Initial Simulations and Machine Learning for the EPIC ZDC

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Deven is our Science Undergraduate Laboratory Internship (SULI) student; I am presenting his work!

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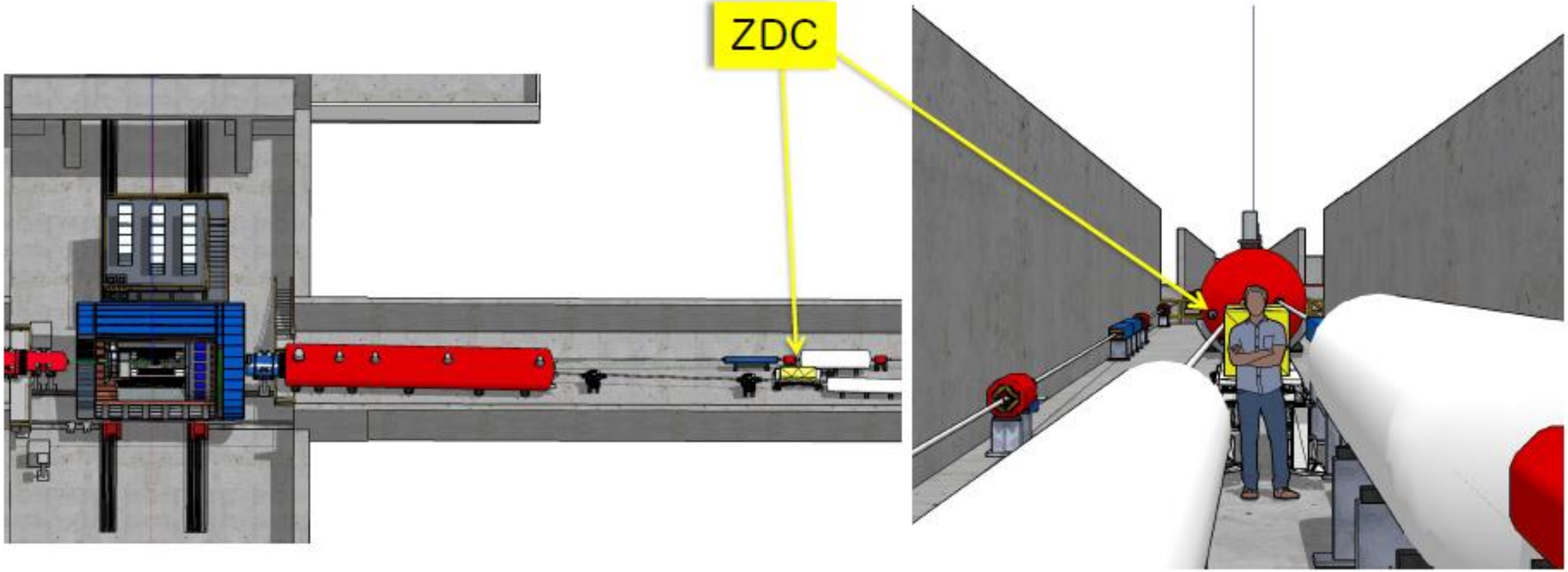
Zero-Degree Calorimeter

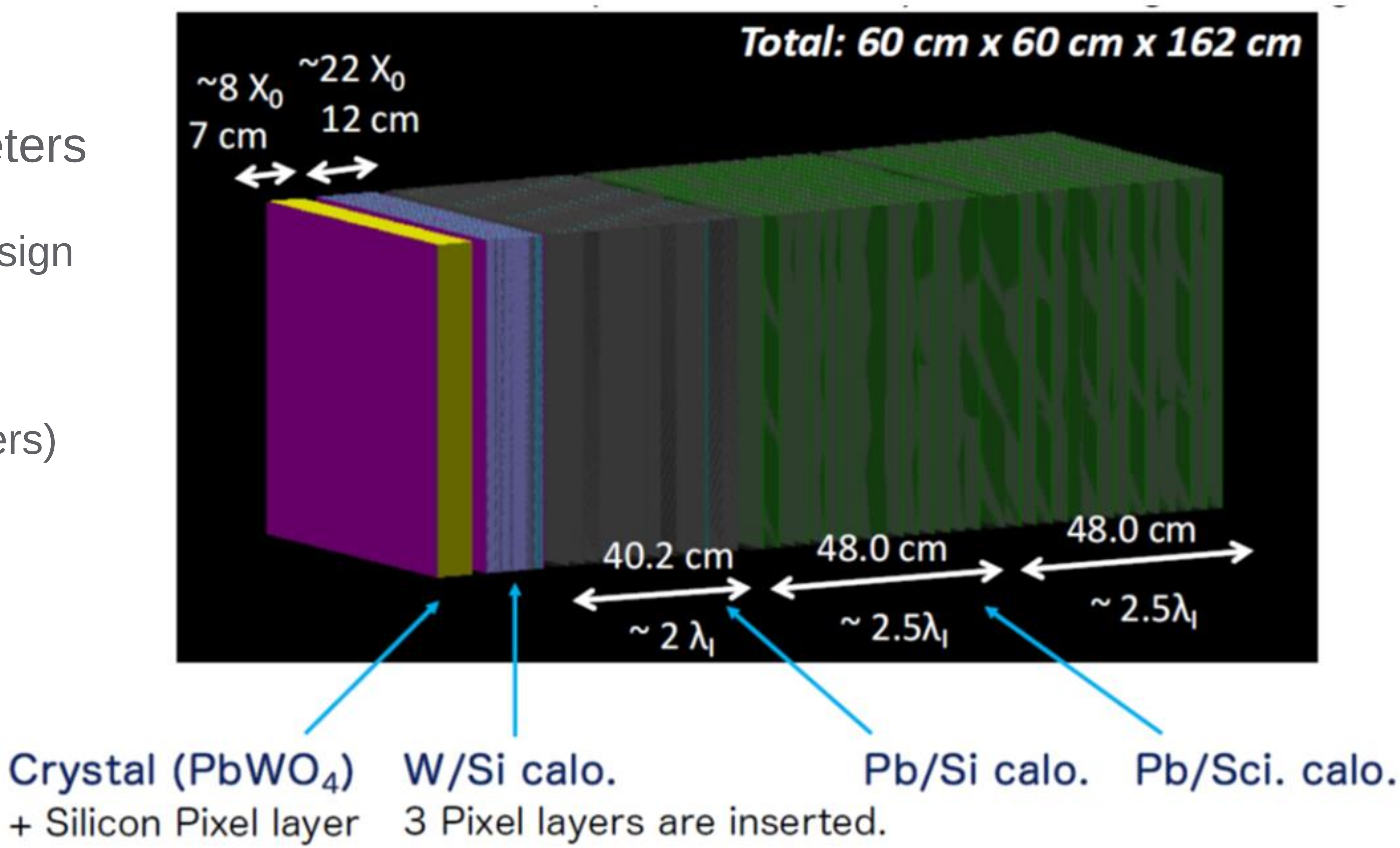
- Responsible for reconstructing photons and neutrons in the far-forward region
- Located 30 m from the interaction point



Current ZDC Design

- Stacked EM and hadronic calorimeters
  - Based on the ALICE FoCal design

- 67 layers:
  - Si tracker (3 layers)
  - PbWO4 crystals
  - 22 W/Si
  - 12 Pb/Si
  - 30 Pb/scint



3cm x 3cm x 7cm

1cm x 1cm pads / 3mm x 3mm pixels

1cm x 1cm

10cm x 10cm

Initial ZDC Simulations Using DD4hep

- Initial studies have focused on high-energy neutrons as test particles
  - 10 / 50 / 100 / 200 GeV neutrons, single particle trajectories along the detector z-axis
- All simulations performed utilizing the EIC EPIC framework

- **Goals**
  - Identify and correct issues in the current dd4hep implementation
  - Straightforward validation of physics reactions
  - First pass at detector response
  - Initial investigations of machine learning for detector response improvements

- **These results are preliminary**
  - Focus is on debugging the simulation code and starting to build ML frameworks, not evaluate detector response (yet)

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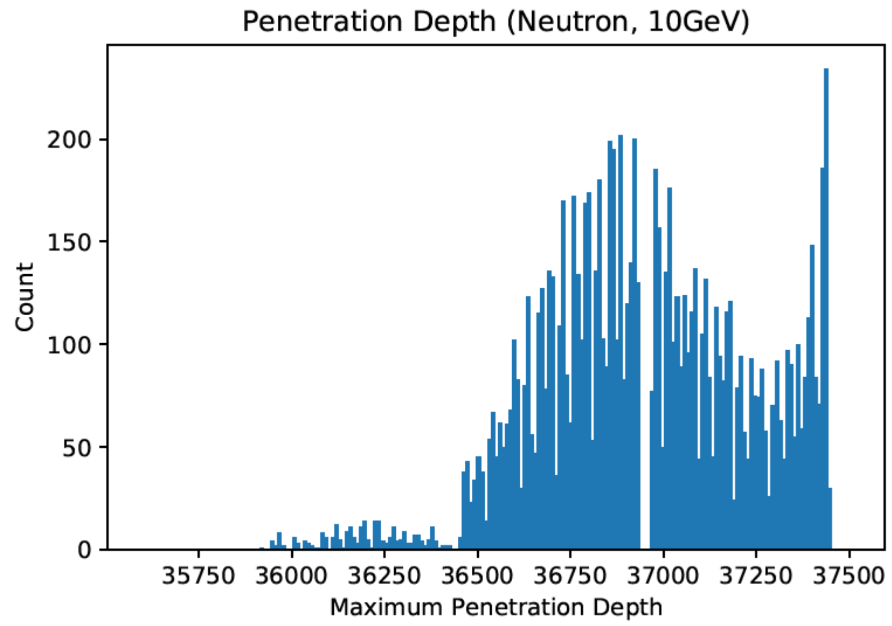
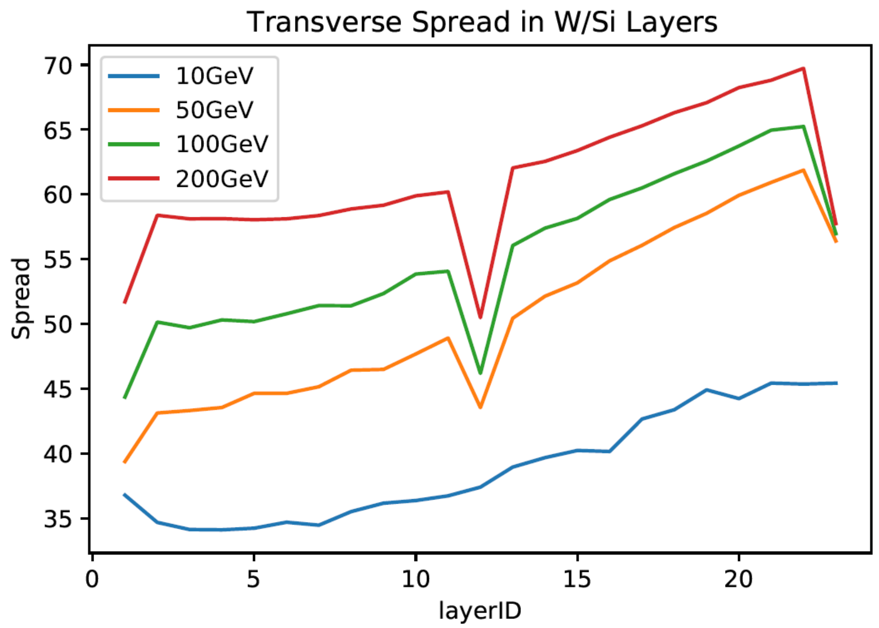
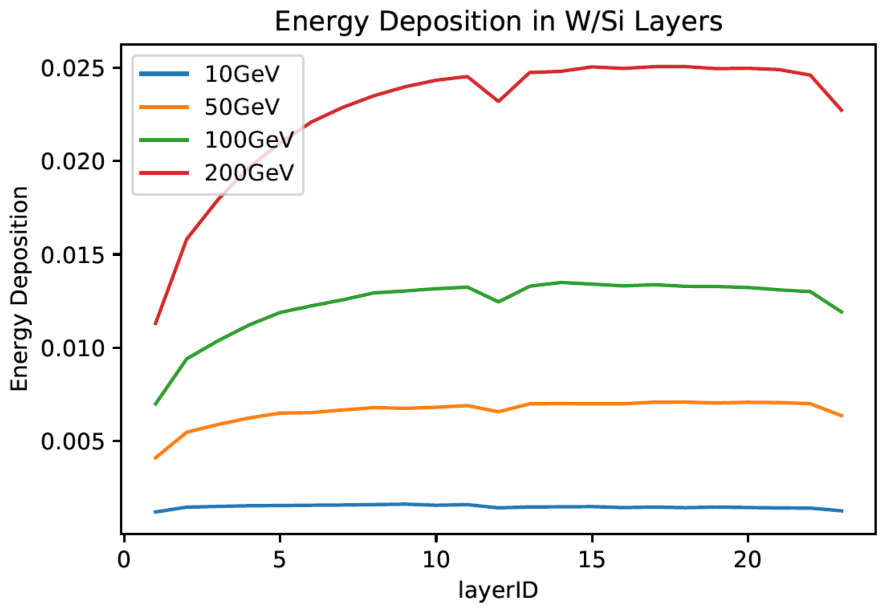
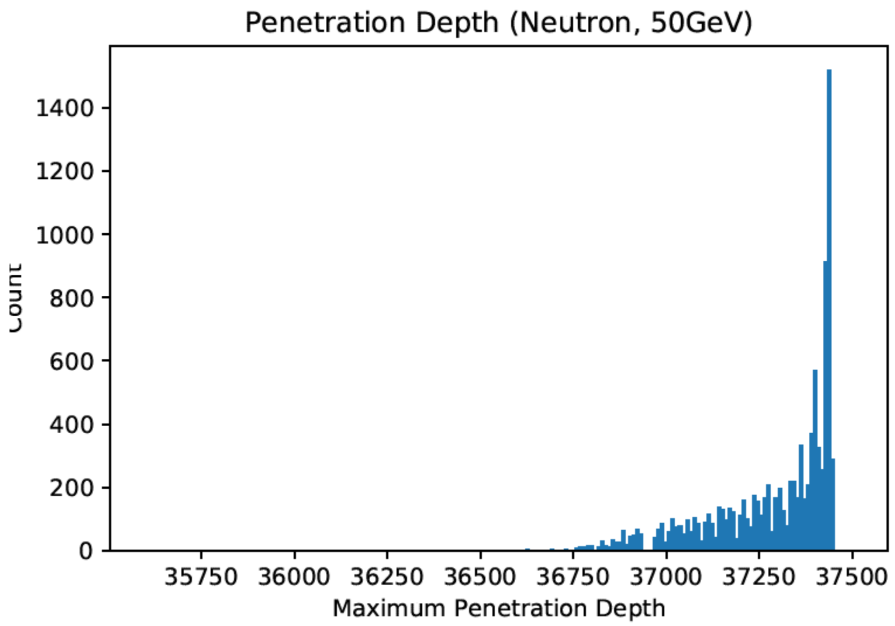
Validation of Basic Physics Processes









Max transverse spread should roughly scale with log(E)

Some potential issues were seen between the pad and pixel layers of the W/Si calorimeter – worked on this with Shima Shimizu (RIKEN) and the DD4hep team, now understood

Also committed fixes for some alignment issues:

https://github.com/eic/ip6/search?q=author%3Ademisra&type=commits

Calibrating Detector Response: Linear Regression

- Standard calorimeter energy resolution function:

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} + \frac{b}{E} + c$$

where *a* = stochastic term, *b* = noise, *c* = systematics and other energy-independent contributions

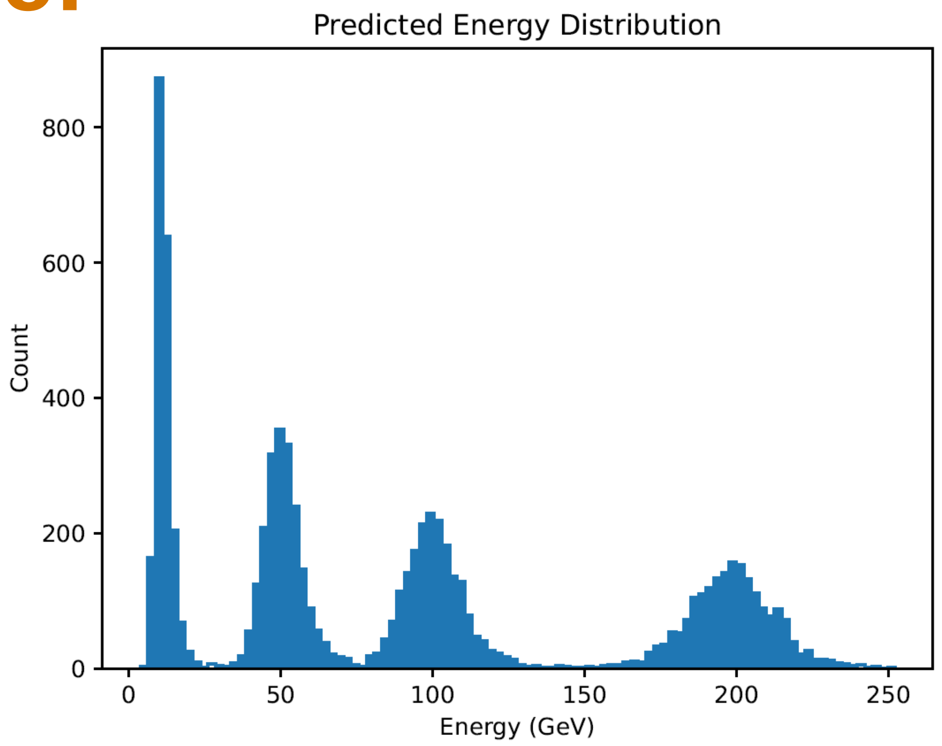
  - For these initial simulations we will only evaluate *a*

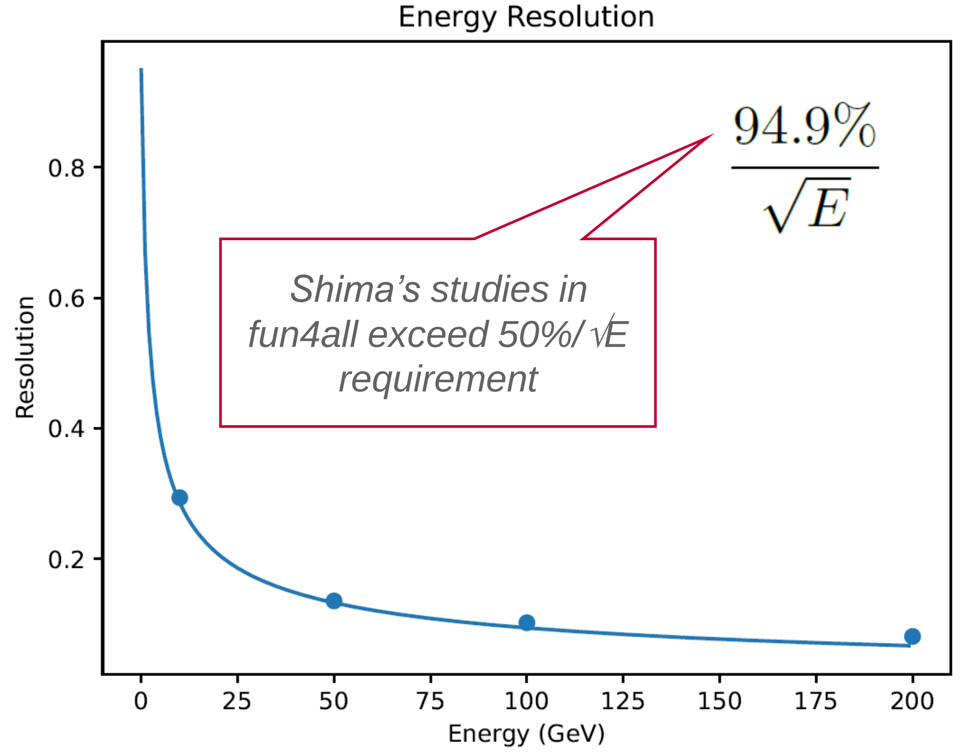
- A straightforward linear regression uses the total energy deposited in each type of layer as input

$$E_{\text{rec.}} = c_1 E_{\text{SiPix}} + c_2 E_{\text{PbWO4}} + c_3 E_{\text{WSi}} + c_4 E_{\text{PbSi}} + c_5 E_{\text{PbScint}} + \text{const.}$$

Utilized a single layer in PyTorch to perform the regression:

$$c_1 = 2.1829 \quad c_2 = 1.1574 \quad c_3 = 100.5793$$
$$c_4 = 401.0872 \quad c_5 = 60.2897 \quad \text{const.} = 2.8002$$

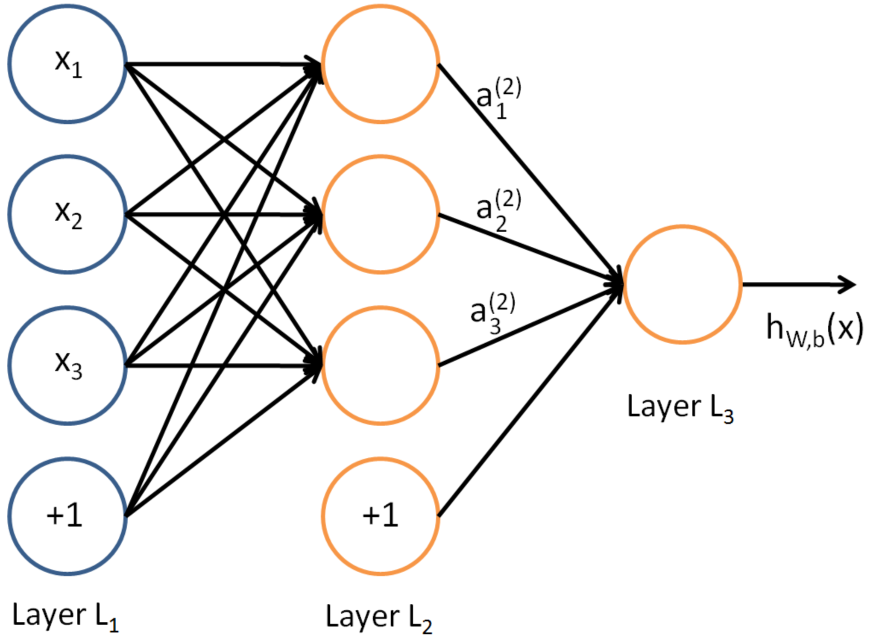




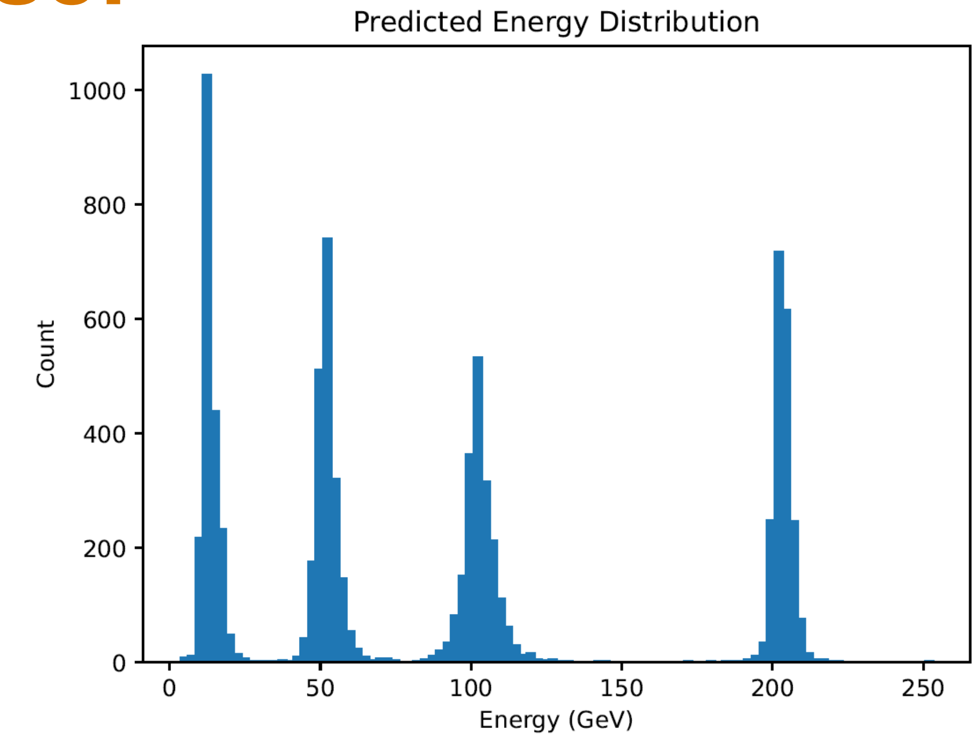
Calibrating Detector Response: Multilayer Perceptron (MLP)

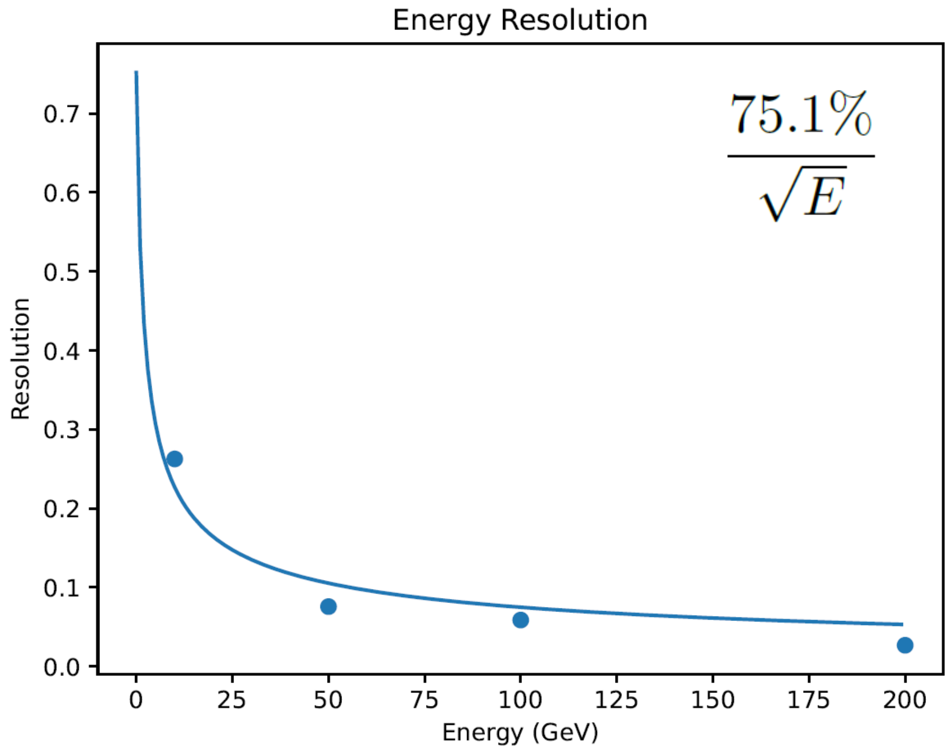
- Taking advantage of some of the segmentation of the system – 20x20 array of PbWO4 crystals plus separate layers instead of total energy per section of the calorimeter
- we can use a simple machine learning model with a single hidden layer

Input energy from crystals (usually just 1) + 64 layers



Source: deeplearning.stanford.edu

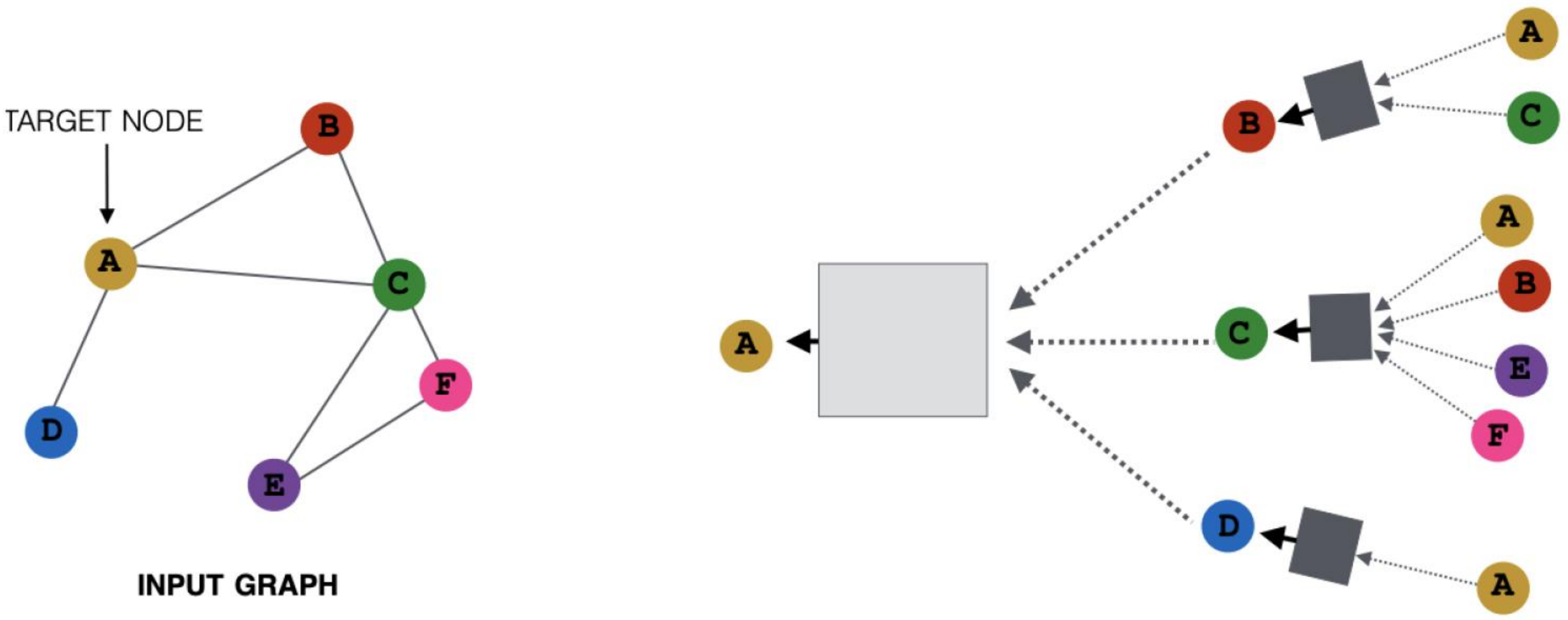




Next Steps in Calibration Detector Response: Graph Convolutional Network

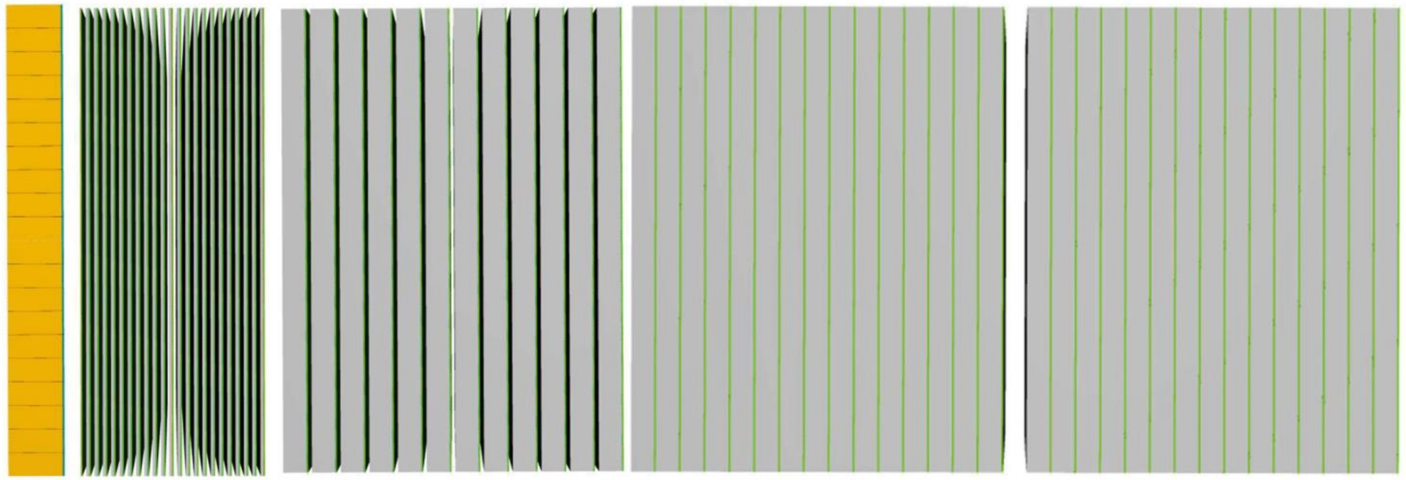
- Further improvement should be possible when the segmentation of all layers is included in the ML model – but ZDC layers have different pixel/pad sizes
  - Standard ML toolboxes are targeted for data sequences and/or grids

  → Graph convolutional networks generically store relationships between nodes



Source: cs224w.stanford.edu

Conclusions



- Initial work is underway to evaluate the ZDC implementation in DD4hep

- PNNL is also starting to investigate machine learning to improve detector response and event ID
  - Initial effort to develop ML models of increasing complexity:
    energy per detector type → energy per layer → energy per cell

- Thank you to Michael Murray, Charles Hyde, and Shima Shimizu for the crash-course in the ZDC and the EIC environment!

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Thank you