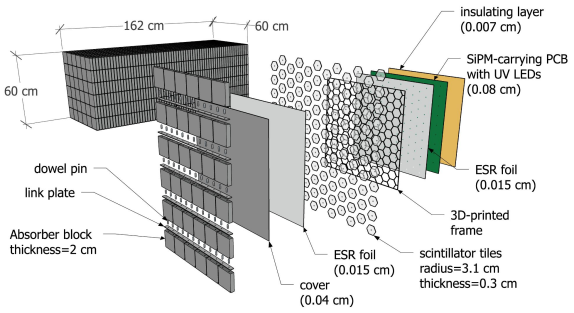
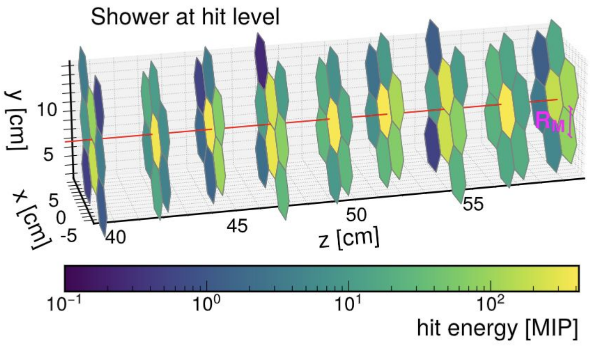
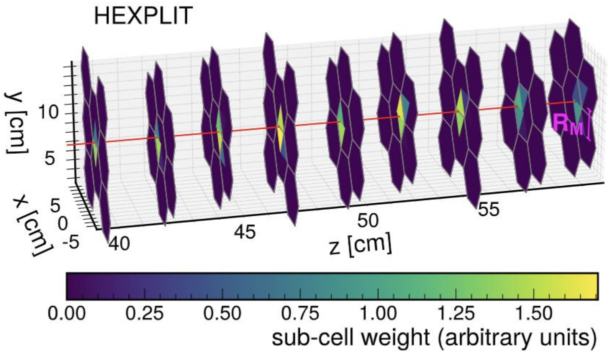
An insert-like ZDC and HEXPLIT







Sebouh J. Paul

8/21/2023

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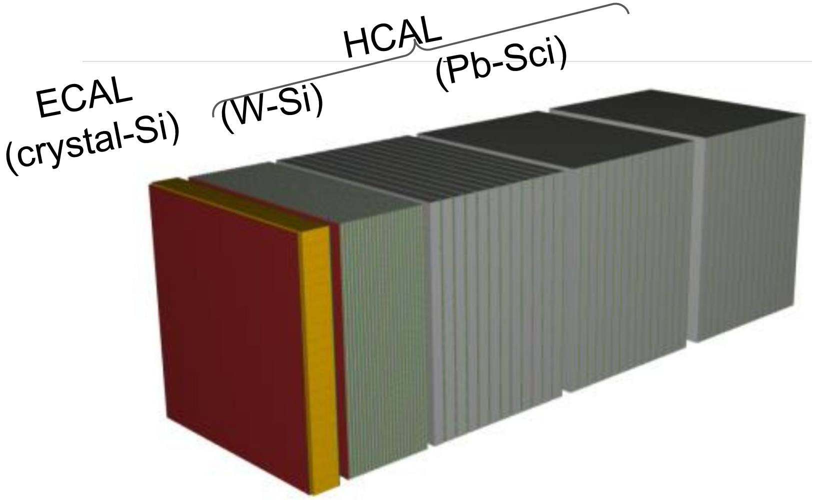
CALIFORNIA EIC CONSORTIUM

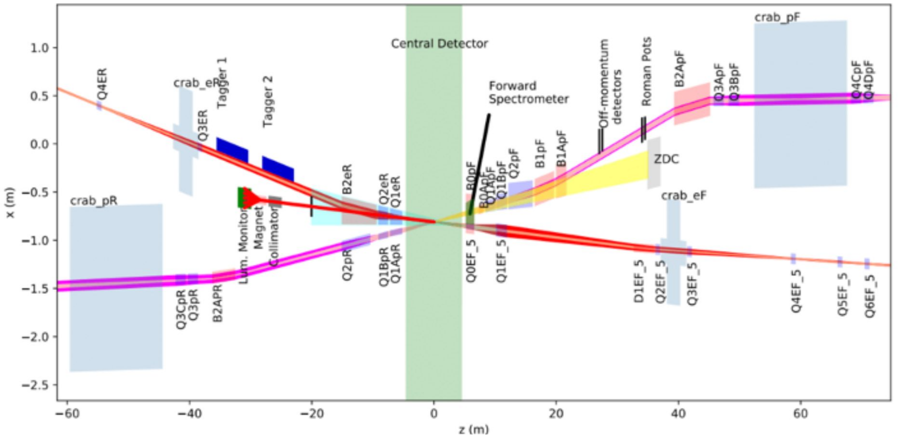
Zero-Degree Calorimeter

- Detect neutral particles (γ, n) in the direction of the hadron beam
- 37.5 m from the IP
- What we can measure with it:
  - distinguishing between coherent diffractive scattering vs. incoherent scattering
  - measuring geometry of e + A collisions,
  - spectator tagging in e + d/^{3}He,
  - asymmetries of leading baryons
  - spectroscopy
- Many of these are exclusive reactions
  - Momentum can be determined from other particles in reaction
  - Angular (position) resolution more critical than energy resolution:

$$\Delta E/E < 50\%/\sqrt{E}$$

$$\Delta\theta < 3\,\mathrm{mrad}/\sqrt{E}$$





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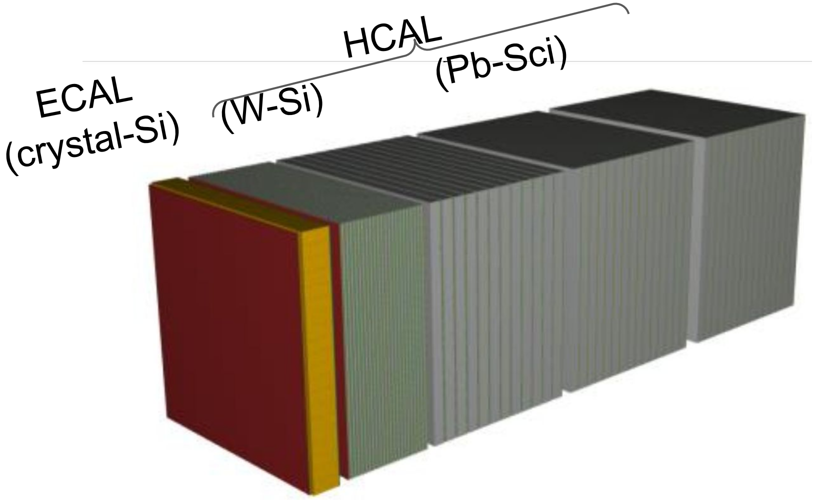
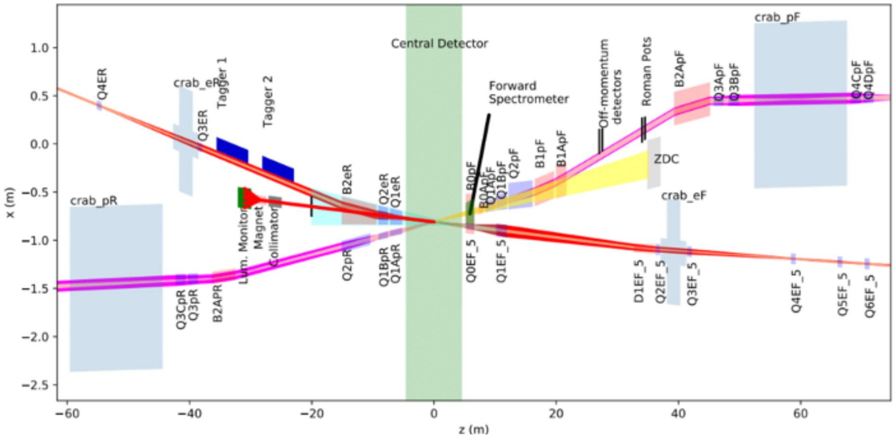
Current design

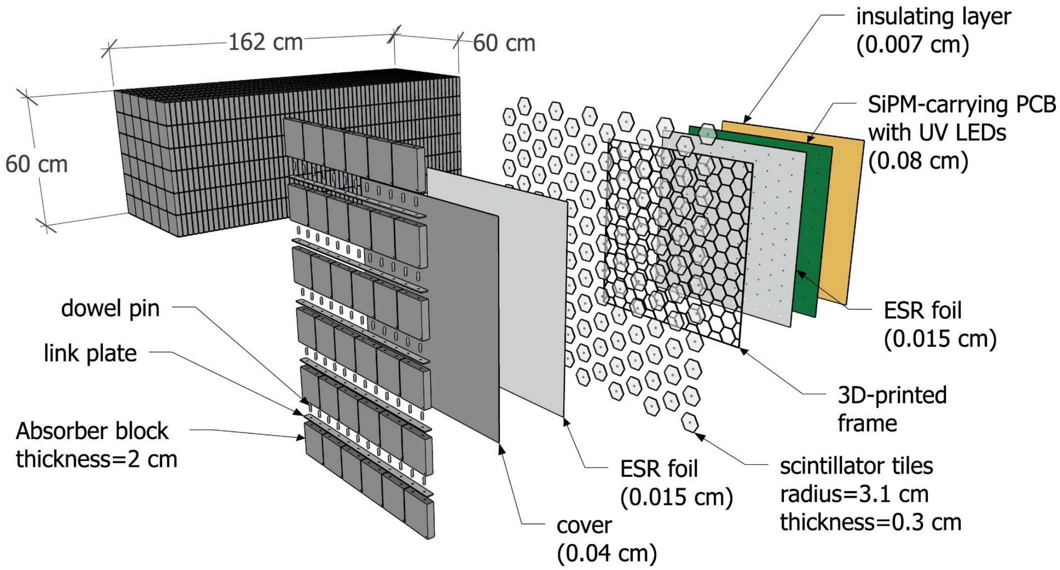
- ECAL
  - Crystals (PbWO4 or LYSO) and silicon
- HCAL
  - Tungsten-silicon “imaging” layers
  - Lead-scintillator for the rest of the detector
- Problem: very expensive
  - Lead and tungsten aren’t cheap
  - Multiple technologies for HCAL





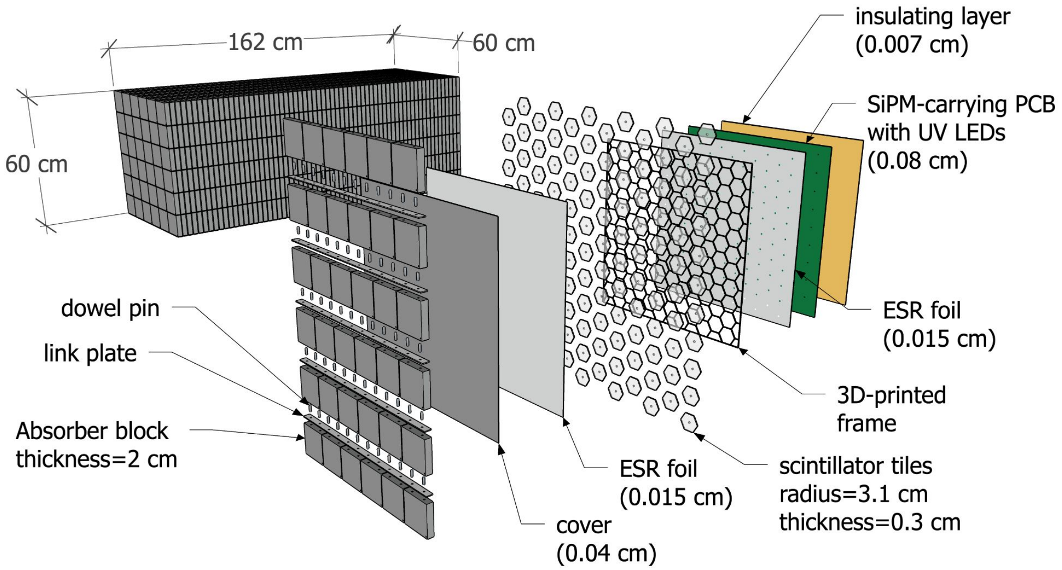
The SiPM-on-tile ZDC design

- Alt. version of the current ZDC HCAL, with similar tech to CALI
  - To be submitted to ePIC collab.
- Saves cost:
  - Reuse 2×10×10 cm^3 absorber blocks from STAR forward HCAL
  - SiPMs & readout are cheap
- High granularity:
  - Hexagonal tiles approximately 1 Molière radius in circumradius (3.1 cm) A~25 cm^2



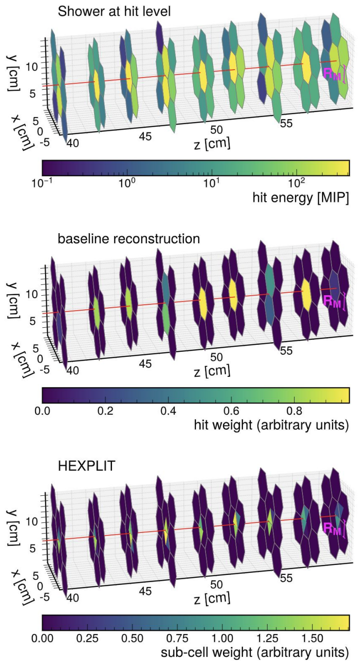
The SiPM-on-tile ZDC design

- Accessible PCB boards
  - Allows SiPMs to be annealed to mitigate radiation damage
  - (10^{11}-10^{12} 1 MeV-equivalent neutron/cm^2 per year)
- Software compensated:
  - EM and hadronic showers distinguished in software
  - Sampling fractions applied based on the type of shower



Recent submission to the arXiv

arXiv:2308.06939



Leveraging Staggered Tessellation for Enhanced Spatial Resolution in High-Granularity Calorimeters

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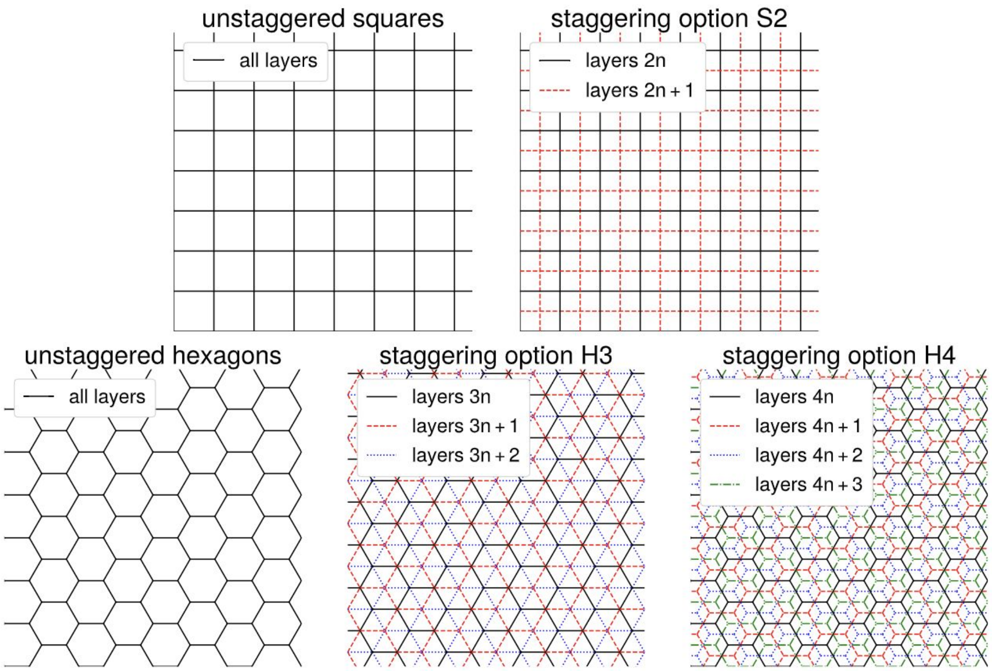
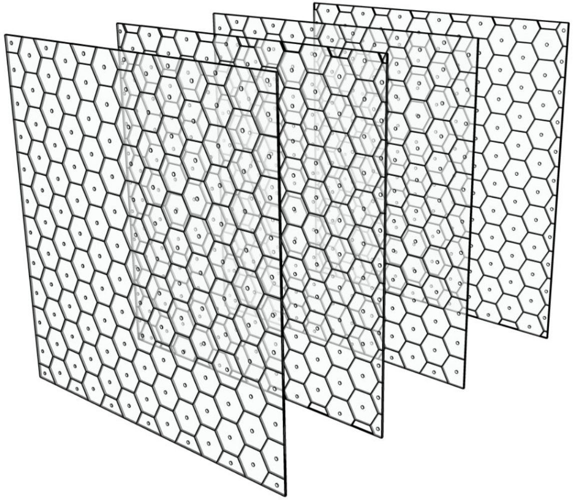
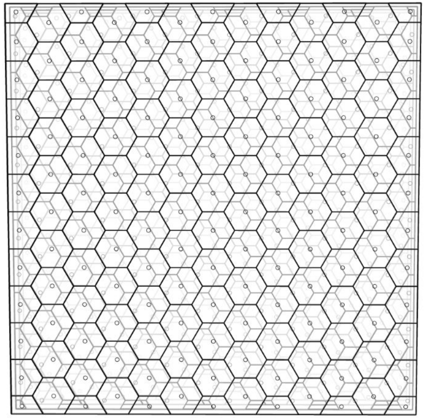
Abstract: We advance the concept of high-granularity calorimeters with staggered tessellations, underscoring the effectiveness of a design incorporating multifold staggering cycles based on hexagonal cells to enhance position resolution. Moreover, we introduce HEXPLIT, a sub-cell re-weighting algorithm tailored to harness staggered designs, resulting in additional performance improvements. By combining our proposed staggered design with HEXPLIT, we achieve an approximately twofold enhancement in position resolution for neutrons across a wide energy range, as compared to unstaggered designs. These findings hold the potential to elevate particle-flow performance across various forthcoming facilities.

Keywords: Calorimeters; Detector design and construction technologies and materials;

Staggered tessellation patterns in sampling calorimeters





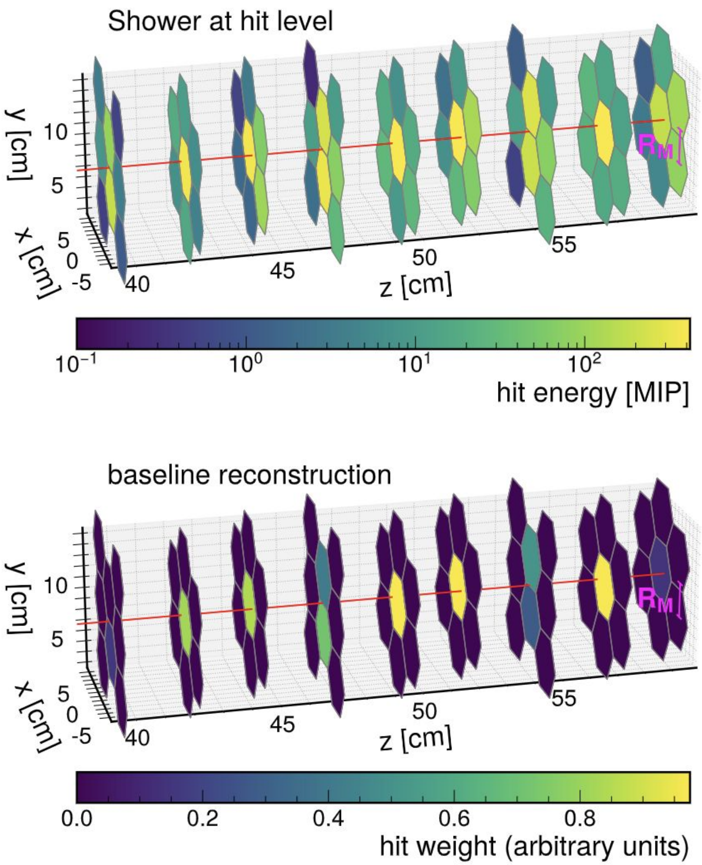


Base-line shower-position reconstruction

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

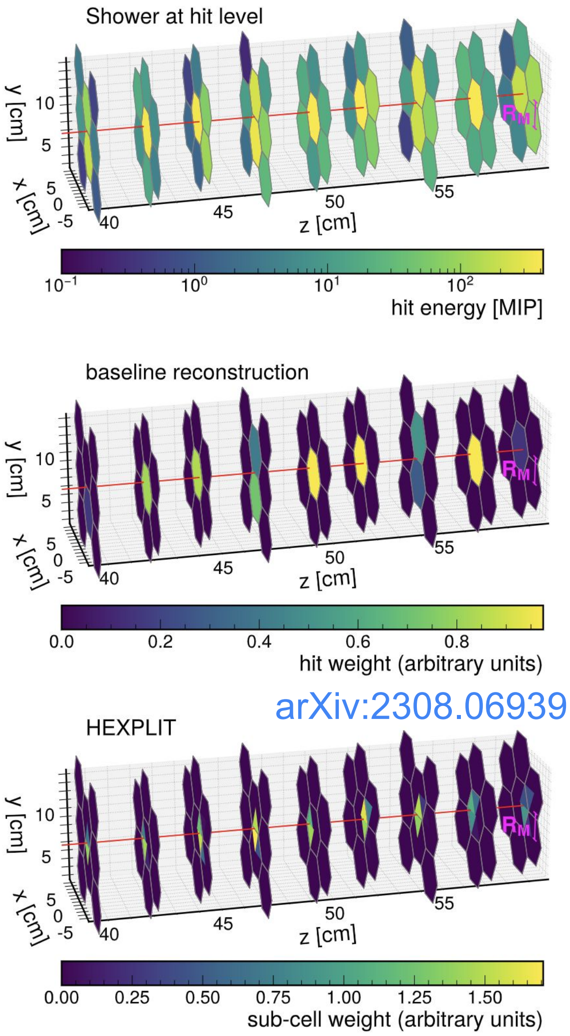
$$w_i = \max\left(0, w_0 + \ln \frac{E_i}{E_{\text{tot}}}\right)$$

Core Portion of Neutron Shower



HEXPLIT algorithm

Core Portion of Neutron Shower



Subcell reweighting

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

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*

Reconstruct shower from subcells

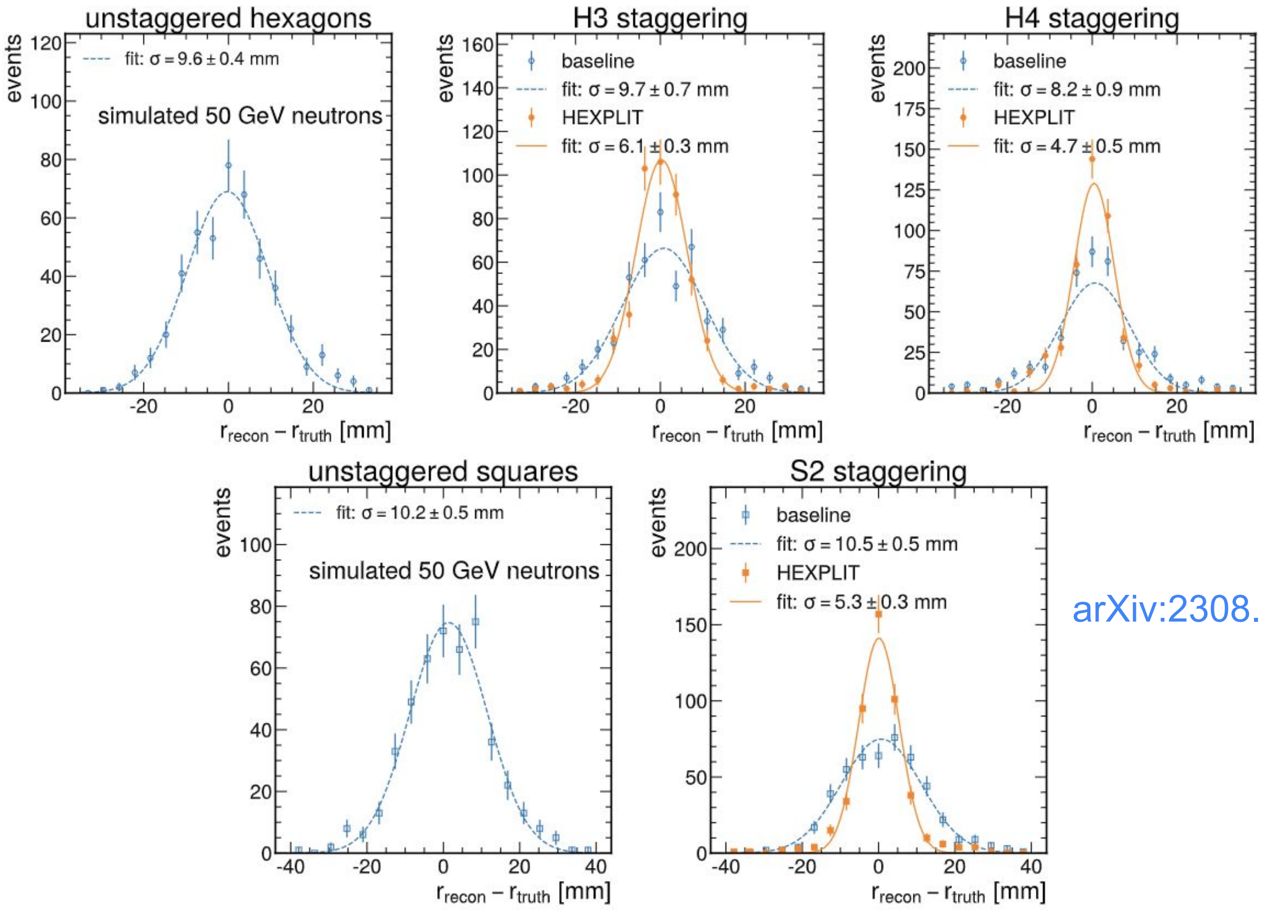
$$\vec{x}_{\text{recon}} = \frac{\sum_{i \in \text{subcells}} \vec{x}_i w_i}{\sum_{i \in \text{subcells}} w_i}$$

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

arXiv:2308.06939

Neutron-shower performance for the ZDC-like calorimeter

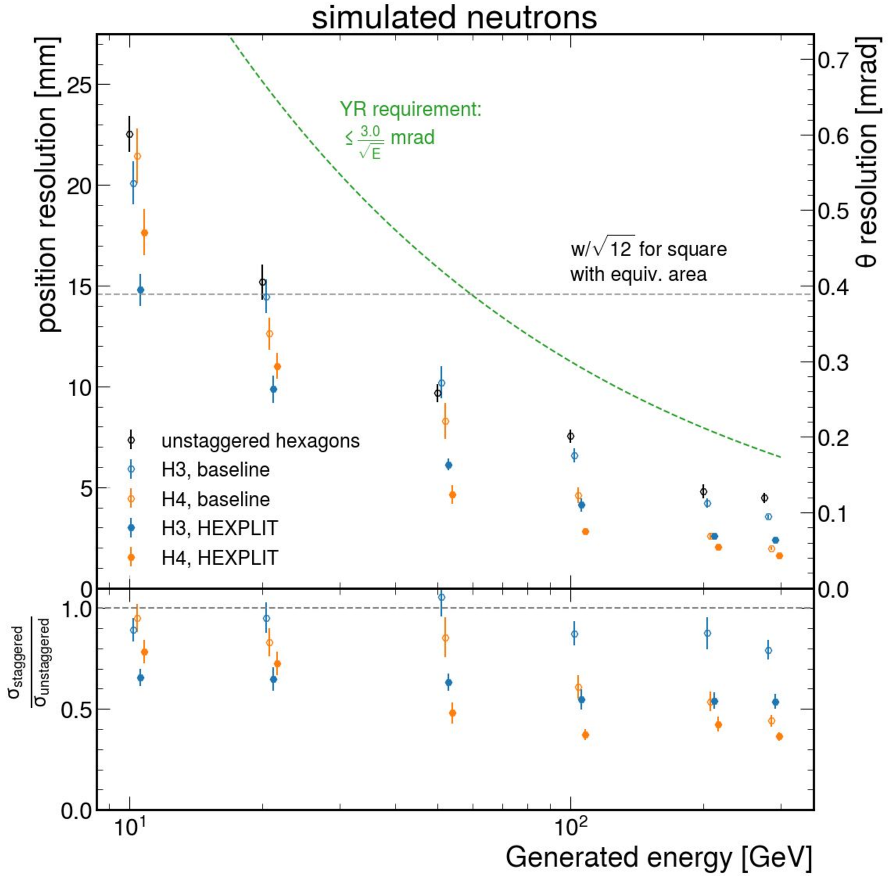
Factor of 2 improvement



arXiv:2308.06939

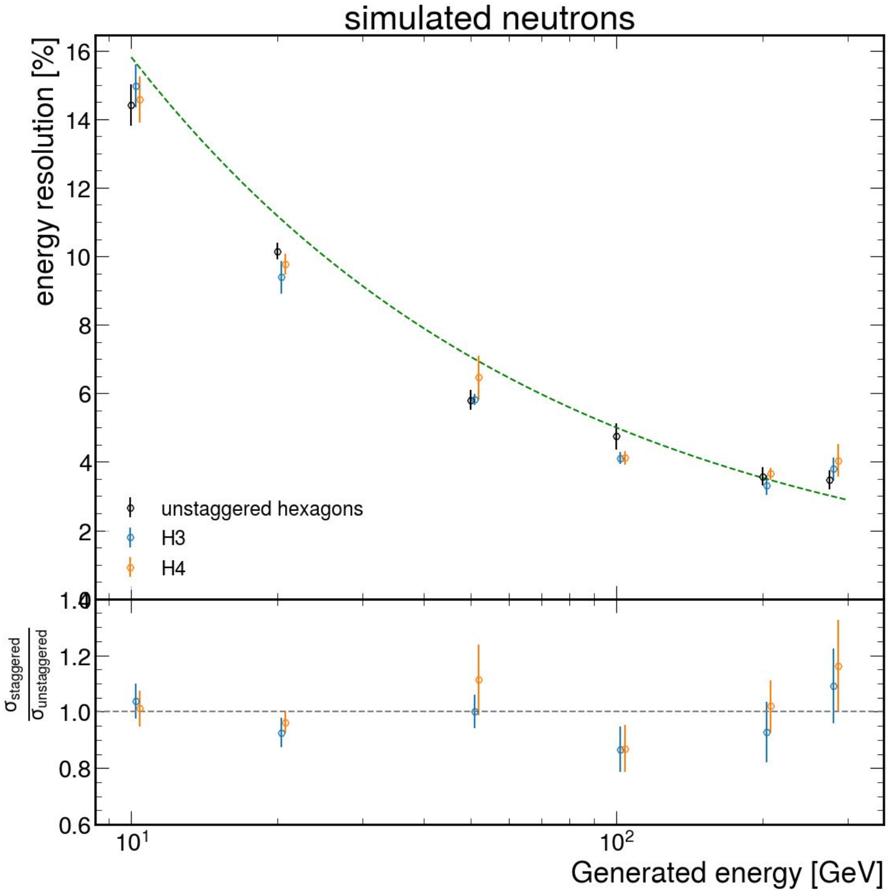
Energy dependence of position resolution

- H4 staggering improves the resolution by up to 60%, when utilizing the HEXPLIT algorithm
- Well below the YR requirement for the position resolution



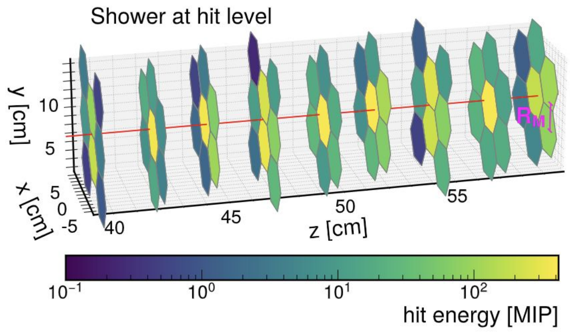
Energy resolution

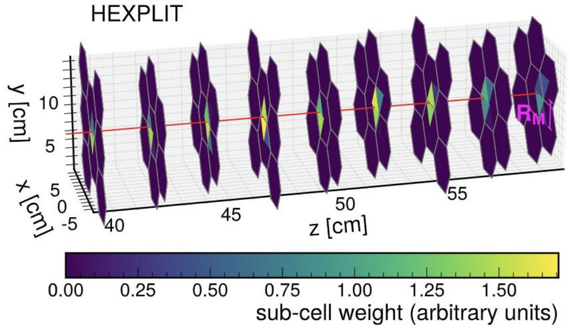
- Naive reconstruction (directly summing hit energies) fulfills YR requirement for most of the energy range
    - Energy resolution appears independent of staggering
- Further improvement can come from better energy-recon algorithms (for instance, using AI)



Conclusions

- New ZDC HCAL design incorporates SiPM-on-tile technologies, similar to our CALI design
- Staggered tessellations in sampling calorimeters such as the ZDC can improve their spatial resolution
- The HEXPLIT algorithm can take advantage of the staggering for further improvement,
  - Roughly a factor of 2 on spatial resolution across a wide range of energy.
  - Local algorithm, can be used for input in cluster finding and multi-particle shower recon

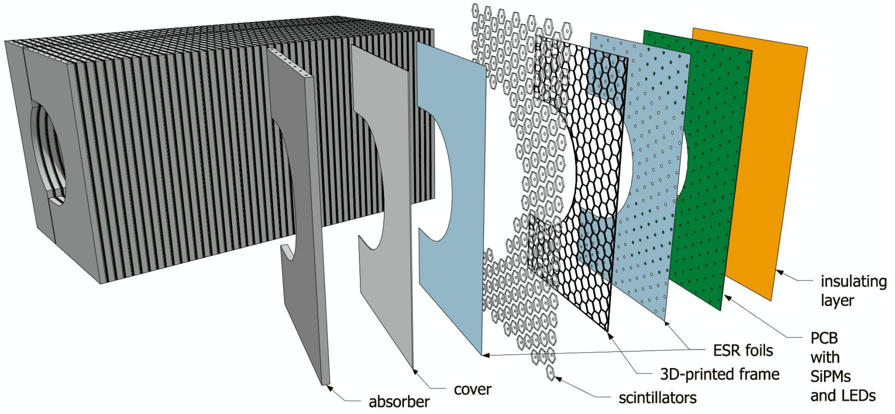


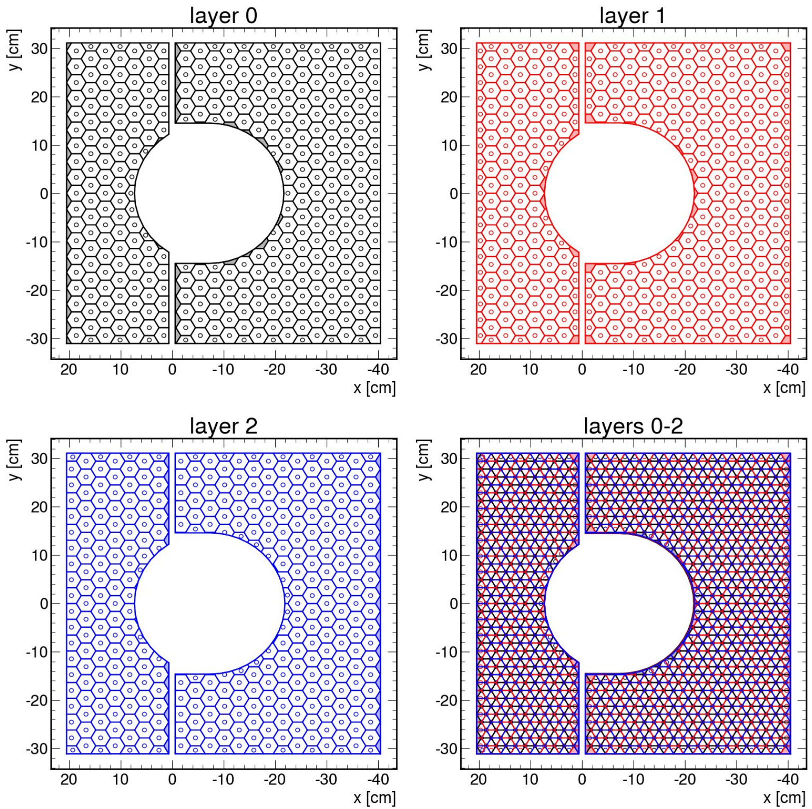


Backup slides

HG-CALI design can also incorporate staggering!

High-Granularity Calorimeter Insert





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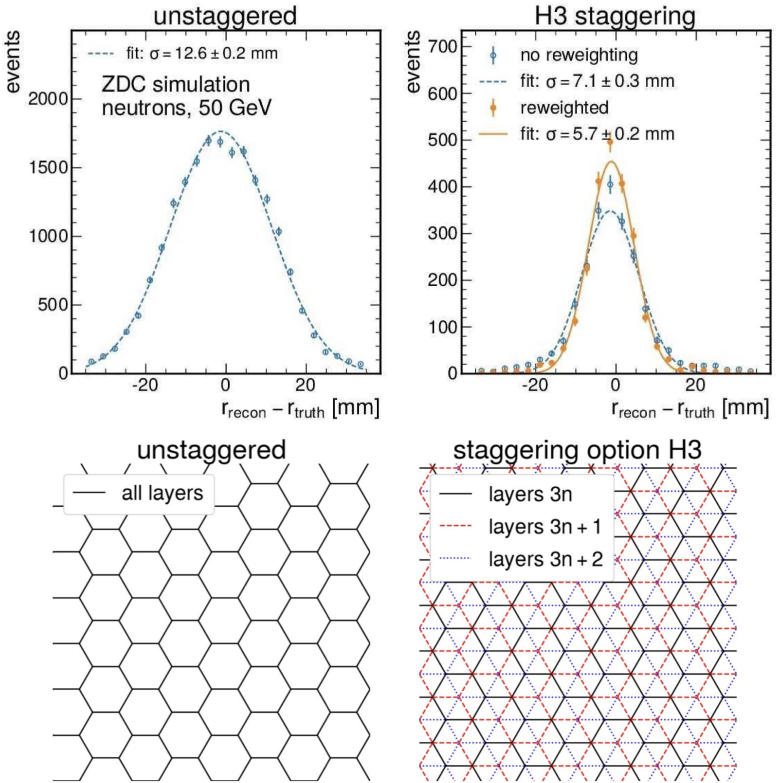
Preliminary results for the HG-CALI

Nearly two-fold improvement with H3 staggering and baseline recon

Exceeds two-fold improvement when using HEXPLIT algorithm

*H4 not shown, since we didn't have the implementation ready at the time



Generalized HEXPLIT

HEXPLIT is a local algorithm, it could work with multiparticle showers too. End result would be core of showers. This could help clustering, and help determine multiple shower axes precisely.

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

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*

Example of two showers in HG-CALI

Nucl.Instrum.Meth.A 1047 (2023) 167866