

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





EEEMCal crystals

- To maximize the performance, a homogeneous calorimeter was selected
- Composed of lead tungstate (PbWO4) 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 μ m 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



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EEEMCal readout

16 Individual

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10.0	210_0 49	210_0 45	210_0 41	210_0 37	208_1	208_1 25	208_1 30	208_1 34	208_1 49	200_1 45	200_1 41	200_1 37	209_0 21	209.0 25	209,0 30	209,0 34	210_0 68	210_0 64	210_0 58	210_0 54
L	-10.0 -7.5		-5.0			-25		0.0			25		50		75					

- 400 total channels
- 530 pF per channel



- 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-overthreshold measurement
- A prototype utilizing a Xilinx KCU for readout was used for the EEEMCal test beam as well as several other



Test beam prototype

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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 $1/16^{th}$ to build a finer picture of the signal
- Demonstrates the effect that increased SiPM capacitance has



Signal extraction

- Two types of signals to process
- ADC
 - Higher sensitivity to low energy events
 - Samples signal every 25 ns
 - Signal from $ADC_{max} ADC_{ped}$, 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



Event display (energy per crystal in GeV)



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Event display (energy per crystal in GeV)

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

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- 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

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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

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