Status and plans of the Tilemodule assembly centre at DESY

Quality control procedure for Tileboards and Tilemodules

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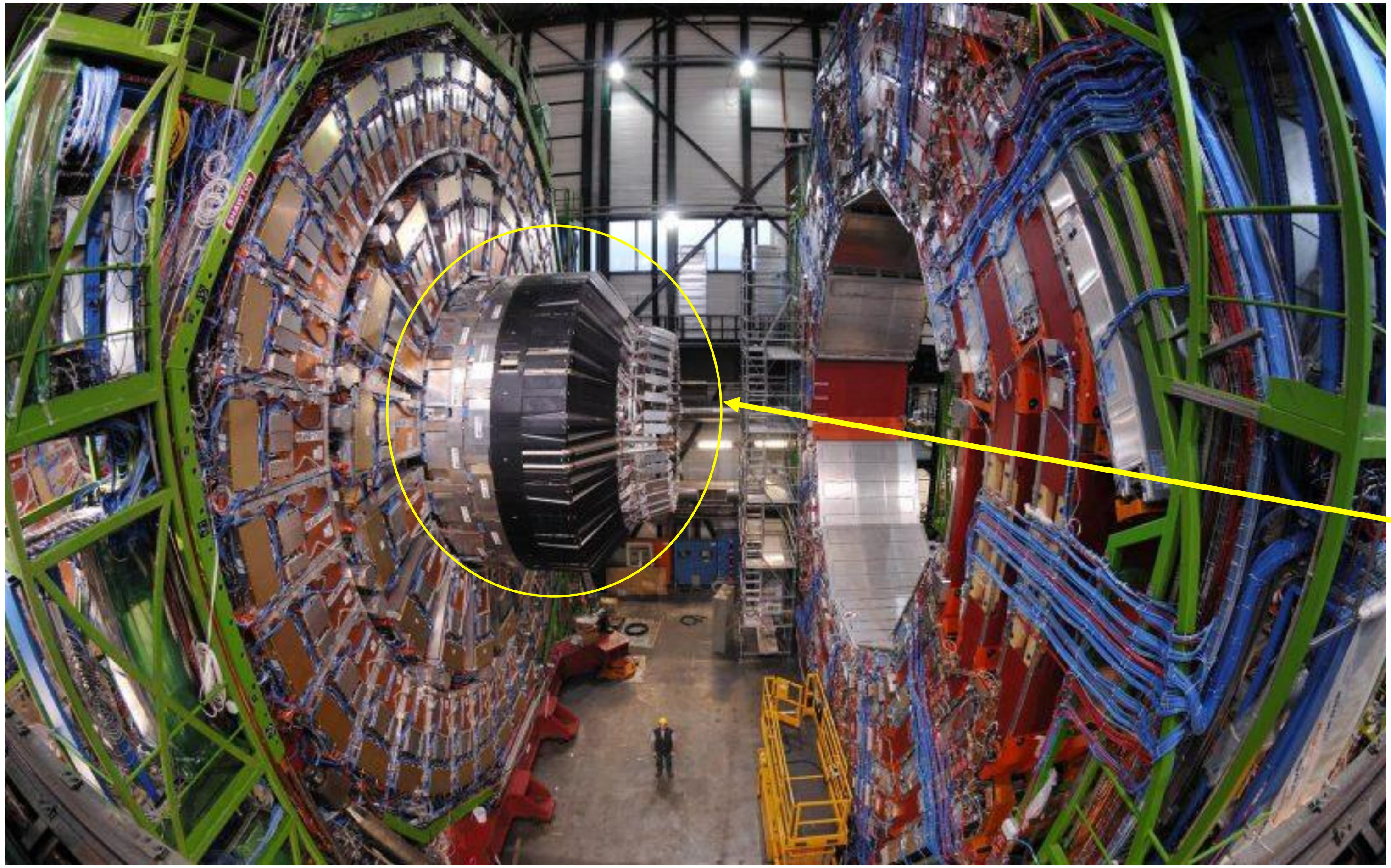
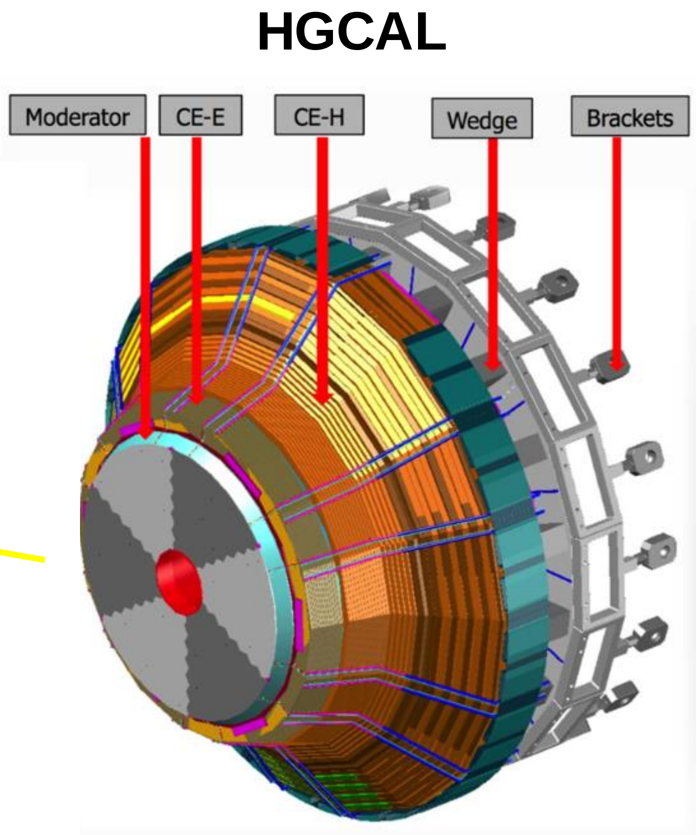
16 Oct 2024

High Granularity Calorimeter (HGCAL)

What is HGCAL. Basic structure and purpose.



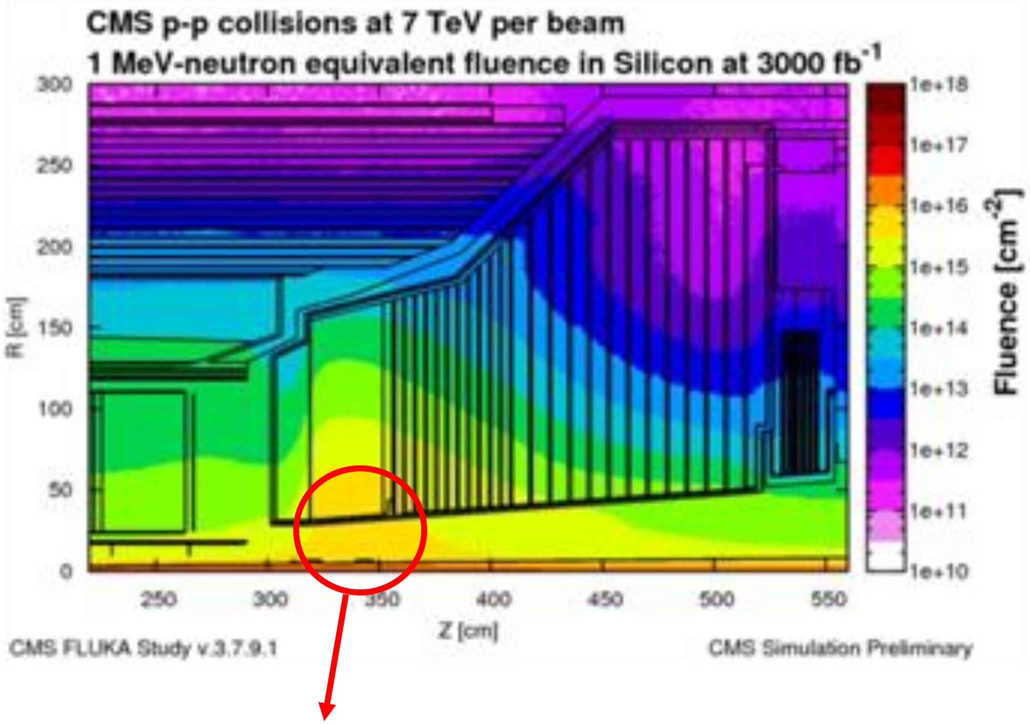


- As part of the CMS phase-II upgrade, HGCAL will replace **the current endcap** of the CMS detector for the **HL-LHC**.

What is HGCAL, and why do we need it

Basic structure and purpose.

- It'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.



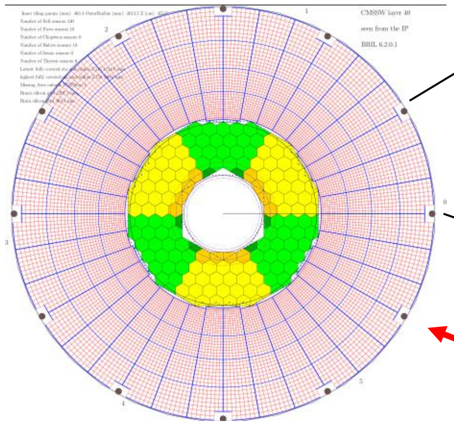
Up to 2 MGy absorbed dose

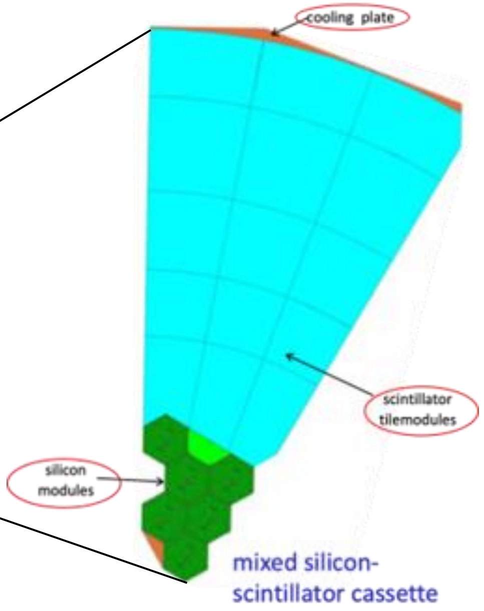
Basic structure of the High Granularity Calorimeter (HGCAL)

What is HGCAL. Basic structure and purpose.

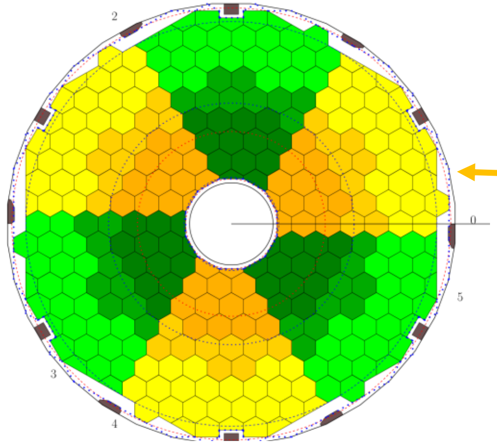
- **Silicon section** (using **silicon sensors**): Cover the electromagnetic calorimeter (**CE-E**) and part of the Hadronic calorimeter (**CE-H**)
- **Scintillator section** (using **SiPM-on-tile technology**): Cover the **CE-H** where the expected end-of-life neutron fluence is less than 5×10^{13}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

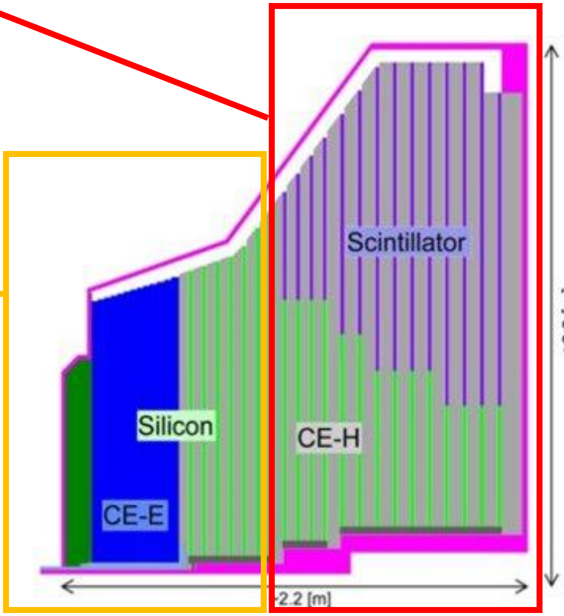
Mix layer of silicon and scintillator section





Layer with only silicon section





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:**

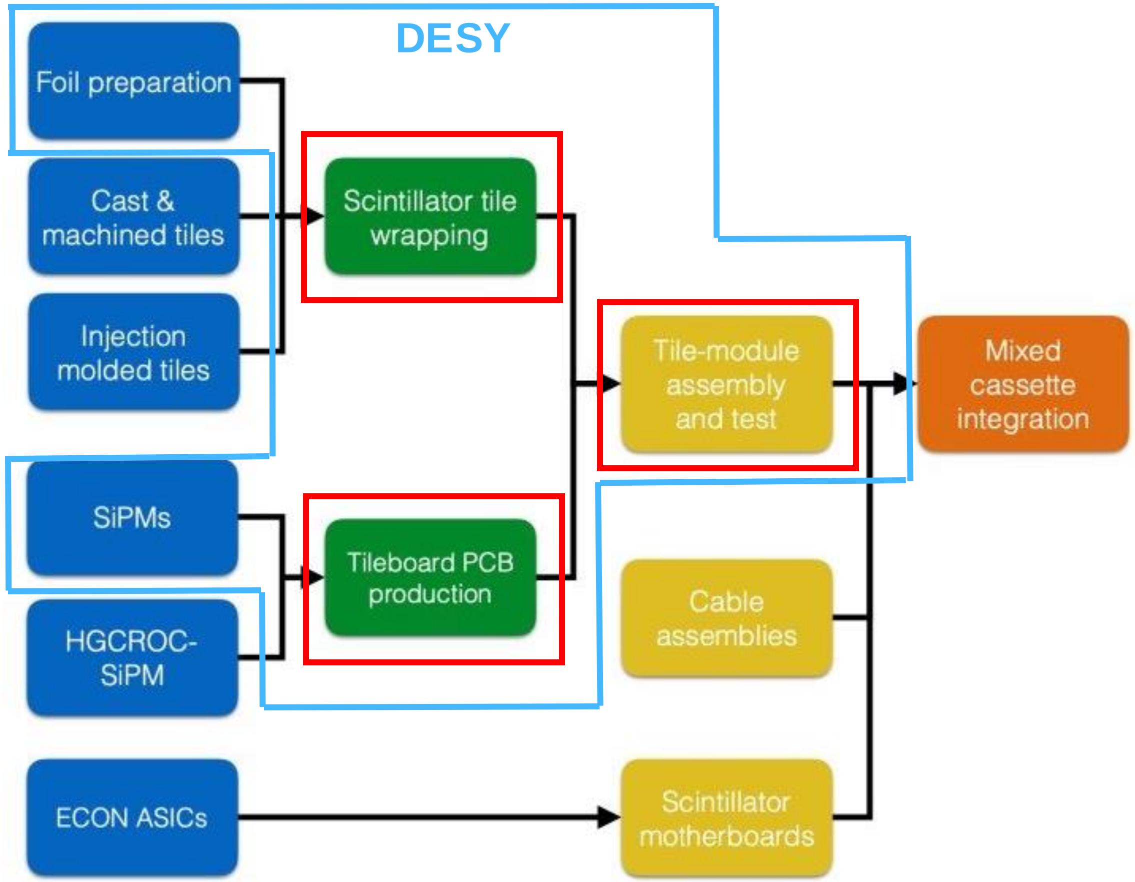
  - cold test (**1 thermal cycle**. Temperature: **-35** ~ **20** °C):

    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**.



DAQ system

which is used now in DESY

DAQ system at DESY:

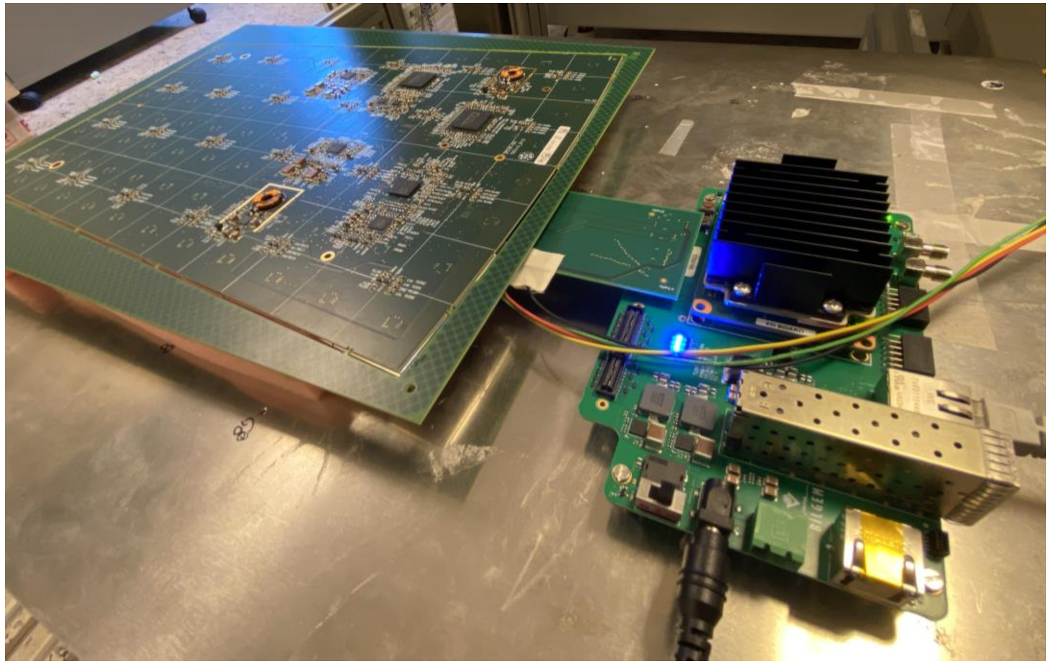
- **Software** - using **SWAMP** for slow control scripts.
- **Firmware** - using **transactor** firmware block for slow control
- **Hardware** - **Kria** controller (replaced the tbtester)
- The DAQ system has been tested that it **can receive external trigger** with customized RJ45 adaptor.

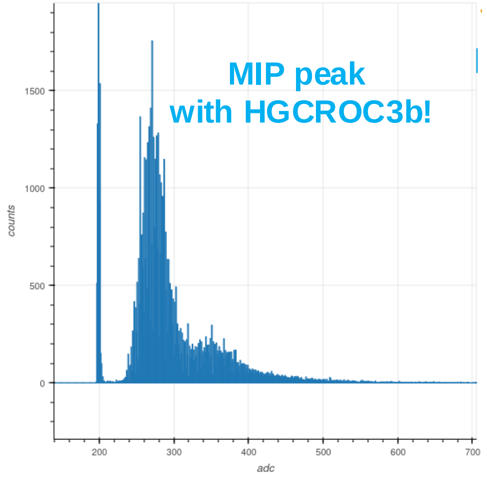
The DAQ system is already tested with:

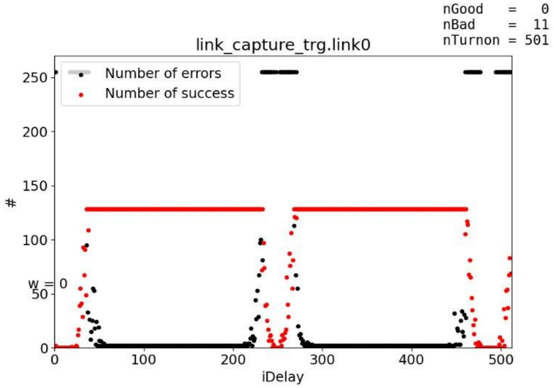
- **Tilemodules** equipped with **1 HGCROC** (**3a** and **3b**)
- **Tilemodules** equipped with **2 HGCROCs** (**3a** and **3b**)

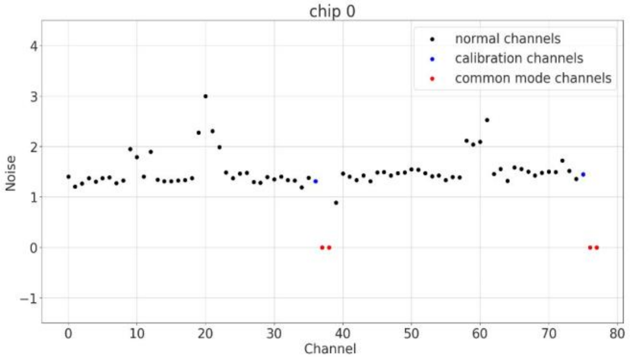
Next step:

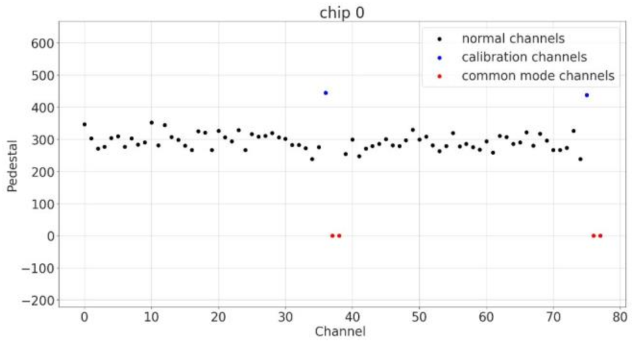
- **Muti-TB readout system** - can test up to 3 Tilemodules simultaneously with one Kria.





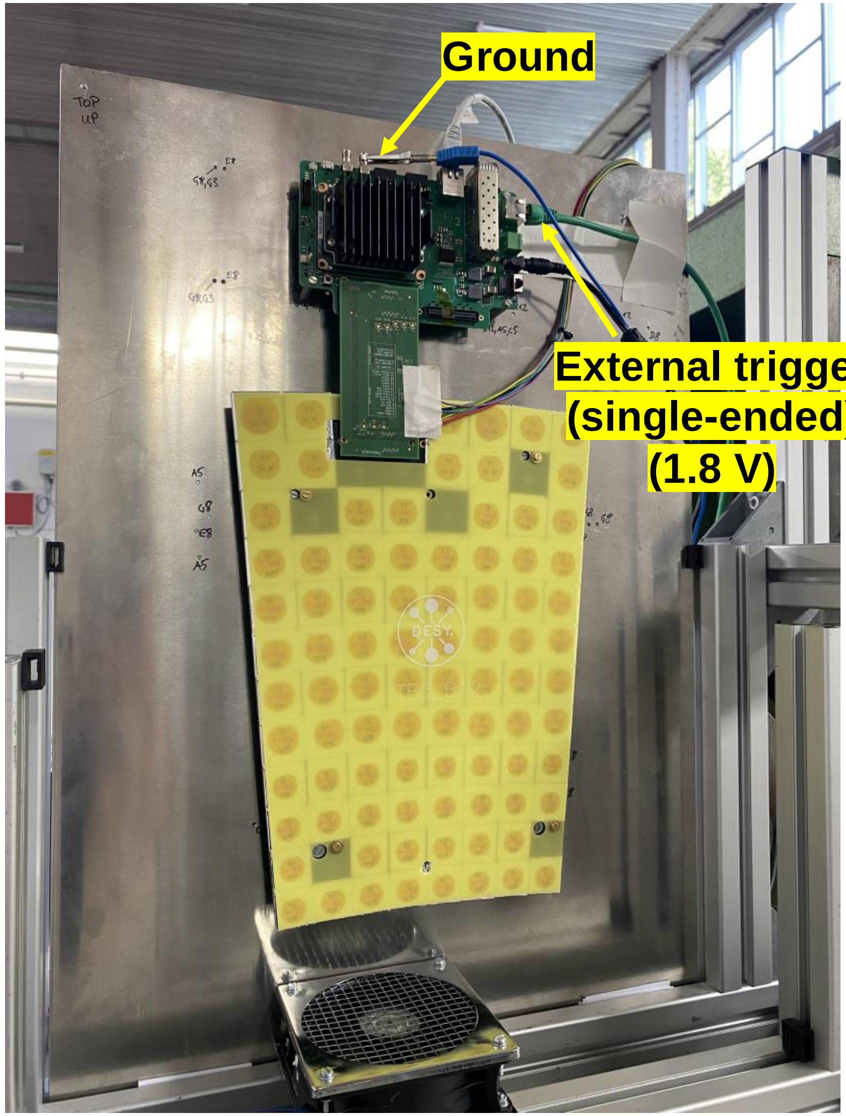




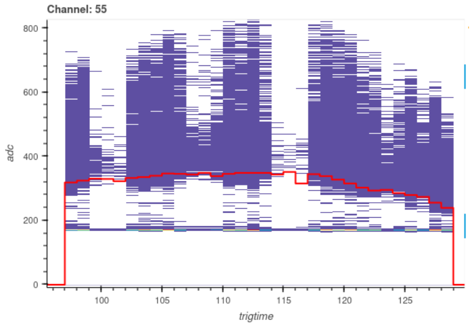


DAQ system

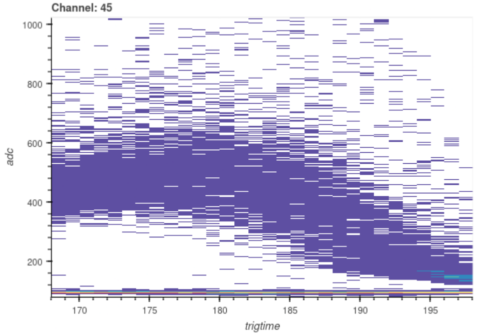
External trigger



- The DAQ system has been tested that it **can receive external trigger** and has been used in test beams in DESY (July and August 2024).
- Using **RJ45 port** and a **customized RJ45 adaptor** to get **external trigger signal** via **LEMO**.
- This setup is using **internal clock**.
- Required **additional cable clips** as the **ground** of the external trigger.
- The trigtime distribution looks gated when using the customized RJ45 adaptor. (which is not the case for the TBtester)



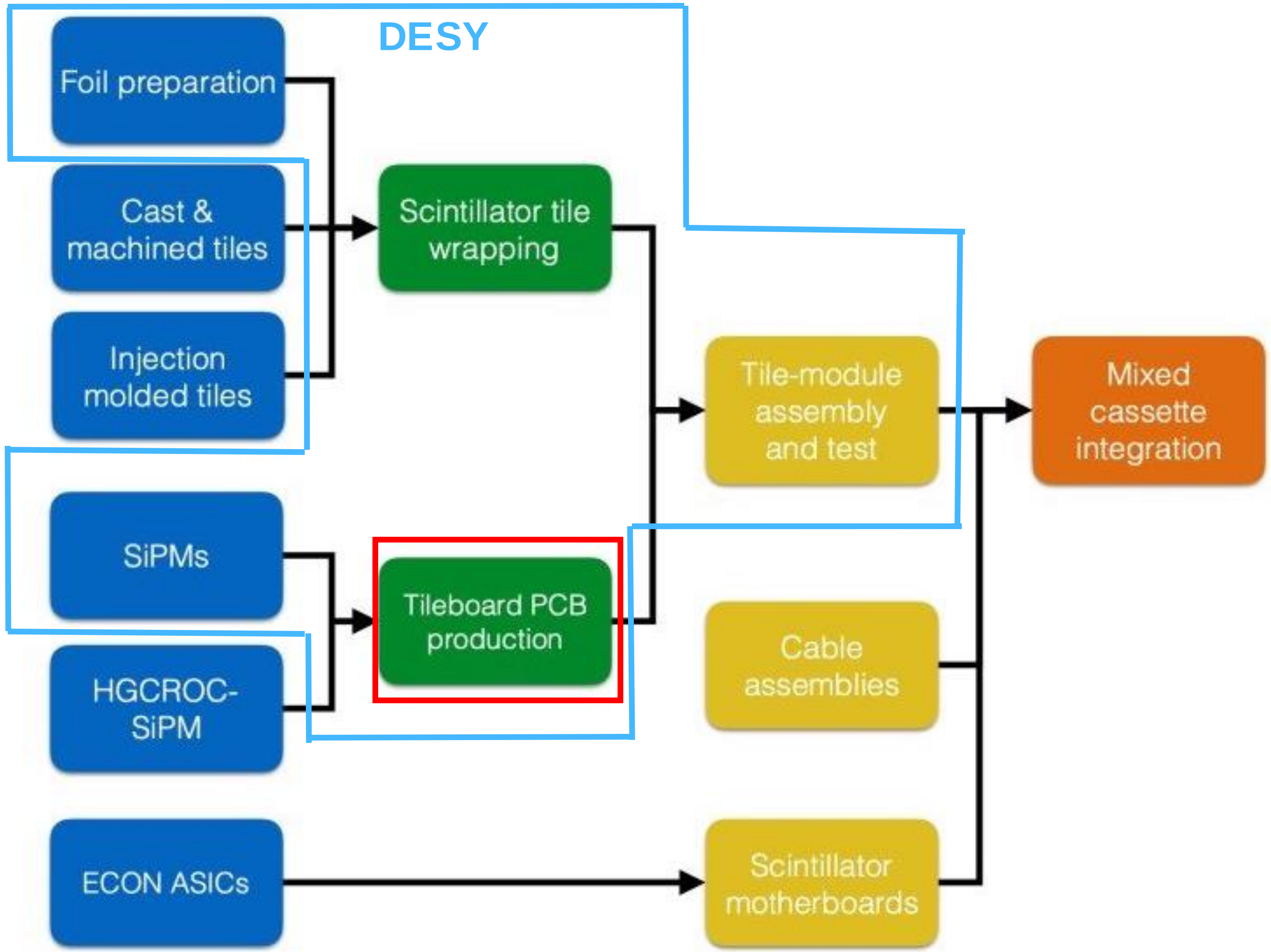
Trigtime
(Kria + RJ45 adaptor)



Trigtime
(TBtester + trigger mezzanine)

Quality control for Tileboards at DESY

Without tiles



Cold test for pre-series Tileboards (no tile)

procedure

- **Testing temperature: -35°C** and **20°C**
- **Total time per cycle: ~2.5 hours**
- **Procedure:**

  - **Step 0: Connect** the **Tileboards** to the TB adaptors. (**~10 minutes**)

  - **Step 1: Test** the **Tileboards** with pedestal run, delay scan, and LED run in **room temperature**. (**~20 minutes**)

  - **Step 2: Cooling** the climate chamber down to **-35°C** (**~30 minutes**).

  - **Step 3:** Wait until the temperature **stabilized** (**~10 minutes**) and then **test** the **Tileboard** again (**~20 minutes**).

  - **Step 4: Warming** the chamber to **20 °C** (**~30 minutes**), wait until it **stabilized** (**~10 minutes**), and then take the **measurements** again (**~20 minutes**).

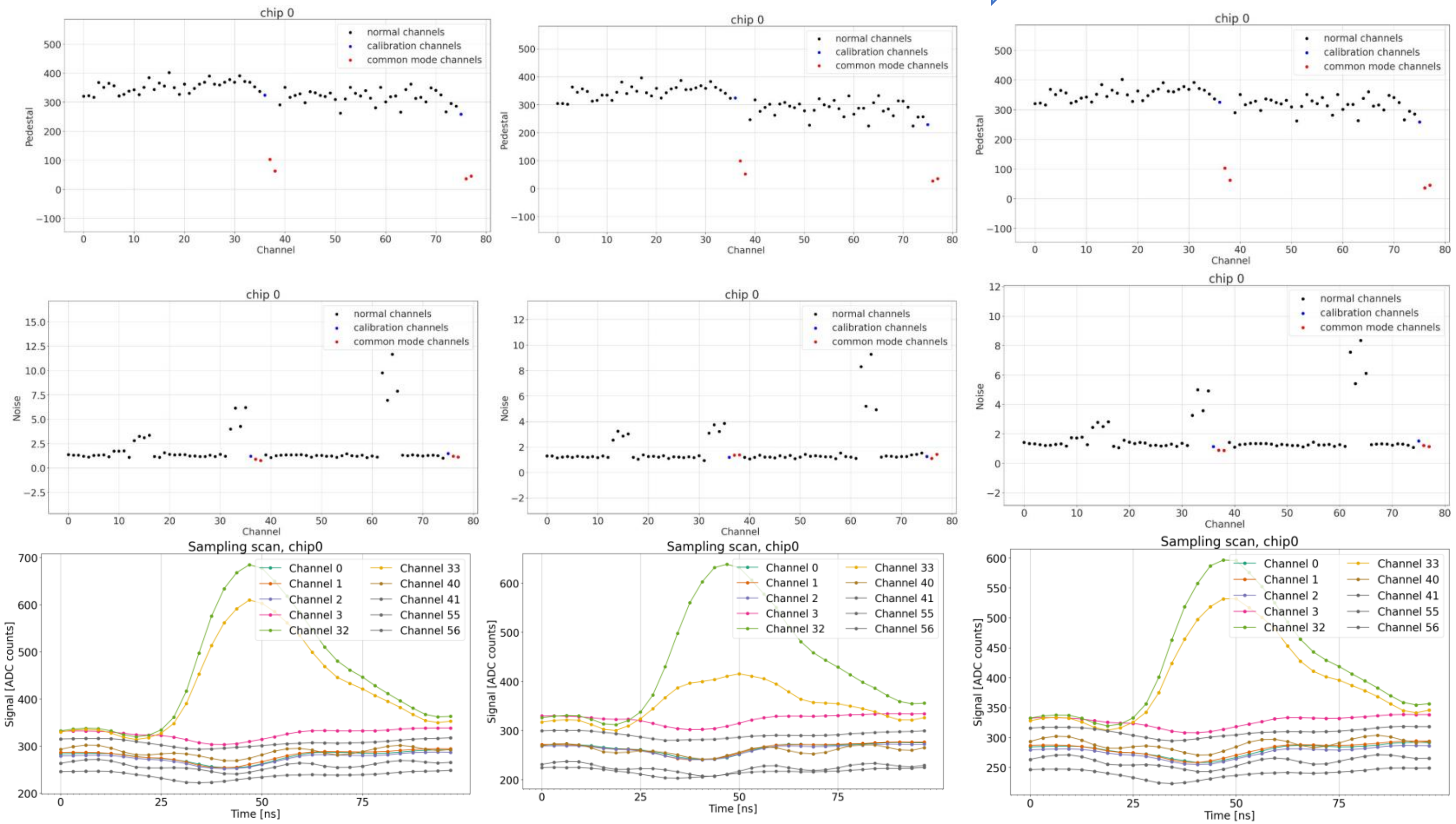
Cold test for pre-series Tileboards (no tile)

Example of "good" Tileboard in cold test

- To be defined "**Good**", The Tileboard has to show its **ability to detect LED light**. And also with **reasonable pedestal** and **noise** value.

TB3_G8_6

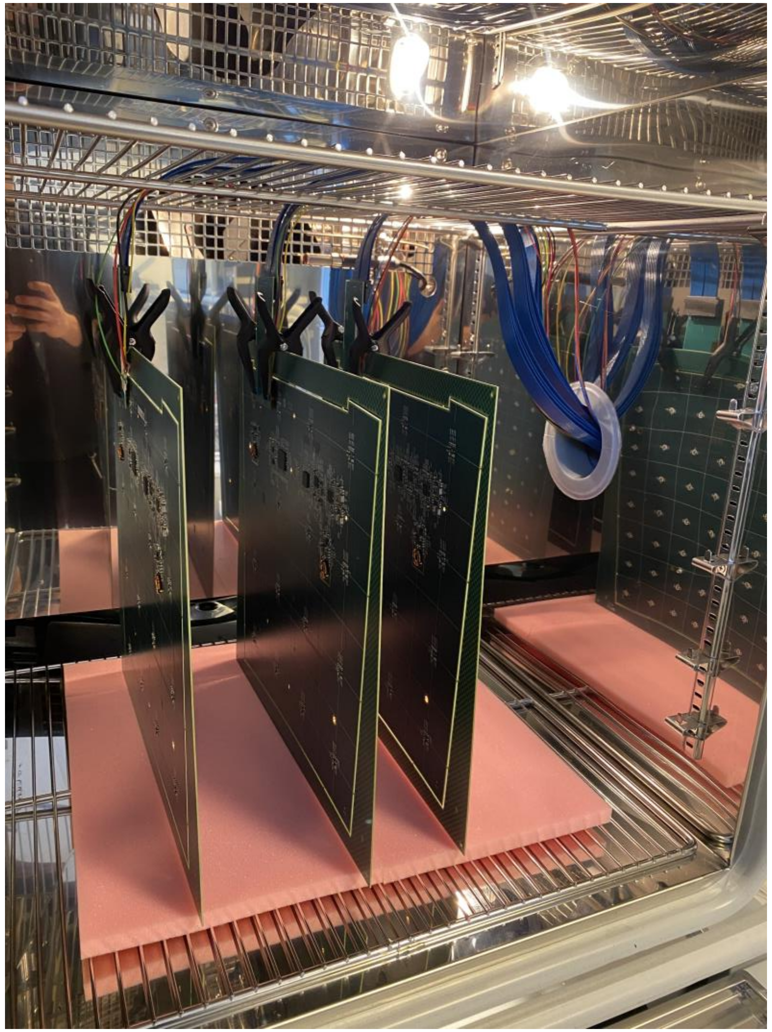
Room temperature → **-35 °C in climate chamber** → **20 °C in climate chamber**



Cold test for pre-series Tileboards with HGCROC3a

Tested Tileboards

Tested Tileboards		
A5_1	D8_2	E8_1
A5_2	D8_3	E8_2
A5_3	D8_4	E8_3
A5_4	D8_5	E8_4
A5_5	D8_6	E8_5
A5_6	D8_7	E8_6
B12_3	D8_8	G8_1
B12_4	D8_9	G8_3
B12_5	D8_10	G8_4
B12_6	D8_11	G8_5
	D8_12	G8_6



Cold test for pre-series Tileboards with HGCROC3a

results

Test result			
	Room temperature	-35 °C	20 °C
A5_1	Good!	Good!	Good!
A5_2	Good!	Good!	Good!
A5_3	Good!	Good!	Good!
A5_4	Good!	Good!	Good!
A5_5	Good!	Good!	Good!
A5_6	Good!	Good!	Good!
D8_2	Good!	Good!	Good!
D8_3	Good!	Good!	Good!
D8_4	Good!	Good!	Good!
D8_5	Good!	Weird LED pattern	Good!
D8_6	Good!	Weird LED pattern	Good!
D8_7	Good!	Good!	Good!
D8_8	Good!	Weird LED pattern	Good!
D8_9	Good!	Good!	Good!
D8_10	Good!	Good!	Good!
D8_11	Good!	Weird LED pattern	Good!
D8_12	Good!	Good!	Good!

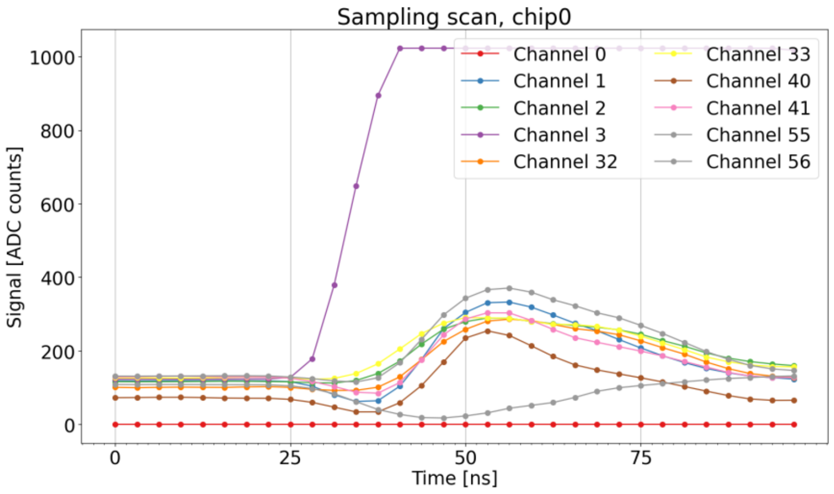
Test result			
	Room temperature	-35 °C	20 °C
B12_3	Good!	Weird LED pattern	Good!
B12_4	Good!	Connection fail	Good!
B12_5	Good!	Good!	Good!
B12_6	Good!	Connection fail	Good!
E8_1	Good!	Good!	Good!
E8_2	Good!	Good!	Good!
E8_3	Good!	Good!	Good!
E8_4	Good!	Good!	Good!
E8_5	Good!	Good!	Good!
E8_6	Good!	Good!	Good!
G8_1	Good!	Good!	Good!
G8_3	Good!	Good!	Good!
G8_4	Good!	Good!	Good!
G8_5	Good!	Good!	Good!
G8_6	Good!	Good!	Good!

- The **weird LED pattern** is due to the provided low **LED bias voltage** was **too low**
- The **Connection fail** is due to **poor connection** of the adaptor, which is now **solved** by using a **new adaptor version**

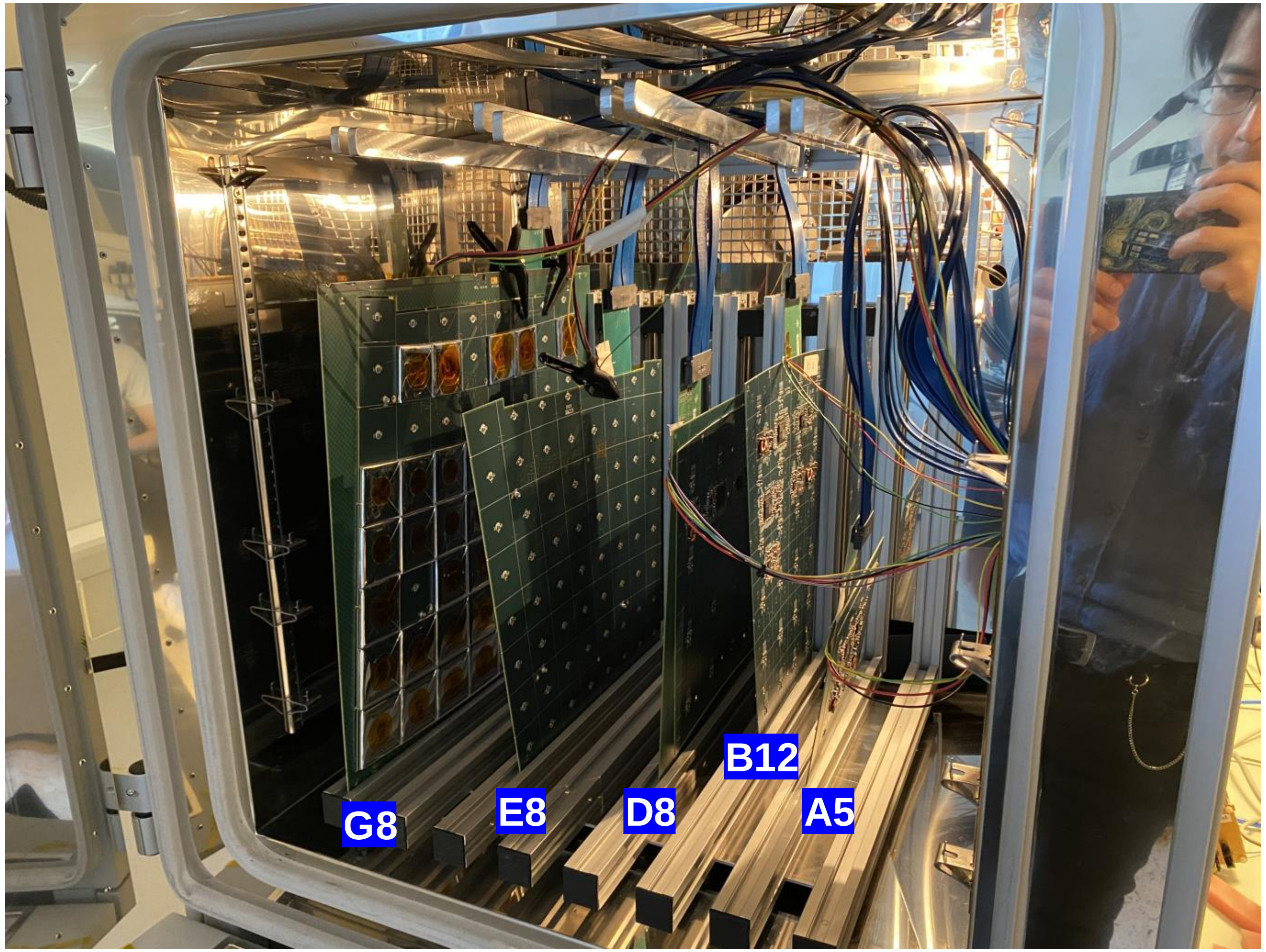
Cold test for Tileboards with HGCROC3b

results

	Room temperature	-35 °C	20 °C
A5	Good!	Good!	Good!
B12	Good!	Good!	Good!
D8	Good!	Good!	Good!
E8	Good!	Good!	Good!
G8	Good!	Good!	Good!

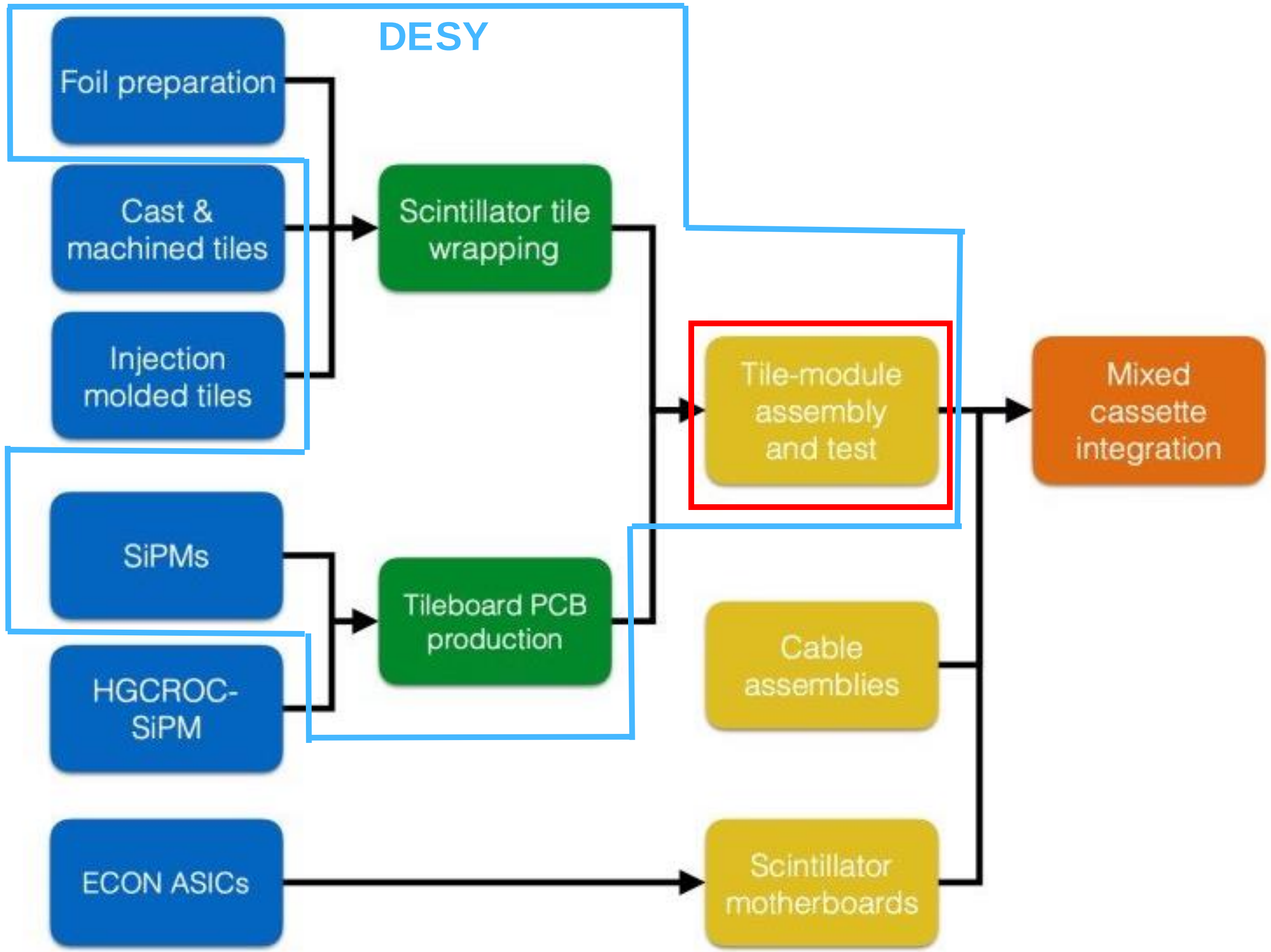


LED run for D8 **(–35 °C)**



Quality control for Tilemodules at DESY

With tiles

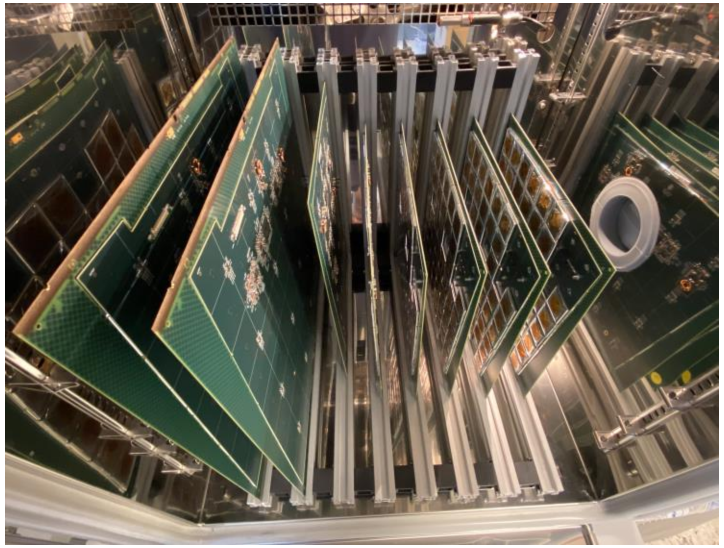


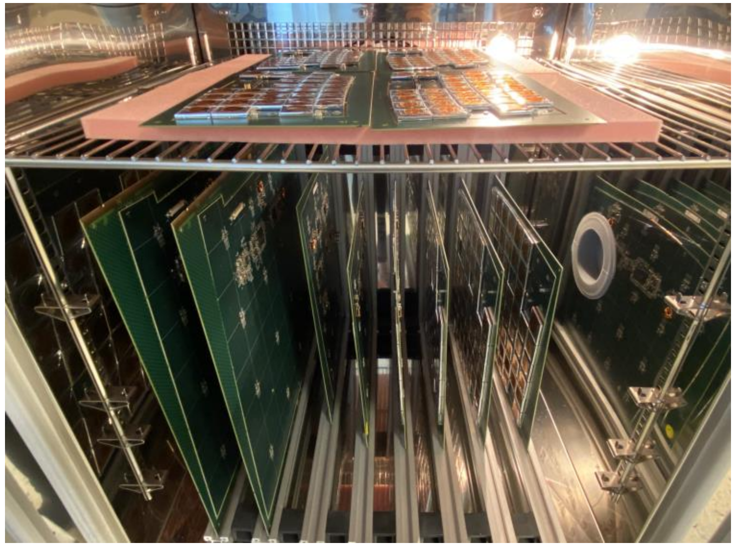
Mechanical cold test – Tilemodules with HGCROC3a

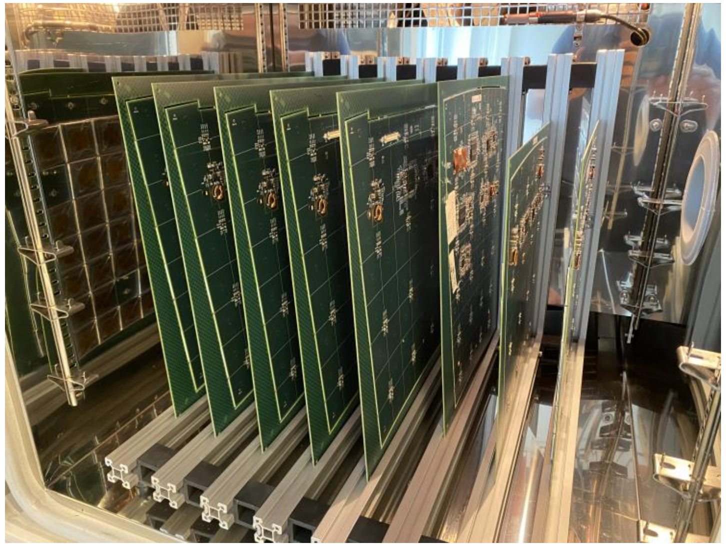
For all pre-series Tilemodules equipped with tiles

- **All pre-series Tilemodules** with tiles were **tested under –35 °C.** -> **No tiles fall off**. **No visible damage.**

- Tested Tilemodule: **A5_1**, **A5_2**, **A5_5**, **A5_6**, **B12_1**, **B12_2**, **D8_3**, **D8_4**, **D8_5**, **D8_6**, **D8_8**, **D8_10**, **D8_11**, **D8_12**, **E8_2**, **E8_3**, **E8_4**, **E8_5**, **E8_6**, **G8_4**, **G8_6**



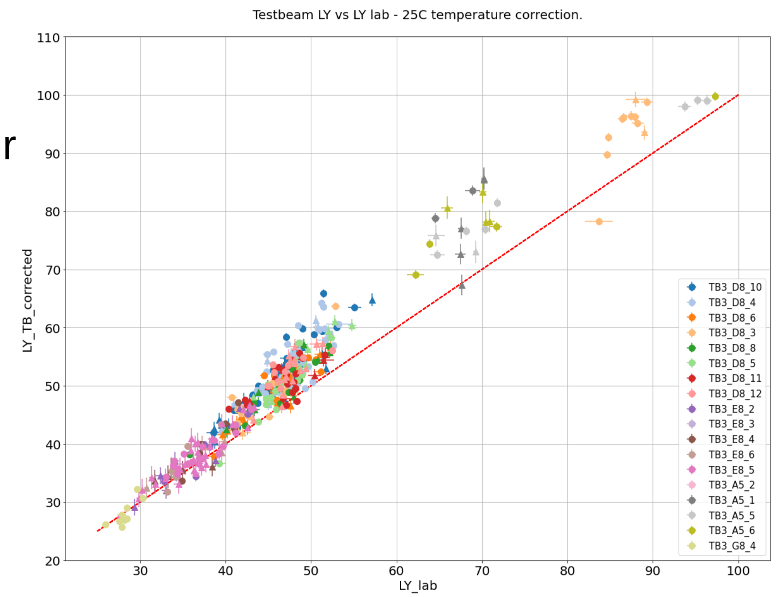


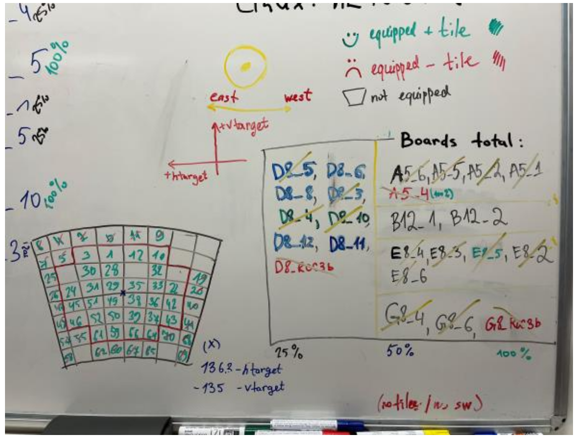


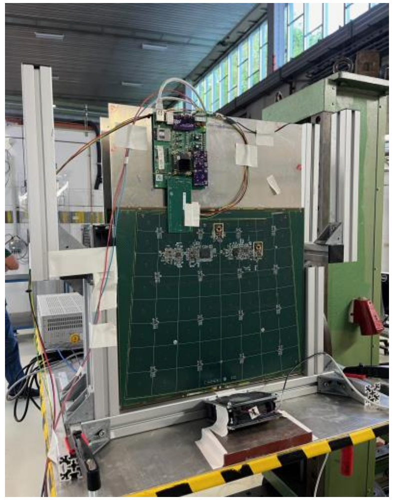
Test beams of the pre-series Tilemodules (HGCROC3a) at DESY

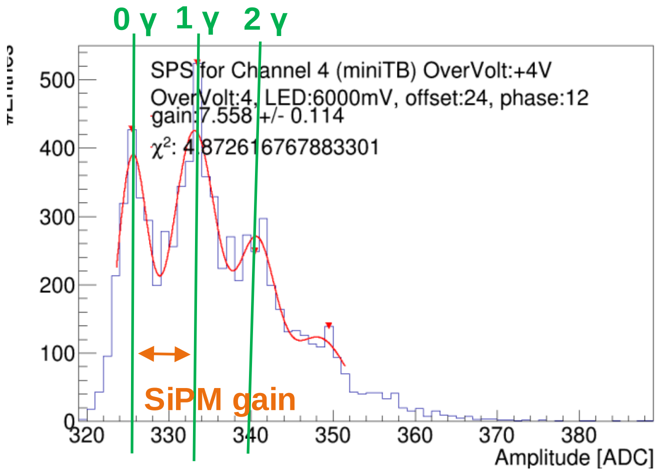
Checking channels equipped with SiPM and tile

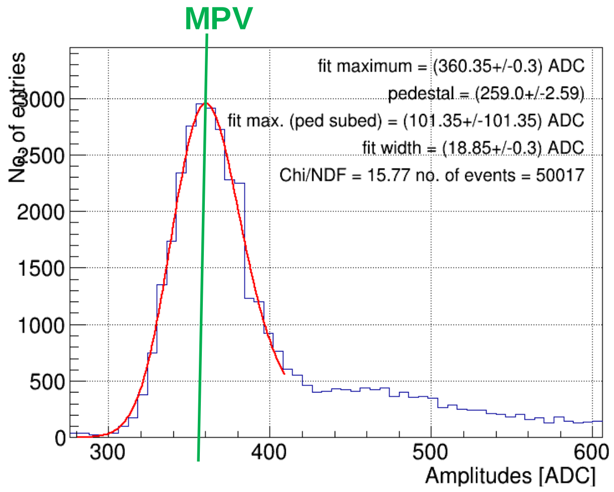
- The pre-series Tilemodules were **tested with beam** -> this **will be replaced** by the **cosmic test stand** for the **Tilemodule quality control**.
- **Test beam** for the **pre-series Tilemodules**. -> using **two single-Tilemodule DAQ in parallel**.
- The **LY** measured with beam **agrees with** the **Sr90 LY test stand**!











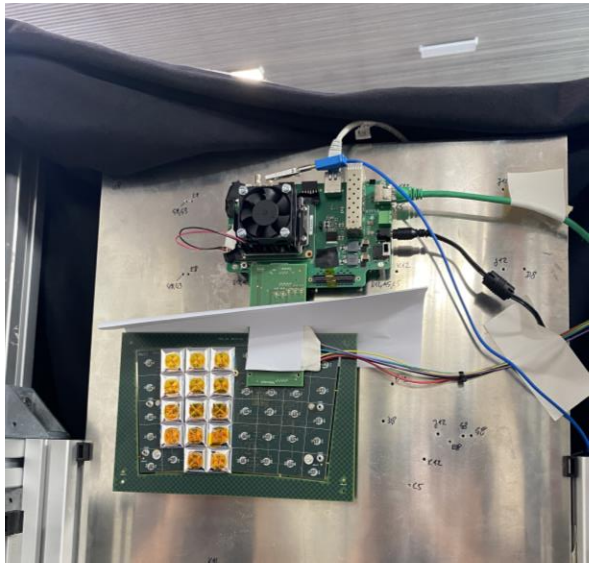
$$Light\ Yield\,[p.e.] = \frac{MIP\ maxima\,[ADC]}{SiPM\ gain\,[ADC]}$$

Test beams of the Tilemodules (HGCROC3b) at DESY

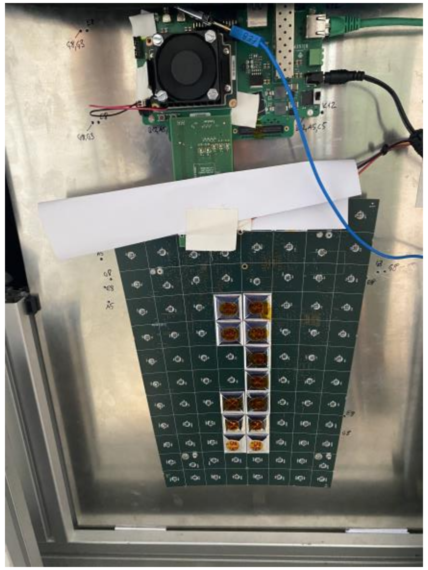
Checking channels equipped with SiPM and tile

- Beam test for Tilemodules (**A5**, **B12**) equipped with **HGCROC3b**
- Both Tilemodules can see **clear MIP peaks**
- LED data need to retake for getting better SPS.
- The analysis for LY is still ongoing.
- Took shower data for the B12 and can see TOA and TOT signal

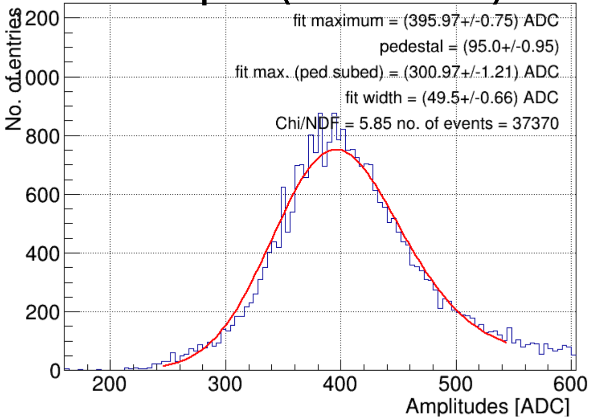
TB3_A5 (ROC3b)



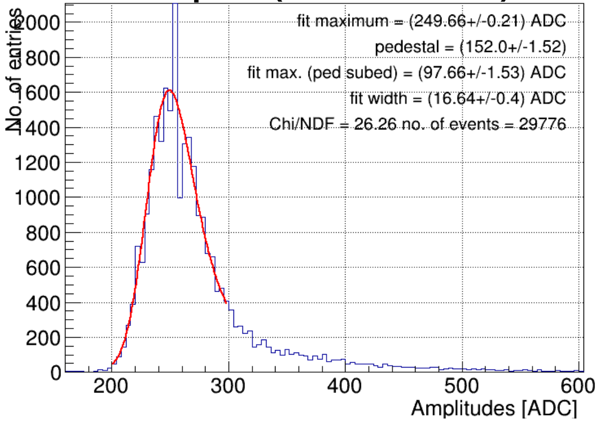
TB3_B12 (ROC3b)



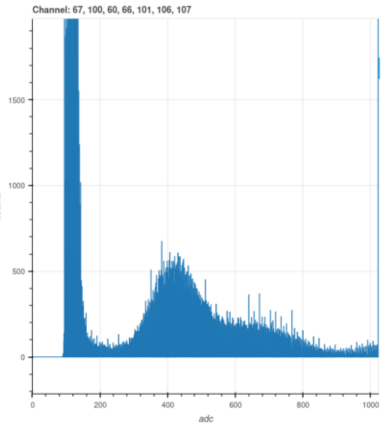
MIP peak (A5 with ROC3b)



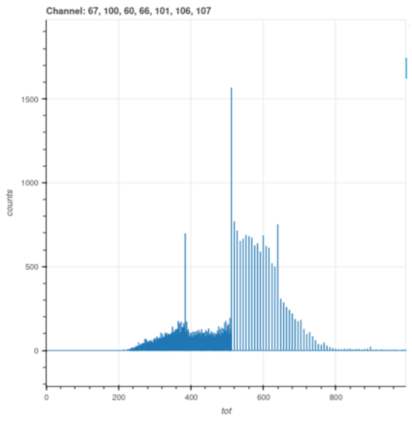
MIP peak (B12 with ROC3b)



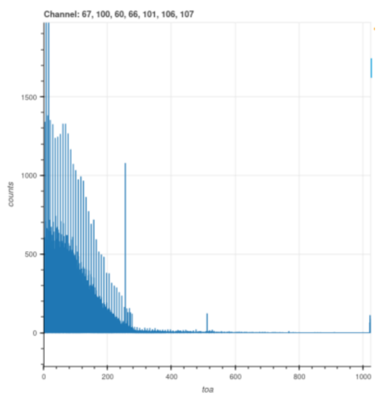
ADC (shower data)



TOT (shower data)



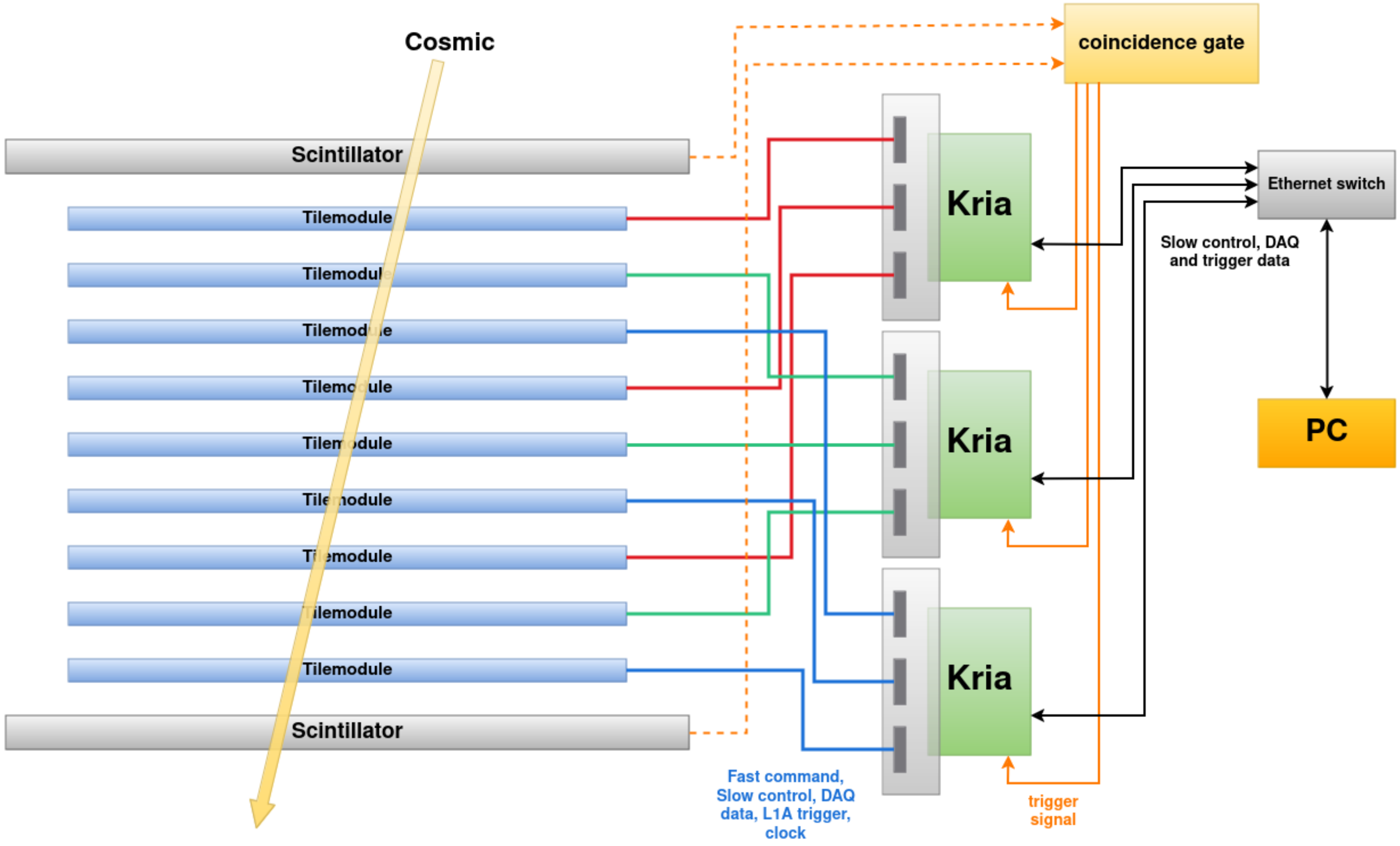
TOA (shower data)



DAQ system: Multi-Tilemodule

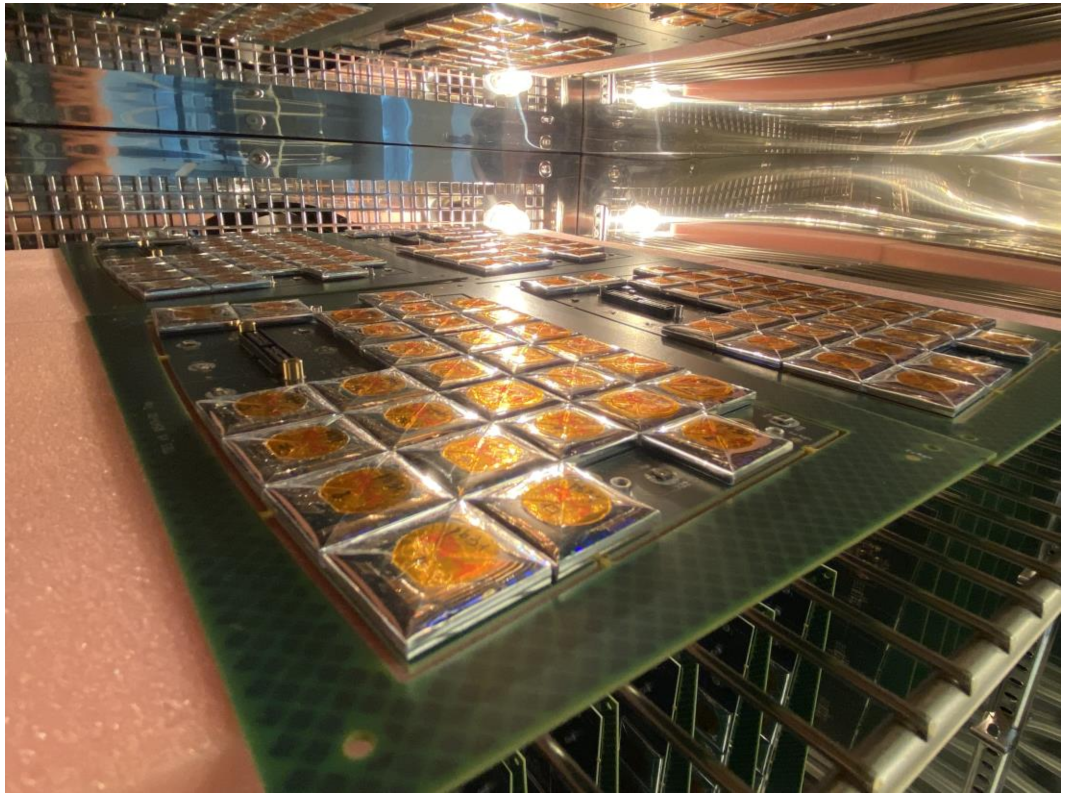
Under development

- Can test 9 Tilemodules simultaneously with 3 Kria.
- Will be used in **cosmic test** stand for quality control.
- Dedicated **Kria adaptors** and the corresponding **firmware** and **software** are needed.



Summary

- The **new DAQ** system with **Kria works** well for Tilemodules with **HGCROC3a** and **HGCROC3b**.
- The results of the **cold test** for **pre-series Tileboards (HGCROC3a)** and **Tileboards (HGCROC3b)** are **mostly good**.
- **Mechanical cold test** for **Tilemodules** shows **no visible damage** -> no tiles fall off.
- **LY** measured from the **test beam** **agrees with** LY from **Sr90 test stand** for the pre-series Tilemodules in the May 2024 test beam at DESY.
- Next step: **multi-Kria test system** for **cosmic test stand.**



Thank you

Contact

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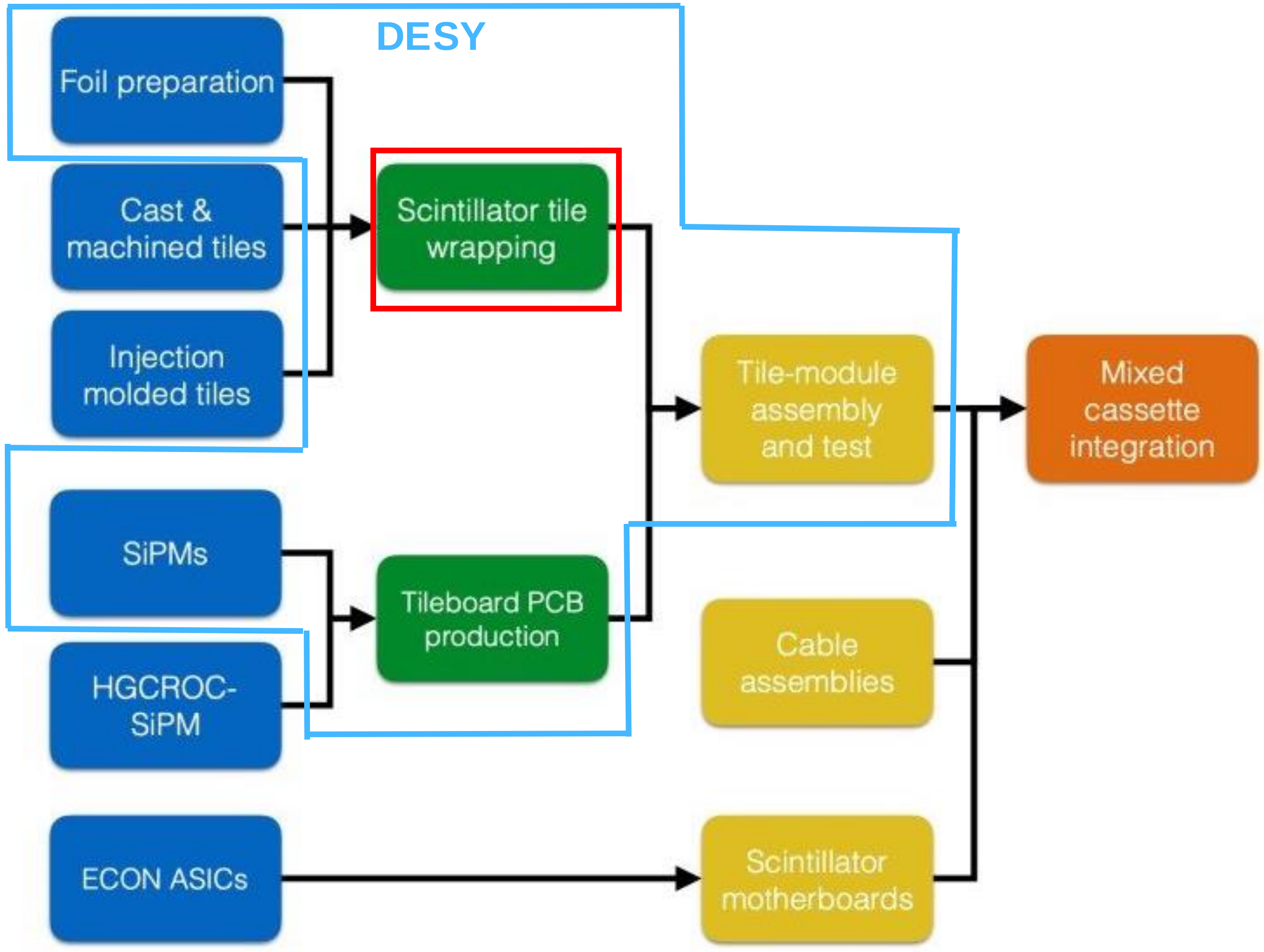
Backup

Quality control for Wrapped tiles at DESY

Without tiles

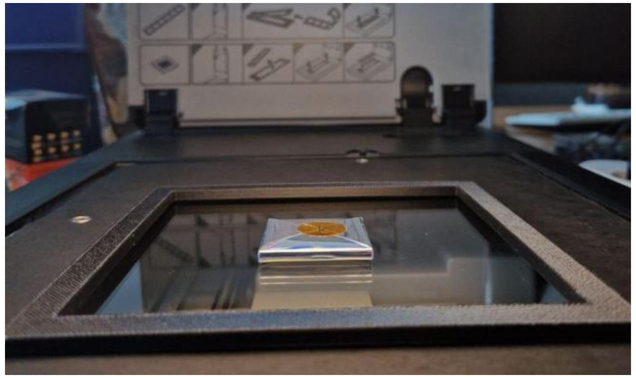


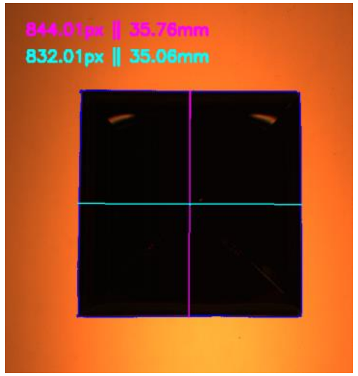
Quallity control for wrapped tiles

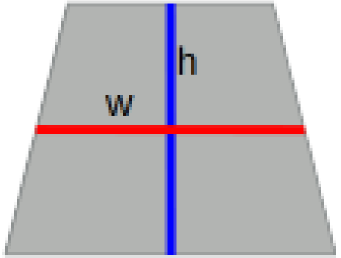
Tile size and Light Yield measurement

Tile size after wrapping

- A flatbed scanner and an external light source for a "shadow" image analyzed by OpenCV software
- Height and width obtained in mm



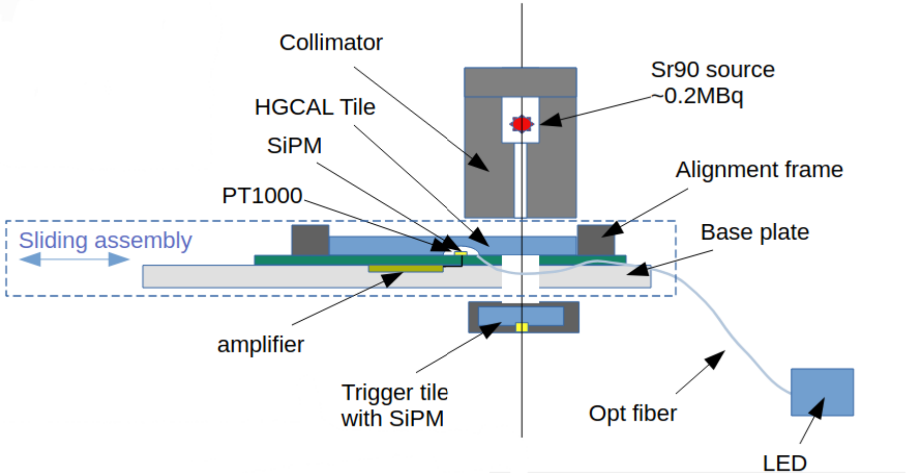


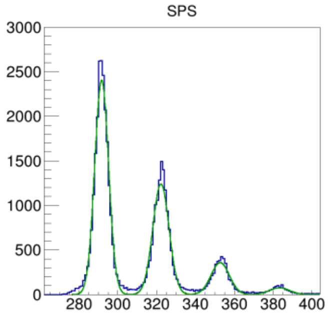


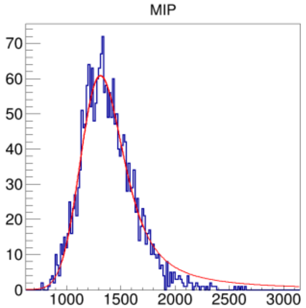
33.305 < w < 33.905
33.68 < h < 34.28

Tile Light Yield

- Sr90 source of MIPs, LED for gain monitoring. SPS and MIP spectra obtained at the same time, temperature recorded for further corrections

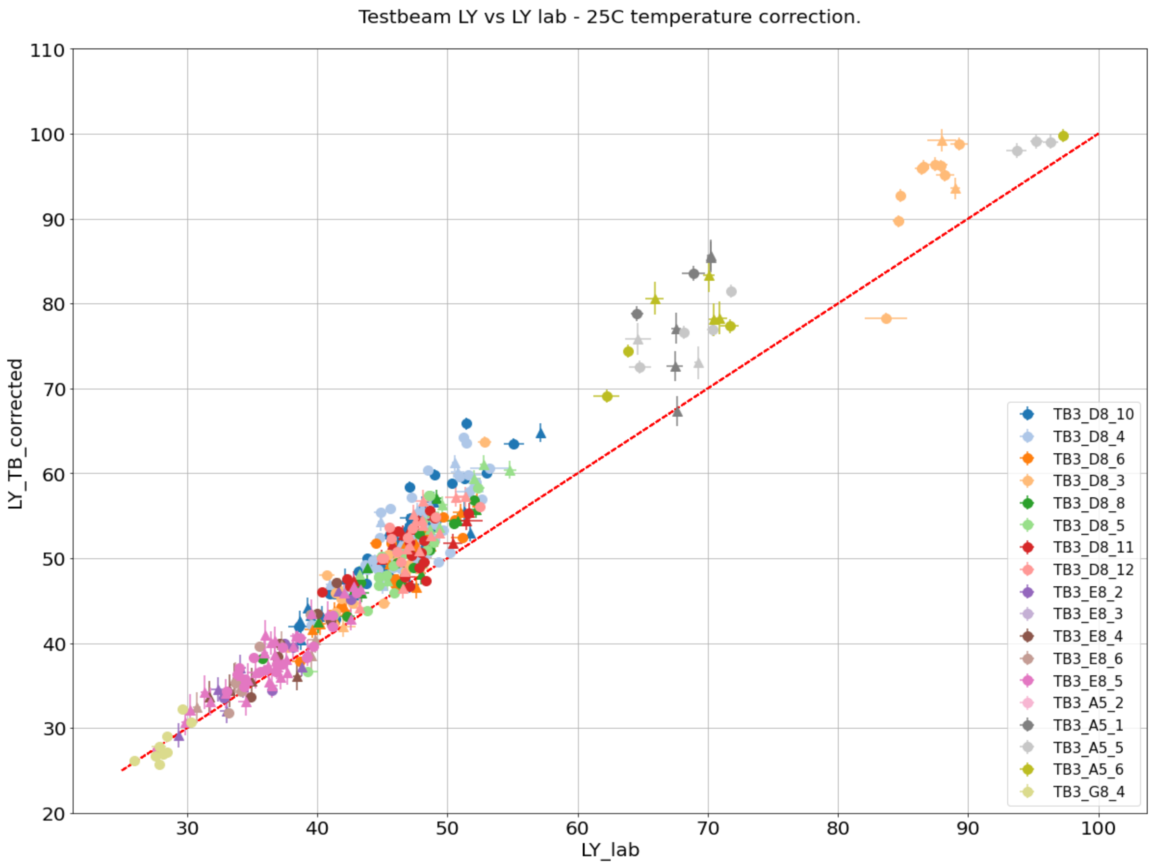




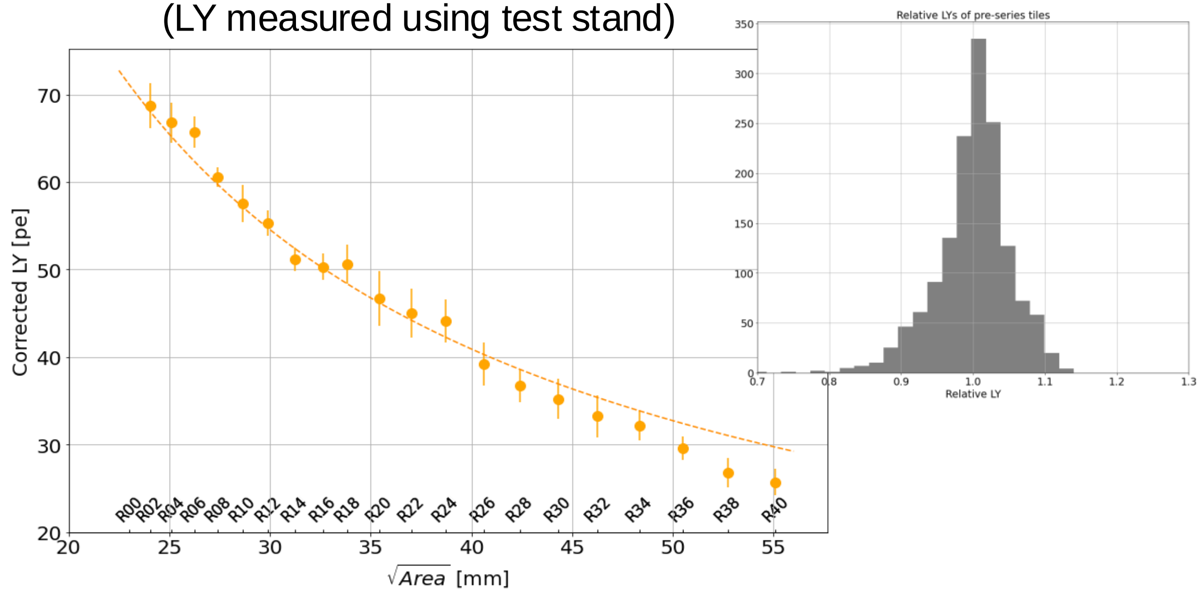


Light yield for pre-series tiles

Light yield measured with Sr90 test stand



LY vs Tile edge length
(LY measured using test stand)



- Pre-series tiles used to assemble Tileboards and LY measured during DESY testbeams
- Extracted LY can be compared with LY measured using the Sr90 test stand
- For some channels Gain values were not extracted, so an average value was used to calculate LY_testbeam (triangles)

Basic structure of the High Granularity Calorimeter (HGCAL)

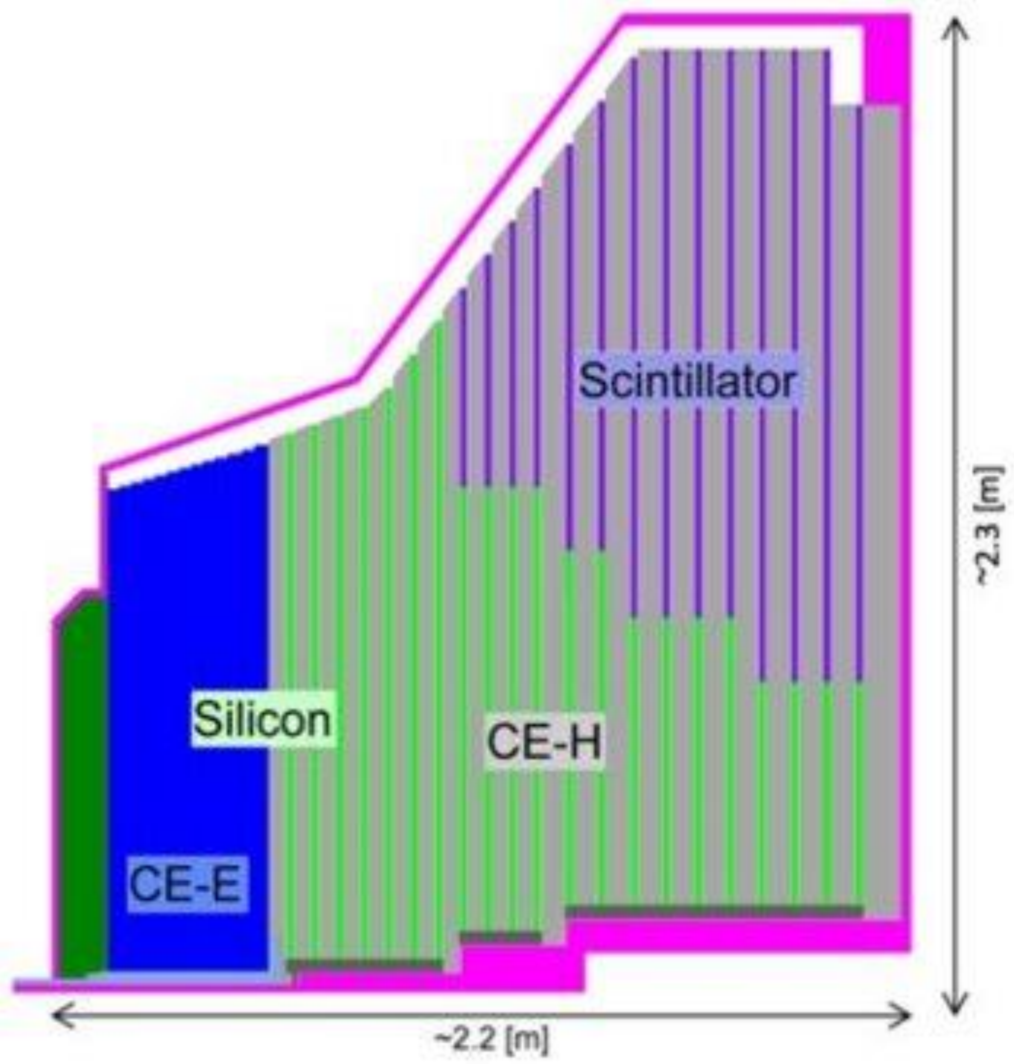
Active elements and key parameters

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:

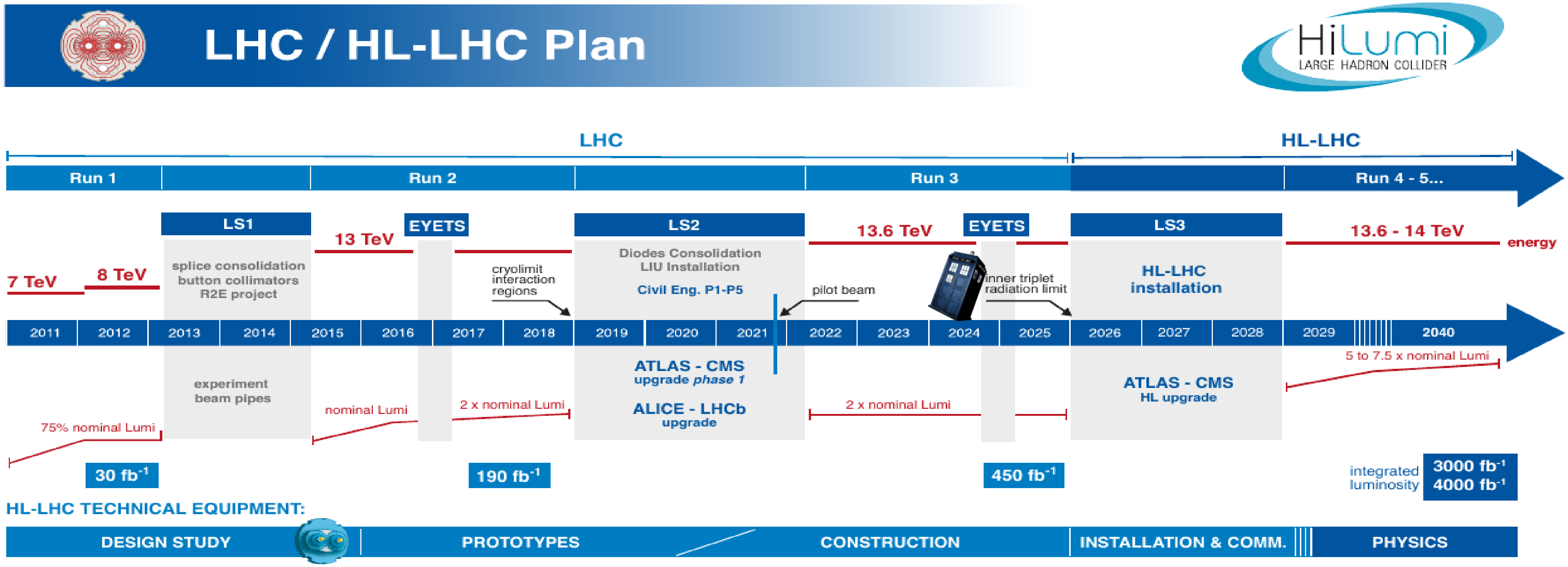
Coverage: $1.5 < |\eta| < 3.0$
~215 tonnes per endcap
Full system maintained at -30°C
~620m^2 Si sensors in ~26000 modules
~6M Si channels, 0.6 or 1.2cm^2 cell size
~370m^2 of scintillators in ~3700 boards
~240k scint. channels, 4-30cm^2 cell size
Power at end of HL-LHC:
~125 kW per endcap



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

Schedule of the HL-LHC

Plan for the next decays



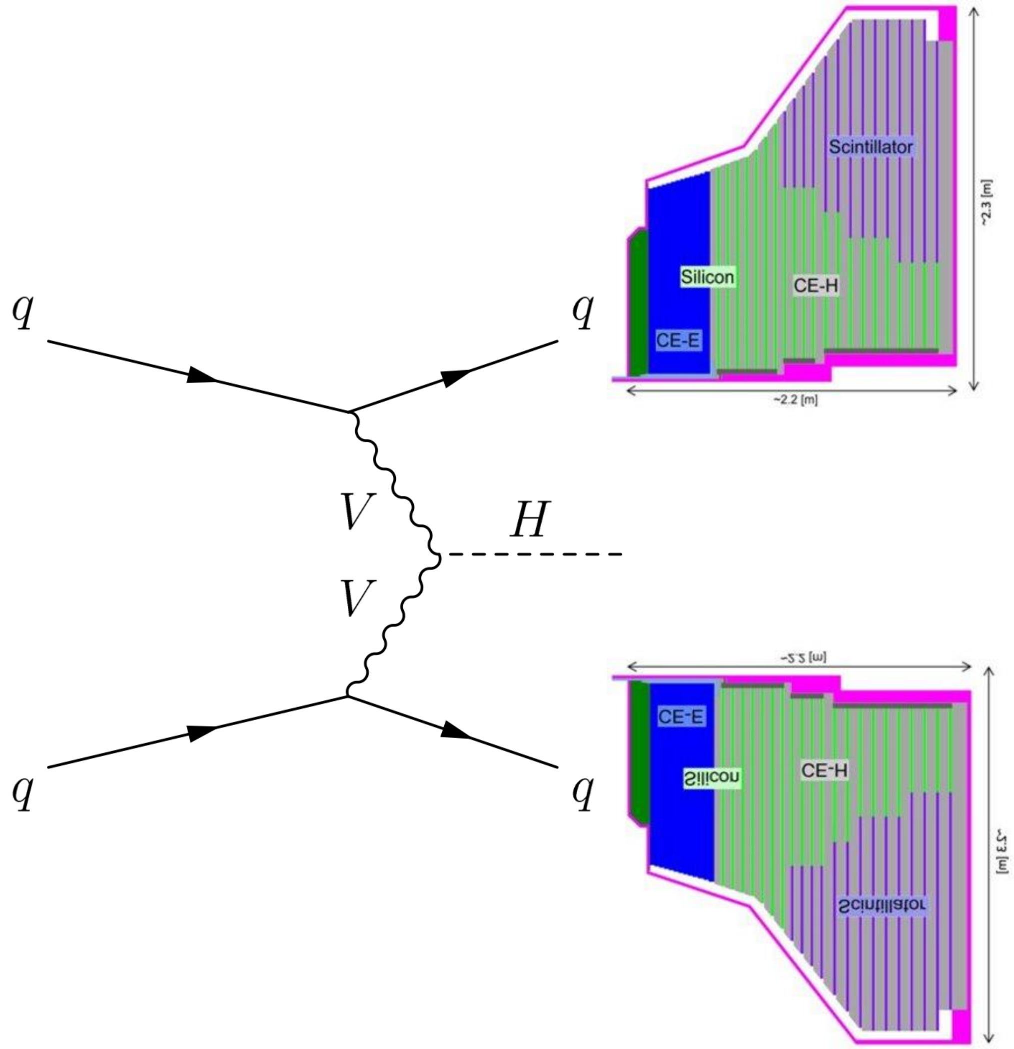
- Lowering, installation, and commissioning of the detector will be done during Long Shutdown 3 (LS3).
- Expected instantaneous luminosity = 5×10^{34} /cm²s, and pileup = 140 (can reach 50 % even higher)

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

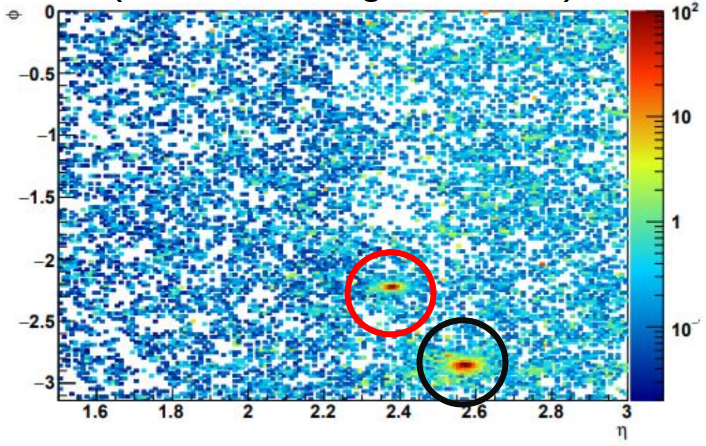
- The **high granularity** of HGCAL can help improving **jet identification**.

What is HGCAL, and why do we need it

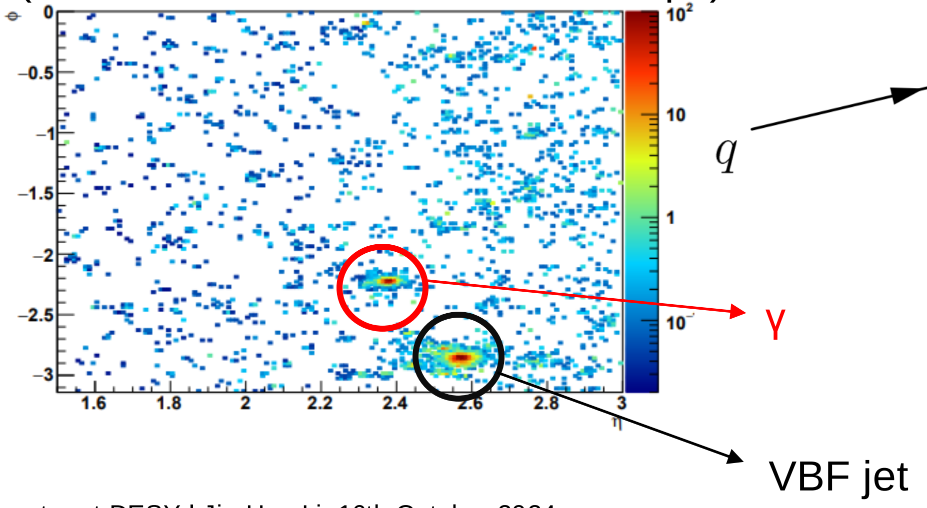
The importance of precision about time and space

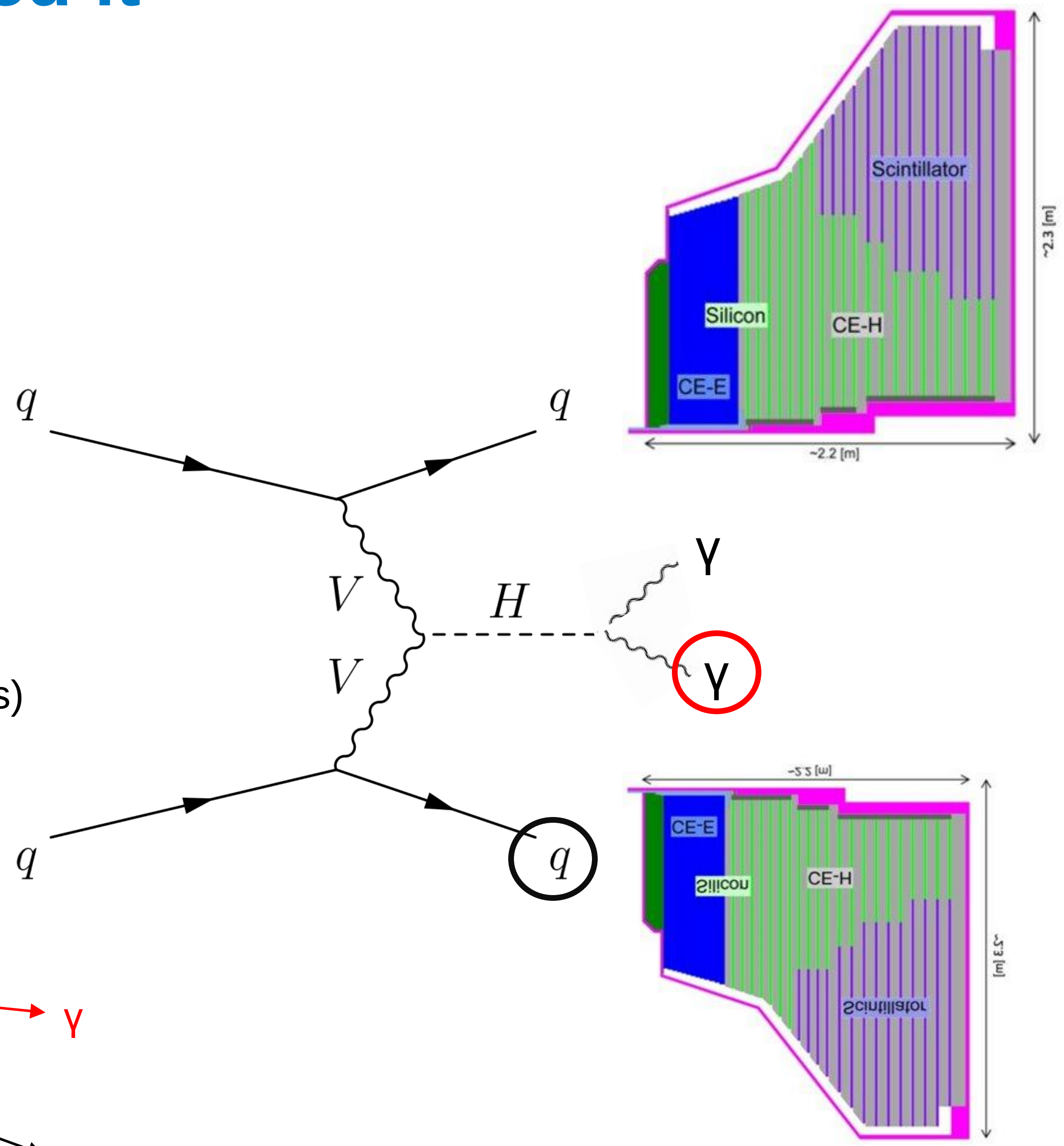
- With the **high granularity**, HGCAL will be able to identify **VBF jets.**
- The **pileup issue** can be greatly **improved** with good **timing resolution** (tens of picoseconds) of the HGCAL. (Ex: VBF H -> γγ)

VBF H -> γγ
(without timing selection)



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

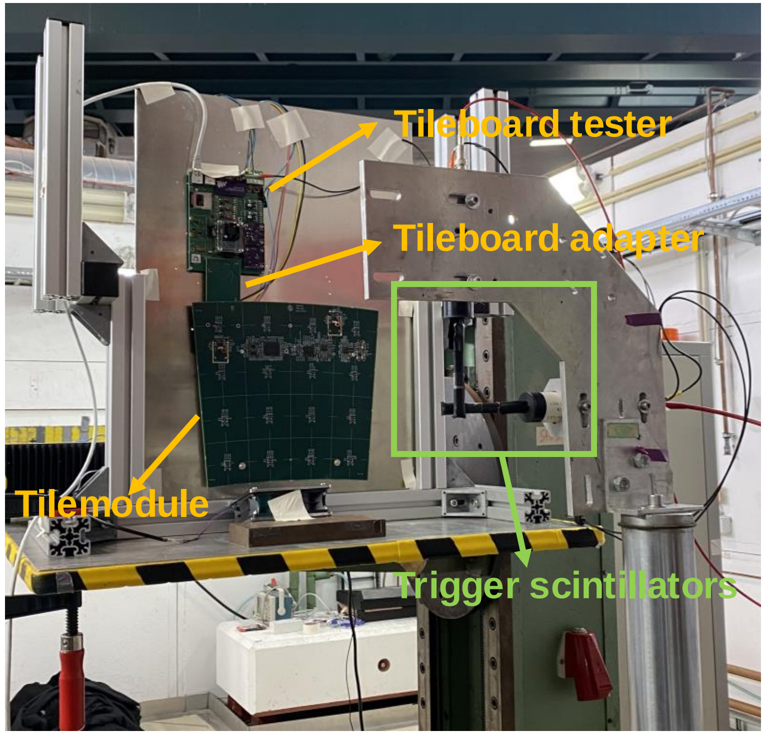


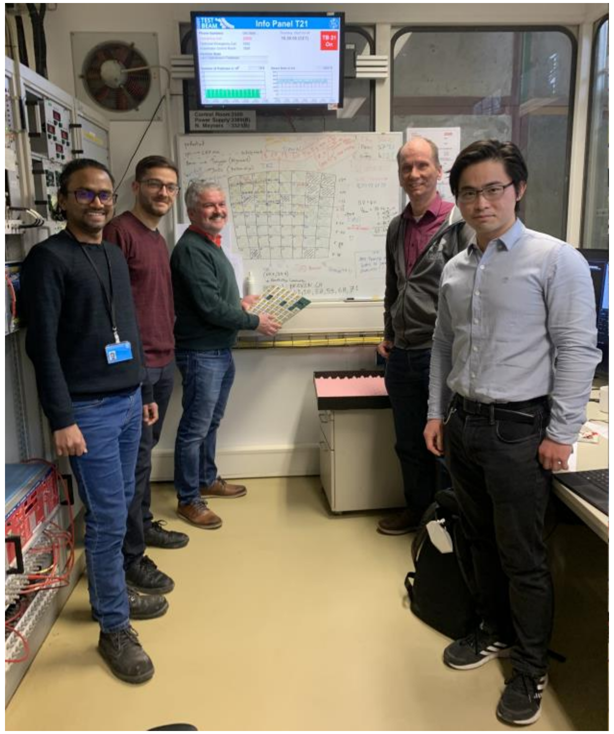


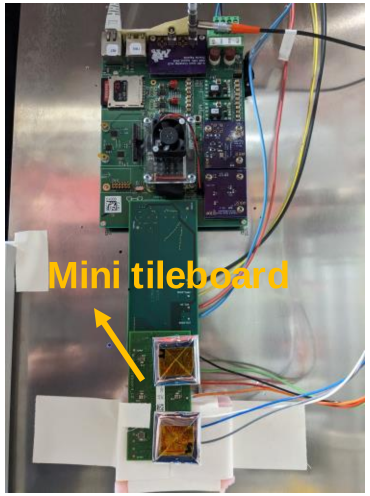
Test beams of the Tilemodules at DESY

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





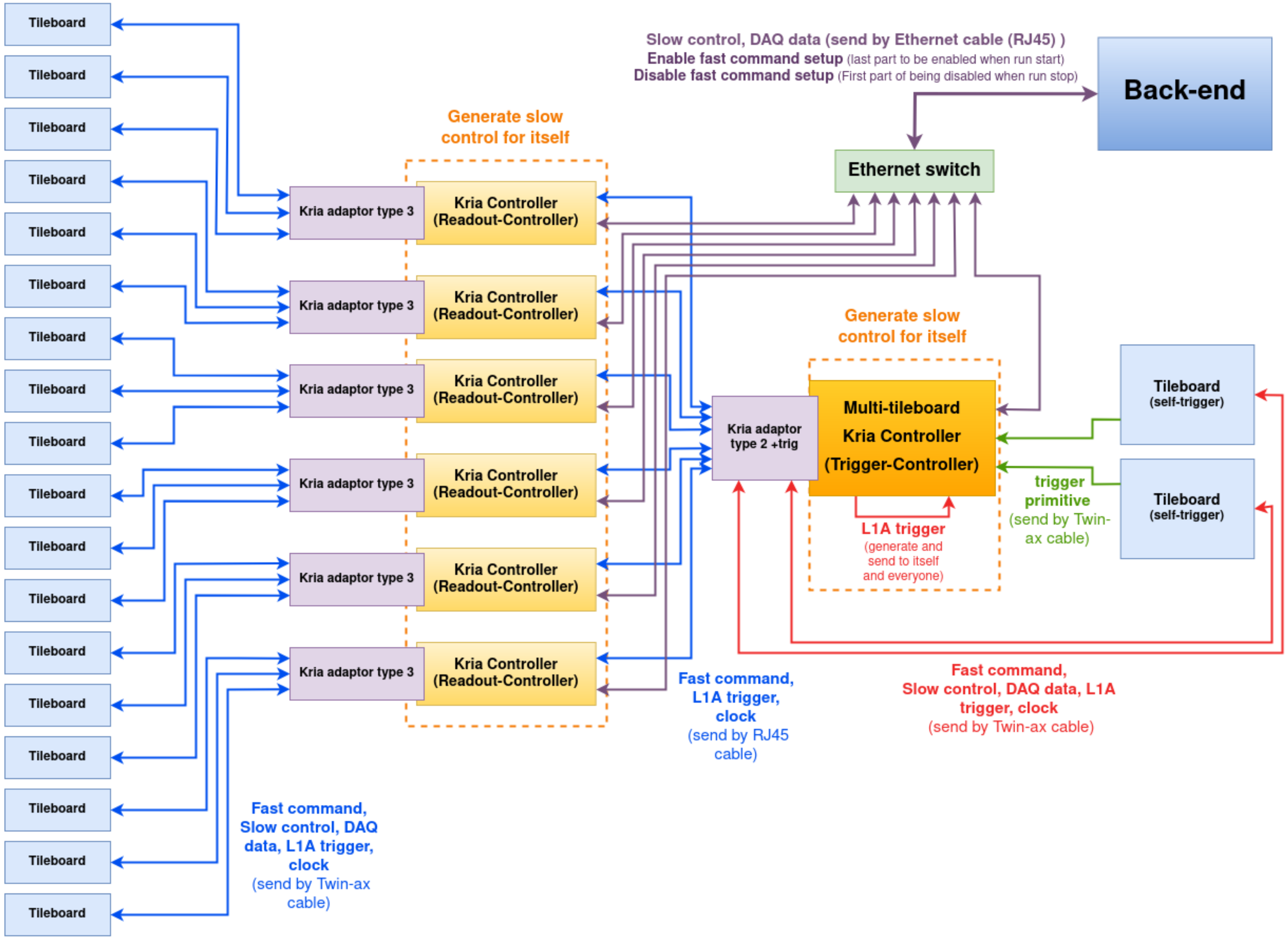


Multi-Tilemodule test system – previous plan

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

Multi-Tilemodule test system (under development)

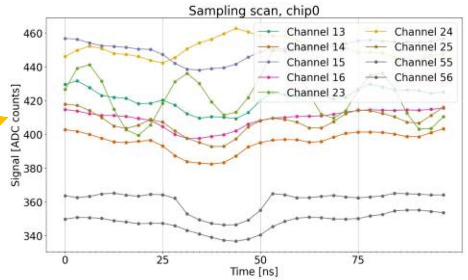
- Can **measure up to 20 Tilemodules** at the same time.
- Will be used in **cosmic test** stand for quality control.
- The same system will be used in an **EM stack** (15 Tilemodules interleafed with steel absorber) for **shower analysis** in **test beam**.
- Dedicated **Kria adaptors** and the corresponding **firmware** and **software** are needed.

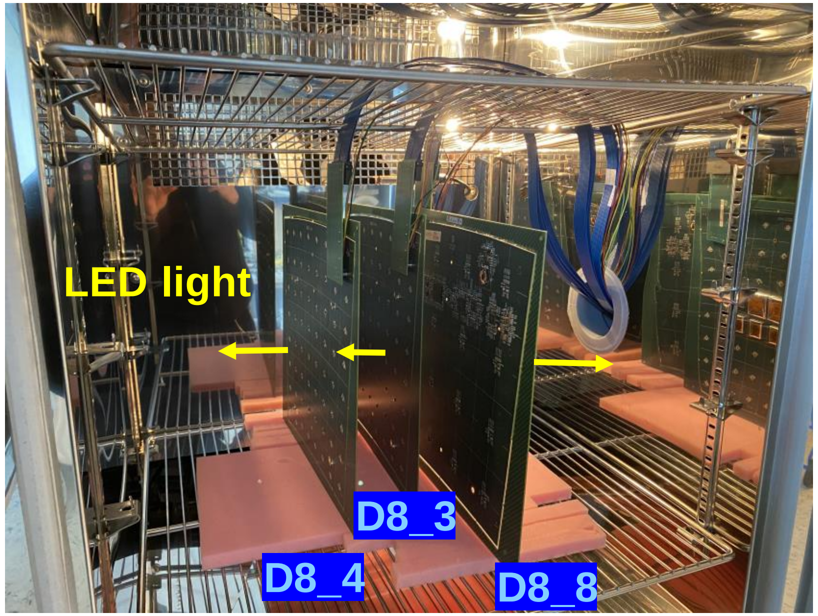


Cold test for pre-series Tileboards

Tileboards which have weird behaviour

Test result			
	Room temperature	-35 °C	20 °C
D8_5	Good!	Weird LED pattern	Good!
D8_6	Good!	Weird LED pattern	Good!
D8_8	Good!	Weird LED pattern	Good!
D8_11	Good!	Weird LED pattern	Good!
B12_3	Good!	Weird LED pattern	Good!
B12_4	Good!	Connection fail	Good!
B12_6	Good!	Connection fail	Good!

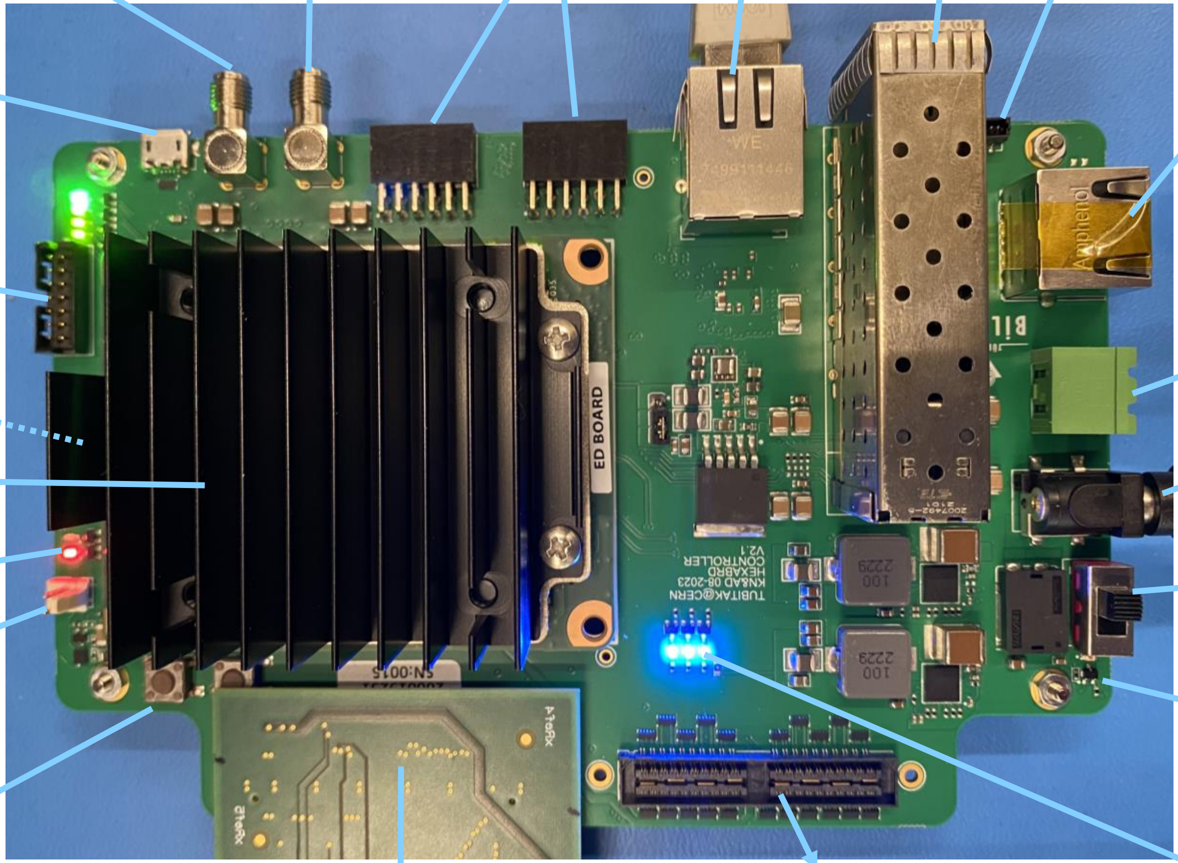




- **B12_4** and **B12_6** has **connection issue** under –35 °C -> **Commands** from the tester **cannot reach** the Tileboards -> the connection between TB adaptor and Tileboards might be bad under low temperature -> **New adaptor with holes to screw** it on the Tileboard **will arrive soon**. This might fix the issue.

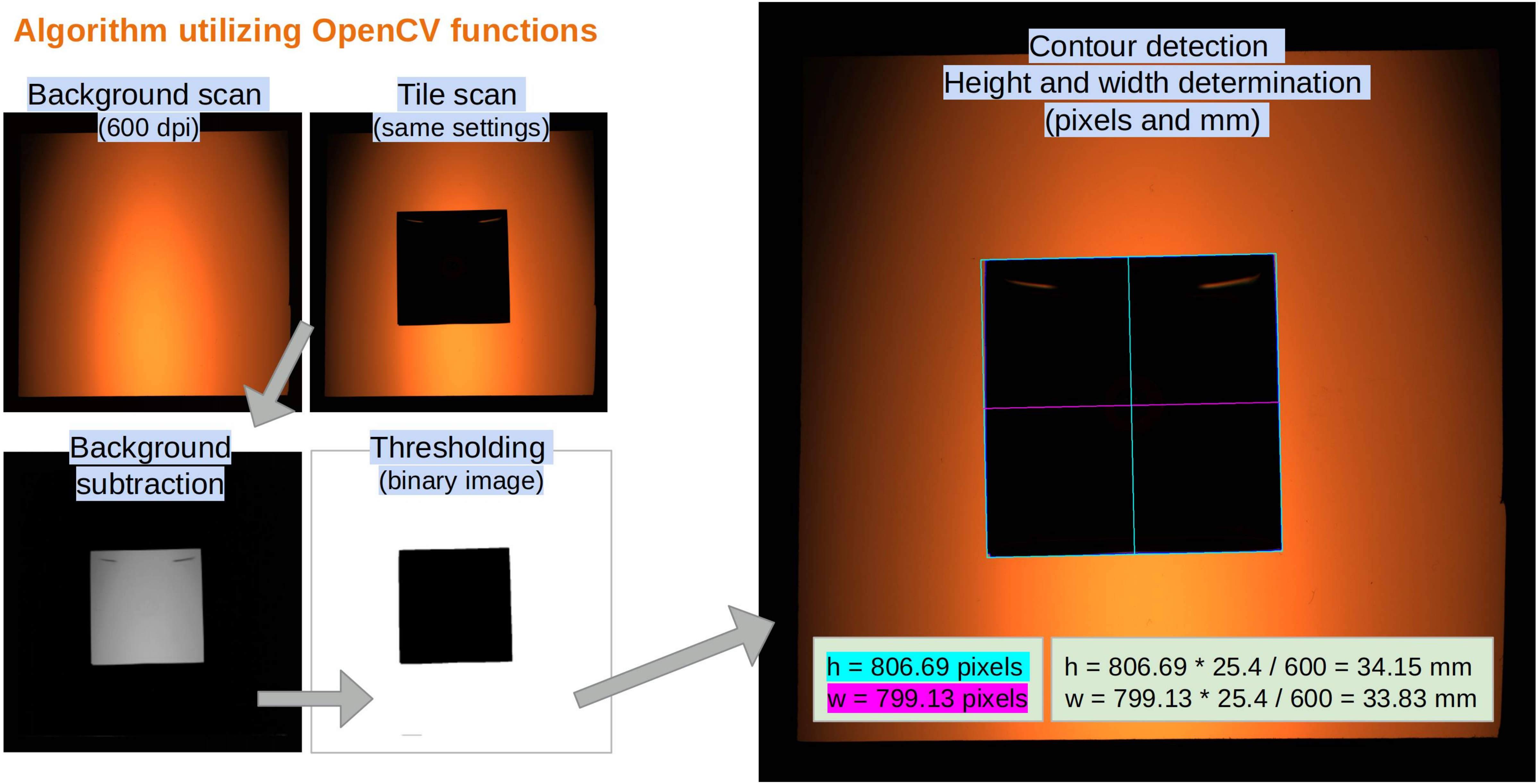
Kria

According to Kivanc's slide and what I know so far



Tile size test stand

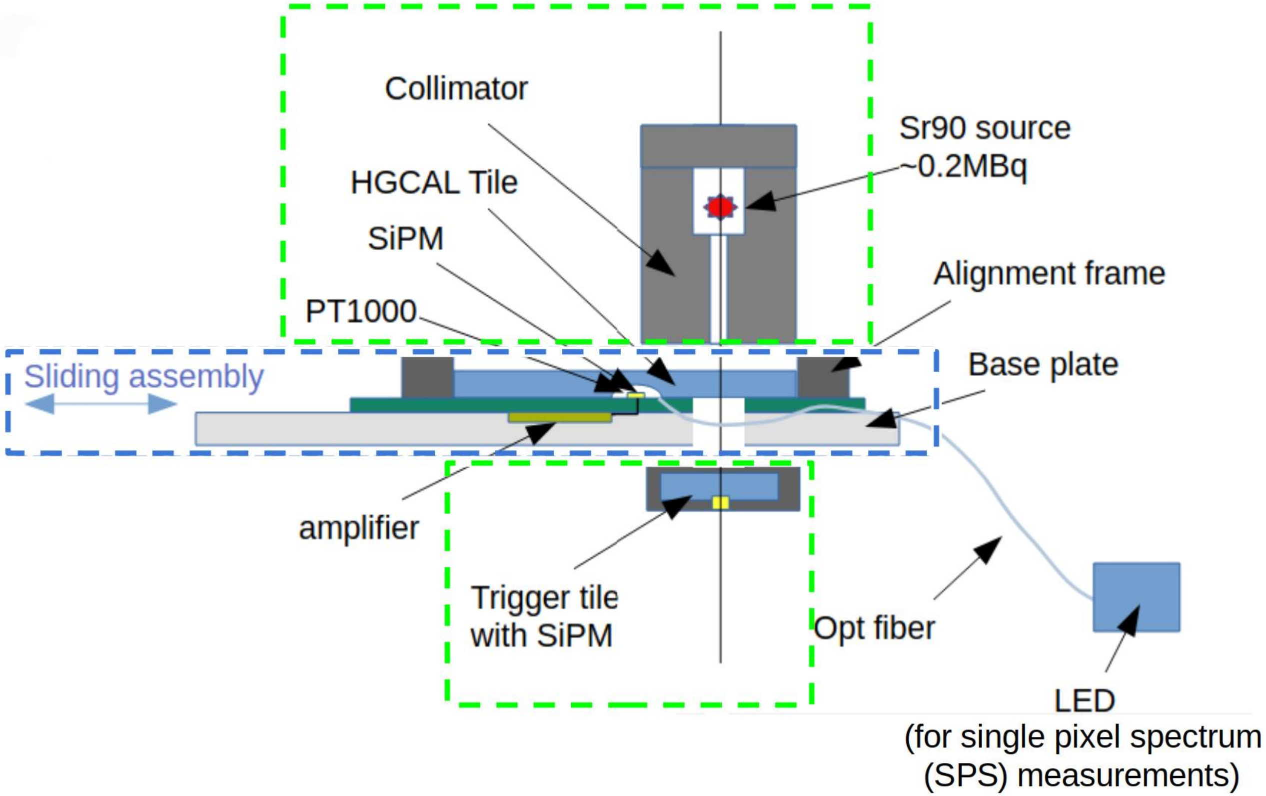
Algorithm utilizing OpenCV functions

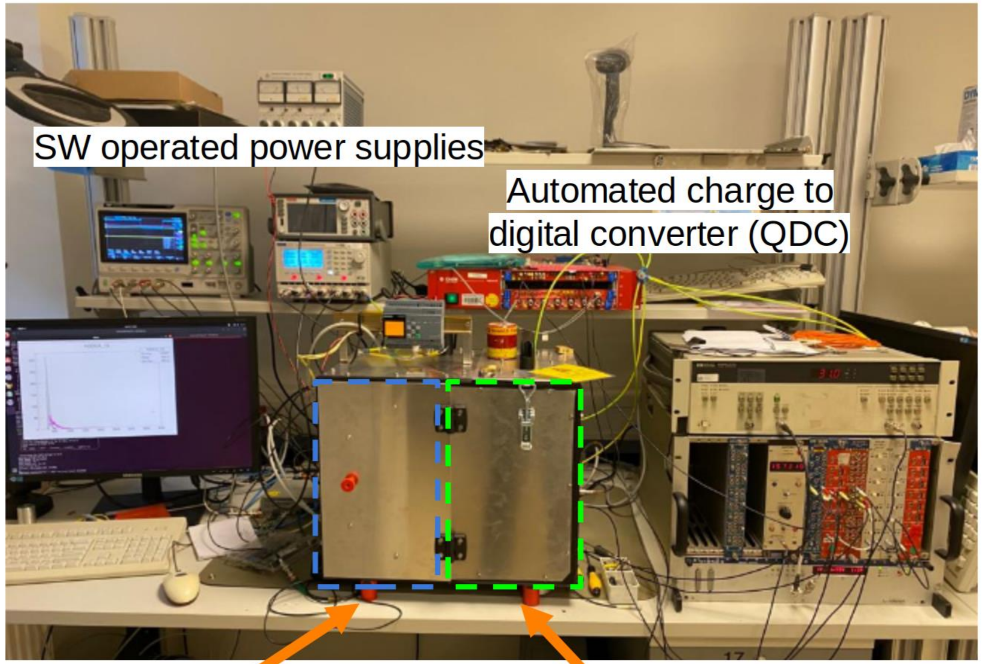


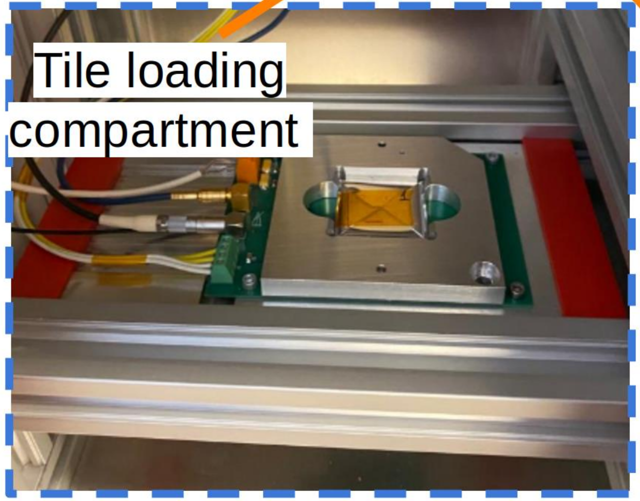
Light Yield test stand

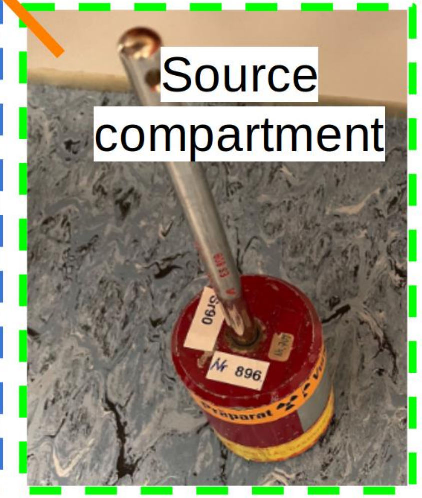
Motivation and setup

- Want to maintain high LY during production (critical for signal-to-noise ratio after irradiation)
- Ensuring uniformity will ease production







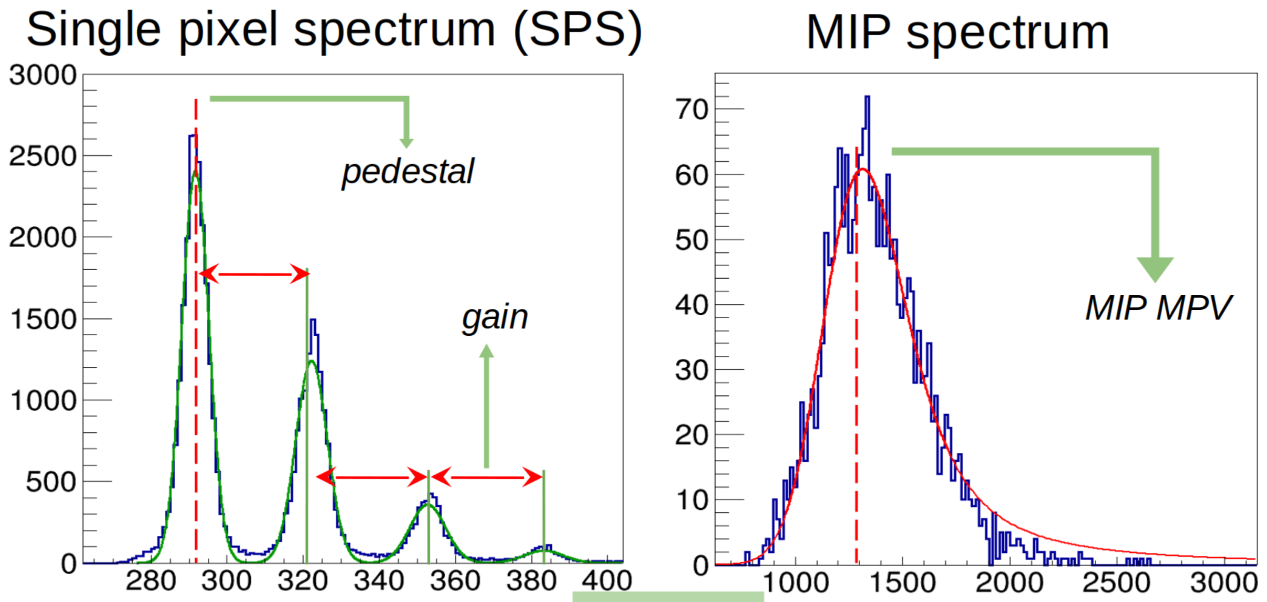


Light Yield test stand

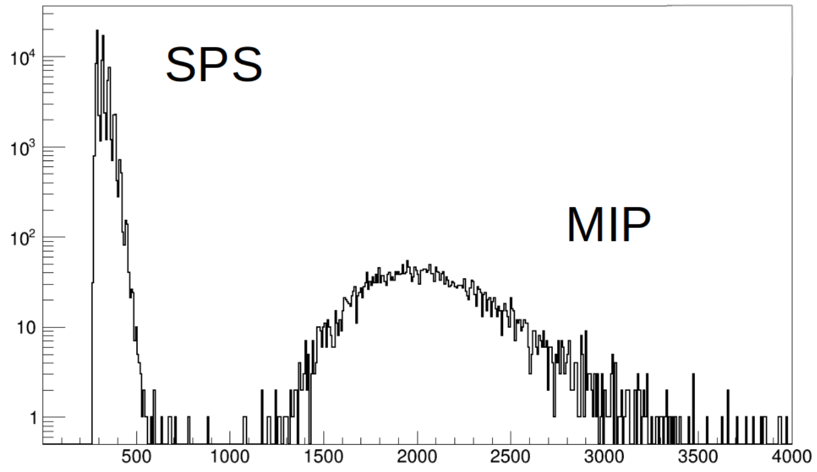
Measurements

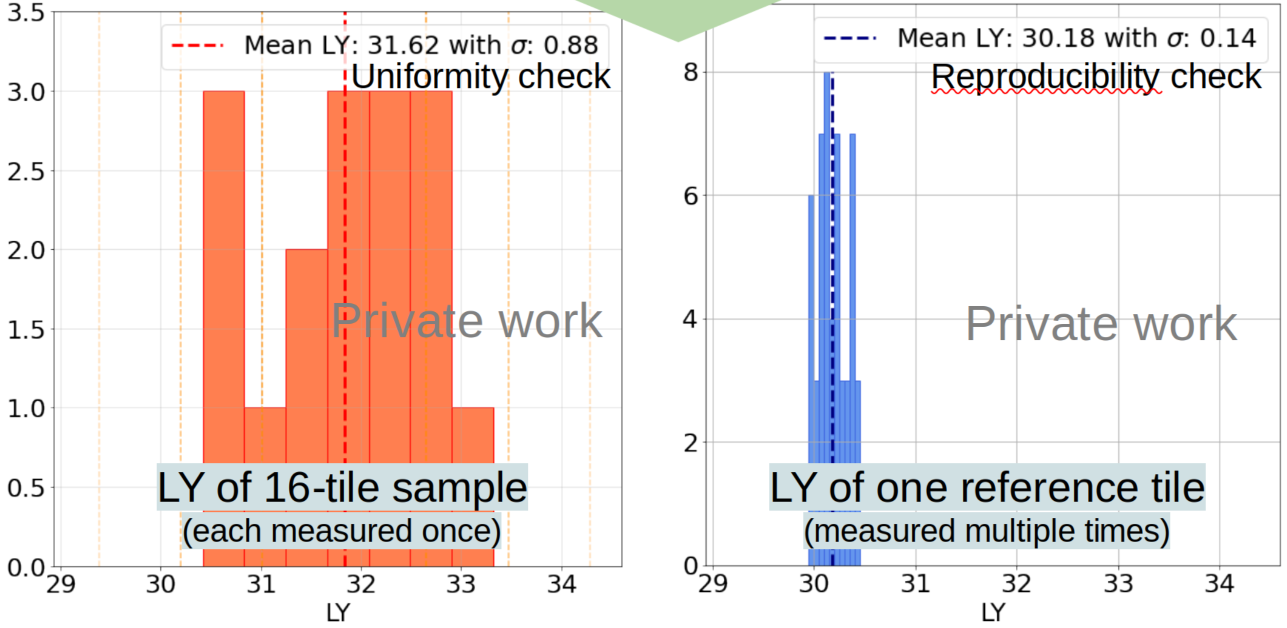
Light yield as the number of photoelectrons detected for a minimum ionising particle

- Perform regular Light yield measurements of tile samples for feedback to producers and uniformity checks
- SPS and MIP spectra obtained at the same time, measurement conditions recorded (e.g. Overvoltage, Temperature)



$$LY = \frac{MIP\ \ MPV - ped}{gain}$$



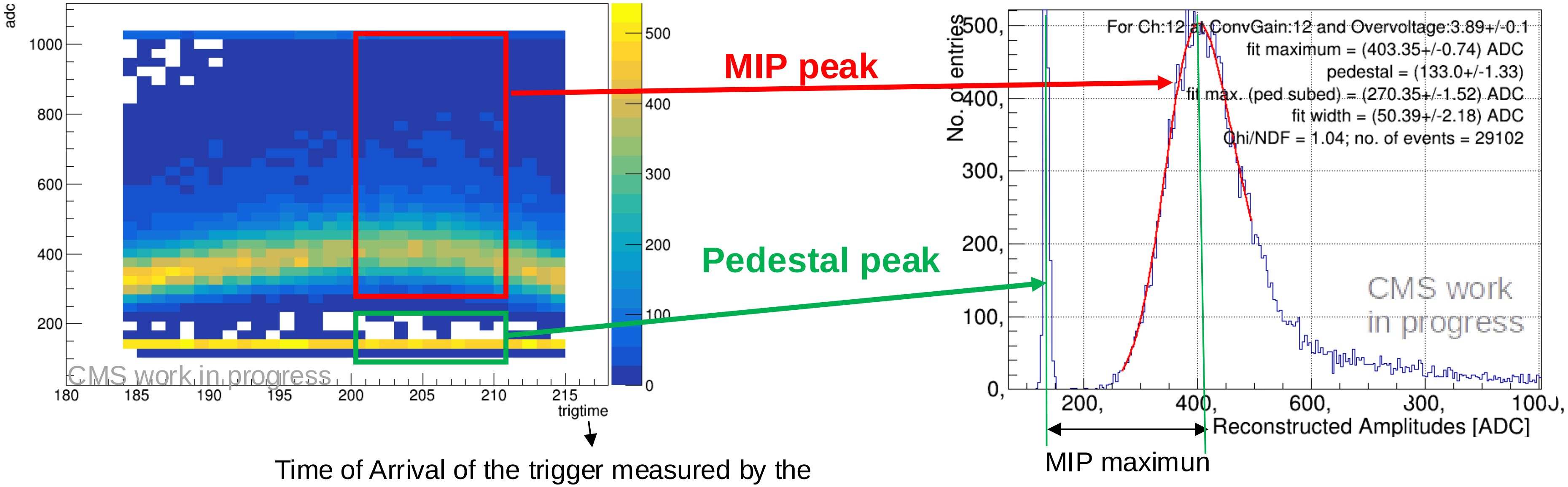


- Measurements of LY with ~0.6% uncertainty

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

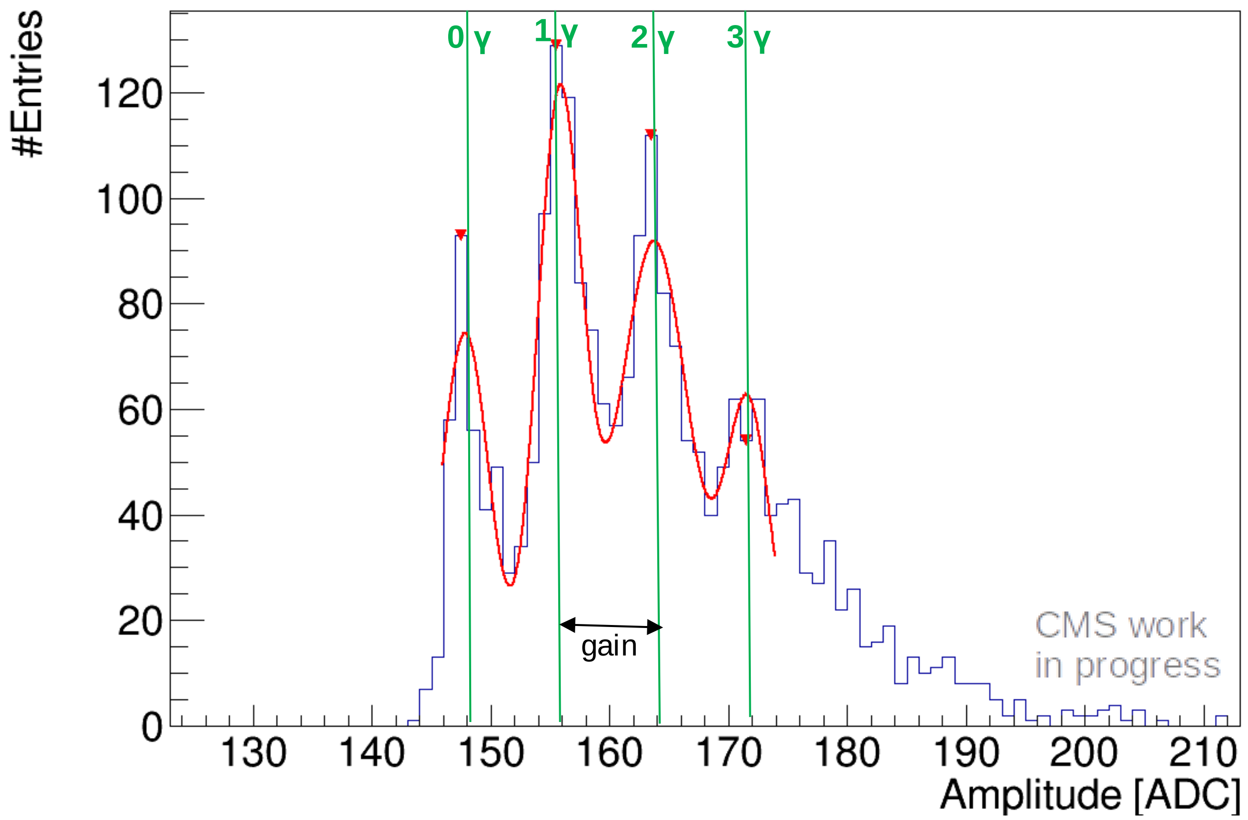
Measure SiPM gain from single photon spectrum

- 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):

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

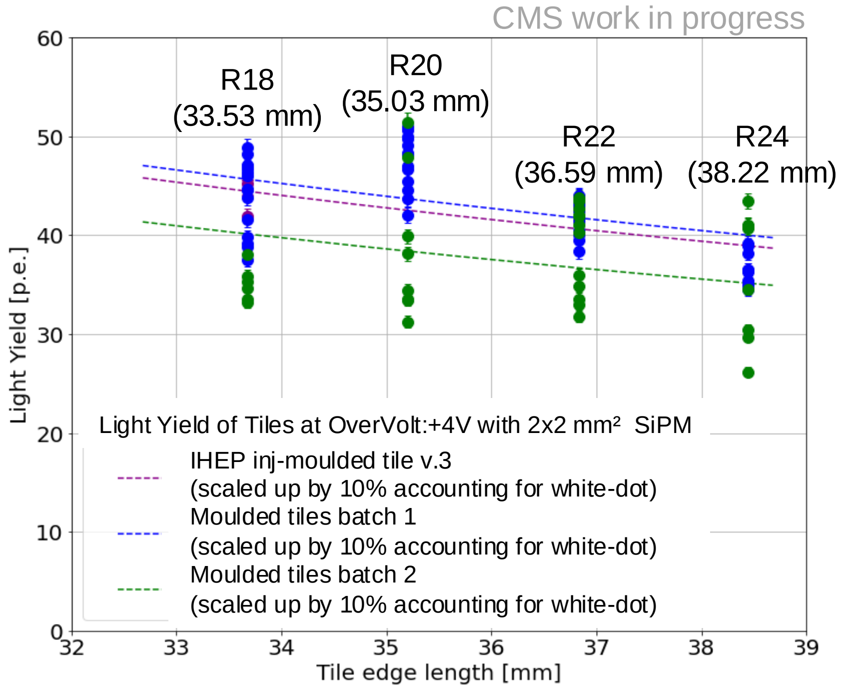
Single photon spectrum



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**.

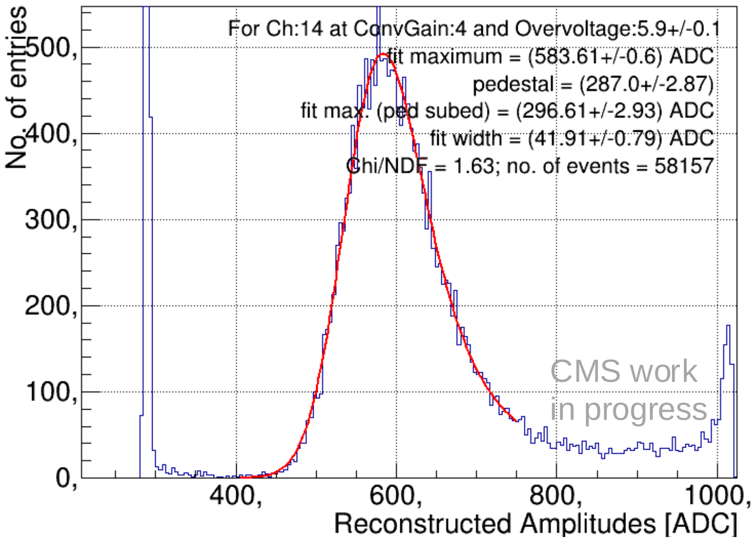


Test beam of the Tilemodule at DESY

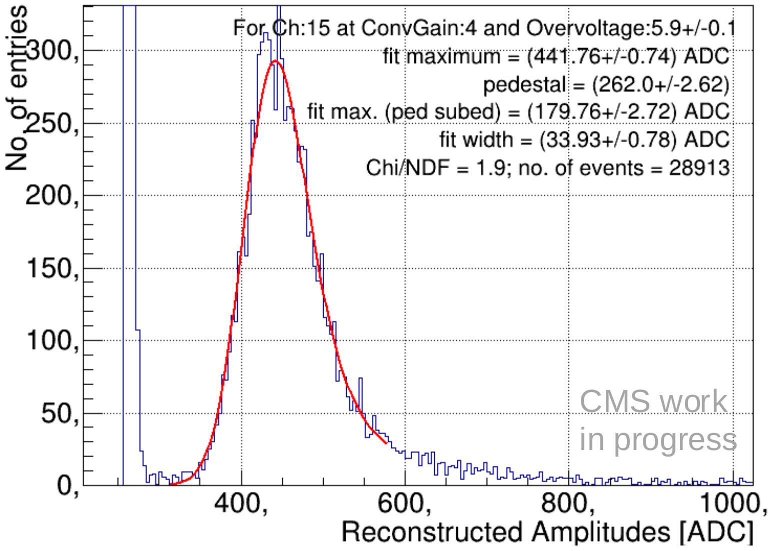
Different SiPM size (non-irradiated SiPM)

- 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)

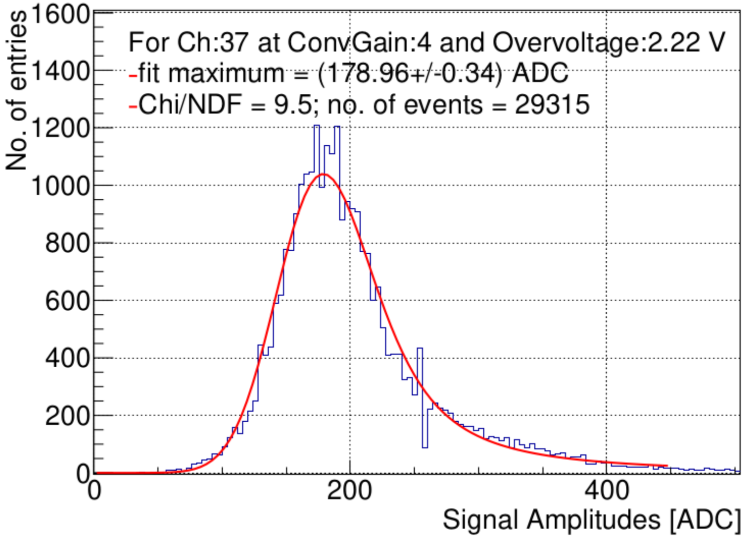


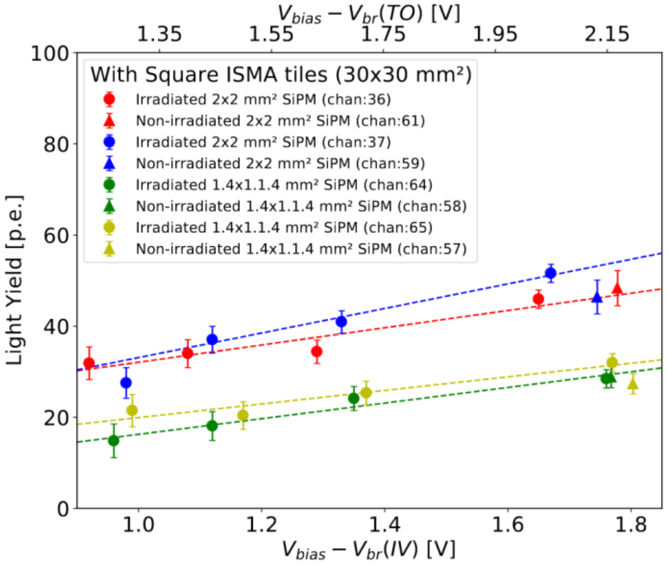
Test beam of the Tilemodule at DESY

Irradiated SiPMs

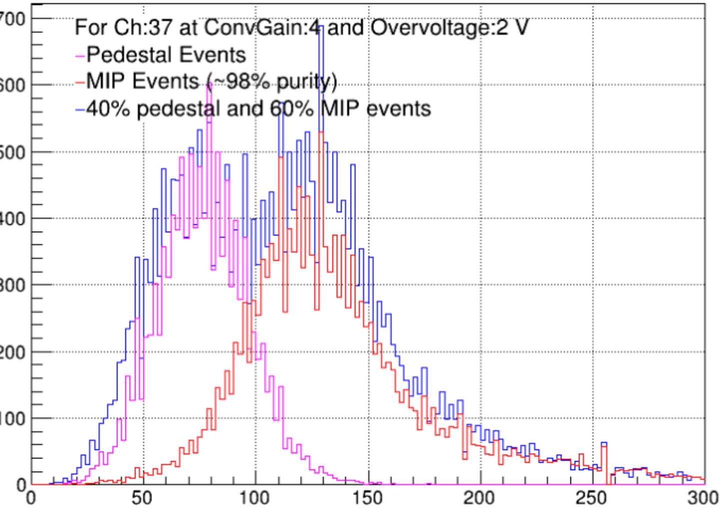
- In comparison with the non-irradiated SiPMs, the **pedestal** signal will be **"wider"** for the **irradiated SiPMs**.
- **Cannot easily separate the MIP peak and pedestal peak** with irradiated SiPMs.
- Need to adjust the beam line to hit in the middle of scintillator tile to mitigate data contamination 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

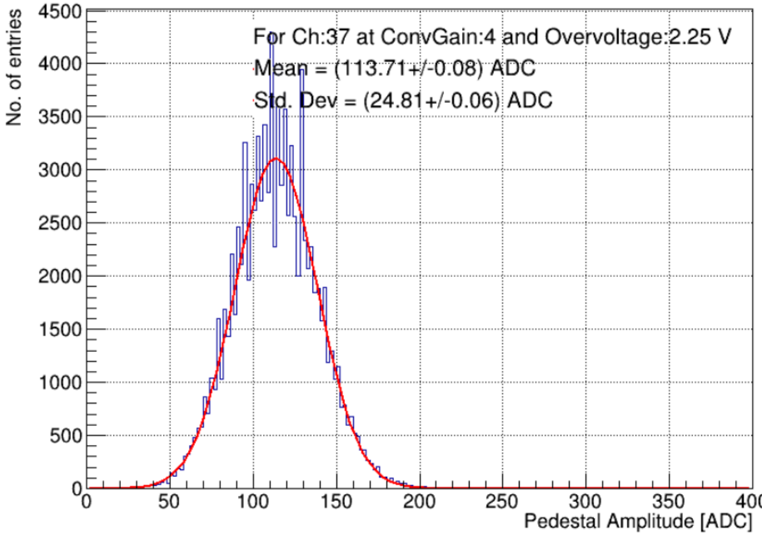




Beam data with pedestal contamination



Data from pure pedestal wiout beam



Plots made by Malinda de Sliva