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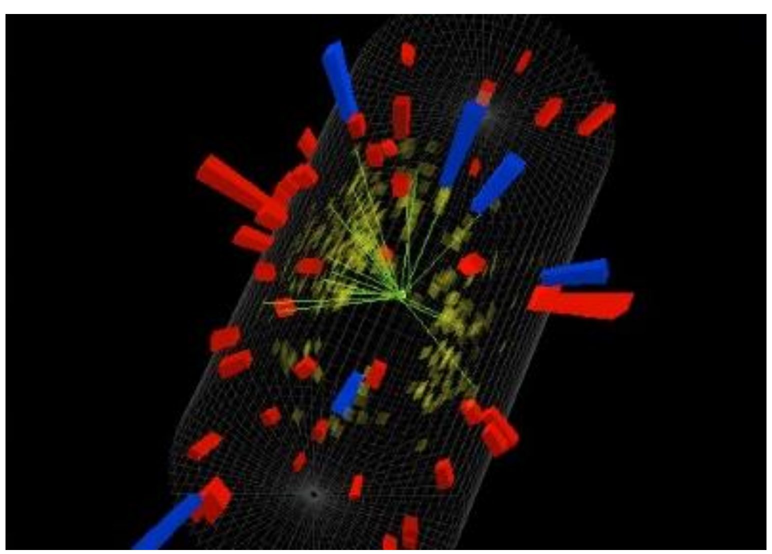
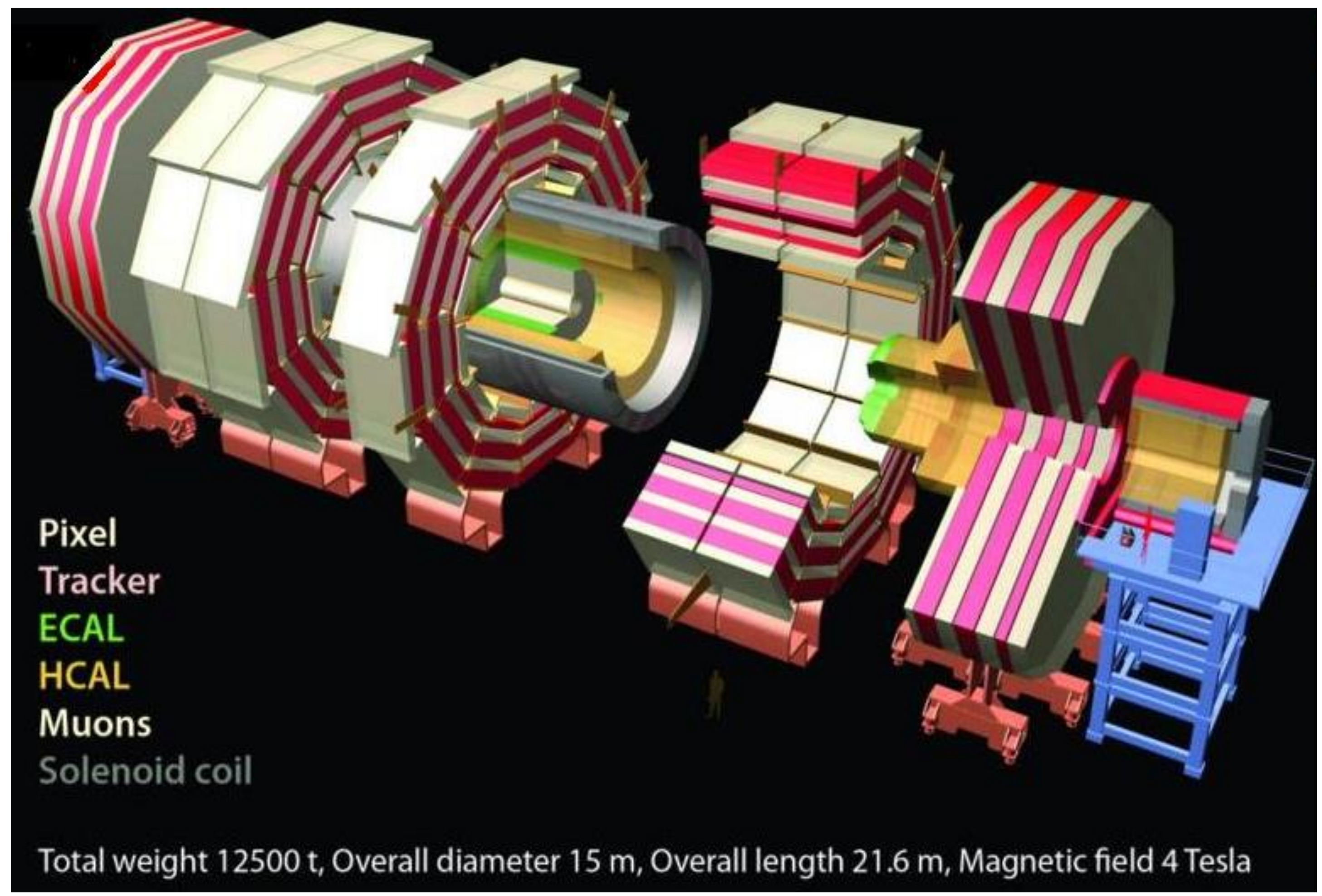
INTERNATIONAL MASTERCLASSES

hands on particle physics

CMS Masterclasses 2017
S'Cool LAB





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The LHC and New Physics

It's a time of exciting new discoveries in particle physics!

At CERN, the LHC succesfully completed Run I at 8 TeV of collision energy, confirming that the measurements correspond well to the ***Standard Model*** *and then finding the Higgs boson. The LHC is now into Run II at an amazing 13 TeV and the task is to look for new phenomena… and we are off to a great start.*

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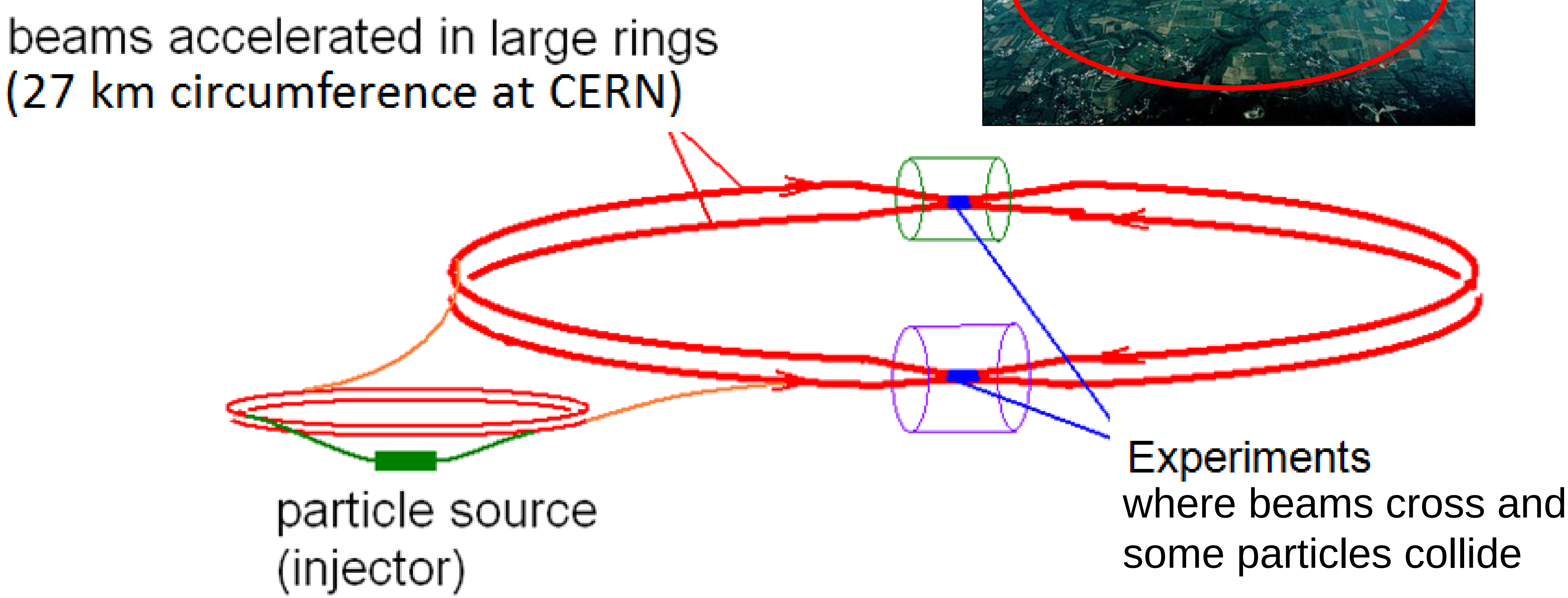
The LHC and New Physics

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



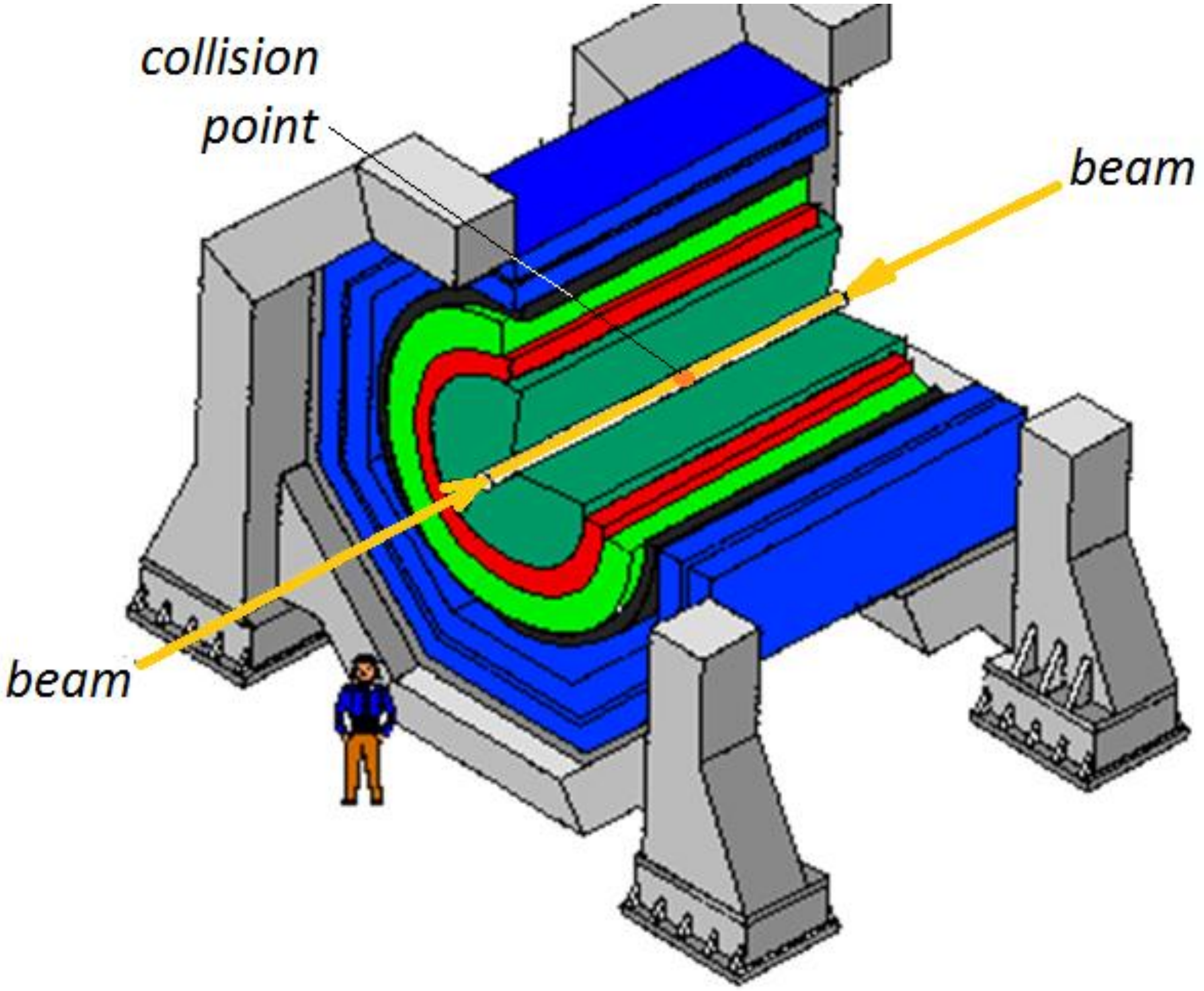
Detector Design

Generic Design

Cylinders wrapped around the beam pipe

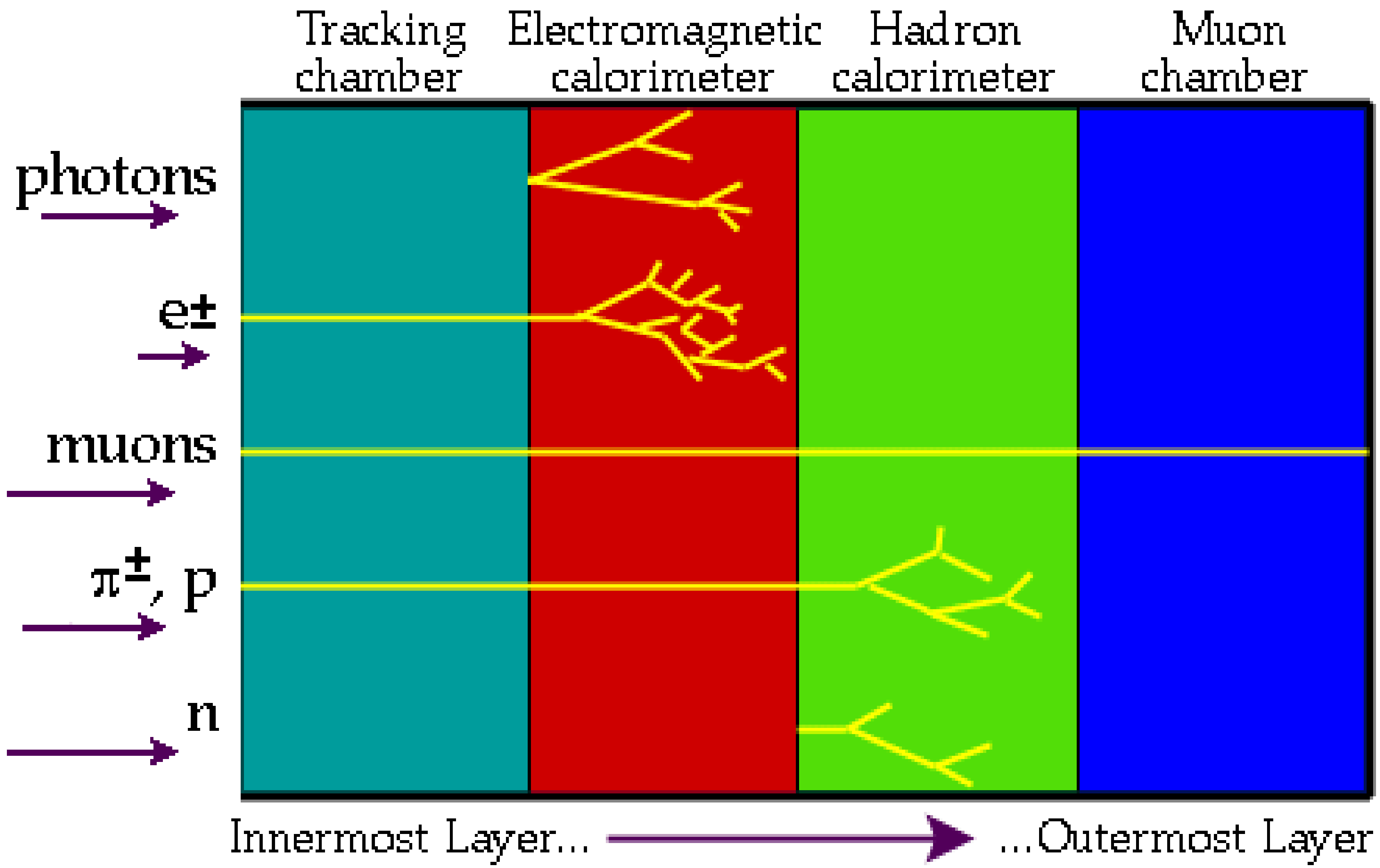
From inner to outer…

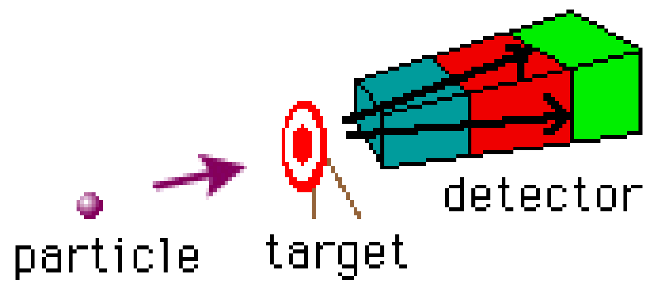
- Tracking
- Electromagnetic calorimeter
- Hadronic calorimeter
- Magnet*
- Muon chamber



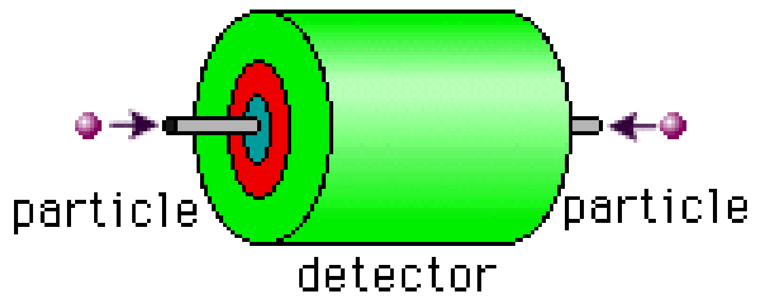
* *Localization of magnet depends of specific detector design*

Detectors





Fixed Target



Collider

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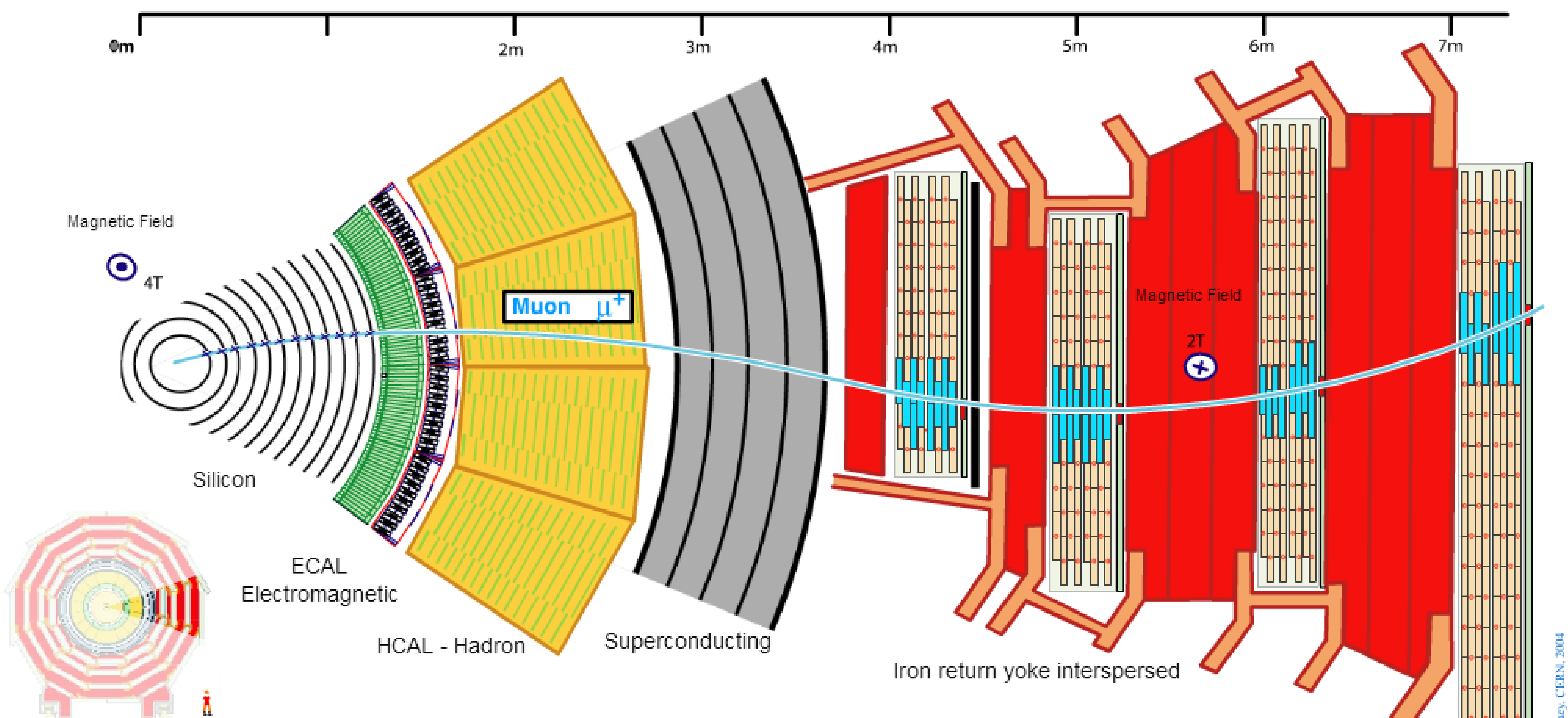
Detector Tracks

Web Version

Transverse Slice of the Compact Muon Solenoid (CMS) Detector

Muon (μ^+) | Electron | Neutral Hadron | Charged Hadron | Photon



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

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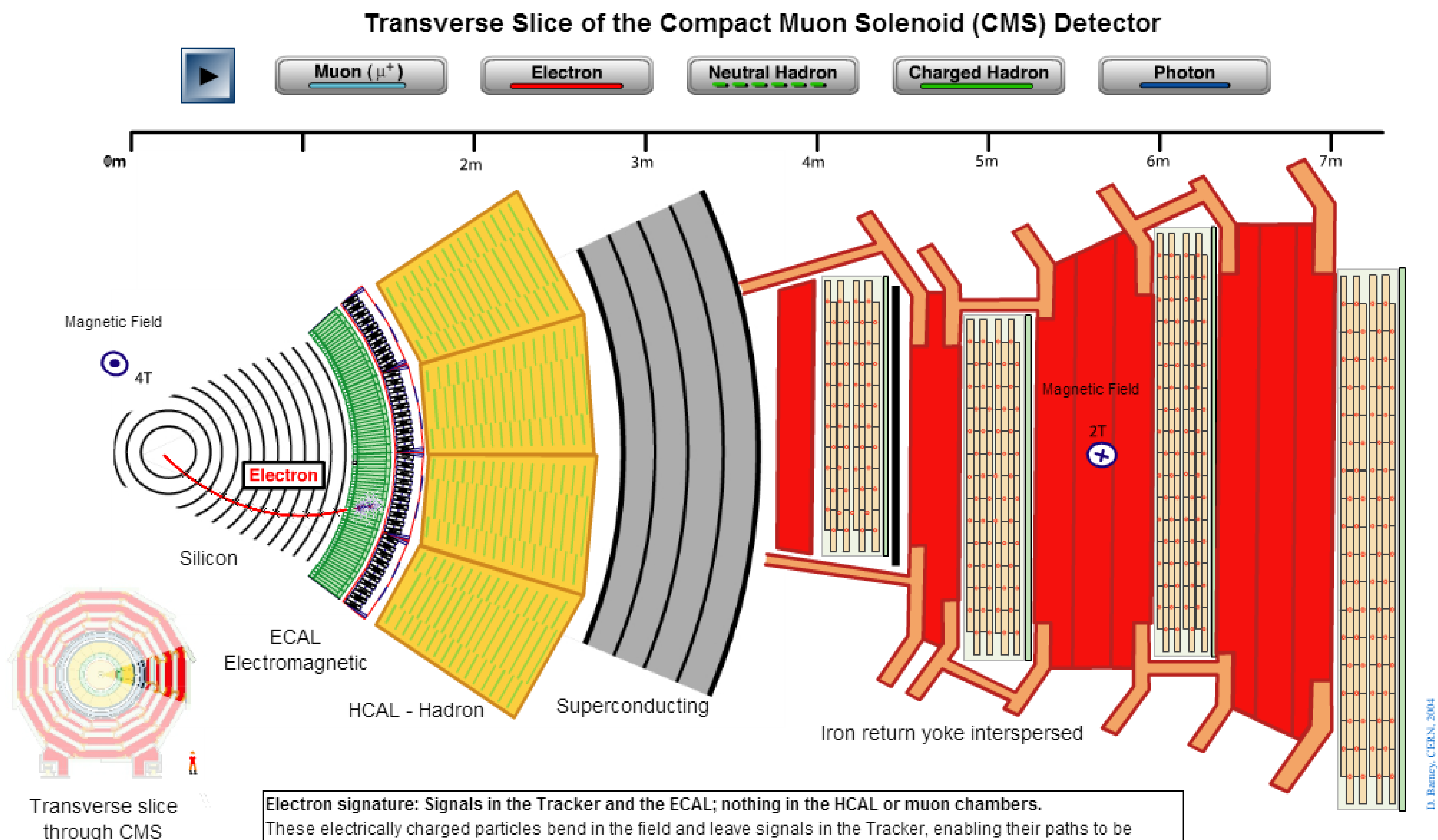
Detector Tracks

Web Version



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

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Detector Tracks

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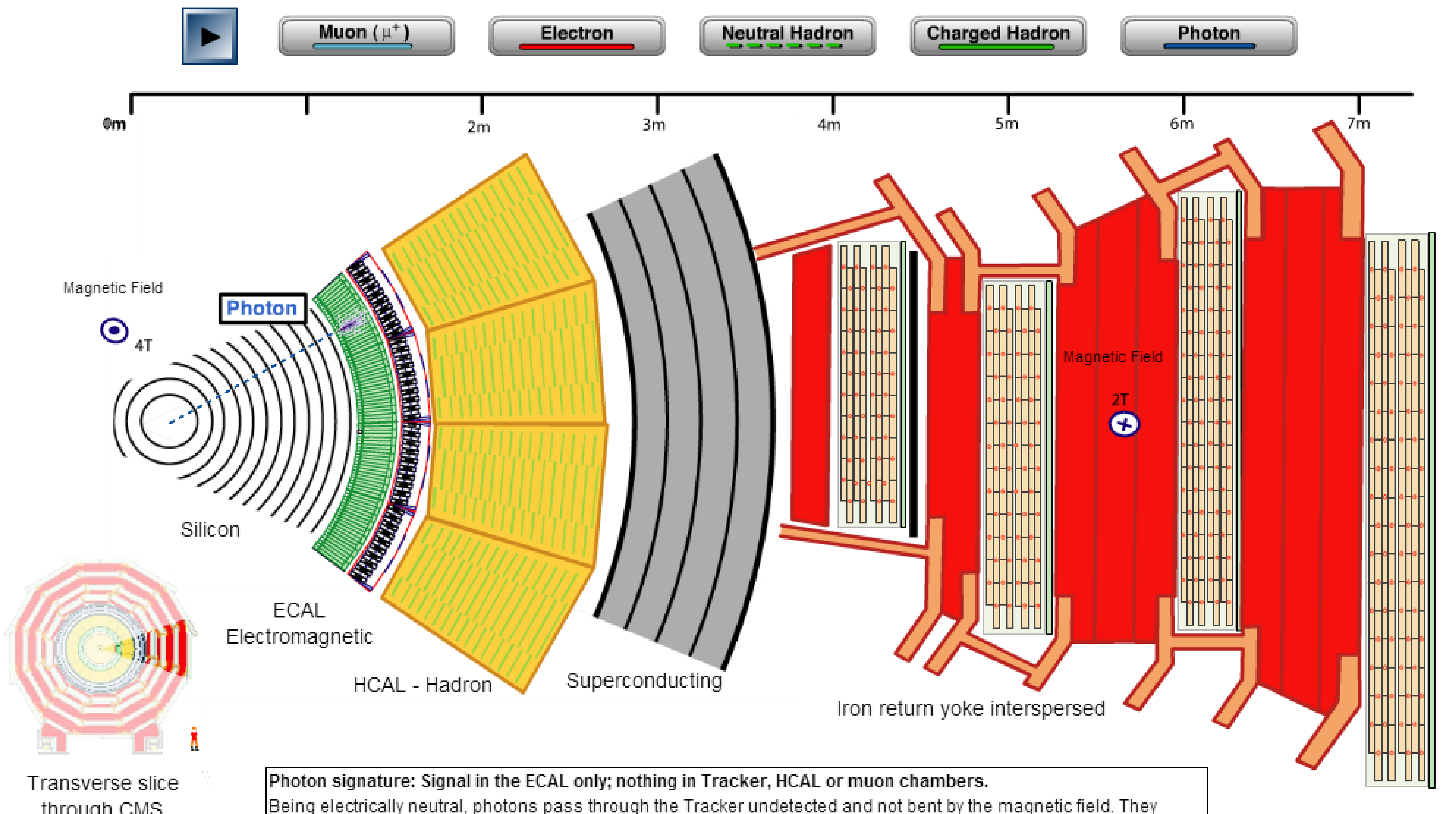
Web Version

Transverse Slice of the Compact Muon Solenoid (CMS) Detector



Photon signature: Signal in the ECAL only; nothing in Tracker, HCAL or muon chambers.
Being electrically neutral, photons pass through the Tracker undetected and not bent by the magnetic field. They interact in the ECAL in a similar way to electrons, producing electromagnetic showers that leave their energies in the form of light that is detected.

Derived from CMS Detector Slice from CERN

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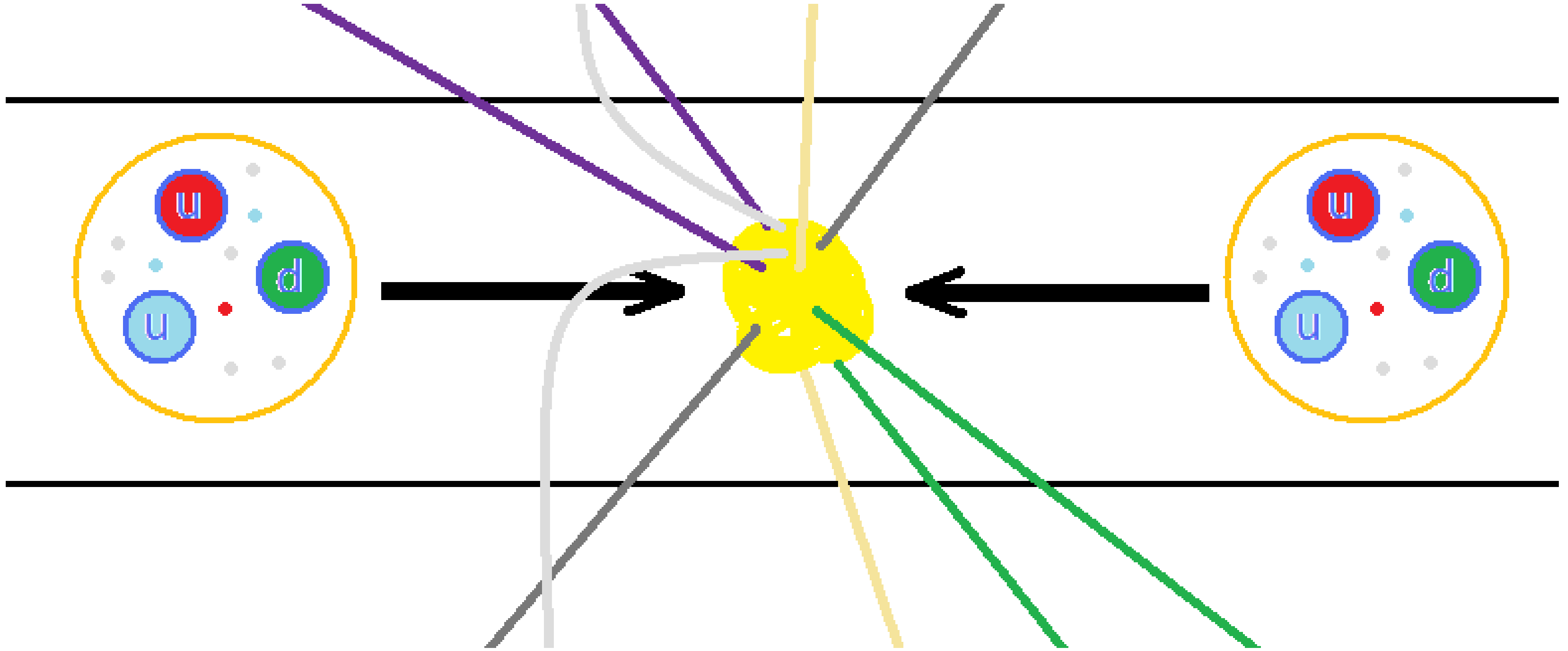
Energy & Particle Mass

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!*



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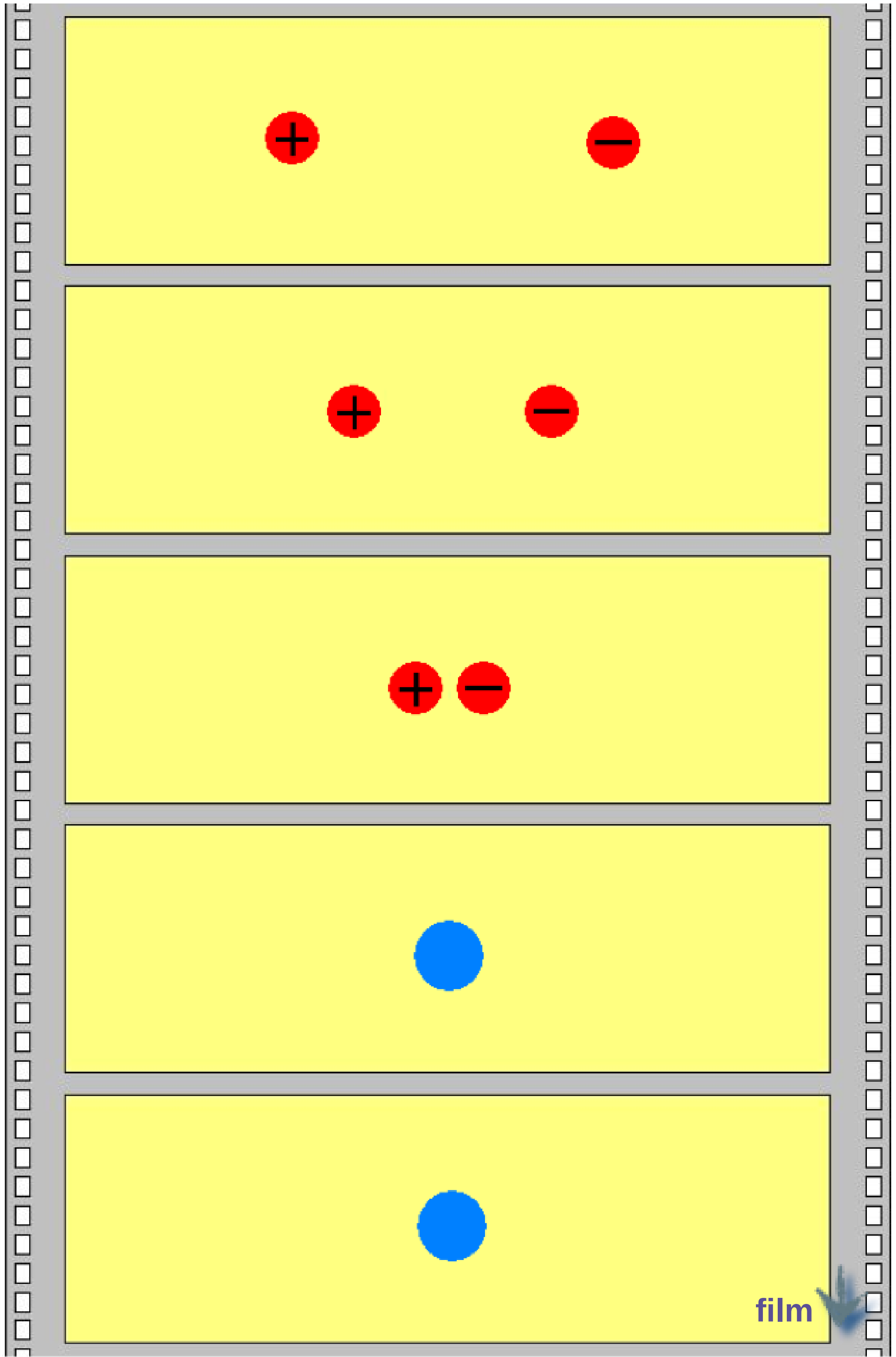
Particle Decays

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.

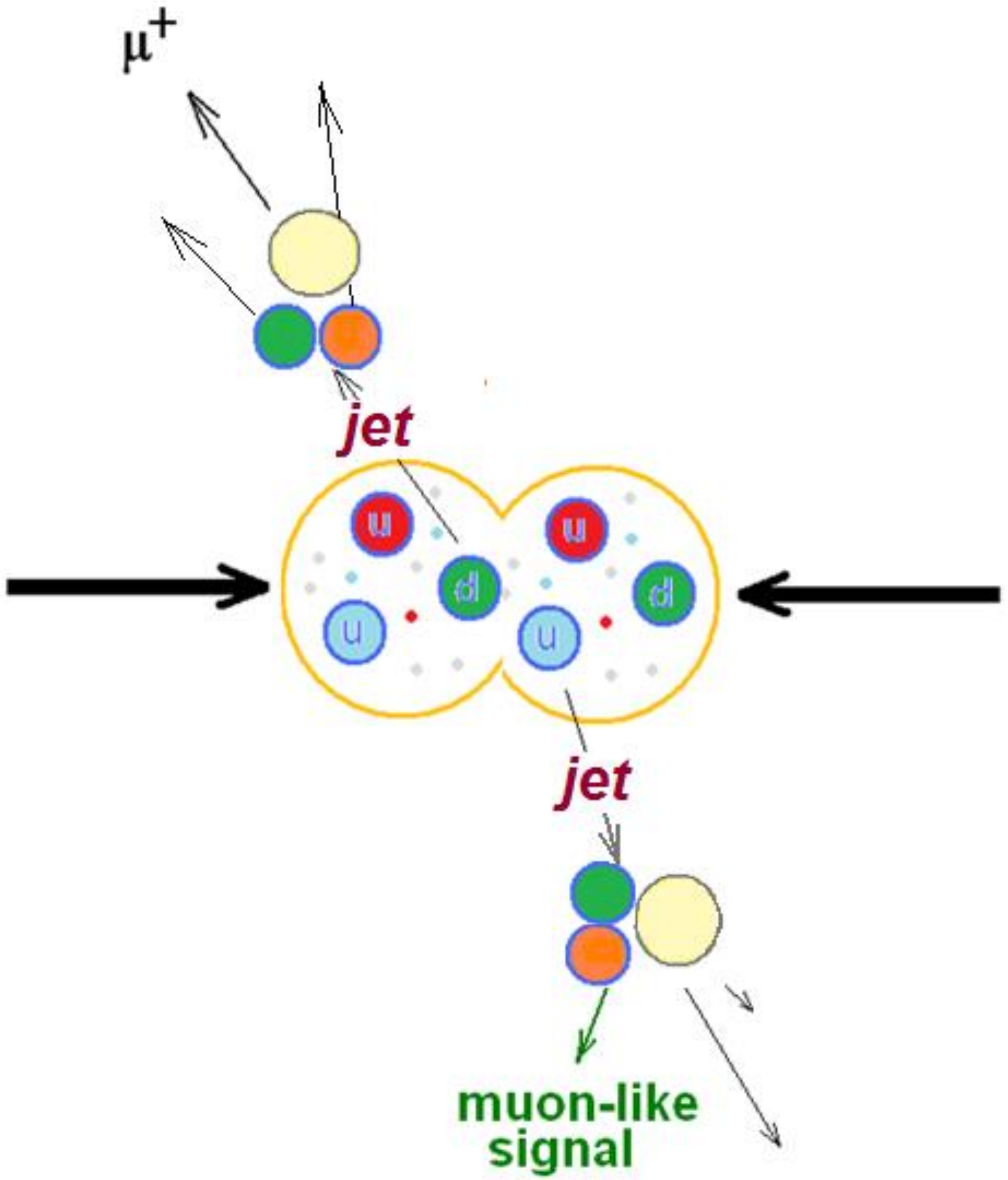


Background Events

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.



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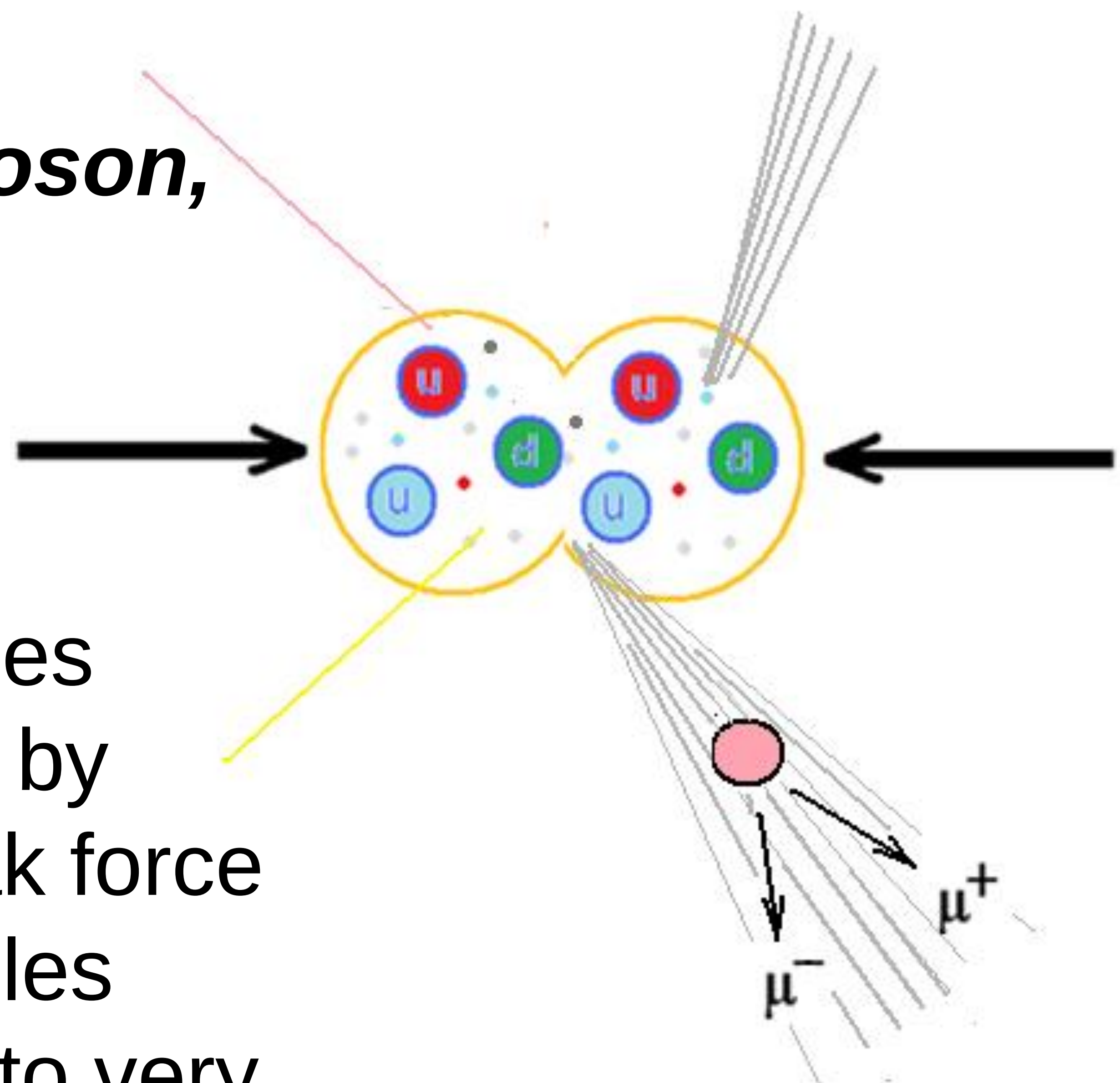
W and Z Particles

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.

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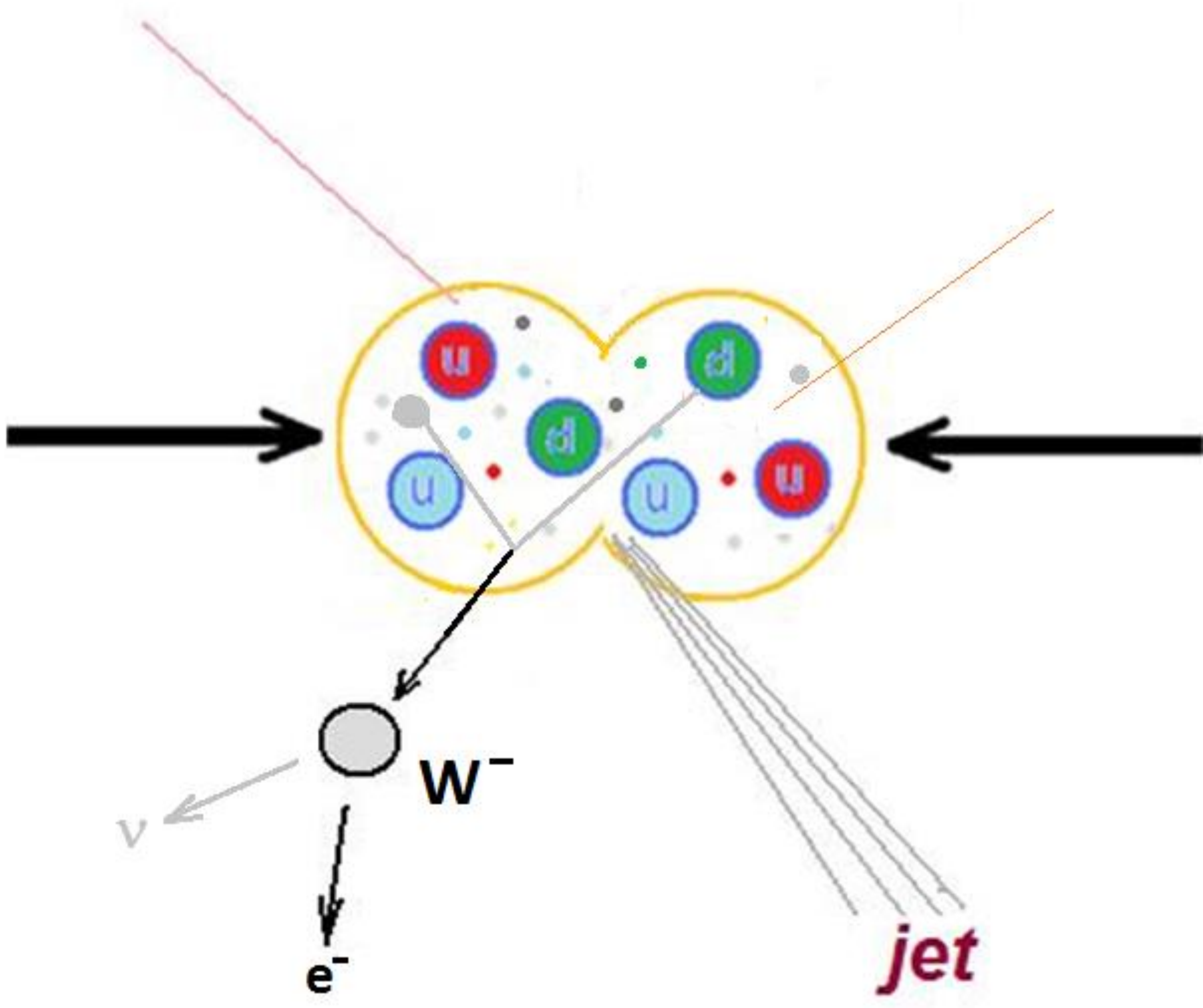
W and Z Particles

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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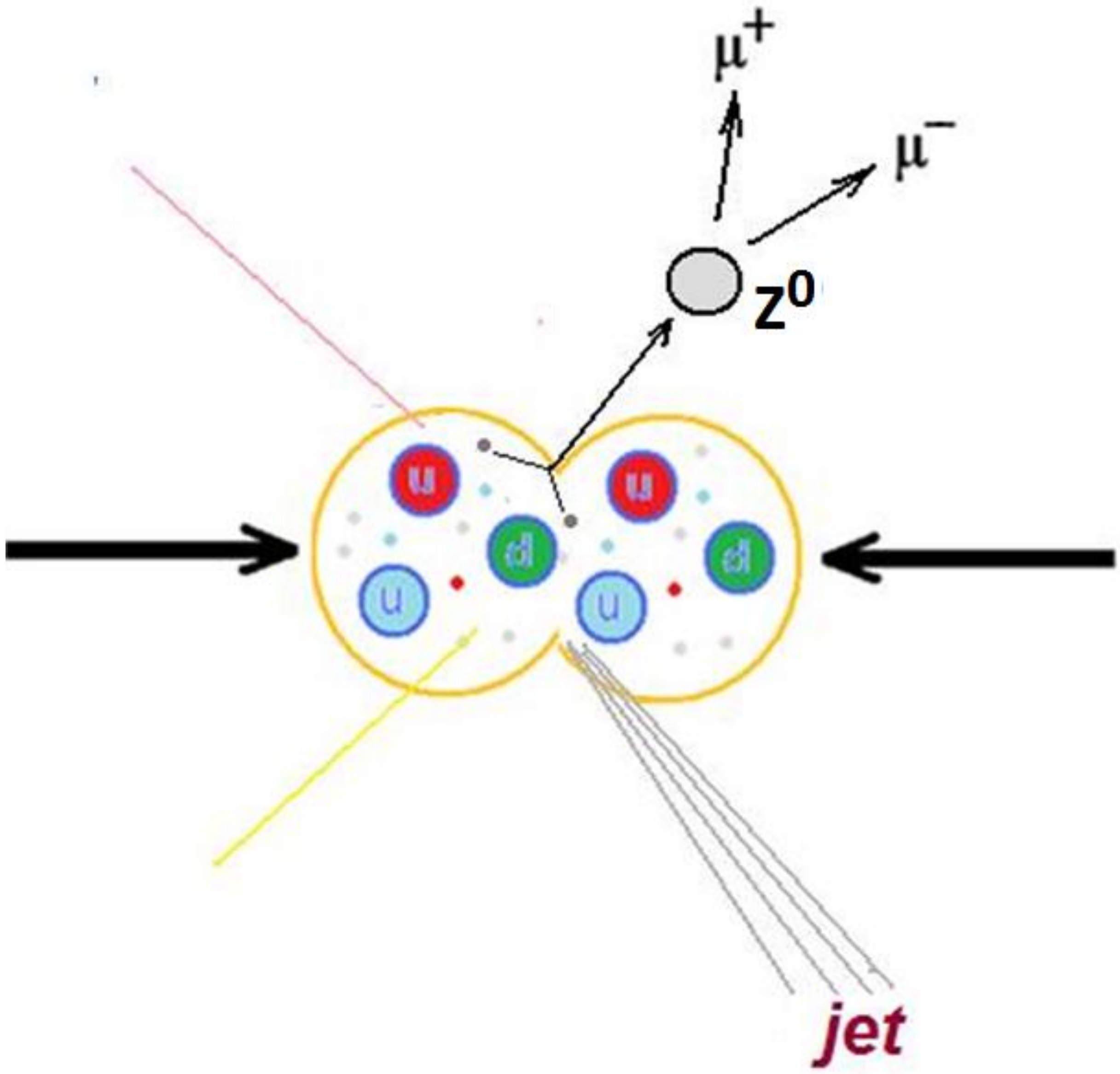
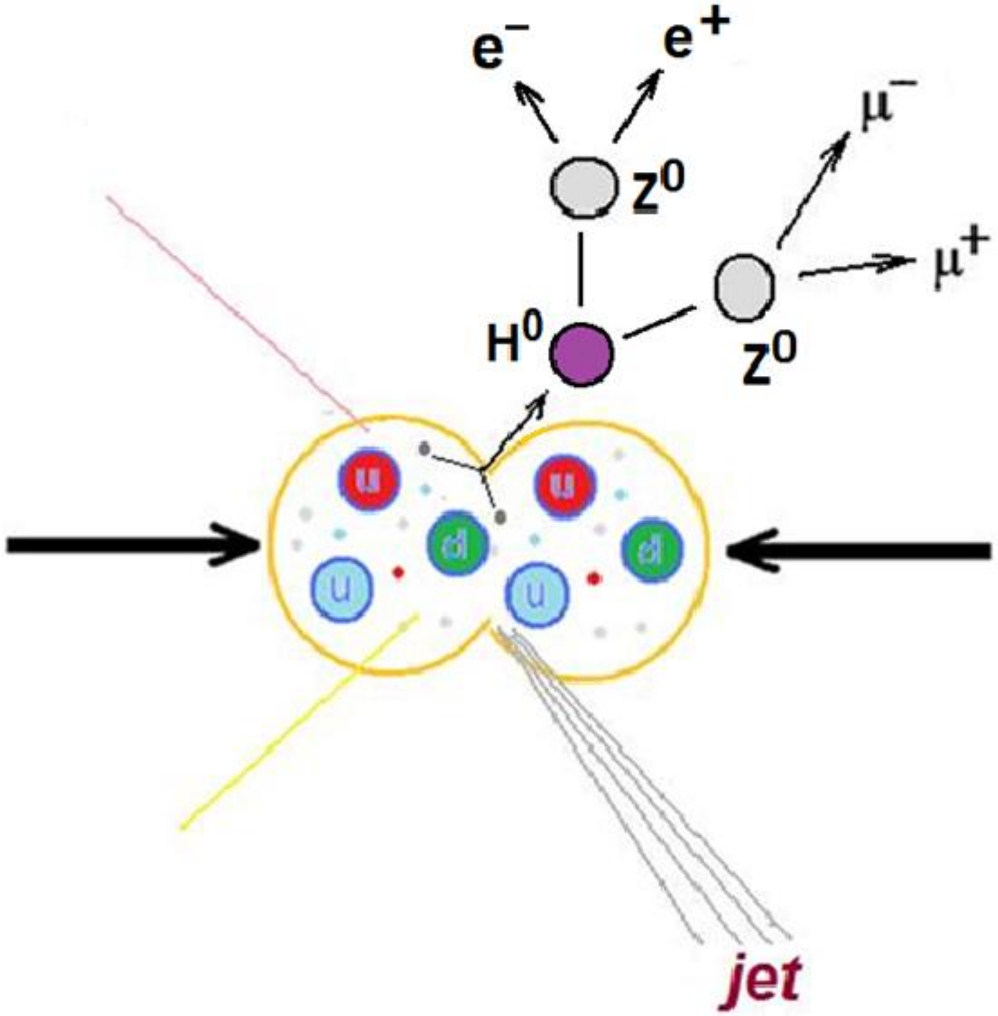


Higgs Particles

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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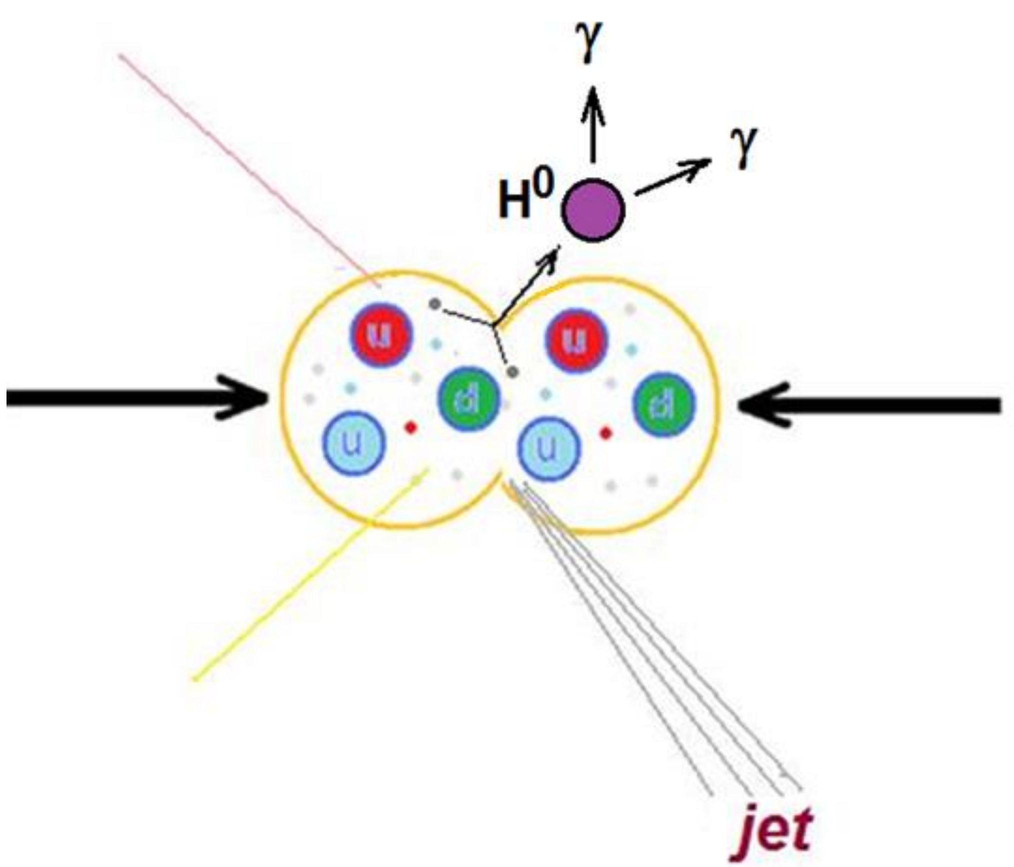
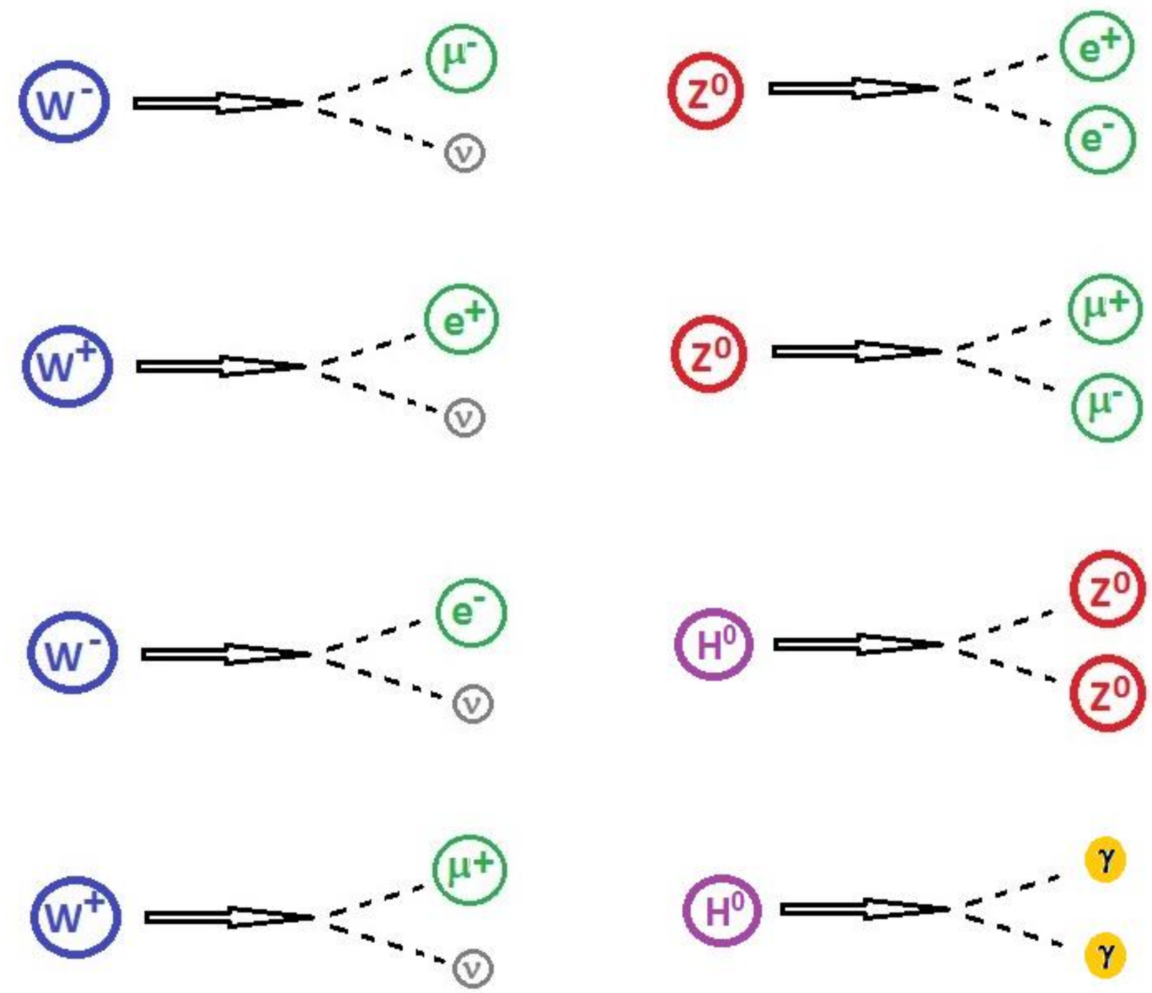


W and Z Decays

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"

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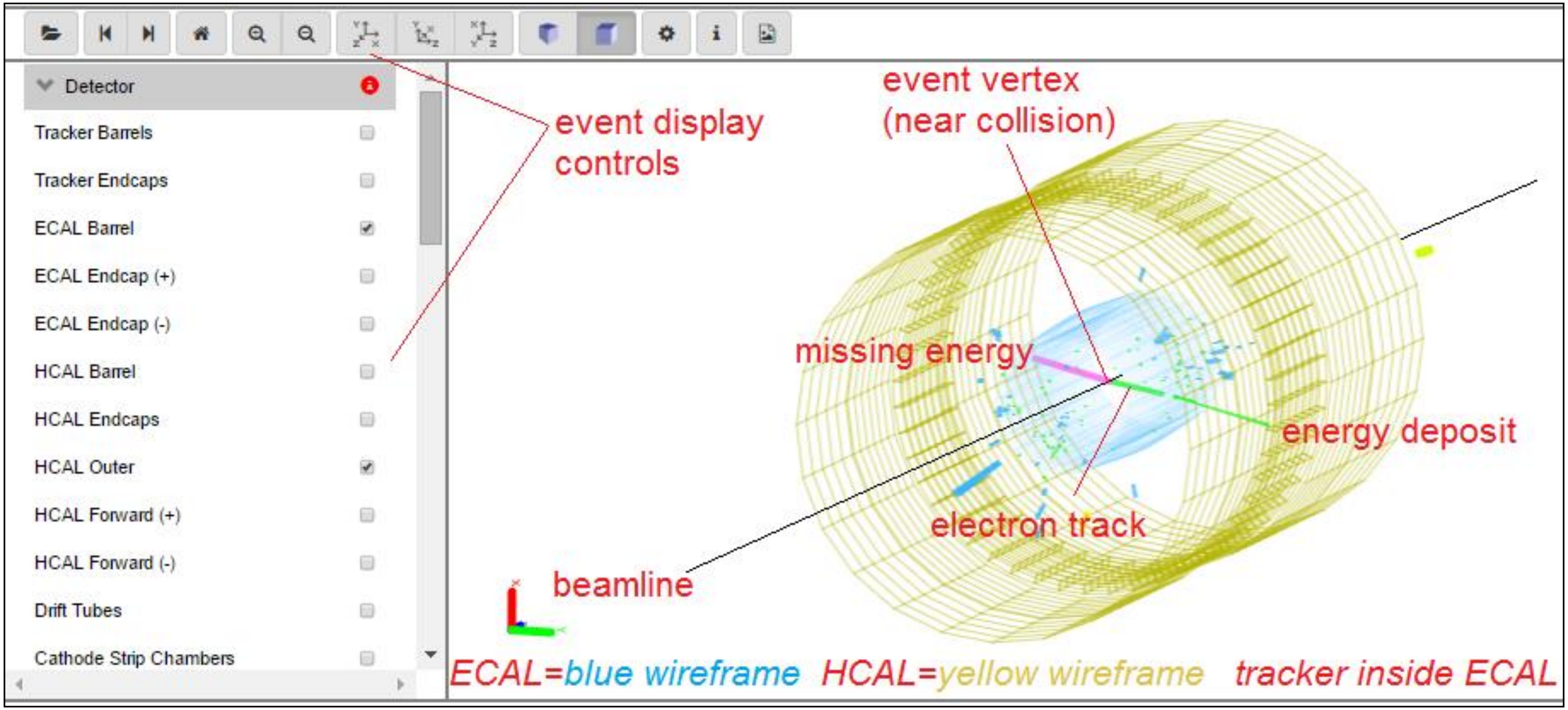
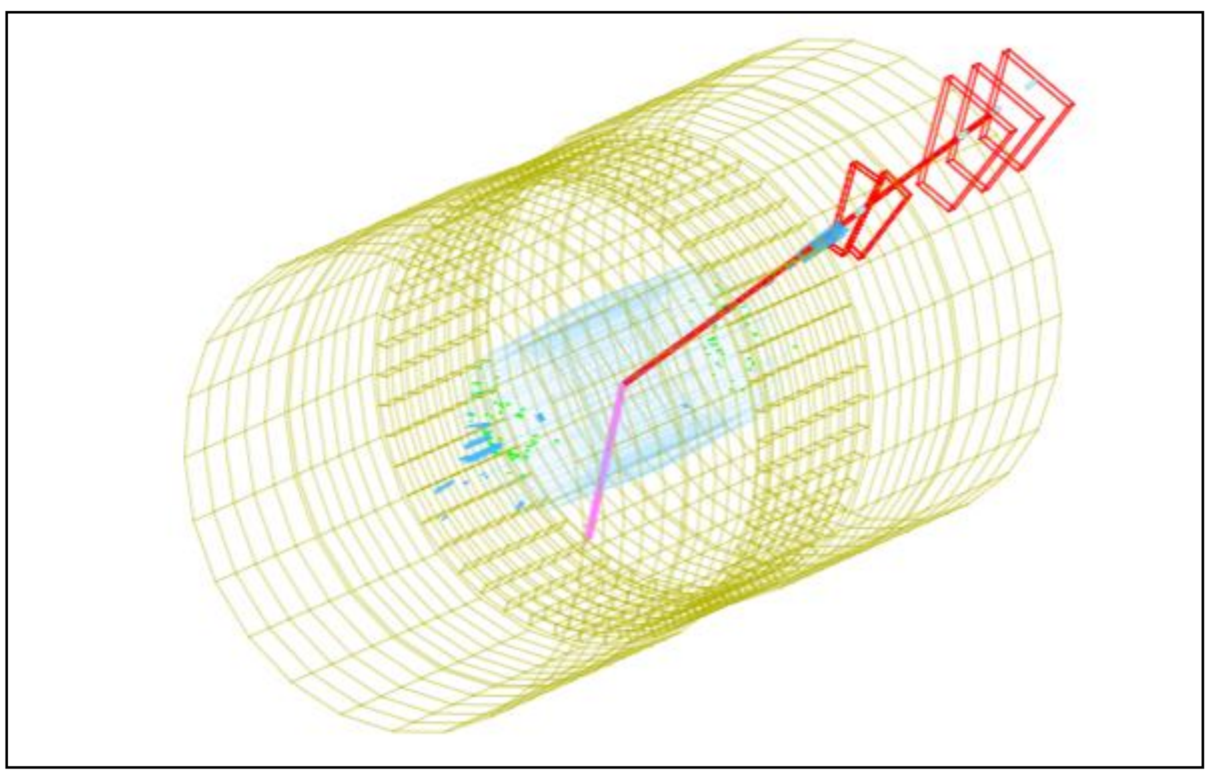
iSpy-webgl

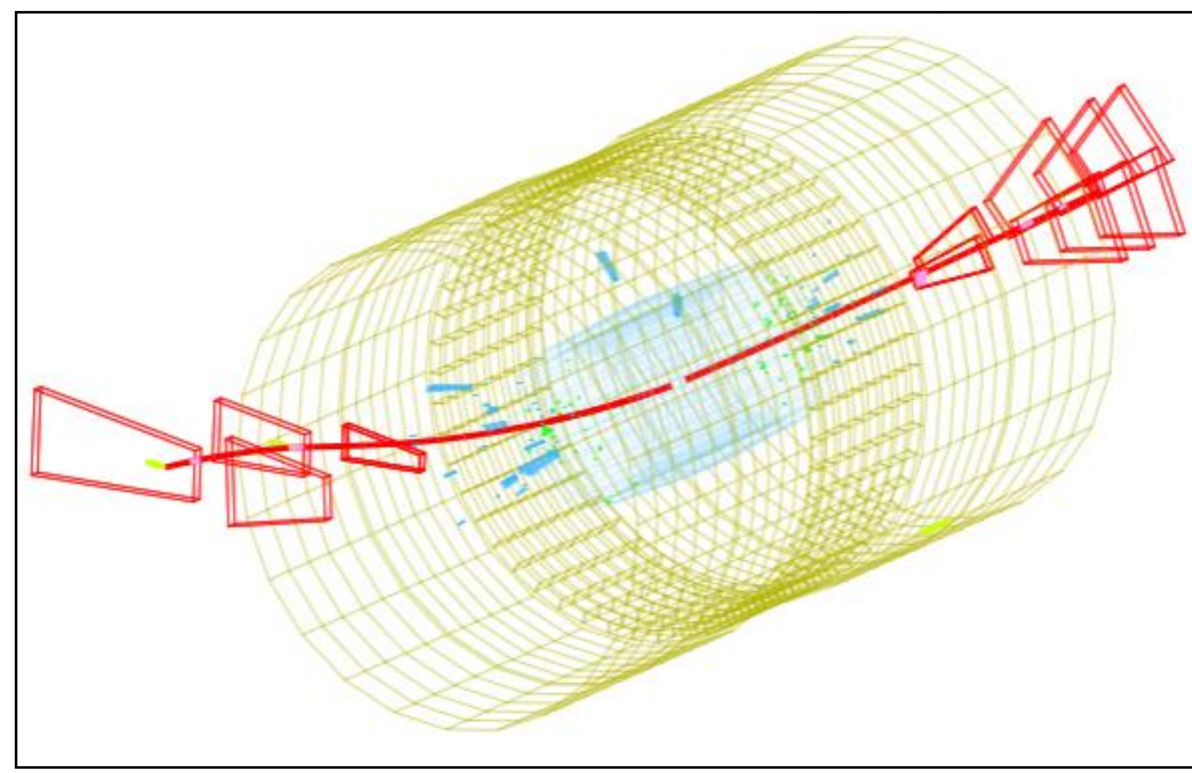


Today’s Task

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

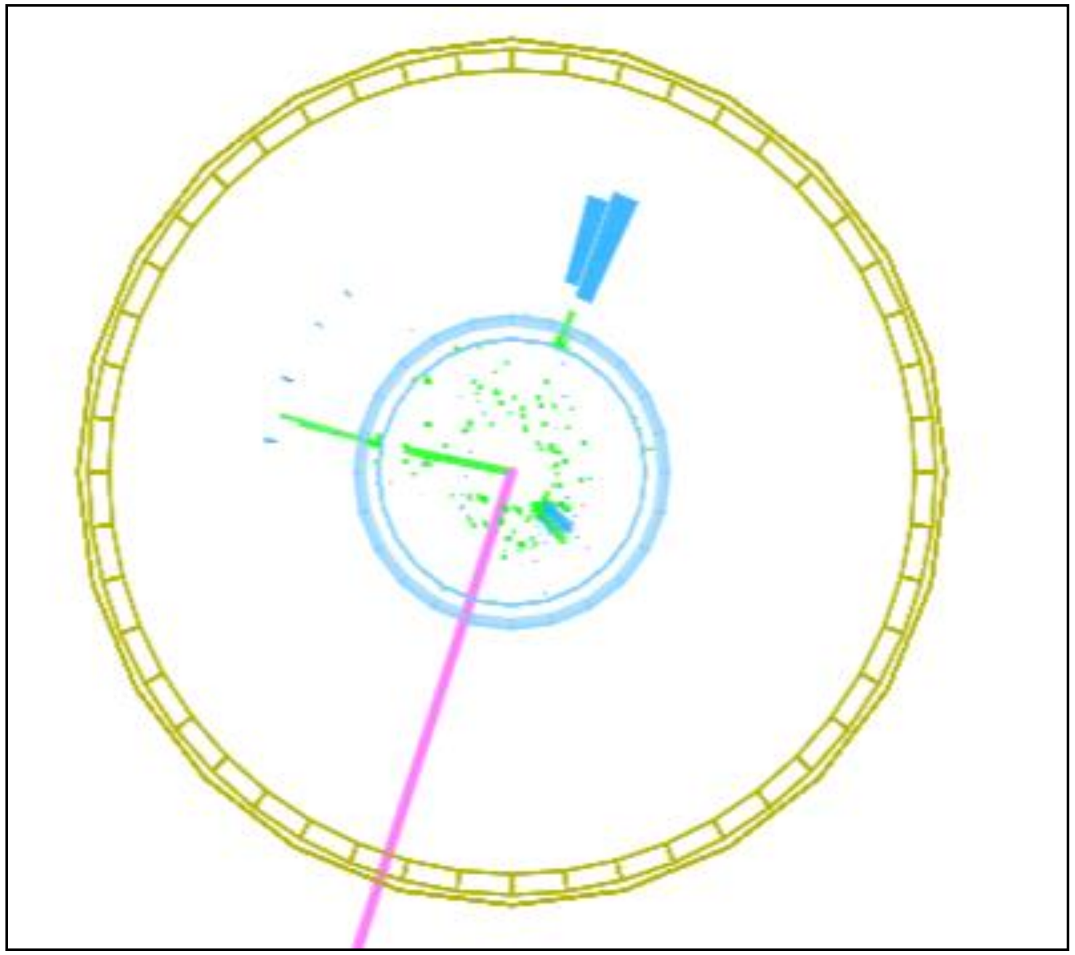
- Can we distinguish W from Z candidates?

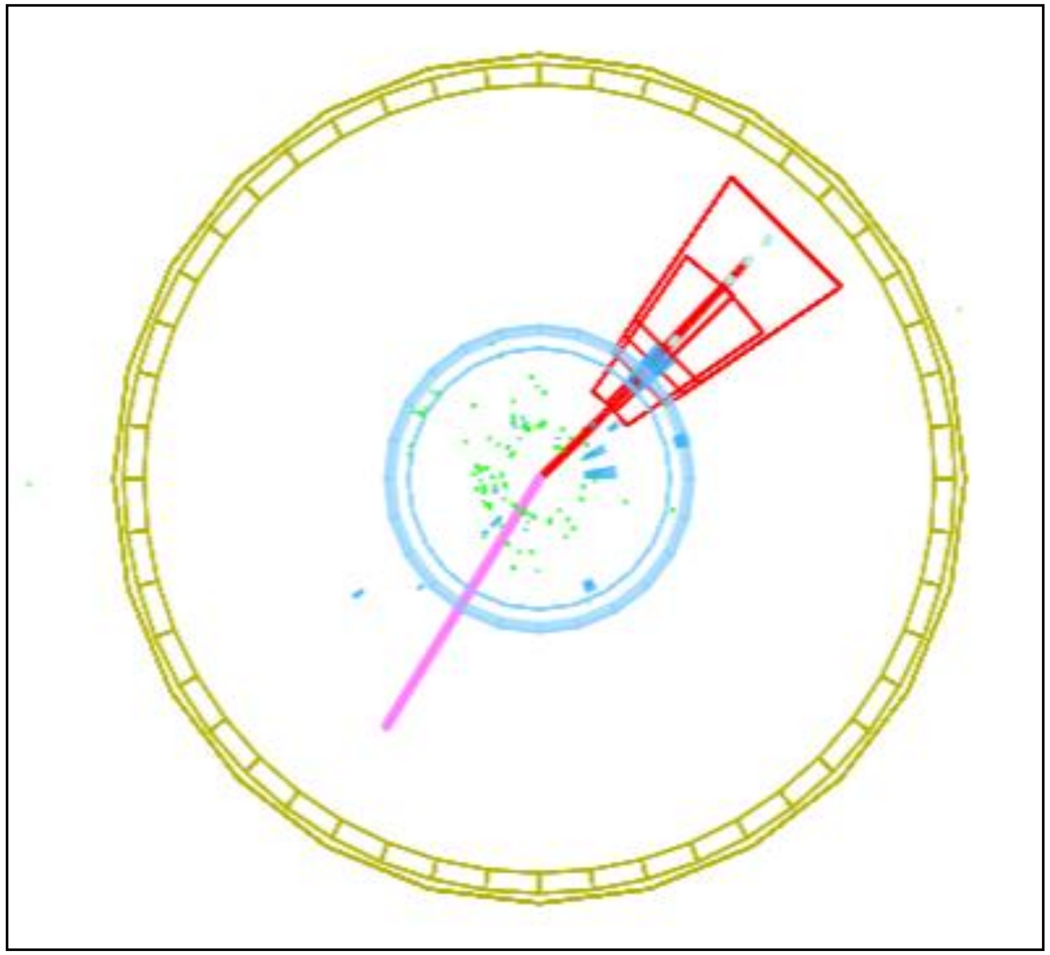




Today's Task

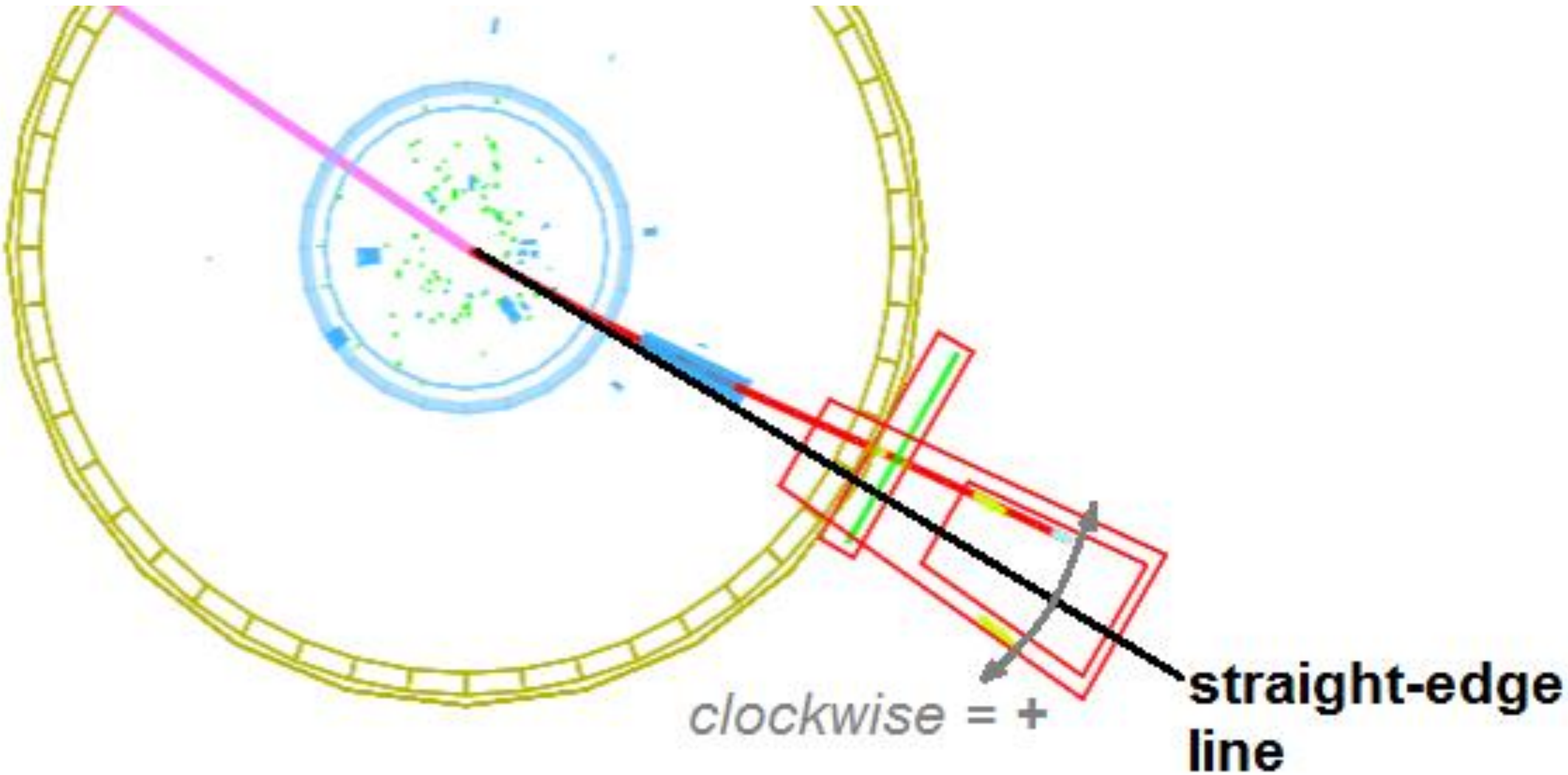
- Can we calculate the e/μ ratio?





Today's Task

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



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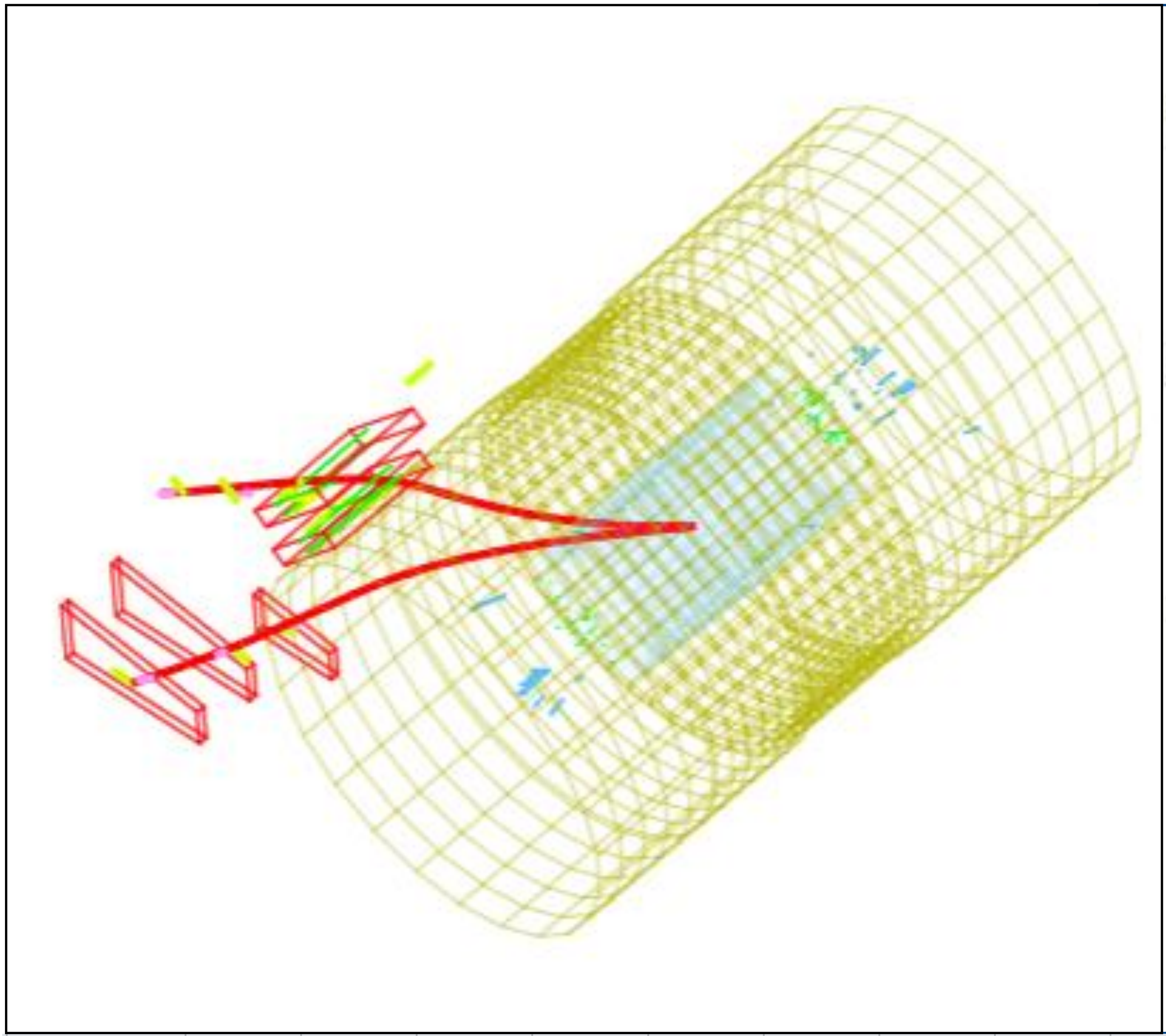
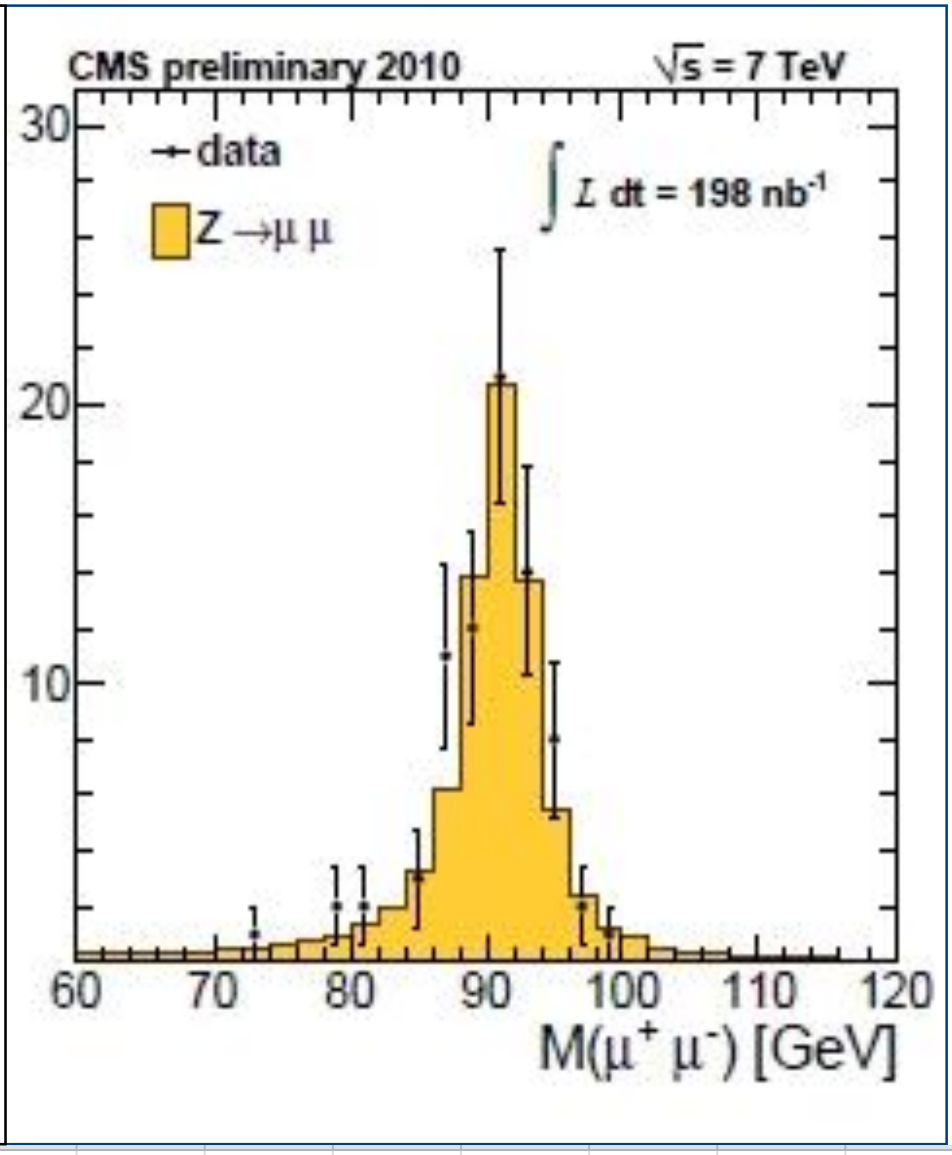
Today's Task

- Can we make mass plot of Z candidates?





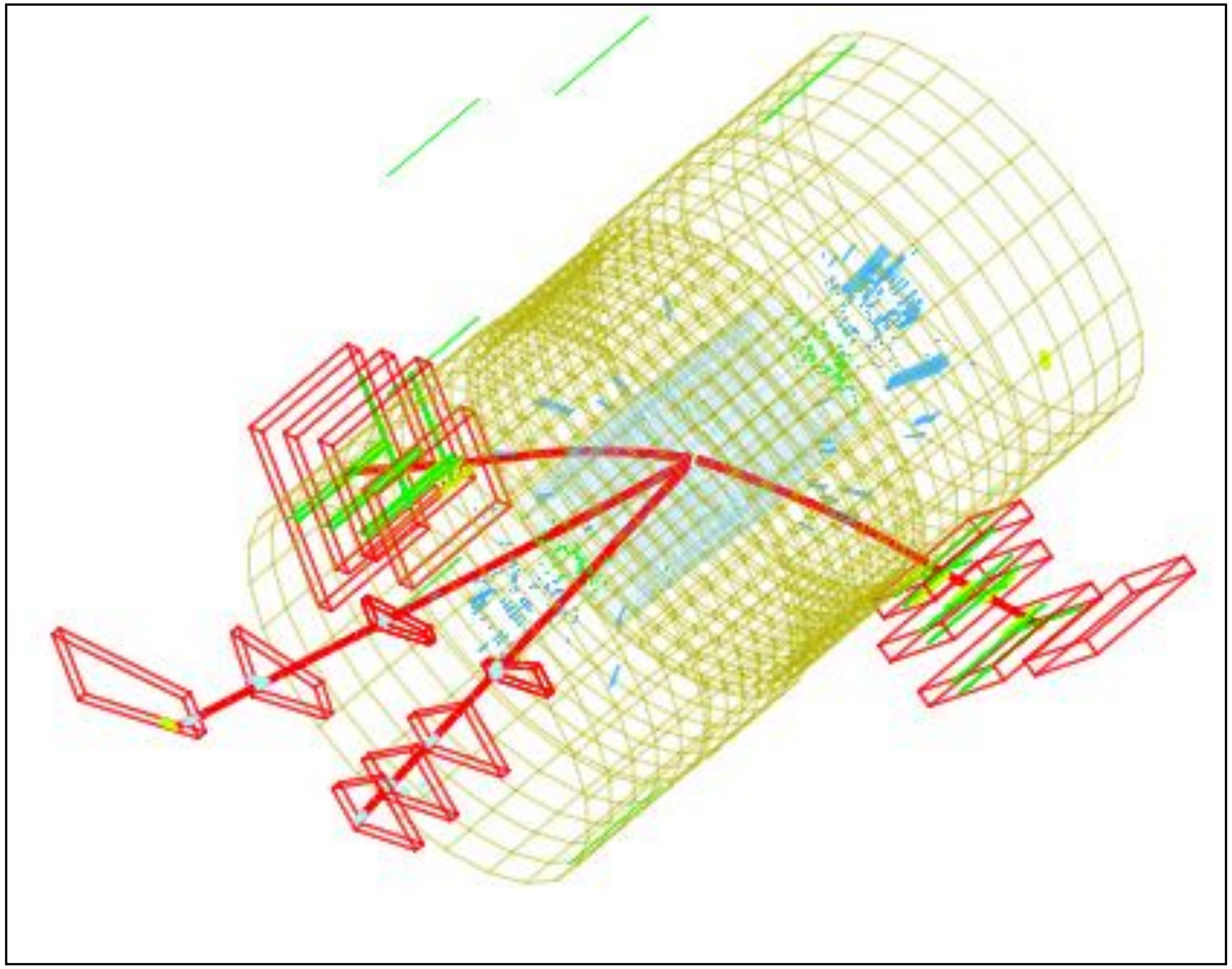
EvNo	E1	px1	py1	pz1	pt1	eta1	phi1	Q1	E2	px2	py2	pz2	pt2	eta2	phi2	Q2	M
128943239	72.89895	13.36098	-26.087	66.74727	29.3095	1.5612	-1.09746	1	37.6277	-10.9181	35.80517	-3.82334	37.3966	-0.10197	1.86677	-1	90.31227

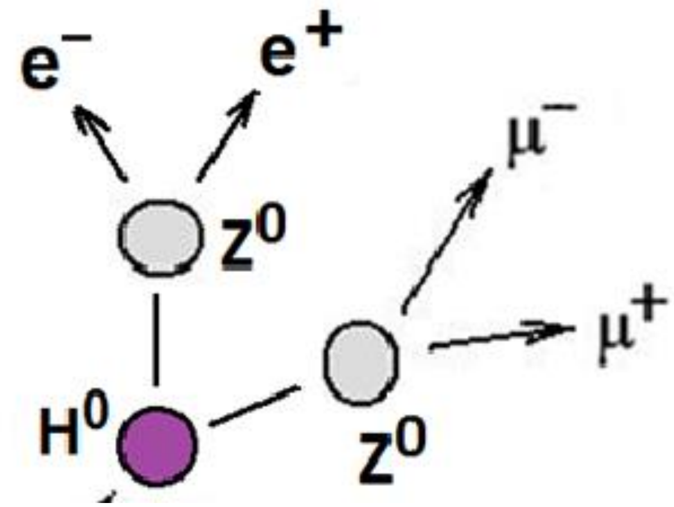
Today's Task

- Can we find rare 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?





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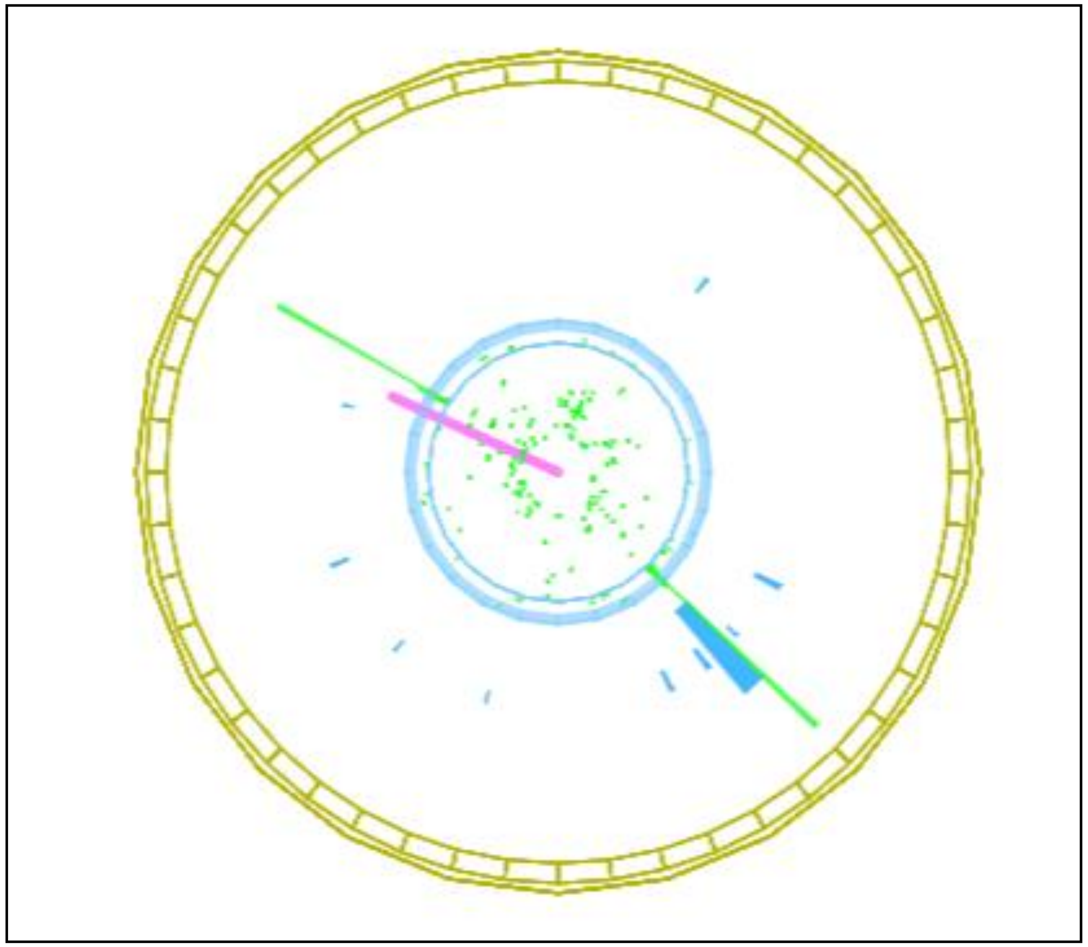
Today's Task

- Can we find some $H \rightarrow \gamma\gamma$ events?



How do we spot photons that leave no track?

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

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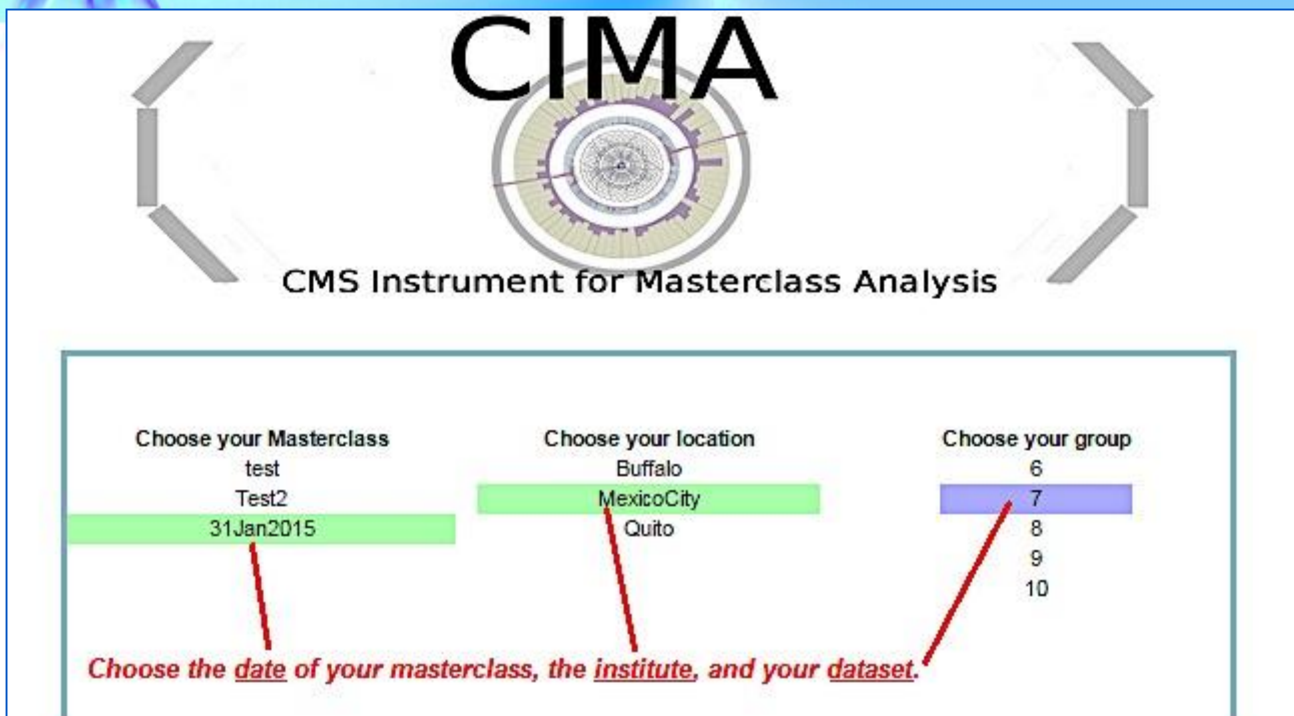
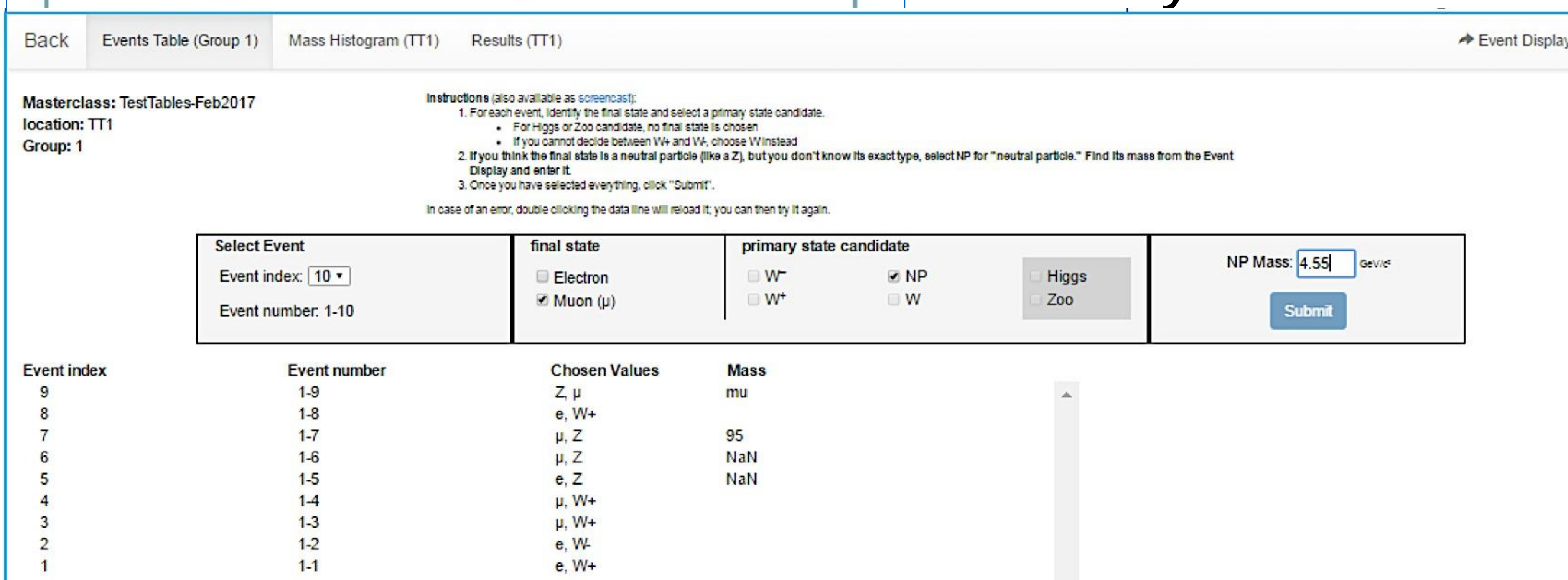
Recording event data



Find your dataset.

Record parent particles and decay modes.



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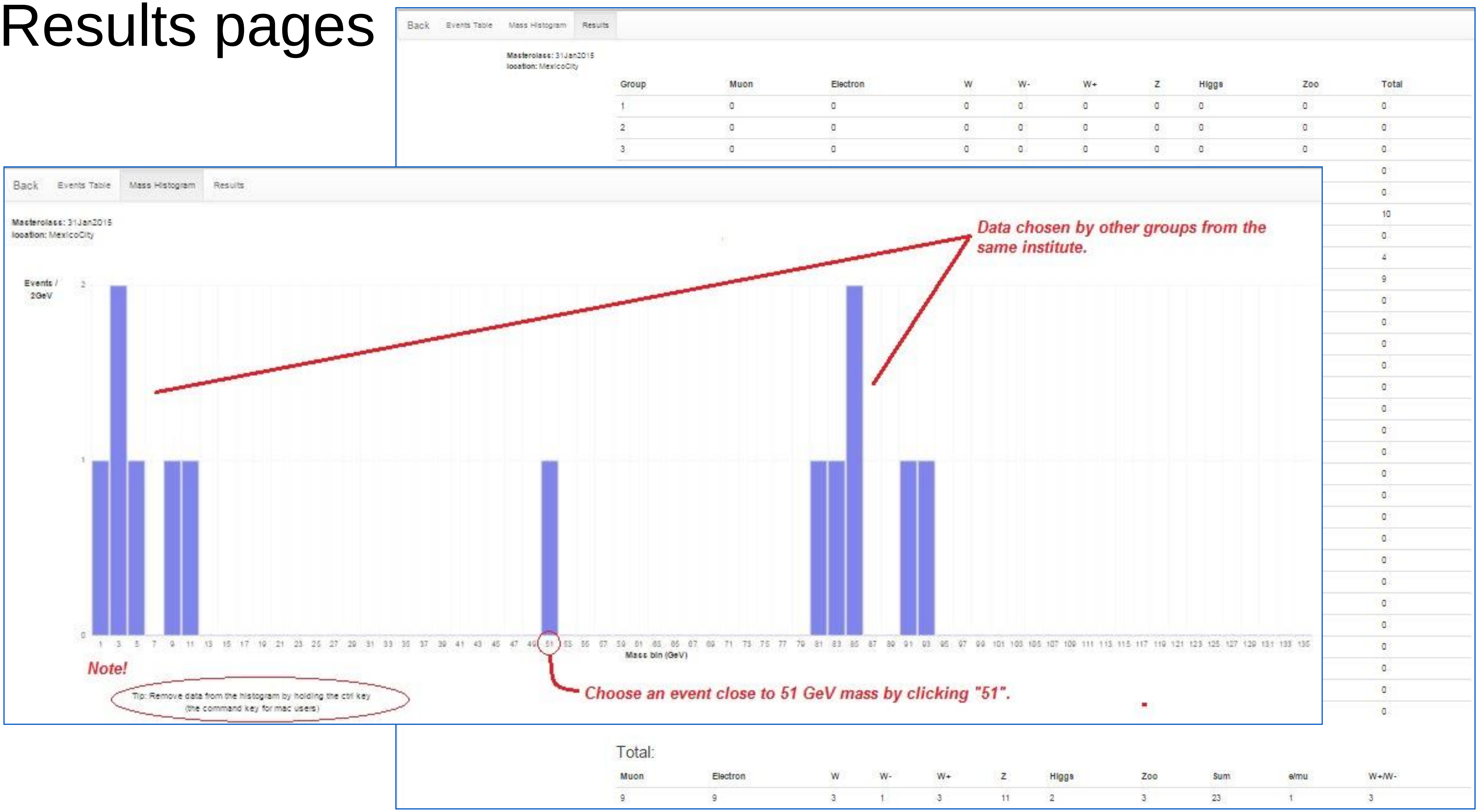
Recording event data

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: 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.