CMS Detector Development:

- Phase II Tracker Upgrade
- GEM

Inna Makarenko on behalf of IIHE Phase II tracker and GEM teams

IIHE Colloquium

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IIHE-CMS Phase II Tracker Upgrade

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HL-LHC: CMS Phase II Tracker Upgrade

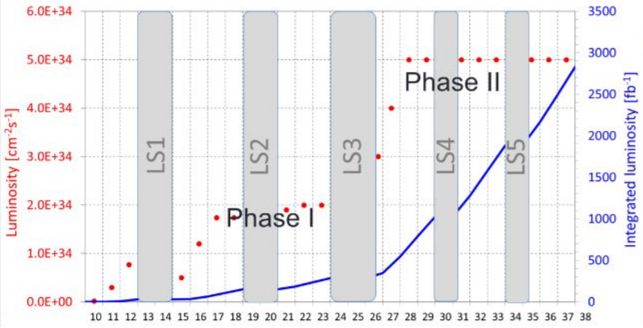
HL-LHC:

- 5-7 times higher beam intensity

  →An integrated luminosity of 3000 fb^{-1}

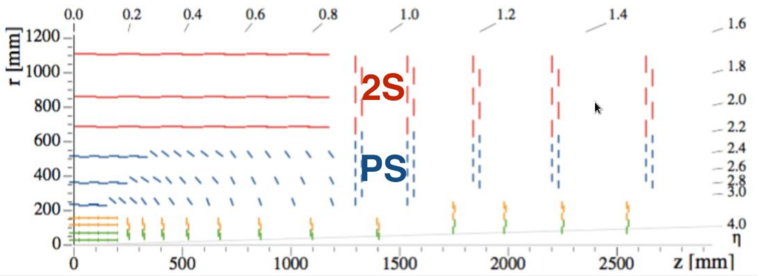
  →Pile-up 140-220 collisions per bunch crossing

leads to tracker features...↓



Tracker requirements:

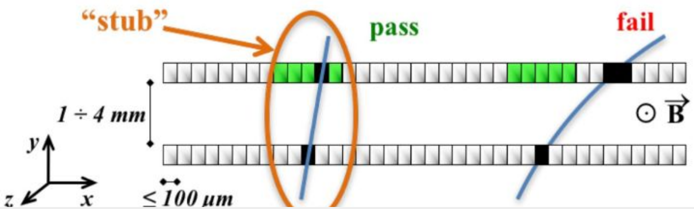
High radiation tolerance, increased granularity, improved momentum resolution and two-track separation, low material budget, extended tracker acceptance and first-level (L1) trigger

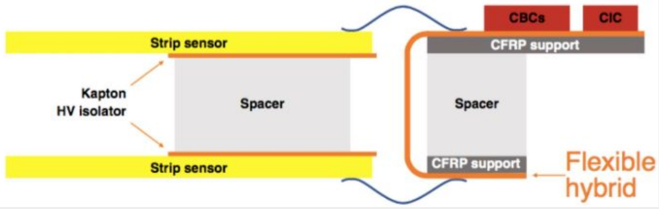


Readout chips will be able to perform fast reconstruction of momentum mini-vectors (stubs) of charged particles traversing two sensors of the detector module

Tracker features:

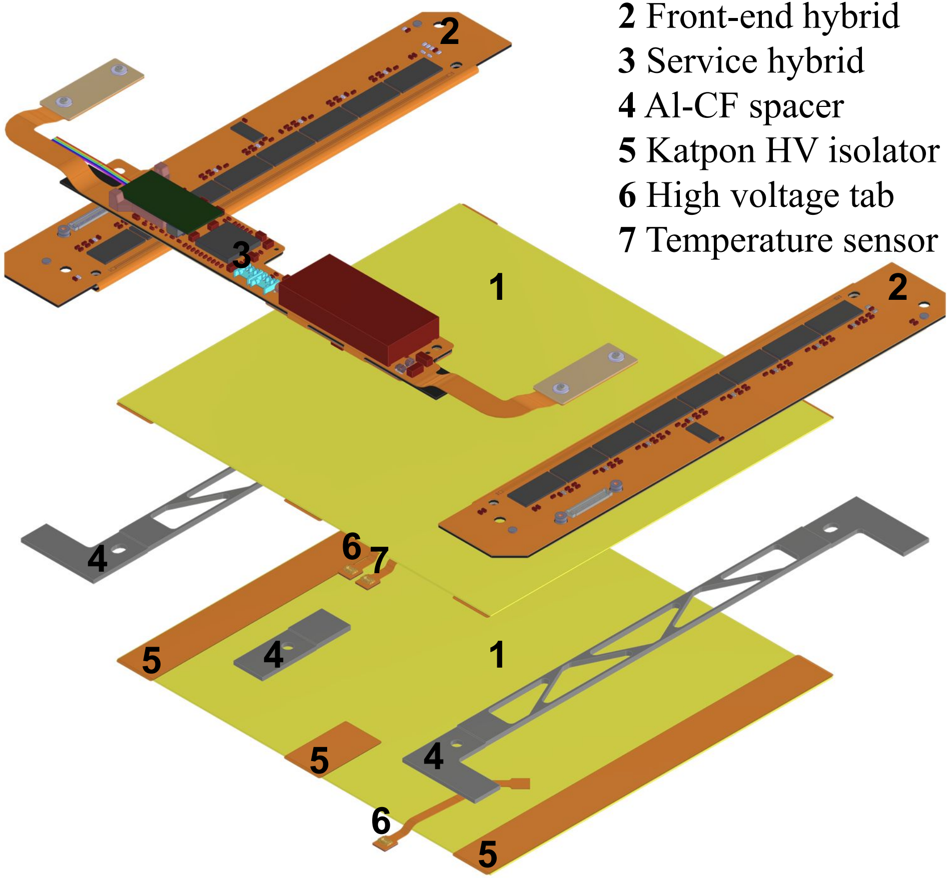
Trigger rates will be limited to 750 kHz at L1 and 7.5 kHz at the HLT. The L1 trigger latency will be about 12.5 μs



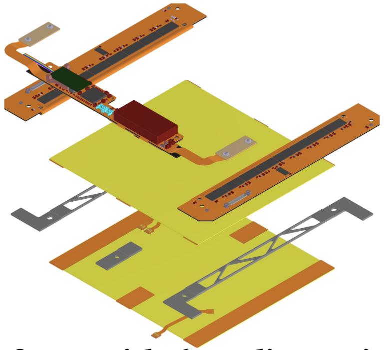


2S Outer Tracker Modules

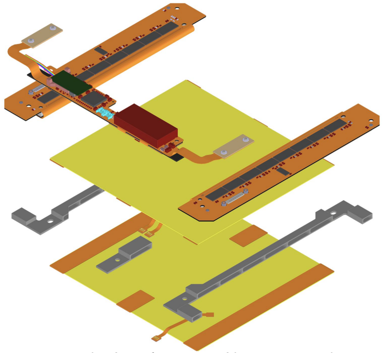
1 Strip sensor
2 Front-end hybrid
3 Service hybrid
4 Al-CF spacer
5 Katpon HV isolator
6 High voltage tab
7 Temperature sensor



1.8mm with 5 cooling points



1.8mm with 6 cooling points



4mm with 6 cooling points

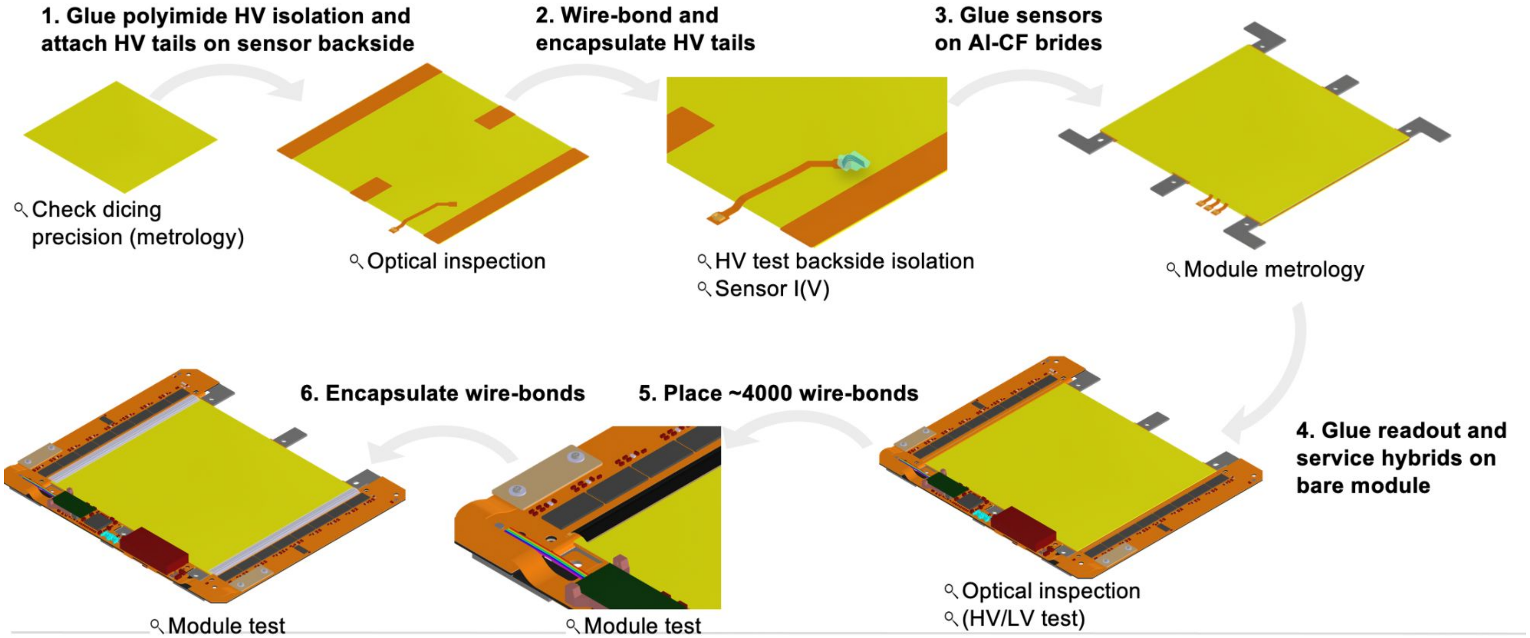
Requirements on the track stub transverse-momentum resolution close to an envisaged turn-on trigger threshold (about 5% for tracks with transverse momentum of 2 GeV) give following specifications for the sensor to sensor alignment:

- a shift perpendicular to the strips must be less than 50 μm
- a shift along the strips must be < 100 μm
- a tilt angle between the strips smaller than 400 μrad in 2S modules

Phase II Upgrade Schedule

- 2S Module pre-production & testing: scheduled to *start on 22nd of November 2022 for 35 weeks*
- 2S Module production & testing: *2nd of August 2023 - 2nd July 2025*

Assembly and Test Procedure of 2S Modules

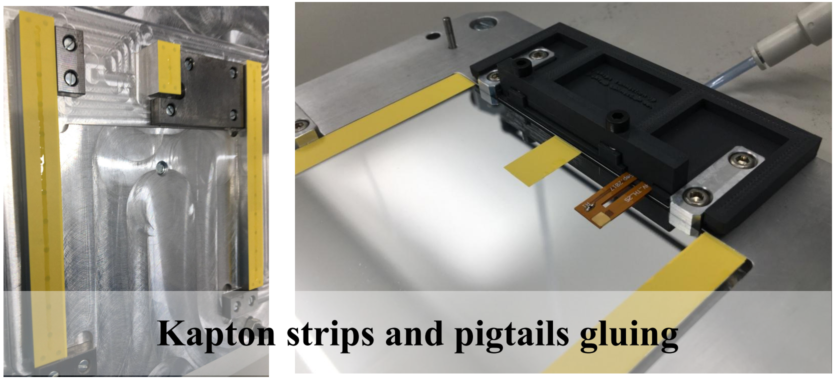


- *2000 2S modules (+spares) will be assembled in the production center at IIHE and delivered to DEES assembly centers*

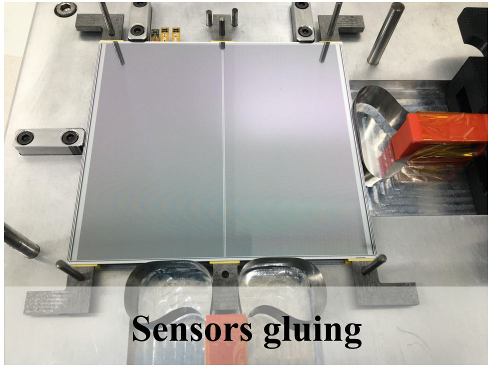
Production flow: acceptance of module parts, kapton gluing, HV tail building in, sensor gluing, metrology measurements, hybrids gluing, wire bonding, read-out module test, bonds pull test, encapsulation, read-out module test, thermal cycling, storing, shipping to DEES assembly centers

2S Modules Assembly: Gluing

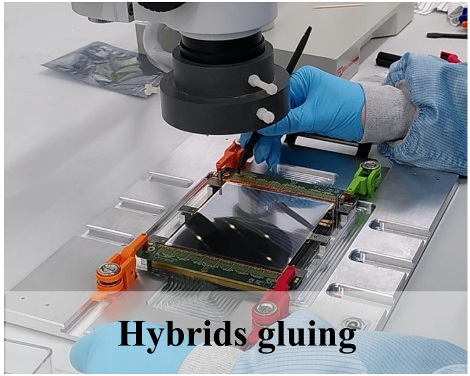
Construction precision is achieved using manual jig-based assembly techniques



Kapton strips and pigtails gluing

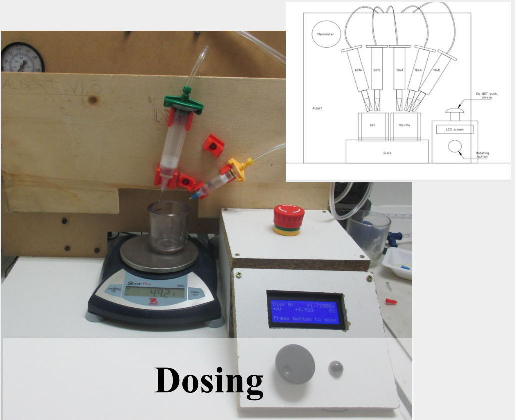


Sensors gluing



Hybrids gluing

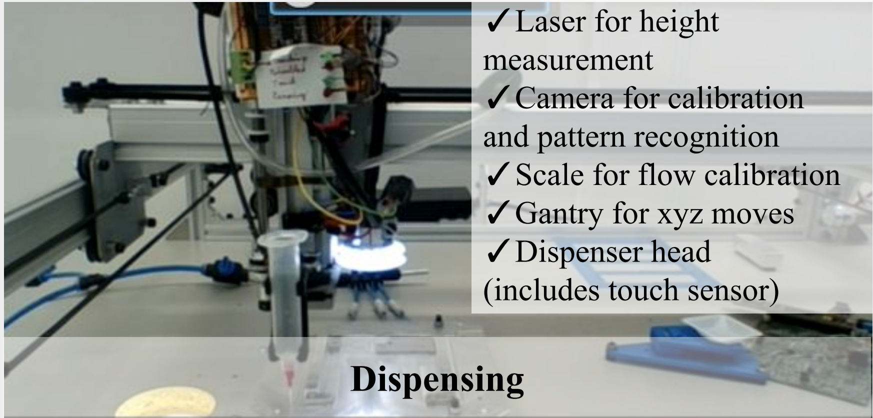
Multicomponent glues require:



Dosing

Mixing

Centrifuge

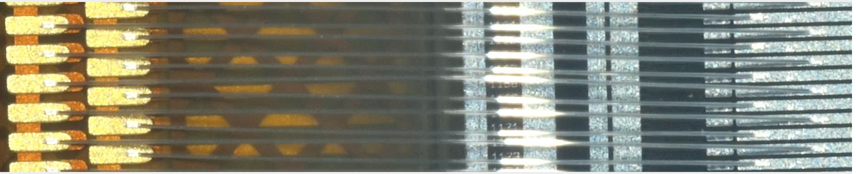


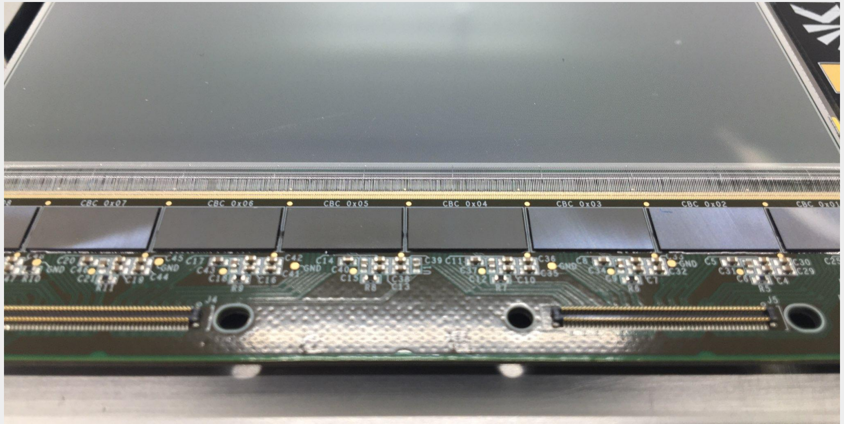
- ✓Laser for height measurement
- ✓Camera for calibration and pattern recognition
- ✓Scale for flow calibration
- ✓Gantry for xyz moves
- ✓Dispenser head (includes touch sensor)

Dispensing

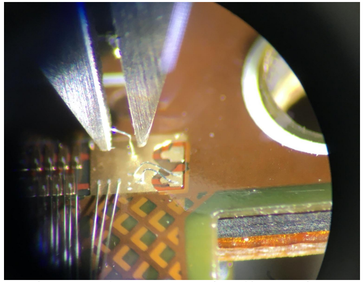
2S Modules Assembly: Wire Bonding and Pull Tests

High-end ***Hesse BondJet 820 bonding machine***
→capable of making 3-7 bonds per second at a pitch of less than 100 microns
→4176 bonds/2S functional module
→pitch size is 90um
→Al wire with 25um diameter





Royce650 pull tester machine includes also tweezer module for removing bonds:

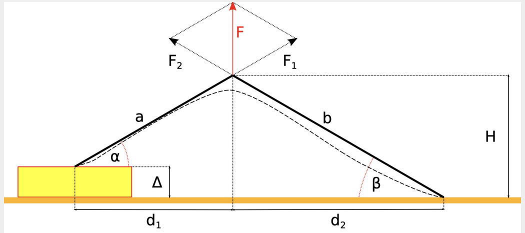


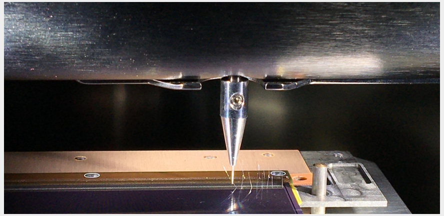
<u>We are developing automated procedure for predefined sequences [for example: dispose of broken wires]</u>

Bonds quality

6. Pull test requirements (for all extra readout pull test wires added in a module, minimum 10 wires per row, thus 40 wires total, also note that pull force values should be corrected for angle): mean > 8g, RMS<10% of mean, <20% lifts. In

see next slides





Always good and consistent results → each parameter satisfies requirements

Sensor and sandwich metrology

Why metrology?

Dimensions of sensors and correct alignment of the two sensors of the 2S module ("sandwich") crucial to later determine p_T and position of charged particles correctly!

Measurement types:

✓Dicing angles: silicon strip sensors correctly sliced?

- *HOWTO:* usage of xyz stages and camera plus automatic edge detection (openCV package) and fit of edge positions to determine dicing angle of each edge

✓Sensor alignment: no tilt and no shifts between top and bottom sensor of sandwich?

- *HOWTO:* usage of xyz stages and slightly tilted camera plus automatic z focusing; taking pictures of two corners (top and bottom sensor), then rotating sensor by 180° for other two corners (correction for camera tilt)

✓Hybrid alignment: pads of hybrid aligned with pads of top sensor?

- *HOWTO:* usage of xyz stages and camera, taking pictures of first and last bond pad of each hybrid and of top sensor

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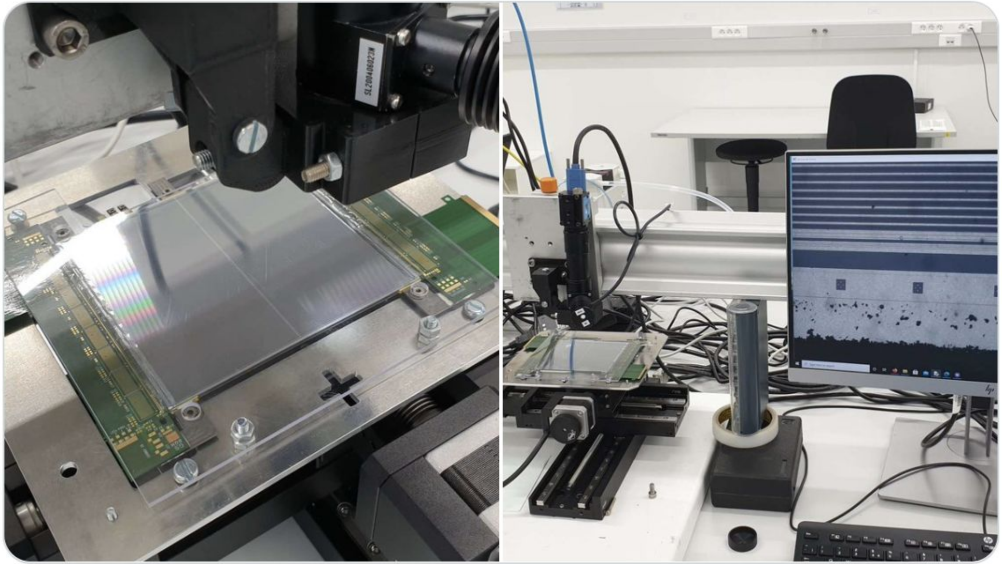
@IIHE_BXL

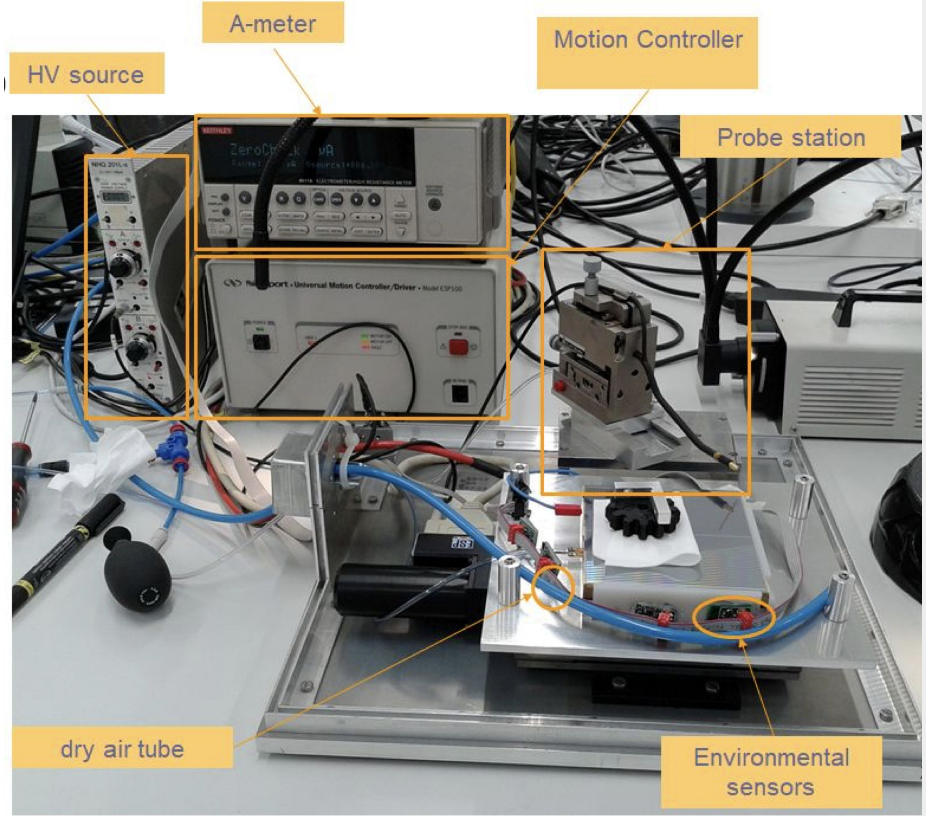
Did you know we are building an important part of the #CERN @CMSExperiment in #Brussels? This sensor uses technology similar to a phone camera, thousands of them will be combined by 2027. The machine aims to always take sharp pictures to check the sensor @FWOVlaanderen @frsFNRS



Uncertainty of ±10 μm on all measurements

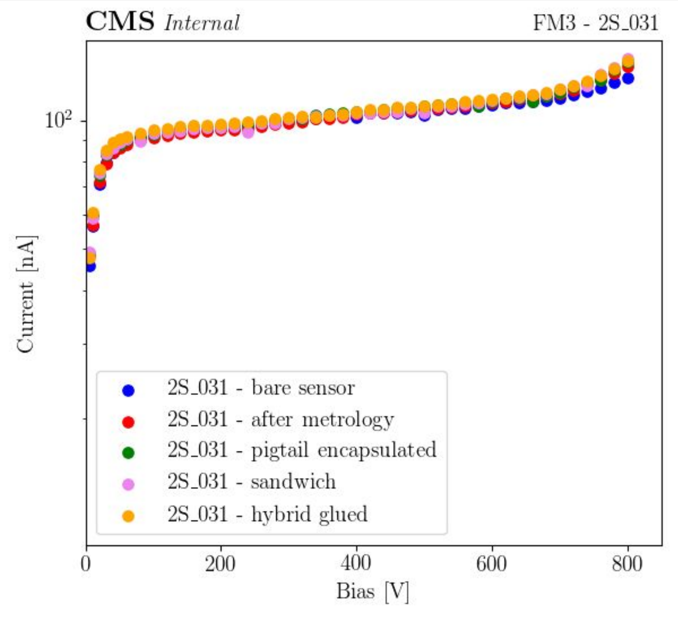
IV (leakage current vs. reverse-bias voltage) measurements

IV measurement allows for finding almost all possible problems in the sensor production process by a deviation from the expected shape



The leakage current is sensitive to damages and contaminations

→ it is a measure of the quality of the sensor modules and the assembly procedure



During prototyping stage, IV measurements are performed at almost every step of the complex module assembly process

Hybrids and modules tests

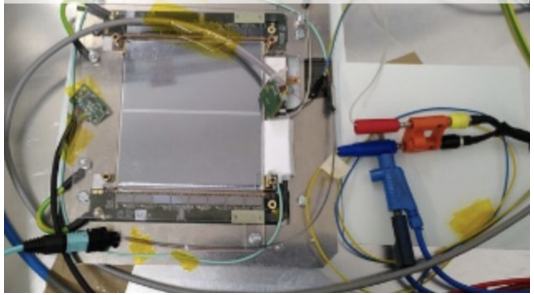
Main goals of hybrids QC are:

- ensure that the end product fulfils quality criteria according to specification
- ensure high reliability of the product
- achieve high yield and uniform properties of delivered components

Testing of hybrids and modules during production will be based on *noise measurements*

Noise originates from many sources
→ Environment
→ Temperature
→ **Electronics**
→ **Sensors**

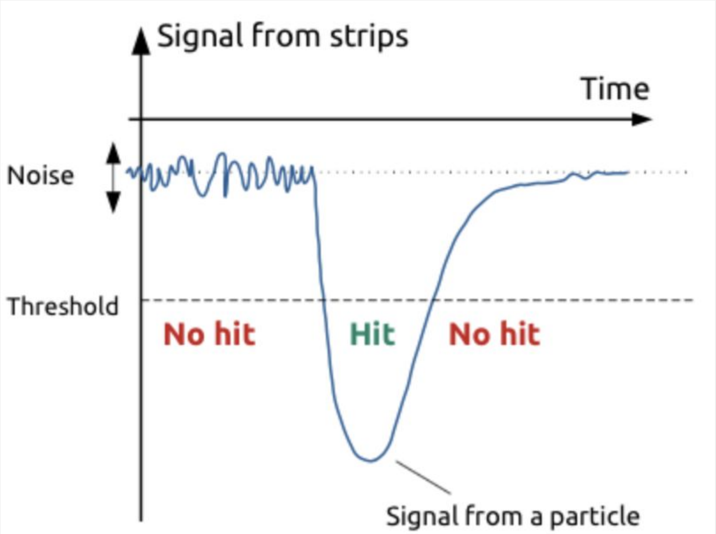
Modules noise measurement setup



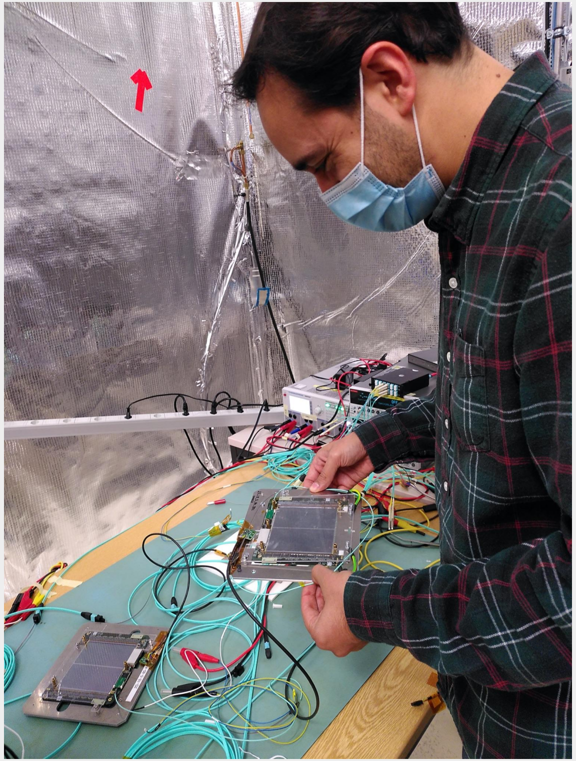
Measuring its value during production allows to detect possible defects :

→ Badly connected chip
→ Broken wire bond
→ Scratches on silicon
→ ...

Even with no particle crossing the sensors, the signal from strips will randomly fluctuate



Our first functional module with optical readout is running successfully in the CERN test beam environment!!!

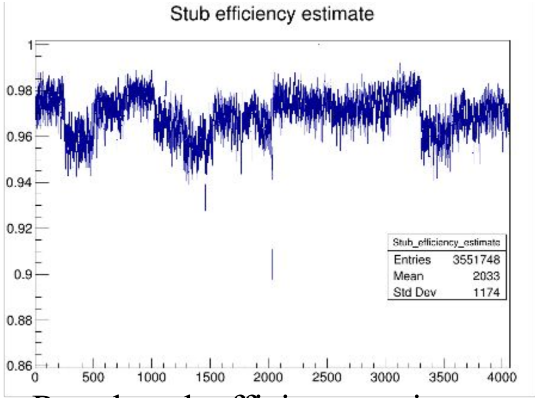


Our module was just placed in a beam line at CERN

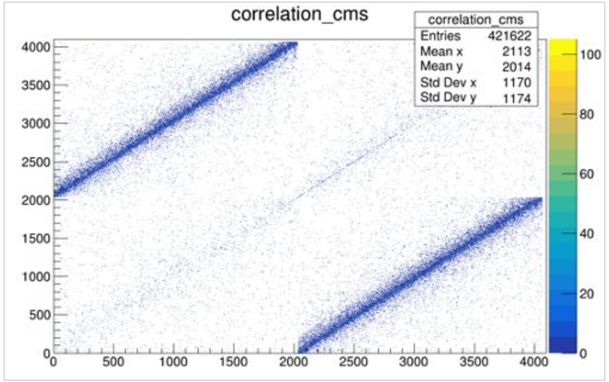
→ Continuous 40MHz stubs read-out

→ Multiple modules

First peek at data looks encouraging!

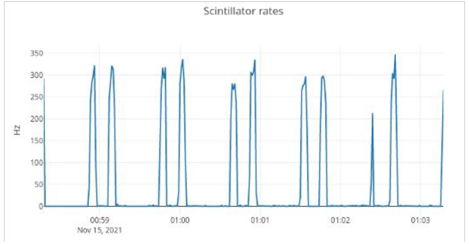


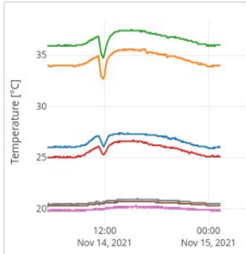
Rough stub efficiency estimate



Correlation between modules

__Our custom environment monitoring setup has proven once again to be very useful!__



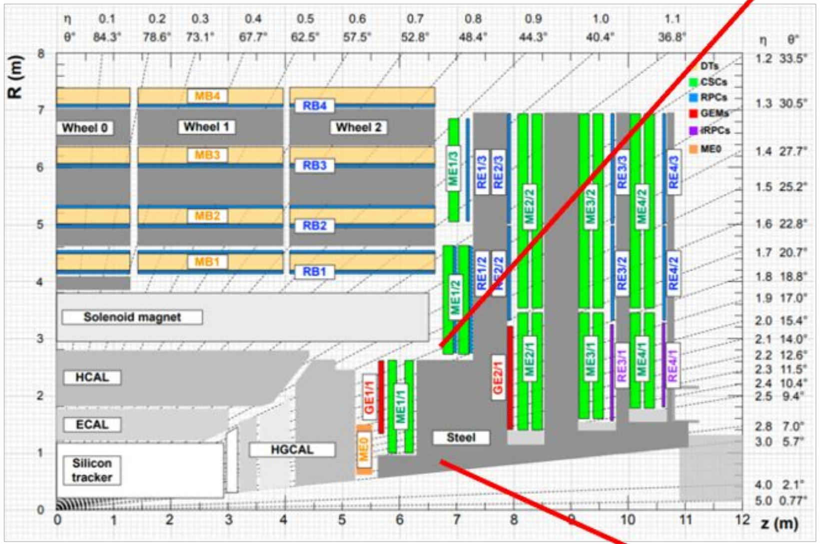


GEM

Itana Bubanja, Patrick De Harenne, Gilles De Lentdecker, Benoît Denègre, Aamir Irshad,
Johny Jaramillo, Michael Korntheuer, Laurent Pétré, Yifan Yang

GE1/1

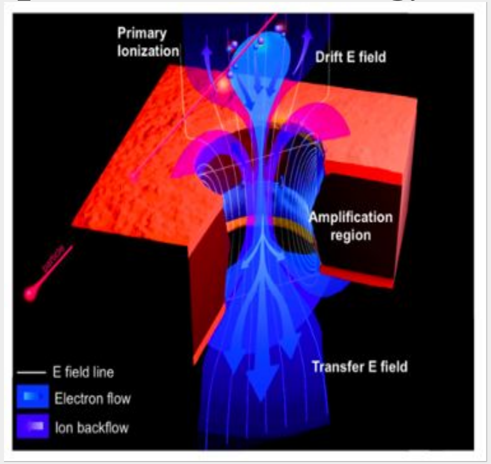
- To improve muon trigger & tracking capability in the most forward part of CMS
- Use space left vacant (<10 cm of space) by un-installed RPC
- Particle rate > 1 kHz/cm^2



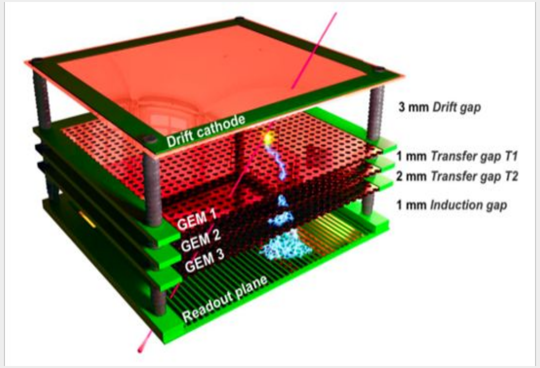
Coming next:

- GE2/1 (2023-24): ***increases the level of hits for a traversing muon from six to eight***
- ME0 (2025-26): ***will act as the very forward muon tagger***

Triple-GEM technology:

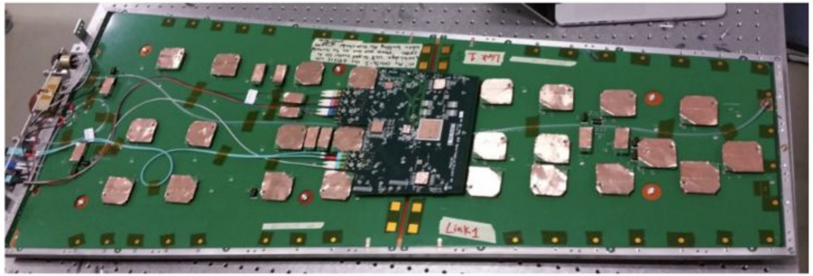


The ionized electrons multiply at each foil layer, for a total gain of approximately 10^4 at the readout board

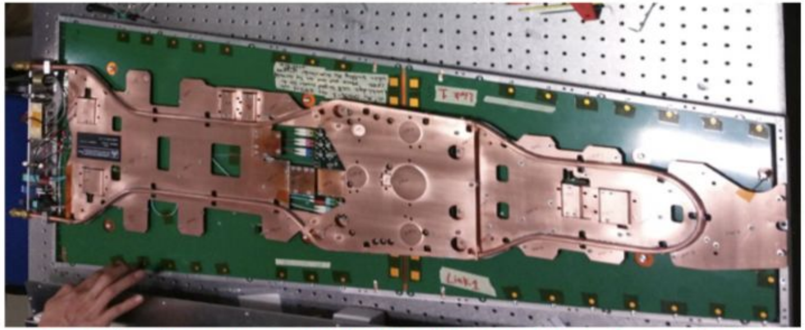


GE1/1

- GE1/1 detectors are the largest GEM detectors ever built
- GE1/1 consists of 144 detectors assembled in pairs called super-chambers (36 super-chambers per endcap)

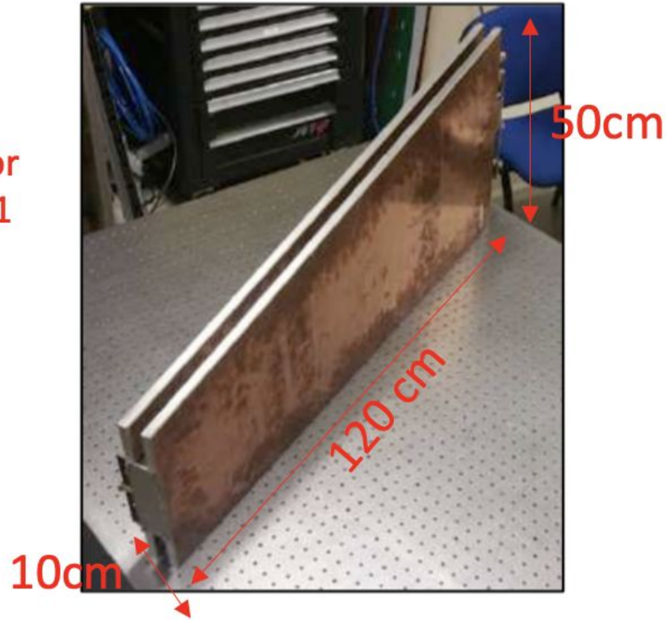


GE1/1 detector with FE electronics



GE1/1 detector with FE electronics & cooling

3072 channels/detector
442k channels in GE1/1

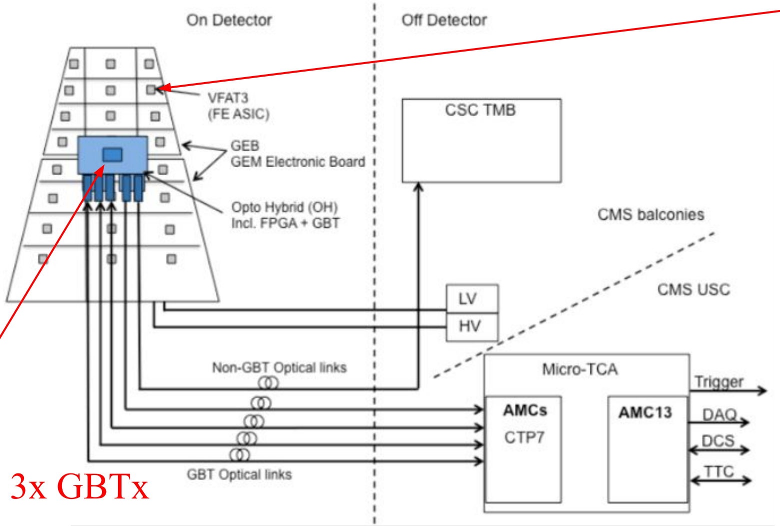


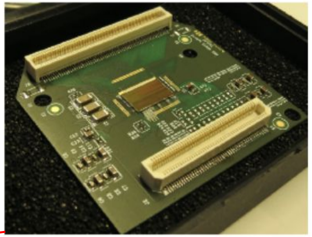
A GE1/1 super-chamber

GE1/1

- IIHE contributions:
  - Electronics design & coordination
  - DAQ software (framework and code)
  - Detector Control system (DCS)
  - Data (including trigger) analysis
  - …

GE1/1 electronics architecture:

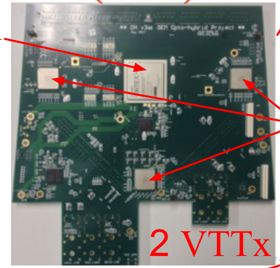




VFAT3 hybrid
(Aamir)

Complex small (5x5 cm^2) PCB hosting VFAT3 FE chip
Naked VFAT3 die assembled on Hybrid PCB

Opto-hybrid
(Yifan)



FPGA

3x GBTx

2 VTTx

3 VTRx

CERN radhard
optical transmitters

GE2/1 & ME0 are based on the same concepts:
VFAT3
GBT -> LpGBT
VTRx -> VTRx+
μTCA -> ATCA

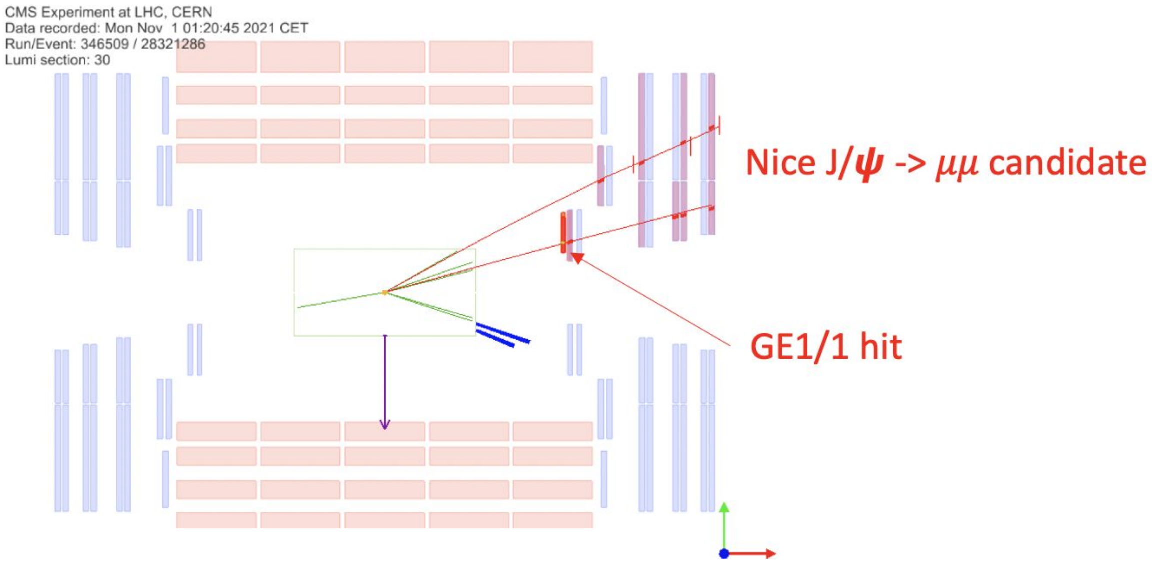
GE1/1

- First endcap installation completed by Oct. 2019
- Second endcap installation completed by Oct. 2020
  - delay of 6 months due to COVID
- Since then: commissioning, commissioning, commissioning,…
- … skipping many steps to keep short:
  - Summer 2021: 5 weeks of CMS Global Run without magnetic field
  - Oct. 15: CMS magnet stable at 4 T !
    - 1st time GE1/1 operates with 4T
  - Oct. 18: LHC Pilot beam started
    - 1st time GE1/1 has to respond to LHC state
  - Oct. 27: 1st stable LHC beam since 2018

Note: we basically had no time to become familiar with those new conditions: a lot of stress on the (small) team on site to operate GE1/1.

GE1/1

- GE1/1 first LHC collision data (900 GeV)



- Between now and spring 2022 (when LHC will restart)
  - CMS magnet is OFF to complete some work on detectors (see next slide)
  - Still a lot of work for GEM team:
    - Optimize the detector configurations according to LHC state (injection, stable, dump,…) to reduce occurence of HV trips during state transitions
    - Investigate the observation of events with large (O 10^3) hits in GE1/1
    - Synchronization of GE1/1 with muon L1 trigger
    - Complete DAQ and DCS software developments, etc., etc…

GE1/1

- And after ?
- GE2/1 and ME0…

On Monday Nov. 1st , installation of the GE2/1 demonstrator

GE2/1 demonstrator will be operated in parallel with GE1/1 but its data will not be stored with the rest of CMS data (we will use local DAQ)