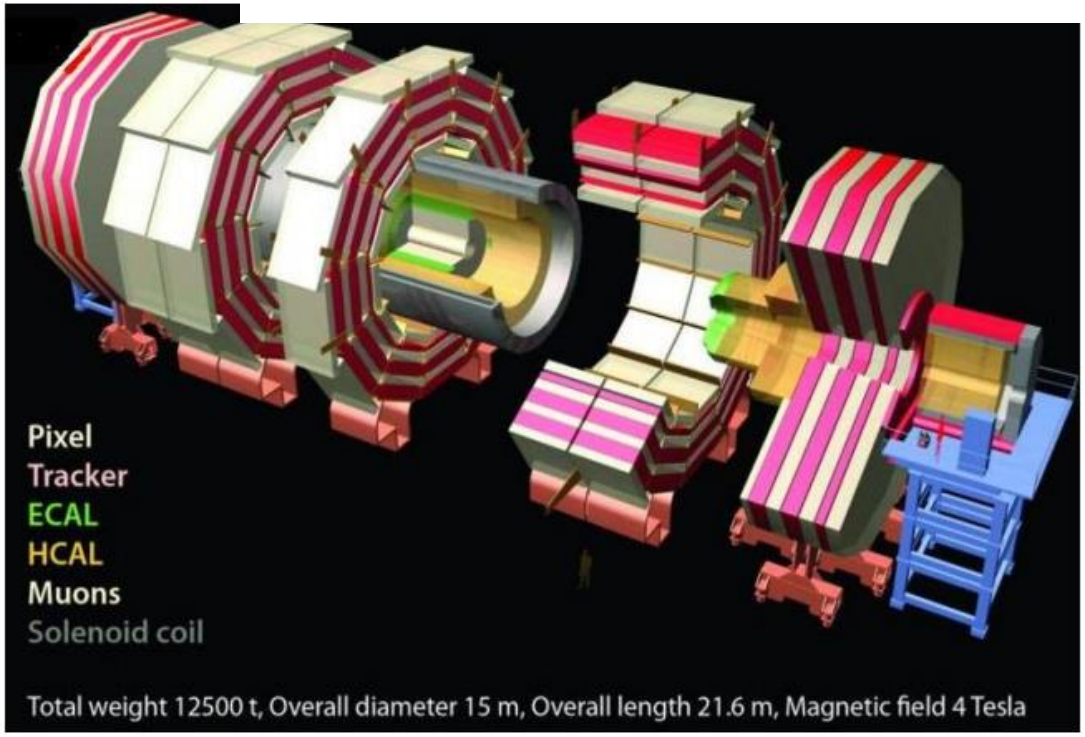
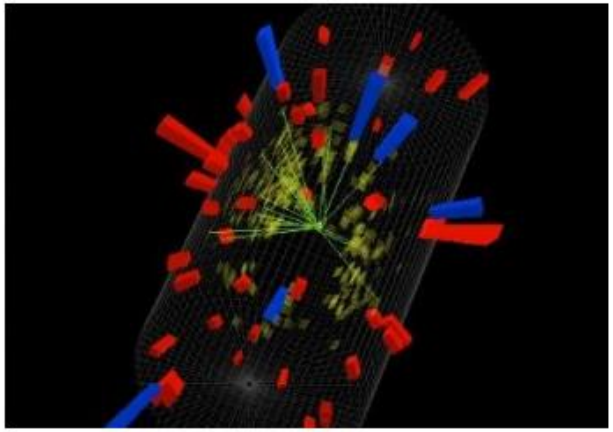
# CMS WZH Masterclass

## *Introduction for scientists*



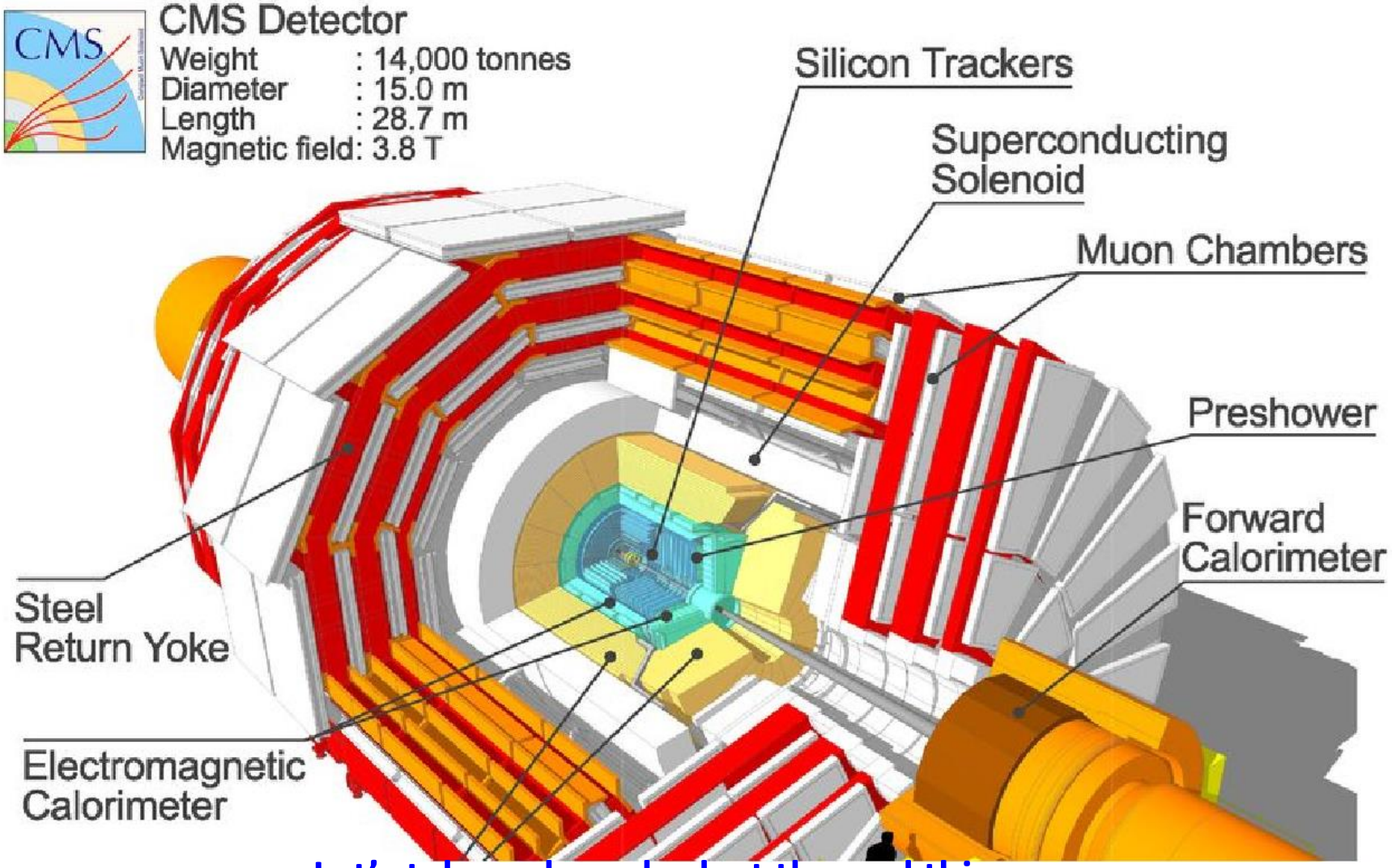
INTERNATIONAL MASTERCLASSES

hands on particle physics

Fermilab

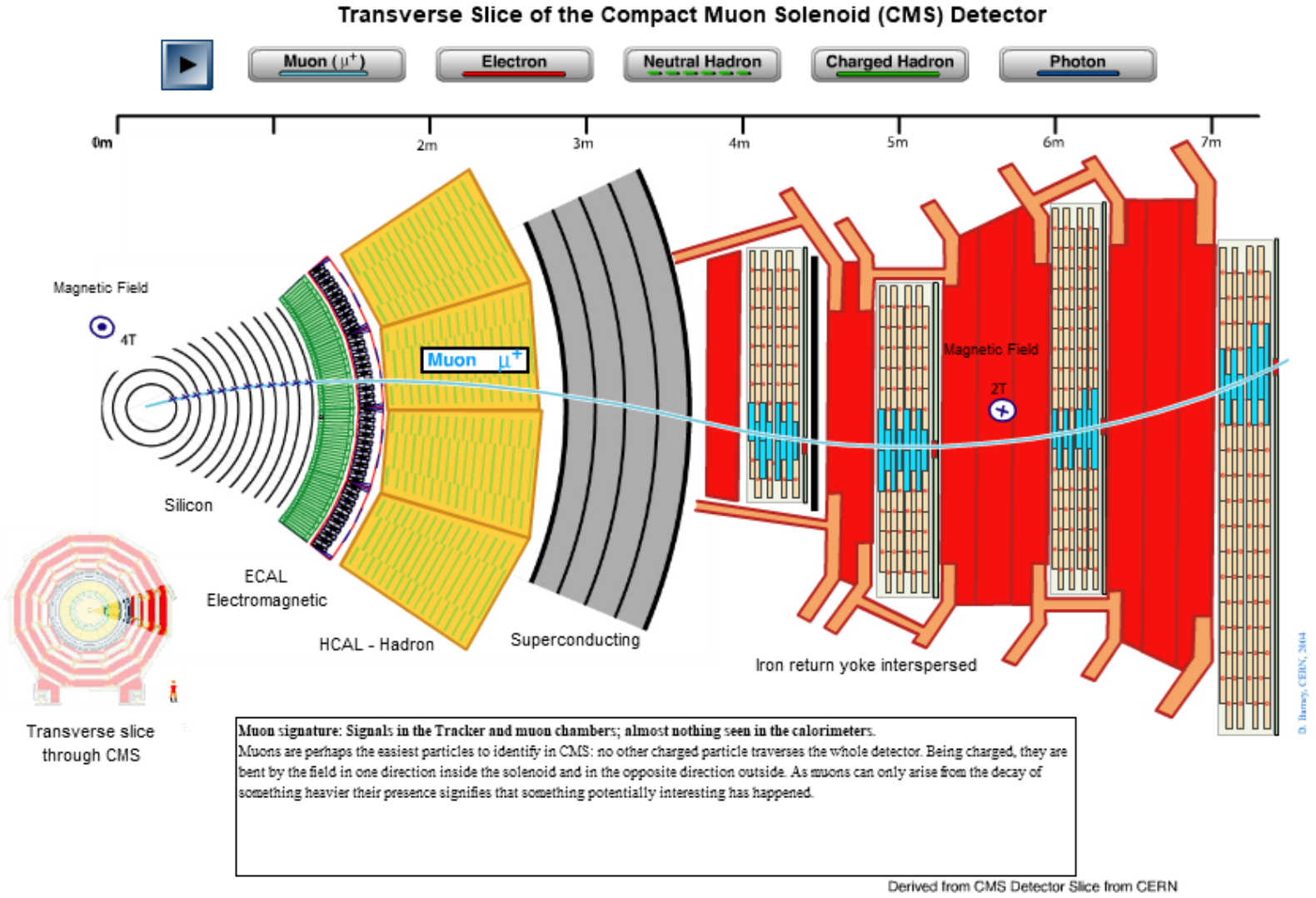
UNIVERSITY OF NOTRE DAME

# The Compact Muon Solenoid (CMS)




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

# Leptons in CMS

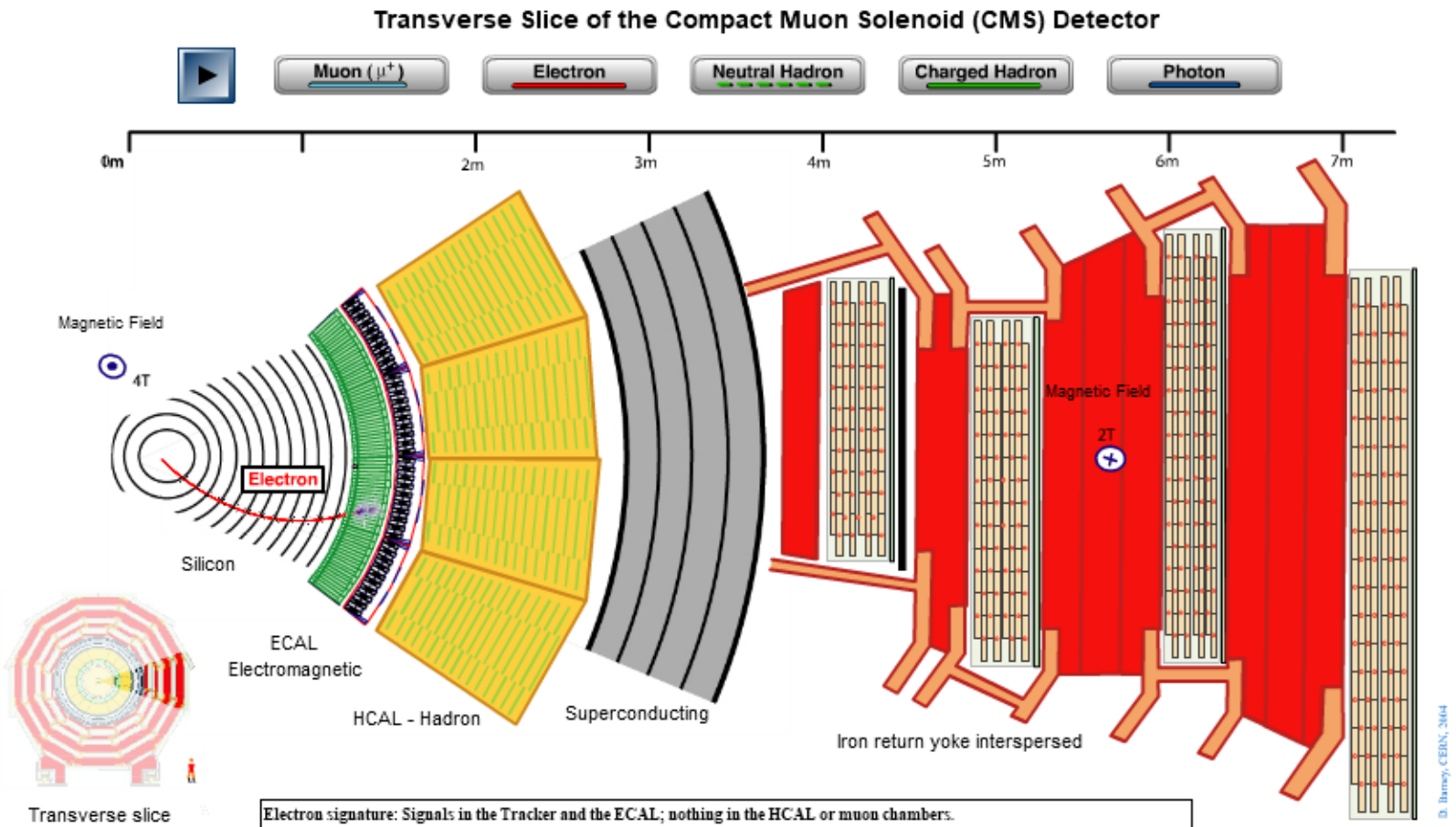



Transverse slice through CMS

**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



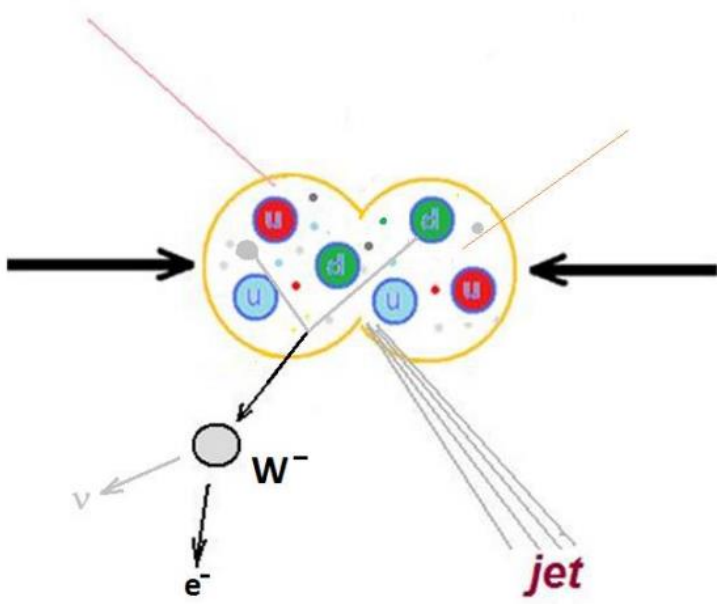

Transverse slice through CMS

**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

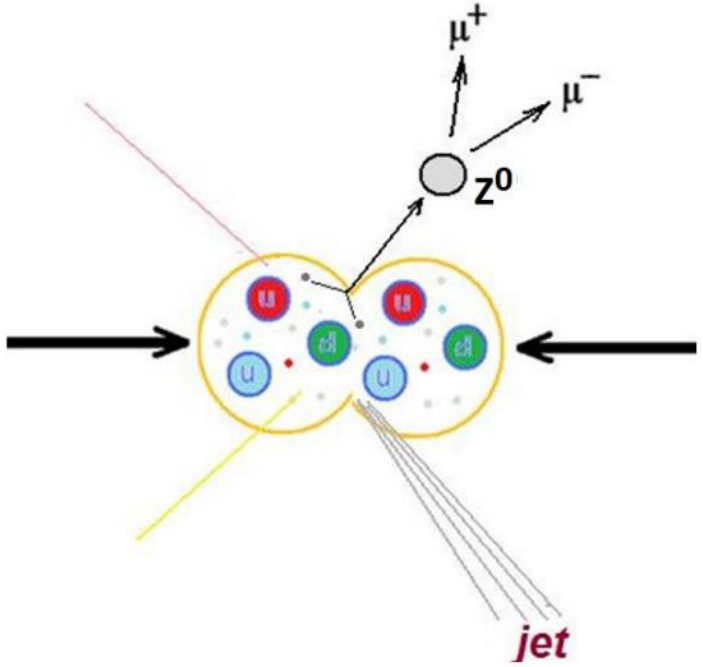
# One-lepton events

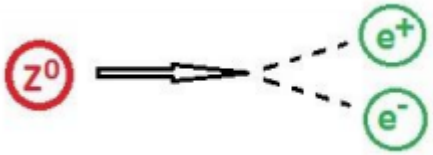
**The + or – charged W boson decays into a neutrino and another lepton – electron or muon. Since CMS cannot detect the neutrino directly, we can call this a one-lepton event.**

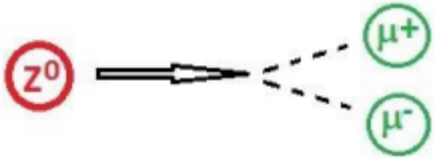



# Two-lepton events

The Z boson and some other neutral particles decay into two leptons of the same type but opposite charge – electron and positron or muon and antimuon. There are other decay paths but we are not looking for these.



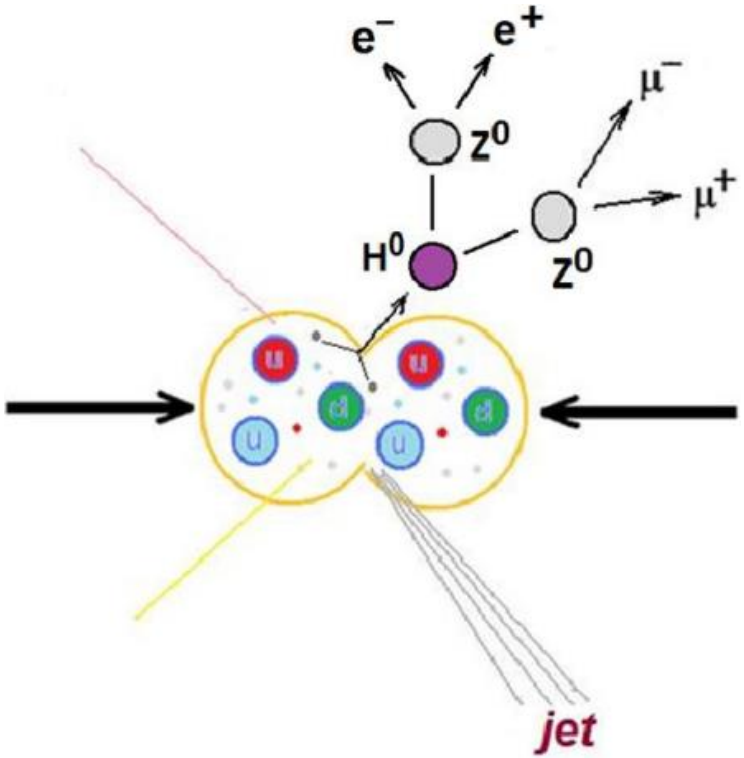



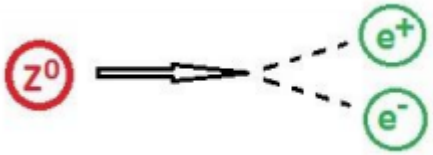



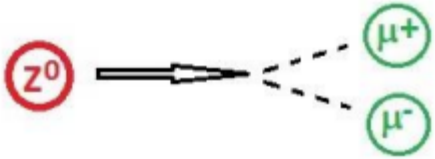
# Four-lepton events

Two Z bosons or a Z boson that radiates a photon can decay into four leptons. Thus we can get 2 muons and 2 electrons *or* 4 muons *or* 4 electrons.

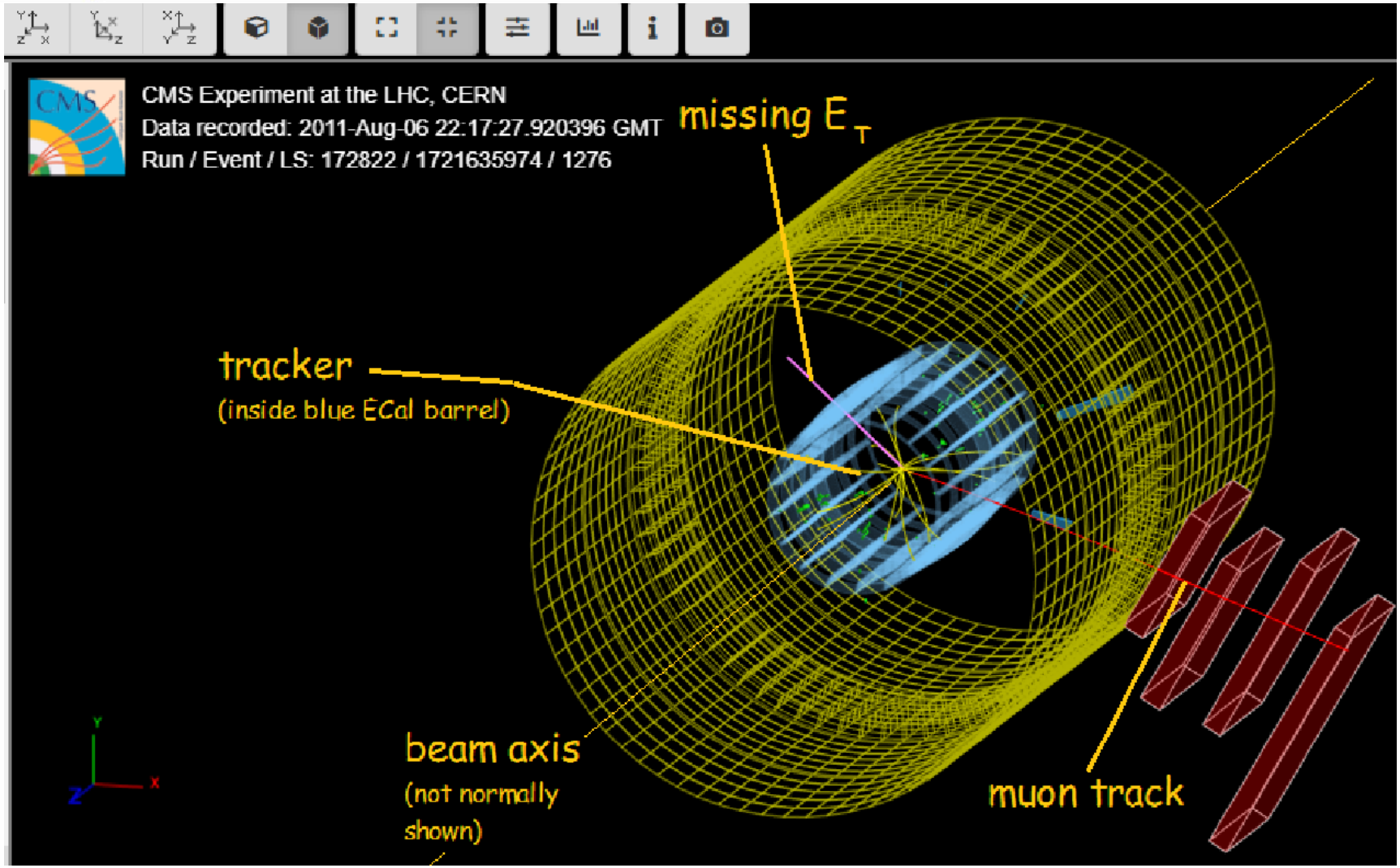
One decay mode of the Higgs is into two Z bosons, which themselves promptly decay.



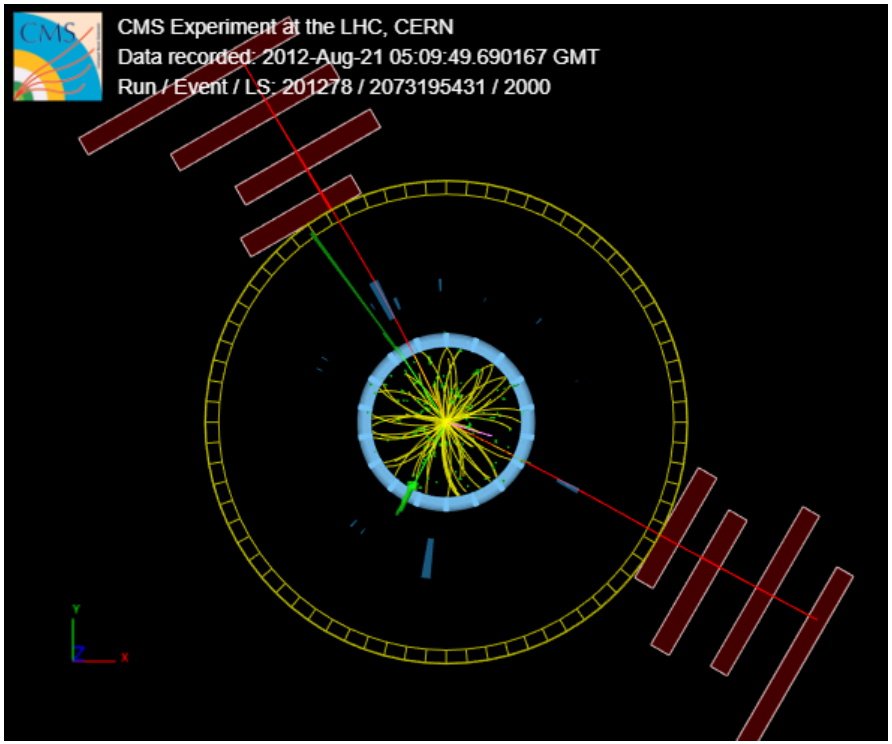



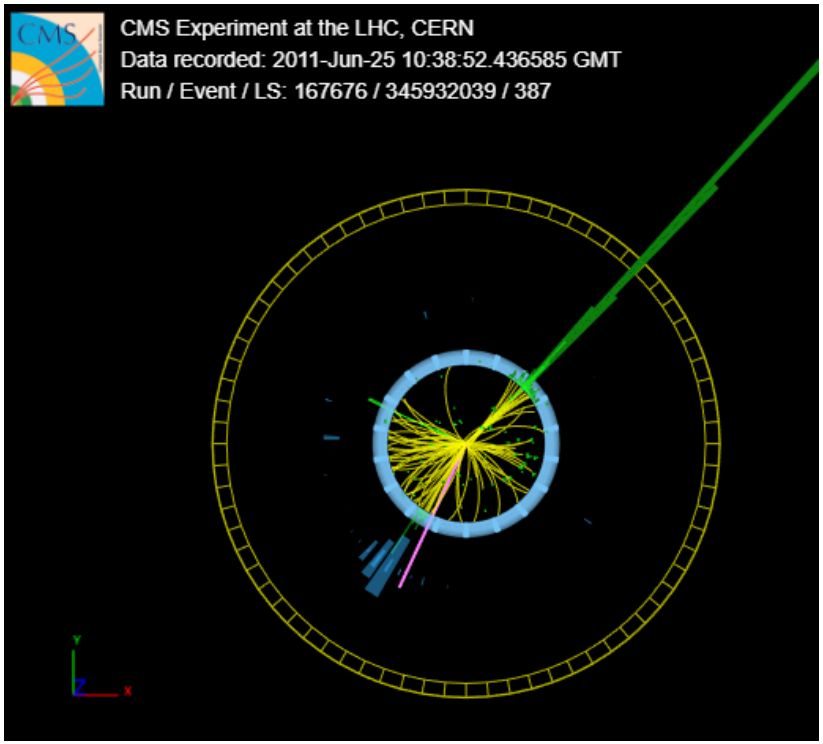
# iSpy event display for CMS



# 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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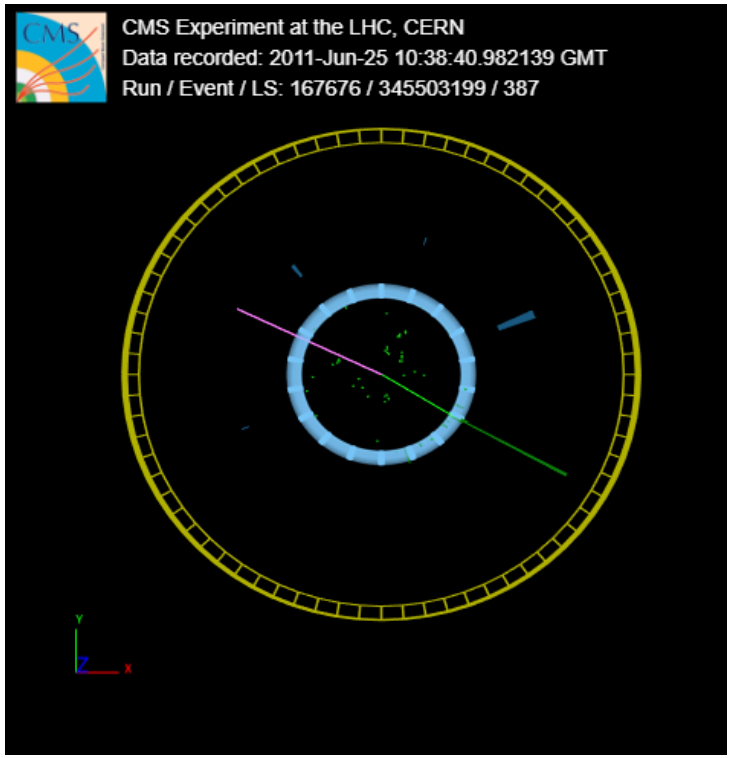


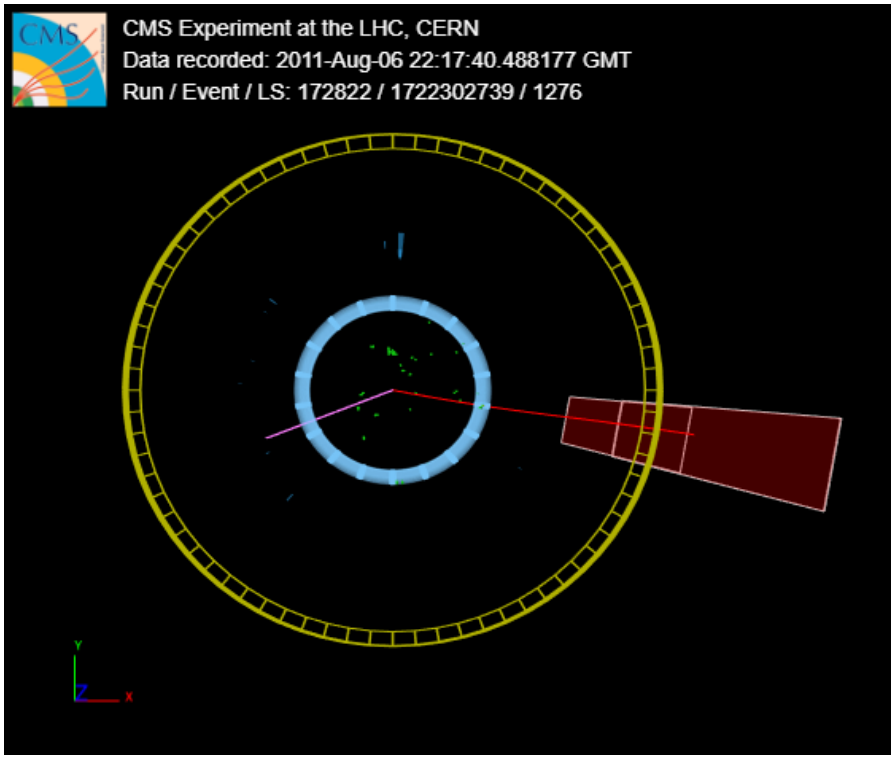

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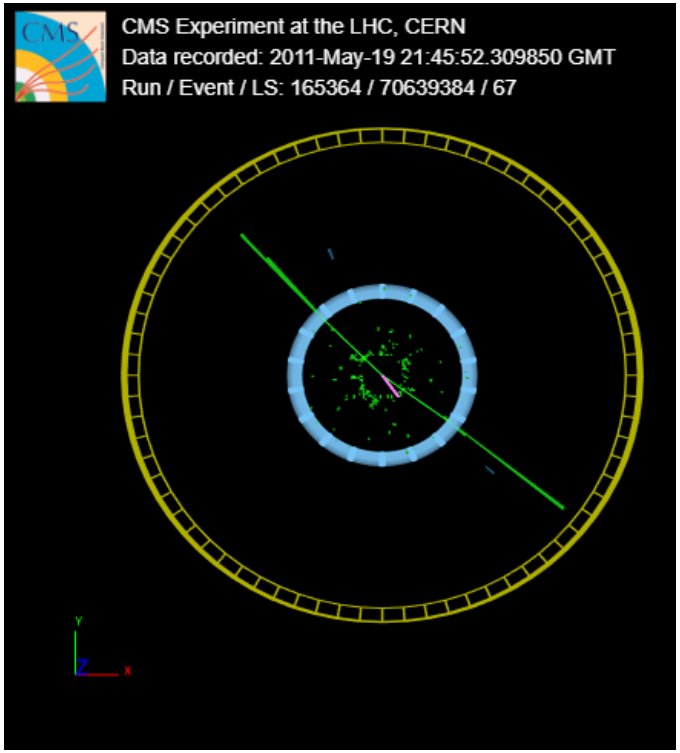
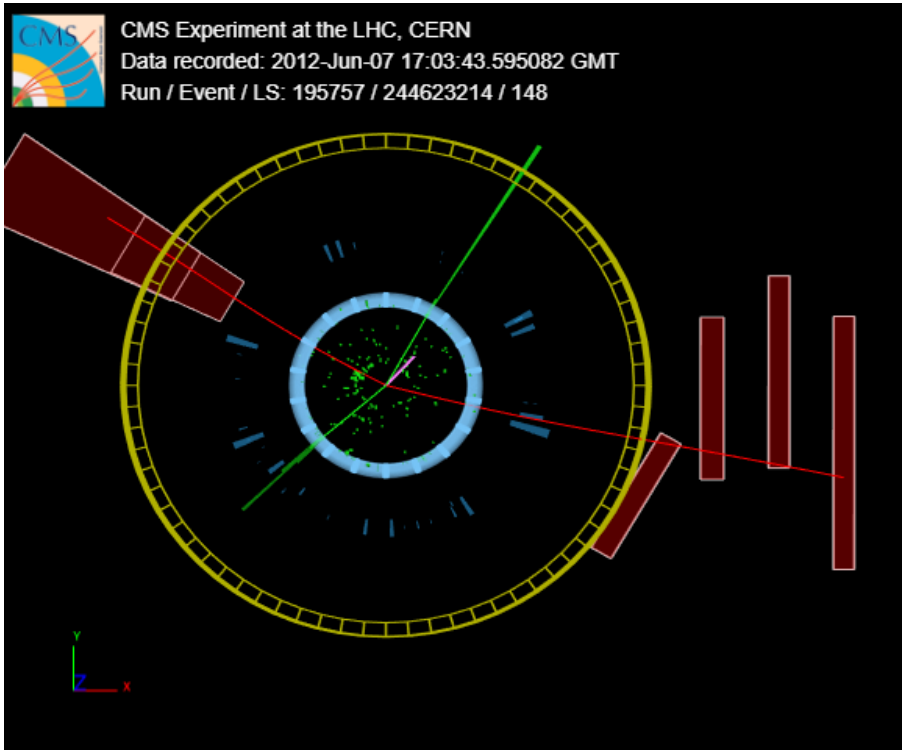
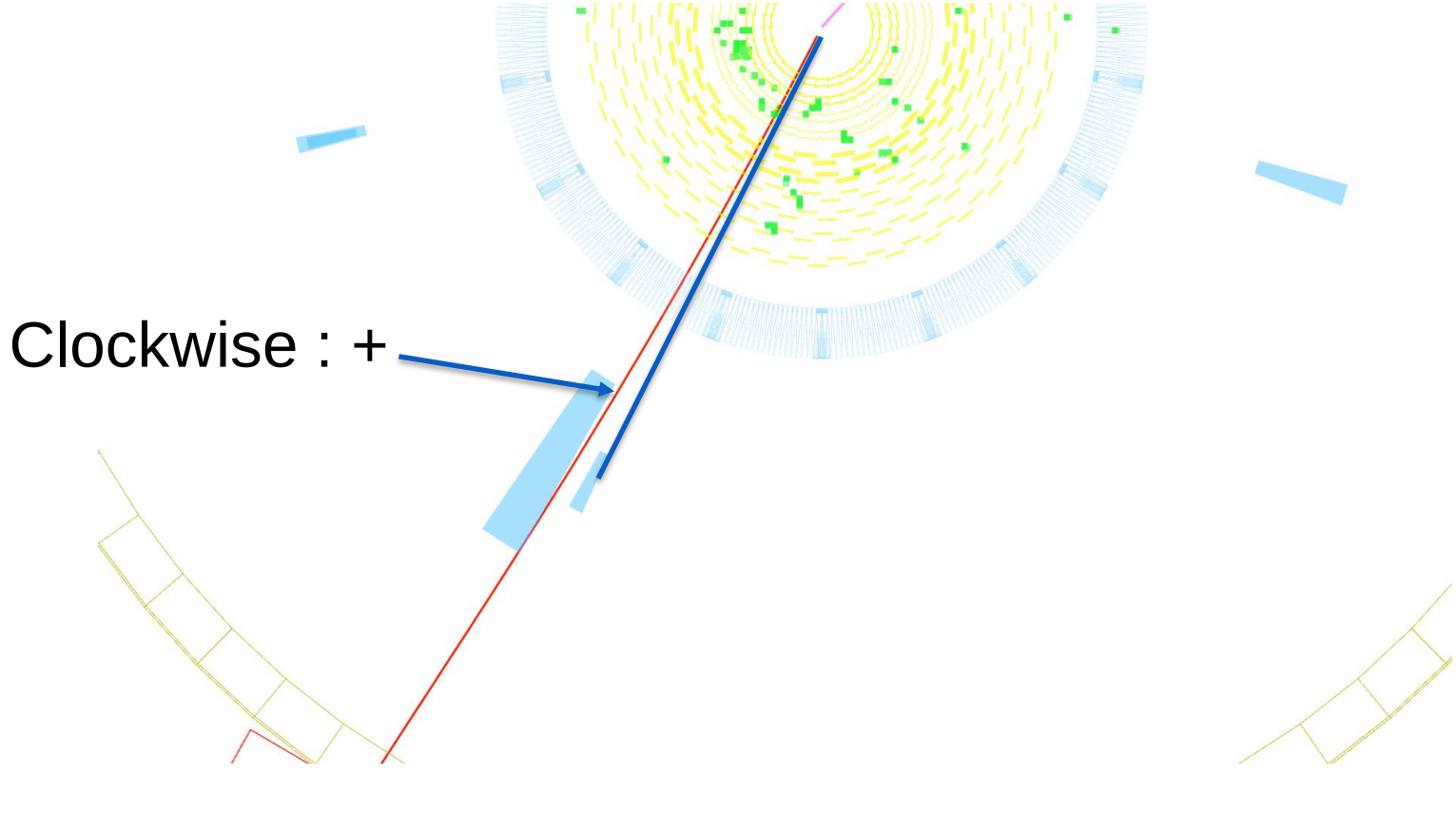
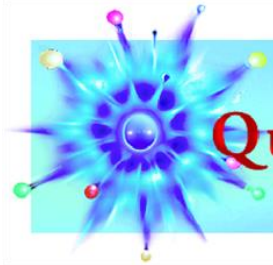


# Charge of W from lepton

We visually distinguish W+ from W- using track curvature!






# CMS Instrument for Masterclass Analysis (CIMA)

## Enter data on each event:

Back | Events Table (Group 1) | Mass Histogram (Table01) | Results (Table01) | Event Display

**Masterclass:** Event01
**location:** Table01
**Group:** 1

**Select Event**

Event index: 14

Event number: 1-14

**Final State**

- e ν
- e e
- 4e
- 2e 2μ
- μ ν
- μ μ
- 4μ

**Primary State**

Charged Particle:
- W+
- W-
- W±

Neutral Particle (Z, H)

Zoo

**Enter Mass**

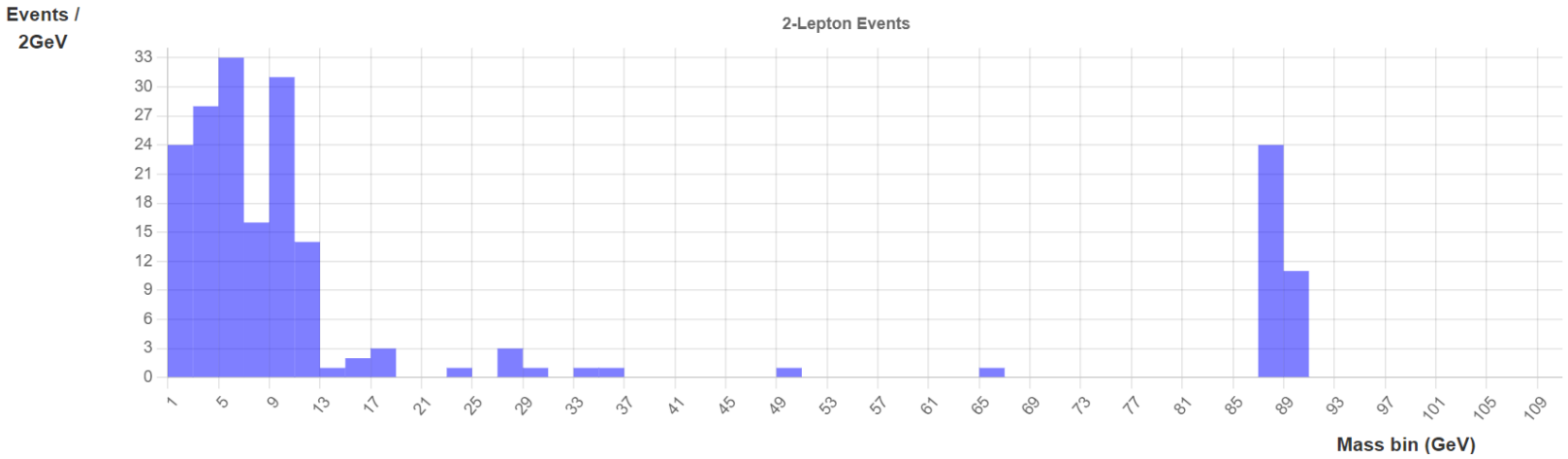
GeV/c²

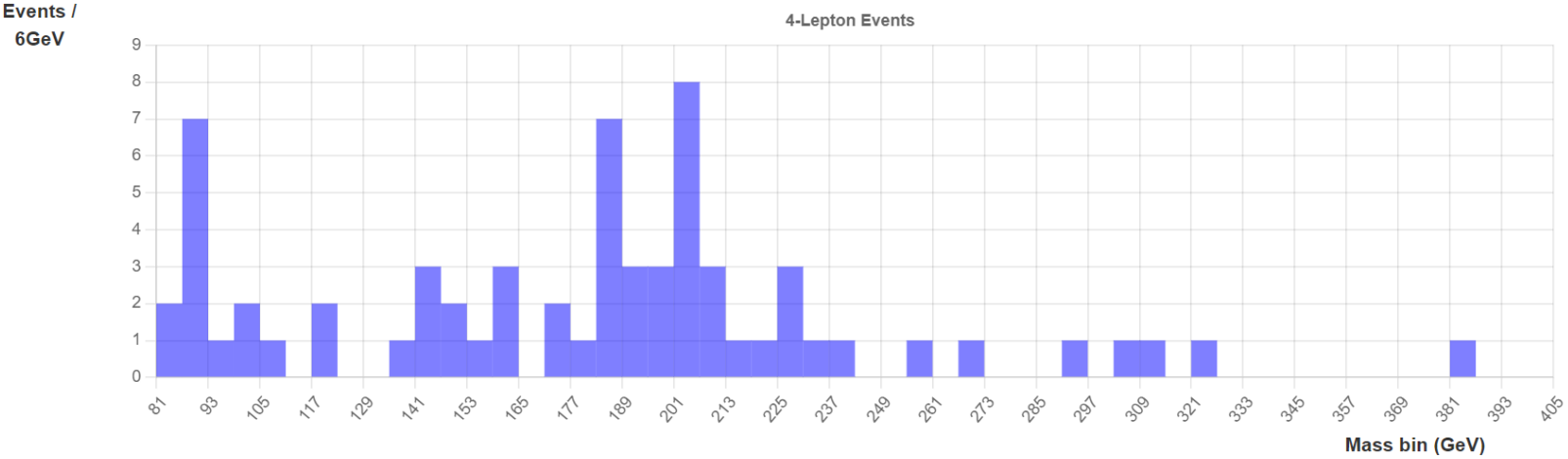
Next

| Event index | Event number | Final state | Primary state | Mass |
|---|---|---|---|---|
| 13 | 1-13 | μν | W± | |

# 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 |