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Scintillator Section of the CMS High Granularity Calorimeter Upgrade (HGCAL)

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For the high luminosity LHC (HL-LHC) phase, the calorimeter end-cap of the CMS detector will be upgraded with a High Granularity Calorimeter (HGCAL). This sampling calorimeter will use silicon sensors and scintillator tiles read out by silicon photomultipliers (SiPMs) as active material (SiPM-on-tile). The complete HGCAL will be operated at $-30\,^{\circ}$C. The primary detector module in the SiPM-on-tile section is the tile module, consisting of a printed circuit board (PCB) with one or two HGCAL Read Out Chips (HGCROC) ASICs, reading up to 144 SiPM-on-tiles. For geometric reasons, the tile modules and the tiles on the tile modules will increase in size with increasing radial distance from the beam pipe. Eight variations of tile modules have been designed to cover the total area of $370\,\mathrm{m}^2$. This includes using two different SiPM sizes and 21 different tile sizes manufactured using two different materials. Production of tile modules for the upgrade is foreseen to start in 2024. An overview of the current status and production plans of the SiPM-on-tile section will be presented in this contribution.

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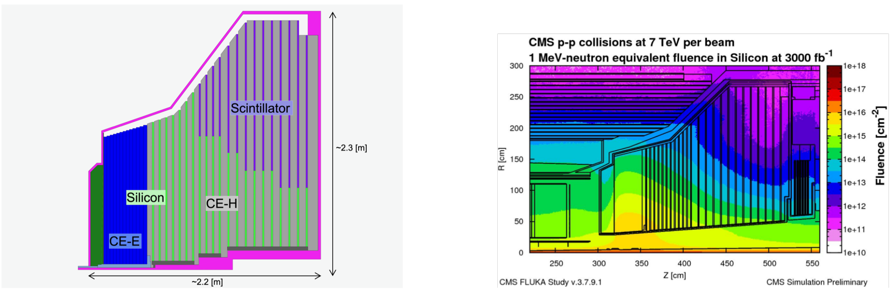
1. Introduction

The CMS HGCAL which will be installed in the HL-LHC will be a novel calorimeter with an unprecedented transverse and longitudinal granularity. As shown in Fig. 1a, the active detectors uses two technologies: hexagonal silicon sensors will be used in areas where the expected neutron fluence at end-of-life is above $5 \times 10^{13}\ n_{eq}/cm^2$ (see Fig. 1b), covering the entire electromagnetic and part of the hadronic calorimeters; and trapezoidal scintillator tiles individually wrapped and placed on SiPMs (SiPM-on-tiles) will be used in the rest of the hadronic calorimeter. Both detector systems are designed to have a signal-to-noise ratio of >3 for minimum ionising particles throughout the detector's lifetime [1]. The scintillator part of the detector was inspired by the CALICE AHCAL [2], a prototype of which was successfully operated in a combined beam test [3] together with a prototype of the silicon section of the HGCAL.



(a) **(b)**

Figure 1: (a) shows a schematic view of the CMS high granularity end-cap calorimeter [4]. (b) shows the expected 1 MeV equivalent neutron fluence in silicon obtained from FLUKA studies at the end-of-life [1].

2. The Scintillator Section of the CMS HGCAL

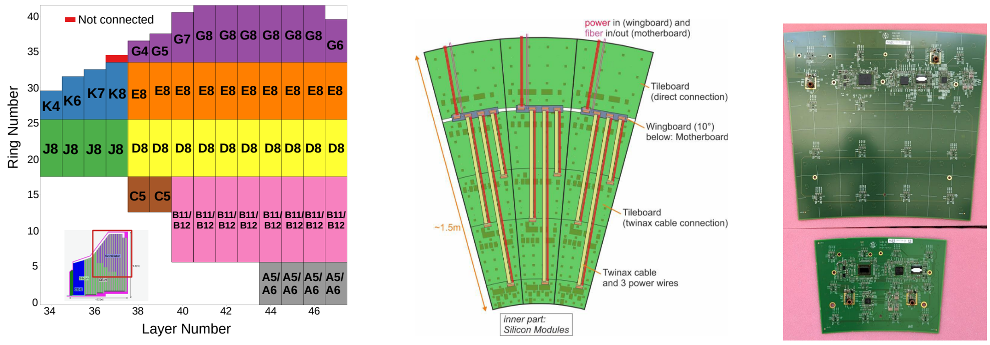
The scintillator section, features 21 different scintillator tiles with areas ranging from $4\,cm^2$ to $32\,cm^2$, covering a total area of approximately $370\,m^2$ out of the HGCAL's $1000\,m^2$ area. These scintillator tiles are coupled with novel HDR-2 SiPMs (S14160 series [5]) produced by Hamamatsu Photonics K.K. (HPK) with a pitch size of 15 µm and active areas of $2 \times 2\,mm^2$ and $3 \times 3\,mm^2$. These SiPMs contain custom-made radiation-hard packaging with an improved thermal contact for the HGCAL upgrade.

Signals from up to 72 SiPMs can be simultaneously read by the HGCROC readout ASIC at the 40 MHz LHC collision frequency. The HGCROC amplifies and digitises the signal, converting it to an ADC or time-over-threshold (TOT) value. It also provides a timing measurement in terms of a time-of-arrival (TOA) value to aid pileup reduction.

2.1 HGCAL Tile Modules

The tile module is a comprehensive component, consists of the PCB, HGCROC, SiPM-on-tiles, LED system for calibrations and all other onboard electronics. The exact number of detector channels can vary between 40 and 144 for the different board sizes, with most of them having 64 detector channels or less. Eight primary geometries of tile modules (labelled A to K, in Fig. 2a) and

35 variants cover the area of the detector. Up to five tile modules placed radially from the beamline form a basic 10 ° detector unit. Three sectors are sketched in Fig. 2b and in Fig. 2c two tile modules are shown.



(a) **(b)** **(c)**

Figure 2: (a) shows the base layout of tile module geometry in a 10 ° sector to be used in the HGCAL. The letter symbolises the tile module type, and the number refers to the number of rings in the tile module. (b) shows the top view of a 30 ° sector showing only the scintillator tile modules [6]. (c) shows the largest tile module (G8) (top) and the smallest tile modules (A5) (bottom) placed next to each other.

2.2 Front-End Electronics

In the CMS HGCAL, most tile modules utilize a single HGCROC, with B-type tileboards housing two HGCROCs. Within a basic 10 ° detector unit, a single connector is used to transmit signals to and from the tile modules, as well as providing power, as shown in Fig. 2b. Twin-axial cables communicate between the tile modules in a 10 ° sector and the motherboard via an intermediary board known as a wingboard. Information from each HGCROC is sent via two data e-links (at 1.28 Gbps each) and four trigger e-links (at 1.28 Gbps each) to an ECON-D (data) and two ECON-Ts (trigger) concentrator chips on the motherboard respectively. The ECON-D performs a zero suppression and concentration of the data from the HGCROCs before transmitting the data at rates up to 1.28 Gbps. The ECON-Ts, which obtain trigger information from the HGCROCs, select and compress interesting HGCROC trigger data according to preprogrammed trigger algorithms in real-time and transmit this data at rates up to 1.28 Gbps.

Data from the ECON-D is collected at one Low Power GigaBit Transceiver (LpGBT) ASIC [7], while the data from the two ECON-Ts are collected at the second LpGBT ASIC. The information is sent to the back-end via the VTRx+ chip [8], which optically transmits the data via fibres to the back-end DAQ FPGA in the service cavern. The back-end generates the Level 1 (L1) trigger, which, along with the 320 MHz clock and the slow and fast commands are sent via the VTRx+ to one of the LpGBTs that distributes it to the rest of the front-end electronics.

3. Tile Module Production, Assembly and Quality Control

Tile module production for the final detector is scheduled to begin in 2024. The final assembled end-caps will be lowered into the CMS cavern in August 2027. Shown in Fig. 3 is the workflow diagram for the tile module production.

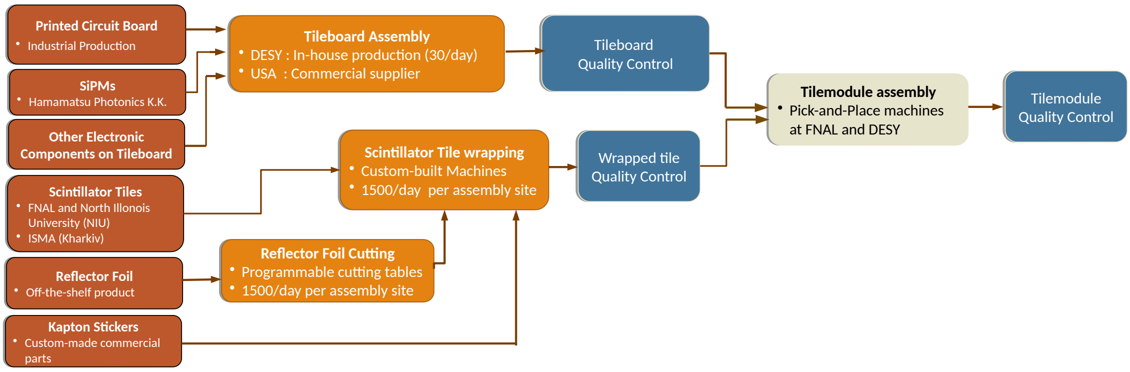
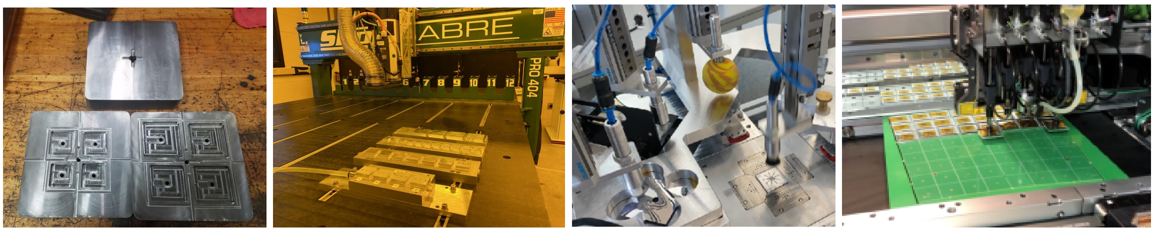


Figure 3: CMS HGCAL tile module production workflow [9]. tile modules before scintillators are installed are typically called as Tileboards.

The scintillator tiles will be produced at three primary locations. The polystyrene-based tiles will be produced via injection-moulding at the Fermi National Laboratory (FNAL) and the Poly-Vinyl-Toluene (PVT)-based BC-412 tiles [10] will be machined at North Illinois University (NIU) and the Institute for Scintillator Material (ISMA) in Kharkiv. Omega Microelectronics will produce the HGCROCs, and all other components will be bought from CERN and commercial vendors. The tile modules will be produced and assembled at DESY, Hamburg and at FNAL. Dedicated stations will wrap the scintillator tiles with reflective foil, and pick-and-place machines will assemble the final tile module with scintillator tiles. Some of the machinery which will be used in the production are shown in Fig. 4.



(a) **(b)** **(c)** **(d)**

Figure 4: Four systems used in the production and assembly line. (a) shows the moulds used for the production of polystyrene-based injection-moulded scintillator tiles at FNAL [11]. (b) shows the machine at FNAL which will be used to cut the PVT-based tiles into shape [11]. (c) shows the tile wrapping station at DESY. (d) shows the pick-and-place machine used at DESY.

There will be multiple test stands to monitor the production quality throughout the production process. The tile modules before and after assembly with the scintillators will undergo thermal cycling in dedicated climate chambers at DESY and FNAL (see Fig. 5c). Some of the SiPMs will undergo performance tests at both NIU and CERN (see Fig. 6). Once wrapped in reflective foil, the scintillator tiles will undergo tests to ensure the dimensions are within the required limits (see Figs. 5a and 5b). They will then be tested using Strontium-90-based setups at DESY and CERN to ensure their performance is within 10 % of the expected value (see Fig. 7). A cosmic ray test stand will be used to determine the overall quality of the fully assembled tile modules (see Fig. 5d).

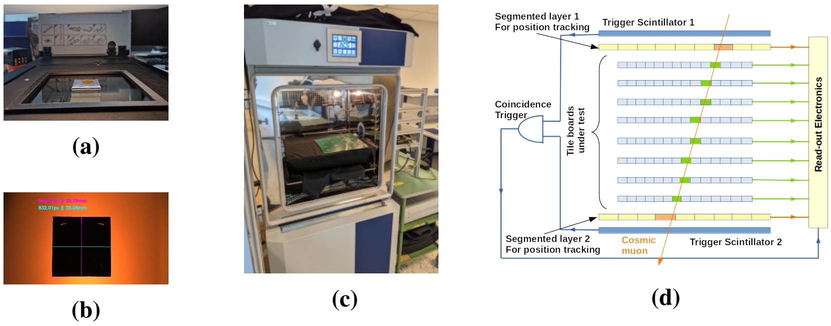


Figure 5: Three setups used for the quality control is shown here. (a) shows the scanning setup used at DESY to measure the tile sizes after wrapping in foil with one exemplary tile scan shown in (b) [12]. (c) shows a climate chamber at DESY which will be used for the thermal cycling of the PCB and fully equipped tile modules. (d) shows the sketch of a (conceptual) cosmic test stand for tile modules to be used at DESY.

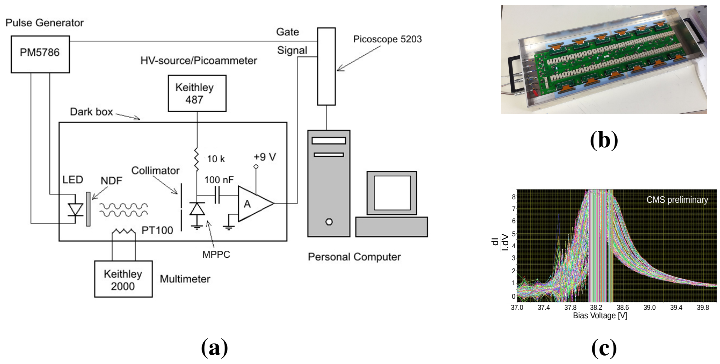


Figure 6: (a) shows a schematic of the SiPM quality control setup at CERN [13]. (b) is an array of SiPMs tested with this system. (c) shows the breakdown voltages measured.

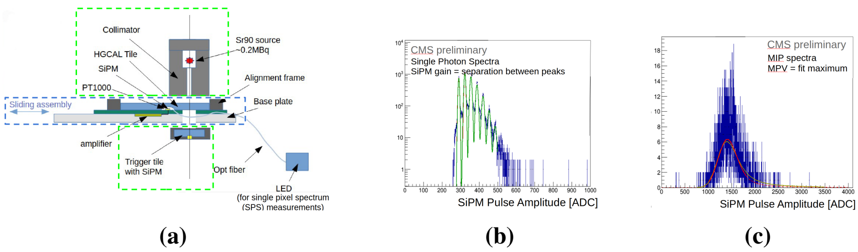


Figure 7: (a) shows the Strontium-90-based setup for scintillator quality control at DESY and CERN [14]. (b) shows a single-photon spectra from the SiPM and (c) shows a MIP peak obtained from a Scintillator under test.

4. Summary

The tile module has been designed to host the SiPMs, scintillators, HGCROC and all other electronics for the scintillator section of the HGCAL. With the final detector layout being finalised, the production of the components will start in 2024. The machinery needed for production and test stands for quality control have been designed and are in place. The final assembled end-caps will be lowered into the CMS cavern in August 2027.

References

[1] CMS Collaboration. *The Phase-2 Upgrade of the CMS Endcap Calorimeter*. techreport, CERN, Geneva, 2017. URL: http://cds.cern.ch/record/2293646

[2] Felix Sefkow and Frank Simon. *A highly granular SiPM-on-tile calorimeter prototype*. J. Phys. Conf. Ser., 1162(1):012012, 2019. DOI: 10.1088/1742-6596/1162/1/012012.

[3] B. Acar et al., *Performance of the CMS High Granularity Calorimeter prototype to charged pion beams of 20-300 GeV/c*, Journal of Instrumentation, 2023, 18 P08014, DOI: 10.1088/1748-0221/18/08/P08014

[4] David Barney. *Overview slide of CE with main parameters*, 2022. URL: https://cms-docdb.cern.ch/cgi-bin/PublicDocDB/ShowDocument?docid=13251 [Accessed Date: 5th September 2023]

[5] Hamamatsu Photonics K.K. *MPPC S14160 Series Specification Sheet*. Hamamatsu Photonics K.K., August 2018

[6] M. Reinecke et al., *CMS HGCAL - Scintillator detector's LV and BV powering requirements*. Technical report, CMS Collaboration, 2023.

[7] lpGBT Team, *LpGBT-FPGA Documentation*, CERN, 2023, URL: http://lpgbt-fpga.web.cern.ch/doc/html, [Accessed Date: 10th October 2023].

[8] J. Troska et al., *The VTRx+, an Optical Link Module for Data Transmission at HL-LHC*, 2018. DOI:10.22323/1.313.0048.

[9] Felix Sefkow, *Scintillator Tile Module Production Readiness Review*. Internal Communications, 2023.

[10] Saint Gobain Crystals. *BC-400,BC-404,BC-408,BC-412,BC-416 Premium Plastic Scintillator datasheet*. Saint-Gobain Crystals, 2018.

[11] Vishnu Zutshi et al., *Tile Production: Molded and Machined*, Internal Communications, 2023

[12] Daria Selivanova et al., *Quality Control of Wrapped Scintillator Tile Sizes*, Internal Communications, 2023

[13] Y. Musienko et al., *SiPM Quality Control Setup at CERN*. Internal Communications, 2023.

[14] A. Kaminskiy et al. *Tile Light Yield Measurements at DESY*. Internal Communications, 2022.