SiPM-on-tile ZDC Test Module Jefferson Lab Results

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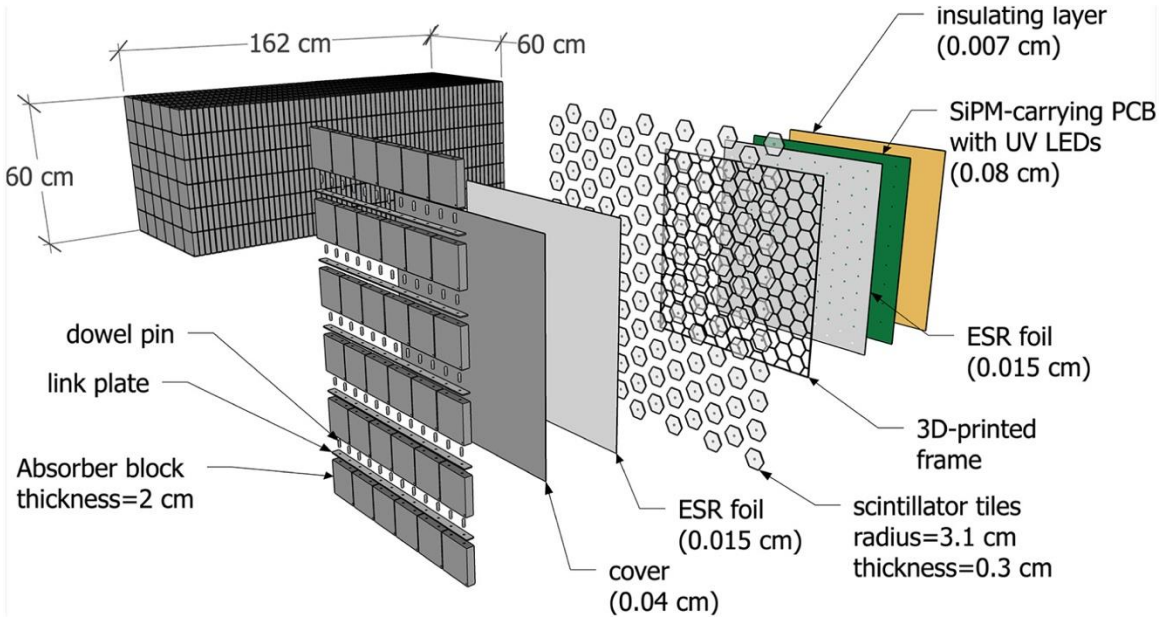
7/30/25

Background

- This test serves as the pre-production effort for the SiPM-on-tile Zero Degree Calorimeter, building off previous prototype tests
- Assess the performance and scalability of the design
- Determine assembly steps, QA check procedures, and other final improvements

Initial SiPM-on-tile ZDC design



Design and simulation of a SiPM-on-tile ZDC for the future EIC, and its performance with graph neural networks

Ryan Milton [a], Sebouh J. Paul [a], Barak Schmookler [a], Miguel Arratia [a,*], Piyush Karande [c], Aaron Angerami [b], Fernando Torales Acosta [d], Benjamin Nachman [d,e]

Previous Test Beams

- Gen I prototype consisted of 10 sampling layers, 40 channels
  - Tested with 4 GeV positrons at Jefferson Lab in Jan 2023

instruments

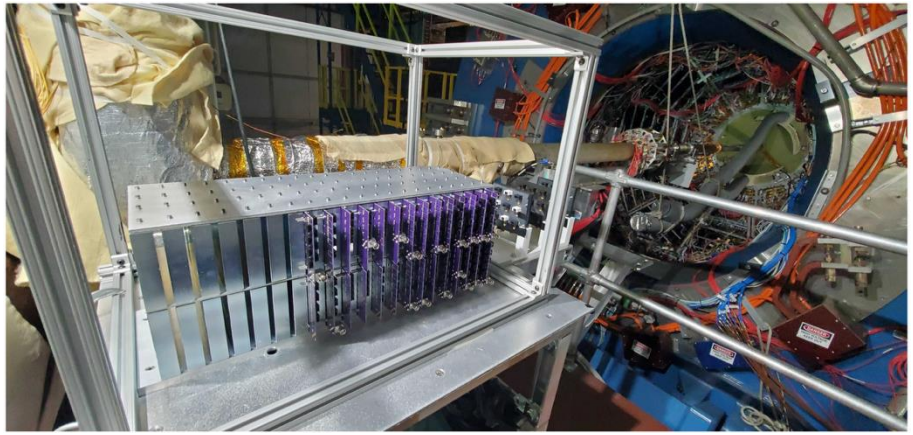
MDPI

Article

Beam Test of the First Prototype of SiPM-on-Tile Calorimeter Insert for the EIC Using 4 GeV Positrons at Jefferson Laboratory

Miguel Arratia [1,2,*], Bruce Bagby [1], Peter Carney [1], Jiajun Huang [1], Ryan Milton [1], Sebouh J. Paul [1], Sean Preins [1], Miguel Rodriguez [1] and Weibin Zhang [1]

- Gen II prototype consists of 9 sampling layers, 192 channels
  - Tested in the STAR experiment hall at RHIC, run from April – October 2024
  - Currently running now



First-ever deployment of a SiPM-on-tile calorimeter in a collider: a parasitic test with 200 GeV *p p* collisions at RHIC.

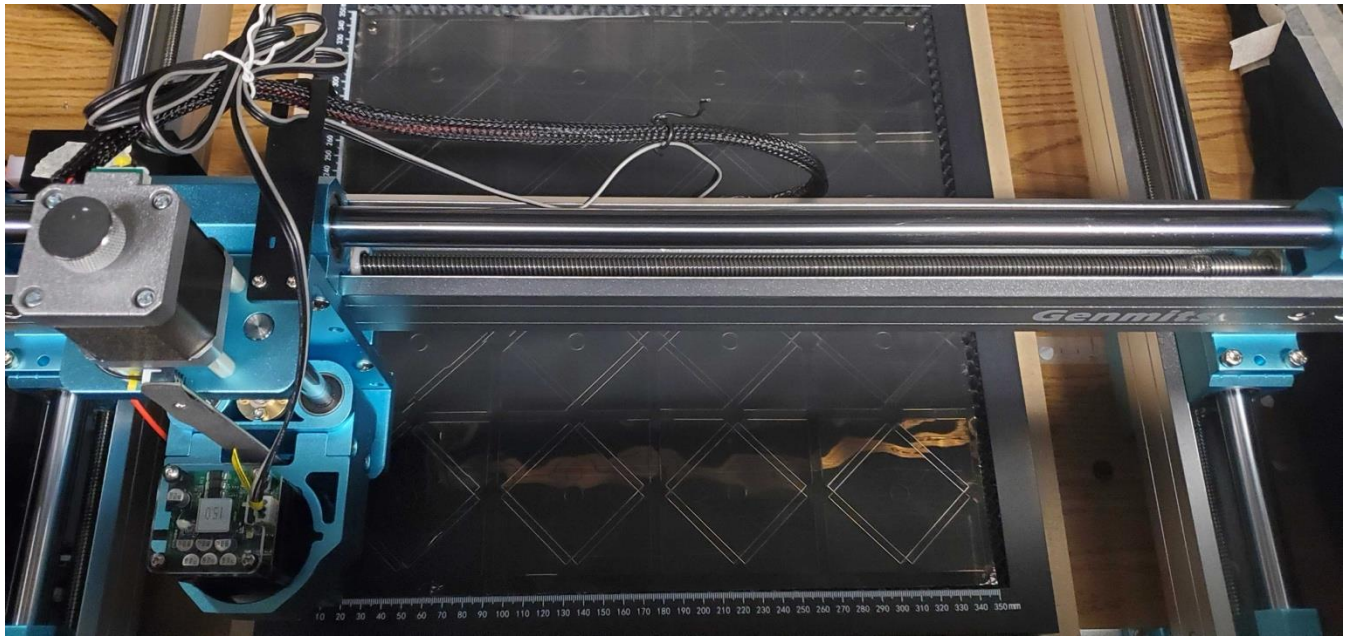
To cite this article: Weibin Zhang *et al* 2025 *JINST* 20 P06029

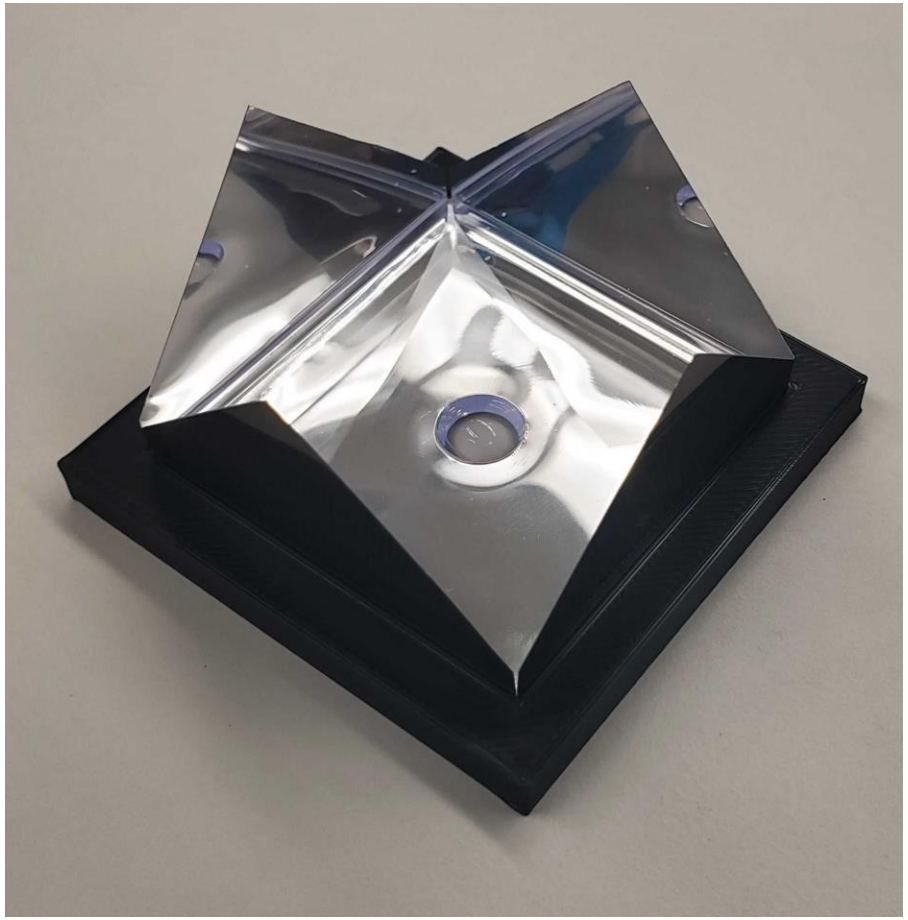
Generation III Prototype Design

- Area of 29.4 cm x 28.8 cm
- Each layer consists of 5 x 5 square scintillating tiles, shifted diagonally every other layer
- 15 layers, 25 channels per layer
- 375 channels total
- 7 dead channels, 98.1% channels functional. No dead channels in shower core region.

2 cm of iron = 1.1 X_0

Tile Construction

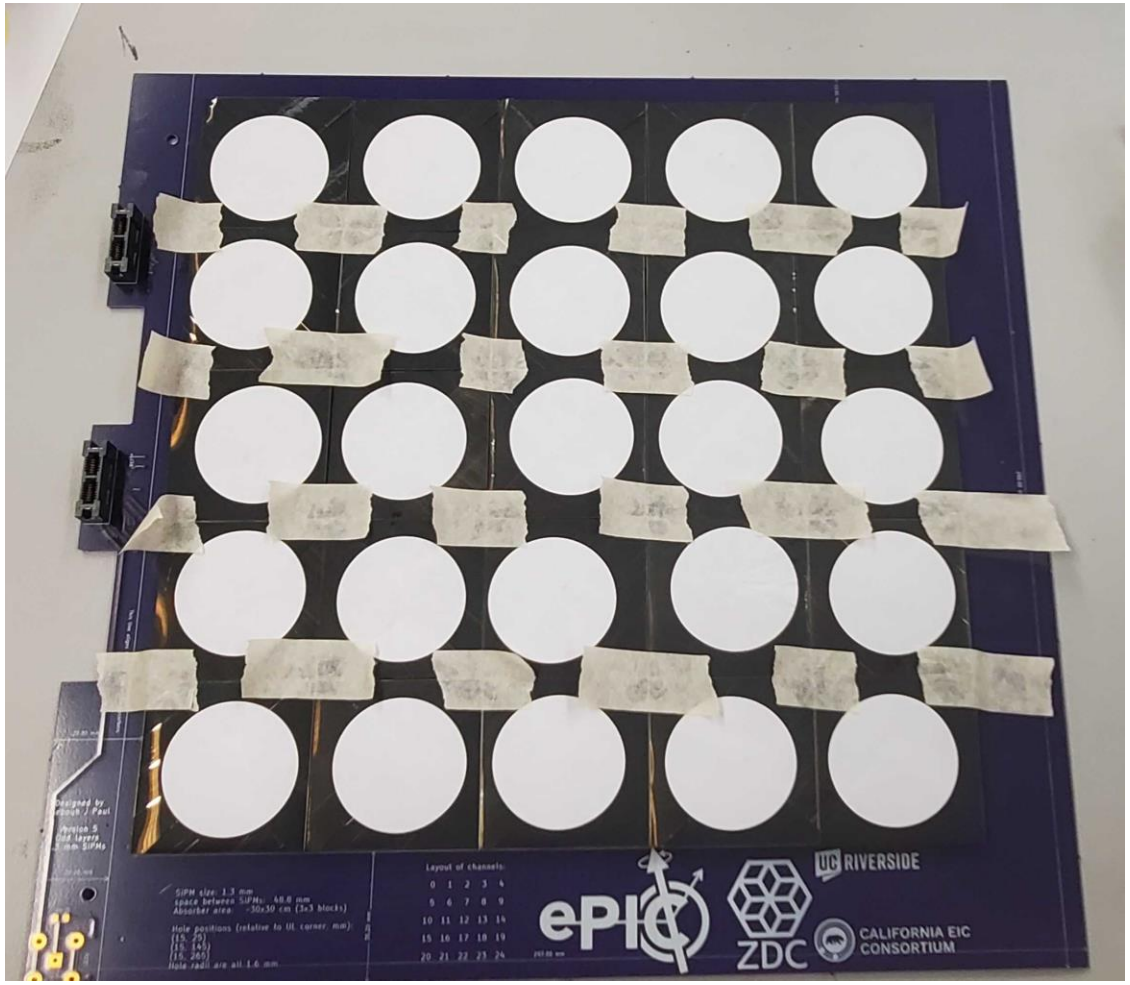


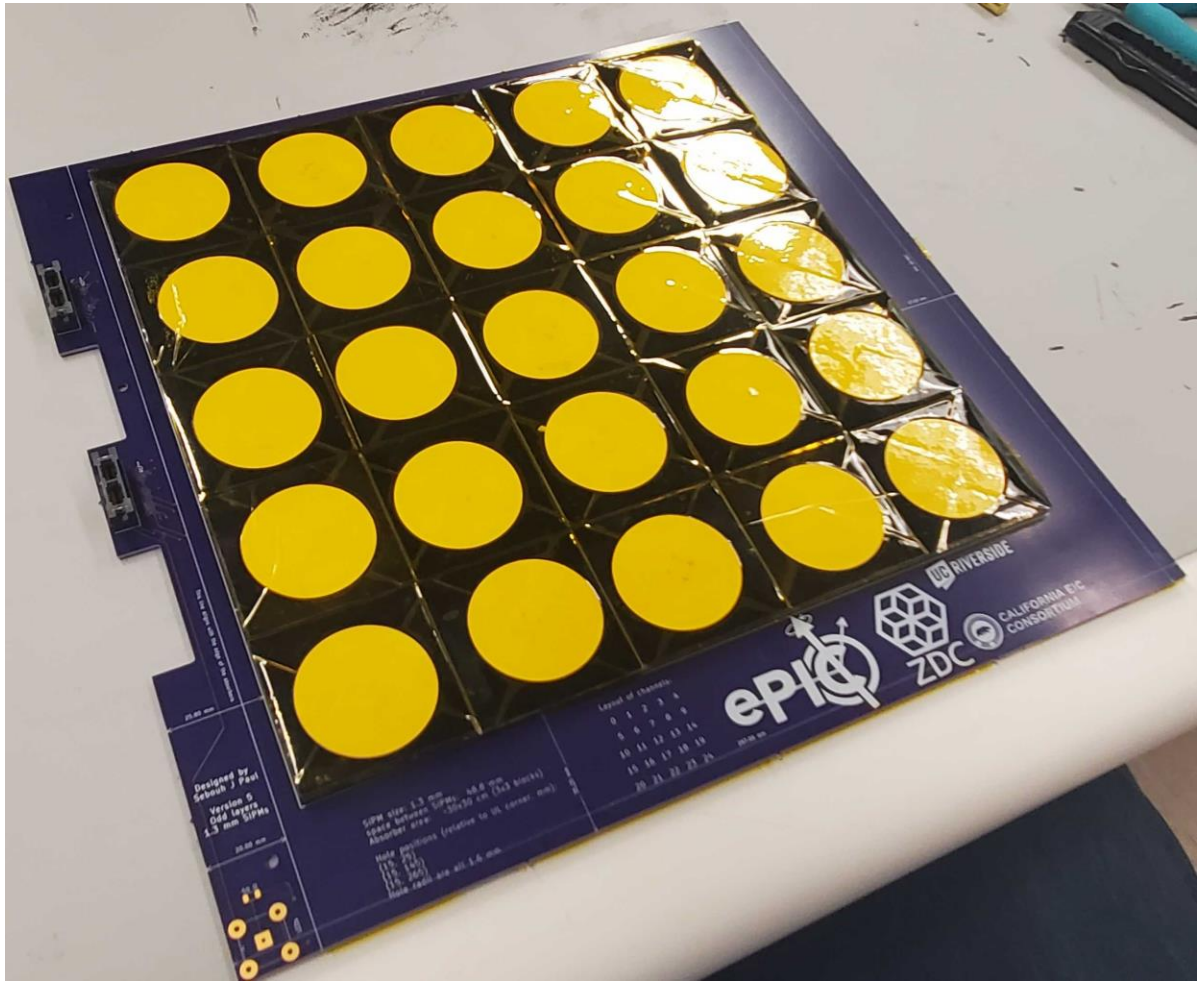


- ESR foil is cut using a CNC laser, and individually folded around each tile
- Tile dimensions 48.8 mm x 48.8 mm x 4 mm

PCB Construction

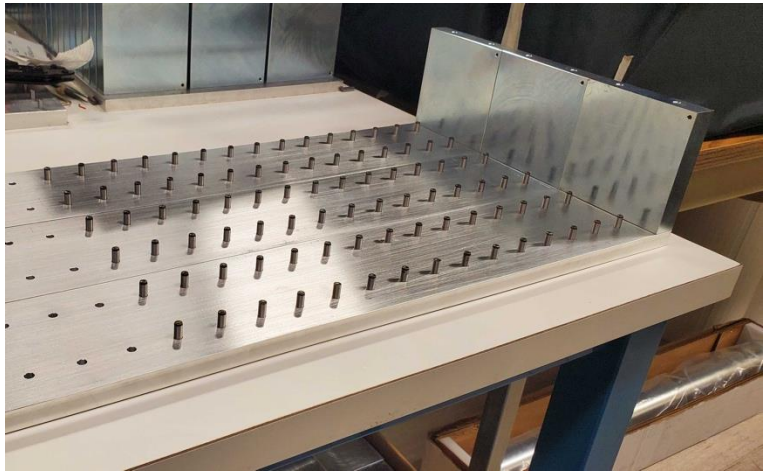
- Hamamatsu s14160-1315PS 1.3 mm SiPMs are soldered to the PCB using an IR oven

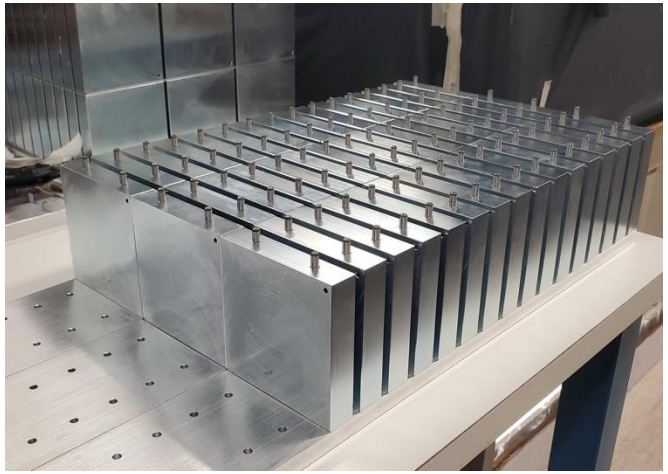


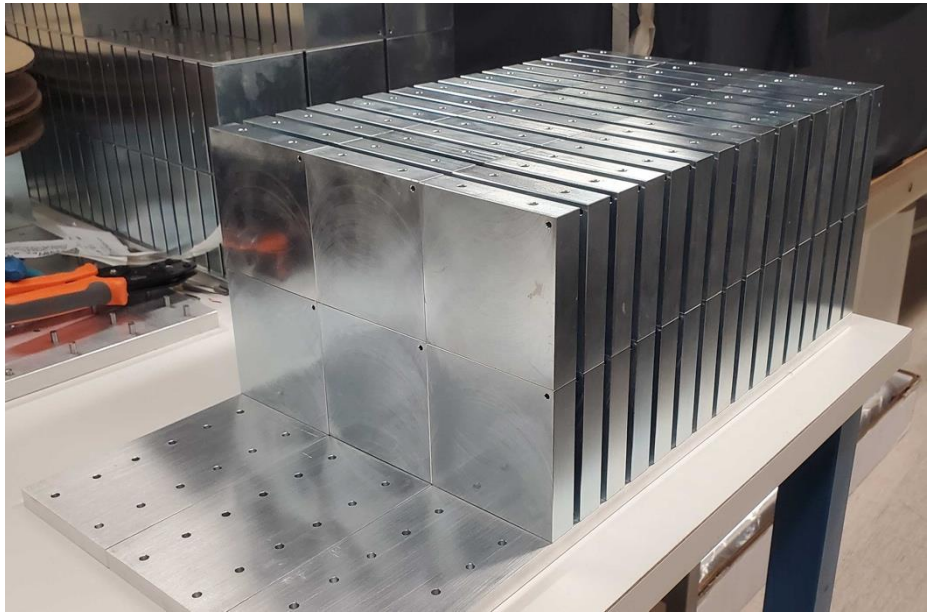


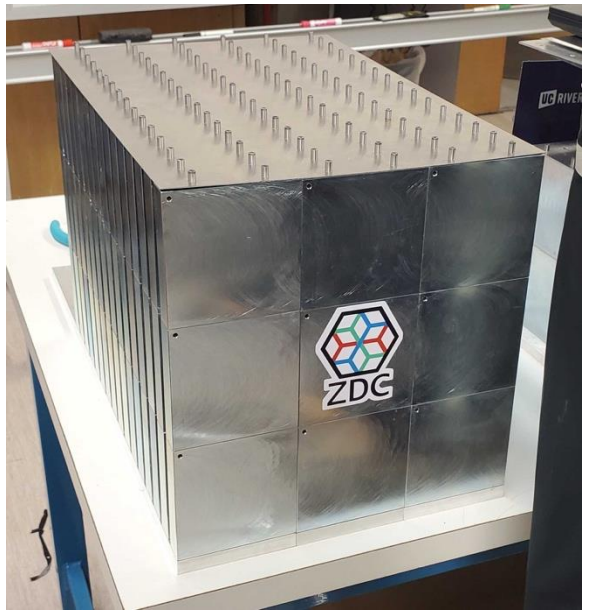
- After QA checks, tiles are affixed to the board via double-sided tape
- Polyimide film is placed on the front and back of the board to protect it from damage

Iron Structure Construction





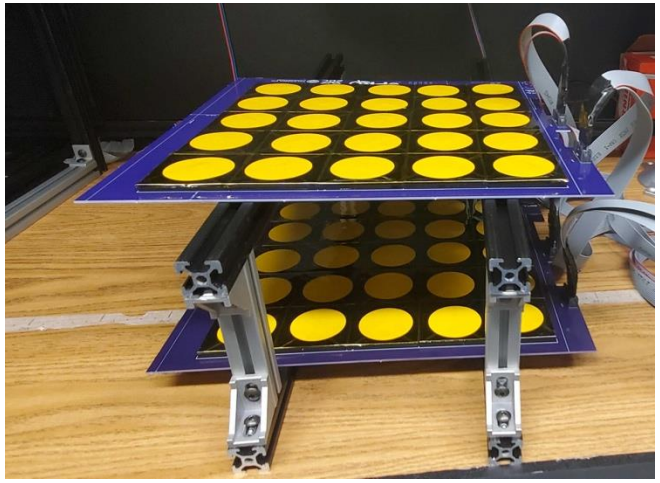


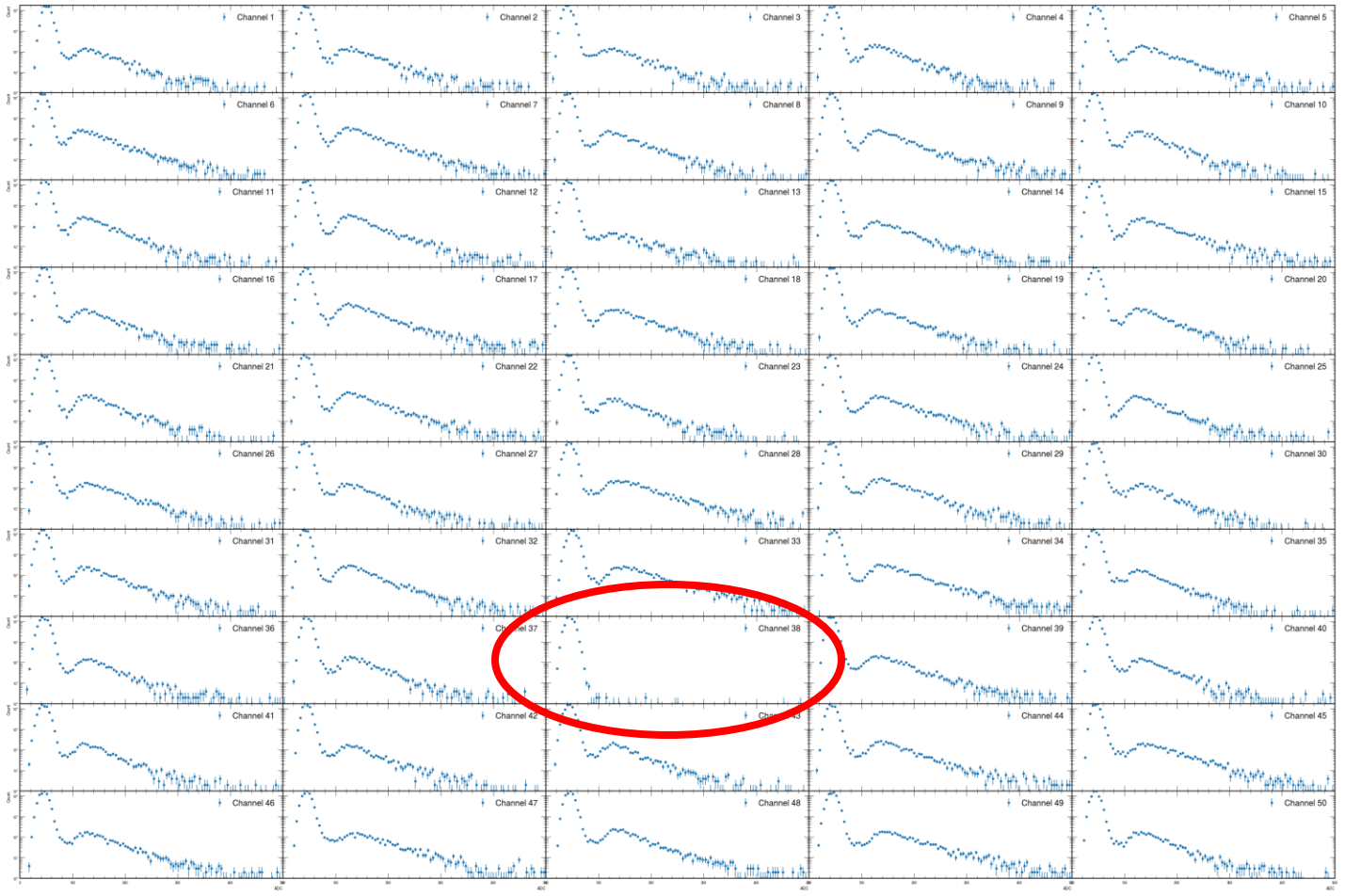


- LEGO-style pin-and-block assembly
- Active components can be placed in their respective slots post-assembly

Benchtop QA Checks

- Finalized layers are checked with a pedestal test, IV scan test, and cosmic test
- Layers are then tested with cosmic rays two at a time with a MAJ=2 trigger, to confirm that it begins to record a landau curve

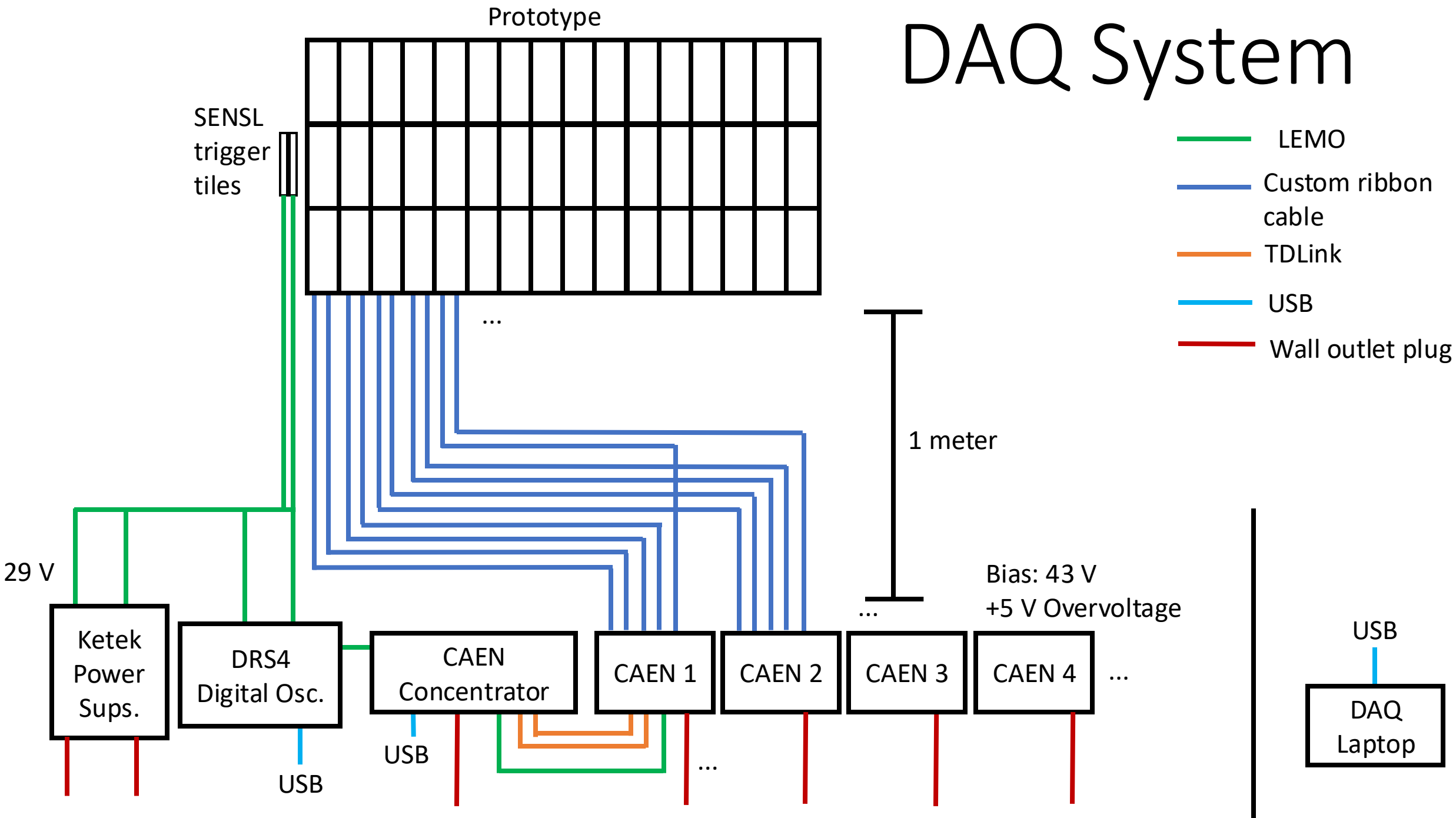


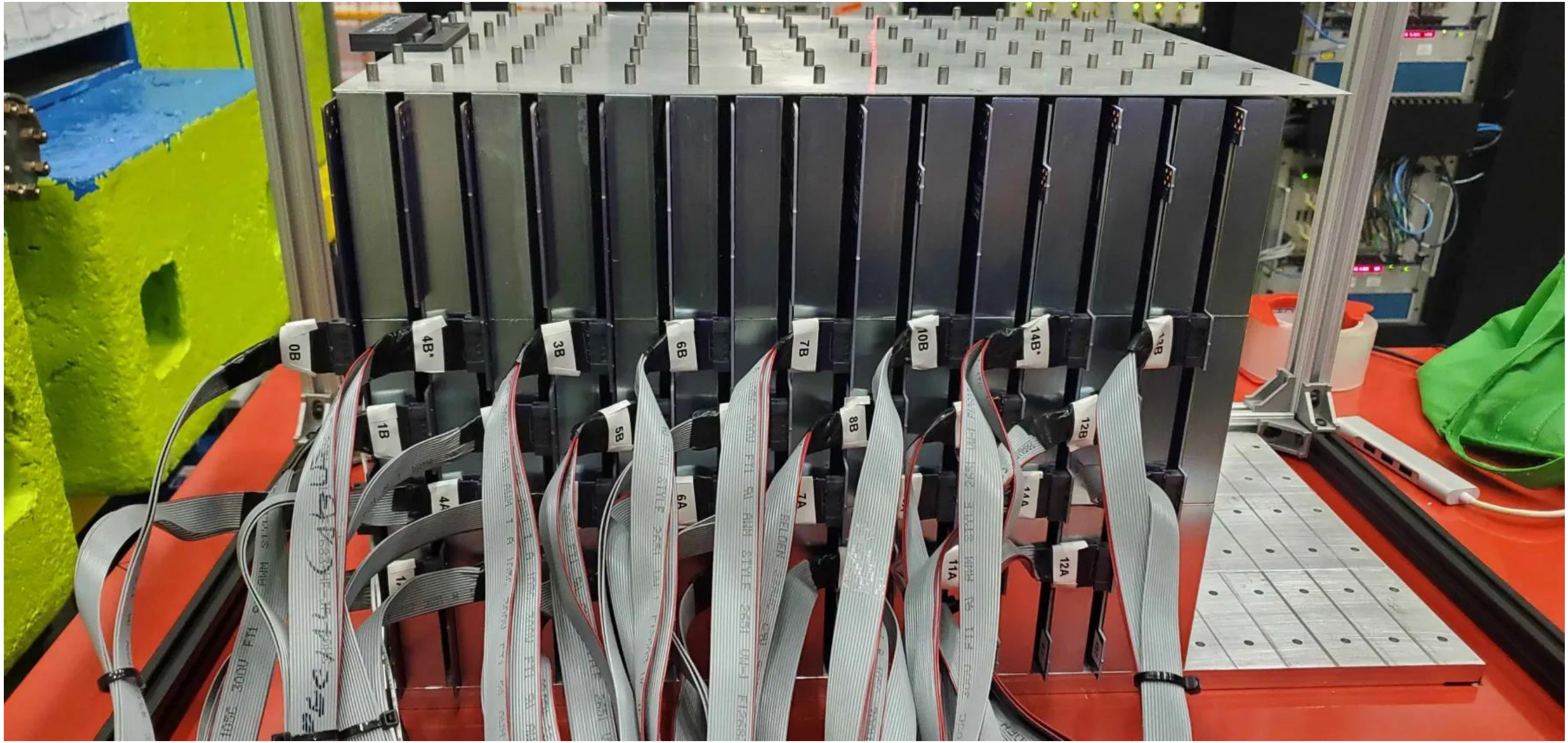


DAQ System

- PCBs send signals to 6 CAEN DT5202 units using custom soldered ribbon cables
- Signals are then collected by a CAEN DT5215 Concentrator Board via fiber optic cables
- Data is collected on a laptop being controlled remotely via VNC Viewer
- System is triggered by an external trigger system at the front center of the module

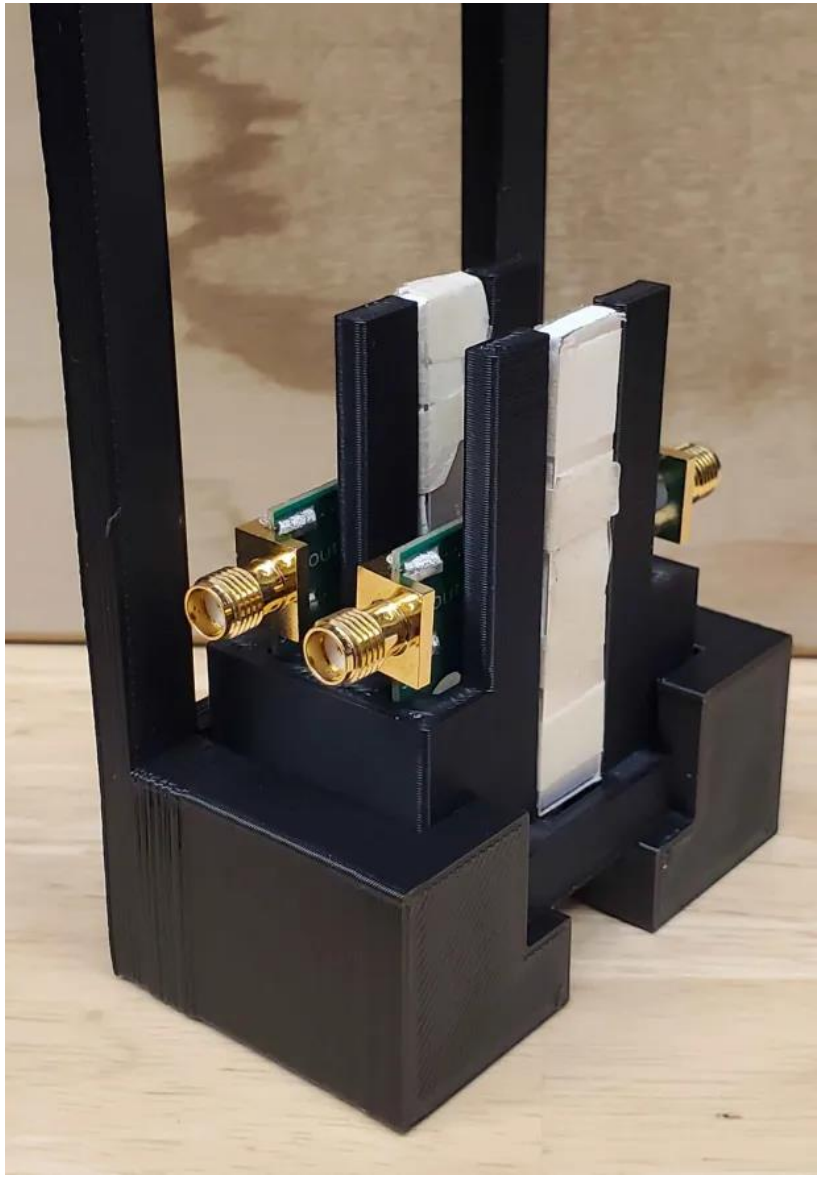
DAQ System

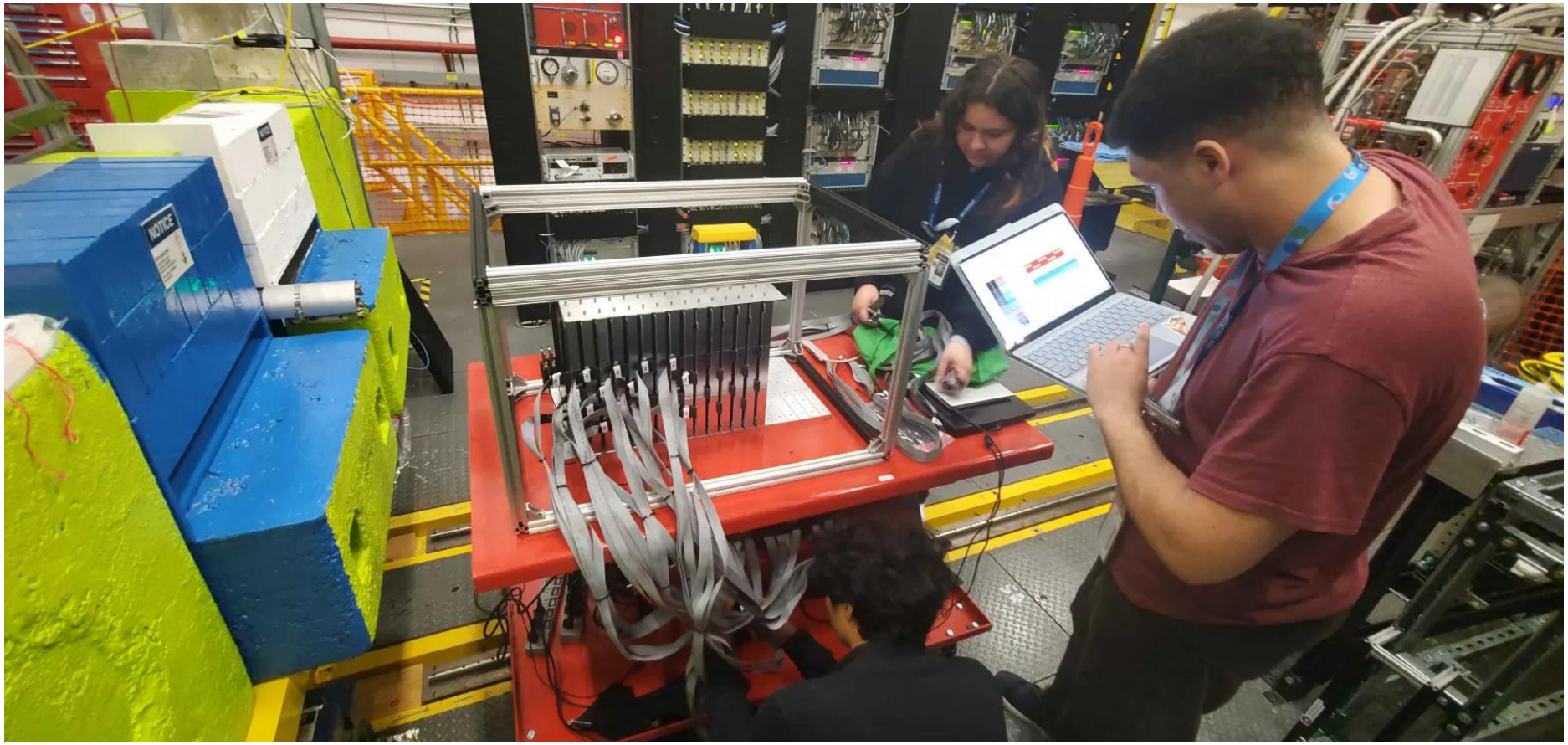

Prototype
SENSL
trigger
tiles
...
LEMO
Custom ribbon
cable
TDLink
USB
Wall outlet plug
1 meter
29 V
Ketek
Power
Sups.
DRS4
Digital Osc.
USB
CAEN
Concentrator
USB
CAEN 1
CAEN 2
CAEN 3
CAEN 4
...
...
Bias: 43 V
+5 V Overvoltage
USB
DAQ
Laptop


0B
4B'
3B
6B
7B
10B
14B'
13B
1B
5B
8B
12B
4A
6A
7A
11A
12A

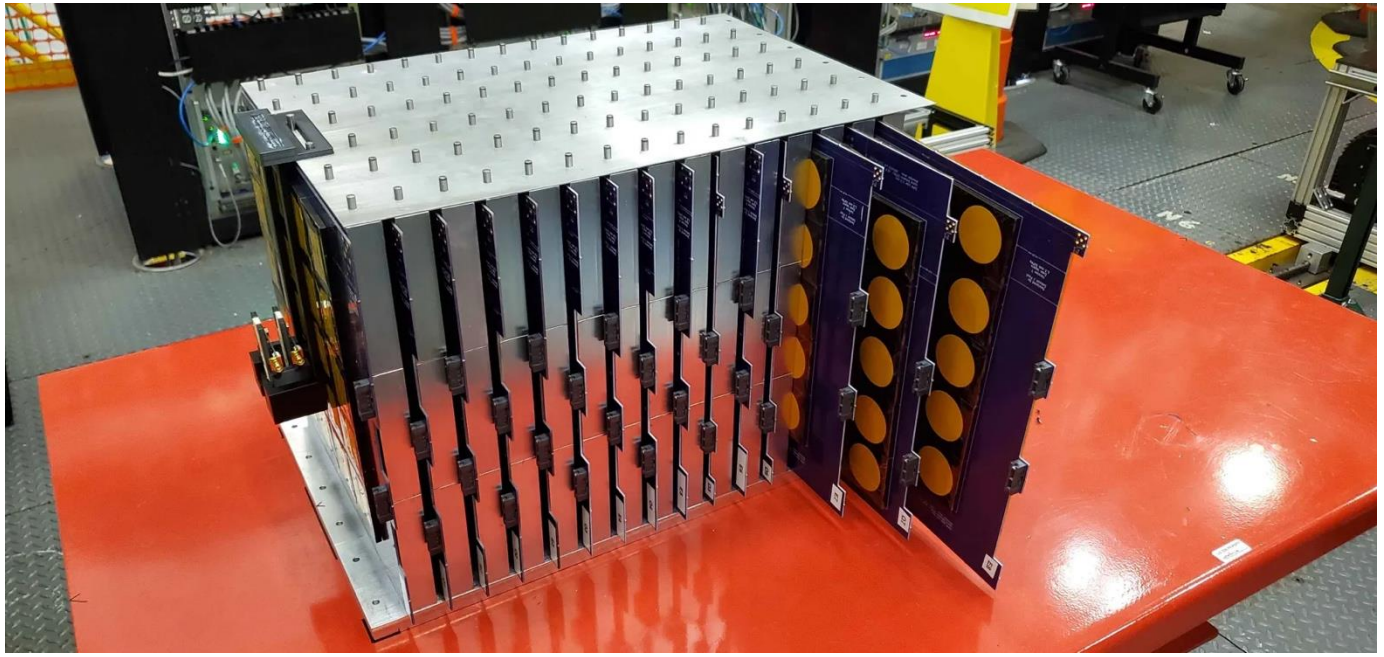
Trigger System

- Trigger system consists of two thin scintillating strips air-coupled to SiPMs on SENSL boards
- A DRS4 digital oscilloscope is set to trigger on AND logic for the two boards with a threshold of 5 mV.
- System is held at the front center of the prototype using a 3D printed mount





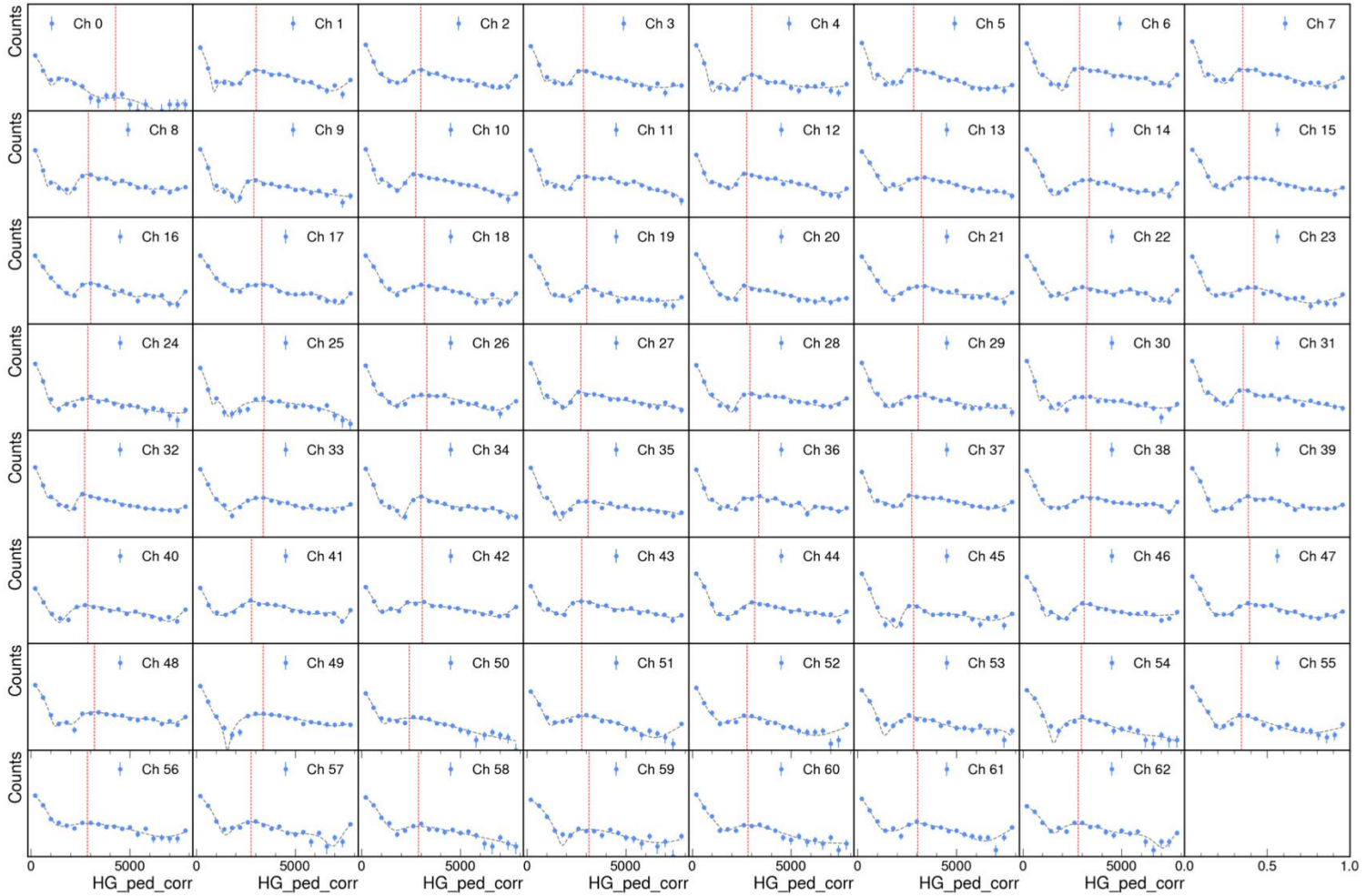
- Initially installed at the Jefferson Lab Hall D pair spectrometer on February 6
- Final adjustments made on April 23
- Positioned 5.4 degrees from the beamline, estimated to have received 5 GeV positrons

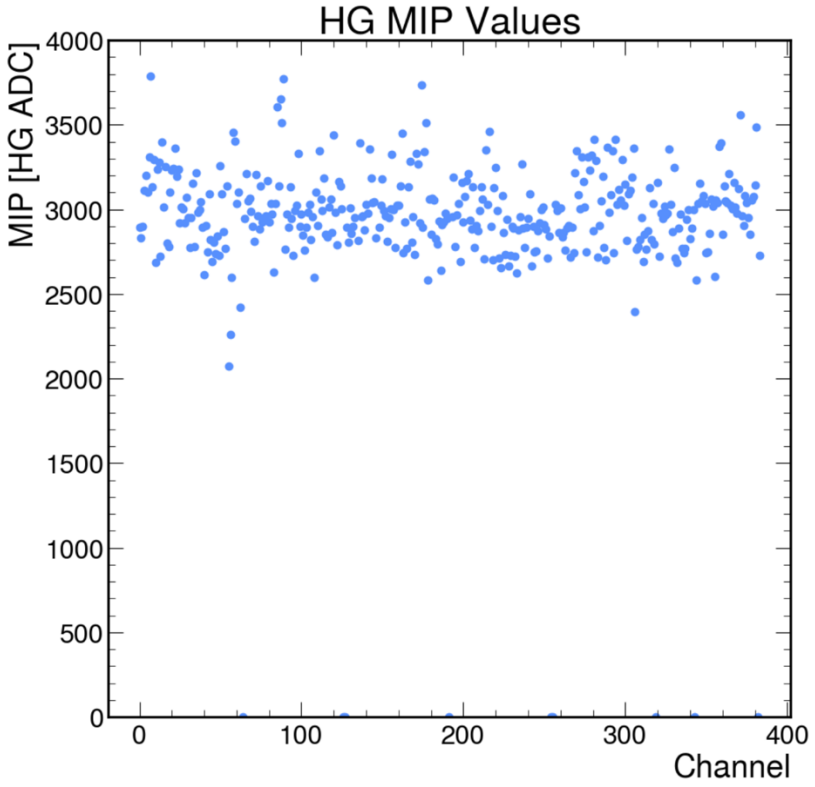


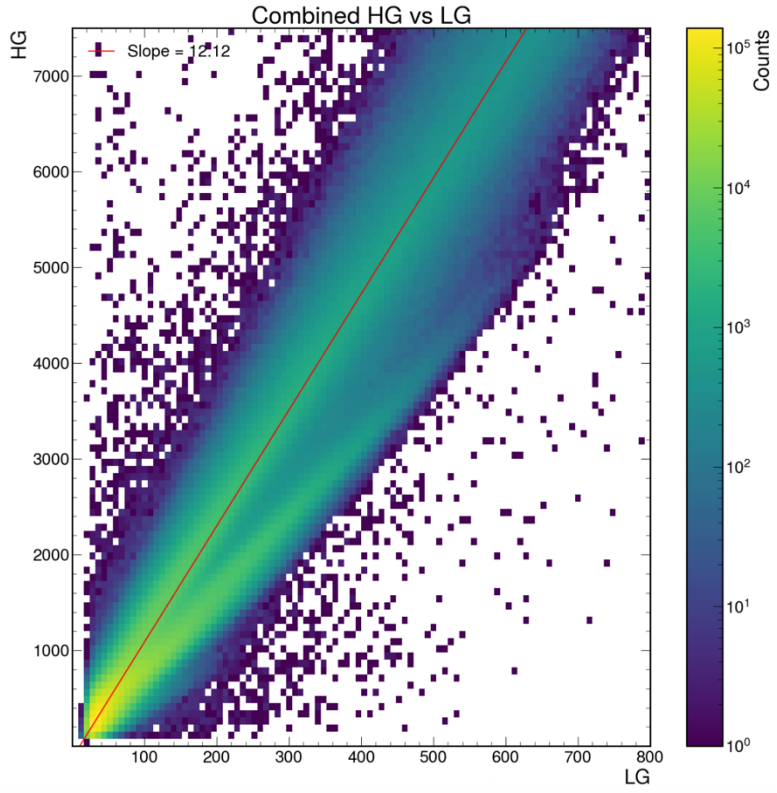
- Aligned using a laser system
- Module housed in a black-out fabric dark box
- Collected 15.7 million events
- Recorded with 14 different setting configurations, 6M events collected with one set

Calibration

- Devoted pedestal runs were recorded for each setting used
- 12 hours of cosmic ray data were collected before the beam was delivered
- The MIP scale in the simulation was determined similarly







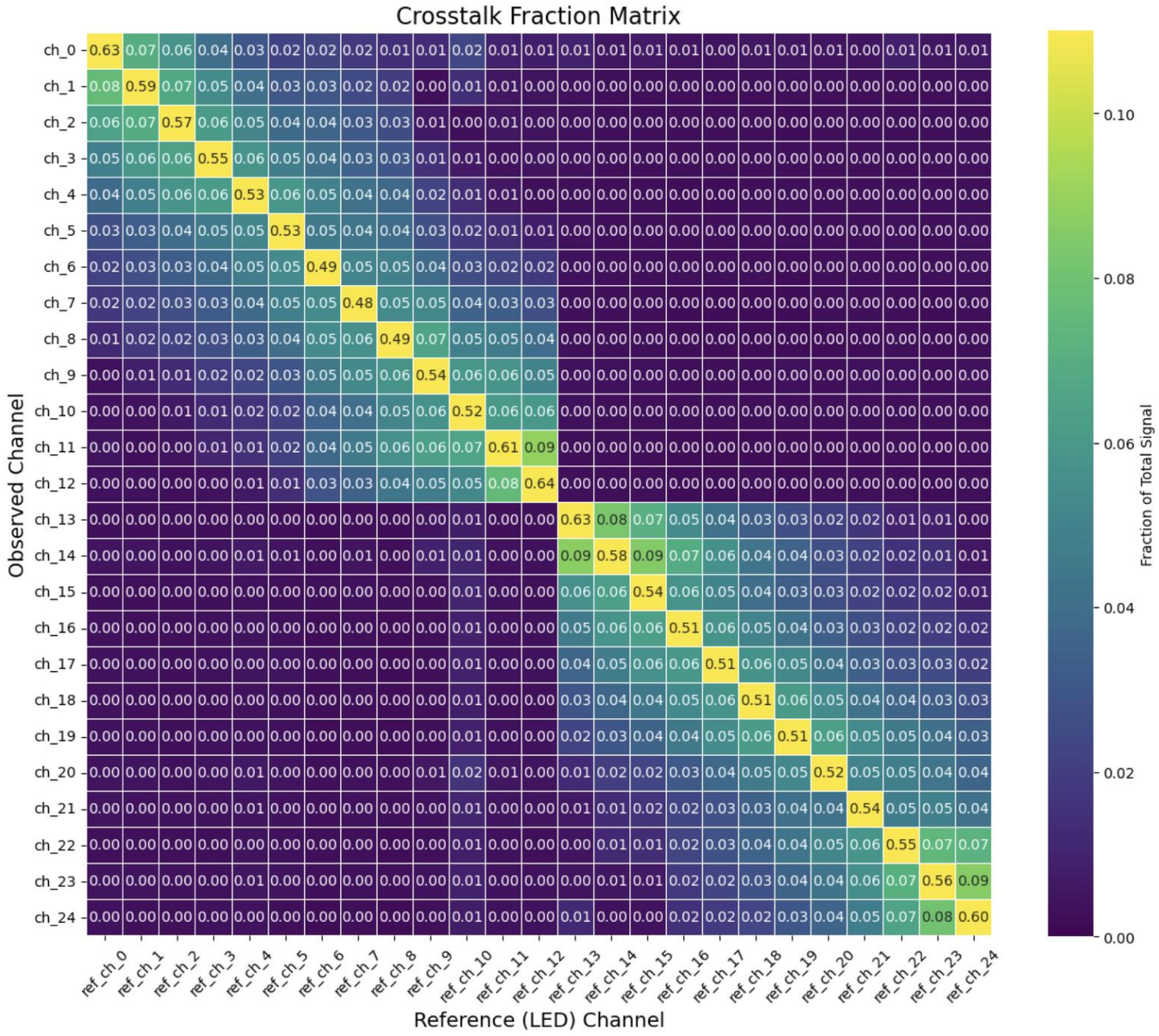
- After pedestal subtraction, the LG readout of each channel is brought to the MIP scale using

$$E_i = E_{LG,\,i} * \text{Avg MIP}_{HG} * \text{HG LG Ratio}_{\,i}$$

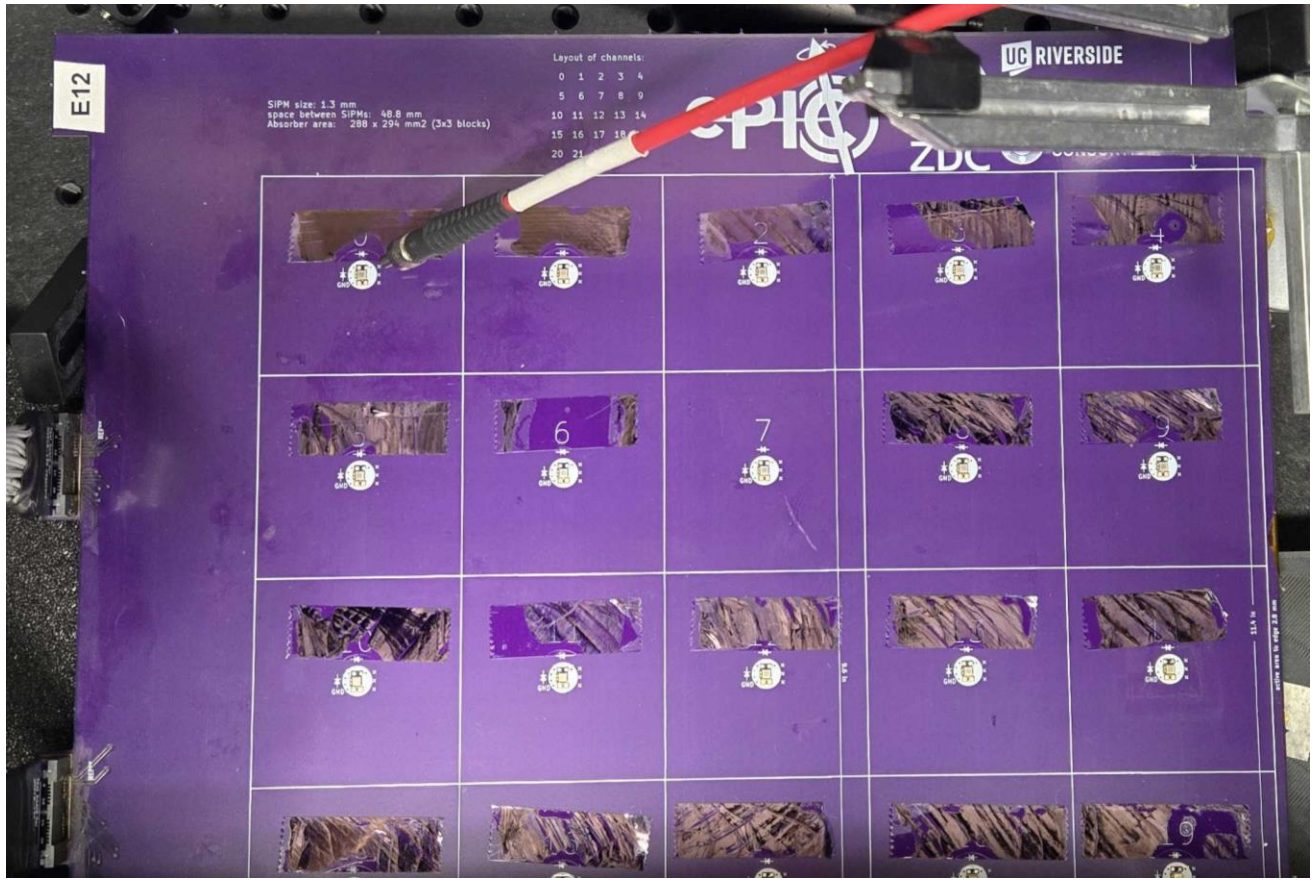
- Factor of 0.8 was applied to the MIP calibration to agree with simulation, likely from large angular distribution of cosmic rays

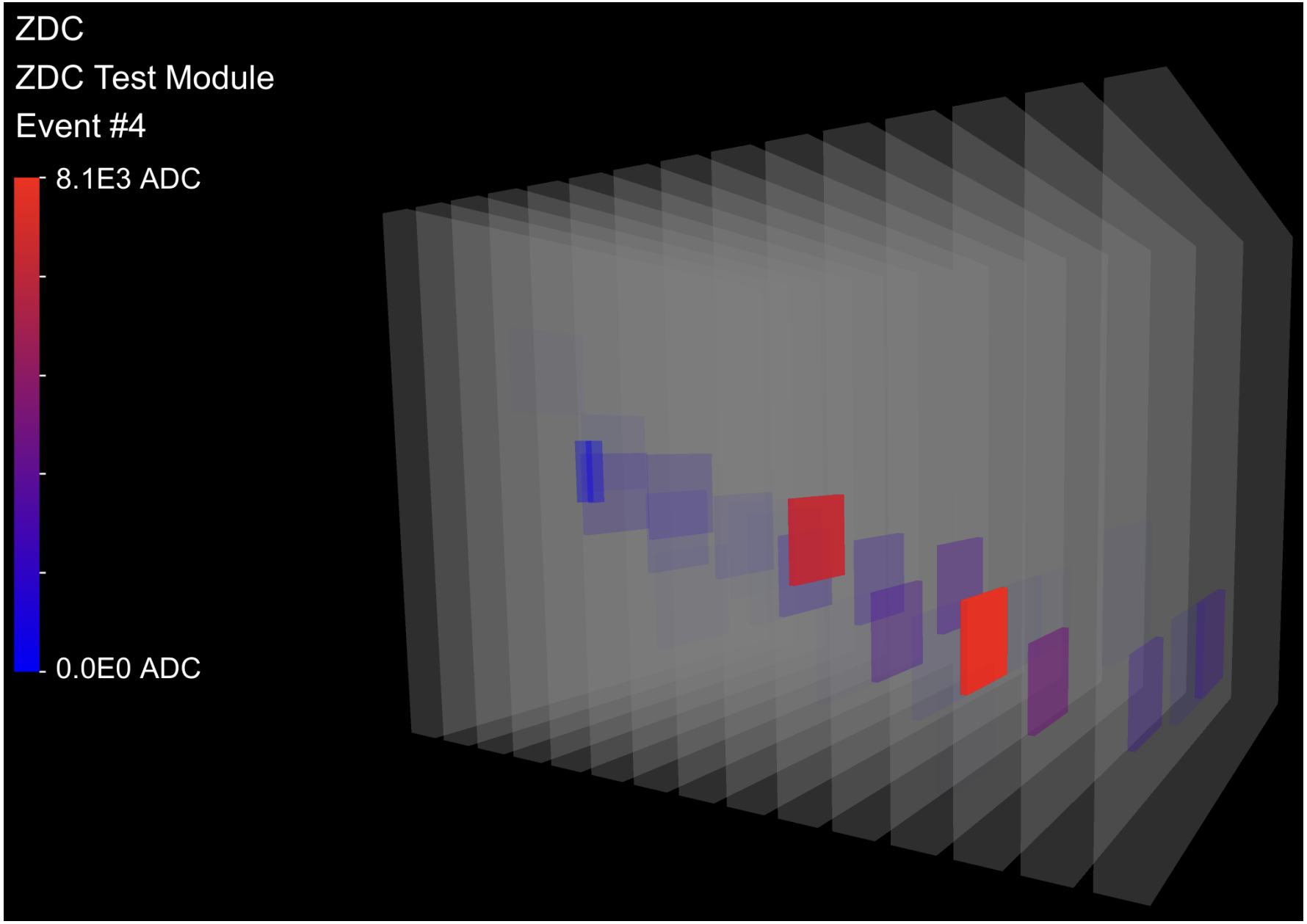
Electrical Cross-Talk

- After a careful inspection of the pedestal region and HG/LG ratios, we found electrical cross-talk to have a very significant effect
- A “map” of cross-talk effects was determined from bench-top LED tests, imposed on simulation
- The unshielded ribbon cables were found to be the source



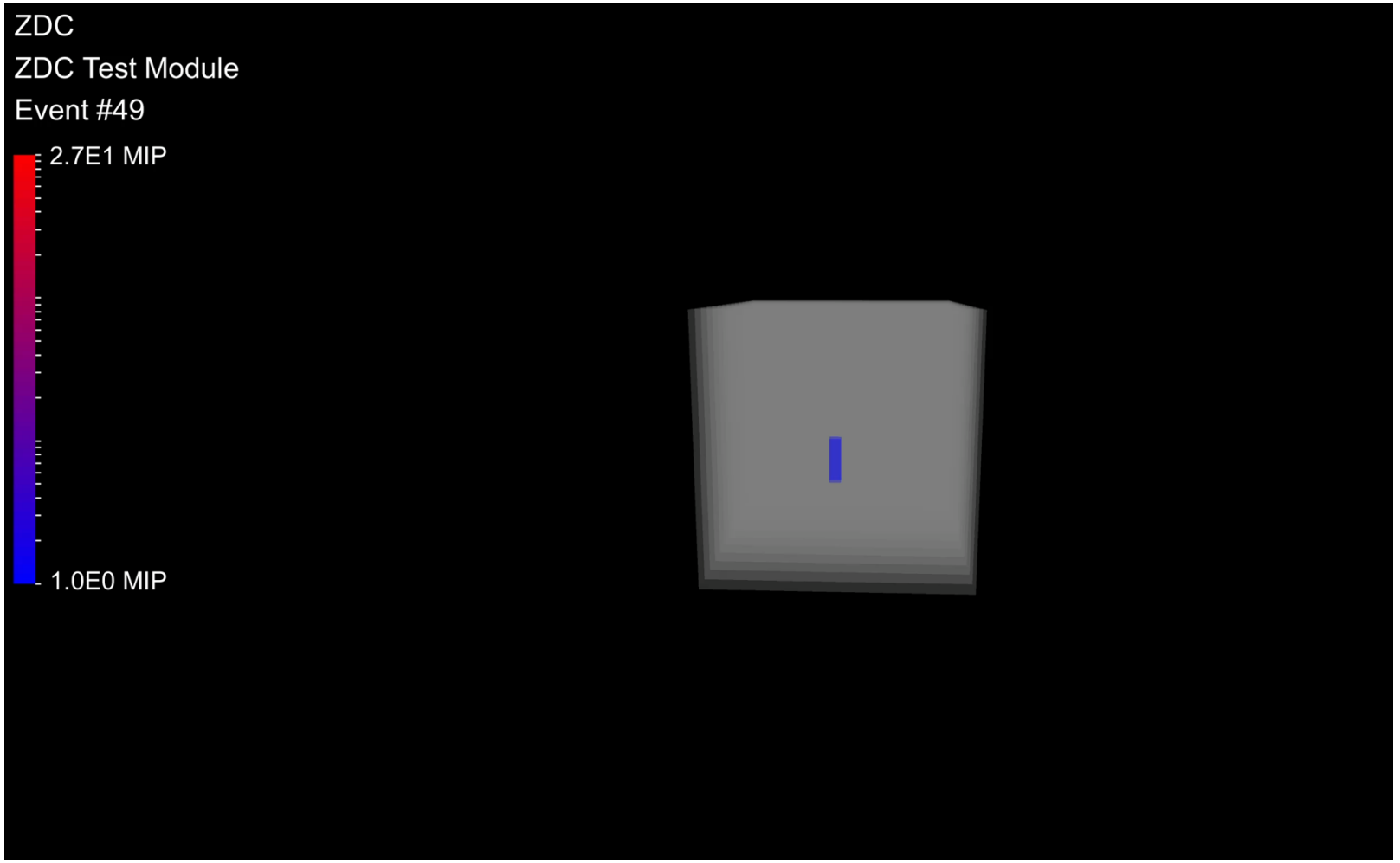
- An LED light source was pulsed into each channel to determine what fraction of the signal is distributed into the other channels
- The other channels were covered with black out fabric to prevent optical cross-talk
- When the ribbon cable was peeled apart, the cross-talk entirely went away





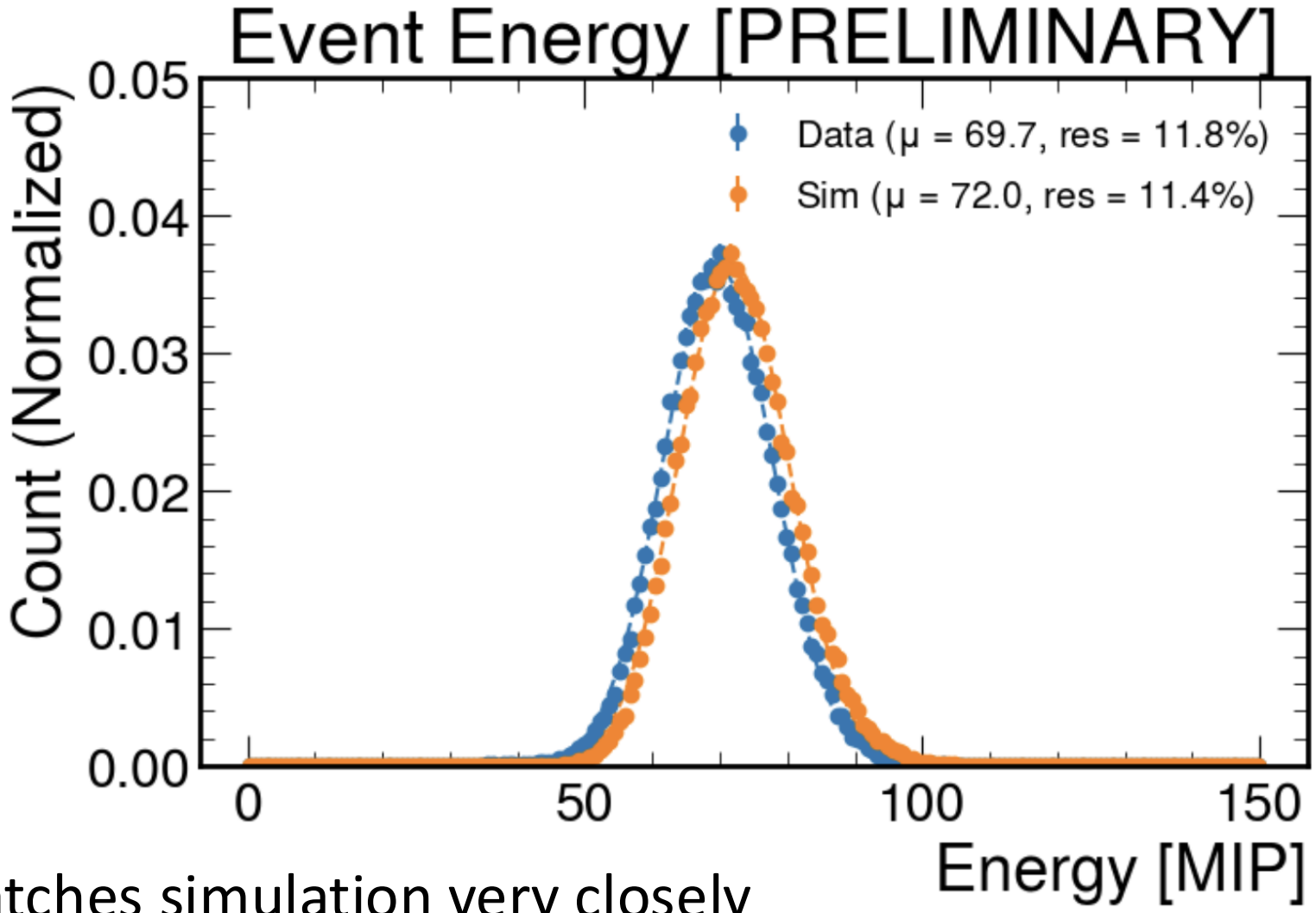
- Cosmic ray track reconstruction verifies event building

Preliminary Results

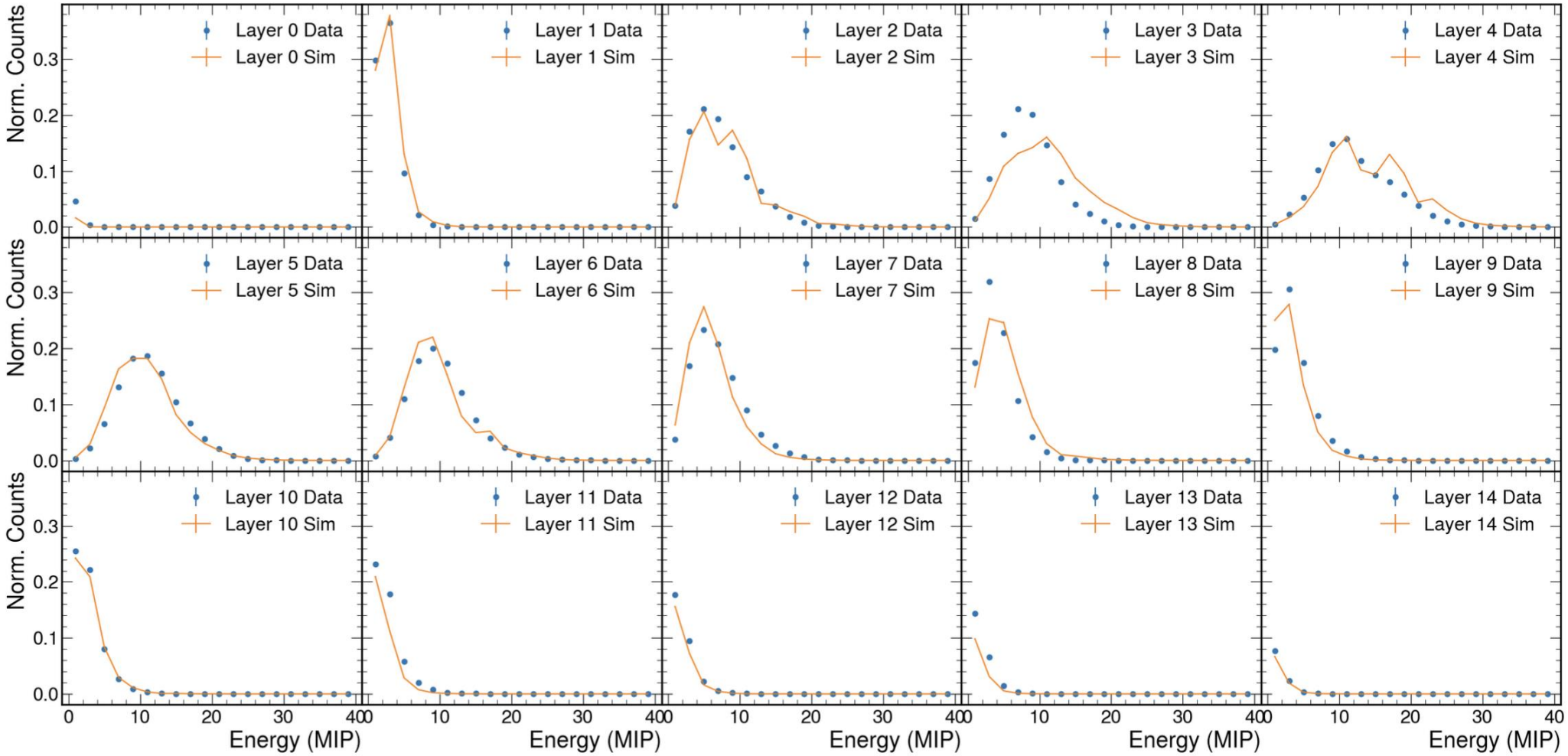


- Results are compared with a DD4HEP simulation of 5 GeV positrons
- 1.0 MIP hit energy cut applied to both simulation and data
- Initial estimate of 3-degree incident angle, 1 cm vertical shift

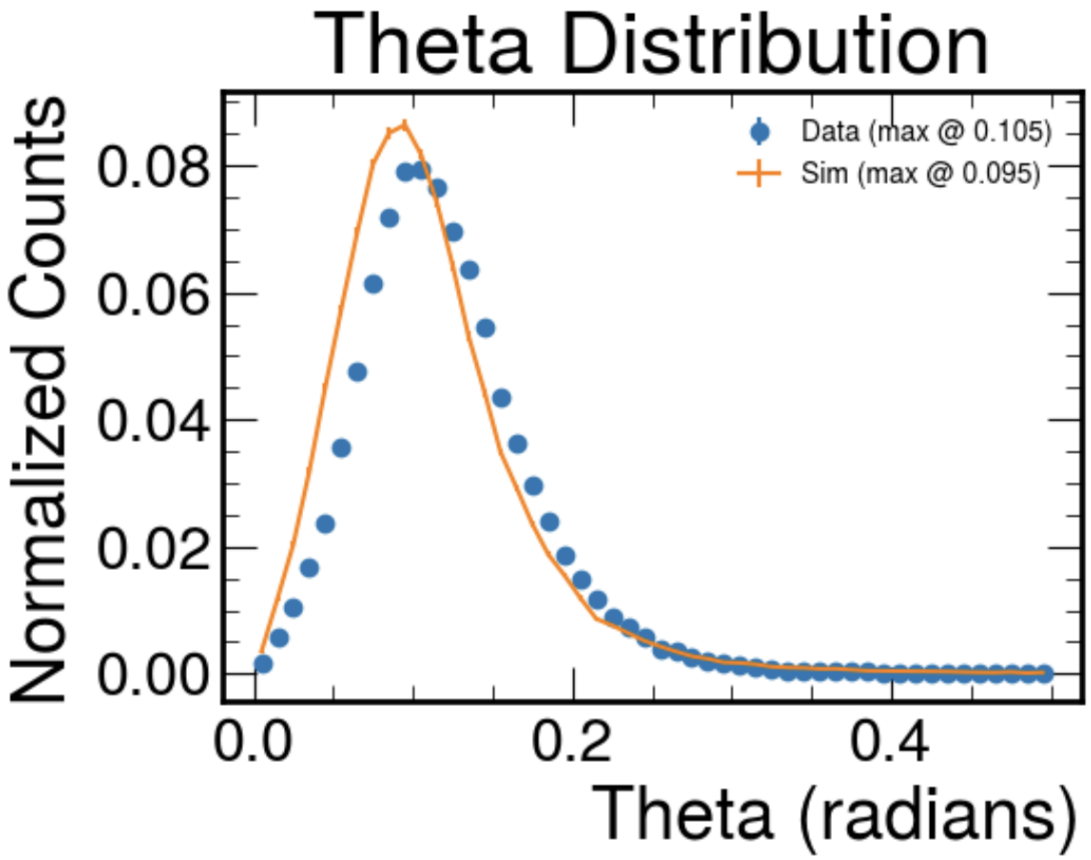
Preliminary Results

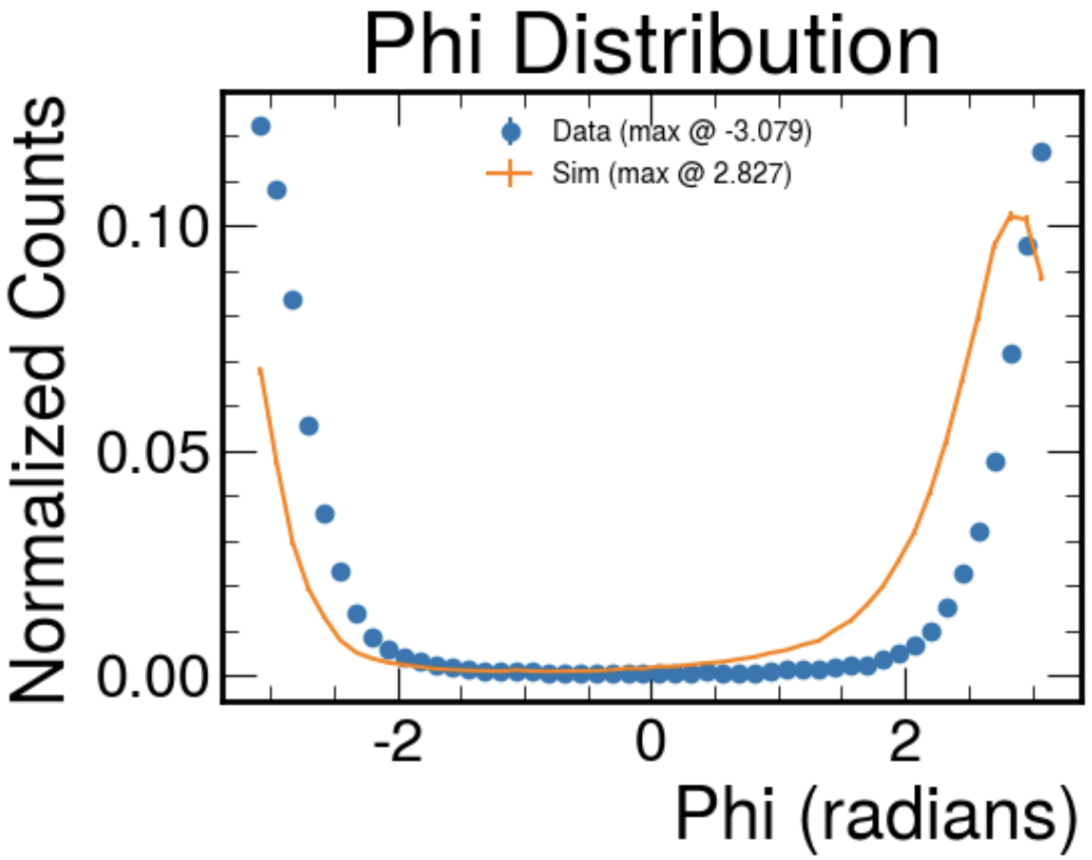


- Energy resolution matches simulation very closely
- Extra MIP calibration factor of 0.8 needs to be verified

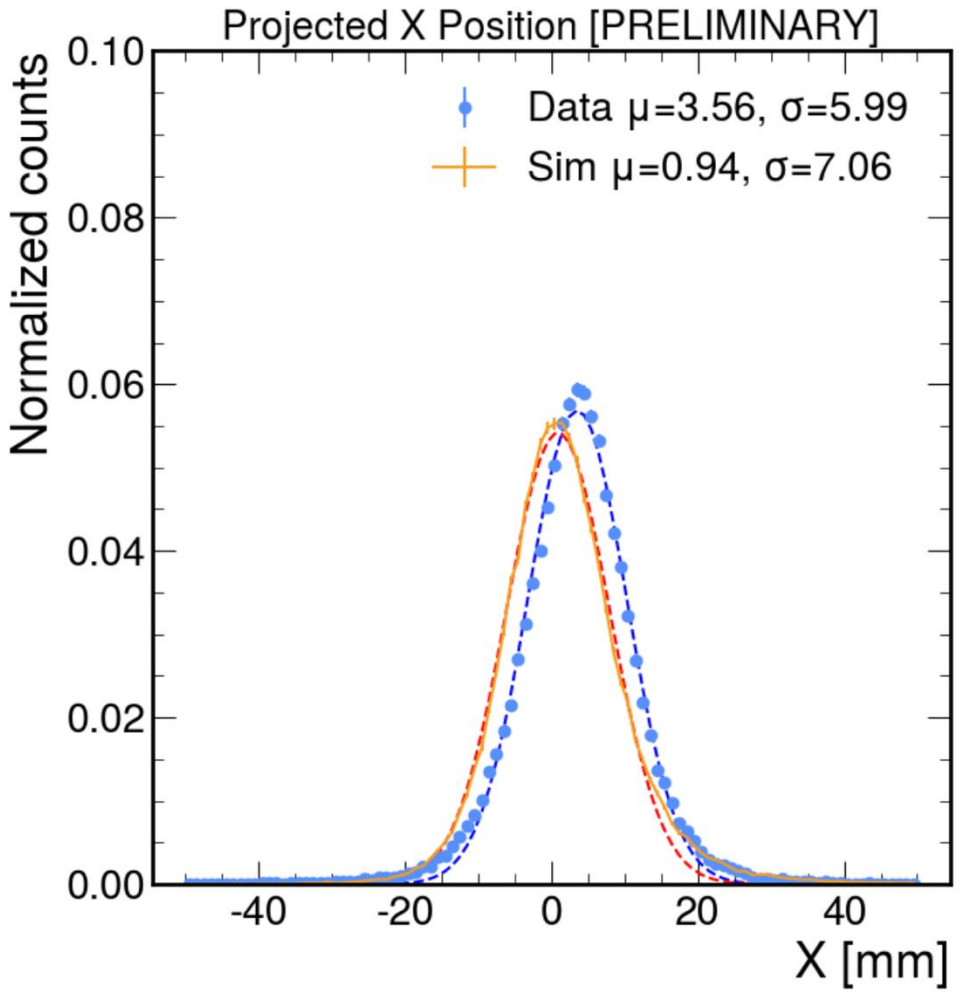


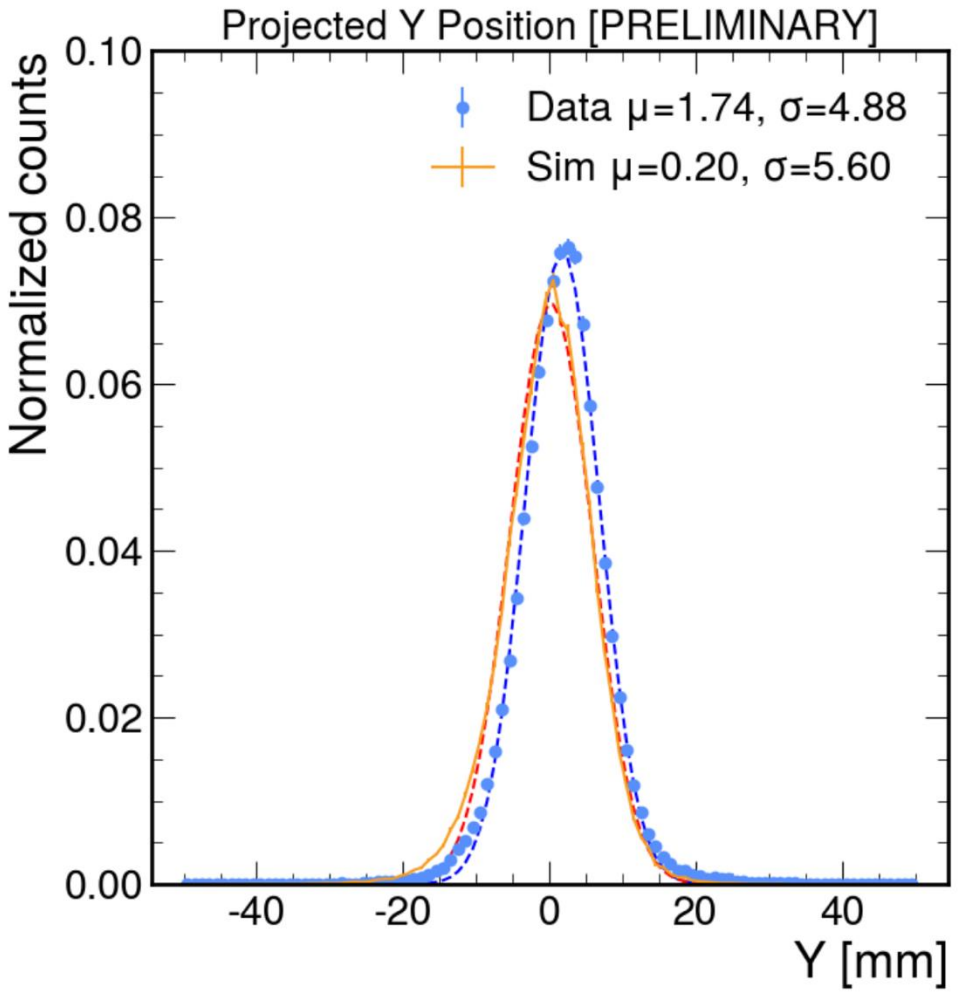
- Layer energy distributions match reasonably well, need to inspect layer 3 more





- Theta distribution used to determine a 3-degree incident angle
- Phi angle can be tuned further in the simulation





- Horizontal trigger window / vertical beam spread effects subtracted in quadrature from the data
- Position resolution agrees to ~1 mm

Next Steps

- Implement HEXPLIT clustering algorithm to take advantage of the staggered layer design of the detector
- Simulate angular distribution of cosmic rays for proper MIP calibration in the simulation
- Analyze full dataset, analyze different settings configurations
- Design final ZDC PCB
  - Connectors will be routed out of the top instead of the side
  - Each layer will be three vertical strips instead of four quadrants