

Introduction to CMS Open Data

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CERN 21.02.2017

Acknowledgements

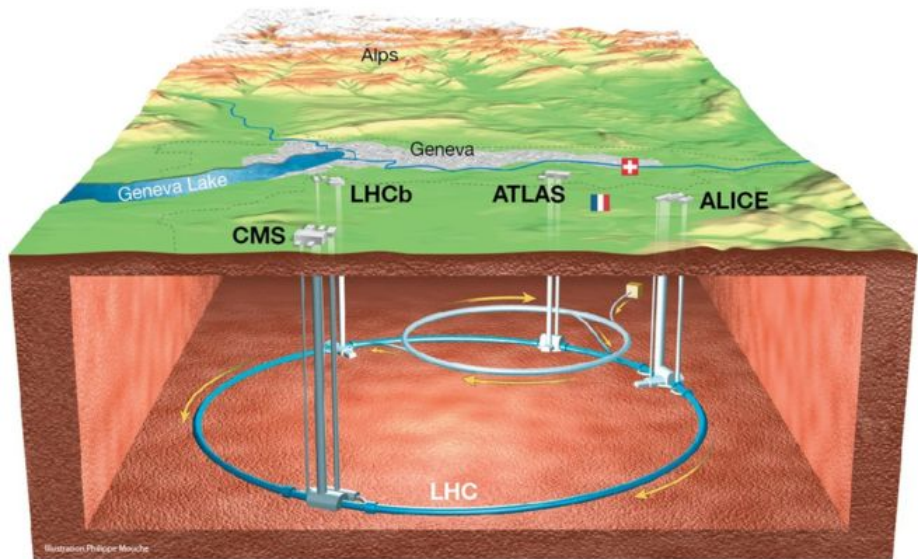
Material shown in this presentation comes from

- CERN Open Data Portal and contributors [▶ Go](#)
- Paavo Rikkilä (a future physics teacher, trainee at CERN and HIP)
- Project coder [▶ \(more\)](#)
- Working group 5 of the CERN High-School Physics Teacher course July 2016 [▶ \(more\)](#)

Great thanks to all of them!



LHC at CERN





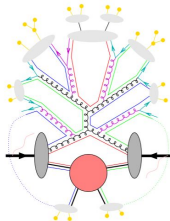
Figures: The particle zoo

Particle collisions

From

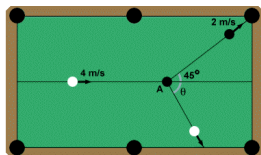


Photo credits: Manatari

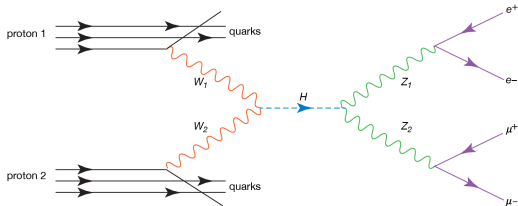


Zeppenfeld - Lecture

to



SparkNotes Editors. (n.d.). SparkNote on Linear Momentum: Collisions. Retrieved February 20, 2017.



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Encyclopedia britannica

/Higgs/4lepton.ig:Events/Run_178424/Event_66626491

The image shows a 3D visualization of the CMS detector. The detector is represented by a green wireframe cylinder. A central collision point is shown with a dense cluster of tracks in various colors (blue, green, orange, red). Several tracks are highlighted in red and extend outwards, passing through various detector components. The components are shown as red wireframe boxes. A 3D coordinate system with x, y, and z axes is visible in the bottom right corner.

Detector Model ?

- Tracker Barrels
- Tracker Endcaps
- ECAL Barrel
- ECAL Endcaps
- ECAL Preshower
- HCAL Barrel
- HCAL Endcaps
- HCAL Outer
- HCAL Forward
- Drift Tubes (muon)
- Cathode Strip Chambers (muon)
- Resistive Plate Chambers (muon)

Tracking ?

- Tracks (reco.)
- Clusters (Si Pixels)
- Clusters (Si Strips)
- Rec. Hits (Tracking)

ECAL ?

- Barrel Rec. Hits ▷
- Endcap Rec. Hits ▷
- Preshower Rec. Hits ▷

HCAL ?

- Barrel Rec. Hits ▷
- Endcap Rec. Hits ▷
- Forward Rec. Hits ▷
- Outer Rec. Hits ▷

Muon ?

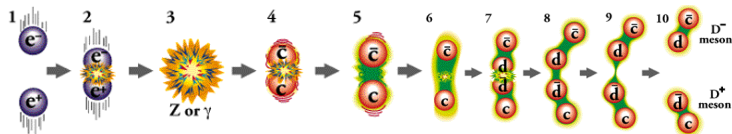
Controls:

- rotate
- Ctrl** + → pan x/y
- Ctrl** + → pan x/y
- Shift** + → zoom
- Shift** + → zoom

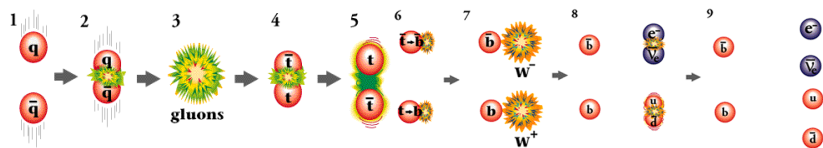
What happens in a collision?

Examples:

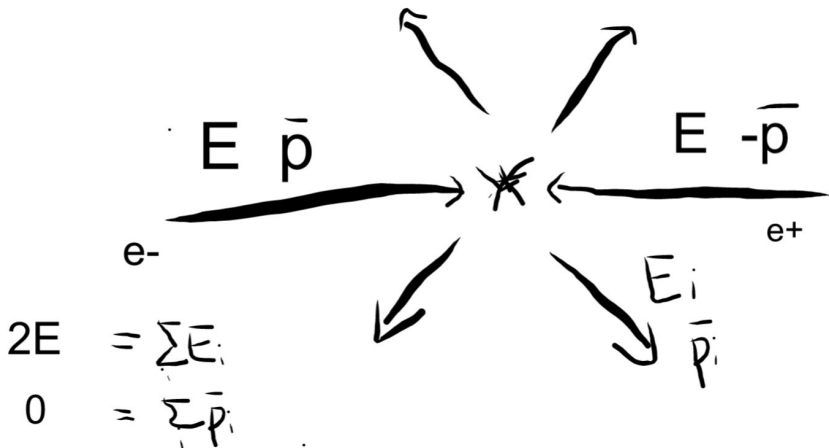
- Electron-positron collision

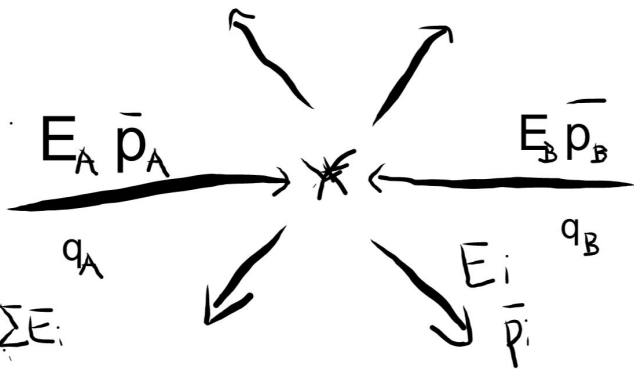


- Proton-(anti)proton collision



Figures: The Particle Adventure





$$? = E_A + E_B = \sum E_i$$

$$? = \vec{p}_A + \vec{p}_B = \sum \vec{p}_i$$

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 ($100 \times 150 \mu\text{m}$) $\sim 16\text{m}^2$ $\sim 66\text{M}$ channels
 Microstrips ($80 \times 180 \mu\text{m}$) $\sim 200\text{m}^2$ $\sim 9.6\text{M}$ channels

SUPERCONDUCTING SOLENOID

Niobium titanium coil carrying $\sim 18,000\text{A}$

MUON CHAMBERS

Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
 Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER

Silicon strips $\sim 16\text{m}^2$ $\sim 137,000$ channels

FORWARD CALORIMETER

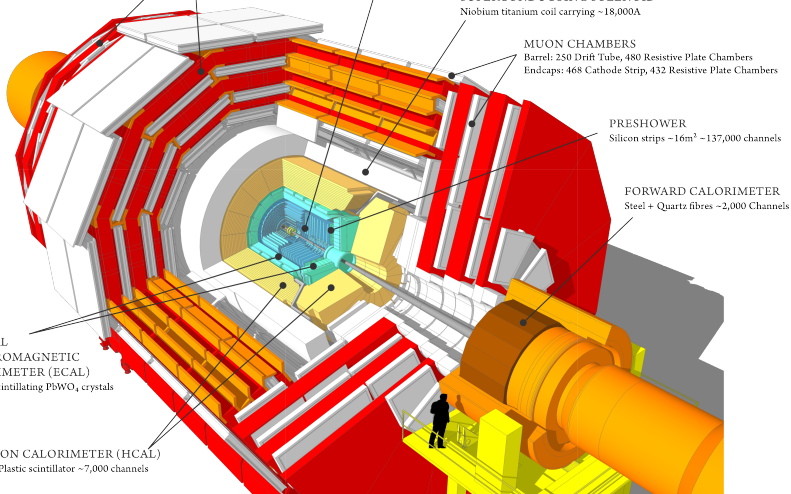
Steel + Quartz fibres $\sim 2,000$ Channels

CRYSTAL
ELECTROMAGNETIC
CALORIMETER (ECAL)

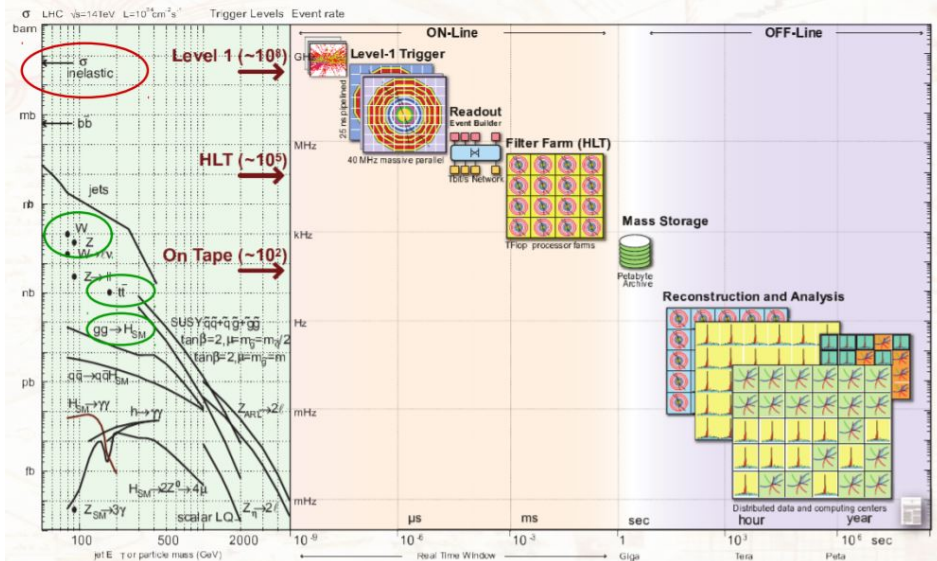
$\sim 76,000$ scintillating PbWO_4 crystals

HADRON CALORIMETER (HCAL)

Brass + Plastic scintillator $\sim 7,000$ channels



How do we get the data?



Andrea Bocci - Triggers for LHC Physics



What do the data look like?

CMS-Open-Data-1.2.0 [Running] - Oracle VM VirtualBox
 File Machine View Input Devices Help
 Applications Menu ROOT Object Browser Terminal - cms-openda... Terminal - cms-openda... Terminal - cms-openda... 19:11

ROOT Object Browser
 Browser File Edit View Options Tools Help

Files | Draw Option:

- extra1 JetPartSides_1extraPartSides_Tau_REC0.
- extra1 MuonPartSides_1extraPartSides__RECO.
- recoBasicJets_ak7BasicJets__RECO.
- recoCaloClusters_hyEMClusters__RECO.
- recoCaloClusters_hybridSuperClusters_hybridBarrelBasicClusters_REC0.
- recoCaloClusters_mkt5SuperClusters_mkt5S5ErknapBasicClusters_REC0.
- recoCaloClusters_phElectronTranslator_phElectronTranslator__RECO.
- recoCaloClusters_phPhotonTranslator_phPhotonTranslator__RECO.
- recoCaloClusters_hybridSuperClusters_uncleanedOnlyHybridBarrelBasicClusters_REC0.
- recoCaloJets_ak4CaloJets__RECO.
- recoCaloJets_ak7CaloJets__RECO.
- recoCaloJets_JH4CaloJets__RECO.
- recoCaloJets_H5CaloJets__RECO.
- recoCaloMETs_corMetGlobalMeans__RECO.
- recoCaloMETs_mkt5__RECO.
- recoCaloMETs_mkt5HO__RECO.
- recoCaloMETs_mkt5HF__RECO.
- recoCasterTowers_CasterTowerReco__RECO.
- recoConversions_akConversions__RECO.
- recoConversions_conversions__RECO.
- recoConversions_uncleanedOnlyAllConversions__RECO.
- recoConversions_phPhotonTranslator_phPhotonTranslator__RECO.
- recoGfElectrons_gfElectrons__RECO.
- recoGfElectrons_gfElectrons__RECO present
- recoGfElectrons_gfElectrons__RECO obj
 - recoGfElectrons_gfElectrons__RECO obj.eph3
 - recoGfElectrons_gfElectrons__RECO obj.eph4
 - recoGfElectrons_gfElectrons__RECO obj.eph5
 - recoGfElectrons_gfElectrons__RECO obj.eph6
 - recoGfElectrons_gfElectrons__RECO obj.eph7
 - recoGfElectrons_gfElectrons__RECO obj.eph8
 - recoGfElectrons_gfElectrons__RECO obj.eph9
 - recoGfElectrons_gfElectrons__RECO obj.eph10
 - recoGfElectrons_gfElectrons__RECO obj.eph11
 - recoGfElectrons_gfElectrons__RECO obj.eph12

Canvas_1 Editor 1
 recoGsfElectrons_gsfElectrons__RECO.obj.pt_

htemp
 Entries 23388
 Mean 32.94
 RMS 32.13

recoGsfElectrons_gsfElectrons__RECO.obj.pt_

Command |
 Command (local):

Filter: All Files (*.*)

CTRL DROITE

How can **you** look at the data?

- 1 Visualize particle collisions: [▶ Go](#)
 - ▶ Immediate, right in your browser, possibly in your phone
 - ▶ Minimum time 15 min
 - ▶ Any level
- 2 Study simplified data derived from the original data
 - ▶ Use spread-sheets, scilab, or python in jupyter notebooks
 - ★ [▶ Teachers](#) [▶ Excel for students](#) [▶ Excel instructions](#) [▶ SciLAB instructions](#)
 - ★ [▶ Getting started with Jupyter](#) [▶ Learning material in Finnish](#)
 - ▶ Minimum time estimated 1.5 hours, for a quick online view: [▶ Go](#)
 - ▶ High-school level
- 3 Analyse data like a physicist
 - ▶ Download the virtual machine image [▶ Go](#)
 - ▶ Run an example code (C++, python) [▶ Go](#)
 - ▶ Minimum time <1 hour to get started (copy-paste), but much longer to learn about data analysis
 - ▶ University level

Some important concepts for particle data analysis

- We search and/or measure short-lived particles which cannot be directly observed
 - ▶ Observe their decay products.
- Rely on quantities that stay constant (initial state - final state):
 - ▶ Conservation laws (energy - momentum)
 - ▶ Invariant mass: $m = \sqrt{(E_1 + E_2)^2 - |\vec{p}_1 + \vec{p}_2|^2}$
- Many similar or similar looking signatures
 - ▶ Signal - background
 - ▶ Examples: Higgs boson decaying into ▶ two photons ▶ four leptons
- Statistical analysis requires a lot of data.

