eRD107: Longitudinally separated Forward HCal (LFHCal)

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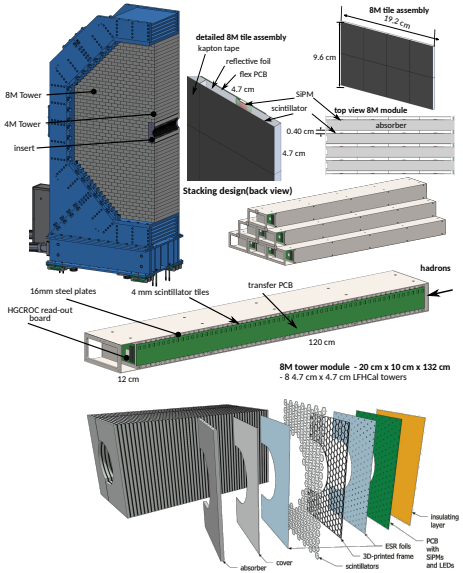
for the eRD107 consortium

Participating institutes: ORNL, BNL, FNAL, ISU, GSU, Yale, UCR, UTK, UTA, Valpo, Debrezen

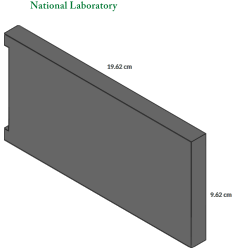
The General Idea

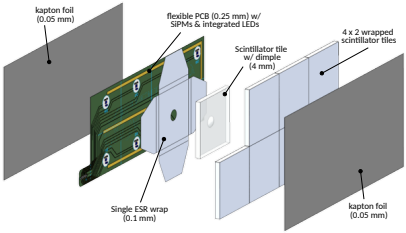
Concept:

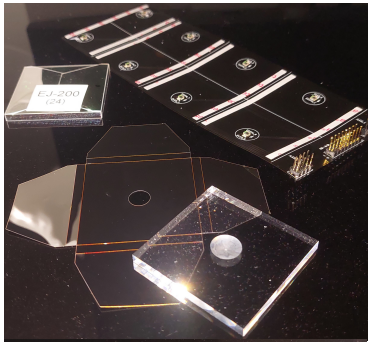
- CALICE AHCal inspired Fe-Scintillator calorimeter with SiPM on-tile-readout (modification since last review)
- Two main parts:
  - LFHCal built mostly out of $10x20x132$ cm^3 8M modules (modified length to accommodate larger amount of services in barrel)
  - Insert built out of 2 halves surrounding the beam pipe
- **LFHCal:**
  - 60 layers of steel interleaved with scintillator material
  - Transverse tower size $5x5$ cm^2
  - Multiple consecutive tiles summed to 7 longitudinal segments per tower
- **Insert:**
  - 60 layers of steel interleaved with scintillator
  - Hexagonal tiles of 8 cm^2 each read-out individually

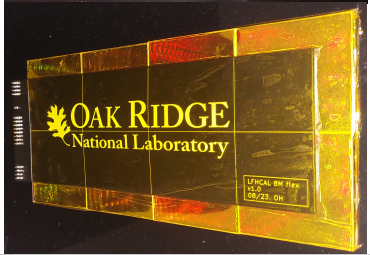


LFHCal 8M Scintillator Tile assembly



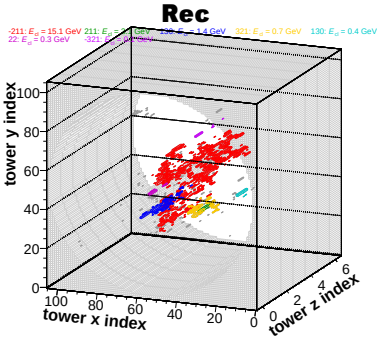




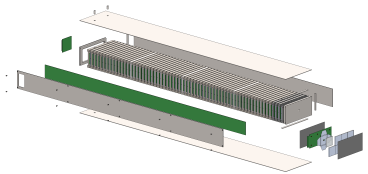


- Tiles of $\approx 0.4x5x5$ cm^3 with dimples individually wrapped in ESR foil assembled in a grid of $4x2$ tiles
- 8 tiles are backed by a flexible PCB equipped with 8 SiPMs and LEDs sandwiched with Kapton foil
- Flexible PCB wrapped around side of absorber to connect with long PCB along the side of the module
- Tiles either injection molded or machined out of cast sheets

Read-out LFHCal & insert

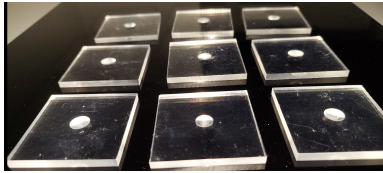


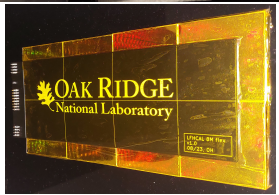
LFHCal, Event 30
e-p: 18× 275 GeV, $Q^2 > 100$ GeV

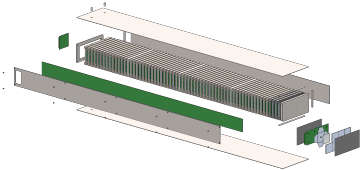


- High granularity needed to try to distinguish shower maxima close to beam pipe
- **LFHCal**:
  read out in 7 layers longitudinally (5 or 10 SiPMs summed)
  desirable min measurable tower energy 3-5 MeV, max 20-30 GeV in single tower segment
- **insert**:
  read out every single tile
  desirable min measurable tower energy $\sim 0.1 - 0.5$ MeV/ tile
- SiPMs mounted to flexible PCBs, passive signal transfer to back side of calorimeter using long transfer PCB
- 1 SiPM-HGCROC (up to 70 channels) per 8M module (56 channels) in the back, 320 HGCROCs for insert readout

Reminder: Remaining eRD107 Milestones



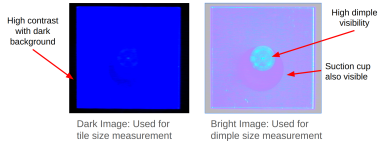


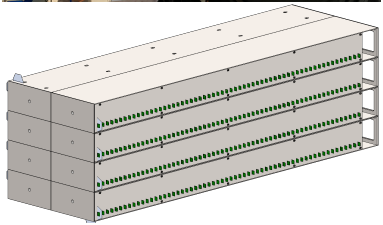


1. **Tile production optimization using machining & injection molding**
   - Evaluation of tolerance compliance for machined tiles
2. **Test module assembly & beam test**
   - First prototype of full 8M module
   - Integration of final read-out
   - Test beam evaluation of prototype (optionally with ECal in front)

eRD107 - Progress - executive summary

1. **Prototype tile production using machining & injection molding**
   - Evaluation of tolerance compliance for machined tiles completed
2. **Integration of final read-out**
   - Third iteration of sensor board produced and operated in TB
   - First passive summing test board produced
   - First test beam with HGCROC read-out for LFHCal completed reading every single SiPM & analysis ongoing
3. **Preparations for 2025 TB-campaigns & TB analysis**
   - Test beam analysis from 2023 & 2024 on-going, aiming at paper combined paper for late summer
   - Preparations for large scale 8 x 8M module test beam CERN at SPS & PS in Oct/Nov ongoing



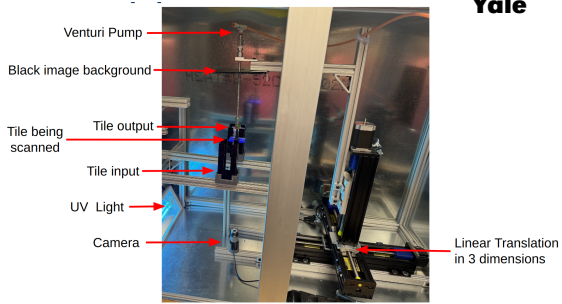


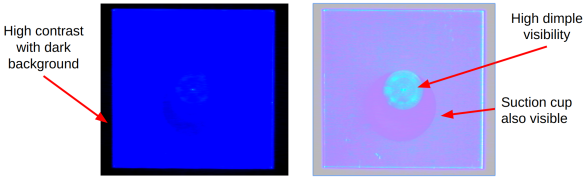
Largest fraction of TB components and efforts from 2024 & 2025 have been financed by PED, $\approx 1/20$ for 2024 from remaining R&D funds.

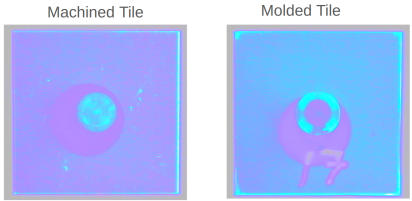
Scintillator Production - Tolerance evaluation (1)

Yale

- Yale setup created for fully automated tile dimension scanning using X-Y translation stage, camera & UV light source
- Evaluation of outer dimensions of machined tiles & dimple size
- Large scale evaluation possible without significant human intervention

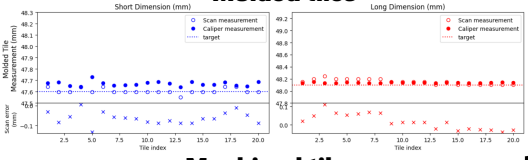




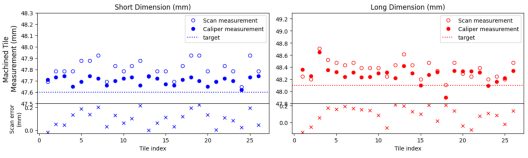


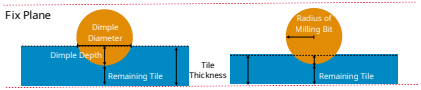
Scintillator Production - Tolerance evaluation (2)

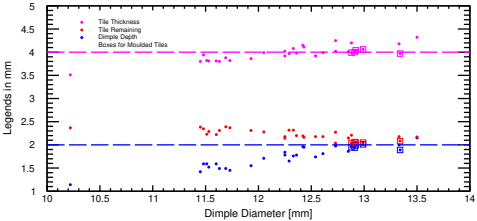
Molded tiles



Machined tiles







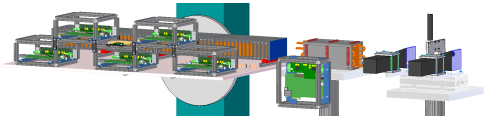
- Measured dimensions molded and machined tiles with calipers (for external size) and automated measurement
- Molded tiles compliant within measurement uncertainties with specifications
- Machined tiles with significant variations beyond acceptable limits
- Variations in particular on thickness beyond expected values

⇒ Need to incorpate these variations in design and possible specification modifications for the machined tile production

Test beam - August 2024

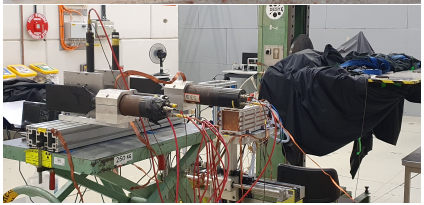
Dates: 28th Aug-11th Sept 2024 **Location:** PS - T09

Main purpose: First full module test & H2GCROC tests



Setup:

- Full 8M module testing 65 layers of absorber & scintillator per layer 8 channels (swapping scintillator geometry either 8M module or insert)
- Readout with multiple CAEN DT5202 64ch CITIROC SiPM readout units (2nd week) and H2GCROCs (1st week)
- Had to be postponed from May to August due to delays in deliveries of components & new H2GCROC firmware and boards tested during the ALICE FoCal TB in May 2024

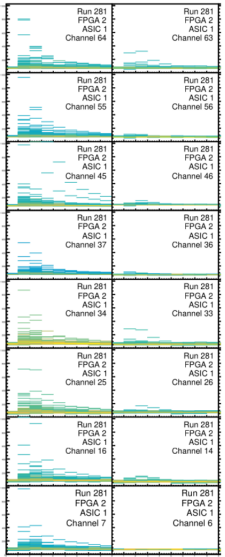


Main expected measurements:

- Energy resolution estimates for hadrons and electrons for full length module with both read-out versions
- Assessment of longitudinal leakage
- Longitudinal shower development
- Read-out validation
- Part of campaign with EEEMC in front

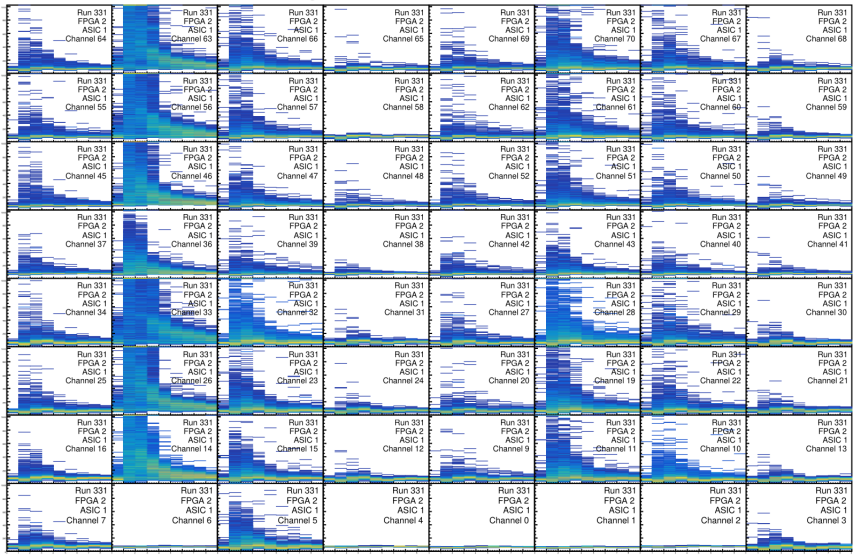
HGCROC online monitoring

μ for calibrations



4 GeV e^- for first energy resolution

layer 1-8



2023/2024 Test Beam analysis

Test Beam data:

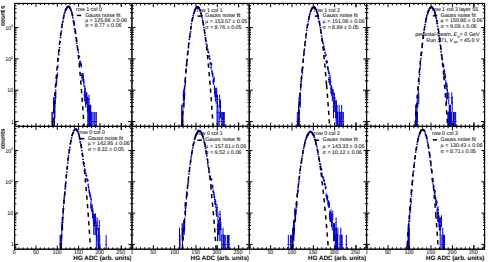
- 2023: Data primarily used for scintillator evaluation
- 2024: Two large data sets with HGCROC & CAEN read-out collected with massive support from ePIC collaborators from various institutes

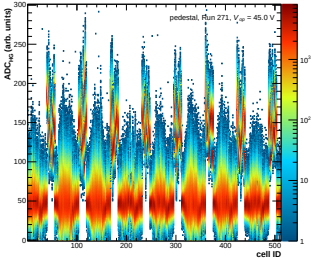
Test Beam analysis:

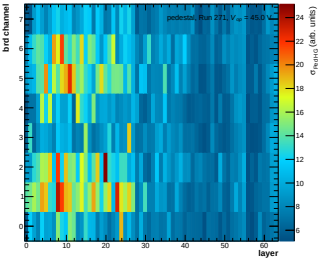
- Large participation in test beam analysis from grad students & under-grad students
- Common framework developed and being used for all existing TB campaigns, analysis full done in this
- Current focus on establishing stable calibrations (single cell level) for all channels & runs within each data set
- Aiming at full publication in late summer based off the 2023 & 2024 test beam campaigns

Calibrations

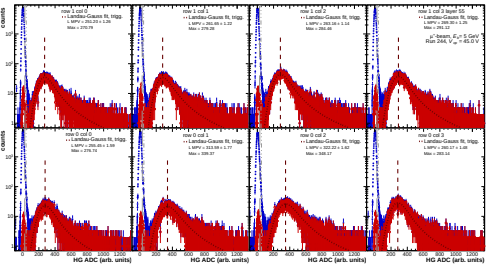
Pedestal run

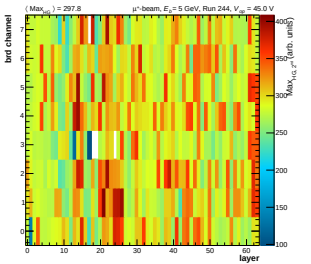


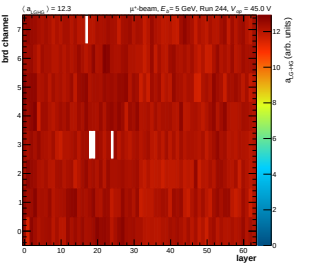




μ beam 5 GeV

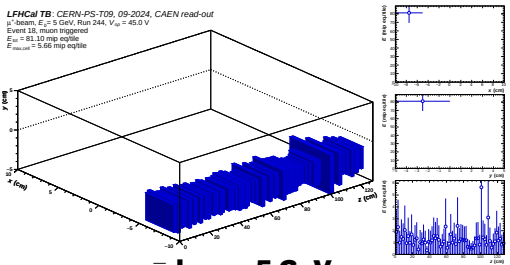




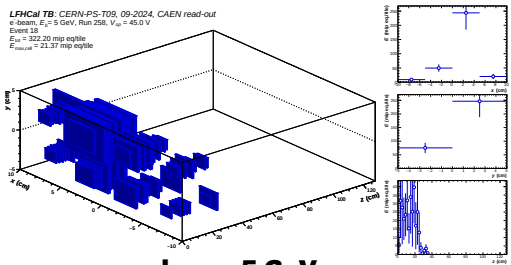


First Calibrated Event displays from last year

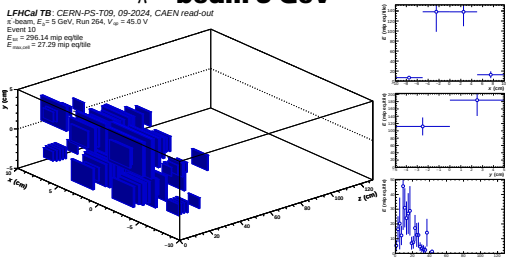
μ beam 5 GeV



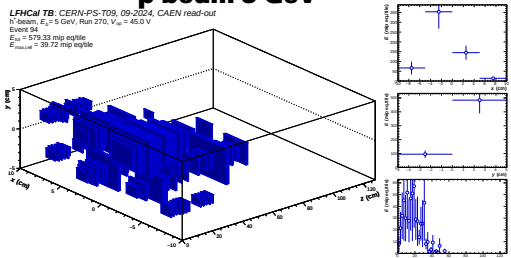
e$^-$ beam 5 GeV



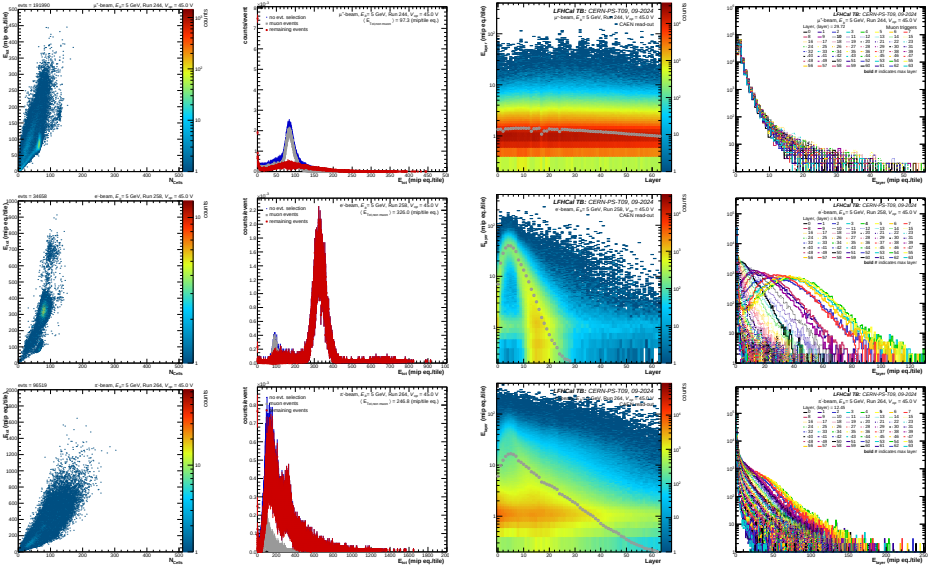
π^- beam 5 GeV



p beam 5 GeV



First Highlights from last year



μ beam 5 GeV

e- beam 5 GeV

π^- - beam 5 GeV

Test Beam Plans 2025

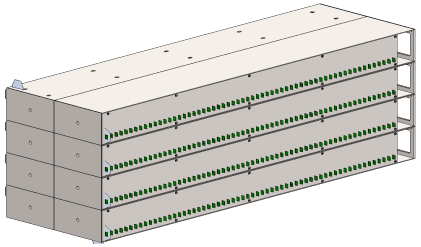
Requested time: 1 week each

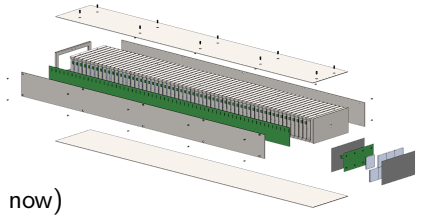
Main purpose: Resultion studies

Location: CERN SPS (29th Oct) & PS (17th Nov.)

Setup:

- Very similar to 2024 setup, with more modules
- 8 full 8M modules (ideally 40x40x132 cm)
- Readout with H2GCROCs
- Same setup in both areas





Main expected measurements:

- Energy resolution for hadrons and electrons
- Assessment of longitudinal/transversal leakage
- Longitudinal shower development
- Final-Flexible PCB validation & first long PCB validation

Where we are?:

- 8 Absorber structures produced (last 3 at Nickel-plating right now)
- Flex-PCB design available & SiPMs to be delivered in June
- First design of long board available, will be send for prototype production within the next weeks
- Evaluation board for passive summing created and under test

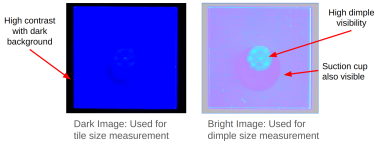
eRD107 - milestones & executive summary

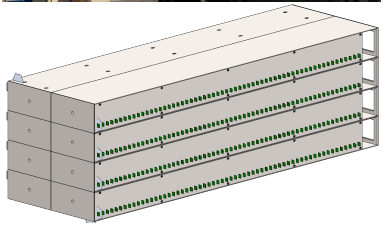
Milestones

1. **Tile production optimization using machining & injection molding**
   - Evaluation of tolerance compliance for machined tiles
2. **Test module assembly & beam test**
   - First prototype of full 8M module
   - Integration of final read-out
   - Test beam evaluation of prototype (optionally with ECal in front)

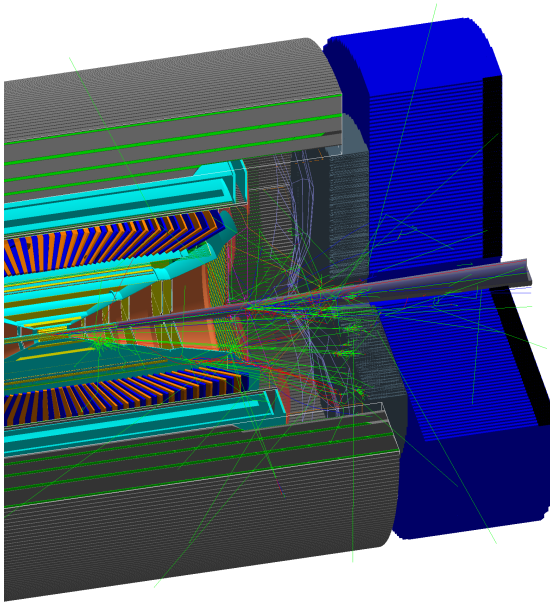
Executive summary

1. **Prototype tile production using machining & injection molding**
   - Evaluation of tolerance compliance for machined tiles completed
2. **Integration of final read-out**
   - Third iteration of sensor board produced and operated in TB
   - First passive summing test board produced
   - First test beam with HGCROC read-out for LFHCal completed reading every single SiPM & analysis ongoing
3. **Preparations for 2025 TB-campaigns & TB analysis**
   - Test beam analysis from 2023 & 2024 on-going, aiming at paper combined paper for late summer
   - Preparations for large scale 8 x 8M module test beam CERN at SPS & PS in Oct/Nov ongoing



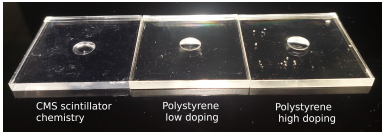


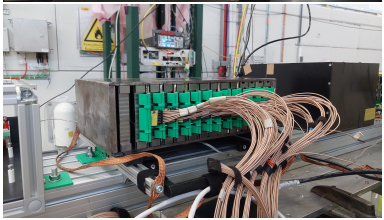
Thanks!



eRD107 - Progress - executive summary - 2024

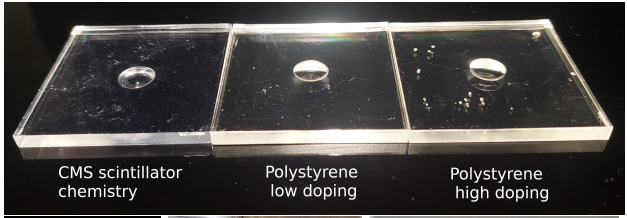
1. **Reconstruction optimization**
   - Realistic implementation of geometry in ePIC software stack
   - ML assisted absorber optimization in full geometry setup
2. **Prototype tile production using machining & injection molding**
   - Ongoing machining studies for tile production
   - First tile production with injection molding at Fermilab with different tile chemistries
3. **Tile Characterization**
   - Light yield studies of machined & injection molded tiles with different dimple sizes, machining techniques and wrappings ongoing
   - Position scan of response on-going
4. **Sensor board development**
   - Third iteration of sensor board produced in three different processes
   - Tests of calibration circuits ongoing
5. **Preparations for third TB-campaign (Aug 2024) & TB analysis**
   - Test beam analysis from Sept. & Oct. 2023 on-going
   - Currently setting up in PS beam line, TB starting today

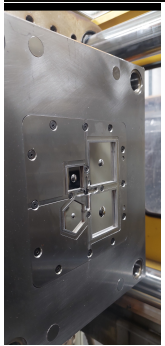




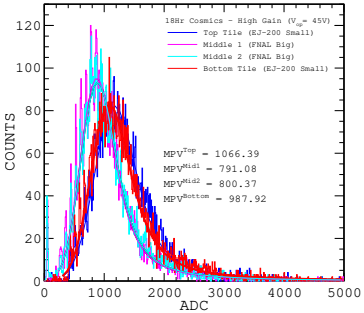
Tile production R&D

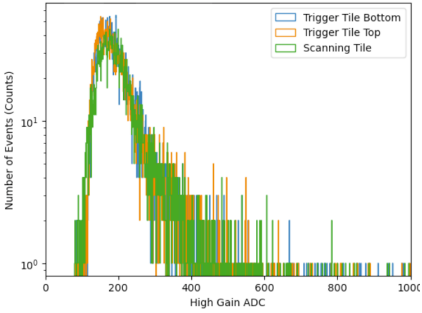
- First larger scale injection molding production by Fermilab with 3 different chemistries
- Additional scintillator machining studies on the way
- Produced tiles with different dimple sizes
- Additional production to come in the coming months to equipp August test beam modules

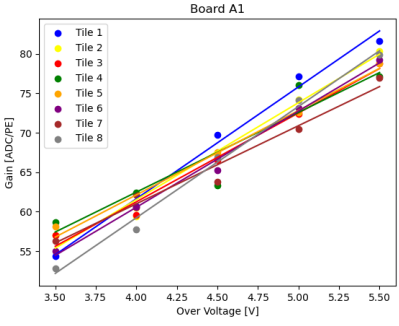




Scintillator Characterization & Optimization

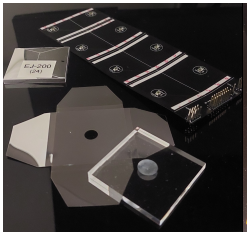






- Started measuring cosmics MIP light yields for different SiPMs types
  - 1.3×1.3 mm
  - $\rightarrow \approx 12 - 14$ p.e. for machined tiles
  - $\rightarrow \approx 11 - 13$ p.e. for injection molded tiles,
  - 3×3 mm
  - $\rightarrow \approx 60 - 76$ p.e for machined tiles
- Testing different scintillator materials (EJ-200, BC-408 & Fermilab injection molded with different chemistries)
- Sytematic evaluation of impact of machining defects ongoing and large scale sample on-going
- Single photon spectra for every SiPM of the TB assemblies vs V_{ov}

LFHCal: Test beams 2023



Dates:

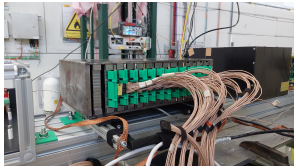
- **SPS**: $6^{th} - 13^{th}$ Sept.
- **PS**: $11^{th} - 18^{th}$ Oct.

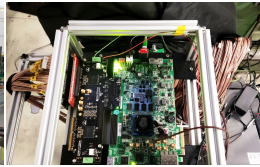
Setup:

- Parasitic to FoCal-H/FoCal-E at SPS and PS
- Setup consists out of maximum 14 layers of 8M tile assemblies
  Sept: w/o absorber layers
  Oct: w/ absorber layers (4 tungsten, 10 steel)
- Read-out: CAEN DT5202 64ch CITIROC SiPM readout unit or H2GCROC

Main expected measurements:

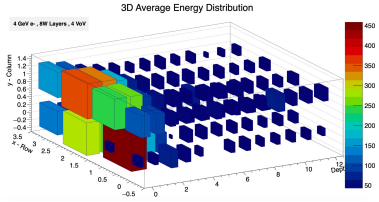
- Light yields per tile
- Shower profile measurements with different absorbers
- Cross talk estimates of different tiles
- Use it as testing setup for SiPM-H2GCROC
- If placed behind FoCal-H, measure part of leakage

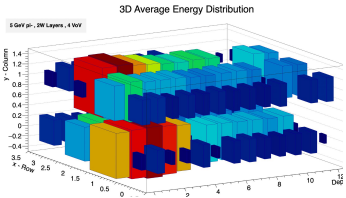


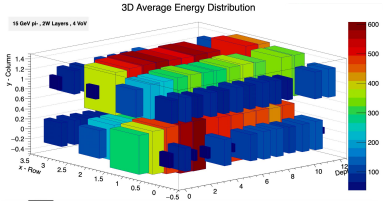


LFHCal TB 2023: Data obtained - CAEN read-out

October campaign







September campaign - Hodoscope setup

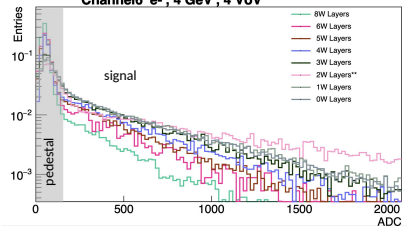
- Full V_{ov} scan e^-/h
- Gain-scan
- Position scan
- Possibly leakage measurement of FoCal-H

October campaign - mini-LFHCal

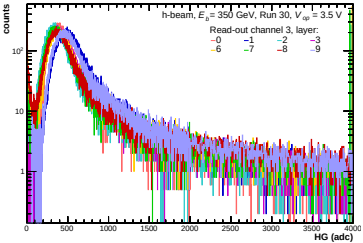
- Full V_{ov} & gain scan e^-/π^-
- Position scan
- Scan with additional W-plates upfront (e^-)
- e^- shower development (1-5 GeV)
- π^- shower development (5,10,15 GeV)

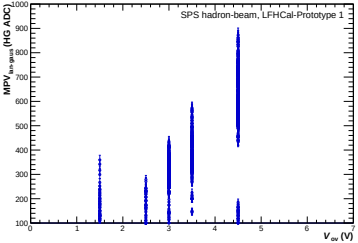
LFHCal TB 2023: First results - CAEN read-out

Additional W-plate scan

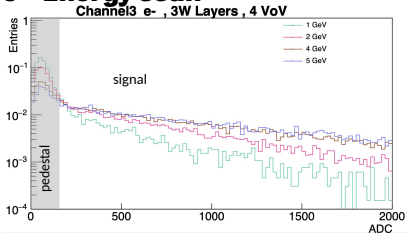


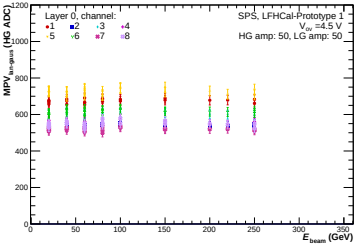
MIP response for scintillators

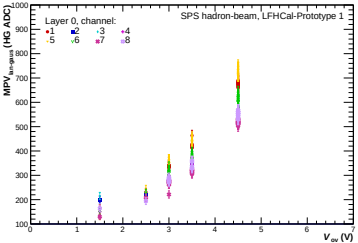




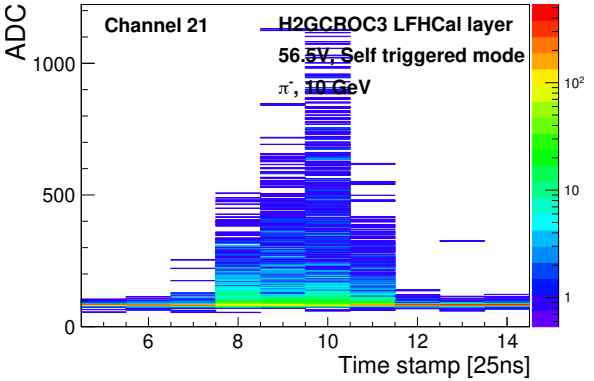
e^- Energy scan

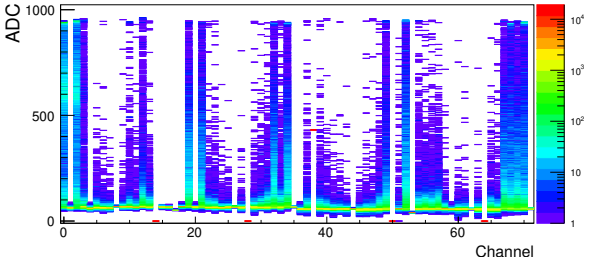






LFHCal TB 2023: First results - H2GCROCv3a





- H2GCROC read-out ready just in time for last 1.5 days of data taking (Oct.)
- Self-triggered data obtained
- Unfortunately externally triggered setup couldn't be operated due to beam stop of PS during last night
- New prototype board on time for delivery for testing significantly ahead of TB