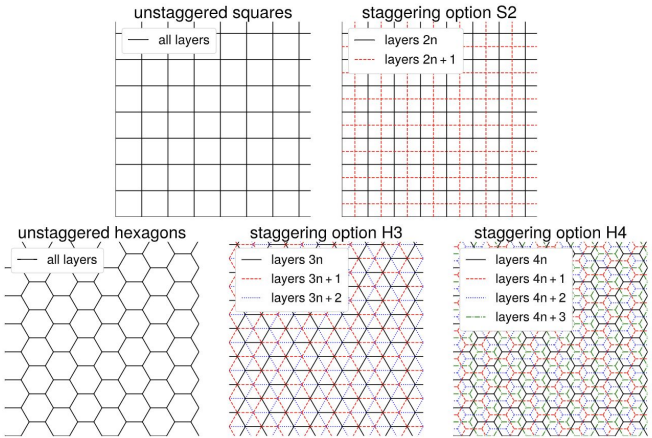
Hexagonal and staggered cartesian segmentations in DD4hep



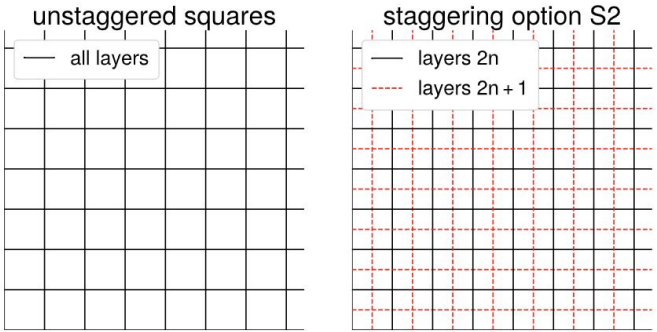
Sebouh Paul
UC Riverside
9/20/2023

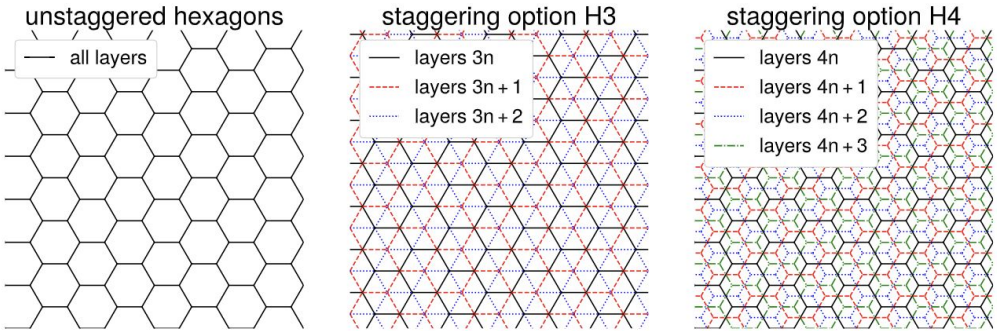
UC RIVERSIDE

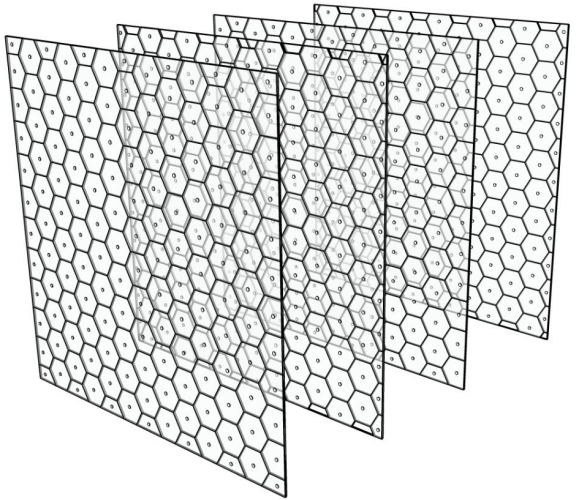
CALIFORNIA EIC CONSORTIUM

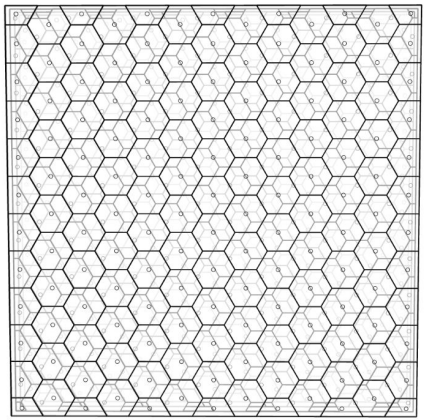
Staggering

- Improves position resolution in a sampling calorimeter by allowing recon algorithms (such as HEXPLIT*) to take advantage of the overlap between cells.







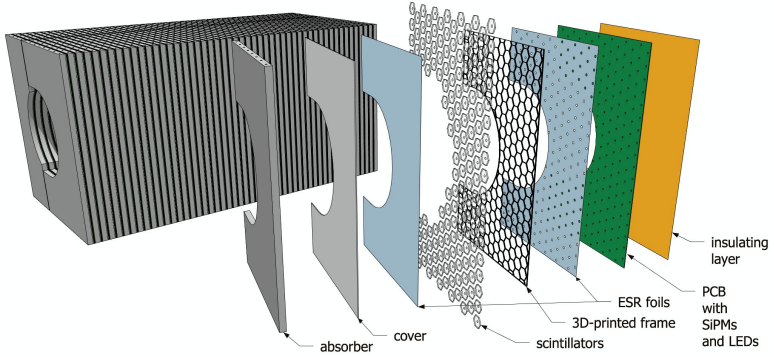


*https://arxiv.org/abs/2308.06939

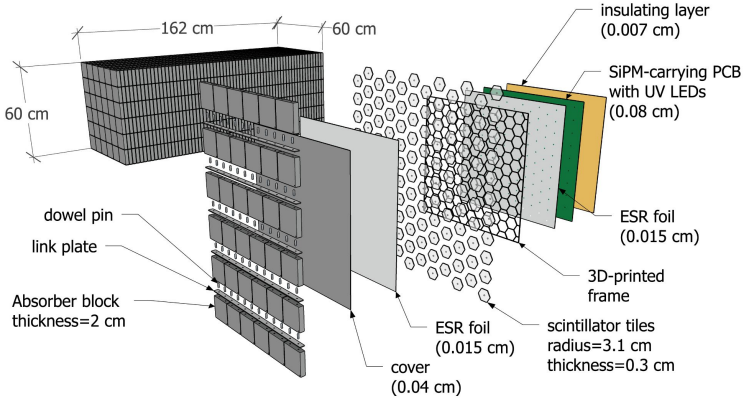
Which detectors would use this?

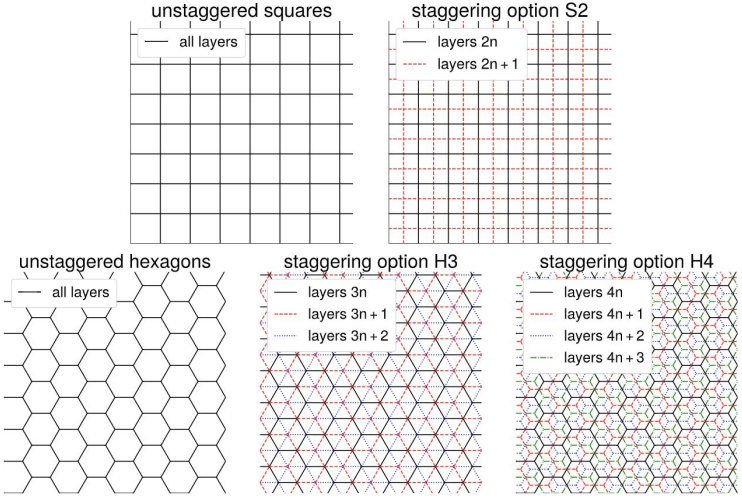
- ePIC's CALI (calorimeter insert)
- SiPM-on-tile design for the ZDC based on similar tech (to be submitted to ePIC collab)

CALI



SiPM-on-tile ZDC (zero-degree calorimeter)

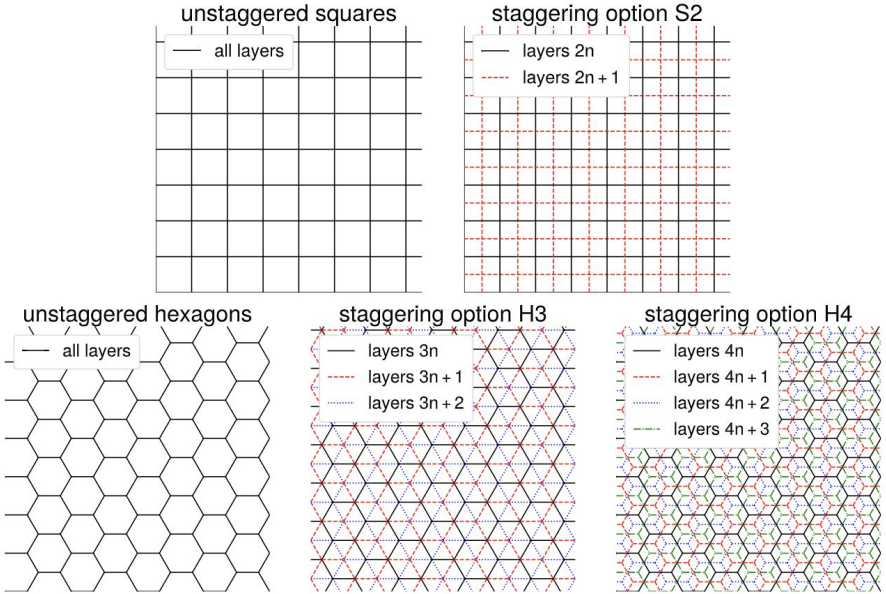




New segmentation classes in DD4hep

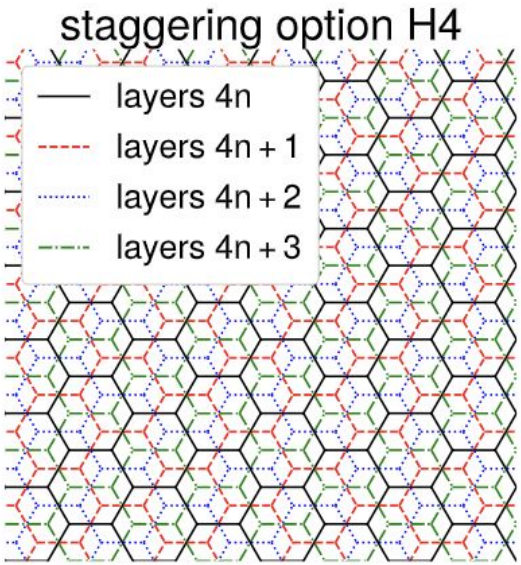
Pull request approved today!

- CartesianGridXYStaggered
  - Copy of CartesianGridXY with options for staggering in X and/or Y
- HexGrid
  - Options for unstaggered, H3 staggering, and H4 staggering



HexGrid

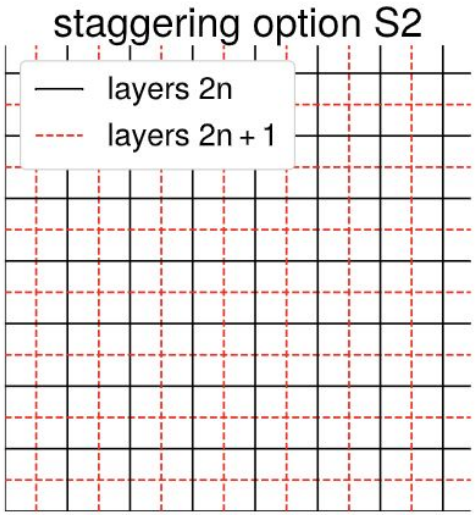
```
<readouts>
  <readout name="ZDCHits">
    <segmentation
      type="HexGrid"
      side_length="3.13*cm"
      stagger="2"
      offset_x="0"
      offset_y="0"
      stagger_keyword=”layer”
      />

<id>system:8,barrel:3,module:4,layer:8,slice:5,x:32:-16,y:-16
</id>
  </readout>
 </readouts>
```



side_length:
  Side length of a hexagonal cell.
  Equivalently its circumradius
stagger: (default=1)
  0=unstaggered
  1=H3
  2=H4
offset_x, offset_y: (default=0,0)
  Global offsets in x,y, in
  addition to staggering offset
stagger_keyword: (default=”layer”)
  volumeID identifier
  corresponding to a “layer”

CartesianGridXYStaggered

```
<readouts>
  <readout name="ZDCHits">
    <segmentation
      type="CartesianGridXYStaggered"
      grid_size_x="5*cm"
      grid_size_y="5*cm"
      stagger_x="1"
      stagger_y="1"
      offset_x="0"
      offset_y="0"
      stagger_keyword="layer"
      />
    <id>system:8,barrel:3,module:4,layer:8,slice:5,x:32:-16,y:-16</id>
  </readout>
</readouts>
```

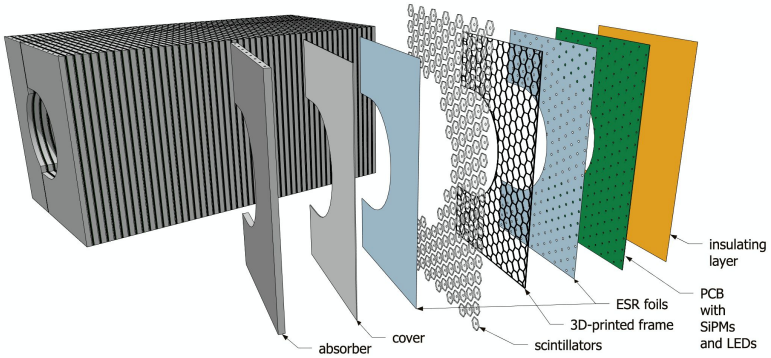


grid_size_x, y:
  Dimensions of rectangles in x, y
Stagger_x, y: (**default=0**)
  1= stagger in x or y
  0= don't stagger in x or y.
offset_x, offset_y: (default=0,0)
  Global offsets in x,y, in addition to staggering offset
stagger_keyword: (default="layer")
  volumeID identifier corresponding to a "layer"

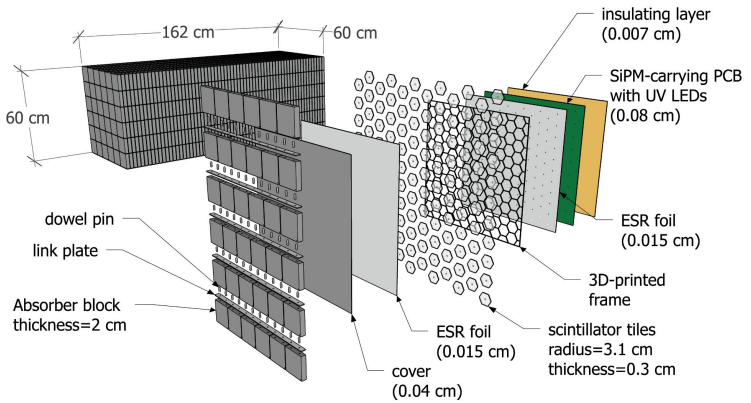
Summary

- DD4hep now has segmentation classes for hexagonal (staggered and unstaggered) and staggered rectangles/squares
- These classes can be used in ePIC detectors such as CALI and the SiPM-on-tile version of the ZDC.

CALI (calorimeter insert)



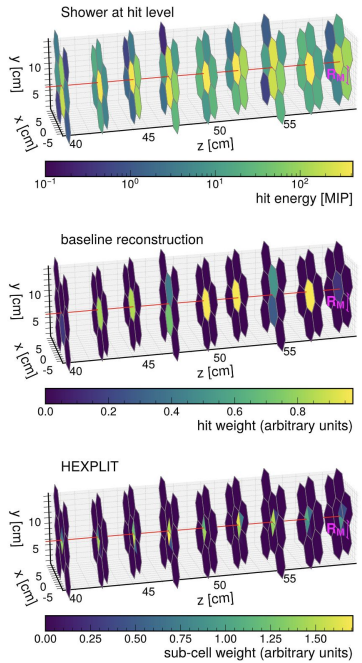
SiPM-on-tile ZDC (zero-degree calorimeter)



Backup slides

Recent submission to the arXiv

arXiv:2308.06939



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

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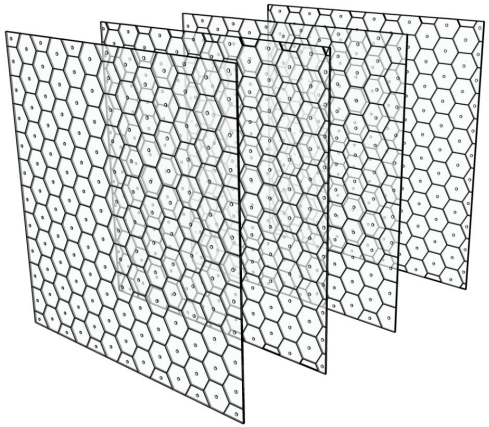
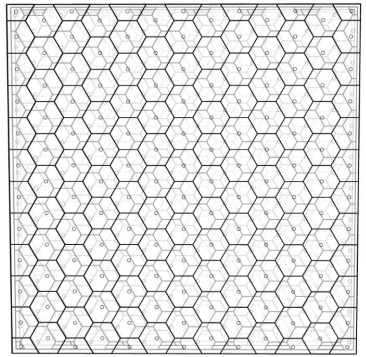
Abstract: We advance the concept of high-granularity calorimeters with staggered tessellations, underscoring the effectiveness of a design incorporating multifold staggering cycles based on hexagonal cells to enhance position resolution. Moreover, we introduce HEXPLIT, a sub-cell re-weighting algorithm 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.

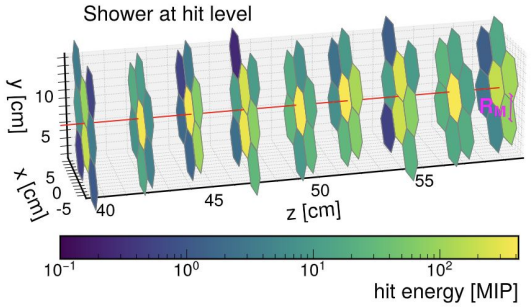
Keywords: Calorimeters; Detector design and construction technologies and materials;

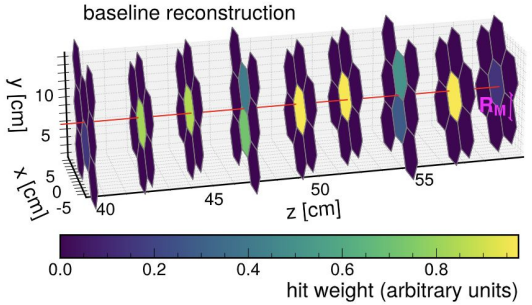
Position resolution improved through staggering

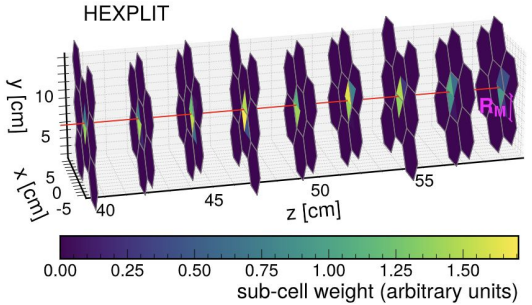
- Simulations show that position resolutions can be improved two-fold by using staggering and the recently developed HEXPLIT algorithm





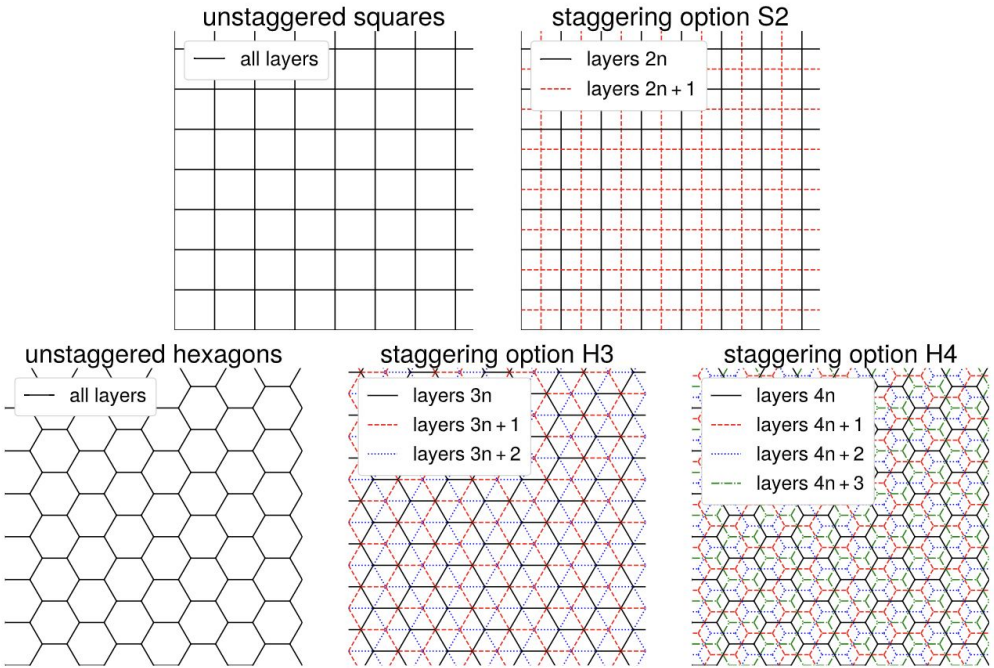


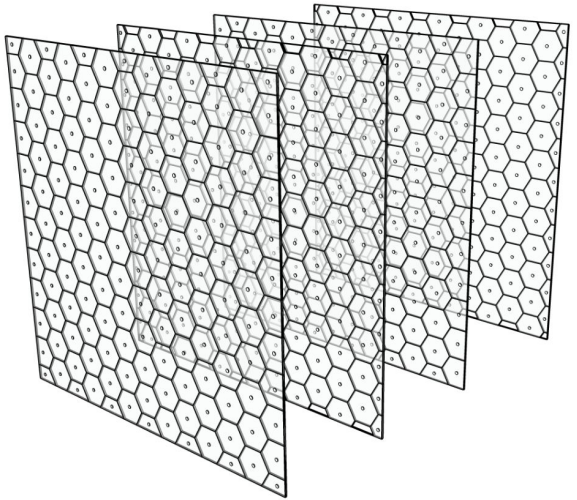


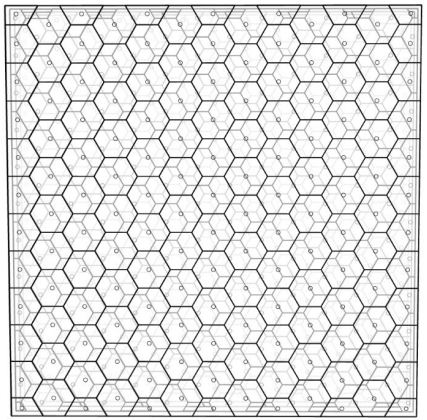


arXiv:2308.06939

Staggered tessellation patterns in sampling calorimeters





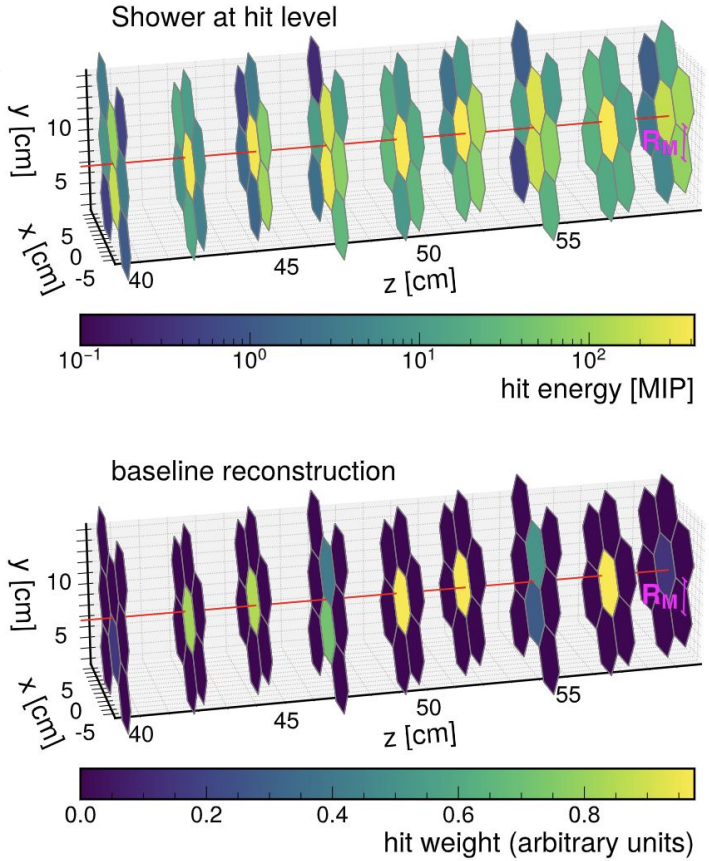


Baseline shower-position reconstruction

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

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

Core Portion of Neutron Shower



The 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

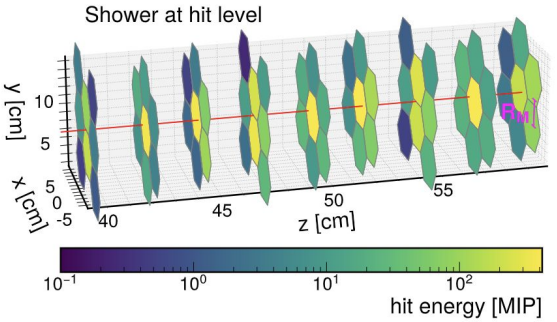
$$E_i = E_{\text{tile}} W_i / \sum_j W_j.$$

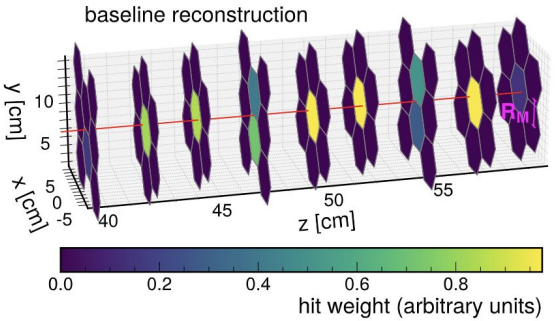
Energy in a given subcell, *i*

Reconstruct shower from subcells

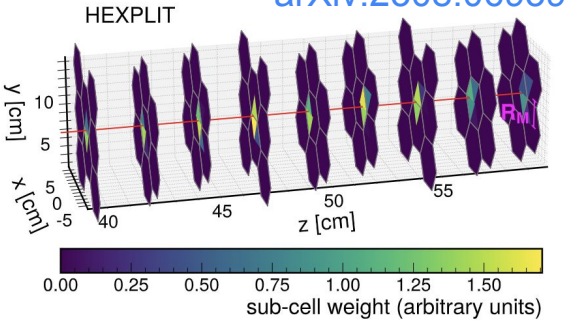
$$\vec{x}_{\text{recon}} = \frac{\sum_{i \in \text{subcells}} \vec{x}_i w_i}{\sum_{i \in \text{subcells}} w_i}$$

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

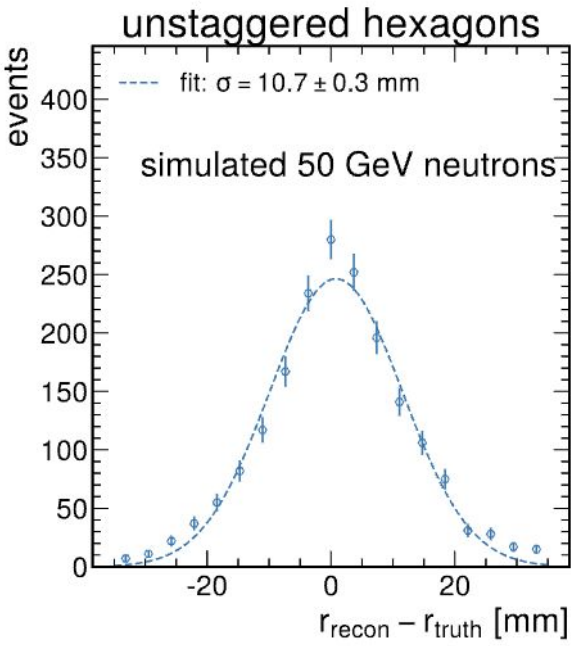


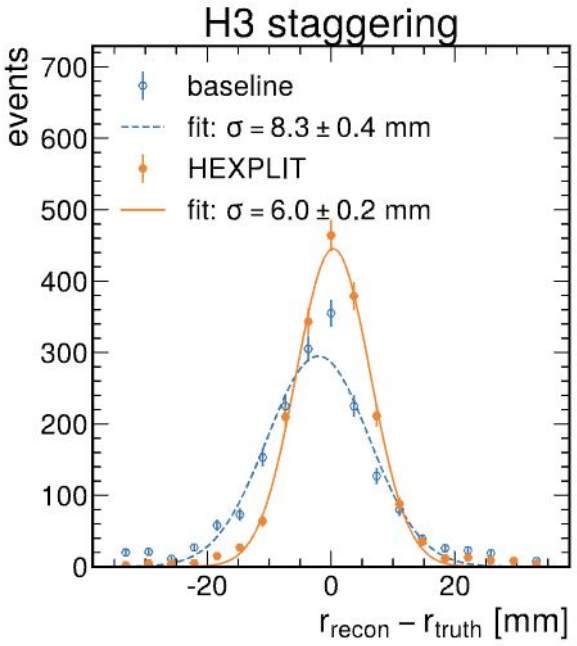


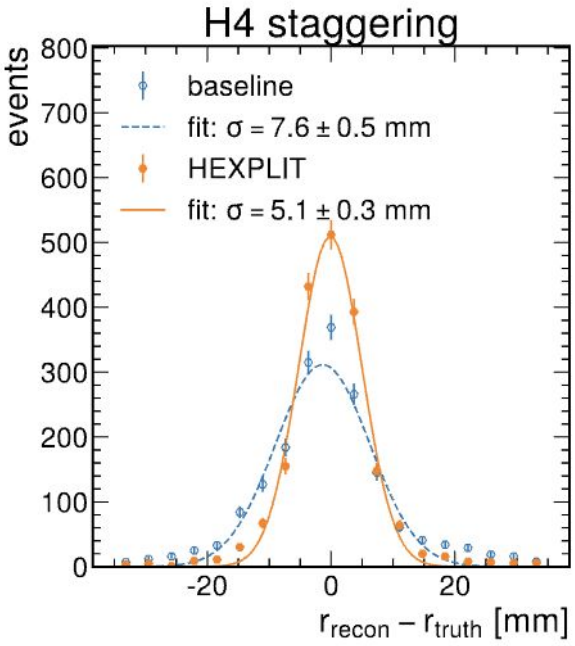
arXiv:2308.06939



Neutron-shower performance for the ZDC-like* calorimeter







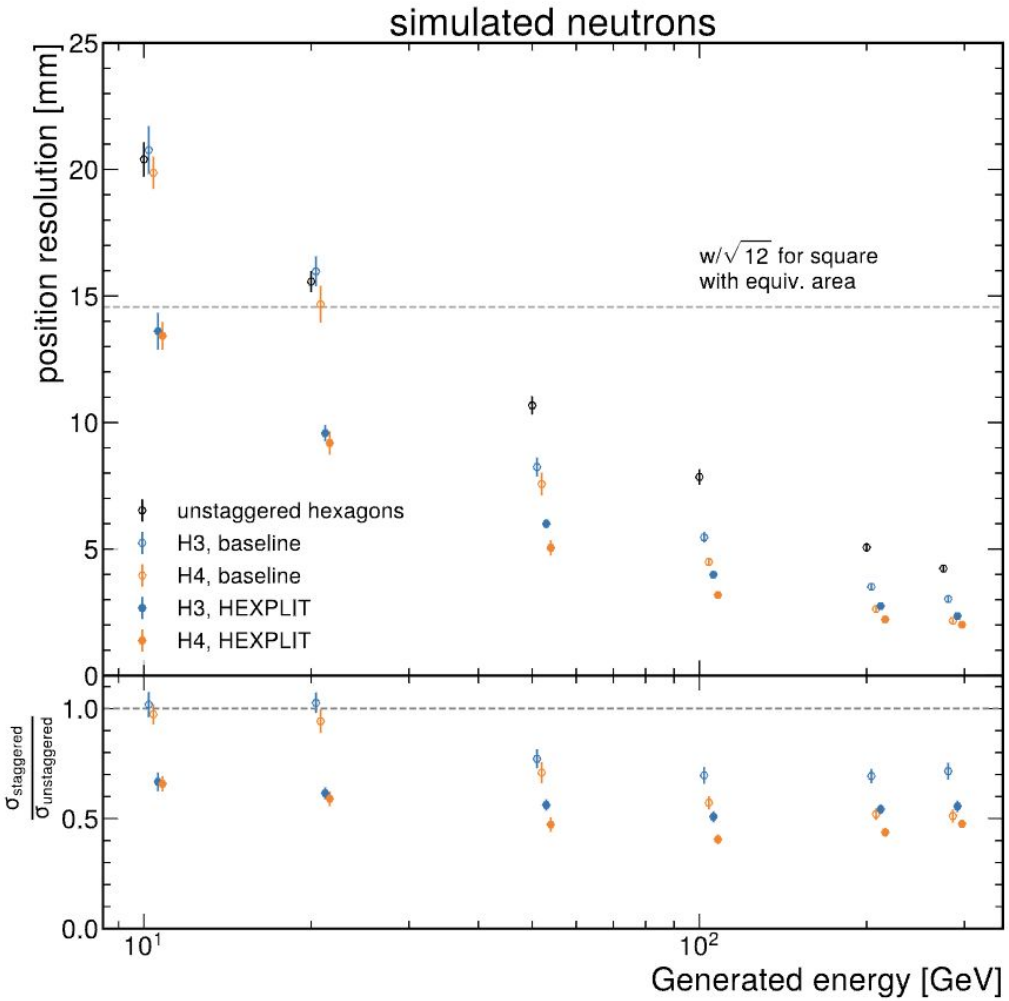
*Simulations in this paper used much larger transverse dimensions to avoid edge effects.

arXiv:2308.06939

- Factor of 2 improvement

Energy dependence of position resolution

- H4 staggering improves the resolution by up to 60%, when utilizing the HEXPLIT algorithm



arXiv:2308.06939

*Simulations in this paper used much larger transverse dimensions than ZDC to avoid edge effects.