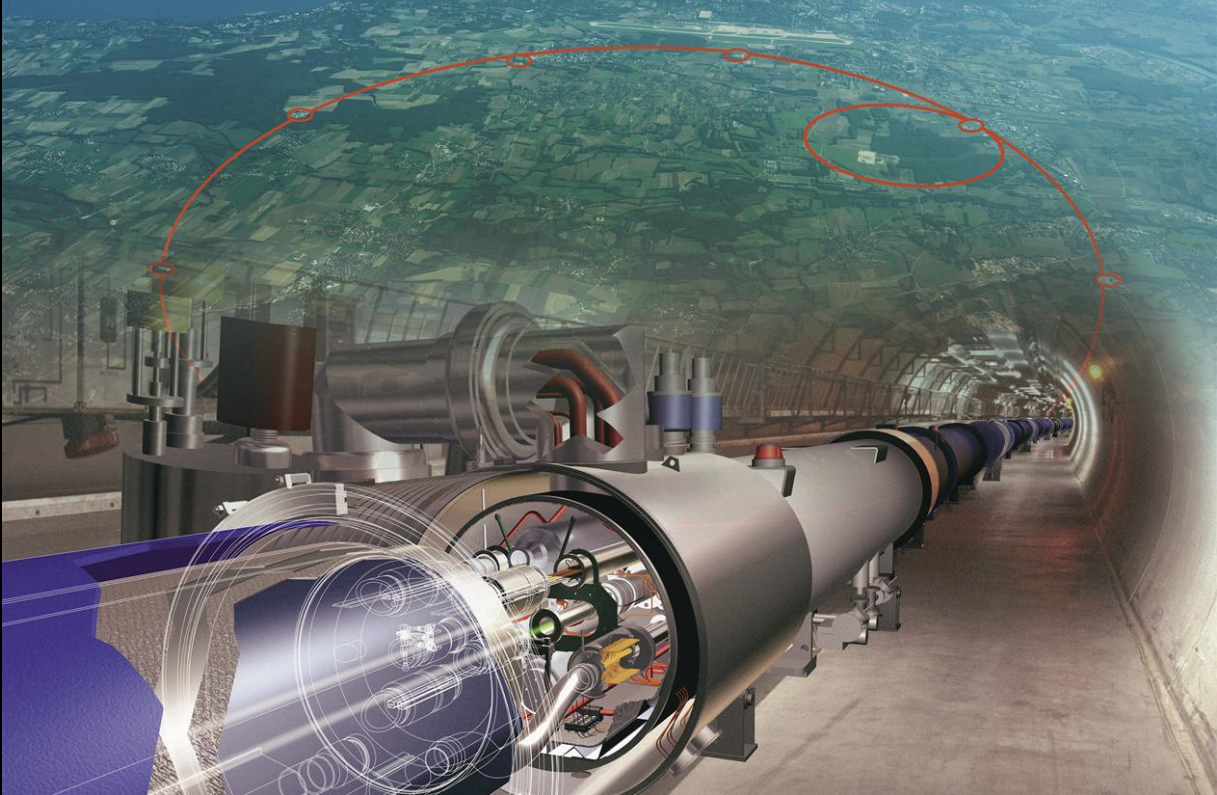




*SILICON TRACKER ENDCAP FOR THE UPGRADED  
CMS EXPERIMENT AT THE HL-LHC AT CERN*



# International collaboration including a Belgian consortium

Most of Belgian universities are involved in CMS, with directors/teamleaders:

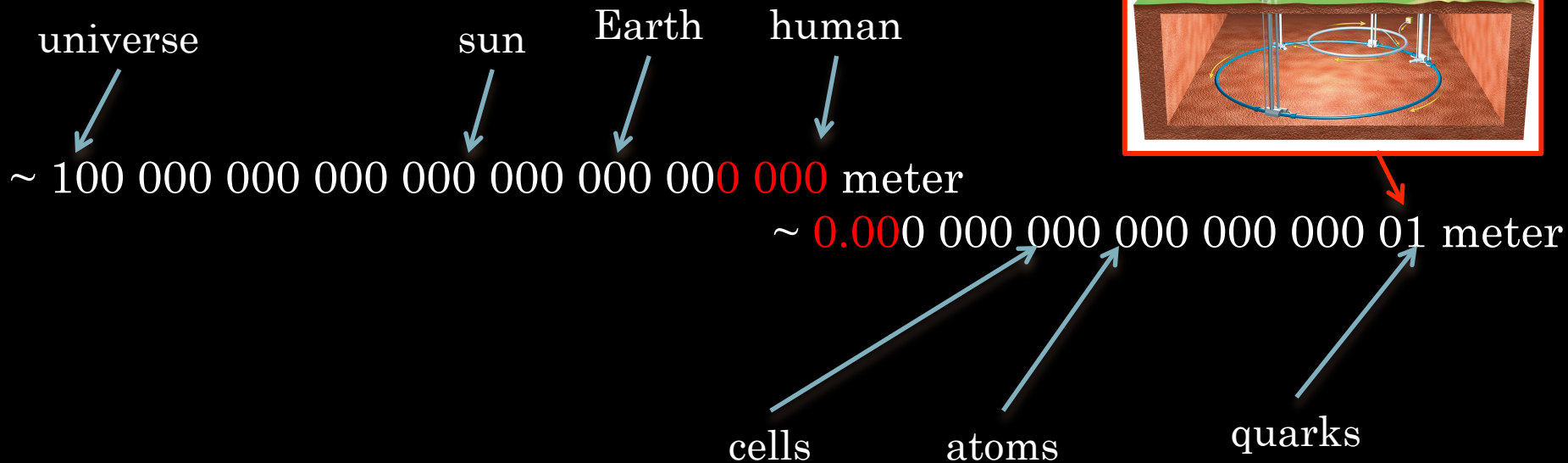
Prof. Jorgen D'Hondt	Vrije Universiteit Brussel – promoter-spokesperson
Prof. Pierre Van Mechelen	Universiteit Antwerpen
Dr. Michael Tytgat	Universiteit Gent
Prof. Vincent Lemaitre	Université Catholique de Louvain
Prof. Pascal Vanlaer	Université Libre de Bruxelles

In total 51 researchers in Flanders and 49 researchers in Wallonia.

In total 17 faculty members (professor or equivalent).

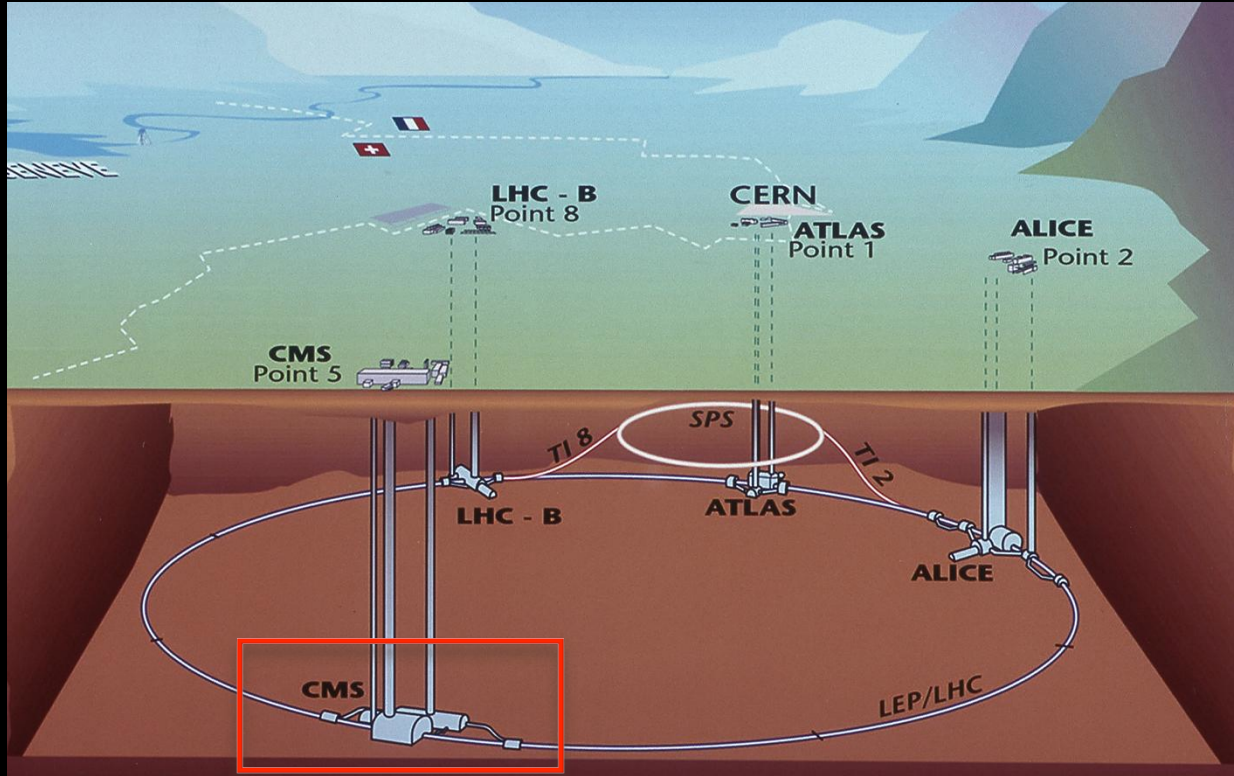


# The field of High-Energy Physics (HEP)



Discover the fundamental constituents of nature and understand how they interact among each other. Develop dedicated instruments to measure the phenomena at the largest possible energies.

# The Large Hadron Collider @ CERN



1990-2000  
designs and R&D

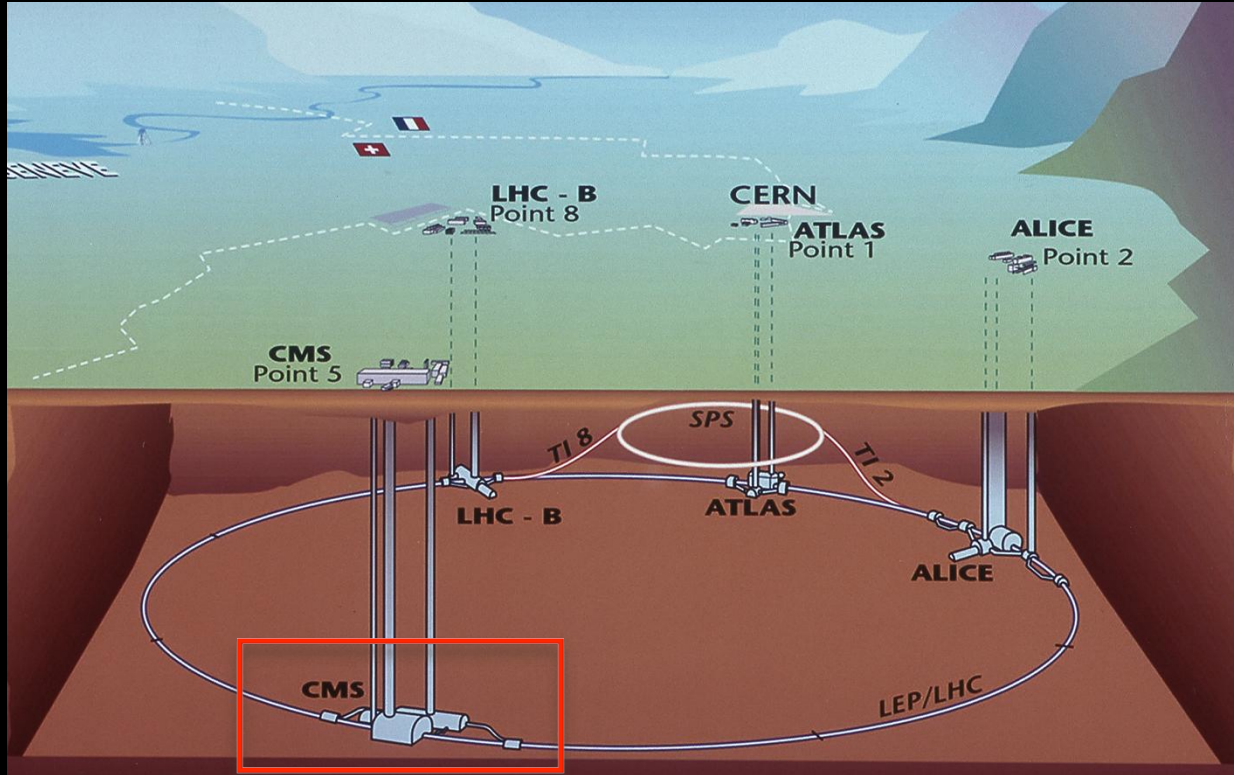
2000-2008  
construction LHC  
construction CMS

2009-2023 (LHC)  
operational Phase-1

2026-2037 (HL-LHC)  
Phase-2 of the program

A unique collider worldwide at the highest energies ever, and with a step-by-step increasing proton-proton collision rate from the LHC to the HL-LHC Phase.

# The Large Hadron Collider @ CERN



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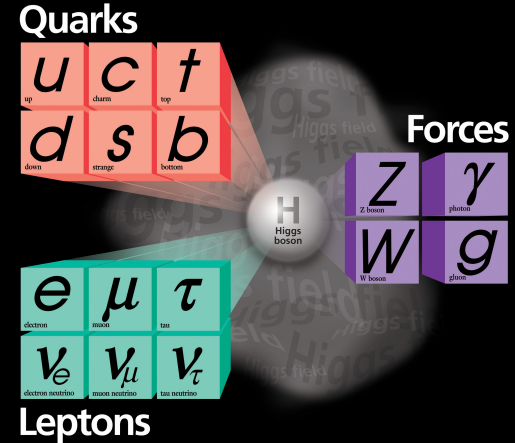
2009-2023 (LHC)  
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Phase-2 of the program

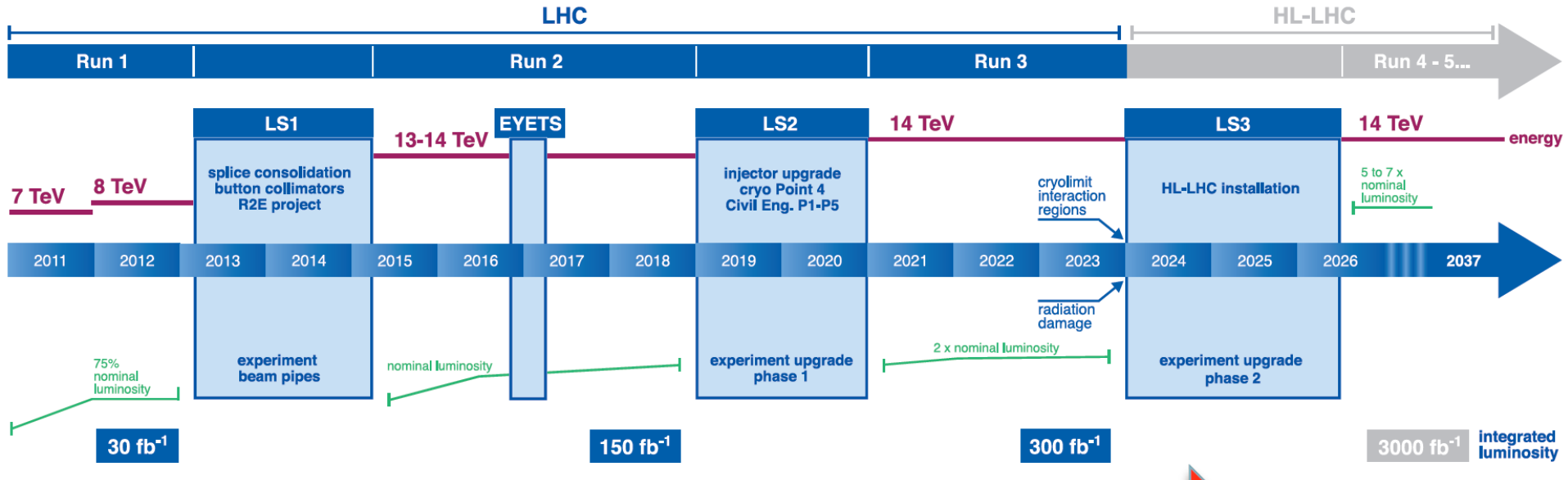
**Important:** the LHC/HL-LHC accelerator is financed and supported by the CERN laboratory; the CMS detector by the researchers involved

# State of the Art, and key objectives of the LHC/HL-LHC

- ✓ In 2012 we discovered the Higgs particle as one of the key goals and milestones for the LHC
- ✓ The Standard Model emerged during the last decades as the theory for fundamental interactions and its validity was tested extensively, also at the LHC
- ✓ The research field is very active, with our experimental results cited highly in related fields of theoretical and astro(-particle) physics
  - Our quest with the LHC/HL-LHC aims for insights into several fundamental questions: dark matter, matter vs anti-matter, hierarchy problem,...
  - The LHC and its successor, the High Luminosity LHC, are identified as the first priority for the particle physics community at large to make progress



# Timeline of the LHC and HL-LHC

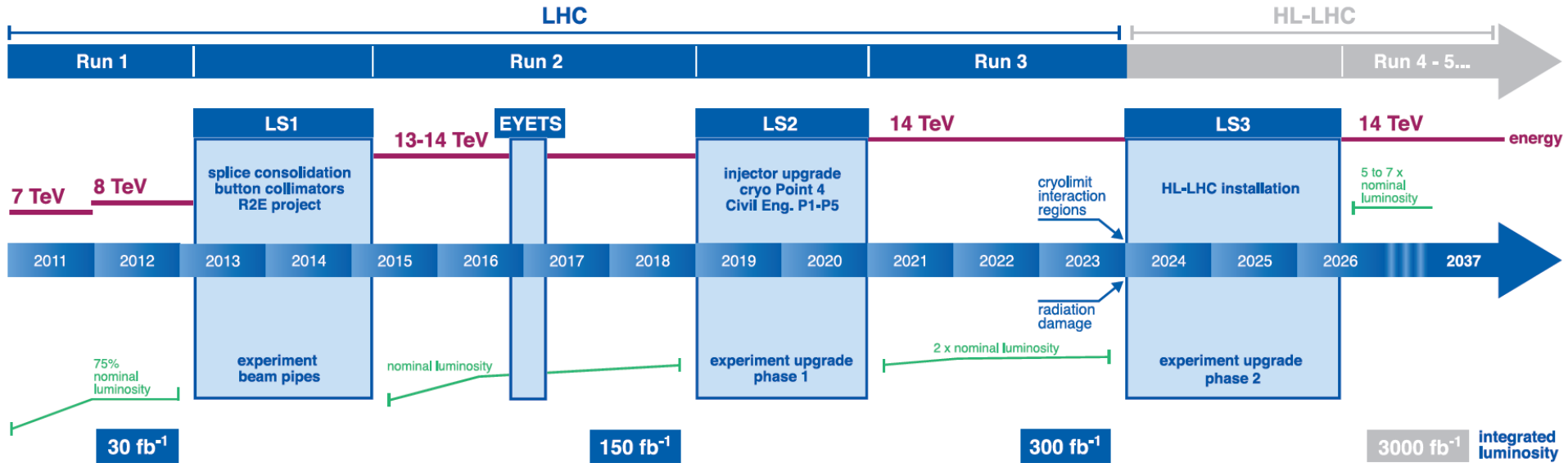


*construct a new detector*

>530 publications  
on this data by the  
CMS Collaboration  
(incl Higgs discovery with >6400 citations)

Collect an equal amount of  
collisions per year as during  
the whole Phase-1 period

# Timeline of the LHC and HL-LHC



- This Hercules application is to financially support the purchase and the construction of a detector instrument that will be vital for the physics exploration in the HL-LHC phase of the program.
- Preparations for the construction have to start now in order to be timely.



# The CMS Collaboration and experiment

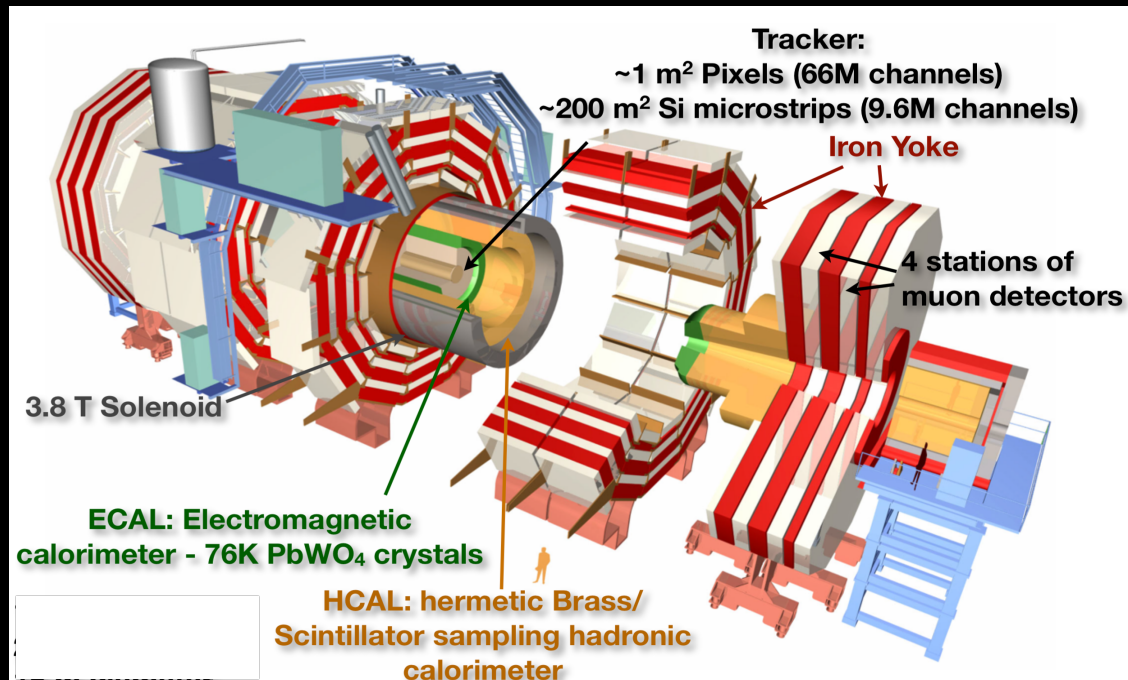
A worldwide collaboration established 23 years ago, and still growing

43 countries

>200 institutions

2680 scientists

1140 engineers & technicians



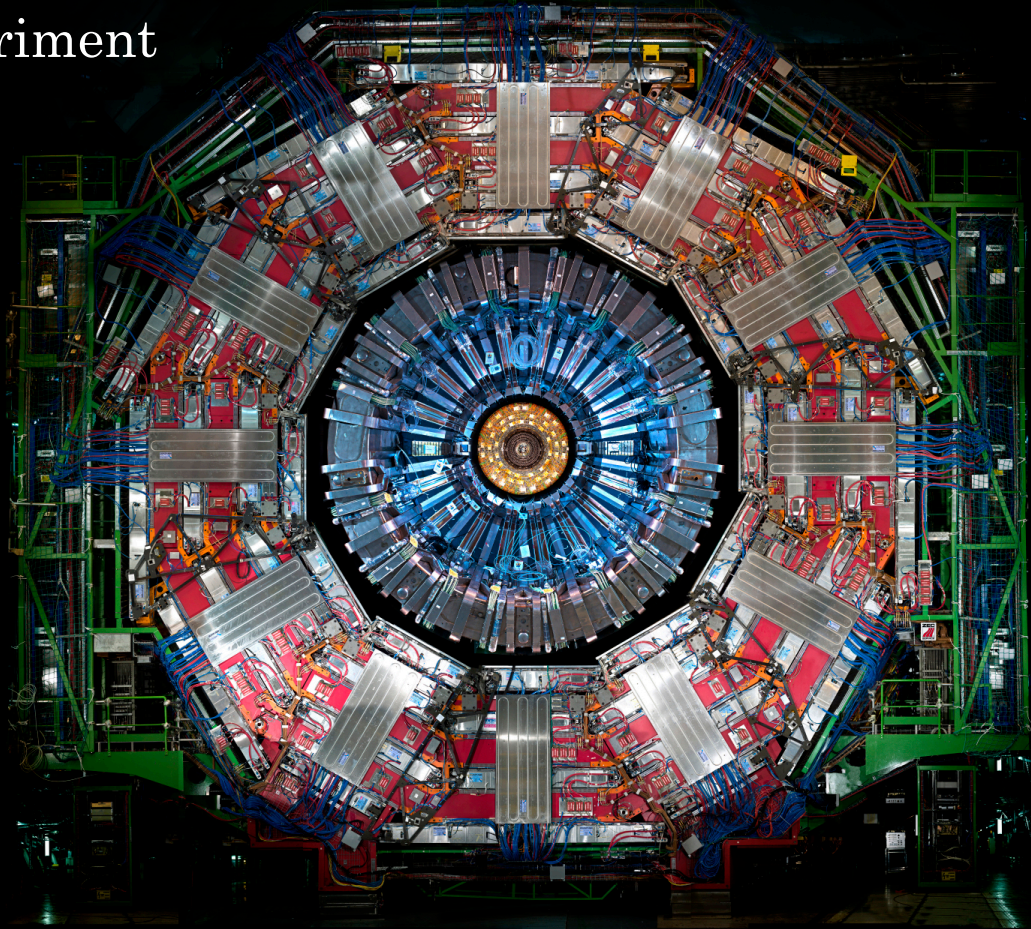
Several instruments have to be integrated and synchronized together to make the experiment a success. The responsibility to construct, commission, operate, maintain each instrument is typically connected to a consortium of institutions.

## Belgium in the CMS Collaboration

- For a relative small Belgian financial investment, we have access to one of the worlds most unique and powerful scientific instruments.
- Operational funding relates to the number PhD-titled authors
- 2.9% of the PhD-titled authors are at Belgian institutions
- 4.4% of the authors on CMS publications (+52% over our “fair-share”)
- 5.3% of the number of PhD students (+83% over our “fair-share”)
- 6.6% of physics area conveners (+128% over our “fair-share”)
- 8.3% of the major conference talks (+186% over our “fair-share”)
- 17% (1/6) of the Collaboration Board chairs (+490% over our “fair-share”)
- 33% (6/18) of the Best PhD Thesis Awards (+1040% over our “fair-share”)

**a “small” country over performing in a “large” collaboration**

# The CMS experiment

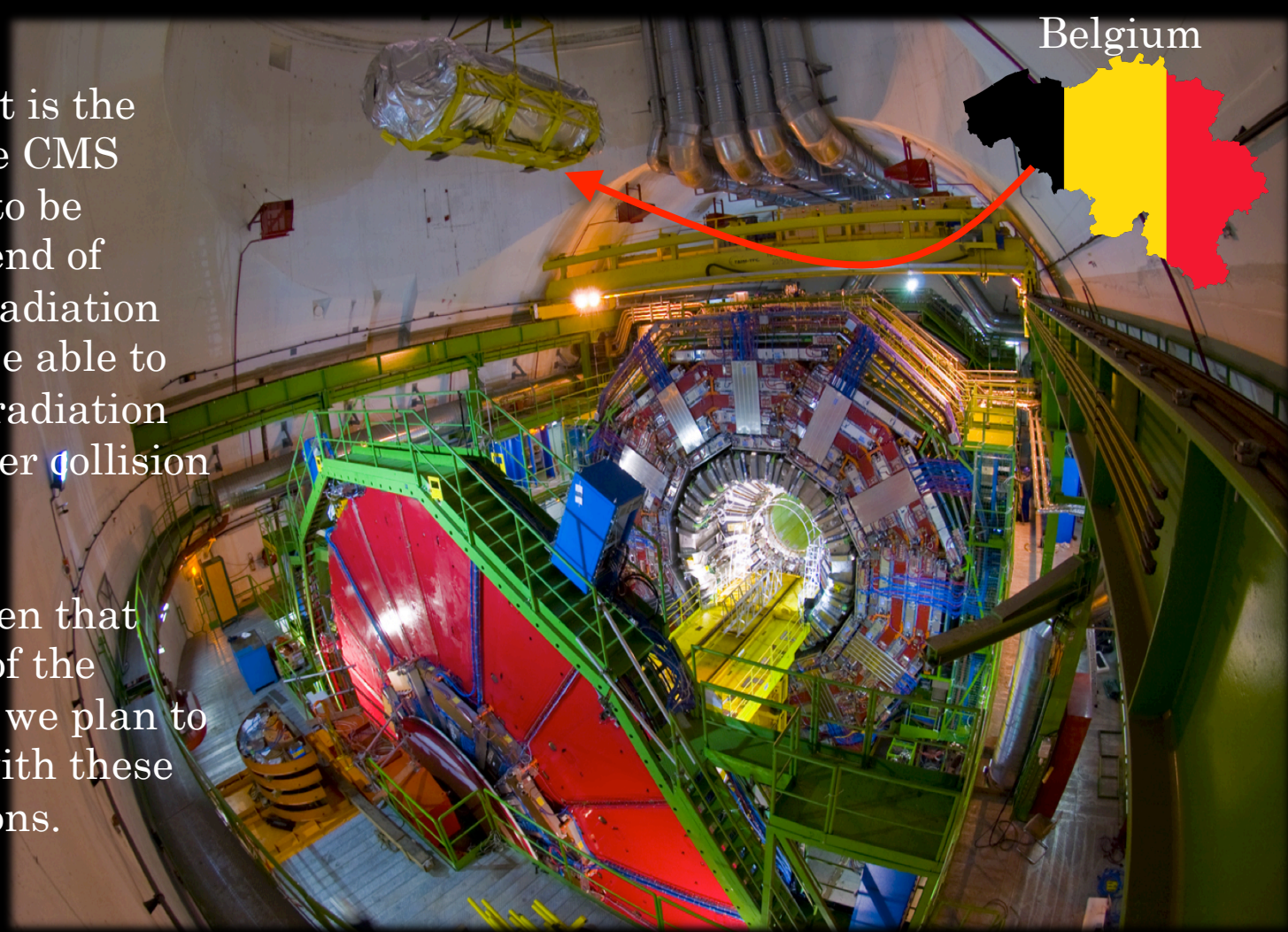


15m

*CMS = Compact Muon Solenoid*

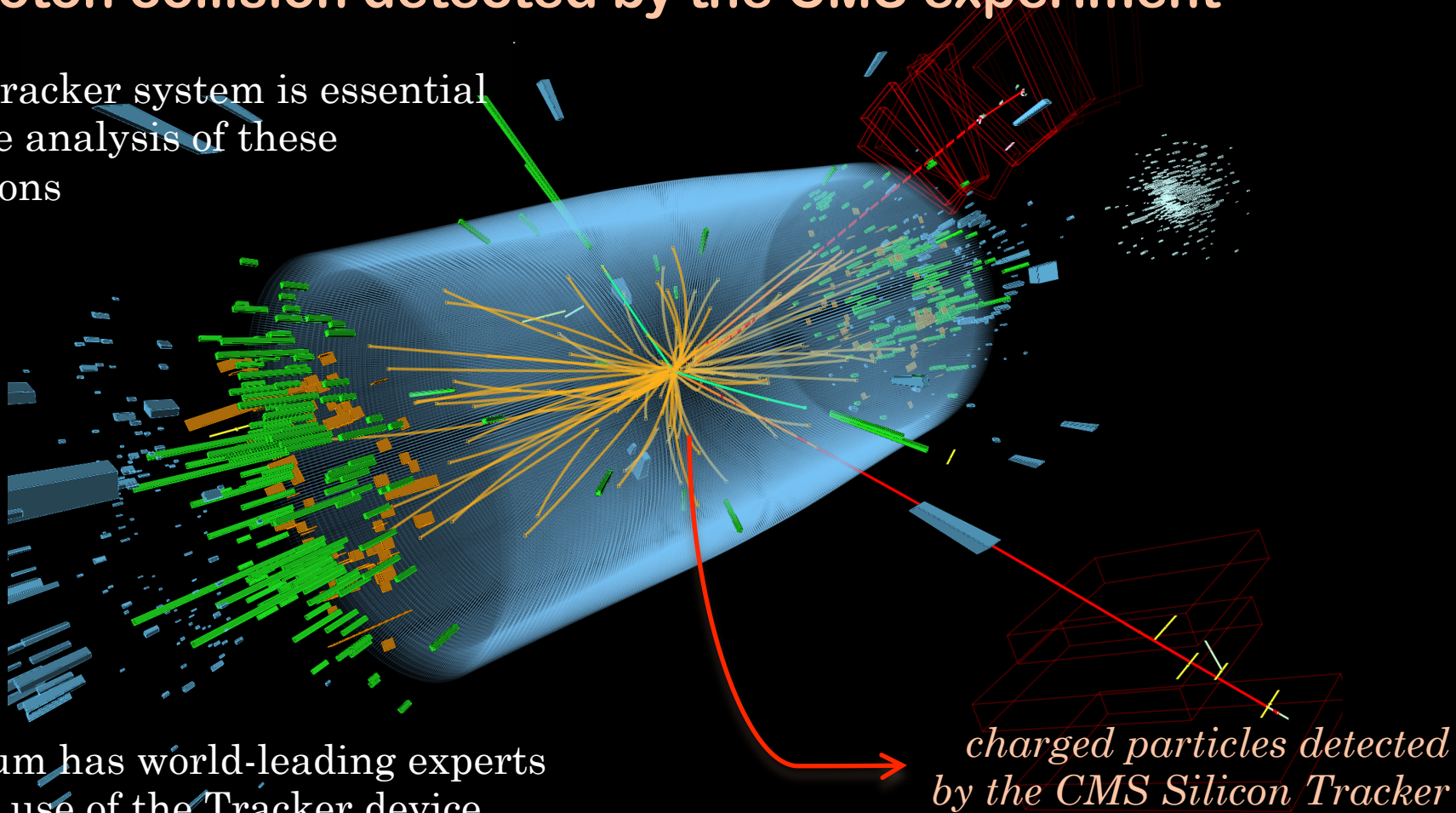
The Tracker part is the major part of the CMS detector that is to be replaced at the end of Phase-1 due to radiation damage and to be able to cope with more radiation and a much larger collision rate in Phase-2.

It has been proven that the new design of the Tracker Endcap we plan to build can cope with these extreme conditions.



# A proton collision detected by the CMS experiment

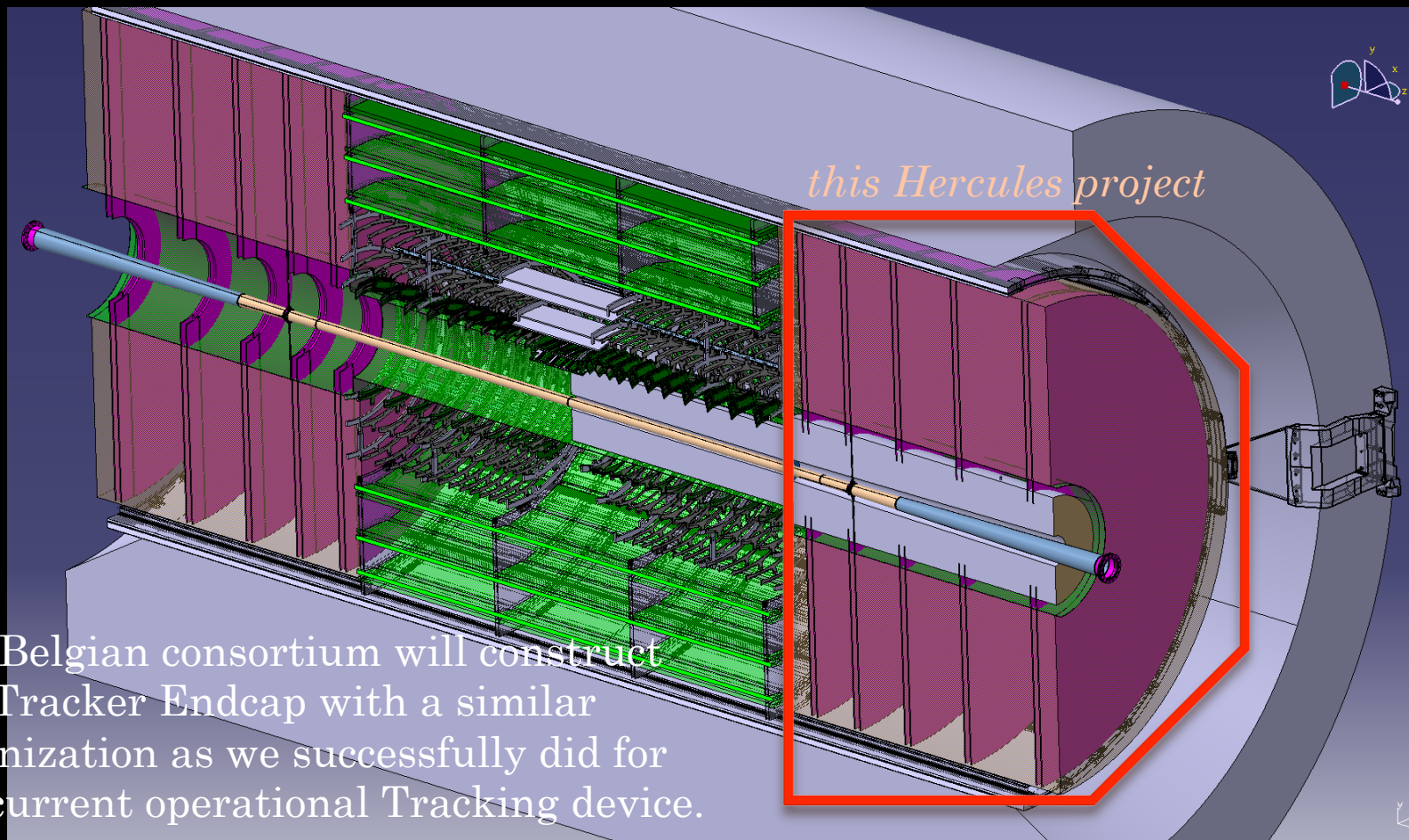
The Tracker system is essential for the analysis of these collisions



Belgium has world-leading experts in the use of the Tracker device

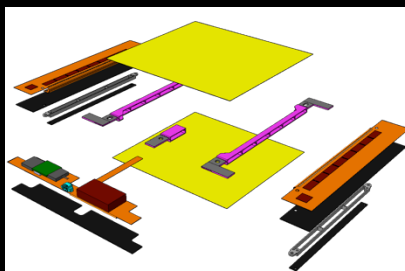
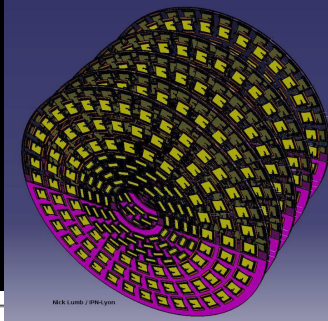
*charged particles detected by the CMS Silicon Tracker*

# Belgian ambition to construct a key instrument

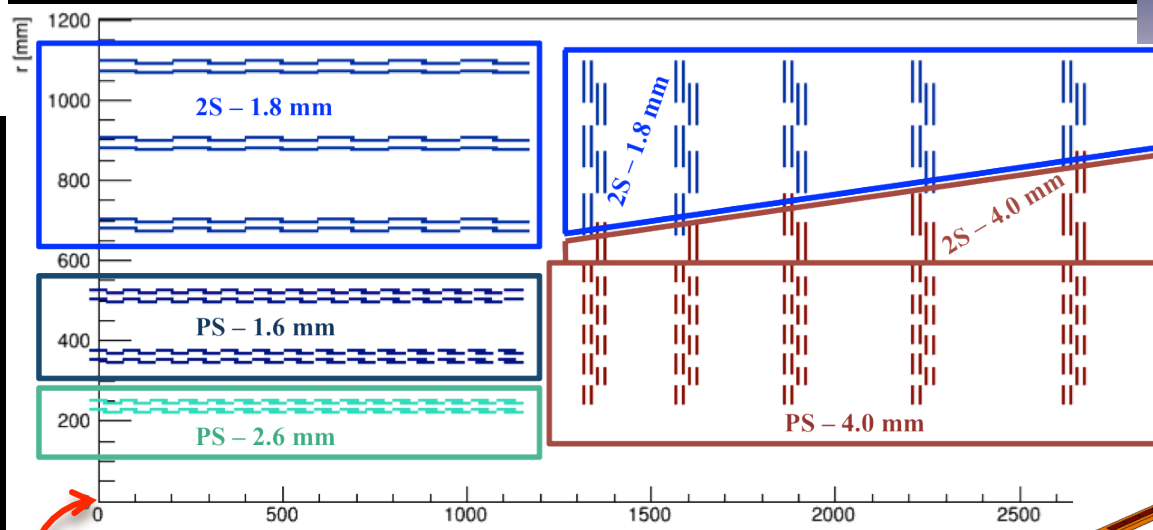


The Belgian consortium will construct one Tracker Endcap with a similar organization as we successfully did for the current operational Tracking device.

# The new Silicon Tracker Endcap

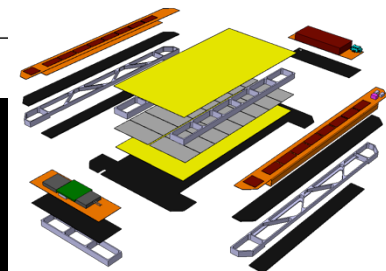


**2S modules (in total 8424)**  
*90  $\mu\text{m}$  pitch & 5 cm length*



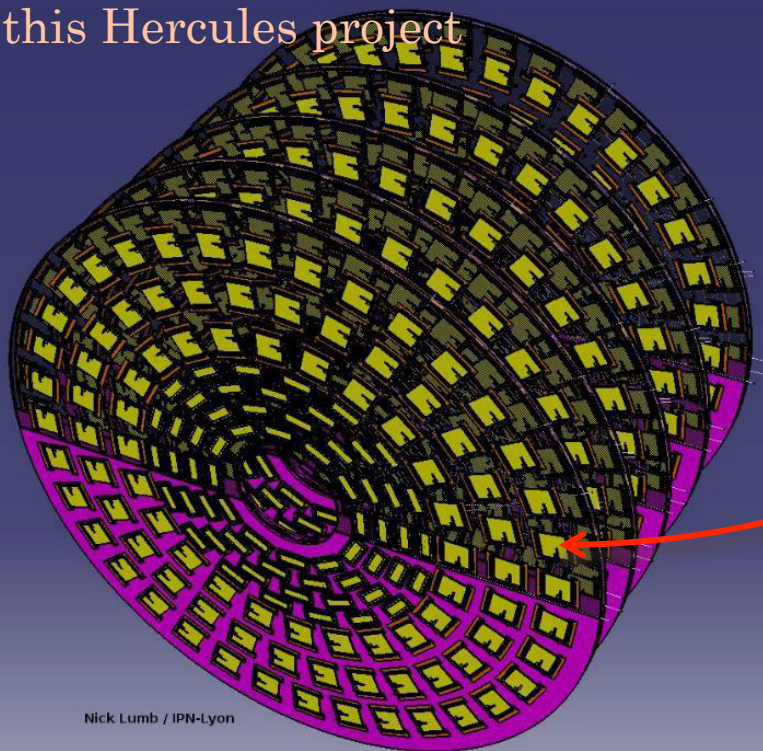
*collision point*

**PS modules (in total 7084)**  
*100  $\mu\text{m}$  pitch & 2.5 cm length*  
*100  $\mu\text{m}$  x 1.5 mm macro-pixels*

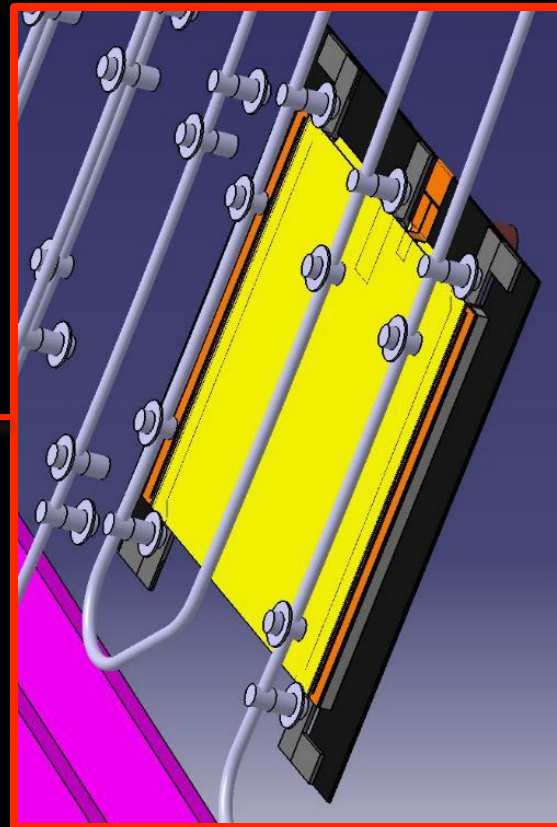


# The Silicon Tracker Endcap: a dedicated assembly project

this Hercules project

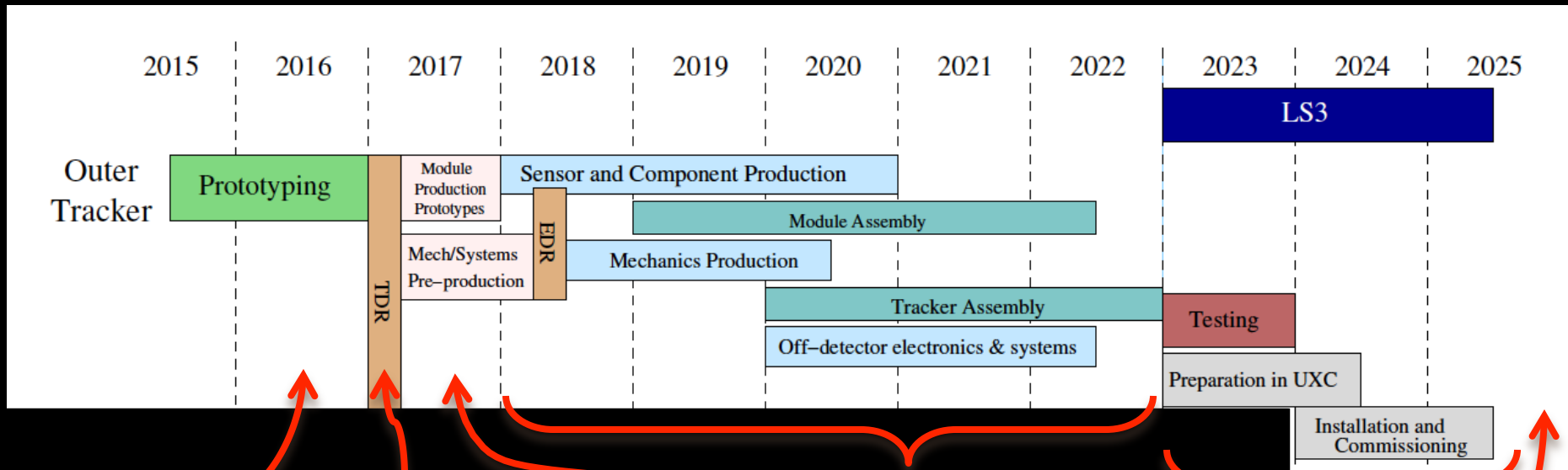


Nick Lumb / IPN-Lyon





# The Silicon Tracker Endcap: construction timeline



Final design in  
Technical Design  
Report (TDR)

Window for commitments in  
the construction  
(incl financial)

Construction and  
assembly window

Setup the assembly and  
testing facilities

Integration in  
CMS experiment

Start of new CMS  
experiment at HL-LHC  
(until about 2037)

# The Silicon Tracker Endcap: cost table

The core cost of the instrument has been scrutinized on an international level by dedicated committees installed by CERN. Maintenance and Operation costs of the CMS experiment are covered by the FWO Big Science program in Flanders.

Flanders	core cost	4,80 M€
	construction	0,39 M€
Wallonia	core cost	4,61 M€
	construction	0,38 M€
Total		10,18 M€

Core cost: the Silicon sensors, the Front End Electronics, the service hybrids, the mechanical structures, the cooling circuits, the cost for bump/wire bonding

Additional construction costs: cleanrooms, transport boxes and shipping, test electronics, CO<sub>2</sub> cooling plant, mechanical support structures for assembly

*total cost new CMS detector is 255 M€  
BE 4.4% of authors → BE 4% of cost*

Being the key instrument for 100 researchers in Belgium for a program that will take 15 years, this represents an investment of 6,3 k Euro per researcher per year.

# The unique national & international context of the project

- The HL-LHC project is the top priority in the international vision for particle physics (conclusion from US and European advisory panels)
- The instrument will be the center piece for ~100 HEP researchers at Belgian institutions for about 15 years, and connects naturally to theoretical/astrophysics research
- We deploy novel detector technology to enhance our research potential
- The construction of the instrument is monitored on an international level to optimize the financial resources as well as the feasibility in timeline and performance
- The requested investment (10,2 M Euro) will allow access for Belgian institutes to the data of the full CMS experiment at CERN (255 M Euro)
- Based on our international reputation confirmed by the panel reviewer and a thorough experience to construct, commission and operate the instrument

# The opportunities for scientific research

- The envisaged physics results with the CMS detector at HL-LHC are novel and unique, and recent history illustrated they might lead to groundbreaking insights in fundamental physics
- Expect about ~60-80 publications per year (on average ~80 citations each)
- At our universities we are typically labeled as a center of excellence with adequate strategic support to perform the fundamental research with the instrument; we have maintenance and operational support from the FWO Big Science program (equivalent for our Walloon partners)
- The project will solidify the position of Belgium/Flanders in HEP at the highest level, and strengthen our international reputation
- Career horizon of professors involved spans the full timeline of the HL-LHC

# Reviews and follow-up

- CERN does organize international reviews on the research projects performed in the laboratory
- LHCC (LHC Committee): scientific review of the LHC experiments (including the CMS experiment), gathering 4-5 times per year for 2-3 days, and reporting the CERN management and the RRB; members are international experts independent from the experiments
- CRG and UCG: dedicated cost review groups for the operational costs and upgrade costs of the LHC experiments, they review (and propose corrections/improvements) in detail all cost items and report to the CERN management and the RRB
- RRB (Resources Review Board): each funding agency delegates a members to the board (including FWO, Prof. Catherine De Clercq), they take note of the scientific report, the cost review groups and the financial report, they approve and follow-up the financial plans of the experiments for their operational and upgrade plans; they meet 2 times per year; the FWO delegate reports back to the FWO