Testing of Pre-Series Tile Modules at DESY II for the CMS HGCAL Upgrade

Test Beam at DESY in March 2023

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19 April 2023

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CMS

FTX

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Outline

About this talk

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- High Granularity Calorimeter (HGCAL)
- SiPM-on-tile technology and the Tilemodule
- Mini Tileboard

02 Test beam at DESY in March 2023

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- Light yield comparison

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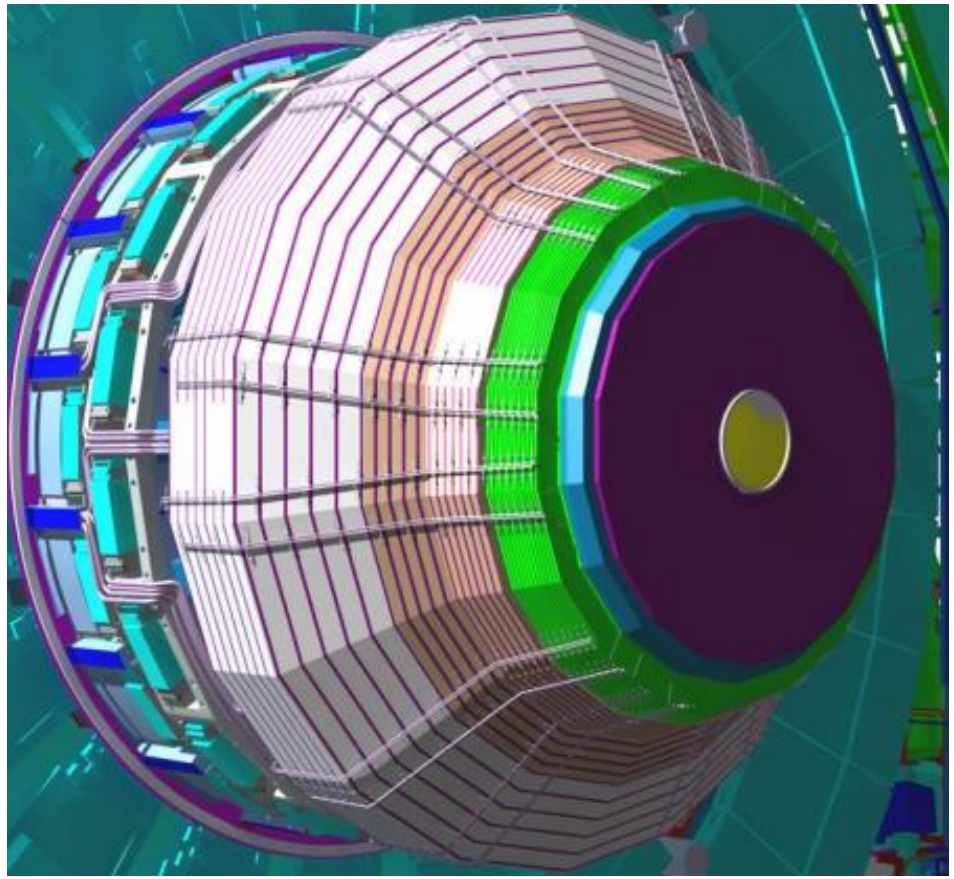
Introduction

High Granularity Calorimeter (HGCAL)

What is HGCAL. Basic structure and purpose.

What is HGCAL, and why do we need it

- Designed for the **replacement of the current endcap** of the CMS detector in **HL-LHC**.
- It's a **5-D calorimeter** which can measure energy deposition, time, and shower shape.
- It is designed to cope with the larger number of interactions per bunch crossing (**event pileup**) and **higher radiation dose** in HL-LHC.

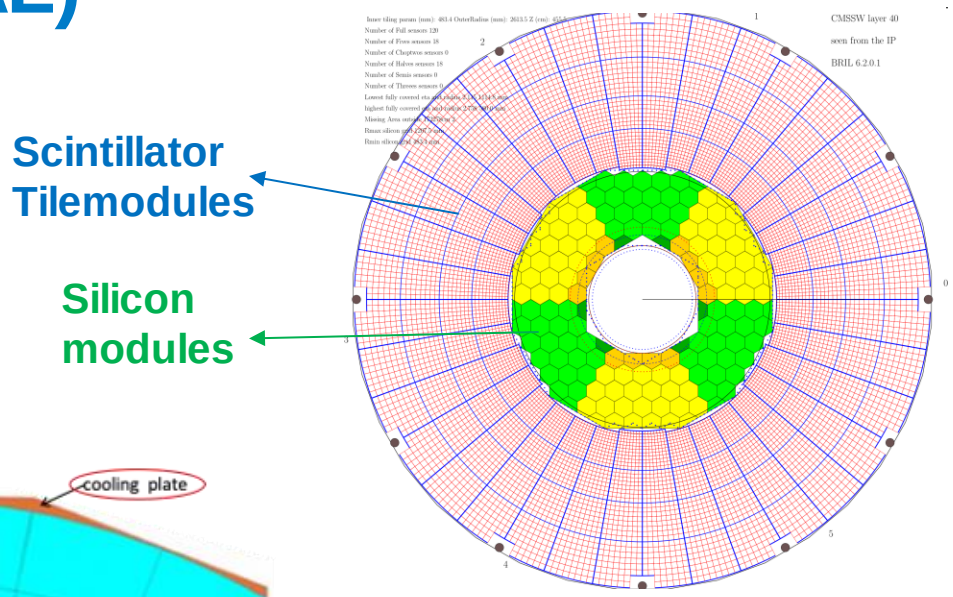


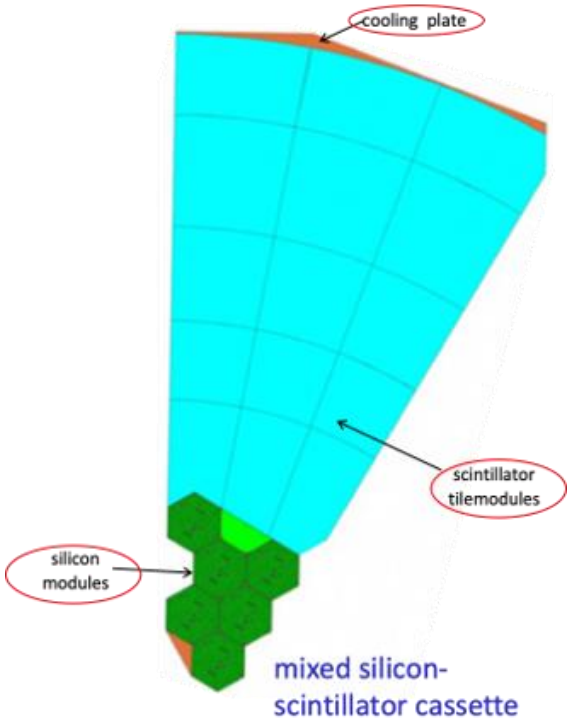
High Granularity Calorimeter (HGCAL)

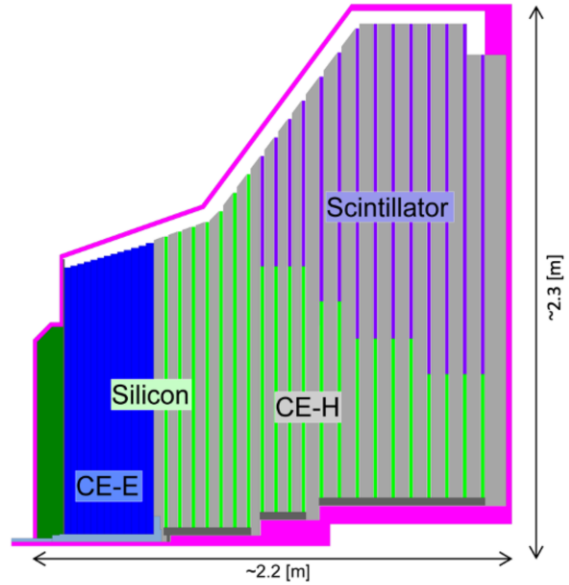
What is HGCAL. Basic structure and purpose.

The basic structure of the HGCAL

- Silicon section (using silicon sensors): Cover the electromagnetic calorimeter (CE-E) and part of the Hadronic calorimeter (CE-H)
- **Scintillator section (using SiPM-on-tile technology)**: Cover the CE-H where the expected end-of-life neutron fluence is less than 5×10^{13} n/cm^2





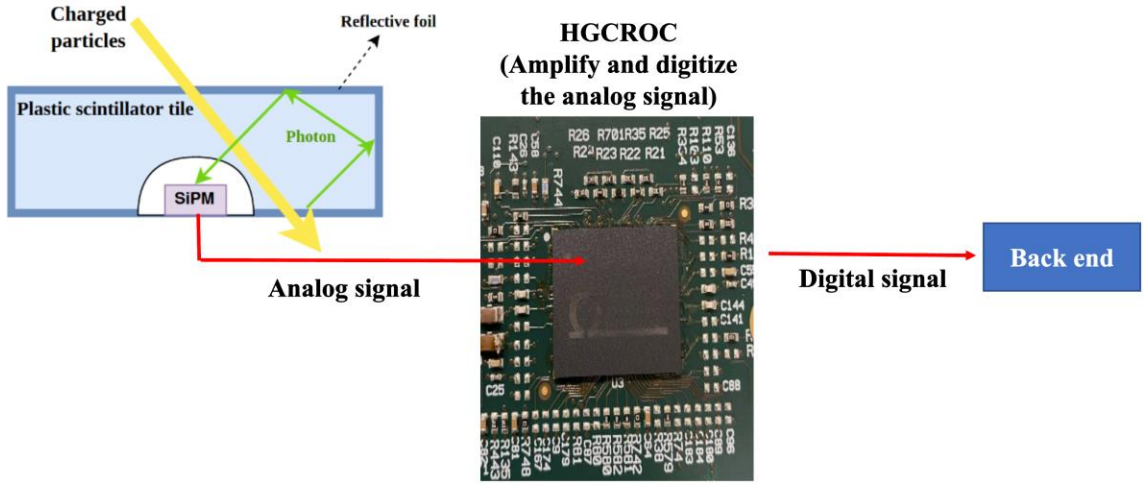


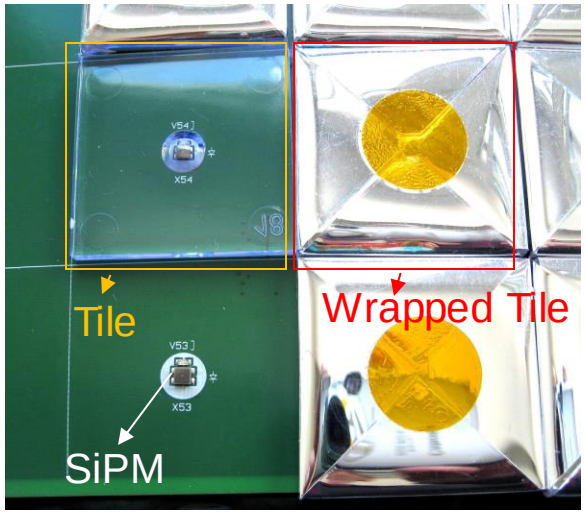
SiPM-on-tile technology in the scintillator section of HGCAL

Components, readout system

Components and readout system

- The SiPM-on-tiles include **wrapped plastic scintillator tiles** and **silicon photomultiplier (SiPM)**
- Tiles are wrapped in reflective foil.
- SiPM can detect photons from the tiles.
- Analogue signals from the SiPM are collected by a readout chip, HGCROC.





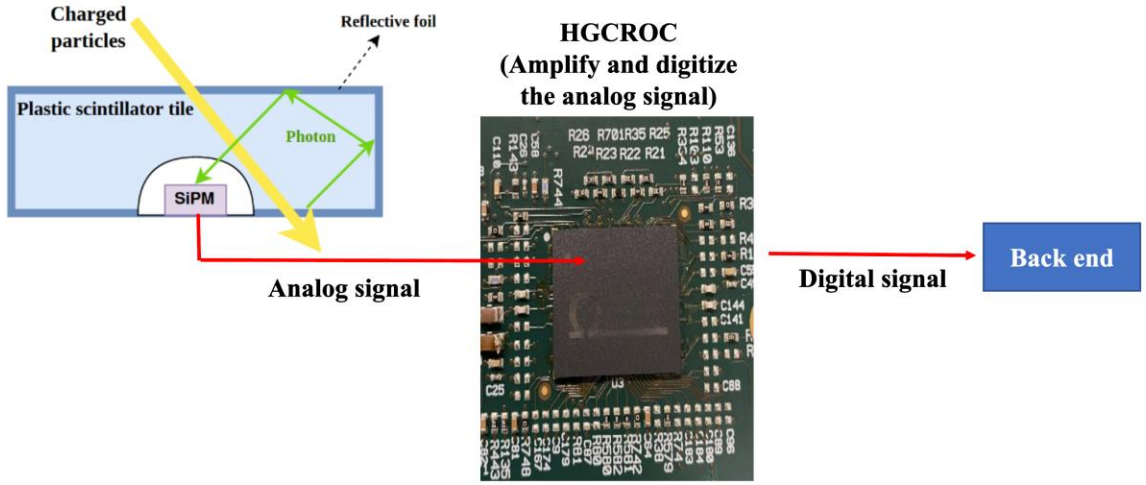
SiPM-on-tile technology in the scintillator section of HGCAL

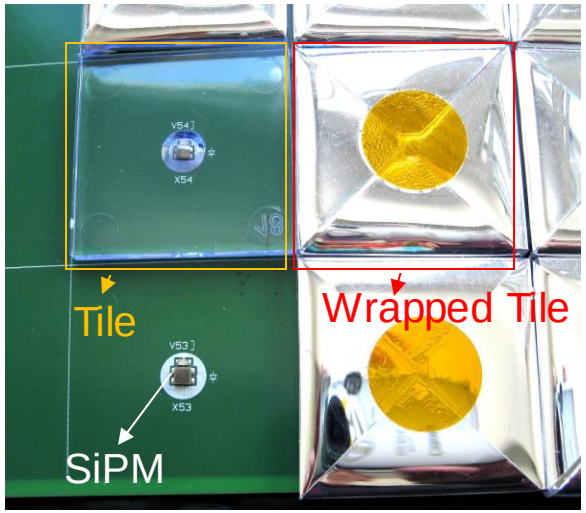
Components, readout system

Tiles and SiPMs to be examined

- There are 21 different sizes of tiles in 2 different materials.
- 2 different sizes of SiPM (4 mm² and 9 mm²)

To decide which type of tiles and SiPMs have the better performance to be used in the HGCAL. We need to do test beam for measuring and comparing the light yield.

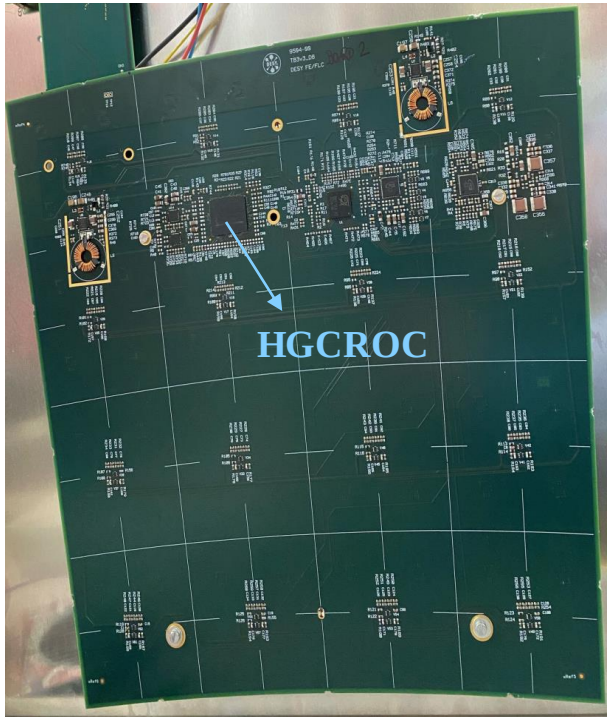


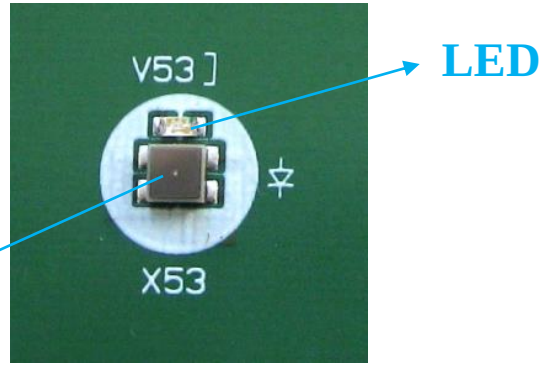


Tilemodule with SiPM-on-tile technology

Components of a Tilemodule

- A complete **Tilemodule** is a **basic unit** for particle detection in the **scintillator section** of the HGCAL.
- The Tilemodule includes wrapped scintillator tiles, SiPMs, HGCROC, LED calibration system, and other electronics.
- The HGCROC **readout 64 channels** from the Tilemodule.
- The HGCROC has **2 DAQ elinks** and **4 trigger elinks** (1.28 Gbps/elink) for **data readback**.



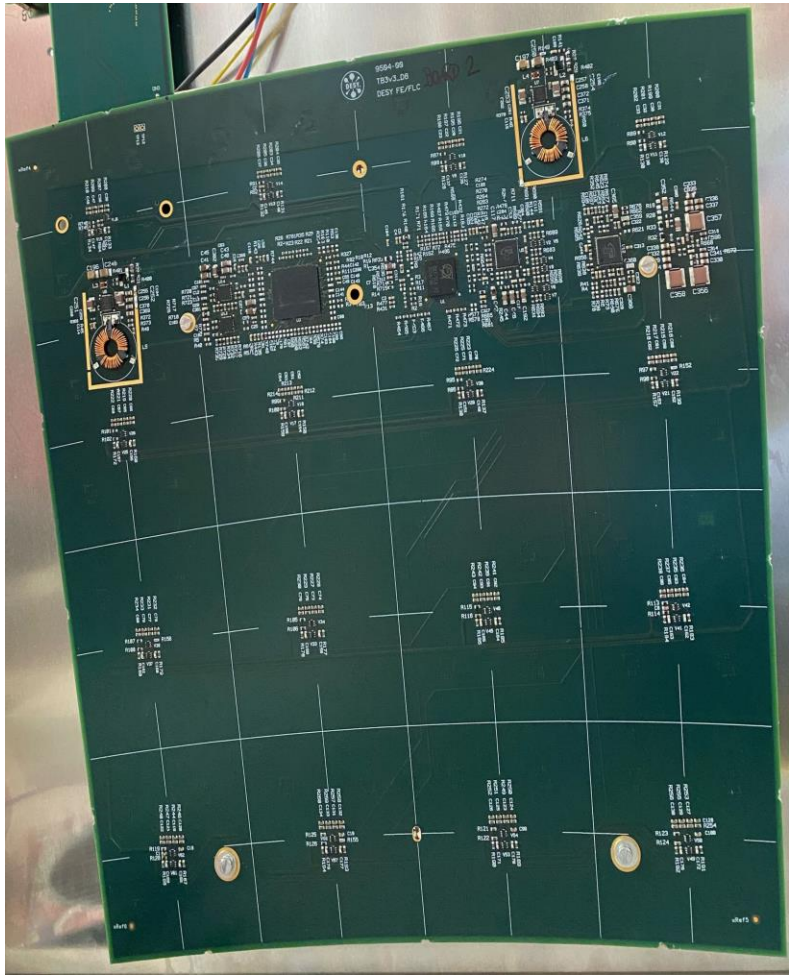


Features of Tilemodule v3 with HGCROC v3

Advantages of Tilemodule v3

Tilemodule v3

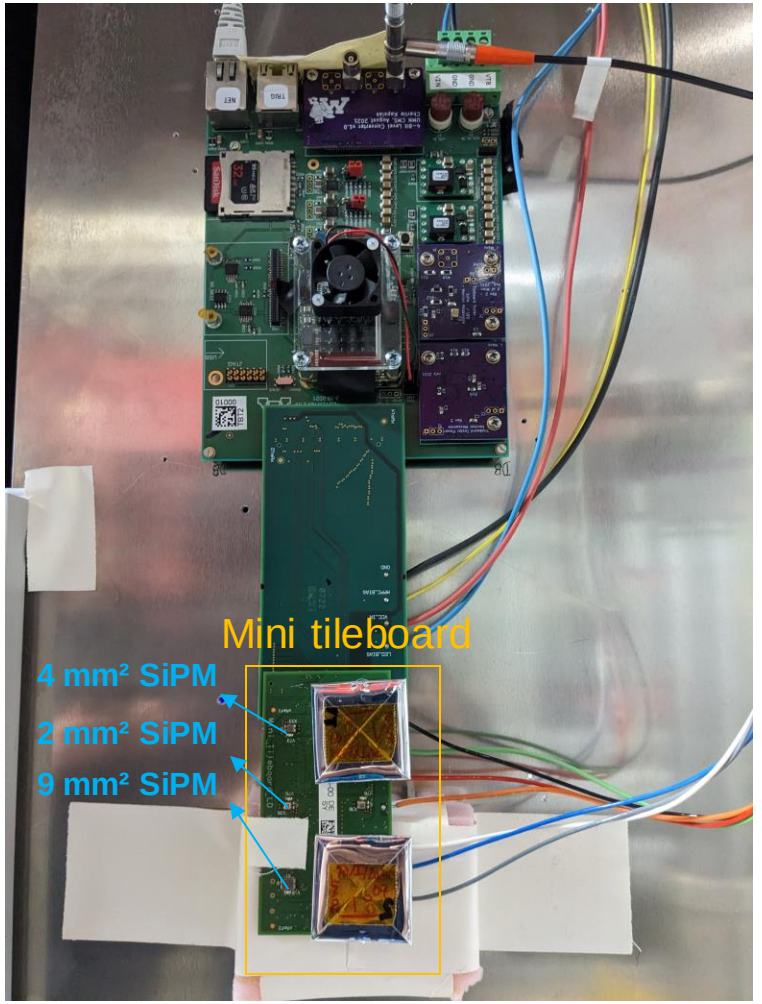
- Is the latest tileboard generation and is **very similar to the final version used in the HGCAL.**
- **Will be used in the pre-series test**, including all quality control and quality assurance steps.
- Equipped with **SiPM** which has the **latest radiation hard package** and is **foreseen to be used in the final experiment.**



Mini Tileboard

Components of a Mini Tileboard

- The mini Tileboard contains **6 SiPM channels**, **LED system**, **HGCROC**, and **slow control chip**.
- As it **does not have any power regulators**, all power are supplied externally.



Main motivation

- The **size** of the mini Tileboard **can fit into most of the standard tubes used at irradiation facilities.**
  - **This allows us to test the radiation hardness of the whole module**.

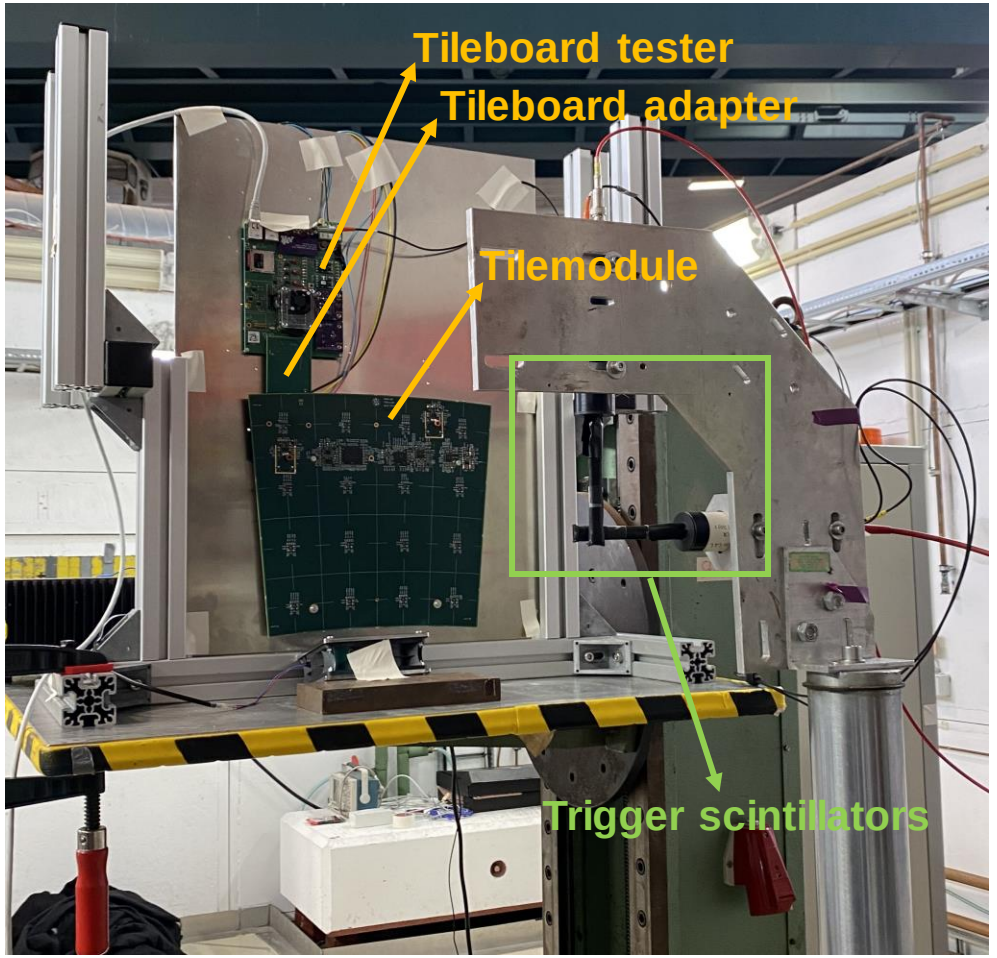
Test beam at DESY in March 2023

Objective and data taking of the Test beam

Test beam setup and goal

The goal of the test beam

- Test and **measure** the **performance** from **all channels** on the **two v3 Tilemodules**.
- Test and **measure** the **performance** from channels with **9 mm²** and **4 mm² SiPM** on the **mini Tileboard**. Compare the difference in light yield between 9 and 4 mm² SiPM
- **Compare** the **performance** measured from **different sizes** of **SiPM** and **different sizes** and **materials** of **tiles** to decide which one has a better performance.



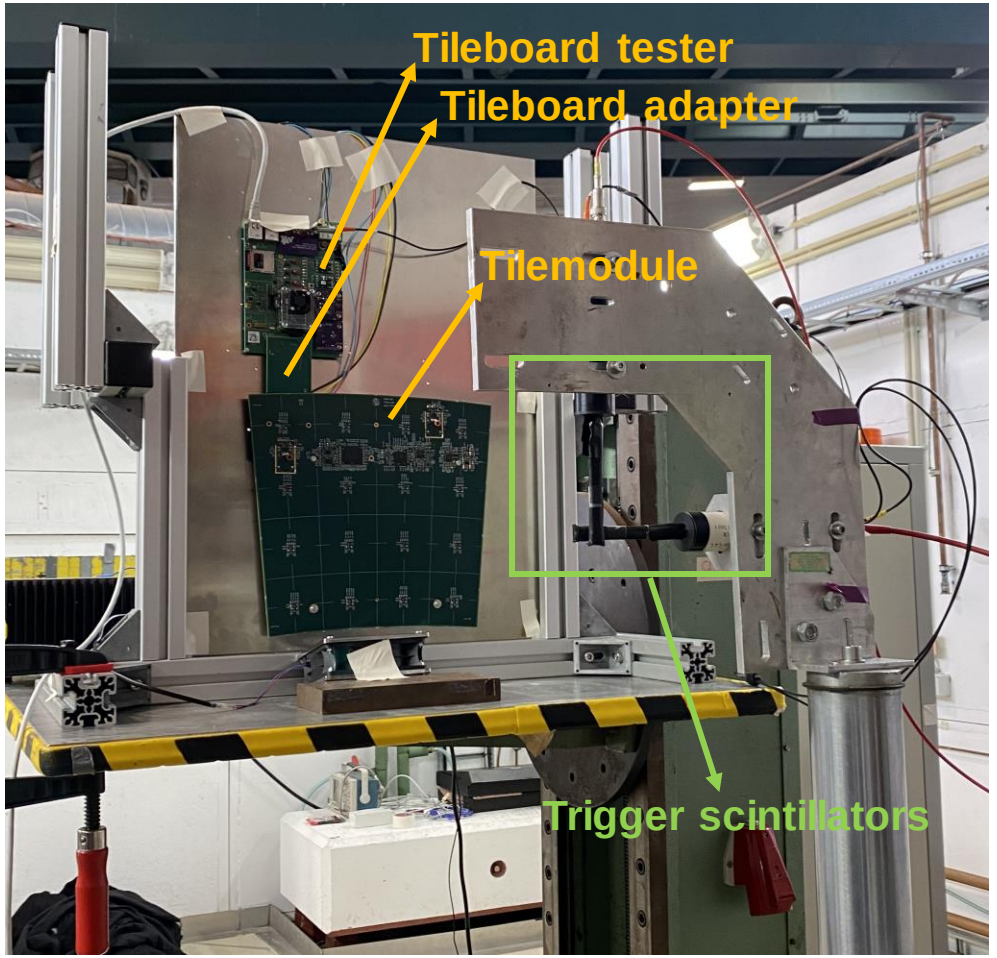
Objective and data taking of the Test beam

Test beam setup and goal

Data taking

- Measure **MIP spectrum** by taking **100,000 events per channel** with **3 GeV electron beam**.
  - Signal responses from 3 GeV electrons are very similar to Minimum Ionizing Particles (MIPs)
  - Has been verified with muon beams of 120 GeV energy at CERN SPS

- Using the on-board LED system to measure single photon spectrum (**SPS**) by taking **3,000 events per channel.**



Modules tested in the test beam

Two type of module were tested in the test beam

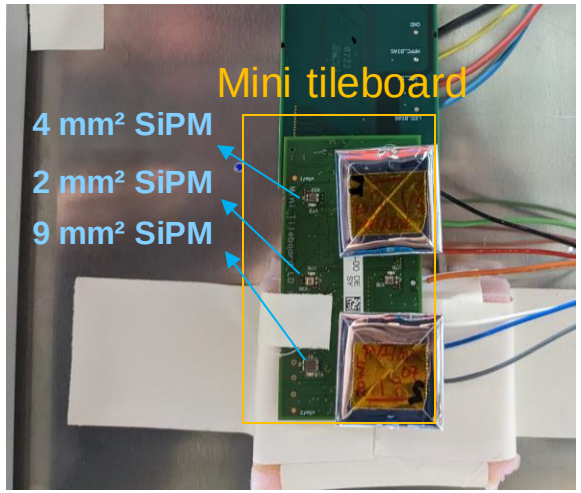
- **Tilemodules**

TB3 board 1
equipped with **moulded tiles Batch 1**
with pre-series 4mm² SiPMs

TB3 board 2
equipped with **moulded tiles Batch 2**
with pre-series 4mm² SiPMs

The **tiles equipped** here are **produced by** the **institute expected to make the final tiles** for HGCAL.

- **Mini Tileboard**



Mini Tileboard
equipped with **IHEP v2 tiles**

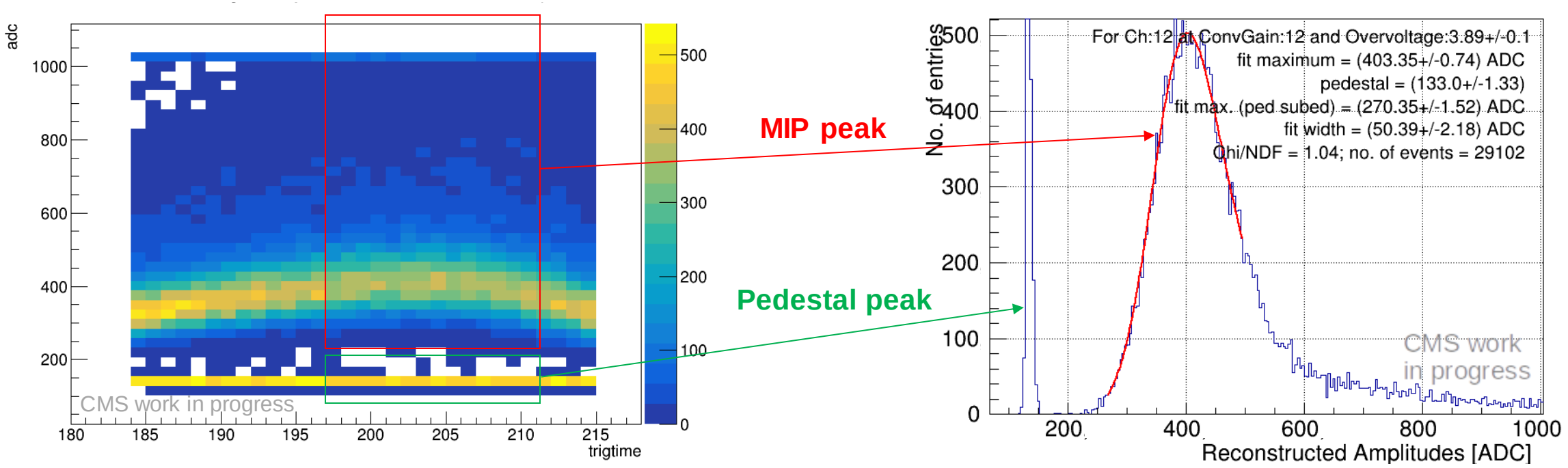
with pre-series
4mm² SiPMs and
9mm² SiPMs

- All Tilemodules use a custom-made DAQ system which is driven by Zynq FPGA for data acquisition.

Using pulse shape and trigger information for MIP extraction

Time selection for MIP signal

- The plot on the bottom left is the analogue SiPM signal (in ADC) received by the HGCROC with respect to the time when the HGCROC receive a trigger signal from the backend.
- The MIP spectrum can be found by selecting a time window which capture the peak of the SiPM signals.



Parameter definition of the MIP and SPS spectrum

The targeted parameters measured in the test beam

- **MIP maximum:**

  The **MIP maximum** can be obtained by measuring the **peak** value of the MIP spectrum and then **subtracting the pedestal**.

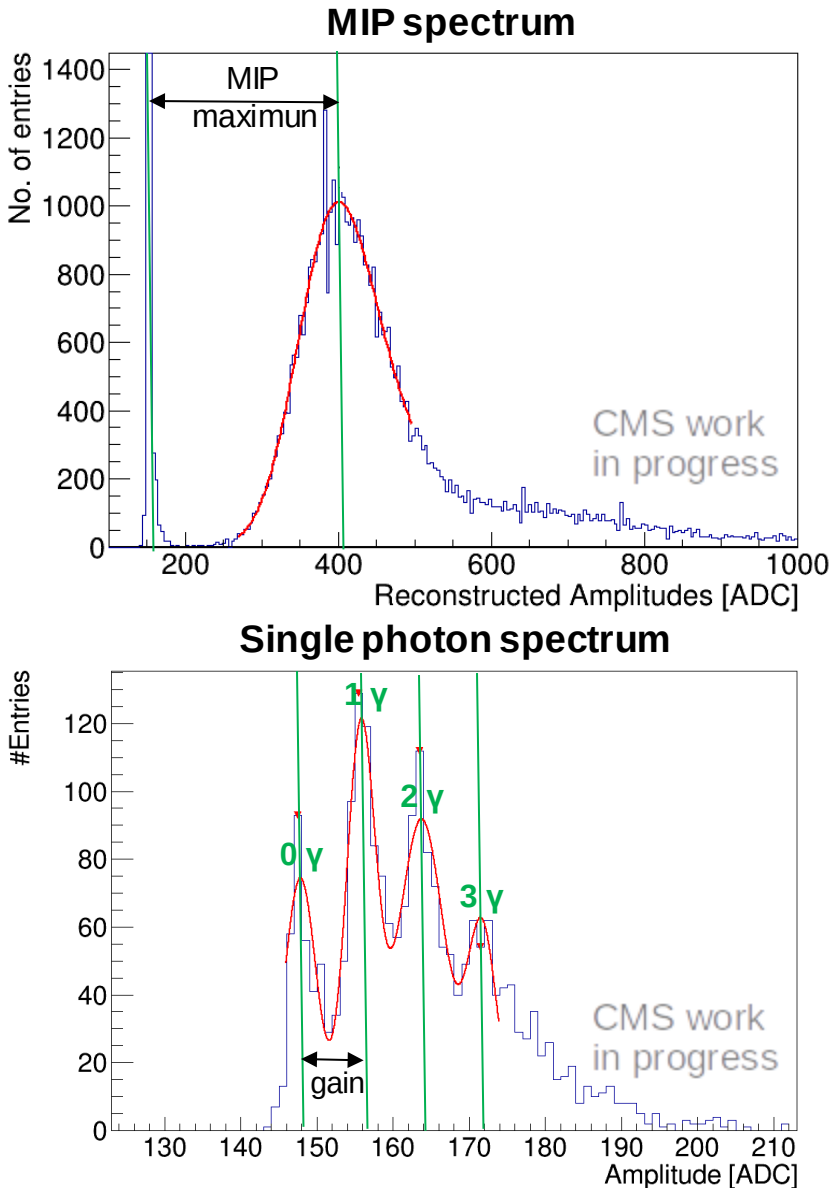
- **SiPM gain:**

  - The **distance between two consecutive peaks** in the single photon spectrum (SPS) is the **SiPM gain.**

- The **SPS** can be obtained for **all channels** using the **onboard LED system**. And the **SiPM gain** can then be measured from these SPS.

- **The definition of light yield is**

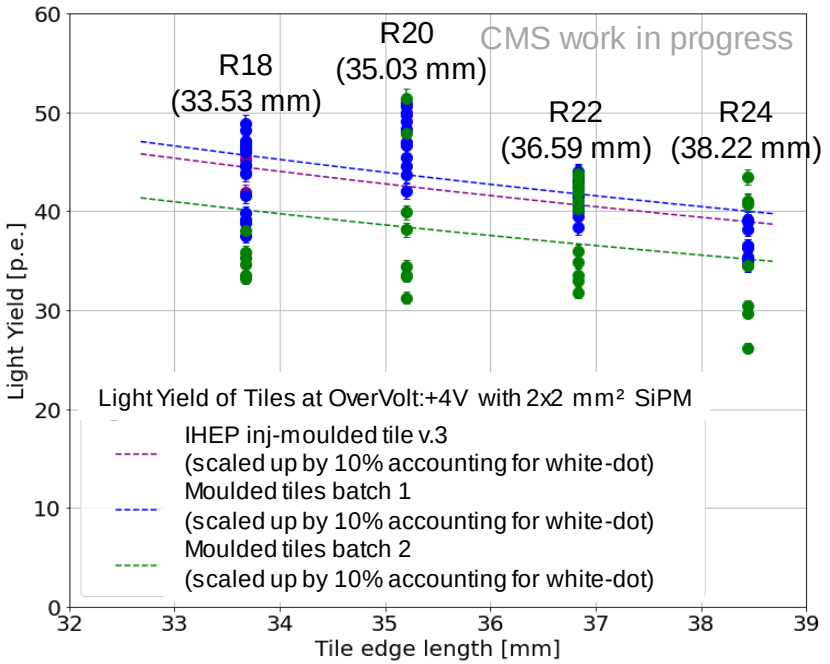
$$Light\ Yield\,[p.e.] = \frac{MIP\ maxima\,[ADC]}{SiPM\ gain\,[ADC]}$$



Light yield comparison with different tiles

Compare light yield measured from different type and size of tiles

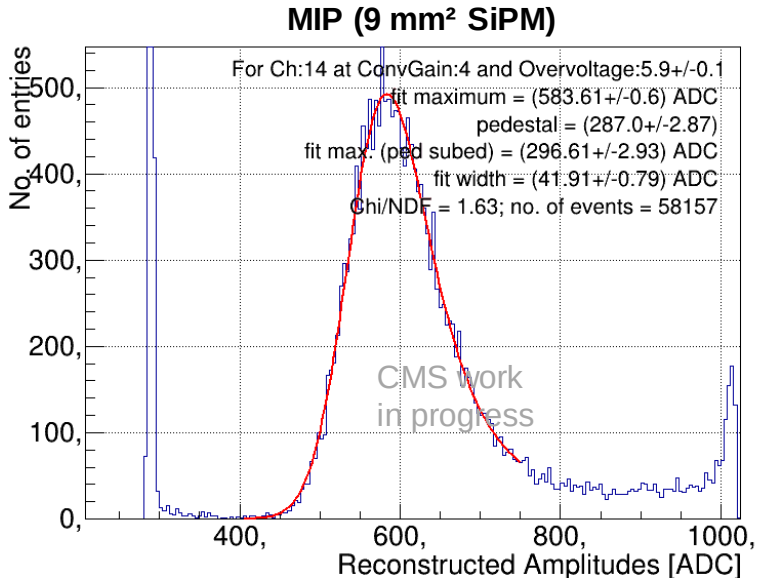
- The **moulded tiles batch 1** (made by the current producer) has a **light yield close to** the **IHEP inj-moulded tile v.3** (made by the previous producer, not available for tile production anymore).
- There are **4 different size of tiles** on the Tilemodule tested.
  - 33.53 mm (R18), 35.03 mm (R20), 36.59 mm (R22), 38.22 mm (R24) side lengths.
- The two **moulded tile batches** use different **material compositions**. **Further investigation** is needed to understand the **differences** between these **two batches**.
- Light yield is inversely proportional to the squared root of the tile area, so **smaller tiles have a larger light yield**.

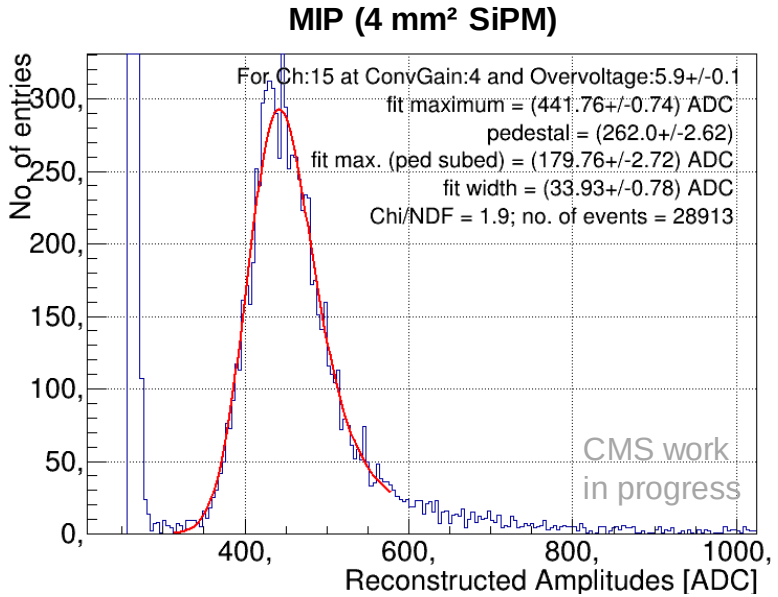


Light yield and MIP spectrum measurement for Mini Tileboard

Measurement for 4 mm² and 9 mm² SiPM

- Measure the **MIP** spectrum for **4 mm²** and **9 mm²** **SiPM** on the **mini Tileboard** with the same configuration and same type of tile (IHEP inj-molded v.2 tile).
- The **MIP maximum** for the **9 mm² SiPM** is **larger than** the **4 mm² SiPM**
- Apply **correction** to the **light yield** measured from 4 mm² and 9 mm² SiPM in Mini Tileboard
  - temperature correction (25°C)
  - over voltage correction (6 V)
- The **light yield** for **4 mm²** SiPM is **46.6 p.e**.
- The **light yield** for **9 mm²** SiPM is **106.8 p.e**.
- The **ratio** between 9 and 4 mm² SiPM is **2.29**, which is **close to the expected ratio**, of **2.25 (estimated from the size of the two SiPMs)**.



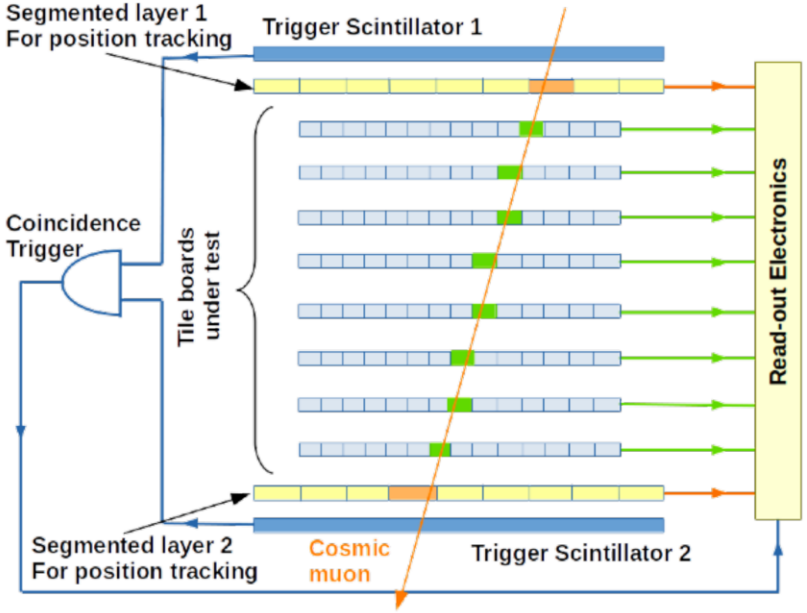


Outlook and Summary

Outlook

Plan for the next steps

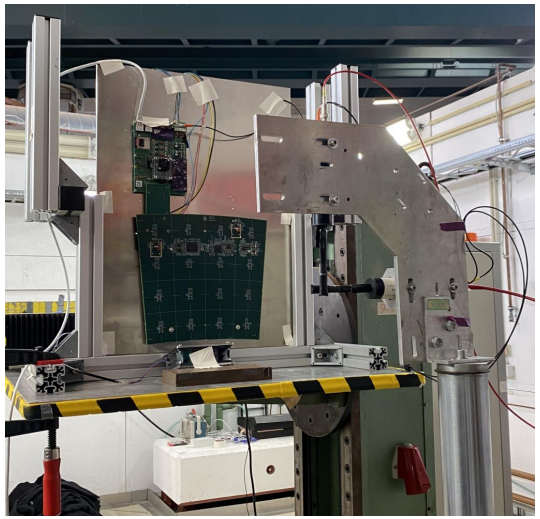
- Production of more pre-series Tilemodules with different sizes of SiPMs and tiles.
- Build a cosmic test stand to be used for quality control of final Tileboards produced for HGCAL.
  - Pre-series Tilemodules to be used to develop and test the setup.
- Build an electromagnetic stack (EM stack) which use 15 pre-series Tilemodules interleaved with steel absorber.
  - The same DAQ system will be used to test both the EM stack and cosmic test stand.
- Production of the first Tilemodules which will be installed on the CMS detector will begin in 2024.

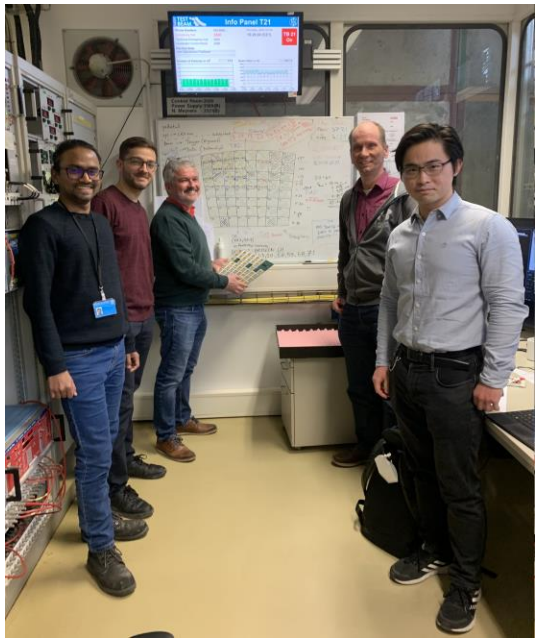


Summary

Take away information

- The **test beam in May** 2023 at DESY **tested** **2 Tilemodules** and **1 mini Tileboard**.
- The **Tilemodule v3** and **SiPMs** tested in this test beam are the **latest generation** which will be used in the pre-series test.
- The **light yield** measured from the tiles on **Tilemodule v3** perform as well as the tiles used previously.
- The **light yield ratio** between **9 mm²** and **4 mm² SiPM** is very **close to what we expected.**
- **Upcoming test beam** this year at **DESY** and **CERN** to **test** a **small electromagnetic stack** with 15 pre-series Tilemodules.





Thank you

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Backup

Terminology

definition

- **SiPM gain:**
  Charge amplification factor of the SiPM

$$SiPM\ Gain = \frac{(Charge\ Collected\ per\ SPAD)}{(Charge\ of\ an\ electron)}$$

- **Overvoltage (OV):**
  Difference between bias and breakdown voltage

$$Overvoltage = (Bias\ voltage) - (breakdown\ voltage)$$

SiPM gain comparison in the Mini Tileboard

Compare SiPM gain between 2 mm² , 4 mm², 9 mm² SiPM

- The SPS gain shown in the plot use **special configuration** to **reduce the shaper capacitance** in the HGCROC so that the SPS can be observed in the 9 mm² SiPM.
  - which make the signals shorter and **more easier to find the peaks in the SPS**.
- The **Maximum value** of **SPS gain** for all three sizes of SiPM are **observed in different delay**.
- This plot shows that the **SPS gain changes in different delay.**
- There are **no tiles attached to the 2 mm² SiPM** in this measurement
  - might be the reason for the early drop of the SPS gain.