam Corey, OSU

- Revisit for different configurations during sampling fraction study to optimize geometry
- 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 $0.75\,\mathrm{MeV}$ per layer
- E_{th} has the biggest impact
- $100\,\mathrm{ns}$ 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 $100\,\mathrm{ns}$
  - 70% for $E = 1\,\mathrm{GeV}$ neutrons





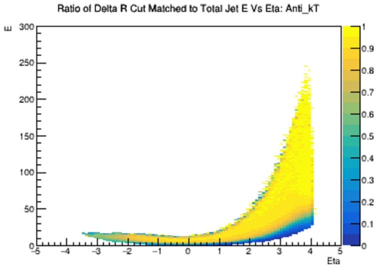
- Independent vs. integrated readout from layers
  - Affects 3D clustering etc. (loss of information)
  - If removed, most likely no effect on energy resolution
  - Can reduce channels by up to factor of 10
  - Using 3 segments gives each segment $\approx \lambda_0$ (similar to LFHCAL)
  - May be harder to detect low energy neutrons with integrated readout due to higher threshold
- Investigate if adding extra scintillator layer as a charged veto helps isolate neutral showers
  - This extra layer needs to be thicker eg. 2 cm to leave enough signal
  - Can have better granularity than standard tiles

Geometry versions to investigate

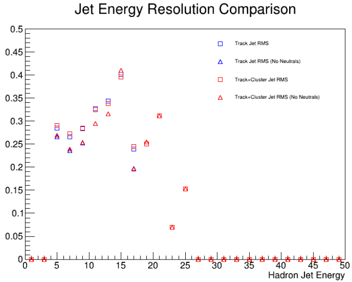
1. Tile and absorber thickness
   1. $4\,\mathrm{cm}$ steel, $4\,\mathrm{mm}$ scintillator, 10 layers $45\,\mathrm{cm}$ total
   2. $4\,\mathrm{cm}$ steel, $3\,\mathrm{mm}$ scintillator, 10 layers $44\,\mathrm{cm}$ total
   3. $3\,\mathrm{cm}$ steel, $4\,\mathrm{mm}$ scintillator, 13 layers $45.2\,\mathrm{cm}$ total + air gaps
   4. can check more in principle
2. Detector length
   1. $4\,\mathrm{cm}$ steel, $4\,\mathrm{mm}$ scintillator, 10 layers $45\,\mathrm{cm}$ total
   2. $4\,\mathrm{cm}$ steel, $4\,\mathrm{mm}$ scintillator, 12 layers $54\,\mathrm{cm}$ total + air gaps
   3. $4\,\mathrm{cm}$ steel, $4\,\mathrm{mm}$ scintillator, 15 layers $67.5\,\mathrm{cm}$ total + air gaps
3. Use parameters below to optimize geometry:
   - e/h response
   - energy resolution
   - neutron detection efficiency

3. Jet and diffractive dijet study

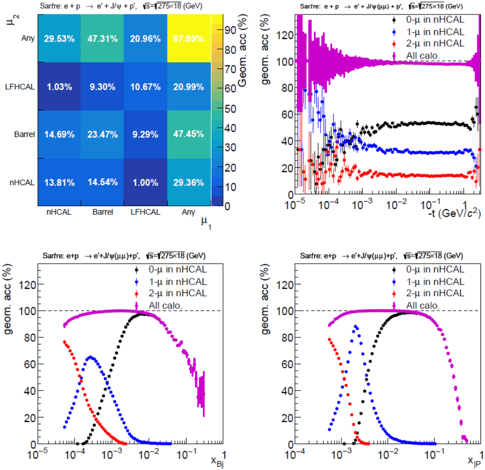
Reconstruction performance



Energy resolution

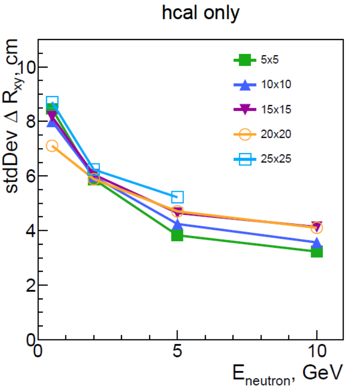


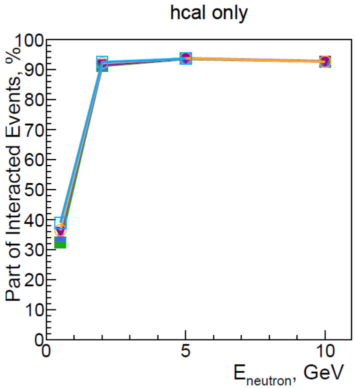
- Optimize tiles for neutron identification vs. charged hadron identification
    - Preliminary studies show that 10 cm x 10 cm tiles are good enough - based on cluster/MC particle distances
- Use realistic track/cluster matching (coming soon from reco software group)
    - In the meantime look at MC truth clusters
    - Calculate jet energy resolution for 2 samples (including neutrals and excluding neutrals)
- This is my focus in coordination with Brian
- Diffractive dijet cross section $\sigma \approx 10^{-4}\,\mathrm{mb}$ from PYTHIA simulation with $\hat{p_T} > 4\,\mathrm{GeV/c}$ and $Q^2 < 1\,(\mathrm{GeV/c})^2$
- With integrated luminosity per year of $10 - 100\,\mathrm{fb}^{-1}$ this gives 10^7 jets/year



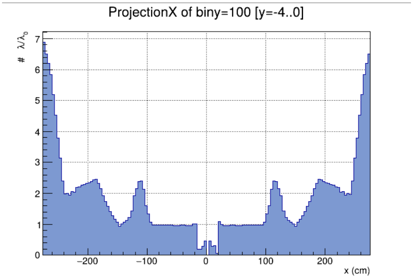
- Study of VM meson reconstruction complete: https://doi.org/10.5281/zenodo.14200156
- Need to optimize tiles for the muon detection
- Study muon identification efficiency and purity
- Similar study for decays containing K_L (part of it started)

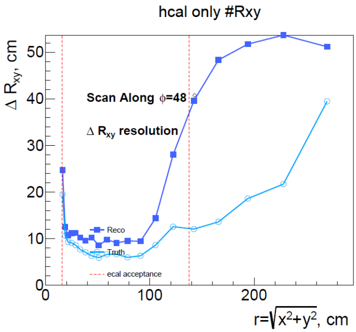
Alexandr Prozorov, CTU





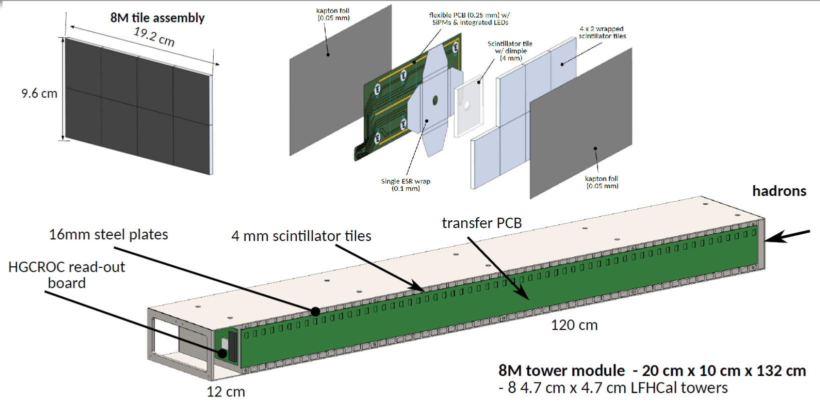
- Use full ePIC geometry
- Shoot single neutrons and compare ideal projections to RECO clusters
- Vary energy and tile size to obtain scaling
- Even large tiles up to 25 cm seem to be OK
- Need track projections and cluster matching in realistic DIS events - next steps





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
- Revisit position resolution study with full geometry - previous one may be affected by the clustering bug: `https://github.com/eic/EICrecon/pull/1598`



- 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`
- Different module length and structure for nHCal
  - However, size in x, y is the same: $20\ \mathrm{cm} \times 10\ \mathrm{cm}$
- Modules need to be produced with electron beam welding in a vacuum.

More details in the link:

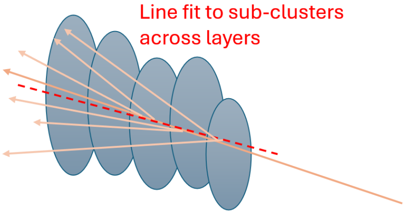
`https://docs.google.com/spreadsheets/d/1Ow8v9TIoMQJZNTNtyoKcaHm0iRpucCt0eg8JCz44JwM/edit?usp=sharing`

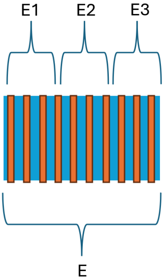
Summary

- Presented most important tasks
- Clear path forward for completing the design
- Coordinate within DSC to implement this

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

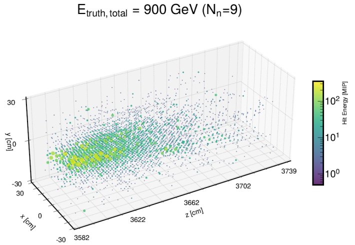
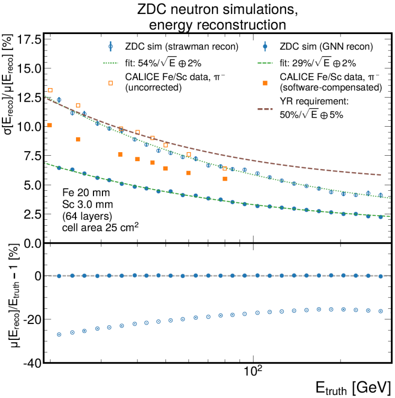
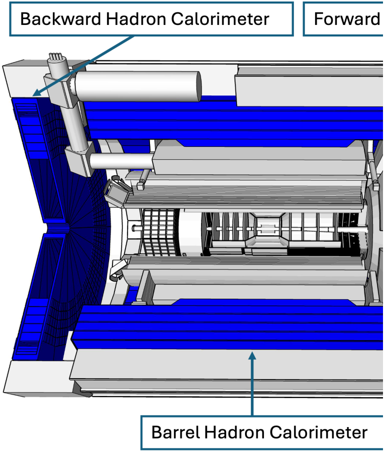


Figure 7: Examples of 4 reconstructed 3D shower shapes in the ZDC for events with 1 neutron (N_n = 1), 2 neutrons (N_n = 2), 4 neutrons (N_n = 4), and 9 neutrons (N_n = 9). The color code represents hit energy in terms of E_{MIP}. The marker size is displayed proportionally to hit energy for display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



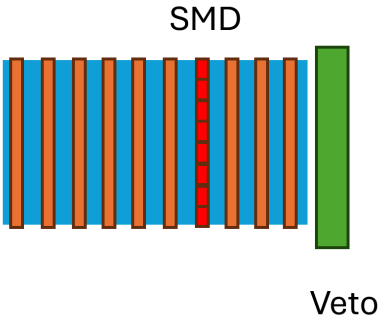
- Potential to use machine learning to improve shower reconstruction
- Studies done by LFHCAL Insert/ZDC group (UC Riverside)
  - Applied Graph Neural Networks (GNN): `https://arxiv.org/abs/2406.12877`
  - [Nucl.Instrum.Meth.A 1047 (2023) 167866]
- Revisit later

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?

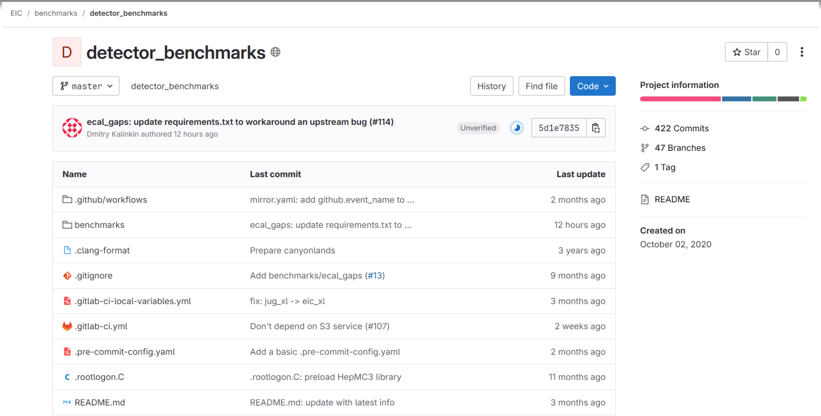
Additional charged veto and SMD layer



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 cm to leave enough signal
3. Can have better granularity than standard tiles

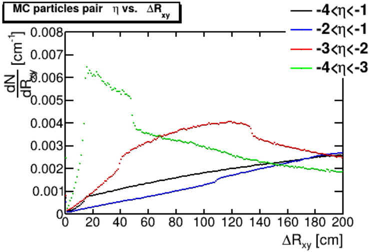
1. Revisit option of adding an SMD layer with high position resolution
2. Initially no plans to reuse STAR EEMC SMDs, because of too low light yield
   - `https://wiki.bnl.gov/athena/images/6/60/ATHENA_bnHCal_Notes_v1.pdf`
3. Similar idea to KLM
4. Another option to use smaller tiles

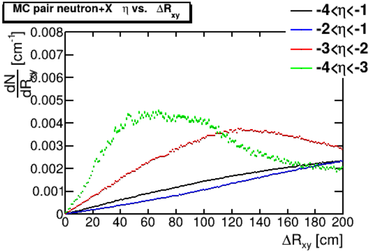
Benchmarks for CD/CI



- 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





- Neutron MC particle vs. charged MC particle separation
- 0.7% of charged MC particles are within 30 cm from a neutron