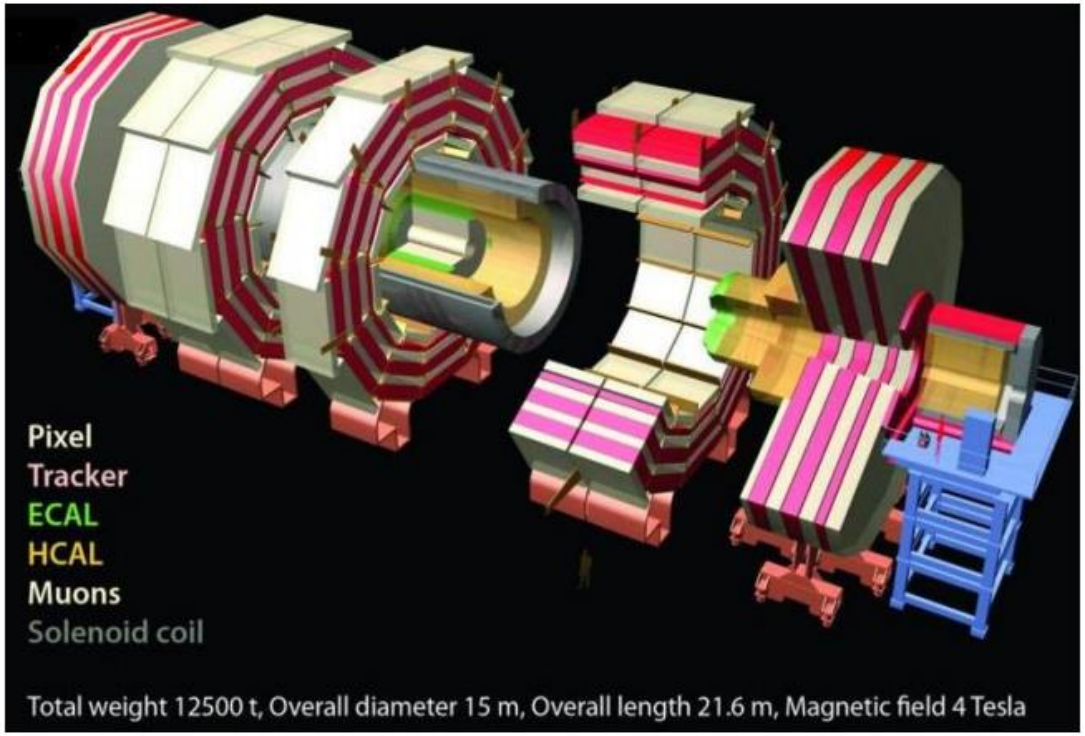
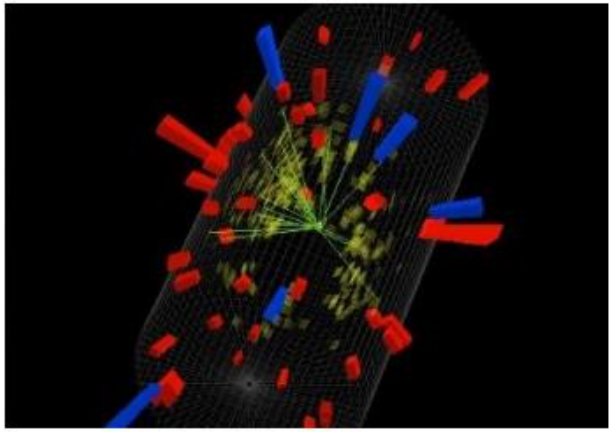
QuarkNet

BAMC Masterclass





INTERNATIONAL MASTERCLASSES

hands on particle physics

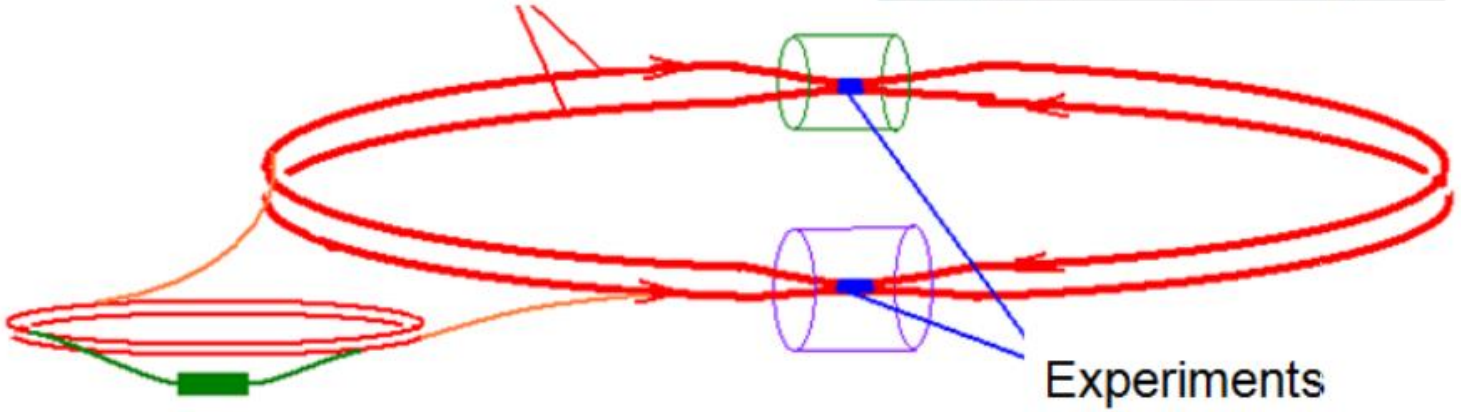
Fermilab

UNIVERSITY OF NOTRE DAME

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)



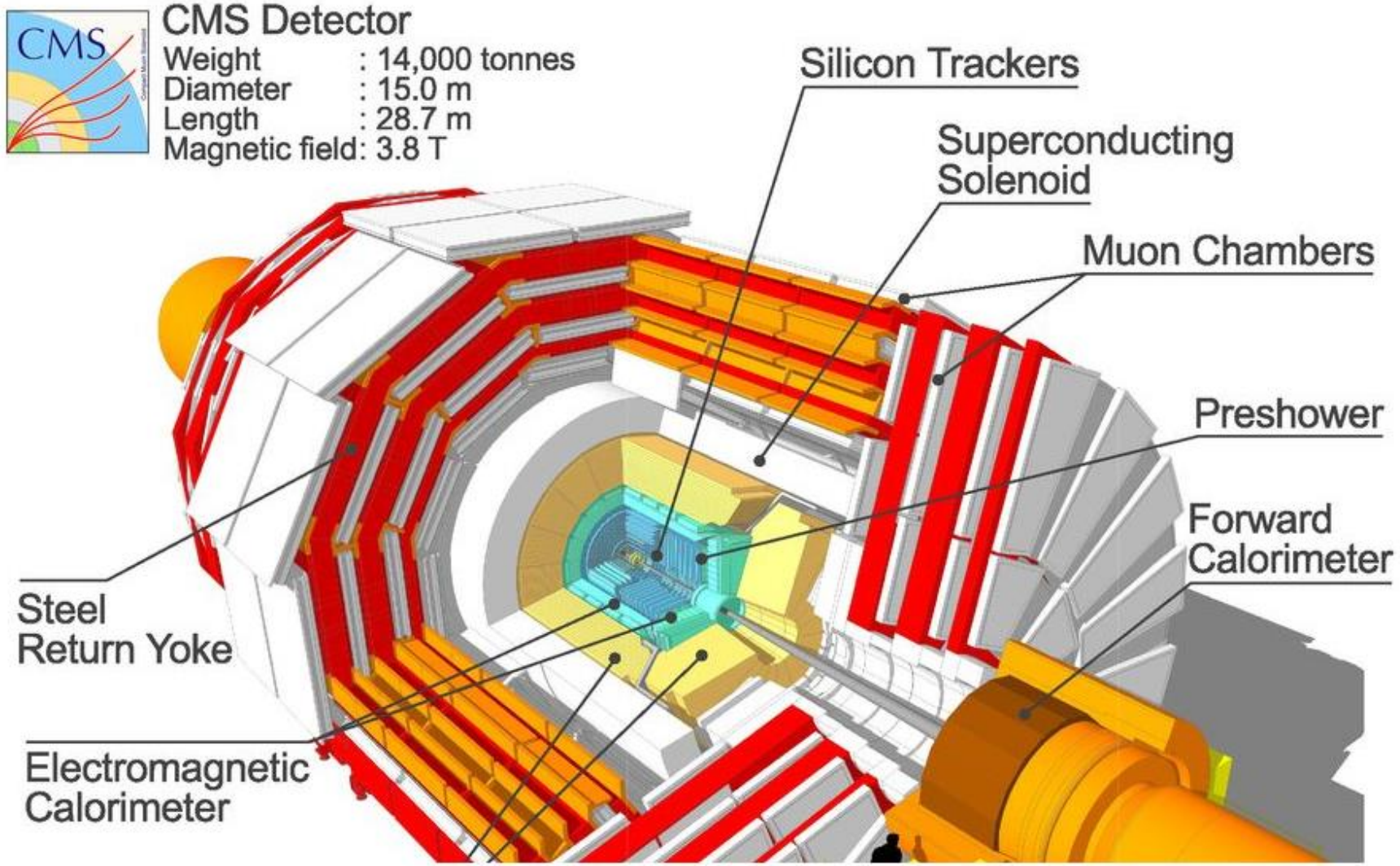
particle source
(injector)

Experiments
where beams cross and
some particles collide

The LHC and the new physics

Large Hadron Collider (LHC) at CERN – inside the tunnel.

The Compact Muon Solenoid (CMS)

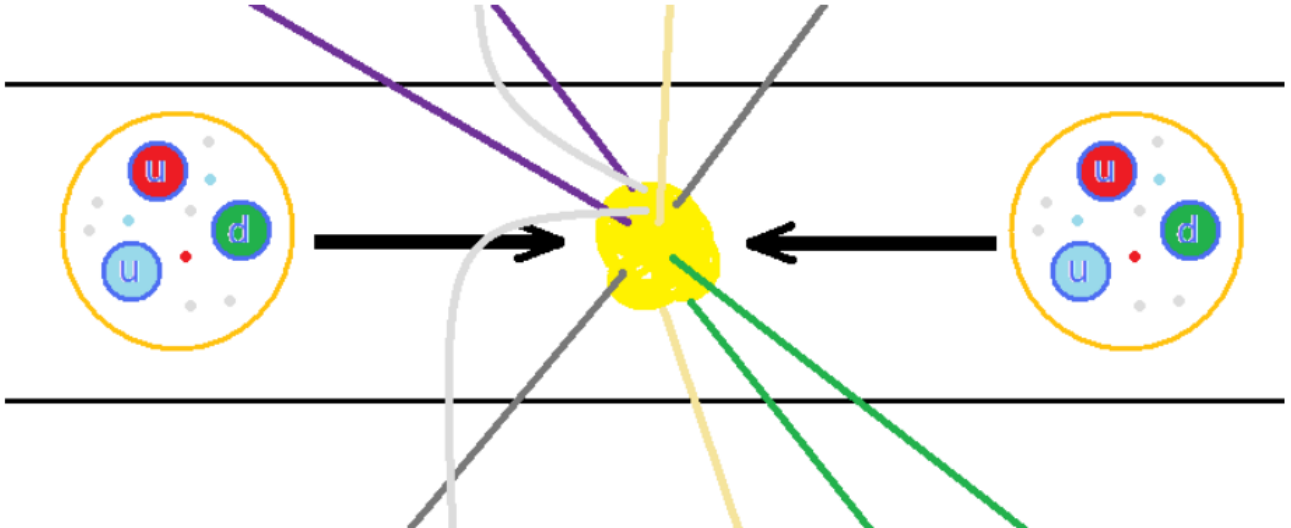


Let's take a closer look at the real thing.

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.

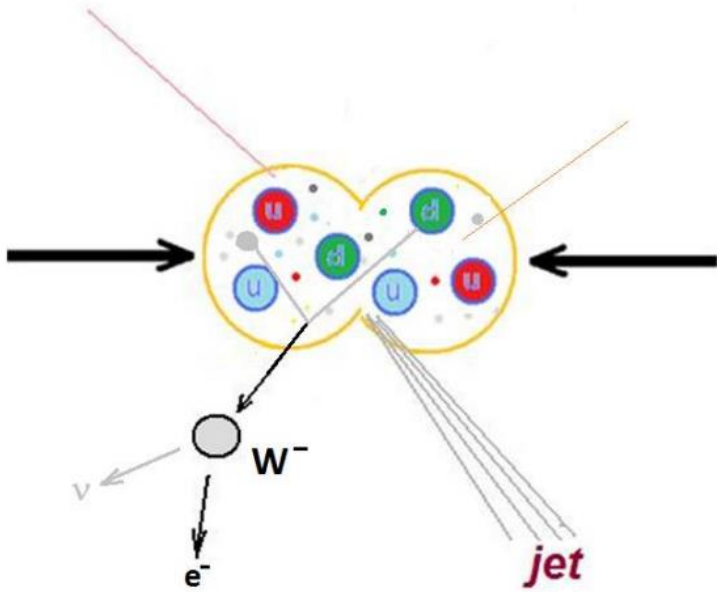
But protons are not just particles: they are more like bags of quarks and gluons. When they collide, *anything* can happen. And we are looking something specific.

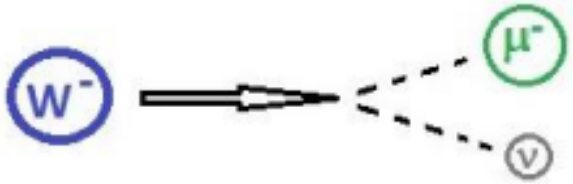


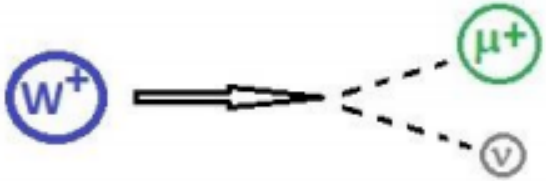
One-muon events

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

It decays into a neutrino and another lepton (electron or muon). Since CMS cannot detect the neutrino directly and we only look at muons, we can call this a one-muon event.



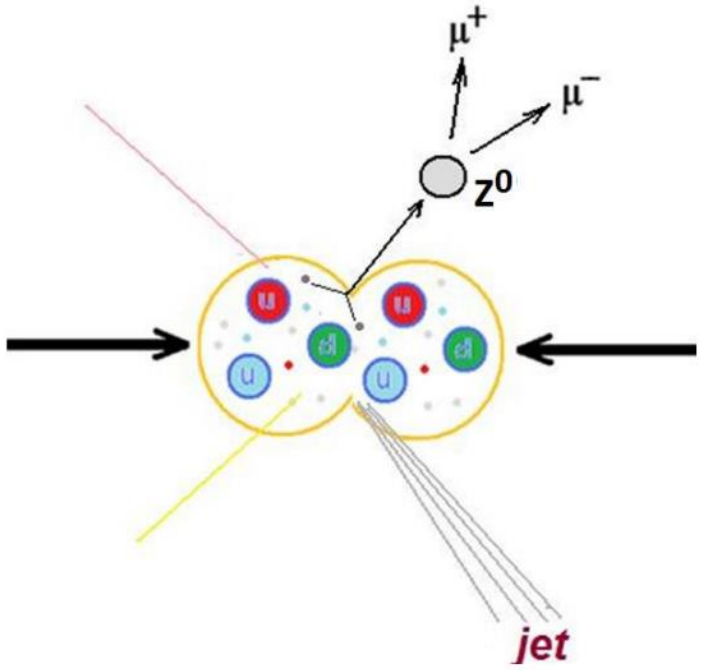


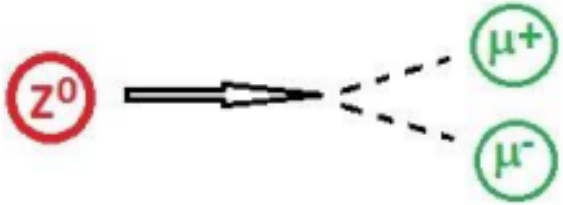


Two-muon events

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. We are only looking for muon-antimuon pairs. We will call these two-muon events.

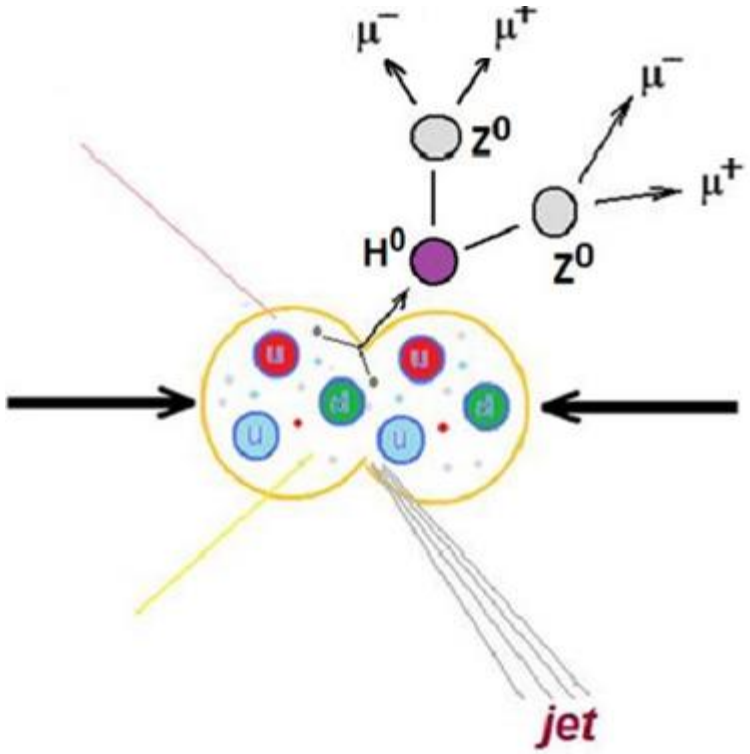


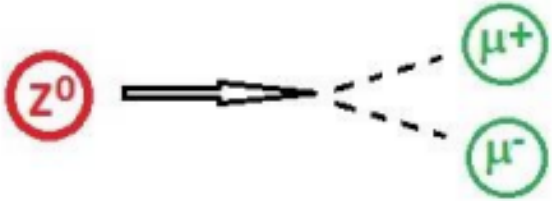


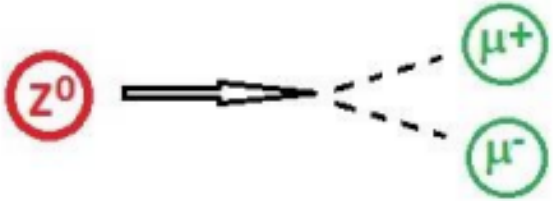
Four-muon events

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

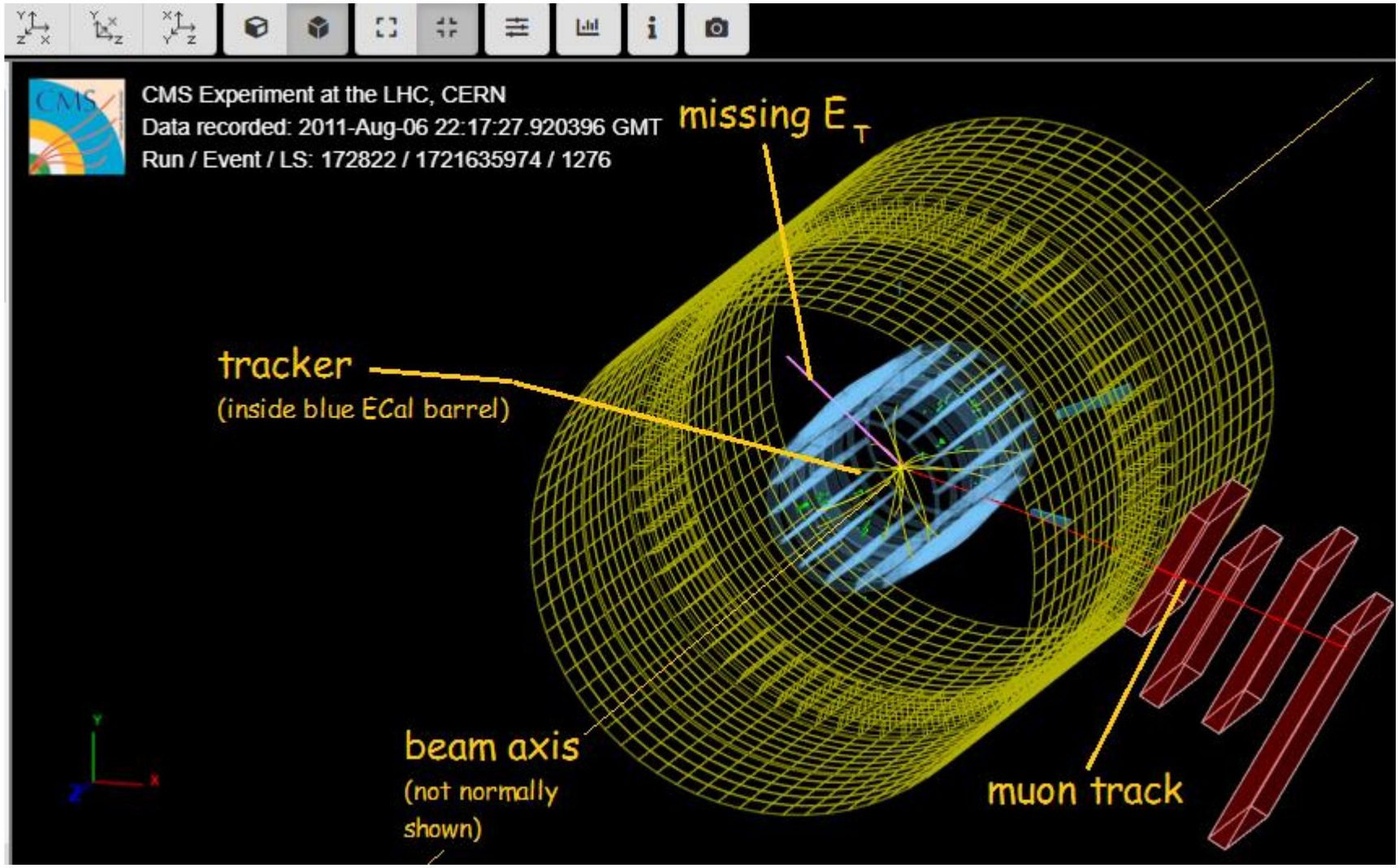
One decay mode of the Higgs is into two Z bosons, which themselves promptly decay. Thus we can get 2 muons and 2 electrons *or* 4 muons *or* 4 electrons. We will only seek 4 muon events.





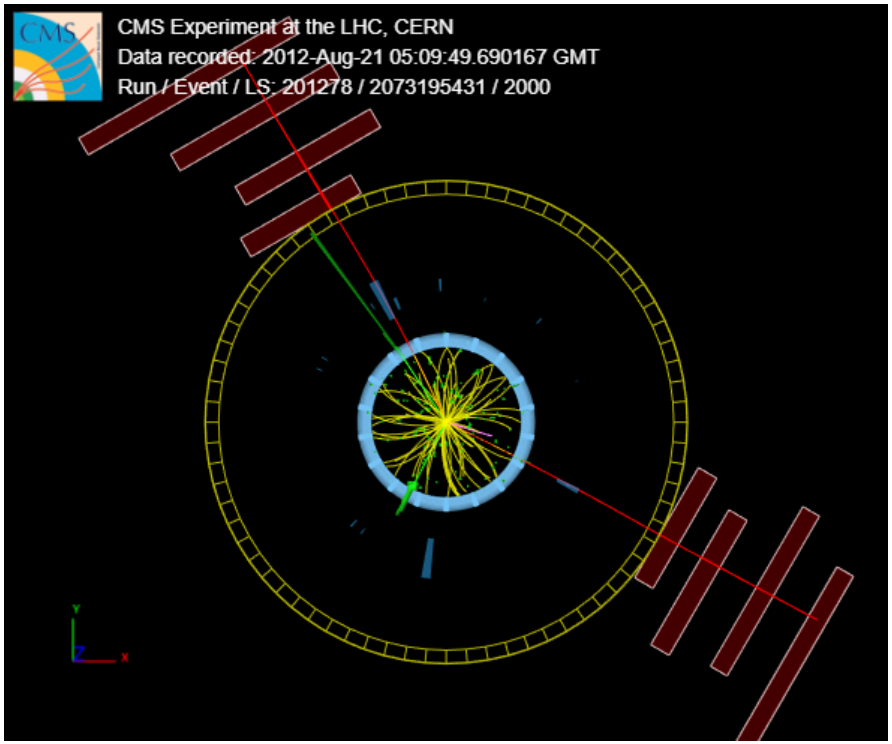


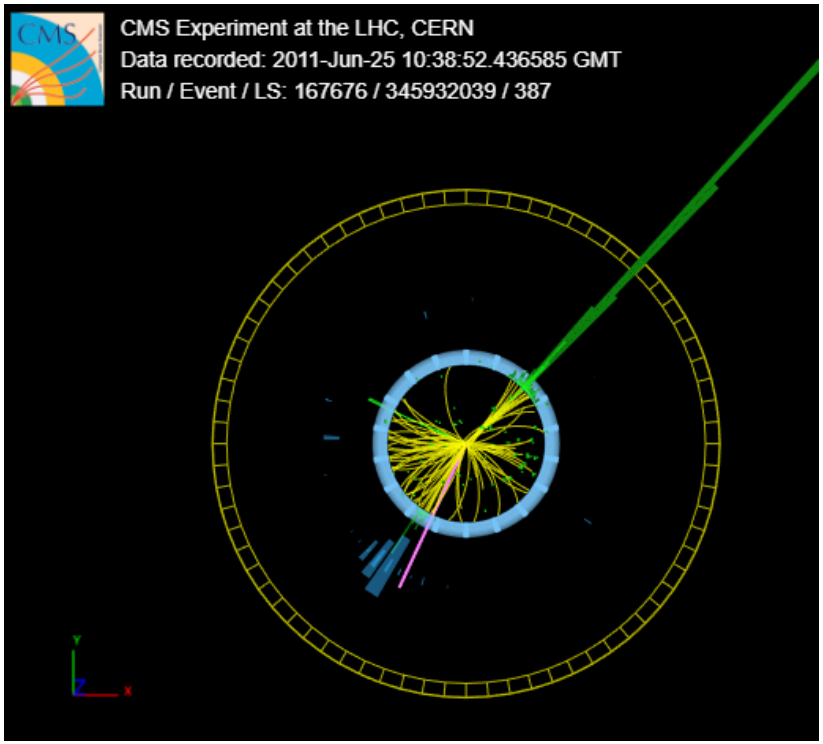
iSpy event display for CMS



1, 2, or 4 muons?

Which of these events is has muons? Is it a 1-, 2-, or 4-muon event?





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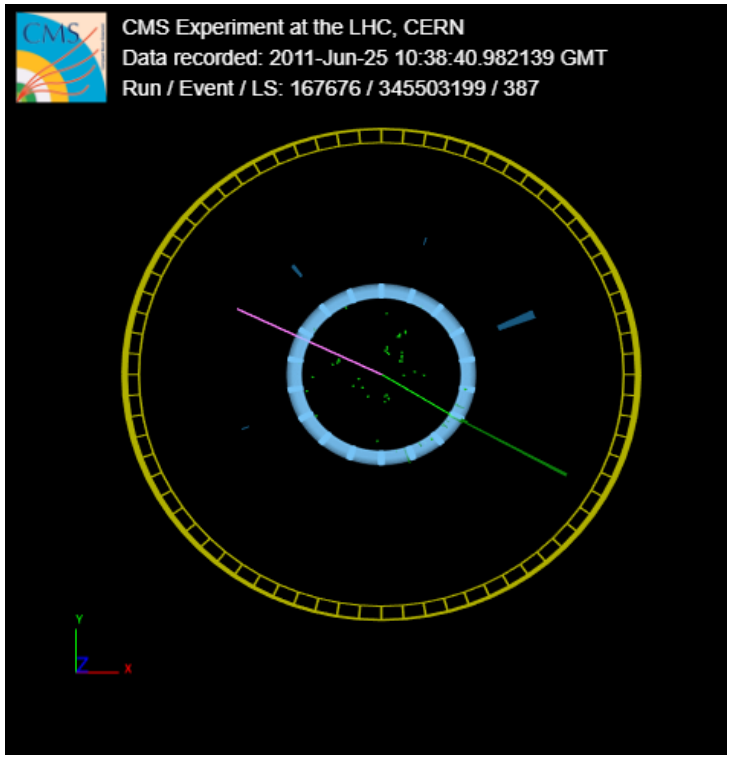

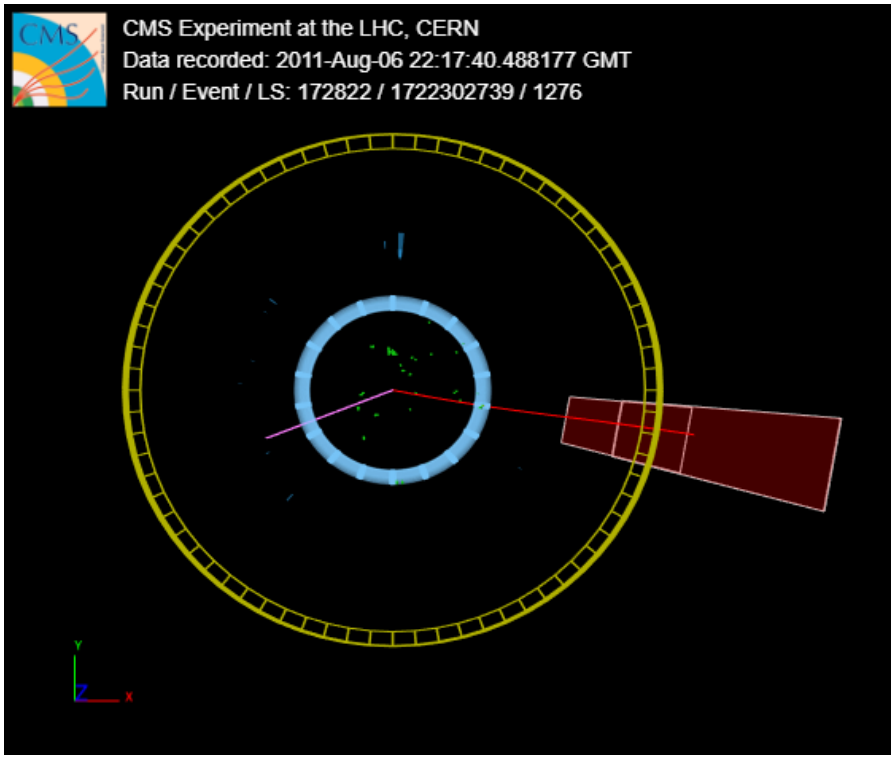

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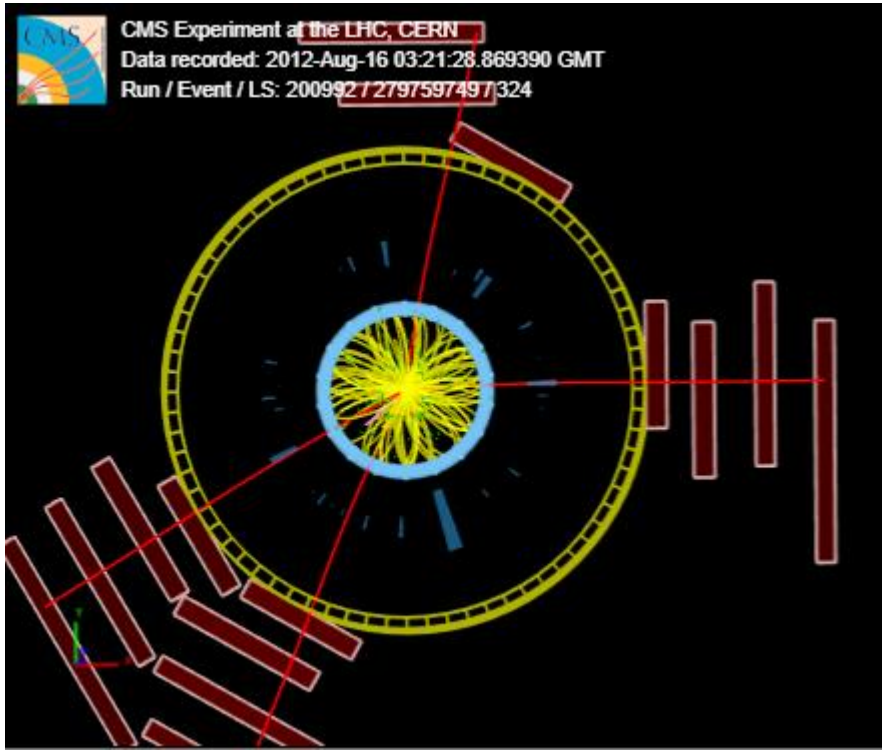
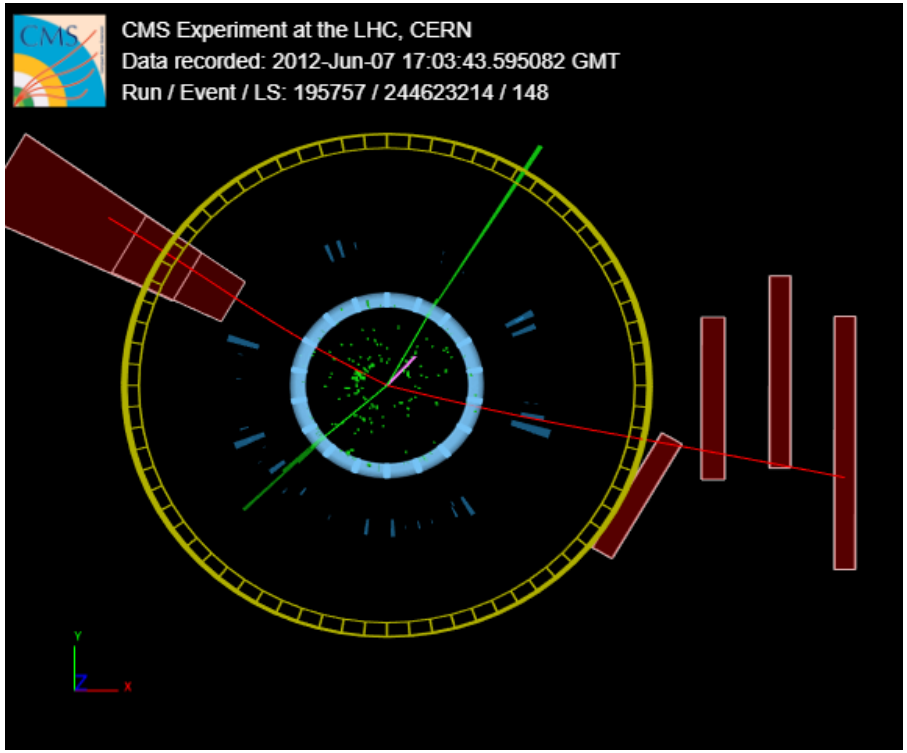
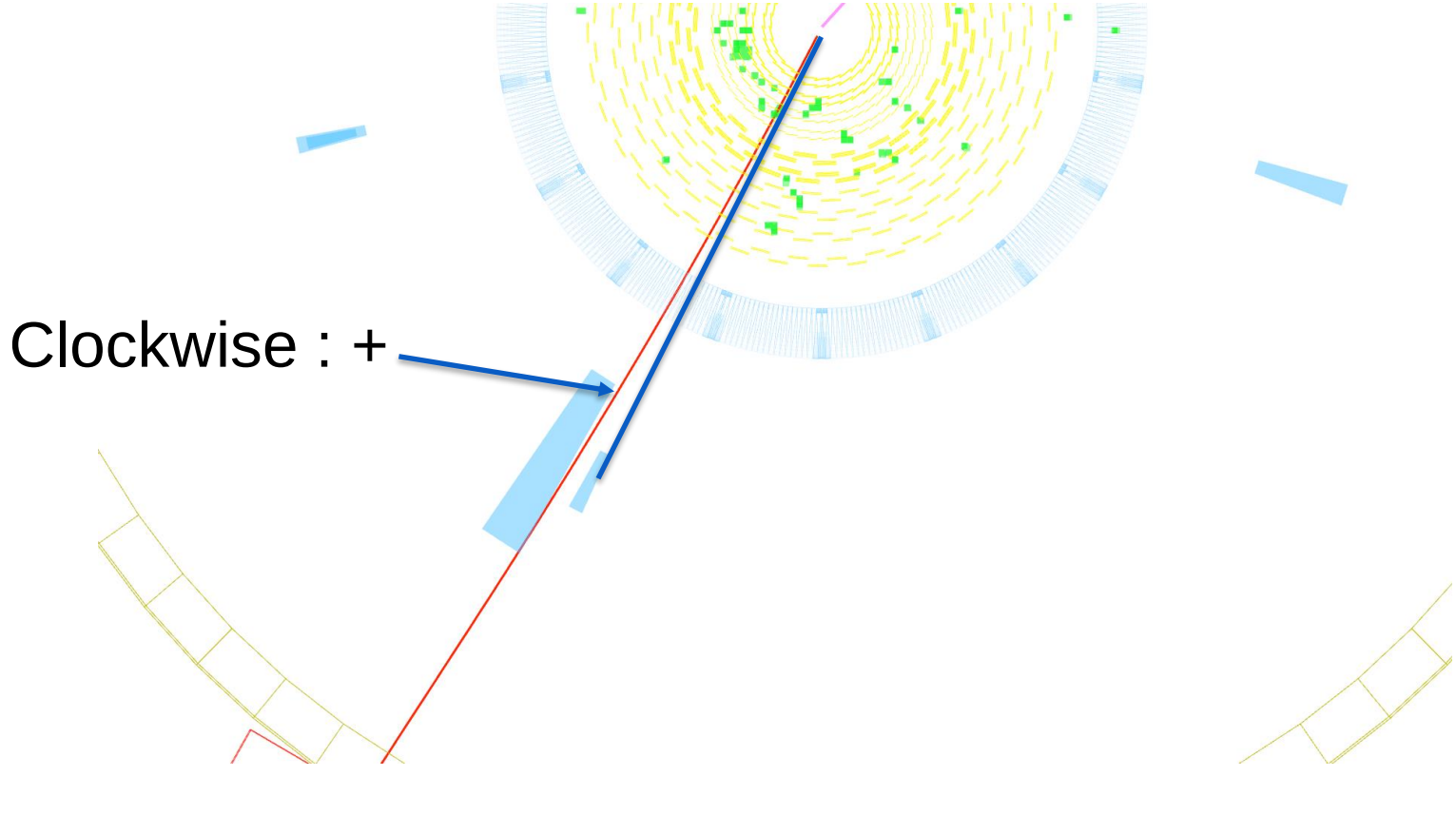


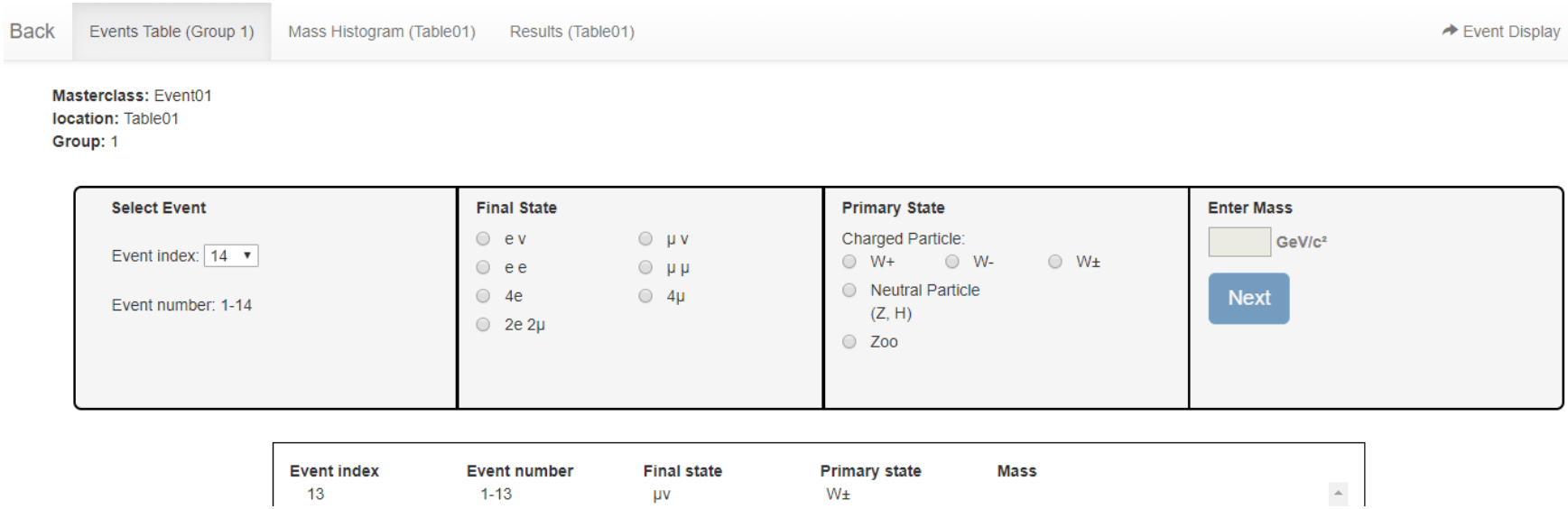


Charge of W from muon

Can you distinguish W+ from W- using track curvature?

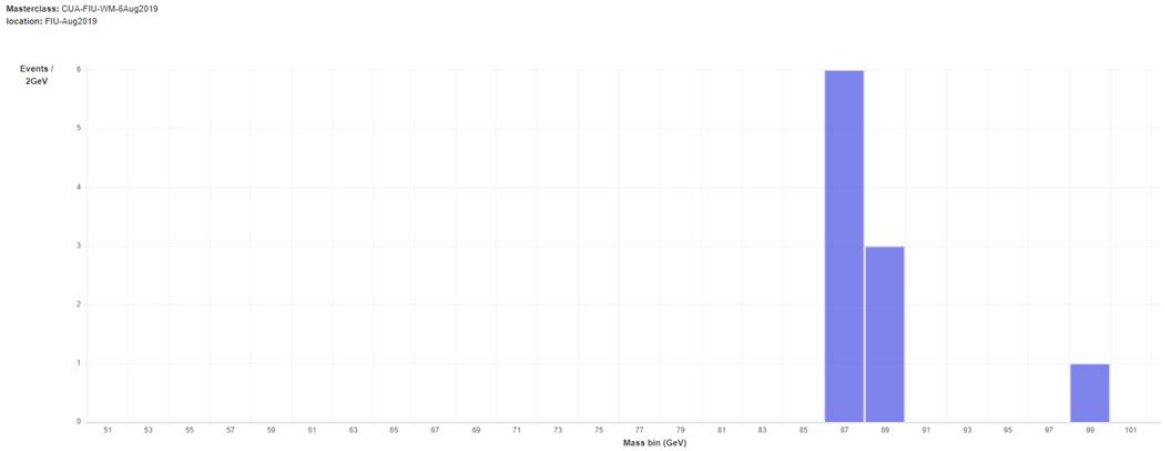


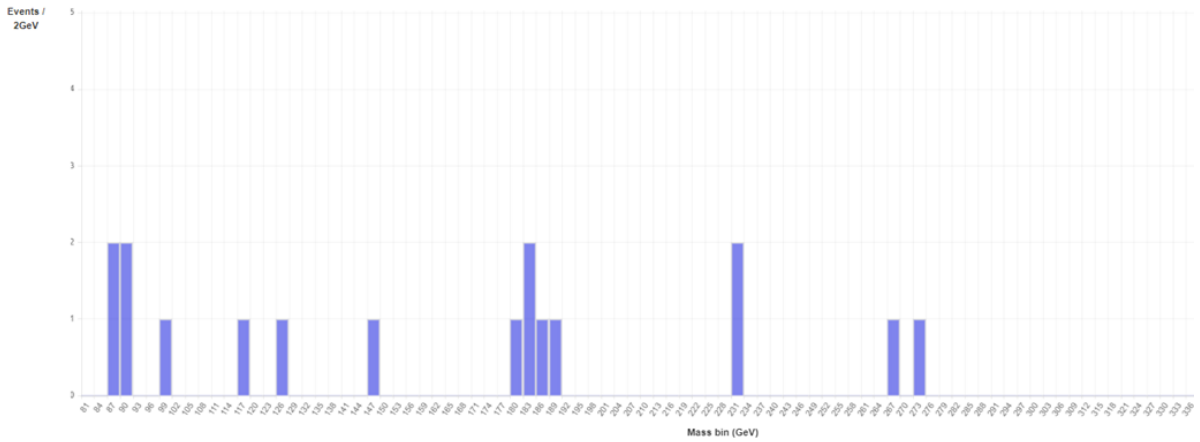
Enter data on each event:



CMS Instrument for Masterclass Analysis (CIMA)

CIMA makes mass histograms automatically:





CIMA tabulates 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:

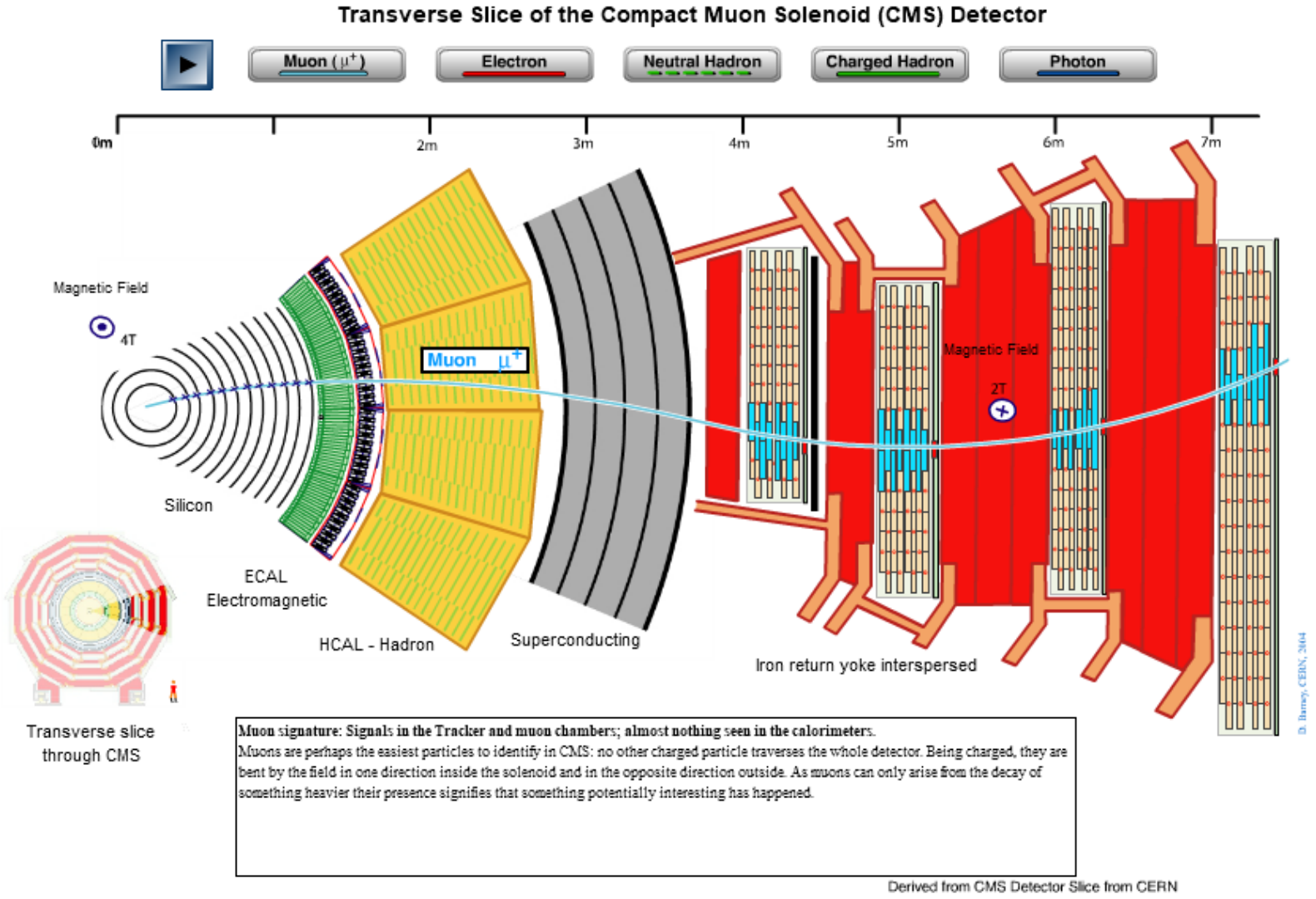
Group	e	μ	W+	W-	W±	Neutral	Zoo	Total
All	77	90	55	64	1	34	2	156

Ratios:

e/μ	W+/W-
0.92	0.86

Extra slides follow.

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.

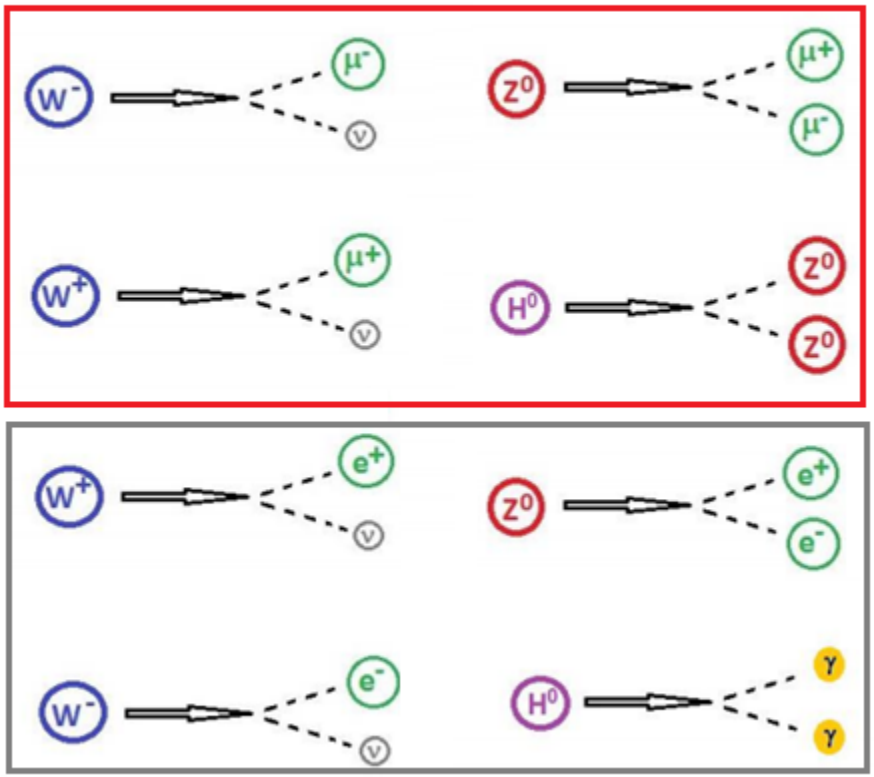
Derived from CMS Detector Slice from CERN

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"

1, 2, or 4 muons?

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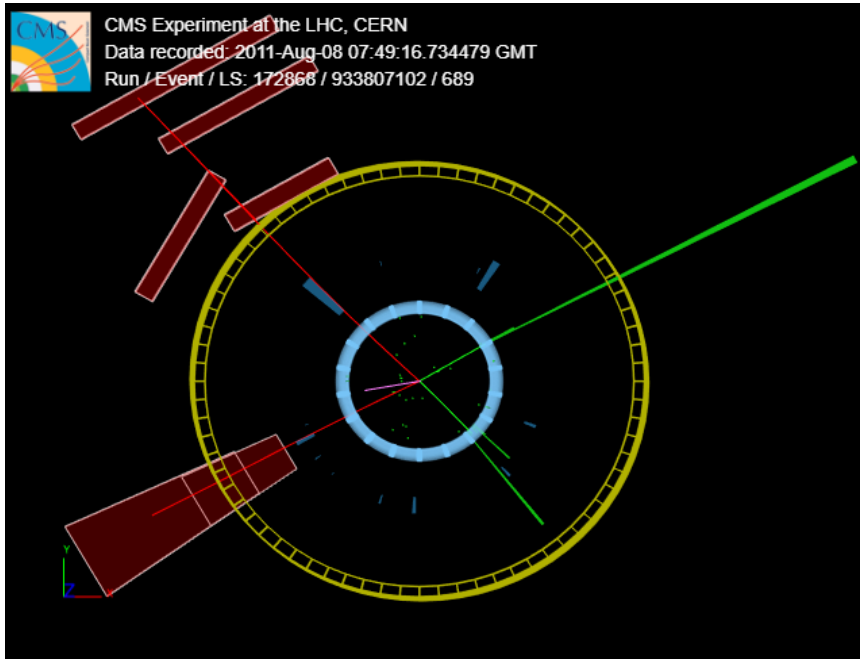

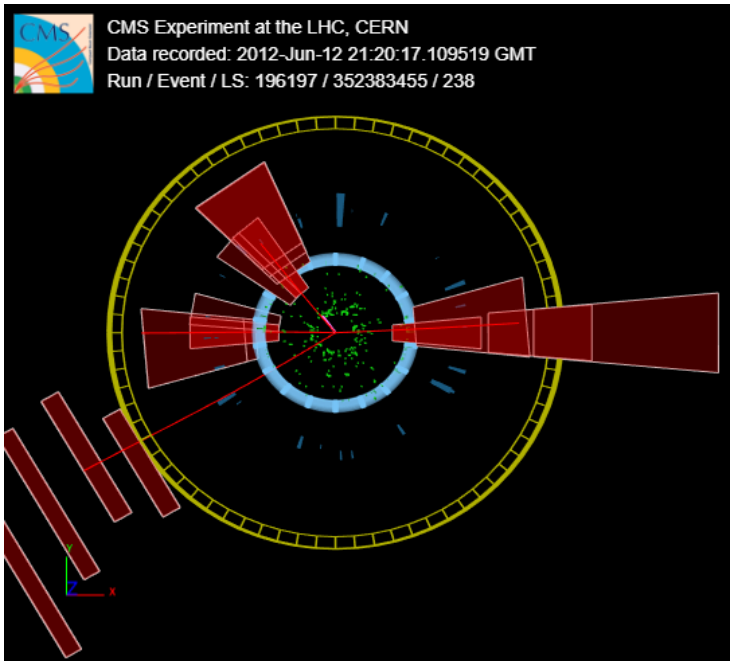

Parting words…

"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.