eRD107: Longitudinally separated Forward HCal (LFHCal)

August 28, 2023

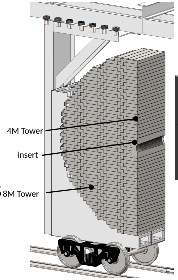
Friederike Bock (ORNL)
for the eRD107 consortium

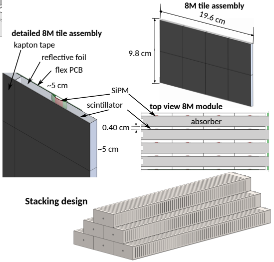
Participating institutes: ORNL, BNL, FNAL, ISU, GSU, Yale, UCR, UTK, Valpo

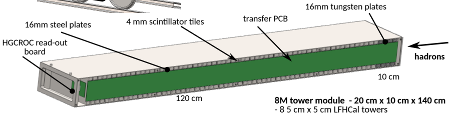
The General Idea

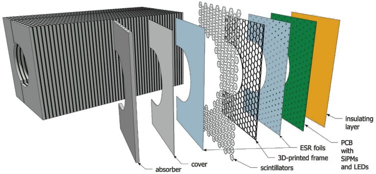
Concept:

- CALICE AHCal inspired W/Fe-Scintillator calorimeter with SiPM on-tile-readout (modification since last review)
- Two main parts:
  - LFHCal built mostly out of 10x20x140 cm^3 8M modules
  - Insert built out of 2 halves surrounding the beam pipe
- **LFHCal:**
  - 4 layers of tungsten + 61 layers of steel interleaved with scintillator material
  - Transverse tower size 5x5 cm^2
  - Multiple consecutive tiles summed to 7 longitudinal segments per tower
- **Insert:**
  - 10 layers of tungsten + 54 layers of steel interleaved with scintillator
  - Hexagonal tiles of 8 cm^2 each read-out individually

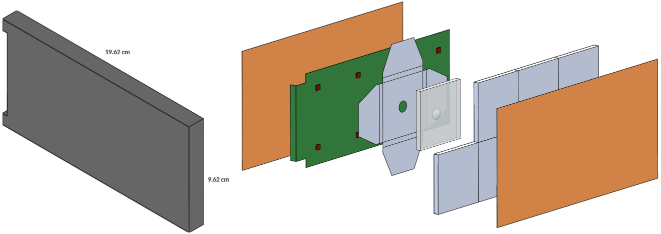


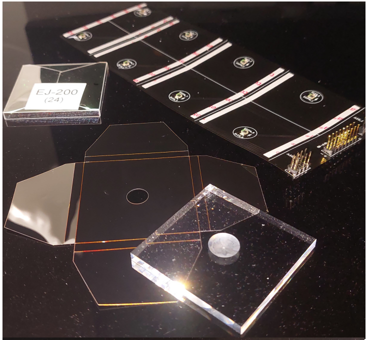


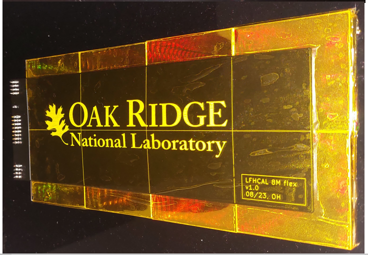




LFHCal 8M Scintillator Tile assembly

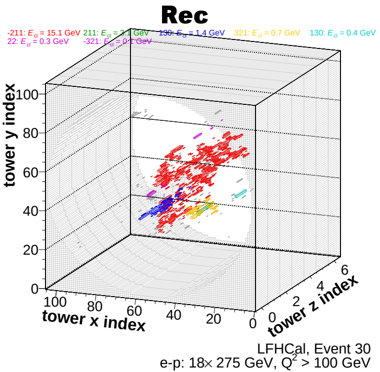






- Tiles of $\approx 0.4x5x5$ cm^3 with dimples individually wrapped in ESR foil assembled in a grid of 4x2 tiles
- 8 tiles are backed by a flexible PCB equipped with 8 SiPMs and LEDs sandwiched with Kapton foil
- Flexible PCB wrapped around side of absorber to connect with long PCB along the side of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

Read-out LFHCal & insert

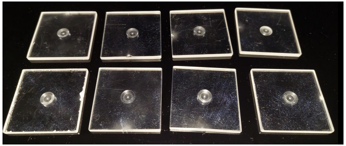


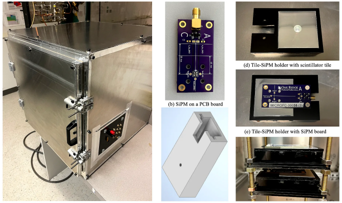
- High granularity needed to try to distinguish shower maxima close to beam pipe
- **LFHCal**:
  read out in 7 layers longitudinally (5 or 10 SiPMs summed)
  desirable min measurable tower energy 3-5 MeV, max 20-30 GeV in single tower segment
- **insert**:
  read out every single tile
  desirable min 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), 320 HGCROCs for insert readout

eRD107 - 2023 Progress - executive summary

1. **Prototype tile production using machining & injection molding**
   - Ongoing machining studies for tile production
   - Mold production for injection molded tiles in progress
2. **Reconstruction optimization**
   - Realistic implementation of geometry in ePIC software stack
   - Integration with high granularity insert in progress
3. **Tile Characterization**
   - Vendor survey of SiPM vendors and types conducted
   - First light yield studies of machined tiles with different dimple sizes, machining techniques and wrappings ongoing
4. **Sensor board development**
   - First prototype of sensor board delivered and being tested prior to test beam
5. **Small test module assembly**
   - First prototype of single segment of 8M module being assembled for TB in Sep./Oct.

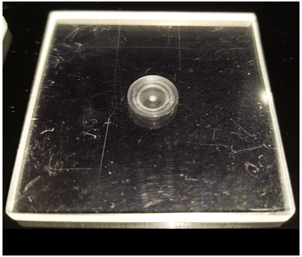


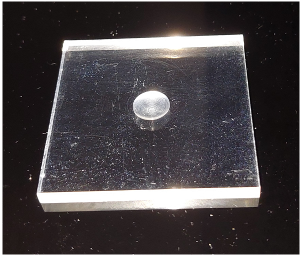


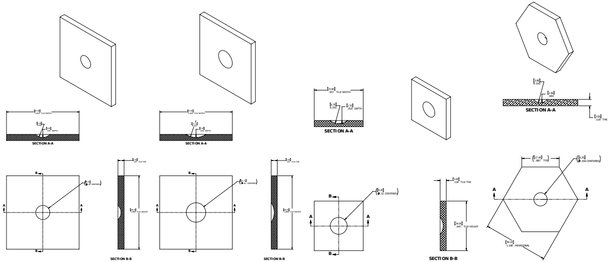
(a) Light-tight Faraday box with connector panel
(b) SiPM on a PCB board
(c) SiPM Holder with hole to shine 400 nm LED photons
(d) Tile-SiPM holder with scintillator tile
(e) Tile-SiPM holder with SiPM board
(f) Two Tile-SiPM holders on shelf

Tile production R&D

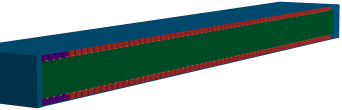
- Started machining tiles at ORNL in LFHCal geometry
  - Established procedures for high quality tile machining
- Produced tiles with different dimple sizes
- Received machined tiles from Eljen $\rightarrow$ larger variance in size than anticipated
- Mold in production for original sized tiles with different dimples, 1/4-size tiles & hexagonal tiles for insert

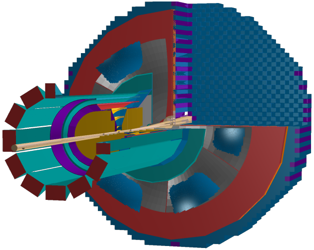




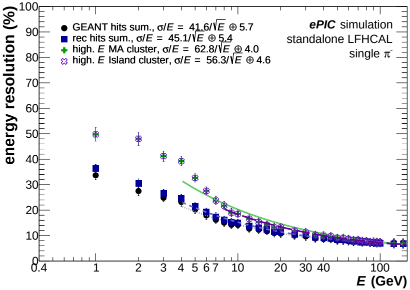


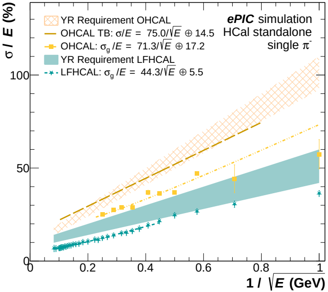
Reconstruction optimization





- Implementation of realistic geometry in ePIC software stack
- Single pion response in accordance with expectations & meeting YR requirements
- First version of clusterization algorithm working well at high E
- Integration with insert ongoing
- Ongoing studies to improve clusterization algorithm using ML started during several workshops
  - ePIC Calorimeter Workshop (Apr. 23')
  - HGS-HIRe Power Week - Machine Learning (Jul. 23')

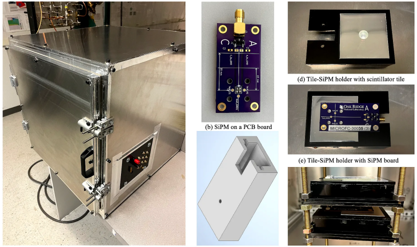




Scintillator Characterization & Optimization (1)

- Two parallel test setups for tile characterization (Yale & ORNL)
- SiPM test board produced
- Developed multiple 3D printed test stands for single SiPM & Cosmics data taking
- Vendor survey for available ≈ 1x1 mm & 3x3 mm SiPMs regarding
  - Availability
  - Data accuracy in data sheets
  - Production stability

Yale



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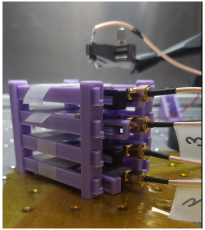
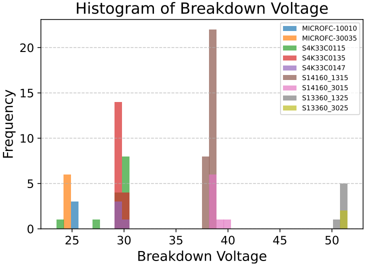
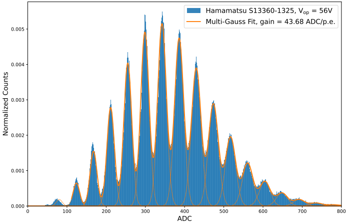
ORNL

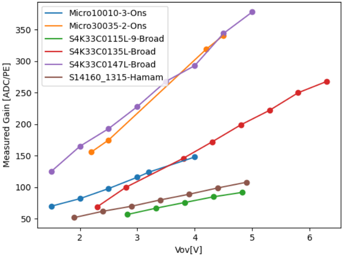


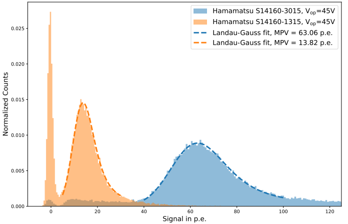


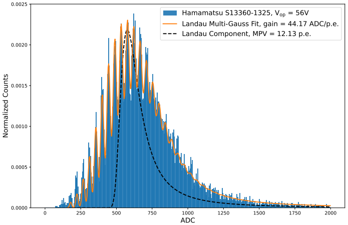
Scintillator Characterization & Optimization (2)

- Single photon spectra for every SiPM
- Characterized different SiPM gains as function of V_{ov}
- Started measuring cosmics MIP light yields for different SiPMs types
- Testing different scintillator materials (EJ-200, BC-408 & Fermilab injection molded)
- Sytematic evaluation of impact of machining defects ongoing







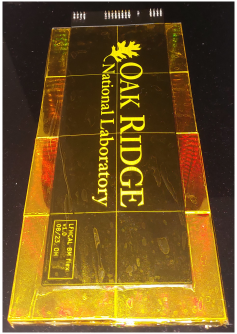


Test beam plans & preparation Sep. 23'

Dates: 6^{th} – 13^{th} Sept.

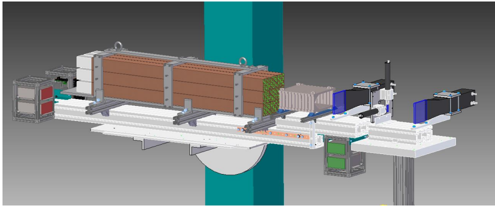
Main purpose: Scintillator characterization & HGCROC tests

- Parasitic to FoCal-H test beam at SPS
- Setup consists out of maximum 10 layers of 8M tile assemblies
- Fixed in plastic frame with cut outs in the center with slots for holding assemblies
- Each 8M tile assembly with 8 channel readout
- Connected via 16 channel $\approx$ 8 m micro-coax-cable assemblies to CAEN DT5202 64ch CITIROC SiPM readout unit or HGCROC



Main expected measurements:

- Light yields per tile
- Cross talk estimates of different tiles
- Use it as testing setup for SiPM-HGCROC while taking data with Focal-H using CAEN & VMM read-out
- If placed behind FoCal-H, measure part of leakage



Test beam plans & preparation Oct. 23'

Dates: 11^{th} – 18^{th} Oct.

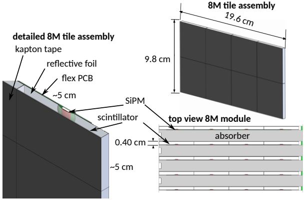
Main purpose: Scintillator characterization & HGCROC tests

- Parasitic with FoCal-E at PS
- Setup consists out of maximum 14 layers of 8M tile assemblies & corresponding layers of absorber plates out of steel or tungsten
- Fixed in steel frame with slots for tile assemblies & absorber plates
- Same read-out setup as for September test beam

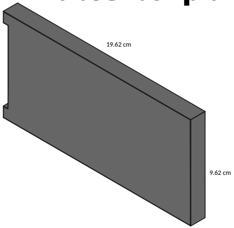
Main expected measurements:

- Shower profile measurements with different absorbers
- Cross talk estimates of different tiles
- Use it as testing setup for SiPM-HGCROC

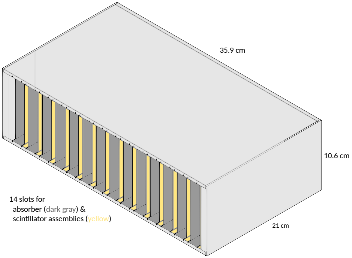
8M tile assembly



absorber plate

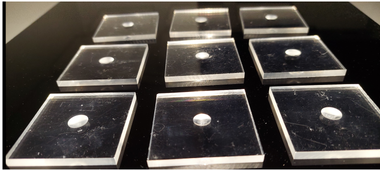


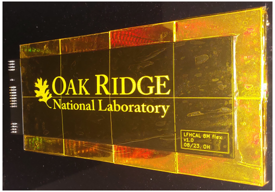
Steel frame

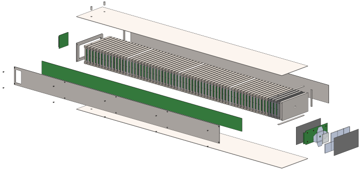


eRD107 FY24 Plans & Milestones

1. **Tile production optimization using machining & injection molding (04/24)**
   - Evaluation of different scintillator machining techniques
   - Comparative review of different vendor capabilities regarding adherence to tolerances as well as optimizing the light yield and its stability for large number of tiles
   - Documentation of procedures for optimizing the light yield of injection molded tiles during the production process
   - High quality prototype tiles to equip two 8M modules for test beam studies
2. **Reconstruction optimization (09/24)**
   - Write-up of optimization results from simulations
3. **Sensor board development (03/24)**
   - First prototype of sensor board for Si-PM readout (together with eRD109)
4. **Test module assembly (04/24)**
   - First prototype of full 8M module
5. **Tile Characterization (08/2024)**
   - Write-up of test bench & test beam measurement for all assembled tile-prototypes
   - First concept of a monitoring system to be installed in the LFHCal







eRD107 FY24 Funding request

Table 4: Total funding request by institution for each R&D activity.

activity	cost in FY24 k$ ORNL	FNAL	Yale	total cost in FY24 k$
Tile Production R&D	15.0	11.6	5.0	31.6
Tile Char. (Lab)	0	0	19.0	19.0
Sensor Board	23.0	0	0	23.0
Total	38.0	11.6	24.0	**73.6**

Table 3: Total funding request and breakdown by institution.

institute	cost in FY24 k$ eng. and tech.	material	equipment	travel	total cost in FY23 k$
ORNL	13.0	20.0	0	5.0	38.0
FNAL	11.6	0	0	0.0	11.6
Yale	0	5.0	16.0	3.0	24.0
Total	24.6	25.0	16.0	8.0	**73.6**

Table 5: Estimated funding requests for LFHCAL R&D efforts in FY25-26.

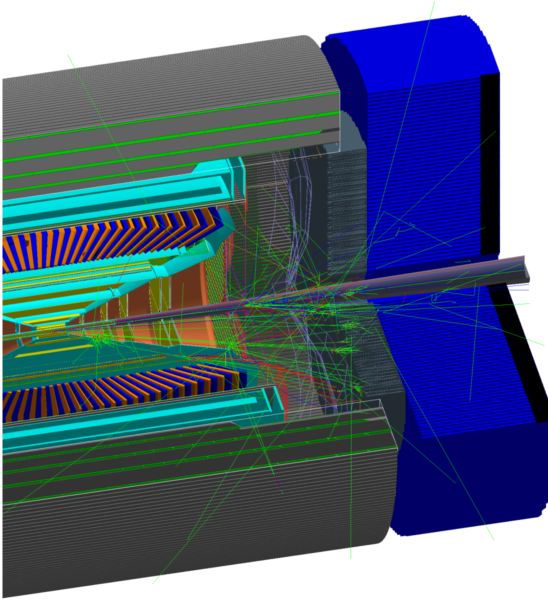
Task	**Estimated cost in $ per year** **FY25**	**FY26**
mechanical engineering	30K	20K
electrical engineering	30K	20K
materials	40K	40K
test beam support	10K	10K
total	110K	90K

- Funding for continuation of started R&D mainly on tile production & characterization
- Largest fraction of funding for equipment & material procurement
- Small travel funds for TB travel & visits at different test sites
- Significant in-kind contribution from universities and laboratories for assembly, simulation and data analysis

Table 6: Funding allocation and approximate completion dates for respective milestones for FY24.

Institute	**Item**	**Cost per item in $**	**Number of items**	**Total cost in $**	**To be compl. by**
	Tile Production R&D:				Q2/2024
ORNL	cast material			15K	
FNAL	raw material + dopant			(in kind) 0K	
FNAL	injection molder setup + operation	180/h	64h	11.6K	Q4/2023
ORNL/UTK/Yale	tile assembly		40h	(in kind) 0K	Q1/2024
ORNL	travel			5K	
	Tile Characterization (Lab Bench):				Q3/2024
Yale	scintillator material characterization		100h	(in kind) 0K	Q1/2024
Yale	source measurement unit & led pulser, other material	19K	1	19K	
GSU/Yale/UCR	tile lightyield testing		160h	(in kind) 0K	Q3/2024
Yale	travel			3K	
	Sensor Board:				Q1/2024
ORNL	electrical engineering	180/h	72h	13K	Q4/2023
ORNL	connectors & cables			5K	Q4/2023
ORNL	sensor board production, assembly		160	5K	Q4/2023
ORNL/UTK	testing		40h	(in kind) 0K	Q1/2024
	Reconstruction Optimization:				2025
UTK/Yale/BNL	simulations/digitization/reconstruction/analysis		640h	(in kind) 0K	
Total				**73.6K**	

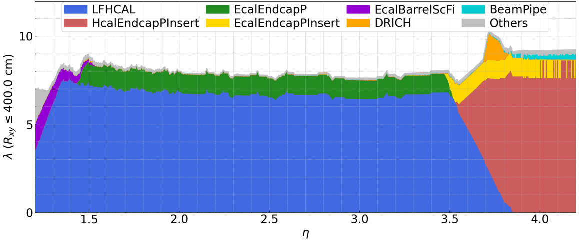
Thanks!



LFHCal in Numbers

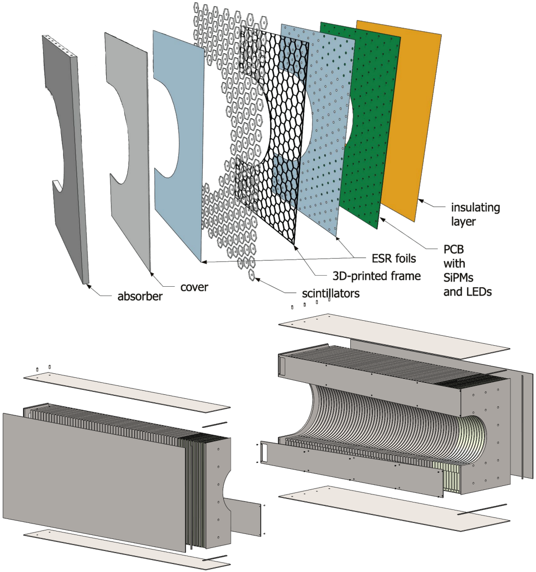
- Acceptance: $1.2 < \eta < 2.8$
- Interaction length: $6.5\lambda/\lambda_0$
- Inner modules ($R < 1$m) equipped with machined scintillator tiles & 3mm SiPMs
- Outer modules equipped with injection molded tiles & 1.3mm SiPMs
- 565,760 SiPMs, 60,928 read-out channels
- CD3-A/B procurement: Steel, Tungsten & SiPMs
- Current estimated total cost: $\sim$ 15.8M

parameter	LFHCal
inner x, y	60 cm
outer radius (envelope)	270 cm
η acceptance	$1.2 < \eta < 3.5$
tower information	
x, y	5 cm
z (active depth)	130 cm
z read-out	10 cm
# scintillator plates	65 (0.4 cm each)
# absorber sheets	61 (1.52 cm steel)
	4 (1.52 cm tungsten)
interaction lengths	$6.5\ \lambda/\lambda_0$
Sampling fraction f	0.035
# towers	8704
# modules	
8M	1050
4M	76
# read-out channels	7 x 8704 = 60,928

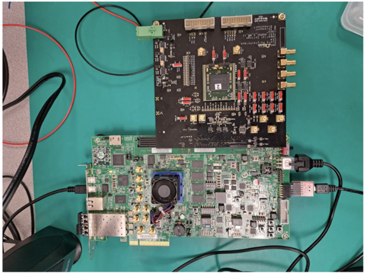


Insert in Numbers

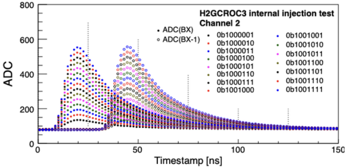
- Acceptance: $2.7 < \eta < 4.4$
- Interaction length: $7.5\lambda/\lambda_0$
- Similar sampling structure as LFHCal
- 10 layers of tungsten, 55 layers of steel
- 360 hexagonal tiles with SiPMs per layer, staggered positions in different layers
- Maximum η coverage with minimum dead area in combination with LFHCal
- CD3-A/B procurement: Steel, Tungsten & SiPMs
- Current estimated total cost: $\sim$ 1M



HGCROC testing



Test setup in ORNL EIC lab:
- We have a KCU105 with the testboard and H2GCROC3
- Firmware/Software done and working
- Testing the feasibility of the ASIC for the EIC:
  - Signal shapes
  - Gain, dynamic range reach
  - TOA/TOT calibration



Internal injection test on all channels (one shown)

Prepared the H2GCROC3 testboard:
- Readout board is compatible with the CAEN commercial unit for ease of use
- 2 H2GROC per board - to test the I2C in series
- Communication board to test the readout and cables used in final detector:
  - Samtec HQDP for 1-10 m length