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

Weibin Zhang

2023-11-07

arXiv > physics > arXiv:2309.00818

Search...

Help |

Physics > Instrumentation and Detectors

[Submitted on 2 Sep 2023]

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

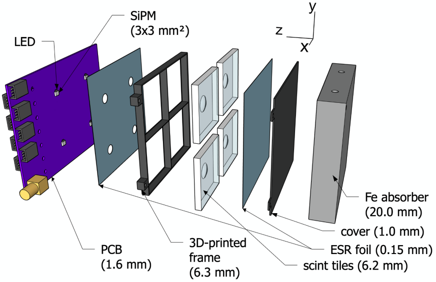
Miguel Arratia, Bruce Bagby, Peter Carney, Jiajun Huang, Ryan Milton, Sebouh J. Paul, Sean Preins, Miguel Rodriguez, Weibin Zhang

We recently proposed a high-granularity calorimeter insert for the Electron-Ion Collider (EIC) that uses plastic scintillator tiles read out by SiPMs. Among its innovative features are an ASIC-away-of-SiPM strategy for reducing cooling requirements and minimizing space use, along with employing 3D-printed frames to reduce optical crosstalk and dead areas. To evaluate these features, we built a 40-channel prototype and tested it using a 4 GeV positron beam at Jefferson Laboratory. The measure energy spectra and 3D shower shapes are well described by simulations, confirming the effectiveness of the design, construction techniques, and calibration strategy. This constitutes the first use of SiPM-on-tile technology in EIC detector designs.

Introduction

- Proof of concept 40-channel prototype of the Calorimeter Insert
- Beam test in Hall D at JLab on Jan 23, 2023
- $\sim$ 4 GeV positrons
- Testing two innovations:
  1. ASIC is away from SiPM (unlike CALICE/CMS) NIMA.2022.167866
  2. 3D printed frames are used to define megatiles and suppress optical crosstalk JINST 18 P05045

Prototype

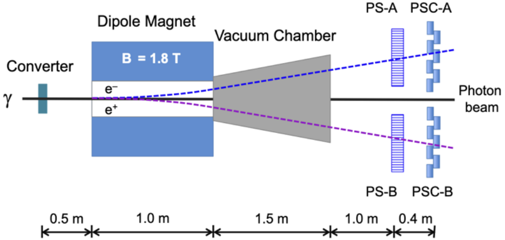


- 10 sampling layers
- 2 cm Fe absorber (1.1 X_0)
- Scintillating tiles sandwiched between a pair of ESR foils
- A plastic frame to suppress optical crosstalk
- 3×3 mm^2 SiPM

Scintillating Tiles

- 4 square layers (0-3) + 6 hexagonal layers (4-9)
- 9.5×9.5 cm^2 transverse active area
- Square tiles measured 22 cm^2 and hexagonal ones 13 cm^2

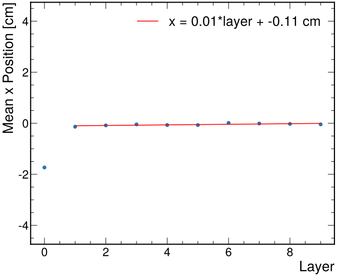
Experimental Setup

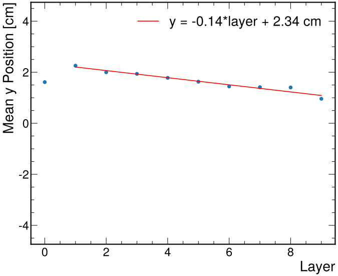


Prototype

- Positrons from the Pair Spectrometer (PS) in Hall D
- No tracker in front
- Separated DAQ and trigger system: CAEN FERS-5200 + laptop

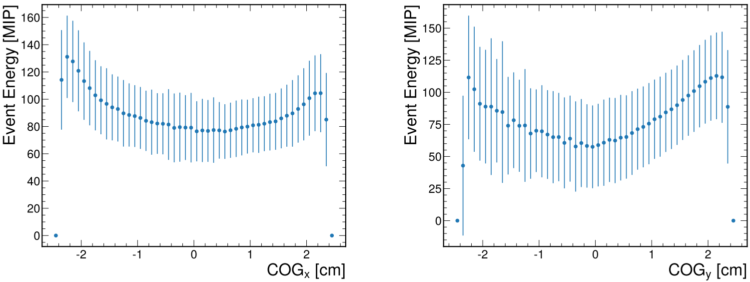
Data Characteristics: Energy Weight Layer X/Y Mean





- A slope is seen in the Y direction
  - The incoming beam is slightly tilted in the Y direction
  - The incoming beam is shifted in the Y direction

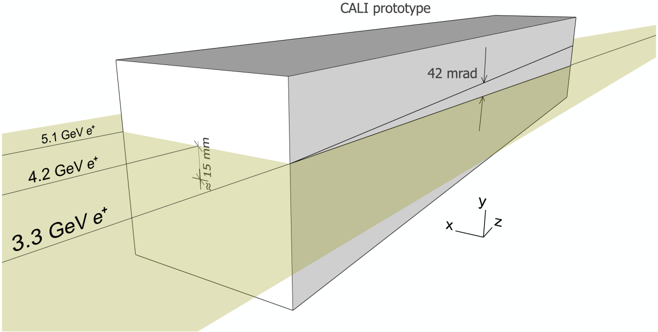
Data Characteristics: Event Energy in Different Positions



$$\mathrm{COG} = \frac{\sum_i E_i \cdot \vec{X}_i}{\sum_i E_i}$$

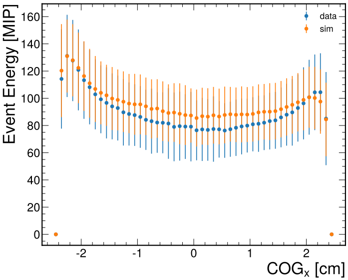
- COG roughly indicates the impact parameter
- Beam energy changes along X

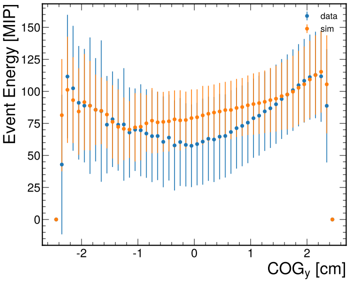
Fine Tuned Beam Conditions in the Simulation



- Beam is spread in the X direction due to the PS
- Beam is shifted about 15 mm up the prototype center with a tilt polar angle of $40 < \theta < 44$ mrad
- Beam energy is linearly dependent on the X position

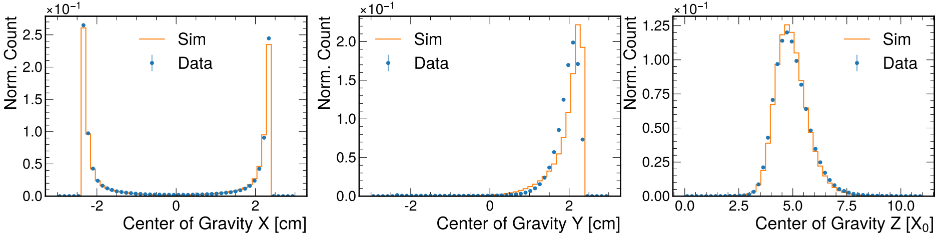
Simulation





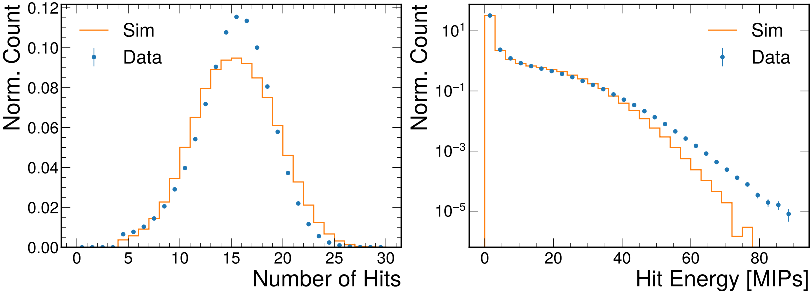
- DD4HEP framework
- Digitalization, and pedestal mean and width measured from data
- Tuning of the beam energy spread to mimic the actual beam profile

Result: 3D Shower Shape – Center of Gravity



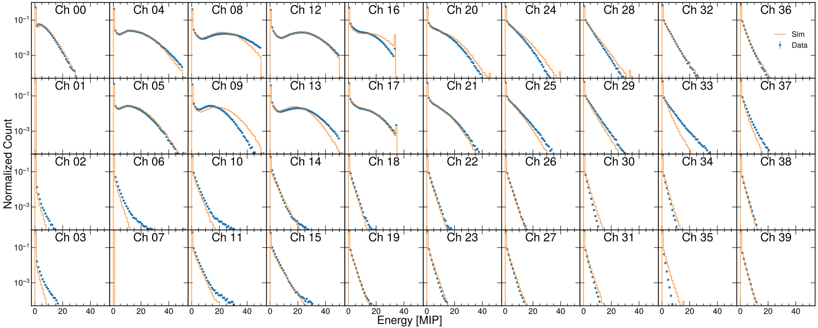
- Nearly perfect match in the X and Z directions
- Symmetric pattern in the COG X plot, indicating a flat and evenly spreaded beam in the horizontal plane
- Single peak in the COG Y plot means shift and tilt angle in the vertical plane

Result: Hit Multiplicity and Energy



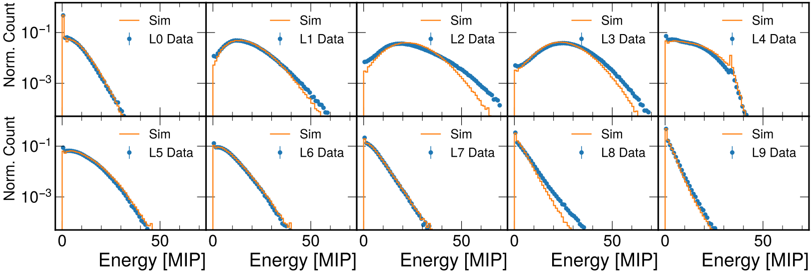
- Due to the tilt angle, showers extend to nearby cells in the same column after about the fourth layer
- Good aggrement between data and simulation in the low- and mid-energy region in the hit energy spectra

Result: Cell Energy



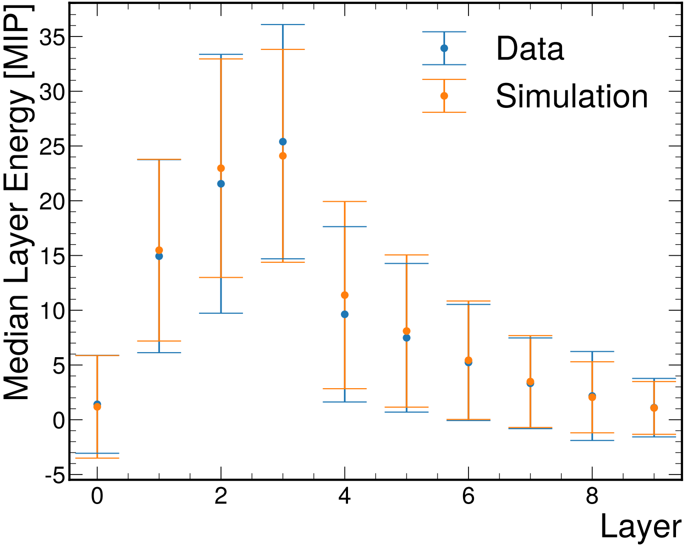
- Channel 01 and 07 were dead due to non functioning cables
- The ending spikes in channels 16 and 17 were due to a cap set by the CAEN unit
- Good aggrement between data and simulation
- The mismatches in channels 09 and 16 possibly came from wrong MIP scales in these 2 channels

Result: Layer Energy



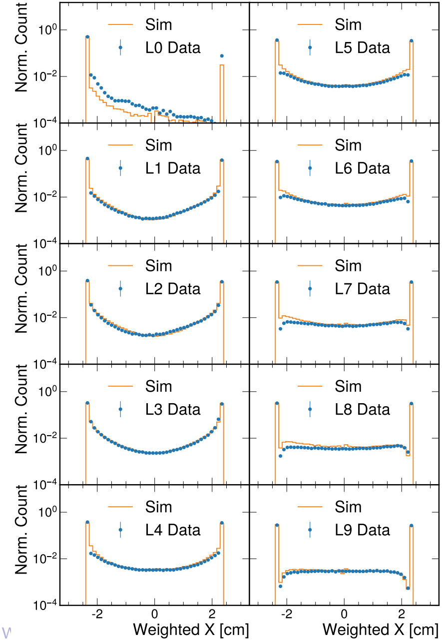
- Most showers happen in the first 4 layers
- The kink in layer 4 results from the capping effect observed in channels 16 and 17

Result: Layer Energy Median and RMS



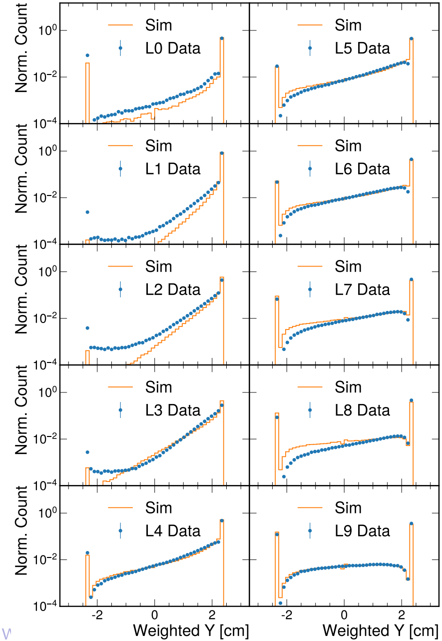
- Not only the median values (markers), but also their RMS (error bars) overlap with each other

Result: Energy Weighted Layer X



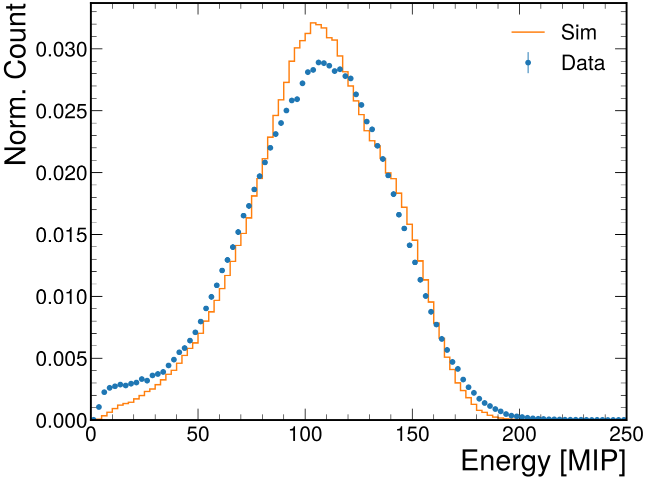
- Excellent match in the X distribution, except in the first layer due to a dead channel in that layer

Result: Energy Weighted Layer Y



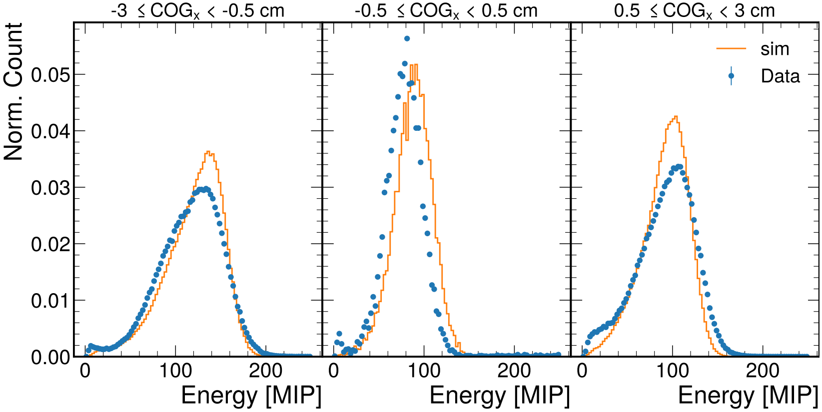
- Good match in the Y distribution
- No optical crosstalk was simulated, so the good agreement in energy weighted positions indicates that optical crosstalk was suppressed in data

Result: Total Energy



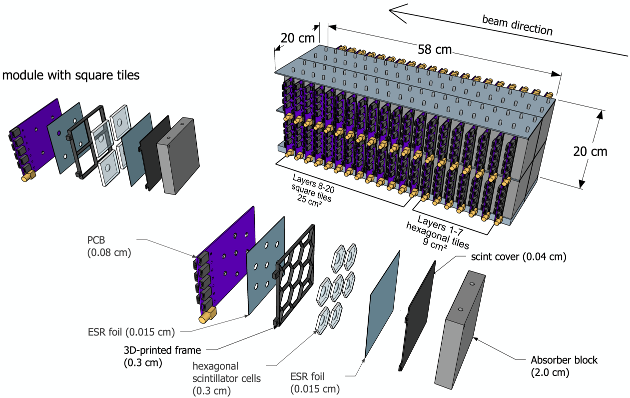
- Simulation agrees with data in both mean and width
- Beam energy spread dominates the width of the event energy distribution

Result: Energy Distribution Dependence on Shower Position



- Resolution for centred beam is significantly better
- Energy leakage on both sides

Generation-II Prototype



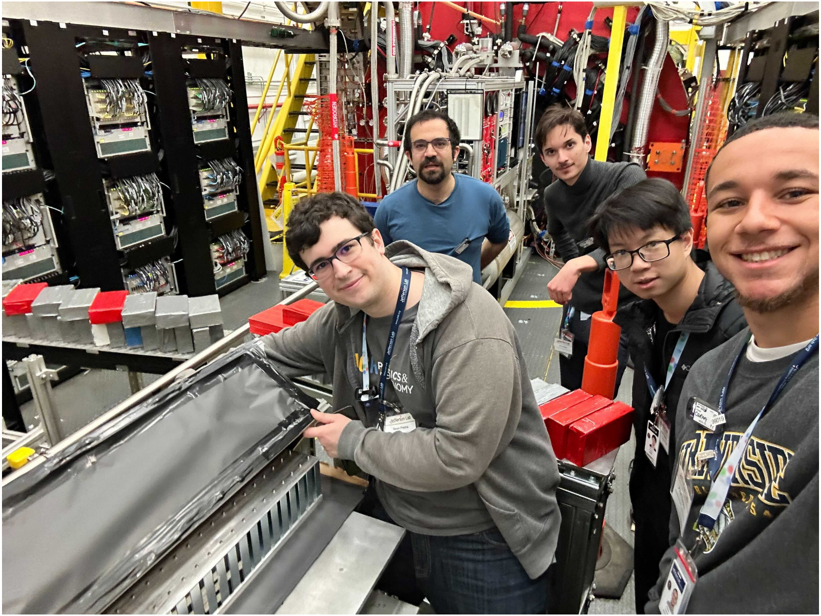
- 40 channels scaled up to 400 channels
- Hexagon cells + square cells
- Beamtest in BNL next year

Summary

Our paper: arXiv 2309.00818

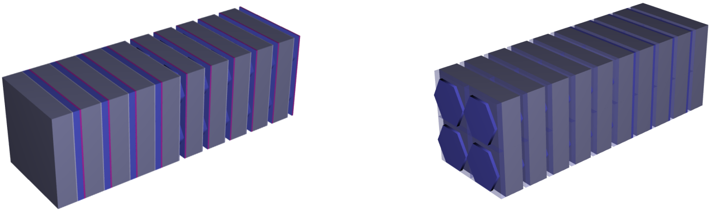
- Construct and test a proof-of-concept prototype of the Calorimeter Insert
- Explore the feasibility of the ASIC-away-of-SiPM/SiPM-on-tile strategy
- Test the 3D printed frame idea for the first time, which effectively suppress optical crosstalk
- Carry out 3D shower shape analysis, which is reasonably described by simulation
- Develop expertise and insights for scaling up the Calorimeter Insert
- Next generation prototype and beamtests are on the way

Thank You



Backup

Geometry in Simulation



- 4 layers of square cells + 6 layers of hexagonal cells
- absorber + scintillator cover + ESR foil + scintillator tile + frame + ESR foil + PCB

Event Selection

For Data:

- Extract pedestal for each channel using dedicated pedestal runs, apply this pedestal cut for all data

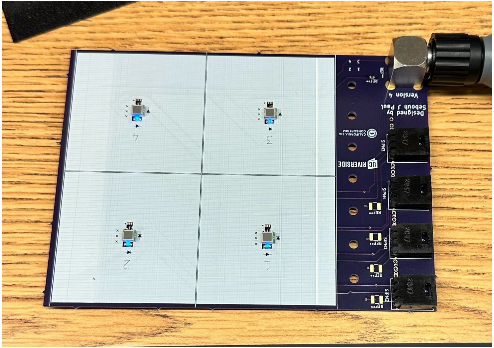
For both data and simulation:

- Extract MIP scale for each channel using cosmic runs and muon simulations
- Convert ADC signals to MIP scale values

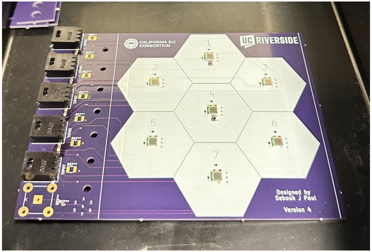
$$E_i[\mathrm{MIP}] = \frac{(E_i[\mathrm{ADC}] - \langle \mathrm{pedestal} \rangle_i[\mathrm{ADC}])}{\mathrm{MPV}_i[\mathrm{ADC/MIP}]}$$

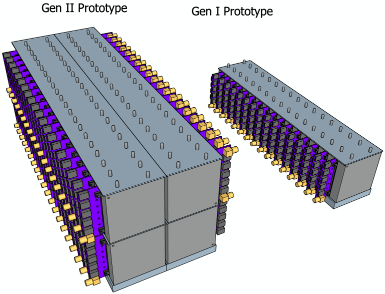
- $E_i > 0.3\ \mathrm{MIP}$

Gen-I Board



Ongoing Work





- Smaller hexagonal cells (~ 9 cm^2)
- Refined machining of the cell and the dimple
- Annealing of scintillators to relieve mechanical stress