

CMS at LHC

Diego Barón

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Universidad de Antioquia, Instituto de Física.

Table of contents

1. Motivation.
2. The problem.
3. First LHC.
4. Other experiments at LHC.
5. CMS.

Motivation.

Particle physics experiments can be made studying cosmic rays, solar neutrinos, dark matter in galaxies, etc.

But don't forget accelerators...

This experiments are the most popular because we can control almost all the initial conditions:

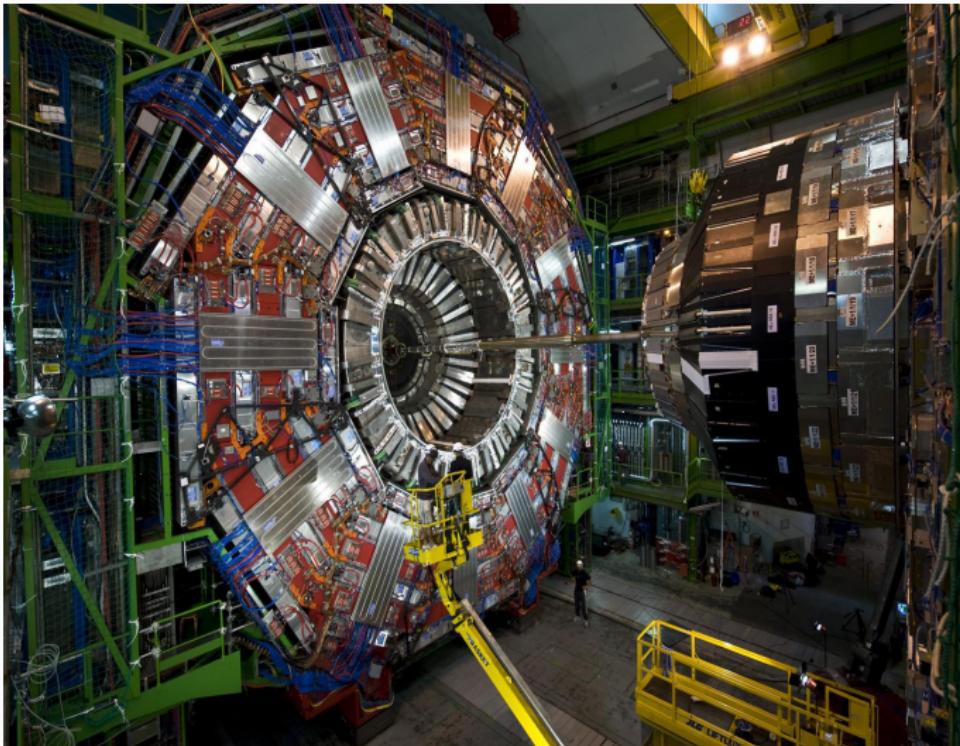
- The particles involved.
- The energy of the beams.
- The geometry of the experiment
- The amount of particles.

Experimental particle physicists must know and understand how experiments works in order to know:

- What to look for.
- And how to.

The problem.

The problem.



The question is...

¿How does CMS at LHC works?

First LHC.

LHC.

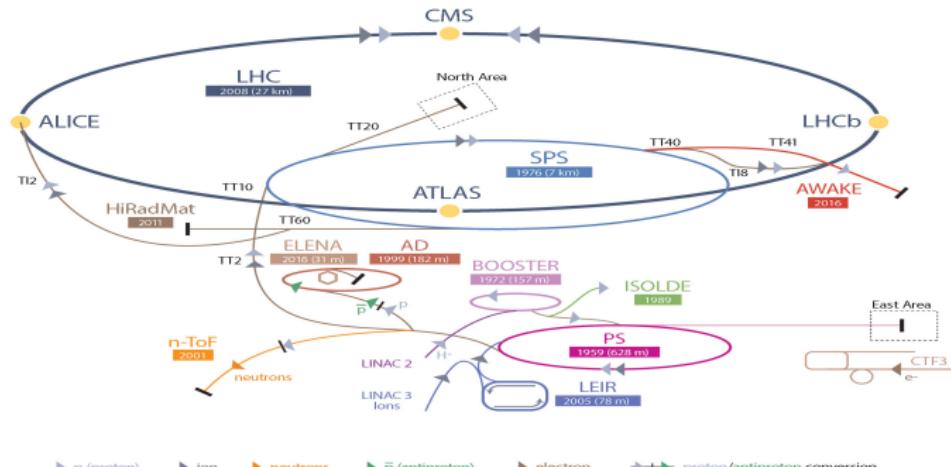
Is the main accelerator managed by CERN (European Organization for Nuclear Research). 21 member states-113 participant countries.

It's the biggest particle collider on Earth:

- 27 km circumference.
- 14 TeV at the center of mass. (8 TeV reached at Run 1)
- 100 m under the ground.
- 4 main experiments (detectors): ALICE,CMS,ATLAS,LHCb

The two principal parts are the injector chain and the main ring.

CERN's Accelerator Complex

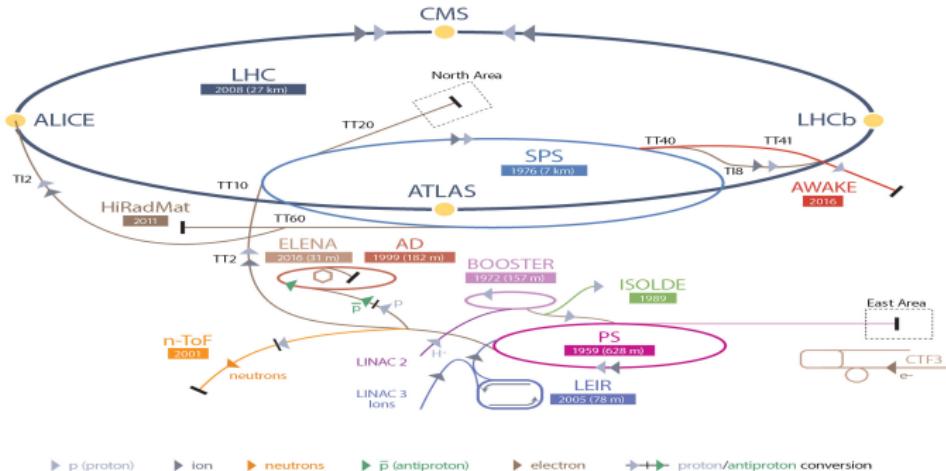


The injector chain.

Before reaching main ring, protons pass by a series of stages:

- Extracted via ionization of Hydrogen in the Duoplasmatron Proton Ion Source.
- Accelerated at 50 MeV in Linac2 (1978).
- Linac2 injects protons in the Proton Synchrotron Booster (PSB) and are accelerated up to 1.4 GeV.
- From PSB, protons are delivered to the Proton Synchrotron (PS) where they reach 28 GeV. They are also split from 6 initial bunches to 72, spaced by 25 ns.
- Finally, the pre-acceleration chain is finished by the SPS, the Super Proton Synchrotron. There, the bunches are accelerated up to 450 GeV.

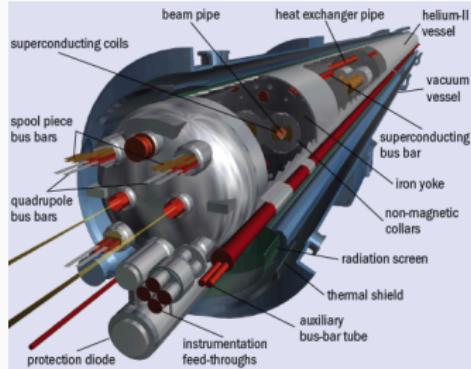
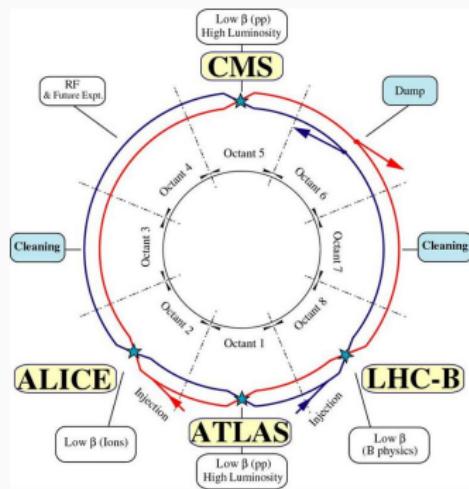
CERN's Accelerator Complex



LHC main ring.

It's composed of two rings that accelerate the proton bunches in opposite directions.
Some characteristics of the design are:

- 15m magnets with a strong magnetic field of 8,33T.
- Superconductivity involved (1.9 K).
- Ultra high vacuum of 10^{-9} mbar.
- In addition LHC has other magnets to correct different characteristics of the beams: 520 quadrupoles, 2464 sextupoles, 1232 octupoles.



LHC main ring.

In collider experiments the main character is Luminosity:

$$L = \frac{k_n N_b^2 f_{rev}}{4\pi\sigma_x\sigma_y} R$$

In LHC design, this parameters have the following values:

Energy[GeV]	7000
Luminosity[cm ⁻² s ⁻¹]	10 ³⁴
k_b Number of bunches	2808
Bunch spacing [ns]	24.95
N_b intensity per bunch [protons/bunch]	1.15 × 10 ¹¹
f_{rev} revolution frequency [kHz]	11.25
$\sigma_x = \sigma_y$ Beam Standard Deviation [cm]	7.7
R Geometric reduction factor	0.8

Cross section of a proton-proton collision at 14 TeV is 100-110 mb, 3 different processes are involved:

- Elastic scattering: Protons exchange momenta but their structure remains unchanged.
- Diffractive scattering: Momenta exchange but additional particles are generated apart from the final protons.
- Inelastic scattering: Partons interchange a big amount of momentum and produce several particles.

LHC RUN 1.

On February 10th of 2013, the first run of LHC reached an end, this is called RUN 1, started on November 20th of 2009. The achieved center of mass energy was $\sqrt{s} = 8 \text{ TeV}$.

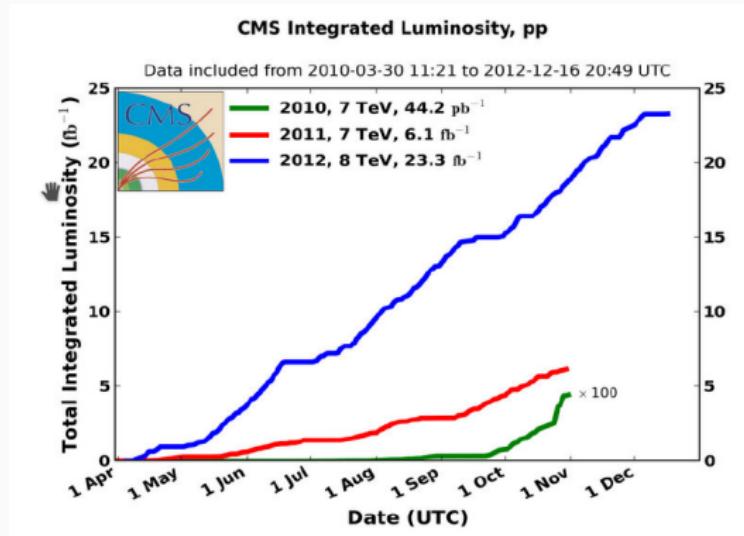
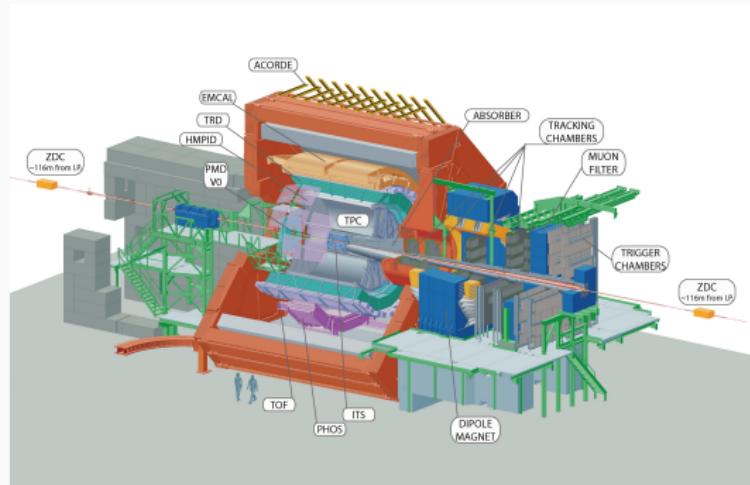


Figure 1: Integrated Luminosity at LHC RUN 1.

Other experiments at LHC.

A Large Ion Collider Experiment is located at point 2 of the LHC main ring.

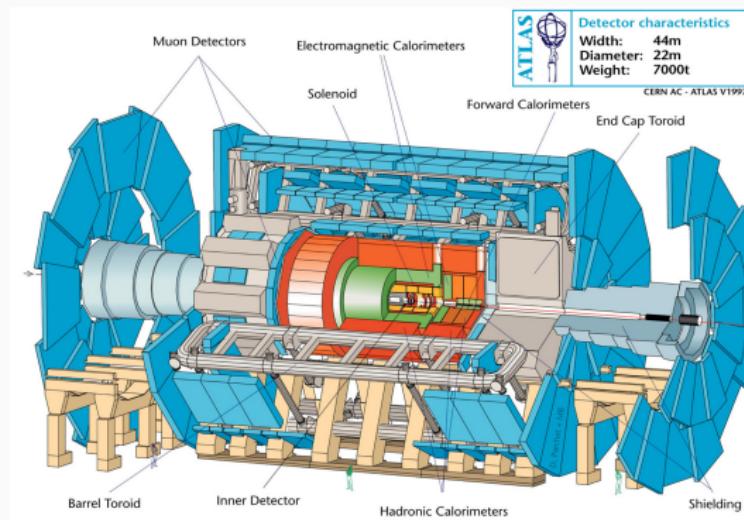
Designed for Heavy Ions Physics.



- $H=16\text{m}, W=16\text{m}, L=26\text{m}$.
 $\text{Weight}=10000 \text{ Tons}$.
- Able to detect an extremely high number of tracks per event.
- Main subsystem: Time projection chamber, a 90 m^3 gas chamber operated in a solenoid of 0.5T .

ALICE collaboration counts around 1500 people from 154 physics institutes in 37 countries.

A Toroidal LHC ApparatuS is the biggest LHC experiment, located at point 1.



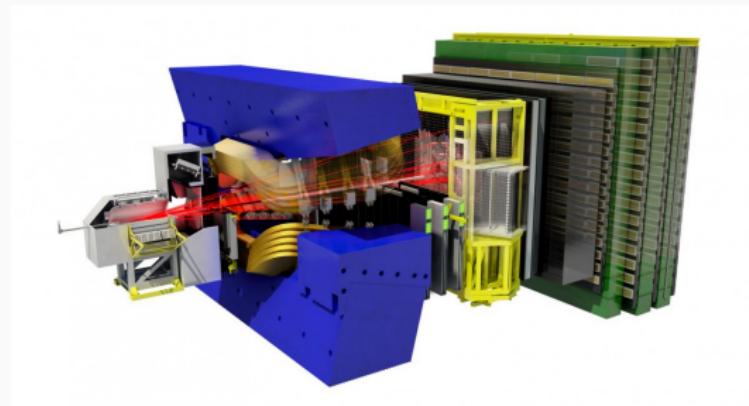
- $H=25\text{m}, L=45\text{m}$.
Weight=7000 Tons.

Its main components are:

- Tracker system.
- EM Calorimeter.
- Hadron calorimeter.
- Muon chambers.

ATLAS collaboration counts around 3000 people from 117 physics institutes in 38 countries.

Located at point 8, it was designed to detect particles produced close to the beam direction. Smaller than CMS and ATLAS and conically shaped.



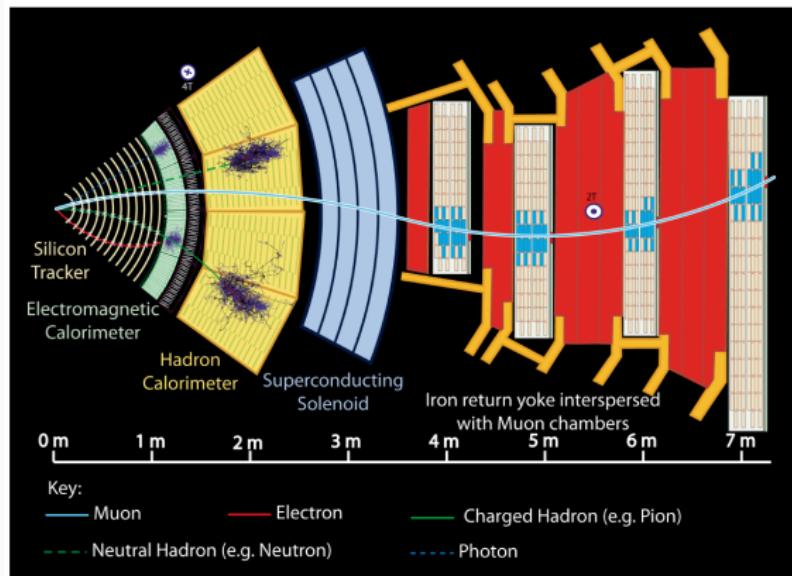
- $H=10\text{m}, L=21\text{m}, W=13\text{m}$.
Weight=4500 Tons.
- It has a system to detect different type of Hadrons.
- Very precise vertex locator system.

LHCb collaboration counts around 700 people from 69 physics institutes in 17 countries.

CMS.

The Compact Muon Solenoid.

Located at point 5, its the second biggest LHC experiment, its called compact because the calorimeters are inside the magnet, and muon solenoid because it has a very precise muon detection system.



- $H=15\text{m}, L=28.7\text{m}$.
Weight = 14000 Tons.
- 3.8T magnetic field.
- The energy of jets with $p_T > 20\text{GeV}/c$ can be measured with 4% uncertainty.

CMS collaboration counts around $3500+3$ people from 181+1 physics institutes in 41 countries.

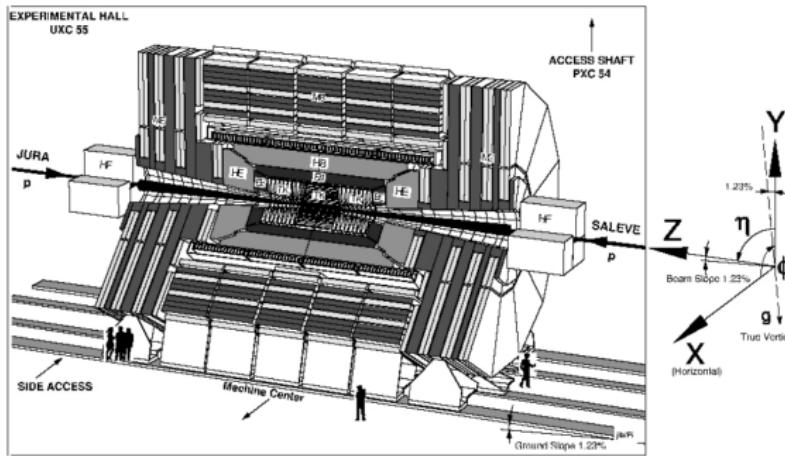
Coordinate system.

The coordinate origin is located at the center of CMS, in the "interaction point".

Z axis: defined in the beam direction, pointing towards Jura mountains.

Y axis: defined towards the zenith. X axis: pointing to the center of LHC ring.

ϕ angle: Defined in x-y plane from x to y. θ angle: Located at z-y plane, from z to y.



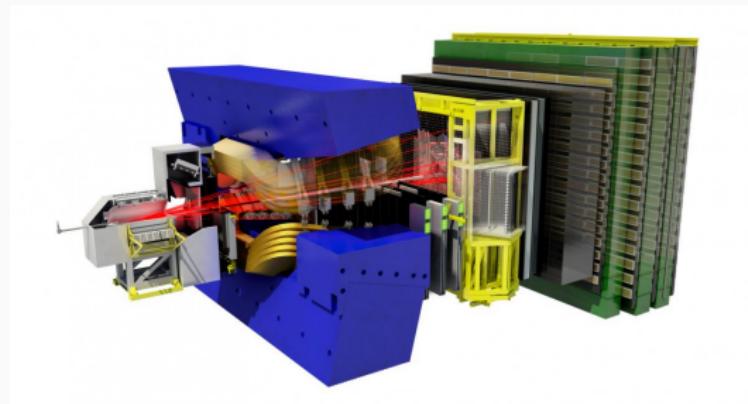
The commonly used momentum variables are:
 p_L Momenta in the z axis.
 p_T Momenta in the x-y plane.

Magnet The CMS has a large solenoid capable of producing a 4T constant magnetic field inside the 6m diameter and 13m long magnet. It weights 12000 and is made of 4 Layers of windings of NbTi cable at 4.45K to achieve superconducting state.

Outside the magnet 5 wheels and 3 disks of iron are placed to return the magnetic flux and inducing an external field of 2T.

Tracker system.

Located at point 8, it was designed to detect particles produced close to the beam direction. Smaller than CMS and ATLAS and conically shaped.

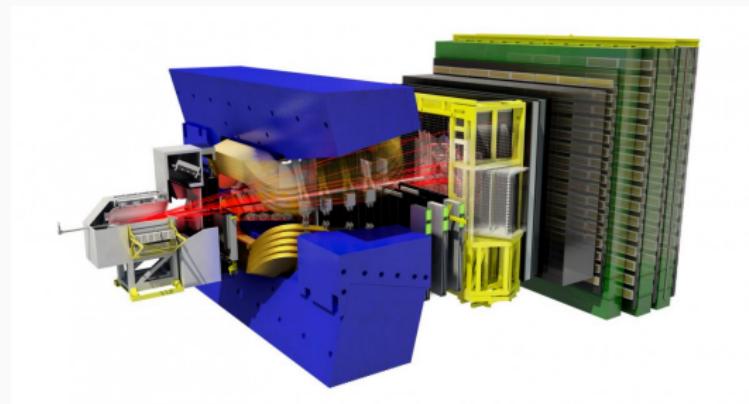


- $H=10m, L=21m, W=13m$.
Weight=4500 Tons.
- It has a system to detect different type of Hadrons.
- Very precise vertex locator system.

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Electromagnetic Calorimeter.

Located at point 8, it was designed to detect particles produced close to the beam direction. Smaller than CMS and ATLAS and conically shaped.

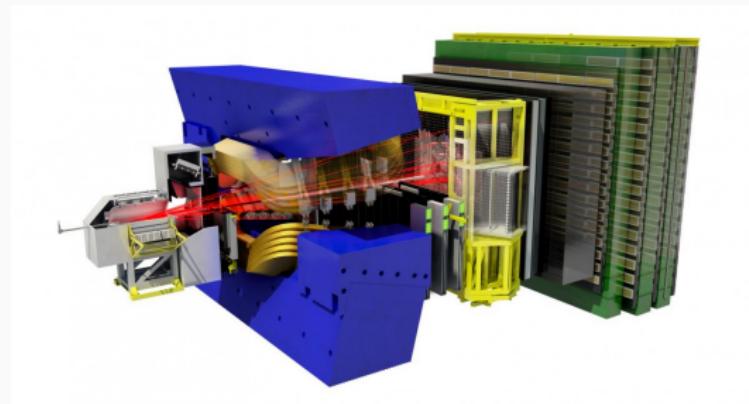


- $H=10\text{m}, L=21\text{m}, W=13\text{m}$.
Weight=4500 Tons.
- It has a system to detect different type of Hadrons.
- Very precise vertex locator system.

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Hadronic Calorimeter.

Located at point 8, it was designed to detect particles produced close to the beam direction. Smaller than CMS and ATLAS and conically shaped.

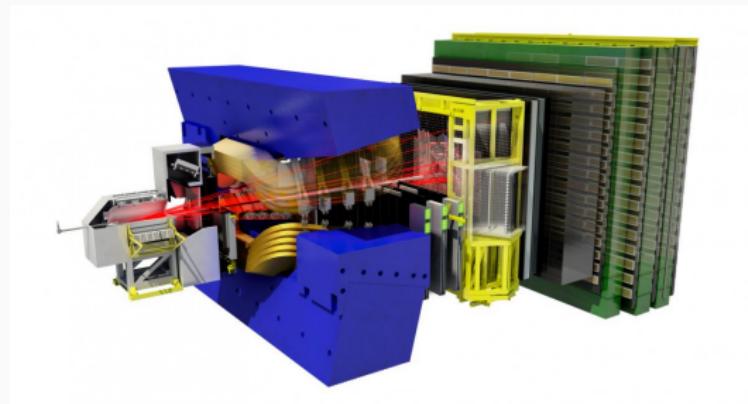


- $H=10m, L=21m, W=13m$.
Weight=4500 Tons.
- It has a system to detect different type of Hadrons.
- Very precise vertex locator system.

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Muon Chambers.

Located at point 8, it was designed to detect particles produced close to the beam direction. Smaller than CMS and ATLAS and conically shaped.



- $H=10m, L=21m, W=13m$.
Weight=4500 Tons.
- It has a system to detect different type of Hadrons.
- Very precise vertex locator system.

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