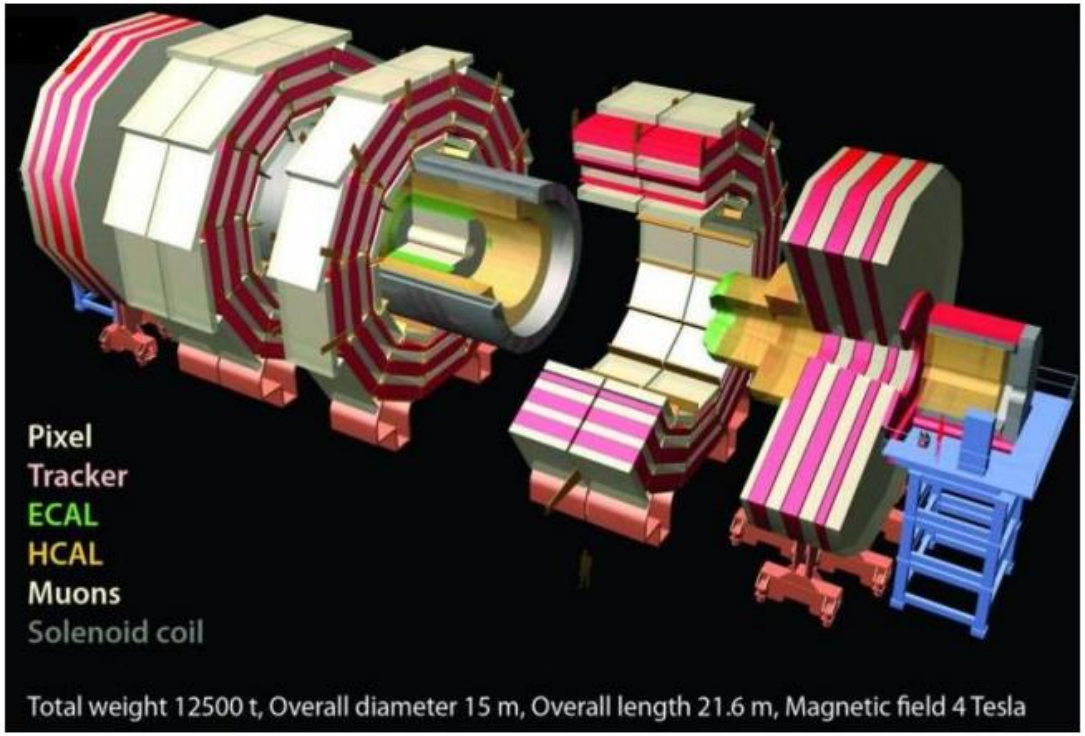
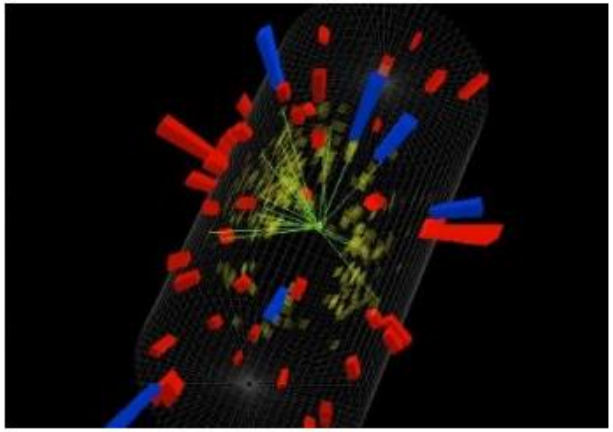
CMS WZH Masterclass





INTERNATIONAL MASTERCLASSES
hands on particle physics

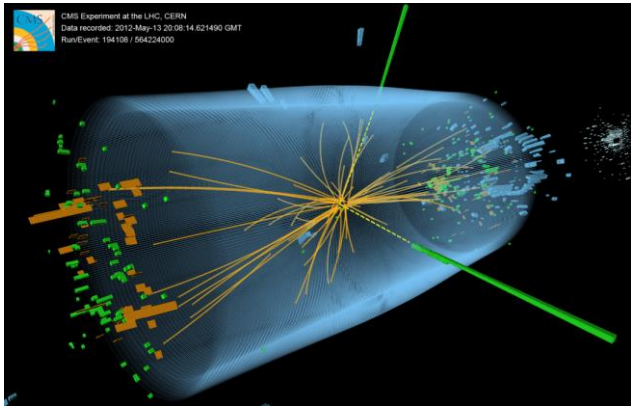
Fermilab

UNIVERSITY OF NOTRE DAME

The LHC and the new physics

It is a time of exciting new discoveries in particle physics.

At CERN, the LHC successfully completed Run 1 at 8 TeV of collision energy, confirming that the measurements correspond well to the Standard Model and then finding the Higgs boson.

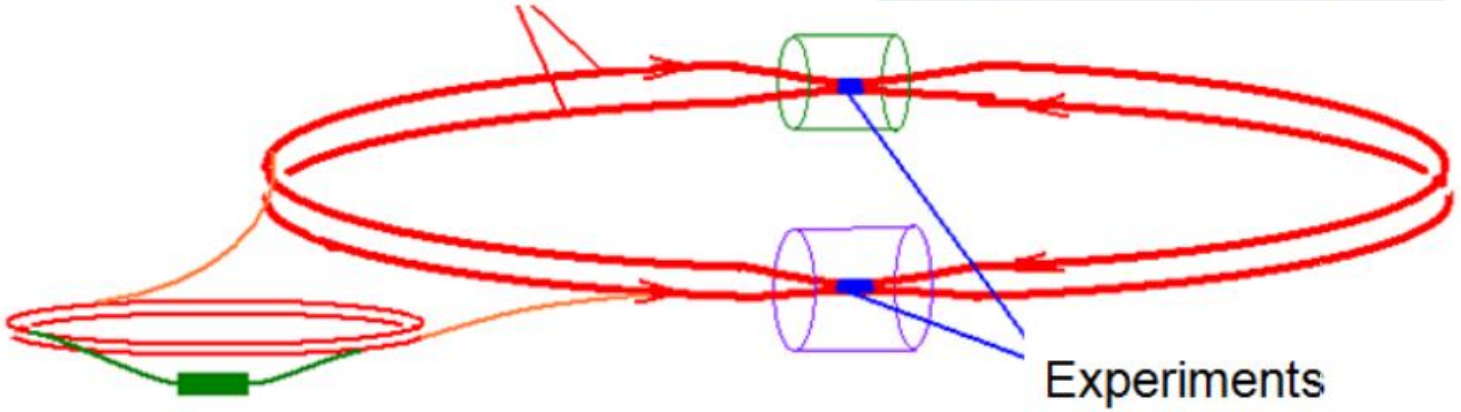


The LHC has now completed Run 2 at 13 TeV, and is shut down in order to make upgrades for Run 3, which is scheduled to begin in 2022.

The LHC and the new physics

The LHC is buried ~100 m below the surface near the Swiss-French border.

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



particle source
(injector)

Experiments
where beams cross and
some particles collide

The LHC and the new physics

Generic Design

Cylinders wrapped around the beam pipe

From inner to outer . . .

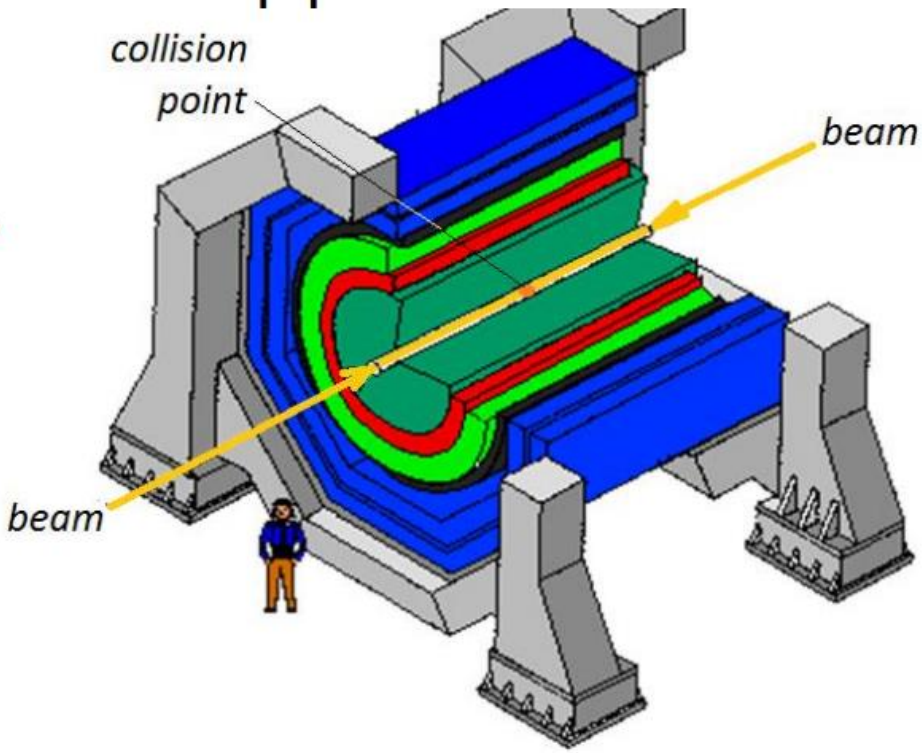
Tracking

Electromagnetic calorimeter

Hadronic calorimeter

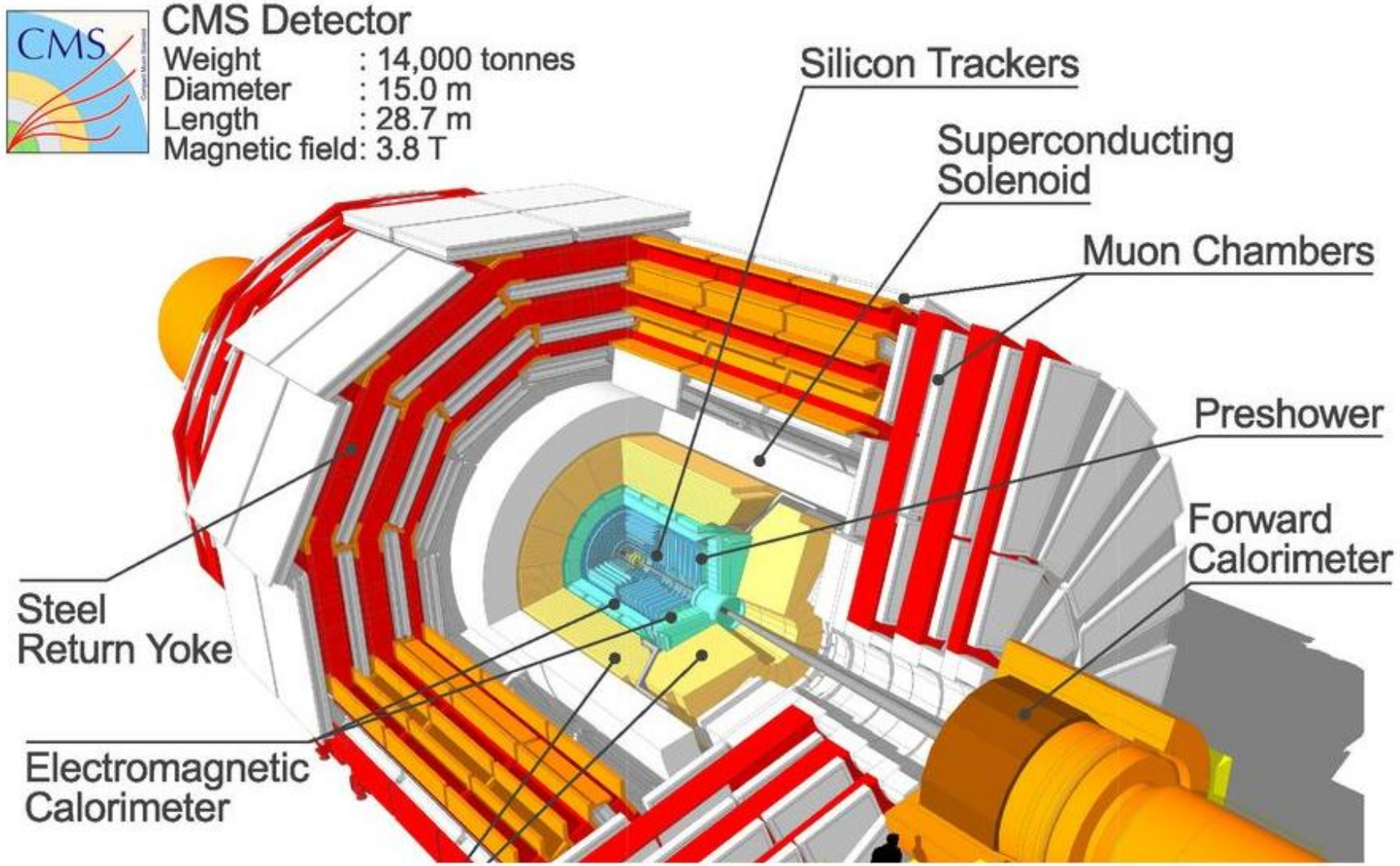
Magnet*

Muon chamber



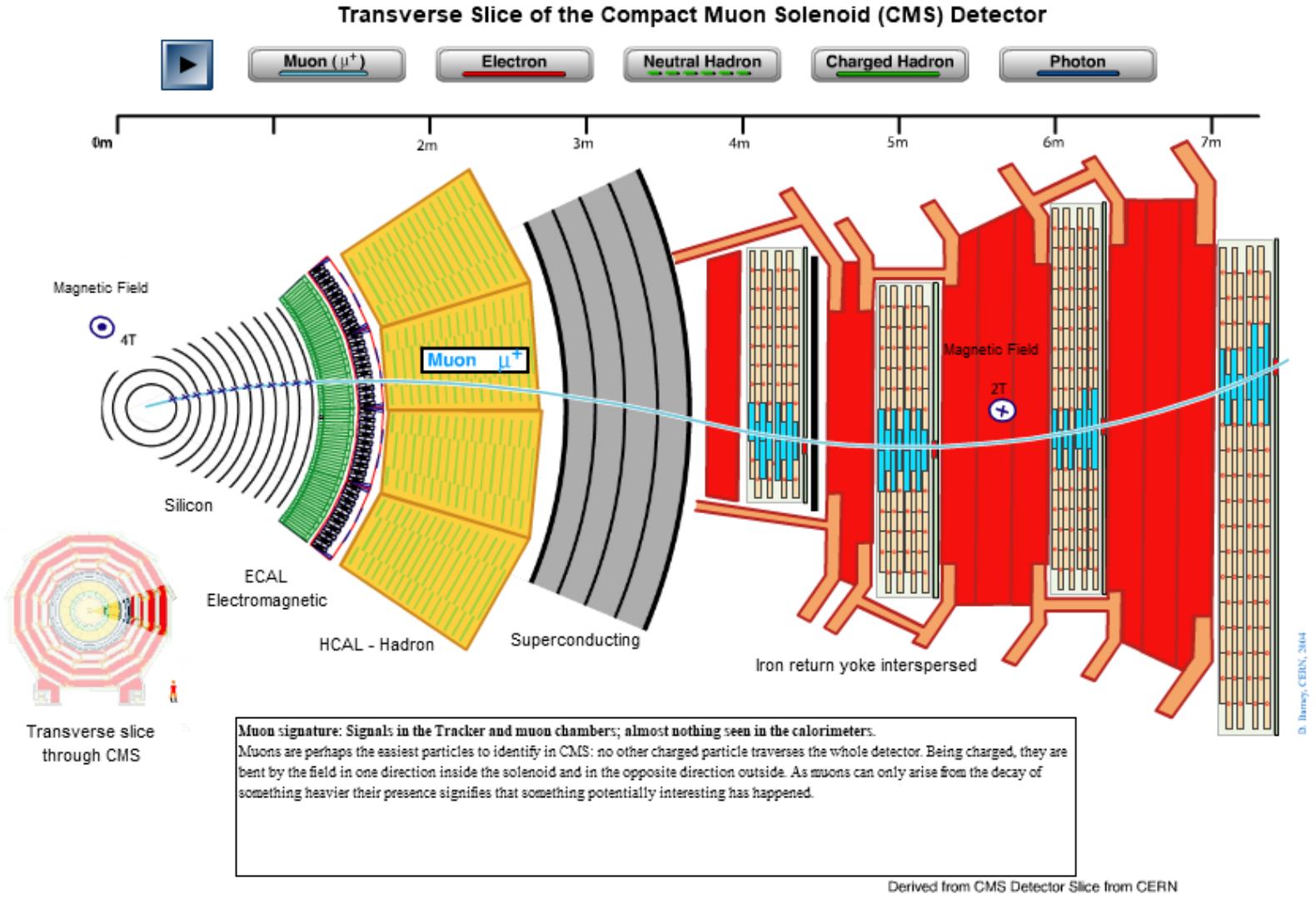
* *location of magnet depends on specific detector design*

The Compact Muon Solenoid (CMS)



Let's take a closer look at the real thing.

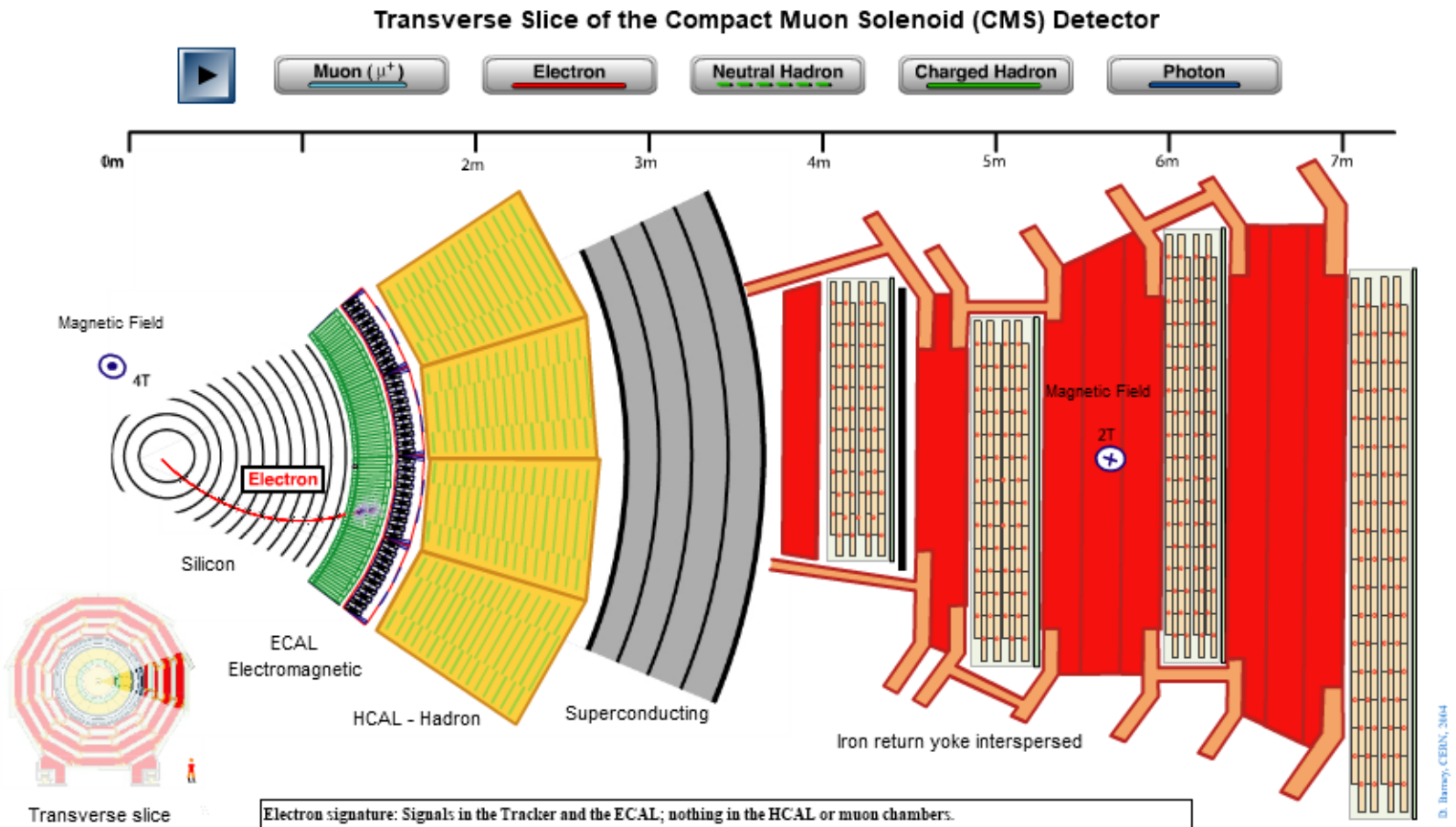
Leptons in CMS



Muon signature: Signals in the Tracker and muon chambers; almost nothing seen in the calorimeters.
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

Leptons in CMS



Transverse slice through CMS

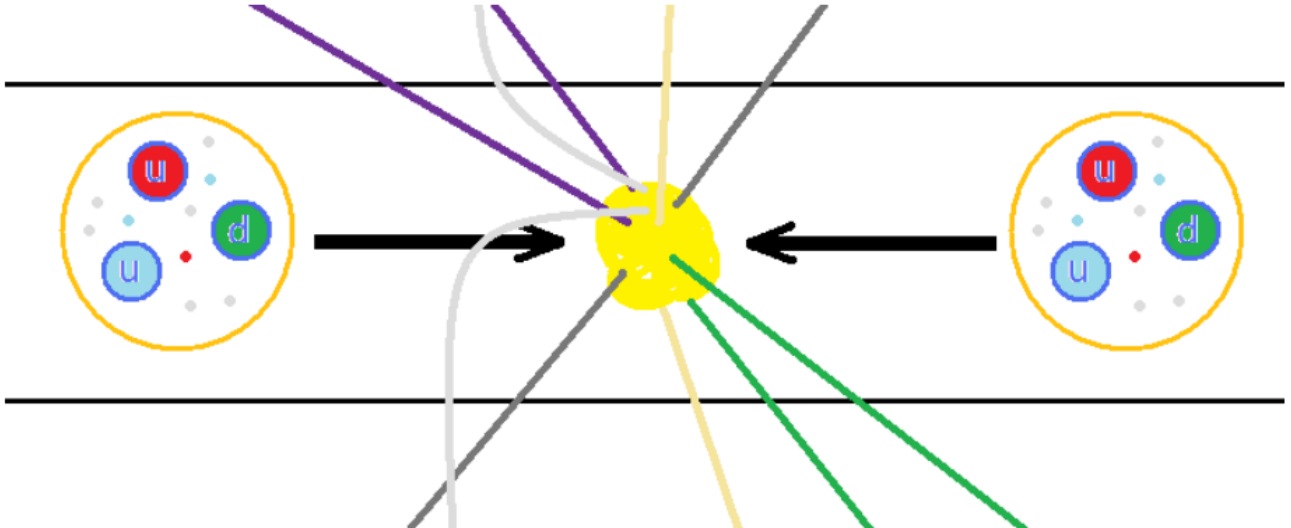
Electron signature: Signals in the Tracker and the ECAL; nothing in the HCAL or muon chambers.
These electrically charged particles bend in the field and leave signals in the Tracker, enabling their paths to be reconstructed. The amount of bend depends on the momentum they carry, with the radius of curvature, r, being given by the momentum, p, divided by 0.3xB, 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.

Derived from CMS Detector Slice from CERN

Protons collide inside CMS

The LHC accelerates protons to as much as 6500 times the energy equivalent of their mass. The protons circulate in opposite directions and collide in the center of CMS.

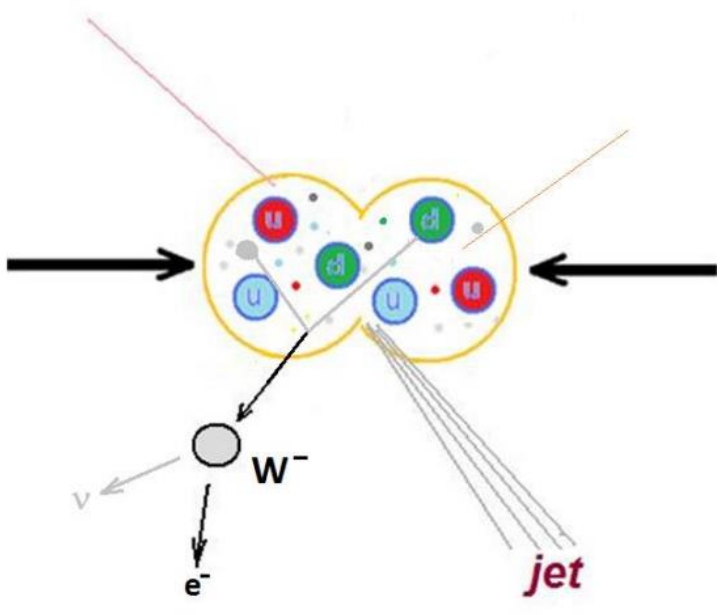
But protons are not just particles: they are more like bags of quarks and gluons. When they collide, *anything* can happen. And we are looking something specific.



One-lepton events

The + or – charged W boson enables radioactive decay by transforming neutrons into protons.

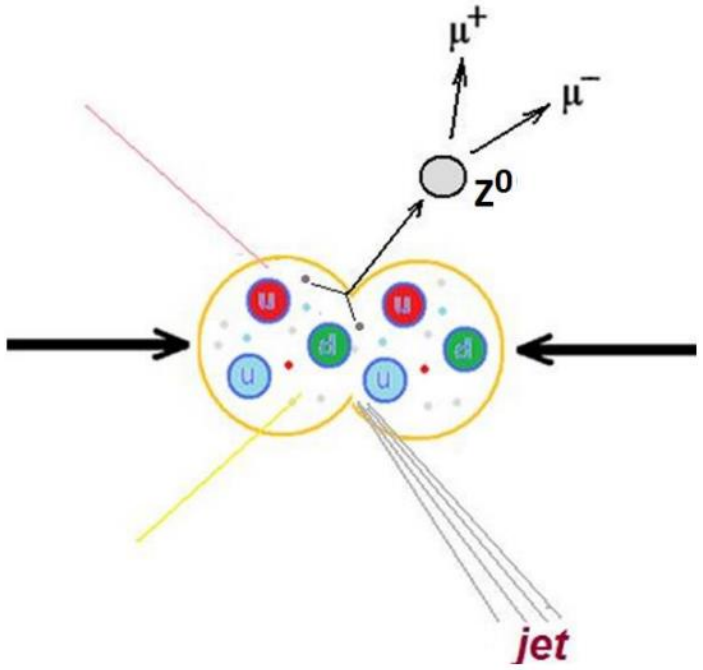
It decays into a neutrino and another lepton. Since CMS cannot detect the neutrino directly, we can call this a one-lepton event.

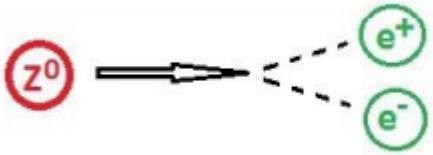


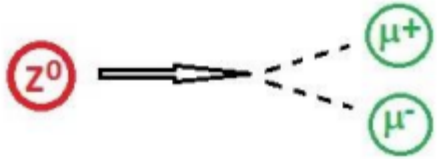
Two-lepton events

The Z boson is a neutral cousin of the W. It enables the “weak neutral current”.

It decays into two leptons of the same type but opposite charge – electron and positron or muon and antimuon. It has other decay paths but we are not looking for these.



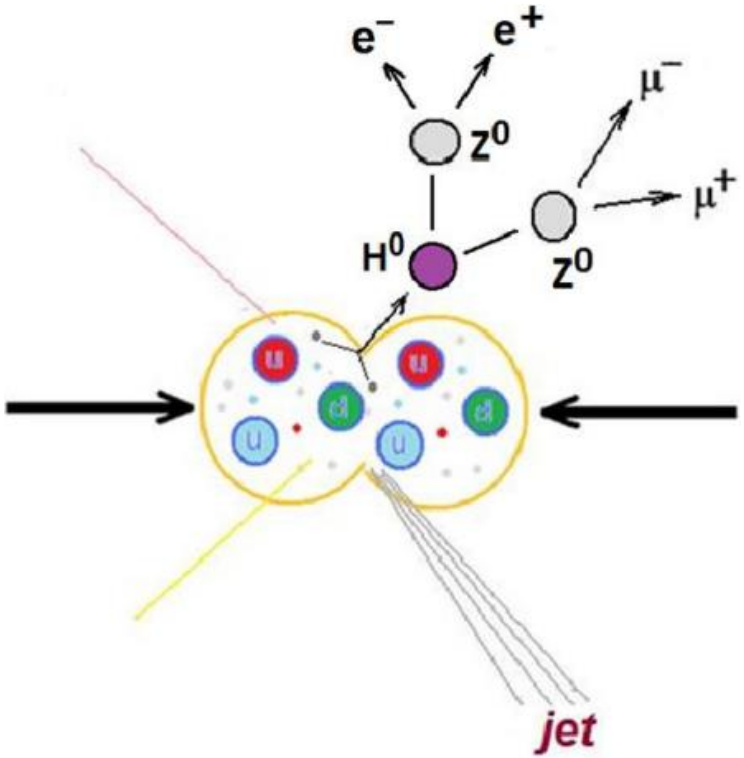


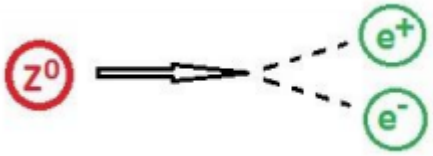


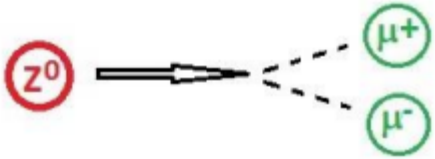
Four-lepton events

The Higgs boson is an expression of the field that gives other particles mass.

One decay mode of the Higgs is into two Z bosons, which themselves promptly decay. Thus we can get 2 muons and 2 electrons *or* 4 muons *or* 4 electrons.





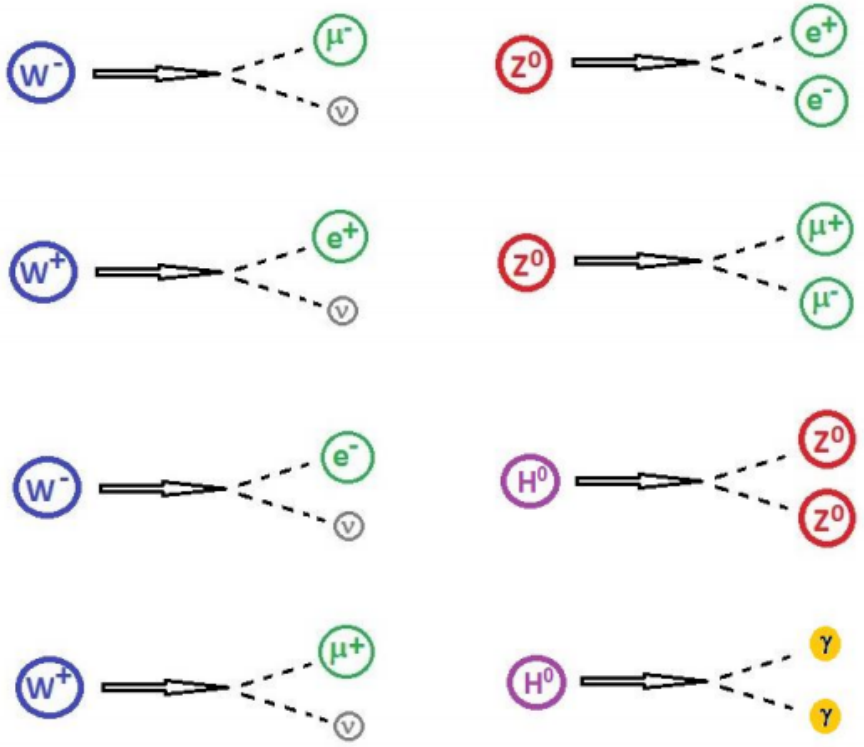


Decay summary

Because bosons only travel a tiny distance before decaying, CMS does not "see" them directly.

CMS *can* detect :

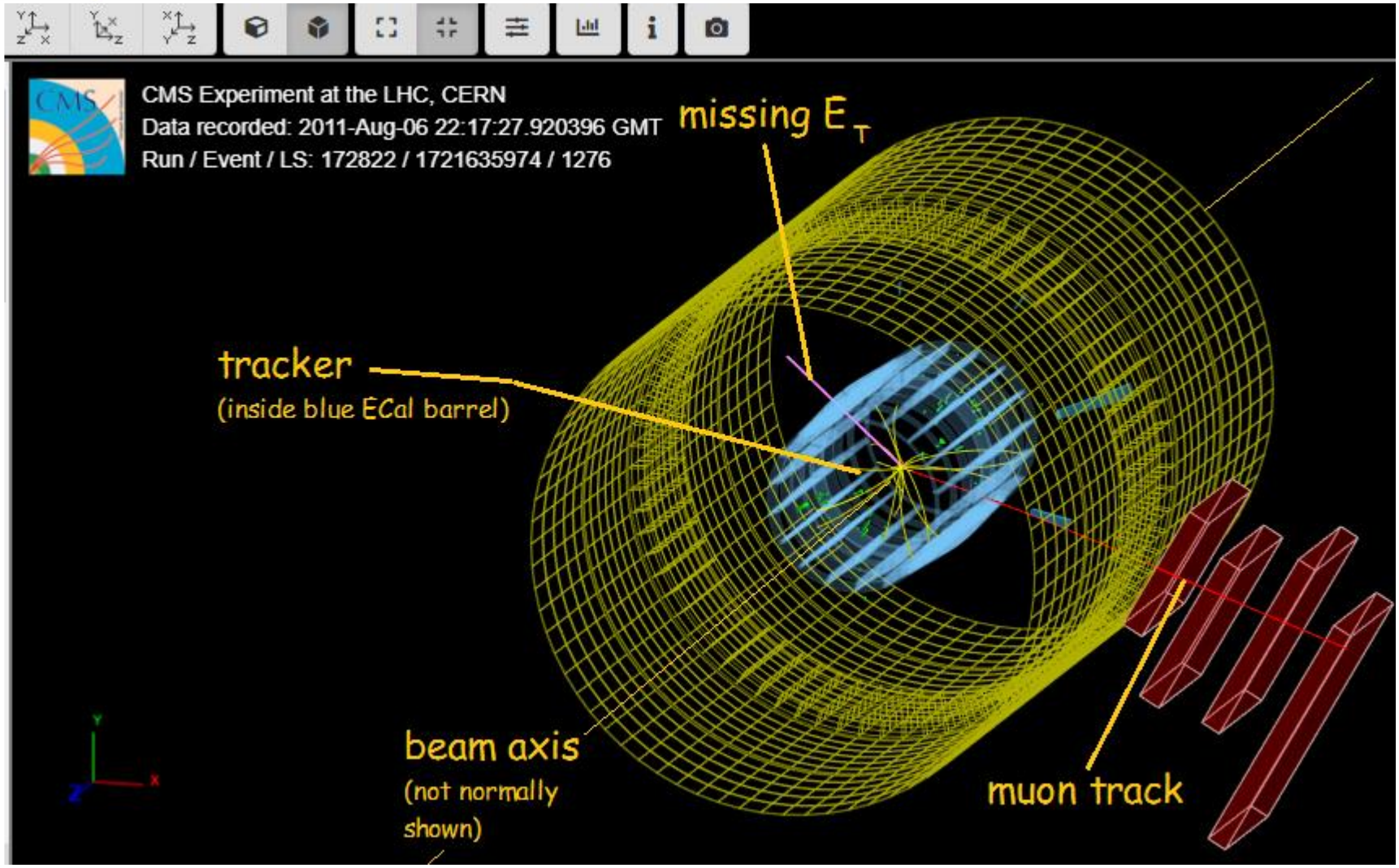
- electrons
- muons
- photons



CMS can infer:

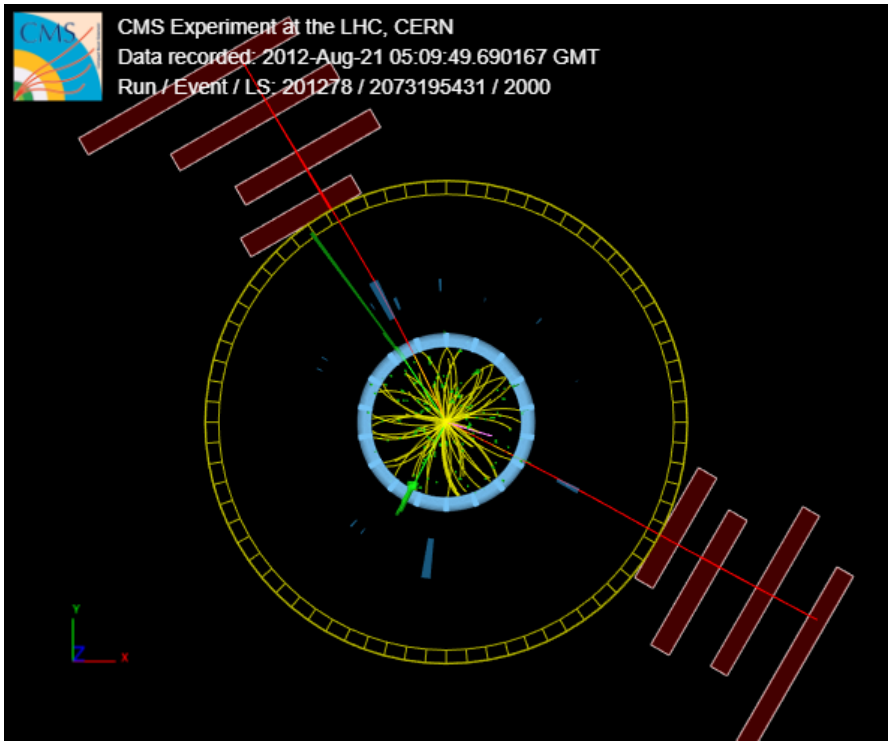
- neutrinos from "missing energy"

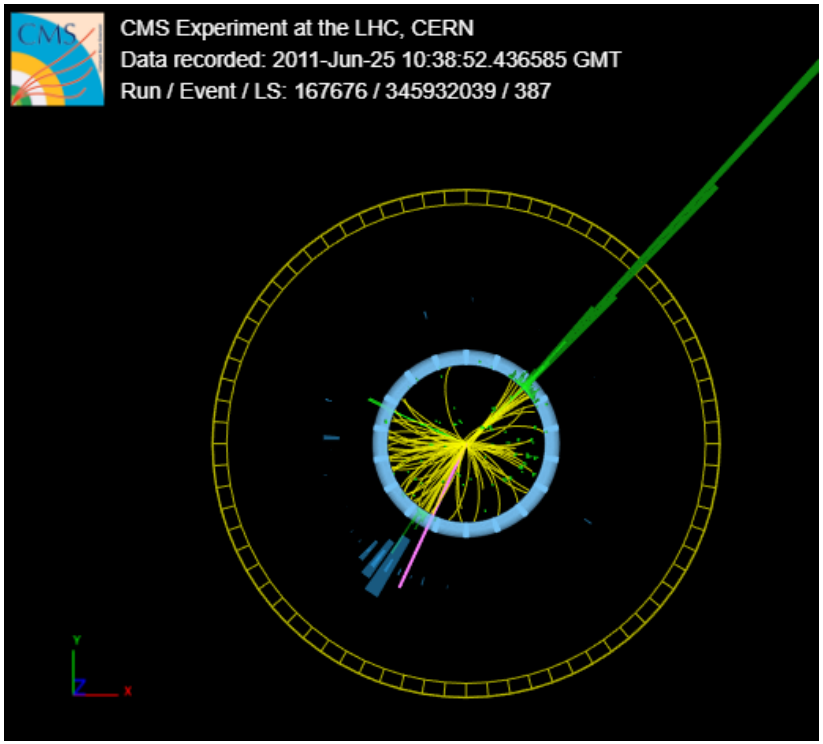
iSpy event display for CMS



1, 2, or 4 leptons?

Which of these events is 1-, 2-, or 4-lepton? Which flavors of leptons? What else do you see?





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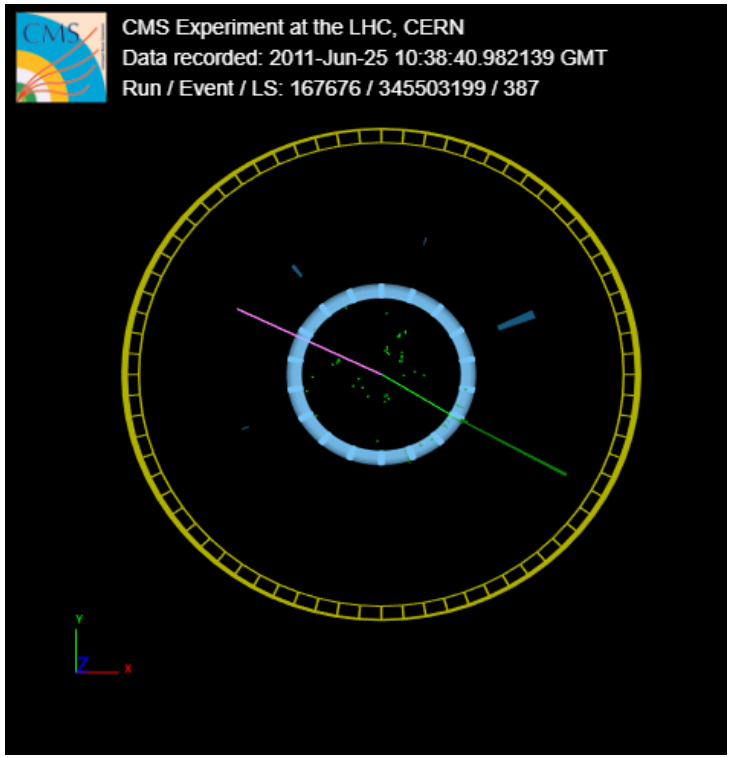

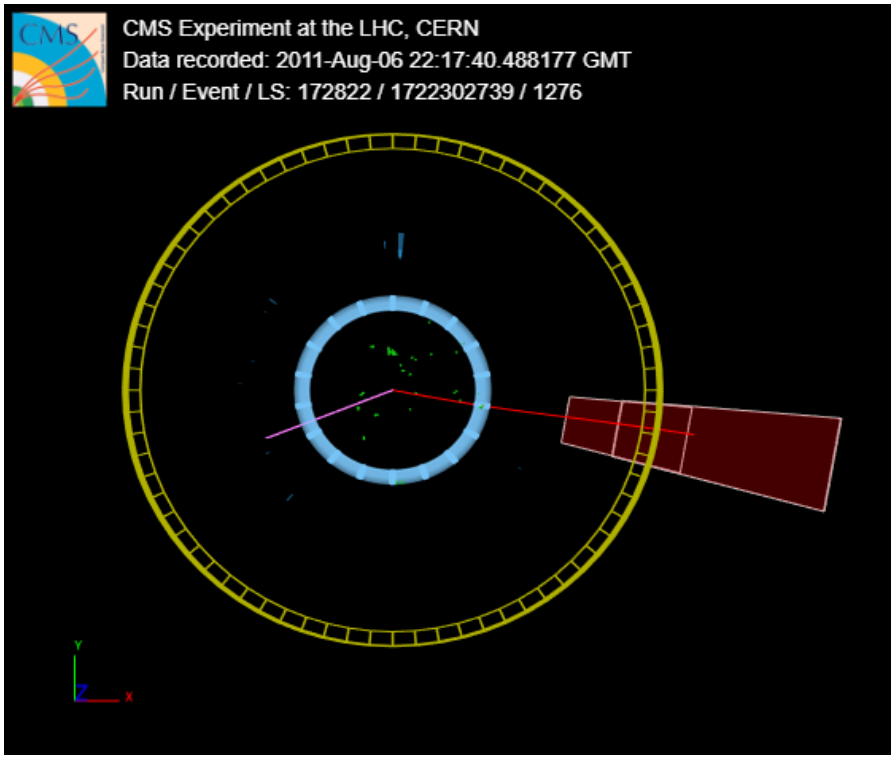

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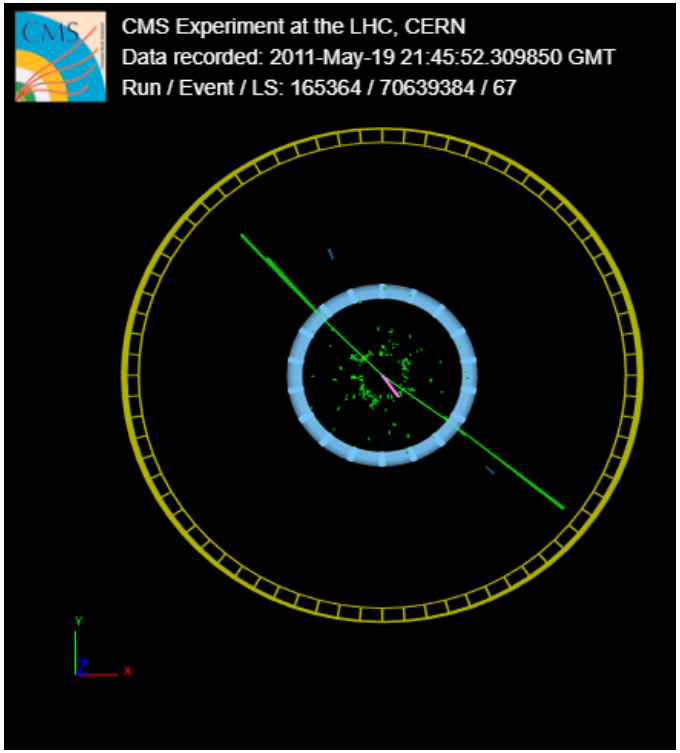

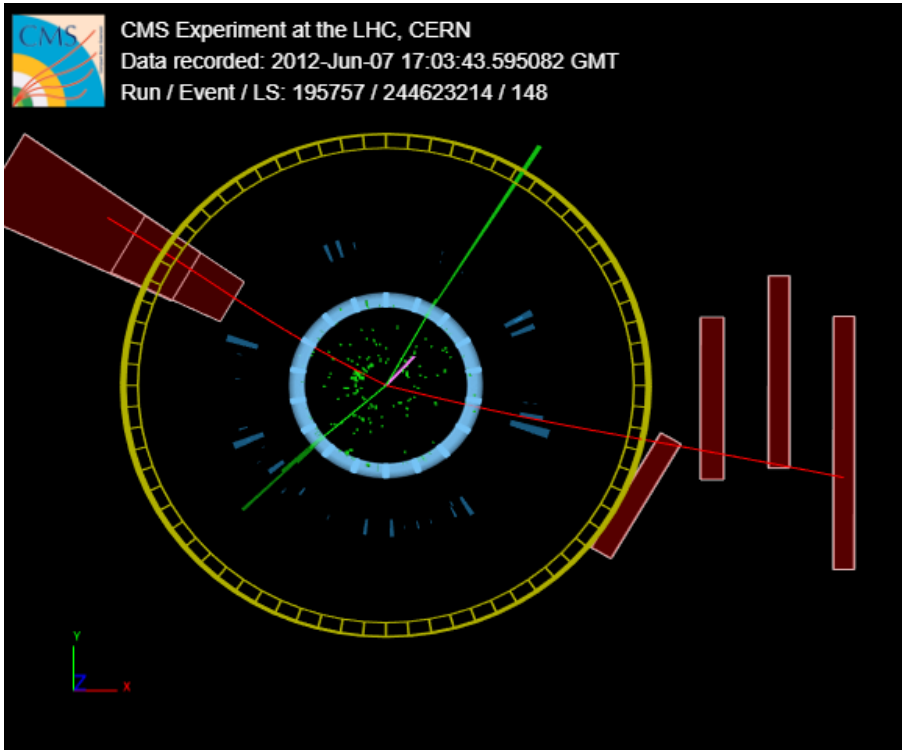

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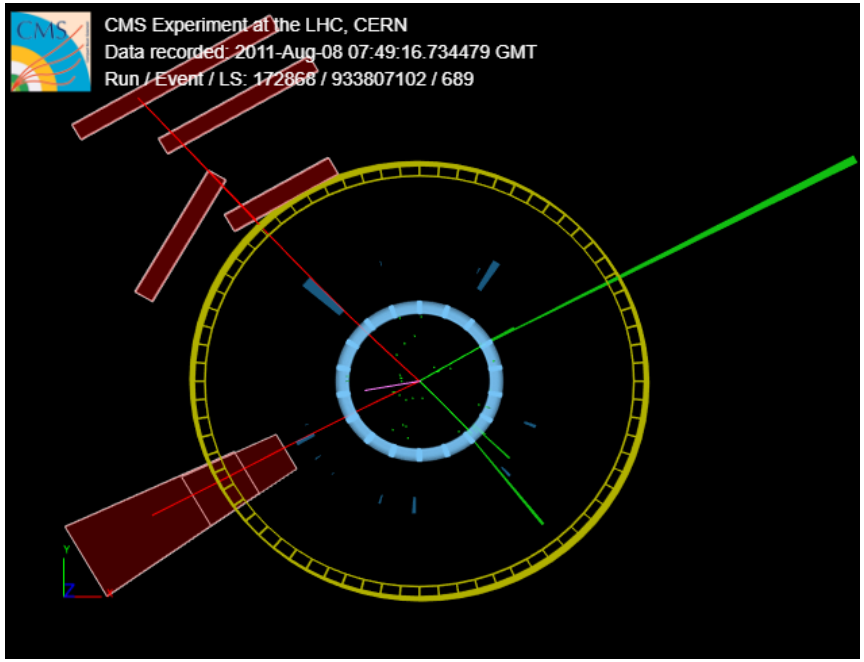
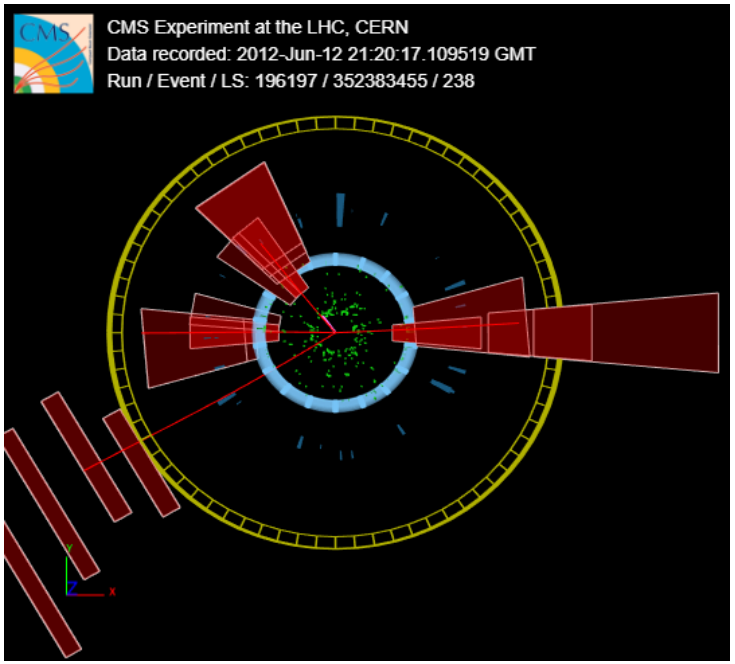
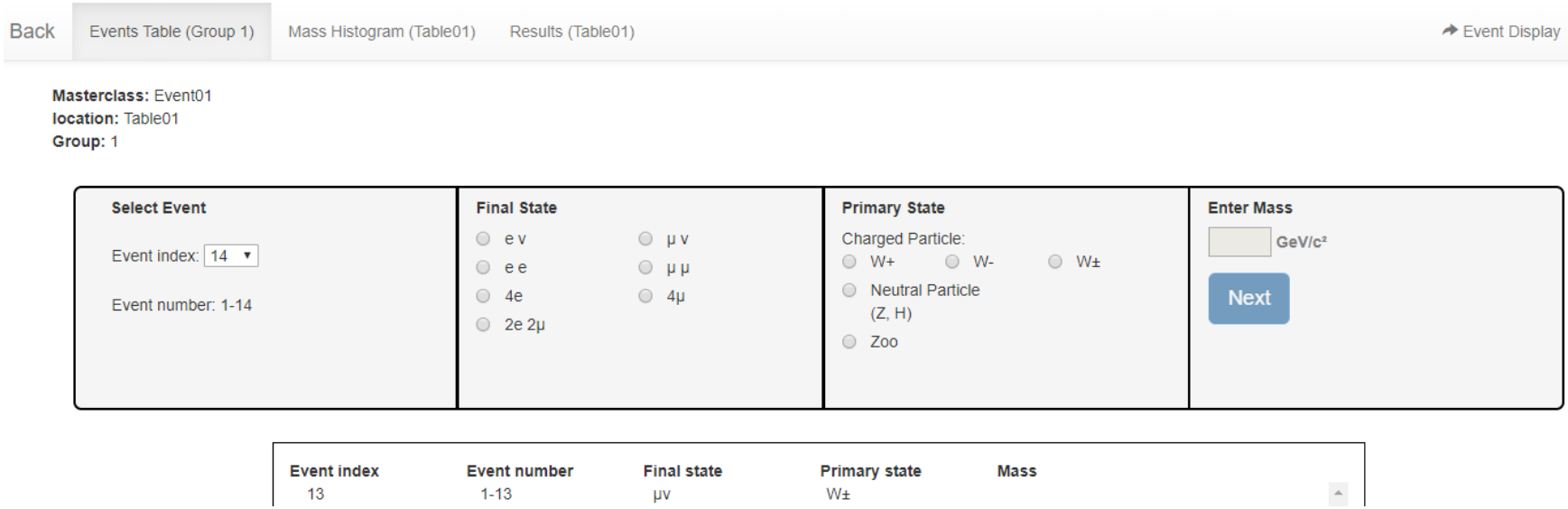


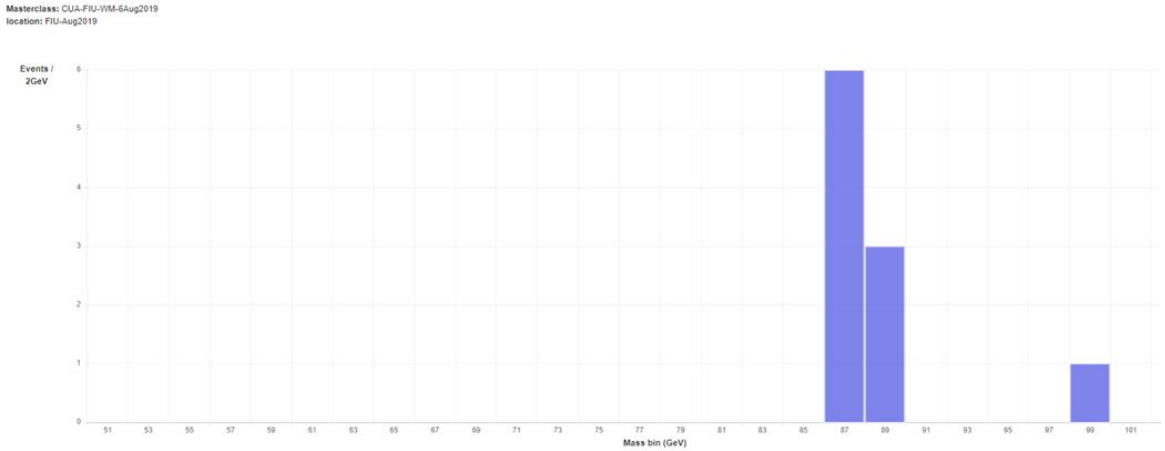


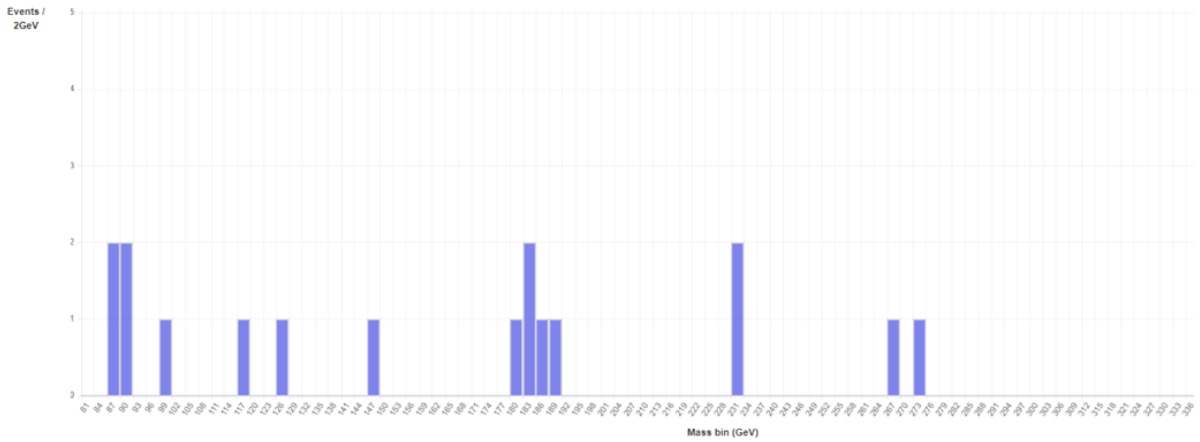
Enter data on each event:



CMS Instrument for Masterclass Analysis (CIMA)

CIMA makes mass histograms automatically:





CIMA tabulate data for key ratios:

Back | Events Table (Group 21) | Mass Histogram (FIU-Aug2019) | Results (FIU-Aug2019)

Masterclass: CUA-FIU-WM-6Aug2019
location: FIU-Aug2019

Group	e	μ	W+	W-	W±	Neutral	Zoo	Total
21	26	32	21	21	0	13	0	55
22	41	46	24	38	1	16	1	80
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	10	12	10	5	0	5	1	21

Total:

Group	e	μ	W+	W-	W±	Neutral	Zoo	Total
All	77	90	55	64	1	34	2	156

Ratios:

e/μ	W+/W-
0.92	0.86

Parting words…

"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.