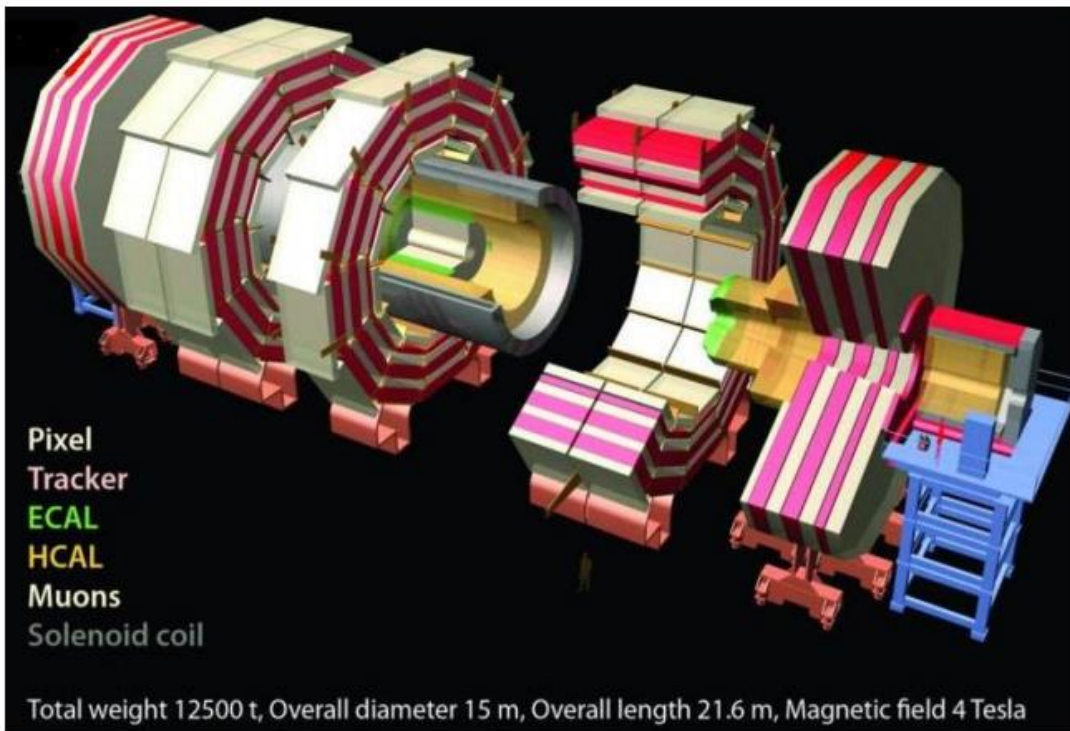
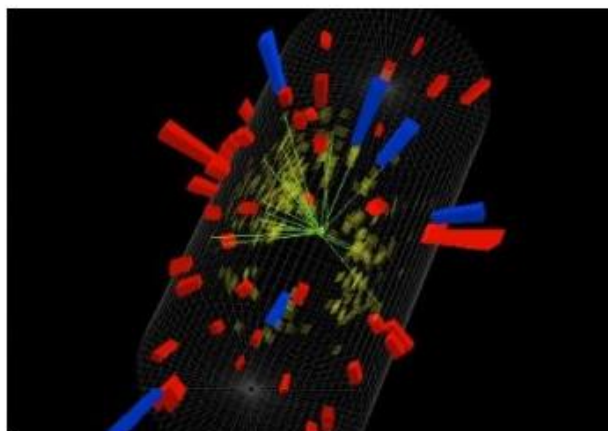


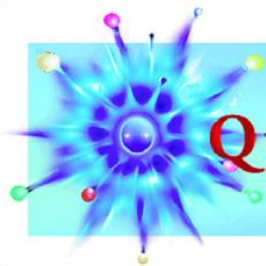
QuarkNet

# CMS WZH Masterclass



INTERNATIONAL  
**MASTERCLASSES**  
hands on particle physics



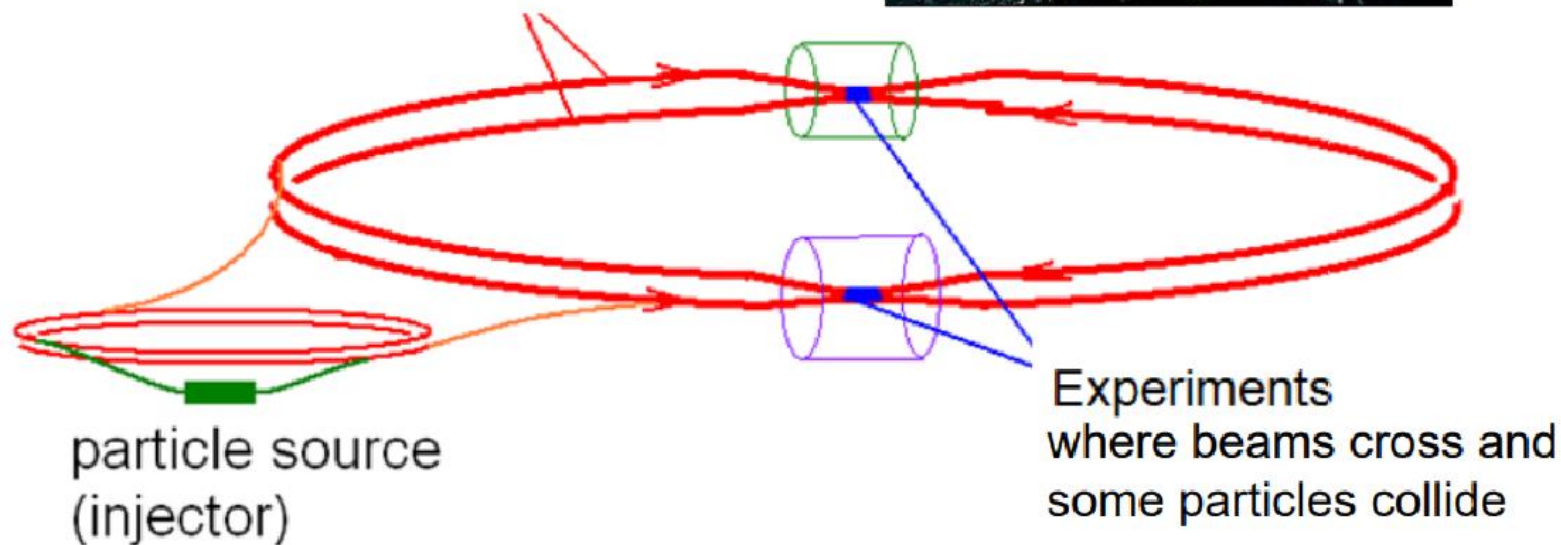


QuarkNet

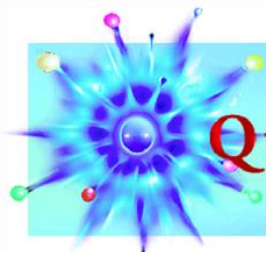
# The LHC and the new physics

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

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

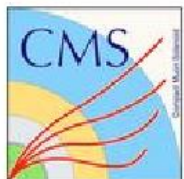






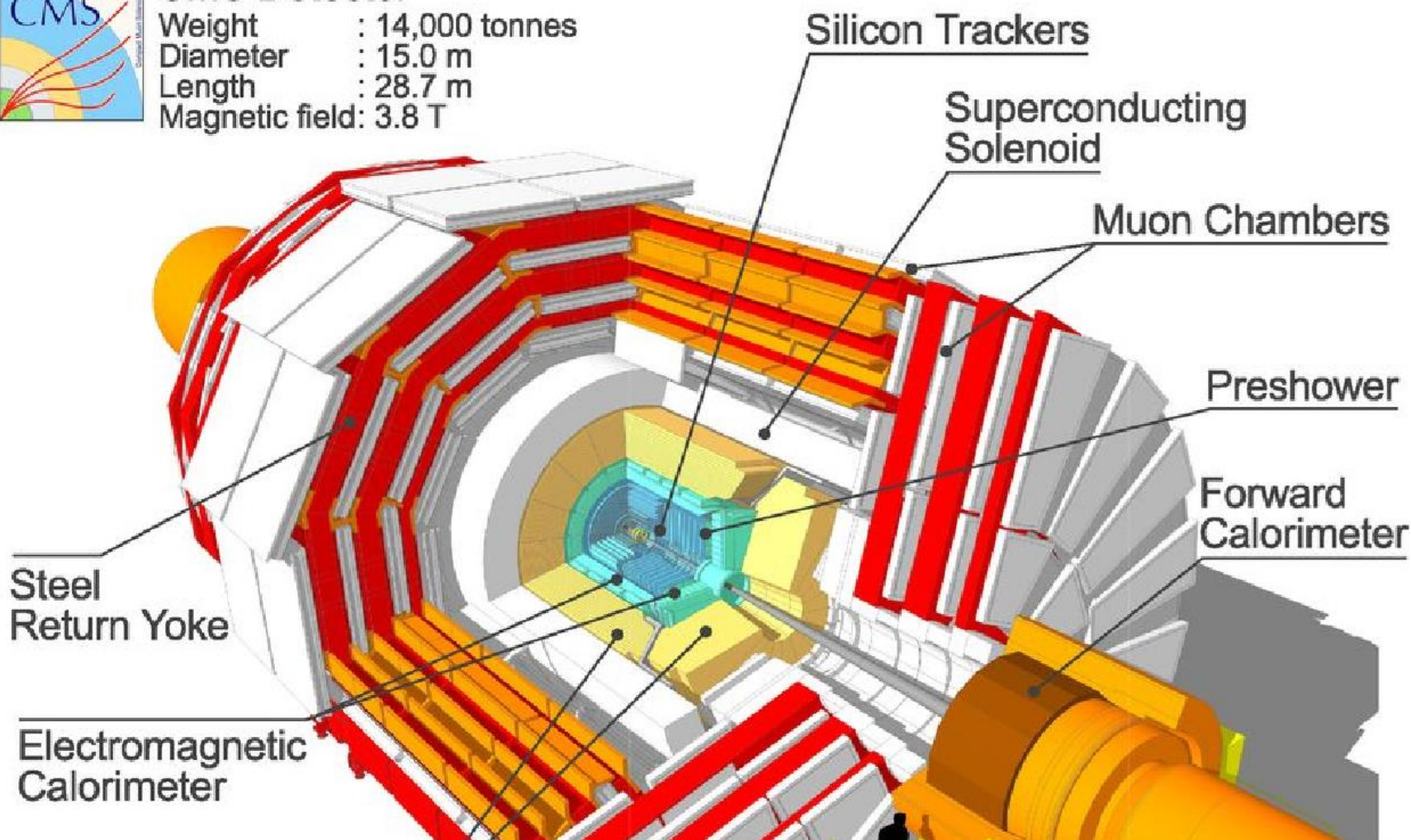
QuarkNet

# The Compact Muon Solenoid (CMS)

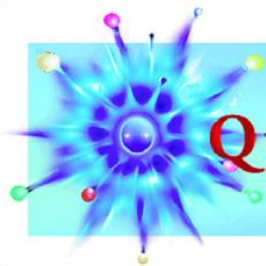


## CMS Detector

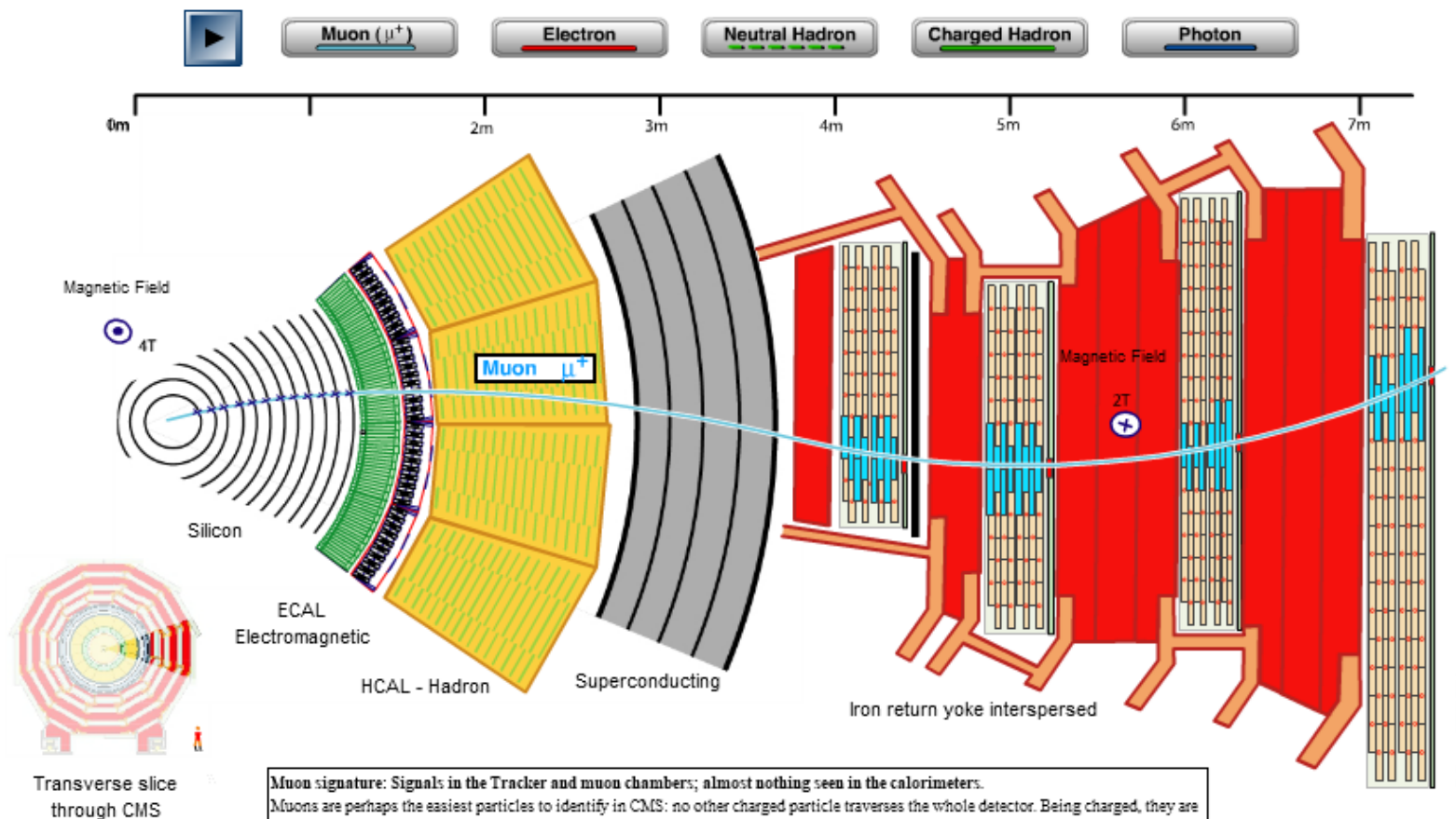
Weight : 14,000 tonnes  
Diameter : 15.0 m  
Length : 28.7 m  
Magnetic field: 3.8 T



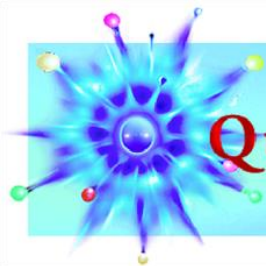
[Let's take a closer look at the real thing.](#)



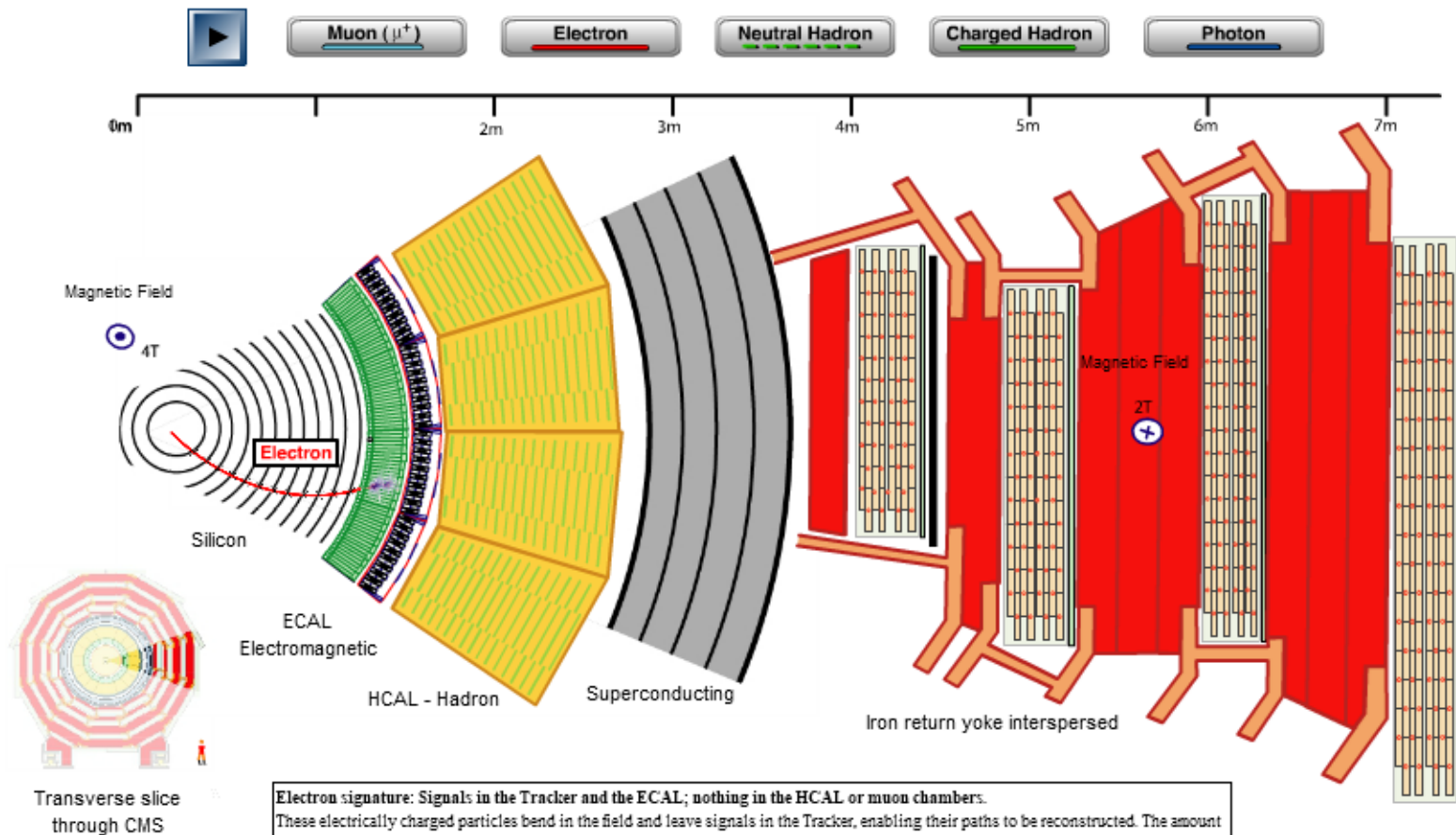
Transverse Slice of the Compact Muon Solenoid (CMS) Detector



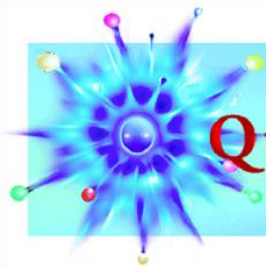
D. Barney, CERN, 2004



Transverse Slice of the Compact Muon Solenoid (CMS) Detector



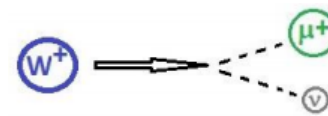
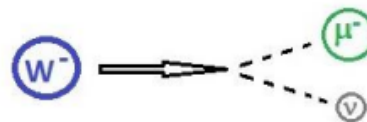
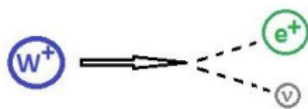
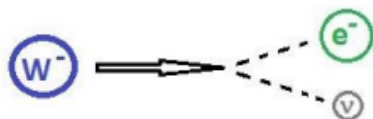
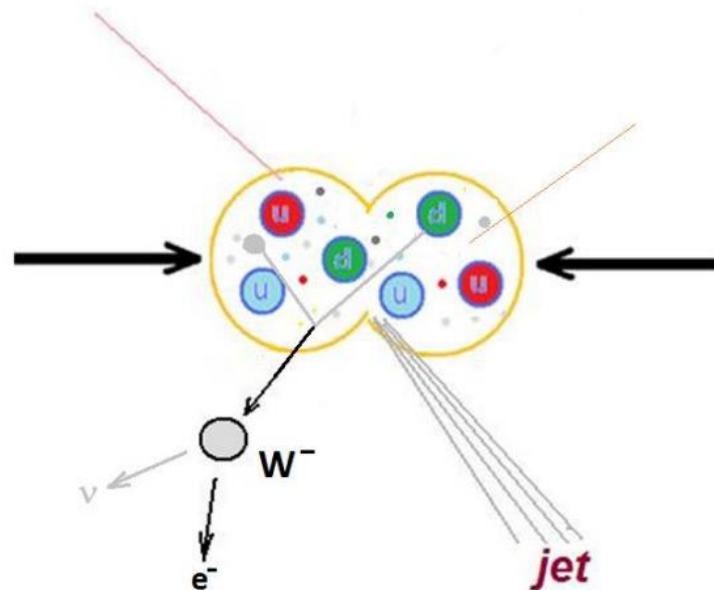


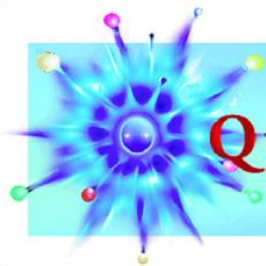


# One-lepton events

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.

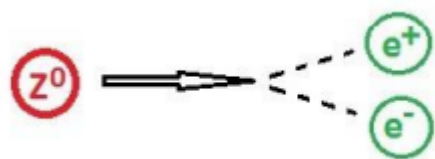
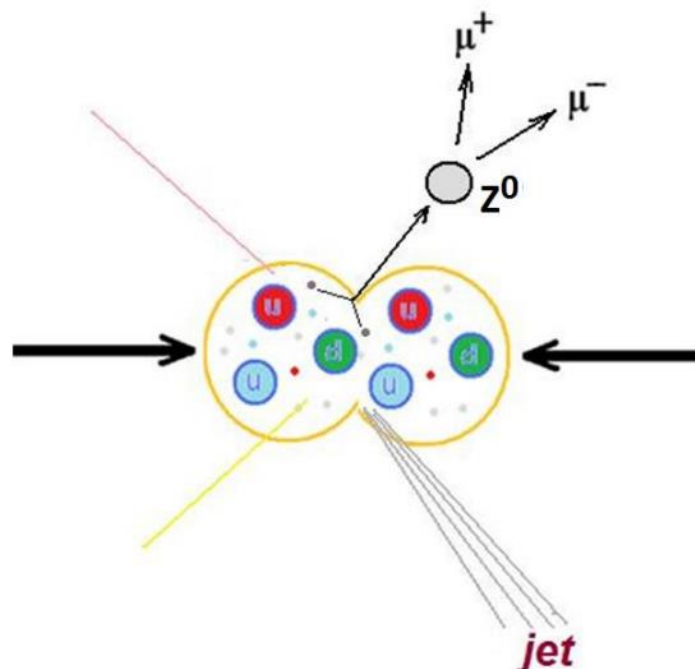


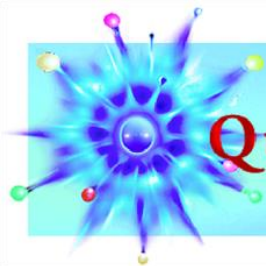


# Two-lepton events

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.

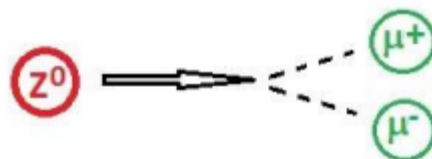
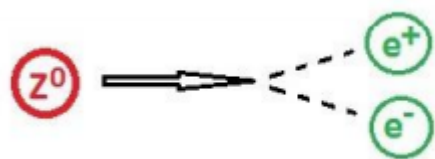
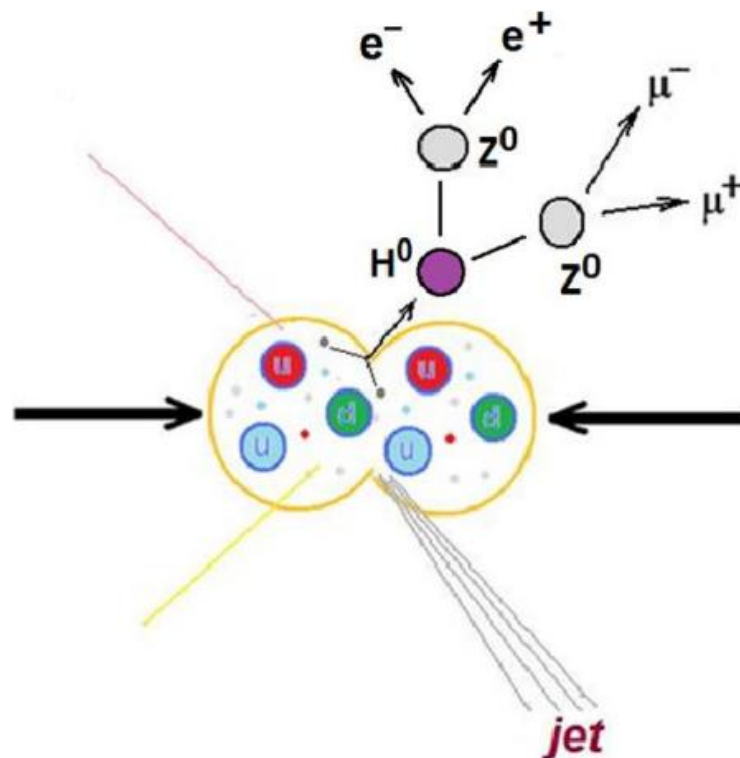




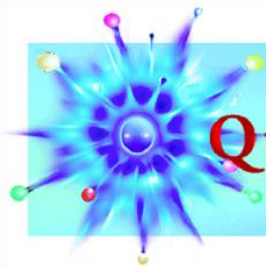
# Four-lepton events

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.

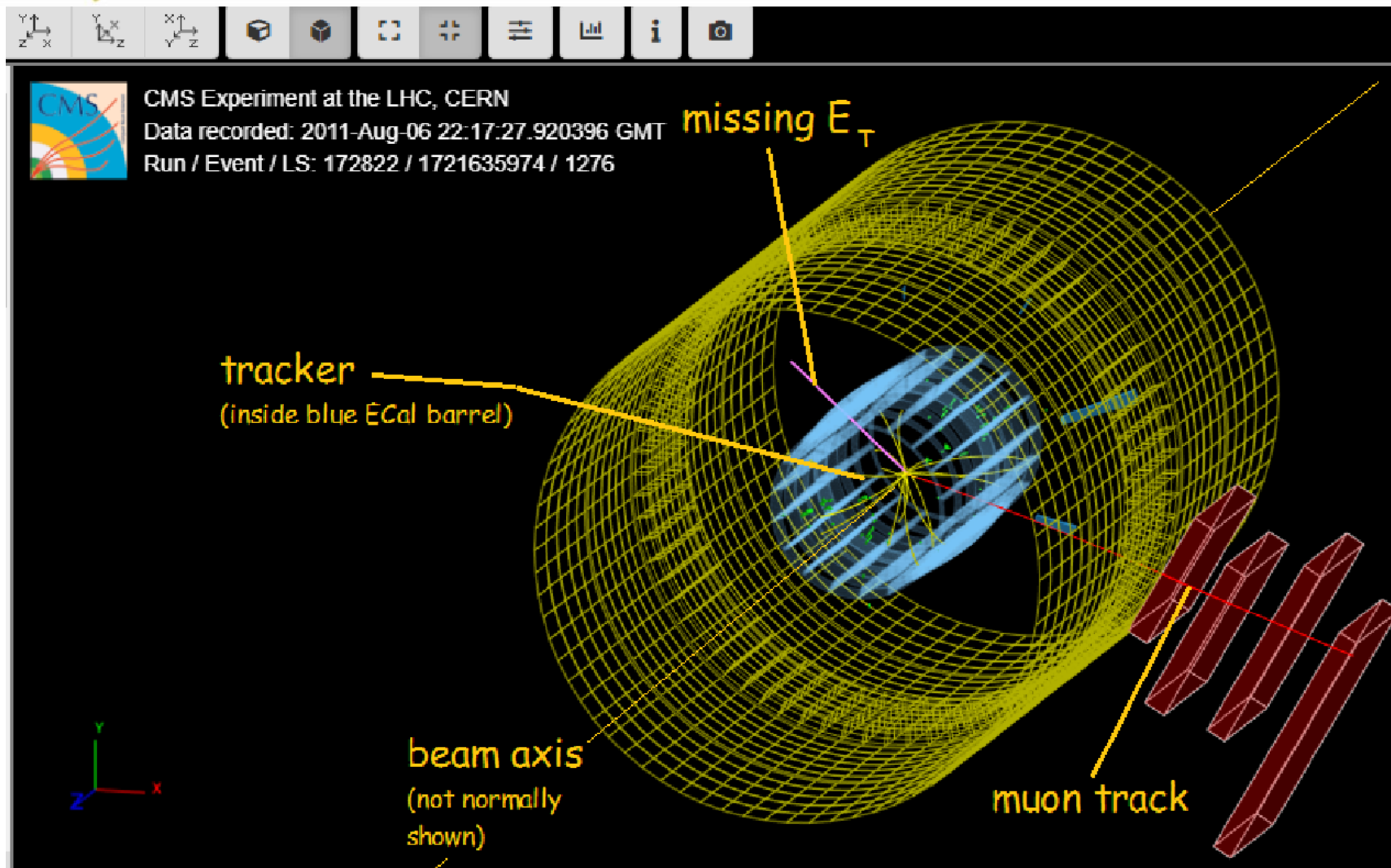


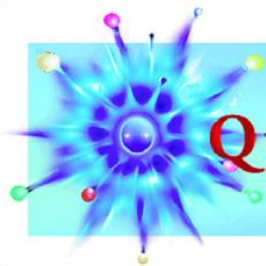




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# iSpy event display for CMS

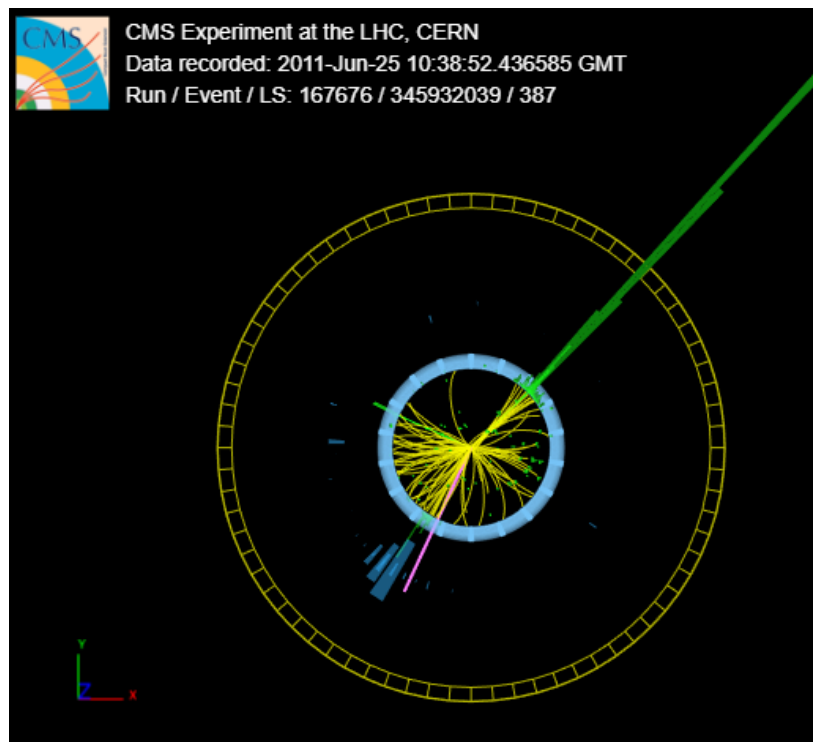
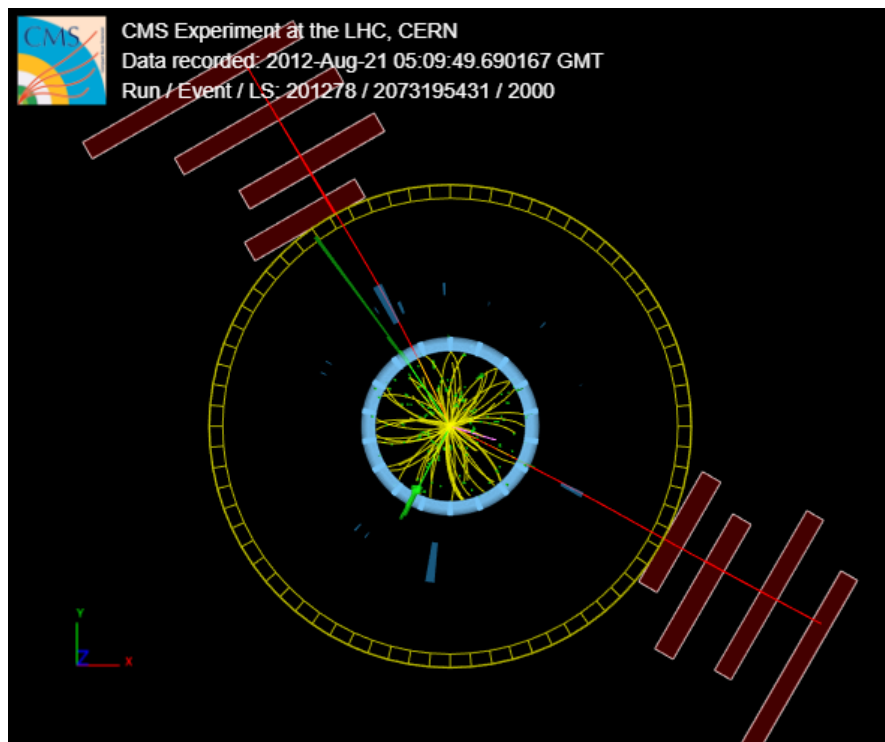


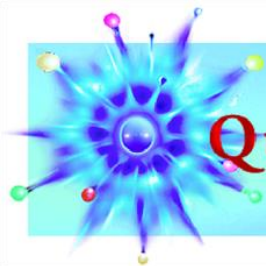


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# 1, 2, or 4 leptons?

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

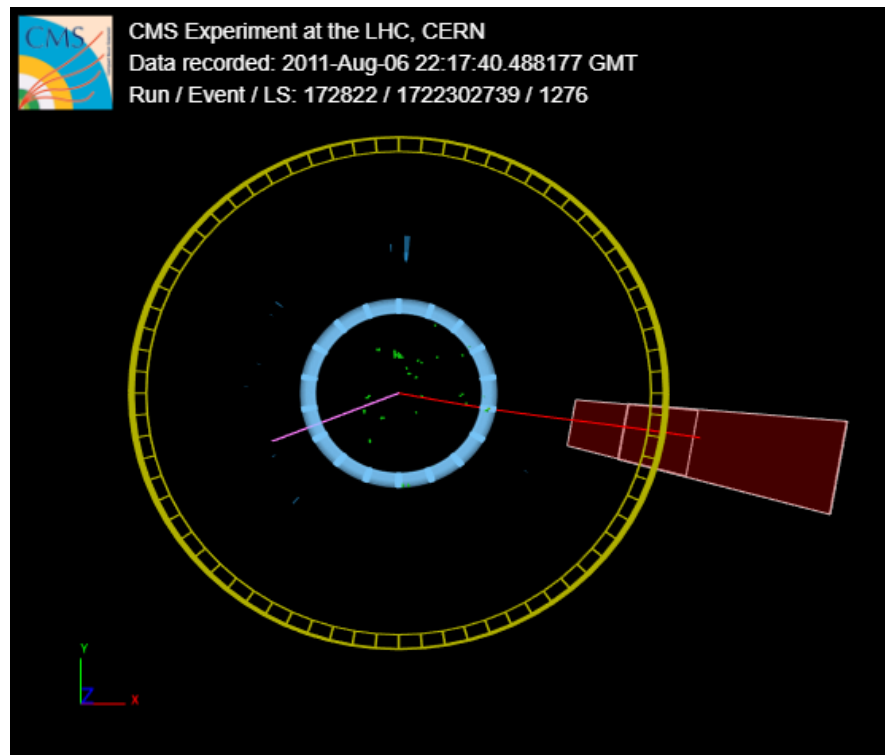
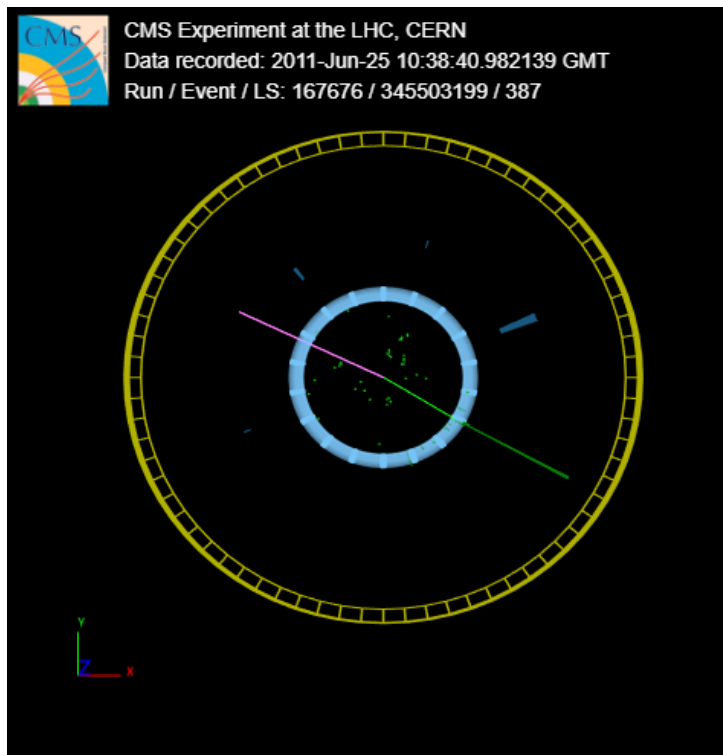




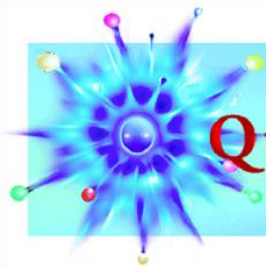
QuarkNet

# 1, 2, or 4 leptons?

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



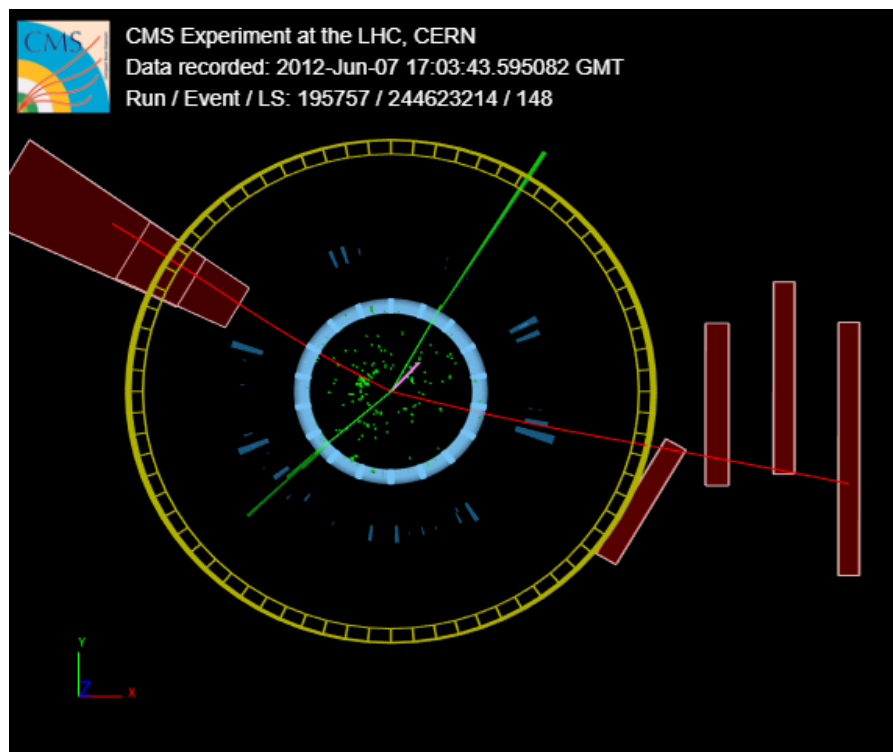
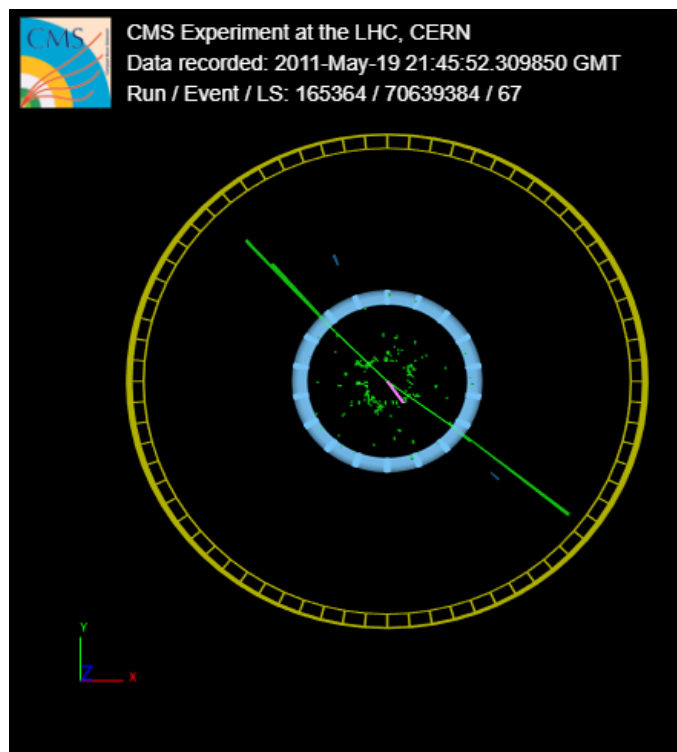


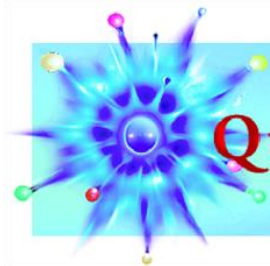


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# 1, 2, or 4 leptons?

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





# QuarkNet

## CMS Instrument for Masterclass Analysis (CIMA)

### Enter data on each event:

Back Events Table (Group 1) Mass Histogram (Table01) Results (Table01)

➔ Event Display

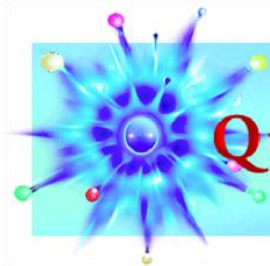
Masterclass: Event01

location: Table01

Group: 1

<b>Select Event</b>  Event index: 14 ▾  Event number: 1-14	<b>Final State</b>  <input type="radio"/> e ν <input type="radio"/> μ ν <input type="radio"/> e e <input type="radio"/> μ μ <input type="radio"/> 4e <input type="radio"/> 4μ <input type="radio"/> 2e 2μ	<b>Primary State</b> Charged Particle: <input type="radio"/> W+ <input type="radio"/> W- <input type="radio"/> W± <input type="radio"/> Neutral Particle (Z, H) <input type="radio"/> Zoo	<b>Enter Mass</b> <input type="text"/> GeV/c <sup>2</sup>  <input type="button" value="Next"/>
--	--	---	---

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

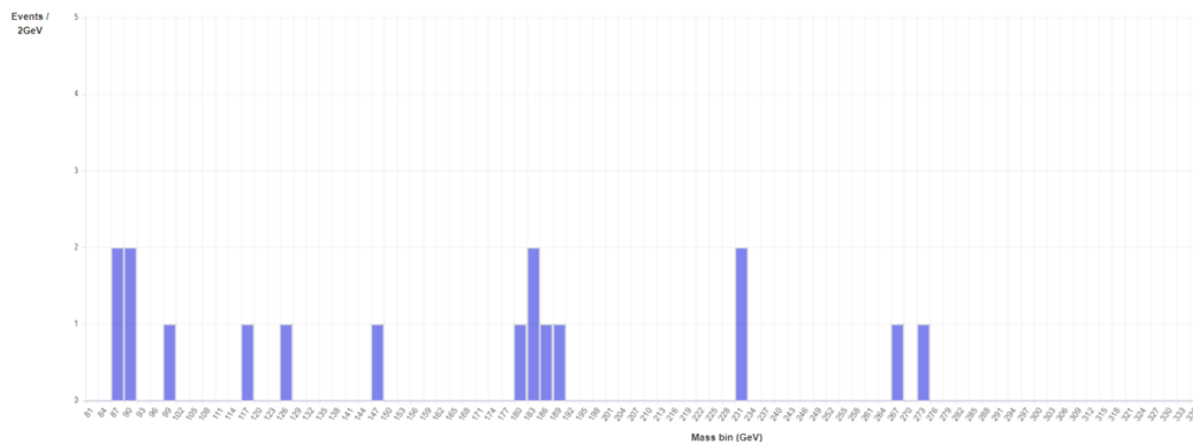
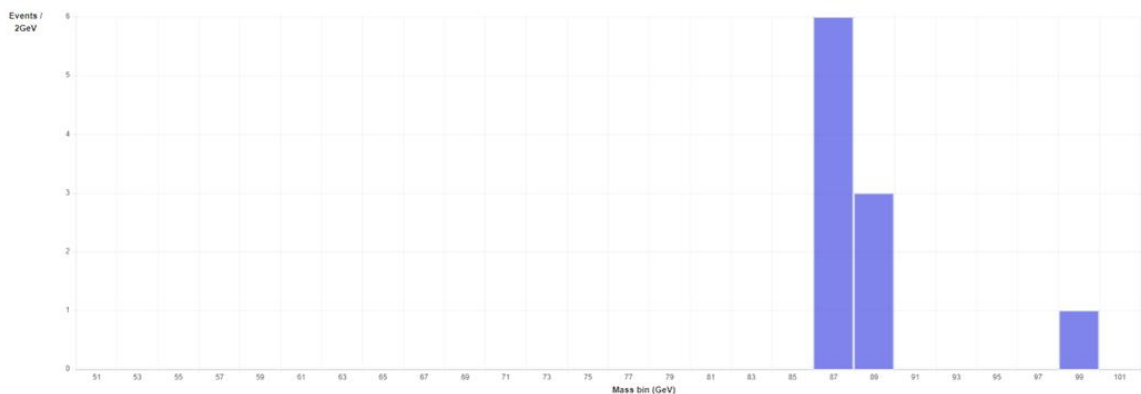


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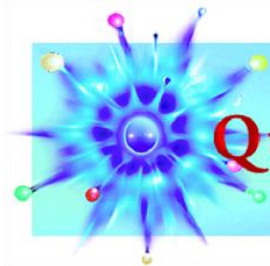
# CMS Instrument for Masterclass Analysis (CIMA)

## CIMA makes mass histograms automatically:

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







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# CMS Instrument for Masterclass Analysis (CIMA)

## 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

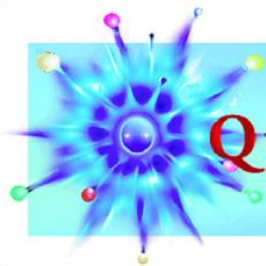
Group	e	$\mu$	W+	W-	W $\pm$	Neutral	Zoo	Total
21	26	32	21	21	0	13	0	55
22	41	46	24	38	1	16	1	80
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	10	12	10	5	0	5	1	21

Total:

Group	e	$\mu$	W+	W-	W $\pm$	Neutral	Zoo	Total
All	77	90	55	64	1	34	2	156

Ratios:

e/ $\mu$	W+/ $W^-$
0.92	0.86



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# 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.*

*Let's study some collisions!*

