Longitudinally segmented Forward HCal (LFHCal) & Insert

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EIC Project Detector Calorimetry Review

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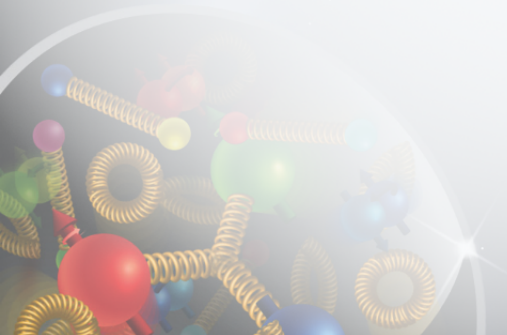
Electron-Ion Collider

Brookhaven National Laboratory · Jefferson Lab · U.S. Department of Energy | Office of Science

Concept & Assembly



Reminder Charge questions

1. Are the technical performance requirements complete for all detector systems that employ SiPMs, documented, and understood?
2. Are the plans for achieving detector performance and **construction sufficiently developed and documented for the present phase of the project**? (I.e., are they commensurate with the initiation of the SiPM procurement?)
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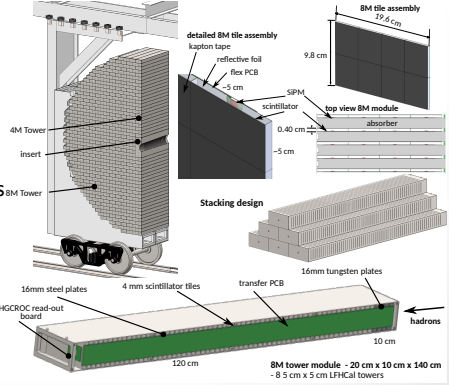
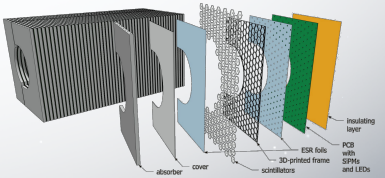
6. Have previous review recommendations been adequately addressed to initiate the SiPM procurement?
7. **Have ES&H and QA considerations been adequately incorporated in the SiPM procurement planning?** (This includes a quality assurance plan for receipt of material meeting specifications.)
8. Is the procurement approach sound and the procurement schedule credible?

The General Idea

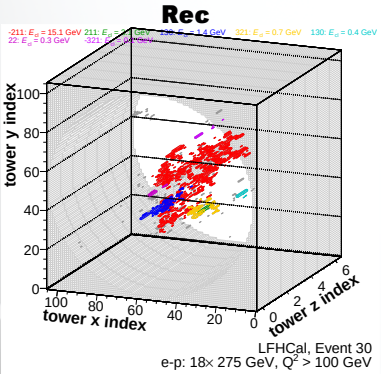
Concept:

- 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





General Facts on Read-out LFHCal & insert

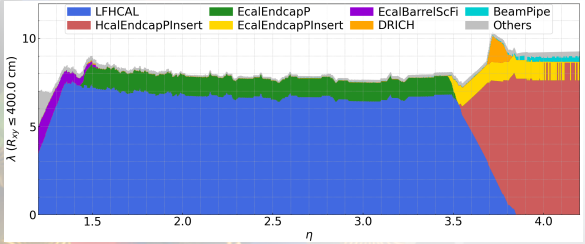


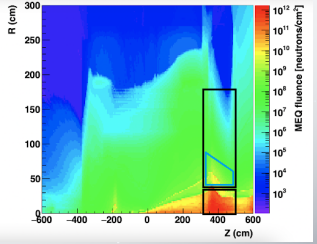
- High granularity needed to try to distinguish shower maxima close to beam pipe
- **LFHCal**:
  read out in 7 layers longitudinally (5 or 10 SiPMs summed)
  desirable min measurable tower energy 3-5 MeV, max 20-30 GeV in single tower segment
- **insert**:
  read out every single tile
  desirable min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

LFHCal in Numbers

- Acceptance: $1.2 < \eta < 3.5$
- Interaction length: $6.5\lambda/\lambda_0$
- SiPMs not accessible after installation
  - Inner modules ($R < 1$m) equipped with machined scintillator tiles & 3mm SiPMs $\rightarrow \sim 11\% = 83200$ tile/ SiPMs
  - Outer modules equipped with injection molded tiles & 1.3mm SiPMs $\rightarrow \sim 89\% = 482560$ tile/ SiPMs
- 565,760 SiPMs, 60,928 read-out channels
- CD3-A/B procurement: Steel, Tungsten & SiPMs
- Current estimated total cost: $\sim$ 15.8M

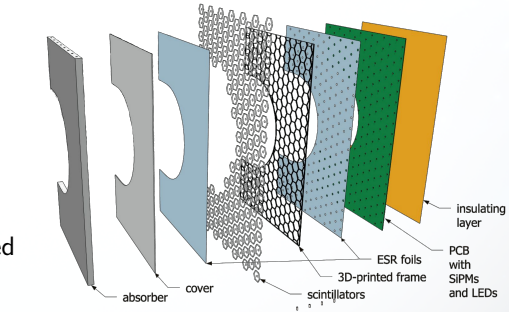
parameter	LFHCal
inner x, y	60 cm
outer radius (envelope)	270 cm
η acceptance	$1.2 < \eta < 3.5$
tower information	
x, y	5 cm
z (active depth)	130 cm
z read-out	10 cm
# scintillator plates	65 (0.4 cm each)
# absorber sheets	61 (1.52 cm steel)
	4 (1.52 cm tungsten)
interaction lengths	6.5 λ/λ_0
Sampling fraction f	0.035
# towers	8704
# modules	
8M	1050
4M	76
# read-out channels	7 x 8704 = 60,928





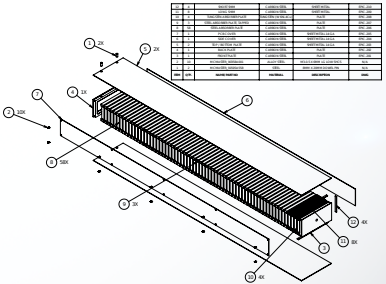
Insert in Numbers

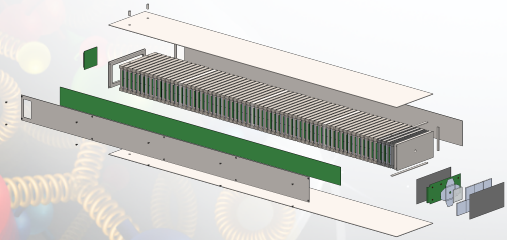
- Acceptance: $3.5 < \eta < 4.4$
- Interaction length: $7.5\lambda/\lambda_0$
- Similar sampling structure as LFHCal
- 10 layers of tungsten, 55 layers of steel
- Maximum η coverage with minimum dead area in combination with LFHCal
- 360 hexagonal tiles with SiPMs per layer, staggered positions in different layers
  $\rightarrow$ 23400 SiPMs/tiles & read out channels
- Scintillator & SiPM assemblies accessible during end-of-year access, designed to be possible to be annealed every few years or replaced
- CD3-A/B procurement: Steel, Tungsten & SiPMs
- Current estimated total cost: $\sim$ 1M

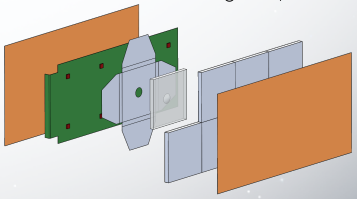


Construction Procedure

- Construction done in units of modules:
  1058× 8M, 76× 4M, right & left side of insert
- Construction & QA steps per unit:
  1. Assembly of absorber structure without cover-plate
  2. Assembly of tiles & PCB per layer & testing
  3. Installation of tile assemblies in absorber structure
  4. Connection of transfer PCB & connectivity tests
  5. Mounting of cover plate
  6. Cosmics tests per module

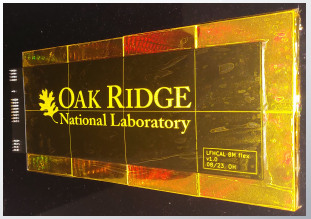






ES&H & QA considerations

- Permanent test setup of 8× 8M-modules included in purchase order, allows for
  - test beam measurements of final modules during construction and operation phases
  - final qualification of performance without significant shower leakage
  - reproduction of possible problems in the lab
- Procurement of SiPMs includes 1% margin for possible production losses
- Foreseen SiPM testing process:
  - Vendor testing and qualification for V_{op} within 0.1V/ delivery unit
  - Testing at PCB vendor after flex-PCB assembly (connectivity)
  - Cosmics tile assembly testing & classification for each module prior & after installation in module (same procedure for insert)



Simulated Performance

Current R&D Programm

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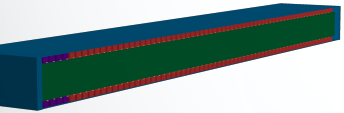
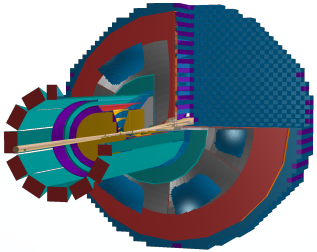
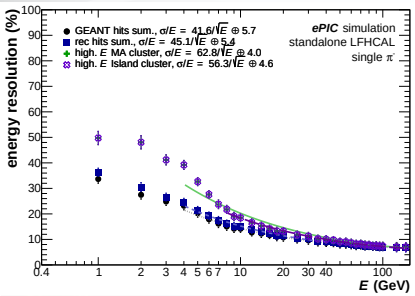
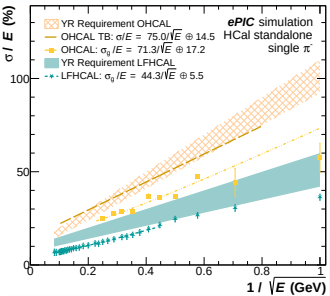
Simulated performance







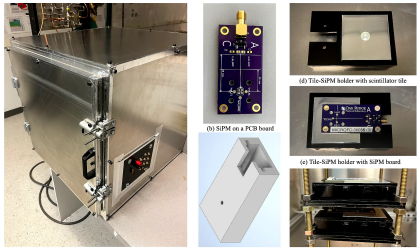


- Implementation of realistic geometry in ePIC software stack
- Single pion response in accordance with expectations & meeting YR requirements
- First version of clusterization algorithm working well at high *E*
- Integration with insert ongoing
- Ongoing studies to improve clusterization algorithm using ML started during several workshops
- Ongoing development of full fledged software compenstation

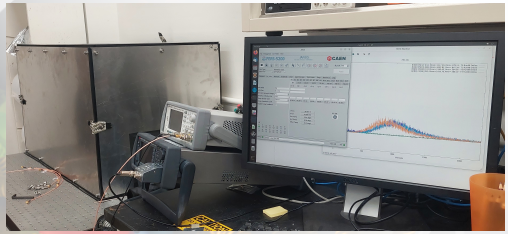
Scintillator & SiPM Characterization

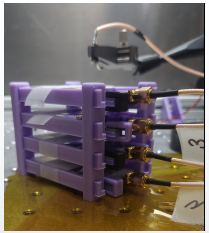
- Three parallel test setups for tile characterization (Yale, ORNL, UCR)
- SiPM test boards produced
- Developed multiple 3D printed test stands for single SiPM & Cosmics data taking
- Vendor survey for available $\approx 1x1$ mm & $3x3$ mm SiPMs regarding
  - Availability
  - Data accuracy in data sheets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

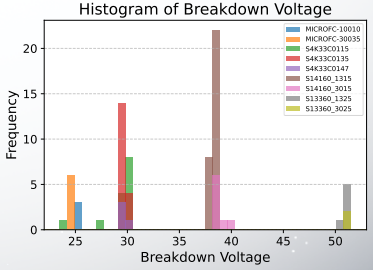
Yale



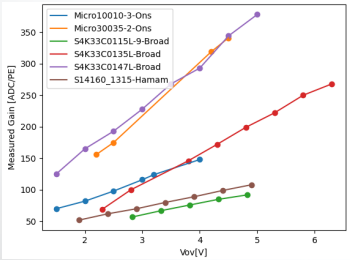
ORNL

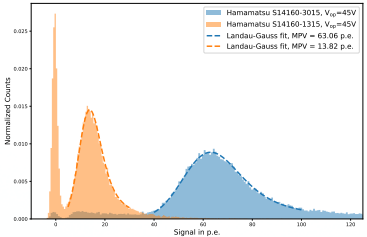


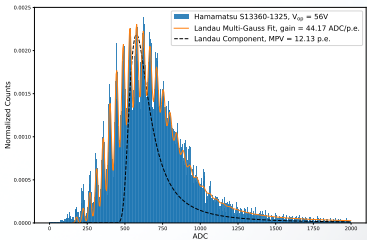




LFHCal Scintillator & SiPM Characterization

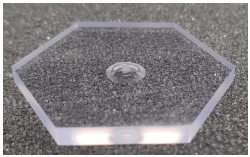




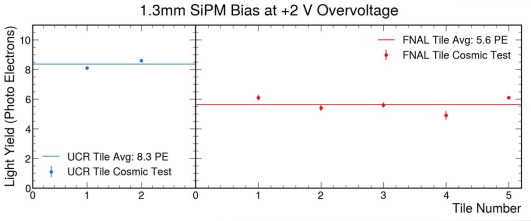


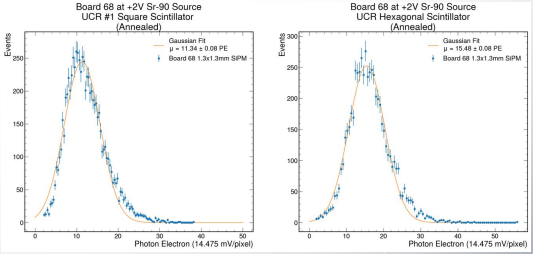
- Single photon spectra for every SiPM
- Characterized different SiPM gains as function of V_{ov}
- Started measuring cosmics MIP light yields for different SiPMs types
  - 1.3×1.3 mm $\approx 12 - 14$ p.e. for machined tiles
  - 3×3 mm $\approx 60 - 76$ p.e for machined tiles
- Testing different scintillator materials (EJ-200, BC-408 & Fermilab injection molded)
- Sytematic evaluation of impact of machining defects ongoing

Insert Scintillator & SiPM Characterization



- Initially compared LY using Cosmics for $\approx 3 \times 3$x0.35 cm^3 CMS machined & injection molded tiles at $V_{ov} = 2$V
  - machined: ≈ 8.3 p.e
  - injection molded: ≈ 5.6 p.e
- As expected approx. 30% reduction in LY for injection molded tiles
- Improved wrapping and painting increased LY by up to 30%
- Hexagonal machined tiles $\approx$ 30-35% more light yield ≈ 15 p.e. at $V_{ov} = 2$V
- Irradiation test planned for the fall





SiPM requirements

- Considering 2 different types depending on radiation, ideally relatively high fill factor ($> 40\%$) & reasonably many pixels (15-25 mm pitch),
  - 1.3.3 mm low radiation ($\sim 90\%$) LFHCal & insert with annealing i.e:
    Hamamatsu S13360-1325PE (2668 pixel, fill 47%, PDE $\sim 25\%$)
    Hamamatsu S14160-1315 (7284 pixel, fill 49%, PDE $\sim 32\%$)
  - 3 mm high radiation ($\sim 10\%$) LFHCal i.e:
    Hammatsu S13360-3025PE (14400 pixel, fill 47%, PDE $\sim 25\%$)
    Hammatsu S14160-3015 (39984 pixel, fill 47%, PDE $\sim 25\%$)
  - Prefer newer generation due to larger number of pixel allowing not to saturate
- Vop Selection:
  - Groups with same Vop selection +/- 0.1-0.2V for LFHCal, grouped according to 8M module (520)
  - Groups with same Vop selection +/- 0.05V for insert, grouped according to layer (360)
  - HGCROC allows individual channel voltage trim for gain adjustment,

Summary Charge Questions

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   Yes
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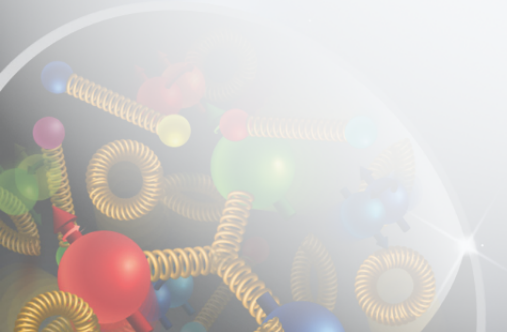
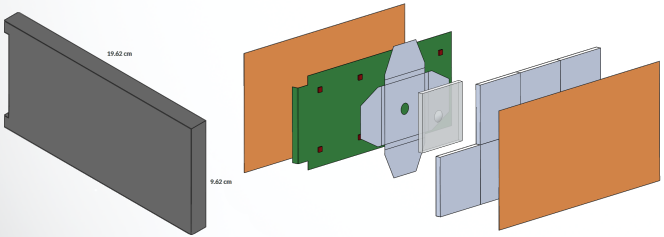
Back-up

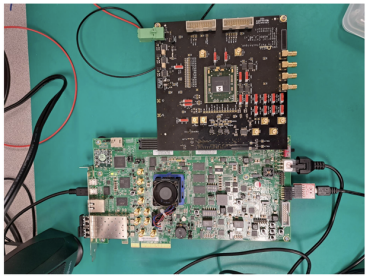


LFHCal 8M Scintillator Tile assembly



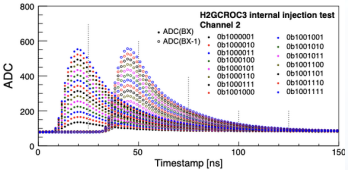
- Tiles of $\approx 0.4x5x5$ cm^3 with dimples individually wrapped in ESR foil assembled in a grid of $4x2$ tiles
- 8 tiles are backed by a flexible PCB equipped with 8 SiPMs and LEDs sandwiched with Kapton foil
- Flexible PCB wrapped around side of absorber to connect with long PCB along the side of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

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