# Performance of a Zero-Degree Calorimeter for the EIC using Graph Neural Networks

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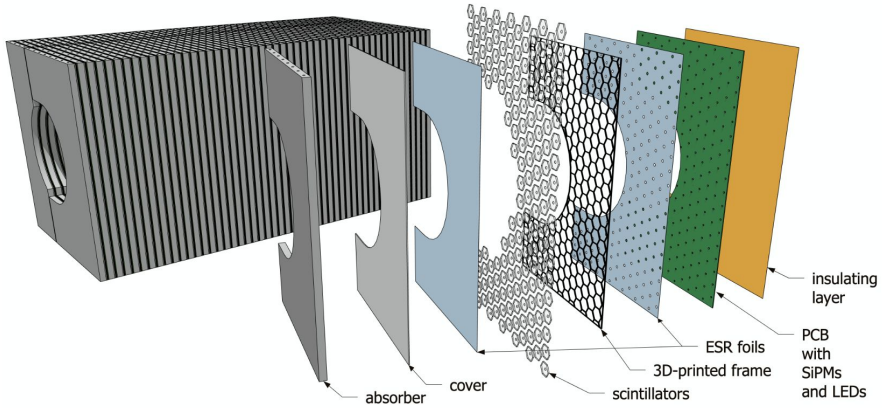
# The Zero-Degree Calorimeter (ZDC)

- SiPM-on-tile design, similar to insert
- Fe/Sc sampling calorimeter
  - 64 layers of 2.0 cm/0.3 cm Fe/Sc (~8 λ)

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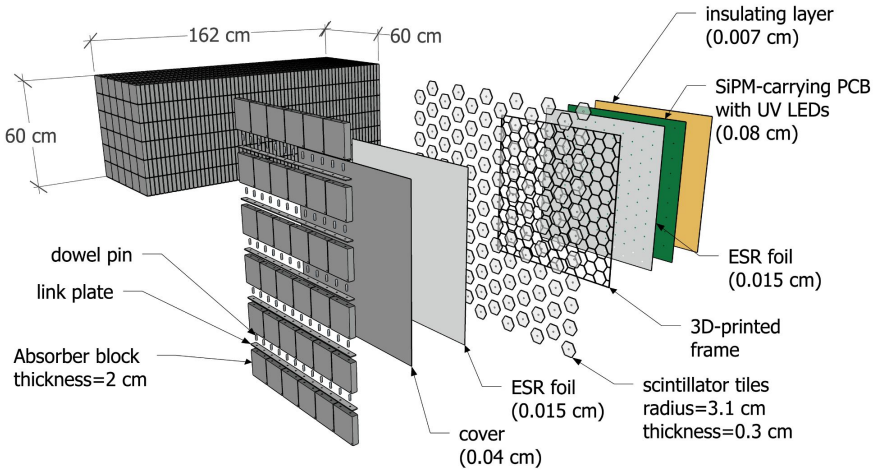
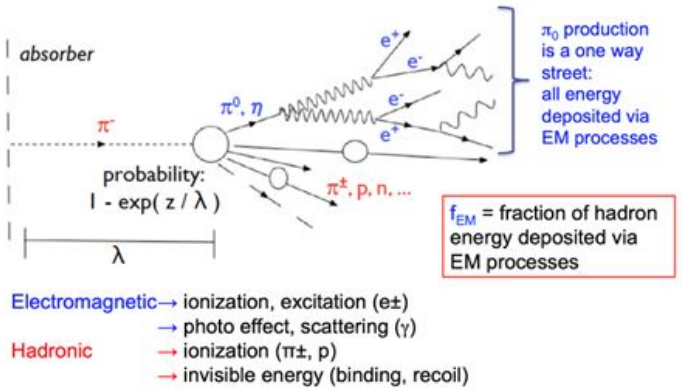
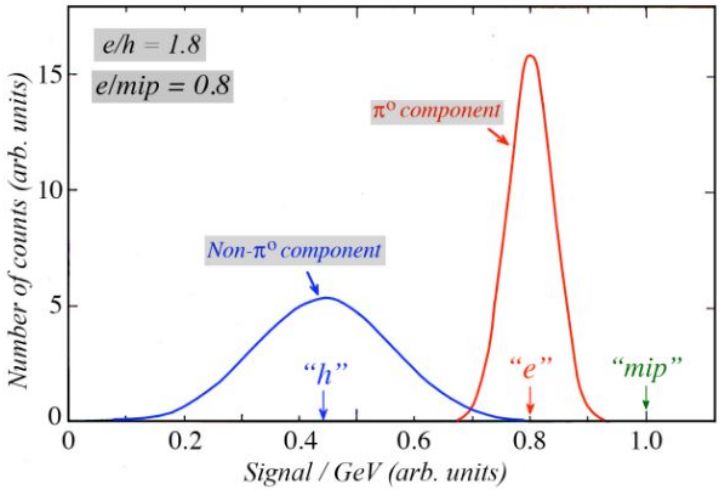



**ZDC**

# Non-compensation in hadronic calorimeters

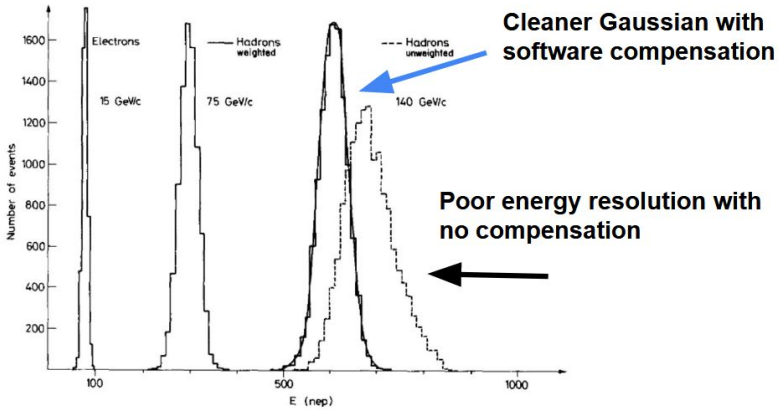
- Hadronic showers have EM and hadronic components
- EM component usually has larger response in calorimeter
  - Leads to deterioration of energy resolution
  - Resolution - How well signals can be separated from each other
- One possible solution: Using specific absorbers and scintillators
  - Imposes strict requirements on material



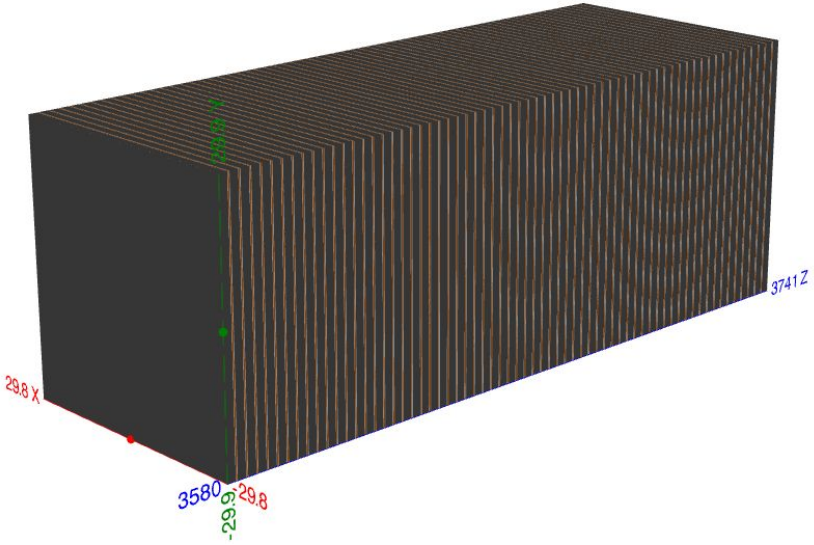
# Methods to address non-compensation

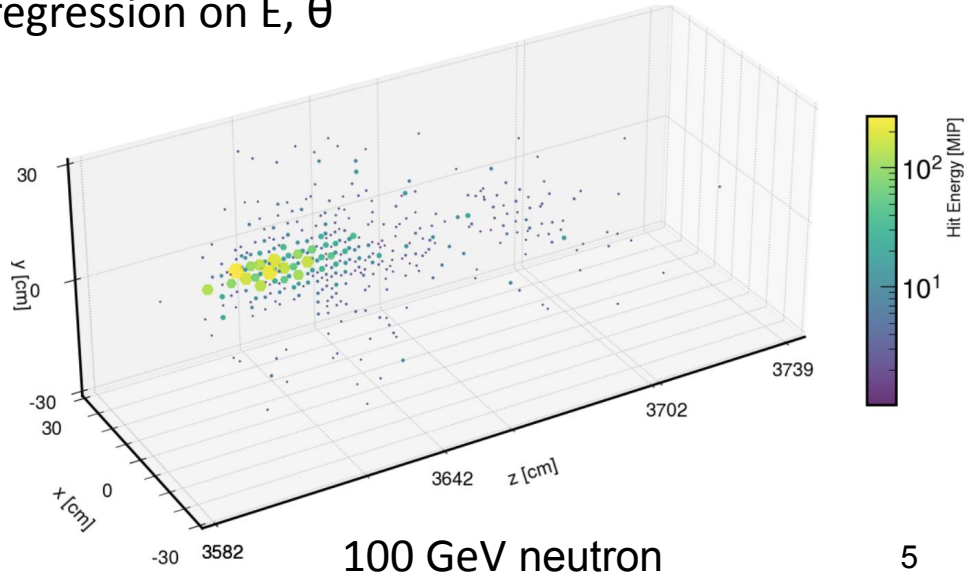
- Assigning weights to EM and hadronic energies in cells, event-by-event
  - Example (CERN, 1980): $E_{cell,weighted} = E_{cell}(1 - \frac{.03}{\sqrt{E_{total}}} \cdot E_{cell})$
  - Example (CALICE, 2012): $E \propto \sum_i E_{HCAL,i}\, \omega_i$, $\omega_i$ is energy density dependent weight
- AI/ML-based reconstruction
  - Seen in ATLAS
- **These methods are employed & optimized after detector construction and data-taking**



# Simulation and Procedure

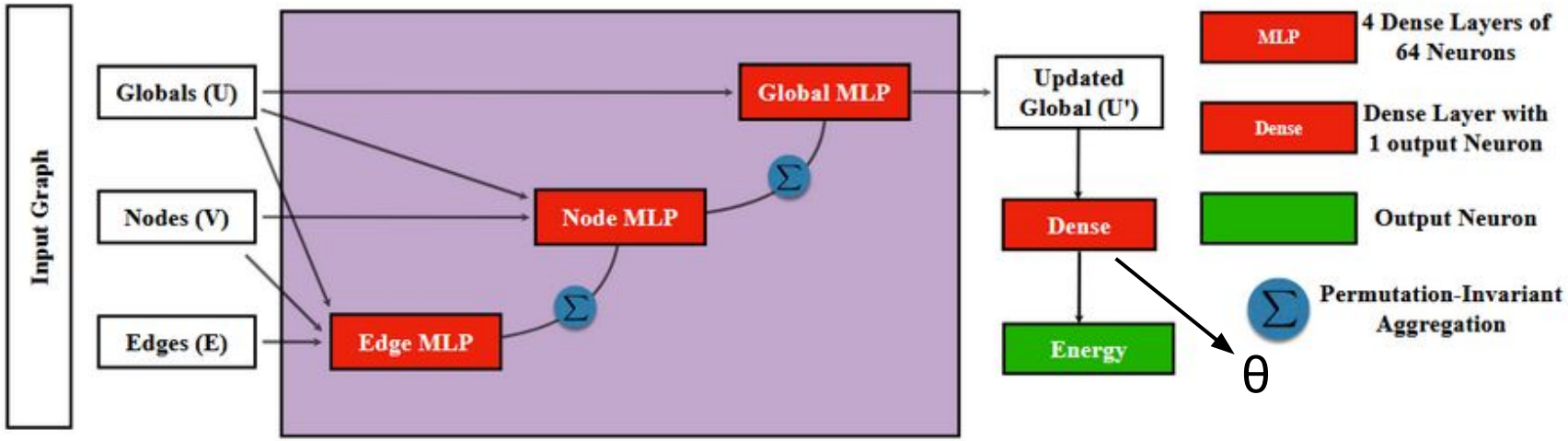
- Goal: To measure angle and energy of neutrons at small angles, η>6
- Standalone DD4hep simulation of ZDC
- Investigate energy and angular resolutions in single neutron events
  - 10 < E < 300 GeV, 0 < θ < 0.5
- Employ graph neural networks (GNNs) for regression on E, θ



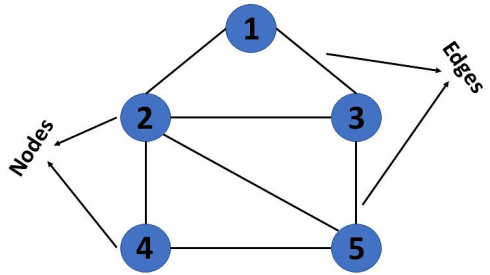




100 GeV neutron

# Model Schematic

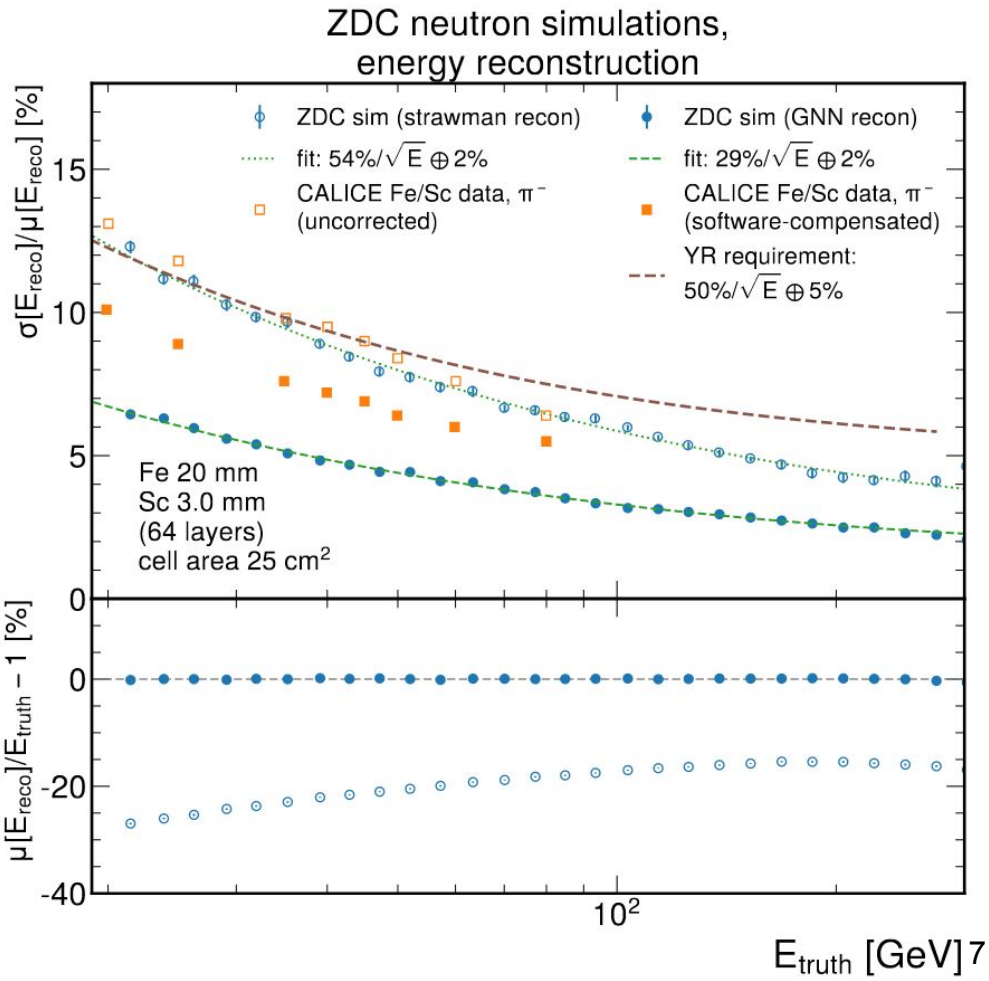



- Model outputs energy and θ of incident particle
- Graph structure:
  - Nodes - Cell (E, x, y, z)
  - Edges - (E, x, y, z) of ten neighboring cells



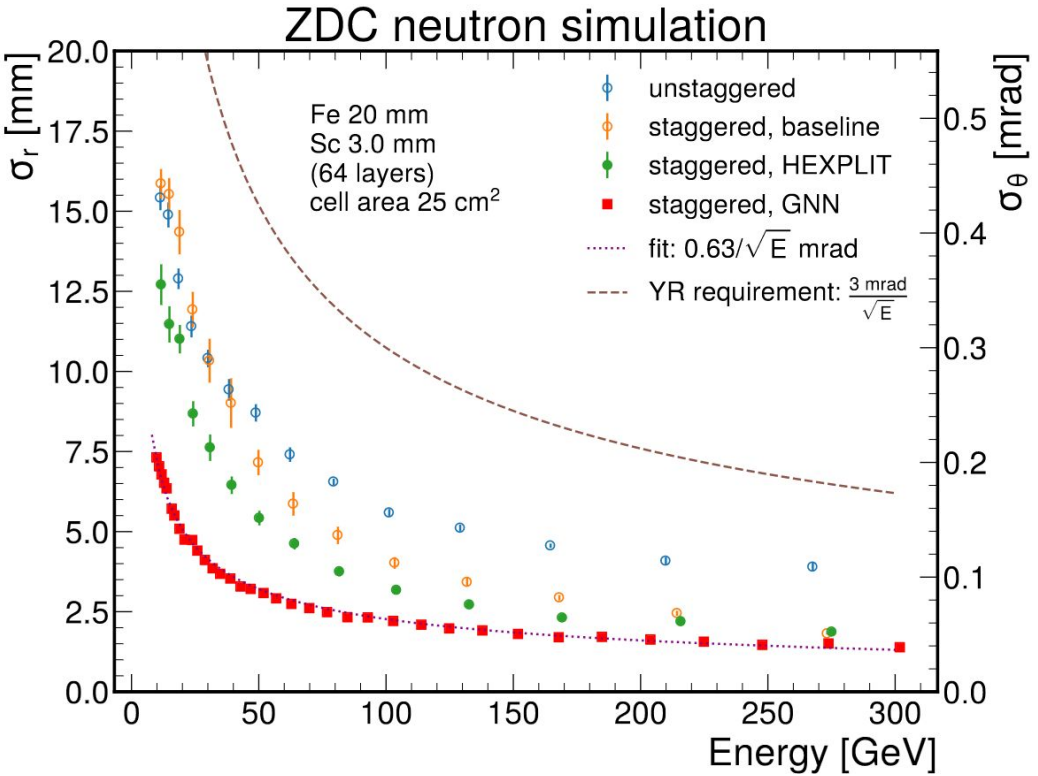
# Energy Resolution

- GNN improves energy resolution compared to strawman
  - Strawman is simple sum of cell energies
- Outperforms CALICE software compensation results
  - JINST **7** (2012) P09017
  - CALICE SC: ~45%/√E



# Angular Resolution

- Defined as the sigma of a Gaussian fit of $\Delta r = r_{reco} - r_{truth}$
- See improvements with staggered design
- HEXPLIT & GNNs improve it even further
  - HEXPLIT is a reweighting procedure detailed in [NIM A **1060** (2024) 169044]



# Takeaways

- Can use machine learning to improve the performance of the ZDC
- Gives insight into how well we can measure certain physics processes
  - Example: $\Lambda^0 \rightarrow n+\pi^0 \rightarrow n+\gamma+\gamma$ requires accurate neutron angle reconstruction
- By doing this during the design phase, we can optimize the detector design to best measure the relevant physics processes

**Thanks!**