High Granularity Scintillator Tiles for the High Luminosity Upgrade of the CMS Endcap Calorimeter

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CMS
FTX
DESY.

Introduction

Motivation for the upgrade: High Luminosity LHC

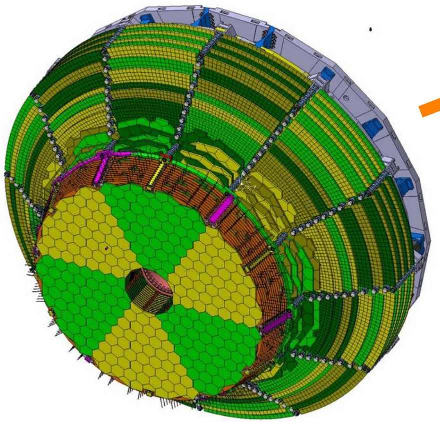
High Luminosity LHC aims to achieve:

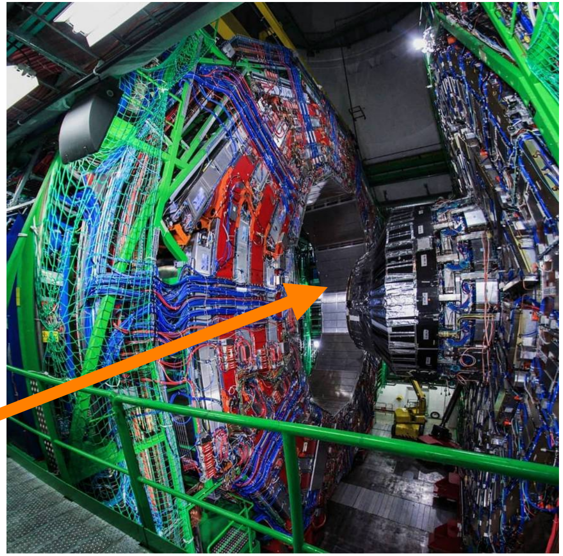
- 3000 fb^{-1} end-of-life integrated luminosity - ten times higher than the LHC
- Mean number of collisions (pile-up) per bunch crossing ~140

Main detector upgrade requirements: high radiation tolerance and pile-up rejection ability

High Granularity Calorimeter (HGCAL):

- Sampling calorimeter with fine lateral and longitudinal segmentation: 47 layers, over 6M channels
- Silicon based for maximum radiation hardness and excellent timing capabilities





The CMS detector with the current calorimeter endcap

~5% Production finished — Today

Tilemodule assembly finished — Early 2027

Commissioning — 2030

Data taking

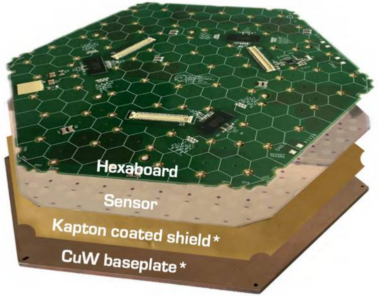
Introduction

Technologies used

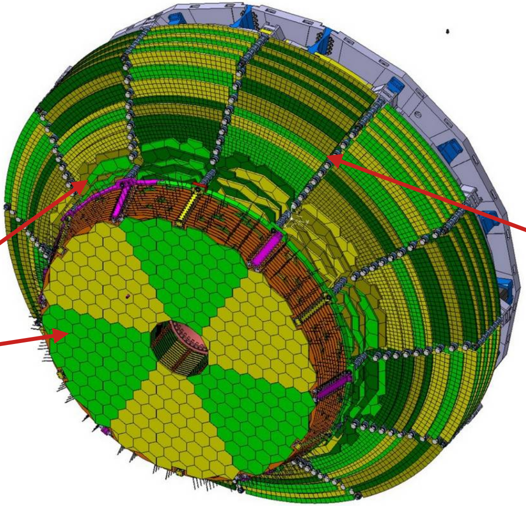
Silicon modules in the harsh radiation areas, Scintillators in a region where fluence below $5x10^{13}$ n_{eq}/cm^2

Electromagnetic calorimeter (CE-E):

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



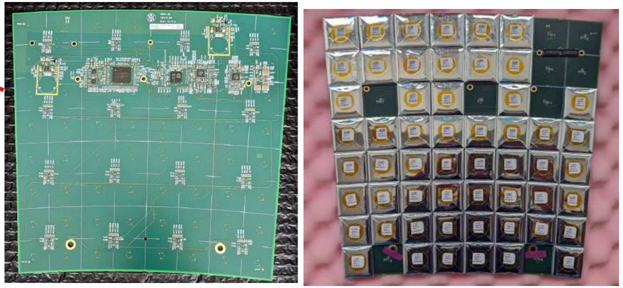
Si module



Operated at -30 °C
3.8 T magnetic field

Hadronic calorimeter (CE-H):

- Both Si and scintillator modules



Scintillator tile module with trapezoidal tiles

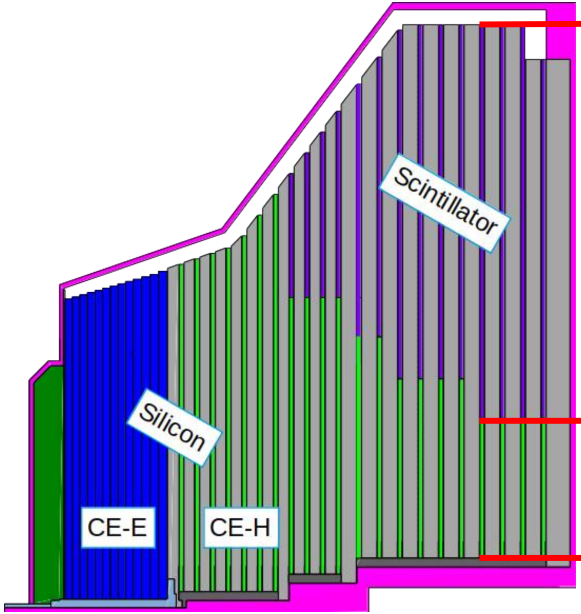
Overview talk by Rajdeep Mohan Chatterjee (Plenary Session-II, 03/02/36 11:20) + more talks on electronics throughout

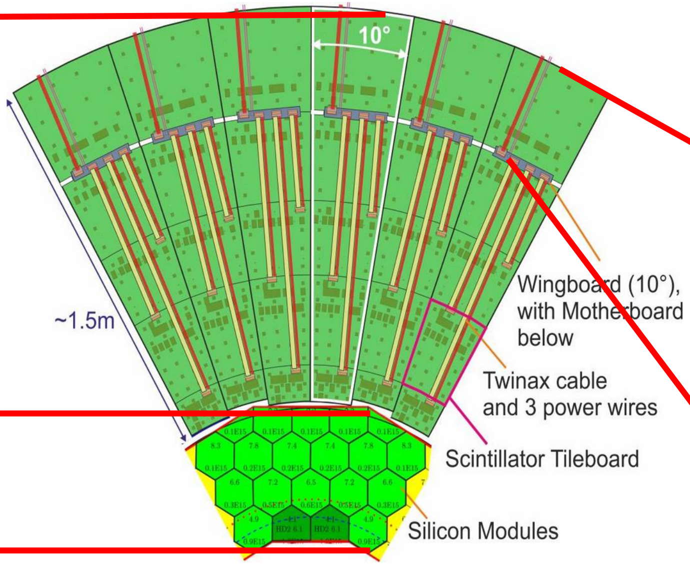
Scintillator section of CE-H

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

~ 280k scintillator channels

~ 3700 scintillator modules



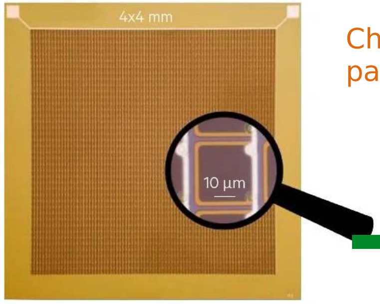


Tile module:
basic detector unit

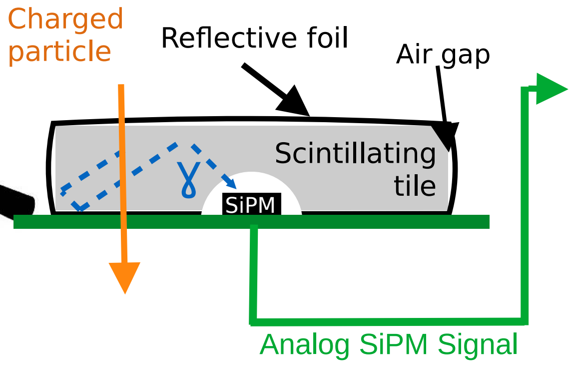
SiPM-on-tile technology

Response to charged particles

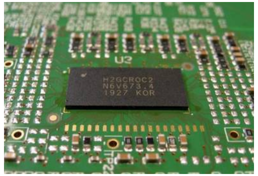
- Plastic scintillators (3 mm thick), wrapped in reflective foil, coupled to a Si Photo-Multiplier (SiPM)
- Signals from the SiPM are digitised by the HGCAL read-out chip (HGCROC): receive an ADC value
- Response to a MIP – a standard candle



SiPM – a pixilated device
Image credit: First Sensor



Signal amplification and Digitization



HGCROC
(HGCAL Read Out Chip)

(talk by Damien Thienpont, Parallel Session-IV 15:30)

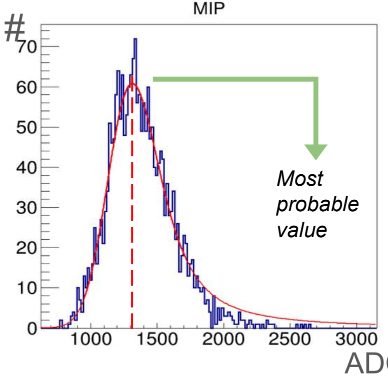


Illustration of a SiPM-on-tile channel response to a charged particle

DESY Tile assembly centre

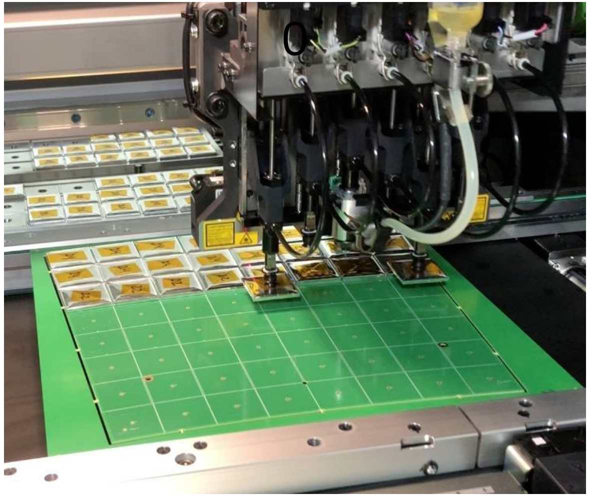
Quality control and spot sampling

DESY is one of two Tile Assembly Centres that perform quality control at every stage

- Assembly impossible without automation → strict constraints on mechanical precision
- Spot sample approach for tiles → testing only a small fraction

35 tile variants:
- Trapezoidal and rectangular shapes
- Two production techniques and materials (cast – PVT, injection-molded – polystyrene)

35 Tilemodule variants
- Number of channels range 24 – 144 (1-2 read-out-chips)



Ask for videos of wrapping and assembly machines in action
CAUTION: very cool!

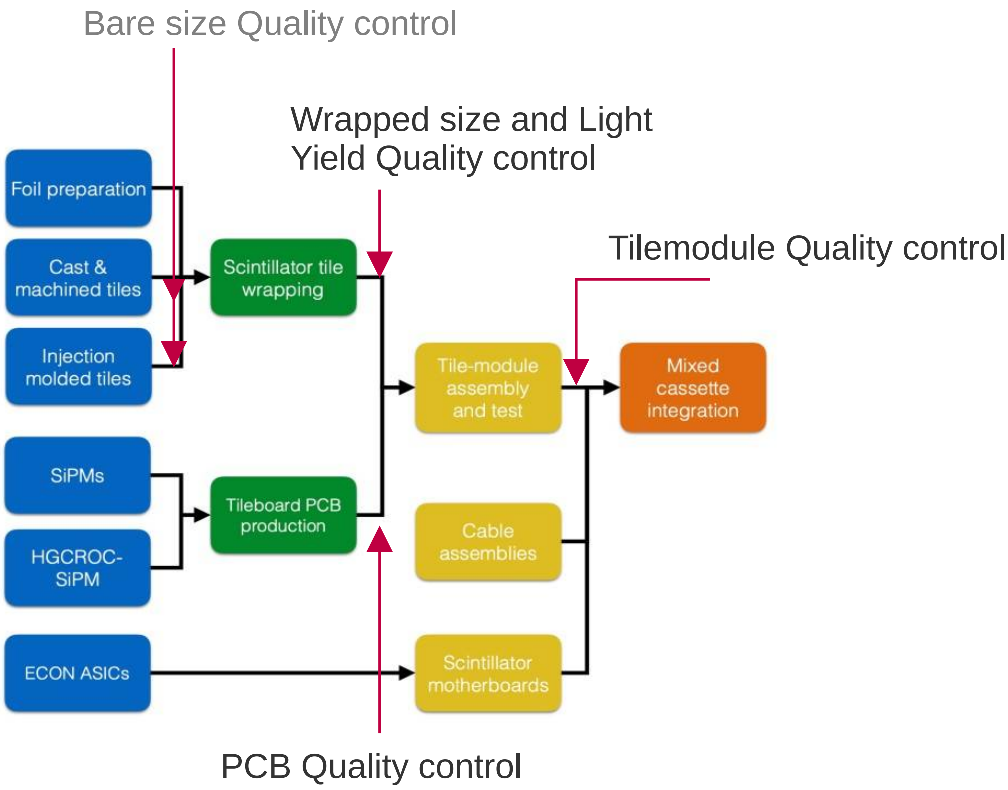
DESY Tile assembly centre

Assembly workflow

DESY upgrade share for tiles:

- ~160’000 tiles to be processed
  - Bare size QC of 5-10%
  - Tile wrapping
    - 10’000 tiles/month
  - Wrapped tile QC 5-20%

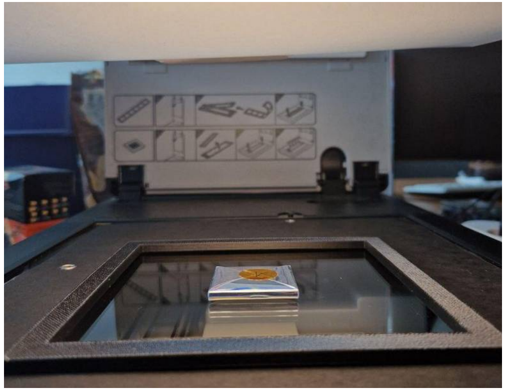
- Assembly of ~2000 Tilemodules

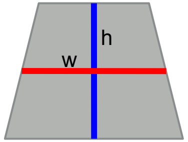


Quality control

DESY Wrapped tile dimensions test stand

Tile size after wrapping





33.305 < w < 33.905
33.68 < h < 34.28

Required before the automated Tilemodule assembly to verify that size fits into accepted range: not exceeding 600 µm above bare scintillator size

Quality control test stand:

- Optical measurements
  - Mechanical not possible, wrapped tile has rounded edges
  - Still challenging due to reflections
- Setup: a flatbed scanner
  - an external light source used for a “shadow” image to remove reflections
- Analysed by OpenCV software for measurements of height and width in mm
- Achieving precision requirement of 50µm
- ~ 30s/tile, spot sampling

Quality control

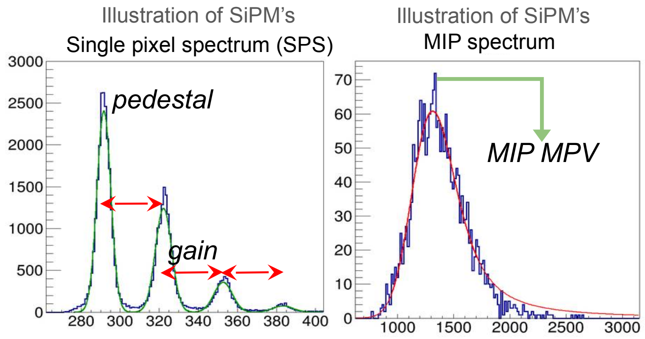
DESY Tile Light Yield test stand

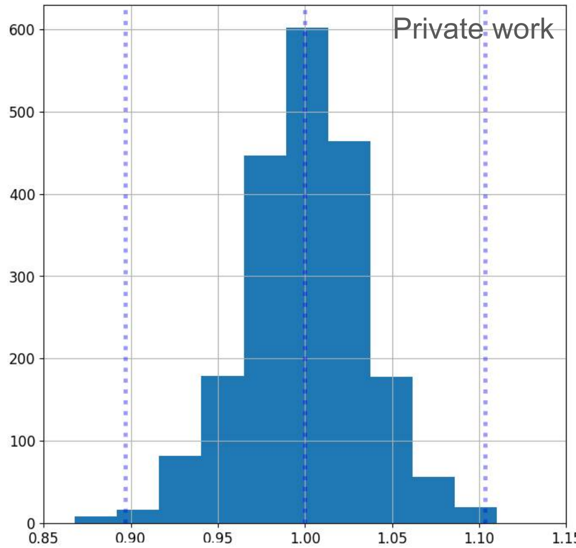
Required for ensuring high light yield is maintained during production before assembly

- Tile light yield is defined as the number of photo-electrons per minimum ionising particle (MIP) to cancel out SiPM gain

Quality control test stand:

- A fixed SiPM, low intensity LED and temperature sensor in vicinity
- Dedicated readout, different from the final system
- Sr90 radioactive source of charged particles, low intensity LED for SiPM gain measurements
- Easily exchangeable frames for all tile variants allow for non-permanent coupling of scintillator to the SiPM
- ~90s/tile, spot sampling





Relative light yield distribution for more than 2000 tiles (~20% fraction)

Tilemodule quality control

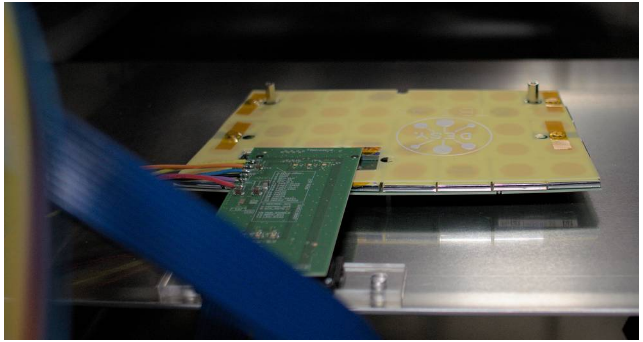
Verifying the operation of the final system

Tileboard PCB quality control tests to verify operation of electrical components after assembly:

- Cold and Warm QC, determining standard read-out chip parameters for further operation
- Any faulty components can still be replaced

After Tilemodule assembly, quality is assured via the cosmic test stand:

- Cosmic muons for the MIP signal, LED for SiPM gain measurements
- ~48h required for enough statistics
- Maximum 18 Tilemodules at a time
- First time measurements of the light yield for ALL tiles: initial calibration



Light yield

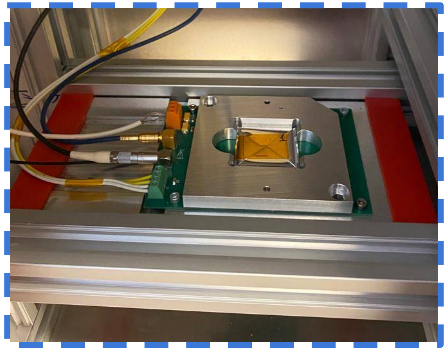
Bringing tiles and Tilemodules together

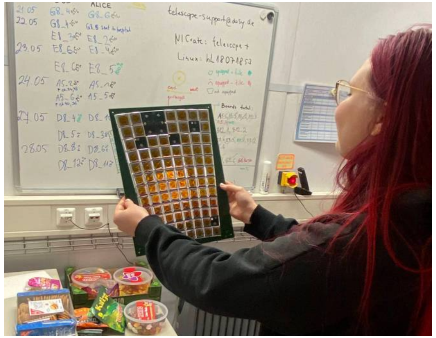
Light Yield test stand:

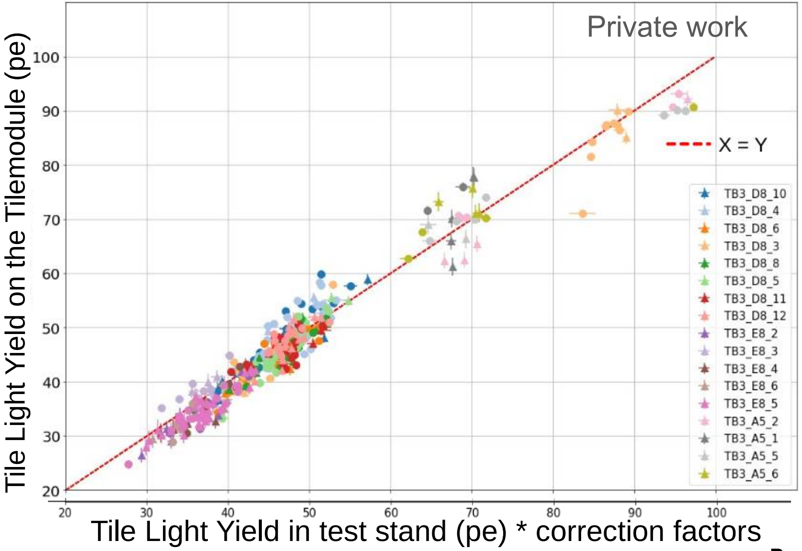
- Quick and reliable measurements of the tile response
- The readout is different from the final system

Cross calibration of test stand and Tilemodule results

- Provides correction factors for the Light Yield measurements for the test stand
- Efficacy verified during testbeam runs with the final prototype



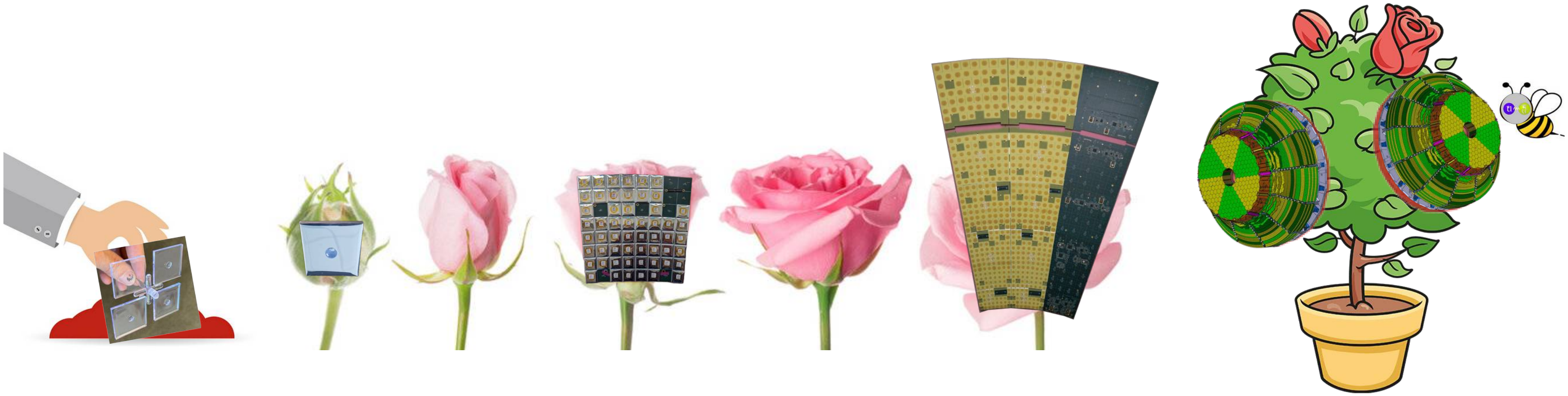




Conclusion

Milestones

- HGCAL will be the first high granularity calorimeter for a collider
- Any challenges experienced during production = more knowledge and expertise for future projects
- Tilemodule production started, production and quality control run at required speed
- Quality control performed at every stage shows all components meet the requirements



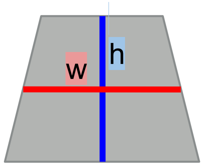
Backup

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



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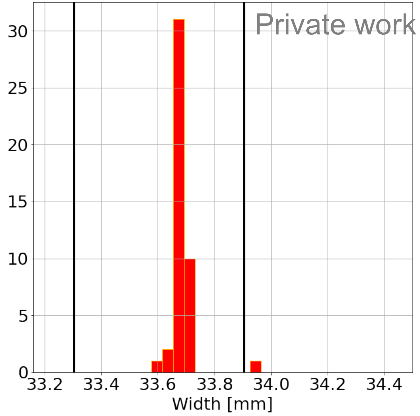

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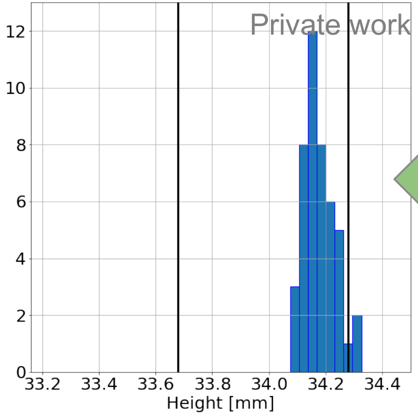
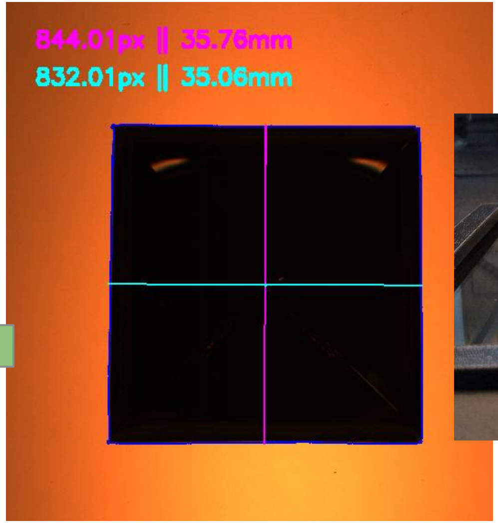
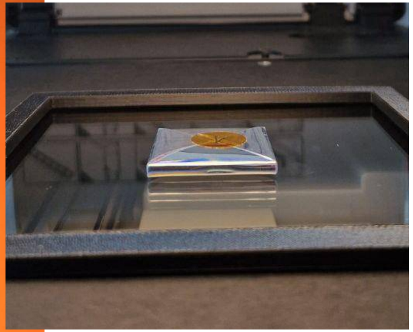


Solution: perform optical measurements!

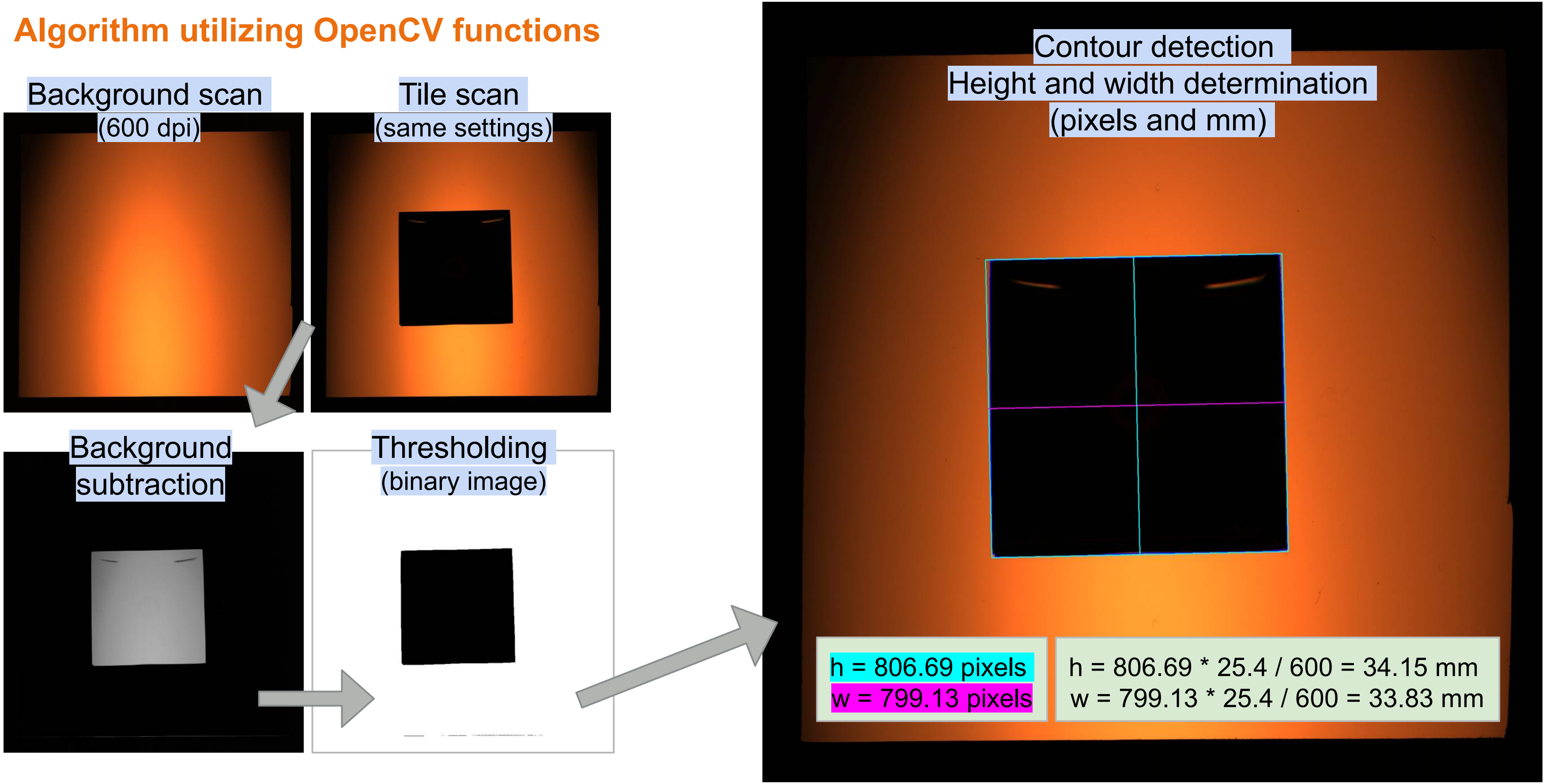
A flatbed scanner and an external light source for a "shadow" image analyzed by OpenCV software





Tile size test stand

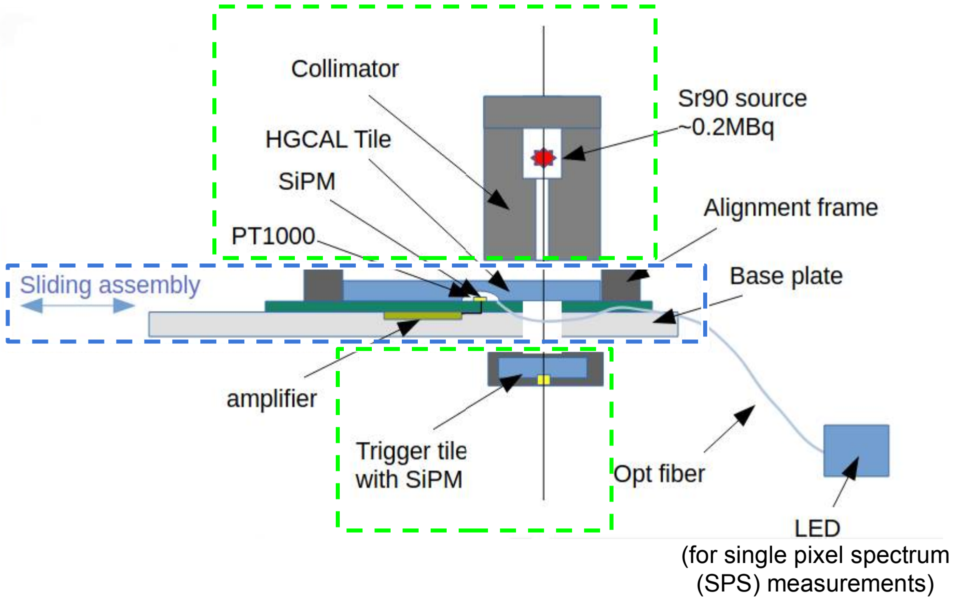
Algorithm utilizing OpenCV functions

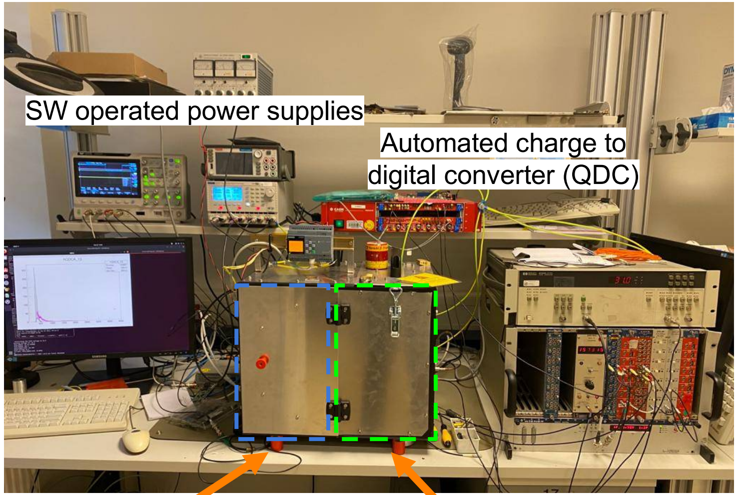


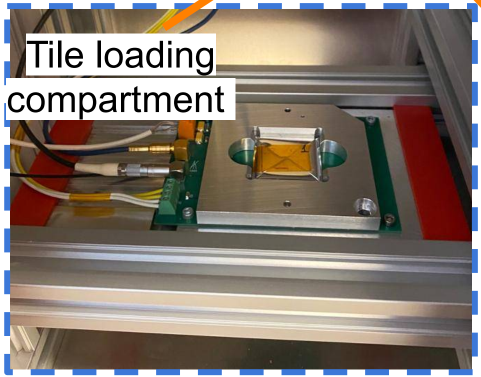
Light Yield test stand

Motivation and setup

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







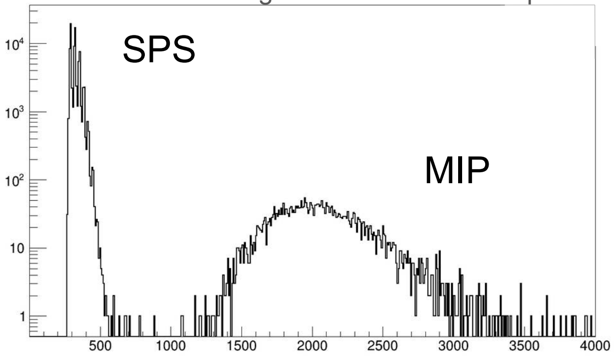
Light Yield test stand

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)

Illustration of the Light Yield test stand response



- Measurements of LY with ~0.6% uncertainty

Illustration of SiPM's Single pixel spectrum (SPS)

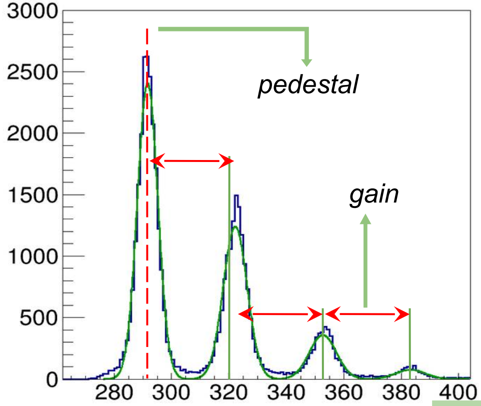
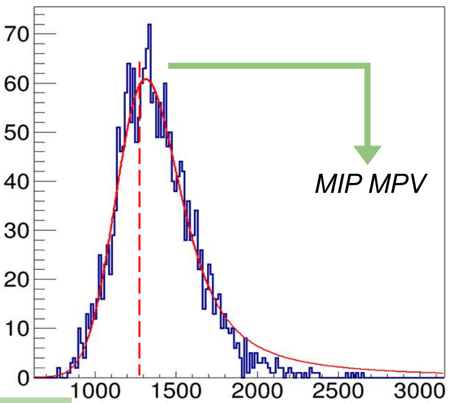
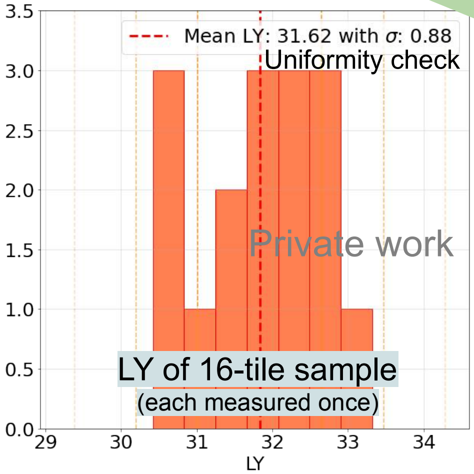
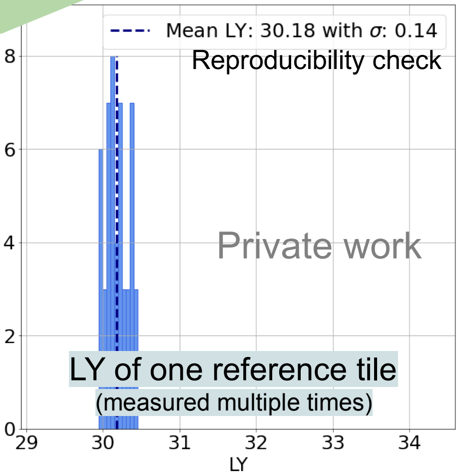


Illustration of SiPM's MIP spectrum



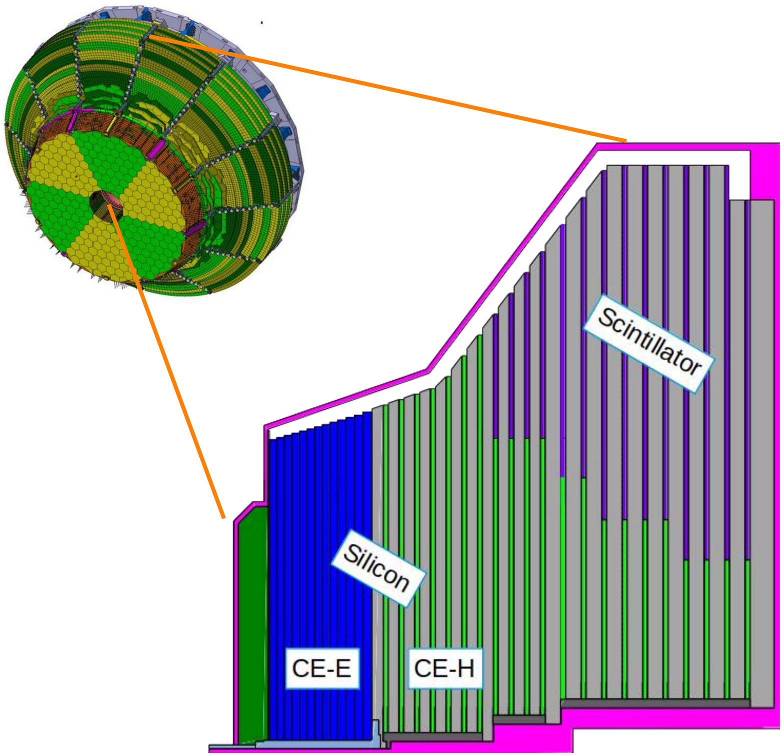
$$LY = \frac{MIP\ \ MPV - ped}{gain}$$

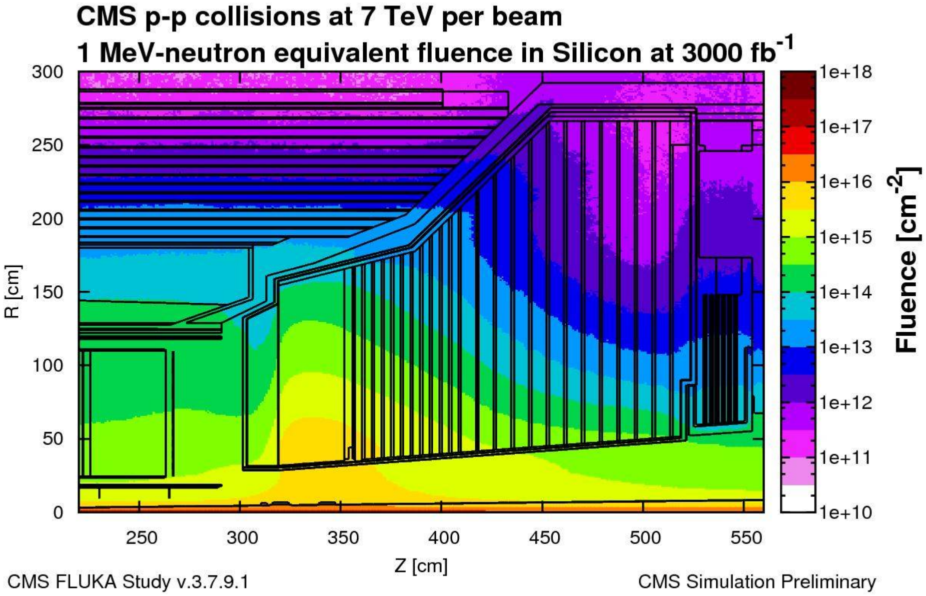




HGCAL

Hadronic section segmentation





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