Masterclass: what to do in practice

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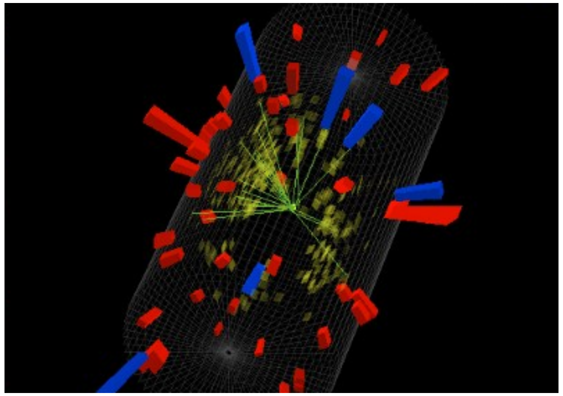
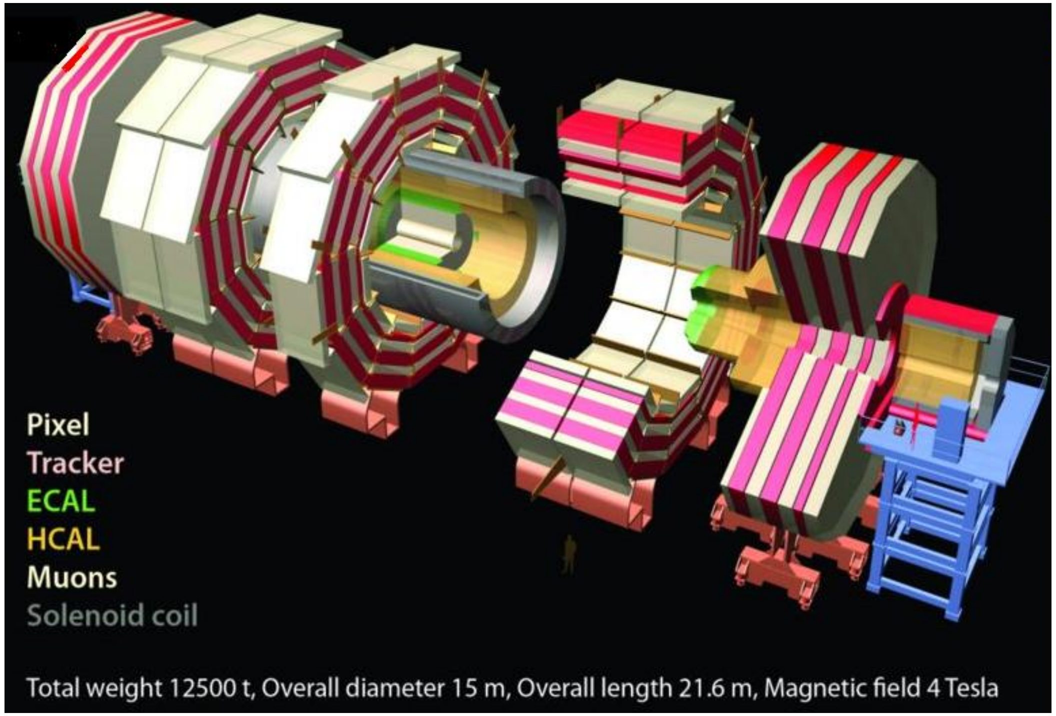
INTERNATIONAL MASTERCLASSES

hands on particle physics

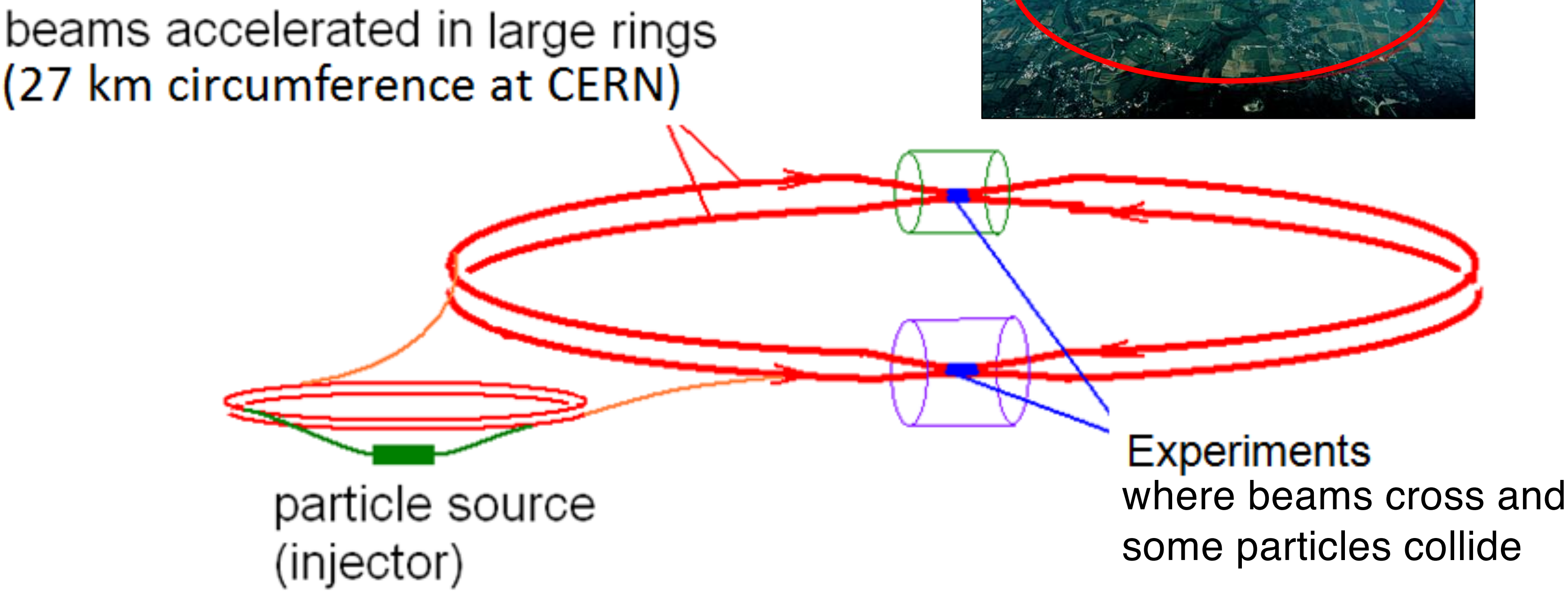
CMS Masterclass





The LHC and New Physics

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



Detector Design

Generic Design

Cylinders wrapped around the beam pipe

From inner to outer . . .

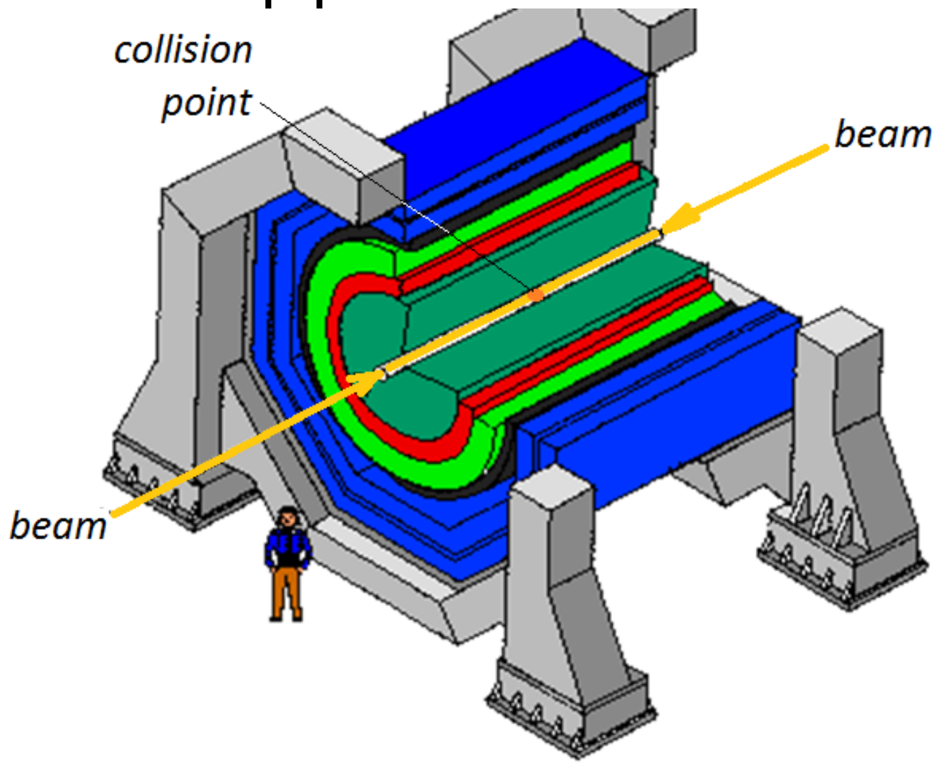
Tracking

Electromagnetic calorimeter

Hadronic calorimeter

Magnet*

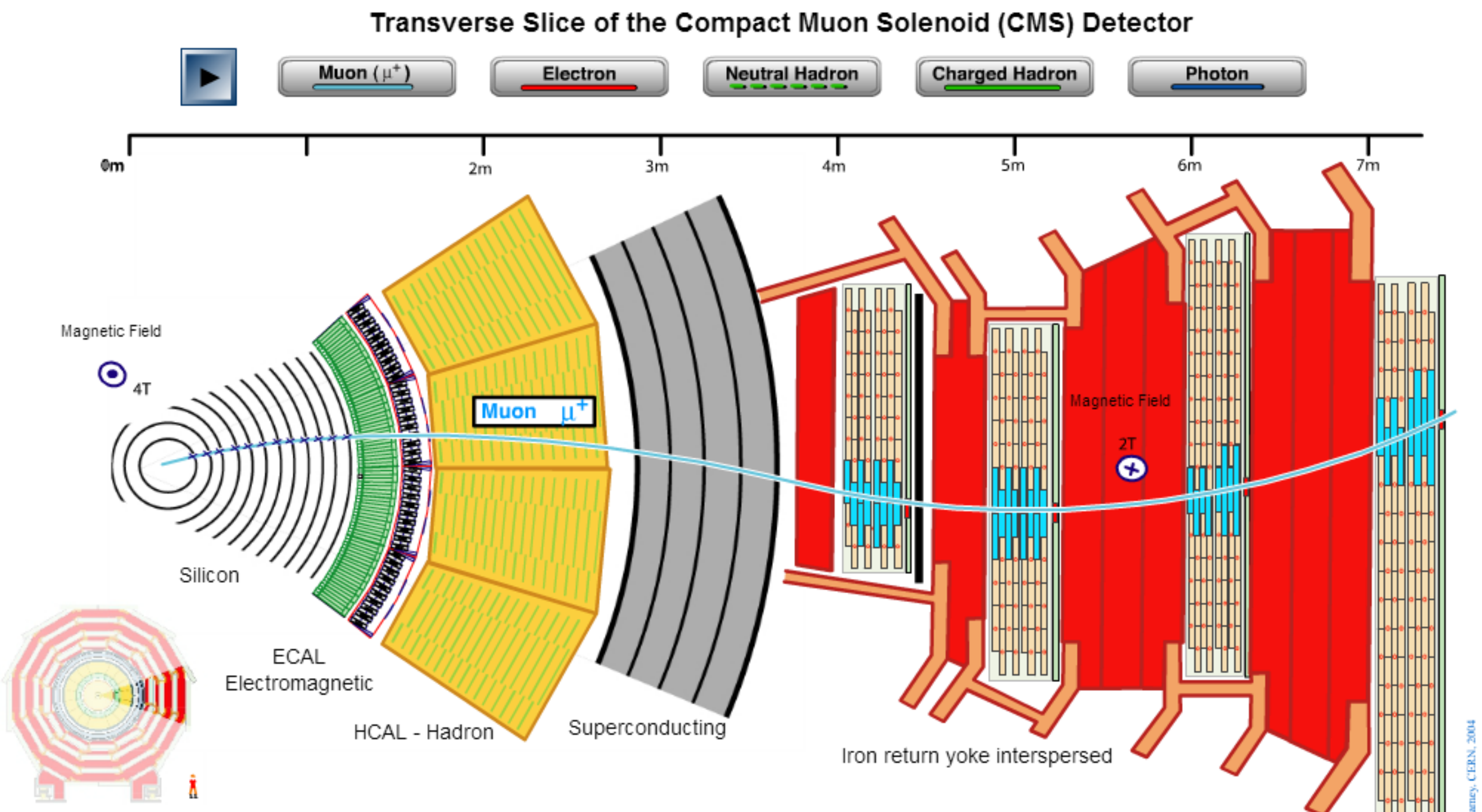
Muon chamber



* *location of magnet depends on specific detector design*

Detector Tracks

Web Version



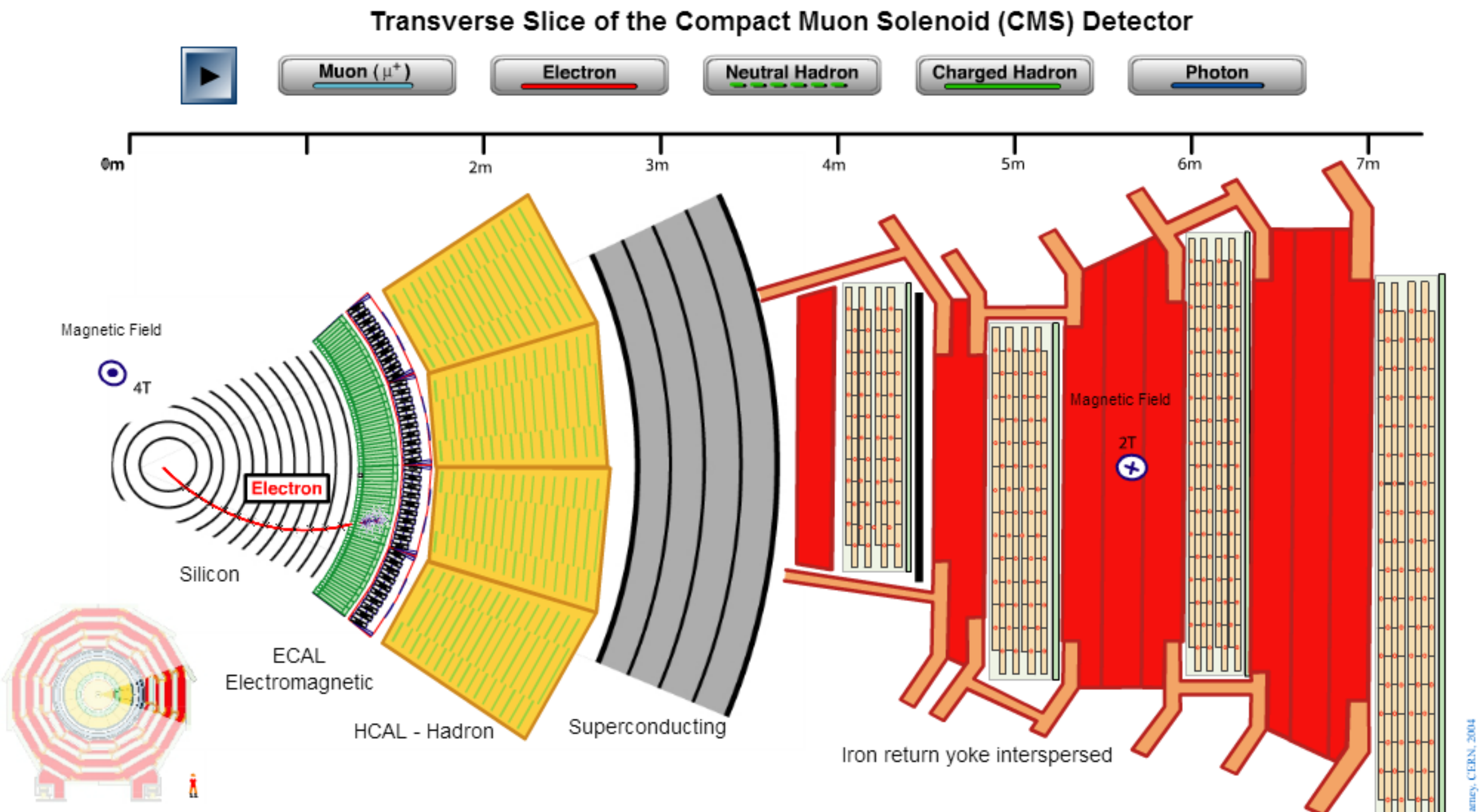
Transverse slice through CMS

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

Detector Tracks

[Web Version]



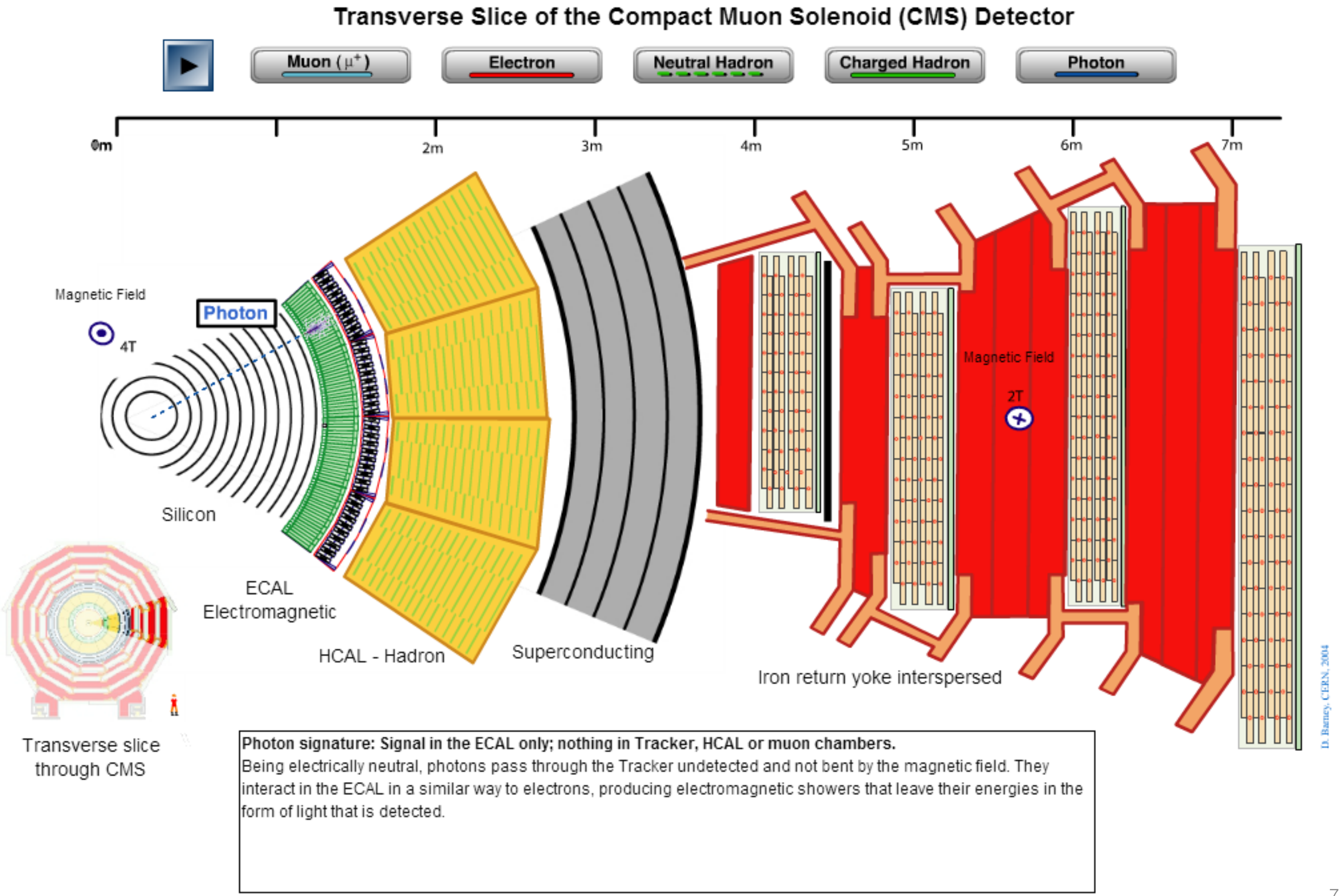
Transverse slice through CMS

Electron signature: Signals in the Tracker and the ECAL; nothing in the HCAL or muon chambers.
These electrically charged particles bend in the field and leave signals in the Tracker, enabling their paths to be reconstructed. The amount of bend depends on the momentum they carry, with the radius of curvature, r, being given by the momentum, p, divided by 0.3xB, where B is the magnetic field strength (3.8T in CMS). Electrons are slowed to a stop in the transparent lead tungstate crystals of the ECAL, producing a **shower** of electrons, photons and positrons along the way and depositing their energy in the form of light, which is detected. The amount of light is proportional to the electron energy.

Derived from CMS Detector Slice from CERN

Detector Tracks

Web Version



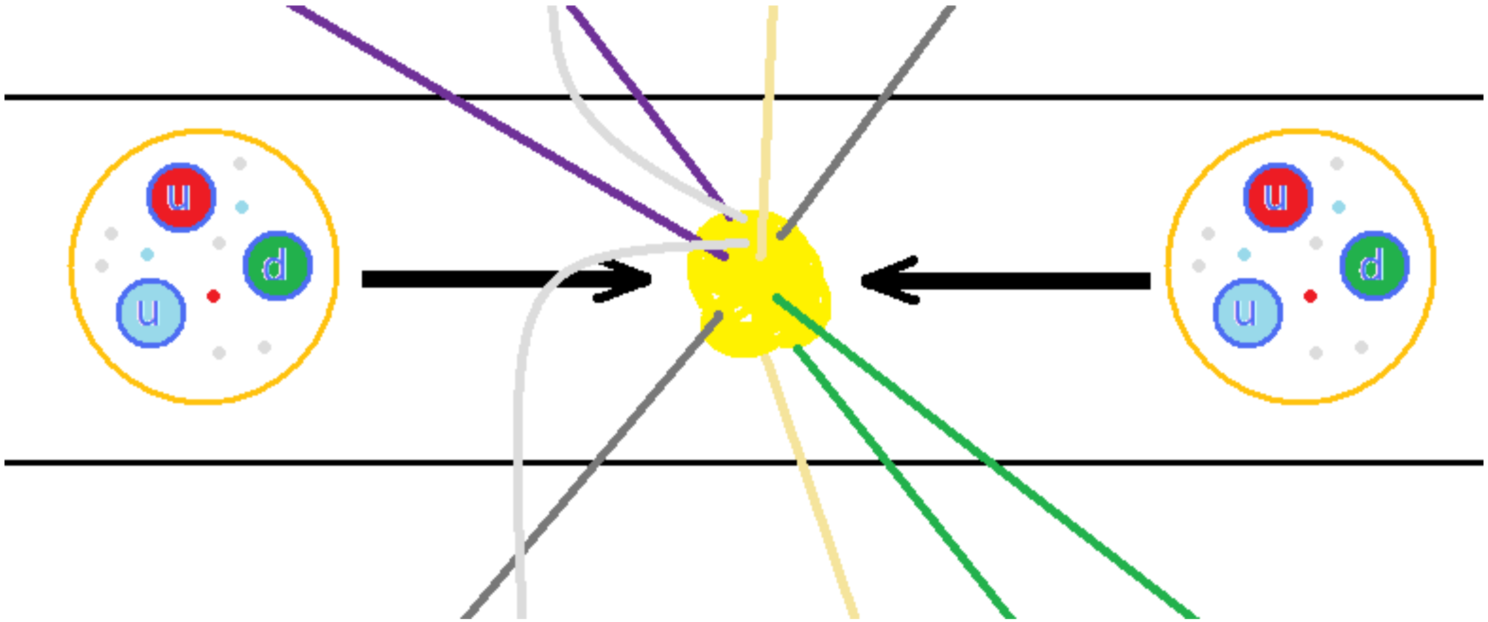
Derived from CMS Detector Slice from CERN

Energy & Particle Mass

We will look at Run I, in which proton energy is 4 TeV*.

- The total collision energy is 2 x 4 TeV = 8 TeV.
- But each particle inside a proton shares only a portion.
- So a newly created particle's mass ***must be*** smaller than the total energy.

** In Run II, this was increased to 6.5 GeV!*

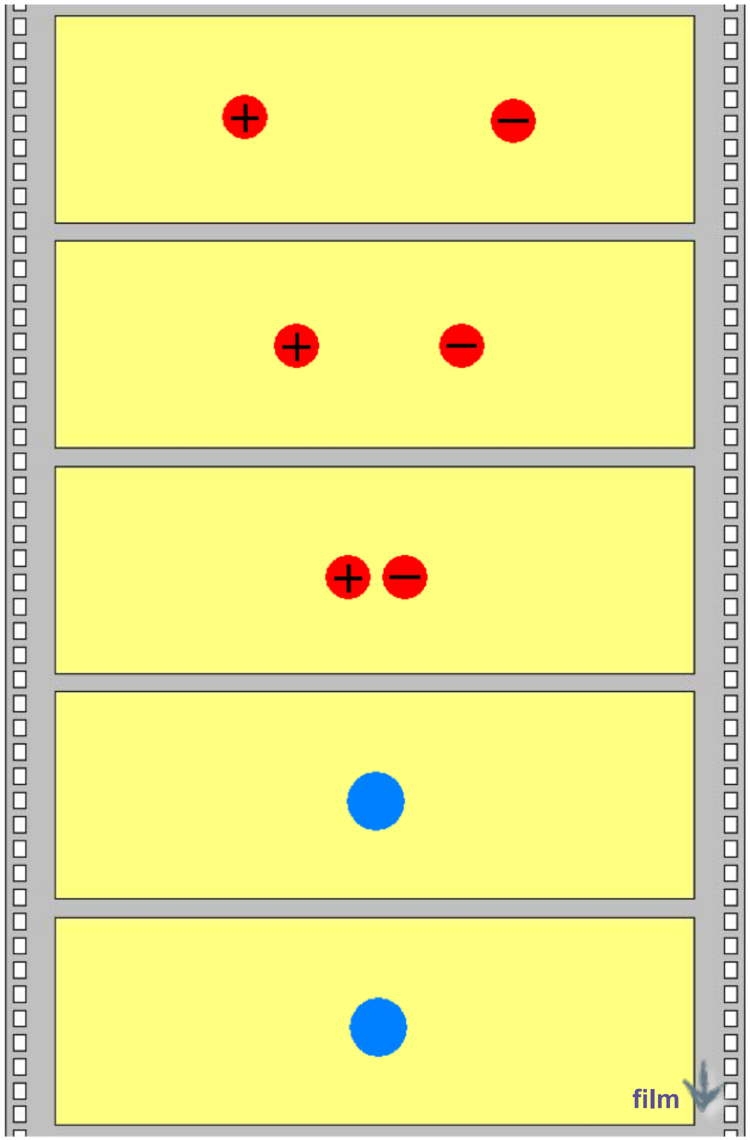


Particle Decays

The collisions create new particles that promptly decay. Decaying particles *always* produce lighter particles.

Conservation laws allow us to see patterns in the decays.

Try to name some of these conservation laws.

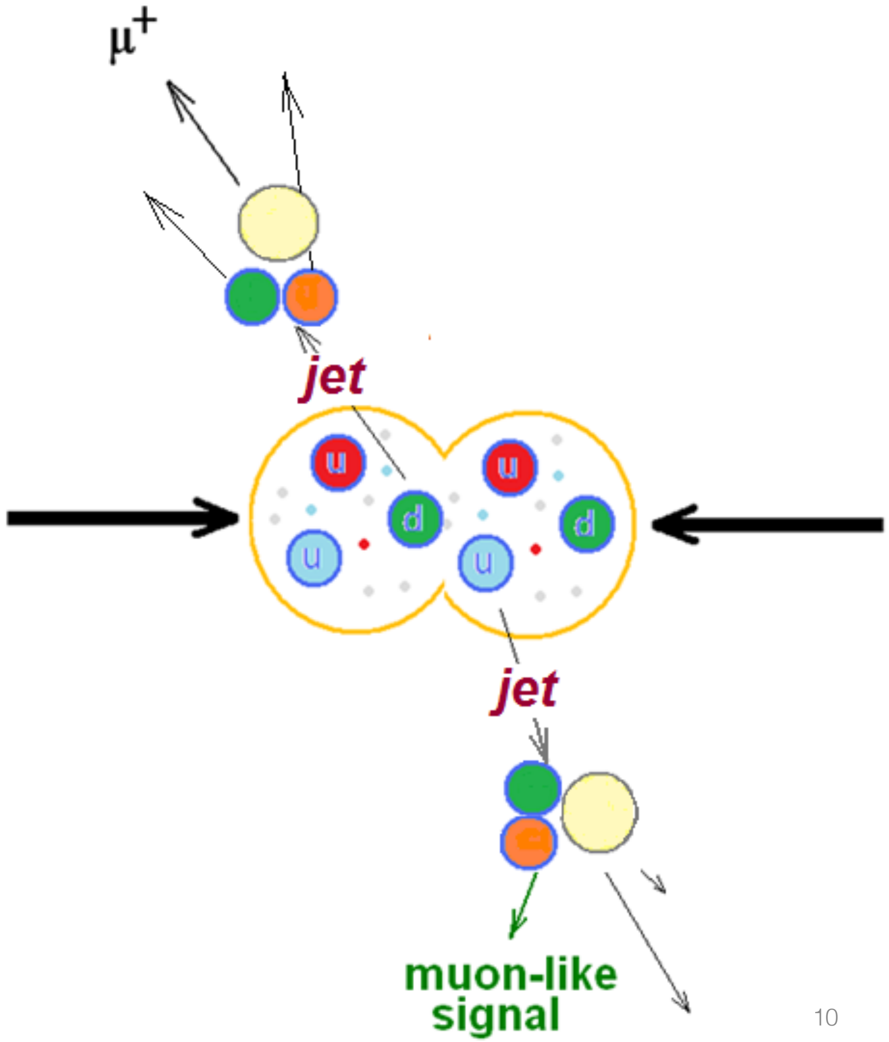


Background Events

Often, quarks are scattered by proton collisions.

As they separate, the binding energy between them converts to sprays of new particles called ***jets.*** Electrons and muons may be included in jets.

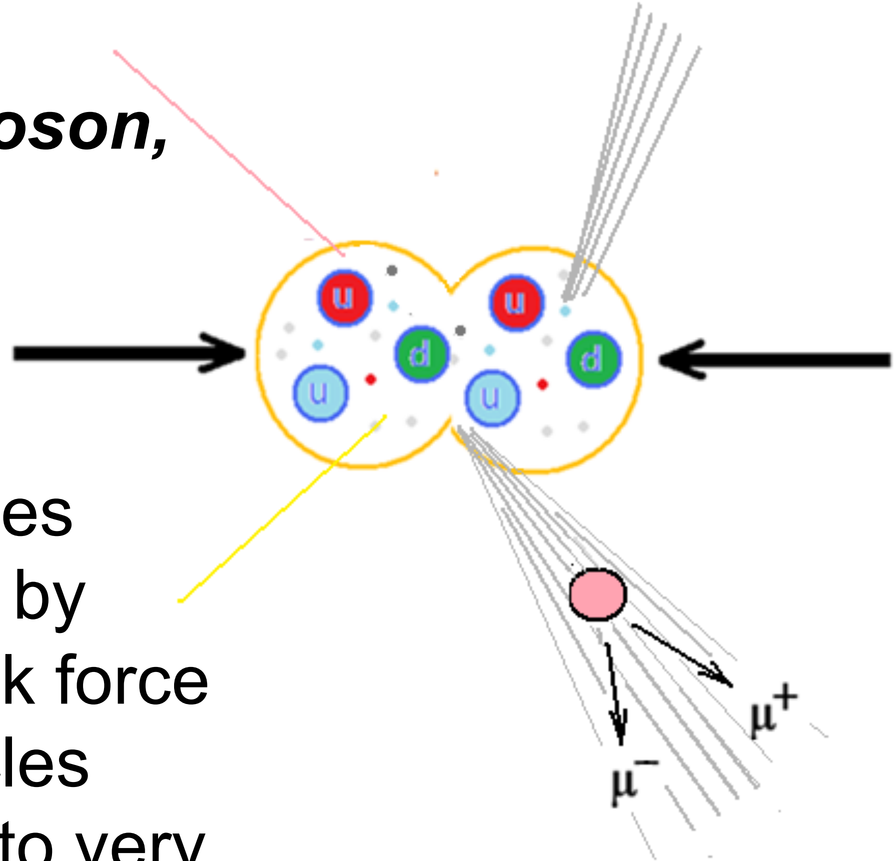
Software can filter out events with jets beyond our current interest.



W and Z Particles

We are looking for the mediators of the ***weak interaction:***

- electrically charged ***W^+ boson,***
- the negative ***W^- boson,***
- the neutral ***Z boson***.



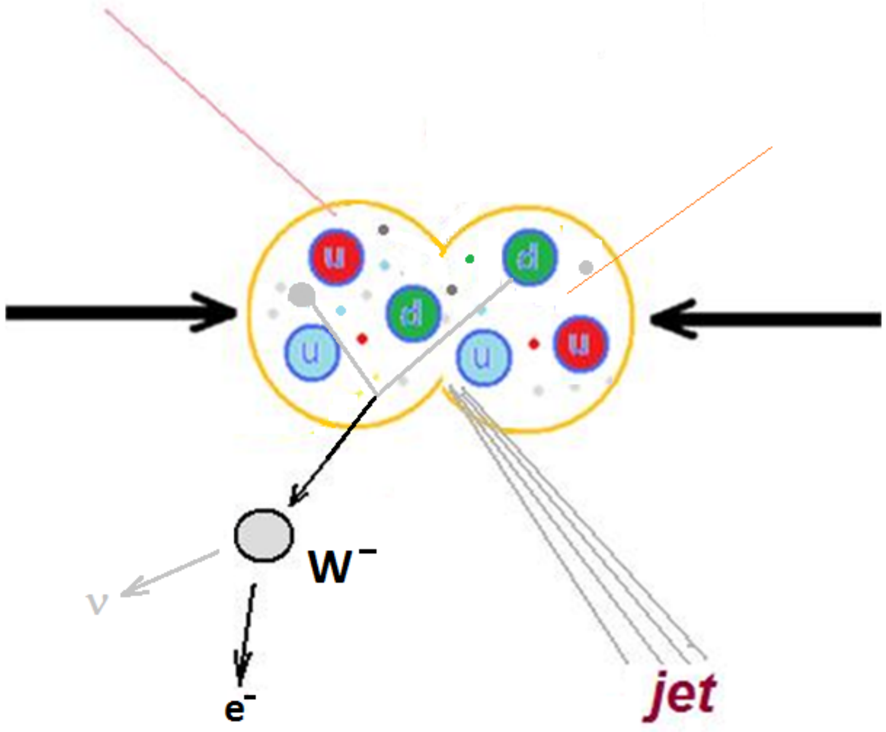
Unlike electromagnetic forces carried over long distances by massless photons, the weak force is carried by massive particles which restricts interactions to very tiny distances.

W and Z Particles

The W bosons are responsible for radioactivity by transforming a proton into a neutron, or the reverse.

Z bosons are similarly exchanged but do not change electric charge.

Collisions of sufficient energy can create W and Z or other particles.



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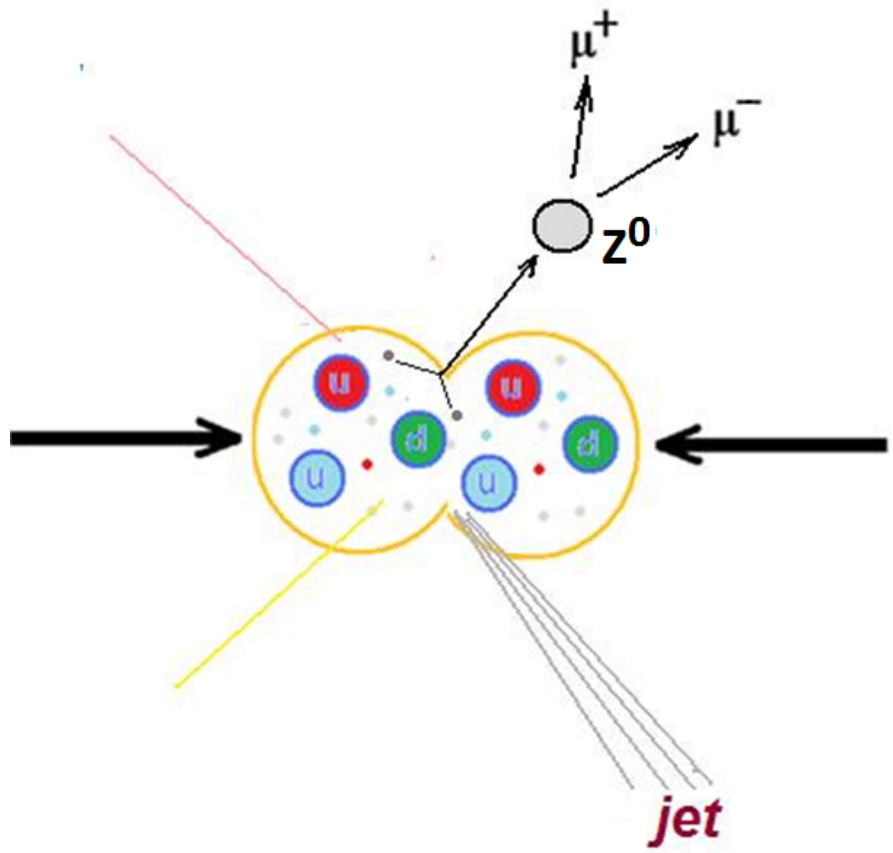
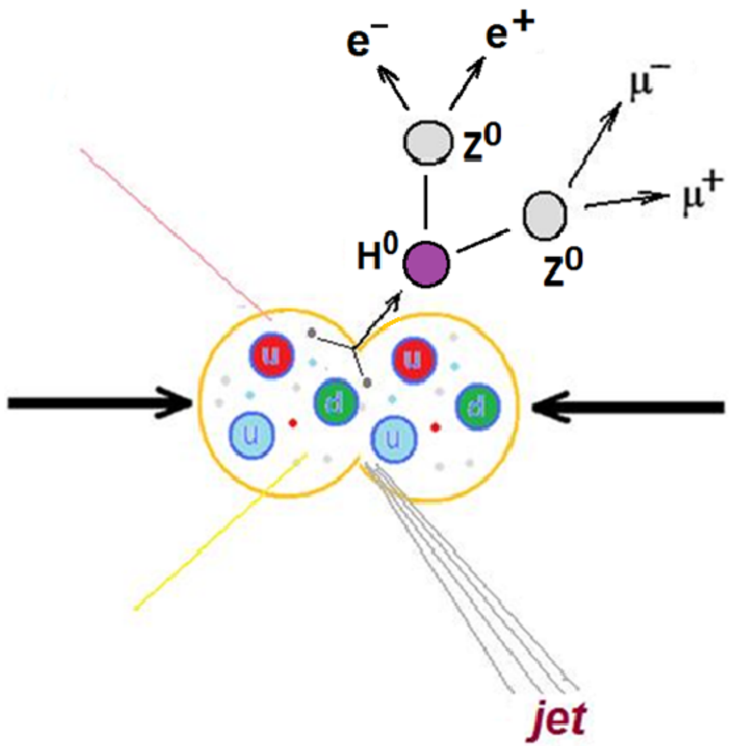


Higgs Particles

The Higgs boson was discovered by CMS and ATLAS and announced on July 4, 2012.

This long-sought particle is part of the “Higgs mechanism” that accounts for other particle having mass.



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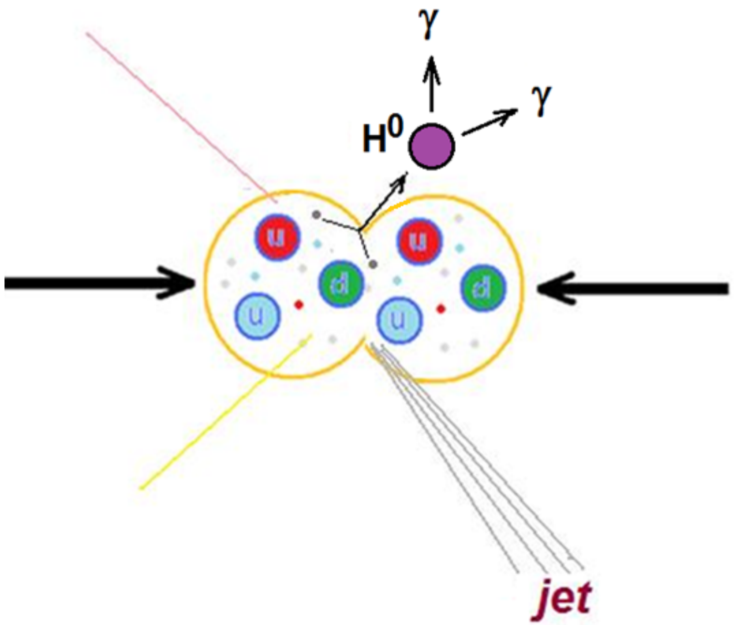
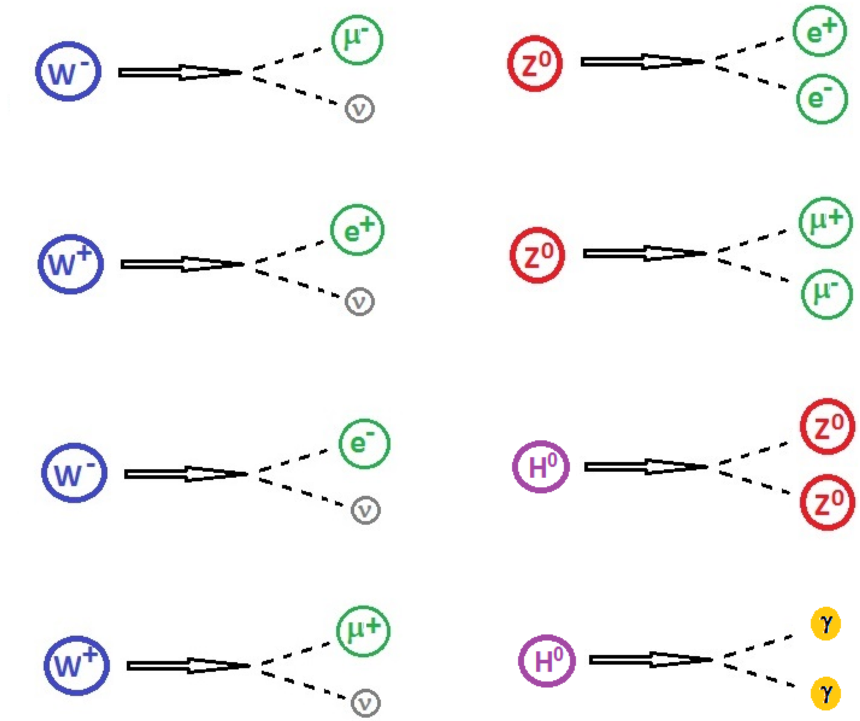


W and Z Decays

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

CMS *can* detect :

- electrons
- muons
- photons



CMS can infer:

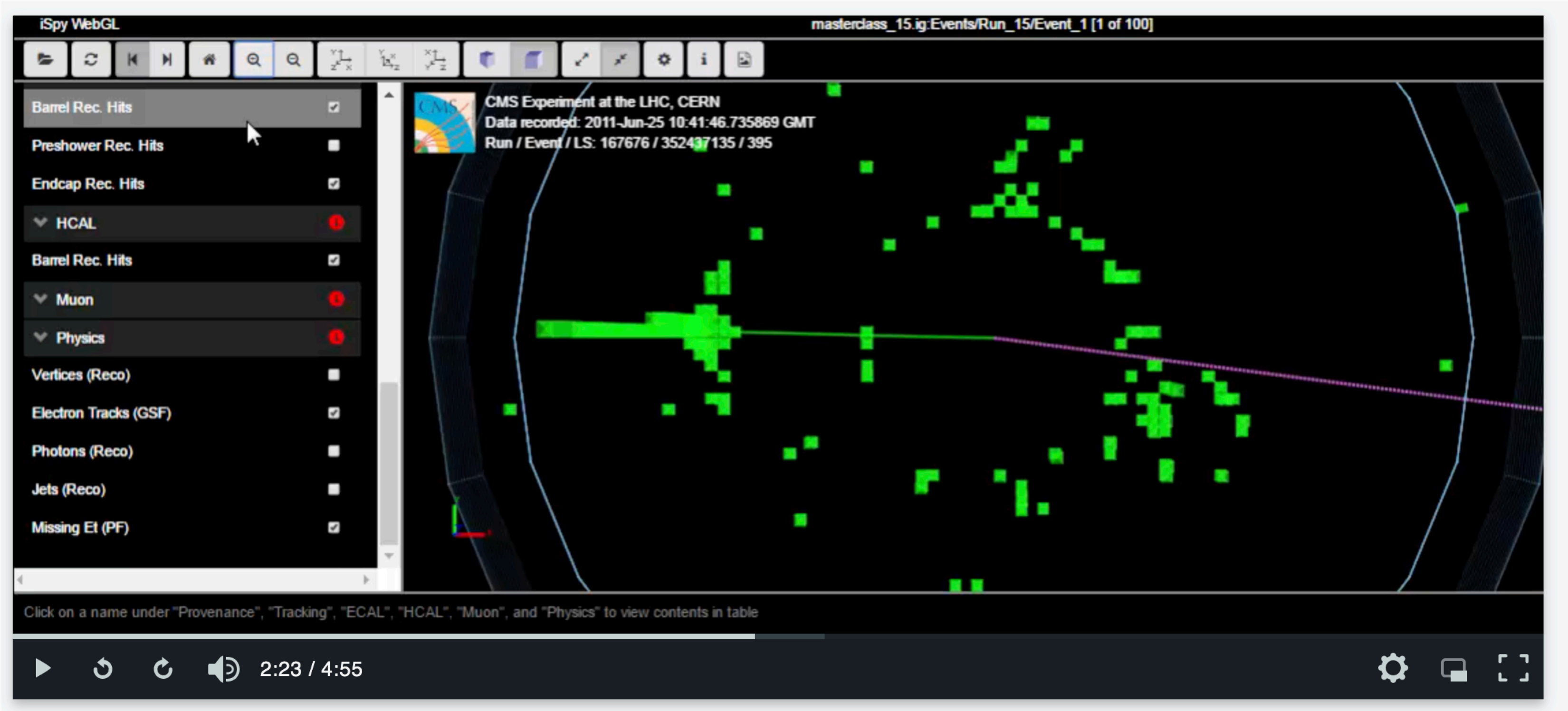
- neutrinos from “missing energy”

Homework

Learning how to identify different particles in the CMS experiment is easy! As preparation for Saturday, when we will actually look at LHC data, please watch the video here:

https://www.screencast.com/t/SLQyyXy8

All slides from today, links to the ZOOM room, and extra videos you can find here: https://indico.iihe.ac.be/event/1450/

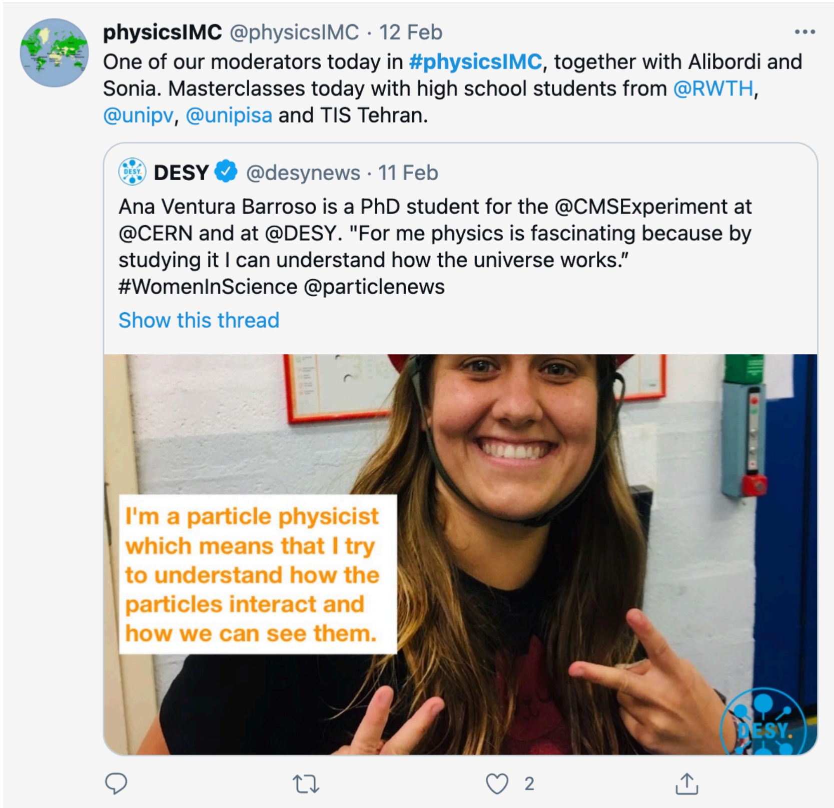


Social media

Social media is an important part of our life. International Masterclasses are on Social Media.

- Our hashtag is #physicsIMC.
- Use it on your social media channels, Twitter or Instagram and communicate your Masterclass experience to the world!

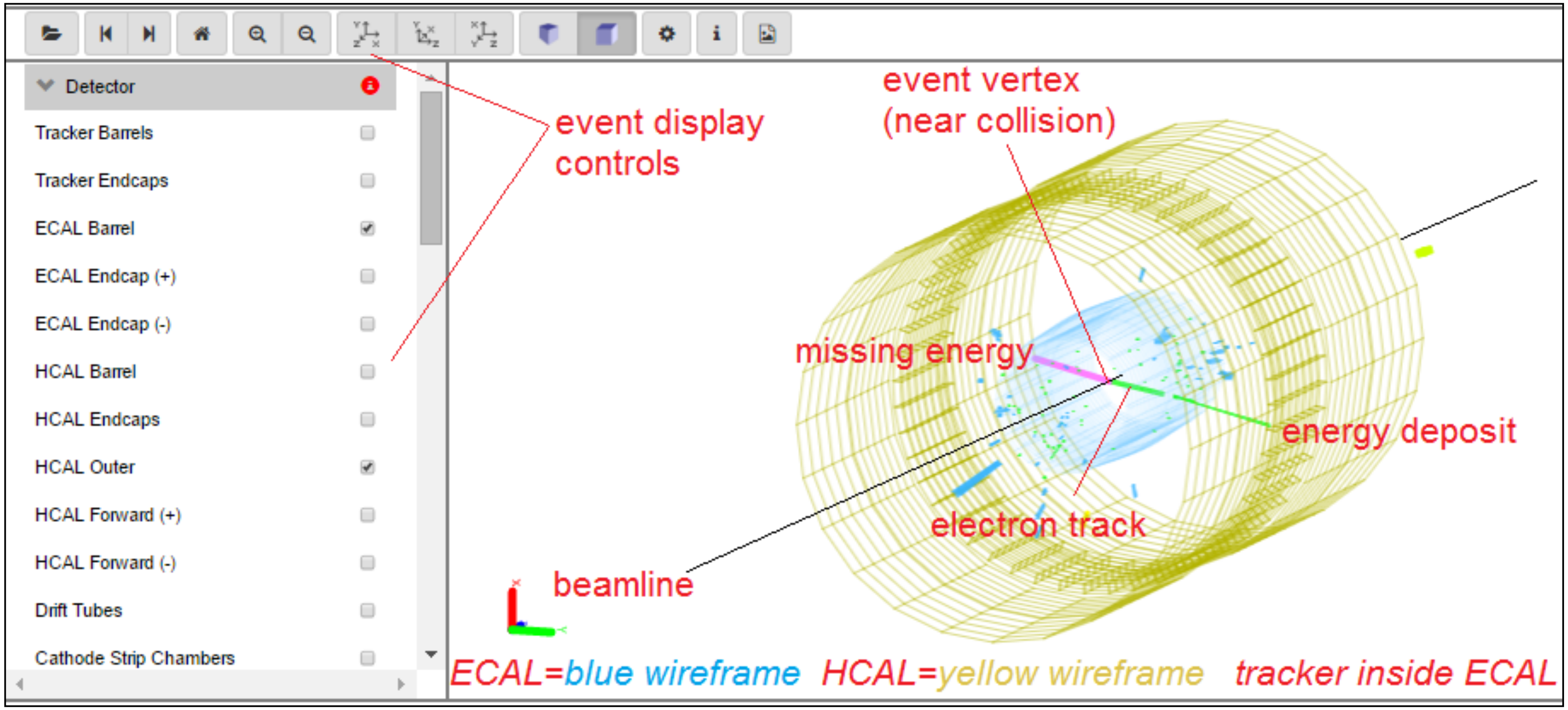
- The organisers welcome, follow and will share your photos and posts if appropriate! Note: Before putting someone's picture online, always ask them.
- Bonus homework: you are totally encouraged to make your own #physicsIMC meme, tiktok, video, story, etc



For Saturday 20 February

The following slides will be discussed on 20 February

iSpy-webgl

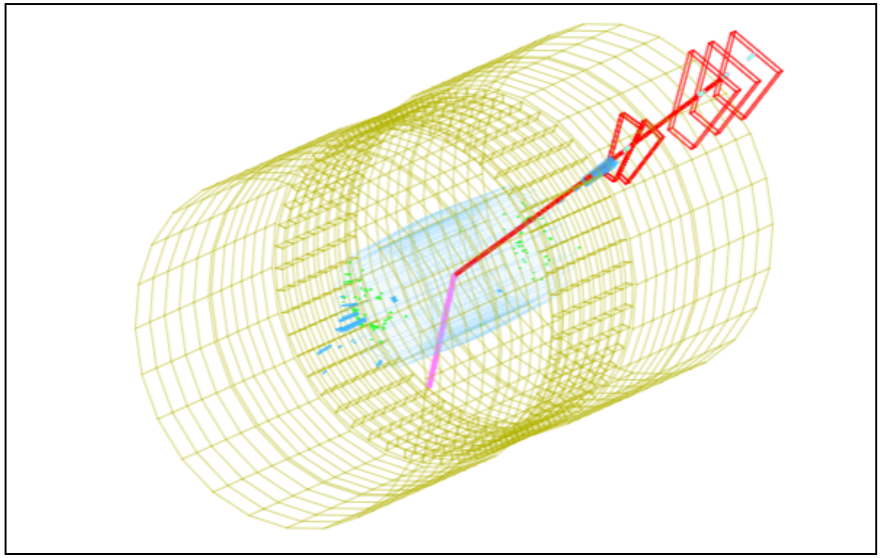


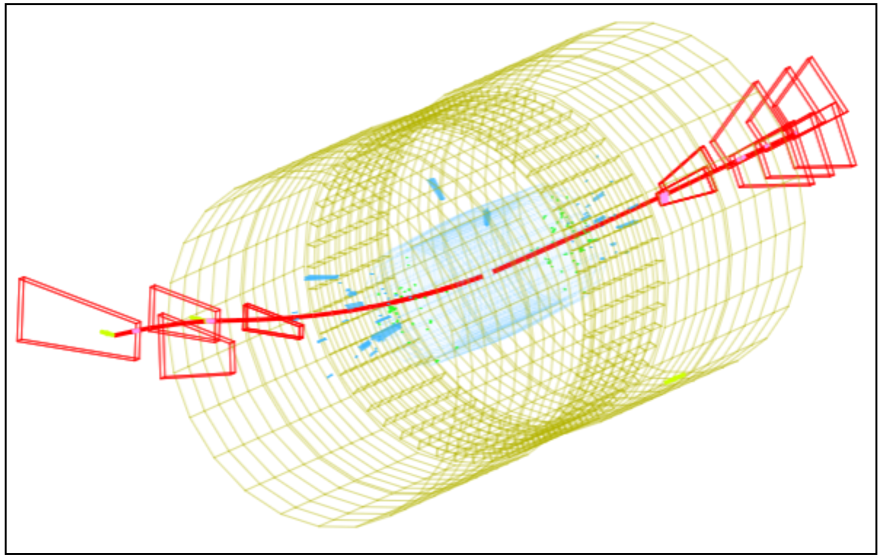
Detector
Tracker Barrels
Tracker Endcaps
ECAL Barrel
ECAL Endcap (+)
ECAL Endcap (-)
HCAL Barrel
HCAL Endcaps
HCAL Outer
HCAL Forward (+)
HCAL Forward (-)
Drift Tubes
Cathode Strip Chambers
event display controls
event vertex (near collision)
missing energy
energy deposit
electron track
beamline
ECAL=blue wireframe HCAL=yellow wireframe tracker inside ECAL

Today's Task

Use new data from the LHC in iSpy to test performance of CMS:

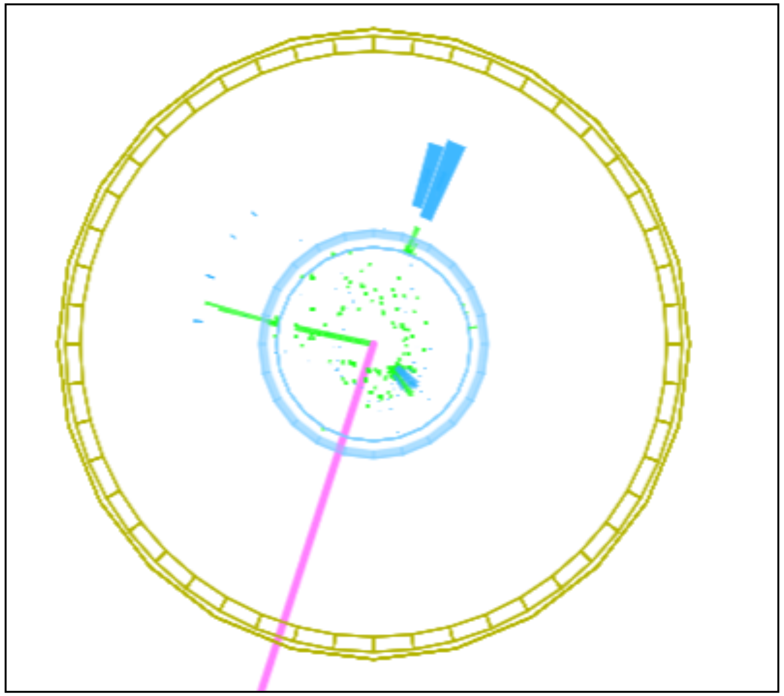
- Can we distinguish W from Z candidates?

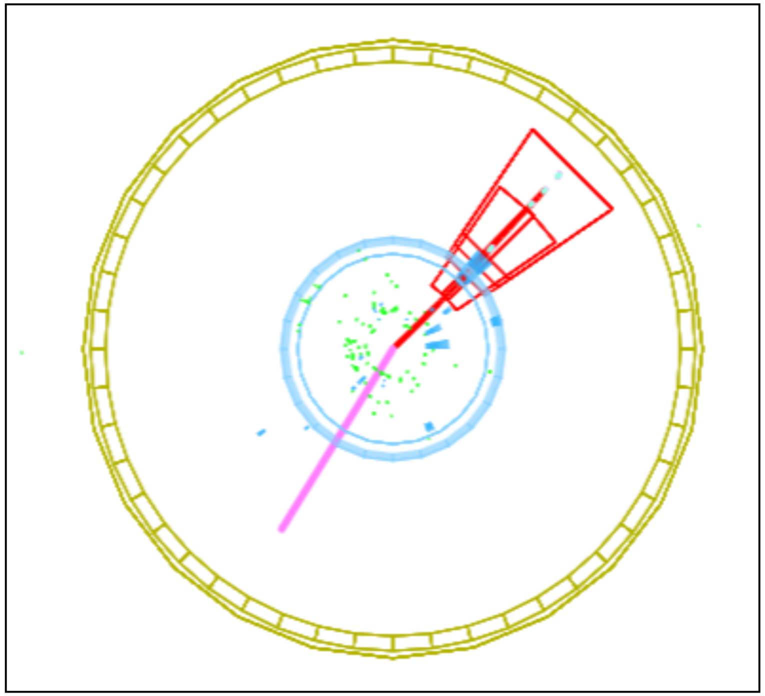




Today's Task

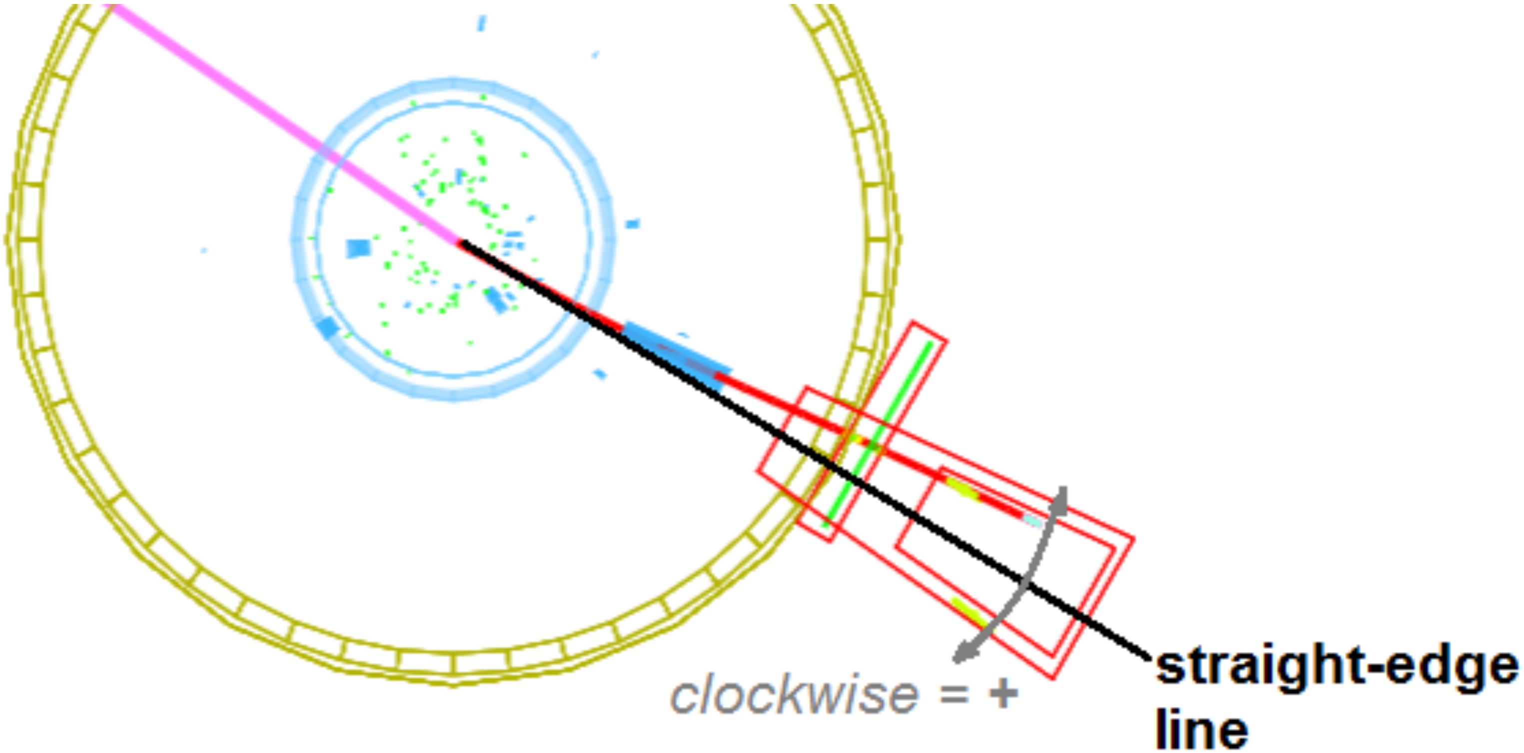
- Can we calculate the e/μ ratio?





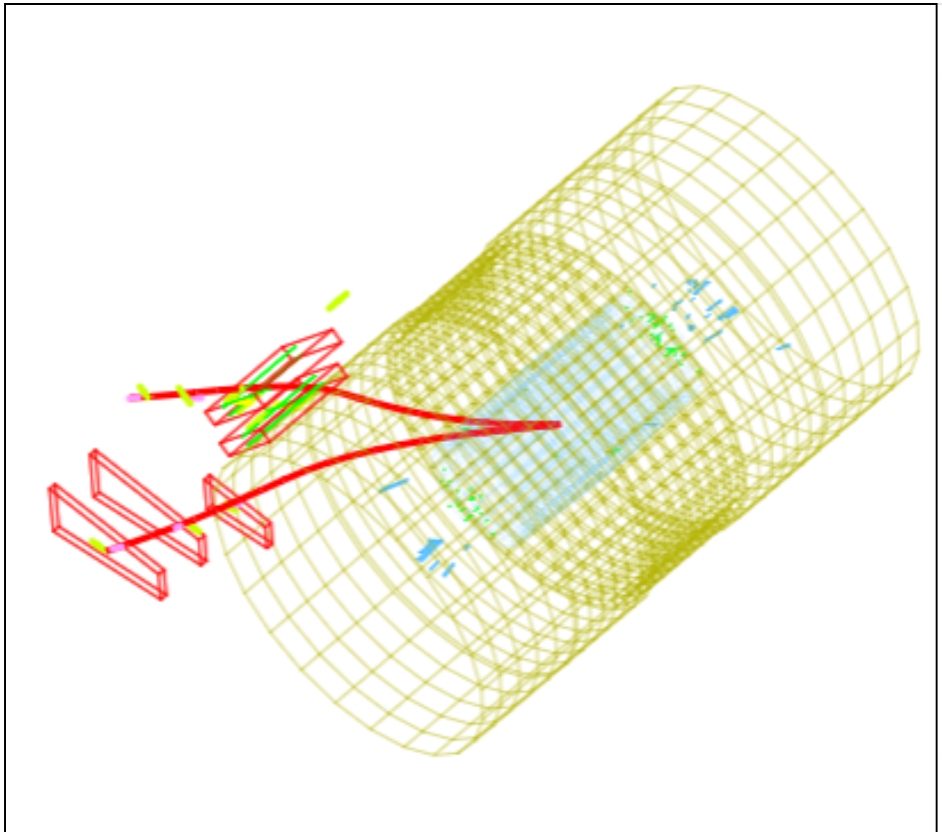
Today's Task

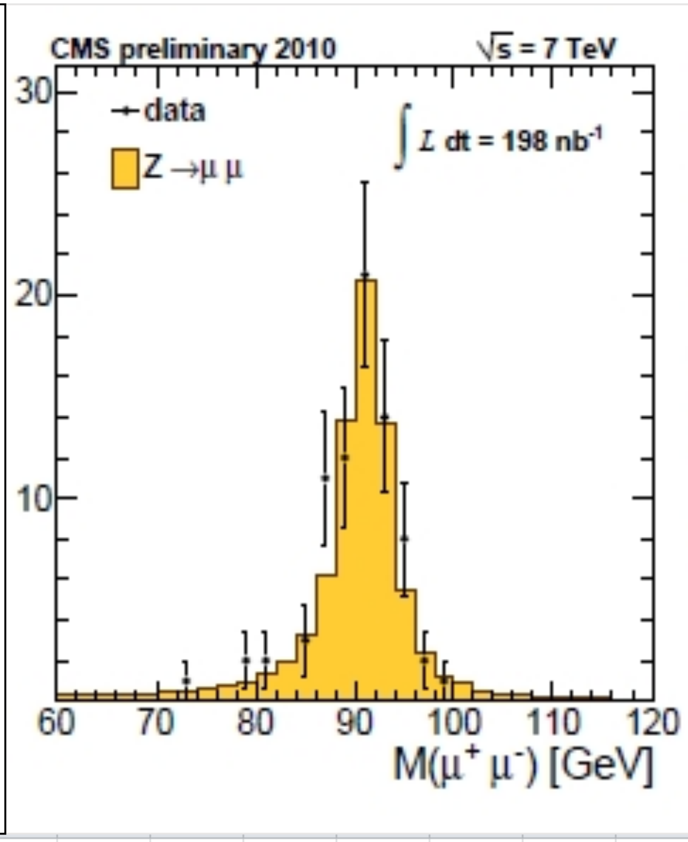
- Can we calculate a W+/W- ratio for CMS?



Today's Task

- Can we make mass plot of Z candidates?





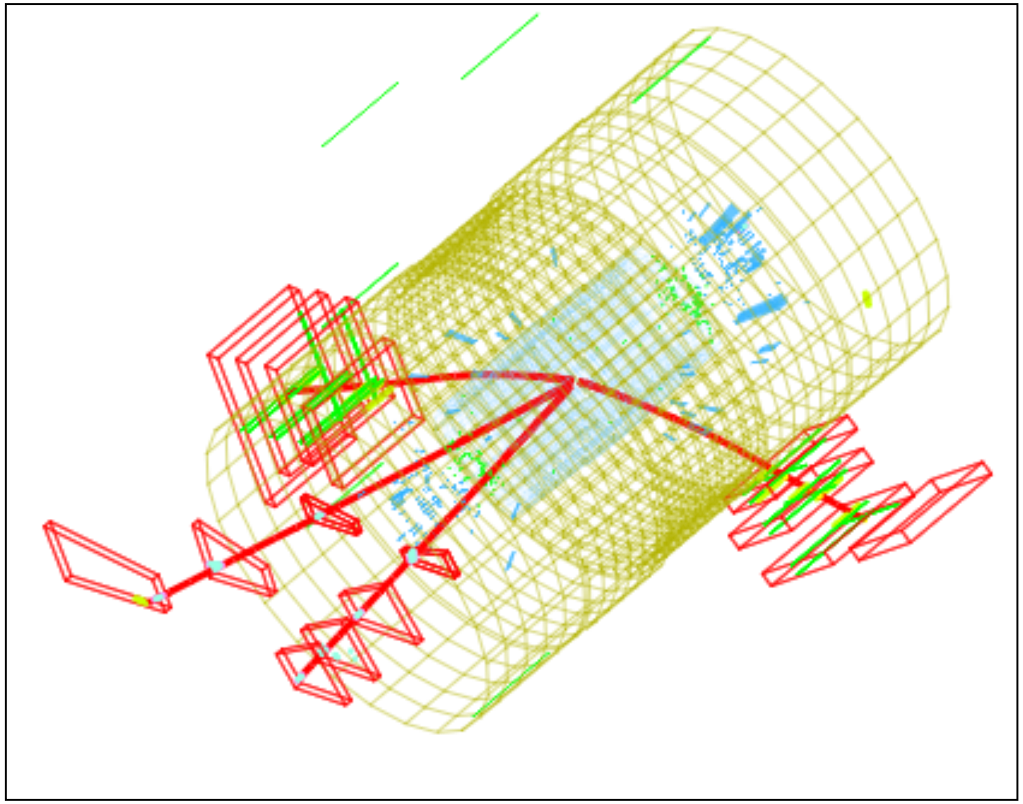
EvNo	E1	px1	py1	pz1	pt1	eta1	phi1	Q1	E2	px2	py2	pz2	pt2	eta2	phi2	Q2	M
128943239	72.89895	13.36098	-26.087	66.74727	29.3095	1.5612	-1.09746	1	37.6277	-10.9181	35.80517	-3.82334	37.3966	-0.10197	1.86677	-1	90.31227

Today's Task

- Can we find rare collisions, like H→ZZ events?
  - Z → e+e-
  - Z → μ+μ-

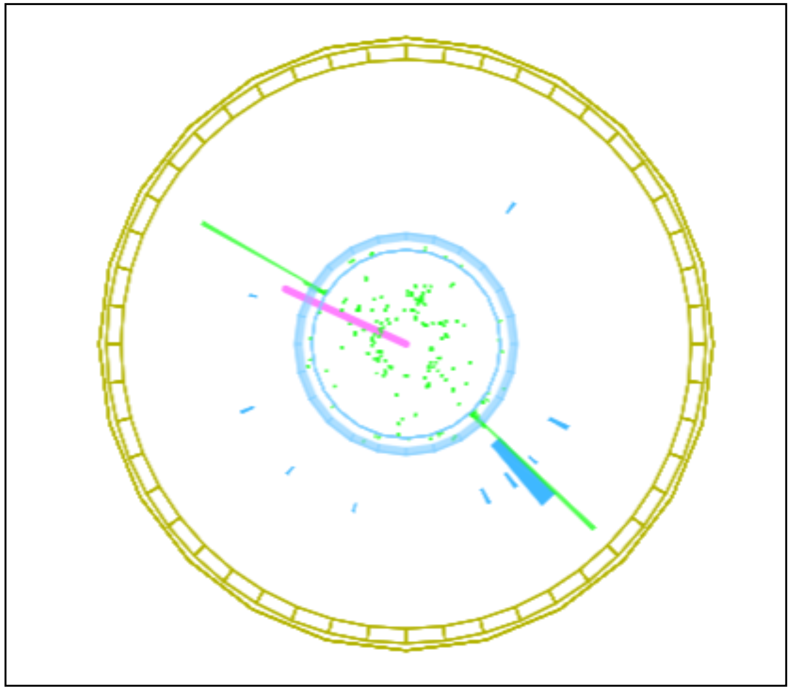
Can we pick out electrons and/or muons?

How should an event be filtered so we can recognize the correct tracks?



Today's Task

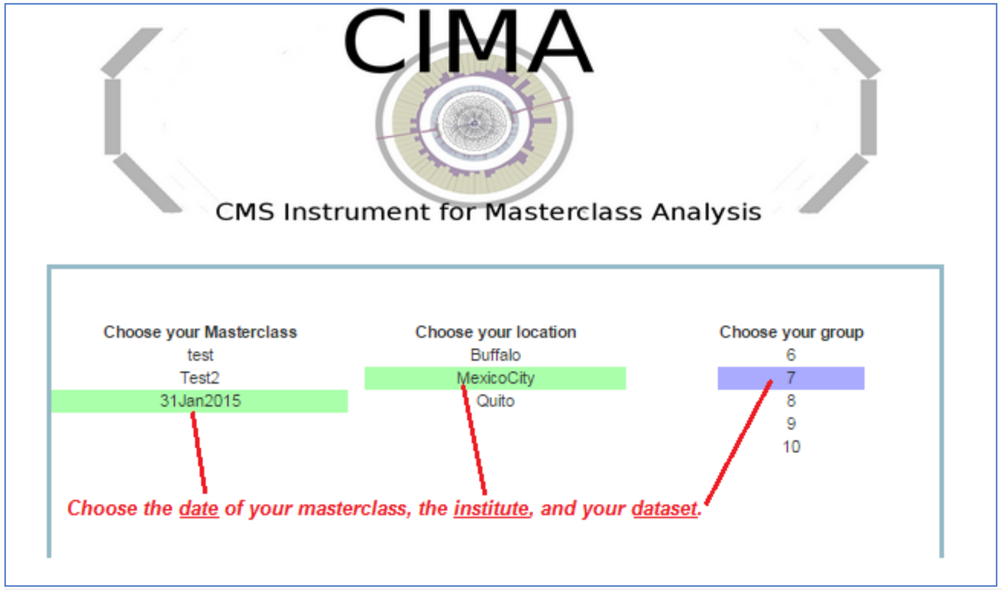
- Can we find some H→γγ events?



How do we spot photons that leave no track?

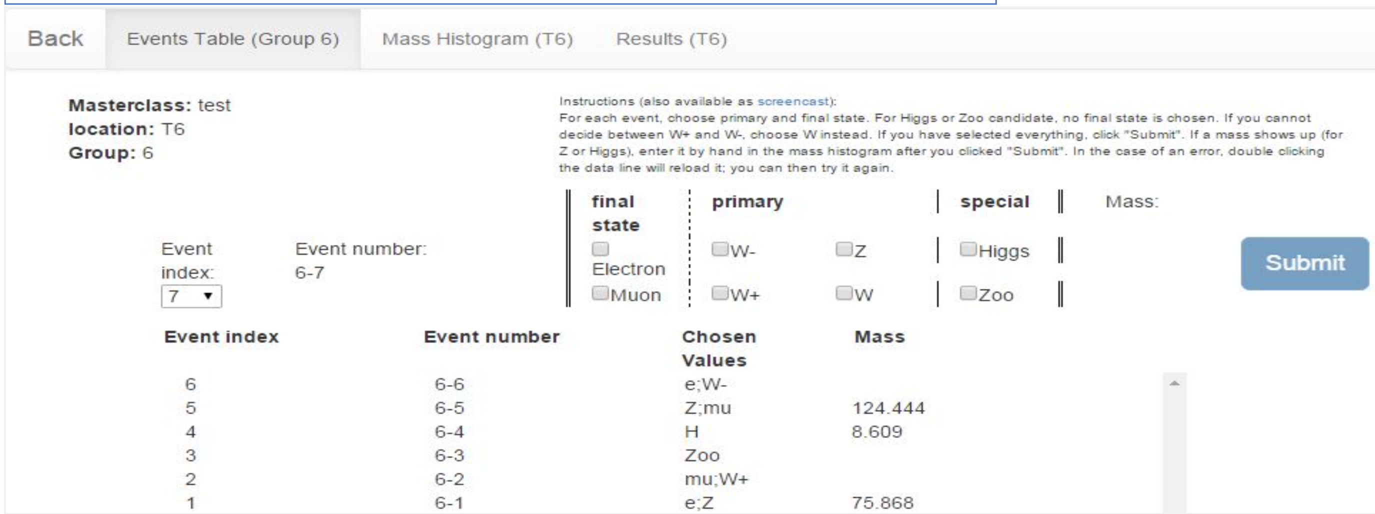
Where should we look? What should we see – and not see?

Recording event data



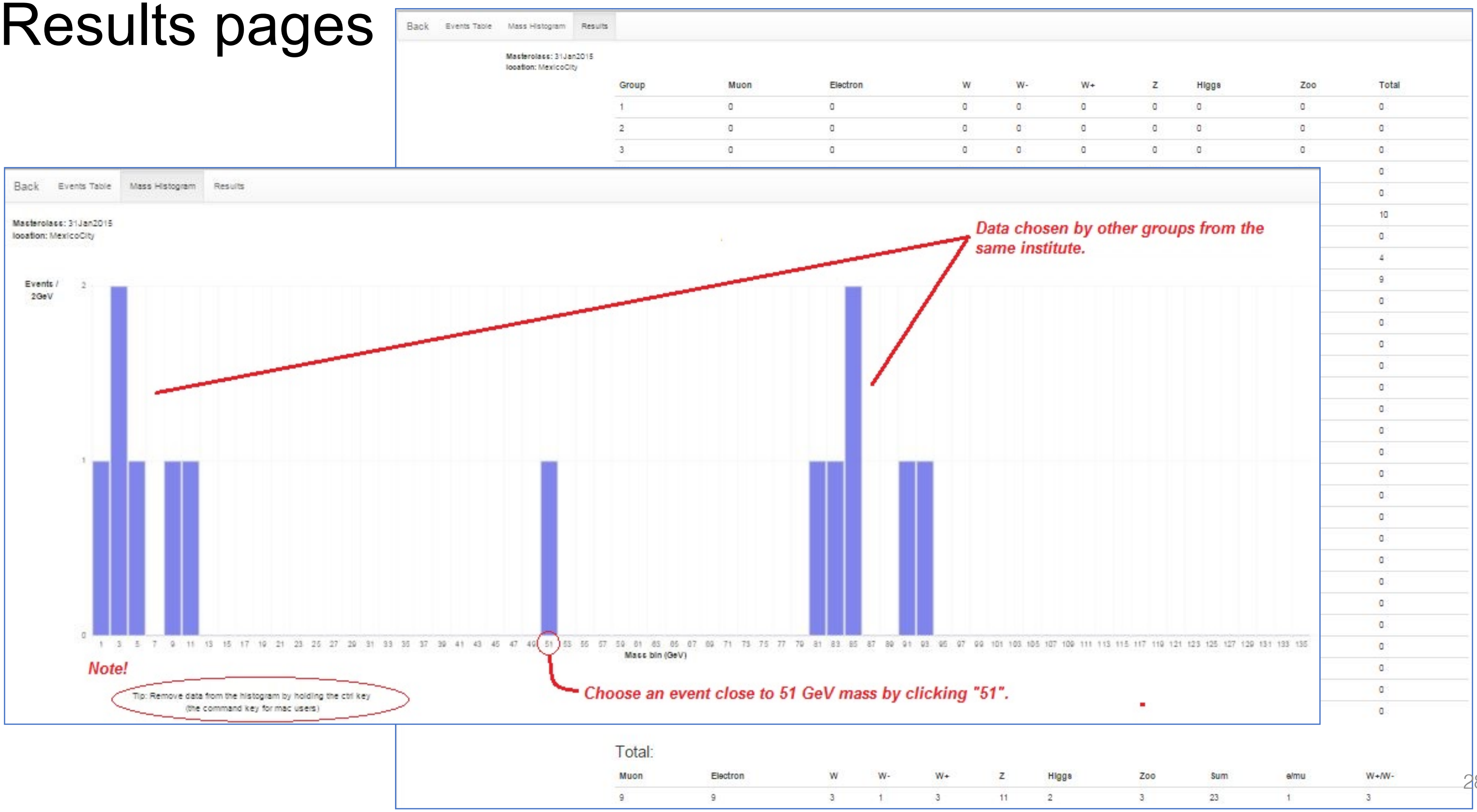
Find your dataset.

Record parent particles and decay modes.



Recording event data

Mass Histogram and Results pages



Keep in Mind . . .

"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.

Everyone analyzes 100 events.

Talk with physicists about interpreting events. We will put you in small groups to do this efficiently

After that we will share and combine our results.

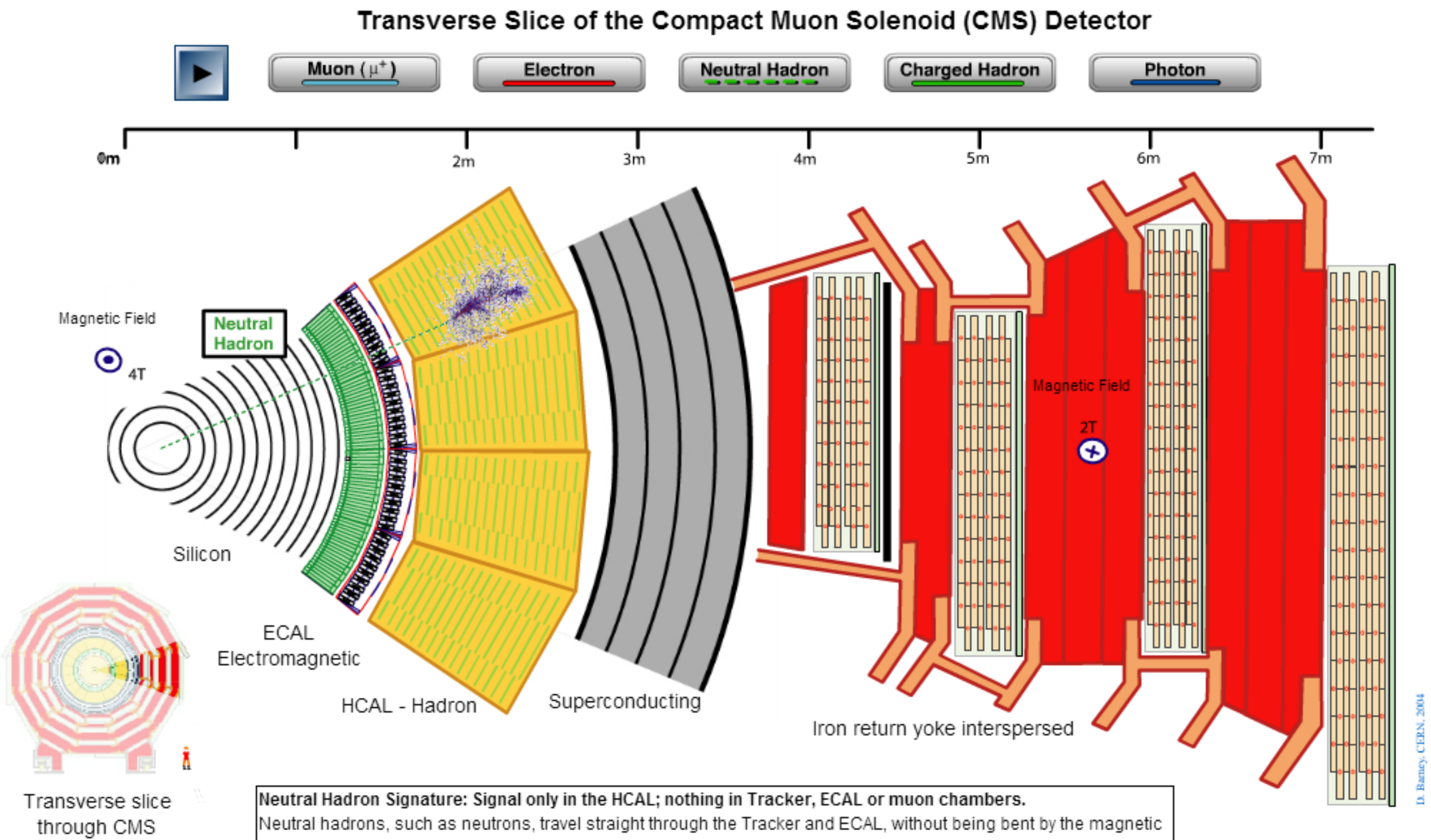
Backup slides with extra information

Helping Develop America's Technological Workforce

QuarkNet

Detector Tracks

Web Version



Neutral Hadron Signature: Signal only in the HCAL; nothing in Tracker, ECAL or muon chambers.
Neutral hadrons, such as neutrons, travel straight through the Tracker and ECAL, without being bent by the magnetic field or leaving any signals. Like charged hadrons, they are slowed to a stop in the HCAL, depositing their energy and leaving signals in the form of light in the plastic scintillators. The amount of light is proportional to the energy of the incoming hadron.

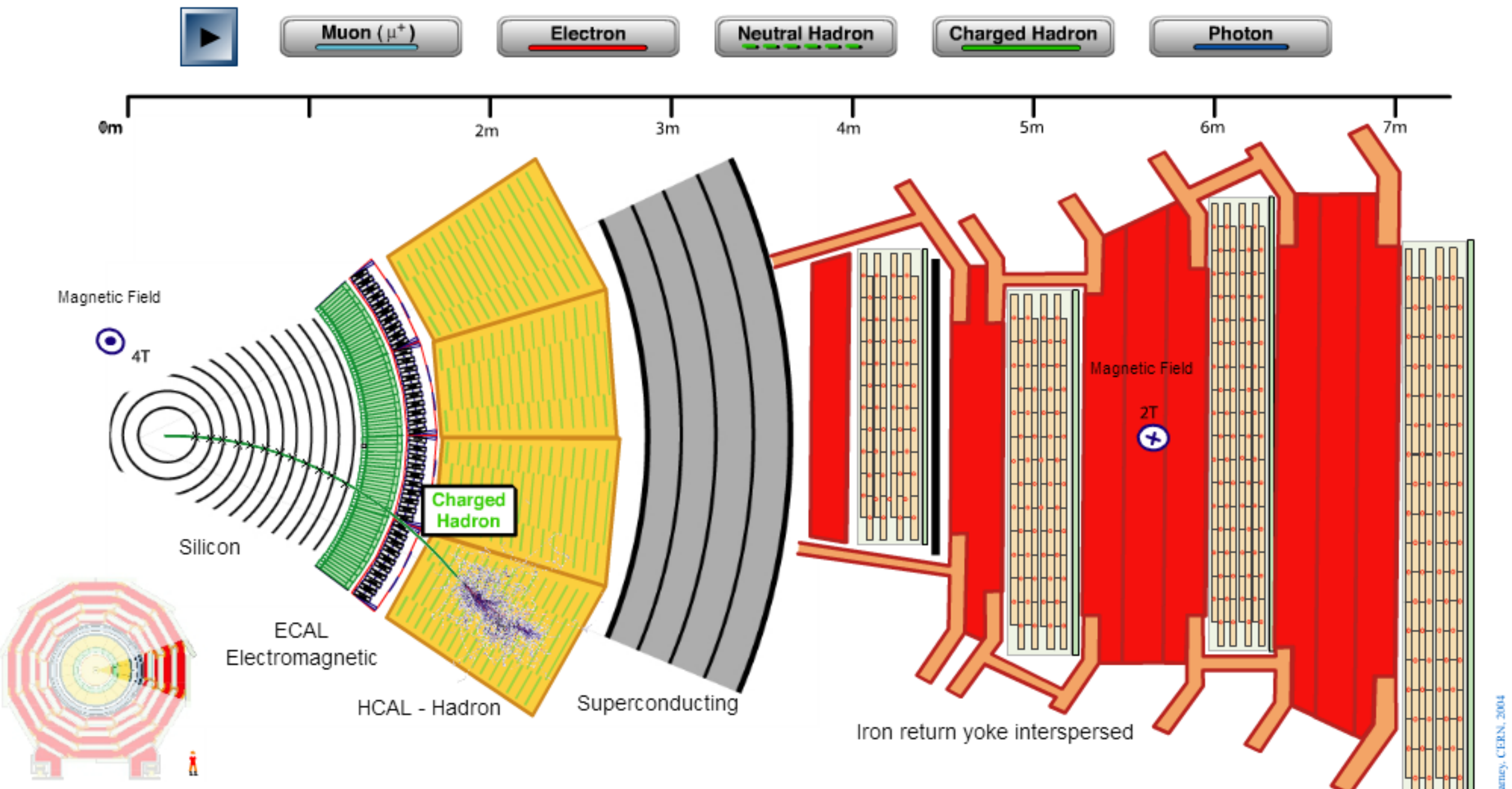
Derived from CMS Detector Slice from CERN

QuarkNet

Detector Tracks

Web Version

Transverse Slice of the Compact Muon Solenoid (CMS) Detector



Transverse slice through CMS

Charged Hadron signature: Signals in the Tracker and HCAL; almost nothing in ECAL and nothing in the muon chambers.
Charged hadrons, such as protons and pi plus or pi minus (made of pairs of quarks), are bent by the magnetic field and travel straight through the ECAL leaving almost no signals. Upon reaching the HCAL they are slowed to a stop by the dense materials, producing showers of secondary particles along the way that in turn produce light in thin layers of plastic **scintillator** material. The amount of light is proportional to the energy of the incoming hadron.

Derived from CMS Detector Slice from CERN