Spain@CERN 2014

http://spain-at-cern.web.cern.ch

• CERN Particle Detectors Systems and Applications •

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CERN, October 29th 2014

• Outline •

- The LHC Context
- Particle Detectors
- Experiment's Life Cycle
- Detector Upgrades, Opportunities

- *Followed by C.Lascasta talk, detailing technologies of a specific detector upgrade project*

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- Today HEP main priority is to investigate the new energy domain opened by the Large Hadron Collider (LHC): 7+7 TeV CM energy
- To arrive there the overall HEP community has invested, as never before, in a single facility at CERN, the LHC:

Accelerator ***Detectors***

Trigger, DAQ

Data Analysis

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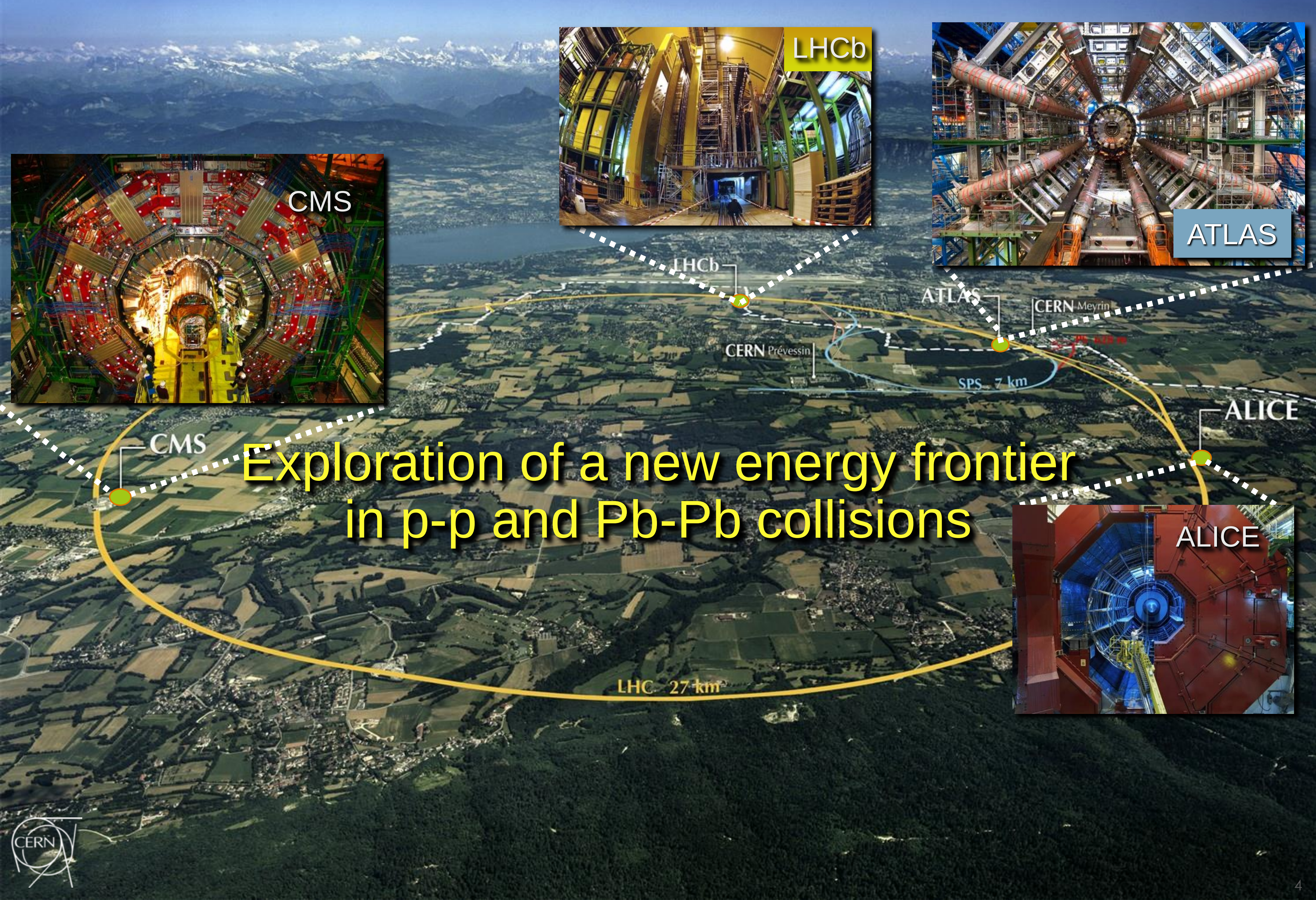
New Era in Fundamental Science



Exploration of a new energy frontier in p-p and Pb-Pb collisions

LHC Collision registered by a Detector

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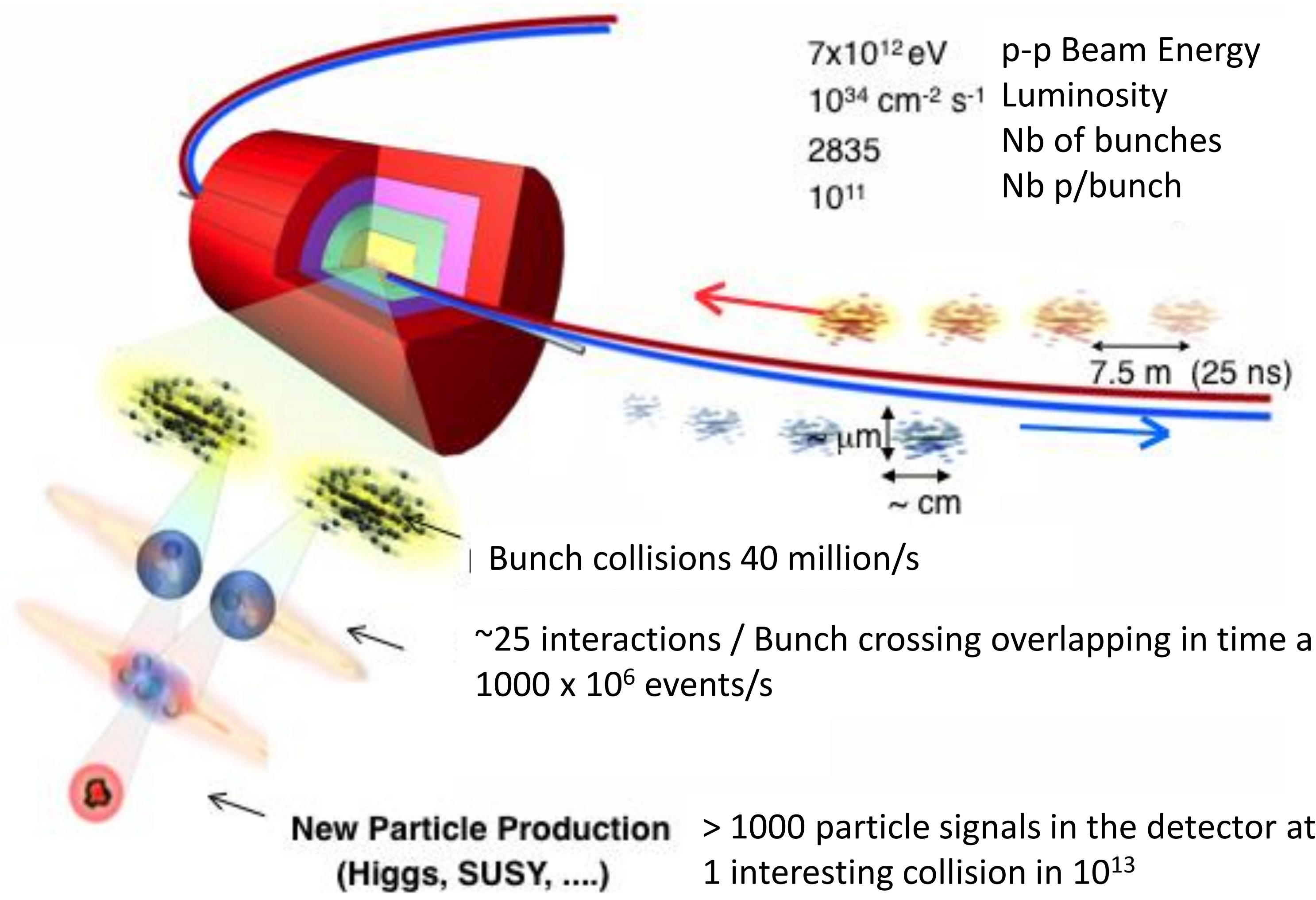
• LHC•



7×10^{12} eV	p-p Beam Energy
10^{34} cm^{-2} s^{-1}	Luminosity
2835	Nb of bunches
10^{11}	Nb p/bunch

Bunch collisions 40 million/s

~25 interactions / Bunch crossing overlapping in time and space
1000 x 10^6 events/s

> 1000 particle signals in the detector at 40MHz rate
1 interesting collision in 10^{13}

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• Very Difficult Environment•

Slide: M.Nessi, CER

- Bunch crossings every 25 ns …. Fast detector response (ns) …. Bunch crossing identification event by event in order not to mix uncorrelated energy depositions….. Readout at 40 MHz …. 1 Pbytes/sec of data produced

  At each bunch crossing ~ 20 independent events overlap ~ 1000 individual particles to be identified every 25 ns …. Interesting events have large transverse energy …. High density of particles imply high granularity in the detection system … Large quantity of data …. **Large quantity of readout services (100 M channels/active components)**

- **Large neutron fluxes, large photon fluxes** capable of compromising the mechanical properties of materials and of short-circuiting the electronics components and the semiconductors at large

- Large Magnetic Fields in large volumes, which imply usage of **superconductivity (cryogenics)** and attention to **magnetic components** (electronics components, mechanical stress, ….)

- Induced radioactivity in high Z materials (activation) which will add complexity to the **maintenance process**

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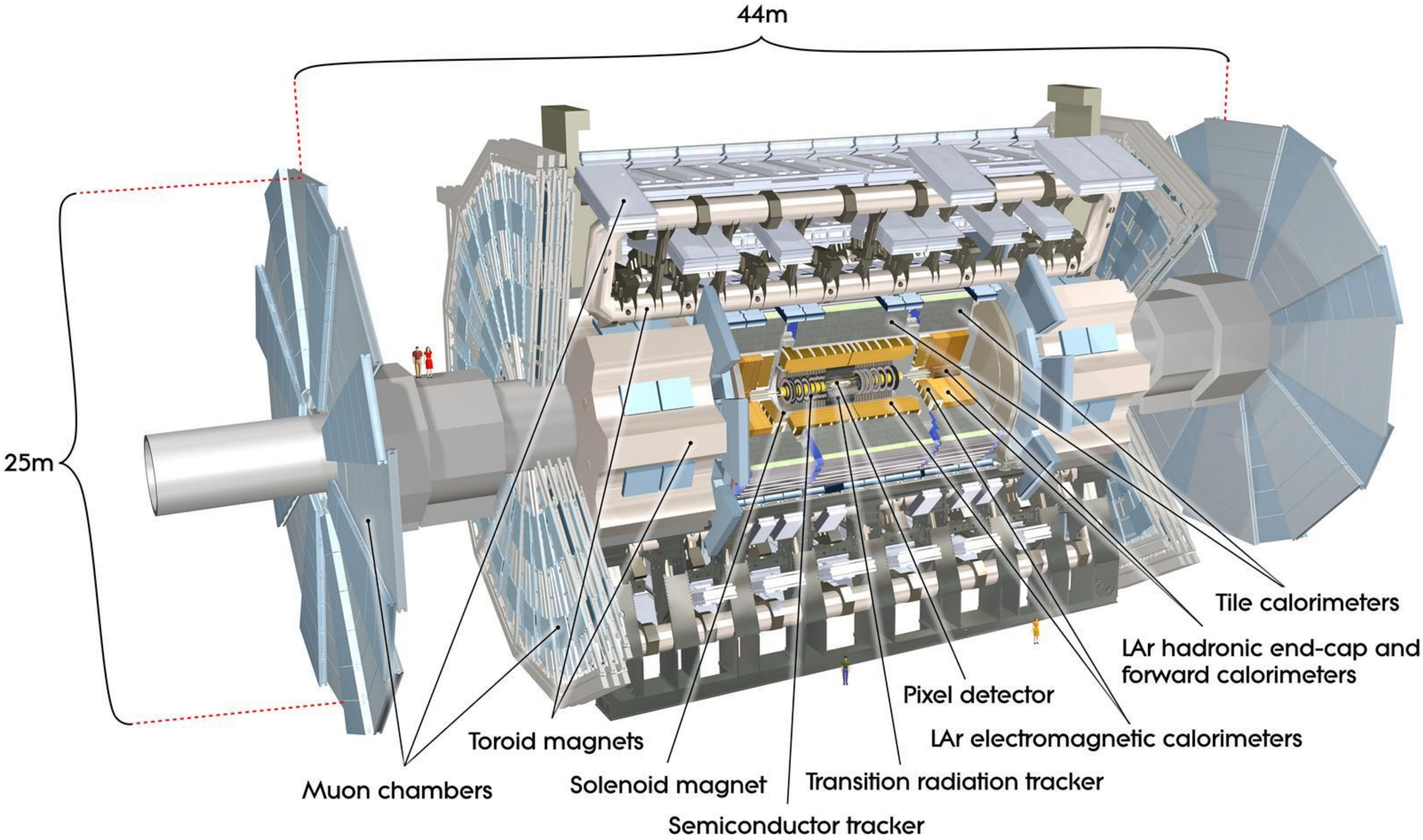
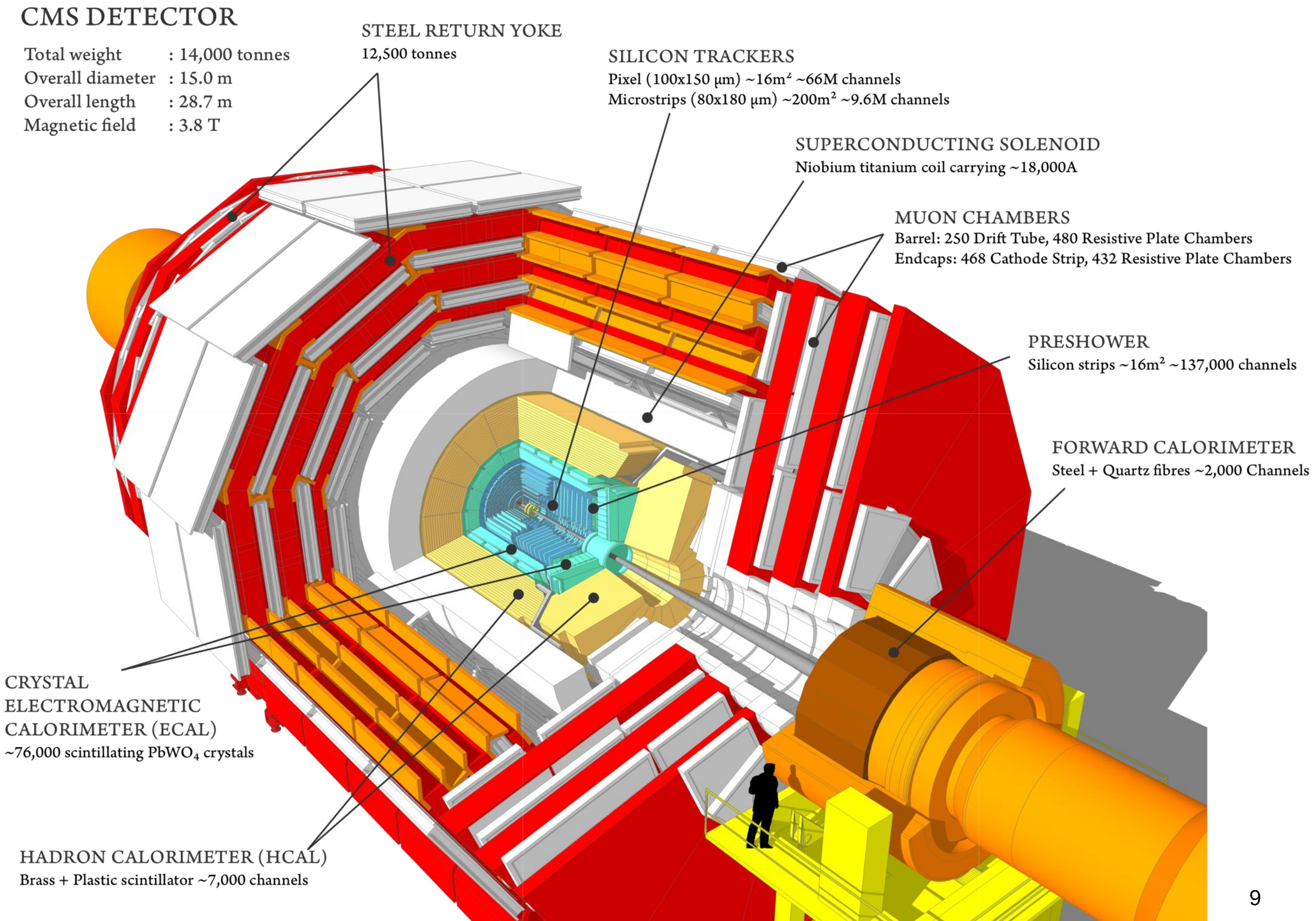
• ATLAS Detector •



CMS Detector



CMS DETECTOR

Total weight	: 14,000 tonnes
Overall diameter	: 15.0 m
Overall length	: 28.7 m
Magnetic field	: 3.8 T

STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating $PbWO_4$ crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

• Detector Technologies•

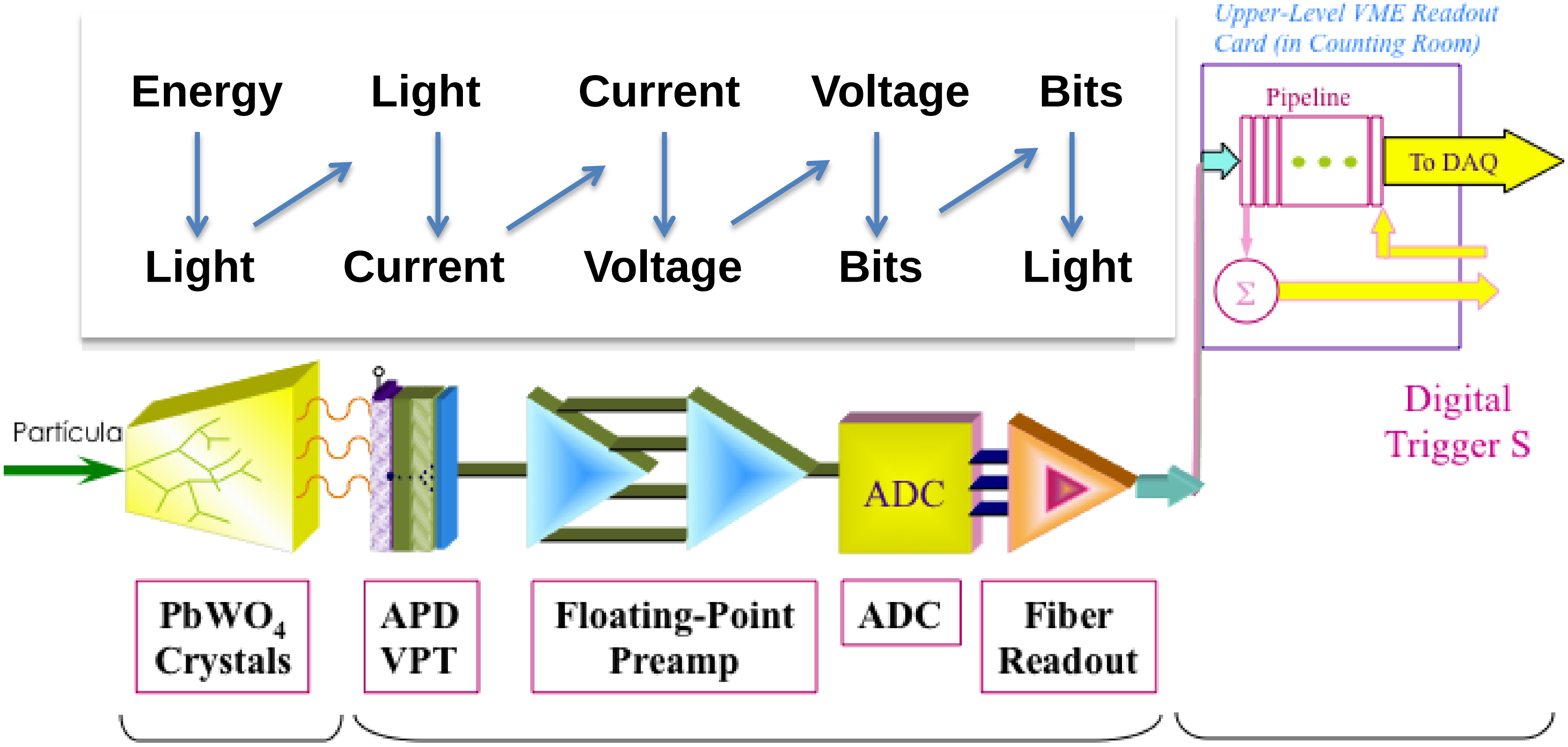
- Three effects/**detector technologies** are usually used :
  1. Ionisation
  2. Semiconductors
  3. Scintillation

  and these are used in either for tracking (and triggering), energy measurements, particle identification, etc

  How are reactions of the various particles with detectors turned into electrical signals. We would like to extract position and energy information channel by channel from our detectors

  and from then on, it is all online **(trigger, DAQ)** and offline treatment and analysis (IT) …. And **systems controls & monitoring**, **infrastructure** (detector gas, cooling systems), **safety**…

• Signals•



Energy → Light

Light → Current

Current → Voltage

Voltage → Bits

Bits → Light

Detector

Electrónica

Adquisición

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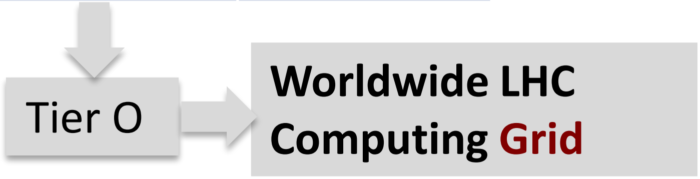
• Data Acquisition, Storage, Distribution and Processing •

Data flow and data processing is unprecedented… **as complex as the detector itself**

- Large data production (~PB/sec) versus storage capability (~GB/sec) forces huge online selection
- 3 levels of triggers (first level fully electronics based)
- Data distribution for offline processing using GRID system

Trigger	Método	Entrada Sucesos/s	Salida Sucesos/s	Factor de reducción
Nivel 1	HW (⌠, Calo)	40 000 10^3	100 10^3	400
Nivel 2	SW (RoI, ID)	100 10^3	3 10^3	30
Nivel 3	SW	3 10^3	0.2 10^3	15



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Worldwide LHC Computing Grid

• HEP Detectors•

Last generation of HEP detectors are incredibly complex and state of the art pieces of technology

- Detector systems have increased in size and complexity at least a factor 10
- Projects span over a lifetime of 3-4 decades and involve thousands of scientists

Experiment	Countries	Institutions	Scientists
ALICE	36	131	~1200
ATLAS	38	177	~ 3000
CMS	42	182	~ 3000
LHCb	16	65	~ 700

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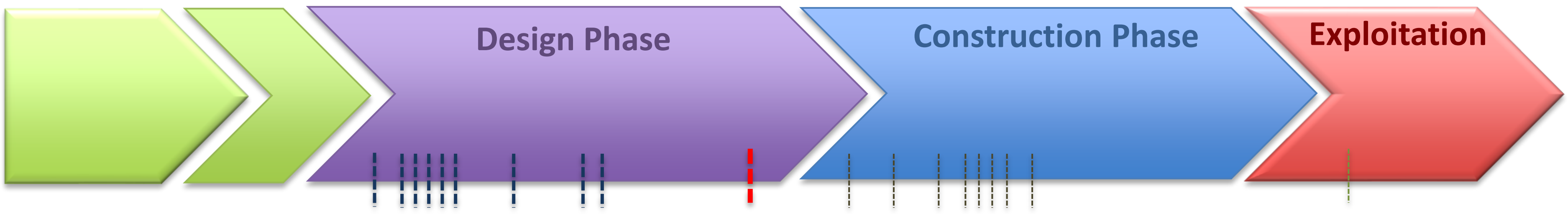
Experiment's Cycle

Expression of Interest
EoI

Letter of Intent
LoI
Ex ATLAS 1992

Memorandum of Understanding
MoU

M&O MoU
Ex ATLAS 2003



R&Ds

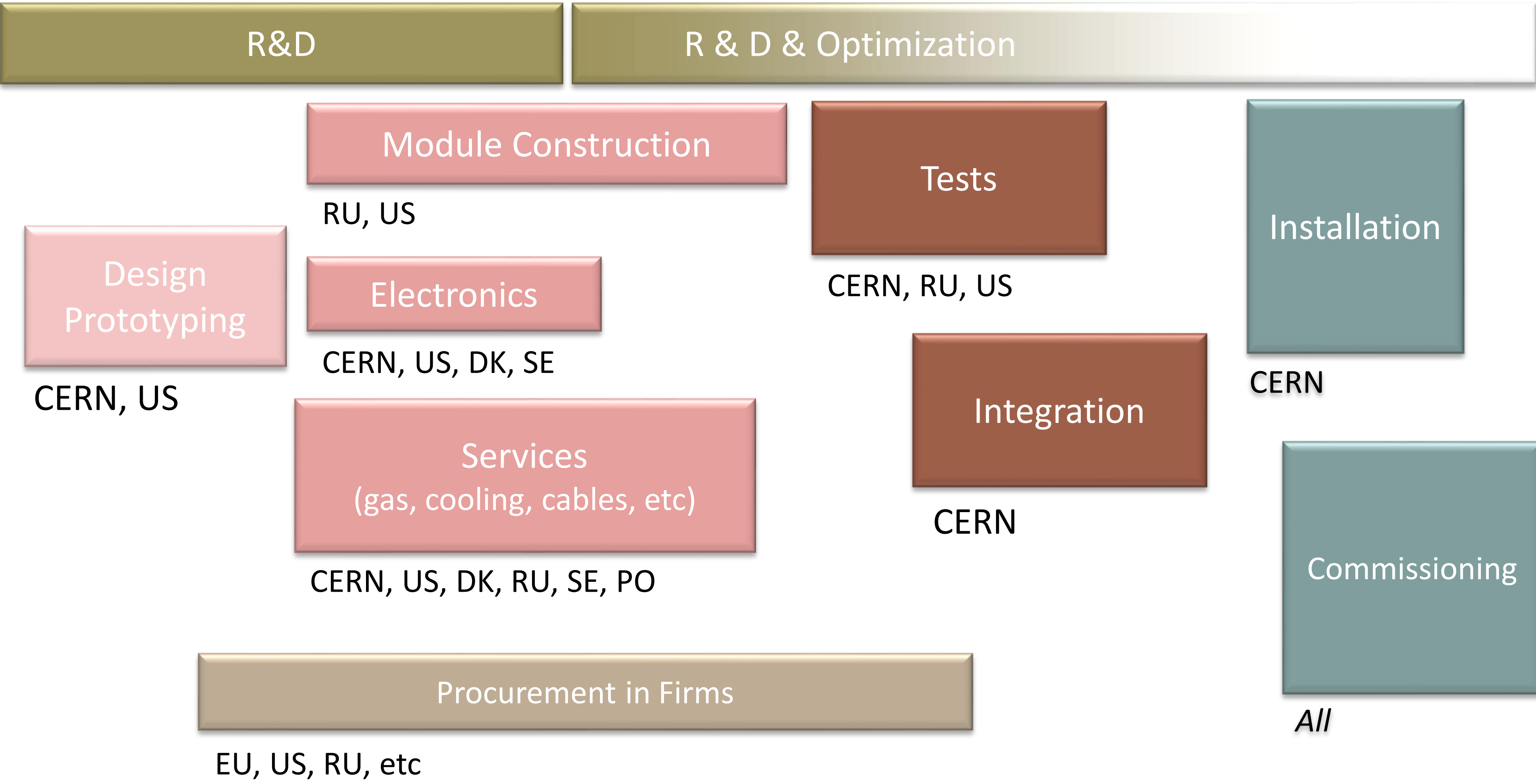
Technical Proposal
TP
Ex ATLAS 1994

Technical Design Reports
TDR
Ex ATLAS, from 1996

Beam
2008

• Distributed/Collaborative Projects •

(Large LHC Detector Subsystem Example Case)



R&D

R & D & Optimization

Design Prototyping

CERN, US

Module Construction

RU, US

Electronics

CERN, US, DK, SE

Services (gas, cooling, cables, etc)

CERN, US, DK, RU, SE, PO

Procurement in Firms

EU, US, RU, etc

Tests

CERN, RU, US

Integration

CERN

Installation

CERN

Commissioning

All

• Opportunities •

- The solutions and **main industrial partners are identified early** in the development cycle, as they provide the basis for a technical evaluation, costs, schedule, risk analysis
- From a national perspective it is important that researchers with detector technology expertise and industries **work together** – and with international partners – to establish competitive expertise and construction capabilities
- The early (R&D) stages are also a very productive phase for involvement and students, R&D gains, providing basis for later spin-off and also international exposure and competition
- Many of the spin-offs and educational/training aspects will be there whether the specific technology and industry **are/are not** chosen for a final implementation
- Therefore R&D for world class instrumentation involving Spanish industry should be a priority for national funding at an early stages (for **LHC upgrades means now**)

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• Cost•

(Large LHC Experiment Case)

- The **construction** was planned for 475M, increased to 540M in the end (by 2008). The latter increase was called C&I .. commissioning and integration. The CORE costs of 475 MCHF were established around 1995
- Out of this total ~43% where Common Fund items, the rest sub detectors (…some heavy part of sub detectors are common fund items –e.g. cryostats-)
- A country would pick up sub-detector items matching skill and resources, and some common fund items (or pay that part cash). In the end little was paid cash, but contributed as items.
- Estimating **R&D** at 20% seems reasonable, but no consistent overview exists (…some items are more R&D heavy than others so it varies)
- The **operation** costs are ~22 MCHF/y, paid according to number of authors. In addition the institutes contribute with hundreds of FTE for operation
- **Upgrades** are estimated to around 275 MCHF

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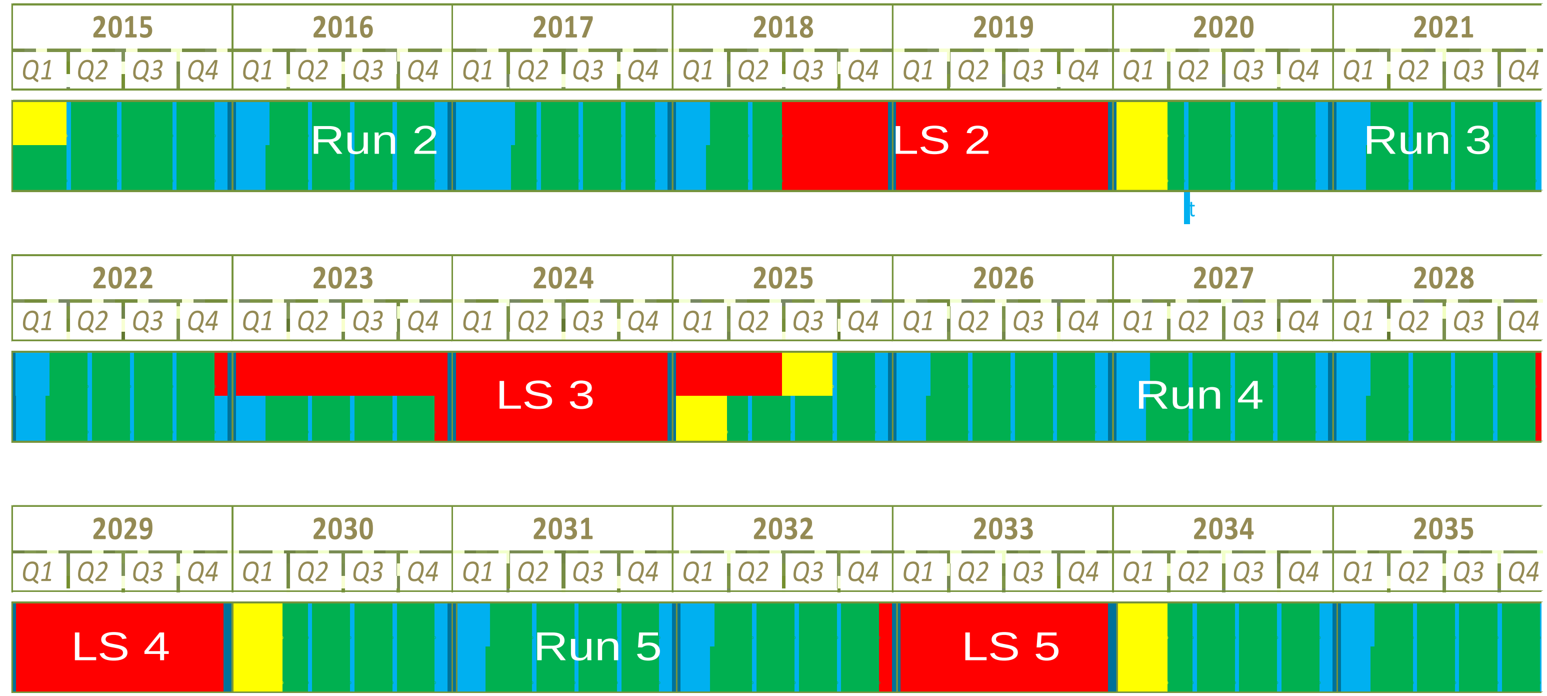
Future

CERN’s priority is the explotation of the LHC to its maximum potential… 2035

- 2008 – 2012 7-8 TeV ~ 2000 Higgs
- 2015 – 2018 13-14 TeV



LS2 and LS3

Currently, LHC Operation and R&D and construction of detectors for the Upgrade occur at the same time

LoI - R&D – TP –TDR - Construction

ALICE Upgrade targets 2018/19 (LS2)

1. LoIs approved
2. CDR and addendums to LoI with subsystems descriptions approved, TDRs are next

LHCb Upgrade targets 2018/19 (LS2)

1. LoIs approved in 2011
2. Framework TDRs & common MoU submitted in 2012
3. TDRs per subsystem submitted

ATLAS Upgrades target 2018/19 (LS2) and >2023 (LS3)

1. LoI LS2 and LS3 approved
2. 4 TDRs for LS2 submitted

CMS Upgrades target 2018/19 (LS2) and >2023 (LS3)

1. TP for LS2 submitted, TP for HL-LHC in 2015
2. Subsystems TDRs submitted (Pixel & HCAL in 2012) or being prepared for 16/17

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• Detector Upgrades •

- **Trackers R&D Efforts**
  - Improved radhard
  - Optimization of sensor thickness and geometry
  - 3D sensors and combined sensor and electronics in one chip (MAPS on CMOS)
  - On detector thermal management (CO_2)
- **Calorimeters R&D Efforts**, towards rad tolerant systems
  - Rad-tolerant crystal scintillators (LYSO, YSO, Cerium Fluoride), WLS fibres in quartz capillaries, rad-tolerant photo-detectors (e.g. GaInP), change layout of tile calorimeter using WLS fibres within scintillator, High granularity Particle flow / Imaging Gas Calorimetry…
  - *Electronics upgrades:* On-detector front-end electronics with sufficient resolution and large dynamic range
- **Muon systems R&D Efforts**
  - Improved rate capability and timing, using novel detector technologies (e.g. MPGD)
- **Electronics**
  - Development of new front-end chips to cope with increased channel densities, develop high density interconnects, optiize power distribution, develop High speed links ($\gtrsim$10 Gbps)
- **Trigger/DAQ/Offline computing**
  - New trigger strategies, processing, networks, storage, CPU, CLOUD-computing…
- **Experiments' Infrastructure**

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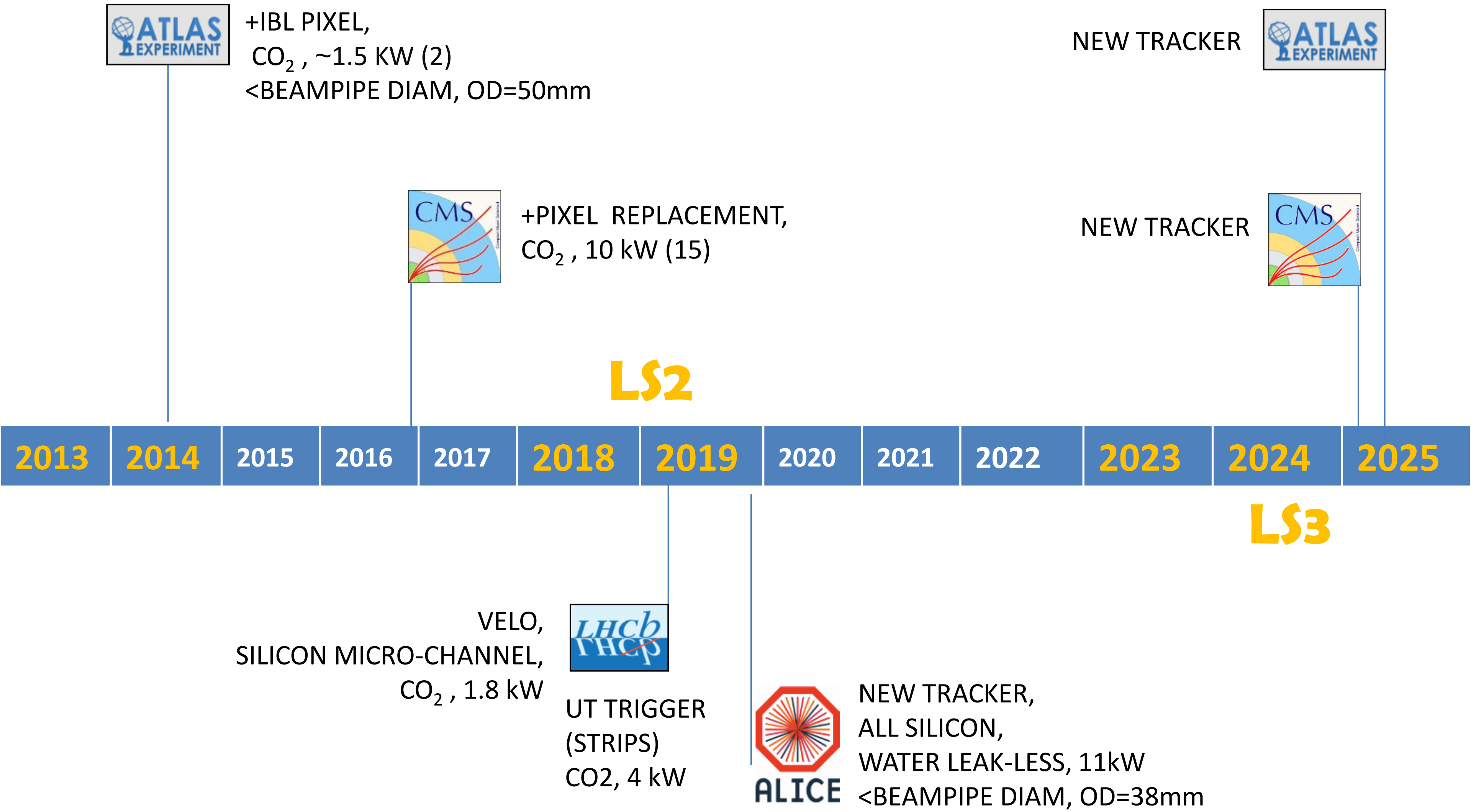
Tracker Upgrades



+IBL PIXEL,
CO$_2$, ~1.5 KW (2)
<BEAMPIPE DIAM, OD=50mm

NEW TRACKER

+PIXEL REPLACEMENT,
CO$_2$, 10 kW (15)

NEW TRACKER

LS2

2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025

LS3

VELO,
SILICON MICRO-CHANNEL,
CO$_2$, 1.8 kW

UT TRIGGER
(STRIPS)
CO2, 4 kW

NEW TRACKER,
ALL SILICON,
WATER LEAK-LESS, 11kW
<BEAMPIPE DIAM, OD=38mm

Slide: C.Gargiulo, CERN

Some CERN R&D very relevant for new detector projects

- **RD50** http://rd50.web.cern.ch/rd50/
  - Radiation hard **semiconductor devices** for very high luminosity colliders
  - 49 Institutions, with CNM Barcelona, IFAE Barcelona, IFIC Valencia, CSIC-UC Cantabria

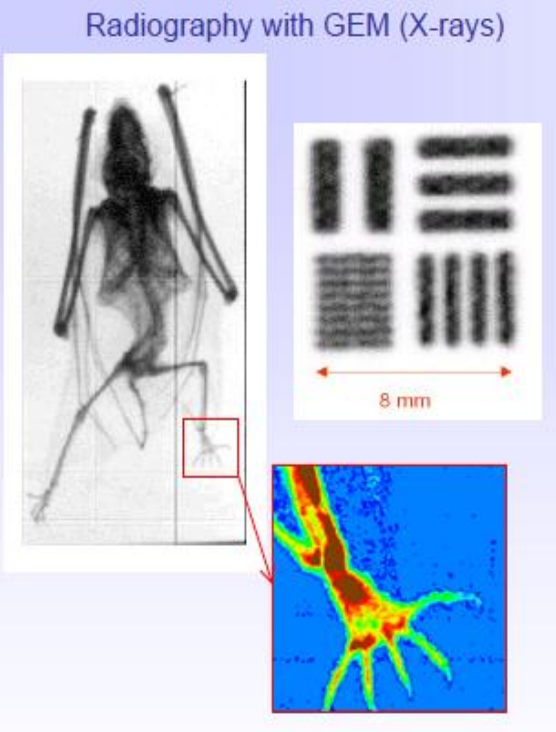
- **RD51** http://rd51-public.web.cern.ch/RD51-Public/
  - Development of **Micro-Pattern Gas Detectors** Technologies
  - 90 Institutions, with FAE (UAB), VALENCIA (IFC) neutrino, VALENCIA Uni Politecnica, Zaragoza Laboratorio de Física Nuclear y Astropartículas

- **RD53** http://rd53.web.cern.ch/RD53
  - Will develop tools and designs needed to produce the next generation of **pixel readout chips**
  - Originally 17 institutes, Universidad de Sevilla and Instituto de Cantabria recently joined

- **CERN Neutrino platform…** **ν detector R&D** e.g.2-phase large Liquid Ar TPC, muon tracking

- **Medical Physics…**

Other Fields of Application



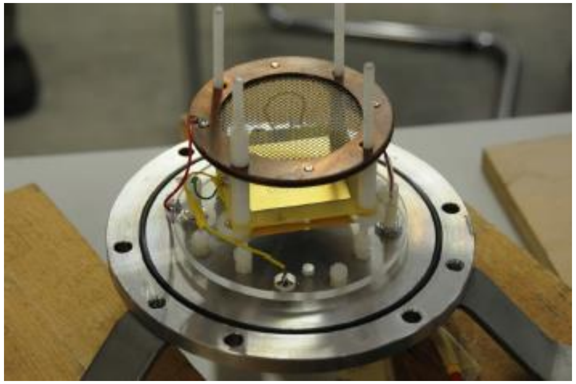
Fast and Therma Neutron Detection
Non-destructive diagnostic, Biology, Nuclear plants, …

Xray Low Energy
Radioactive waste…

Pixelated GEMs
Microdosimetry, Direct measurements with real tissue, Radon monitors….

Gamma High Fluxes
Radiotherapy…

High Intensity Beam Monitors
Hadrontherapy, Ions beam monitoring…



Highly sensitive GEM-based UV flame and ***smoke detector***

RETGEM-based detectors are able to reliably detect a 1.5 m^3 fire at a ~1 km distance

Ref. http://arxiv.org/pdf/0909.2480.pdf

• Conclusions•

- Detector development for HEP is a very linked activity between researchers and industry – leading up to MoU for construction, technical choices, costs estimates …
- Early involvement provides the best opportunity and is also the best training and development phase for young researchers and industrial partners
- **National contributions are based on the competencies and sub-detector collaborations built up during the R&D phase**
- Industrial contracts are based on tendering among qualified companies, where the qualification is happening during the R&D phase
- Investment by national funding agencies and industries are most effective if done early

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Thanks for your attention!

Spare Slides

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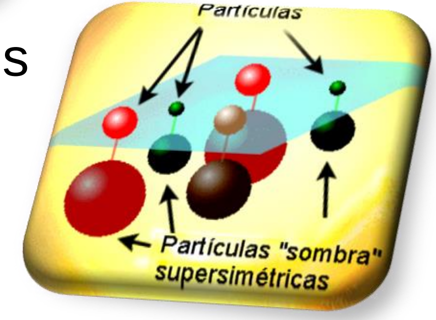
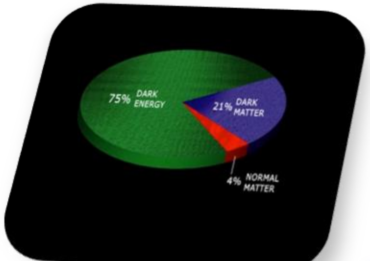
• Challenges •

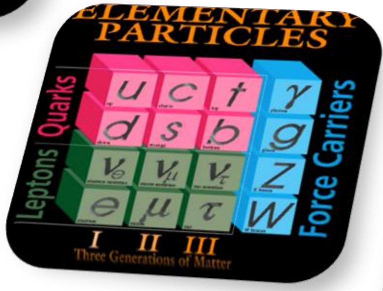
- Mass of particles: Higgs Boson(



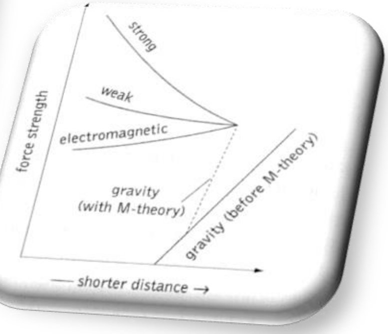
- Matter, Dark Matter: Super symmetric particles



- Matter VS Antimatter



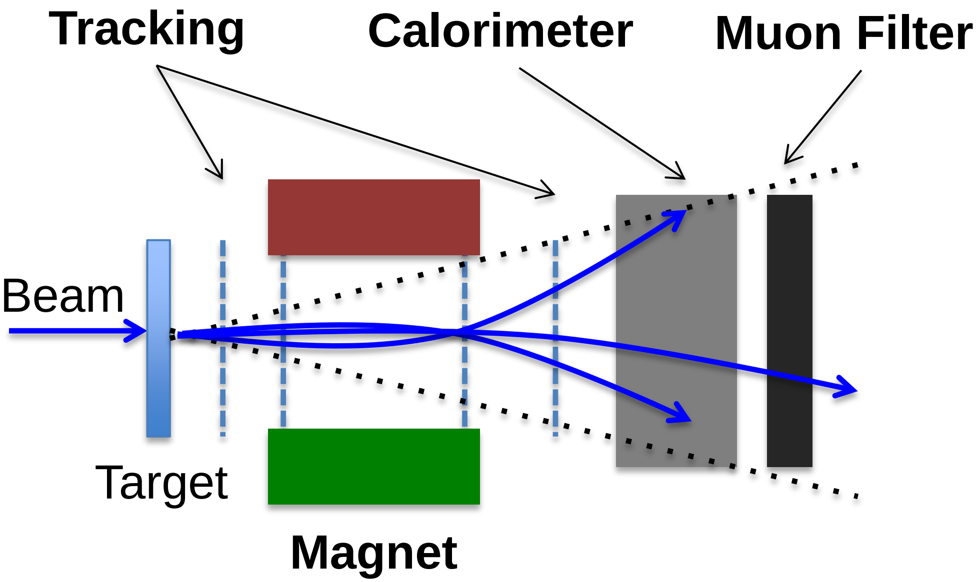
- Fundamental Particles



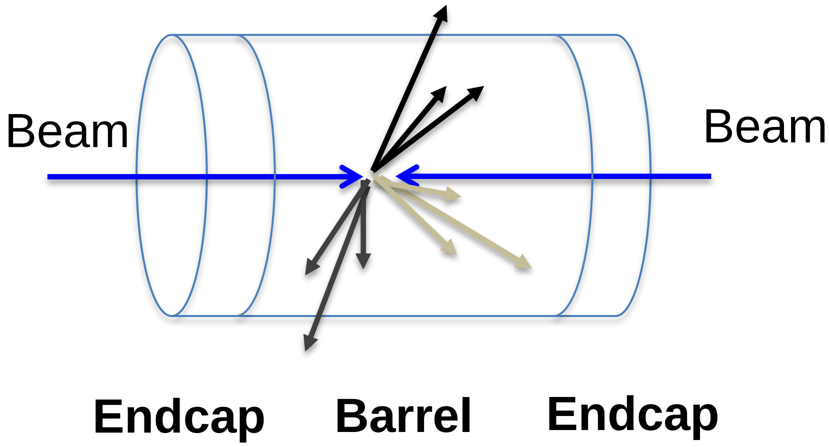
- New forces, extra dimensions…

• Detector Systems•

Fix Target Geometry



Collider Geometry



Low density → High density
High precision → Low precision
High granularity → Low granularity

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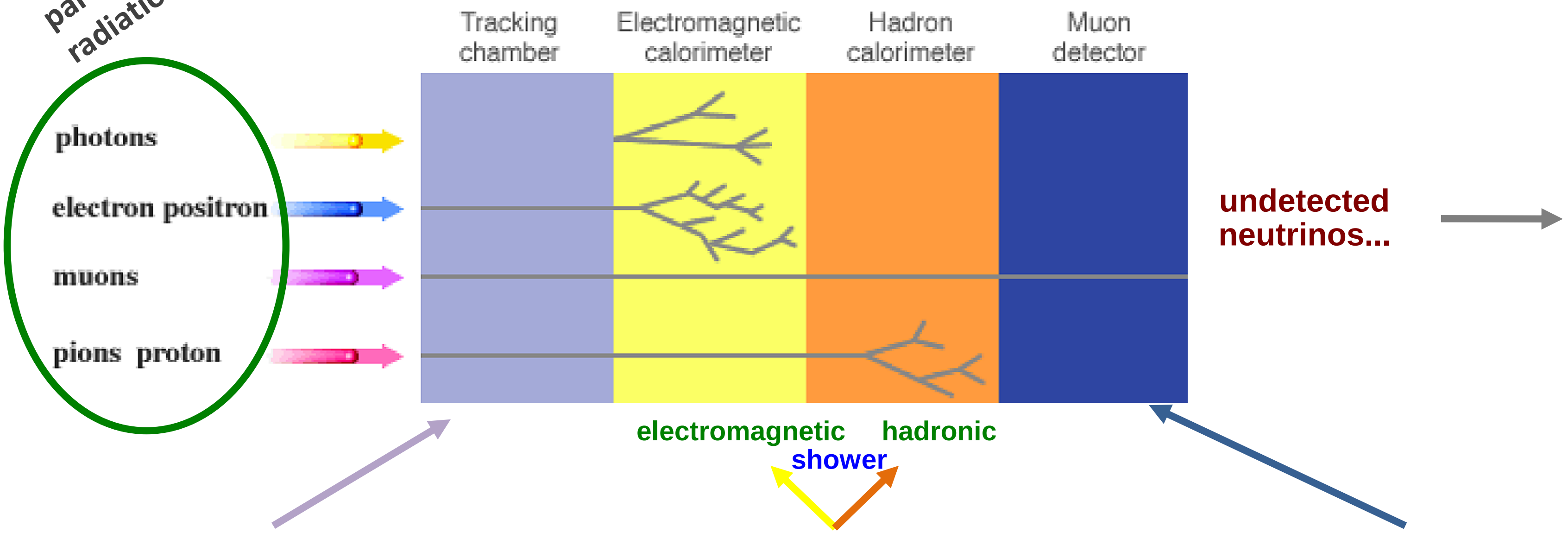
Interactions in the Detector

Many detection techniques available, chosen based on precision, fast response, particle ID capability, radiation resistance...

Low density → High density
High precision → Low precision
High granularity → Low granularity



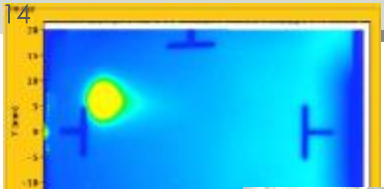
momentum measurement
by curvature in magnetic field

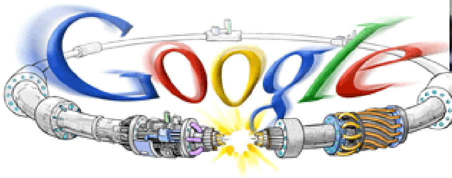
energy measurement
by creation and total absorption of showers

muon detection with improved momentum measurement (long lever arm)

3.5 TeV

August 2008
First injection test



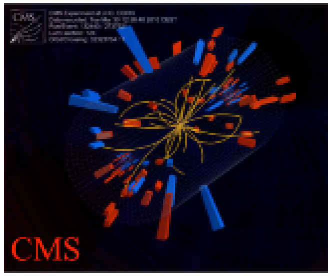


September 10, 2008
First beams around

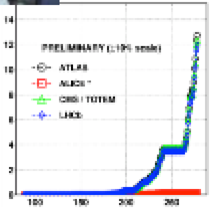
September 19, 2008
Disaster
Accidental release of 600MJ stored in one sector of LHC dipole magnets

November 29, 2009
Beam back

March 30, 2010
First collisions at

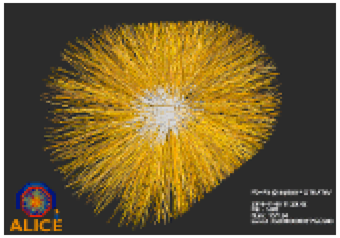


April 2010
Squeeze to 3.5 m



October 14 2010
1e32
248 bunches

November 2010
Ions



June 28 2011
1380 bunches

1380

fb-1
1380
bunches

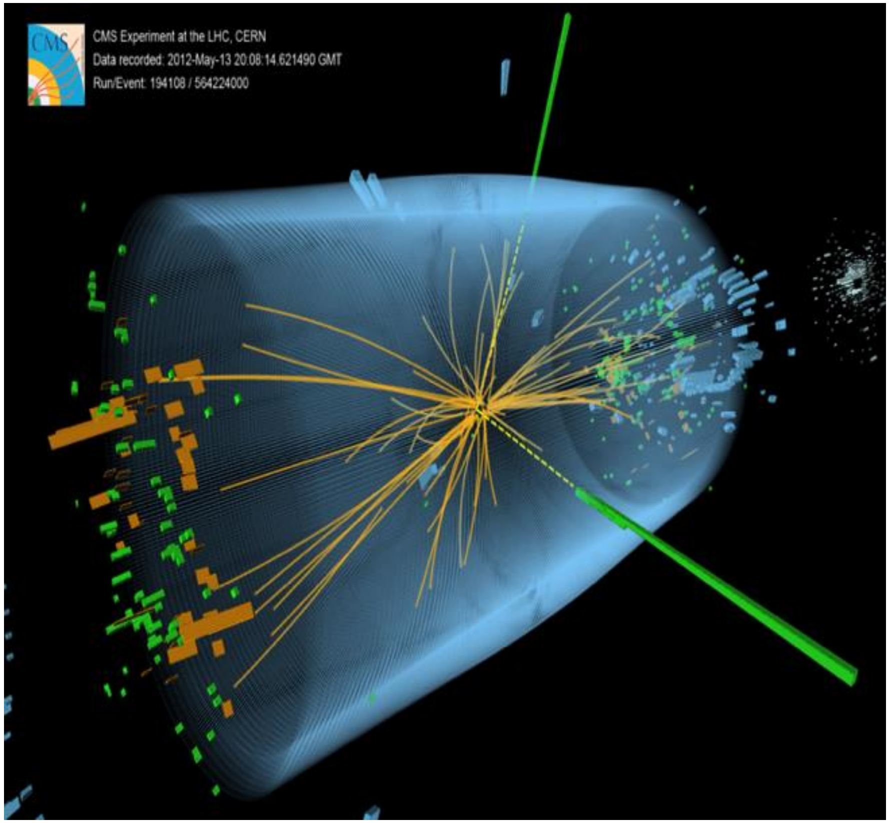
6 June, 2012
6.8e33

18 June, 2012
6.6 fb^{-1}
to ATLAS & CMS

4 July, 2012
Higgs discovery

2008 | 2009 | 2010 | 2011 | 2012

pp → H → $\gamma\gamma$



Dots = Datos

Lines = Simulation