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

OAK RIDGE National Laboratory

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:**
  - 65 layers of steel interleaved with scintillator material
  - Transverse tower size $5x5$ cm^2
  - Multiple consecutive tiles summed to 7 longitudinal segments per tower
- **Insert:**
  - 65 layers of steel interleaved with scintillator
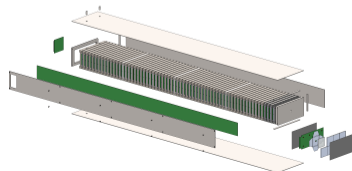 - Hexagonal tiles of 8 cm^2 each read-out individually
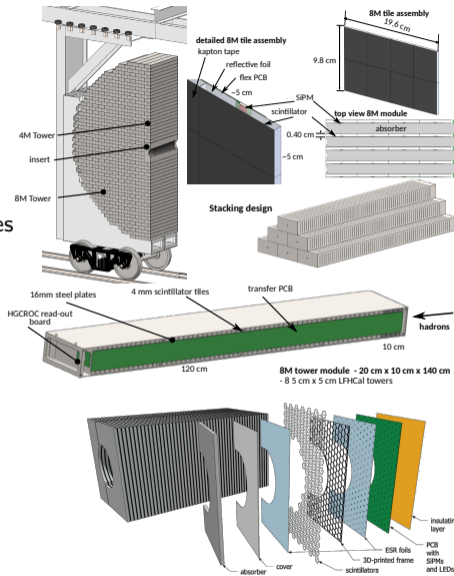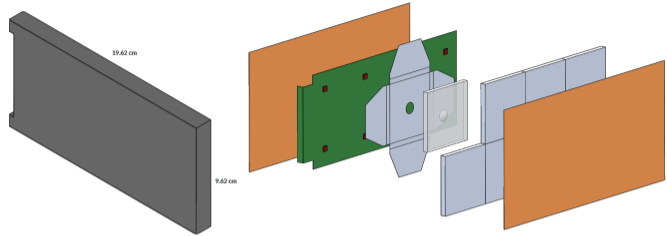
- Tiles of $\approx 0.4x5x5$ cm^3 with dimples individually wrapped in ESR foil assembled in a grid of $4x2$ tiles
- 8 tiles are backed by a flexible PCB equipped with 8 SiPMs and LEDs sandwiched with Kapton foil
- Flexible PCB wrapped around side of absorber to connect with long PCB along the side of the module
- Tiles either injection molded or machined out of cast sheets

Rec

tower y index

tower x index

tower z index

LFHCal, Event 30
e-p: 18× 275 GeV, Q^2 > 100 GeV
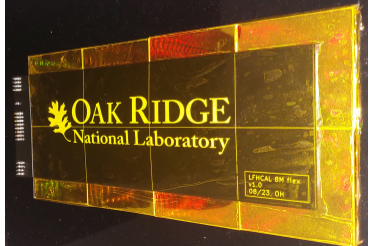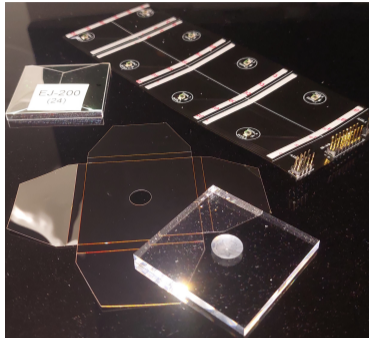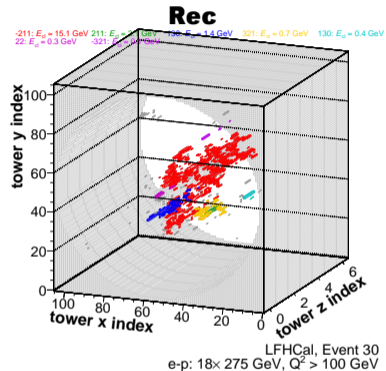
- High granularity needed to try to distinguish shower maxima close to beam pipe
- **LFHCal**:
  read out in 7 layers longitudinally (5 or 10 SiPMs summed) desirable min measurable tower energy 3-5 MeV, max 20-30 GeV in single tower segment
- **insert**:
  read out every single tile
  desirable min measurable 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

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
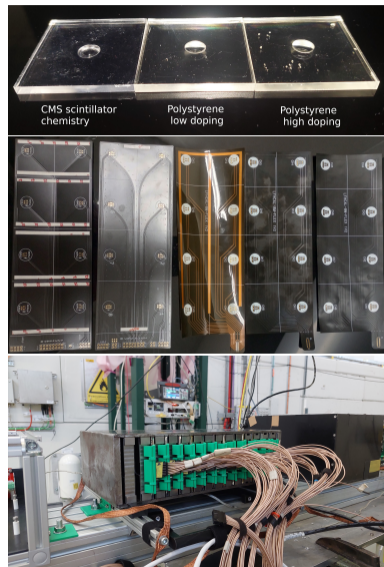
3. Tile Characterization
- ▶ Light yield studies of machined & injection molded tiles with different dimple sizes, machining techniques and wrappings ongoing
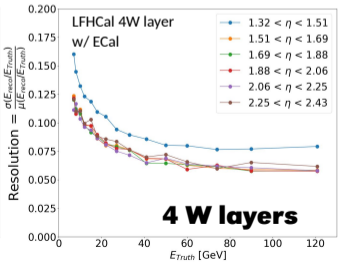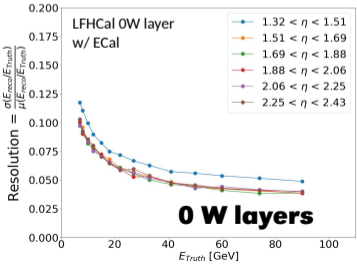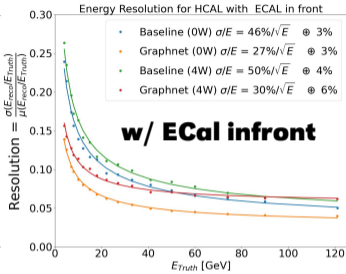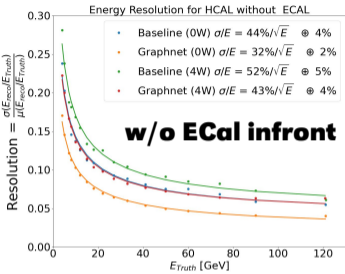- ▶ Position scan of response on-going

4. Sensor board development
- ▶ Third iteration of sensor board produced in three different processes
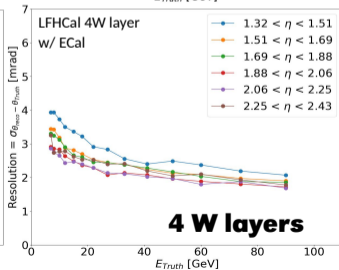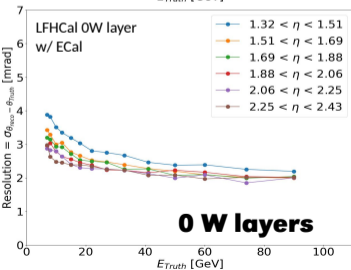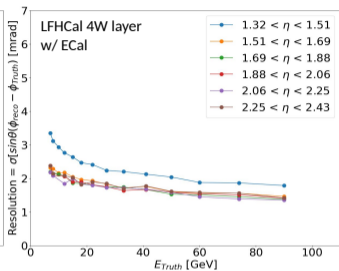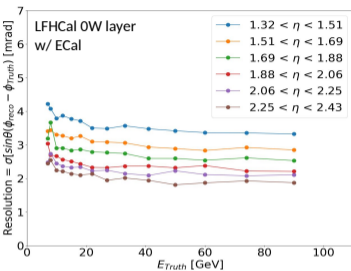- ▶ Tests of calibration circuits ongoing

5. Preparations for 2024 TB-campaigns & 2023 TB analysis
- ▶ Test beam analysis from Sept. & Oct. 2023 on-going
- ▶ All components for test beam campaign ordered and on time for being tested ahead of time

CMS scintillator chemistry | Polystyrene low doping | Polystyrene high doping

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Energy Resolution for HCAL without ECAL

- Baseline (0W) $\sigma/E = 44\%/\sqrt{E} \oplus 4\%$
- Graphnet (0W) $\sigma/E = 32\%/\sqrt{E} \oplus 2\%$
- Baseline (4W) $\sigma/E = 52\%/\sqrt{E} \oplus 5\%$
- Graphnet (4W) $\sigma/E = 43\%/\sqrt{E} \oplus 4\%$

w/o ECal infront

Energy Resolution for HCAL with ECAL in front

- Baseline (0W) $\sigma/E = 46\%/\sqrt{E} \oplus 3\%$
- Graphnet (0W) $\sigma/E = 27\%/\sqrt{E} \oplus 3\%$
- Baseline (4W) $\sigma/E = 50\%/\sqrt{E} \oplus 4\%$
- Graphnet (4W) $\sigma/E = 30\%/\sqrt{E} \oplus 6\%$

w/ ECal infront

LFHCal 0W layer w/ ECal

- $1.32 < \eta < 1.51$
- $1.51 < \eta < 1.69$
- $1.69 < \eta < 1.88$
- $1.88 < \eta < 2.06$
- $2.06 < \eta < 2.25$
- $2.25 < \eta < 2.43$

0 W layers

LFHCal 4W layer w/ ECal

- $1.32 < \eta < 1.51$
- $1.51 < \eta < 1.69$
- $1.69 < \eta < 1.88$
- $1.88 < \eta < 2.06$
- $2.06 < \eta < 2.25$
- $2.25 < \eta < 2.43$

4 W layers

- Implementation of realistic geometry in ePIC software stack
- First version of clusterization algorithm working well at high E
- Absorber optimization with ML assistance and full software compensation
  - ▸ Software compensation with full detector system optimized with graphnet-algorithmn
  - ▸ Improved E-resolution w/o tungsten layers
  - ▸ Little impact on spatial resolutions w/ or w/o tungsten layers
  - ⇒ Tungsten layers removed & replaced with steel

Reconstruction optimization

- Implementation of realistic geometry in ePIC software stack
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Scintillator Characterization - Test Stands

Yale

- Two parallel test setups for tile characterization (Yale & ORNL)

- Yale setup being extendend for $X - Y$ scanning of tiles

- 3D-printed tile and assembly holders developed for effective tile scanning

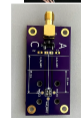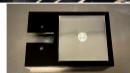- Further test stands being setup at GSU & Valpo
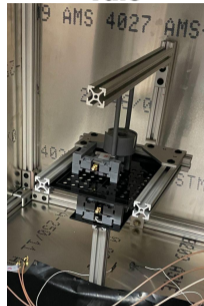
ORNL
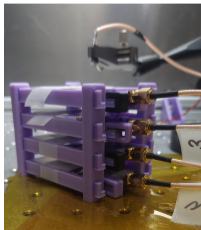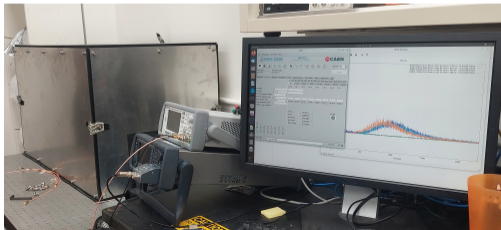
(a) Light-tight Faraday box with connector panel

(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

- 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

CMS scintillator chemistry

Polystyrene low doping

Polystyrene high doping
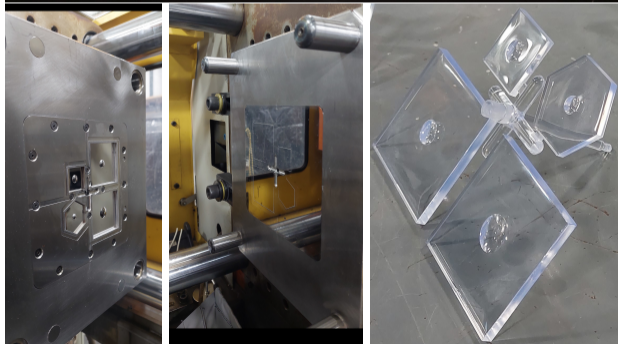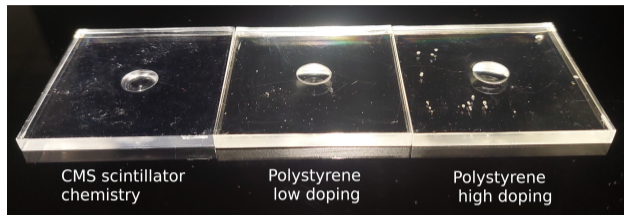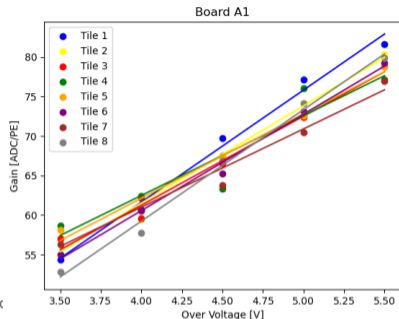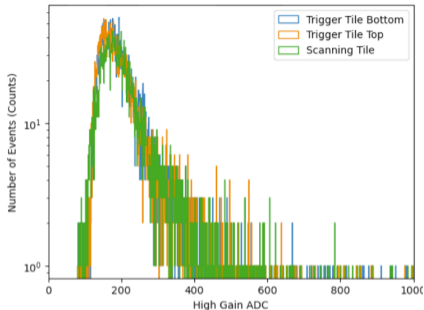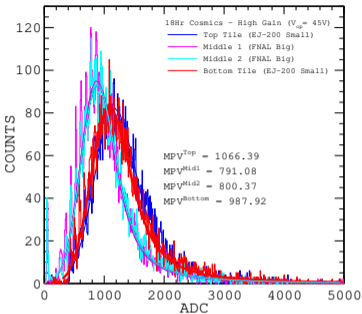
- Started measuring cosmics MIP light yields for different SiPMs types
  - 1.3×1.3 mm
  - $\rightarrow \approx 12 - 14$ p.e. for machined tiles
  - $\rightarrow \approx 11 - 13$ p.e. for injection molded tiles,
  - 3×3 mm
  - $\rightarrow \approx 60 - 76$ p.e for machined tiles

- 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
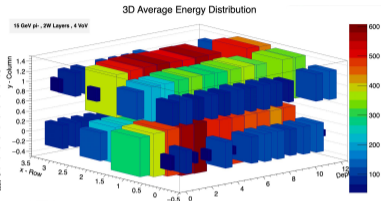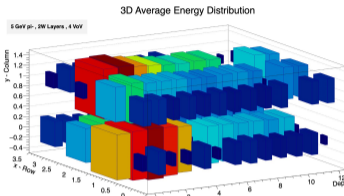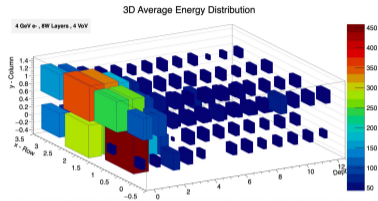 **Oct**: w/ absorber layers (4 tungsten, 10 steel)
- Read-out: CAEN DT5202 64ch CITIROC SiPM readout unit or H2GCROC

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
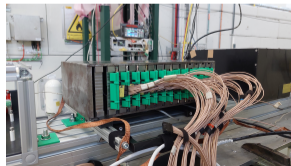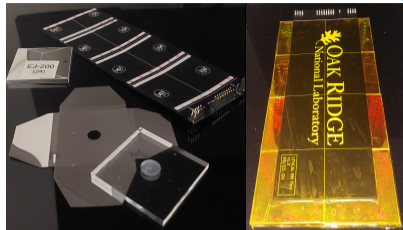
October campaign
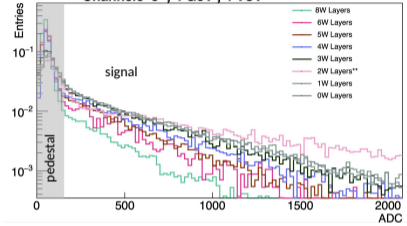

September campaign - Hodoscope setup

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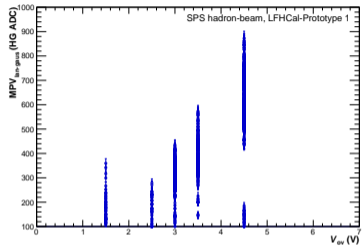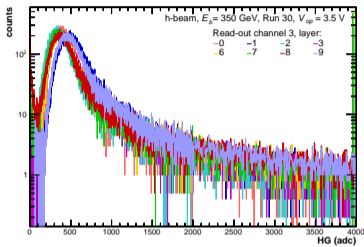- Possibly leakage measurement of FoCal-H

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)
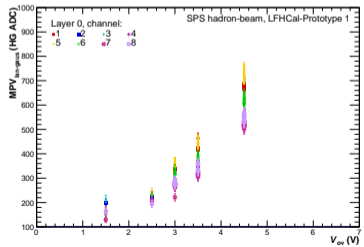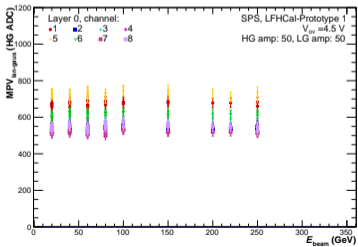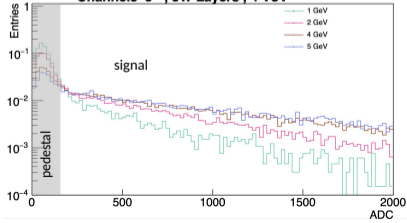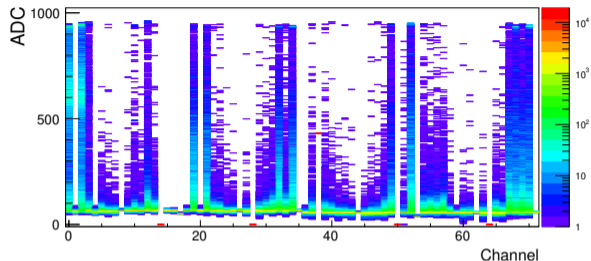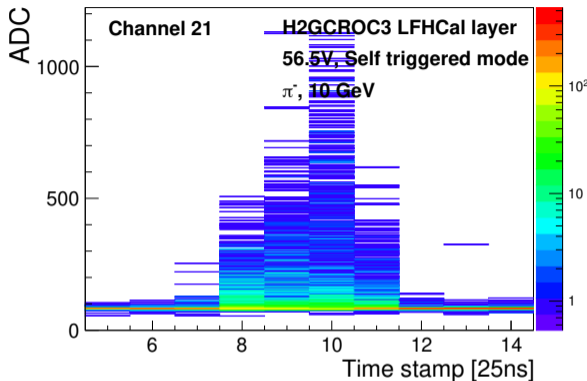- π^- shower development (5,10,15 GeV)

Additional W-plate scan

MIP response for scintillators

e⁻ Energy scan

- 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

**Dates:** $15^{th} - 22^{nd}$ May   **Location:** PS - T10
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 or H2GCROCs

Main expected measurements:

- Energy resolution estimates for hadrons and electrons for full length module
- Assessment of longitudinal leakage
- Longitudinal shower development
- Read-out validation
- Ideally part of the campaign with the addition of the ECal in front
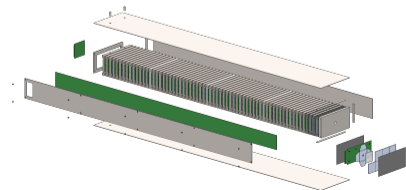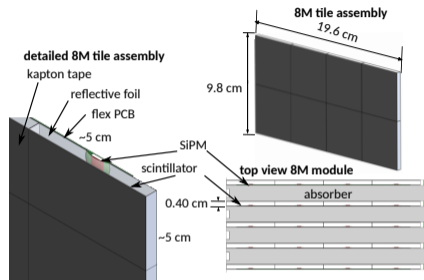
**Dates:** 28th Aug-4th Sept **Location:** PS - T09
Main purpose: Resolution studies
Setup:

- 4-8 full 8M modules (ideally 40×40×140 cm), optionally with ECal upfront
- Readout with H2GCROCs

Main expected measurements:

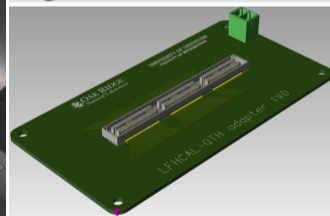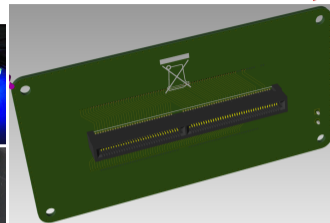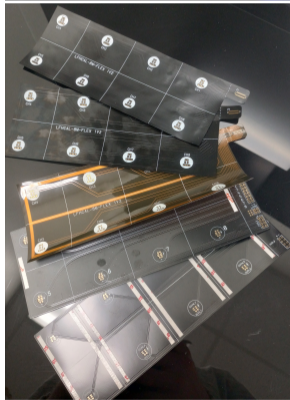- Energy resolution for hadrons and electrons
- Assessment of longitudinal/transversal leakage
- Longitudinal shower development
- Final-Flexible PCB validation & first long PCB validation
- Ideally part of the campaign with the addition of the ECal in front
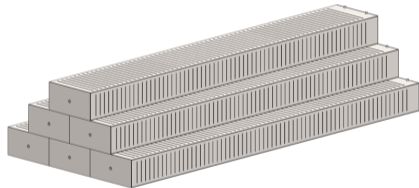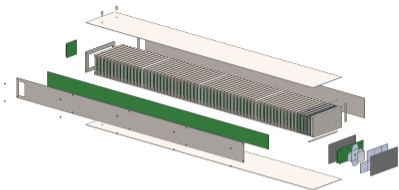
Test beam preparation

- 3rd iteration of SiPM-carrier board developed and produced in 3 different processes
- LED-calibration circuit included in latest SiPM carrier board
- New high density connectors on SiPM carrier boards & intermediary interface boards
- First version of *short* long-transfer board
- First full 8M absorber assembly being produced
- New assembly production with inj. molded tiles, after SiPM board testing

eRD107 - Progress - executive summary

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 (May 2024) & TB analysis**
   - Test beam analysis from Sept. & Oct. 2023 on-going
   - All components for test beam campaign ordered and on time for being tested ahead of time

CMS scintillator chemistry   Polystyrene low doping   Polystyrene high doping
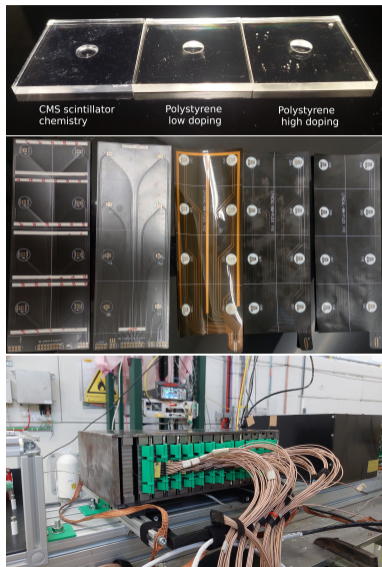
Thanks!
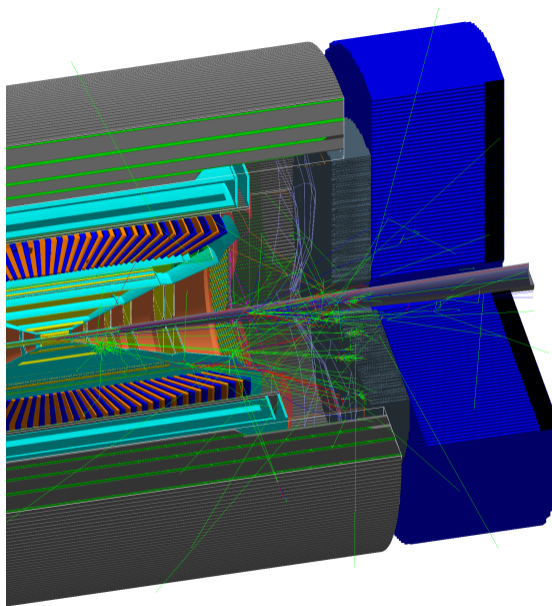
① **Tile production optimization using machining & injection molding (04/24)**

- ▶ 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
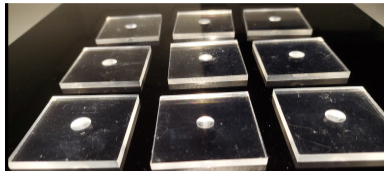
② **Reconstruction optimization (09/24)**

- ▶ 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