The SiPM-on-tile system of the CMS High Granularity Calorimeter Upgrade (HGCAL)

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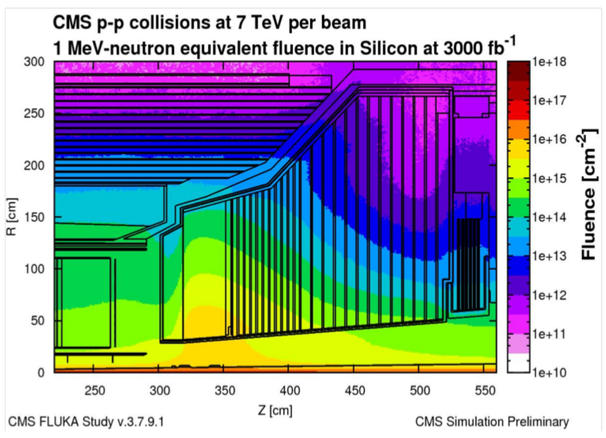
for the CMS HGCAL Collaboration

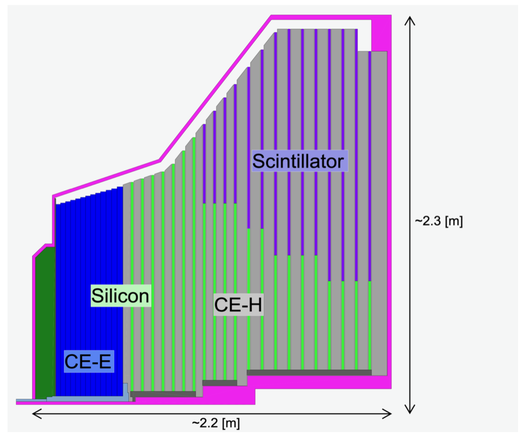
The High-Granularity Calorimeter upgrade

- High-Luminosity LHC to start in 2029 → increased pileup and radiation damage.
- → Need to replace the current endcap calorimeters → **5D (imaging) calorimeter using particle flow**, operating at -35°C.
- Use both silicon sensors and SiPM-on-Tile technologies, depending on the expected fluence at the end-of-life.



Electromagnetic calorimeter (ECAL):
- 27.7X_0 or 1.5λ
- Cu / CuW / Pb absorbers

Hadronic calorimeter (HCAL):
- 8.5λ
- steel absorbers

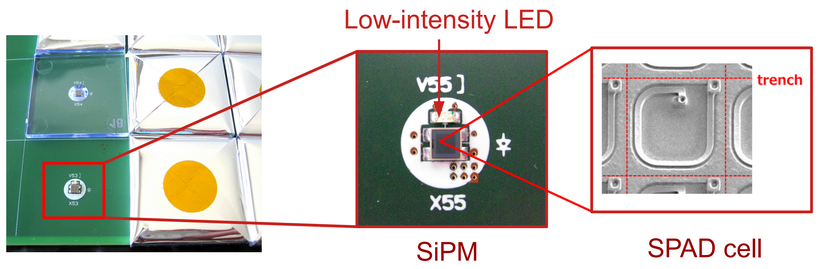


- **Silicon detector section**: where expected fluence at end of life > 5x10¹³ n/cm².
  - Consists of hexagonal silicon sensors.
  - Covers the ECAL and innermost part of the HCAL.
  - Cell size varies depending on its location in the calorimeter.
  - More than **6M silicon sensors** covering 620 m² area.
- **Scintillator section**: where expected fluence at end of life < 5x10¹³ n/cm².
  - Consists of trapezoidal plastic scintillators tiles read out by silicon photomultipliers (SiPM-on-tiles technology).
  - Covers the outermost part of the HCAL.
  - Ensures S/N > 3 for minimum ionizing particles throughout the detector lifetime.
  - Cell size increases radially from the beam line
  - More than **240,000 SiPM-on-tiles** covering 370 m² area

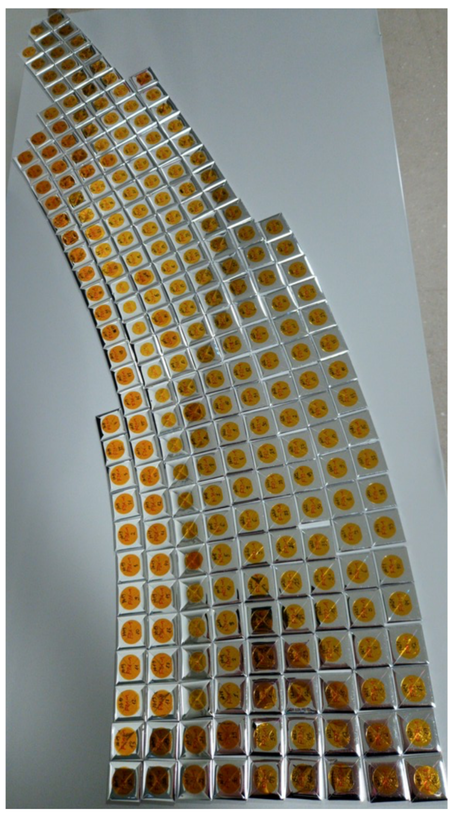
The HGCAL SiPM-on-Tile section

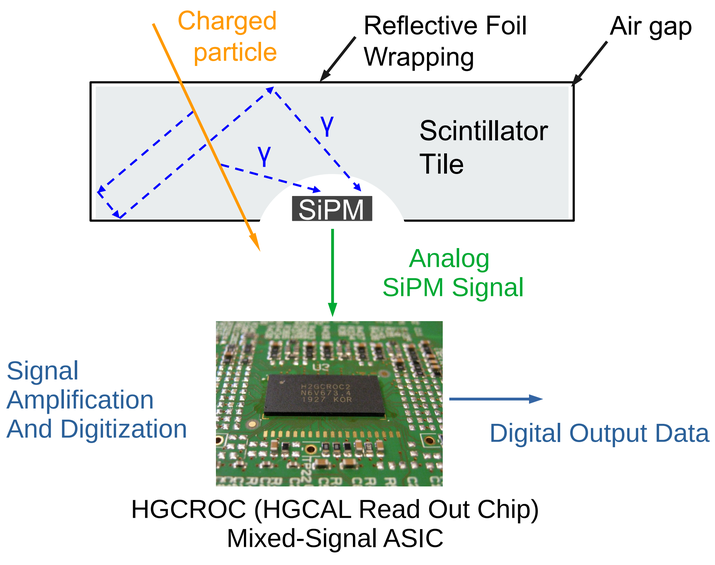
Sensors: the SiPM-on-Tile Technology

Individually wrapped plastic scintillator tiles, **glued on the tileboard** directly on top of SiPM.



1 SiPMs = thousands of single photon avalanche diodes (SPAD) working in Geiger mode.



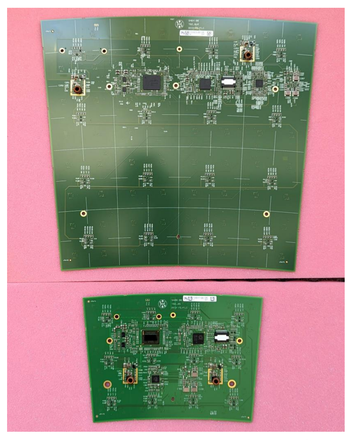


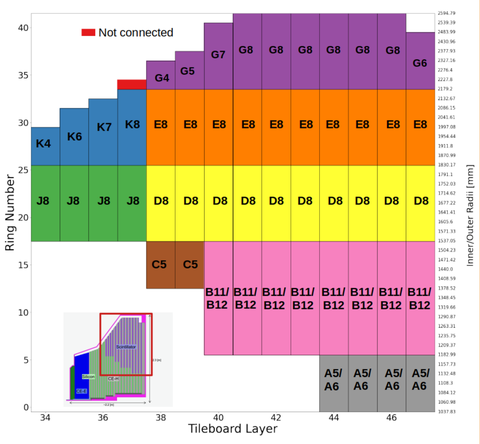
HGCROC (HGCAL Read Out Chip)
Mixed-Signal ASIC

- Tiles are plastic based, **injection moulded or cast**.
- **21 scintillator tile sizes** (23 mm to 55 mm side length).
- All SiPM: 9mm².
- One low intensity **LED for calibration next to each SiPM**.

HGCAL Tilemodules

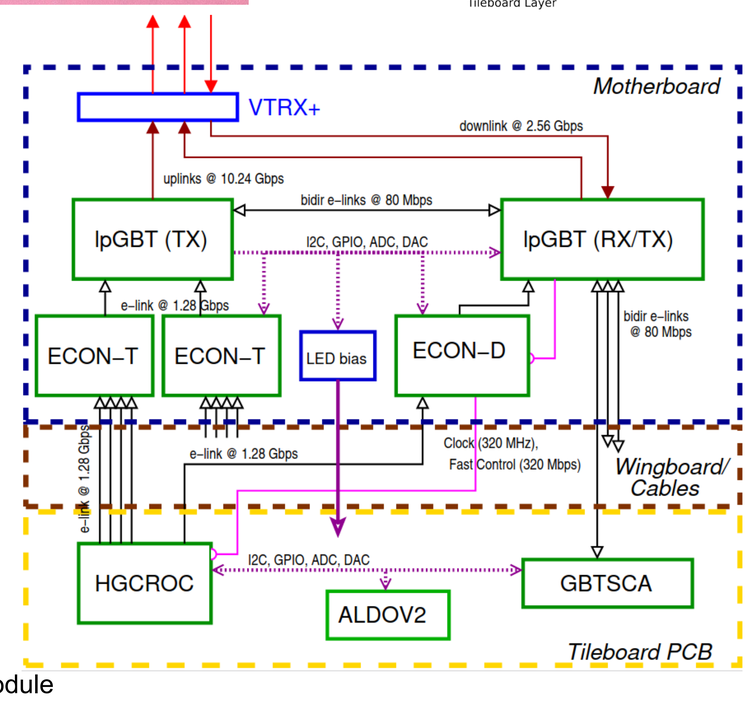
- The basic detector module in the SiPM-on-tile section:
  - PCB,
  - SiPMs + scintilators,
  - HGCROC + front-end electronics.
- **8 main tilemodule types**:
  - Typically 64 channels / board, (up to 108),
  - **~15x20 cm2 up to ~45x45 cm²**,
  - … with **35 variants**.





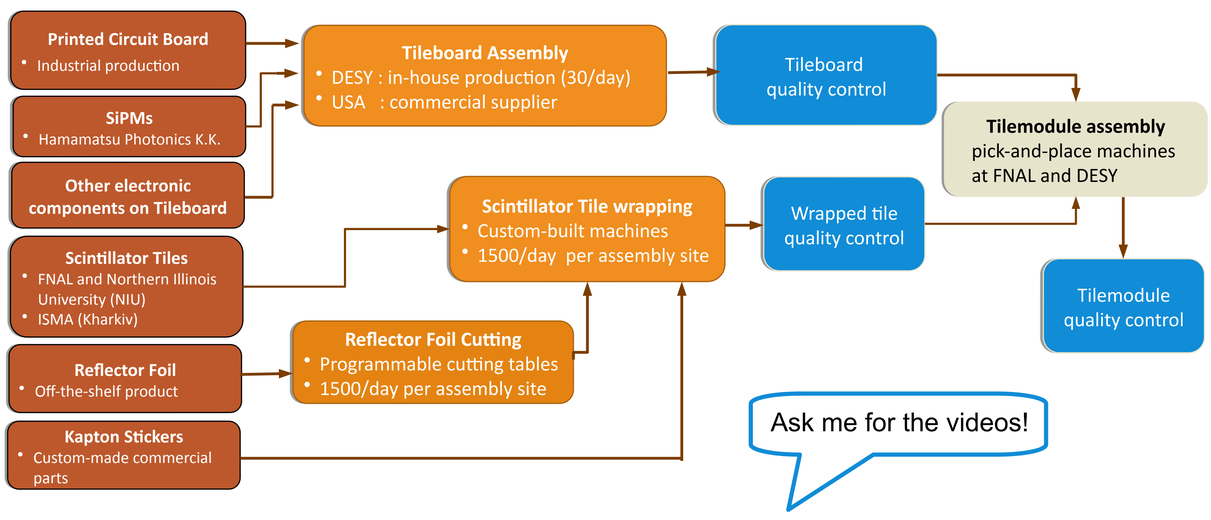
Front-End Electronics

- **VTRx+:**
  - Optically sends and receives signals from the back-end
- **ECON-T:**
  - Receives trigger data from HGCROC
  - Concentrates data and sends to LpGBT
- **ECON-D:**
  - Receives data from HGCROC
  - Concentrates data and sends to LpGBT
- **LpGBT:**
  - Transmits data to back-end via VTRx+
  - Distributes clock, fast commands and configurations to the front-end electronics
- **HGCROC:**
  - Reads out the SiPM-on-tiles on the Tilemodule
  - Up to 72 channels (**1 or 2 per Tilemodule**)
- **GBT-SCA:** Responsible for all slow control tasks on the Tilemodule
- **ALDOV2 :** Voltage regulator chip for SiPMs on the Tilemodule

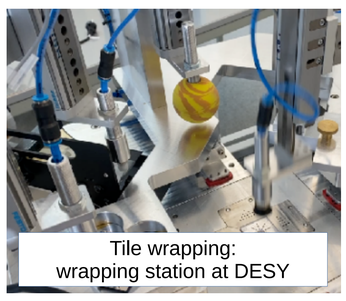


Tilemodule production and assembly

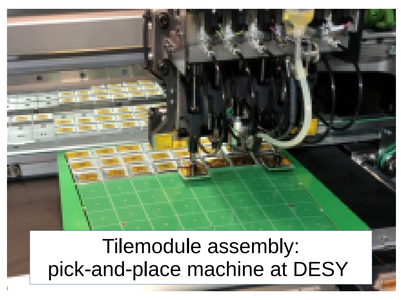
- **Tilemodule production for the final detector to begin this summer!**
- Tilemodules will be produced and assembled at DESY (Hamburg, Germany) and Fermilab (USA).
- Final assembled end-caps to be lowered into the CMS cavern in August 2027



Scintillator tile production (FNAL):
injection-moulded tile production station



Tile wrapping:
wrapping station at DESY

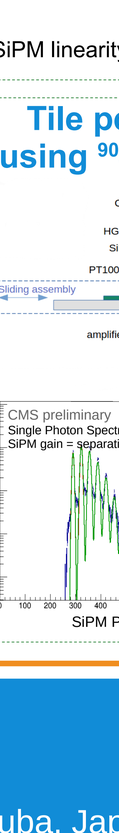


Tilemodule assembly:
pick-and-place machine at DESY

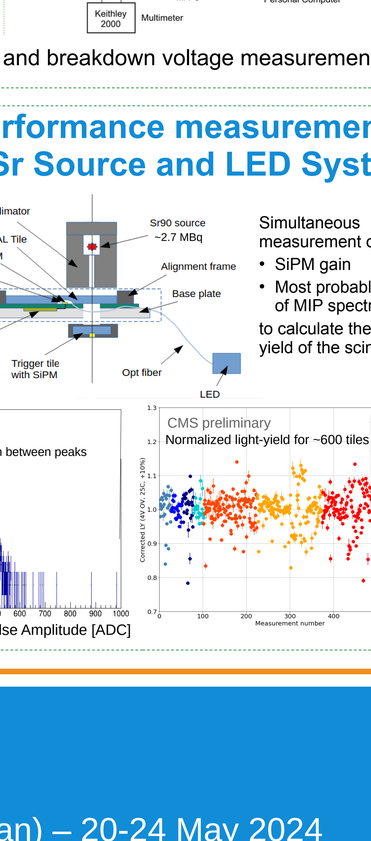
Quality Control

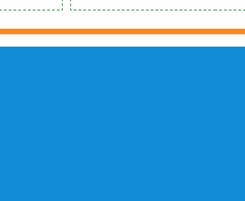
LED based SiPM quality control setups

Setup at NIU (USA)



Setup at CERN





SiPM linearity and breakdown voltage measurement.

Tile size after wrapping

Document scanner 600 dpi
+ OpenCV image software.

Tile performance measurement using ^{90}Sr Source and LED System

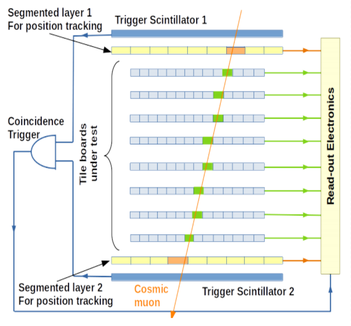
Simultaneous measurement of
- SiPM gain
- Most probable value of MIP spectra

to calculate the light yield of the scintillator.

Cold test in a climate chamber

Thermal cycling of Tilemodules before and after assembly
→ **test 100% modules**.

Cosmic test stand



Performance test of Tilemodules:
- using cosmic muons,
- using onboard LED system.

→ **test 100% modules**.

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