How the IIHE is preparing the CMS Silicon Strip Tracker for high-luminosity

IIHE annual meeting

Martin Delcourt on behalf of the IIHE Tracker group

29 May 2024

Introduction

- Goal of this talk:
  - Explain **why and how the CMS Silicon Strip Tracker will be upgraded?**
  - Underline the IIHE/Belgian role in this project

- This public has both:
  - People from different fields
  - Experts from within the field

Introduction

- Goal of this talk:
  - Explain **why and how the CMS Silicon Strip Tracker will be upgraded?**
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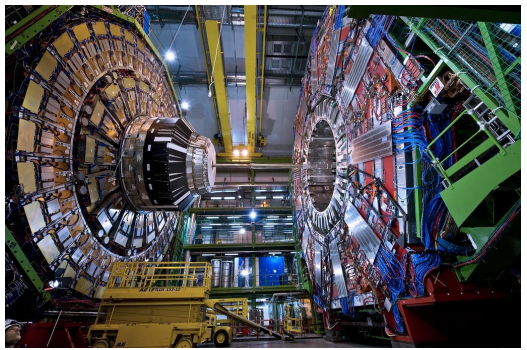
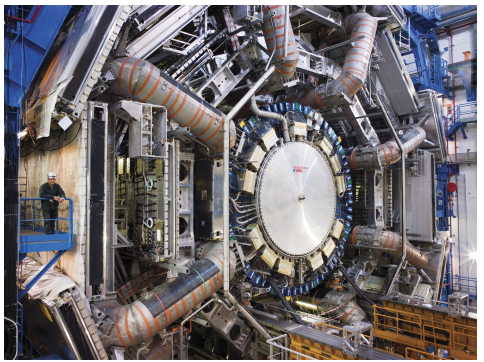
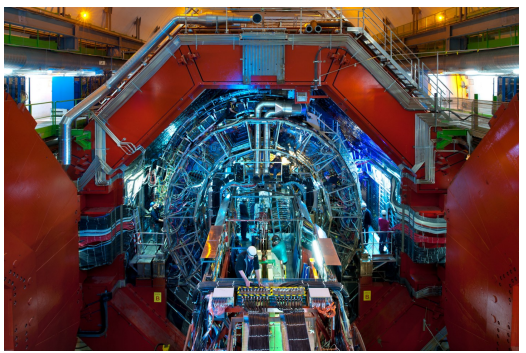
- This public has both:
  - People from different fields → Try to not be too technical
  - Experts from within the field → Try to not be too general

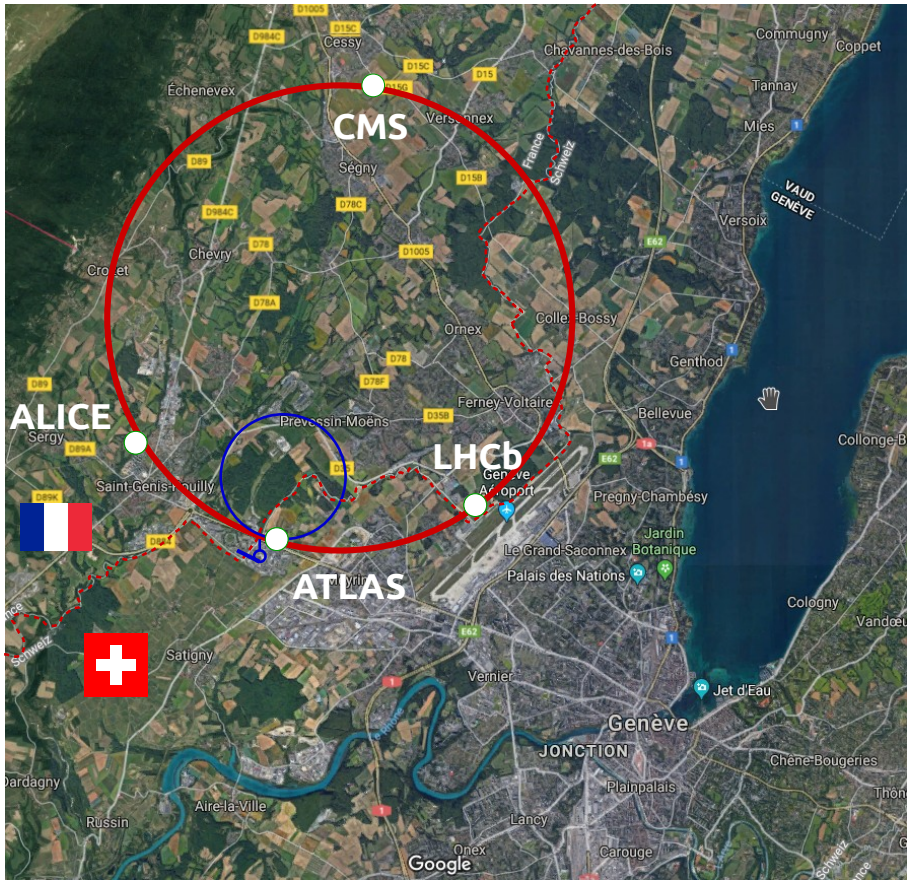
Additional challenge:

CERN and the Large Hadron Collider

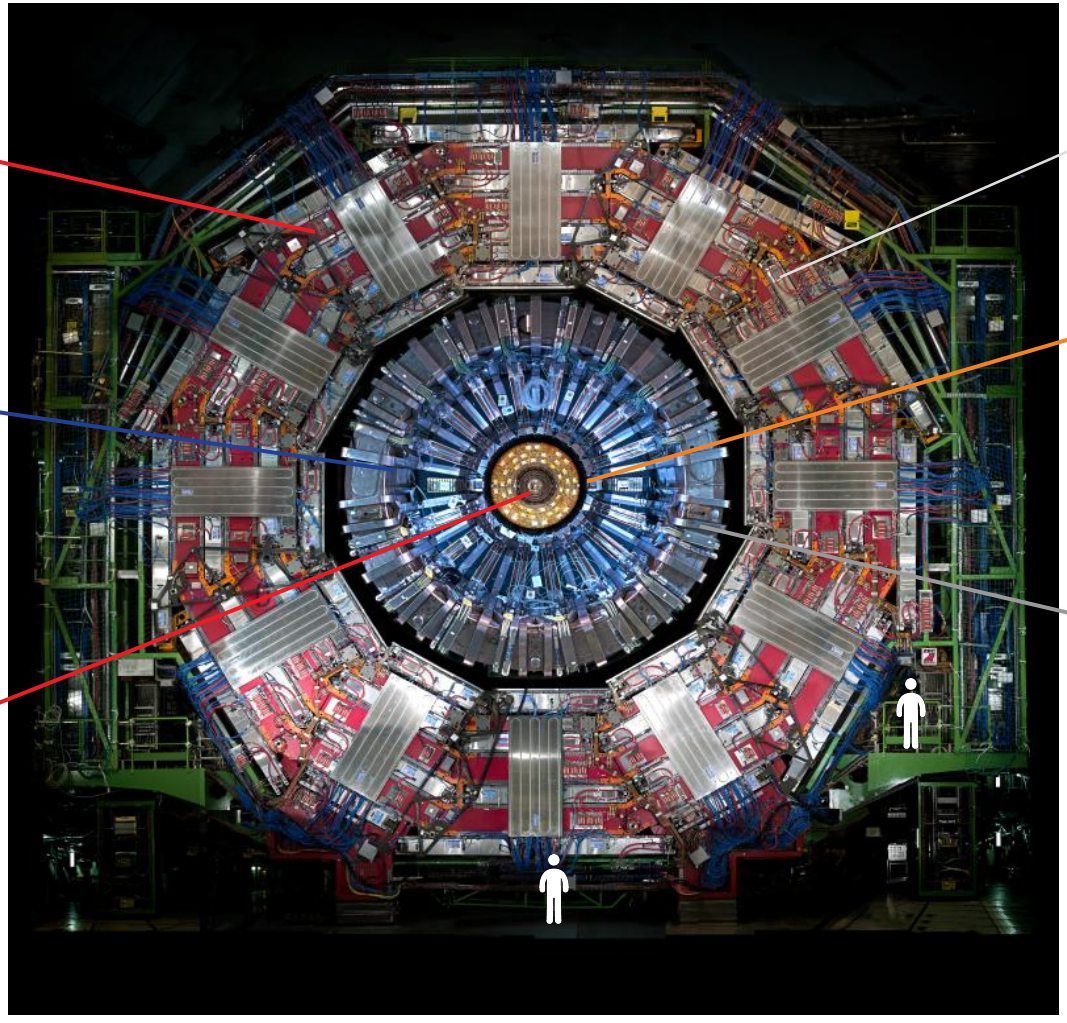








The compact muon solenoïd



Iron

Calorimeters
Measure the particle energy

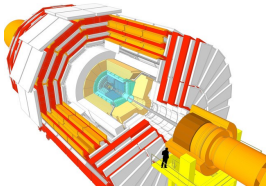
Collisions
~40-60 collisions
40 million times/s

Muon chambers

Silicon tracker
Mesures charged particle trajectory

Magnet
Bends charged particle's trajectory

Recording all this data

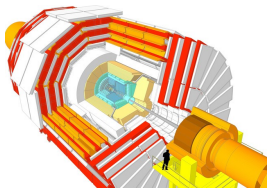


40 MHz

Detector

128 evt = **3.2µs**

Recording all this data



40 MHz

Small fraction
of the event

Accept

~0.25%

128 evt = **3.2µs**

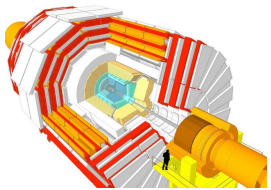
Detector

Service cavern

Level-1 Trigger

→ Hardware based
→ Basic information (**no tracker**)
→ 3.2µs to reject 99.75% of events
→ **Decides what to read**

Recording all this data



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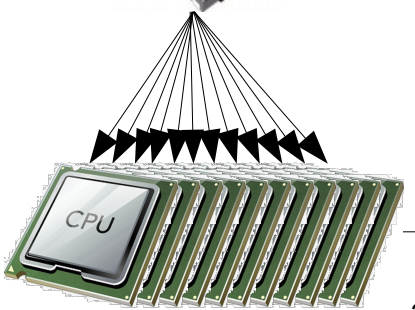
Surface



High-level Trigger

→ CPU/GPU farm
→ Partial reconstruction
→ ~1s to reject 99% of events
→ **Decides what to store**

~1 kHz

~2.5Gb/s

~200Tb/day*

*Theoretical maximum

The HL-LHC

- The LHC is undergoing a major luminosity upgrade

The HL-LHC

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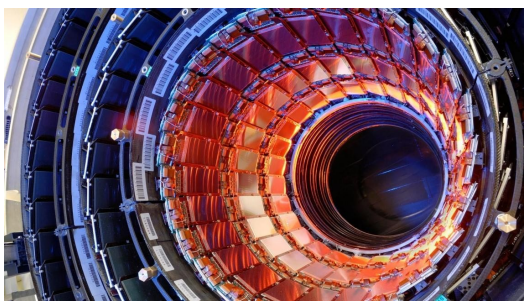
  - Big increase in **integrated luminosity**

$$\mathcal{L}_{int} \sim 450\text{fb}^{-1} \longrightarrow \mathcal{L}_{int} \sim 3 - 4000\text{fb}^{-1}$$

- Bringing major challenges to the experiments
  - Big increase in **radiation damage**



The HL-LHC

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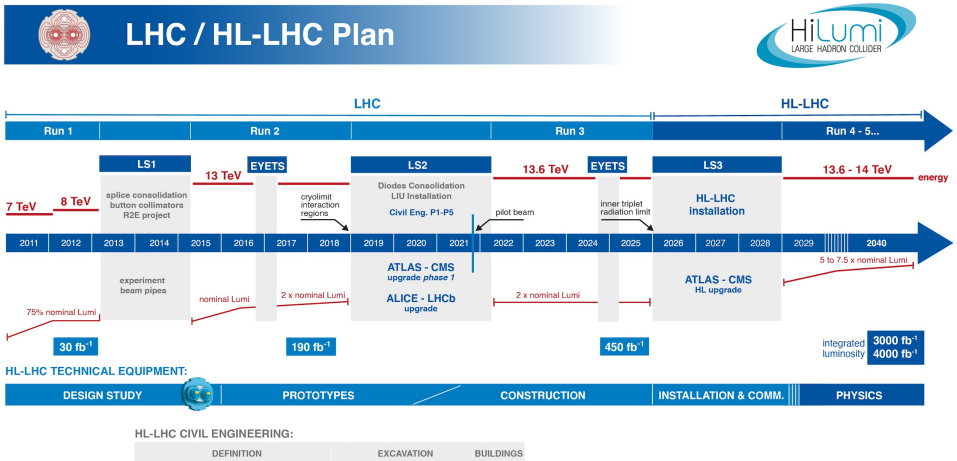
  - Big increase in **integrated luminosity**

$$\mathcal{L}_{int} \sim 450\text{fb}^{-1} \longrightarrow \mathcal{L}_{int} \sim 3 - 4000\text{fb}^{-1}$$

  - Big increase in **instantaneous luminosity**

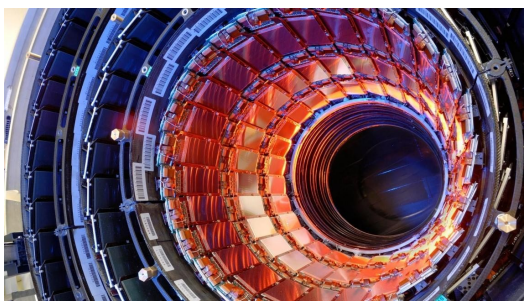
2024 $\quad \mathcal{L}_{peak} \sim 2.2 \cdot 10^{34} cm^{-2} s^{-1}$, $\langle PU \rangle_{peak} \sim 65$

Run 4+ $\quad \mathcal{L}_{peak} \sim 5 - 7.5 \cdot 10^{34} cm^{-2} s^{-1}$, $\langle PU \rangle \sim 140 - 200$

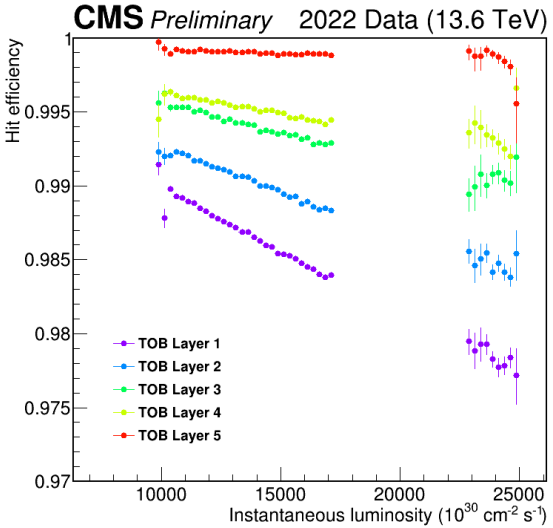


- Bringing major challenges to the experiments
  - Big increase in **radiation damage**
  - Big increase in **pile-up**

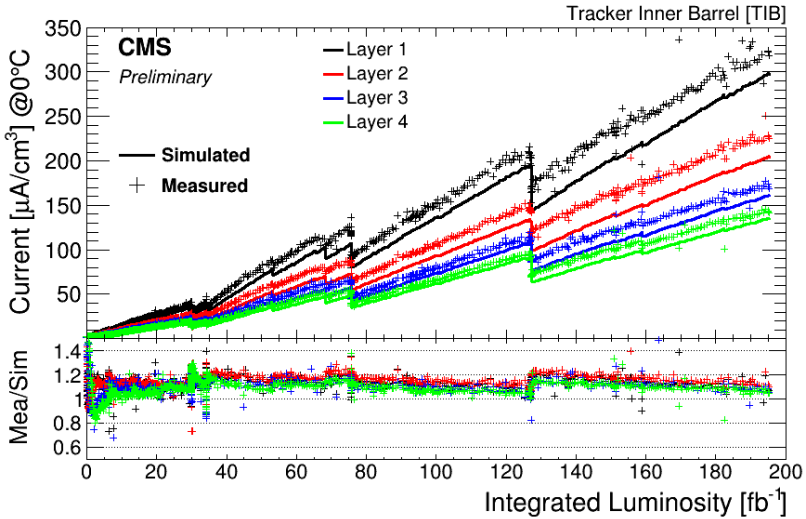
→ Impact on triggering, occupancy, tracking efficiency/resolution,…



Performance of the current detector



Internal

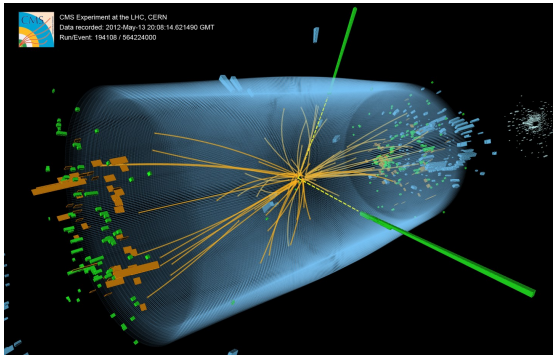


- Current detector is still performing remarkably well, but…
  - Efficiency degrades with instantaneous luminosity
  - Decrease of Signal-To-Noise ratio
  - Increase of leakage current, risking thermal runaway
- Under control for LHC data-taking
  - **Going 10x over design luminosity will require a new detector!**

Side note:
Belgium is heavily involved in the Tracker project, from operations to offline calibration and tracking!

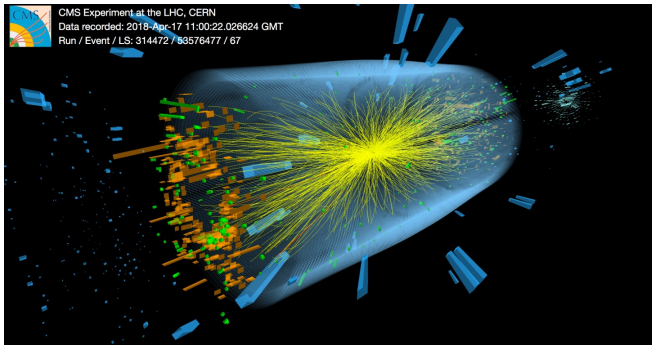
Triggering

What's the deal with triggering?



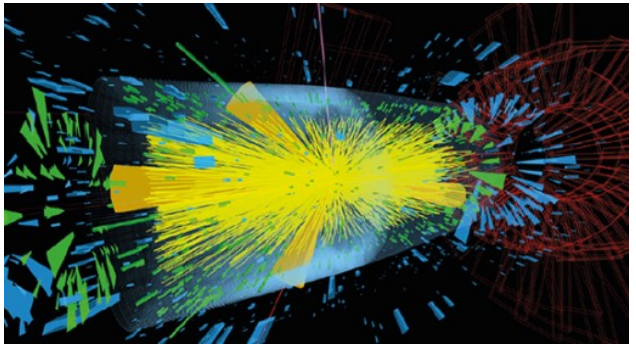
2011

~ 10 collisions
20 000 000 /s



2018

~ 40 collisions
40 000 000 /s



HL-LHC

Up to 200 collisions
40 000 000 /s

Triggering

200 collisions at the same time… What's the big deal ?

→ The level-1 trigger has a 3.2µs to select/discard events based on partial detector read-out

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Triggering

200 collisions at the same time… What's the big deal ?

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Am I in the middle of these 184 physicists?

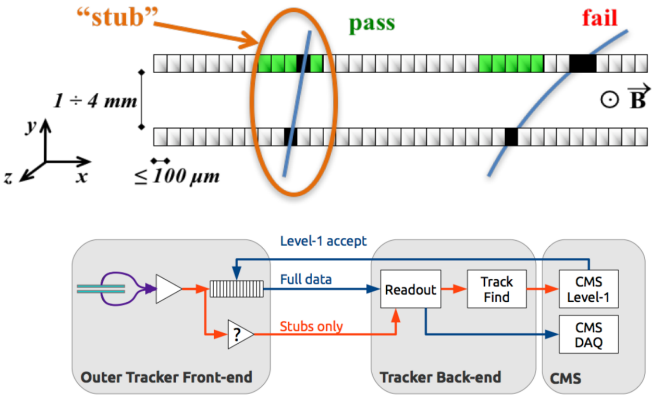
→ We need a better resolution

→ We need to select possible candidates

Here, bearded guys with glasses

The CMS phase-2 upgrade

- Tracking at Level-1 requires data reduction
  - High transverse momentum tracks can be selected by correlating hits on two sensors
    - **2GeV cut** → data reduction of **10x to 100x**
    - "**Stubs**" read-out at 40MHz
    - **Full-data** read-out if triggered (~750kHz)



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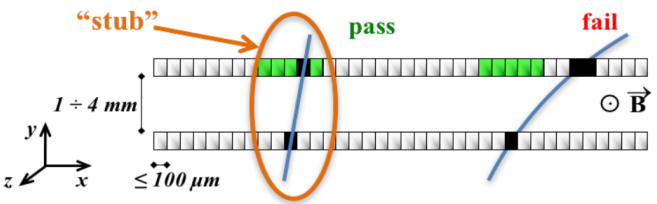
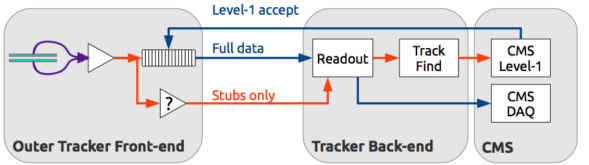
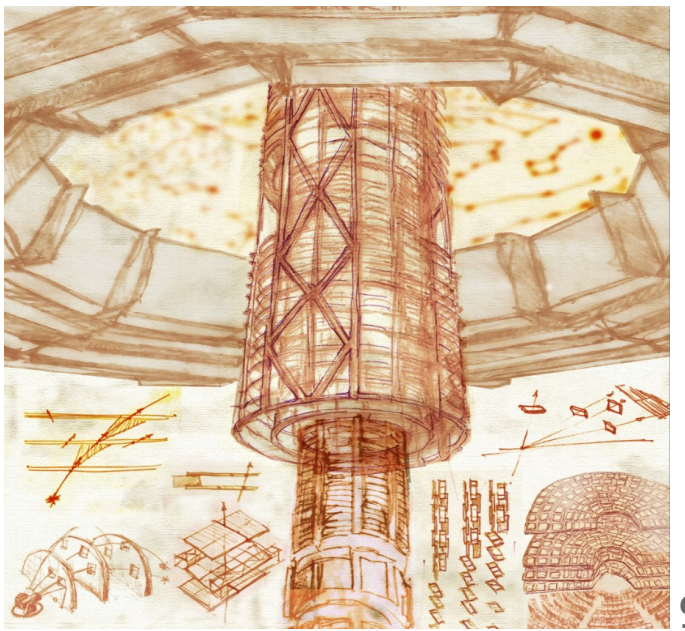




- Goals of the upgraded detector:

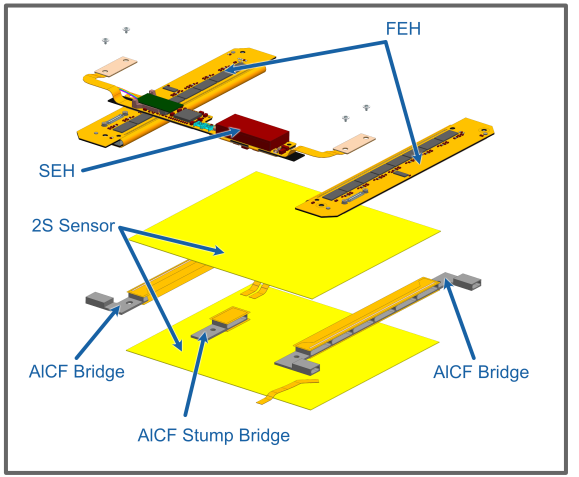
→ **Participation in Level-1 triggering**
→ **Radiation tolerance**
→ **Improved granularity**
→ **Reduced material budget**
→ **Expanded eta coverage**

⟶ ***Improve the detector's capabilities in more challenging environment***



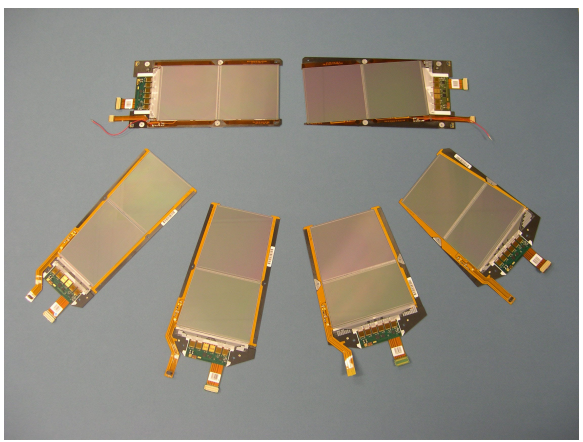
2S modules

- Outer tracker modules:
  - Planar n-in-p, 320μm thick sensors
  - Binary read-out chips
  - Zero-suppression and data aggregation at module level

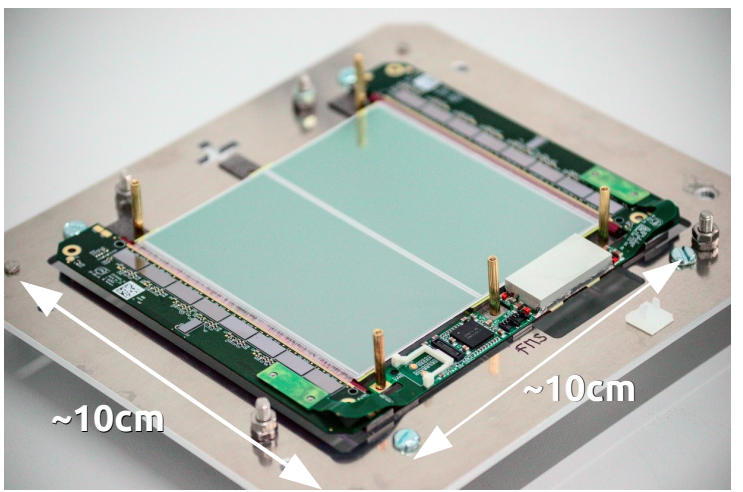


2Strip modules	Pixel Strip modules
2x1016 strips ~5cm x 90μm	2x960 strips ~2.4cm x 100μm
2x1016 strips ~5cm x 90μm	32x960 macro-pixels ~1.5mm x 100μm

Current SiStrip modules



2S module



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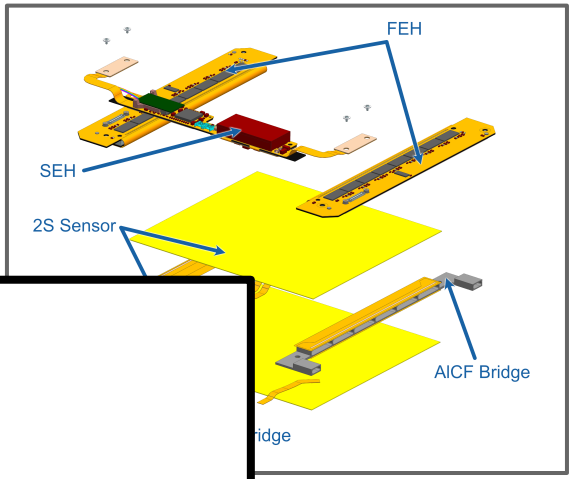
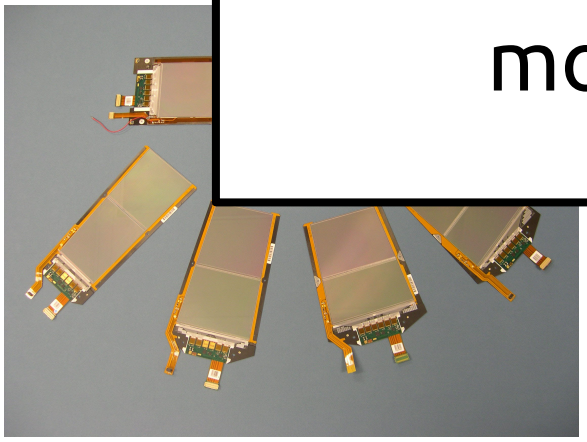
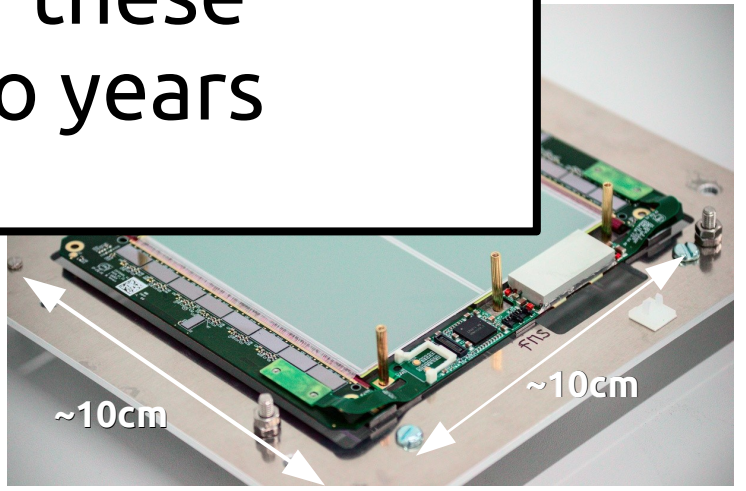


IIHE's mission:

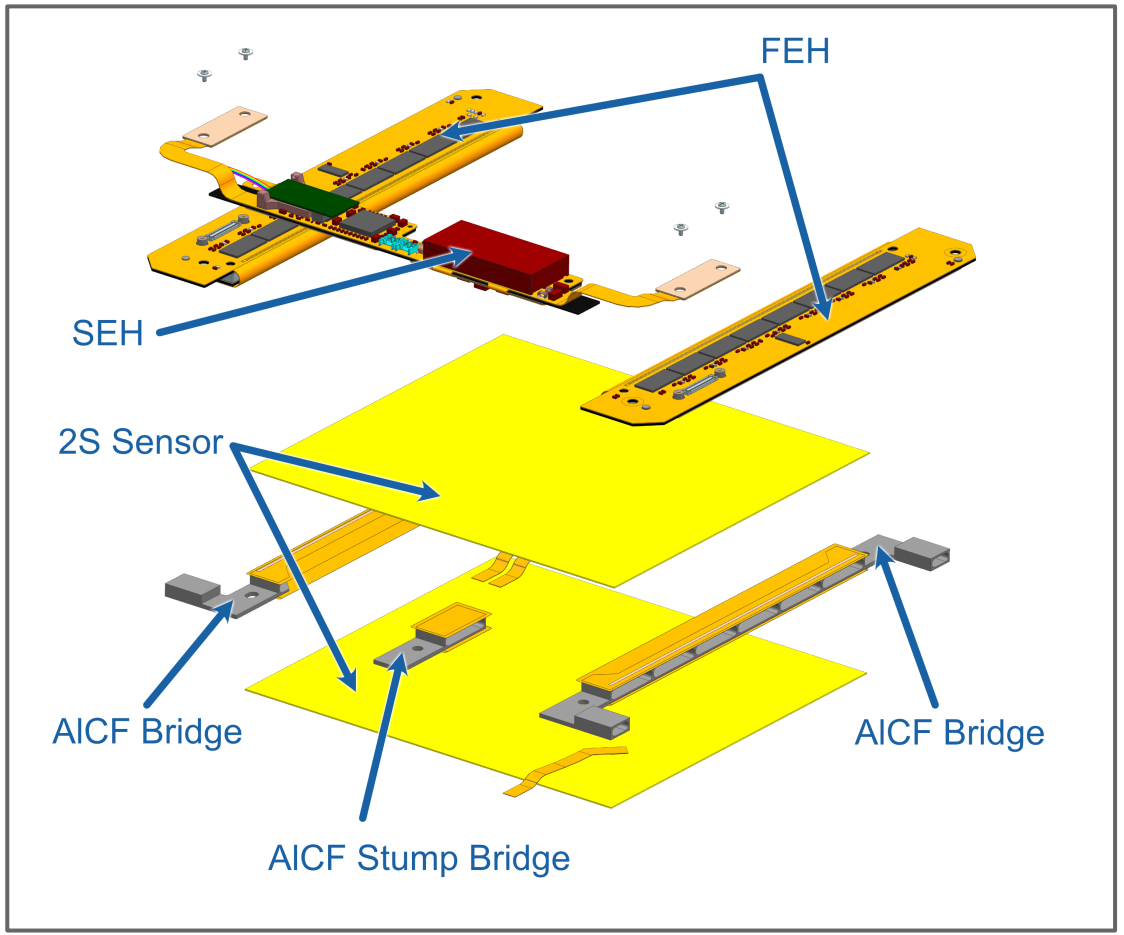
Build **>1500** of these modules in two years

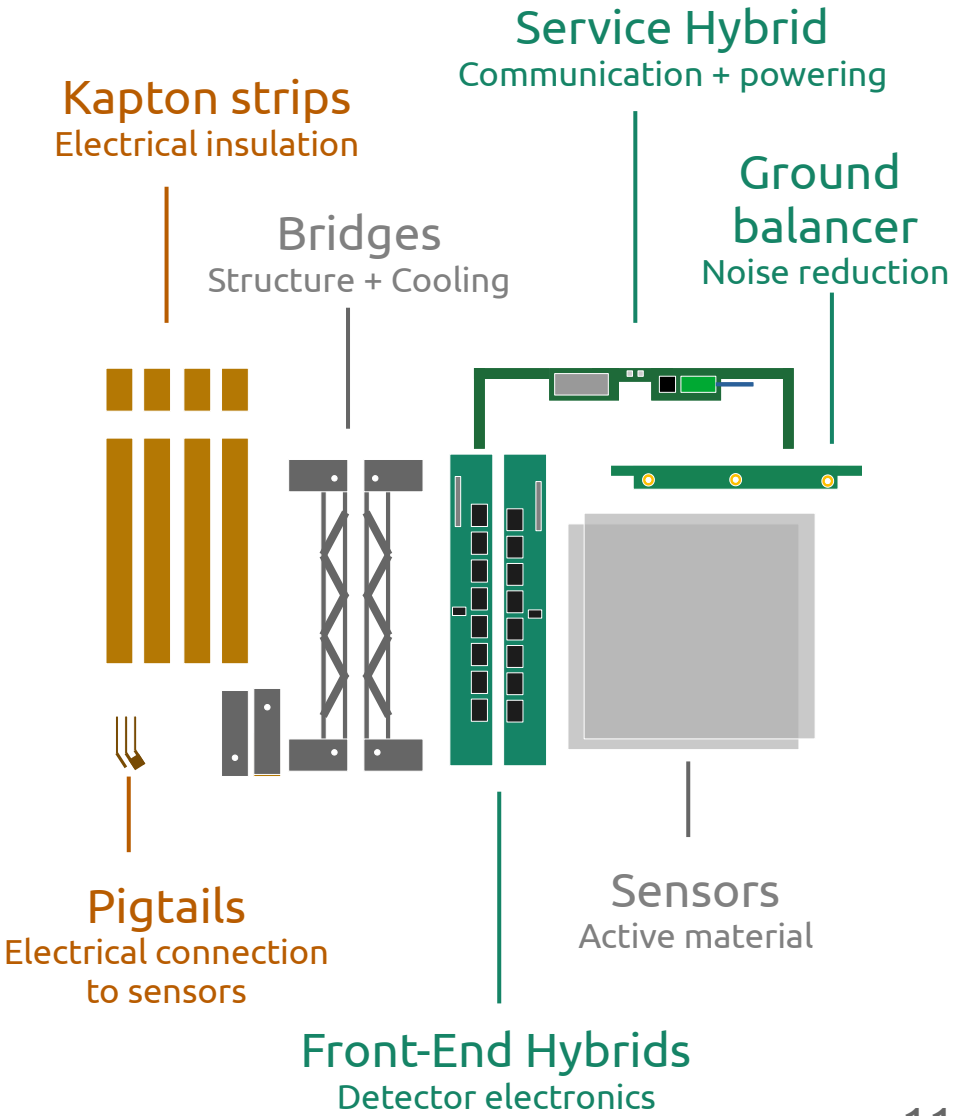
Curren





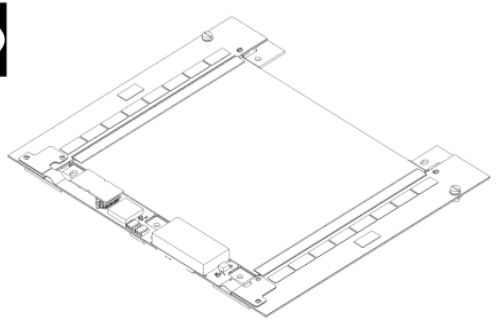
What is a 2S module?

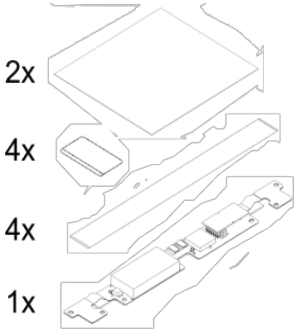


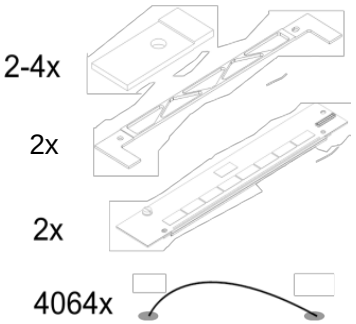


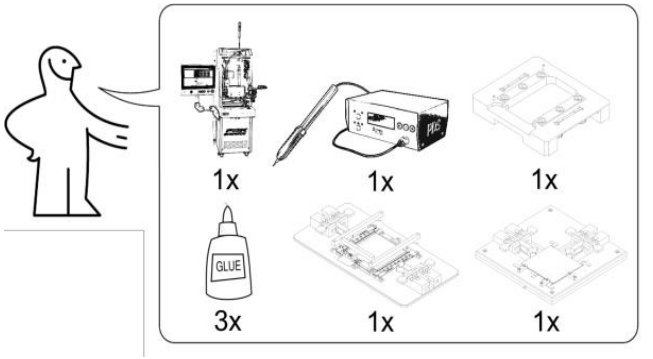
2S MODULÖ

CMS

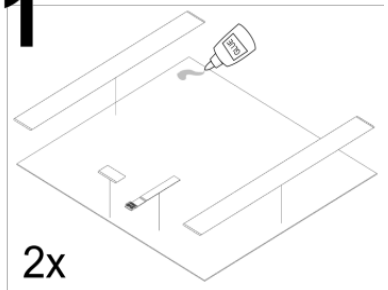








1



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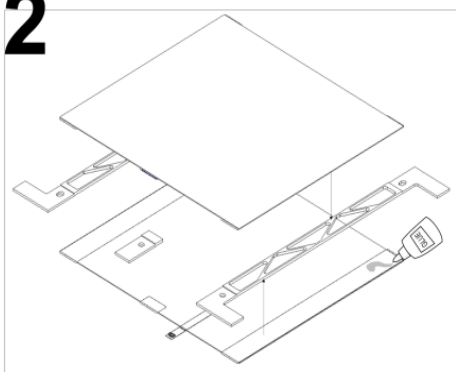

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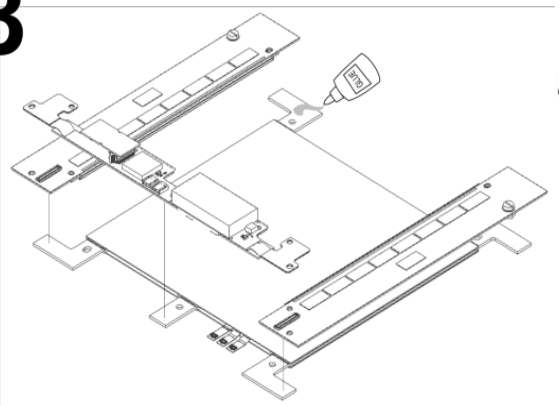

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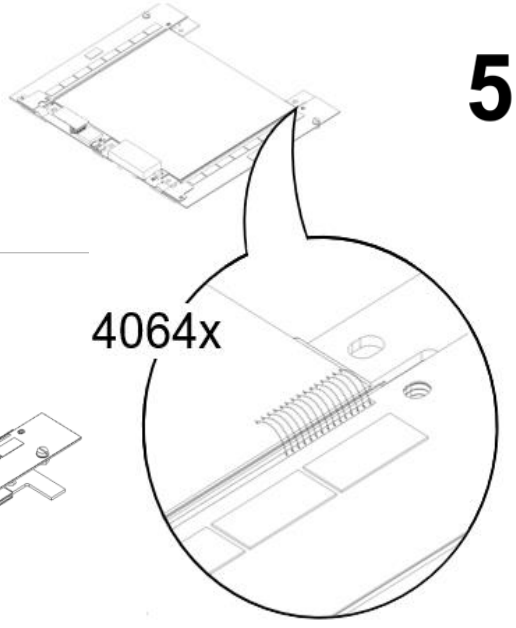

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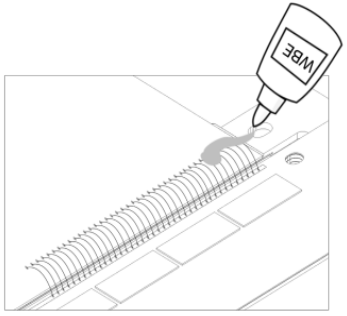

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Kapton strips

HV tails

Sensors

Dimensional QC

VI, electrical QC

VI, edge QC

Kapton and tails gluing

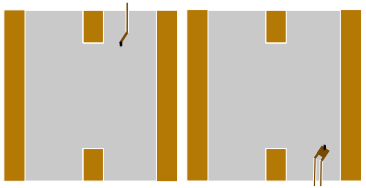
24h

Wirebond

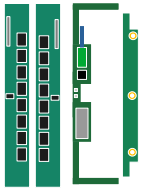
Pull test

Encapsulate

1h



HV QC
IV QC

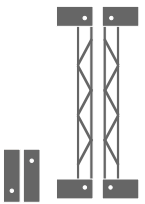


Hybrids

VI

Skeleton assembly

Functional test

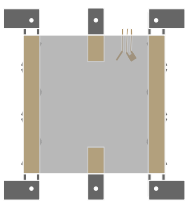


Bridges

Dimensional QC

Assemble bare module

24h

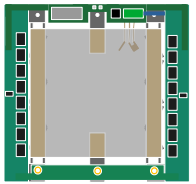


Bare module
aka “sandwich”

Metrology
IV QC

Module gluing

24h



Wirebonding

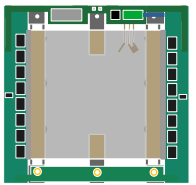
Pull test
Functional test
IV QC

Encapsulate top

24h

Encapsulate bottom

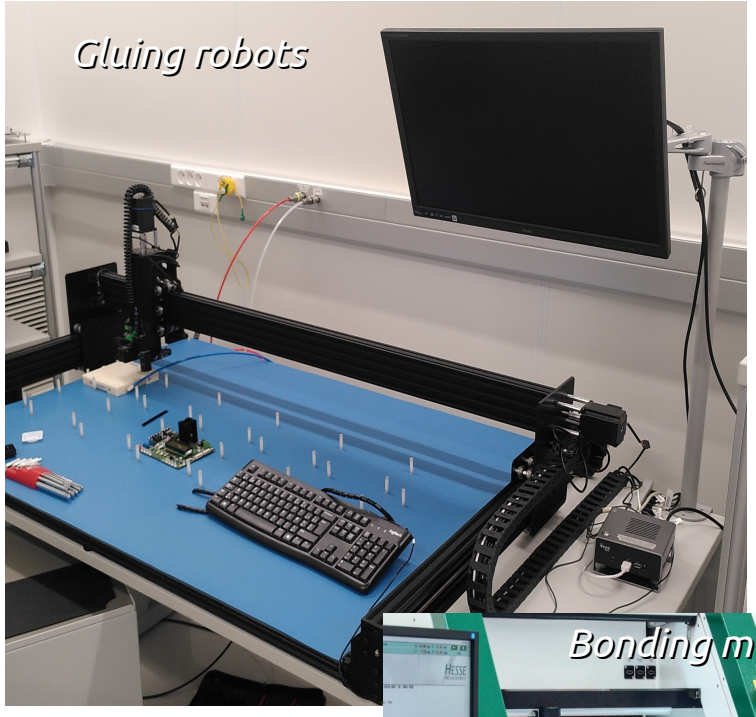
24h



Final module

Functional test
IV test
Burn-in test

Belgian 2S module assembly center


Gluing robots


Overview of the cleanroom


Skilled operators


Bonding machine


Thermal cycling station

Belgian 2S module assembly center


Gluing robots

Come visit us!

If you want to visit the cleanroom,
now is the perfect time!

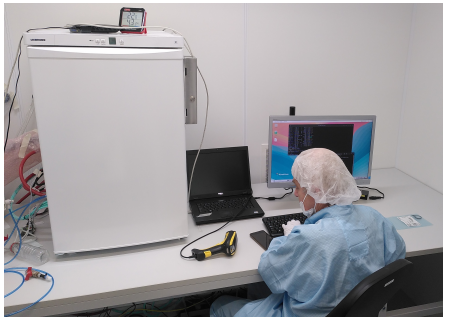
Get in touch, and we'll organise
it in the coming weeks

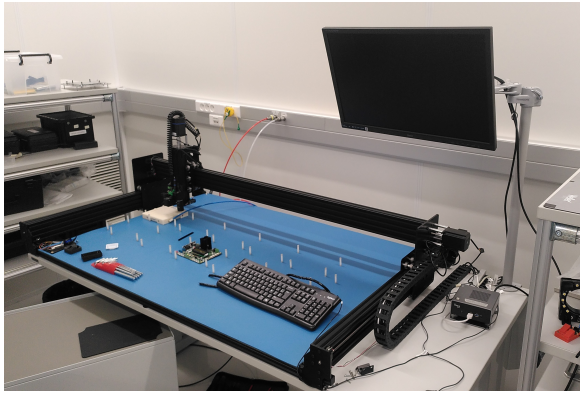

Skilled operators

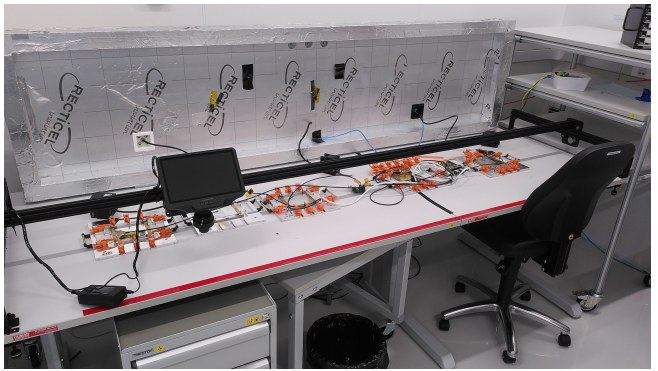

Thermal cycling station

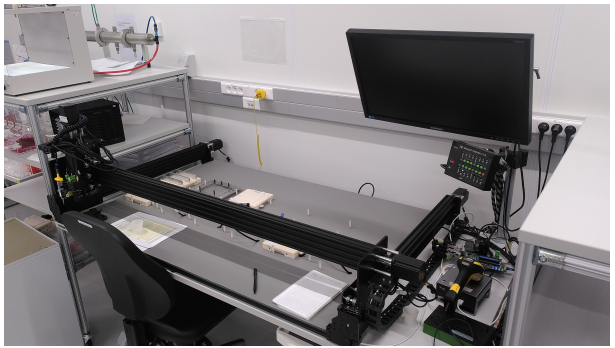
Milestones this year

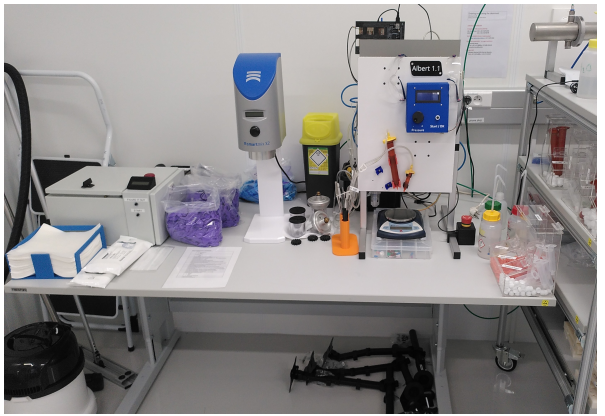
- So. Many. Improvements.
  - I can’t go into the details…
  - I could list 20 items and miss so many of them…
  - **A tremendous work has been done by the team this year to transform the cleanroom!**







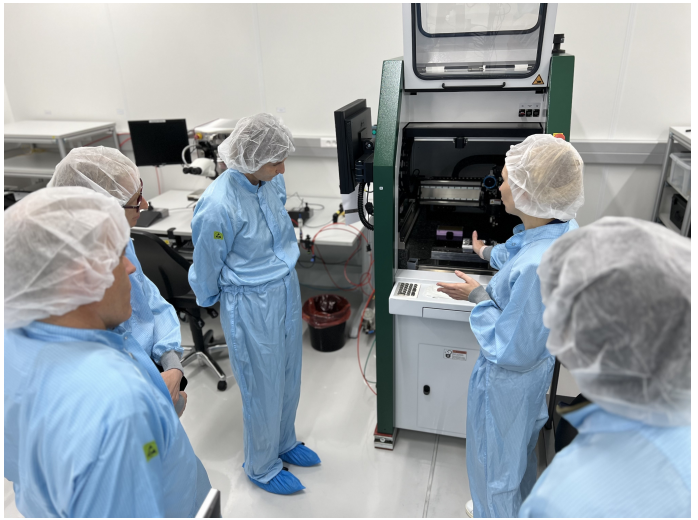




Milestones this year

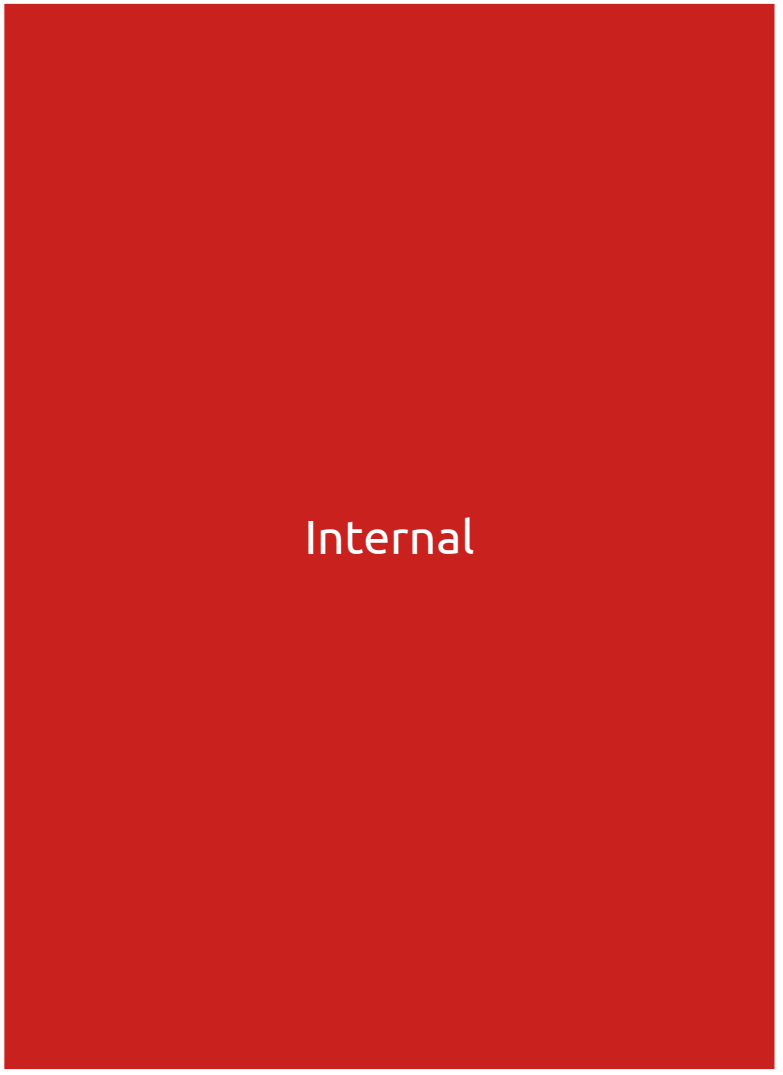
- So. Many. Improvements.

- Site visit & stage-3 qualification
  - Visit of Tracker management
    - **Very positive & constructive feedback**
  - On our way to be “fully-qualified”
    - Just need a few more modules



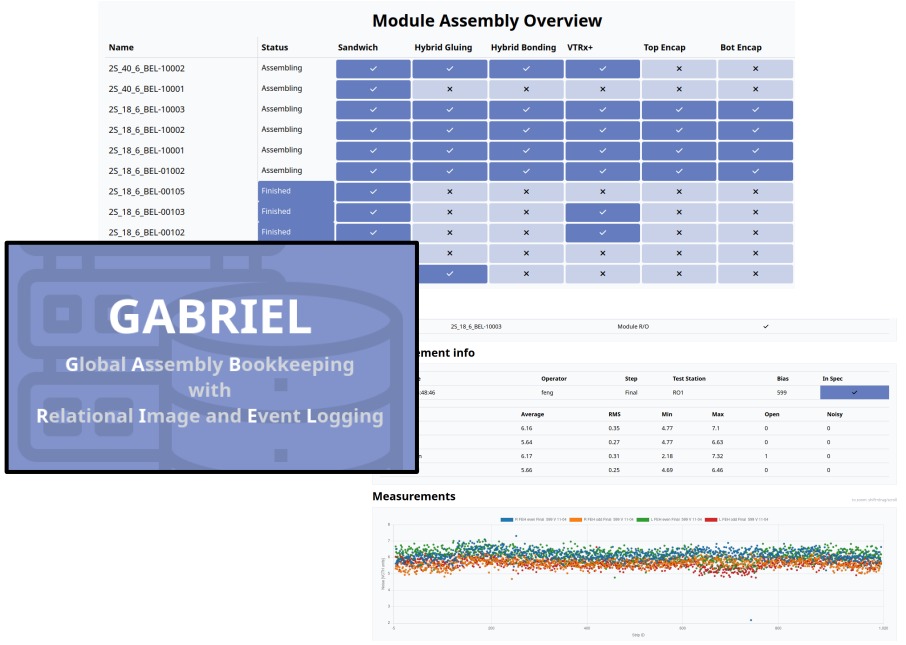
Milestones this year

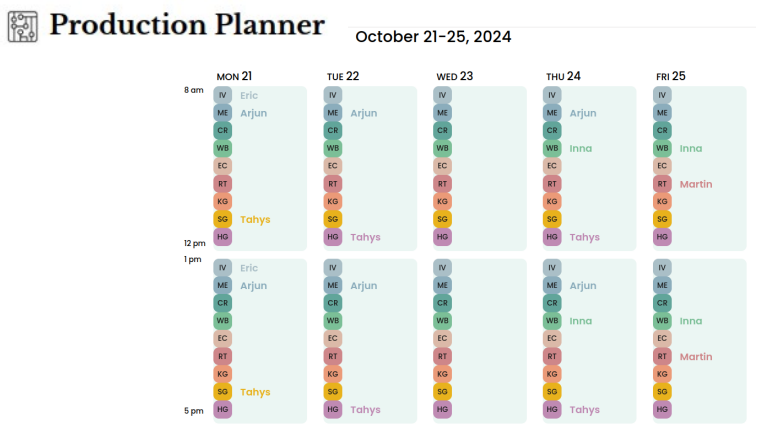
- So. Many. Improvements.
- Site visit & stage-3 qualification
- Training & documentation
  - Expert-based → Operator centered
  - **Team growing in size and experience**
  - Big effort in training & documentation



Milestones this year

- So. Many. Improvements.
- Site visit & stage-3 qualification
- Training & documentation
- Planning & database
  - Tools to coordinate, log & report
  - Huge thanks to IIHE support!



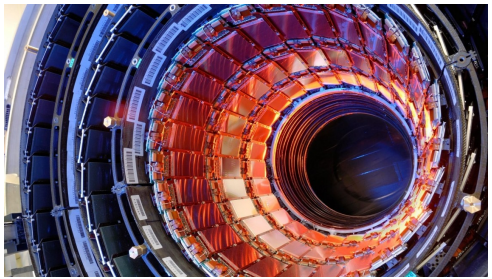


Milestones this year

- So. Many. Improvements.
- Site visit & stage-3 qualification
- Training & documentation
- Planning & database
- Start of pre-production

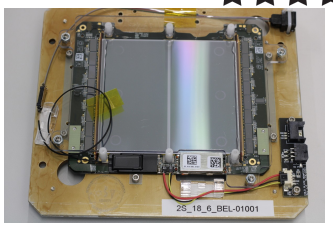
		# modules
2020	First early module built	2
2021	First prototype module built	6
2022	Prototype modules	
2023	Kickoff modules	4
2024	Pre-series & **pre-production**	6
2025	*Production (1/2)*	>1500
2026	*Production (2/2)*	

Summary



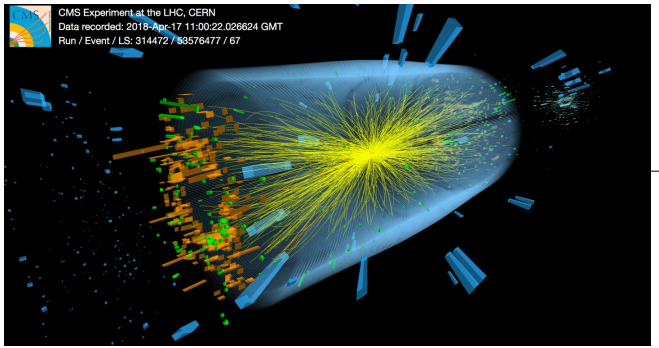
- The CMS silicon strip tracker is the biggest in the world
  - Has been performing remarkably well for over 15 years
  - Built and operated with the help of the Belgian community

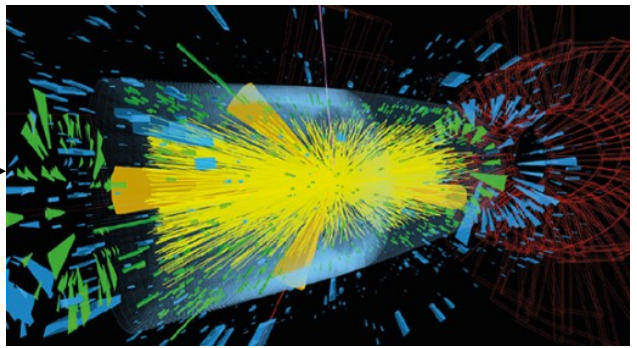
- A new tracker has been designed for the High-Luminosity LHC
  - Design thoroughly tested over the years
  - More than 1500 modules to be built right here

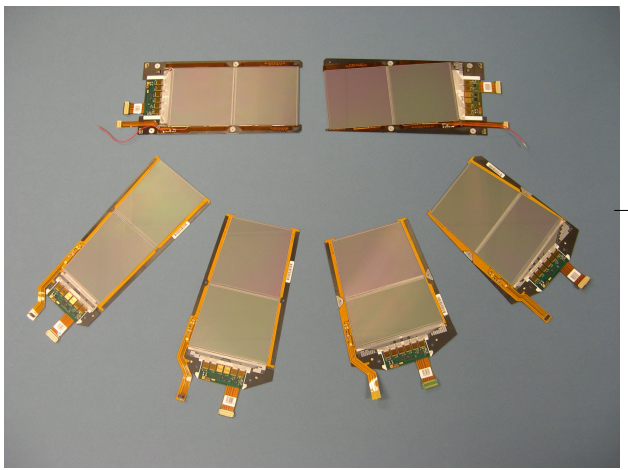


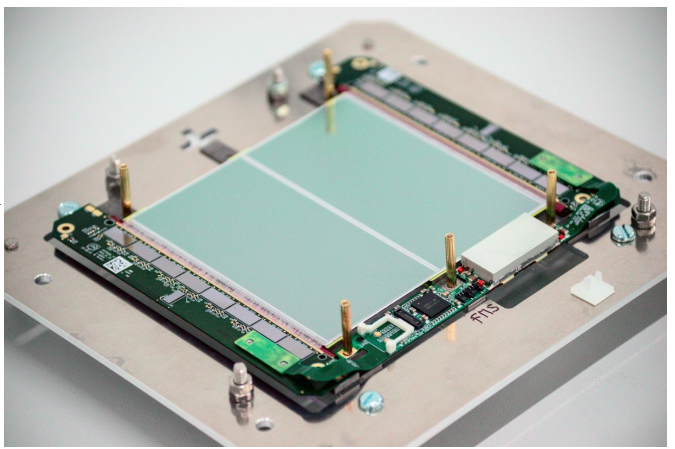
- **Module pre-production started, we now have 2 years to build more than 1496 of these**

Conclusion

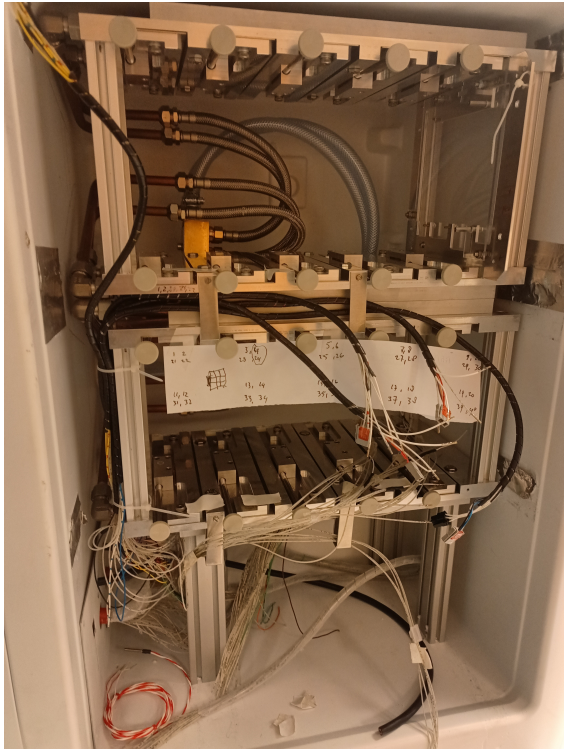


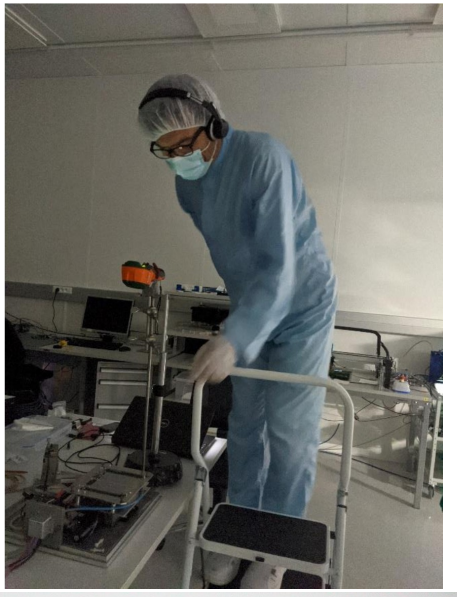






Let’s build this detector!





Thank you!