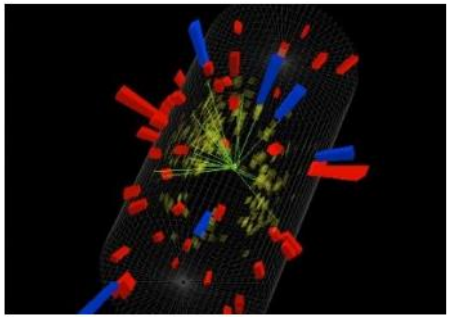
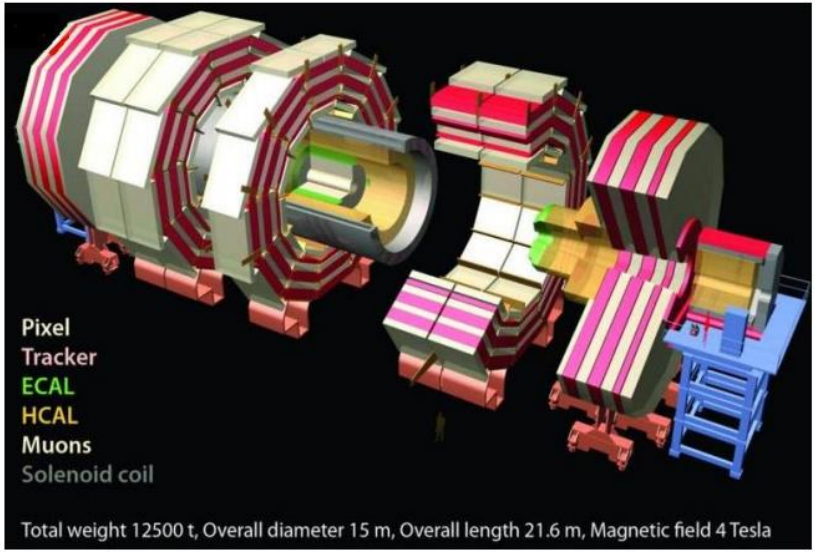
QUARKNET

CMS WZH Masterclass





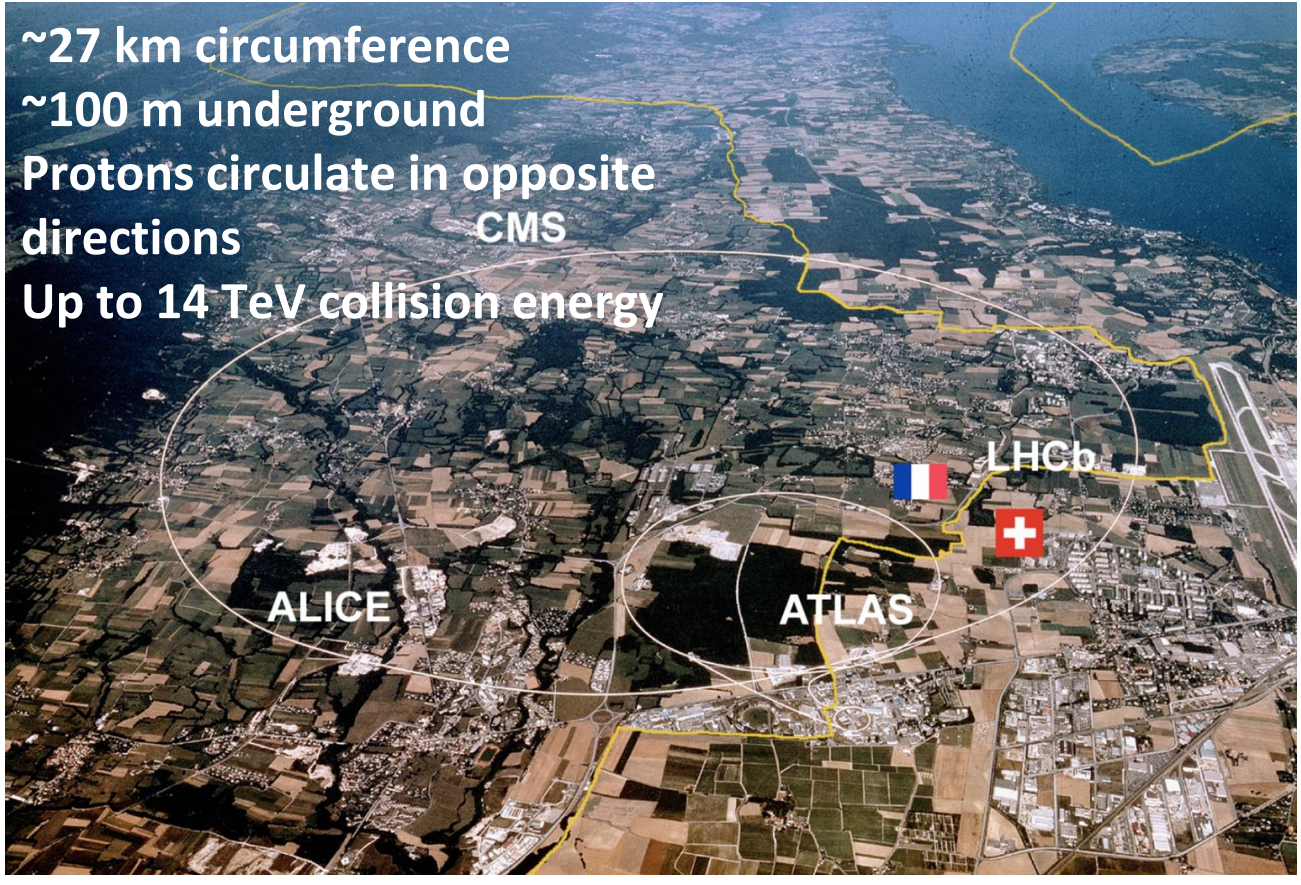
INTERNATIONAL MASTERCLASSES
hands on particle physics

Fermilab

UNIVERSITY OF NOTRE DAME

QUARKNET

LHC@CERN



The LHC and the new physics

Generic Design

Cylinders wrapped around the beam pipe

From inner to outer . . .

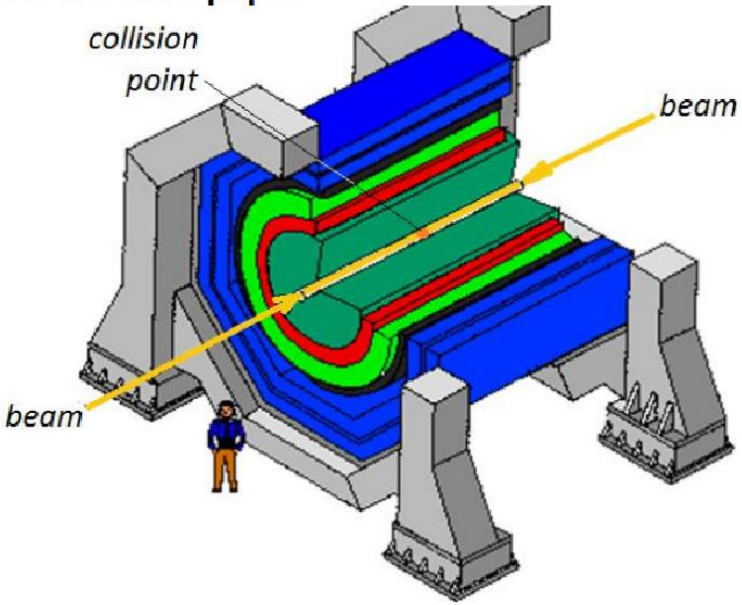
Tracking

Electromagnetic calorimeter

Hadronic calorimeter

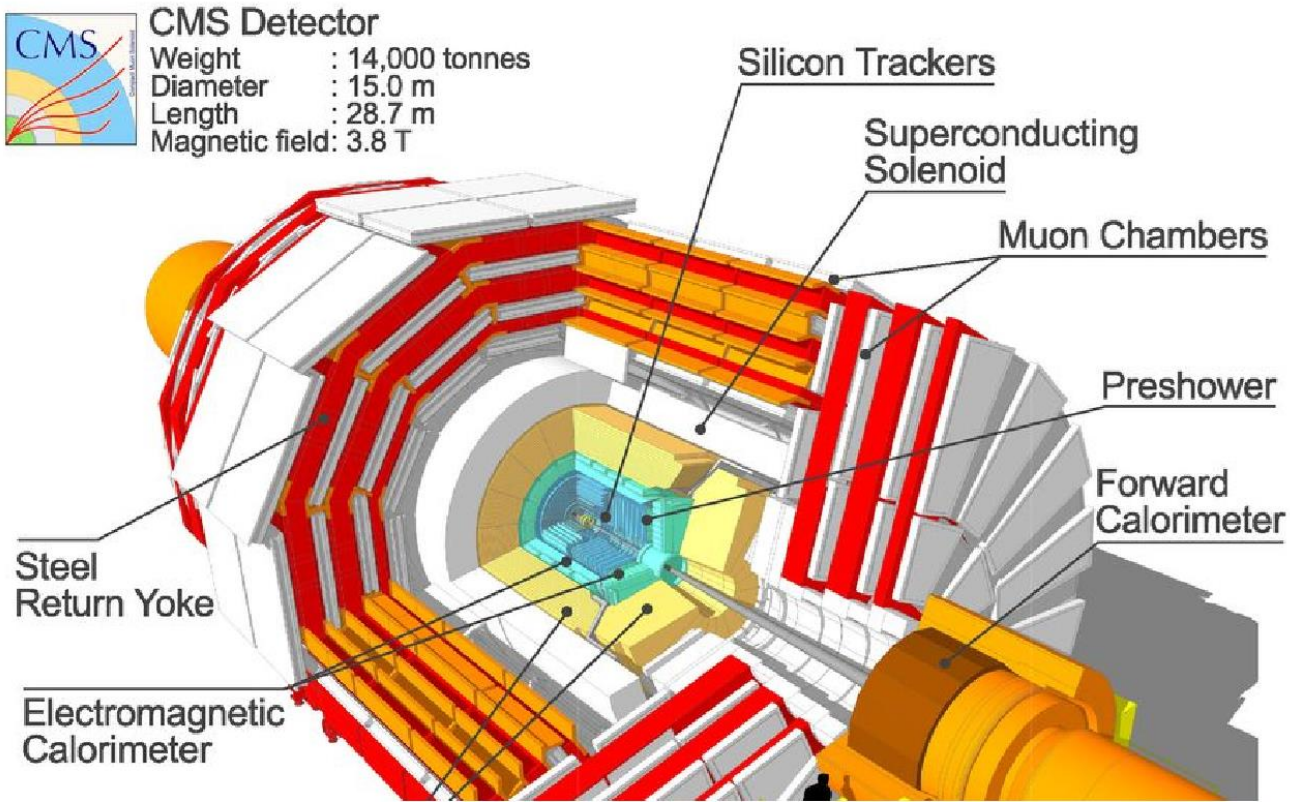
Magnet*

Muon chamber



* *location of magnet depends on specific detector design*

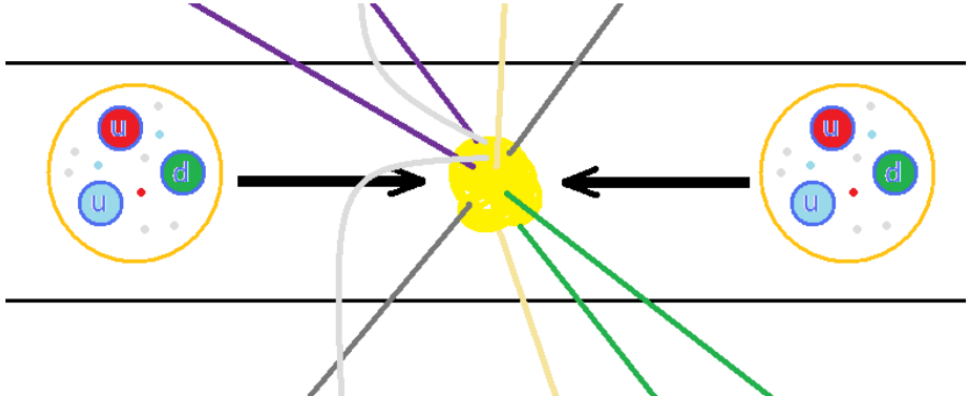
The Compact Muon Solenoid (CMS)



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.



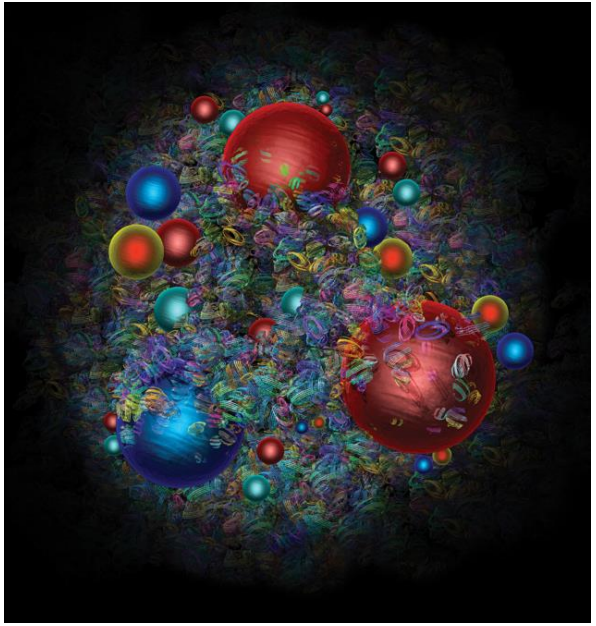
What do the protons tell us?

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!**

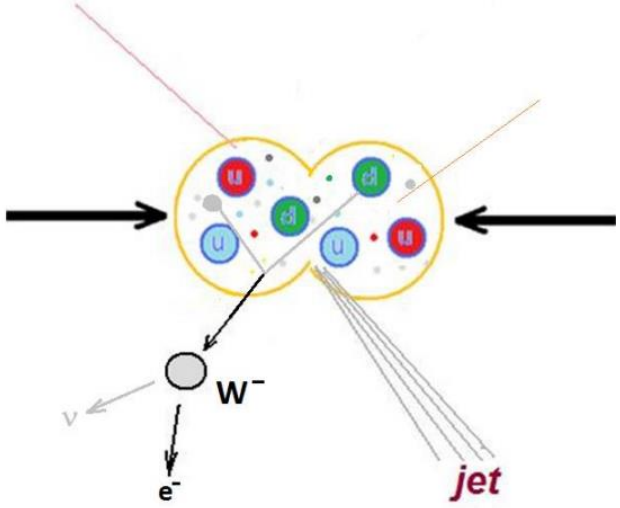


Artist's image of a proton from CERN Courier. Learn more here and even more here.

One-lepton events

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

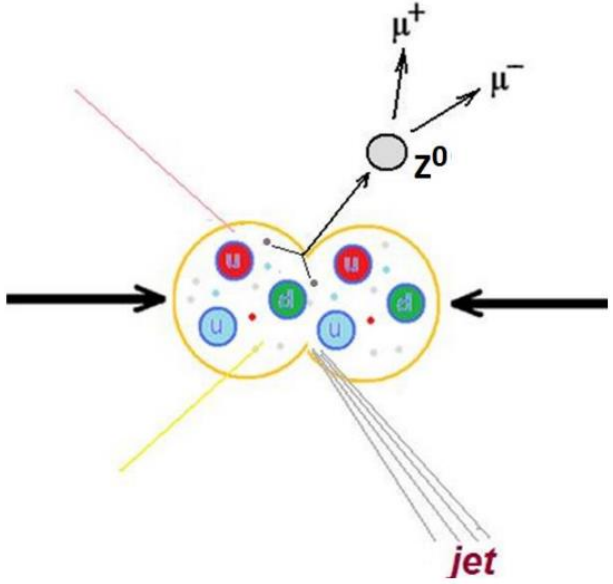
It decays into a neutrino and another lepton. Since CMS cannot detect the neutrino directly, we can call this a one-lepton event.

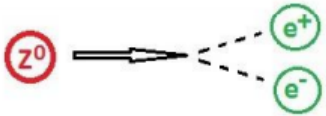


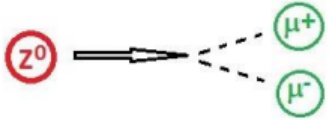
Two-lepton events

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.



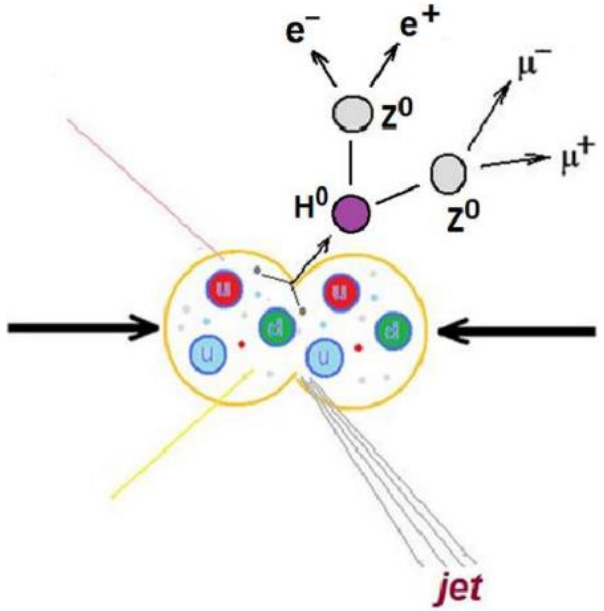


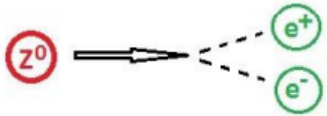


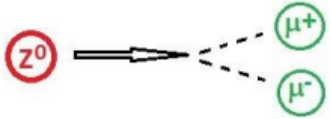
Four-lepton events

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.





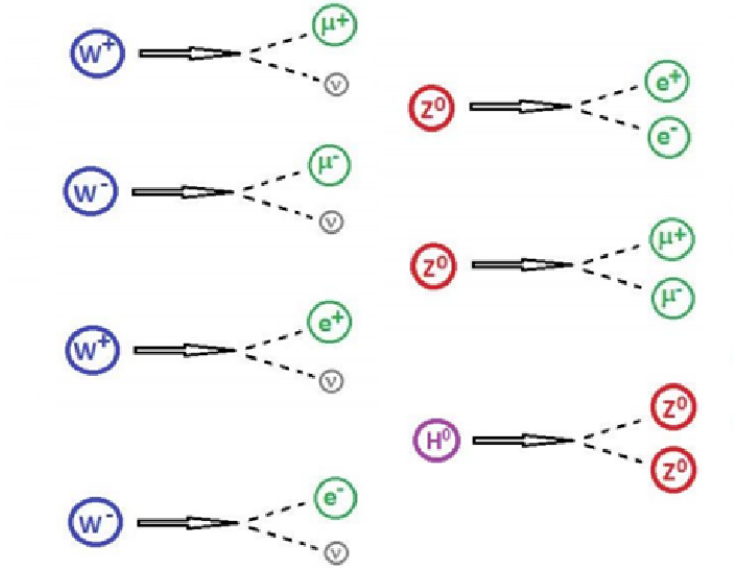


Decay summary

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

CMS *can* detect :

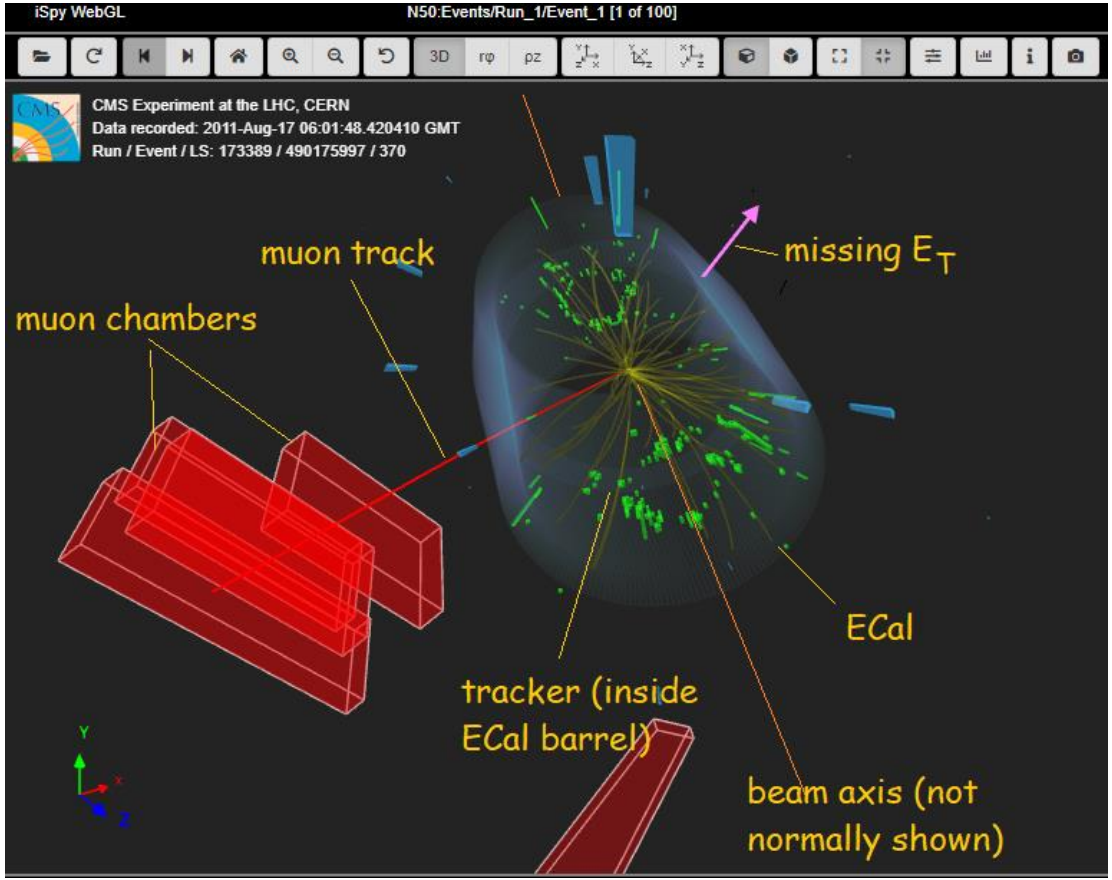
- electrons
- muons
- photons



CMS can infer:

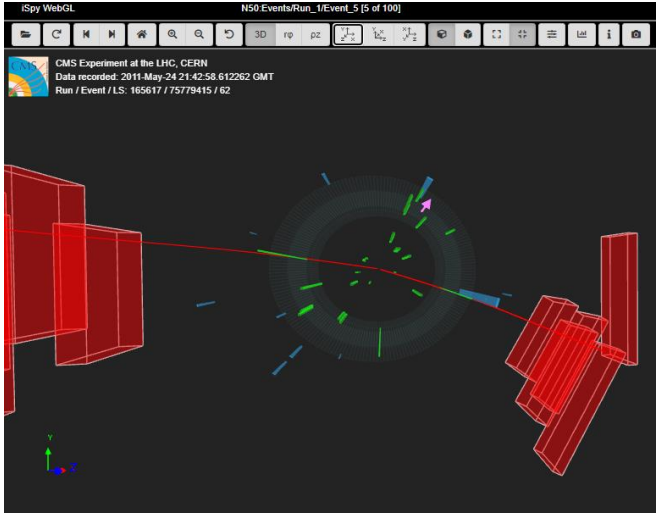
- neutrinos from "missing energy"

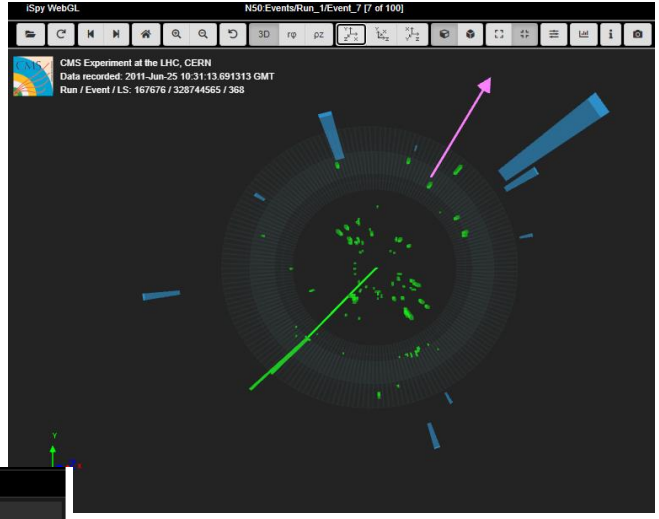
iSpy event display for CMS



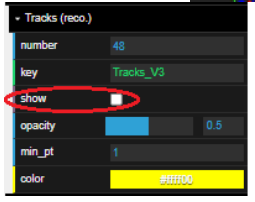
1, 2, or 4 leptons?

Which of these events has 1, 2, or 4 charged leptons? Which flavors of leptons? What else do you see?





Note Tracks (reco) turned OFF.



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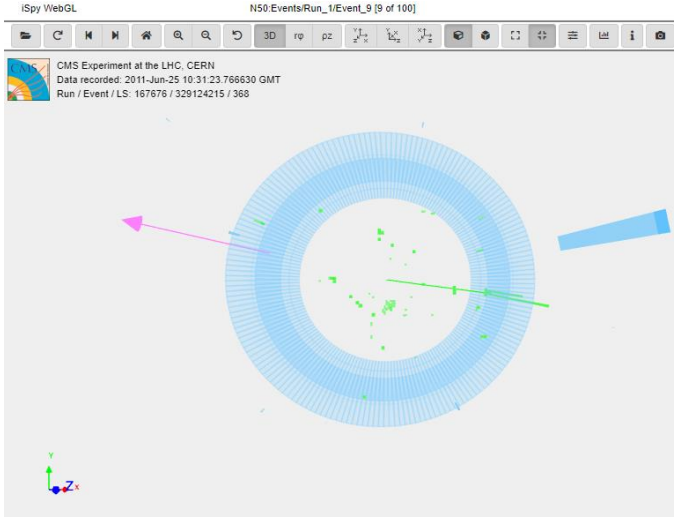
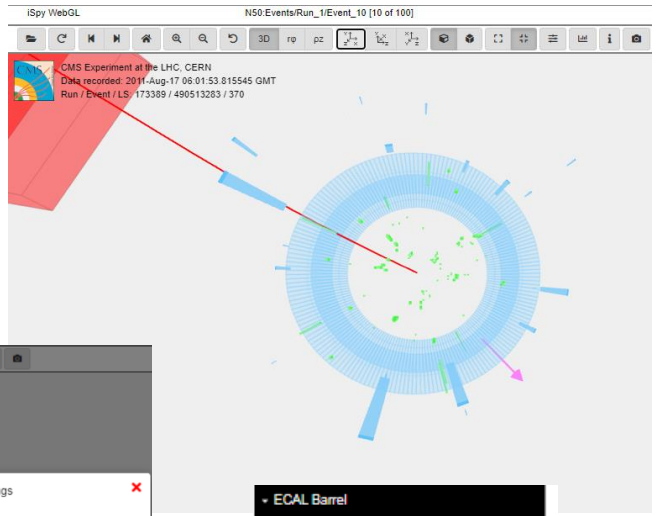
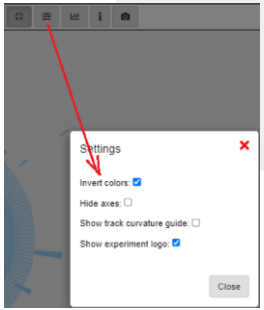
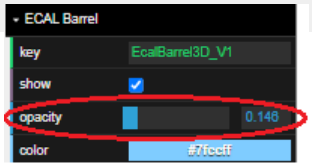




Note Inverted Colors and increased ECal Barrel opacity.





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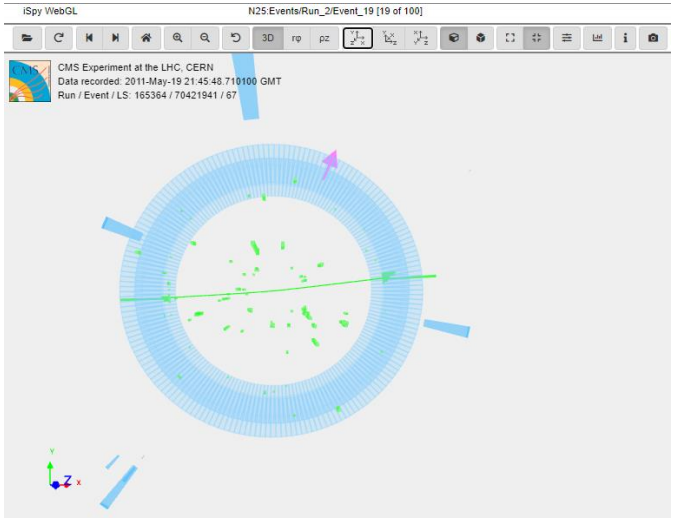

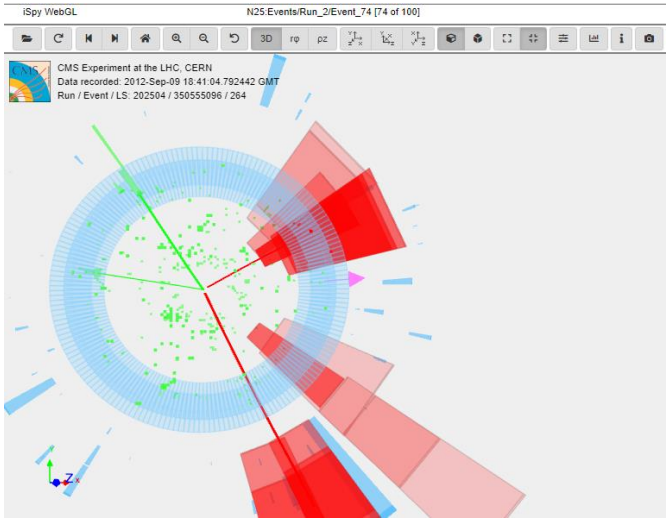

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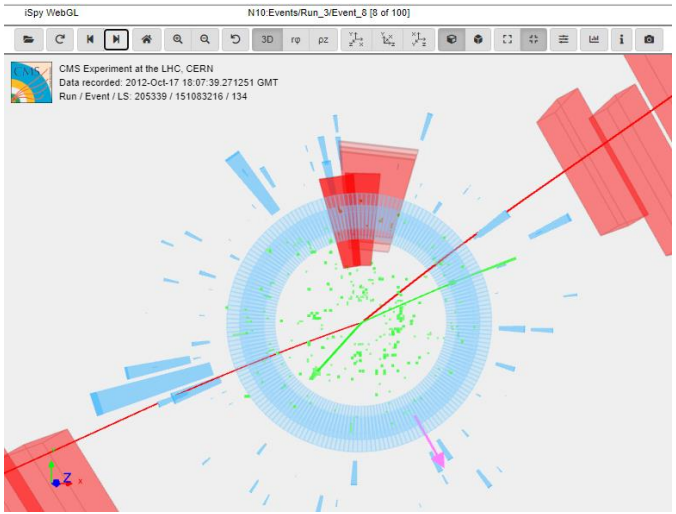
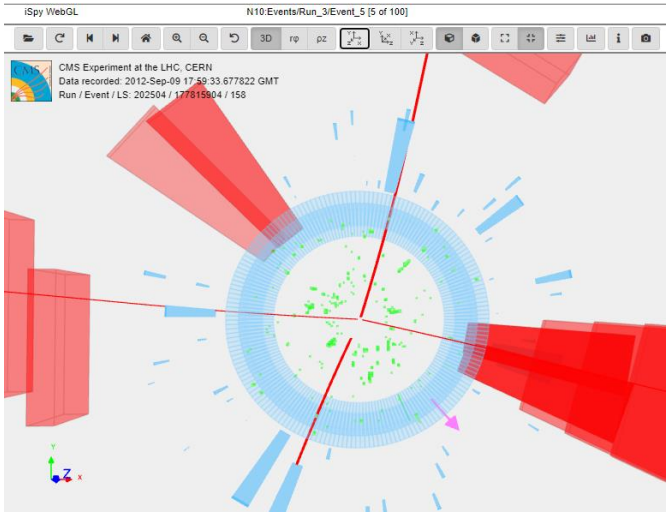
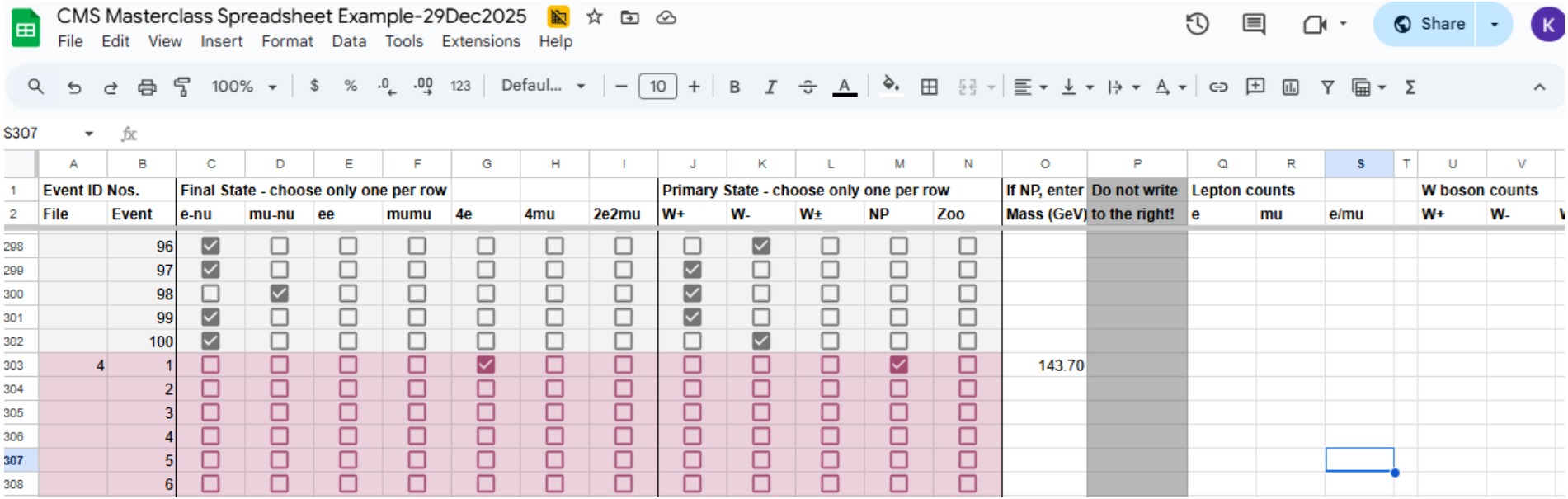




CMS Masterclass Spreadsheet

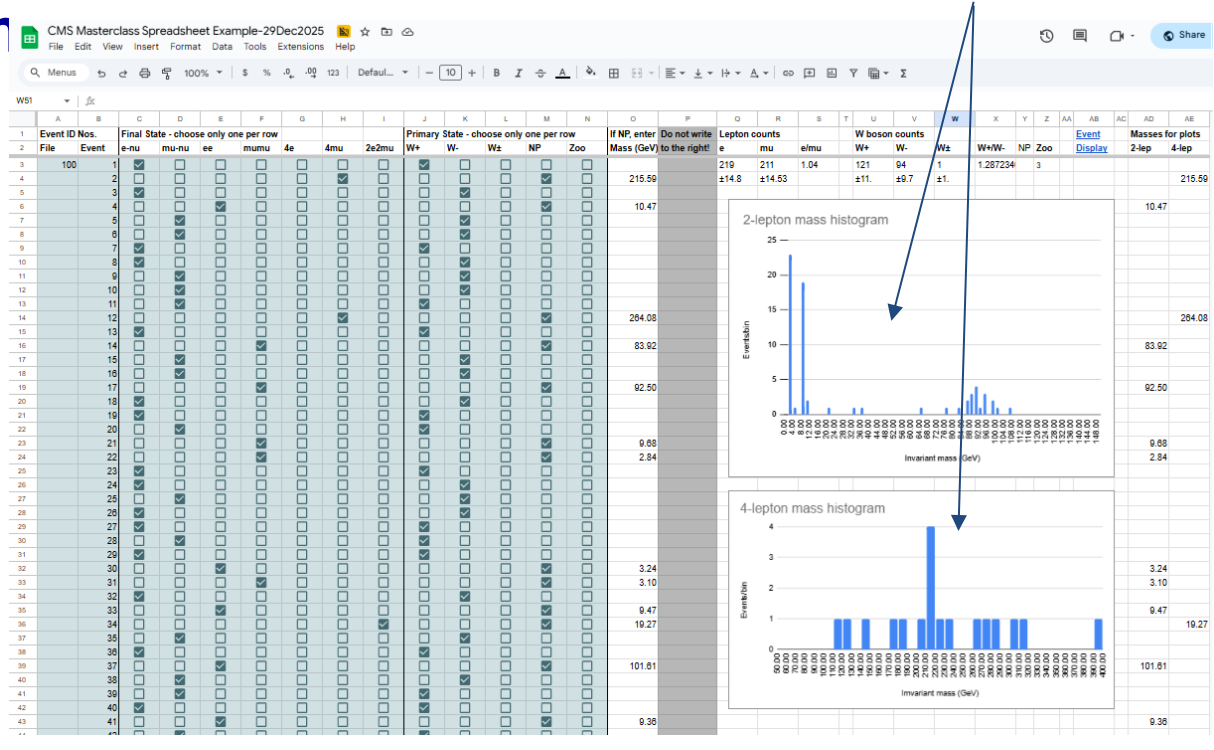
Enter data on each event in the Google Sheet:



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	Event ID Nos.		Final State - choose only one per row							Primary State - choose only one per row					If NP, enter	Do not write	Lepton counts				W boson counts	
2	File	Event	e-nu	mu-nu	ee	mumu	4e	4mu	2e2mu	W+	W-	W±	NP	Zoo	Mass (GeV)	to the right!	e	mu	e/mu		W+	W-
298		96	☑	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐								
299		97	☑	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐								
300		98	☐	☑	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐								
301		99	☑	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐								
302		100	☑	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐								
303	4	1	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☑	☐	143.70							
304		2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐								
305		3	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐								
306		4	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐								
307		5	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐								
308		6	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐								

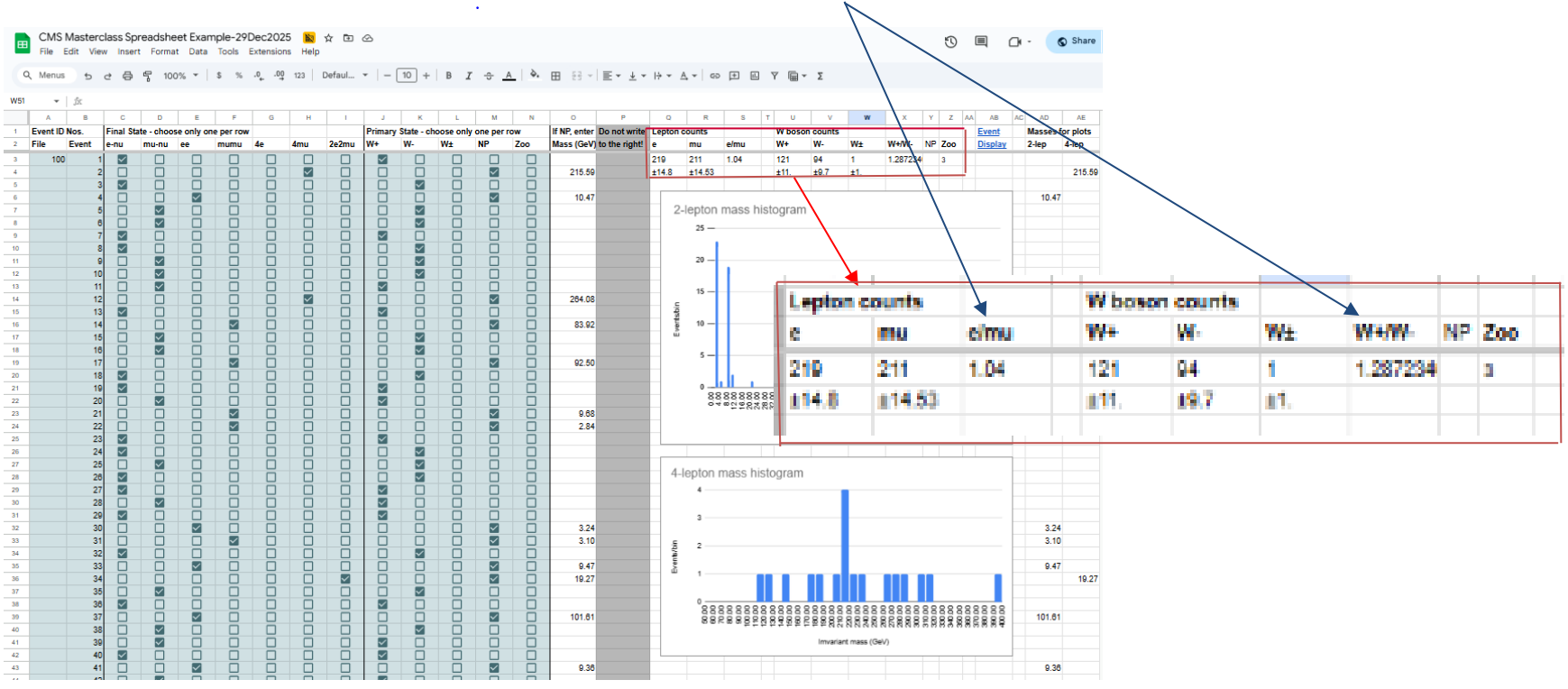
CMS Masterclass Spreadsheet

Your spreadsheet makes mass histograms autom



CMS Masterclass Spreadsheet

It also tabulates data for key ratios:



Follow the flow

Your data file

- **CMS masterclass has 100 data files**
- **Each file has 100 events**
- **Two students analyze one assigned data file**

Google Sheet

- Scroll down until you find your data file in column A
- Event numbers are in column B
- Enter results in columns C-N
  - Final State C-D → Primary State J-K only
  - Final State E-I → Primary State L, N only
  - Can't answer? Column M (use rarely)

Event display

- Go to file folder
- Events frm web
- File names "masterclass_xx.ig" → "xx" replaced by your file number
- Choose your file then scroll up to first event (top, right in window)
- Choose that and then Load
- You are now in file xx, event 1
- Right arrow advances to the next events, up to event 100

Screencast: cern.ch/cms-cast2026

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.