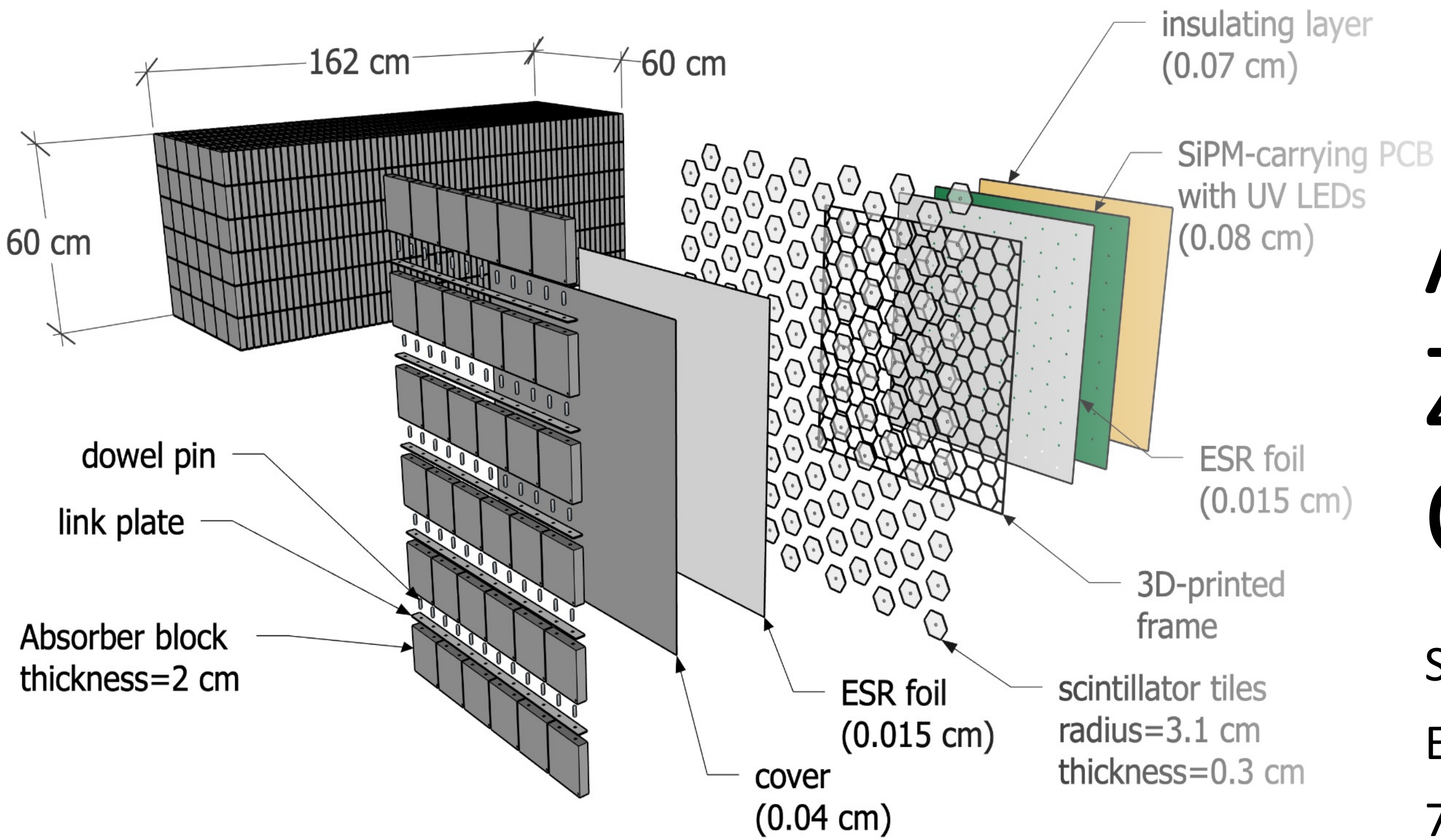


A SiPM-on-tile Zero Degree Calorimeter

Sean Preins

EIC Early Career Workshop

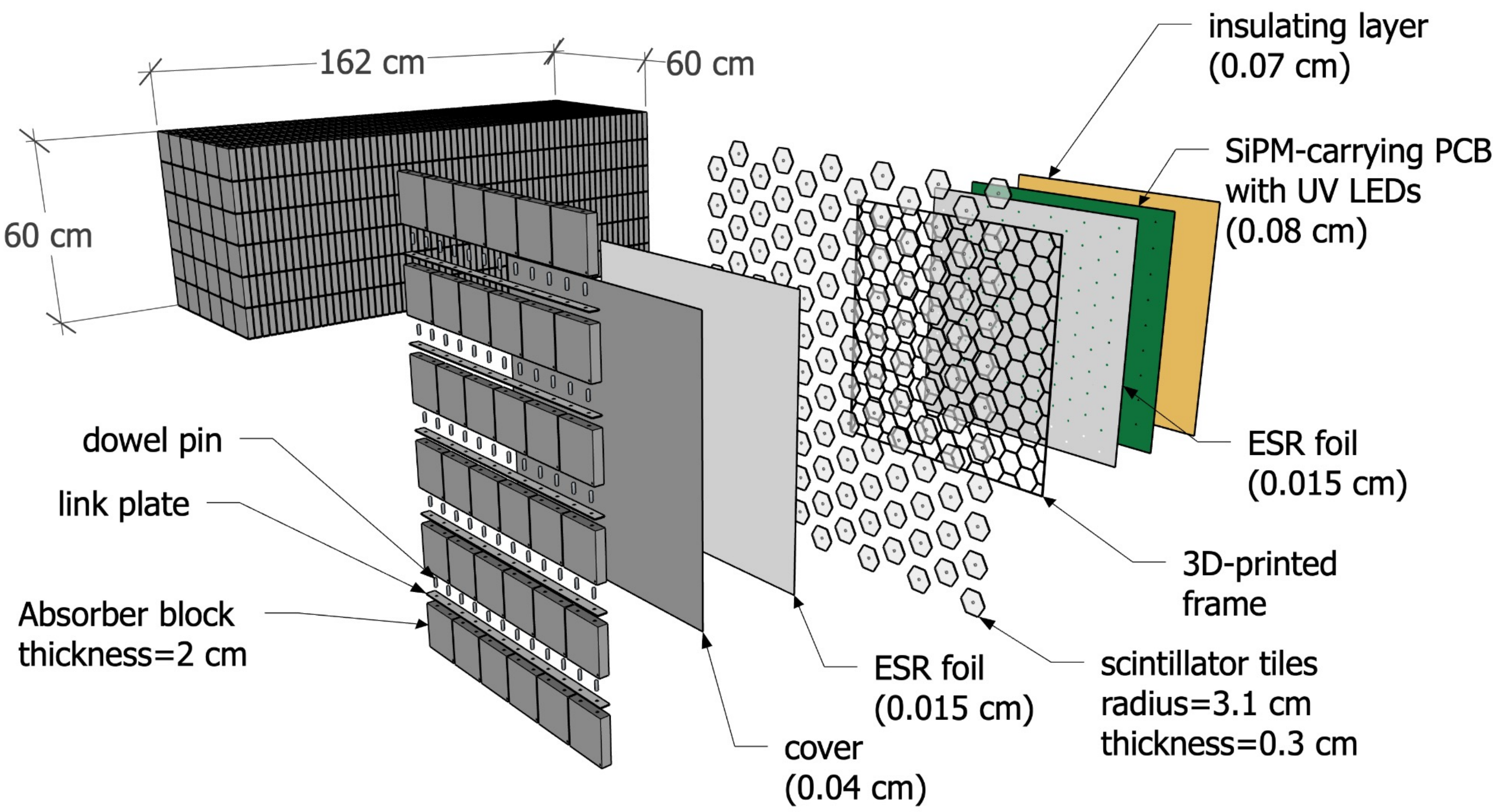
7/24/2023

Motivation

- A Zero Degree Calorimeter would be situated far downstream of the proton beam, where charged particles have been steered away
- The baseline design for the ZDC is subdivided into an EM and hadronic section, and utilizes lead for absorber plates
- Lead absorbers provide a similar response for EM and hadronic showers (hardware compensation)
- Switching lead for iron would simplify assembly, and compensation could instead be done in software using high granularity shower-cell topology

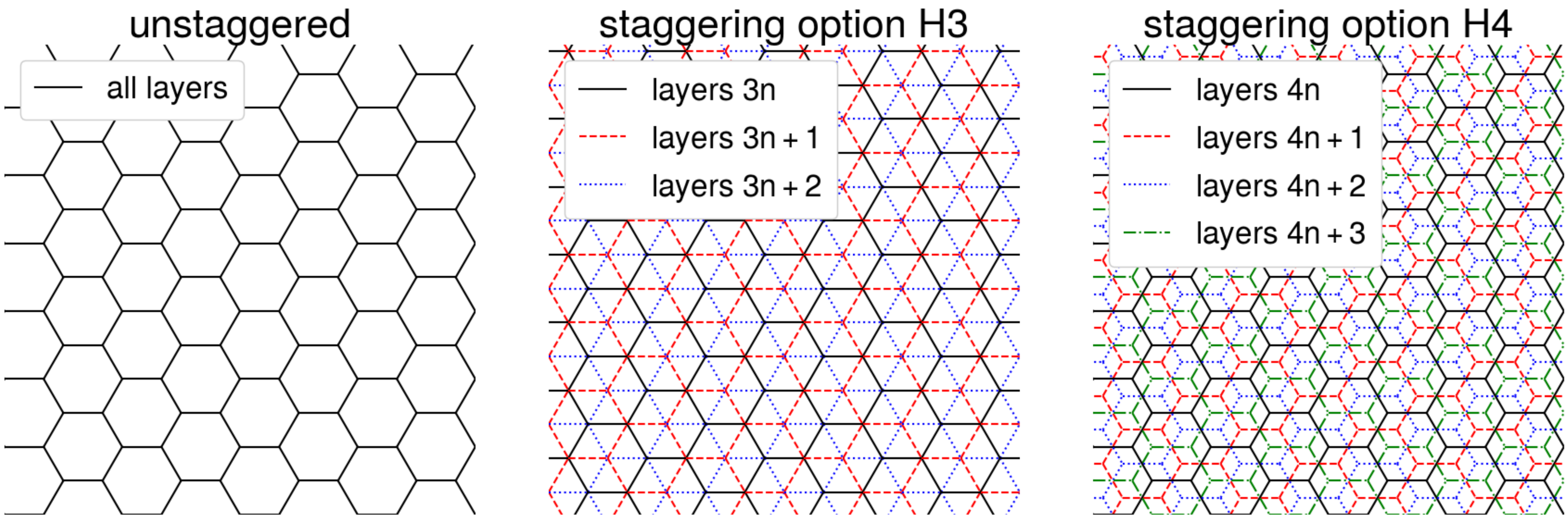
A SiPM-on-Tile ZDC for ePIC

- Reuses STAR-HCAL Fe blocks
- Utilizes a similar SiPM-on-Tile design as the calorimeter insert
- Uses ~5x5 cm^2 hexagon tiles
- Positioned at z = 35m

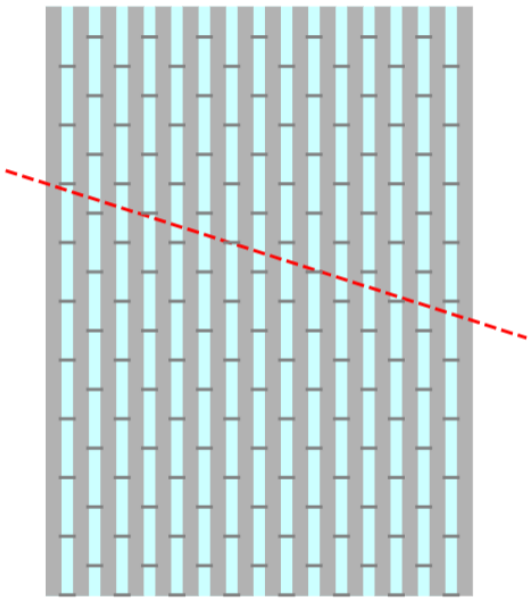


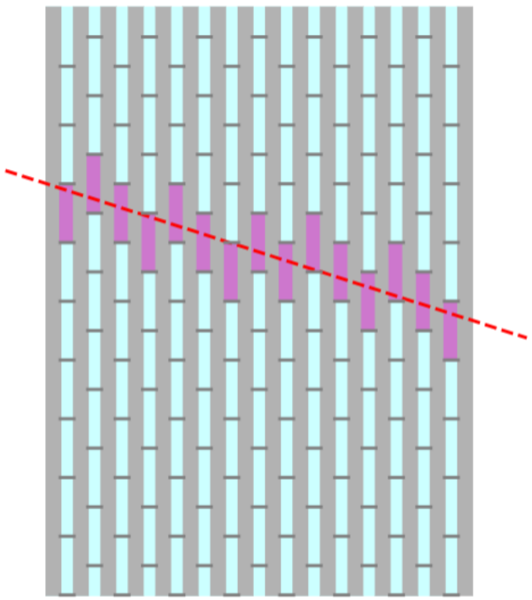
Tile Staggering

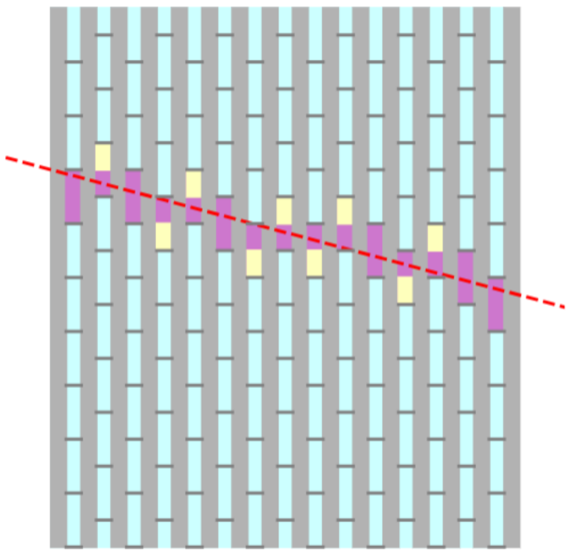
- Hexagons were chosen minimize dead space, and improve tile response uniformity
- Staggering layers can improve angular resolution and optimize performance

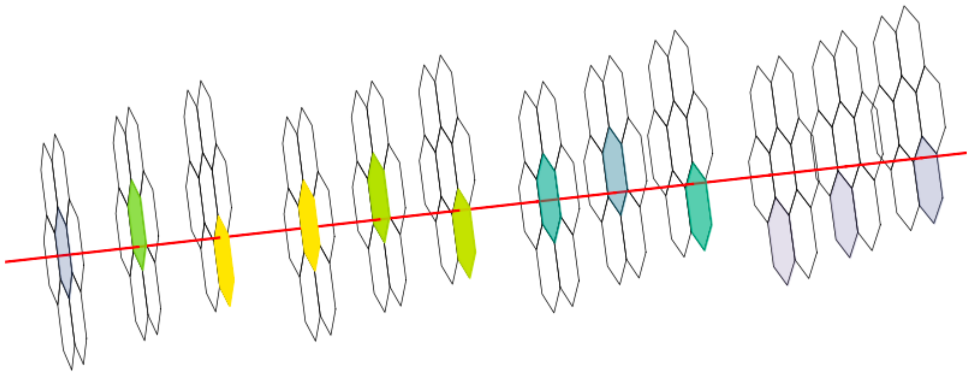


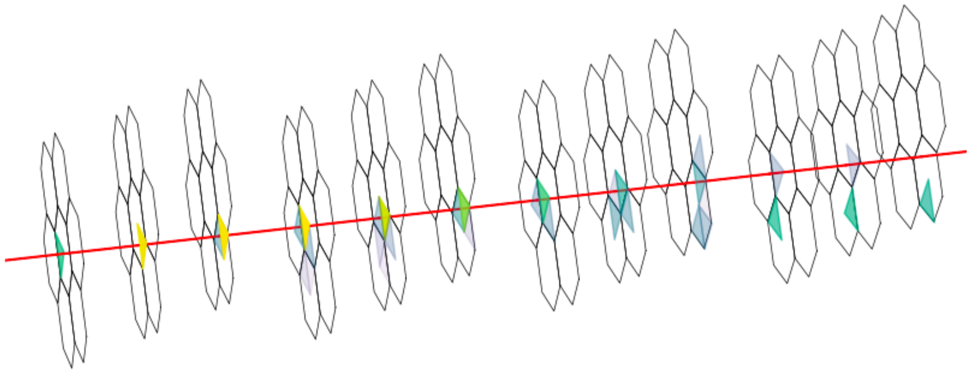
Tile Staggering



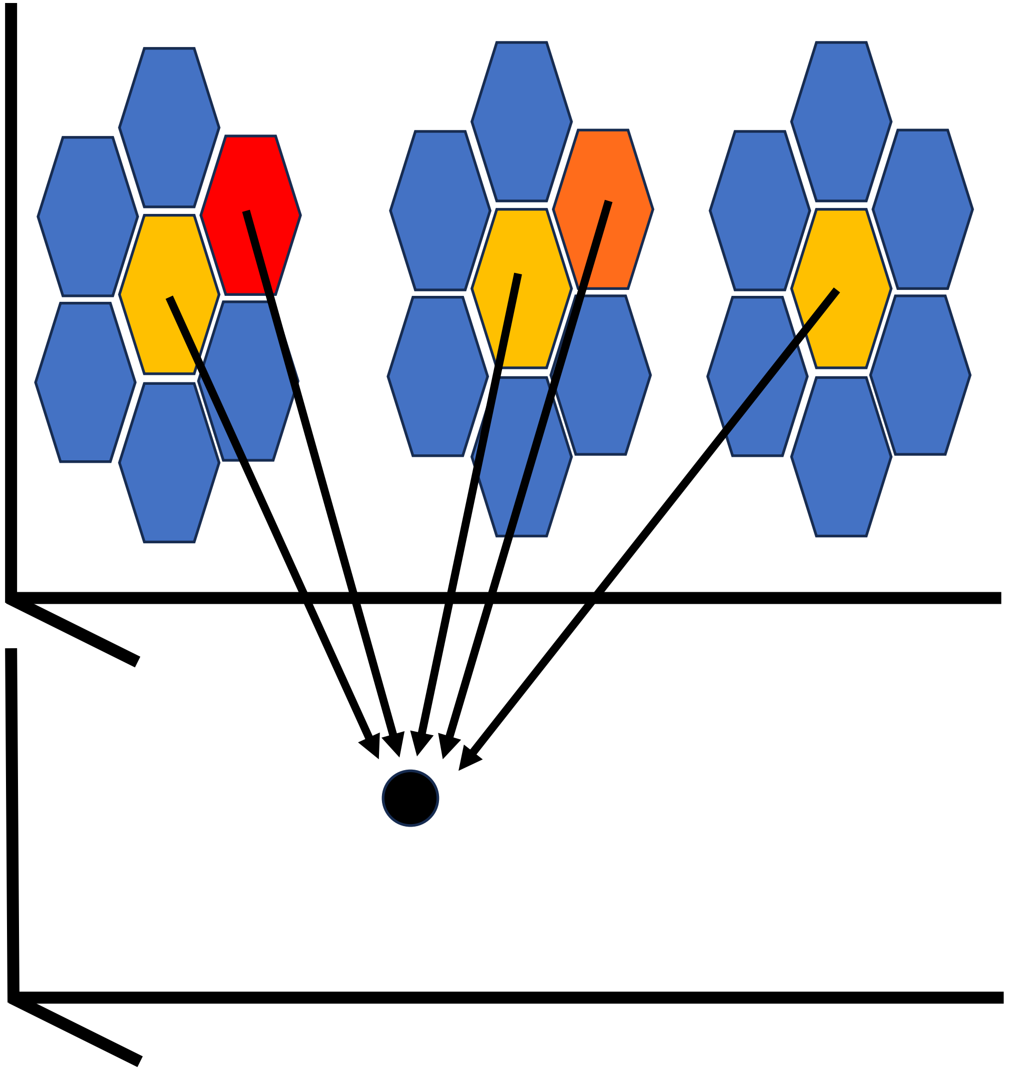








Traditional Shower Position Reconstruction



$$\vec{x} = \sum_{i \in \text{hits}} \vec{x}_i w_i,$$

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

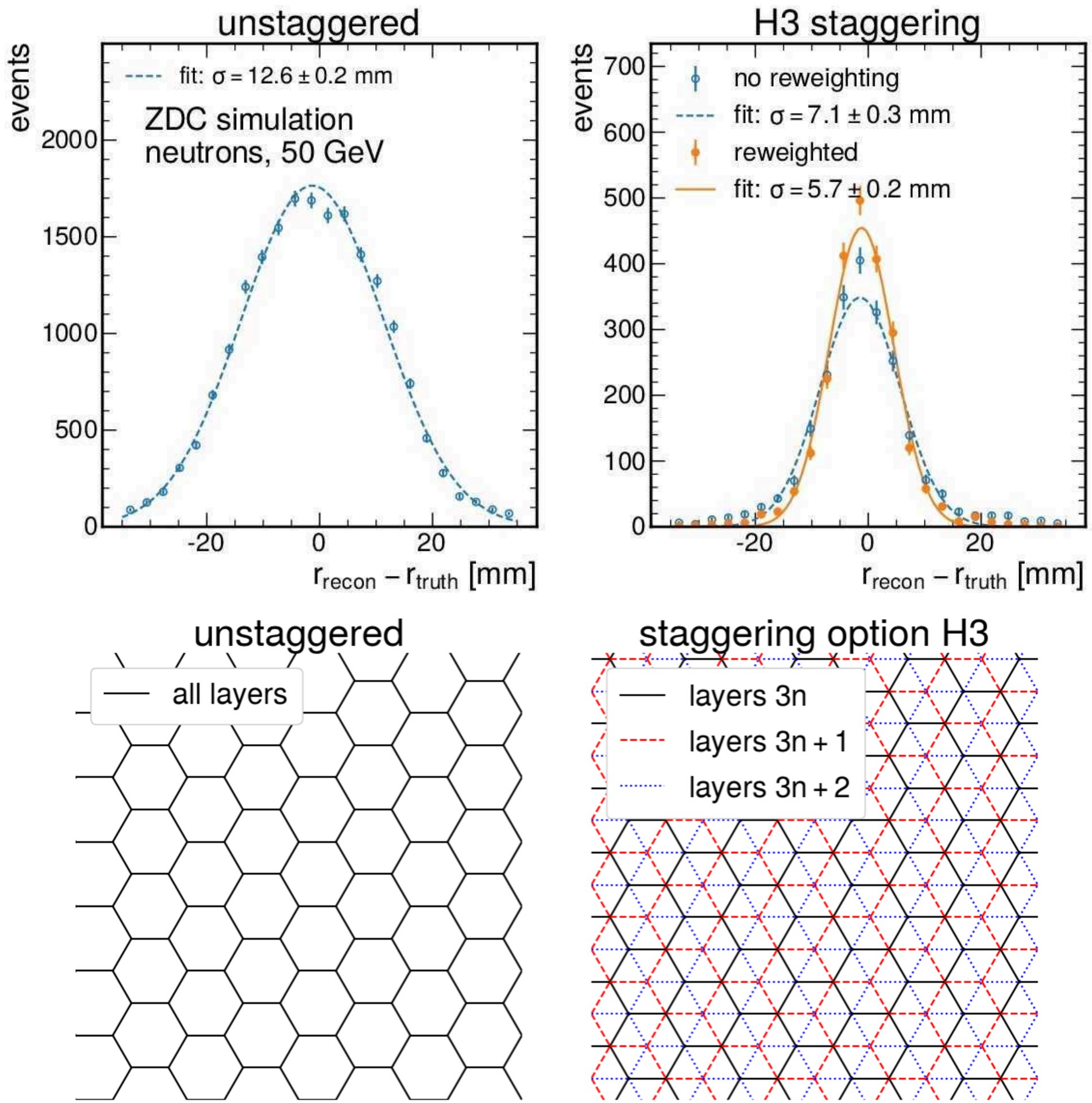
$$\text{using} \;\; w_0 = 4.0$$

- Traditional method of shower position reconstruction uses cell-energy logarithmic weighting
- $\boldsymbol{w}_0$ was picked to be 4.0, but this value was not optimized

Position Resolution with and without staggering

- Using GEANT4 in the DD4HEP framework, we simulated single 50 GeV neutron events

- We observe significant improvements with staggering, even with a simple algorithm



Shower Position Reconstruction with Sub-Cell Weighting

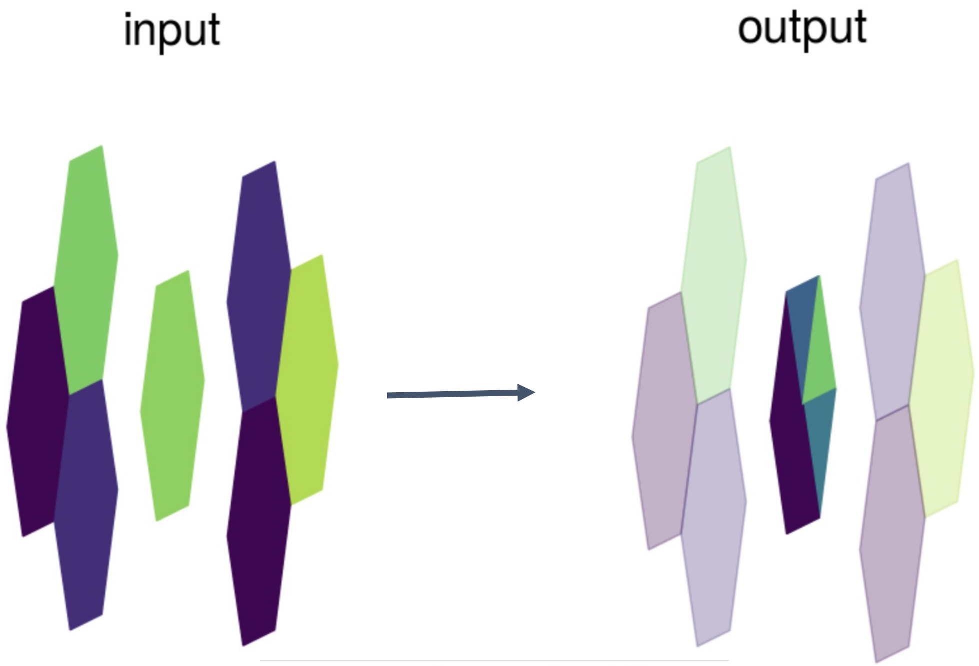
$$\vec{x} = \sum_{i \in \text{subcells}} \vec{x}_i w_i,$$

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

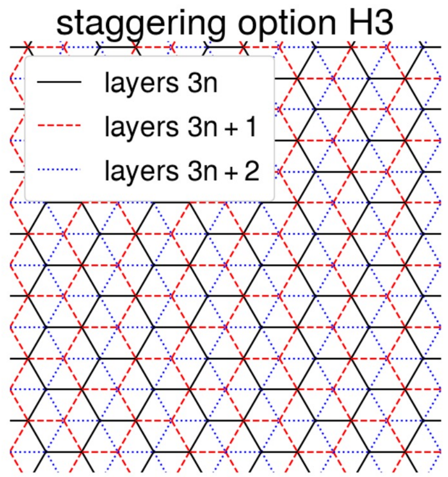
$$\text{using} \;\; w_0 = 5.0$$

$$E_i^{\text{rwt}} = E_{\text{hit}} w_i^{\text{rwt}}$$

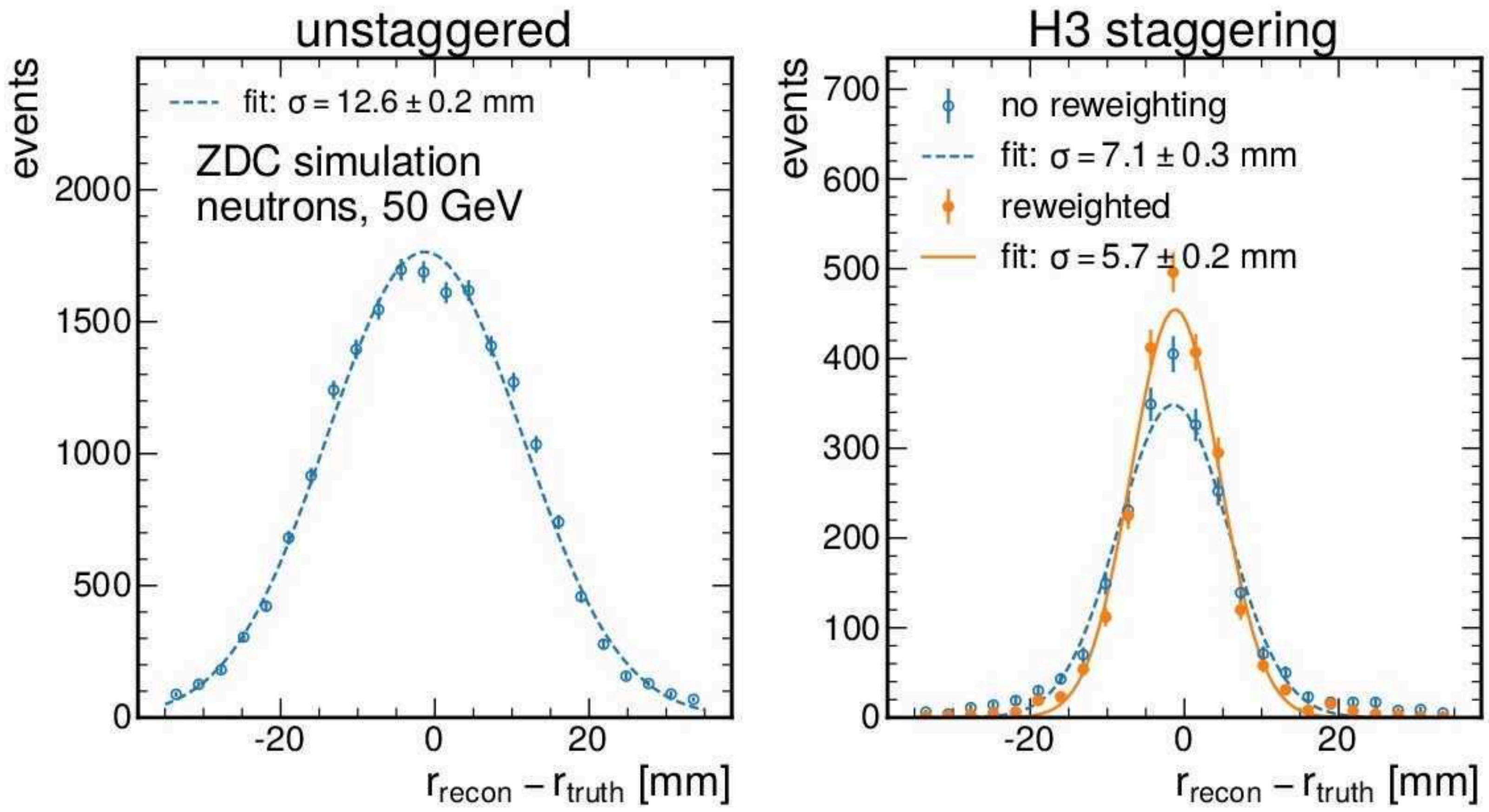
$$w_{\text{rwt}}^i \propto (E_i^{\text{up}} + \epsilon)(E_i^{\text{down}} + \epsilon)$$



- Each cell is divided into "sub-cells", with energy contributions from overlapping cells upstream and downstream



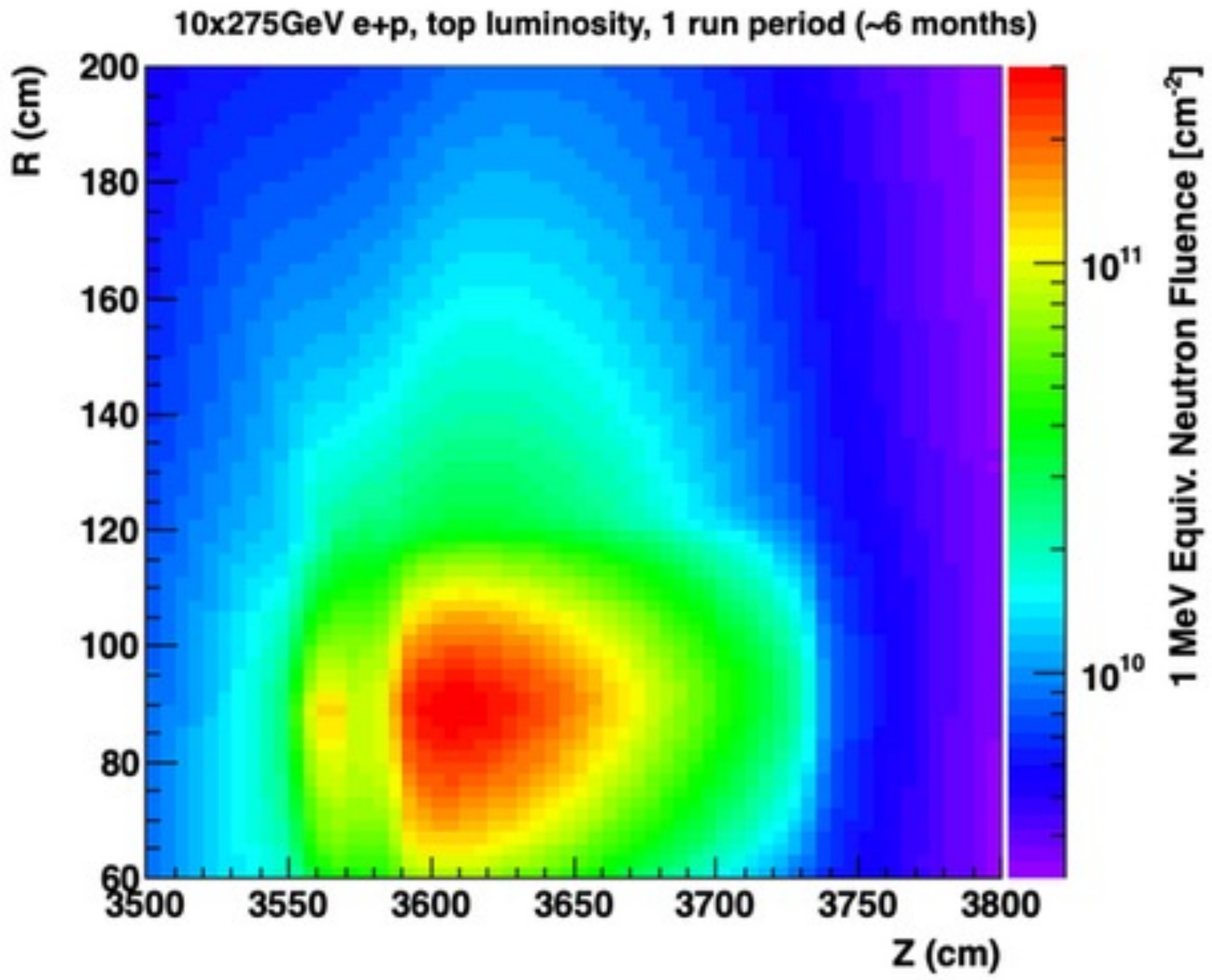
Staggering and sub-cell reweighting improves position resolution by factor of 2!



Neutron Flux Expected in the ZDC Region

- SiPMs can survive this neutron flux for the course of one run
- After each run, SiPMs can be annealed to recover functionality
- Berkeley radiation test incoming!

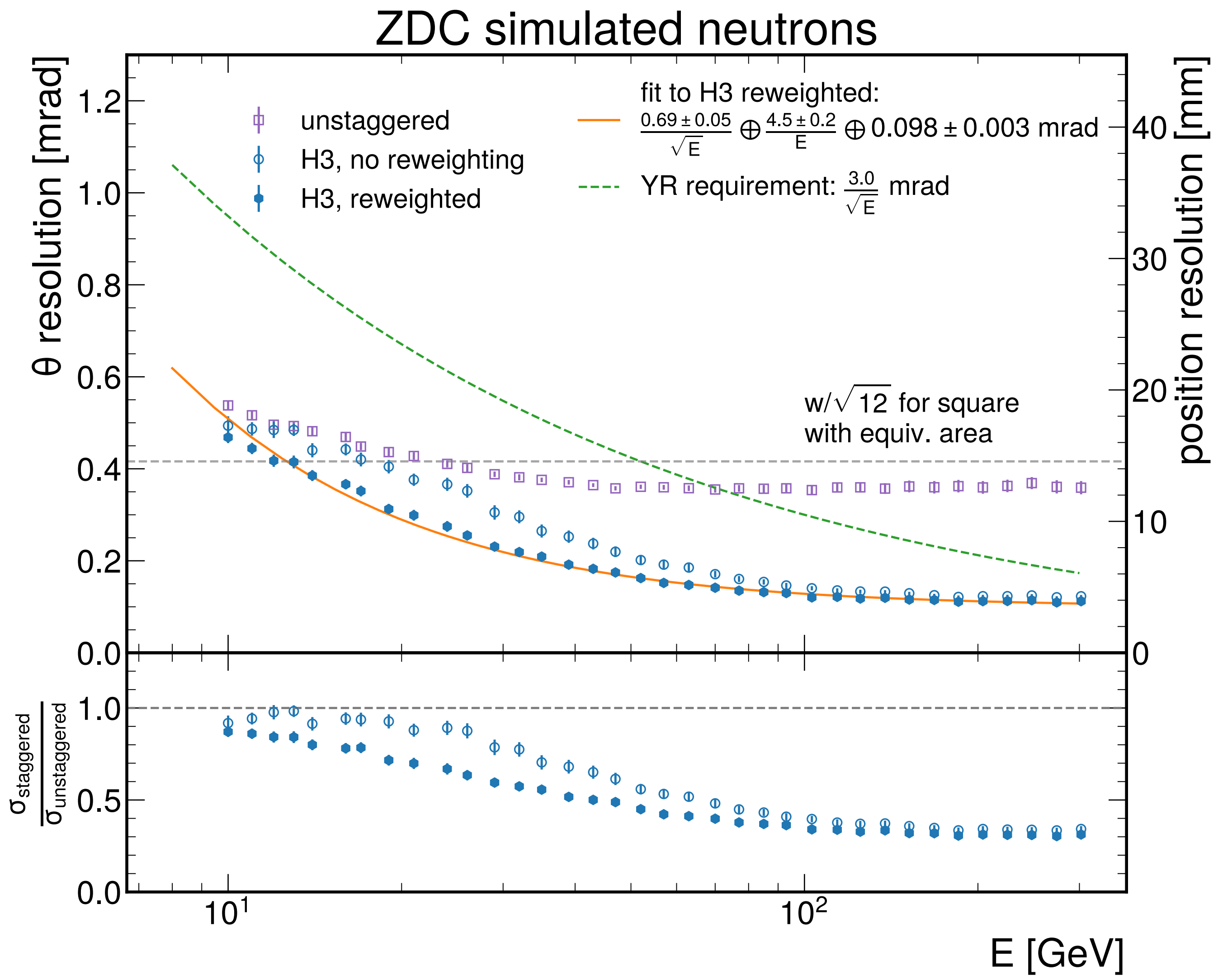
1 MeV equivalent neutron fluence for minimum-bias PYTHIA e+p events at 10x275 GeV at top luminosity for 6 months



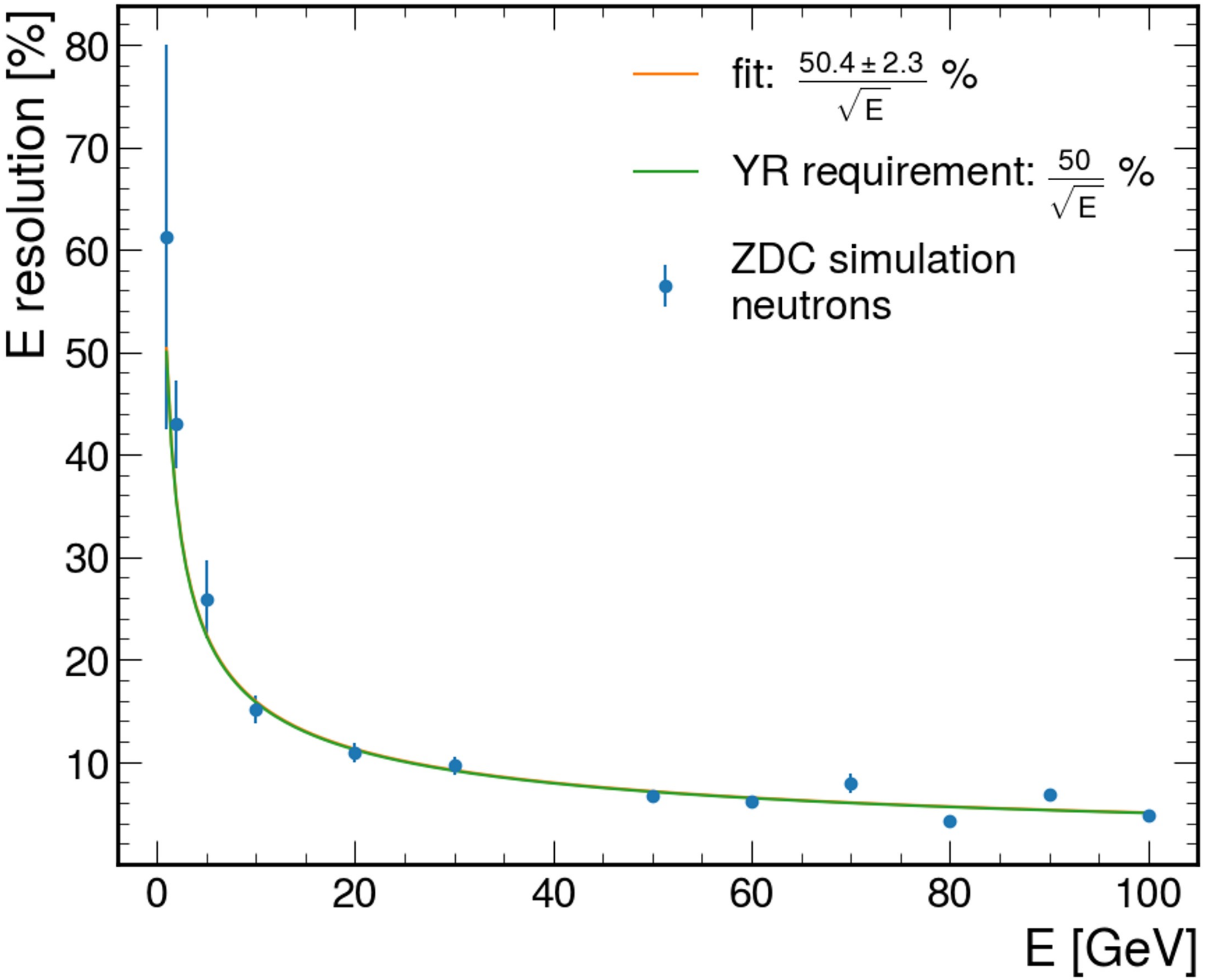
https://wiki.bnl.gov/EPIC/index.php?title=Radiation_Doses

SiPM-on-tile ZDC Position Resolution

- Simulated performance exceeds Yellow Report requirements
- Position reconstruction algorithm can be optimized further
- Sub-cell reweighting improves position resolution by ~10%
- Detector geometry parameters can be tuned to improve performance even further, such as cell size

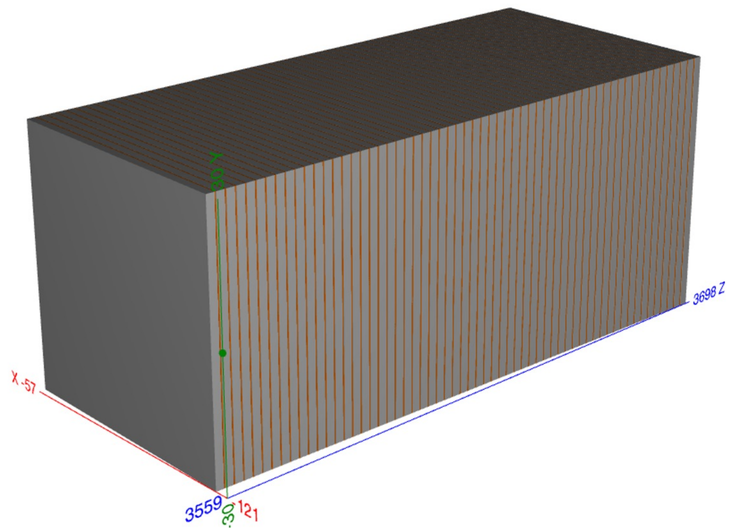


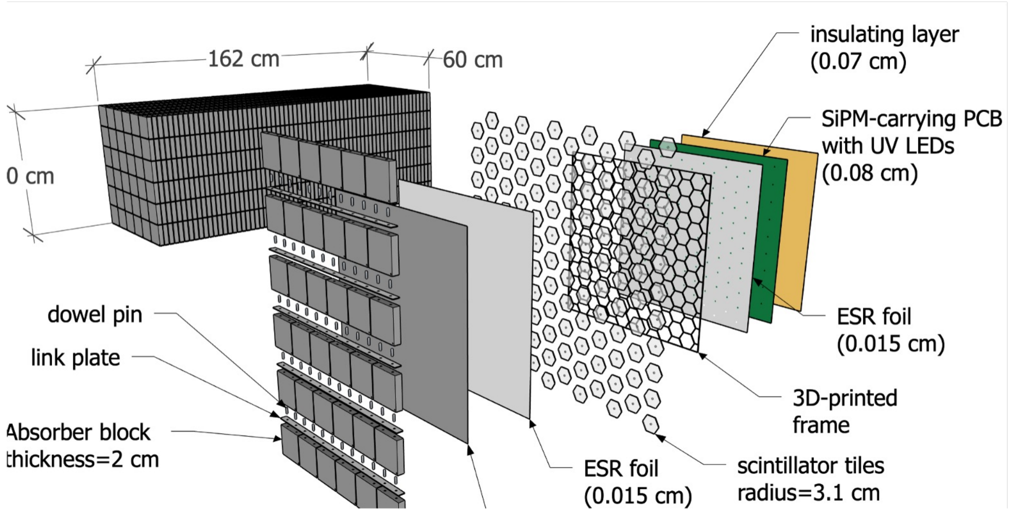
Energy Resolution Before Software Compensation



- No software compensation yields an energy resolution of ~50%/$\sqrt{E}$, meeting the Yellow Report requirement
- Performance can be improved with software reweighting to somewhere between 40-45%/$\sqrt{E}$
- We are carrying out compensation studies similar to what we did with the HCAL Insert

Summary





- An HCAL Insert-style ZDC meets the Yellow Report requirements for both position and energy resolution
- Compensation via reweighting can take advantage of the high granularity design
- Fe absorber blocks can be recycled from STAR, significantly helping cost and construction
- Each channel can be easily calibrated and monitored individually via LEDs
- SiPMs remain accessible for easy maintenance, annealing will help the ZDC survive in the high fluence environment long-term