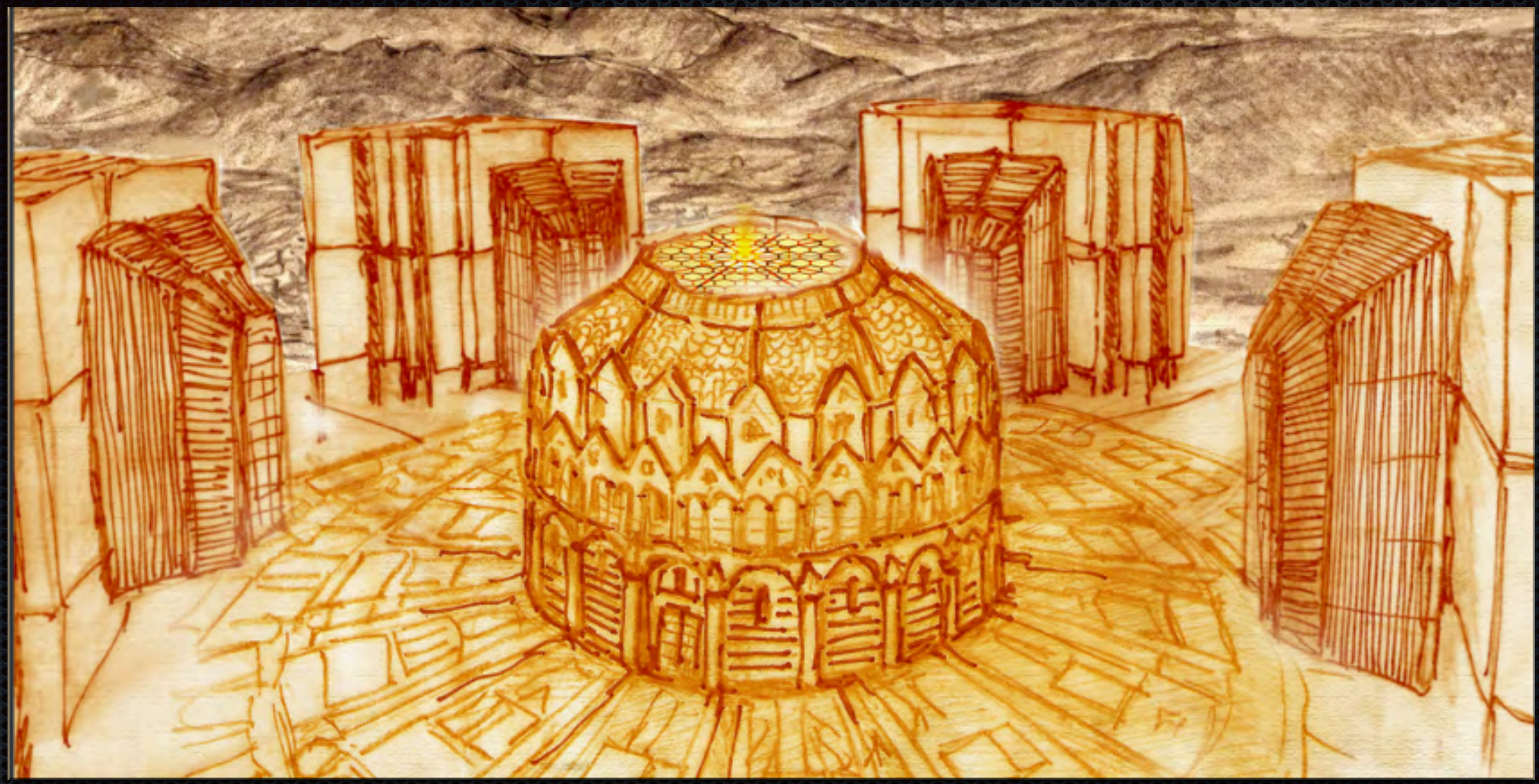


Beam Tests of HGCAL Prototypes at CERN

Matteo Bonanomi
CMS
CNRS, LLR-Ecole Polytechnique
@matteobonanomi
@mbonanom

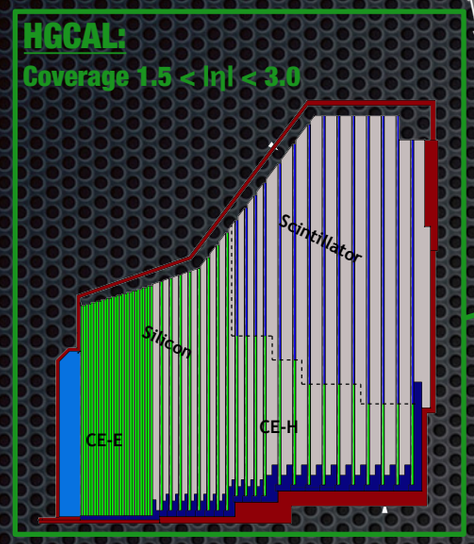
15th Topical Seminar on Innovative Particle and Radiation Detectors
Siena
17/10/2019

Who am I?

- Matteo Bonanomi, 24 yo;
- Second year PhD student at Laboratories Leprince-Ringuet (**LLR**) **(École Polytechnique)** with the **CMS** esperiment;
- Working on the CMS **High Granularity Calorimeter** (**HCGAL**) upgrade with beam tests group;

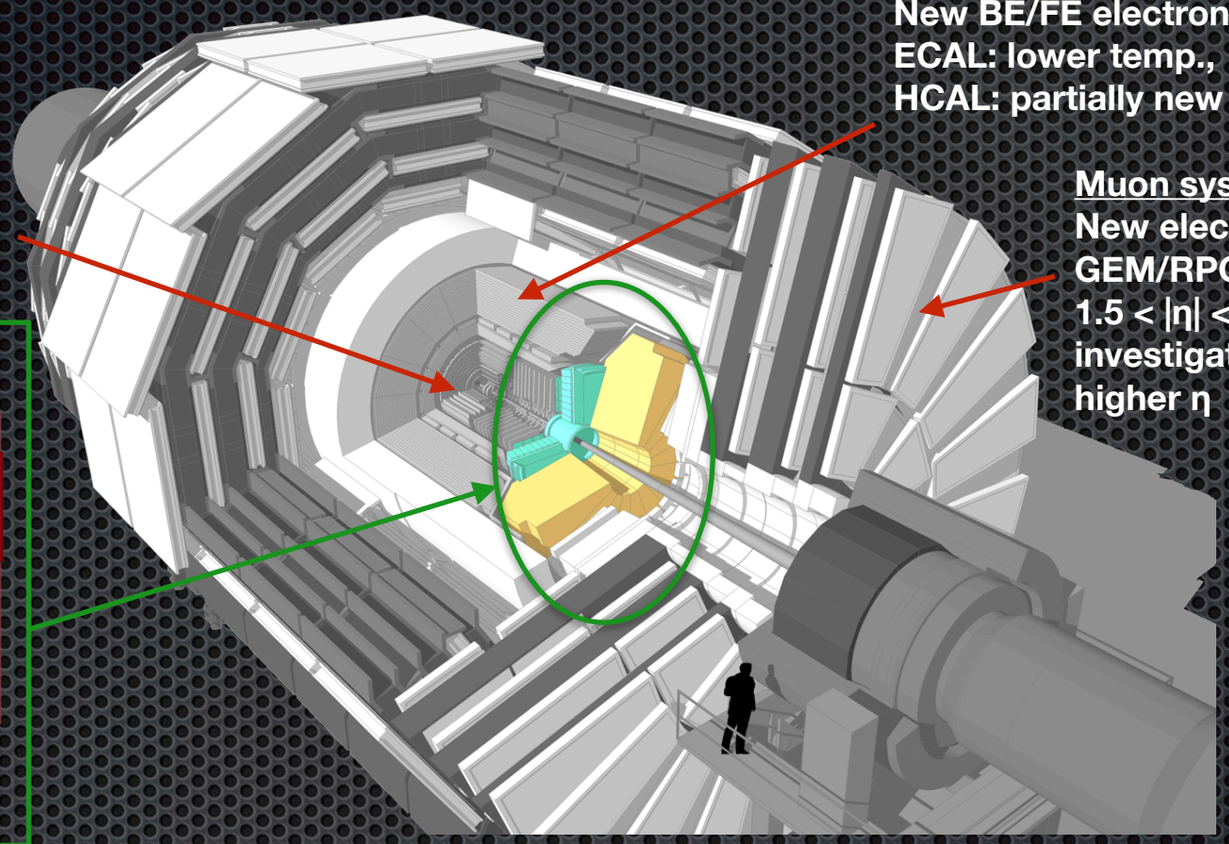
The CMS Upgrades for HL-LHC

Tracker:
Radiation tolerant,
high granularity,
less materials, tracks in
hardware trigger (L1),
coverage up to |η| = 3.8



Barrel Calorimeter:
New BE/FE electronics,
ECAL: lower temp.,
HCAL: partially new scintillator

Muon system:
New electronics
GEM/RPC coverage in
1.5 < |η| < 2.4,
investigate muon tagging at
higher η



High-Luminosity LHC (**HL-LHC**) will integrate 10 times the current LHC luminosity (~3000fb^{-1})

☢ **Large dose** (~2MGy) 🆙 **High pile-up rate** (O(140/200))

Major challenge: maintain physics performances!

The CMS Upgrades for HL-LHC

Tracker:
Radiation tolerant,
high granularity,
less materials, tracks in
hardware trigger (L1),
coverage up to |η| = 3.8

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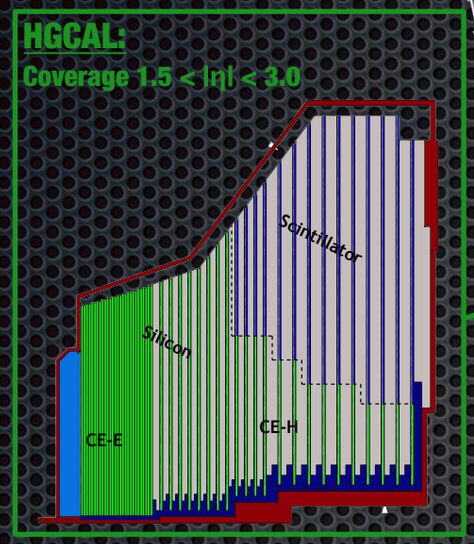
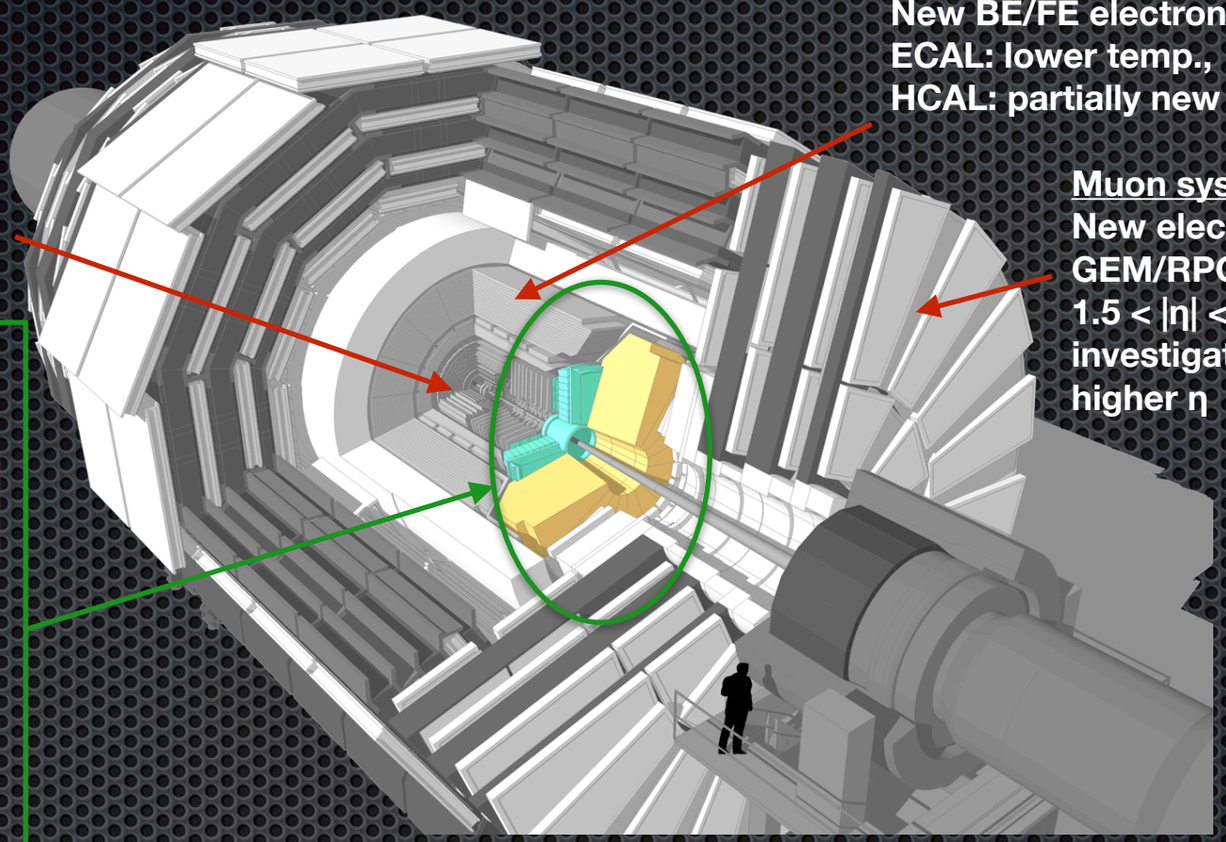




☢ **Large dose**

Radiation hard detectors

🆙 **High pile-up rate**

High granularity detector
Precise timing information

The CMS High Granularity Calorimeter

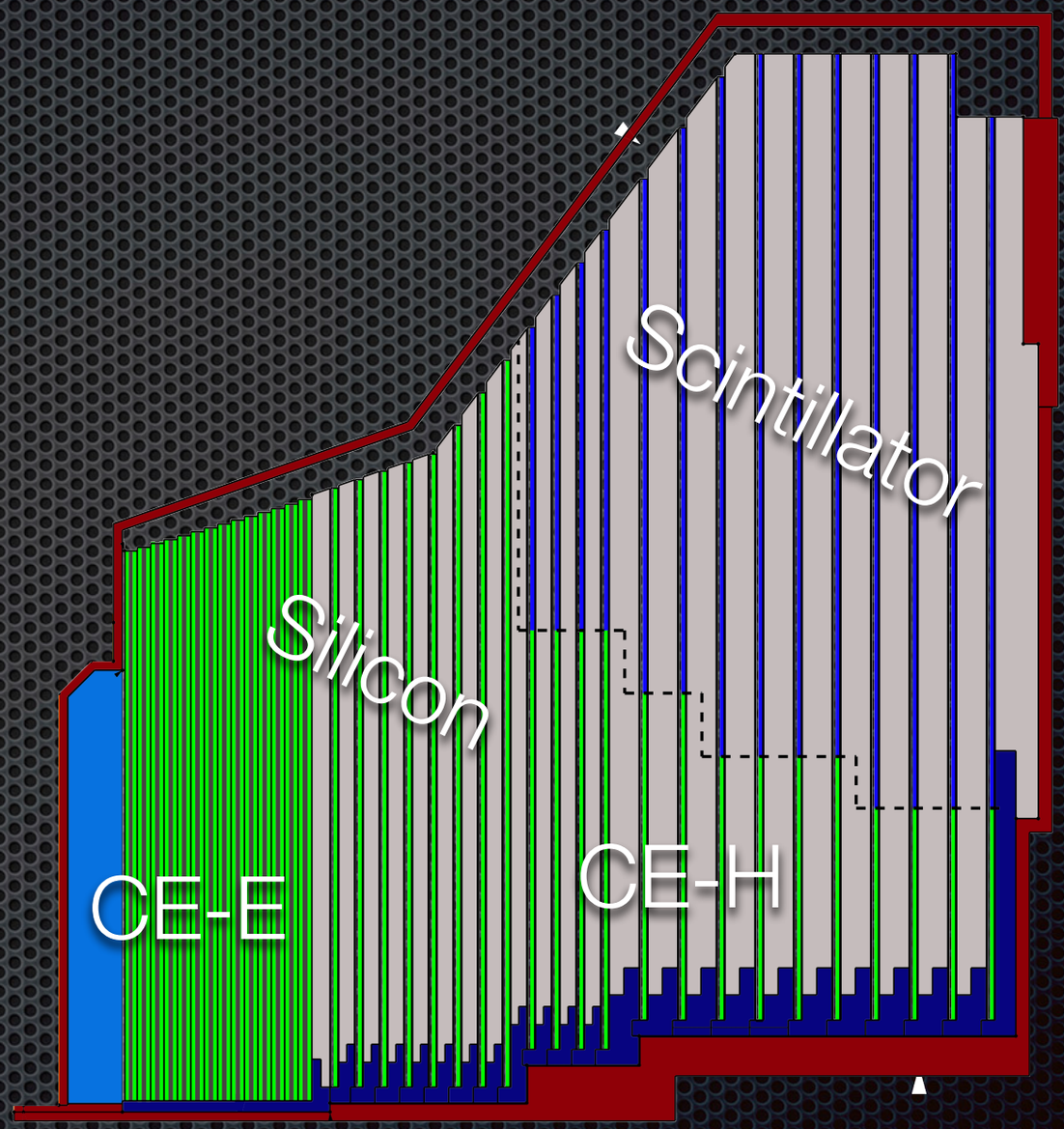
The High-Granularity Calorimeter (HGCAL)

Sampling calorimeter with:

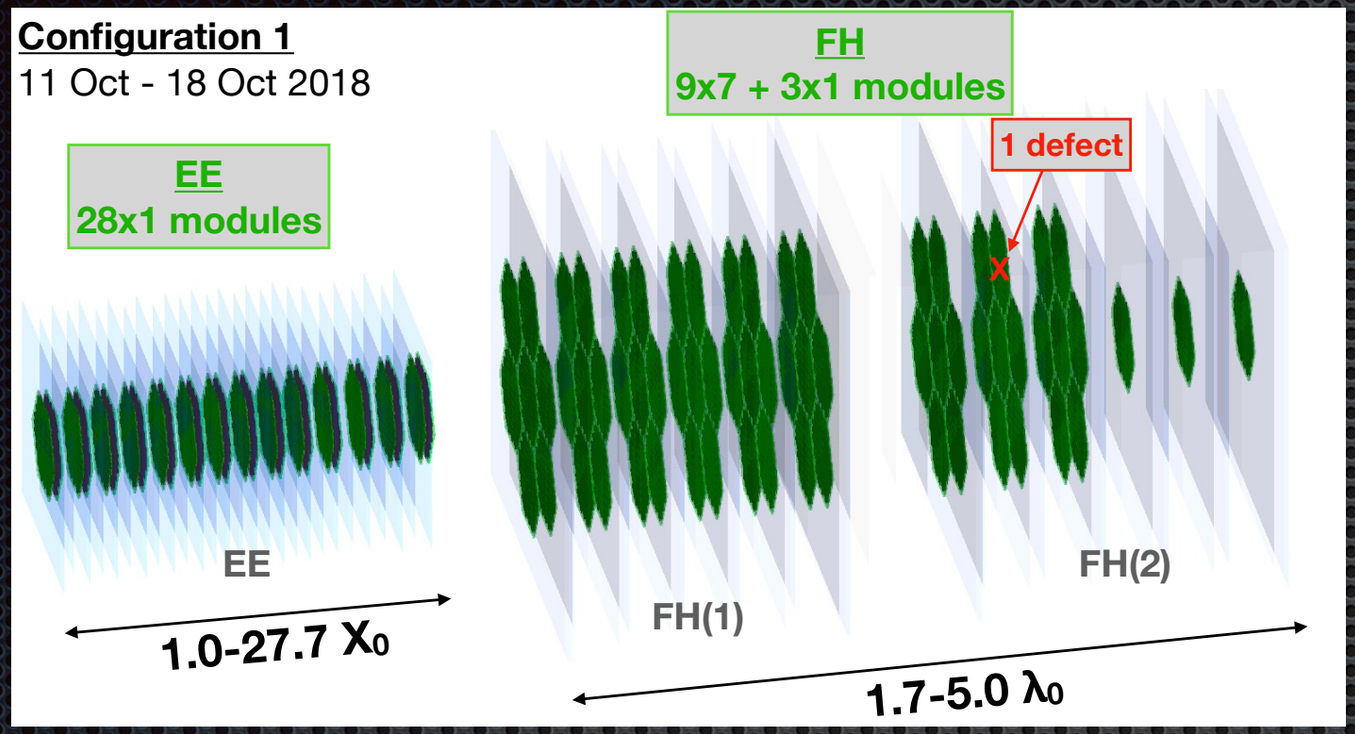
- Si-based EM compartment (25 X_0)
- Si-based + Scintillator tiles for hadronic compartment

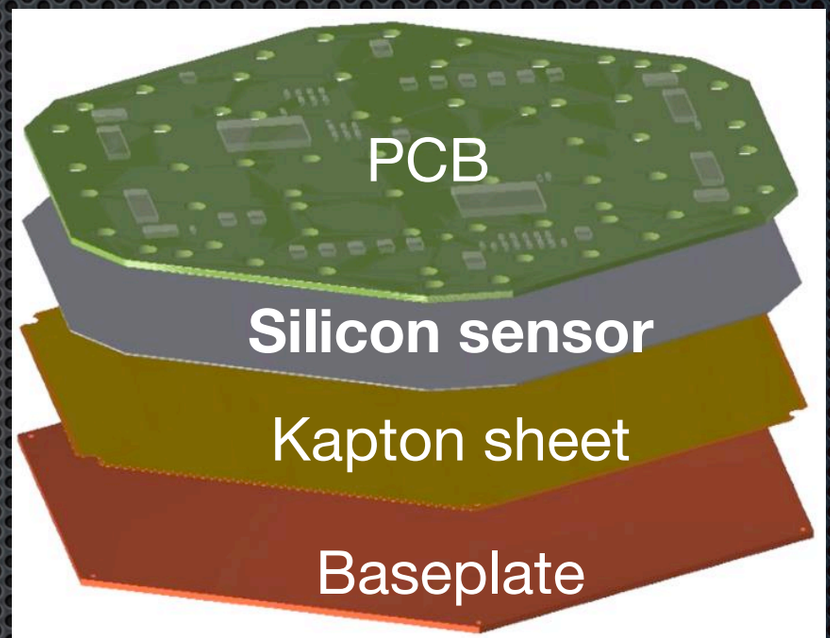
Total thickness ~**9.7λ**

High-Granularity: imaging/5D calorimeter, particle flow



HGCAL Beam Tests at CERN

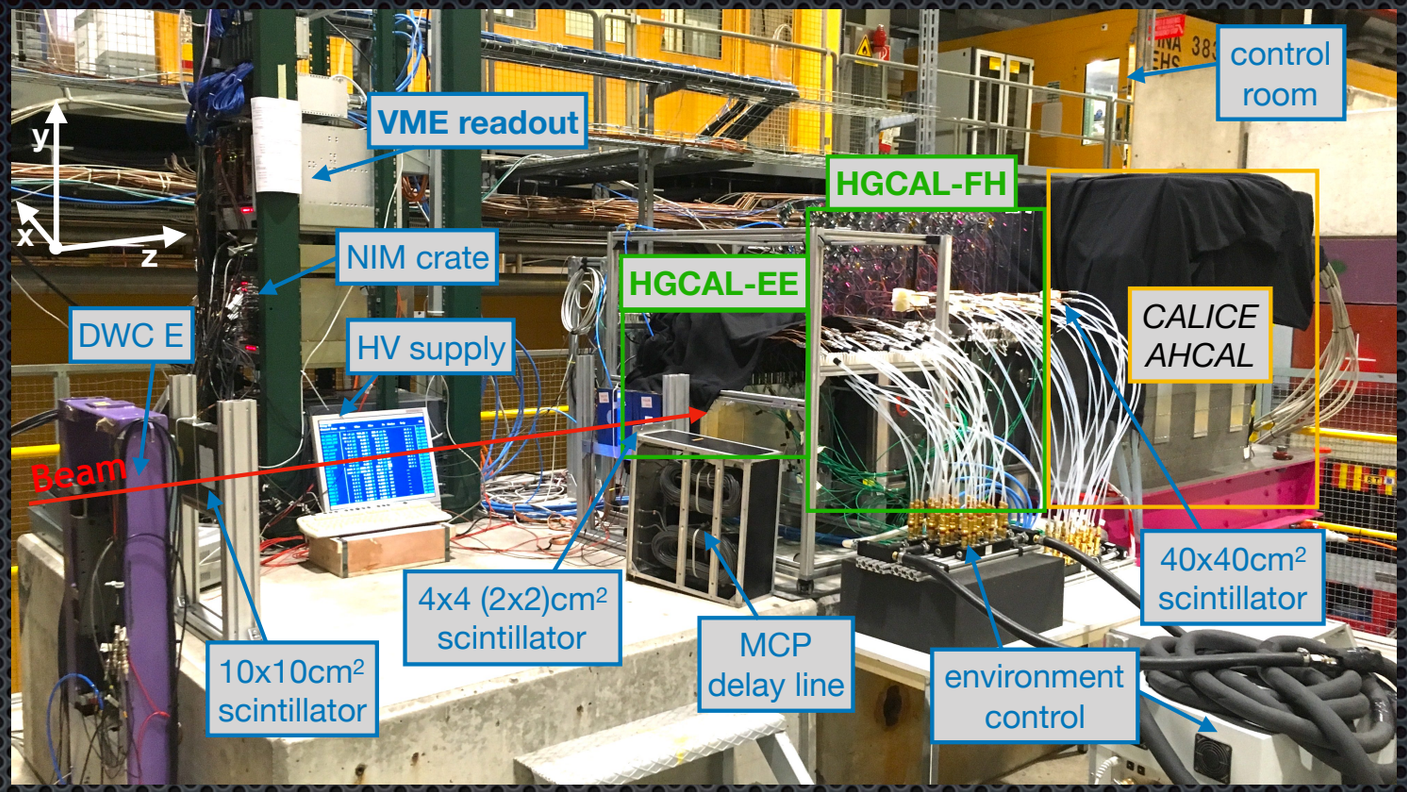




October 2018 first beam test of a **full HGCAL prototype** **@CERN-SPS** (H2 beamline)

- 94 hexagonal 6’ Si modules + 39 layer CALICE AHCAL SiPM-on-tile section;

HGCAL Beam Tests at CERN



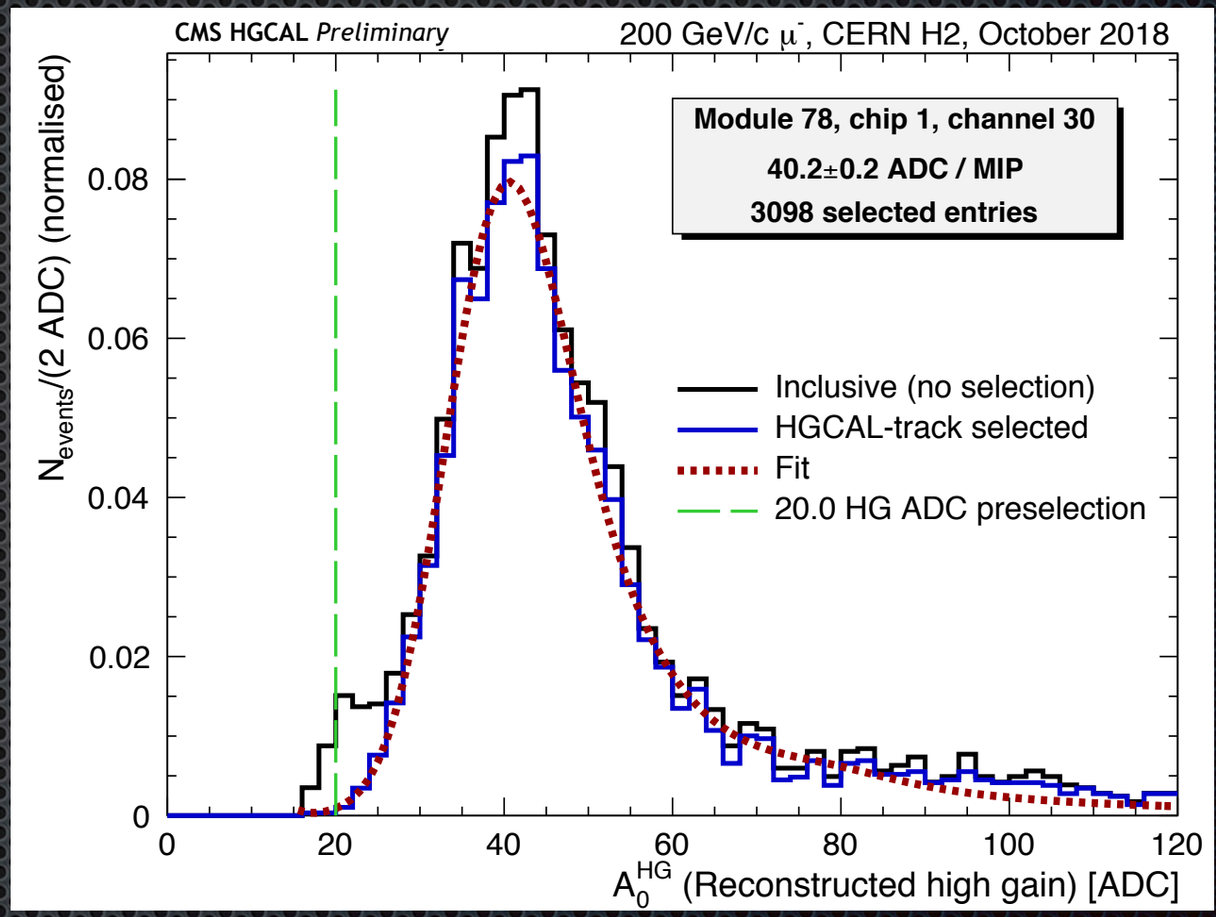
October 2018 first beam test of a **full HGCAL prototype @CERN-SPS** (H2 beamline)

- 94 hexagonal 6' Si modules + 39 layer CALICE AHCAL SiPM-on-tile section;
- e^+, π^- in energy range 20-300 GeV;
- 200 GeV μ (+parasitic beam time) for **MIPs calibration**;
- O(10^6) events collected to be analysed.

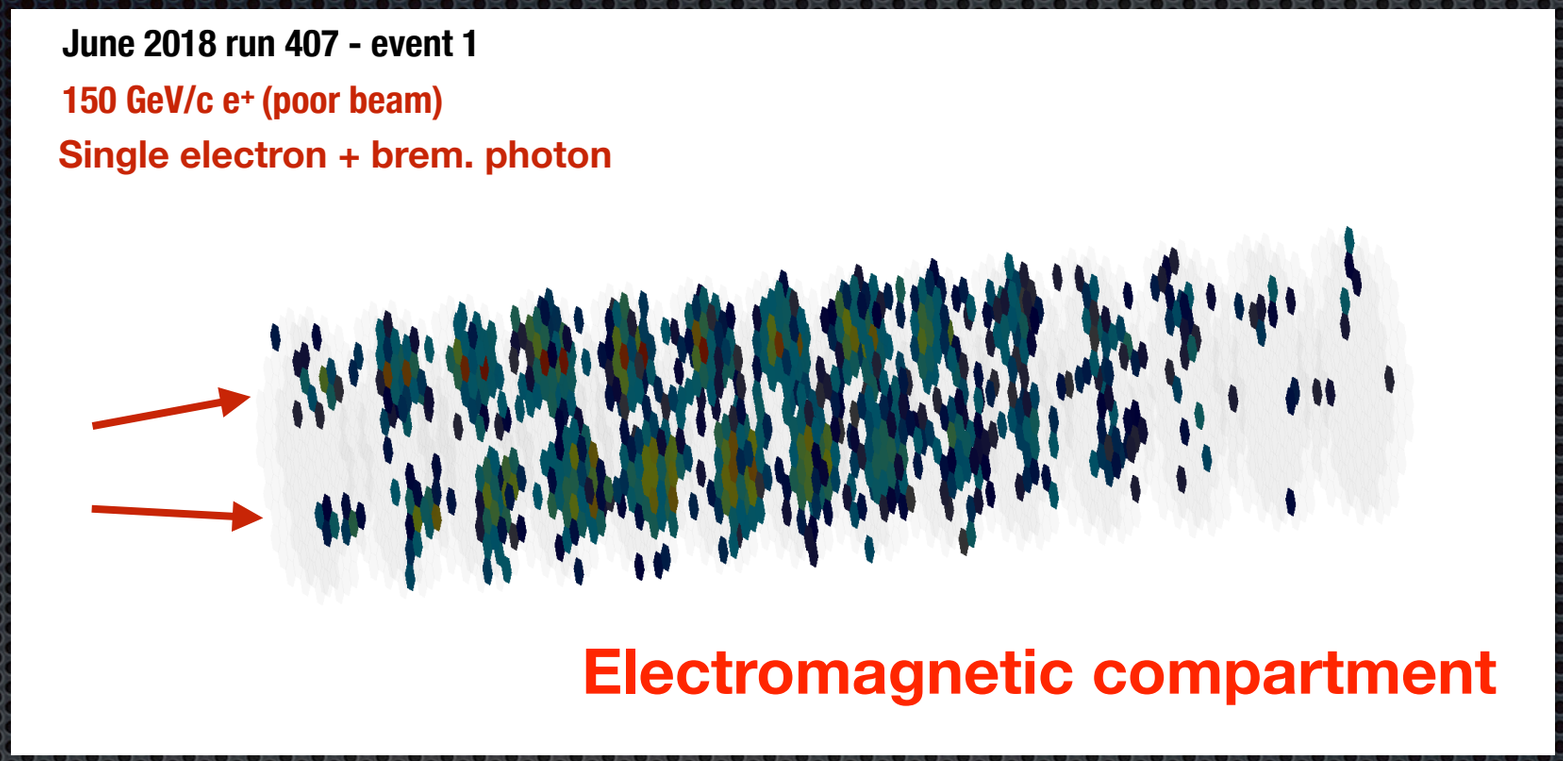
MIPs Calibration

MIPs calibration foreseen in the final HGCAL design:

- Conducted in all beam tests to gain experience with the methodology;
- MIPs used also for tracking/ alignment in HGCAL beam tests;
- **85% of the cells** have been **calibrated** during October beam test



Reconstruction Performance: Electrons

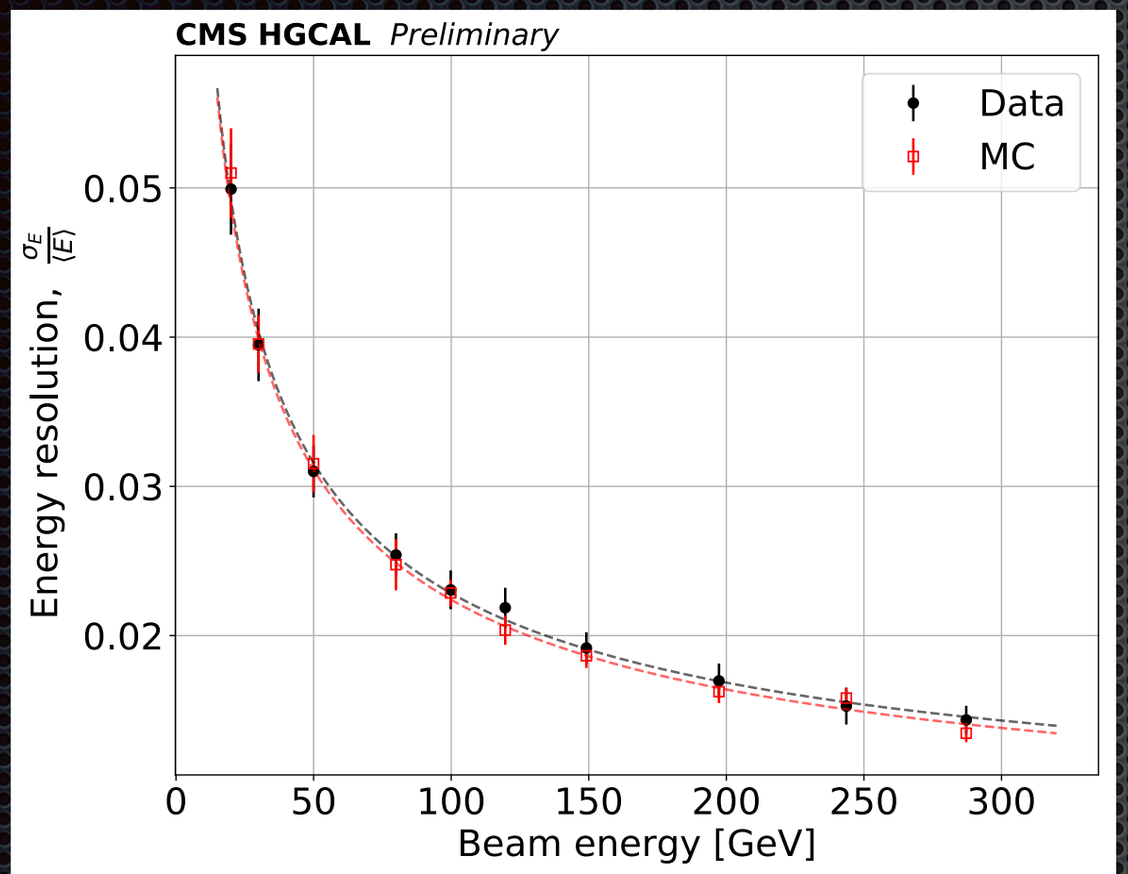


High granularity allows to have an **imaging calorimeter**

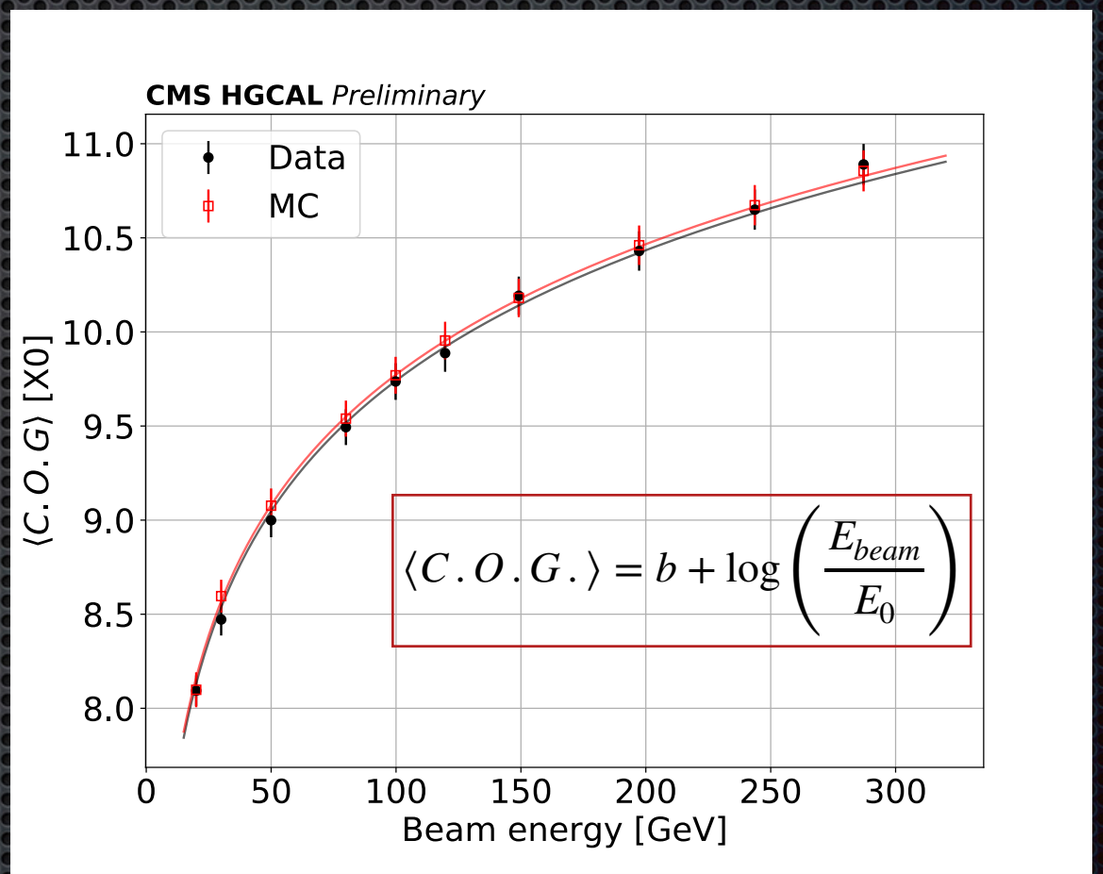
HGCAL has **great separation power**, e.g. in resolving multiple tracks such es showering electron(s) accompanied by a hard bremsstrahlung photon.

Reconstruction Performance: Electrons

Energy resolution



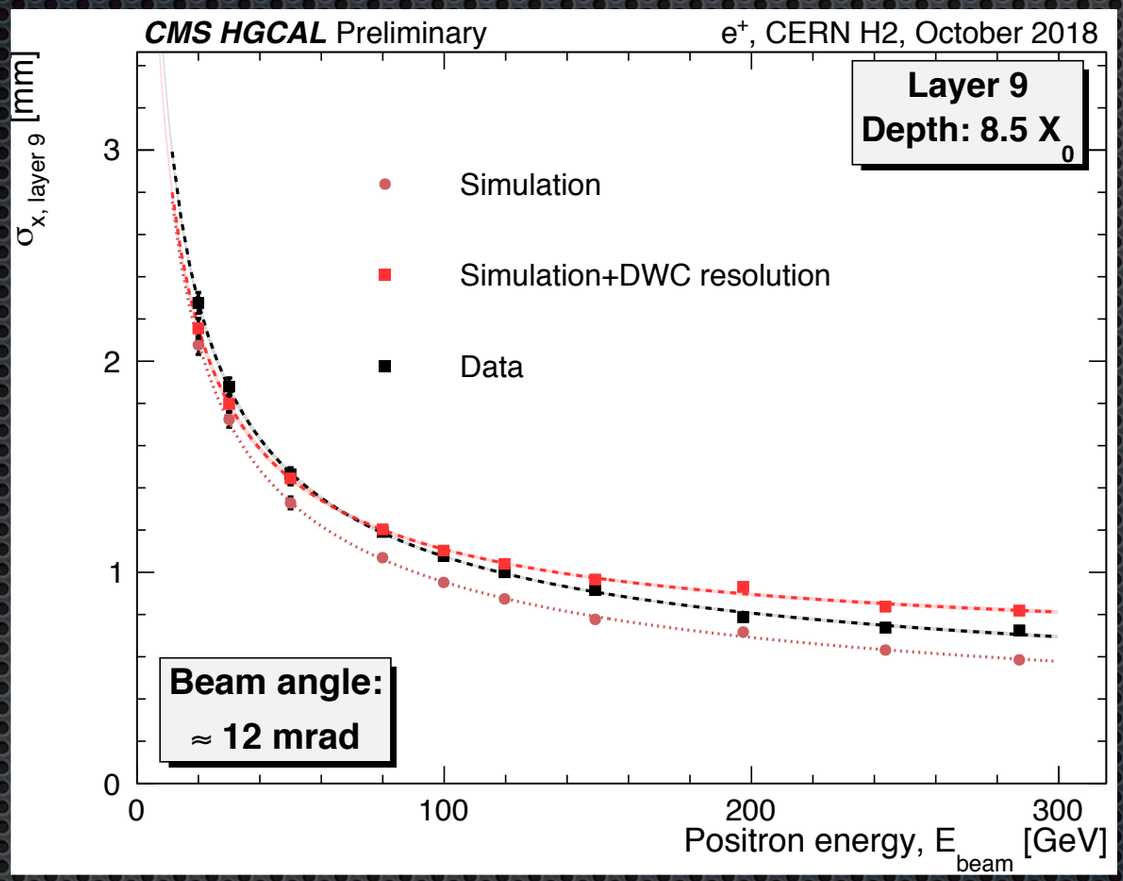
Shower depth



Good agreement between the dedicated GEANT4 simulation and the beam test analysis results, for all the observables describing electromagnetic showers.

Reconstruction Performance: Electrons

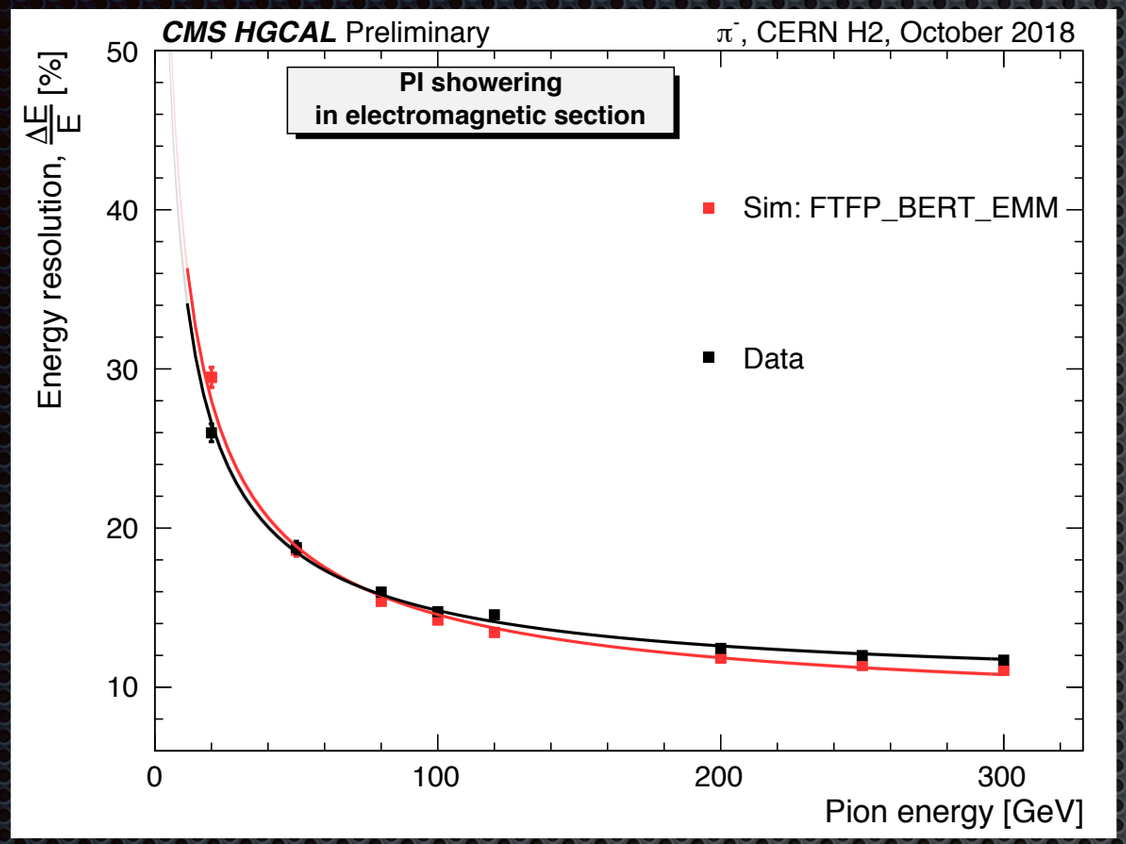
Position resolution



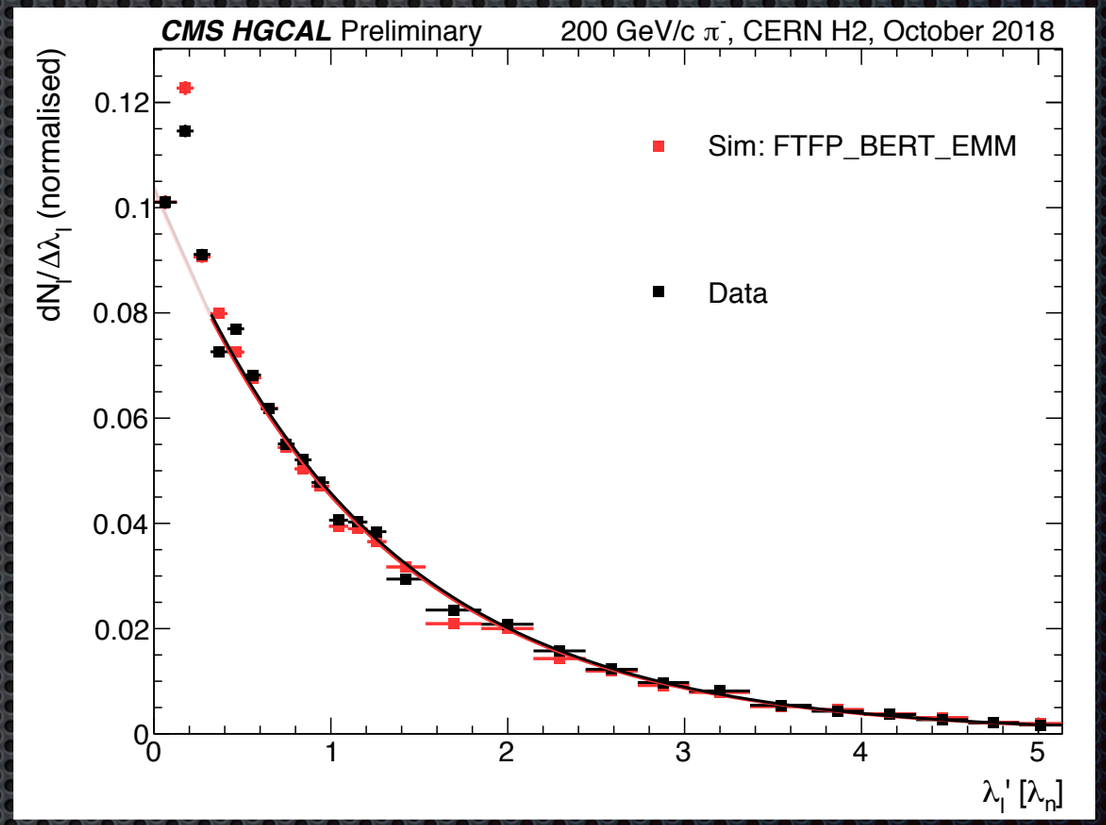
Good agreement between the dedicated GEANT4 simulation and the beam test analysis results, for all the observables describing electromagnetic showers.

Reconstruction Performance: Hadrons

Energy resolution

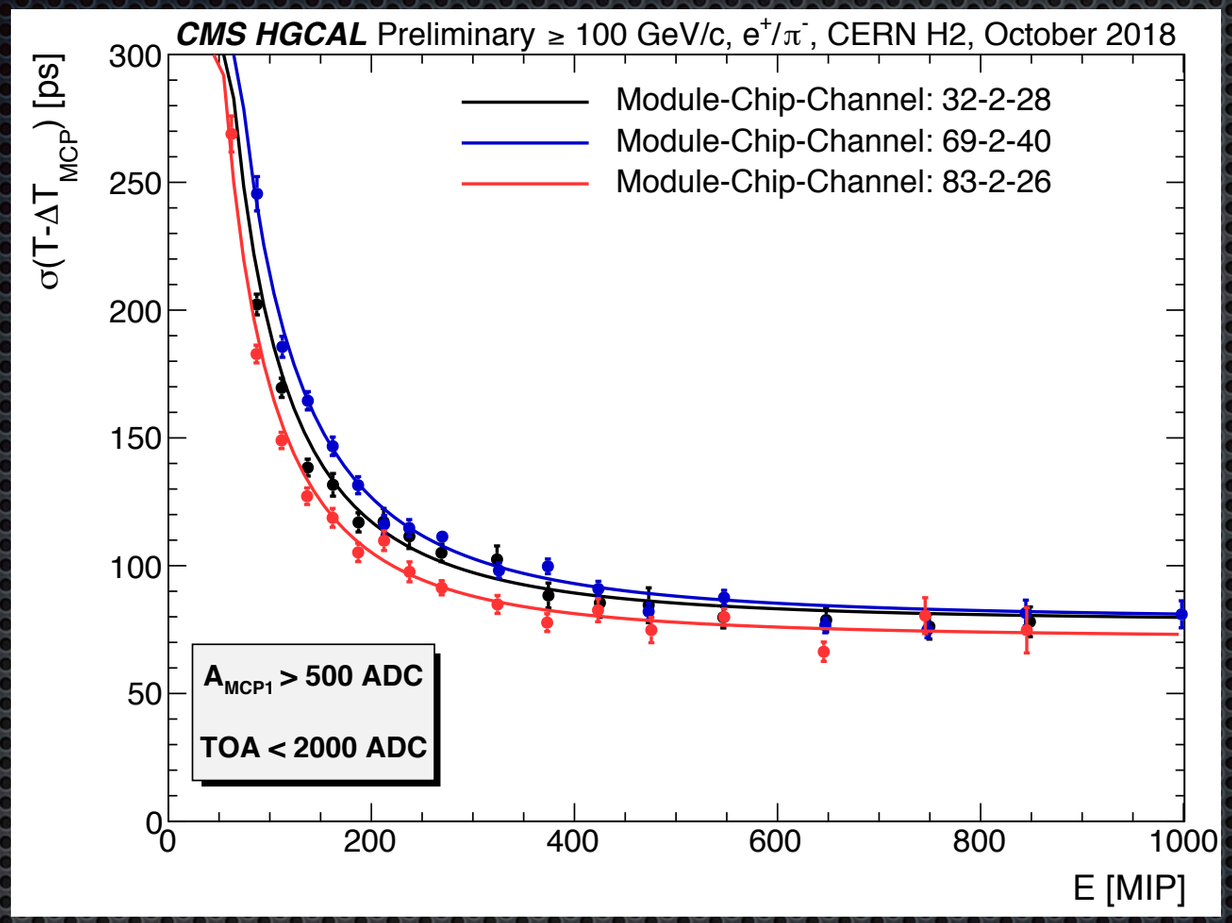


Identified primary interaction depth



Assess electromagnetic compartment performance for hadrons;
Identification of the starting position of hadrons' showers;
Comparison with GEANT4 simulation show good agreement.

Reconstruction Performance: Timing



HGCAL also provides precise **timing measurement**: tens of ps!

Fundamental handle for **pile-up mitigation**;
In October beam test timing performance was studied for the very first time;
MCP-TMP as timing reference + Skiroc2-CMS **TOA** to measure time resolution for channels close to the shower maximum, achieving **~50/70ps !**

Conclusions

HGCAL is an **imaging** and **5D** calorimeter designed for particle flow;

Several beam tests campaigns as proof of concept of its design;

In October 2018 **first** beam test of **large scale HGCAL prototype:**

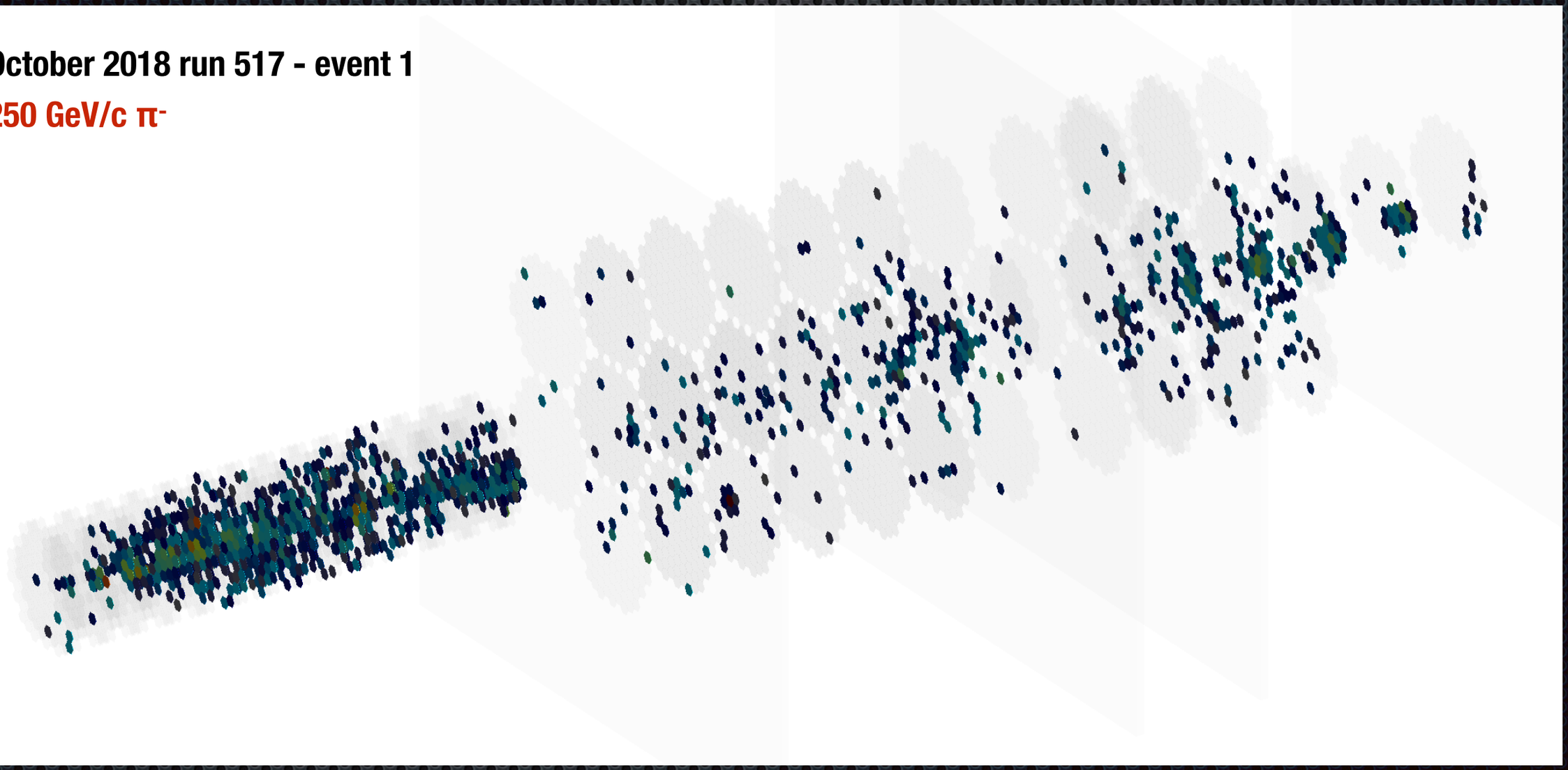
- Analysis results show **good agreement** with the dedicated GEANT4 **simulation** developed;
- Allowed good understanding of **longitudinal granularity** performance;
- For the first time the **timing performance** was studied, showing a precision close to the design value of the Skiroc2-CMS chip used;
- Position, energy and time (**5D calo.**) were assessed, showing very promising results already close to the HGCAL design performance!

There is no such thing as a "typical hadronic shower profile"

- R. Wingmans

October 2018 run 517 - event 1

250 GeV/c π^-

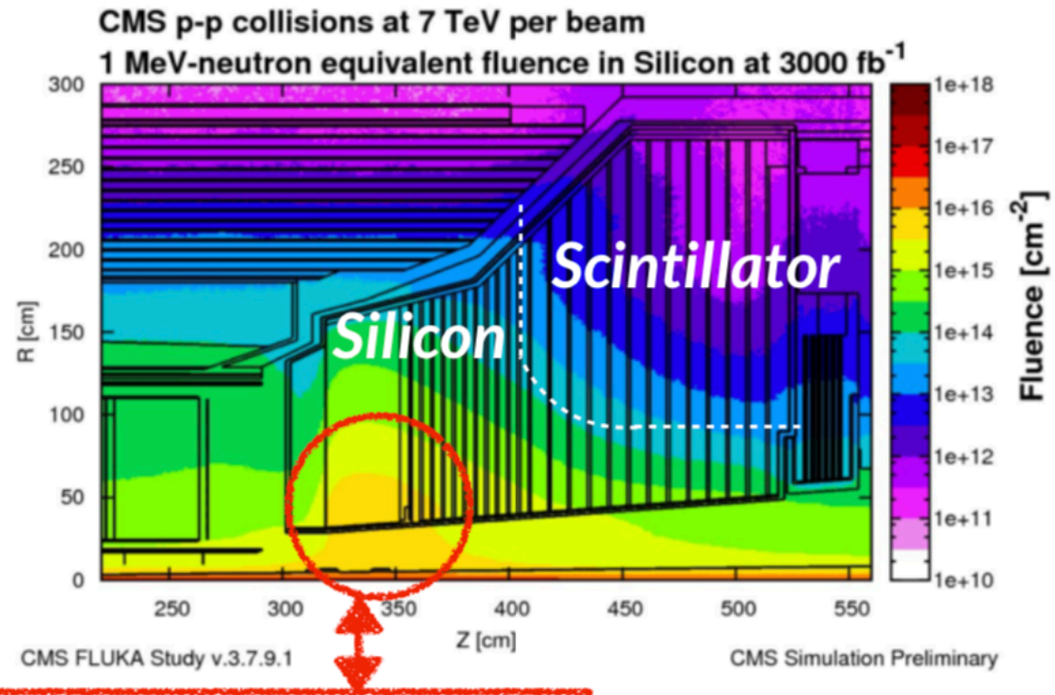


BACKUP SLIDES

Silicon and radiation hardness

High Granularity Calorimeter Active Elements

- ***Silicon*** detectors are
  - **Radiation tolerant** enough
  - **Fast** enough to mitigate pile-ups
  - Can be **finely segmented** to allow high granularity



Fluences of up to 10^{16} n_{eq}/cm^2
Doses of up to 2 MGy

Strong dependence on |η| and |z|

- ***Active elements of High Granularity Calorimeter:***
  - Silicon in high radiation area (600 m^2)
  - Scintillator in lower radiation area (400 m^2) ***(To reduce cost)***

Maral Alyari 6

See Maral Alyari's talk for details on HGCAL!

Experimental area

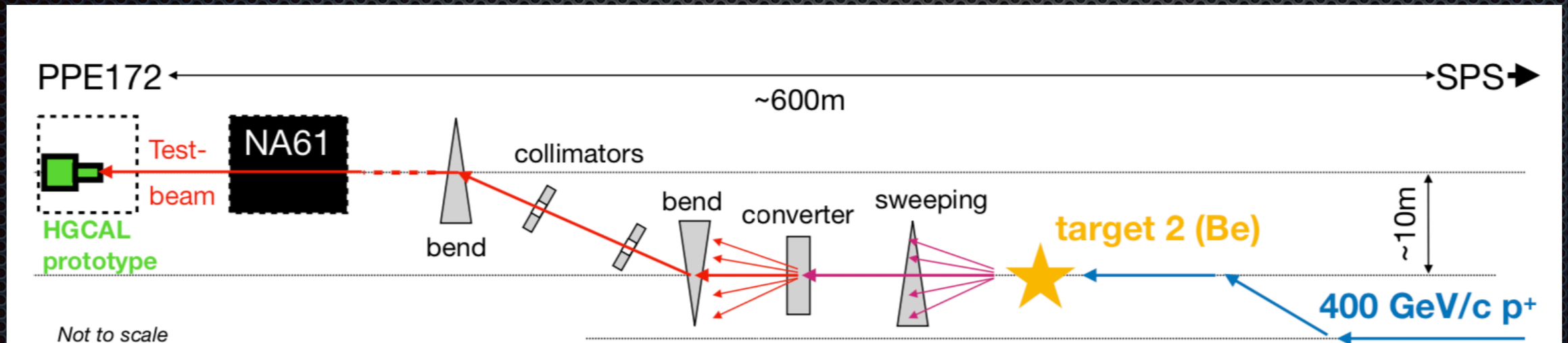
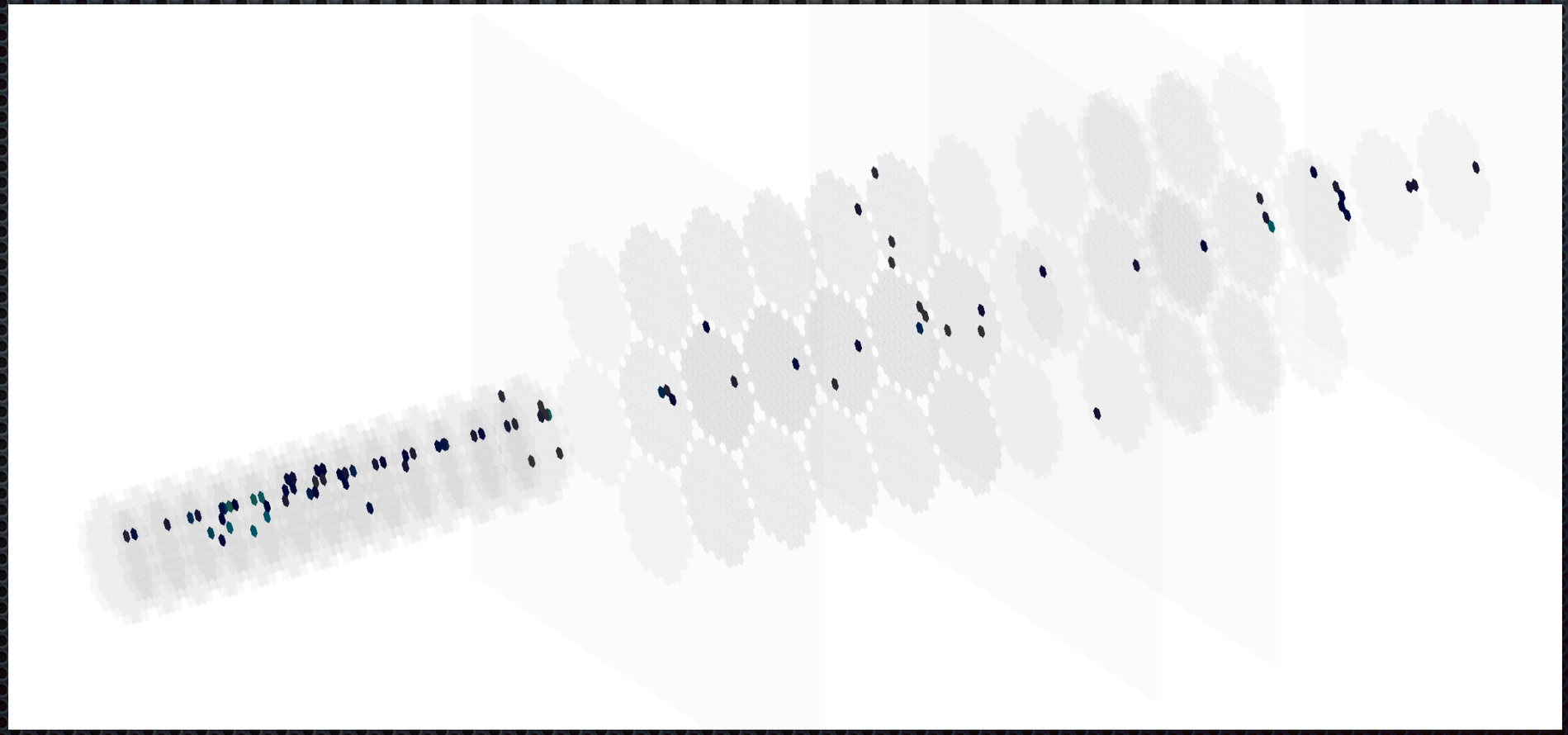


Figure 6.10: Sketch of the H2 beam line operated with electron beam. The entire beam line from

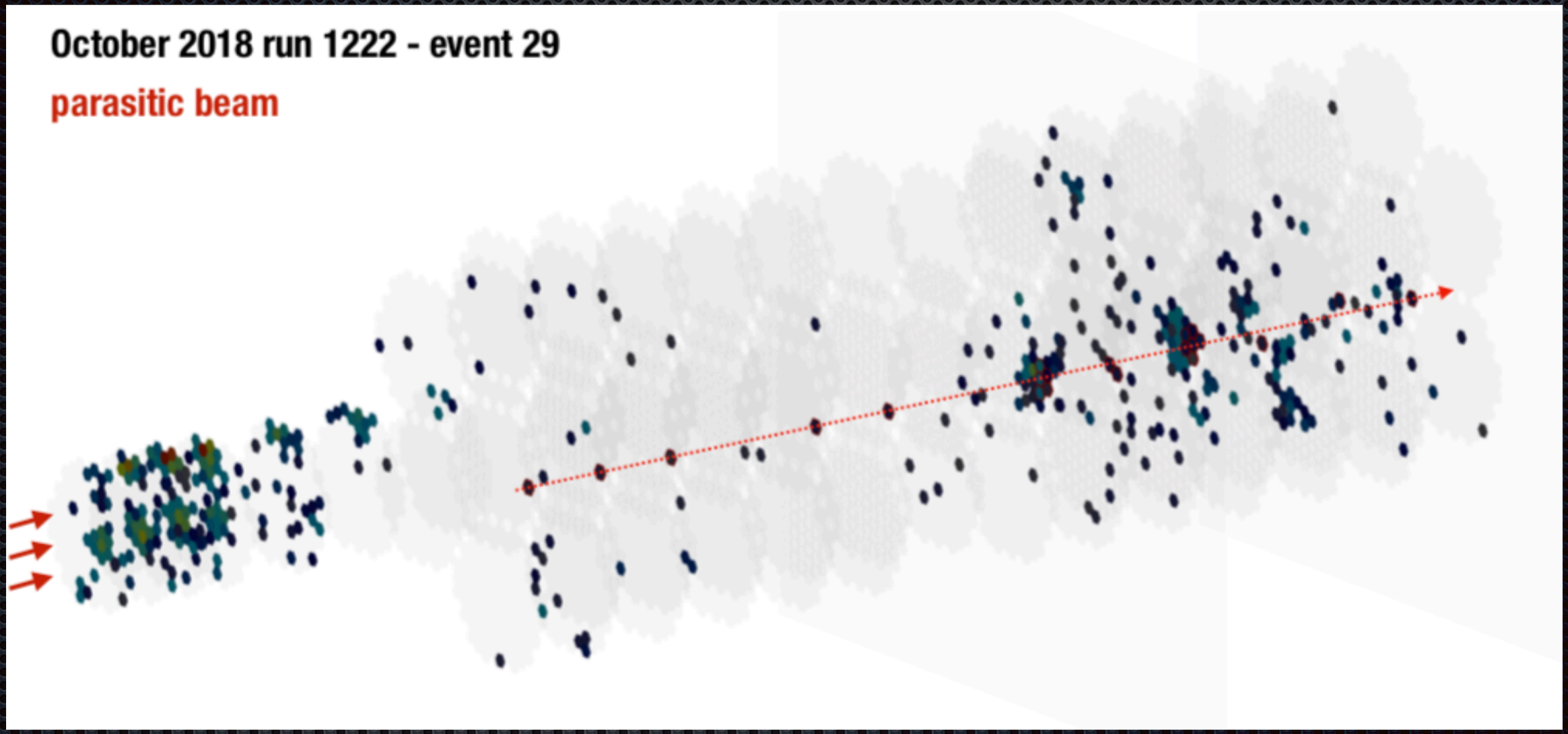
MIPs Calibration

Due to their overall negligible energy loss compared to the initial momentum of multiple GeV/c, the amount of deposited energy per distance can be regarded independent of the calorimeter depth. In consequence, ***MIPs are suitable for the equalisation through calibration of the electric response throughout the detector.***

CMS Collaboration, "Construction and Commissioning of CMS HGC prototype silicon modules." In preparation for submission to JINST, Draft: 24 August 2019.



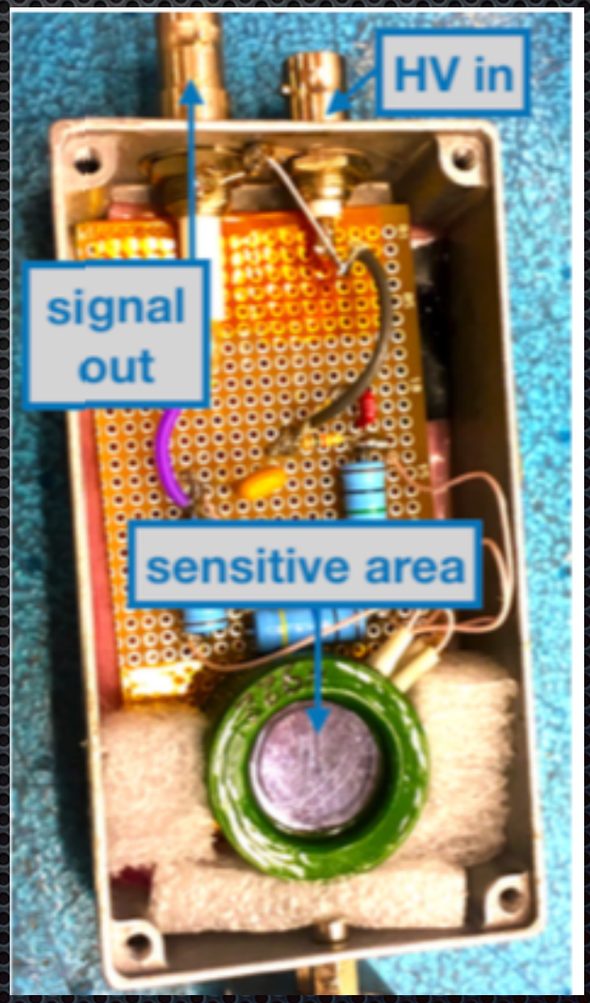
HGCAL Separation Power



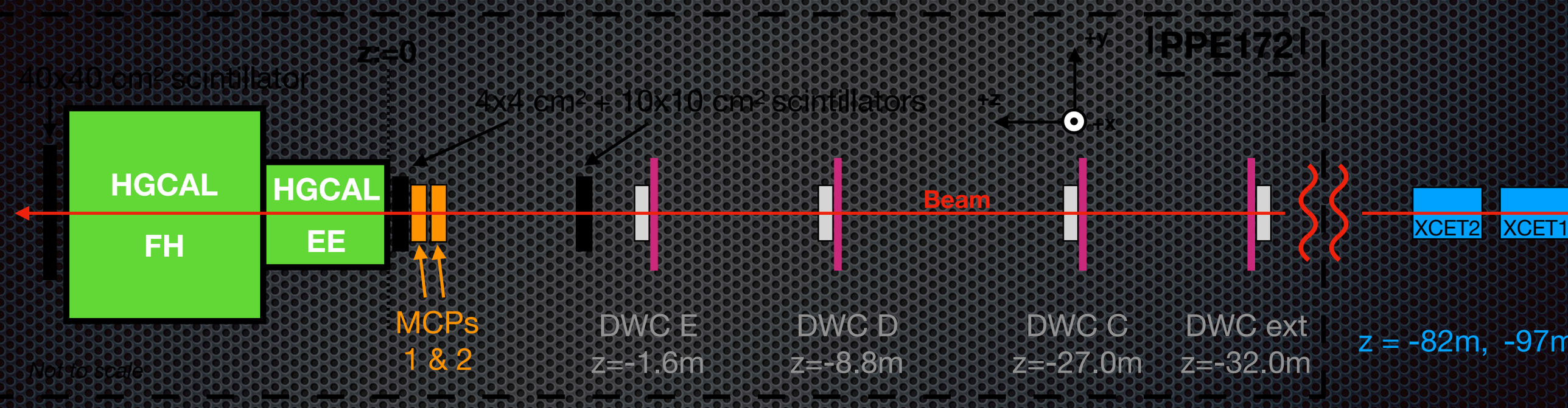
MCPs

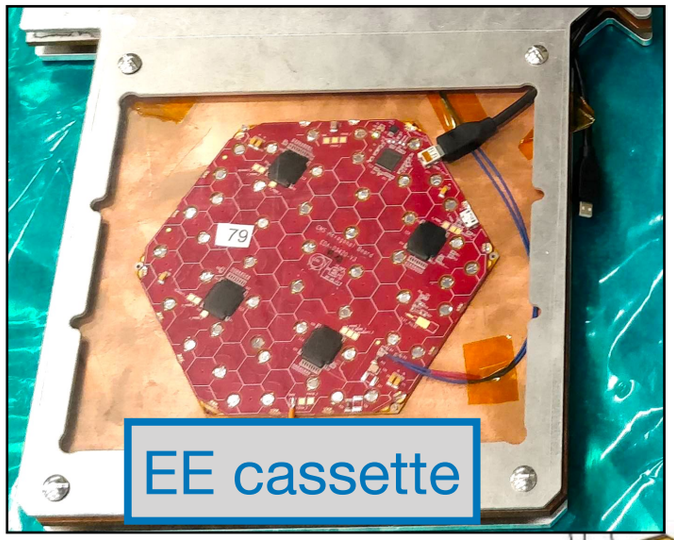
Microchannle Plate Timing Detector

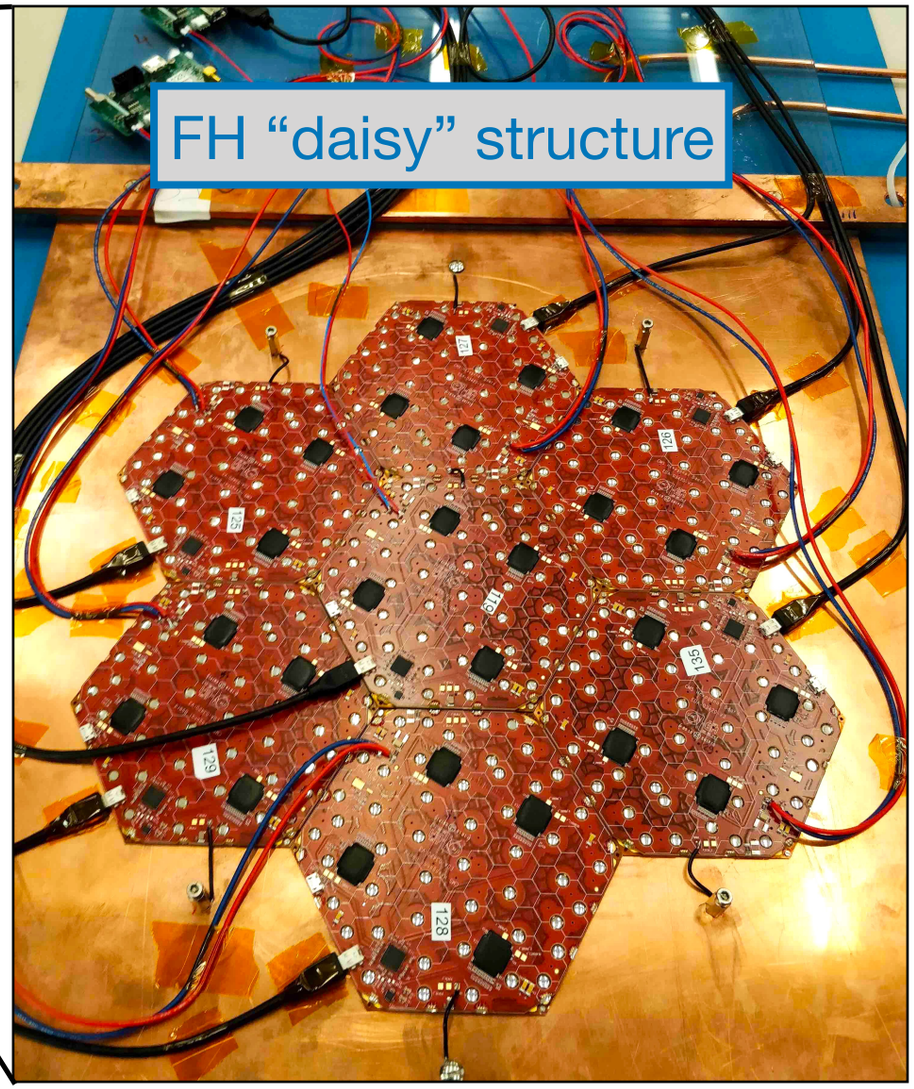
Devices used for detection of single particles via electron multiplication in secondary emission.



Experimental setup







passive material