LFHCal: CALOROC questions

Friederike Bock (ORNL)

January 21, 2026

ePIC collaboration meeting, BNL, Upton, NY, US

CALOROC questions:

- 1. What is the capacitance of the detector per channel? (pF)
  - Largest fraction of detector summing 10(5) 1.3mm SiPMs (S14160-1315PS) $\Rightarrow$ 1000 (500) pF
  - 10% of detector summing 10(5) 3mm SiPMs (S14160-3015PS) $\Rightarrow$ 5300 (2650) pF
- 4. Do you have a measurement with certain settings of MIP peak, other fixed signal? (With the H2GCROC and settings)
  - Yes various (i.e see TB slides), can provide it at various HV with same gain setting (0.3)
- 6. What is your timing requirements/measurements?
  - Timing resolution $<<$ bunch crossing frequency (10ns)
- 8. What is the maximum hit rate per channels needed if all channels are activated at the same time?
  - Is this meant per CALOROC?
- 12. How many number of samples you require as minimum (max is 7 now in CALOROC)?
  - Right now we are reading out 11 (1 SiPM) - hard to tell in the future should be able to tell you after beam test in April

LFHCal: TB 2025 & CALOROC requirements

Friederike Bock (ORNL)

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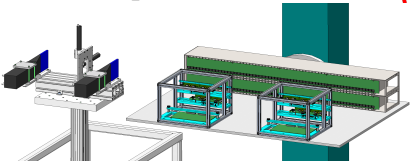
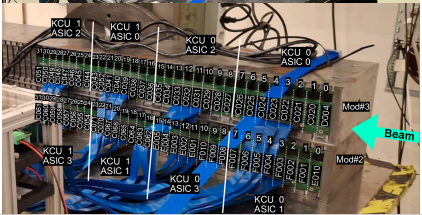
ePIC collaboration meeting, BNL, Upton, NY, US

Test Beam - November 2025 - setup

Requested time: 1 week
Main purpose: Resolution studies & longitudinal shower development
Location: CERN PS (19th Nov.)
Setup:

- Very similar to 2024 setup, with more modules
- 2 full 8M modules (20x20x130cm)
- Readout with H2GCROCs
- 512 channels (8 HGCROCs), 1.3mm SiPMs





Main expected measurements:

- Energy resolution for electrons
- Longitudinal shower development
- Final-Flexible PCB validation

Test Beam - November 2025 - Pictures

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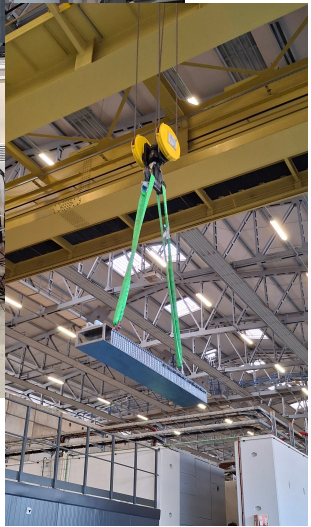

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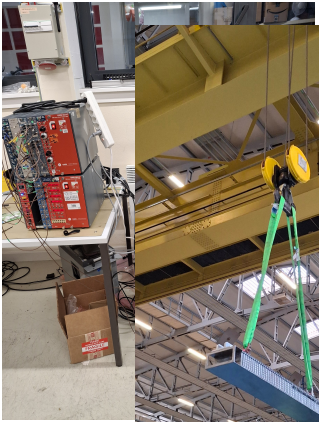

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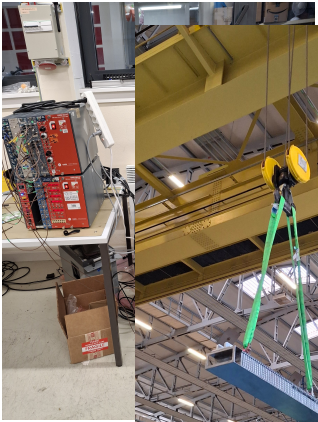

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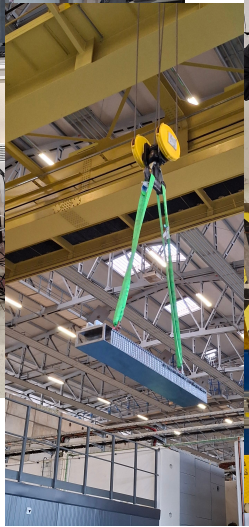
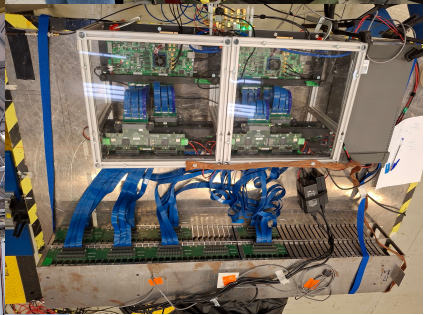
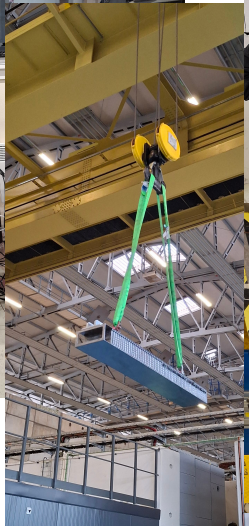
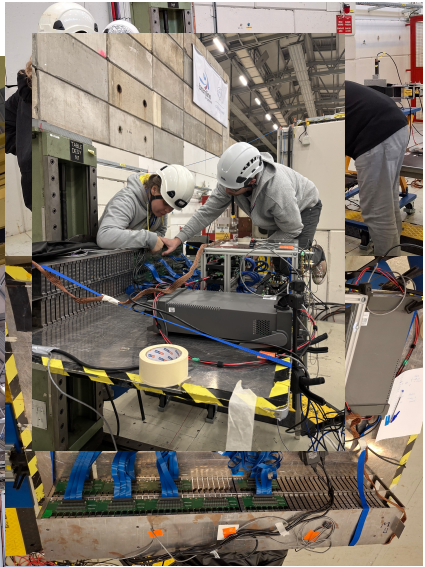


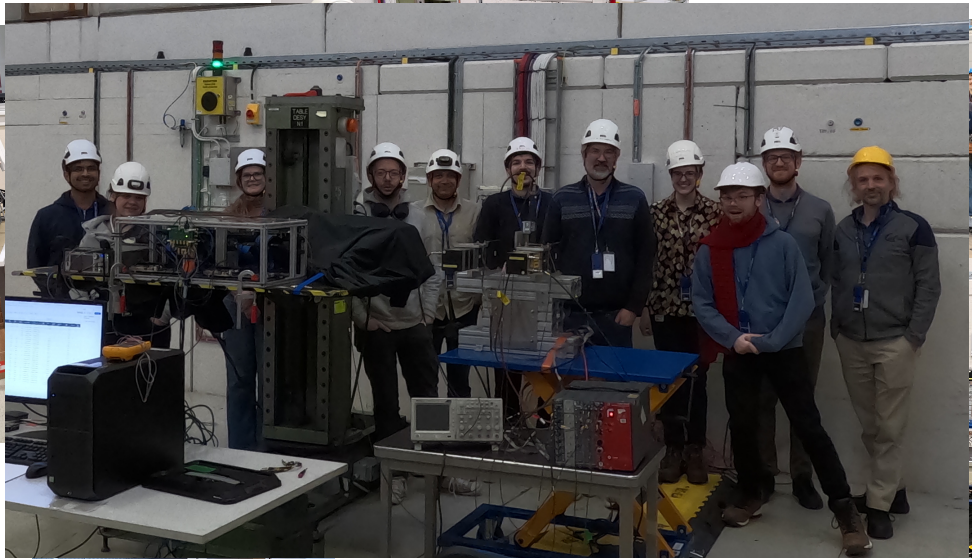


Test Beam - November 2025 - Pictures





Test Beam - November 2025 - Pictures



Test Beam - 08/2024 vs. 11/2025

Key differences to last year:

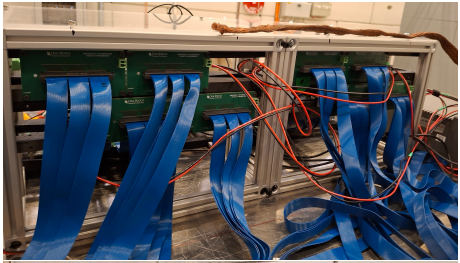
- 2 modules, but same number of RO-channels
- New firmware enabling:
  - 2 Proto-boards per KCU
  - 10 GB ethernet transfer KCU to DAQ PC
  - New UDP data format

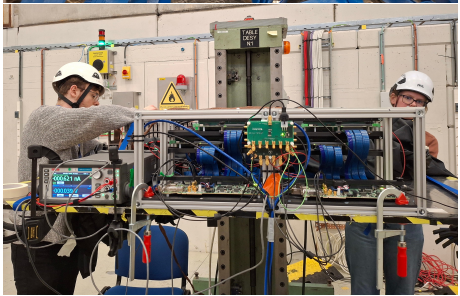
Why did we request the new firmware?

- Last year significant problem with syncronization of 4 KCUs and full event buidling after packet losses over UDP connection
- Significantly rate limited at PS/SPS otherwise
- Data format more efficient and easier to detect packet losses

Documentation & How-To

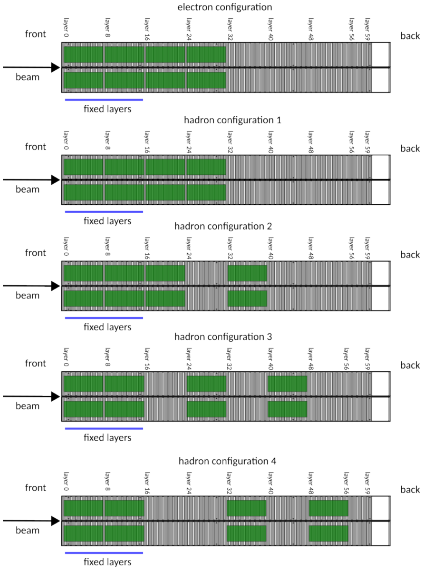
- **How-To starting point**
- Tried to improve documentation in one page (for full TB setup & operation)
- Python based software stack see here: 10





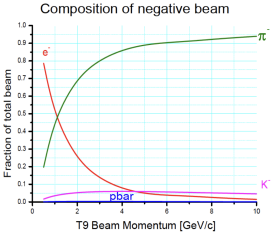
What kind of data did we take?

- Electon resolution: 3 sets (Full set A & B, electron set C) at 3 different $V_{op} = 44, 45, 42.5$ V
- Gain scan: 2 muon HV scan (41-46 V)
- Hadron depth scan: 4 different layer configurtions
- Calibration sets: for each set of the above
  - at least 1 full set of muon runs in 4 beam positions (200k each)
  - at least 1 pedestal run with same settings (10k)
- Full sets A & B also contained hadron data for comparison with same settings

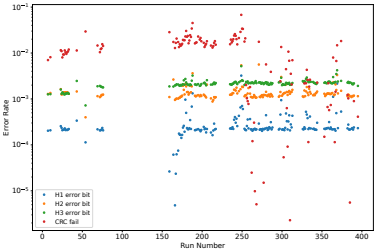


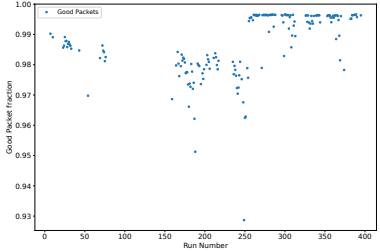
Avaiable species & energy

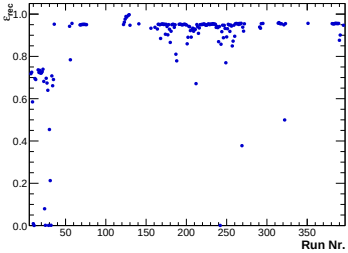
- μ^+: 5 GeV
- e^+/e^-: 1, 2, 3, 4, 5 GeV
- h^+/h^-: 3, 5, 8, 10, 12, 15 GeV
- details TB wiki



What were we able to reconstruct?







- Several packet level checks during data taking running semi-online:
  - packet integrity: CRC, hamming codes
  - packet loss: Do we receive all packets from FPGA (UDP packet ID consecutive?)
  - Significant losses in beginning due to bug in DAQ for high instantenous rate → fixed after run 160
- Event building:
  - a) waveform building (all 11 samples available) per asic & KCU → KCU events
  - b) both KCUs events reconstruted:
    - based on event ID stored in data-package header
    - possible offset corrected using time difference between first few fully reconstructed events in both KCUs
- Total number of received triggers: 26.8Mio, $< \varepsilon_{rec} > = 0.91$ (> run 160)

Calibration Strategy

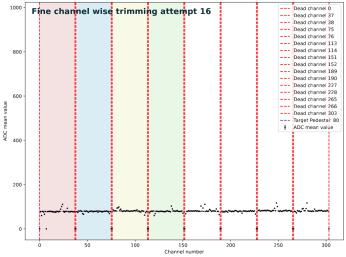
Online calibrations

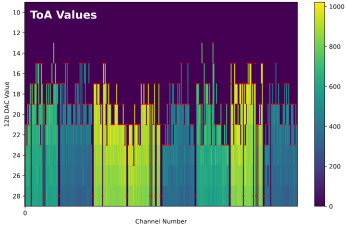
- HGCROC calibrated for only one gain setting (conv_gain = 0.3 (1100)), calibration done with full setup (i.e. SiPMs connected)
- Pedestal target 80 ADC
- ToA threshold set at 20 DAC, ToT threshold set to 300 DAC (this might have been too low)

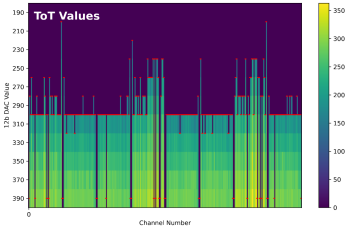
Offline calibrations

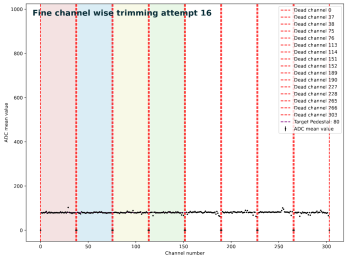
- Pedestal calibration based on random triggers (10k events) for each set
- Max ADC-MIP calibration for every tile/SiPM/channel based on dedicated muon position scans (4 positions, each $\sim$ 200K events)
- ToA calibration to be implemented
- ToT calibration to be implemented
- Ch-by-Ch calibrations to be applied

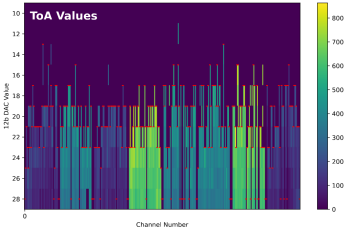
Online calibrations

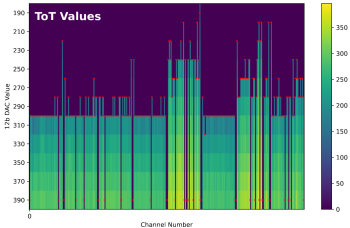




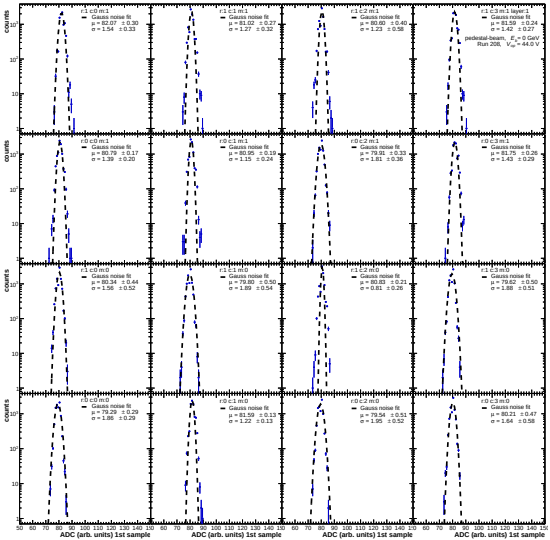


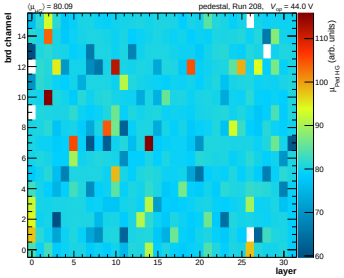


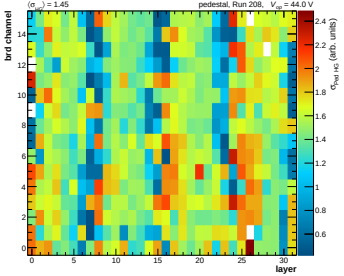




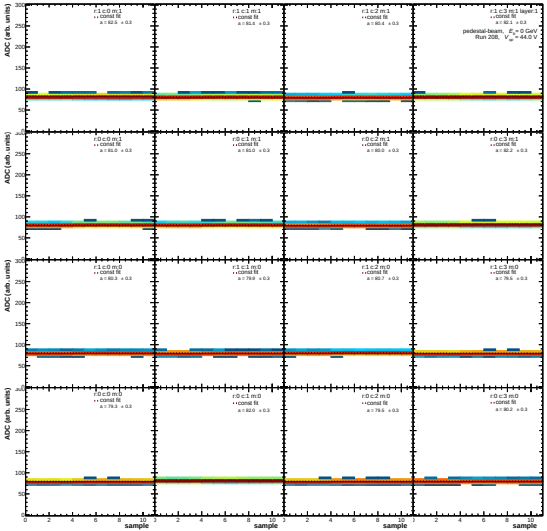
Pedestal Calibration - Full Set A- 2

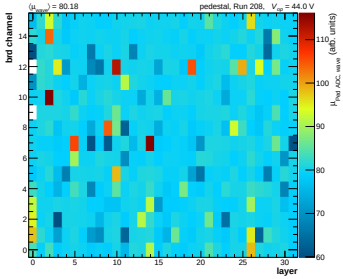


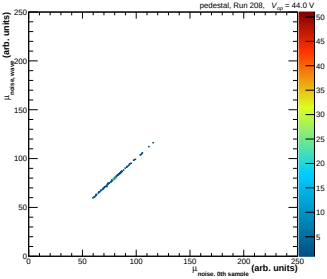




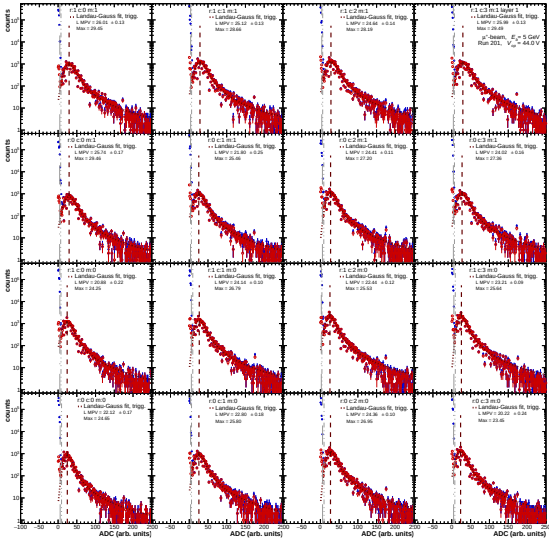
Pedestal Calibration - Full Set A- 2

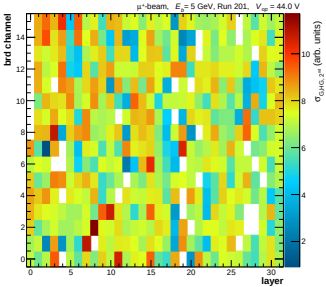


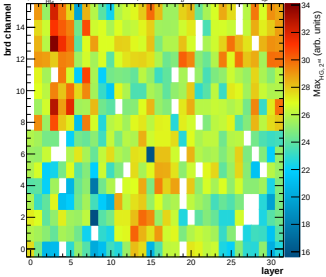




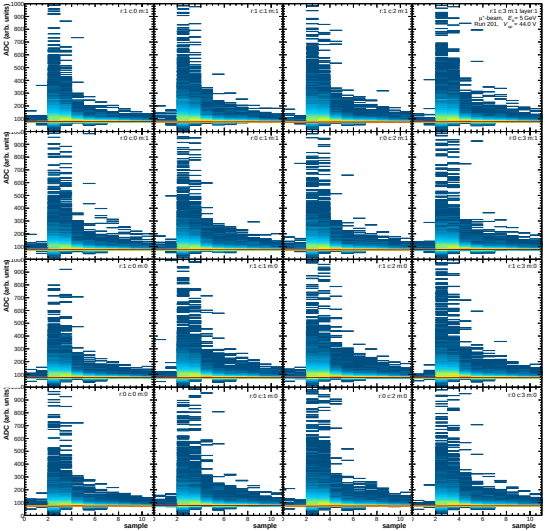
MIP Calibration - Full Set A- 2

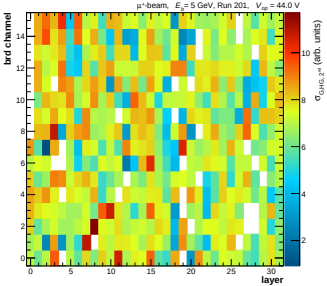


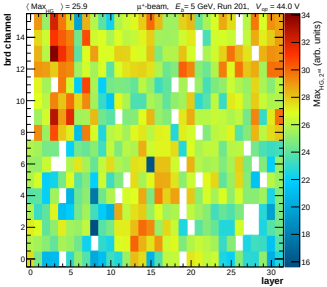




MIP Calibration - Full Set A- 2







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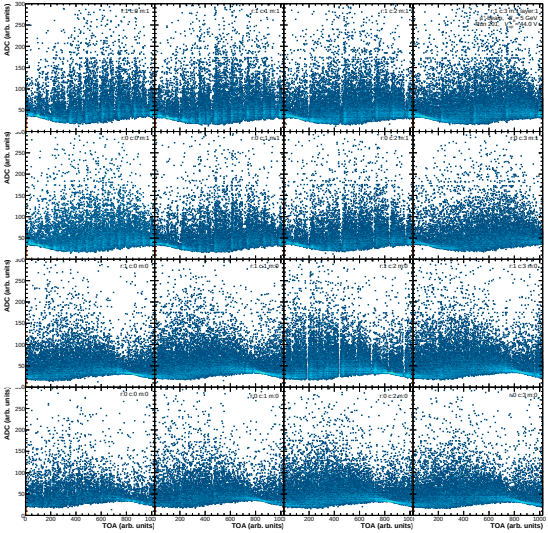

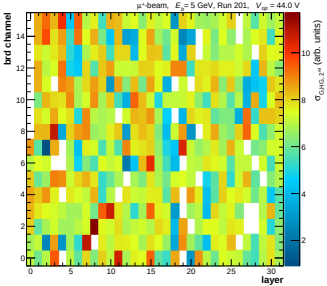

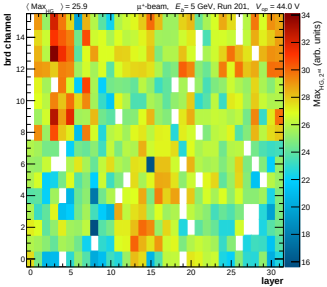

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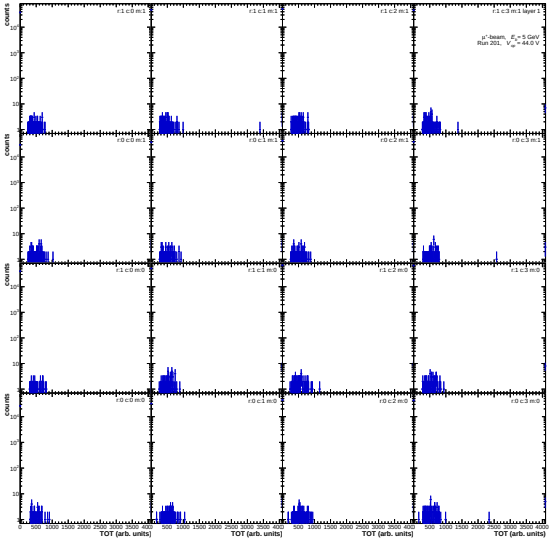
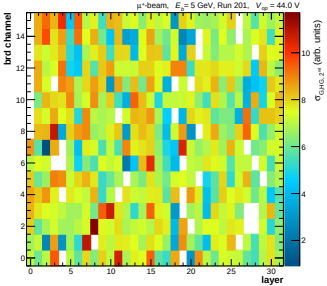
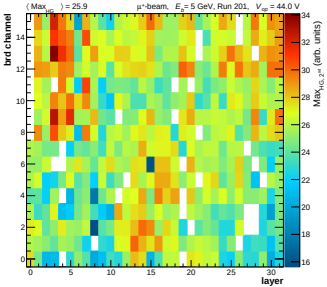
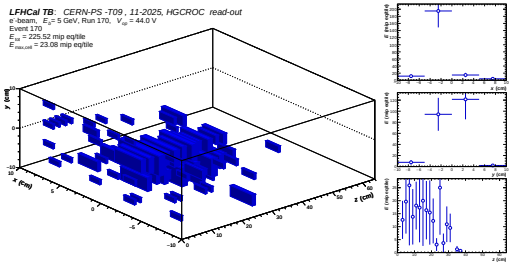
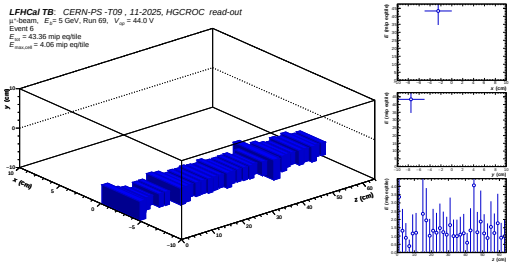


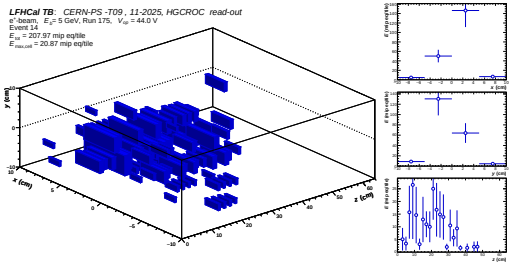


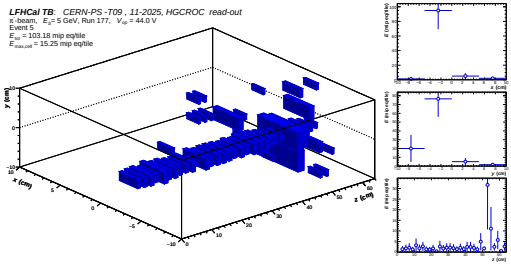


First Calibrated Event Displays

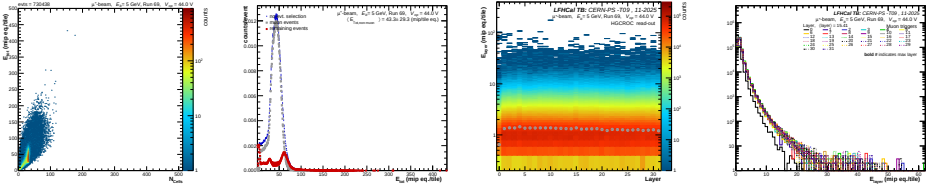






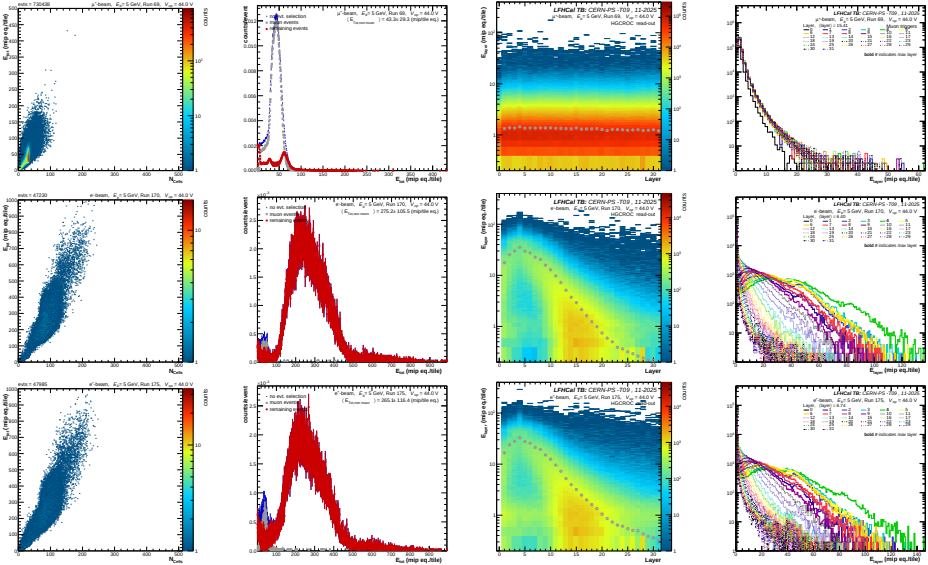


First Look at MIP calibrated data

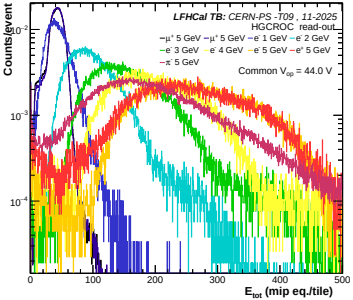


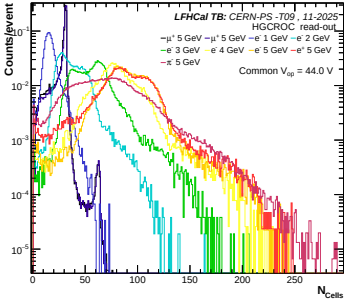
μ **beam 5 GeV**

First Look at MIP calibrated data

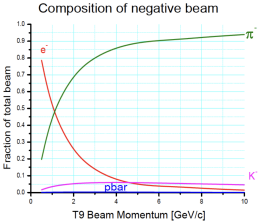


First Look at MIP calibrated data - Full Set A



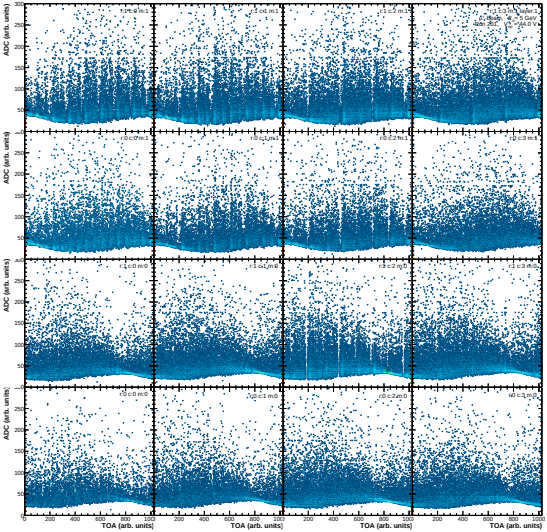


- E_{tot} estimated purely based of max ADC in 1 sample (same as for MIP calibration)
- No specific event selection done (except attempt at muon rejection)
- Significant contamination in all beam types → need to disentagle particle types, beam hit positions...



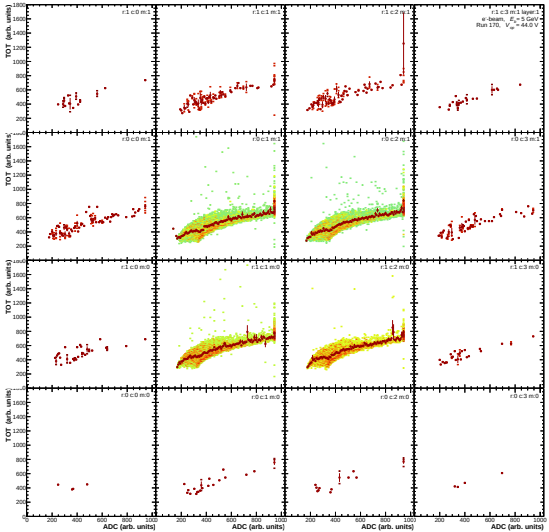
QA looks encouraging, but long way to go!

Challenges with the data



- ToA and ToT online calibration thresholds not optimally choosen
  - ToA calib at 20 DAC did not succeed for all channels, ToA phase not aligned, not all mips trigger ToA
  - ToT calib at 300 DAC too low, very large overlap with ADC range & possible saturation for highest signals even in ToT
- Observe crosstalk in fraction of data, need to disentagle possible sources
  - SiPM flex board
  - Connector boards (flex end & proto board end) & high density cable
  - Proto board
  - HGCROC

Challenges with the data



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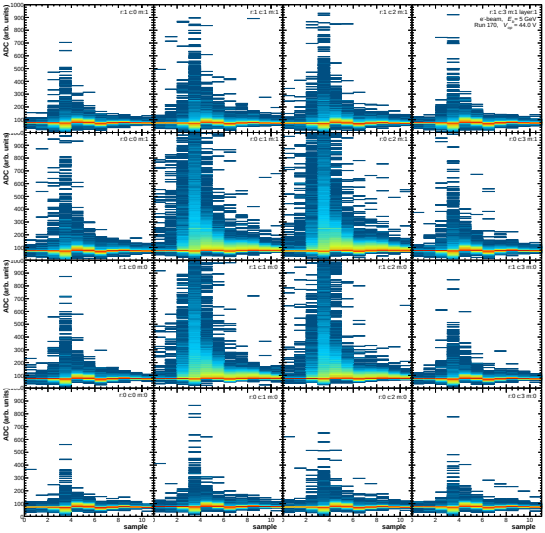

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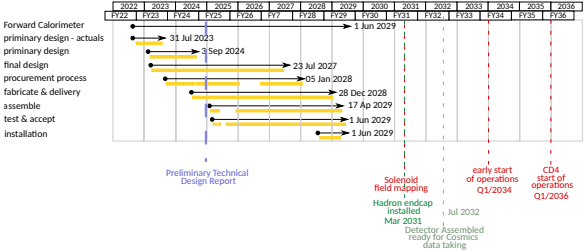
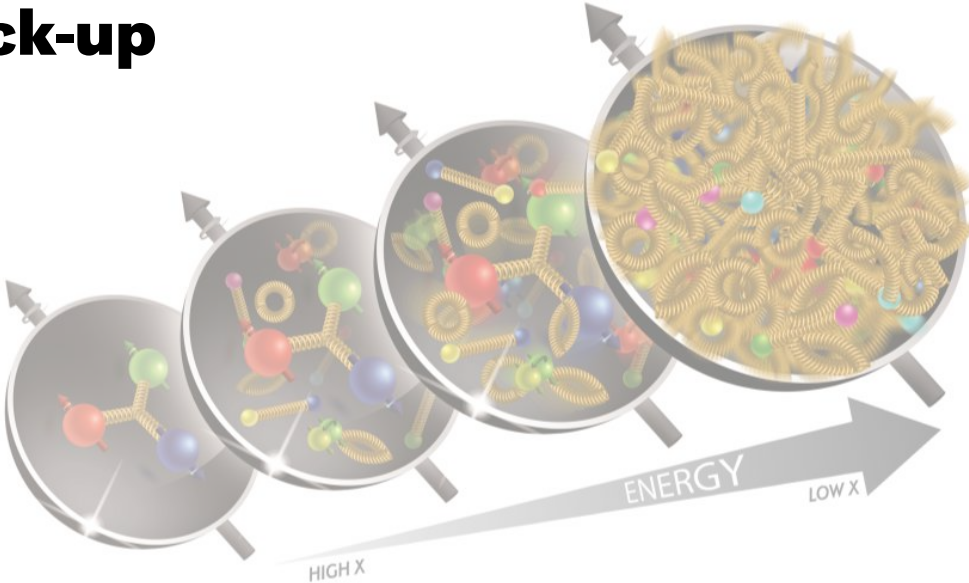
LFHCal timeline



Lots of data to analyse!

Next beam time is coming fast!

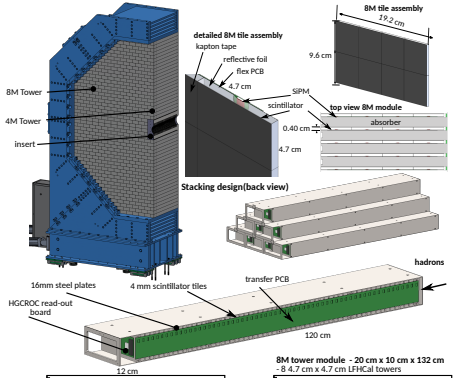
Back-up

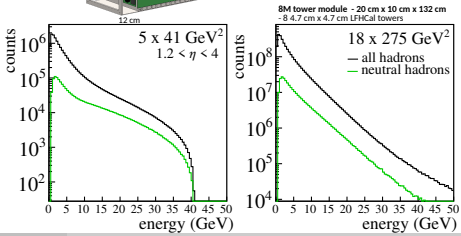


LFHCal - The General Idea

Concept:

- CALICE AHCal inspired Fe-Scintillator calorimeter with SiPM on-tile-readout
- SiPMs, absorber & support structures part of LLP
- Two main parts:
  - LFHCal built mostly out of $10x20x132$ cm^3 8M modules
  - Insert built out of 2 halves surrounding the beam pipe
- **LFHCal:**
  - 60 layers of steel interleaved with scintillator material
  - Transverse tower size $5x5$ cm^2
  - Multiple consecutive tiles summed to 7 longitudinal segments per tower
- **Insert:**
  - 60 layers of steel interleaved with scintillator
  - Hexagonal tiles of 14 cm^2 & 25 cm^2 each read-out individually





LFHCal in Numbers

8M & 4M modules

- Acceptance: $1.2 < \eta < 3.5$
- Inner modules ($R < 1$m): machined scintillator tiles & 3mm SiPMs $\rightarrow \sim 11\% = 57800$ tile/ SiPMs
- Outer modules: injection molded tiles & 1.3mm SiPMs $\rightarrow \sim 89\% = 467320$ tile/ SiPMs

$\rightarrow$ 525,120 SiPMs, 61,264 read-out channels

Insert modules

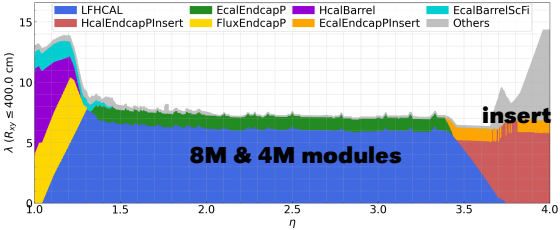
- Acceptance: $3.5 < \eta < 4.4$
- ~ 120 hexagonal tiles/layer for first 16 layers (4.2 cm width) and ~ 80 for remaining (6.5 cm width), staggered positions in different layers

$\rightarrow \sim 7000$ SiPMs/tiles & read out channels

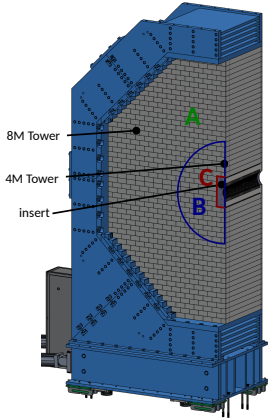
SiPMs part of CD-3A:

$\rightarrow$ 130K delivered since 06/2025, total CD-3A 320K
$\rightarrow$ Manual test stand available

parameter	LFHCal 8M & 4M modules	insert modules
inner x,y (R)	-20 cm $> x > 40$ cm, -30 cm $> y > 30$ cm	$R > 17$ cm
outer R (x,y)	$R <$ 270 cm	-20 cm $> x > 40$ cm, -30 cm $> y > 30$ cm
η acceptance	$1.2 < \eta < 3.5$	$3.5 < \eta < 4.4$
tower information		
x, y	5 cm	$\approx$ 4.2 cm (layer 1-20) $\approx$ 6.5 cm (layer 21-60)
z (active depth)	120 cm	120 cm
z read-out	$\approx$ 8.4 cm	$\approx$ 8.4 cm
# scintillator plates	60 (0.4 cm each)	60 (0.3 cm)
# absorber plates	60 (1.52 cm)	60 (1.52 cm)
interaction lengths	5.8-6.5 λ/λ_0	5.8 λ/λ_0
# towers	8752	
# modules		2
8M	1058	
4M	72	
# read-out channels	7 x 8752 = 61264	$\approx$ 7000



Impact of Radiation Damage on Design



Radiation Regions

A: $R > 1$ m: $< 5 \cdot 10^9$ neq/cm^2/year

B: $R < 1$ m: $10^9 - 10^{11}$ neq/cm^2/year

C: $\sim 10^{11}$ neq/cm^2/year

Mitigation for different regions:

A: 8M & 4M modules with inaccessible SiPMs

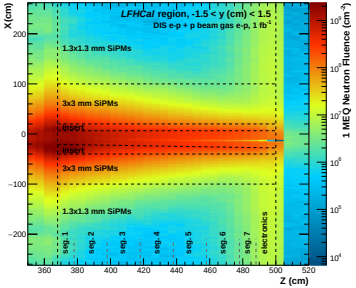
- 1.3×1.3 mm^2 SiPMs & injection molded scintillator

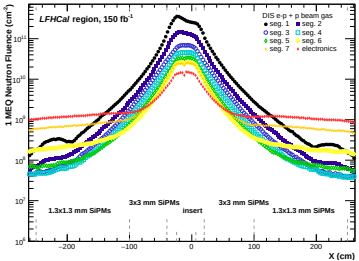
B: 8M & 4M modules with inaccessible SiPMs

- 3×3 mm^2 SiPMs & scint. mach. from cast material

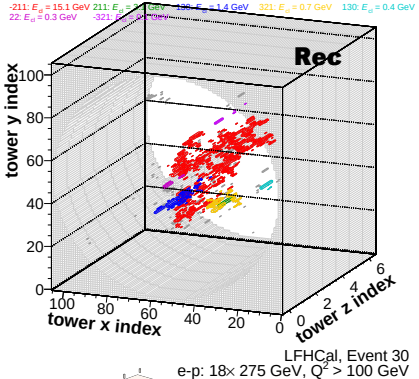
C: Insert modules

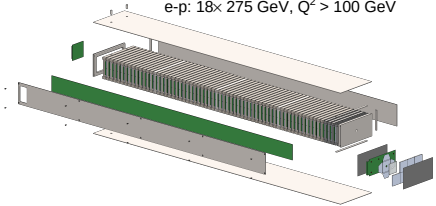
- **Replacement or annealing of SiPMs & tiles possible**
- **Scintillator & SiPM assemblies accessible during longer shutdowns** (after removal of dust cover)





General Facts on the Read-out

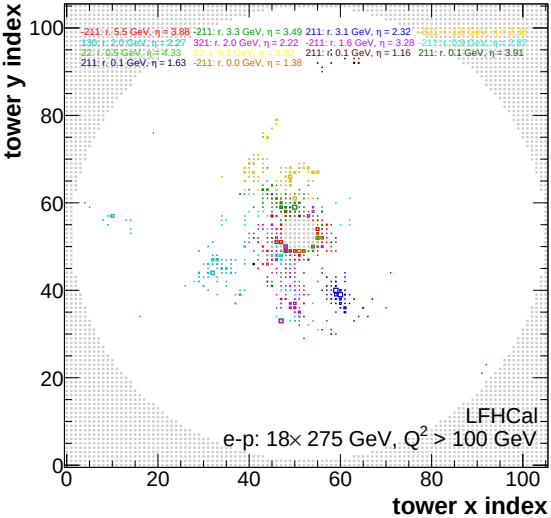




- High granularity needed to try to distinguish shower maxima (single particles/sub-jets) close to beam pipe
- **8M & 4M modules**:
  read out in 7 segments longitudinally (5 or 10 SiPMs summed in depth) desirable min measurable tower energy < 0.5 MIP/segment, max. ≈ 1500 MIP/segment
- **insert modules**:
  read out every single tile desirable min measurable energy < 0.5 MIP/tile , max. ≈ 500 MIP/tile
- SiPMs mounted to flexible PCBs, passive signal transfer to back side of calorimeter using long transfer PCB
- 2(1) CALOROC (up to 36 channels/chip) per 8M(4M) module in the back, 210 CALOROCs for insert readout

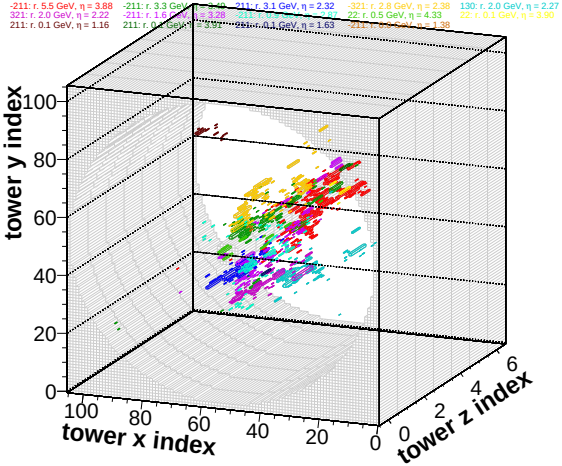
LFHCal full event reconstruction

MC particle, classical readout



LFHCal full event reconstruction

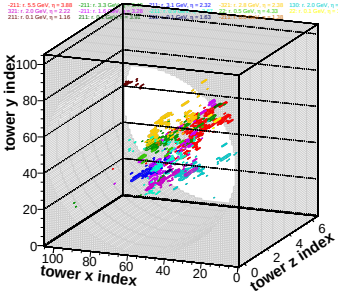
MC particle, LFHCal readout



LFHCal, Event 30
e-p: 18× 275 GeV, Q^2 > 100 GeV

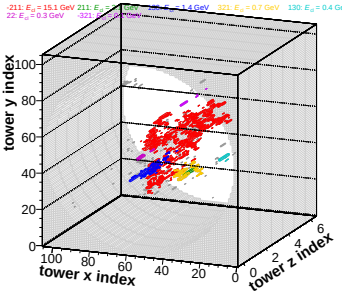
LFHCal full event reconstruction

MC particle, LFHCal readout



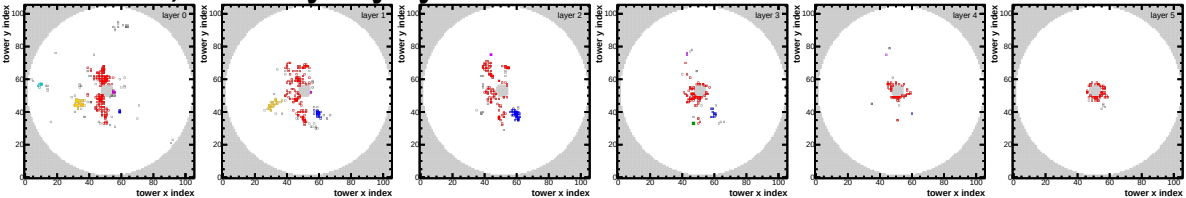
LFHCal, Event 30
e-p: 18× 275 GeV, Q^2 > 100 GeV

Rec. clusters, LFHCal readout



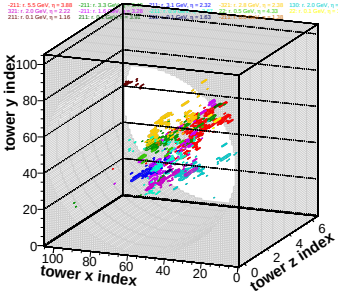
LFHCal, Event 30
e-p: 18× 275 GeV, Q^2 > 100 GeV

Rec. clusters, LFHCal layer-by-layer



LFHCal full event reconstruction

MC particle, LFHCal readout



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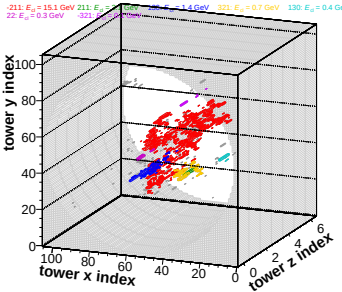
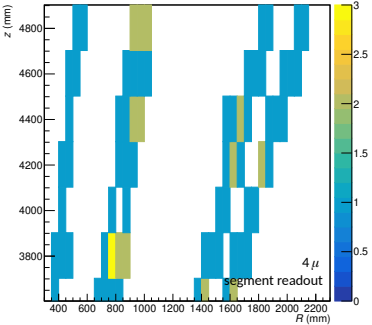
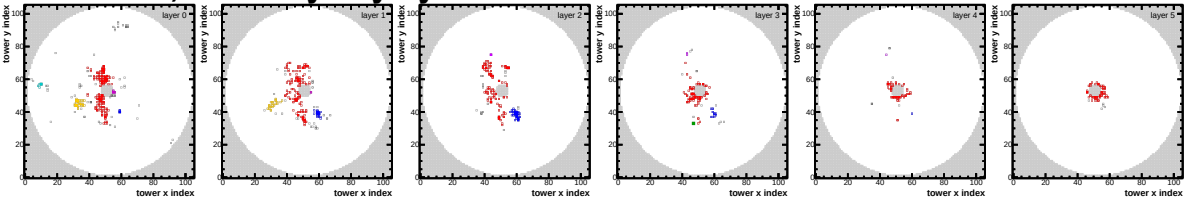


LFHCal, Event 30
e-p: 18× 275 GeV, Q^2 > 100 GeV

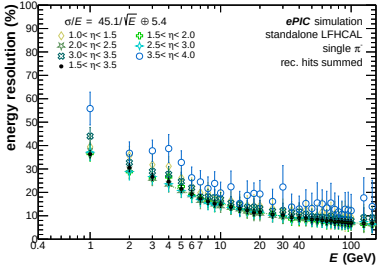
Muon id. possible

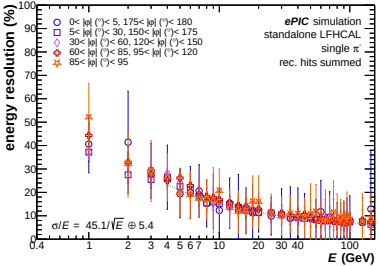


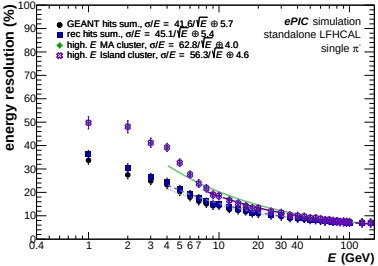
Rec. clusters, LFHCal layer-by-layer



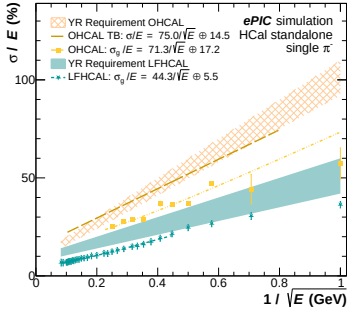
LFHCal single particle simulations



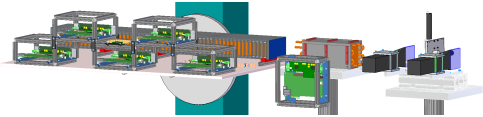




- No strong η or φ performance dependence
- Standalone standard LFHCal performance sufficient to $\eta \approx 3.2$ complemented by insert beyond that
- Ongoing studies to improve clusterization algorithm using ML started during several workshops
  - ePIC Calorimeter Workshop (Apr. 23')
  - HGS-HIRe Power Week - Machine Learning (Jul. 23')
- Meets YR requirements



Test beam - August 2024



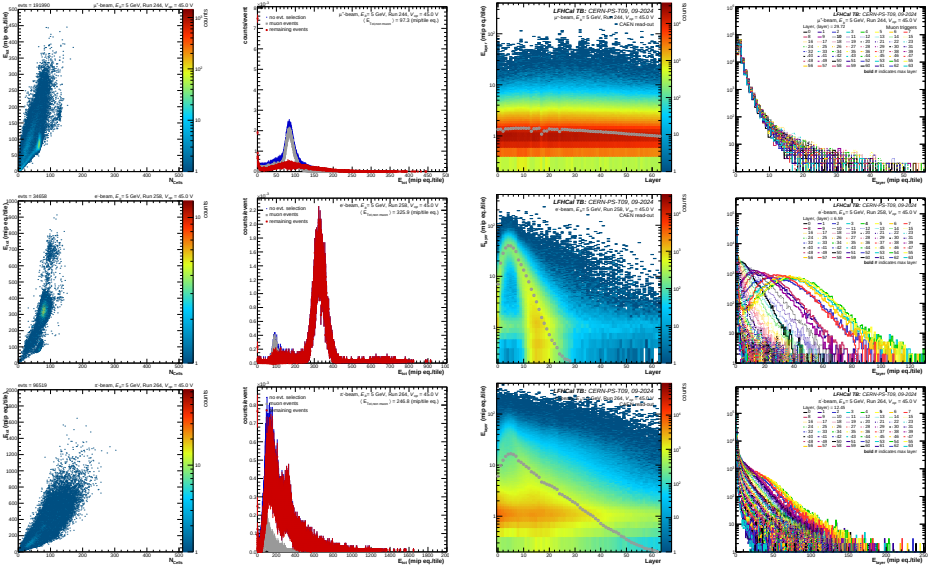
Dates: 28th Aug-11th Sept 2024 **Location:** PS - T09
Main purpose: First full module test & H2GCROC tests
Setup:

- 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 (2nd week) and H2GCROCs (1st week)

Main expected measurements:

- Energy resolution estimates for hadrons and electrons for full length module with both read-out versions
- Assessment of longitudinal leakage
- Longitudinal shower development
- Read-out validation
- Part of campaign with EEEMC in front

Test beam 2024: First Highlights



μ **beam 5 GeV**

e- beam 5 GeV

π^-**- beam 5 GeV**

Test Beam - November 2025 - Software-Stack (1)

Configuration Software - H2GConfig

- Currently in private branch *branch:10GBNorbertdevel*
- Working very well for up to 2 KCUs with up to 4 HGCROCs (might need apatations for larger number of KCUs)

Calibration Software - H2GCalib

- Currently in private branch *branch:10GBNorbertdevel*
- Working very well for up to 2 KCUs with up to 4 HGCROCs (might need apatations for larger number of KCUs)
- Under development: *H2GCalibX* - not yet tested for multiple KCUs

Configuration Software - H2GDAQ

- Currently in private branch *branch:main*
- Significantly changed after discovery of bottleneck with python based socket to 100MB data bursts
  - Backend now using *nc*(netcat) to write data directly to disk (might be system dependent which one to use)
  - Allows for 18kHz instantenous data burst processing
  - Attention: *Ext Trg DeadTime* not correctly taken into account (likely a bug in current H2GDAQ), trigger inhibits should be set using NIM logic
- Afterwards working very well for up to 2 KCUs with up to 4 HGCROCs (might need apatations for larger number of KCUs)

Test Beam - November 2025 - Software-Stack (2)

Online monitoring - h2g_online_monitoring: *link*

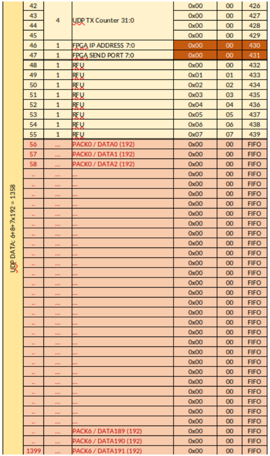
- Working very well for up to 8 HGCROCs (2 KCU each 4 HGCROC or 4 KCU each 2 HGCROC)
- Provides general overview pictures and detector specific overview plots (i.e LFHCal, FoCal, EEEMC)

Data quality check - h2g_validator *link*

- Checks new UDP packet & data structure integrity
- New format can fit 7 data-packets/ long UDP-packet -
  1 event/ KCU contains 11(*machine gun +1*)*2(*1/2 asic*) * 4 (*nr. asics*)
  $= 88$ data packs or 12.6 UDP packets

Data Decoding & Event building - h2g_decoder *link*

- Can decode data but event building not quite working yet
- Fully backward compatible



UDP DATA: 6+8+7x192 = 1358	42	4	UDP TX Counter 31:0	0x00	00	426
	43			0x00	00	427
	44			0x00	00	428
	45			0x00	00	429
	46	1	FPGA IP ADDRESS 7:0	0x00	00	430
	47	1	FPGA SEND PORT 7:0	0x00	00	431
	48	1	RFU	0x00	00	432
	49	1	RFU	0x01	01	433
	50	1	RFU	0x02	02	434
	51	1	RFU	0x03	03	435
	52	1	RFU	0x04	04	436
	53	1	RFU	0x05	05	437
	54	1	RFU	0x06	06	438
	55	1	RFU	0x07	07	439
	56	...	PACK0 / DATA0 (192)	0x00	00	FIFO
	57	...	PACK0 / DATA1 (192)	0x00	00	FIFO
	58	...	PACK0 / DATA2 (192)	0x00	00	FIFO
	..	...	...	0x00	00	FIFO
	..	...	...	0x00	00	FIFO
	..	...	...	0x00	00	FIFO
	..	...	...	0x00	00	FIFO
	..	...	...	0x00	00	FIFO
	..	...	...	0x00	00	FIFO
	..	...	...	0x00	00	FIFO
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	..	...	...	0x00	00	FIFO
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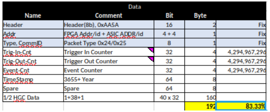
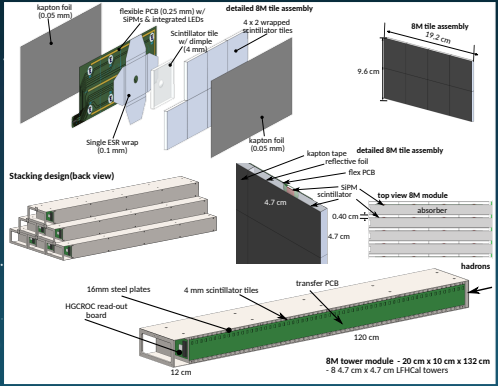
	..	...	...	0x00	00	FIFO
	..	...	...	0x00	00	FIFO
	..	...	...	0x00	00	FIFO
	..	...	...	0x00	00	FIFO
	..	...	PACK6 / DATA189 (192)	0x00	00	FIFO
	..	...	PACK6 / DATA190 (192)	0x00	00	FIFO
	1399	...	PACK6 / DATA191 (192)	0x00	00	FIFO

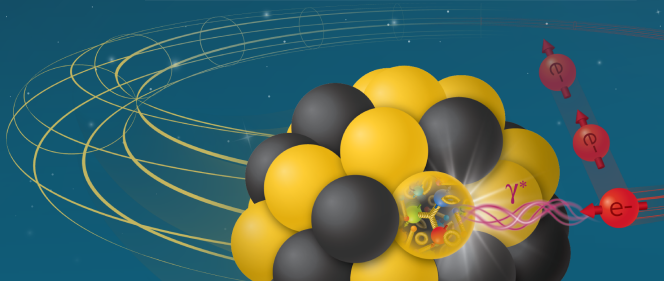


Data				
Name	Comment	Bit	Byte	
Header	Header(8b), 0xAA5A	16	2	Fix
Addr	FPGA Addr/id + ASIC ADDR/id	4 + 4	1	Fix
Type, CommID	Packet Type 0x24/0x25	8	1	Fix
Trig-In-Cnt	Trigger In Counter	32	4	4,294,967,296
Trig-Out-Cnt	Trigger Out Counter	32	4	4,294,967,296
Event-Cnt	Event Counter	32	4	4,294,967,296
TimeStamp	3655+ Year	64	8	
Spare	Spare	64	8	
1/2 HGC Data	1+38+1	40 x 32	160	
			192	83.33%

LFHCAL Components & Technical updates

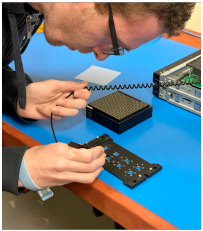
8M/4M Modules

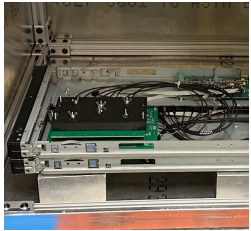


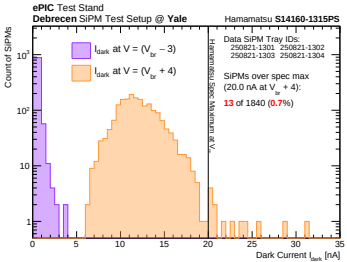


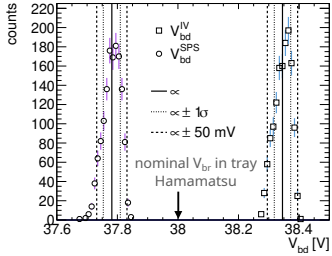
Electron-Ion Collider

Components: SiPMs



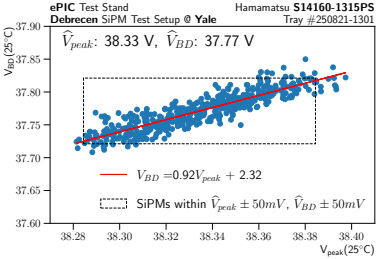




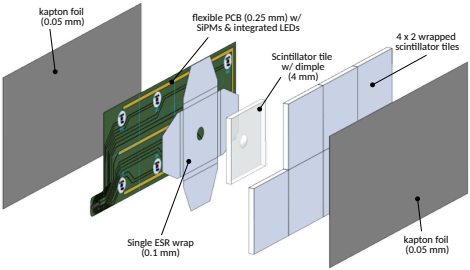


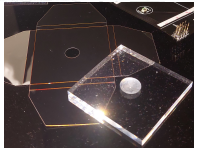
SiPM QA of CD-3A:

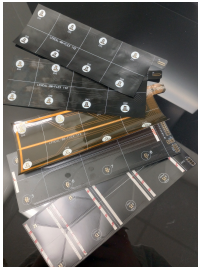
- Started receiving shipments from CD-3A procurement (33K/month since 06/2025) - final delivery 04/2026 (320K total)
- Establishing test procedure for 5% of trays for acceptance testing focussing on break down voltage measurements and visual inspection
  - Manual test stand available since September at Yale (32 SiPMs/h)
  - Automated test stand based on CMS Barrel timing layer under construction (up to 200-250 SiPMs/h) - delivery expected February



Components: Scintillator Tile Assemblies







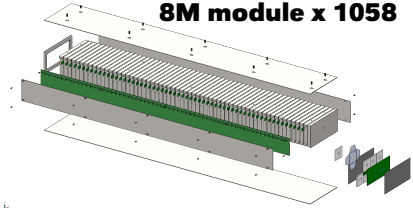
8M & 4M module layers:

- Square injection molded or machined tiles $\approx 0.4x5x5$ cm^3 with dimples individually wrapped in ESR foil assembled in a grid of $4(2)x2$ tiles
- Backed by flexible PCB equipped with 8(4) 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

Progress:

- Tile production at FNAL via injection molding with established processes & chemical composition
- ESR wrap cut with commercial small scale laser cutter, exploring options to out-source process to local companies
- Finalizing Flexible PCB design, 3rd major iteration soon to be tested in test beam at CERN
- Manual tile wrapping & layer assembly process well established currently working on automatization for both

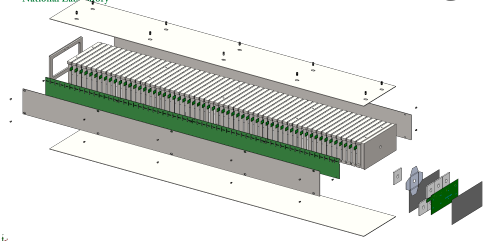
Components: Absorber Structures

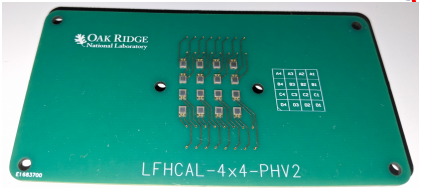


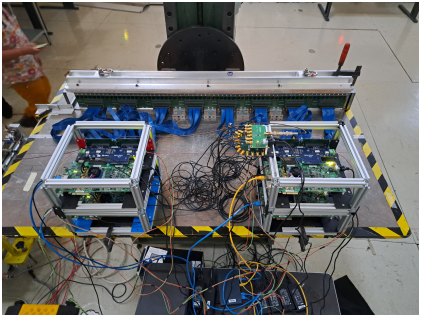
8M Tower Assembly (1320mm) Assembly Dimensions based on Rev 02 GD&T Values											
Dimension #	Description	Importance Category	DRW Tolerance (in)	Prototype 1	Prototype 2	Prototype 3	Prototype 4	Prototype 5	Prototype 6	Prototype 7	Prototype 8
20	Left Side Surface Tol	High	0.08	0.017	0.036	0.052	0.043	0.045	0.028	0.03	0.025
21	Width	Basic	7.795 - 7.875	7.828	7.845	7.831	7.837	7.832	7.842	7.835	7.835
22	Length	Low	±0.05	51.965	51.872	51.917	51.924	51.94	51.92	51.93	51.93
23	Right Side Perpendicularity Tol	High	0.08	0.018	0.03	0.09	0.018	0.035	0.03	0.028	0.01
24	Bottom Flatness Tol	High	0.04	0.015	0.027	0.02	0.025	0.015	0.025	0.015	0.015
25	Front Perpendicularity Tol	Medium	0.04	0.035	0.028	0.045	0.004	0.012	0.025	0.018	0.012
26	Plate Spacing	High	+.011 -.009	.207 / .213	.207 / .216	.167 / .238	.208 / .212	.208 / .212	.210 / .215	.210 / .216	.210 / .213
28	Top Surface Tol	High	0.04	0.018	0.037	0.03	0.042	0.035	0.028	0.032	0.022
29	Height	Basic	3.897 - 3.937	3.96	3.949	3.945	3.946	3.94	3.923	3.925	3.916
30	Location Tapped Plate #1	Low	±0.067	1.114	1.107	1.06	1.114	1.052	1.11	1.108	1.118
31	Location Tapped Plate #2	Low	±0.067	12.413	12.365	12.346	12.38	12.46	12.4	12.39	12.375
32	Location Tapped Plate #3	Low	±0.067	24.52	24.438	24.409	24.461	24.53	24.5	24.486	24.478
33	Location Tapped Plate #4	Low	±0.067	36.624	36.521	36.479	36.56	36.51	36.56	36.65	36.555
34	Location Tapped Plate #5	Low	±0.067	48.73	48.597	48.574	48.634	48.64	48.63	48.635	48.63
35	Horizontal location M12 Hole	Inspection		-	-	-	-	3.917	3.917	3.916	3.918
36	Vertical Location M12 Hole	Inspection		-	-	-	-	1.959	1.959	1.958	1.958

- 2 different module types designed using the same construction process (4M scaled in width by 0.5)
- 60 single absorber plates, front and back plate electron beam welded to top & bottom sheet metal panel
- Established reproducible production procedures for the 8M module production over the past year
- Initial modules not fully within tolerances for some less important measures
- Corrosion prevention by using Nickel plating the whole module
- CD-3A procurement process started

Overview: Signal-Transfer and Read-out







- For maintenance the read-out cards will be placed in the rear of the modules
- Passive signal transfer to the rear with long transfer boards

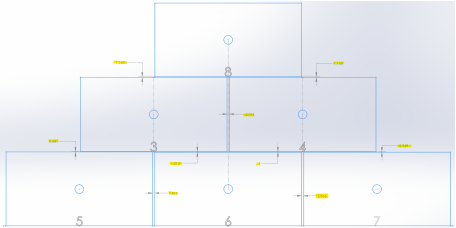
→ First prototype in production

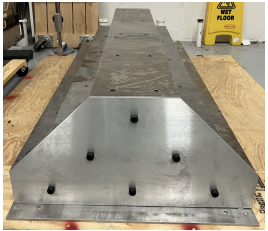
- To keep possibility of future upgrades signal summing done in rear as well

→ Test board employing passive summing produced & currently under test

- Read-out boards using CMS-H2GCROC (precursor to CALOROC) produced and have been operated in test beam since 2023

Components: Absorber stacking

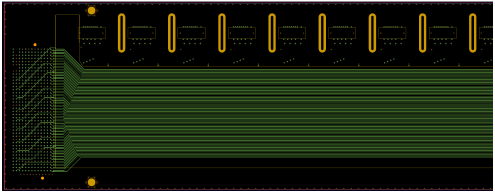


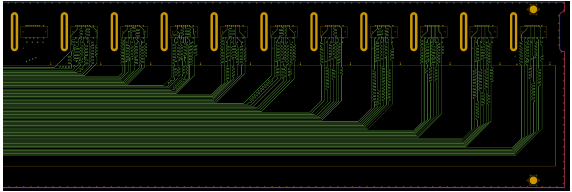


Stacking test

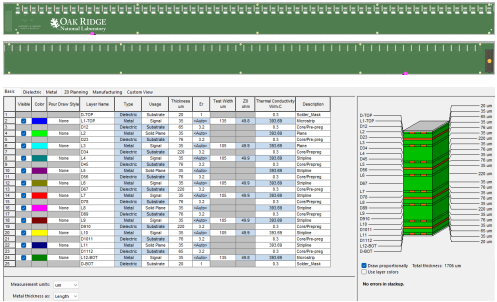
- Performed stacking test with 8 engineering test modules
- Used precomputed stainless-steel shims based on GD&T
  - Easy to assemble with predefined shim heights w/o modifications
- Basic GD&T requested for every (outer dimensions) for every module
- Sorting according to those prior to assembly in hall beneficial

Components: Long Transfer board

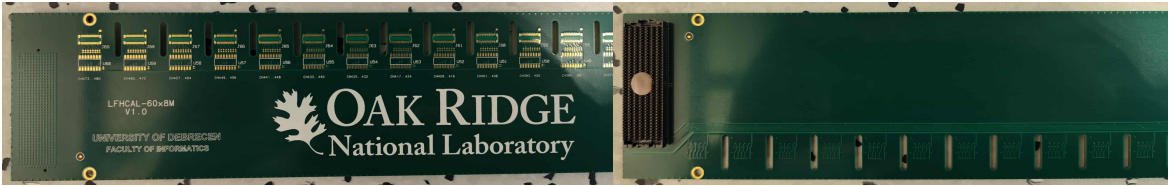




- First prototype in production with 12 layer stackup (total $\sim$ 1.7 mm) and full length of 125.7 cm
- No full trace length matching yet $\Rightarrow$ will require to go to 22 layers for final board
- Few vendors with capabilities to produce such boards (more common length up to 120 cm)
- Production ongoing, expect to receive 2 boards by end of October



Components: Long Transfer board



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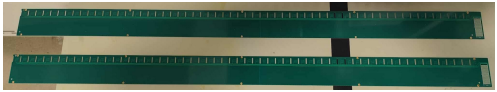
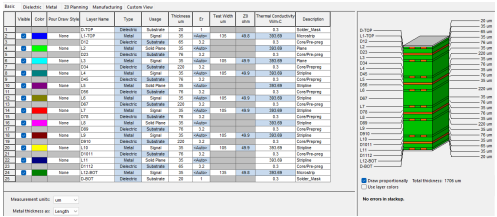
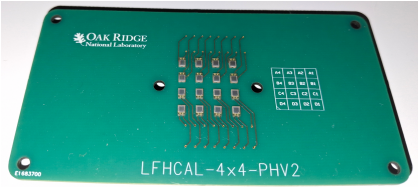
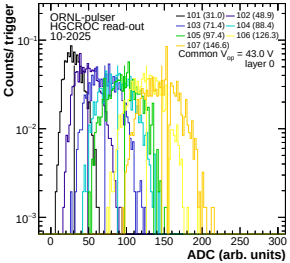


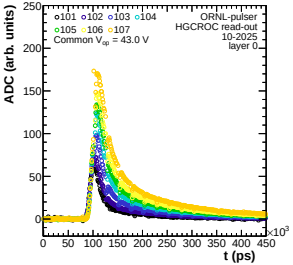


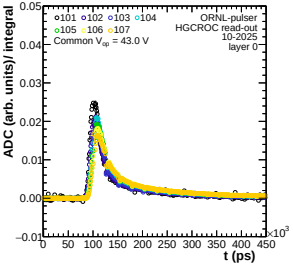
Components: Passive Summing Board



101 - 1 SiPM
102 - 2 SiPMs
103 - 3 SiPMs
104 - 4 SiPMs
105 - 5 SiPMs
106 - 6 SiPMs
107 - 7 SiPMs





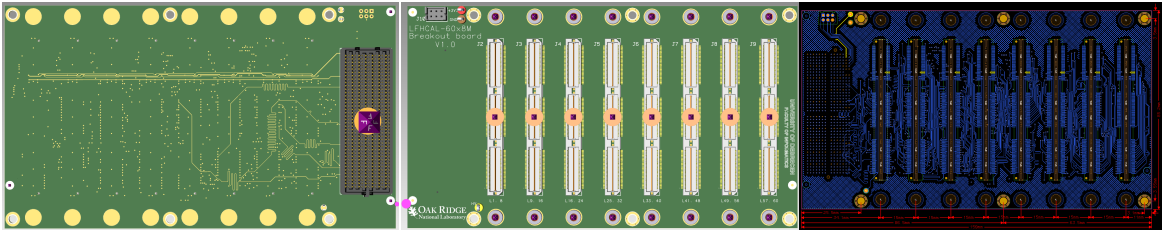


- Small switchable 16 SiPM summing board produced and tested
- Signal increases linearly with summing of additional SiPMs
- Minimal signal broadening observed for 1.3mm x 1.3mm SiPMs

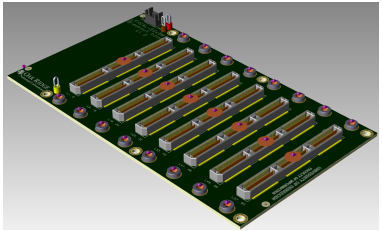
⇒ Passive summing viable solution for 8M/4M modules with smaller SiPMs

- Similar evaluation needed for 3 x 3mm SiPM region

Components: Single Channel Breakout Board

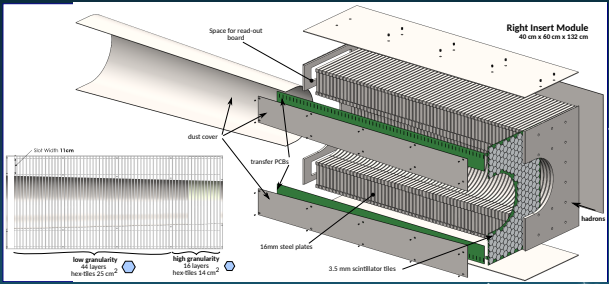


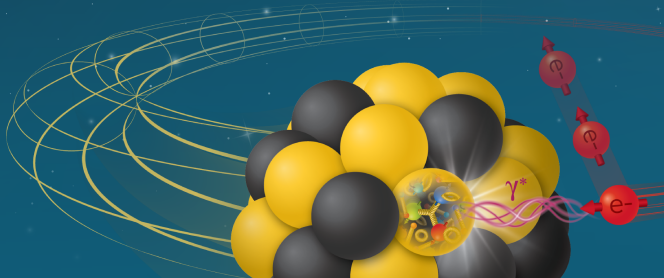
- For testing connectivity of SiPMs from flex board until the end of long transfer board as well as SiPM QA on detector
- Breaks out every single channel to 8 x 64 channel connectors currently used for H2GCROC test boards
- Currently in production and expected delivery by end of October



LFHCAL Components & Technical updates

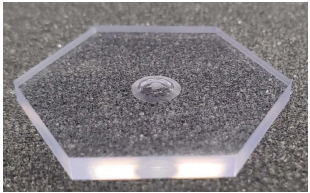
Insert Modules

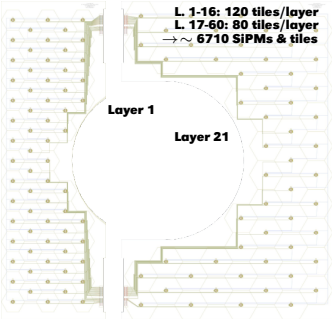




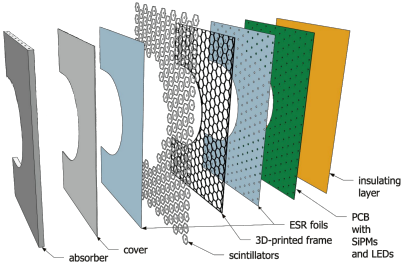
Electron-Ion Collider

Components: Scintillator Tile Assemblies





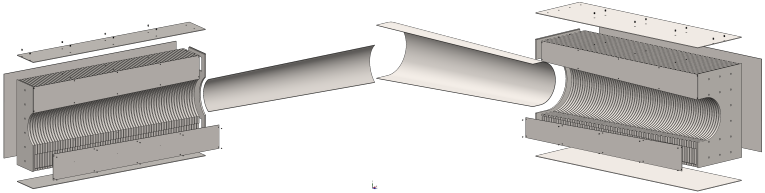
- 2 hexagonal sizes foreseen with staggered positions in different layers
- Tile production established with injection molding & machining
- ESR cutting with commercial small scale laser cutter
- Tile frame printed with commercial 3D printer
- First version of PCB layout for each layer available
  → space constraints largest challenge
- First larger scale prototype layers constructed for ZDC test beam with similar design approach



Components: Absorber Structures

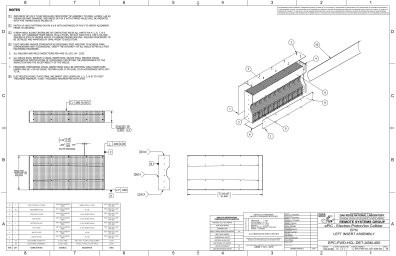
Insert Module Left

Insert Module Right

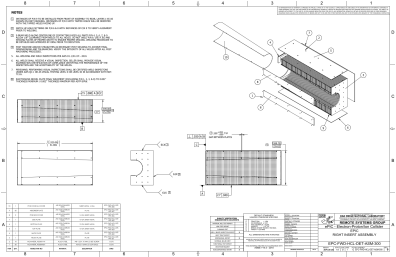


- 2 different module types designed using the same construction process as 8M modules with conical & slanted cut out for beam pipe
- 60 single absorber plates, front and back plate electron beam welded to top & bottom sheet metal panel
  → to be explored whether vertical full length plate to be welded or screwed
- Side panels on inside screwed to welded structure to cover slot with transfer PCB and beam pipe cut-out
- Initial absorber structure design concluded & full drawing pack available

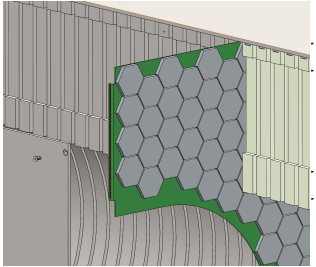
Insert Left drawing pack

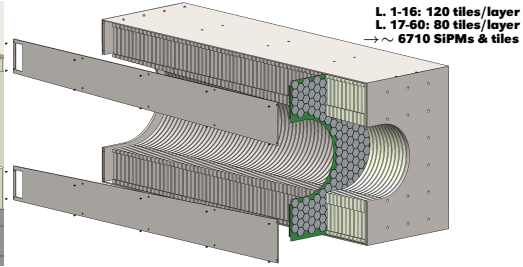


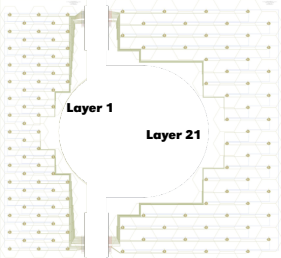
Insert Right drawing pack



Insert Challenges (1)



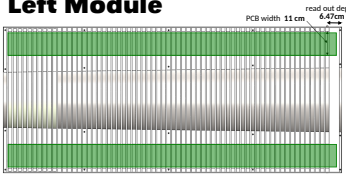




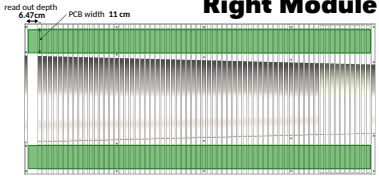
- Higher radiation load close to the beam pipe, needs possibility to replace layers
  ⇒ transfer PCBs situated between left and right module
- Limited space for connectors from each layer → worst case ∼ 80 SiPMs/layer
- Large PCB boards with complex layout and little repetition
- Single channel read-out requires
  ∼ 210 CALOROCs at the back of the module within tight spatial constraints
  ⇒ cooling might be needed

Insert Challenges (2)

Left Module



Right Module

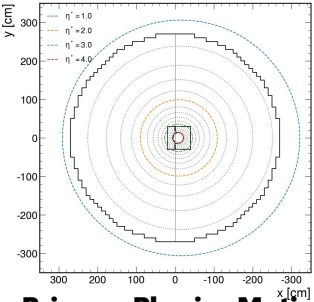


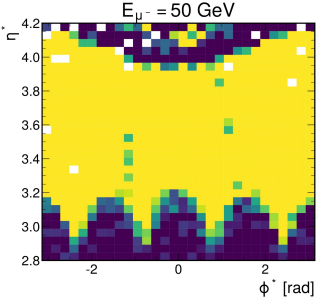
Transfer board simulation & stackup

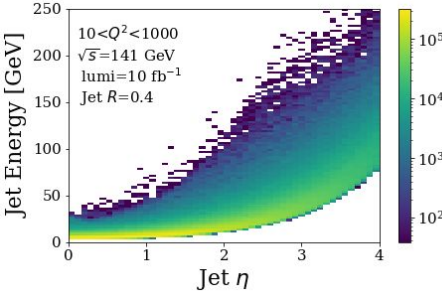
		Cross Talk %			
		Trace Spacing (mil)			
		4	8	16	32
	4	8.650%	6.007%	1.250%	
	8		6.385%	4.321%	1.670%
Dielectric Height (mil)	12				
Estimated Required PCB Layers		30	38	56	
		Estimated Board Thickness (mm)			
	4	3.8	4.5	6.2	
	8	5.3	6.4	9.2	
Dielectric Height (mil)	12	6.8	8.3	12.1	

- Width of transfer PCB limited, channel desity for same cross section very high:
  - **Insert Left: 102 ch/cm** **Insert Right: 204 ch/cm** **8M module: 64 ch/cm**
  - Density of traces even higher, as LED lines need to be provided in addition + double of traces per read-out channel
  - Difficult to find vendor capable of producing such long and high density PCBs
  - Space constraints for connectors in the rear in addition
  - Initial cross talk simulations for single agressor lines on 56 layer PCB still 4.3%
- Joint efforts between mechanical & electrical engineers needed over coming month to realize concept

Recap: Insert Motivation







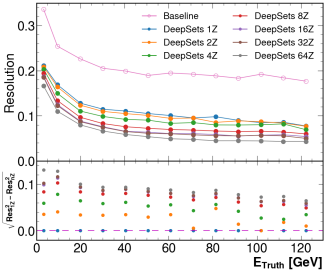
Primary Physics Motivations

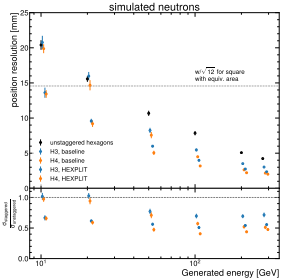
a) Increase coverage for highly energetic hadrons beyond $\eta = 3.0$ for (SI)DIS measurements
b) Improve spatial and energy resolution at high η for substructure measurements

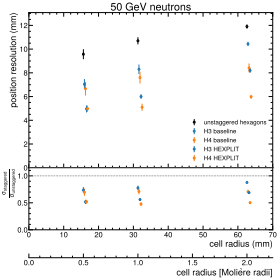
Practical Motivation

- Serves as support structure for the remaining LFHCal 8M & 4M modules atop the beam pipe $\Rightarrow$ similar steel distribution desirable
- Elegant solution for support with optimal usage of instrumented space around beam pipe

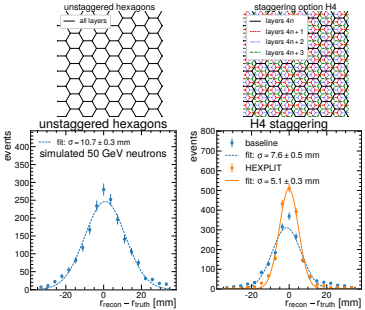
Original Insert Granularity Optimization







- Full jet reconstruction not possible at time of initial design & particle flow not yet implemented
- Optimized for highest single hadron energy & position resolution
- Single layer readout motivated primarily by improvements in energy resolution
- Transverse granularity and tile shape/positioning by spatial resolution



Updated Granularity Comparison

High granularity

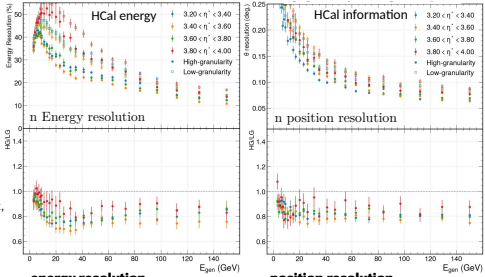
Insert default

single layer readout, hex-tiles

Low granularity

8M default

summed layer readout, square tiles



energy resolution **position resolution**

HCal Insert only

- As expected energy and position resolution worsen by $\sim$ 20% for standalone performance
- Only 10 % worsening after inclusion of ECal response
- Assessment of impact on jets still not fully feasible with existing simulation framework
  $\rightarrow$ Use ρ^0 decay as proxy
- ρ energy resolution with little impact ($\ll$ 10%)
- ρ identification significantly better at high E with std. insert granularity

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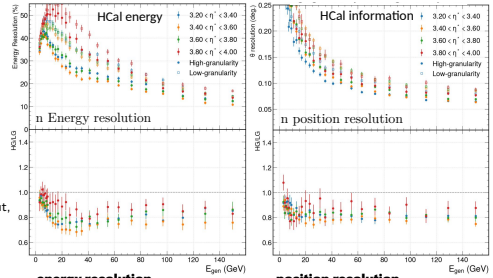
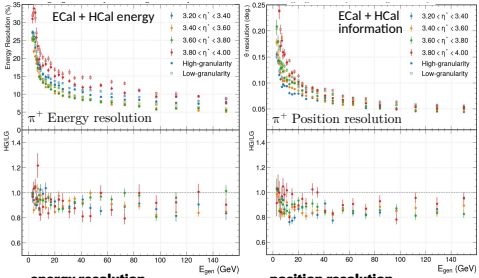


energy resolution **position resolution**

HCal Insert only



energy resolution **position resolution**

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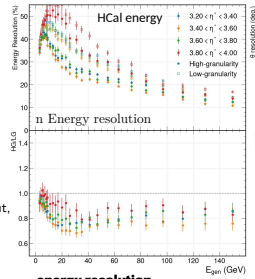
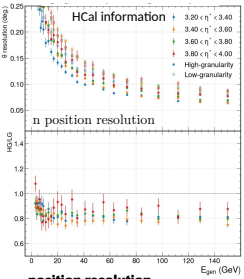
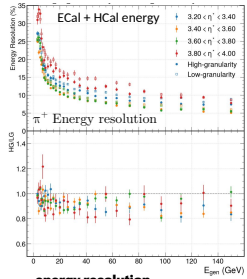


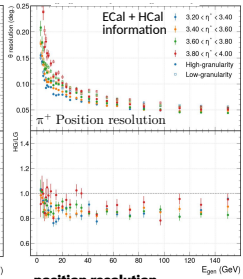
energy resolution



position resolution



energy resolution



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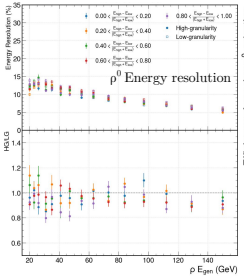
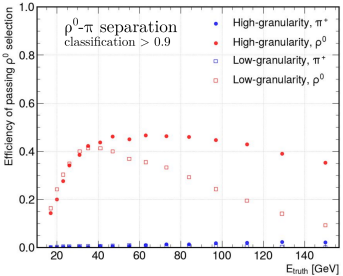




Electro-Mechanical Solution (A)

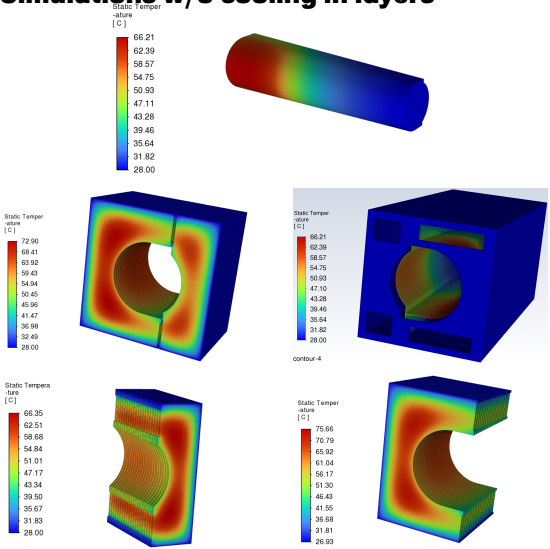
Proposal

- Embedd the CALOROC inside the layers on same board as SiPMs
- Only route digital signal to the rear with fibers or on much simpler transfer board

Implications

- Change of sampling fraction necessary, as PCB boards in layers need more space
- Heat load in layers requires active cooling within the insert
  → limited space for cooling lines (primarily insert outer corners) due to layer maintenance requirements
- Replacement layers would always include CALOROCs
- Simple annealing solution not as easy

Simulations w/o cooling in layers



Electro-Mechanical Solution (B)

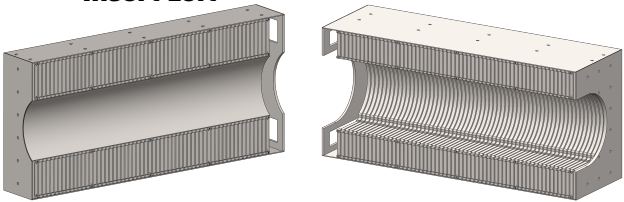
Proposal

- Increase area for long transfer boards by taking out conical structure and part of tilt
- Switch to square tiles to reduce channels/layer

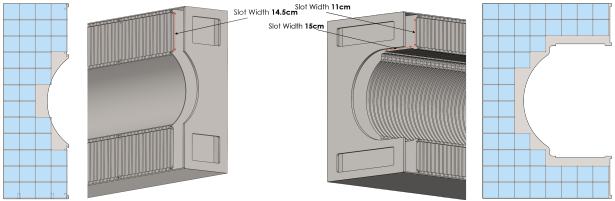
Implications

- Reduced acceptance in η (still needs to be simulated)
- **Insert Left: 2400 ch $\rightarrow$ 83 ch/cm**
  Insert Right: 3240 ch $\rightarrow$ 68 ch/cm
- Possible larger beam induced cross talk in PCBs closest to beam pipe - needs RF simulation & possible RF-shielding
- Reduction of number of CALOROCs: 75 (left) & 102 (right)
- Could employ summing in the back in addition
- Could mechanically fit readout in back

Insert Left



Tile layout & PCB slot arrangement



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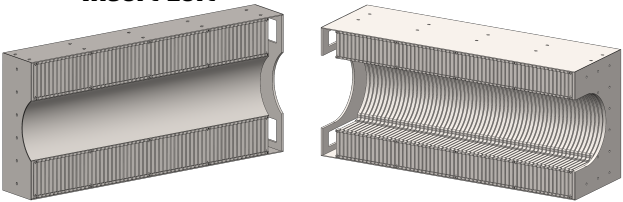
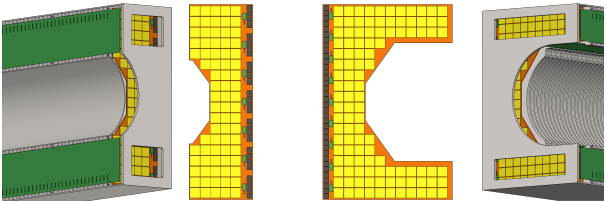


Read-out board layout



Insert: Next Steps

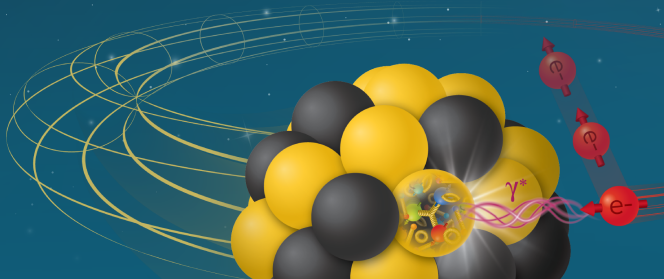
Physics Simulations

- Study impact of Electro-Mechanical Solution (A) & (B) on physics observables
- Evaluate advantages/disadvantages of solutions on clusterization in the transition region between 8M & insert modules
- Continue Implementation of particle flow in ePIC software framework for full jet physics impact evaluation

Engineering

- Fully evaluate Electro-Mechanical Solution (A) & (B) regarding:
  - mechanical stability
  - heat distribution
  - electrical implementation feasibility

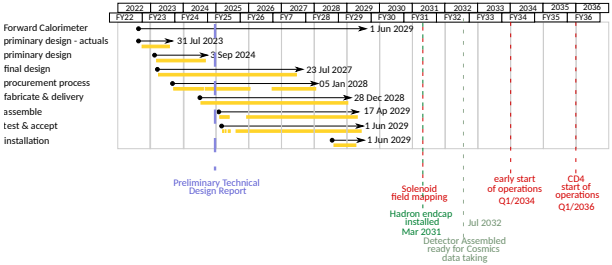
LFHCAL
Construction & Assembly Plans

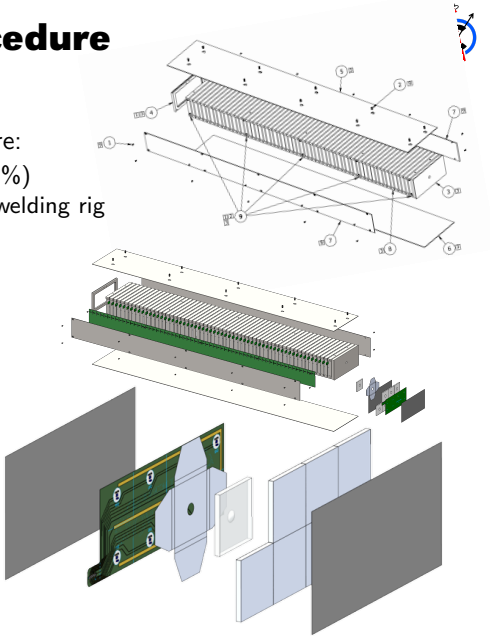


Electron-Ion Collider

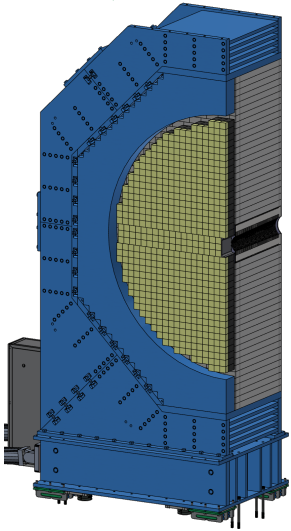
Construction Procedure

- Construction done in units of modules
- Construction & QA steps per unit regarding absorber structure:
  1. Dim. tolerance and material composition measurements ($\approx 5\%$)
  2. E-beam welding of absorber structure w/o cover-plate using welding rig
  3. Stacking tests at vendor
  4. Assembly of tile-assemblies and installation
  5. Mounting of transfer PCB & cover plate
  6. Storing & Transport of modules to BNL
  7. Assembly in cradle at IP6





Support structure & ECal Integration



- Cradle build in multiple components
- Simultaneous construction of LFHCal stack and outer shell during installation at BNL
- 1-inch perforated steel plate mounted to front of LFHCAL serving as anchoring structure for both HCal & ECal modules
- Individual ECal blocks installed after completion of HCal construction
- Additional flux return steel mounted between Barrel HCal, forward ECal outer edge & LFHCal
- Purchase of support structures requested as part of CD3-B