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

Quality control for HGCAL Tilemodules

Jia-Hao Li on behalf of CMS HGCAL group

9th February 2024

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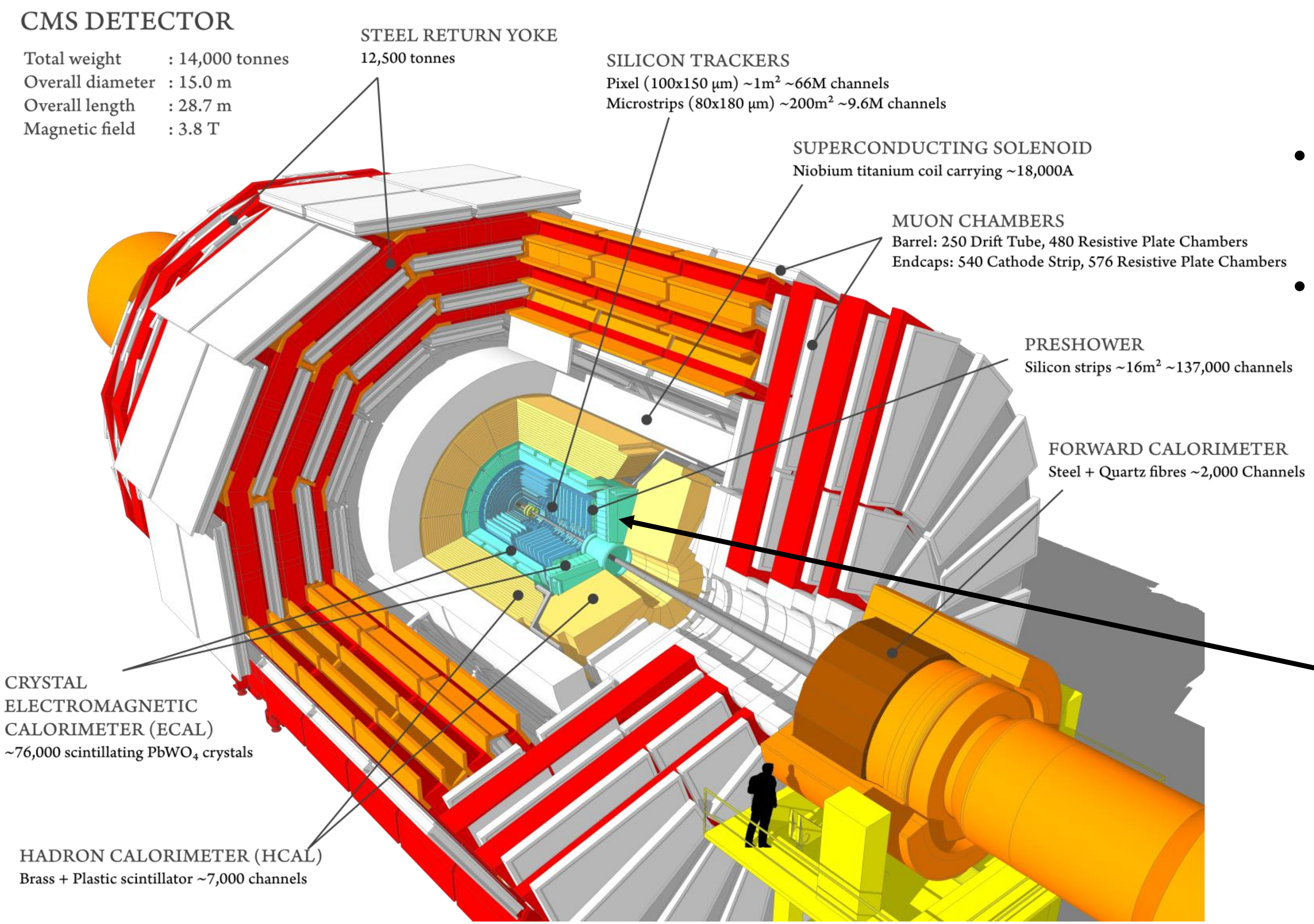
CMS

FTX

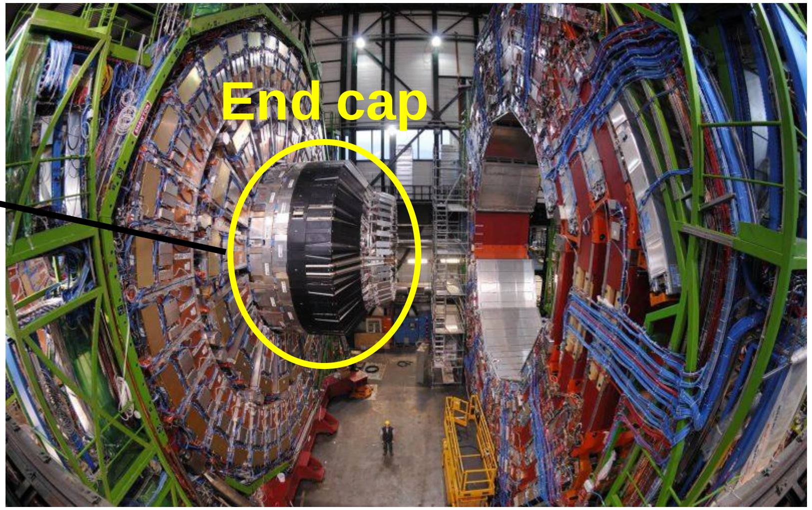
DESY.

The Compact Muon Solenoid (CMS) detector

Basic information



- Take "**3D photographs**" of particle collisions (up to 40 million times per second) in all directions.
- Weight 14000 tonnes. 15 metres high, 21 metres long.
- **Physics goal**: standard model, beyond standard model, Higgs boson mechanism, boost Higgs, dark matter, extra dimensions...etc.



What is HGCAL, and why do we need it

What is HGCAL. Basic structure and purpose.

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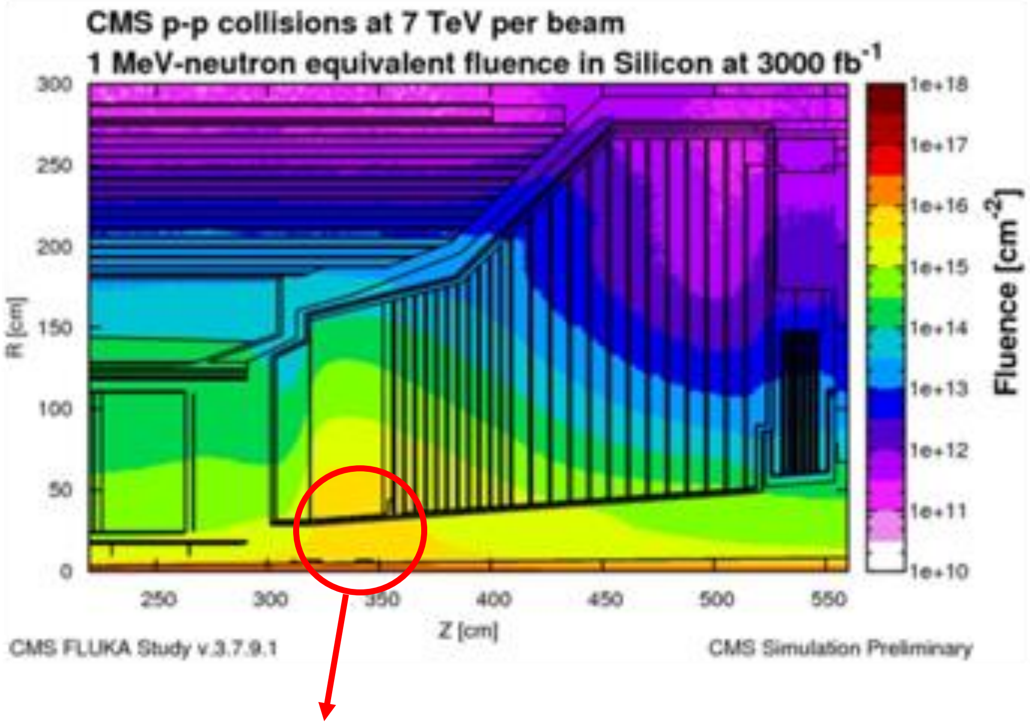
- It's a **5-D calorimeter** with high granularity which can measure energy deposition, time, and shower shape.
- It is designed to cope with the larger number of collisions per bunch crossing (**event pileup**) and **higher radiation dose** in HL-LHC.

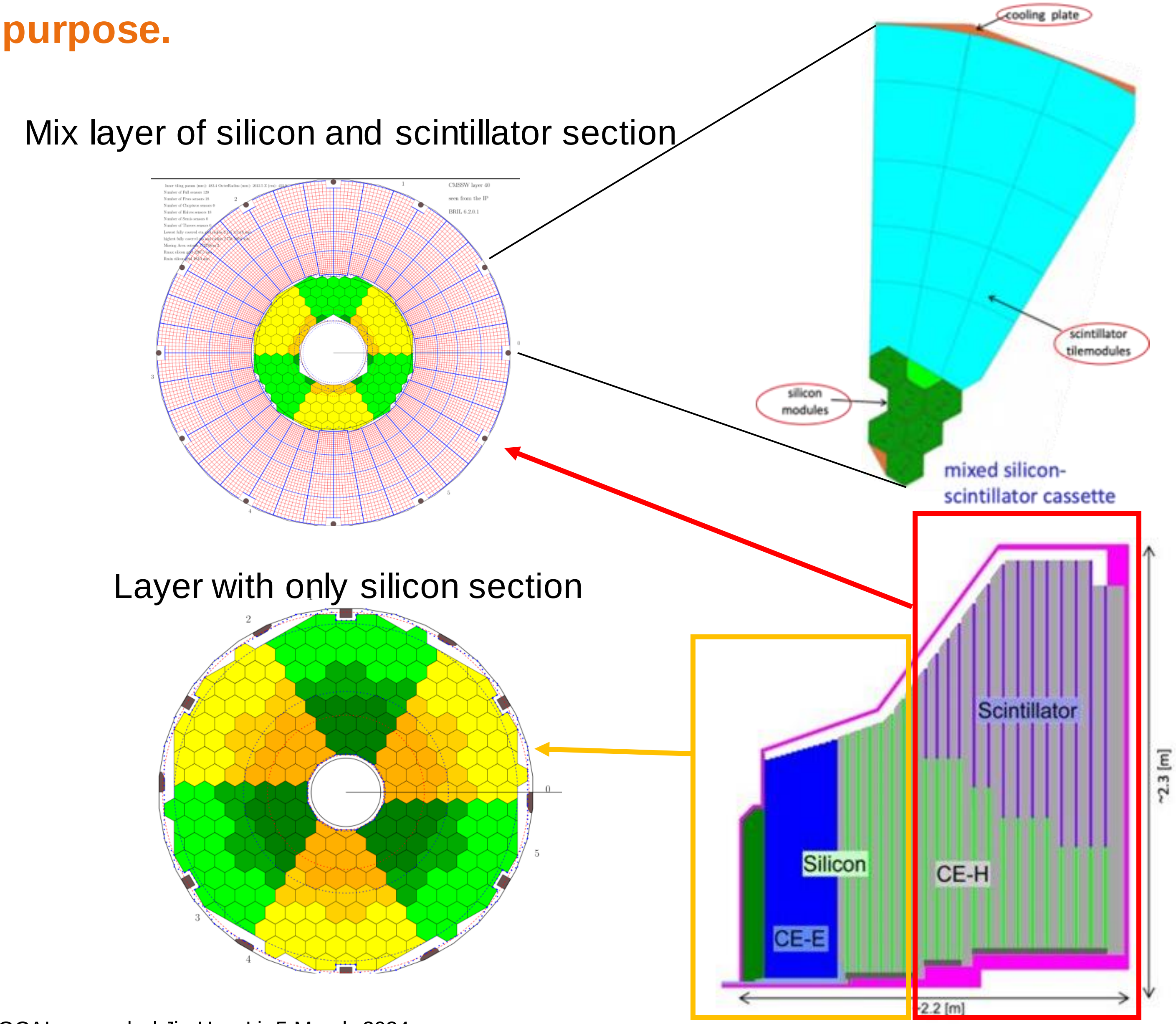


Up to 2 MGy absorbed dose

Basic structure of the High Granularity Calorimeter (HGCAL)

What is HGCAL. Basic structure and purpose.

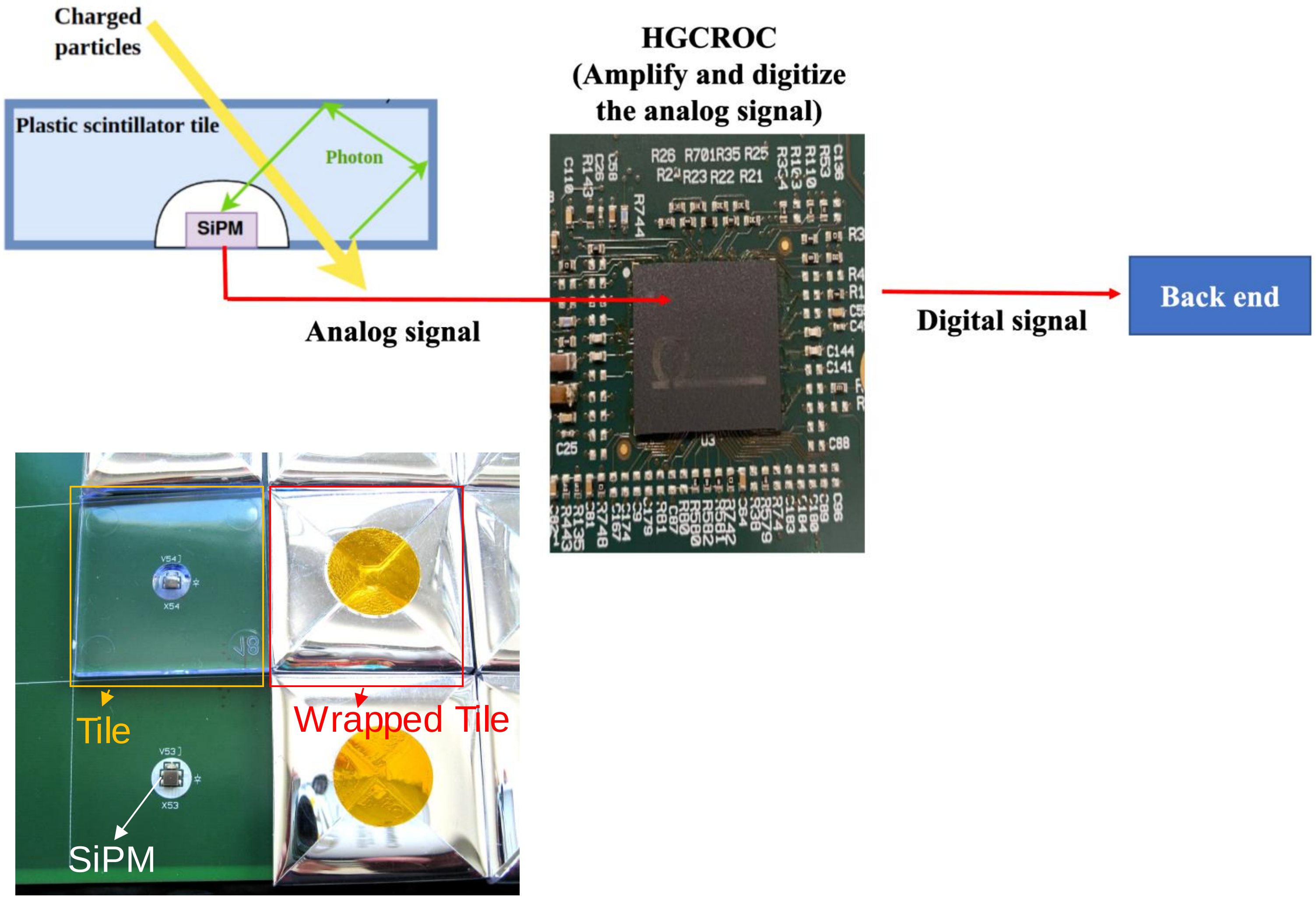
- **Silicon section** (using silicon sensors): Cover the electromagnetic calorimeter (CE-E) and part of the Hadronic calorimeter (CE-H)
- **Scintillator section** (using SiPM-on-tile technology): Cover the CE-H where the expected end-of-life neutron fluence is less than 5×10^{13} n/cm^2



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

Components, readout system

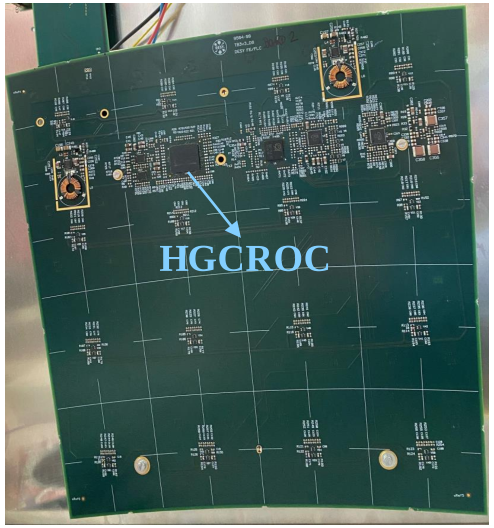
- The SiPM-on-tiles include **wrapped plastic scintillator tiles** and **silicon photomultiplier (SiPM)**
- Tiles are wrapped in reflective foil which can maximize the chance of light reaching the SiPM.
- **Smaller tile** size and **larger SiPM** size can **collect more light** to the SiPM.
- The **size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

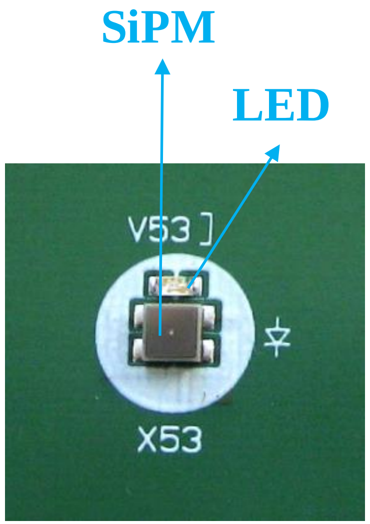


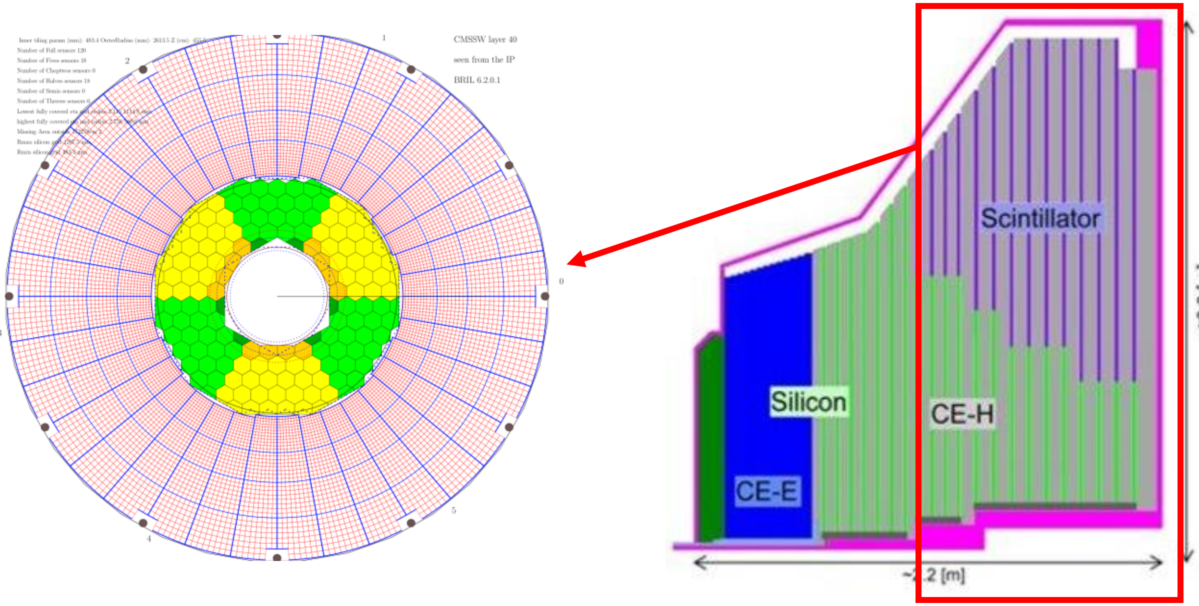
Tilemodule with SiPM-on-tile technology

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 **240k channels** in the Scintillator part in the HGCAL.
- With scintillator **tile size 4 ~ 30 cm^2**, and **SiPM size 4 mm^2** and **9 mm^2**
- 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**.

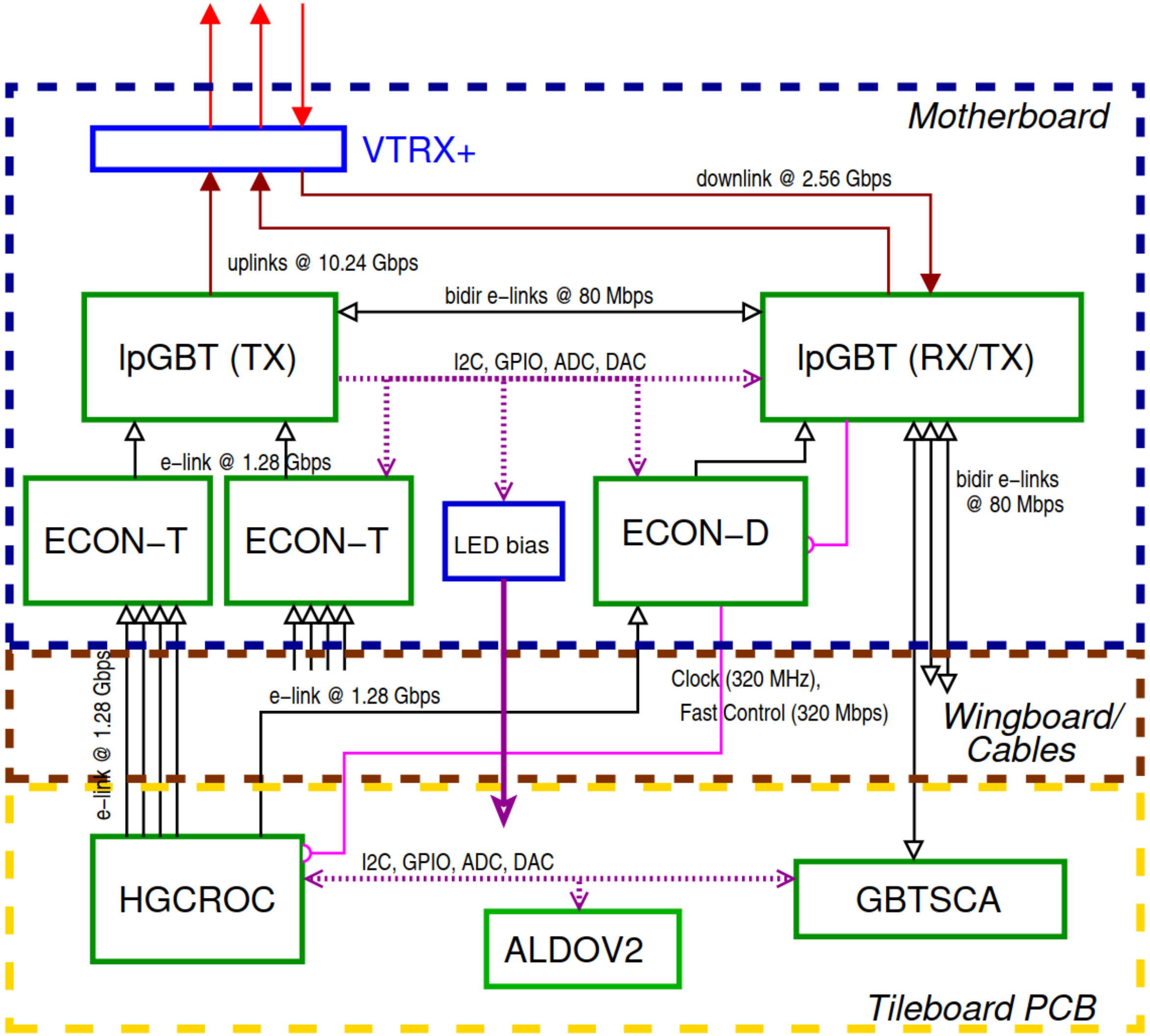


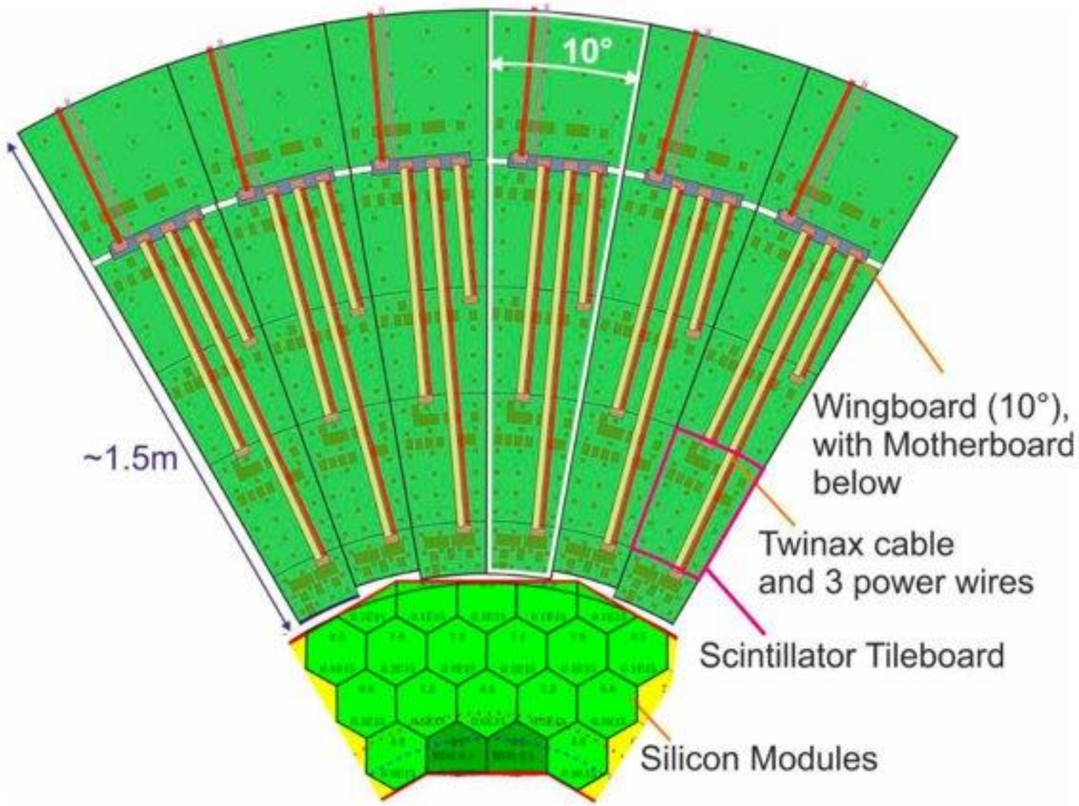




Frontend data acquisition (DAQ) system

Where the data go





Quality control and Tile assembly centre at DESY

TAC and QC

Tile Assembly Centre (TAC) at DESY is one of only two centers performing **Tilemodule production** and **quality control (QC)** at every stage for the CMS HGCAL.

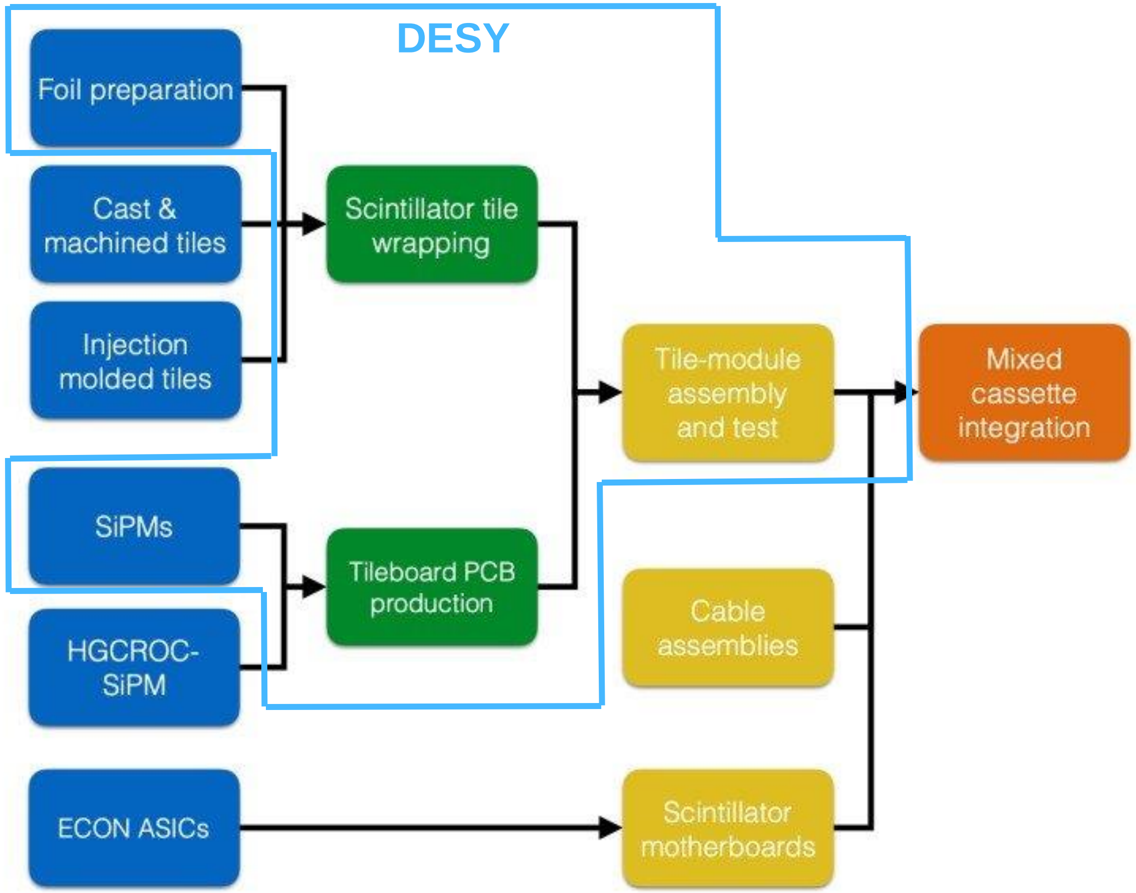
Objective is to assure top performance based on tests of small fractions of main components

Developing test stands:

- Wrapped tile size
- Light yield (LY)
- SiPM gain and saturation
- Tileboards and Tilemodules

To achieve:

- **High accuracy** of measurements at **fast pace**
- **Tile-to-tile wrapping** and **light yield uniformity**, **SiPM breakdown voltage** uniformity
- Speed of Tilemodule assembly ~**150/month**



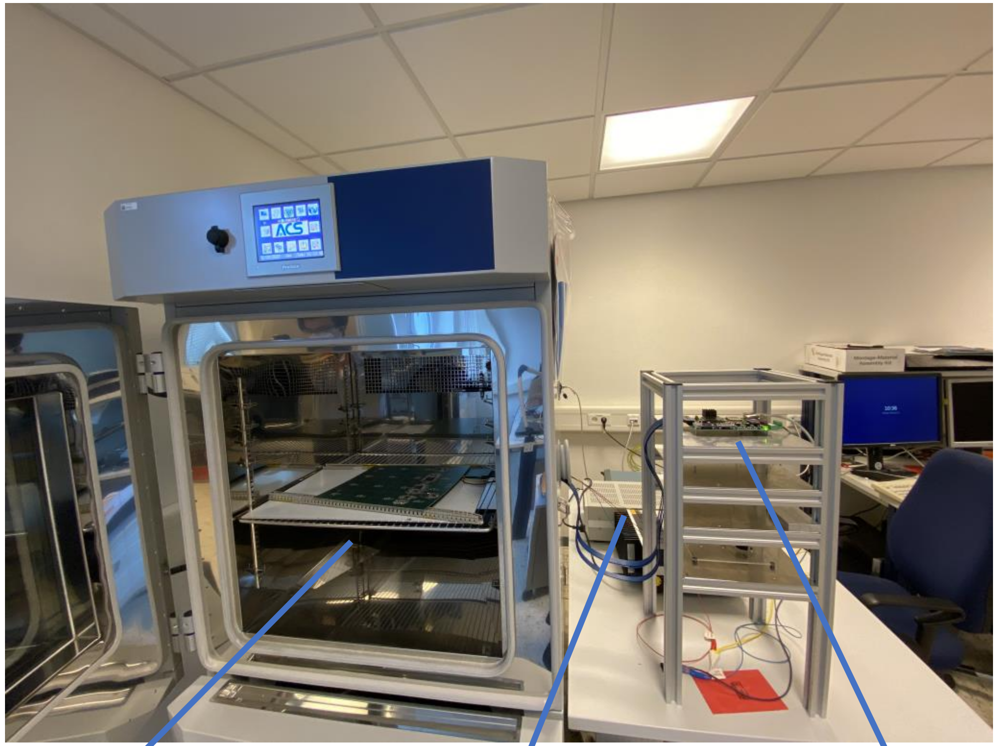
Tilemodule test stand

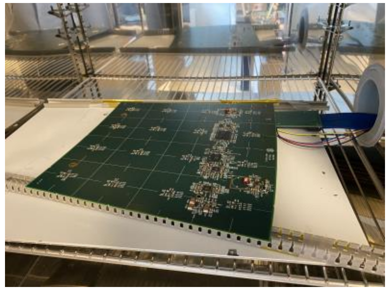
Code test

Quality control for all Tilemodules produced for the HGCAL:

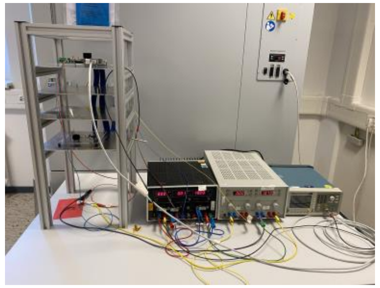
- **Thermal cycling** (-30 °C ~ 25 °C) and **cold test** using built-in LED system with climate chamber.

  - **The goal is to check if there is any disconnection or short of the electronics after cool down, and test the data read-out at -30 °C (HGCAL operation temperature).**

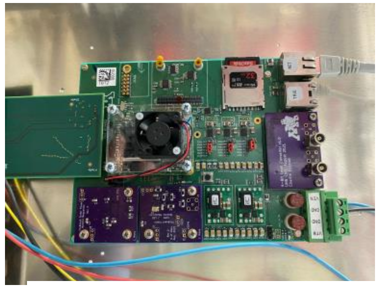




Tileboard



Power supplies



Tileboard tester
(small back-end for slow control and fast command)

Multi-Tilemodule test with cosmic ray

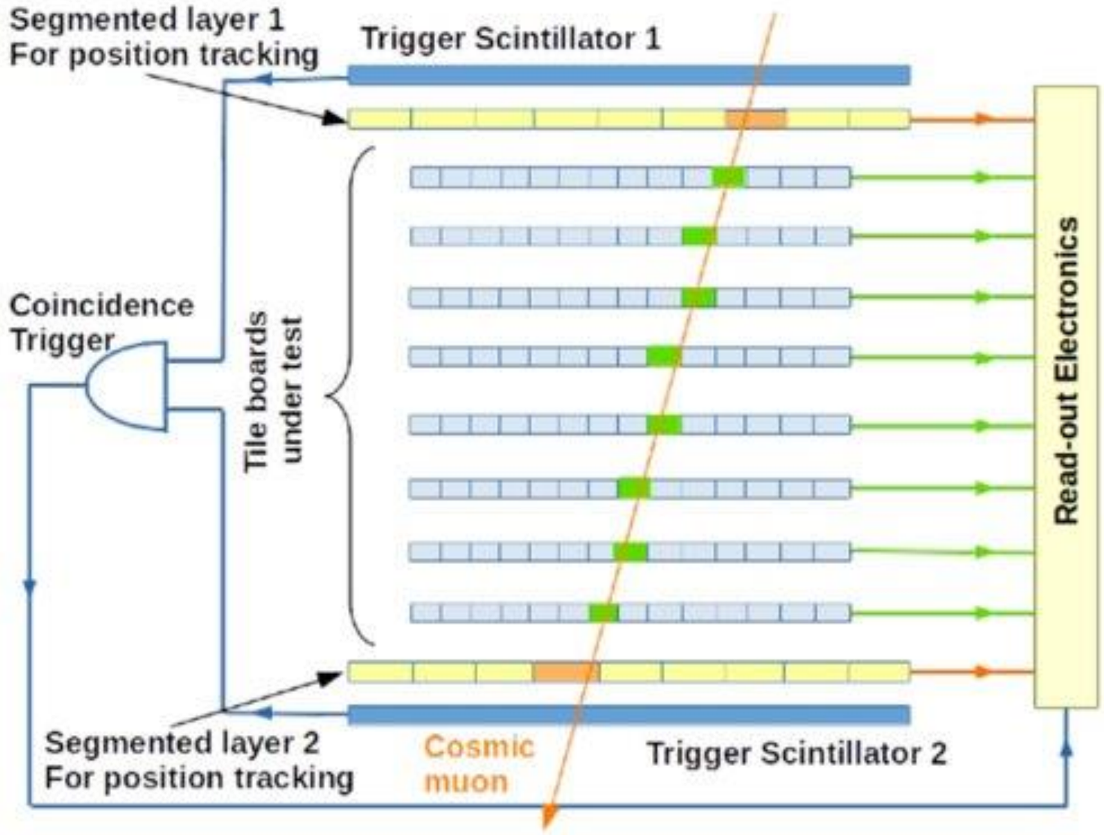
Will be used in cosmic ray test stand and also a small EM stack in test beam for quality control.

Cosmic test with multi-layer Tilemodule system.

- All Tilemodules produced for the CMS HGCAL will be tested with cosmic ray for quality control.
- MIP calibration and energy measurement.

Challenges of the multi-Tilemodule test system development:

- Synchronization of all Tilemodules in the test system. (Fast commend, slow control, trigger signal...etc)
- Required Hardware, firmware, and software are all still under development.

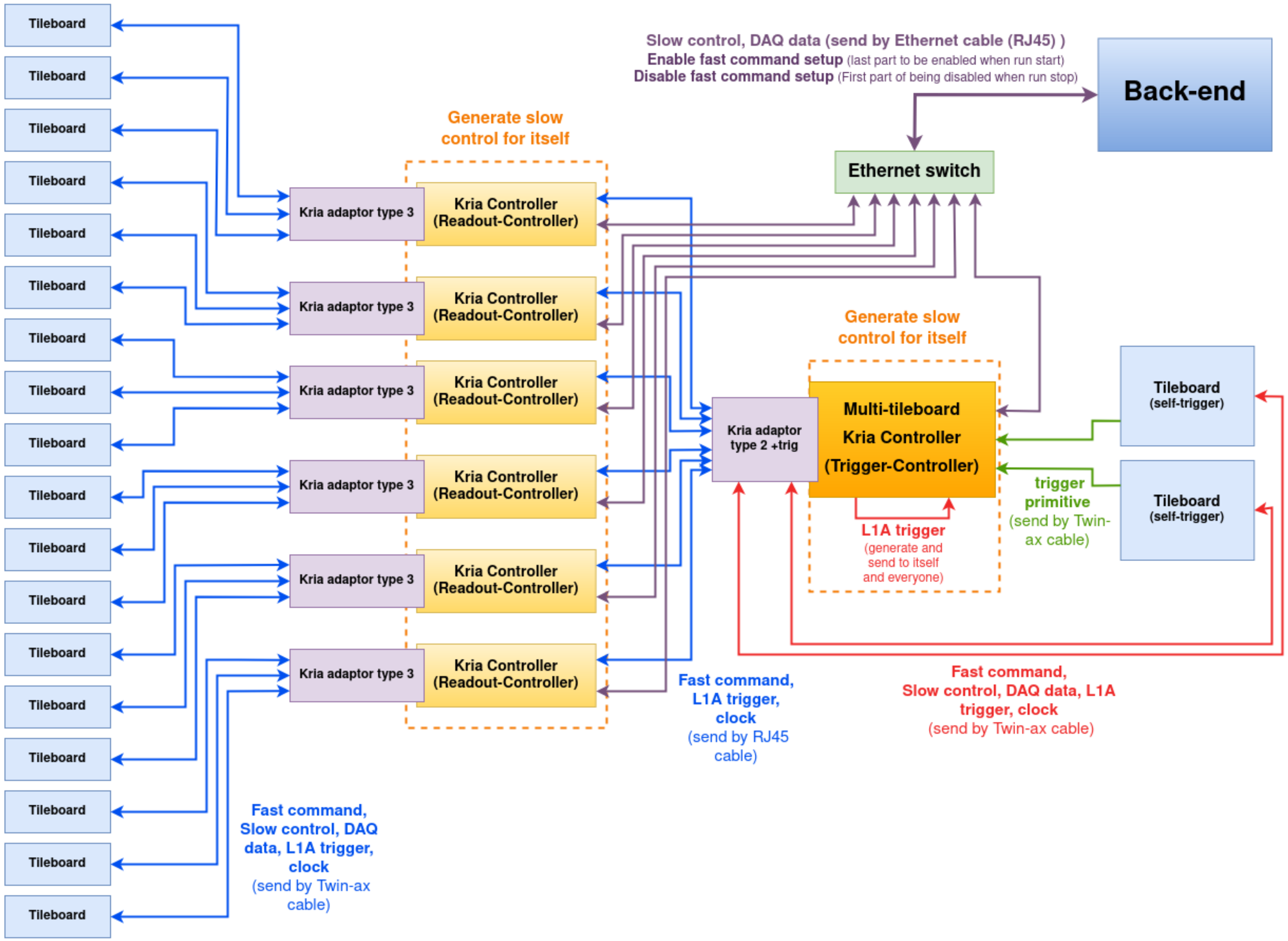


Multi-Tilemodule test system

Will be used in cosmic ray test stand and also a small EM stack in test beam for quality control.

Multi-Tilemodule testsystem (under develop)

- Can measure up to 20 Tilemodules at the same time.
- Will be used in cosmic test stand for quality control.
- The same system will be used in an EM stack (15 Tilemodules interleafed with steel absorber) for shower analysis in test beam.



Plan for the future

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

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.

Summary

- HGCAL is going to replace the current CMS endcap in the high luminosity phase of LHC.
- All Tilemodules produced for HGCAL will be tested with cosmic ray, thermal cycling and cold test.
- Full production of the Tilemodule will start next year.
- Multi-Tilemodule test system under development.

Thank you

Contact

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Synchrotron DESY

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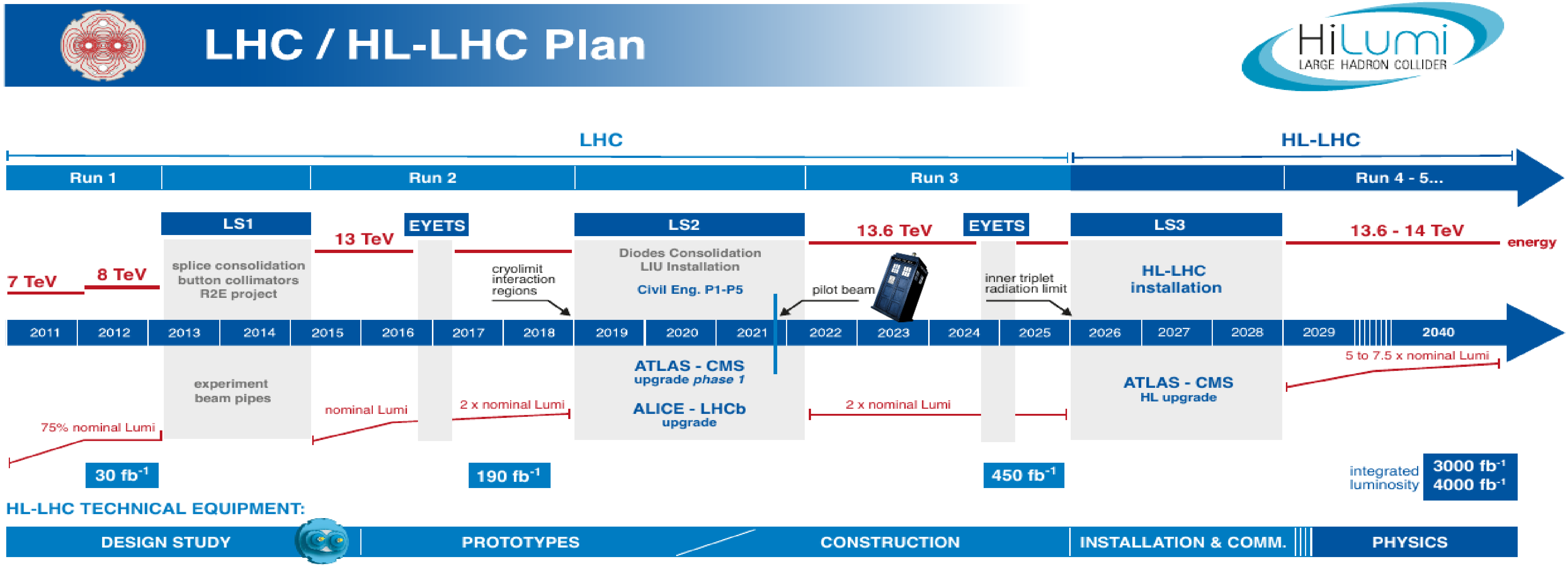
Backup

Schedule of the HL-LHC

Plan for the next decays



- Lowering, installation, and commissioning of the detector will be done during Long Shutdown 3 (LS3).
- Expected instantaneous luminosity = 5×10^{34} /cm²s, and pileup = 140 (can reach 50 % even higher)

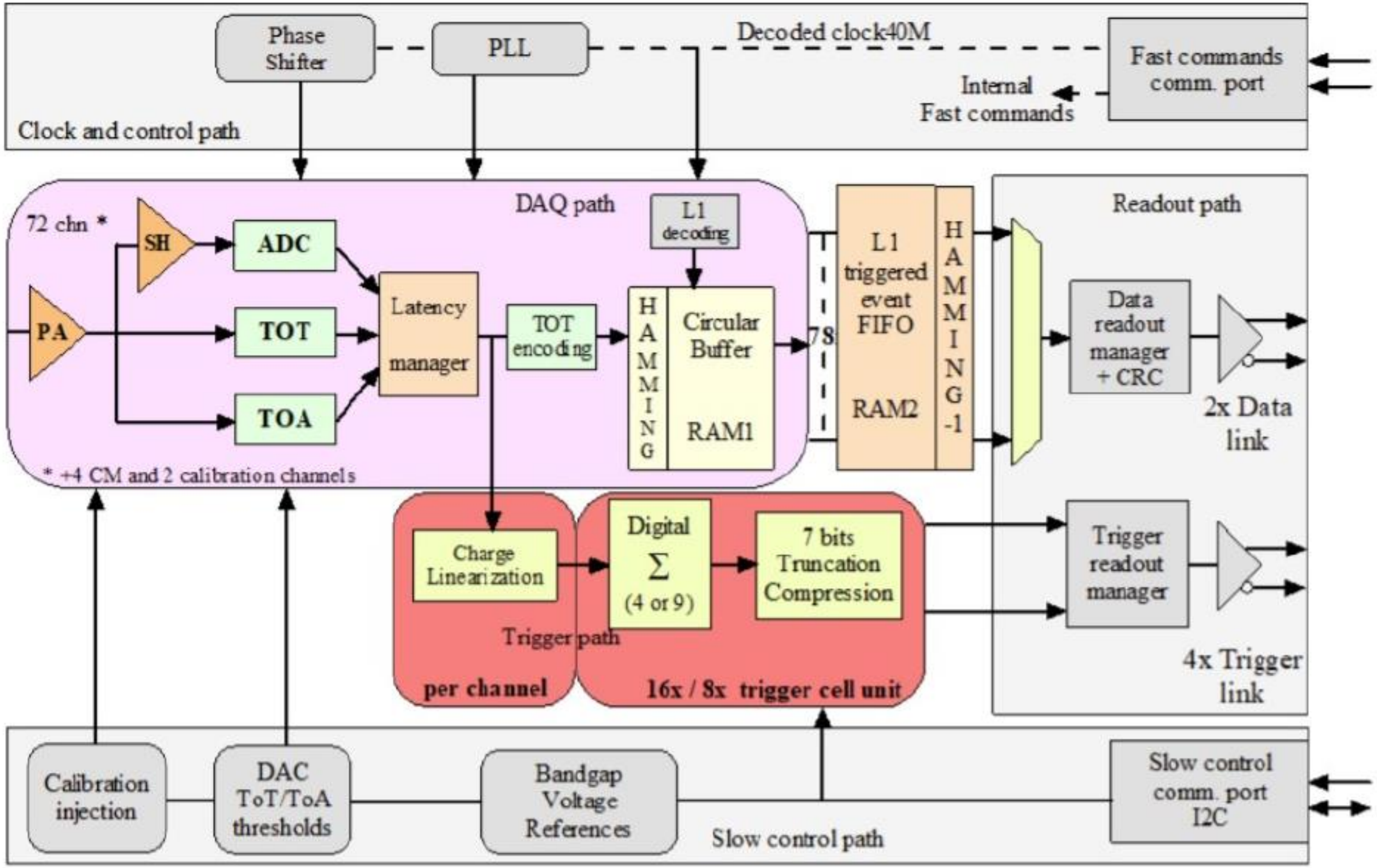
HGCAL readout chip (HGCROC)

Informatino about the data readout chip

- 72 active channels, 2 calibratin channels, and 4 common mode channels.
- Dynamic range ~ 0.2 pC to 10 pC.
- Peaking time ~ 20 ns.
- Linearity < 1%.
- Energy measurement:

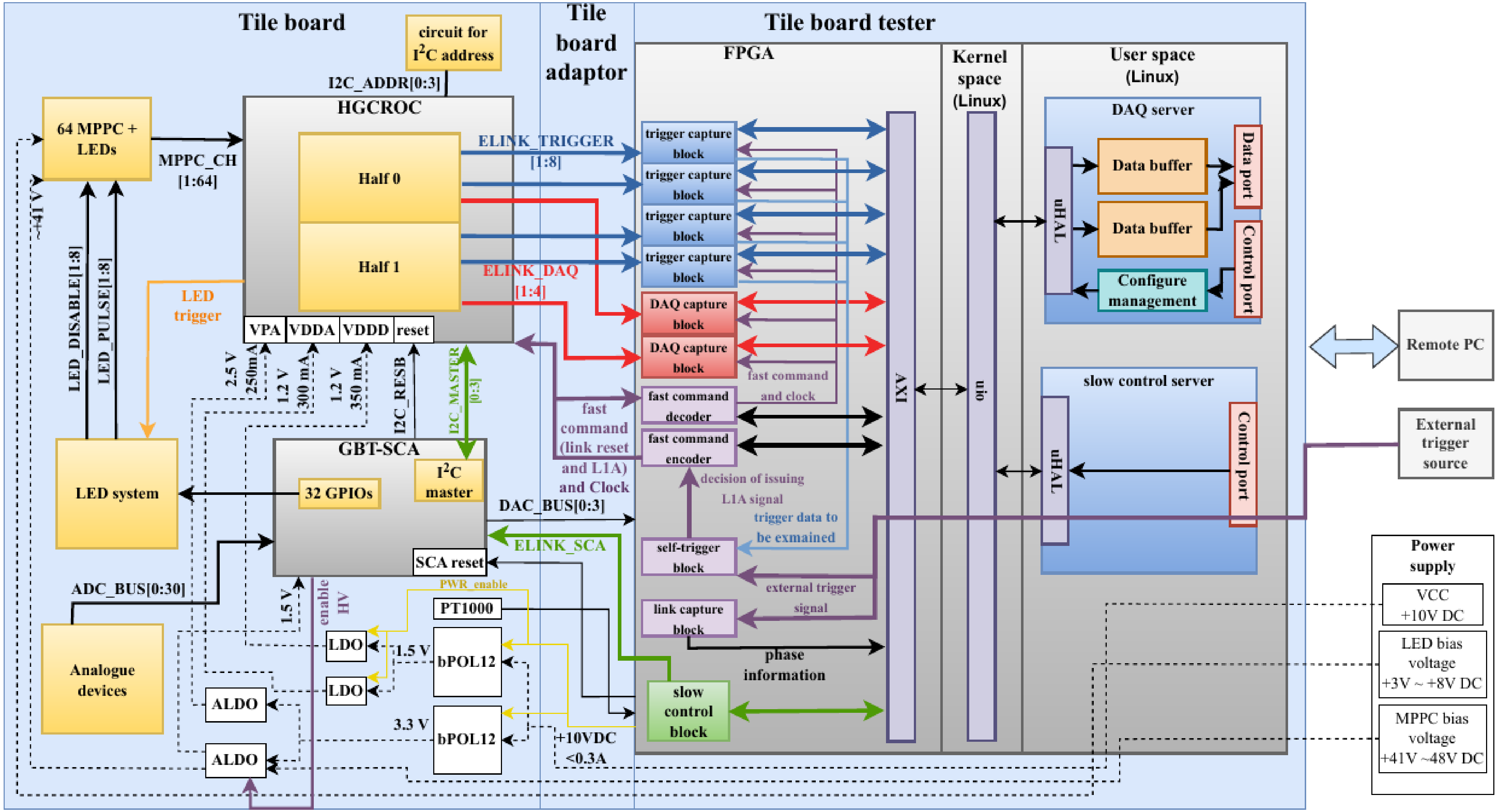
  - ADC 10-bit SAR, range 0 ~ 100 fC

  - TOT range 100 fC ~ 10 pC, with bin size = 2.5 fC.
- TOA: 10-bit TDC, LSB < 25 ps, 25ns full range
- Data readout path: Latency up to 12.5 μs. With 2 outputs in 1.28 Gbps.
- Trigger readout path: Latency up to 36 BX. With 4 outputs in 1.28 Gbps.
- 320 MHz clock.



Single Tilemodule test system

Block diagram



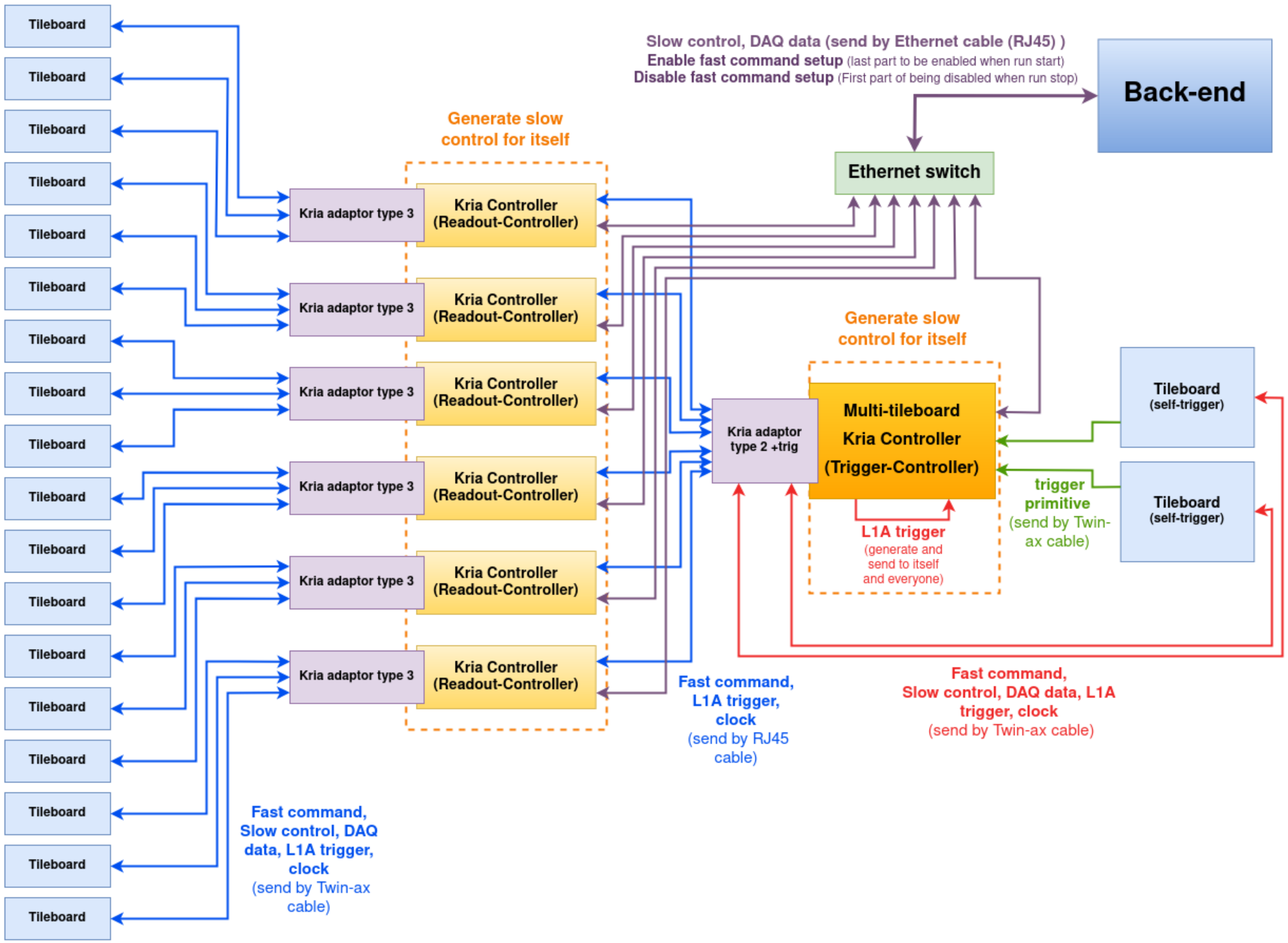
Block diagram made by Jia-Hao Li

Block diagram of the multi-Tilemodule test system

On the hardware perspective, what do we need

The system includes

- 7 Kria controllers
  - 1 as Trigger-Controller
  - 6 as Readout-Controllers
- 1 Kria adaptor type 2 + trig
- 6 Kria adaptor type 3
- 20 Tilemodules
  - up to 18 Tilemodules under test
  - 2 triggering Tilemodules
- 1 ethernet switch
- 1 PC and power supplies



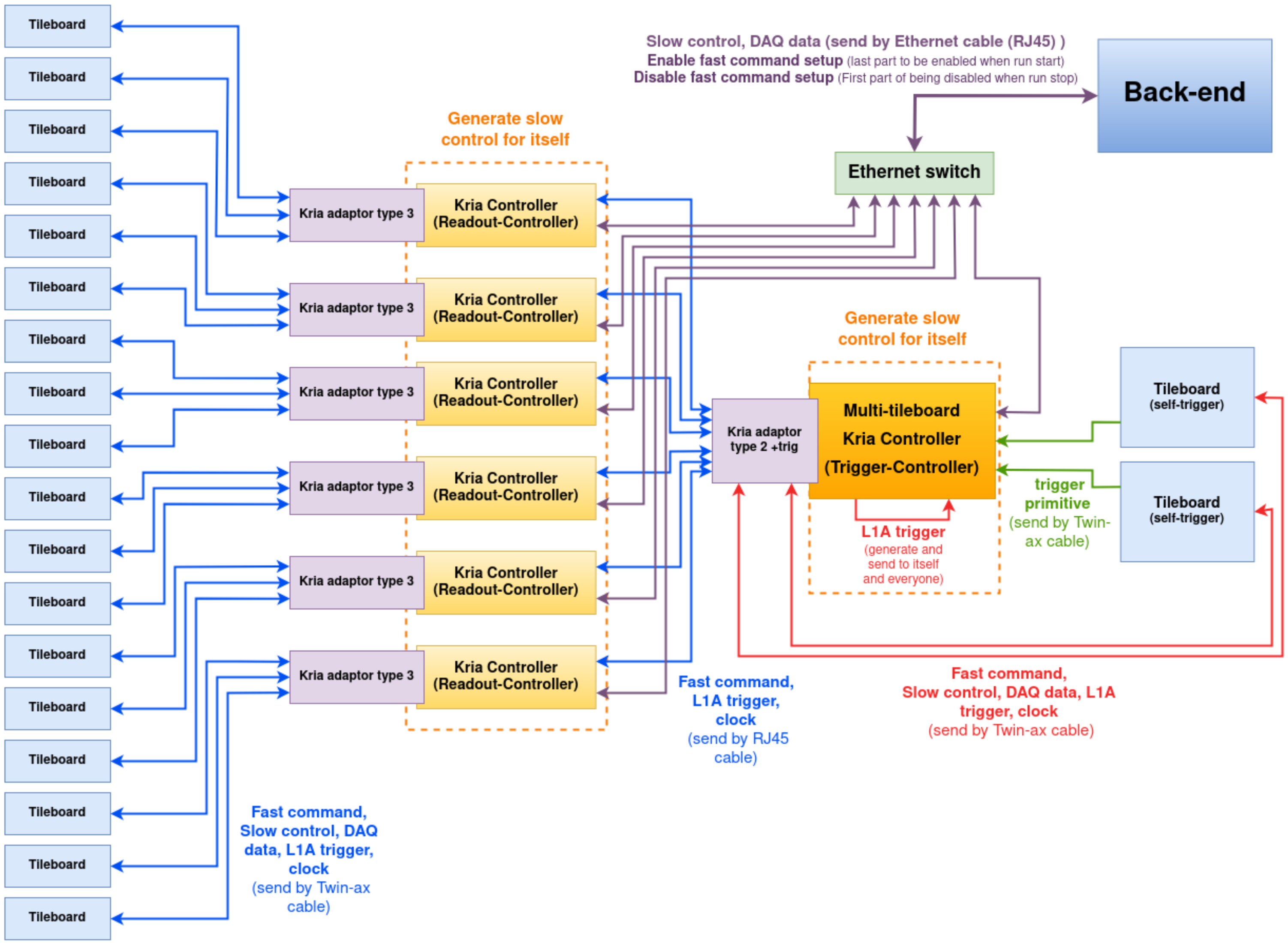
L1A trigger of the multi-Tilemodule test system

How the system generate the L1A trigger

- **The L1A trigger will be generated by the Trigger-Controller**.
- The L1A trigger is encoded in the fast command stream.
- **Steps:**

  - 2 **triggering Tilemodule** will **sent trigger primitives** (trigger sums over 4 cells every 25 ns) by trigger elinks

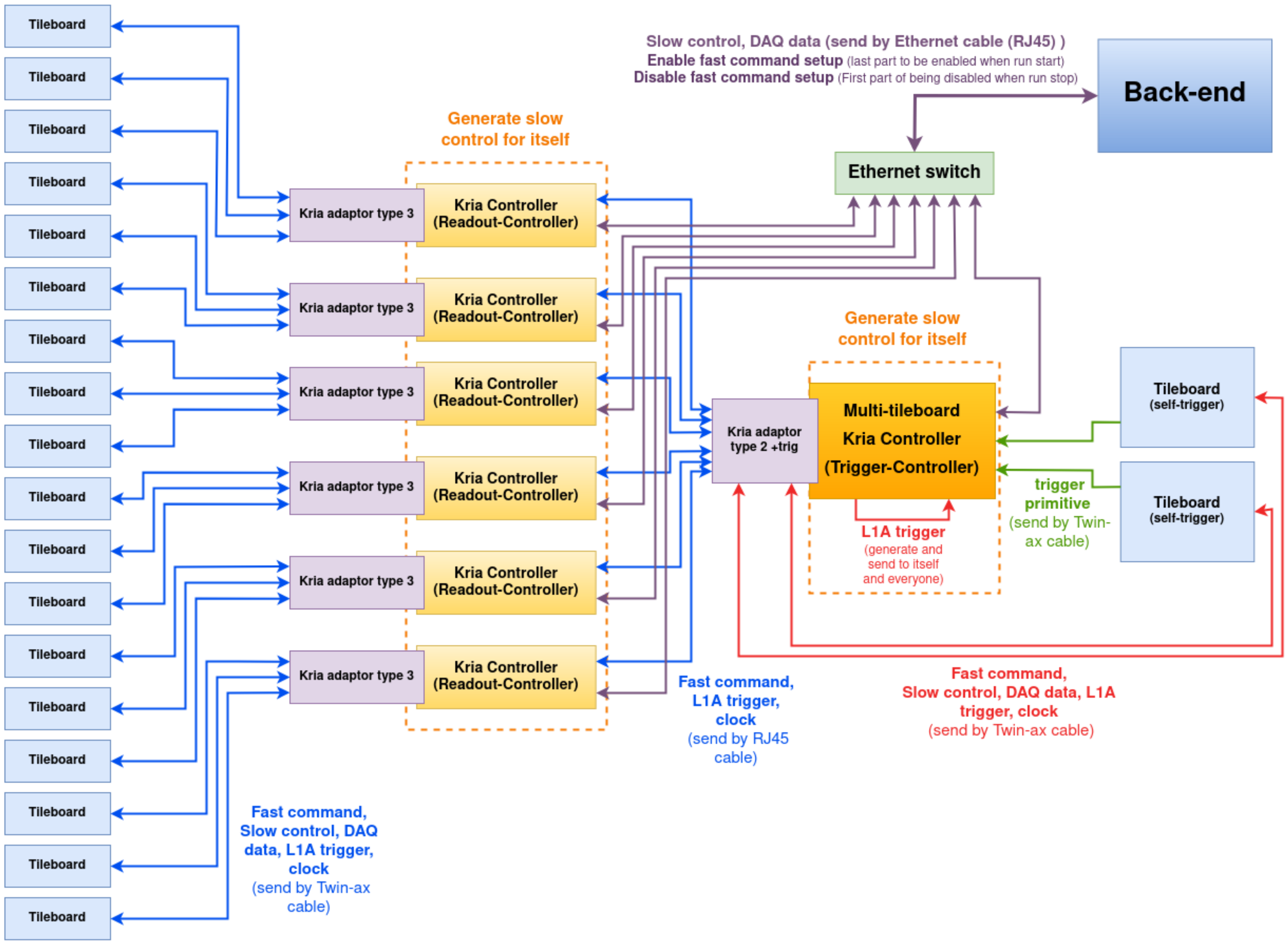
  - The Trigger-Controller will process this trigger information and make the decision to generate the L1A trigger if not receiving any "busy" flag from other Tileboards.



L1A trigger of the multi-Tilemodule test system

How the system generate the L1A trigger

- The Trigger-Controller will apply some **algorithms** for making the decision, such as **coincidence**, **masking with respect to time** to avoid two L1A triggers too close to each other.)

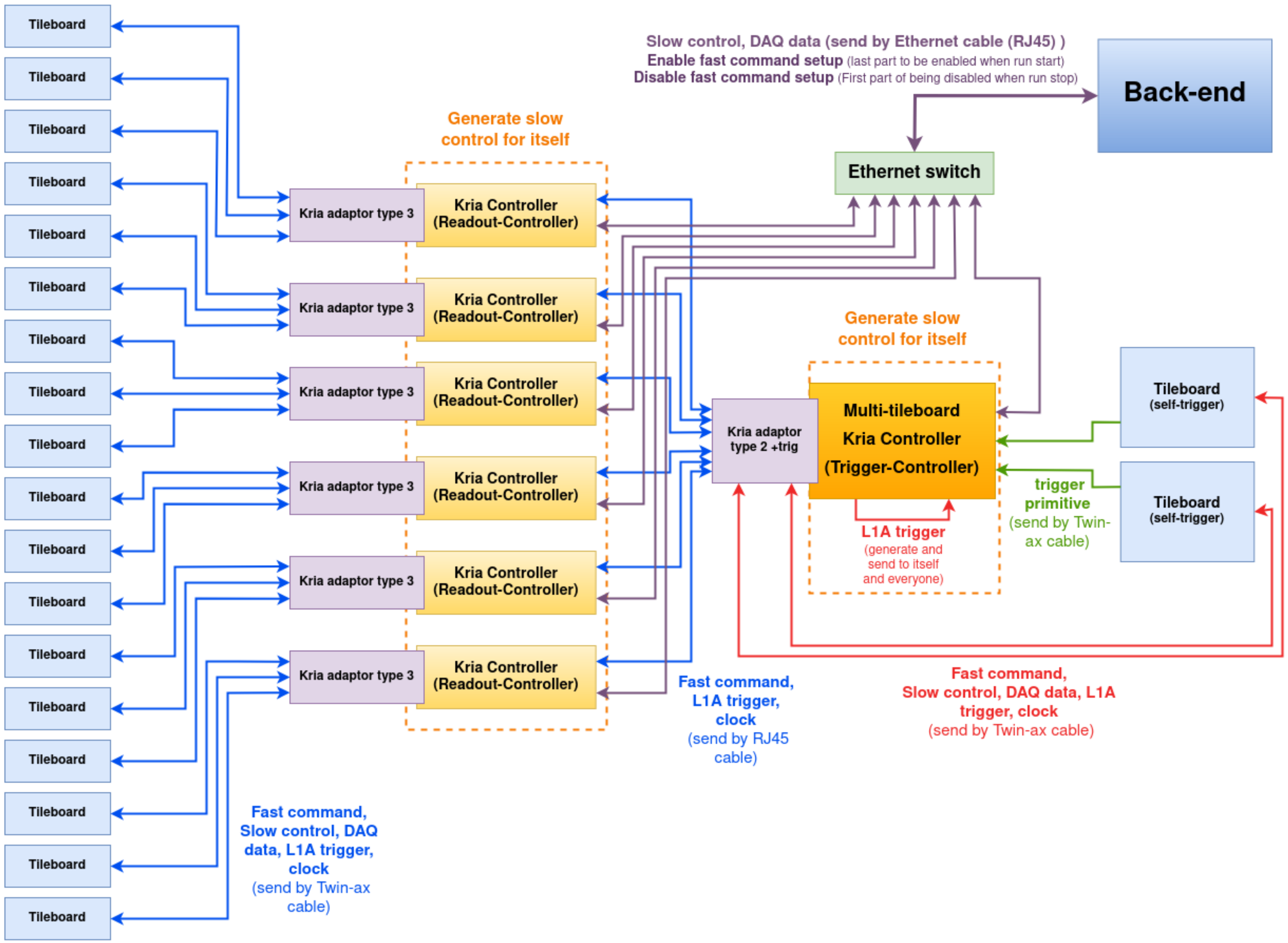


Slow control of the multi-Tilemodule test system

How the system generate the slow control

- **The slow control will be generated by the Trigger-Controller and Readout-Controller themself seperately.**

  - all 7 Kria controller are connectted to the Back-end through Ethernet cable.

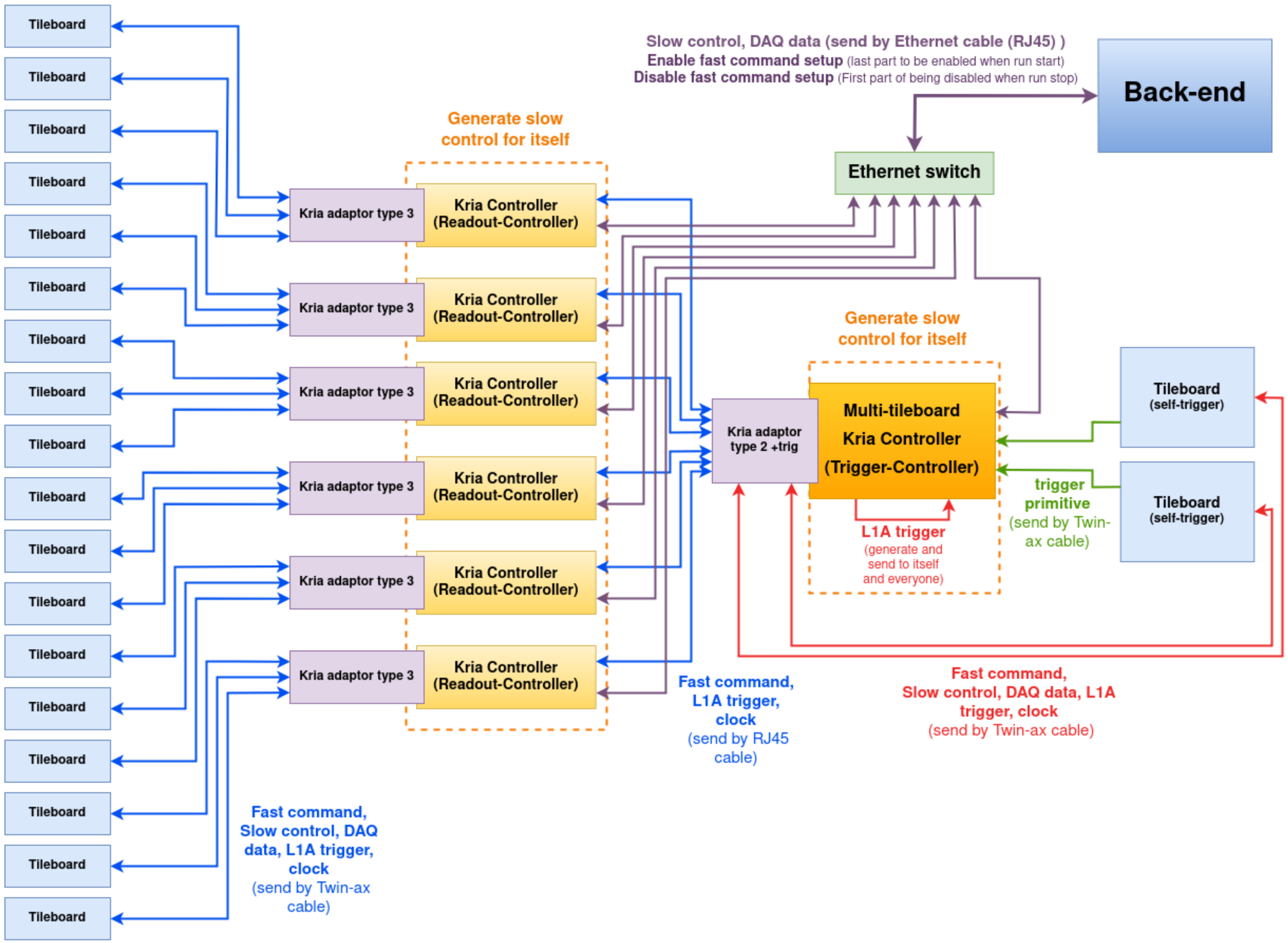


Fast command of the multi-Tilemodule test system

How the system send fast command

- **The fast command is send from the Trigger-Controller.**
- The fast command setup in the Trigger-Controller will be enable or disable through ethernet cable from the back-end.
- The fast command setup is the last one to be enabled when a run starts. And it is the first one to be disabled when a run stop.
- The fast command goes:
  - Trigger-Controller -> Kria adaptor type 2 +trig -> RJ45 cable -> Readout-Controller-> Kria adaptor type 3 -> Tilemodules-under-test

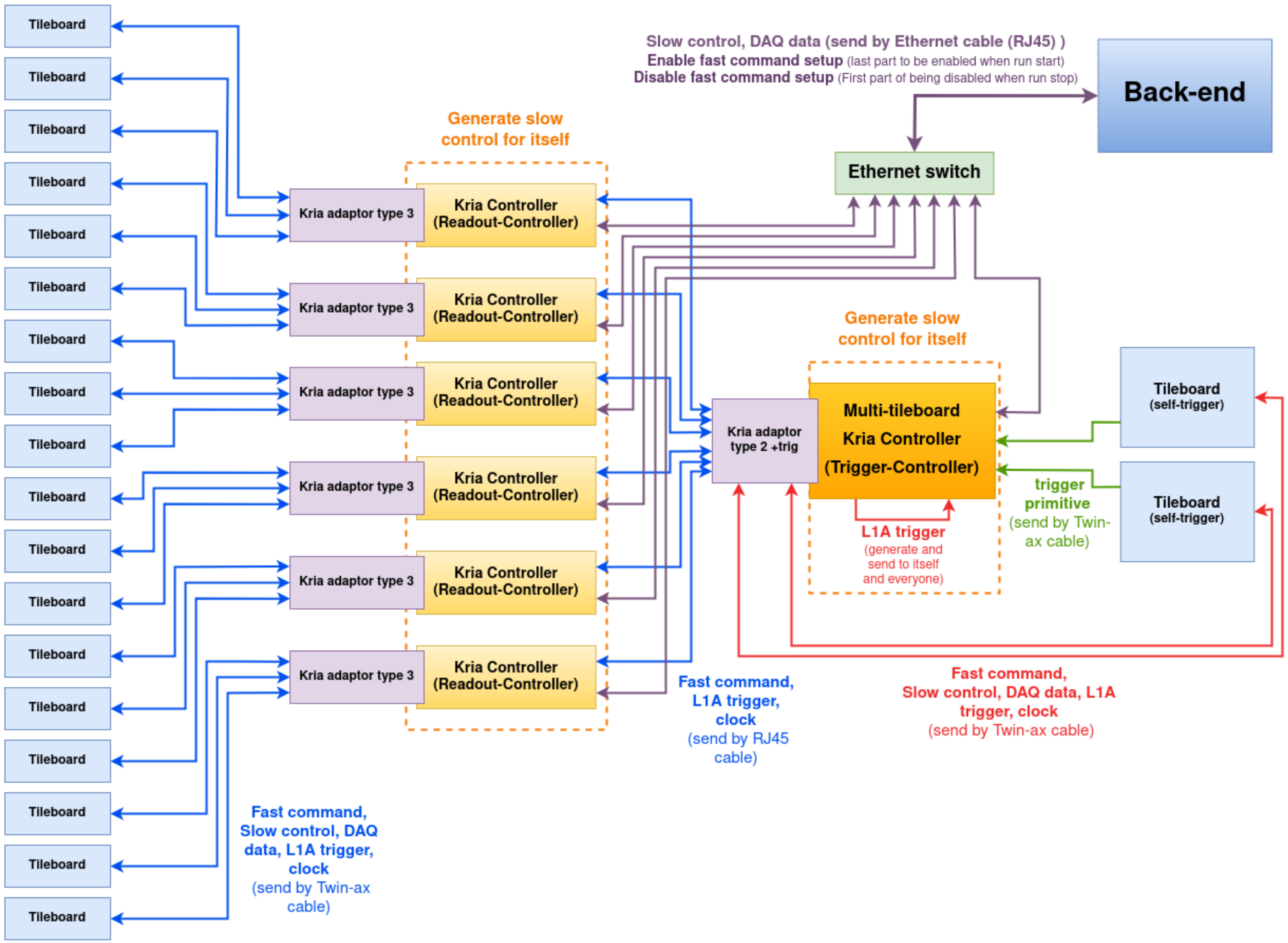
  -Trigger-Controller-> Kria adaptor type 2 +trig-> triggering Tilemodules



DAQ data of the multi-Tilemodule test system

How the system collect DAQ data

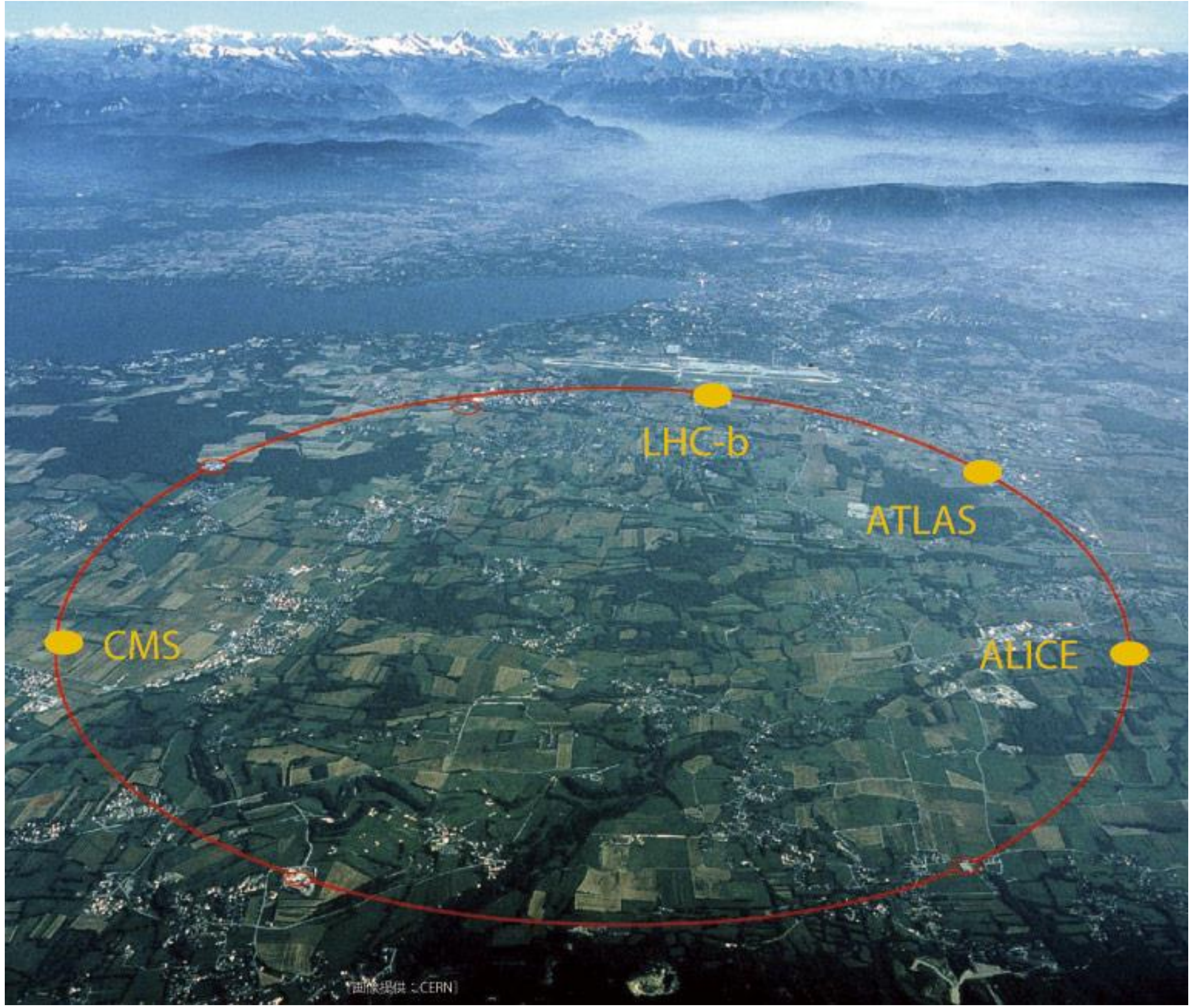
- **The DAQ data of all 20 Tilmodules (18 Tilmodule-under-test + 2 triggering Tilemodules) are collected from the 7 Kria controller through ethernet cable.**



01 Introduction

The Large Hadron Collider (LHC) at CERN

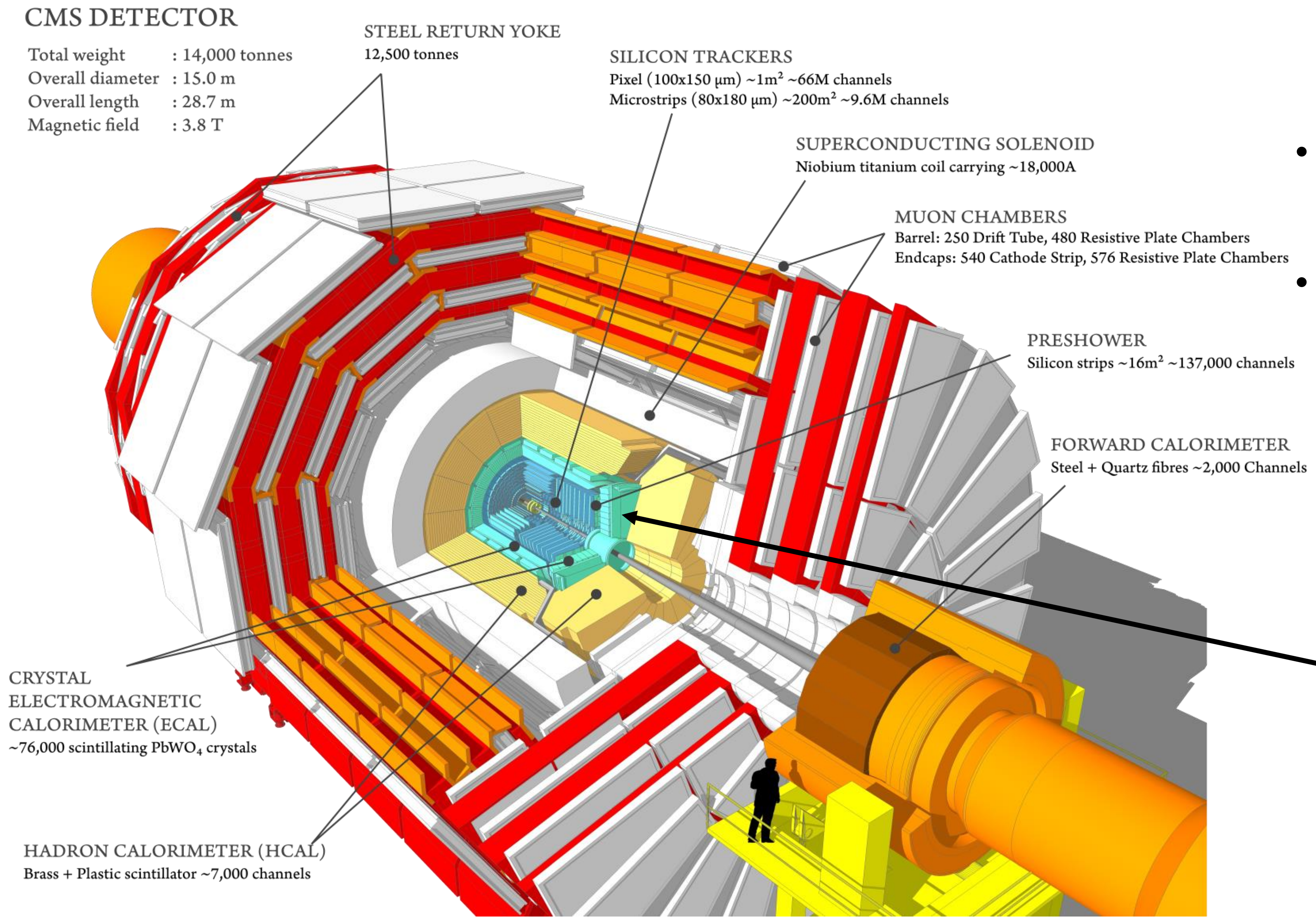
Basic information



- The **largest particle accelerator in the world**.
- Located **100 metres underground** at CERN with **27 km** superconducting magnet **ring**.
- **4 collision points** around the accelerator ring.
- **4 different particle detectors** in each collision point: **CMS, ATLAS, ALICE, and LHCb**.
- **Goal**: Standard model physics, the origin of mass, supersymmetry, dark matter, dark energy, matter v.s antimatter, quark-gluon plasma...etc.

The Compact Muon Solenoid (CMS) detector

Basic information



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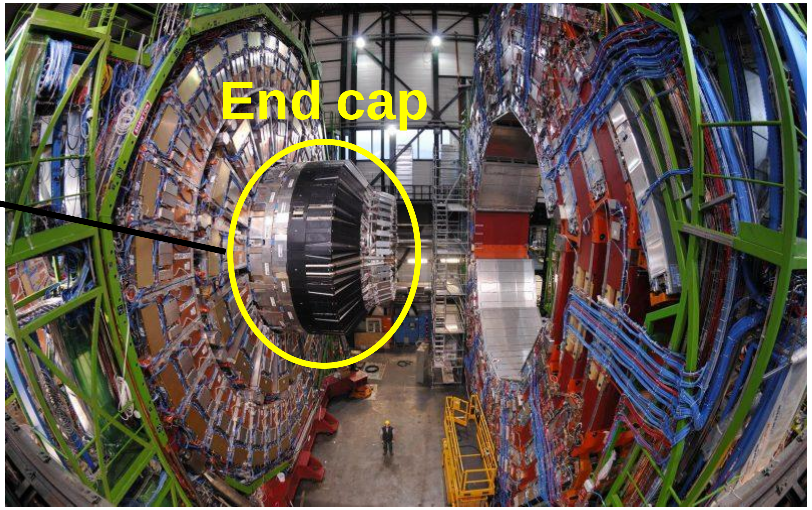
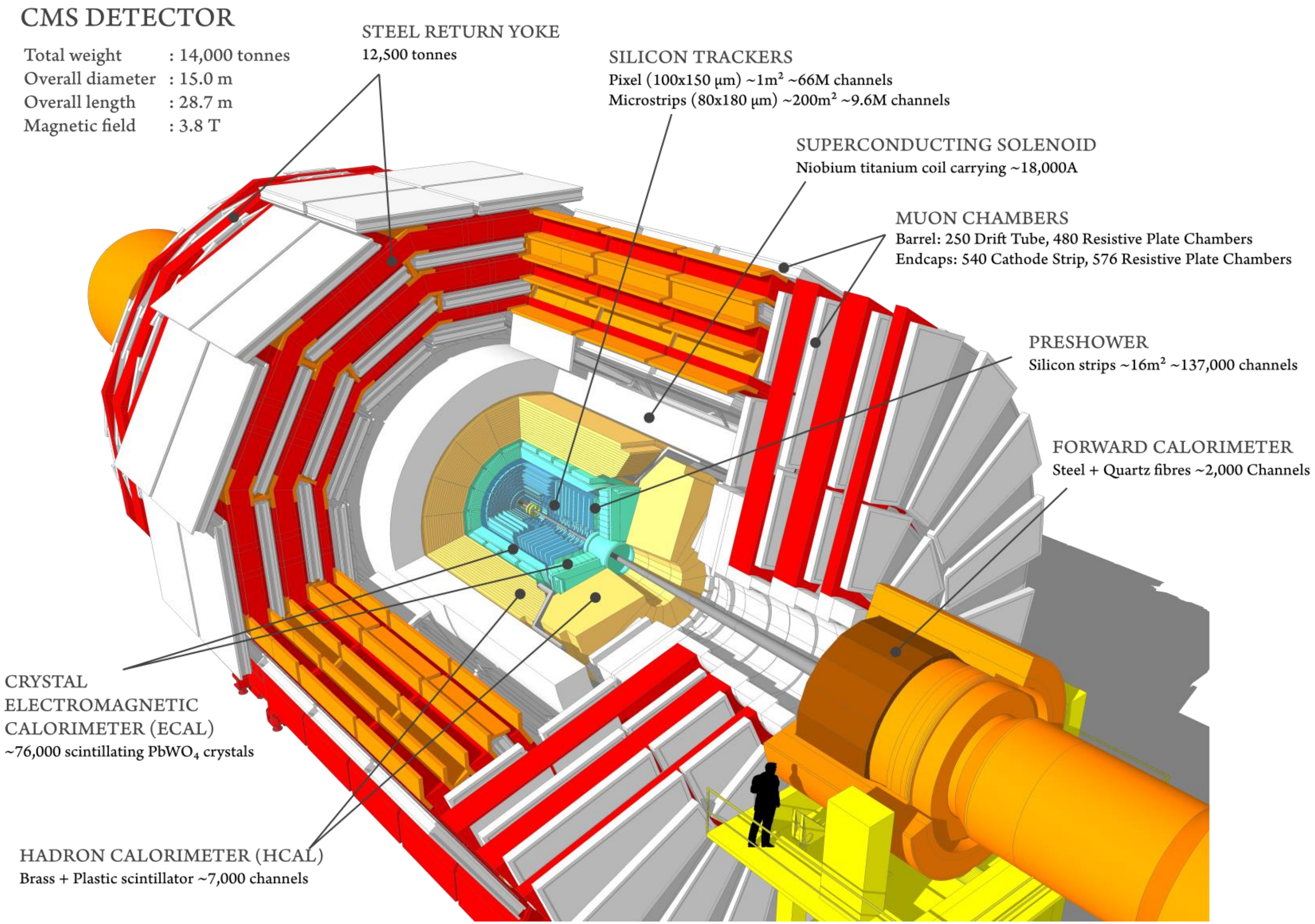


The Compact Muon Solenoid (CMS) detector

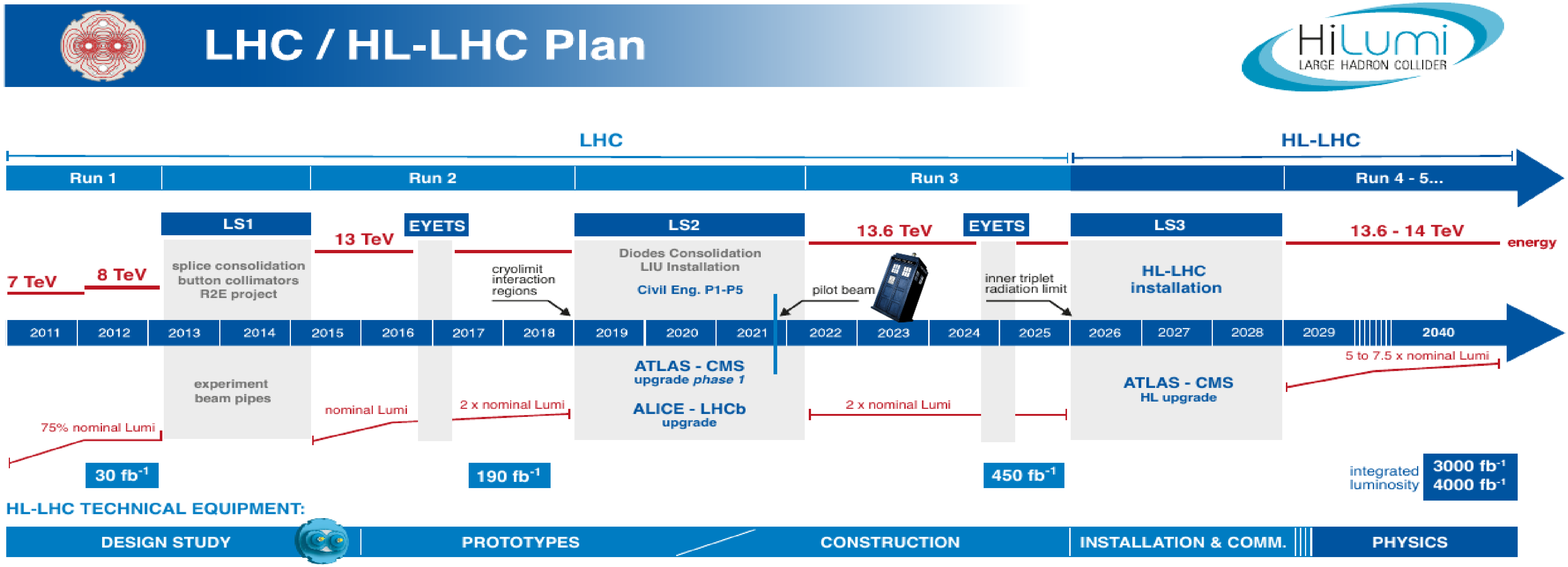
How it works.



1. **Bending** the trajectories of charged **particles** (by using magnetic field ~ 4 tesla): identify particle charge, measure particle momentum.
2. **Identifying tracks** of the bent charged particles (done by silicon tracker)
3. **Measuring energy** of particles produced in each collision: Electromagnetic Calorimeter (ECAL) => electrons, photons. Hadron Calorimeter (HCAL) => hadrons (quarks and gluons)
4. **Detect Muons**: can also measure its momentum by tracking devices and muon chambers.

Schedule of the HL-LHC

Plan for the next decays



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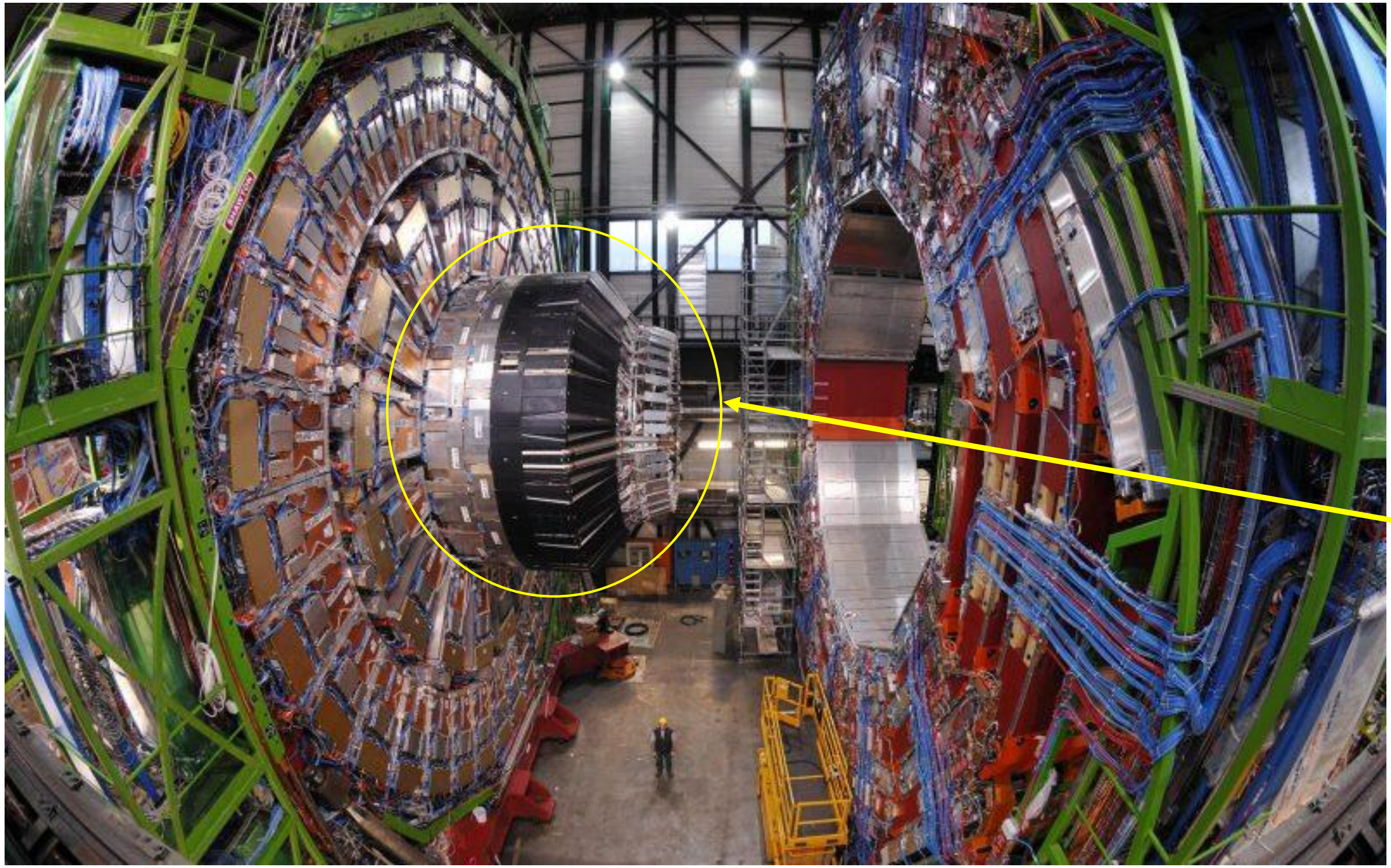
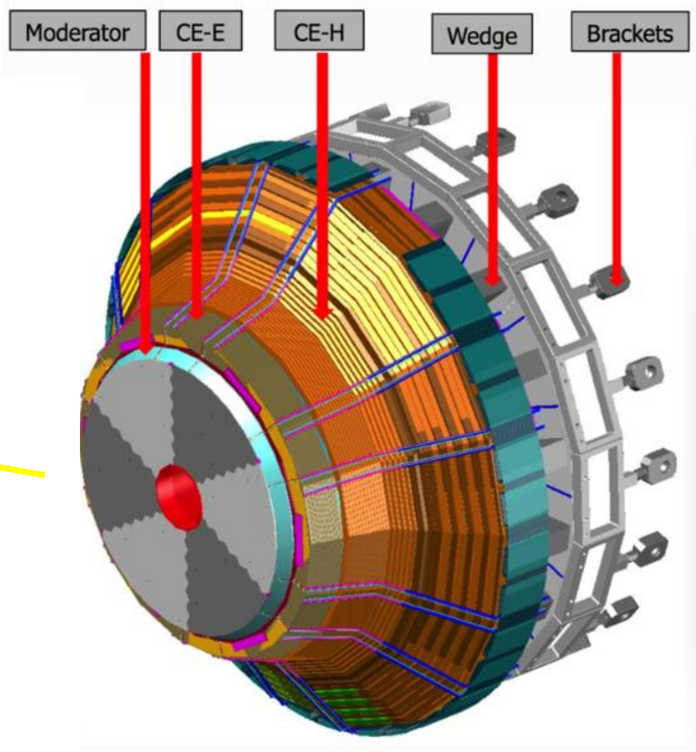
High Granularity Calorimeter (HGCAL)

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 in the **HL-LHC**.

What is HGCAL, and why do we need it

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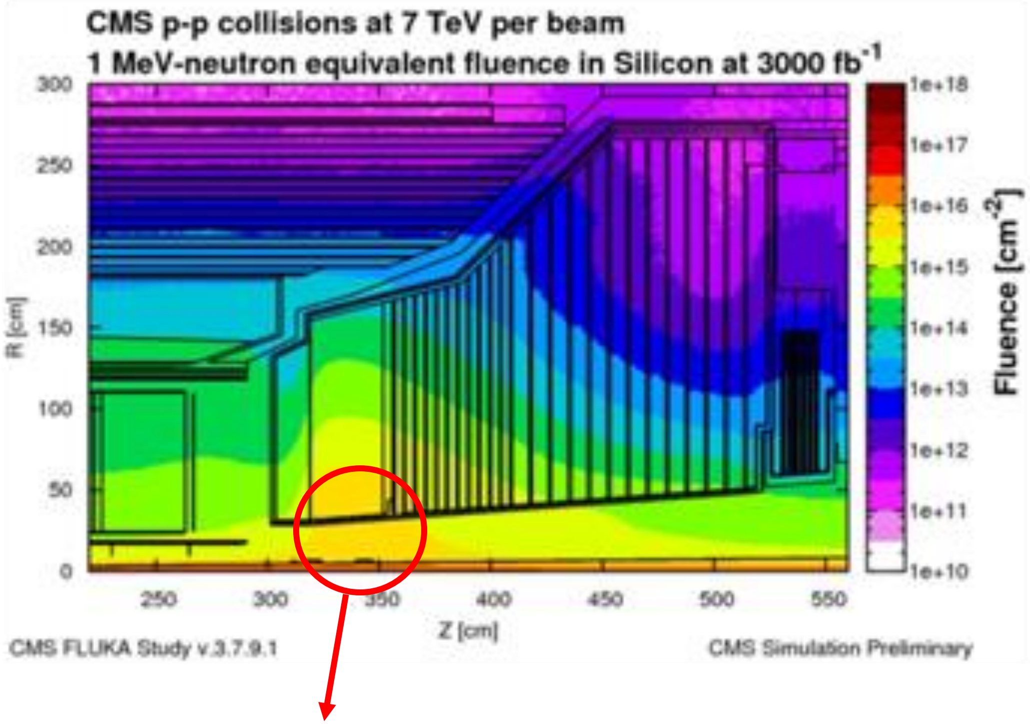

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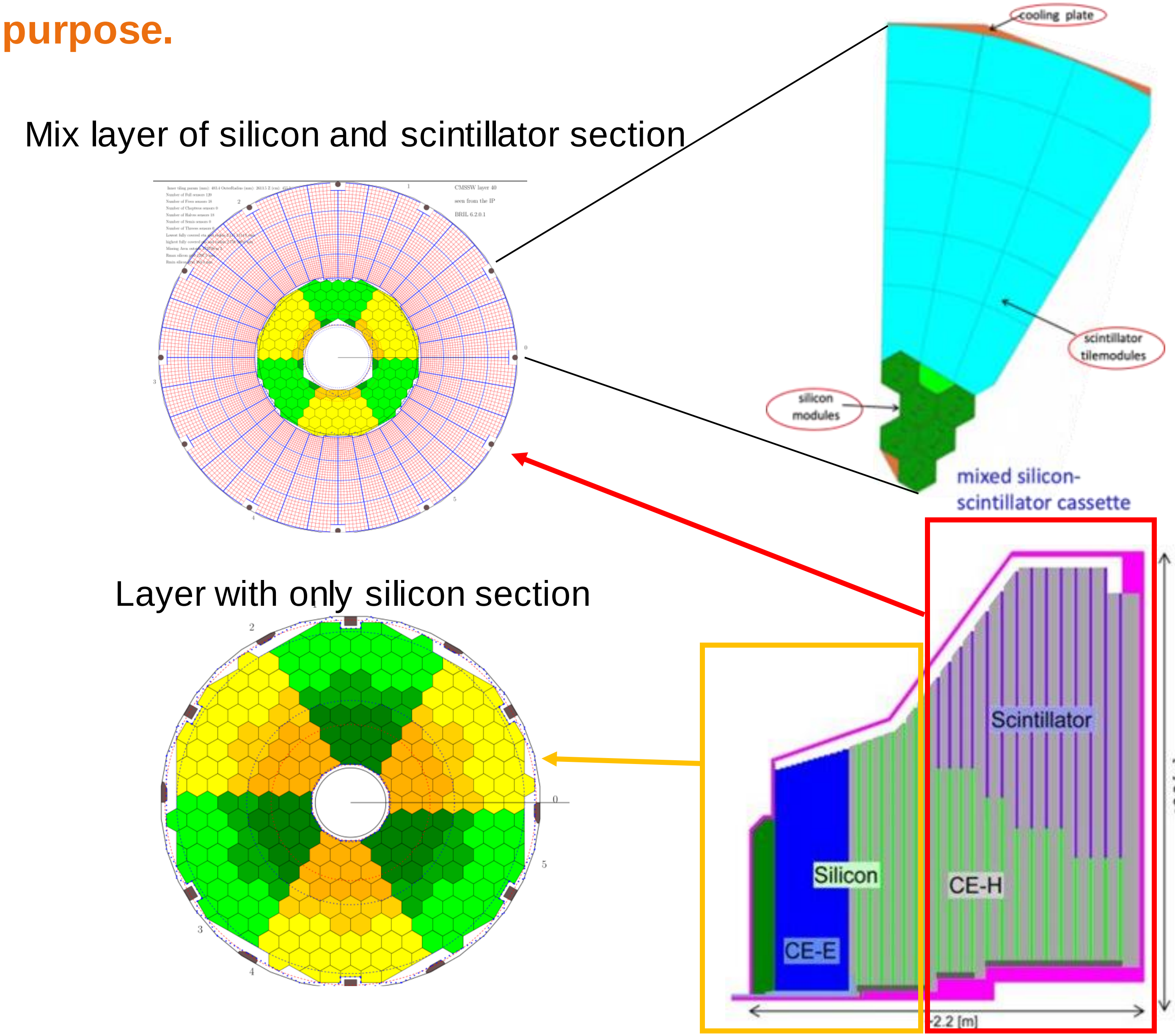


Basic structure of the High Granularity Calorimeter (HGCAL)

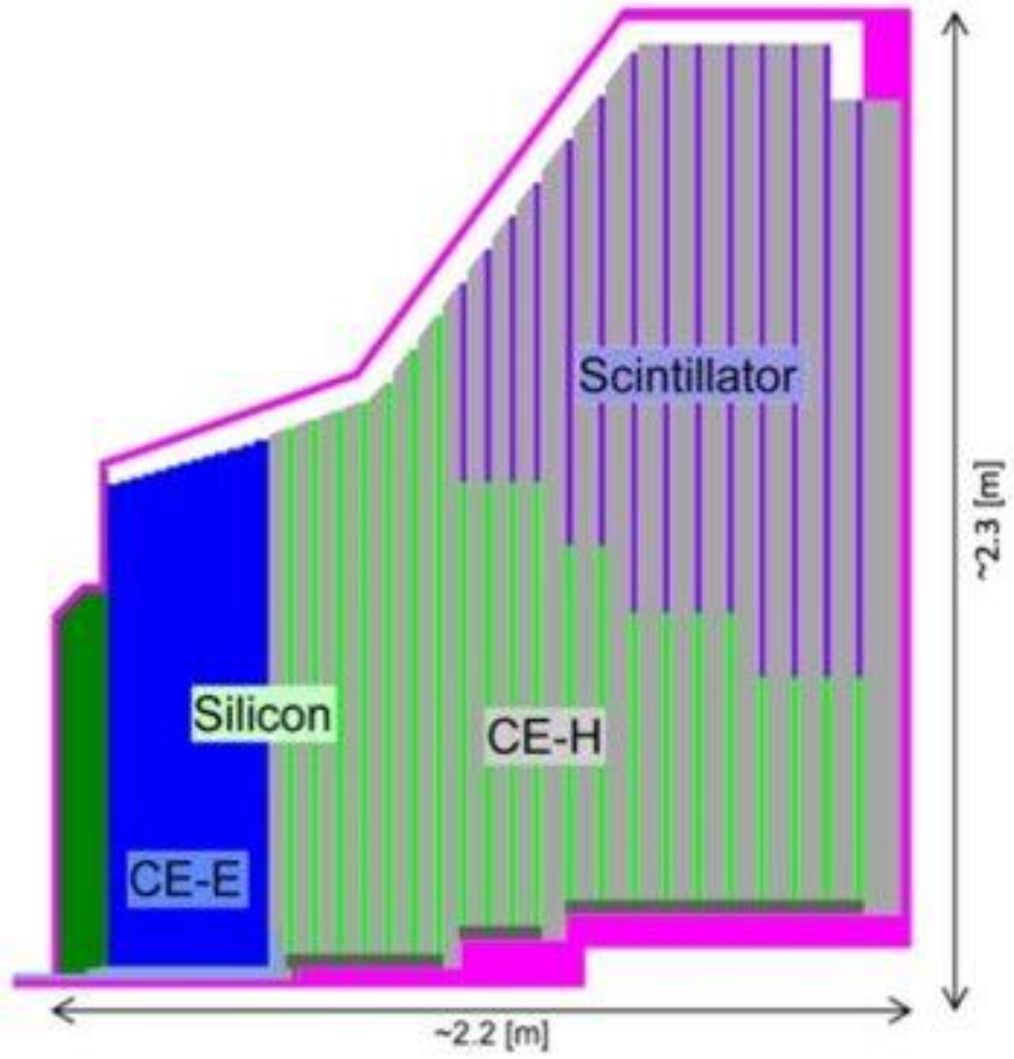
Active elements and key parameters

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
~620m² Si sensors in ~26000 modules
~6M Si channels, 0.6 or 1.2cm² cell size
~370m² of scintillators in ~3700 boards
~240k scint. channels, 4-30cm² 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

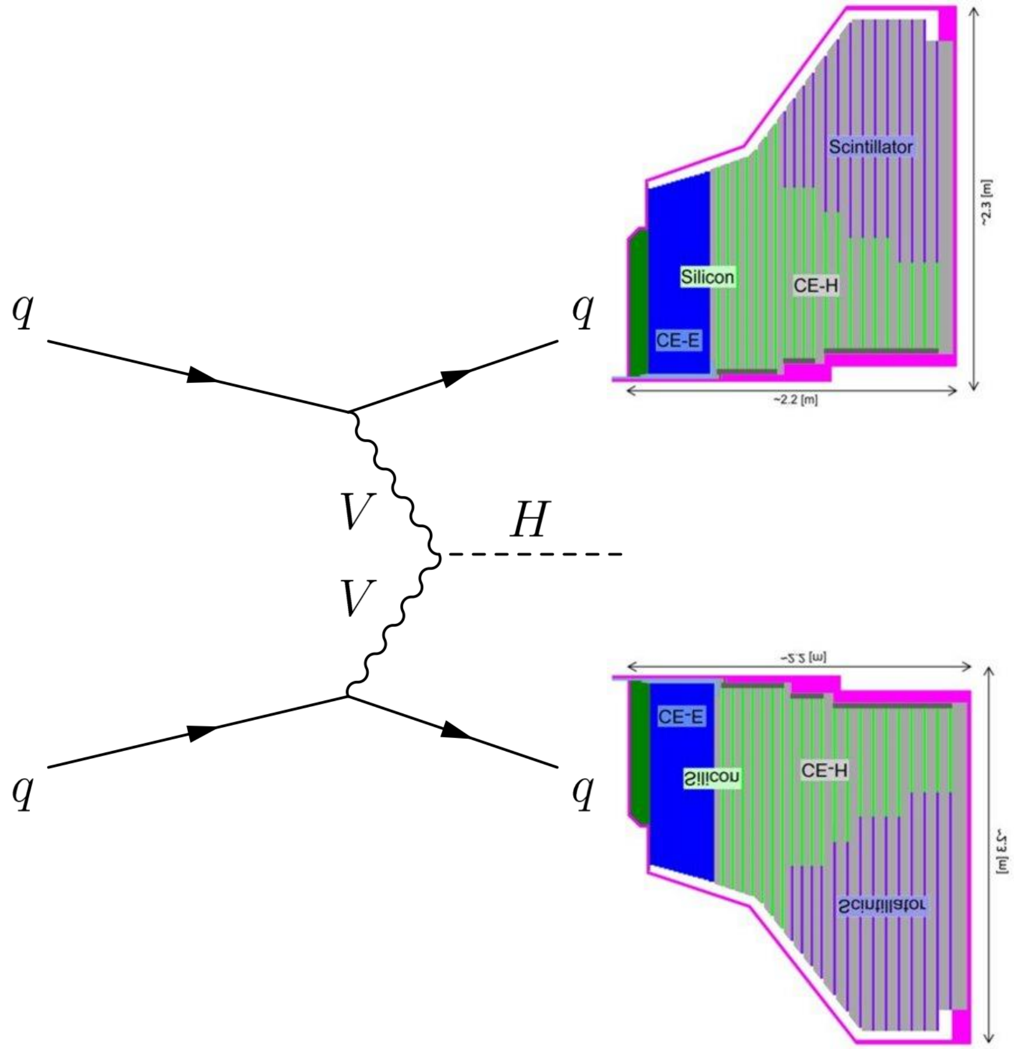
Physics motivations

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

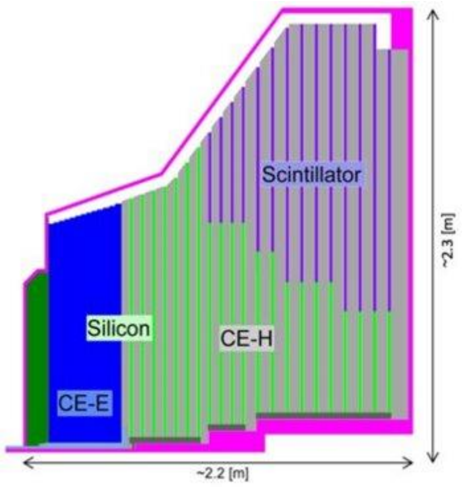
- The **high granularity** of HGCAL can help improving **jet identification**.

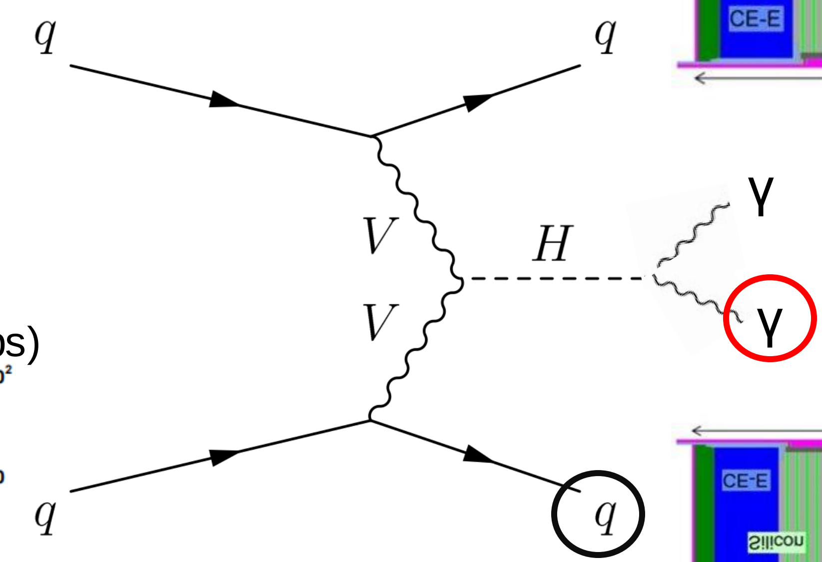


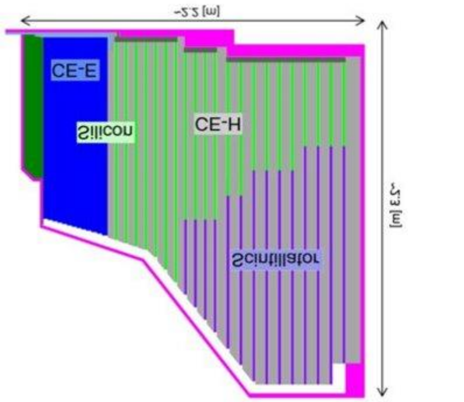
What is HGCAL, and why do we need it

The importance of precision about time and space

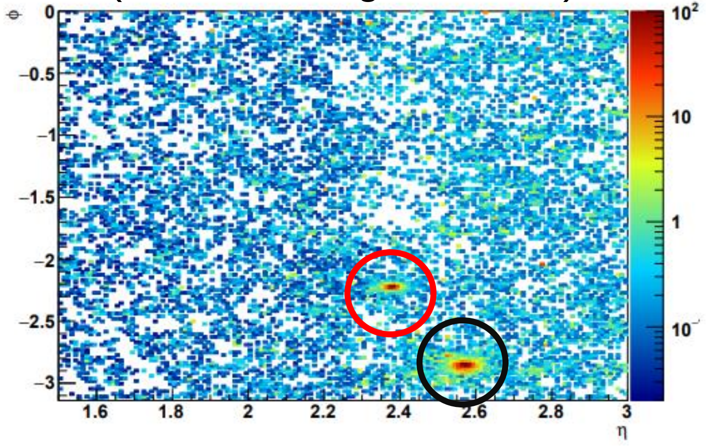
- With the **high granularity**, HGCAL will be able to identify **VBF jets.**
- The **pileup issue** can be greatly **improved** with good **timing resolution** (tens of picoseconds) of the HGCAL. (Ex: VBF H -> γγ)



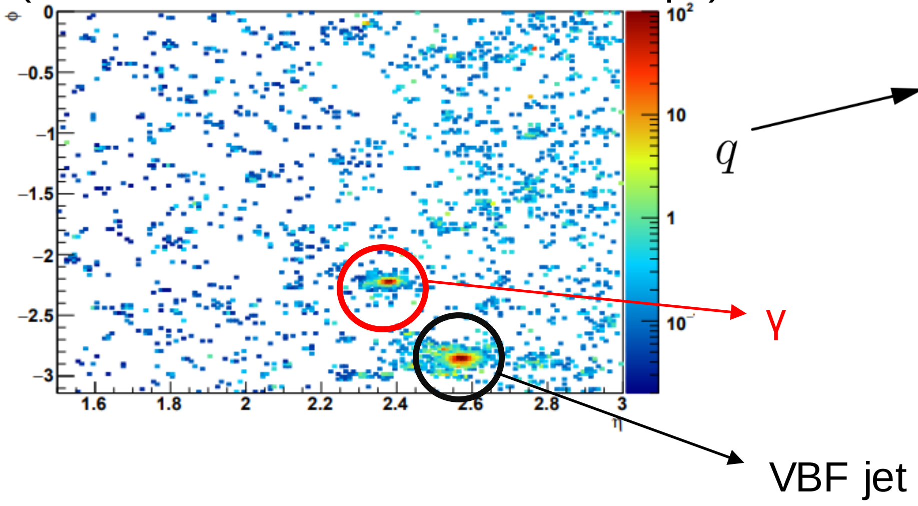




VBF H -> γγ
(without timing selection)



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

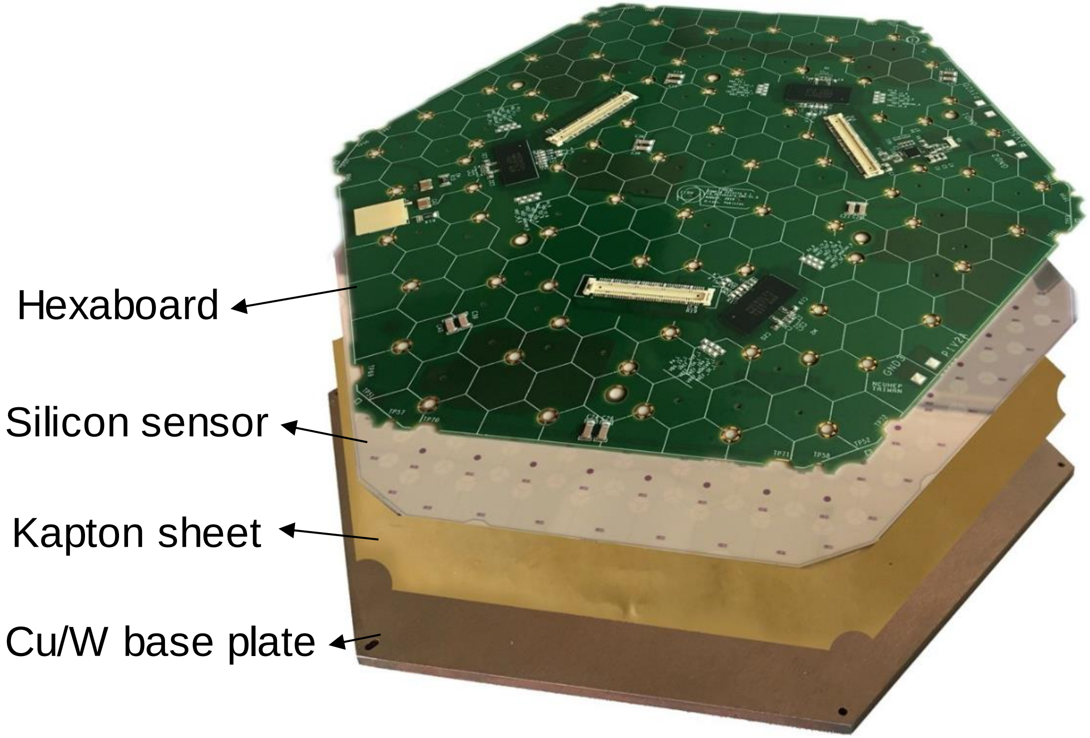


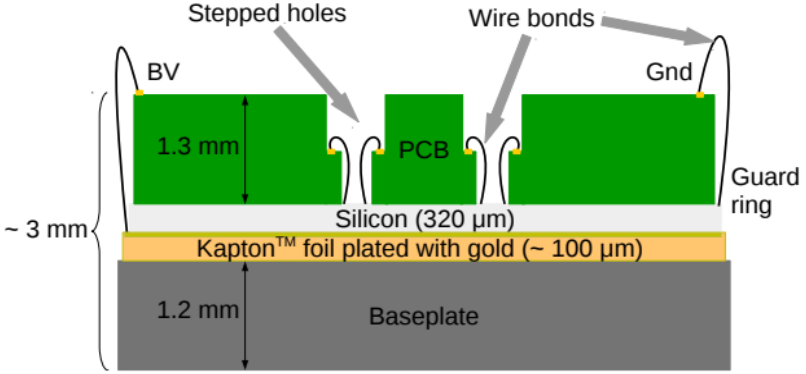
02 Silicon section of the HGCAL

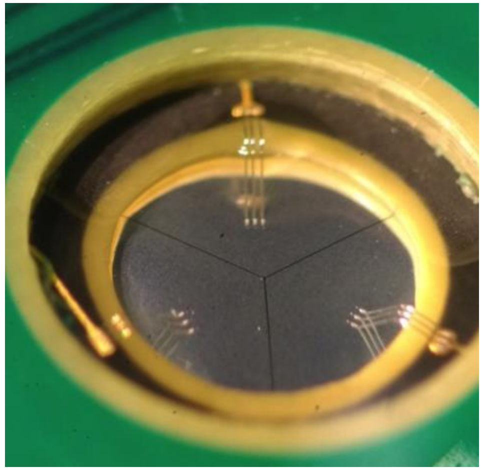
Silicon module (hexaboard)

Structure of the hexaboard

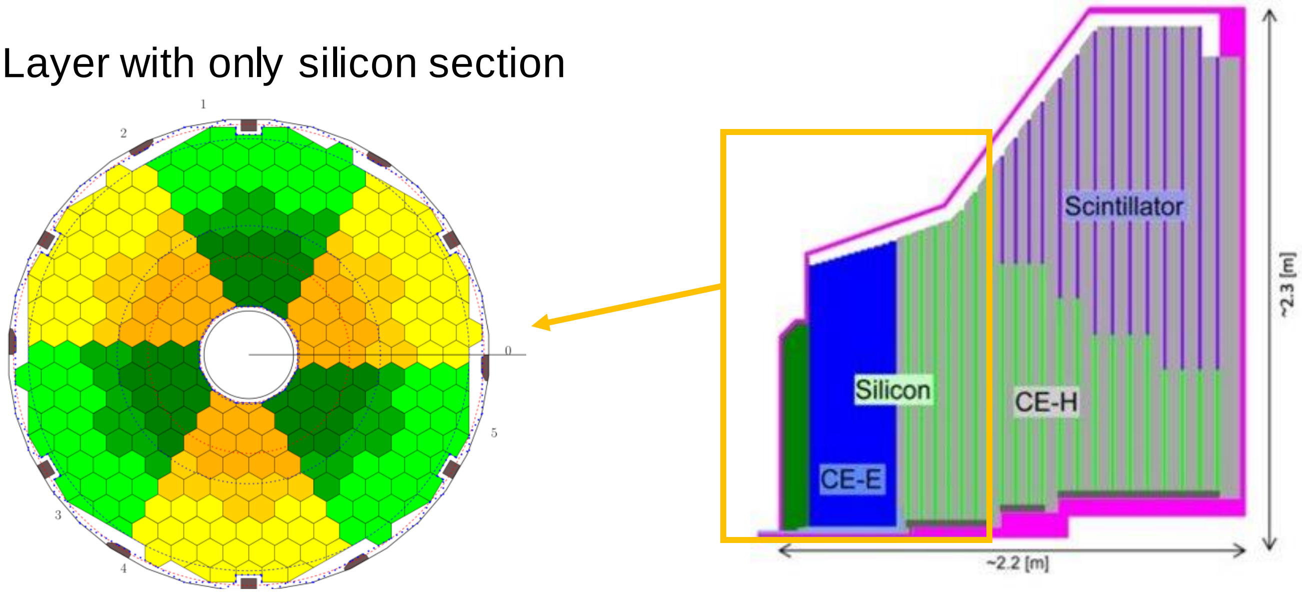
- The basic element in the silicon section of the HGCAL is called **hexaboard**.
- Silicon cell size: **0.5** (for **HD** hexaboard) and **1 cm^2** (for **LD** hexaboard).
- Data readout by **HGCROC** chip.





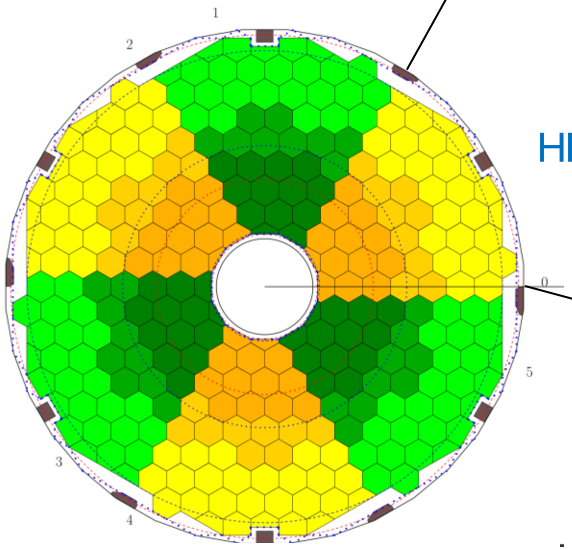


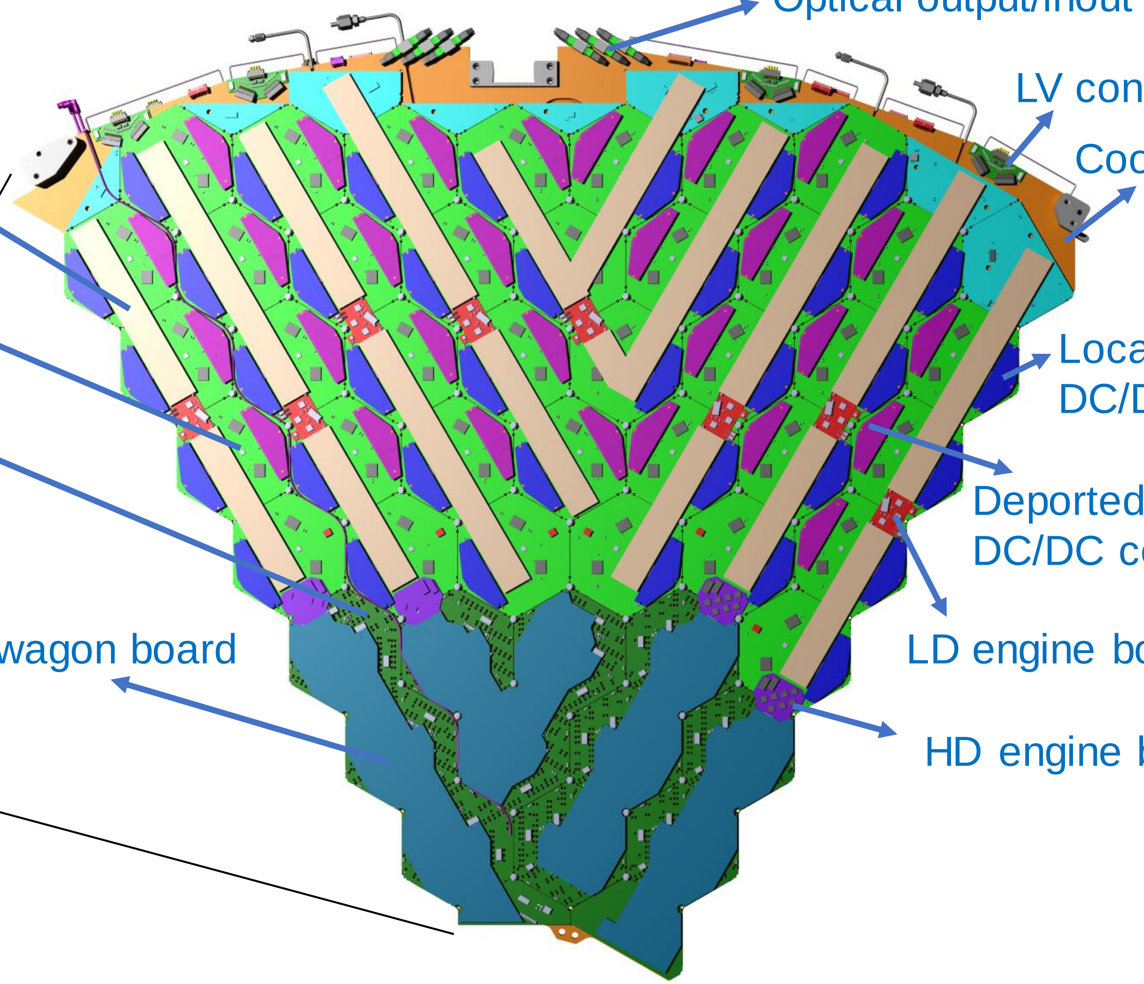
Layer with only silicon section



A cassette in the silicon section

Structure of the hexaboard





Low density region

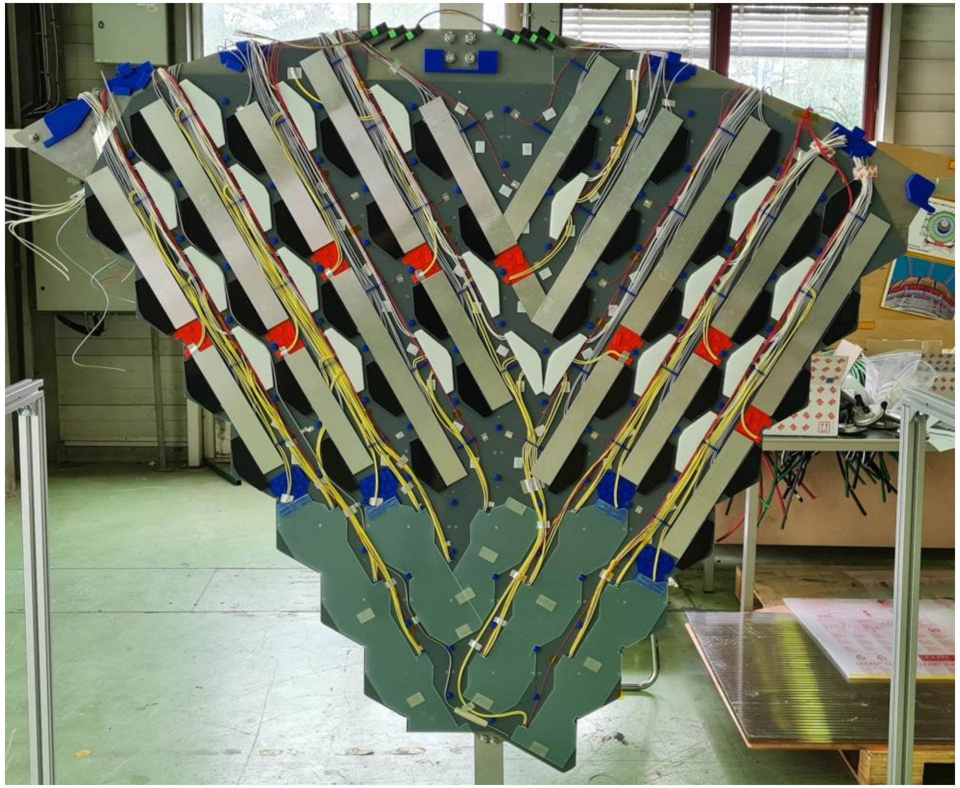
- Silicon sensor thickness: **200** and **300 µm**.
- **192 channels** per hexaboard.

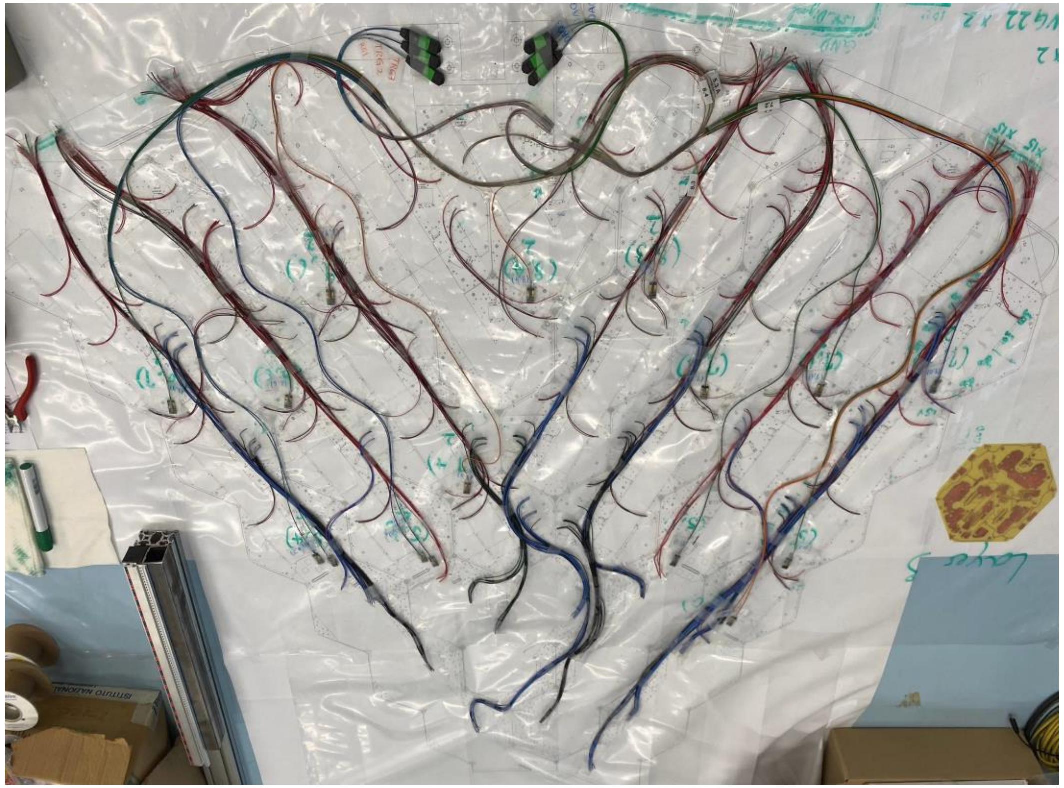
High density region

- Silicon sensor thickness: **120 µm**.
- **432 channels** per hexaboard.

A cassette in the silicon section

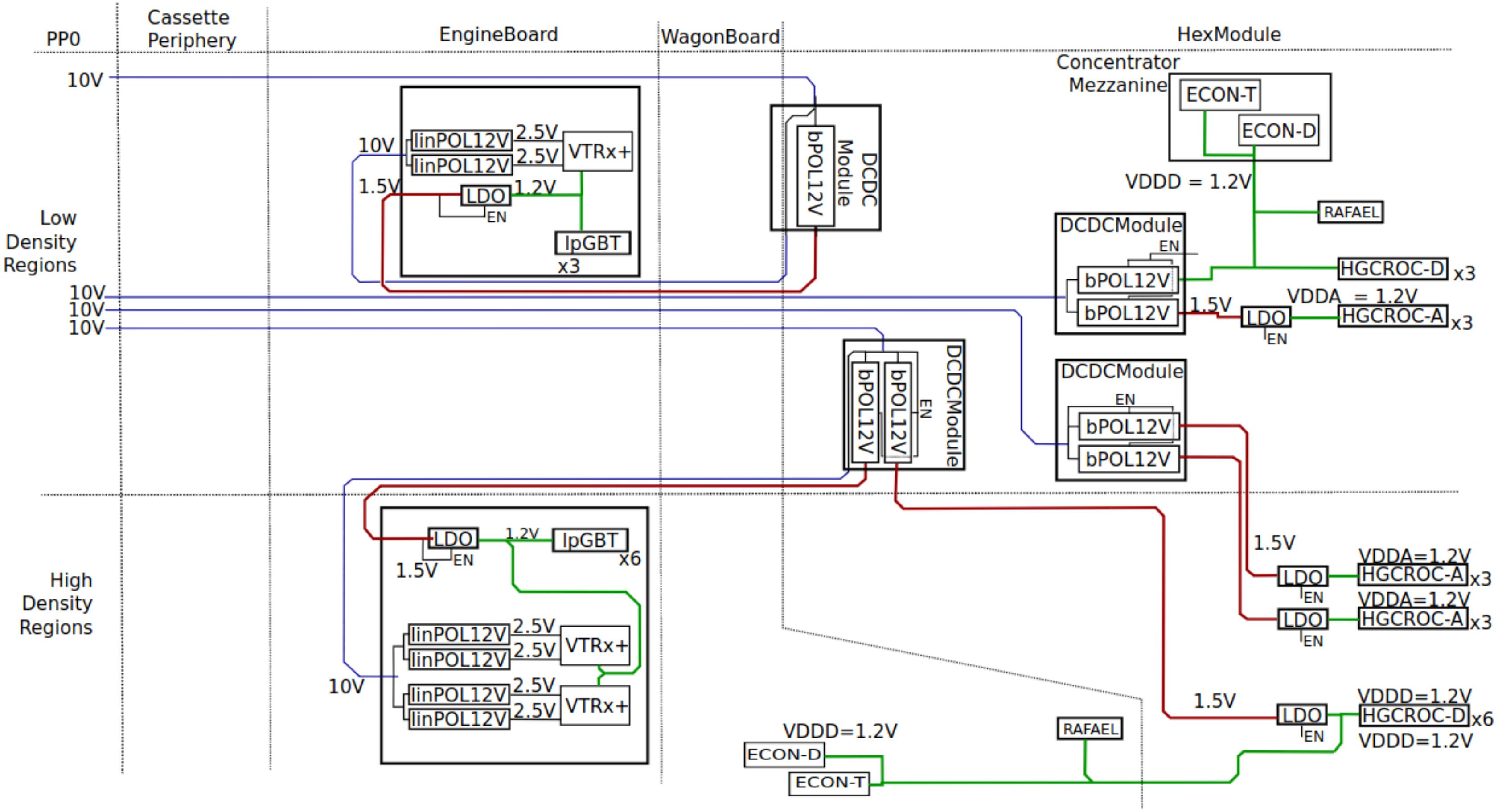
Mockup cassette in the silicon section





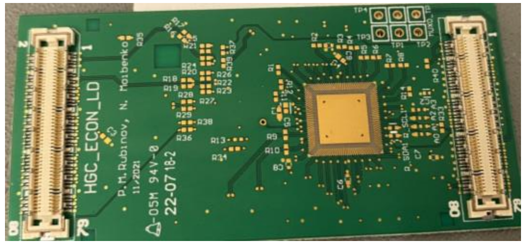
Power tree of cassette

For the cassette with only hexaboards



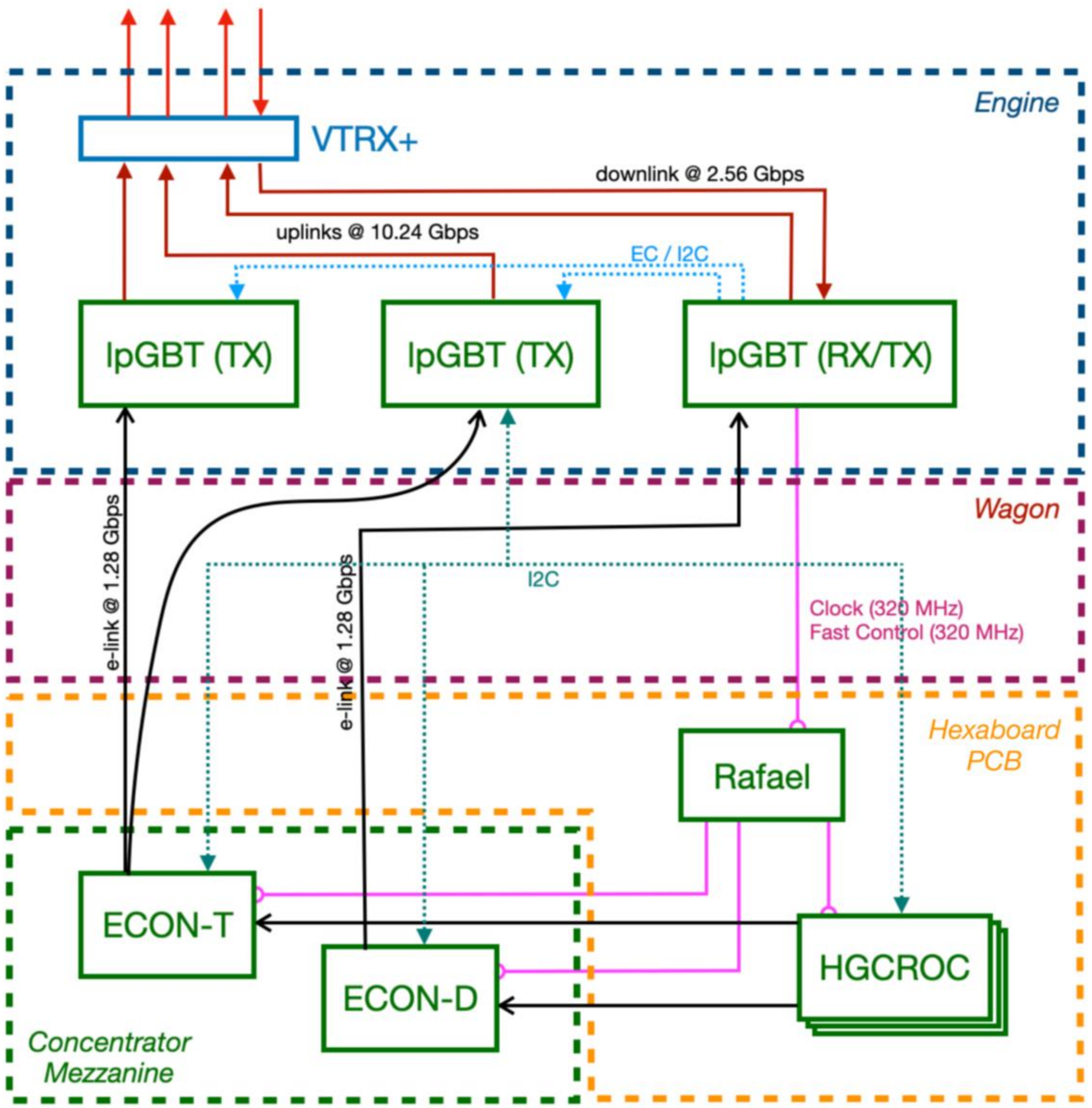
DC/DC module

ECON mezzanine



Front-end data acquisition (DAQ) system

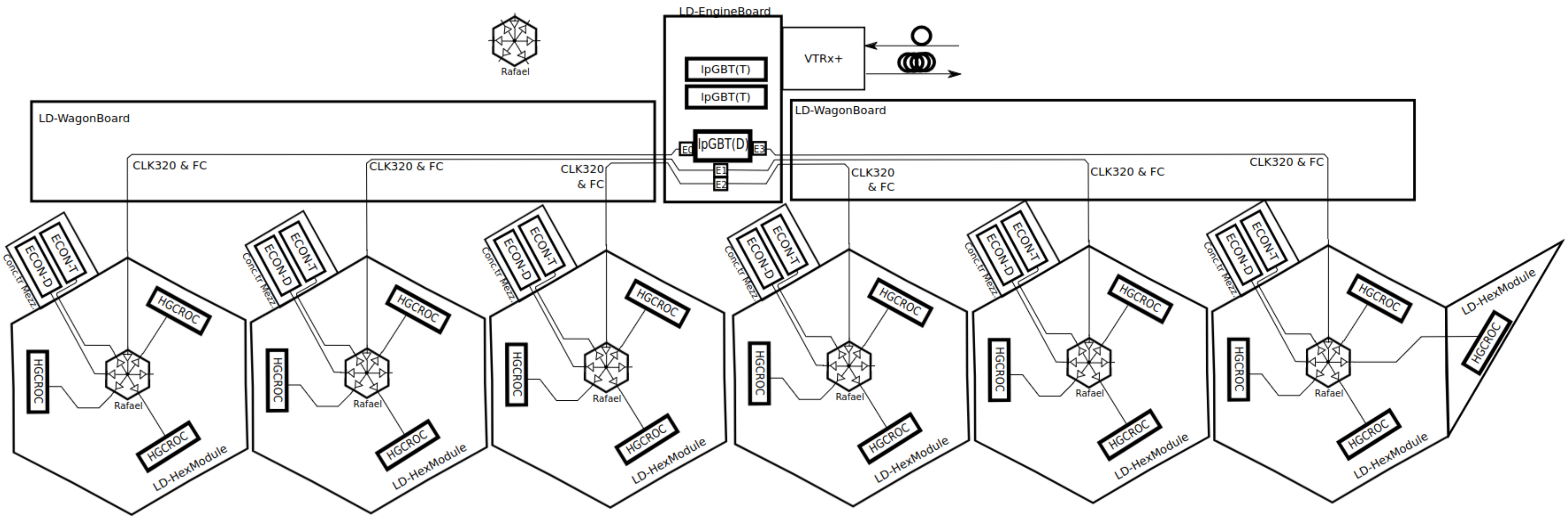
Where the data go



- **HGCROC**: **Data readout chip**. There are 3 of it on the LD hexaboard, and 6 on the HD hexaboard. Receive and digitize signals coming from the silicon sensor.
- **ECON-T**: **Concentrator chip for trigger path**. Select and compress trigger data from the HGCROC. Trigger data transmission in 40 MHz.
- **ECON-D**: **Concentrator chip for DAQ path**. Channel alignment and zero suppression. Collect data from the HGCROC after level 1 trigger accept (L1A). DAQ data transmission in 750 kHz.
- **Rafael**: **fanout chip** for clock and fast control.
- **lpGBT**: **Send and receive data, clock, fast commend** from versatile transceiver (VTRx+). Also responsible in sending **slow control** via I2C

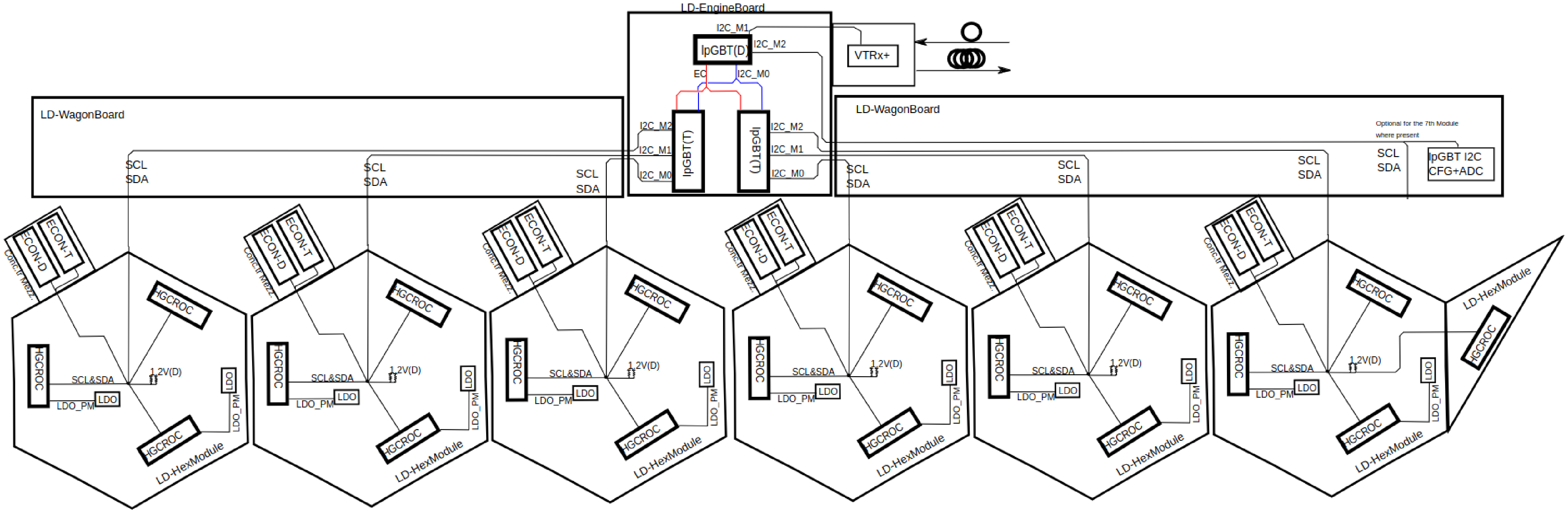
Frontend data acquisition (DAQ) system

Fast command and clock for the LD hexaboard.



Frontend data acquisition (DAQ) system

Slow control for the LD hexaboard.

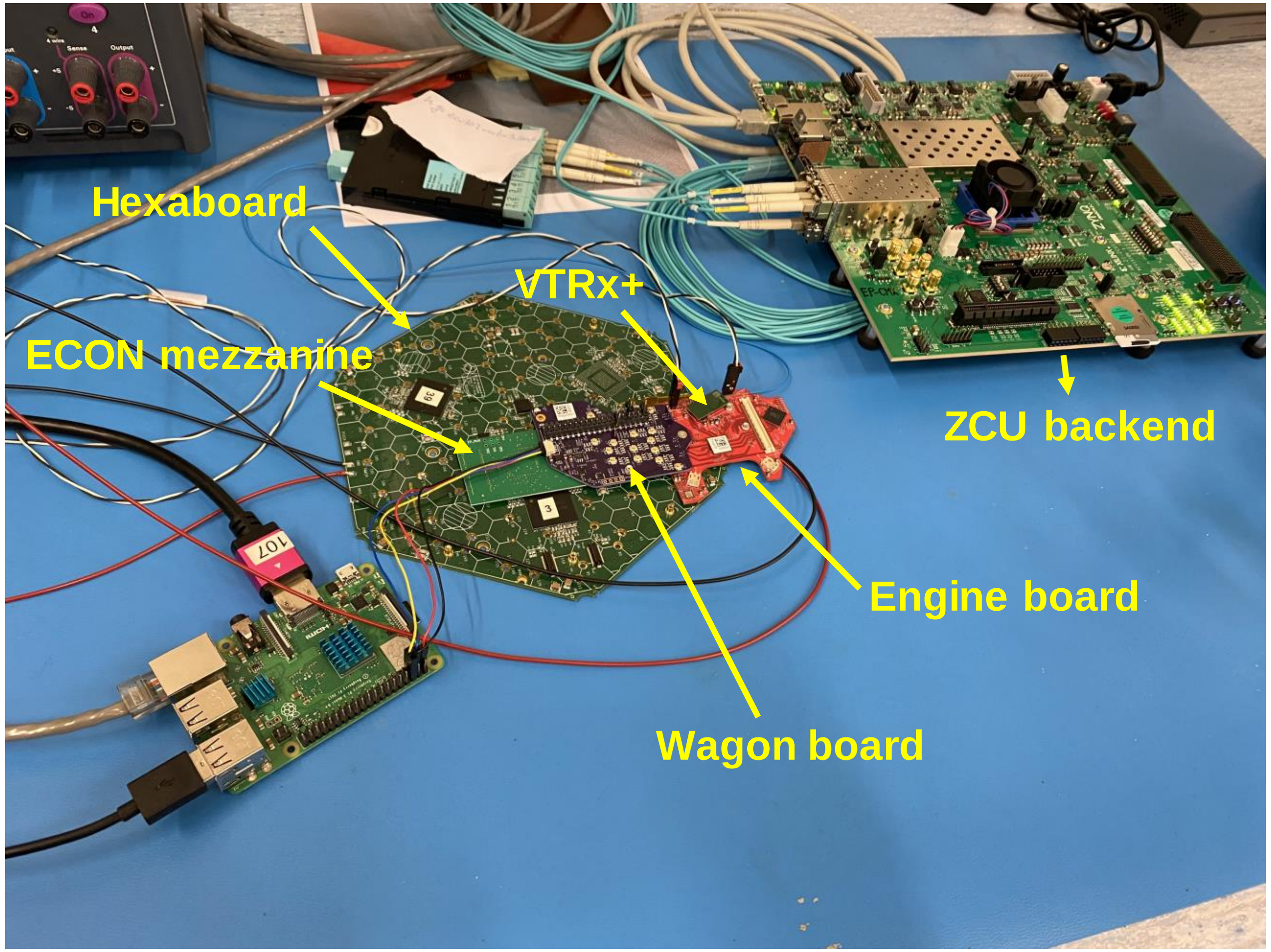


System test for the LD hexaboard

System test of the v3 hexaboard

- With **ECON mezzanine** (only equipped with ECON-T), **Wagon board**, **VTRx+**, **mini backend (zcu102)**.
- Able to send **slow control**, **fast command**, and **read/write to registers** in the front end ASICs.
- Able to **transmit trigger** and **event data** from the HGCROC. (configured to send dummy data)

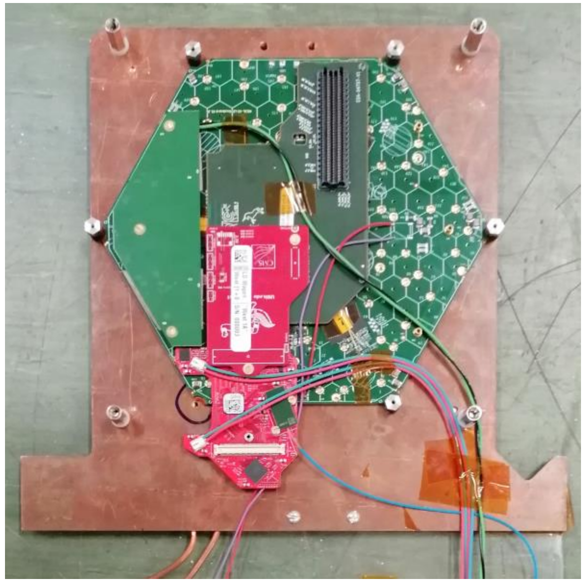
A successful I2C transaction between two front end ASIC



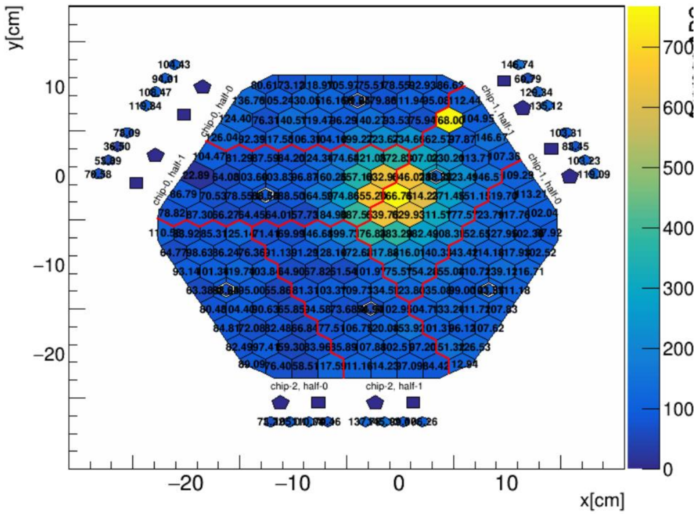
Test beam at CREN in August 2023

Test beam for hexaboard

Mounted hexaboard on a Cu cooling plate



Successfully detect the beam



Front end setup

The group that make it happen!

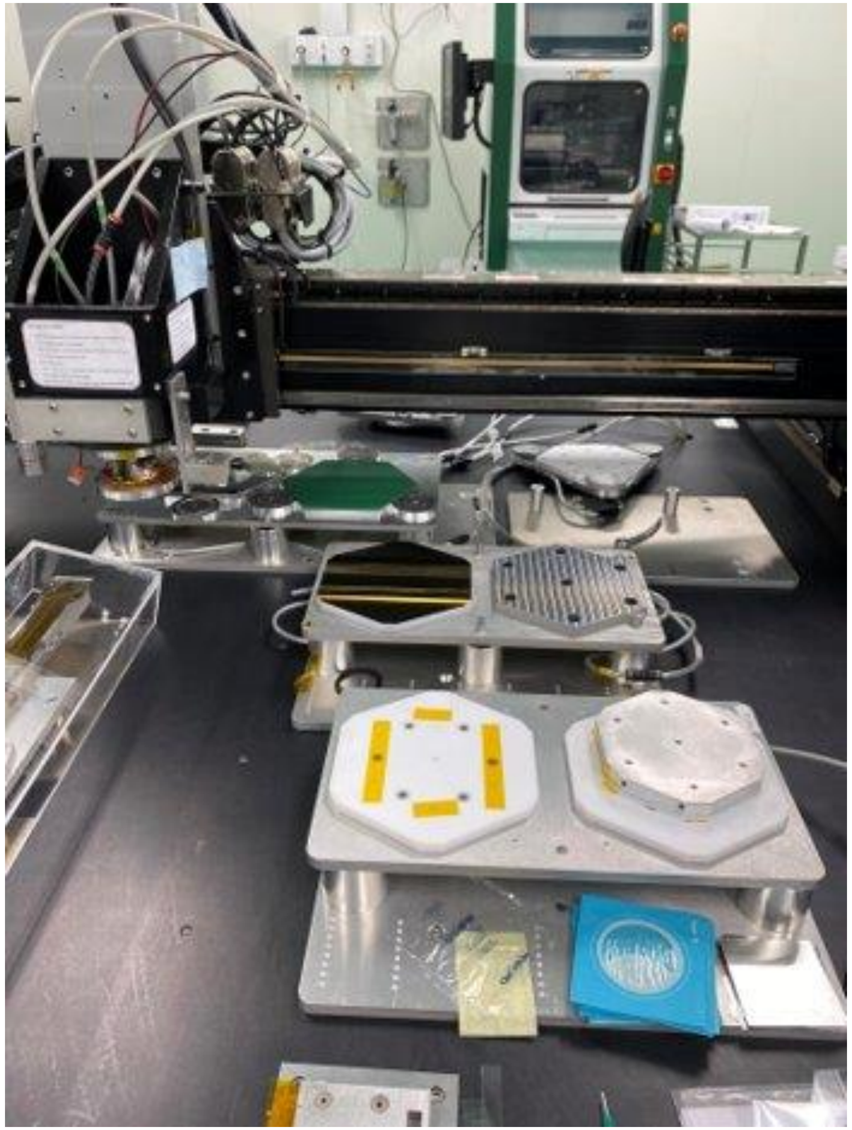
Setup demonstrated on a desk

Module assembly

System test of the v3 hexaboard

- There are currently **6 module assembly centres (MAC)** for producing hexaboards.
- Video of the hexaboard module assembly procedure (from the NTU MAC in Taiwan):

https://www.youtube.com/watch?v=f0fYa6sCFZY&t=407s

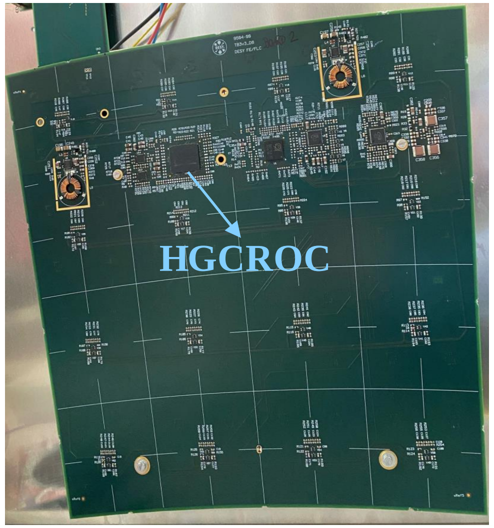


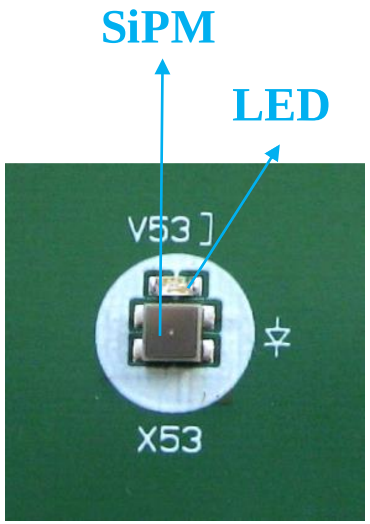
03 Scintillator section of the HGCAL

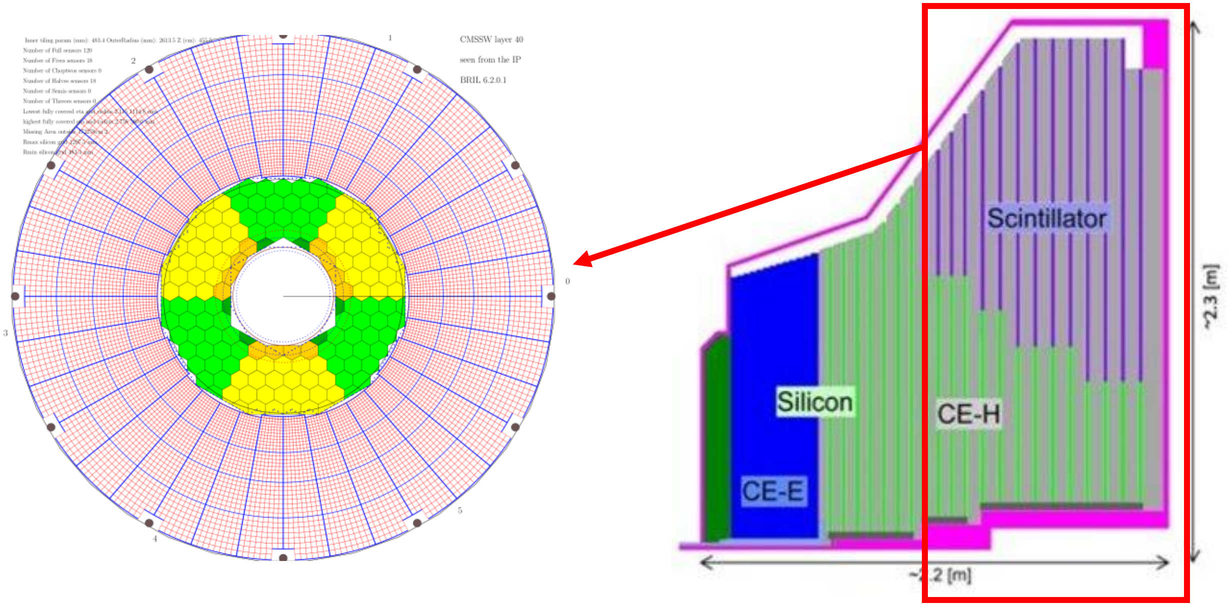
Tilemodule with SiPM-on-tile technology

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 **240k channels** in the Scintillator part in the HGCAL.
- With scintillator **tile size 4 ~ 30 cm^2**, and **SiPM size 4 mm^2** and **9 mm^2**
- 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**.

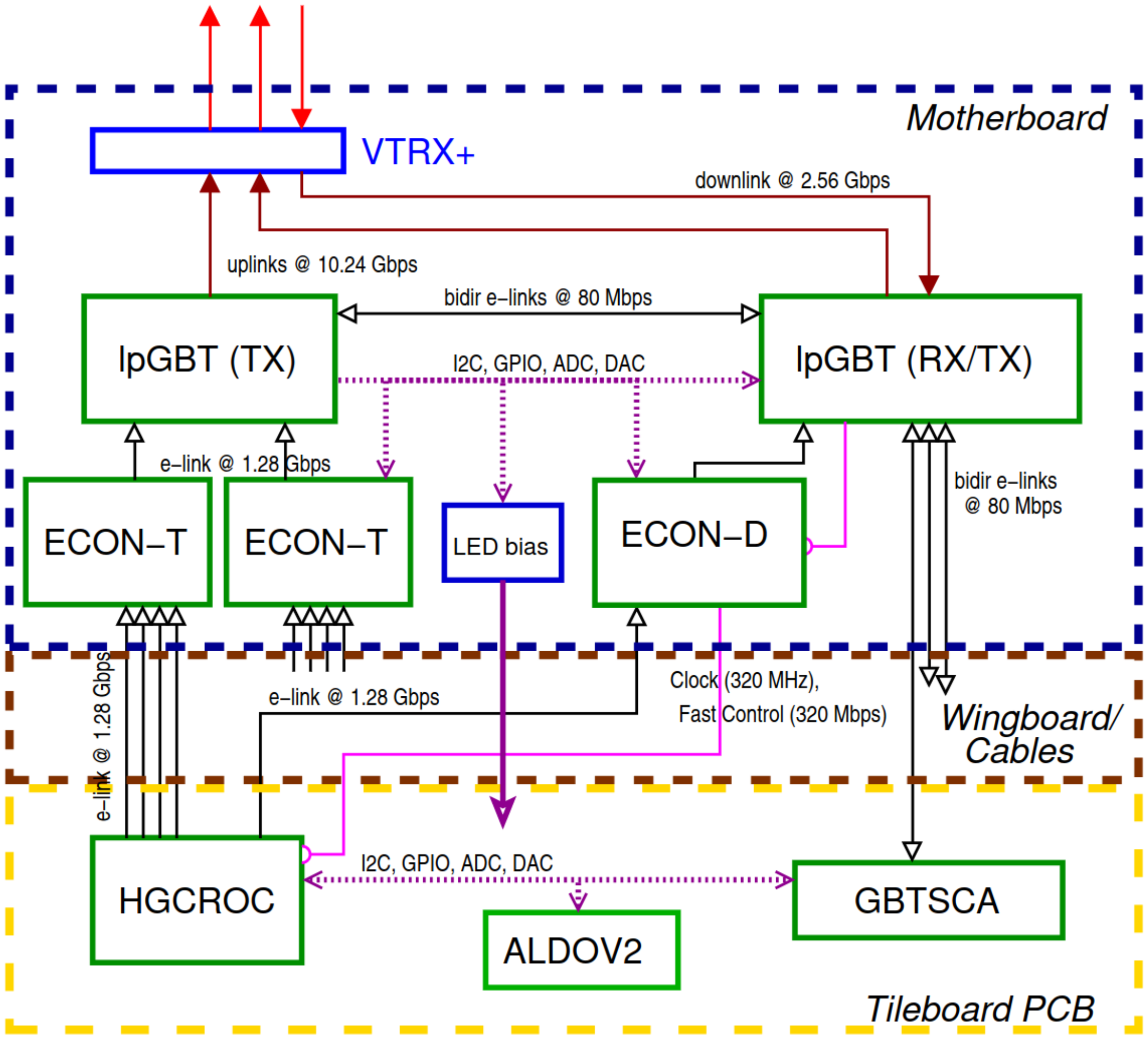


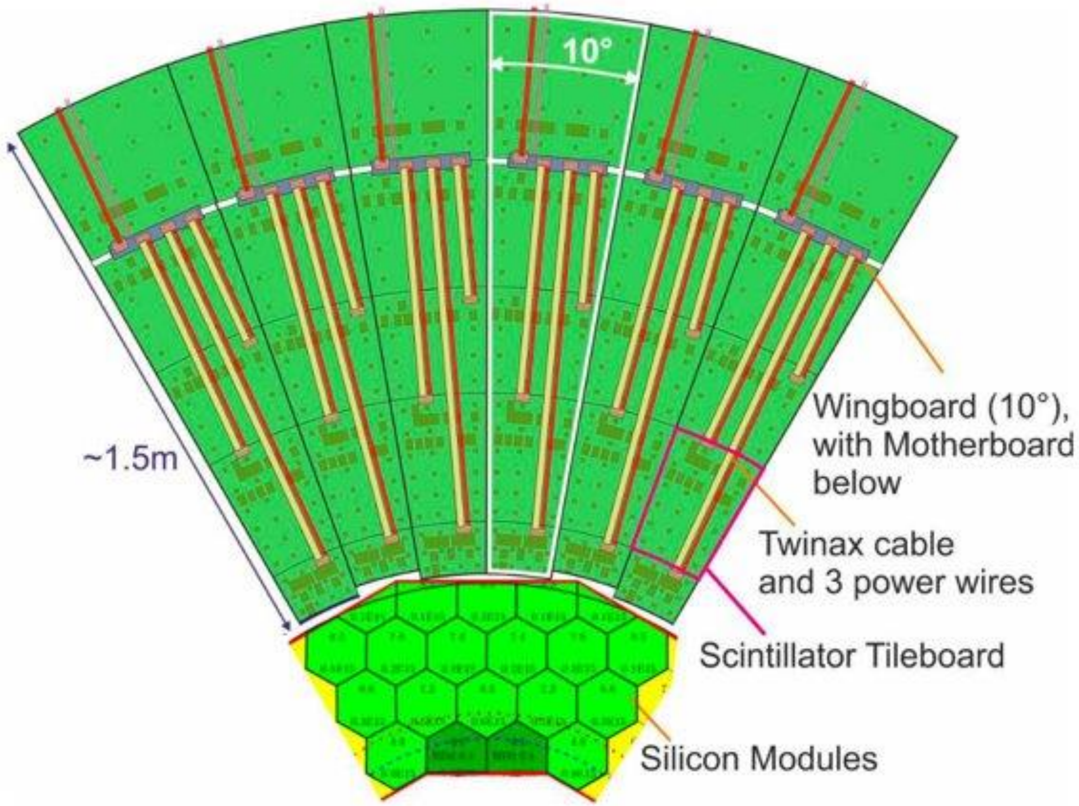




Frontend data acquisition (DAQ) system

Where the data go

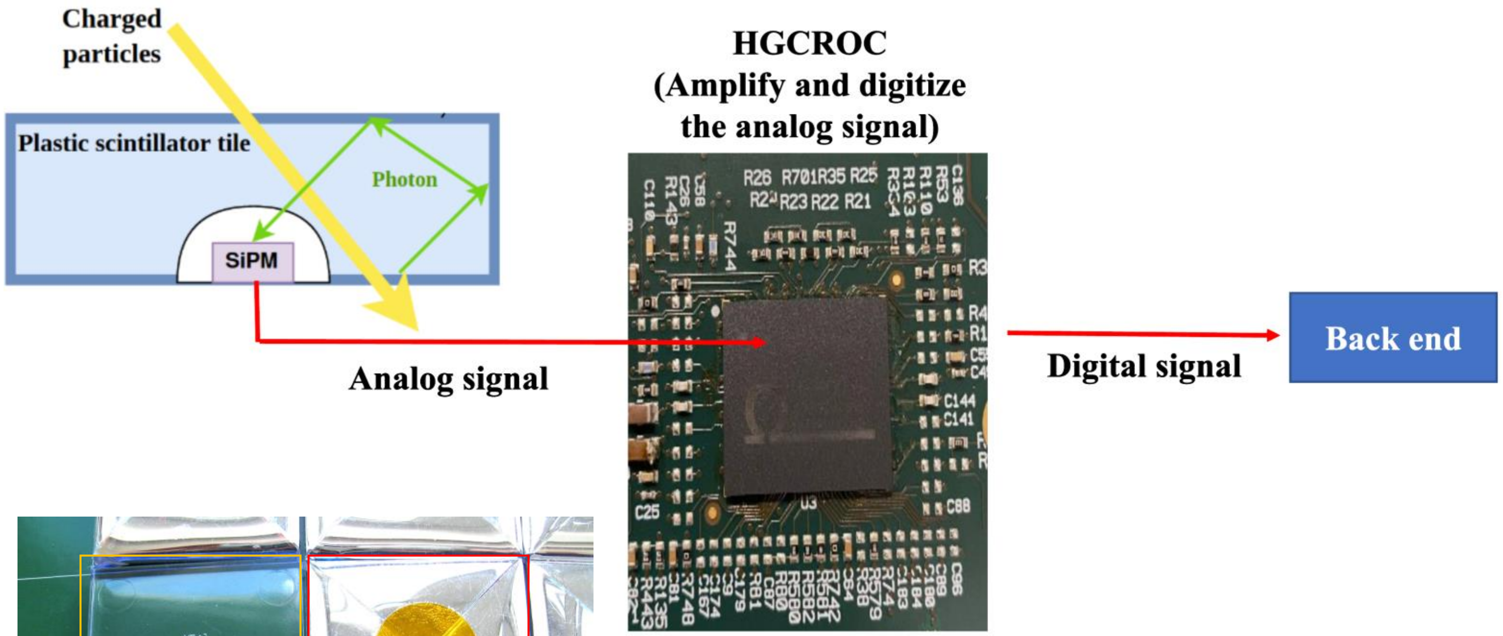


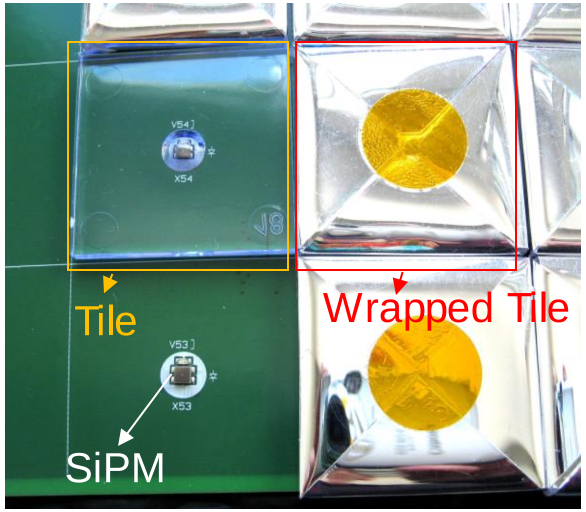


SiPM-on-tile technology in the scintillator section of HGCAL

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 can detect photons from the tiles.

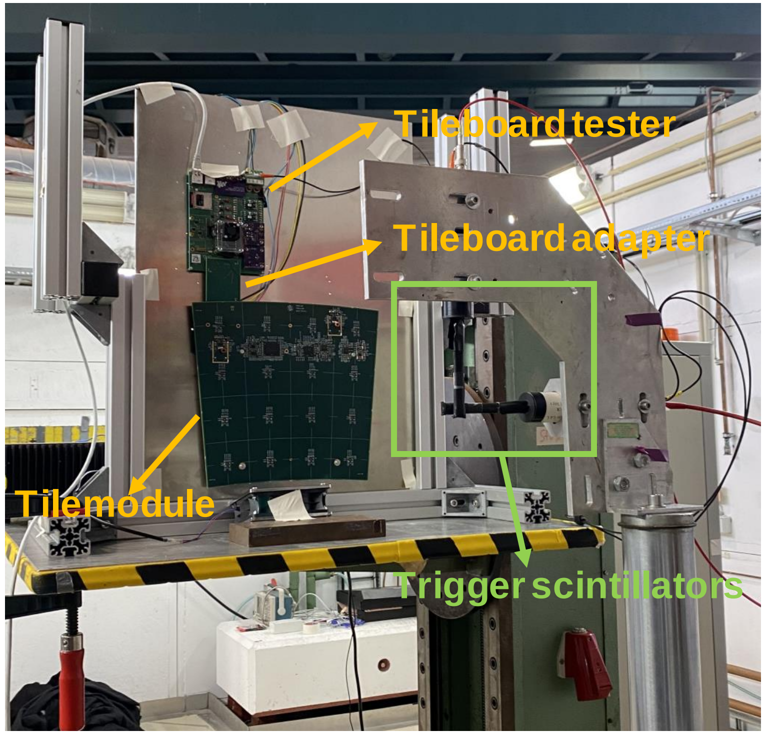


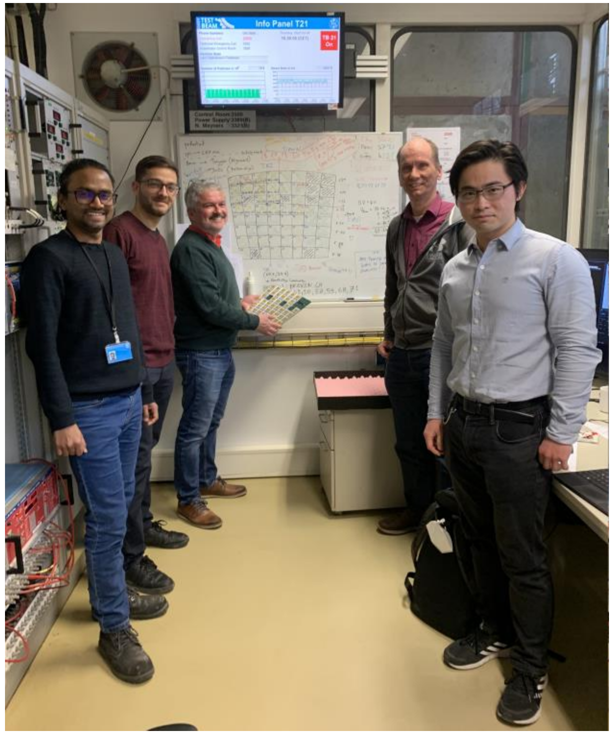


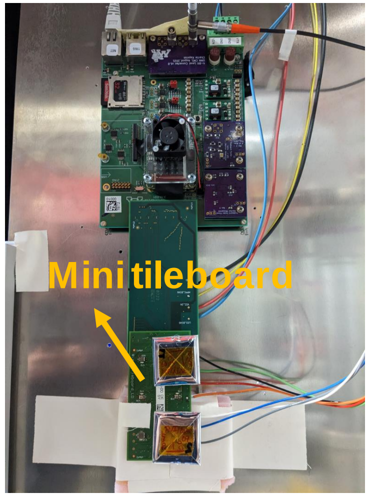
Test beams of the Tilemodules at DESY

Test beams that has been done at DESY

- **Validated** the **performance** of the **SiPM-on-tile** on **Tilemodules** with all the on-board electronics.
- Using **3 GeV electrons** at the DESY-II test beam facility.
- This includes:
  - Different **SiPM sizes**
  - Different **scintillator tile sizes**
  - Different **scintillator materials** produced using different **techniques**
  - **Irradiated** and **Non-irradiated** SiPMs



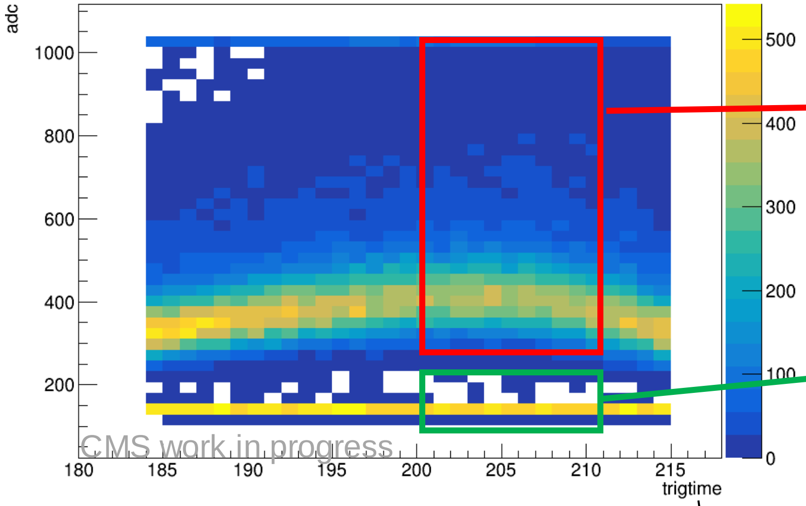




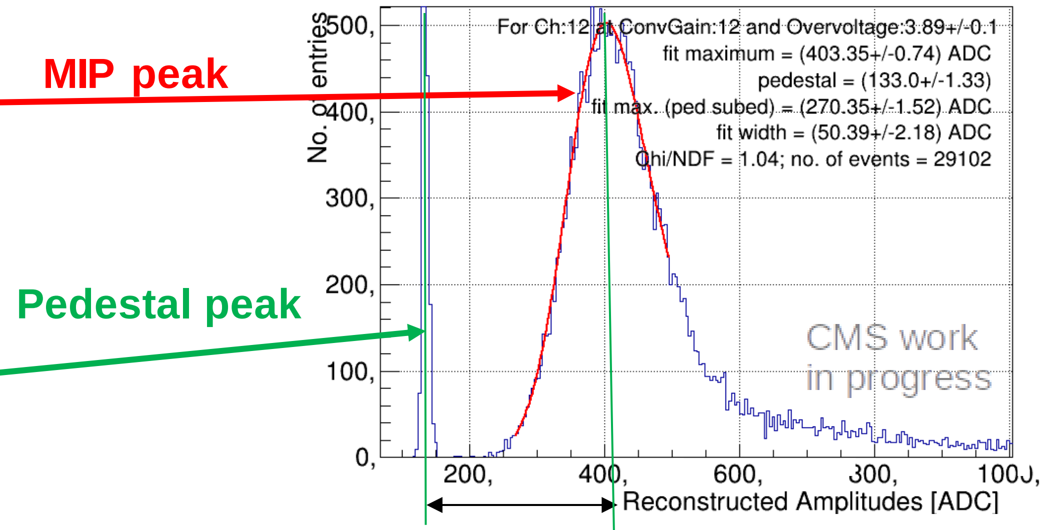
Test beam of the Tilemodule at DESY

Using pulse shape and trigger information for MIP extraction

- The HGCROC is designed to work in sync with the 40 MHz LHC clock.
- The DESY clock is asynchronous to this. Therefore the signal could come anytime within a clock cycle.
- The DAQ system also has an internal clock which measures the TOA measurement of the trigger with ~0.8 ps resolution for each event. This trigtime information therefore can be used to reconstruct the pulse shape as seen in the plot below.
- The **MIP maximum** can be obtained by measuring the **peak** value of the MIP spectrum and then **subtracting the pedestal**.



Time of Arrival of the trigger measured by the DAQ system with respect to 40 MHz clock



Test beam of the Tilemodule at DESY

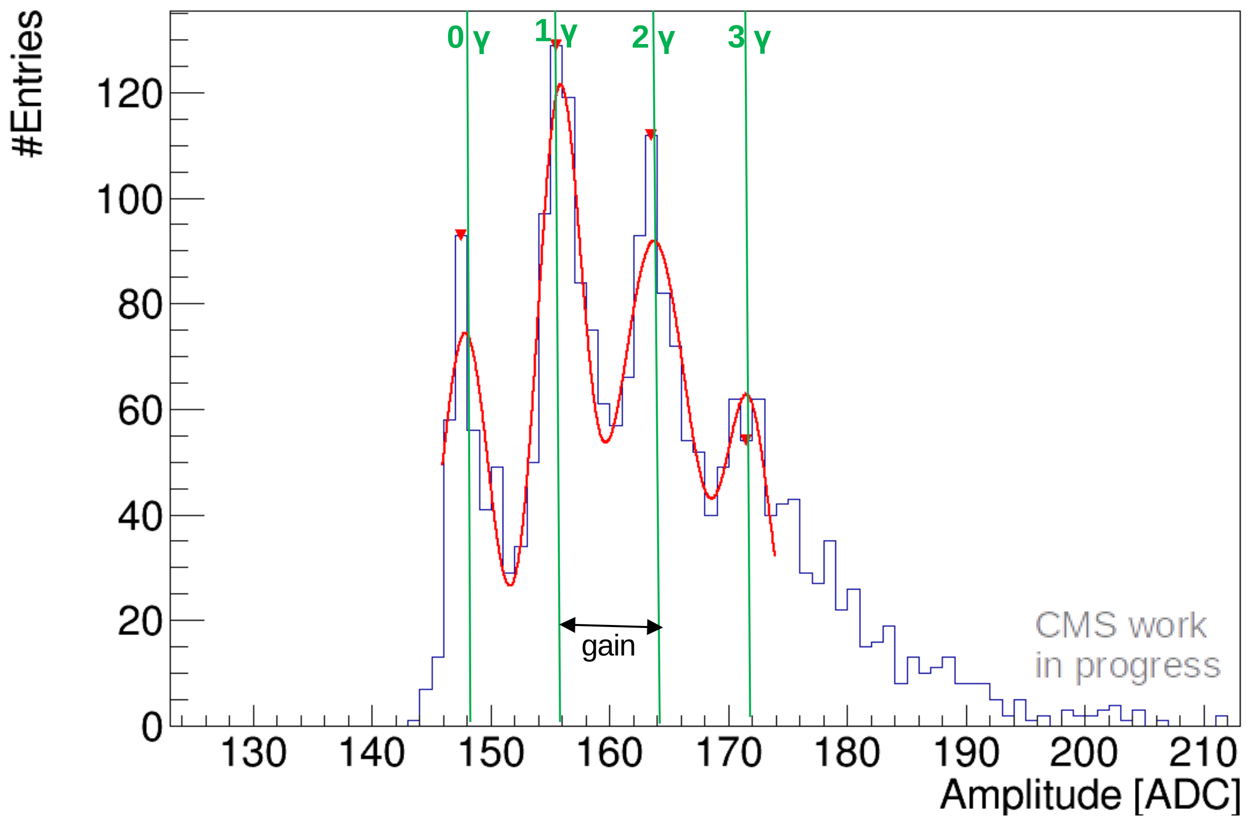
Measure SiPM gain from single photon spectrum

- A **low intensity LED** is equipped **next to each SiPM** on the Tilemodule.
- Photons produce by the LED are captured by the SiPM.
- Sampled SiPM signals will produce a **Single Photon Spectrum (SPS)** with each peak corresponding to the **number of photons** detected by the SiPM.
- The **difference between two peaks** is defined as the **SiPM gain** in photon equivalent units (p.e.).

Light Yield (number of photo-electrons captured):

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

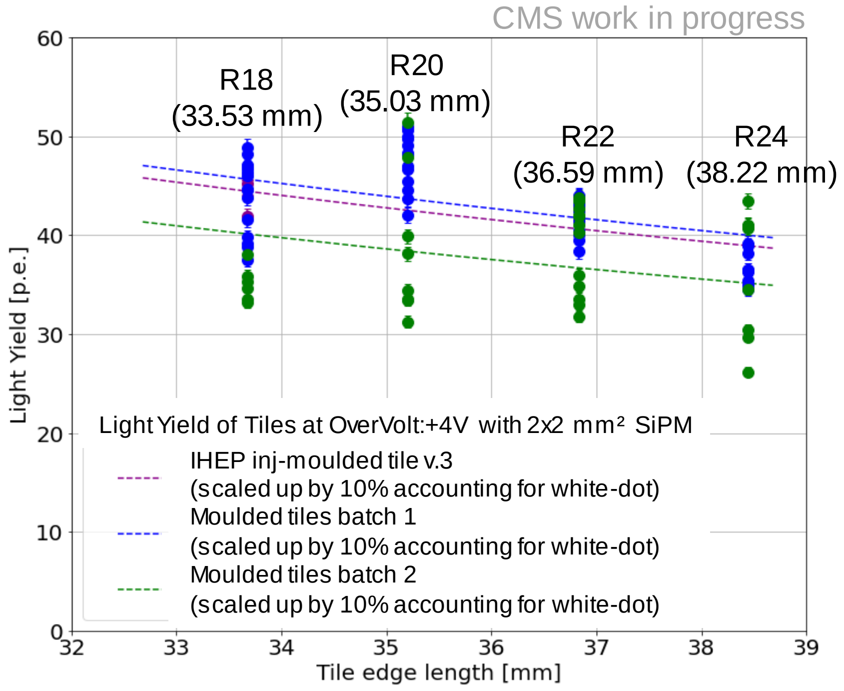
Single photon spectrum



Test beam of the Tilemodule at DESY

Compare light yield measured from different type and size of tiles

- 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.
- Light yield is inversely proportional to the squared root of the tile area, so **smaller tiles have a larger light yield**.
- 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).
- The three moulded tile batches use different **material compositions** which explain the **different light yields**.

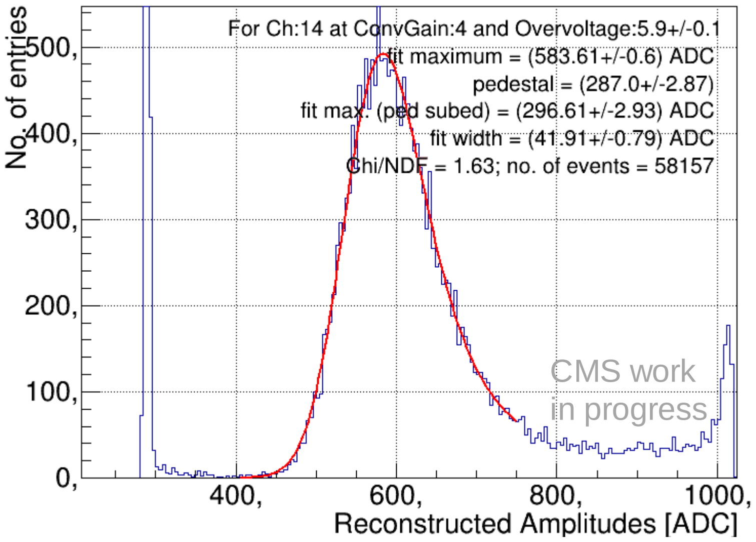


Test beam of the Tilemodule at DESY

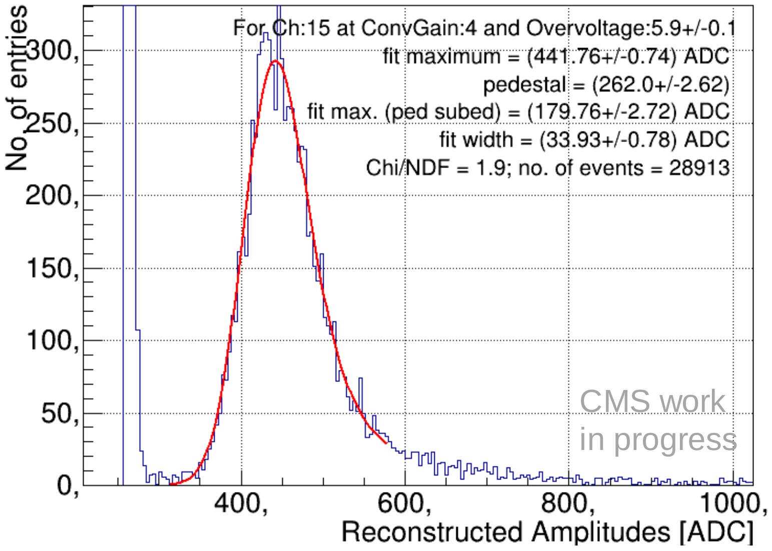
Different SiPM size (non-irradiated SiPM)

- 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)**.

MIP (9 mm² SiPM)



MIP (4 mm² SiPM)

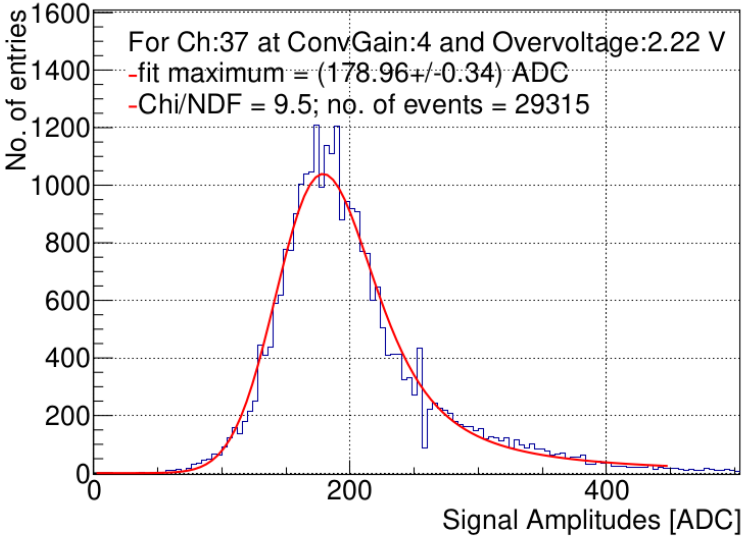


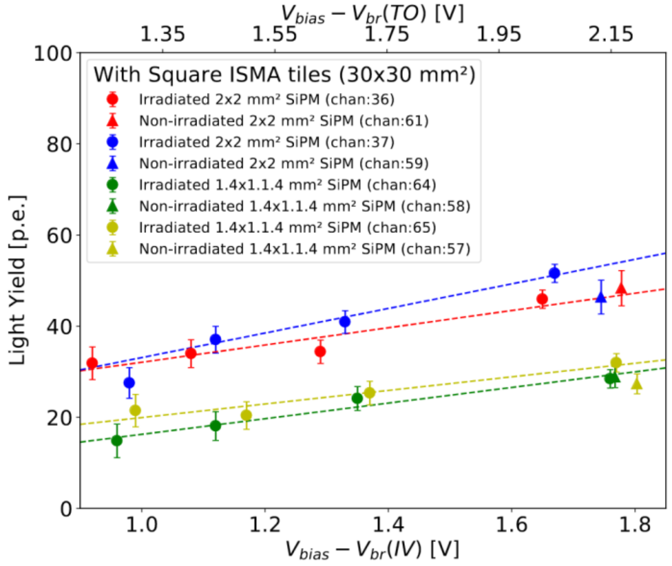
Test beam of the Tilemodule at DESY

Irradiated SiPMs

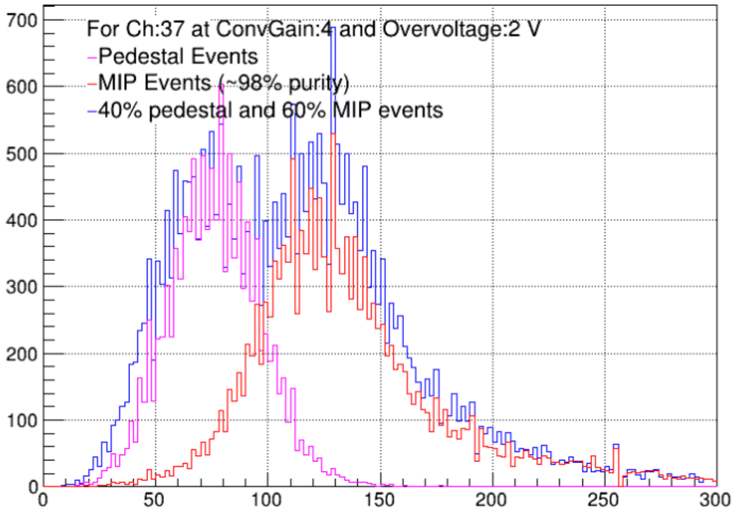
- In comparison with the non-irradiated SiPMs, the **pedestal** signal will be **"wider"** for the **irradiated SiPMs**.
- **Cannot easily separate the MIP peak and pedestal peak** with irradiated SiPMs.
- Need to adjust the beam line to hit in the middle of scintillator tile to mitigate data contamination from pedestal (try to aim all particles from the beam to reach the same tile).
- The light yield measured from irradiated and non-irradiated SiPM are similar.

MIP data with beam directed hitting the SiPM area

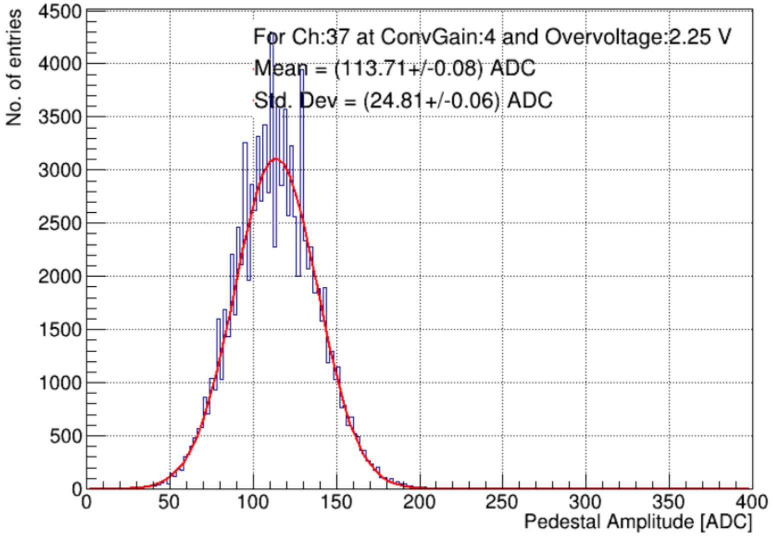




Beam data with pedestal contamination



Data from pure pedestal wiout beam



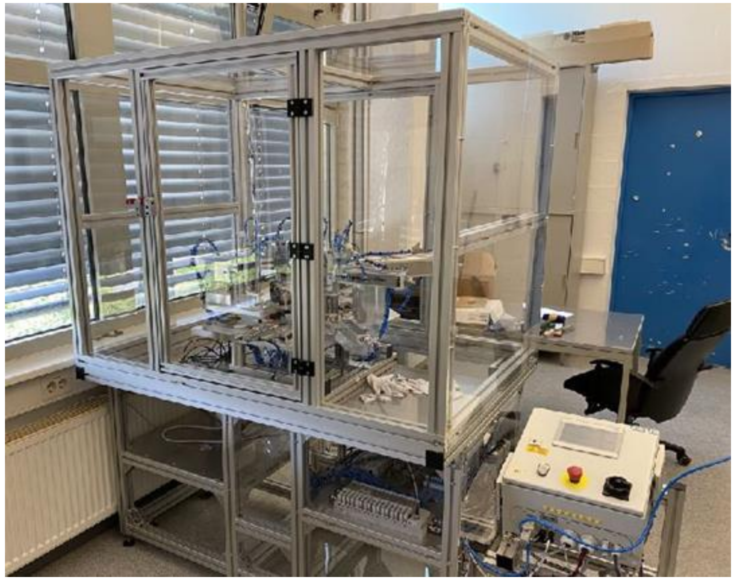
Plots made by Malinda de Sliva

Tilemodule assembly centre

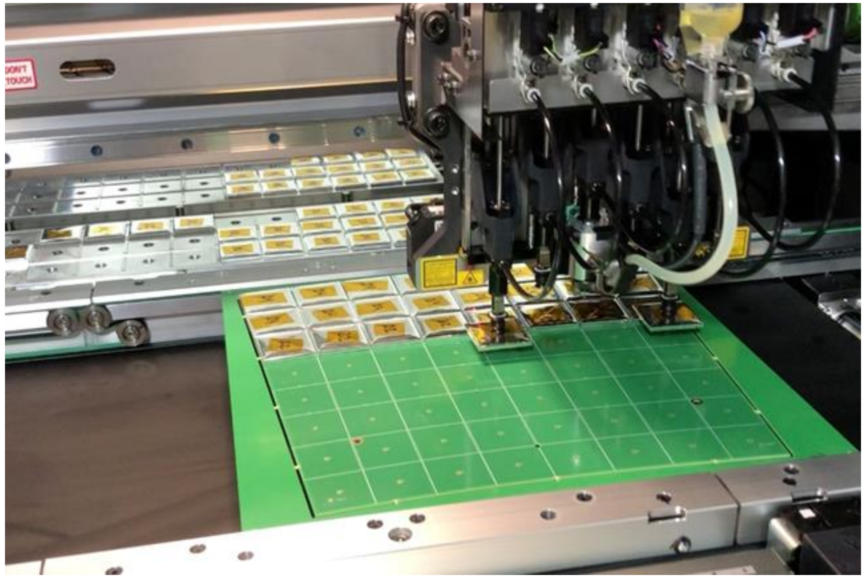
Tile wrapping and pick-and-place machine at DESY TAC

- The full production of the Tilemodules will start in 2024.
- There are currently two Tilemodule assembly centres (TAC). One of them is in DESY and the other is in Fermilab (FNAL).

Tile wrapping machine



Pick-and-place machine

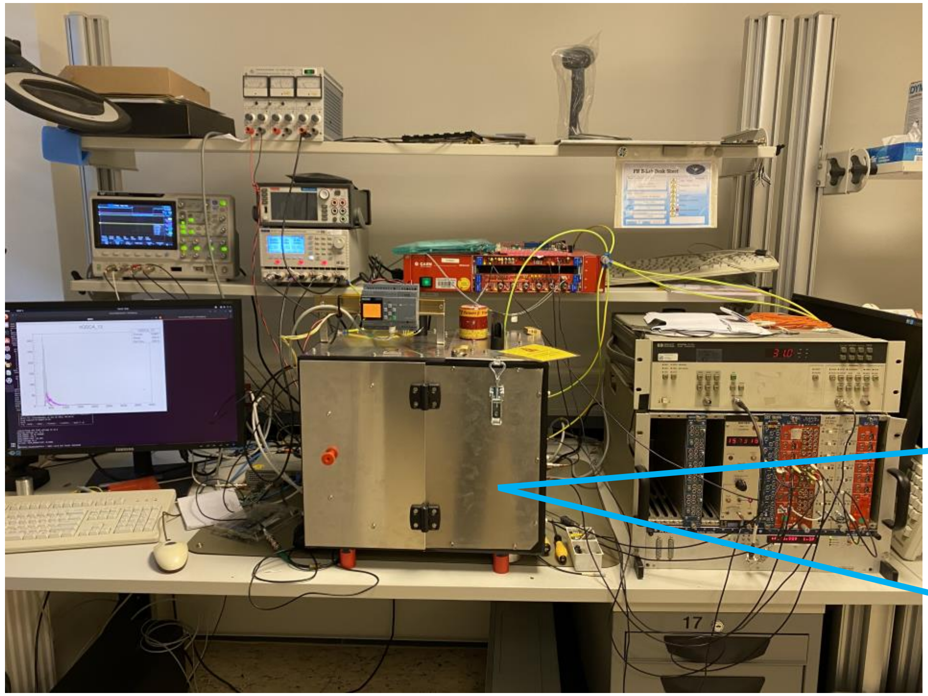


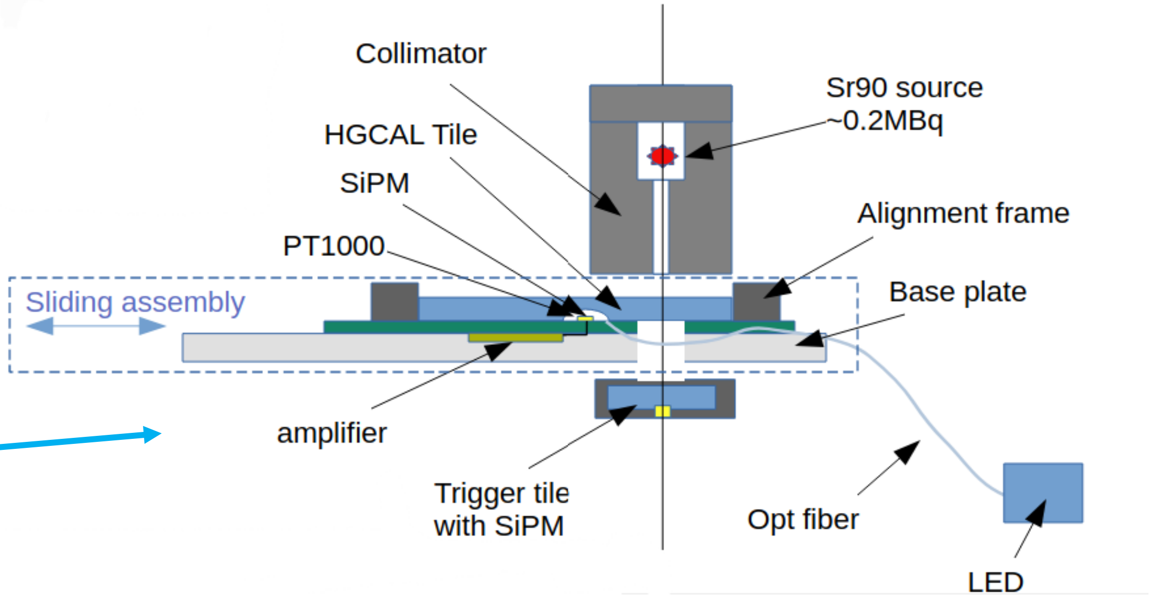
From DESY TAC.

- Many setups have been developed for quality control.

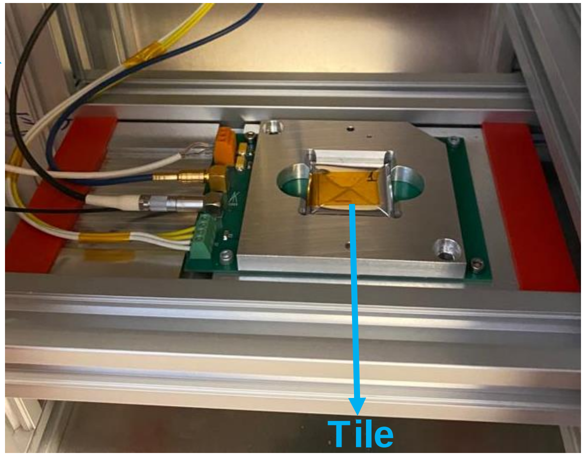
Quality control for scintillator tiles

This is part of the quality control of the Tilemodule



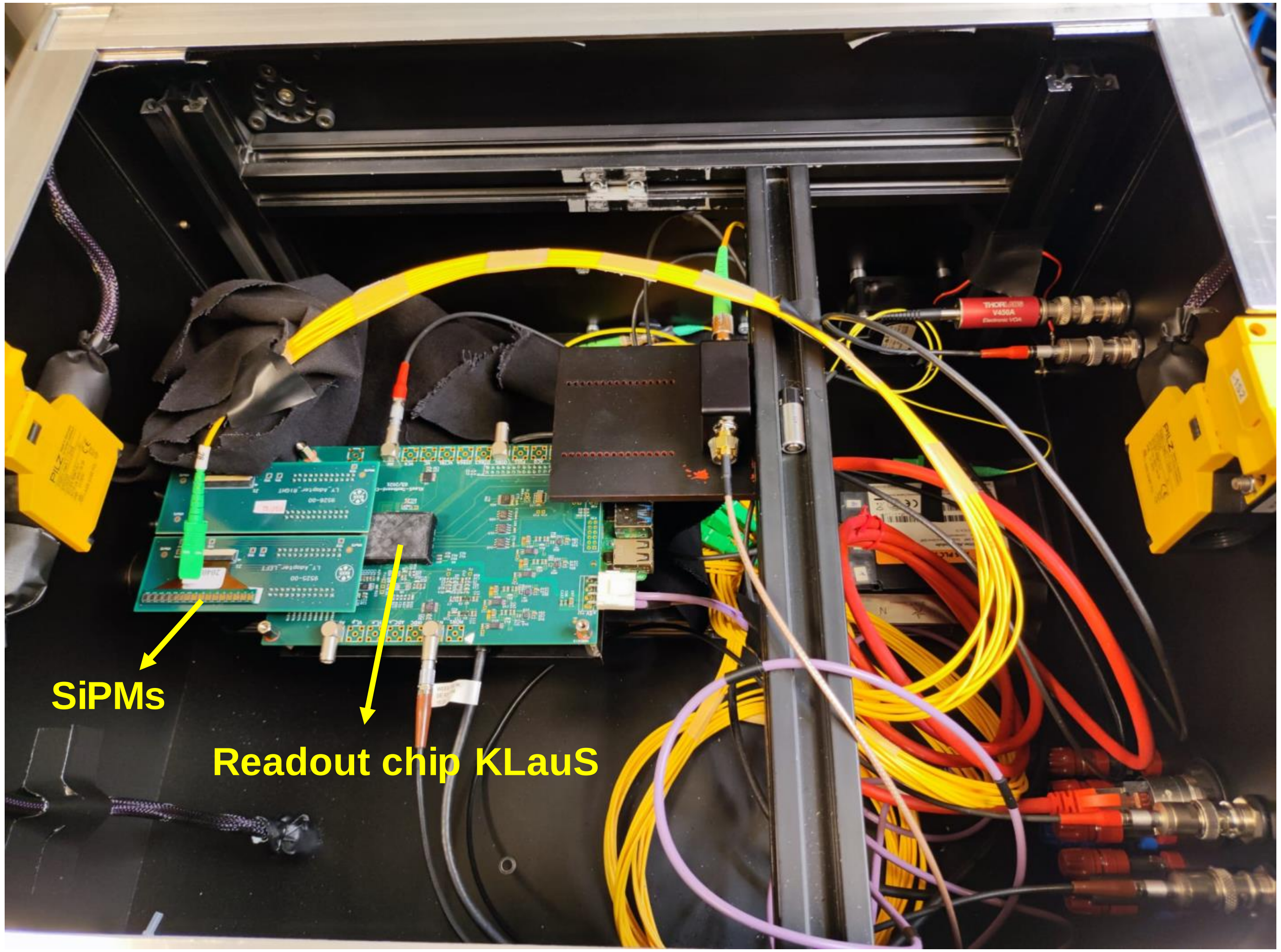


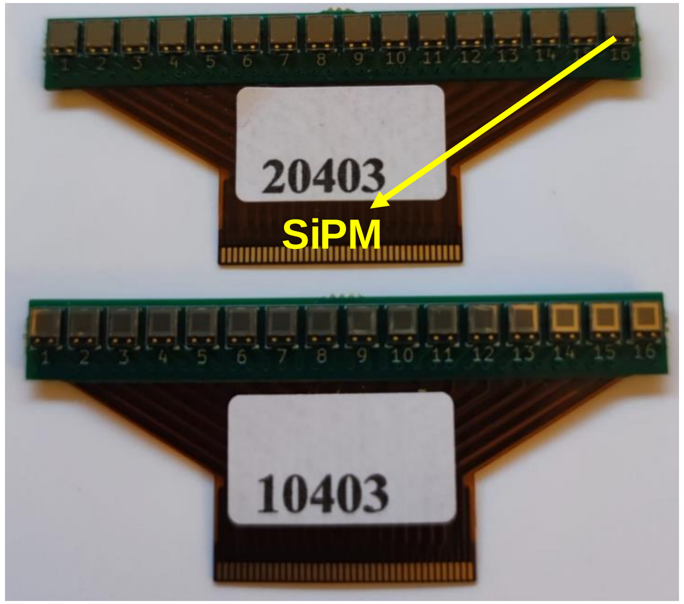
- Light yield test stand for scintillator tiles.
- Tested with **Sr90 source**.
- Measure **light yield** for quality control.
- Small fraction of tiles produced will be tested with this setup.



Quality control for the SiPMs

This is part of the quality control of the Tilemodule

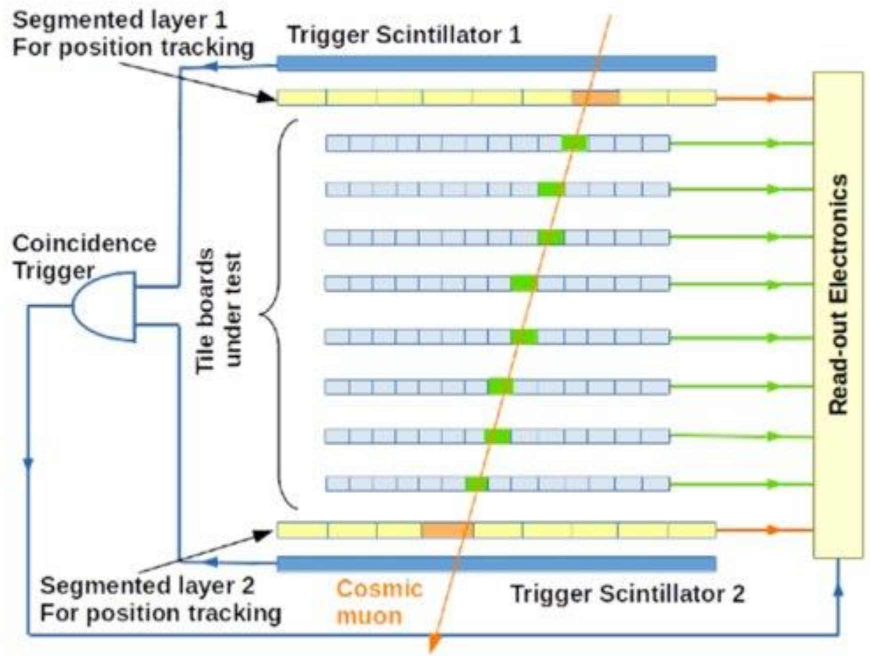




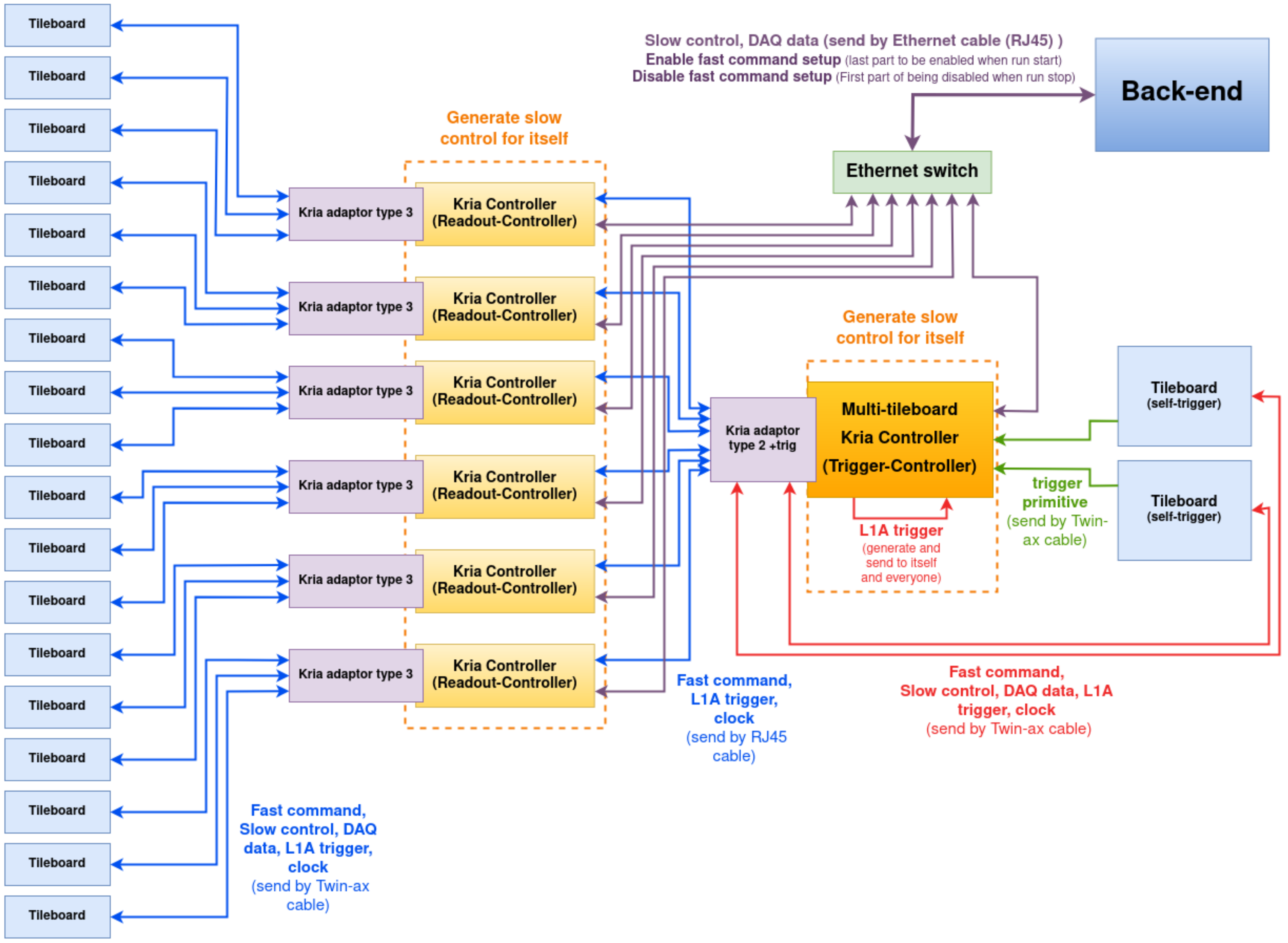
- Data readout by KLauS6-ASIC.
- Pulsed laser (510 nm at 40 mW) with optical attenuator and fibre splitter.
- Can measure **32 SiPMs** at the same time.
- Measure **SPS**.
- Study the **correlation** between **photon released** by the device and **photon detected** by the **SiPM** with high light intensity.

Quality control for Tilemodules

Will be use in cosmic ray test stand and also a small EM stack in test beam for quality control.



- **All Tilemodules produced** will be tested with the **cosmic test stand**.
- Additionally, an **EM stack** with 15 Tilemodules will be built for **shower analysis** in test beam.



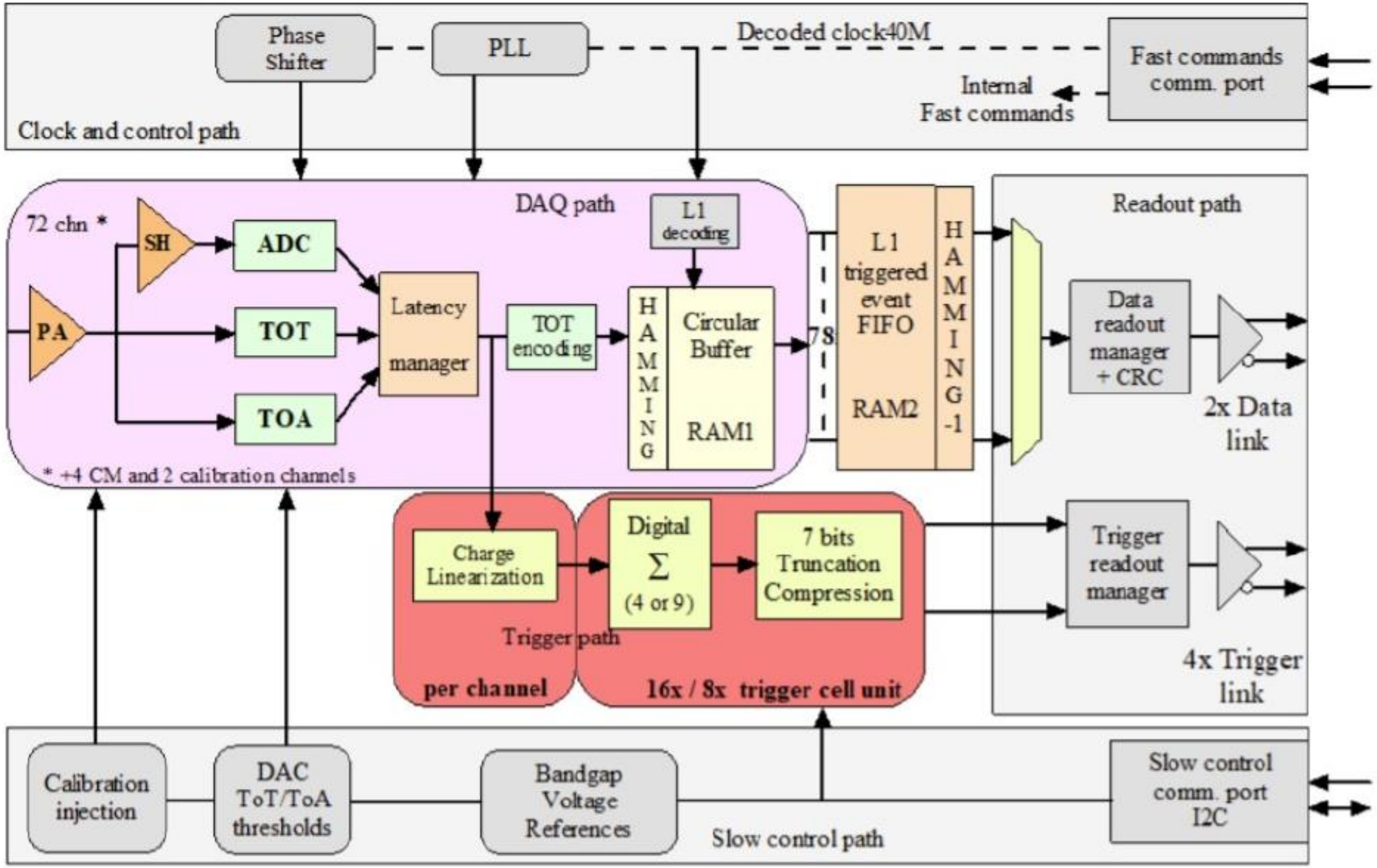
HGCAL readout chip (HGCROC)

Informatino about the data readout chip

- 72 active channels, 2 calibratin channels, and 4 common mode channels.
- Dynamic range ~ 0.2 pC to 10 pC.
- Peaking time ~ 20 ns.
- Linearity < 1%.
- Energy measurement:

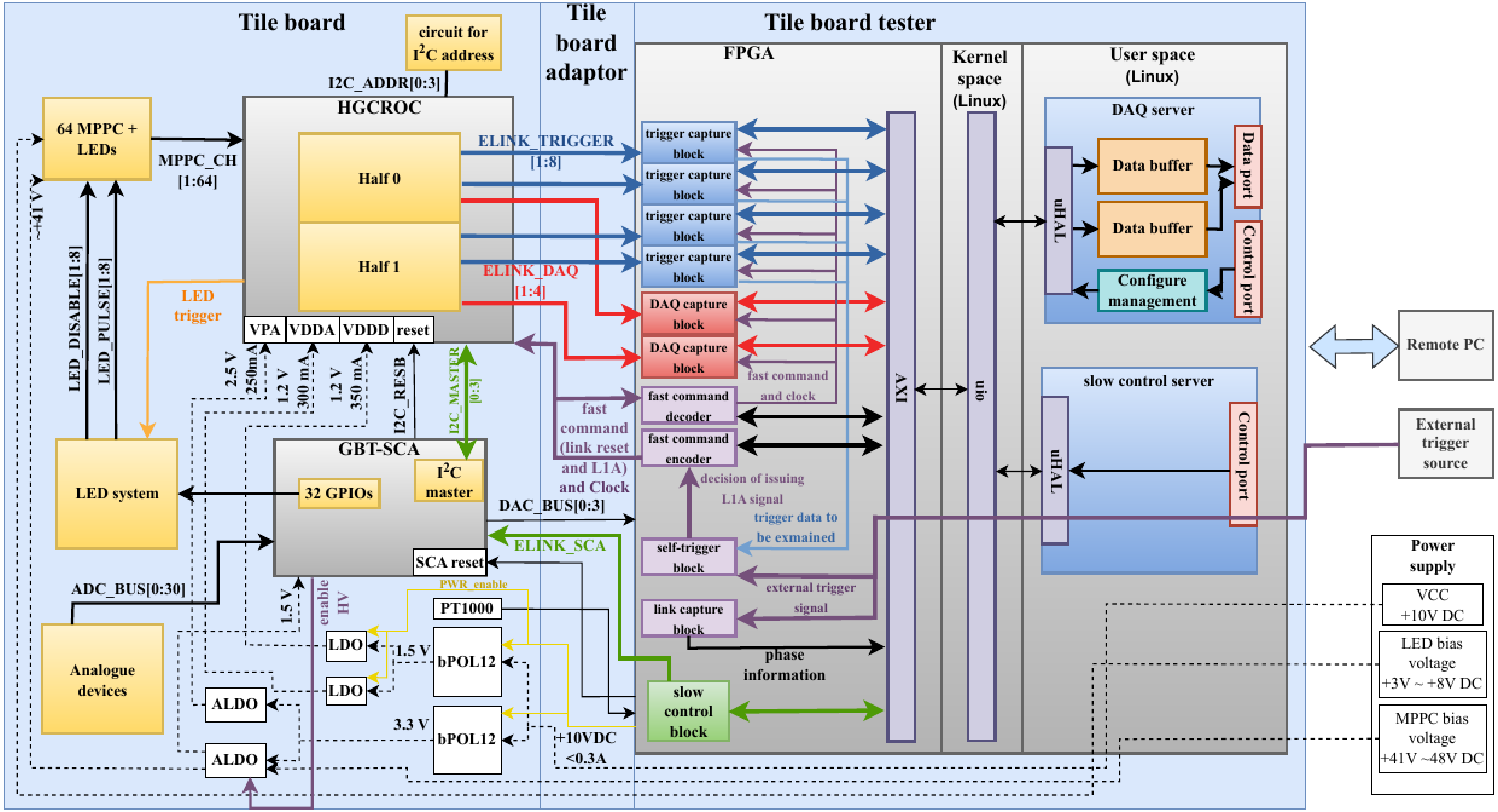
  - ADC 10-bit SAR, range 0 ~ 100 fC

  - TOT range 100 fC ~ 10 pC, with bin size = 2.5 fC.
- TOA: 10-bit TDC, LSB < 25 ps, 25ns full range
- Data readout path: Latency up to 12.5 µs. With 2 outputs in 1.28 Gbps.
- Trigger readout path: Latency up to 36 BX. With 4 outputs in 1.28 Gbps.
- 320 MHz clock.



Single Tilemodule test system

Block diagram



Block diagram made by Jia-Hao Li

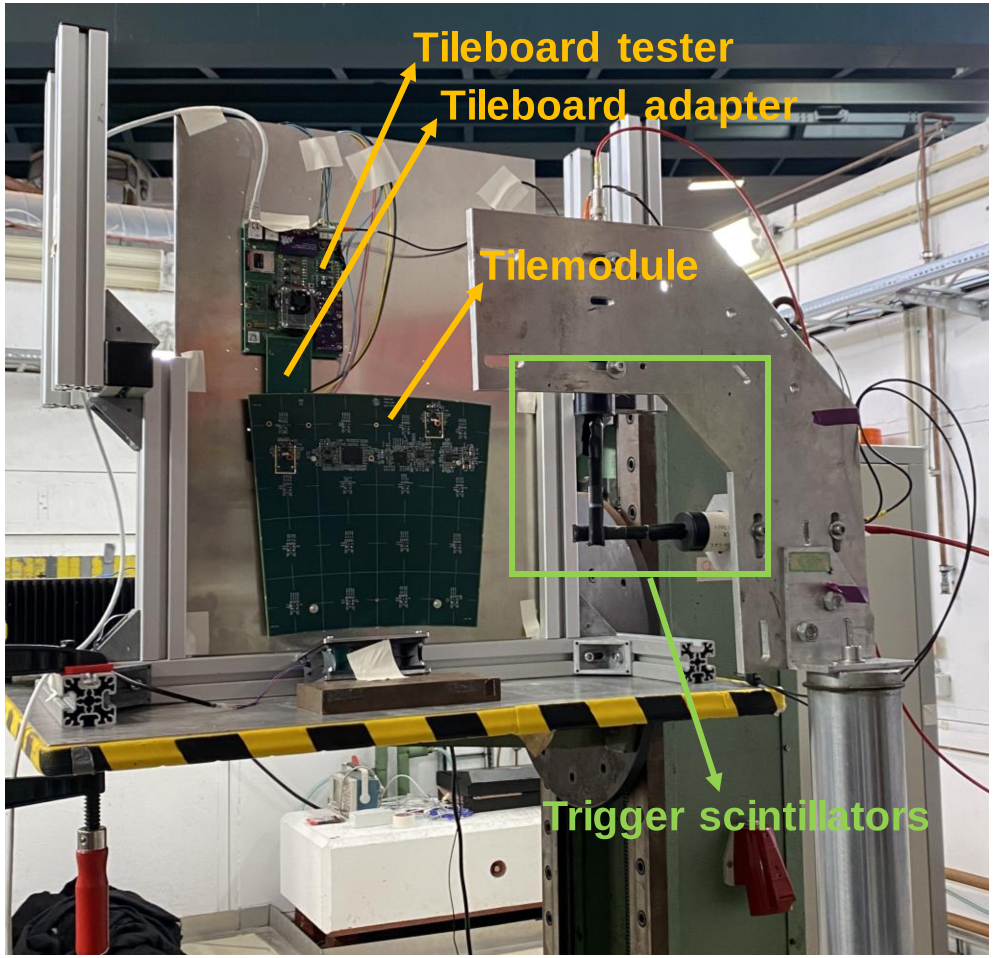
Test beam of the Tilemodule at DESY in May 2023

Test beam setup and goal

Data taking

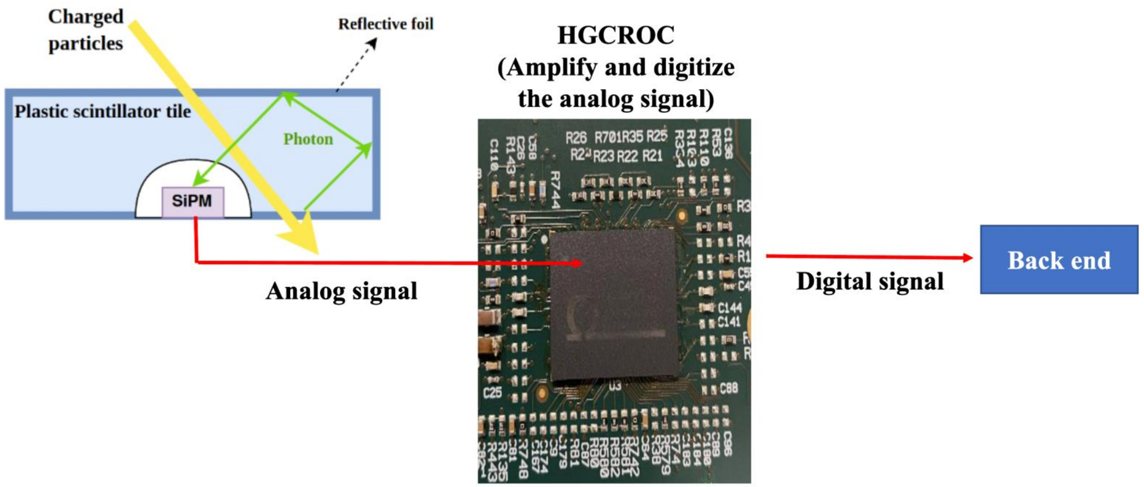
- Measure **MIP spectrum** by taking **100,000 events per channel** with **3 GeV electron beam**.
  - Signal responses from 3 GeV electrons are very similar to Minimum Ionizing Particles (MIPs)
  - Has been verified with muon beams of 120 GeV energy at CERN SPS

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



Test beam of the Tilemodule at DESY in May 2023

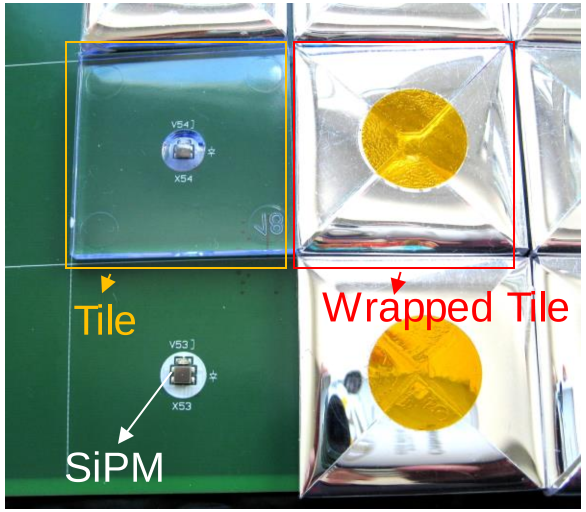
Test beam setup and goal



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.

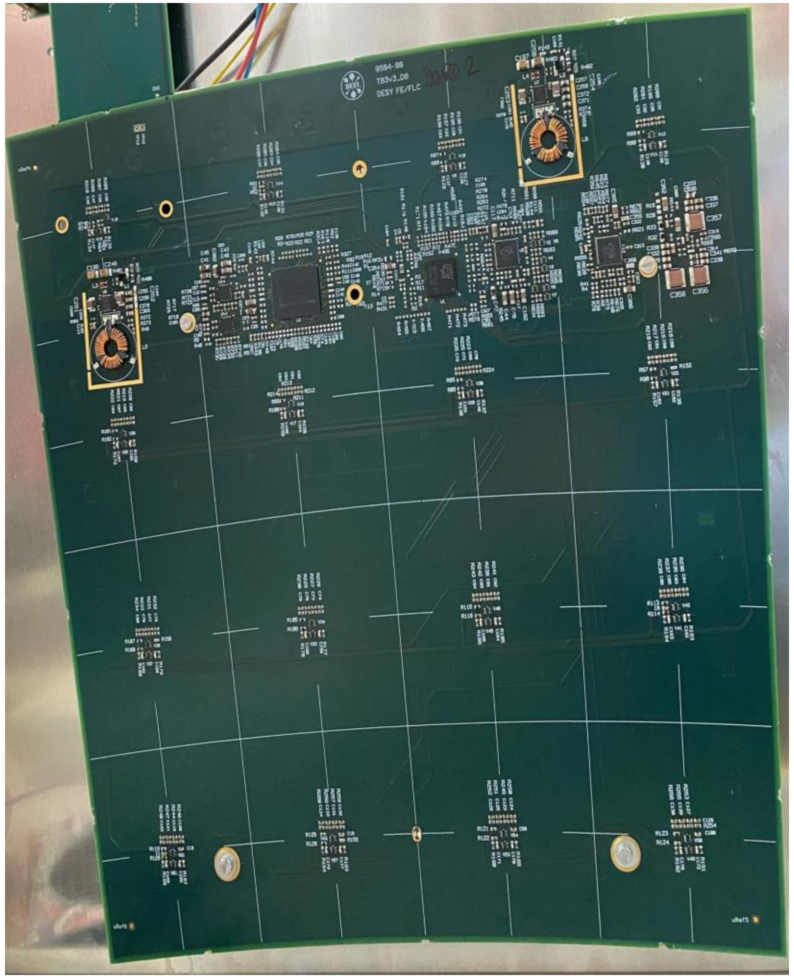


Test beam of the Tilemodule at DESY in May 2023

The Tilemodule tested in the test beam

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.**



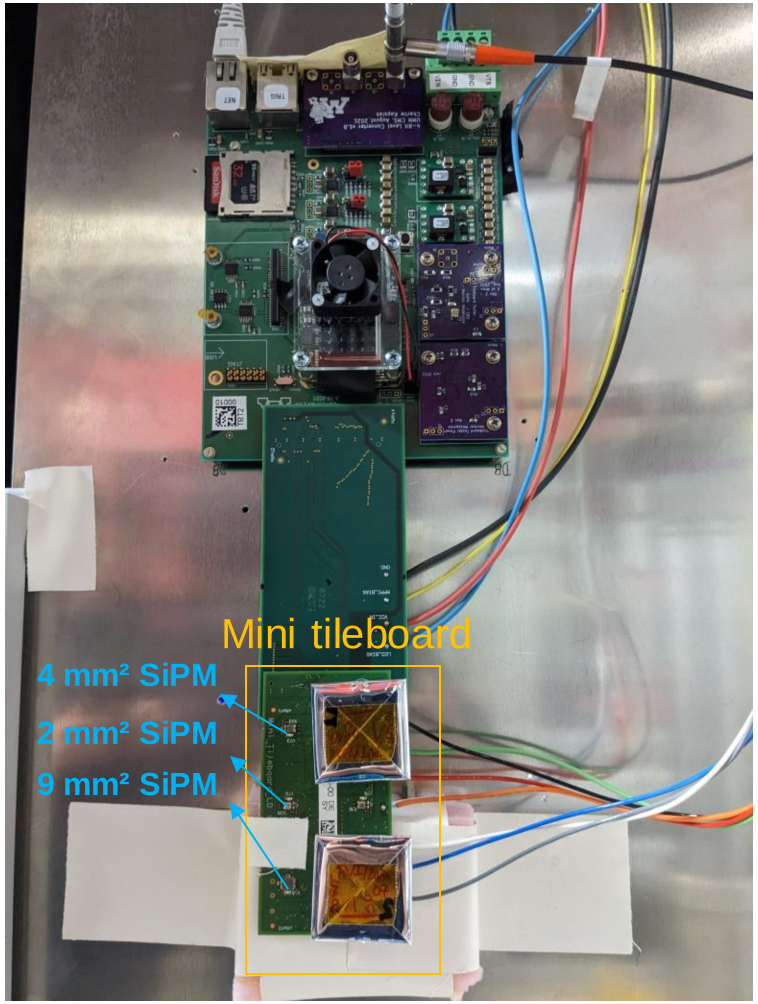
Test beam of the Tilemodule at DESY in May 2023

The Mini Tileboard tested in the test beam

- 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 of the Tilemodule at DESY in May 2023

Two type of module were tested in the test beam

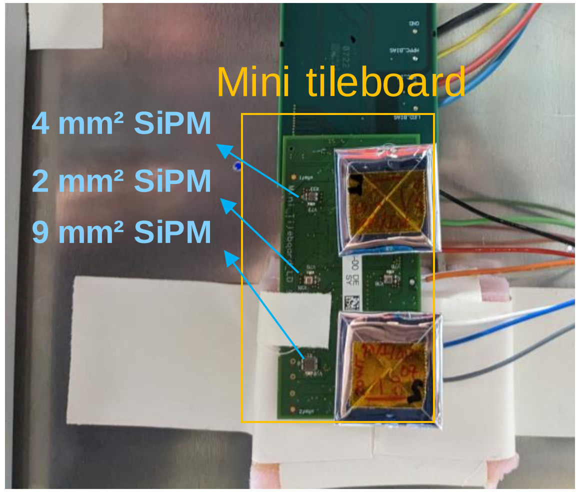
- **Tilemodules**

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**



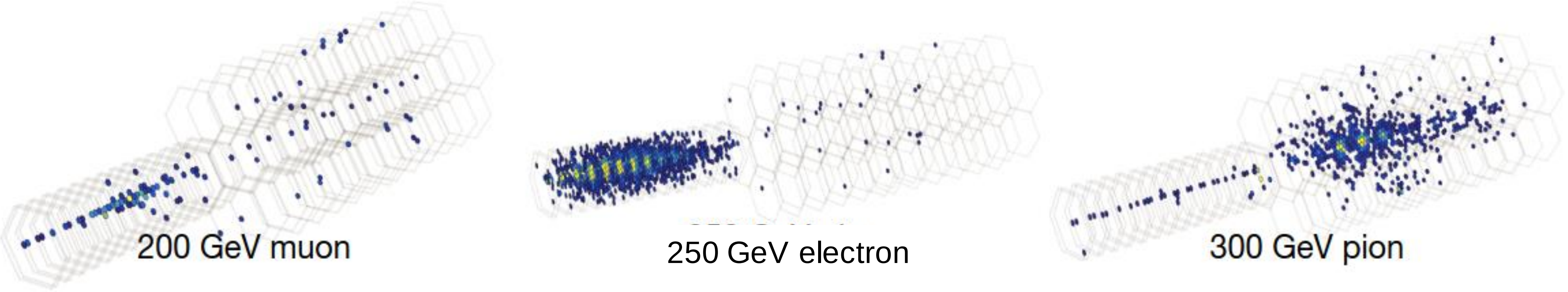
Mini Tileboard
equipped with **IHEP v2 tiles**

with pre-series **4mm² SiPMs** and **9mm² SiPMs**

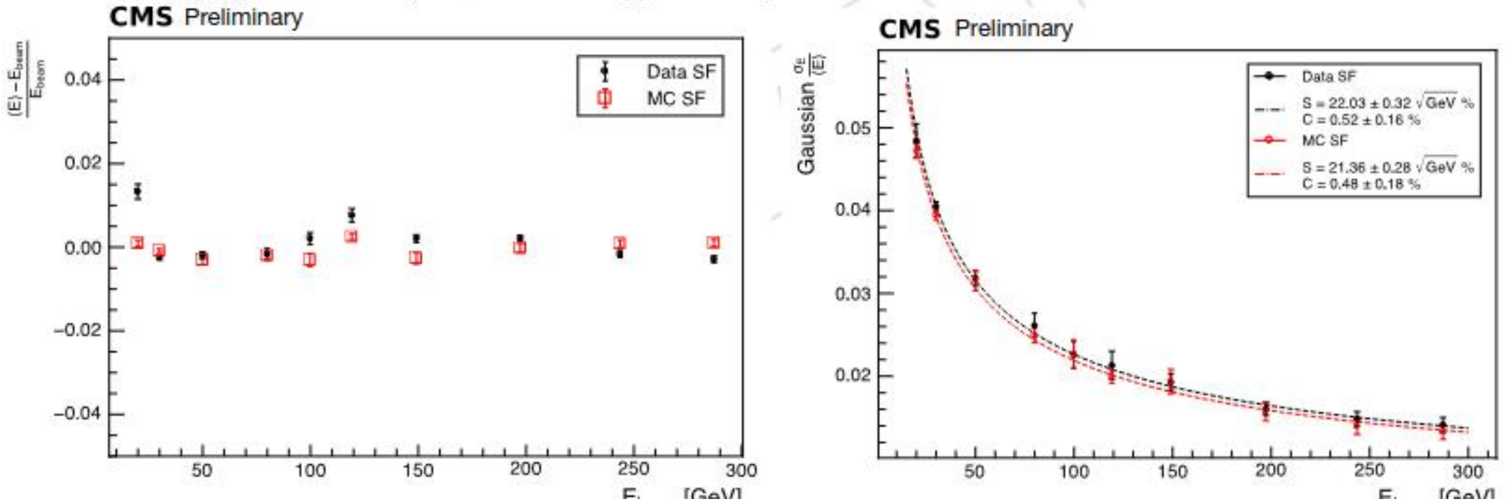
- All Tilemodules use a custom-made DAQ system which is driven by Zynq FPGA for data acquisition.

Test beam in Oct 2018 at CREN

Test beam for hexaboard



2018 TB results on positron energy linearity and resolution



Block diagram of the multi-Tilemodule test system

Kria controllers

- **Trigger-Controller:**

  - is a **Kria controller** connected to a **Kria adaptor type "2 + trig"**

  - hosts 2 triggering Tilemodules by Twin-ax cable

  - drives up to 6 Readout-Controller by RJ45 cable

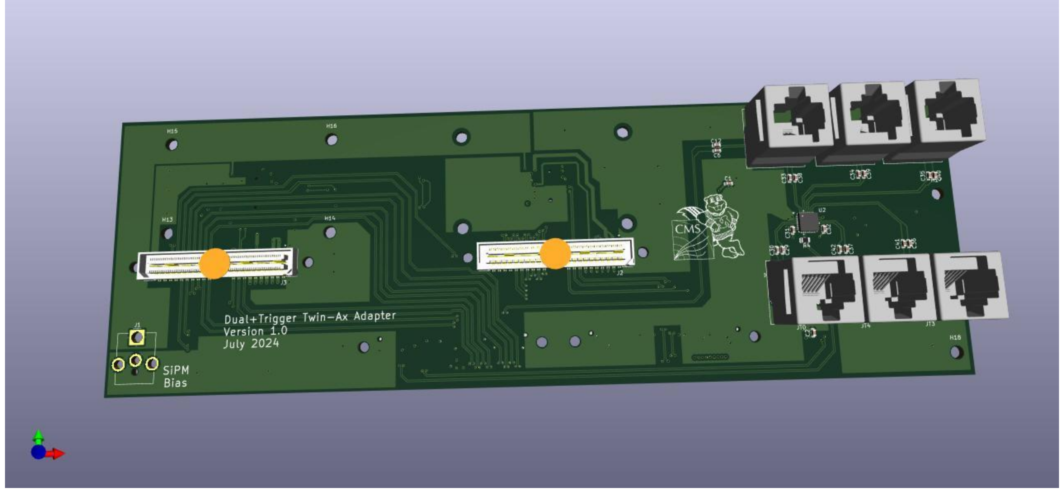
- **Readout-Controller:**

  - is a **Kria controller** connected to a **Kria adaptor type "3"**

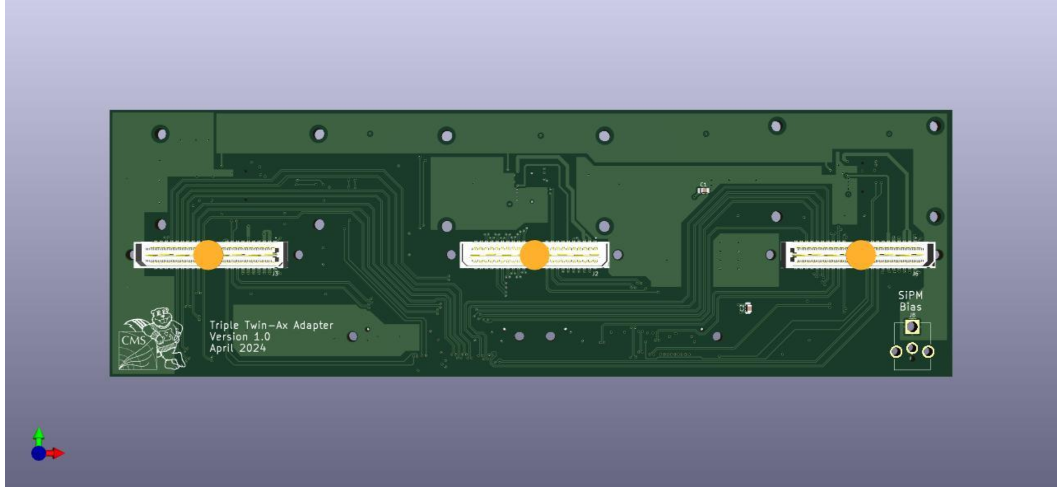
  - can control up to 3 Tilemodules by Twin-ax cable

- Both of the Trigger and Readout-Controller are using the **same type of Kria Controller**. They use **different type** of **Kria adaptor** and **firmware**.

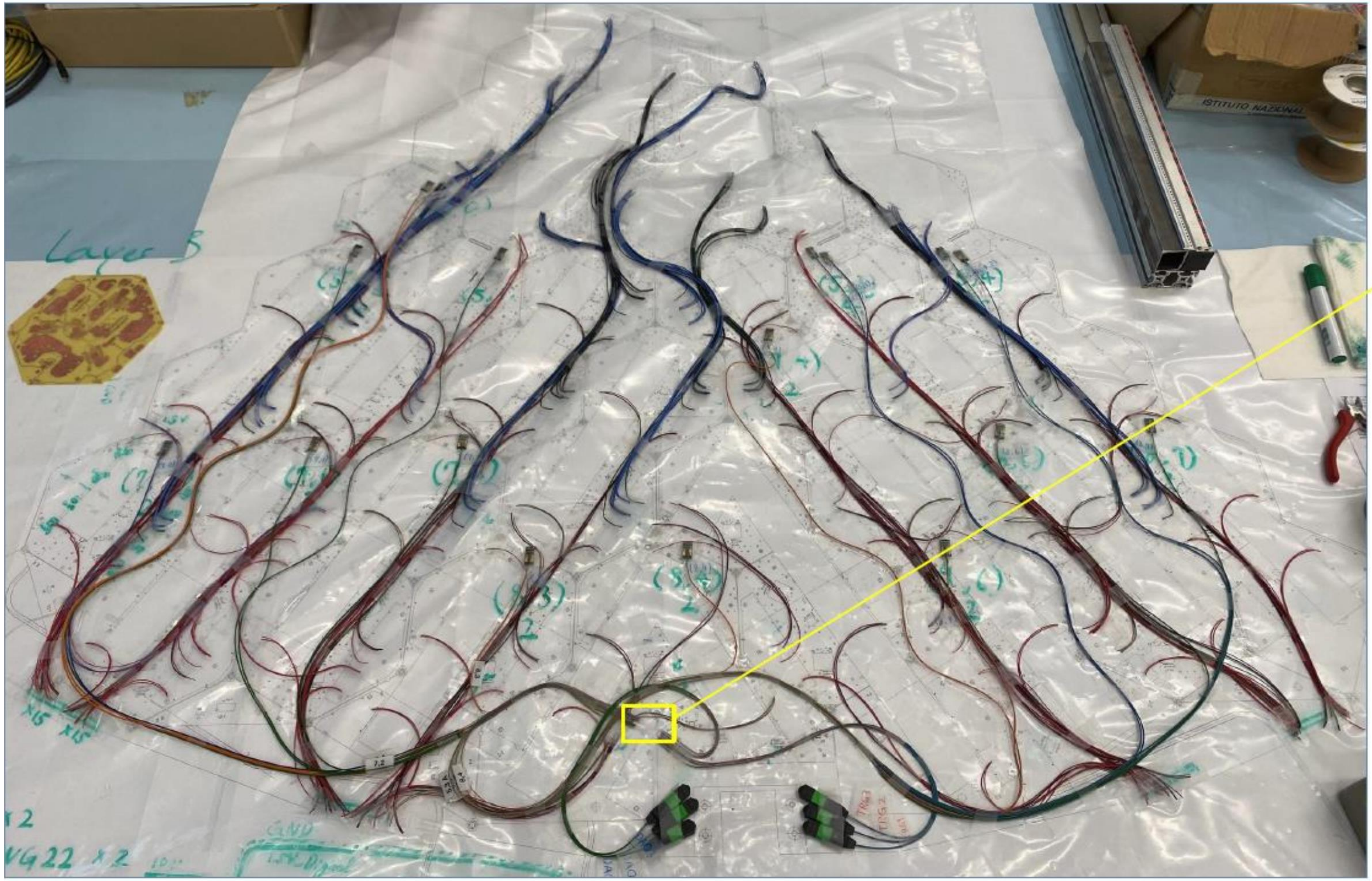
Kria adaptor type 2 + trig



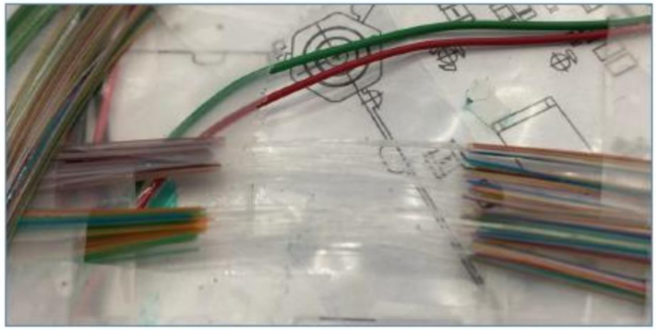
Kria adaptor type 3

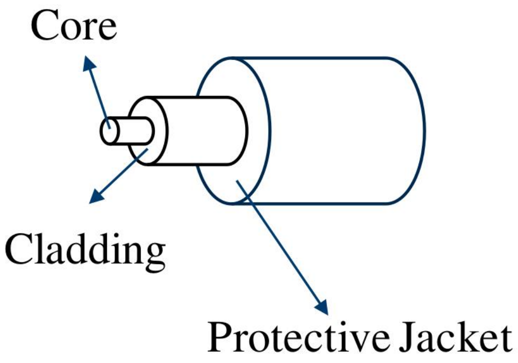


Fibre splicing

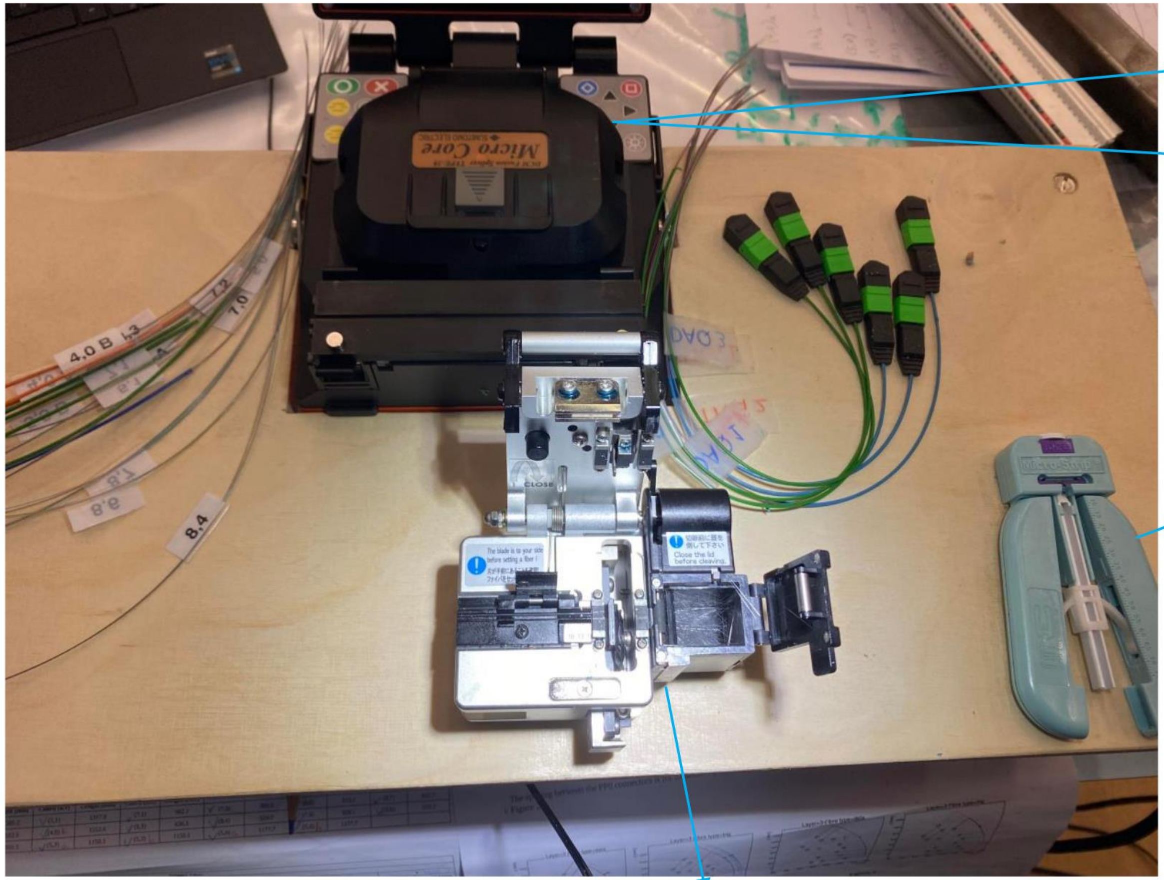


- All 72 splicing points are located in the same region.

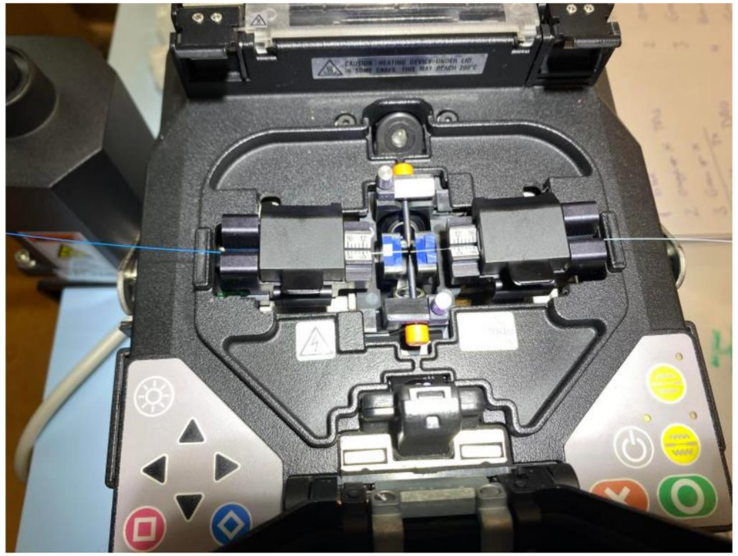




Fibre splicing



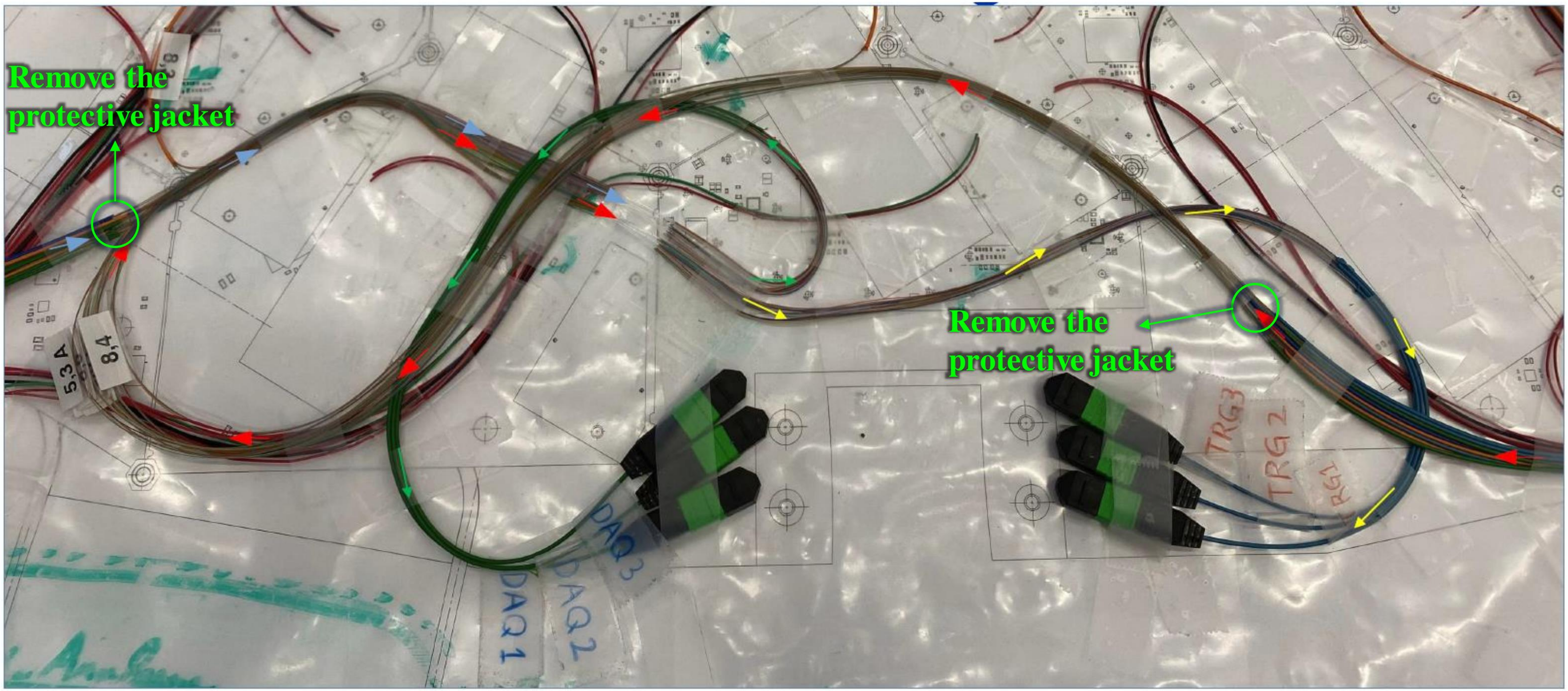
Splicing machine



Remove the cladding

Fibre Optic Cleaver (Cut the core at 90 degree angle with smooth surface)

Fibre splicing



- The light blue arrows indicate the fibres coming from the left side of the cassette. And the red arrows indicate the fibres coming from the right side.

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

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