

Overview of the CMS High Granularity Calorimeter and its current status

SFP 2025 - Mini Colloque: Derniers Resultats du LHC + Techniques pour les
accélérateurs du futur (FCC) et physique au FCC

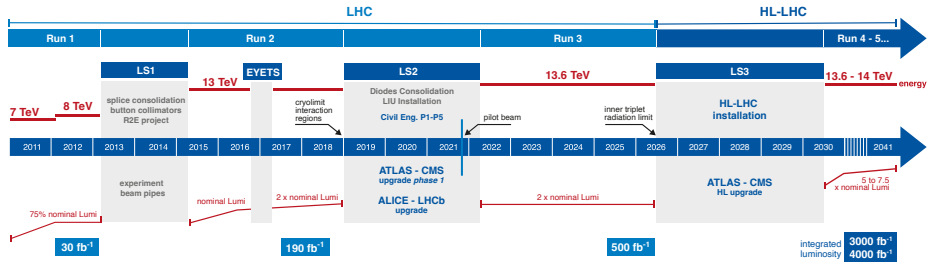
Arnaud Steen

July 1, 2025

High-luminosity LHC



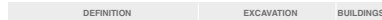
LHC / HL-LHC Plan



HL-LHC TECHNICAL EQUIPMENT:

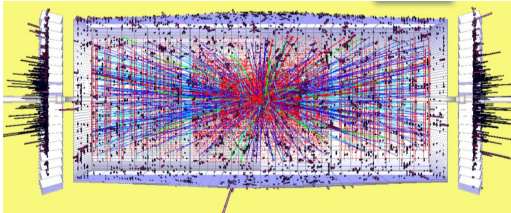


HL-LHC CIVIL ENGINEERING:



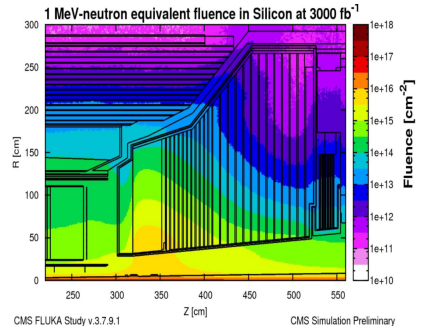
CMS at HL-LHC

- Higher luminosity (5 to 7.5 nominal luminosity)
- Pile-Up of 140 to 200



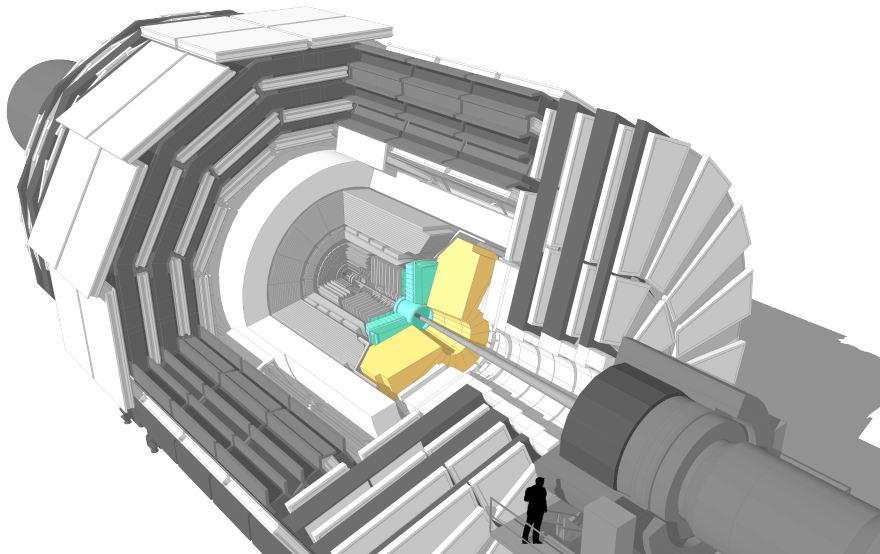
- Harsh radiation environment
 - ▶ Replacement of CMS Tracker and End-cap Calorimeters
 - ▶ Colder operation of the Barrel ECAL
 - ▶ Upgrade of electronics overhaul of the Barrel Calorimeters and Muon systems

- Harsh radiation environment



- Pile-Up of 140 to 200
 - ▶ Improved granularity
 - ▶ Use timing for Pile-Up mitigation → Precision Timing detectors (30ps)
- Higher luminosity:
 - ▶ Upgrade of the trigger and DAQ systems

Replacing CMS End-cap Calorimeters ...



... with the High Granularity CALorimeter (HGCal)

Active Elements:

- Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
- “Cassettes”: multiple modules mounted on cooling plates with electronics and absorbers
- Scintillating tiles with on-tile SiPM readout in low-radiation regions of CE-H

Key Parameters:

Coverage: $1.5 < |\eta| < 3.0$

~215 tonnes per endcap

Full system maintained at -35°C

~620m² Si sensors in ~30000 modules

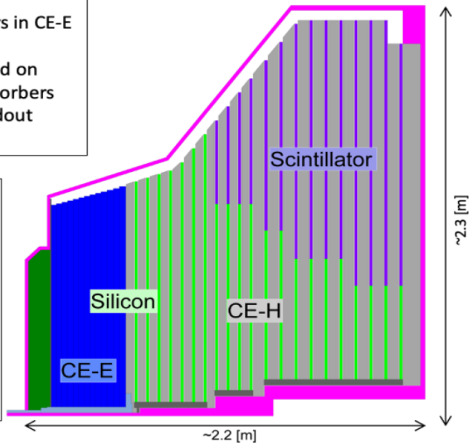
~6M Si channels, 0.5 or 1cm² cell size

~400m² of scintillators in ~4000 boards

~240k scint. channels, 4-30cm² cell size

Power at end of HL-LHC:

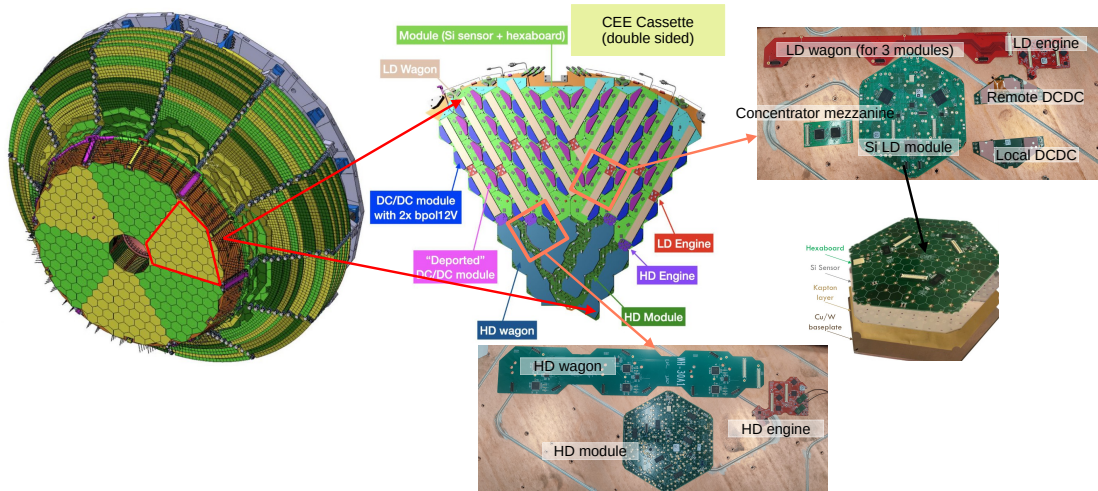
~125 kW per endcap



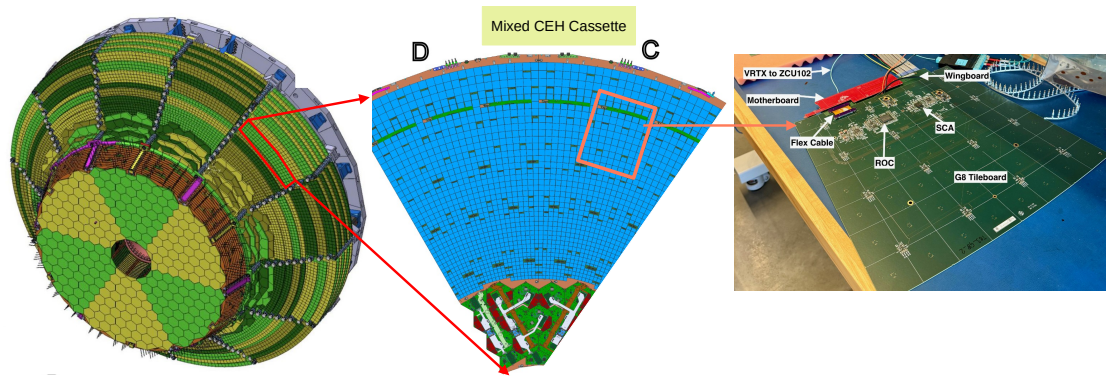
Electromagnetic calorimeter (CE-E): **Si**, Cu & CuW & Pb absorbers, 26 layers, $25 X_0$ & $\sim 1.3\lambda$

Hadronic calorimeter (CE-H): **Si** & **scintillator**, steel absorbers, 21 layers, $\sim 8.5\lambda$

CMS HGCAL

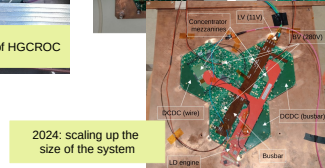


CMS HGCAL



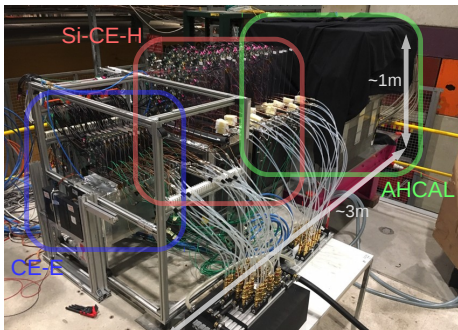
Validating CMS HGCal design

- Evaluation of the performance of silicon modules during beam tests
 - ▶ 2016-2018: with $94 \times 6''$ silicon modules (without "HL-LHC" electronics)
 - ▶ 2021: first tests with 8'' modules, equipped with first version of CMS-HGCal electronics
 - ▶ 2022: same with newer electronics
 - ▶ 2023: same with newer electronics + first test with full electronic system
 - ▶ 2024: new electronics + scaling up the size of systems + test with 3T magnetic field
 - ▶ 2025 (Spring): new electronics + test of HD system in 3T magnetic field
 - ▶ 2025 (Fall): test of small EM calorimeter stack with latest Si and SiPM-on-tile modules
- Goal of the beam tests:
 - ▶ Energy linearity and resolution
 - ▶ S/N with muon beam
 - ▶ Timing resolution

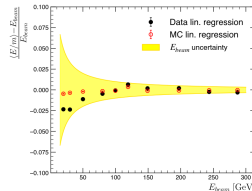
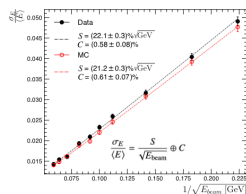
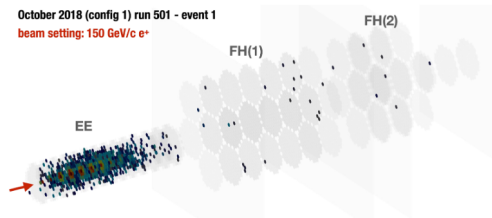


2018 beam test prototype

- Large prototype with 94 silicon modules
 - ▶ Electromagnetic Calorimeter: 28 layers with 1 Si module
 - ▶ Front Hadronic Calorimeter: 12 layers with up to 7 Si modules
 - ▶ 12000 silicon cells in total
- CALICE AHCAL as back Hadronic calorimeters (SiPM-on-tile modules)
- Tested with beam of electrons, pions and muons

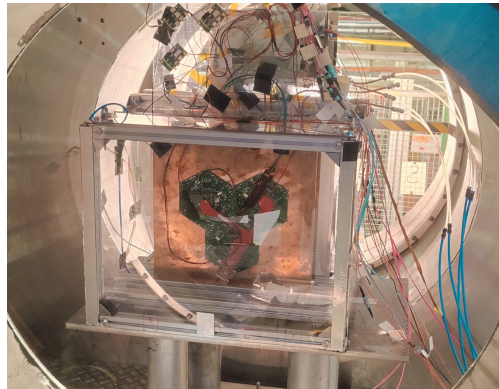


October 2018 (config 1) run 501 - event 1
beam setting: 150 GeV/c e^+



2024 HGCal beam test in magnetic field

- Goals of the tests:
 - ▶ Operation of larger trains than in 2023 (3 modules per train vs 1 in 2023) and of **SiPM-on-tile full electronic chain** (1st time with beam)
 - ▶ Operation of **HGCal silicon and tile modules in a magnetic field** (1st time) → study the effect on the S/N with muon beam and on larger signals with electron beam
 - ▶ Study ToA performance after the trimming of the TDC
- Data acquisition:
 - ▶ with muon and 200 GeV electron beam
 - ▶ event rate: ≈ 10 kHz during spills for electron runs

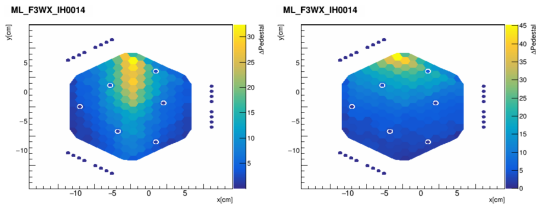


DQM plots (using CMS DQM)

From 200 GeV electron runs

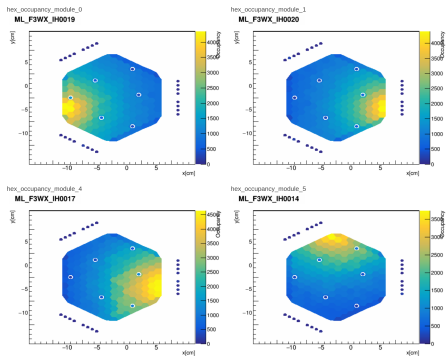
- Effect of magnetic field:

- ▶ $\Delta_{ADC} = ADC - ADC_{BX-1}$
- ▶ Left: with Bfield at 3T
- ▶ Right: without Bfield



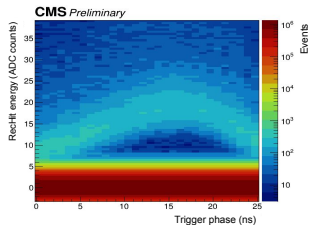
- Occupancy plot with zero suppression: only channels satisfying $P + 3\sigma$ condition are transmitted by the ECON-D:

$$ADC_{ch} > Pedestal_{ch} + 3\sigma_{ADC,Er_x} \quad \text{or} \quad ToT_{ch} > 0$$

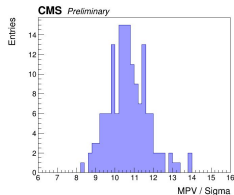
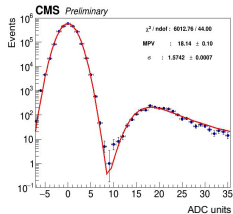


Beam test data analysis

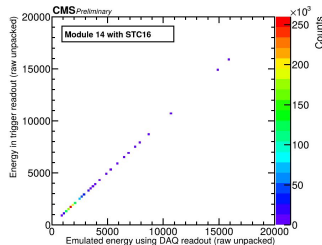
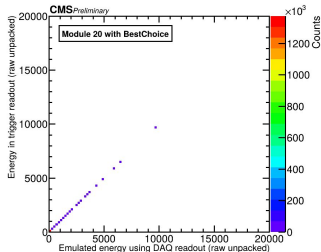
- Signal (from muon beam) vs trigger phase:



- Signal over noise ratio extracted from muon runs:

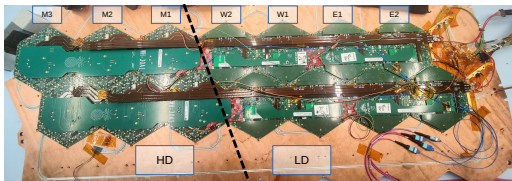


- Energy correlation of the DAQ and trigger data for silicon layers

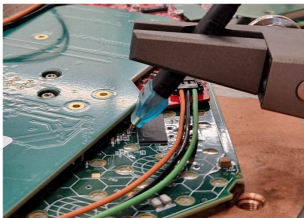


Validation in the lab

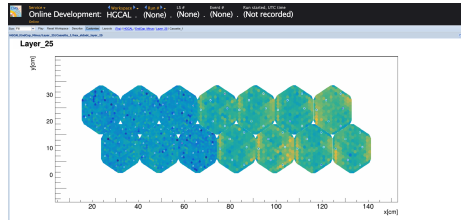
- "ESR2" system - 14 modules assembled on a copper plate



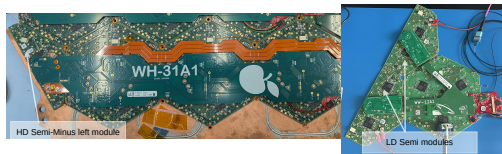
- Clock distribution



- Noise, study, trimming and calibration



- Test with nominal trigger rate
- Cold test (-35°C)
- Many variants:



Status of HGCAL

- Many parts are in (pre-)Production
- 94% of silicon sensors received
- Assembly of Silicon module ramping up (target 12 modules per day)
- 100% of SiPM received
- Assembly of SiPM-on-tile module starting
- Almost all ASICs and boards are in production
- Plan: finish production of parts by the end of 2026

- CE-H Absorber structure ($\approx 170\text{t}$) for the 1st End-cap in Pakistan



- Will be shipped to CERN in the coming weeks

HGCAL status: CE-E pre-series cassette at CERN



HGCAL status: CE-H pre-series cassette at FNAL

