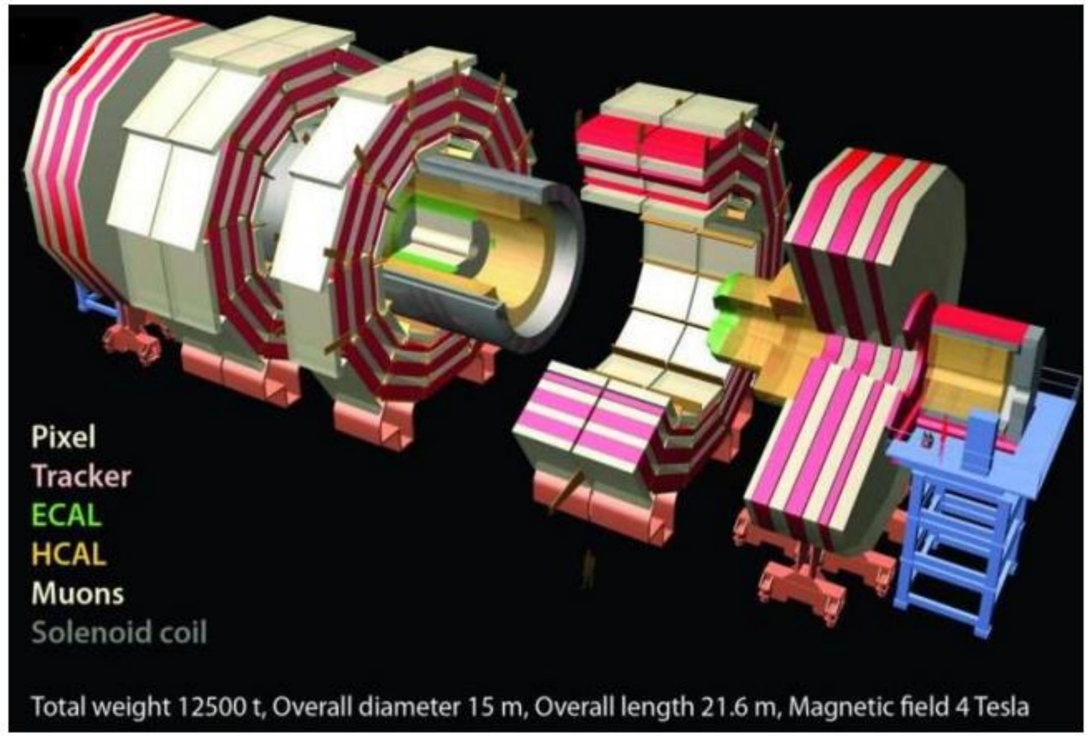
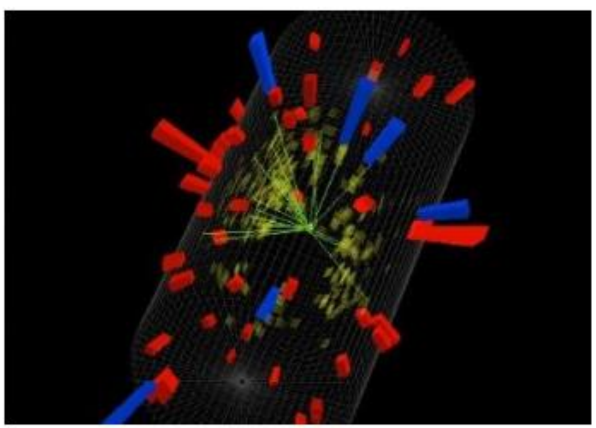
QUARKNET CMS WZH Masterclass





INTERNATIONAL MASTERCLASSES
hands on particle physics

Fermilab CERN UNIVERSITY OF NOTRE DAME

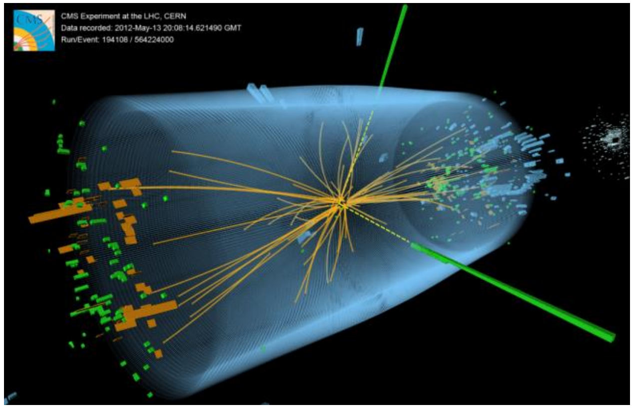
QUARKNET

The LHC and the new physics

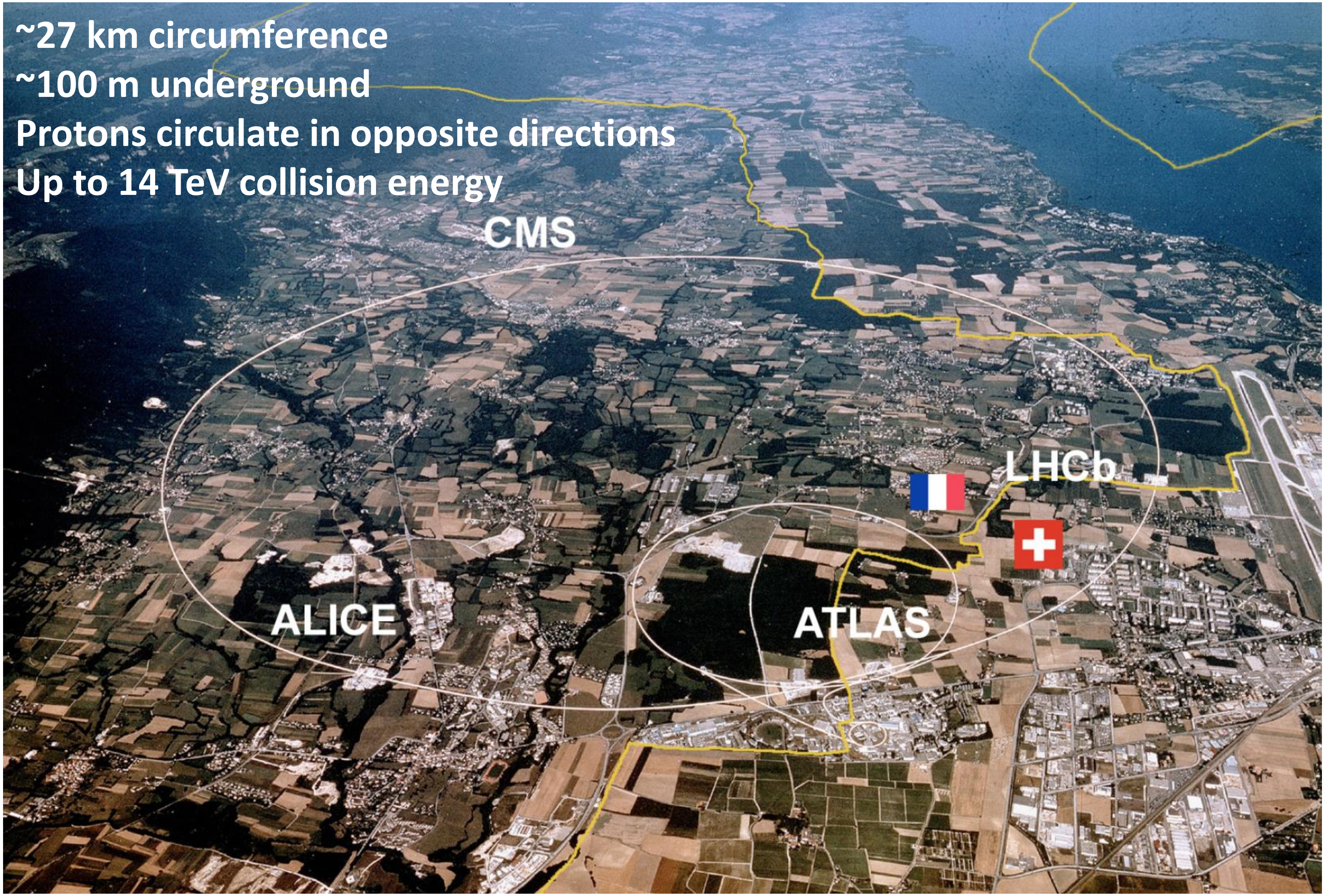
It is a time of exciting new discoveries in particle physics.

At CERN, the LHC is now in Run 3, with its highest collision rates and energies yet. At the same time, there are new questions as the few experimental results vary from the highly reliable Standard Model.

The LHC and CMS are where we need to be to explore these new mysteries.



LHC@CERN


~27 km circumference
~100 m underground
Protons circulate in opposite directions
Up to 14 TeV collision energy
CMS
LHCb
ALICE
ATLAS

The LHC and the new physics

Generic Design

Cylinders wrapped around the beam pipe

From inner to outer . . .

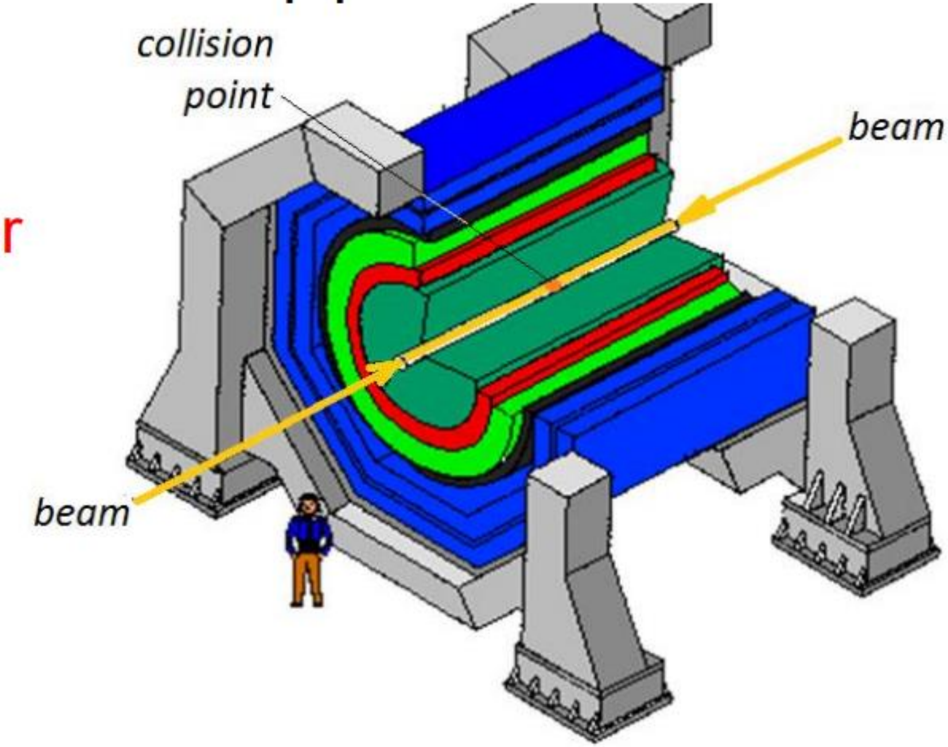
Tracking

Electromagnetic calorimeter

Hadronic calorimeter

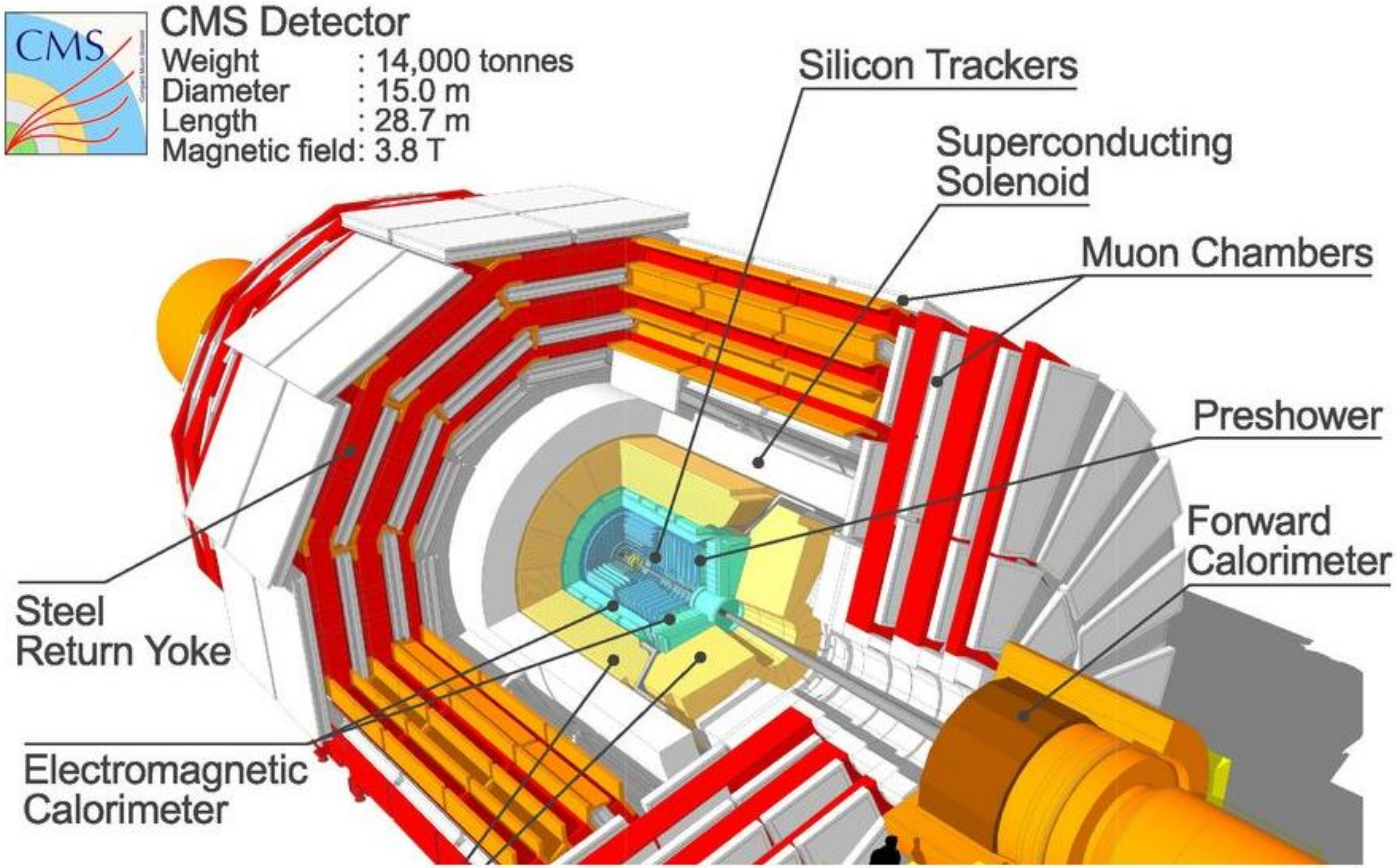
Magnet*

Muon chamber



* *location of magnet depends on specific detector design*

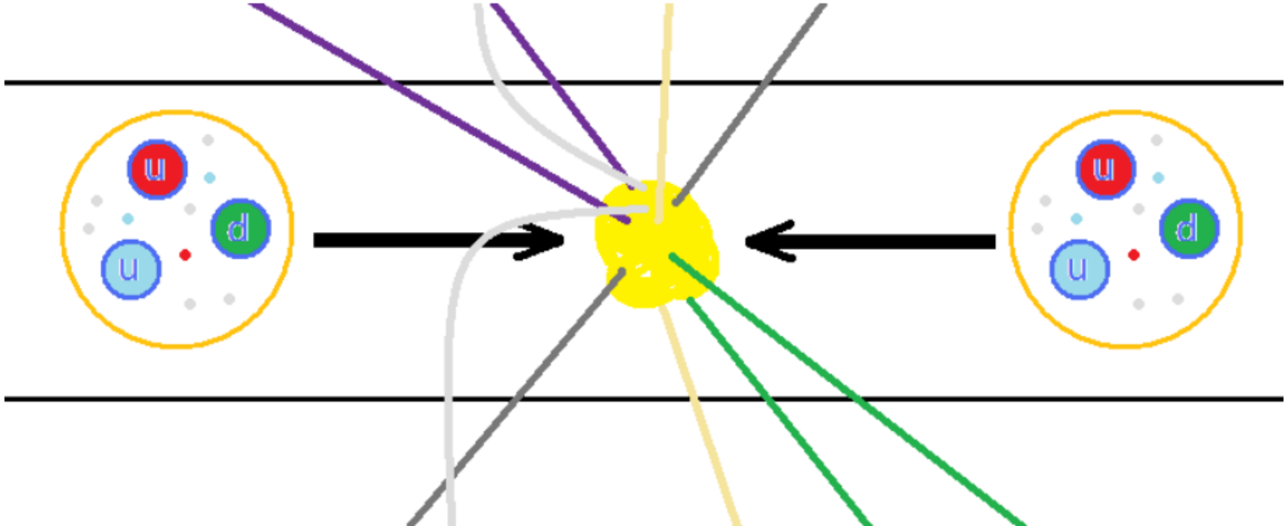
The Compact Muon Solenoid (CMS)



Protons collide inside CMS

The LHC accelerates protons to almost 7500 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 protons collide, all sorts of very short-lived particles can be made from all that energy.



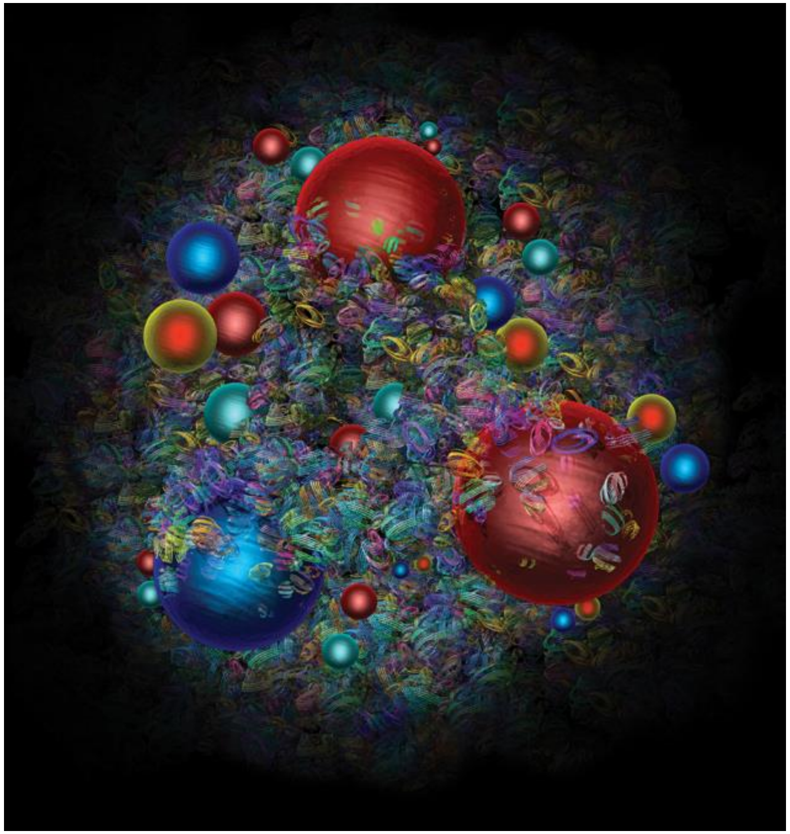
QUARKNET What do the protons tell us?

We learn from what proton collisions produce:

W bosons **give us clues to the proton structure…and they also present a mystery.**

Z bosons **decay (sort of) like lighter particles but are also needed to sort out Higgs data.**

Higgs bosons**, well, are Higgs bosons, the new kid on the block!**

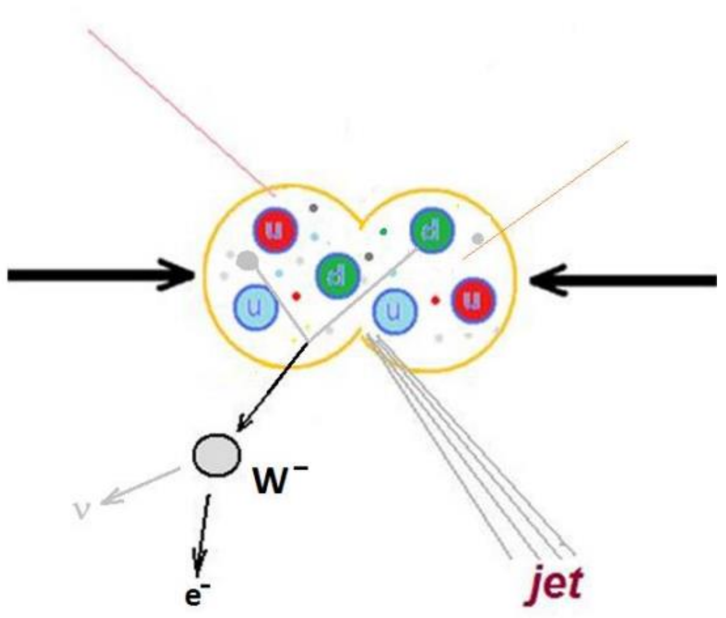


Artist's image of a proton from CERN Courier. Learn more here and even more here.

One-lepton events

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

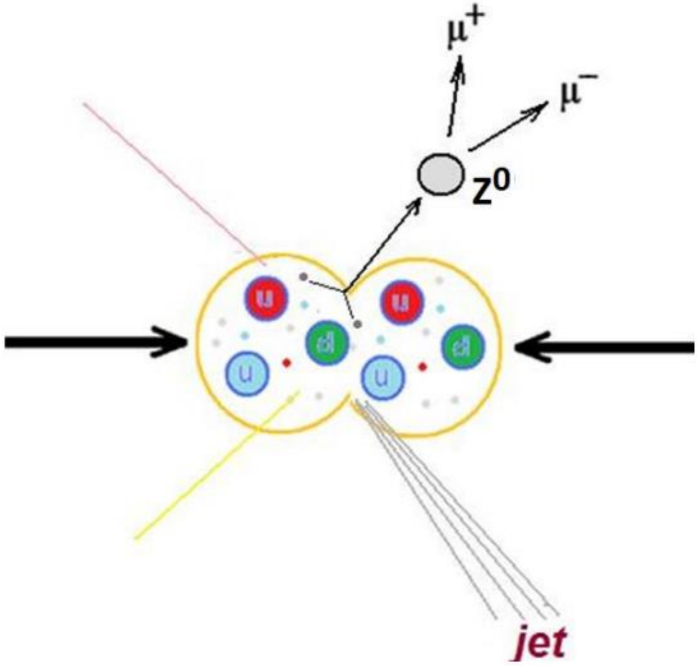
It decays into a neutrino and another lepton. Since CMS cannot detect the neutrino directly, we can call this a one-lepton event.

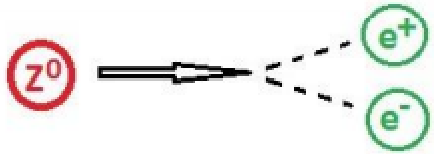


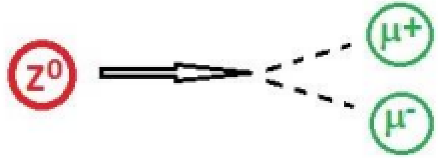
Two-lepton events

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.



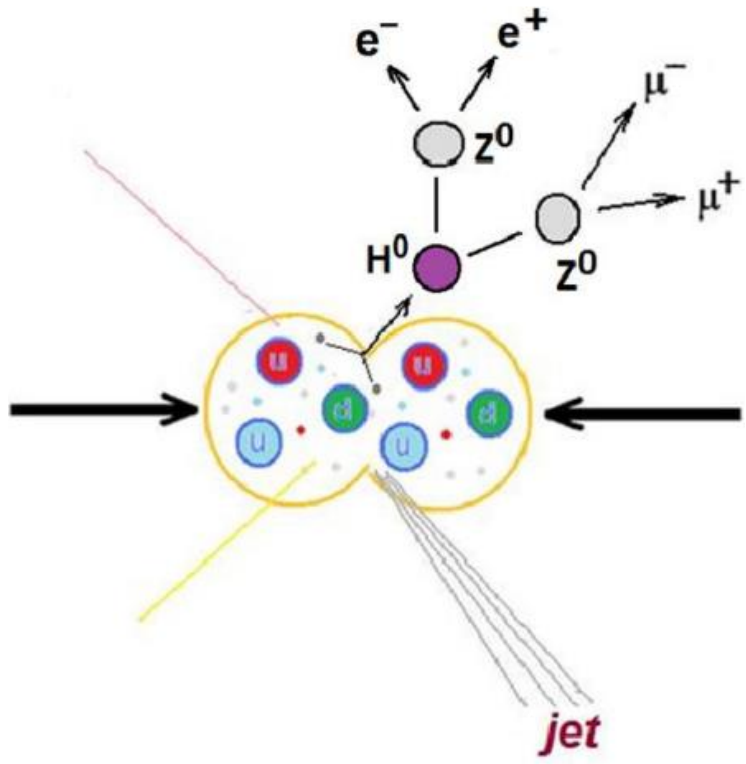


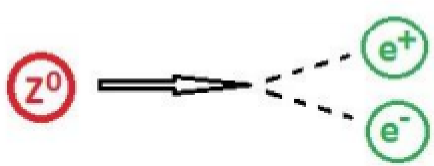


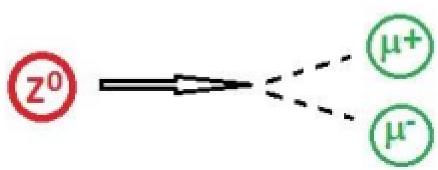
Four-lepton events

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.





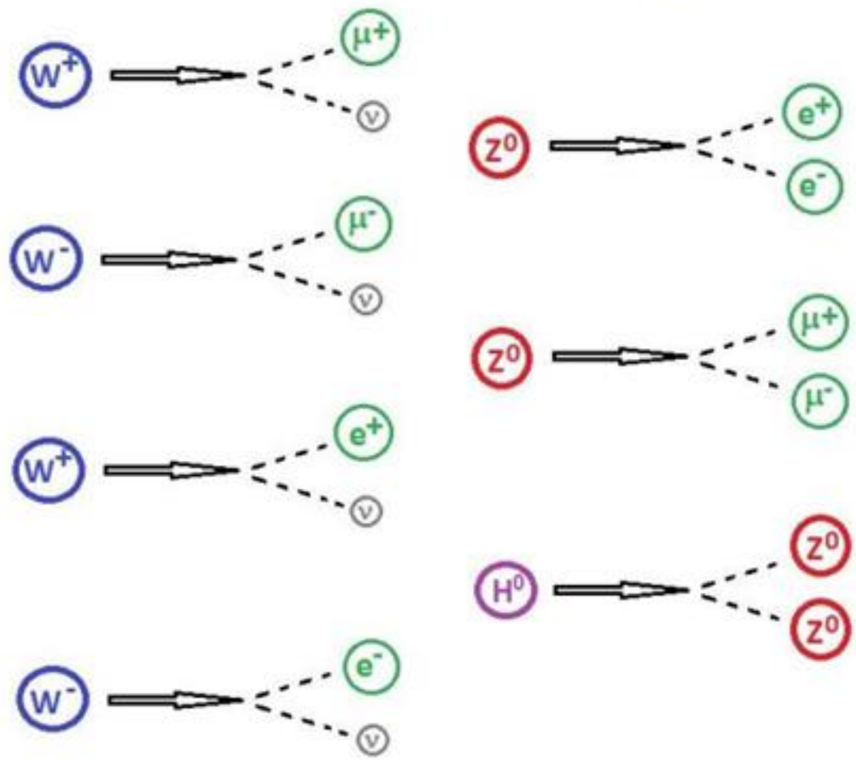


Decay summary

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

CMS *can* detect :

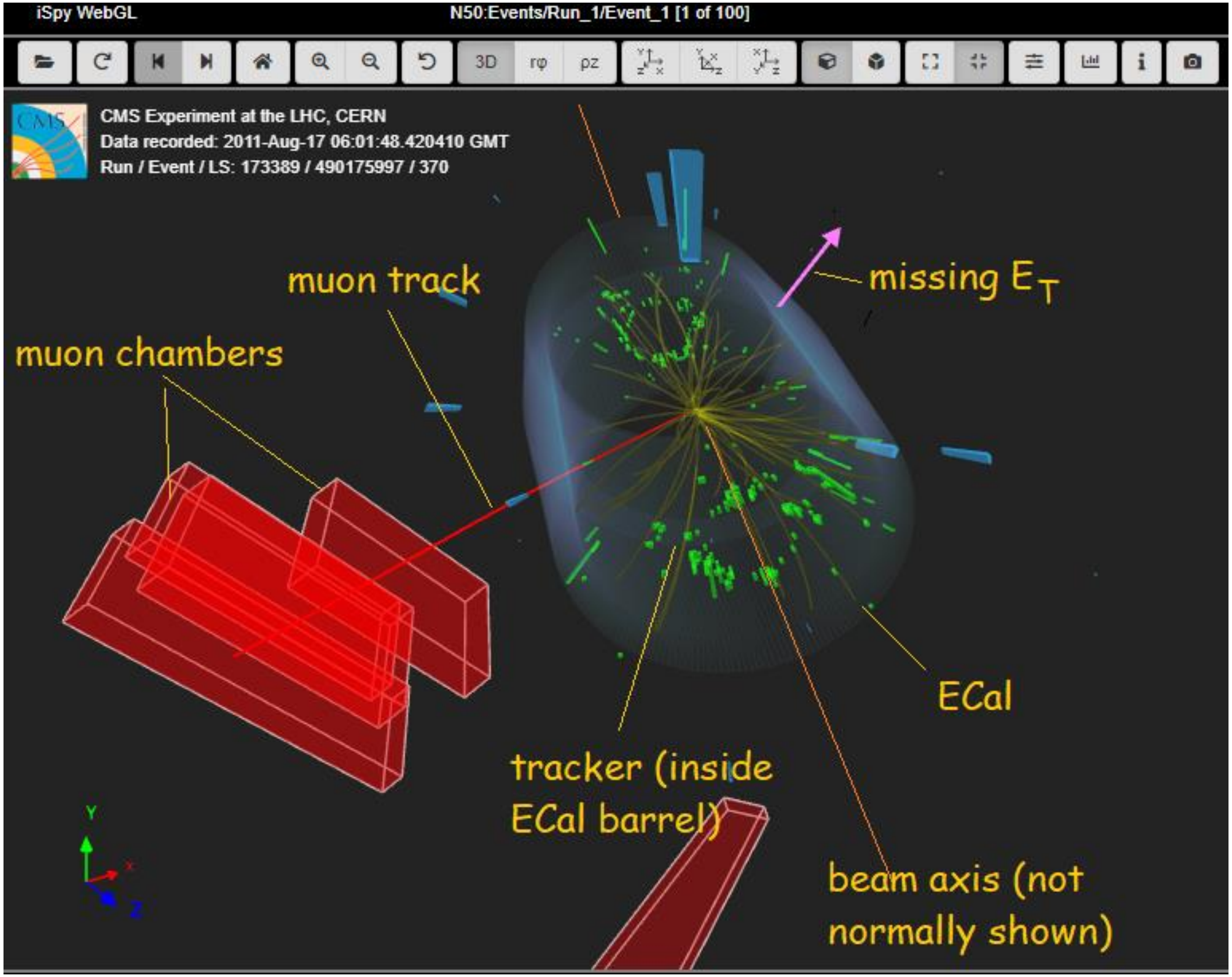
- electrons
- muons
- photons



CMS can infer:

- neutrinos from "missing energy"

iSpy event display for CMS



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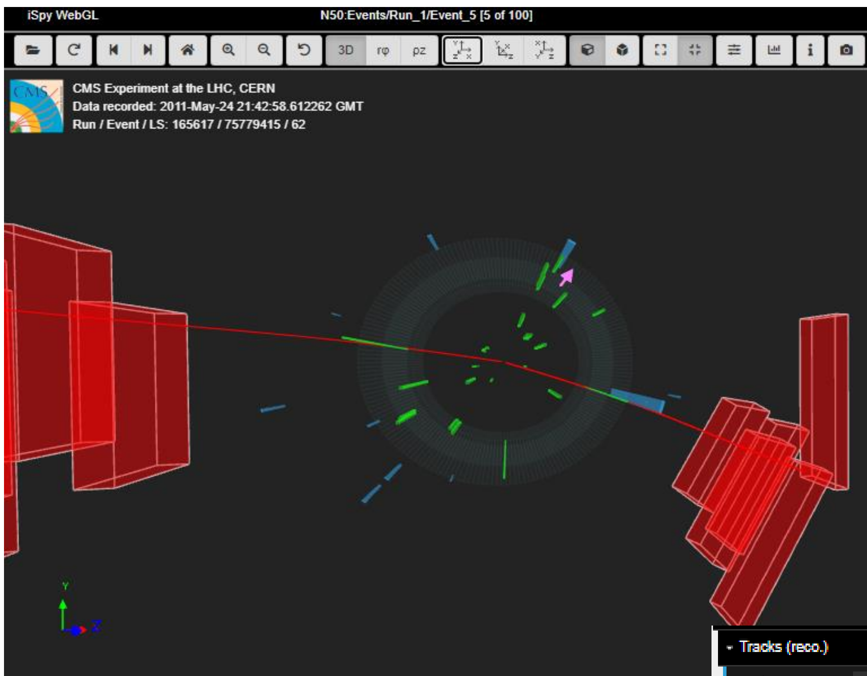
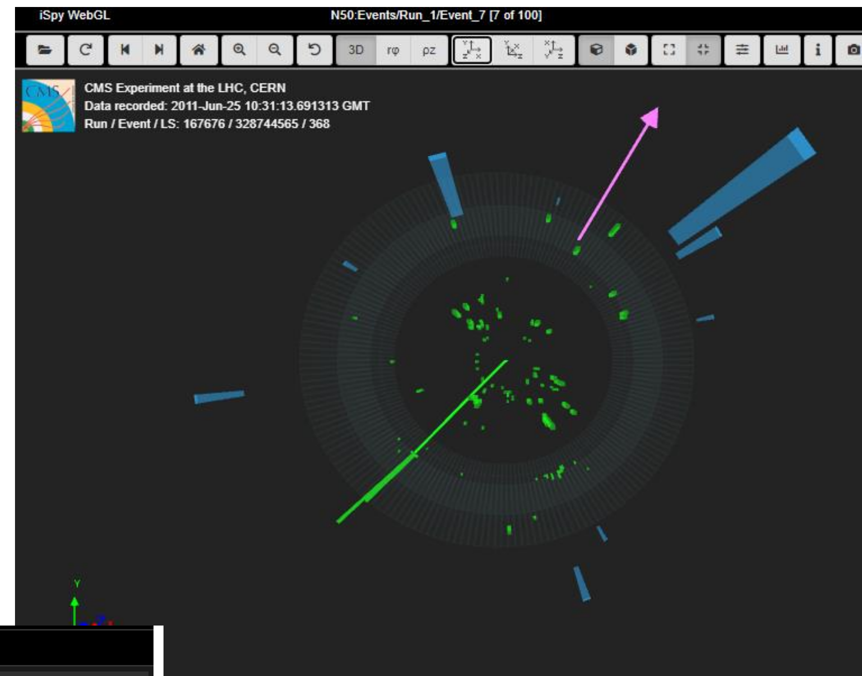
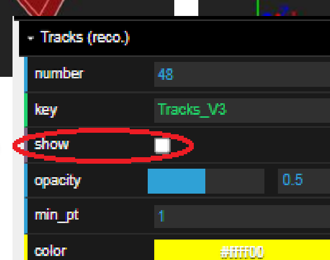
1, 2, or 4 leptons?

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





Note Tracks (reco) turned OFF.



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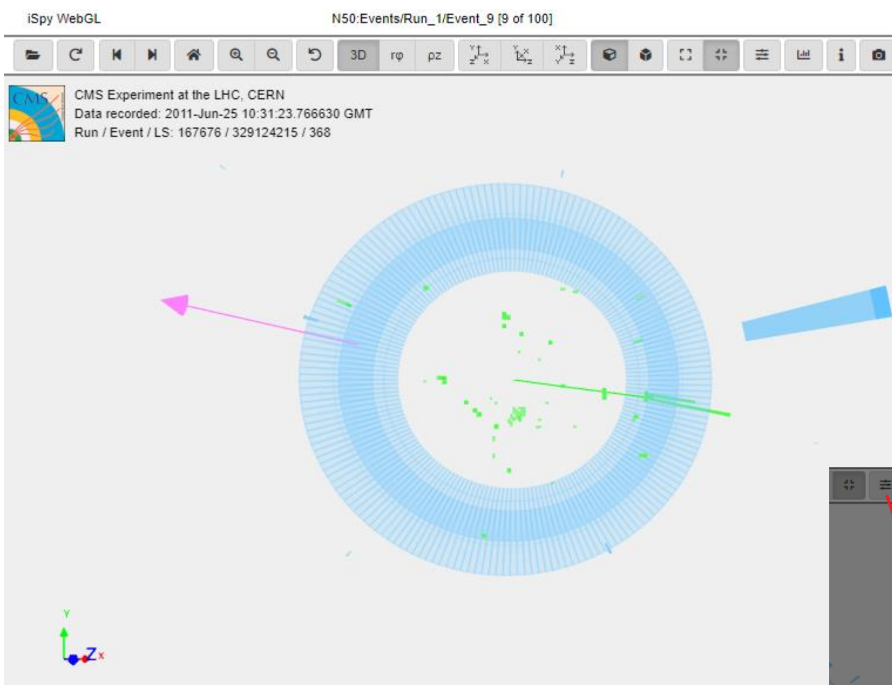
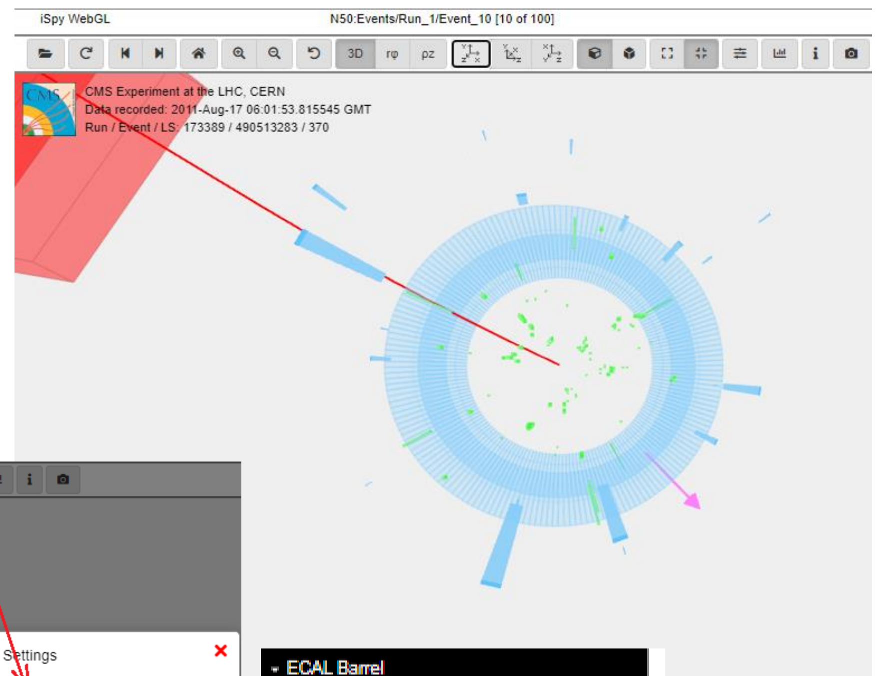
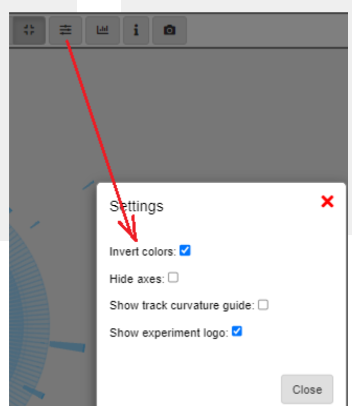
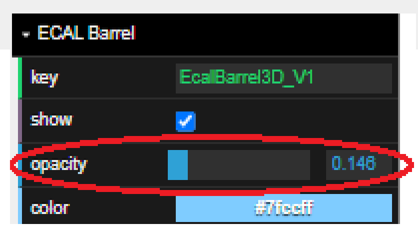




Note Inverted Colors and increased ECal Barrel opacity.





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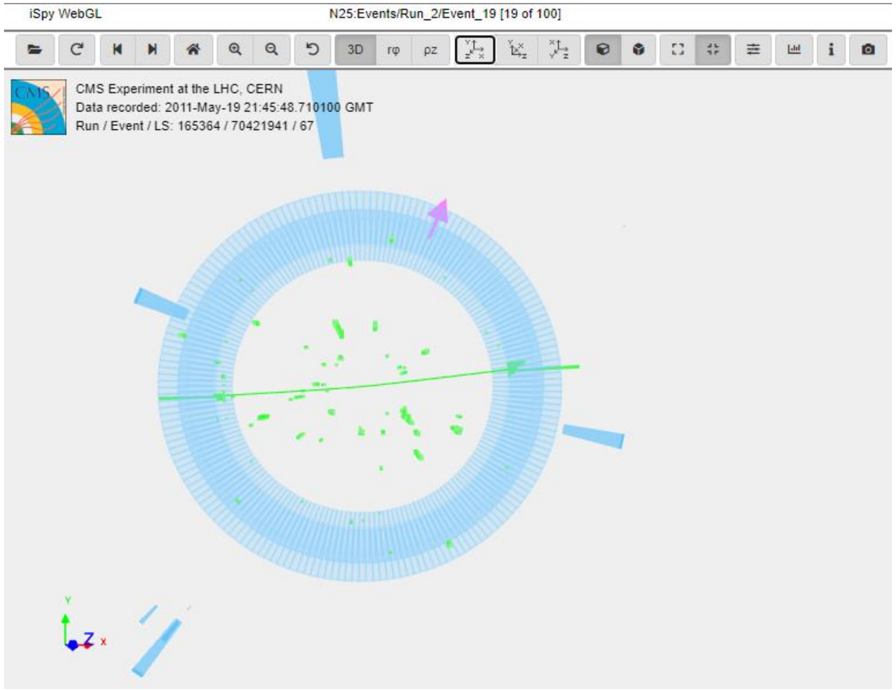

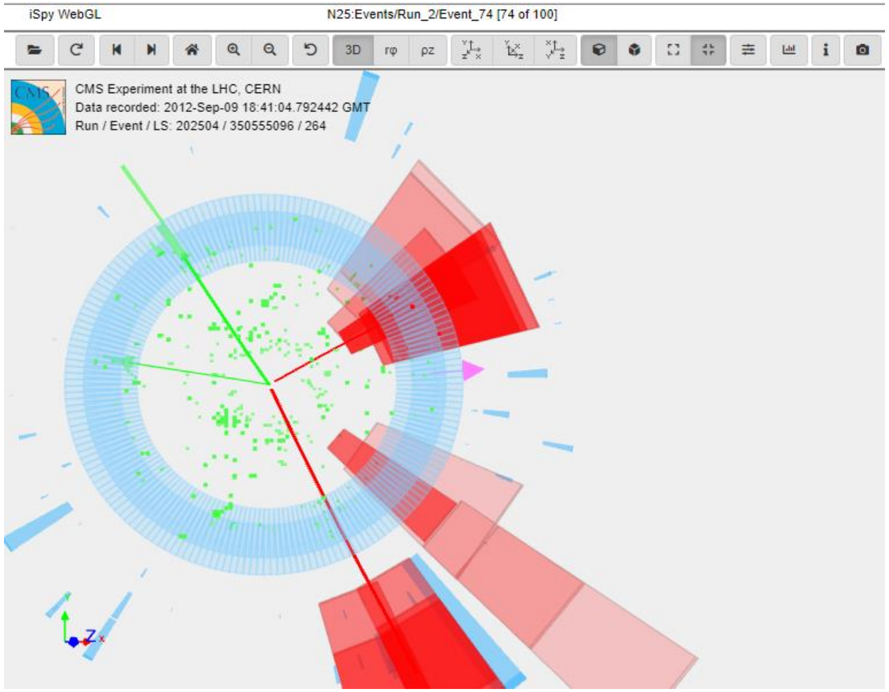

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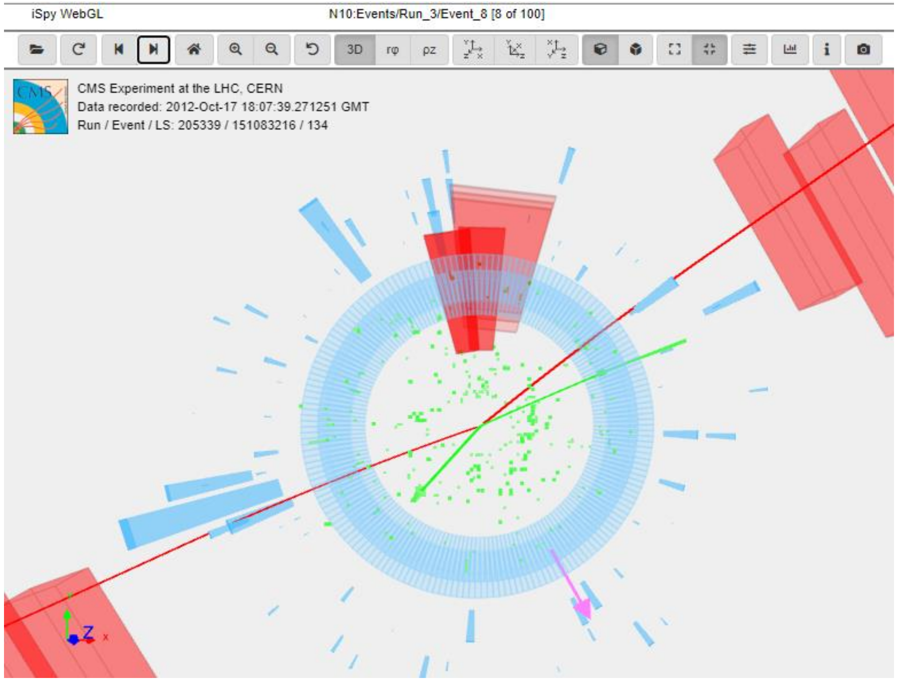
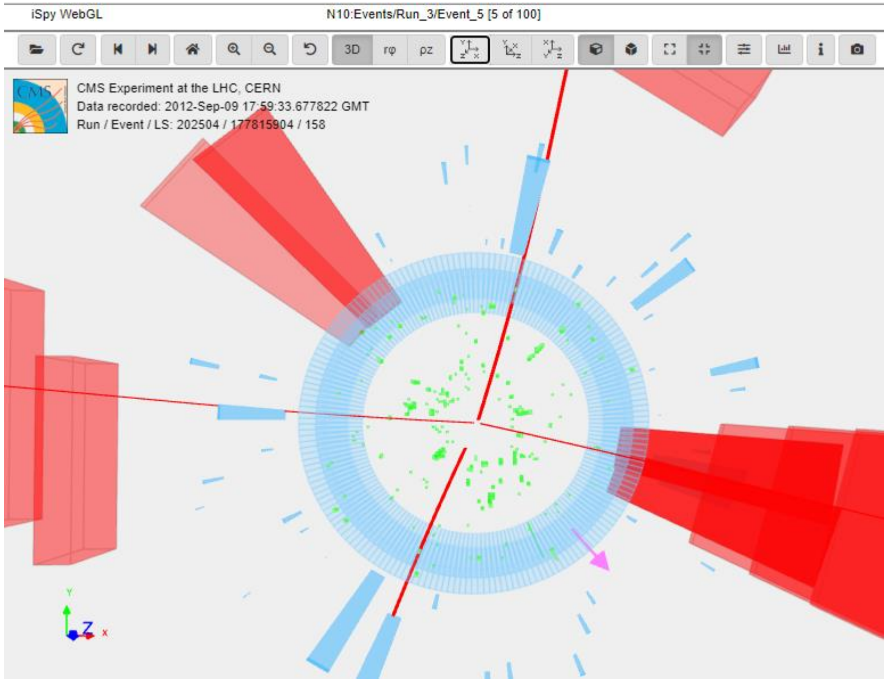
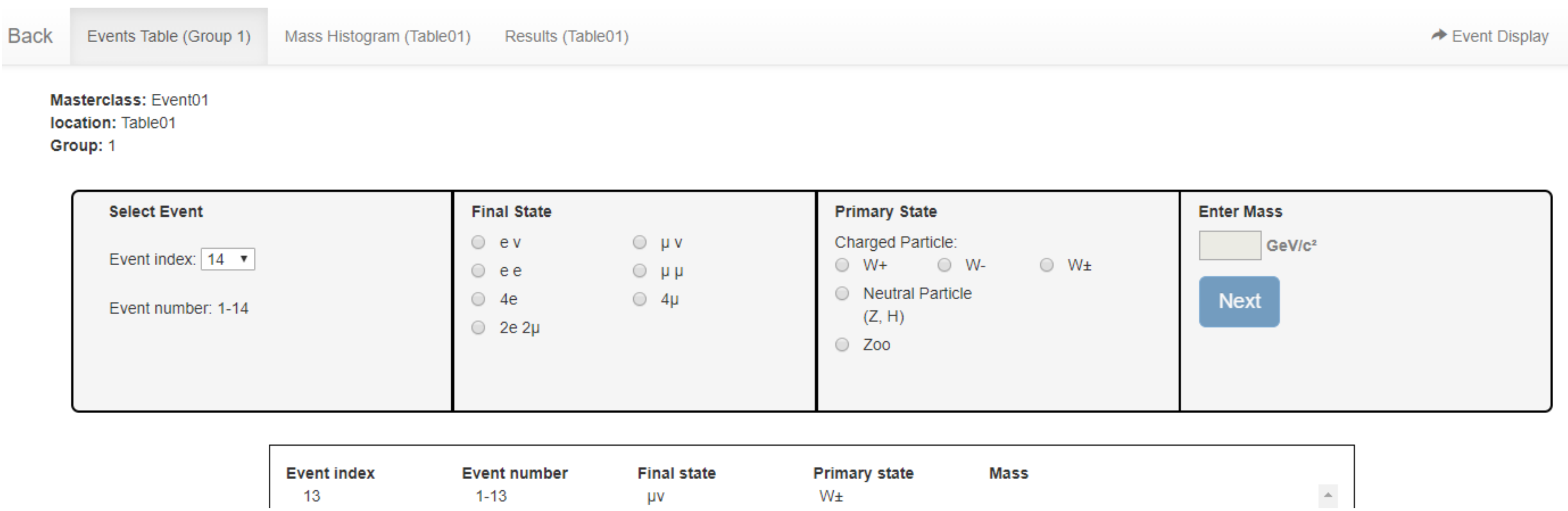




CMS Instrument for Masterclass Analysis (CIMA)

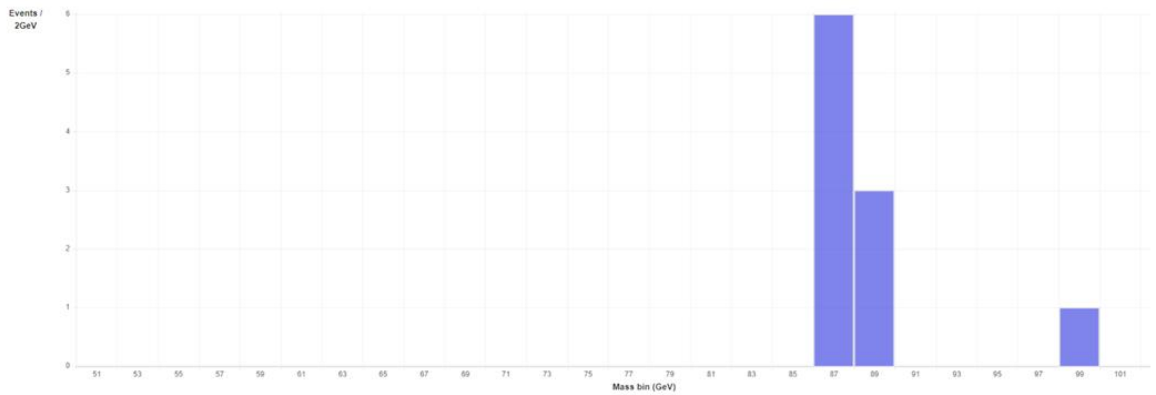
Enter data on each event:

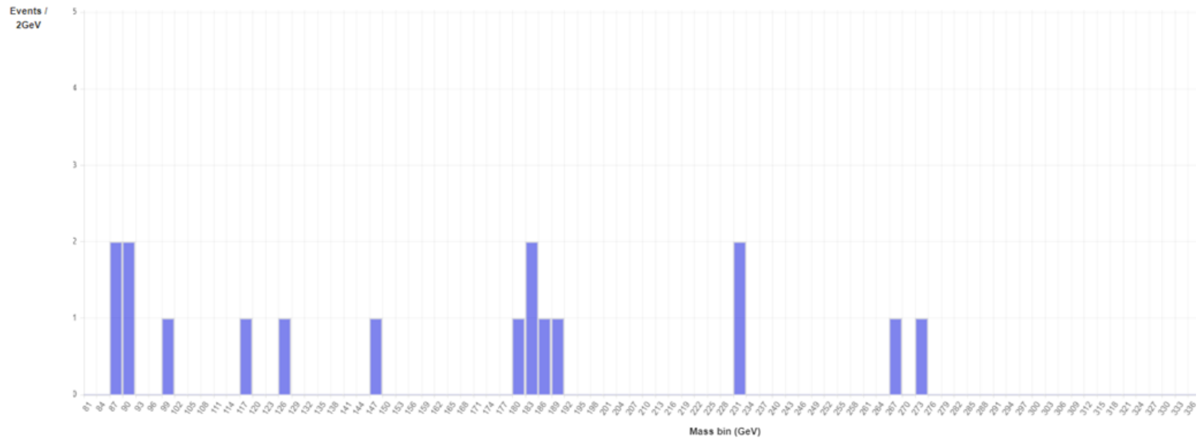


CMS Instrument for Masterclass Analysis (CIMA)

CIMA makes mass histograms automatically:

Masterclass: CUA-FIU-WM-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

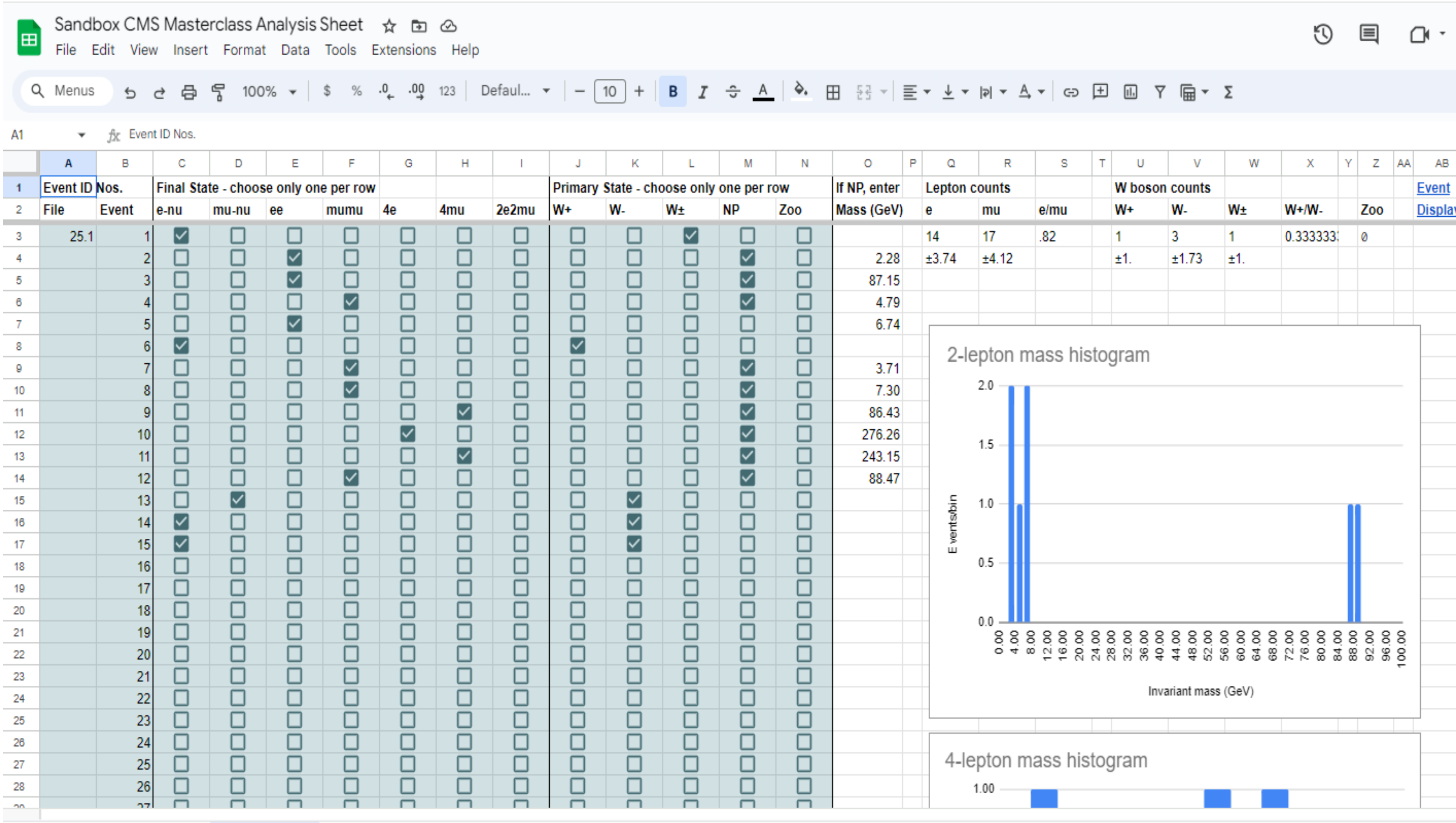
Group	e	μ	W+	W-	W±	Neutral	Zoo	Total
21	26	32	21	21	0	13	0	55
22	41	46	24	38	1	16	1	80
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	10	12	10	5	0	5	1	21

Total:

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

Calculate e/mu and W+/W- !

Google Sheet option



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Event ID Nos.		Final State - choose only one per row							Primary State - choose only one per row					If NP, enter
2	File	Event	e-nu	mu-nu	ee	mumu	4e	4mu	2e2mu	W+	W-	W±	NP	Zoo	Mass (GeV)
3	25.1	1	✓									✓			
4		2			✓								✓		2.28
5		3			✓								✓		87.15
6		4				✓							✓		4.79
7		5			✓										6.74
8		6	✓							✓					
9		7				✓							✓		3.71
10		8				✓							✓		7.30
11		9						✓					✓		86.43
12		10					✓						✓		276.26
13		11						✓					✓		243.15
14		12				✓							✓		88.47
15		13		✓							✓				
16		14	✓								✓				
17		15	✓								✓				
18		16													
19		17													
20		18													
21		19													
22		20													
23		21													
24		22													
25		23													
26		24													
27		25													
28		26													

	Q	R	S	U	V	W	X	Z	AB
1	Lepton counts			W boson counts					Event
2	e	mu	e/mu	W+	W-	W±	W+/W-	Zoo	Display
3	14	17	.82	1	3	1	0.333333	0	
4	±3.74	±4.12		±1.	±1.73	±1.			

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: <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.