Brookhaven National Laboratory
Jefferson Lab
U.S. DEPARTMENT of ENERGY | Office of Science

nHCal (backward hadronic calorimeter)

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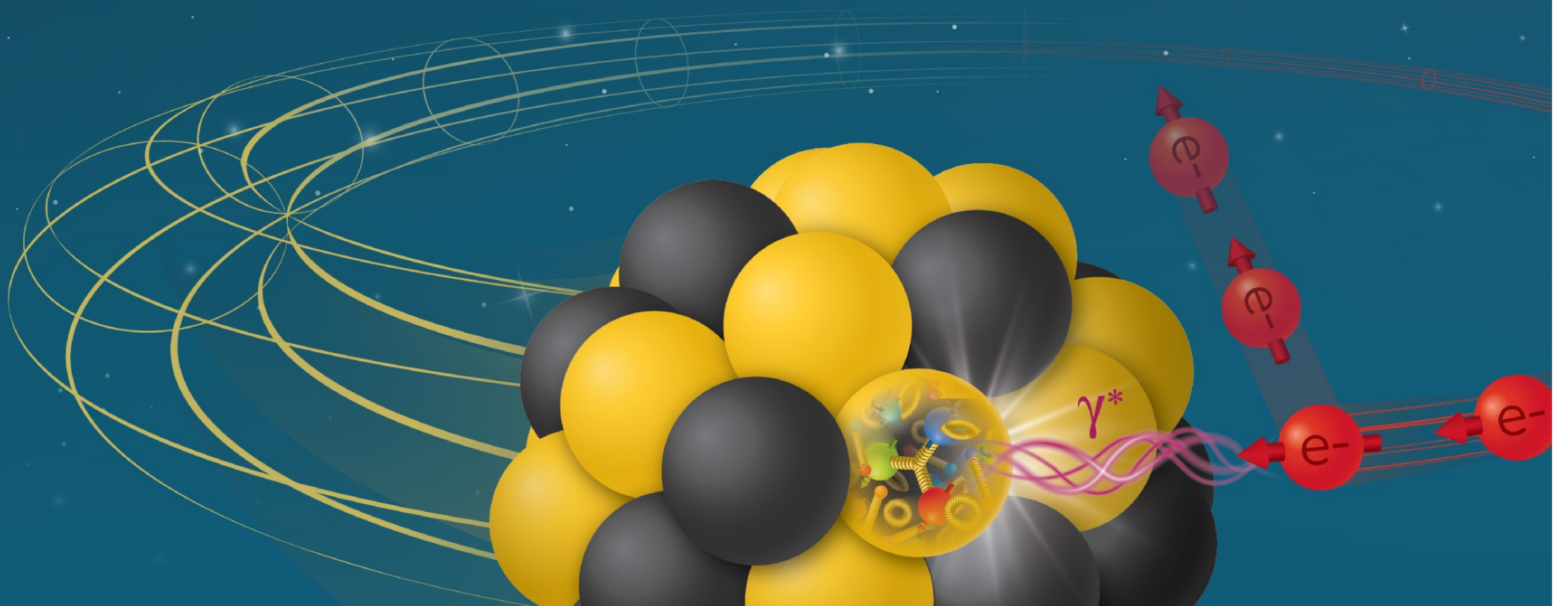
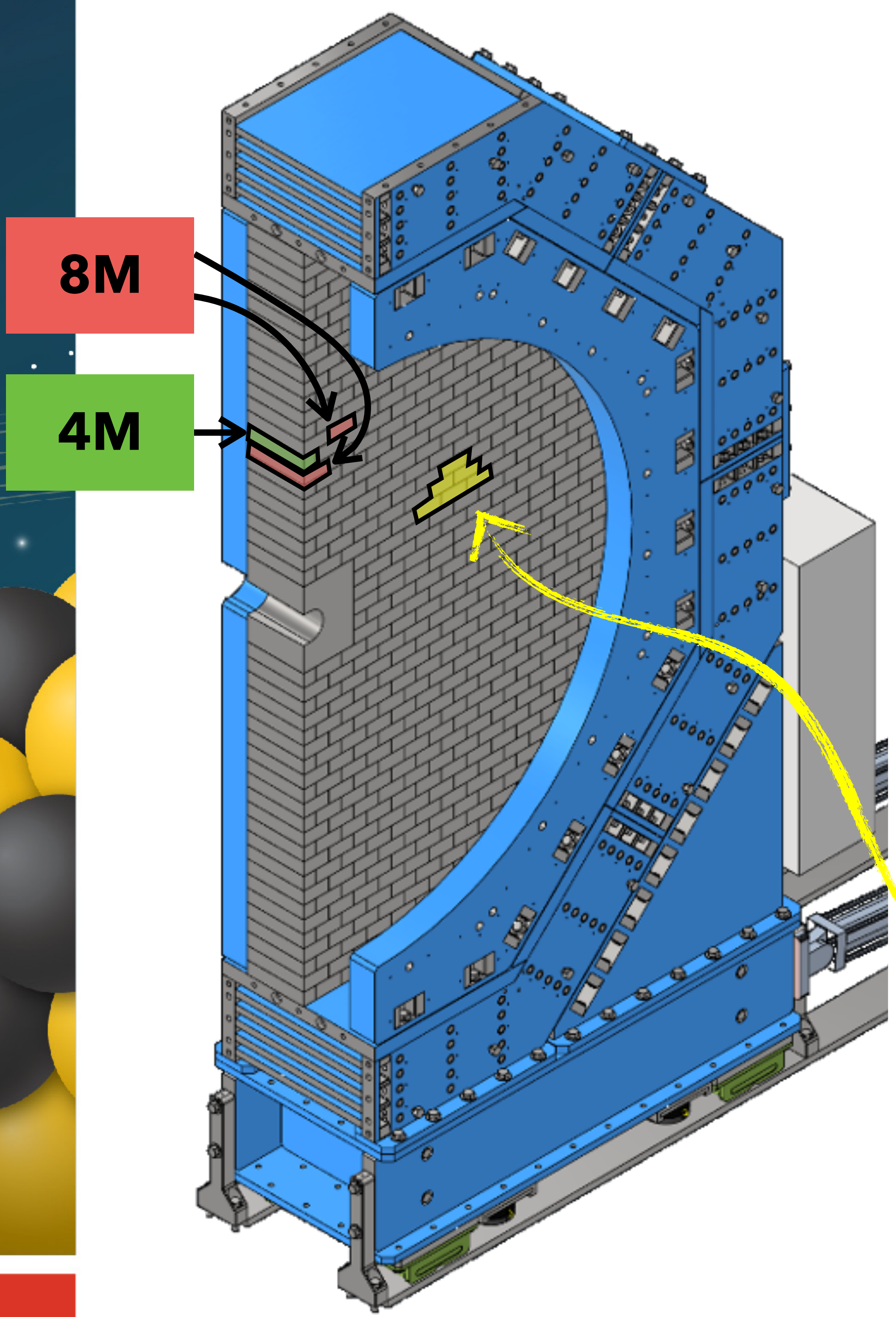
10th EIC DAC Review
June 11th – 13th, 2025



Electron-Ion Collider

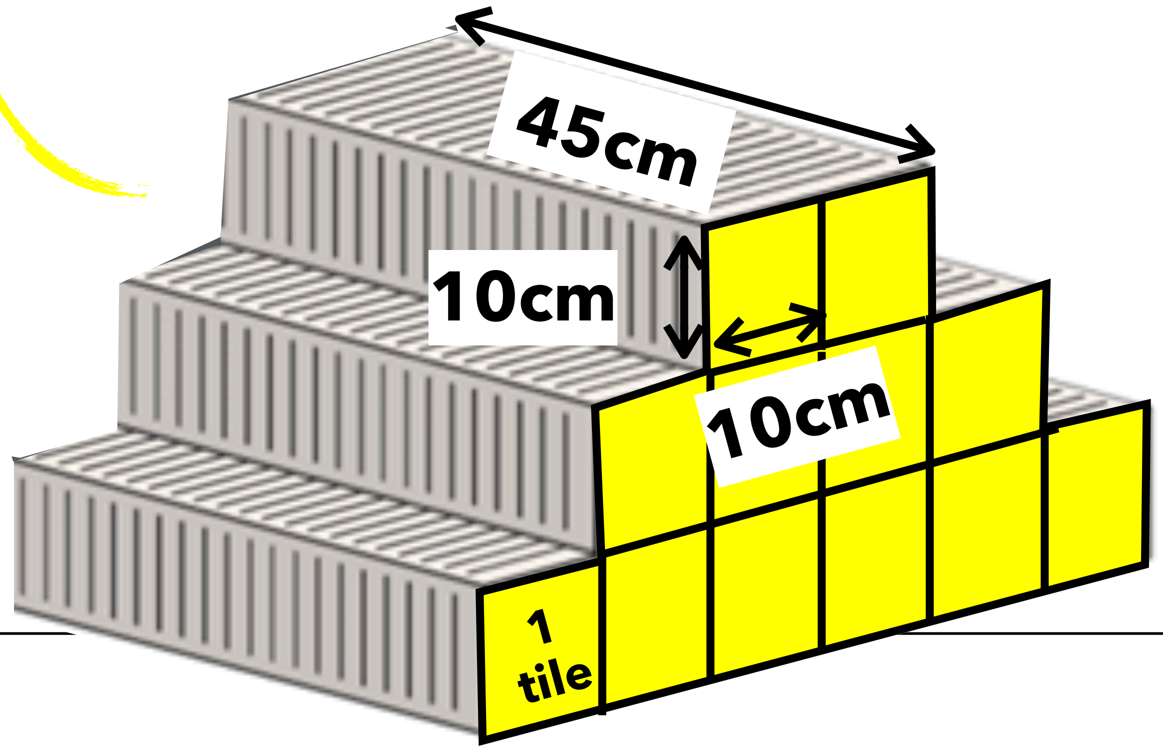
Backward (electron-going) hadronic calorimeter - **nHCal**

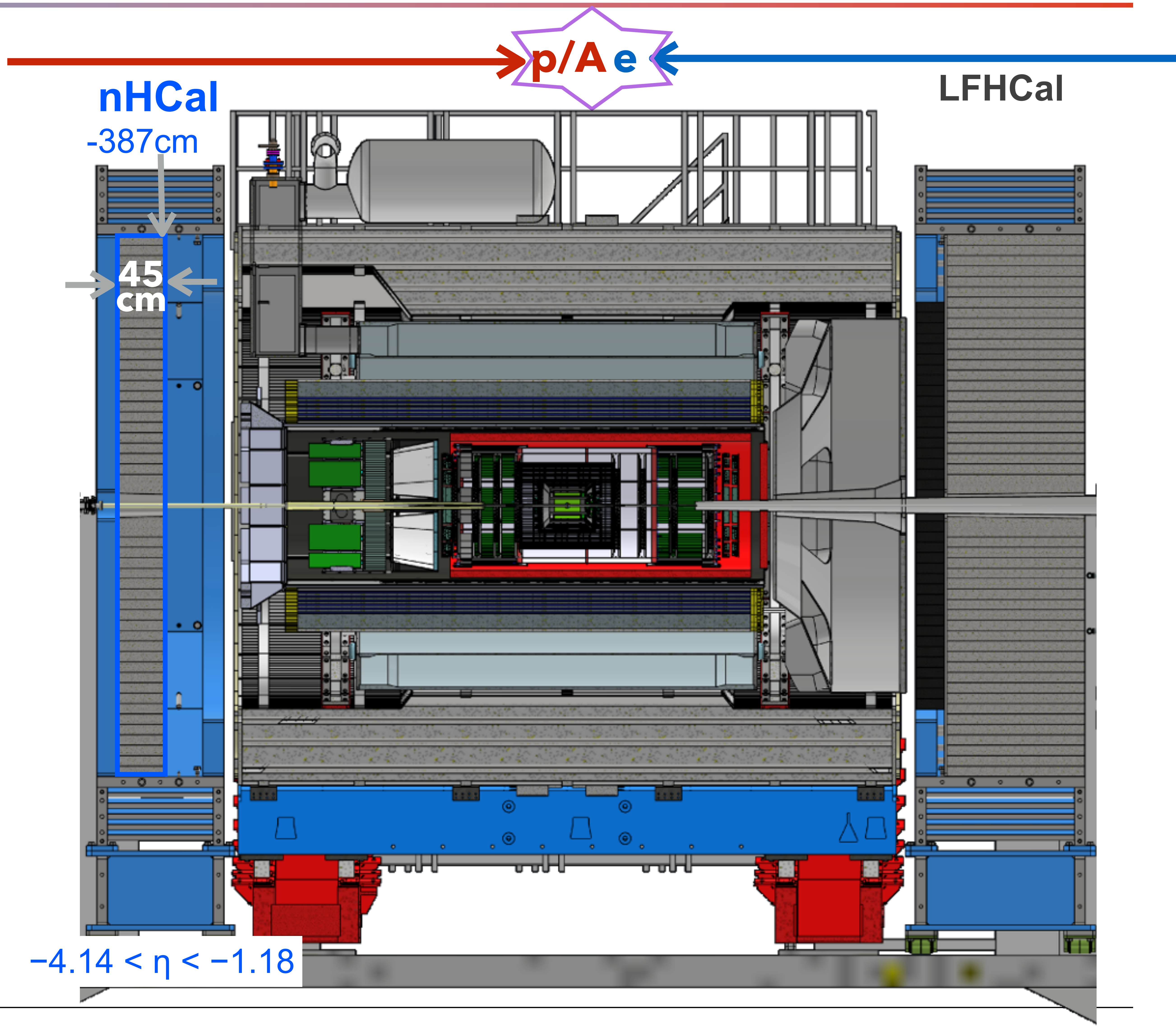
- Tail catcher calorimeter with sampling approach, alternating Fe / SciTiles layers
  - Synergies with LFHCal (choice of technology)



- Interaction lengths: 2.4 (LFHCal: 6)
- Default length = 45cm, up to ~70cm available
- Default design:

10 layers of each
4 cm steel +
4 mm scintillator





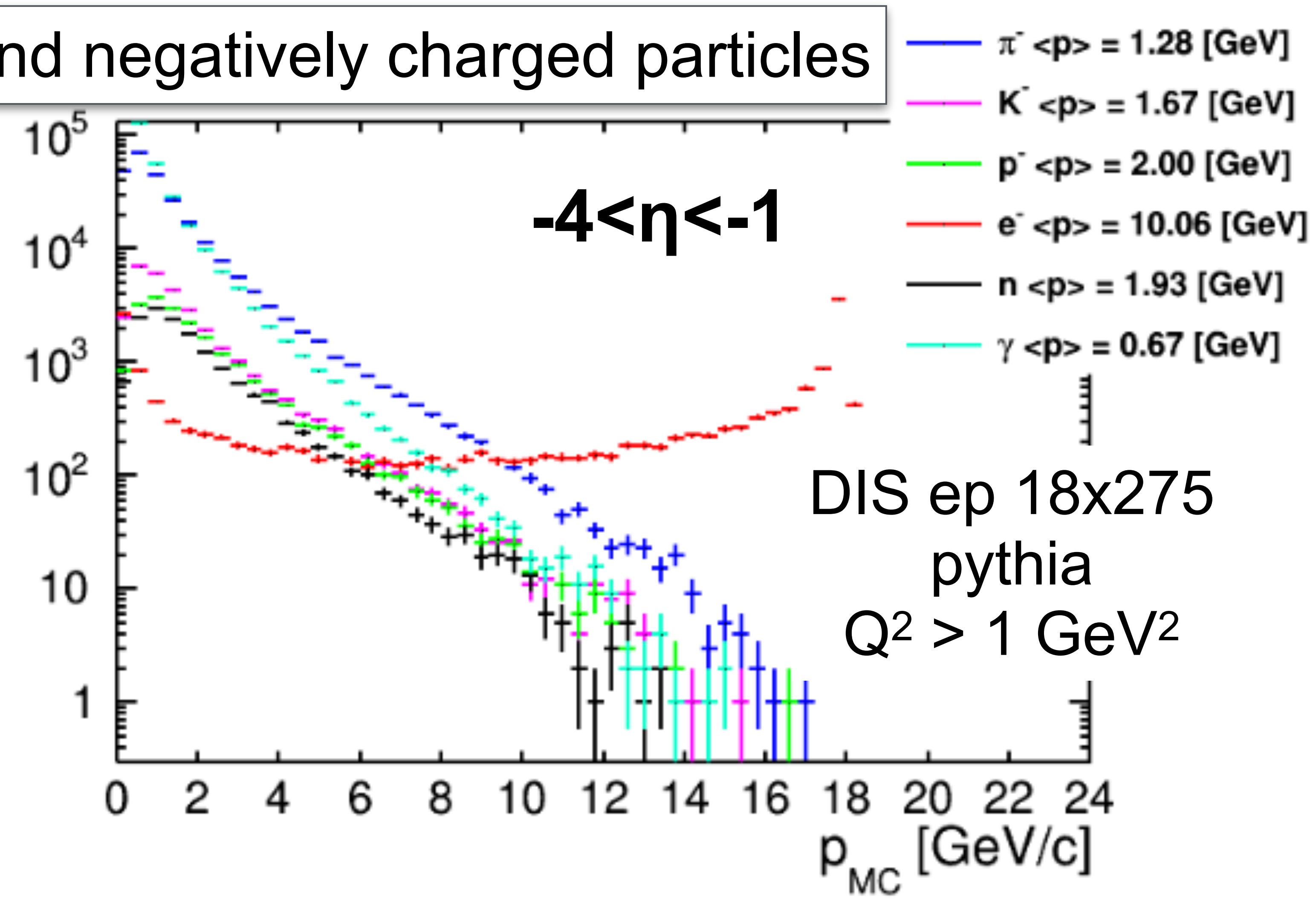
Main purpose of nHCal

- Tail catcher calorimeter in the backward (electron-going) direction
- Important for low-x and -Q2, high-y (high gluon densities) - core aspects of EIC physics mission
  - Diffraction, neutral and charged jets
  - Neutron detection and muon ID
- Lessons from HERA / H1 backward SPACAL

NIMA 386 (1997), 397-408
PLB 665 (2008), 139-146

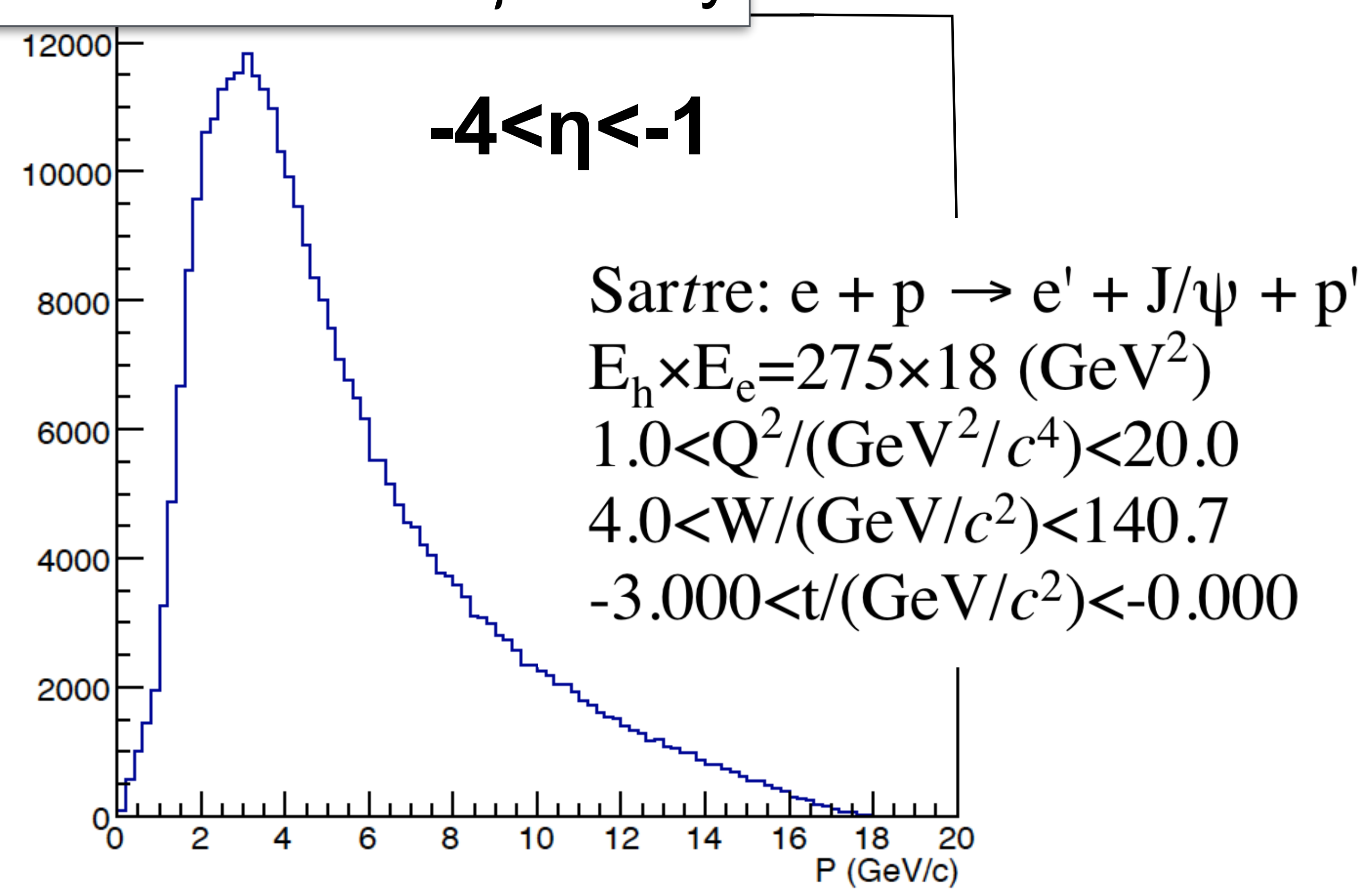
neutrons and negatively charged particles

neutrons in the nHCal:
<p>=1.9 GeV/c
<E>=2.2 GeV



muons from diffractive J/ψ decay

muons in the nHCal:
<p>=5.3 GeV/c
<E>=5.3 GeV



nHCal design optimization via simulations - overview

- **Is the design of the ePIC detector and its sub-systems appropriate and progressing well?**
- Design optimization →
- Variations from default: transverse tile size, number of layers, scintillator & absorber thickness
- Dedicated simulations
  - "Single particle" - in progress
  - Then full simulations with background

Physics impact → / Design parameter ↓	σ_E/E	Eff	μ/π sep.	λ_{int}
Gross length	x	x		
Tile configuration	x	x		
Z-layer readout	x		x	
Sampling fraction, absorber/scintillator ratio				x
Absorber material	x			x

5x5 or 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		

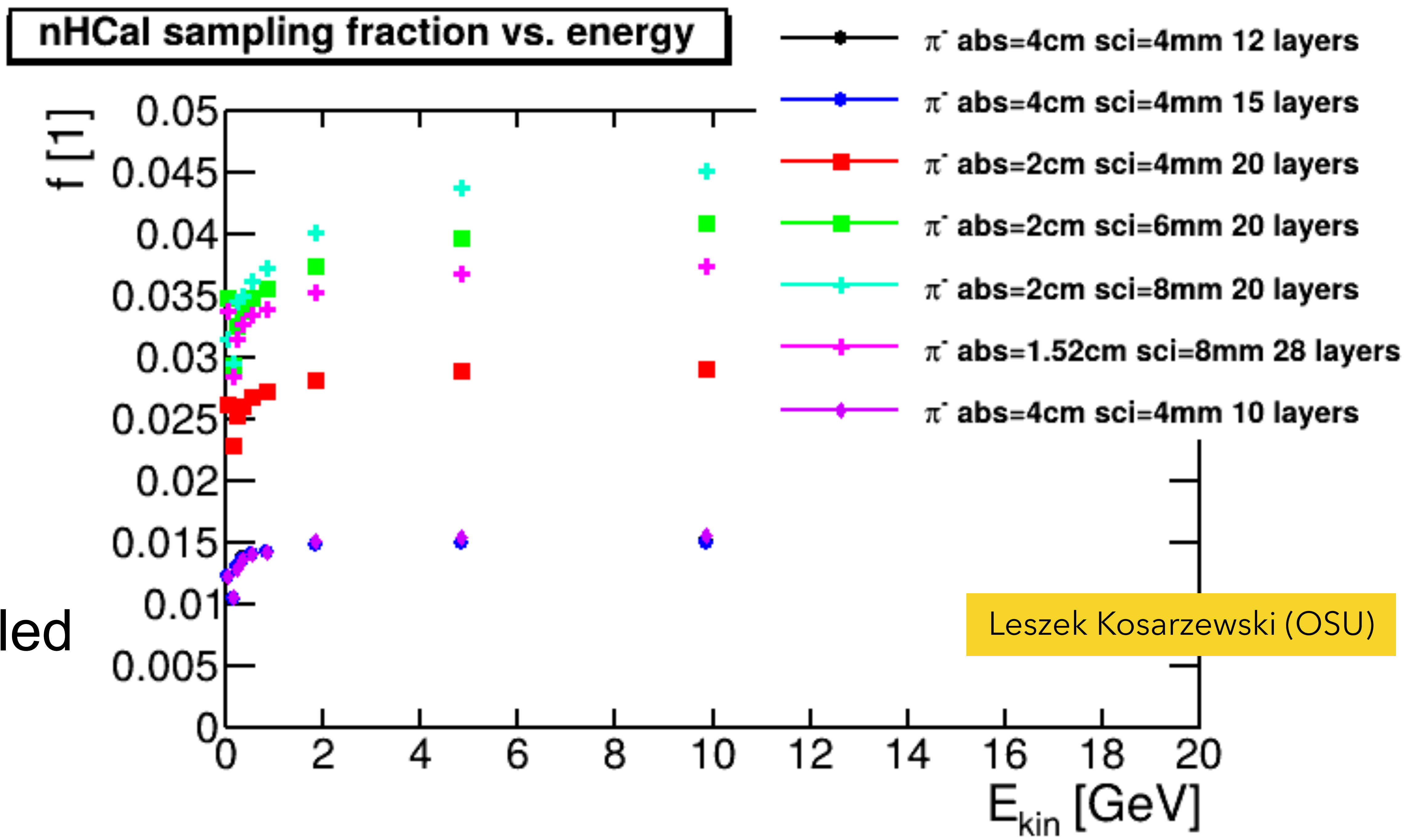
gross length

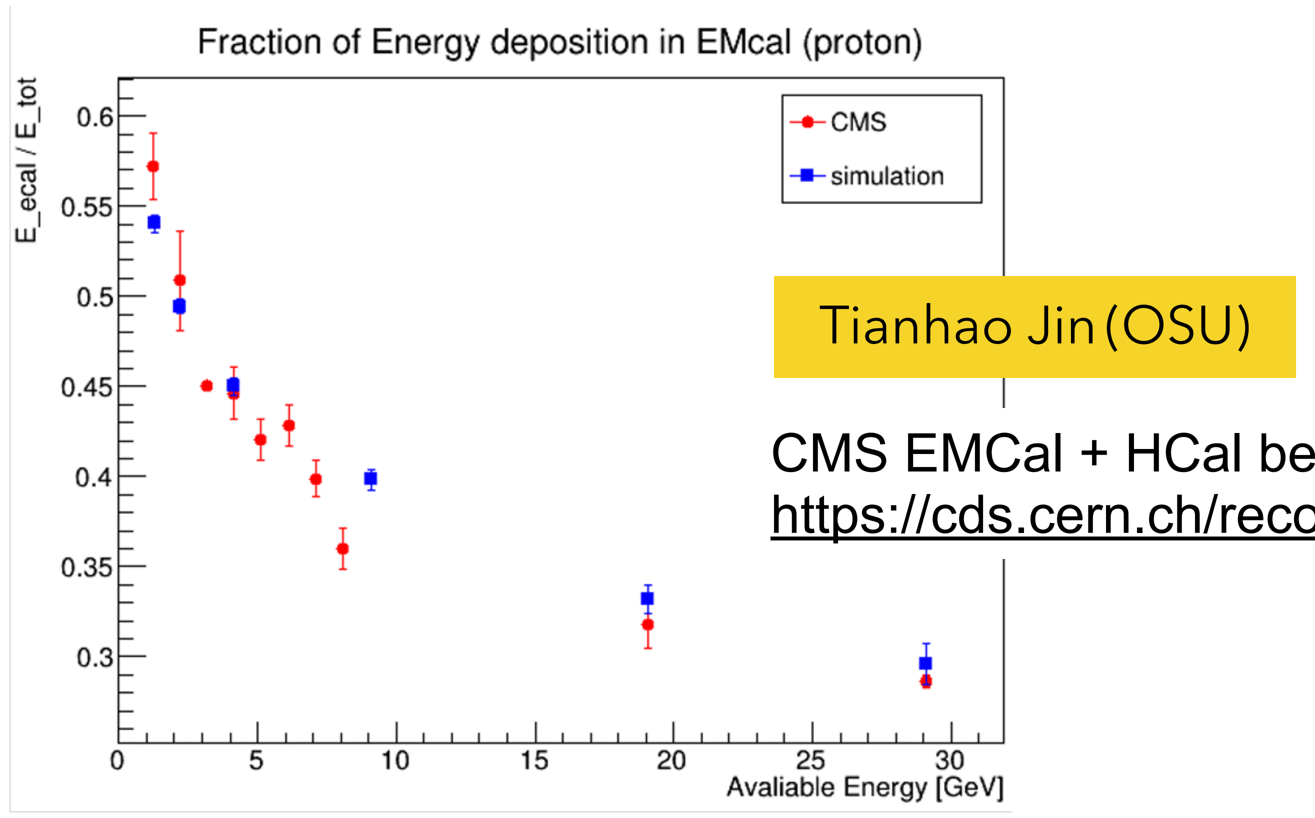
nHCal default design (10x10)

LFHCal configuration (5x5)

Sampling fractions

- Sampling fraction = energy deposit in absorber / incident energy
  - ~ 1-1.5% for default design (10x10, 10 layers, 4cm absorber, 4mm scintillator)
  - ~ 3-4.5% for more layers and/or thicker scintillator
  - Not dependent on particle species (n or π^-)
    - reflects how much of a particle shower can be sampled
  - Not dependent on tile size (10x10 or 5x5)
  - Design optimization driven by other parameters, in particular efficiency
  - Reminder - nHCal is a tail catcher
- Also validated understanding and simulation uncertainty of the material budget upstream of nHCal



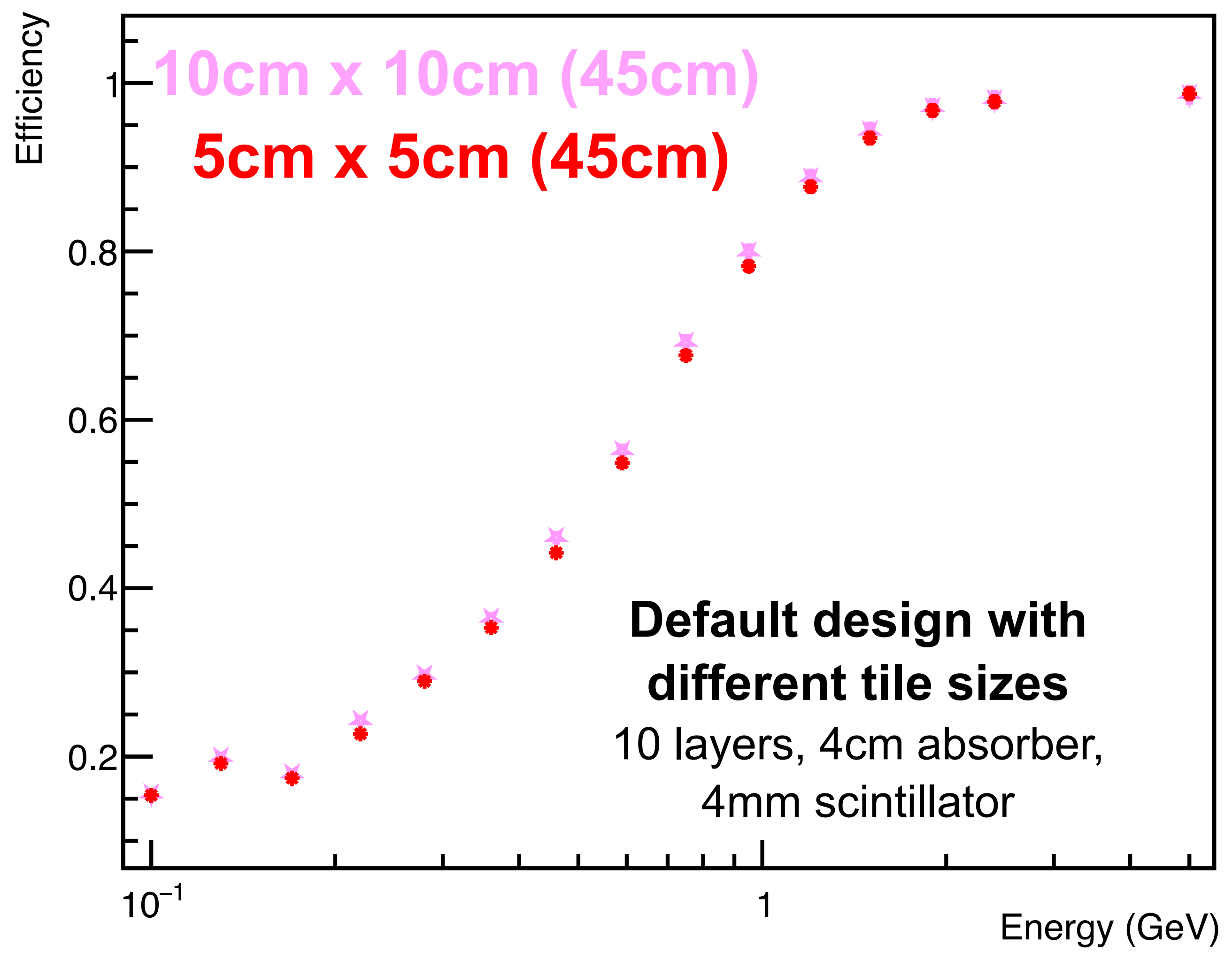


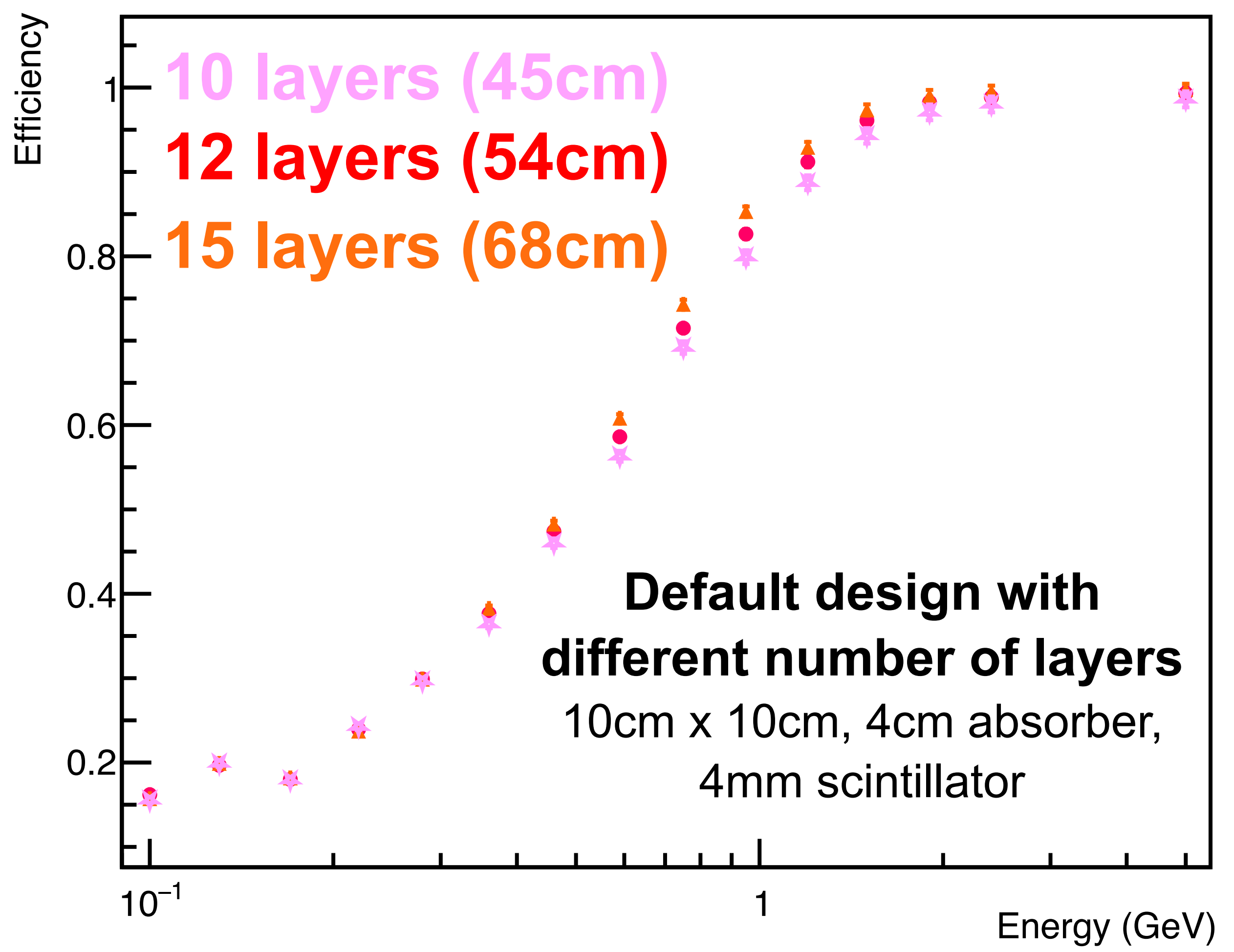
CMS EMCal + HCal beamtest
https://cds.cern.ch/record/1046333

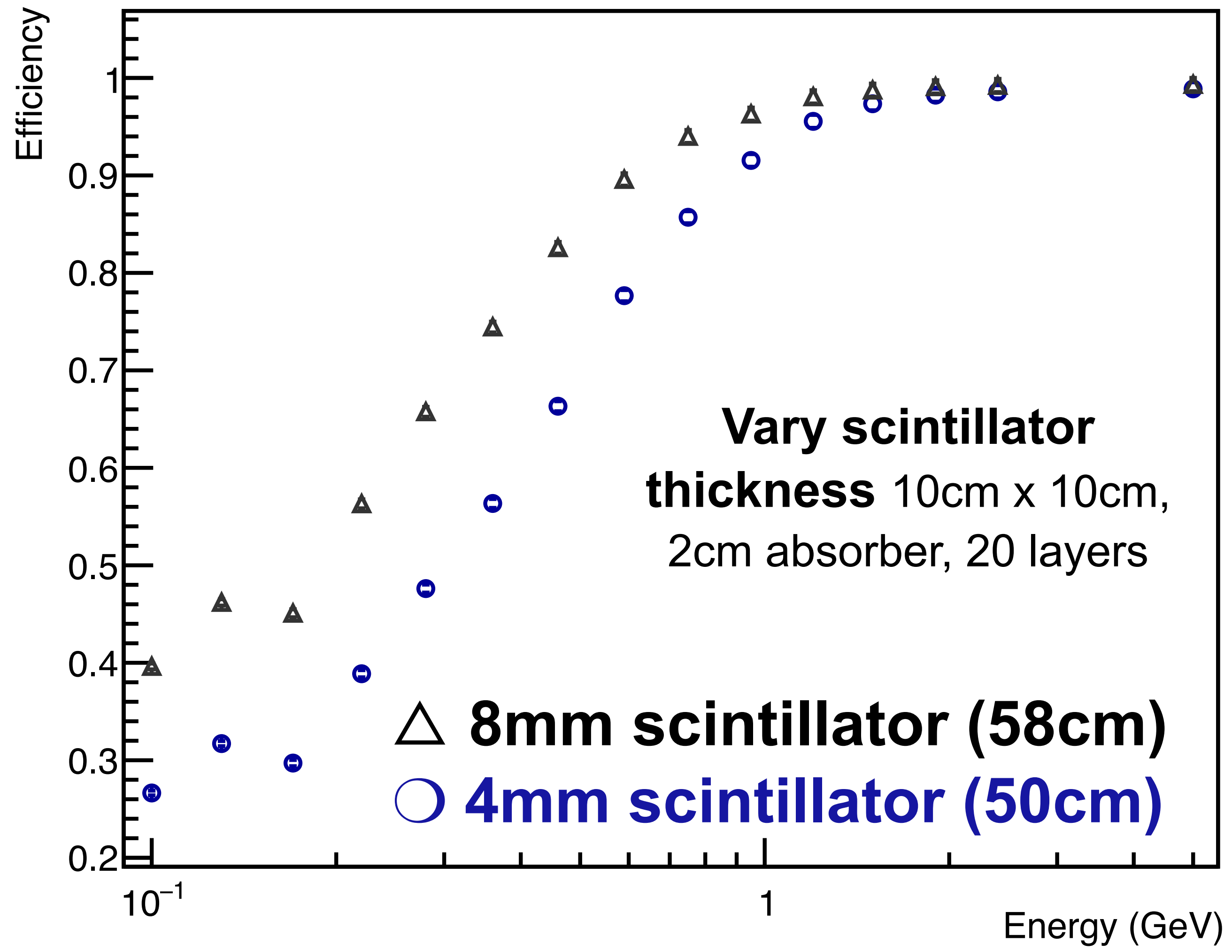
Efficiency for neutrons

- Neutron efficiency for different nHCal geometries
  - Tile size has small impact
  - All scenarios fit into the available depth
- Efficiency increases with
  - Number of layers (⇒ length of calorimeter):

    10 → 15 layers increases efficiency by about 5% for 1 GeV neutrons
  - Scintillator / absorber ratio:
    scintillator 4mm → 8mm increases efficiency by nearly 20% for 0.5 GeV neutrons



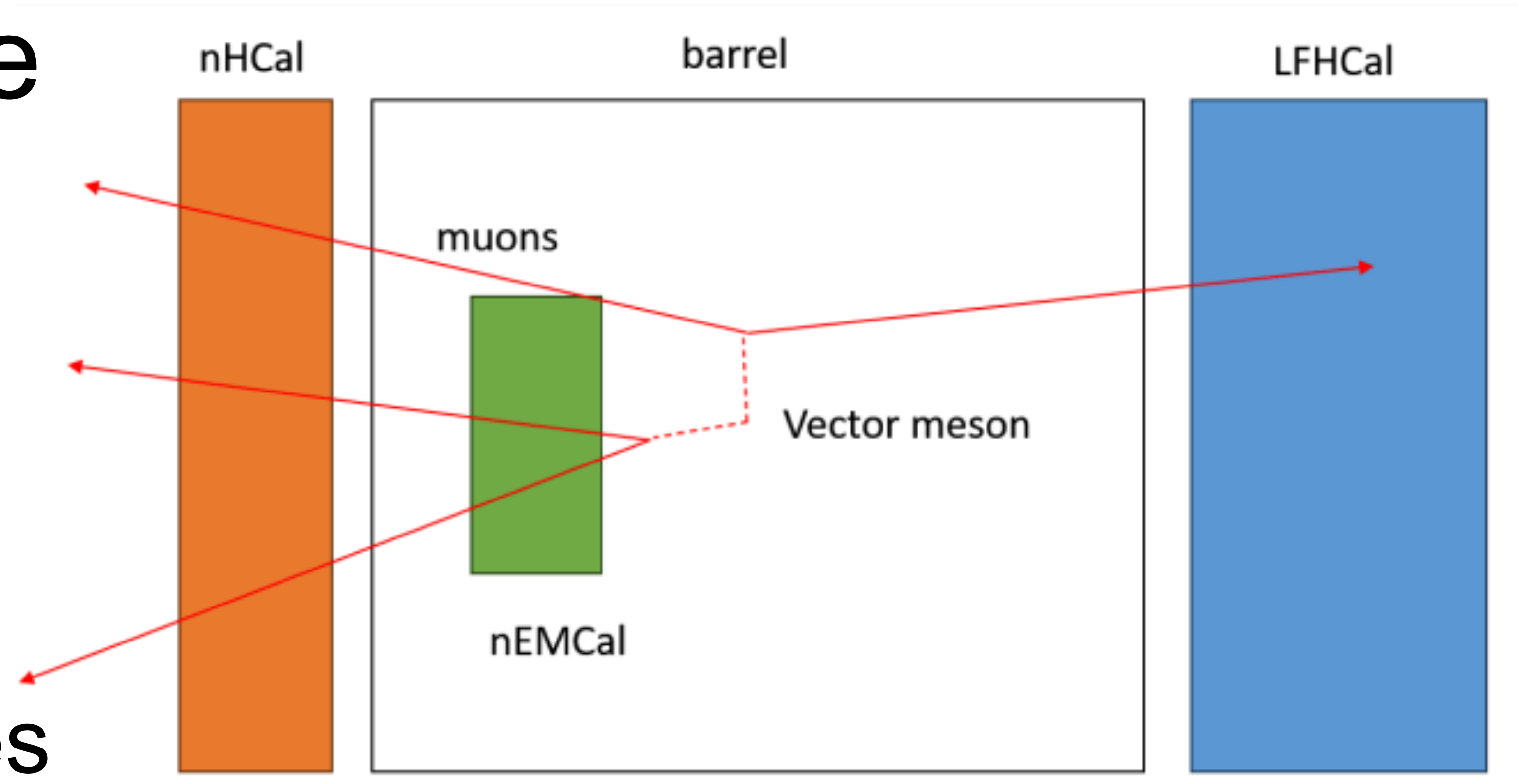


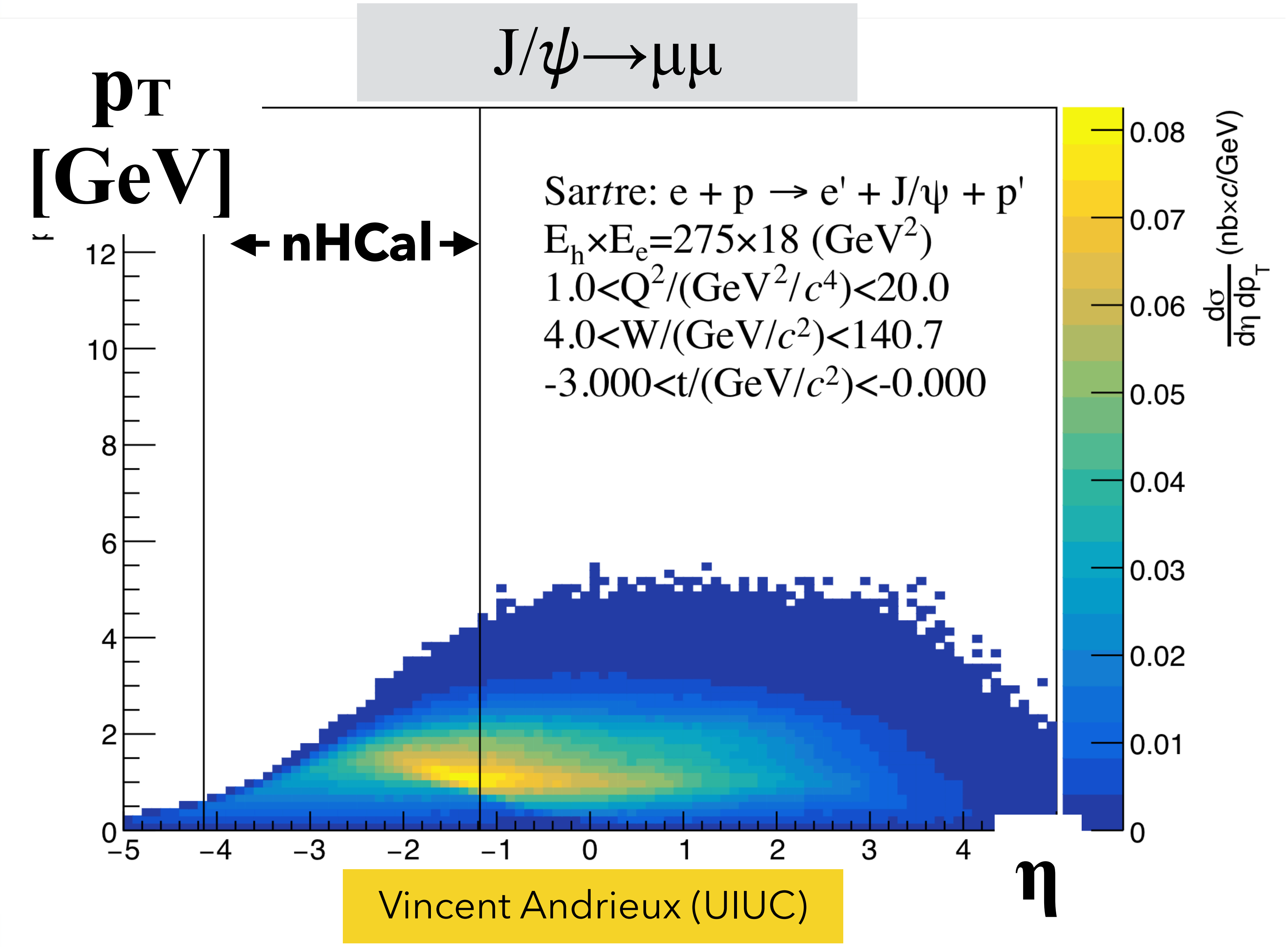


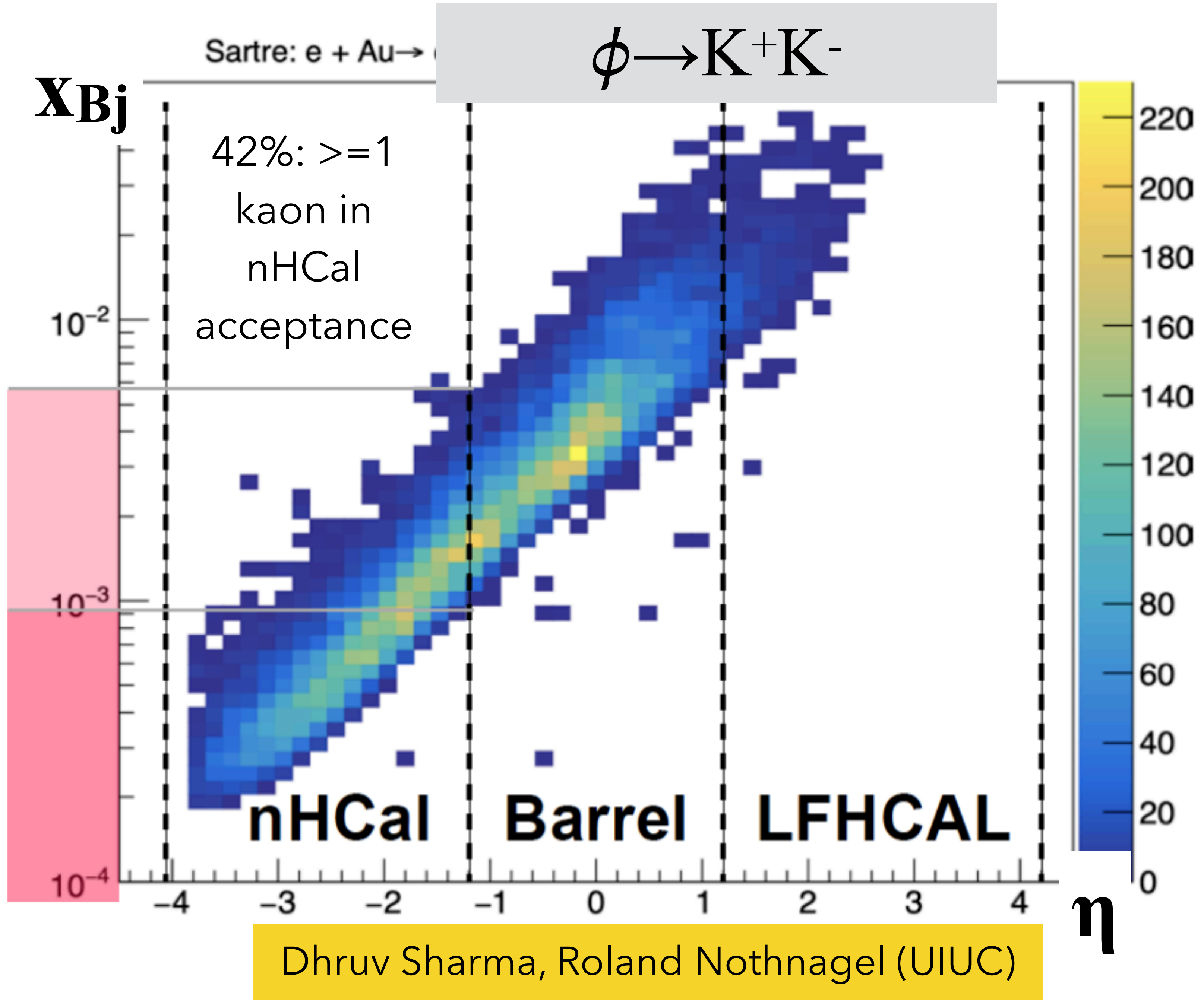
Sam Corey (OSU)

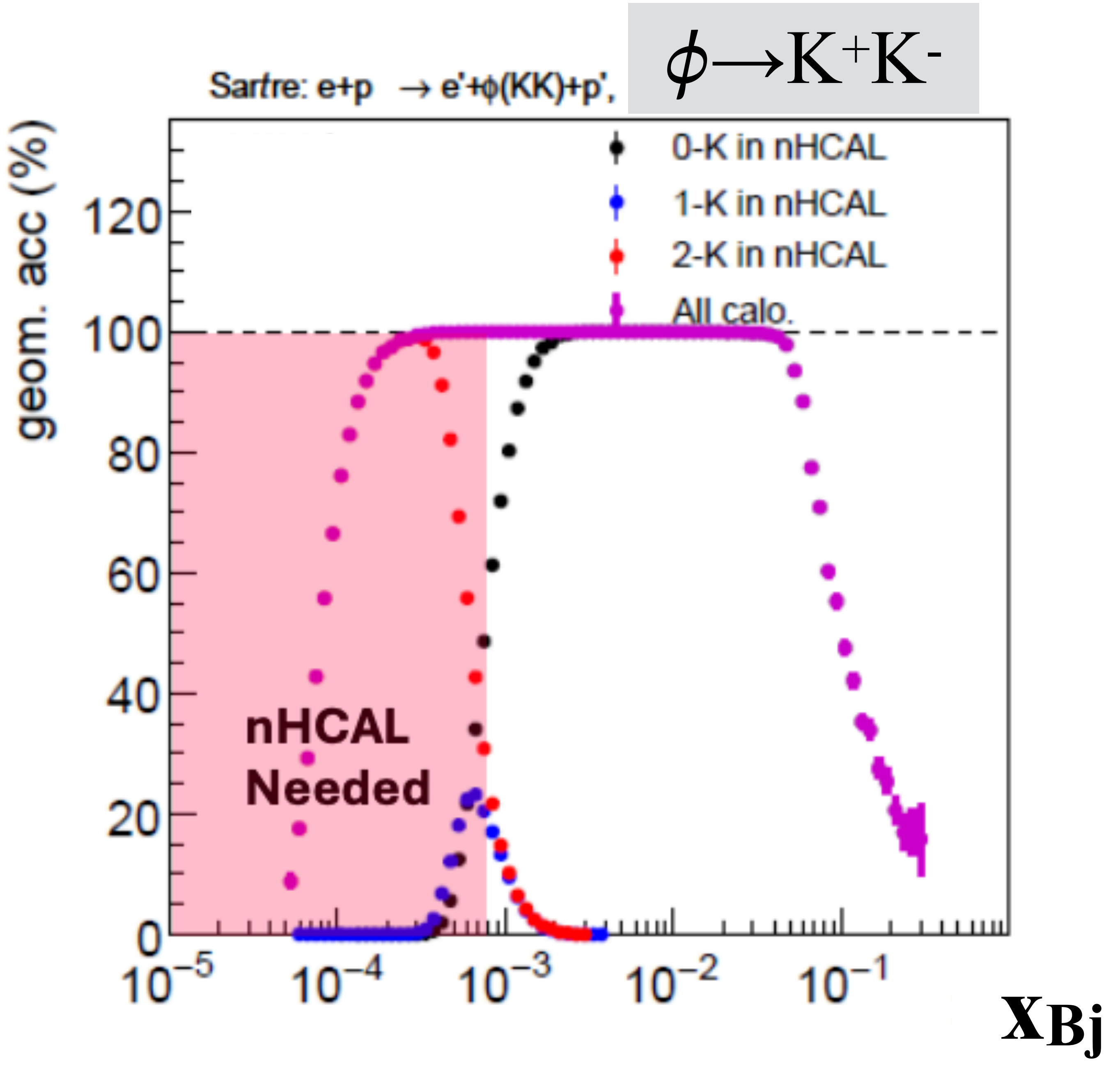
VM decay & efficiency for muon ID

- Additional backward acceptance provides access to a more complete set of vector-meson decay topologies
  - nHCal crucial for low-x
- Muon ID efficiency studies ongoing
  - + enhances clean separation of scattered electron from di-muon final states



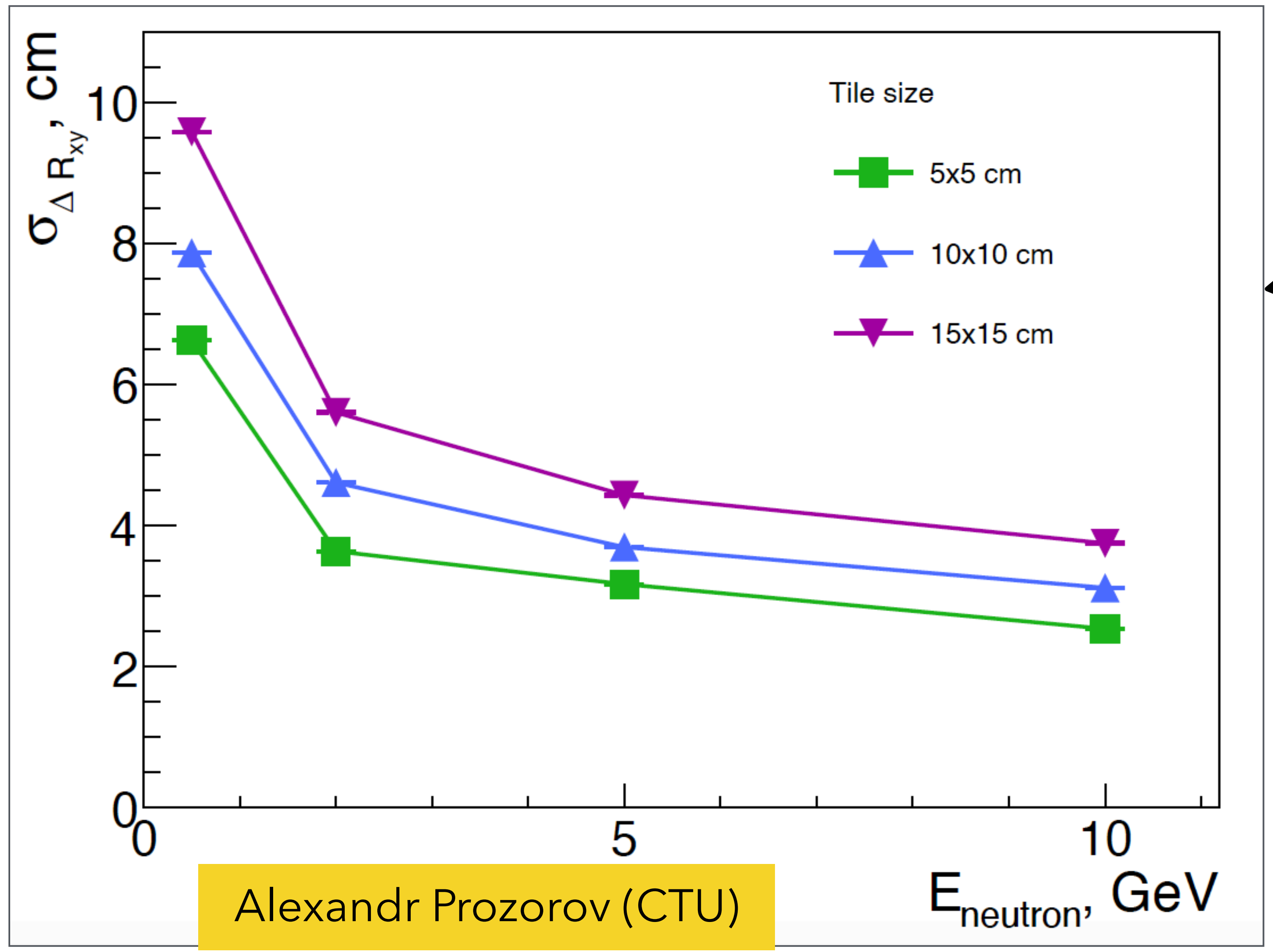




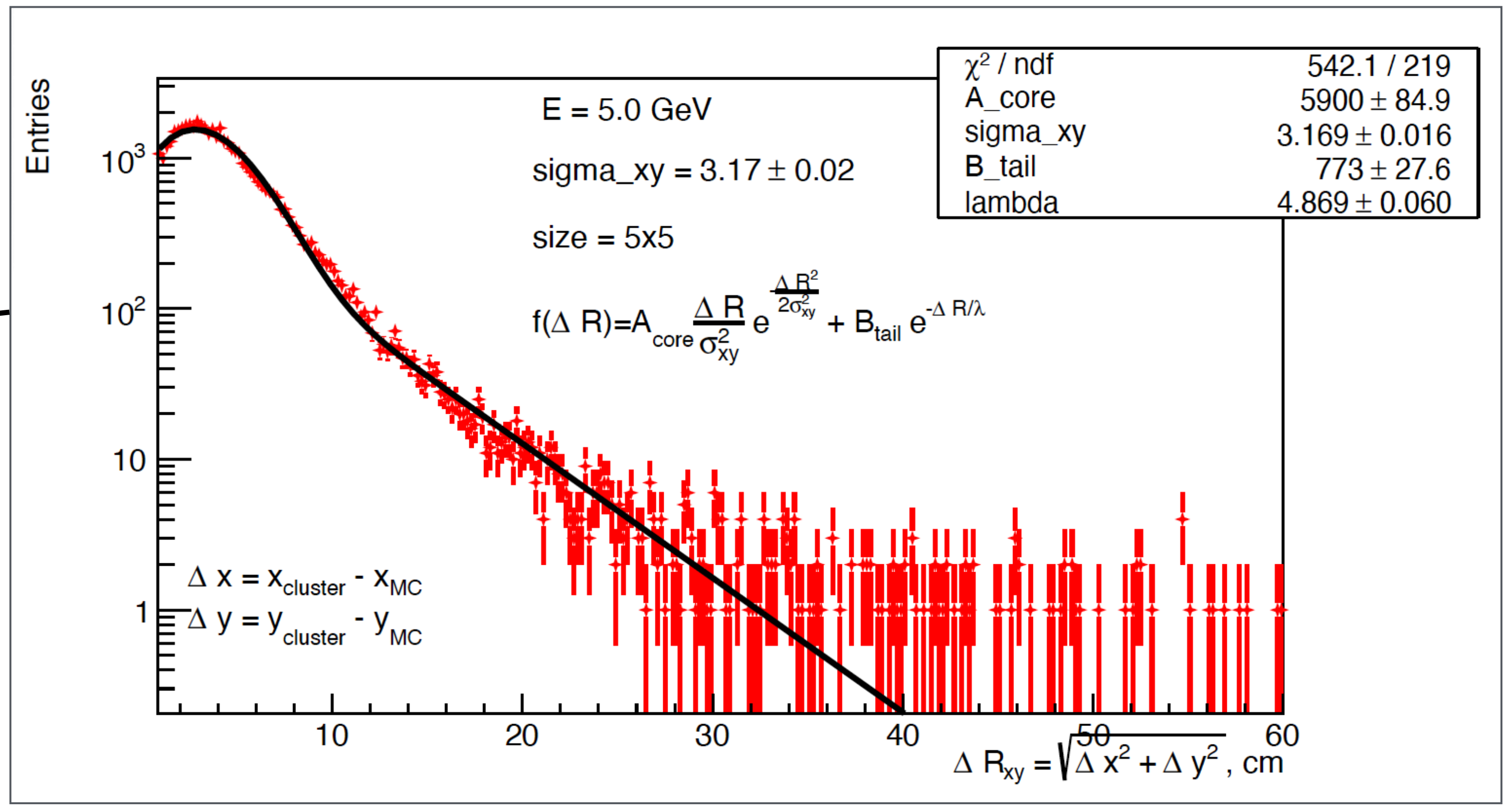


Position resolution for neutrons

- Transverse position resolution
  - Default design with varying tile size
- Neutron position resolution insensitive to tile size
  - Not unexpected due to size of clusters



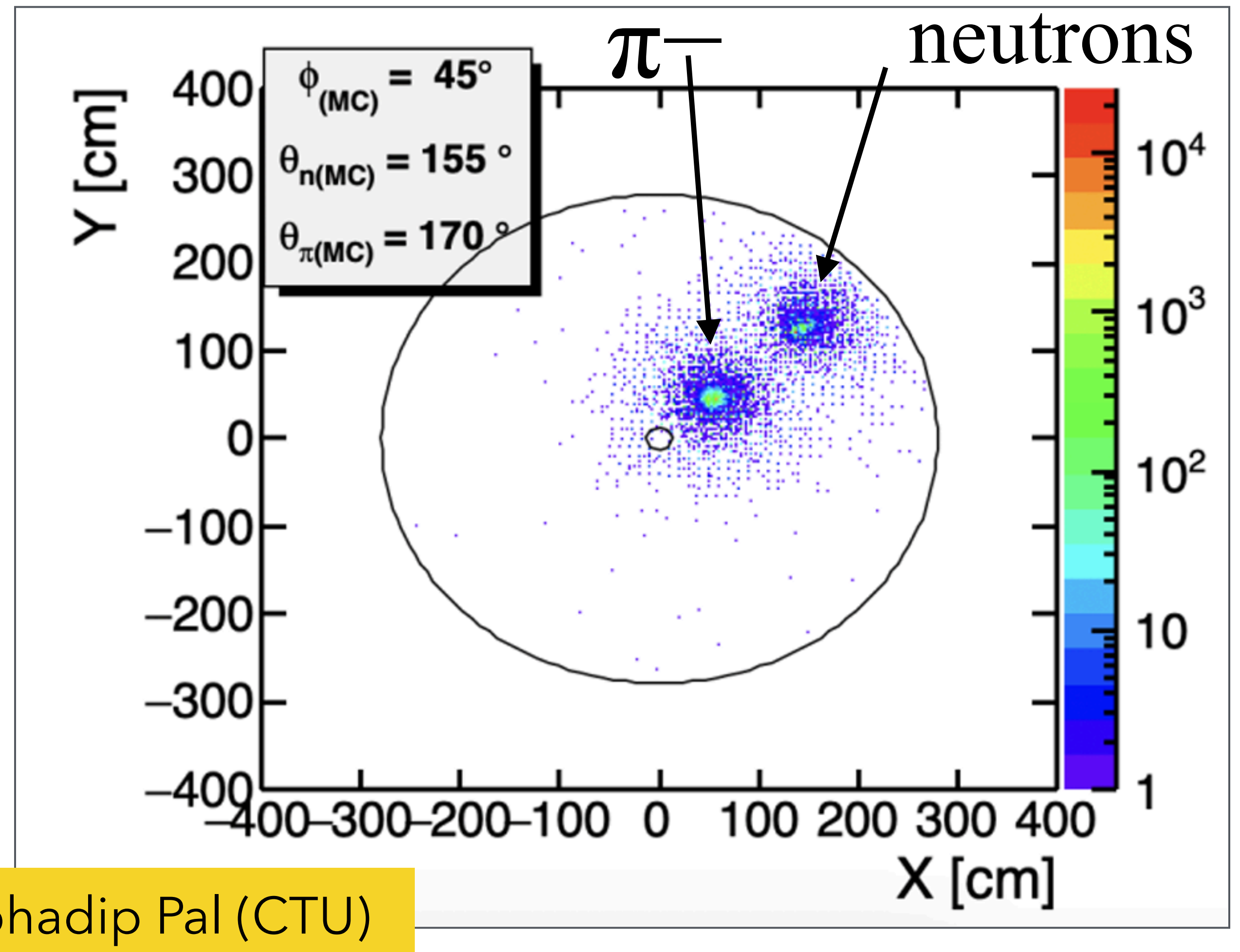
Alexandr Prozorov (CTU)



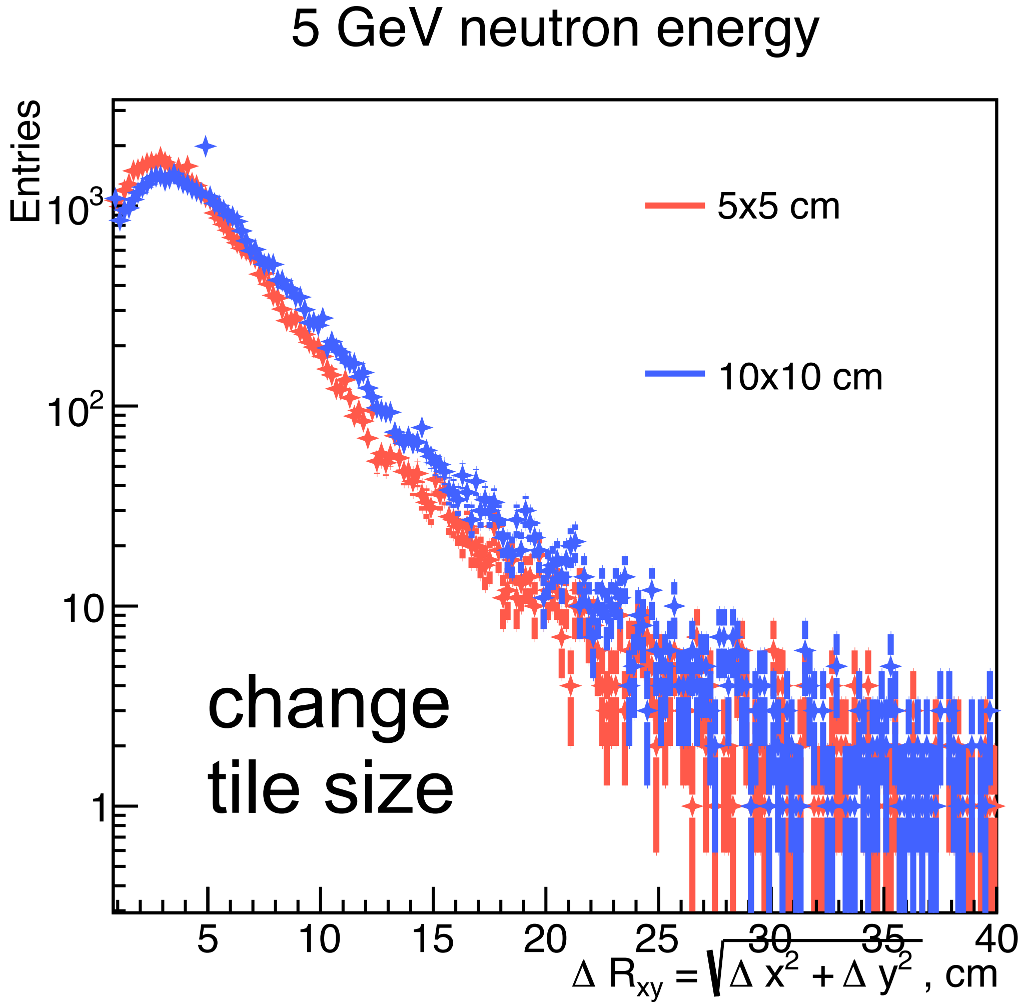
$$\Delta R_{xy} = \sqrt{\Delta x^2 + \Delta y^2}$$

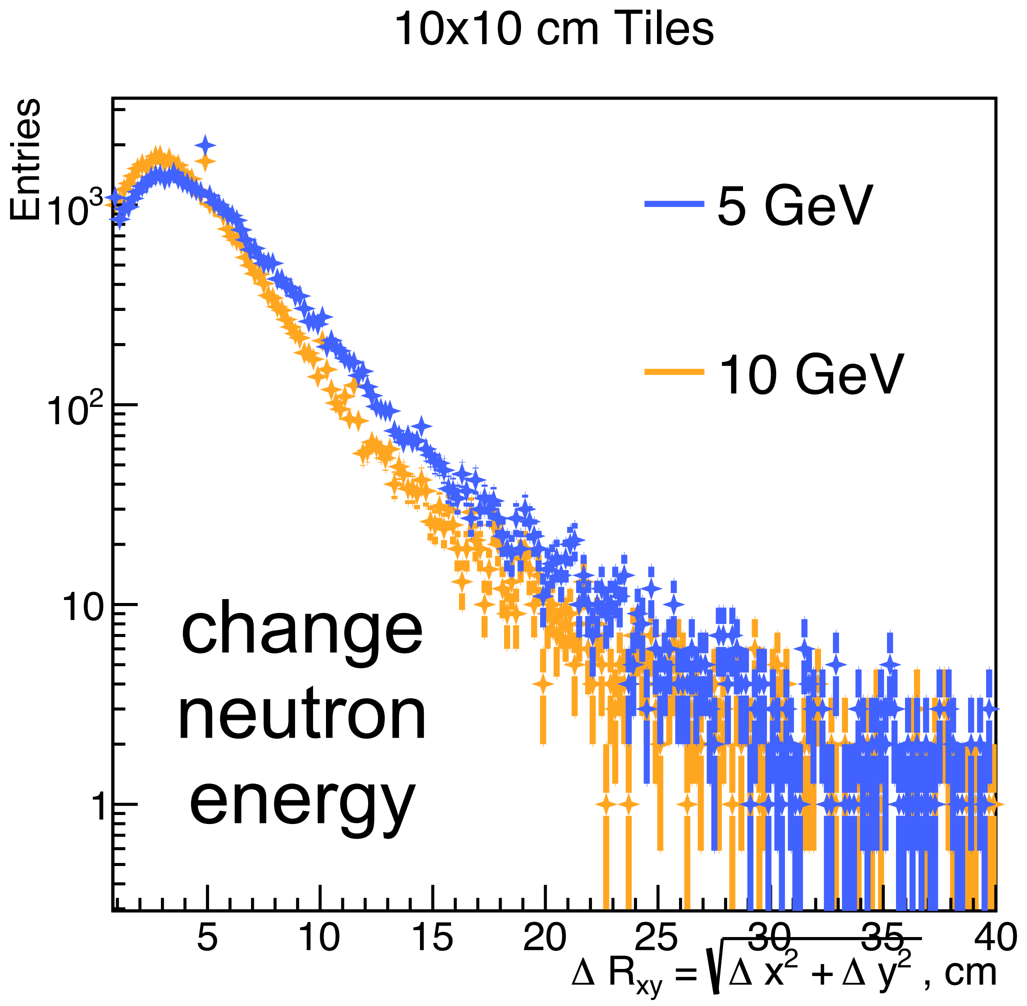
$$\Delta x = x_{cluster} - x_{MC}$$
$$\Delta y = y_{cluster} - y_{MC}$$

- Neutron and pion clusters can be distinguished when separated by ~30cm



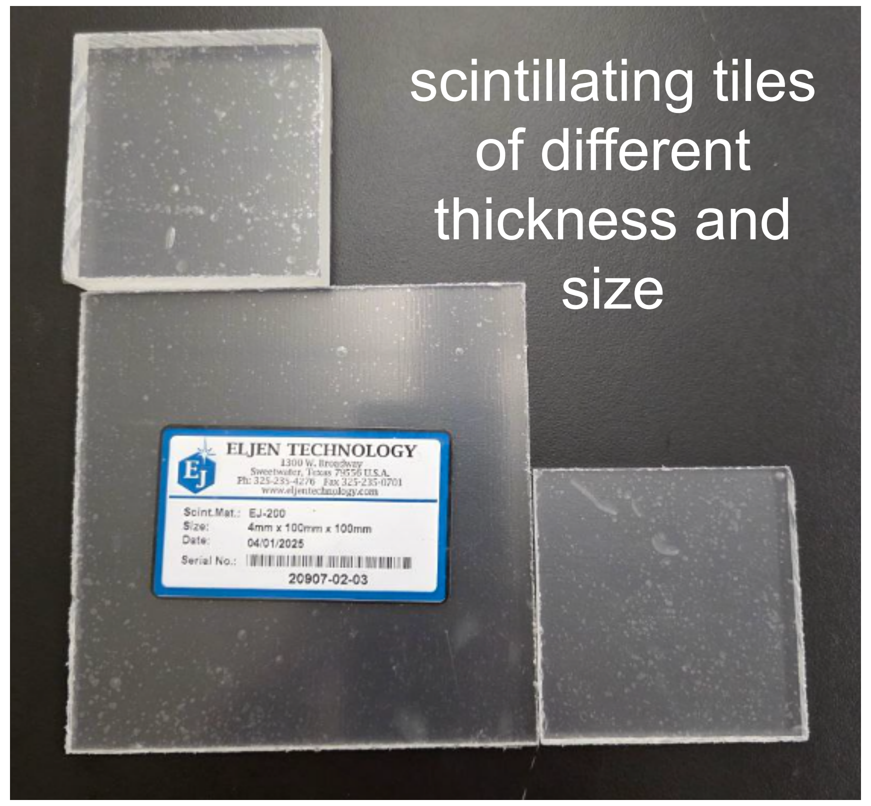
Subhadip Pal (CTU)





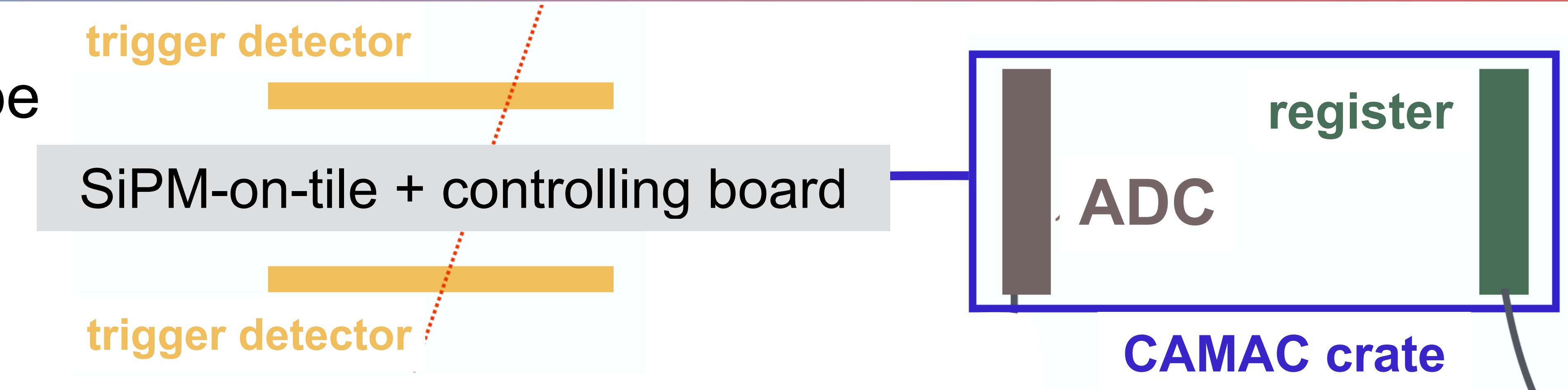
nHCal performance evaluation

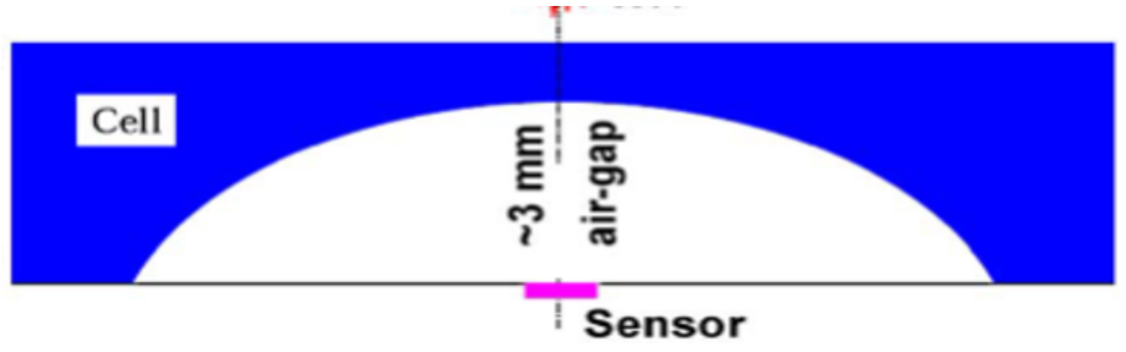
- Tile testing at OSU
  - Cosmics and Sr source
    - Vary tile size (5x5, 10x10)
    - Vary tile thickness (4, 6, 8 mm)
    - Vary SiPM placement (center, corner, edge)
  - Performance evaluation
    - Light yield per MIP, uniformity, cross-talk
  - Completion: July

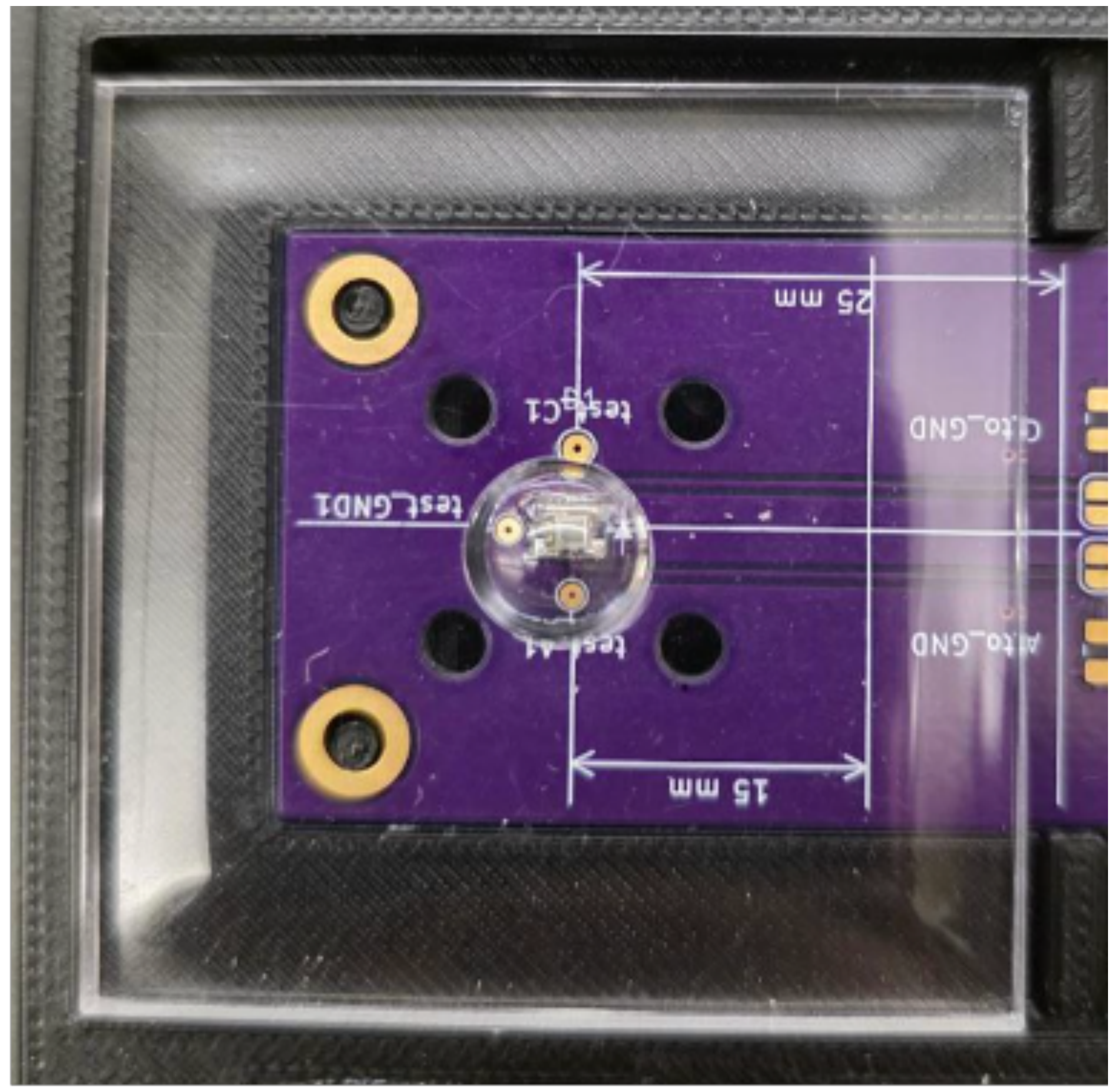


scintillating tiles of different thickness and size

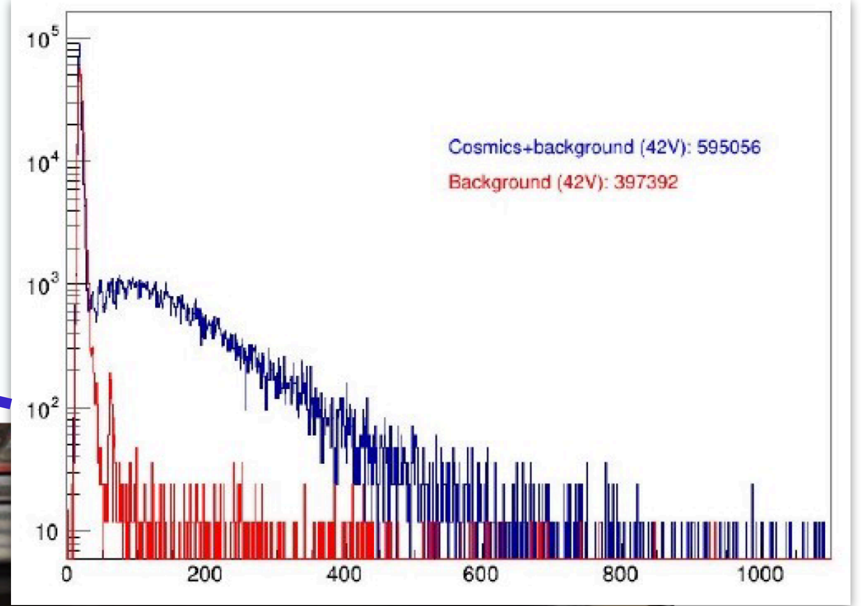
muon telescope for cosmics testing

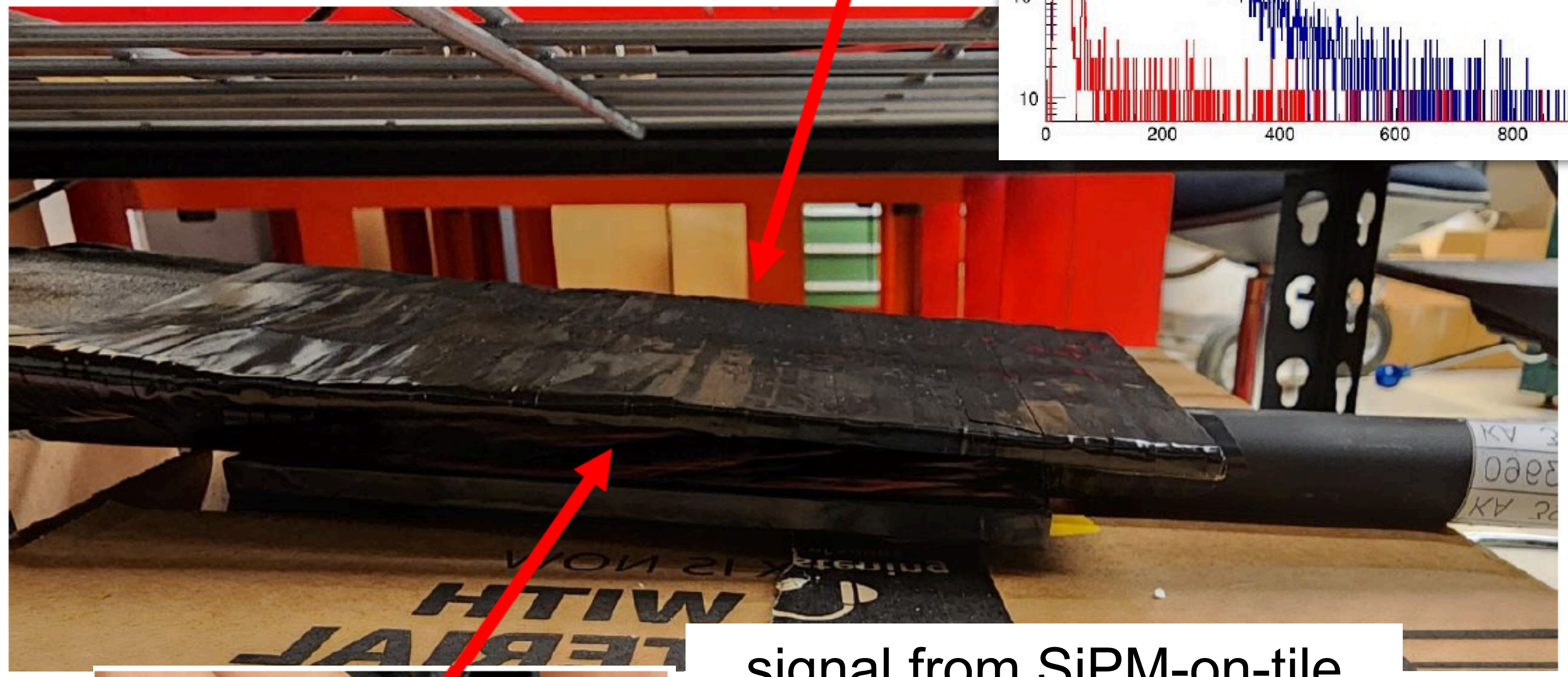


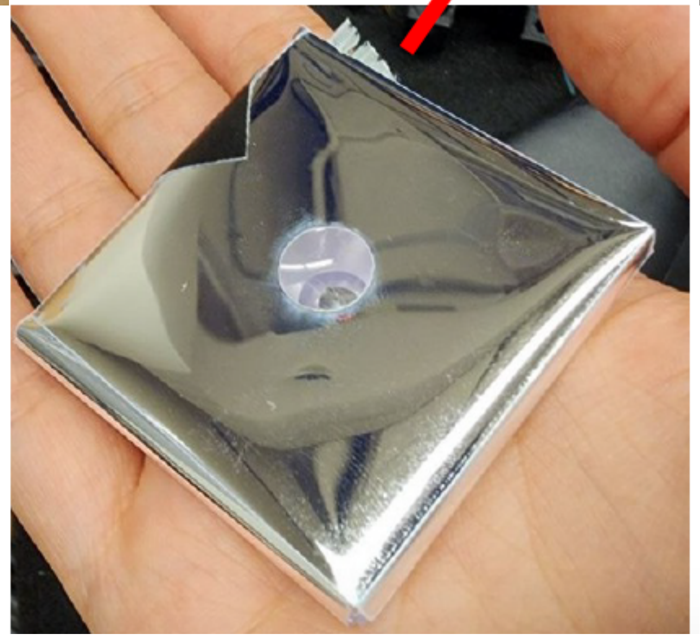




SiPM: S14160-1315PS

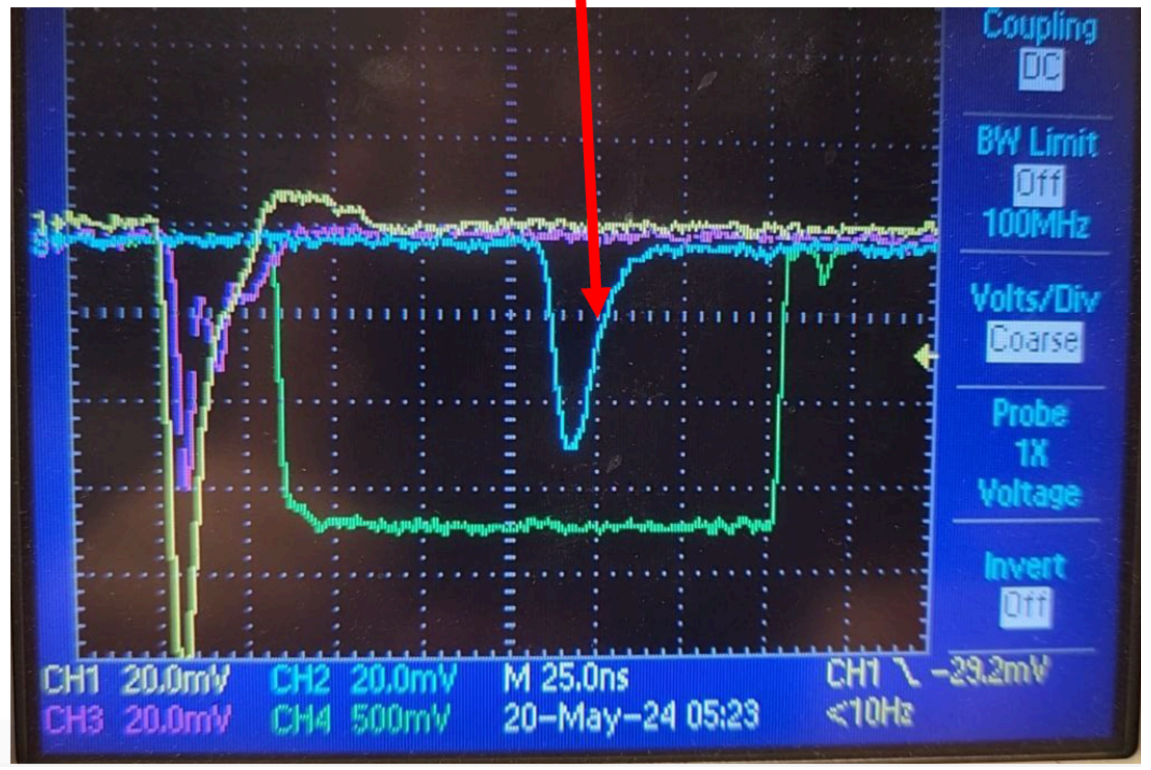




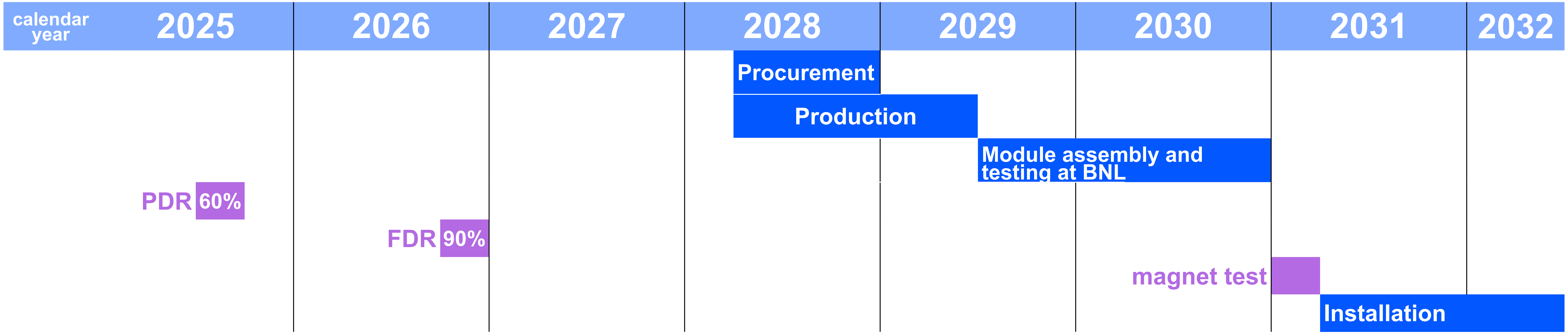


Maria Stefaniak, Yevheniia Khyzhniak (OSU)

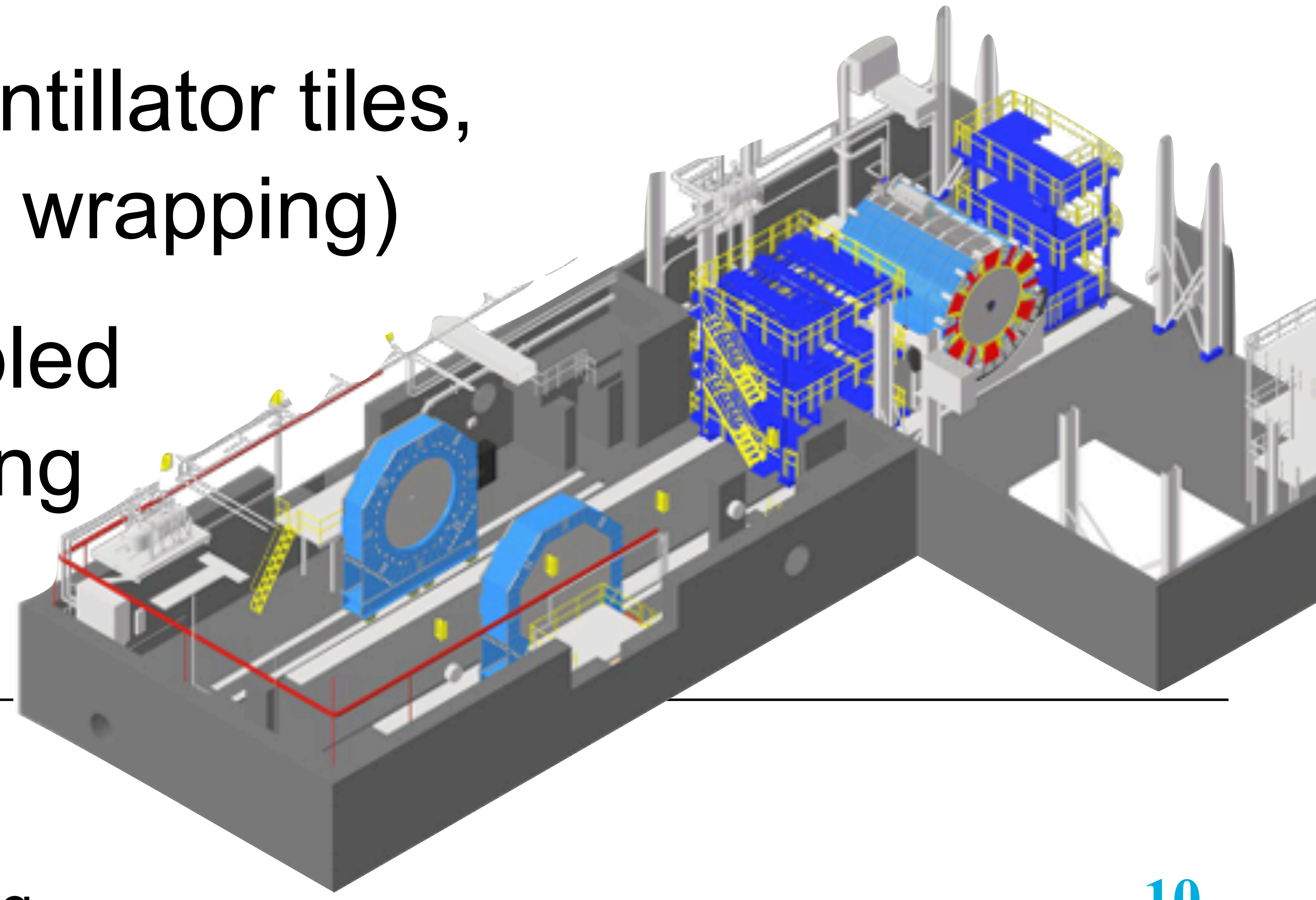
signal from SiPM-on-tile



nHCal baselining and start of construction



- **Will the detector be technically ready for baselining by late 2025?**
  - 60% design maturity (PDR) in fall 2025
- **Will the detector be ready for start of construction by late 2026?**
  - Aim for 90% design maturity (FDR) in 2026. Procurement after CD-3 (SiPMs, scintillator tiles, electronics, steel modules) & start of production (loading of SiPM boards and tile wrapping)
  - The nHCal can be delivered later than most other detectors because it is decoupled from the flux return and does not need to be in place for the solenoid field mapping
  - Ample time after FDR from synergies with the LFHCal



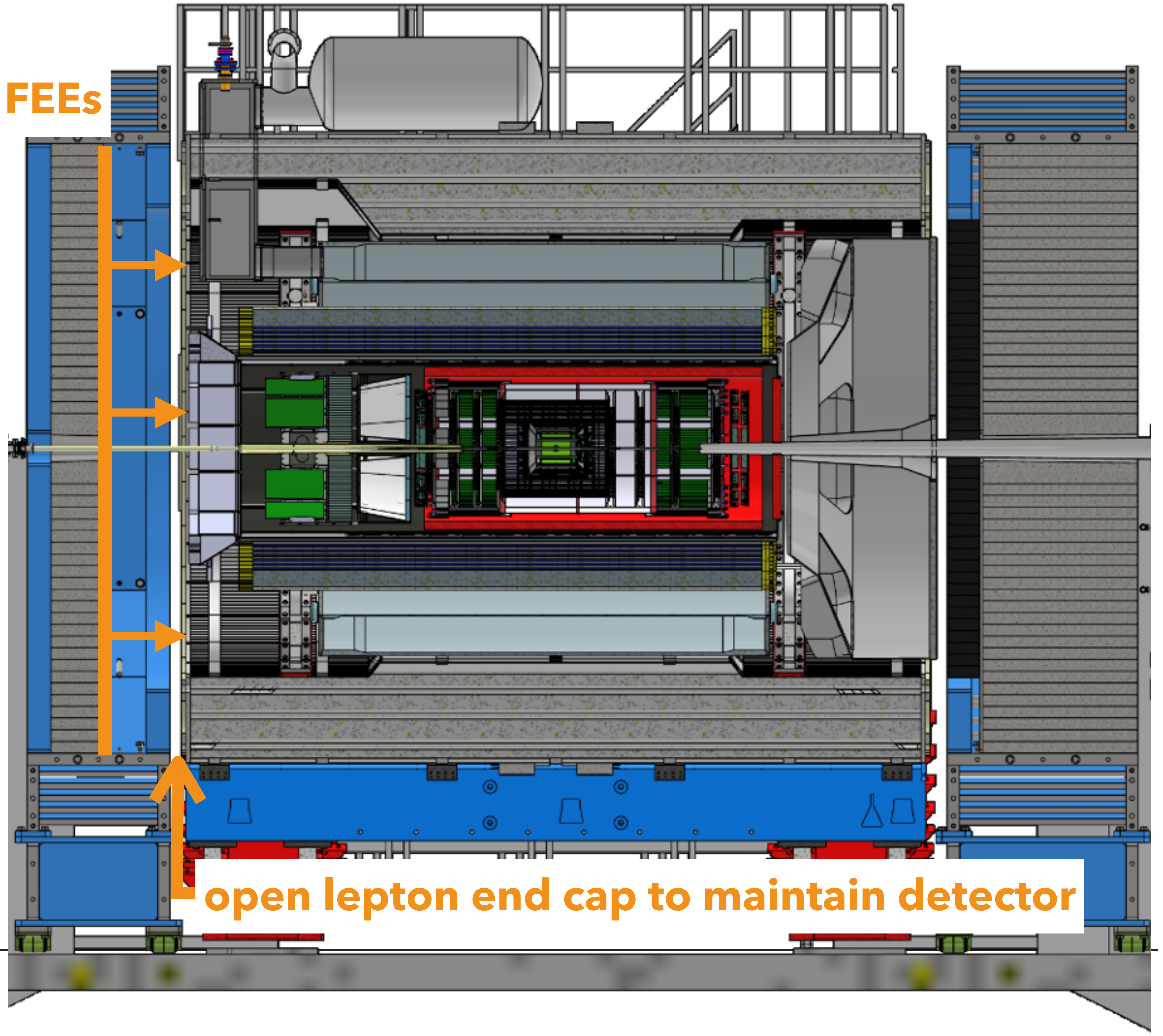
nHCal integration and planning for installation & maintenance

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

- Integration: services (LV, signal, slow control cables) and possibly cooling
  - Total dissipated heat: 0.5-2.4 kW (10cmx10cm tiles)
  - **FEEs** towards the IP ⇒ nHCal has to be serviced and maintained from the front (unlike LFHCal)

Services Summary

Item	Cross Sectional Area	Units	Endpoint 1	Endpoint 2
LV cable to FEE	24x1.13	cm2	FEE	Rack
Data signal cable	24x3.3912	cm2	FEE	Rack
Slow controls cable	24x0.07065	cm2	FEE	Rack



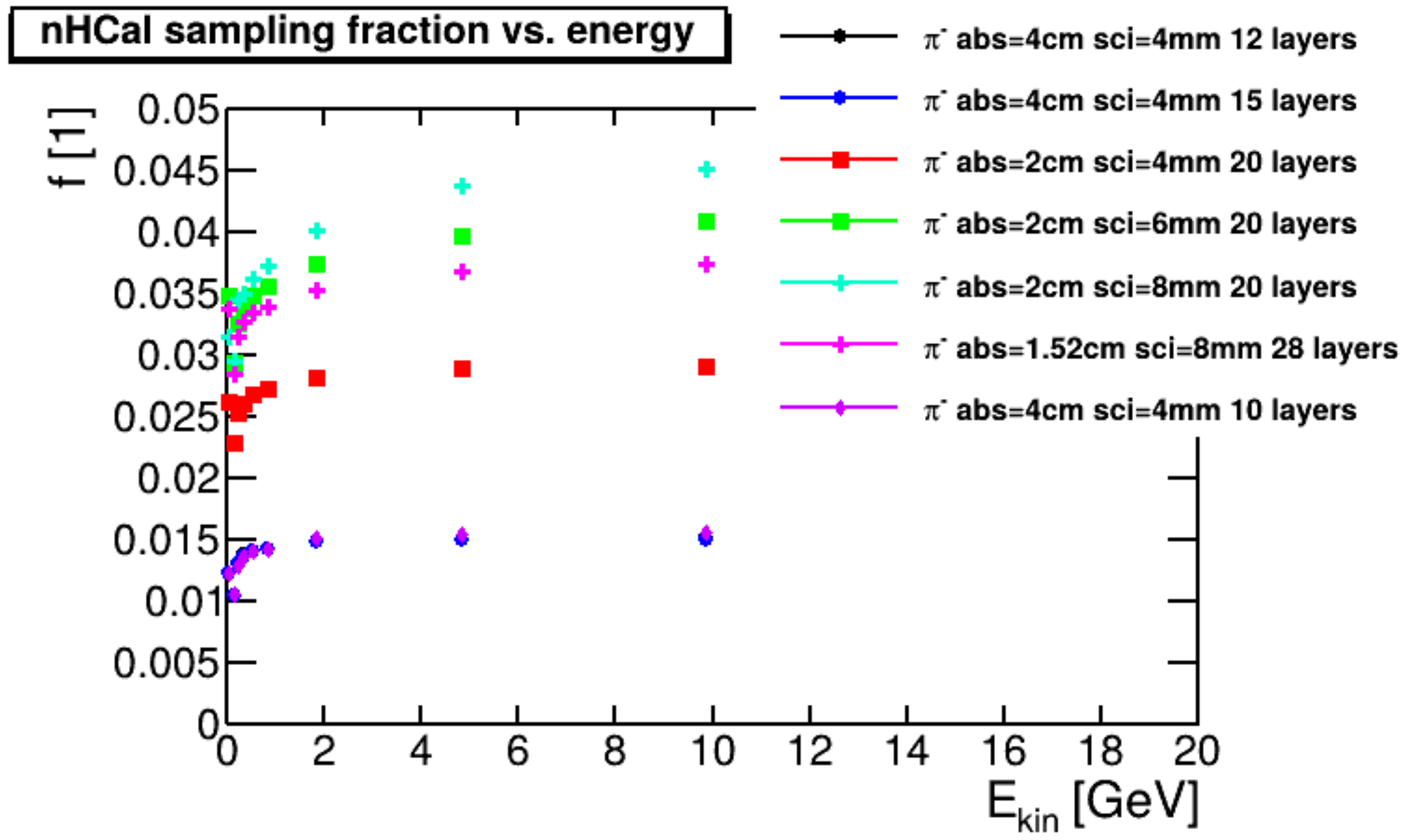
nHCal summary

- Status:
  - Simulation studies with single particles in progress
  - Actively testing scintillating tiles at OSU
  - Preparing PDR2 in ~September 2025
- What is missing until CD-2:
  - Completion of lab tests (July) and simulation campaigns including full simulations (end of year)
  - Optimizing design - tile size, tile and absorber thicknesses, number of layers, gross length - up to CD-2 and beyond
- Desire of beam tests with neutron and muon beams to verify simulations and characterize performance
- Synergy with LFHCal - choice of technology
- Involved institutions: OSU, UIUC, CTU, BNL

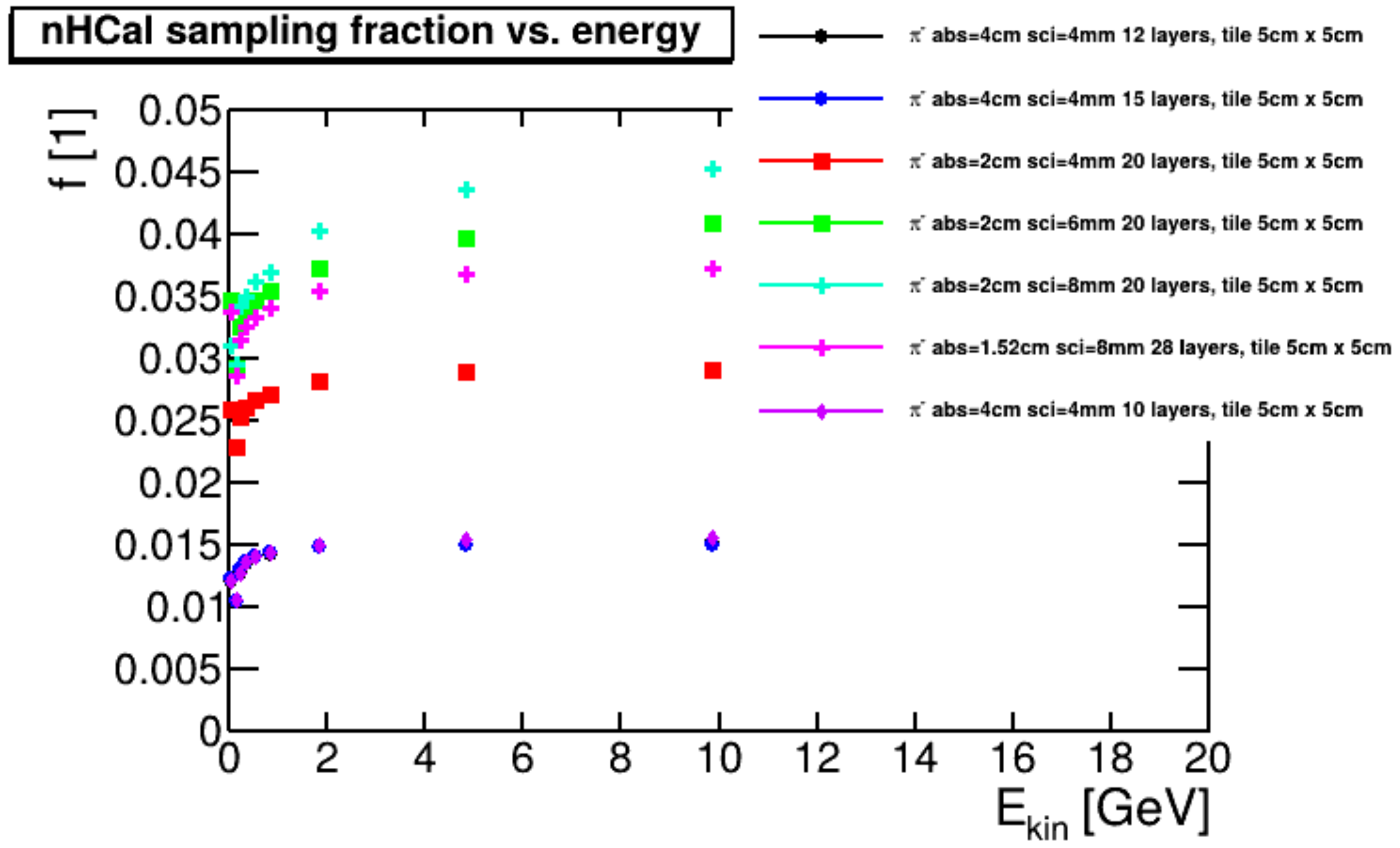
backup slides

Sampling fractions

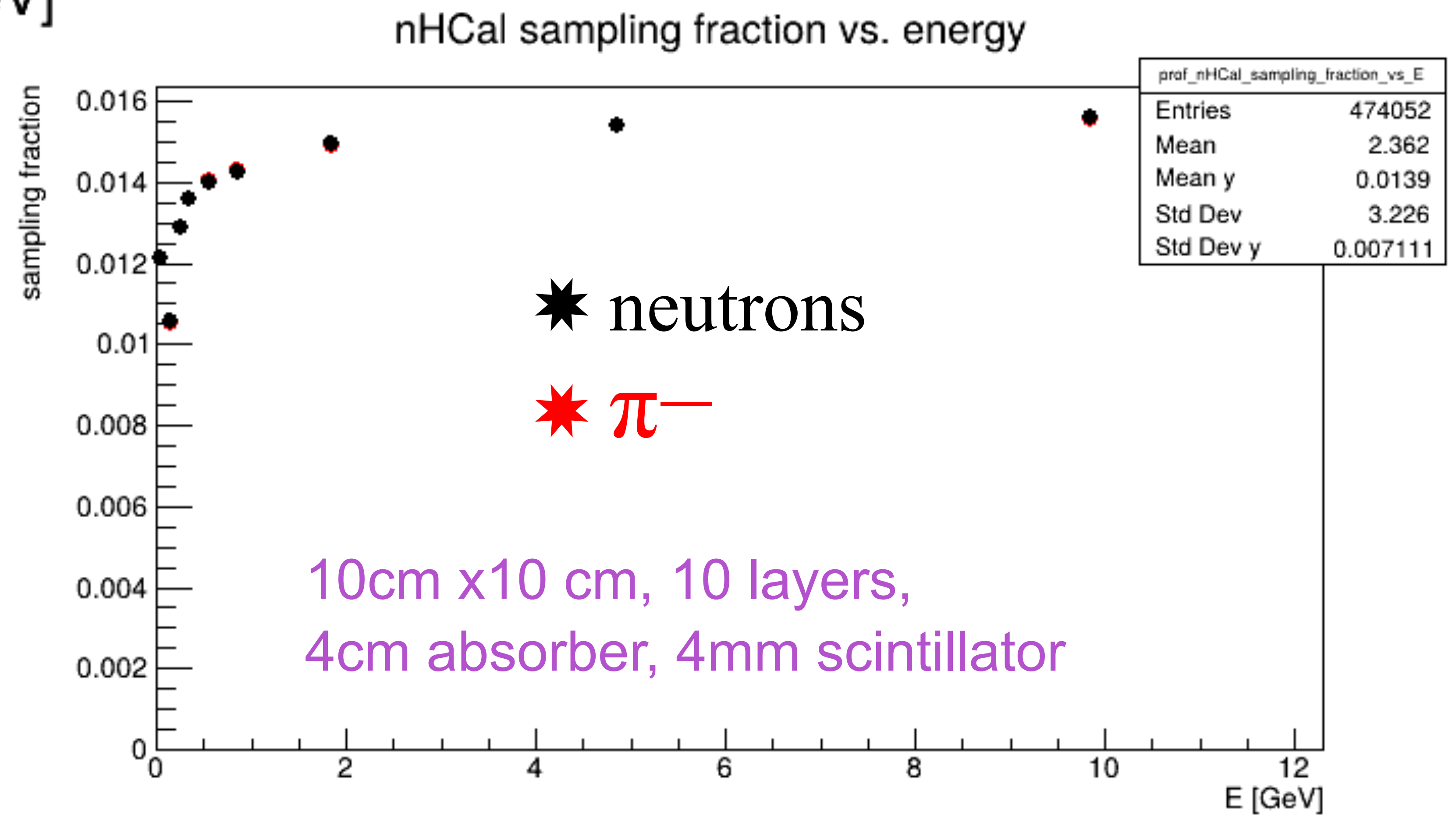
10cm x 10cm tiles



5cm x 5cm tiles



- Top row: vary geometry
- Right: vary particle species



nHCal project design - purposes and requirements

<table>
<tr><th colspan="2">Purpose</th><th>Requirements</th></tr>
<tr><td colspan="2">Low x and Q^2, high y
high gluon densities</td><td>Coverage in backwards direction</td></tr>
<tr><td rowspan="2">diffraction</td><td>vector mesons</td><td>Good μ/π separation via MIP signal</td></tr>
<tr><td>dijets</td><td rowspan="2">High efficiency for low-energy neutron detection</td></tr>
<tr><td colspan="2">Neutral jets / neutral veto</td></tr>
<tr><td colspan="2">Charged jets</td><td rowspan="2">Good spatial resolution to distinguish clusters (neutral vs. charged)</td></tr>
<tr><td colspan="2">Scattered electron ID (h veto)</td></tr>
<tr><td colspan="2">Improved hermiticity
(↗ kinematic resolution in CC)</td><td>Good timing resolution</td></tr>
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nHCal crucial for core aspects of EIC physics mission

Lessons from HERA / H1 backward SPACAL

NIMA 386 (1997), 397-408
PLB 665 (2008), 139-146

nHCal default design - parameters

nHCal similar but not identical to **LFHCal** design. Both are based on the sampling calorimeter technology with alternating layers of absorber and scintillator

	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)