Multi-Tilemodule test system using cosmic rays for the CMS HGCAL upgrade

Status of cosmic test stand for Tilemodule quality control

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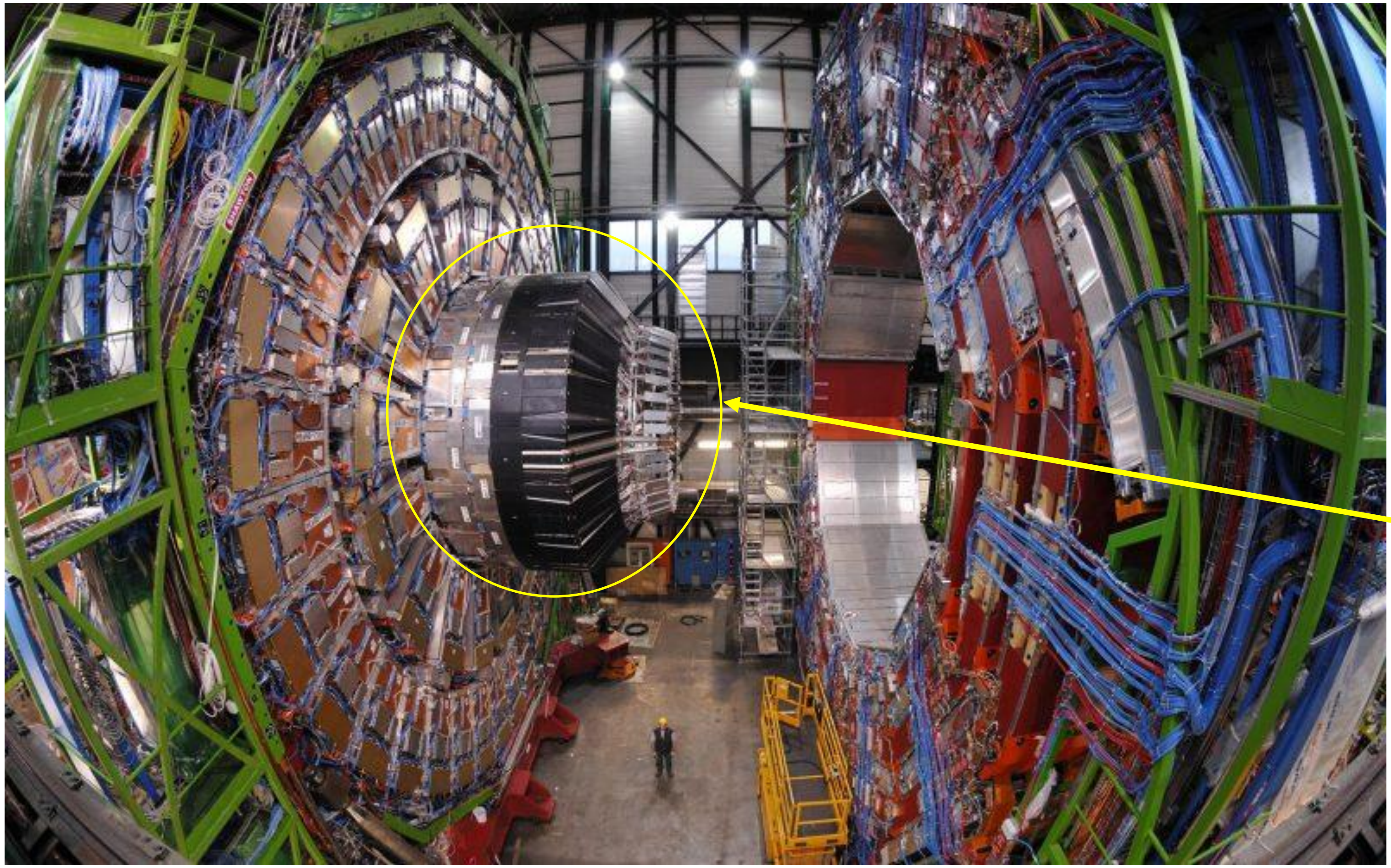
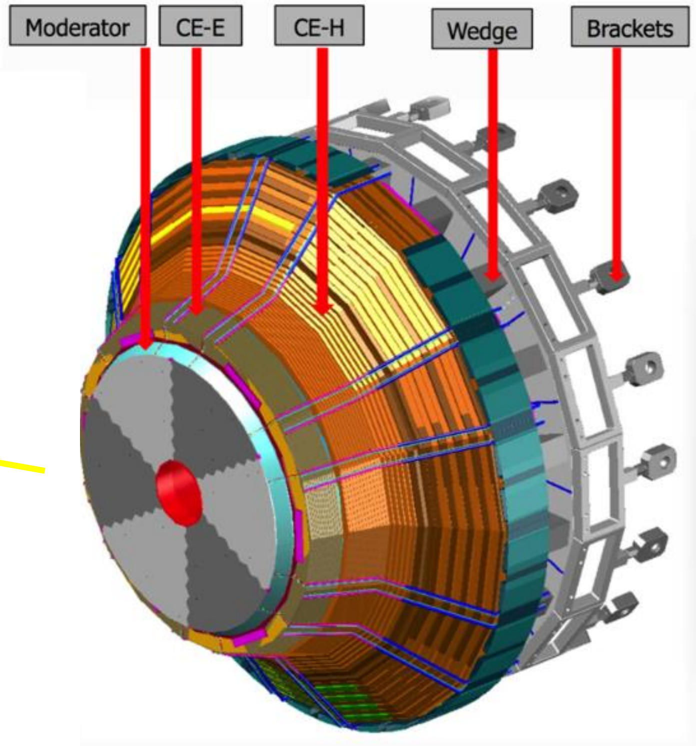
High Granularity Calorimeter (HGCAL)

What is HGCAL. Basic structure and purpose.



HGCAL

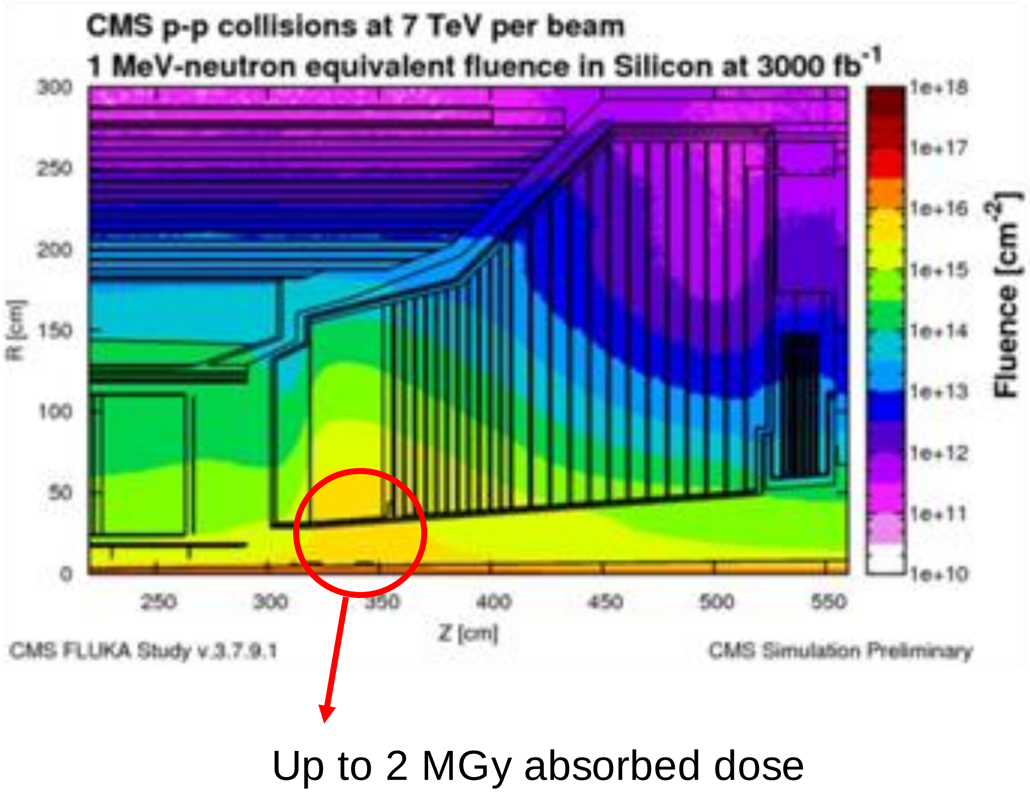


- As part of the CMS phase-II upgrade, HGCAL will replace **the current endcap** of the CMS detector for the **HL-LHC**.

What is HGCAL, and why do we need it

Basic structure and purpose.

- It is a **5-D calorimeter** with high granularity which can measure **energy deposition**, **time**, and **shower shape**.
- It is designed to cope with the larger number of collisions per bunch crossing (**event pileup**) and **higher radiation dose** in HL-LHC.

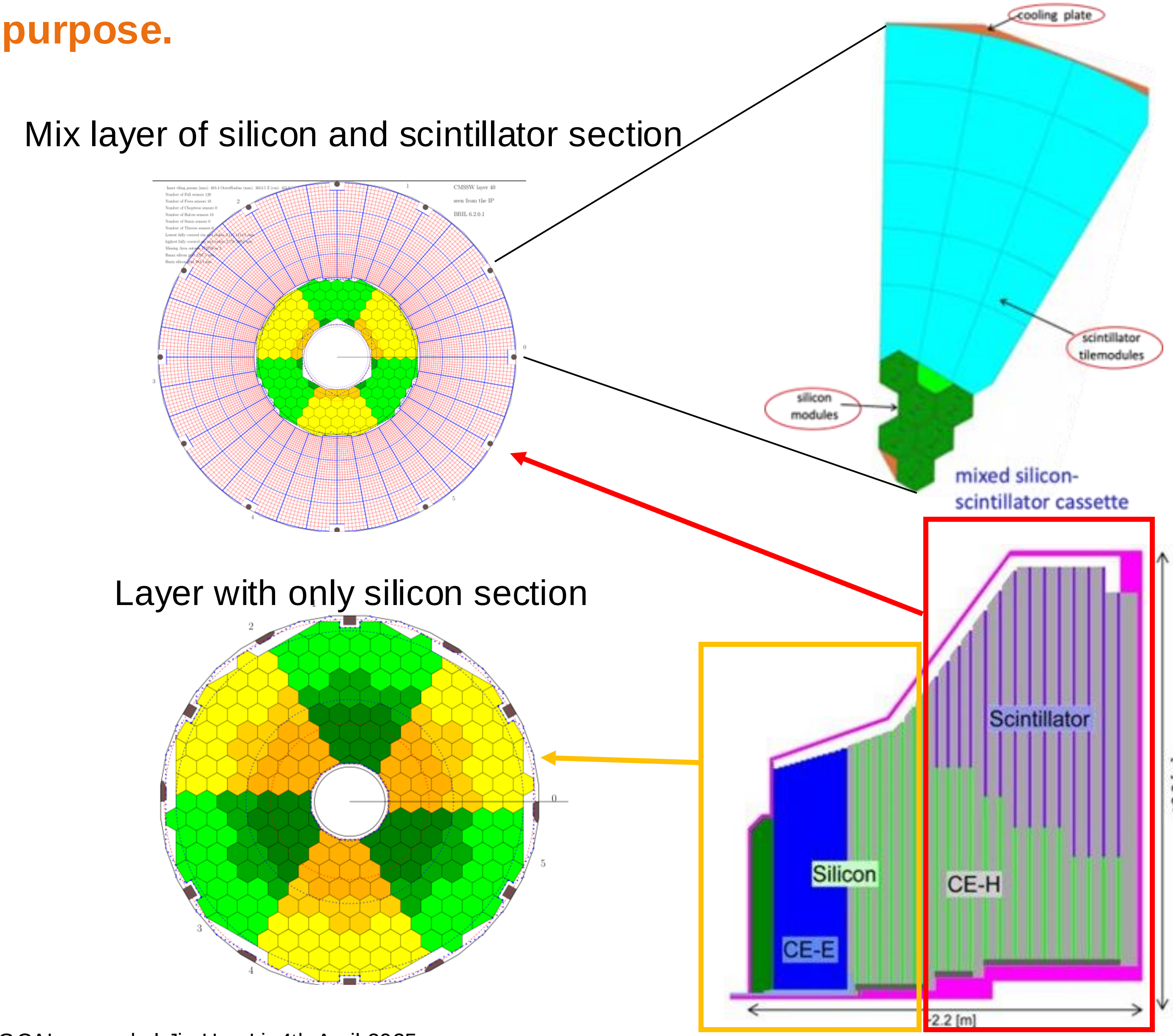


Basic structure of the High Granularity Calorimeter (HGCAL)

What is HGCAL. Basic structure and purpose.

- **Silicon section** (using **silicon sensors**): Cover the electromagnetic calorimeter (**CE-E**) and part of the Hadronic calorimeter (**CE-H**).

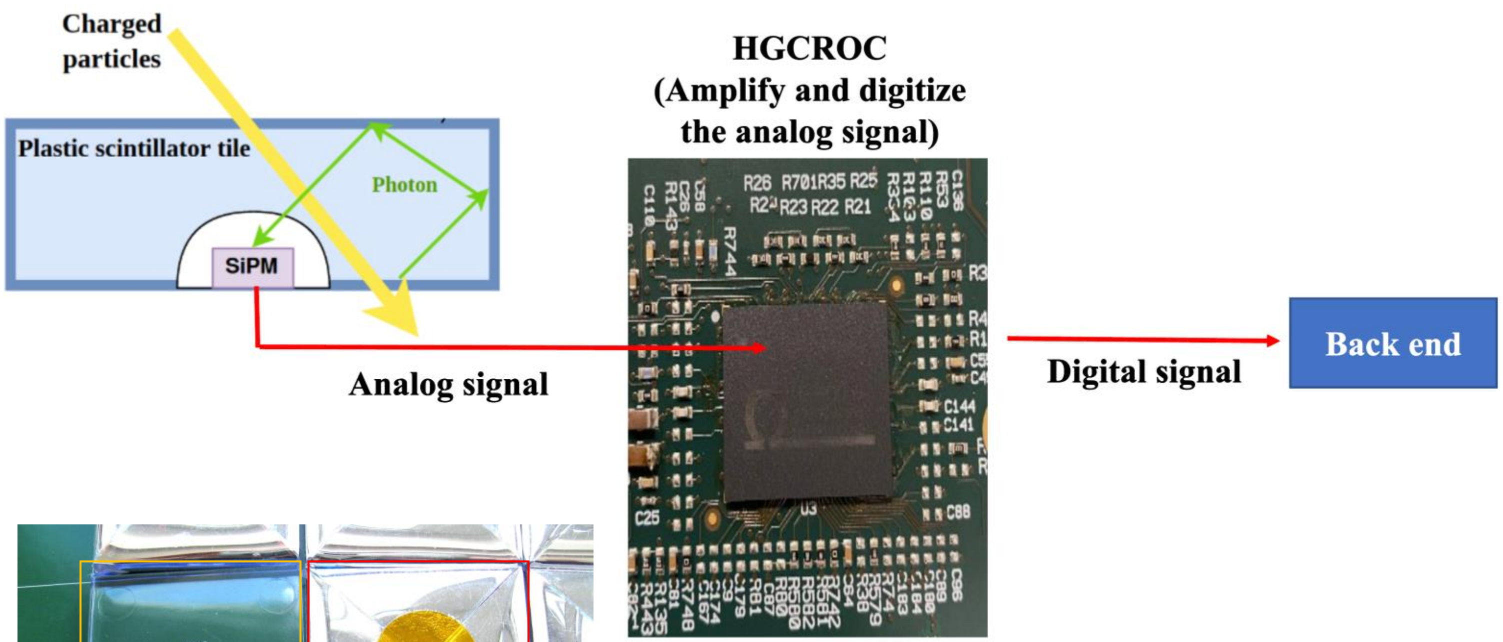
- **Scintillator section** (using **SiPM-on-tile technology**): Cover the **CE-H** where the expected end-of-life neutron fluence is less than 5×10^{13} n/cm^2.

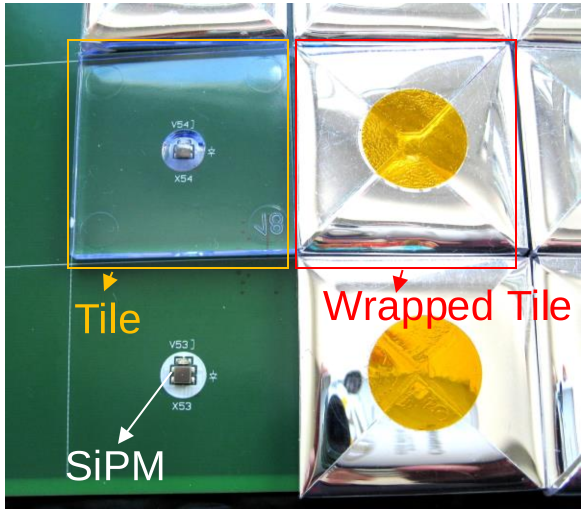


SiPM-on-tile technology in the scintillator section of HGCAL

Components, readout system

- The SiPM-on-tiles include **wrapped plastic scintillator tiles** and **silicon photomultiplier (SiPM).**
- Tiles are wrapped in reflective foil which can maximize the chance of light reaching the SiPM.
- **Smaller tile** size and **larger SiPM** size can **collect more light** to the SiPM.
- The **size of tiles are chosen for good S/N for MIP calibration** (needed until its end of life).
- SiPM detects photons from the tiles.

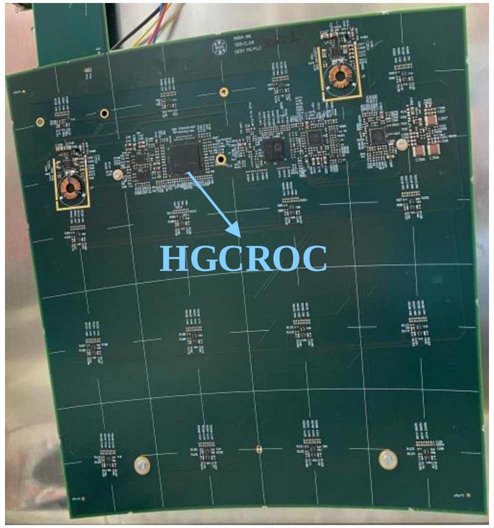


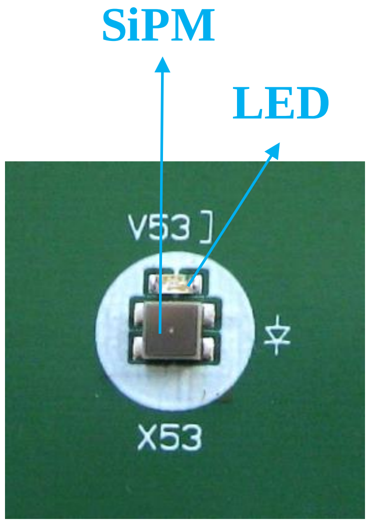


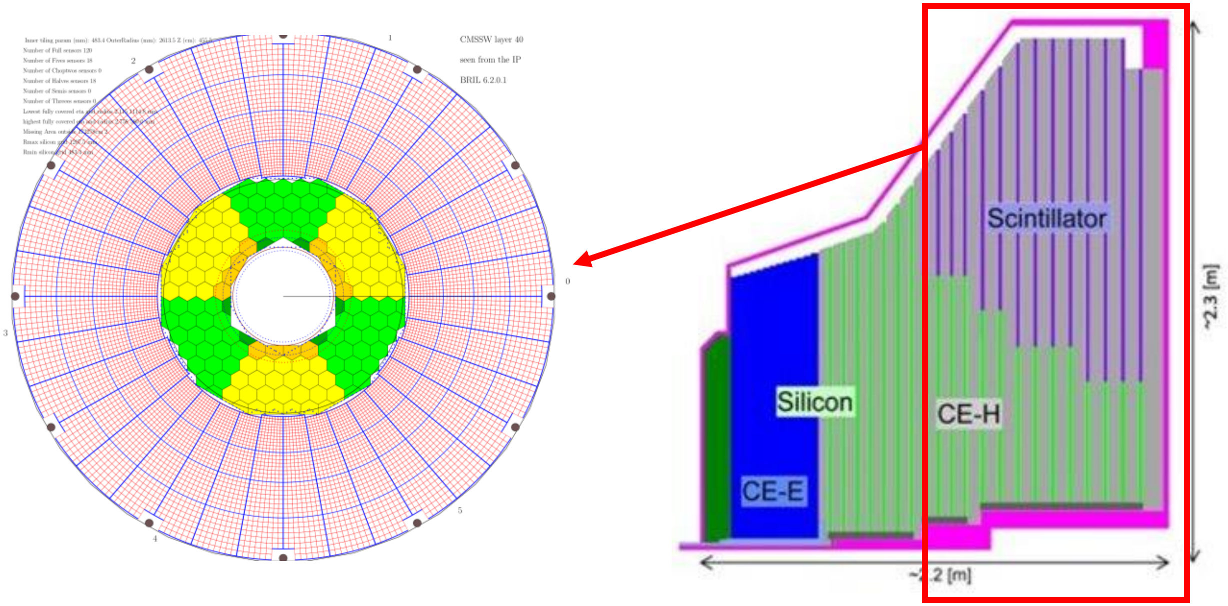
Tilemodule with SiPM-on-tile technology

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.
- There are **280k channels** in the Scintillator part in the HGCAL.
- With scintillator **tile size 4 ~ 30 cm²**, and size of **SiPM is 9 mm²**.
- The HGCROC **readout 72 channels** from the Tilemodule.
- The HGCROC has **2 DAQ elinks** and **4 trigger elinks** (1.28 Gbps/elink) for **data readback**.



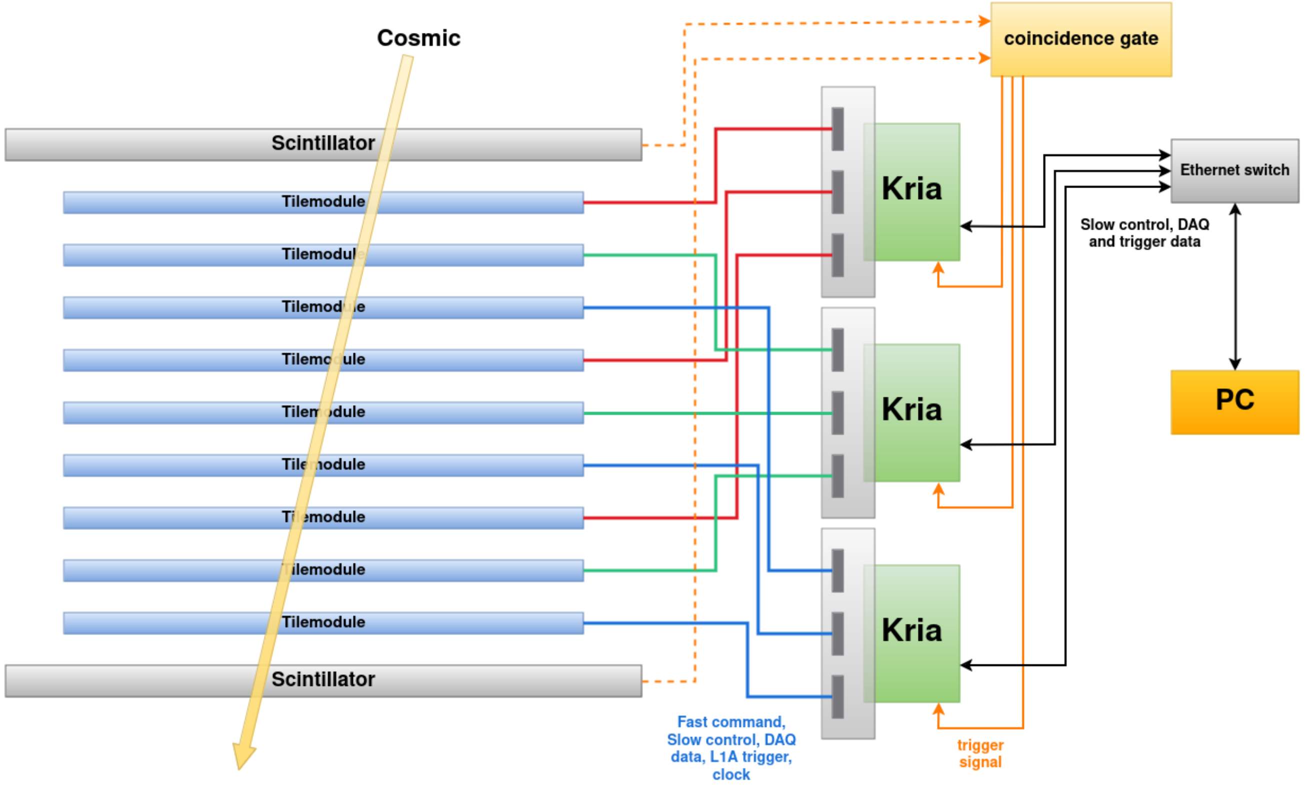




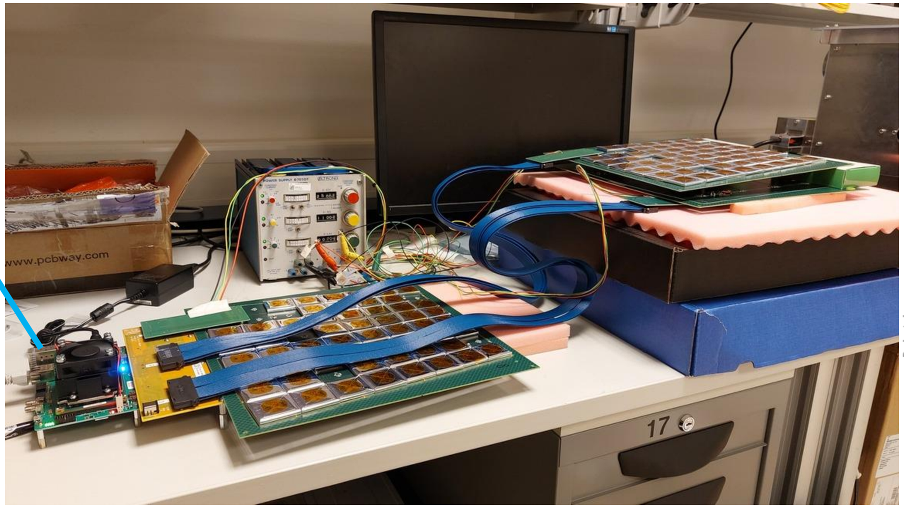
DAQ system: Multi-Tilemodule

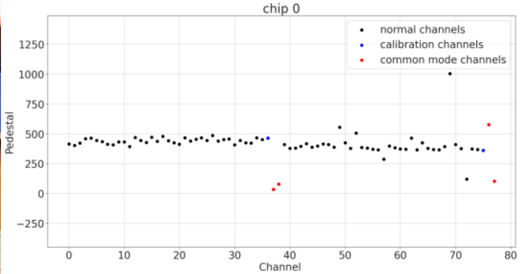
Will be used in cosmic test stand for the quality control of Tilemodule production

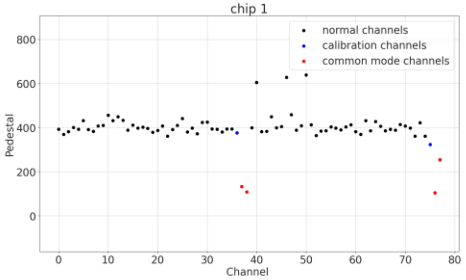
- The test stand will be used to test each channels for MIP calibration with cosmic rays.
- The DAQ will test Tilemodules in **3 independent groups**. Each group has **3 Tilemodules controlled by 1 Kria**. All 3 groups will received the **same trigger** from the **same trigger scintillators**.
- In terms of DAQ development, the system can now **calibrate** and **measure 3 Tilemodules** via **1 Kria**.

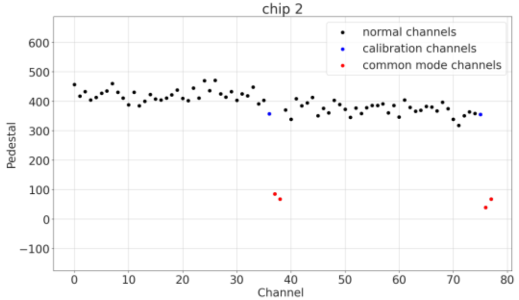


Kria





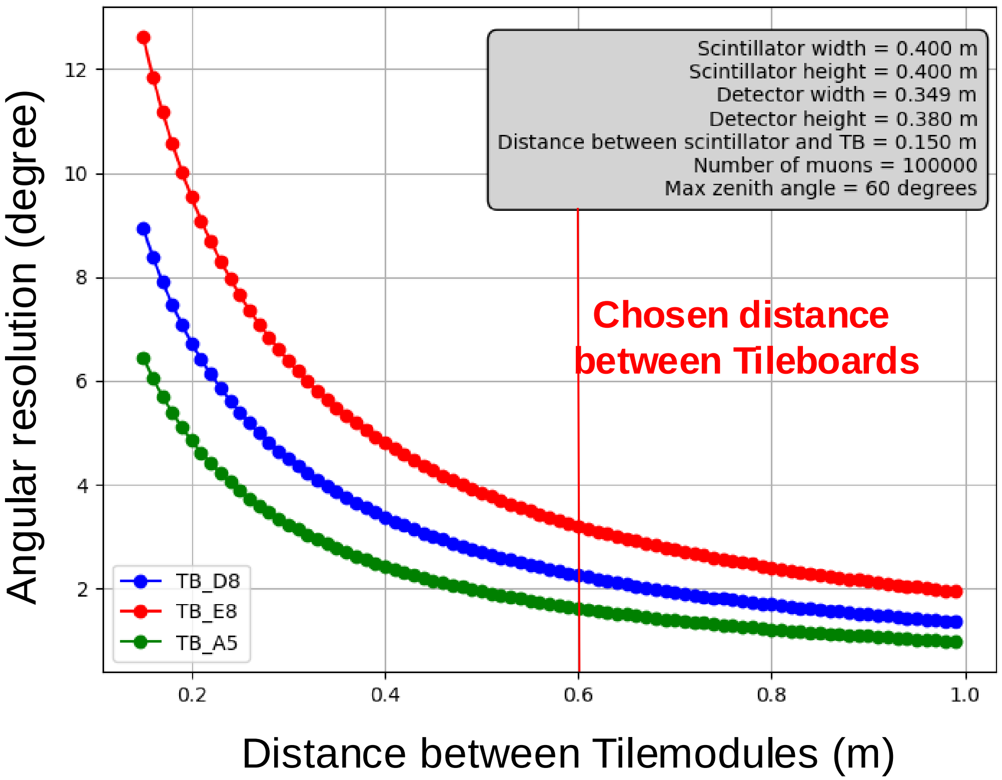


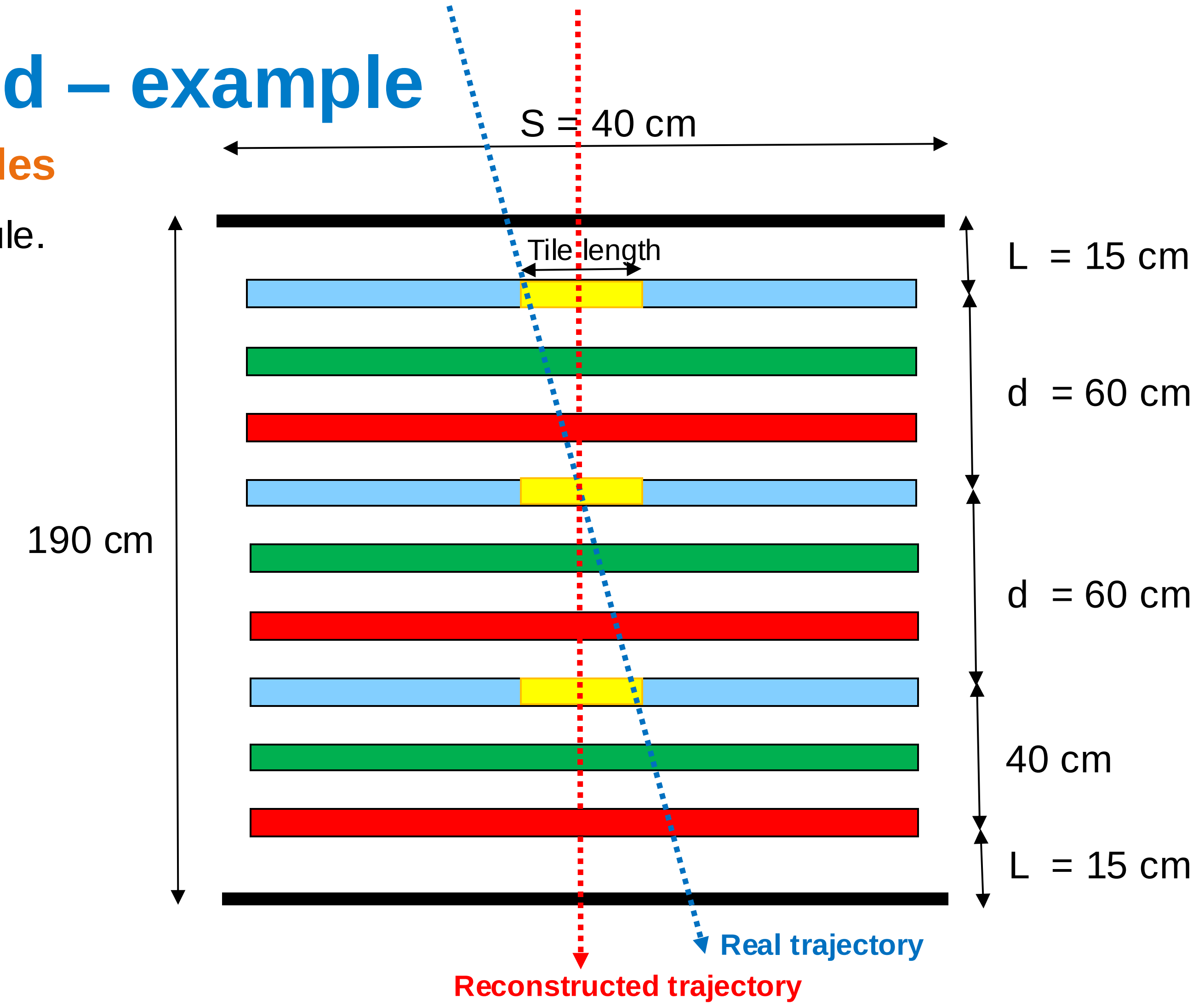


Geometry for cosmic test stand – example

Angular resolution v.s distance between Tilemodules

- **d = 60 cm** ⇨ angular angle ≤ 3 degrees for a Tilemodule.
- **L = 10 ~ 15 cm** ⇨ acceptance rate ~ 90%.
- **Scintillator width ~ 40 cm** (maximum TB size + 2 cm)
  ⇨ Maximum acceptance rate for a Tilemodule.



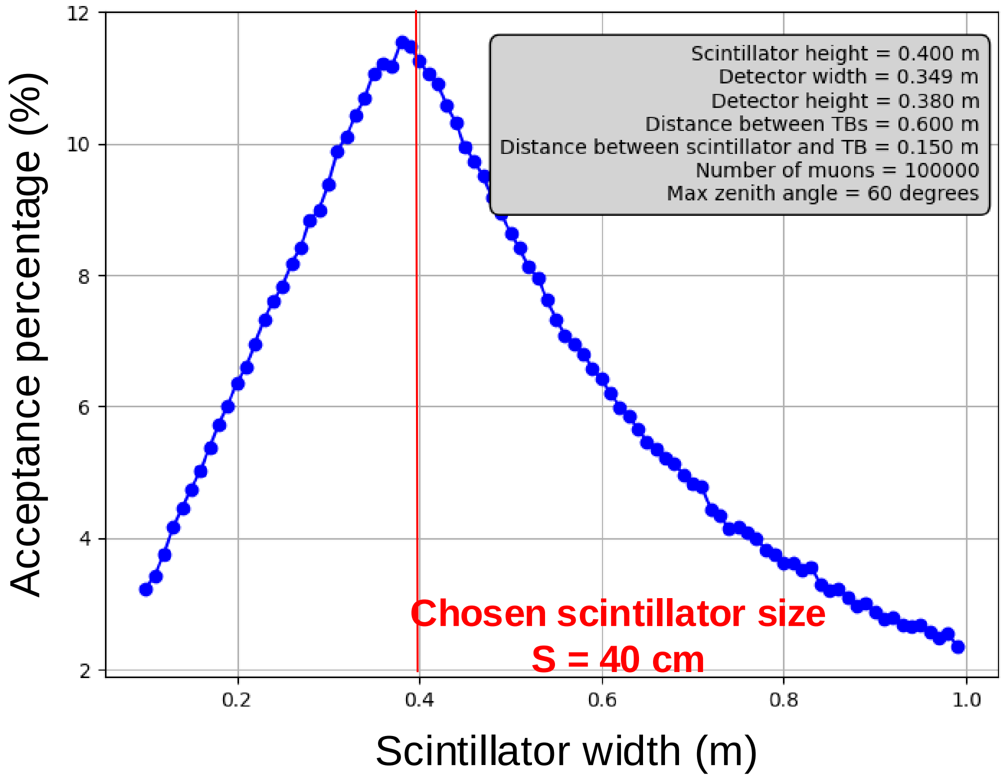


In the above case, the **angular resolution** for the three tiles on top of each other is calculated as the angle between the **reconstructed trajectory** (red dash line) and the **real trajectory** (blue dash line)

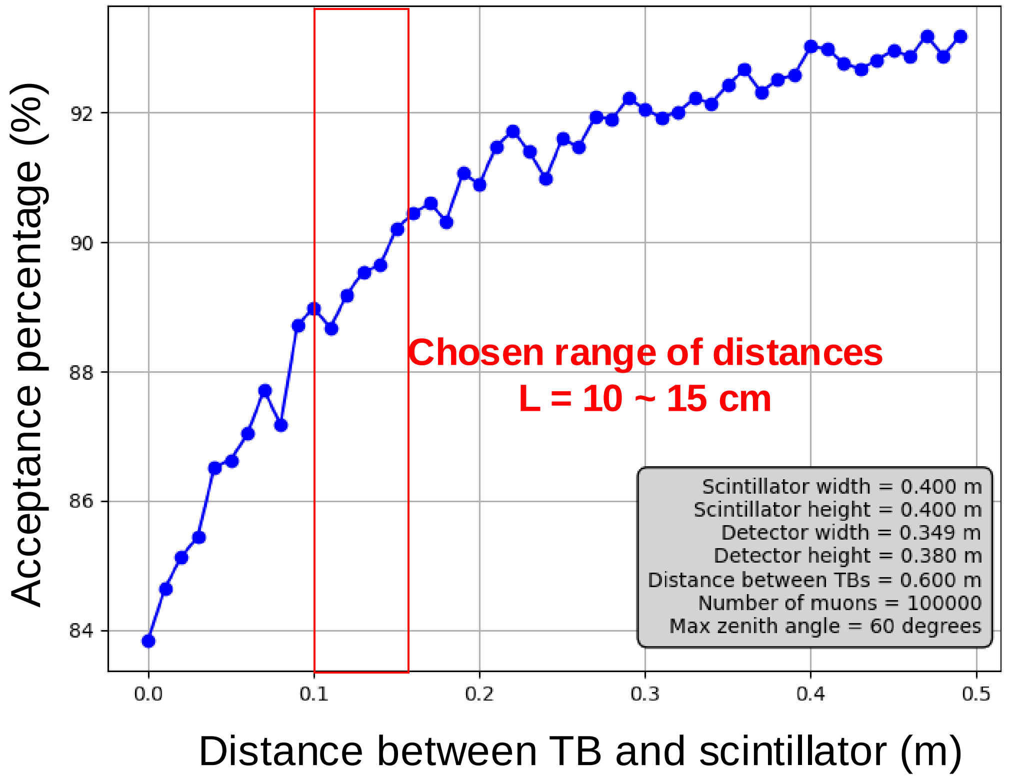
Geometry for cosmic test stand - E8

Acceptance percentage

- **Acceptance percentage** = Successful case / **Number of total events**.
- **Successful case**: pass through 2 scintillators + 3 Tilemodules.
  Total events: simulated cosmic trajectory (all of them pass though the top scintillator)



- **Acceptance percentage** = Successful case / **Number of trigger events**.
- **Trigger events:** pass through both 2 scintillators.



Geometry for cosmic test stand

What we have now in DESY

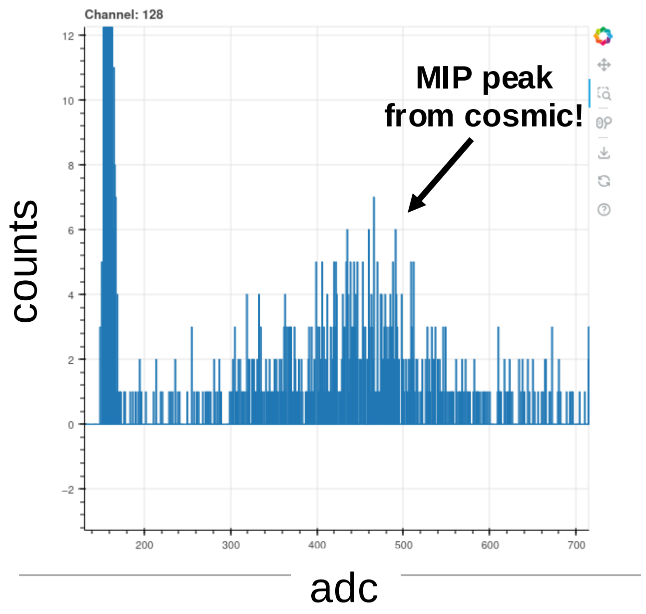
Trigger scintillator
(size: ~45 x 45 cm)

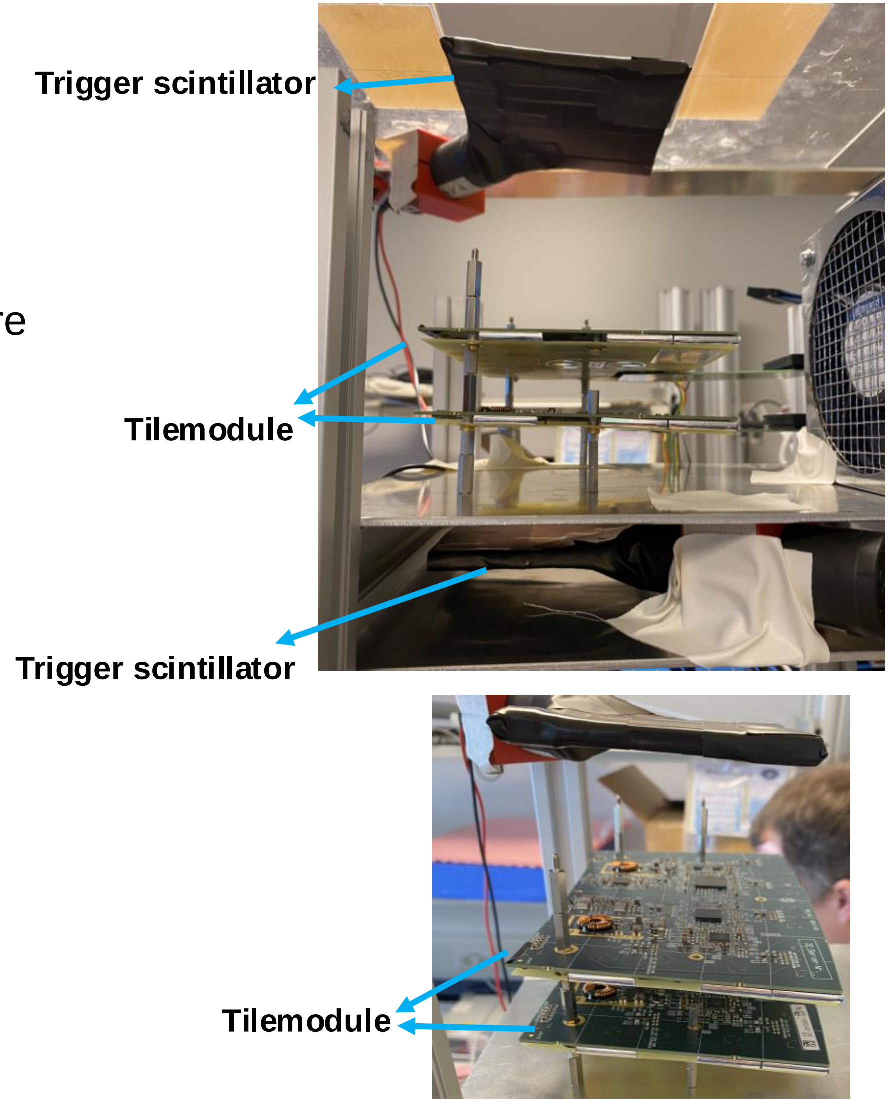
- The distance between each Tileboards is **15 cm** due to the constrain of the height of our lab roof.
- The setup can operate two sets of cosmic test stand. Each setup can test up to 9 Tilemodules.
- The **power supply system** (MPOD) in the setup will allow us to **control** the **LED vias voltage remotely** from the computer, which will then allow us to run an **automatic LED scan**. The MPOD can power up to **18 Tilemodules**. 9 modules in each test bench.

Preliminary Cosmic test stand for DAQ development and testing

Small cosmic test stand with just one Kria and two Tilemodules

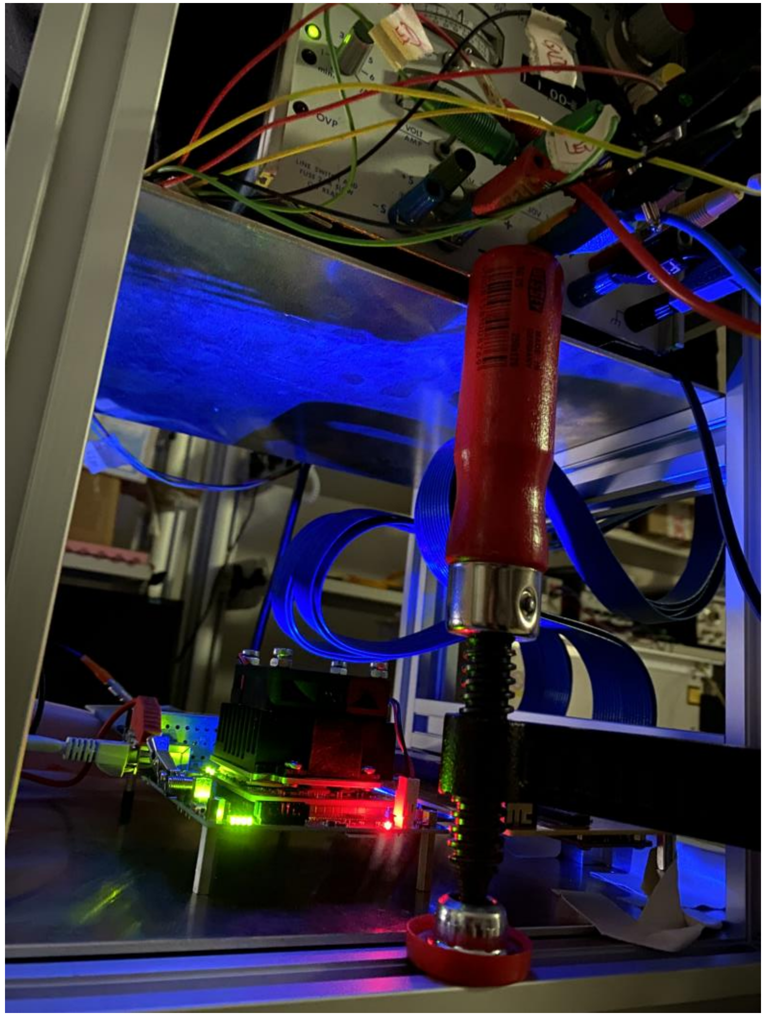
- A preliminary cosmic test stand has been built.
- The trigger using two small scintillators in coincidence.
- The Tileboards successfully measure the MIP (minimum ionizing particle) peak from the cosmic ray muons!





Summary and next step

- The **mechanics** of the **cosmic test stand** have **already been built** in DESY.
- The **DAQ system** which **control** **3 Tilemodules** via **1 Kria** is **in place**.
- A preliminary cosmic test stand has been built for testing the multi-Tilemodule DAQ system and it proves that it can successfully detect cosmic muons from both connected Tilemodules!
- The **next step** is to **set up** and test the **full DAQ system** with the complete cosmic test stand (can test up to 18 Tilemodules at the same time.) and to be ready to the full production of Tilemodule for the CMS HGCAL.



Thank you

Contact

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Backup

Strategy

When will the Tilemodule be built and ready to go

Pre-series Tilemodule (ongoing)

- Close to final components
- Will not be installed to the final detector.
- To be familiar with Tileboard production
- Developing quality control procedure
- All passed cold test.

Full production (will start in 2025)

- Will produce the remaining 90 ~95% of the Tilemodule for the HGCAL.
- Will produce in full speed.

2024 → 2025

Pre-production Tilemodule (will start in 2024)

- Are real detector pieces
- Will be installed in HGCAL.
- Learning phase of full production.
- Will produce first 5 – 10 % of the full production: PCB (October 2024), Electronic assembly (November 2024), Tile assembly (January 2025)

Quality control for Tileboards and Tilemodules at DESY

Test with cosmic rays and cold test

- **Wrapped tiles:**

  - **5% tiles tested** during **production** (~**20%** in **pre-production**).

  - **LY QC** and it's **uniformity** monitored with Sr90 test stand.

  - **Dimensions** (height and width) checked with the scanner test stand.

- **All Tileboards:**

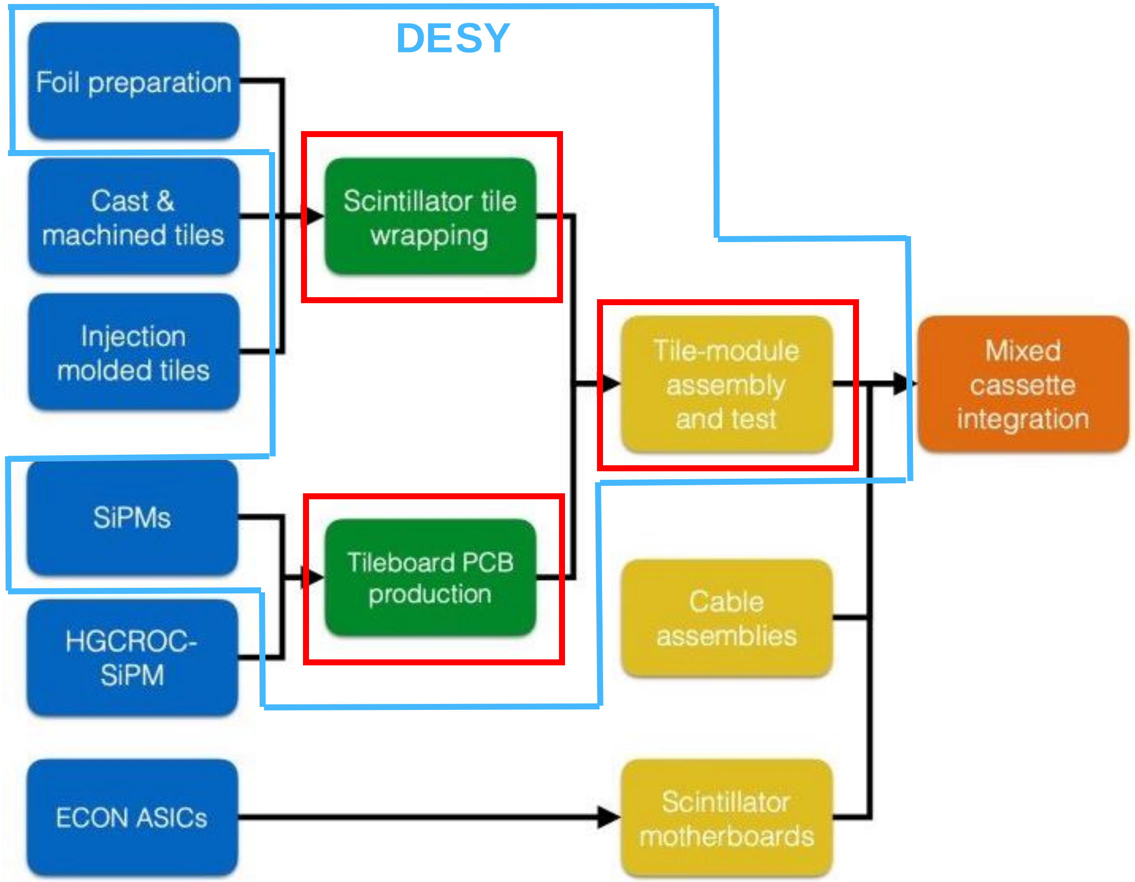
  - cold test (**1 thermal cycle**. Temperature: **-35** ~ **20** °C):

    Check **data readout** and **electronics functionality**.

- **All Tilemodules :**

  - **mechanical cold test**: **check** if **tiles** get **damaged** or **fall off** from Tilemodule.

  - **cosmic ray test:** to **examine all channels** on Tilemodules and to **calibrate MIP**.



Basic structure of the High Granularity Calorimeter (HGCAL)

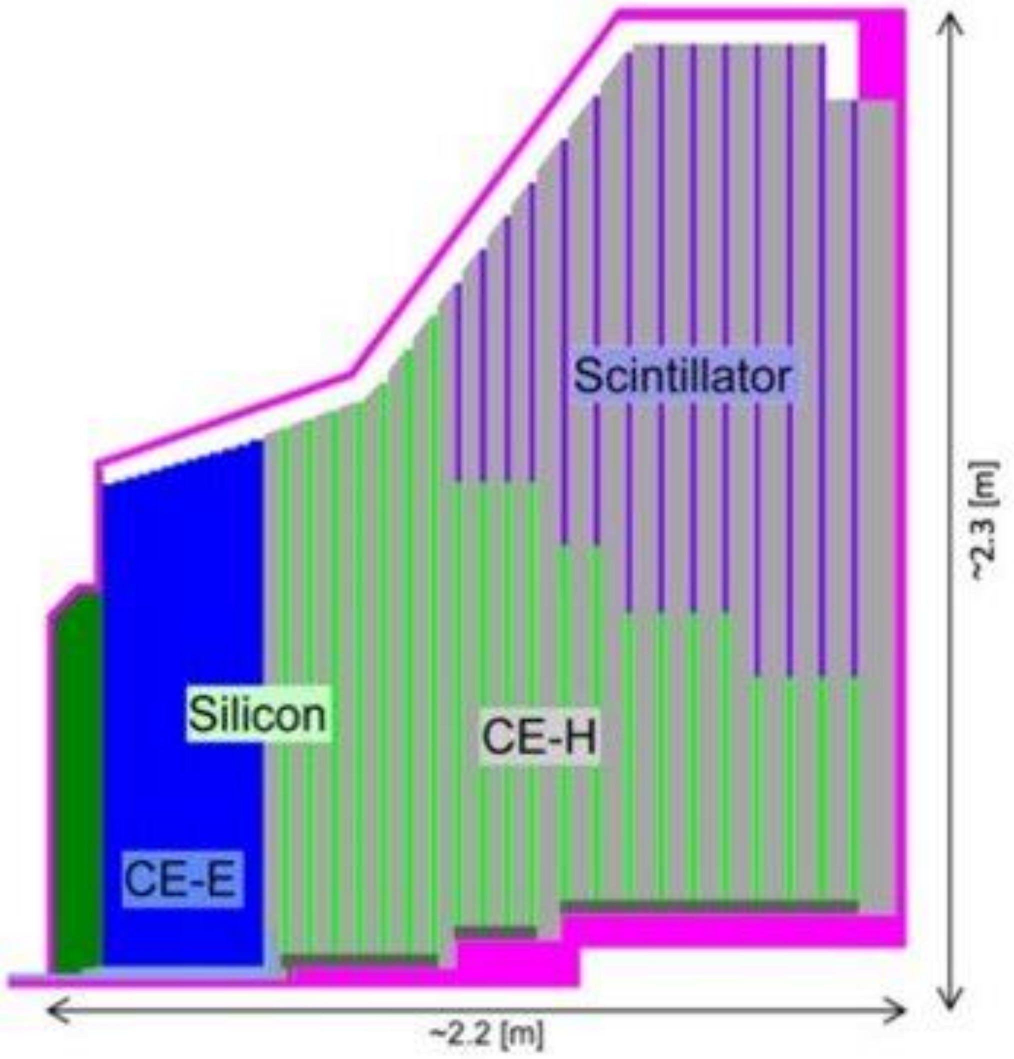
Active elements and key parameters

Active Elements:

- Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
- "Cassettes": multiple modules mounted on cooling plates with electronics and absorbers
- Scintillating tiles with on-tile SiPM readout in low-radiation regions of CE-H

Key Parameters:

Coverage: $1.5 < |\eta| < 3.0$
~215 tonnes per endcap
Full system maintained at -30°C
~620m^2 Si sensors in ~26000 modules
~6M Si channels, 0.6 or 1.2cm^2 cell size
~370m^2 of scintillators in ~3700 boards
~240k scint. channels, 4-30cm^2 cell size
Power at end of HL-LHC:
~125 kW per endcap



Electromagnetic calorimeter (**CE-E**): **Si**, Cu & CuW & Pb absorbers, 26 layers, 27.7 X_0 & ~1.5λ
Hadronic calorimeter (**CE-H**): **Si** & **scintillator**, steel absorbers, 21 layers, ~8.5λ

What is HGCAL, and why do we need it

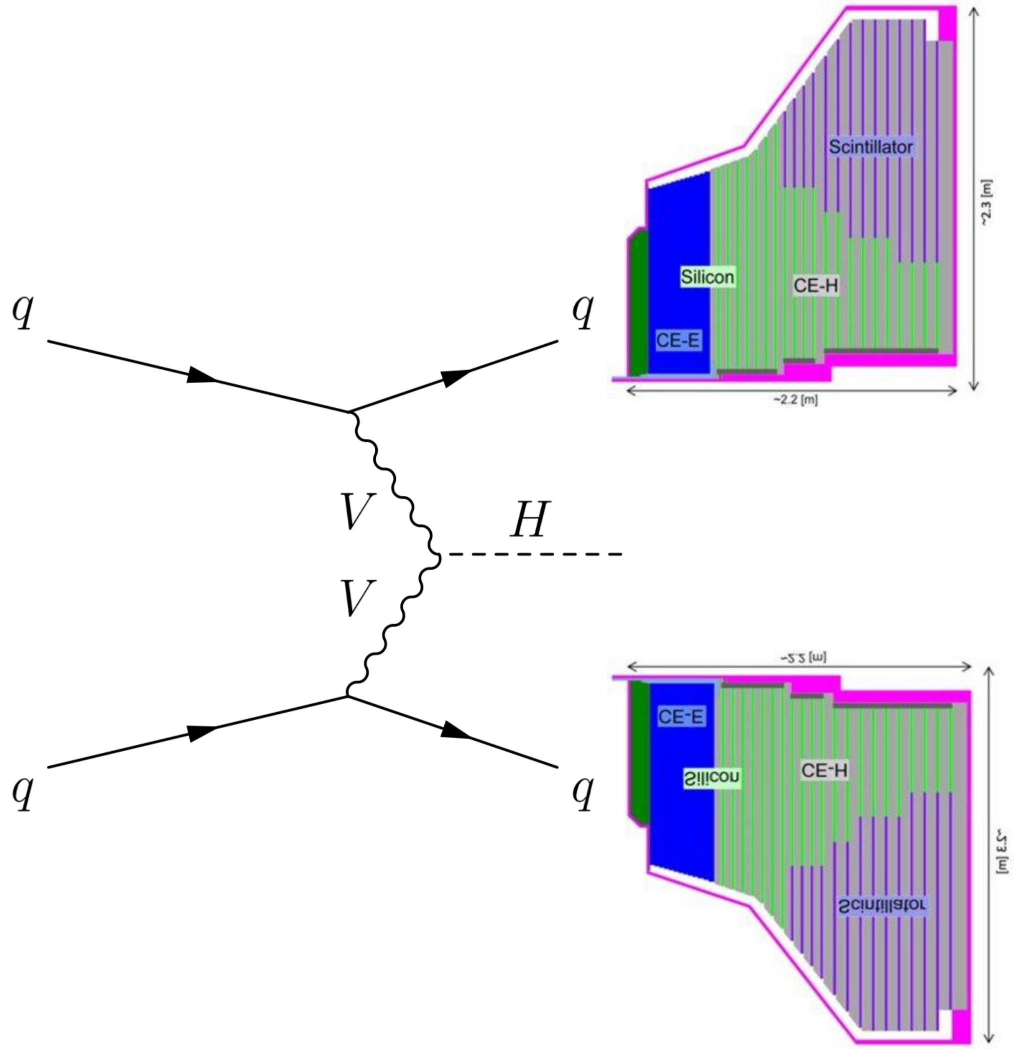
Physics motivations

Vector boson fusion (VBF)

- Two quarks from each of the LHC protons collide with each other. The quark radiate off a heavy vector boson (W or Z) and deflected slightly different from its original direction.
- The **particle jet of the deflected quarks** and the can be detected by the HGCAL.

Quark-Gluon Discrimination

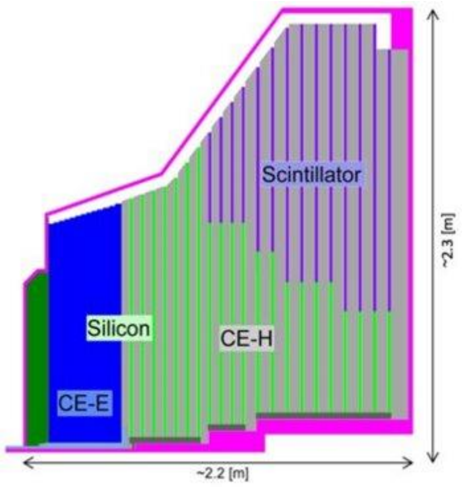
- The **high granularity** of HGCAL can help improving **jet identification**.

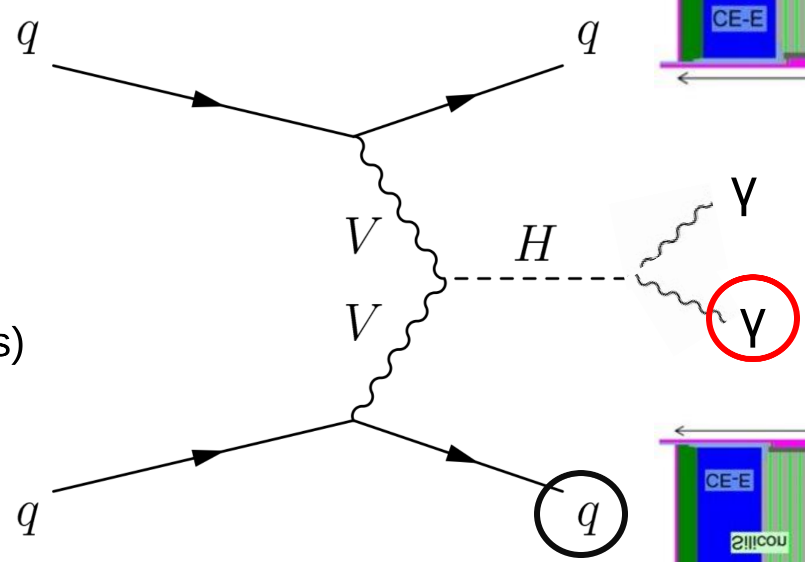


What is HGCAL, and why do we need it

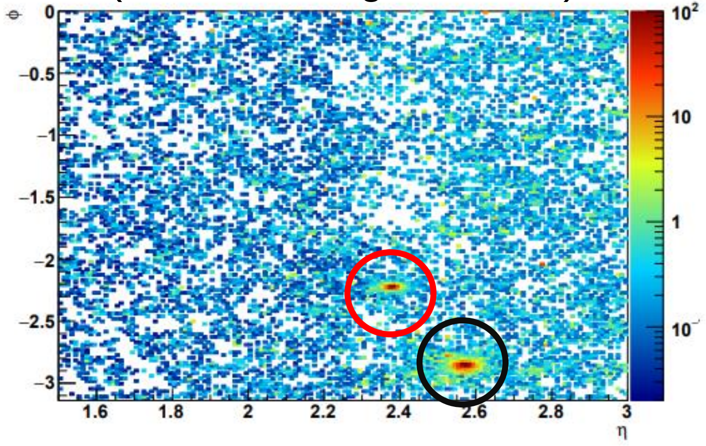
The importance of precision about time and space

- With the **high granularity**, HGCAL will be able to identify **VBF jets.**
- The **pileup issue** can be greatly **improved** with good **timing resolution** (tens of picoseconds) of the HGCAL. (Ex: VBF H -> γγ)

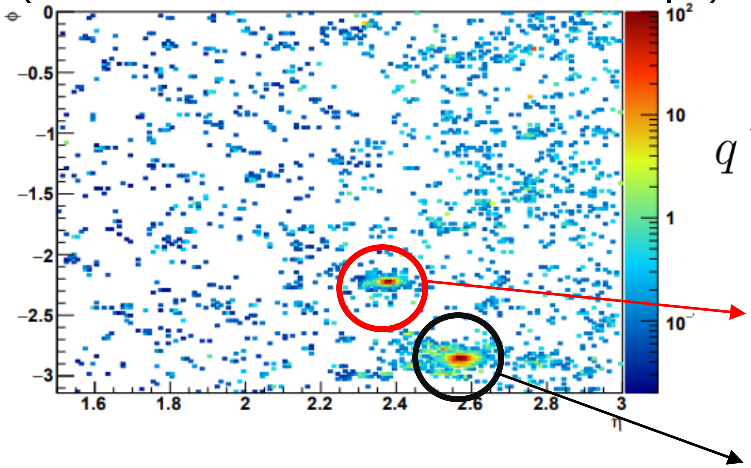




VBF H -> γγ
(without timing selection)

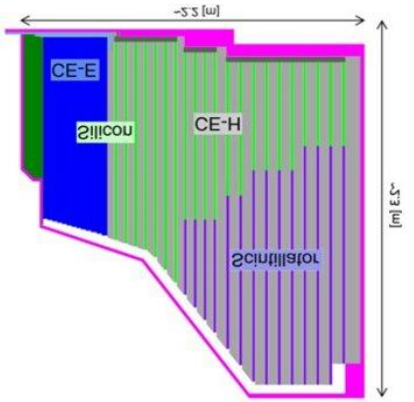


VBF H -> γγ
(select hits with time window < 90 ps)



γ

VBF jet



DAQ system: Multi-Tilemodule (using Tilemodule for triggering)

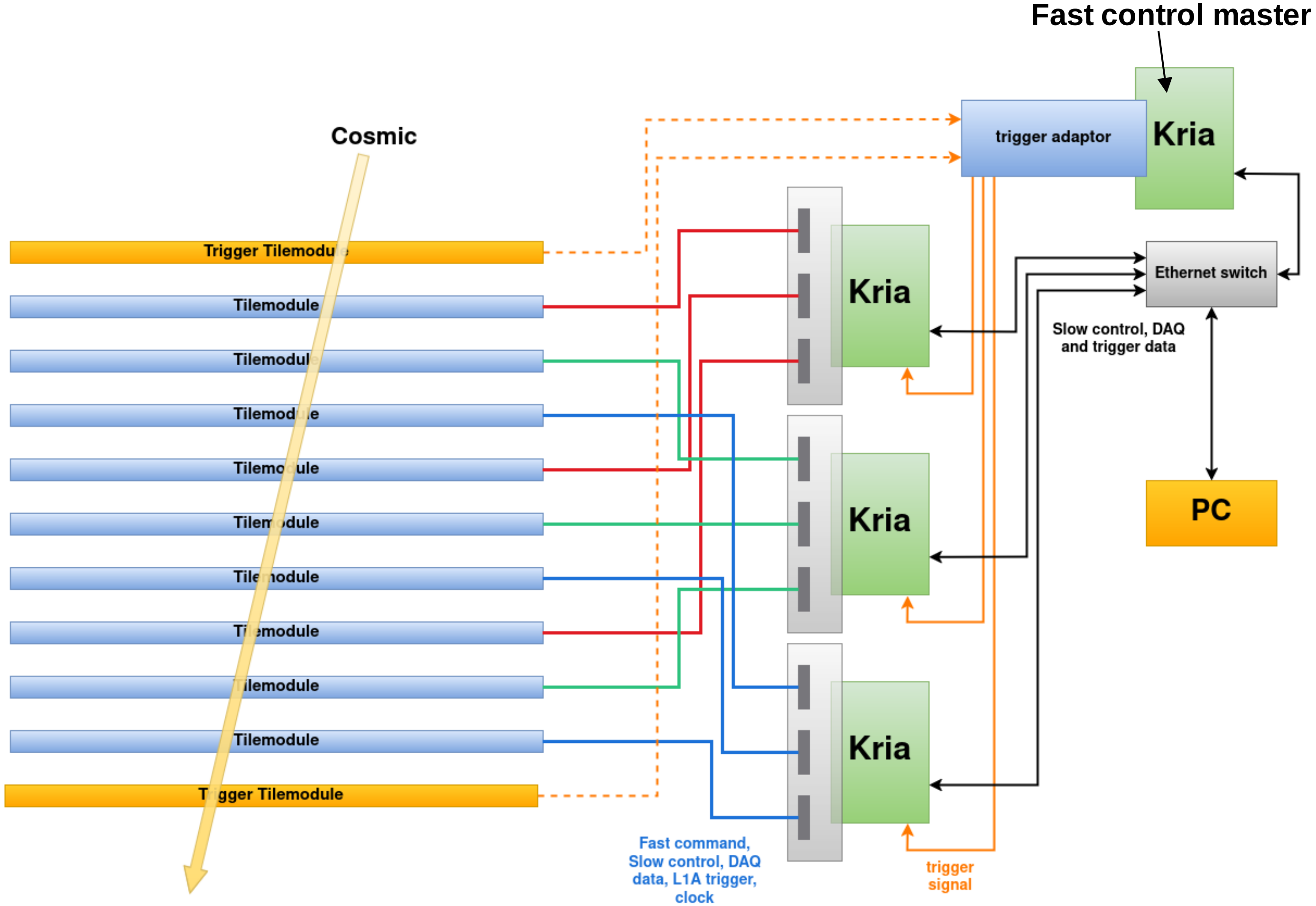
Backup plan if the trigger scintillators running into some issues

- Use the **Kria** connected with the **trigger adaptor** as a **fast control master**, which **distributes** the **fast clock** (320 MHz) and **control signals** to other Kria.

- Will use the **self-trigger block** in the firmware for the two trigger Tilemodules. The **trigger output** of this can be **routed** to the **fast control encoder** via the **trigger xbar** firmware block and then being sent to all Tilemodules.

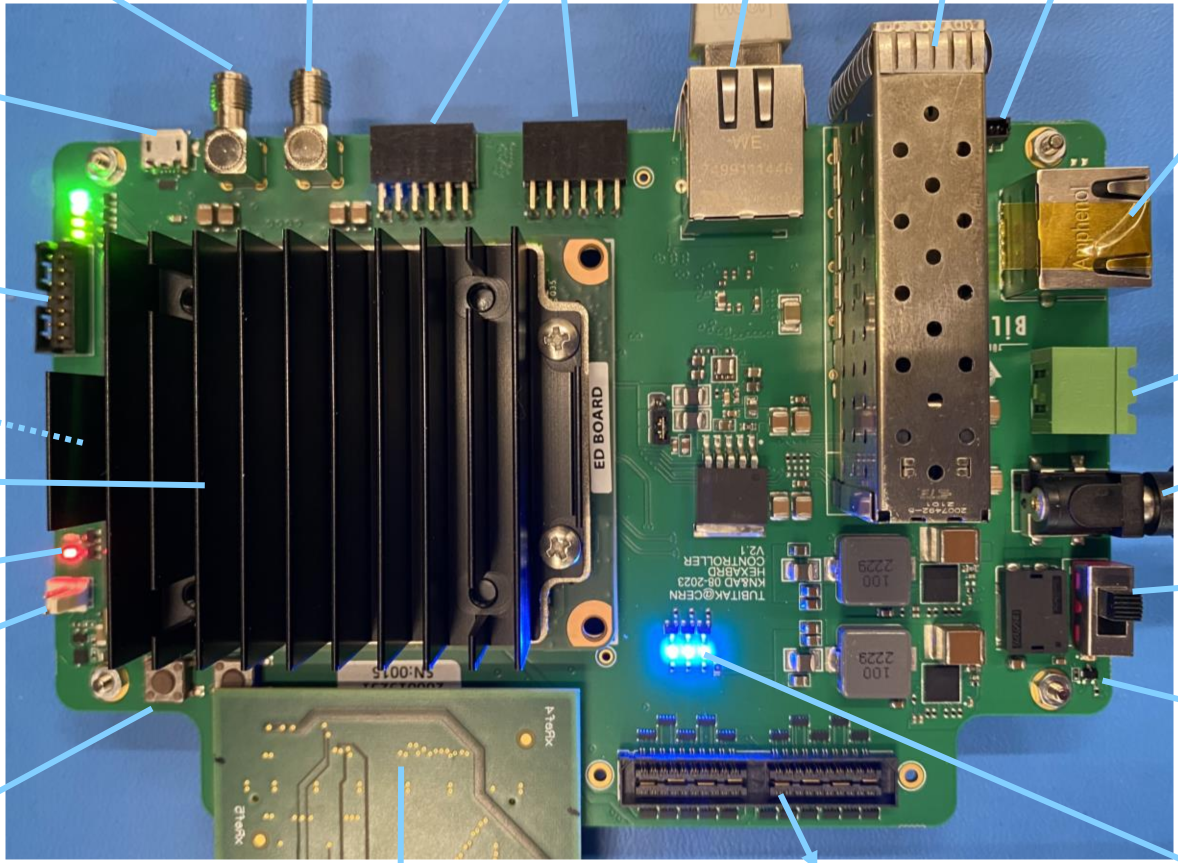
- Can **better reconstruct** the cosmic rays **trajectory** due to the two **additional points** (trigger Tilemodules).

Trigger adaptor
(Just arrived to DESY this week)



Kria

Work as a small back end for sending slow control, fast command, clock, and receiving data measured from the Tilemodule



Micro USB port to Kria serial terminal (can be connected to PC for debugging)

ExtClk_IN

ExtClk_Out

PMOD1

Ethernet

2 x SFP QWICC

Ext_TRG trigger port
4 LVDS clock capable
(can received differential or single-ended signal -> depends On firmware)

JTAG Connector

SD card

FPGA

Power 2

3.5 mm power connector

This LED will be on after loading the firmware

Switch
(can switch off and on the Kria)

Fan power

Under/Over voltage LED

Reset button

J_COMPAT
(This is where to connect TB adaptor)

J_EXTEND

This LED will be on after enable QSH power.
(Will show a lot of timeout error if this one is off)