The SiPM-on-Tile Section of the CMS High Granularity Calorimeter

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Overview

- Opportunities and challenges for **hadronic calorimetry at HL-LHC**.
- Key technology: **SiPM-on-tile**, and its application in the CMS endcap upgrade.
- Have to build the final detector soon → **pre-series in 2022**.
Complete exploration of Higgs sector requires high quality jets and MET, as well as efficient isolation of leptons and photons, over the full detector acceptance.

In particular, VBF Higgs production mechanism produces forward jets.

Also jet substructure over a wider $\eta$ range.
Role of hadronic calorimetry at HL-LHC

Good **MET resolution at high pileup** is the critical ingredient in dark matter searches (or studies!)
Role of hadronic calorimetry at HL-LHC

Long-lived particle searches: many models on the market predict LLP decays **deep inside the calorimeter**, enabling novel trigger and reconstruction strategies.
Design considerations

Requirements of the physics program lead us to the choice of **SiPM-on-tile technology** for hadronic calorimeter (CE-H) in the lower radiation regions:

- **SiPM-on-tile technology** allows us to instrument full (~10 λ) depth of detector in a **cost effective** way.

- HL-LHC radiation dose (target up to ~10^{13} neq/cm^2) favors small tiles, and this in turn results in a **high granularity detector** with applications for **particle flow**.

- **High granularity** provides the ability to match individual showers with tracker and timing measurements, thus **reducing the negative effects of high pileup**.

- **Low-noise** photodetectors enable a **calibration strategy based on MIP reconstruction**.
CMS p-p collisions at 7 TeV per beam

1 MeV-neutron equivalent fluence in Silicon at 3000 fb⁻¹
Conceptual design: SiPM-on-tile

Main inspiration from CALICE AHCAL SiPM-on-tile calorimeter:

- Scintillation light from tiles **directly illuminates the SiPM** photodetector underneath. Dimple in tile equalizes response across tile.

- **Reflective wrapping (ESR)** maximizes light reaching the SiPM.

- Detector **inside cold volume** to limit SiPM noise after irradiation.

- Smaller tiles result in more light reaching the SiPM. Tile sizes chosen in order to maintain a **good S/N for MIP calibration** until end of life. Smaller tiles and larger SiPMs used to maximize light collected in the most radiation-damaged areas.
Active area is covered by fan-shaped tile modules.

- Tiles are 1.25 degrees in $\phi$, with smallest tiles towards the inner part of detector where radiation is highest.

- Module PCB hosts the SiPM photodetectors and the HGCROC readout chips plus associated controls.

- Per-channel LED system for commissioning and monitoring.

- Use a standardized list of module types to cover all layers → minimize complexity of module assembly task.
Conceptual design: cassettes

Hadronic layers are assembled from **cassettes which are inserted into slots** in the absorber structure.

- Innermost portion of cassettes use **silicon sensors** for radiation hardness.
- Outer portion of cassettes is covered by **scintillator tile modules**.
- Data and trigger streams from HGCROC are brought to **motherboards** in the outer portion of the cassette.
  - **Concentrator ASICs** merge data from all ROCs in sector.
  - **Electrical-optical conversion** of outgoing signals.
  - Motherboard also distributes **slow control** signals within the sector.
By the numbers

CE-H scintillator system consists:

• **240k** channels (tile + SiPM)
  - Tile size ranges from **4-30 cm²**
  - SiPM size **2, 4, or 9 mm²**

• **3744** tile modules

• **1008** motherboards

• **336** “mixed” cassettes

Large-scale production favors robust and highly repeatable construction strategy → **automation** where possible.
From conceptual design to production

We have pursued a vigorous prototyping program:

- Characterization of scintillator tiles and wrapping methods (optical system performance).
- Performance of SiPMs under CE-H conditions (irradiated).
- **Electronic systems** development.
- Tile module assembly techniques.
- QC procedures & teststands.
Scintillator rad. hardness

Interesting application for plastic scintillators:

- Total dose \(~300\) kRad
- Very low dose rate \((0.1 - 10\) rad/hr)\)
- Low T \((-30\) C)\)

Long, slow, cold irradiation necessary to understand performance → results so far are consistent with our requirements.

Procurement this summer.
Cast vs. molded scintillator

- Cast (and machined) **PVT-based scintillators preferred in front part** of calorimeter, with highest radiation doses, due to higher light output.

- Injection molded **PS-based scintillators preferred for the rest** due to lower cost (and no need for machining).

Working to optimize distribution of **tile types and SiPM sizes** over full detector volume.
SiPMs

240k channels in 2, 4, and 9 mm² sizes.

- In 2022, characterize 4000 devices from HPK.
- Custom packaging (wire bond).
- Benefit from collaboration with CMS MTD (MIP timing detector): QC test stands at CERN well advanced.
- PDE and noise under irradiation well understood.
Optimized detector layout

MIP S/N at EoL ≳ 3
Tileboard electronics

8 basic types (with some sub-variants) needed to cover all layers.

Tileboard “v3” current generation with close-to-final components.

- To be tested on test stands and in beam tests, as previous versions.
- Mini-TB variant for radiation tests.
- Mechanical design of cooling plate coordinated with TB designs.
Tiles & modules - beam tests

![Image of a tile with wires and a label indicating DESY test beam]

**Graph: Light Yield of Tiles at OverVolt: +2V**

- IHEP Cast tile with 4mm² SiPM
- IHEP inj-moulded tile with 4mm² SiPM

**Axes:**
- **X-axis:** Tile edge length [mm]
- **Y-axis:** Light Yield [p.e.]

**Legend:**
- Blue dots: IHEP Cast tile with 4mm² SiPM
- Pink dots: IHEP inj-moulded tile with 4mm² SiPM
QC test stands

- Precision imaging
- Source based

- Gantry
- LED
- Tileboard (pin registered)

- Climate chamber

Diagram:
- Segmented layer 1
  - For position tracking
  - Trigger Scintillator 1
- Coincidence Trigger
- The boards under test
- Read-out Electronics
- Segmented layer 2
  - For position tracking
  - Cosmic muon
  - Trigger Scintillator 2
Summary

SiPM-on-tile offers a **robust and cost effective** technology for hadronic calorimetry at HL-LHC.

Active prototype program **converging on a detailed design**.

Testing out key technologies for detector construction with a focus on **automation and scalability**.