The SiPM-on-Tile Section of the CMS High Granularity Calorimeter

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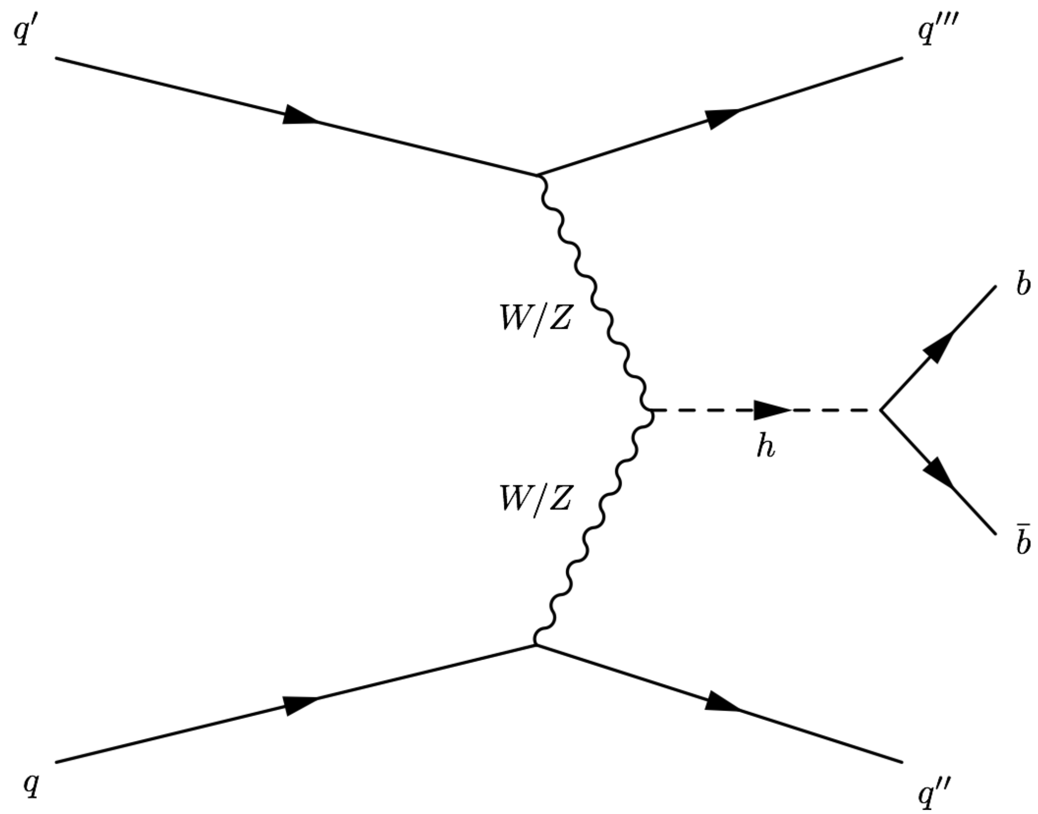
CMS

Overview

- Opportunities and challenges for **hadronic calorimetry at HL-LHC**.
- Key technology: **SiPM-on-tile**, and its application in the CMS endcap upgrade.
- Have to build the final detector soon → **pre-series in 2022**.

Role of hadronic calorimetry at HL-LHC

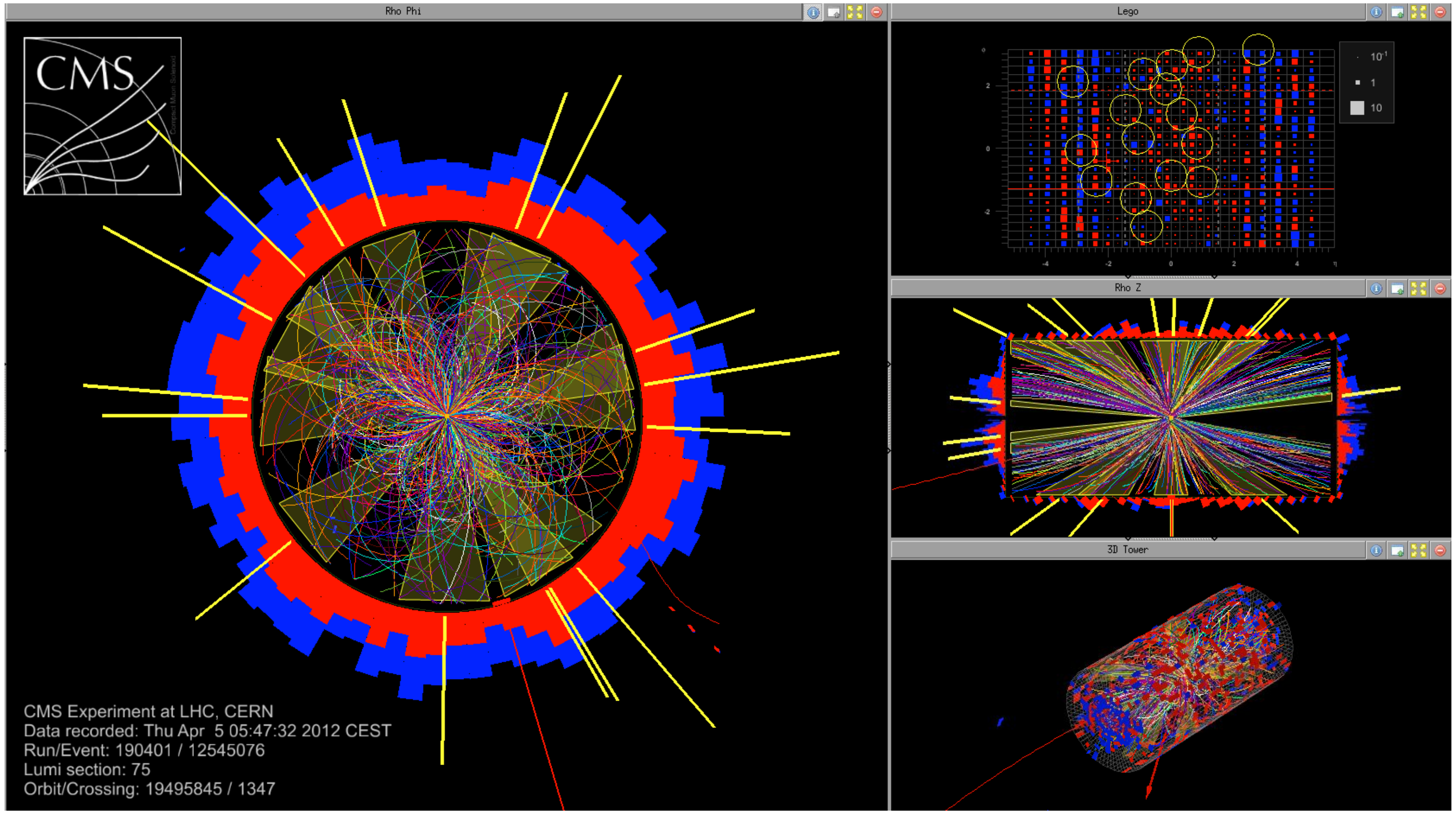


Complete exploration of Higgs sector requires high quality **jets and MET**, as well as efficient **isolation of leptons and photons,** over the full detector acceptance.

In particular, **VBF Higgs production** mechanism produces forward jets.

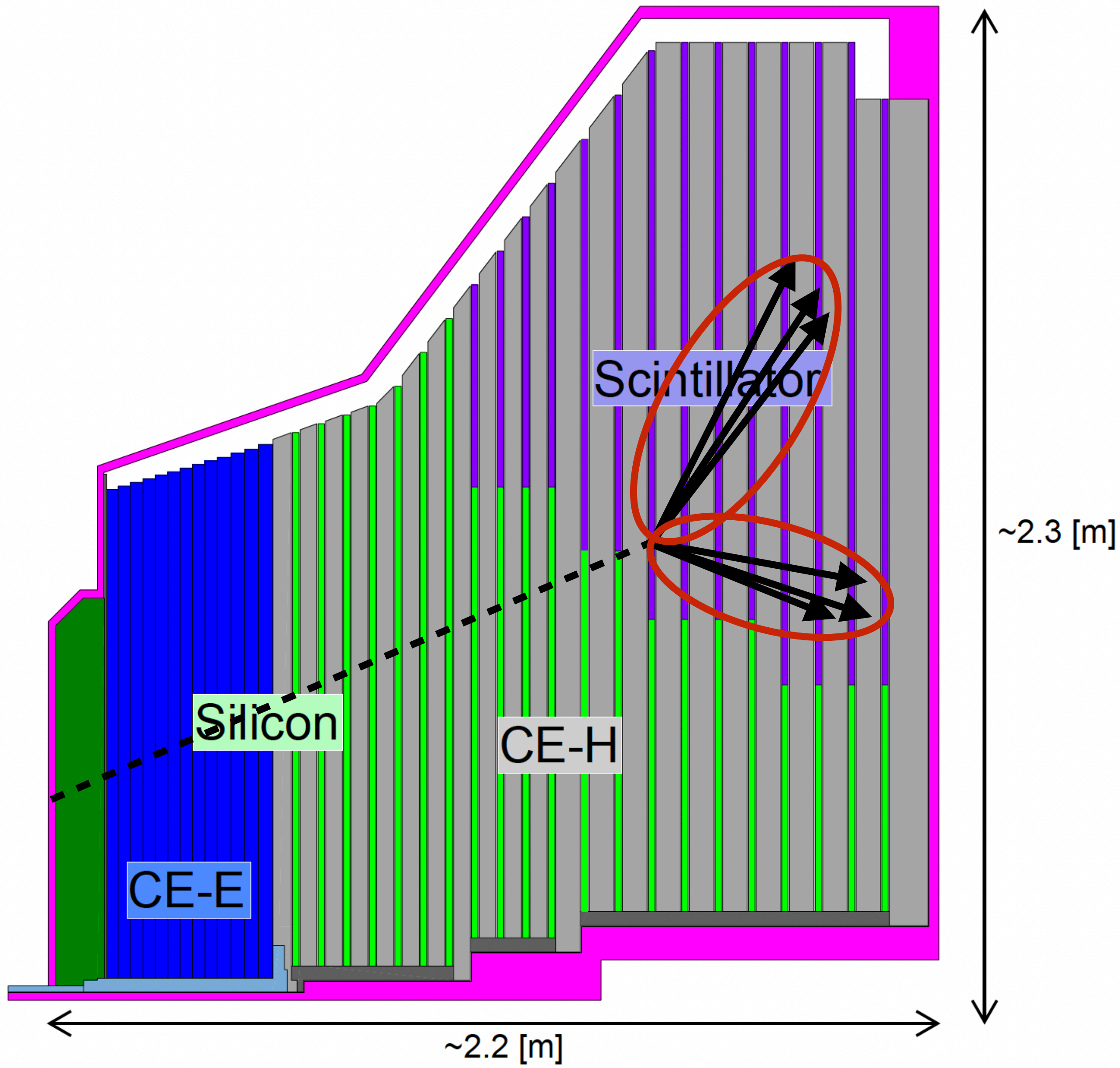
Also **jet substructure** over a wider η range.

Role of hadronic calorimetry at HL-LHC



Good **MET resolution at high pileup** is the critical ingredient in dark matter searches (or studies!)

Role of hadronic calorimetry at HL-LHC

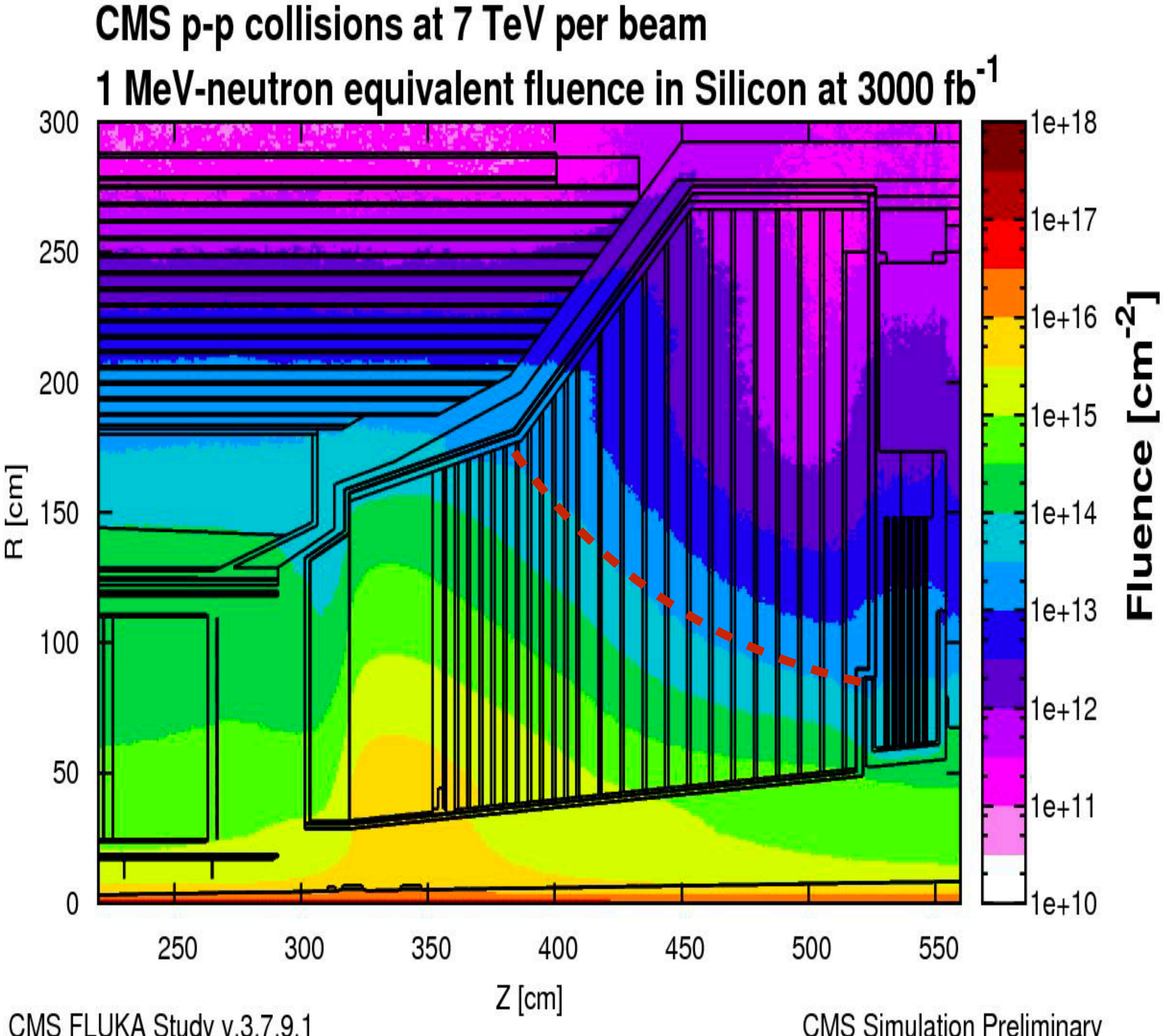


Long-lived particle searches: many models on the market predict LLP decays **deep inside the calorimeter**, enabling novel trigger and reconstruction strategies.

Design considerations

Requirements of the physics program lead us to the choice of **SiPM-on-tile technology** for hadronic calorimeter (CE-H) in the lower radiation regions:

- **SiPM-on-tile technology** allows us to instrument full (~10 λ) depth of detector in a **cost effective** way.
- HL-LHC radiation dose (target up to ~10^{13} neq/cm^2) favors small tiles, and this in turn results in a **high granularity detector** with applications for **particle flow**.
- **High granularity** provides the ability to match individual showers with tracker and timing measurements, thus **reducing the negative effects of high pileup**.
- **Low-noise** photodetectors enable a **calibration strategy based on MIP** reconstruction.



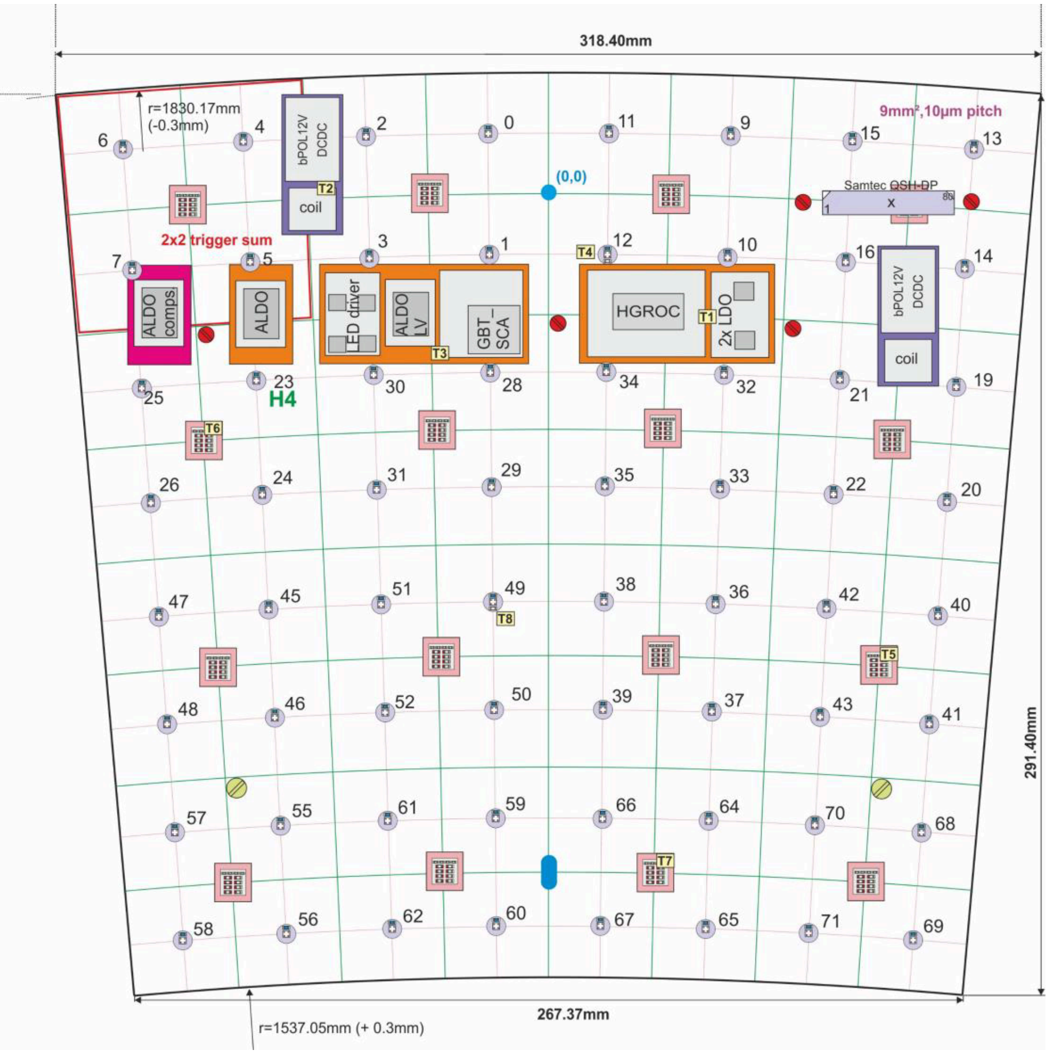
CMS p-p collisions at 7 TeV per beam
1 MeV-neutron equivalent fluence in Silicon at 3000 fb^{-1}
R [cm]
Z [cm]
Fluence [cm^{-2}]
1e+18
1e+17
1e+16
1e+15
1e+14
1e+13
1e+12
1e+11
1e+10
300
250
200
150
100
50
0
250
300
350
400
450
500
550
CMS FLUKA Study v.3.7.9.1
CMS Simulation Preliminary

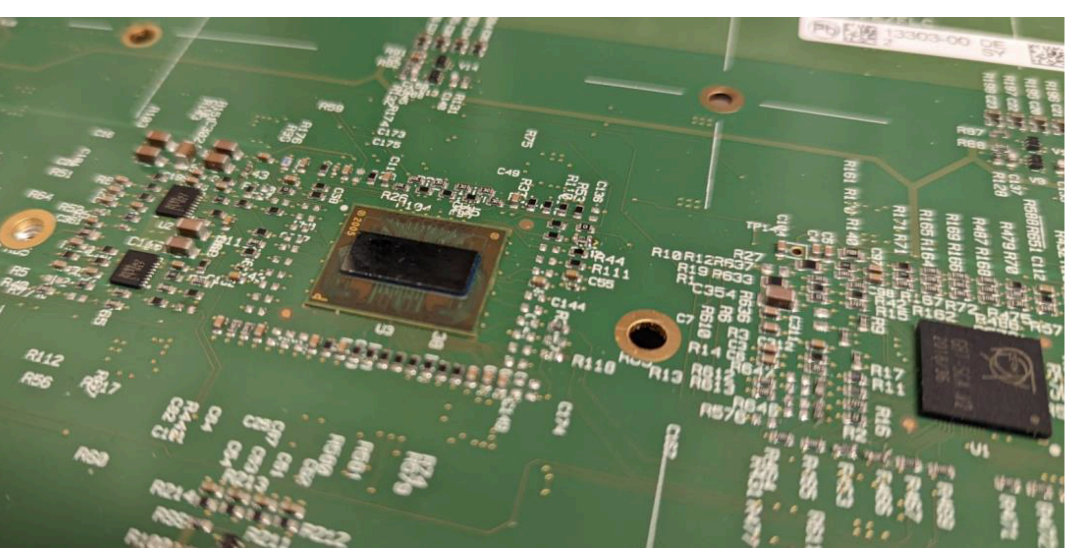
Conceptual design: SiPM-on-tile

Main inspiration from CALICE AHCAL SiPM-on-tile calorimeter:

- Scintillation light from tiles **directly illuminates the SiPM** photodetector underneath. Dimple in tile equalizes response across tile.
- **Reflective wrapping (ESR)** maximizes light reaching the SiPM.
- Detector **inside cold volume** to limit SiPM noise after irradiation.
- Smaller tiles result in more light reaching the SiPM. Tile sizes chosen in order to maintain a **good S/N for MIP calibration** until end of life. Smaller tiles and larger SiPMs used to maximize light collected in the most radiation-damaged areas.

Conceptual design: tile module





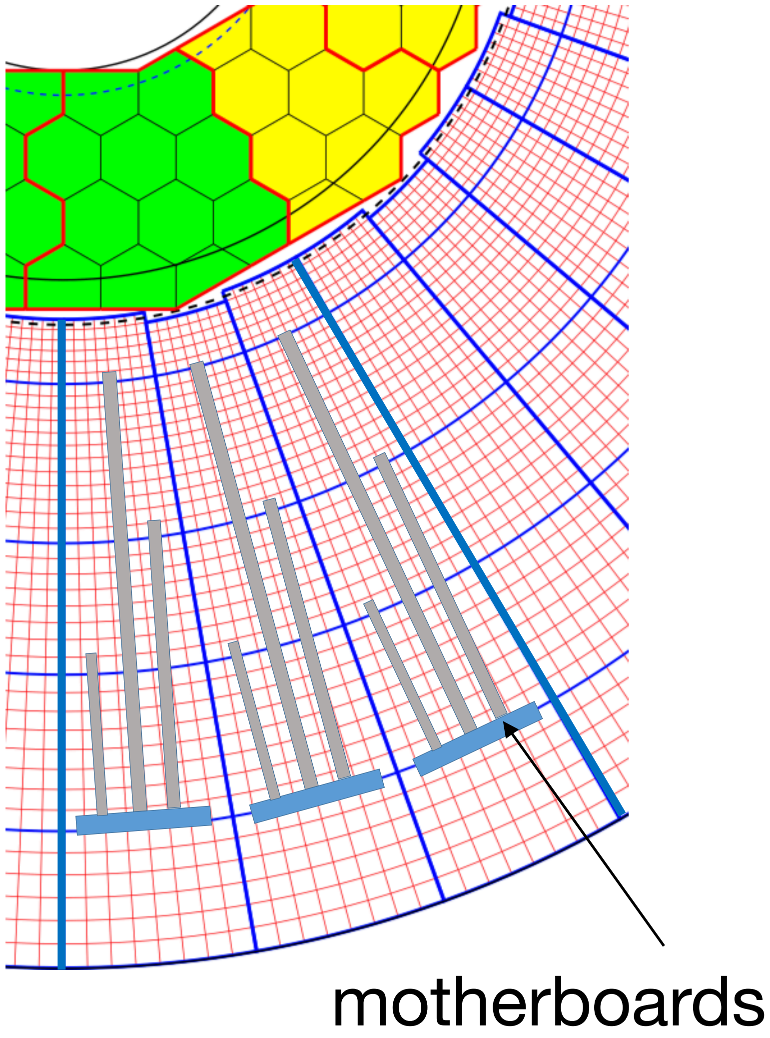
Active area is covered by **fan-shaped tile modules**.

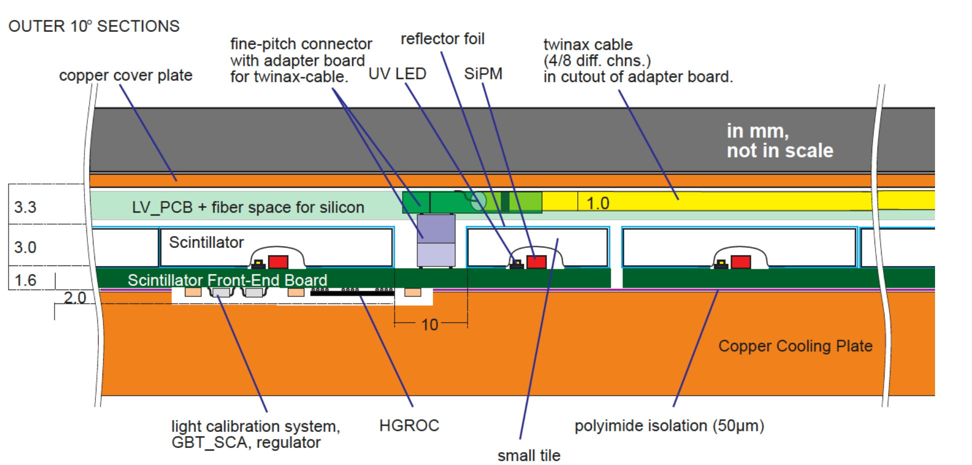
- Tiles are 1.25 degrees in ϕ, with **smallest tiles towards the inner part of detector** where radiation is highest.
- Module PCB hosts the SiPM photodetectors and the **HGCROC readout chips** plus associated controls.
- Per-channel **LED system** for commissioning and monitoring.
- Use a **standardized list of module types** to cover all layers → minimize complexity of module assembly task.

Conceptual design: cassettes

Hadronic layers are assembled from **cassettes which are inserted into slots** in the absorber structure.

- Innermost portion of cassettes use **silicon sensors** for radiation hardness.
- Outer portion of cassettes is covered by **scintillator tile modules**.
- Data and trigger streams from HGCROC are brought to **motherboards** in the outer portion of the cassette.
  - **Concentrator ASICs** merge data from all ROCs in sector.
  - **Electrical-optical conversion** of outgoing signals.
  - Motherboard also distributes **slow control** signals within the sector.





By the numbers

CE-H scintillator system consists:

- **240k** channels (tile + SiPM)
  - Tile size ranges from **4-30 cm²**
  - SiPM size **2, 4, or 9 mm²**
- **3744** tile modules
- **1008** motherboards
- **336** “mixed” cassettes

Large-scale production favors robust and highly repeatable construction strategy → **automation** where possible.

From conceptual design to production

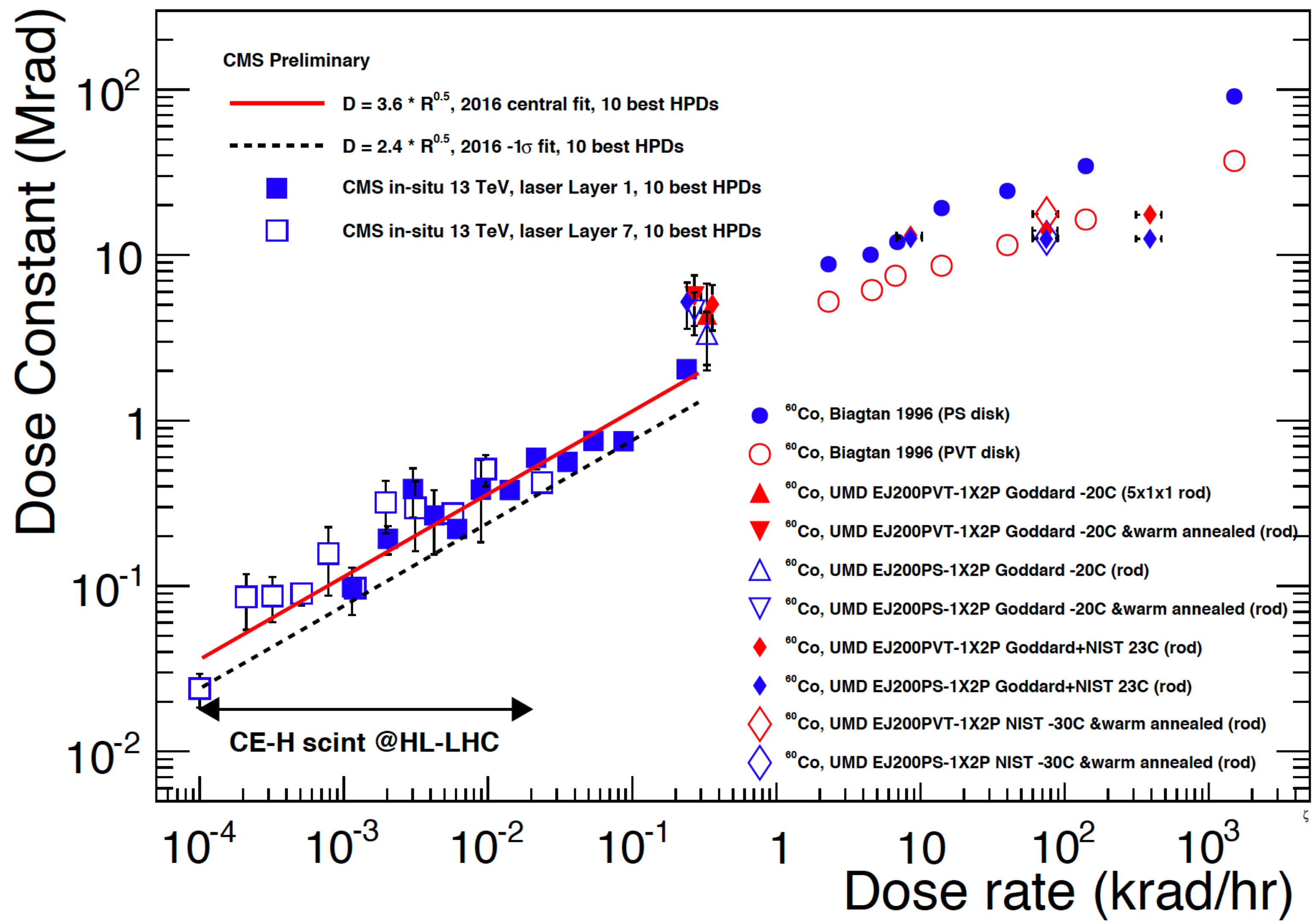
We have pursued a vigorous prototyping program:

- Characterization of scintillator **tiles** and **wrapping** methods (optical system performance).
- Performance of **SiPMs** under CE-H conditions (irradiated).
- **Electronic systems** development.
- Tile module **assembly techniques**.
- **QC** procedures & teststands.

Scintillator rad. hardness

Interesting application for plastic scintillators:

- Total dose **~300 kRad**
- **Very low dose rate** (0.1 - 10 rad/hr)
- **Low T** (-30 C)



Long, slow, cold irradiation necessary to understand performance → results so far are **consistent with our requirements**.
Procurement this summer.

Cast vs. molded scintillator

- Cast (and machined) **PVT-based scintillators preferred in front part** of calorimeter, with highest radiation doses, due to higher light output.

- Injection molded **PS-based scintillators preferred for the rest** due to lower cost (and no need for machining).

Working to optimize distribution of **tile types and SiPM sizes** over full detector volume.

1200 tiles SC301 (Protvino)

Plate thinning and polishing

Tile machining

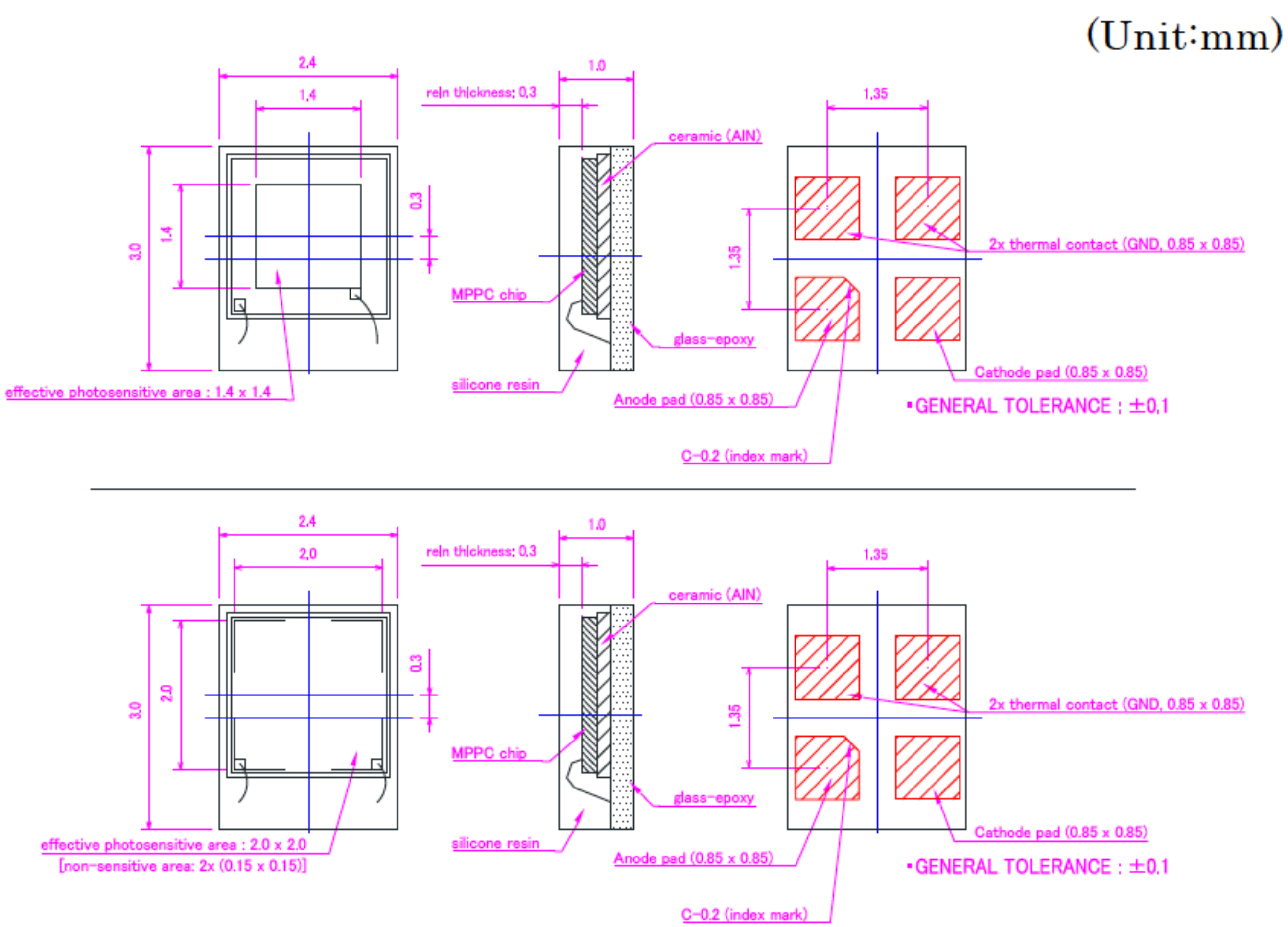
Cast & machined samples (ISMA-Kharkov)

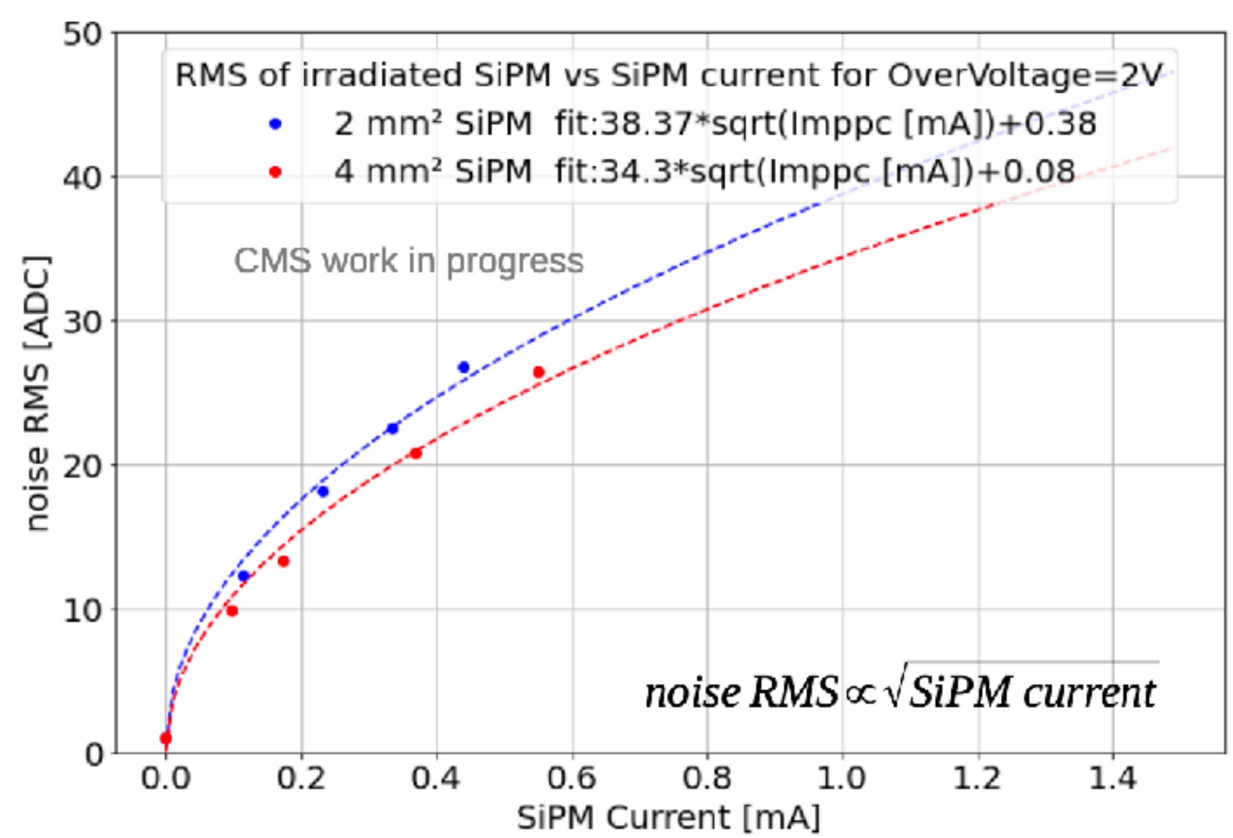
Mechanical QC

SiPMs

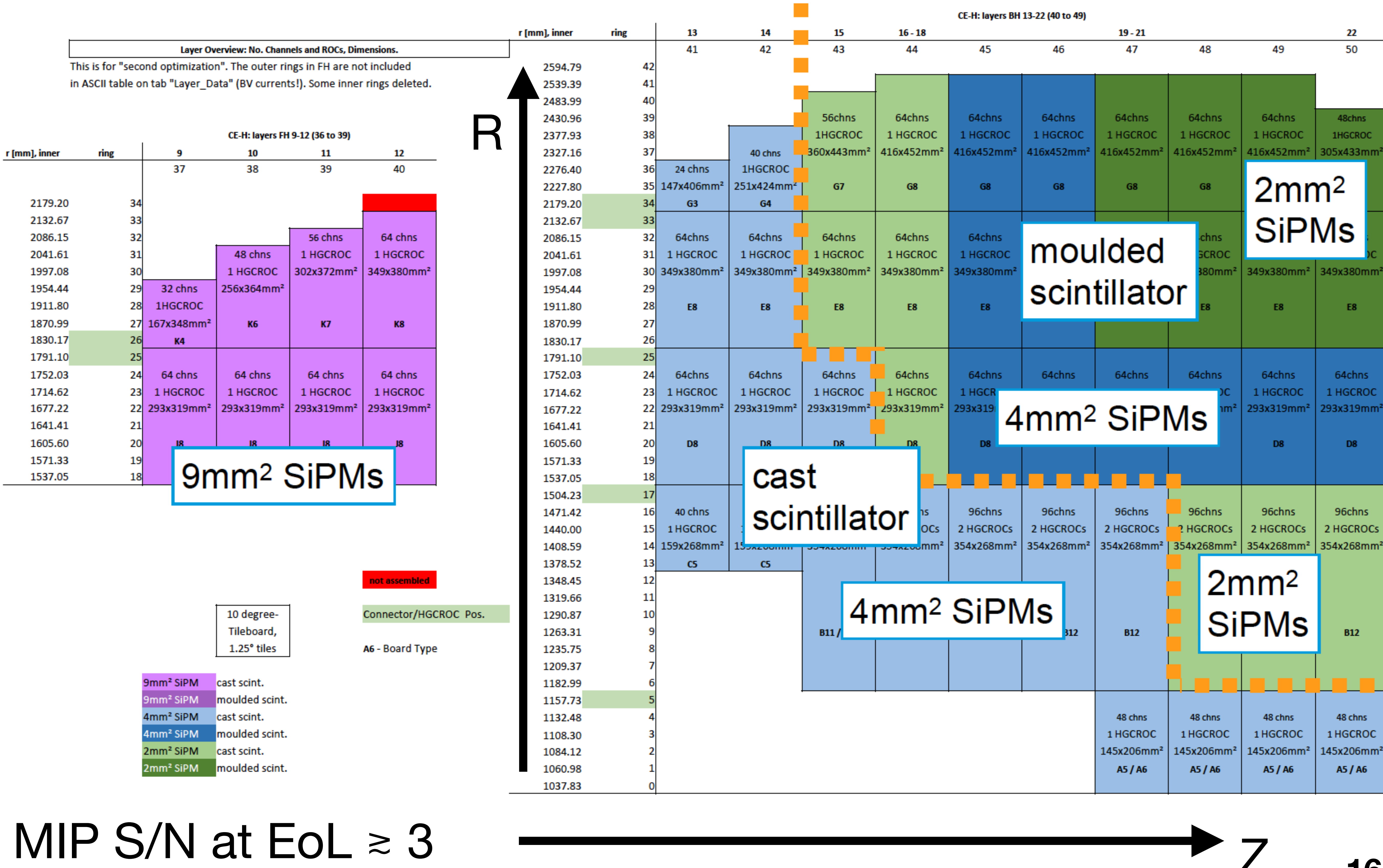
240k channels in 2, 4, and 9 mm^2 sizes.

- In 2022, characterize **4000 devices** from HPK.
- **Custom packaging** (wire bond).
- Benefit from **collaboration with CMS MTD** (MIP timing detector): QC test stands at CERN well advanced.
- **PDE and noise** under irradiation well understood.





Optimized detector layout



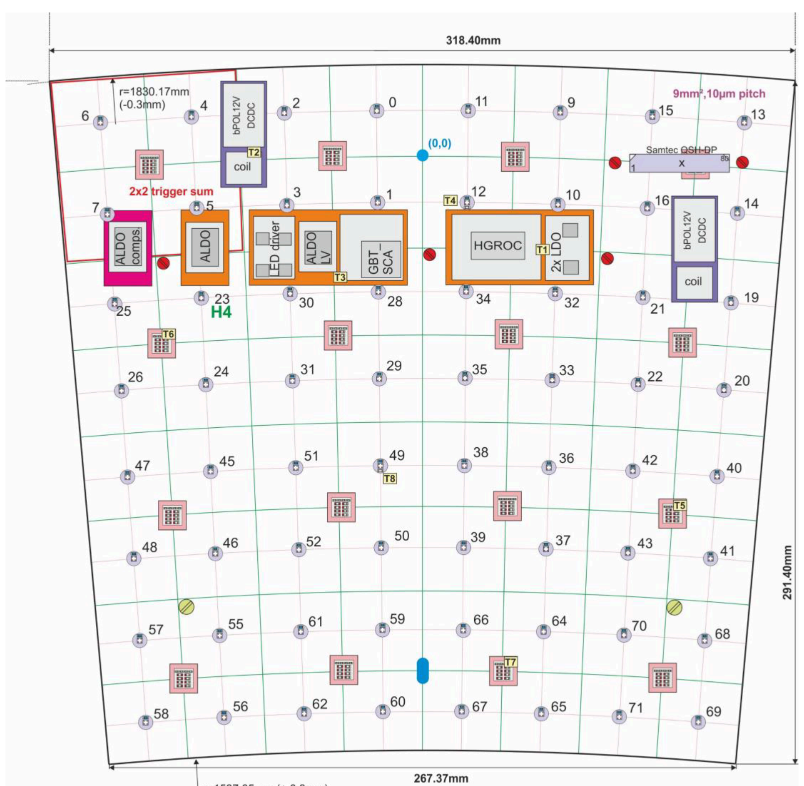
MIP S/N at EoL ≳ 3

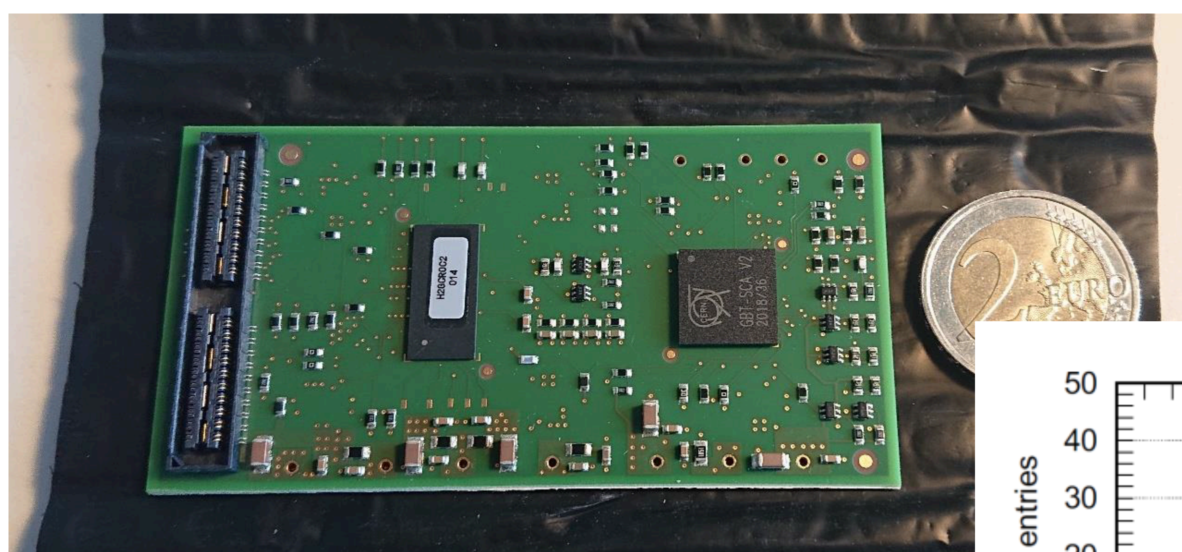
Tileboard electronics

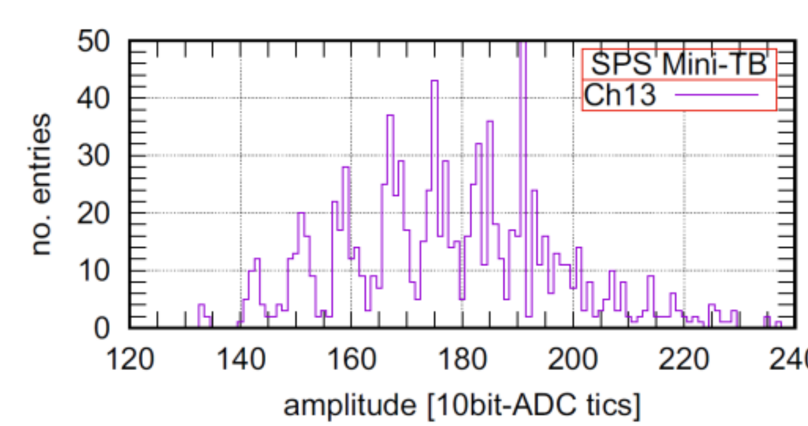
8 basic types (with some sub-variants) needed to cover all layers.

Tileboard “v3” current generation with **close-to-final components**.

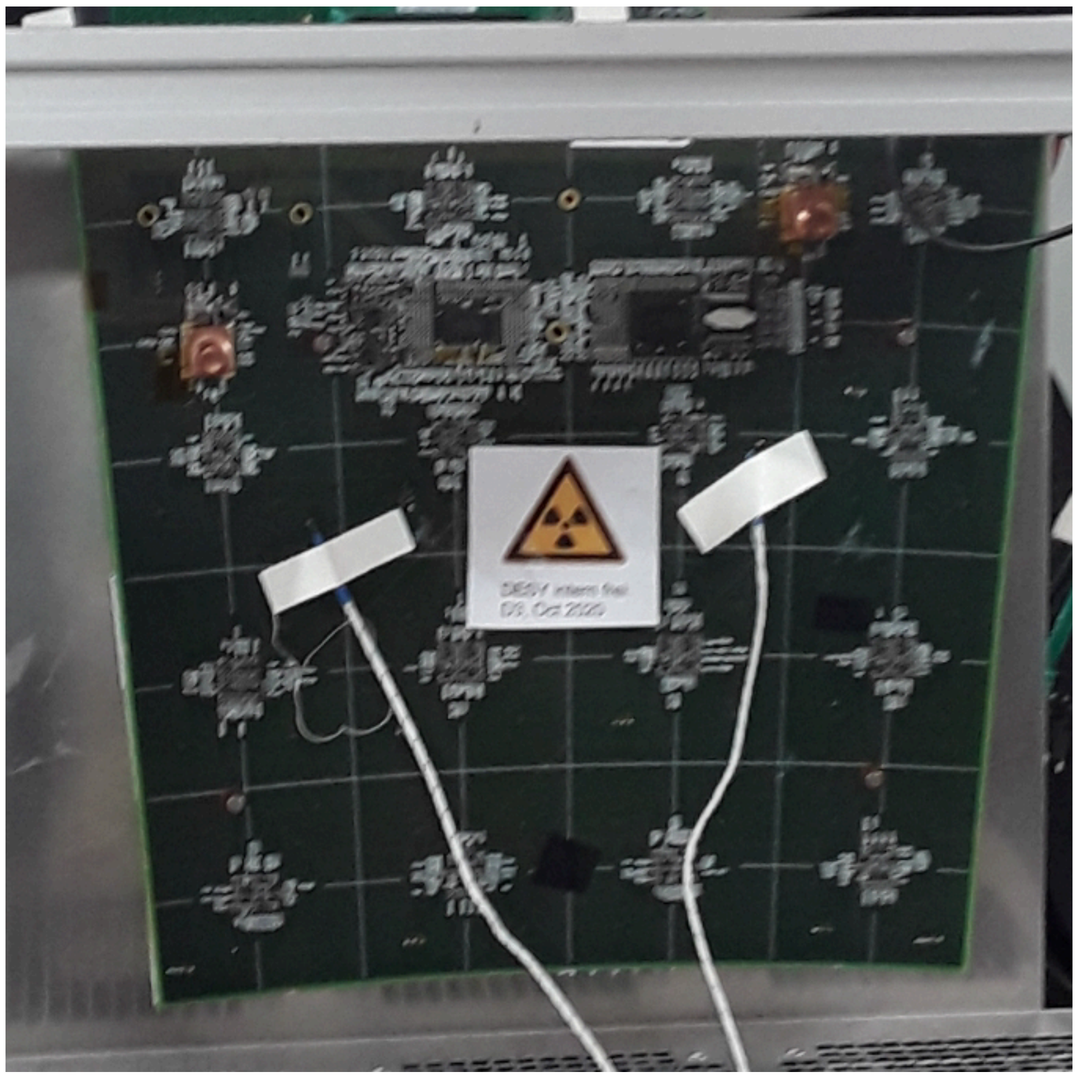
- To be tested on test stands and in beam tests, as previous versions.
- **Mini-TB** variant for radiation tests.
- Mechanical design of cooling plate coordinated with TB designs.

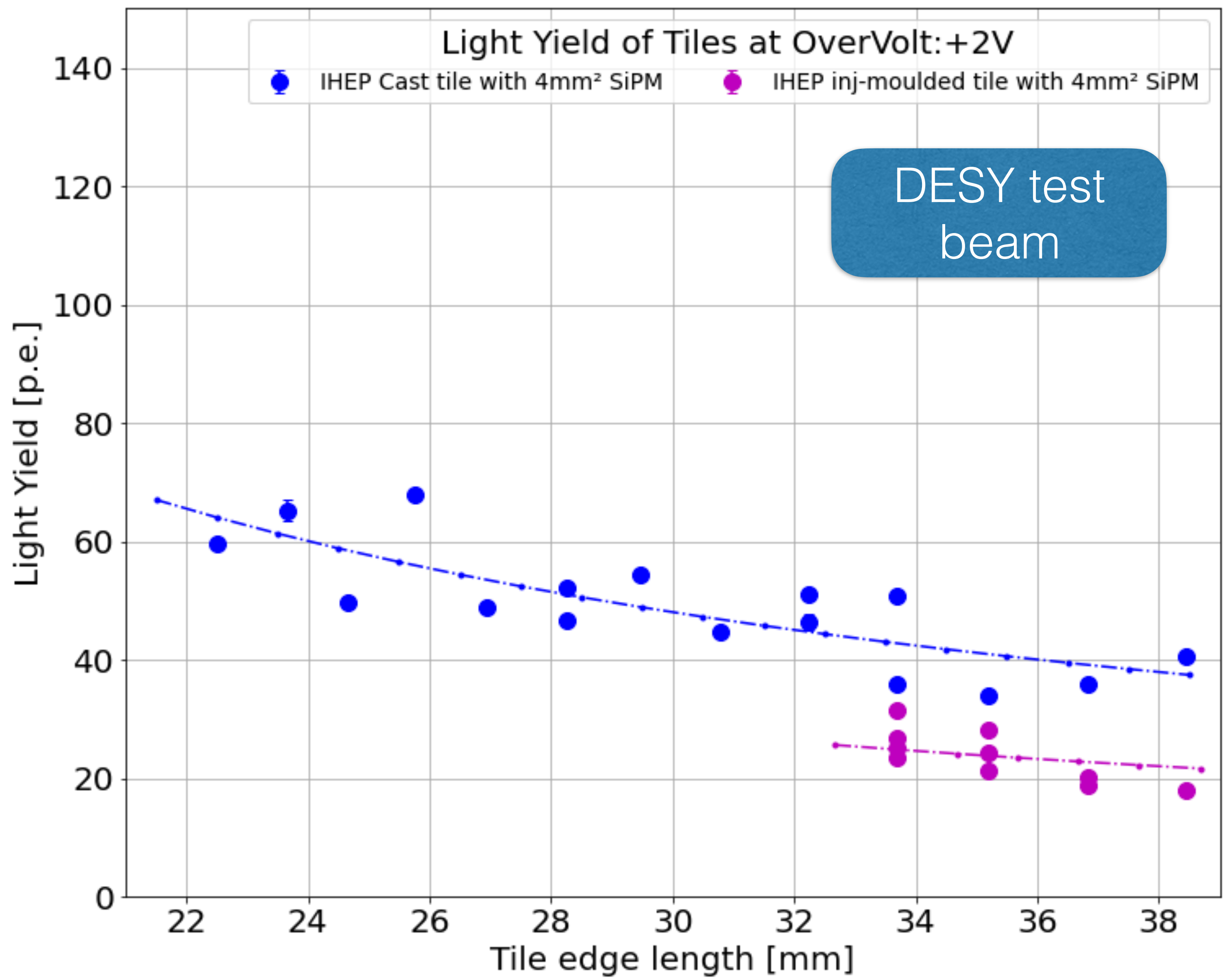




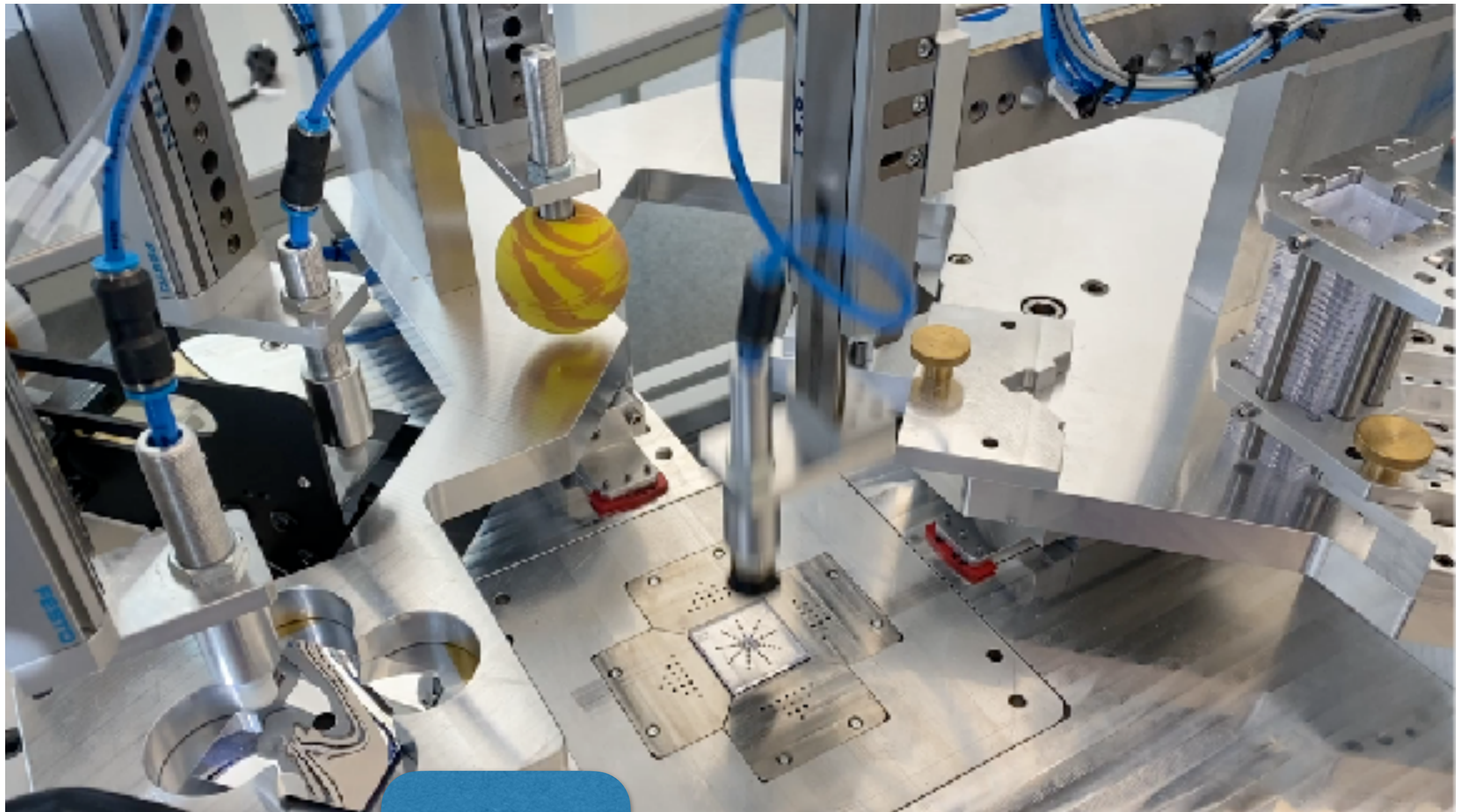


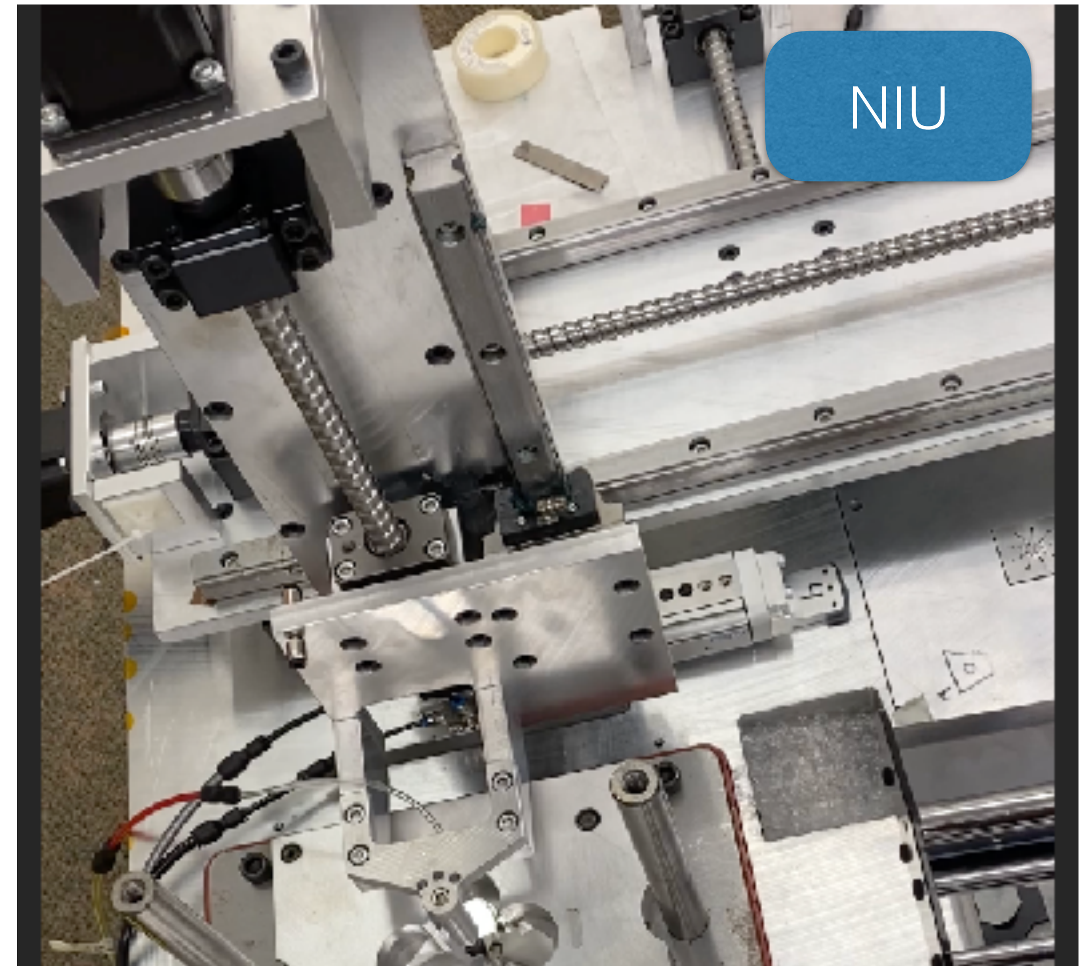
Tiles & modules - beam tests

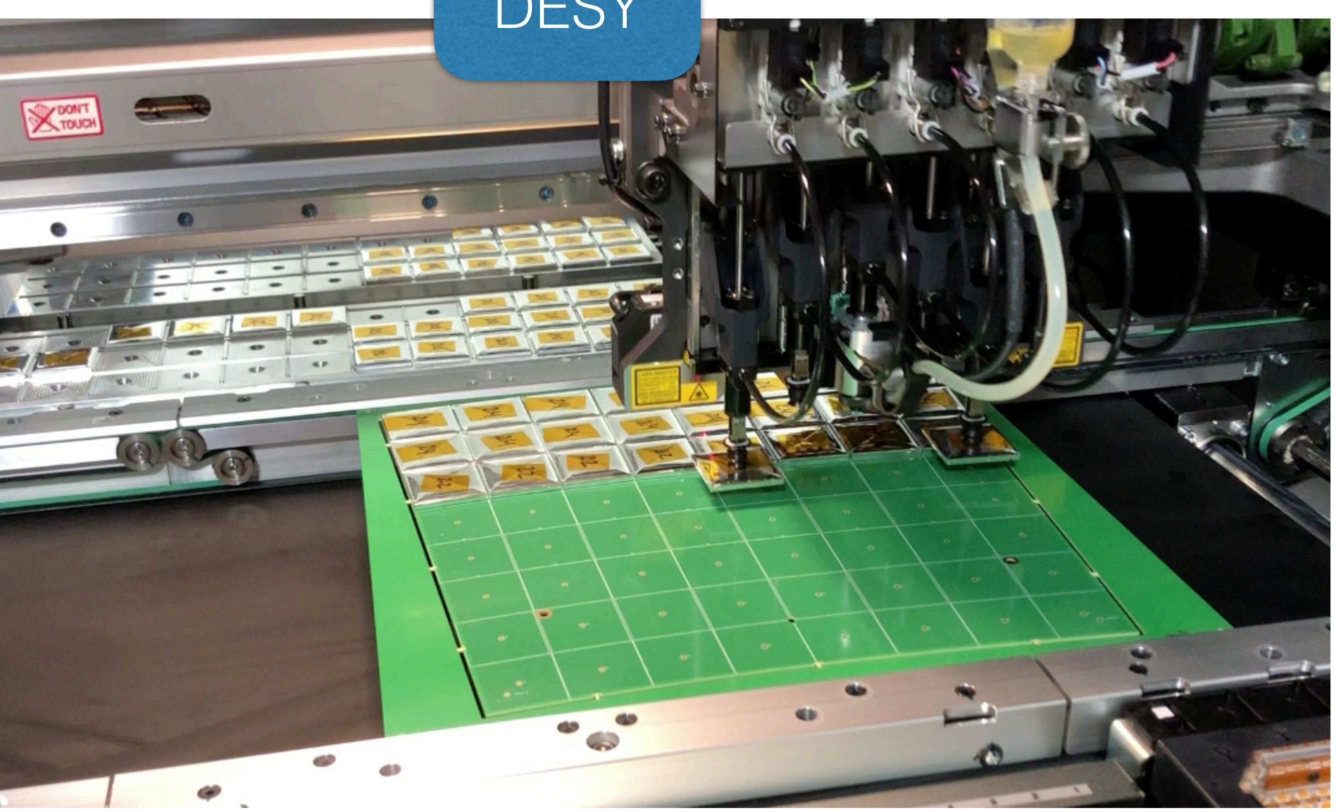


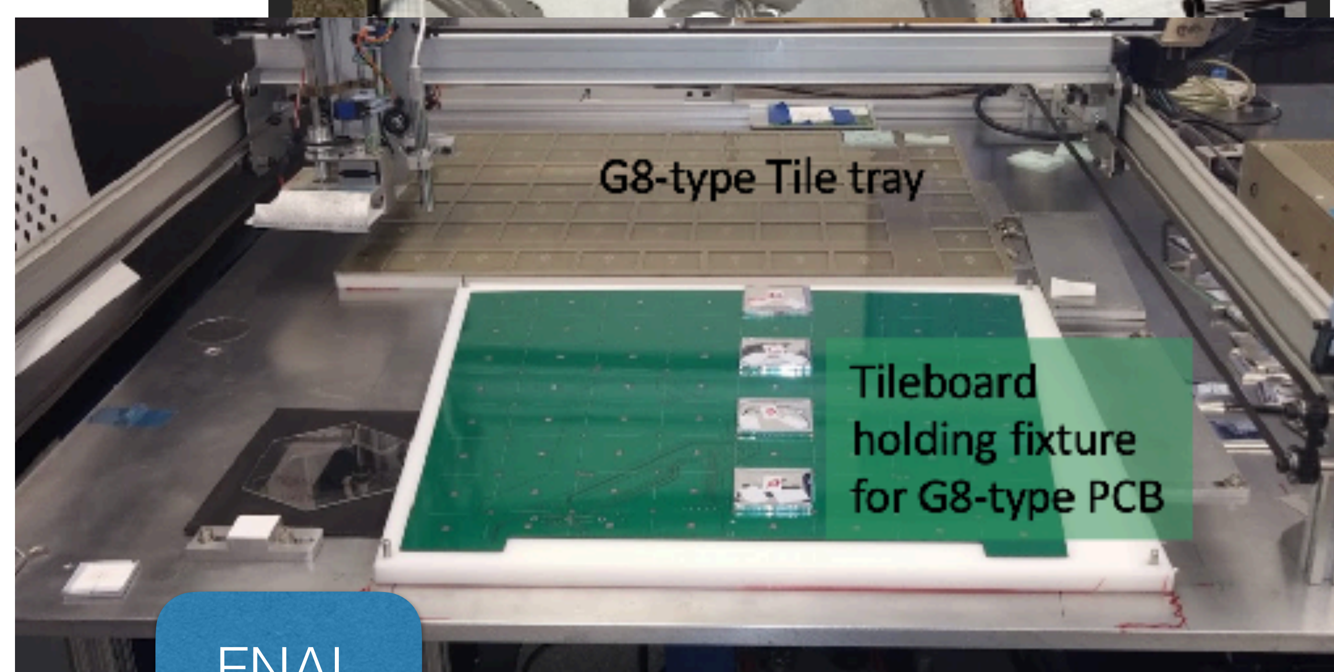


Wrapping & module assembly

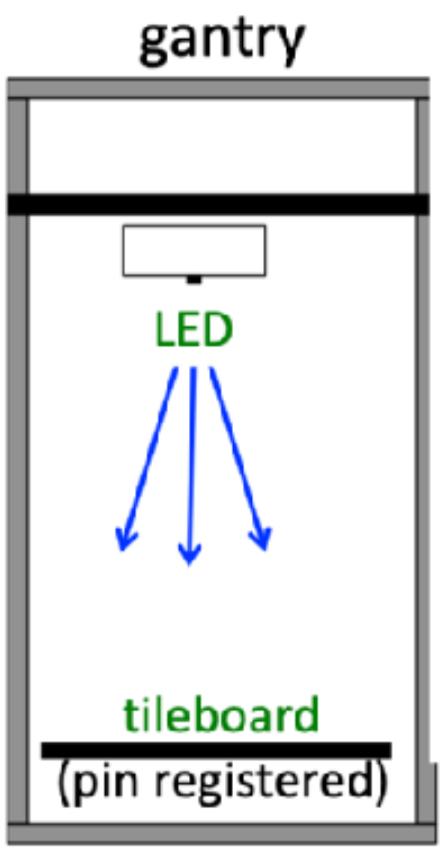


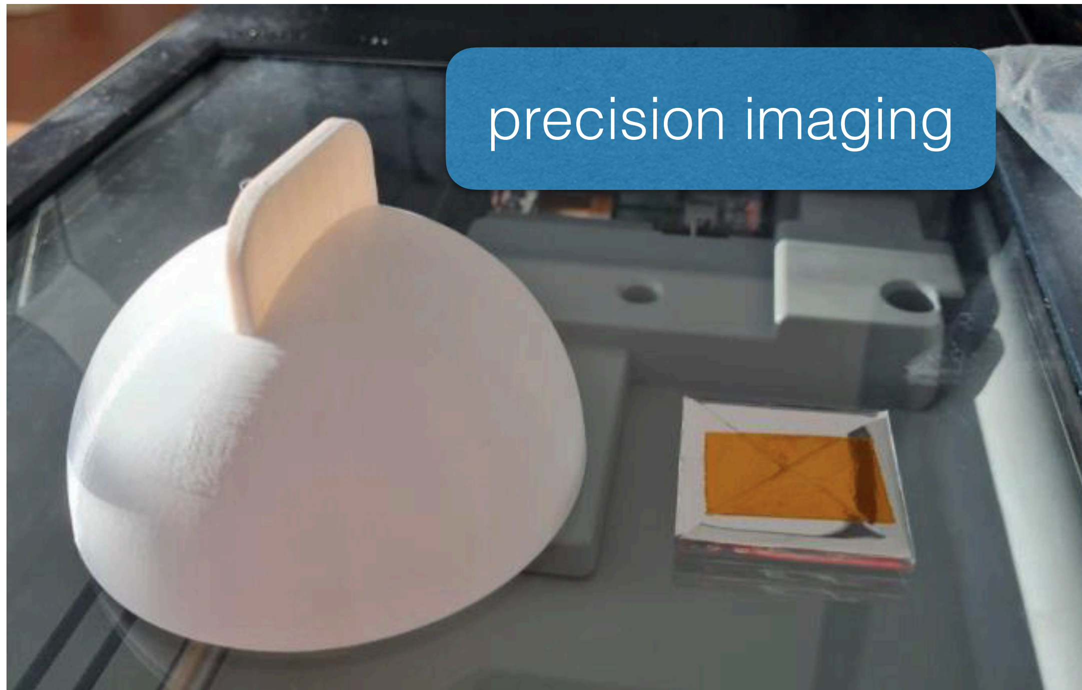


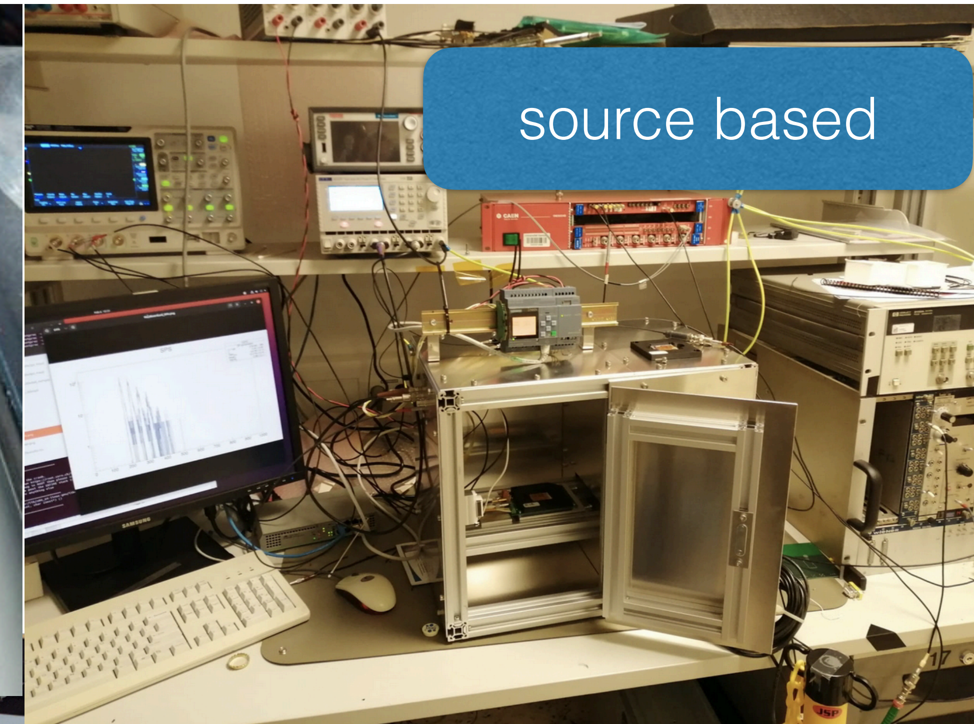


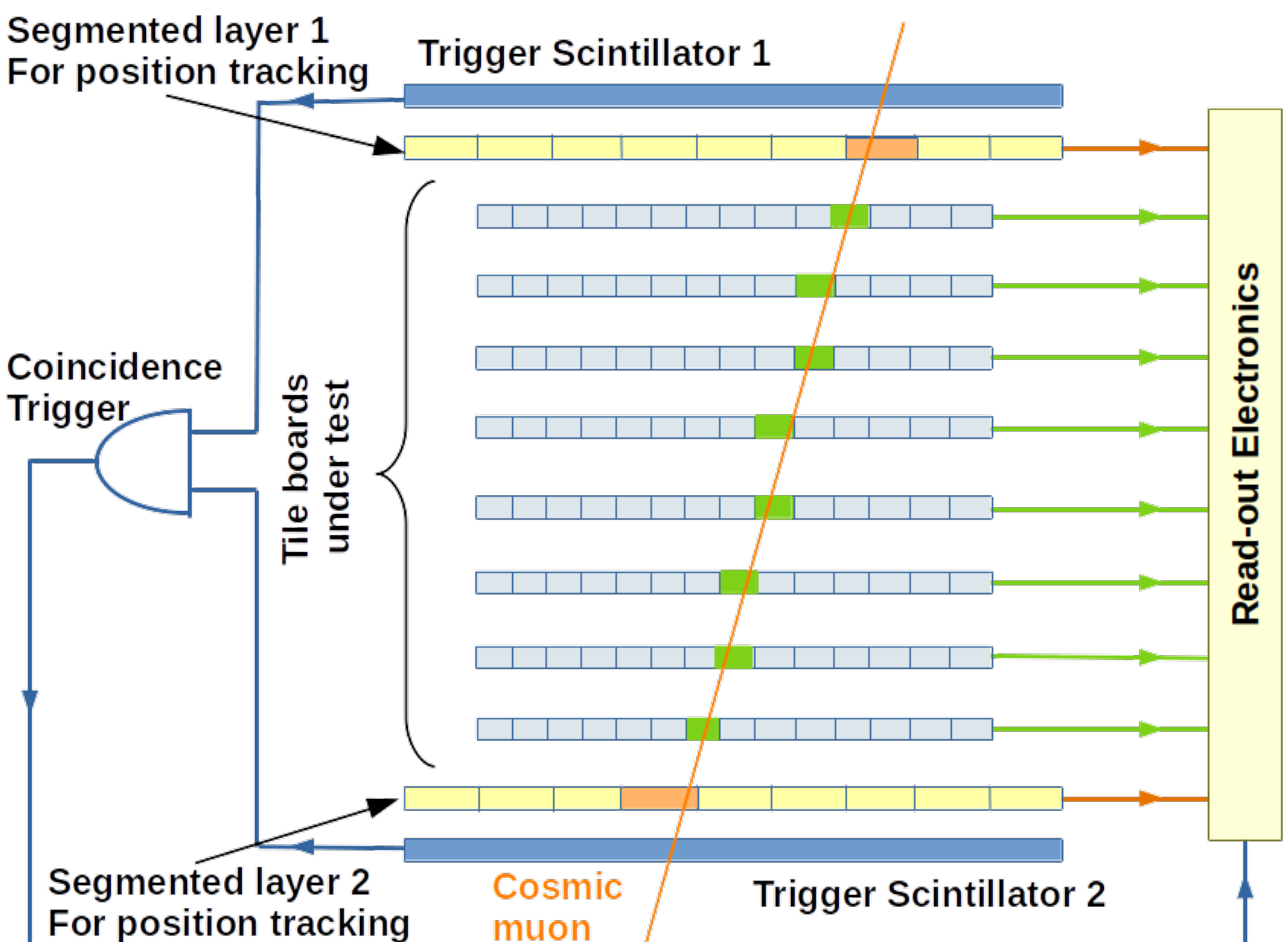


QC test stands









Summary

SiPM-on-tile offers a **robust and cost effective** technology for hadronic calorimetry at HL-LHC.

Active prototype program **converging on a detailed design**.

Testing out key technologies for detector construction with a focus on **automation and scalability**.