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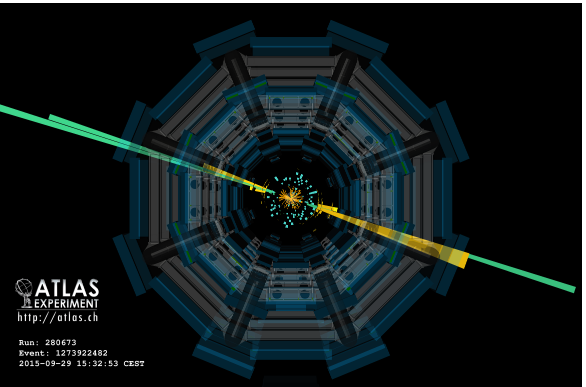
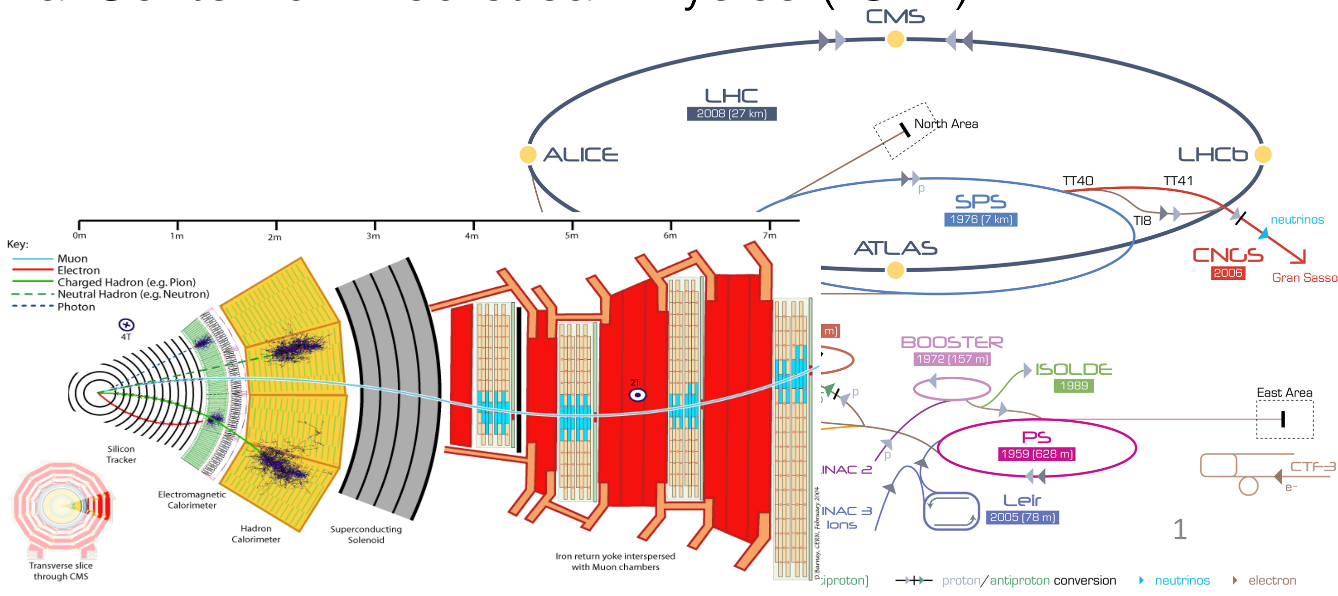
Challenges of the LHC detectors (ATLAS and CMS)

Kate Shaw
INFN Udine-ICTP ATLAS Group
International Center for Theoretical Physics (ICTP)

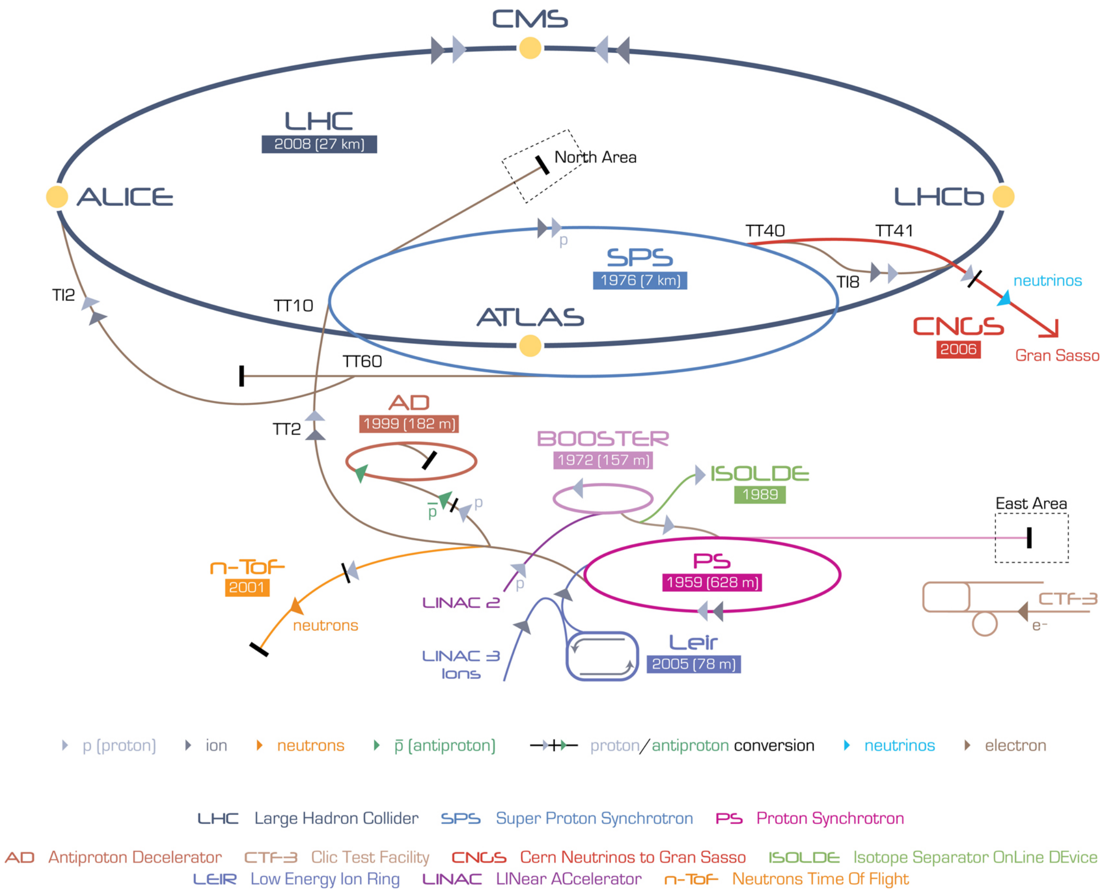




LHC Detectors

LHC was built by CERN between 1998 and 2008

Over 10,000 scientists from over 100 countries

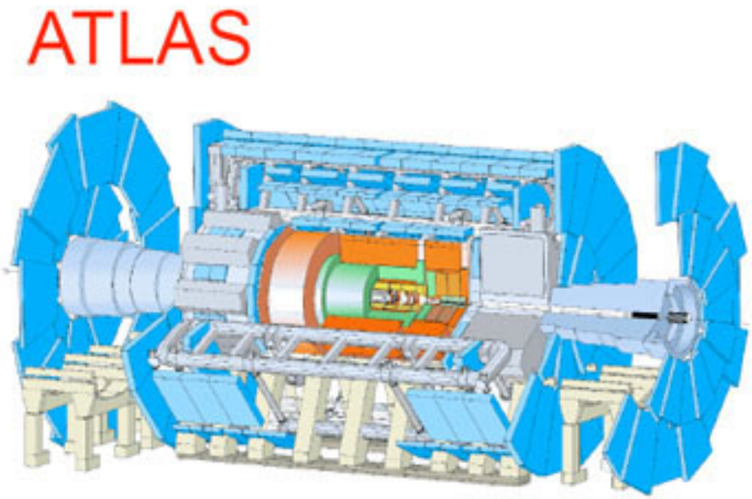


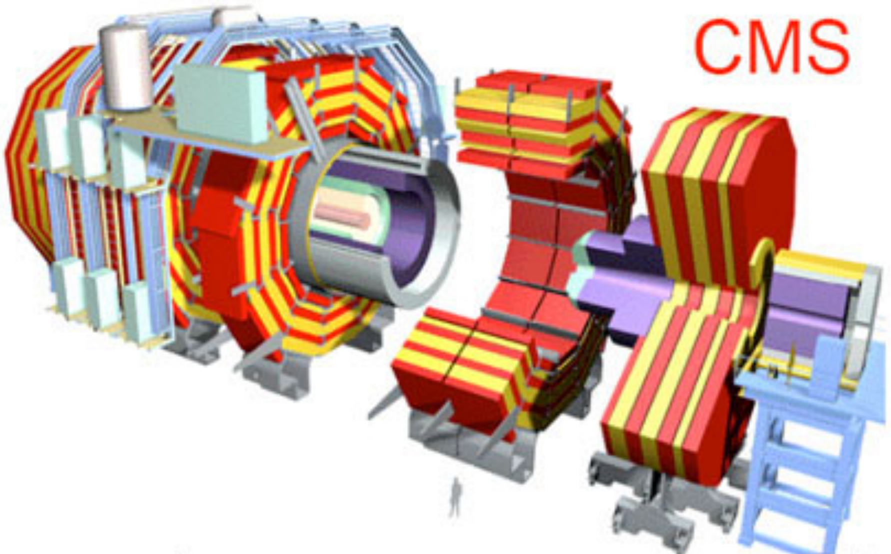
Bunches containing 100 billion protons collide 40 million times a second
Overall pp interaction rate ~10^9 per second

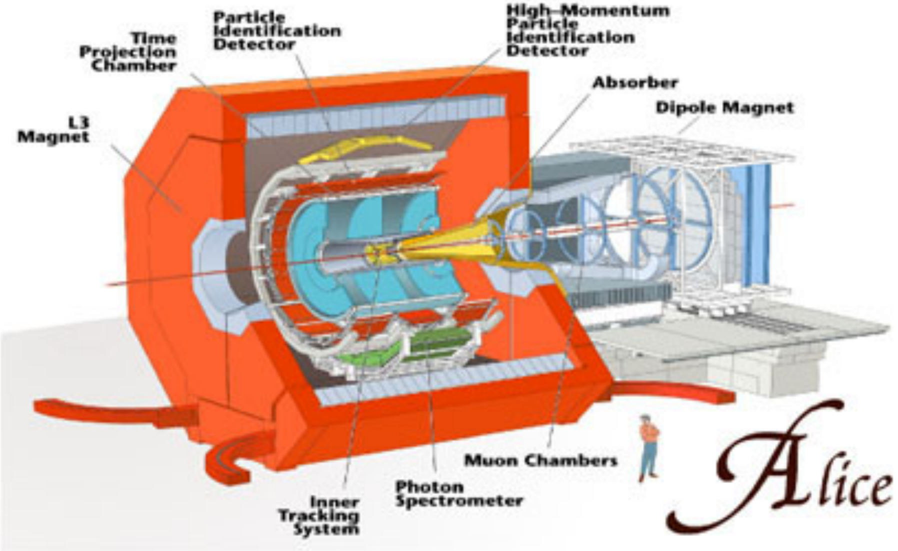
Hadron colliders excellent to produce interesting processes with low cross section times branching ratio (σ X BR)
-> less clean environment
-> harsh radiation environment

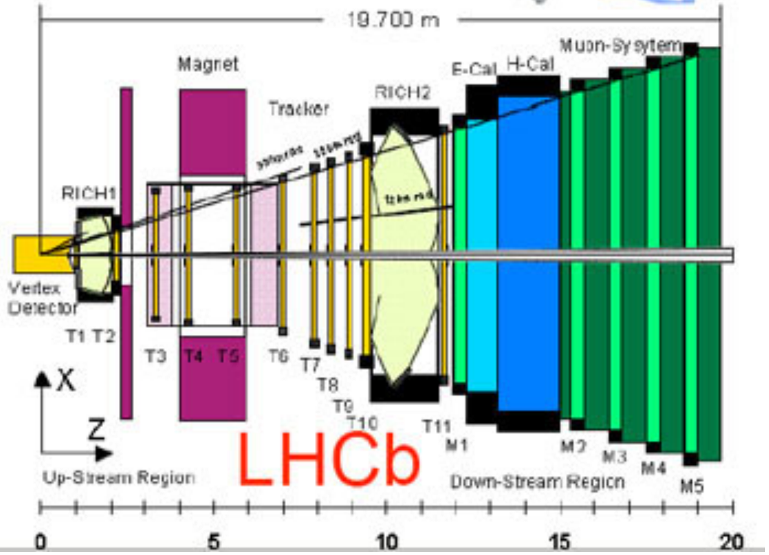
Creates extremely challenging operating environment for the experiments!

LHC Detectors



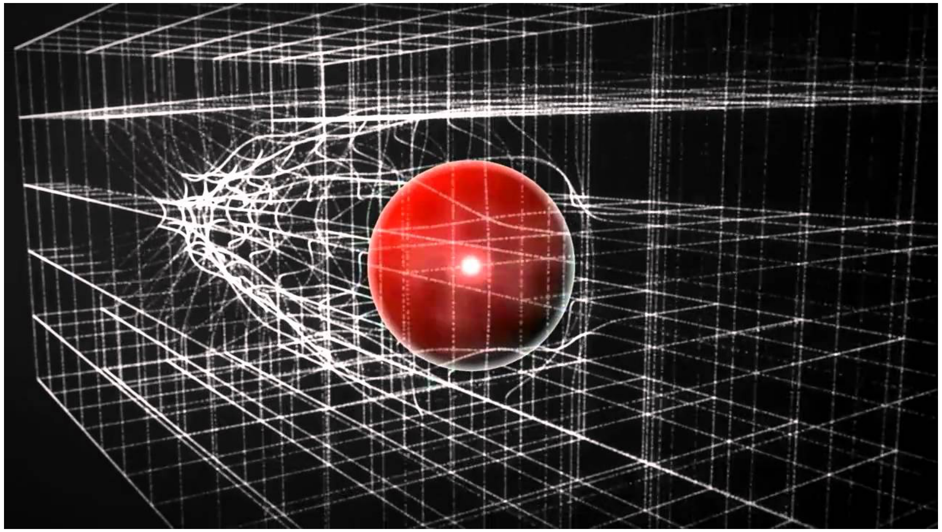


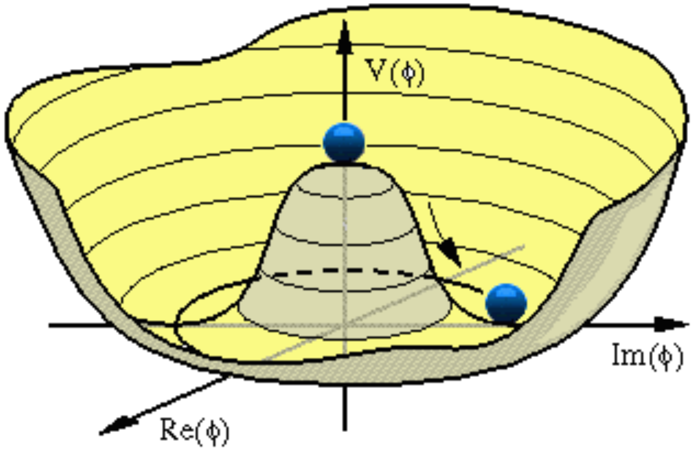




Primary Physics Goals : ATLAS & CMS

- **Origin of Mass: discovery of the nature of electroweak symmetry breaking. Higgs mechanism provides explanation of why W and Z have such large masses (~100 m_p)**





- **Searches for candidate particles to explain dark matter**
- **SUSY, heavy vector bosons, extra dimensions**
- **Pathway to how gravity can be consolidated into a unified theory**
- **Searches for unexpected phenomenon**

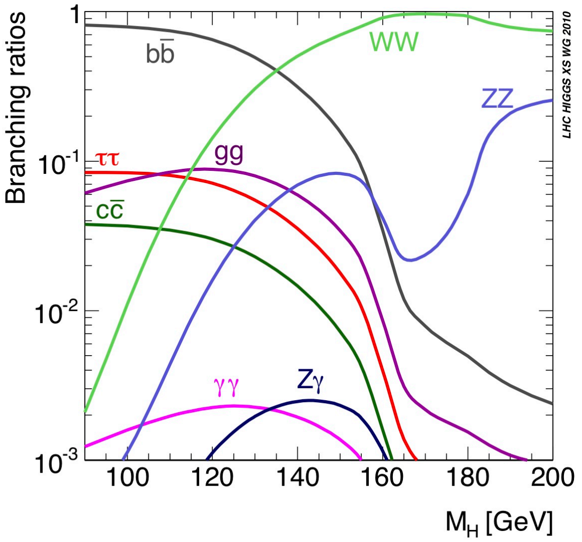
Primary Physics Goals: Higgs boson

Higgs production: highly demanding on detector resolution and background discrimination

Detectors designed to search for Higgs over a wide mass range: 114 GeV – 1TeV

Lifetime of Higgs boson is short (now known ~10^{-22}s) thus only its decay products can be detected

Search for distinctive signatures that can be resolved against background



Diverse final states include 2 photons, 2 tau leptons, 2 W or 2 Z bosons.

In lower mass range decays of Higgs dominated by bb quarks, which has too large background for discovery.

Two photon decay was expected as most likely channel for low mass Higgs

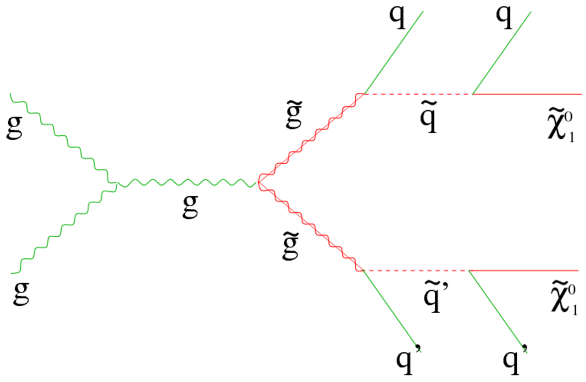
Detector requirements: some benchmarks

Higgs decay into two photons: good electromagnetic energy resolution, pion rejection, efficient photon isolation and vertex reconstruction

Higgs decay in to Z bosons -> 4 leptons: good electron and muon mass resolution, requiring good momentum resolution, efficient lepton isolation and large acceptance.

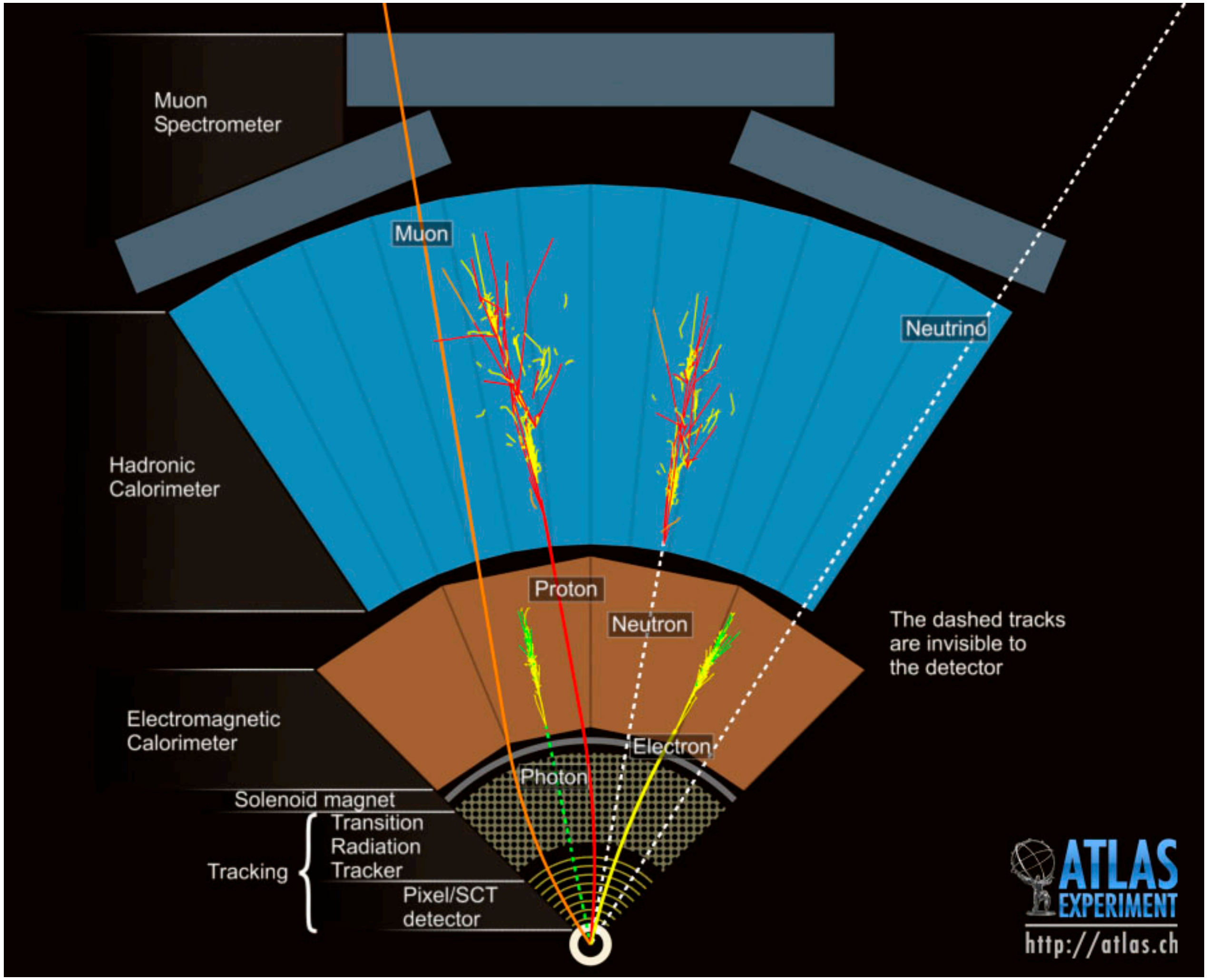
Higgs production through vector boson fusion: good hadronic calorimeter coverage and jet reconstruction especially in forward regions

For searches for SUSY: good missing ET resolution (neutralinos go undetected) and efficient tagging of b quark jets and hadronic decays of tau leptons



General purpose detectors

Full coverage detectors (4π) designed to identify and measure precisely the energies and directions of particles produced in the collisions



Muon chambers– tracks muons and measures their momenta and charge

Hadronic calorimeter– absorbs and measures energy and direction of hadronic jets and hadrons

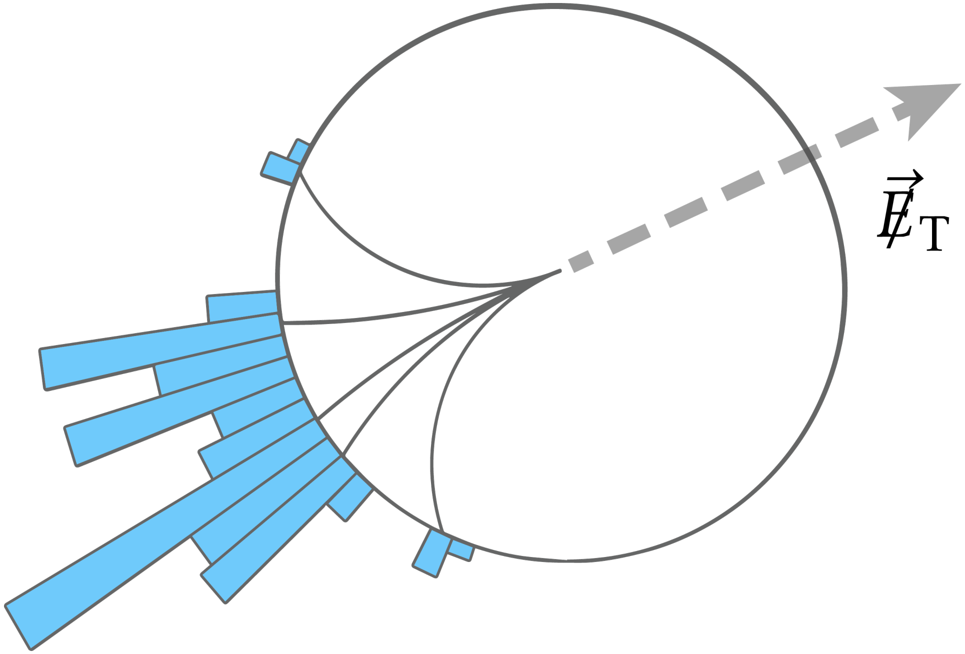
Electromagnetic calorimeter– absorbs and measures energy and direction of electrons and photons

Inner Tracker – tracks charged particles, indicates momenta, charge, origin

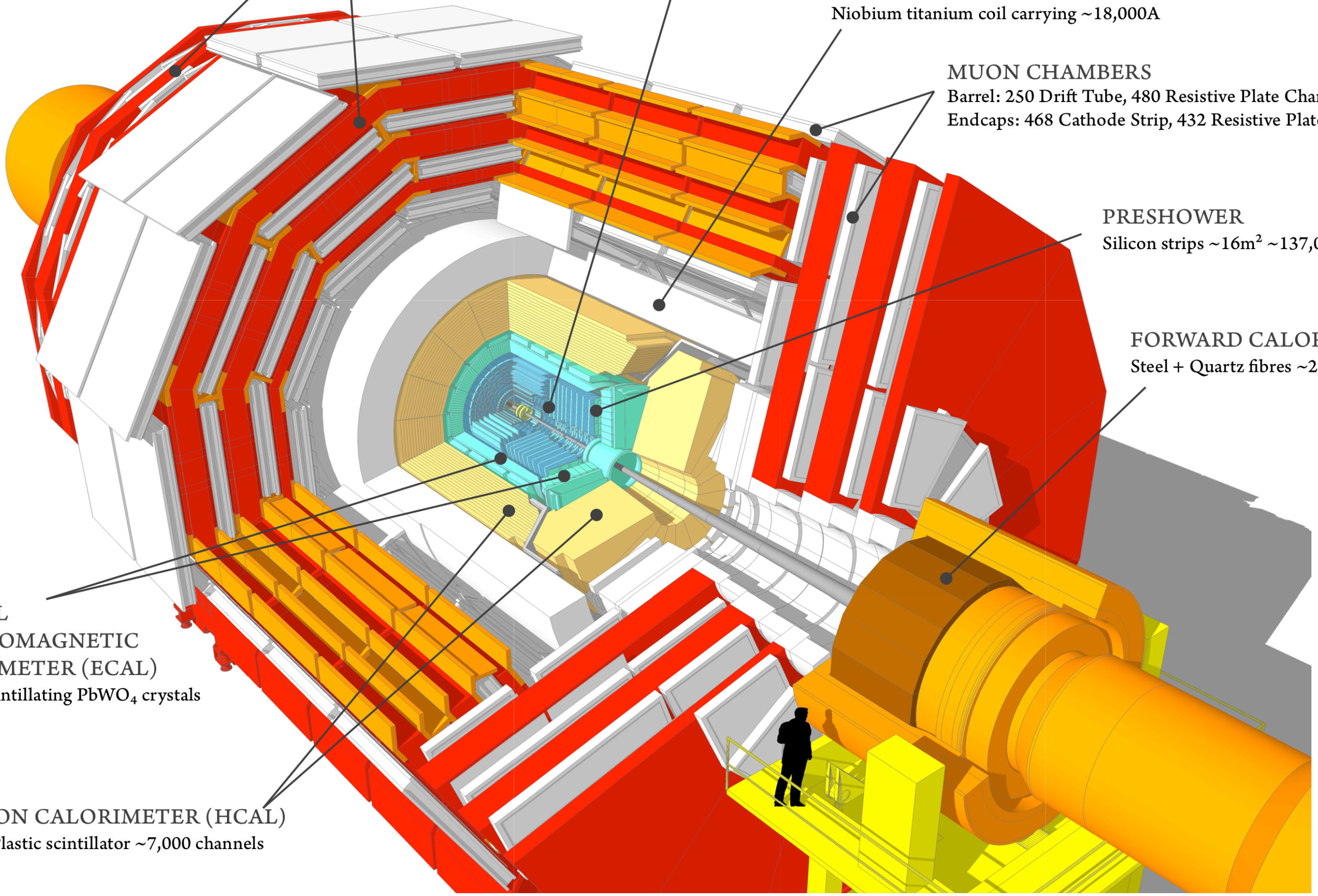
Missing Et

Missing ET

- Colliding parton initial momentum is an unknown fraction of protons momentum
- Transverse momentum is zero in initial state
- Any large net transverse momentum in final state indicates escaping particle (e.g. ν, χ)



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

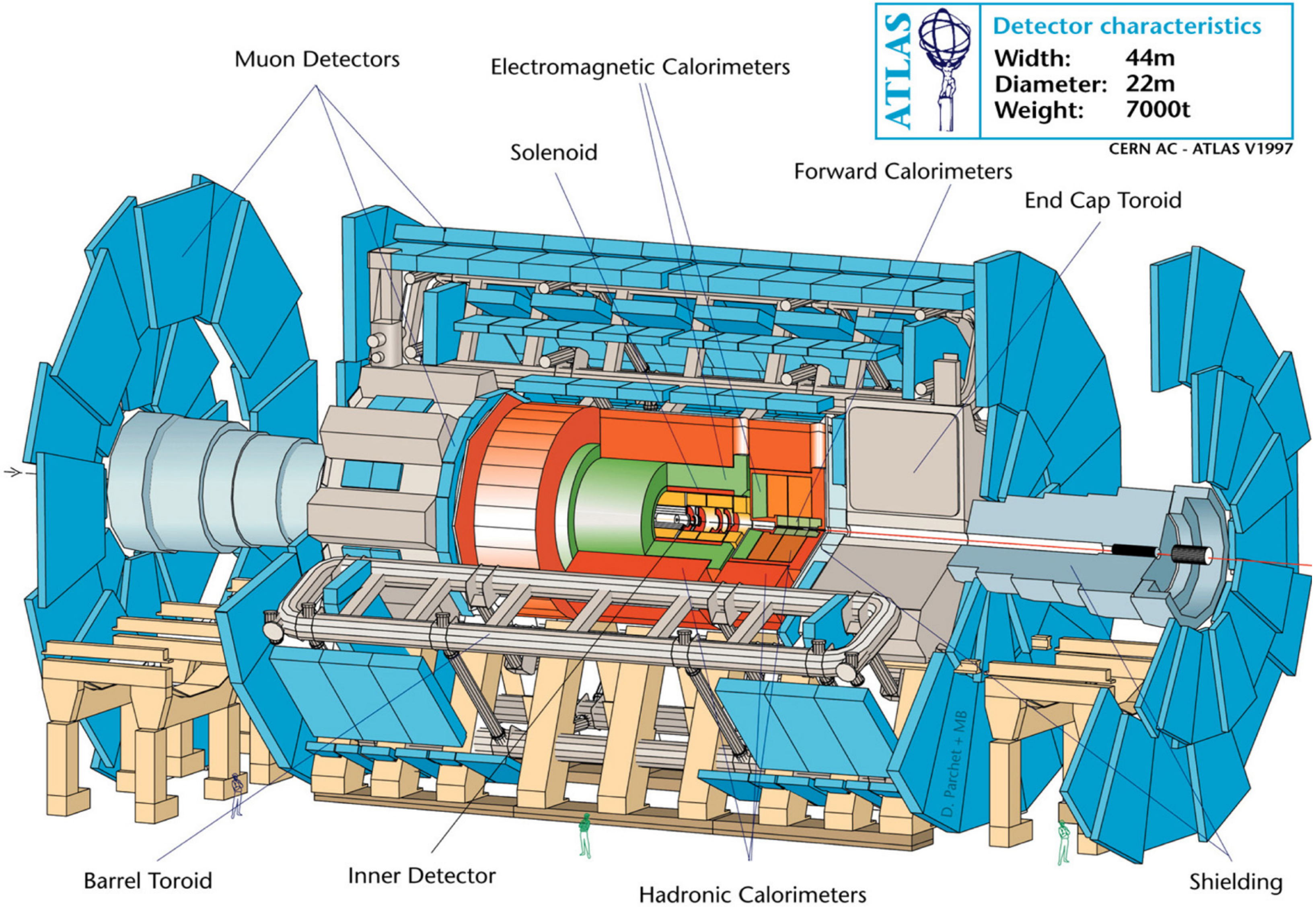
PRESHOWER
Silicon strips ~16m² ~137,000 channels

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

ATLAS detector

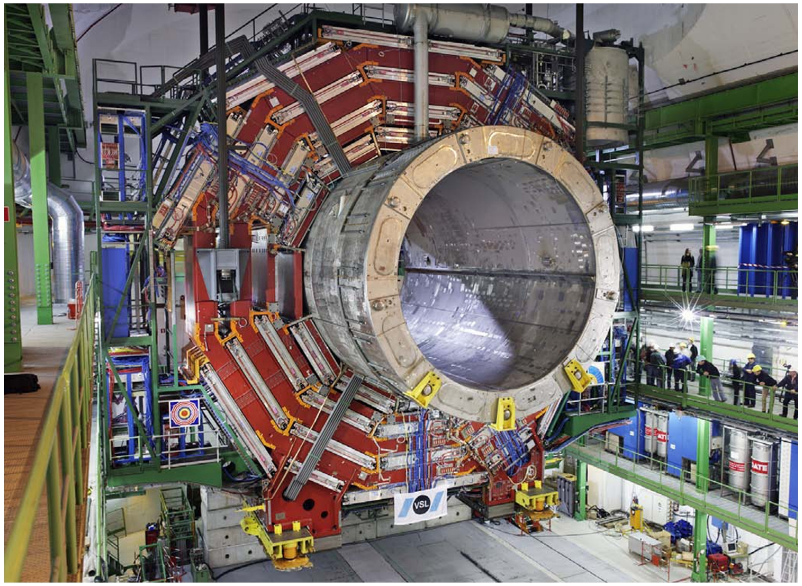


Magnet systems

To measure the momentum and charge of charged particles in the inner tracker and muons in the muon chambers, ATLAS and CMS proposed very different solutions.

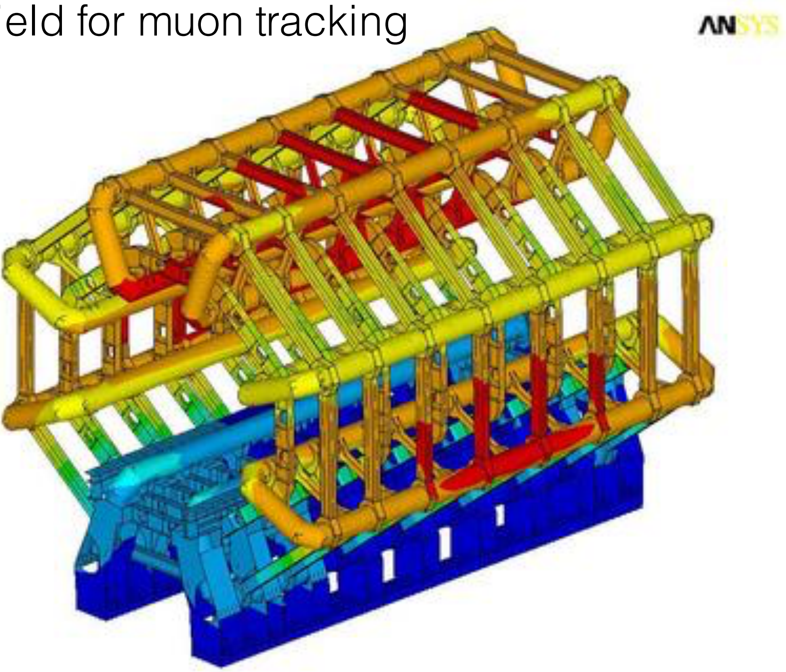
CMS : compact and heavy
Cylindrical experiment 15 m diameter, 24 m long mass 12500t

4T single high field large bore **solenoid** surrounding all tracking and calorimetry, and iron flux return yoke constitutes the muon measurement system.



ATLAS : bigger and lighter
Cylindrical experiment 25 m diameter, 44m long, mass 7000t

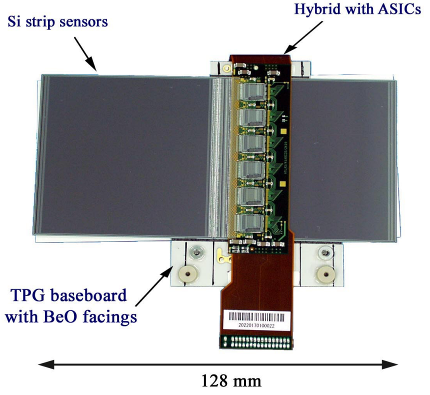
2T thin **solenoid** surrounding the inner detector
0.5T Barrel, **1T** Endcap toriods provide field for muon tracking



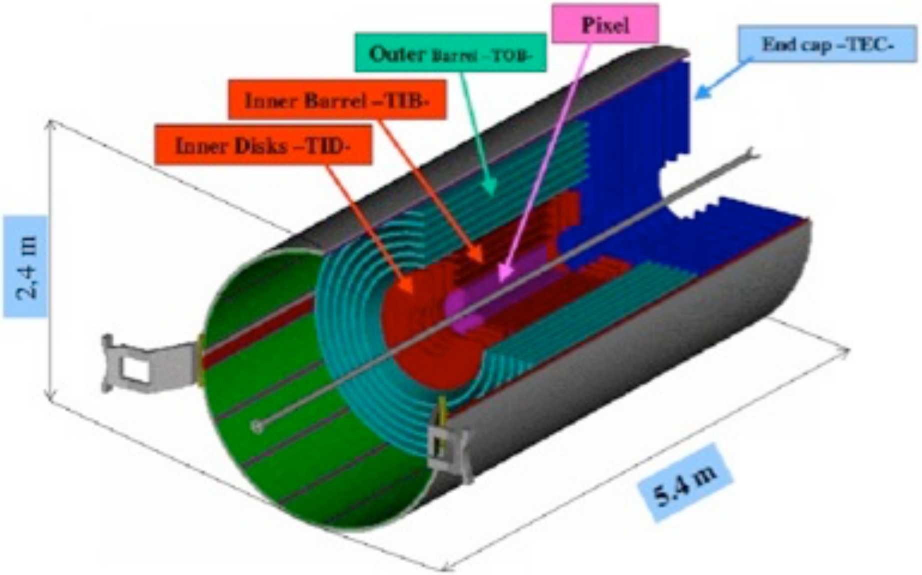
Inner tracker

The tracking system is the first instrumentation particles intercept as the are produced in the collision or subsequent particle decays. The tracker must provide efficient detection of charged particle trajectories.

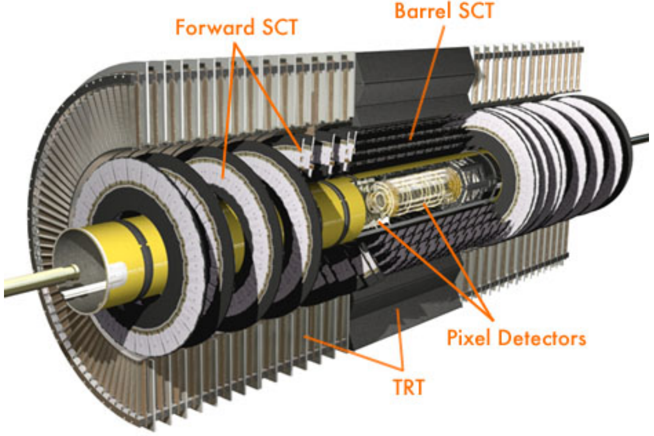
High-precision tracking achieved using radiation hard silicon sensors and front end electronics



CMS:
Pixel Detector (66M channels) (res ~ 10 μm)
Silicon Strip Tracker (10M channels)



ATLAS:
IBL (Upgrade 2014, 80M channels)
Pixel Detector (80M channels) (14 x 155 μm^2)
SCT (6M channels) (res ~ 17 μm)
TRT (0.35M channels) (res~200μm)

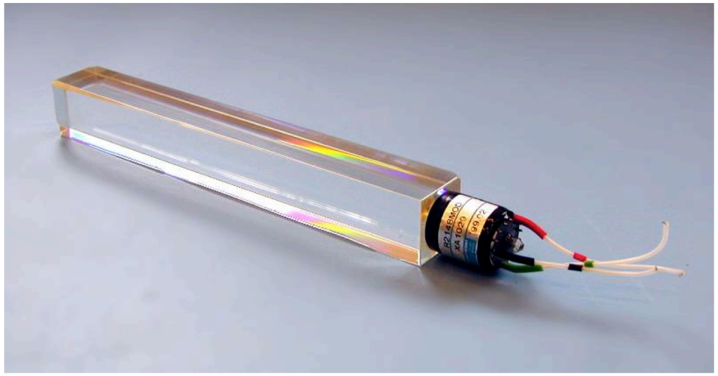


Electromagnetic calorimeters

To provide high precision energy and position resolution for electrons and photons, a fast, radiation hard, low noise calorimeter must be designed. There design was optimised to detect the decay of the Higgs into a pair of photons, precision ~ 0.5%

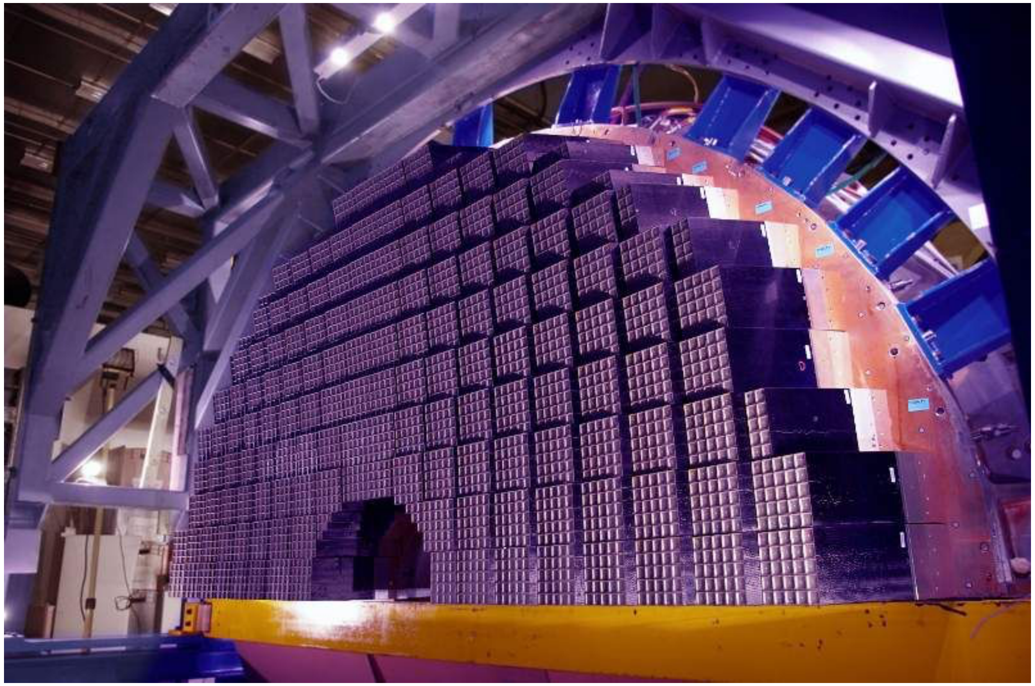
CMS : ECAL Barrel and two endcaps

Homogeneous calorimeter composed of lead tungstate ($PbWO_4$) scintillating crystals (~80000) coupled to a pair of silicon avalanche photodiodes (APDs).



Extremely dense and optically clear material

Precise fast and compact

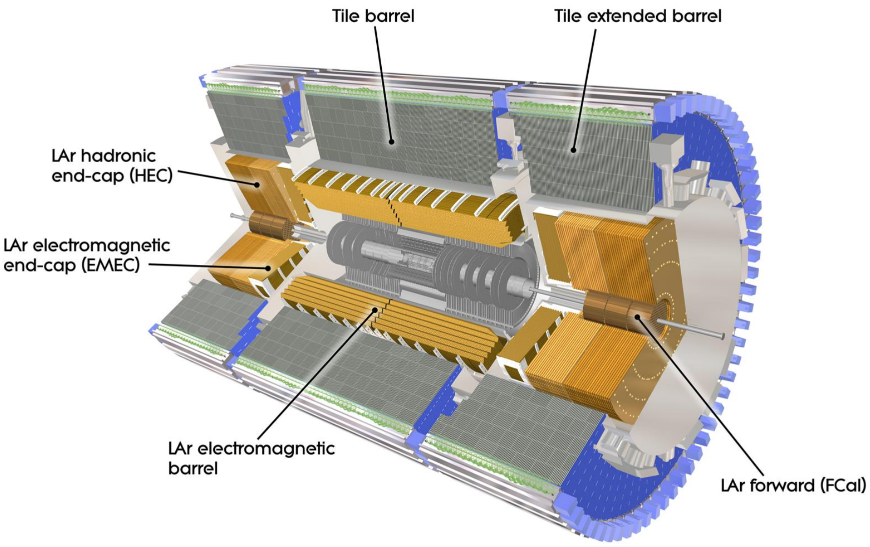


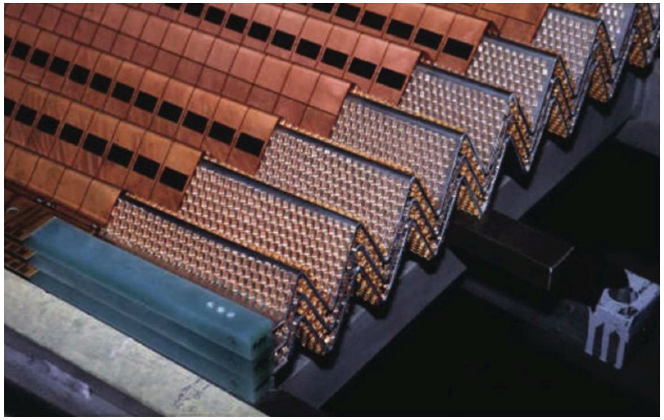
Electromagnetic calorimeters

To provide high precision energy and position resolution for electrons and photons, a fast, radiation hard, low noise calorimeter must be designed. There design was optimised to detect the decay of the Higgs into a pair of photons, precision ~ 0.5%

ATLAS: Barrel and endcap electromagnetic calorimeter

Sampling calorimeter using liquid argon as the active medium and interleaved absorber layers made of lead with an accordion geometry



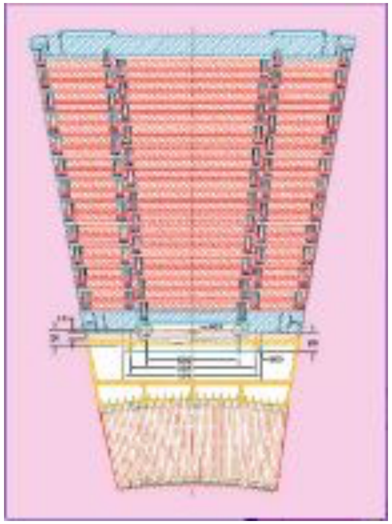


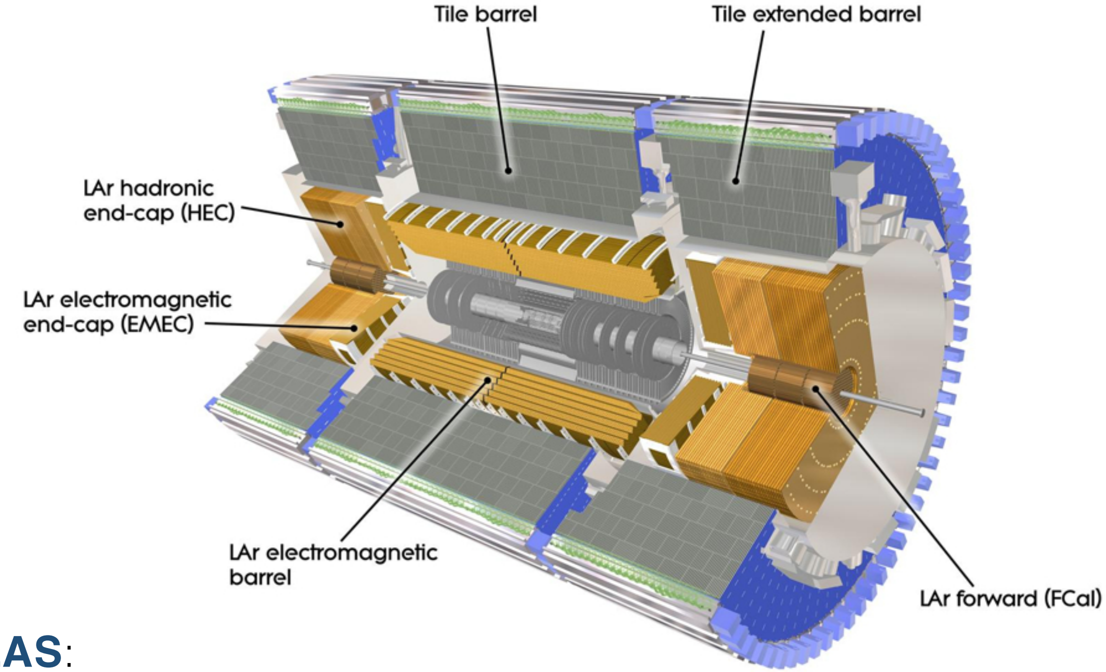
Liquid argon has intrinsic linear behavior, is stable and radiation hard

Accordion geometry provides high granularity and excellent hermeticity, and minimizes inductances in the signal path allowing fast responses

Hadronic calorimeters

To precisely measure jet energies and angles, separate jets, and infer the amount of missing transverse energy. Jet energy scale uncertainty can be dominant in many cross section measurements. (e.g. top mass uncertainty ~ 1 GeV)





CMS:

- HCAL consists of brass or steel interleaved with tiles of plastic scintillators
- Hadronic forward detectors using steel absorbers

ATLAS:

- Tile Cal: steel absorber with scintillating tiles as active material
- Forward hadronic calorimeters use LAr technology
- Hadronic end-cap calorimeters (HEC) use copper absorber
- Forward calorimeter (FCal) consists of three modules of either copper or tungsten

Muon system

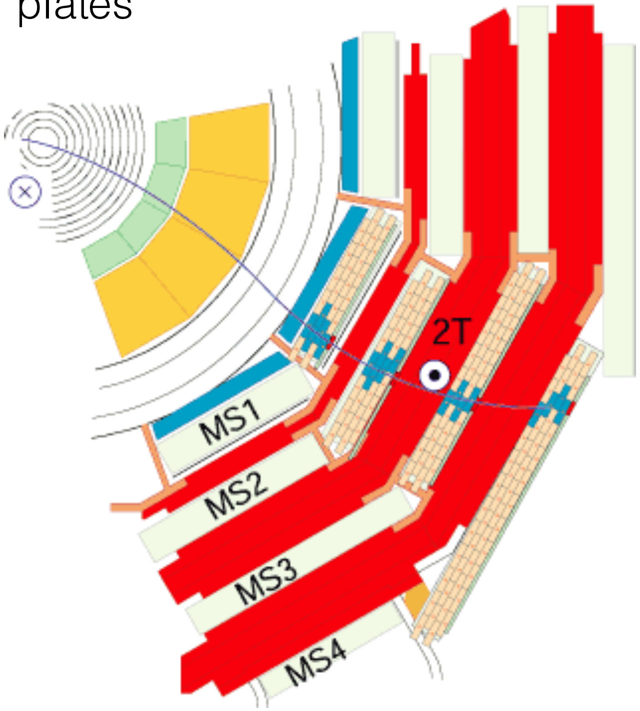
Muon chambers must be able to measure the position of a muon with a high precision > 100μm, and define the overall dimensions of ATLAS and CMS.

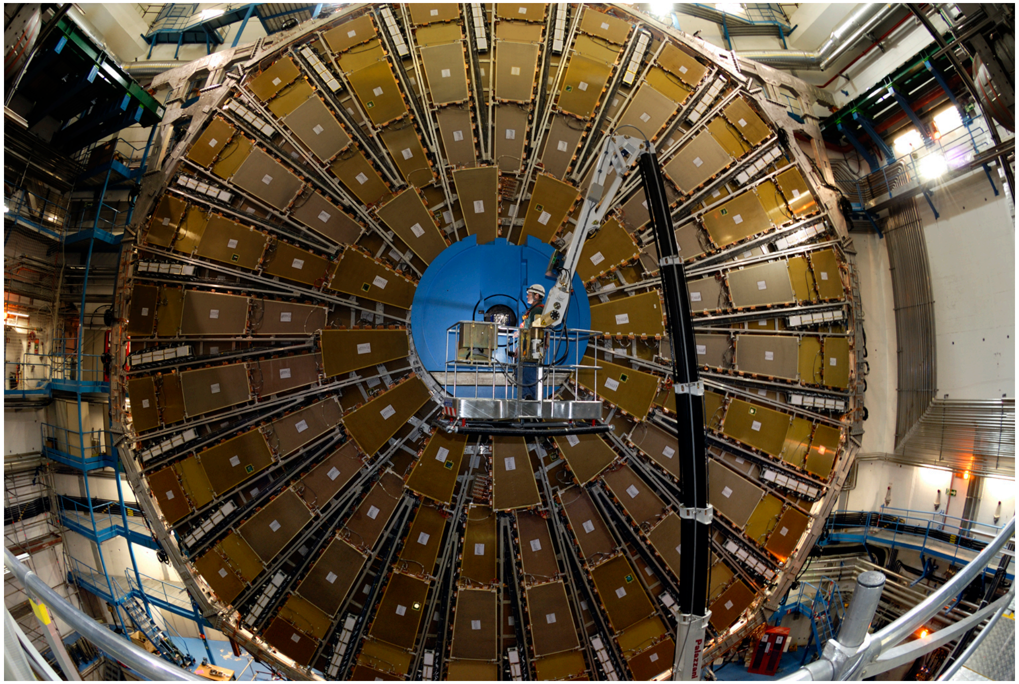
CMS:

- Three types of gas-ionization particle detectors for muon identification
- Utilizes drift tubes, cathode strip proportional planes and resistive plates

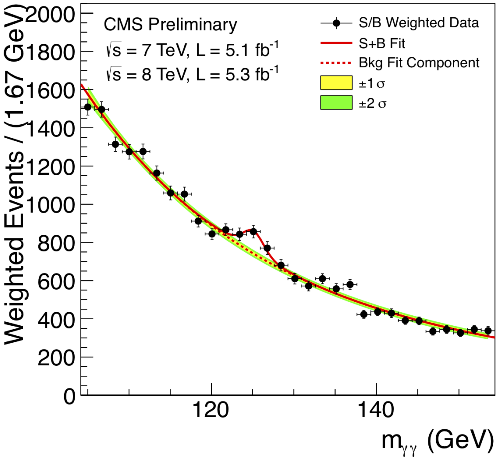
ATLAS:

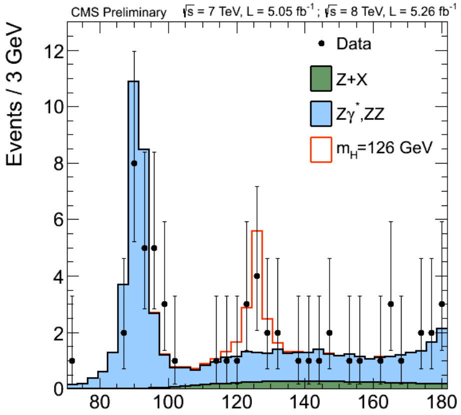
- Muon spectrometer composed of 4000 muon chambers
- System includes thin-gap chambers, cathode strip chambers, resistive plate chambers, and monitored drift tubes (resolution ~ 60-80 μm)

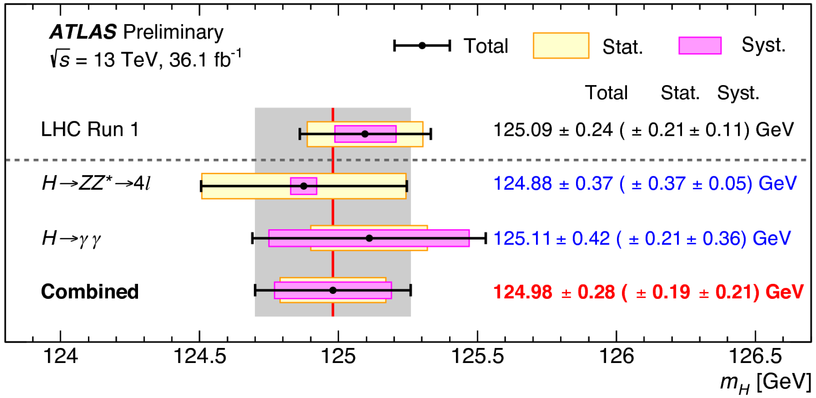


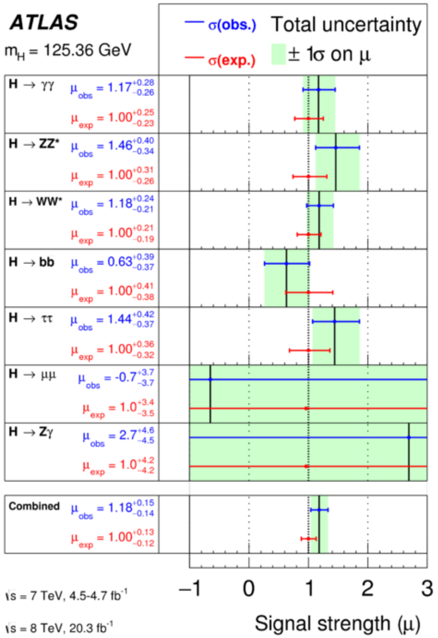


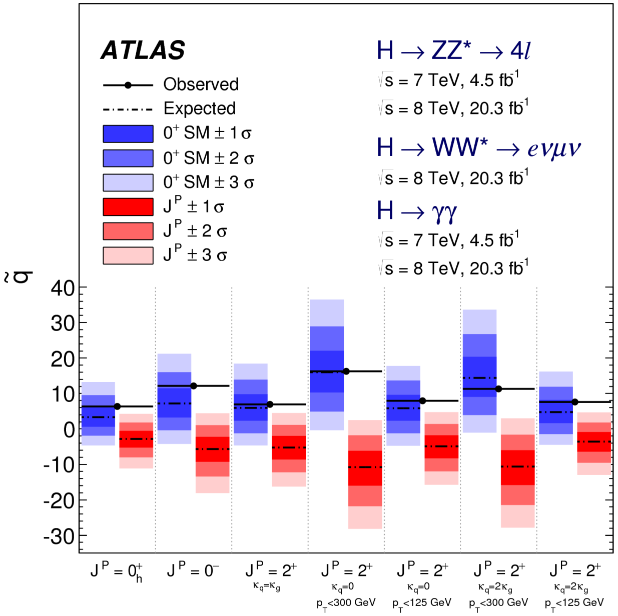
Some Higgs physics highlights

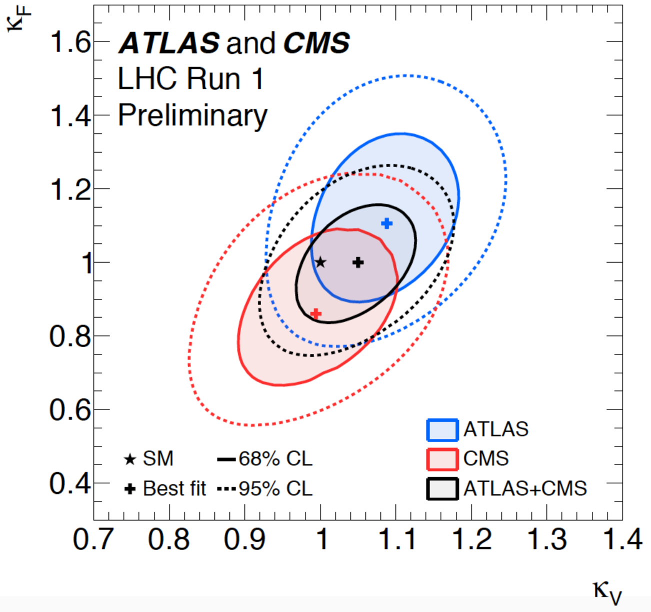




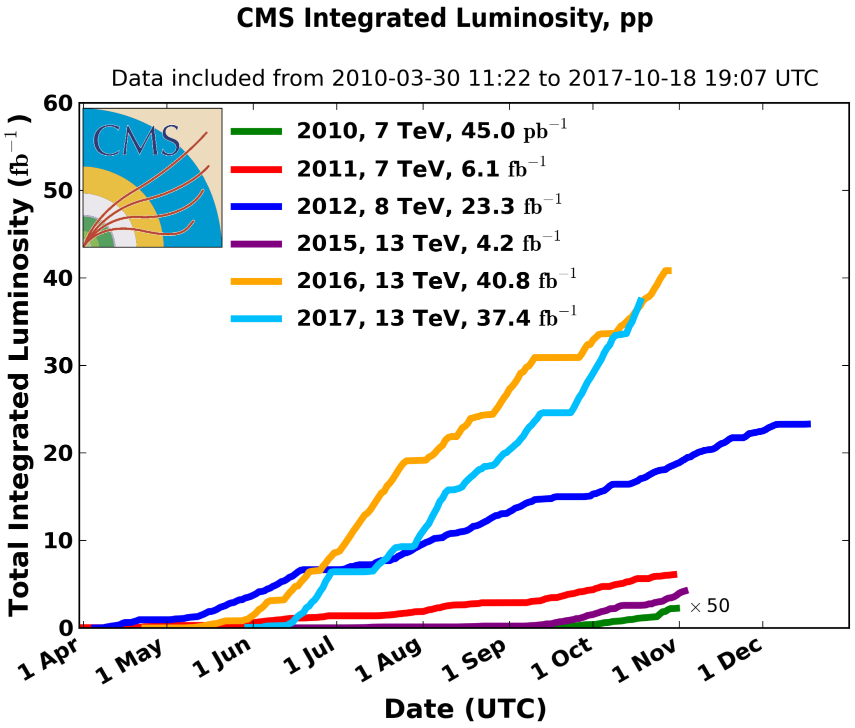


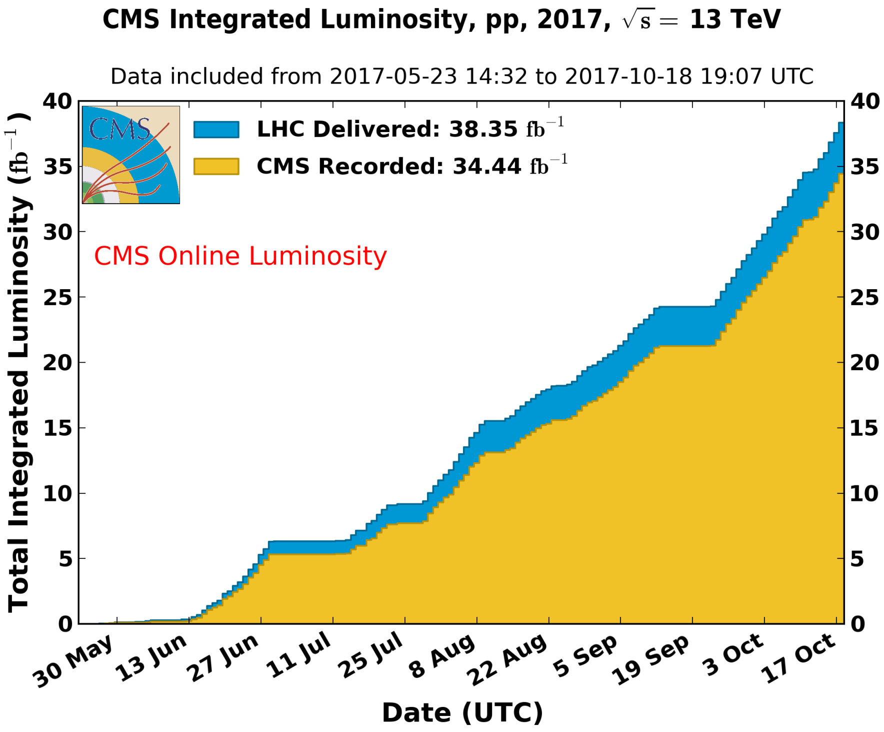






Data taking


CMS Integrated Luminosity, pp
Data included from 2010-03-30 11:22 to 2017-10-18 19:07 UTC
2010, 7 TeV, 45.0 pb^{-1}
2011, 7 TeV, 6.1 fb^{-1}
2012, 8 TeV, 23.3 fb^{-1}
2015, 13 TeV, 4.2 fb^{-1}
2016, 13 TeV, 40.8 fb^{-1}
2017, 13 TeV, 37.4 fb^{-1}
× 50
Total Integrated Luminosity (fb^{-1})
0
10
20
30
40
50
60
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
Date (UTC)


CMS Integrated Luminosity, pp, 2017, $\sqrt{s} =$ 13 TeV
Data included from 2017-05-23 14:32 to 2017-10-18 19:07 UTC
LHC Delivered: 38.35 fb^{-1}
CMS Recorded: 34.44 fb^{-1}
CMS Online Luminosity
Total Integrated Luminosity (fb^{-1})
0
5
10
15
20
25
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30 May
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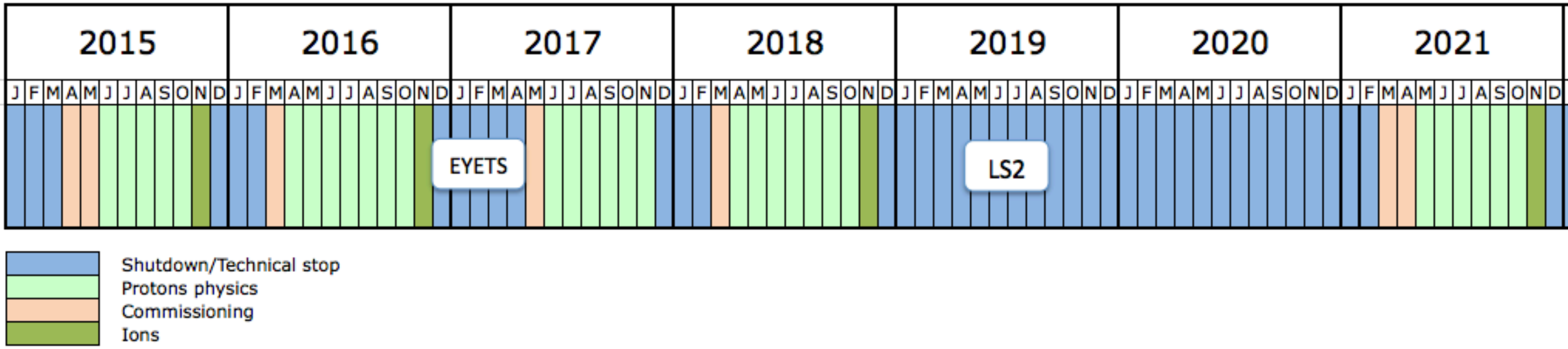
27 Jun
11 Jul
25 Jul
8 Aug
22 Aug
5 Sep
19 Sep
3 Oct
17 Oct
Date (UTC)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J F M A M J J A S O N D
EYETS
LS2
Shutdown/Technical stop
Protons physics
Commissioning
Ions