Belgium in the CMS Upgrade

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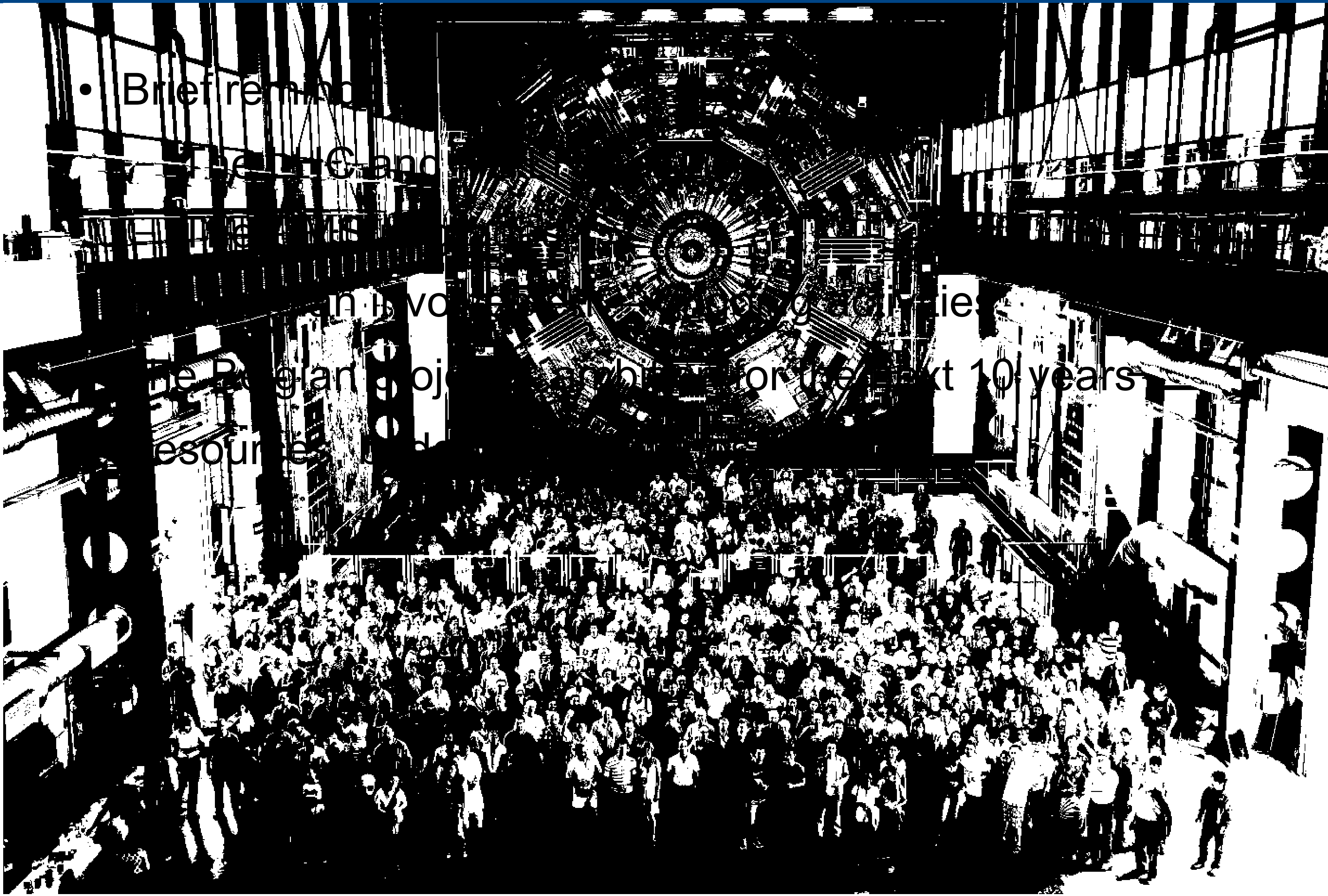
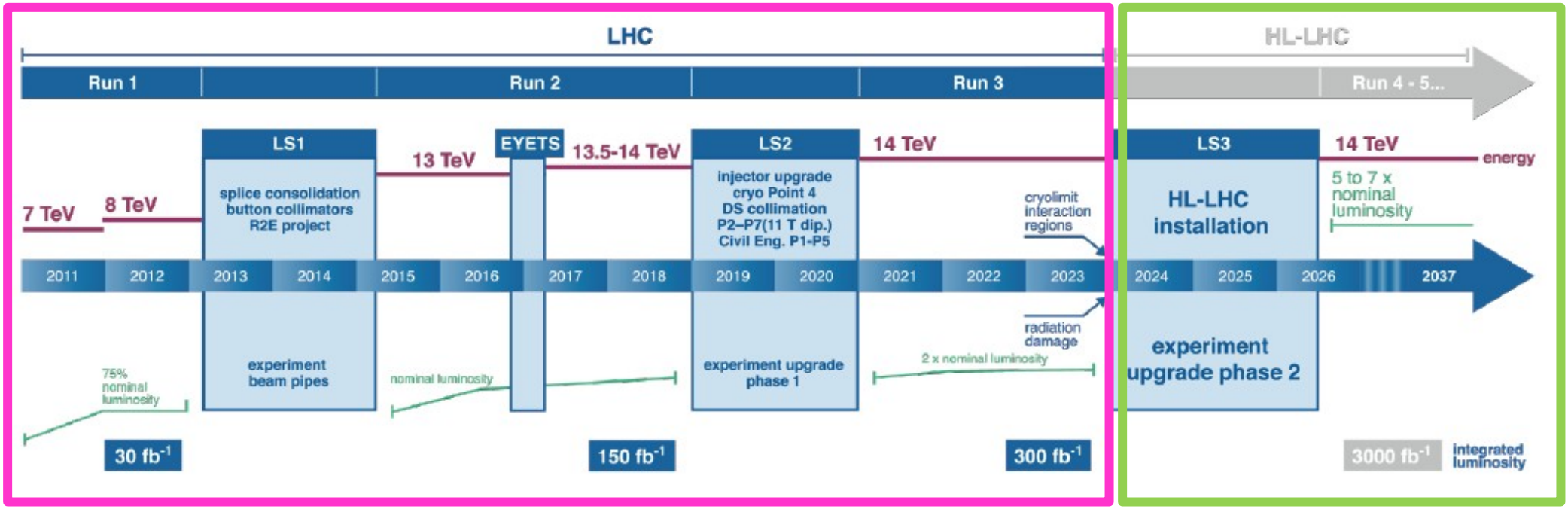
UCL
Université catholique de Louvain

Plan of the presentation



- Brief remind
  - The LHC and
  - The CMS
- ...n involve... ...activities
- The Belgian proj... for the next 10 years
- ...esources, ...

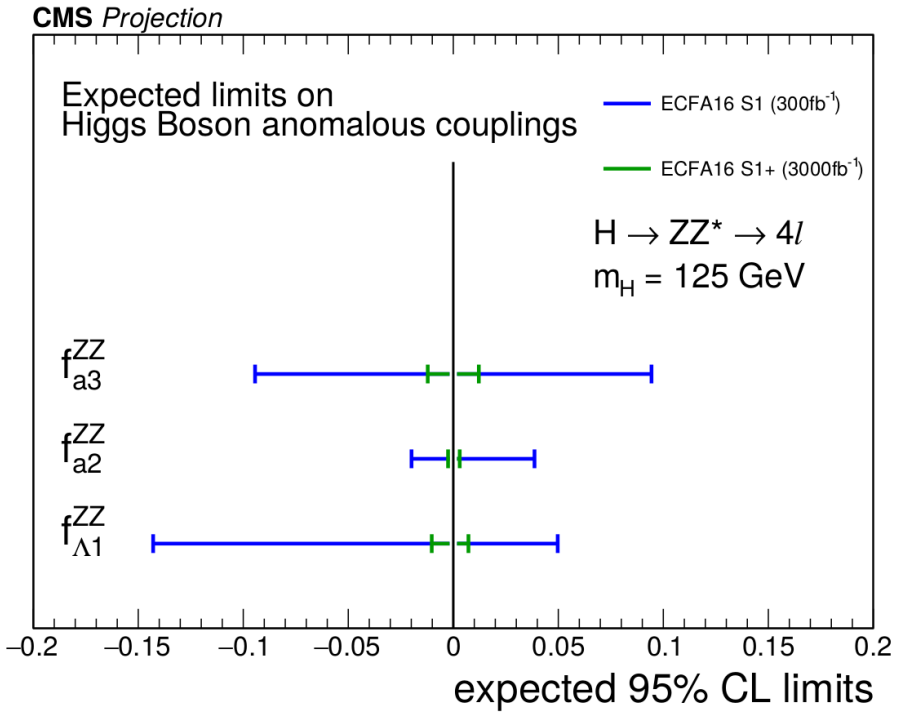
LHC Plan

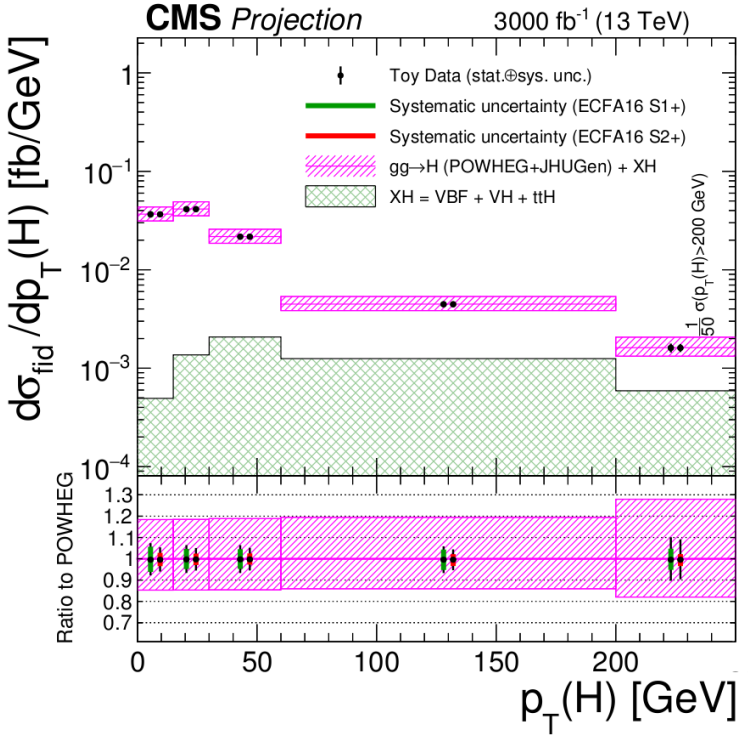


- Run 2
  - Integrated luminosity: 150 fb^{-1}
  - Instantaneous luminosity: 1E34$cm^{-2}s^{-1}$ (nominal)
- Run 3
  - Integrated luminosity: 300 fb^{-1}
  - Instantaneous luminosity: 2E34$cm^{-2}s^{-1}$ (2x nominal)
- Run 4+ (HL-LHC)
  - Integrated luminosity: 3000 fb^{-1}
  - Instantaneous luminosity: 5E34$cm^{-2}s^{-1}$ (5x nominal)

HL-LHC potential (1/2)

- Precision studies of the scalar sector
  - ~5% precision on H coupling to muons, and H self-coupling not measurable without HL-LHC
  - Differential cross sections, anomalous couplings,…

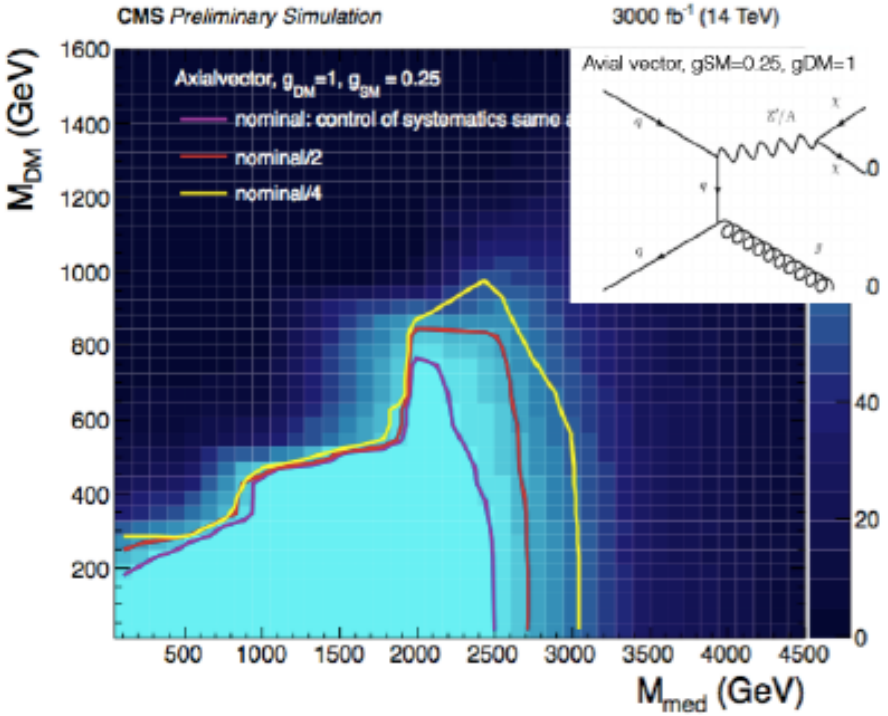


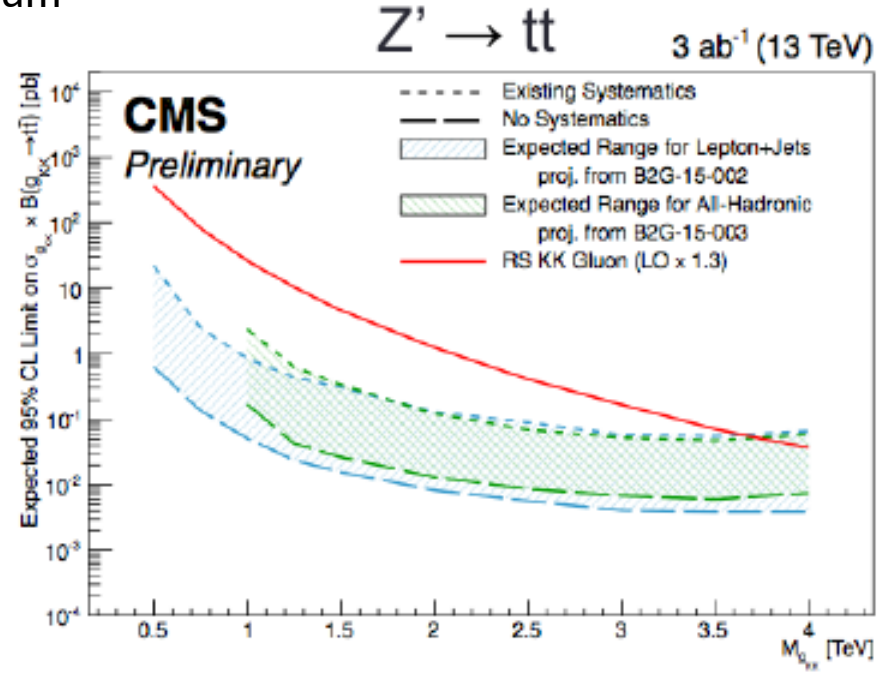


CMS phase-2 upgrade Technical proposal
CERN-LHCC-2015-010
Projections for 3rd ECFA Workshop,
3-6 October 2016 CMS-DP-2016-064

HL-LHC potential (2/2)

- Exploring the TeV scale. E.g.
  - Search for new heavy resonances
    - Z' → tt
    - W' → tb
  - Search for dark matter
    - Mono-jet studies, sensitivity to missing momentum
  - Sensitivity in the 3~4 TeV range





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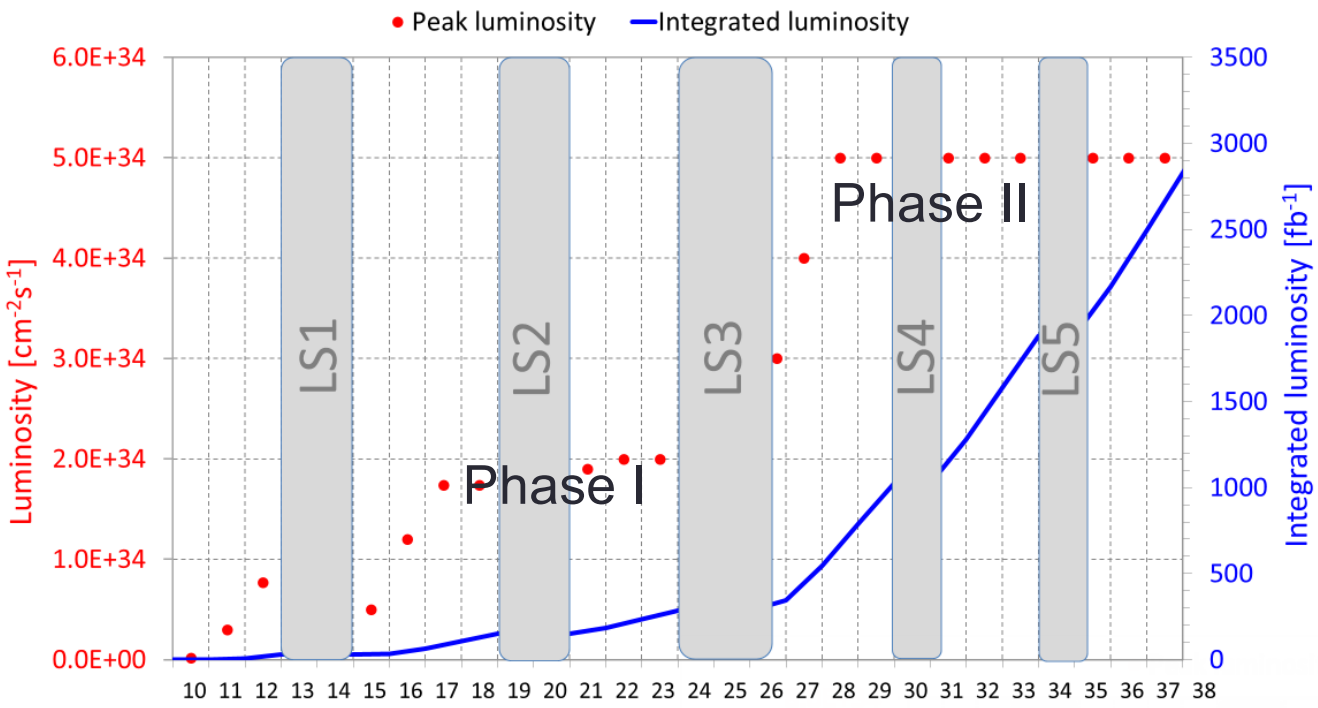
The luminosity frontier...



In order to cope with the higher (integrated) luminosity, CMS has planed two upgrade phases:

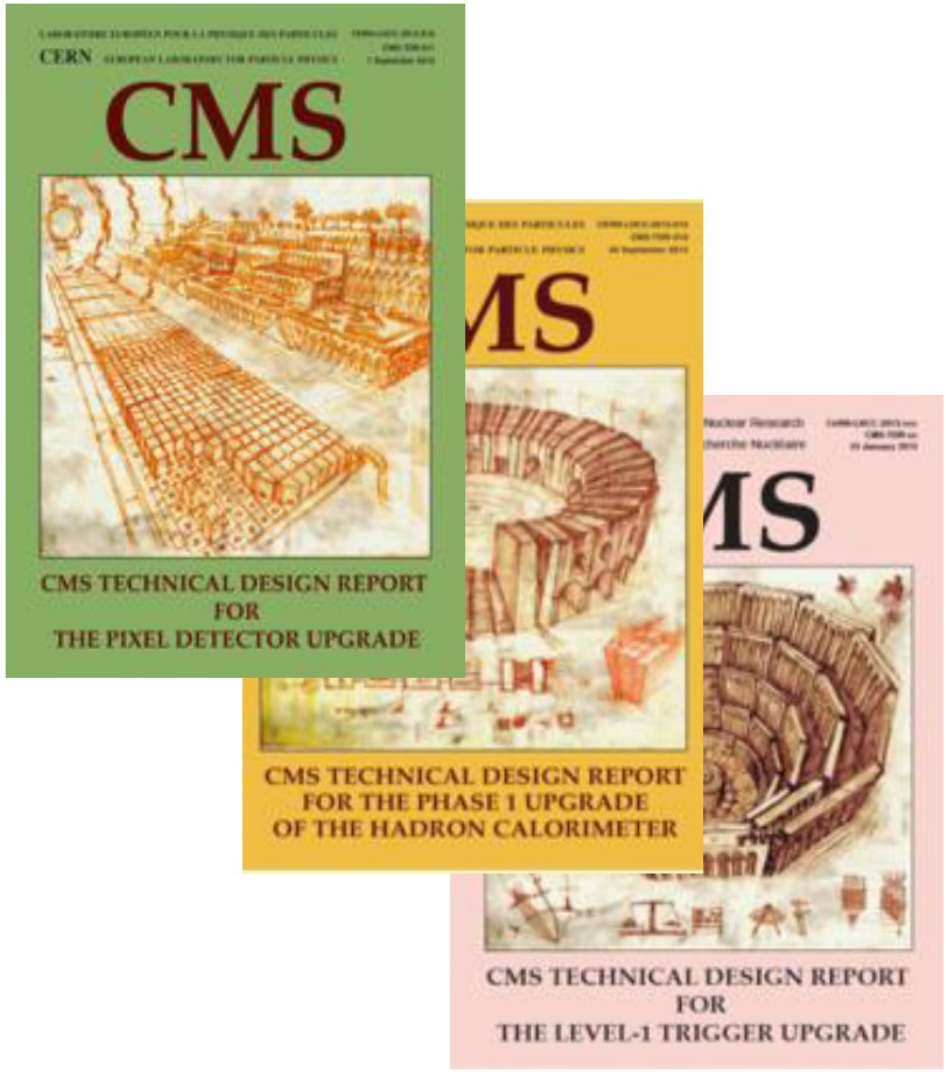
- **Phase-1**: for Run2 and Run3 until 2023
  - Upgrades foreseen by CMS by Long Shutdown 2 (LS2)
  - Consolidating CMS on the way while collecting data from LHC collisions.
- **Phase-2**: for High-Luminosity LHC (HL-LHC) for ~10 years starting in 2026
  - Major upgrades foreseen by CMS during LS3
  - Now entering the prototyping phase, getting ready for construction.

Phase-1 upgrade

Completed in 2016
- L1-Trigger System
  - Exploit additional muon and calorimeter information
  - Move to high-performance FPGA-based electronics

Completed in April 2017
- Pixel Tracker
  - New detector
  - High-rate readout chip

Scheduled for 2017-2018
- Hadronic Calorimeter
  - Improved photodetectors
  - Faster and more robust electronics

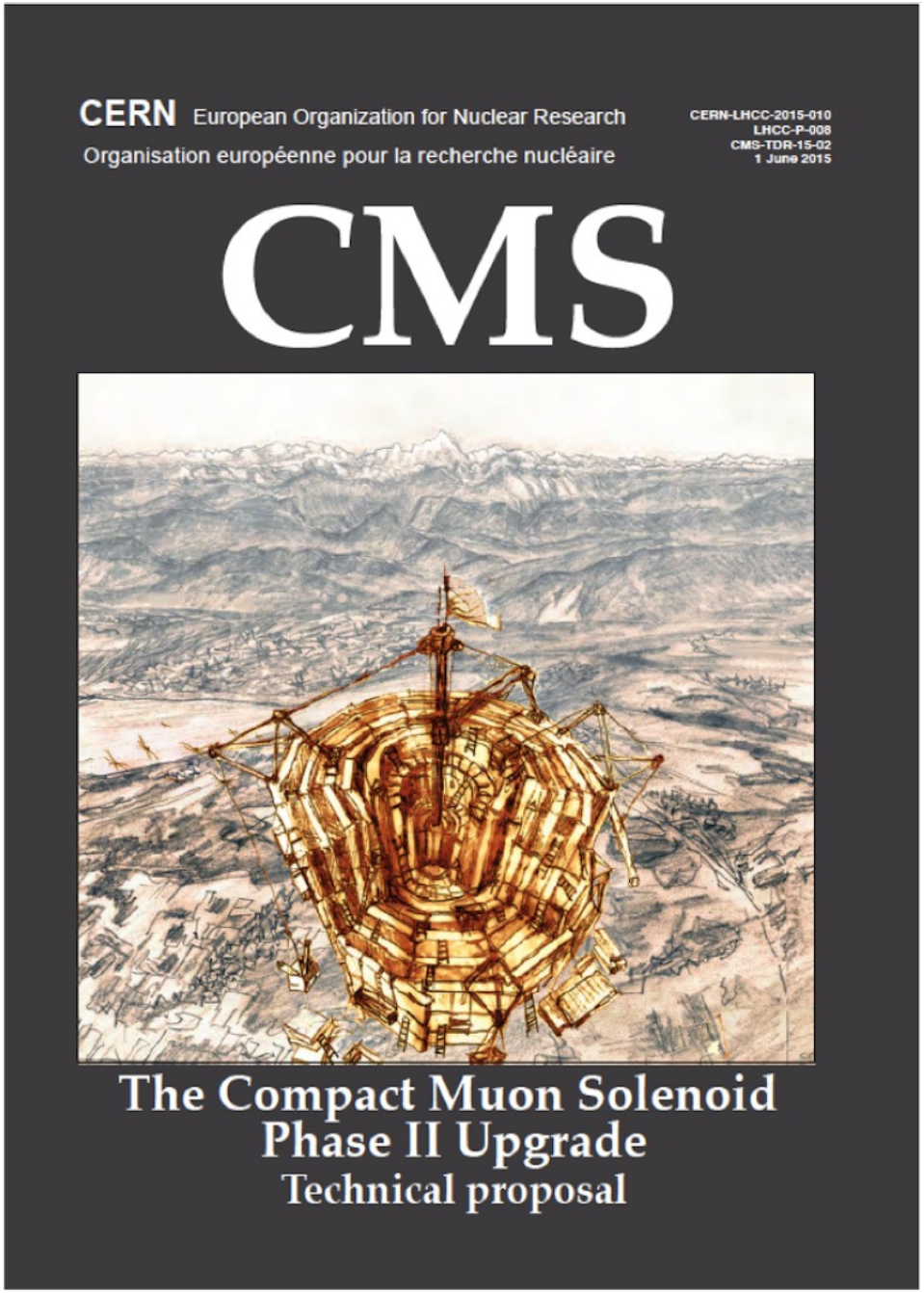


→ n.b.: The Belgian community is not directly involved in these upgrades.

Phase 2 upgrade

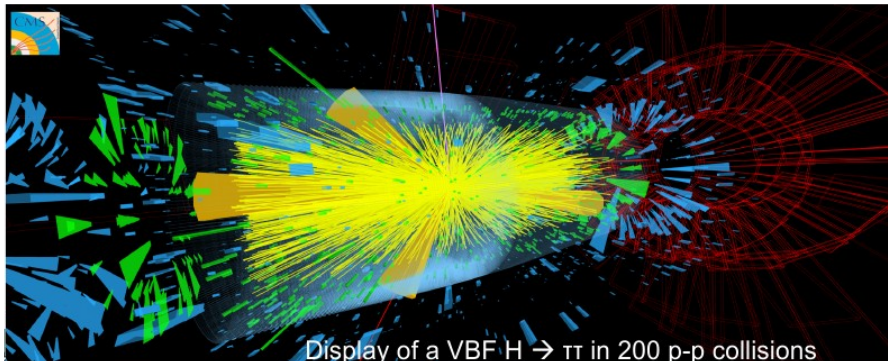
- Goal: exploit LHC physics potential at 3000 fb^{-1} and 14 TeV in 10 years of running
  - Maintain the physics performance despite the harsh conditions
- Challenge: Luminosity
  - Integrated luminosity
    - Radiation-induced aging of detectors after Run 3
  - Instantaneous luminosity
    - 140-200 pile-up interactions (5-7×10^{34} $cm^{-2}s^{-1}$ and 25 ns operation)

TP published in 2015.
First TDRs later this year.



HL-LHC challenges

Instantaneous Luminosity



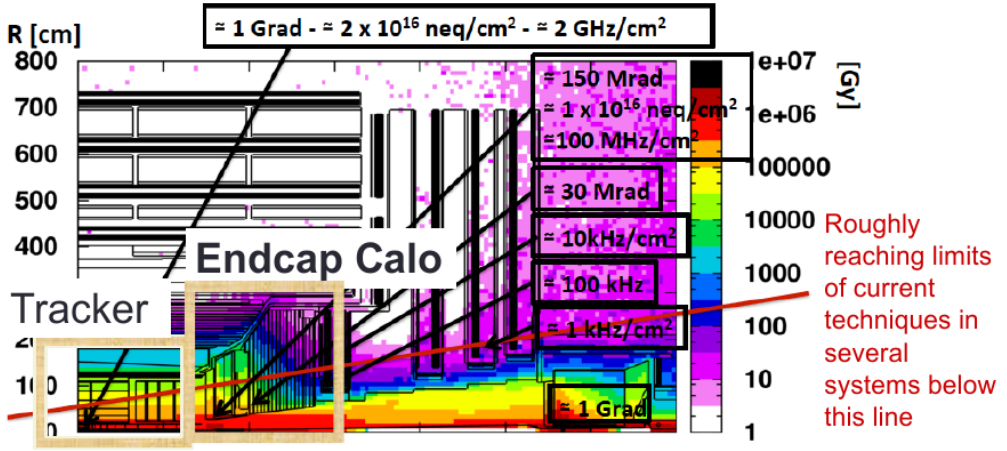
Pileup

- Increases the combinatorial complexity and the rate of fake tracks;
- Adds extra energy to the calorimeters measurements;
- Increases the amount of data to be read out for each collision.

Solutions

- High granularity detectors
- High bandwidth trigger system
- Better timing

Integrated luminosity



Radiation damage

- Detectors and electronics are exposed to high radiation doses;
- Degrades the signals, reduces the detector lifespan.

Solutions

- New central tracker
- New forward calorimeters,
- New forward muon systems

Phase 2 upgrade

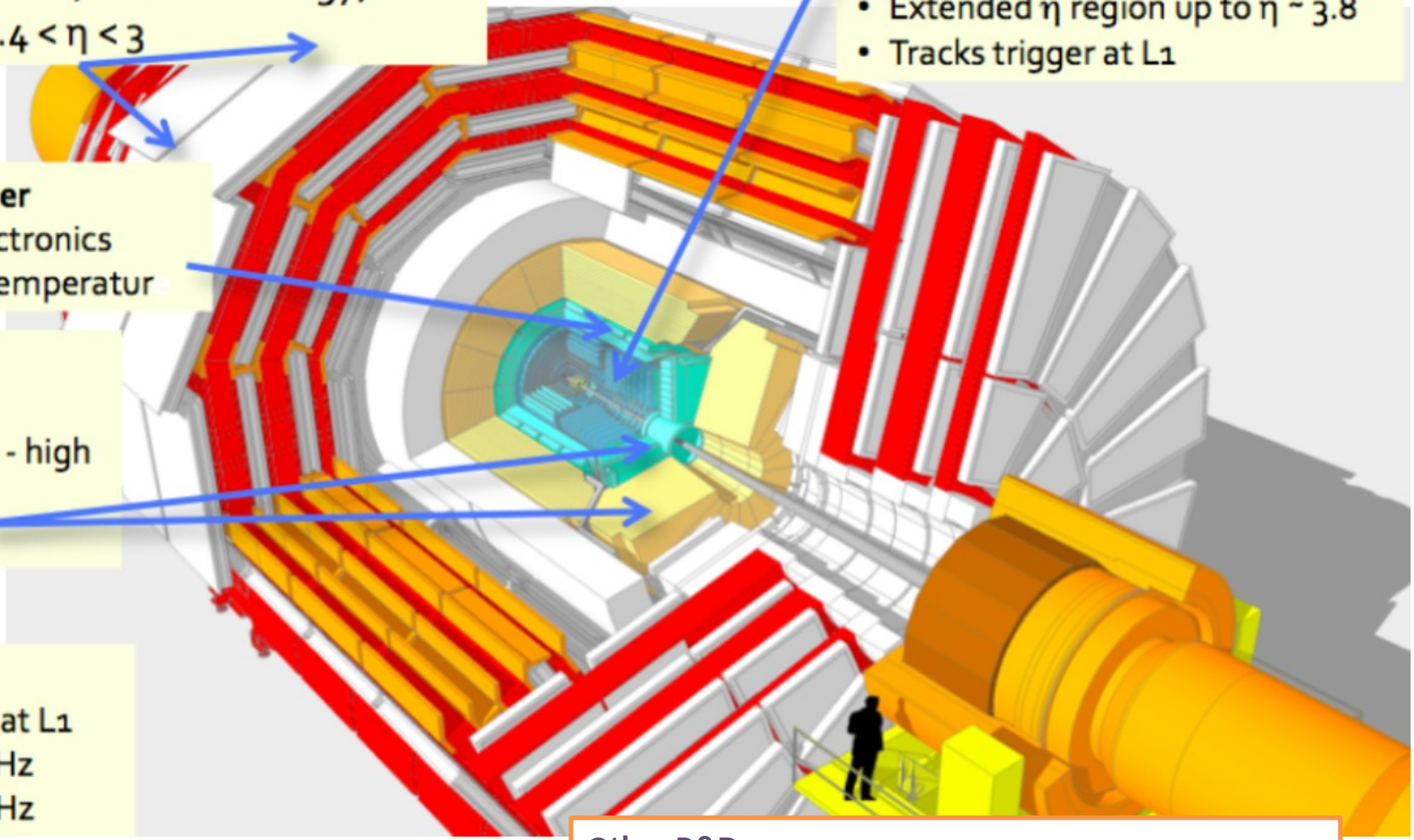
Muon System
- Replace DT & CSC FE/BE electronics
- Complete RPC coverage in region
$1.5 < \eta < 2.4$ (new GEM/RPC technology)
- Muon-tagging $2.4 < \eta < 3$

Barrel EM calorimeter
- Replace FE/BE electronics
- Lower operating temperatur

Replace endcap Calorimeters
- Radiation tolerant - high granularity
- 3D capability

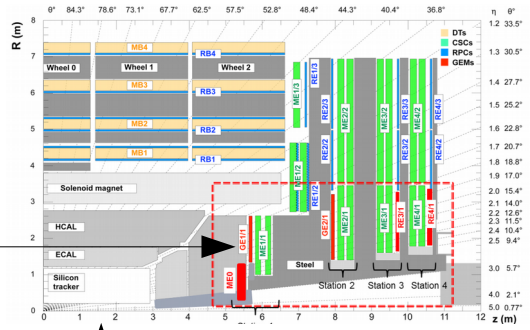
Trigger/HLT/DAQ
- Track information at L1
- L1-Trigger ~ 750 kHz
- HLT output ~7.5 kHz

Replace Tracker
- Radiation tolerant - higher granularity - less material -better p_T resolution
- Extended η region up to $\eta \sim 3.8$
- Tracks trigger at L1



Other R&D
- Fast-timing for in-time pileup suppression

Belgian involvement



GE 1/1 slice test

10 chambers installed during winter 2016-2017

LS2

Installation of the GE 1/1 detectors

LS3

Installation of the CMS phase-2 tracker

2010 | ... | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024

Generic R&D

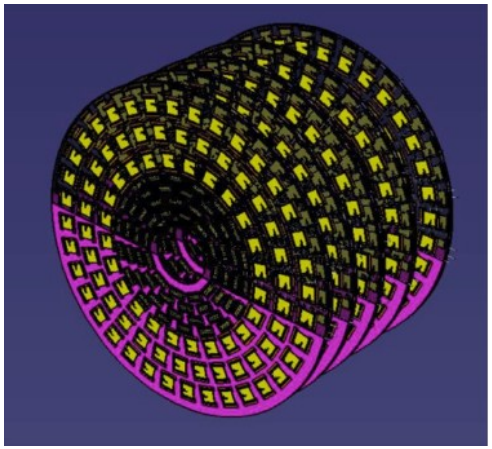
- GEMs
- Phase-2 tracker

Phase-2 tracker prototyping

- Preparation of the infrastructures
- Validations of first prototypes
- Test beams

Phase-2 tracker construction

Belgian ambition: build one endcap



Belgian involvement

The construction of the phase-2 CMS tracker is the central project that brings together the Belgian experimental physics community for the coming years

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GE 1/1 detectors

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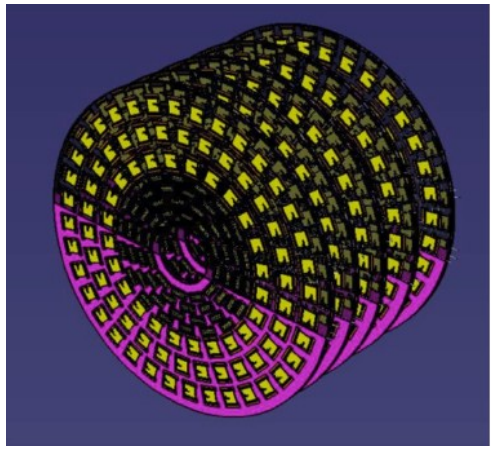
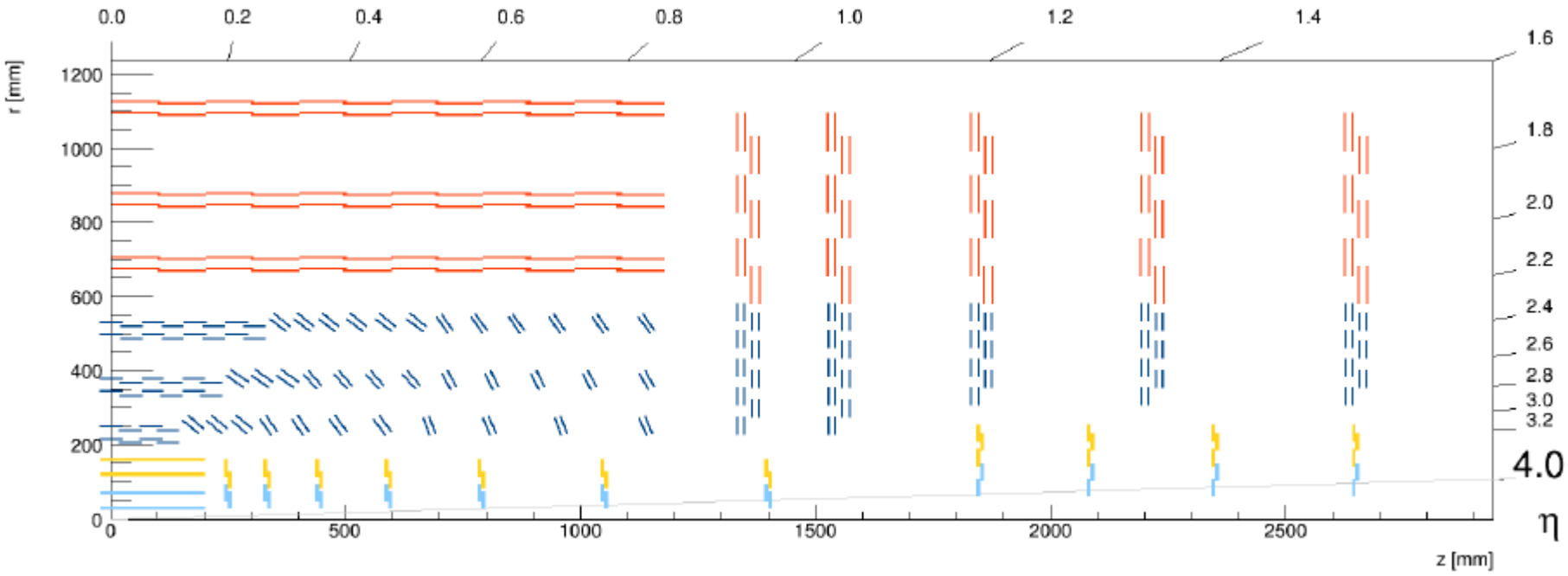


The CMS Phase-2 tracker

- **Extended coverage to high pseudorapidities**
  - Forward pixel system down to η=4
- Specifically designed to provide input to L1 trigger
  - Selects pairs of hits (stubs) compatible with high-Pt (>2GeV) tracks
  - O(10%) of the data sent at 40MHz to the trigger system
- Reduced material budget
- Increased granularity



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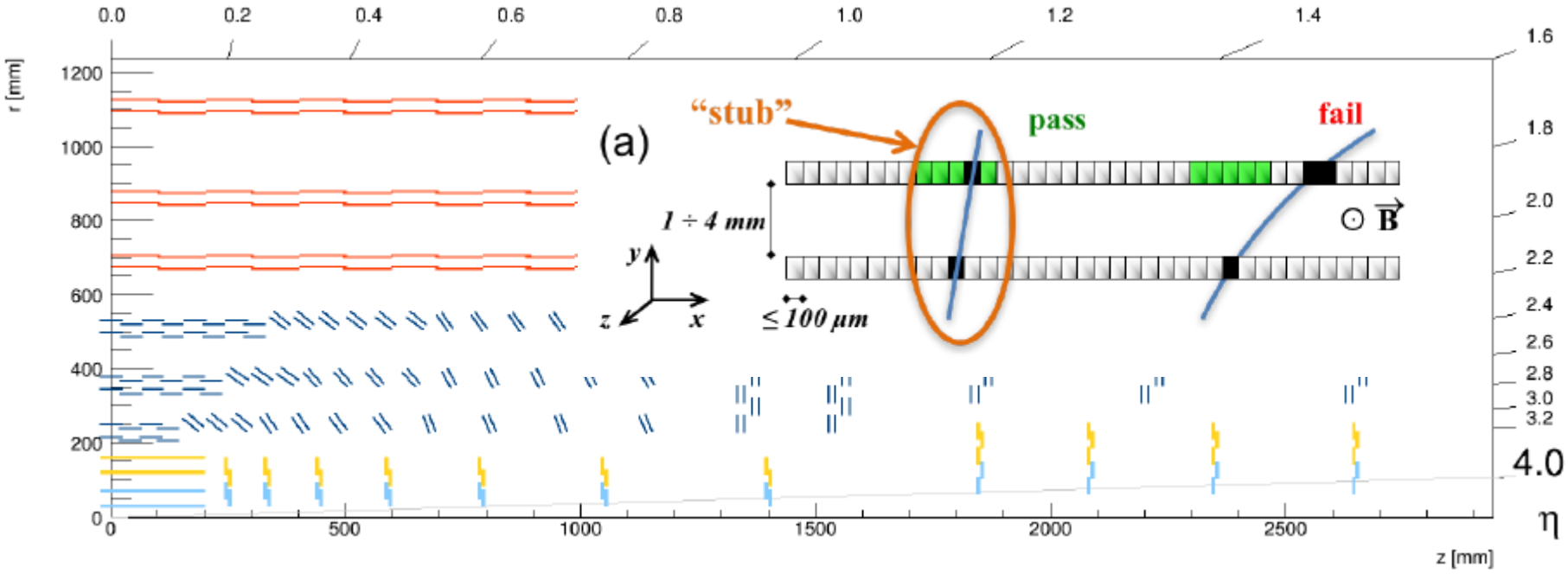

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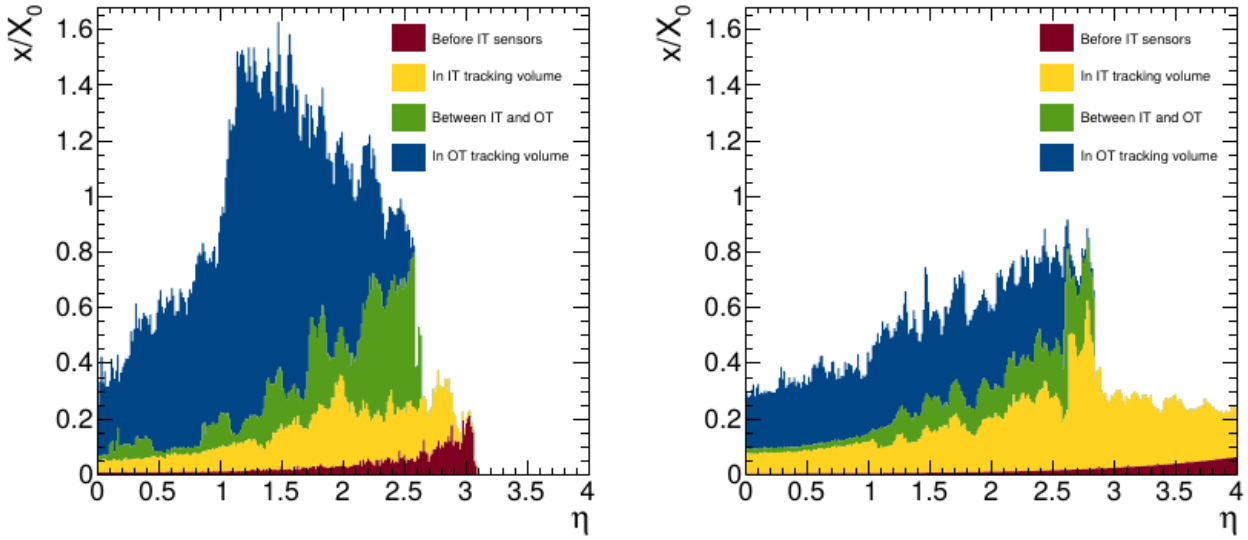

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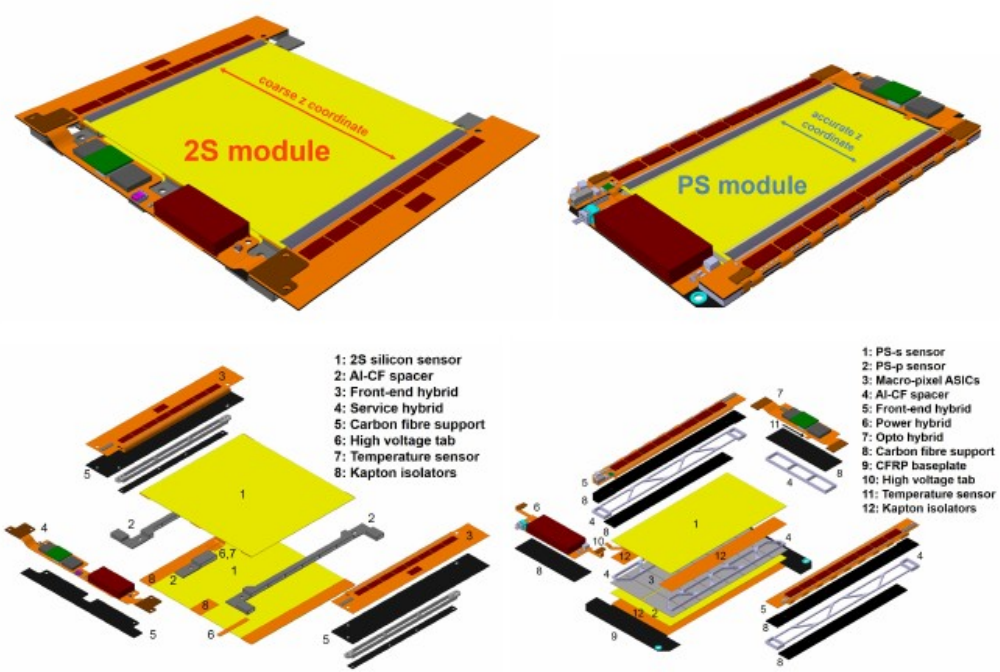
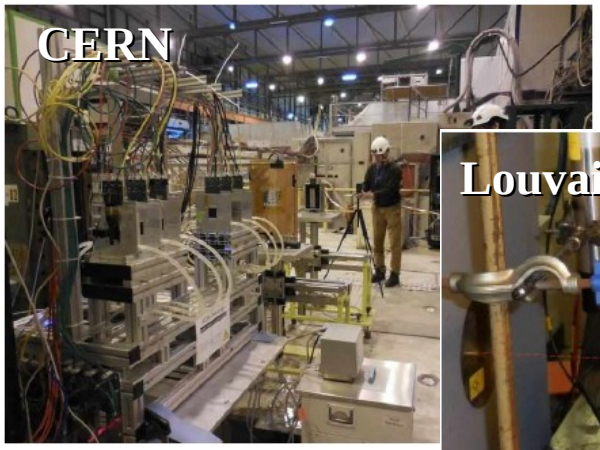


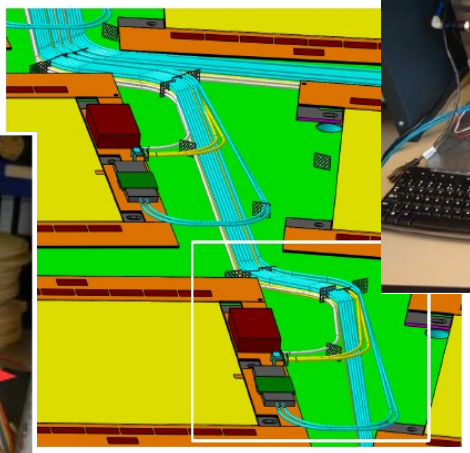
Inner tracker
- 100 um substrate
- 25 um x 100 um pixels

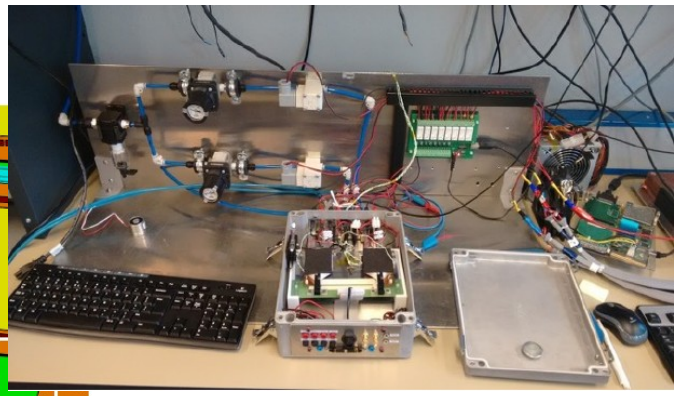
Outer tracker
- 200 um substrate
- 90 um x 5 cm in 2S modules
- 100 um x 2.5 cm strips in PS-s
- 100 um x 1.4 mm pixels in PS-p

Ongoing activities

- The Belgian CMS community got already involved in the phase-2 tracker developments in different ways:
  - Organization and participation to test beam campaigns for 2S modules
    - DESY, CERN, Louvain-la-Neuve (SEU, HIP, …)
    - Validation of the prototypes, system test development
  - Development of the readout hybrid test system
    - In preparation for the production
  - Study of the services routing in the endcap
  - Detector simulation development/studies
  - ...



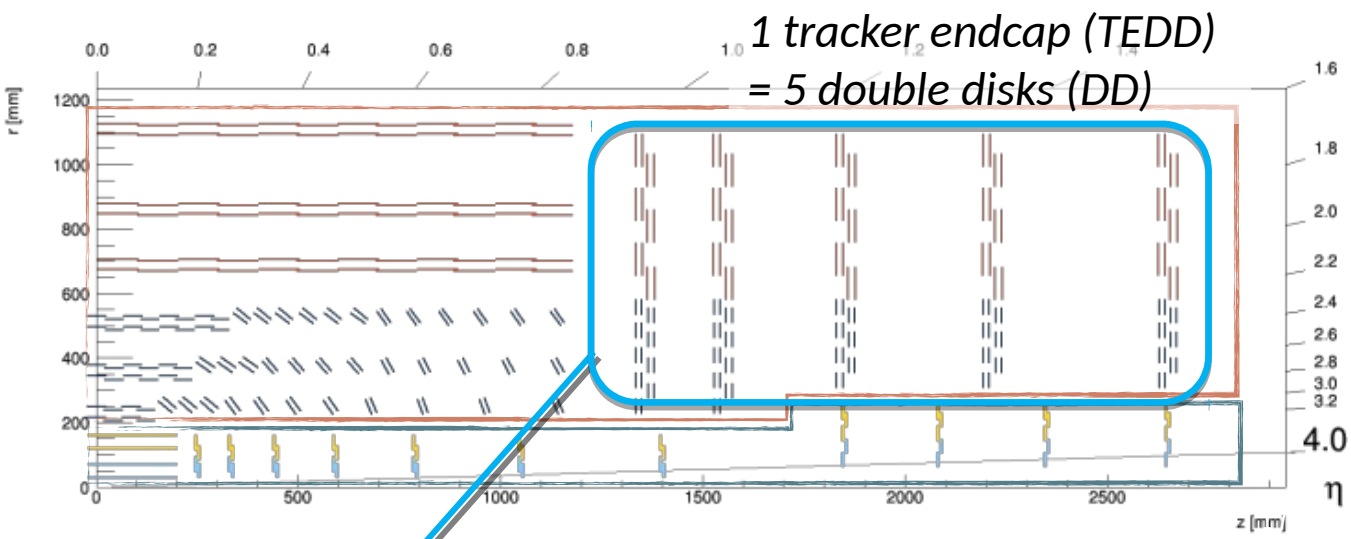




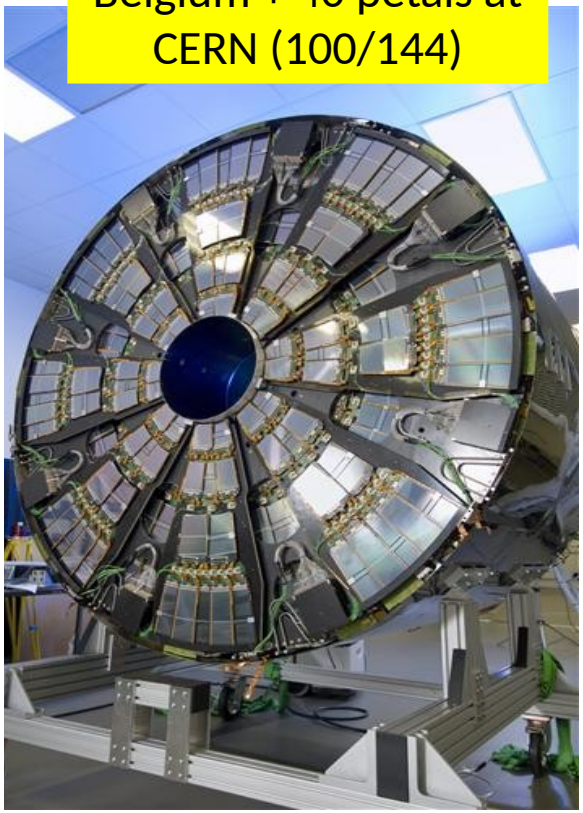
Building one tracker endcap in Belgium

Our ambition: to build one full outer tracker endcap in Belgium

- High-technology project, sizable yet realistic.
- Matches well our expected contribution to CMS and the size of the community.
- Builds on past experience



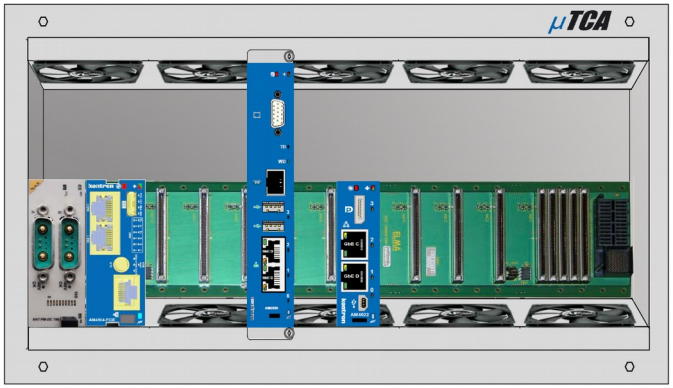
Current endcap:
1200/3200 modules
60 petals made in Belgium + 40 petals at CERN (100/144)



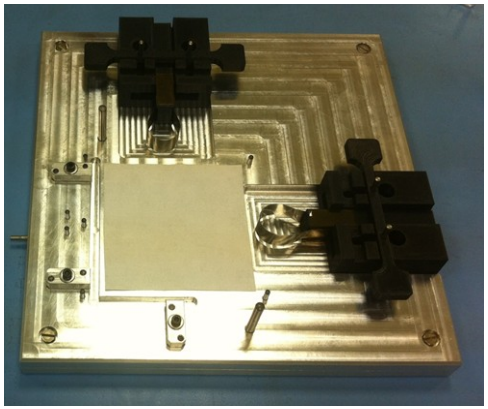
Module assembly and tests

- Assembly and testing of ~2000 2S modules (in Brussels)

1) Pre-test of hybrids
Data acquisition; cold box

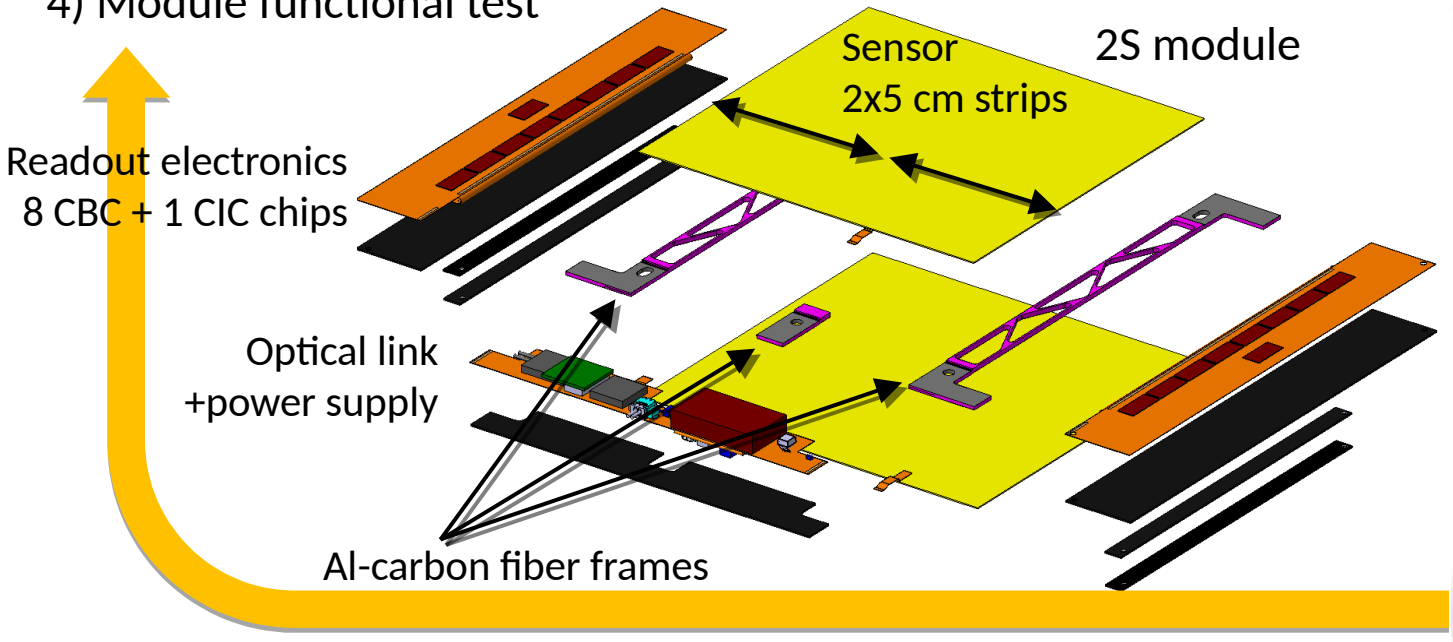


2) Assembly
Precision jigs



3) Wire bonding
Clean room (~120 m²); bonding equipment

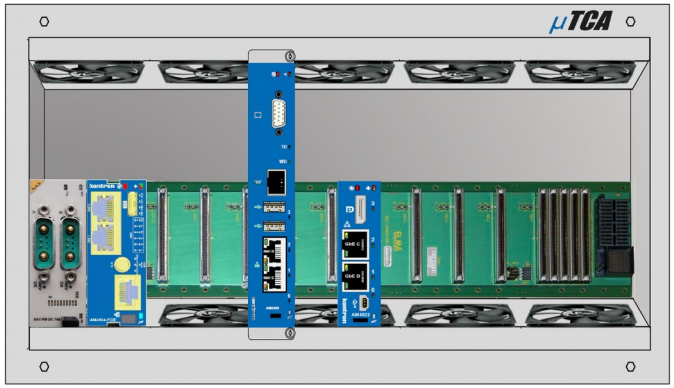
4) Module functional test



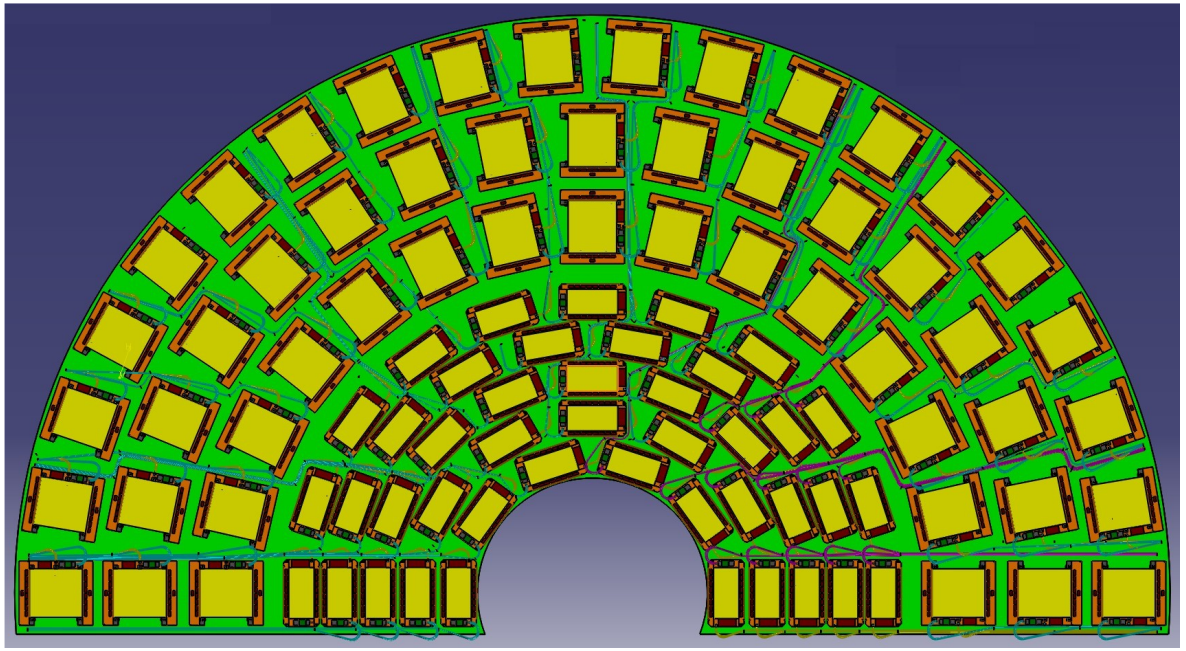
Dee integration

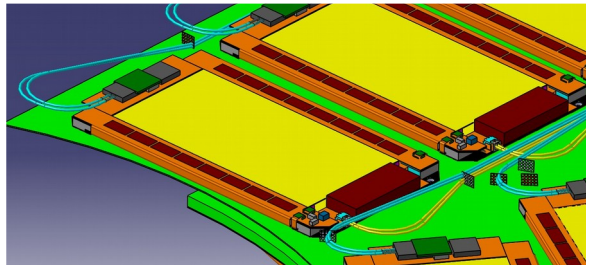
- Integration of 20 Dees (in Louvain-la-Neuve)

1) Burn-in tests of modules
Data acquisition; cold box

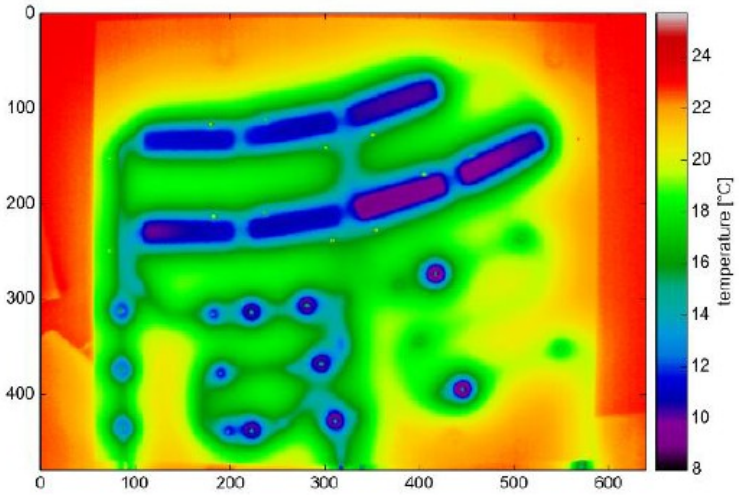


2) Mounting on dees
Clean room (~80 m²); tools



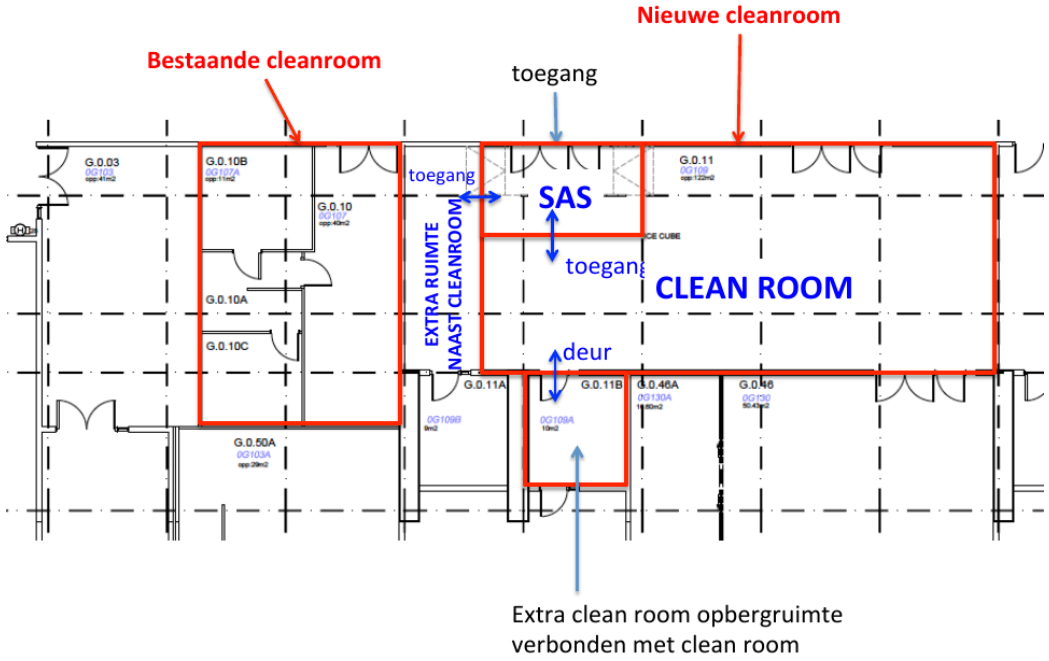


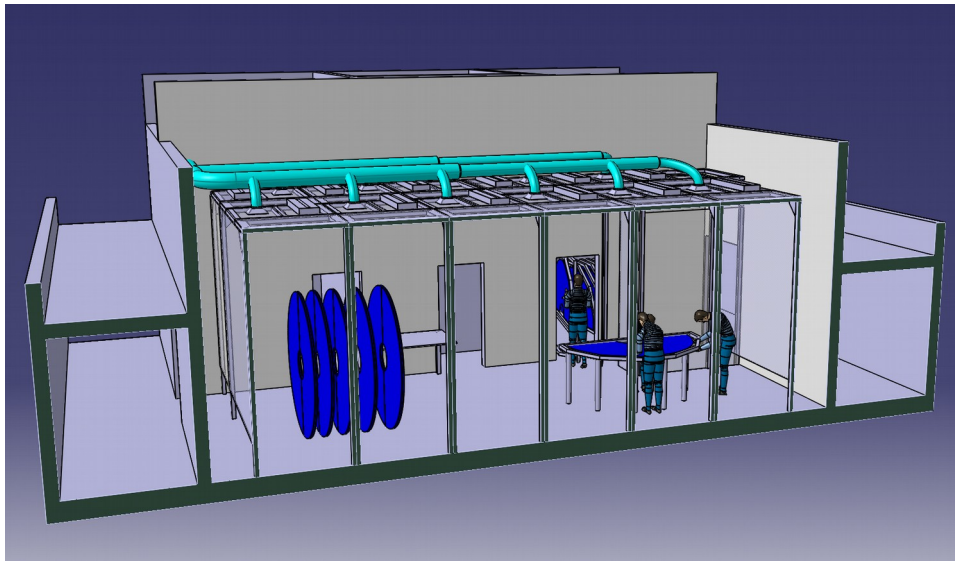
3) Integration tests
CO_2 cooling; cold box; readout



Experimental spaces

- Two clean rooms are being set up for this purpose
  - In Brussels (IIHE), a 120m² clean room budgeted on the Hercules project
    - Module construction and test
    - Class 10'000 – advanced temperature and humidity control
    - Shared with bio-engineers in the beginning – available in 2019
  - In Louvain-la-Neuve, a 90m² clean room financed by IISN
    - TEDD integration and test
    - Class ISO-5 – specs defined in coordination with UCL electronics engineering group.
    - Call for tender soon – available in 2018





Organization

- The Belgian CMS community got organized as a **consortium** regrouping all involved universities: UA, UG, VUB, ULB, UCL
  - **One community,**
  - **One common goal,**
  - **One common project**
- We started to meet regularly to prepare the project, build the community, consolidate our involvement, and develop shared expertise.
  - Already 8 workshops since March 2016
- Present scientific team (people involved part time):
  - 12 academics
  - 4 PhD students
  - 4 post-docs

Budgetary aspects

- Financing the CORE costs
  - Project introduced in the 2015 call of the Hercules foundation (FWO), with the support from the FRS-FNRS restricted board (letter of 9 Sept. 2015).
    - The project was selected and full budget was approved by the FWO board on 24 Feb. 2016.
    - Contribution to the cost of the tracker endcaps: 4.8M€
  - A counterpart from FRS-FNRS is expected, but no funding agreement signed yet.
    - Contribution to the cost of the tracker endcaps: 4.6M€
    - Contribution to the common items: 0.2M€
  - This is matching our fair-share contribution (~4% for Belgium) to the 265MCHF total upgrade cost .
- Financing the local developments
  - Lab equipment (so far):
    - 388.1k€ from Hercules foundation
    - 515.6k€ from IISN
  - Human resources:
    - No additional dedicated manpower so far...

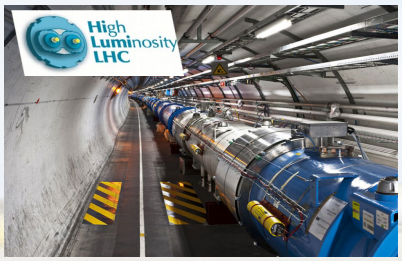
Additional challenge: technical staff

- While the scientific manpower (both permanent and post-docs) evolved in a positive way over the last 10 years, the situation is more problematic for technical staff.
  - Personnel from universities is not always renewed when experienced people retire, or get shared with other entities within the universities.
  - Funding agencies tend to not finance technical staff anymore.
    - e.g.: no more permanent technicians from FNRS (IISN). Recently: no more short-term hiring allowed either (similar situation at FWO).
- Considering engineers and technicians together, one can estimate that our groups were relying on ~23 FTE during the tracker construction period (2005-2008).
- Today, the most recent estimate of the manpower available is ~12 FTE, and further reductions are possible.

We need to maintain at least a minimum level of technical and engineering support in our laboratories!

Looking forward...

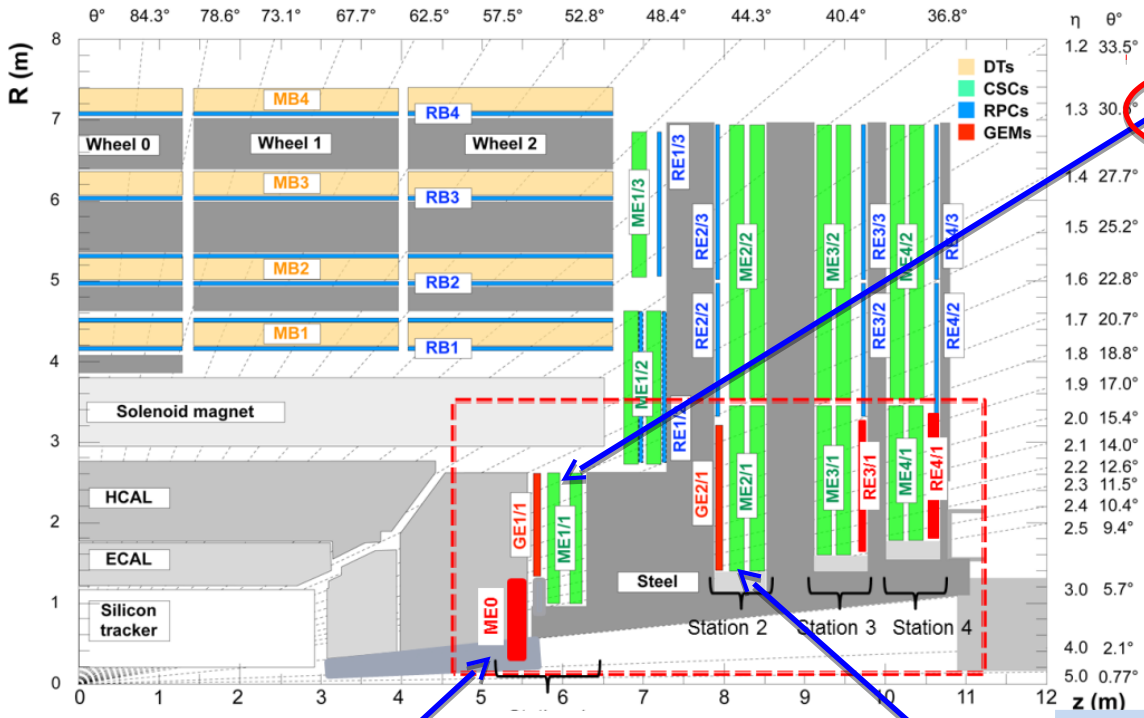
Many questions are still open...
...and many motivating projects ahead of us.



- All the work so far was made possible by the dedication of the community, with the constant support of FWO, FNRS and BELSPO.
- While our attention is turning towards the upgrade in view of the new challenges at the horizon 2025, that support will be more than ever important.

Supplemental material

The CMS GEM project



- 1.55 < |η| < 2.18

GE1/1:

- baseline detector for GEM project
- 36 staggered chambers per endcap, each chamber spans 10°
- One chamber is made of 2 back-to-back Triple-GEM detector
- Will guarantee high trigger performance during late Phase I and throughout Phase II
- Installation: LS2 (2019-20)

GE2/1:

- 1.55 < |η| < 2.45
- 18 staggered chambers per endcap, each chamber spans 20°
- Installation: LS3

ME0:

- Muon tagger at highest η
- 2.0 < |η| < 3.5
- 6 layers of Triple-GEM
- each chamber spans 20°
- Installation:

Slice test:

- 10 GE1/1 detectors
- Installed in winter 2016-17
- Commissioning on-going

Belgian participation - HR

- GEMs
  - UGent involved since 2009
    - One of the founder institutes of the project
    - One of GE1/1 detector production site
    - 2 physicists, 1 PhD students, …
  - ULB involved since 2011
    - Leader of the electronics and DAQ system development
    - 1 physicist (part-time), 1 electronics engineer (part-time), 2 postdocs (one is the project Technical Coordinator), 2 PhD students.
- Tracker (present snapshot)
  - UA
    - 0.5 FTE (physicists, students, staff)
  - UCL
    - 1.5 FTE (incl. 1 PhD)
  - ULB
    - 4.5 FTE (incl. 1.4 post-doc, 0.6 PhD)
  - VUB
    - 1FTE (incl. 0.5 PhD)

7 FTE in 2016;
Planing for up to 23 FTE in 2022