CMS WZH Masterclass

Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil

Total weight 12500 t, Overall diameter 15 m, Overall length 21.6 m, Magnetic field 4 Tesla

INTERNATIONAL MASTERCLASSES

hands on particle physics

NSF

Fermilab

CERN

UNIVERSITY OF NOTRE DAME
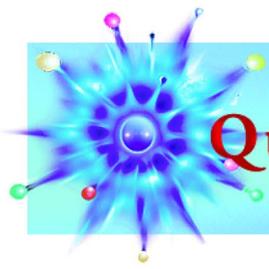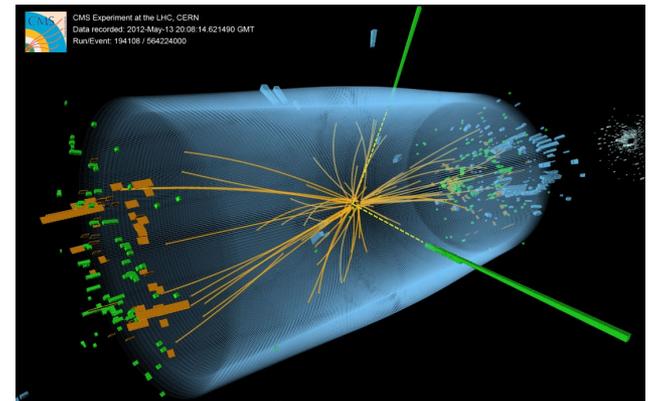
It is a time of exciting new discoveries in particle physics.

*The Large Hadron Collider at CERN has been operating for almost 10 years and had not only shed new light on the Standard Model but discovered new particles, including the cornerstone **Higgs boson**.*
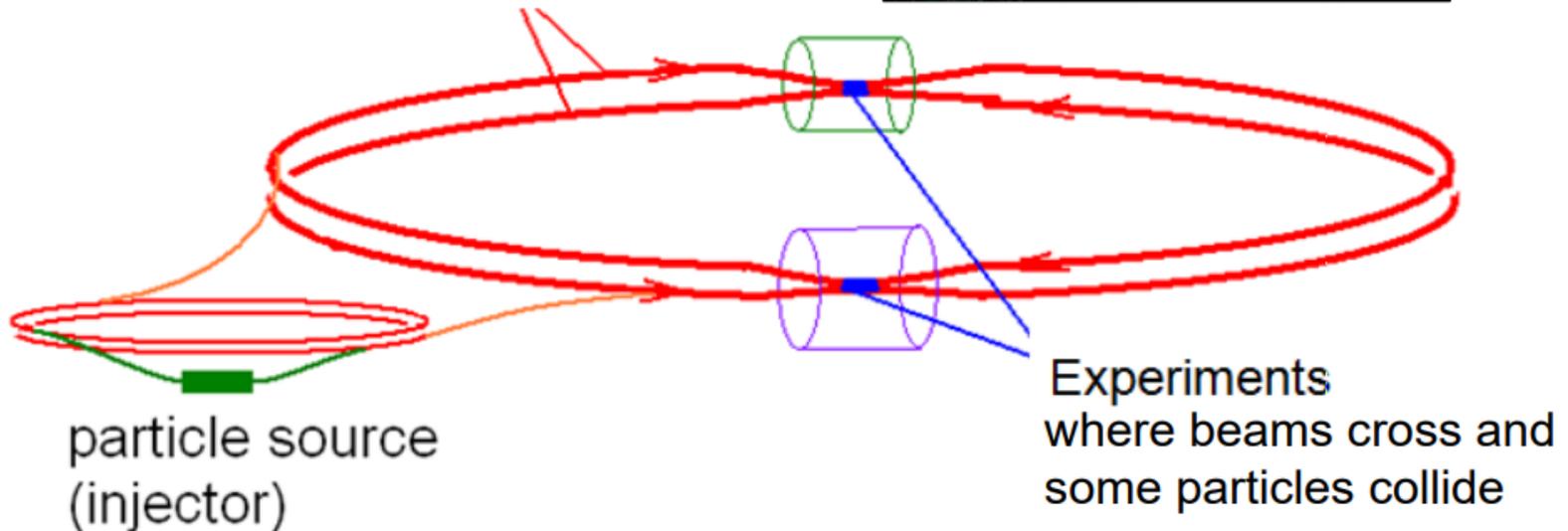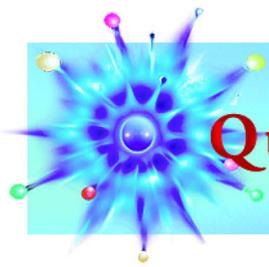
QuarkNet

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

QuarkNet

Generic Design

Cylinders wrapped around the beam pipe

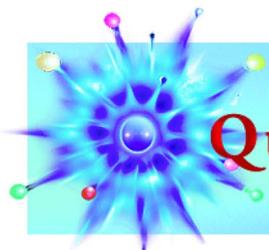From inner to outer . . .

Tracking

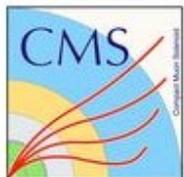Electromagnetic calorimeter

Hadronic calorimeter

Magnet*

Muon chamber

collision point

beam

beam
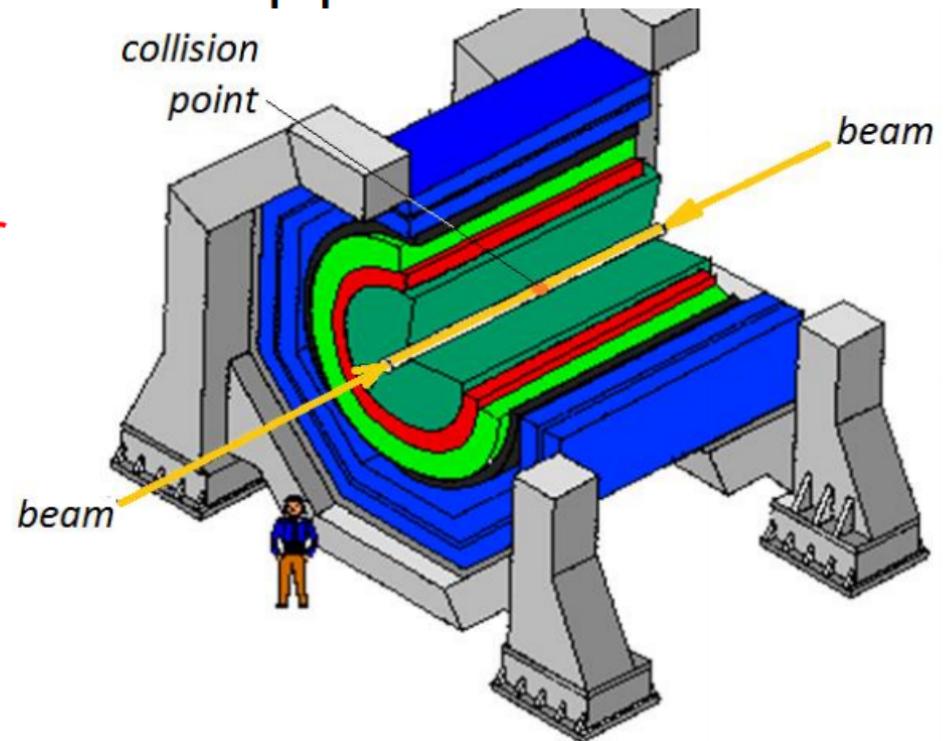
*location of magnet depends on specific detector design

CMS Detector
Weight   : 14,000 tonnes
Diameter   : 15.0 m
Length   : 28.7 m
Magnetic field: 3.8 T

Silicon Trackers

Superconducting Solenoid

Muon Chambers

Preshower

Forward Calorimeter

Steel Return Yoke

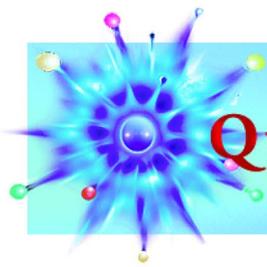Electromagnetic Calorimeter
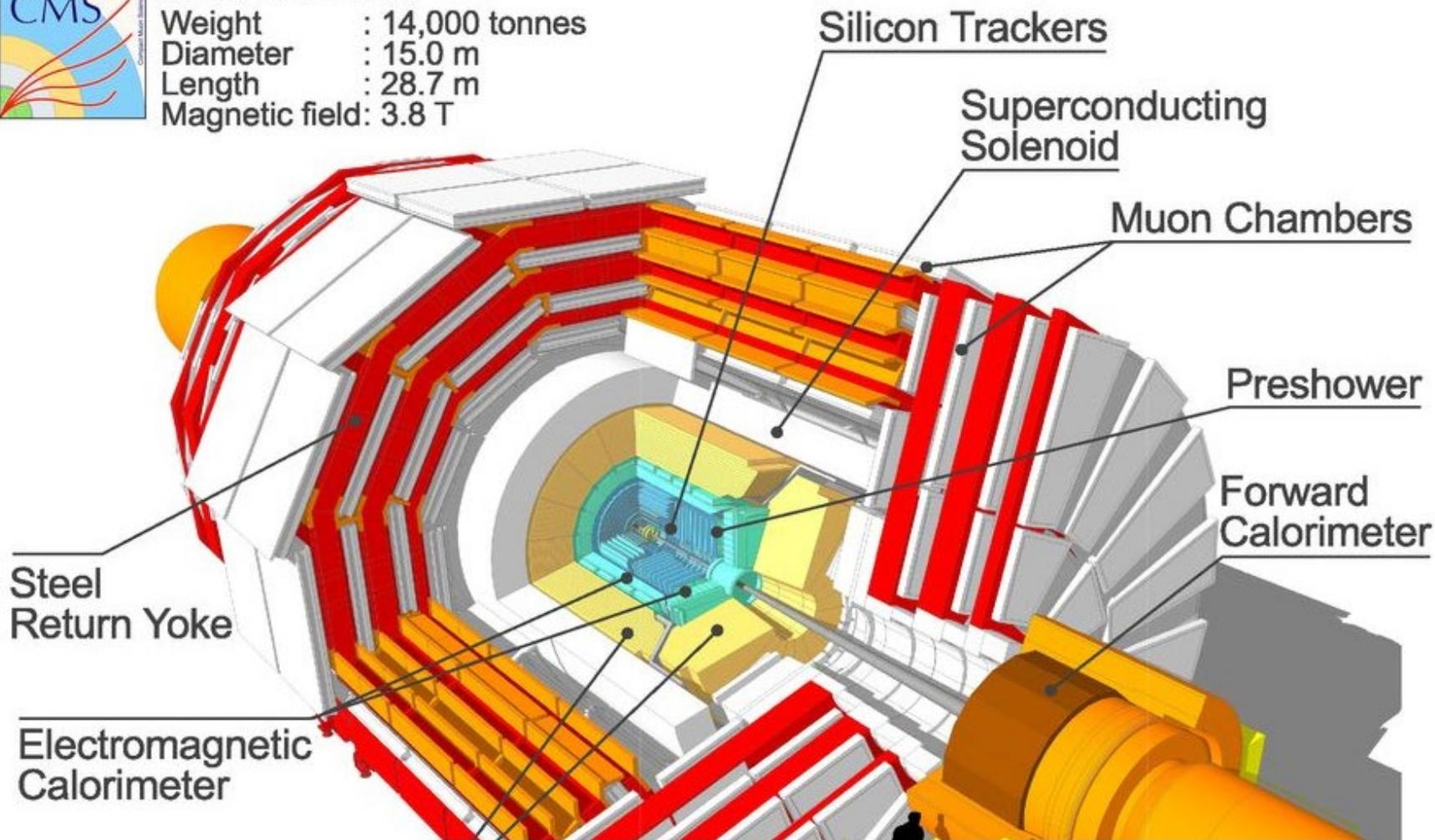
Let's take a closer look at the real thing.
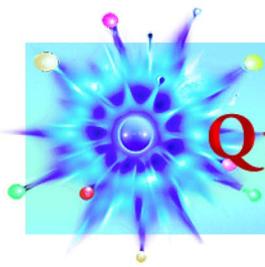
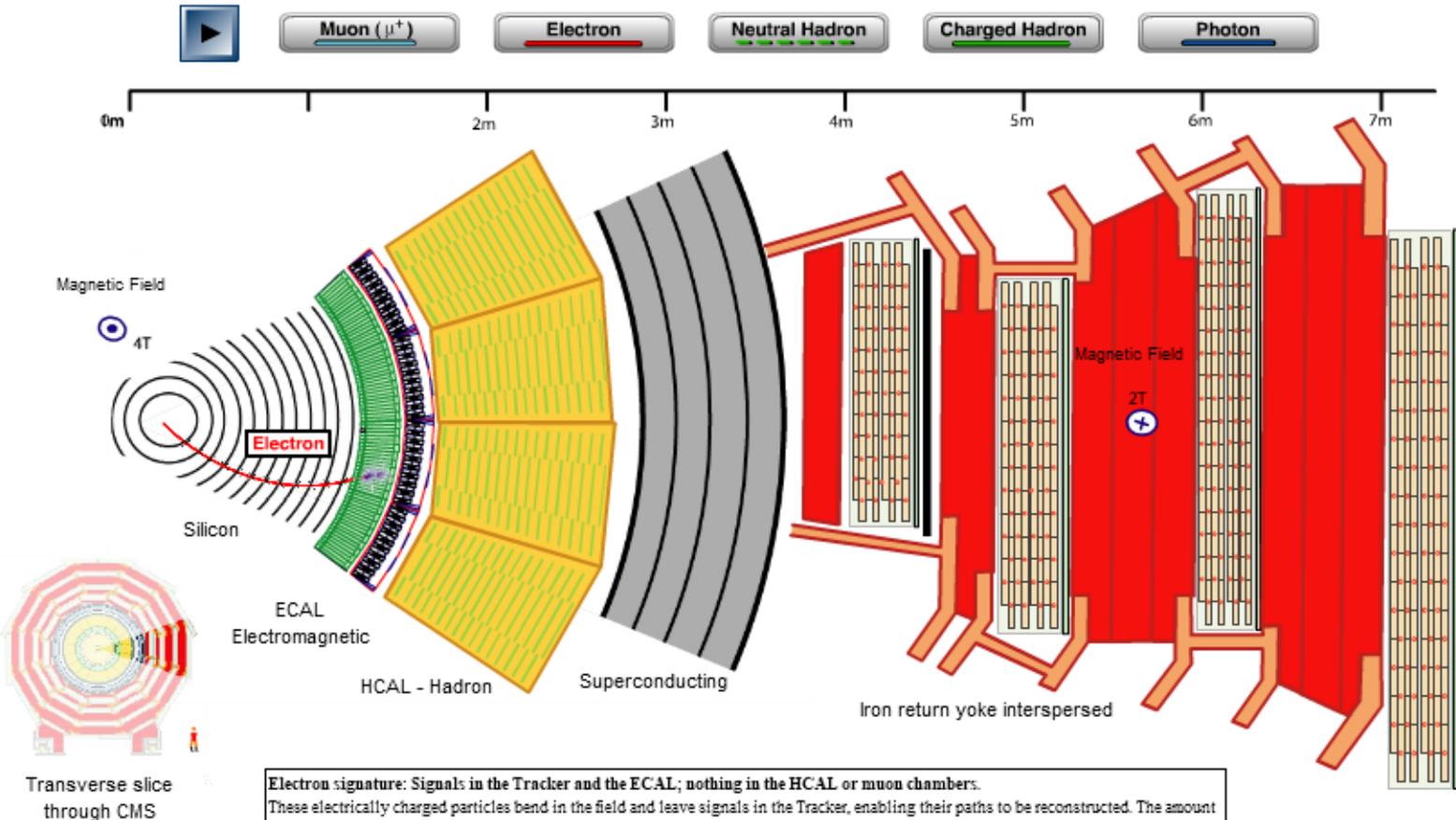Transverse Slice of the Compact Muon Solenoid (CMS) Detector
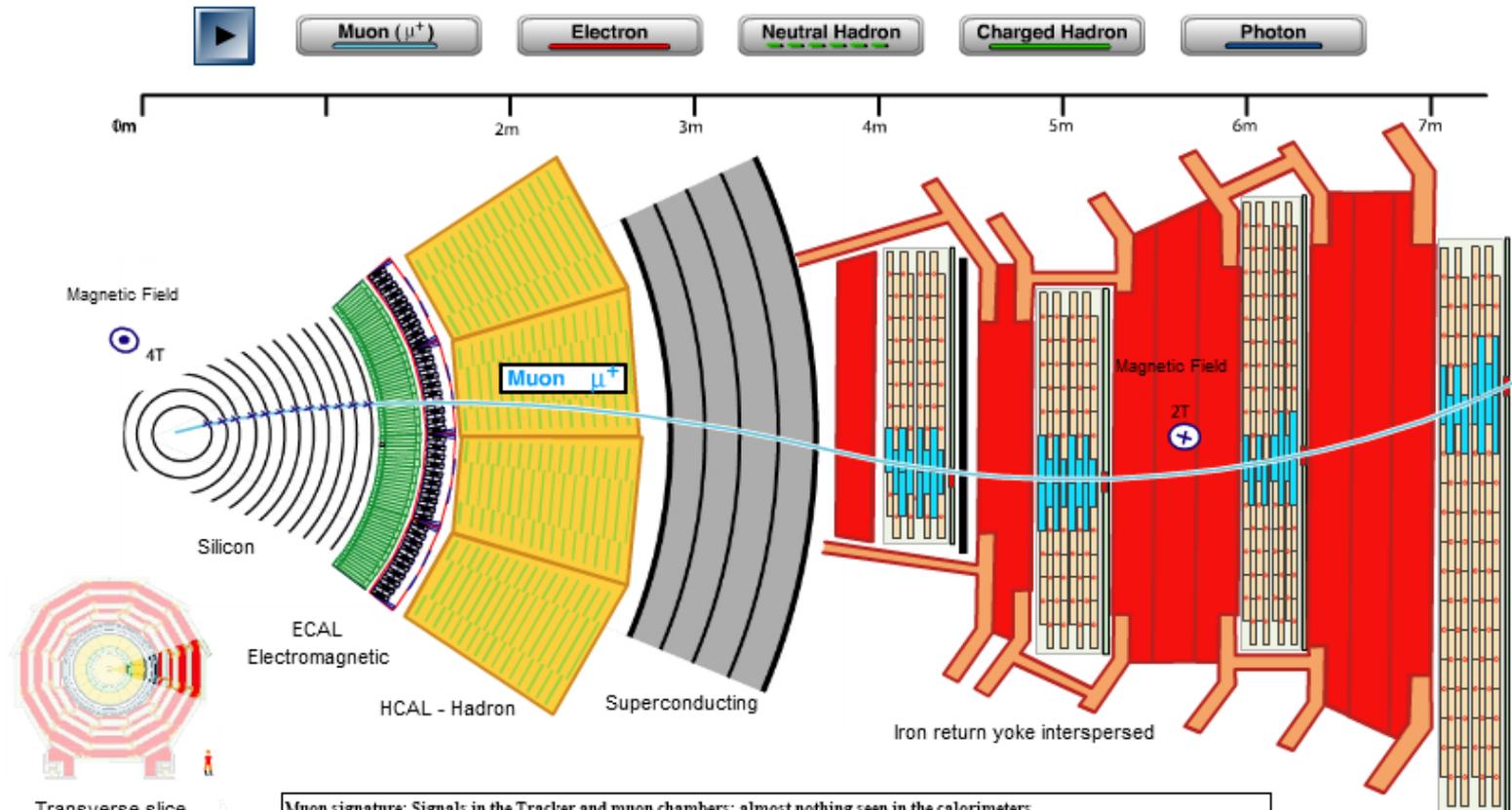
Muon signature: Signals in the Tracker and muon chambers; almost nothing seen in the calorimeters.

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

Transverse Slice of the Compact Muon Solenoid (CMS) Detector

▶ | Muon (μ⁺) | Electron | Neutral Hadron | Charged Hadron | Photon

0m   2m   3m   4m   5m   6m   7m

Magnetic Field
⊙ 4T

Electron

Silicon

ECAL
Electromagnetic

HCAL - Hadron

Superconducting

Magnetic Field
2T
⊕

Iron return yoke interspersed

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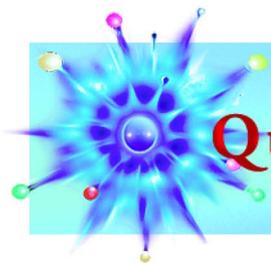
The LHC accelerates protons to as much as 6500 times the energy equivalent of their mass. The protons circulate in opposite directions and collide in the center of CMS.

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.
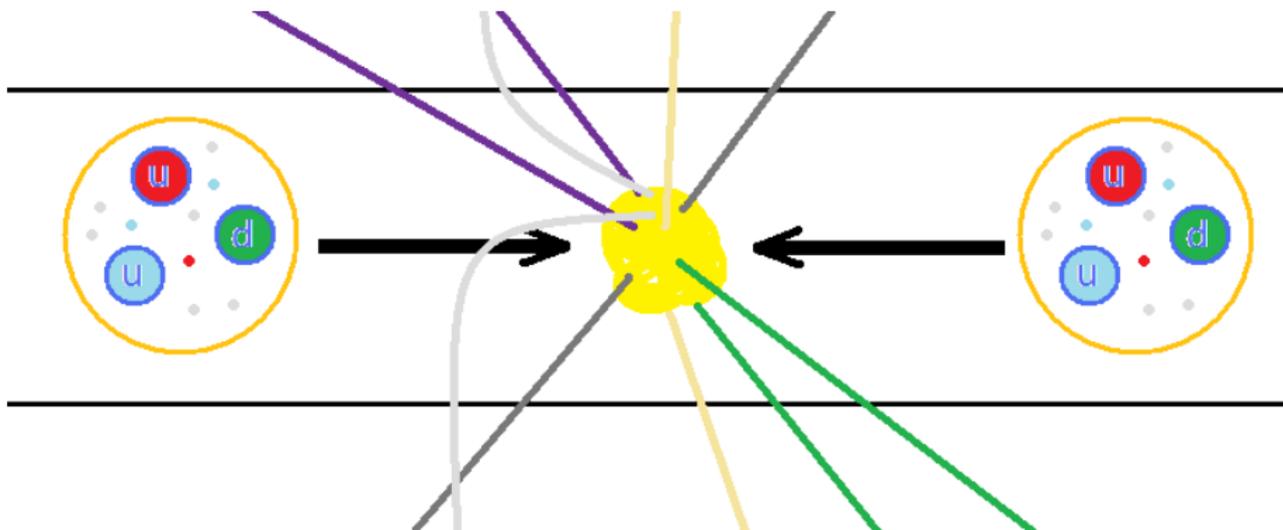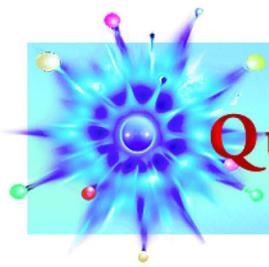
**The + or – charged W boson enables radioactive decay by transforming neutrons into protons.**
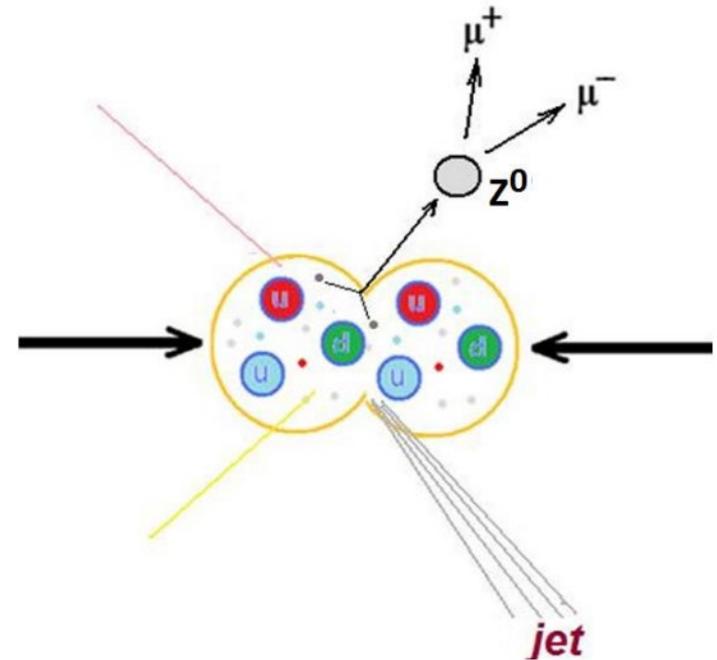
It decays into a neutrino and another lepton. Since CMS cannot detect the neutrino directly, we can call this a one-lepton event.
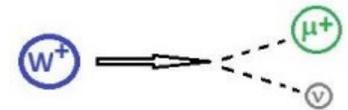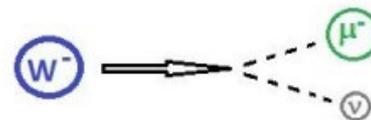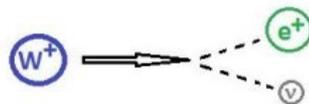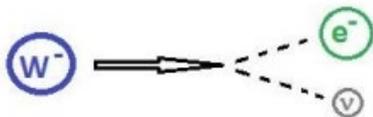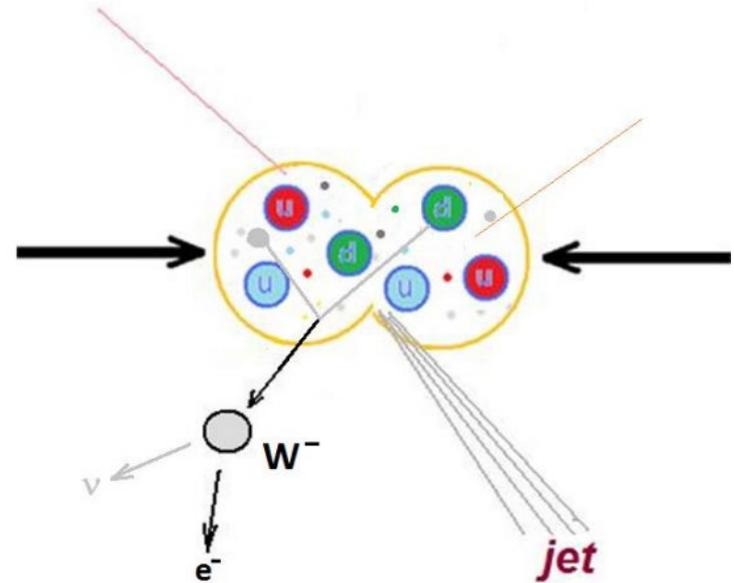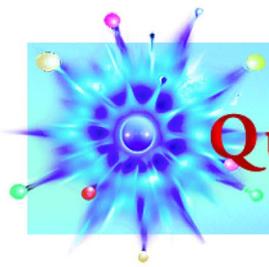
The Z boson is a neutral cousin of the W. It enables the "weak neutral current".

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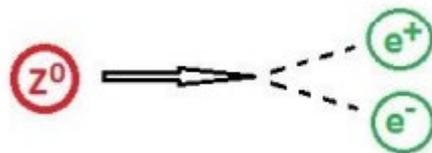
The Higgs boson is an expression of the field that gives other particles mass.

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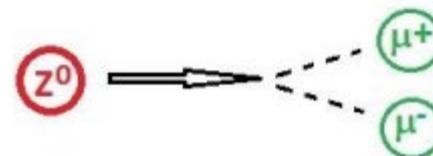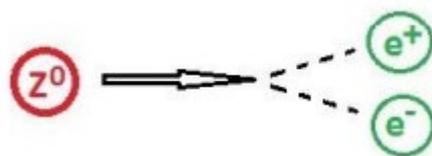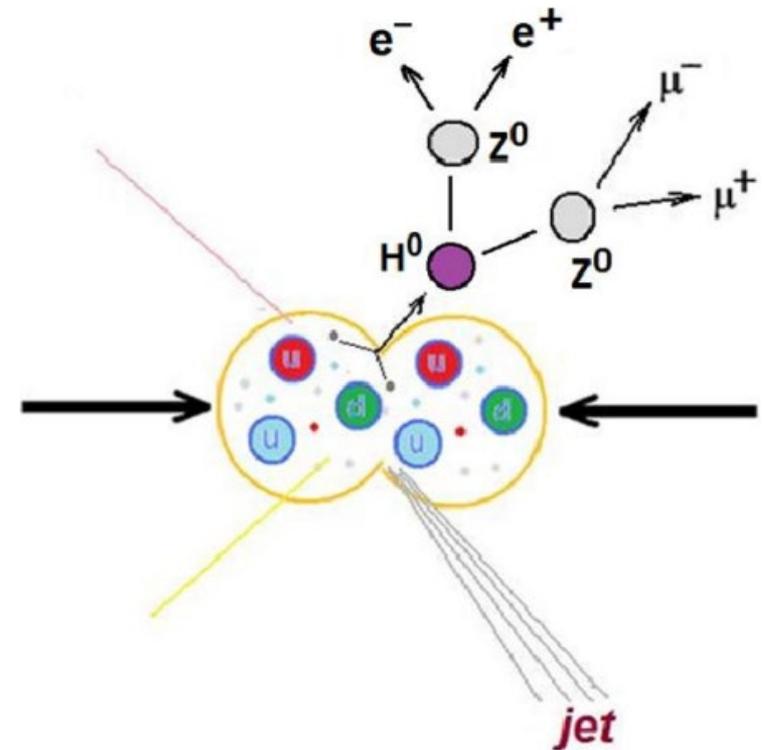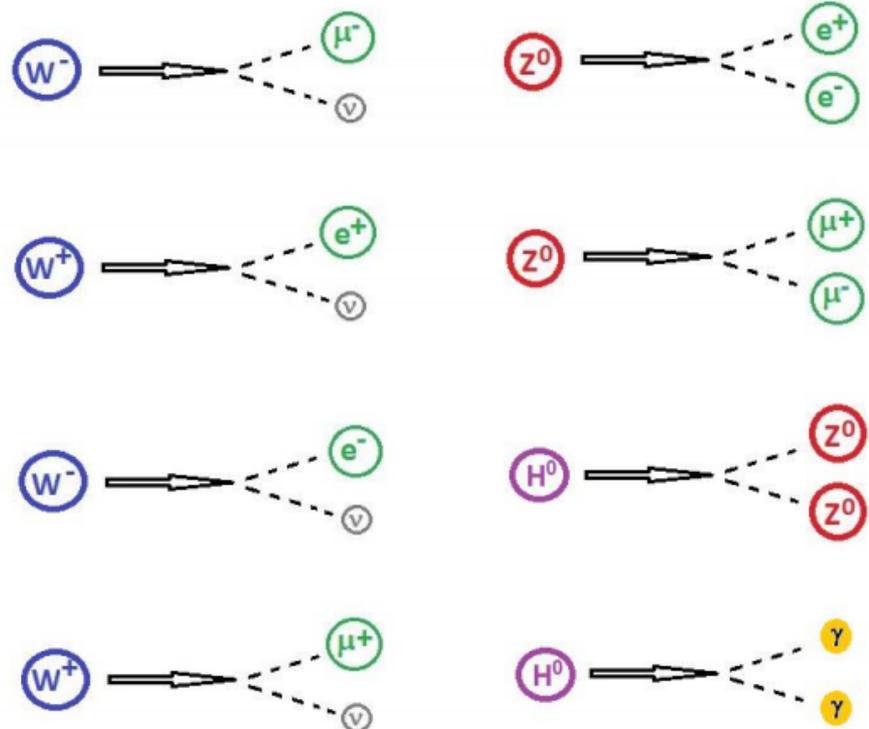
Because bosons only travel a tiny distance before decaying, CMS does not "see" them directly.

CMS *can* detect :
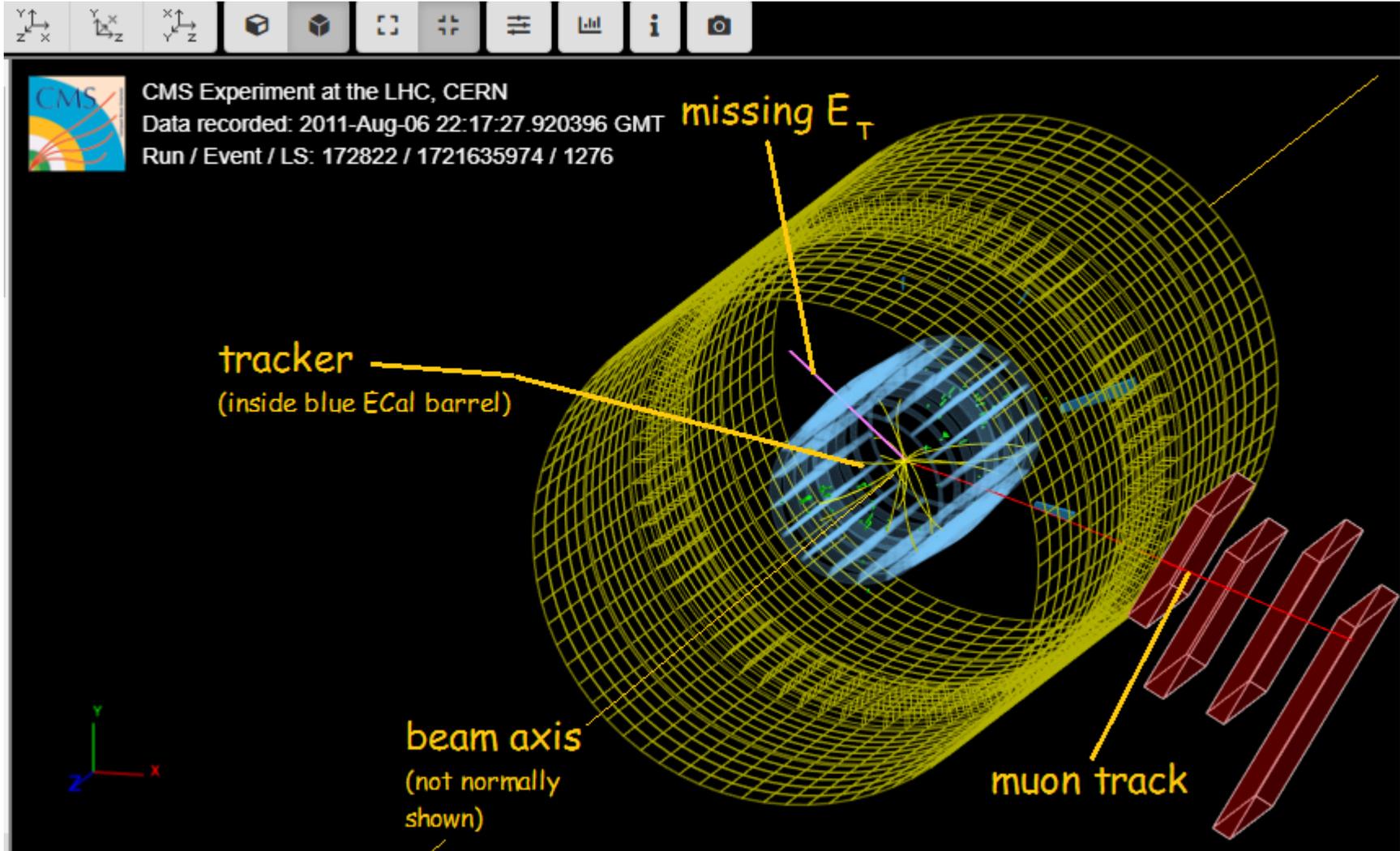- electrons
- muons
- photons

CMS can infer:
- neutrinos from "missing energy"

CMS Experiment at the LHC, CERN
Data recorded: 2011-Aug-06 22:17:27.920396 GMT
Run / Event / LS: 172822 / 1721635974 / 1276

missing E$_T$

tracker
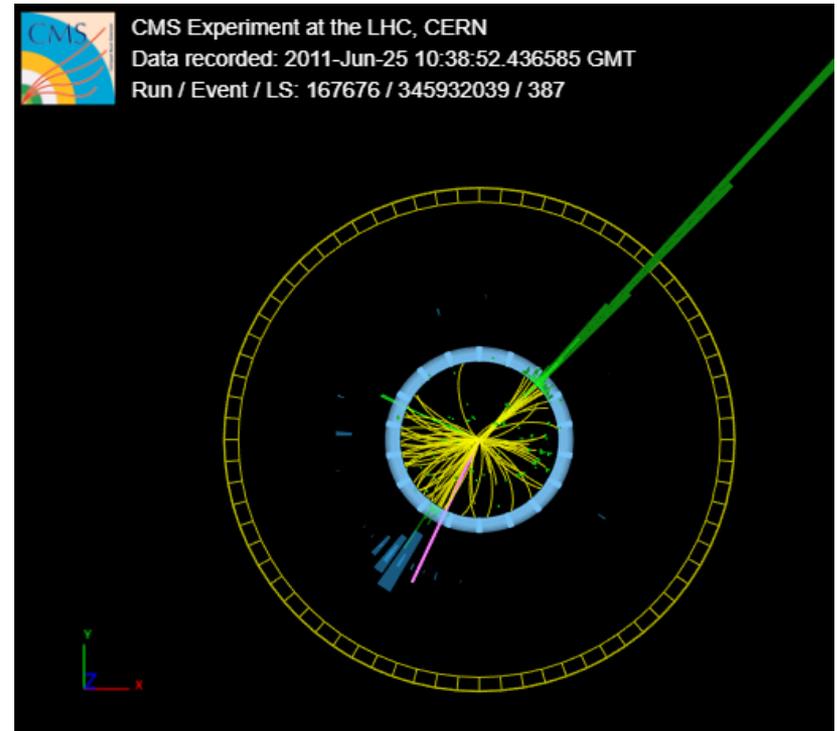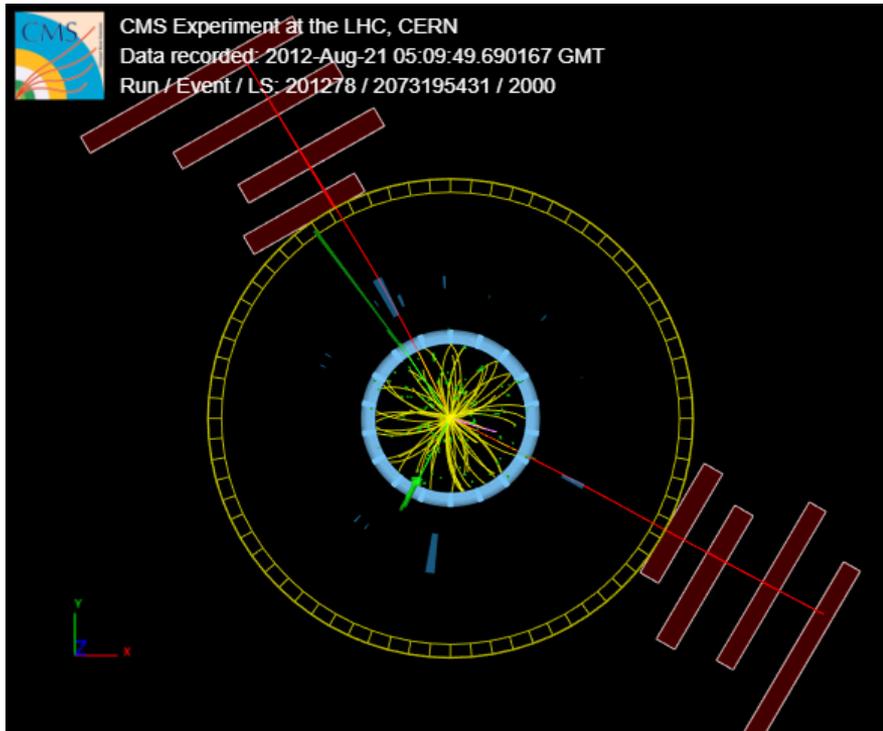(inside blue ECal barrel)

beam axis
(not normally
shown)

muon track

QuarkNet

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

CMS Experiment at the LHC, CERN
Data recorded: 2012-Aug-21 05:09:49.690167 GMT
Run / Event / LS: 201278 / 2073195431 / 2000

CMS Experiment at the LHC, CERN
Data recorded: 2011-Jun-25 10:38:52.436585 GMT
Run / Event / LS: 167676 / 345932039 / 387

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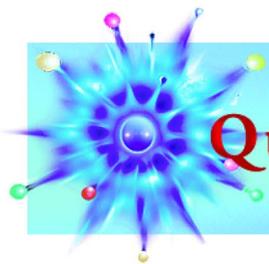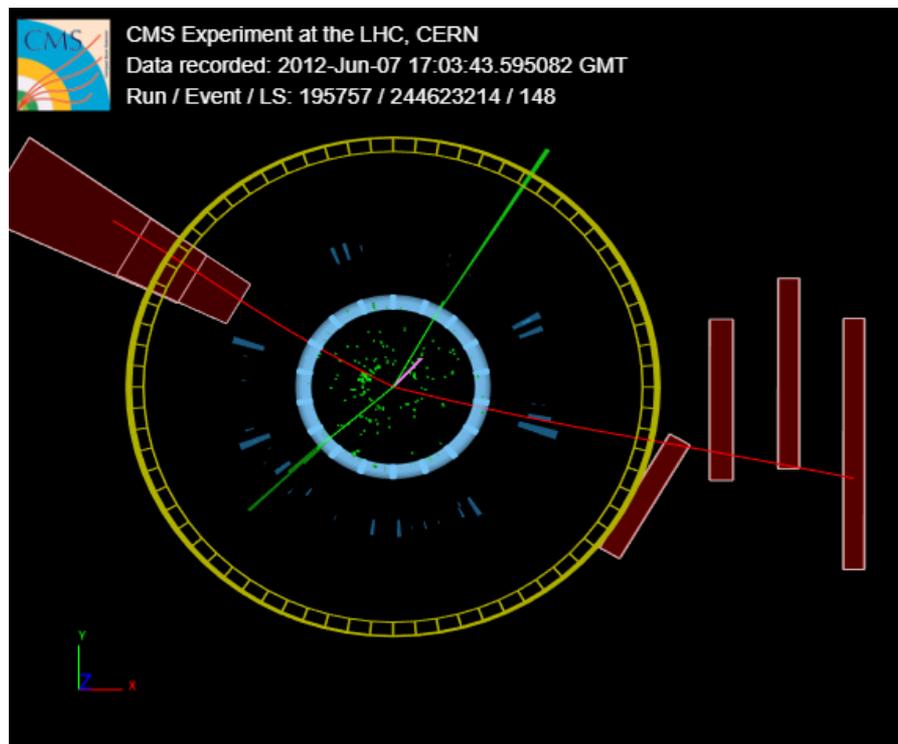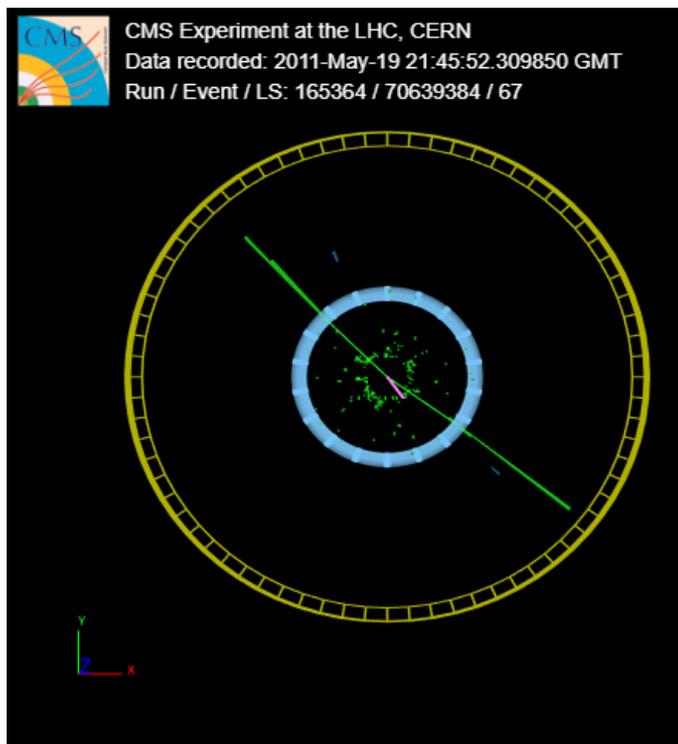
Which of these events is 1-, 2-, or 4-lepton? Which flavors of leptons? What else do you see?
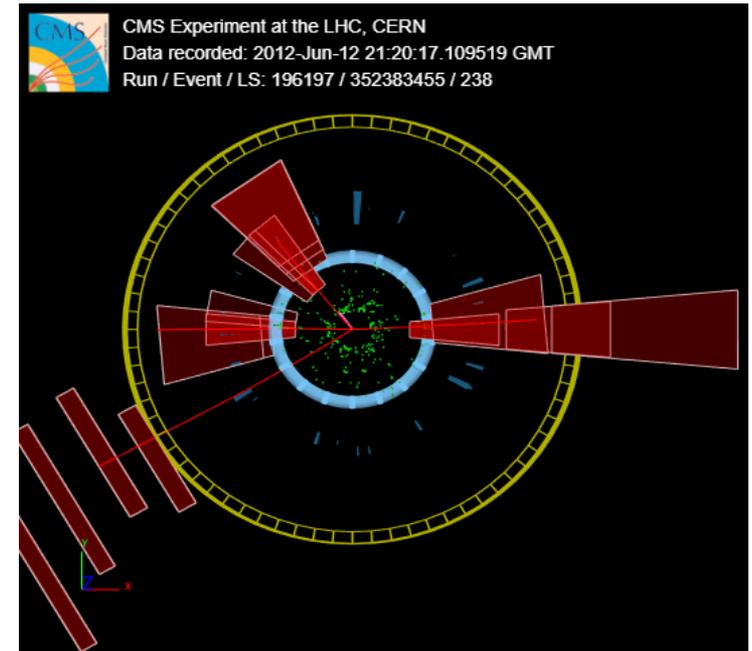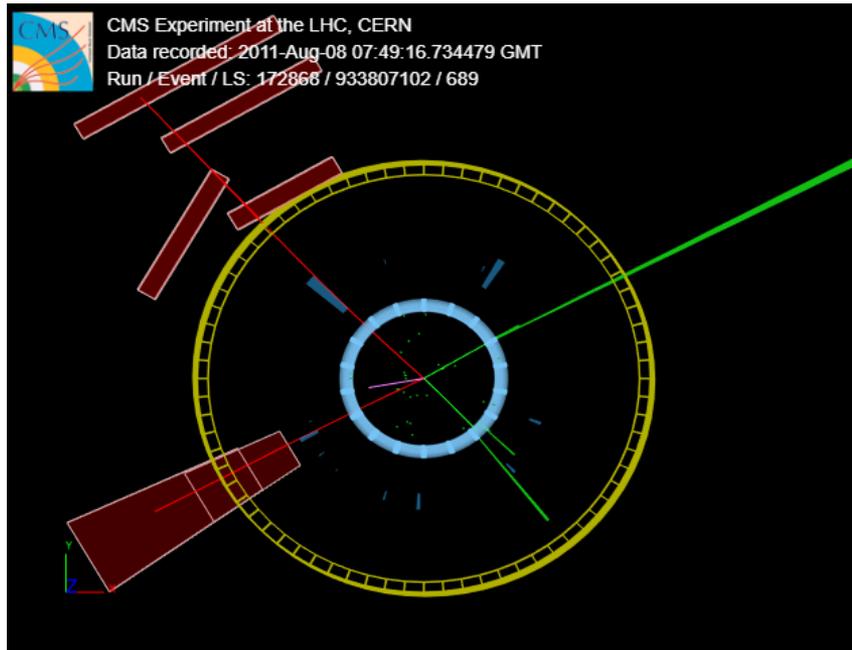
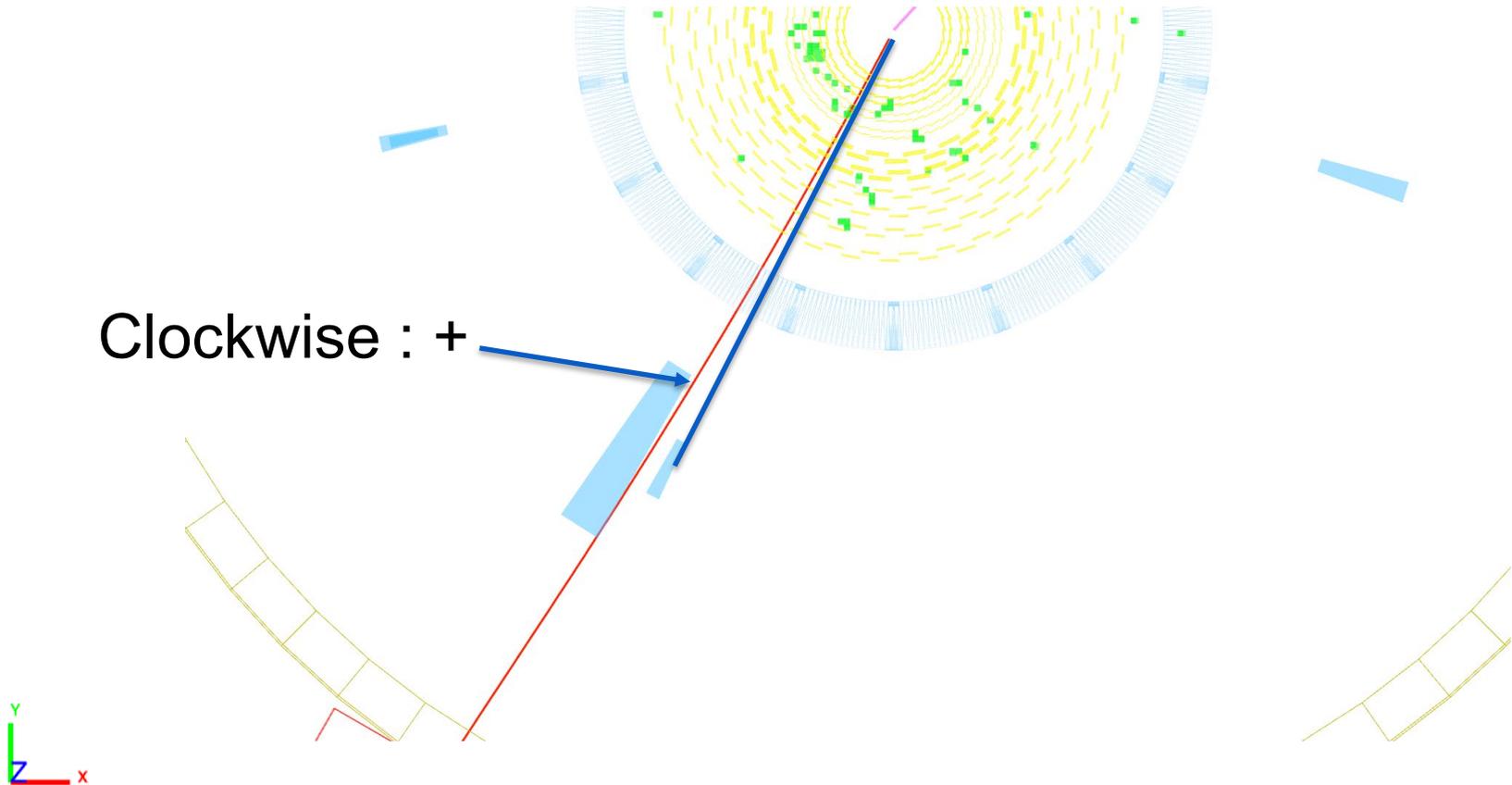**Which of these events is 1-, 2-, or 4-lepton? Which flavors of leptons? What else do you see?**

CMS Experiment at the LHC, CERN
Data recorded: 2011-Aug-08 07:49:16.734479 GMT
Run / Event / LS: 172868 / 933807102 / 689

CMS Experiment at the LHC, CERN
Data recorded: 2012-Jun-12 21:20:17.109519 GMT
Run / Event / LS: 196197 / 352383455 / 238
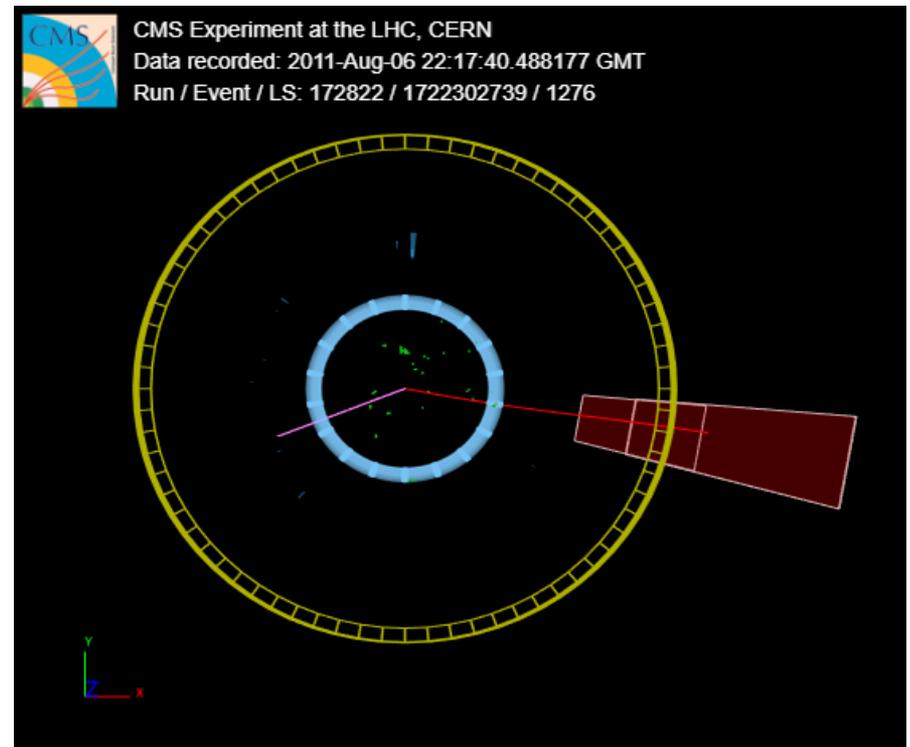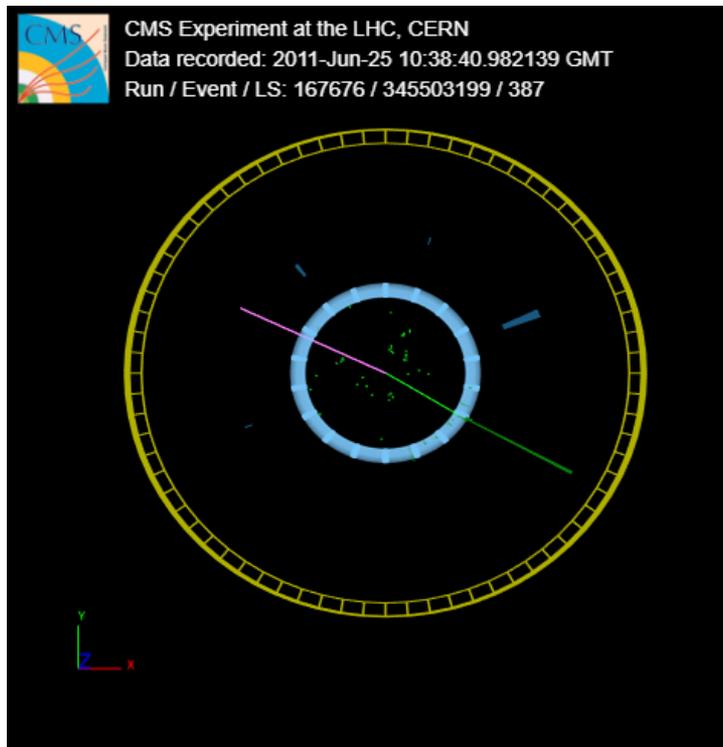
Can you distinguish W+ from W- using track curvature?

Clockwise : +

Enter data on each event:

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
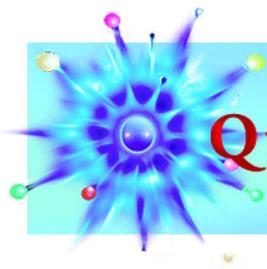
"Science is nothing but developed perception, interpreted intent, common sense rounded out and minutely articulated." *George Santayana*

- Indirect observations and imaginative, critical, logical thinking can lead to reliable and valid inferences.

- Therefore: <u>work together</u>, <u>think</u> (sometimes outside the box), and <u>be critical</u> 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.