



Universidade do Minho
Escola de Ciências



LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia



The Portuguese participation in the upgrade of the Large Hadron Collider at CERN

Nuno Castro

nuno.castro@fisica.uminho.pt

POCI/01-0145-FEDER-029147
PTDC/FIS-PAR/29147/2017
CERN/FIS-PAR/0008/2017

FCT

Fundação
para a Ciência
e a Tecnologia

Lisb@20²⁰

**COMPETE
2020**

**PORTUGAL
2020**



UNIÃO EUROPEIA
Fundo Europeu
de Desenvolvimento Regional

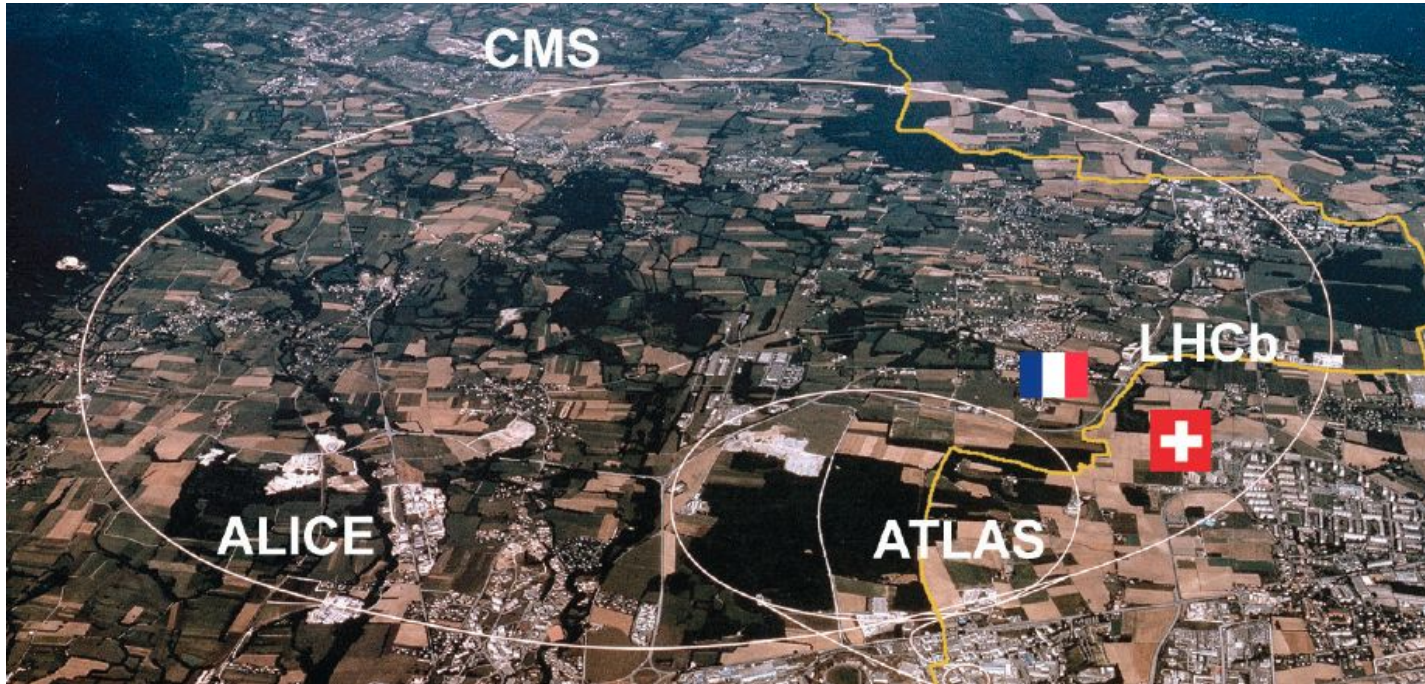
CERN

- 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



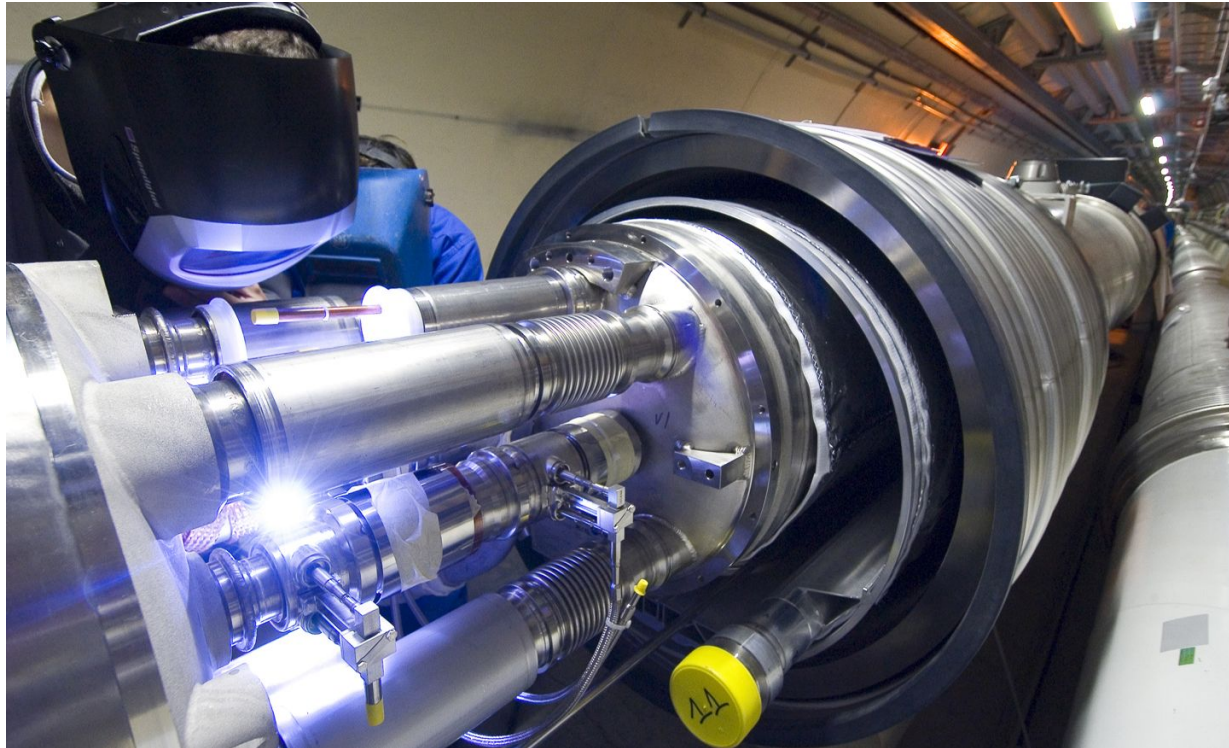
The Large Hadron Collider at CERN

one of the fastest race tracks on the planet



The Large Hadron Collider at CERN

the emptiest space in the solar system



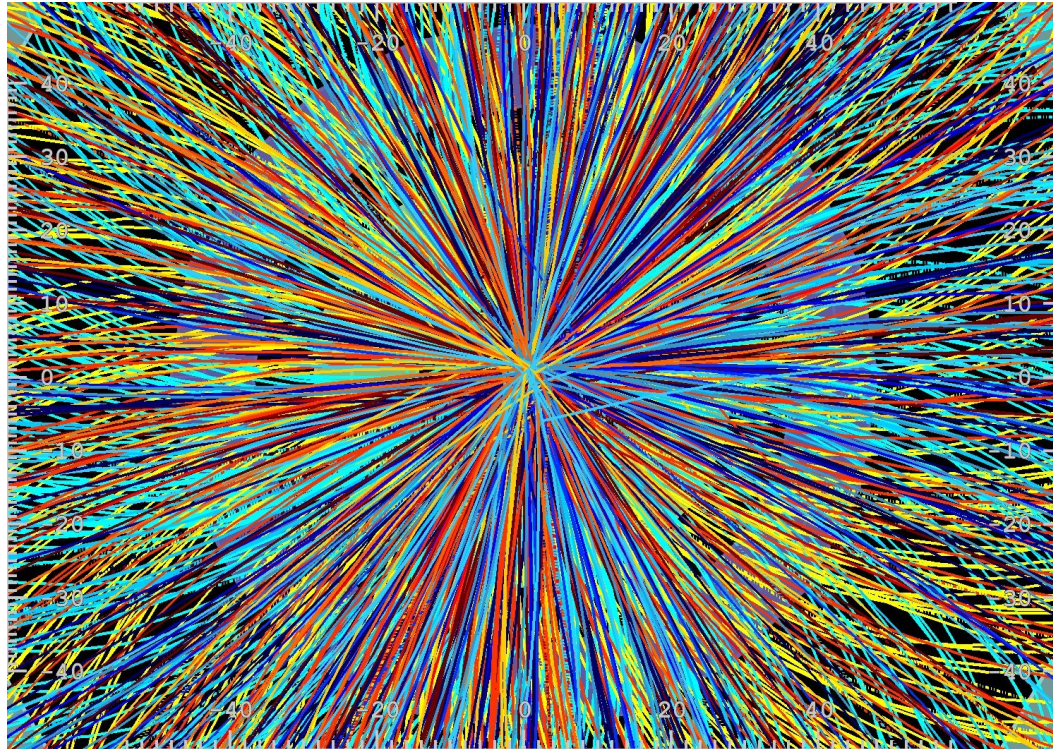
The Large Hadron Collider at CERN

one of the coldest places in the Universe



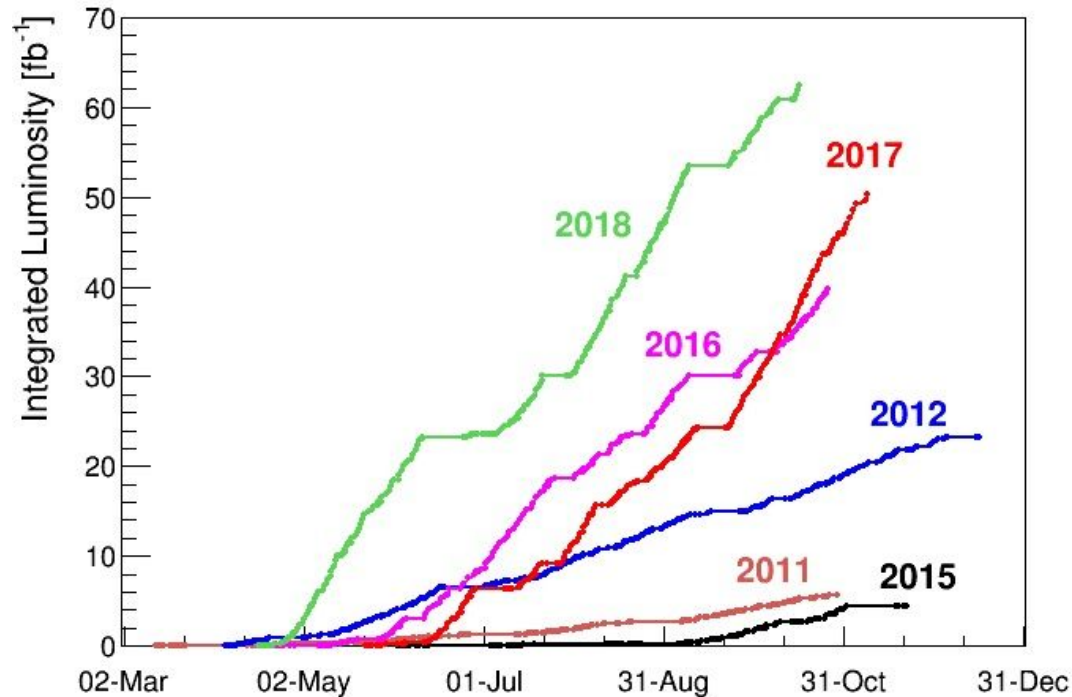
The Large Hadron Collider at CERN

one of the hottest places in the galaxy



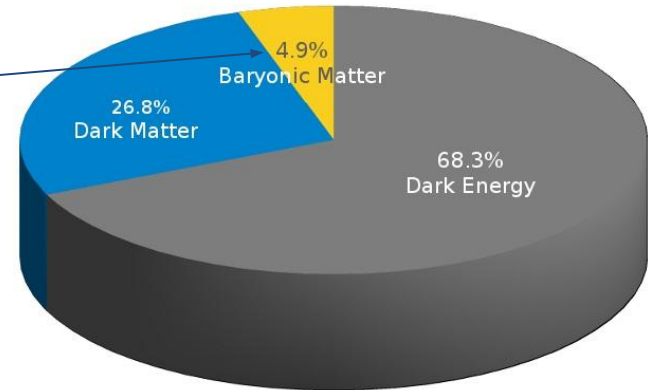
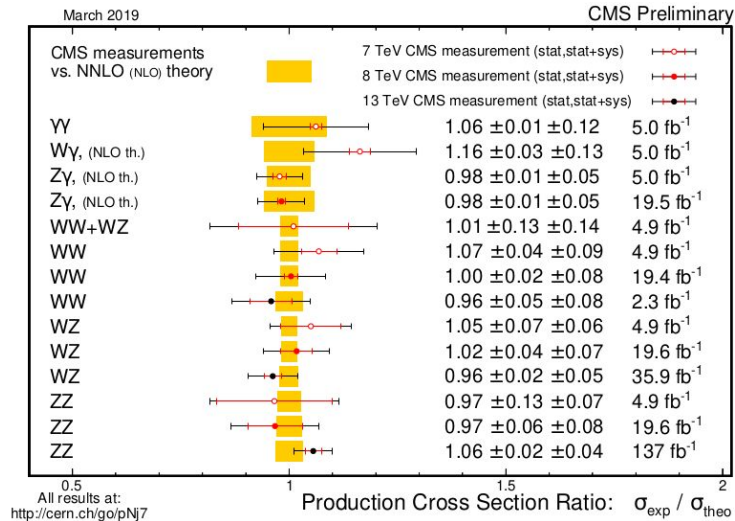
The Large Hadron Collider at CERN

A huge amount of data was collected so far



The Large Hadron Collider at CERN

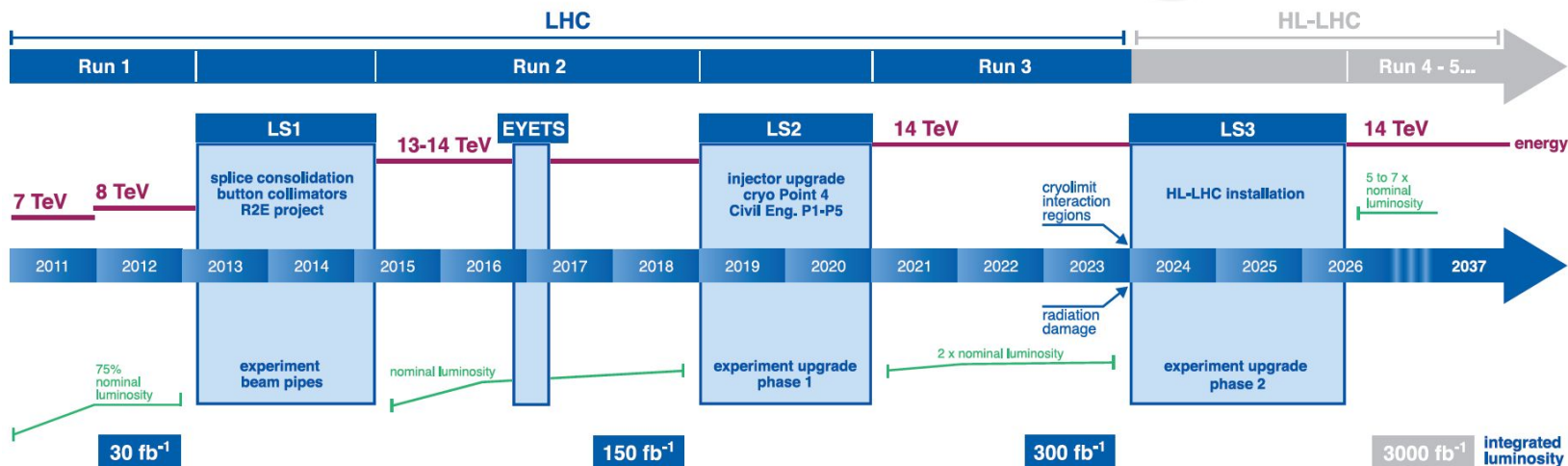
Data in agreement with theory so far - but many open questions



The Large Hadron Collider at CERN

More data needed: the high luminosity upgrade

LHC / HL-LHC Plan



The LHC at CERN

High luminosity phase



NEW TECHNOLOGIES FOR THE HIGH-LUMINOSITY LHC



2

CIVIL ENGINEERING

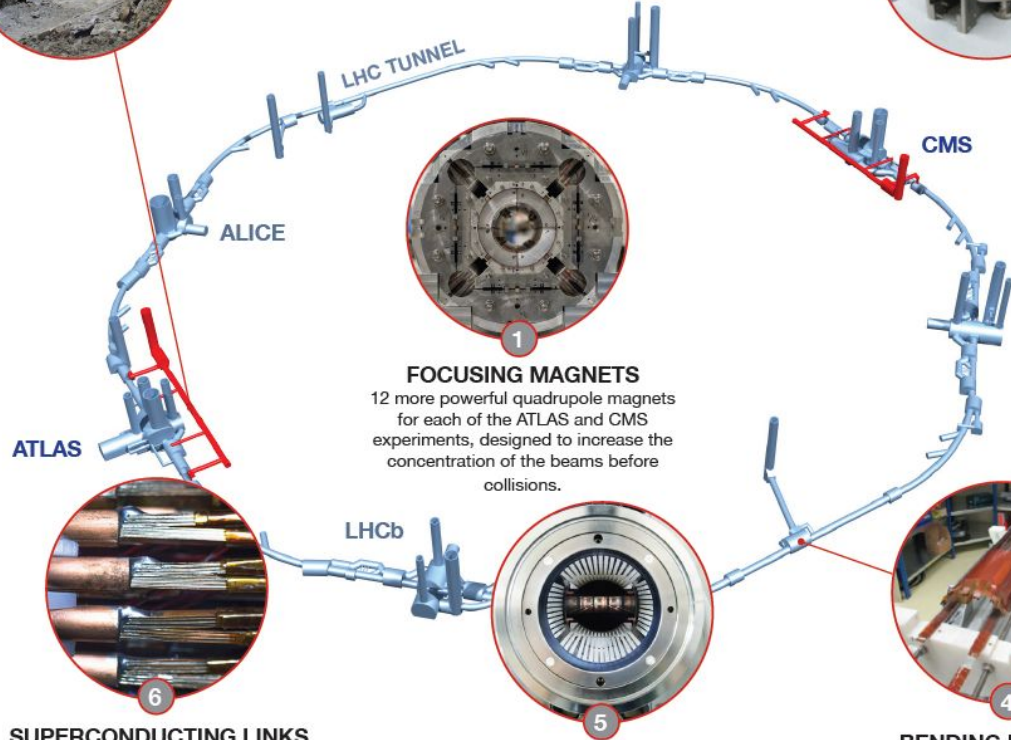
2 new 300-metre service tunnels and 2 shafts near to ATLAS and CMS.



3

"CRAB" CAVITIES

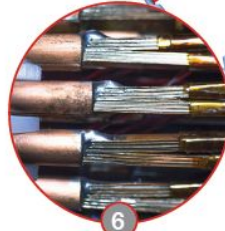
16 superconducting „crab“ cavities for each of the ATLAS and CMS experiments to tilt the beams before collisions.



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

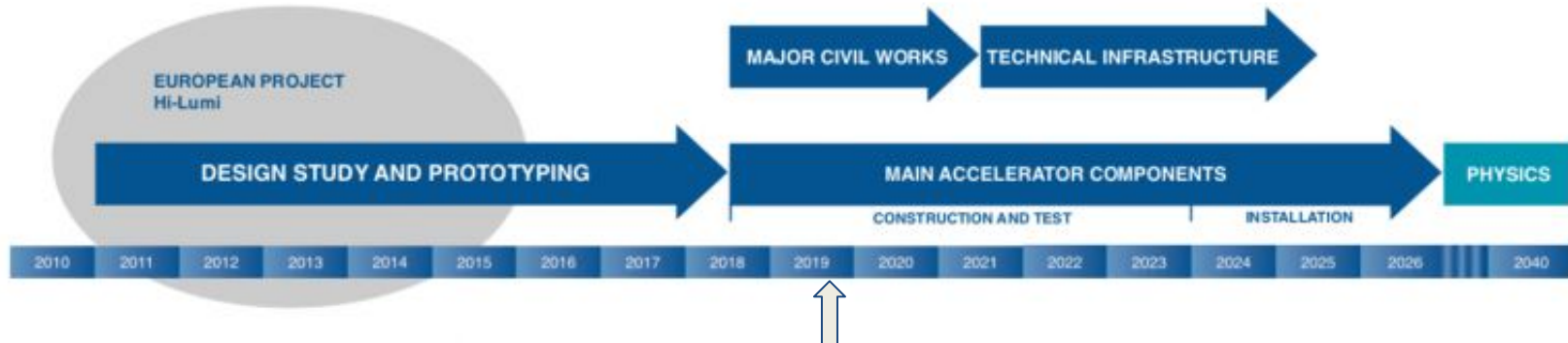
BENDING MAGNETS

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

The Large Hadron Collider at CERN

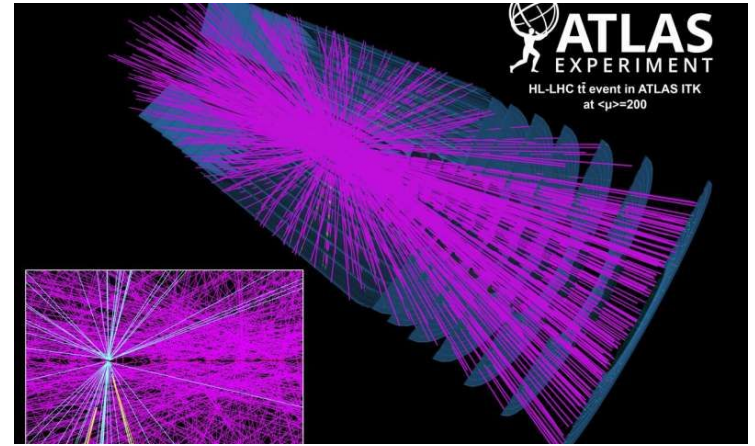
More data needed: the high luminosity upgrade

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 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/ γ at 30 GeV
- ECAL and HCAL new Back-End boards

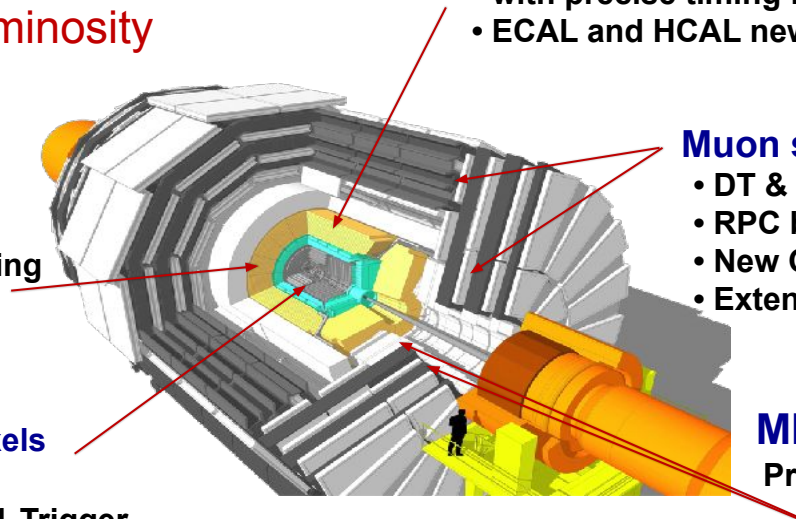
Muon systems

- 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:

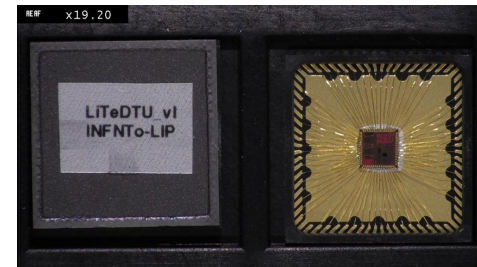
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes



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

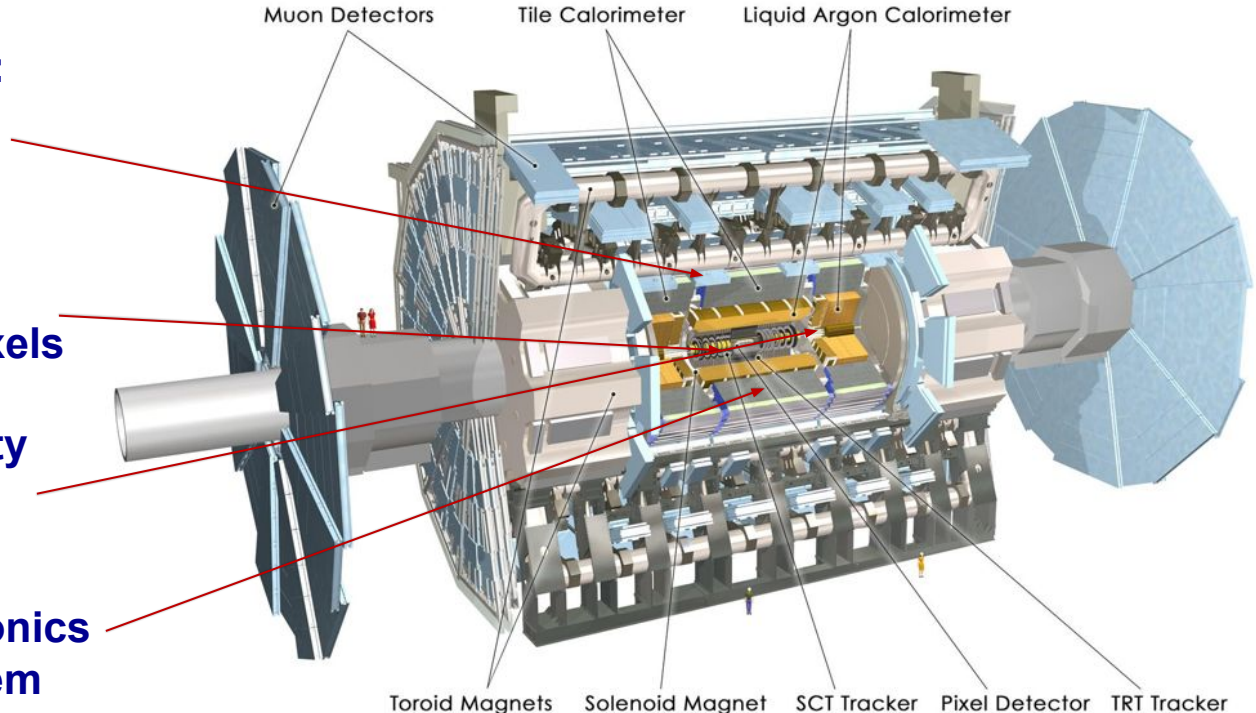
Upgraded trigger and data acquisition system

**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**



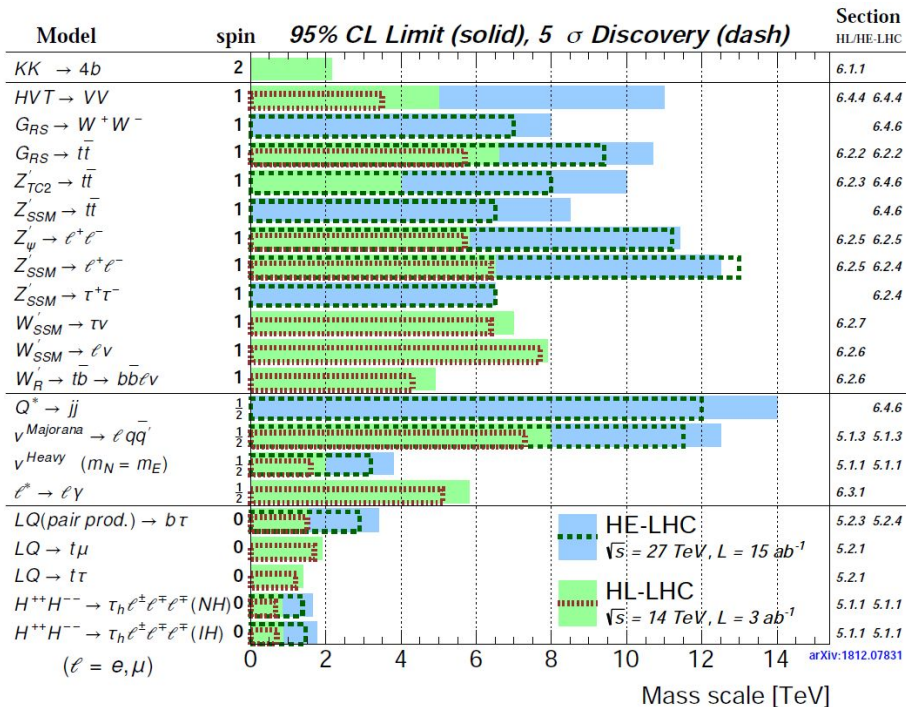
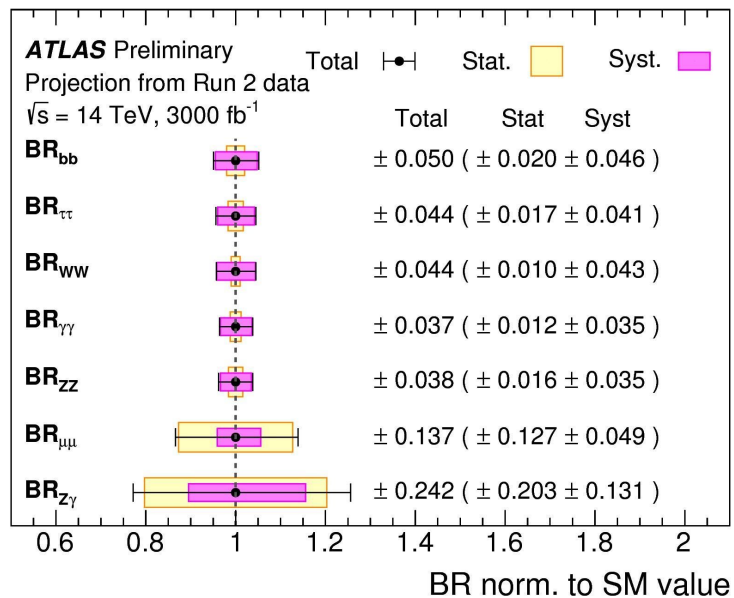
LHC - HL

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

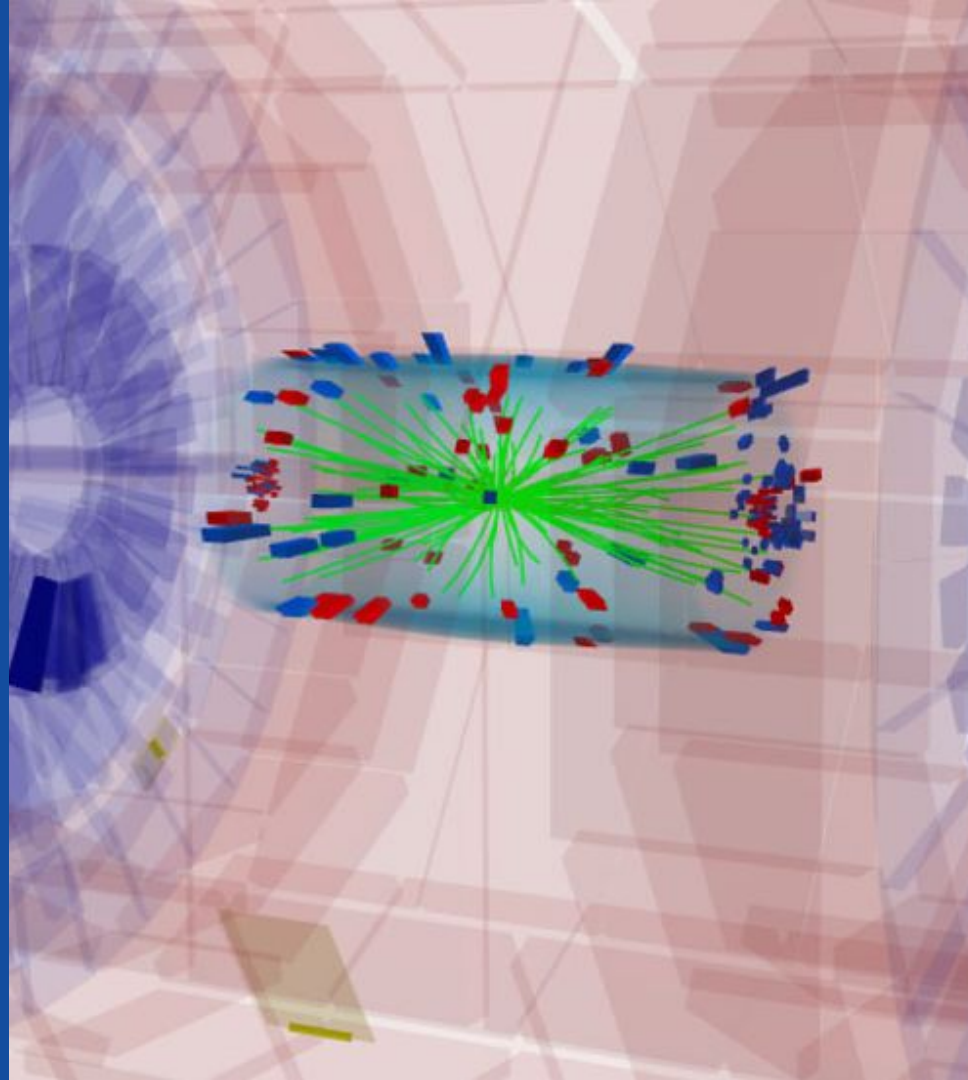
Physics goals: a few examples



summary

- Portuguese teams have been present in ATLAS and CMS since its very beginning...
- ... and are also actively contributing to the LHC-HL upgrade
 - important opportunities for the Portuguese industry - stay tuned!

thanks to João Varela (LIP/CMS-PT)
and Patrícia Conde Muíño (LIP/ATLAS-PT)



Thanks!

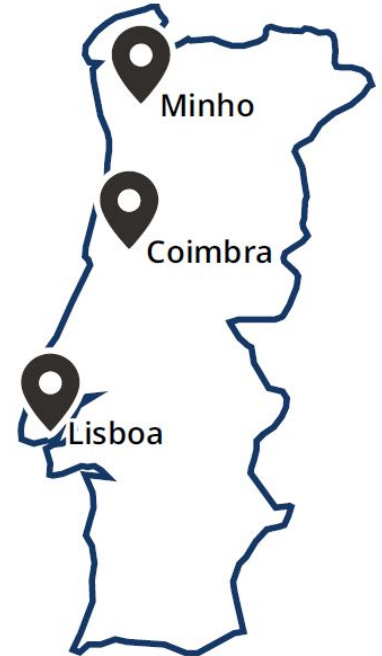
any questions?

you can also find me at nuno.castro@fisica.uminho.pt

LIP

Laboratório de Instrumentação e Física Experimental de Partículas

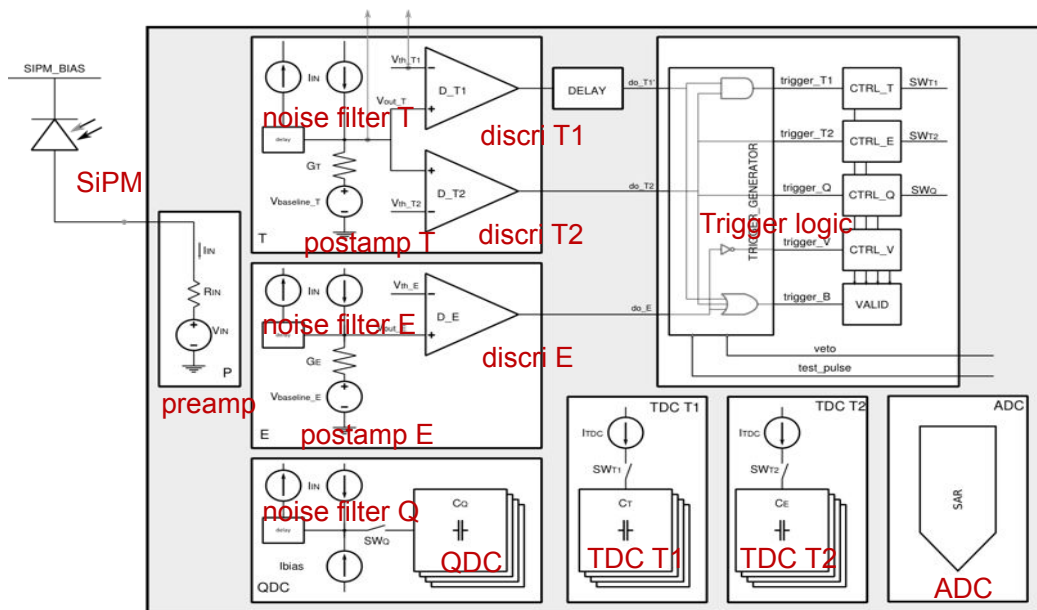
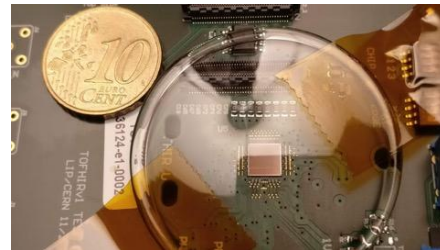
- LIP is the reference laboratory for experimental particle physics and associated technologies in Portugal
- LIP exists for the discovery of the fundamental laws of the Universe, ensuring the full participation of the Portuguese scientific community in this endeavour, and to share this knowledge with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



CMS upgrade

TOFHIR ASIC

Developed by LIP in
collaboration with PETsys

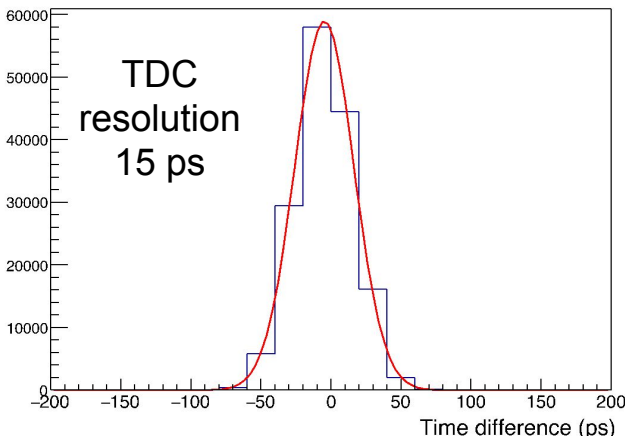
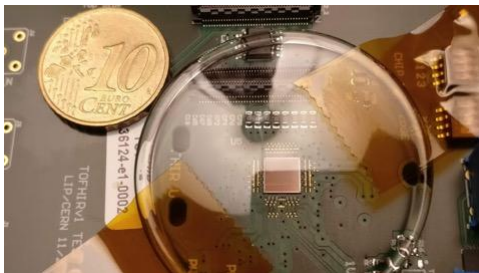


- TOFHIR1 (UMC 110 nm):
 - Available
- TOFHIR2 (TSMC 130 nm):
 - MPW submissions in Q4 2019 and Q4 2020
 - Engineering run in Q2 2021

	TOFHIR1	TOFHIR2
Number of channels	16	32
Technology	UMC 110 nm	TSMC 130 nm
Voltage	1.2 V, 2.5 V	1.2 V
Radiation Tolerance	No	Yes
Compatibility with IpGBT	Yes	Yes
I/O links	LVDS	CLPS
L1, L0 Trigger	Yes, No	Yes, Yes
10-bit SAR ADC (MHz)	10	40
Bandwidth (MHz)	350	350
Input impedance (Ω)	6	6
DCR noise filter	No	Yes
Number of TACs and QACs	4	6
TDC bin (ps)	20	20
Reference voltages	External	Internal
Maximum MIP rate/ch (MHz)	1	2.5
Max low E rate/ch (MHz)	3	5
Clock frequency (MHz)	160	160

CMS upgrade

Summary of TOFHIR1 tests

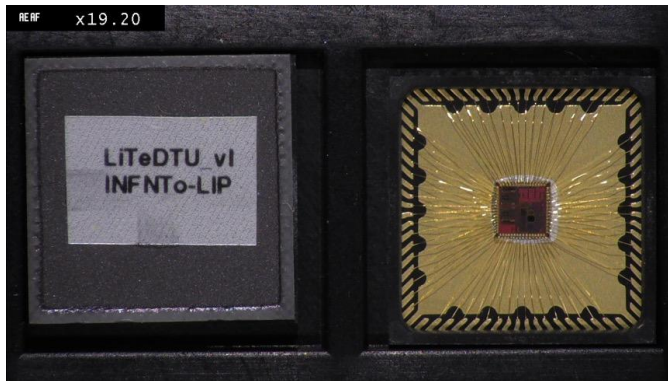


- Preliminary tests of the main TOFHIR1 blocks are concluded
 - performance is matching expectations
 - detailed characterization is on-going
- Digital logic and I/O is working
 - Configuration cycles are validated
 - Data transmission and reception are validated
- 10-bit SAR ADC is working
 - Good linearity; noise 0.8 LSB
- TDC is working
 - Time resolution 15 ps
- Amplifier pulses with SiPM and laser light match the simulation
- Single photon time resolution ~ 140 ps
- Time resolution with laser pulses ~ 20 ps
 - laser pulse 1 k p.e. (~ 10 k p.e. LYSO pulse)
 - with S12572 at OV 4V ($G=2 \times 10^5$)

CMS upgrade

ADC chip for the ECAL

- ADC ASIC for the ECAL front end electronics
 - S3group supplied IP core ADC 12-bit 160 MHz
 - Integration in ECAL LiTE-DTU ASIC (INFN-Torino) concluded and chips produced
 - Test PCB revised by S3group is now under production



ATLAS upgrade

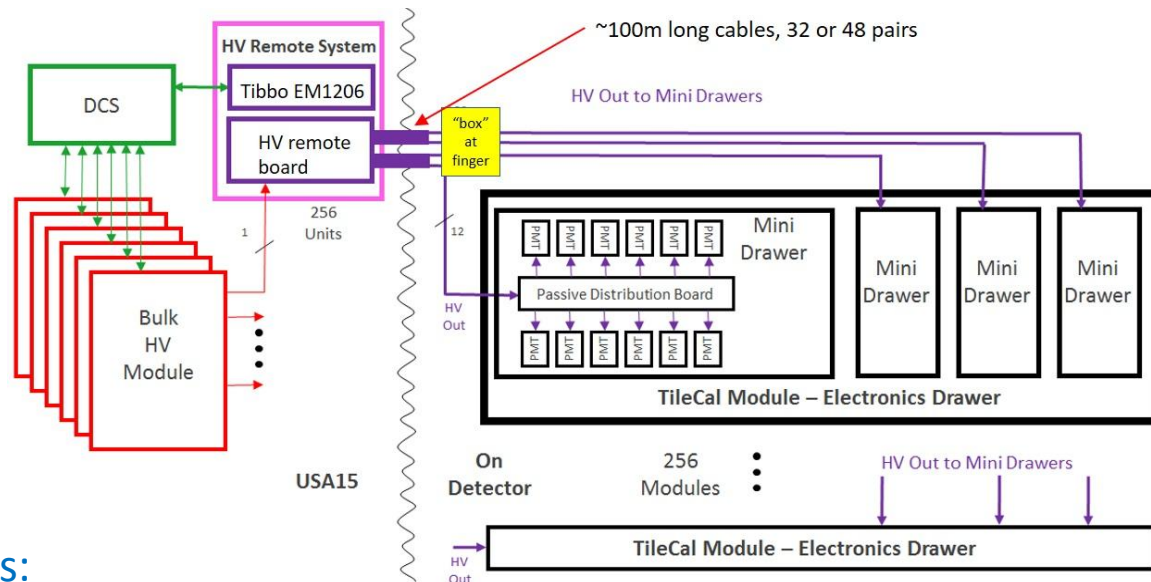
TileCal HL-LHC HV regulation system

Specifications for the HV system:

- ~10 000 PMTs,
- HV < 900 V (average ~750 V)
- Individual currents < 400 μ A
- HV stability < 0.5 V rms

Regulation and control system off detector requisites:

- easy maintenance
- no radiation
- always accessible



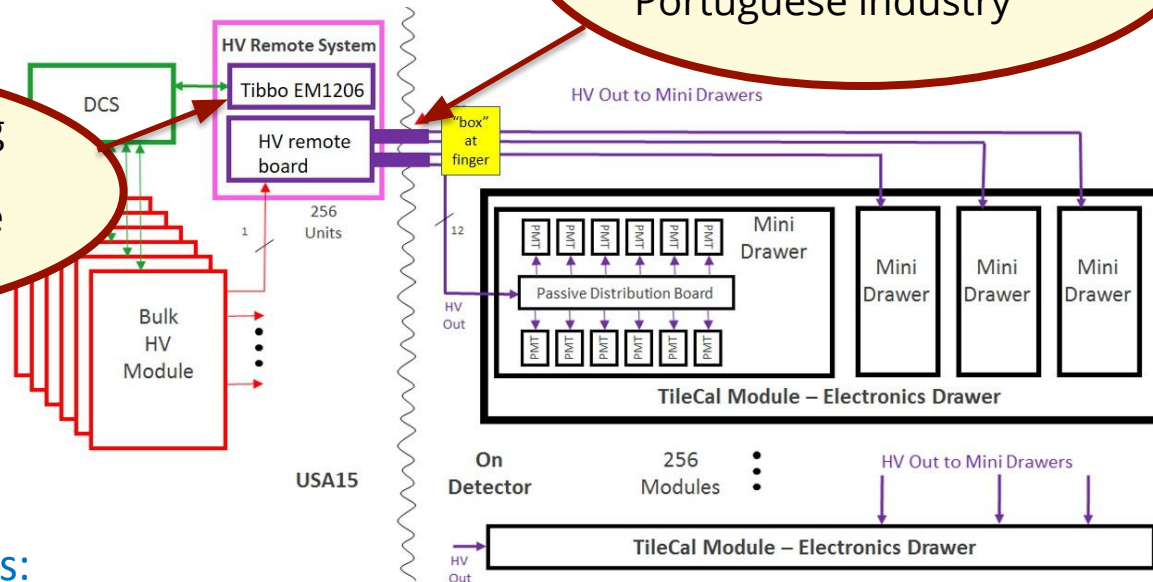
HVbus (passive distribution board) in detector

ATLAS upgrade

TileCal HL-LHC HV regulation system

Distribution boards being designed at LIP
Production in Portuguese industry

Small diameter cables with 48 and 32 pairs being developed by Portuguese industry



Regulation and control system off detector requisites:

- easy maintenance
- no radiation
- always accessible

~20 000 wires
100m long cables

HVbus (passive distribution board) in detector

ATLAS upgrade

Hardware Track Trigger

Will provide

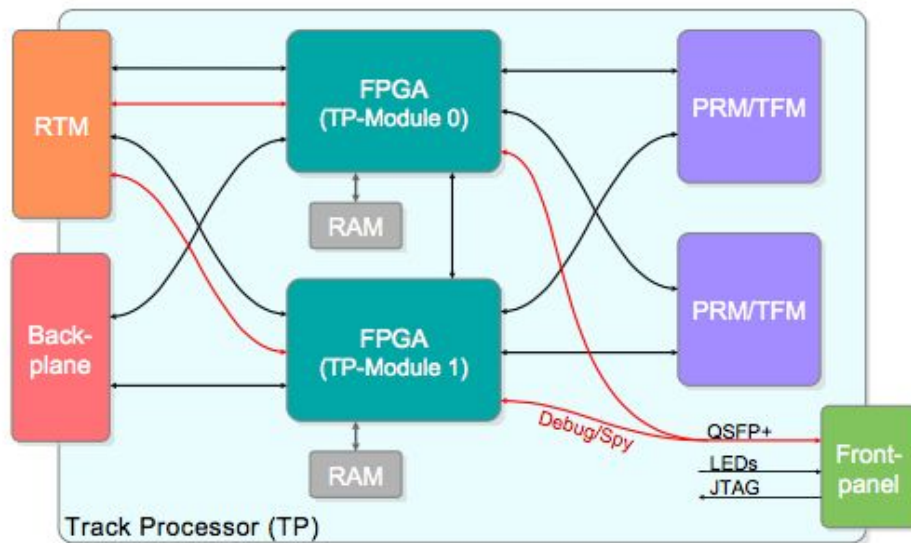
- Regional tracking at 1 MHz rate
- Full event tracking at 1 kHz rate

48 ATCA crates containing

- 576 Tracking Processors

Tracking processors:

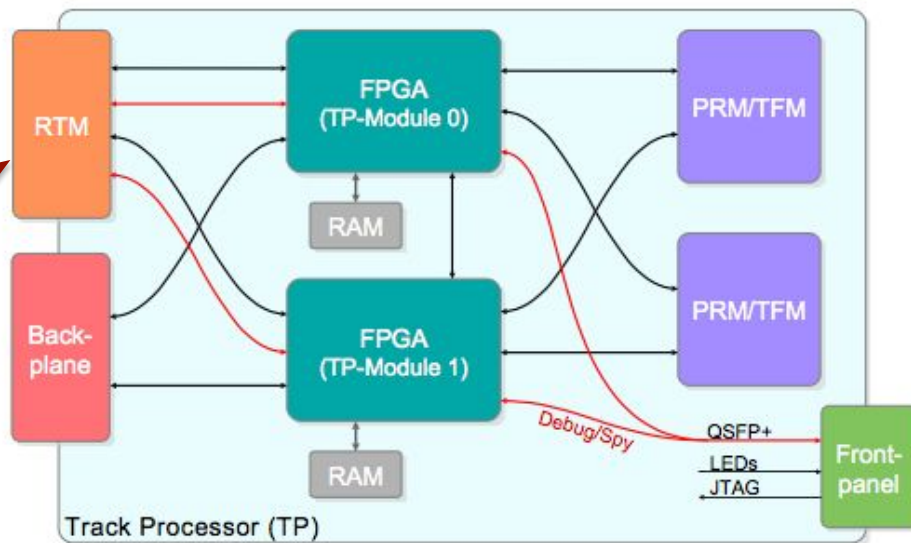
- 2 FPGAs
- Pattern Recognition Mezzanine (associative memory ASICs)
- Communication via Rear Transition Module (RTM)
 - receiving of raw detector data, sharing hits, clusters and tracks; send final tracks



ATLAS upgrade

Hardware Track Trigger

75% of the RTM to be produced in Portuguese industry
Testing and quality control at LIP



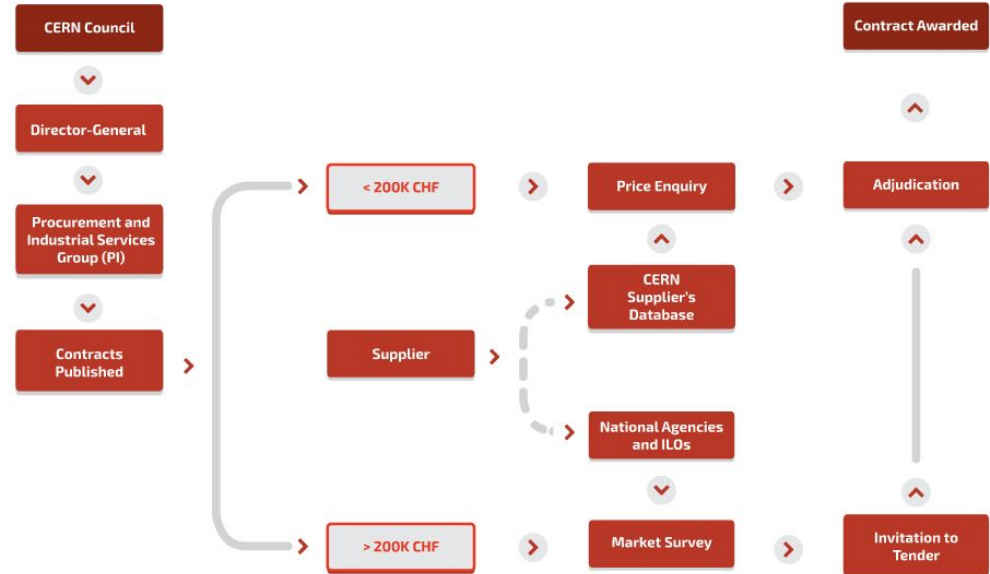
Tracking processors:

- 2 FPGAs
- Pattern Recognition Mezzanine (associative memory ASICs)
- Communication via Rear Transition Module (RTM)
 - receiving of raw detector data, sharing hits, clusters and tracks; send final tracks

CERN

Portuguese companies

- ▶ 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/>