INTERNATIONAL MASTERCLASSES HANDS ON PARTICLE PHYSICS

CMS Masterclass - Introduction

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INTERNATIONAL MASTERCLASSES
hands on particle physics

International Masterclasses

High school students (15-19 y.)

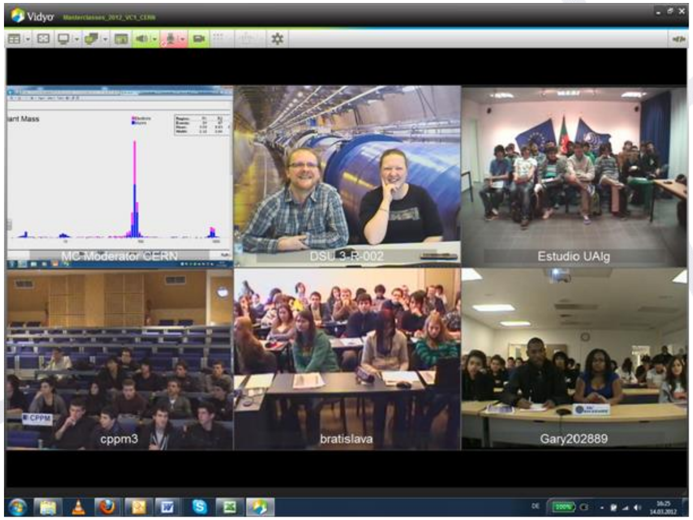
- are made „scientists for one day“
- get invited to a research lab or university

3 elements

1 Introductory talks
standard model, detectors, accelerators

2 measurement with HEP data

3 International videoconference
3-5 groups + 2 physicists as moderators at CERN, Fermilab, KEK, GSI, TRIUMF



Inspiring the next generation

Moderator in 2021 and 2022

“

I did this masterclass in 2012 when in high school and that's why I decided to study physics so I would love to encourage people to join our community.

”

The idea behind Masterclasses

High school students (15-19y) at a university or research lab

Act as a „scientists for one day“

- Close to current research
- Hands-on activity
- Real scientific data
- Relevant methods and tools
- Nature of science
- Organisation of HEP research
- Meeting and discussion with scientists

Broad Scope of Masterclasses

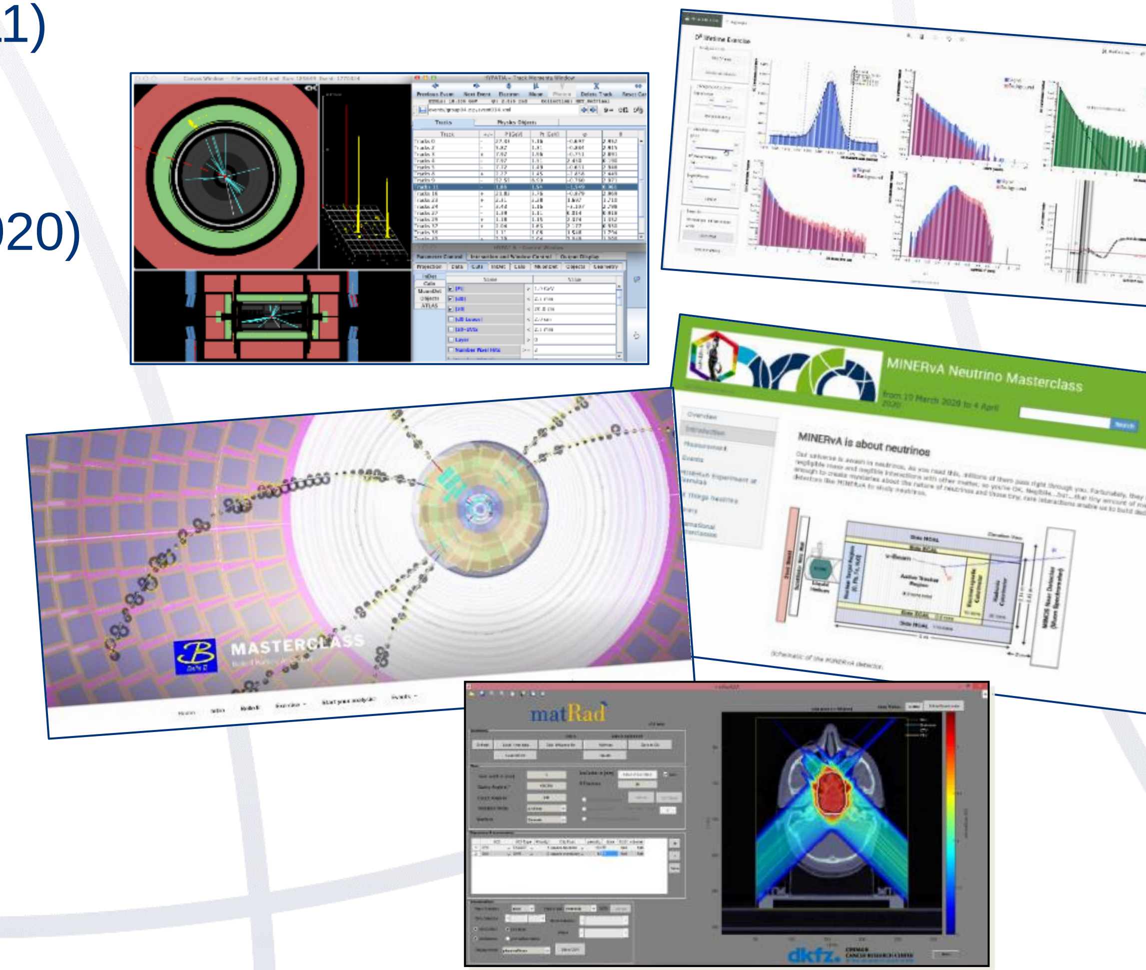
- LEP/LHC (since 2005/2011)
- Belle II (since 2020)
- MINERvA (since 2019)
- Particle Therapy (since 2020)

Under development:

- NOvA
- MicroBooNE

More Masterclasses:

- IceCube
- Pierre Auger
- DarkSide
- …



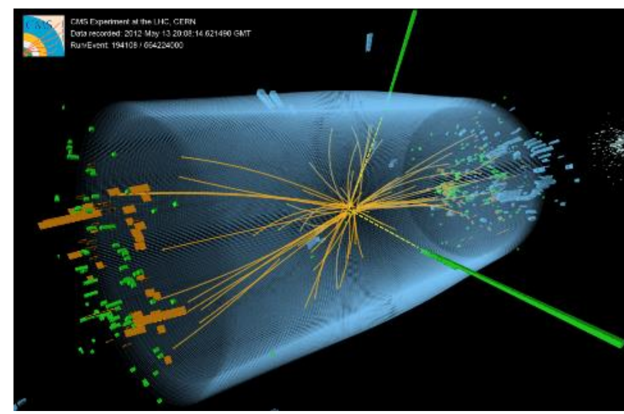
International Masterclasses

- key activity of IPPOG (International Particle Physics Outreach Group)
- Masterclasses: LHC, Belle II, Neutrinos experiments, Auger, Particle Therapy, ...
- Moderation centers: CERN, Fermilab, KEK, GSI, Malargue

The LHC and the new physics

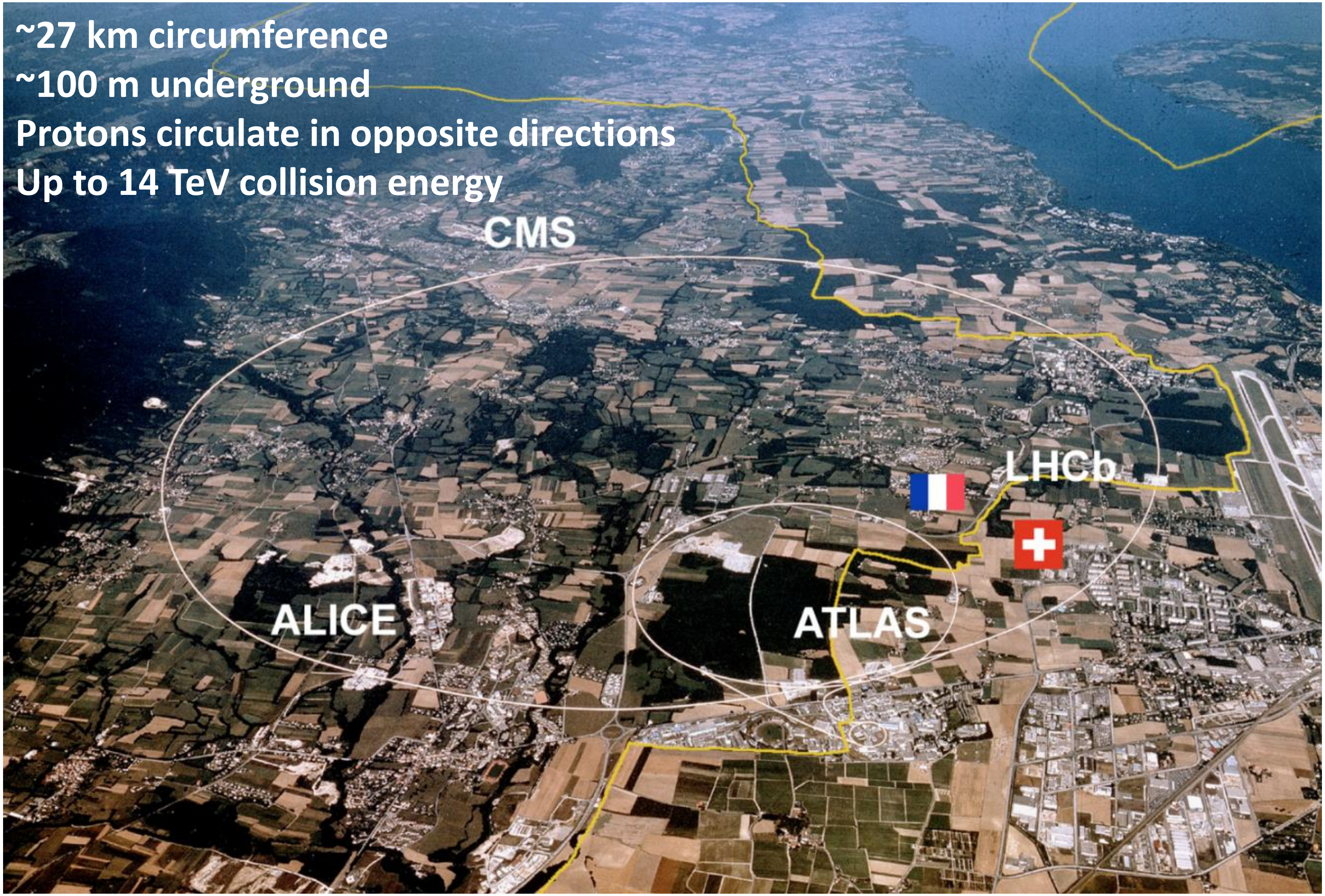
It is a time of exciting new discoveries in particle physics.

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 . . .

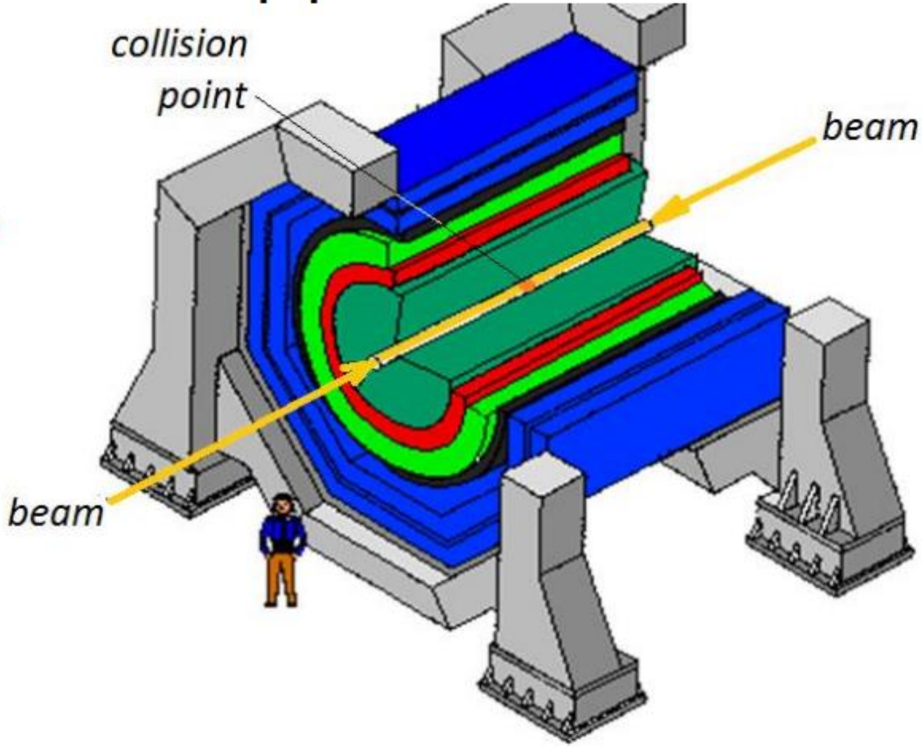
Tracking

Electromagnetic calorimeter

Hadronic calorimeter

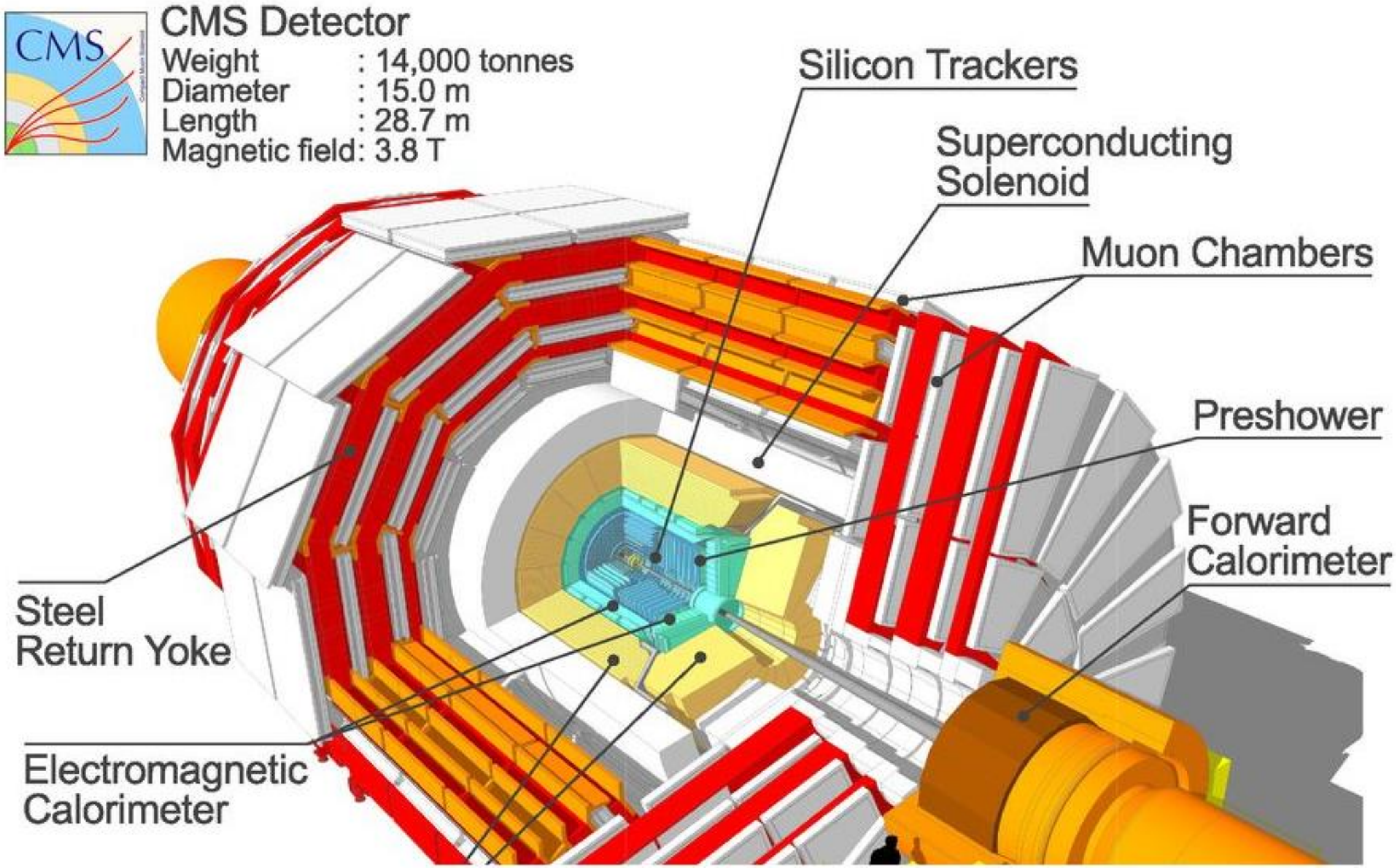
Magnet*

Muon chamber



* *location of magnet depends on specific detector design*

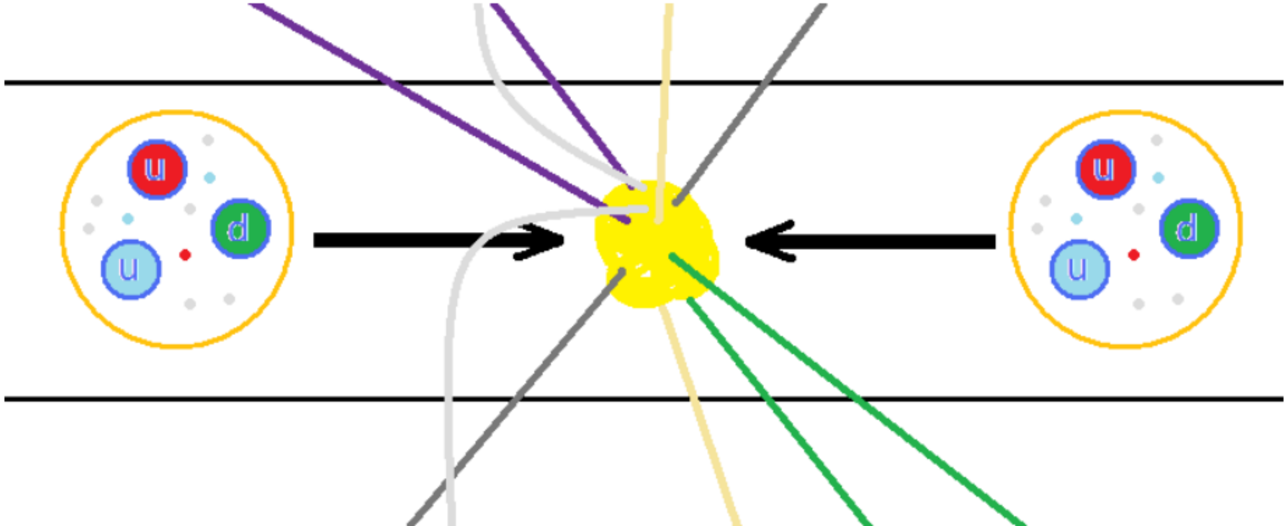
The Compact Muon Solenoid (CMS)



Protons collide inside CMS

The LHC accelerates protons to about 7200 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.



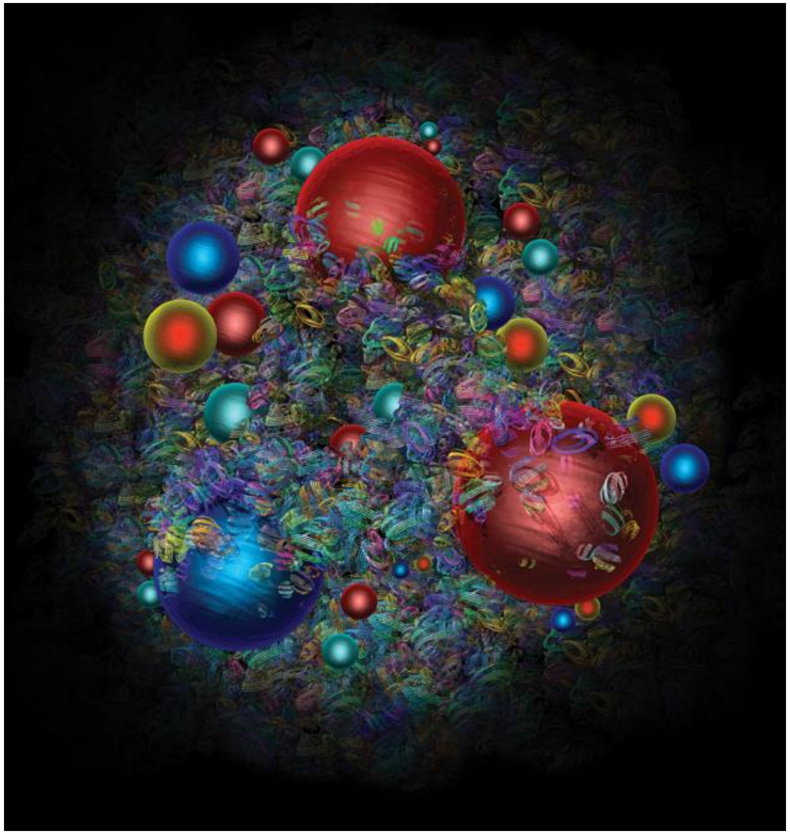
What do the protons tell us?

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 fundamental particle in our zoo!**

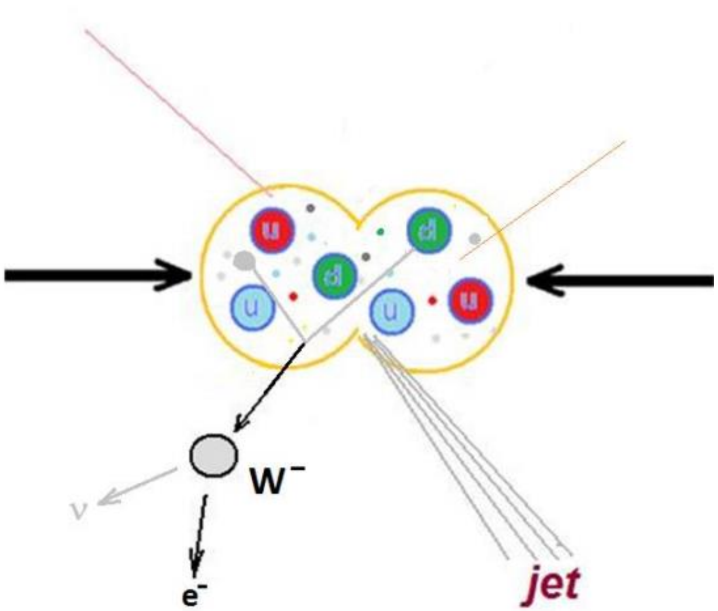


Artist's image of a proton from CERN Courier. Learn more here and even more here.

One-lepton events

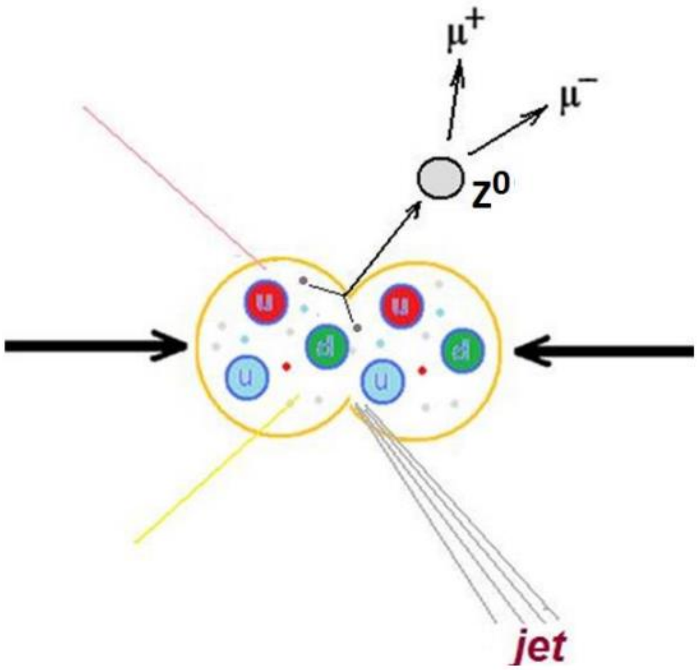
The + or – charged W boson enables radioactive decay by transforming neutrons into protons.

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

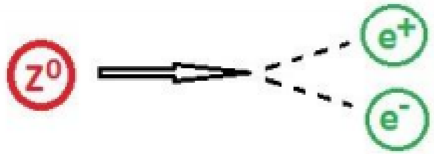


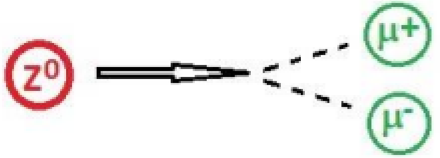
Two-lepton events

The Z boson is a neutral cousin of the W. It enables the “weak neutral current”.



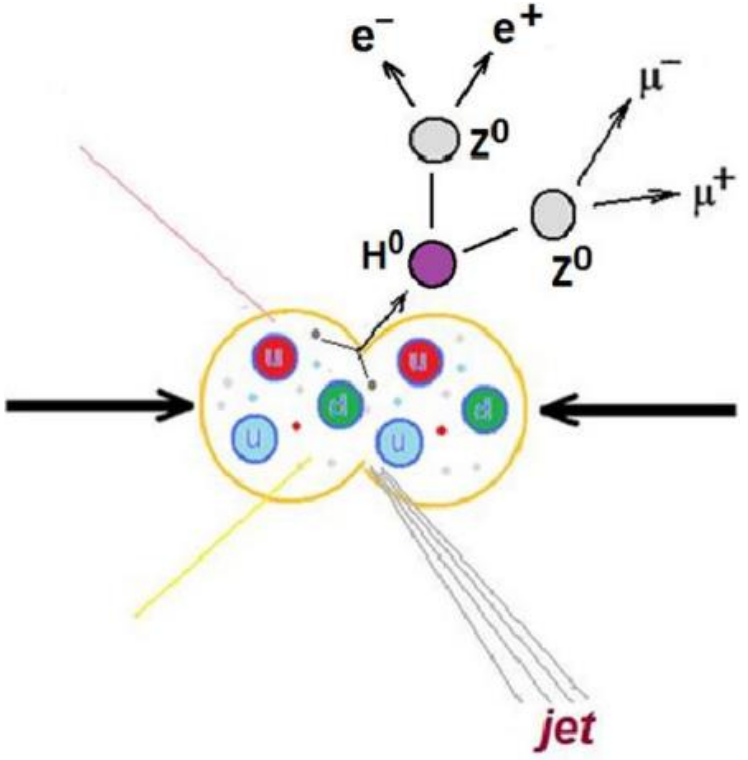
It decays into two leptons of the same type but opposite charge – electron and positron or muon and antimuon. It has other decay paths but we are not looking for these.



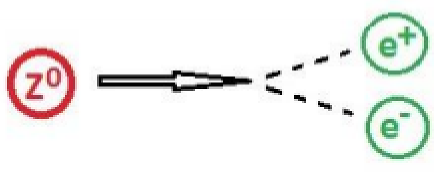


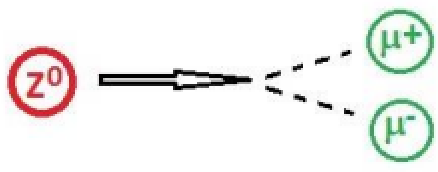
Four-lepton events

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.



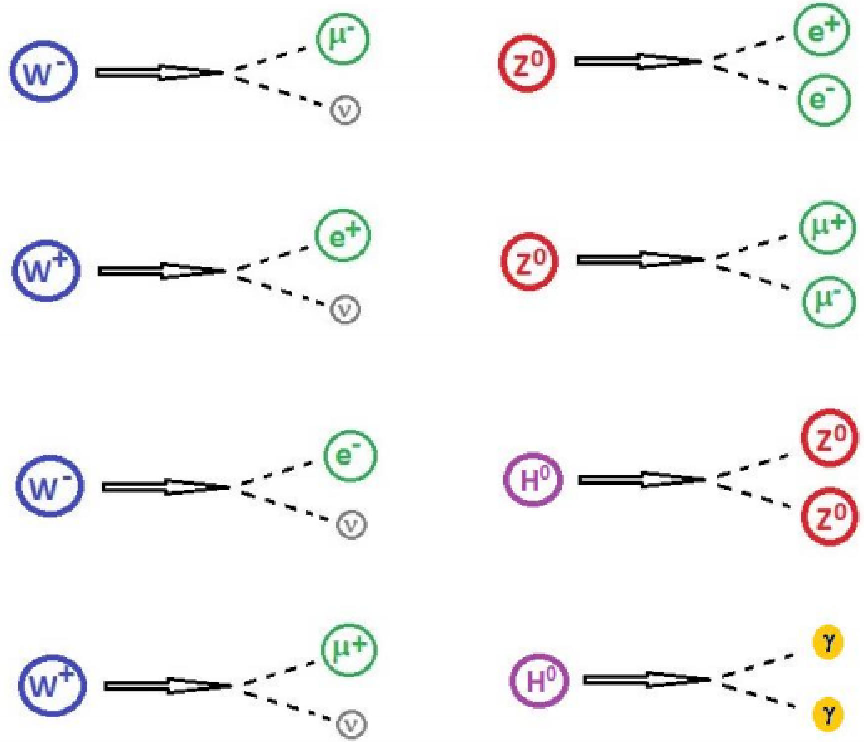


Decay summary

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

CMS *can* detect :

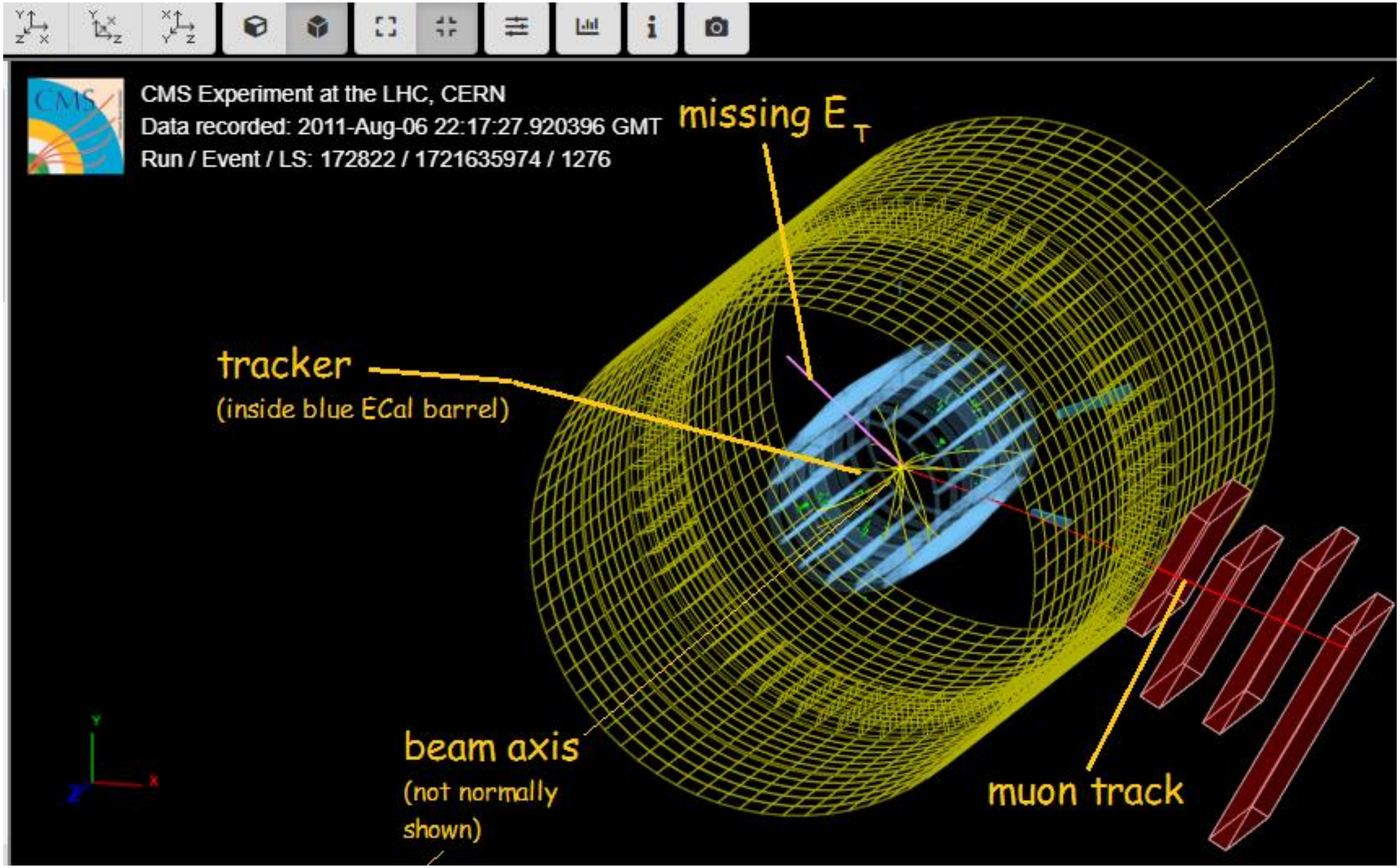
- electrons
- muons
- photons



CMS can infer:

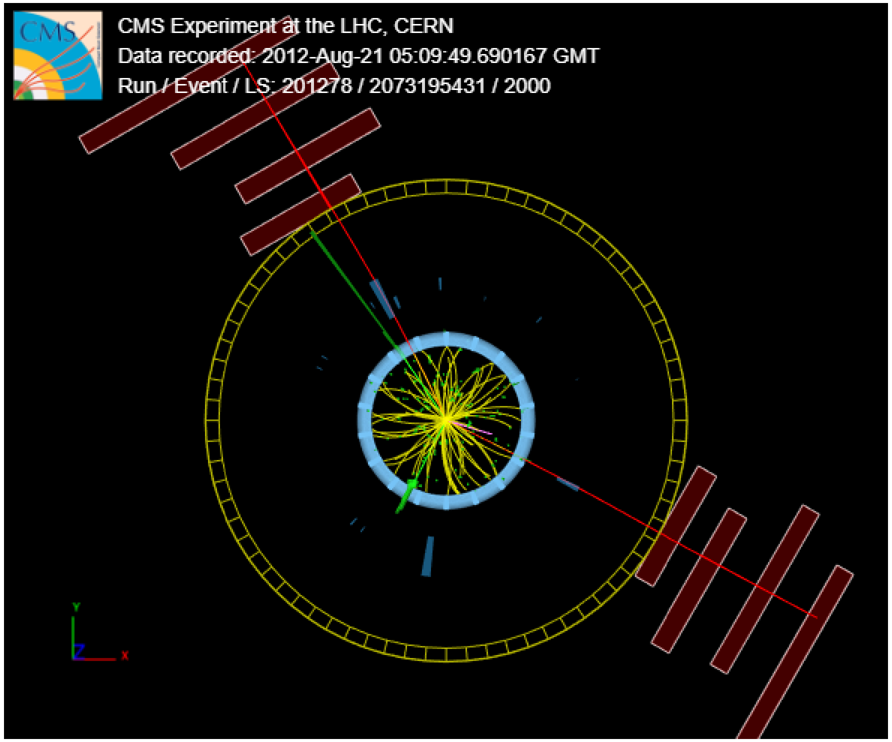
- neutrinos from "missing energy"

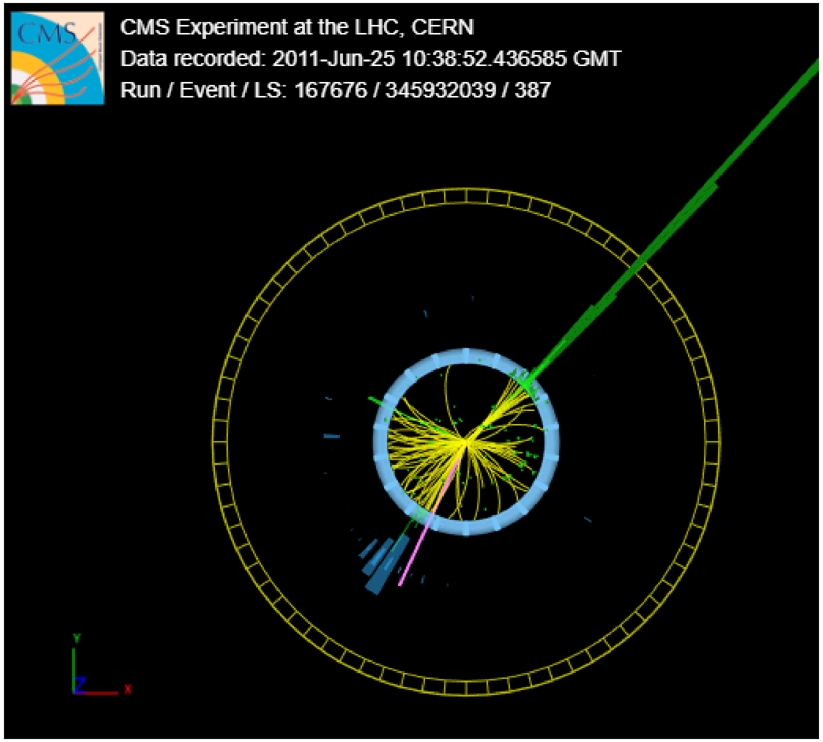
iSpy event display for CMS



1, 2, or 4 leptons?

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





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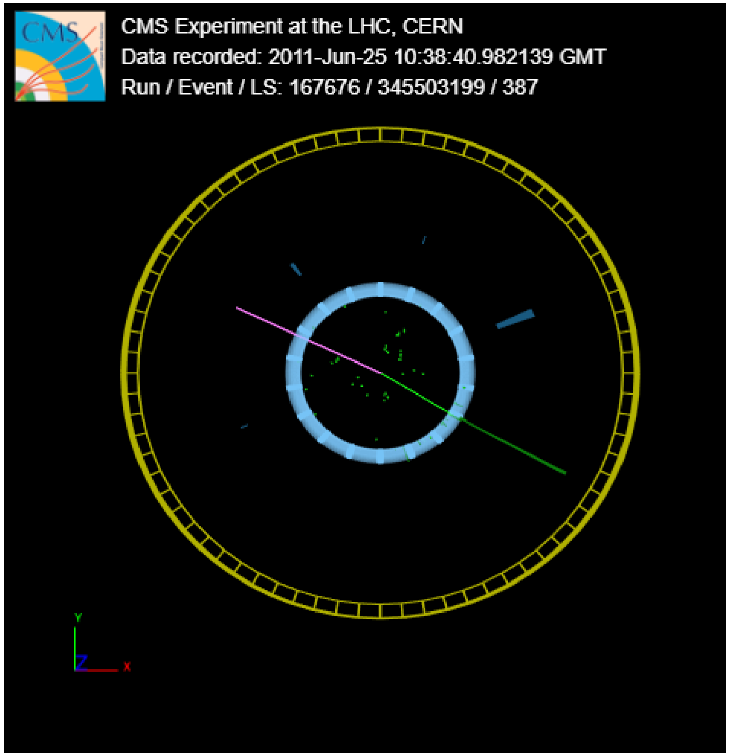

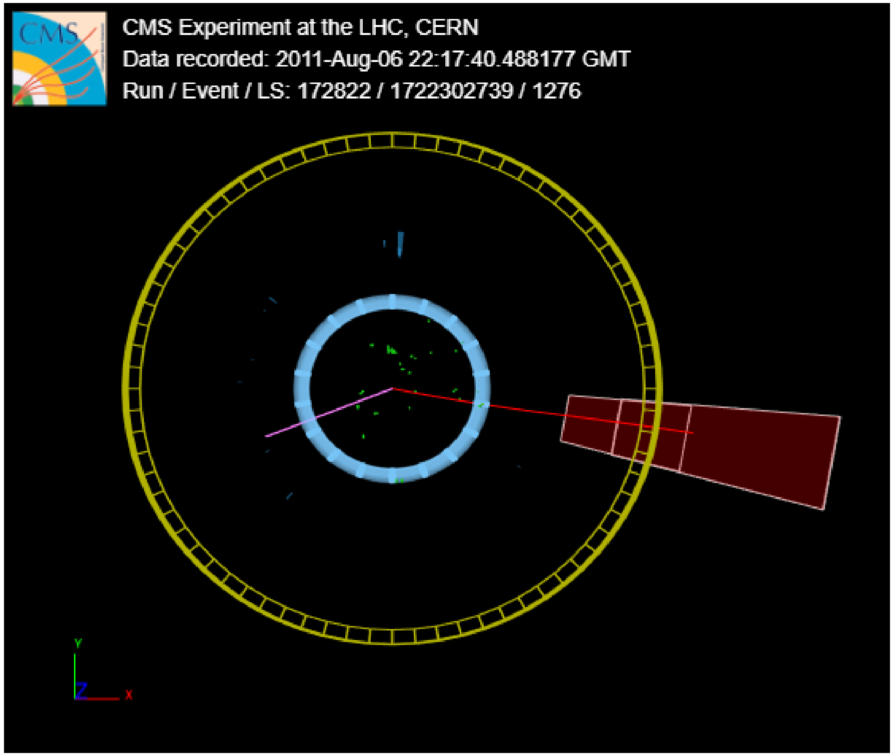

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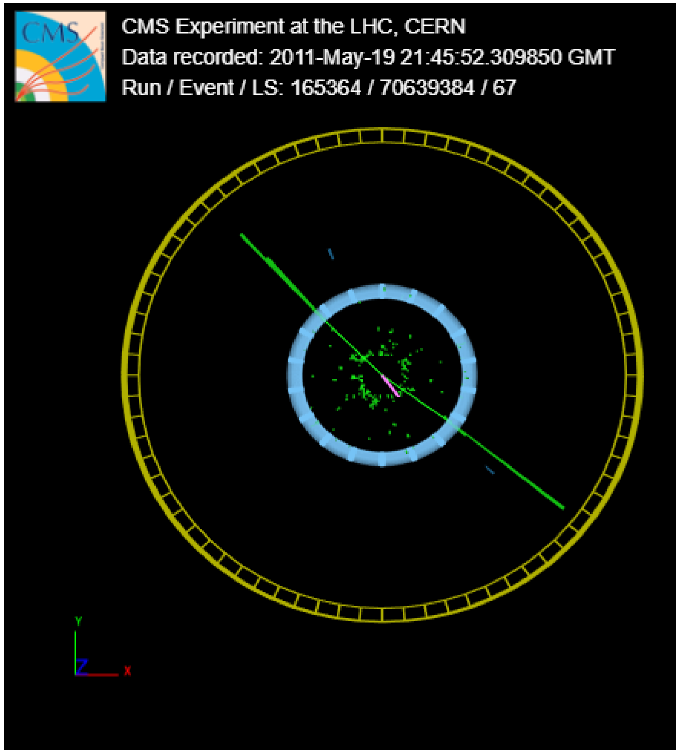

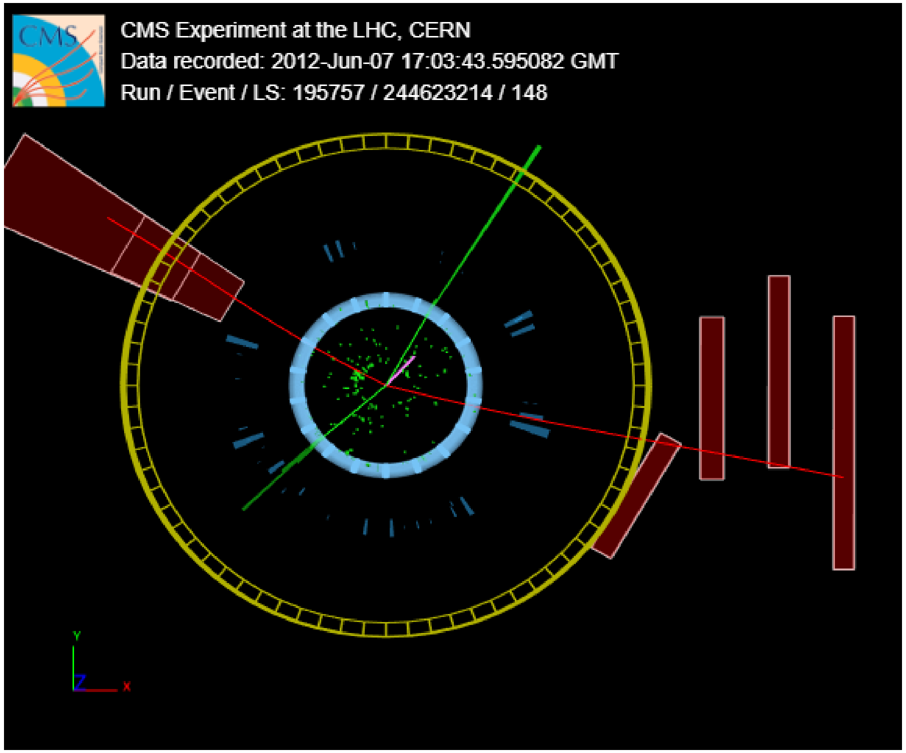

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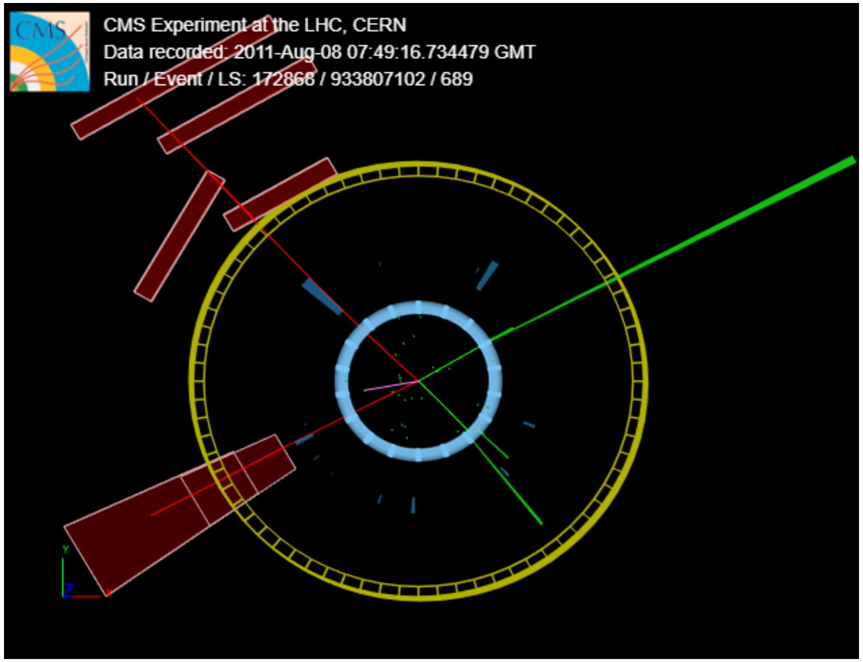
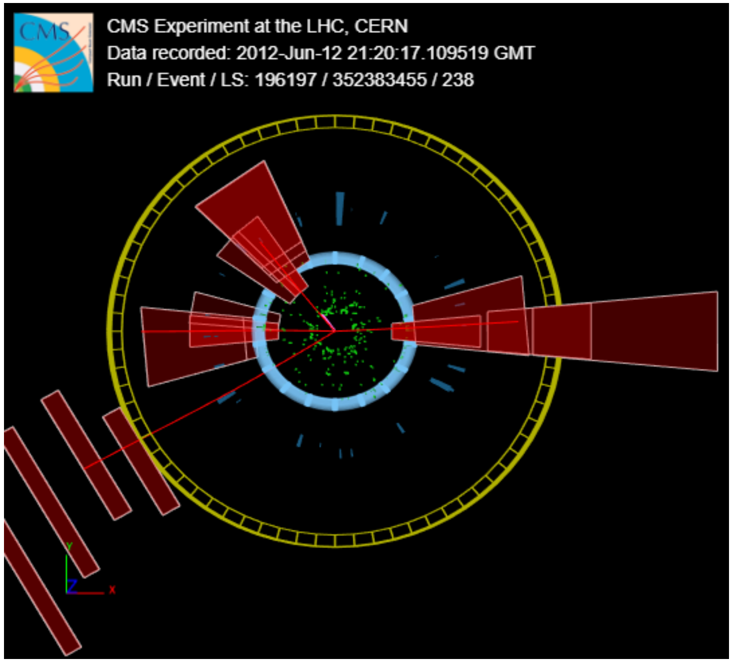
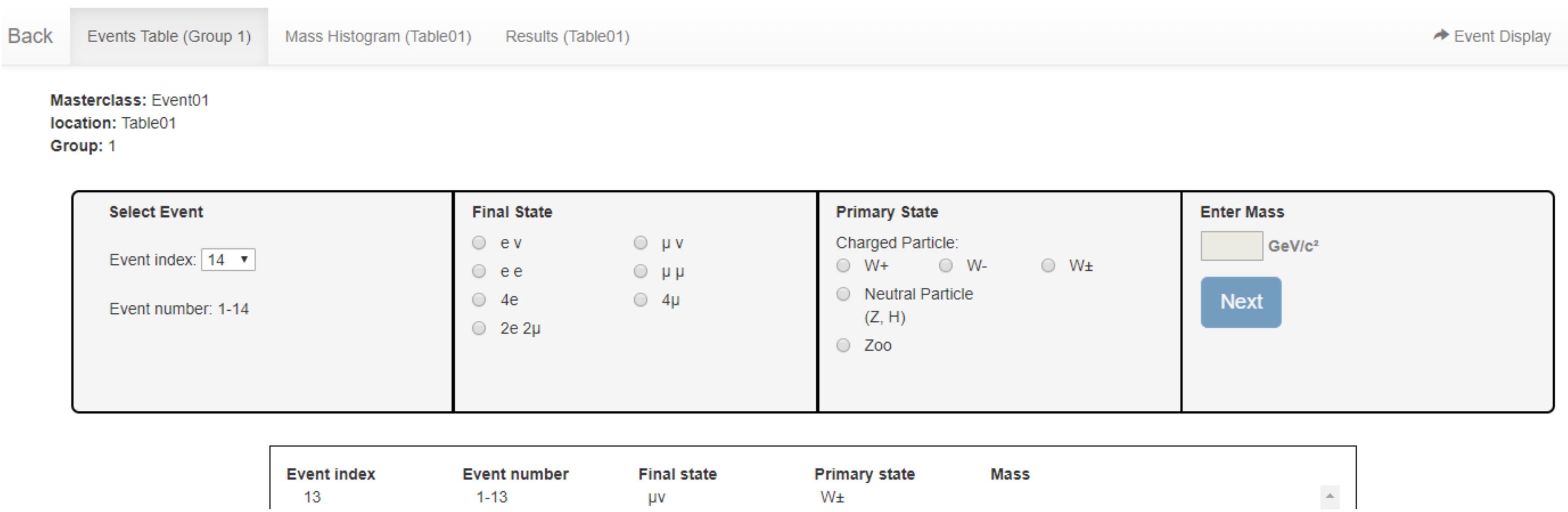




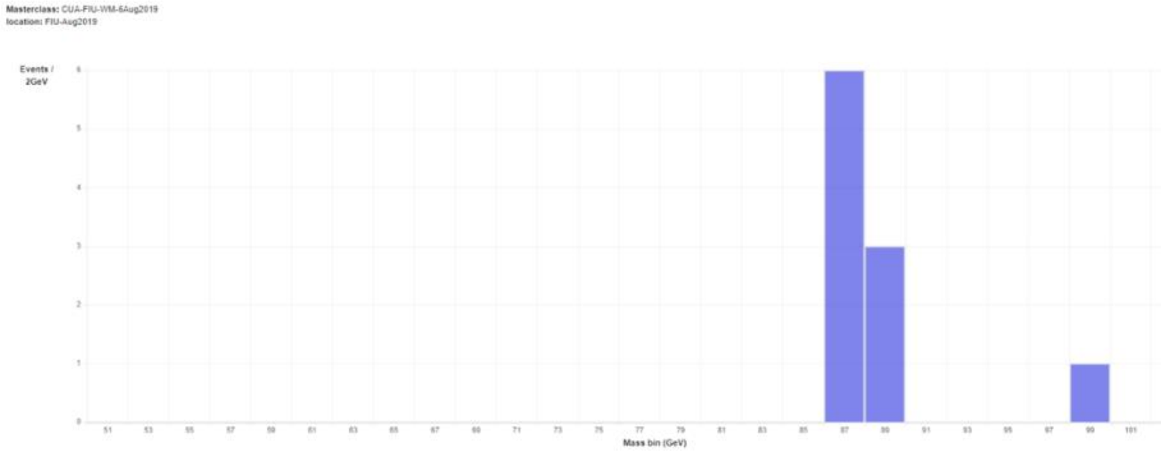
CMS Instrument for Masterclass Analysis (CIMA)

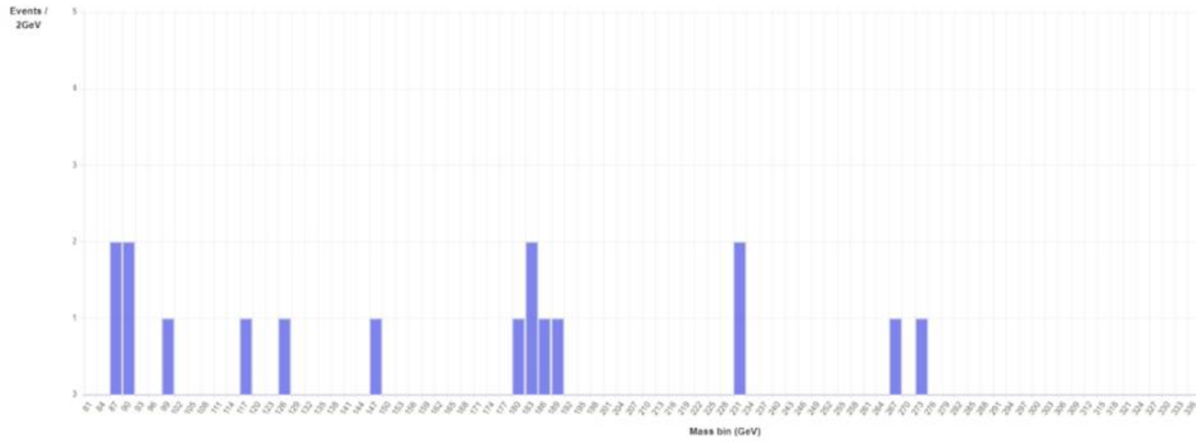
Enter data on each event:



CMS Instrument for Masterclass Analysis (CIMA)

CIMA makes mass histograms automatically:





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

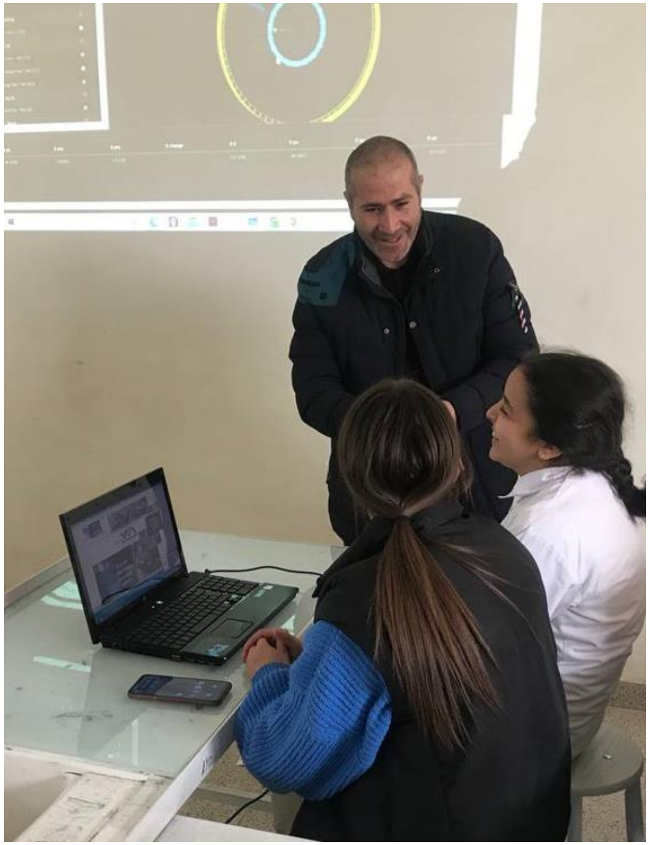
Calculate e/mu and W+/W- !

Have a great masterclass!

Enjoy your data analysis and our discussion of the results.

Remember:

- *Work in groups of two*
- *Check each other*
- *Work together*
- *Think critically*
- *Ask good questions.*



and…

- ***All** questions are good questions!*