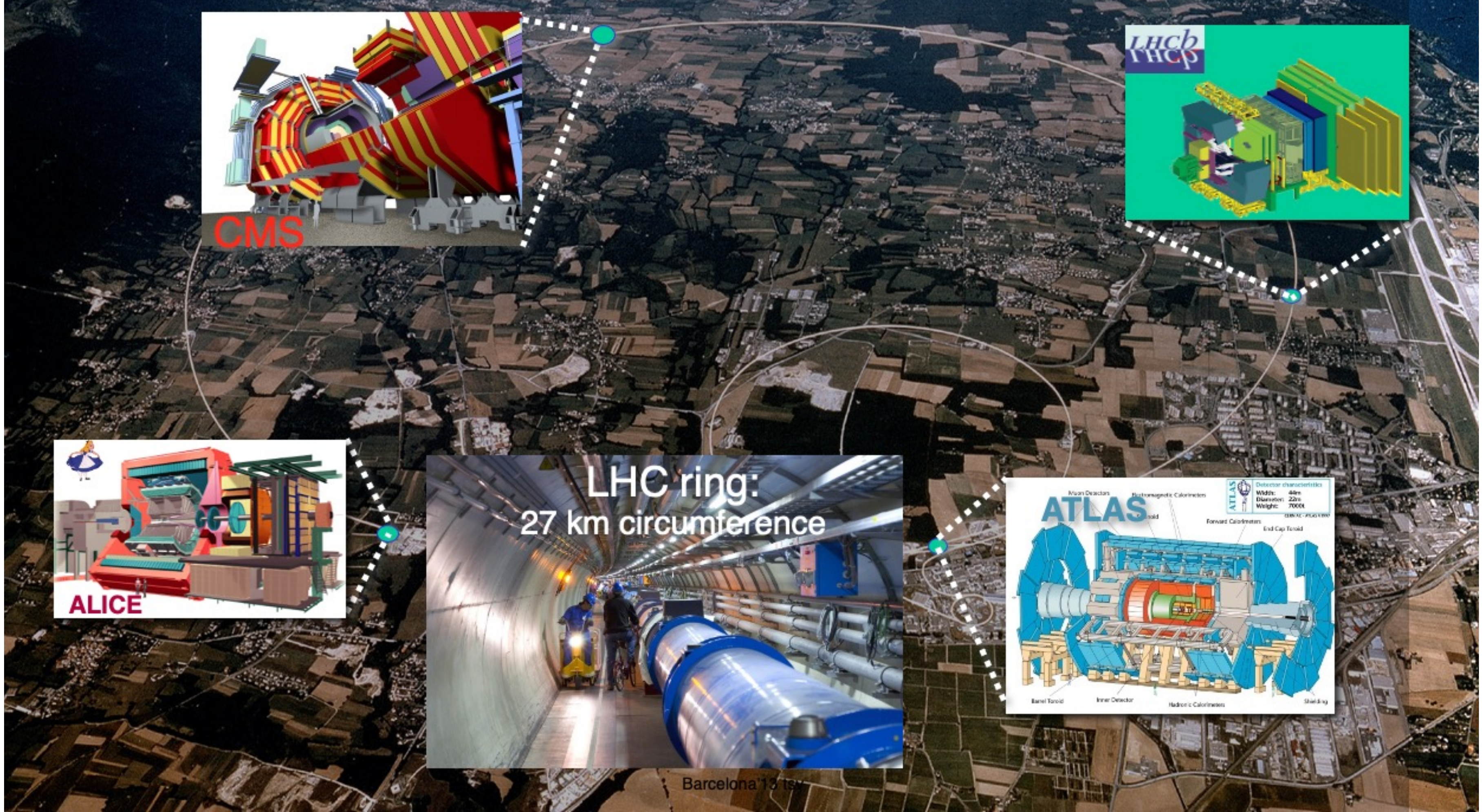
Introduction to LHC Detector Design and Construction

General-purpose (ATLAS and CMS) studying origin of mass, SUSY, …
Dedicated (LHCb) studying origin of matter-antimatter asymmetry,…
Dedicated (ALICE) studying general properties of quark-gluon fluid,…



Particle Physics

Particle physics is a modern name for centuries old effort to understand the laws of nature.

Aims to answer the two following questions:

What are the elementary constituents that make up our universe?

What are the forces that control their behaviour at the most basic level?

Experimentally:

1. Make particles interact and study the products and properties of the result of the interaction
2. Measure the energy, direction and type of the products as accurately as possible
3. Reconstruct what happened during the collision

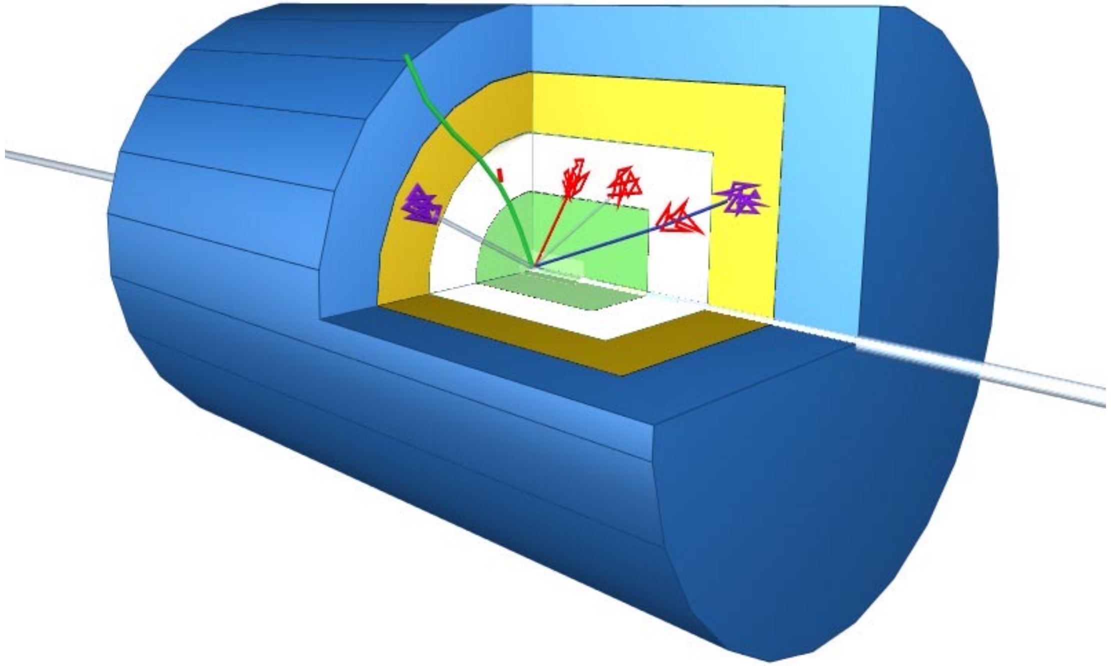
Experimentally Done in a Detector surrounding the collision area: A Schematic Design

Physics requirements drive the design (e.g. search for the Higgs boson, SUSY, BSM,…)

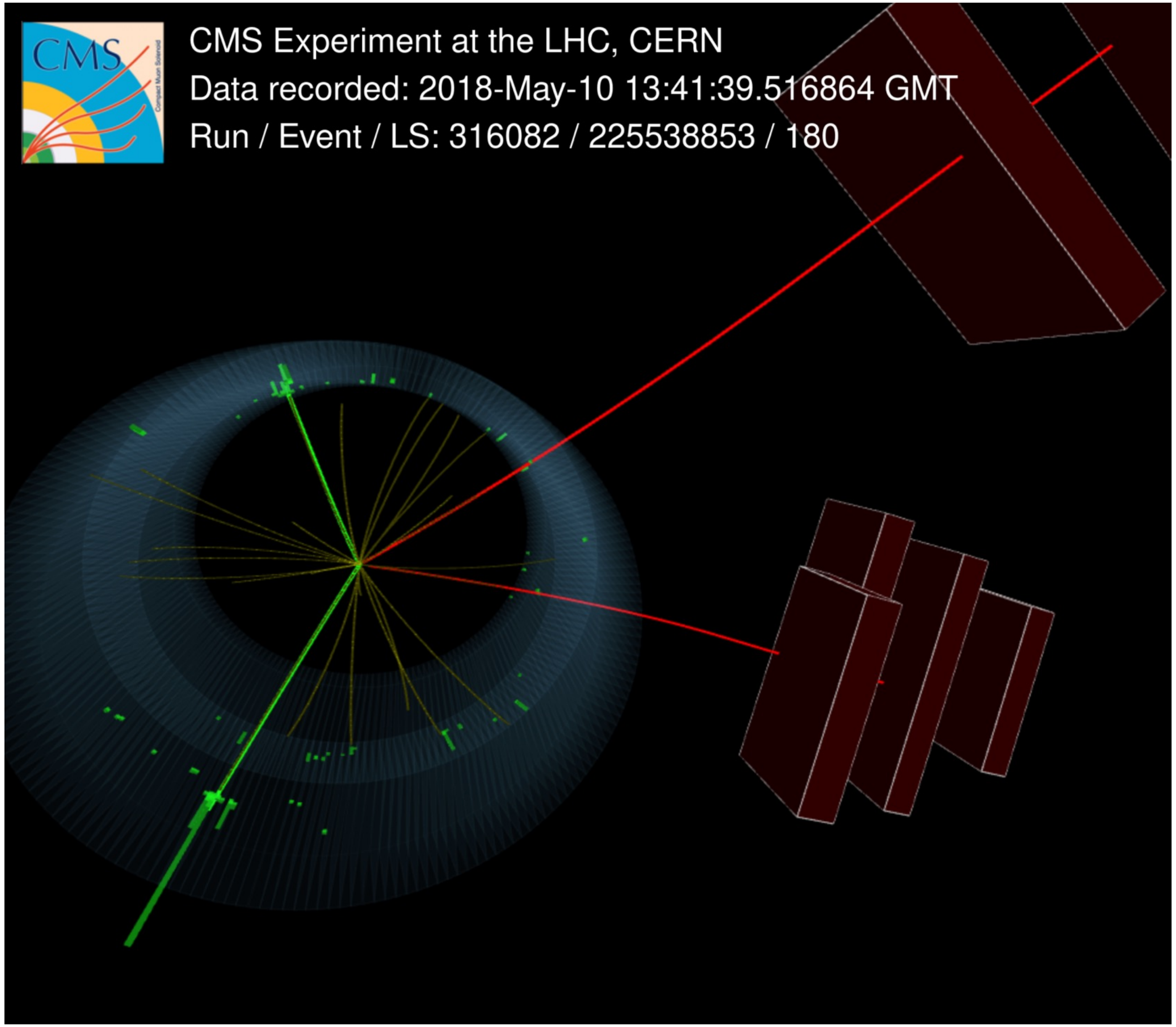
Analogy with a cylindrical onion:

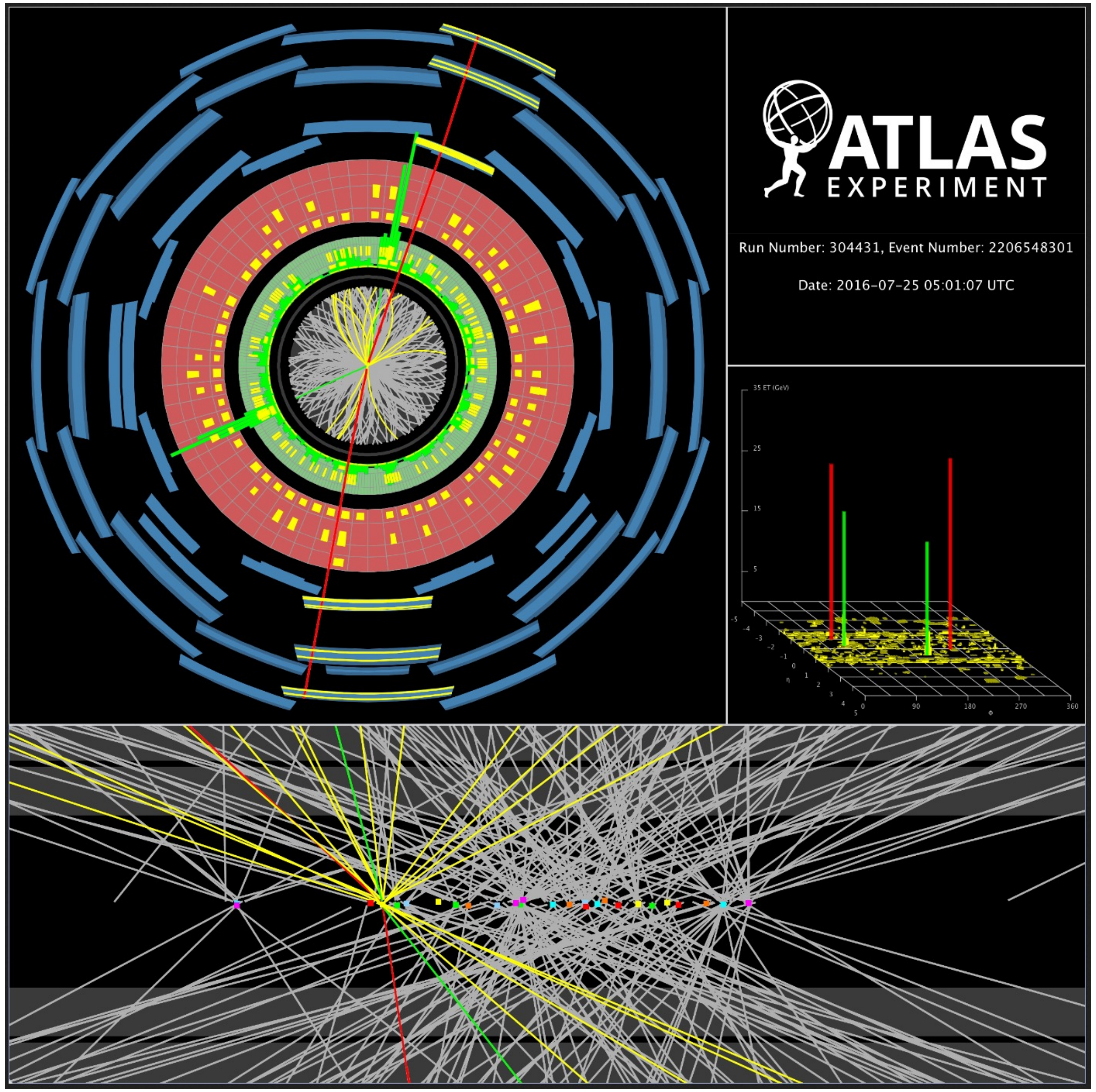
Technologically advanced detectors comprising four principal layers, each designed to perform a specific task.
Together these allow us to identify and precisely measure the energies and directions of all the particles produced in collisions.

1. **Inner Tracker immersed in magnetic field**
2. **Electromagnetic calorimeter**
3. **Hadronic Calorimeter**
4. **Muon system immersed in magnetic field**



The Four Principal Layers Speaking: Higgs boson Candidates: Event Displays





LHC Project Timeline

1984 **Workshop on a Large Hadron Collider in the LEP tunnel, Lausanne**

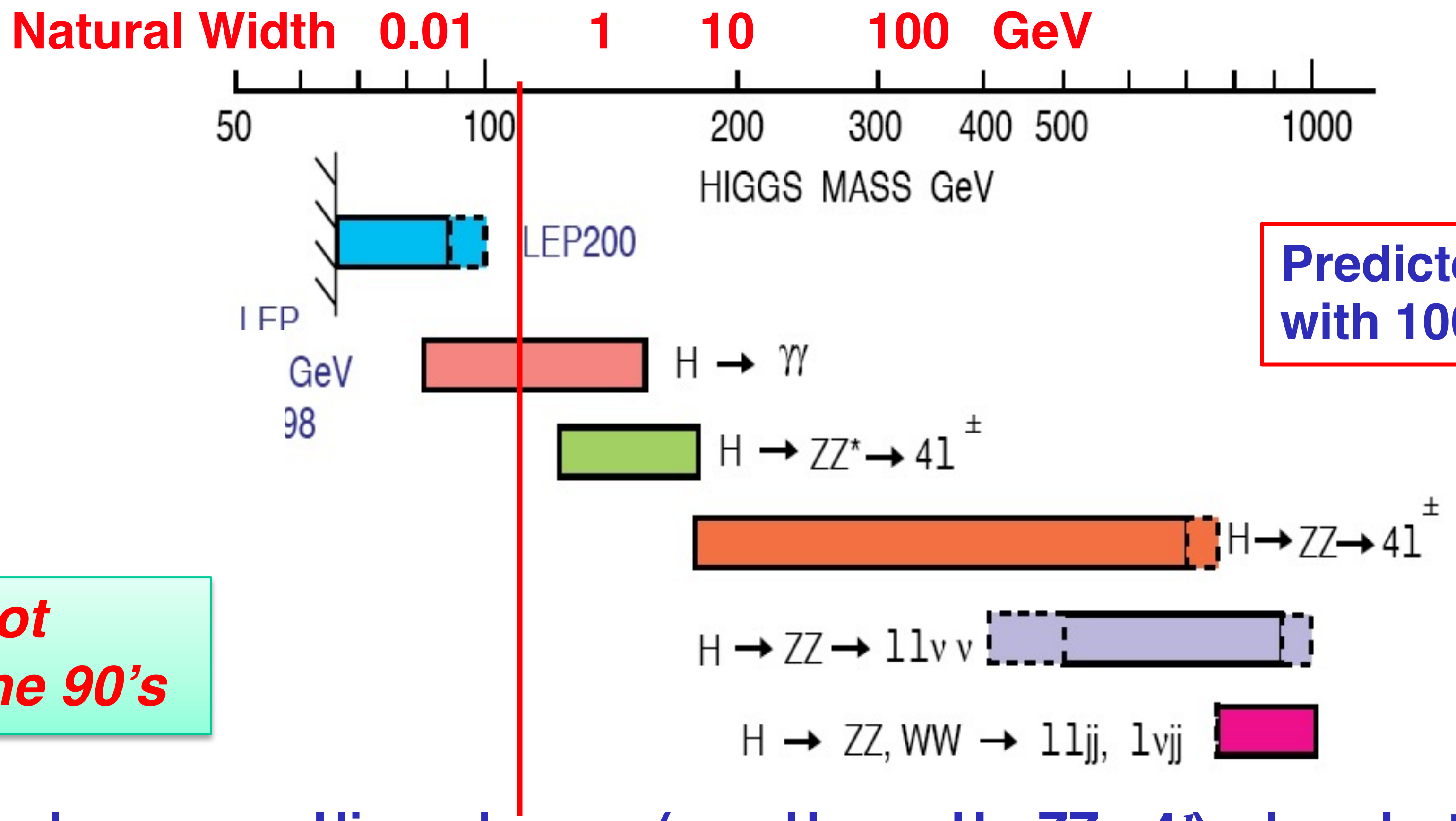
1987 **Rubbia "Long-Range Planning Committee" recommends a high-luminosity hadron collider (Large Hadron Collider) as the right choice for CERN's future**

1990 **ECFA LHC Workshop, Aachen**

General Purpose Detectors (GPD): Physics Drivers 1

Search for the SM Higgs Boson and LHC Experiment Design

The possibility of detection of the SM Higgs boson over the wide mass range, and its diverse manifestations, played a crucial role in the conceptual design of the ATLAS and CMS experiments



Natural width
$\Gamma \sim h/\tau$

Predicted Discovery (5σ) with 100 fb^{-1} at $\sqrt{s}$=14 TeV !

Plot from the 90's

Search for a low mass Higgs boson (e.g. H→γγ, H→ZZ→4*l*) placed stringent performance requirements on ATLAS and CMS detectors (especially momentum (in the tracker) and ECAL energy resolution).

Imperial College London

LHC Project Timeline

1984 Workshop on a Large Hadron Collider in the LEP tunnel, Lausanne

1987 Rubbia "Long-Range Planning Committee" recommends Large Hadron Collider as the right choice for CERN's future

1990 ECFA LHC Workshop, Aachen

1992 General Meeting on LHC Physics and Detectors, Evian les Bains

1993 From three Letters of Intent, ATLAS and CMS selected by LHCC

1994 ATLAS and CMS Technical Proposals Approved

1996 ATLAS and CMS: Approval to move to Construction (materials cost of <475 MCHF_{1996})

1998 ATLAS and CMS: Memorandum of Understanding for Construction Signed

ALICE (1997) and LHCb (1998) - Approval to move to construction.

1998 ATLAS and CMS: Construction Begins (after approval of Technical Design Reports)

2000 Assembly begins of ATLAS and CMS (above ground). LEP closes

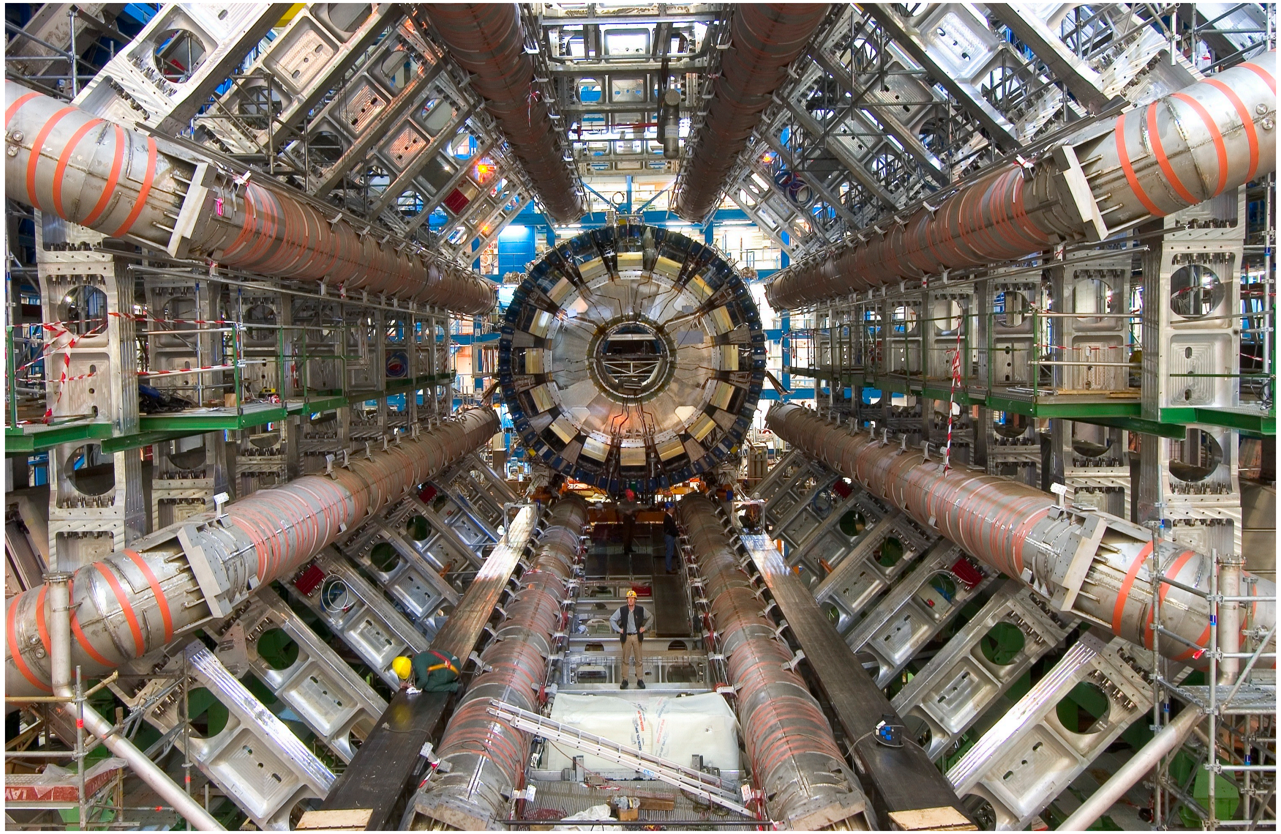
2008 ATLAS & CMS ready for First LHC Beams

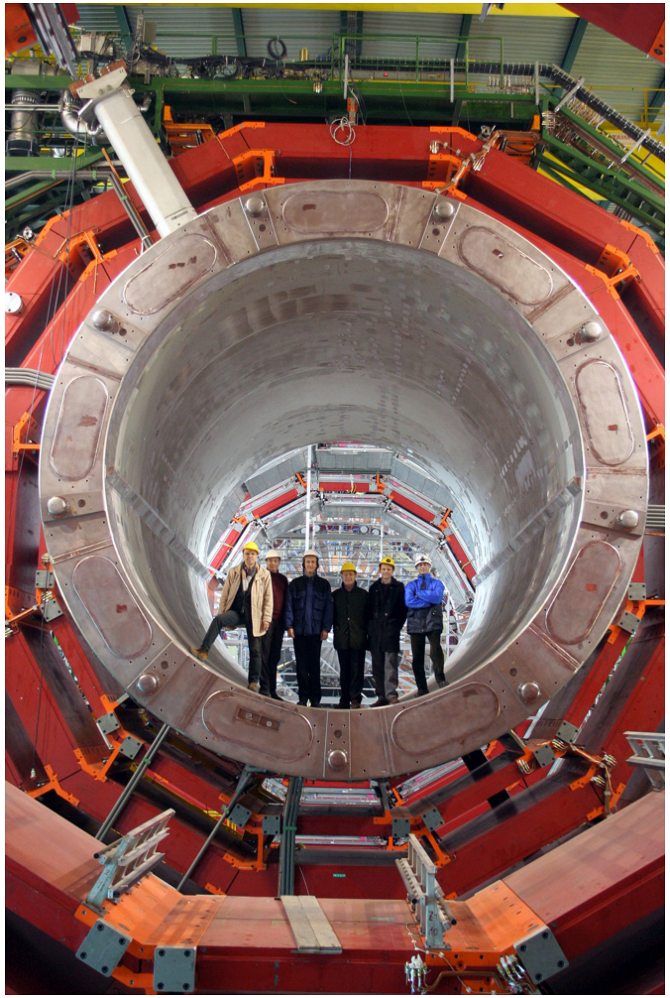
2009 First proton-proton collisions

2012 A new heavy boson discovered with mass ~130 × mass of proton

The Superconducting Magnets

The most important single choice that has to be made is of the magnetic field configuration for muon identification and measurement.

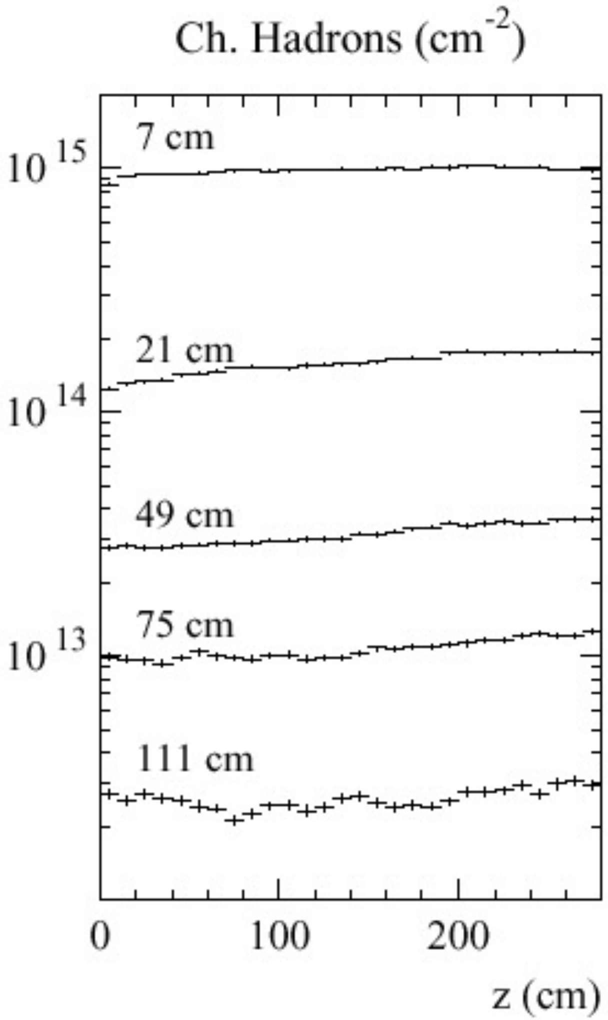




Imperial College London

An Example: Inner Tracking at the LHC

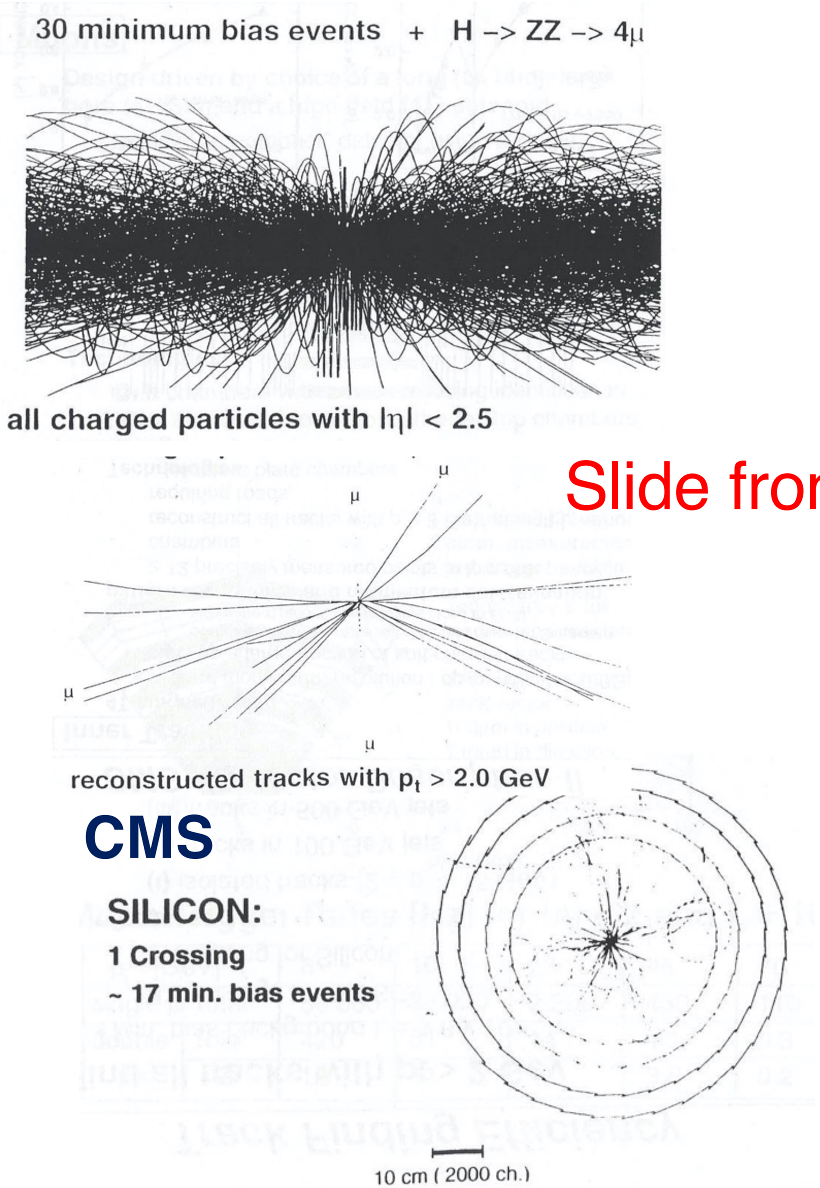
Fluence over 10 years



$\leq 4.10^7$ $h^{\pm}/cm^2/s$
pixels ($\approx 10^4$ μm^2)
occupancy $\approx 10^{-4}$

$\leq 4.10^6$ $h^{\pm}/cm^2/s$
Si μ-strip det.
($\approx$10 mm^2)
occupancy $\approx$ 1%

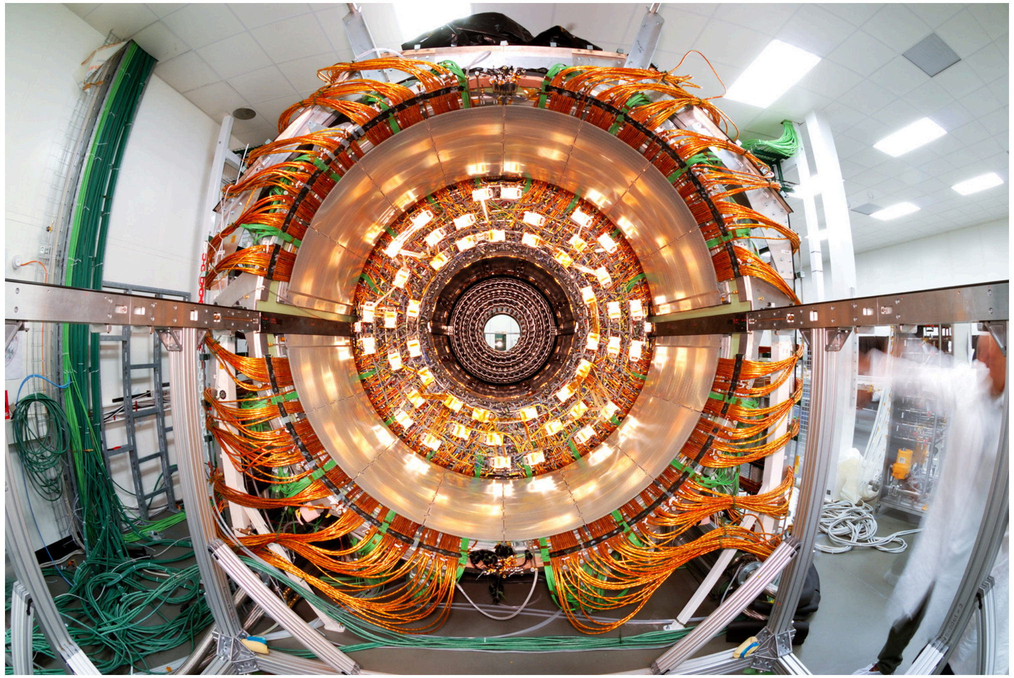
$\leq 4.10^5$ $h^{\pm}/cm^2/s$
Si or Gas detectors.
($\approx$1 cm^2)
occupancy $\approx$ 1%

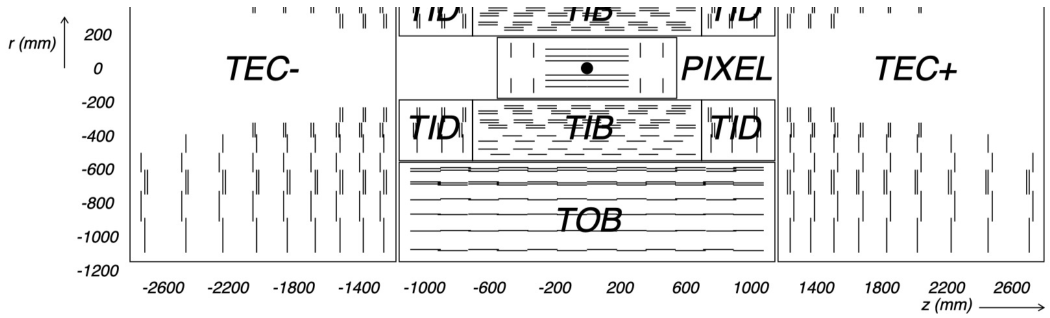


Slide from 1993

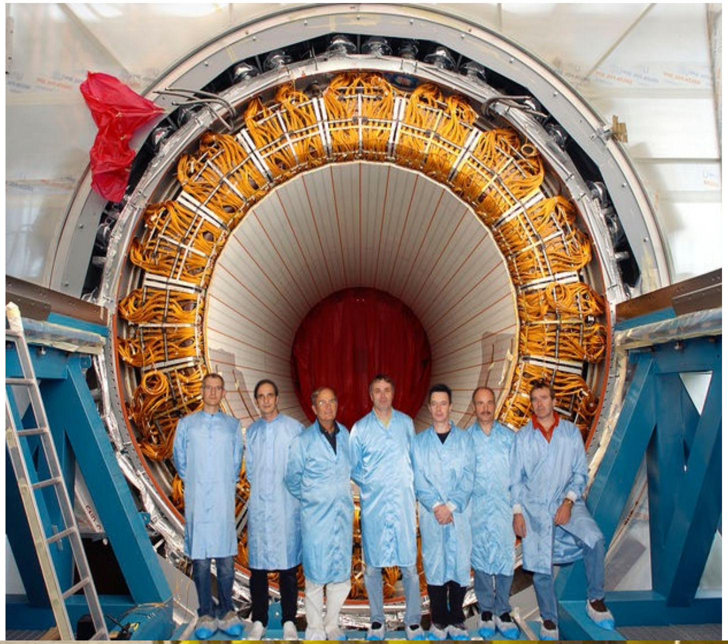
Sub-detectors Ready to be Installed

CMS All-silicon Inner Tracker





ATLAS Barrel LAr em Calorimeter



Imperial College London

An Example of Challenges: CMS Tracker fe -ASIC

CMS – deep sub-micron technology

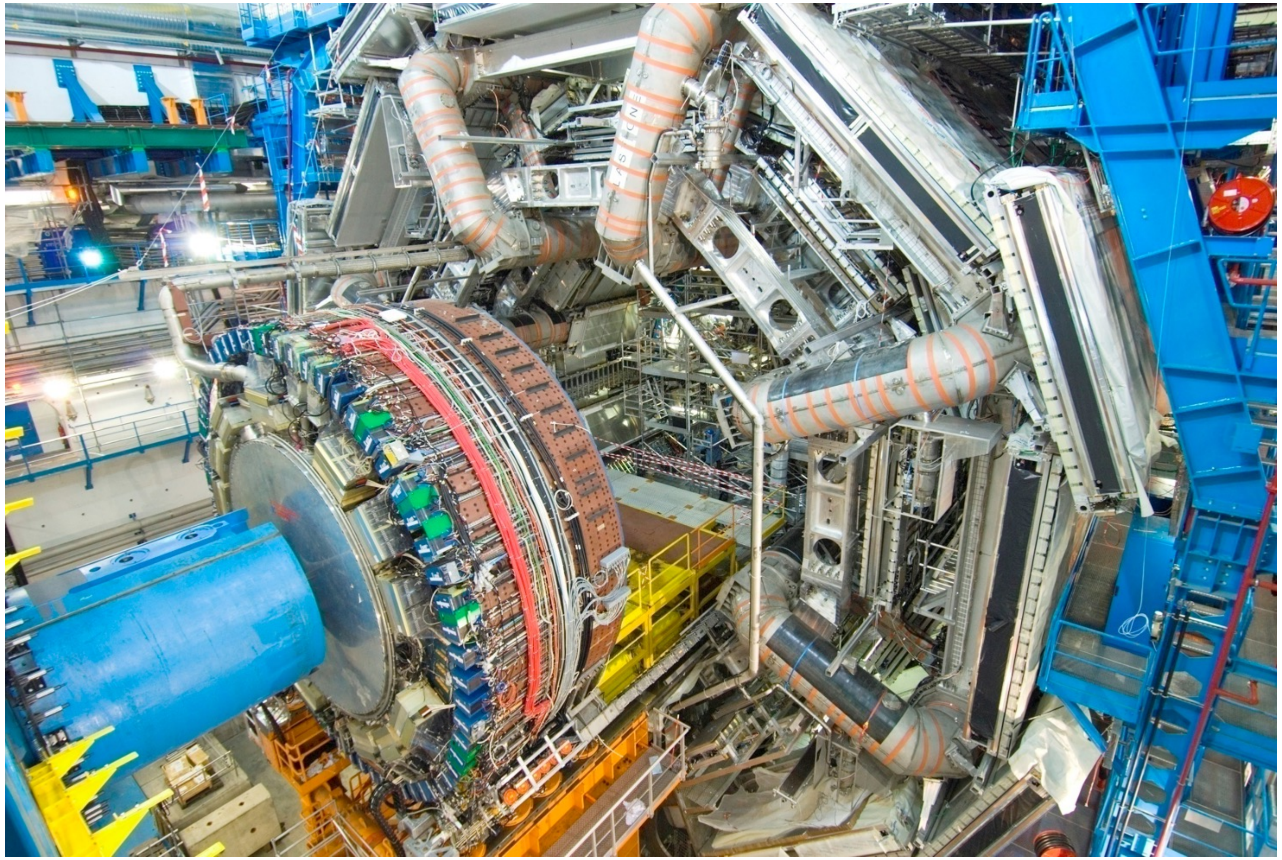
- **1997 – front-end chip for Si microstrip tracker had been finalized, and was ready to go into production**
- **vendor decided to produce the chip in a new foundry (commercial decision)**
- **Radiation hardness could no longer be guaranteed**

- Some far-sighted engineers advocated use of a new 0.25μm technology (many advantages: commercial technology, faster turnaround time, higher yield, lower cost)
    - A CERN staff member had gone on a sabbatical to IBM New York – to study trends in industry
    - With some design tricks this technology was shown to be rad-hard
    - CERN, a national lab and a university group developed/prototyped ASICs in this new technology
- Decision made to proceed - 100k chips manufactured (2000-2004)

Many technical advantages followed such as lower costs, faster turnaround between design iterations, lower intrinsic noise levels and lower power consumption. **Riding this technology wave has allowed costs to be contained in an area that otherwise carries a very high risk.**

Views of Detectors in Experiment Caverns

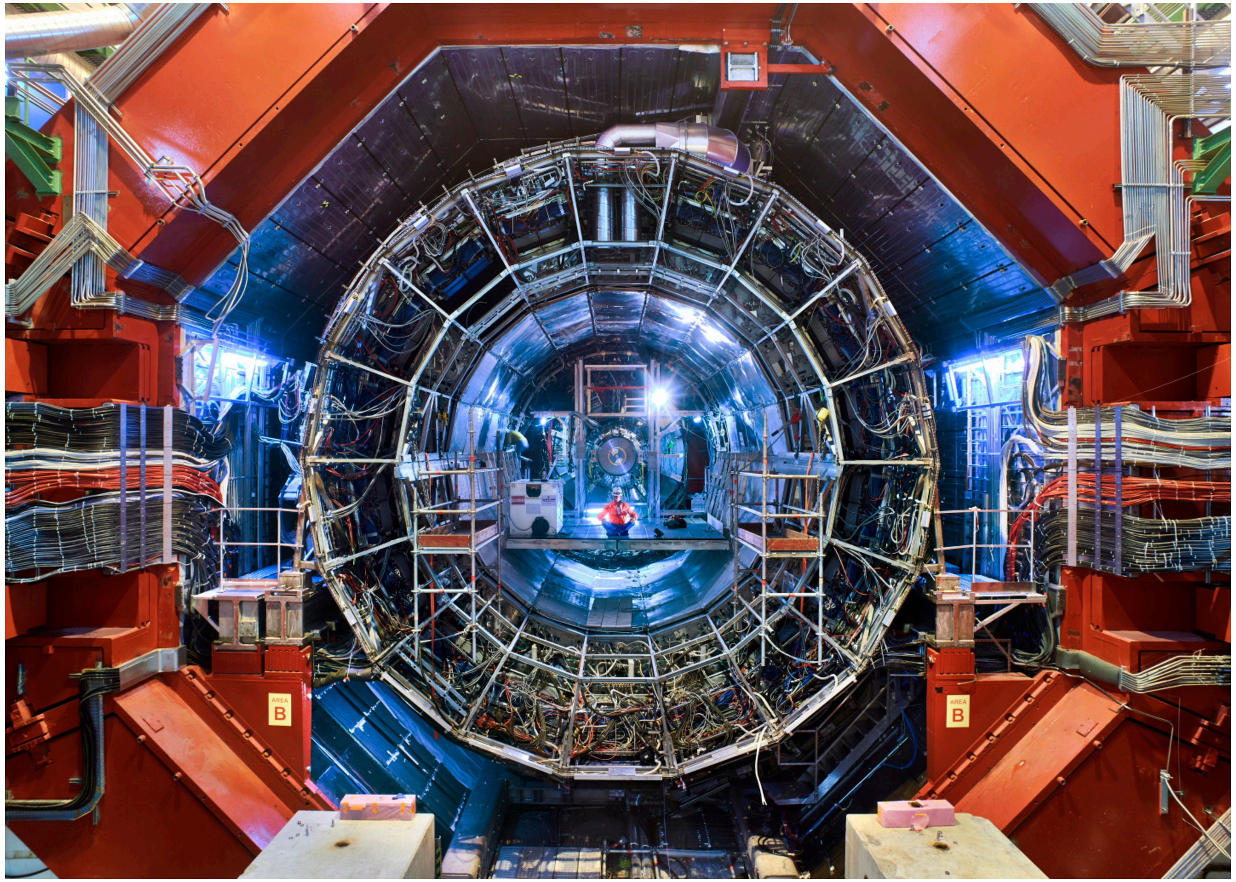
ATLAS



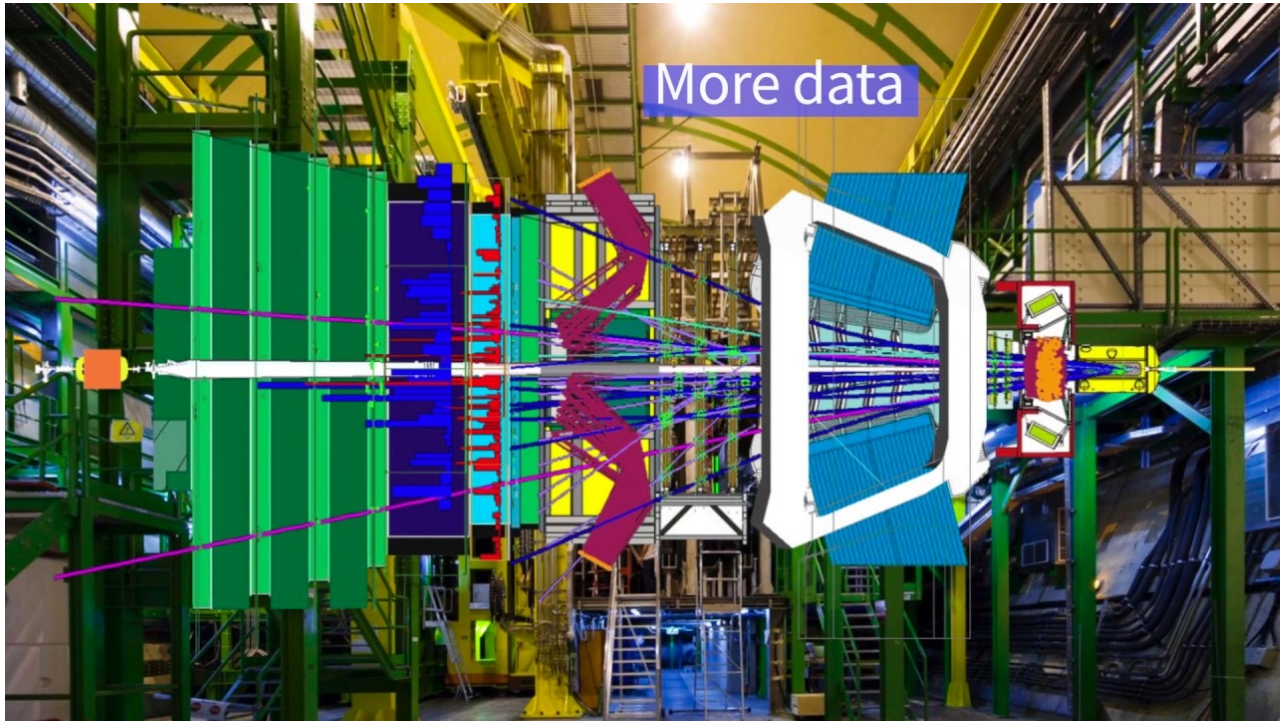
CMS

Views of Detectors in Experiment Caverns

ALICE



LHCb



Summary

- The LHC experiments (and the LHC accelerator) had to overcome many challenges - in their designs and their construction. Existing technologies had to be pushed to their limits and new ones invented and developed.
- The accelerator and the experiments have performed much better than their designers could have dreamed.
- The Higgs boson was discovered much earlier than anticipated and seen in channels which were thought impossible. It appears to be the one predicted by the SM. Now being studied in great detail.
- Over a thousand physics papers have been published (grace of excellent software (data preparation and analysis) and LHC worldwide computing grid.
- No evidence has yet been found for widely anticipated NEW physics, though there are hints.
- However, we are just at the start of the exploration of the Terascale. The LHC and the experiments are being upgraded to draw full benefit from the LHC Project, aiming to collect data corresponding to ten times larger integrated luminosity than originally foreseen.

- What further discoveries await us?
- Several of the open questions today are just as profound as those a century ago.
- LHC remains the foremost place to look for new physics.