SiPM-on-technology option for ZDC HCAL

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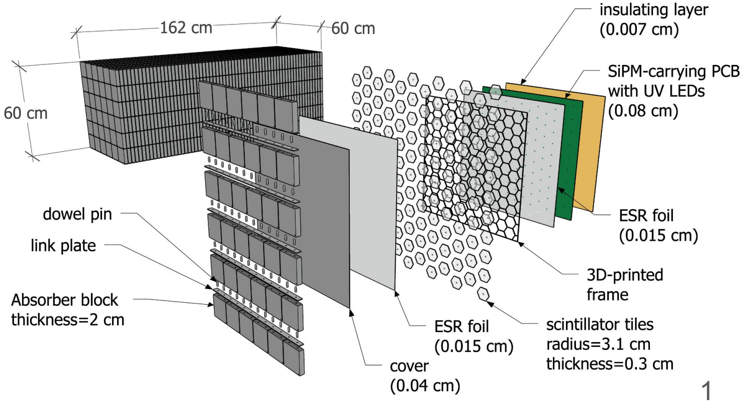
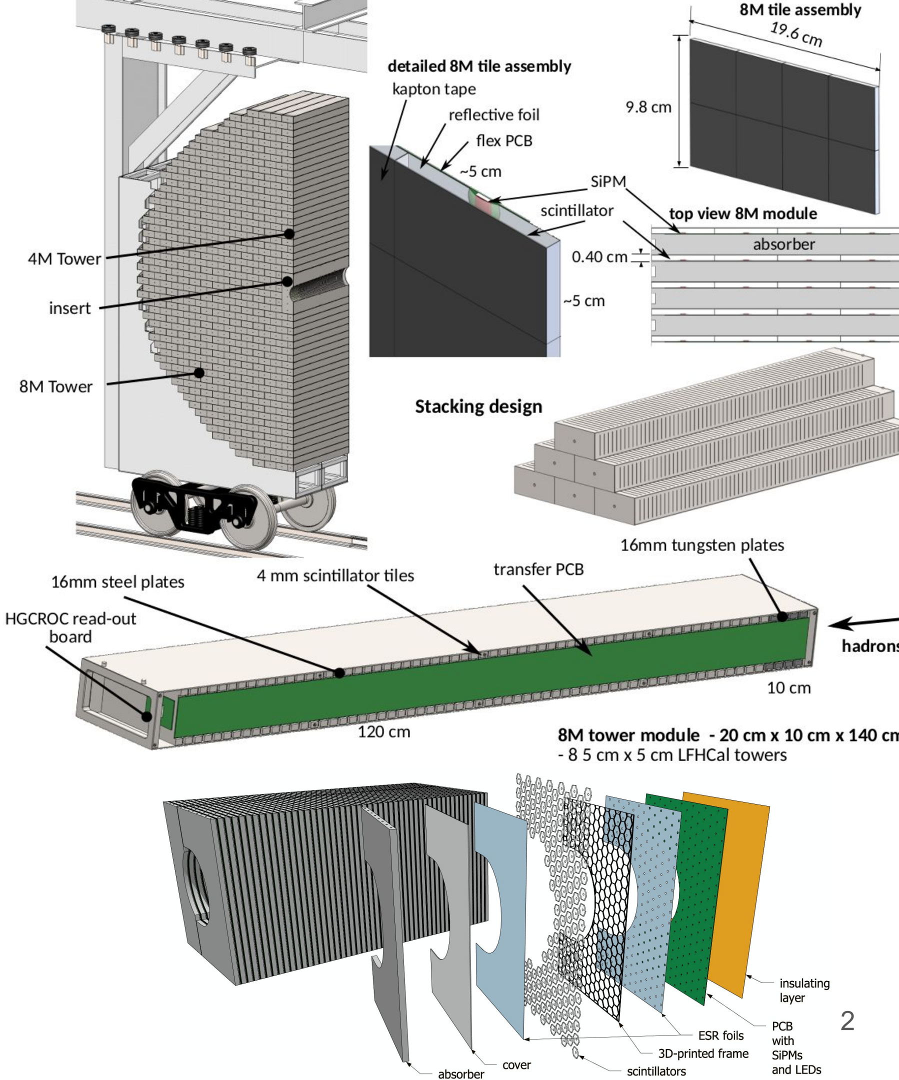


Forward HCAL uses SiPM-on-tile technology

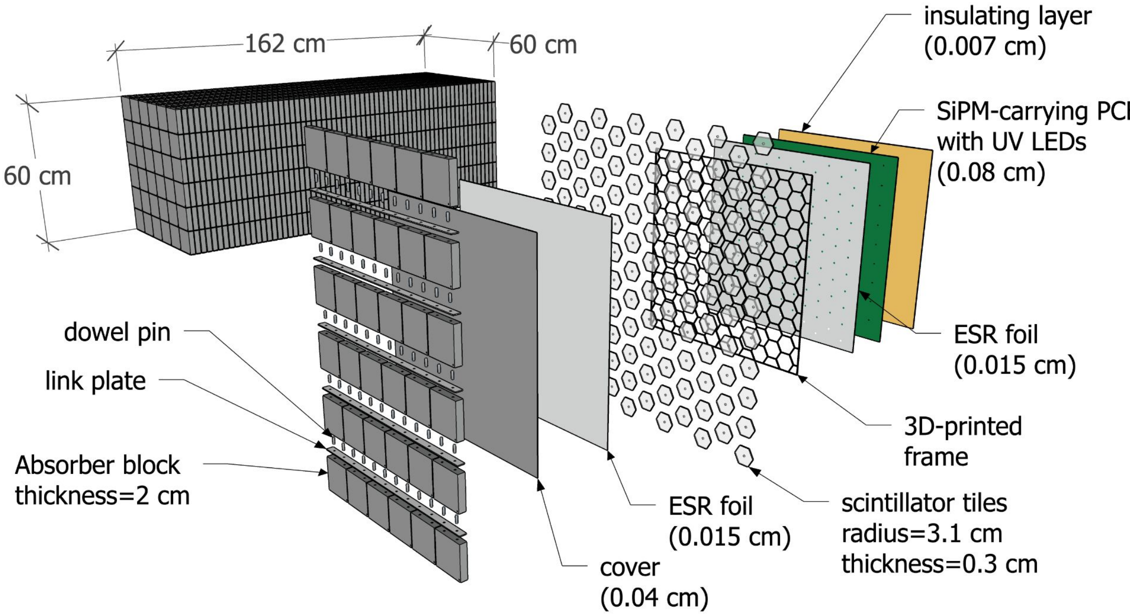
ZDC HCAL might benefit from sharing info, ideas, etc.

Consider what we show today as a starting point in a discussion.



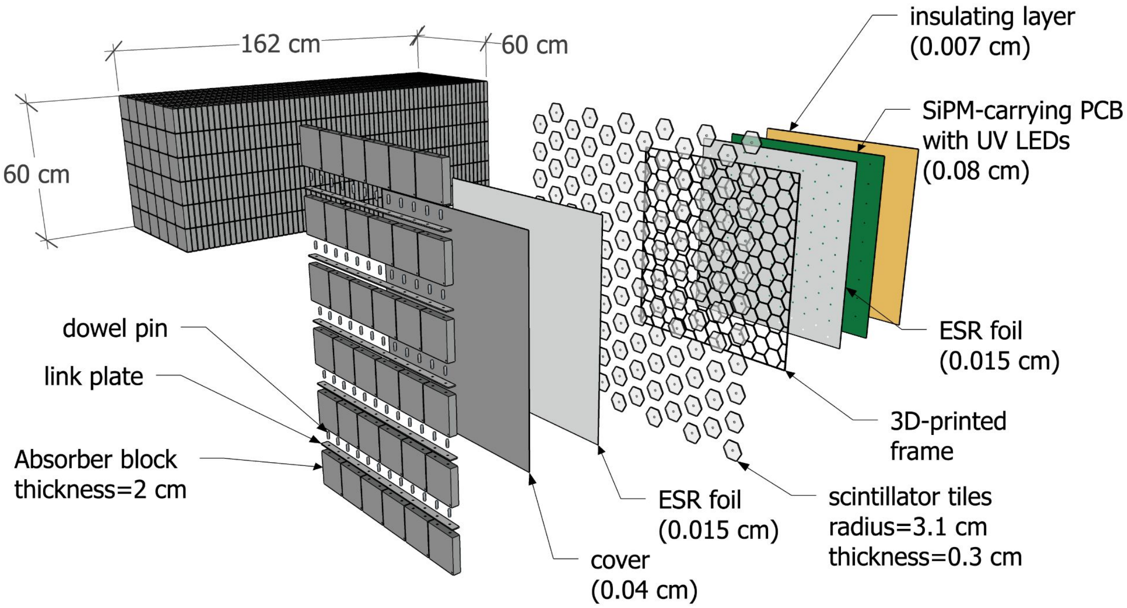
A possible SiPM-on-tile ZDC design

- SiPMs and bias & readout (HGROC) and scintillator cells (injection molding) relatively inexpensive.
- Could work with either Fe or Pb, but if we use Fe it could be very inexpensive:
  - Could reuse $2{\times}10{\times}10$ cm^3 absorber blocks from STAR



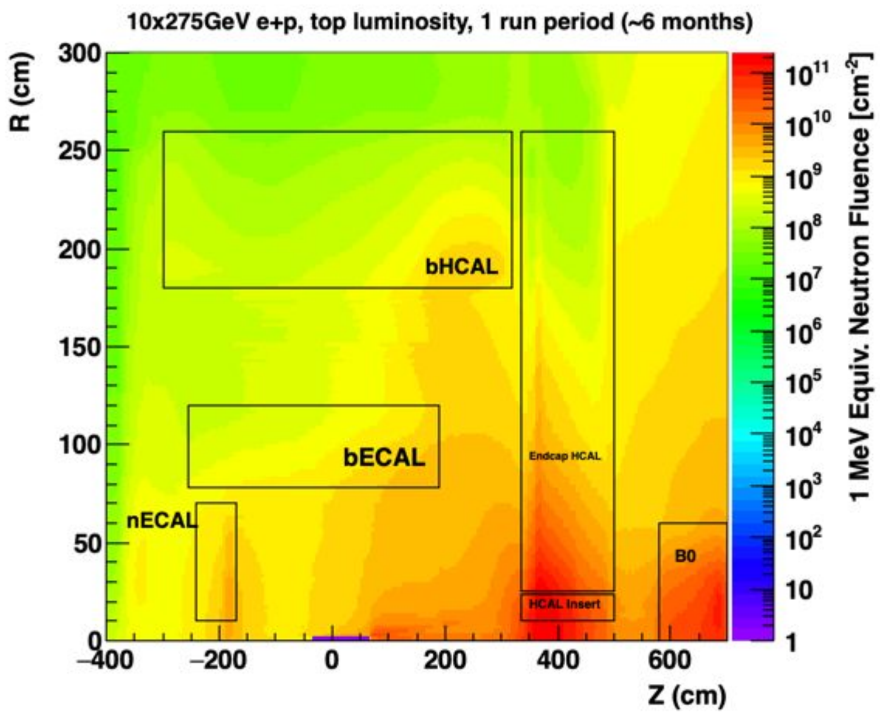
A possible SiPM-on-tile ZDC design

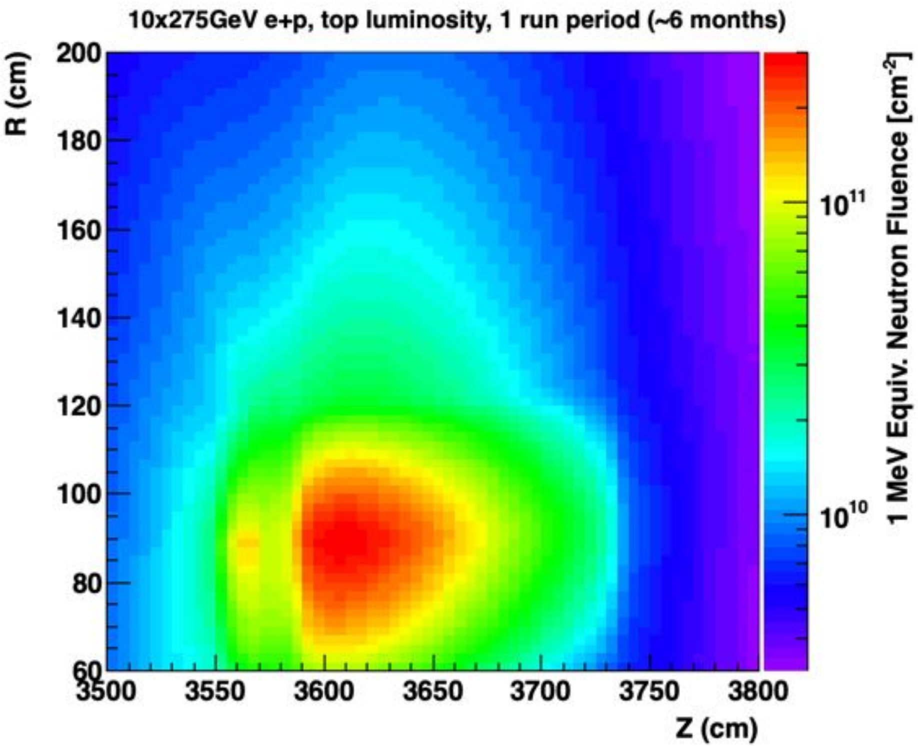
- Accessible PCB boards
  - Allows SiPMs to be annealed to mitigate radiation damage
  - (10^{11}-10^{12} 1 MeV-equivalent neutron/cm^2 per year)
- If using Fe, it could be software compensated:
  - EM and hadronic sub-showers distinguished in software and weighted accordingly



Neutron flux in Insert region is similar to that of ZDC

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





Mitigation strategies discussed for Insert could be used in ZDC

Can the SiPM-on-tile approach meet the YR requirements for ZDC?

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

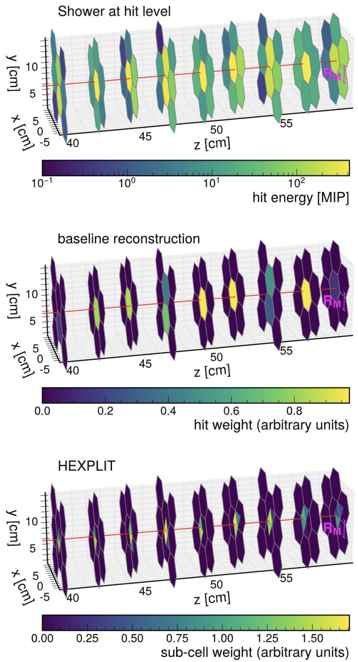
$$\Delta\theta < 3\,\mathrm{mrad}/\sqrt{E}$$

- **Yes**, energy resolution should be within range of technology, as CALICE quotes ~45%/sqrt(E) in test beam for Fe/Sc design, after software compensation.(https://arxiv.org/abs/1207.4210)

- **Yes,** position resolution can be tuned with cell size, and can be improved with dedicated algorithms, like HEXPLIT (described in next slides).

Recent submission to the arXiv

arXiv:2308.06939



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

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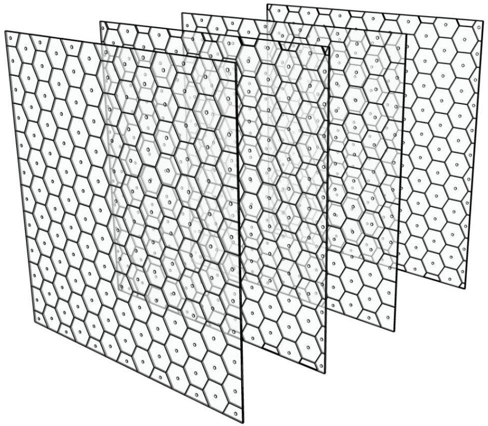
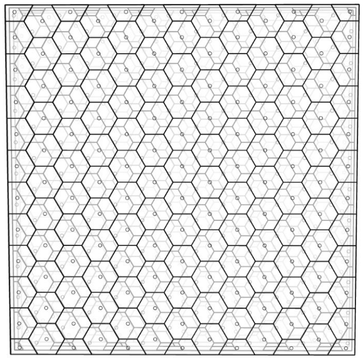
Abstract: We advance the concept of high-granularity calorimeters with staggered tessellations, underscoring the effectiveness of a design incorporating multifold staggering cycles based on hexagonal cells to enhance position resolution. Moreover, we introduce HEXPLIT, a sub-cell re-weighting algorithm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

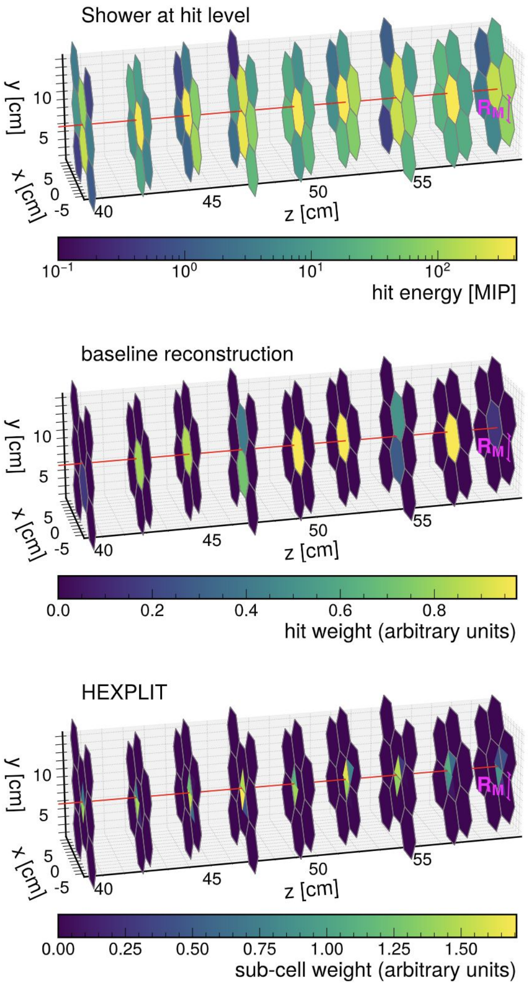
Keywords: Calorimeters; Detector design and construction technologies and materials;

Position resolution improved through staggering

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







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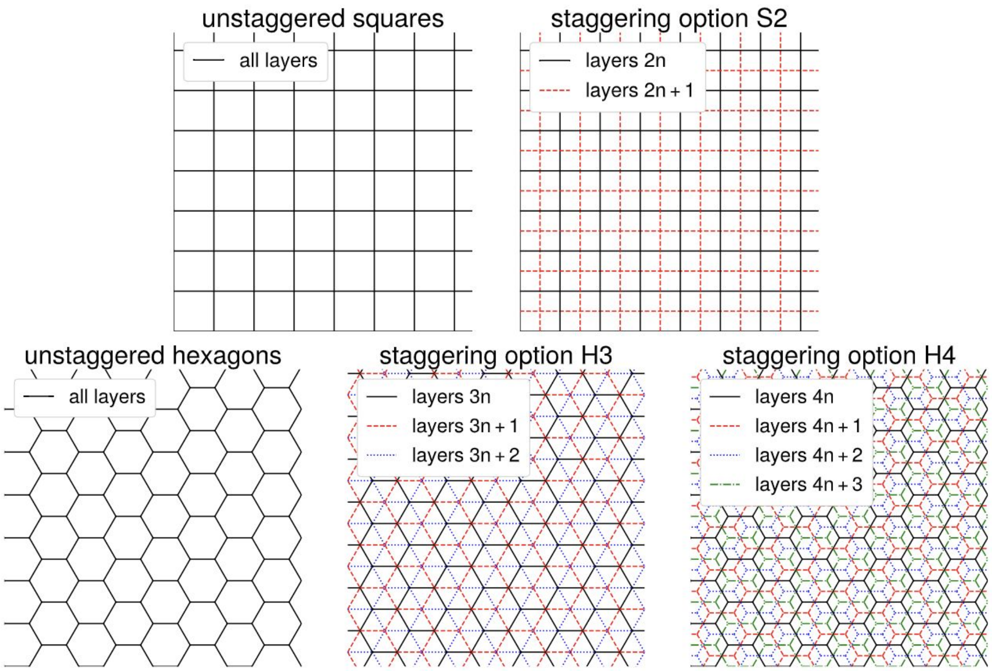
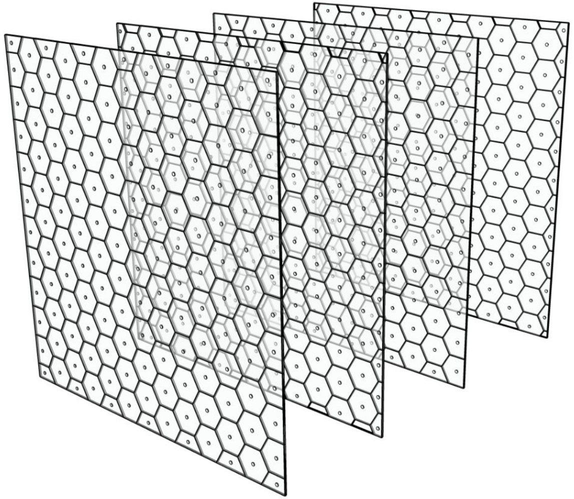
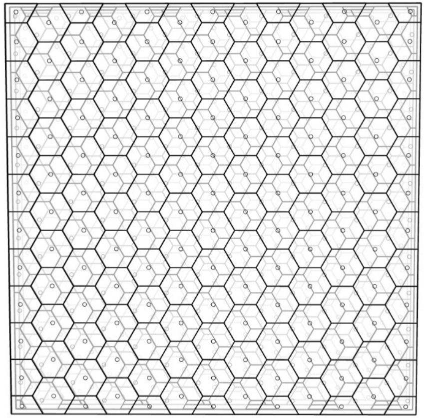
Staggered tessellation patterns in sampling calorimeters





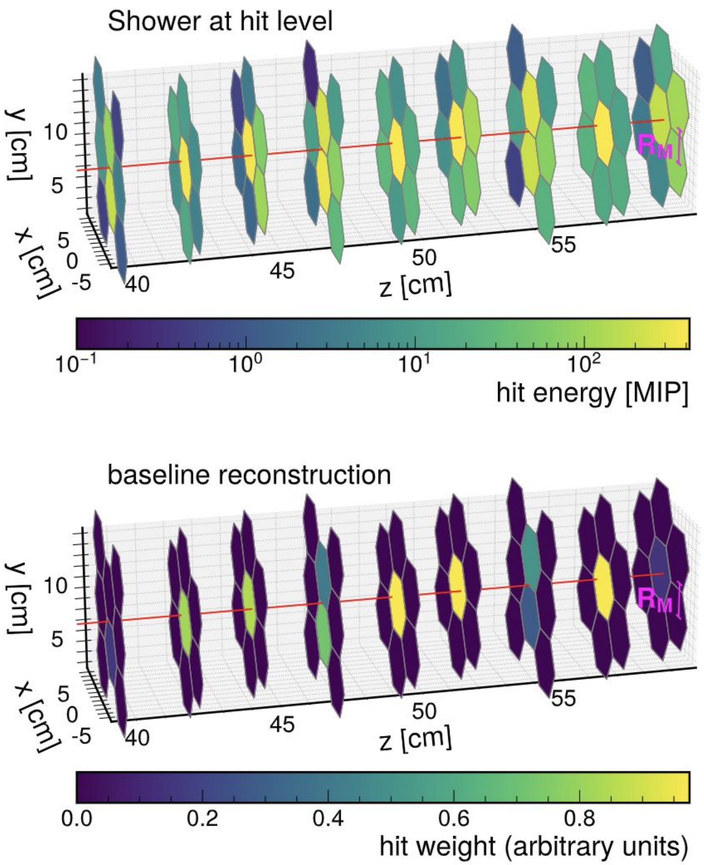


Baseline shower-position reconstruction

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

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

Core Portion of Neutron Shower



The HEXPLIT algorithm

Subcell reweighting

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

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

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

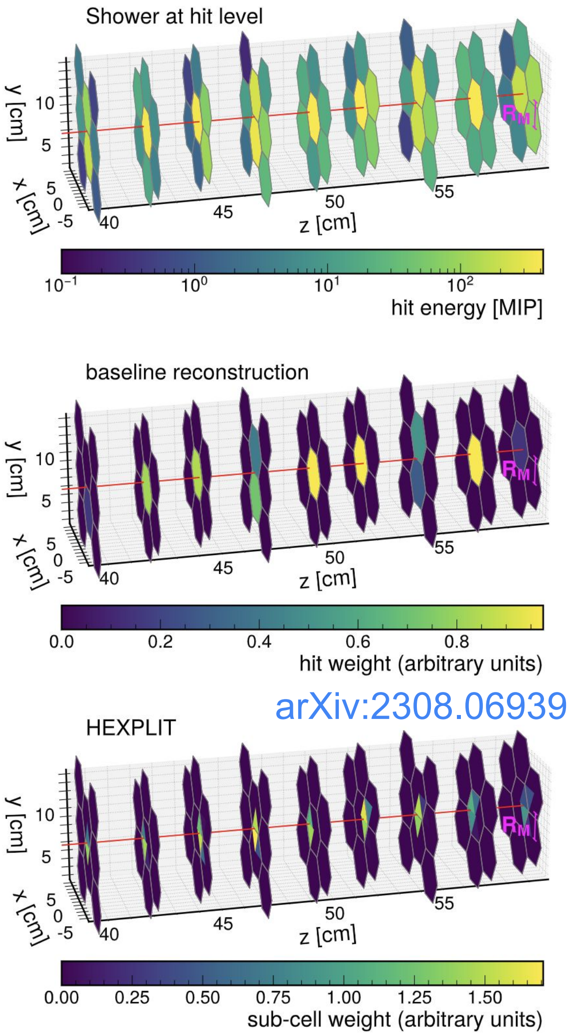
Energy in a given subcell, *i*

Reconstruct shower from subcells

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

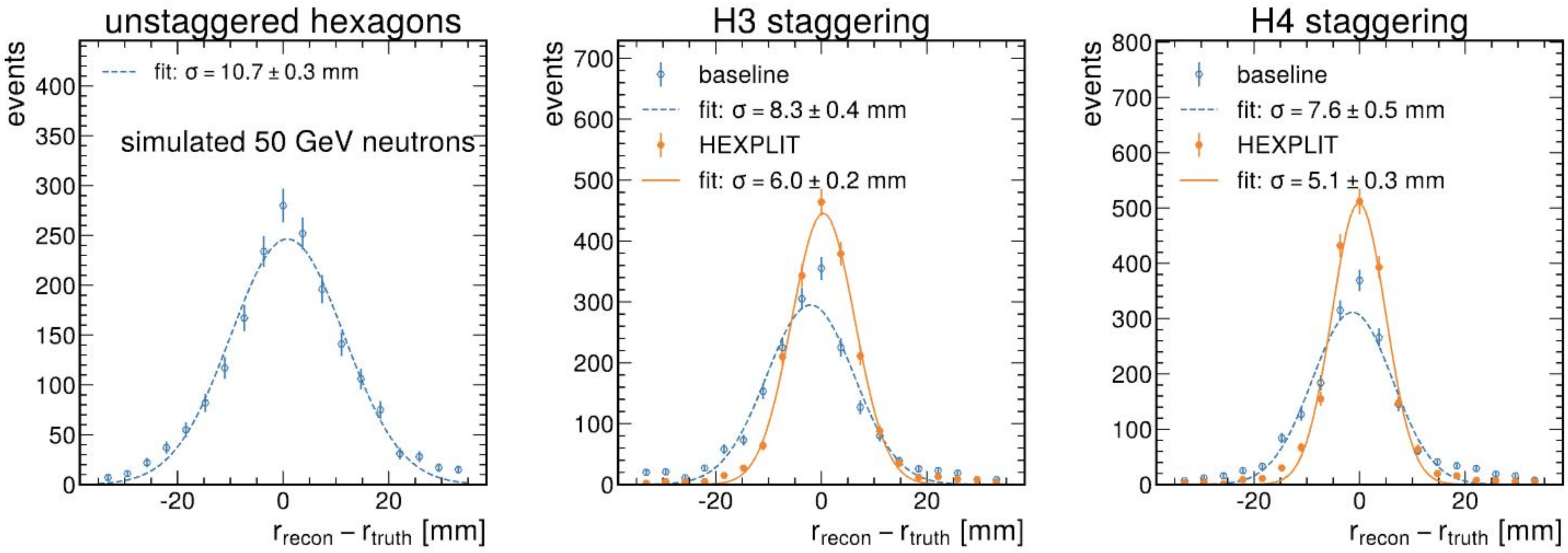
$$w_i = \max\left(0, w_0 + \ln \frac{E_i}{E_{\text{tot}}}\right)$$

Core Portion of Neutron Shower



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

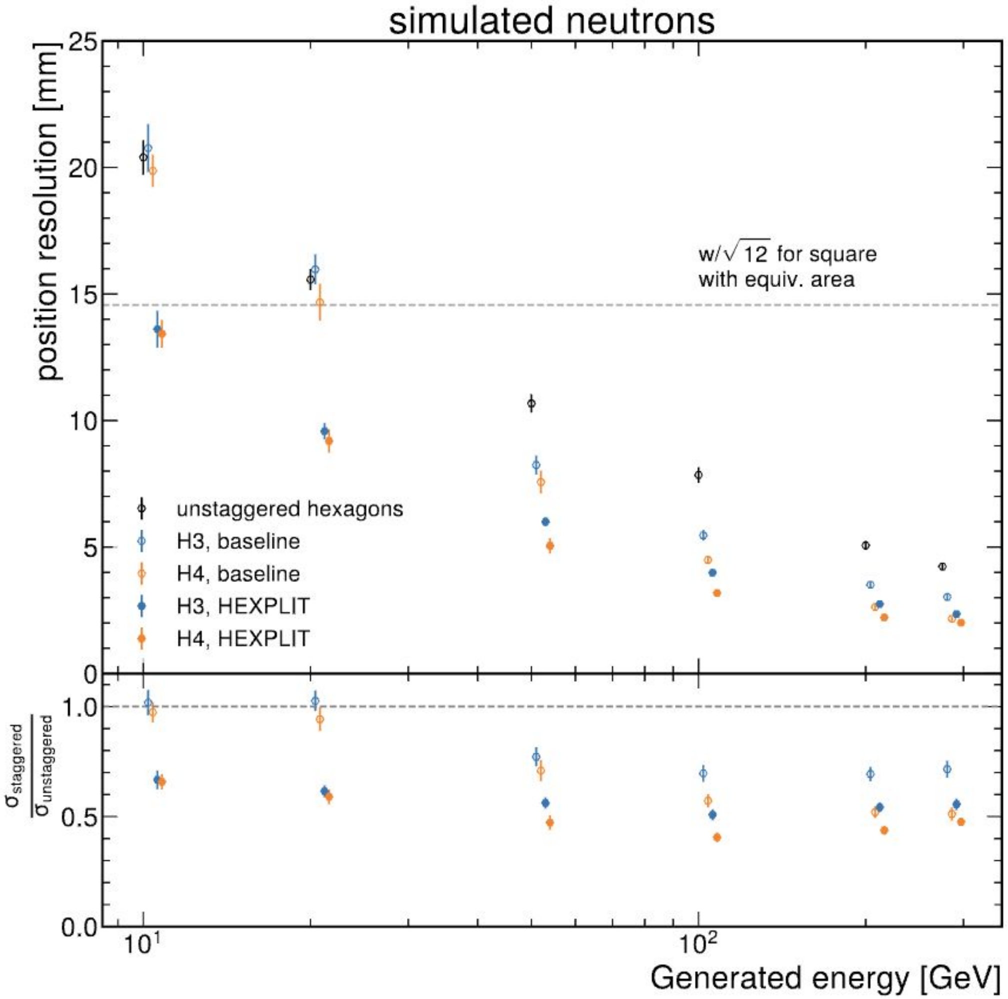
- Factor of 2 improvement

Energy dependence of position resolution

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

arXiv:2308.06939

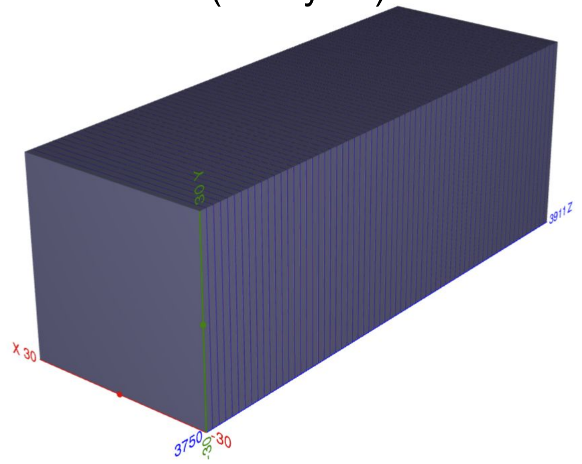
*Simulations in this paper used much larger transverse dimensions than ZDC to avoid edge effects.



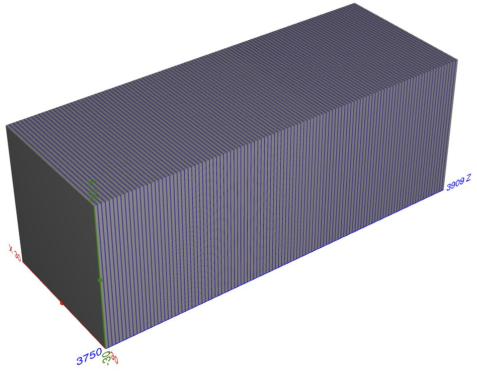
ZDC geometry in DD4HEP

- Two geometries are simulated: Fe/Sc and another Pb/Sc.
- Same digitization and hit-level cuts as applied to HCAL Insert studies (which are based on CALICE studies).
- Larger event sample generated with transverse dimensions of 60x60cm2.
- Neutrons generated over range theta<5.5 mrad and full azimuth

Fe 20 mm/ Sc 3.0 mm (64 layers)



Pb 10 mm/ Sc 2.5 mm (110 layers)



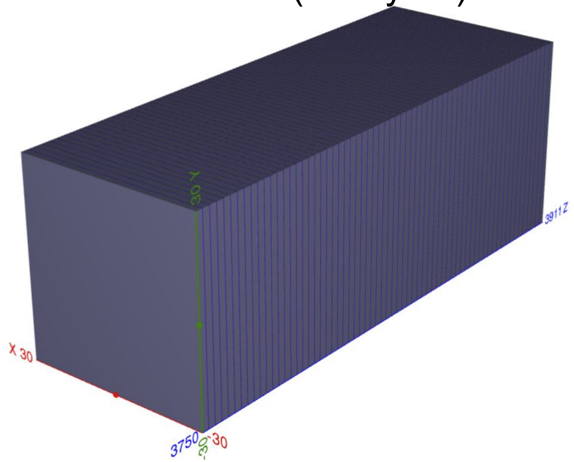
ZDC geometry in DD4HEP

- Geometry:
    - https://github.com/sebouh137/staggered_tesselations/tree/main/dd4hep
- DD4hep plugin for hexagonal segmentation and staggering
    - https://github.com/sebouh137/DD4hep/tree/master

Link to HEXPLIT example code:

https://zenodo.org/record/8245245

Fe 20 mm/ Sc 3.0 mm (64 layers)



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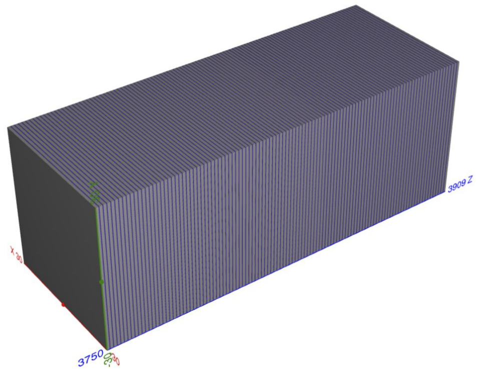
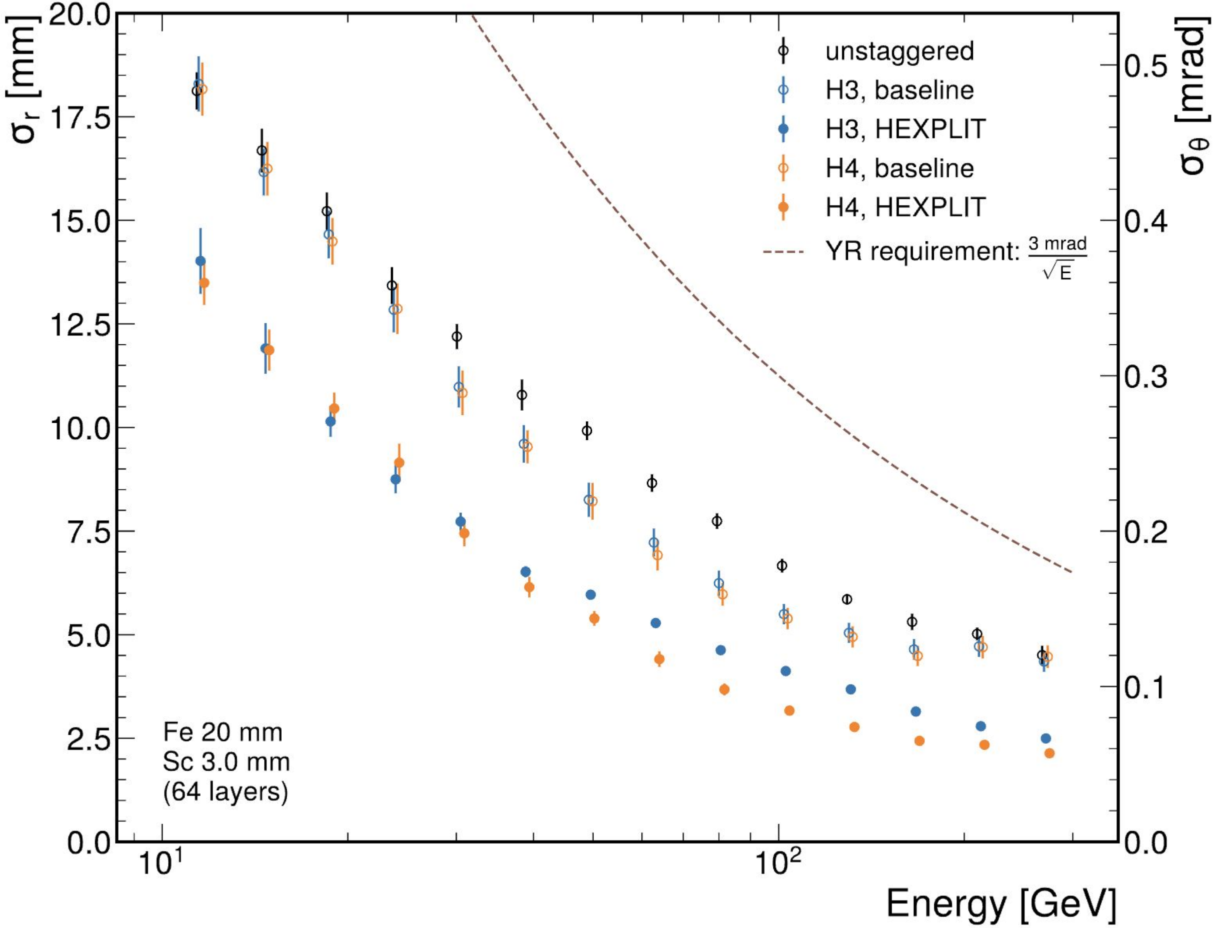


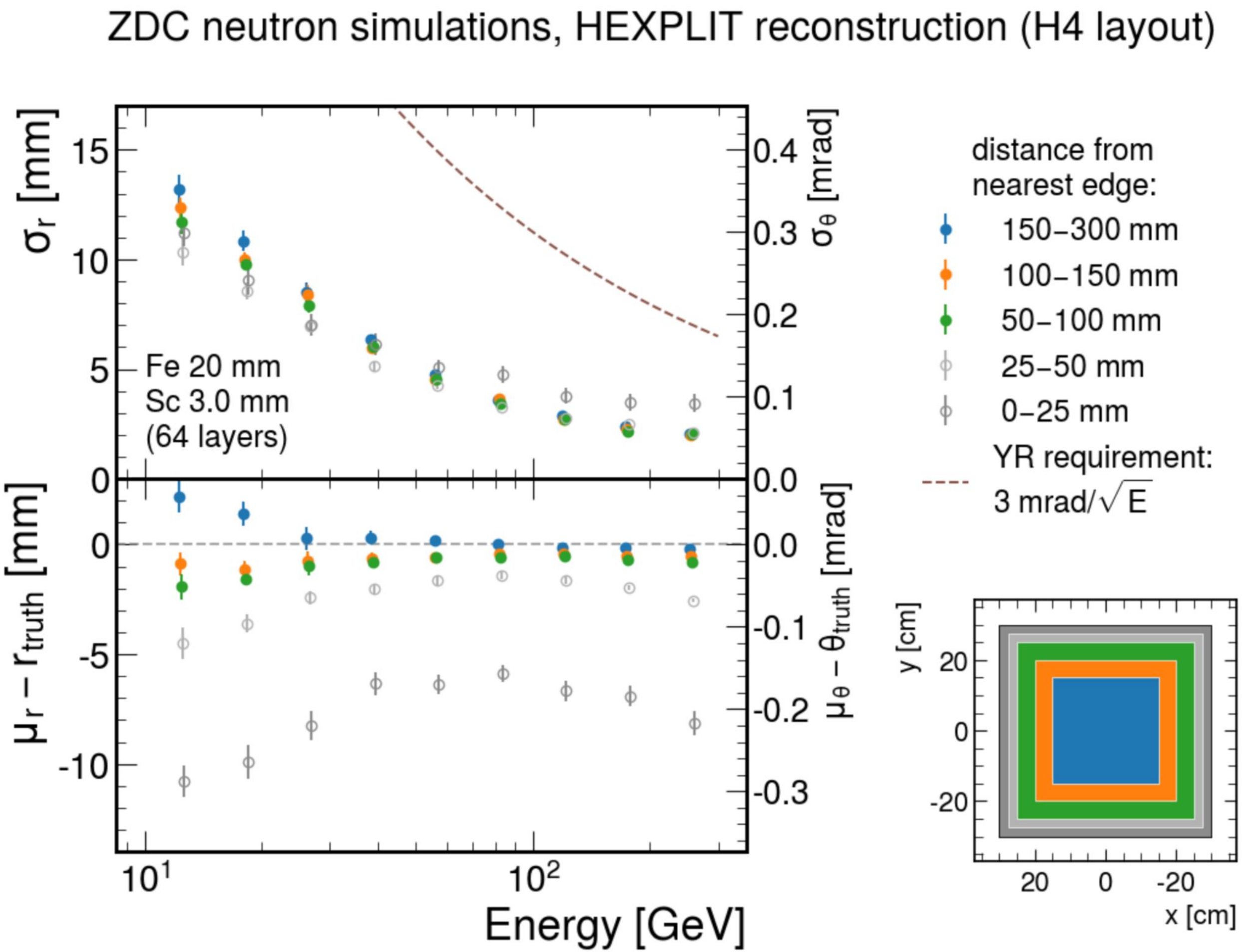
Position resolutions for neutrons with a realistic ZDC model



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

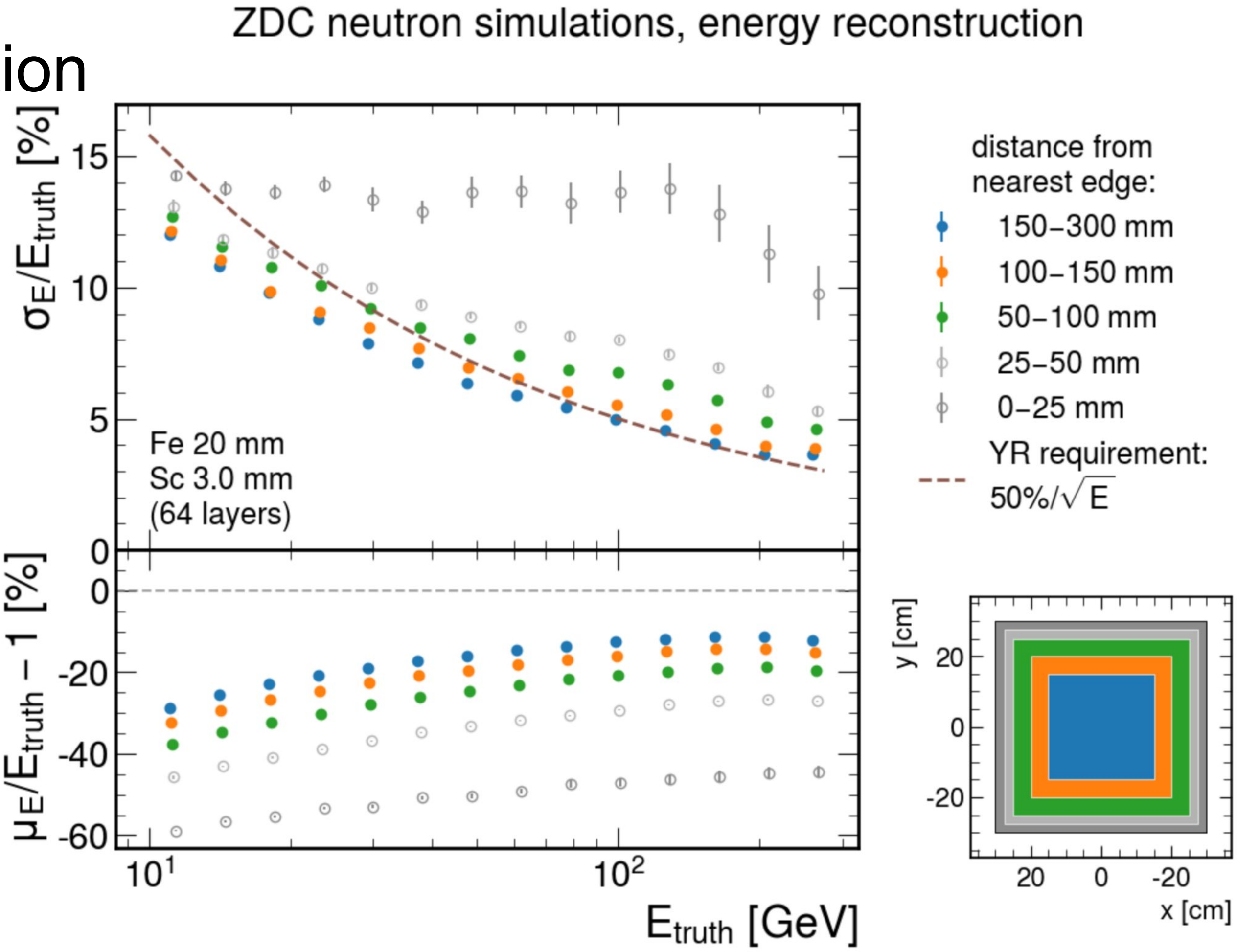
Edge effects in the position reconstruction

- Some bias for shower loss near edge of detector
    - Affects weighted average position of shower
    - < 2 mm (or 0.05 mrad) within fiducial range (>50 mm from edge).
    - Could be corrected for in software



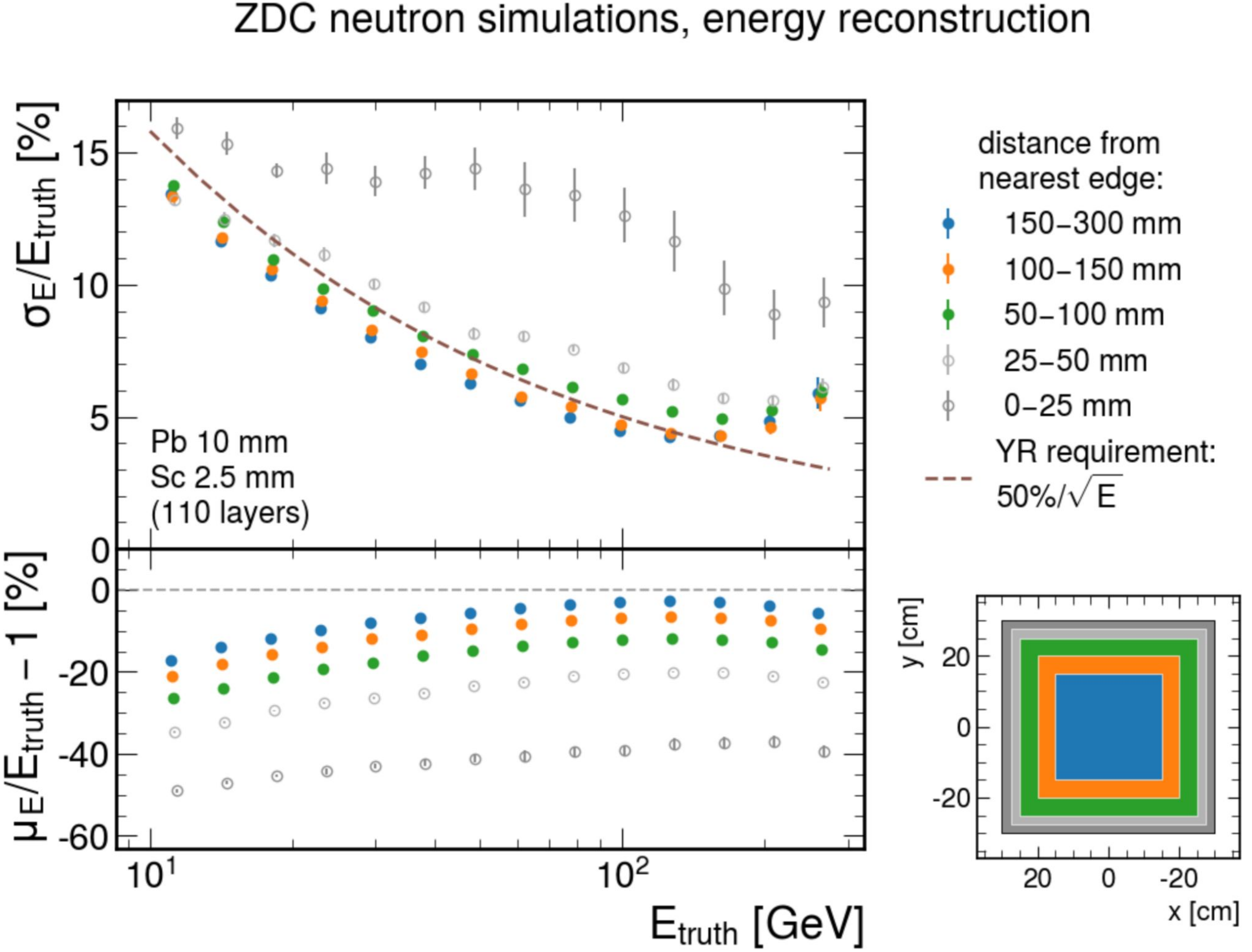
Energy reconstruction

- Baseline or "straw-man" reconstruction adds up energy of all hits with at least 0.5 MIP and divides by the sampling fraction for electrons.
- Bias can be compensated for in "software compensation" techniques, a la CALICE or with AI/ML, which we expect will improve resolution to ~45%/sqrt(E)



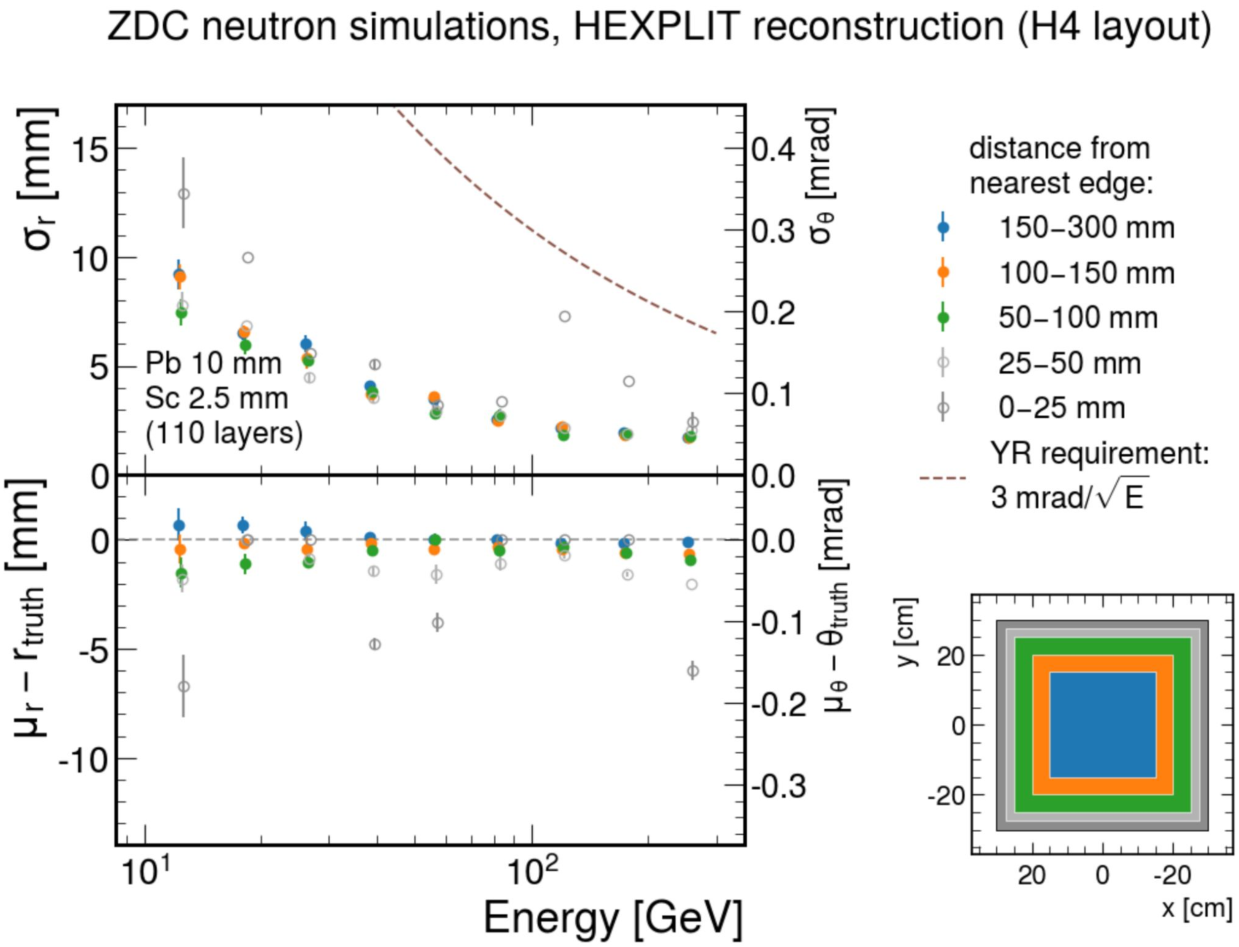
Energy recon (Pb version)

- Smaller bias in the reconstructed energy than in Fe geometry



Position resolution (Pb version)

- Pb has a considerably better position resolution than Fe.



*slide updated since it was presented to show the results of a larger simulated sample that was not yet processed by the time this presentation was presented

Summary and Conclusions

- We think SiPM-on-tile technology, and HEXPLIT design offer cost-effective solution that could benefit/complement ZDC HCAL design.
- We have shown that a Fe-absorber SiPM-on-tile design can meet YR requirements and more (for position resolution). Very low cost.
- We are also exploring a Pb-absorber SiPM-on-tile design.
- We look forward to further discussion/collaboration with all interested parties