

An update on the CMS HGCAL

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on behalf of the CMS collaboration

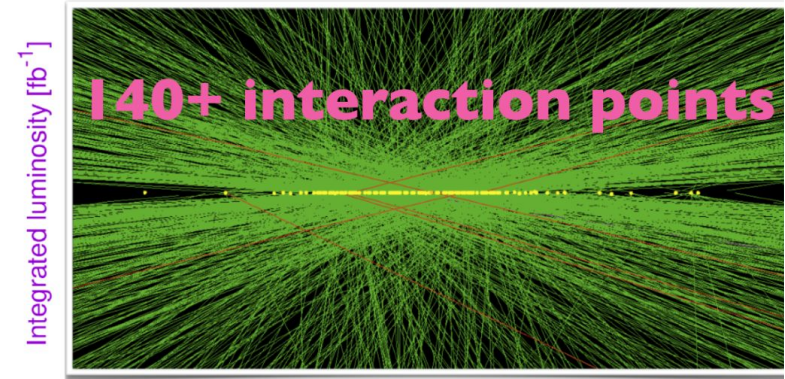
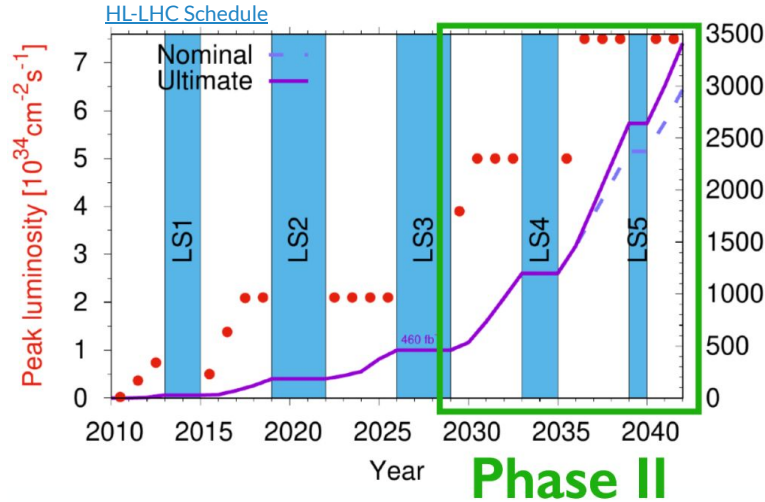
HSTD14

18 November, 2025

National Taiwan University

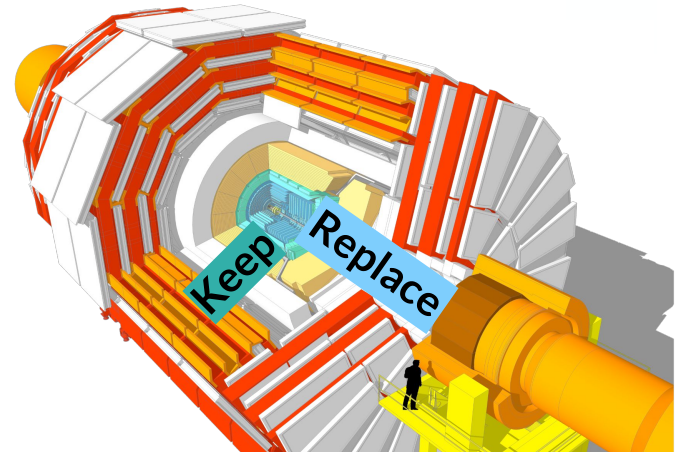


HL-LHC challenges and the CMS calorimeters



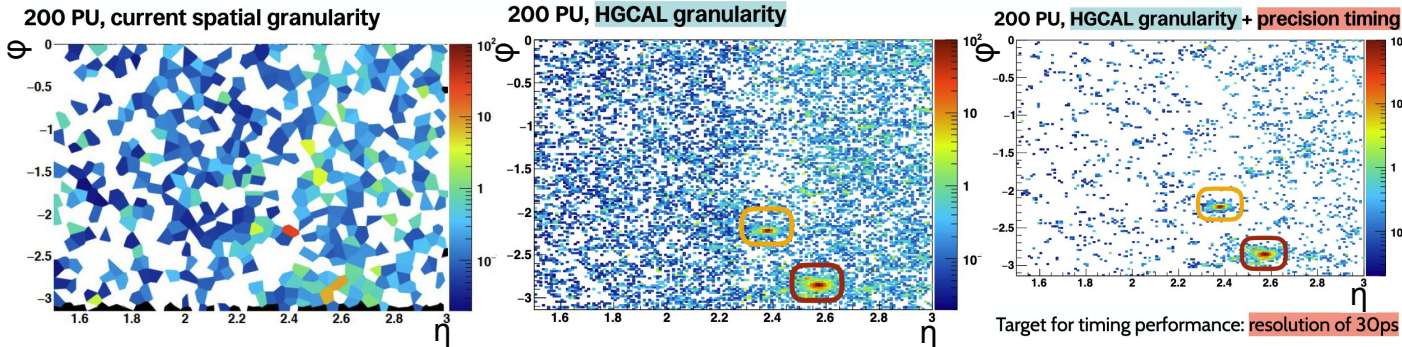
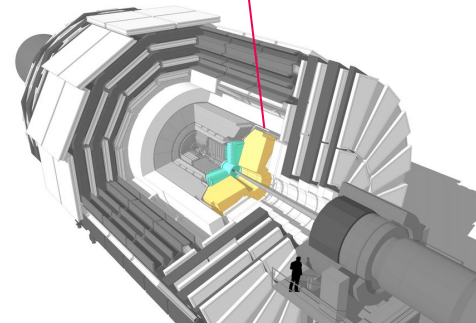
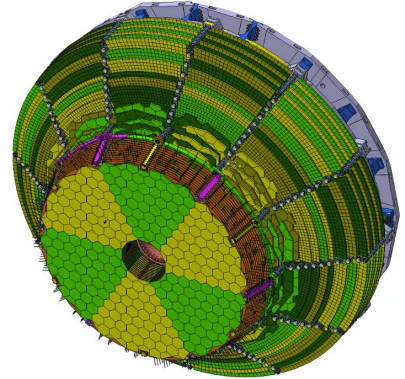
[CMS-CR-2020-204](#)

- Integrated luminosity will be increased over 3000 fb^{-1}
 - More radiation, more pile-up, higher density of tracks ...
- Calorimeter endcaps with high radiation background is especially challenging ($10^{14} \rightarrow 10^{16} \text{ neq /cm}^{-2}$ in Phase II).
 - High radiation tolerance of sensors and electronics
 - Precise timing measurements and high granularity

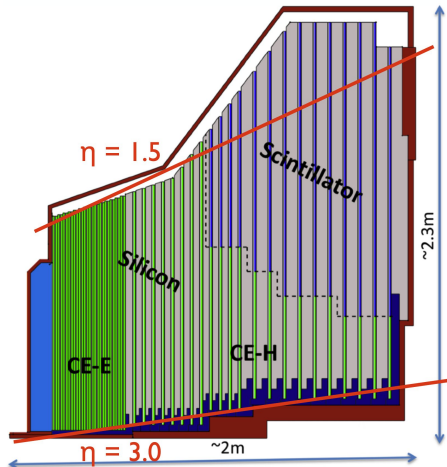
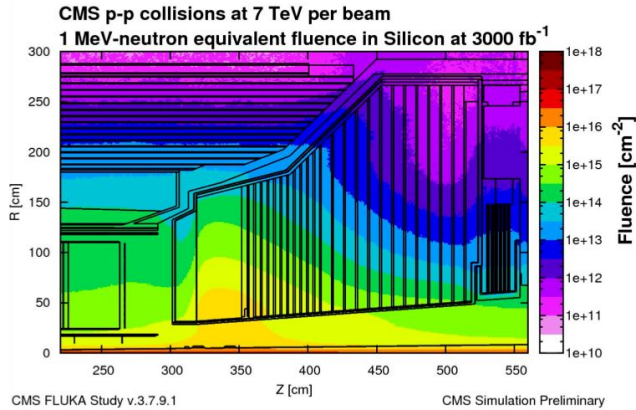


The High-Granularity Calorimeter (HGCAL)

- A novel 5D particle-flow calorimeter
 - Replacing the ECAL and HCAL in endcap regions.
 - Precise 5D information (position, time and energy) for particle showers
 - Unprecedented transverse and longitudinal readout segmentation
- Physics opportunity example: Vector Boson Fusion $H \rightarrow \gamma\gamma$
 - VBF processes are very sensitive to BSM effects (e.g. $VBF \rightarrow HH$)
 - Jets from the production mode at high- η



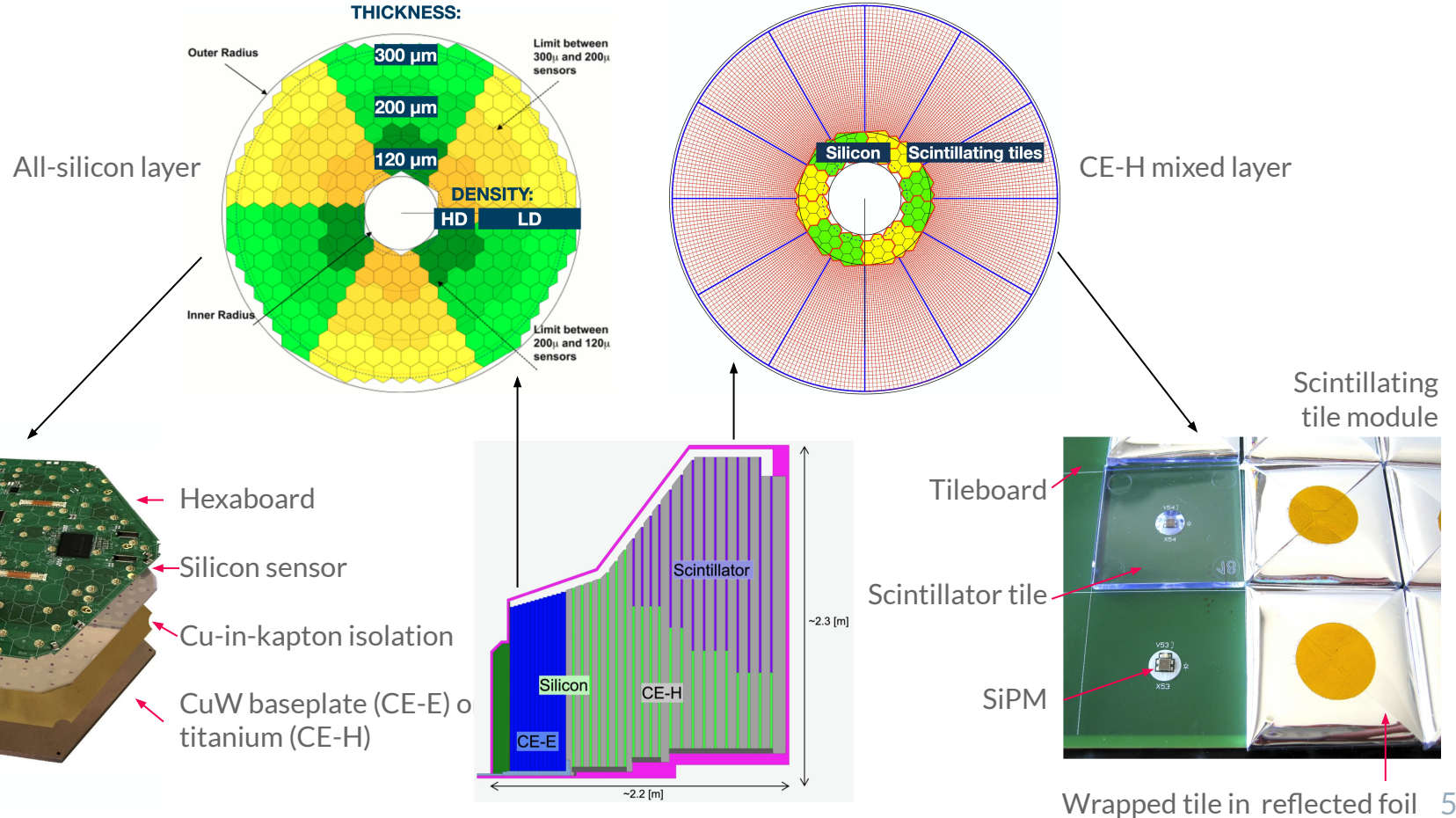
Key parameters



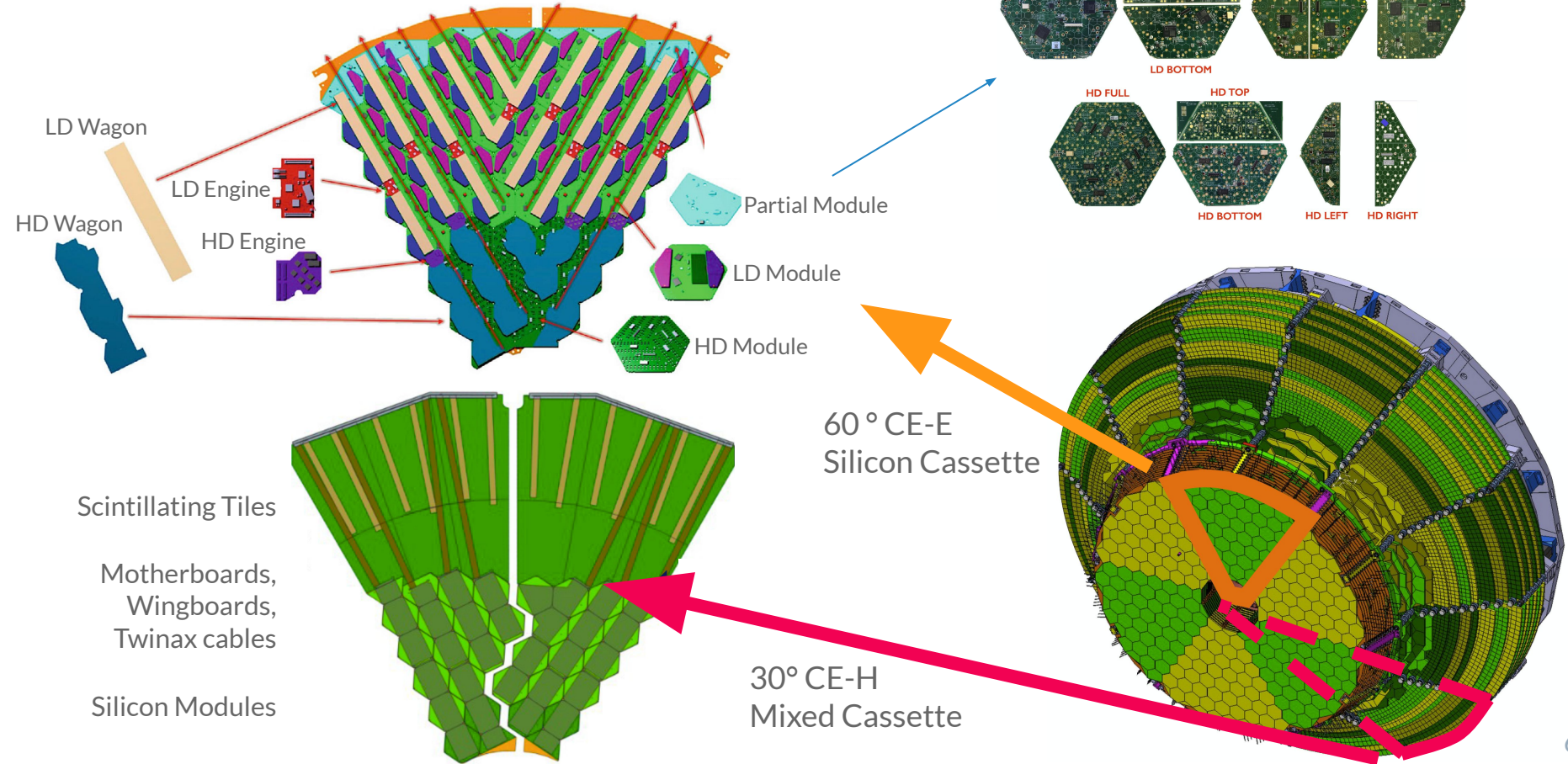
Both Endcaps	Silicon	Scintillator
Area	$\sim 620 \text{ m}^2$	$\sim 370 \text{ m}^2$
Channel Size	$0.5 - 1.2 \text{ cm}^2$	$4 - 30 \text{ cm}^2$
# Channels	$\sim 6 \text{ M}$	$\sim 240 \text{ k}$
# Modules	$\sim 27 \text{ k}$	$\sim 4 \text{ k}$
Op. Temp.	-35°C	-35°C

Per Endcap	CE-E	CE-H	
Active Material	Silicon	Silicon	Silicon + Scintillator
Absorber	Pb, CuW, Cu	Stainless Steel, Cu	
Depth	$27.7 X_0$	10λ	
Layers	26	7	14
Weight	23 t	205 t	

Active Sensor



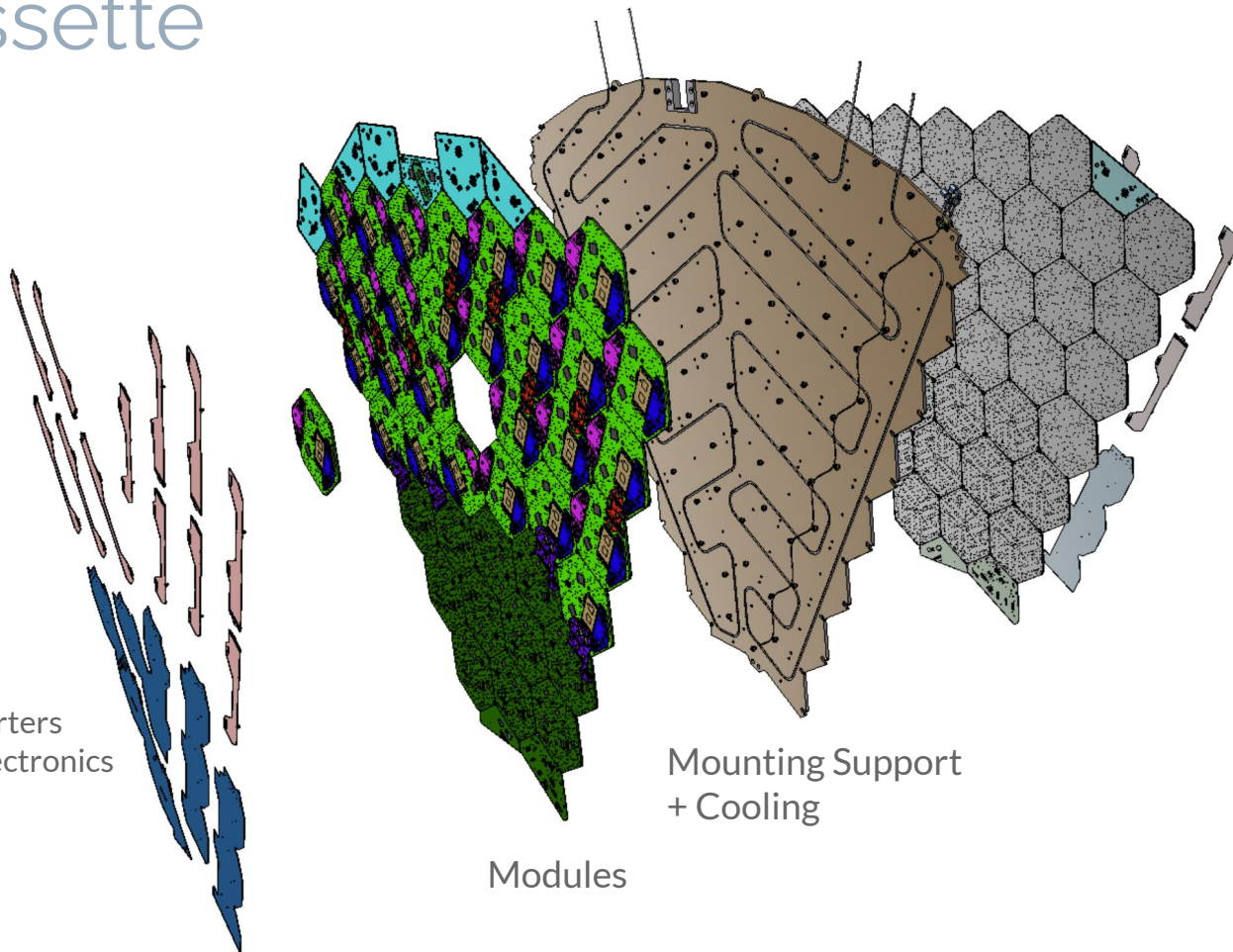
Integration: Cassettes



CE-E Cassette

Auxiliaries:

- DCDC converters
- Front-end electronics
- Services

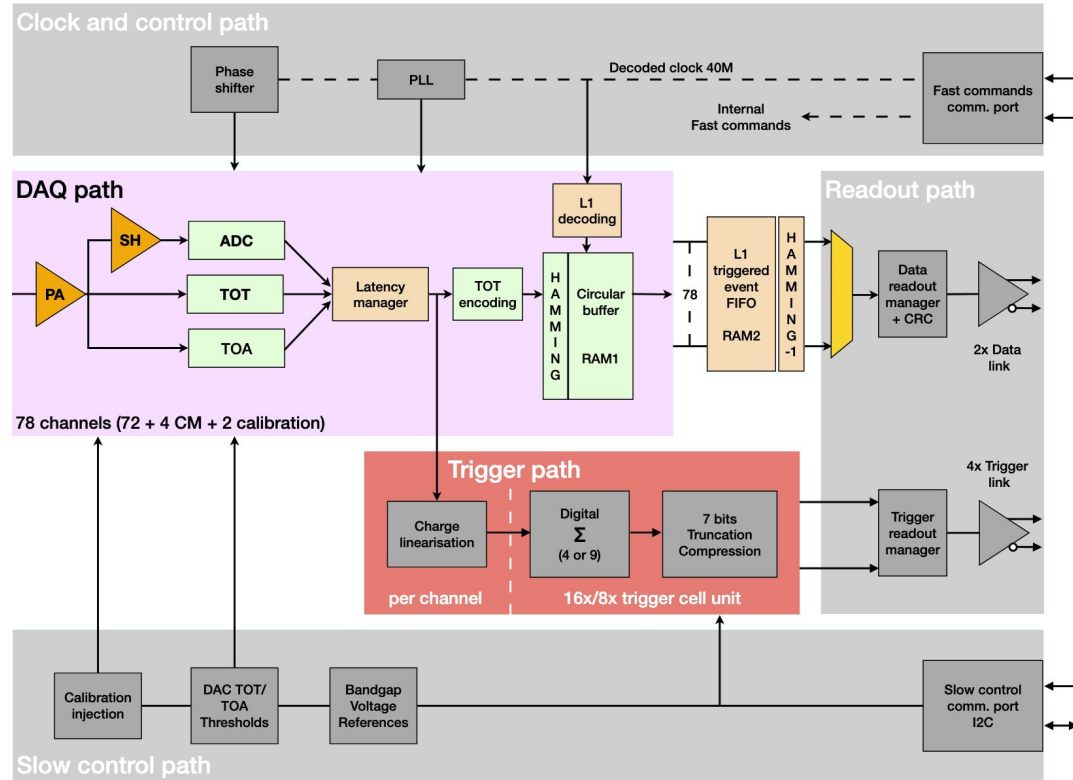
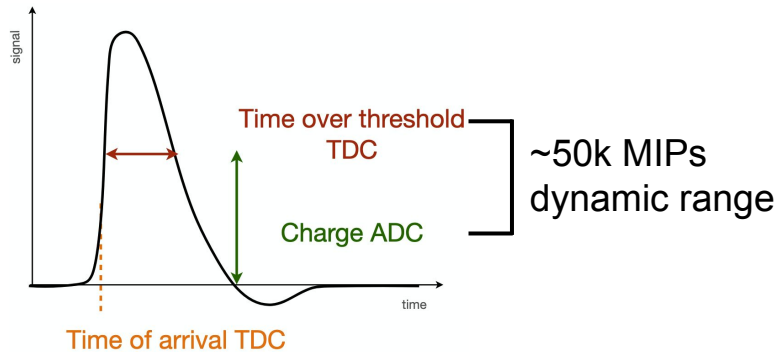


Modules

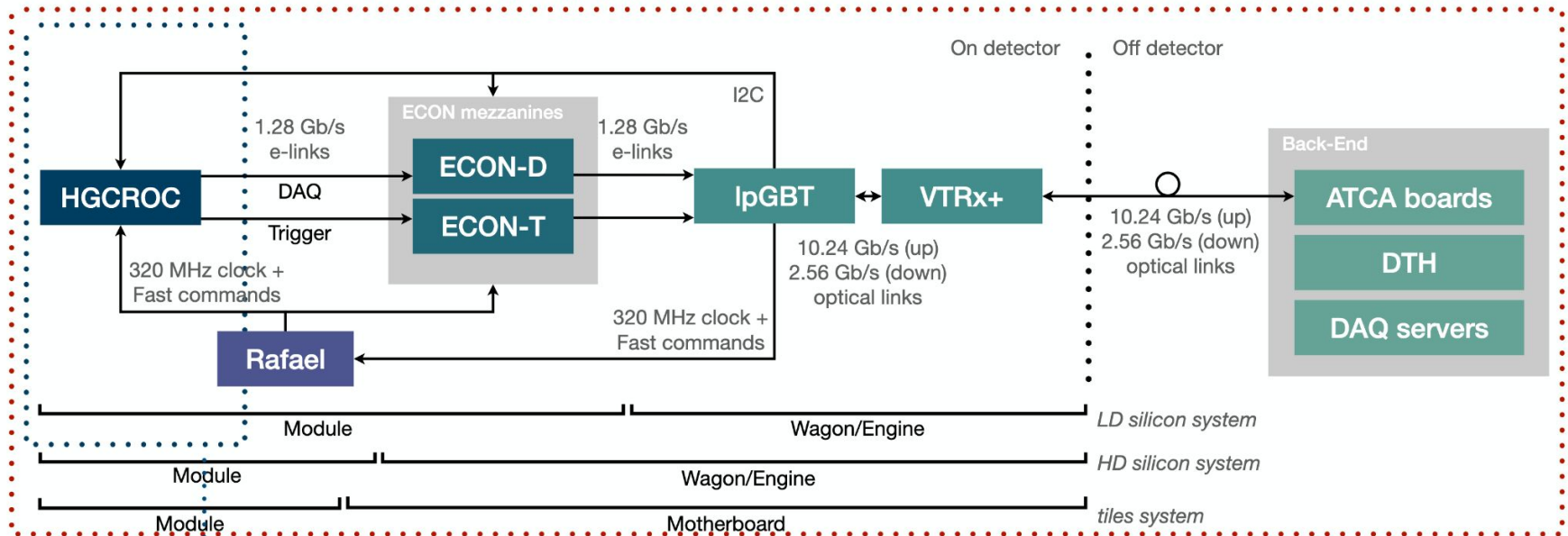
Mounting Support
+ Cooling

Front-end ASICs: HGCROC

- Radiation-tolerant front end chip digitizing and processing sensors signals
- Single readout chip design for silicon and scintillating tile modules
- Provides 3 measurements
 - charge (ADC)
 - preamplifier saturation time (TOT)
 - time of arrival (TOA) with 25ps resolution



Front-to-back-end chain & System tests



Large scale setup at 2018 test beam

- 94 modules in 28 (electromagnetic section) + 12 (hadronic section) layers
- HGCROC prototype electronics

**PHYSICS PERFORMANCE
DEMONSTRATION**

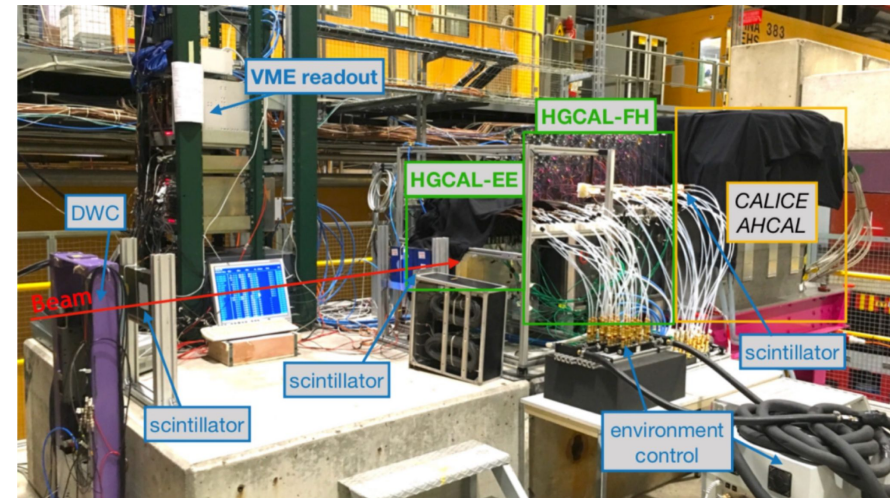
End-to-end readout since 2023 test beam

- Final-like electronics
- Multiple modules (2023-2024), multiple layers (2025)

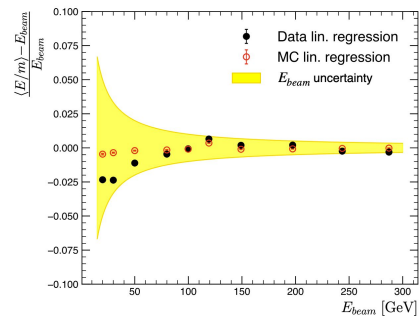
**DATA TRANSMISSION,
DATA QUALITY AND SYSTEM STABILITY**

2018 test beam

- CE-E: Stack of 28 silicon modules ($27X_0$)
- CE-H: 12 layers of up to 7 silicon modules assemblies
- Complemented by CALICE AHCAL
 - 39 layers of scintillator/SiPM-on-tile prototype
- Performance meeting target

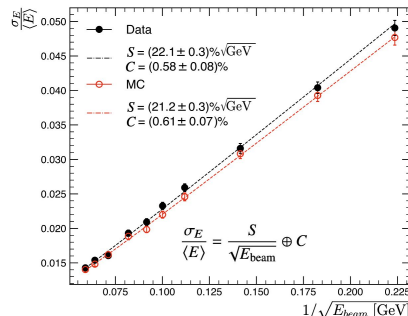


Electron Linearity



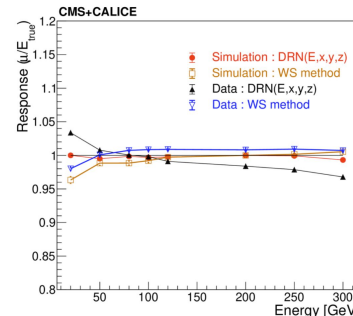
Energy response linear
within $\pm 1.5\%$ above 50 GeV

Electron Resolution



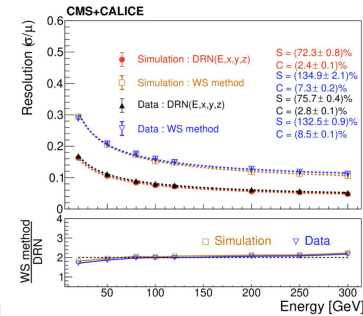
0.6 % constant term

Pion Linearity



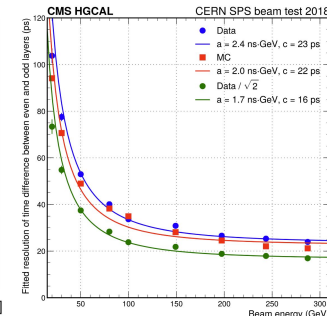
Energy response linear
within few %

Pion Resolution



Excellent data/simulation
agreement

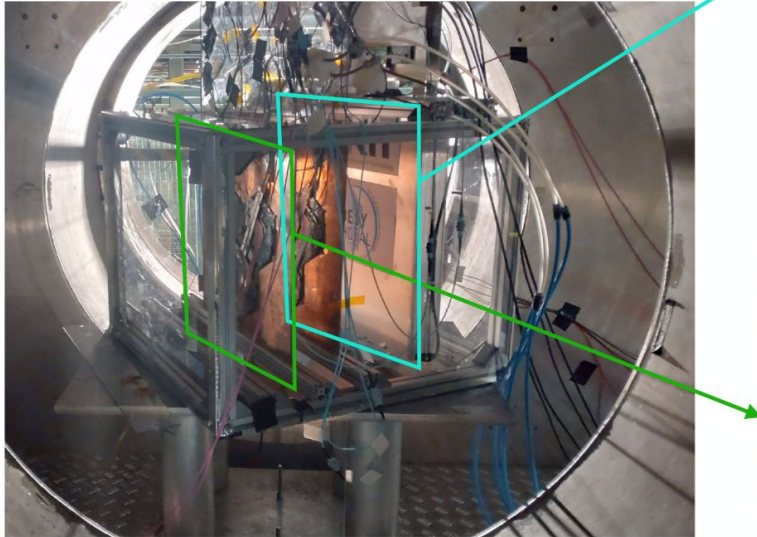
Timing



16 ps constant term

Test in magnetic field at 3T

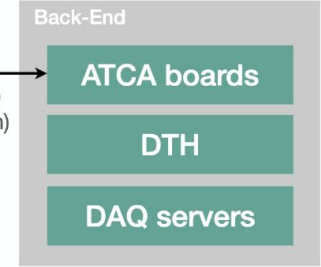
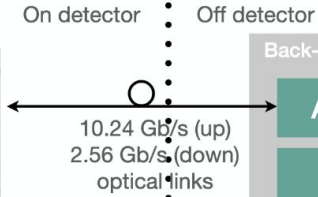
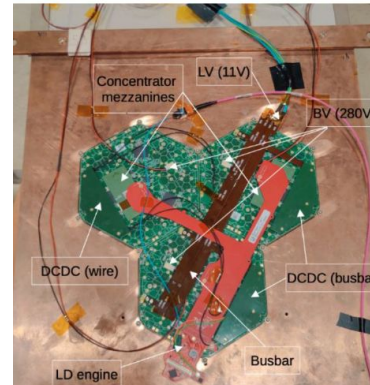
- 2024 beam test
 - e^\pm, π, μ beam of 20 to 300 GeV energy
 - First run test within a 3T field
 - First end-to-end readout test with silicon + scintillating tiles systems
- June 2025 silicon HD system



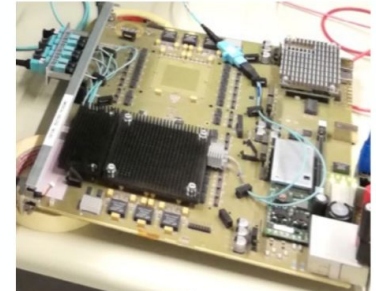
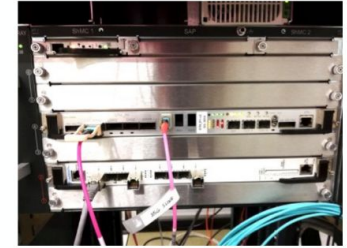
Scintillator tile modules



Silicon modules

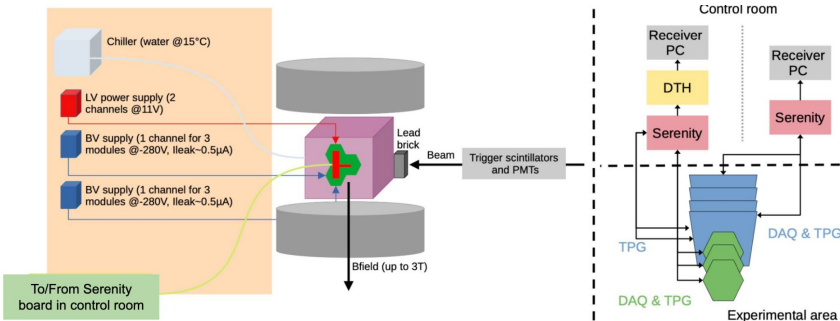


DTH-P1

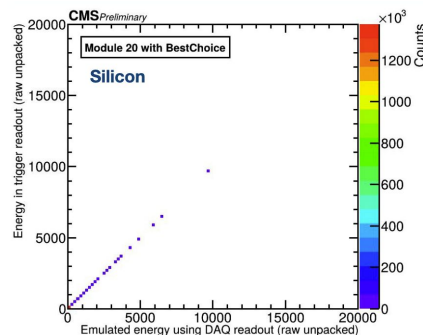


Serenity Z ATCA-based board 11

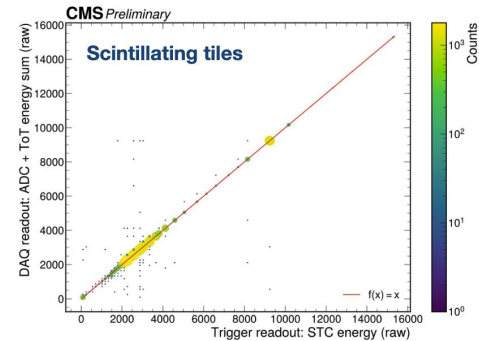
2024 beam test



Trigger readout on electron beam

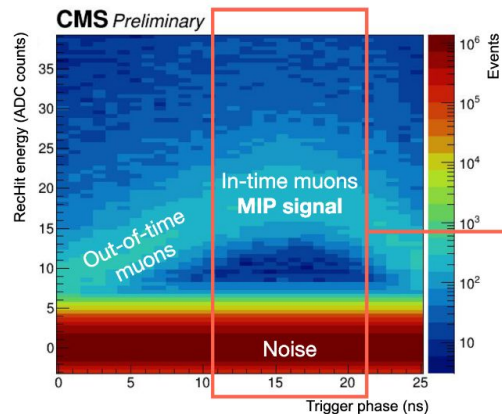


$E(\text{trigger_readout})$ matches that emulated from DAQ data

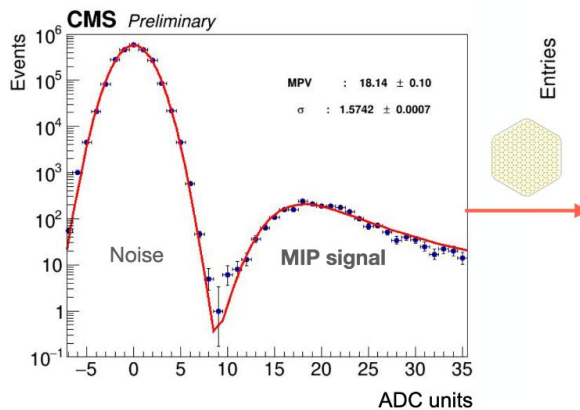


$E(\text{trigger_readout})$ matches the sums of DAQ energy over super trigger cells

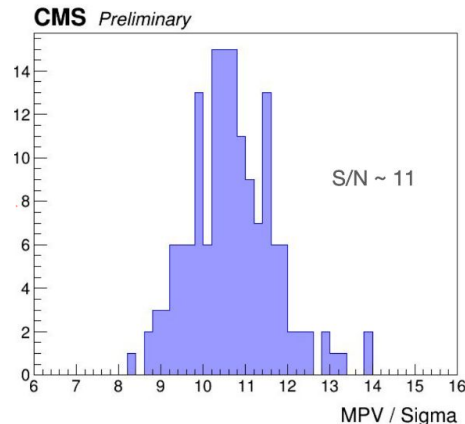
Signal-over-noise measurements with MIPs



Clear MIP peak visible versus time (asynchronous beam)



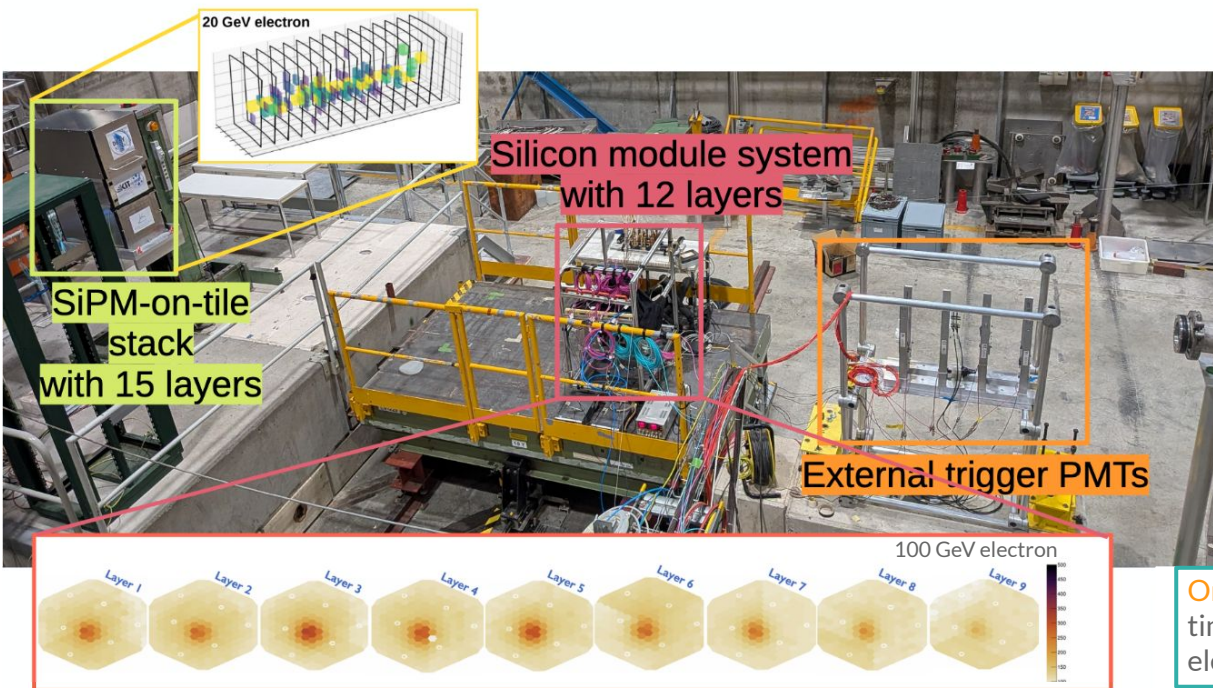
Landau+Gauss fit to pedestal-subtracted distribution in the signal region to extract the scale per-cell



Good performance for channels exposed to beam

October 2025 test beam

- Focus on data-taking for performance characterisation, using a full vertical slice
 - SiPM-on-tile stack with 15 layers
 - 1 silicon system with 12 layers (+ 1 SiPM-on-tile system with 2 tile-modules)
- First large scale tests with the final back-end electronics boards

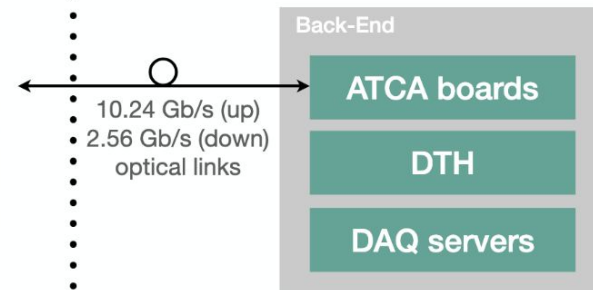


On detector

Off detector



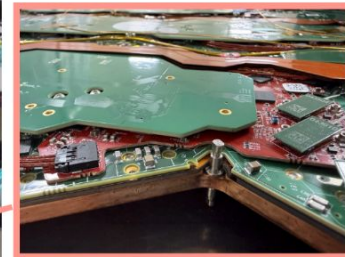
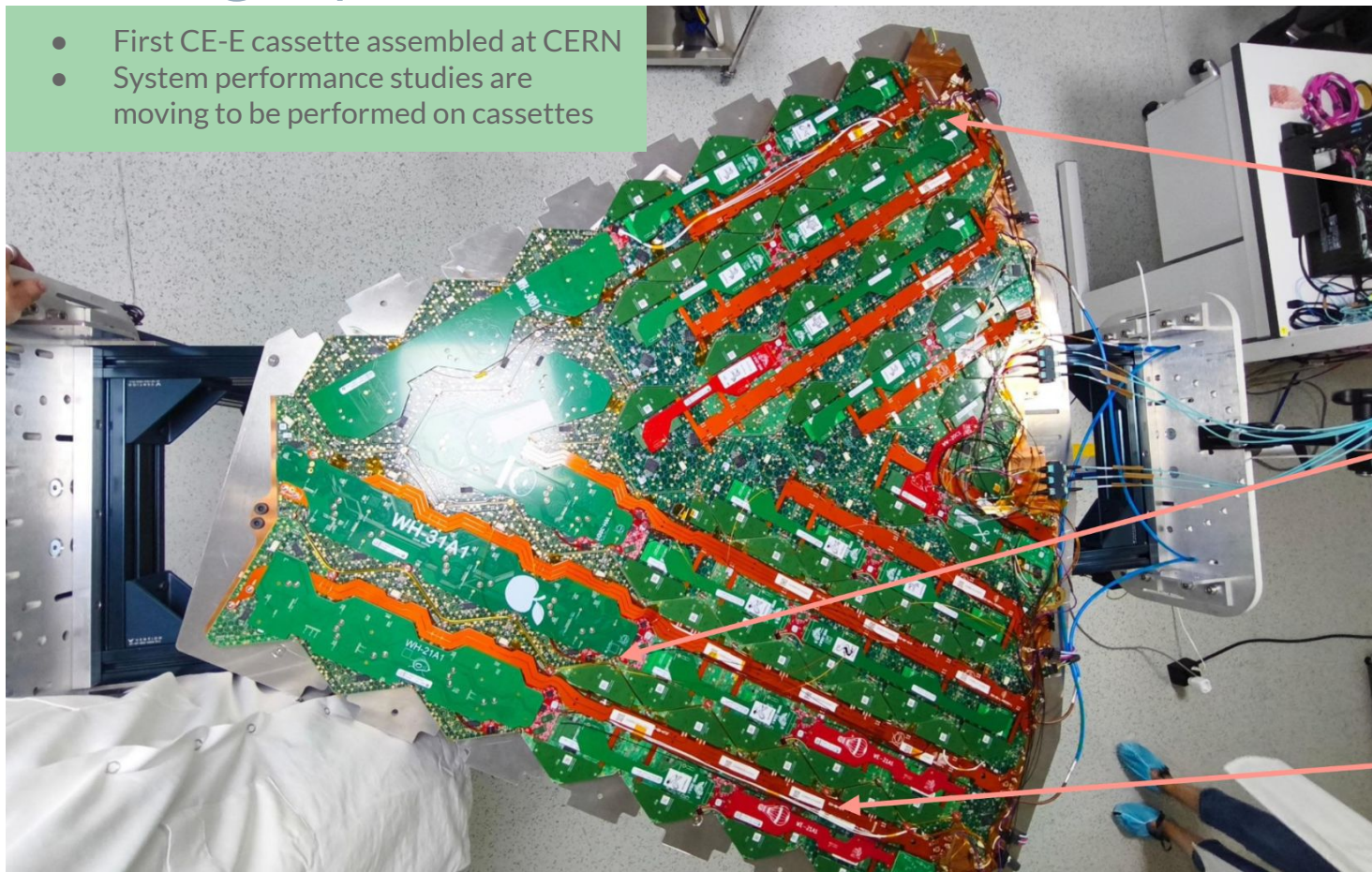
Serenity S ATCA-based board



Ongoing refinements of calibrations, energy and timing performance measurements, study of electromagnetic showers with a rich set of data

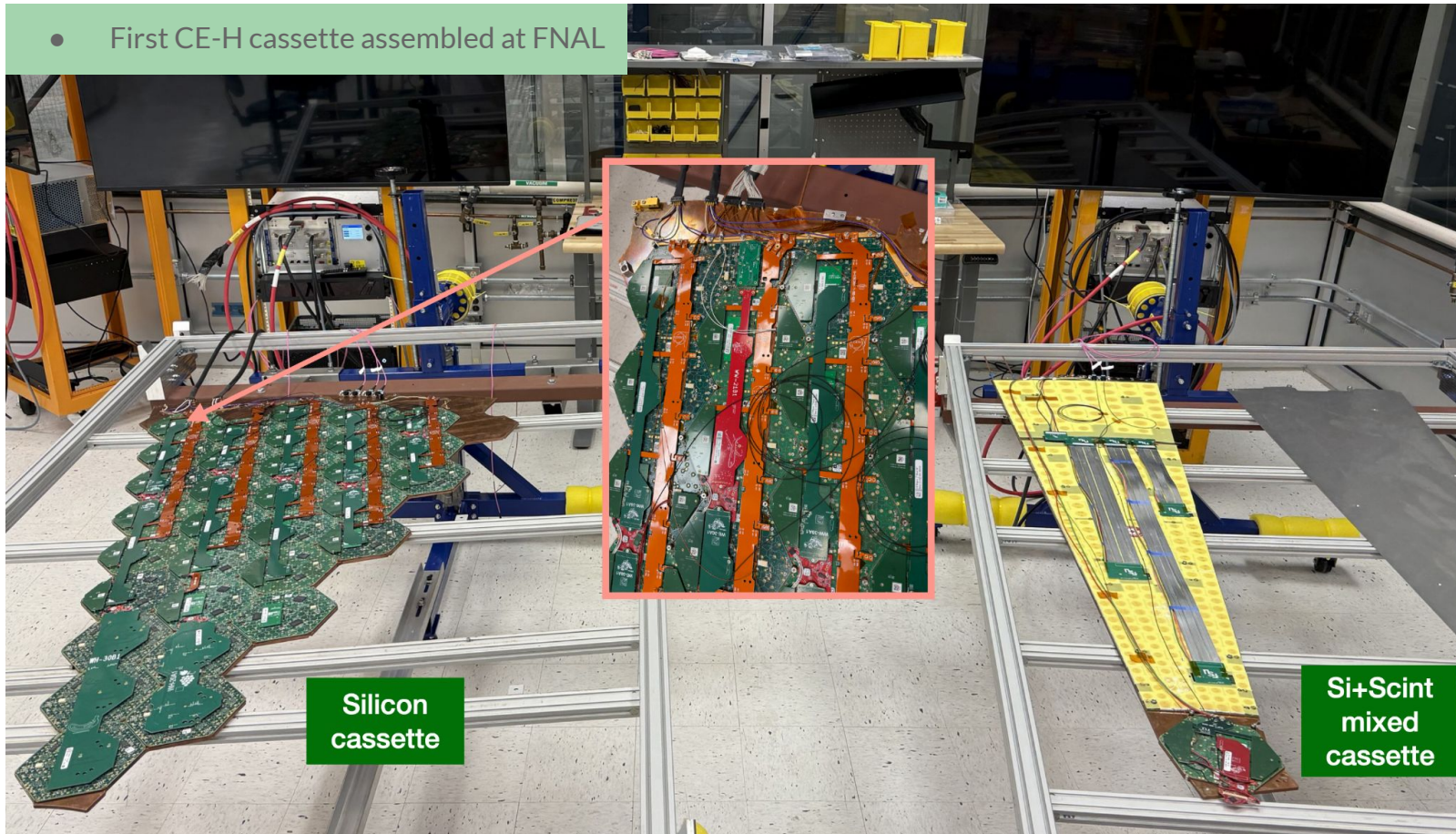
Scaling up towards cassette tests

- First CE-E cassette assembled at CERN
- System performance studies are moving to be performed on cassettes



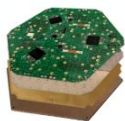
Scaling up towards cassette tests

- First CE-H cassette assembled at FNAL



Recent progress

Modules



- **Silicon sensors delivered**
- PCBs in production
- Mass assembly ramping up



- **All SiPMs delivered**
- **Tiles and wrapping in production**
- Module assembly well underway

Cassette assemblies



- **Readiness of CERN and FNAL assembly facilities advancing**



- **Pre-series silicon and mixed cassettes being tested**
- **CE-H cold tests performed at FNAL**
- CE-E copper plates ready for pre-production

Engineering



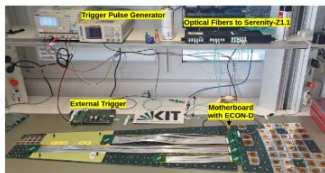
- **First CE-H absorber produced**
- CE-E absorbers going into production

Front-end electronics



- HGCROC in production
- ECON concentrators in production
- Engines and wagons in production

System validation



- Test stands with end-to-end readout
- **Multi-train stacks tested on beam**

Calibration and DQM

- Software well integrated with data-taking at all test stands

Conclusion

- Key Challenges Successfully Addressed:
 - Extreme radiation tolerance: managing 10^{16} neq/cm² dose in endcap regions
 - Unprecedented detector complexity: 6M silicon + 240k scintillator channels
 - Uniform readout electronics (HGCROC, ECON) across heterogeneous detector technologies
 - Mechanical and thermal design for 230-tonne endcap structures
- Design Maturity & Validation:
 - Multi-year test beam campaigns (2018-2025) confirm performance meets targets
 - Energy resolution, linearity, and timing specifications validated
 - End-to-end system demonstrations successful
 - Detector modules transitioned to cassette-level integration
- Production Phase Status:
 - Components delivered, assembly ramping up
 - Pre-series cassettes at CERN and FNAL validation
 - On track for HL-LHC Phase II
- [Overview of the HGCal detector - public talk at CERN detector seminars by Chiara Amendola](#)