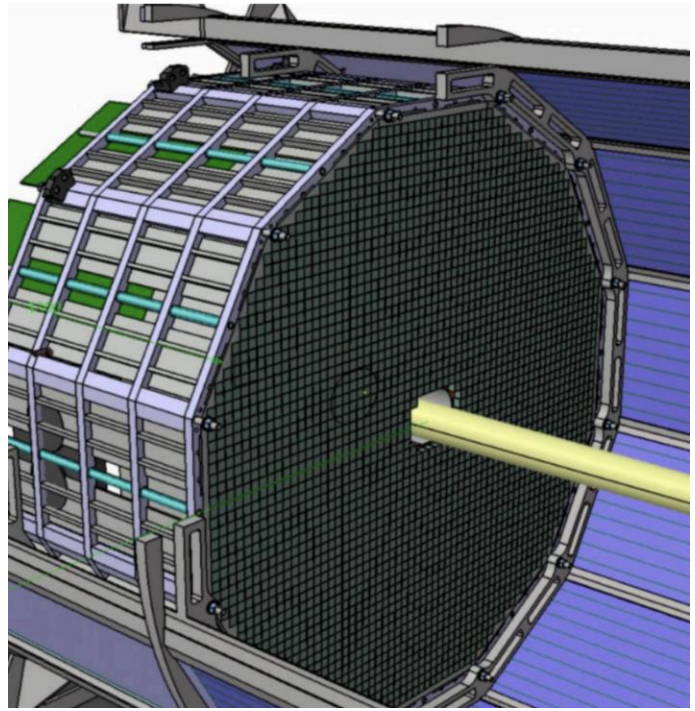
ePIC EEEMCal Test Beam Analysis

EIC Users Group Meeting, July 15th 2025

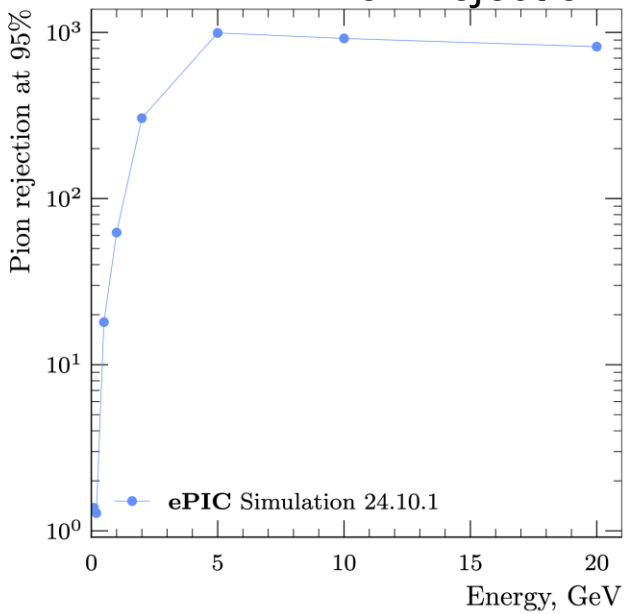
Tristan Protzman
Lehigh University

Electron Endcap Electromagnetic Calorimeter

- Captures the scattered electron in low Q^2 events
  - Electron at small angles to beam line
  - Crucial for defining kinematics in DIS events
  - Requires excellent energy and position resolution
    0.05 - 18 GeV dynamic range
  - Target resolution: $\frac{\sigma_E}{E} \approx \frac{2-3\%}{\sqrt{E}} \oplus 1-2\%$
- Separate electrons and pions
  - In low x events, the final hadronic state is in the backwards direction as well as the scattered electron
  - Excellent pion rejection at high energy to identify DIS electron



Pion Rejection

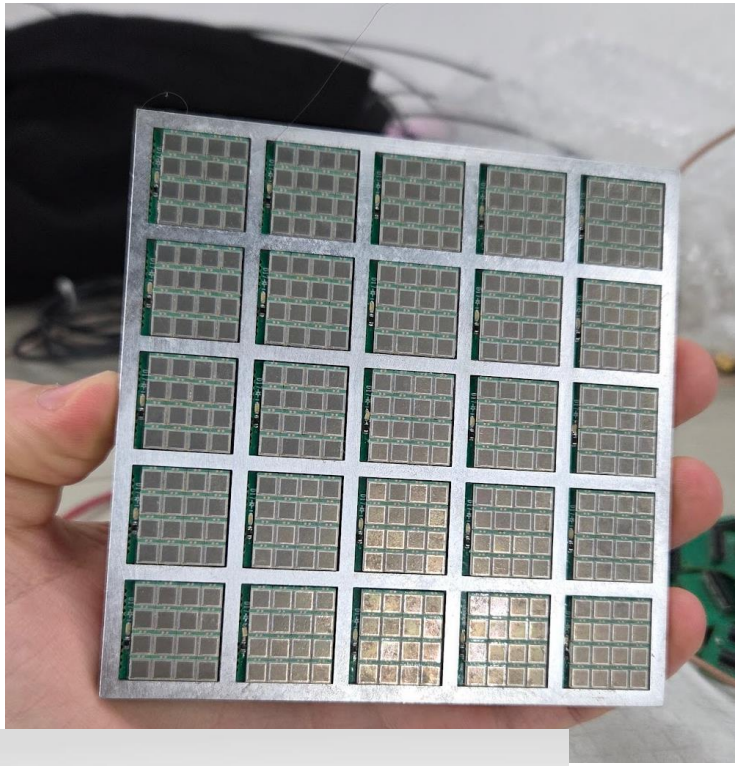


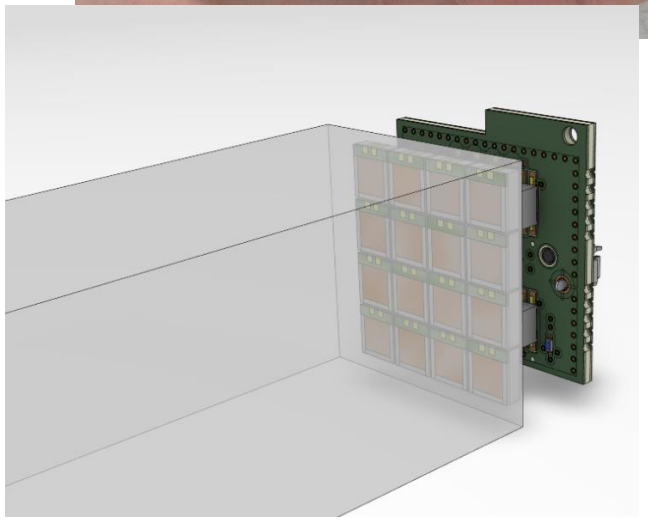
EEEMCal crystals

- To maximize the performance, a homogeneous calorimeter was selected
- Composed of lead tungstate (PbW04) crystals
  - High optical clarity
  - Short radiation length (~0.83 cm)
  - Small Moliere radius (~2 cm)
  - Moderate light yield
- Each crystal is 20 cm long and 2x2 cm on its face
  - 22 radiation lengths in total, and the crystal size matched to the Moliere radius
  - Crystals are individually wrapped in reflective material to maximize the signal and isolate from neighboring crystals
- The light yield of the crystal has a strong temperature coefficient
  - ~2% per degree Celsius

EEEMCal readout

- To cover the wide dynamic range and sensitivity to small signals, SiPMs have been selected for the readout
  - Hamamatsu S14160-3015PS
  - 3x3 mm with 15 μm pixels
  - Work in strong magnetic fields
  - Test bean done at 42 V bias
- Coupled directly to face of crystals with an optical grease
- Multiple readout configurations are being investigated
  - Tradeoff between capacitance and channel count





EEEMCal readout

16 Individual

- 400 total channels
- 530 pF per channel

4 in parallel

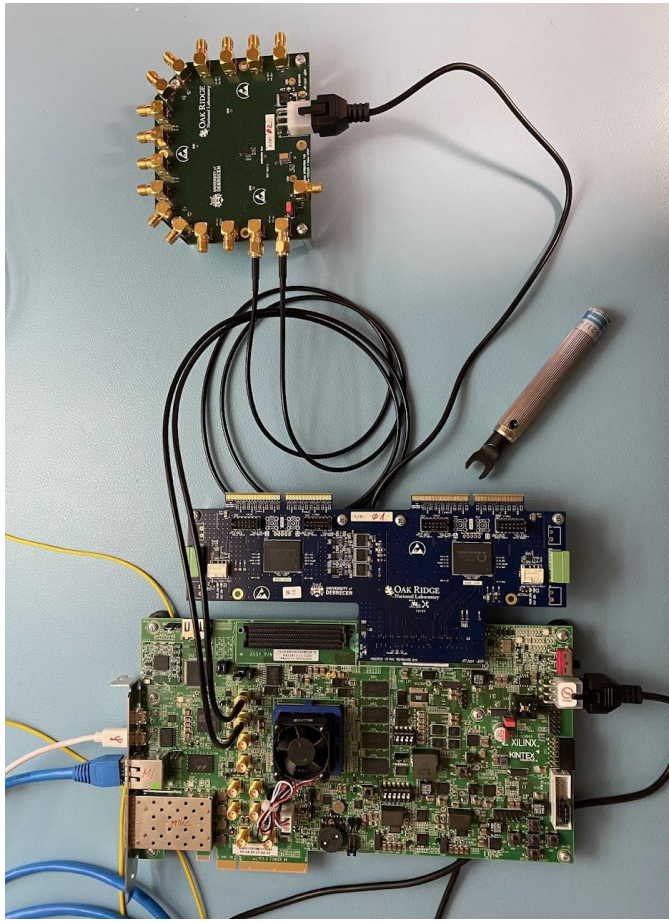
- 100 total channels
- 2120 pF per channel

16 in parallel

- 25 total channels
- 8480 pF per channel

EEEMCal digitization

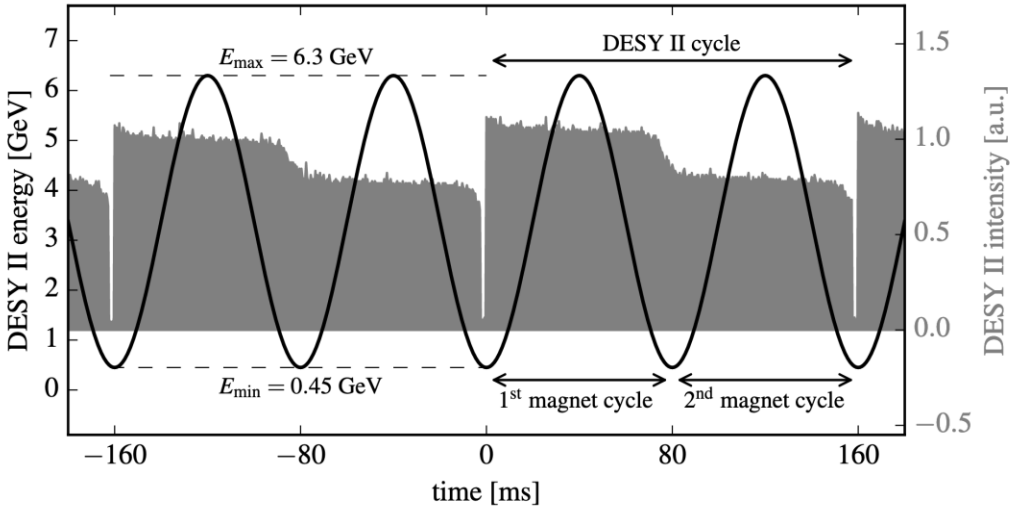
- ePIC digitization is based around the streaming readout concept
  - Recording constantly, not triggered!
- The EEEMCal as well as many other calorimeters will make use of the EICROC readout ASIC
  - ePIC specific implementation of HGCROC developed for CMS HGCal
  - 40 MHz digitization
  - Large dynamic range through through combination of ADC and time-over-threshold measurement
- A prototype utilizing a Xilinx KCU for readout was used for the EEEMCal test beam as well as several other

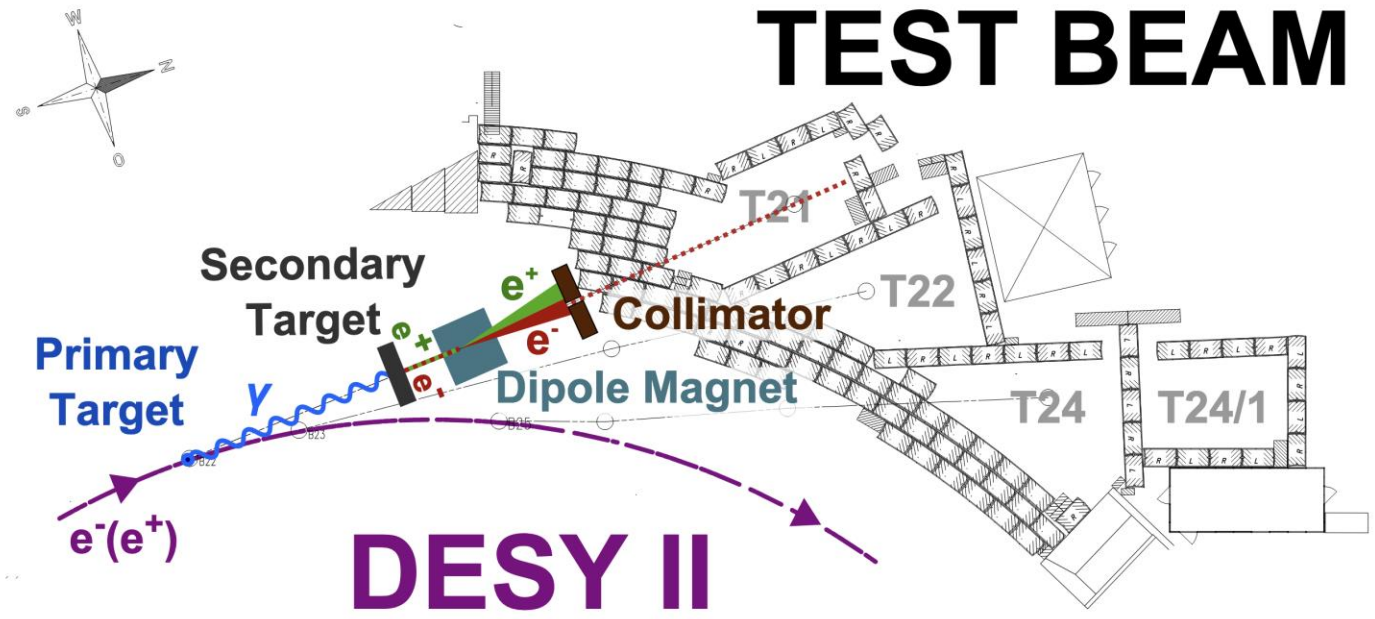


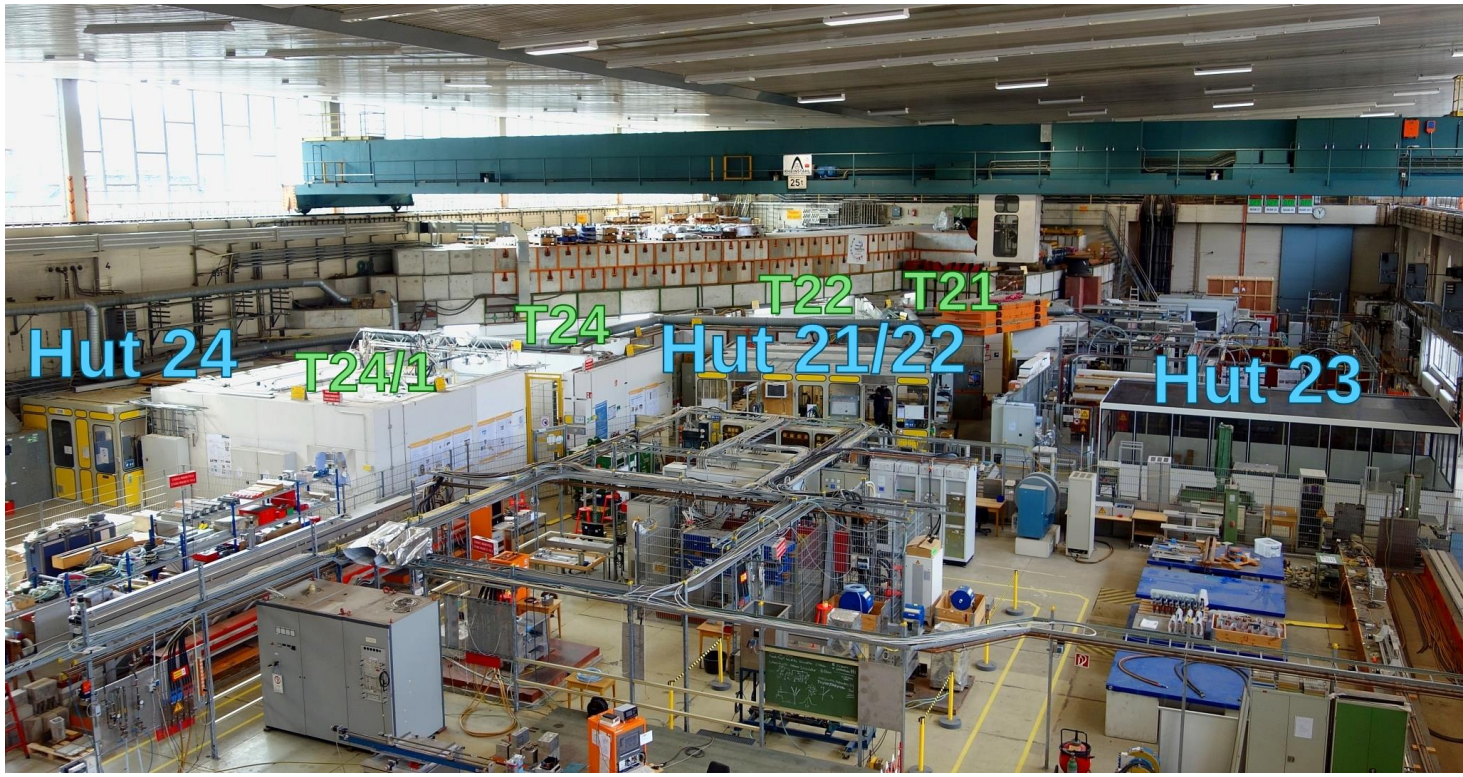
Test beam prototype

DESY II test beam

- DESY II is the electron synchrotron used as an injector into the PETRA light source
- Three test beam lines exit off it through a pair of conversion targets
- Dipole magnets allow the selection of electrons from 1 to 6 GeV

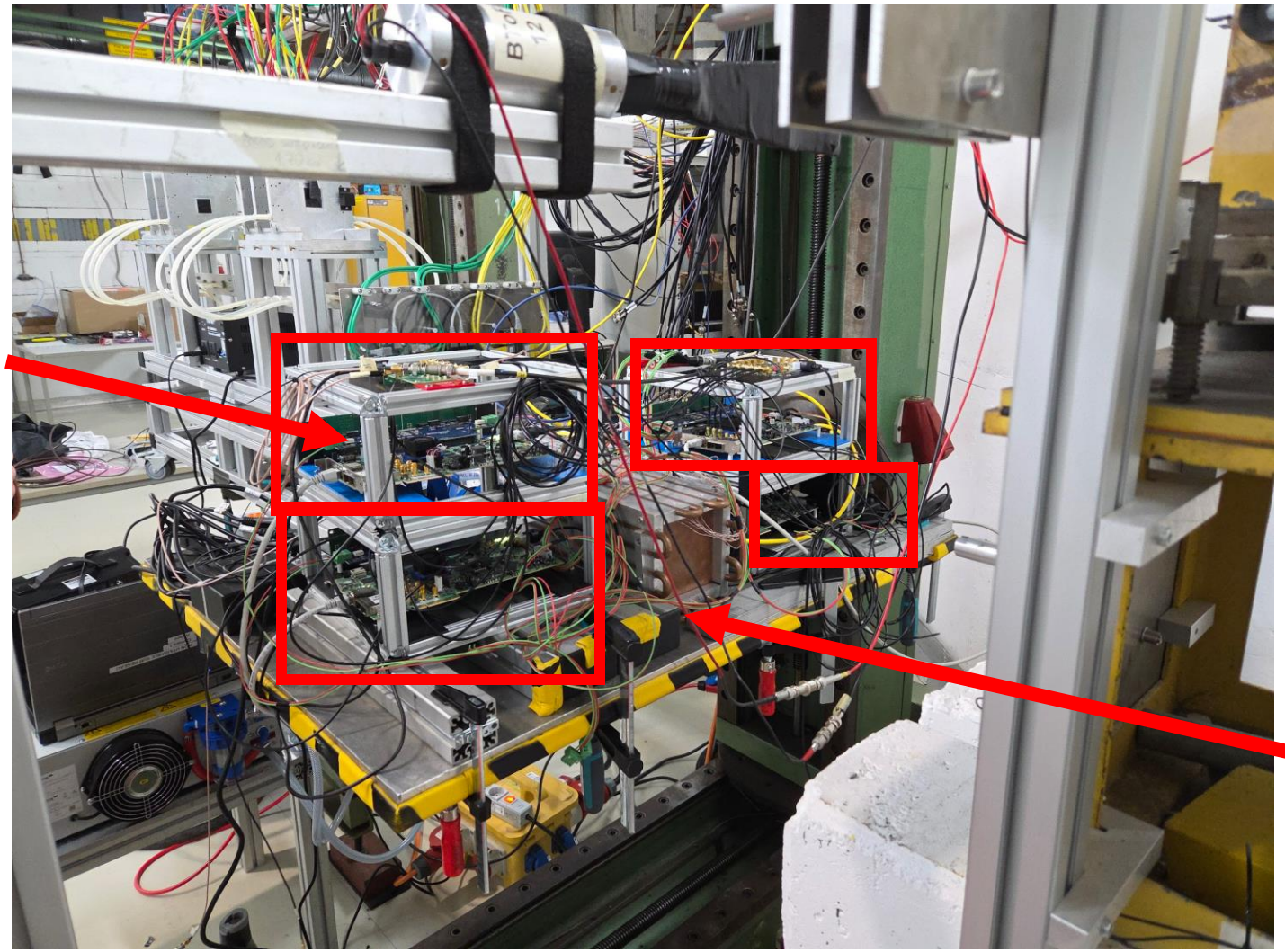






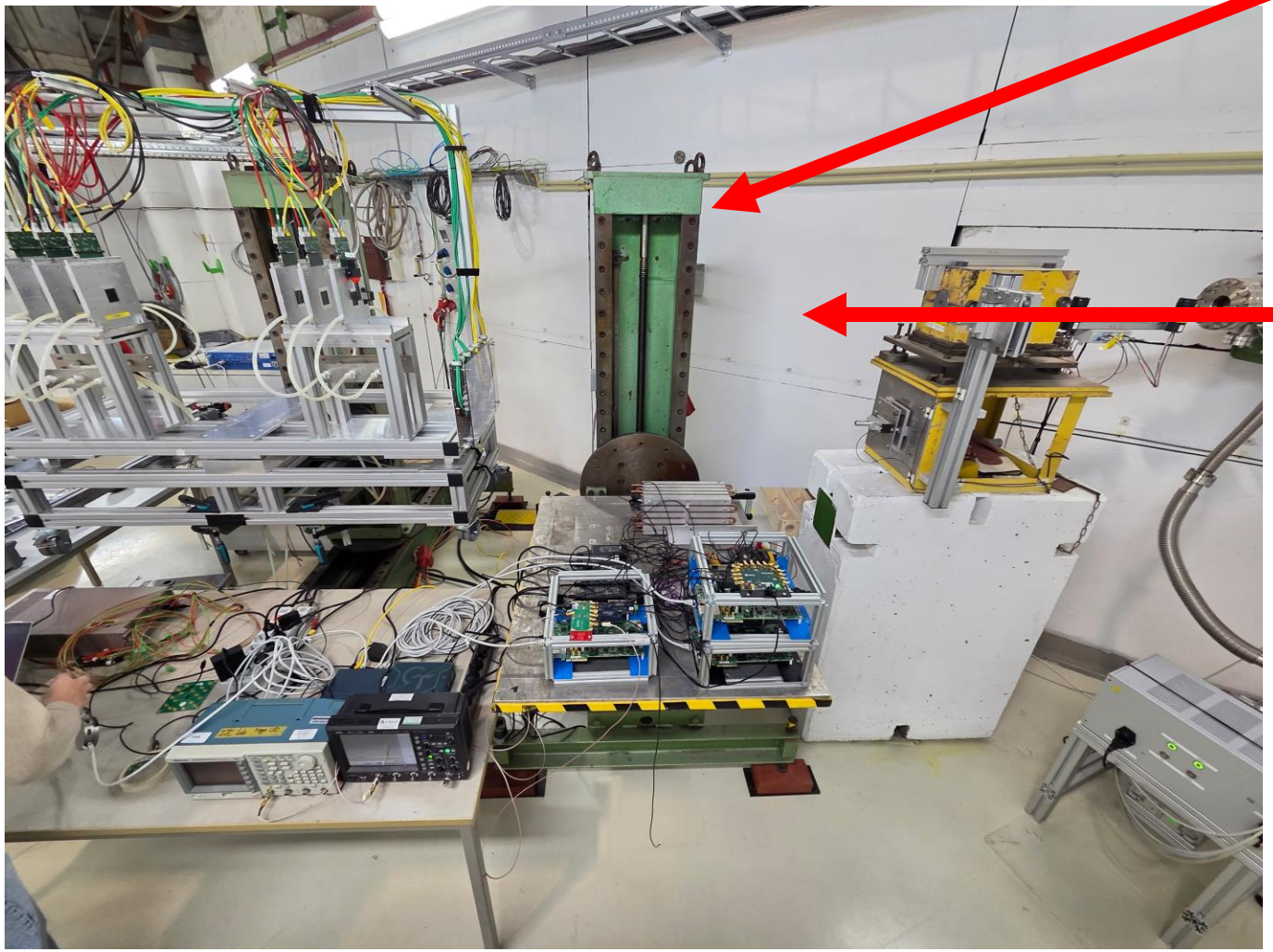
Calorimeter setup

4x KCUs with 2 HGCROC ASICS each



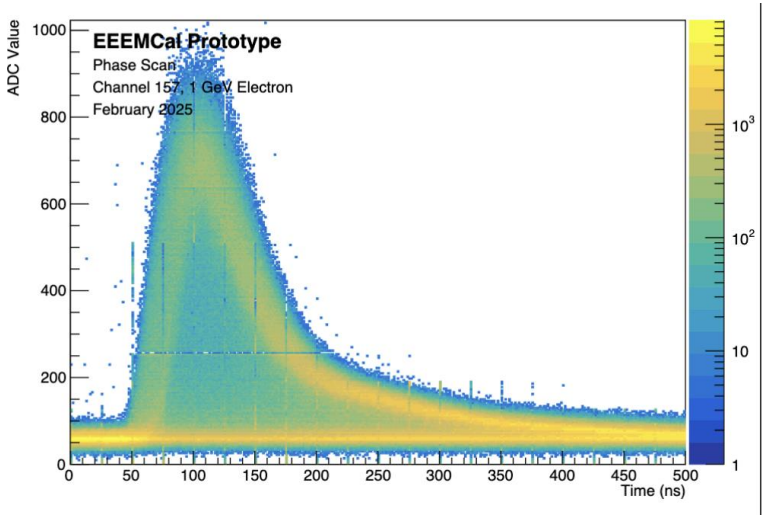
5x5 calorimeter

Calorimeter setup

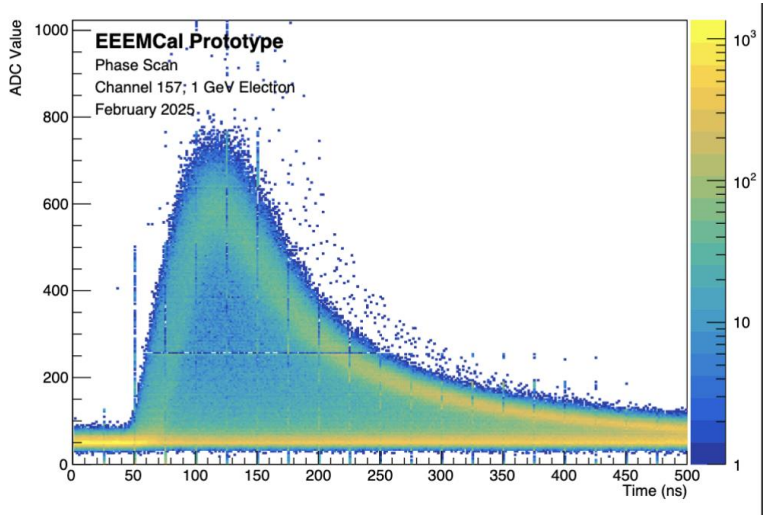


Signal shape

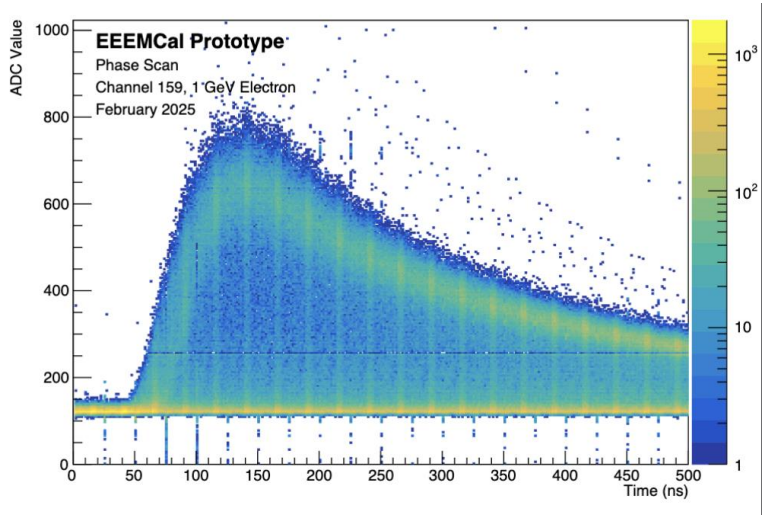
- HGCROC readout samples at 40 MHz, every 25 ns
- The phase of the readout can be stepped in increments of 1/16th to build a finer picture of the signal
- Demonstrates the effect that increased SiPM capacitance has



16 Individual



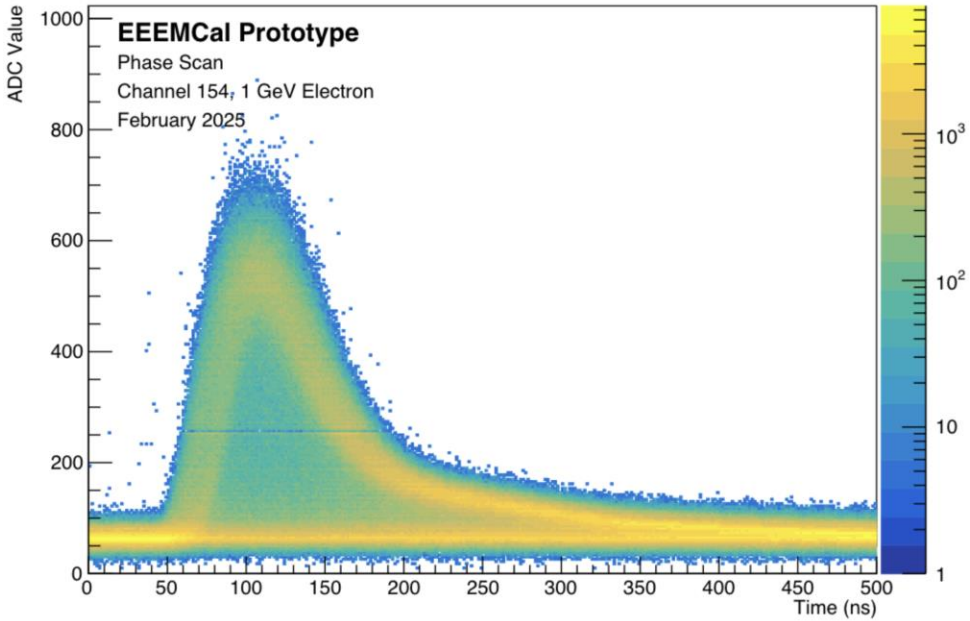
4 in parallel

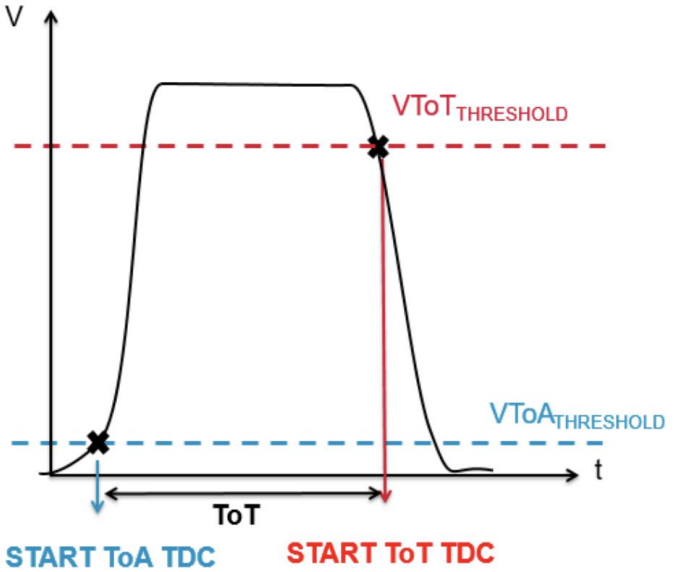


16 in parallel

Signal extraction

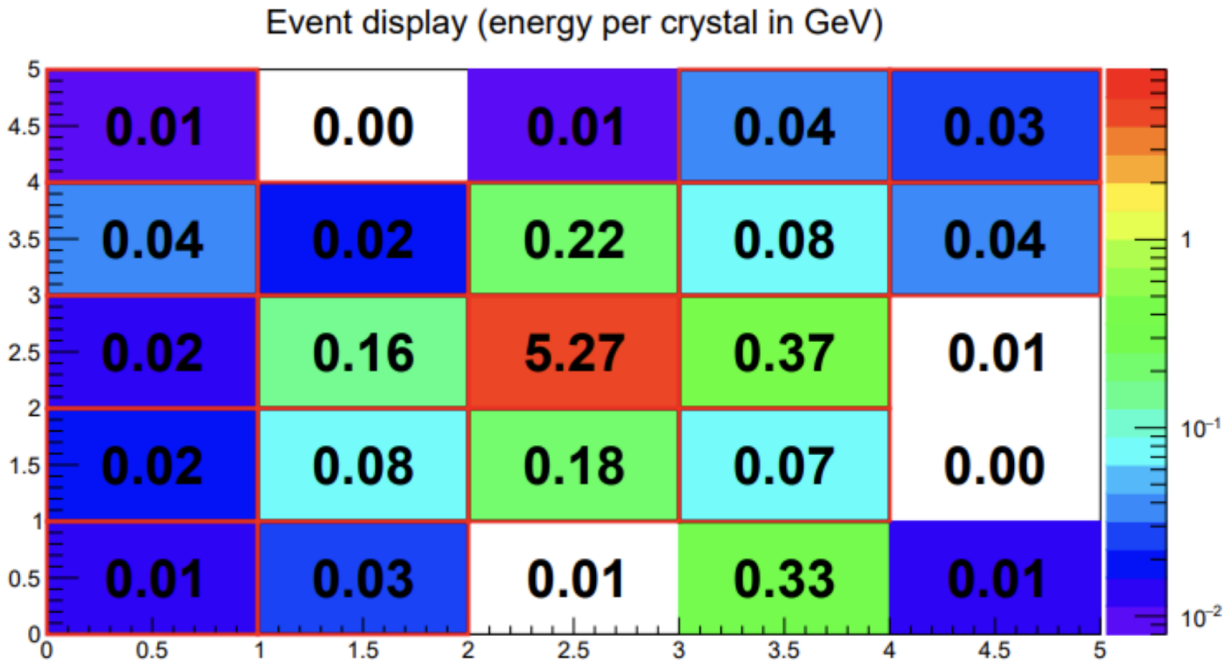
- Two types of signals to process
- ADC
  - Higher sensitivity to low energy events
  - Samples signal every 25 ns
  - Signal from $\mathrm{ADC}_{max} - \mathrm{ADC}_{ped}$, waveform fit, any number of strategies
- ToA/ToT
  - Expands dynamic range by measuring the time the signal is over some threshold
  - One value per “waveform” – most samples are 0
  - If there is a ToT measurement, the ADC measurement is invalid

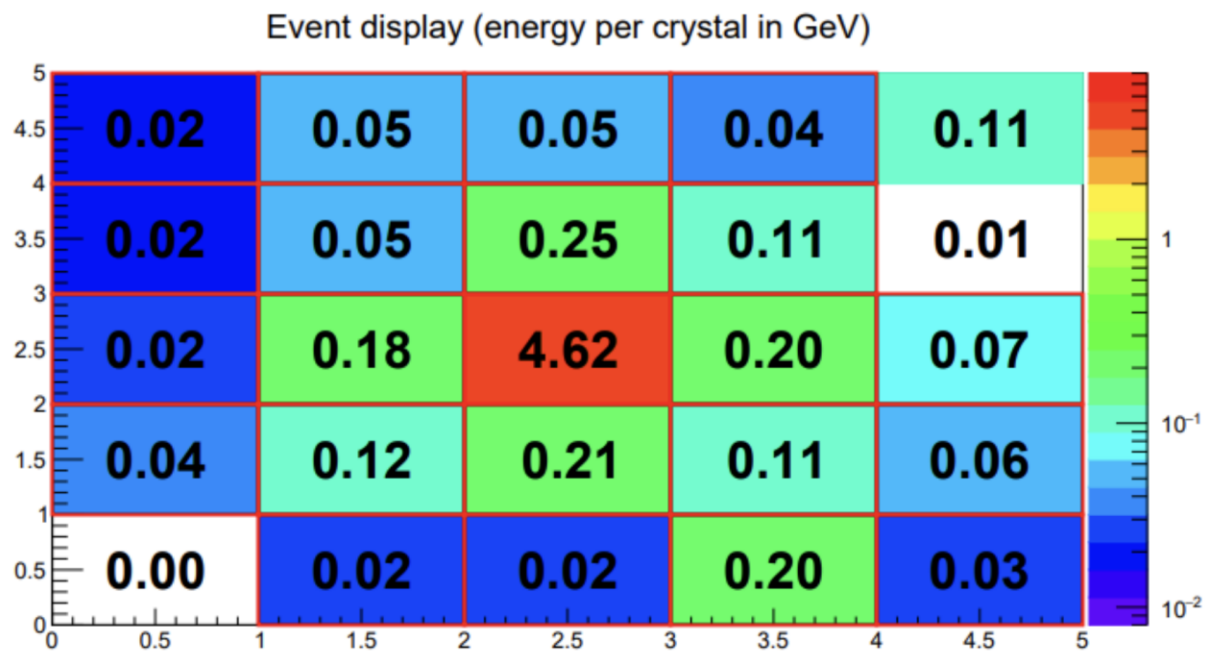




Full events

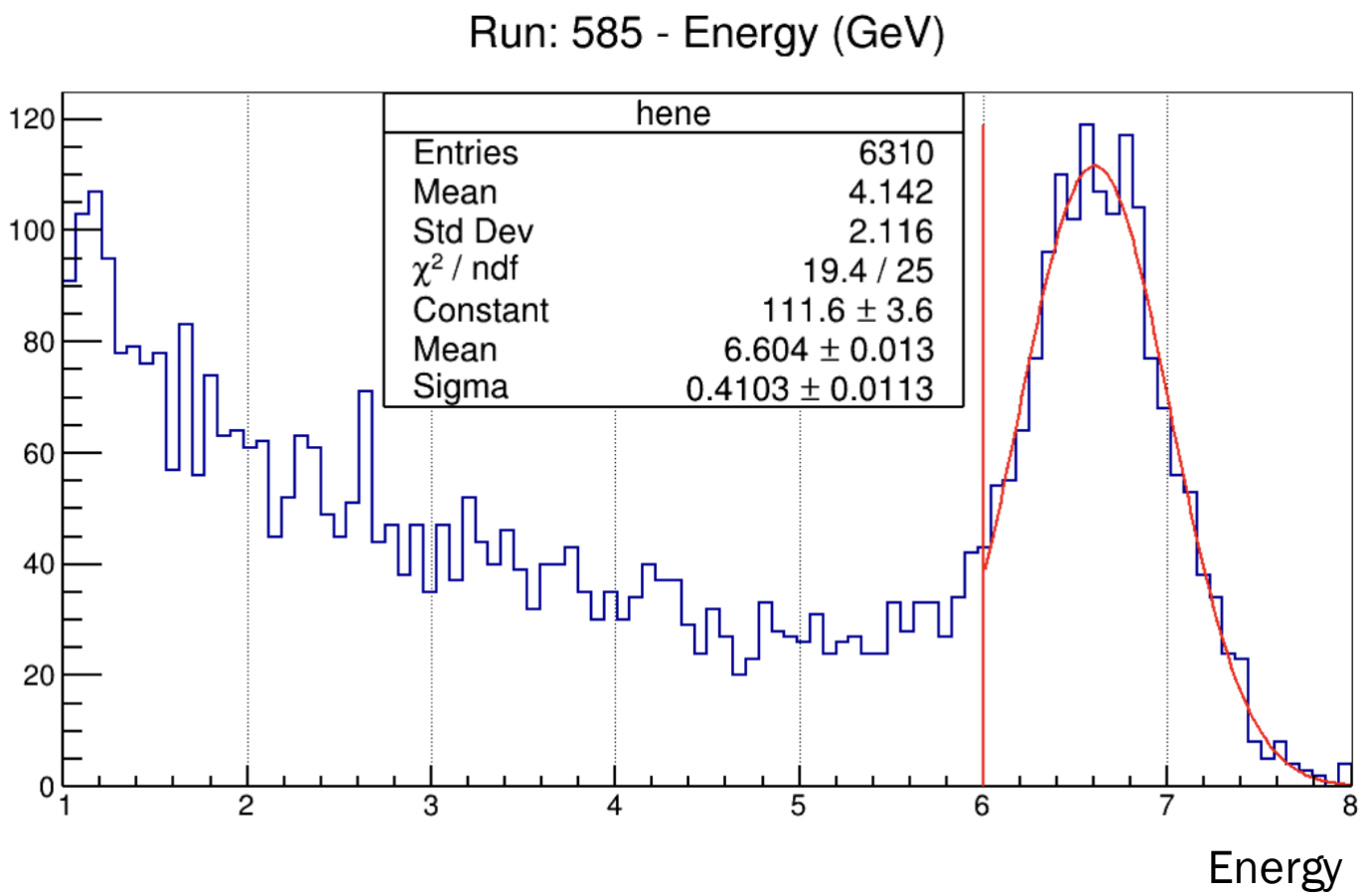
- Event displays show us how energy is distributed amongst the 25 crystals
- 5 GeV electron event
- Calibrations are still a work in progress





Energy resolution

- Current best energy resolution at 5 GeV is 6.2%
  - Far from the required 2%
- Very large low energy tail observed and under investigation
- Since the test beam, some improvements have been found
- A grounding issue between the HGCROC Protoboard and EEMCal backplane has been discovered
- A large ripple in the SiPM bias with the utilized power supply is observed



Conclusions

- A successful test beam at DESY was completed
- The analysis is still ongoing to understand the results
- Several improvements to come include better channel by channel signal shape and calibration and masking of bad channels
- The sources of the low energy background are being investigated and remedied
- Preparations are underway for a second test beam campaign later in the year

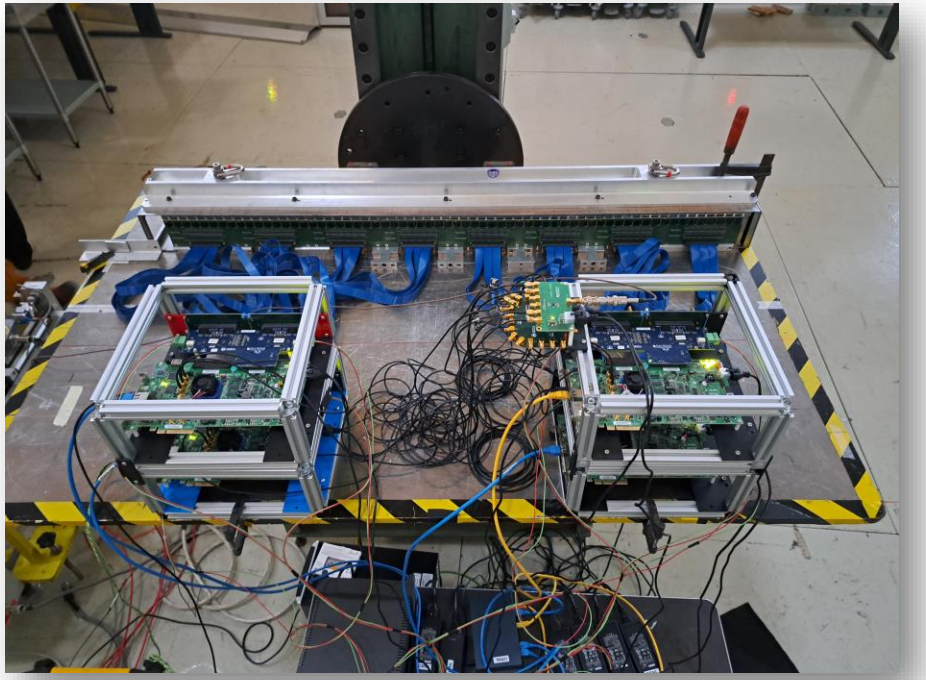
EEEMCal team

J. Bettane[1], E. Cline[8,9], J. Crafts[10], V. Chaumat[1], M. Czeller[4], C. Delafosse[1], P. Dinaucourt[6], C. Domingues Goncalves[1], F. Dulucq[6], P. Dumas Ziehlmann[6], R.H. Fatemi[14], J. Frantz[13], B. Geoffroy[1], A. Hoghmrtsyan[15], C. de La Taille[6], O. Le Dortz[5], D.K. Hasell[8], T. Horn[10,16], M. Imre[1], L.D. Isenhower[12], S. Jia[7], B. Mathon[1], H. Mkrtchyan[15], A. Migayron[1], R.G. Milner[8], C. Muñoz Camacho[1], G. Nagy[4], M. Nguyen[5], T. Nguyen Trung[1], N. Novitzky[3], S. Obraztsov[5], S. Olmo[1], T. Protzman[2], R. Reed[2], A. Shatat[5], D. Thienpont[6], G. Visser[11]

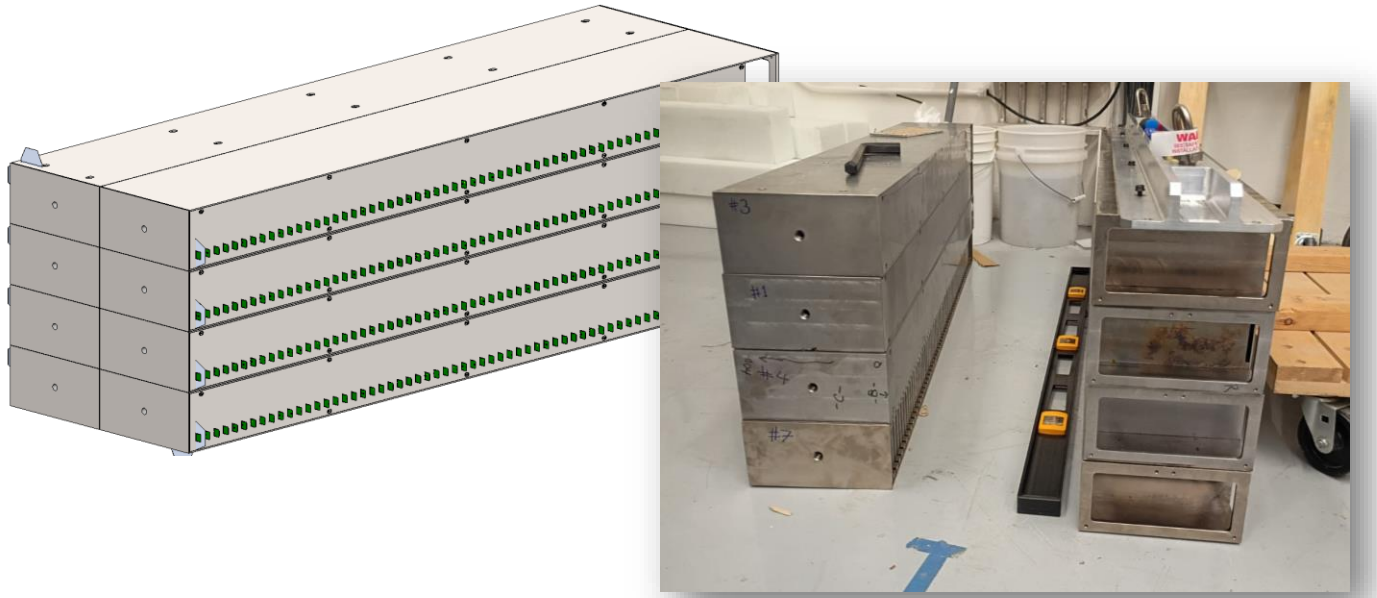
LFHCal test beam

- The Longitudinal Forward Hadronic Calorimeter (LFHCal) test beams make use of the same readout solution as the EEEMCal
  - Lots of common software between the test beams!
- 1 module test beam in September 2024
- Scaling everything up for an 8 module test beam at SPS in November 2025
  - Including summing stage

2024 PS test beam



Preparation for 2025 SPS and PS test beam



Reconstruction software

- Good calorimetry is crucial to supplement tracking and PID information for particle reconstruction
  - Required for electron ID and particle flow algorithms for jets
- Centralized track-cluster matching has been implemented in EICRecon
  - A step towards removing truth associations
- Next steps are to study and tune the matching criteria for each detector region and to integrate into the current electron finder

Distance between track and cluster