eRD107: Longitudinally separated Forward HCal (LFHCal)

October 20, 2022

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for the eRD107 consortium

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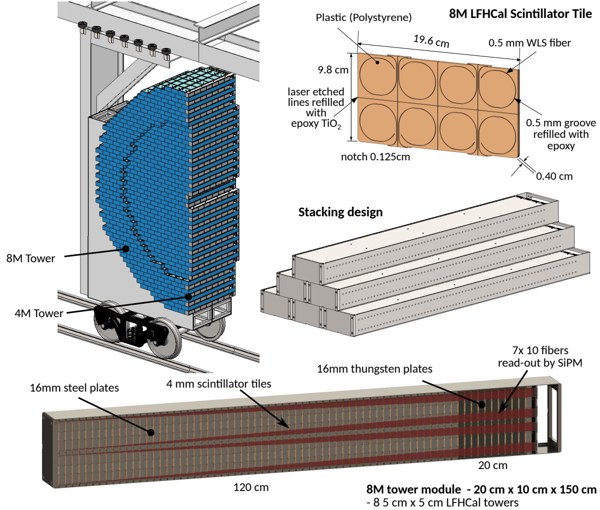
The General Idea



Concept:

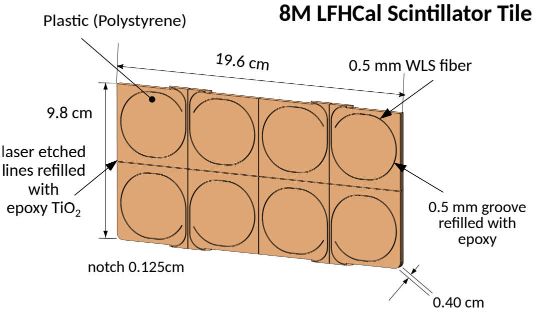
- PSD [link TDR] inspired inspired Fe/W-Scint calorimeter
  60 layers of Steel (160 mm)-Sci plates (4mm) +
  10 layers of W (160 mm)-Sci plates (4mm)
- Multiple towers combined in one module to reduce dead areas, increase granularity
- Read-out:
  - 7 signals per tower (signals combined from 10 Sci-plates)
  - readout position: after full HCal
- Modules of different sizes (8M, 4M, 2M, 1M) to maximize coverage & assembly efficiency

Participating institutes:

- ORNL, BNL, FNAL, ISU, GSU, Yale, UCR, UTK, Valpo

Current 8M Scintillator Plate Design

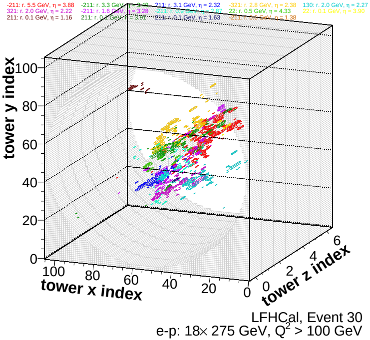
- Most scintillator plates produced as 1 unit of 100x200mm plates (8 single tower tiles)
- Separation of tiles edged into the plate (95%) through, refilled with Epoxy-TiO_2 mix
- Wrapped in Tyvek paper and Kapton tape



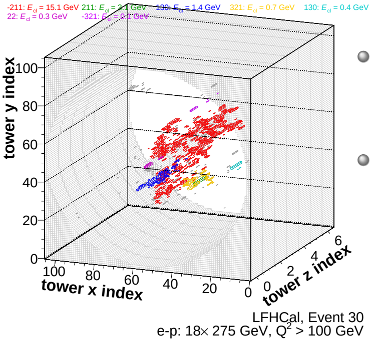
- Fiber thickness chosen for minimal light loss while bending (0.5mm)
  $\rightarrow$ other geometries for embedding under consideration (i.e. 1/4 circle)
- Originally costed from Uniplast as 1 unit of assembly + material
- Updated estimate including (material, fiber installation by engineer, wrapping by students, tooling)
  $\rightarrow$ new estimate driving by labor for fiber installation
- Exploring possible robot supported options for tile assembly

Read-out 8M module

MC



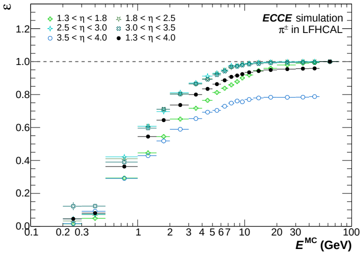
Rec

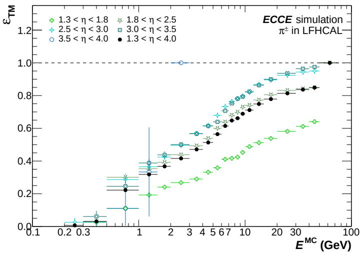


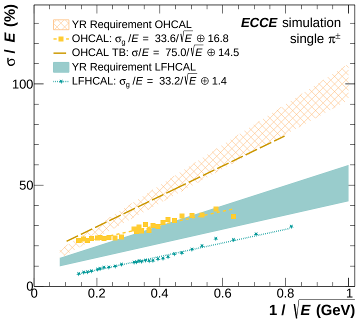
- High granularity needed to try to distinguish shower maxima close to beam pipe
- **HCal**:
  read out in 7 layers longitudinally
  desirable min measurable tower energy 3-5 MeV, max 20-30 GeV in single tower segment

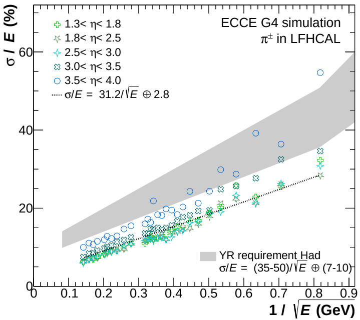
- LFHCal 1 SiPM per 10 fibers (7 per tower) -i.e Hamamatsu S13360-3025PE (14.4K pixels)
- HCal readout at end of module (max. 20cm)
- Small light collection prisms might be needed infront of SiPM
- Idea use each 1 SiPM-HGCROC (up to 70 channels) for readout of HCal (ideally common chip/board design with WSciFi-ECal & ALICE FoCal-H)

LFHCAL Performance



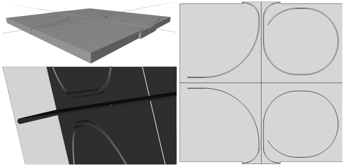




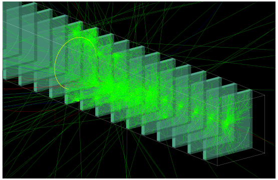


- Cluster finding and track matching efficiencies good in center of LFHCAL, losses towards edges
- Performance overestimated wth standard response implementation in GEANT4 (1.5x from other setups)
- Small η dependence for energy resolution
- Exploring possibility for high granularity insert with different composition & changing granularity of readout as function of R
- Studies to improve clusterization further using ML started

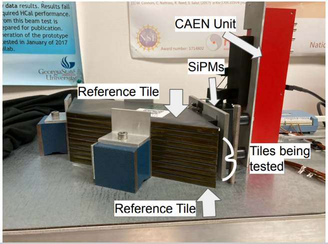
eRD107 - Plans & Milestones



1. **Prototype tile production using machining & injection molding (04/23)**
   - Assembled prototype tiles using machined scintillator plates
   - Assembled prototype tiles using injection molded scintillator tiles
   - Documentation of procedures for manual assembly of tiles & WLS fibers
2. **Reconstruction optimization (09/23)**
   - Write-up of optimization results from simulations

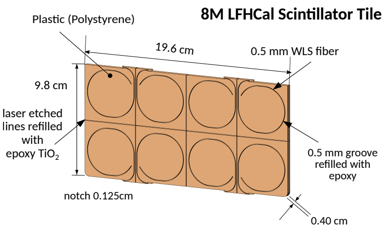


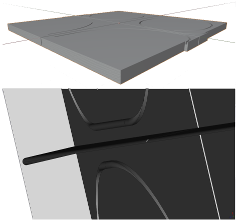
3. **Sensor board development (07/23)**
   - First prototype of sensor board for Si-PM readout (together with eRD109)
4. **Small test module assembly (07/23)**
   - First prototype of single segment of 8M module

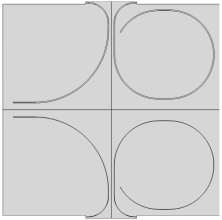


5. **First automated scintillator tile assembly (08/23)**
   - Assembled prototype tiles
   - Documentation and Evaluation of procedures for automated assembly of tiles & WLS fibers
6. **Tile Characterization (08/23)**
   - Write-up of test bench & test beam measurement for all assembled tile-prototypes

Prototype tile production & assembly







Prototype tile production using machining & injection molding

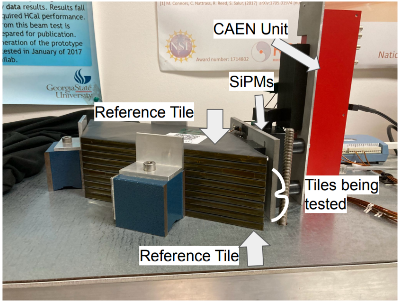
- Vendor replacement needed for Uniplast
  - a) Machining plastic scintillator plates ($\sim$ \$80/tile)
  - b) Injection molding tile ($\sim$ \$4 – 6/tile)
- Opportunity for significant cost reduction w/ injection molding
- Performance and mechanical stability tests needed in both cases

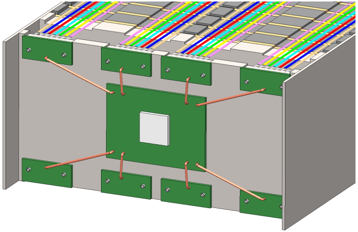
First automated scintillator tile assembly

- Tile assembly time & labor extensive w/ classical methods
- Exploring automated assembly using collaborative robots for:
  - Refilling sub-segmentation with TiO_2
  - Fiber laying and fixating in groves
  - Automatic measurements of WLS-fiber quality

Scintillator Characterization & Optimization

- Characterization of assembled tiles according to:
  - Light yield
  - Cross-talk among different tiles
  - Response uniformity
  - Durability and mechanical stability
- Initial geometry optimization using TracePro simulations
- Usage of available test-stands at universities for tile characterization
- Possibility to test multiple scintillator materials/dopant concentration in particular for injection molding
- Development of a SiPM board and WLS fiber connector suitable for production module





Prototypes and Test beams

- Successively-larger R&D prototype assembly
  1. Scintillator tiles
  2. Single segment of 8M module (20cm) including initial read-out design
  3. Full mechanical mock-up of 8M module
  4. Full 8M modules including initial read-out design
- Main measurements
  - Characterization of spatial distribution and uniformity of MIP response for different tile types
  - Saturation behavior of combined tile and SiPM readout system for single segment
  - Measuring the individual and combined response of tiles to EM-showers
  - Spatial and energy resolution of partial and full module LFHCAL module
  - Combined test-beam w/ pECal to characterize LFHCal partial and full module response behind ECal
- Current Read-out electronics design based on CMS-SiPM-HGCROC (ASIC)
  Final electronics R&D for EIC specific readout board within eRD109 based on same ASIC with possible small modifications

eRD107 Funding request

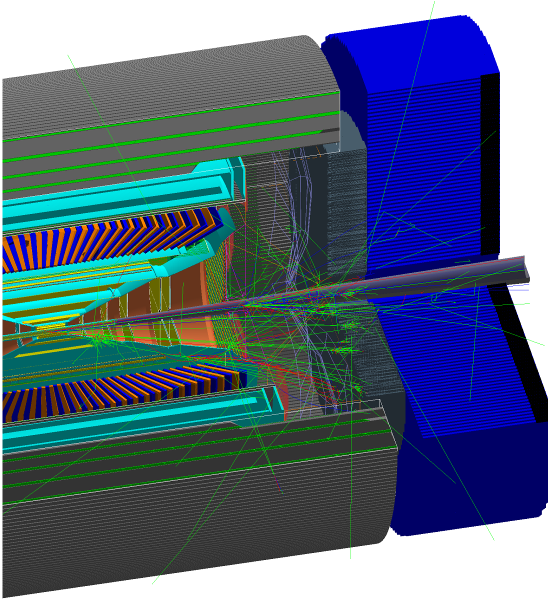
activity	cost in FY23 k$ ORNL	FNAL	BNL	UTK	GSU	Yale	ISU	Valpo	UCR	total cost in FY23 k$
Machined Tiles	11.7	0	0	0	0	0	0	0	0	11.7
Injection Molded Tiles	2.0	52.9	0	0	0	0	0	0	0	54.9
Auto Tile Assembly	20.0	0	0	0	0	0	0	0	0	20.0
Tile Char. (Lab)	16.0	0	0	0	0	0	0	0	0	16.0
Sensor Board	12.2	0	0	0	0	0	0	0	0	12.2
LFHCAL Mechanics	21.7	0	0	0	0	0	0	0	0	21.7
Tile Char. (Beam)	1.0	0	2.0	2.0	2.0	2.0	2.0	1.0	2.0	14.0
Total	84.6	52.9	2.0	2.0	2.0	2.0	2.0	1.0	2.0	**150.5**

institute	cost in FY23 k$ eng. and tech.	material	equipment	travel	total cost in FY23 k$
ORNL	29.8	16.8	36.0	2.0	84.6
FNAL	52.9	0	0	0.0	52.9
BNL	0	0	0	2.0	2.0
UTK	0	0	0	2.0	2.0
GSU	0	0	0	2.0	2.0
Yale	0	0	0	2.0	2.0
ISU	0	0	0	2.0	2.0
Valpo	0	0	0	1.0	1.0
UCR	0	0	0	2.0	2.0
Total	82.7	16.8	36.0	15.0	**150.5**

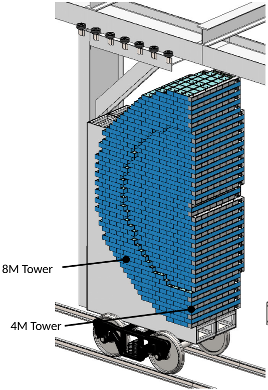
- Largest fraction of funding for engineers and technicians
- Additional funds used for material, test equipment & travel for test beam campaigns
- Significant in-kind contribution from universities and laboratories for assembly, simulation and data analysis ($\sim$ 2140h)
- Parallel PED request for mechanical & electrical engineering support will be submitted to further final design of LFHCAL

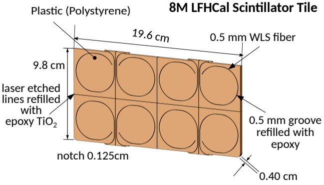
Task	Estimated cost in $ per year FY24	FY25	FY26
mechanical engineering	40K	40K	20K
electrical engineering	30K	30K	20K
materials	30K	30K	40K
test beam support	10K	10K	10K
total	110K	110K	90K

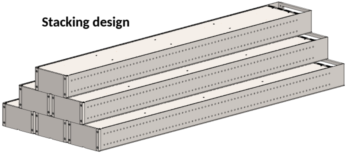
Thanks!

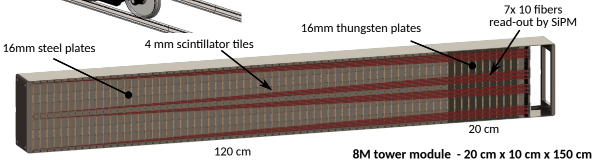


Calorimeter Details & PED request







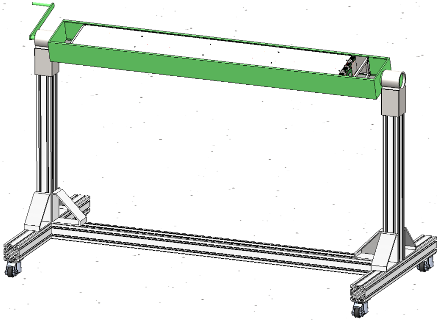


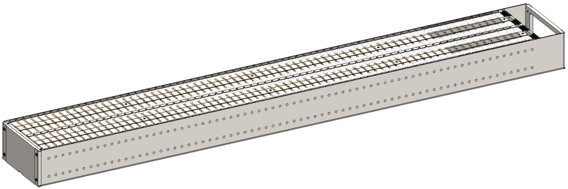
8M tower module - 20 cm x 10 cm x 150 cm
- 8 5 cm x 5 cm LFHCal towers

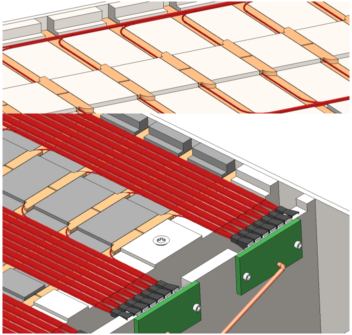
parameter	LFHCal
inner radius (envelope)	17 cm
outer radius (envelope)	270 cm
η acceptance	$1.2 < \eta < 3.5$
tower information	
x, y (R </> 0.8 m)	5 cm
z (active depth)	140 cm
z read-out	10 cm
# scintillor plates	70 (0.4 cm each)
# aborber sheets	60 (1.6 cm steel)
	10 (1.6 cm tungsten)
weight	$\sim$ 30.6 kg
interaction lengths	6.9 λ/λ_0
Molière radius R_M	21.1 cm ($\pi^{\pm}$ shower)
Sampling fraction f	0.040
# towers (inner/outer)	9040
# modules	
8M	1091
4M	76
2M	2
1M	4
# read-out channels	7 x 9,040 = 63,280

activity	cost in FY23 k$ ORNL	BNL	total cost in FY23 k$
Support structure desgin & integration with pECal	75	0	75
Rail/slide design	0	50	50
test production of module	20	0	20
tooling design + function test	50	0	50
Total	145	50	**195**

8M assembly

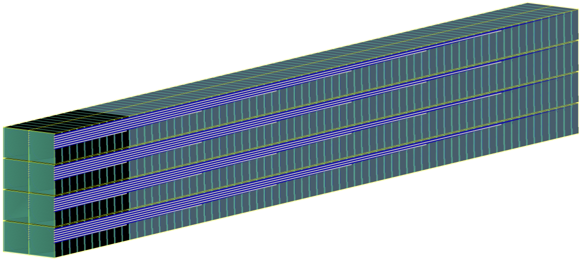


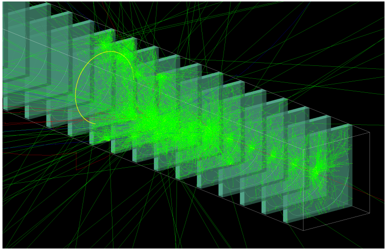


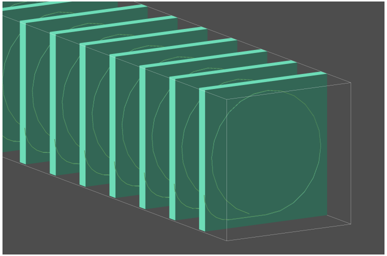


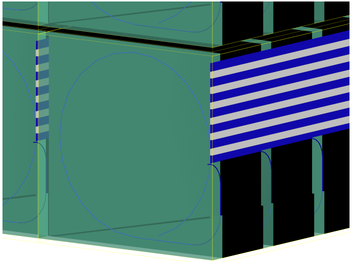
a) single tile assembly (fiber embedding, glueing, wrapping)
b) tile testing
c) assembly of module, alternating steel plate first kept in place by e-beam point welding then Scint-tile
d) fiber channels layed out on front on back
e) SiPM & read-out card installation
f) tower testing
g) close up module with cover plates

GEANT Implementation Fun4All









- largely realistic implementation of geometry (Nicolas), refinements for module edges needed
- first light propagation studies with Nico & soon Craigs students, cross check with test sub-tiles at ORNL (fiber routing)

Conservative Cost Estimate

Example 8M module costs:

Material procurement	Units	Unit Pricing
Absorber plates + support	1	$1750
Scintilator plates	70	$65
tyvek + capton	4.04	$0.4
WLS fibers	1360	$3
8M module cost:	1091	**$9822**

Assembly labor	hours	cost
installing fiber mech. engineer	17.5 h	$2680.5
tile wrapping PhD students	7 h	$140
tower assembly mech. engineer	0.083 h	$12.8
tower assembly PhD Student	1.92 h	$38.4
tower assembly Undergrad	11 h	$220
tower assembly Postdoc	1 h	$71
tower assembly PhD Student	4.5	$90
8M module cost:	1091	**$2252.7**

Electronics	Units	Unit Pricing
SiPMs	56	$10
mounting boards	1	$10
cable+HV/LV	1	~$822
8M module cost:	1091	**$1392**

Additional costs:

- R&D cost: 393K
- Tooling: 200K
- Support Structure: 100K
- Installation: 382K

Total costs:

- estimated for:
  1091x8M module, 76x4M modules, 2x2M modules, 4x1M modules
- Module prices don't exactly scale as labor doesn't scale
- Cost adapted to US prices w/o relying on Uniplast
- **total unescalated cost: $17.7M**
  → estimates w/ Uniplast quotes $11.2M

eRD107: Detailed cost table

Institute	Item	Cost per item in $	Number of items	Total cost in $	To be compl. by
	Machined Scintillator Tiles:				Q1/2023
ORNL	BC-408 plastic scintillator sheet	~ 150	20	3K	
ORNL	BCF-91A WLS fiber	1500	1	1.5K	
ORNL	tile machining	180/h	40h	7.2K	Q4/2022
ORNL/UTK	tile assembly		40h	(in kind) 0K	Q4/2022
	Injection Molded Scintillator Tiles:				Q2/2023
FNAL	mold design + production	50 000	1	50K	Q4/2022
ORNL	travel			2K	
FNAL	raw material + dopant			(in kind) 0K	
FNAL	injection molder setup + operation	180/h	16h	2.9K	Q1/2023
ORNL/UTK	tile assembly		40h	(in kind) 0K	Q1/2023
	Automated Tile Assembly:				2024
ORNL	robotic arm	20 000	1	20K	
ORNL	robot programming and evaluation		40h	(in kind) 0K	Q3/2023
	Tile Characterization (Lab Bench):				Q3/2023
ORNL/UTK	scintillator material characterization		20h	(in kind) 0K	Q2/2023
ORNL	waveform sampling readout (8ch)	16000	1	16K	
GSU/Yale/UCR	tile lightyield testing		160h	(in kind) 0K	Q3/2023
ISU/BNL	tile simulation		160h	(in kind) 0K	Q3/2023
	Sensor Board:				Q1/2023
ORNL	mechanical engineer	180/h	15h	2.7K	
ORNL	sensors: silicon photomultipliers	30	300	9K	
ORNL	sensor board production, assembly	50	10	0.5K	Q1/2023
	Reconstruction Optimization:				2025
UTK/Yale/BNL	simulations/digitization/reconstruction/analysis		640h	(in kind) 0K	
	LFHCAL Mechanics:				Q3/2023
ORNL	mechanical engineer	180/h	105h	18.9K	
ORNL	absorber material + fasteners	40	70	2.8K	
UTK/Yale	absorber machining	100/h	20h	(in kind) 0K	Q2/2023
	Tile Characterization (Test Beam):				Q3/2023
ORNL	assembly and shipping			1K	
All	test beam travel			13K	
ORNL/UTK	test beam preparation		80h	(in kind) 0K	Q2/2023
ORNL	test beam		120h	(in kind) 0K	Q3/2023
Yale	test beam		120h	(in kind) 0K	Q3/2023
BNL	test beam		120h	(in kind) 0K	Q3/2023
UTK	test beam		120h	(in kind) 0K	Q3/2023
GSU	test beam		120h	(in kind) 0K	Q3/2023
ISU	test beam		120h	(in kind) 0K	Q3/2023
Valpo	test beam		120h	(in kind) 0K	Q3/2023
UCR	test beam		120h	(in kind) 0K	Q3/2023
Total				**150.5K**	