High Granularity Calorimeter (HGCAL)

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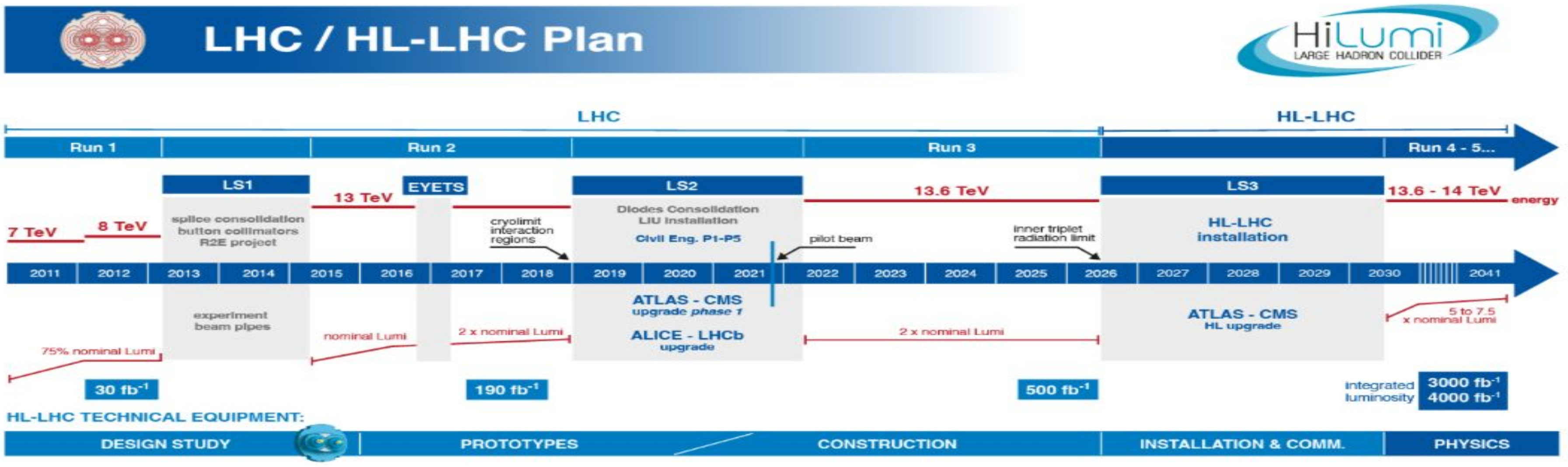
On behalf of the CMS Collaboration

Outline

- HL-LHC and HGCAL
- HGCAL structure
  - Silicon sensors in high radiation region
  - Scintillators in low radiation region
- Electronics
- Physics performance
- Current status
- Summary

Future of LHC



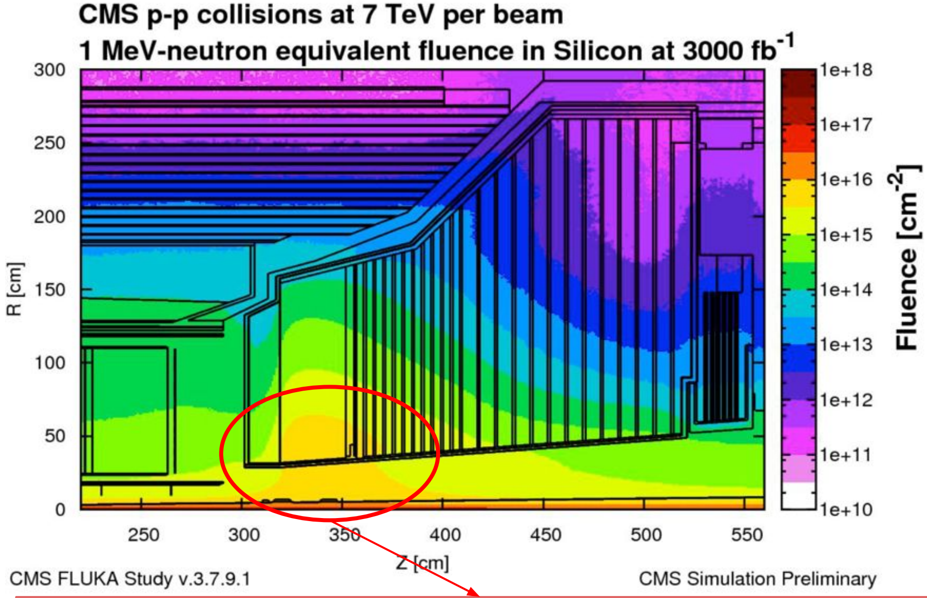
HL-LHC will reach the peak luminosity of 5 ✖ 10^{34} cm^{-2} s^{-1} with pileup of up to 200
Will collect 10 times more data than the full phase 1.

Physics goal:

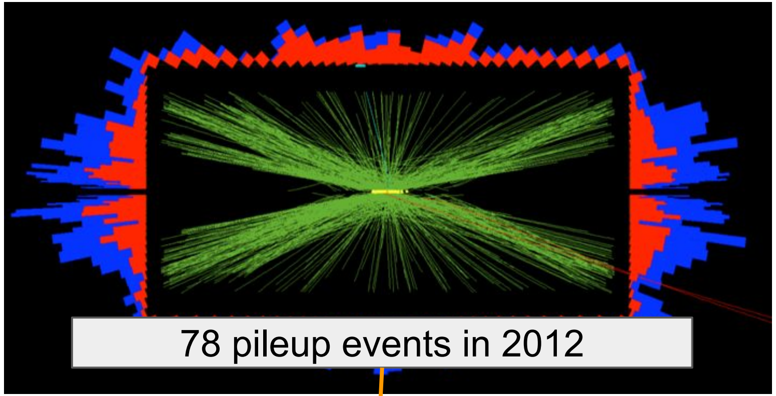
- Precision measurements of Higgs couplings, rare SM processes, and heavy flavor physics
- Searches for BSM physics, VBF processes, and highly-boosted objects
- Reconstruction and triggering of narrow τ jets, merged (W/Z) jets, and MET

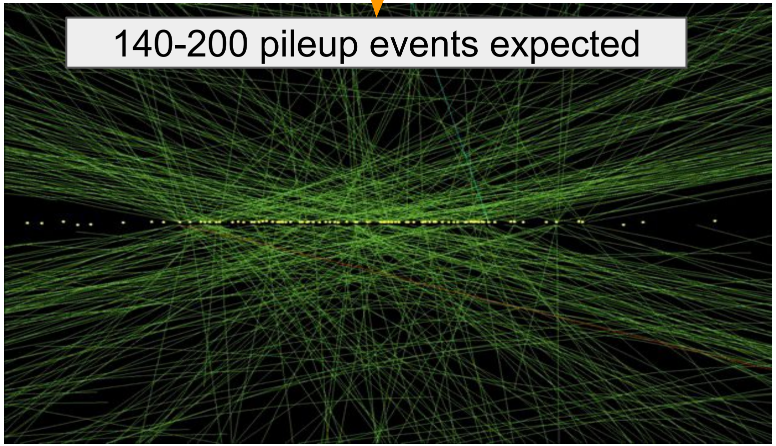
Increased radiation level

Current CMS subdetectors designed for 300 fb^{-1} (Run 3)



Existing calorimeters will suffer irreparable damage in the HL-LHC era.

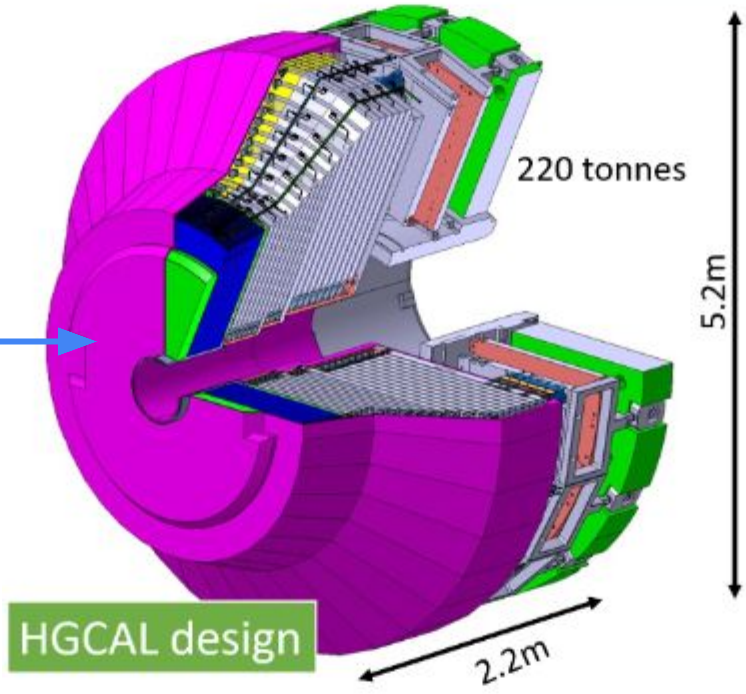




High Granularity Calorimeter (HGCAL)

CMS will replace endcap calorimeters with the HGCAL

Long Shutdown 3

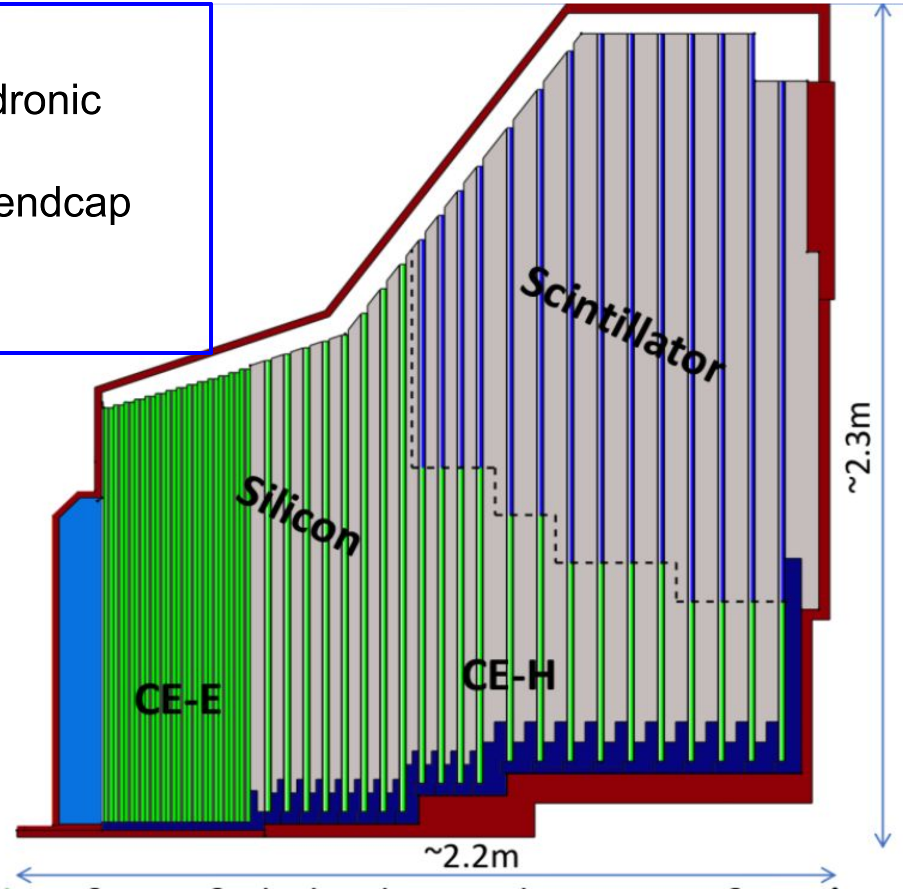


HGCAL structure

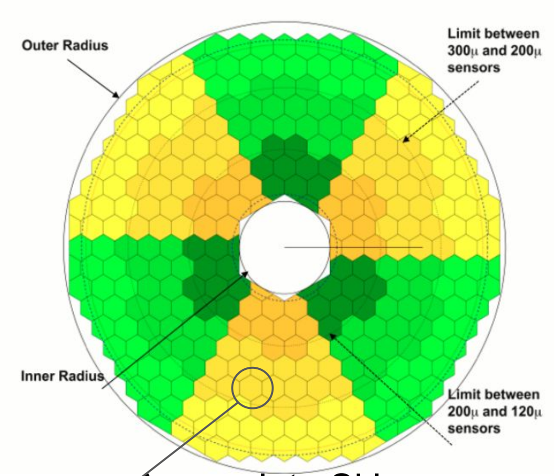
Structure:
Electromagnetic component (CE-E) followed by hadronic component (CE-H), all maintained at -30℃
Coverage: $1.5 < |\eta| < 3.0$, weight: ~220 tonnes per endcap
~ 620 m^2 silicon sensors in ~27000 modules
~ 400 m^2 of scintillators in 4000 tile modules

CE-E:
26 sampling layers
Active element: Hexagonal Si sensor
Absorbers: Cu, CuW and Pb

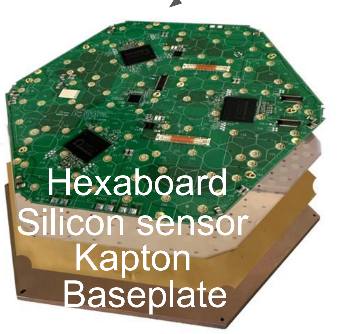
CE-H:
21 sampling layers
Active element: Si sensor + scintillators
Absorbers: Stainless steel

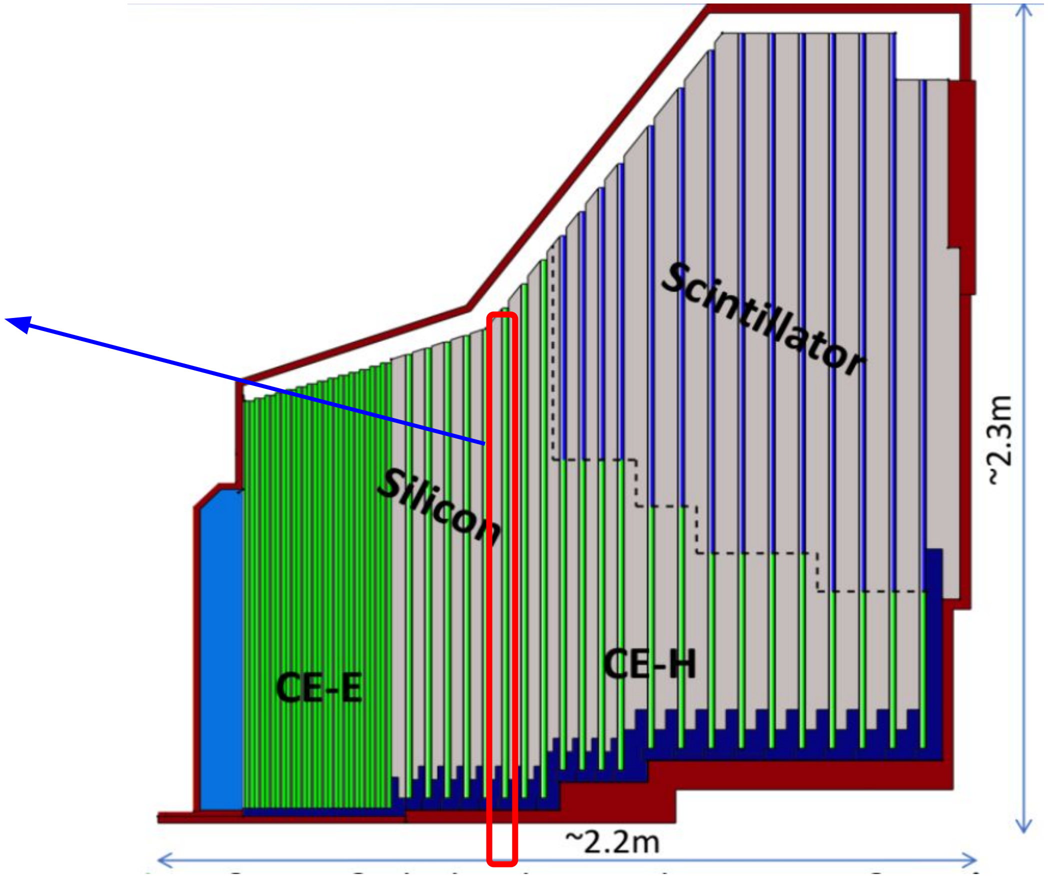


HGCAL design: Silicon sensors in high radiation region



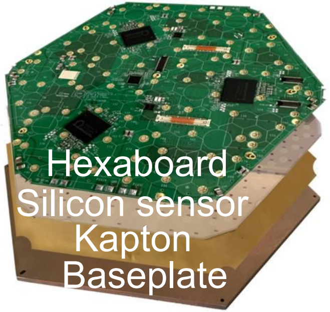
A complete Si layer



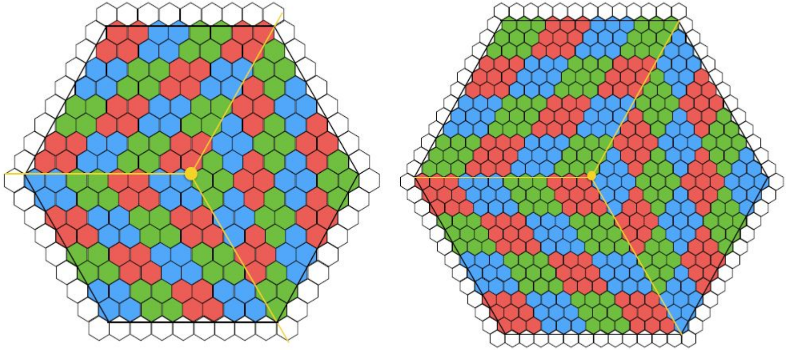


Silicon detector modules

- Hexagonal in shape, entire electromagnetic section (CE-E) and part of hadronic section (CE-H)
- Three variations of active sensor thicknesses: 120 um, 200 um, and 300 um, depending upon the fluence expected.
- Complete module is a sandwich of
  - Hexaboard: Hosts HGCROCs for sensor cell readouts, data transfer
  - Silicon: Active material
  - Kapton: Electrical Insulation from baseplate
  - Baseplate: Provides support and rigidity, acts as absorbing material
- High-density modules have 0.6 cm² cells, while low-density modules have 1.2 cm² cell sizes.



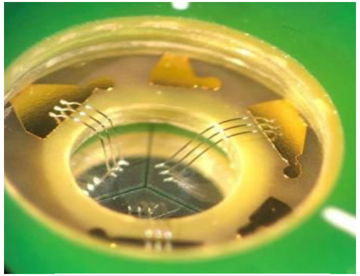
Silicon module stack



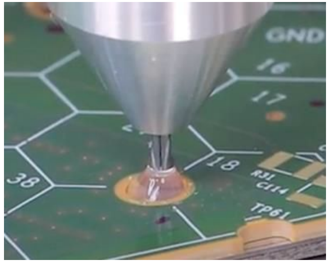
Distribution of sensor cells for low-density (left) and high-density (right) modules

Silicon module assembly

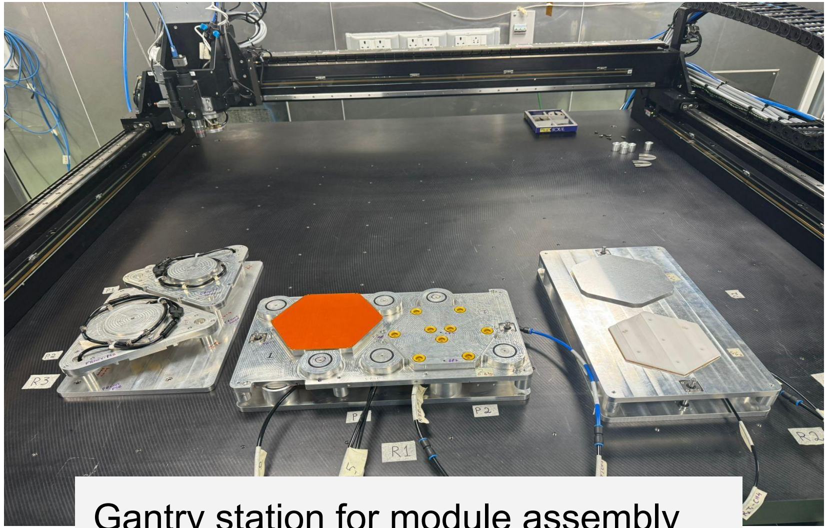
- Total of ~ 27000 silicon modules will be placed in HGCAL
- There are six module assembly centers responsible for producing ~4500 modules each
- The assembly starts with component-level study, e.g., quality assurance (QA) for baseplates and hexaboards
- An automated gantry is used to attach a sensor over the baseplate, followed by gluing hexaboard over the sensor.
- After assembly, electrical connections are made by a wirebonder, followed by the encapsulation of holes to protect wirebonds
- An assembled module is then subjected to mechanical and electrical testing.



Wirebonding

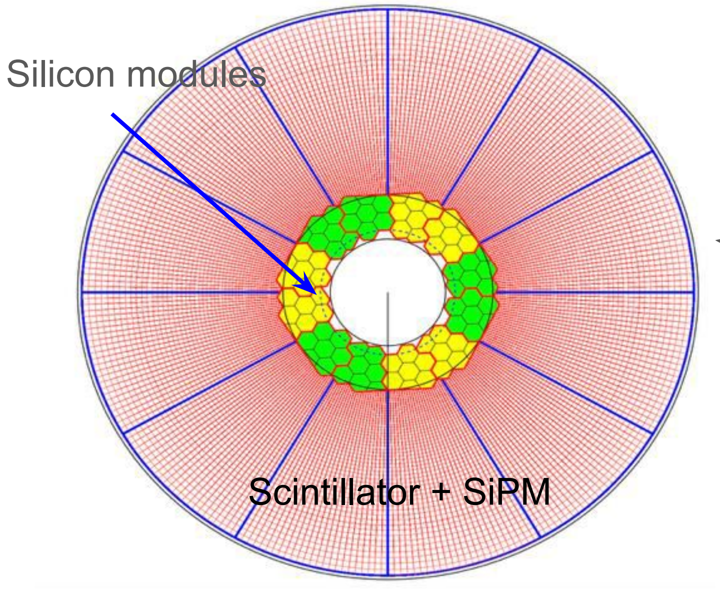


Encapsulation

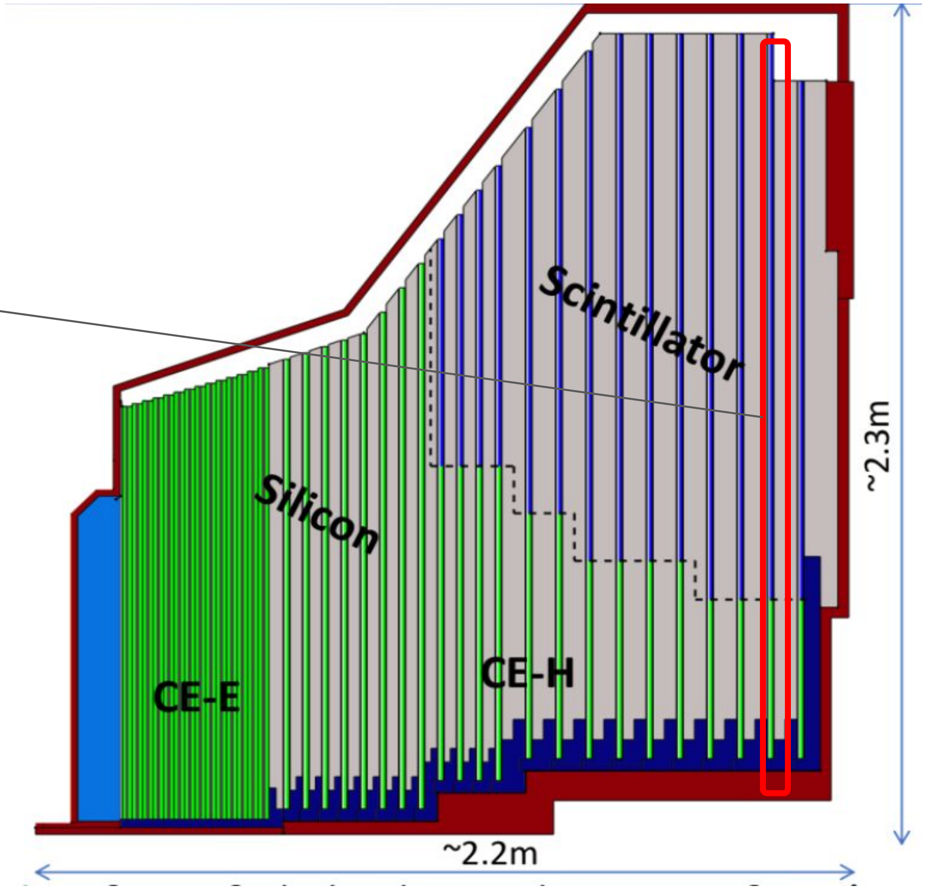


Gantry station for module assembly

HGCAL design: Scintillators in low radiation region

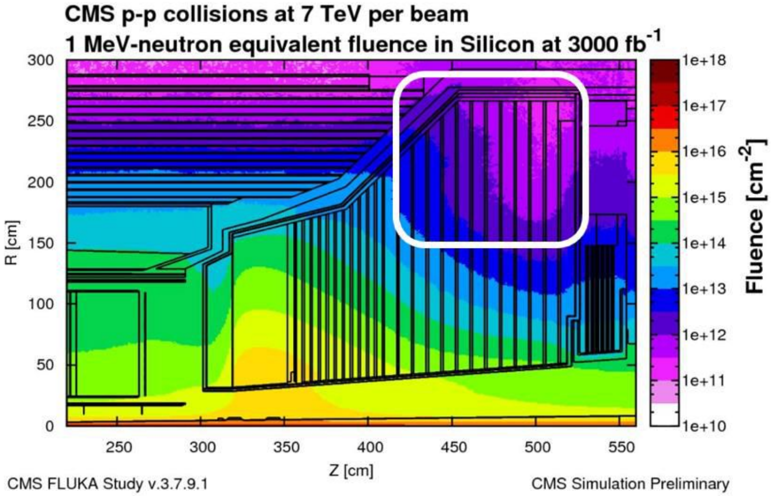


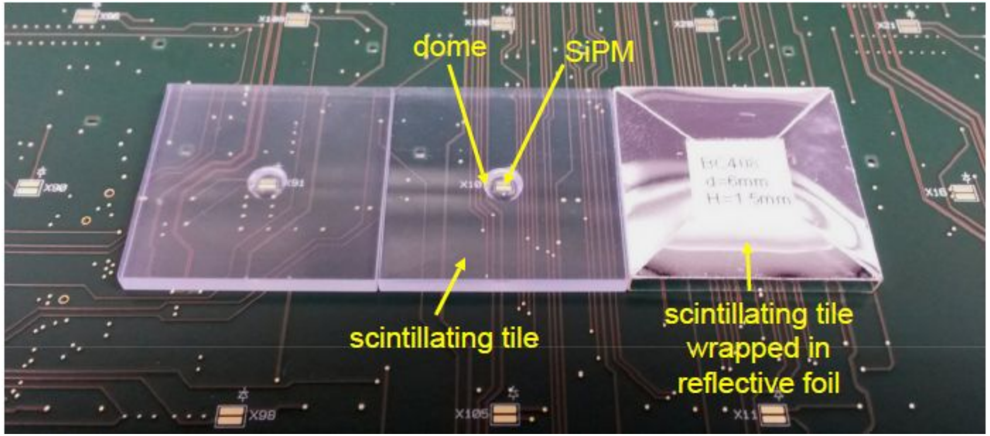
CE-H mixed layer

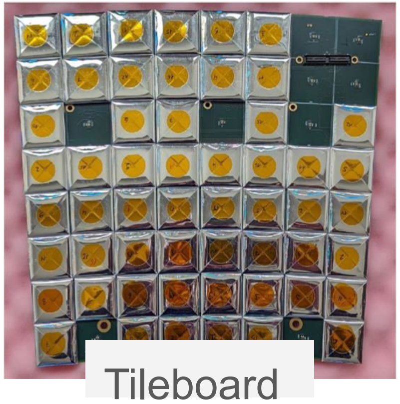


SiPM on scintillator tiles

- In the low radiation region, plastic scintillators with silicon photomultiplier (SiPM) readout will be used
- Individually wrapped plastic scintillator tiles placed on SiPM
- SiPM sits in the dome of the tile for optimized light collection and integration



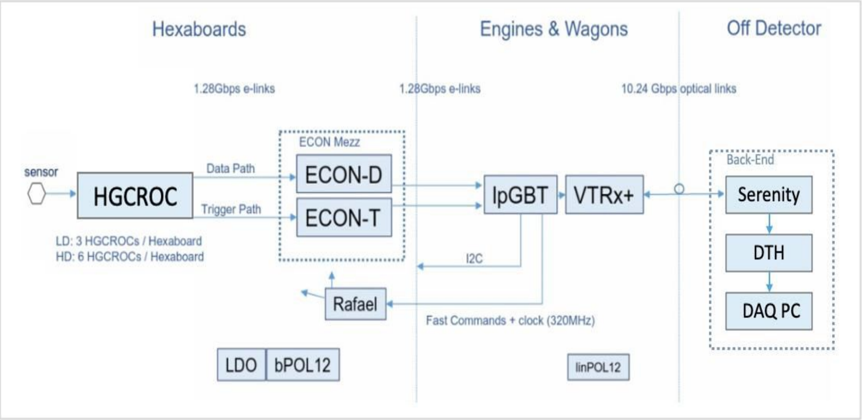




Electronics

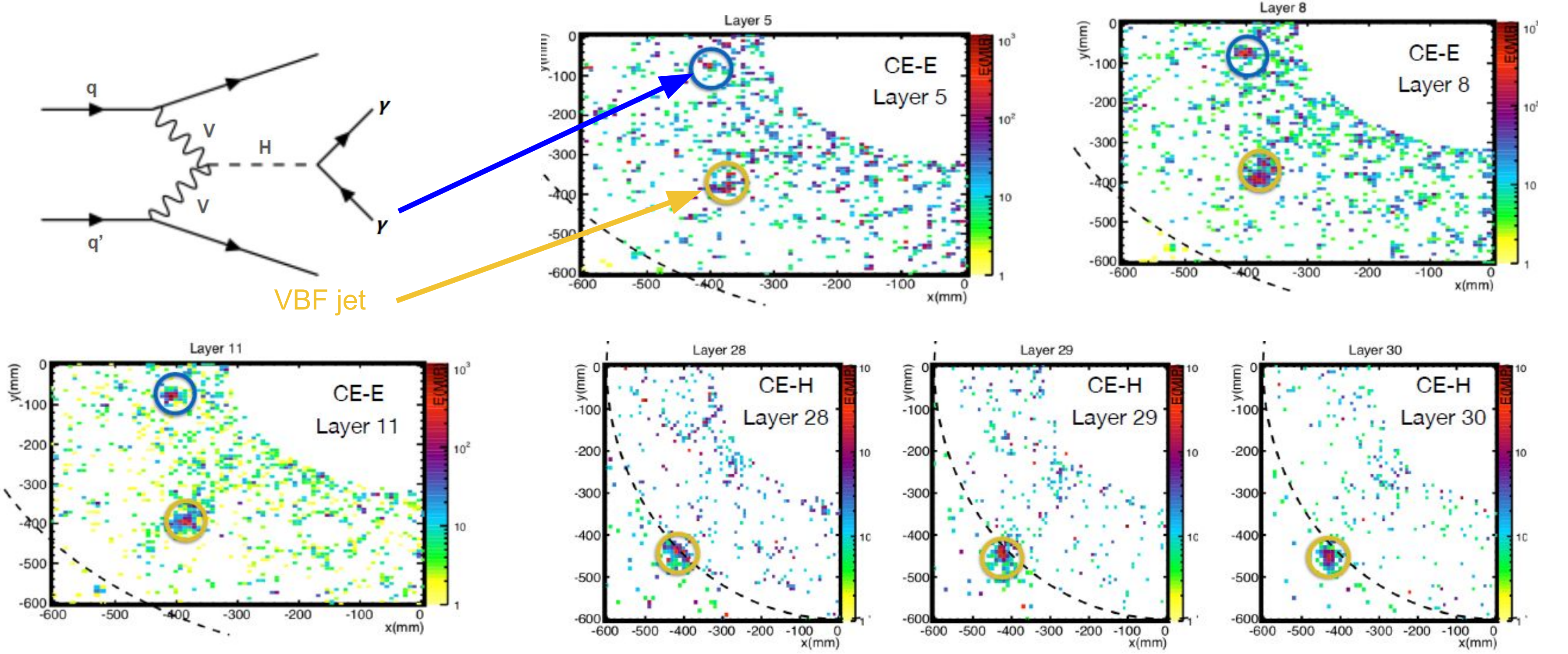
Front-end electronics requirements:

- Low noise (< 2500 e) with high dynamic range (0.2 fC – 10 pC)
- Timing resolution compatible with tens of picoseconds
- Strict cooling limit (< 20 mW per channel)
- Multiple components in the front-end chain: ASICs, readout boards, biasing, interconnects
- Radiation-hard design for HL-LHC dose levels
- High channel density: millions of channels in tight space
- Tight integration with mechanics, cooling, and power distribution



Physics performance expectations: Effect of granularity

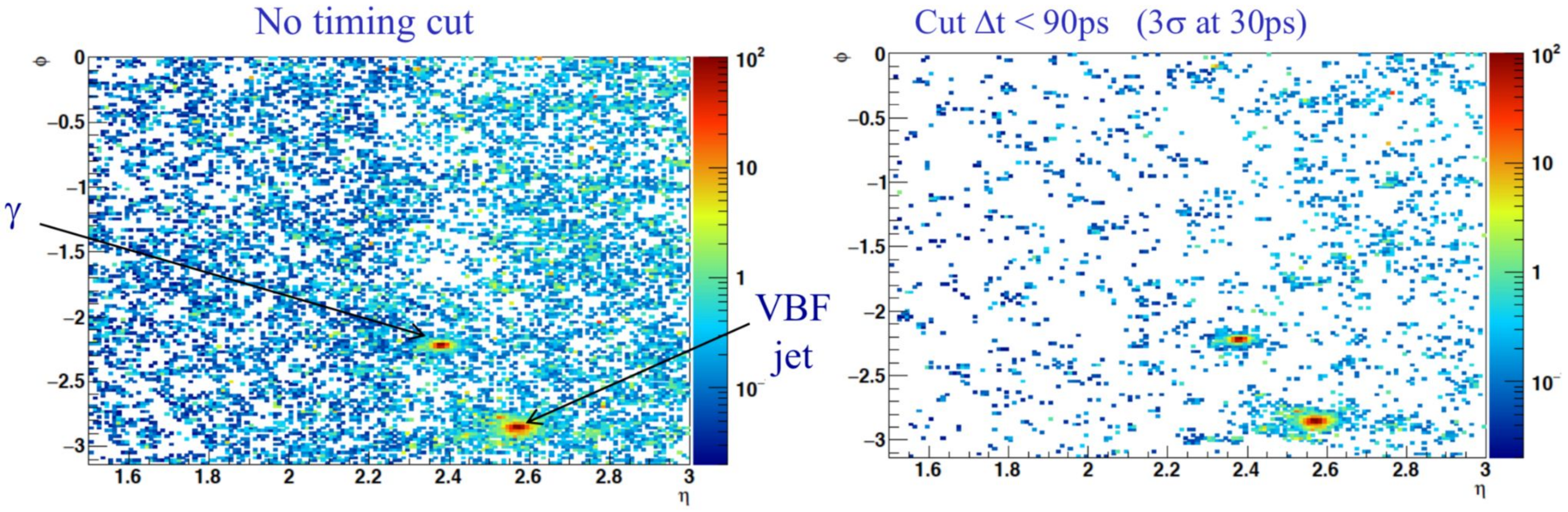
VBF H → **γγ** simulations for the PU of 200: Evolution of VBF jet and **γ** through the layers of HGCAL



[The Phase-2 Upgrade of the CMS Endcap Calorimeter, CMS-TDR-019](#)

Physics performance expectations: With timing information

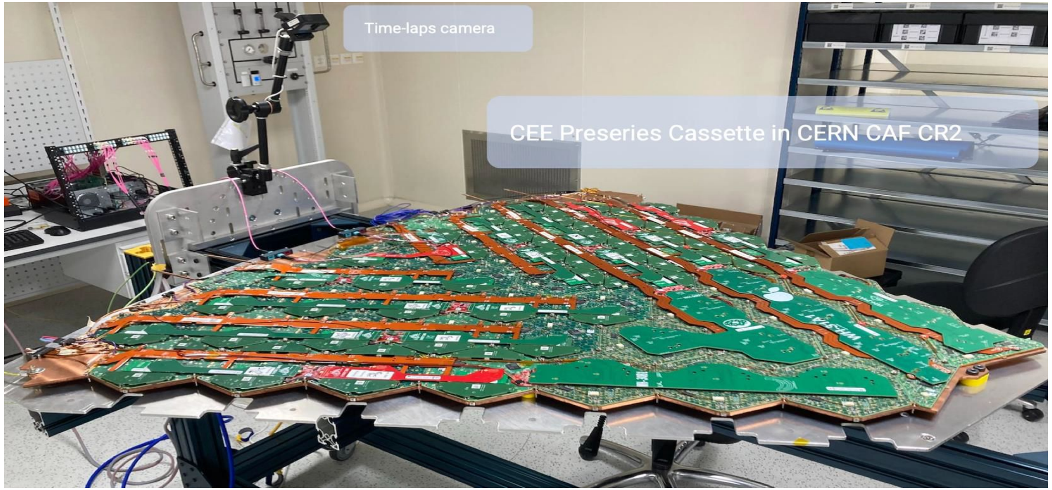
VBF H → $\gamma\gamma$ simulations for the PU of 200: Effect of applying timing cut

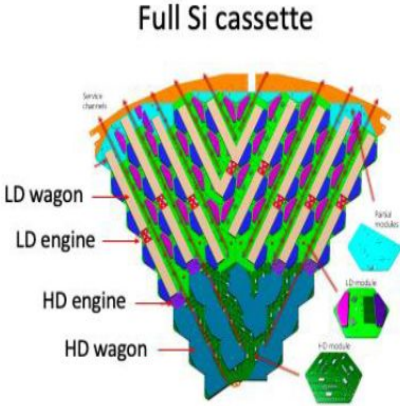


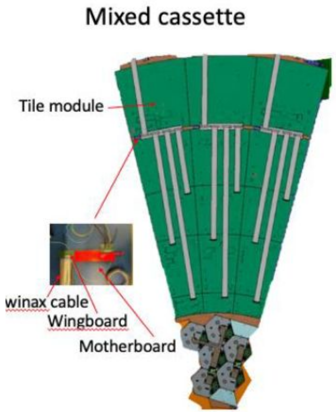
[The Phase-2 Upgrade of the CMS Endcap Calorimeter, CMS-TDR-019](#)

Current status: Cassette assembly

- CE-E cassettes are being assembled at CERN; CE-H cassettes are assembled at FNAL and will be integrated later at CERN.
- A preseries prototype cassette has been assembled (will not go into the detector) to validate assembly procedures, test components, and refine tooling.

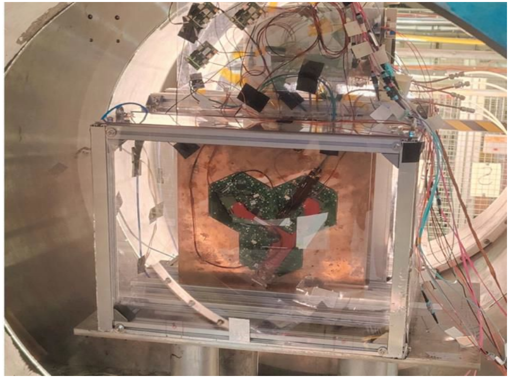






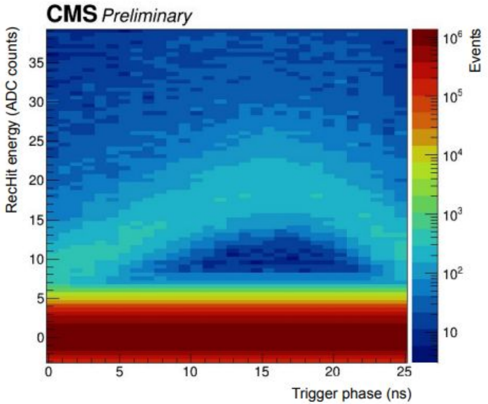
Current status: Test beams

- 2024: 4 weeks of beam tests in a 3-T magnet with 2-3 silicon and 2-4 tile layers.
- 2025: 1 week in June (2 silicon layers in magnet) + 2 weeks in October (10-15 silicon layers + scintillator modules)

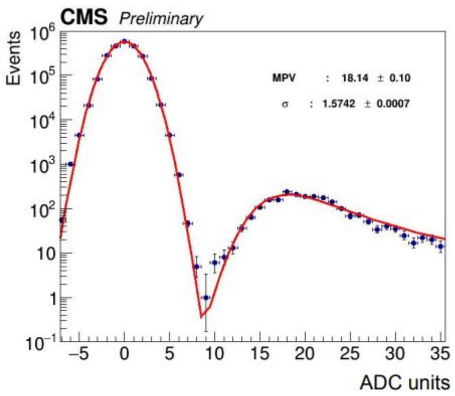


MIP studies from 2024 beam test

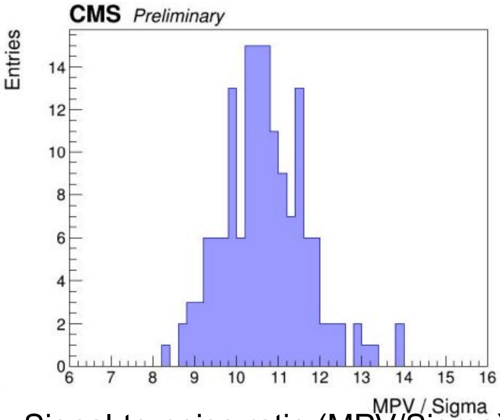
CMS-DP-2025-022



ADC counts vs. trigger phase; shows signal evolution in a single silicon cell for a muon beam



Muon signal and pedestal in a single cell; fit shows pedestal and MIP peak.



Signal-to-noise ratio (MPV/Sigma) distribution across illuminated cells

Summary

- HGCAL will replace the endcap calorimeters of the CMS experiment to meet HL-LHC challenges.
- Unprecedented granularity and precision timing enable 5D particle reconstruction in high pile-up scenarios.
- Combines silicon sensors and scintillator tiles for an optimal performance in different radiation zones.
- Key to delivering precise Higgs, SM, and BSM physics in the HL-LHC era.
- Exciting times ahead!

Thank you