10th EIC DAC Meeting

nHCal

(backward hadronic calorimeter)

Draft shown at nHCal meeting May 20, 2024

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for the ePIC nHCal group
June 13, 2025

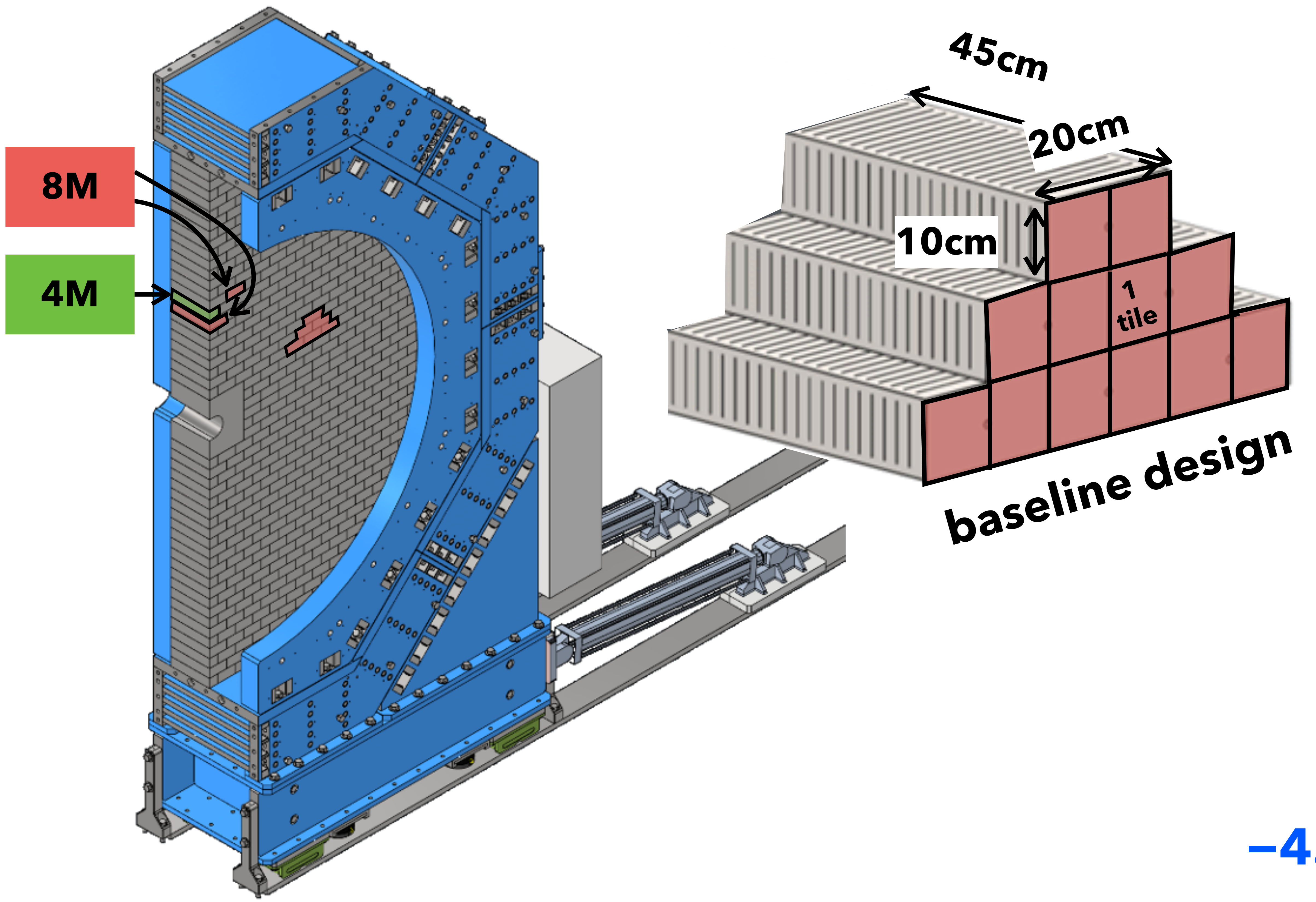
ILLINOIS
The Ohio State University
NSF

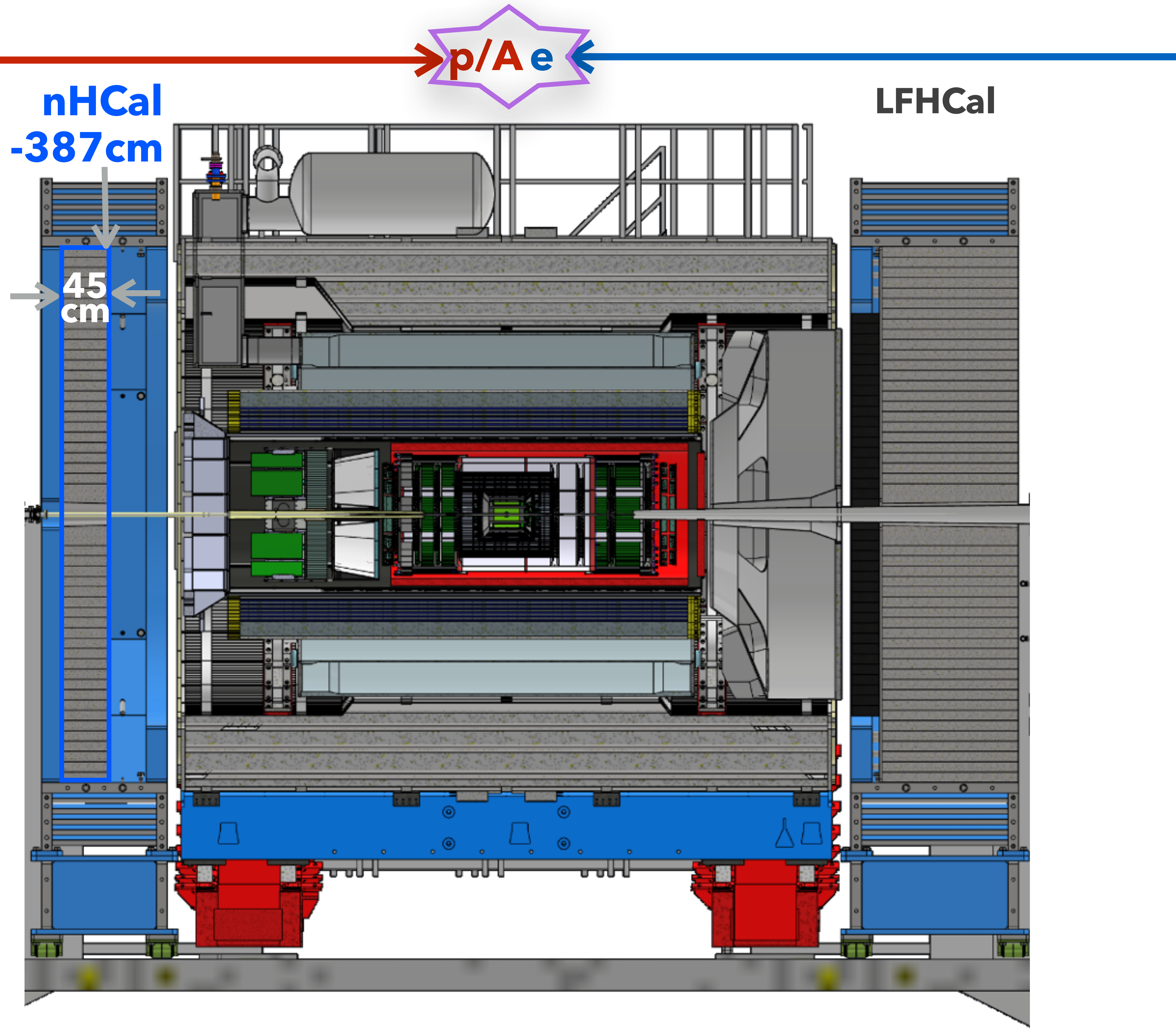
Detector Advisory Committee (DAC) meeting June 11-13, 2025

- https://indico.bnl.gov/event/26584/. Charge attached to top of indico
- Slides preparation - use as baseline slides from "Mini Review" March 25
  - https://indico.bnl.gov/event/27365/ .
- Will need all the latest results and plots from the group members.
- **Focus on work planning plus possible outline of schedule.** The talk will be 20 minutes with questions - the split between "talking" / "questions" can be as high as 50% / 50%. Have about 12 slides
  - May 13-19 - collect content from group (by email)
  - May 20 - draft slides version 1 in nHCal meeting
  - May 27 - draft slides version 2 in nHCal meeting
  - **May** 27-**28**: page-turn / rehearsal for DAC review. "Fully completed talks with the message what the status of the design clearly articulated."
  - Friday May 30 - my target to complete slides
  - ~June 4 - final slides uploaded (the week of the calo workshop at ORNL)
  - Friday **June 13** - nHCal talk at DAC

DAC draft slides

- Sampling calorimeter with alternating Fe / SciTiles layers
- Similar to LFHCal design
- Interaction length: 2.4 (LFHCal: 6)





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nHCal project design - purposes and requirements

nHCal crucial for core aspects of EIC physics mission		
Low x and Q^2, high y		Coverage in backwards direction
diffraction	vector mesons	Good μ/π separation via MIP signal
diffraction	dijets	High efficiency for low-energy neutron detection
Neutral jets / neutral veto		High efficiency for low-energy neutron detection
Charged jets		Good spatial resolution to distinguish clusters (neutral vs. charged)
Scattered **electron ID** (h veto)		Good spatial resolution to distinguish clusters (neutral vs. charged)
Improved hermiticity (improved kinematic resolution in CC)		Good timing resolution

nHCal design optimization

- (A) Is the design of the ePIC detector and its sub-systems appropriate and progressing well?
  - Focus on this aspect. Have 1 slide with example of how the physics goals inform the design
- Design optimization with variations from baseline
- Dedicated simulations with varying tile configurations
  - Studied geometries and purposes: include tables XXX
  - "Single particle" simulations, then full simulations with background
- Performance evaluation in the lab
  - Different tile configurations and sizes

Tables as they are currently in spread sheets

Design parameter	Physics Impact	Options	Goal	Status	Notes
Tile size	Spatial resolution	10x10, 5x5, 10x20			Light-tightness of 10x10 compared to smaller? Paint adds thickness – tolerance? X&Y resolution
Gross length	Energy resolution / scale, efficiency	30 cm 45 cm now Maximum: 70 cm	Maximize sampling fraction etc. Heat impact ~ 1.6 – 2.4 kW (for full length=70cm with 10x10 all read out independently with ~15 layers)	Max length = 70cm + 5 (cables, electronics etc.)	Add more layers and/or make the layers thicker (see ratio row)
Tile configuration	Energy resolution, dead material = efficiency	SiPM on tile, WSF, wavebars, SiPM on corner or side	Maximize light collection, manufacture complexity	Next: 2x2 geom	STAR FWD HCAL uses 10x10 with light bars Uniformity – can we test/quantify in simulation? Cluster size ~ 3x3 tiles(18 cm int length ~= 18 cm radius ~ 80% of shower energy)? Dead space for WSF or lightbars?
Z-layer readout	separation of muons vs. pions / Shower shape for E-resolution / low energy neutrons	None ~ 3 (1 per interaction length)	Determine needed channel count in Z or sum layers		LF: Every tile but integrate 7 layers electronically Map in EICRecon for hit merger
Sampling fraction, Absorber/scintillator ratio	Interaction lengths	10:1 = 4cm:4mm			Requires custom geom for each
Absorber material	Interaction lengths + Energy resolution			STEEL	
Timing resolution					
Allowed Dead space					
Heat dissipation					Effect on other detectors (especially for e.g. more layers) – heat forward towards Emcal – TIC meeting discussion

	tiles 5x5 [cm]						
	scintilator thikr	4				6	8
layers	absorber thikne	4	3	2	1.52	2	4
10		x					
12		x					
13			x				
15		x					
20				x		x	x
25					x		

	tiles 10x10 [cm]						
	scintilator thikr	4				6	8
layers	absorber thikne	4	3	2	1.52	2	4
10		x					
12		x					
13			x				
15		x					
20				x		x	x
25					x		

Table: physics impact vs. design parameters

Physics Impact ➡ Design parameter ⬇	Energy resolution	Efficiency	Mu/Pi separation	interaction lengths
Gross length	X	X		
Tile configuration	X	X		
Z-layer readout	X		X	
Sampling fraction, absorber/scintillator ratio				X
Absorber material	X			X

Tables: studied geometries

5x5	scintillator thickness	0.4				0.6	0.8
[cm]	absorber thickness	4	3	2	1.52	2	4
10 layers		45					
12 layers		54					
13 layers			46				
15 layers		68					
20 layers				50		54	58
28 layers					57		

10x10	scintillator thickness	0.4				0.6	0.8
[cm]	absorber thickness	4	3	2	1.52	2	4
10 layers		45					
12 layers		54					
13 layers			46				
15 layers		68					
20 layers				50		54	58
28 layers					57		

nHCal baseline design

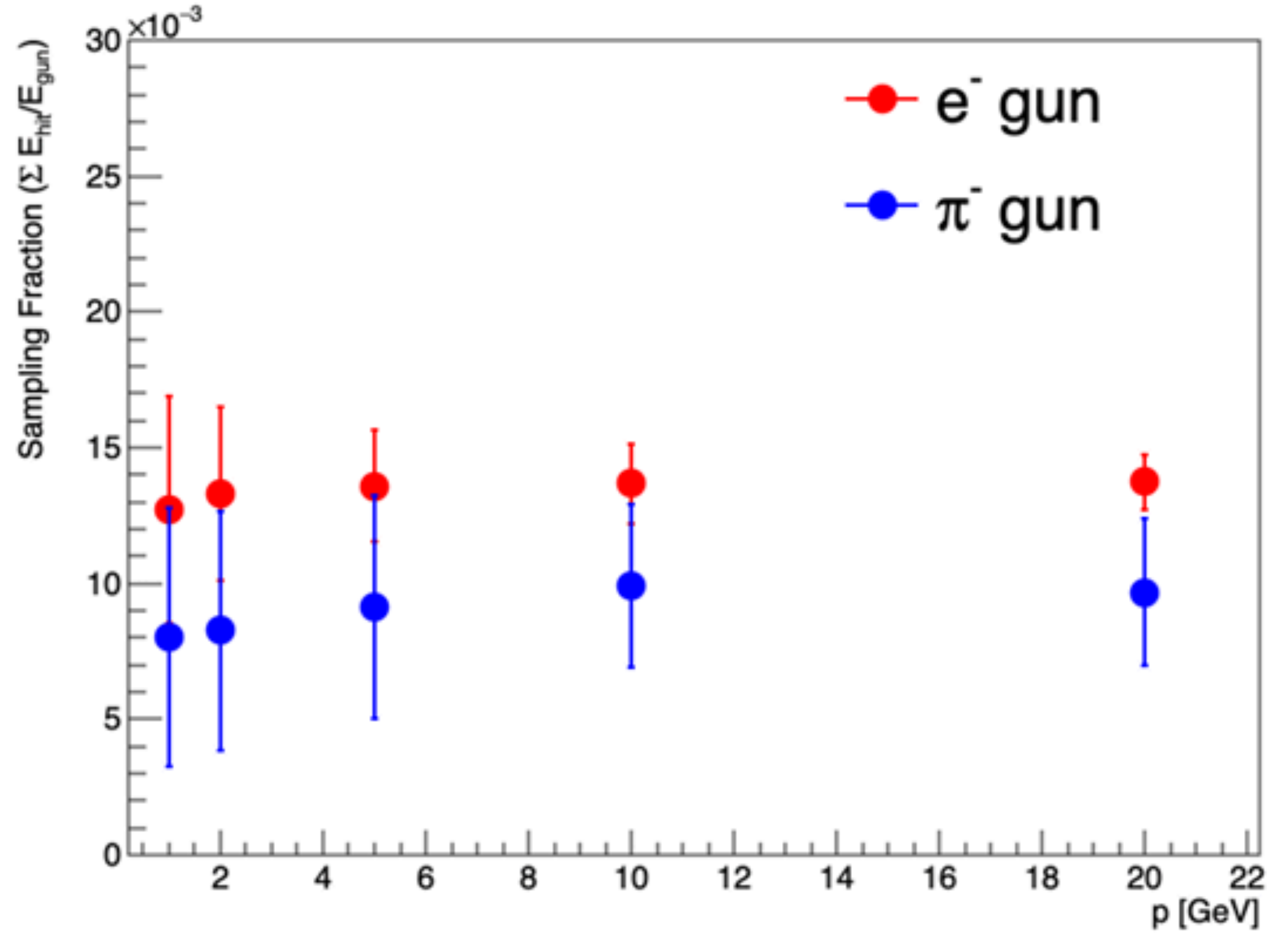
LFHCal configuration

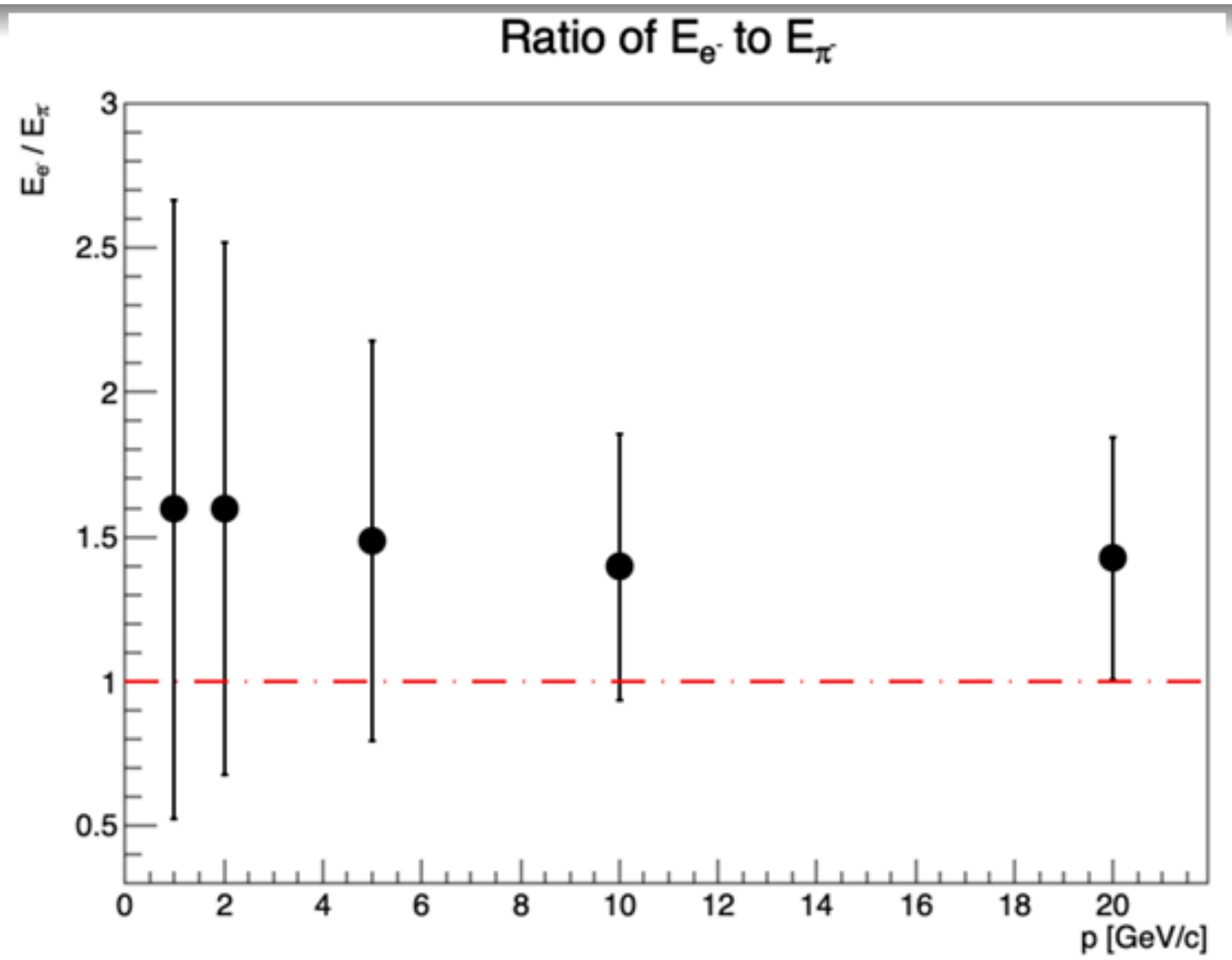
number indicates gross length

10 layers, absorber 4 cm, scintillator 4 mm, total 45 cm (default), 4.4*10=44cm, delta = 1cm
12 layers, absorber 4 cm, scintillator 4 mm, total 54 cm
15 layers, absorber 4 cm, scintillator 4 mm, total 67.5 cm
13 layers, absorber 3 cm, scintillator 4 mm, total 45.5 cm
20 layers, absorber 2 cm, scintillator 4 mm, total 50 cm
20 layers, absorber 2 cm, scintillator 6 mm, total 54 cm, 2.6*20=52cm, delta = 2cm
20 layers, absorber 2 cm, scintillator 8 mm, total 58 cm, 2.8*20=56cm, delta = 2cm
28 layers, absorber 1.52 cm, scintillator 4 mm, total 56.56 cm (LFHCAL configuration), 1.92*28=53.76cm, delta = 2.8cm

where does the delta come from?
Maria has 25, Leszek 28 - what is correct?

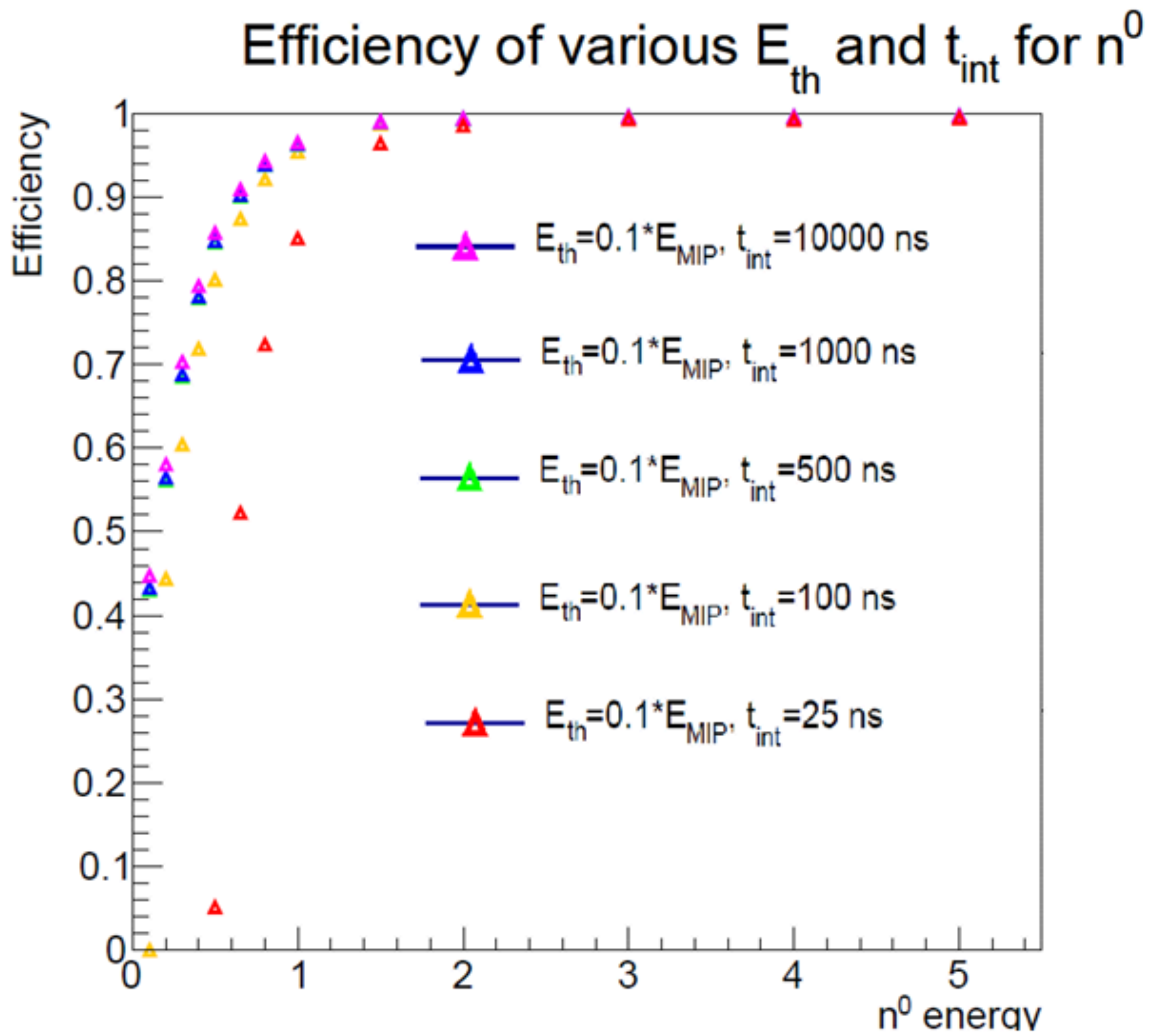
Sampling fractions



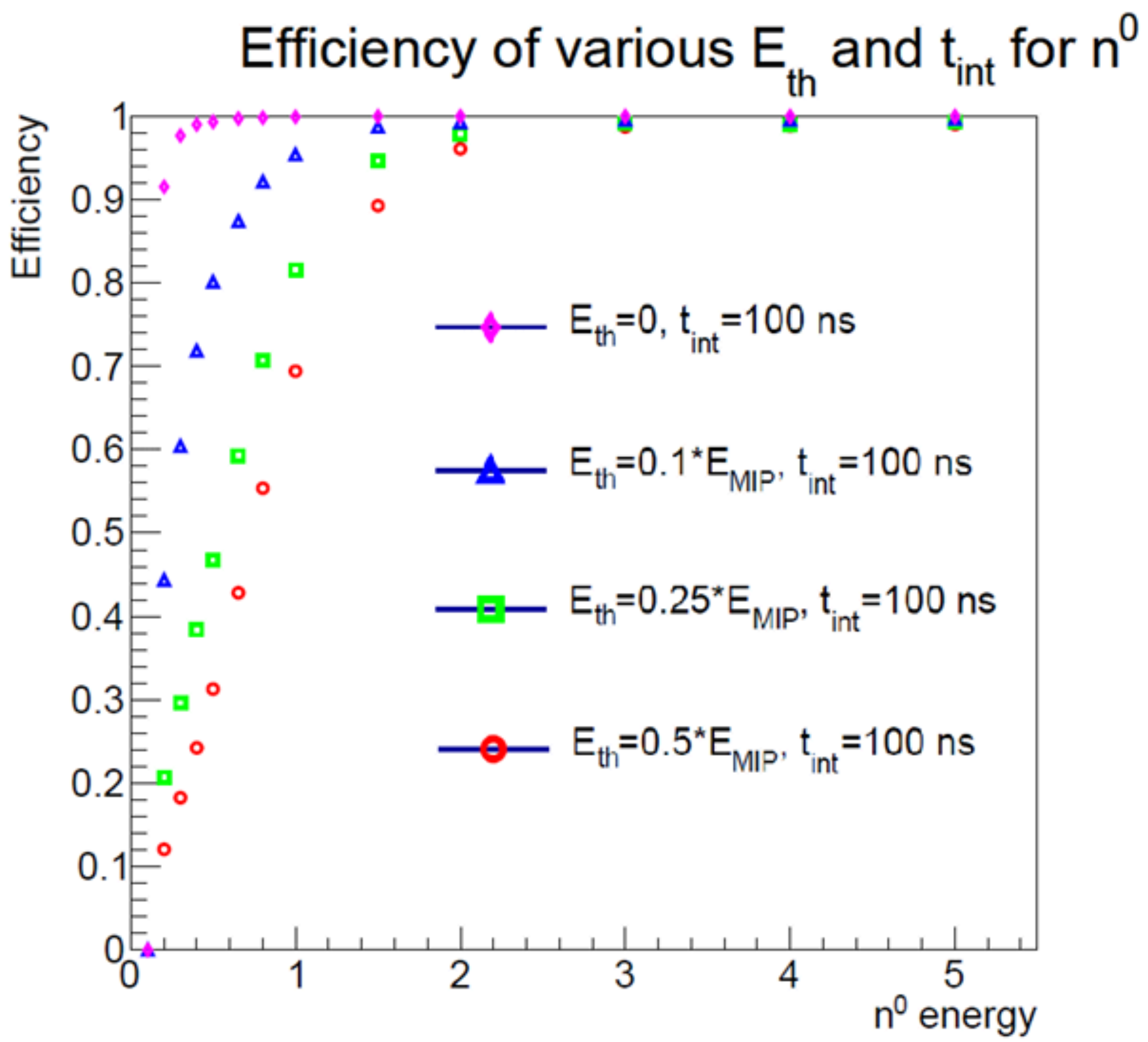


- Neutron detection efficiency (vs. threshold and integration time)
- Muon ID efficiency (vs. ID cuts, e.g.: MIP signal+track matching)
-

Integration time dependence



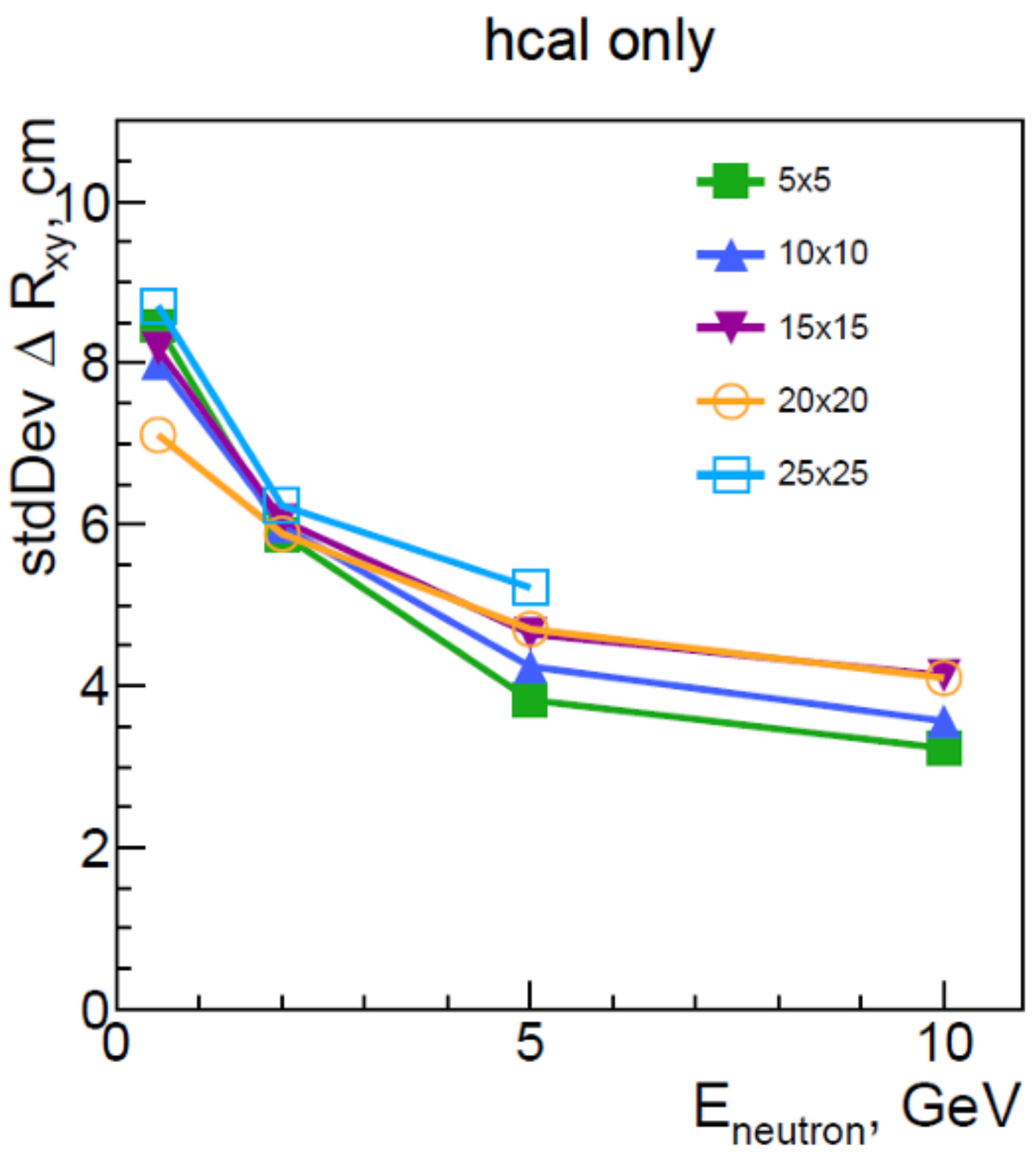
Threshold dependence

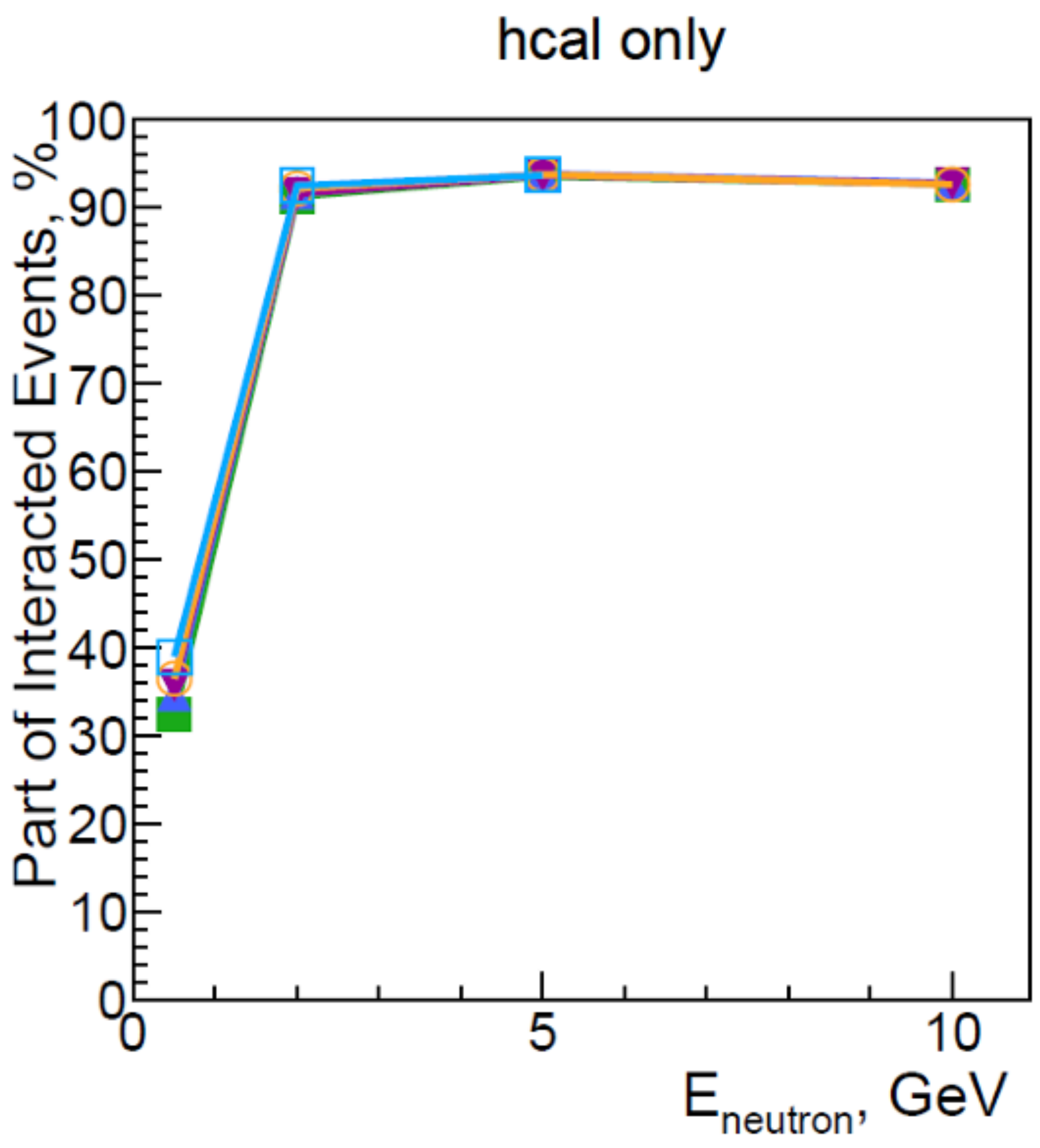


Sam Corey, OSU

Position resolution

Alexandr Prozorov, CTU





nHCal performance evaluation

- Standalone tile testing using cosmic rays and radioactive source
  - Purpose of the tests: evaluate performance of different tile configurations and sizes. Does SiPM-on-tile readout work for larger tiles?
  - Tiles of different sizes (5x5, 10x10) and thickness (4, 8, 16mm) at OSU
- XXX status and photos from OSU
- Towards the final design decision
  - Stand-alone tile testing
  - Full-chain tests
  - Beams tests to verify simulations - measure position resolution, e/h ratio, sampling fraction

Risks and opportunities

- (B) Are the remaining work and technical, cost and schedule risks adequately understood? Are there opportunities?
  - Develop 1 slide in collaboration with barrel HCal and LFHCal, guided by OlegE
  - The question about risks and opportunities is usually aimed at the official risk registry and there is nothing specific in there at the moment.
- XXX

nHCal timeline

Push start of installation later?

Have fancy project management timeline in place for review?

nHCal baselining / key dates

- (C) Will the detector be technically ready for baselining by late 2025?
  - The nHCal won't be (and doesn't have to be) ready for baselining end of 2025. Our milestone is rather the Preliminary Design Review (PDR) in fall 2025, with "60% maturity on paper"

Detector integration and planning for installation & maintenance

- (D) Are the detector integration and planning for installation and maintenance progressing well? Are there areas where further ideas should be pursued?
- Check with LFHCal and what is written in pre-TDR.
- Check document Leszek shared (still up to date?)

  https://docs.google.com/spreadsheets/d/1_yYA_IL1JDk2V1IwX0GcDDyQSEmnvtyn/edit?gid=1549845262#gid=1549845262

- nHCal has to be maintained and serviced from the front, unlike the LFHCal (from the back)

Construction

- (E) Will the detector be ready for start of construction by late 2026?
  - No, see also (C). The nHCal is one of the latest detectors. Find good formulation.
- The flux return is decoupled from the nHCal, consequently:
  - Need to use non-magnetic steel as absorber
  - The nHCal installation will happen after the solenoid field mapping

extra slides

Charge (with comments in color)

(A) Is the design of the ePIC detector and its sub-systems appropriate and progressing well?

- Focus on this aspect. Have 1 slide with example of how the physics goals inform the design

(B) Are the remaining work and technical, cost and schedule risks adequately understood? Are there opportunities?

- Develop 1 slide in collaboration with barrel HCal and LFHCal, guided by OlegE

(C) Will the detector be technically ready for baselining by late 2025?

- The nHCal won't be (and doesn't have to be) ready for baselining end of 2025. Our milestone is rather the Preliminary Design Review (PDR) in fall 2025, with "60% maturity on paper"

(D) Are the detector integration and planning for installation and maintenance progressing well? Are there areas where further ideas should be pursued?

- Check with LFHCal and what is written in pre-TDR. Point out non-magnetic steel, flux return separate

(E) Will the detector be ready for start of construction by late 2026?

- No, see also (C). The nHCal is one of the latest detectors. Find good formulation.

Notes

- The talk will be 20 minutes with questions - the split between “talking” / “questions” can be as high as 50% / 50%. Oleg recommends about 12 slides
- Page turn - listen in and adapt the slides during the first presentations, which are usually discussed at length. We will be the last and we can tune the slides before it’s our turn.
- Detail note: we can mention that as compared to the LFHCal, the nHCal FEEs heat to the front, while they heat to the back, and this may require additional cooling (air or liquid…). While we haven’t determined yet the final plan, we can say that we aware of it. Leszek estimate (asked Norbert, each ASIC produces 4.5W and handles 78 channels): 1.6 kW (for 45cm) (range 0.5 2.4kW 10x20cm)

Outline draft (12 slides)

1. (intro) Locating the nHCal in ePIC and boundary conditions (like non-magnetic steel)
2. (intro) Physics that informs the design (low-x etc; lessons from HERA-H1)
3. (A) Baseline and alternative designs with goals (then detail studies on the following slides)
4. (A) Sampling fraction
5. (A) Neutron efficiency (and muon / K_L?)
6. (A) Position resolution
7. (A) Performance evaluation (tile tests at OSU, beam tests)
8. (B) Work and technical, cost and schedule risks
9. (C-E) Timeline
10. (C-E) Discussion of and conclusions from timeline: baselining end of 2025 vs. PDR (C); planning of integration, installation and maintenance (D); detector construction (E)

nHCal project design - purposes and requirements

We want to do this physics + crucial to EIC Mission = **Detector Requirements**

nHCAL Crucial for:
- Low-x & Q^2, high y
- Diffraction
  - Vector Mesons
  - Dijets
- Charged Jet Measurements
- Neutral Jet / Neutral VETO
- Scattered Electron ID (h VETO)
- Improved Hermiticity (benefit kinematic resolution in CC)

Detector requirements:
- Coverage in backward direction
- Good μ / π separation via MIP signal
- High efficiency low-energy neutron efficiency
- Good spatial resolution to distinguish clusters (neutral vs. charge)
- Good timing resolution

nHCAL: crucial for core aspects of EIC Physics Mission

3/25/25 Daniel Brandenburg 15

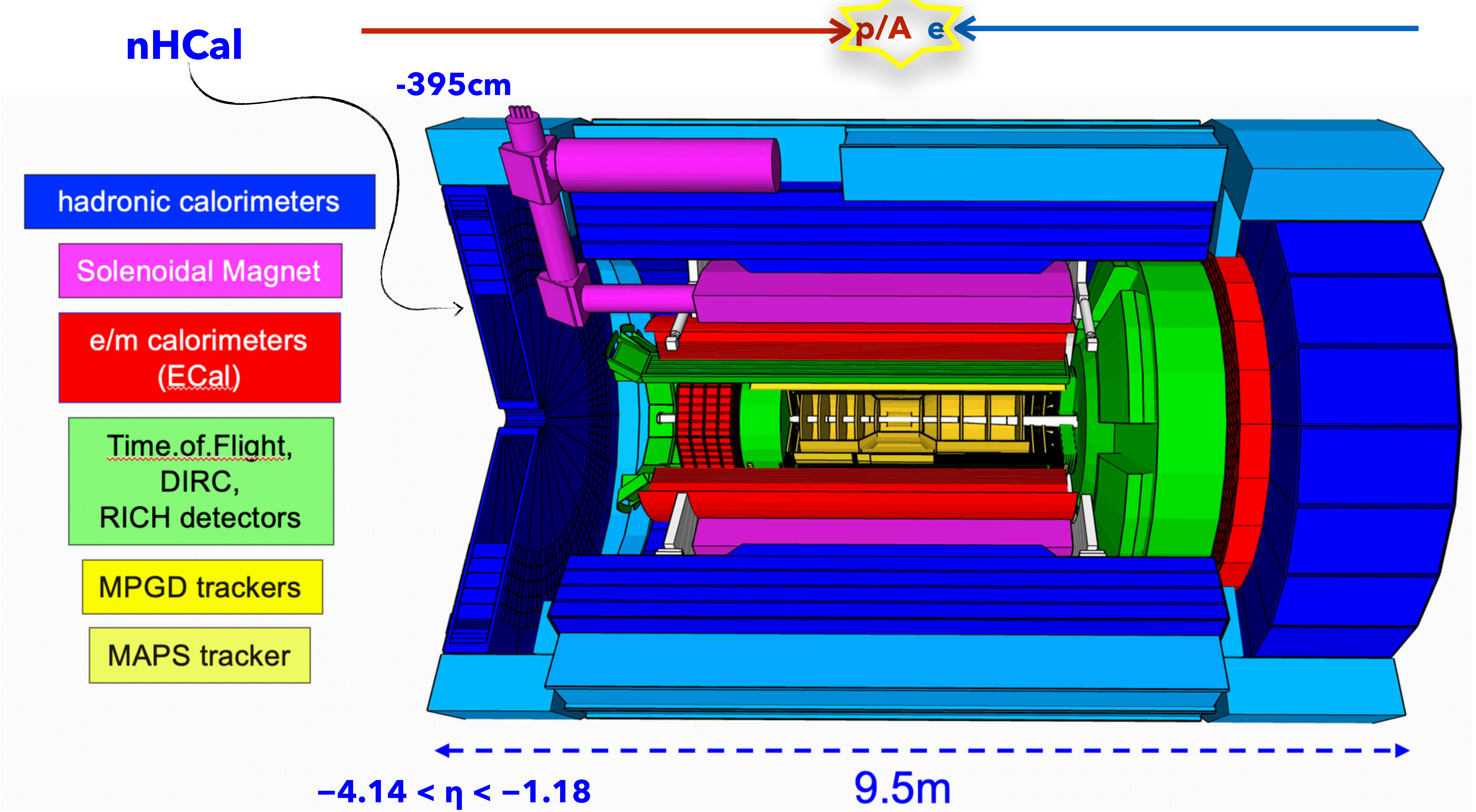
nHCal project design - purposes and requirements

- **nHCal crucial for core aspects of EIC physics mission**
- **Low x and Q^2, high y** → Coverage in backwards direction
- Diffraction
  - vector mesons
  - dijets
- Charged jet measurements
- Neutral jet / neutral veto
- Scattered electron ID (h veto)
- Improved hermiticity (benefit kinematic resolution in CC)

Requirements:

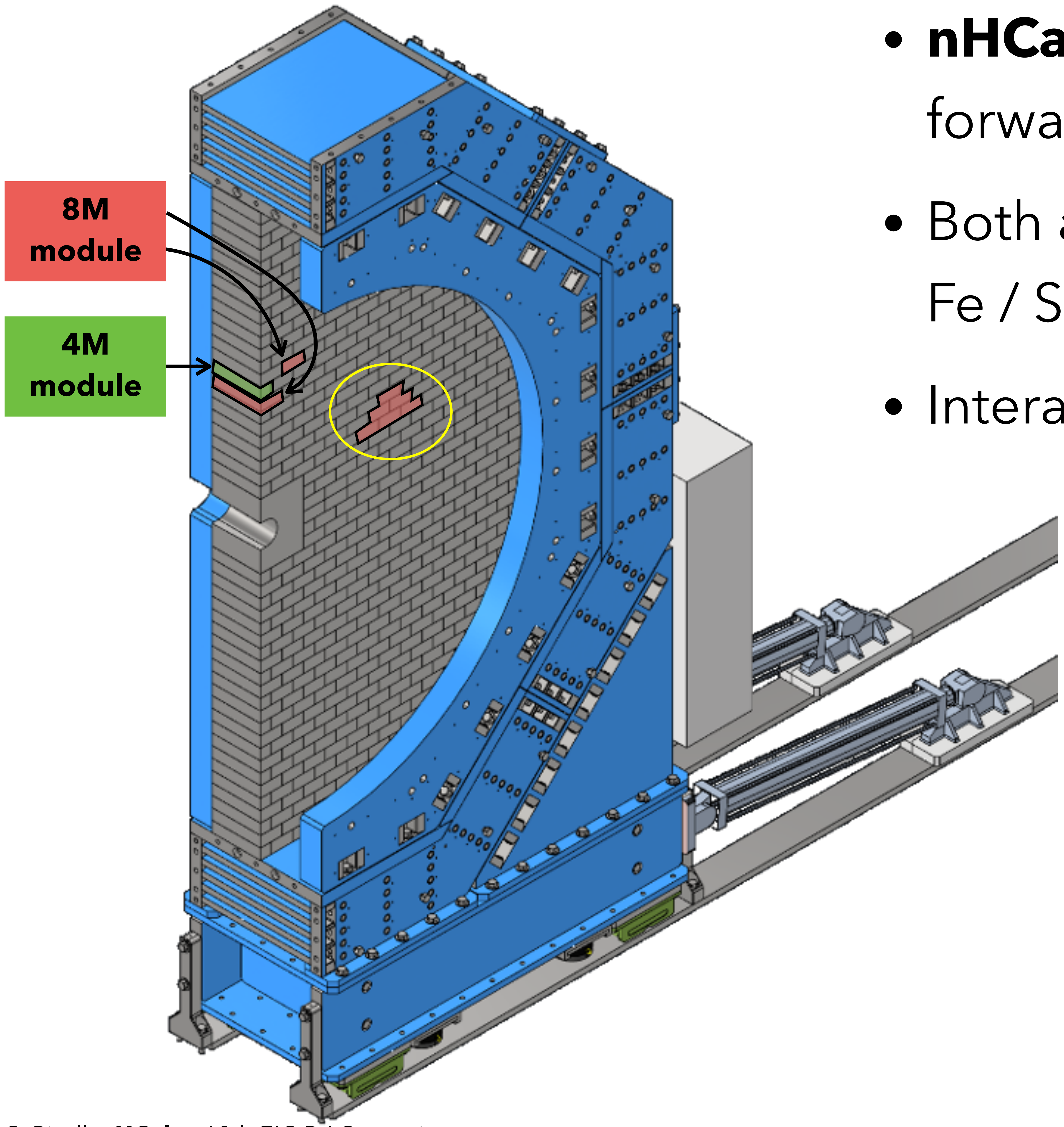
- Coverage in backwards direction
- Good μ/π separation via MIP signal
- Good spatial resolution to distinguish neutral/charged hadrons
- High efficiency for low-energy neutron detection
- Good spatial resolution to distinguish clusters (neutral vs. charged)
- Good timing resolution

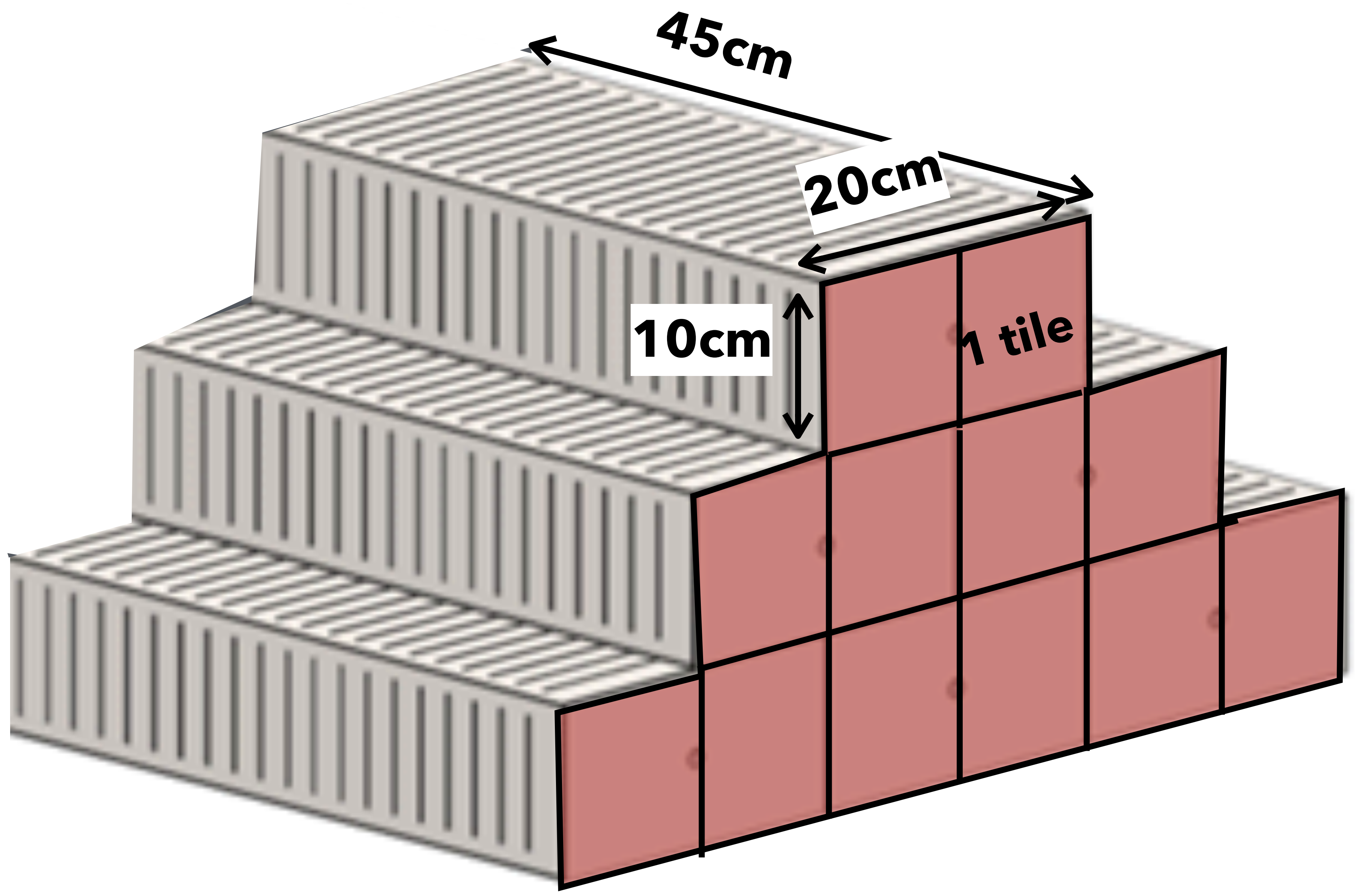
The backward (electron-going) hadronic calorimeter - nHCal



nHCal 8M module

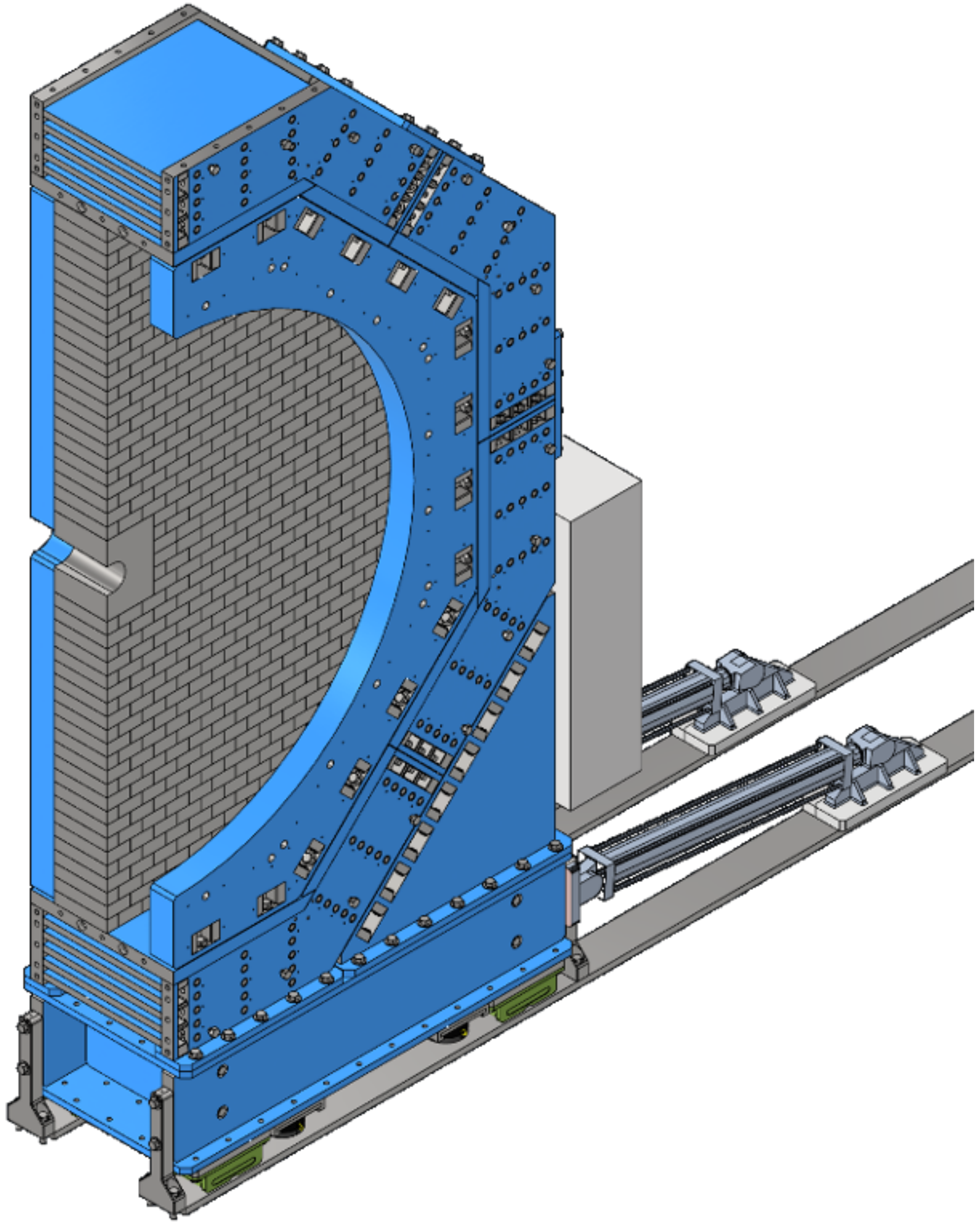
- **nHCal** based on, but not identical to, forward HCal (**LFHCal**) design.
- Both are sampling calorimeters with alternating Fe / SciTiles layers.
- Interaction length: nHCal 2.4, LFHCal 6





nHCal baseline design - parameters

nHCal similar but not identical to **LFHCal** design. Both are sampling calorimeters with alternating layers



	nHCal	**LFHCal**
material	same	Fe / SciTiles
interaction length	2.4	6.0
depth along beam axis	45cm	132cm
number of physical layers	10	60
thickness of layers	40mm / 4mm	16mm / 4mm
tile size	10cm x 10cm	5cm x 5cm
module size	10cm x 20cm x 45cm (8M), 10cm x 10cm x 45cm (4M)	10cm x 20cm x 140cm (8M), 10cm x 10cm x 140cm (4M)
number of modules	same	1058 (8M), 72 (4M)
tiles per layer	2x (1058+72)	8x (1058+72)
number of ROC	10x 2x (1058+72)=22,600	6x 8x (1058+72)=54,240

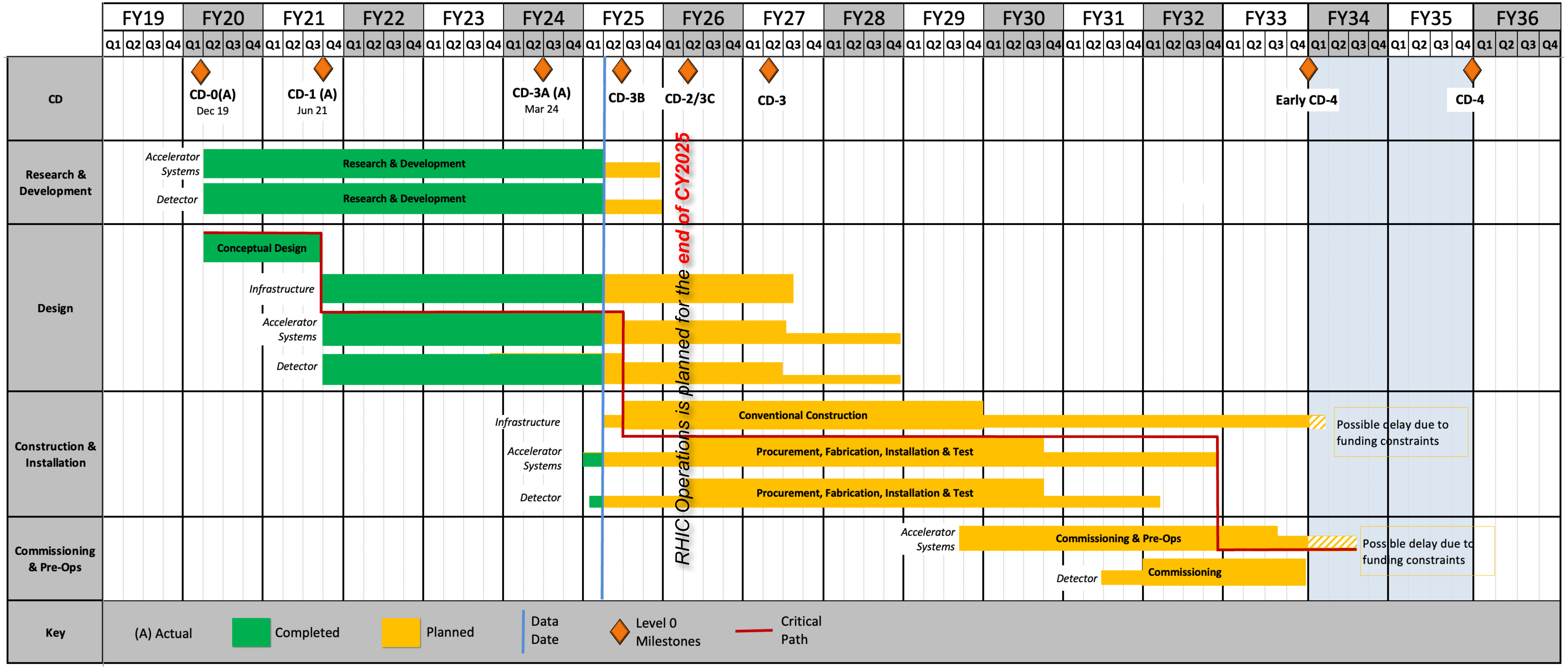
(+ insert modules)

Project design - material specifications and vendors

	Possible candidate(s)	decided	ordered or acquired for prototype	ordered or acquired for project detector	remarks
Tiles	Eljen EJ-200, or injection molding (FNAL)	no	yes	no	Considered choices: 5cm x 5cm,10cm x 10cm https://eljentechnology.com/products/plastic-scintillators/ej-200-ej-204-ej-208-ej-212
SiPMs	S14160-1315PS	yes	no	no	https://www.hamamatsu.com/eu/en/product/optical-sensors/mppc/mppc_mppc-array/S14160-1315PS.html
Light collection	SiPM-on-tile or WLS with SiPM	no	no	no	LFHCal uses SiPM-on-tile design
Front-End Readout	HGCROCv3	yes	no	no	78 channels. Same as for LFHCal. nHCal: placed in front of modules (LFHCal: back)
Absorber structure	Leading Edge Metals & Alloys; Electron Beam Welding, LLC	no	no	no	Absorber: non-magnetic steel; electron beam welding in vacuum

Reference Schedule

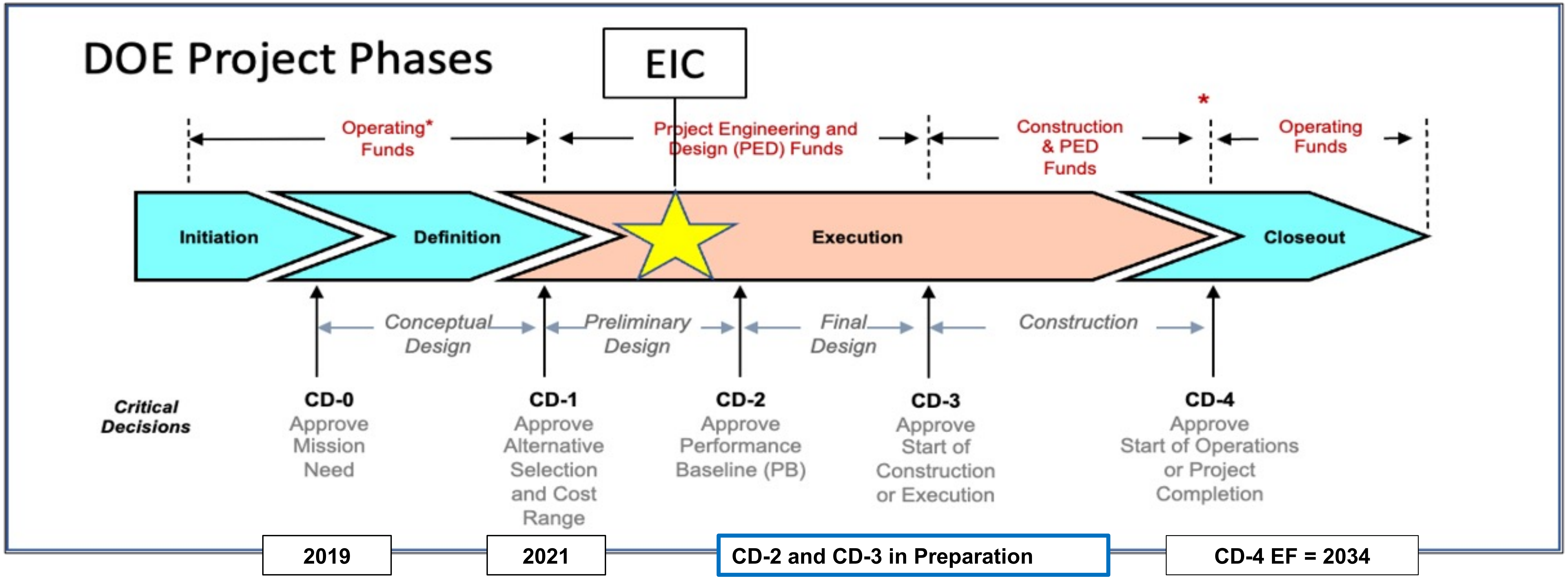
Plans for CD-2 and CD-3 originally aligned with conclusion of RHIC.



Critical Path is Accelerator Systems

Science operations start in roughly a decade

EIC Project-Critical Decisions and Plans



- **CD-3A, Long-Lead Procurement, approved March 2024. Excellent use of IRA funding.**
- **CD-3B, Long-Lead Procurement, approval planned for March 2025 (ESAAB)**

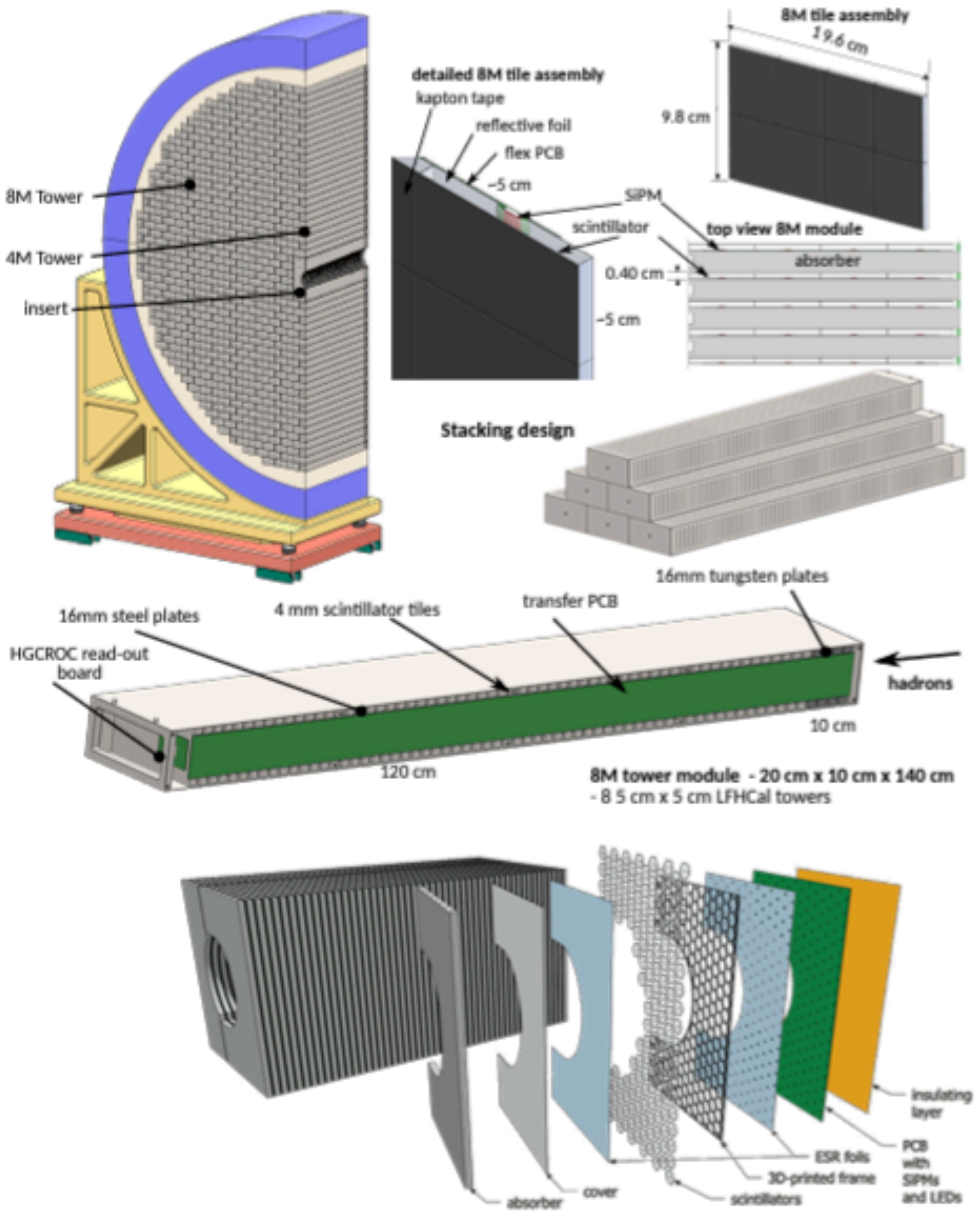
LFHCAL: The General Idea

OAK RIDGE National Laboratory

ePIC

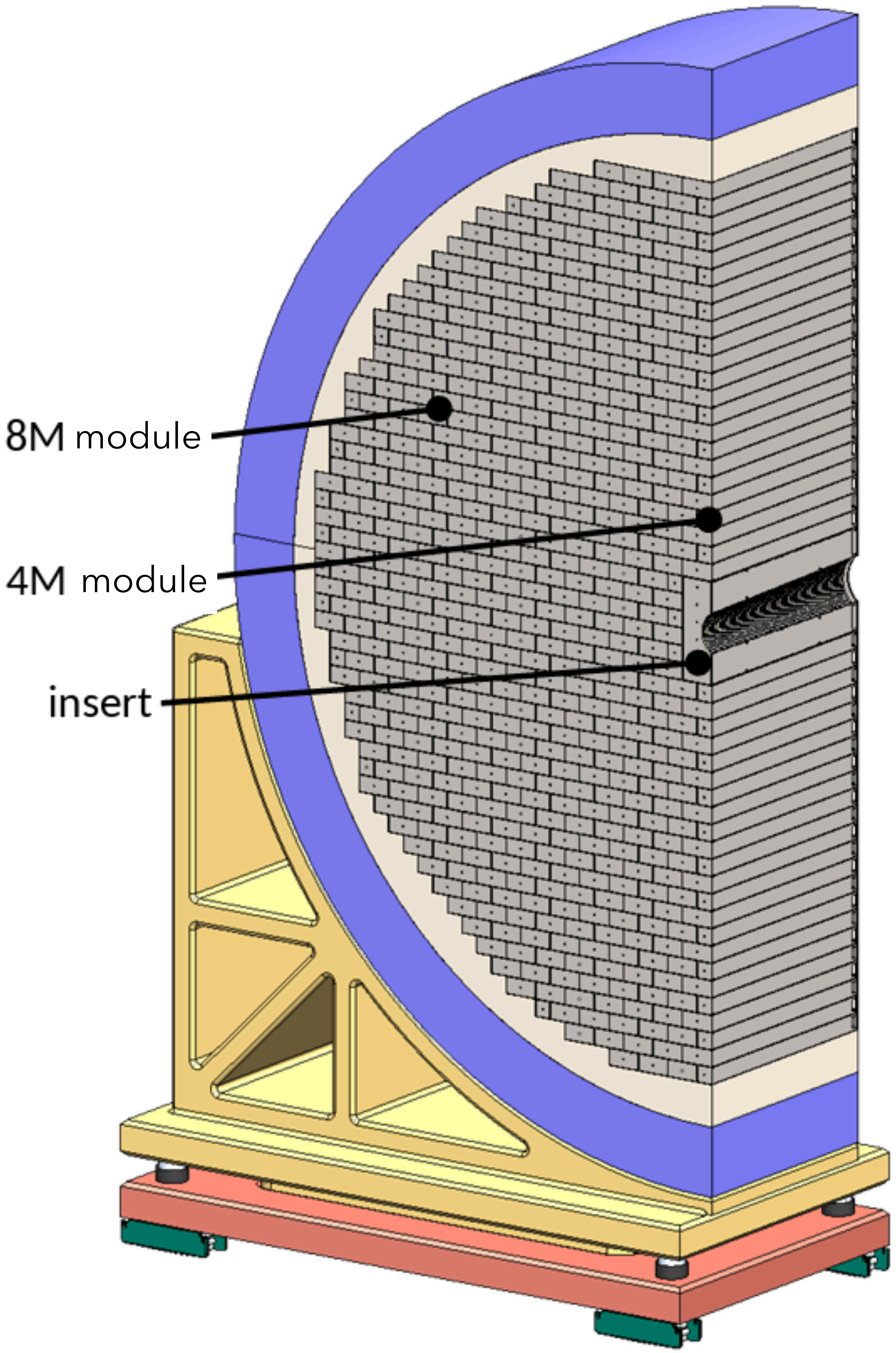
Concept:

- CALICE AHCal inspired W/Fe-Scintillator calorimeter with SiPM on-tile-readout
- Three construction units:
  - 8M modules 10x20x140 cm^3
  - 4M modules out of 10x10x140 cm^3
  - Insert modules built out of 2 halves surrounding the beam pipe
- **8M & 4M modules :**
  - 4 layers of tungsten + 61 layers of steel interleaved with scintillator material
  - Transverse tower size 5x5 cm^2
  - Multiple consecutive tiles summed to 7 longitudinal segments per tower
- **Insert modules:**
  - 10 layers of tungsten + 54 layers of steel interleaved with scintillator
  - Hexagonal tiles of 8 cm^2 each read-out individually

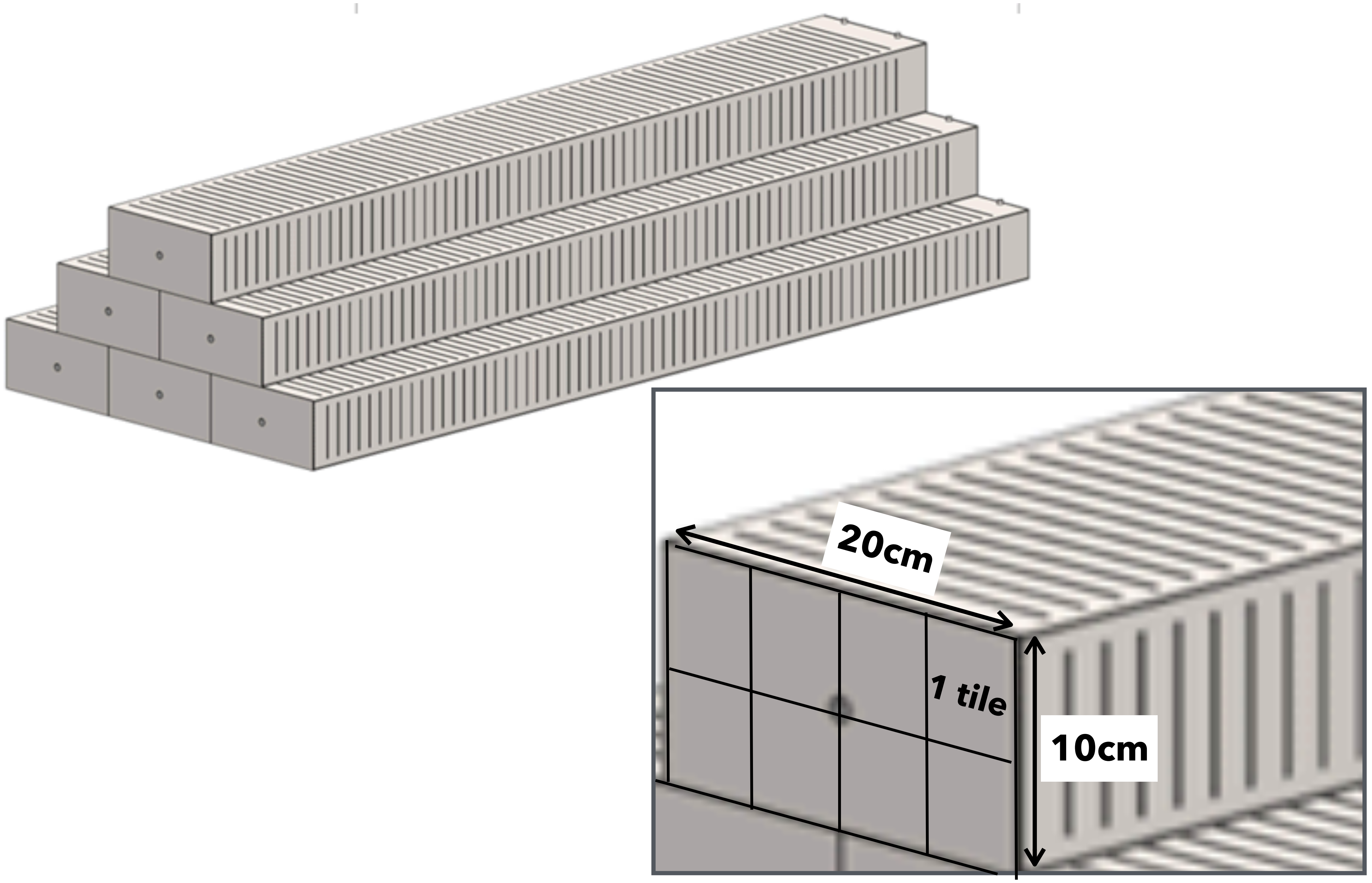


- https://indico.slac.stanford.edu/event/8288/contributions/7678/attachments/3636/9951/cpad23_lfhcal.pdf

LFHCal

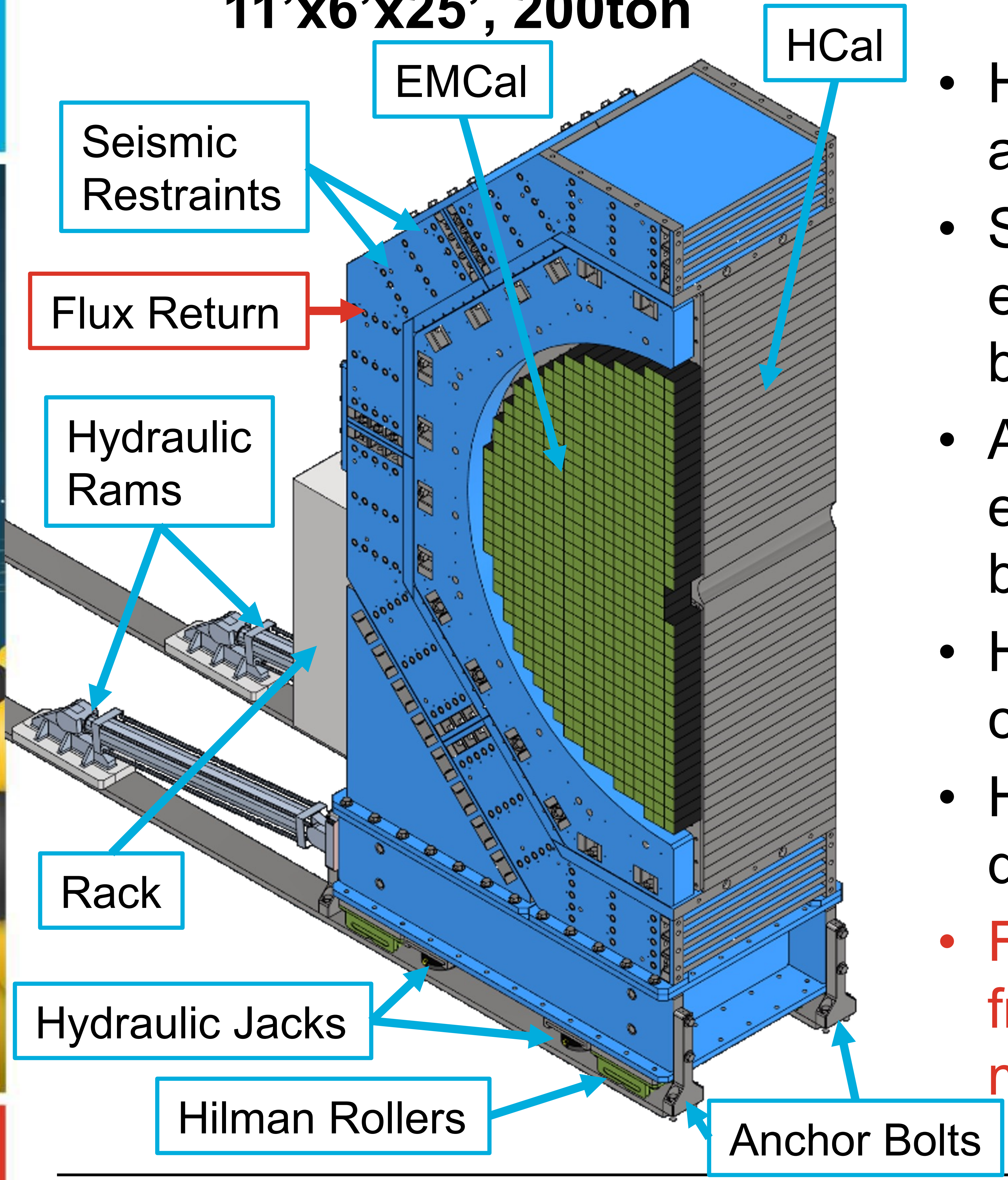


- The nHCal will also contain 8M and 4M modules
- No "insert modules" since radiation damage is less of a worry in the backward electron-going direction



Endcap Interfaces

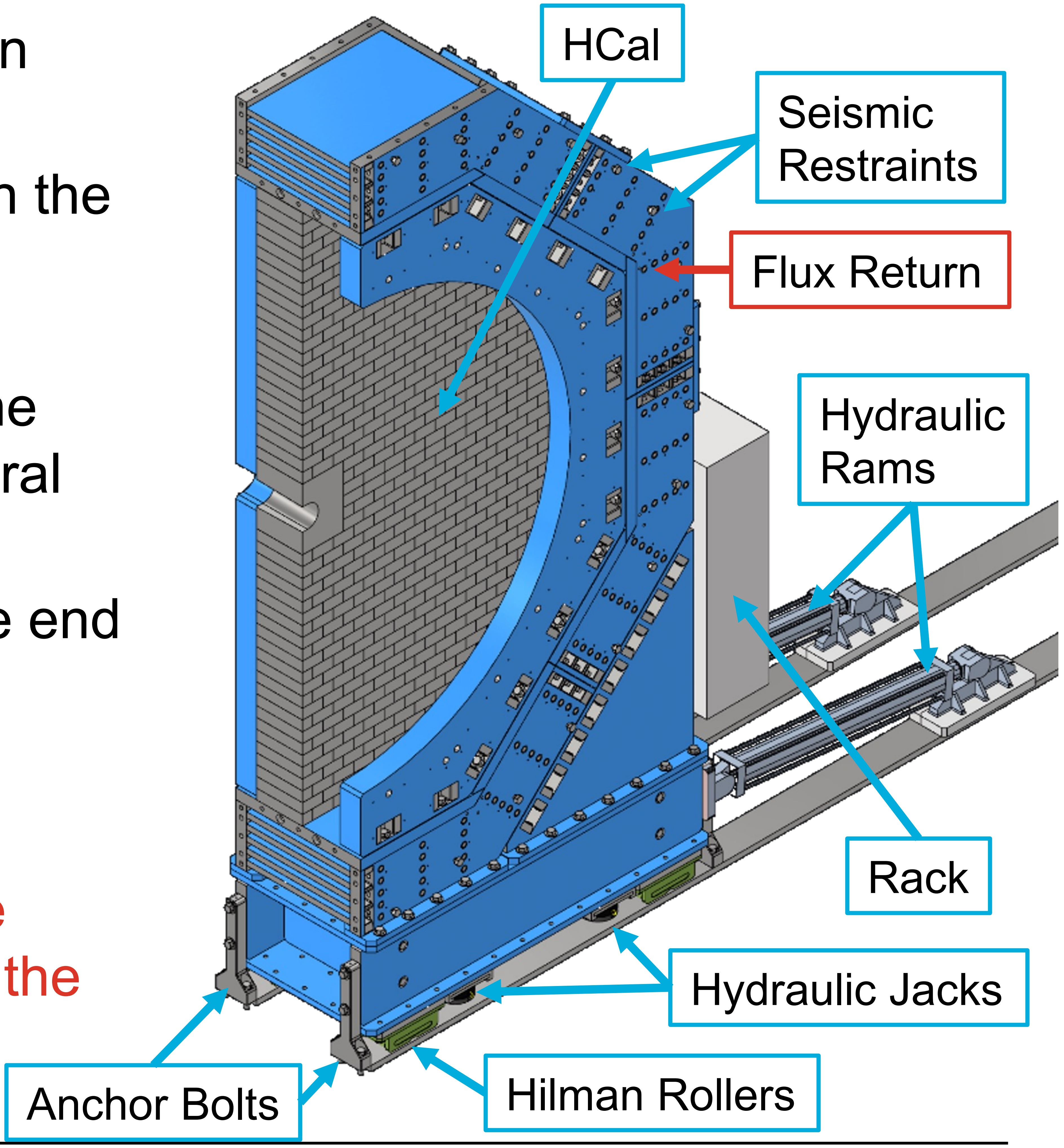
Forward Endcap (FE)
11’x6’x25’, 200ton



Description

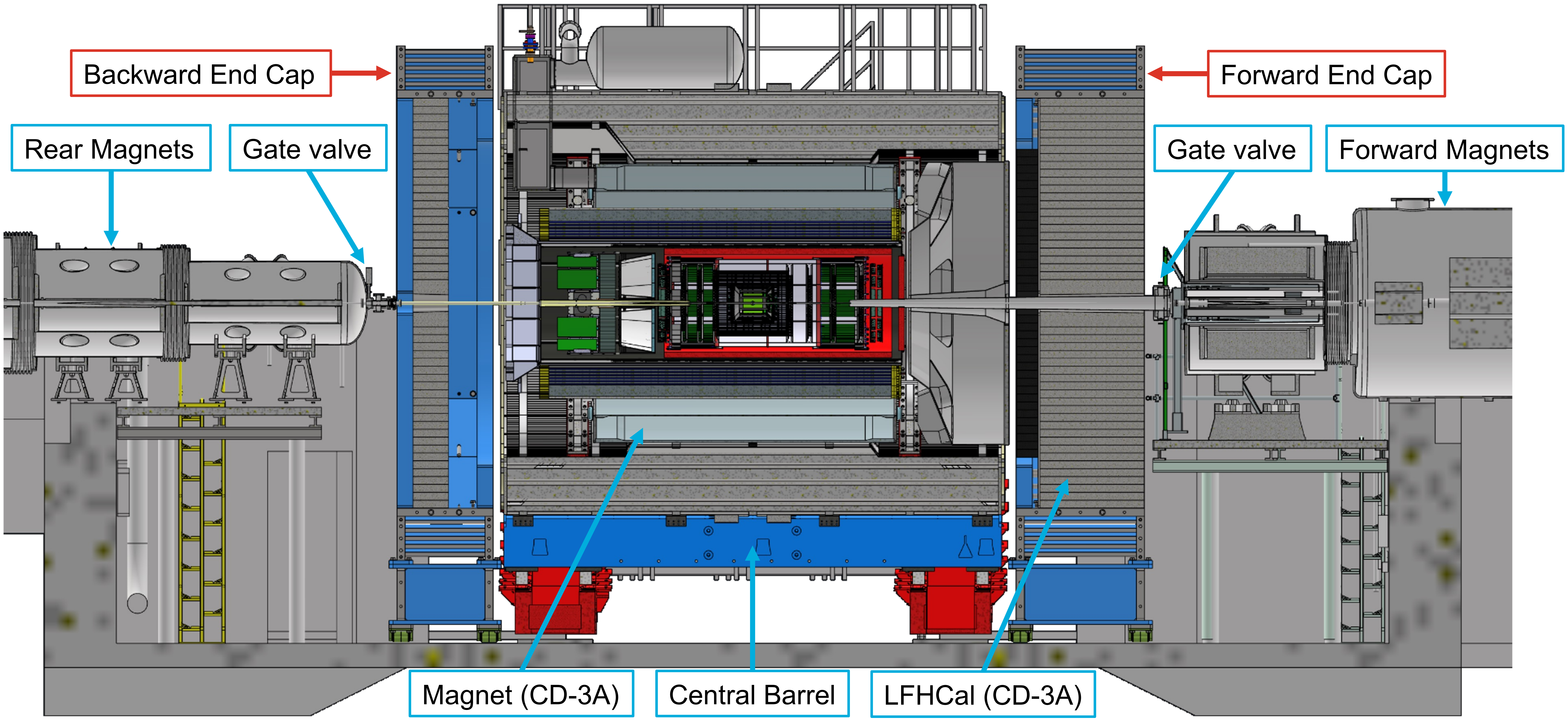
- HCal, EMCal and Lepton are end cap detectors
- Seismic restraints attach the end caps to the central barrel
- Anchor bolts tie down the end caps when the central barrel isn’t available
- Hydraulic rams push the end caps on Hilman rollers
- Hydraulic jacks lift the detector for alignment
- Flux return minimize the fringe field and balance the magnetic forces

Backward Endcap (BE)
11’x4’x25’, 125ton



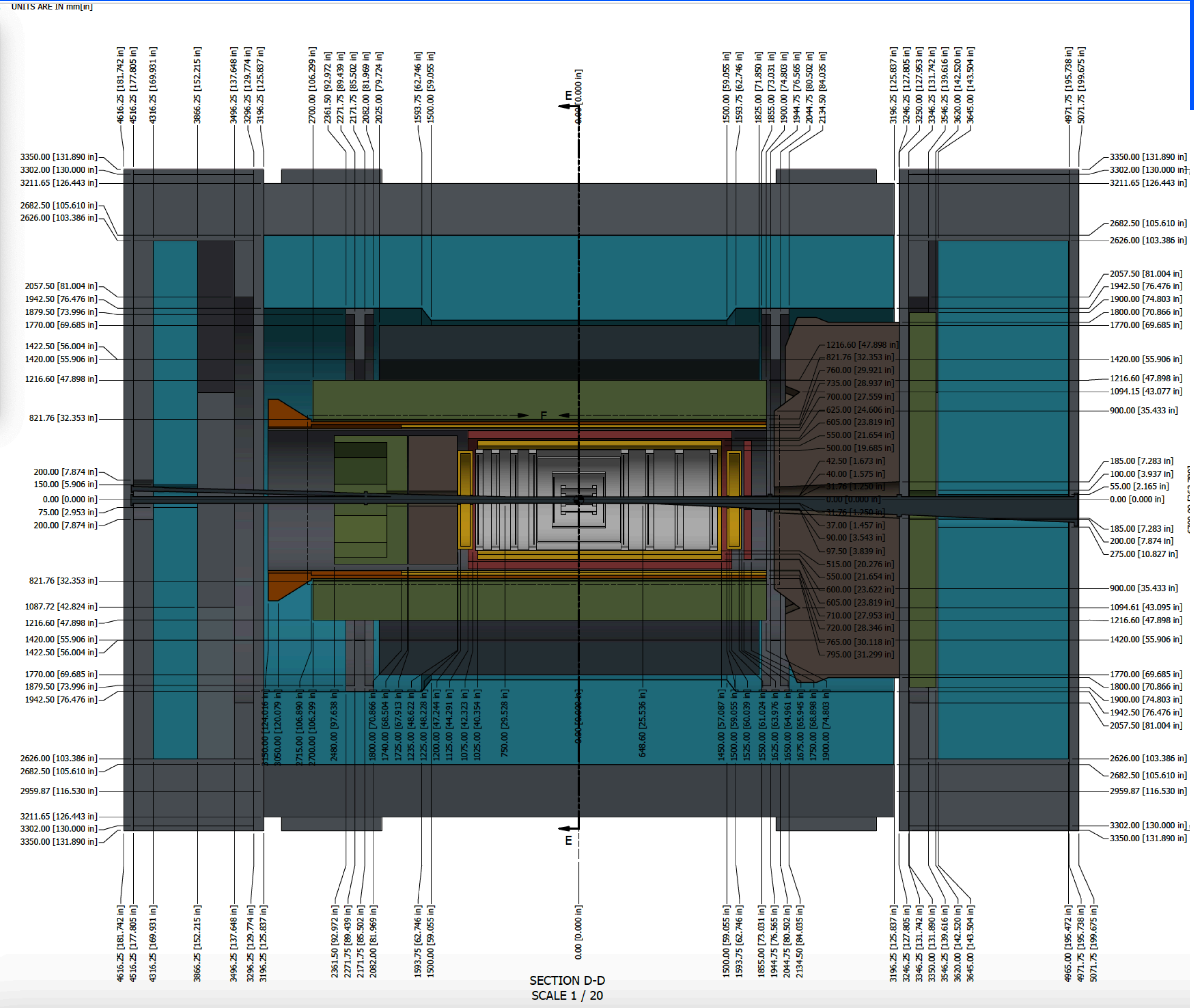
https://agenda.infn.it/event/43344/contributions/252099/

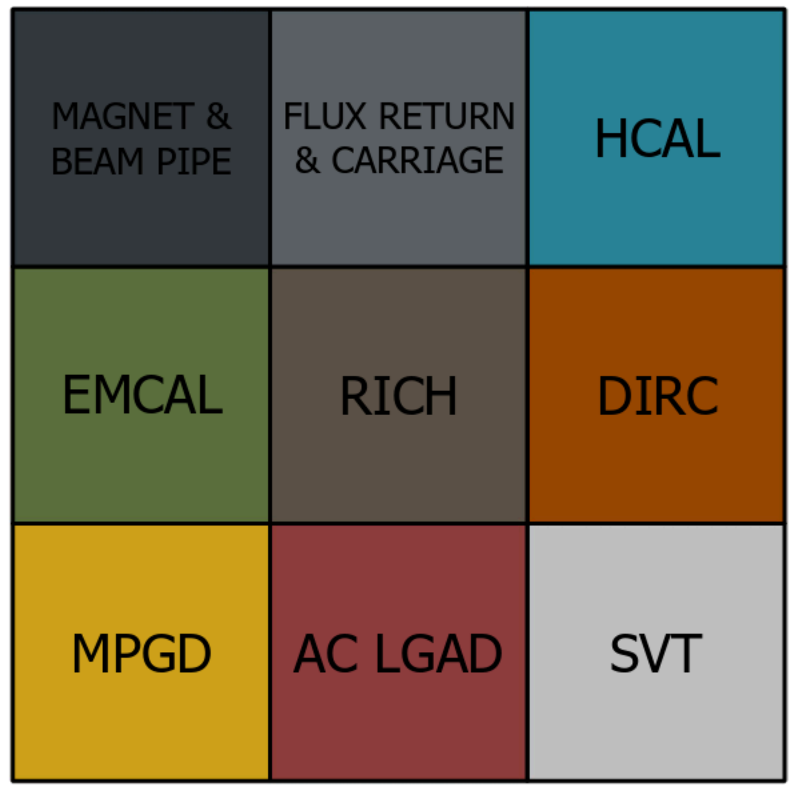
Integration Model in Experimental Hall



End caps fit between the central barrel and the magnets/valves

https://agenda.infn.it/event/43344/contributions/252099





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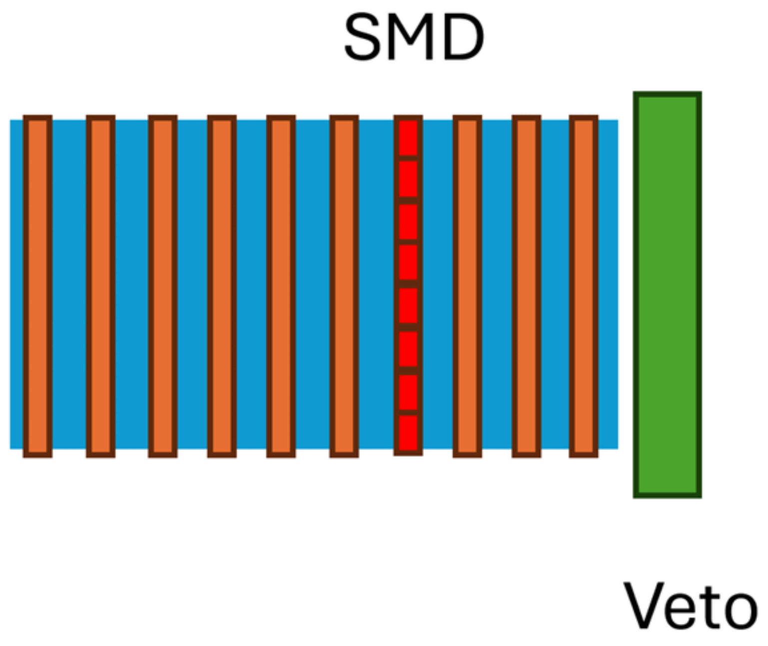
https://indico.bnl.gov/event/27009/contributions/103847/attachments/60284/103518/EPIC%20Envelope%20-%2003-03-2025.pdf

Previous discussion between nHCal DSC and Project

- Communication with Project in October 2024:
  - Module size is 45 cm x 20 cm x 10 cm; for details see posted drawing package.
  - Maximum length of the module can be 70 cm in z but then maintenance close to the oculus will be difficult
  - Electronics sits towards the IP
  - The segmentation inside the module is free to vary as long as it fits in the 45 cm x 20 cm x 10 cm
- See also https://indico.bnl.gov/event/25021/

- For better energy resolution - make nHCal deeper (up to ~70 cm)?
- Add charge veto to help isolate neutral showers
- Add in addition SMD with high position resolution?

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

15.1.2025 L. Kosarzewski OSU 10

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?

Beam tests for nHCal prototypes

- Difficulty to get hadron beam test time
  - No test beam at FNAL in 2025, and 2026 unclear (transformer problems for the main injector)
  - CERN LHC long shutdown mid-2026++

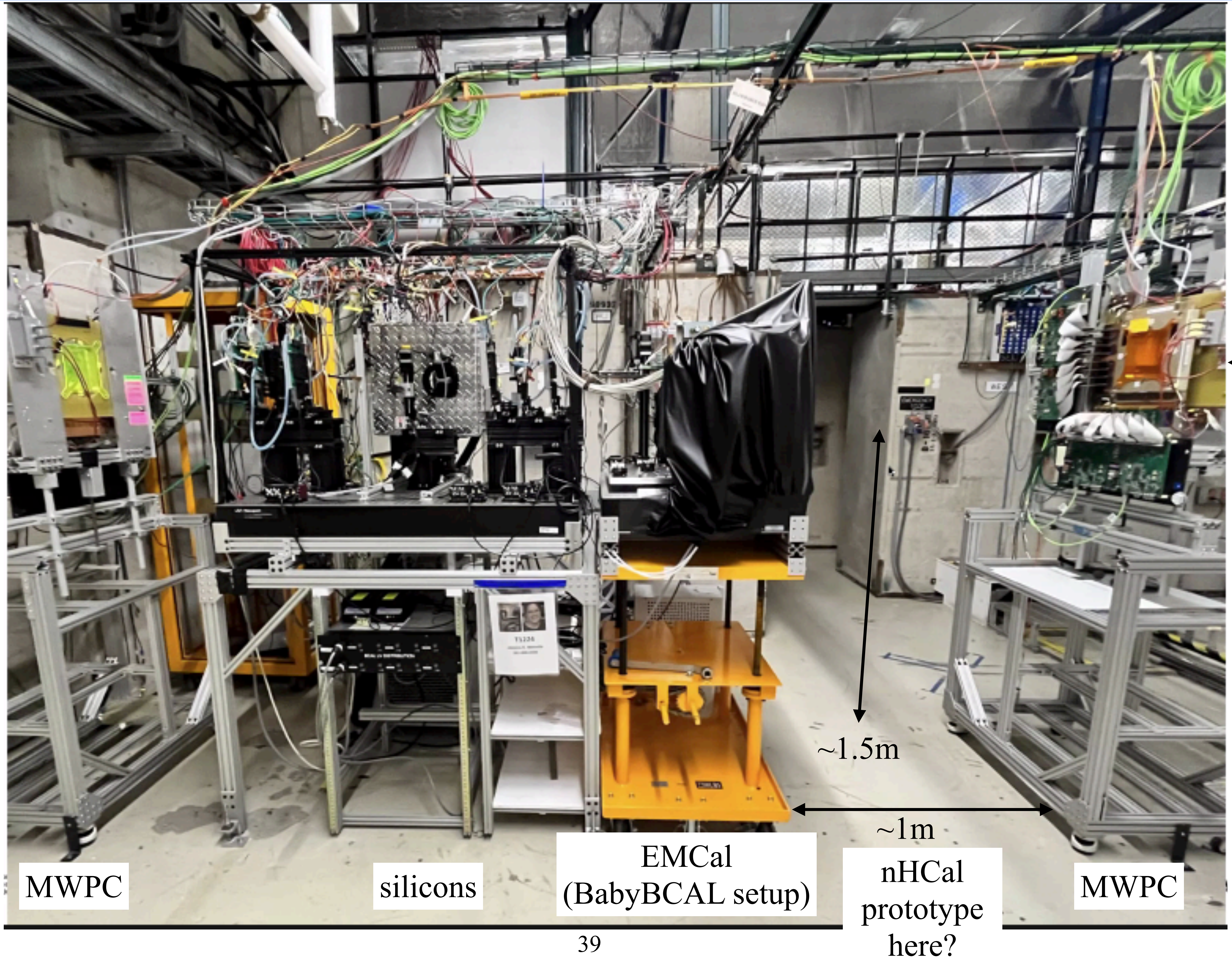
See also https://cernbox.cern.ch/external/public/wRuLiYuAwqgS5xx/InternationalTBplan-worldwide.xlsx

- Considered possibilities:
  - **FNAL 2026** - jointly with EMCal barrel? Initial planning with Argonne group in 2024 about collaboration in 2025
  - **CERN spring 2026** - jointly with ATLAS/CMS ZDC? (co-led by UIUC)
    - Not in parallel (ZDC is an HCal too and has 5.5 interaction lengths → parasitically behind the setup is not an option), but potentially serially in time. Synergies in sharing person power, DAQ, trigger scintillators, readout cables, tables… UIUC/ZDC plans to request beam time for spring 2026 (call not open yet). If jointly with nHCal, request one additional consecutive week.
  - **CERN fall 2025** - jointly with lfHCal?
    - lfHCal TB time for PS scheduled Nov 19-26. Again, issue with parallel HCal beam time - won't be possible at the same time
  - **Parasitic at RHIC fall 2025**?
    - There is a temporary shutdown in summer (no beam from July 1 – August 18, 2025 to avoid heat/humidity-related inefficiencies) and this downtime could be used to prepare the setup. Would require communication with sPHENIX asap.

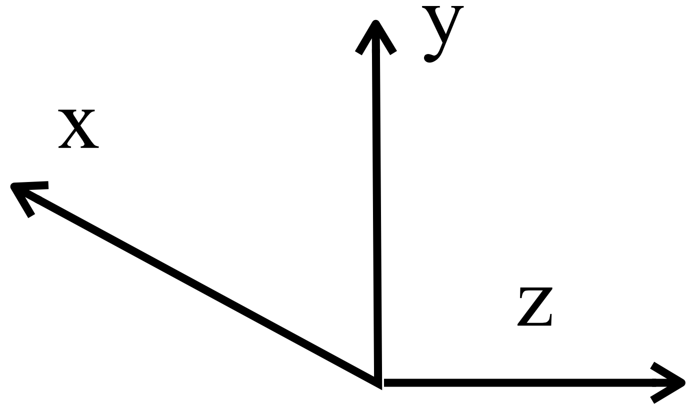
Test beam for ePIC barrel EMCal in June 2024 at FNAL

protons 120 GeV

electrons / pions
2-32 GeV
fractions vary
depending on E
(~15% pions at lowest)



~3-4 feet

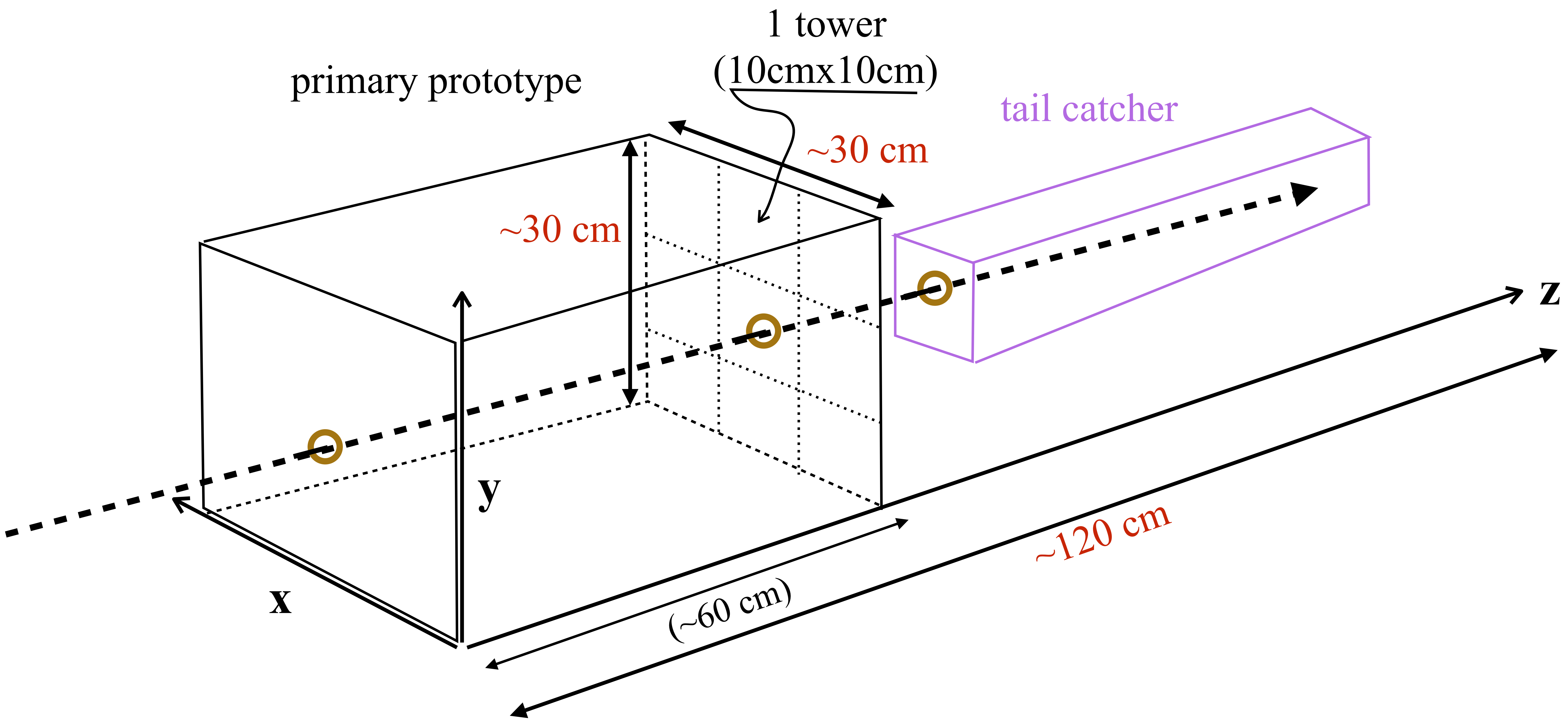


Proposal for an ePIC nHCal beam test at FNAL

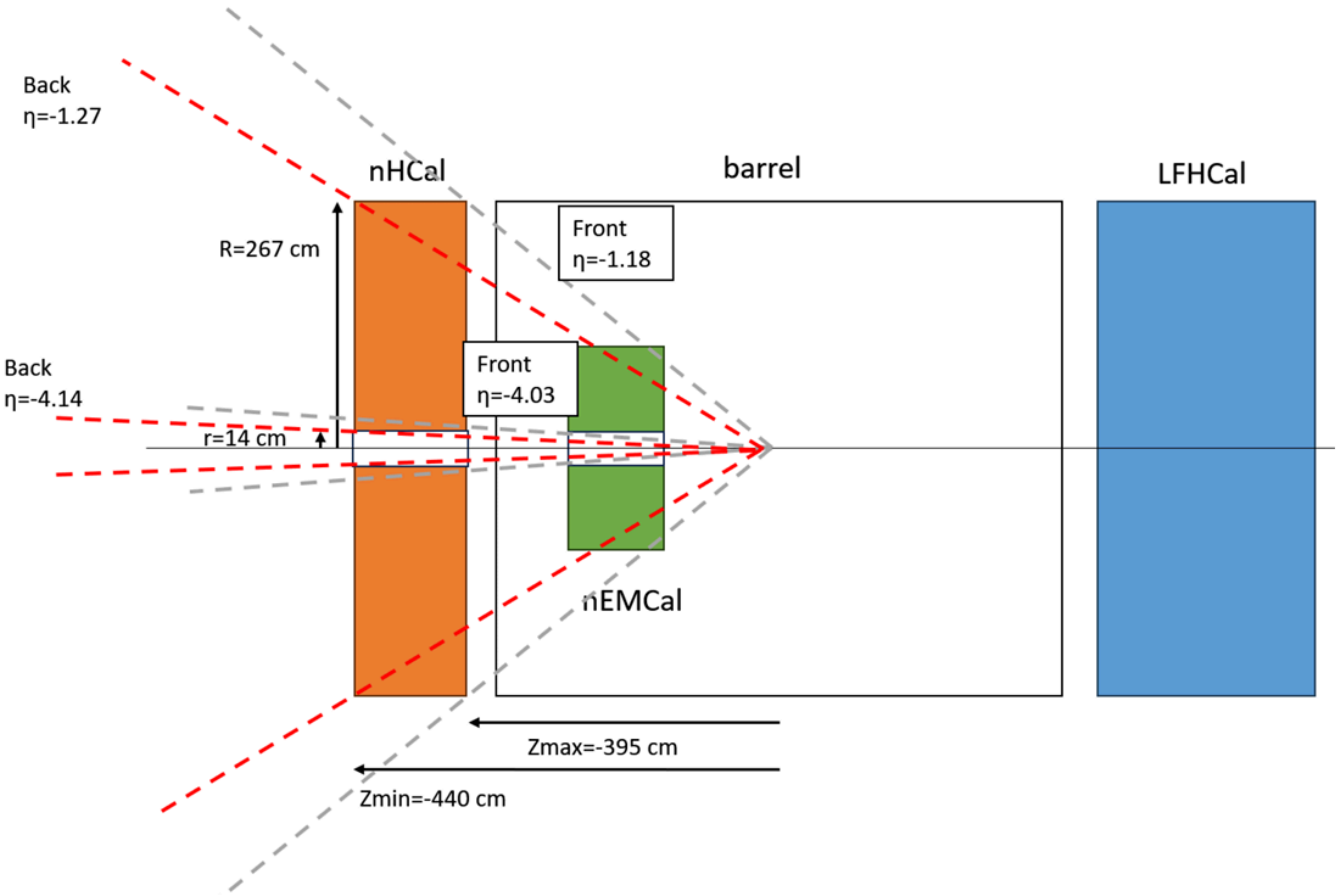
(August 2024 - Caroline Riedl in communication with Sylvester Joosten, Maria Zurek, Manoj Jadhav, Henry Klest)

- Space: ~120cm in z; ~30cm in y; ~30cm in x, which likely implies that we will sit downstream of the 2nd MWPC. This is the preferred scenario. (see supporting drawing on the next page)
  - The nHCal is only 3-4 hadronic interaction lengths deep, which means the hadronic showers will not be fully contained. We would therefore would like to place a tail catcher downstream of the primary prototype to measure the energy leakage.
  - In this scenario, the distance between EMCal and HCal prototypes corresponds to the actual distance between the two calorimeters in the backward endcap.
- If "120cm in z" is not possible, we can also accommodate only ~60cm in z and sit directly downstream of the EMCal.
- There will be RO cables and possibly other connections extending further in x and/or y.
- Tested detector: 2 ePIC nHCal prototypes (primary with 9 towers, tail catcher with 1 tower) - scintillator-absorber sandwich
- Depending on the existing setup at FNAL, we will need to bring a platform that allows moving our setup in x and y to allow the beam to enter at different locations
- SiPM cooling?

Proposal for an ePIC nHCal beam test at FNAL



Acceptance check



- 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): $-4.16 < \eta < -1.16$

Construction of project nHCal

- After successful beam test? Full chain test sufficient?
- When will the material be ordered? (prerequisites?) Need FDR –> CD2/3
- When will the production site be prepared?

- Preparation of FDR: draft of Money + FTEs have to be 90% final, lists in P6