CMS Masterclasses 2017
S’Cool LAB

Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil

Total weight 12500 t, Overall diameter 15 m, Overall length 21.6 m, Magnetic field 4 Tesla
It’s a time of exciting new discoveries in particle physics!

At CERN, the LHC successfully completed Run I at 8 TeV of collision energy, confirming that the measurements correspond well to the **Standard Model** and then finding the Higgs boson. The LHC is now into Run II at an amazing 13 TeV and the task is to look for new phenomena… and we are off to a great start.
The LHC is buried ~100 m below the surface near the Swiss-French border.

beams accelerated in large rings (27 km circumference at CERN)

Experiments where beams cross and some particles collide

particle source (injector)
Generic Design
Cylinders wrapped around the beam pipe
From inner to outer…
• Tracking
• Electromagnetic calorimeter
• Hadronic calorimeter
• Magnet*
• Muon chamber

* Localization of magnet depends of specific detector design
Detectors

- Fixed Target
- Collider
Muons are perhaps the easiest particles to identify in CMS: no other charged particle traverses the whole detector. Being charged, they are bent by the field in one direction inside the solenoid and in the opposite direction outside. As muons can only arise from the decay of something heavier their presence signifies that something potentially interesting has happened.

Derived from CMS Detector Slice from CERN
Electron signature: Signals in the Tracker and the ECAL; nothing in the HCAL or muon chambers.
These electrically charged particles bend in the field and leave signals in the Tracker, enabling their paths to be reconstructed. The amount of bend depends on the momentum they carry, with the radius of curvature, $r$, being given by the momentum, $p$, divided by $0.3B$, where $B$ is the magnetic field strength (3.8T in CMS). Electrons are slowed to a stop in the transparent lead tungstate crystals of the ECAL, producing a shower of electrons, photons and positrons along the way and depositing their energy in the form of light, which is detected. The amount of light is proportional to the electron energy.
Transverse Slice of the Compact Muon Solenoid (CMS) Detector

Photon signature: Signal in the ECAL only, nothing in Tracker, HCAL or muon chambers. Being electrically neutral, photons pass through the Tracker undetected and not bent by the magnetic field. They interact in the ECAL in a similar way to electrons, producing electromagnetic showers that leave their energies in the form of light that is detected.
We will look at Run I, in which proton energy is 4 TeV*.  
- The total collision energy is $2 \times 4 \text{ TeV} = 8 \text{ TeV}$.  
- But each particle inside a proton shares only a portion.  
- So a newly created particle’s mass must be smaller than the total energy.

*In Run II, this was increased to 6.5 GeV!
The collisions create new particles that promptly decay. Decaying particles always produce lighter particles.

Conservation laws allow us to see patterns in the decays.

Try to name some of these conservation laws.
Often, quarks are scattered by proton collisions.

As they separate, the binding energy between them converts to sprays of new particles called jets. Electrons and muons may be included in jets.

Software can filter out events with jets beyond our current interest.
We are looking for the mediators of the \textit{weak interaction}:

- electrically charged $W^+$ \textit{boson},
- the negative $W^-$ \textit{boson},
- the neutral $Z$ \textit{boson}.

Unlike electromagnetic forces carried over long distances by massless photons, the weak force is carried by massive particles which restricts interactions to very tiny distances.
The W bosons are responsible for radioactivity by transforming a proton into a neutron, or the reverse.

Z bosons are similarly exchanged but do not change electric charge.

Collisions of sufficient energy can create W and Z or other particles.
The W bosons are responsible for radioactivity by transforming a proton into a neutron, or the reverse.

Z bosons are similarly exchanged but do not change electric charge.

Collisions of sufficient energy can create W and Z or other particles.
The Higgs boson was discovered by CMS and ATLAS and announced on July 4, 2012.

This long-sought particle is part of the “Higgs mechanism” that accounts for other particle having mass.
The Higgs boson was discovered by CMS and ATLAS and announced on July 4, 2012.

This long-sought particle is part of the “Higgs mechanism” that accounts for other particle having mass.
Because bosons only travel a tiny distance before decaying, CMS does not “see” them directly.

CMS can detect:
- electrons
- muons
- photons

CMS can infer:
- neutrinos from “missing energy”
QuarkNet

iSpy-webgl

Helping Develop America’s Technological Workforce

Detector
- Tracker Barrels
- Tracker Endcaps
- ECAL Barrel
- ECAL Endcap (+)
- ECAL Endcap (-)
- HCAL Barrel
- HCAL Endcaps
- HCAL Outer
- HCAL Forward (+)
- HCAL Forward (-)
- Drift Tubes
- Cathode Strip Chambers

event display controls

event vertex (near collision)

missing energy

energy deposit

electron track

beamline

ECAL=blue wireframe  HCAL=yellow wireframe  tracker inside ECAL
Use new data from the LHC in iSpy to test performance of CMS:
• Can we distinguish $W$ from $Z$ candidates?
Can we calculate the $e/\mu$ ratio?
• Can we calculate a $W^+/W^-$ ratio for CMS?
Today’s Task

- Can we make mass plot of Z candidates?
• Can we find rare $H \rightarrow ZZ$ events?
  • $Z \rightarrow e^+e^-$
  • $Z \rightarrow \mu^+\mu^-$

Can we pick out electrons and/or muons?

How should an event be filtered so we can recognize the correct tracks?
• Can we find some $H \rightarrow \gamma \gamma$ events?

How do we spot photons that leave no track?

Where should we look? What should we see – and not see?
Recording event data

Find your dataset.

Record parent particles and decay modes.
Recording event data

Mass Histogram and Results pages

Data chosen by other groups from the same institute.

Choose an event close to 51 GeV mass by clicking "51".

Total:

<table>
<thead>
<tr>
<th>Group</th>
<th>Electron</th>
<th>Wc</th>
<th>Z+</th>
<th>Z−</th>
<th>Wc^-</th>
<th>Z+</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
“Science is nothing but developed perception, interpreted intent, common sense rounded out and minutely articulated.” George Santayana

• Indirect observations and imaginative, critical, logical thinking can lead to reliable and valid inferences.
• Therefore: work together, think (sometimes outside the box), and be critical of each other’s results to figure out what is happening.

Form teams of two. Each team analyzes 100 events. Talk with physicists about interpreting events. Pool results.