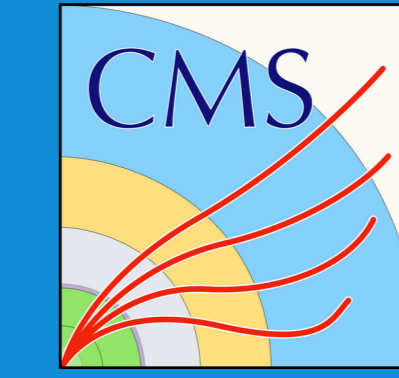


The SiPM-on-tile system of the CMS High Granularity Calorimeter Upgrade (HGCal)

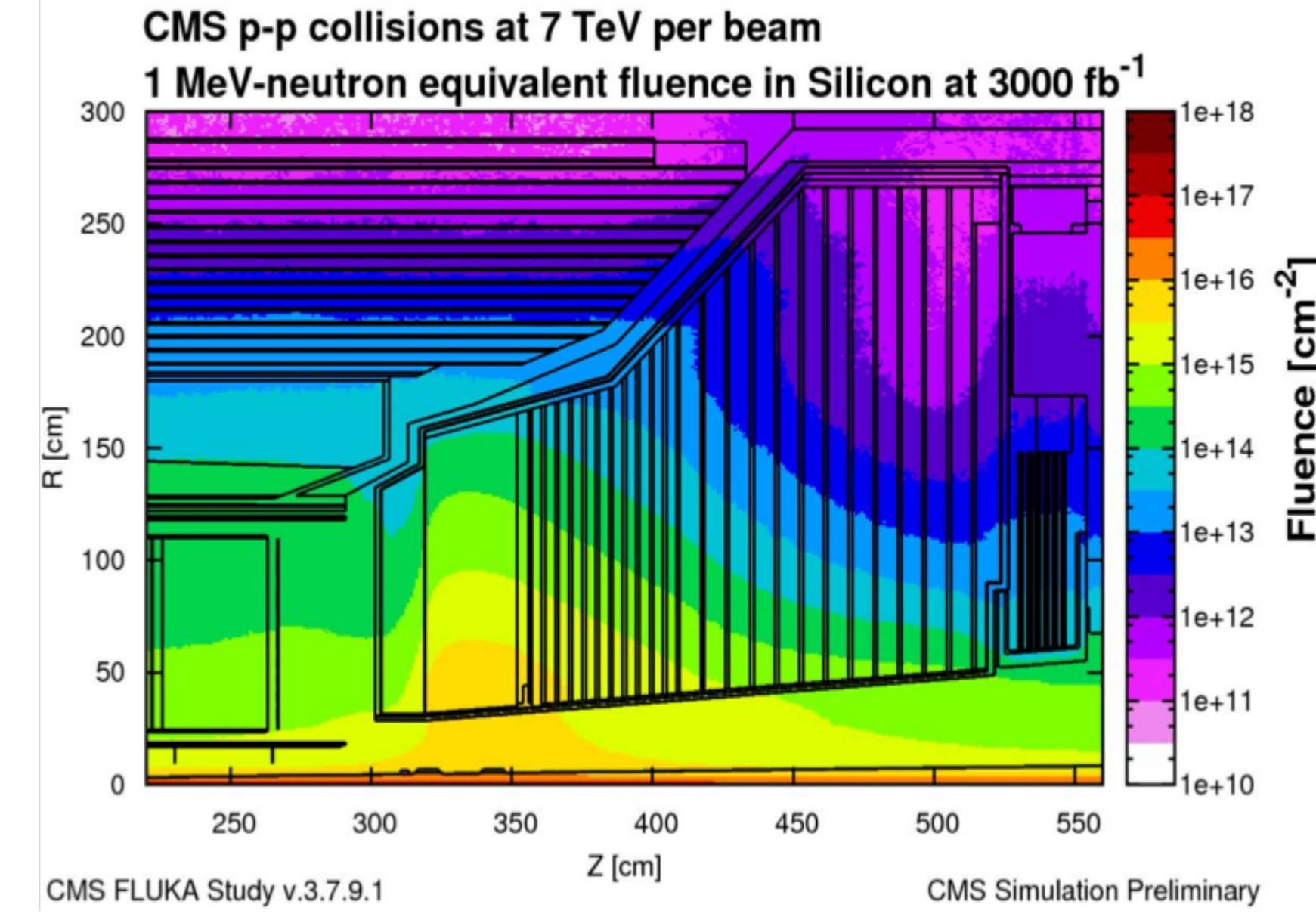


Antoine Laudrain (DESY)
for the CMS HGCal Collaboration

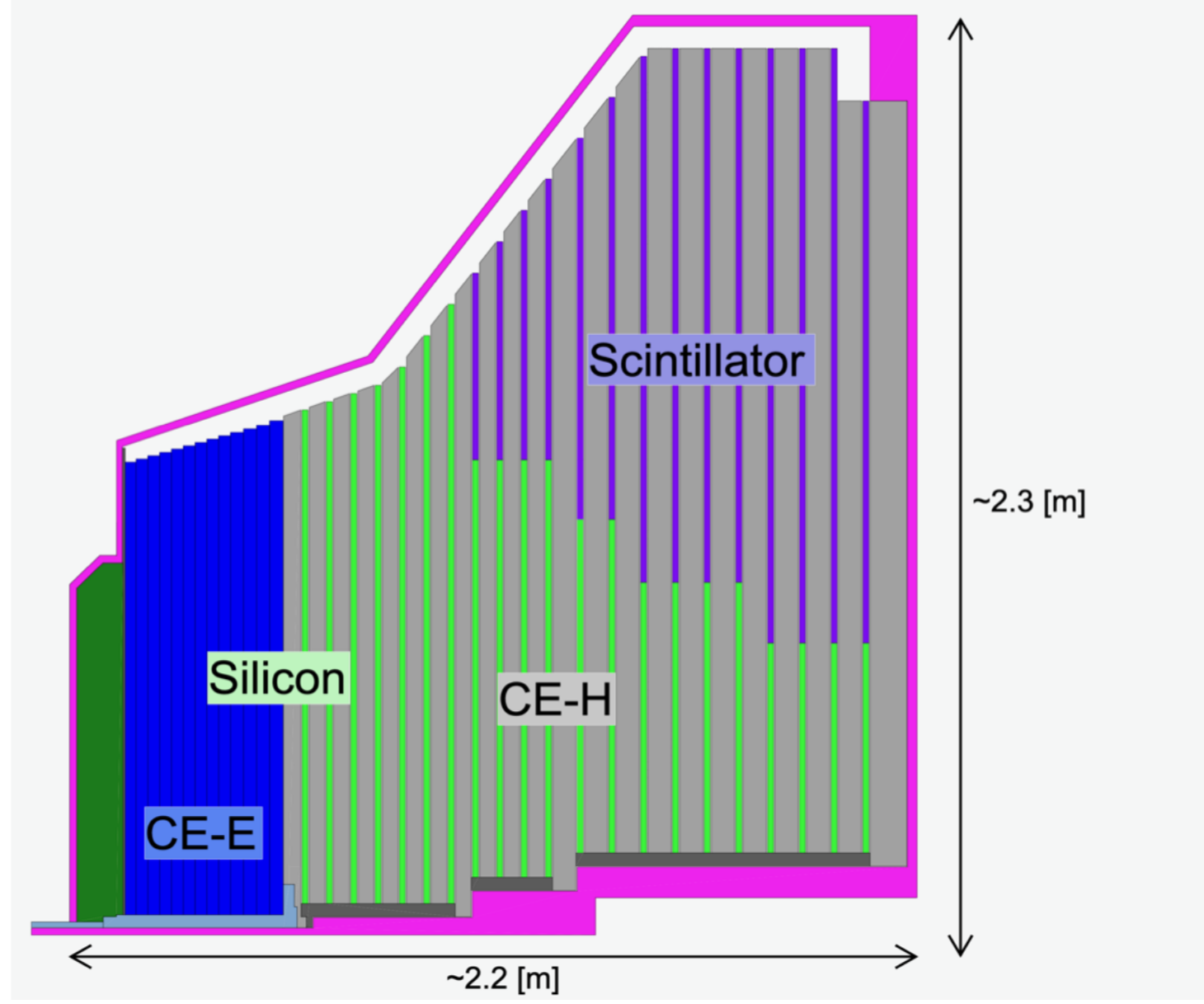


The High-Granularity Calorimeter upgrade

- High-Luminosity LHC to start in 2029 → increased pileup and radiation damage.
- Need to replace the current endcap calorimeters → **5D (imaging) calorimeter using particle flow**, operating at -30°C .
- Use both silicon sensors and SiPM-on-Tile technologies, depending on the expected fluence at the end-of-life.



- Electromagnetic calorimeter (ECAL):**
- $27.7X_0$ or 1.5λ
 - Cu / CuW / Pb absorbers
- Hadronic calorimeter (HCAL):**
- 8.5λ
 - steel absorbers

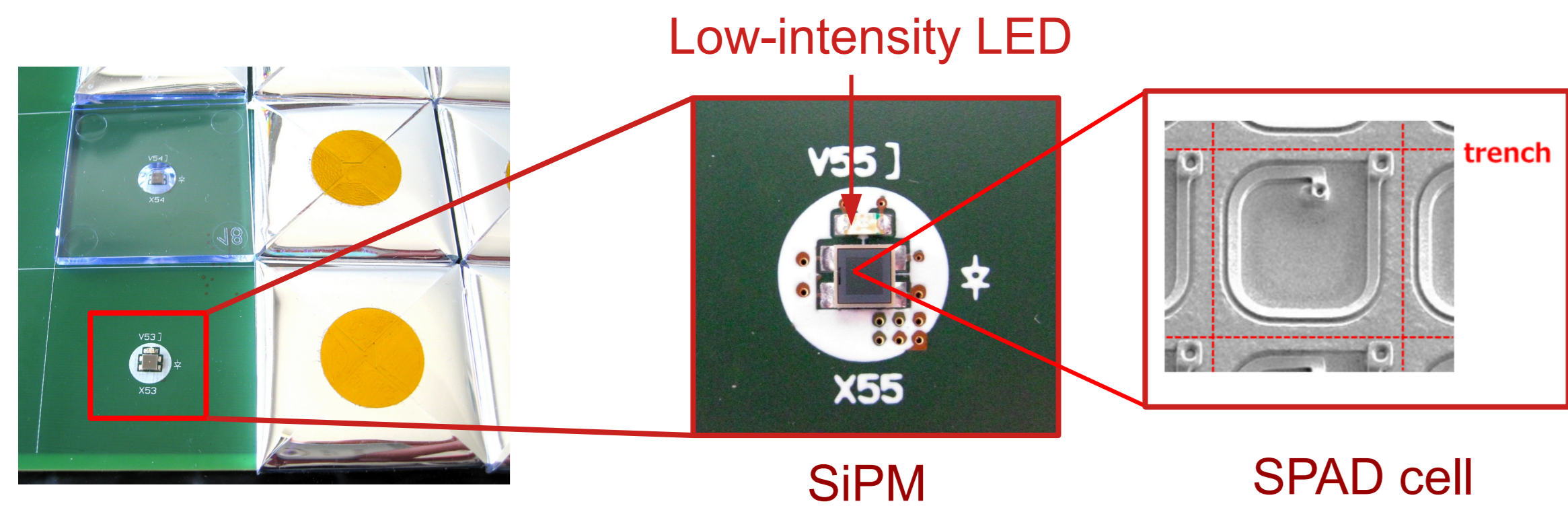


- Silicon detector section:** where expected fluence at end of life $> 5 \times 10^{13} \text{ n/cm}^2$.
 - Consists of hexagonal silicon sensors.
 - Covers the ECAL and innermost part of the HCAL
 - Cell size varies depending on its location in the calorimeter.
 - More than **6M silicon sensors** covering 620 m^2 area.
- Scintillator section:** where expected fluence at end of life $< 5 \times 10^{13} \text{ n/cm}^2$.
 - Consists of trapezoidal plastic scintillators tiles read out by silicon photomultipliers (SiPM-on-tiles technology).
 - Covers the outermost part of the HCAL.
 - Ensures $S/N > 3$ for minimum ionizing particles throughout the detector lifetime.
 - Cell size increases radially from the beam line
 - More than **240,000 SiPM-on-tiles** covering 370 m^2 area

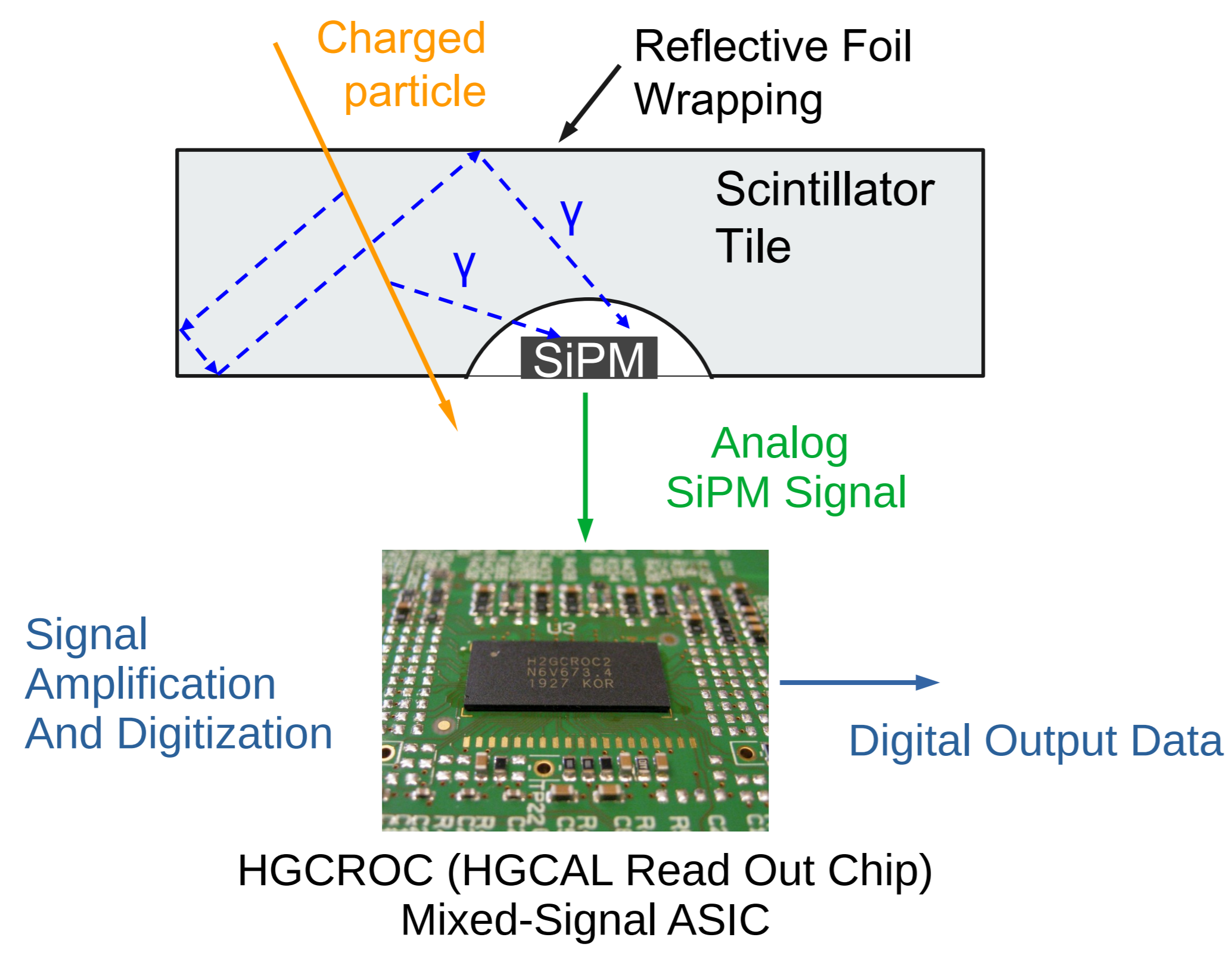
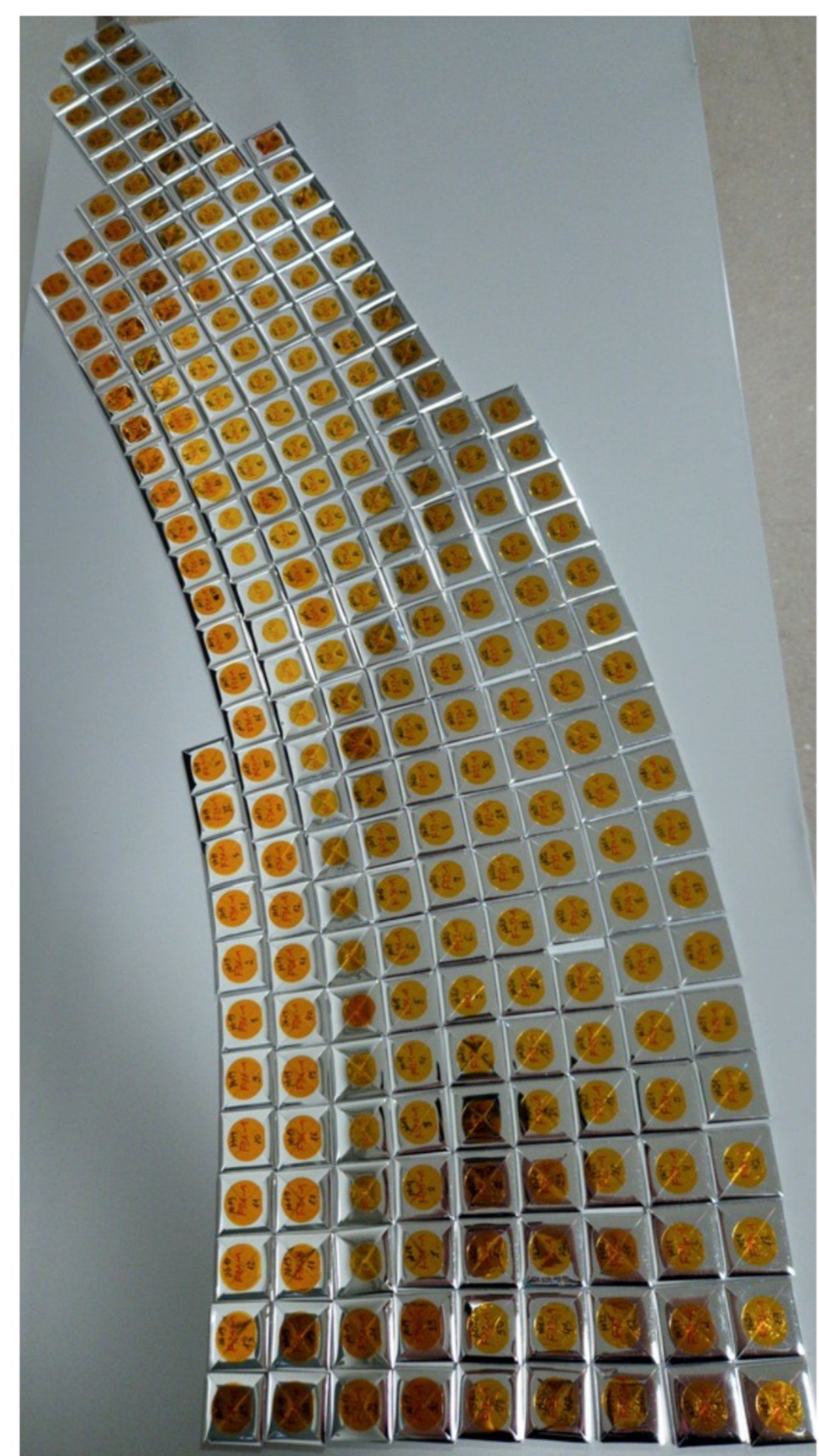
The HGCal SiPM-on-Tile section

Sensors: the SiPM-on-Tile Technology

Individually wrapped plastic scintillator tiles, glued on the tileboard directly on top of SiPM.



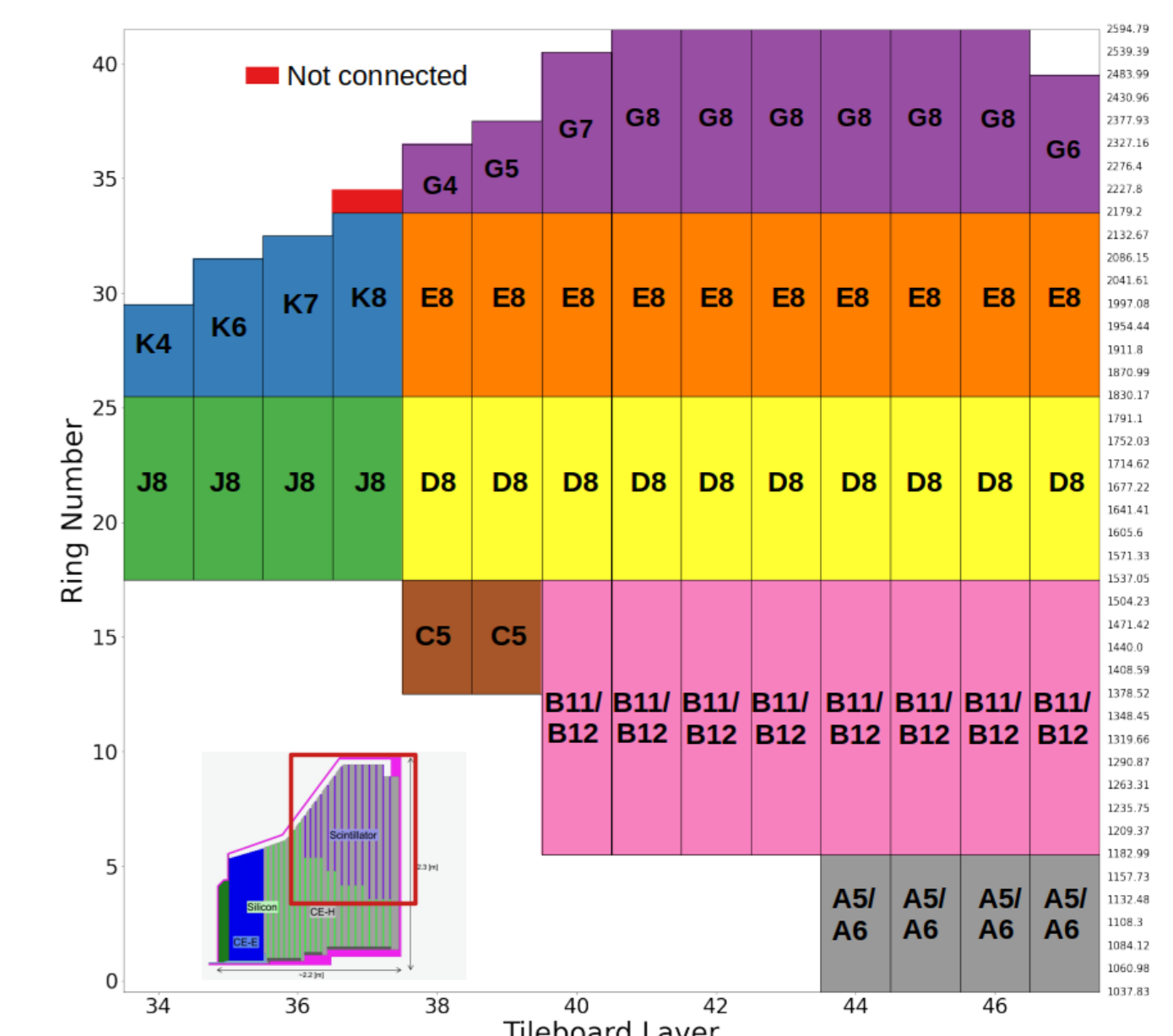
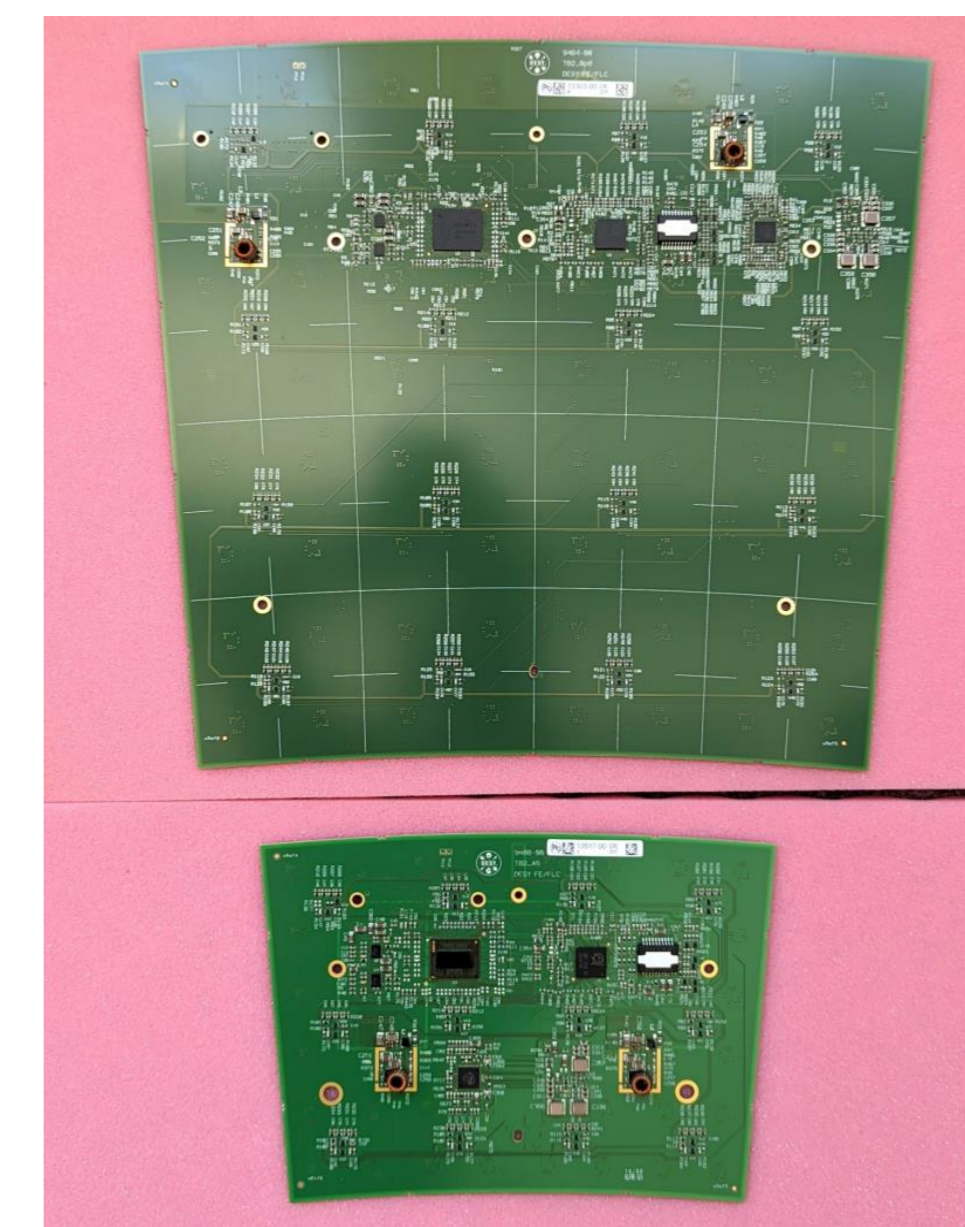
1 SiPMs = thousands of single photon avalanche diodes (SPAD) working in Geiger mode.



- Tiles are plastic based, injection moulded or cast.
- **21 scintillator tile sizes** (23 mm to 55 mm side length).
- All SiPM: 9mm^2 .
- One low intensity LED for calibration next to each SiPM.

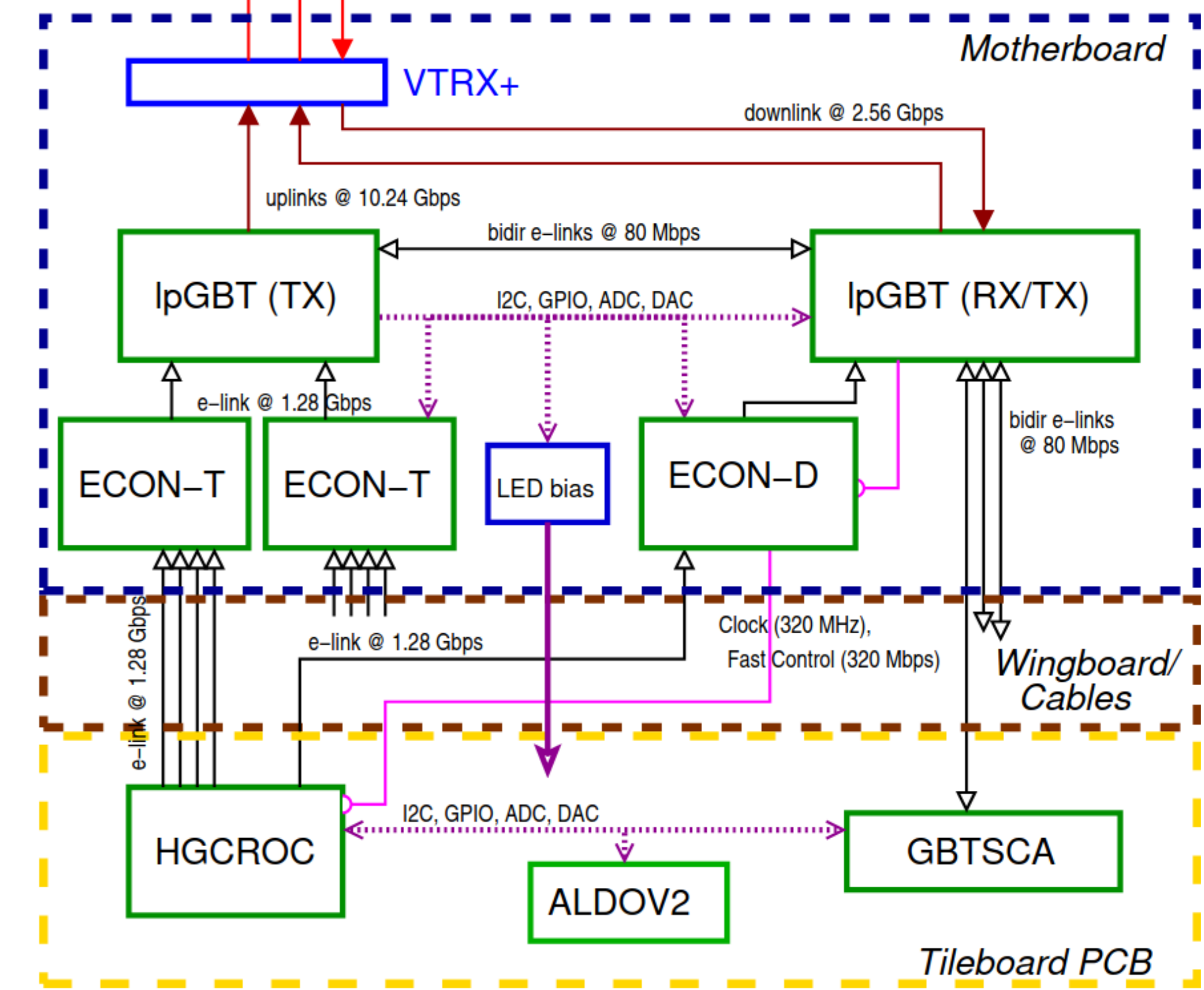
HGCal Tilemodules

- The basic detector module in the SiPM-on-tile section:
- PCB,
- SiPMs + scintillators,
- HGROC + front-end electronics.
- **8 main tilemodule types:**
- Typically 64 channels / board, (up to 108),
- $\sim 15 \times 20 \text{ cm}^2$ up to $\sim 45 \times 45 \text{ cm}^2$,
- ... with 35 variants.



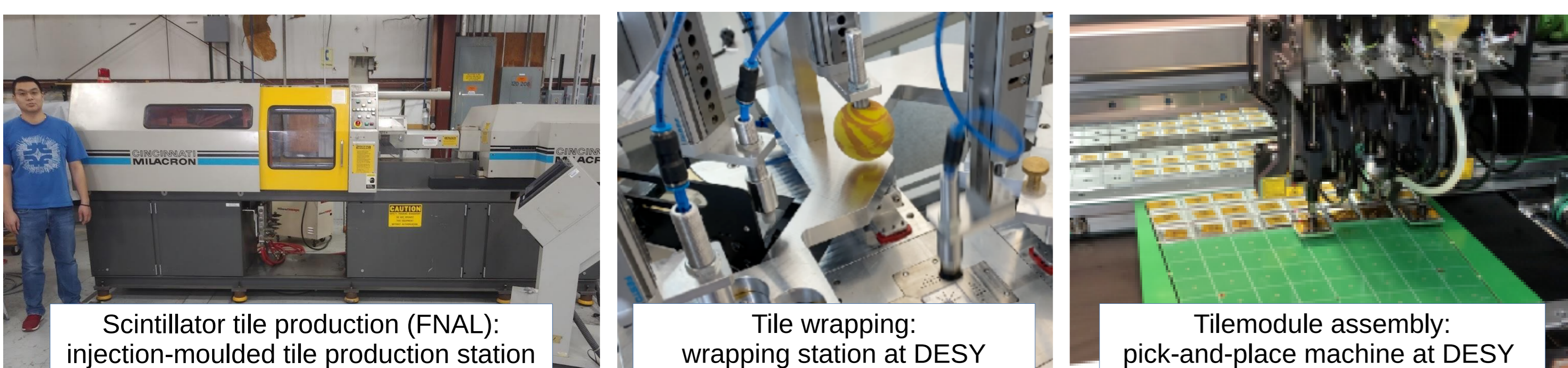
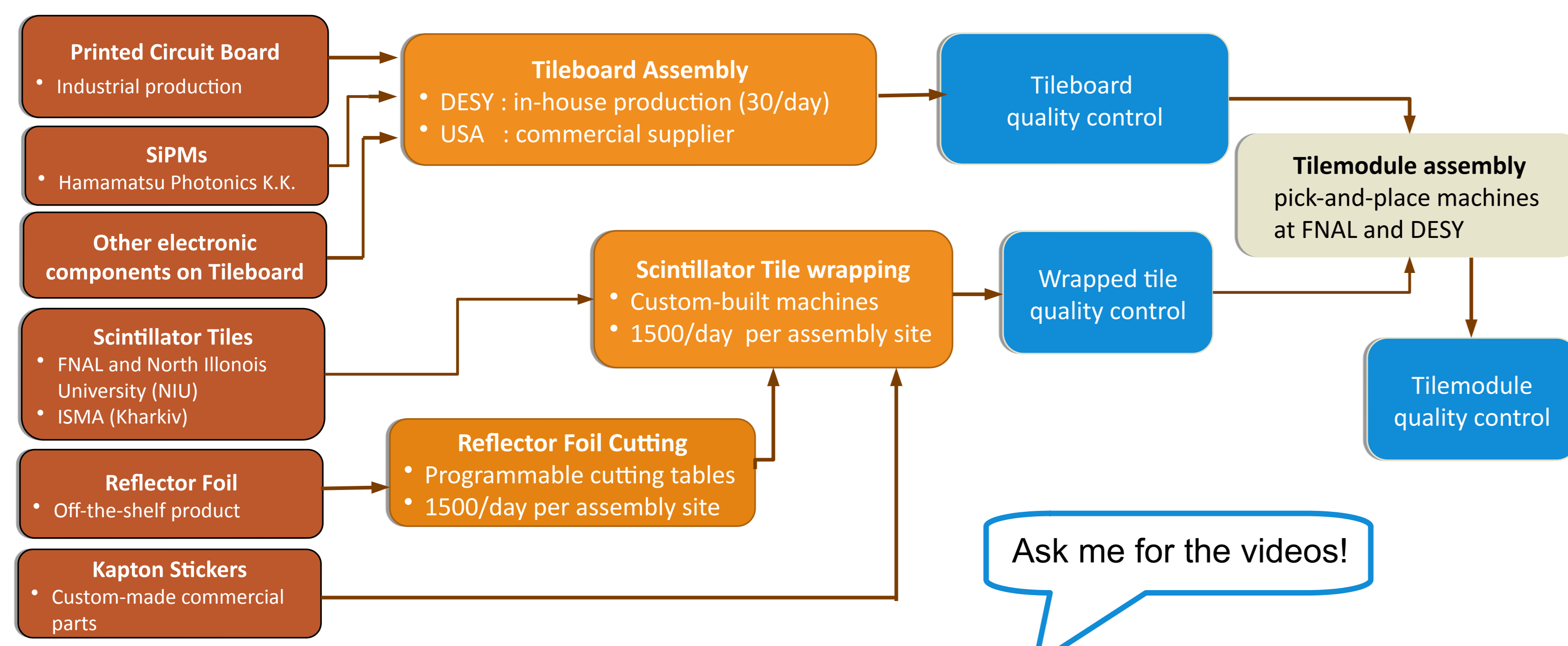
Front-End Electronics

- **VTRx+:**
 - Optically sends and receives signals from the back-end
- **ECON-T:**
 - Receives trigger data from HGROC
 - Concentrates data and sends to LpGBT
- **ECON-D:**
 - Receives data from HGROC
 - Concentrates data and sends to LpGBT
- **LpGBT:**
 - Transmits data to back-end via VTRx+
 - Distributes clock, fast commands and configurations to the front-end electronics
- **HGROC:**
 - Reads out the SiPM-on-tiles on the Tilemodule
 - Up to 72 channels (1 or 2 per Tilemodule)
- **GBT-SCA:** Responsible for all slow control tasks on the Tilemodule
- **ALDOV2:** Voltage regulator chip for SiPMs on the Tilemodule



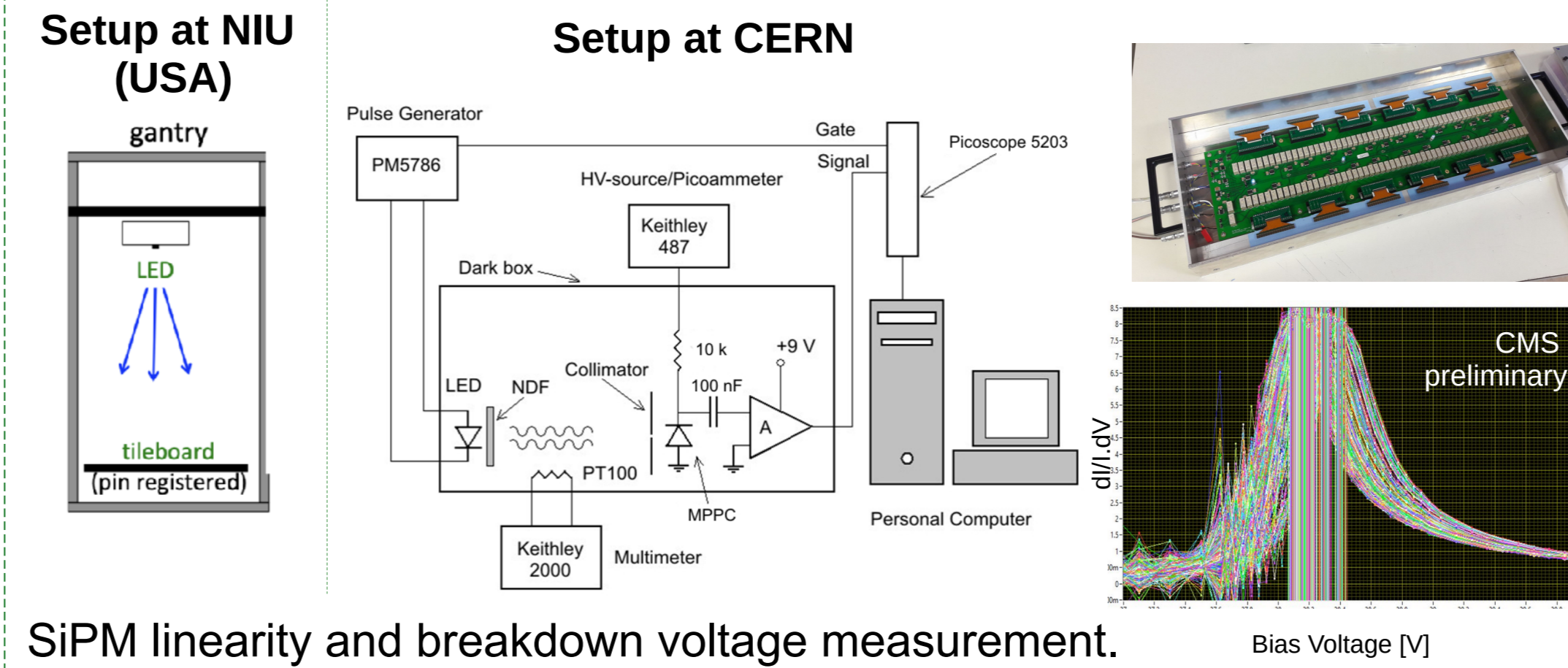
Tilemodule production and assembly

- Tilemodule production for the final detector to begin this summer!
- Tilemodules will be produced and assembled at DESY (Hamburg, Germany) and Fermilab (USA).
- Final assembled end-caps to be lowered into the CMS cavern in August 2027



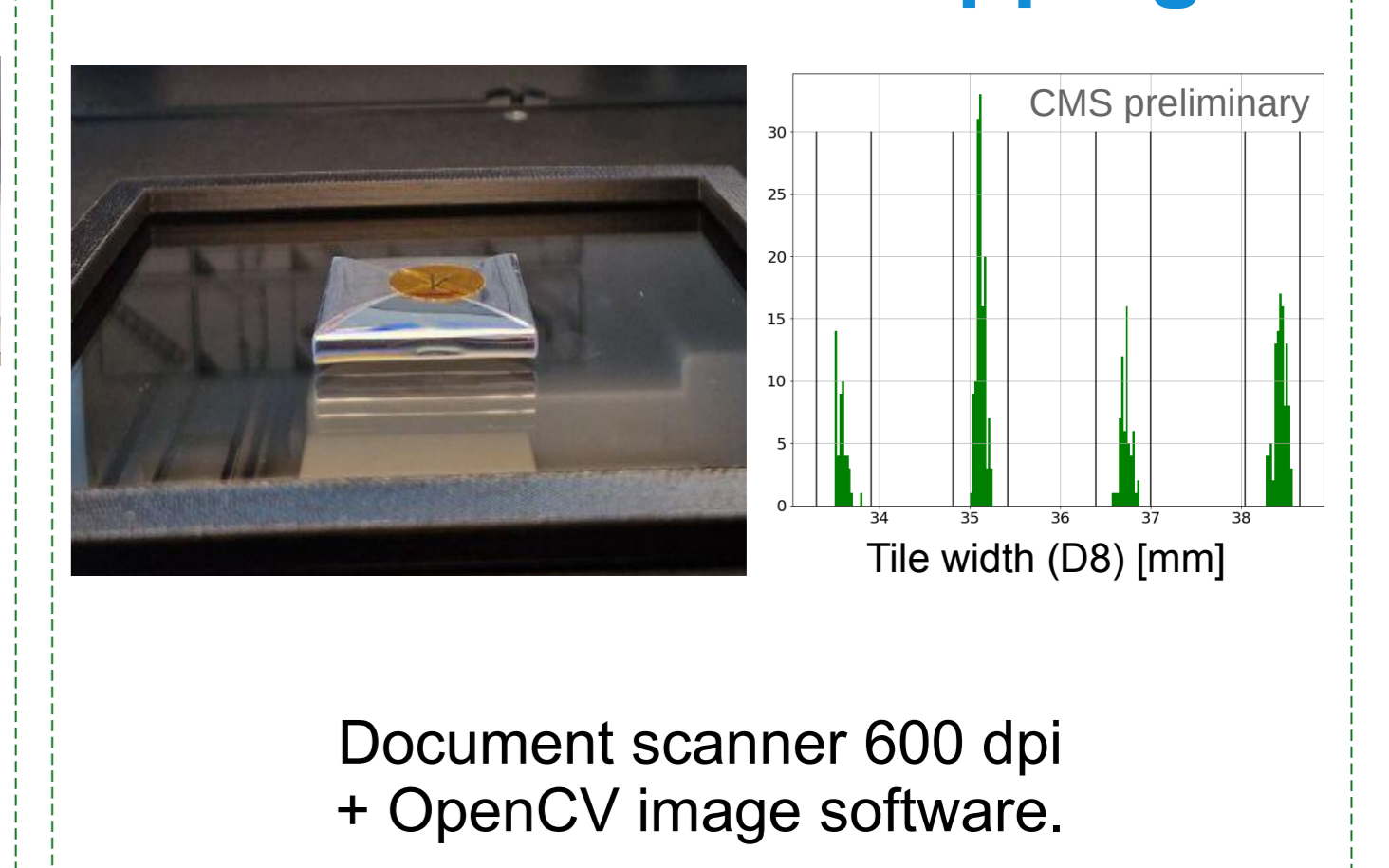
Quality Control

LED based SiPM quality control setups



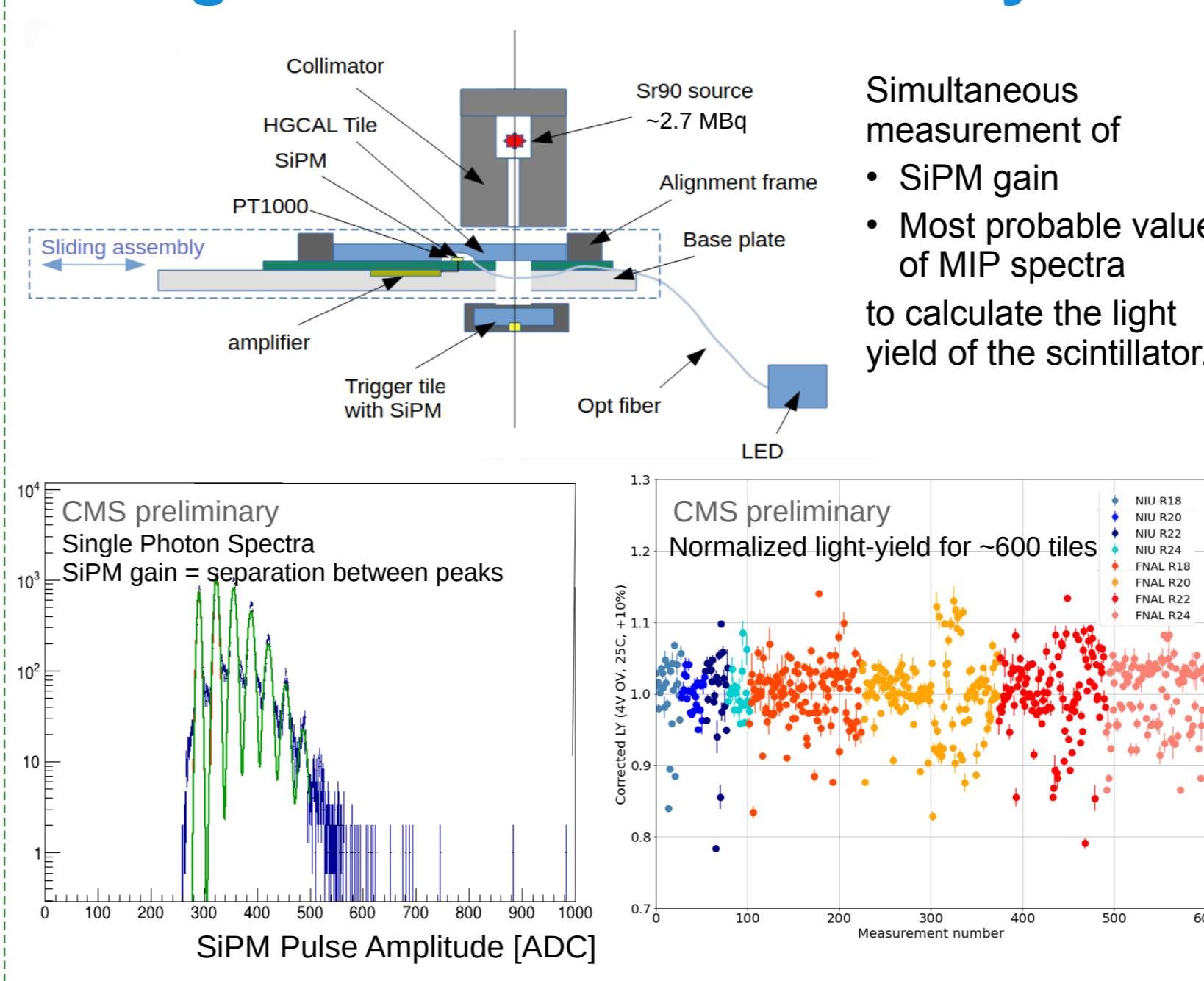
SiPM linearity and breakdown voltage measurement.

Tile size after wrapping

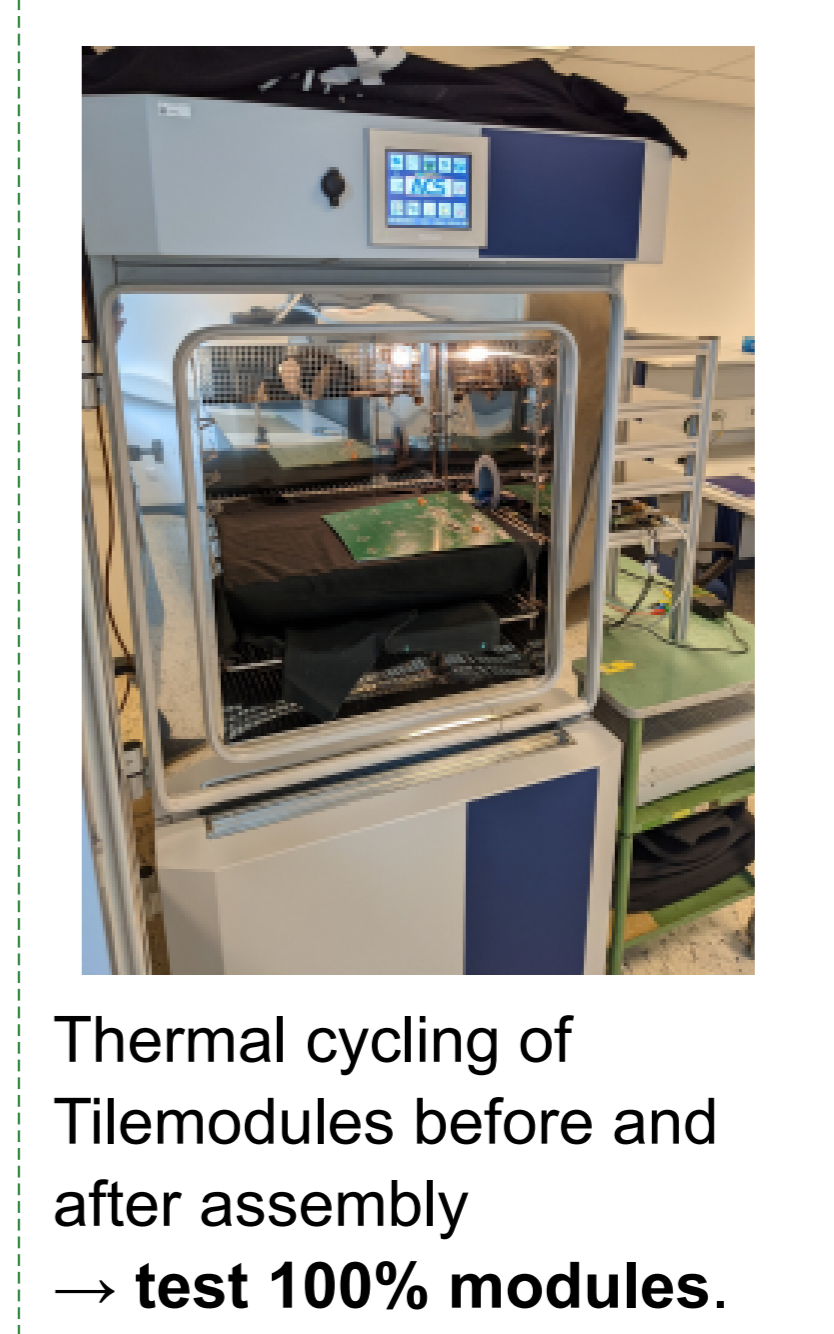


Document scanner 600 dpi + OpenCV image software.

Tile performance measurement using ^{90}Sr Source and LED System

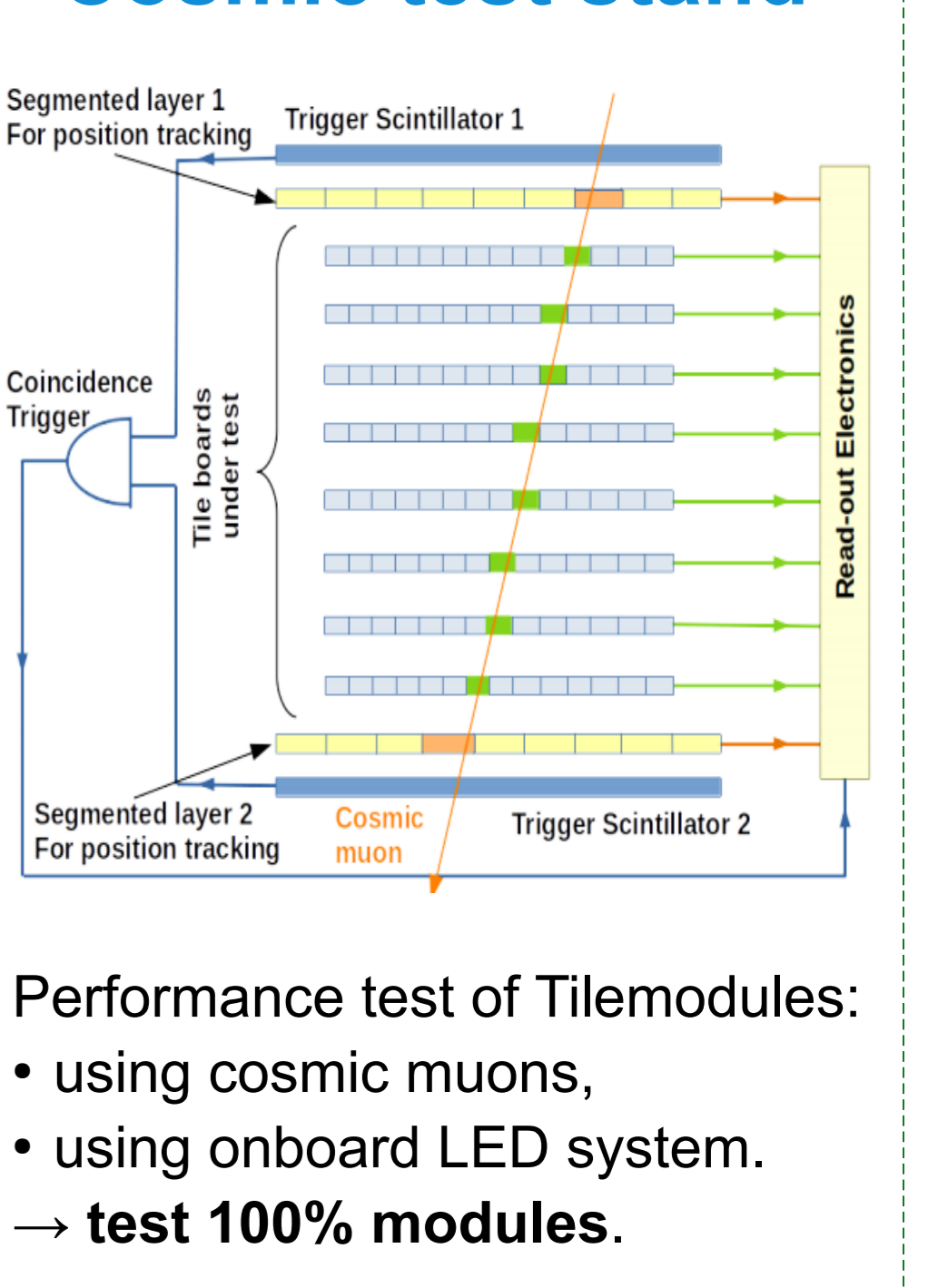


Cold test in a climate chamber



Thermal cycling of Tilemodules before and after assembly → **test 100% modules.**

Cosmic test stand



Performance test of Tilemodules:

- using cosmic muons,
- using onboard LED system.

 → **test 100% modules.**