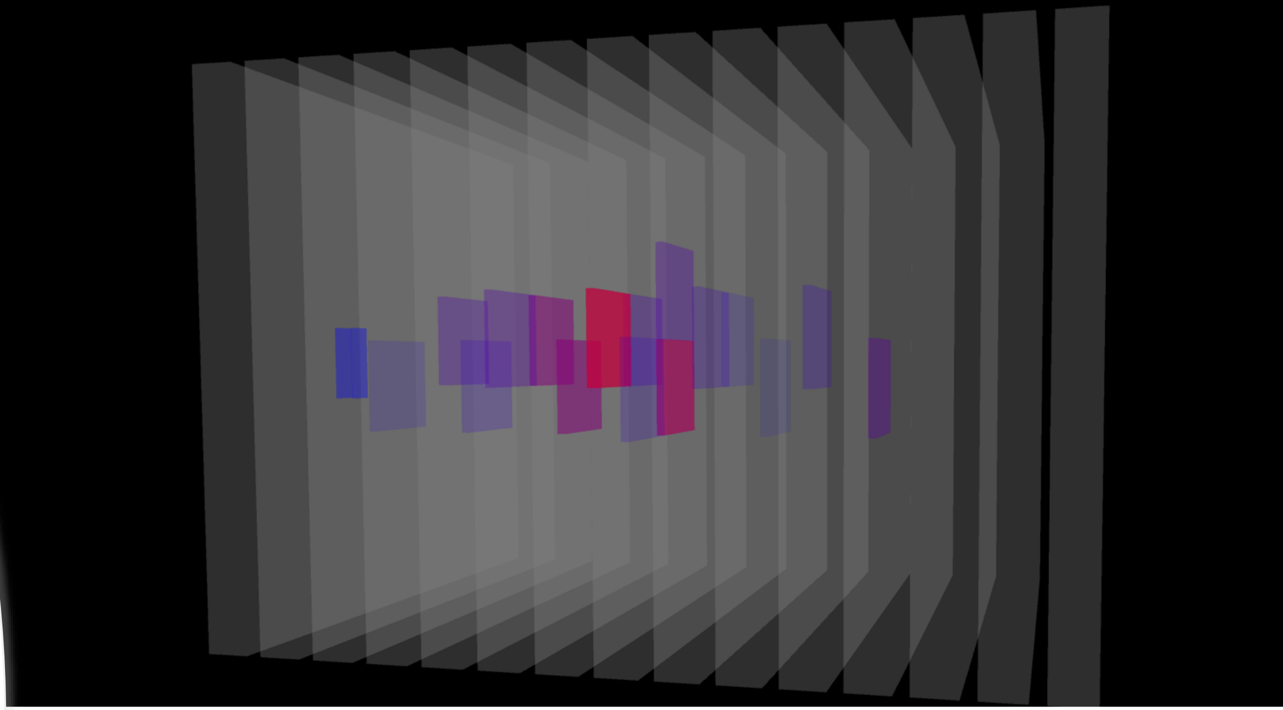
Beam Test of a SiPM-on-Tile ZDC Prototype with 5.3 GeV Positrons at Jefferson Laboratory

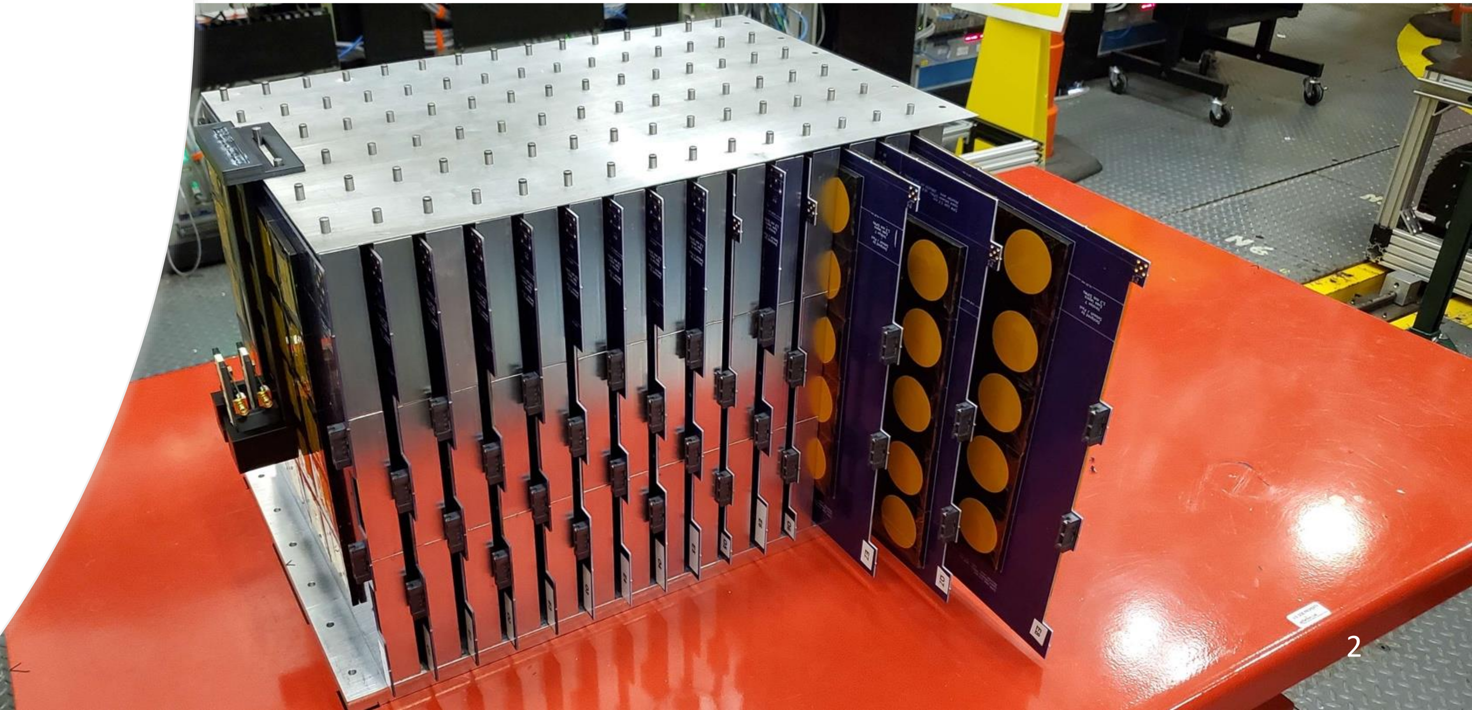
Sean Preins

2026 EIC Early Career (EC) Workshop

Outline

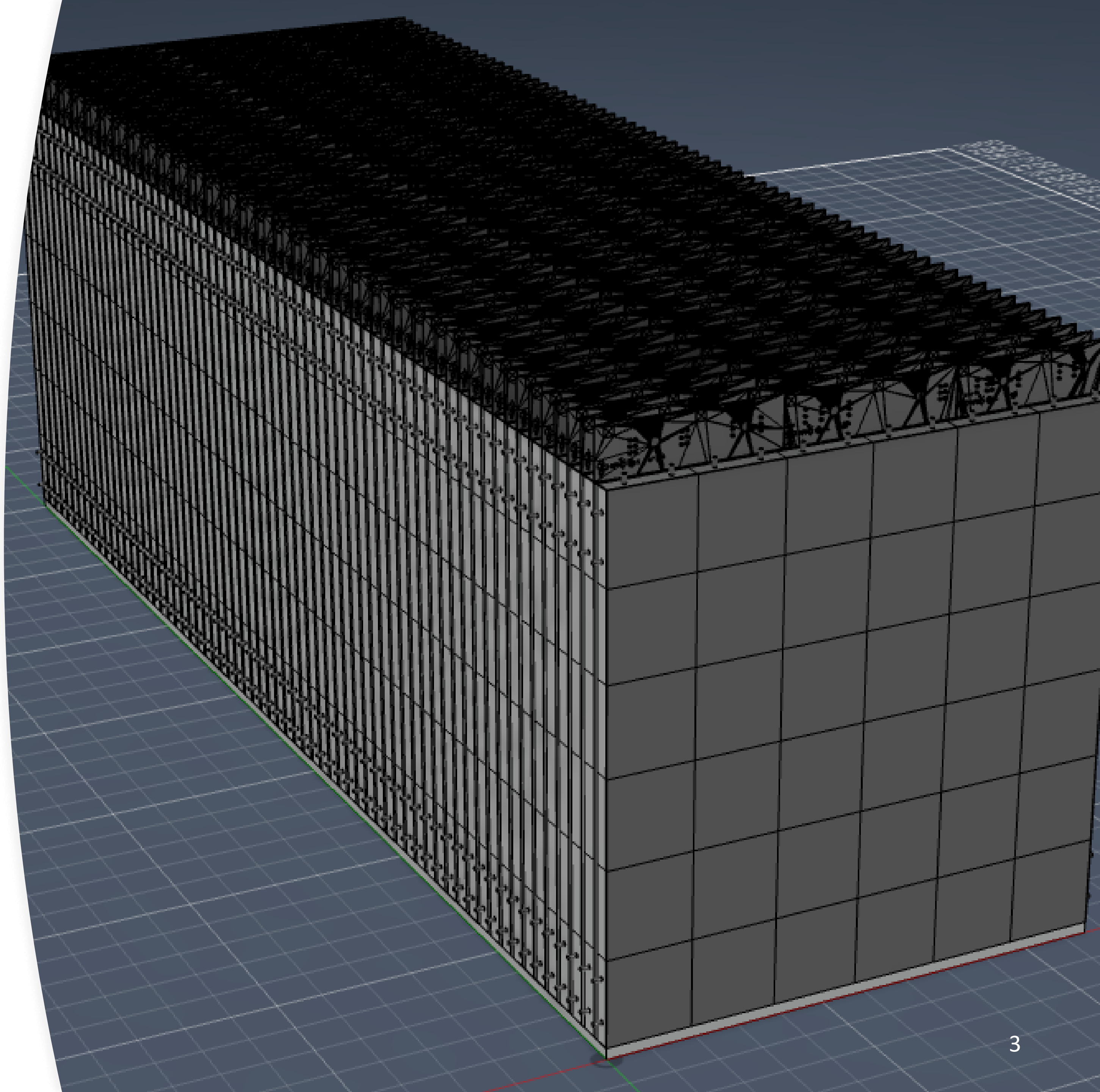
- ePIC Zero Degree Calorimeter
- 15-layer SiPM-on-tile prototype
- Jefferson Lab beam test
- Event reconstruction and calibration
- Comparison with simulation
    - Position resolution
    - Shower shapes
    - Energy resolution
- Impact on the final ZDC design





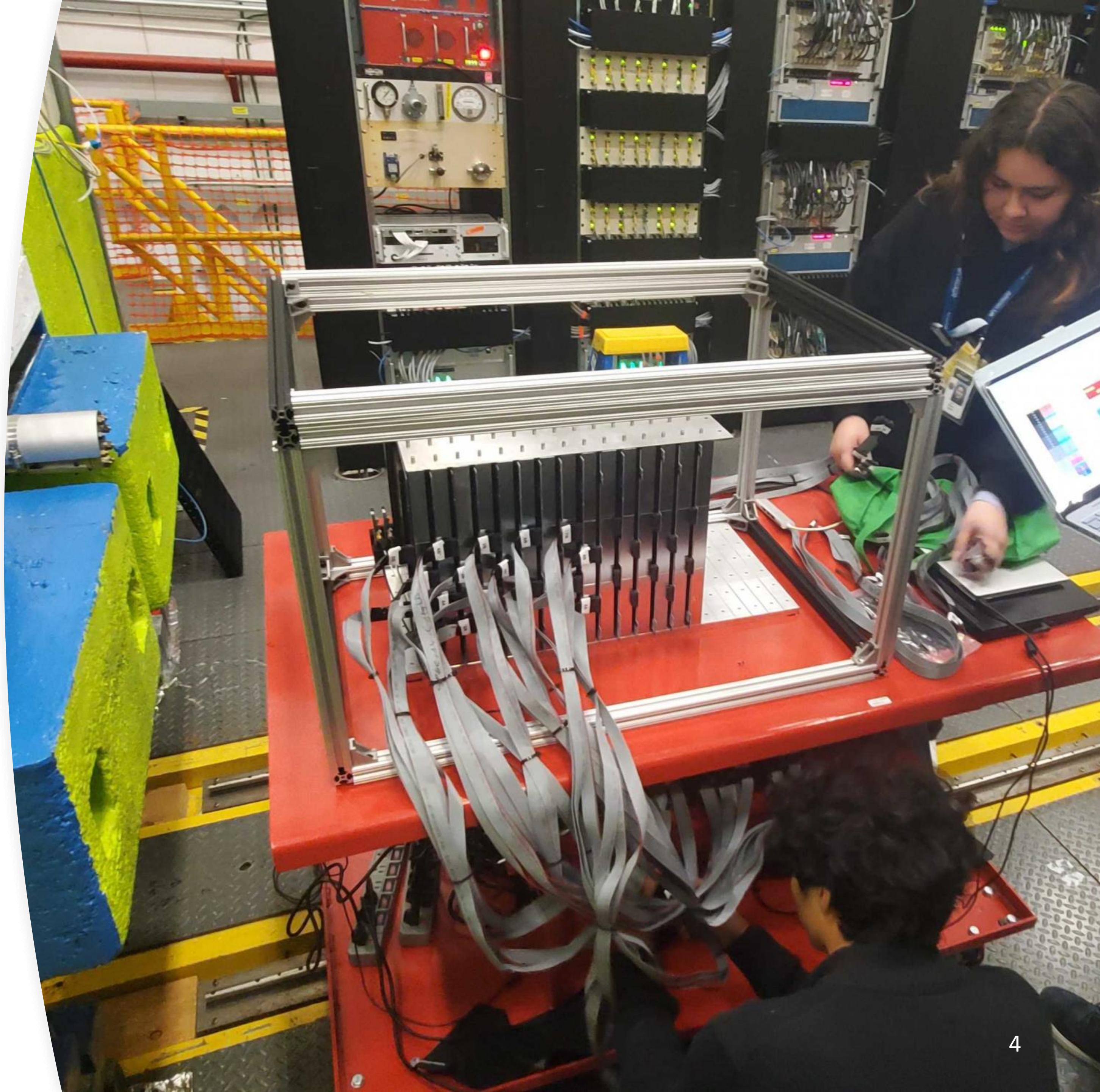
ZDC HCAL Design Overview

- 64-layer SiPM-on-tile iron sampling calorimeter
- ASIC-away-of-SiPM readout architecture
- 1.3 mm SiPMs with 48.8 × 48.8 mm scintillator tiles
- 8096 channels (121/132 per layer)
- Alternate layers shifted by half a cell
- Removable layers for SiPM annealing



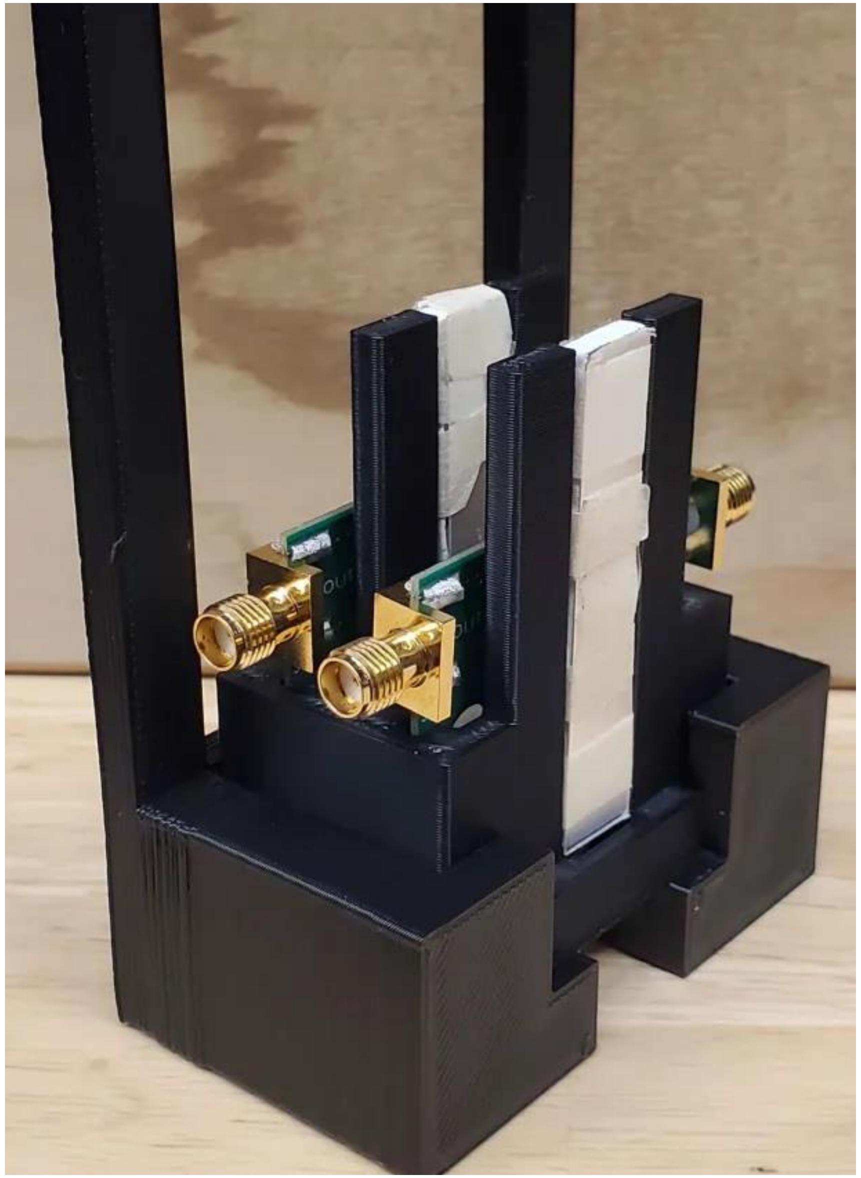
Prototype Overview

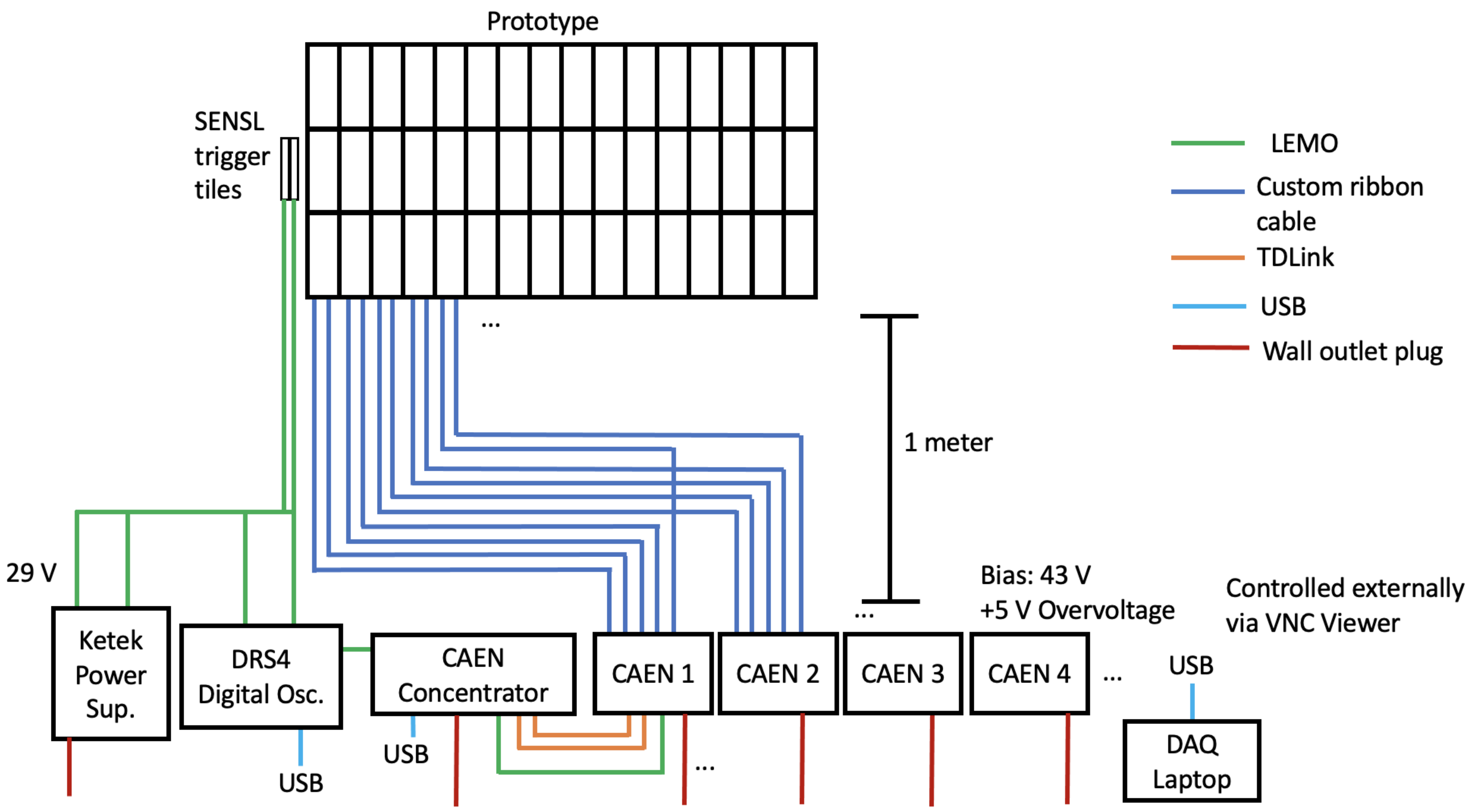
- 15-layer SiPM-on-tile prototype
- Installed at Jefferson Lab Hall D Pair Spectrometer (April 2025)
- 5×5 tiles per layer with staggered geometry
- 370 instrumented channels (~10% of final detector)
- 5.3 GeV positron beam
- 6.6 million events, 98.7% channels operational



DAQ System

- Six CAEN DT5202 digitizers
- DT5215 concentrator board
- DRS4 trigger readout
- Two scintillator trigger counters
- 3D-printed trigger mount




Prototype
SENSL
trigger
tiles
...
LEMO
Custom ribbon
cable
TDLink
USB
Wall outlet plug
1 meter
29 V
Bias: 43 V
+5 V Overvoltage
Controlled externally
via VNC Viewer
...
Ketek
Power
Sup.
DRS4
Digital Osc.
CAEN
Concentrator
CAEN 1
CAEN 2
CAEN 3
CAEN 4
...
USB
DAQ
Laptop
USB
USB
...

Beam Test Goals

- Measure energy response
- Study shower development
- Measure position resolution
- Compare with GEANT4 simulation
- Guide the final ZDC design

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Beam Test of a SiPM-on-Tile ZDC Prototype with 5.3 GeV Positrons at Jefferson Laboratory

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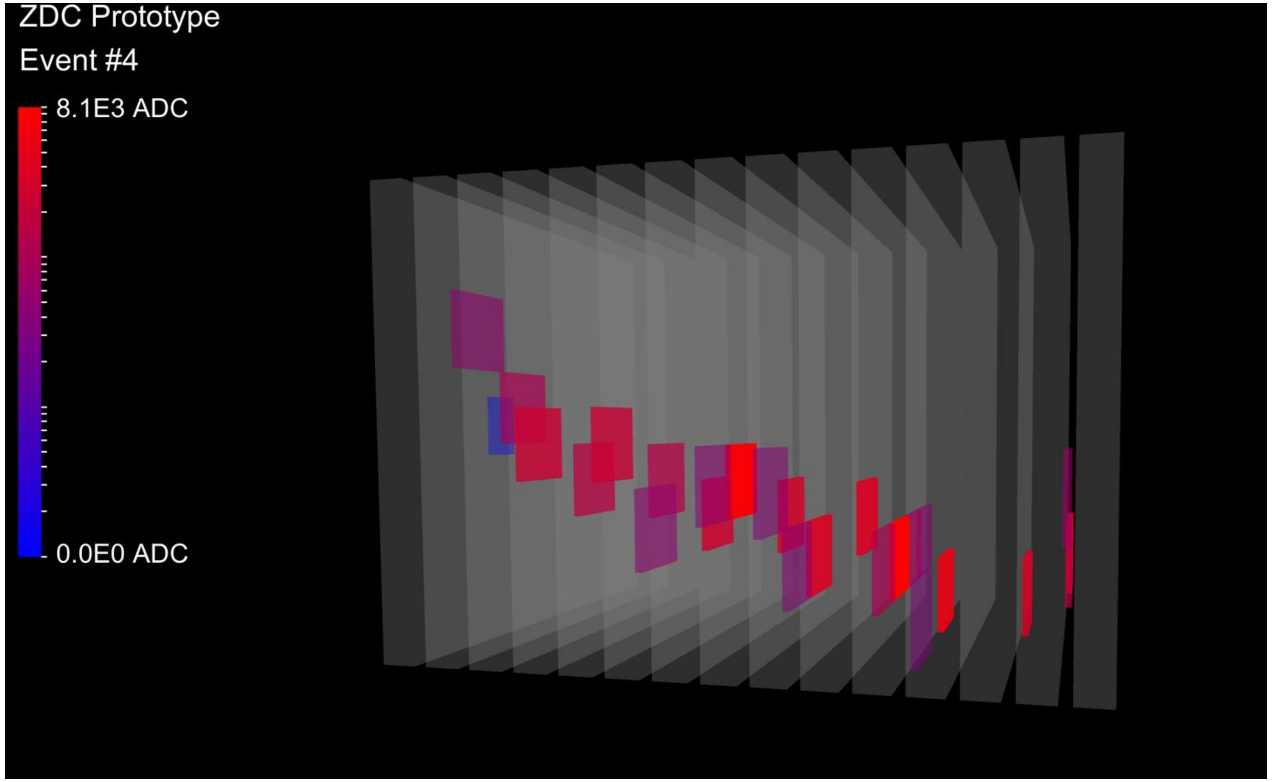
Event Building



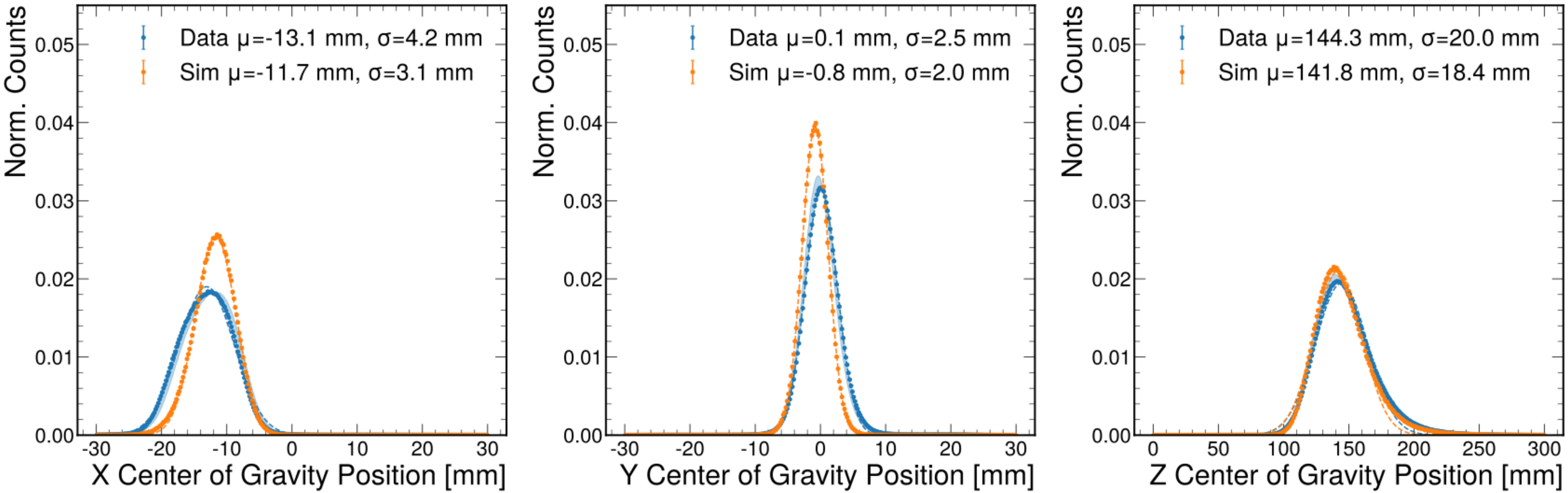
- Subtract channel pedestals
- Suppress hits within 3σ of pedestal
- Equalize channels using cosmic rays
- Determine HG/LG gain ratio from beam data
- Apply global energy calibration
- Verify channel mapping and synchronization

Systematic Errors

- Beam position uncertainty: ±1.3 cm, resulting in a total beam energy uncertainty of ±2%
- Two alternative datasets were formed with energy scaled by ±2%
- Alternative dataset was formed without equalization
- This produced a −0.9% impact on the energy resolution , a −2.1% impact on the y pos. resolution , and a +8.1% impact on the x pos. resolution

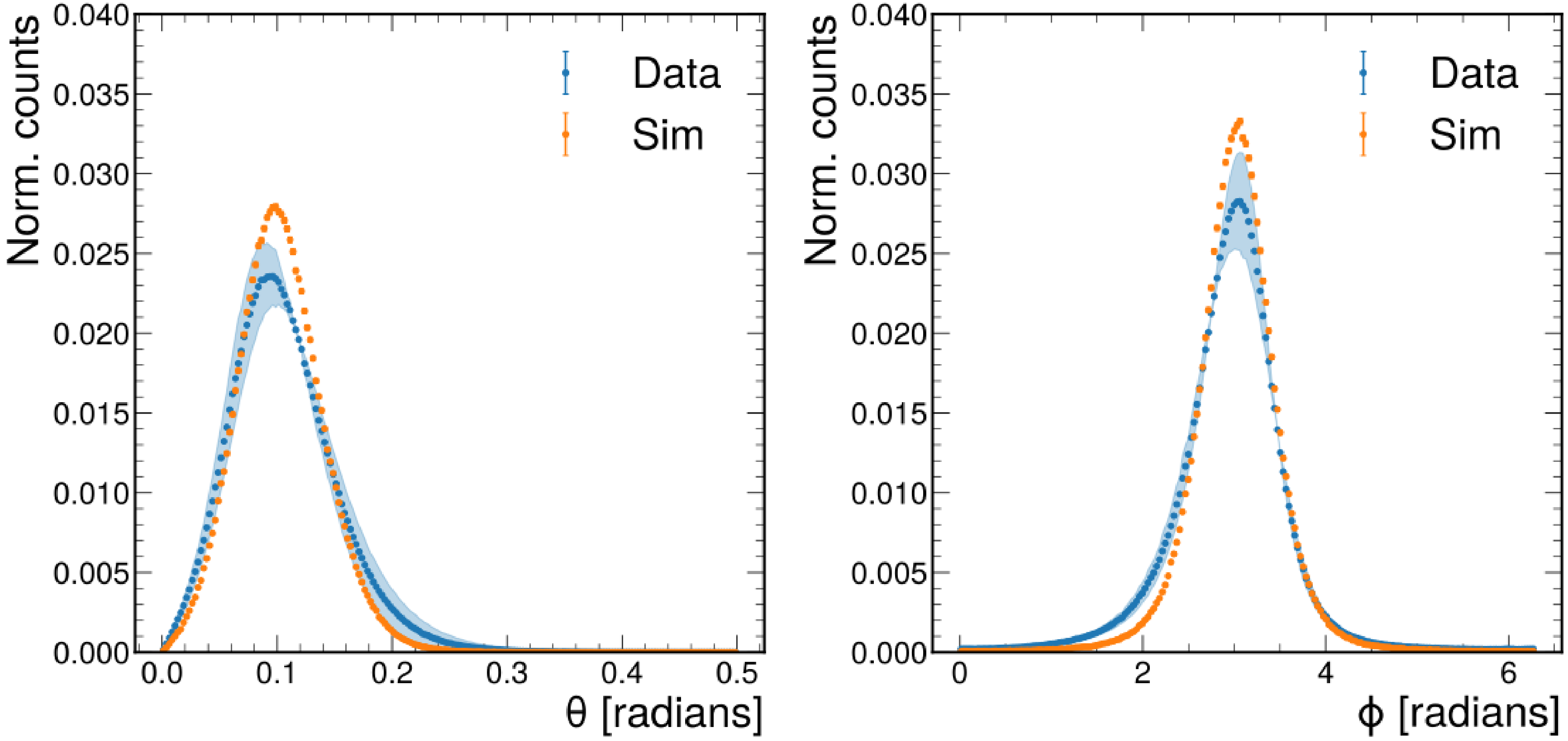
Center of Gravity Results

- Results were compared with a GEANT4 simulation of 5.3 GeV positrons
- The shower center of gravity and shower angle distributions were used to determine the beam orientation



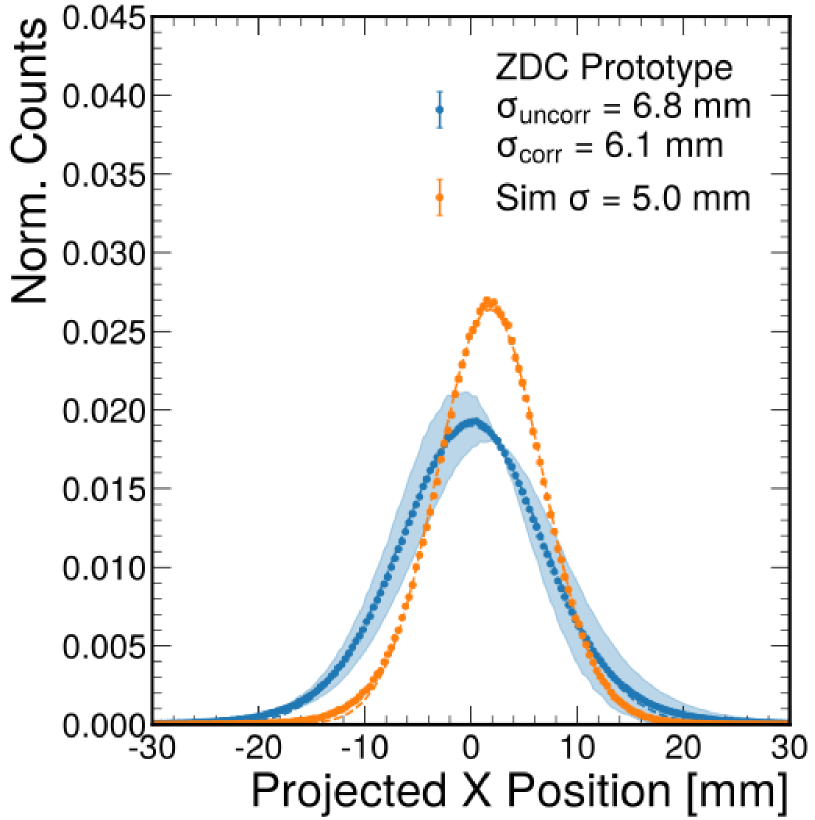
Shower Angle Results

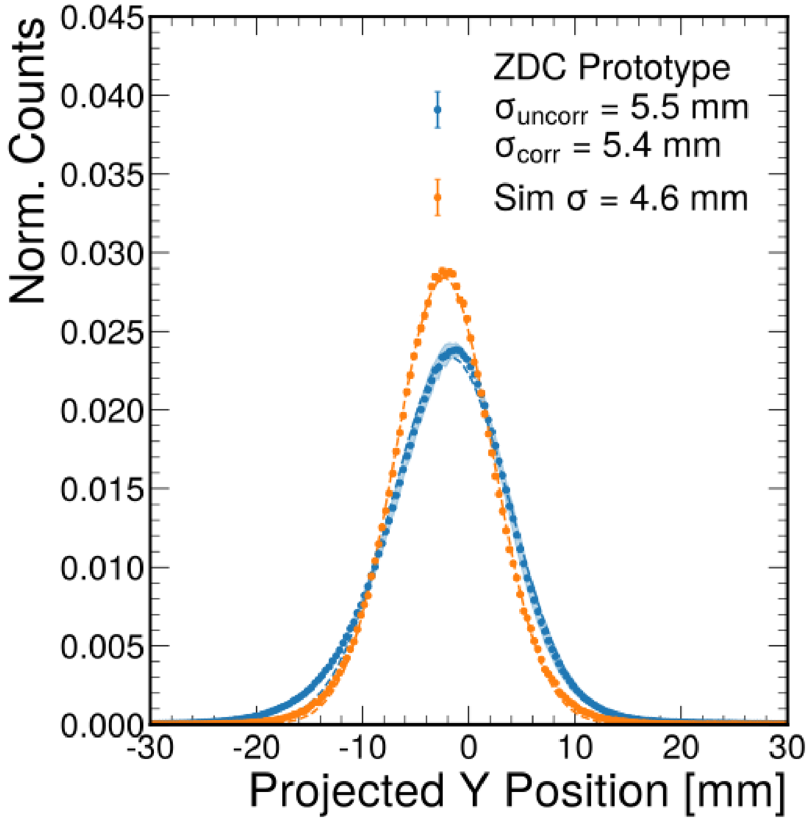
- Shower angles were determined from the eigenvectors of the moment matrix of the shower
- The beam orientation was determined to be x = -1.2mm, y = -10mm, θ = 0.07 rad, φ = -0.52 rad



Position Res. Results

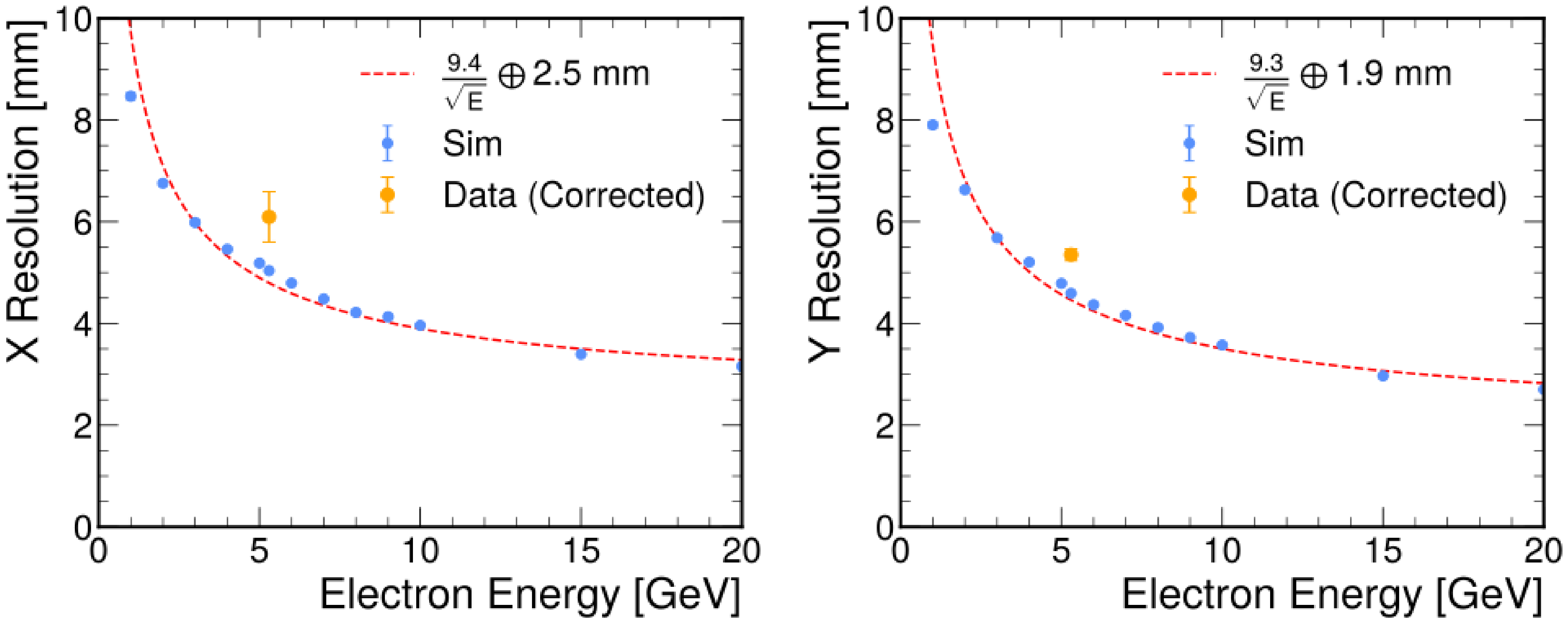
- The beam impact position was determined by projecting the moment matrix eigenvectors from the COG to the front face of the detector
- Beam spread effects were subtracted in quadrature from the data





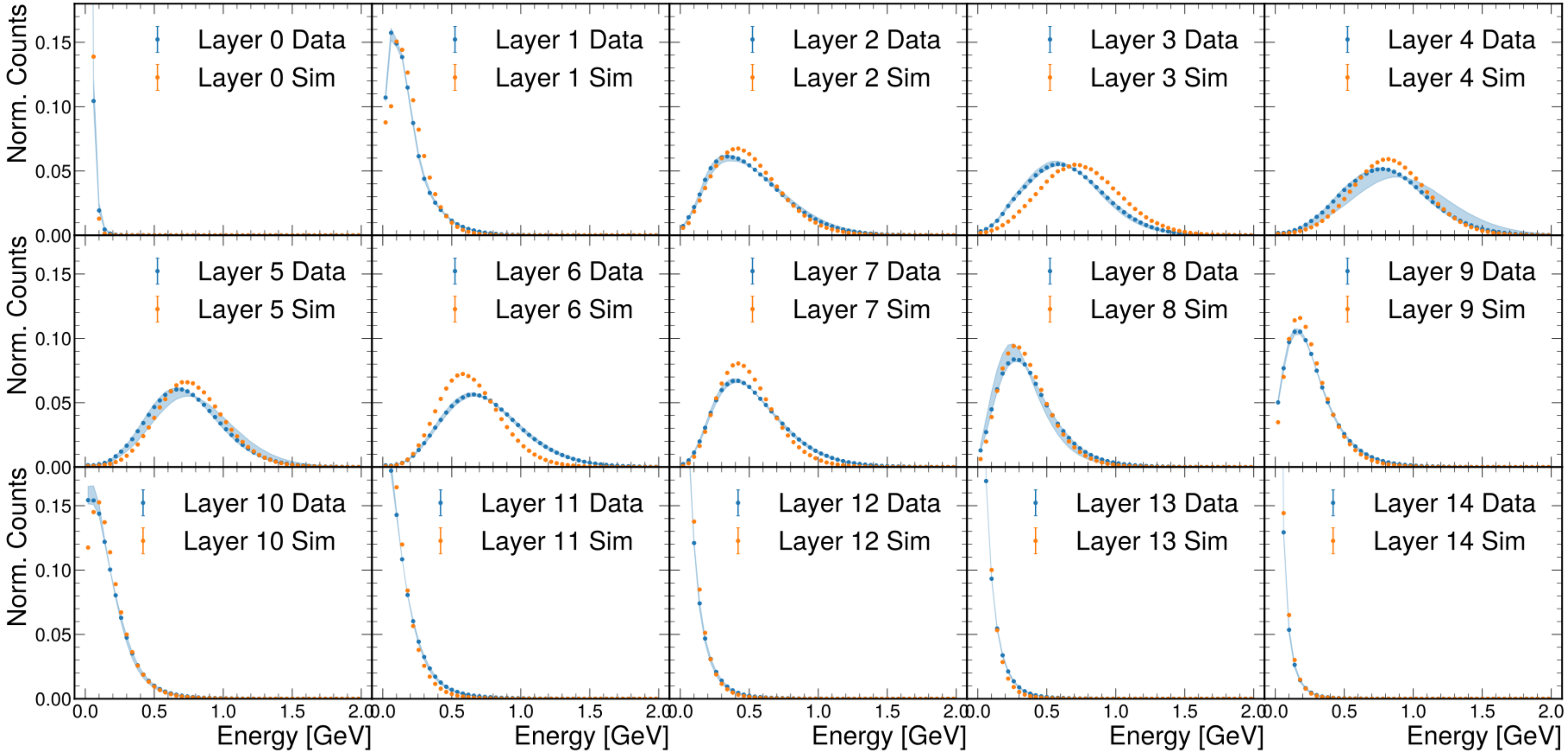
Position Res. Results

- Expected energy dependance for position resolution for the ZDC prototype, with the measured position resolution



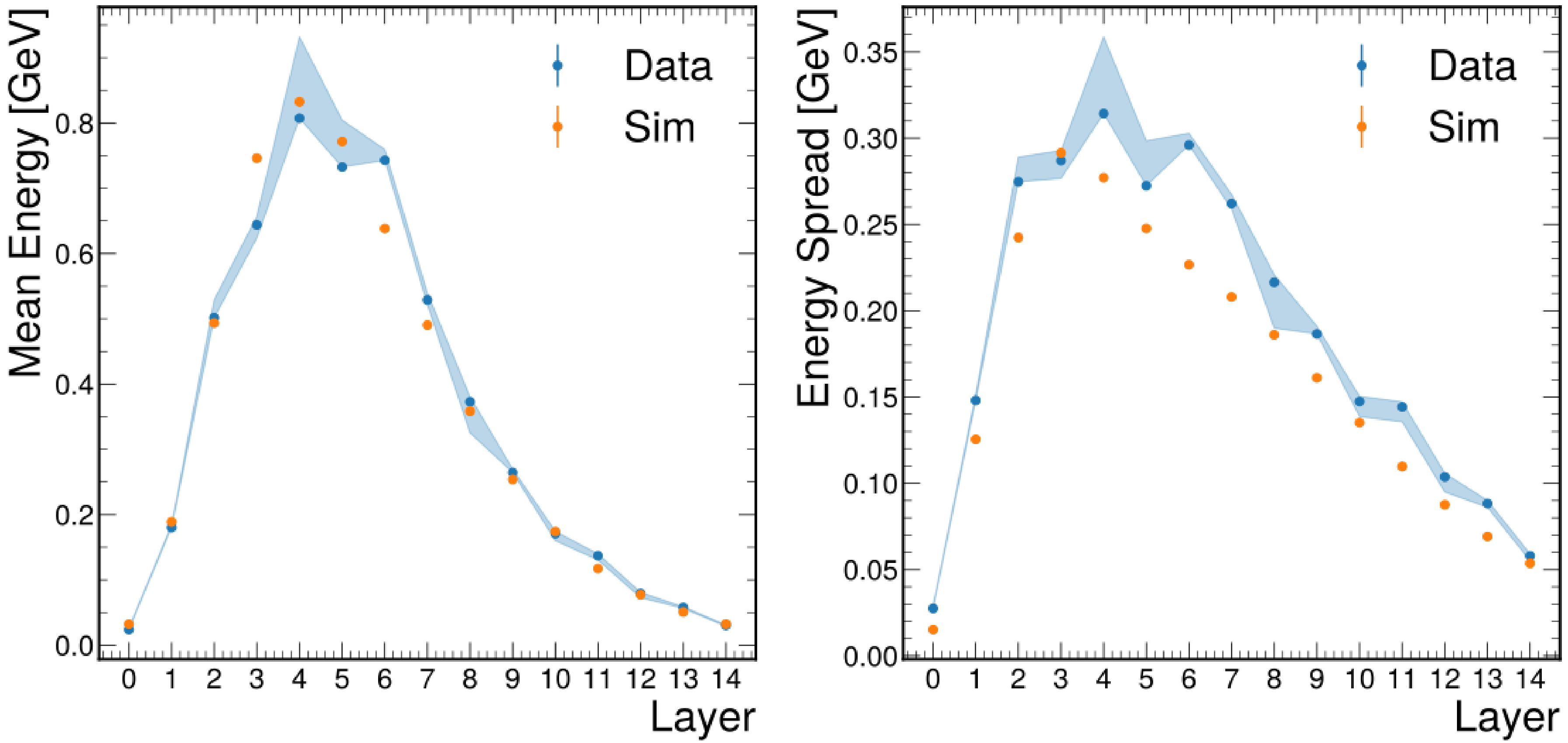
Shower Shape Results

- Summed event energy distribution for each layer characterize longitudinal shower shape



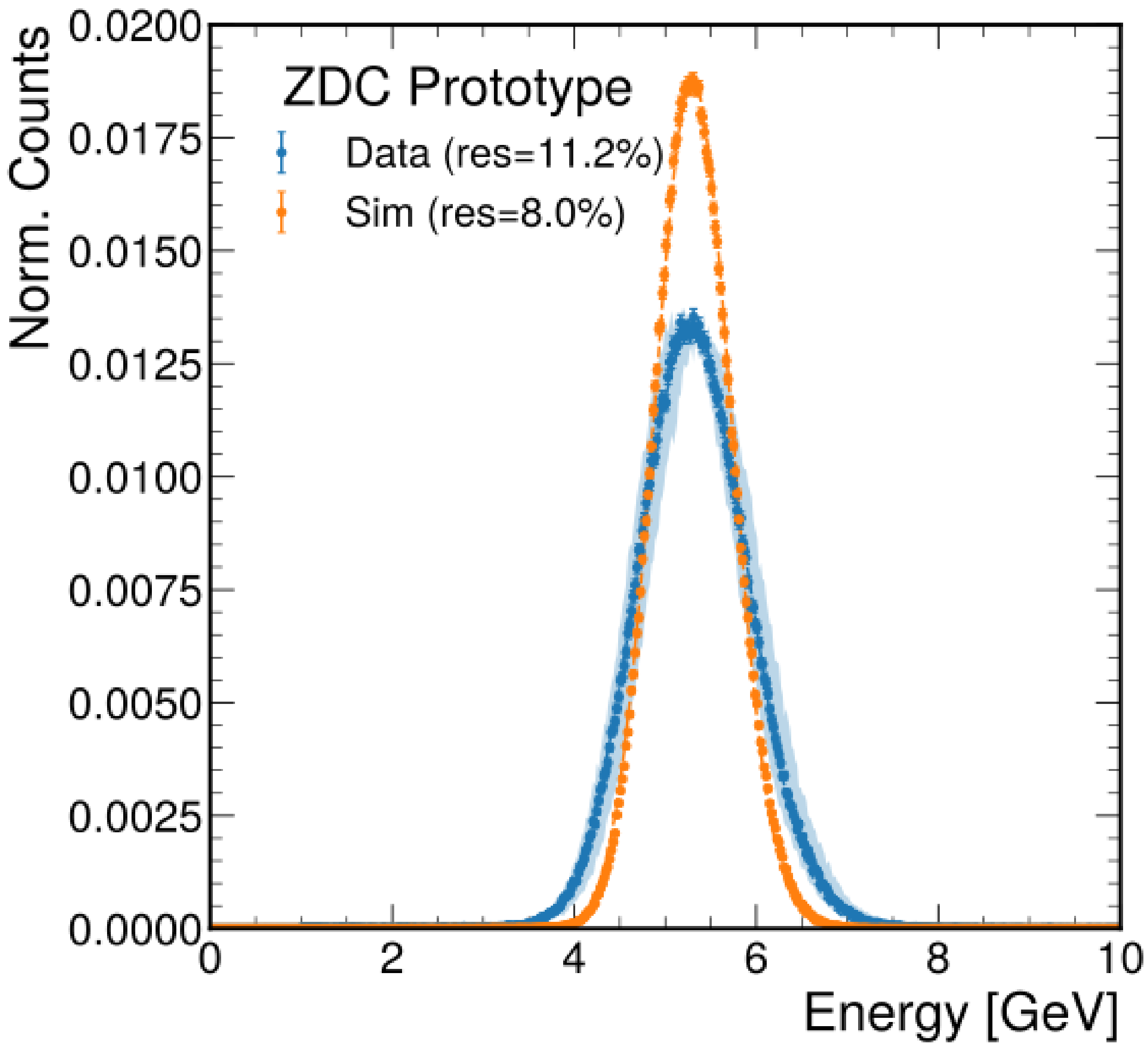
Shower Shape Results

- Mean and standard deviation of layer event energy distributions



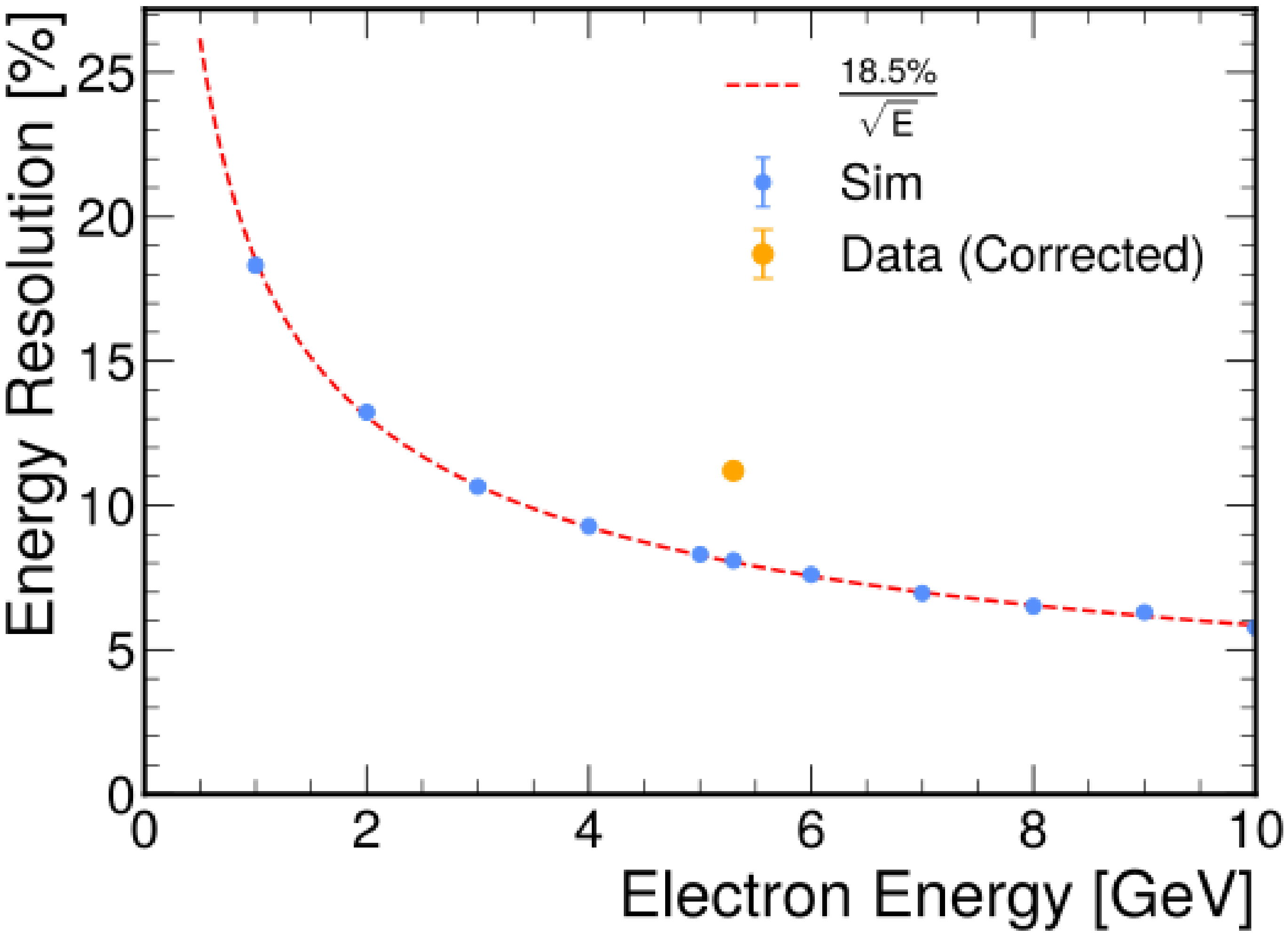
Energy Res. Results

- Total event energy distribution compared to simulation
- Energy spread effects not represented in simulation have a negligible impact on energy resolution



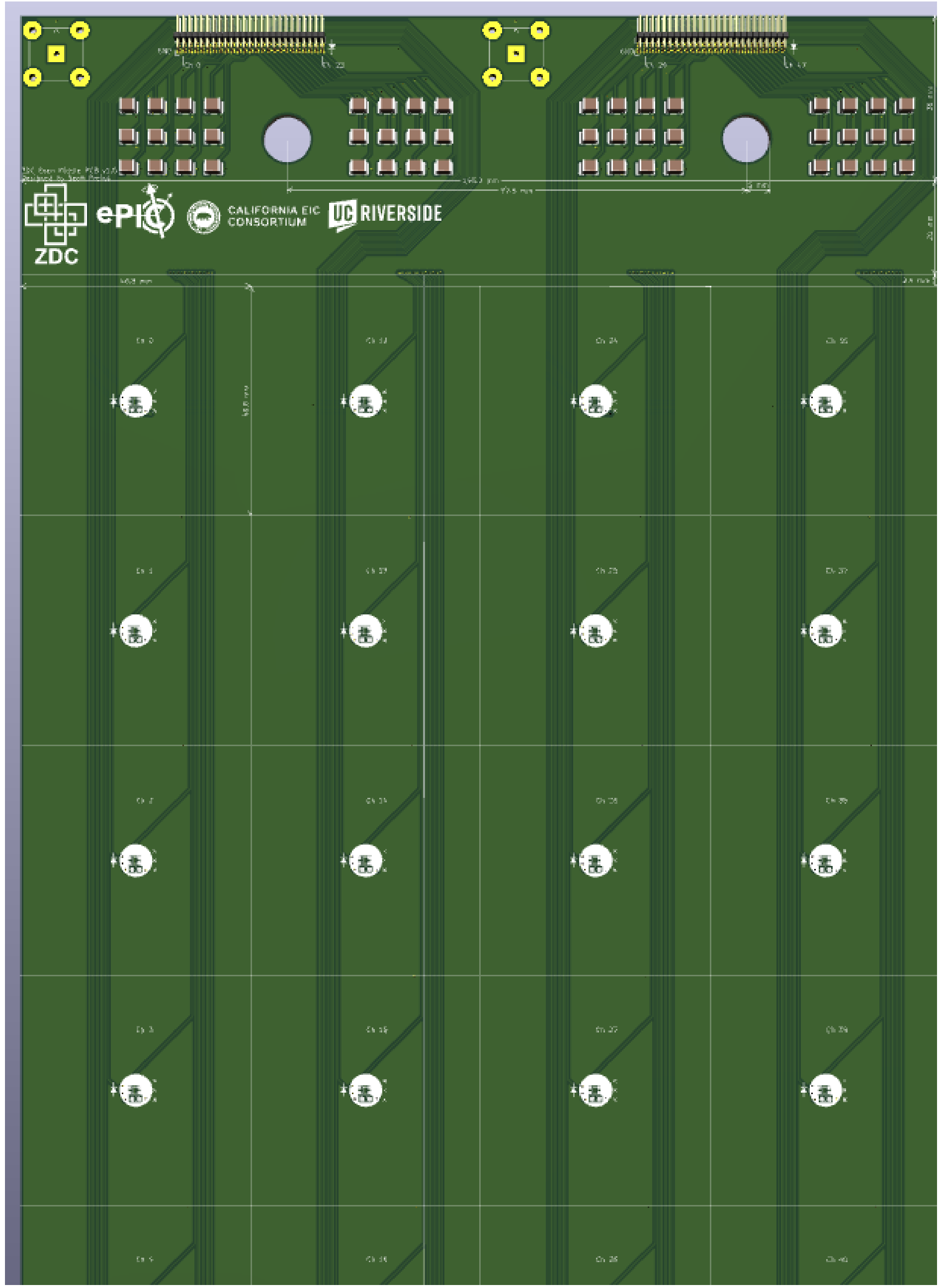
Energy Res. Results

- Expected energy dependence on energy resolution for the ZDC prototype, with the measured energy resolution
- Significant difference may be attributed to detector effects not included in simulation (electrical cross-talk, non-ideal equalization)

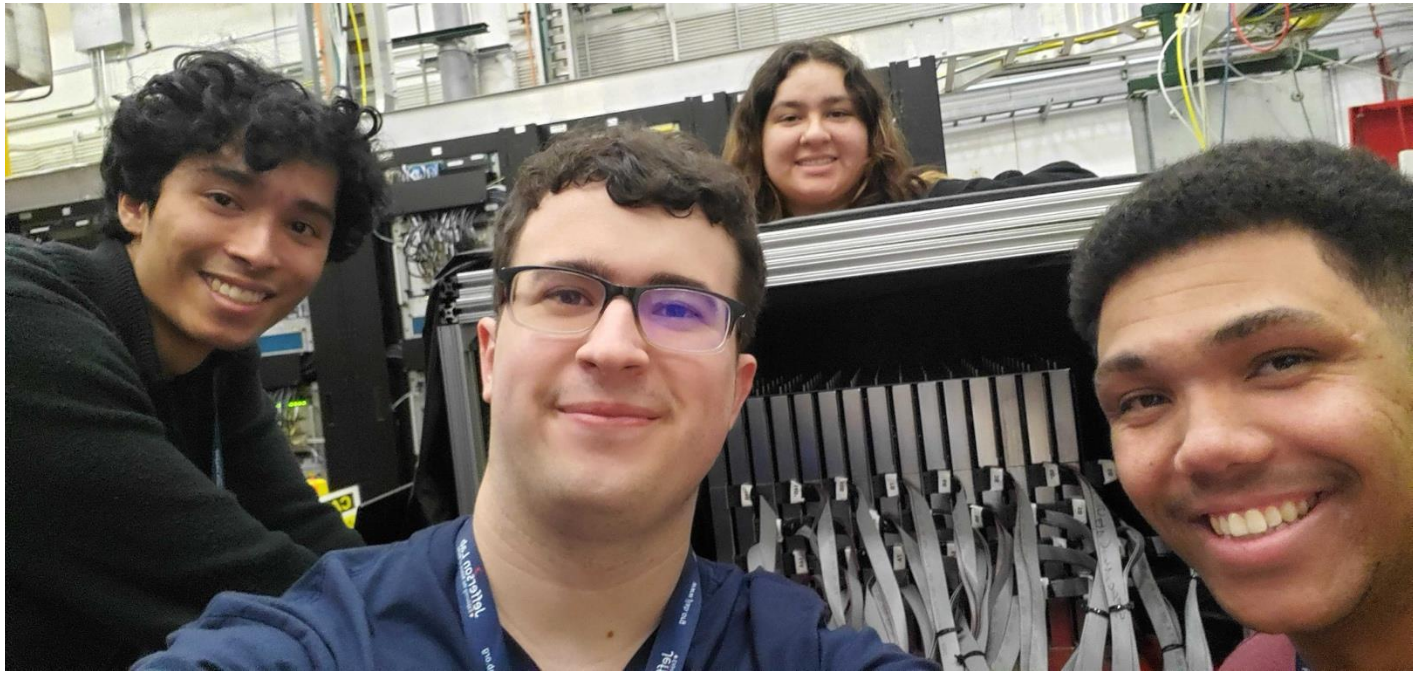


Final ZDC Design

- Prototype informed updated mechanical design
- Three removable PCBs per layer
- New connectors improve construction and reliability
- LEDs integrated for calibration
- Shielded ribbon cables reduce crosstalk



Conclusions



- We successfully constructed and operated our third generation SiPM-on-tile sampling calorimeter at the Jefferson Lab Hall D Pair Spectrometer
- Shower shape and spatial reconstruction are reasonably reproduced by simulation, and we have identified sources of remaining discrepancies
- This experience gave us valuable insight into the design, construction methods, calibration procedure, and operation that informs the final design of the ePIC ZDC

Thank you!