

# The amazing trip of the protons in the CERN accelerators complex





*Thanks to all Contributors*





# The amazing LHC performances and CERN's bright future

Dr. José Miguel Jiménez, CERN Technology Department Head



# Main topics

An European or a Worldwide success?

A Laboratory for Physicists or Technologists?

A vibrant R&D on breakthrough technologies!

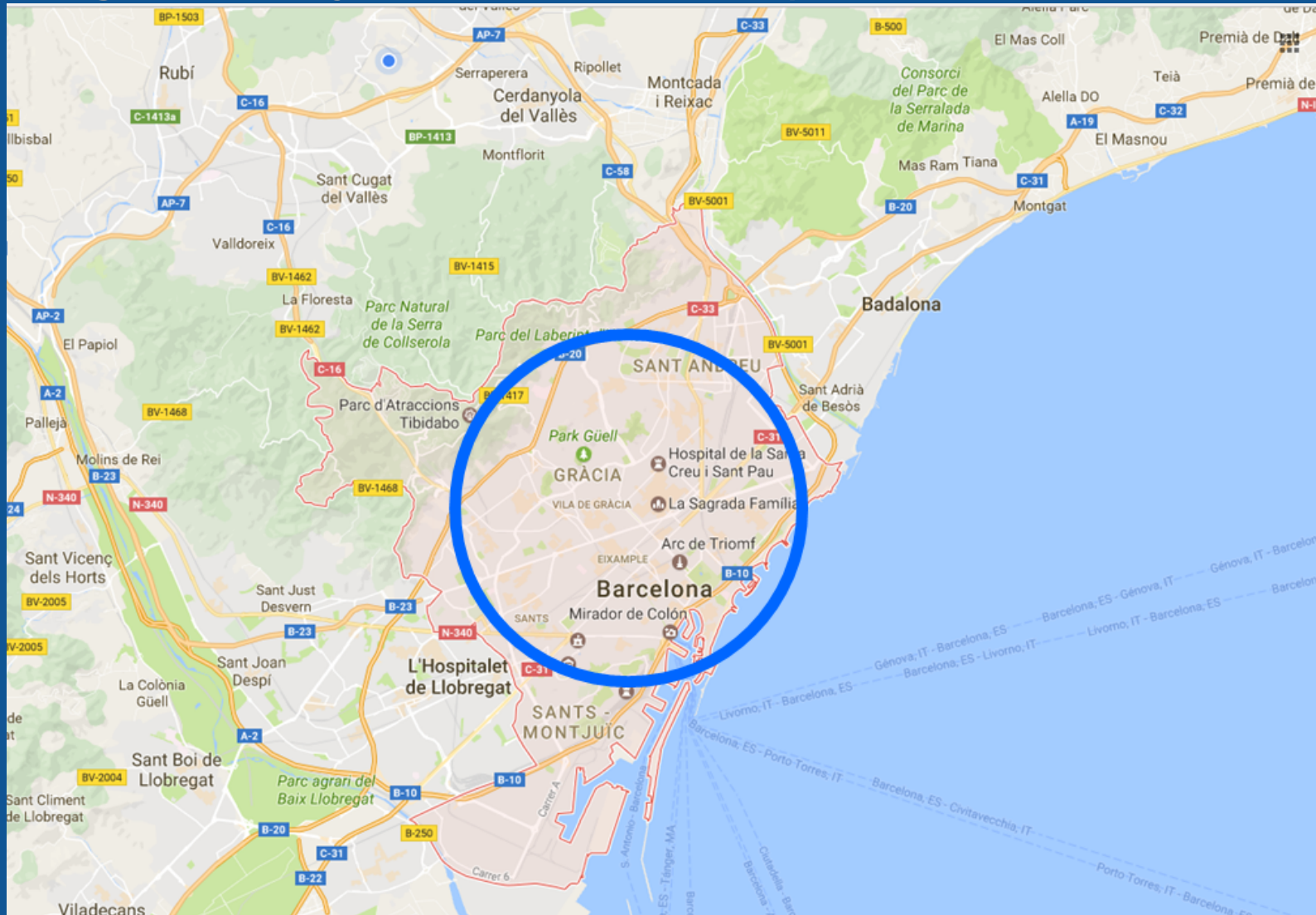
Any obstacle to Theoretician's dreams?

Longest genesis and lifecycles!

At the crossing of the roads?

# An European or a Worldwide success?

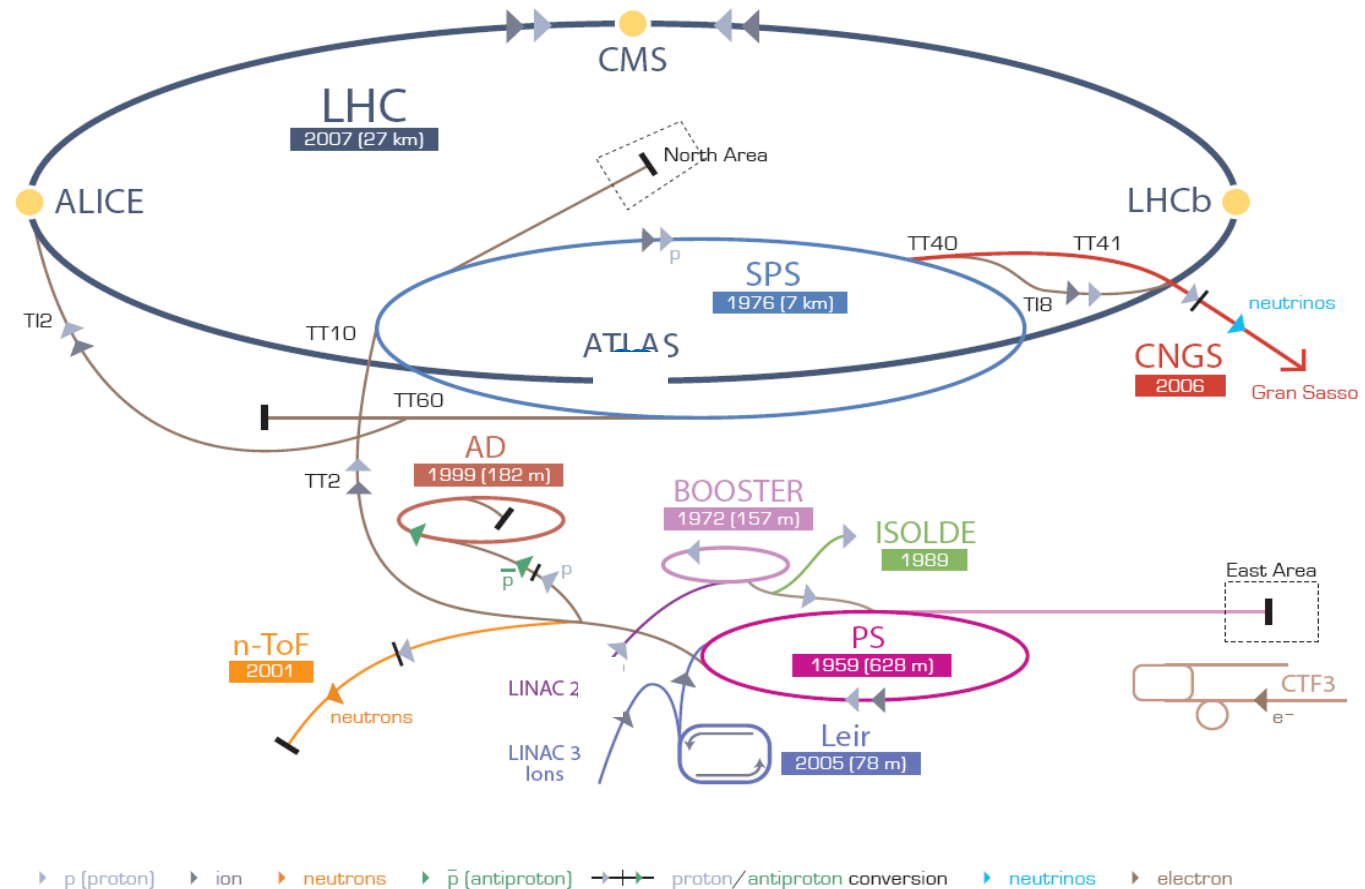
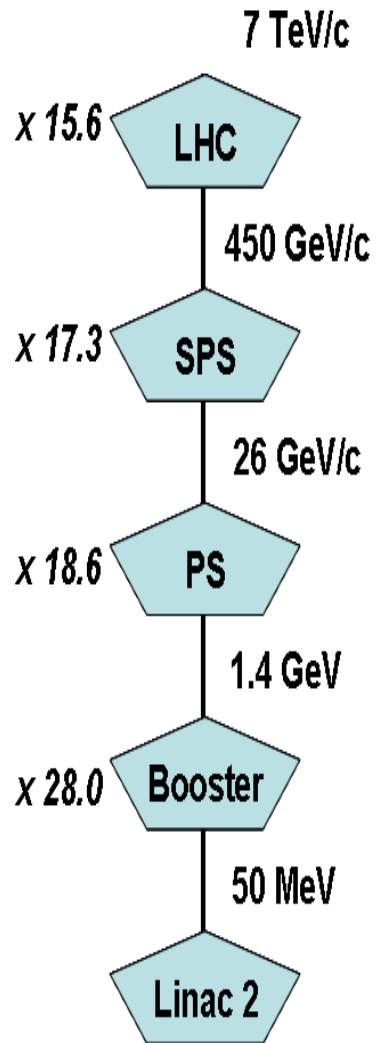
*Amongst the major accelerator complex worldwide!*





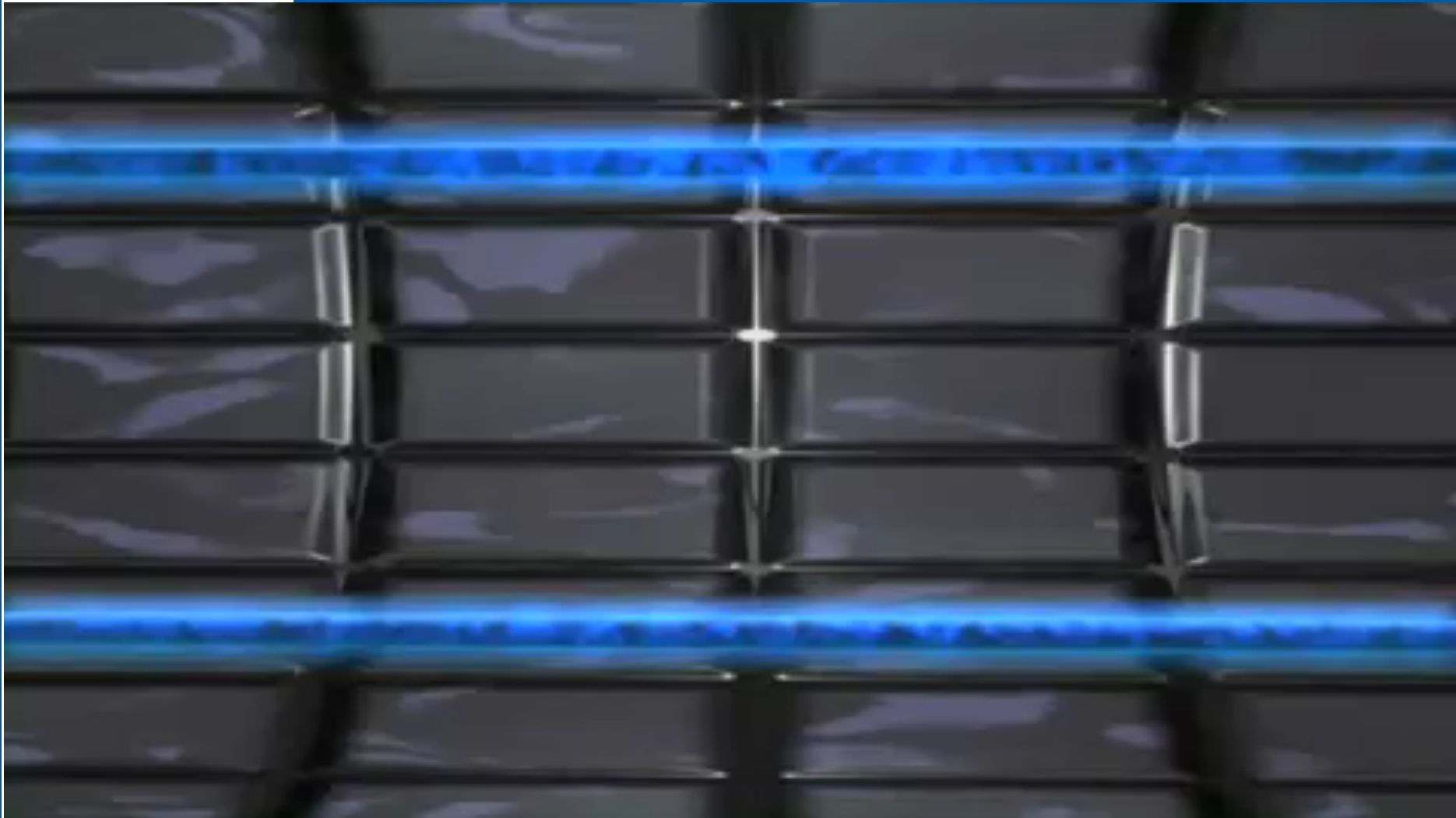
# An European or a Worldwide success?

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*The amazing LHC performances  
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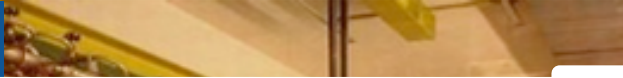
*Feb'17*

*J.M. Jimenez  
CERN, Technology Department Head*

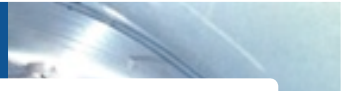
# An European or a Worldwide success?

*Amongst the major accelerator complex worldwide!*

LINAC2



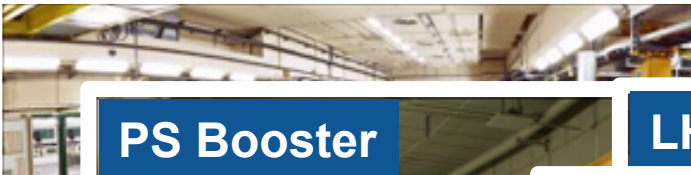
Super Proton Synchrotron



Large Hadron Collider



PS Booster



LHC RF cavities



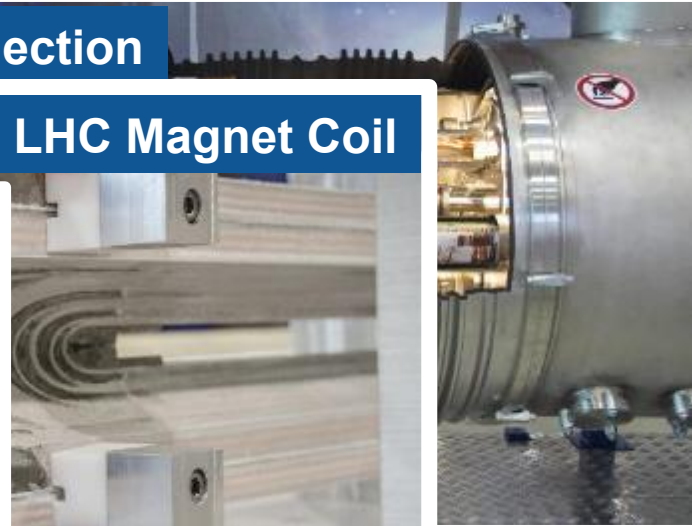
LHC straight section



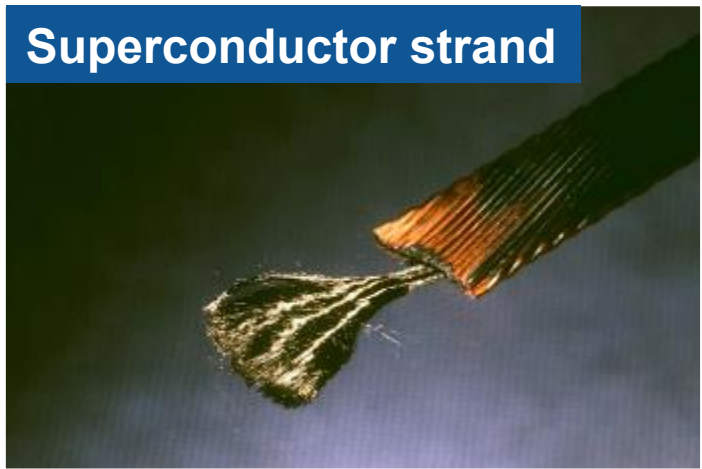
Pro LHC interconnection



LHC Magnet Coil



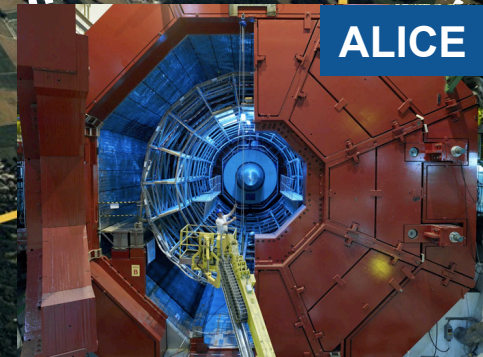
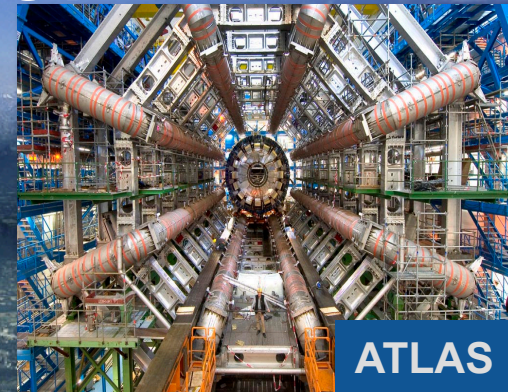
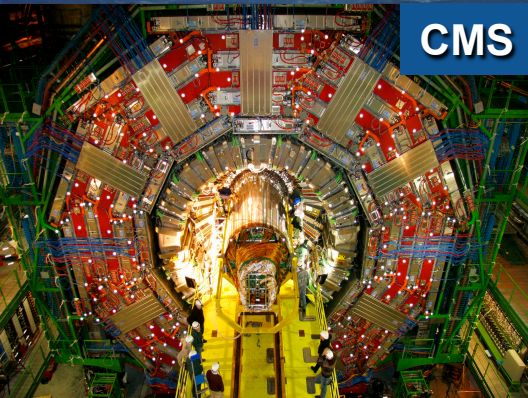
Superconductor strand





# An European or a Worldwide success?

*Amongst major Instruments of Humanity!*

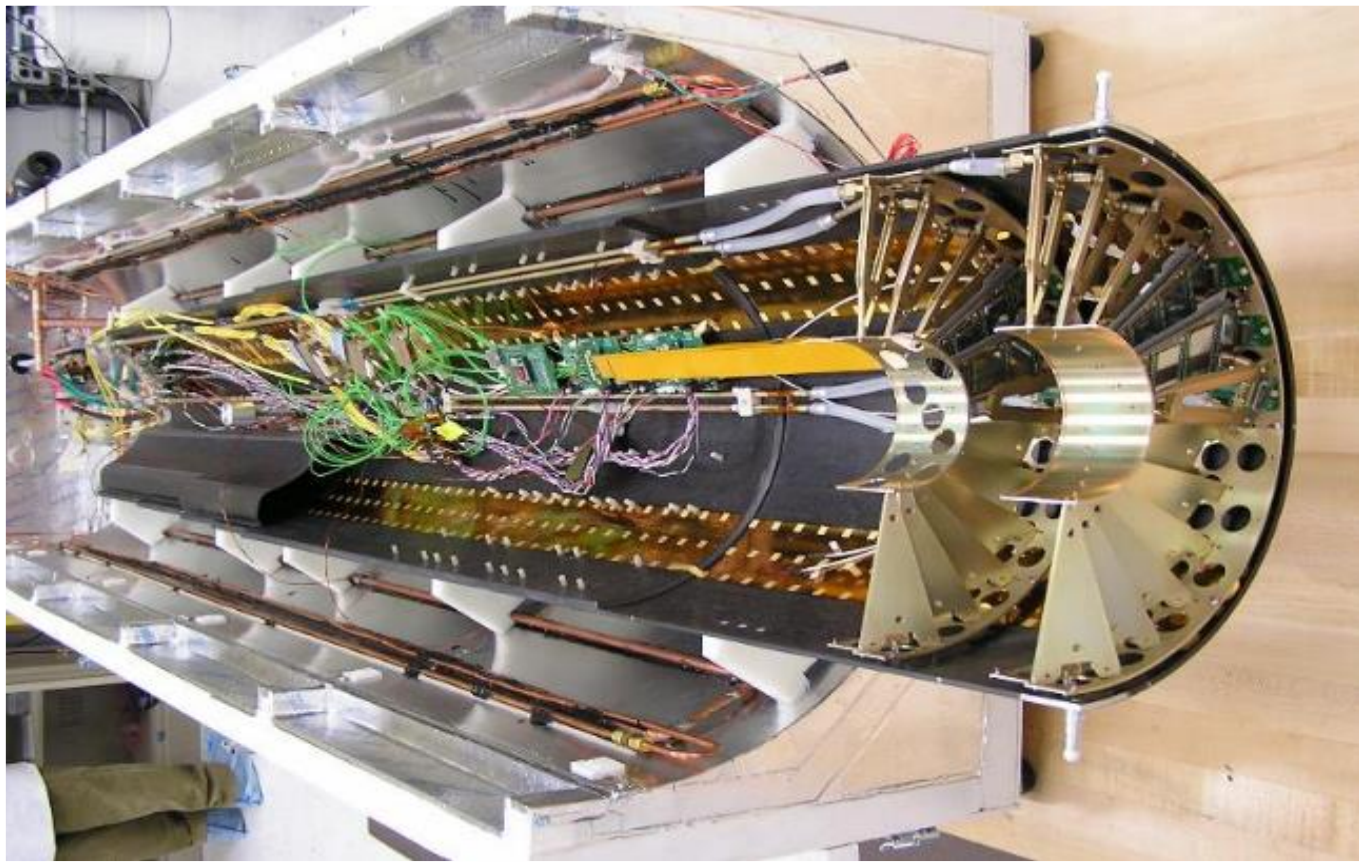




# An European or a Worldwide success?

*Amongst major Instruments of Humanity!*

ATLAS

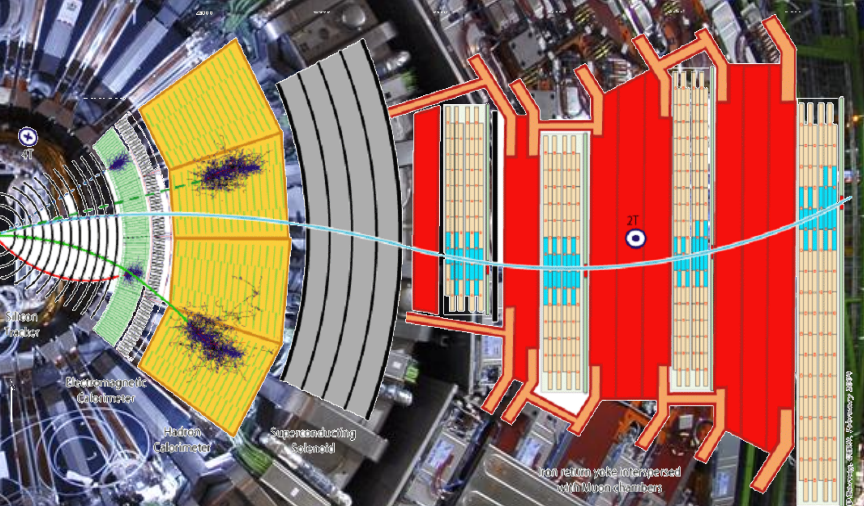
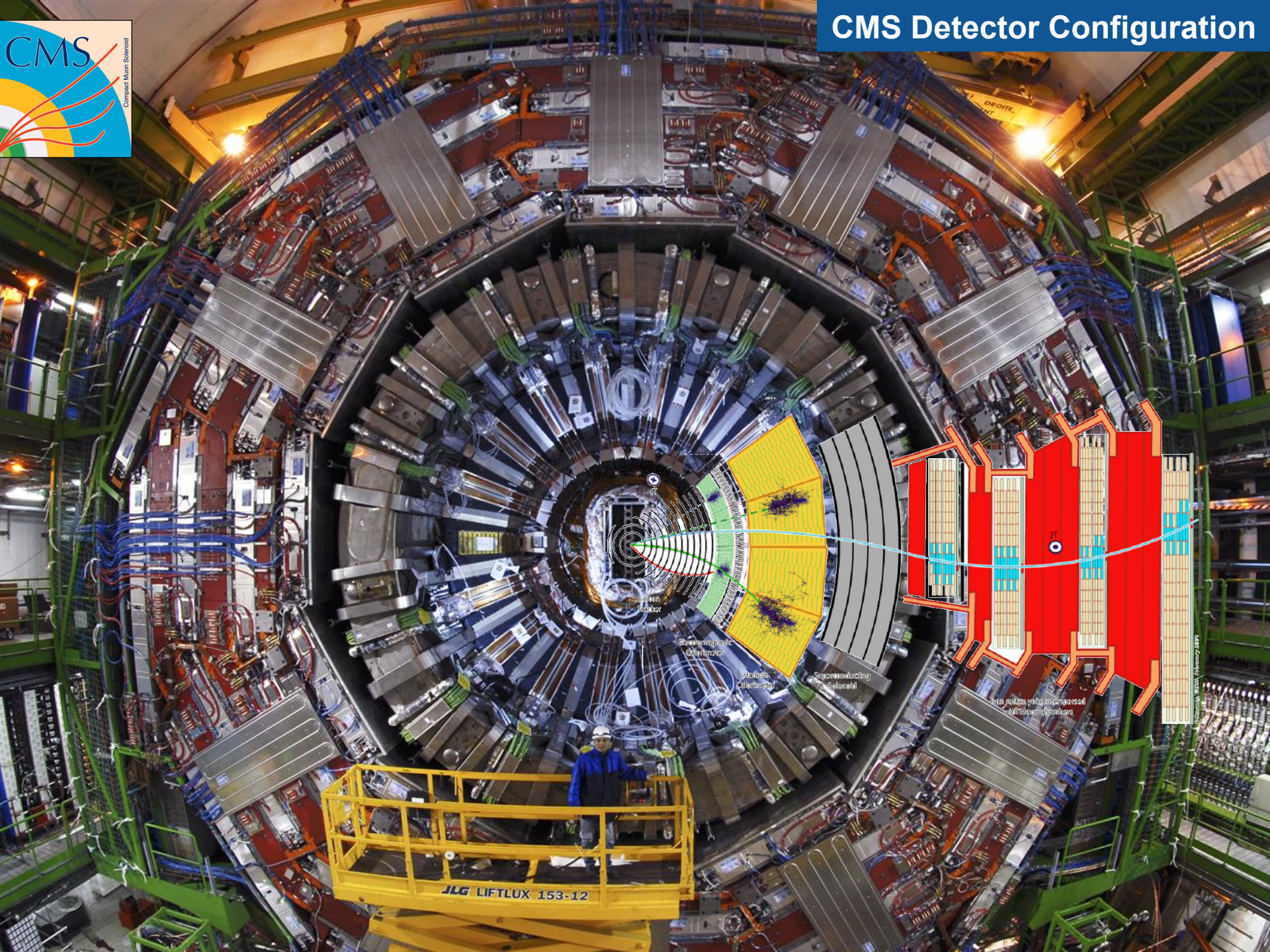














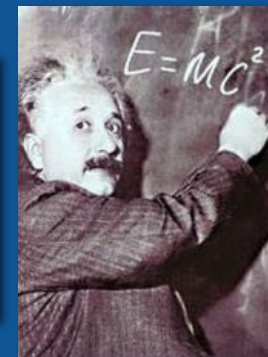


# A Laboratory for Physicists or Technologists?

*CERN Mission*

## ❑ Push back the frontiers of knowledge

E.g. the secrets of the Big Bang ... what is the matter like within the first moments of the Universe's existence

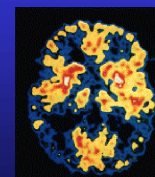
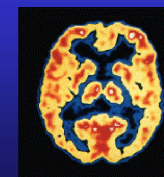


## ❑ Develop new technologies and detectors

Information technology  
Medicine - diagnosis and therapy



Brain Metabolism in Alzheimer's Disease: PET Scan



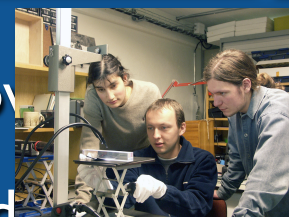
Normal Brain

Alzheimer's Disease

**Research**

## ❑ Train scientists and engineers of tomorrow

## ❑ Unite people from different countries and cultures



The amazing LHC performances  
and CERN's bright future.

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J.M. Jimenez  
CERN, Technology Department Head



# A Laboratory for Physicists or Technologists?

*Medium term plan guiding principle*

- **Driven by Science** and aiming at implementation of European Strategy for Particle Physics.
- Takes into account **technical feasibility and financial affordability**.
- Ensure **adequate resources for maintenance and consolidation** of scientific and general infrastructure, and for **compliance with Safety** requirements.
- Next 10 years dominated by construction of **High Luminosity LHC project (HL-LHC)** ~950 MCHF.



# A Laboratory for Physicists or Technologists?

*Three main scientific pillars*

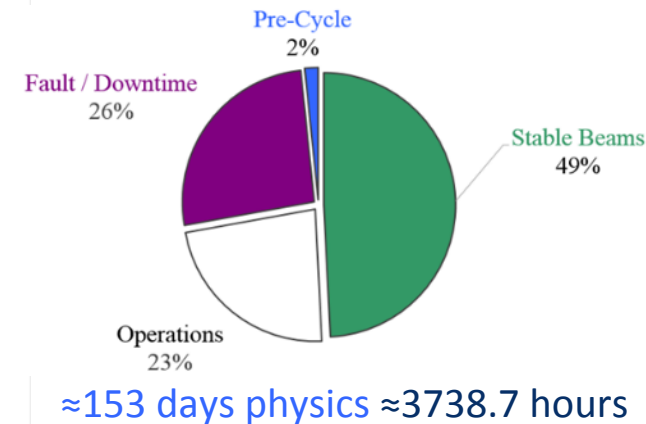
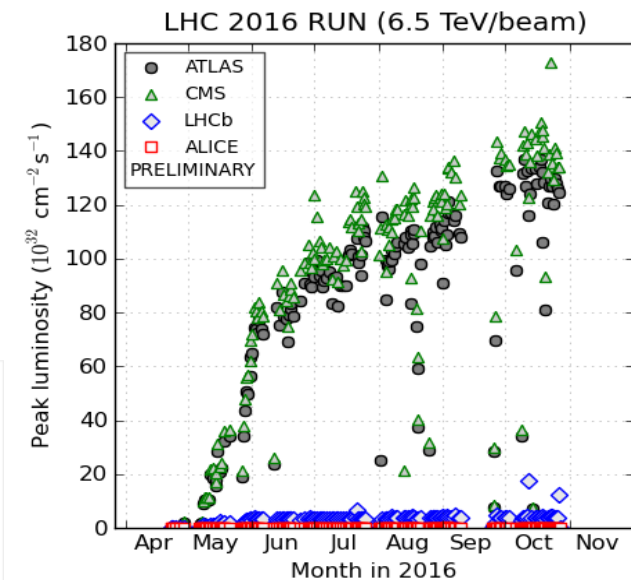
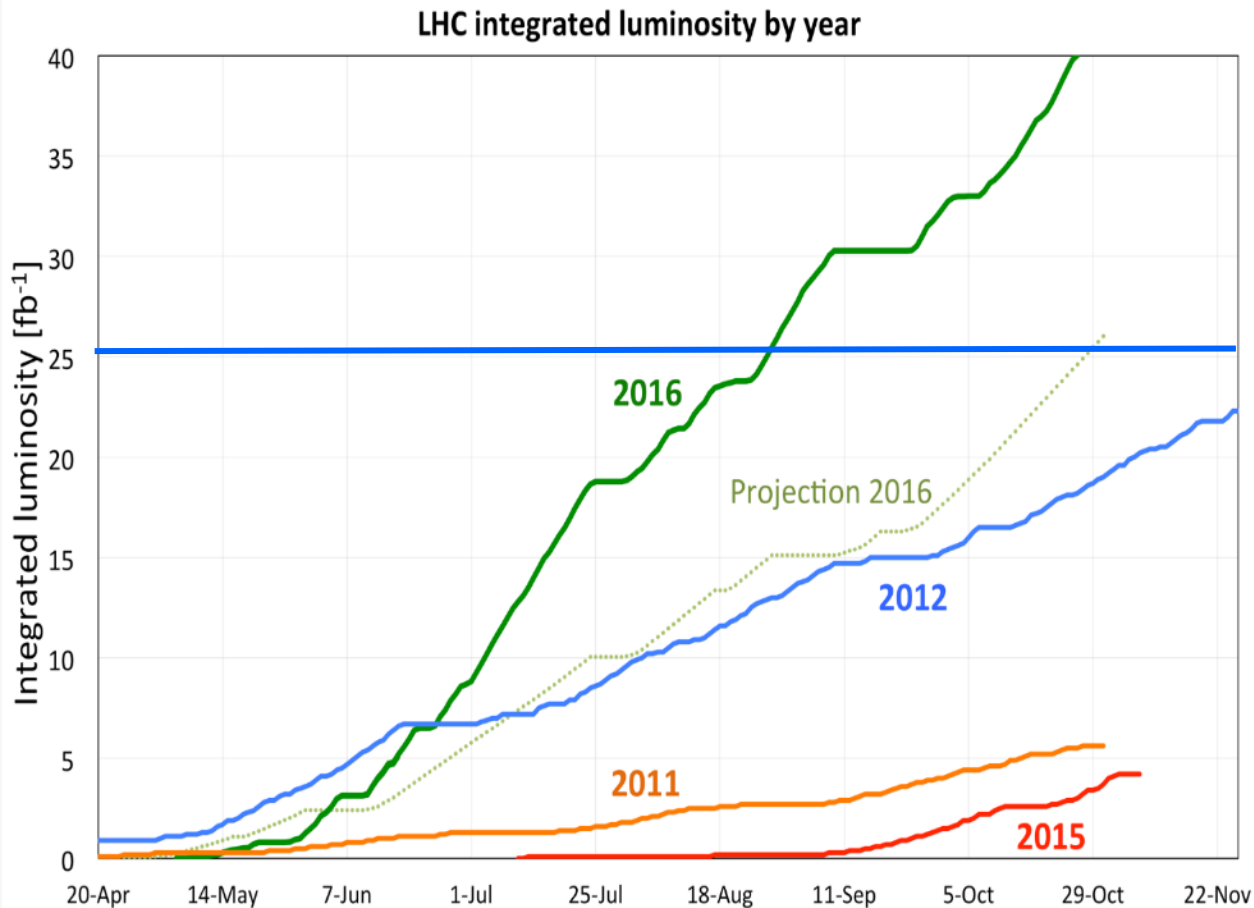
- **Full exploitation of the LHC:**
  - successful Run 2, LS2, and Run 3 start-up.
  - Upgrade of LHC Injectors; on-track construction of HL-LHC.
- **Scientific diversity programme** serving a broad community:
  - ongoing experiments and facilities at Booster, PS, SPS and their upgrades.
  - participation in accelerator-based neutrino through CERN Neutrino Platform.
- **Preparation of CERN's future:**
  - vibrant accelerator R&D programme exploiting CERN's strengths and uniqueness.
  - design studies for future accelerators: CLIC, FCC (includes HE-LHC).
  - future opportunities of diversity programme: "Physics Beyond Colliders".

Important milestone: update of the European Strategy for Particle Physics (ESPP) in 2019-2020.



# 2016 LHC : Production year

Peak luminosity >  $1.4 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$   
OVER 25  $\text{fb}^{-1}$  in both ATLAS and CMS



	Duration [h]
Stable Beams	1839.5
Fault / Downtime	980.0
Operations	857.9
Pre-Cycle	61.3



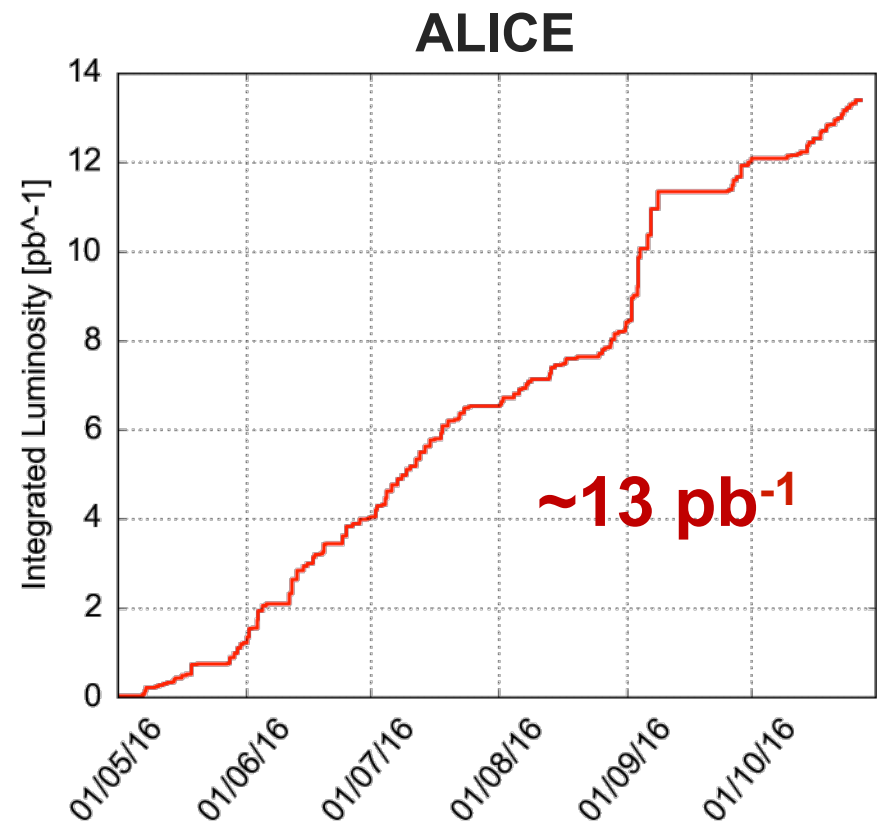
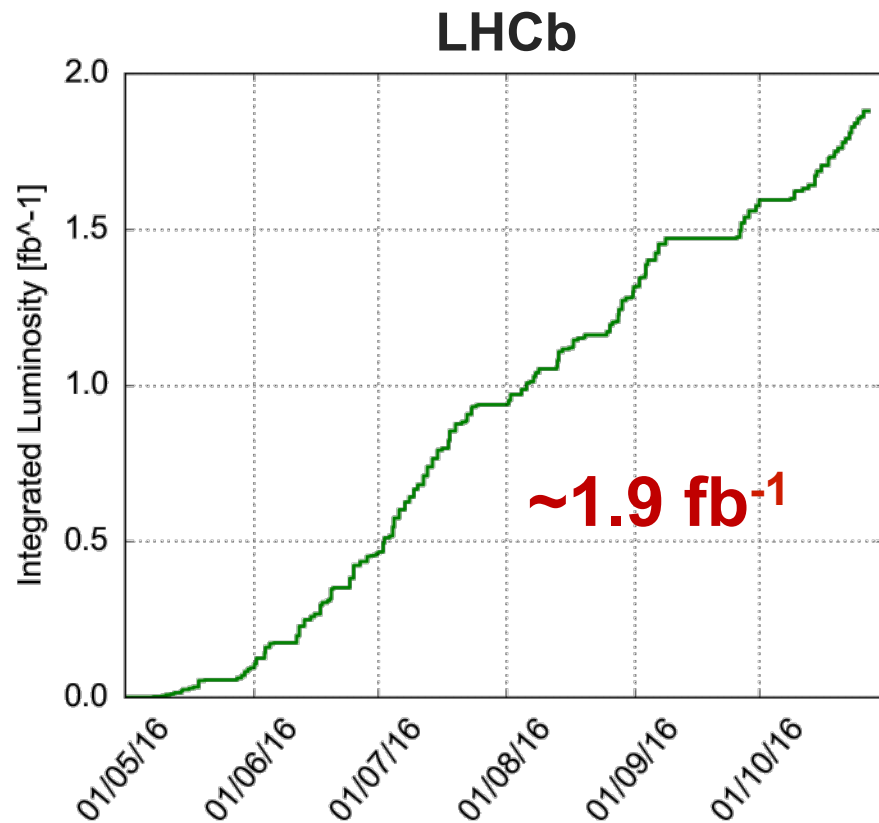
The amazing LHC performances  
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TS1 - TS2 : stable beams 58 %  
TS2 - TS3 : stable beams 54 %

# 2016 p-p physics – ALICE and LHCb

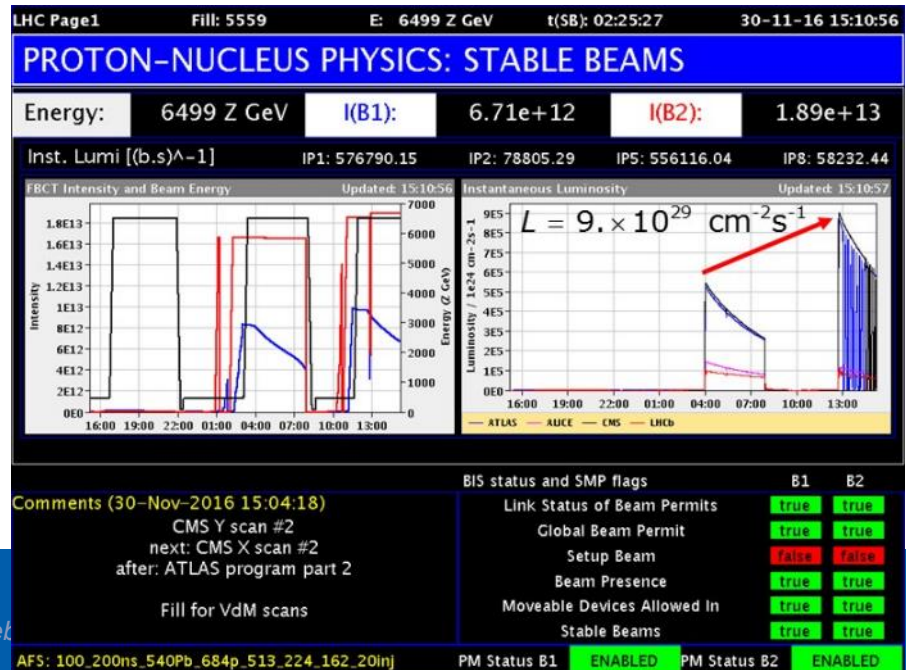
with luminosity leveled at their required values during the p-p fills





# LHC Goals of p-Pb run surpassed

Configuration	Goal		Achieved
5 TeV p-Pb ( $E_{\text{beam}}=4 \text{ Z TeV}$ )	ALICE	$700 \times 10^6$ min bias events	<b><math>780 \times 10^6</math></b>
8 TeV p-Pb ( $E_{\text{beam}}=6.5 \text{ Z TeV}$ )	ATLAS - CMS	$50 \text{ nb}^{-1}$	<b><math>69.5 - 65.5 \text{ nb}^{-1}</math></b>
	LHCb - ALICE	$10 \text{ nb}^{-1}$	<b><math>14 - 13 \text{ nb}^{-1}</math></b>
	LHCf	9-12 h at $10^{28} \text{ cm}^{-2}\text{s}^{-1}$	<b>9.5 h</b>
8 TeV Pb-p ( $E_{\text{beam}}=6.5 \text{ Z TeV}$ )	ATLAS - CMS	$50 \text{ nb}^{-1}$	<b><math>124 - 118 \text{ nb}^{-1}</math></b>
	ALICE - LHCb	$10 \text{ nb}^{-1}$	<b><math>25 - 19 \text{ nb}^{-1}</math></b>



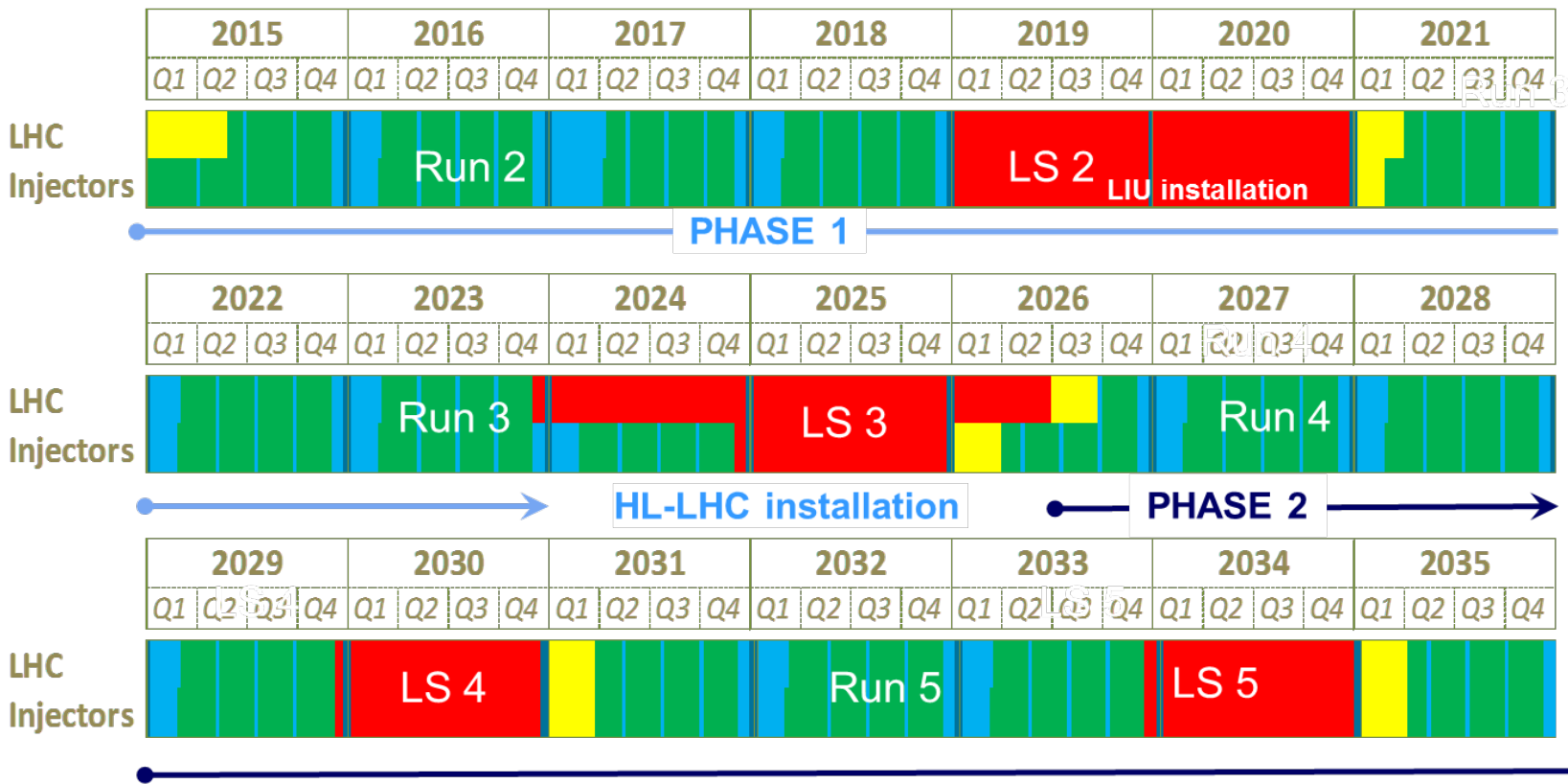
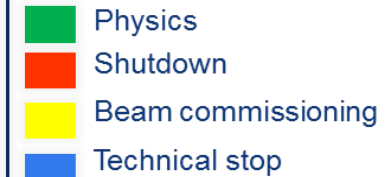
# A Laboratory for Physicists or Technologists?

## LHC Roadmap

LS2 starting in 2019 => 24 months + 3 months BC

LS3 LHC: starting in 2024 => 30 months + 3 months BC

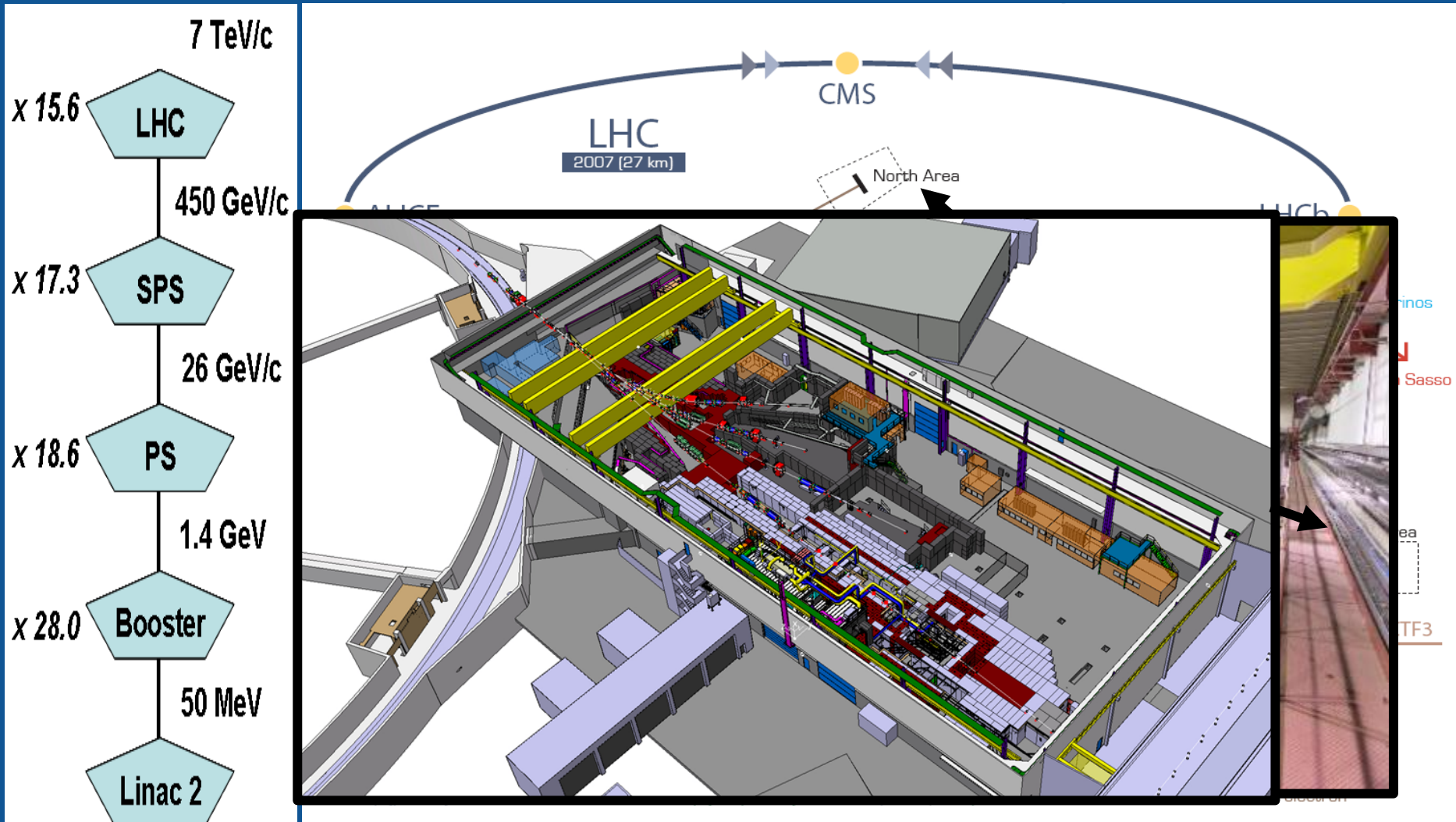
Injectors: in 2025 => 13 months + 3 months BC





# A Laboratory for Physicists or Technologists?

*Integrating a dimension of Scientific diversity...*



# A vibrant R&D on breakthrough technologies!

## *Fundamental role of accelerators*

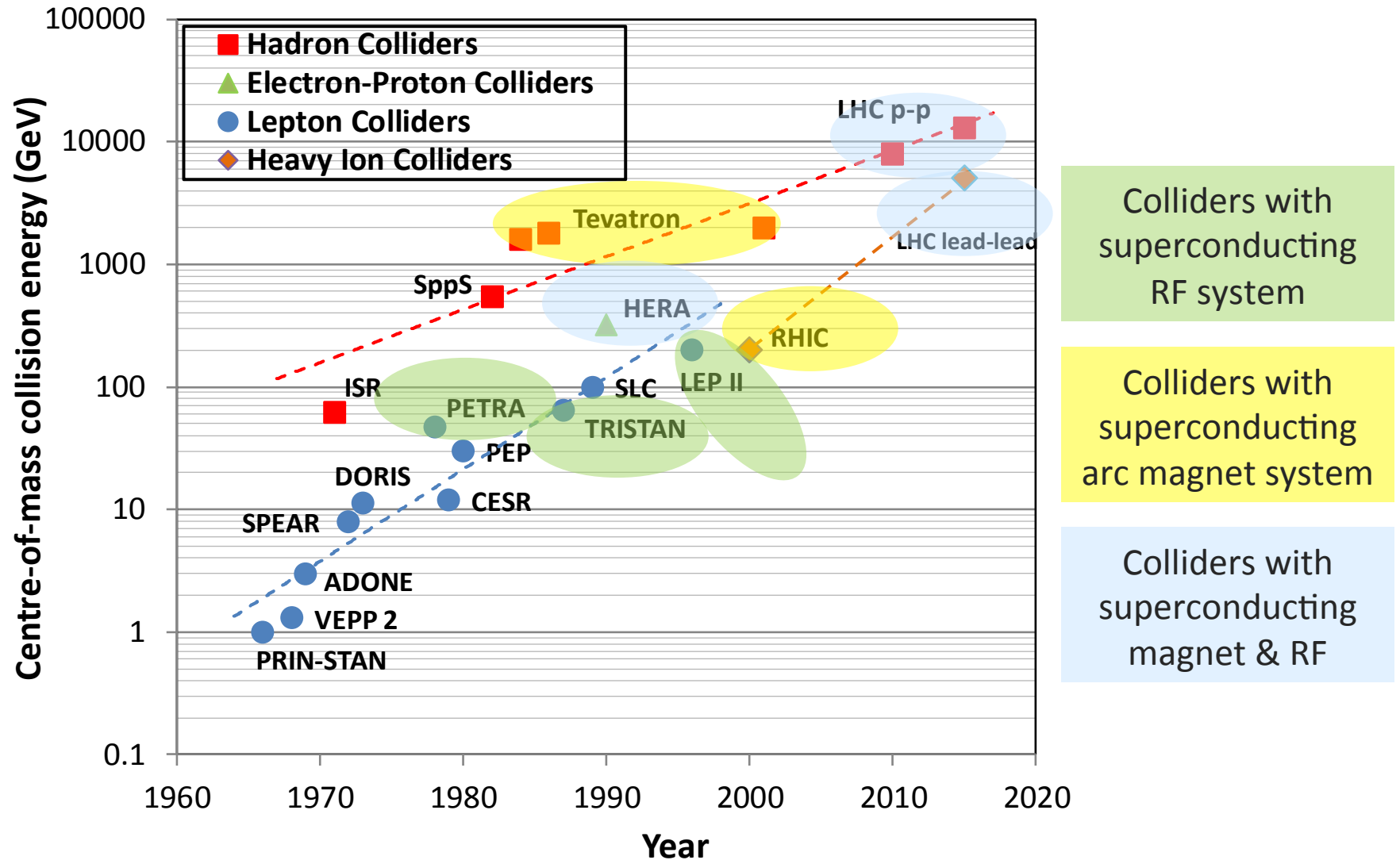
- Using **electrical fields (RF cavities)** to accelerate and **magnetic fields (accelerator magnets)** to guide and collide **charged particle beams** (electrons, protons & anti-particles)
- **Aim at higher energy accelerators for 2 reasons:**
  - **Production of new heavier particles (according to Einstein):**  $E = mc^2 \leq 2E_{\text{beam (collider)}}$
  - **Resolving smaller distances (according to de Broglie):**  
**Wavelength**  $\lambda = hc/E$  **for LHC**  $\sim 2 \cdot 10^{-18}$  cm

Higher energy → **Increased potential for discoveries**



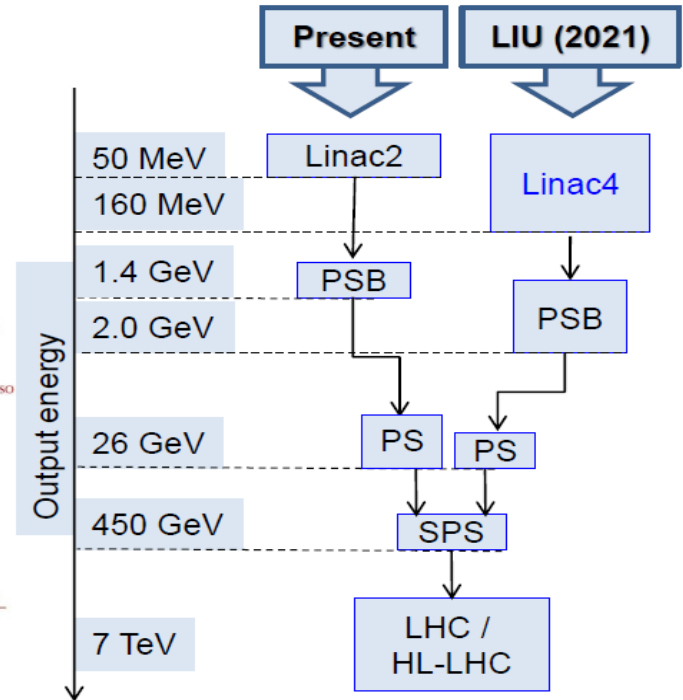
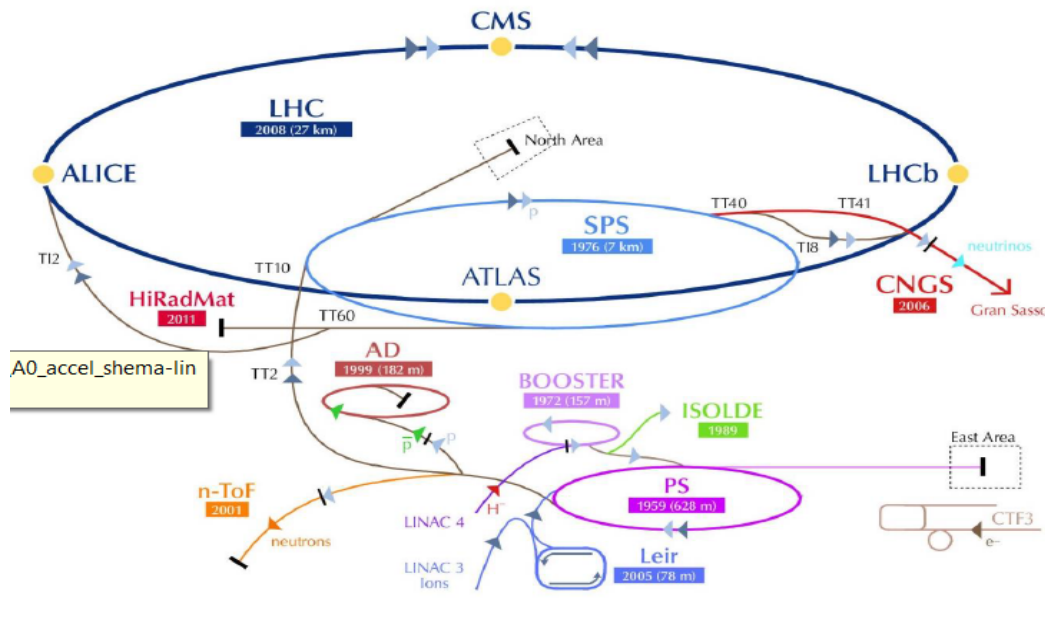
# A vibrant R&D on breakthrough technologies!

## Fundamental role of Colliders



# A vibrant R&D on breakthrough technologies!

## LHC Injectors Upgrade Project



### LIU Mandate - DG-DAT-2010-5

The LHC Injectors Upgrade should plan for delivering reliably to the LHC the beams required for reaching the goals of the HL-LHC. This includes Linac4, the PS-Booster, the PS, the SPS, as well as the heavy ion chain.

The project co-ordinator will have the responsibility for the project management (WBS, technical co-ordination and integration, manpower and budget agreement with the departments as well as budget and timescale control). They will report on a regular basis to the Director of Accelerators and Technology. The executive role for manpower and budget for the projects/studies remains with the technical groups in the departments.



# A vibrant R&D on breakthrough technologies!

## *Vectors of technology! the High Luminosity LHC (HL-LHC)*



2

### CIVIL ENGINEERING

2 new 300-metre service tunnels and 2 shafts near to ATLAS and CMS.

### "CRAB" CAVITIES

16 superconducting „crab“ cavities for each of the ATLAS and CMS experiments to tilt the beams before collisions.



3

Cryo@P1-P5



Cryo@P4

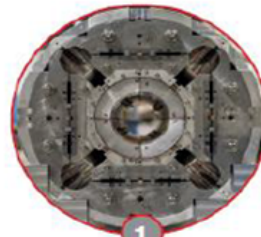


ATLAS

ALICE

LHC TUNNEL

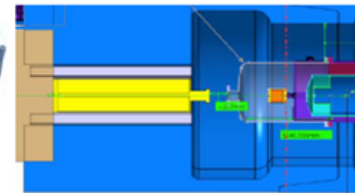
CMS



1

### FOCUSING MAGNETS

12 more powerful quadrupole magnets for each of the ATLAS and CMS experiments, designed to increase the concentration of the beams before collisions.



New TAS and VCX

ATLAS

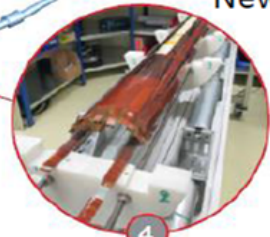
LHCb



5

### COLLIMATORS

15 to 20 new collimators and 60 replacement collimators to reinforce machine protection.



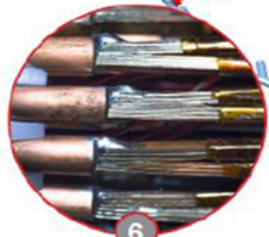
4

### BENDING MAGNETS

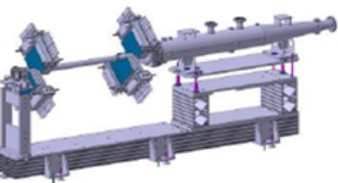
4 pairs of shorter and more powerful dipole bending magnets to free up space for the new collimators.

### SUPERCONDUCTING LINKS

Electrical transmission lines based on a high-temperature superconductor to carry current to the magnets from the new service tunnels near ATLAS and CMS.



6



Beam diagnostics  
BGV



The amazing LHC performances  
and CERN's bright future.

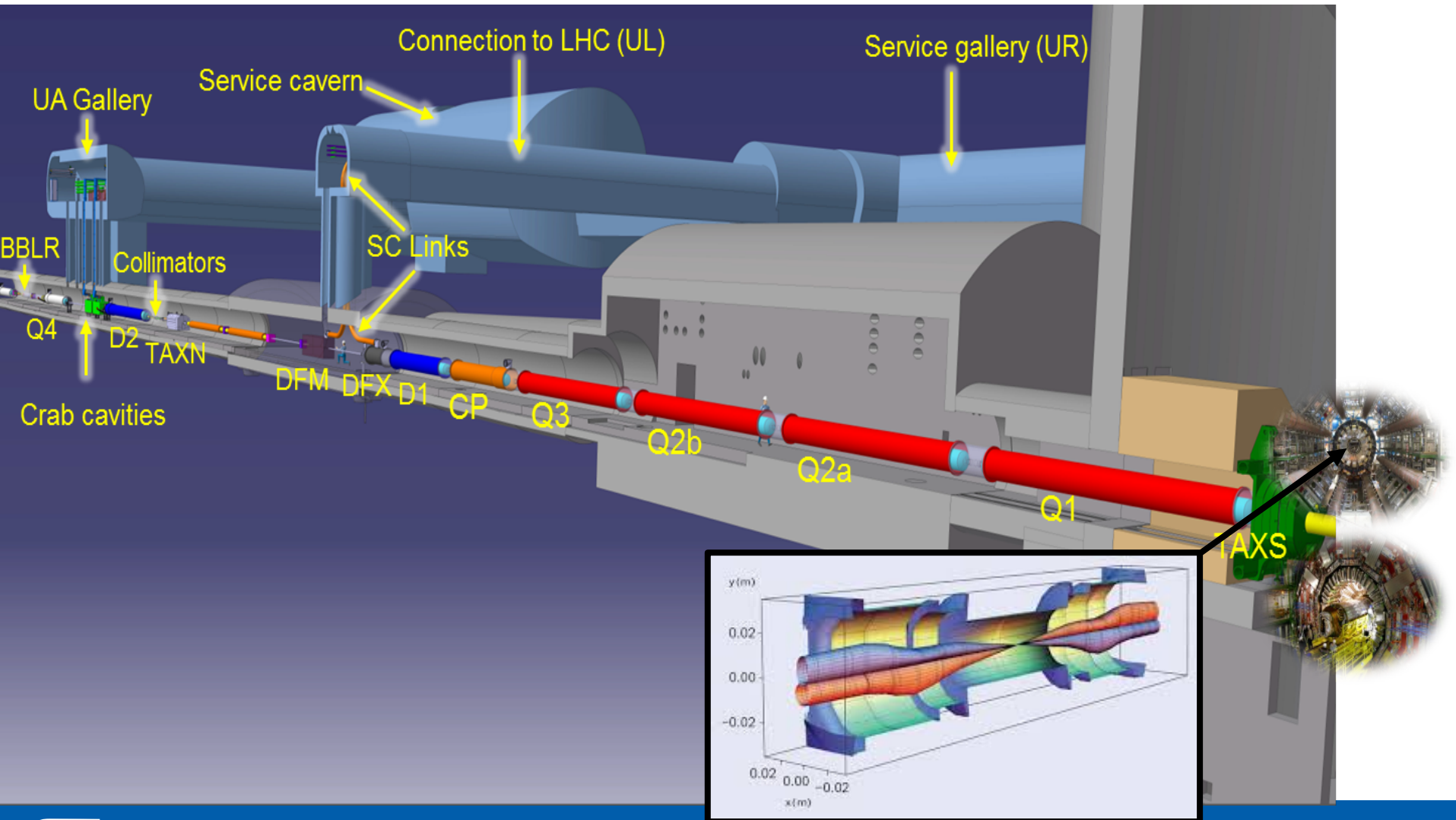
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# A vibrant R&D on breakthrough technologies!

## *Vectors of technology! the High Luminosity LHC (HL-LHC)*

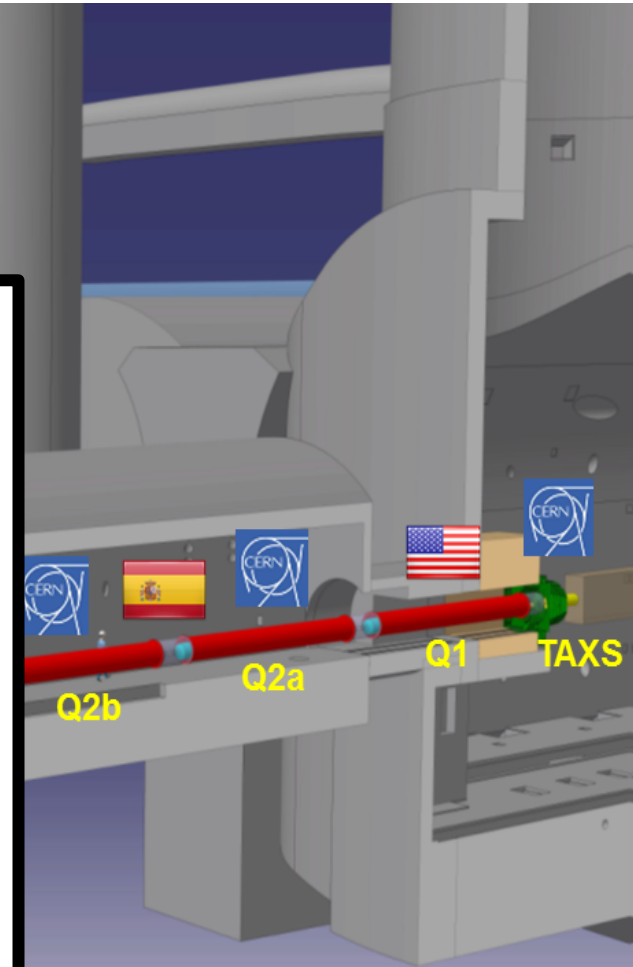
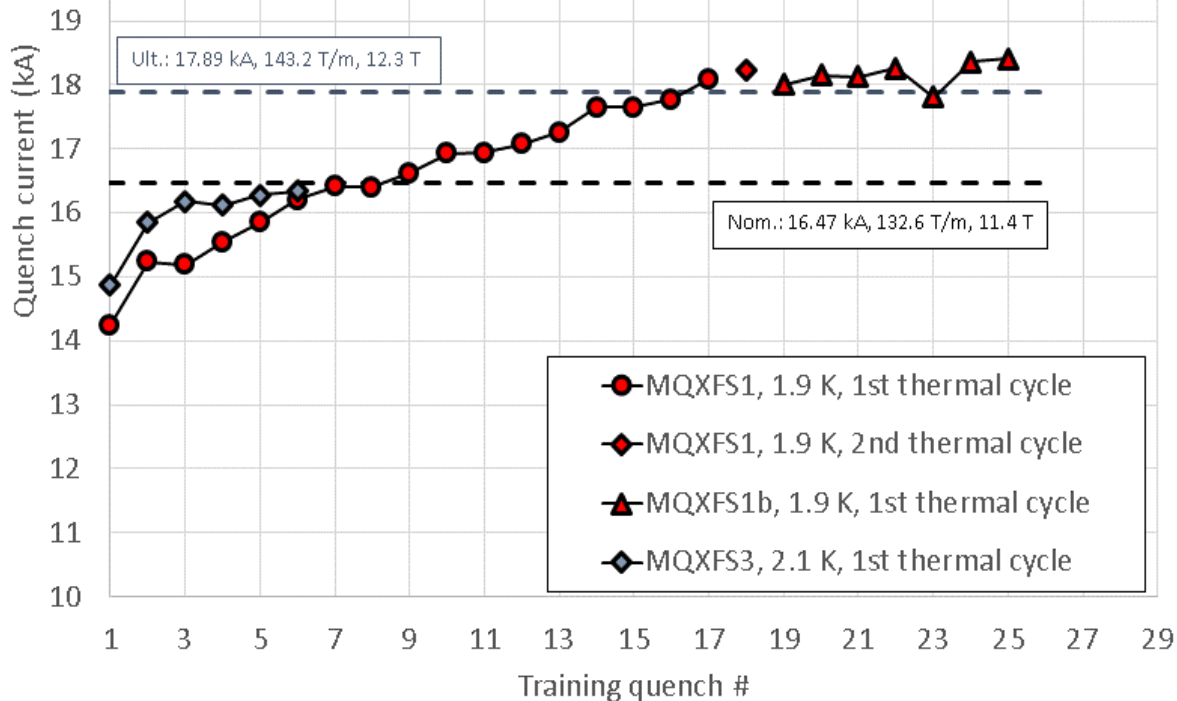




# A vibrant R&D on breakthrough technologies!

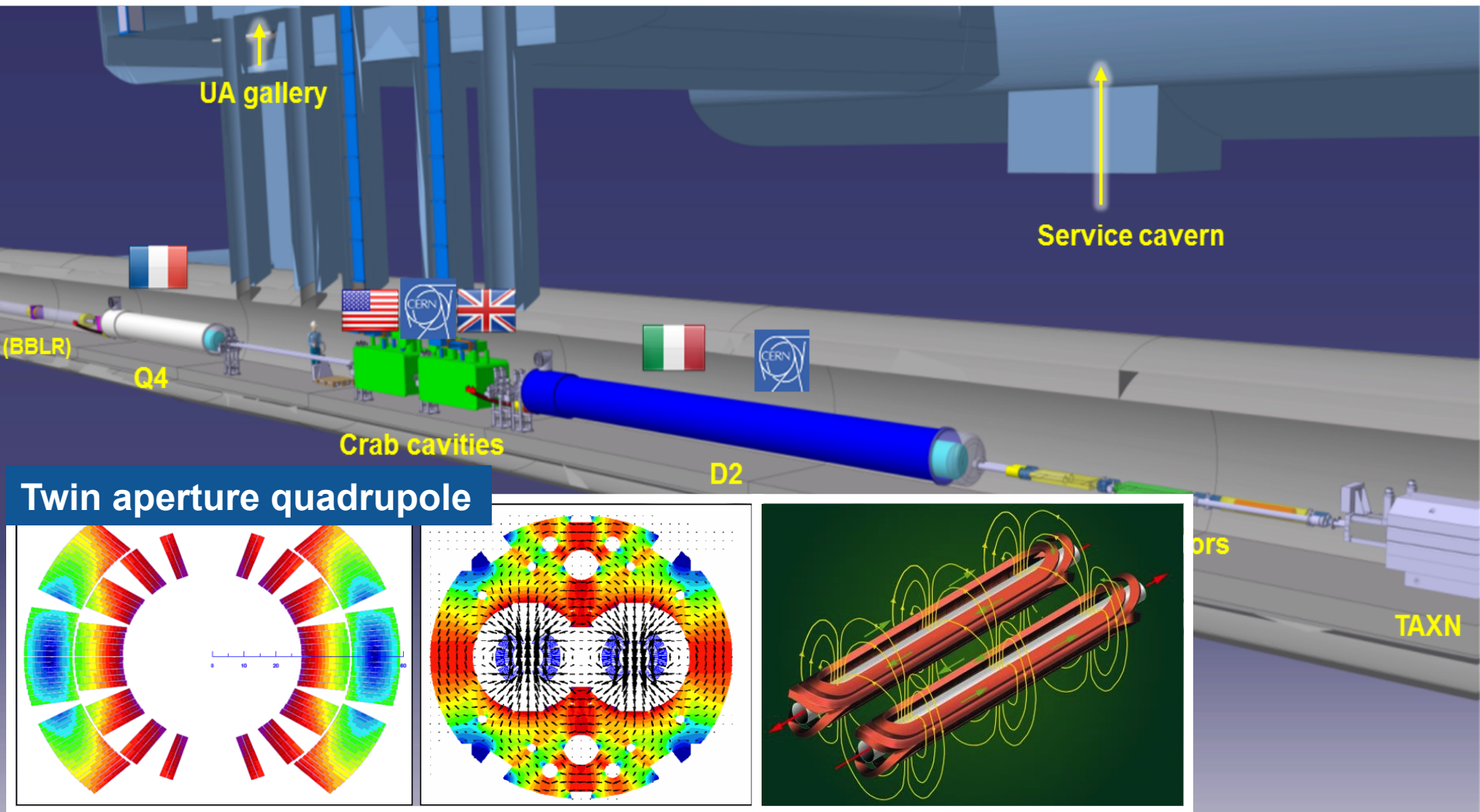
## *Vectors of technology! the High Luminosity LHC (HL-LHC)*

### Focusing Quadrupole



# A vibrant R&D on breakthrough technologies!

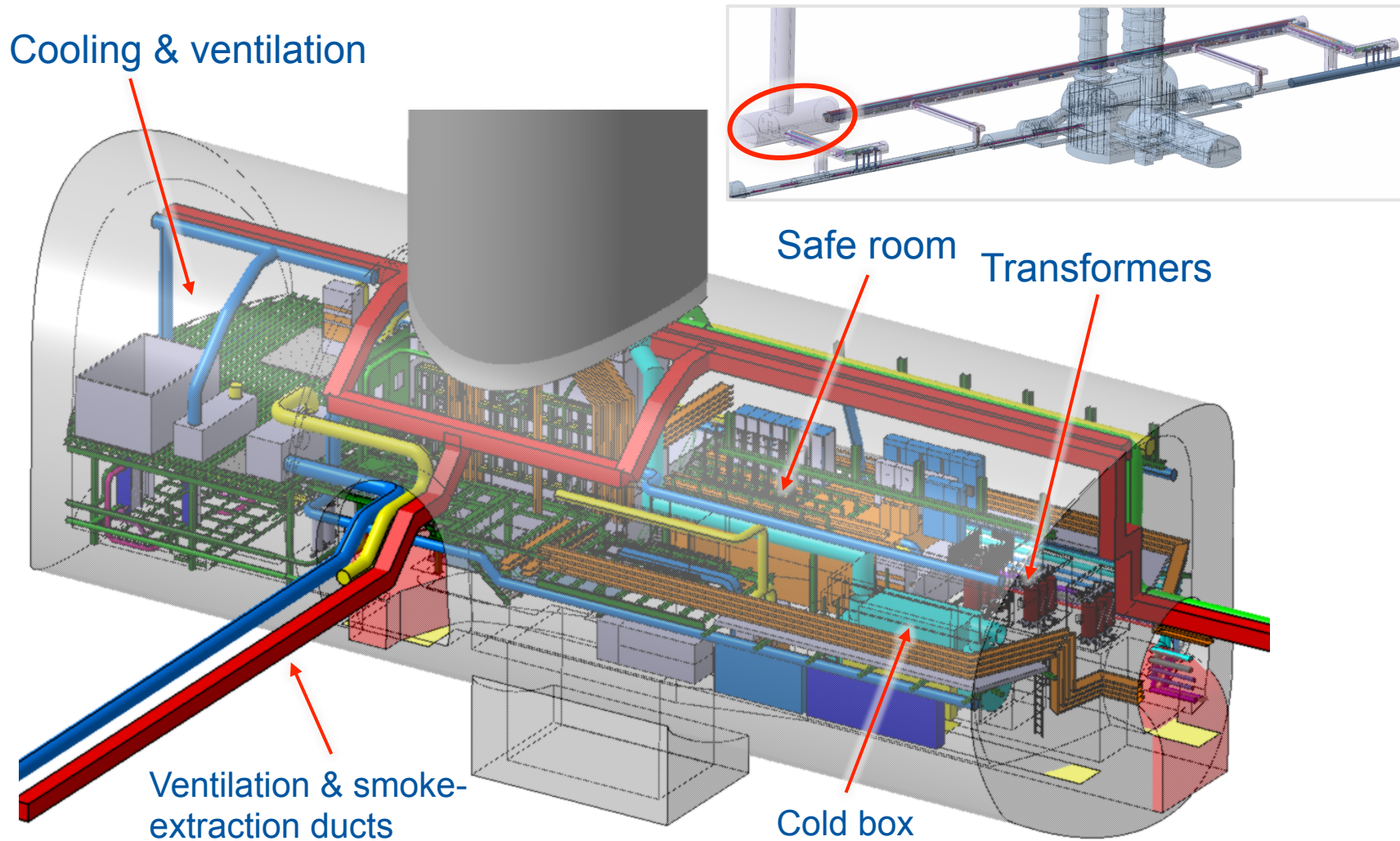
## *Vectors of technology! the High Luminosity LHC (HL-LHC)*





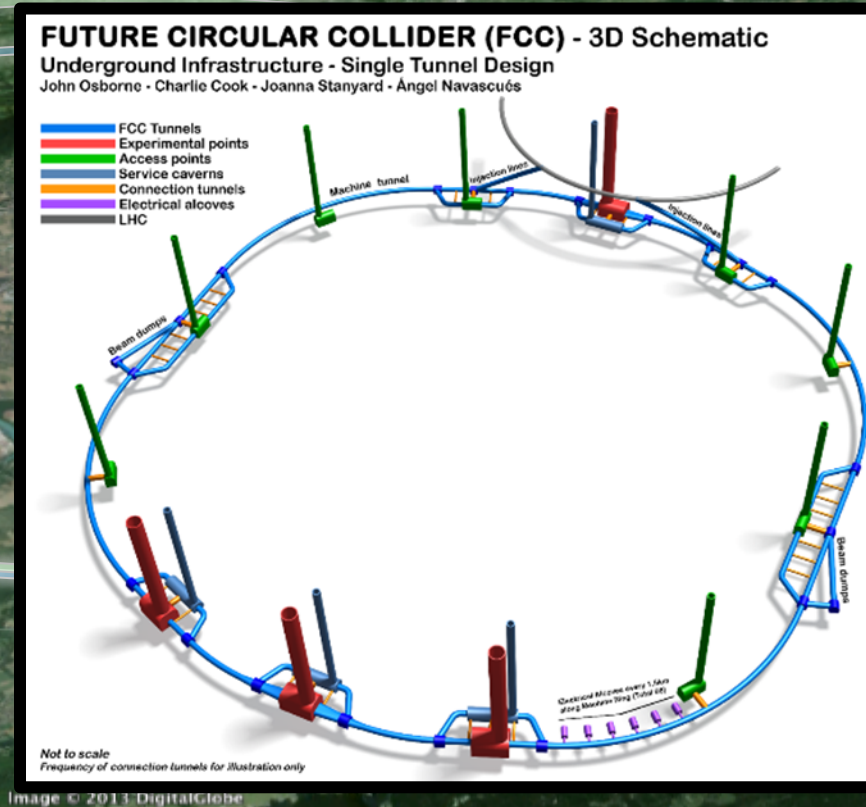
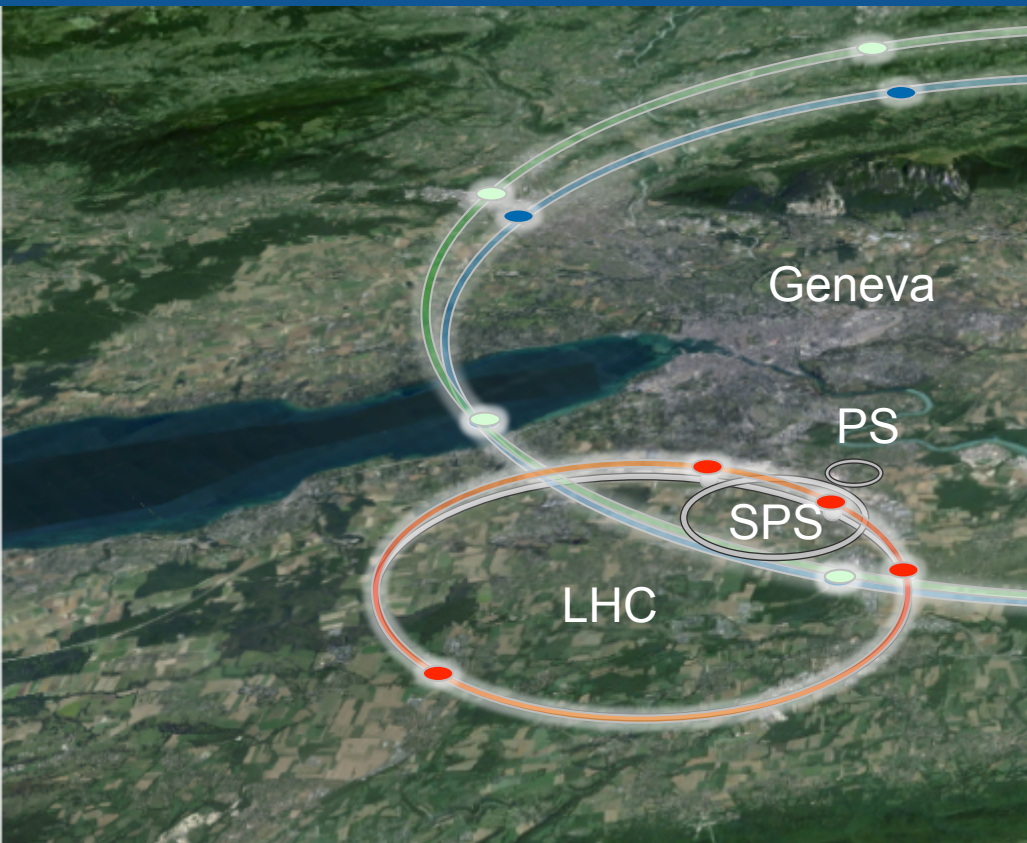
# A vibrant R&D on breakthrough technologies!

## *Vectors of technology! the High Luminosity LHC (HL-LHC)*



# A vibrant R&D on breakthrough technologies!

## *Vectors of technology! the Future Circular Collider (FCC)*



**LHC**  
27 km, 8.33 T  
14 TeV (c.o.m.)  
1300 tons NbTi

**HE-LHC baseline**  
27 km, 16 T  
26 TeV (c.o.m.)  
2500 tons Nb<sub>3</sub>Sn

**FCC-hh baseline**  
100 km, 16 T  
100 TeV (c.o.m.)  
10000 tons Nb<sub>3</sub>Sn

**FCC-hh**  
80 km, 20 T  
100 TeV (c.o.m.)  
2000 tons HTS  
8000 tons LTS





# A vibrant R&D on breakthrough technologies!

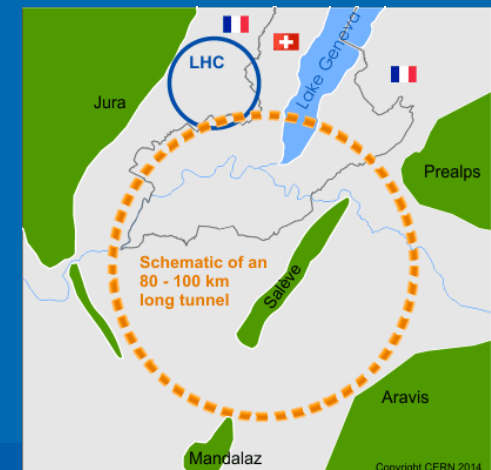
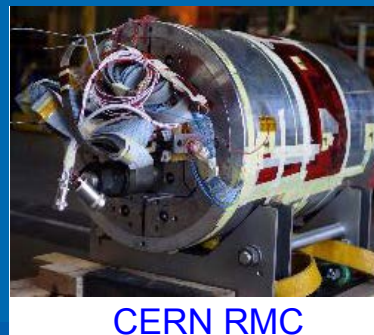
*Vectors of technology! the Future Circular Collider (FCC)*



# A vibrant R&D on breakthrough technologies!

## *Vectors of technology! the Future Circular Collider (FCC)*

- CELLS, Coordination of the EuroCirCol WP4 Cryogenic beam vacuum system conception (CELLS, CERN, CIEMAT, INFN, KIT, STFC) and Study beam-induced vacuum effects.
- CIEMAT, participation on EuroCirCol WP4/5: conceptual design for cryogenic beam vacuum system; study accelerator dipole magnet design options. Common coil magnet design, key performance indicators, dipole magnet cost model.
- Consortium Project association between ICMAB, IFAE and CELLS : evaluate the use of high temperature superconducting coated conductors tapes for the beam screens (low surface impedance and high superconducting properties).



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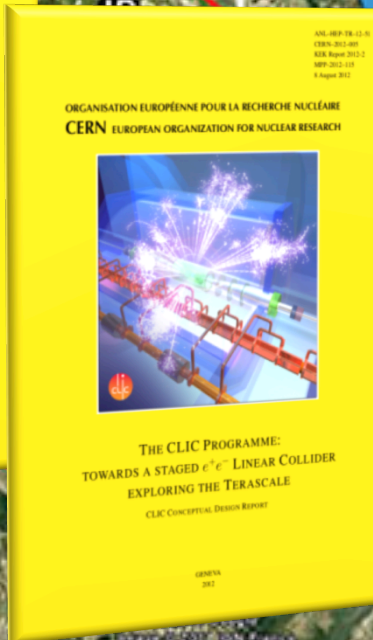
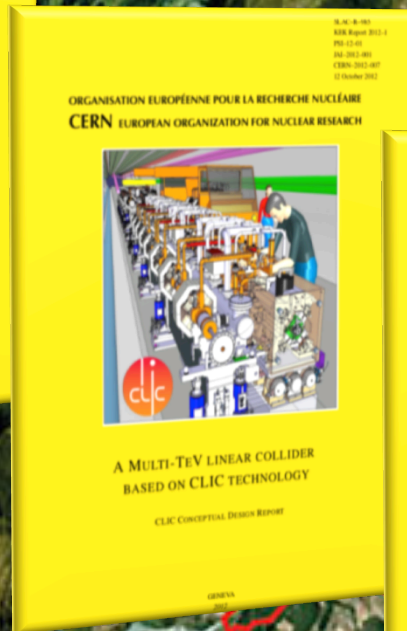
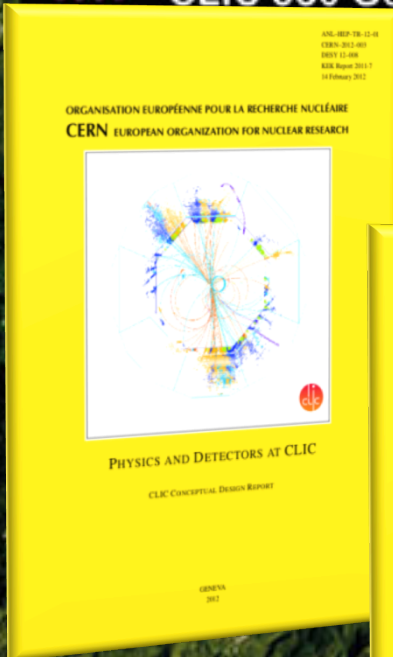


# A vibrant R&D on breakthrough technologies!

## — Vectors of technology! the Compact Linear Collider (CLIC)

Potential underground siting :

●●●● CLIC 380 GeV



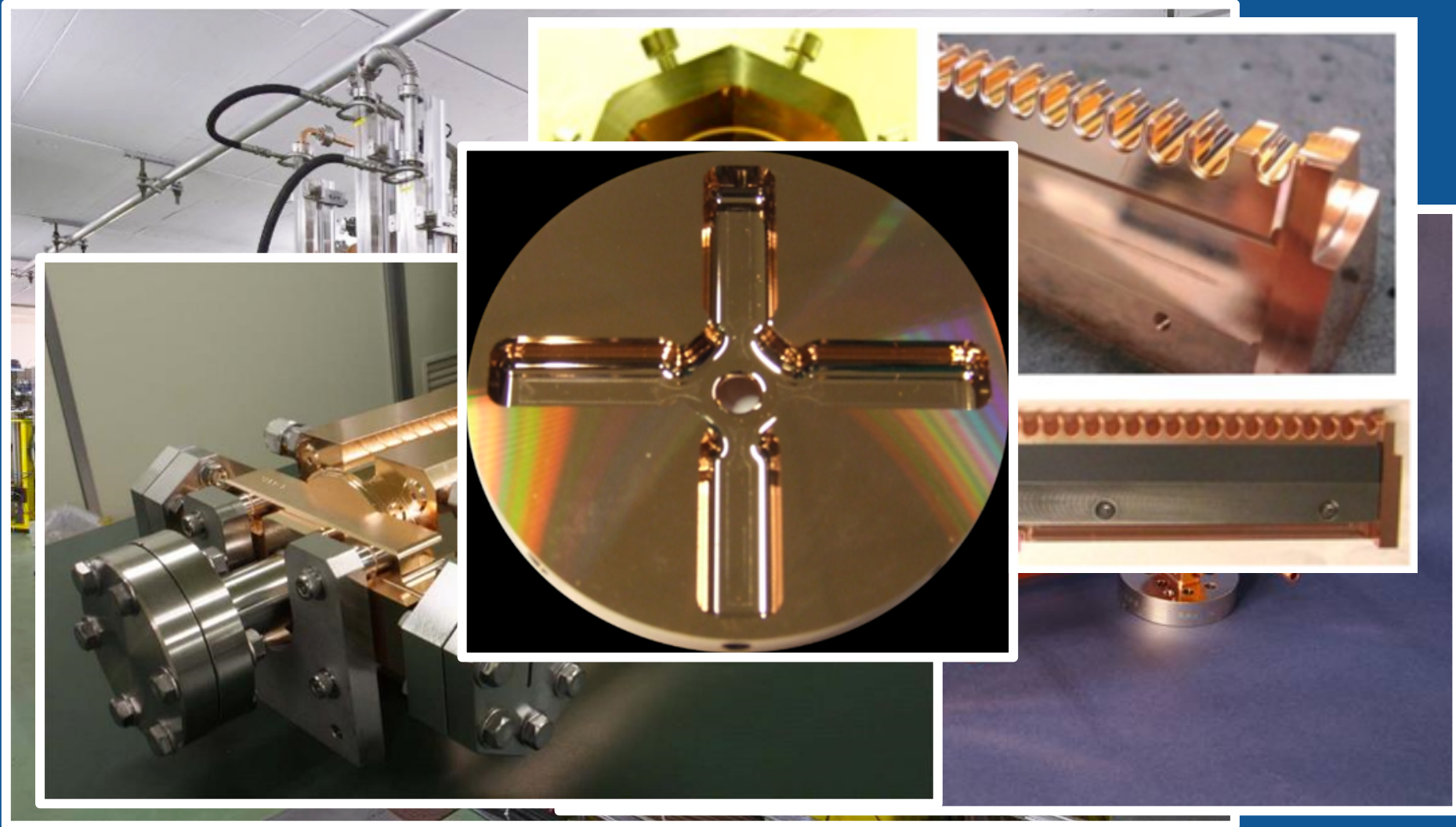
Highest possible energy  $e^+e^-$  with CLIC (CDR 2012)

Multi-lateral collaboration



# A vibrant R&D on breakthrough technologies!

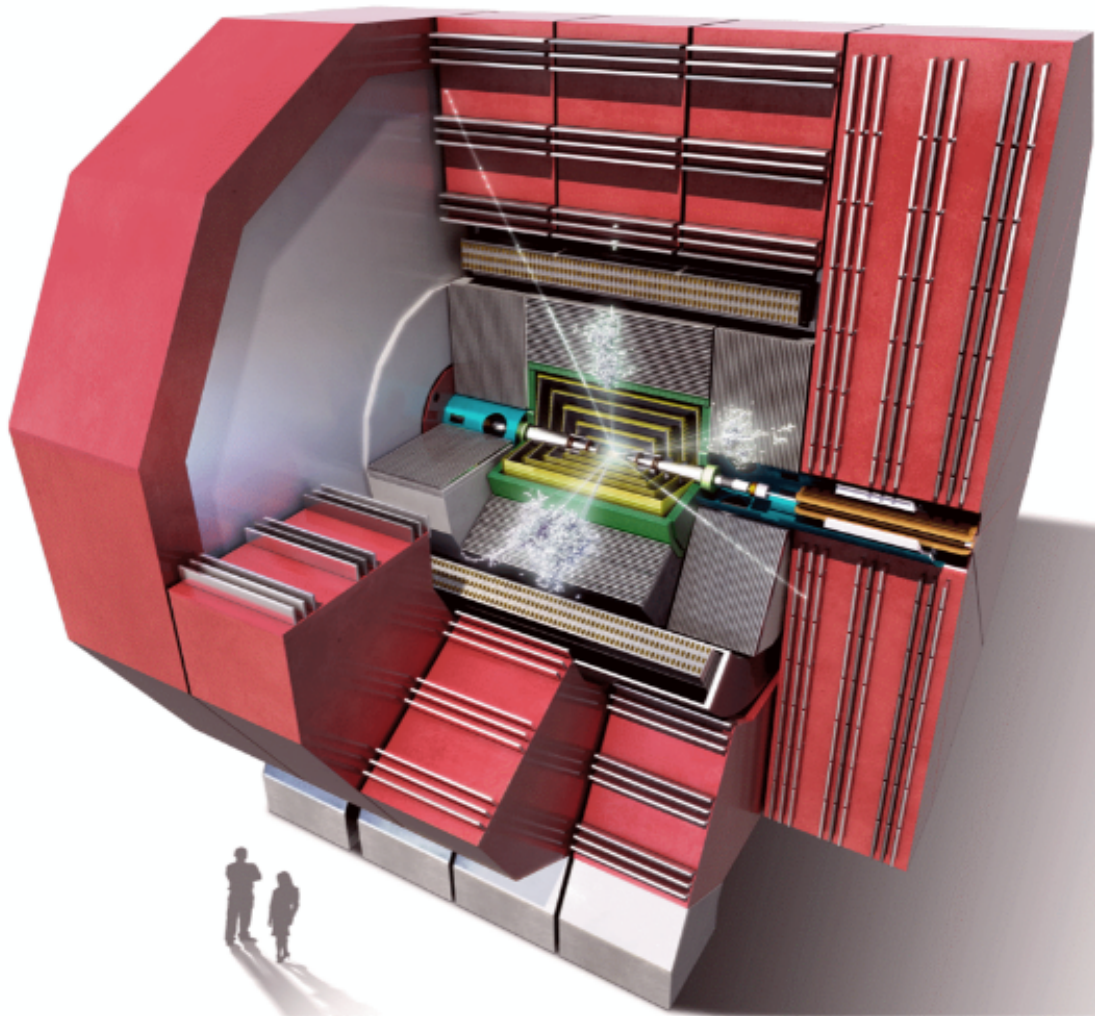
*Vectors of technology! the Compact Linear Collider (CLIC)*





# A vibrant R&D on breakthrough technologies!

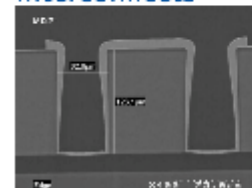
## *Detectors for the Compact Linear Collider (CLIC)*



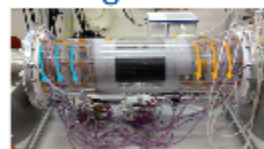
Sensors



Interconnects



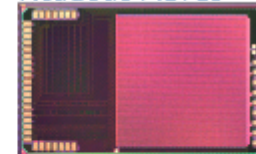
Cooling



Light-weight supports



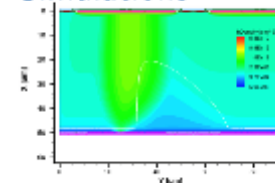
Readout ASICs



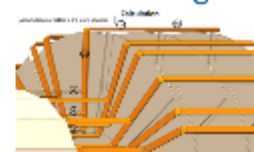
Powering



Simulations

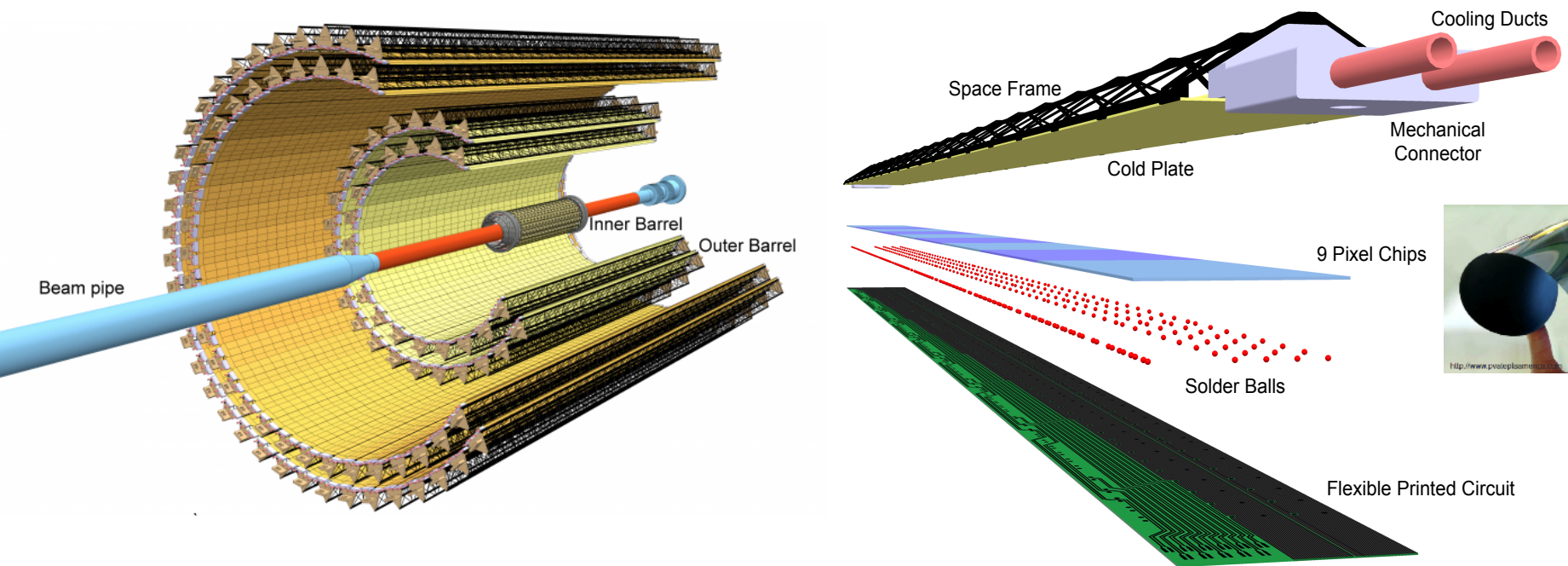


Detector integration



# A vibrant R&D on breakthrough technologies!

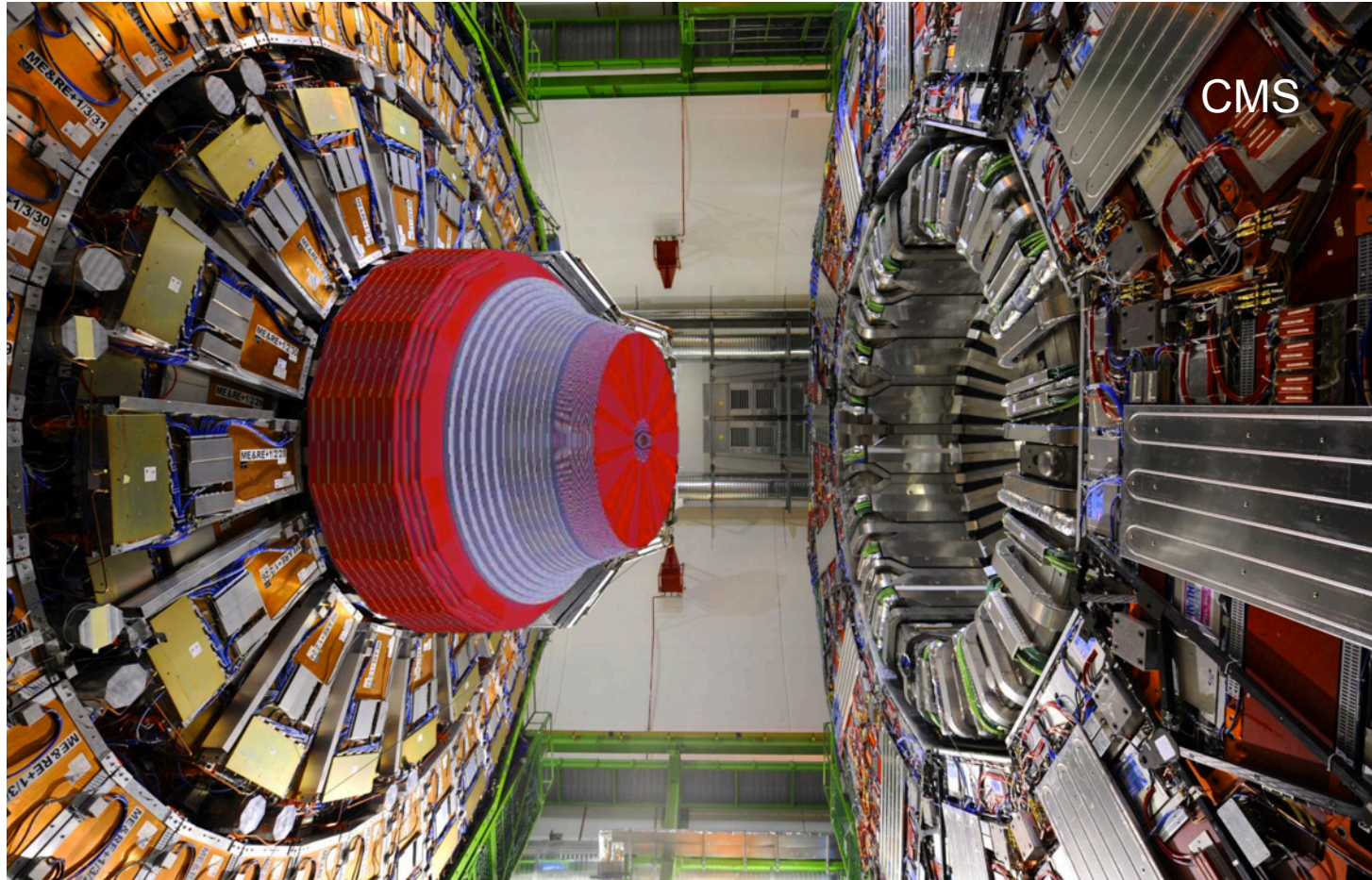
## *R&D on Pixel detectors (silicium)*





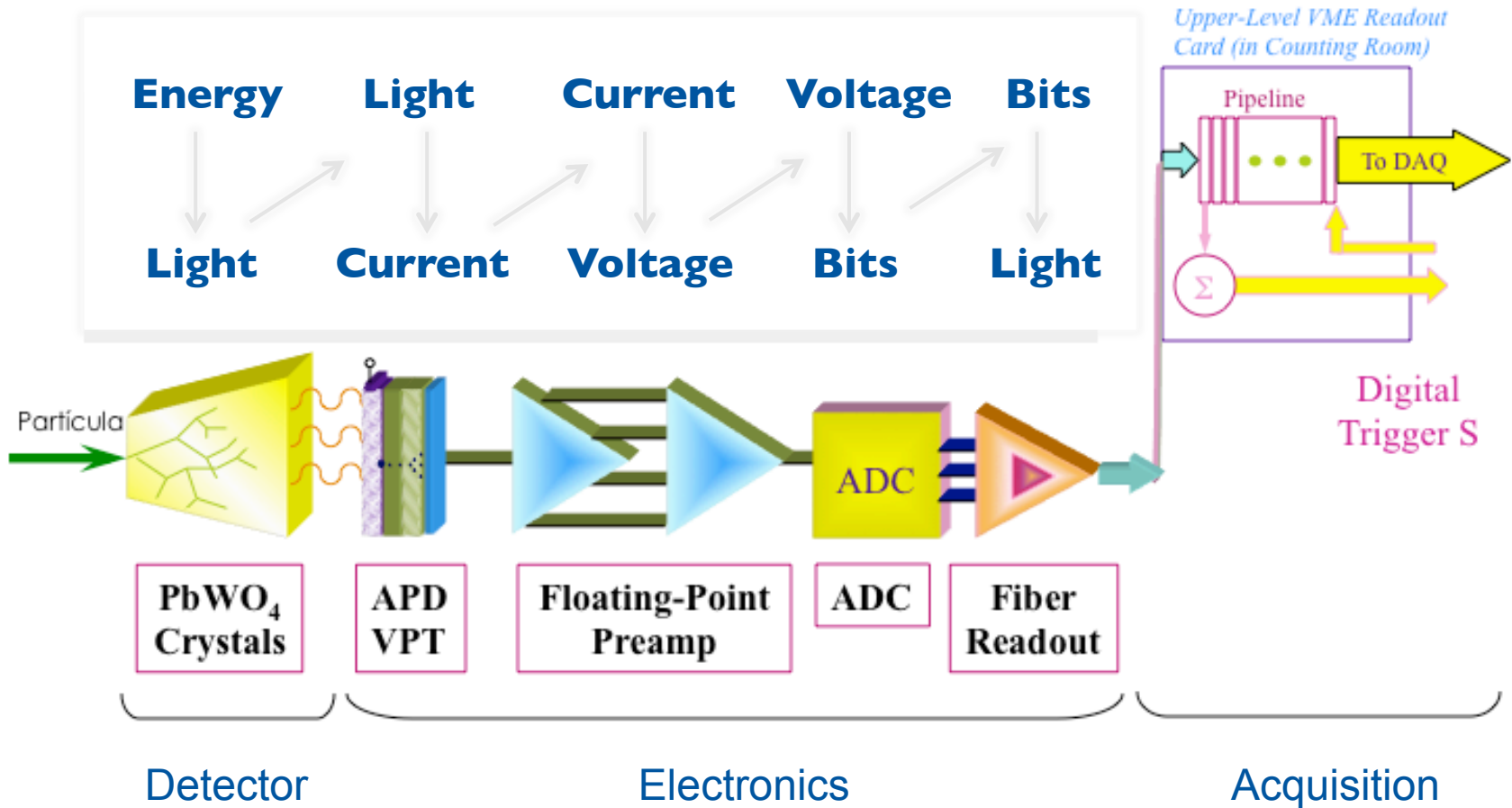
# A vibrant R&D on breakthrough technologies!

*R&D on detectors: futures calorimeters*



# A vibrant R&D on breakthrough technologies!

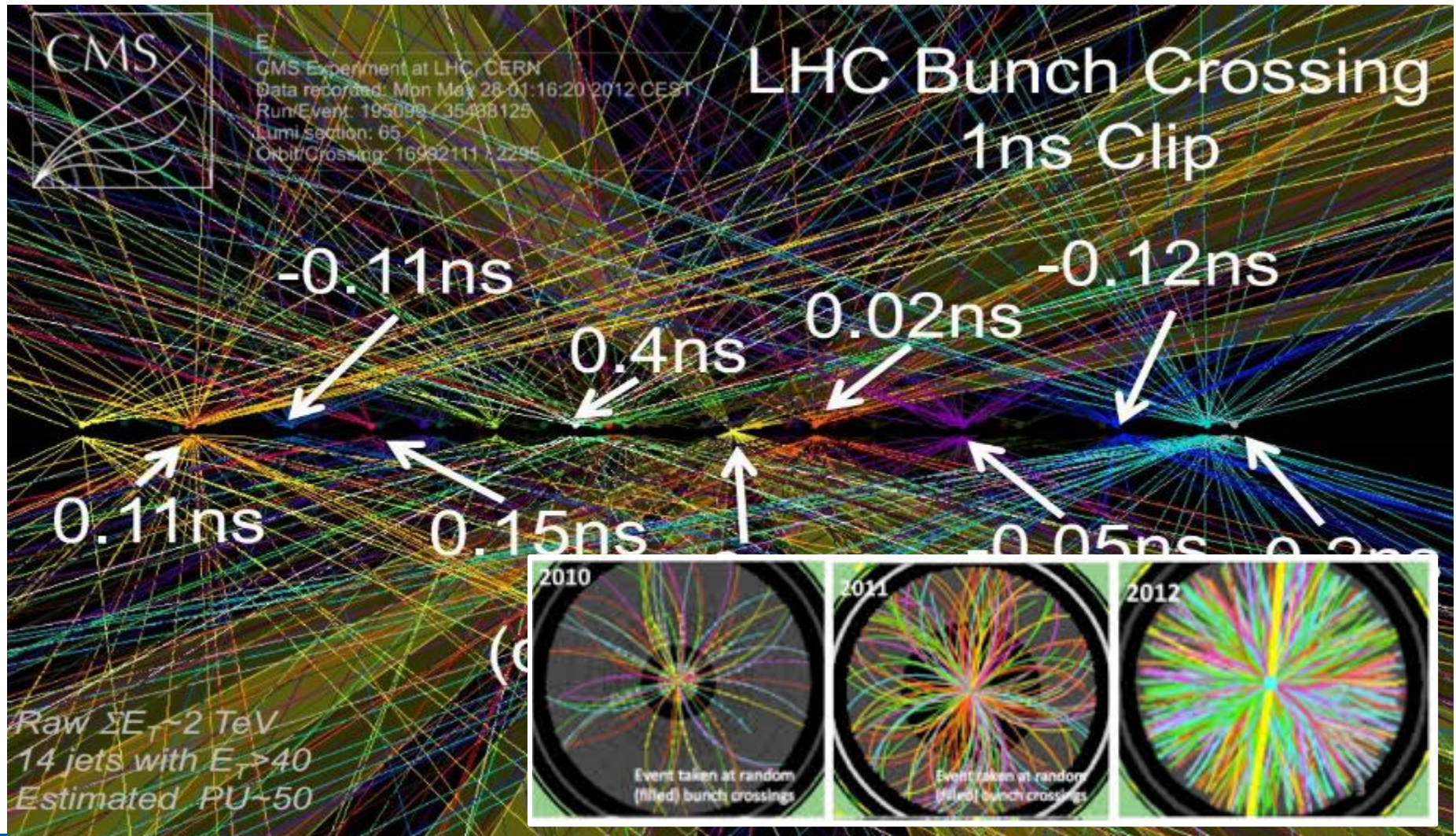
*R&D on detectors: data filtering and Computation*





# Any obstacle to Theoretician's dreams?

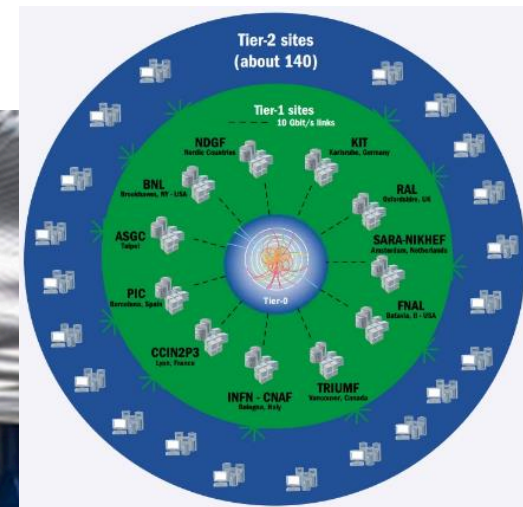
*Ready to digest the data avalanche?*





# Any obstacle to Theoretician's dreams?

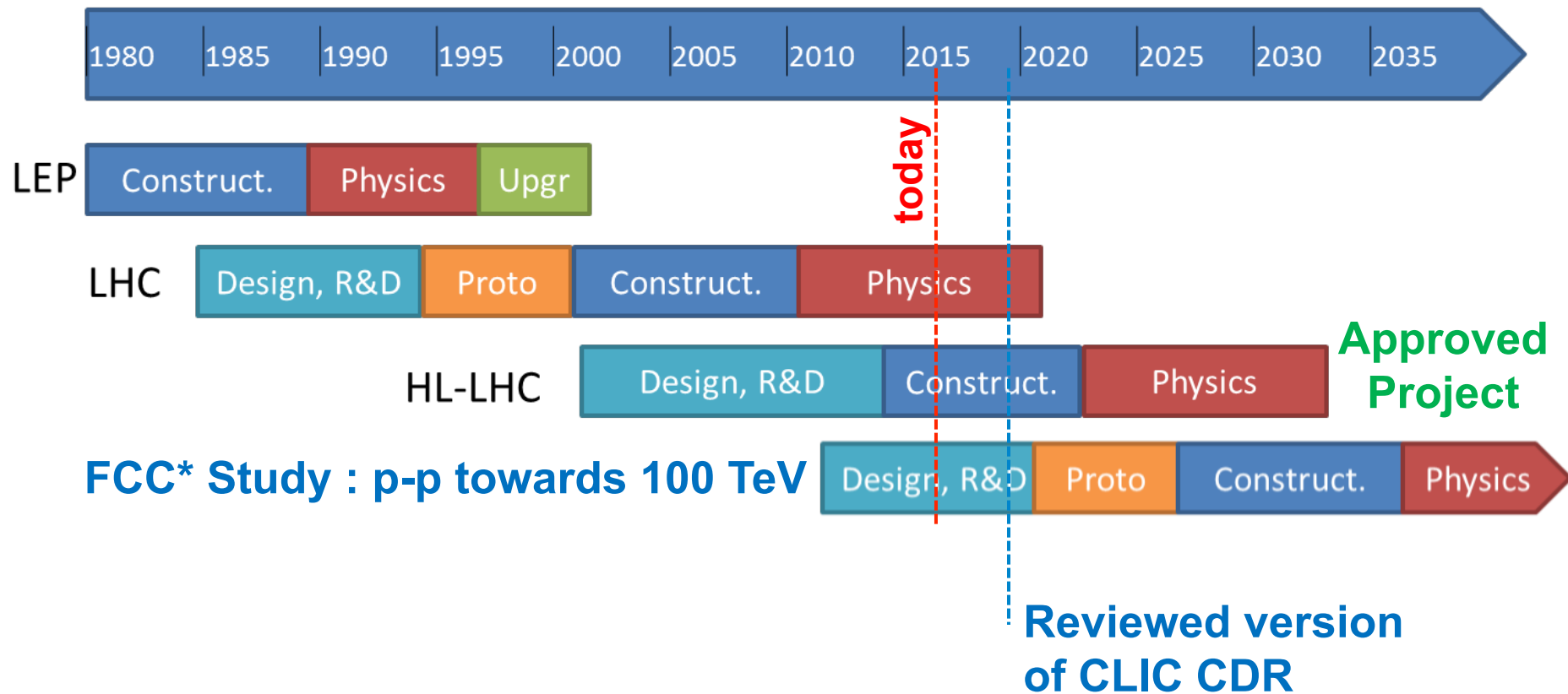
*LHC Data Distribution: WLCG Worldwide LHC Computing Grid*





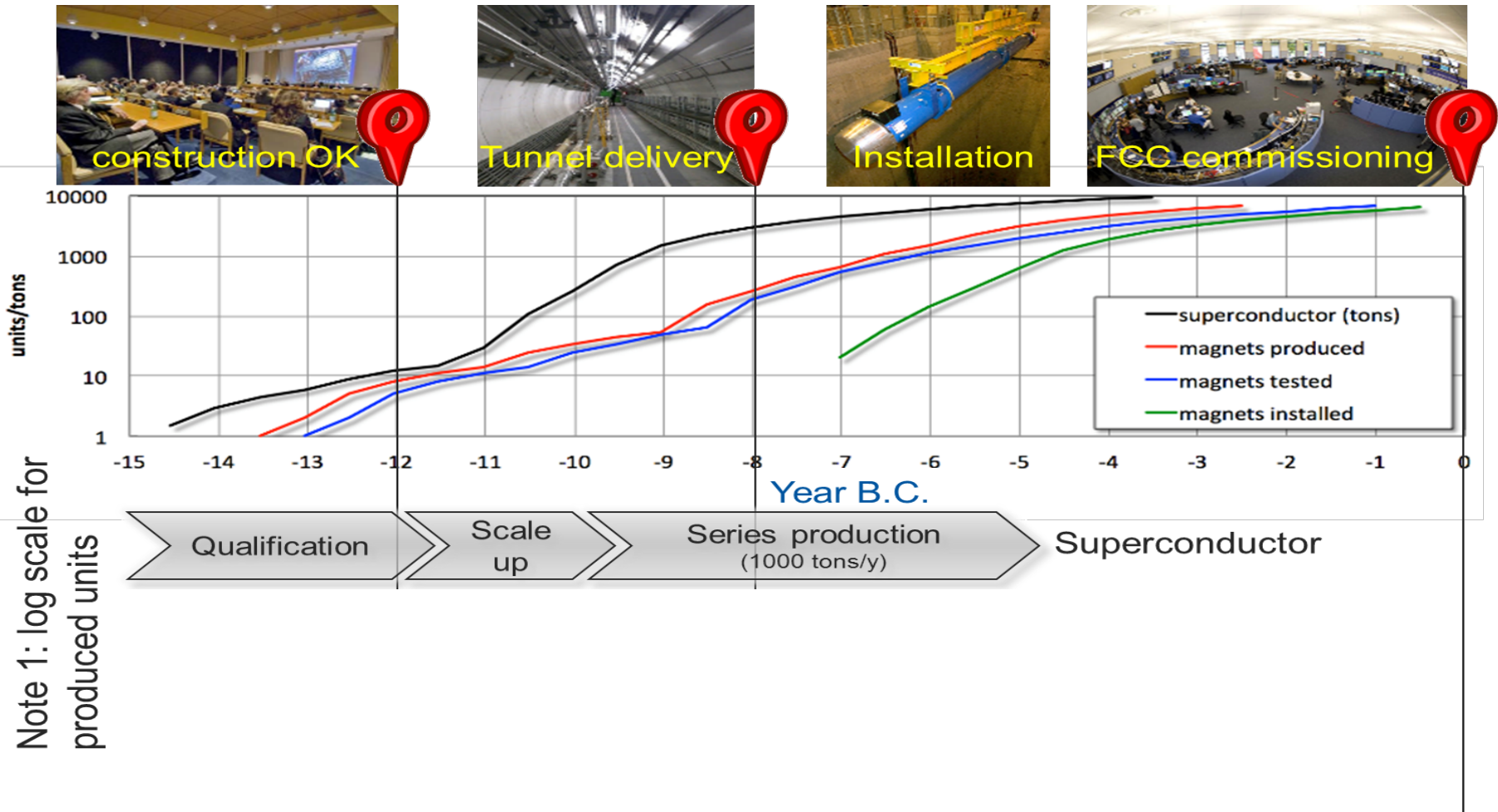
# Longest genesis and lifecycles!

*Phasing the Projects...*



# Longest genesis and lifecycles!

*Industrialization of the superconducting magnets...*



Note 2: B.C. = Before the Collider



# At the crossing of the roads?

*CERN: a peculiar and successful model!*

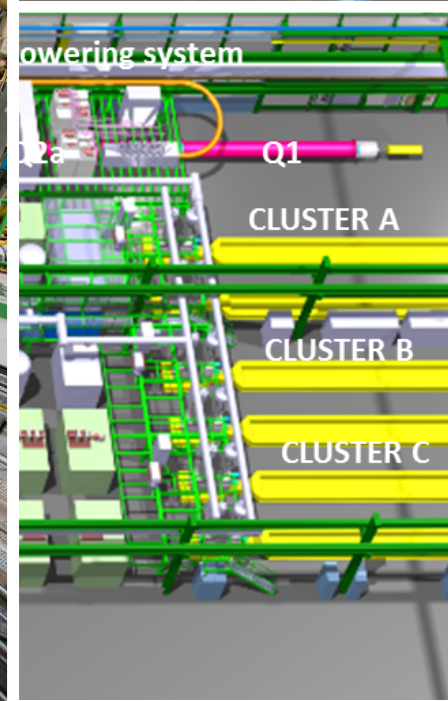




# At the crossing of the roads?

*CERN: a peculiar and successful model!*

## Cryogenic Magnet Test Facility





# At the crossing of the roads?

*CERN: a peculiar and successful model!*





# At the crossing of the roads?

*CERN: a peculiar and successful model!*

Large Magnet Facility





# At the crossing of the roads?

*CERN: a peculiar and successful model!*





# CERN response to its challenges...

- LHC has a lot to deliver, only 2% of its potential so far...!
- Physicists and Theoreticians will continue analysing data till 2024.
- Accelerator and Detector experts will be preparing the:
  - HL-LHC upgrade...
  - Technology breakthrough needed for the future generation of high intensity and energy beams towards discovery frontiers...
- Its vigorous scientific diversity program will complete the needed global picture in Basic Science...
- Letting Physics results telling us... the way to go and the relevant priorities!

Run: 286  
Event: 419161  
2015-11-25 11:12:50 CEST

first stable beams heavy-ion collisions





SUISSE  
FRANCE

LHCb

ATLAS

CERN Meyrin

CERN Prévessin

SPS 7 km

ALICE

CMS

Thanks for your attention

LHC 27 km



*Accelerating Science and Innovation*



