Methods of ~~Marzipan QC~~ Scintillator tile quality control for the High Granularity Calorimeter upgrade of the CMS endcaps

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DRD6 “Marzipan” meeting

11/12/2024

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CMS

FTX

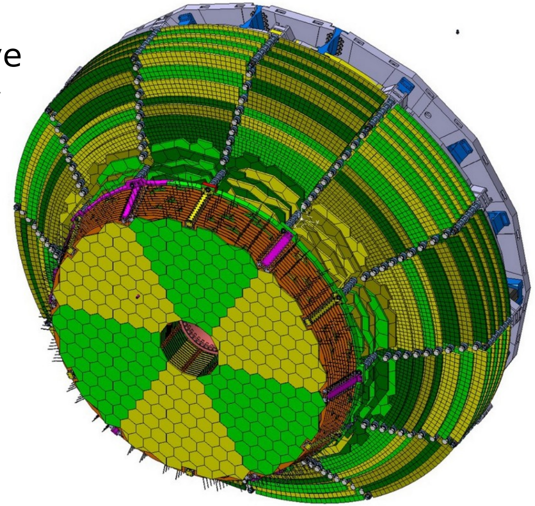
DESY.

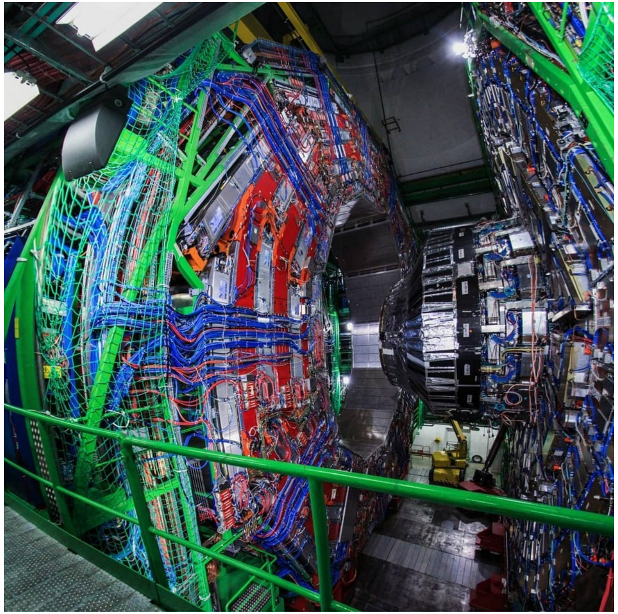
Introduction

HGCAL: CMS endcap upgrade

Key upgrade requirements for the calorimeter:

- Ability to contain the shower
- Fine lateral and longitudinal segmentation for shower separation and sampling of shower development
- Precise timing resolution for pile-up rejection
- Ability to withstand the radiation environment in the cavern and preserve the energy resolution beyond 3000 fb^{-1}





The CMS detector with the current calorimeter endcap

Introduction

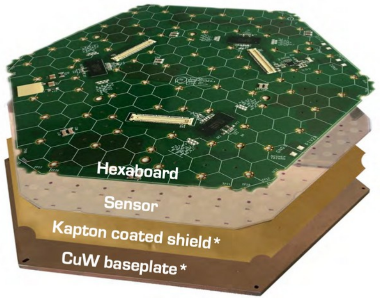
HGCAL: Technologies used

High **G**ranularity **Cal**orimeter **(HGCAL)** to replace existing CMS endcap calorimeter for upcoming HL-LHC: a 5D imaging calorimeter with unprecedented logitudinal segmentaition

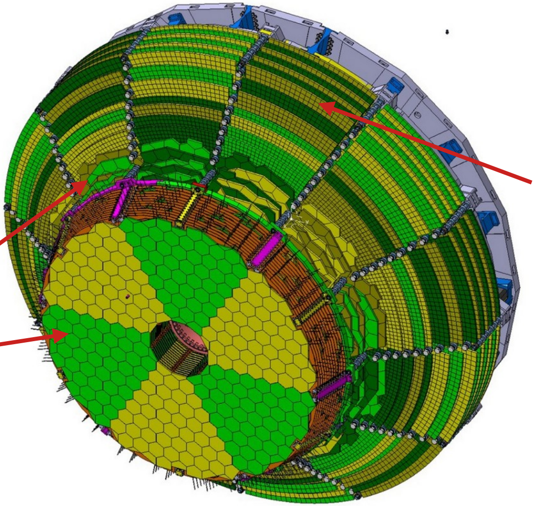
Can perform pile-up rejection utilising Si timing capabilities
Standard candle: response to a MIP - can perform in-situ calibration

Electromagnetic calorimeter (CE-E):

- Hexagonal silicon modules as active elements
- ~ 26 000 modules
- 6M Si channels



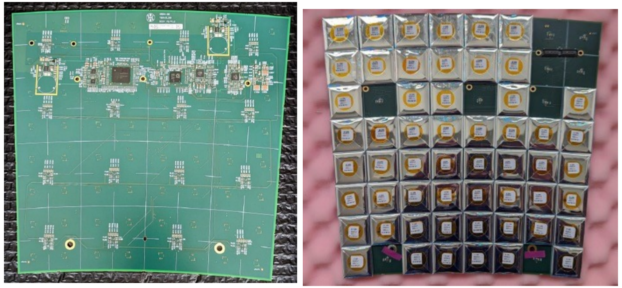
Si module



Operated at -30 °C

Hadronic calorimeter (CE-H):

- Both Si and scintillator modules



Scintillator tile module with trapezoidal tiles

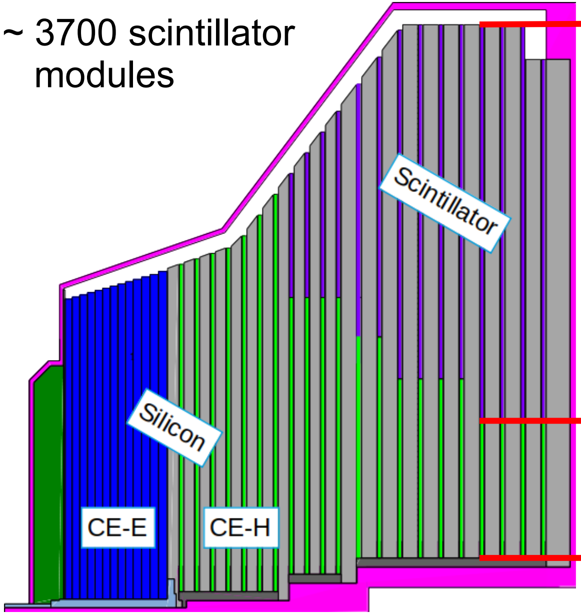
Scintillator section of CE-H

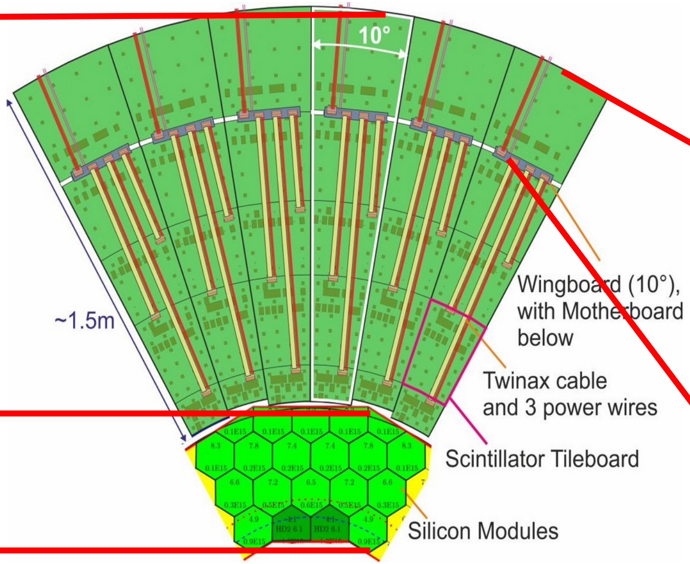
SiPM-on-tile technology for hadronic calirimeter endcal (CE-H)

Scintillator part of CE-H (hadronic calorimeter) based on SiPM-on-tile technology is being developed

~ 280k scintillator channels

~ 3700 scintillator modules





Tile module:
basic detector unit

DESY Tile assembly center

Quality control and spot sampling

DESY is one of the two Tile Assembly Centres performing tile module production and quality control at every stage

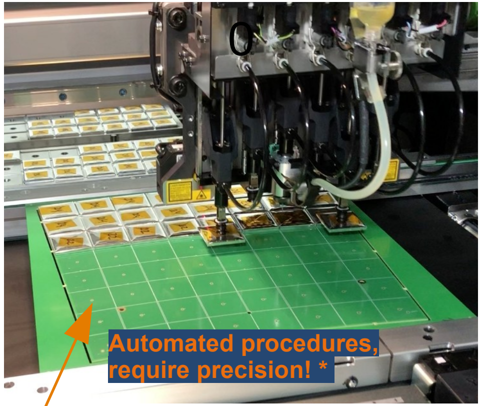
Objective is to assure top performance based on a small fraction (a spot sample) of all tiles

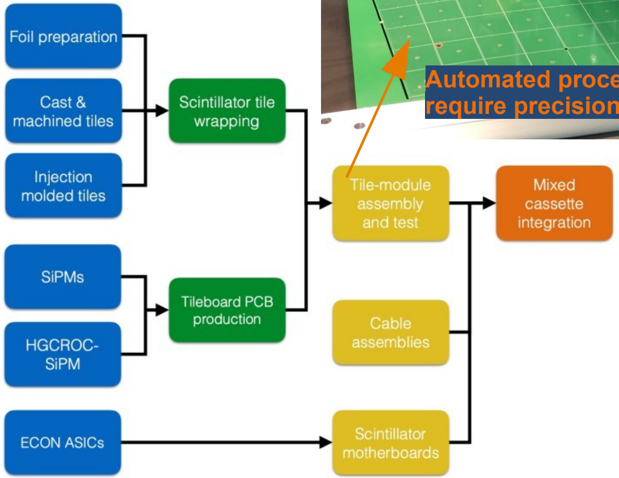
Due to the amount of channels assembly is impossible without automation which places strict constraints on mechanical precision

Need to gain experience and statistics

Milestones!

Pre-series phase: more than 1500 tiles measured
First pre-production tiles measured



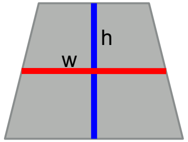


*Ask for videos of wrapping and assembly machines in action for a dopamine boost!

Quality control

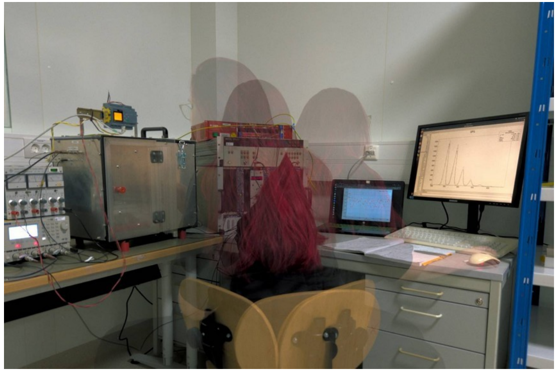
DESY test stands for wrapped tiles

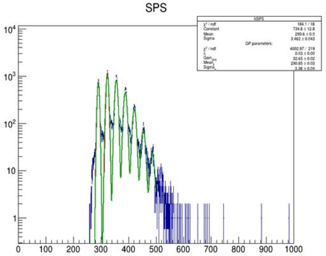
Tile size after wrapping

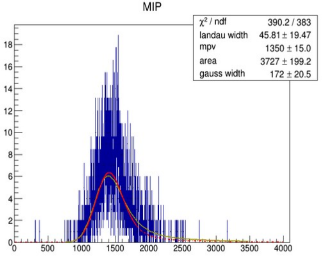


33.305 < w < 33.905
33.68 < h < 34.28

Tile Light Yield





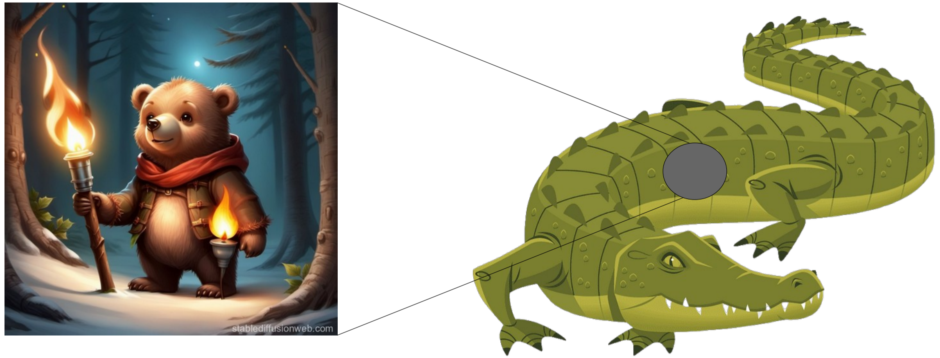


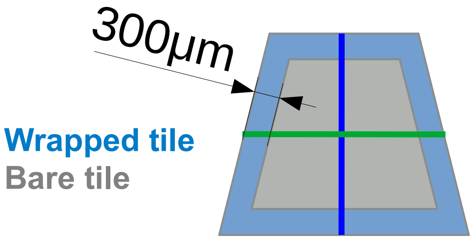
Tile size test stand

Motivation and setup

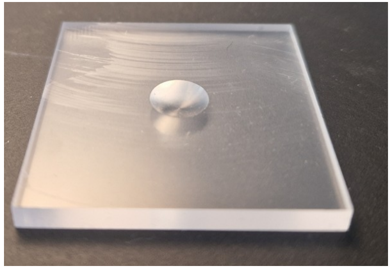
Mechanical measurement (caliper) impossible:

- Wrapping is not rigid: could be bent to incorrect size (or even damaged)
- Trapezoidal shape is challenging
- Good precision is critical
- Strict acceptance range dictated by automation +0 -100µm





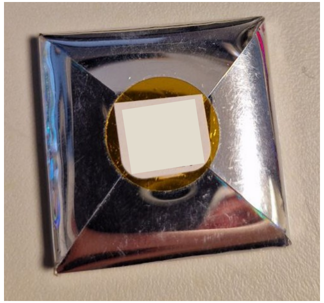
Bare tile



Makes an uncomfortable pillow

Mechanical measurements are easy

Wrapped tile



Fluffy

Enemy of the caliper

Tile size test stand

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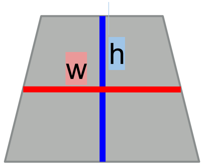
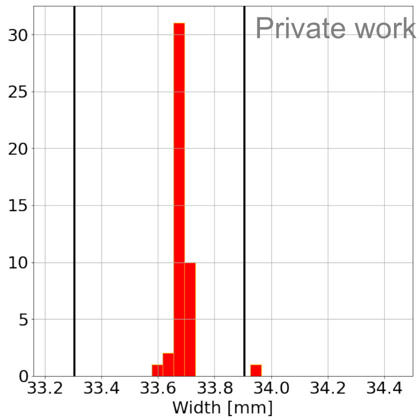
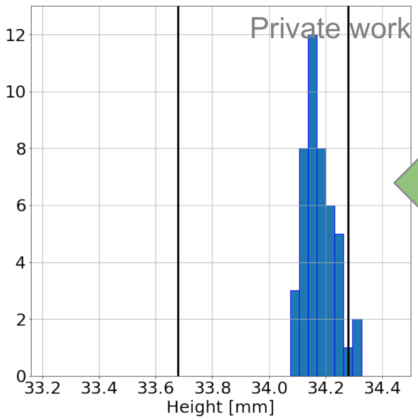
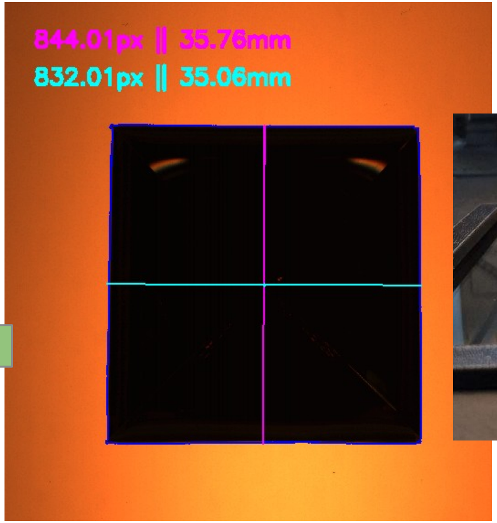


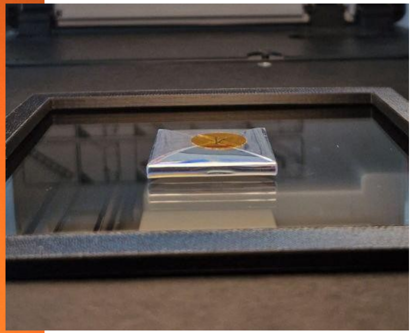




Solution: perform optical measurements!

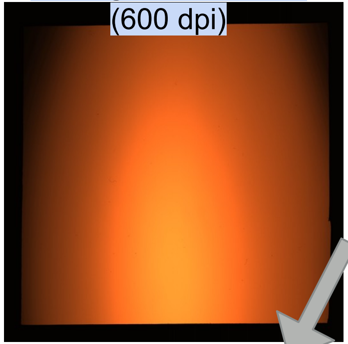
A flatbed scanner and an external light source for a "shadow" image analyzed by OpenCV software

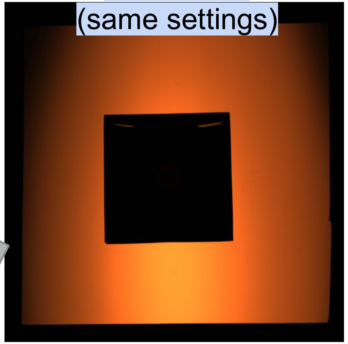


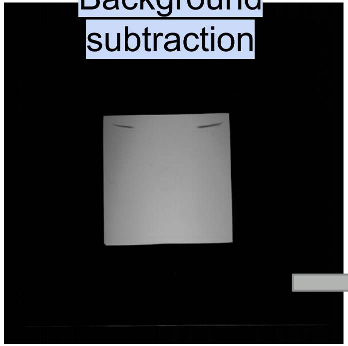


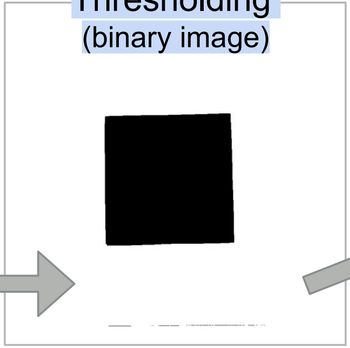
Tile size test stand

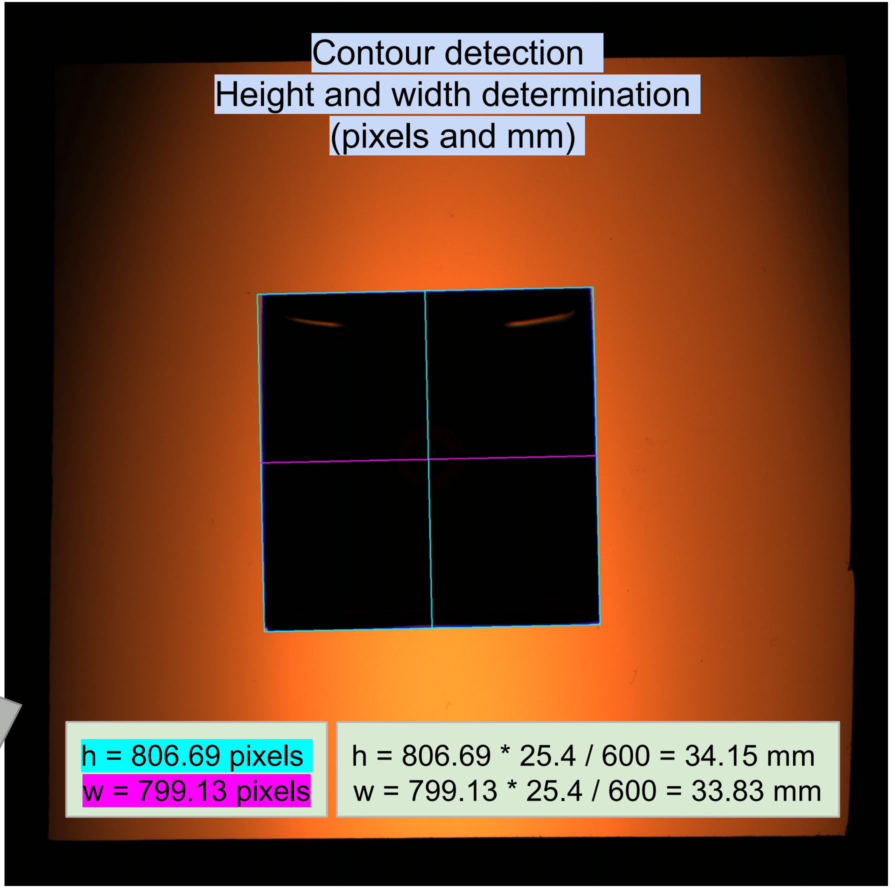
Algorithm utilizing OpenCV functions







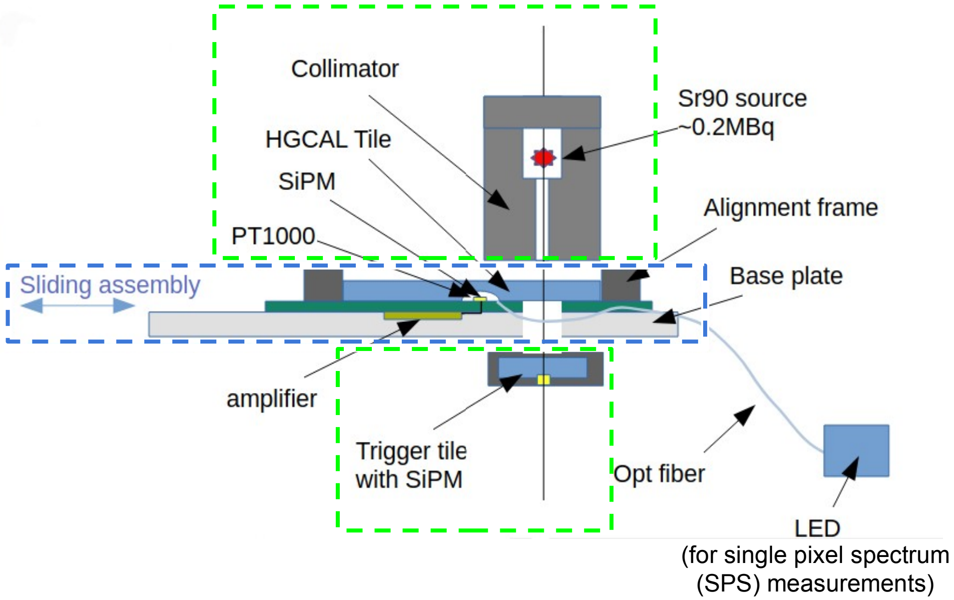


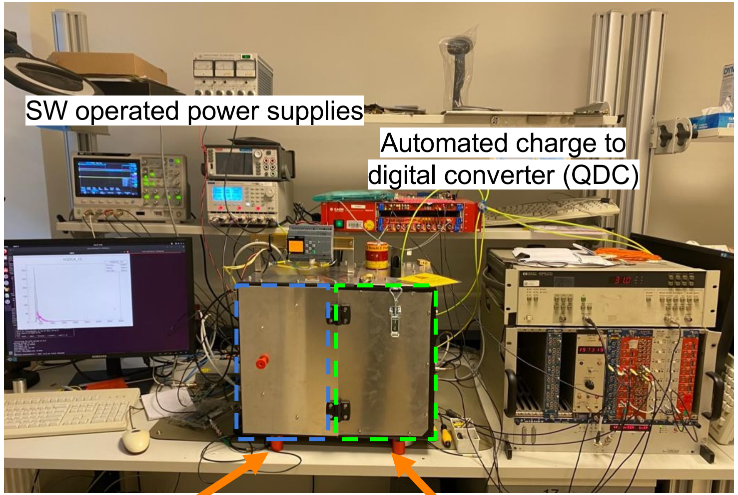


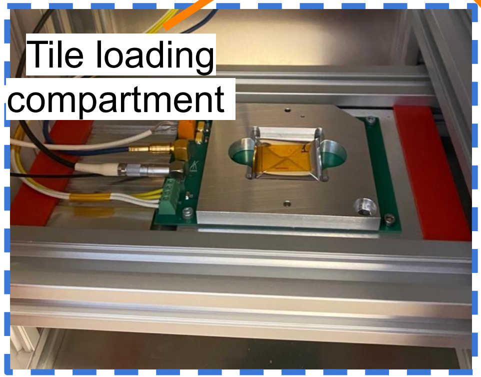
Light Yield test stand

Motivation and setup

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







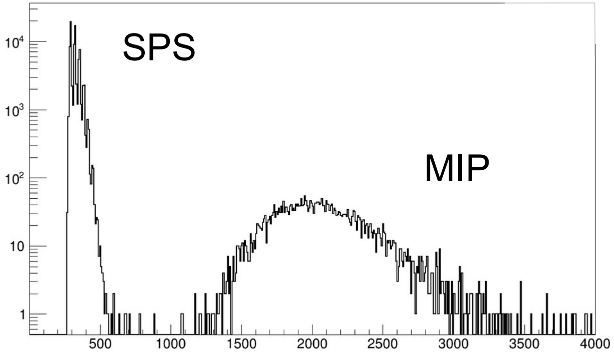
Light Yield test stand

Measurements

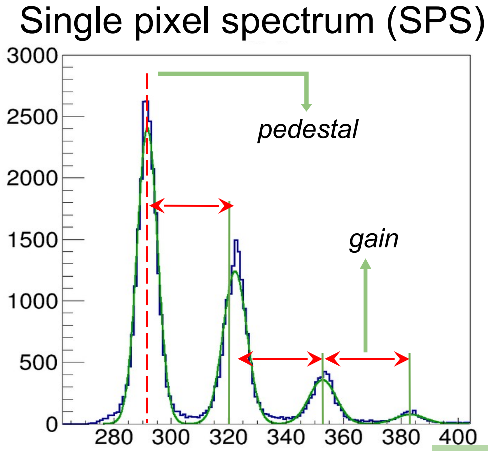
Light yield as the number of photoelectrons detected for a minimum ionising particle

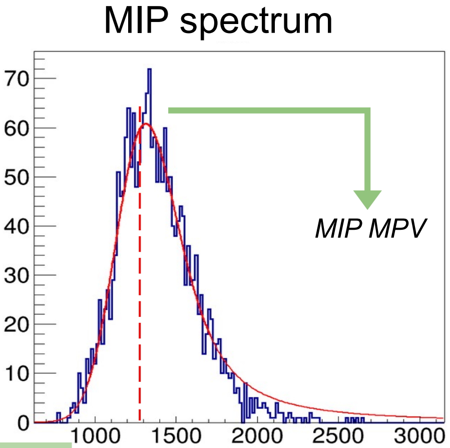
- Perform regular Light yield measurements of tile samples for feedback to producers and uniformity checks

- SPS and MIP spectra obtained at the same time, measurement conditions recorded (e.g. Overvoltage, Temperature)

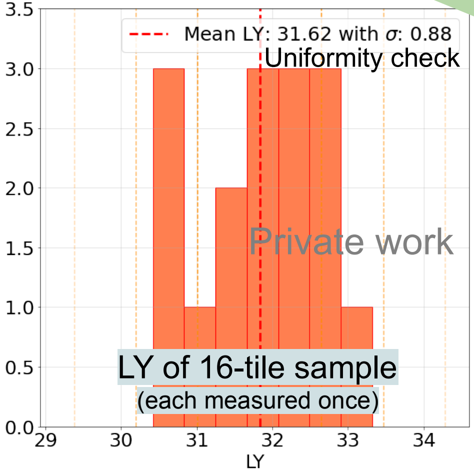


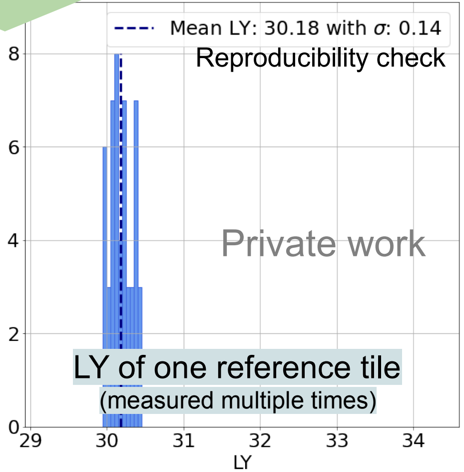
- Measurements of LY with ~0.6% uncertainty





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



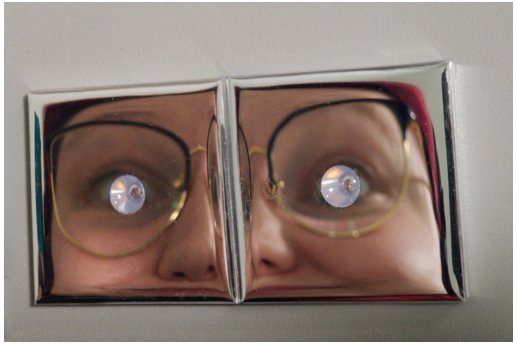


Milestone

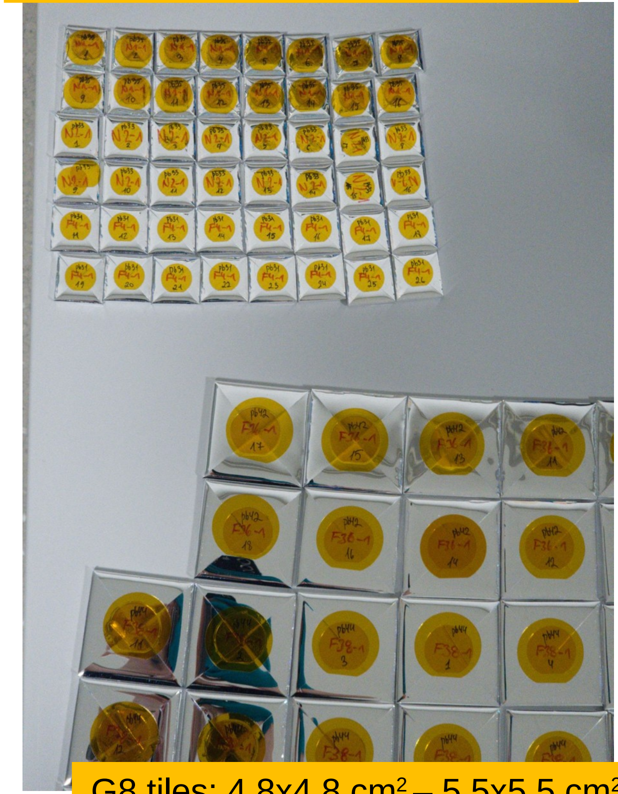
Maddening sample size

Pre-series phase:

1500 tiles
All various sizes ranging from
R0 – R40 : 5.3 cm^2 – 30.36 cm^2

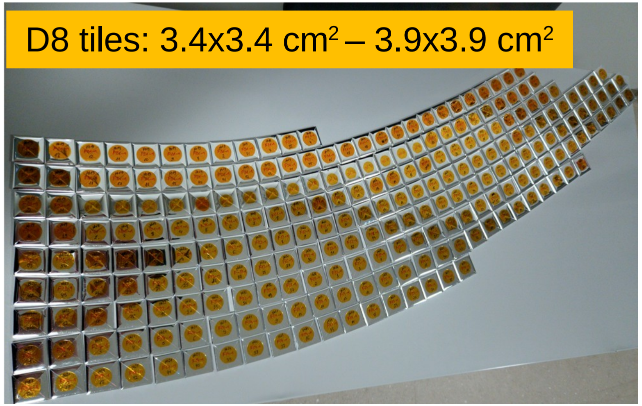


A5 tiles: 2.3x2.3 cm^2 – 2.5x2.5 cm^2



G8 tiles: 4.8x4.8 cm^2 – 5.5x5.5 cm^2

~1500 pre-series tiles



D8 tiles: 3.4x3.4 cm^2 – 3.9x3.9 cm^2

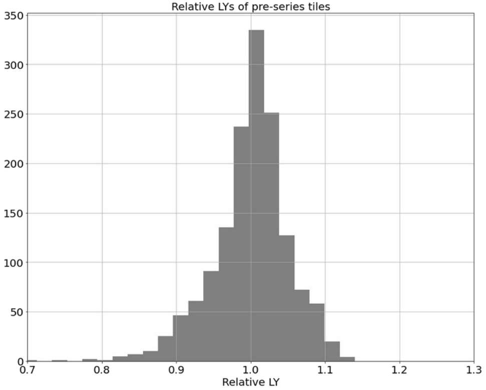
Milestone

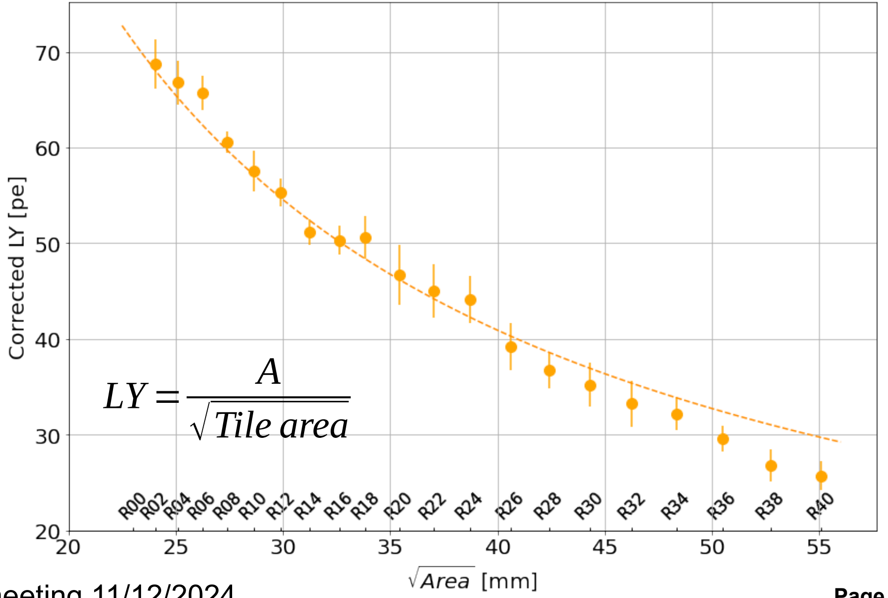
Light yield results for the pre-series tiles

Now with higher statistics we can determine:

- Mean and deviation of LY for each scintillator tile size
- Frequency of outliers
- LY vs tile size dependence

These values will be monitored during production

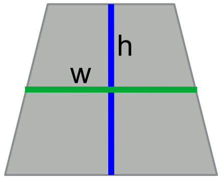


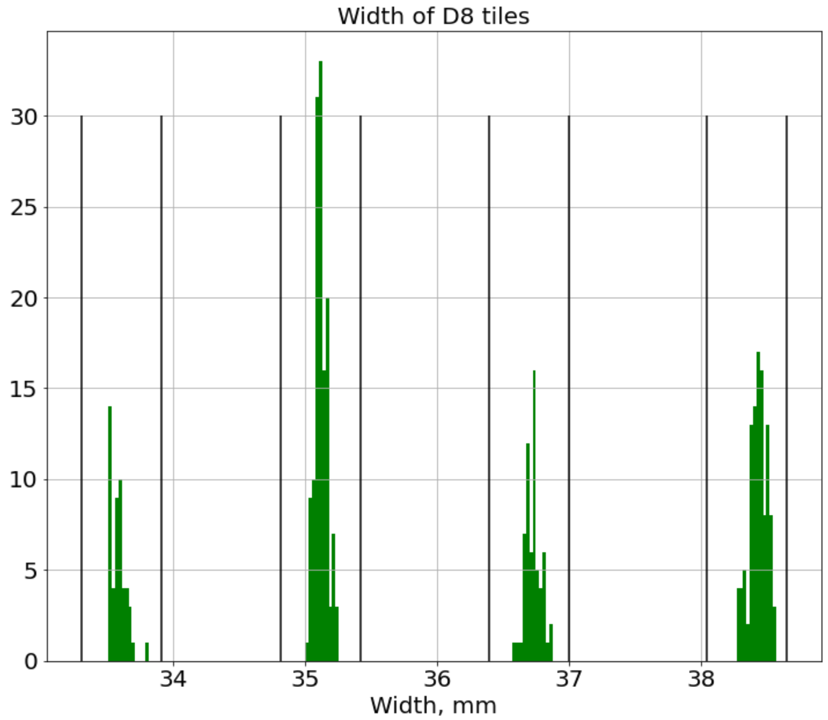


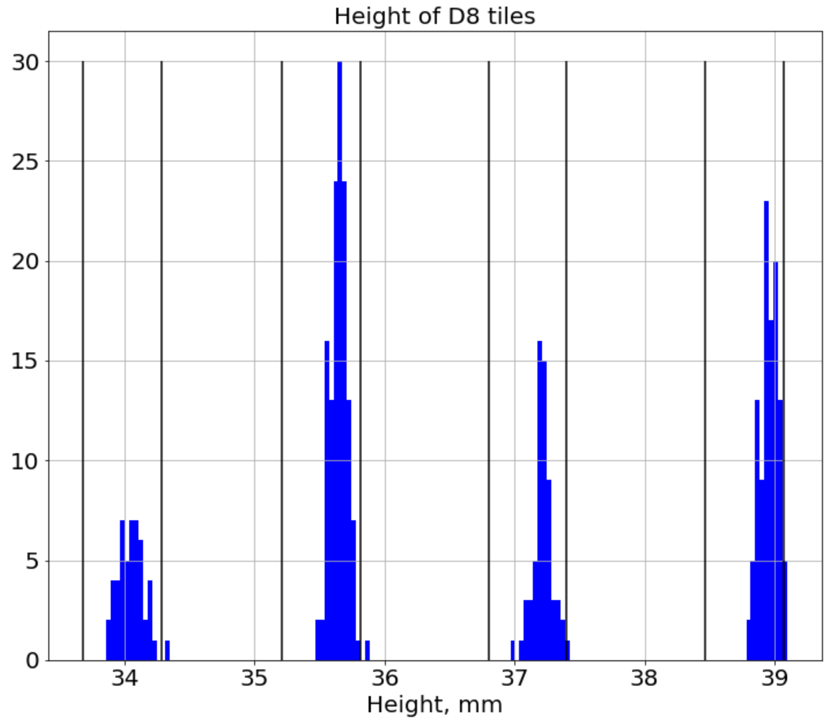
Milestone

Tile size results for the pre-series tiles

Height and width for tiles for rings 18 – 24

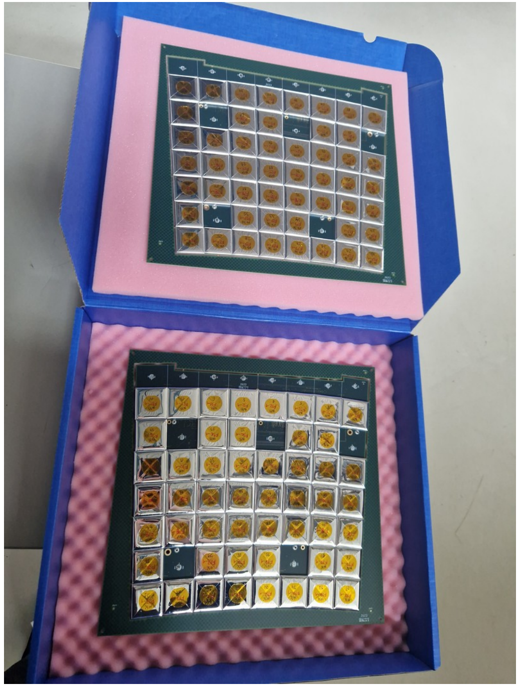




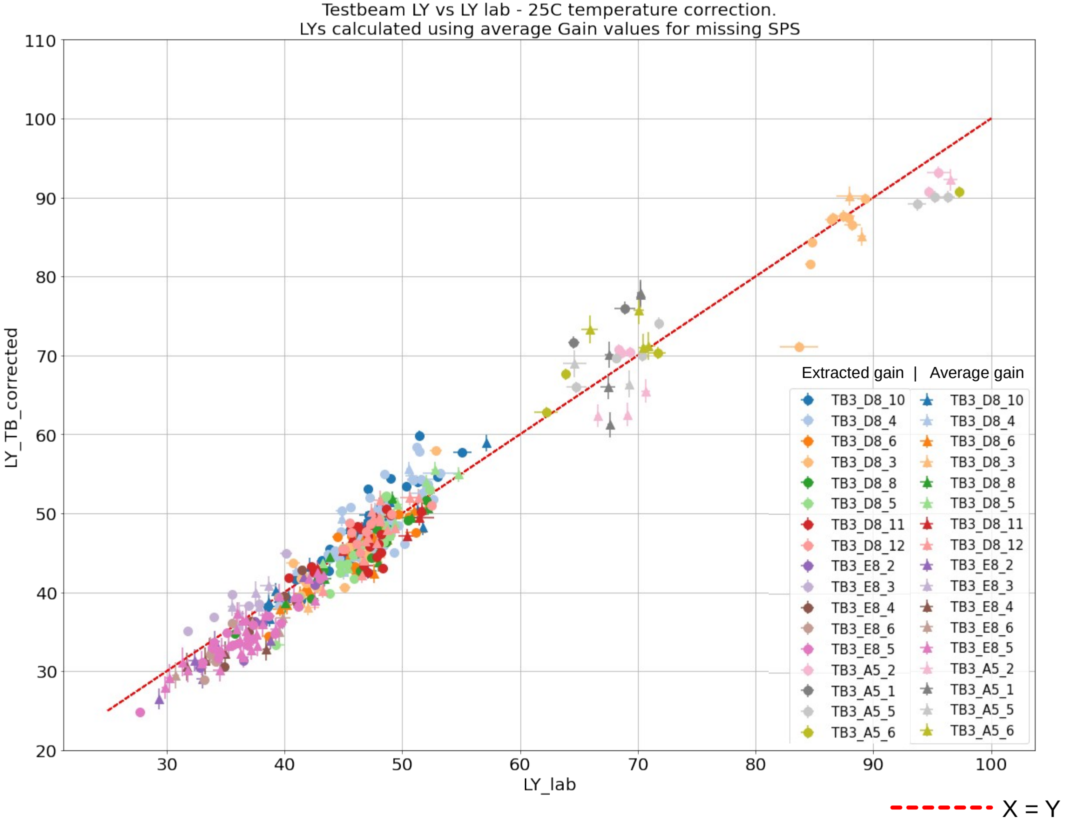


DESY Testbeam May 2024

Tilemodule testing



The pre-series tilemodules assembled and used in the DESY Testbeam

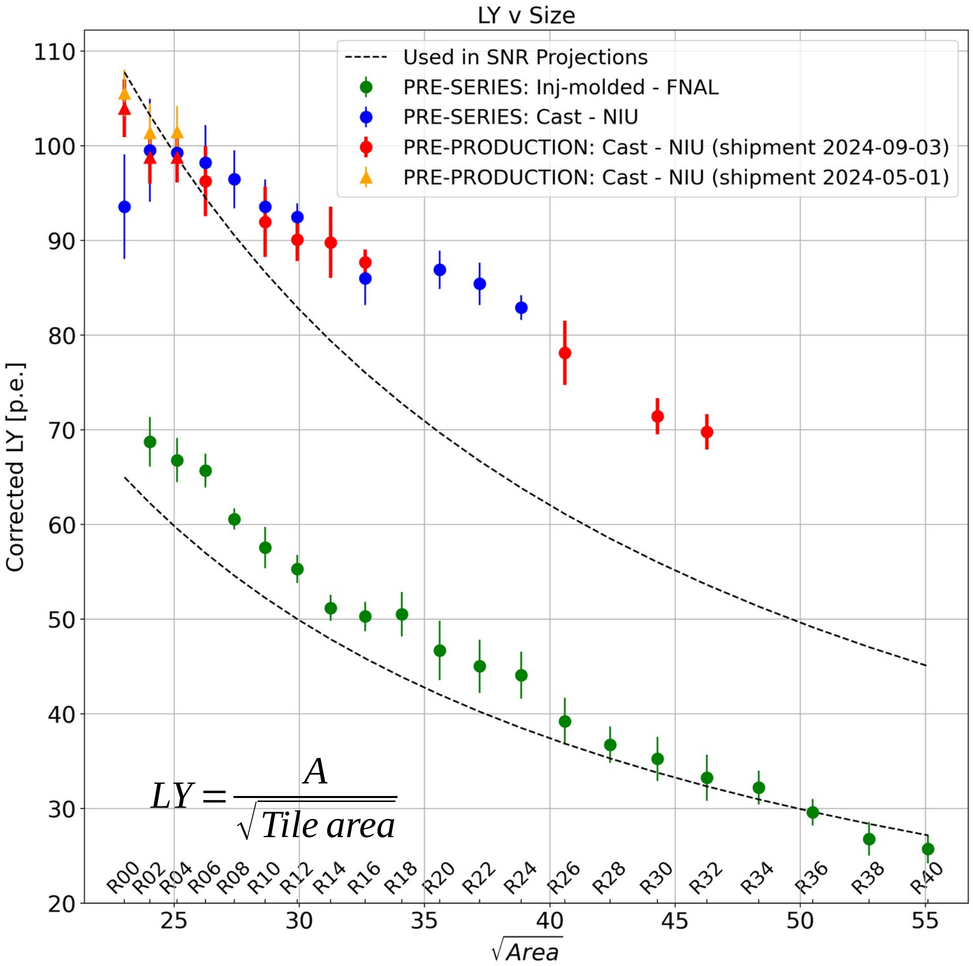


Milestone

Light yield results for the pre-production tiles

The spot sample size for pre-production was 20%

- Approx. 1300 tiles wrapped
- 250 tiles QC'd
- RMS of LY for tiles of one size below 5%
- No outliers so far (<85% of mean LY)



Merry Christmas!

Wish us many presents under the Calorime-Tree

A5

B12

D8

E8

G8

Backup

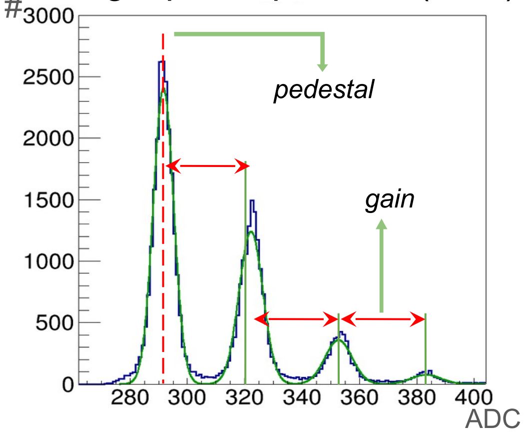
SiPM-on-tile technology

Response to low intensity light – Single Pixel Spectrum

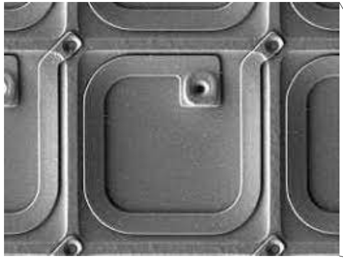
SiPMs: Hamamatsu SiPMs (15 µm pitch) with custom radiation hard packaging with good thermal conductivity. Two size variations:

- 2x2 mm² active area SiPMs
- 3x3 mm² active area SiPMs

Single pixel spectrum (SPS)

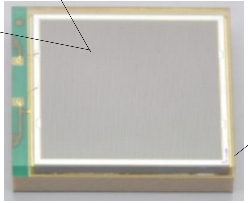


SiPM gain: charge amplification factor of a cell

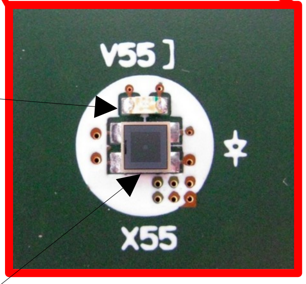


Collection of Single Photon Avalanche Diodes (SPADs) and quenching resistors ~ 40 000

LED



SiPM
3x3 mm²

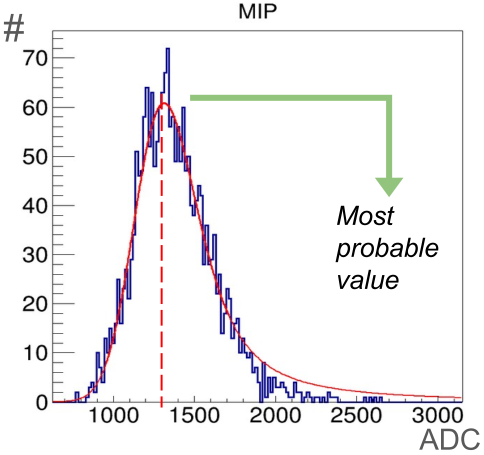


SiPM-on-tile technology

Response to charged particles – Minimum Ionising Particle Spectrum

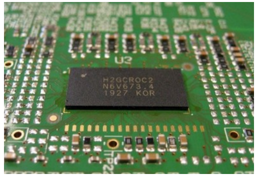
Plastic scintillators (3 mm thick), wrapped in reflective foil, coupled to a Si photomultiplier (SiPM). Signals from the SiPM are digitised by the read-out chip (ROC): receive an ADC value

Extracted Most Probable Value is the response of the channel in ADC units for 1 MIP → change to a MIP scale

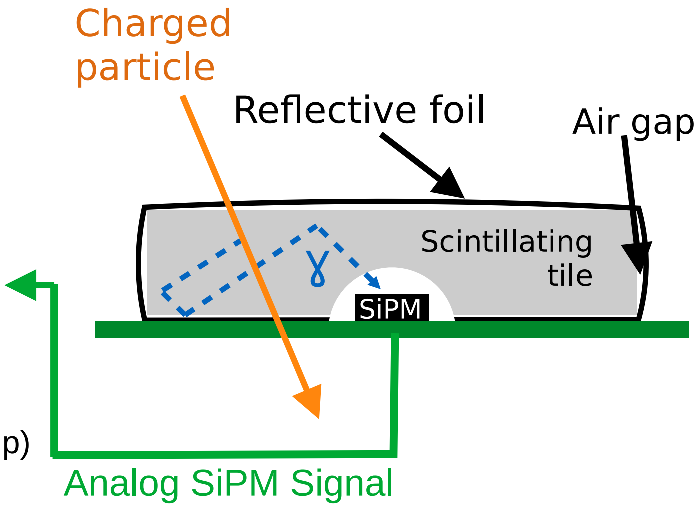


SiPM-on-tile channel response to a Minimum Ionising Particle (MIP)

Signal amplification and Digitization



HGCROC (HGCAL Read Out Chip)



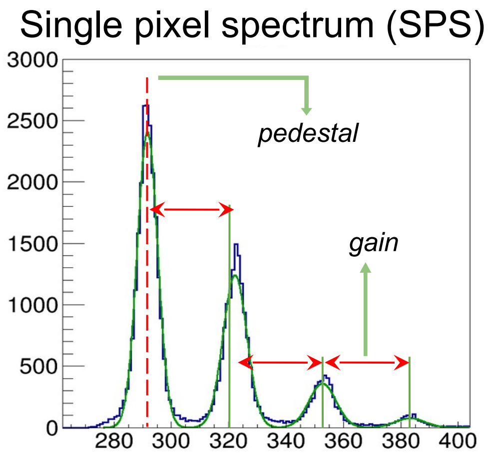
SiPM-on-tile technology

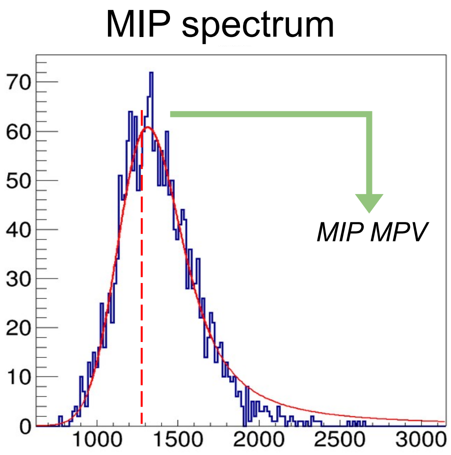
Light yield – optical performance characteristic

By normalizing the most probable value to the gain we can calculate a value that will characterise the optical performance of a given SiPM-on-tile channel:

Light yield (LY) defined as the number of photoelectrons detected for a minimum ionising particle

It can be monitored during production and used for re-calibration in situ





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

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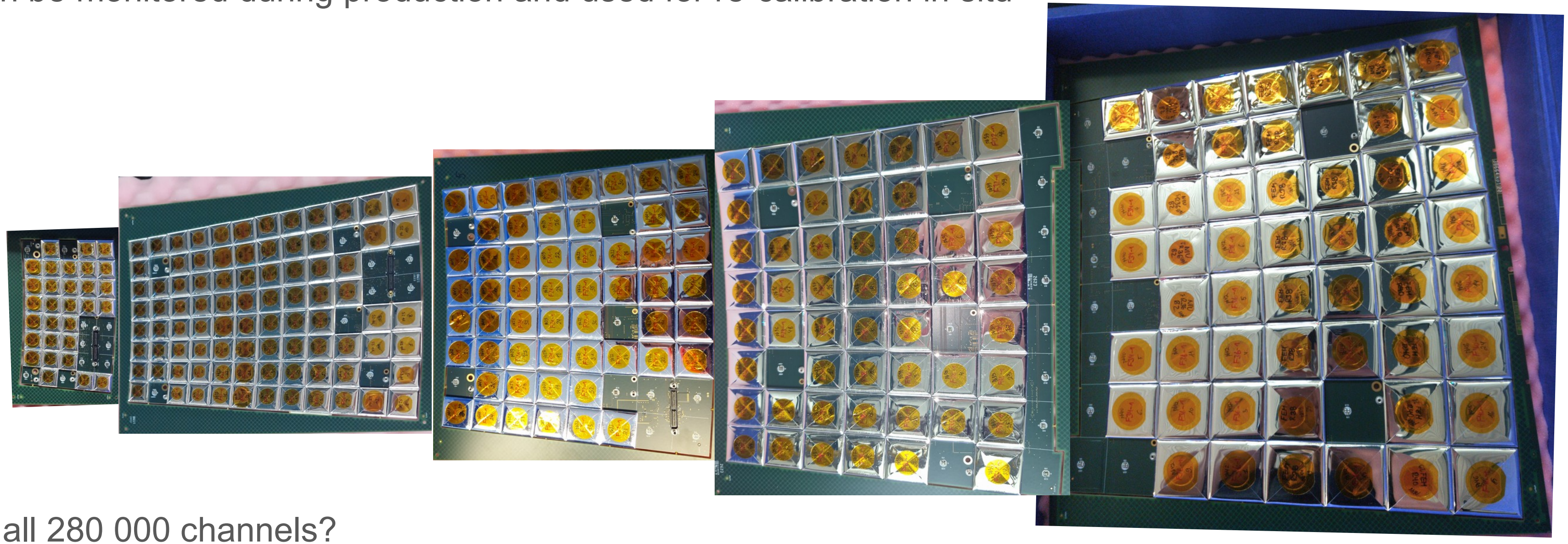


For all 280 000 channels?

Tile size test stand

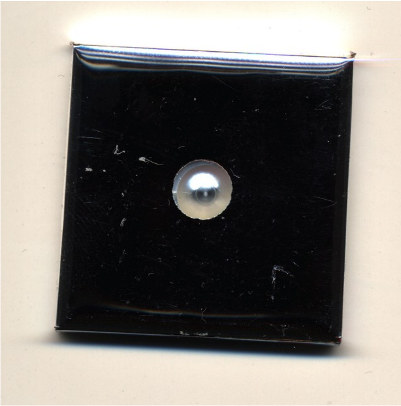
Motivation and setup

Mechanical measurement (caliper) impossible:

- Wrapping is not rigid: could be bent to incorrect size (or even damaged)
- Trapezoidal shape is challenging
- Good precision is critical
- Strict acceptance range dictated by automation +0 -100µm

Solution: perform optical measurements!

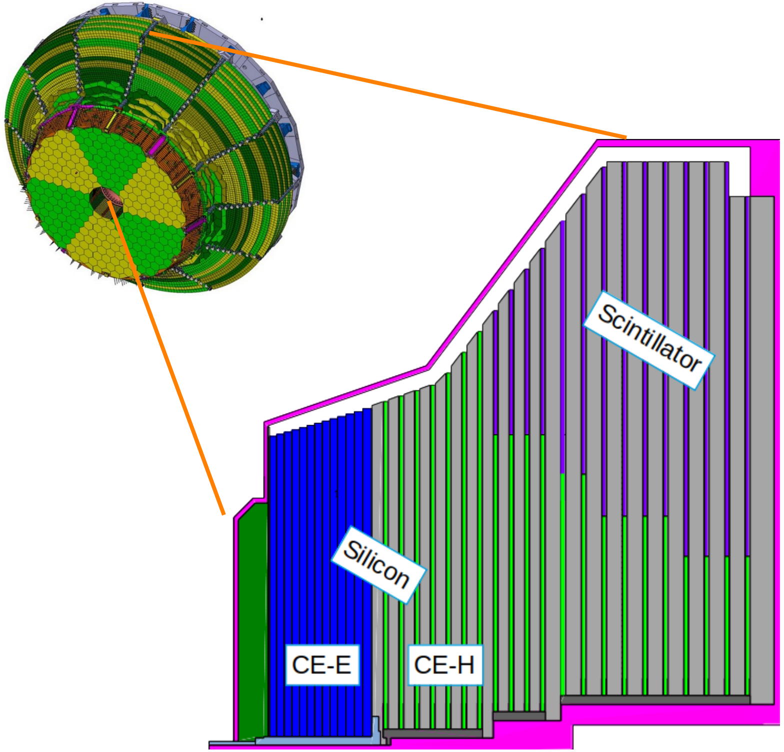
Would pictures work?

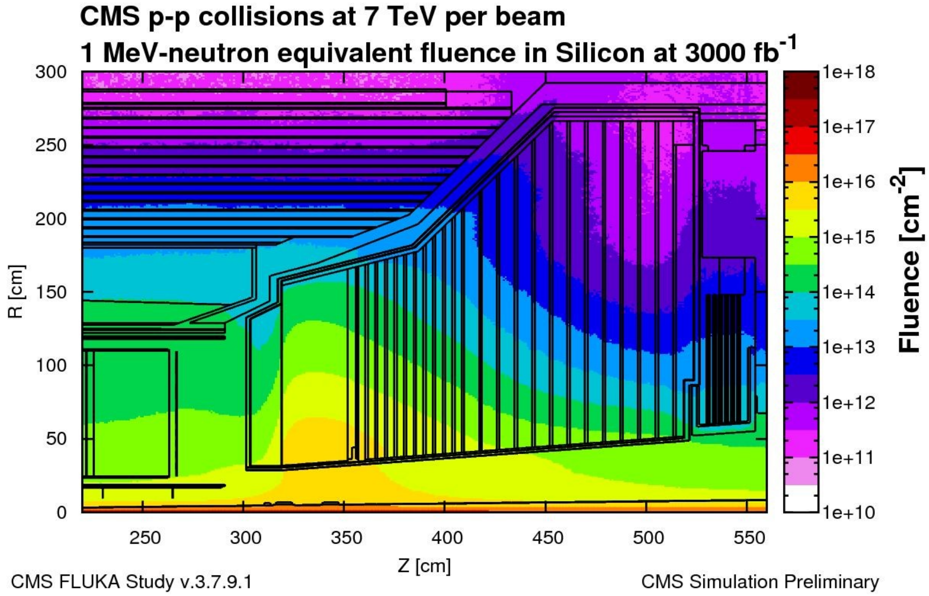


Challenging:
Shadows, reflections, distortions

HGCAL

Hadronic section segmentation





SiPM-on-tile section in regions with neutron fluence < 5×10^{13} n/cm^2

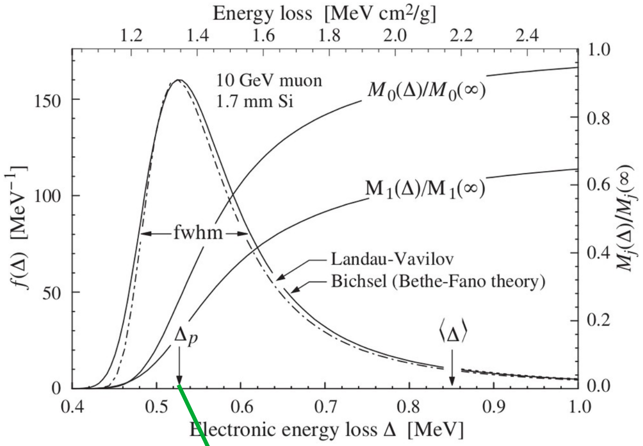
Introduction

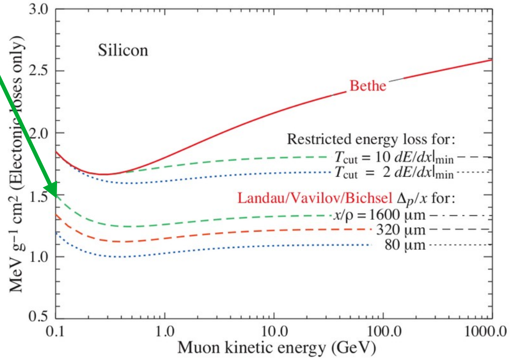
Why do we use MIPs?

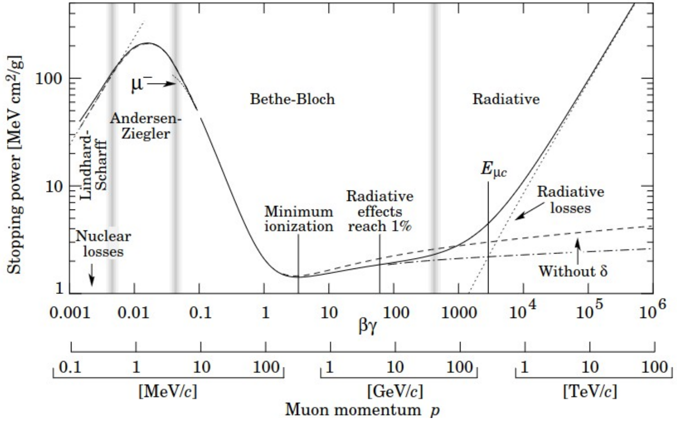
“Standard candle: response to a MIP”

Most probable value for energy loss is well defined experimentally and is used for describing energy loss by single particles

The distribution of energy loss in thin detectors: 1.7 mm Si or 3 mm plastic scintillators





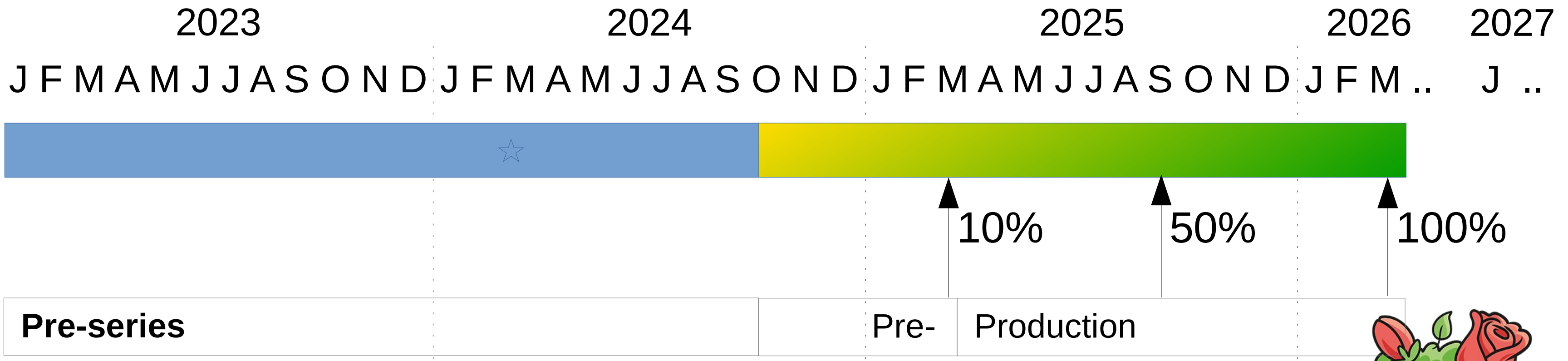


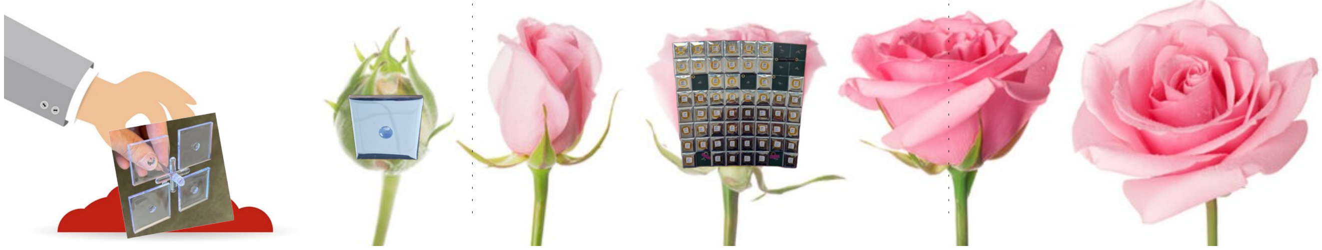
Muon stopping power described by Bethe-Bloch formula, illustrates mean energy loss rate. The mean value for energy loss is subject to large fluctuations due to the statistical nature of the ionisation process.

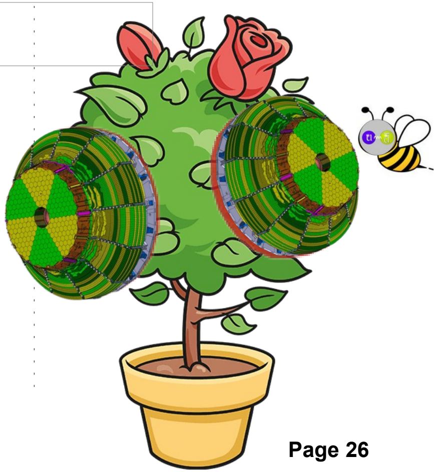
Introduction

Timeline

Schedule sketch of the **Scintillator Tile Module** production





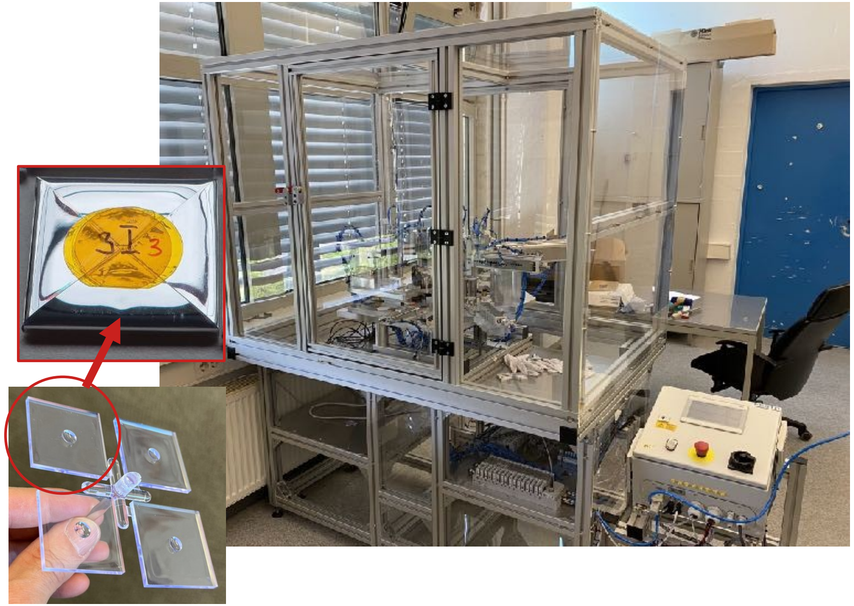


Tilemodule assembly

Automated tile wrapping and placement

Wrapping machine

4 tiles wrapped per minute
Stored in a sequence (in future a reel) for further steps



Pick-and-place machine

Precise centered glueing of tiles
~150 modules/month assembly goal