lfHCal - A Longitudinally Segmented Hadronic Calorimeter for the Forward Region of the Future ePIC Detector at the Electron-Ion-Collider

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Introduction

The Electron-Ion-Collider (EIC) is a new particle accelerator planned for the late 2020s. The EIC will be built at Brookhaven National Laboratory and will be **the first polarized electron-proton collider.**

Some of the main physics goals are:

- **Hadron properties (mass and spin)**
- **3D imagining of the nucleus**
- **Studies of the dense nuclear medium**

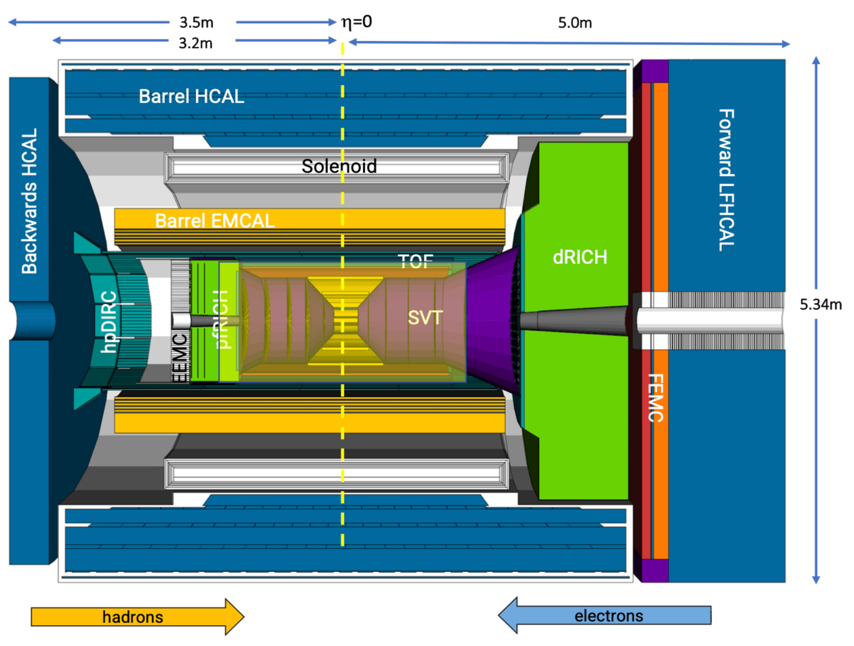
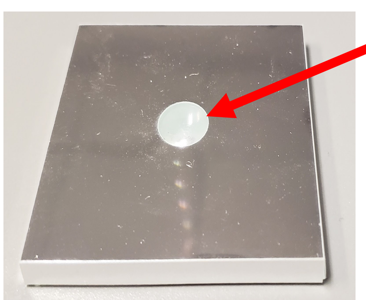


Figure 1. The ePIC Detector Design

The ePIC Forward Calorimeter

The goal of the **Longitudinally Segmented Forward Hadronic Calorimeter (lfHCal)** is to **measure the energy of jets and single hadrons** in the "forward" (**$1.2 < \eta < 3.5$**) hadron-going region.

The lfHCal has a plastic scintillator-steel tower design. The plastic scintillator is segmented into **5 x 5 cm^2 tiles** with each tile **coupled to a silicon photomultiplier** (SiPM) for a total of **62,424 read-out channels.**



Nominal tile dimple. SiPM will be placed there. Tiles are 0.4cm x 5 cm x 5 cm. The nominal dimple size is 0.9 cm across.

The dimple in the tile reduces the light collection hotspot induced by the SiPM location. By reducing the amount of light produced by the scintillator around the SiPM the light uniformity of the tile improves. [1]

Figure 2. Scintillator tile wrapped in 3M ESR foil

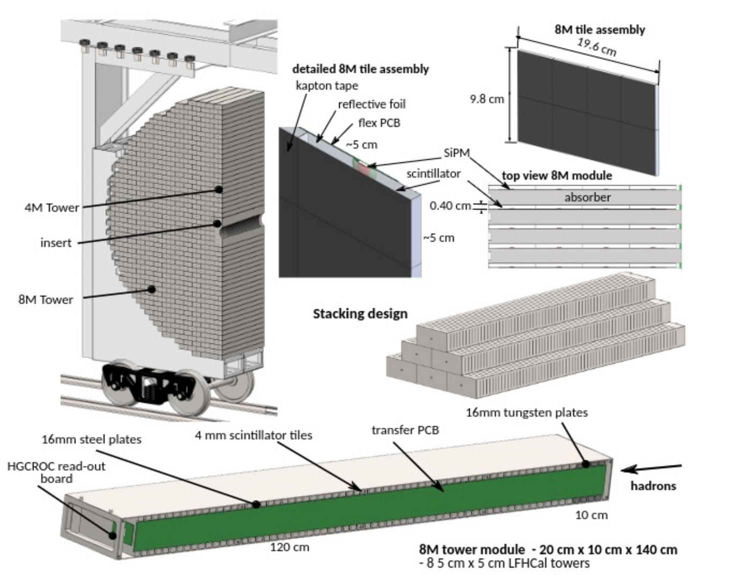


Figure 3. lfHCal Design

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	8916
# modules	
8M	1077
4M	75
# read-out channels	7 x 8916 = 62,414

Table 1. Design properties for lfHCal Design

Ref: Abu-Ajamieh, F., et al. "Test Beam Performance of Directly Coupled Scintillator Tiles using Hamamatsu MPPCs." *Physics Procedia* 37 (2012): 789-795.

R&D Overview

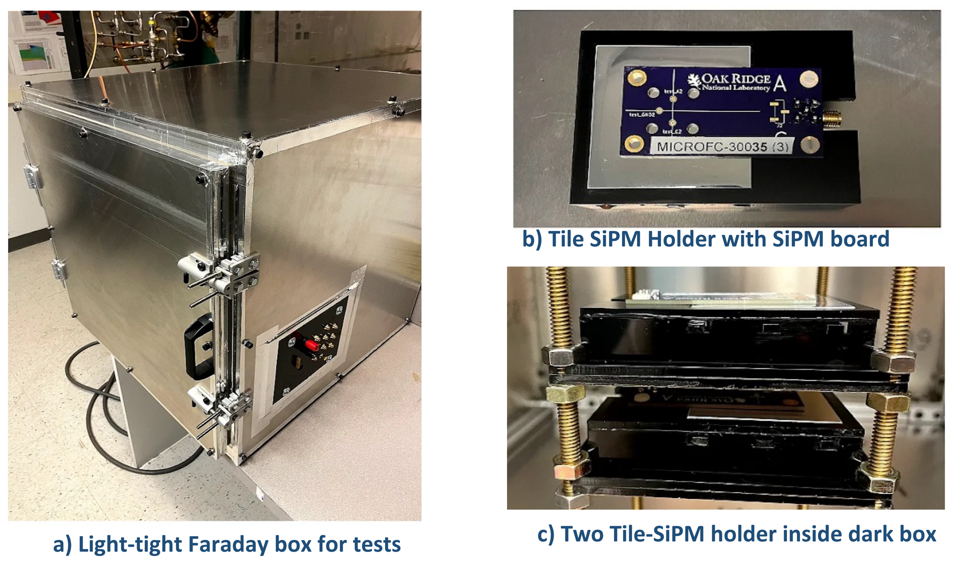
R&D Efforts:

On-going plastic scintillator **scalability studies**.

- More than 600 thousand tiles are needed with similar light yields

SiPM and Tile Characterization (at Yale/ORNL)

- **Testing multiple SiPM manufacturers** and SiPM models to ensure performance
- **Measuring scintillating tile light yield** with cosmic muons
- **Testing light uniformity** and **light yield stability** of the tiles using cosmic muons
- **Test beams** at CERN in Fall 2023 to measure shower profiles with different absorbers, tile cross-talk and new readout electronics



a) Light-tight Faraday box for tests
b) Tile SiPM Holder with SiPM board
c) Two Tile-SiPM holder inside dark box

Figure 4. Lab test set up designed and assembled at Yale to characterize the tiles and SiPMs

SiPM Characterization

3 initial tests started this summer

- IV curves to **determine their breakdown voltage (V_{br})**
- Staircase plots to **determine threshold to reduce noise** due to **dark current rate (DCR)**
- **Single photon spectrum (SPE)** with the LED driver for different over-voltages (V_{ov})

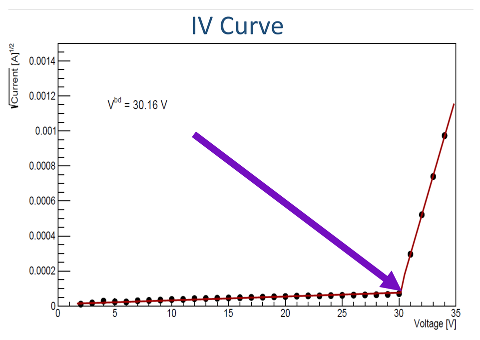
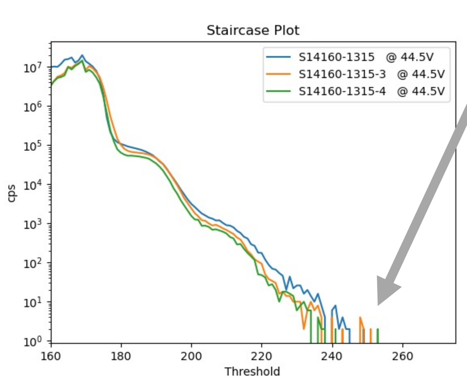


Figure 5. Fit to IV Curve for V_{br}

V_{br} corresponds to the voltage at which photons can trigger an avalanche on the SiPM which causes a sudden increase in current. The cusp point is the breakdown voltage.



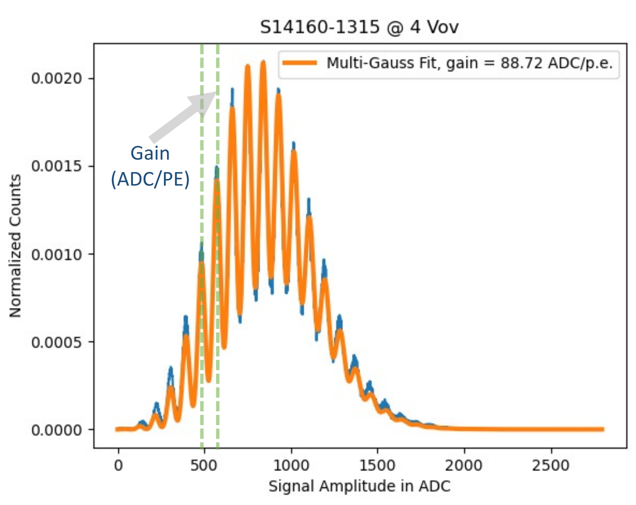
No more noise [DCR – counts per second (cps) ->0] after ~260 trigger threshold for all three Hamamatsu SiPMs.

The different steps in the plot correspond to different PE peaks.

Figure 6. Staircase plot for Hamamatsu SiPMs

The blue histogram is the SPE and the orange line our fit. The different wiggles correspond to different PE peaks. The difference between two PE peaks corresponds to gain

The gain for the spectra is 88.72 ADC/PE



So far, all the SiPMs are behaving as expected.

Figure 7. SPE spectra digitized with the CAEN DT5202 and produced by the CAEN LED driver with λ = 400nm

SiPM Comparison

For every **SiPM model gain calculations were plotted as a function of V_{ov}** to compare SiPM performance.

SiPM Type	Vendor	Pixel Pitch
S14160-1315PS	Hamamatsu	15 μm
S4K33C0115L	Broadcom	15 μm
S4K33C0135L	Broadcom	35 μm
S4K33C0147L	Broadcom	47 μm
MICROFC-10010	Onsemi	10 μm
MICROFC-30035	Onsemi	35 μm

Table 2. SiPM characteristics from vendors

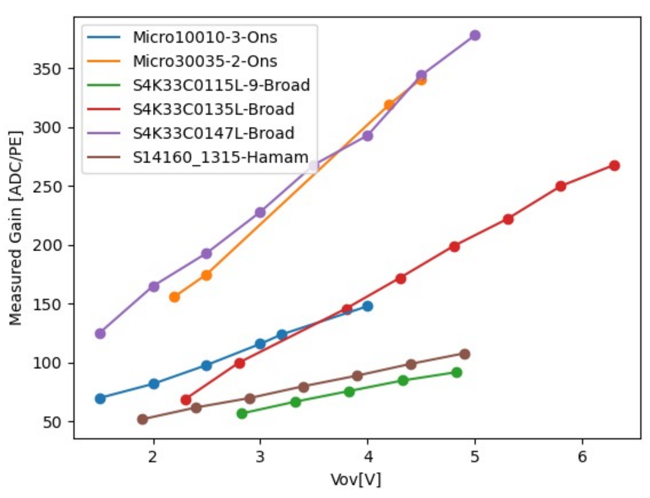


Figure 8. Multiple SiPM Gains at different over voltages

Tile Characterization

The **light yield was tested** while **light uniformity will be tested soon.** A preliminary **comparison between different dimple geometries** have been done.

- Cosmic runs with a 3-tile coincidence to ensure a pure muon sample. Unlike muons, environment backgrounds (**γ**, **α**) cannot cross multiple tiles

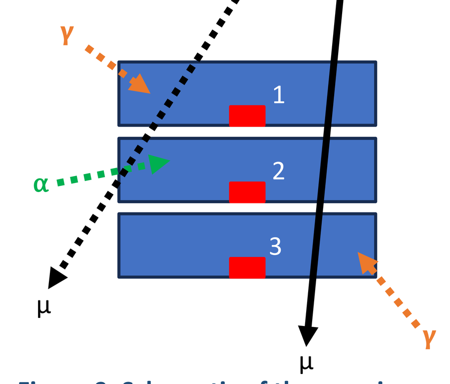


Figure 9. Schematic of the cosmic run set up. The crossing muon (solid) will create light in all tiles (1,2,3). This is the signal. Gammas, alphas and other muons (dash) are backgrounds

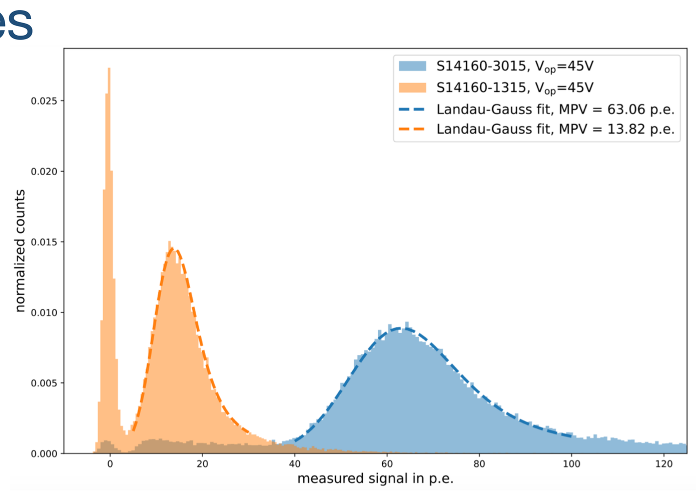


Figure 10. Fitted muon peak with a landau-gaussian function. MIPs traversing matter follow a landau-distributed energy loss (i.e., Muon crossing tile)

The two tile geometries with different dimple sizes were compared.

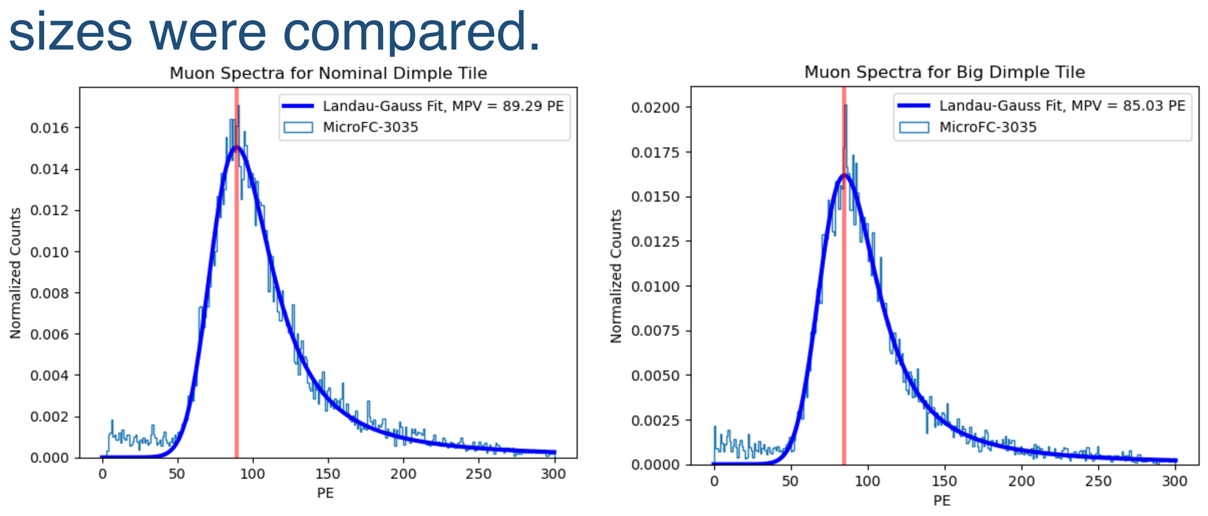


Figure 11. Muon spectra (MicroFC-3035 SiPM 35 μm) comparison for nominal dimple (left) to the bigger dimple geometry. Vertical line corresponds to the MPVs for each dimple.

The big dimple had an MPV = 85.0±1.6 PE and nominal dimple had an MPV = 89.3±0.2 PE.

Conclusions

- We developed a setup and routine to characterize SiPMs and tiles.
- We are working to ensure the scalability of the routine since more than 600,000 will be tested.

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