Calorimeter Insert for the EIC

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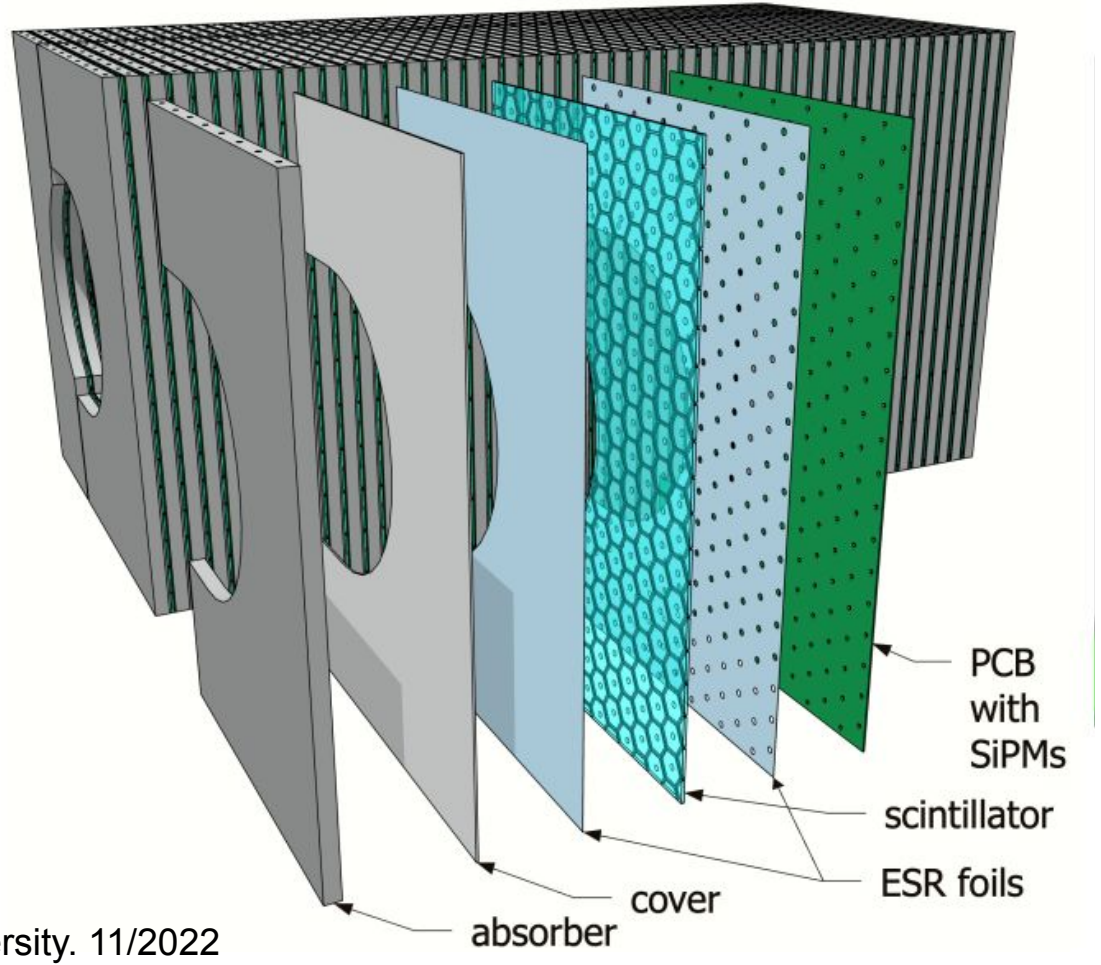
UC RIVERSIDE



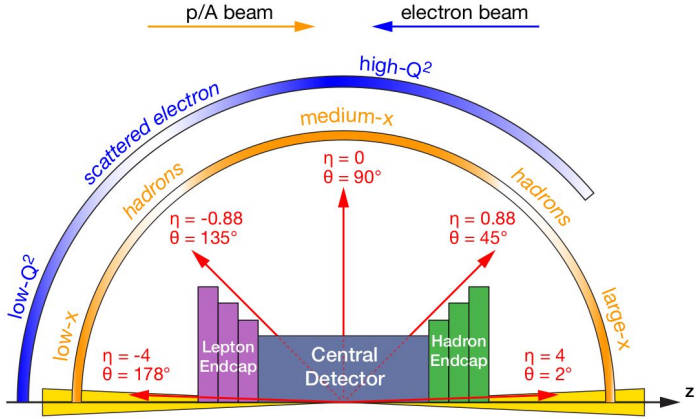
CPAD Workshop 2022 @ Stony Brook University. 11/2022

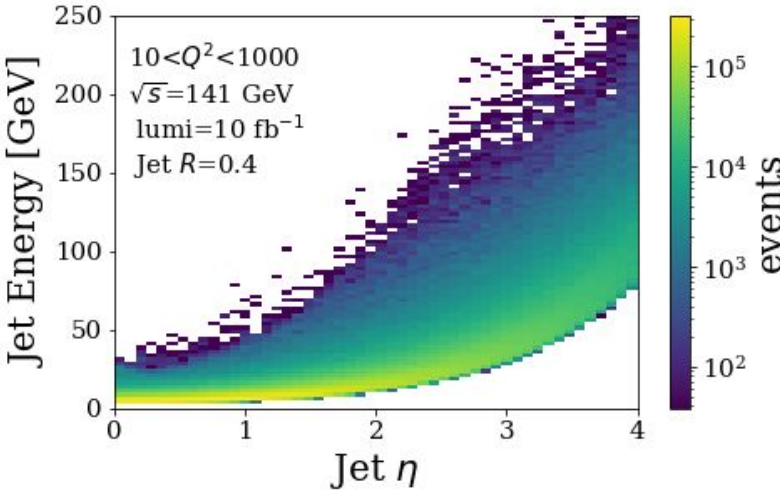
Motivation

EIC detectors should have **“as large coverage as technically possible”**, up to η=4.0

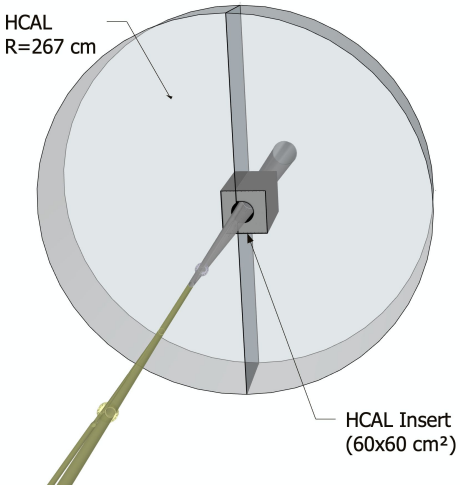
Calorimeters at 3<η<4 crucial to measure for:

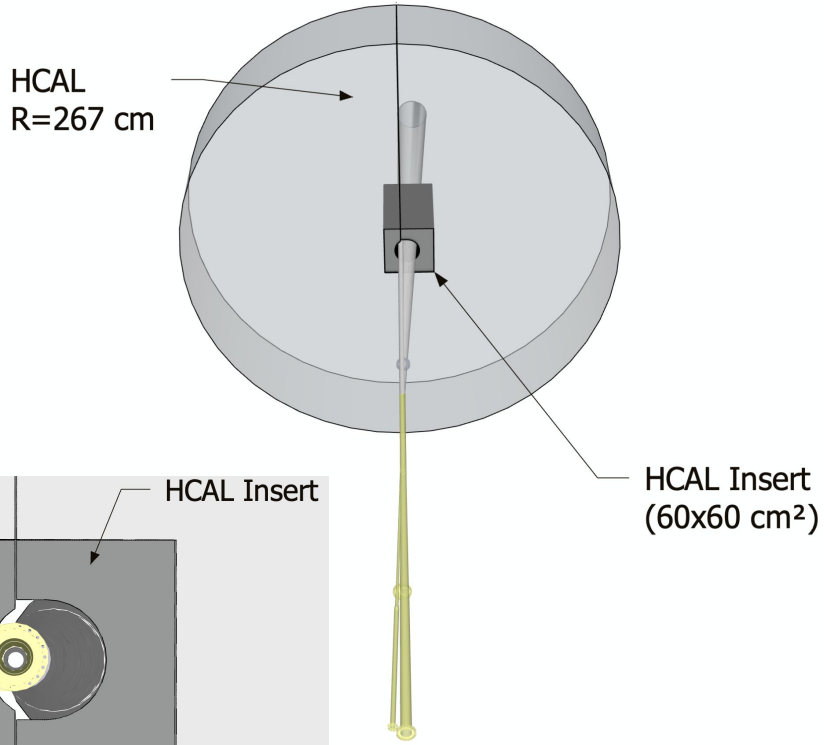
- Highest-energy jets
  (sensitive to both high-x and low-x)
- Hadronic-final-state transverse momentum to reconstruct low-y NC DIS and CC DIS

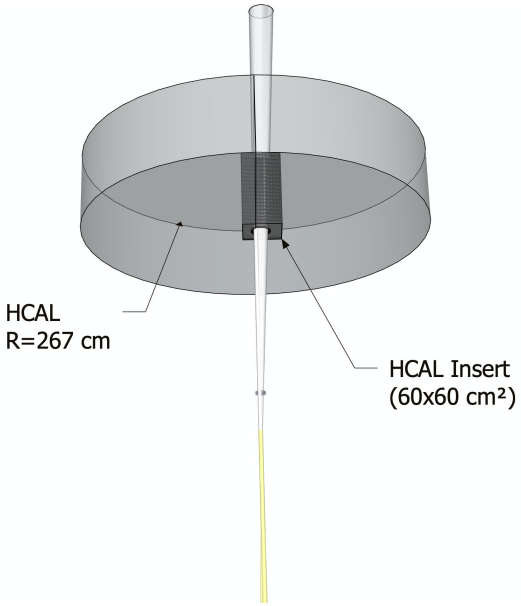


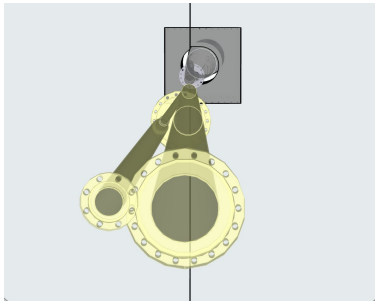


Challenge: crossing-angle complicates geometry near beampipe

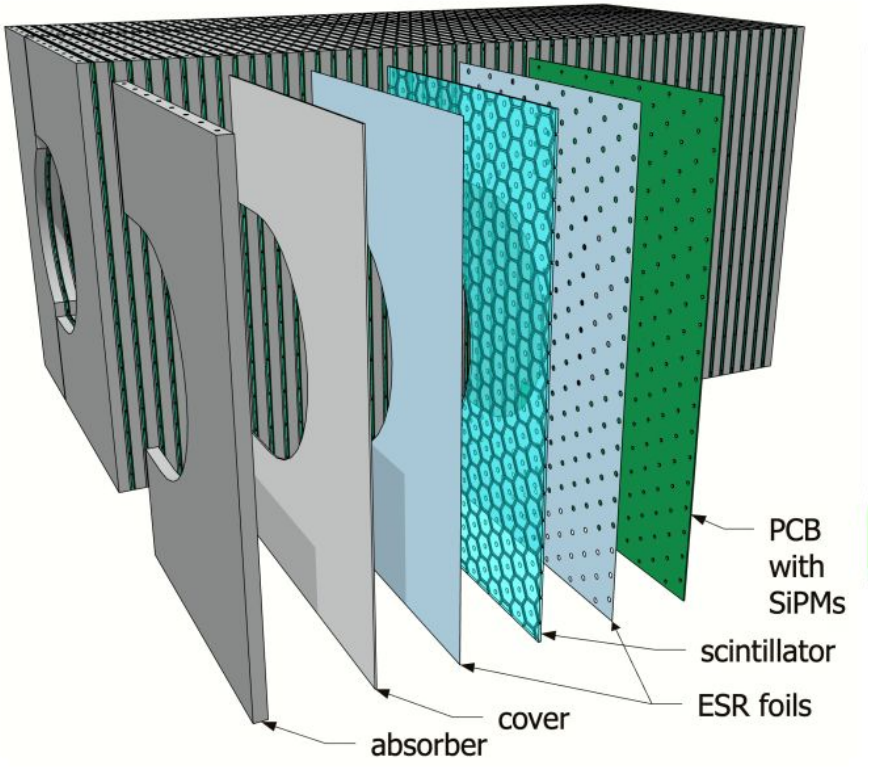








The HCAL insert



What is it?

Scintillator / Fe+W sampling calorimeter. High-granularity with “SiPM-on-tile” tech (CALICE, CMS)

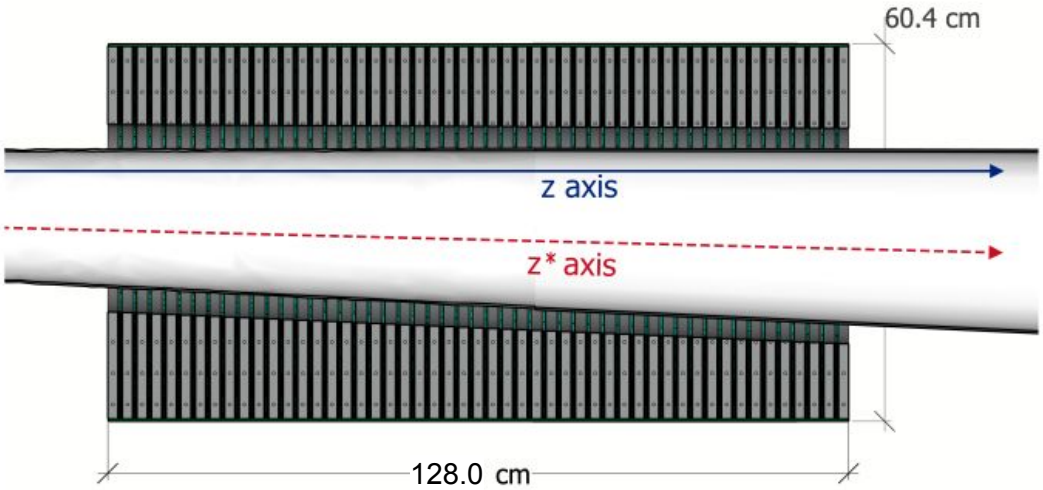
What does it do?

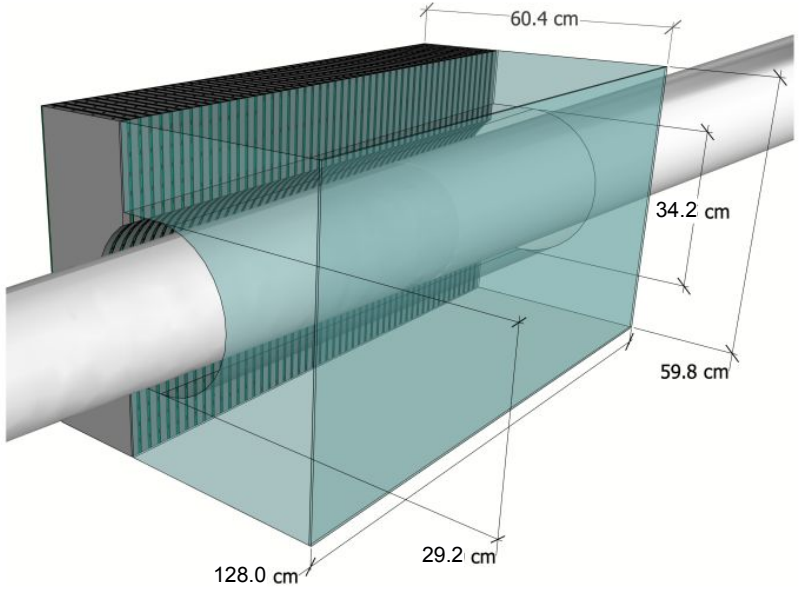
Maximizes acceptance, while fitting rest of end cap thus solving mechanical constraints on tough geometry.

Yields 5D shower info for sophisticated reconstruction algorithms (AI)

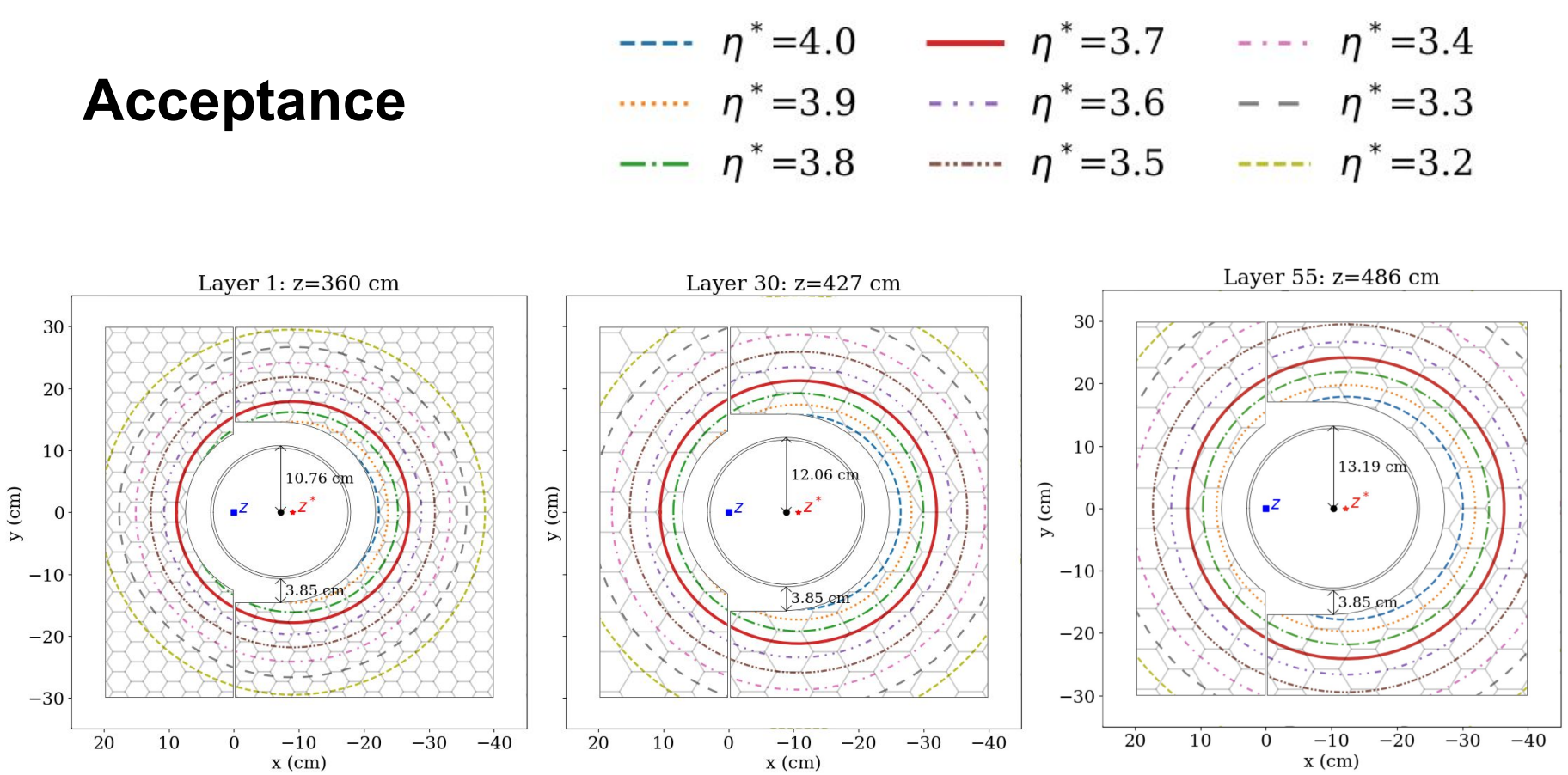
Absorber plate geometry

Custom made for each layer to **maximize acceptance**

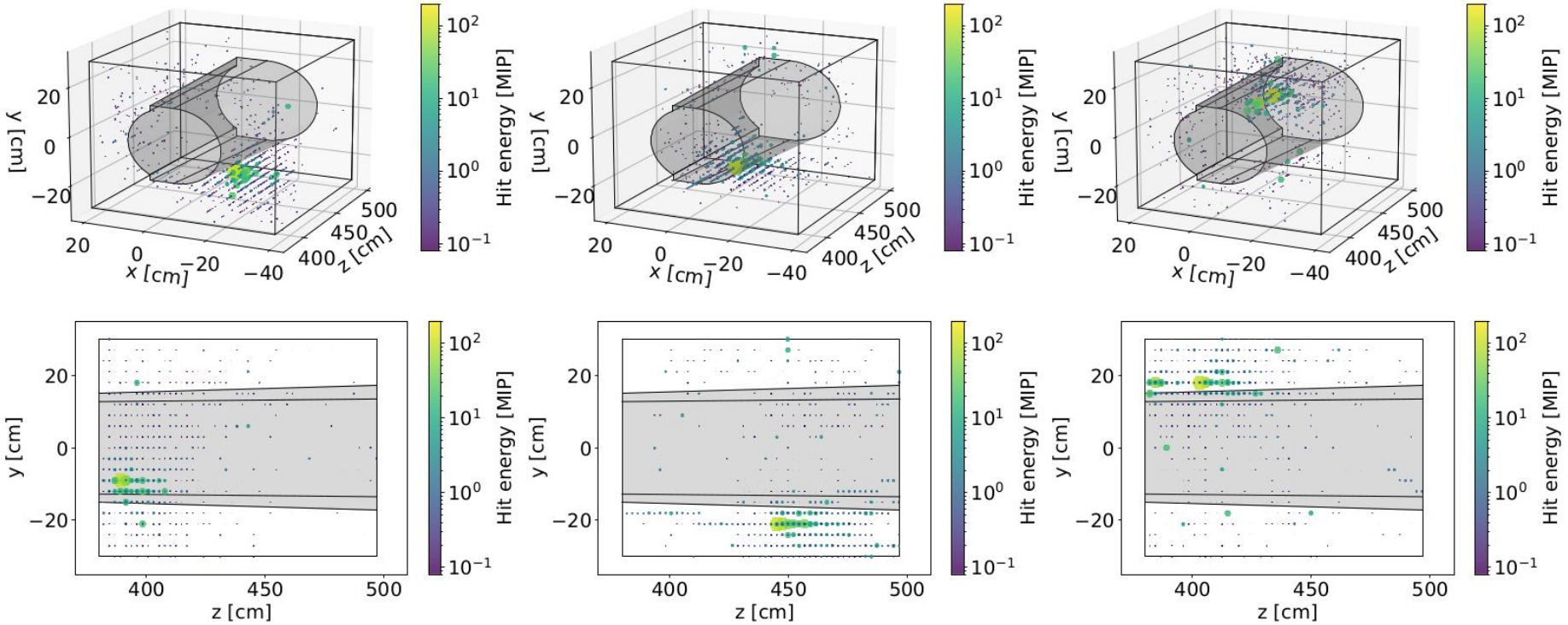




Acceptance

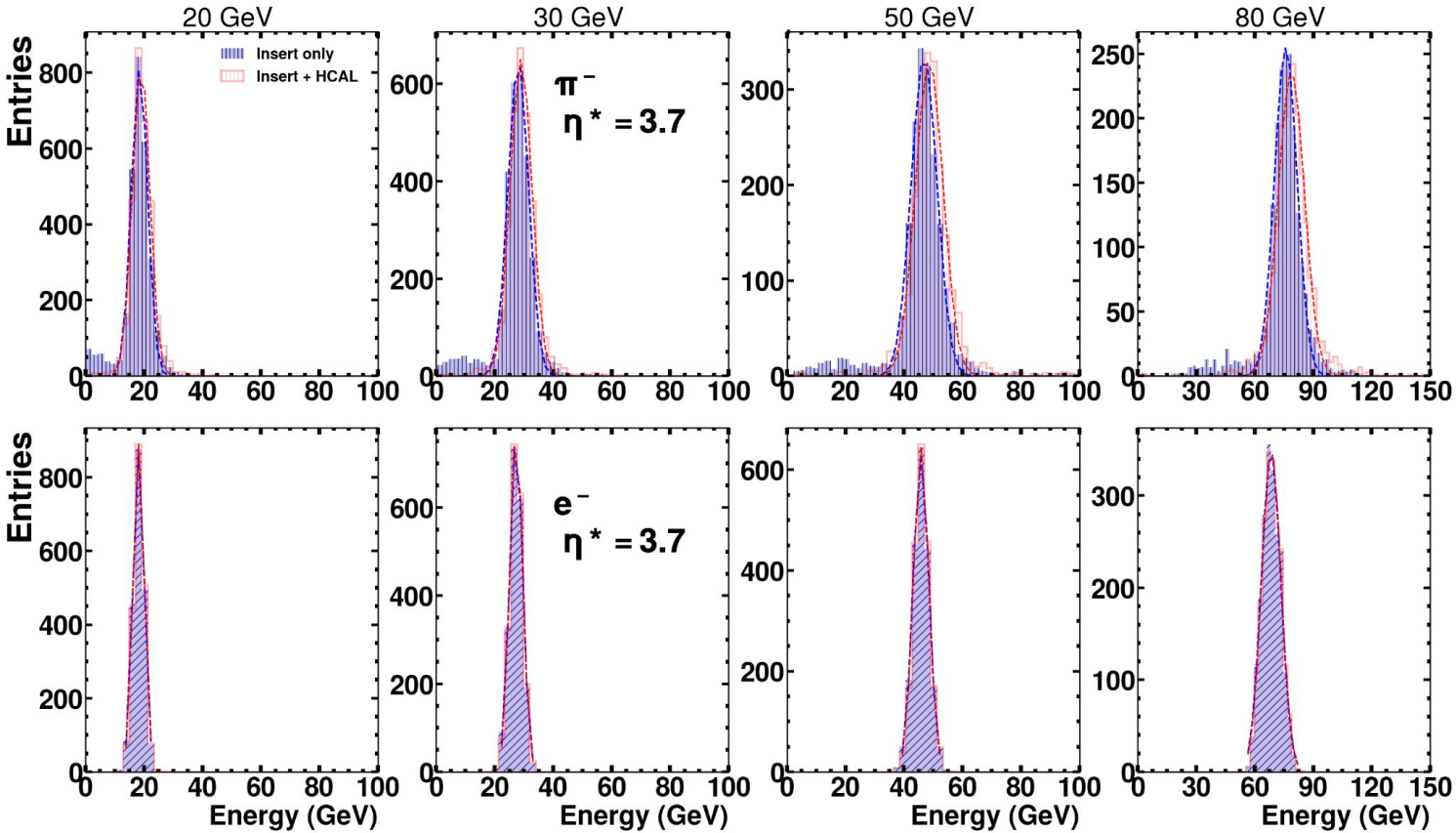

η^*=4.0
η^*=3.7
η^*=3.4
η^*=3.9
η^*=3.6
η^*=3.3
η^*=3.8
η^*=3.5
η^*=3.2
Layer 1: z=360 cm
Layer 30: z=427 cm
Layer 55: z=486 cm
10.76 cm
12.06 cm
13.19 cm
3.85 cm
z
z*
y (cm)
x (cm)

Examples of 50 GeV pion showers at η*=3.7



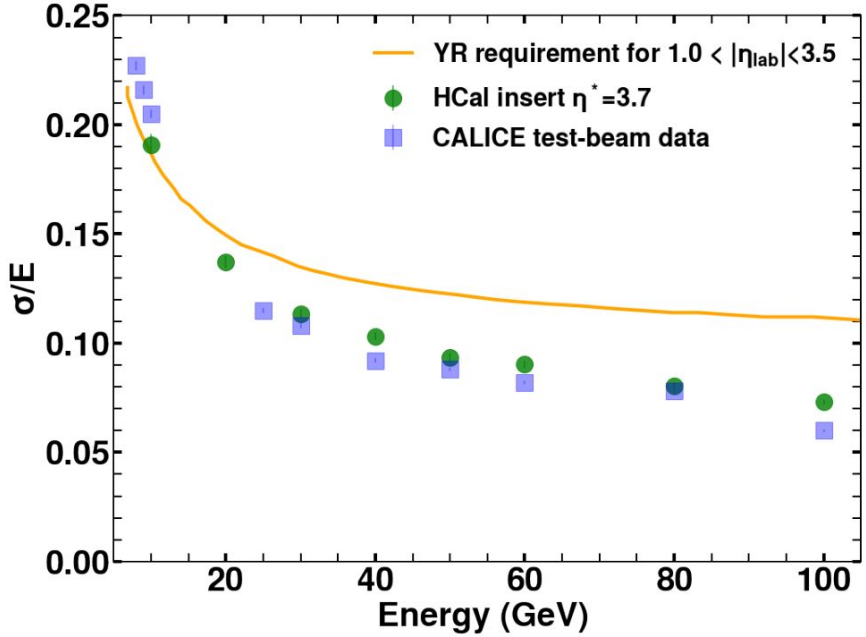
Narrow core of EM-like component contained, diffuse halo (neutrons) can traverse beampipe and be measured on other side

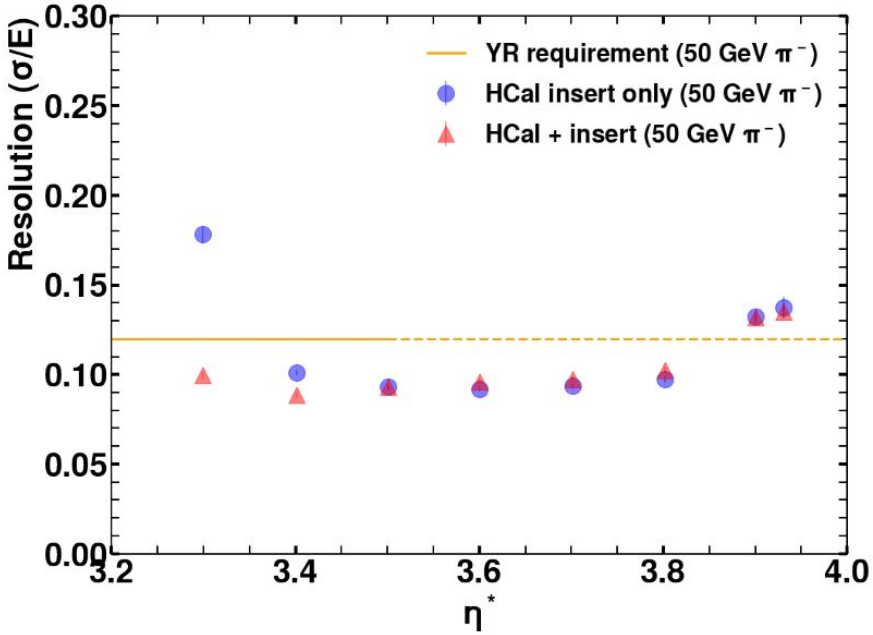
Linear, compensated response (e/h~1)



Single-hadron energy resolution

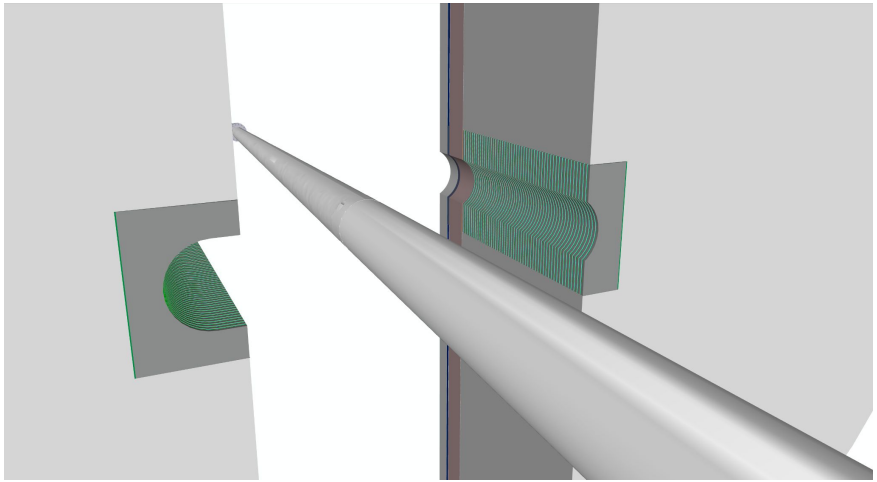
(with basic reconstruction algorithm)





- Performance meets YR requirements. Extends acceptance to true limit
- Projections validated with CALICE data (similar design)

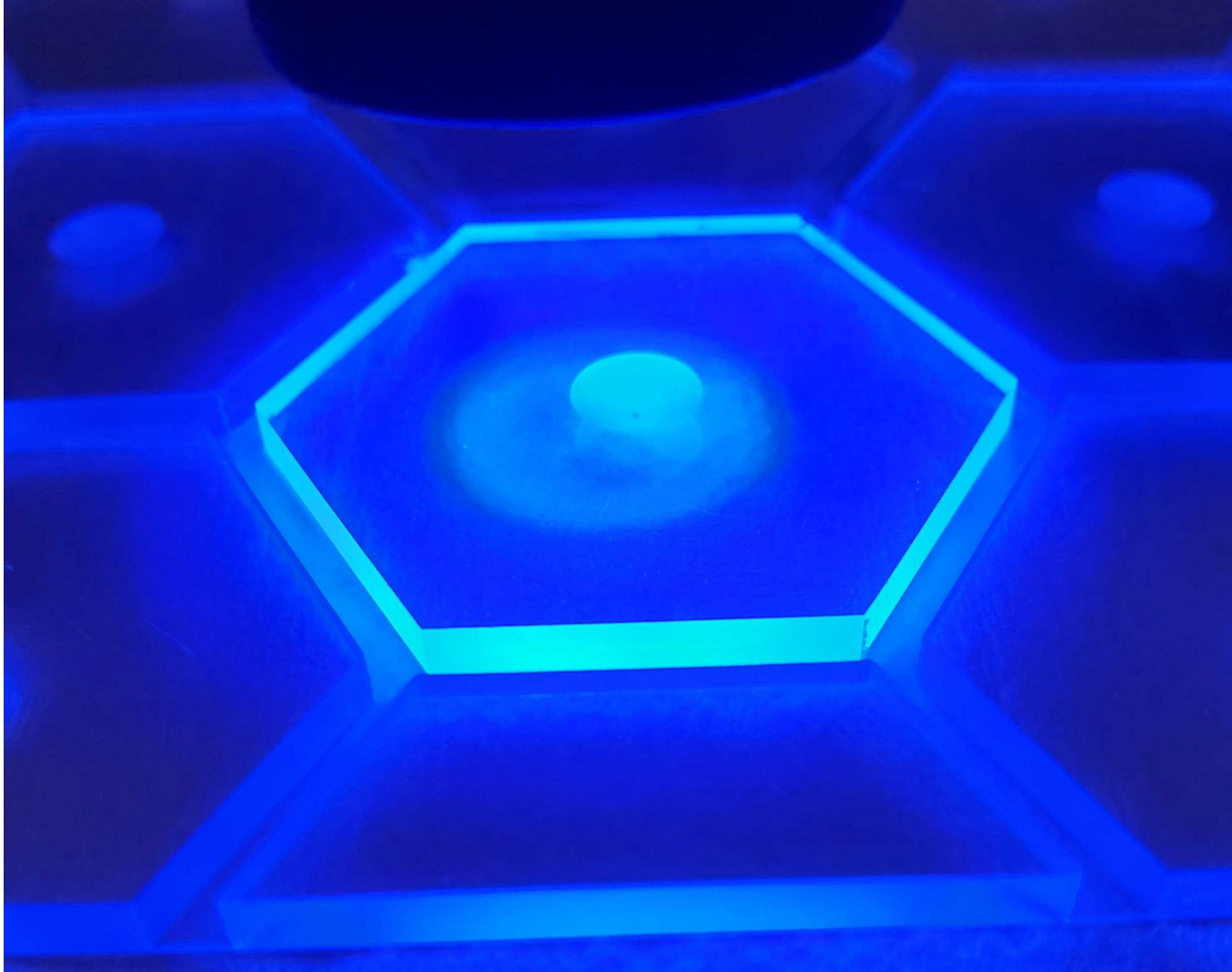
Design will gives us easy access to active layers



Can remove active layers and do **annealing** every shutdown to **mitigate radiation damage** and extend lifetime of SiPMs

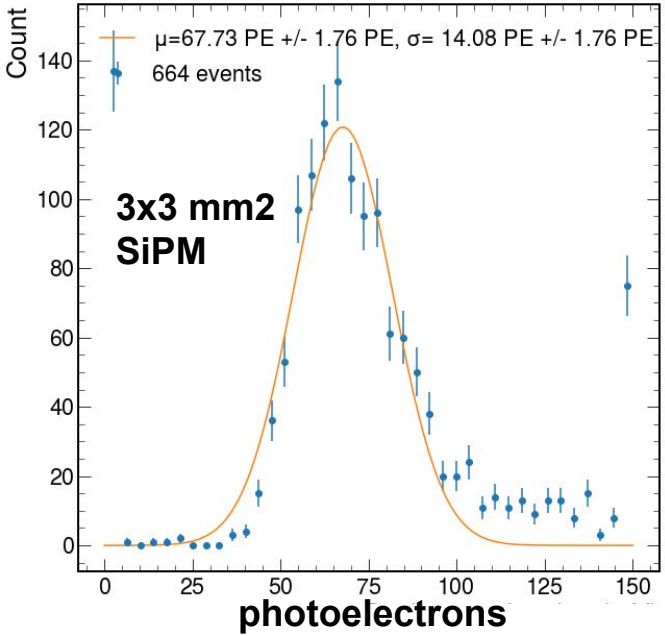
Straightforward access to active elements maximizes potential for **upgrades**
e.g. with glass tiles or dual-tile readout

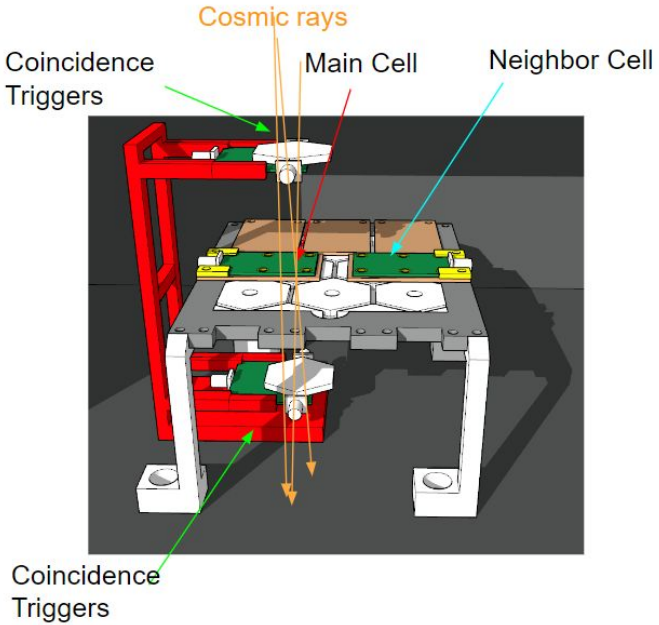
Ongoing and planned R&D

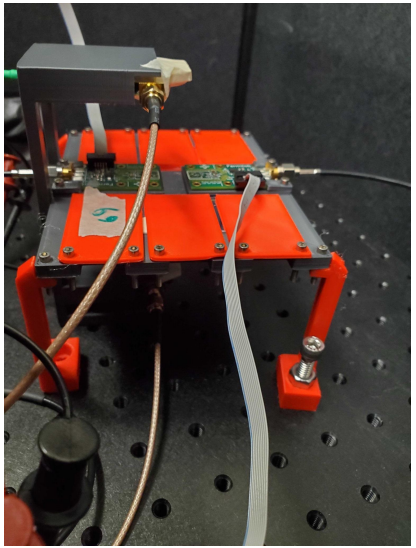


Light yield

measured with cosmics & Sr-90







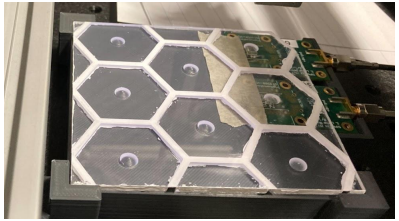
- Enough light yield to ensure high signal-to-noise, low-threshold.
- Adds buffers against degradation due to radiation damage

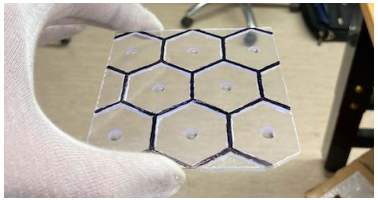
Optical cross-talk

Measured with cosmics & LED

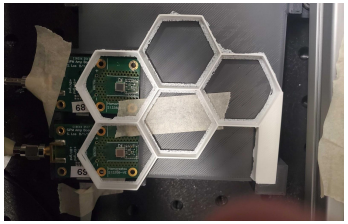
We studied two options:

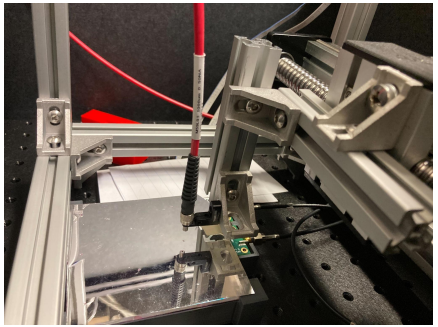
Grooved cells (ala STAR)

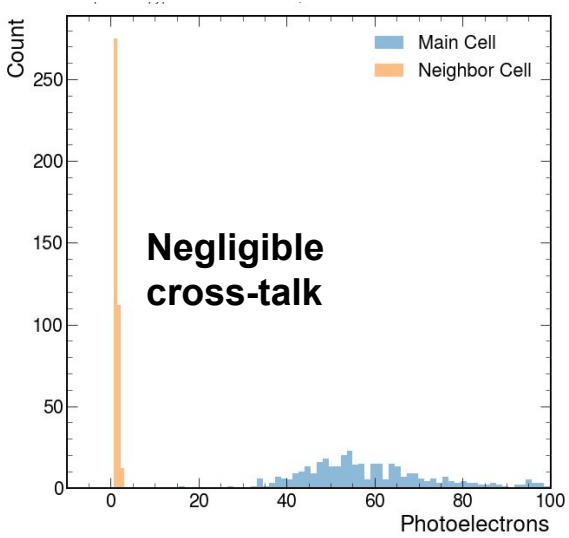




3D-printed frame







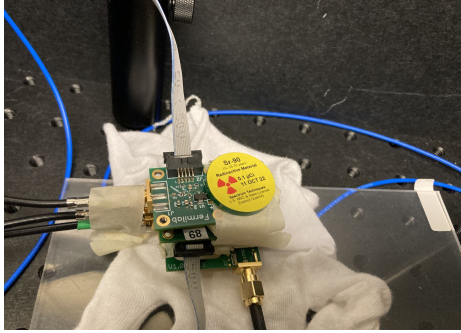
Consistent results between cosmic-ray and LED measurements

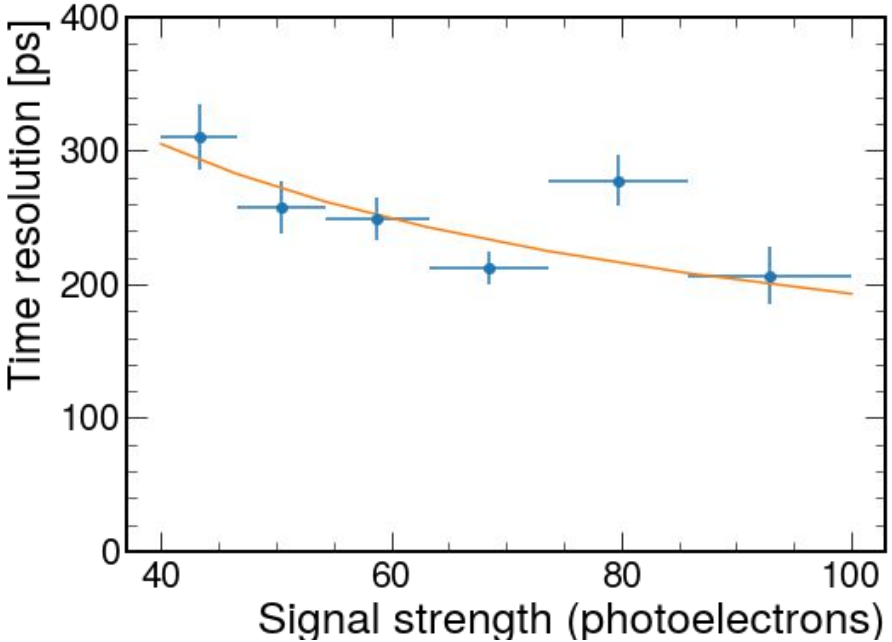
- Grooved cells, edges painted, with black ink at back: **~3% cross-talk**
- 3D printed frame with individual cells, edges painted **<1% cross-talk**

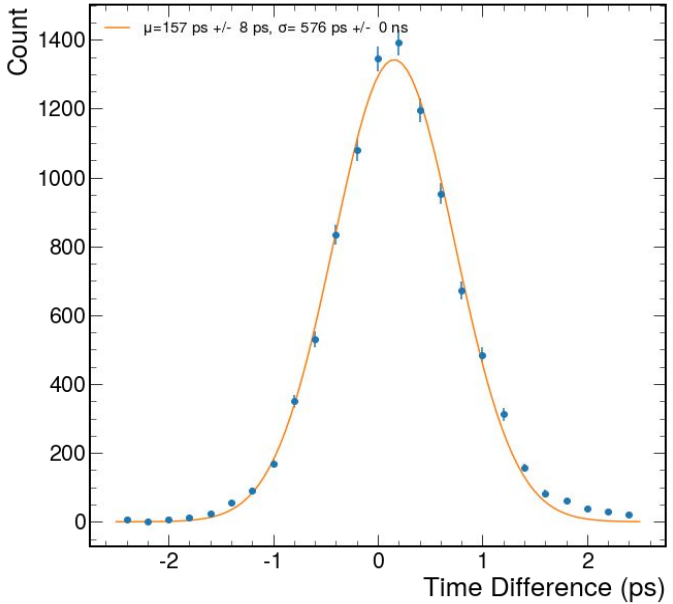
Time resolution

with cosmics, picosecond laser, and Sr-90

- **~250 ps per hit** at MIP, similar to CALICE studies
- **Promising for 5D clustering**. AI-based reco and and bkg rejection

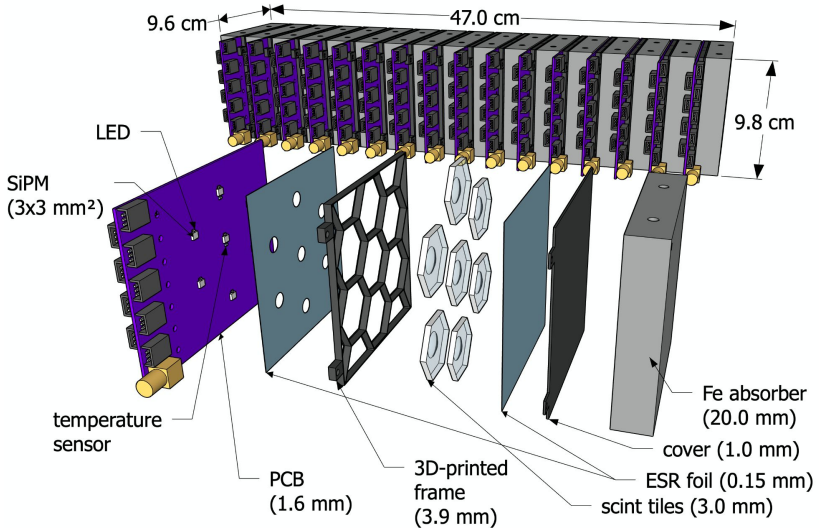






First “ECAL-size” prototype

- ~10x10 cm2, 18 X0 depth and 128 channels.
- Have all the materials at hand, including readout (CAEN FERS-5200), SiPMs, EJ-212, etc.
- Plan to finish in a few months, then to test at JLab, FNAL, maybe RHIC and others.

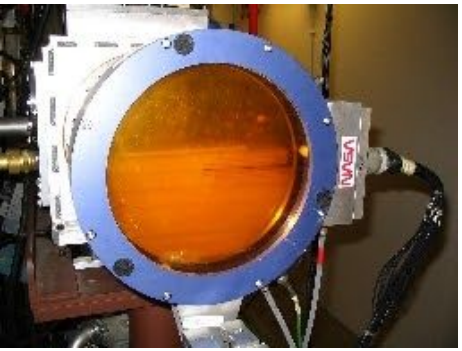


Students completing first layer of calorimeter insert prototype

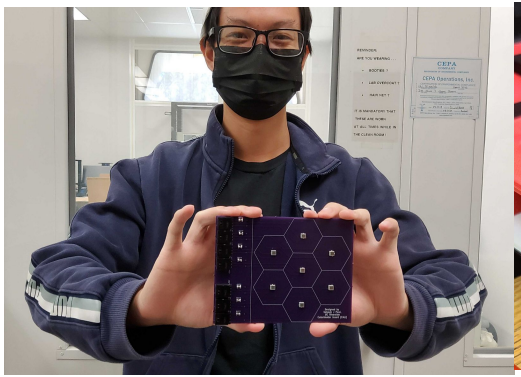
Radiation testing @ Berkeley 88”

BERKELEY ACCELERATOR SPACE EFFECTS

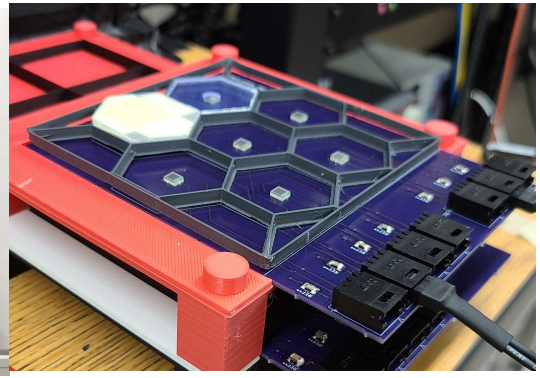
- We are planning to use LBNL 88” cyclotron in collaboration with California EIC consortium.
- 50 MeV proton beams up to 10e12 neutron / cm2 (~1 year @ EIC) then perform annealing studies.
  → Mimicking anticipated rad-damage mitigation after each run
- Seeking opportunistic running, potentially soon



Ion chamber @ the 88”



Student with PCB with SiPMs



Testing non-irradiated SiPMs

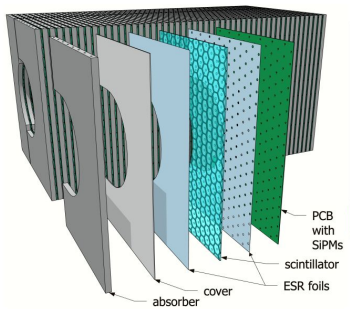
Environmental chamber for annealing studies

We will benefit tremendously from worldwide "SiPM-on-Tile" R&D.
"A new era in calorimetry"

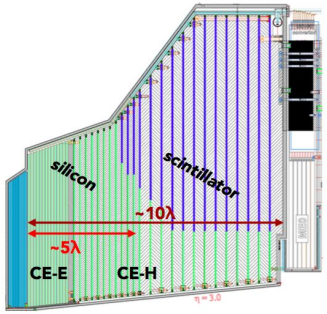
EIC application will be rather small in comparison,
but impactful because of high-rapidity coverage→ **excellent bang per buck**

CALICE Prototype nowadays **~20k channels**

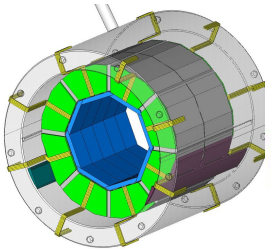
~4k channels

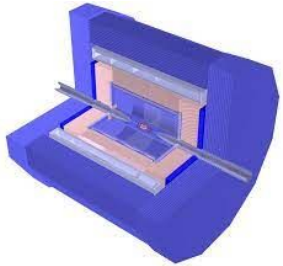


CMS HGCAL **~400k channels**



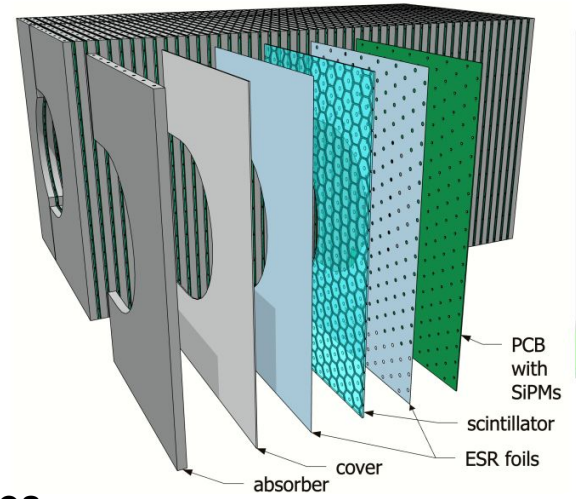
ILD CEPC **~8M channels**





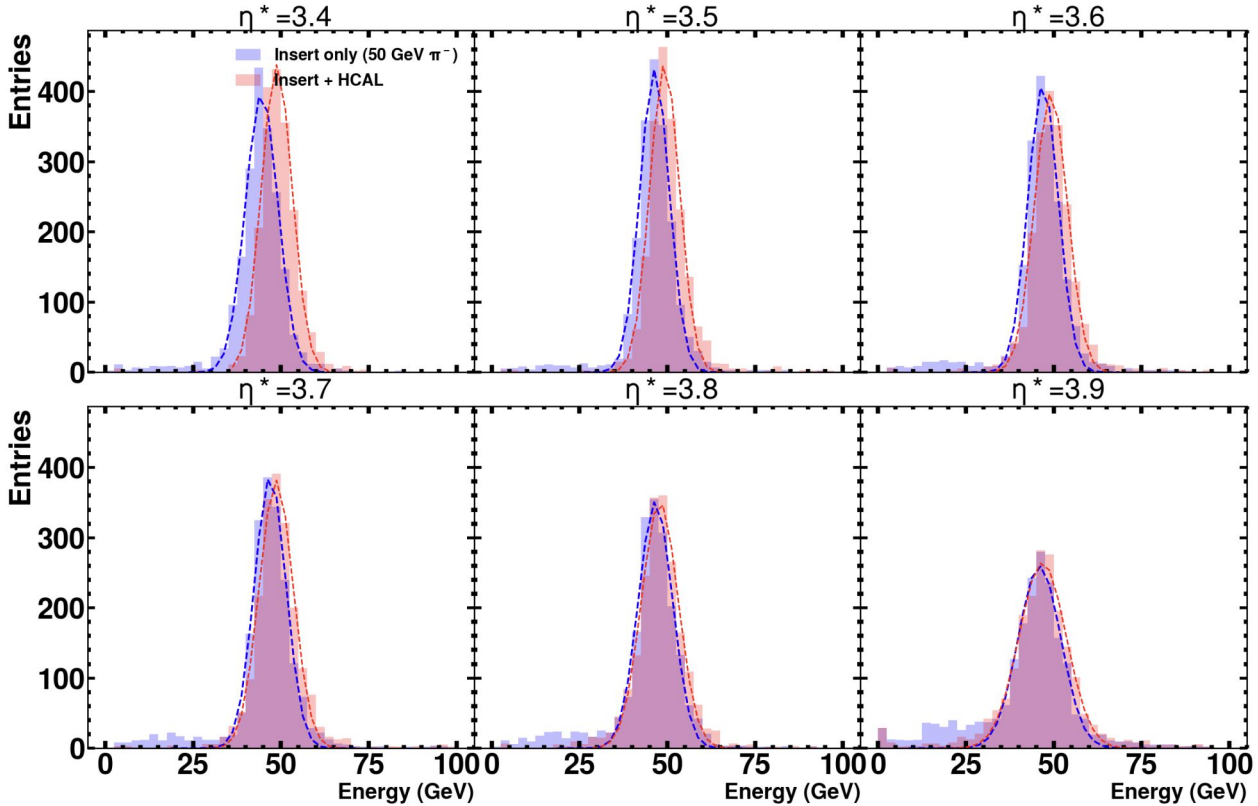
Summary

- Calorimeter insert **essential to deliver** on promise of ***“ coverage as large coverage as technically possible”*** and improves physics capabilities
- SiPM-on-tile technology is ideally suited for insert at EIC
- Particle-flow calorimeter, with **5D hits (energy, time, 3D)** capabilities ideal for AI.
  Meets YR requirements and more even with rudimentary (non-AI) algorithms.
- **Future-proof design** enables easy maintenance and upgrades, (e.g. with glass tiles)



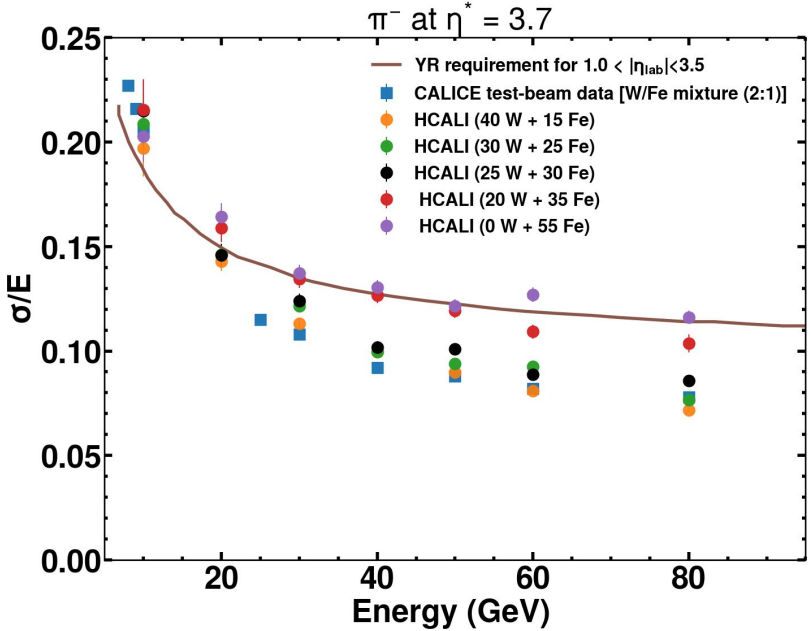
Backup

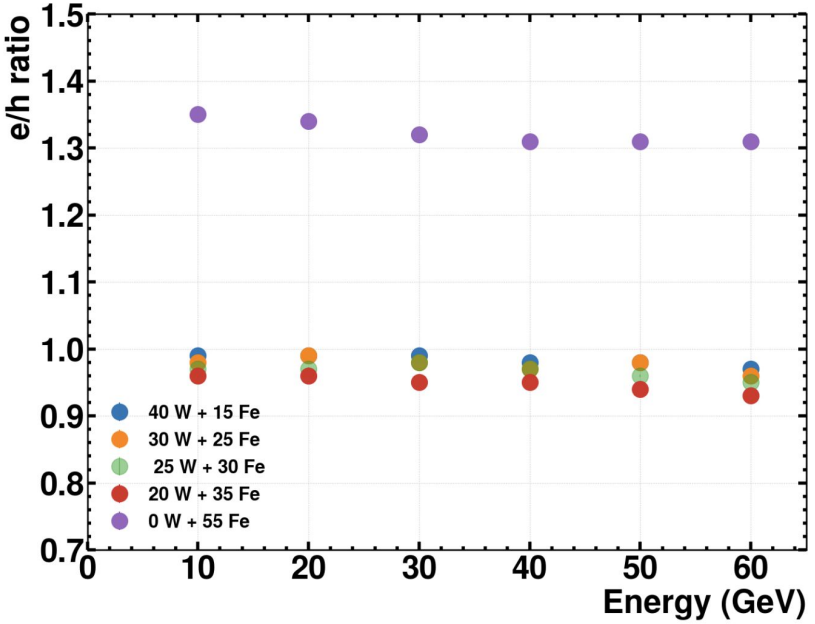
Energy resolution vs angle for 50 GeV charged-pion



- Gaussian like response even up to 3.9.
- Some transverse leakage from insert to HCAL observed (blue tail), but recovered once measurements are combined

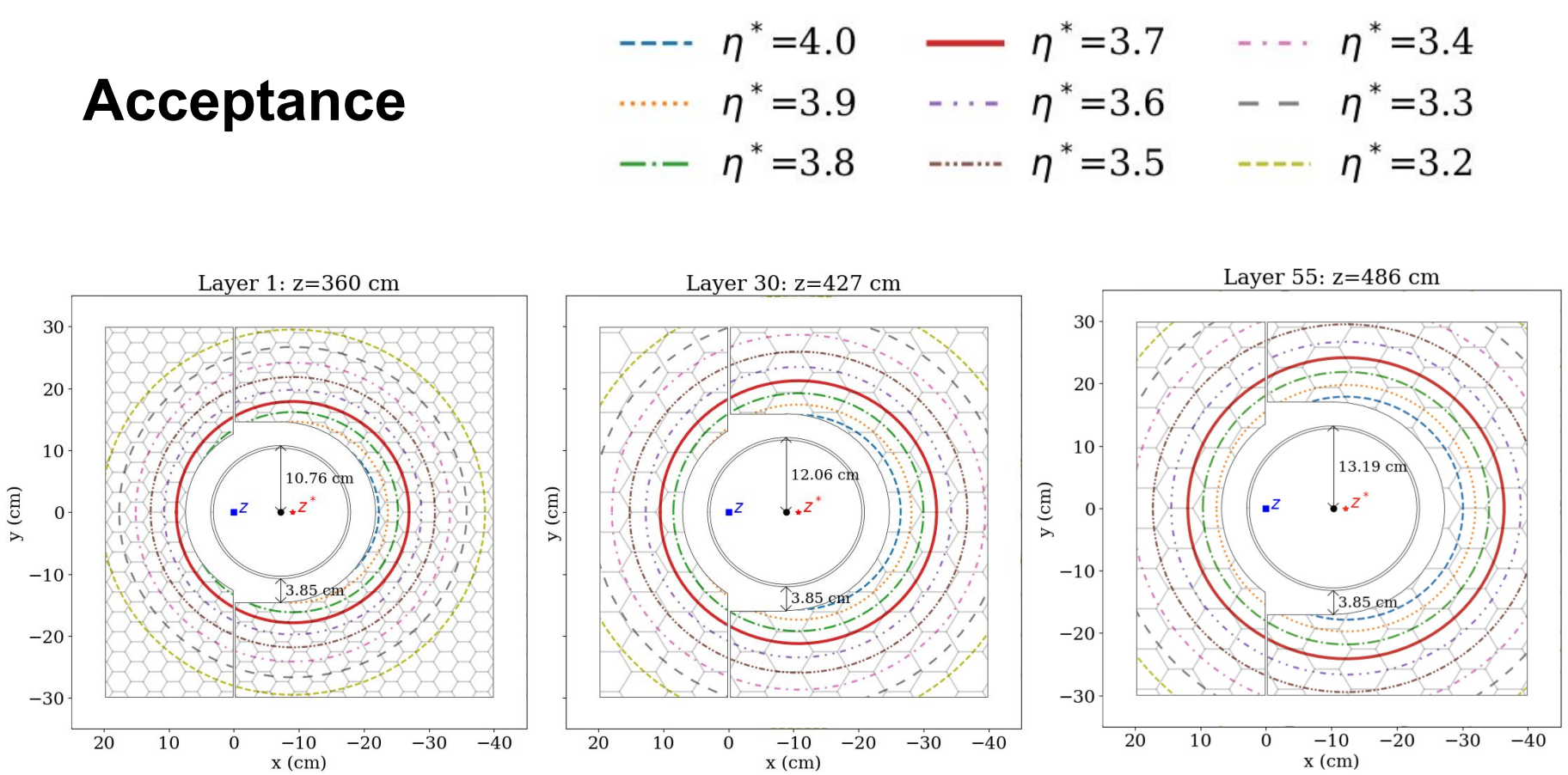
Performance with varying tungsten layers





- Tungsten helps maximize acceptance (reduced leakage of EM-like core of hadronic showers), and yields compensated response
- But if needed, calorimeter insert could work OK even with 0% tungsten

Acceptance


η^*=4.0
η^*=3.7
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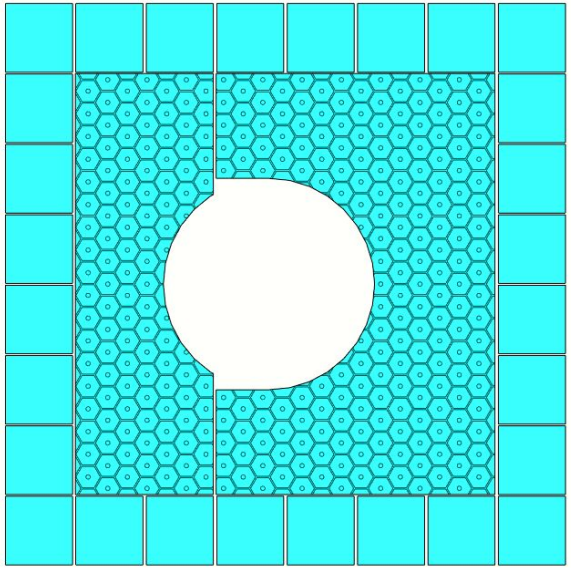
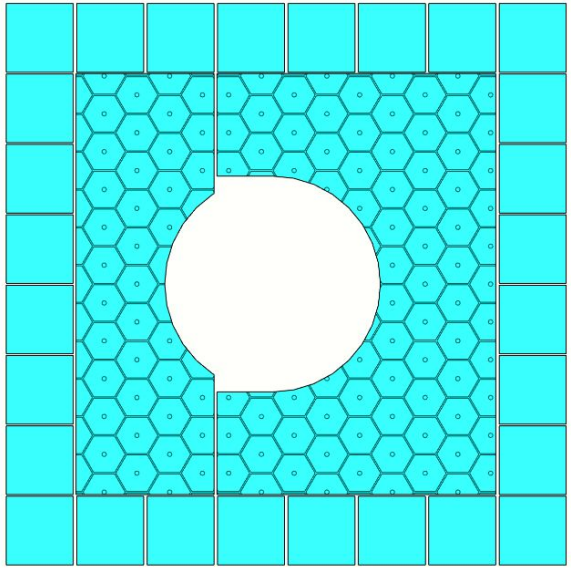
η^*=3.2
Layer 1: z=360 cm
Layer 30: z=427 cm
Layer 55: z=486 cm
10.76 cm
12.06 cm
13.19 cm
3.85 cm
z
z*
y (cm)
x (cm)

Granularity will be optimized, it could be realized like

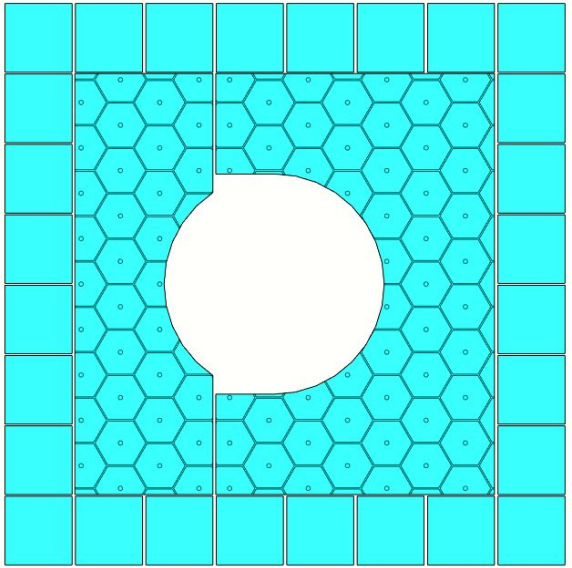
Layers 1-7: 9 cm²



Layers 8-14: 25 cm²

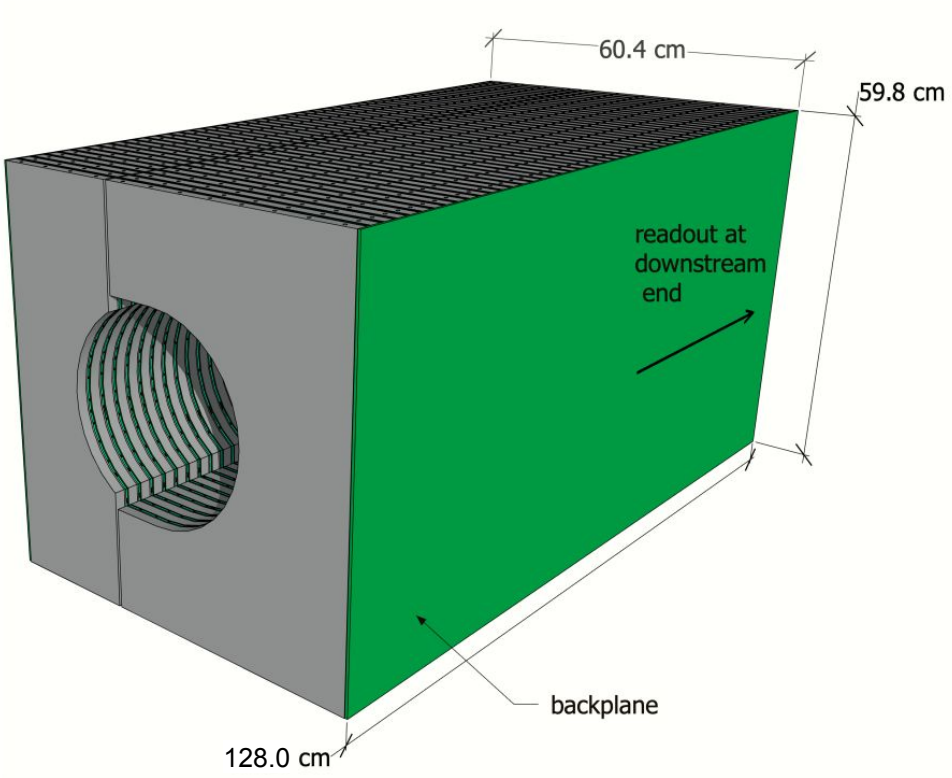


Layers 15-54: 36 cm²



Currently aiming at ~4k channels total

The backplane

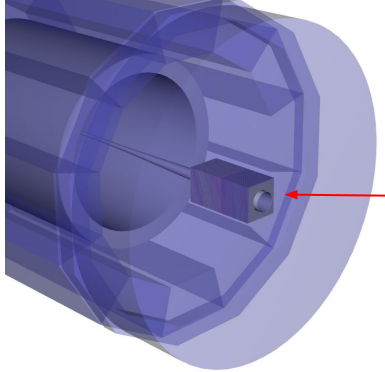


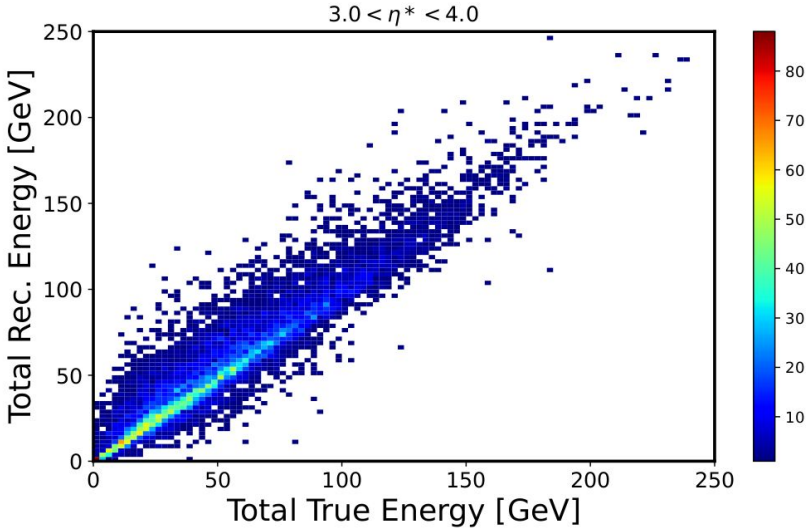
"Like a crate" for SIPM PCB,
which just has passive components

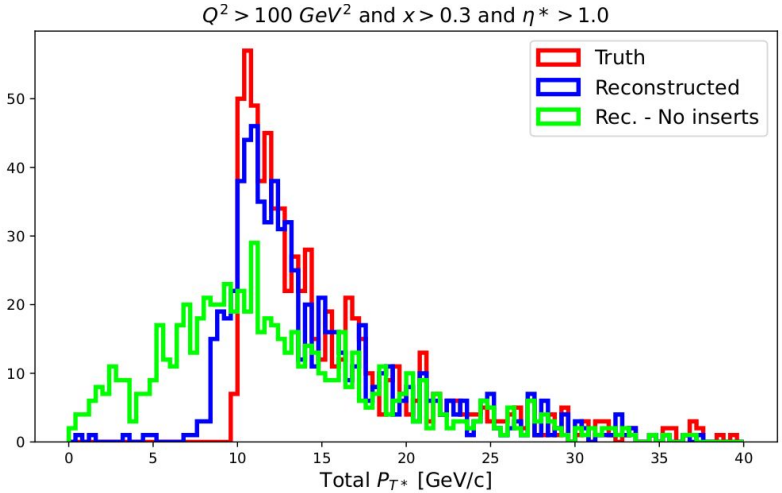
16 layer PCB, 4 mm on both ends

Engineer (Gerard Visser) called it
"Nice scheme"
"That is perfectly reasonable"

Calorimeter Insert in EPIC simulation (Bryce Canyon)

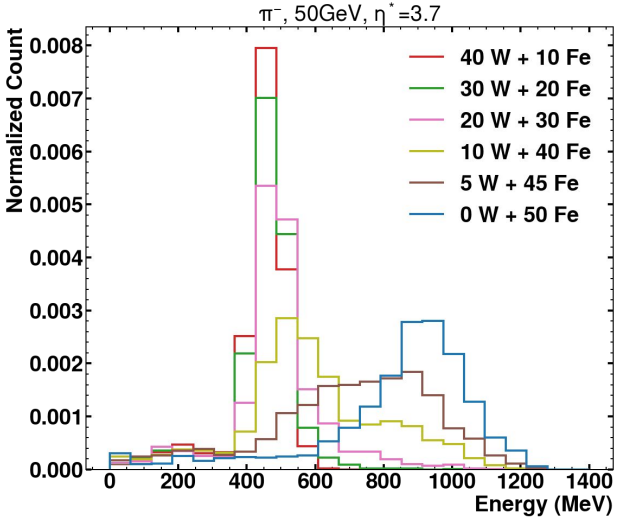


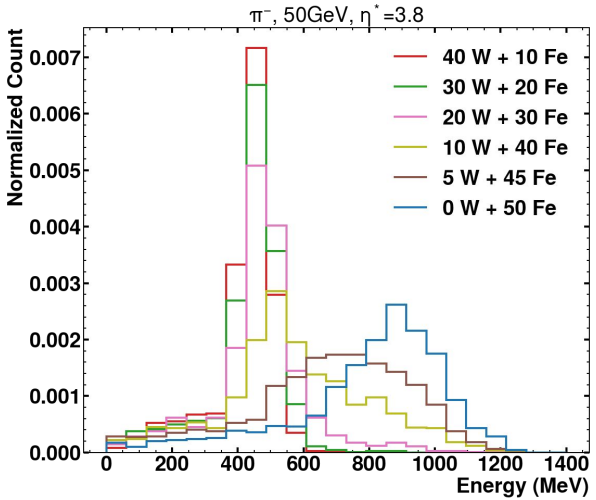


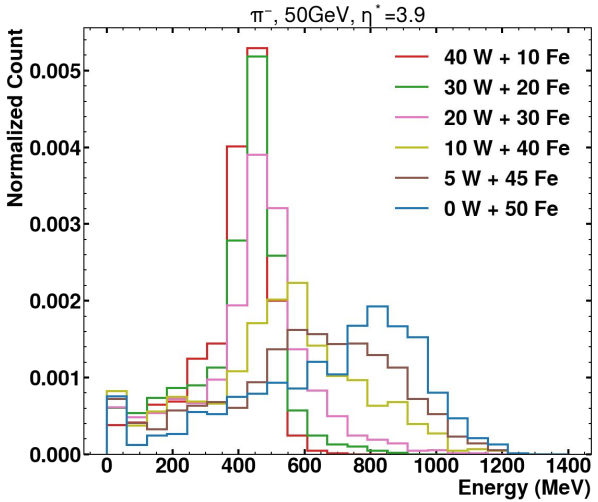


- Performance of key physics quantities being studied in inclusive DIS (Barak et al.) and jet group

HCal Insert response for π^- at 50 GeV
With various W/Fe mixtures

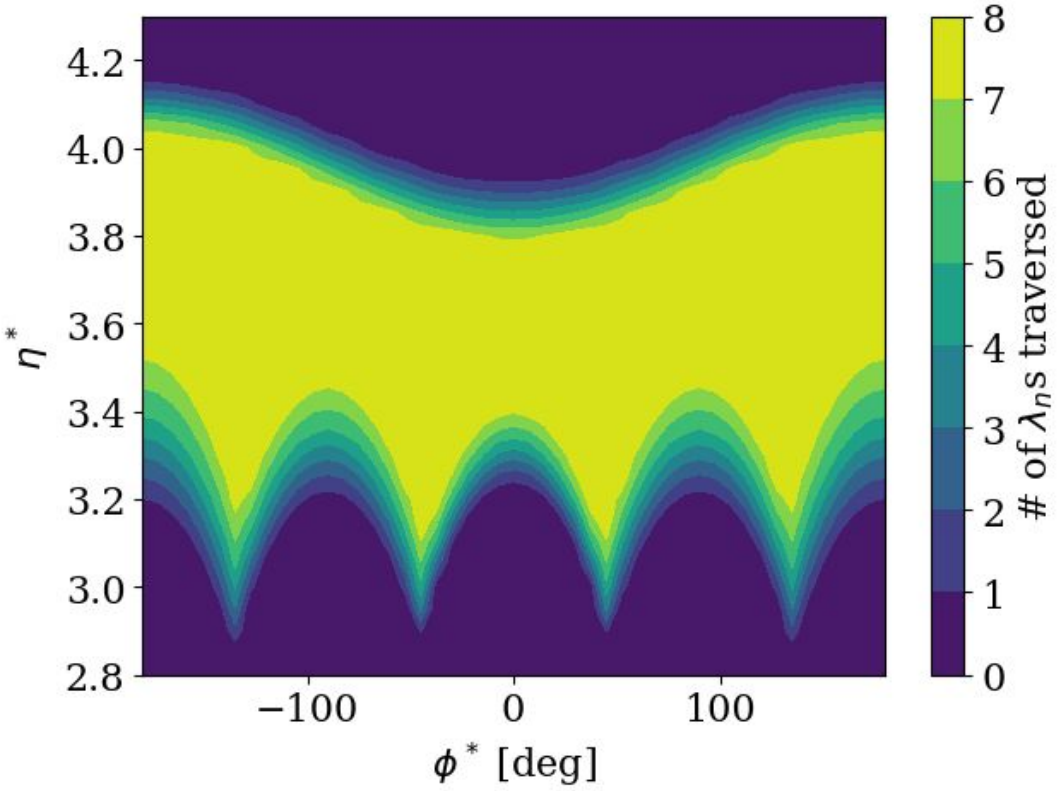






- Worsening of performance by decreasing number of tungsten layer because of leakage of collimated core and reduction of neutron production.

Depth



- Total number of interaction lengths is well matched for energies in this region.
- Even at larger angles, it can provide extremely good shower-start position over good fraction of acceptance.

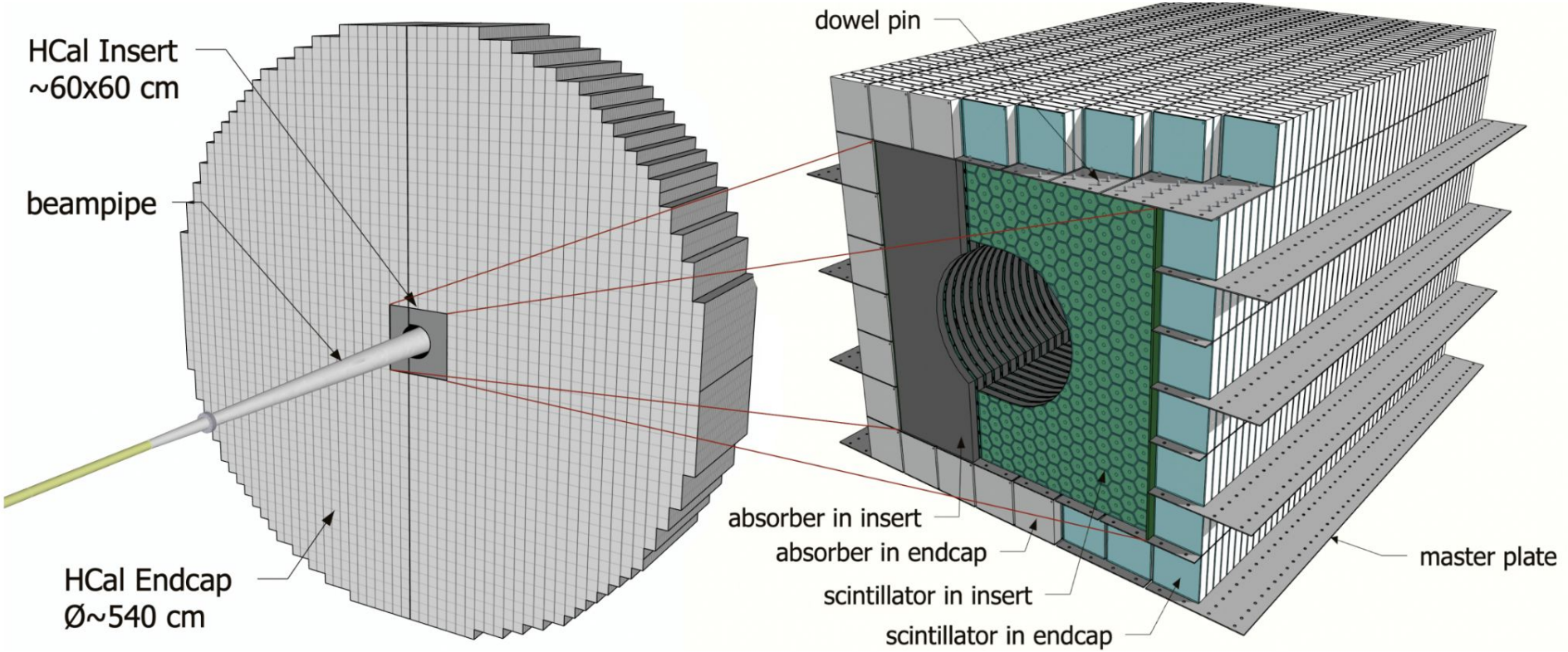
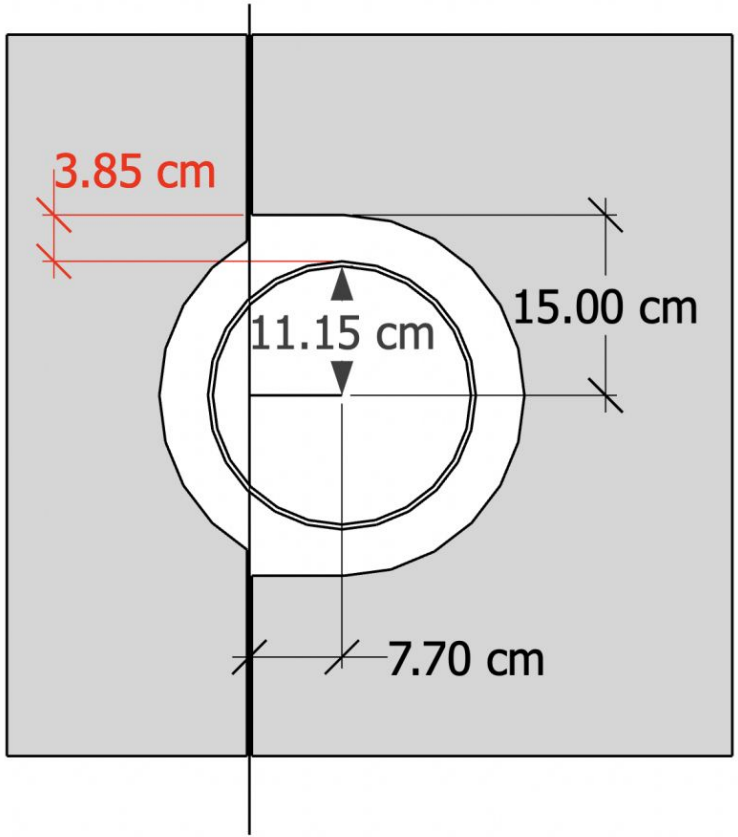
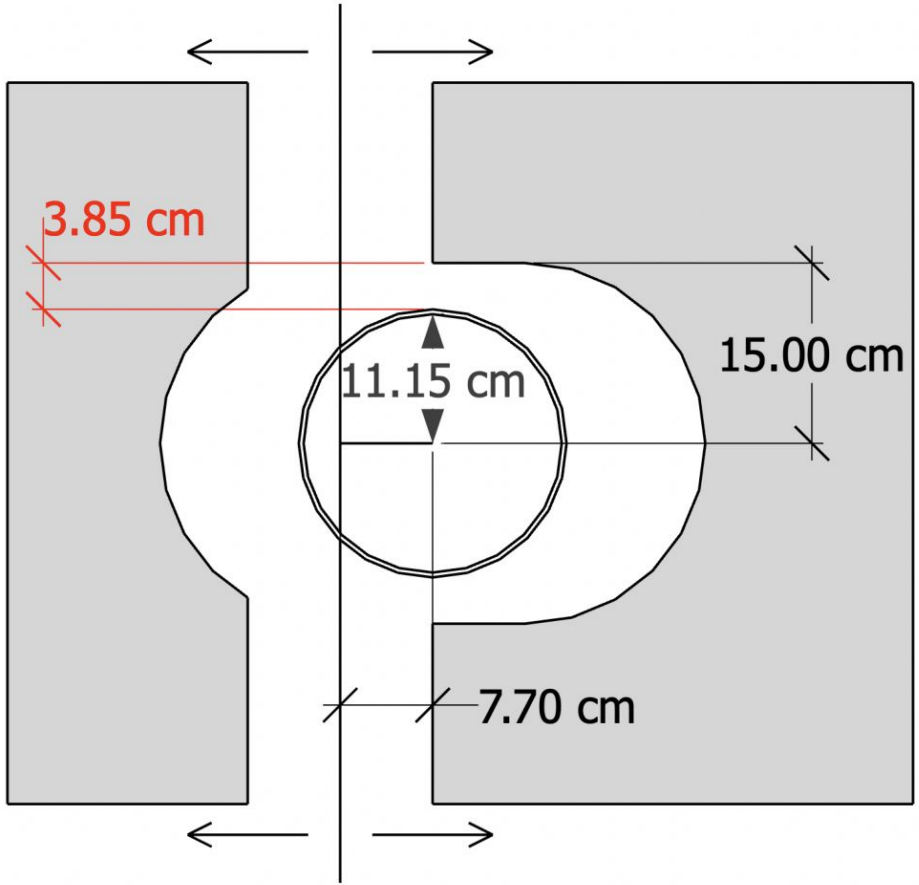
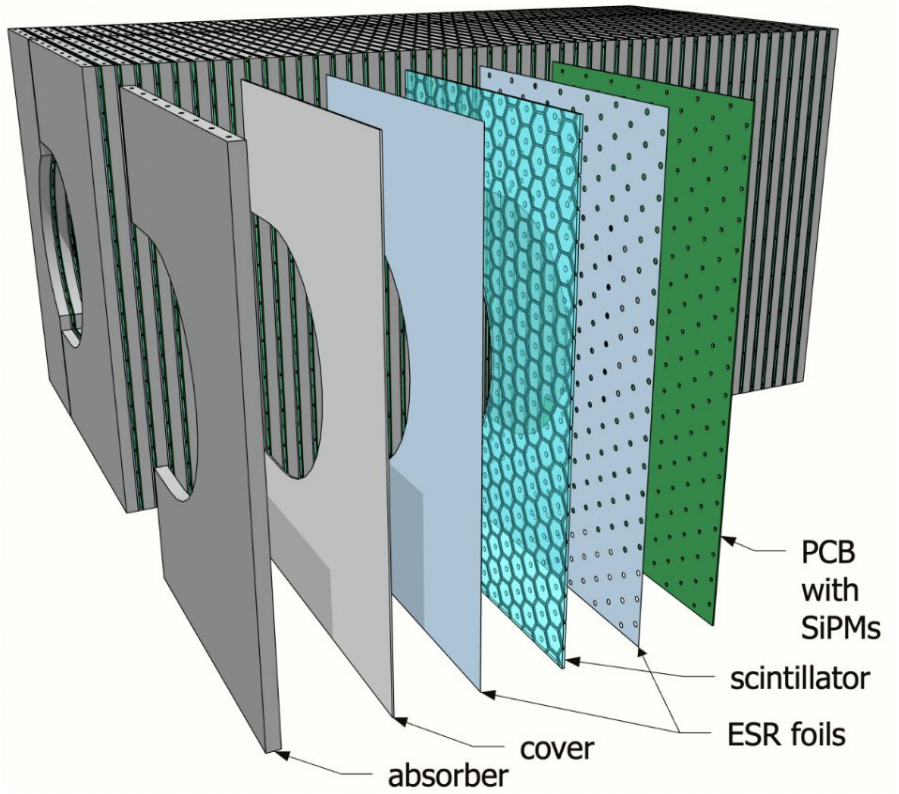
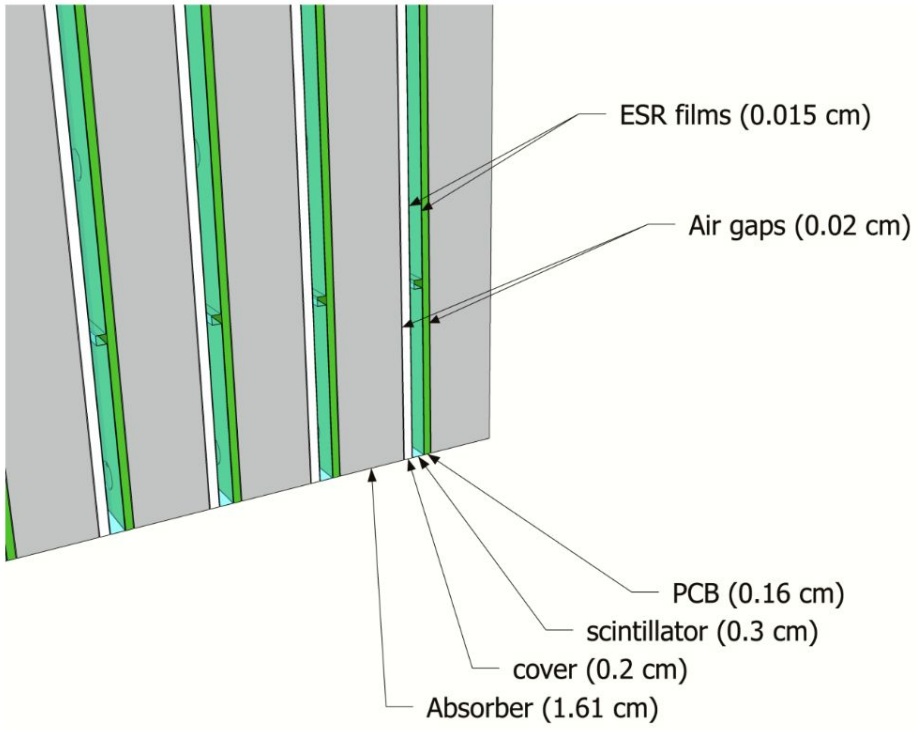


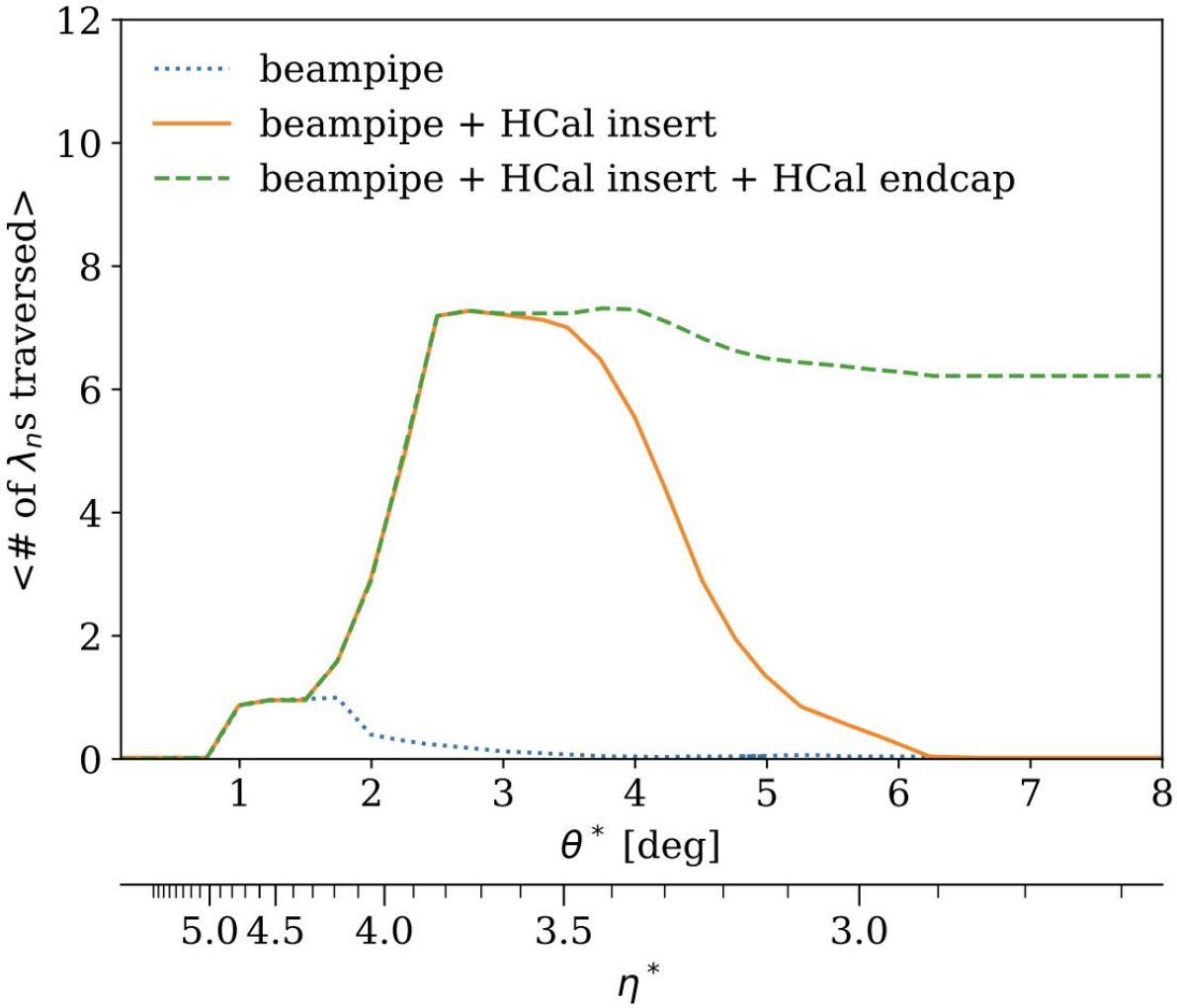
Diagram was for STAR-like calorimeter (needs to be adapted for EPIC)


3.85 cm
11.15 cm
15.00 cm
7.70 cm


3.85 cm
11.15 cm
15.00 cm
7.70 cm


PCB
with
SiPMs
scintillator
ESR foils
cover
absorber


ESR films (0.015 cm)
Air gaps (0.02 cm)
PCB (0.16 cm)
scintillator (0.3 cm)
cover (0.2 cm)
Absorber (1.61 cm)


beampipe
beampipe + HCal insert
beampipe + HCal insert + HCal endcap
<# of λ_ns traversed>
θ^* [deg]
η^*
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
5.0
4.5
4.0
3.5
3.0