An introduction to LHC and CMS

21 Tir 91
Hamed Bakhshian
Outline

• LHC
  • What is it?
  • How it works?
  • 2010 Startup
  • Current Status

• CMS
  • Important numbers
  • 2010 data taking
LHC - 1

• Large Hadron Collider

• A high vacuum is required. The pressure in some parts is over $10^{-9}$ Pa.
• Operating temperature: 1.9 K
• Injected beam energy: 450 GeV (protons)
• Nominal beam energy in physics: 4.0 TeV (protons)
• Revolution frequency: 11.2455 kHz.
• Magnetic field at 8 TeV: 8.35 Tesla
1) The collisions at the LHC begin life in a bottle of hydrogen. Protons are extracted from hydrogen.

2) The protons are accelerated first by the LINAC2 accelerator to 50MeV.

3) Then are boosted by the PSB to 1.4GeV.

4) Next they head to the PS and get accelerated to 25GeV.

5) Then on to the SPS where they really pick up speed, 450 GeV.

6) Finally they reach the LHC and go in opposite directions where they will reach 8000GeV (8TeV) in head on collisions in the experiments, ALICE, ALTAS, CMS or LHCb.

7) Filling time is about 4'20". It takes 20 minutes to reach to the nominal energy of 8TeV.
LHC Animation

This video can be downloaded from http://cdsweb.cern.ch/record/1125472/
Total Energy

- Each proton beam at full intensity will consist of 2808 bunches per beam.
- Each bunch will contain $1.15 \times 10^{11}$ protons per bunch at the start of nominal fill.

$$2808 \text{ bunches} \times 1.15 \times 10^{11} \text{ protons} @ 8 \text{ TeV each.} = 2808 \times 1.15 \times 10^{11} \times 8 \times 10^{12} \times 1.602 \times 10^{-19} \text{ Joules} = 415 \text{ MJ per-beam}$$

- Comparing to Tevatron, it's about 280 times larger
- This energy is equivalent to the energy of 150 KG of TNT
- It's enough to melt ~1 tonne of copper
  - If it's not directed well, can damage LHC
- Total Power consumption: ~120 MW
Luminosity I

• It’s a measurement of the number of collisions that can be produced in a detector per cm$^2$ and per second.

• $L \sim f \cdot N^2 / (S_{\text{eff}})$
  - $F$ is the bunches crosses frequency
  - $N$ is Number of protons per bunch
  - $S_{\text{eff}}$ : section effective of collision that depends on the cross section of the bunch (“effective” because the beam profile doesn’t have a sharp edge); the formula for this is given by : $S_{\text{eff}} = 4 \cdot \pi \cdot \sigma^2$

• Luminosity is usually expressed in units of inverse barn per second :
  - 1 barn = $10^{-24}$ cm$^2$

• Total collected data is the integral of the luminosity over time :
  $$L = \int L \, dt$$
Luminosity II

- We can also express the Luminosity in terms of \( \varepsilon \) (emittance) and \( \beta \) (amplitude function) as:

\[
L = f \cdot N^2 / (4 \cdot \varepsilon \cdot \beta^*)
\]

- Transverse emittance, \( \varepsilon \), is a beam quality concept reflecting the process of bunch preparation (the injector chain), extending all the way back to the source for hadrons. A low emittance particle beam is a beam where the particles are confined to a small distance and have nearly the same momentum.

- The amplitude function, \( \beta \), is determined by the accelerator magnet configuration (basically, the quadrupole magnet arrangement) and powering.
Luminosity III (Values over time)

- The energy of each beam and N Protons per bunch reached to the nominal values very soon.
- Two important parameters that are still far from nominal values are N Bunches per beam and $\beta$.

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>0.6 m</td>
<td>0.55 m</td>
</tr>
<tr>
<td>N Bunches</td>
<td>1380</td>
<td>2808</td>
</tr>
<tr>
<td>Luminosity</td>
<td>7e33</td>
<td>1e34</td>
</tr>
</tbody>
</table>

Cross sections of some physical processes:

<table>
<thead>
<tr>
<th>Process</th>
<th>Xsection (pb)</th>
<th>Nevents so far (6 fb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wjets$\rightarrow$lnu</td>
<td>36250</td>
<td>217.5 M</td>
</tr>
<tr>
<td>Z $\rightarrow$ ll</td>
<td>3503</td>
<td>21 M</td>
</tr>
<tr>
<td>TTbar</td>
<td>225.2</td>
<td>1.35 M</td>
</tr>
<tr>
<td>Higgs 125GeV</td>
<td>~20</td>
<td>12000</td>
</tr>
<tr>
<td>SUSY LM5</td>
<td>1.879</td>
<td>282</td>
</tr>
</tbody>
</table>

All calculations need PDF of proton as input.
Keep updated

To see the current status of LHC, go to:

When LHC sets world record beam intensity
Compact Muon Solenoid

- Total weight: 12500 tonnes
- Diameter: 15m
- Length: 21.6m
- Magnetic field: 4 Tesla
Solenoid

• A solenoid is essentially a cylinder of wire. Passing an electric current down the wire creates a magnetic field
• The CMS solenoid is designed to provide an axial magnetic field of 4 teslas – about 100000 times that of the earth
• The current required is ~20 k amperes → need to use a superconducting wire (zero resistance)
• The superconductor chosen is Niobium Titanium (NbTi) wrapped with copper – needs to be cooled to ~4K
• The CMS solenoid is 13m long with an inner diameter of 5.9m
• The solenoid is sufficiently large that the tracking and all central calorimeters can fit inside
  • Charged particles only bend in one projection (looking along the beam line)
ATLAS vs. CMS

ATLAS: Toroidal LHC Apparatus

CMS: Compact Muon Solenoid
Tracker

- Largest silicon-sensor system ever made
  - More than 220m$^2$ of sensors
  - More than 60 million electronics channels (pixels and microstrips)
  - 6m long, ~2.2m diameter, operates at -15°C
Calorimeter

**ElectroMagnetic**
- Lead tungstate (PbWO$_4$) crystals create electromagnetic showers and produce scintillation light
- Barrel: ~64000 crystals
- Endcaps: ~16000 crystals

**Hadron**
- Barrel HCAL made of 36 brass wedges, each of which is ~35 tonnes
- Endcap HCAL made from brass recuperated from Russian military
- Forward HCAL (known as HF) made from steel embedded with quartz fibres
The CMS Animation
Physics Object Reconstruction

- **Electron**
  - Find the hits in Ecal crystals, make the clusters
  - Find the tracks using the hits in tracker
  - If a cluster in Ecal matches a track, it's a candidate for an electron
  - An electron from a physical process should be isolated

- **Photons**
  - An electron with no track (!!!)

- **Muon**
  - Match two tracks from Muon system and inner tracker
Reconstruction, a work in progress

- Inefficiency in reconstruction
  - Some of the objects can't be reconstructed well
- Impurities in reconstruction
  - Some objects are reconstructed by mistake
  - For example: a real electron always passes the jet reconstruction criteria and fakes as a jet
  - Taus and jets are also barely indistinguishable
- The value of these inefficiencies and impurities are important to claim a discovery ...
- The collaboration works to improve the algorithms
CMS and 2012 data taking

CMS Total Integrated Luminosity, 2012, p-p, $\sqrt{s} = 8$ TeV
Data included from 2012-04-04 23:57:30 to 2012-07-10 05:36:43 UTC

- LHC Delivered: 7.21 fb$^{-1}$
- CMS Recorded: 6.67 fb$^{-1}$