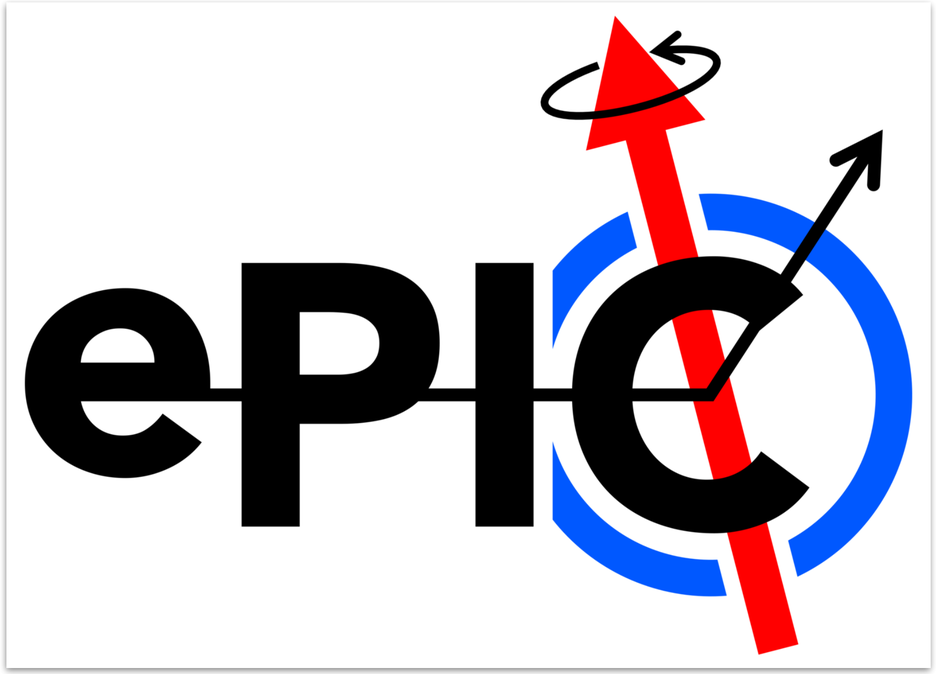


nHCal “mini Project Review”

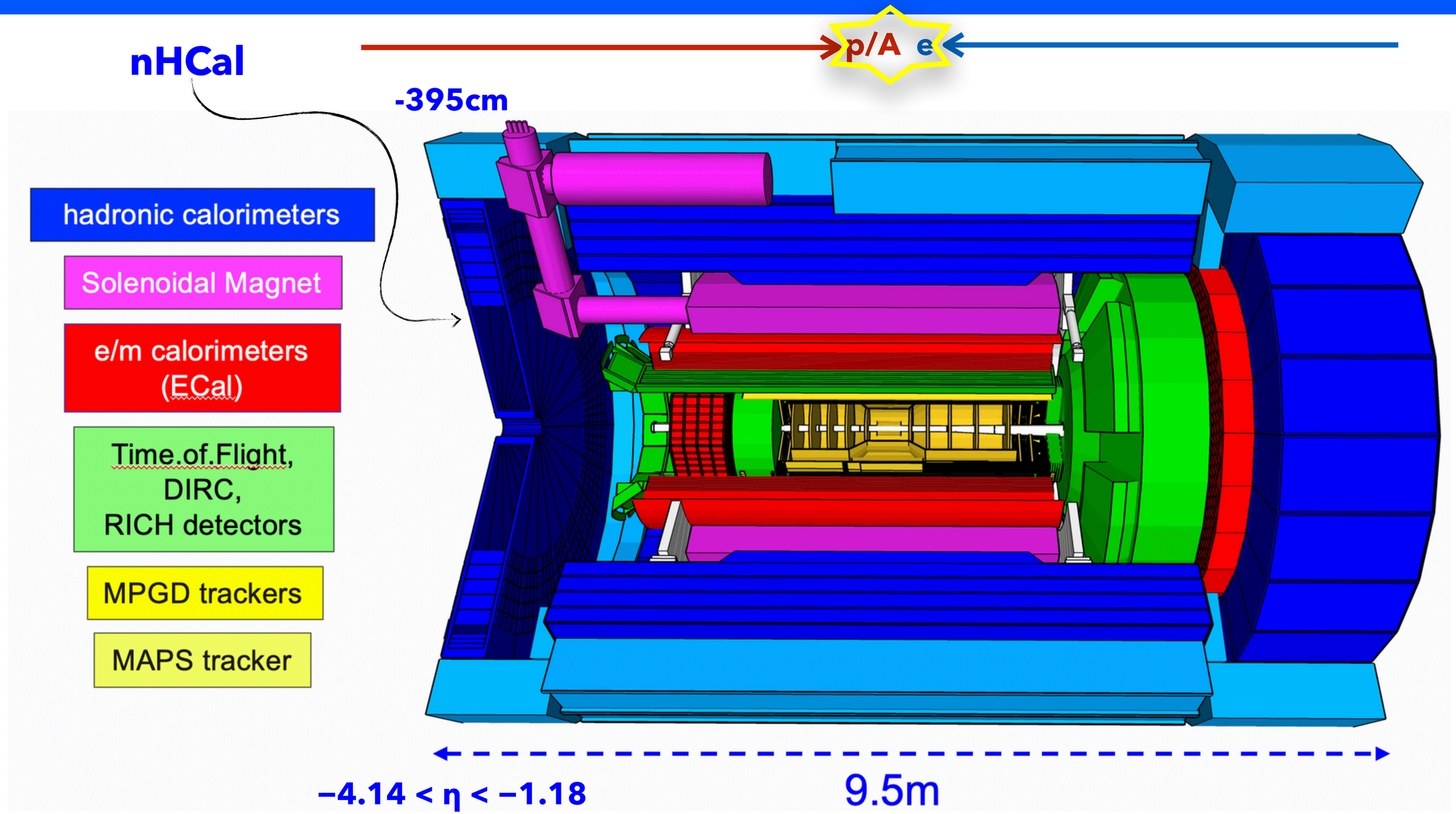
Physics requirements: Daniel Brandenburg
Technical realization: Caroline Riedl
Planning: Leszek Kosarzewski

Caroline Riedl (UIUC)
for the ePIC nHCal group
March 25, 2025

nHCal - technical realization

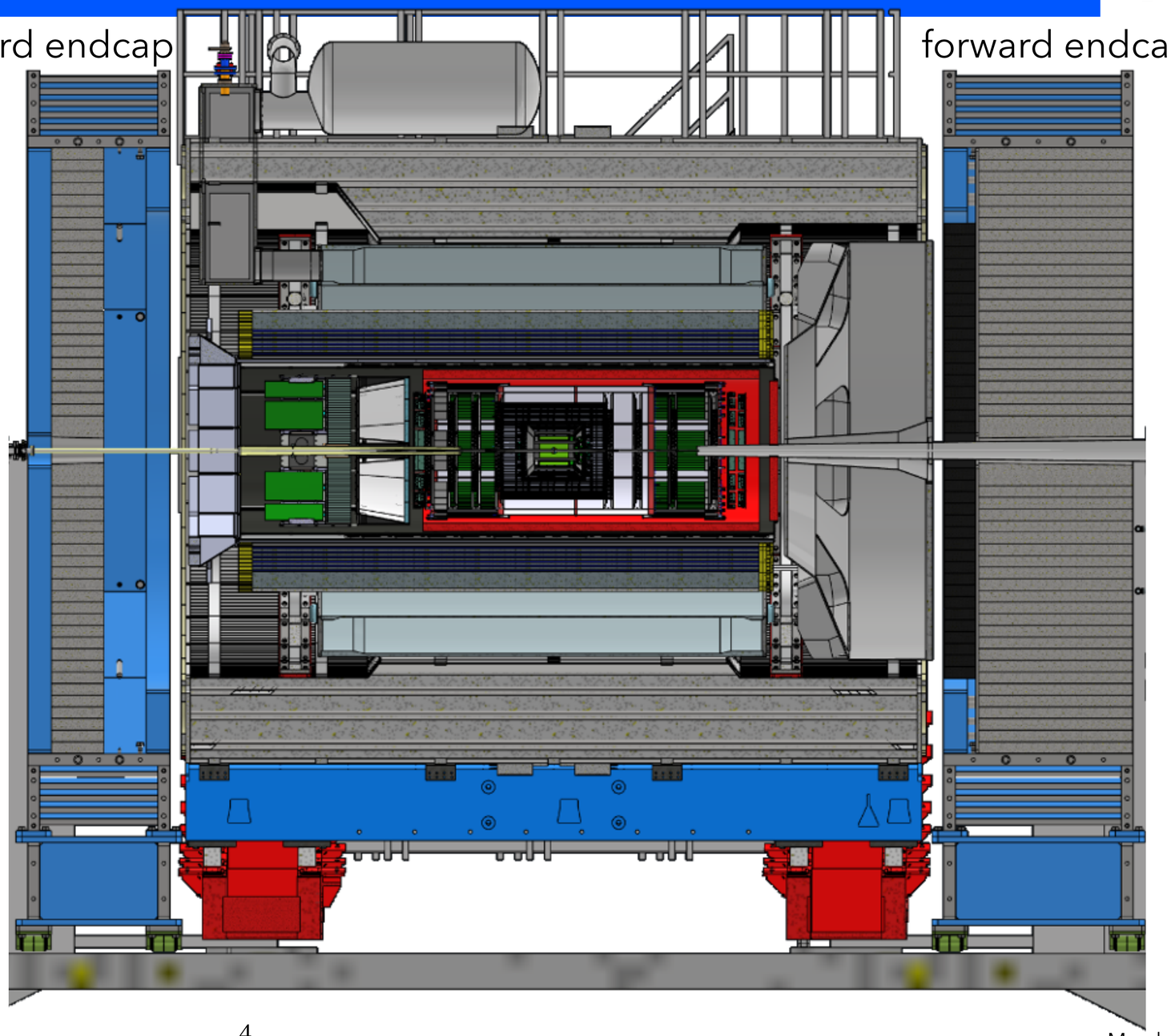
- Timeline I
- Project design
  - Purposes and requirements
  - Parameters
  - Materials and vendors
- Performance evaluation
- Timeline II

The backward (electron-going) hadronic calorimeter - nHCal

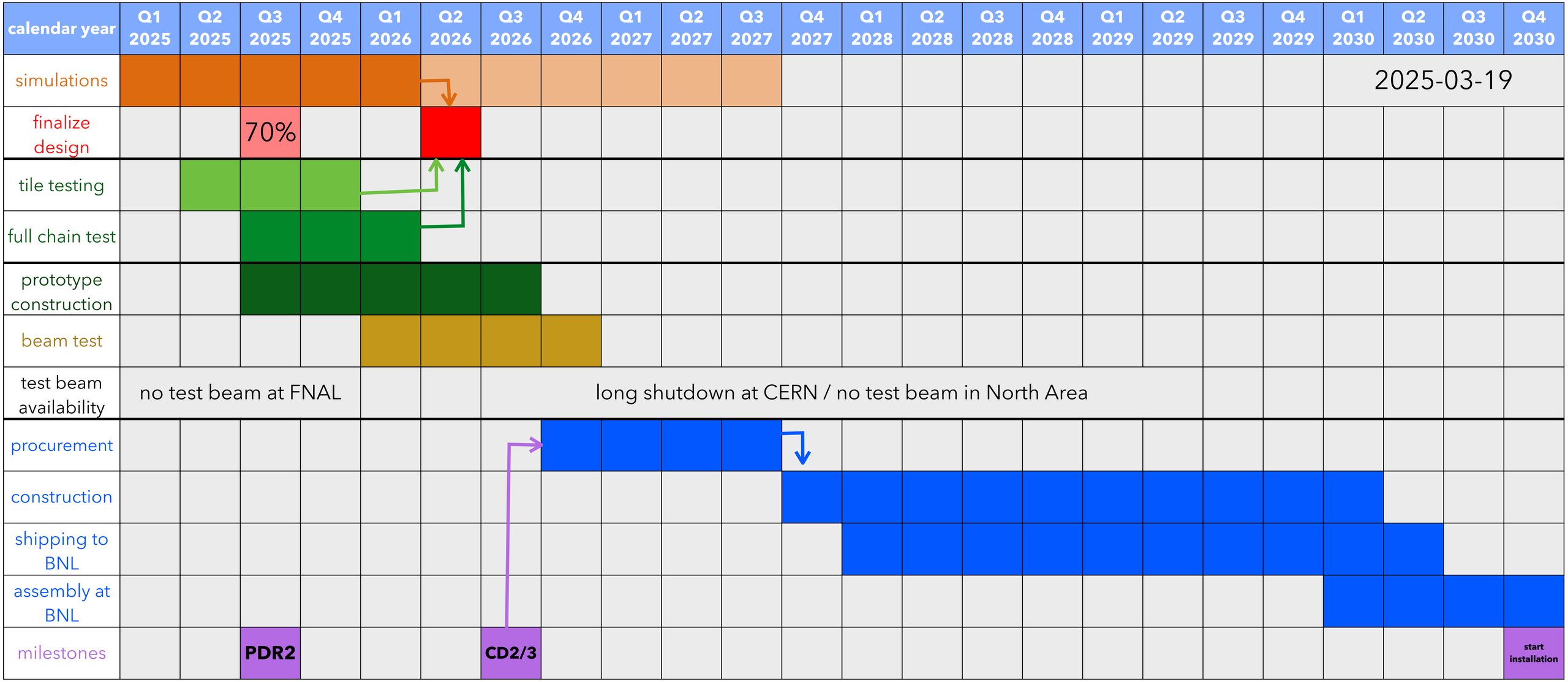


nHCal in ePIC

- The nHCal is surrounded by an outer collar, backed by a flux return plate and has an oculus ring placed in front.
- The flux return is decoupled from the nHCal ☞ need to use non-magnetic steel as absorber.



nHCal timeline



nHCal project design - purposes and requirements

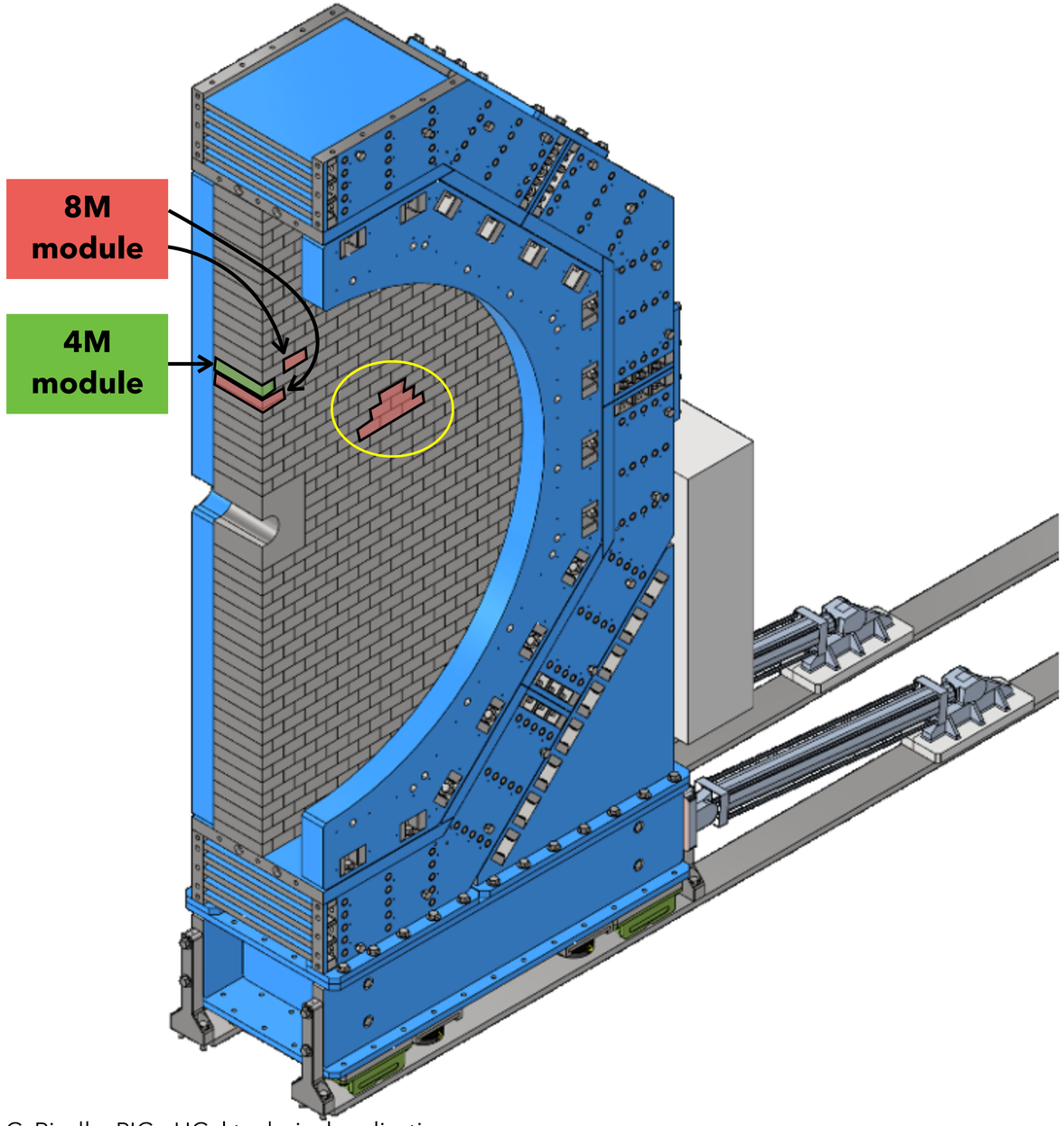
We want to do this physics + crucial to EIC Mission = **Detector Requirements**

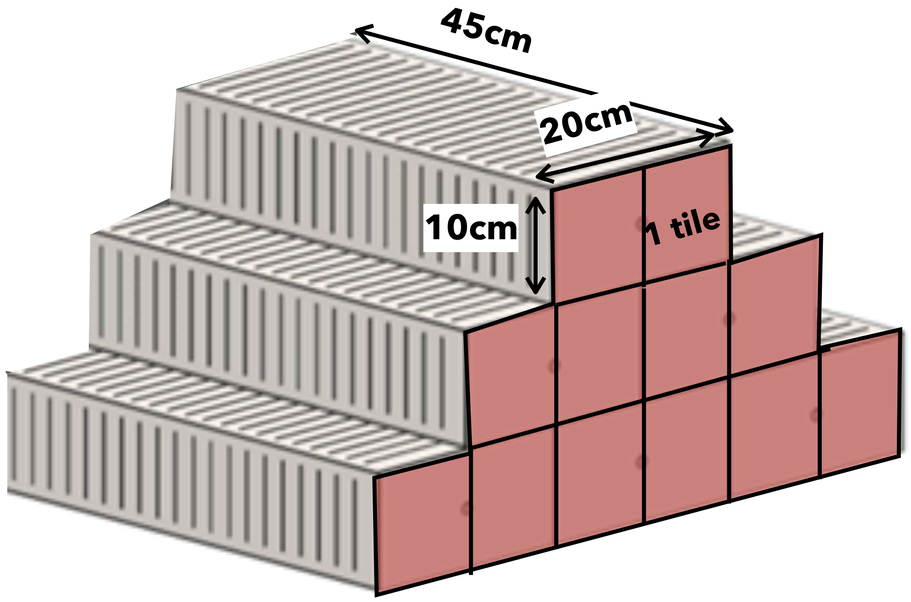
nHCAL Needed for:

- **Low-x & Q^2, high y**
- **Diffraction**
- **Vector Mesons**
- **Dijets**
- **Charged Jet Measurements**
- **Scattered Electron ID**
- **Hadron-beam background mitigation**

- Good μ/π separation of tracks with MIP signal
- Good spatial resolution to distinguish neutral/charged hadrons
- High efficiency for low-energy neutron detection (track-cluster matching)
- Good timing resolution

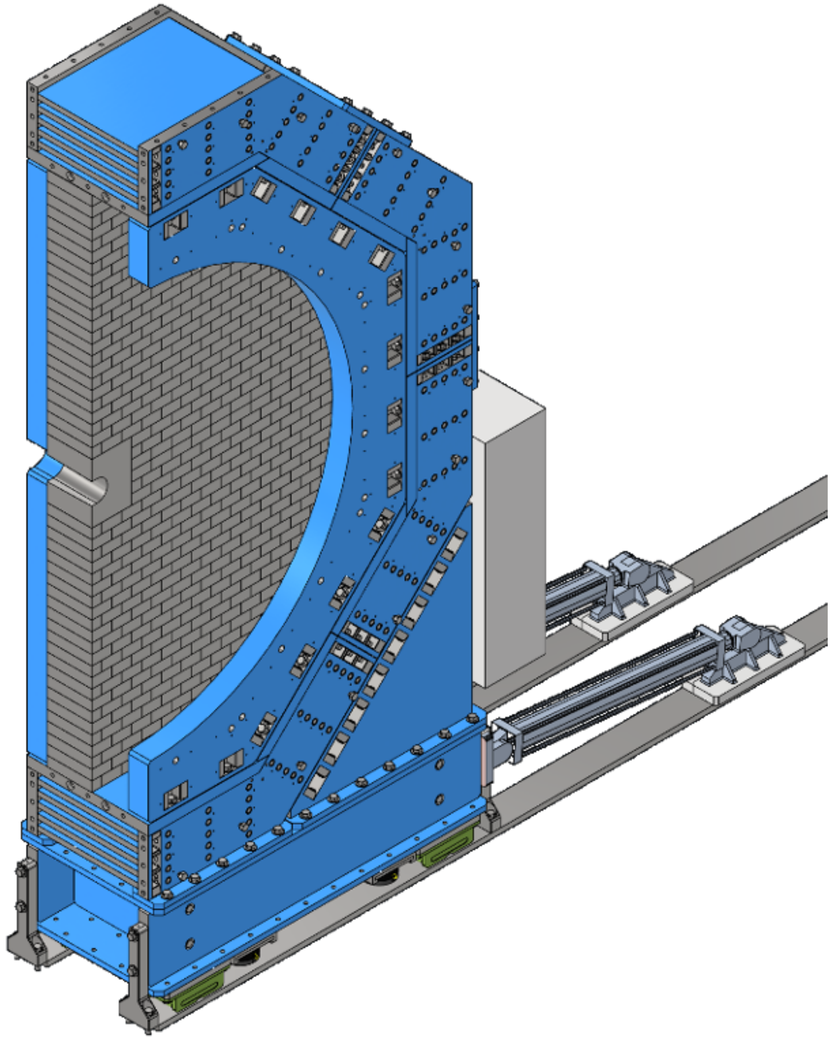
nHCal 8M module





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

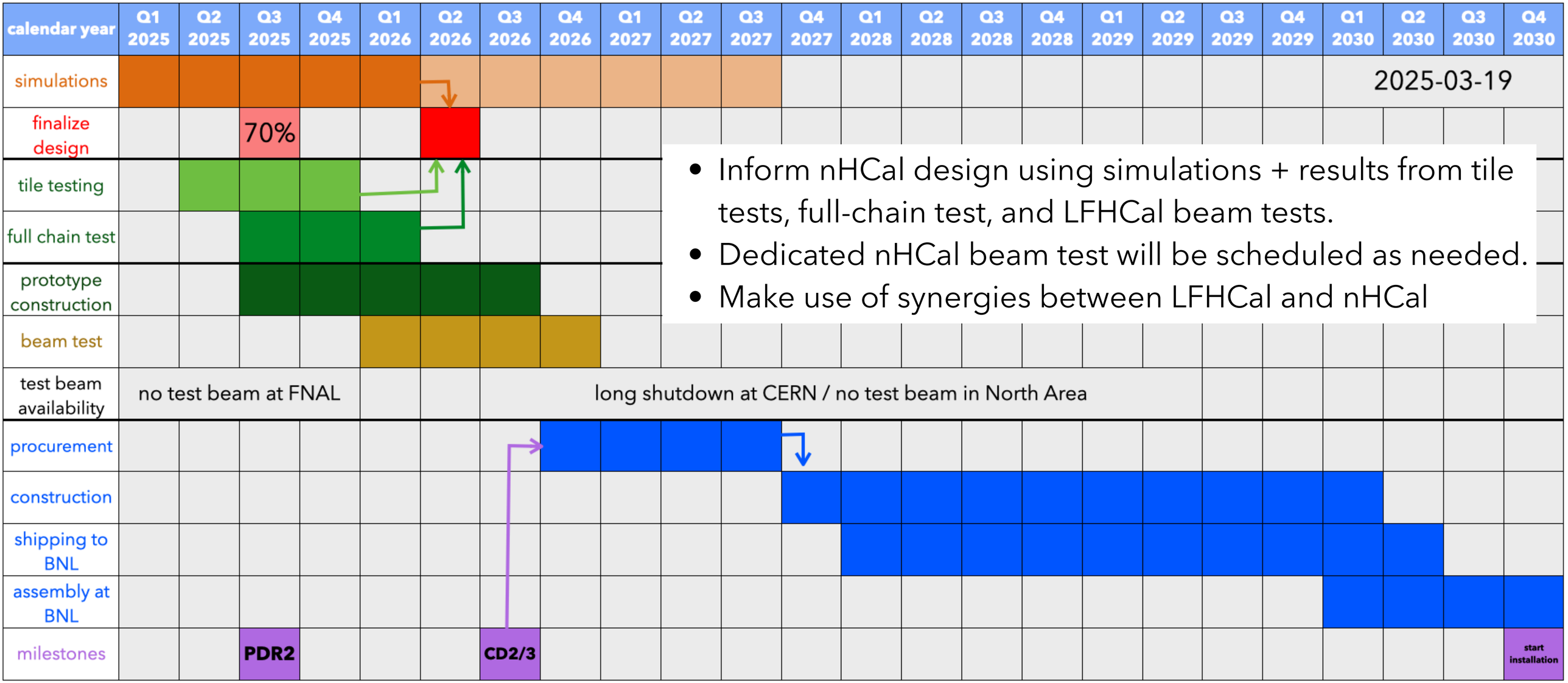
nHCal performance evaluation

- Standalone tile testing using cosmic rays and radioactive source.
  - Purpose of the tests: evaluate performance of different tile configurations and sizes
  - Tiles of different sizes (5x5, 10x10) and thickness (4, 8, 16mm) were ordered by Project.
- Looking into what the best approaches are, cost- and physics-wise, which includes exploring different techniques
- Exploring the necessity to build a prototype and test beam opportunities
- Instead, set up full-chain test?
- A detailed plan will be made including required resources (FTE and $) and a time sequence.

Test beams for nHCal

- Goal of beam tests: verify simulations
  - Measure position resolution, e/h ratio, sampling fraction.
  - For an nHCal-dedicated test beam, we need to build a prototype and find hadron test-beam time (currently not easy)
- Towards the final design decision - stand-alone tile testing, full-chain tests, and beams tests
  - LFHCal and nHCal parameters not identical
  - (Continue to) support LFHCal team in their future test beam campaigns
  - Schedule dedicated beam test as needed

nHCal timeline - returning to the bigger picture

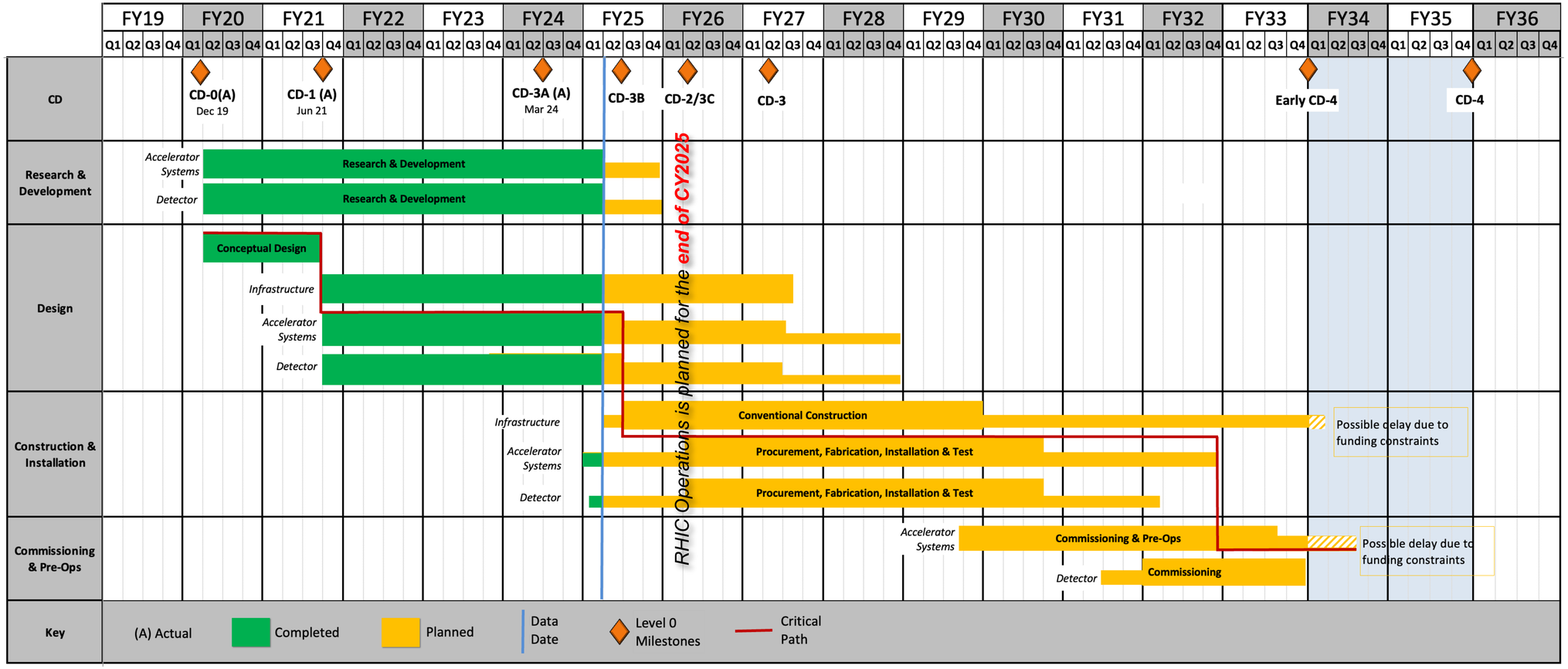


- Inform nHCal design using simulations + results from tile tests, full-chain test, and LFHCal beam tests.
- Dedicated nHCal beam test will be scheduled as needed.
- Make use of synergies between LFHCal and nHCal

extra slides

Reference Schedule

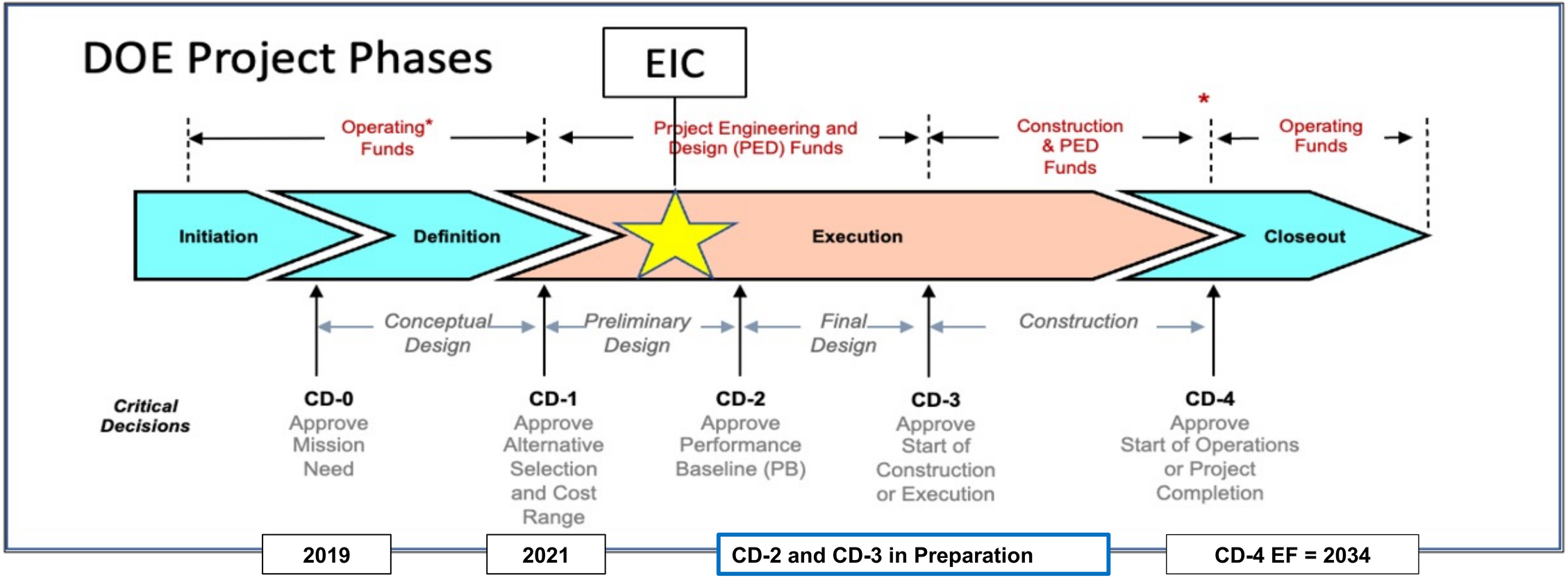
Plans for CD-2 and CD-3 originally aligned with conclusion of RHIC.



Critical Path is Accelerator Systems

Science operations start in roughly a decade

EIC Project-Critical Decisions and Plans

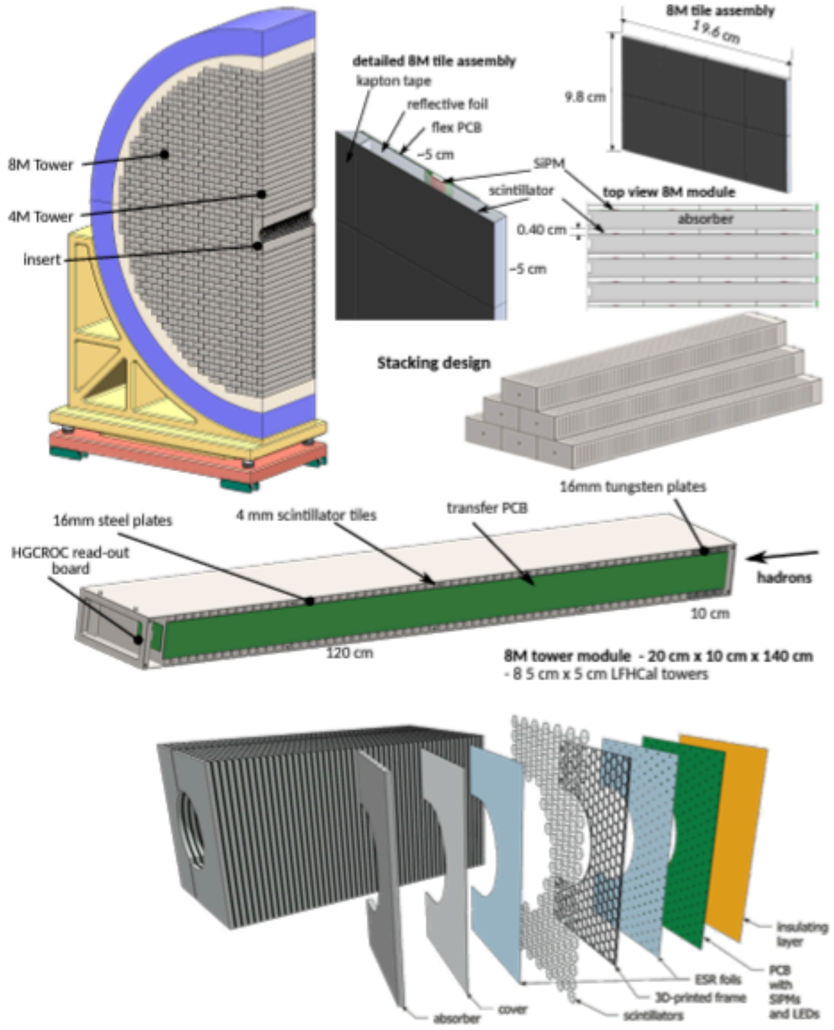


- **CD-3A, Long-Lead Procurement, approved March 2024. Excellent use of IRA funding.**
- **CD-3B, Long-Lead Procurement, approval planned for March 2025 (ESAAB)**

LFHCAL: The General Idea

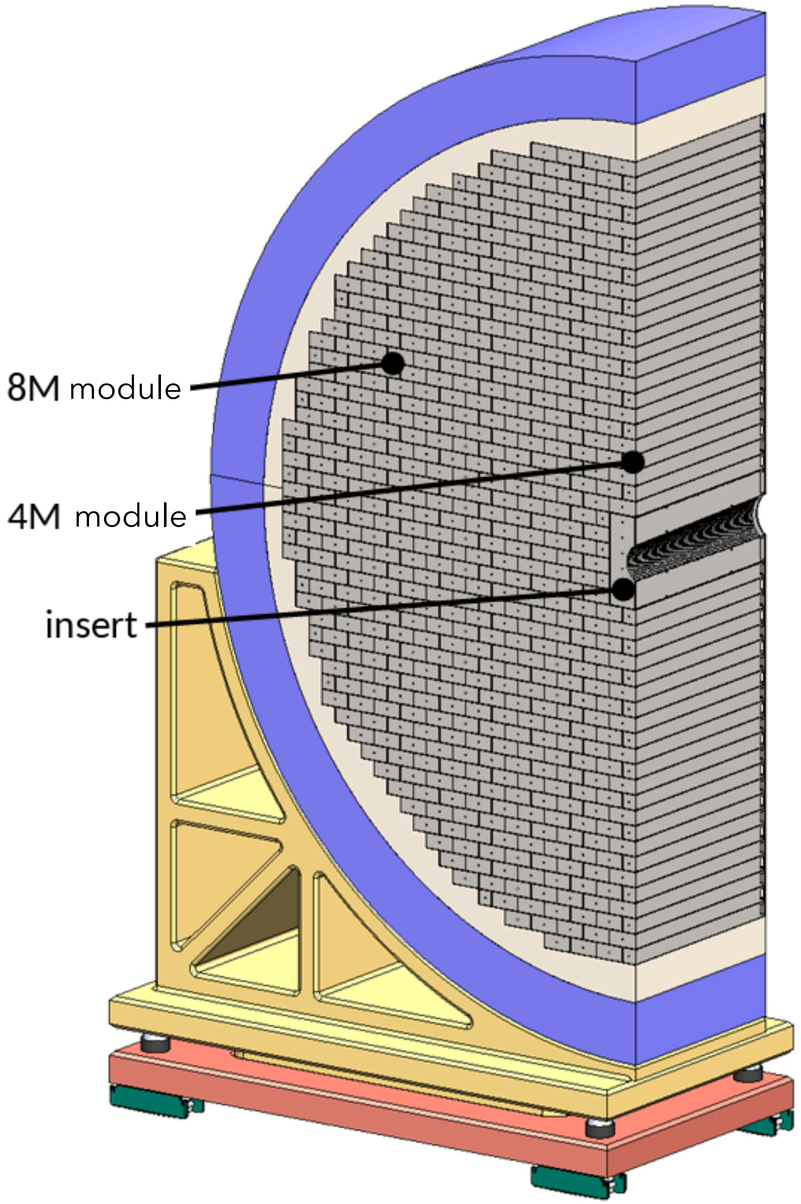
Concept:

- 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

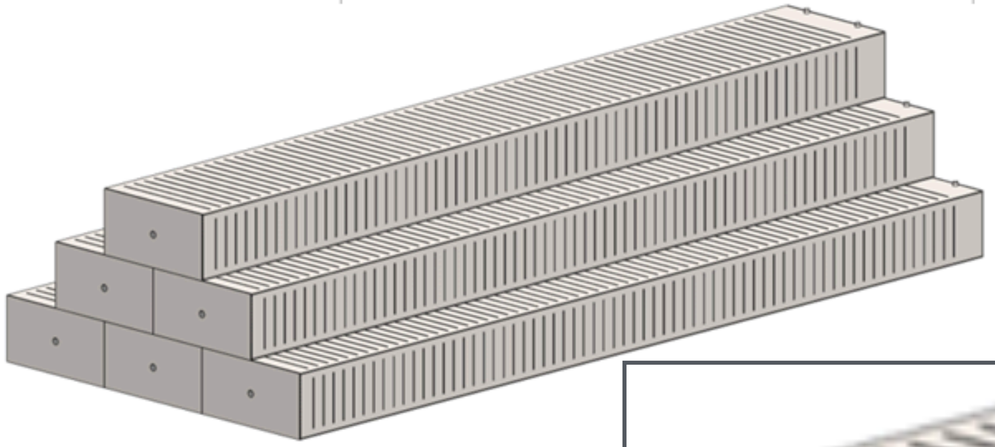


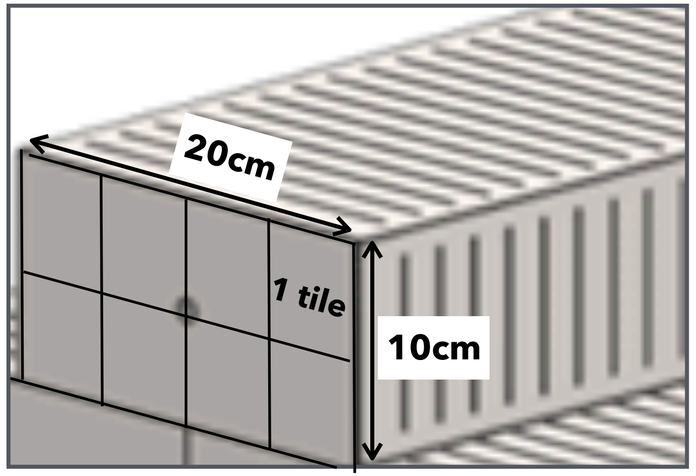
- https://indico.slac.stanford.edu/event/8288/contributions/7678/attachments/3636/9951/cpad23_lfhcal.pdf

LFHCal



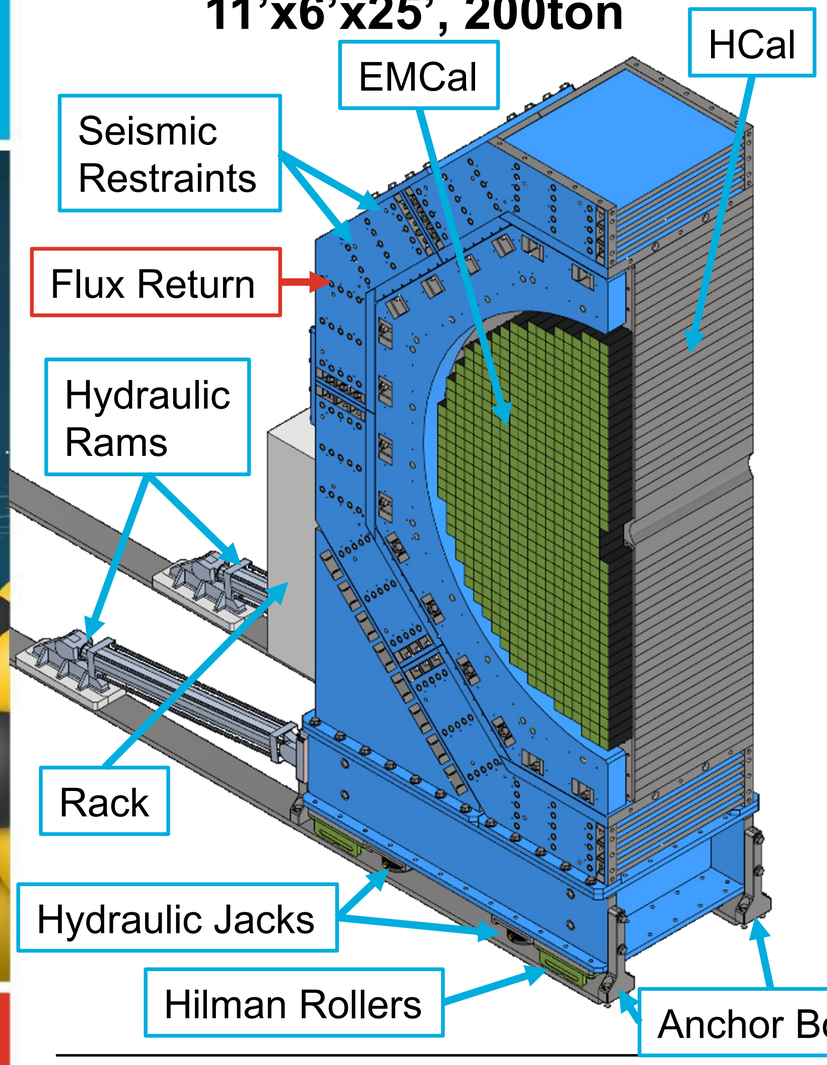
- The nHCal will also contain 8M and 4M modules
- No “insert modules” since radiation damage is less of a worry in the backward electron-going direction





Endcap Interfaces

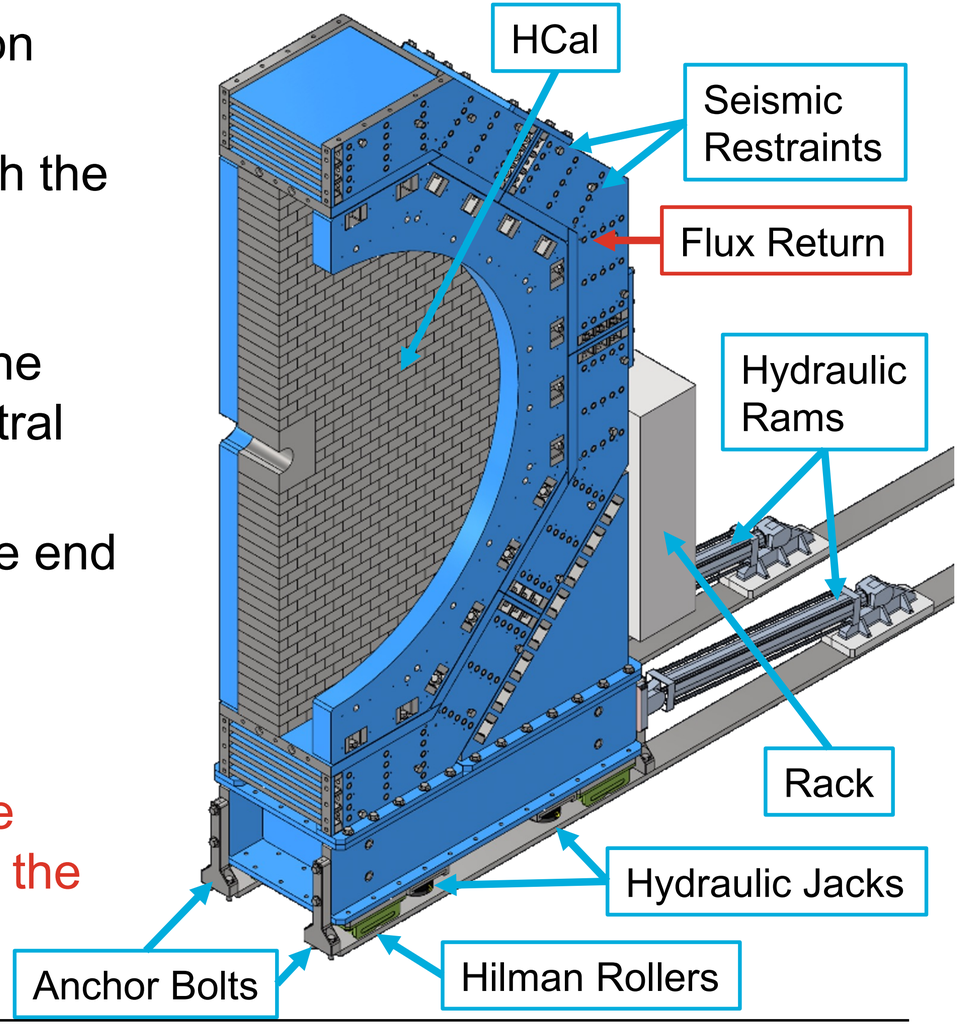
Forward Endcap (FE)
11’x6’x25’, 200ton



Description

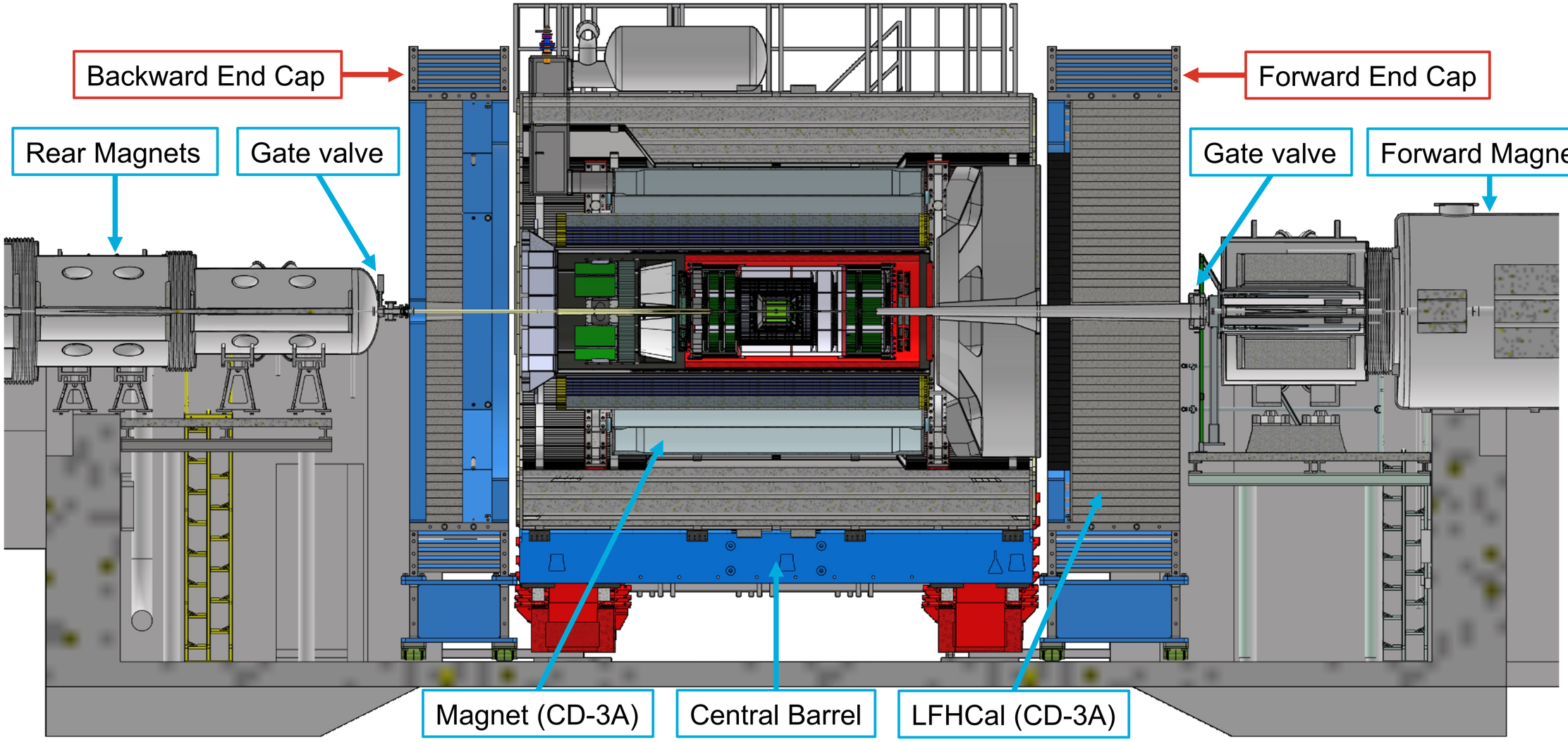
- HCal, EMCal and Lepton are end cap detectors
- Seismic restraints attach the end caps to the central barrel
- Anchor bolts tie down the end caps when the central barrel isn’t available
- Hydraulic rams push the end caps on Hilman rollers
- Hydraulic jacks lift the detector for alignment
- Flux return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

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



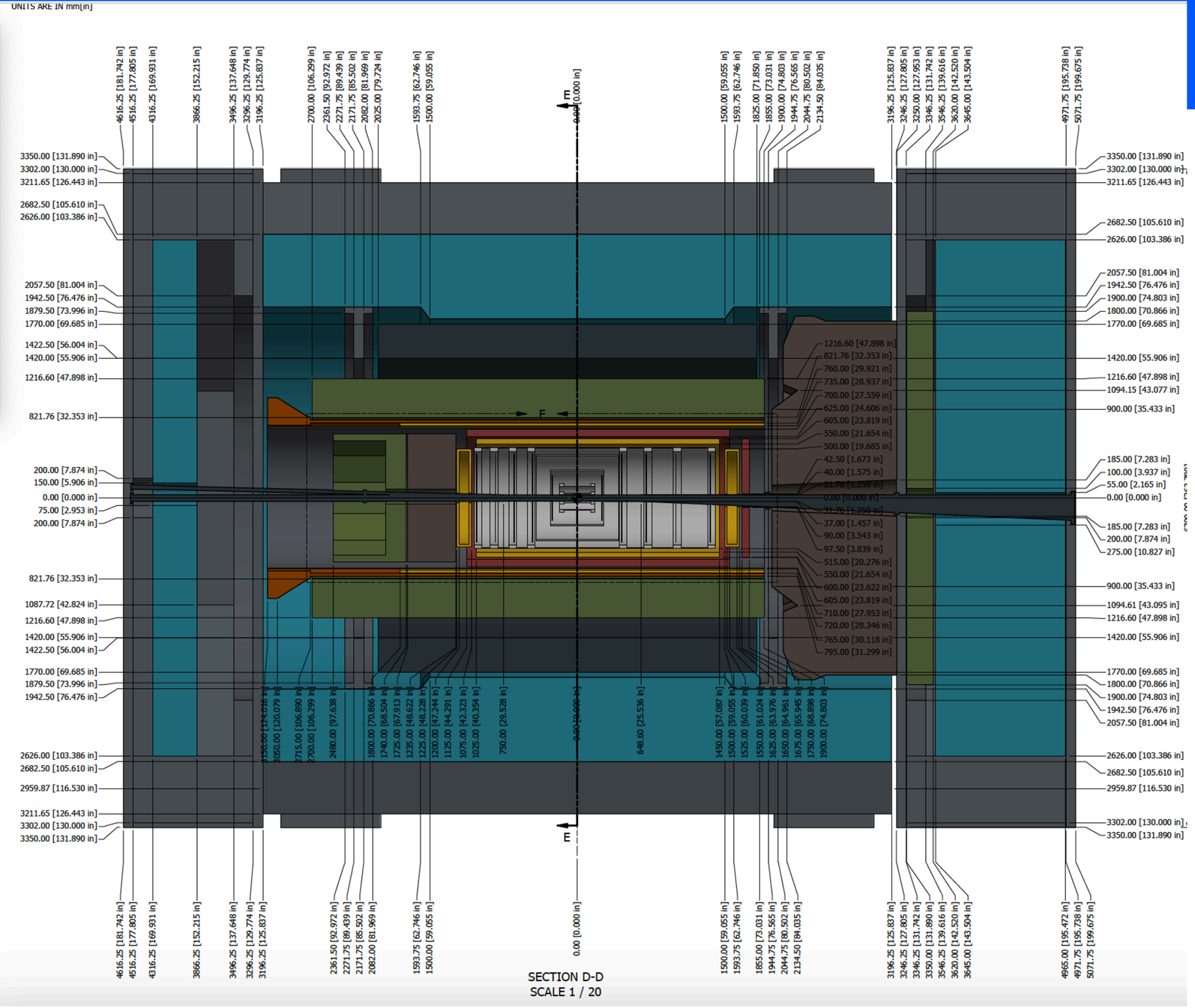
https://agenda.infn.it/event/43344/contributions/252099/

Integration Model in Experimental Hall



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

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



MAGNET & BEAM PIPE	FLUX RETURN & CARRIAGE	HCAL
EMCAL	RICH	DIRC
MPGD	AC LGAD	SVT

COLOR CODE

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

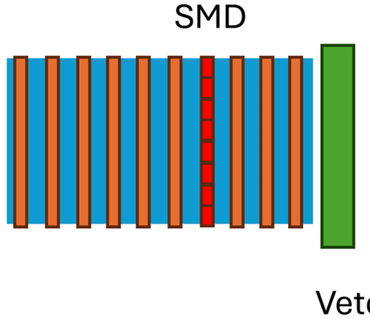
Previous discussion between nHCal DSC and Project

- 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/

nHCal project design - possible design modifications

- 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++

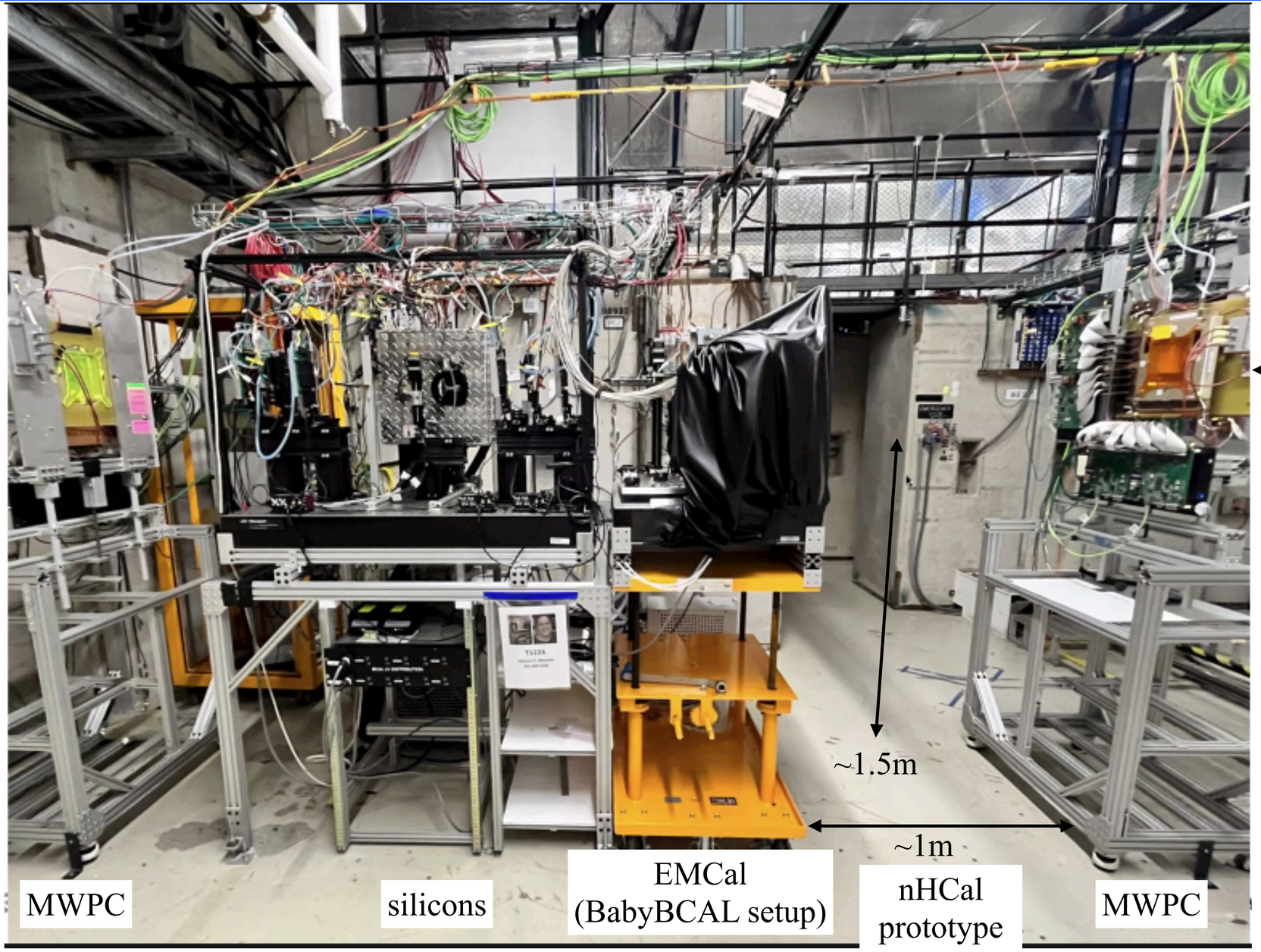
See also https://cernbox.cern.ch/external/public/wRuLiYuAwqgS5xx/InternationalTBplan-worldwide.xlsx

- 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)

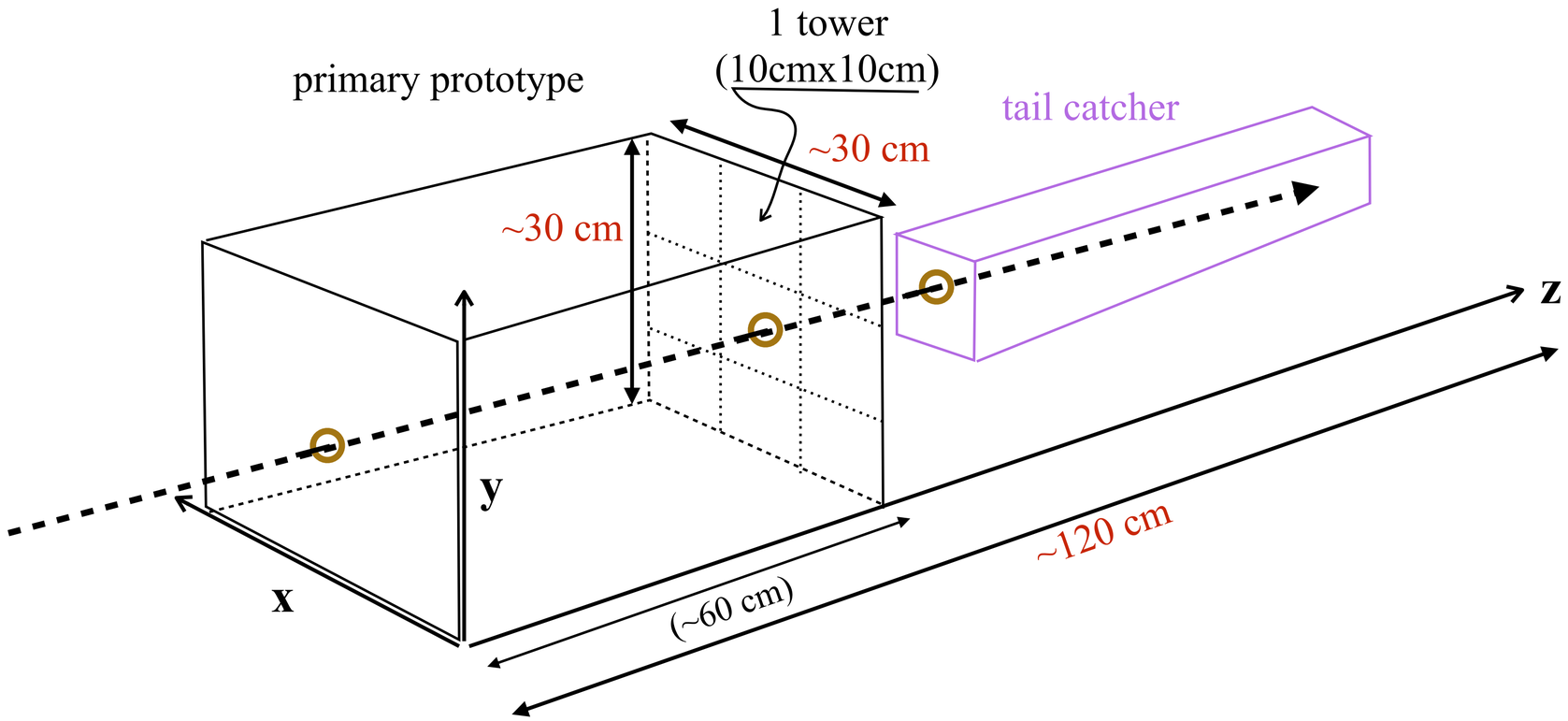


Proposal for an ePIC nHCal beam test at FNAL

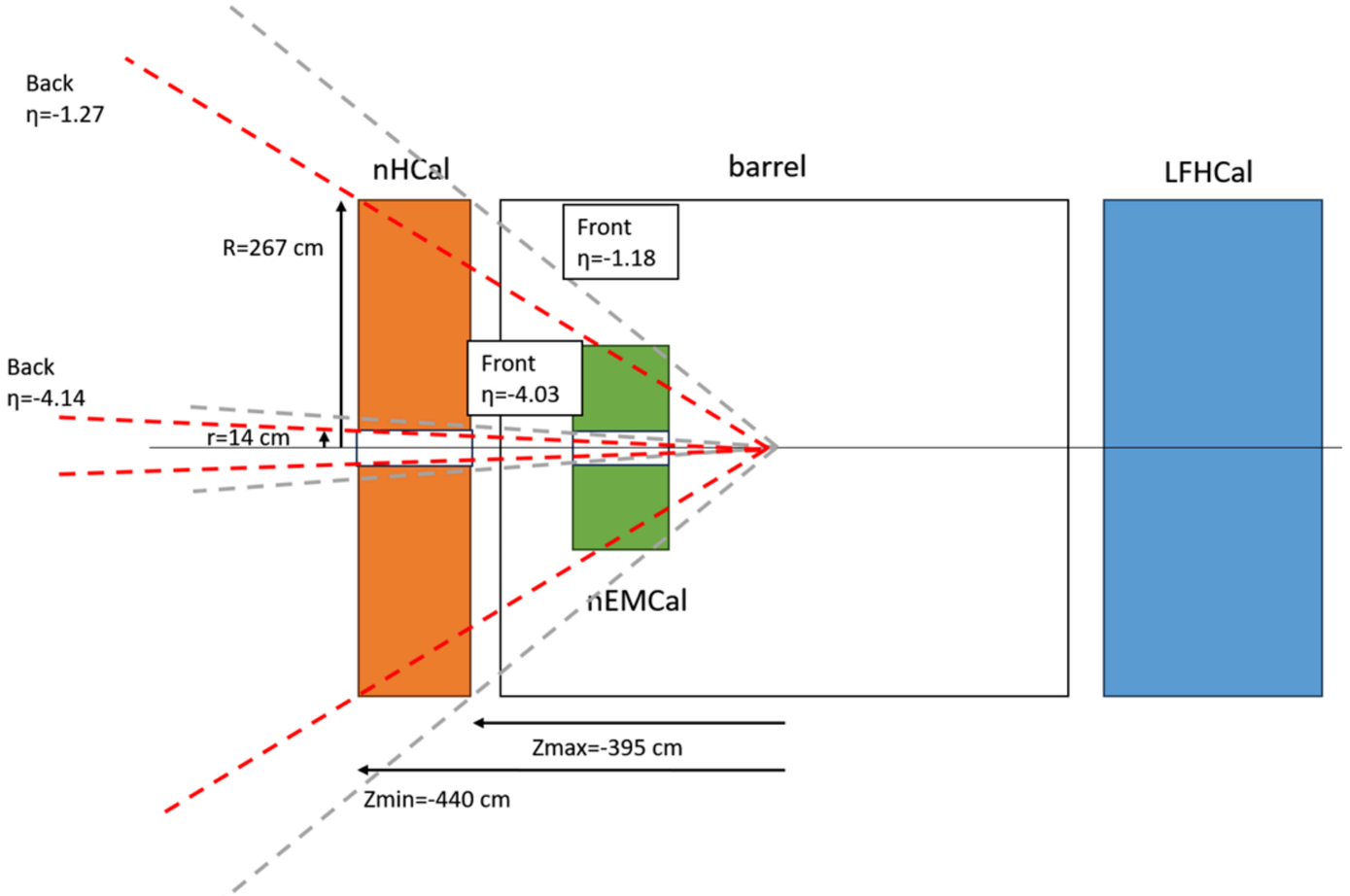
(August 2024 - Caroline Riedl in communication with Sylvester Joosten, Maria Zurek, Manoj Jadhav, Henry Klest)

- 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