



Universidade do Minho  
Escola de Ciências



LABORATÓRIO DE INSTRUMENTAÇÃO  
E FÍSICA EXPERIMENTAL DE PARTÍCULAS  
*partículas e tecnologia*



# CERN and particle physics: challenges and opportunities

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**FCT**

Fundação  
para a Ciência  
e a Tecnologia

UIDP/50007/2020  
LA/P/0016/2020  
CERN/FIS-PAR/0010/2021

**observable universe**  
 $8.8 \cdot 10^{26} m$

**quarks**  
 $< 10^{-19} m$

1'000'000'000'000'000'000'000'000'000'000'000.000'000'000'000'000'000'01 meter

distance to galactic center

distance light travels in one year

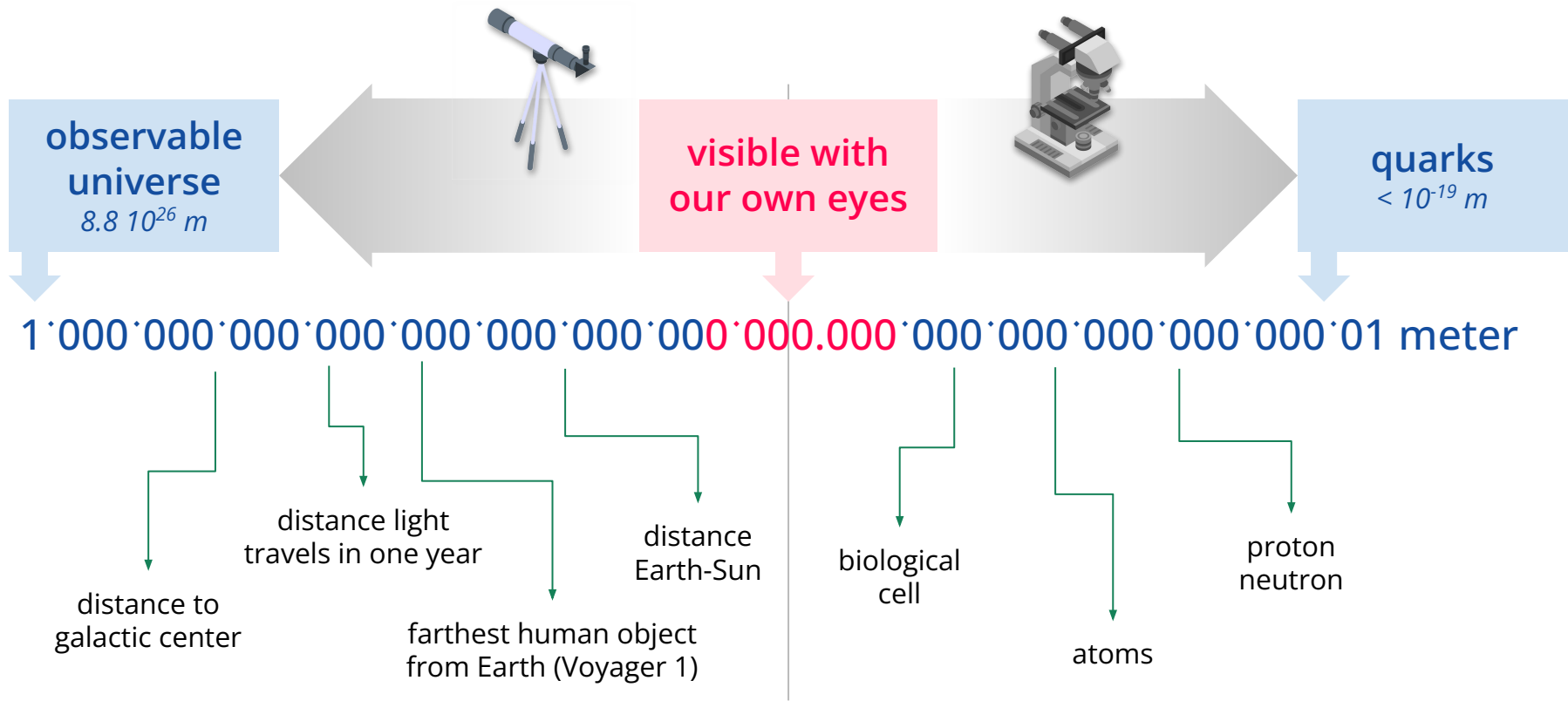
farthest human object from Earth (Voyager 1)

distance Earth-Sun

biological cell

atoms

proton neutron



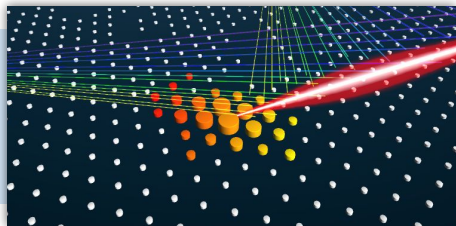
age universe  
 $4.4 \cdot 10^{18} \text{ s}$

large surface/volume  
observatories

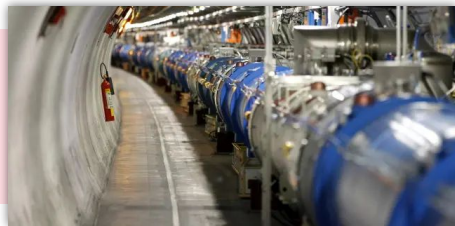
powerful accelerators

lifetime top quark  
 $5 \cdot 10^{-25} \text{ s}$

observable  
universe  
 $8.8 \cdot 10^{26} \text{ m}$



visible with  
our own eyes



quarks  
 $< 10^{-19} \text{ m}$

1'000'000'000'000'000'000'000'000'000'000'000.000'000'000'000'000'000'01 meter

distance to  
galactic center

distance light  
travels in one year

farthest human object  
from Earth (Voyager 1)

distance  
Earth-Sun

biological  
cell

atoms

proton  
neutron

lifetime star  
 $10^{13}\text{-}10^{16} \text{ s}$

duration  
supernova & GRB  
0.1-100 s

lifetime proton  
 $> 3 \cdot 10^{41} \text{ s}$

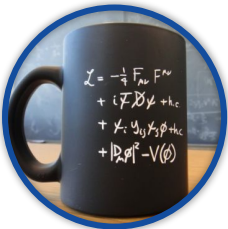
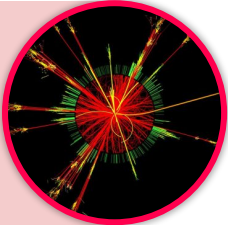
lifetime kaon ( $K^\pm$ )  
 $1.2 \cdot 10^{-8} \text{ s}$

1'000'000'000'000'000'000'000'000'000'000'000'000'000'000'000'000'000'000'000'01 meter

1·000·000·000·000·000·000·000·000·000·000·000·000·01 meter



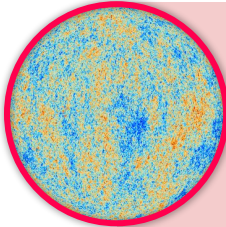
observations how  
small objects  
behave in our  
laboratories



$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \bar{\psi} i \not{\partial} \psi + \bar{\psi} \gamma_5 \psi + h.c. + \mathcal{L}_m - V(\phi)$$

Standard Model of  
Particle Physics

1 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 01 meter

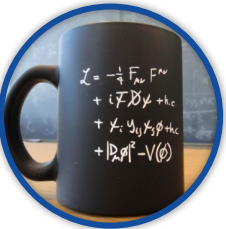
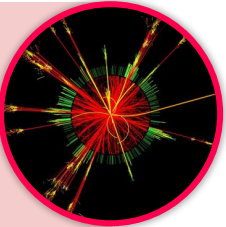


observations how large objects behave in our universe



Standard Model of Cosmology

observations how small objects behave in our laboratories



Standard Model of Particle Physics

1'000'000'000'000'000'000'000'000'000'000'000'000'000'000'01 meter

building blocks of life on the human scale

observations how large objects behave in our universe

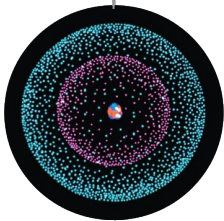
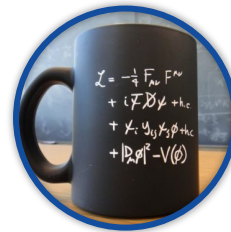
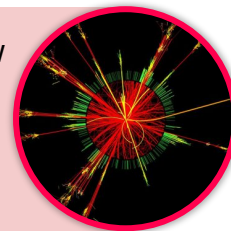
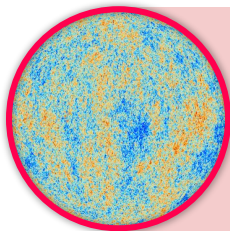
observations how small objects behave in our laboratories

e.g. creation of chemical elements

e.g. nuclei built from quarks and gluons

Standard Model of Cosmology

Standard Model of Particle Physics





communication  
satellites  
GPS

World Wide Web  
touchscreens

# A century of scientific revolutions

1 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 000 · 01 meter

building blocks of life on the human scale

production of particles and radiation  
nuclear diagnosis and medicine

observations how  
large objects  
behave in our  
universe

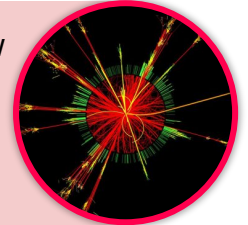
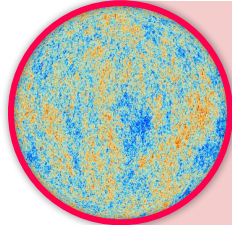
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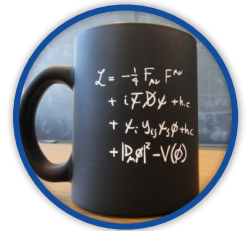
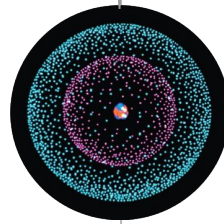
e.g. nuclei built from  
quarks and gluons

“Scientific curiosity which ends up in your pocket”

*Rolf Heuer (previous Director General of CERN)*



Standard Model of  
Cosmology



Standard Model of  
Particle Physics

# CERN

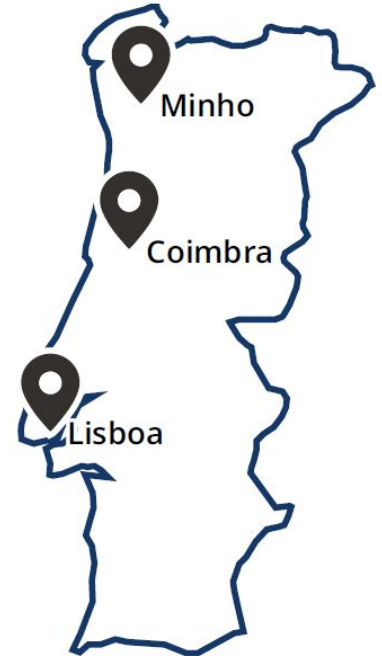
- The European Laboratory for Particle Physics
- Located in the franco-swiss border
- Portugal is a member since 1986, with LIP being the reference portuguese partner



# LIP

## Laboratório de Instrumentação e Física Experimental de Partículas

- LIP is the reference laboratory for experimental particle physics and associated technologies in Portugal
- LIP exists for the discovery of the fundamental laws of the Universe, ensuring the full participation of the Portuguese scientific community in this endeavour, and to share this knowledge with society
- The laboratory is nation-wide, with nodes in Lisbon, Coimbra and Braga, in close collaboration with the local universities



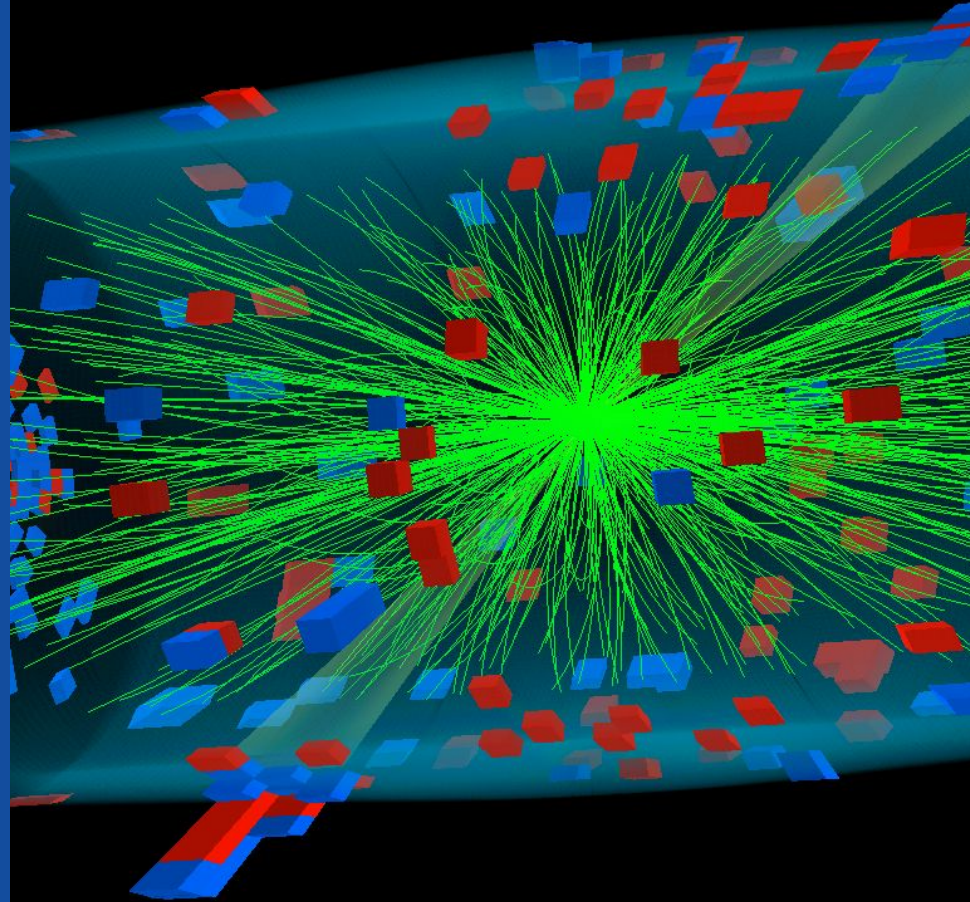
# CERN

Four pillars underpin its mission

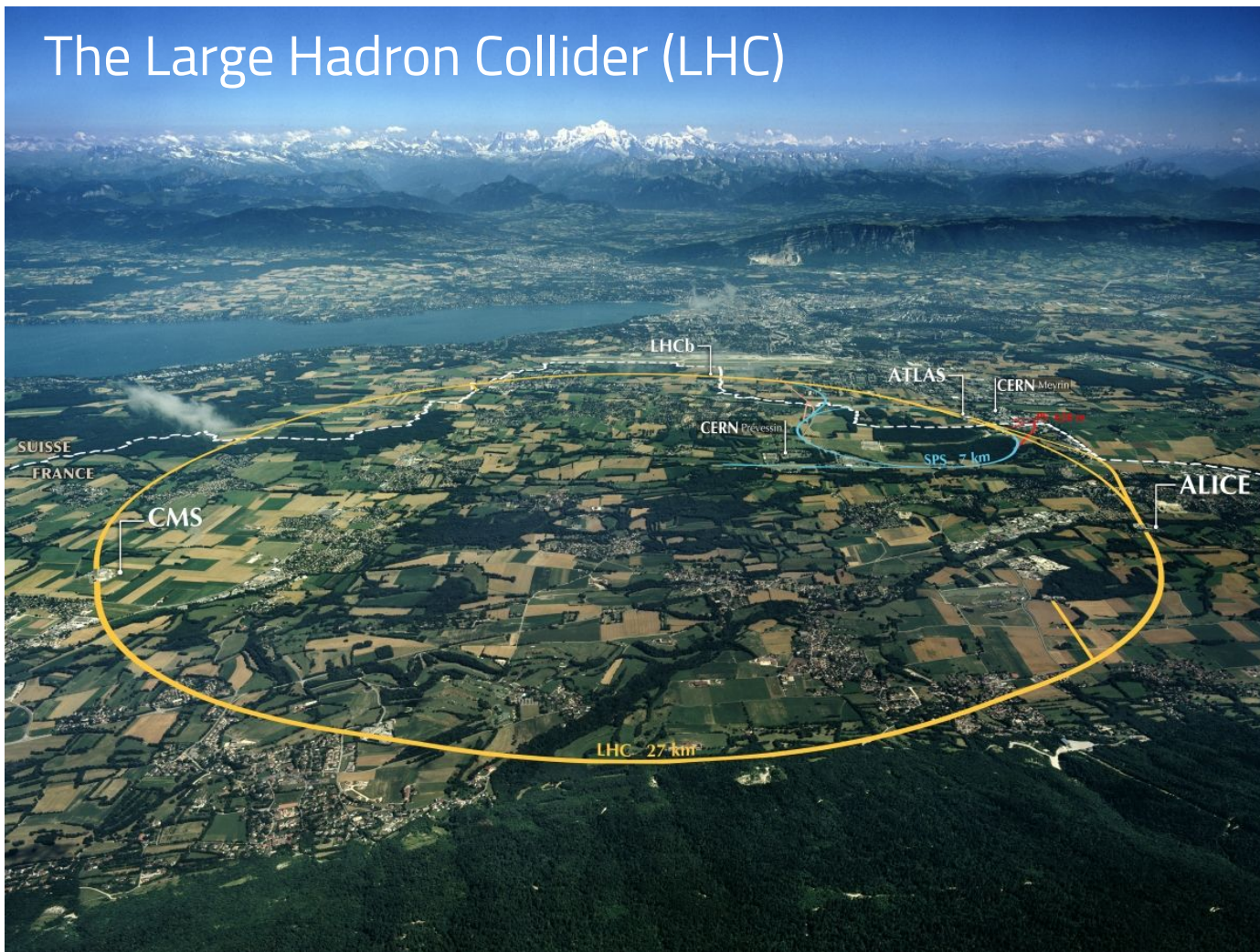


# in the frontier of science

- 95% of the mass and energy of the universe is unknown
- Is there only one Higgs boson and does it behave as expected?
- Why is the universe made mostly from matter, with hardly any antimatter?
- Why is gravity so weak compared to the other forces?

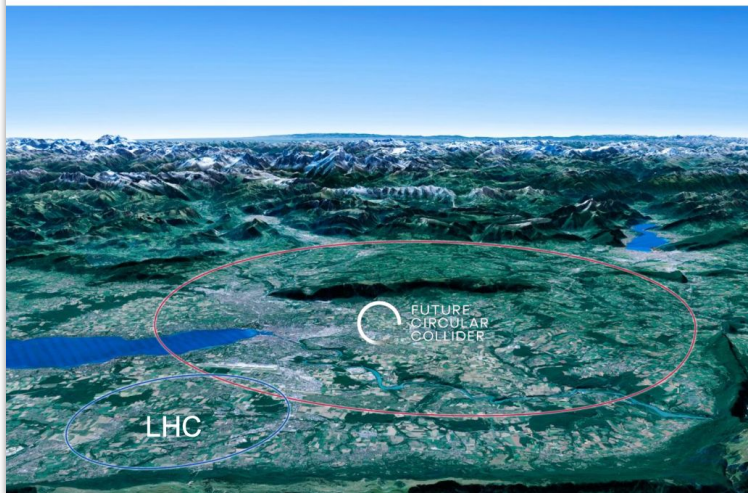
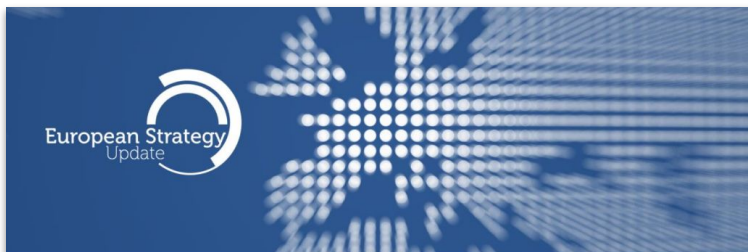


# The Large Hadron Collider (LHC)



# The Future Circular Collider

The frontiers of precision and energy



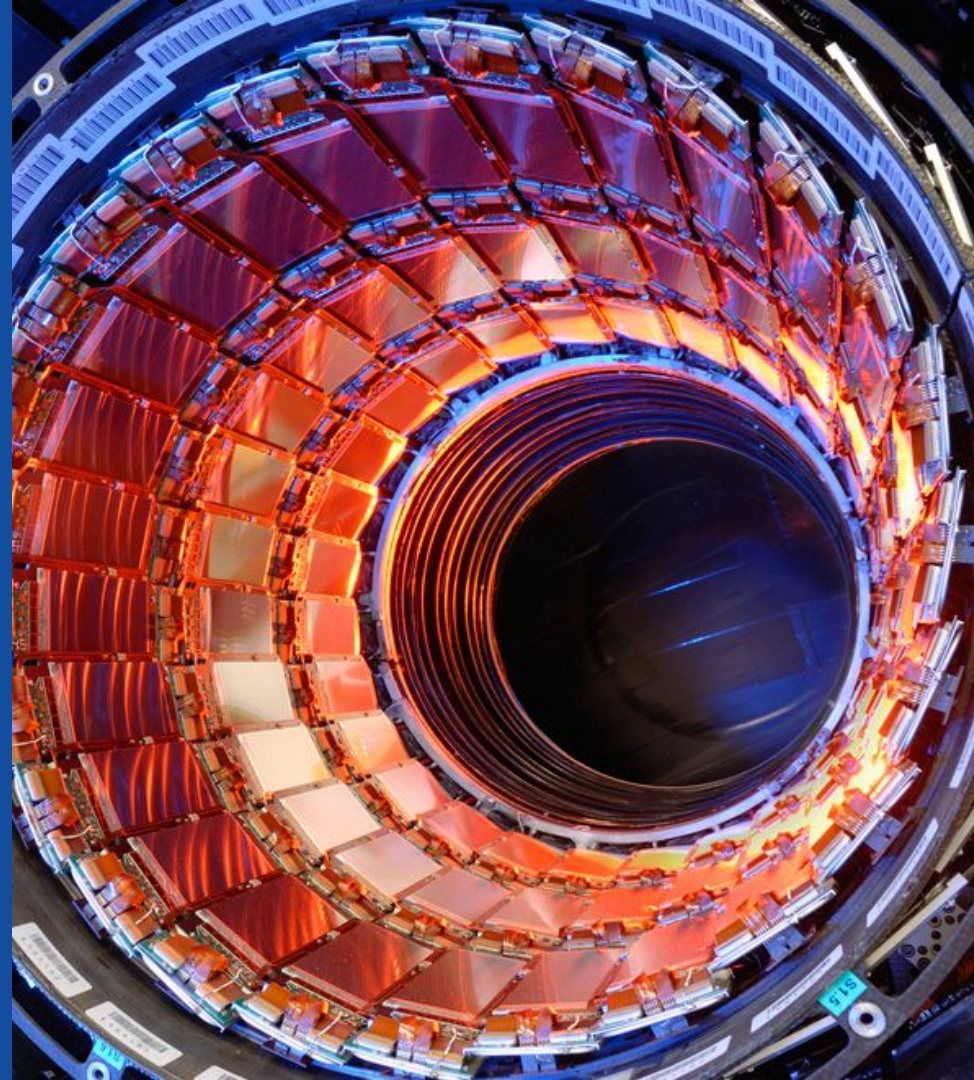
## Scientific priorities for the future

Implementation of the recommendations of the **2020 Update of the European Strategy for Particle Physics**:

- Fully exploit the HL-LHC
- Build a Higgs factory to further understand this unique particle
- Investigate the technical and financial feasibility of a future energy-frontier 100 km collider at CERN
- Ramp up relevant R&D
- Continue supporting other projects around the world

# in the frontier of the technology

- Particle physics accelerators and detectors are amongst the most complex devices built by the humankind
- Being on the edge of the technology is required







- **Civil engineering:**
  - Construction
  - Renovation of buildings
  - Metallic structures
  - Earthworks
  - Roads
- **Cooling and ventilation equipment**



- **Mechanical engineering:**
  - Machining
  - Sheet metal work and arc welding
  - Special fabrication techniques
  - Offsite engineering and testing



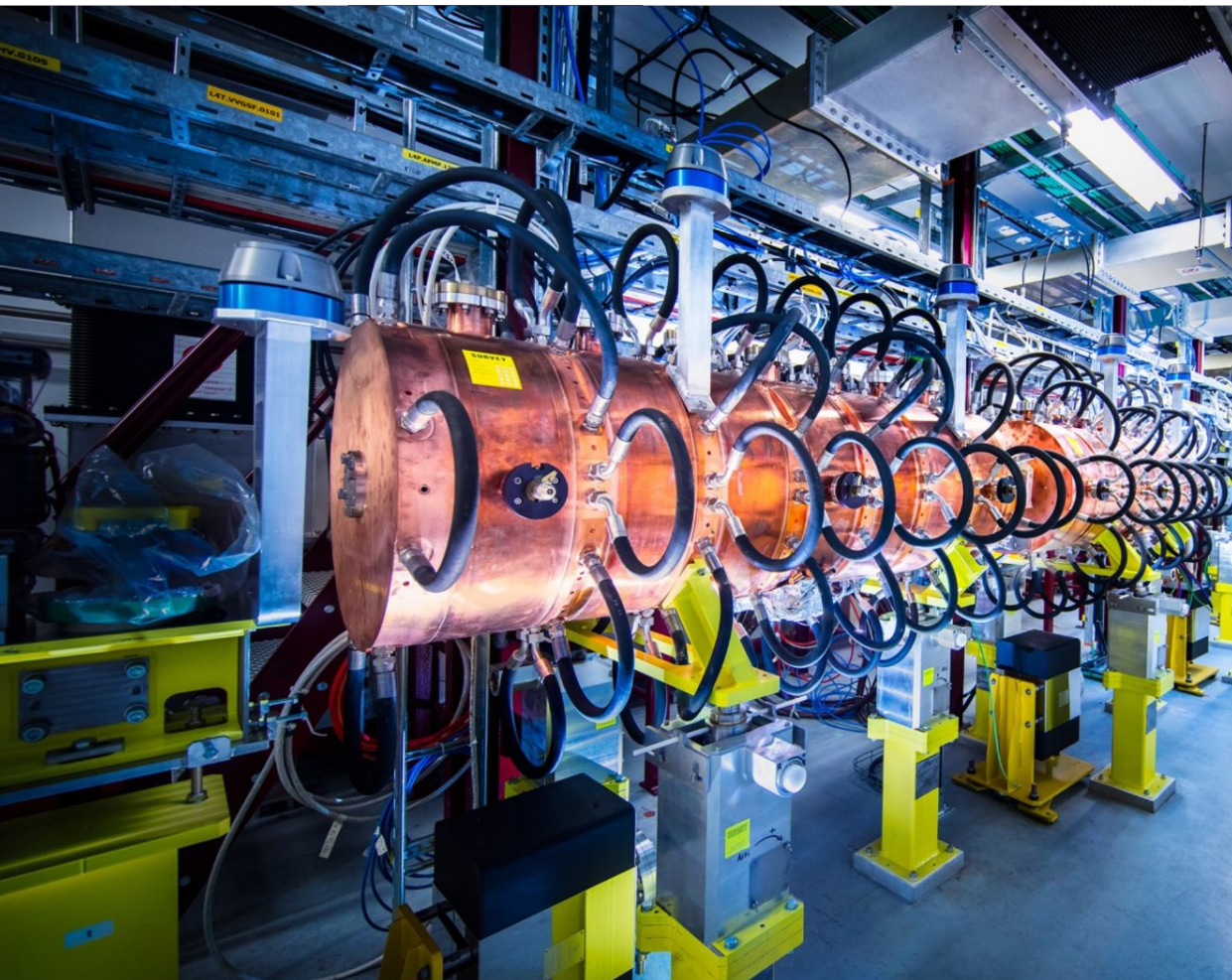
- **Electrical engineering and magnets**

- Transformers
- Switchboards and switchgear
- Cables
- Automation
- Power supplies
- Magnets

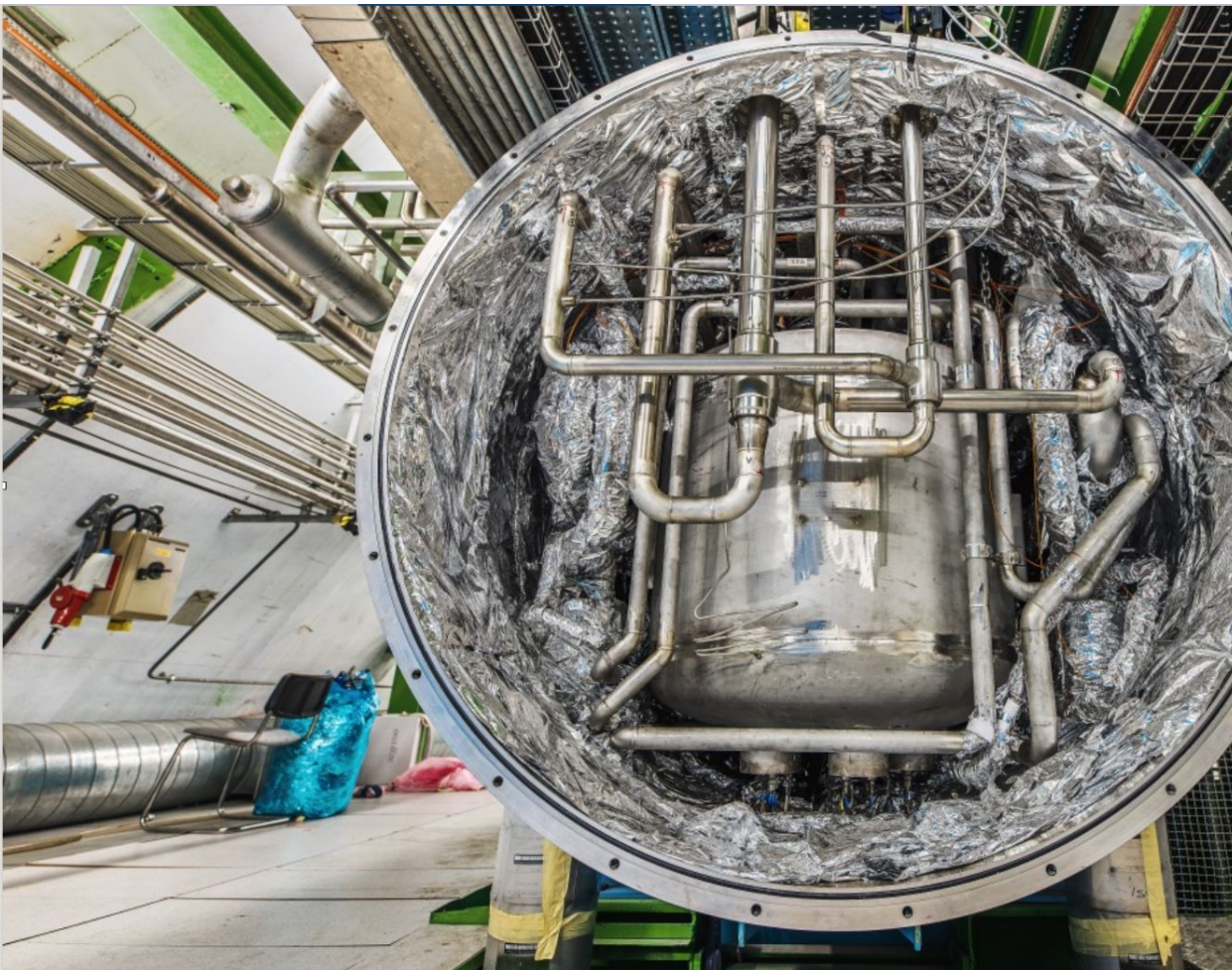


## • Information Technology

- Computing systems
- Servers
- Software
- Network equipment



- **Electronics and radio-frequency:**
  - Electronic components (active, passive)
  - PCBs and assembled boards
  - LV and HV power supplies
  - Radio-frequency plants
  - Amplifiers

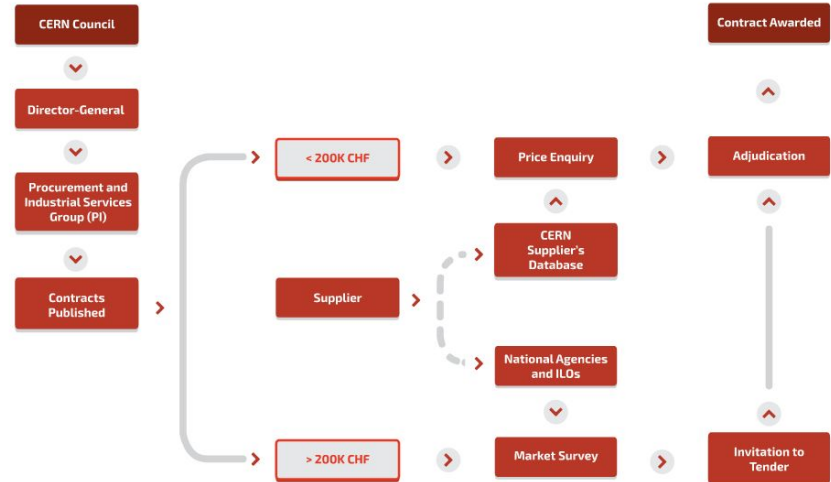


- Cryogenic and vacuum equipment
- Optics and photonics
- Particle and photon detectors
- Health and safety equipment
- Transport and handling equipment

# Industrial return

## Portuguese companies & CERN procurement

- ▶ A. Silva Matos
- ▶ Active Space
- ▶ Cudell
- ▶ Cunhol
- ▶ Efacec
- ▶ Glintt
- ▶ Incomef
- ▶ ISQ
- ▶ NCP Metal
- ▶ Siroco
- ▶ Solidal



NOTE: For more information on the procurement process by CERN, consult:  
<http://procurement.web.cern.ch/>

# Advanced training

## In particle physics and related technologies

>3000 PhD students are registered at CERN.

600 PhD theses are completed each year.

300 undergraduate students in Summer programmes.



~800 fellows in research and applied physics, engineering and computing.

~200 Technical and Doctoral Students in applied physics, engineering and computing.

CERN organises schools for undergraduates and postgraduates, in all regions.



# Advanced training

Portugal has a leading role in the training of engineers at CERN



ESCE-IPS	1	ESCE-IPS - Escola Superior de Ciências Empresariais do Instituto Politécnico de Setúbal
FCTUC	7	FCTUC - Faculdade de Ciências e Tecnologia da Universidade de Coimbra
FCTUNL	16	FCTUNL - Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa
FCUL	18	FCUL - Faculdade de Ciências da Universidade de Lisboa
FCUP	4	FCUP - Faculdade de Ciências da Universidade do Porto
FEUP	51	FEUP - Faculdade de Engenharia da Universidade do Porto
IPLisboa	1	IPLisboa - Instituto Politécnico de Lisboa
IPLeiria	2	IPLeiria - Politécnico de Leiria
ISA	2	ISA - Instituto Superior de Agronomia
ISCTE-IUL	3	ISCTE-IUL - ISCTE - Instituto Universitário de Lisboa
NOVA IMS	1	NOVA IMS - NOVA Information Management School
ISEL	2	ISEL - Instituto Superior de Engenharia de Lisboa
ISEP	2	ISEP - Instituto Superior de Engenharia do Porto
U. Europeia	1	U. Europeia - Universidade Europeia
IST	104	IST - Instituto Superior Técnico
ISTP	1	ISTP - Instituto Superior de Transportes de Lisboa
U. Algarve	2	U. Algarve - Universidade do Algarve
U. Aveiro	20	U. Aveiro - Universidade de Aveiro
U. Birmingham	1	U. Birmingham - University of Birmingham
U. Coimbra	21	U. Coimbra - Universidade de Coimbra
U. Évora	2	U. Évora - Universidade de Évora
U. Lusíada	2	U. Lusíada - Universidade Lusíada de Lisboa
U. Minho	14	U. Minho - Universidade do Minho
U. Nova de Lisboa	15	U. Nova de Lisboa - Universidade Nova de Lisboa
U. Porto	1	U. Porto - Universidade do Porto
U. Wisconsin	1	U. Wisconsin - University of Wisconsin
UTAD	4	UTAD - Universidade de Trás-os-Montes e Alto Douro
U. Beira Interior	4	U. Beira Interior - Universidade da Beira Interior
U. Southampton	1	U. Southampton - University of Southampton

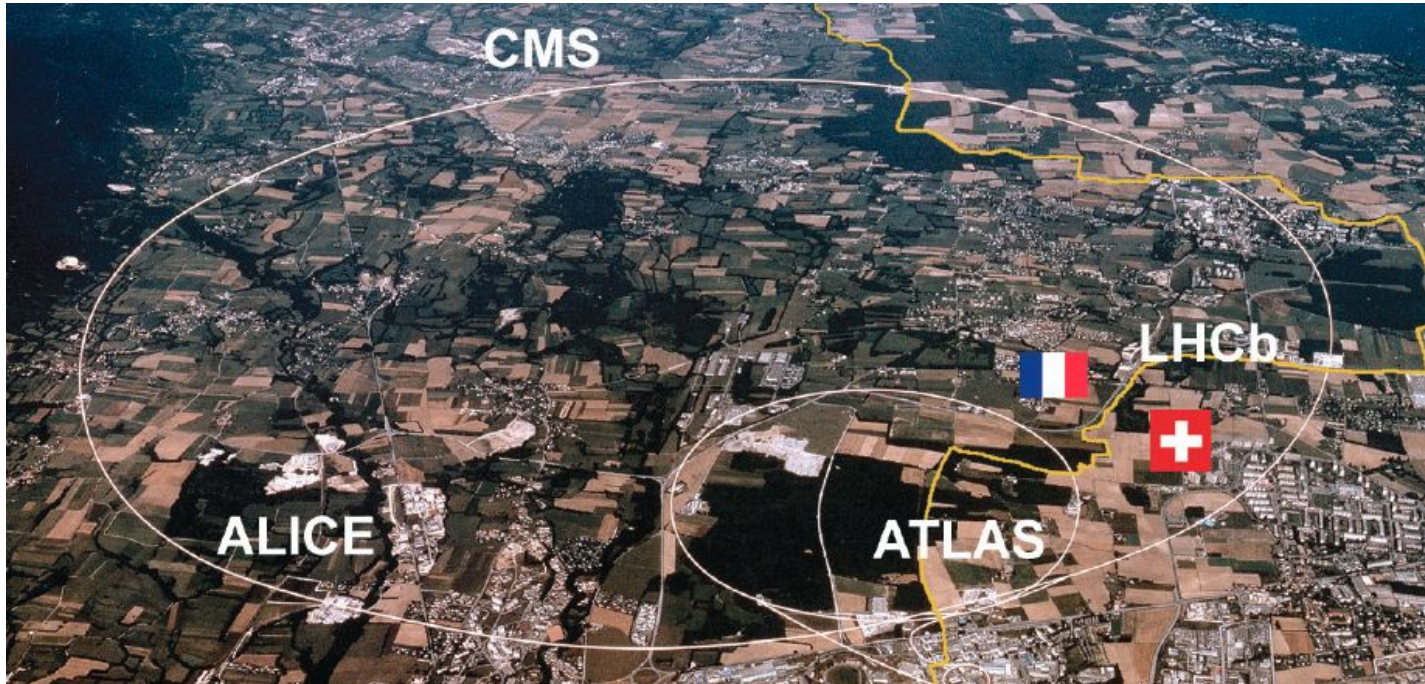
# Thanks!

any questions?

you can also find me at [nuno.castro@cern.ch](mailto:nuno.castro@cern.ch)

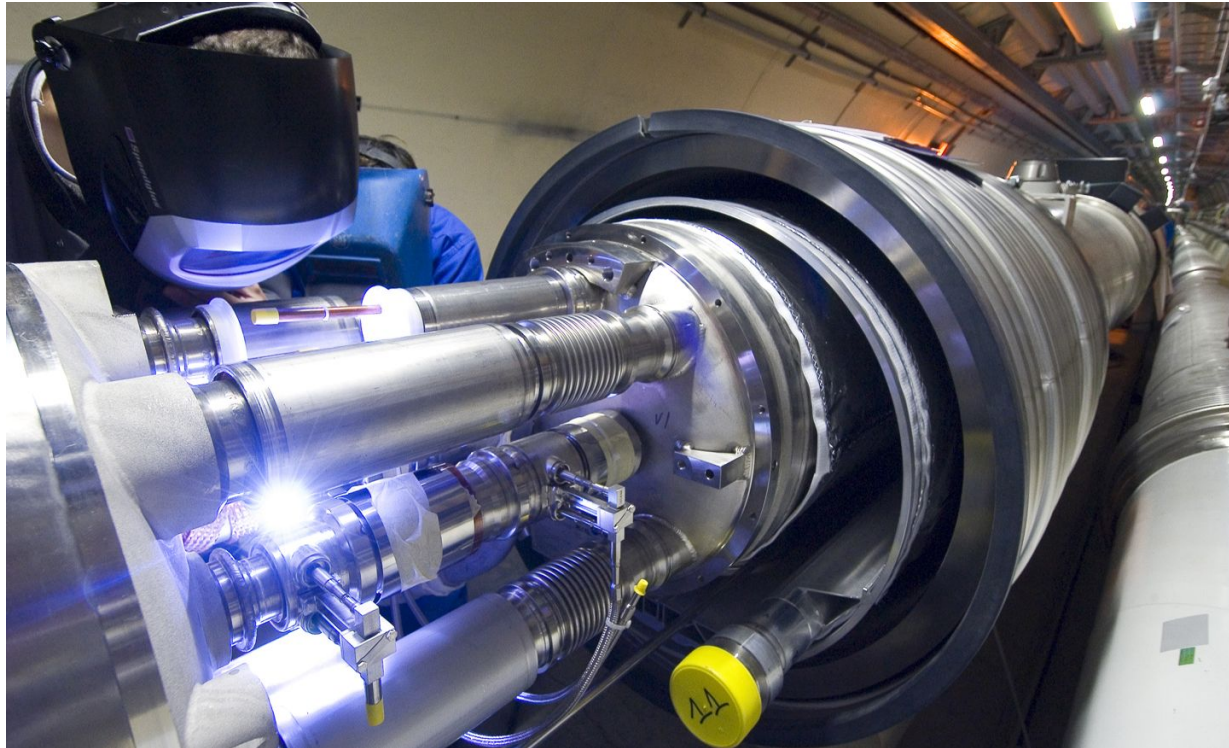
# The Large Hadron Collider at CERN

one of the fastest race tracks on the planet



# The Large Hadron Collider at CERN

the emptiest space in the solar system



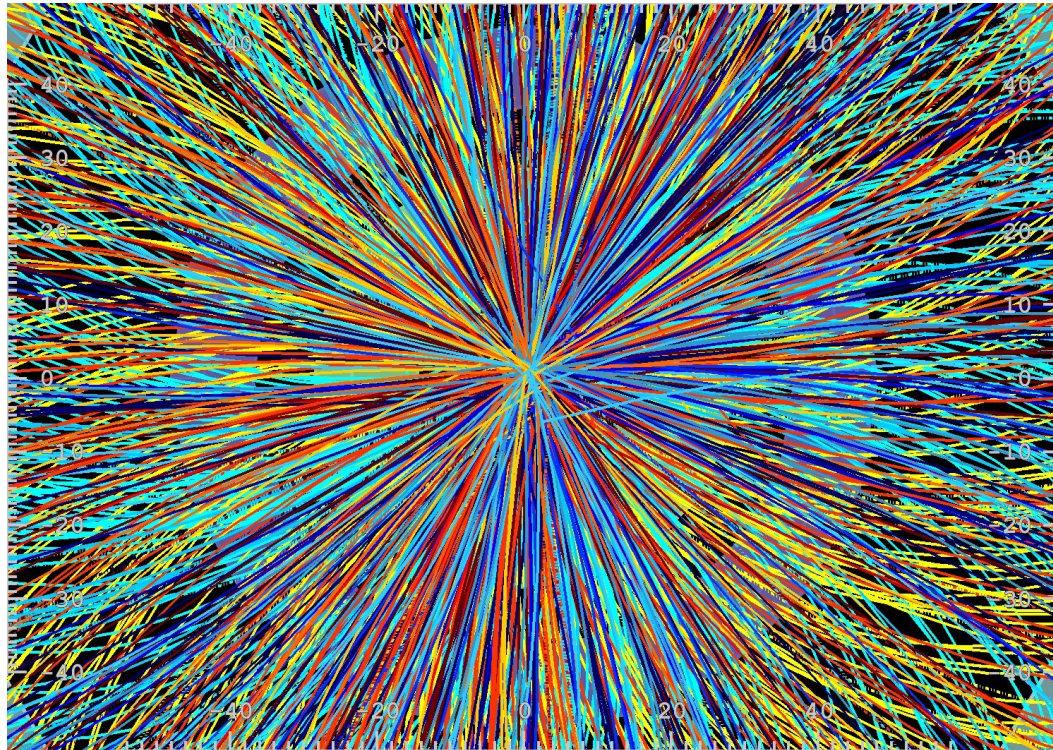
# The Large Hadron Collider at CERN

one of the coldest places in the Universe

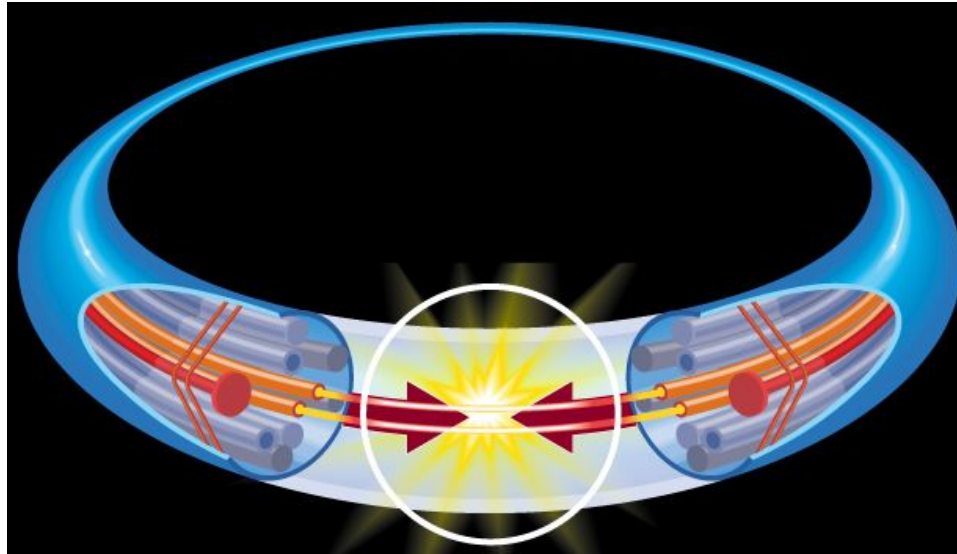


# The Large Hadron Collider at CERN

one of the hottest places in the galaxy



# from data to physics at the Large Hadron Collider a long and complex path



- 40 million proton-proton collisions per second

# The LHC at CERN

## High luminosity phase



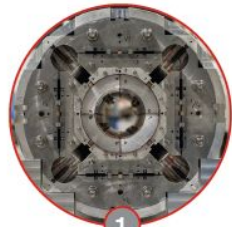
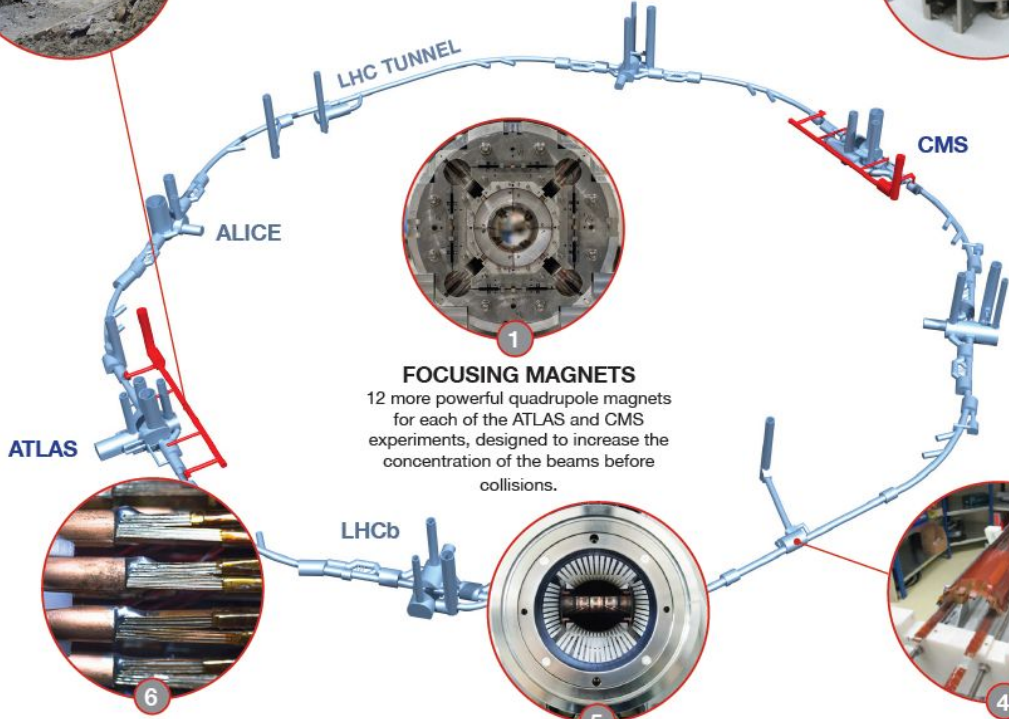
### NEW TECHNOLOGIES FOR THE HIGH-LUMINOSITY LHC



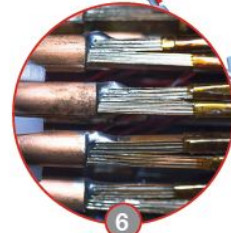
**2 CIVIL ENGINEERING**  
2 new 300-metre service tunnels and  
2 shafts near to ATLAS and CMS.



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



**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.



**6 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.



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



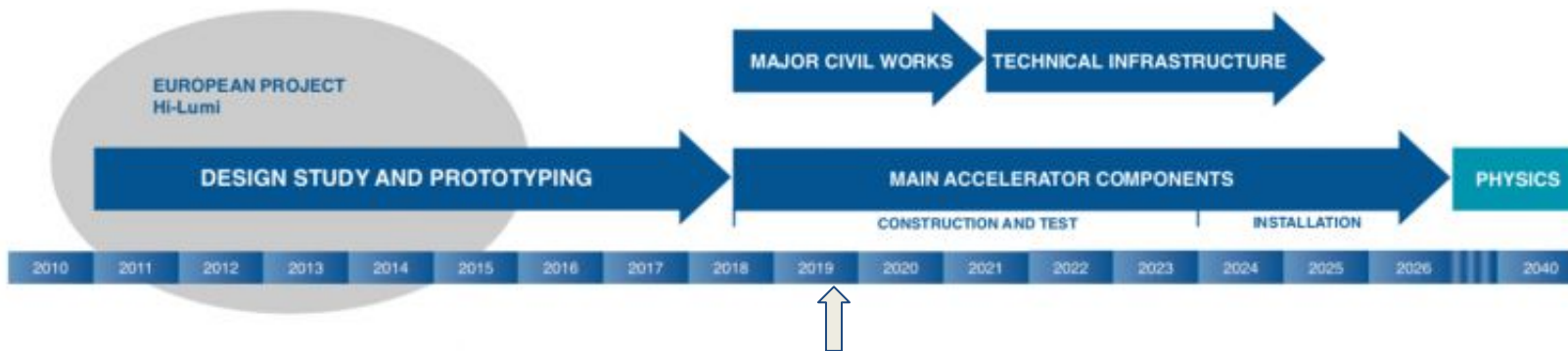
**4 BENDING MAGNETS**  
4 pairs of shorter and more  
powerful dipole bending magnets  
to free up space for the new  
collimators.



# The Large Hadron Collider at CERN

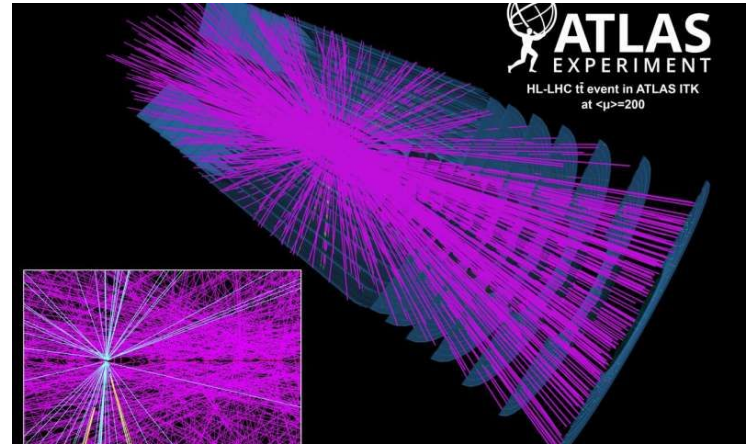
More data needed: the high luminosity upgrade

## HL-LHC Plan



# The Large Hadron Collider

## High luminosity phase upgrade



- HL-LHC: upgrade of LHC and injectors to increase beam intensity
  - $L_{\text{inst}} > 5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ , up to 140-200 pileup (< 60 up to now)
  - Ultimate integrated luminosity target of  $3000 \text{ fb}^{-1}$  (10x LHC) - baseline
- Experiments: ATLAS and CMS upgrades for HL-LHC conditions
  - Radiation hardness
  - Mitigate physics impact of high pileup ( more than 5x LHC )

# LHC - HL

## CMS experiment upgrade

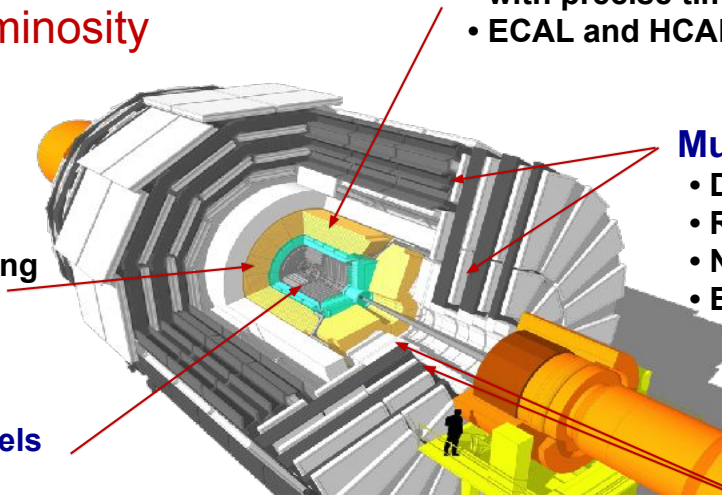
New paradigms (design/technology) for an HEP experiment to fully exploit HL-LHC luminosity

### Calorimeter Endcap

- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

### Tracker Si-Strip and Pixels increased granularity

- Design for tracking in L1-Trigger
- Extended coverage to  $\eta \approx 3.8$



### L1-Trigger/HLT/DAQ

- Tracks in L1-Trigger at 40 MHz
- PFlow-like selection 750 kHz output
- HLT output 7.5 kHz

### Barrel Calorimeters

- ECAL crystal granularity readout at 40 MHz with precise timing for e/ $\gamma$  at 30 GeV
- ECAL and HCAL new Back-End boards

### Muon systems

- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC  $1.6 < \eta < 2.4$
- Extended coverage to  $\eta \approx 3$

### MIP Timing Detector

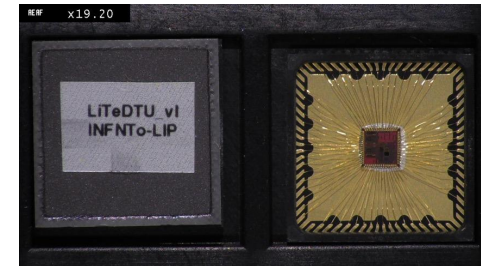
Precision timing with:

- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

# LHC - HL

## CMS experiment upgrade - Portuguese participation

- Portuguese contribution:
  - Primary responsibility and leadership
    - Readout system of the new Barrel Timing Layer (BTL) of MTD
  - Secondary contributions
    - New front-end electronics system of the ECAL
    - Trigger system of the new High-Granularity Calorimeter
- ASICs supplied by Portuguese industry:
  - TOF ASIC for the BTL frontend electronics.
  - ADC ASIC for the ECAL frontend electronics
  - LVR ASIC for the HGCal frontend electronics



# LHC - HL

## ATLAS experiment upgrade

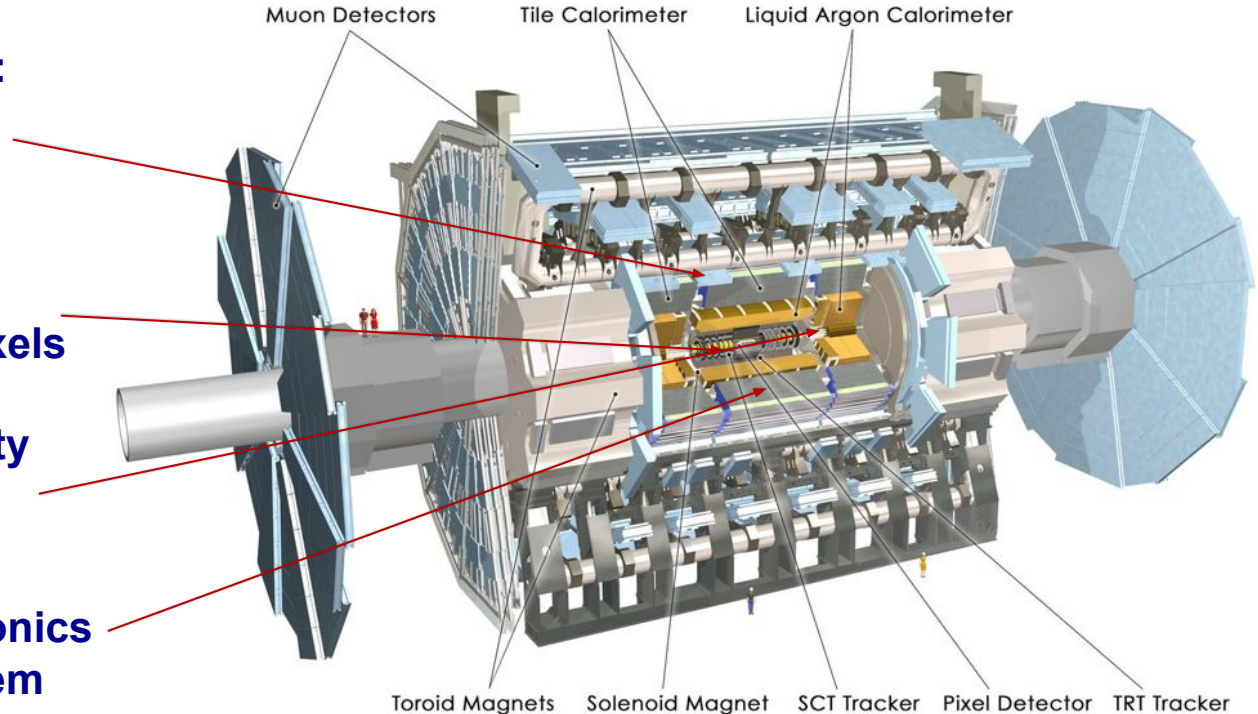
## Upgraded trigger and data acquisition system

**Muon system upgrade:  
new chambers in the  
inner barrel region**

**New Inner Tracking  
Detector: Strips and Pixels**

**New High Granularity  
Timing Detector**

**TileCal: new electronics  
and powering system**



Toroid Magnets Solenoid Magnet SCT Tracker Pixel Detector TRT Tracker

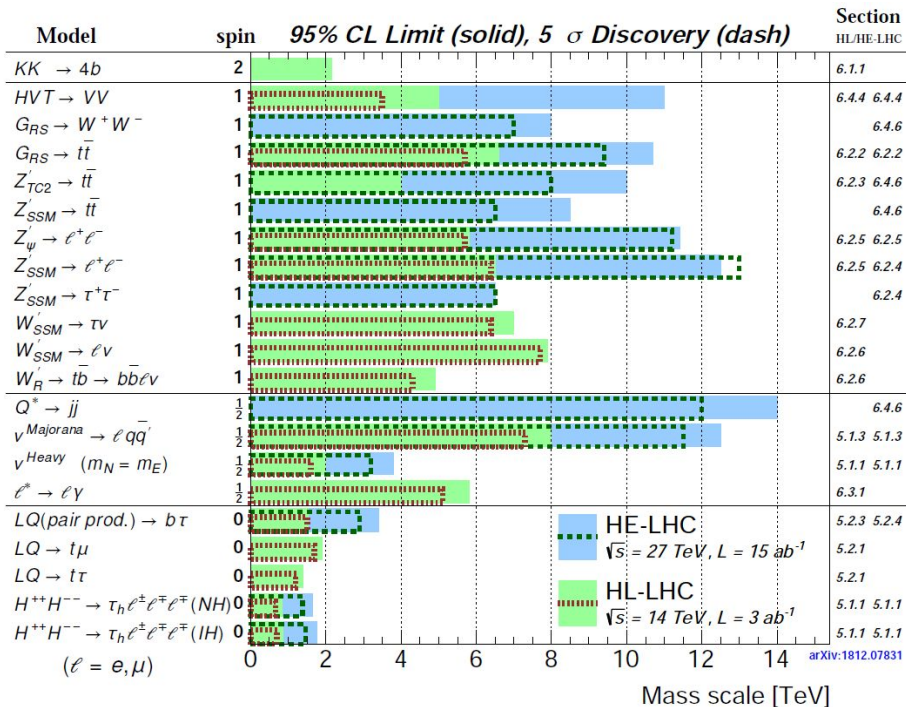
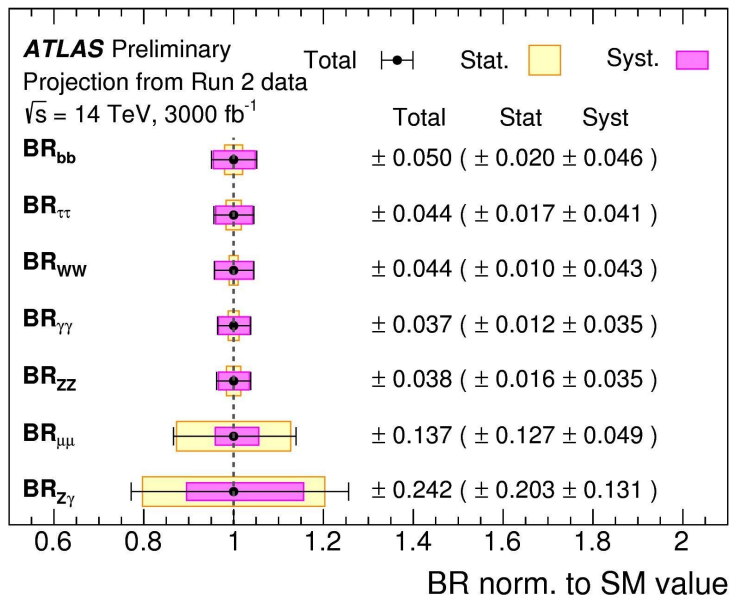
# LHC - HL

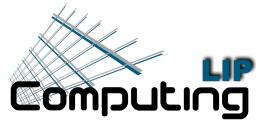
## ATLAS experiment upgrade: Portuguese participation

- Tilecal high voltage regulation system
  - Primary responsibility and leadership
    - distribution boards being designed at LIP and production will be done in the Portuguese industry
    - small diameter cables being developed by Portuguese industry
- Hardware Track Trigger (HTT)
  - Will provide local tracking at 1 MHz and full event tracking at 1 kHz
  - Rear Transition Modules:
    - 75% to be produced in Portuguese industry
    - Testing and quality control at LIP

# LHC - HL

## Physics goals: a few examples





R&D projects and infrastructures



- Software management coordination
- Piloting data repositories
- HPC and virtualization for machine learning
- Cloud for research
- IBERGRID coordination
- EUDAT national node
- EGI pan-European middleware coordination
- WLCG national node

Support

Knowledge Capabilities

OPENCoastS	GBIF biodiversity data portal	LHC data processing
Cosmic rays	Genome data eliXir PORTUGAL	Neutrino physics
Computational chemistry	EC EARTH Climate	...

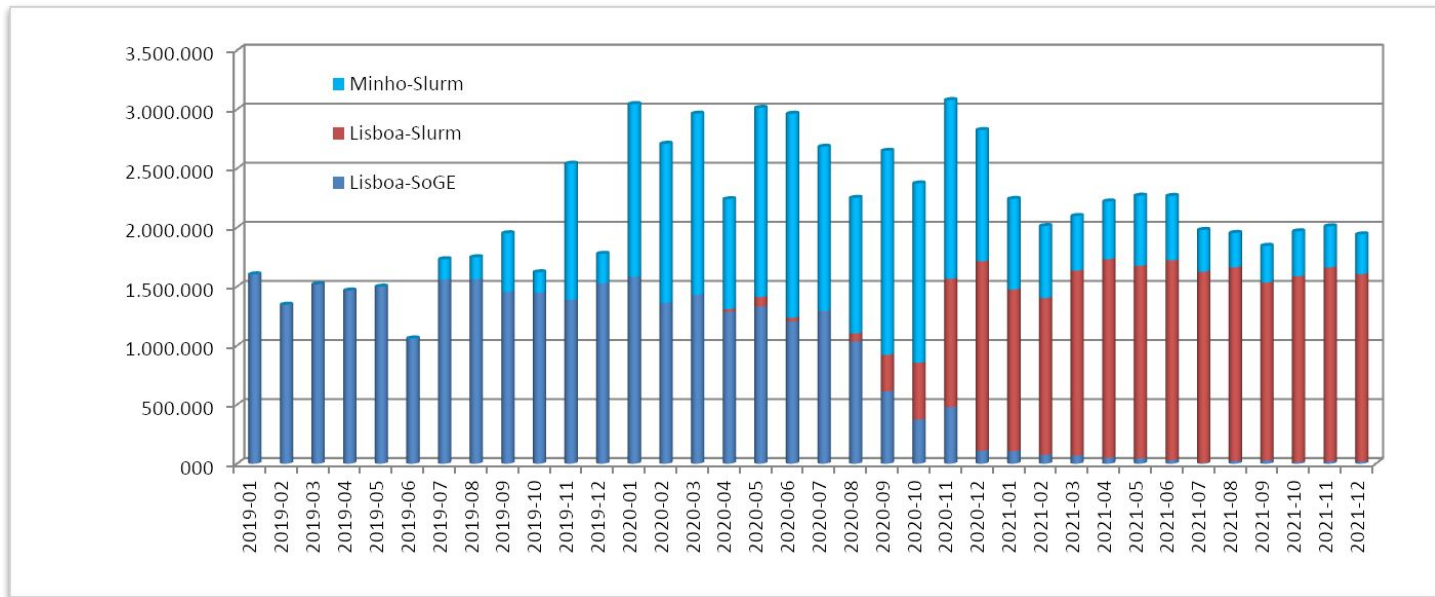
  
  
  
  

Shared computing and data services for the academic and research communities

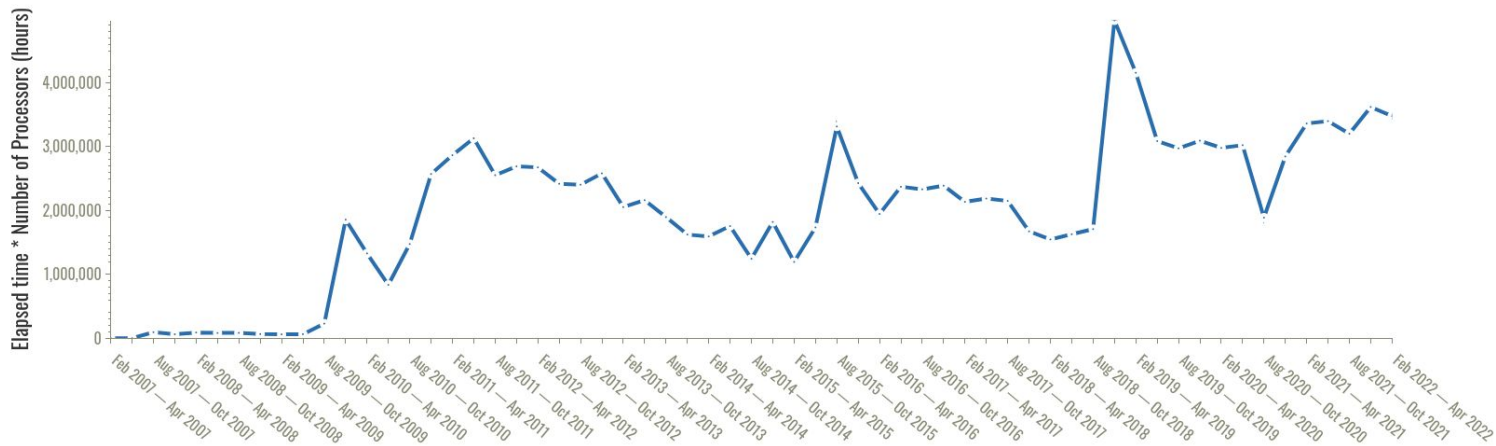
**LIP | FCT-FCCN | LNEC**







**2021 batch clusters (HTC+HPC): 24.789.806 hours**



**2021 total GRID/PT usage: 13.500.265 hours**



# Portugal and CERN



- Portugal joined CERN as a Member State in 1986
- The Laboratório de Instrumentação e Física Experimental de Partículas (LIP) was created at the same time to carry out all activities related to experimental particle physics, involving researchers coming from universities as well as LIP's own scientific staff
- Strong participation in LHC (ATLAS, CMS) and non-LHC (CLOUD, COMPASS, ISOLDE, nTOF) programme and strong partner in the GRID
- Strong participation in R&D programmes for medical application (Clear PEM, PET consortium)
- Training/Education:
  - Excellent example of engineer training programme
  - Very successful teacher training and outreach programmes
- Very balanced approach between contributions at CERN and investments at home and very good industrial relations



# Contributions to the ATLAS and CMS experiments at LHC



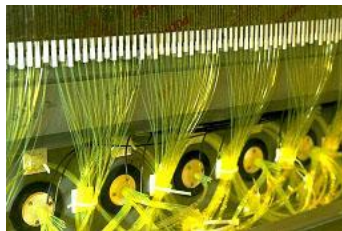
LIP is a member of ATLAS since 1992



Major role in the construction of the TileCal Hadron Calorimeter and Trigger/Data Acquisition system, in collaboration with industry and technology institutes



Robot for fiber insertion.  
600 000 fibers inserted in Lisbon and later in Coimbra



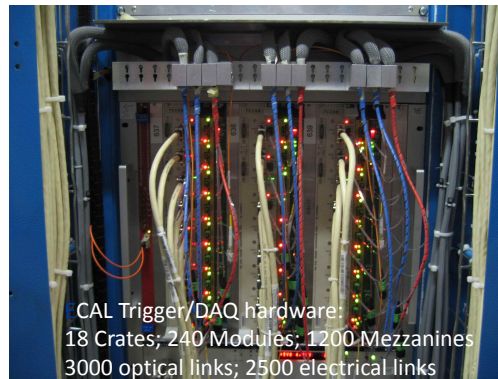
WLS optical fibers routing.  
Fiber aluminization done in Lisbon

Detector Commissioning and Operation  
Data analysis

LIP is a member of CMS since 1992



Major role in the construction of the Trigger and Data Acquisition of the Electromagnetic Calorimeter, in collaboration with industry and technology institutes



CAL Trigger/DAQ hardware  
18 Crates; 240 Modules; 1200 Mezzanines  
3000 optical links; 2500 electrical links

Detector Commissioning and Operation  
Data analysis



# Portugal and CERN



- Over 200 PT participants in the Engineer Traineeship program
- Over 700 PT/PALOP participants in the High School Teachers School at CERN
- More than 1000 PT students every year participating in the International Masterclasses on Particle Physics
- Strong participation of the PT companies in the CERN procurement
  - formal commercial offers:

