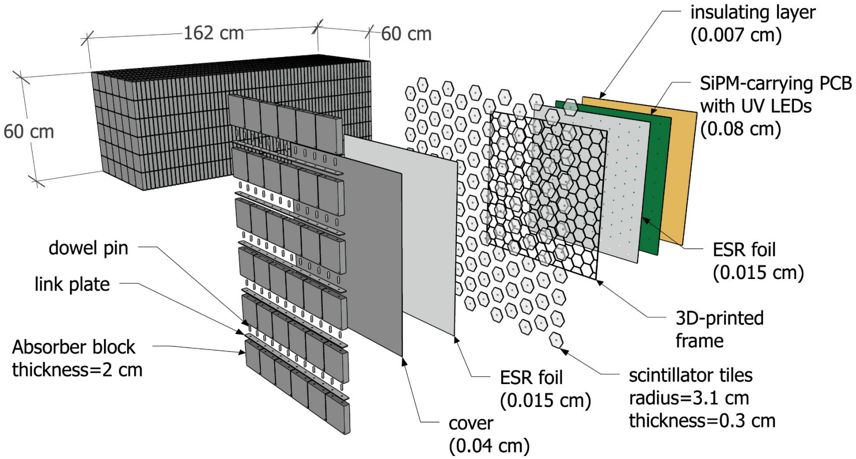
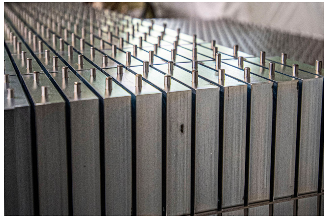
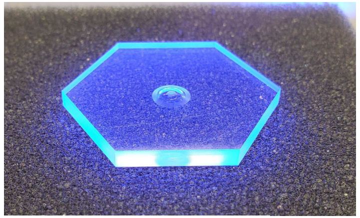
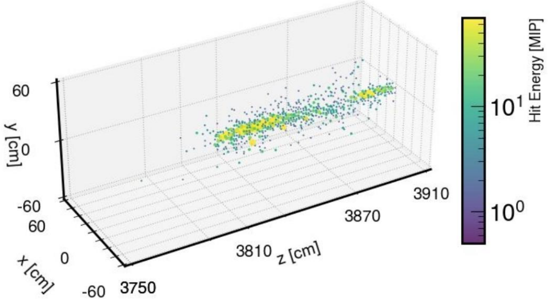
SiPM-on-Tile ZDC HCAL









Miguel Arratia

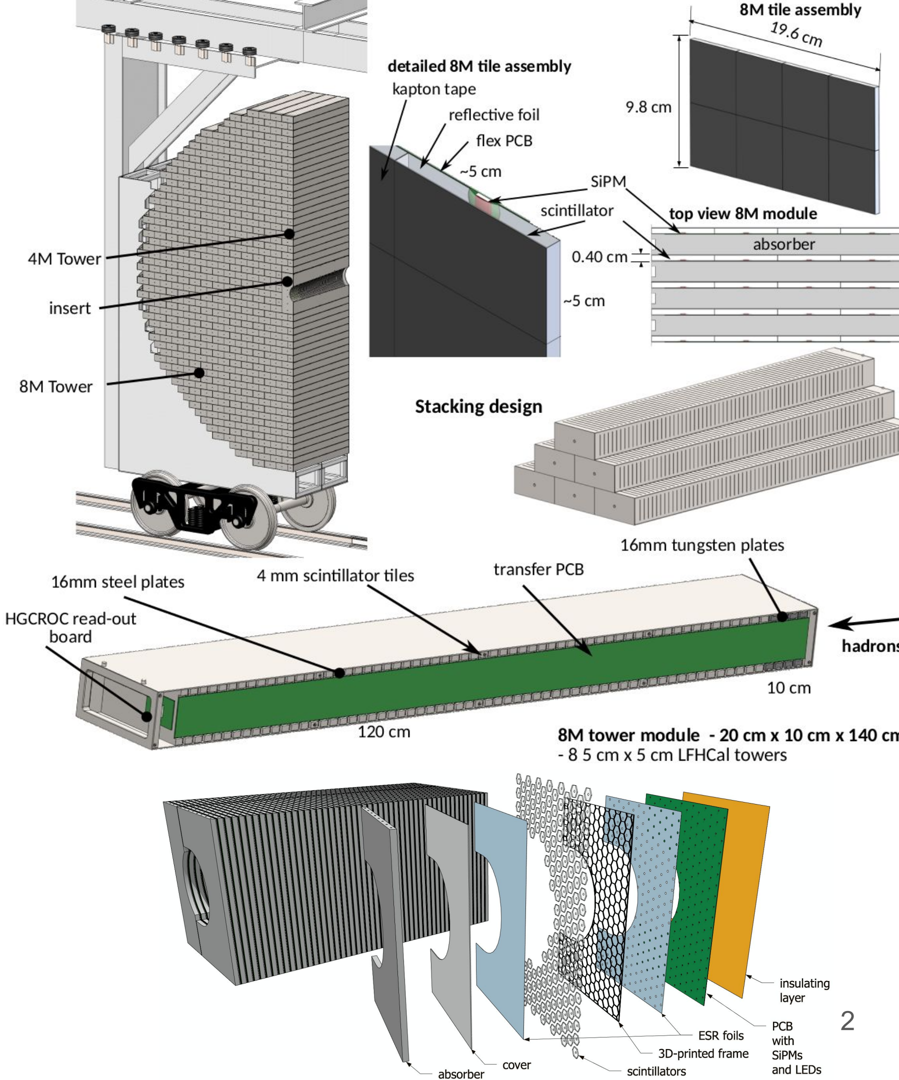
UC RIVERSIDE

TIC meeting 10/08/2023

Forward HCAL uses SiPM-on-tile technology

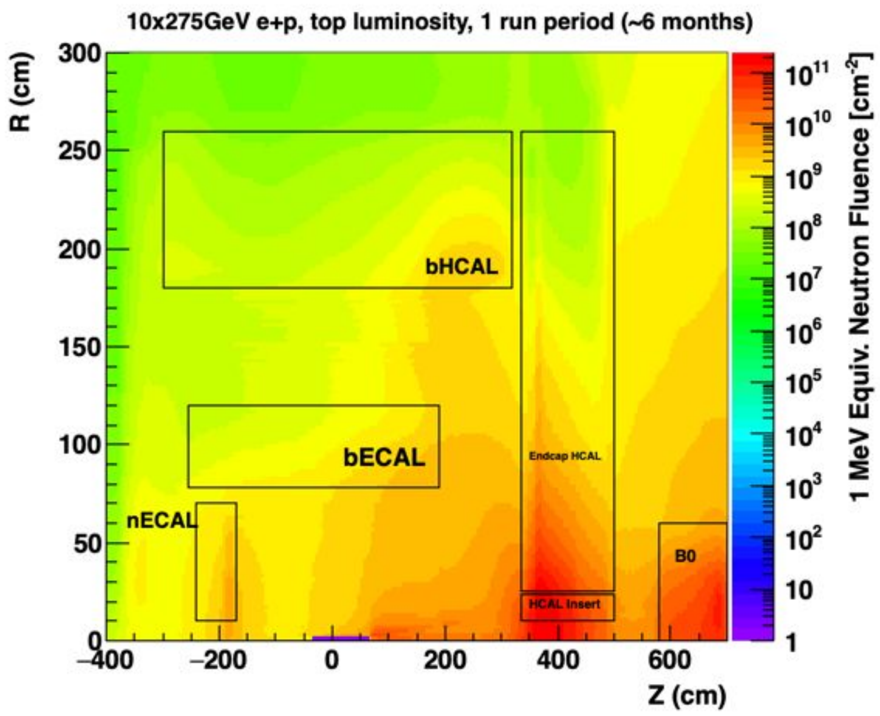
ZDC HCAL might benefit from sharing:

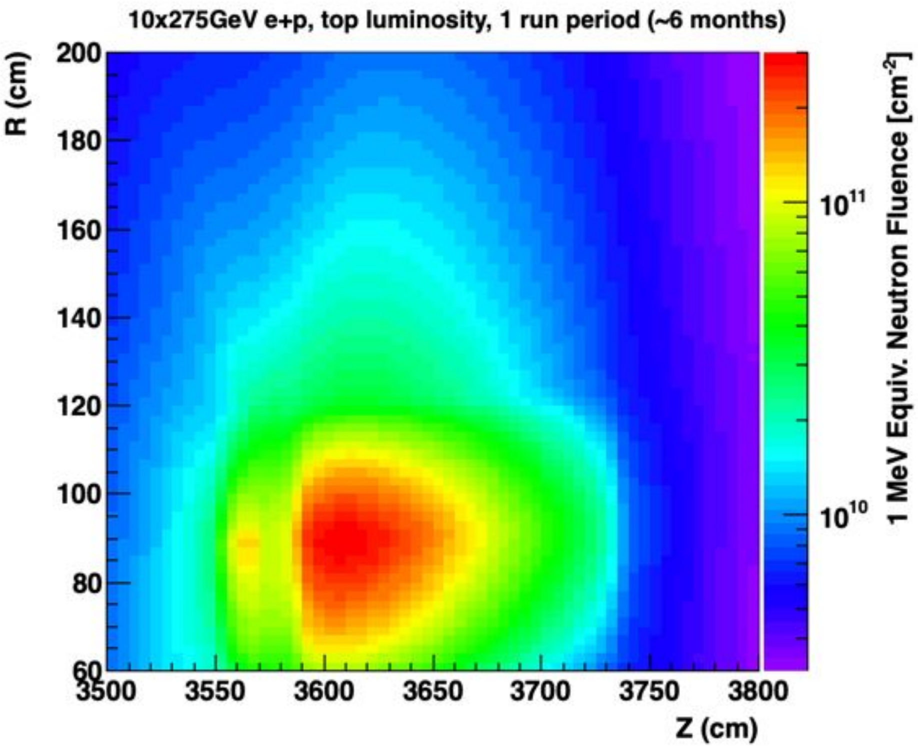
- Design ideas
- R&D and PED
- Simulations and Algorithms
- Personpower
- Bulk purchase and production



Neutron flux in Insert region is similar to that of ZDC

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

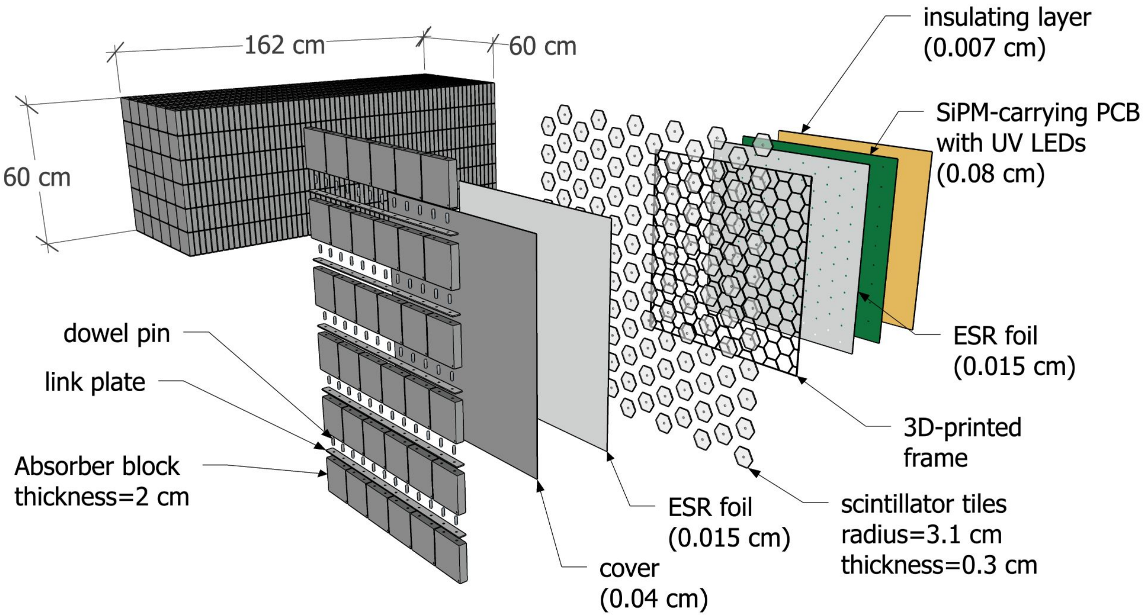




Design and mitigation strategies discussed for Insert and HCAL could be used in ZDC

A possible SiPM-on-tile ZDC design like Insert

- SiPMs and bias & readout (HGROC) and scintillator cells (injection molding) relatively inexpensive.
- Reuse 2×10×10 cm^3 Fe absorber blocks from STAR

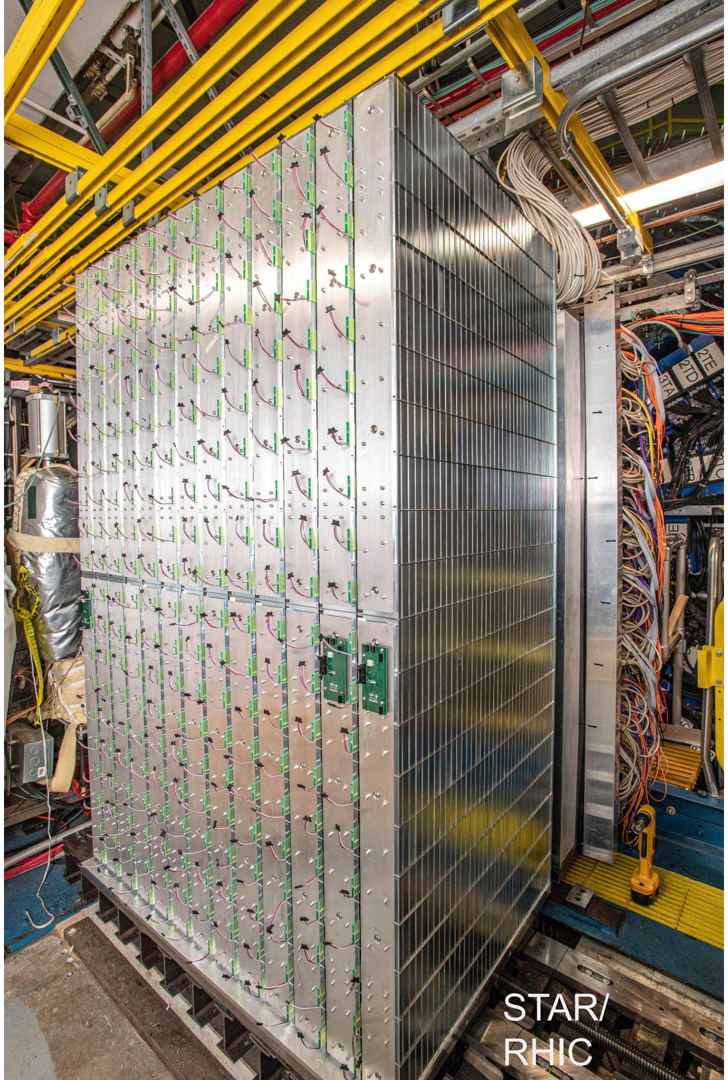


Reusing STAR HCAL blocks

Modular “LEGO” design ideal for reuse.

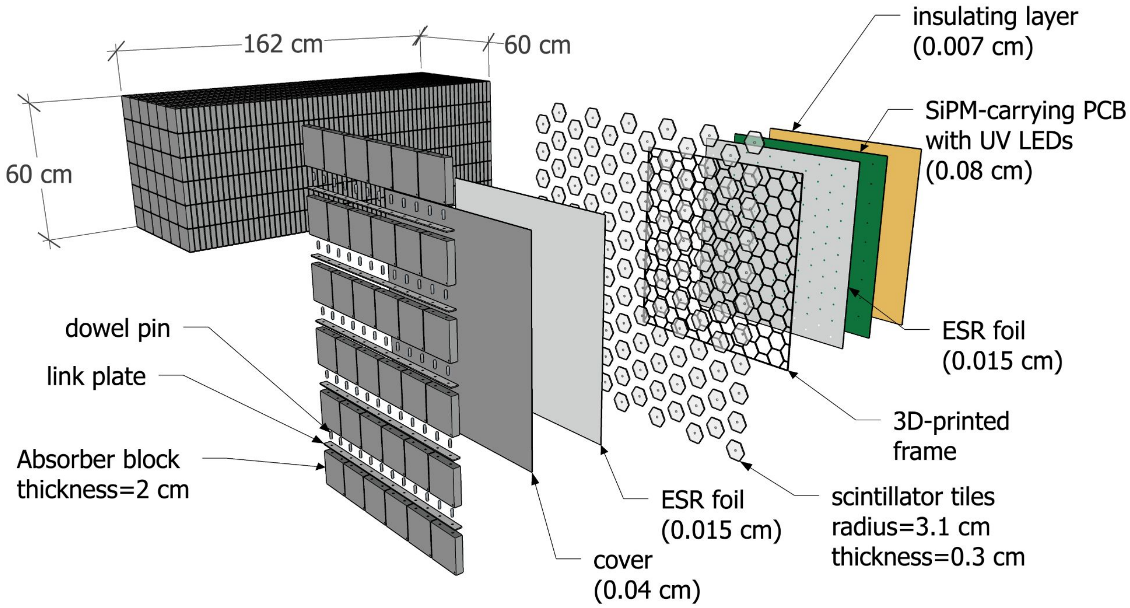
Can simplify ZDC mechanical design.

Zinc plated Fe blocks, ~10x10x2 cm3.



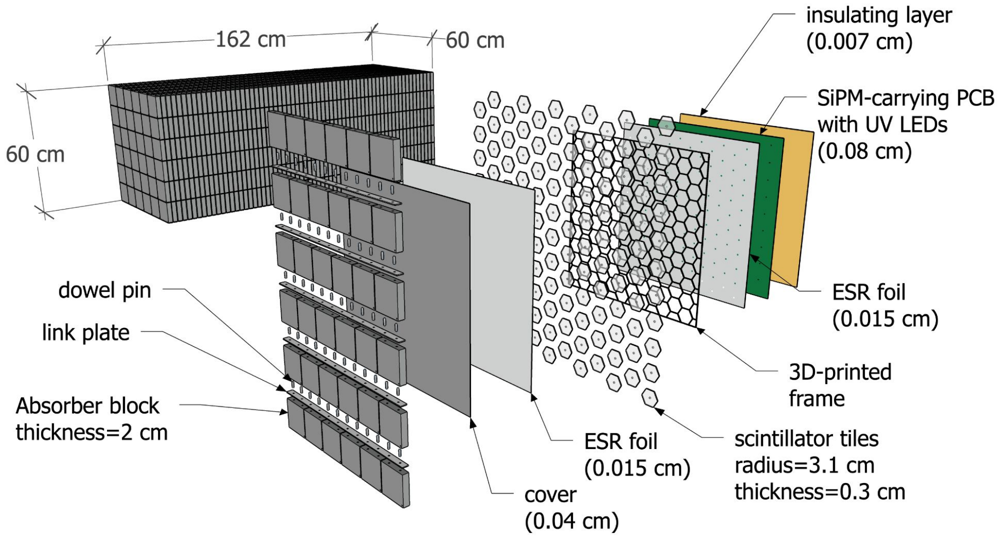
SiPM-on-tile ZDC design

- Accessible PCB boards
  - Allows SiPMs to be annealed to mitigate radiation damage (10^{11}-10^{12} 1 MeV-equivalent neutron/cm^2 per year)
- Fine granularity enables excellent position resolution, software compensation, bkg and radiation resilience



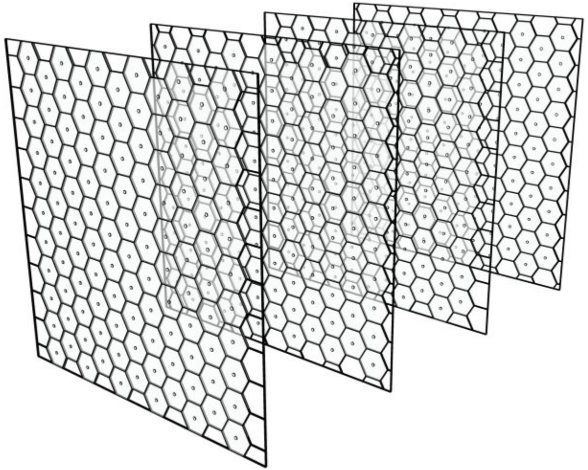
Recipe for Fe/SiPM-on-tile option

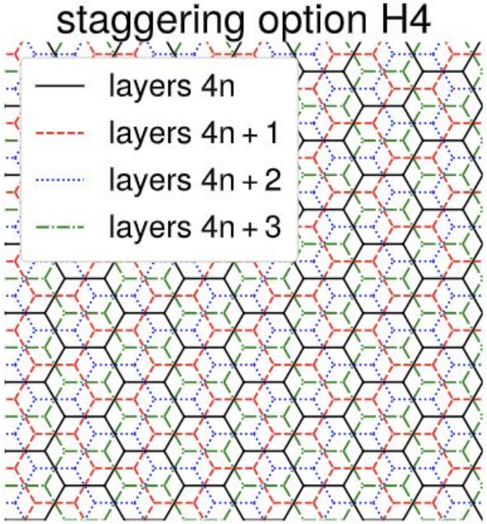
- **Fe blocks:** 2304 units of 10x10x2 cm3
  Cost: **0$** (reused from STAR HCAL)
  Not even shipping cost!
- **7.5k SiPM-on-tile channels**, each of which is:
  - 1 **SiPMs:** 1.3 mm size. Cost: **~7$/unit**
  - 1 **Tile:** ~25 cm2 size. Cost: **~2$/unit**
  - 1 **Readout & bias:** HGROC **~1-2$/ch**

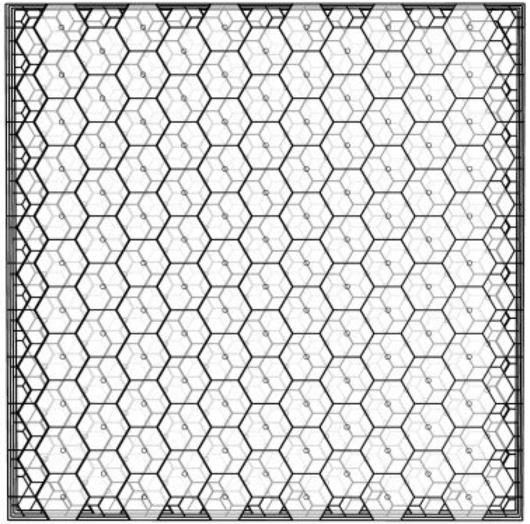


Staggered design

3D printed frames define layers populated with identical cells





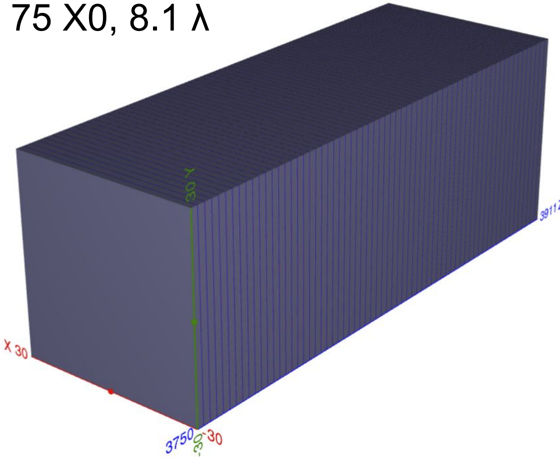


SiPM-on-tile ZDC simulation in DD4HEP and ePIC

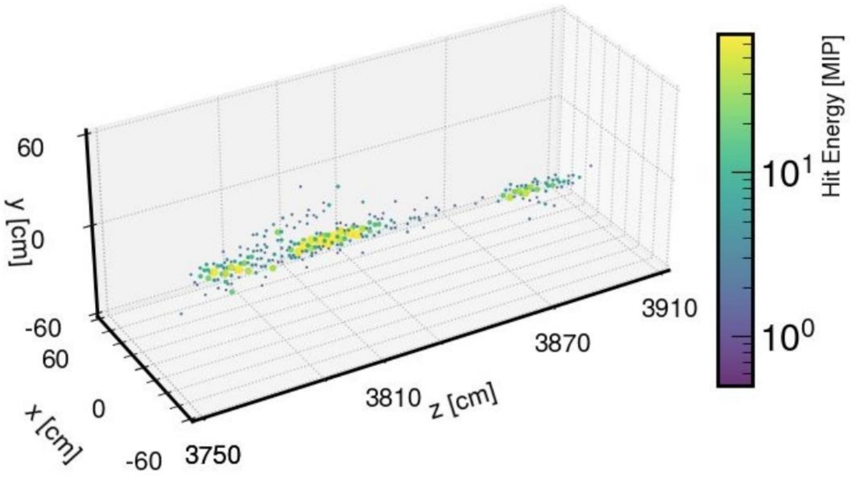
- DD4hep plugin for hexagonal segmentation and staggering was added to official DD4HEP core software
    - https://github.com/AIDASoft/DD4hep/pull/1161
- ZDC Fe/SiPM-on-tile was added to official ePIC sim:
    - DD4HEP geometry model
    - Reconstruction benchmark using HEXPLIT
- Neutrons generated over θ<5.5 mrad and full azimuth
- Hit cuts: E > 0.5 MIP, t < 150 ns.

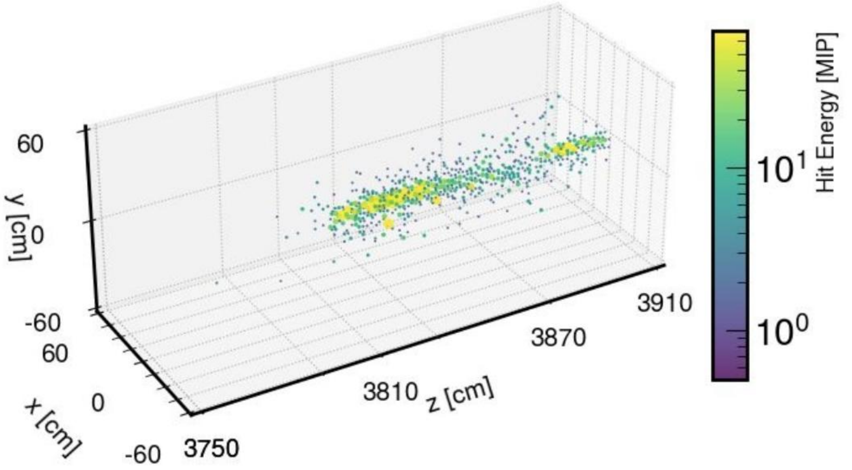
Fe 20 mm/ Sc 3.0 mm (64 layers)

75 X0, 8.1 λ

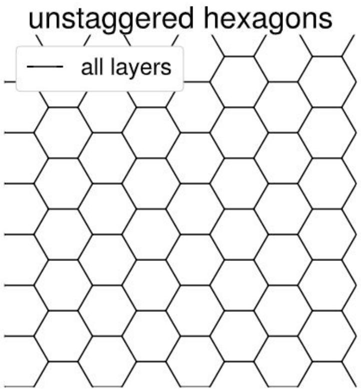


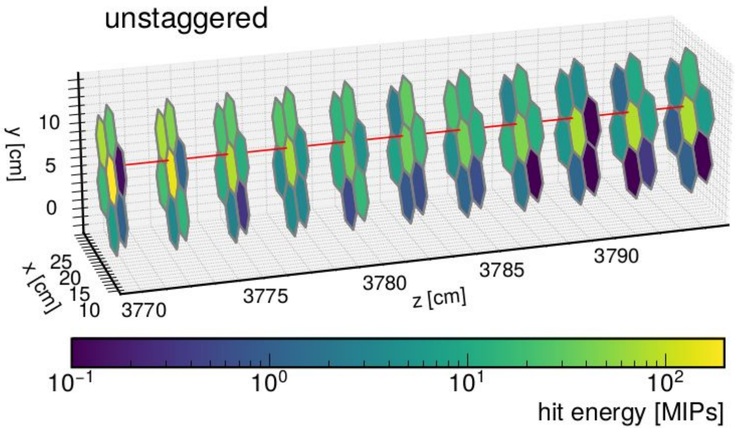
Example neutron showers



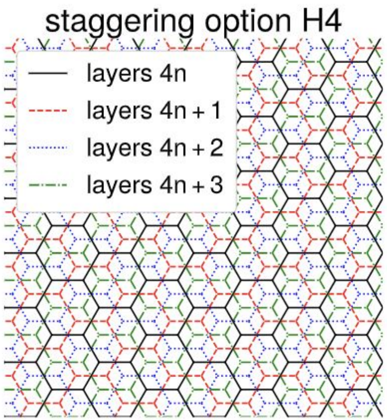


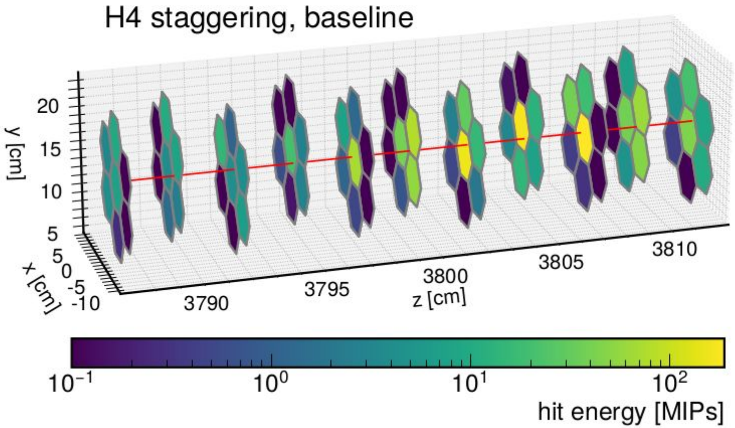
Staggering of layers samples better shower direction





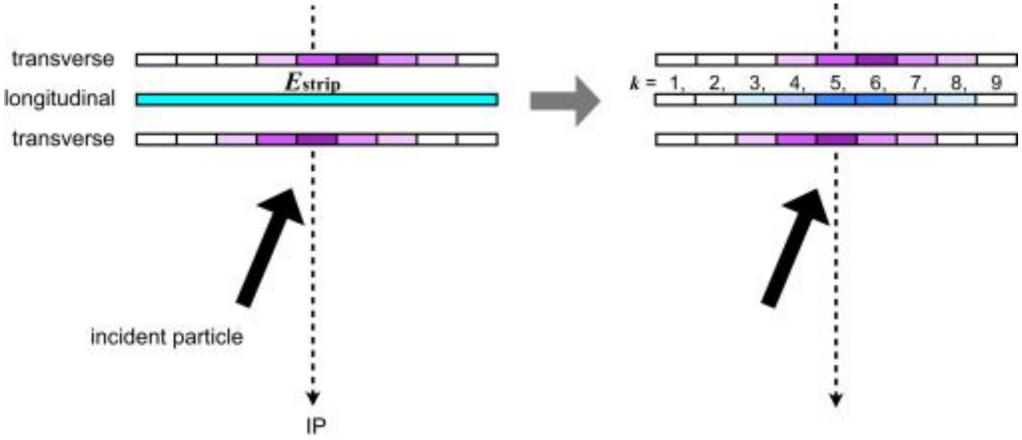
Core Portion of Neutron Shower





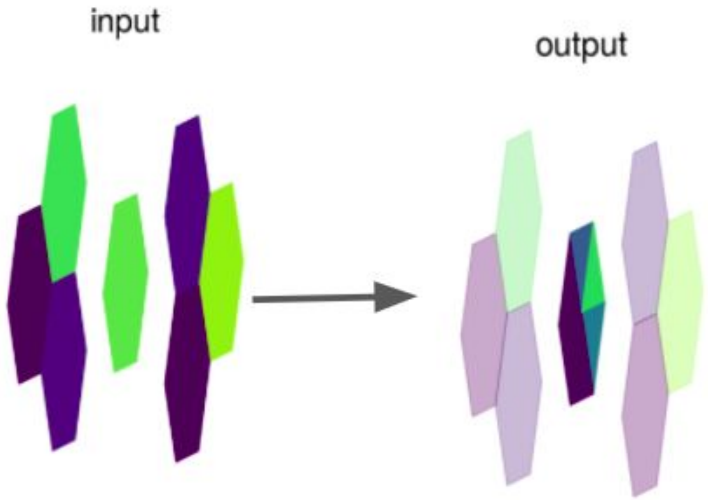
Staggering leads to partial overlap that can be used to define “subcells”. Algorithms can estimate subcell energy according to neighbour info

Strip-Split Algorithm



[Kotera et al. NIMA 789 (2015) 158-164,](#)

HEXPLIT Algorithm



[S. Paul, M. Arratia arXiv:2308.06939](#)

The HEXPLIT algorithm

arXiv:2308.06939

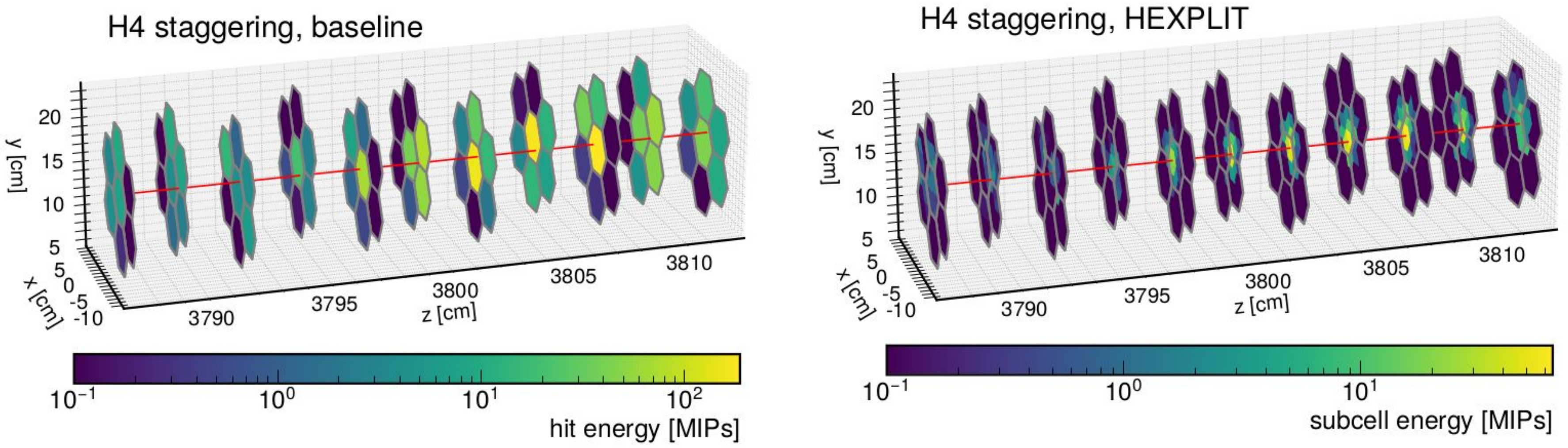
Define subcells with overlap and assign weights:

$$W_i = \prod_{j=1}^{N-1} \max(E_j, \delta),$$

Product over overlapping cells, *j*, in neighboring layers

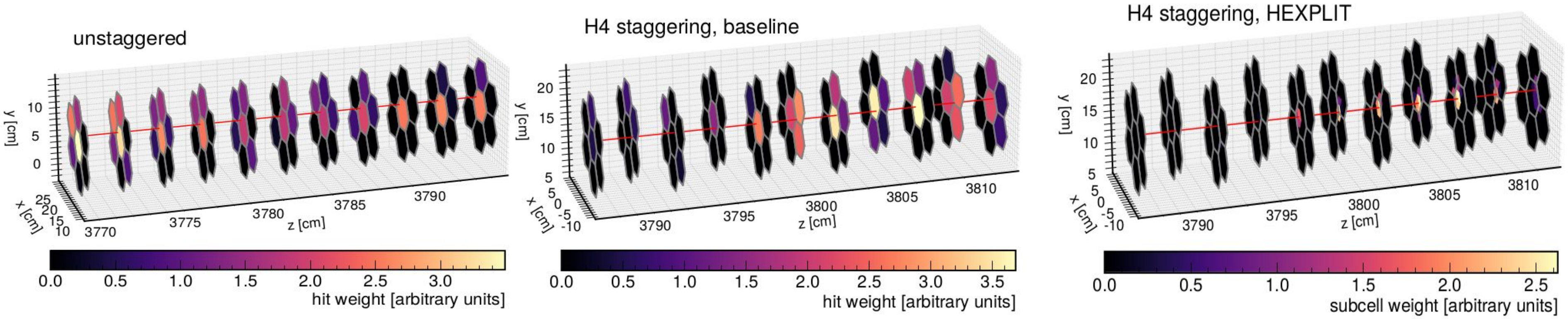
$$E_i = E_{\text{tile}} W_i / \sum_j W_j.$$

Energy in a given subcell, *i*



Same event before and after HEXPLIT

Shower reconstruction

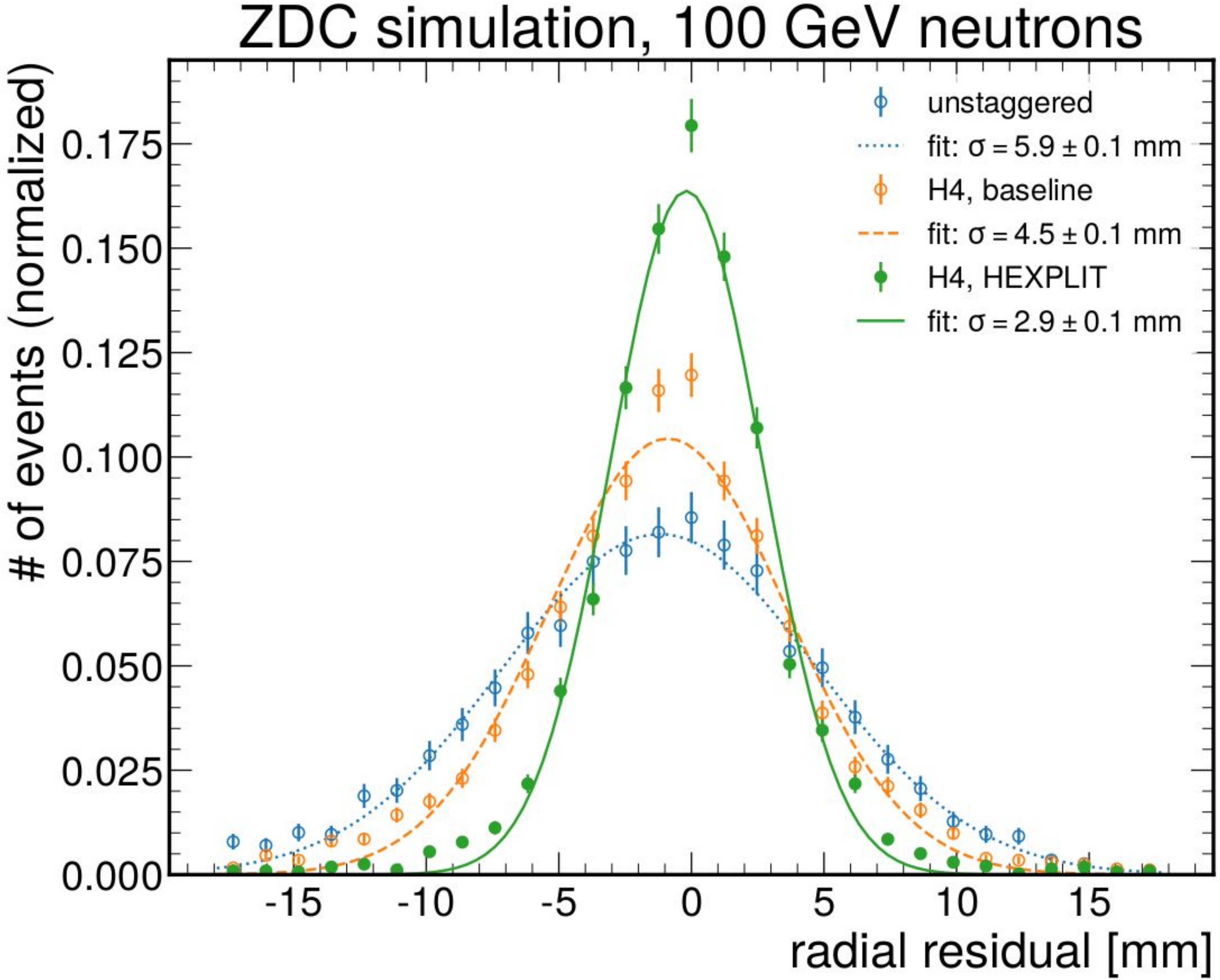


$$\vec{x}_{\text{recon}} = \frac{\sum_{i\in\text{hits}} \vec{x}_i w_i}{\sum_{i\in\text{hits}} w_i}$$

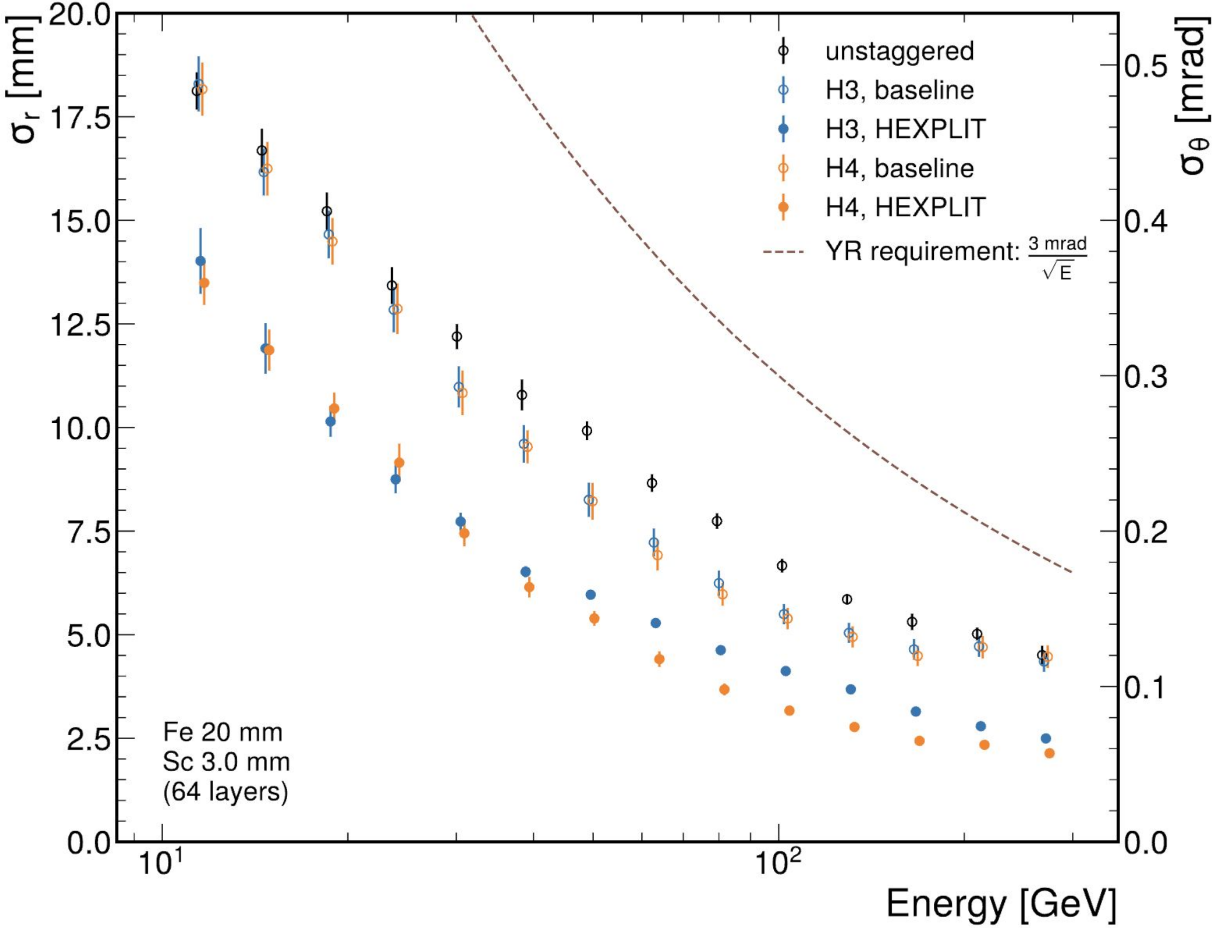
$$w_i = \max\left(0, w_0 + \ln\frac{E_i}{E_{\text{tot}}}\right)$$

$$\vec{x}_{\text{recon}} = \frac{\sum_{i\in subcells} \vec{x}_i w_i}{\sum_{i\in subcells} w_i}$$

$$w_i = \max\left(0, w_0 + \frac{E^i_{\text{subcell}}}{E_{\text{shower}}}\right).$$


ZDC simulation, 100 GeV neutrons
# of events (normalized)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
-15
-10
-5
0
5
10
15
radial residual [mm]
unstaggered
fit: σ = 5.9 ± 0.1 mm
H4, baseline
fit: σ = 4.5 ± 0.1 mm
H4, HEXPLIT
fit: σ = 2.9 ± 0.1 mm

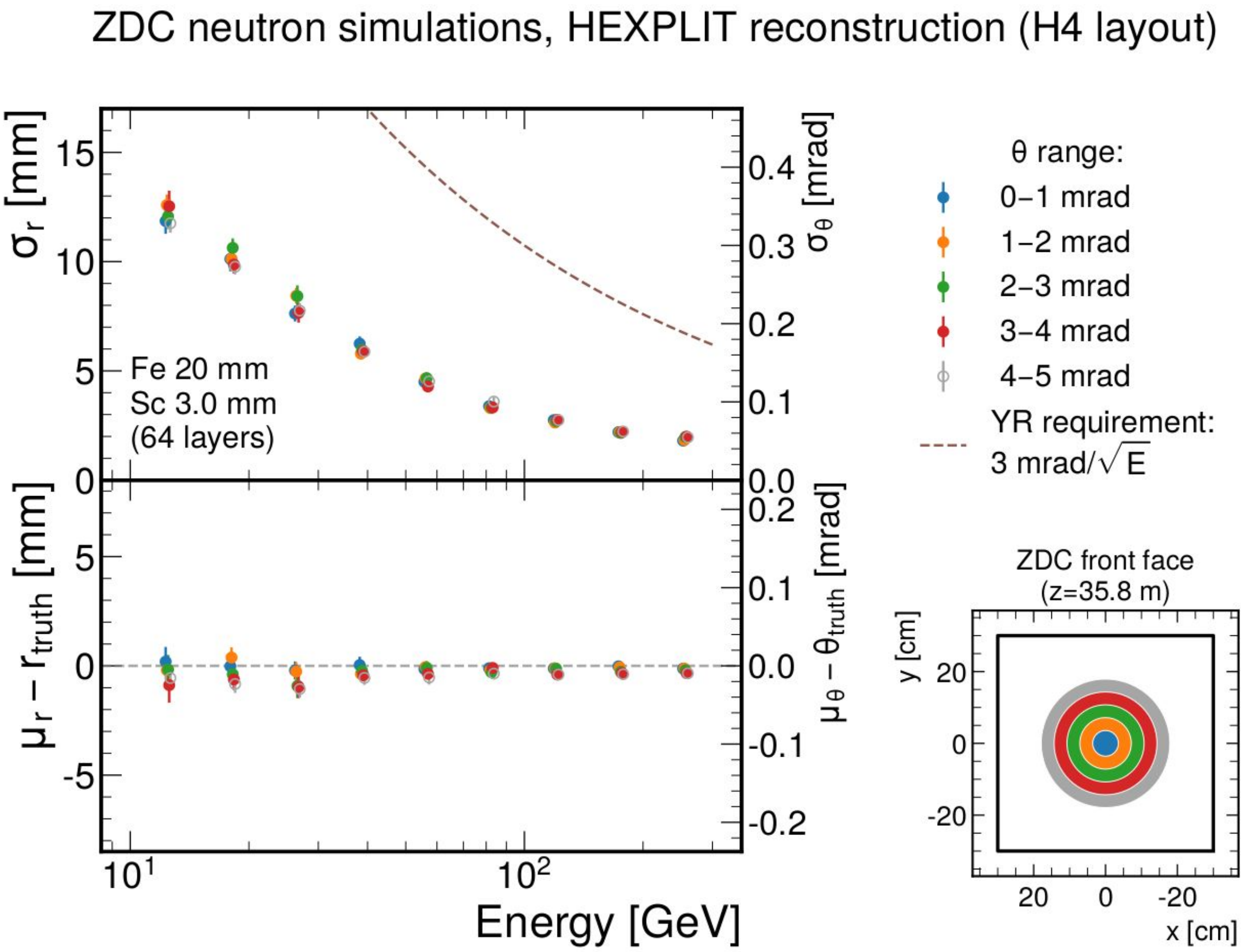
ZDC Neutron position resolution

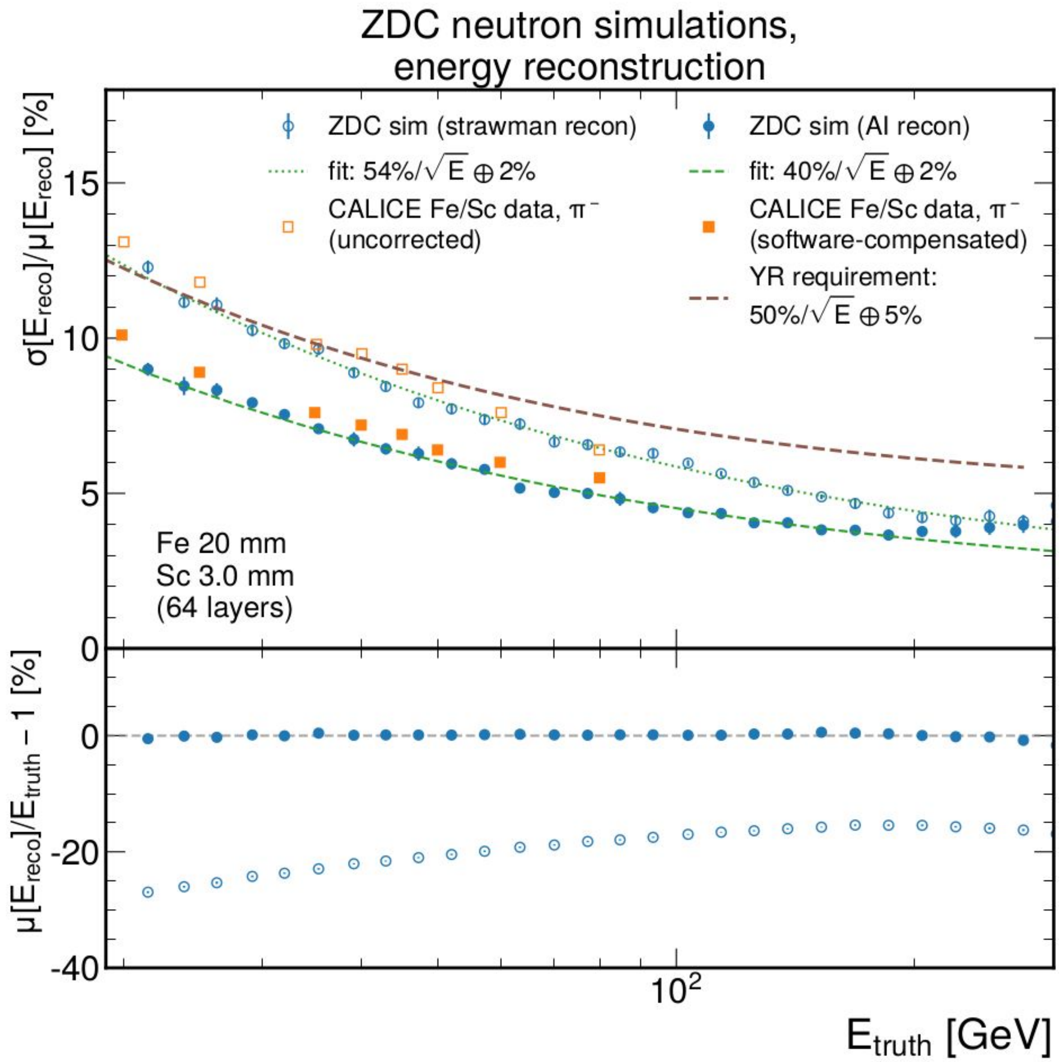


- Design meets YR requirements with ~25 cm2 cell size, (can be tuned to optimize granularity)
- Meets even ambitious goals relevant for pion structure studies

Edge effects In position resolution

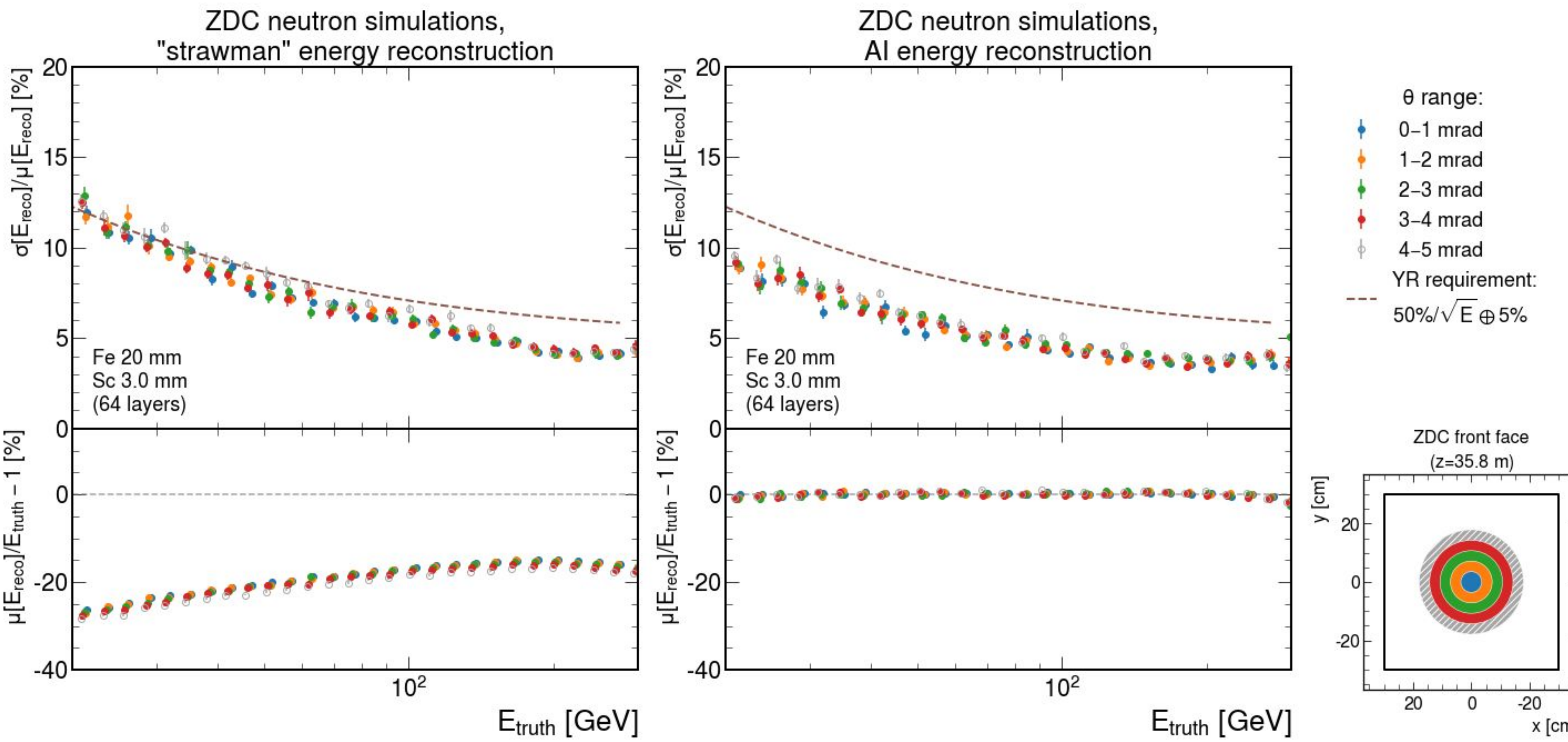
- Fiducial region (colored) far enough away from edge that edge effects are negligible





- Strawman= add all hits above 0.5 MIP, multiply by sampling fraction of electrons.
- Non-compensated response fixed with AI approach (described in https://indico.bnl.gov/event/19383/)
- Simulation matches closely CALICE AHCAL data, before and after software compensation

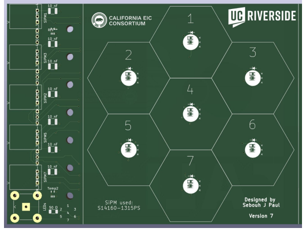
Study of edge effects in energy reconstruction

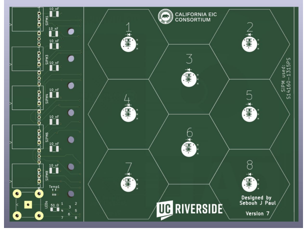


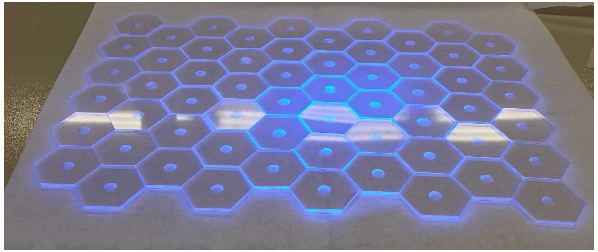
“Gen 2” Insert prototype
~400 channels (x10 times Gen 1):

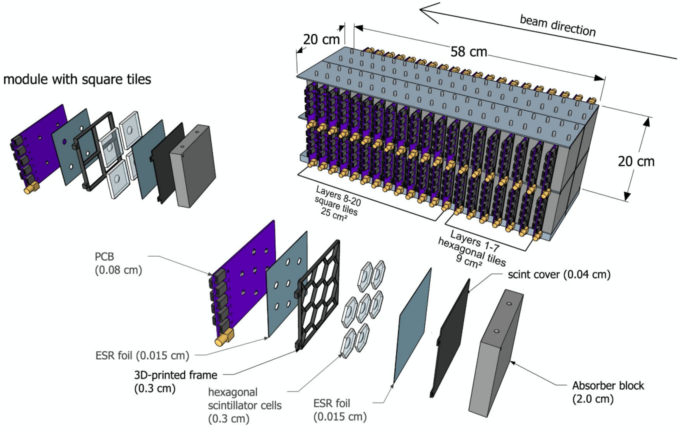
R&D for Insert
relevant for SiPM-on-tile ZDC:

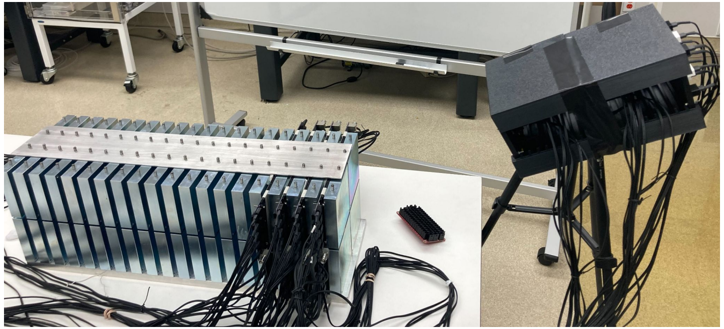
- Planned rad damage test at LBNL or UC Davis
- Planned 2nd testbeam at JLab to staggered design and HEXPLIT algorithm
- Planned test beam at RHIC in 2024 to demonstrate In situ calibration, stability, rad damage mitigation





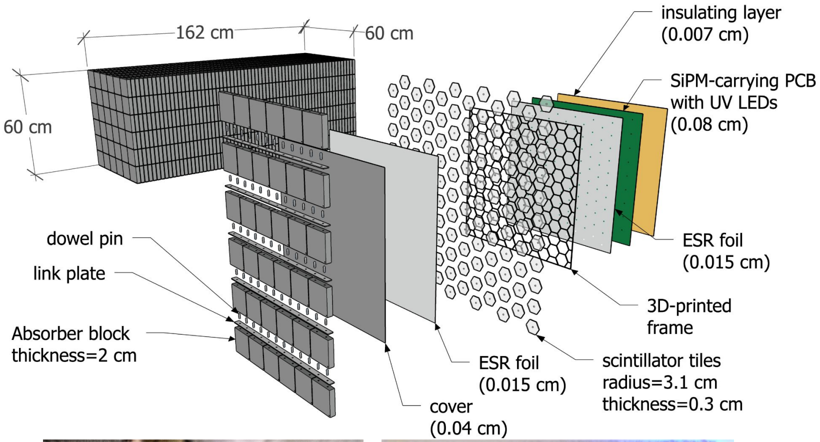


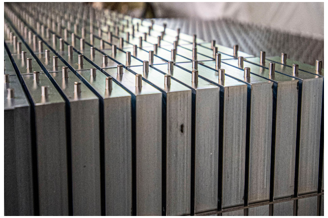


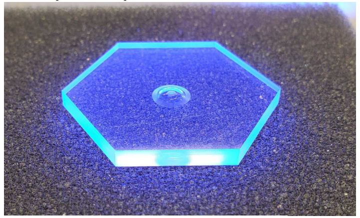


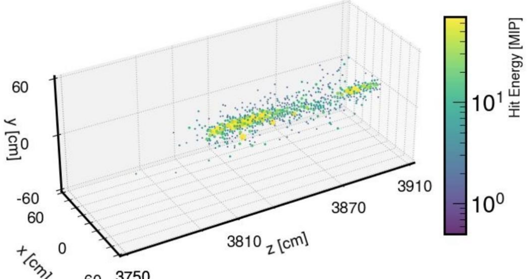
More info of Insert R&D in:

- M. Arratia et al. “Beam Test of the First Prototype of SiPM-on-Tile Calorimeter Insert for the Electron-Ion Collider Using 4 GeV Positrons at Jefferson Laboratory.”
  arXiv:2309.00818
- S. Paul, M. Arratia “Leveraging Staggered Tessellation for Enhanced Spatial Resolution in High-Granularity Calorimeters”
  arXiv:2308.06939
- M. Arratia et al. “Studies of time resolution, light yield, and crosstalk using SiPM-on-tile calorimetry for the future Electron-Ion Collider”
  JINST 18 (2023) 05, P05045
- M. Arratia et al. “A high-granularity calorimeter insert based on SiPM-on-tile technology at the future Electron-Ion Collider”
  Nucl.Instrum.Meth.A 1047 (2023) 167866





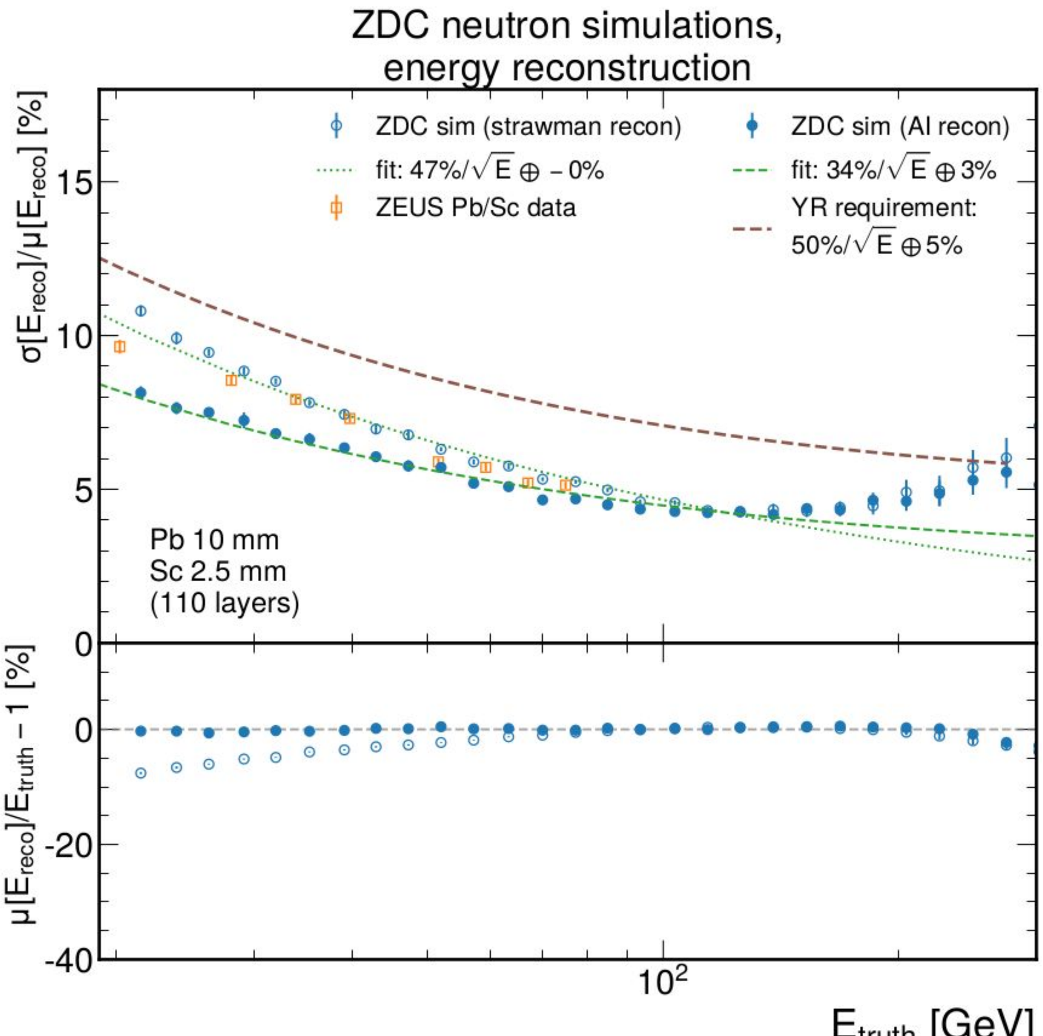




Summary

- SiPM-on-tile is an attractive option for ZDC HCAL, as it would bring multiple benefits of piggybacking on forward HCAL. Cost effective implementation of “imaging” design.
- Energy and position resolution studies completed and validated against CALICE AHCAL data. Meet YR requirements over entire fiducial region.
- Can be combined with other ideas such as timing layers

backup


ZDC neutron simulations,
energy reconstruction
ZDC sim (strawman recon)
fit: 47%/√E ⊕ −0%
ZEUS Pb/Sc data
ZDC sim (AI recon)
fit: 34%/√E ⊕ 3%
YR requirement:
50%/√E ⊕ 5%
Pb 10 mm
Sc 2.5 mm
(110 layers)
σ[E_reco]/μ[E_reco] [%]
μ[E_reco]/E_truth − 1 [%]
E_truth [GeV]
15
10
5
0
0
-20
-40
10^2

ZDC neutron simulations, energy reconstruction