The IIHE Contribution to the CMS Silicon Strip Tracker Upgrade

IIHE Annual Meeting 2025

***A. K. Das**, on behalf of the CMS Tracker Group*

Inter-University Institute For High Energies (IIHE), ULB

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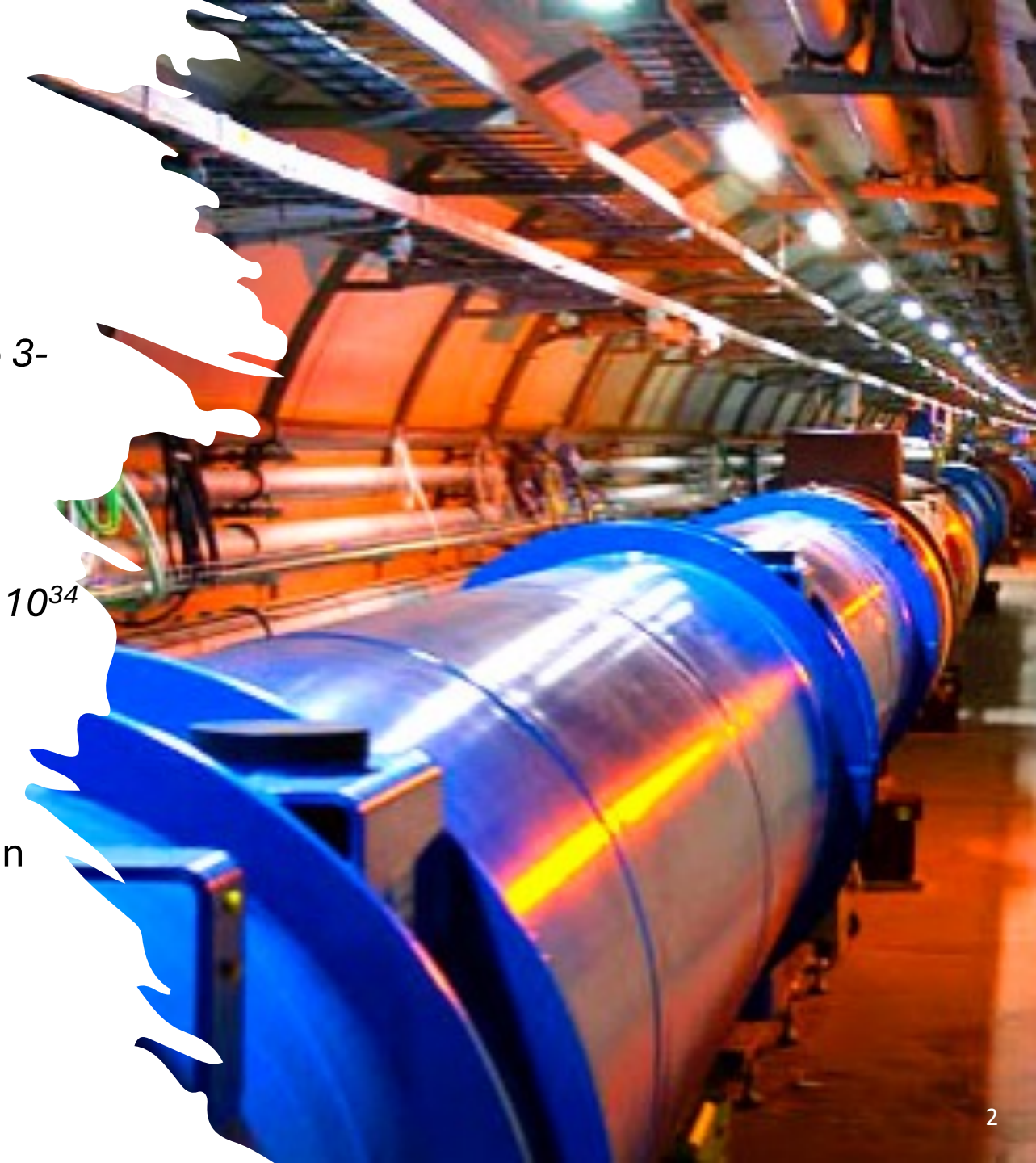
The HL-LHC :

- The LHC is getting upgraded
  - Increase in Integrated luminosity from *450fb^{-1}* to *3-4000fb^{-1}*
    - High radiation damage to the detector
  - Increase in Instantaneous luminosity from *2.2 x 10^{34} cm^{-2} S^{-1}* to *5-7.5 10^{34} cm^{-2} S^{-1}*
    - Average pile-up increases from 65 to ~200.
- To cope with this high pile-up and radiation condition

  we need better detector



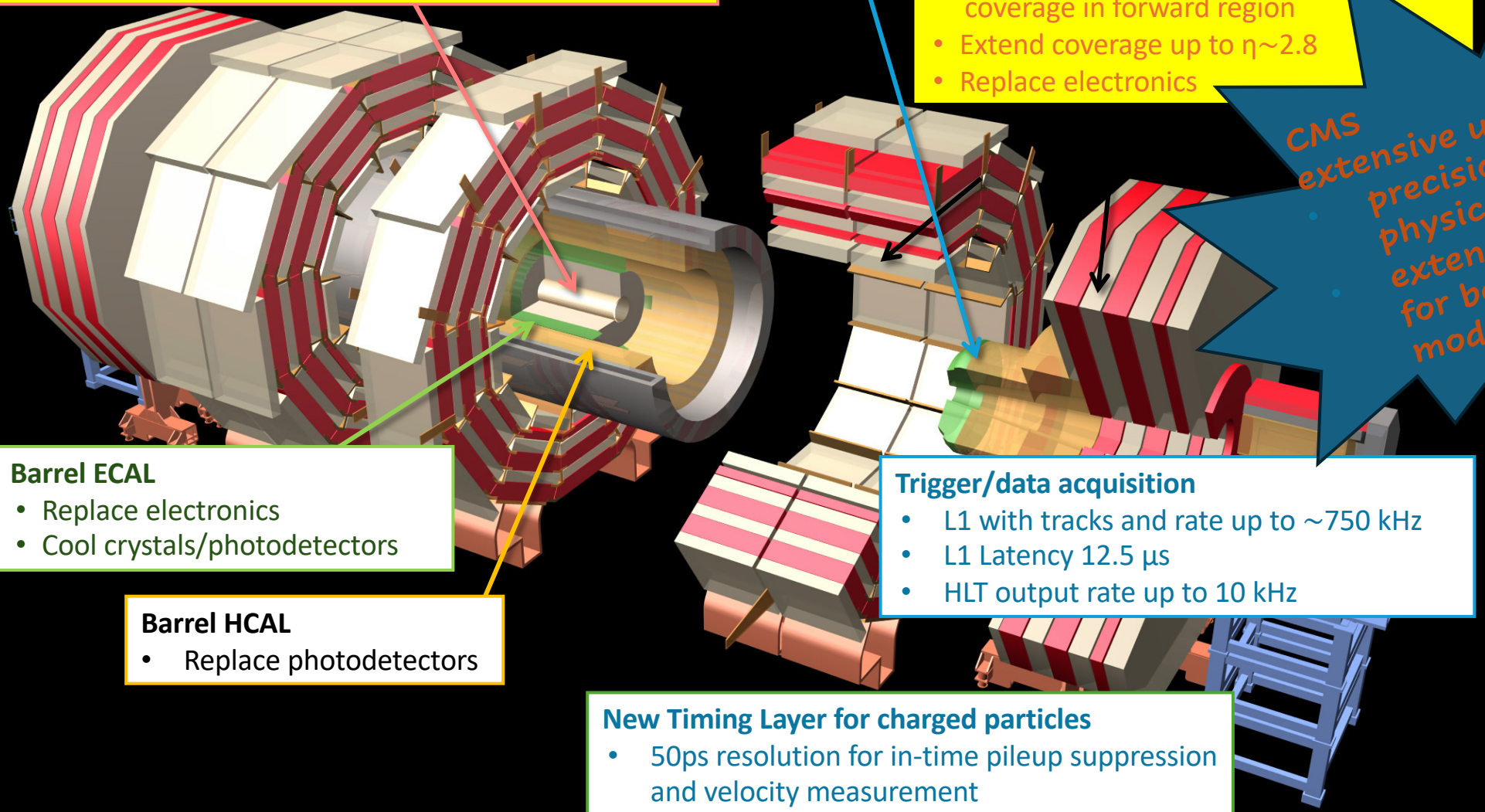
CMS Upgrade:

New Tracker
- Tracks in hardware trigger (L1) up to η~2.5
- Coverage closer to the beam (up to η~4)
- More precise momentum and impact parameter
- Radiation tolerant - high granularity - less material

New Endcap Calorimeters
- Radiation tolerant
- High granularity

Muons
- Complete resistive plate chambers coverage in forward region
- Extend coverage up to η~2.8
- Replace electronics

CMS extensive upgrade for precision H boson physics extended acceptance for beyond-standard model physics



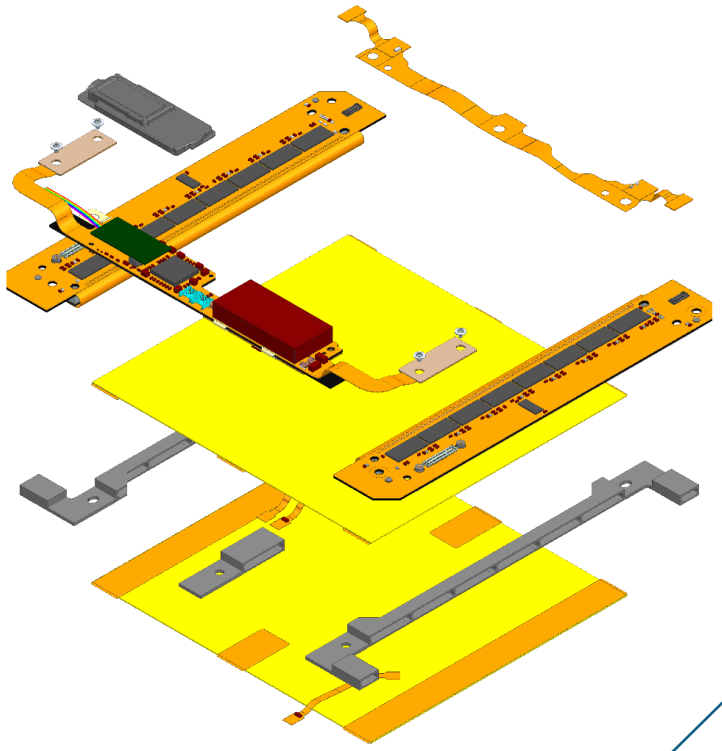
Barrel ECAL
- Replace electronics
- Cool crystals/photodetectors

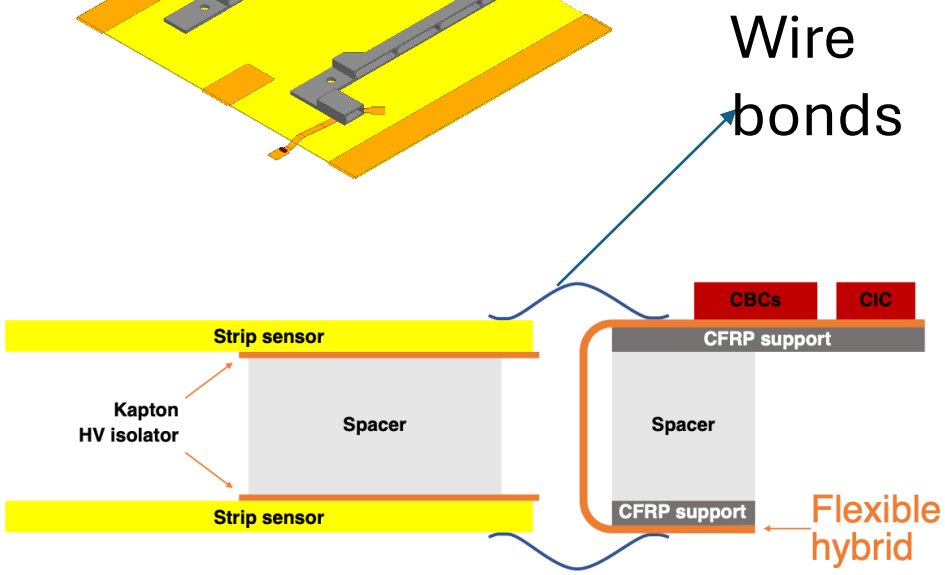
Barrel HCAL
- Replace photodetectors

Trigger/data acquisition
- L1 with tracks and rate up to ~750 kHz
- L1 Latency 12.5 μs
- HLT output rate up to 10 kHz

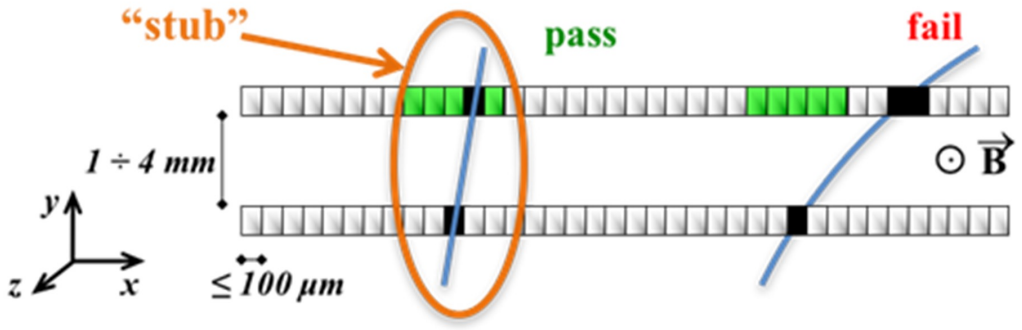
New Timing Layer for charged particles
- 50ps resolution for in-time pileup suppression and velocity measurement

Focus on Phase 2 Upgrade of CMS Outer Tracker



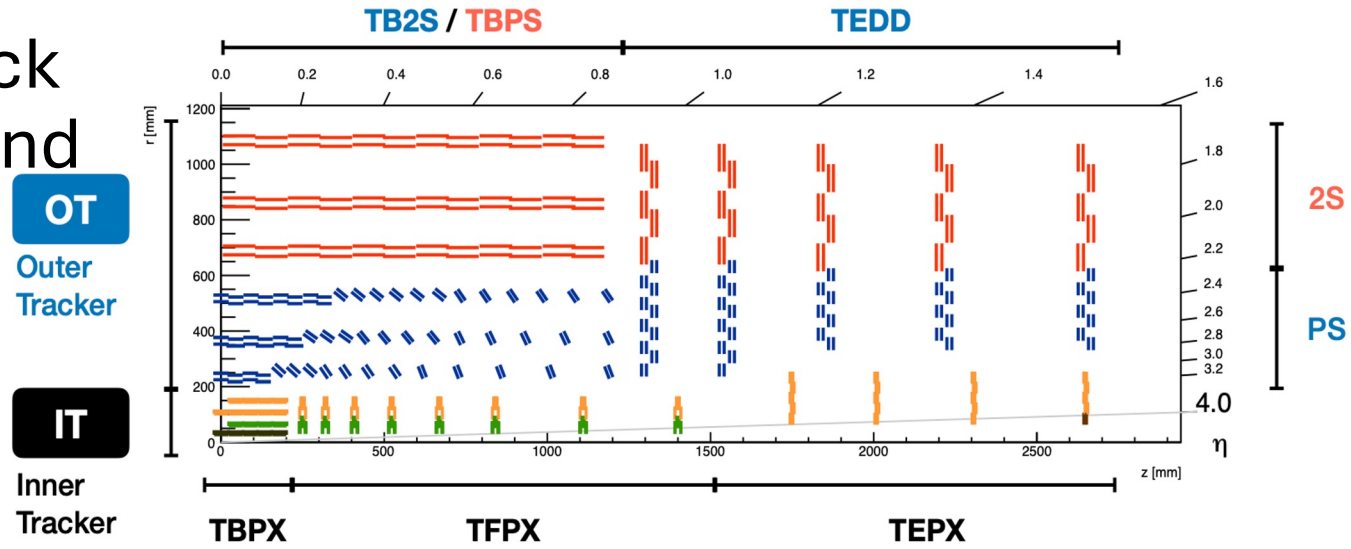


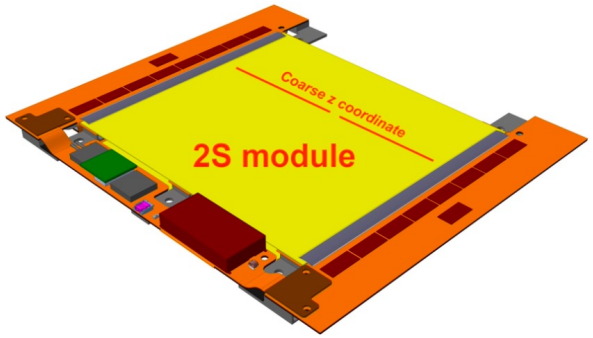
- Tracking triggering at Level1
  - Correlated hits on two closely placed silicon sensors
  - Predefined window on the second sensor discards low transverse momentum particles
  - This concept is called “track stub”

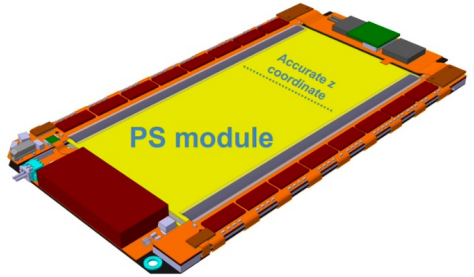


Outer tracker modules for Phase 2

- There are two different types of track stub modules organized in barrel and endcaps
  - **Strip-Strip(2S) module**
    - ~90cm2 area per sensor
    - 2x1016 strips: 5cm x 90μm per sensor
    - Forming the outer layers/rings
  - **Pixel-Strip(PS) module**
    - ~2 ×45 cm2 active area
    - 2 ×960 strips:~2.4 cm ×100 μm
    - 32 ×960 macro-pixels:~1.5 mm ×100 μm
    - Forming the inner layer/rings



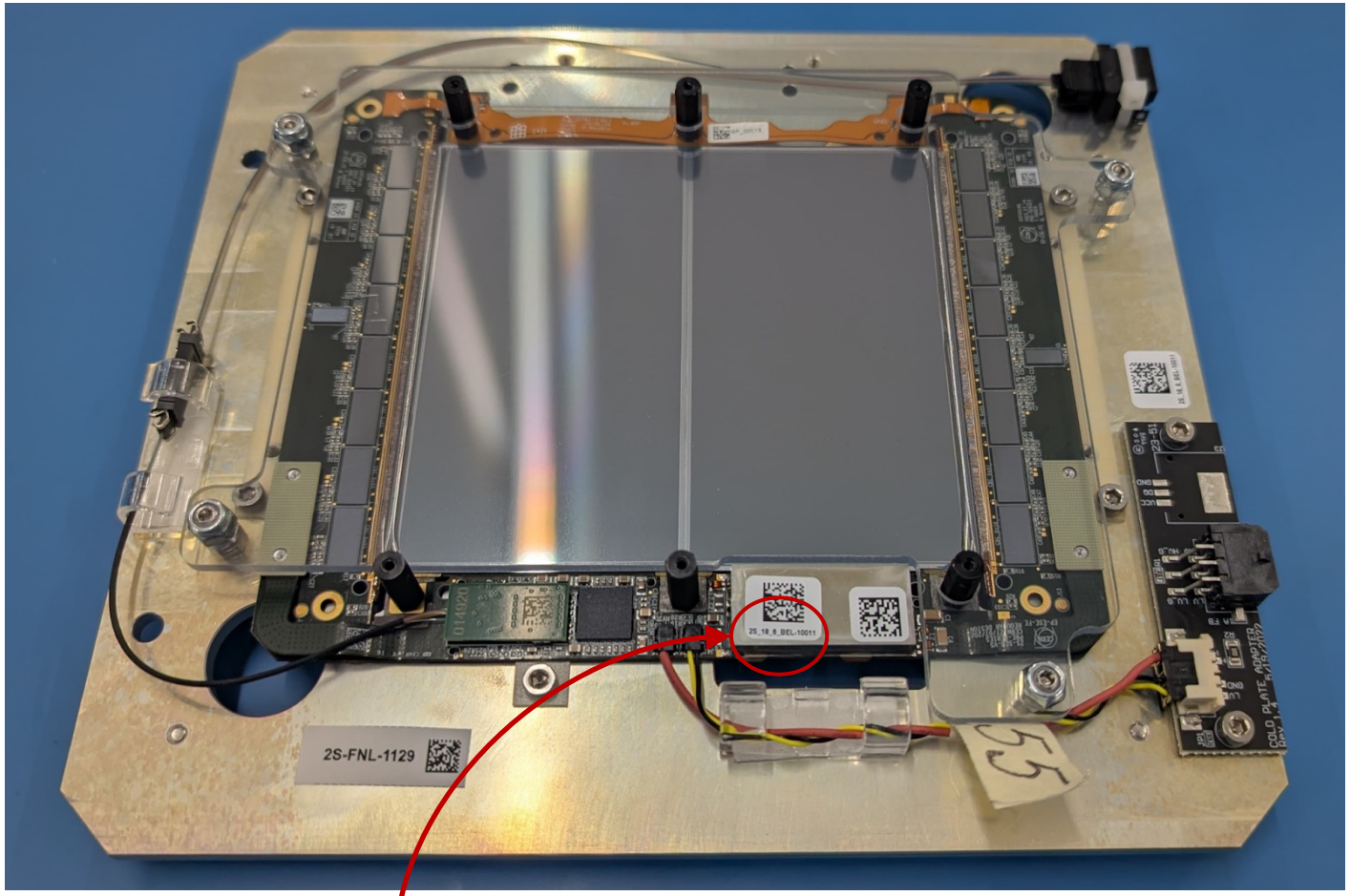




Total 13200 modules: 2S(7608), PS(5592)

- Being assembled in multiple centers across world

How a 2S module looks after the assembly at IIHE



18 : 1.8mm sensor spacing

6 cooling points

BEL assembly site

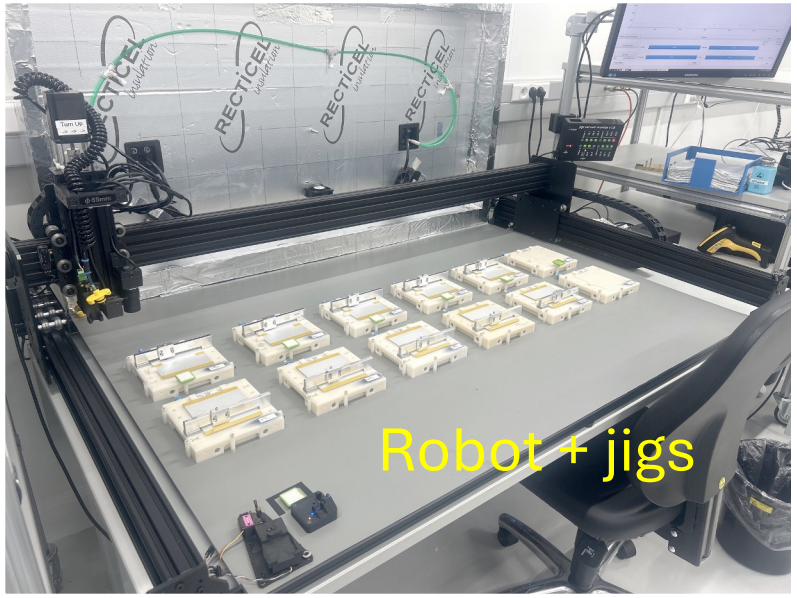
production label 10011

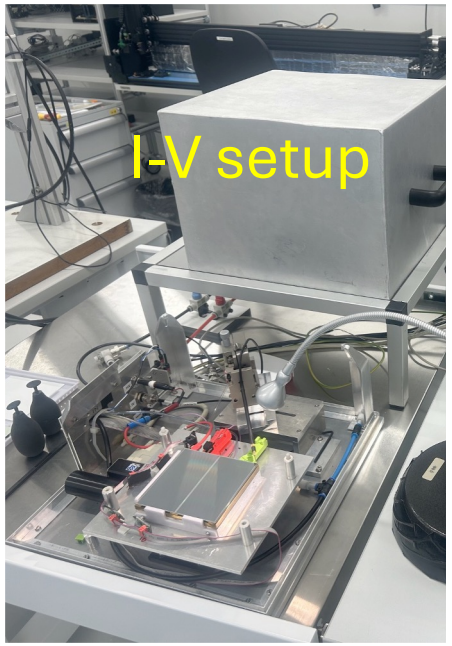
Belgian contribution to the CMS phase-2 tracker upgrade

- ✓ Team of >35 people from Universiteit Antwerpen, Universiteit Gent, Université Libre de Bruxelles, Vrije Universiteit Brussel collaborated at IIHE to:
  - ✓ Deploy 1 out of the 7 module production sites
  - ✓ **Build 1523 2S modules** + spares and test them fully
- ✓ Setting up and building facilities started 2016
- ✓ **Built more than 150 modules** already as of October 2025.
- ✓ In September we reached our **nominal throughput of 24 modules per week**.
- ✓ Integration and test of Dees and double disks (DD): in UCLouvain

University of Antwerp UCLouvain GHENT UNIVERSITY UNIVERSITÉ LIBRE DE BRUXELLES ULB VUB VRIJE UNIVERSITEIT BRUSSEL

2S module production site at IIHE





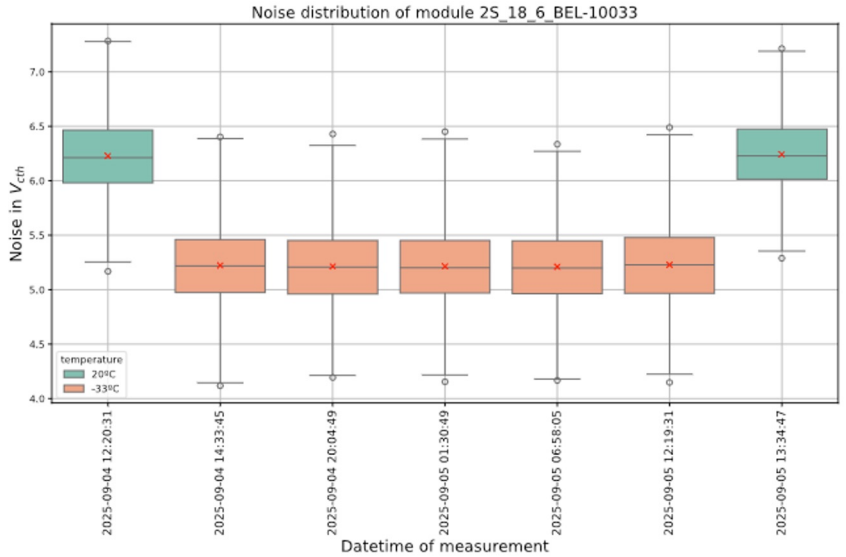
- **Local developments started in 2017**
  - clean room, glue doser, gluing robots, Si I-V setup, metrology, one type of jig (also for other 2S sites)
  - local database, production planner, GUI's
- Other jigs, setups for functional tests (KIT design), thermal cycling setup (Fermilab design)
- Industrial wire bonding equipment; high-end digital microscopes; dry storage,…
- Capacity of 6 modules per day

We make fine modules...

Two thermal cycling setups in Belgium

at IIHE

at UCLouvain



Noise of a module at 20°C and -33°C during 5 thermal cycles

MUonE 2025 test run

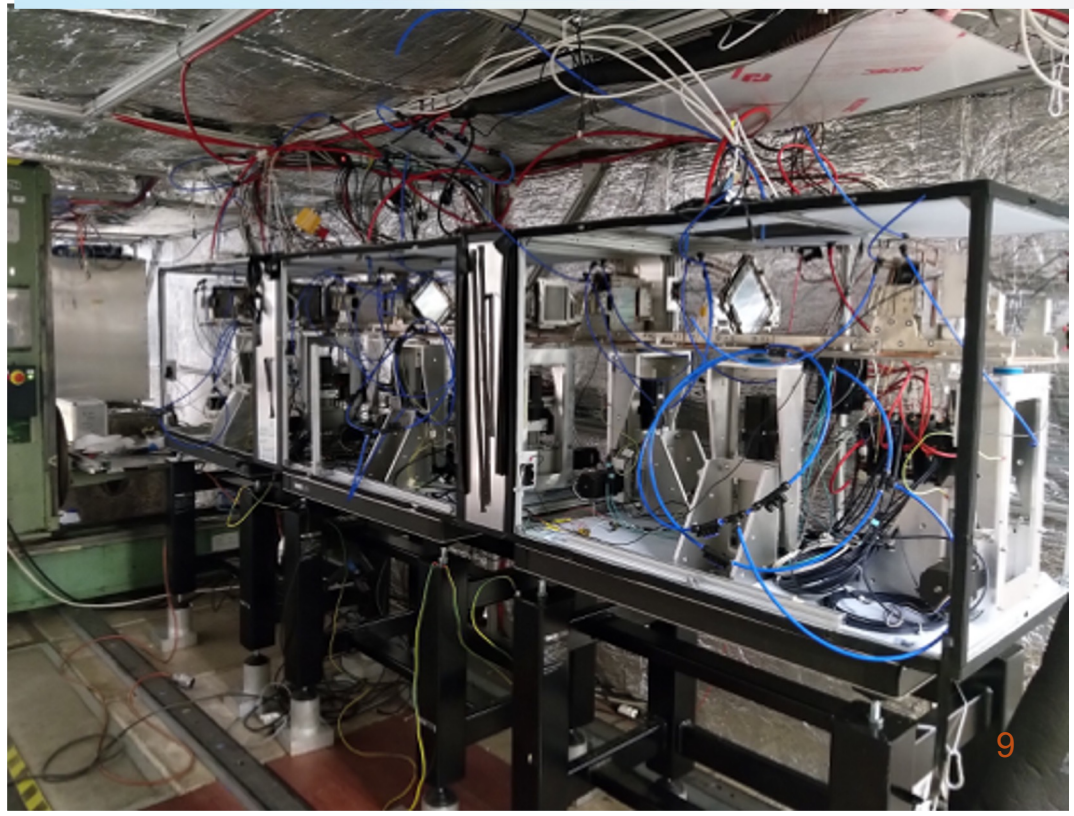
7(→6) production modules out of 18

STATION 1	
X0	2S_18_6_KIT-01002
Y0	2S_18_6_BEL-01002
U	2S_18_5_BRN-01001
V	2S_18_6_BRN-10001
X1	2S_18_6_KIT-10004
Y1	2S_18_5_KIT-10001

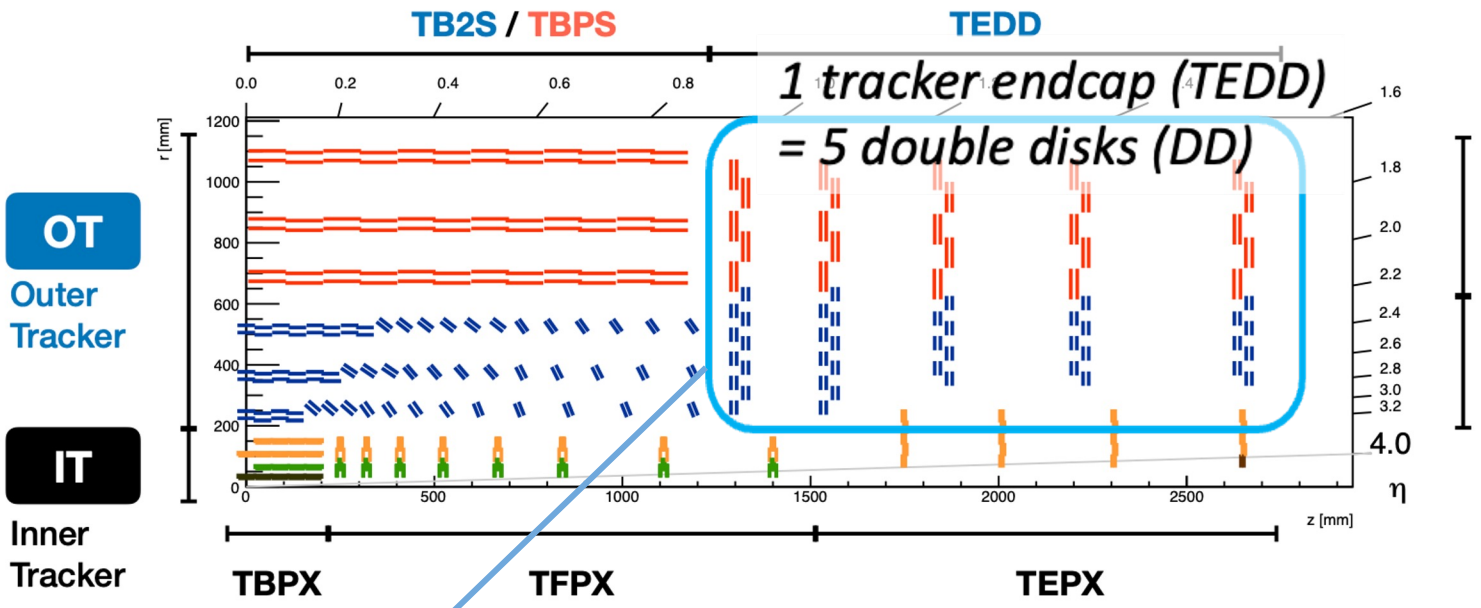
STATION 2	
X0	2S_18_6_BEL-10004
Y0	2S_18_6_BEL-10005
U	2S_18_6_BEL-10002
V	~~2S_18_6_BEL-10003~~
X1	2S_18_6_BEL-10009
Y1	2S_18_6_BEL-10010

2S_18_5_NIS-10001

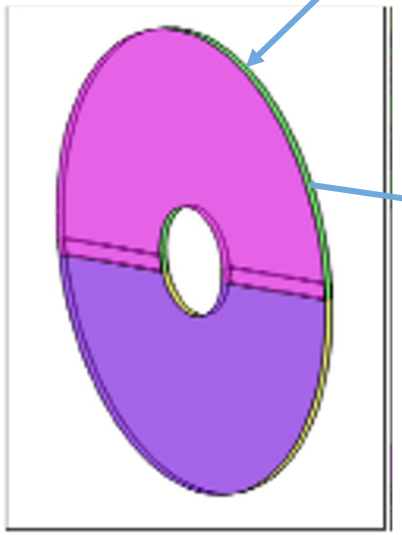
STATION 3	
X0	2S_18_6_KIT-10005
Y0	2S_18_6_KIT-10001
U	2S_18_6_KIT-10002
V	2S_18_6_KIT-10006
X1	2S_18_6_KIT-10003
Y1	2S_18_6_BEL-10001



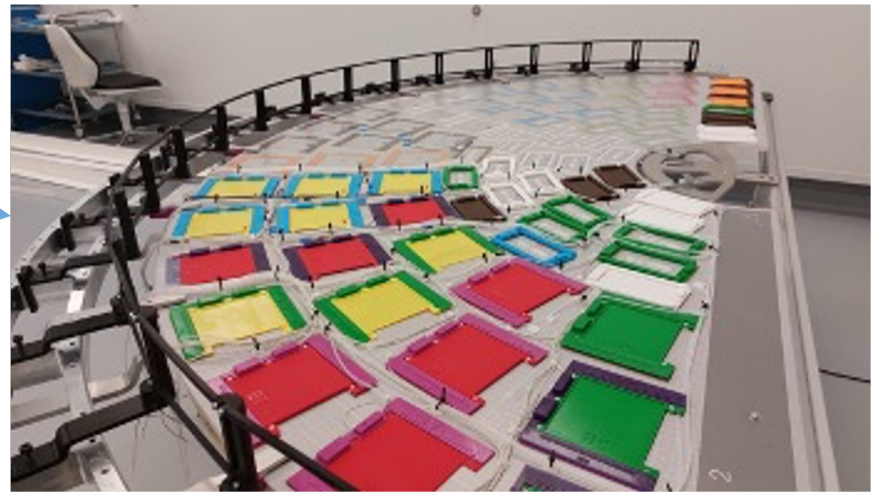
Dees and Double-Disks



1 DD = 4 Dees



1 Dee = 170 modules



In UCLouvain:

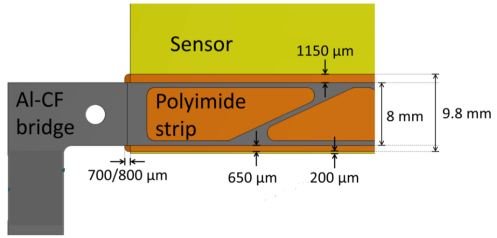
- Design TEDD services
- Design Dee integration process and deploy 1 Dee integration facility
- Integrate 12 Dees
- Deploy 1 of the 2 DD integration facilities
- Integrate 5 DD

- Services design was validated with mockups
- First Dee integration test done in April together with DESY and Lyon teams
- Dee test box is functional
- DD assembly was exercised successfully

UCLouvain

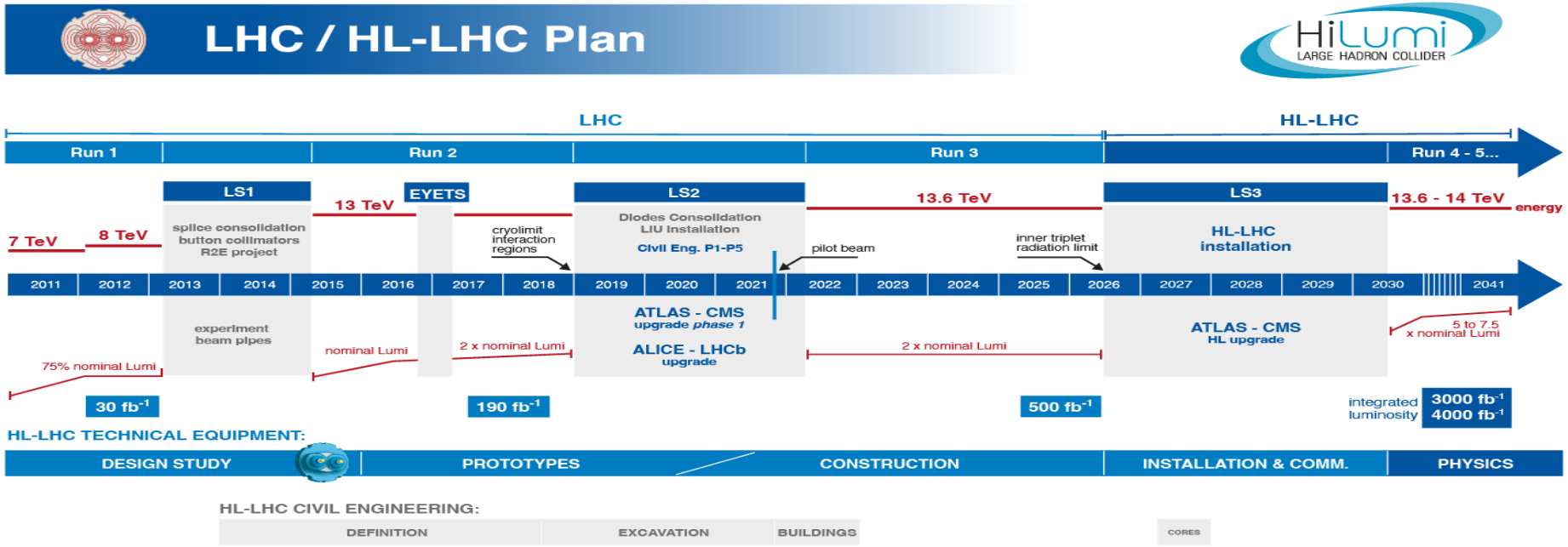
Current Challenges and Issues:

- Back End Power On Logic (BPOL12V) failure:
  - Local 12V DC-DC voltage converter in modules seems to fail/misbehave after irradiation and multiple power cycles
  - Chip that is used in all HL-LHC experiments and in most parts of each experiments
- Ground pin contact issue in Font End Hybrid(FEH):
  - Seems to be loosing contact with CF structure.
  - Addional soldering sloves the issue.
- Sparking between Service End Hybrid(SEH) and the sensor:
  - Observed in High Voltage when SEH is too close to sensors
  - Solved with additional Kapton strip Isolator attached at the edge of SEH
- Kapton isolator flim positioning accuracy:
  - Inaccurary may lead sparking between sensor and Al-CF spacors.
  - Very crucial specially with high througput
  - Image proccessing system being developed to monitor and ensure accuracy



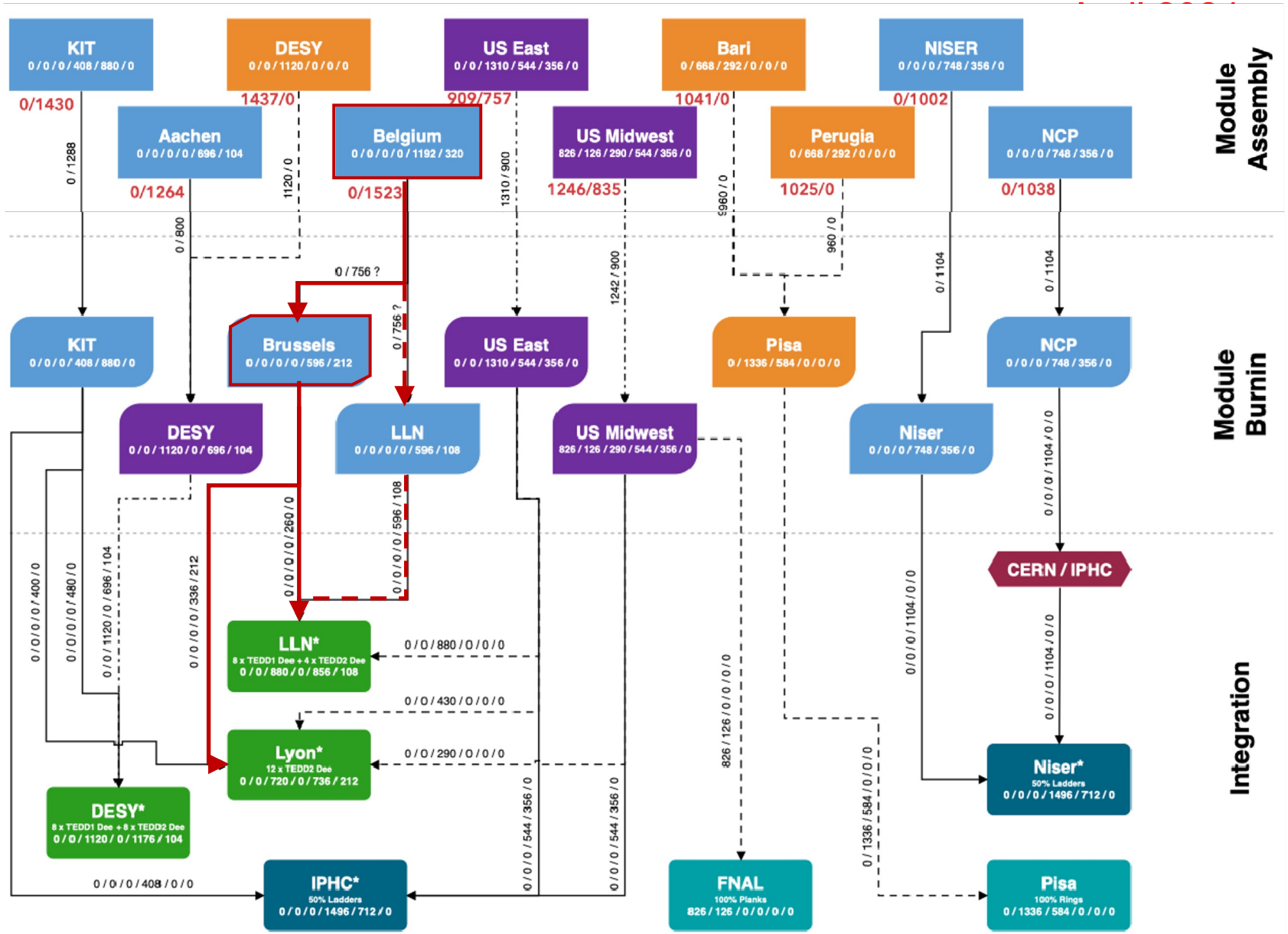
Summary:

- With HL-LHC, CMS Outer tracker is getting huge upgrade
- Financially and person power-wise, the largest Belgian contribution to a HEP project so far
- Our modules are performing well in MUonE test beam and in integration tests
- Learnt lessons from non-compliant modules and improvement being implemented
- Despite local and central challenges, we are determined to keep running our schedule



CMS Spoke person visit to our cleanroom

Back Up



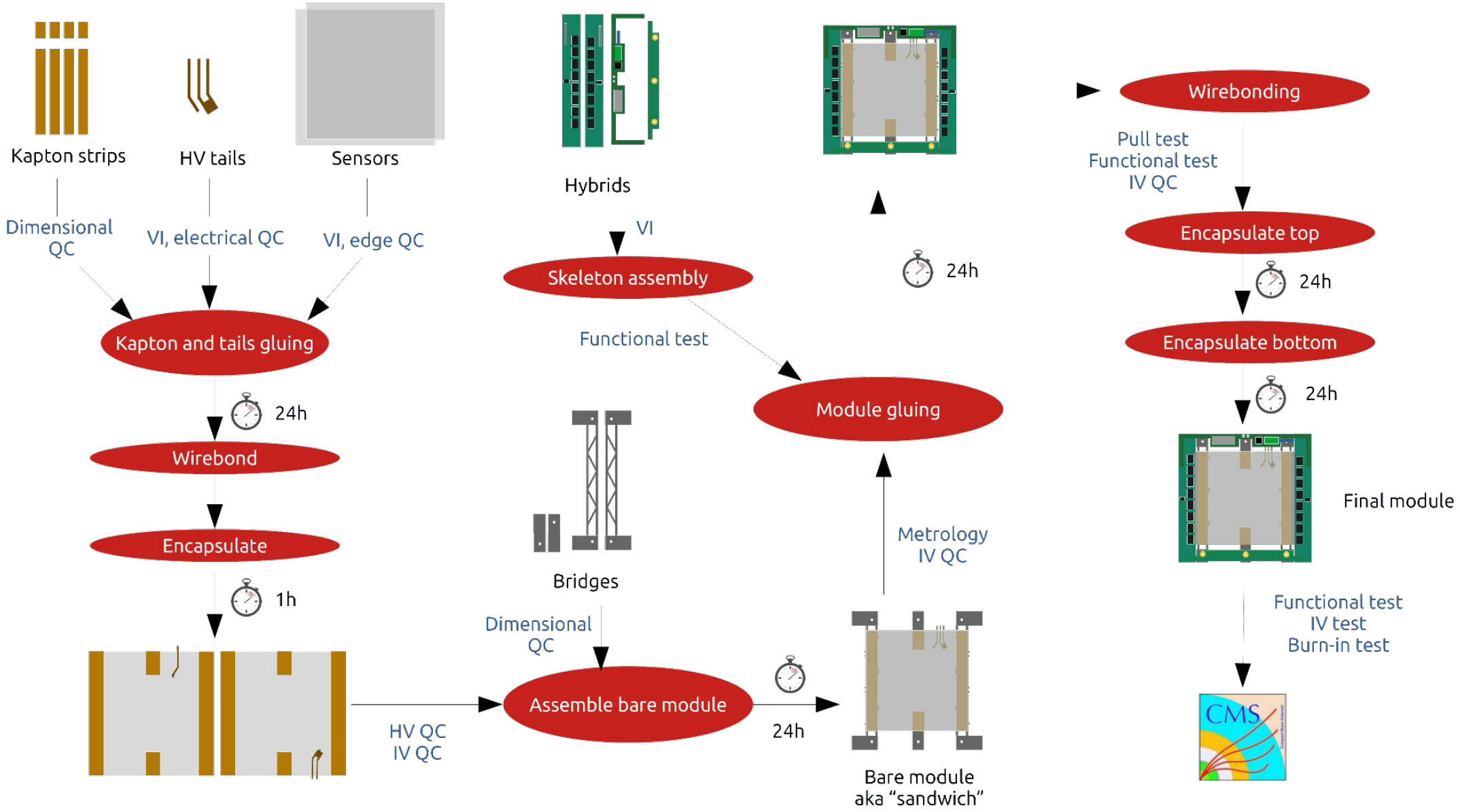
Module type list: 1.6 mm PS / 2.6 mm PS / 4.0 mm PS / 1.8 mm 2S 5CP / 1.8 mm 2S 6CP / 4.0 mm 2S

* Integration centers requiring setup for quick module reception tests

2S | PS | 2S & PS | TBPS | TB2S | TEDD

2S
PS
2S & PS

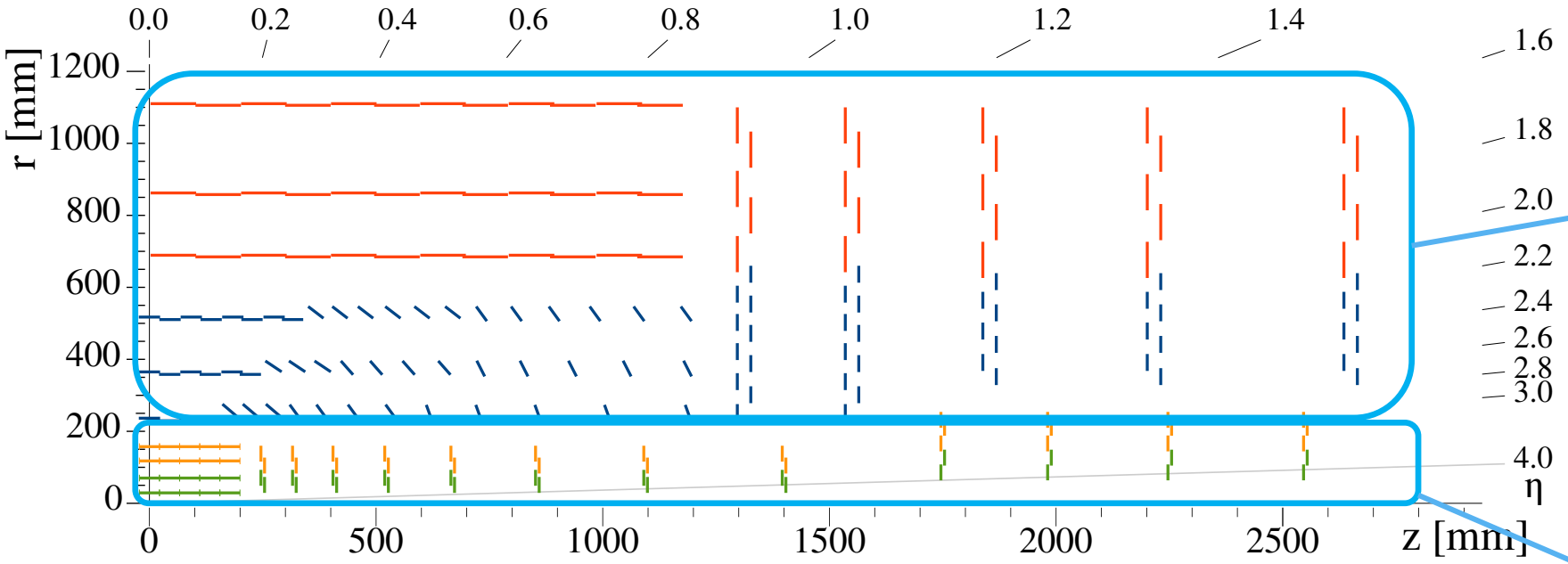
2S module assembly procedure



Our center specific development to ease the assembly process

- Production planner and Local database
  - Eases the task planning, book keeping of every parts and incidents
- Glue dosing system, Centrifugule to remove glue bubble
  - Eases the process of glue preparing and updating log in database
- Two self made gluing robot
  - one for kapton isolator gluing and other one for encapsulation of wire bonds, Kapton isolator gluing jig
- Glue curing system
  - To make sure the glue is cured in time
- Microscope on rails to monitor the sandwich gluing and hybrid gluing
- Metrolgy to test mechanical precision of the module
  - Autofocusing and Pattern Recognition and flexibility to easily switch between different category of 2S modules (4mm and 1.8 mm)

Tracker

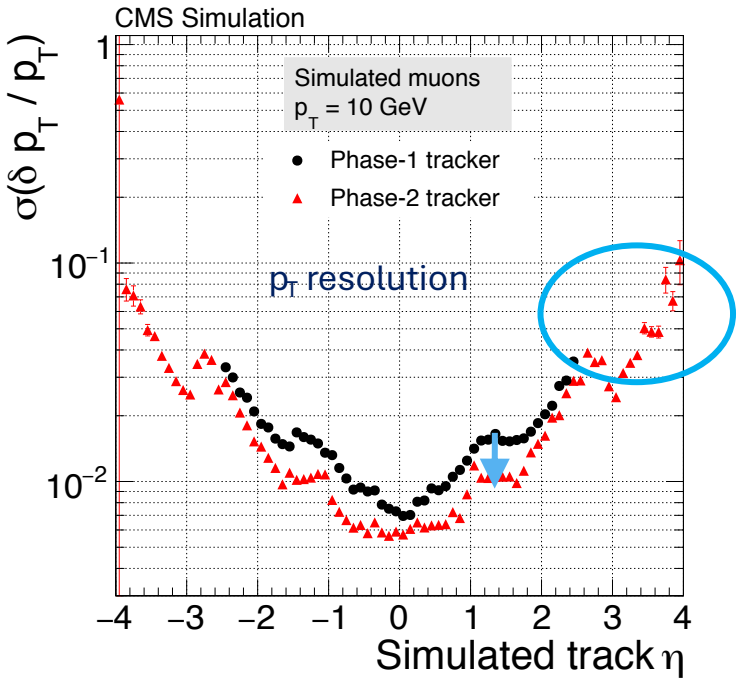


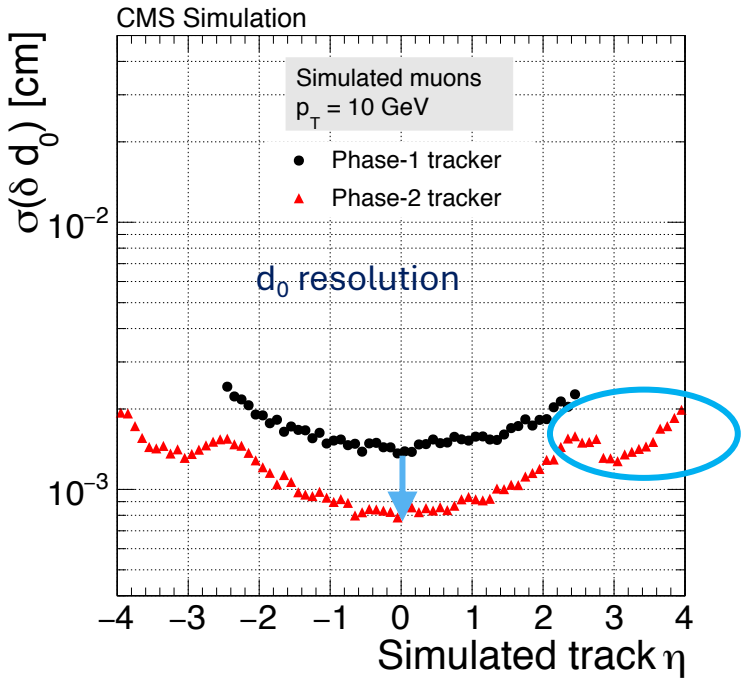
Outer tracker

- **"p_T modules"** with 2 sensors read out together
- **Tracking at 1st trigger level** downto p_T~2GeV, $|\eta|$~2.5

Inner tracker

- **6x smaller pixels than Phase-1 pixel detector**
- **coverage up to $|\eta|$=4**

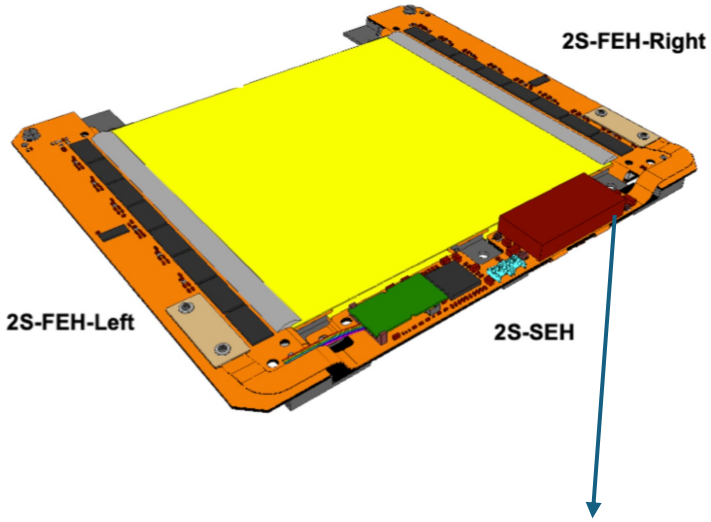




- More precise track parameters compared to Phase-1 tracker
- Extended coverage, allowing e.g. better forward jet reconstruction

Back **E**nd **P**ower **O**n **L**ogic (BPOL12V) Radiation-Induced Failures:

- **Function:**
  - Converts 12 V bus to 2.5 V for OT/IT modules.
  - Feeds second-stage buck converter (bPOL2V5) → supplies final ASIC voltages.
- **Issue**
  - Failures observed after Co-60 irradiation (35–70 MRad) during thermal cycling (ATLAS ITk, Summer 2025).
- **Investigations**
  - Failure traced by ATLAS teams in Freiburg.
  - Reproduced by CERN EP-ESE team using X-ray tests at B14.
  - CMS groups confirmed similar effects in irradiated 2S-SEHs and PS-POHs (protons 2023/24, neutrons 2022).
- **Observed Symptoms**
  - Input voltage spikes at power-on, worsening with thermal/power cycles.
  - Partial shorting between switches, more severe < −30 °C.
  - Failures accelerate at cold; annealing at room temperature further degrades devices.
  - Problem understood at chip level and can not be used in the presently foreseen way.
- **Impact**
  - Critical for OT & IT modules operating in high-radiation, sub-zero regions of CMS.
  - Significant delays to be expected for CMS Phase-2 upgrades

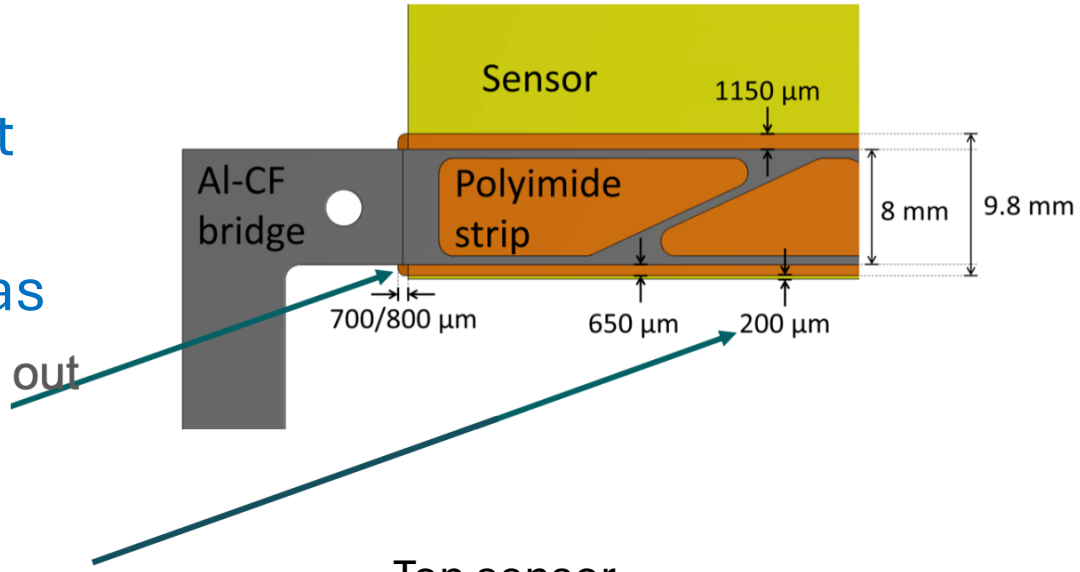


bPOL12V DC-DC converter

Kapton positioning in the module:

- Kapton strips are thermally conductive but act as electrical isolator between the CF spacor and the sensor backplane as well as sensor edge

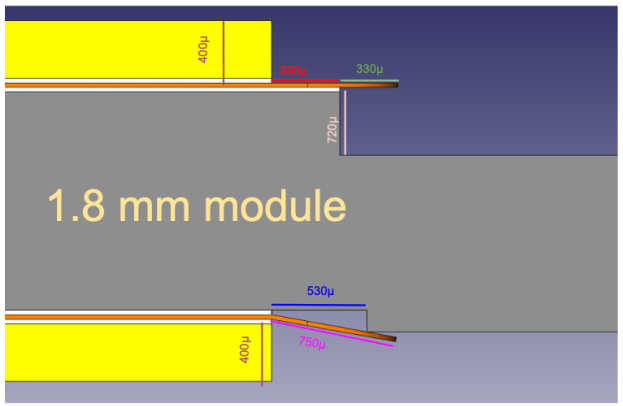
Sensor edge to sticking out kapton edge
700µ -200/+200µ



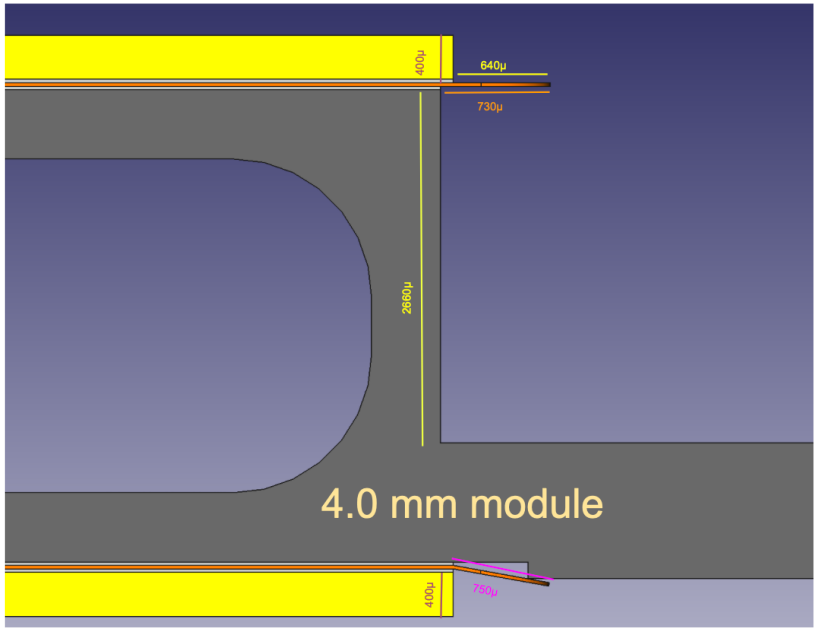
Top sensor

Kapton to sensor edge:
200µ, -200/+150µ

Top sensor



Bottom sensor



Bottom sensor

Dee and DD integration at UCLouvain

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- Dee test box is functional
- DD assembly was exercised successfully