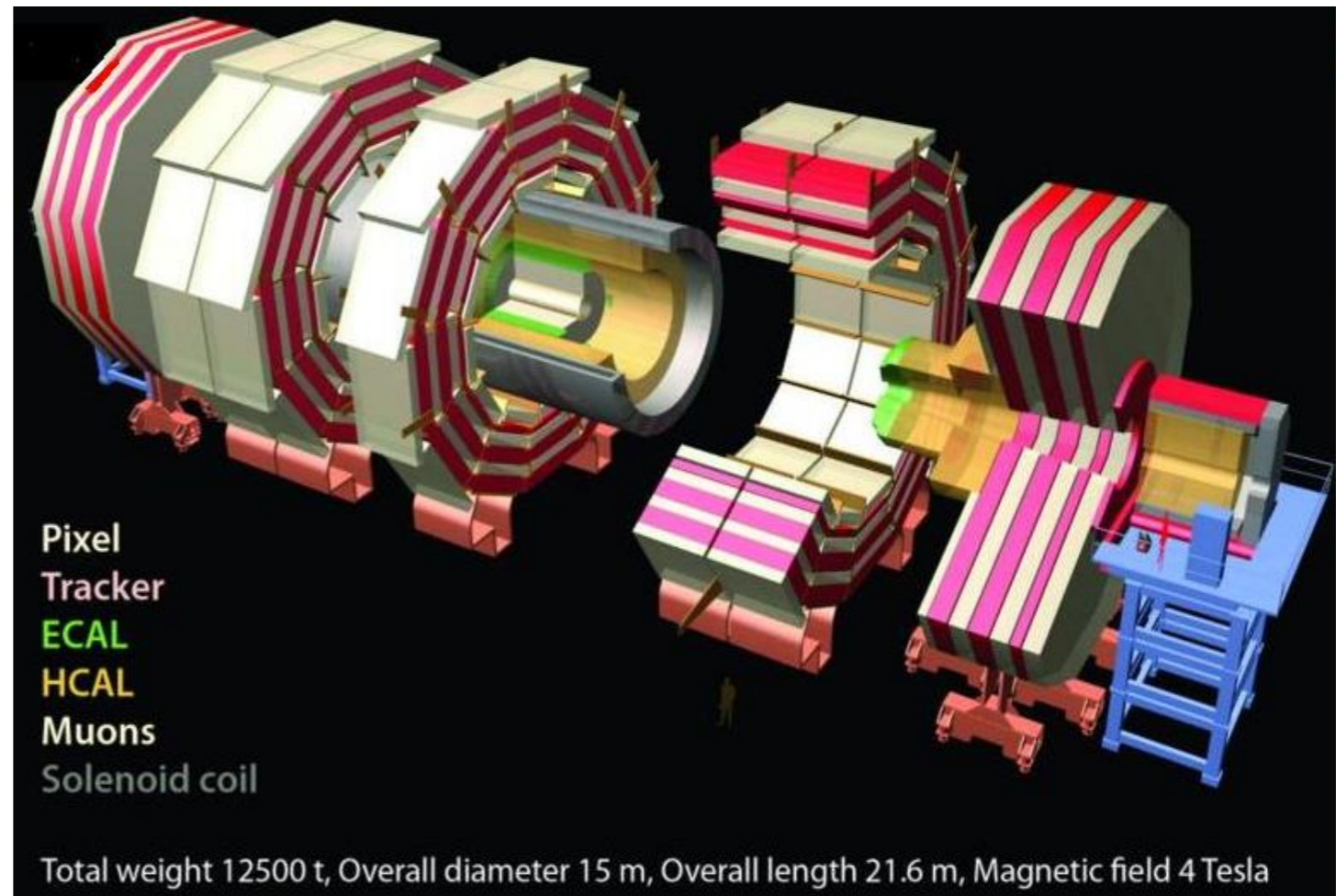
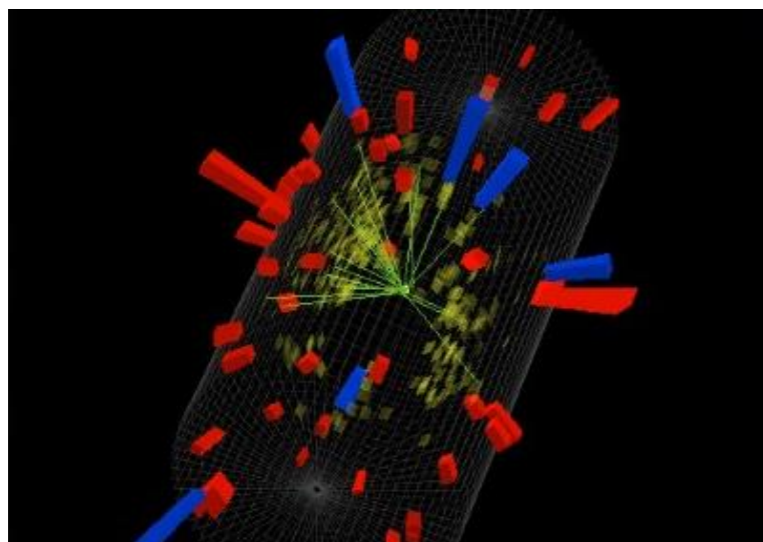
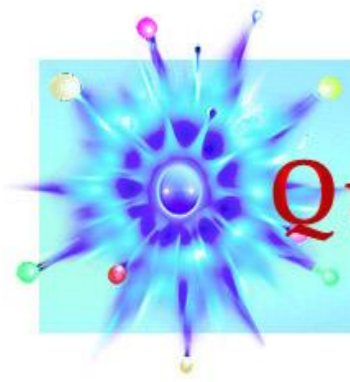


Helping Develop America's Technological Workforce



CMS Masterclasses 2017 S'Cool LAB





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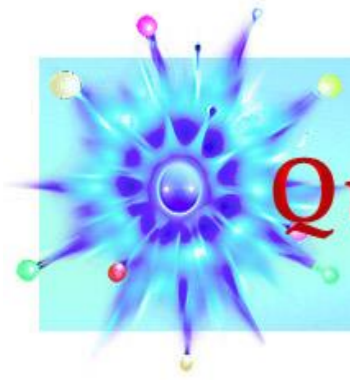
The LHC and New Physics

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

At CERN, the LHC successfully 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.*





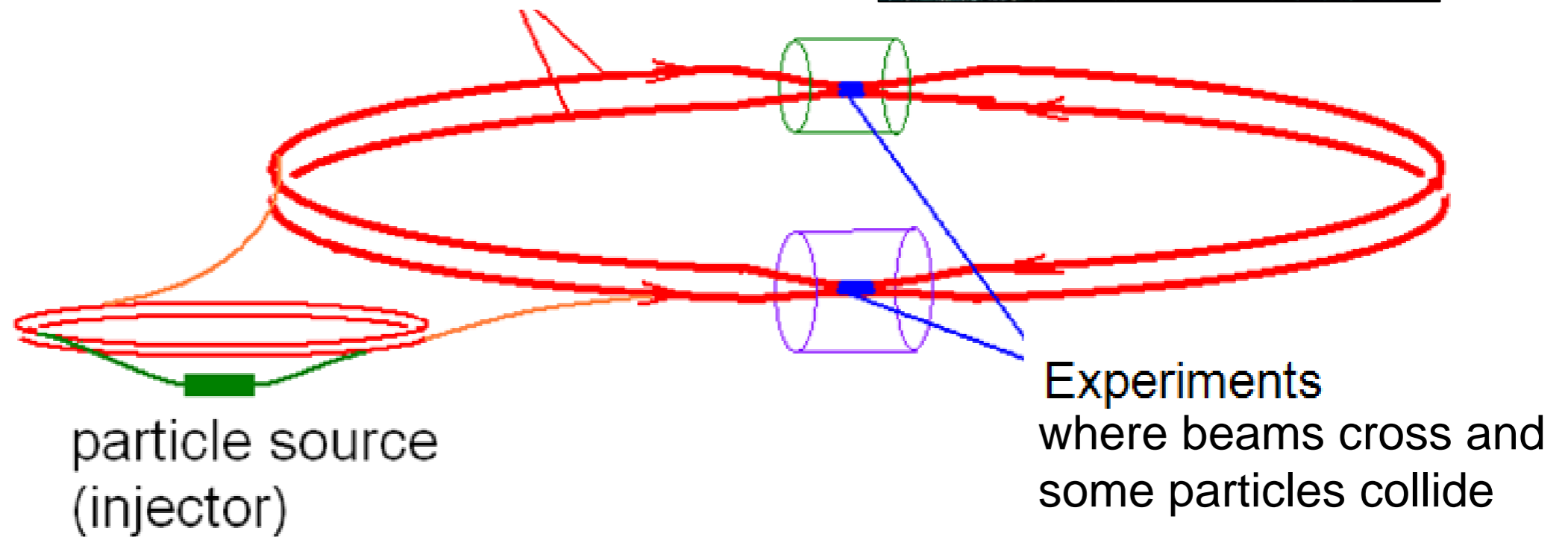
QuarkNet

The LHC and New Physics

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



beams accelerated in large rings (27 km circumference at CERN)



particle source (injector)

Experiments where beams cross and some particles collide



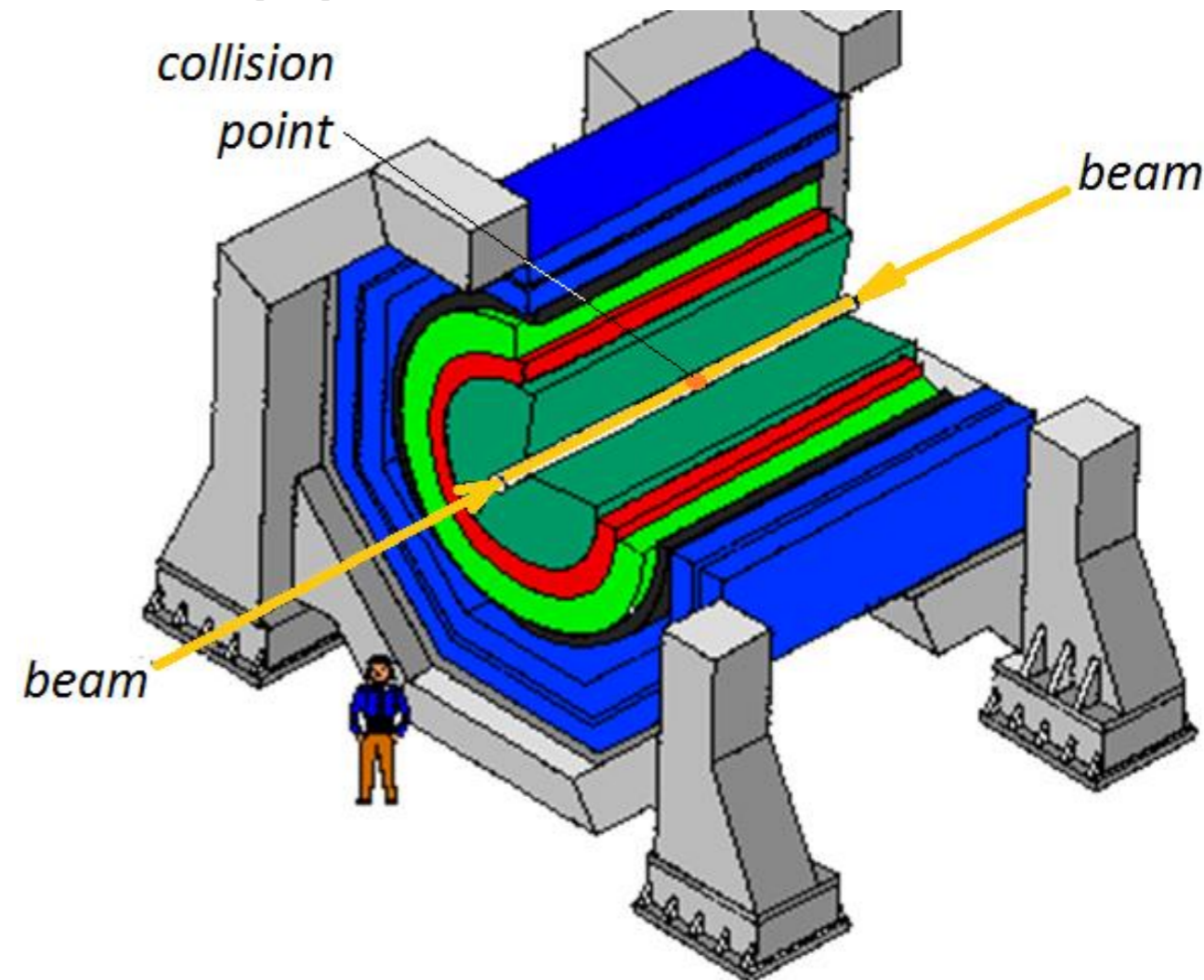
Detector Design

Generic Design

Cylinders wrapped around the beam pipe

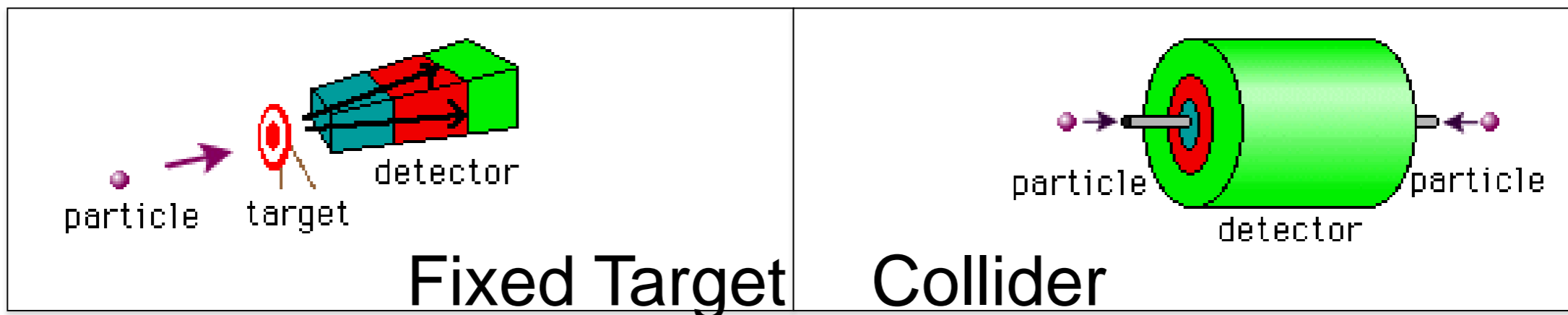
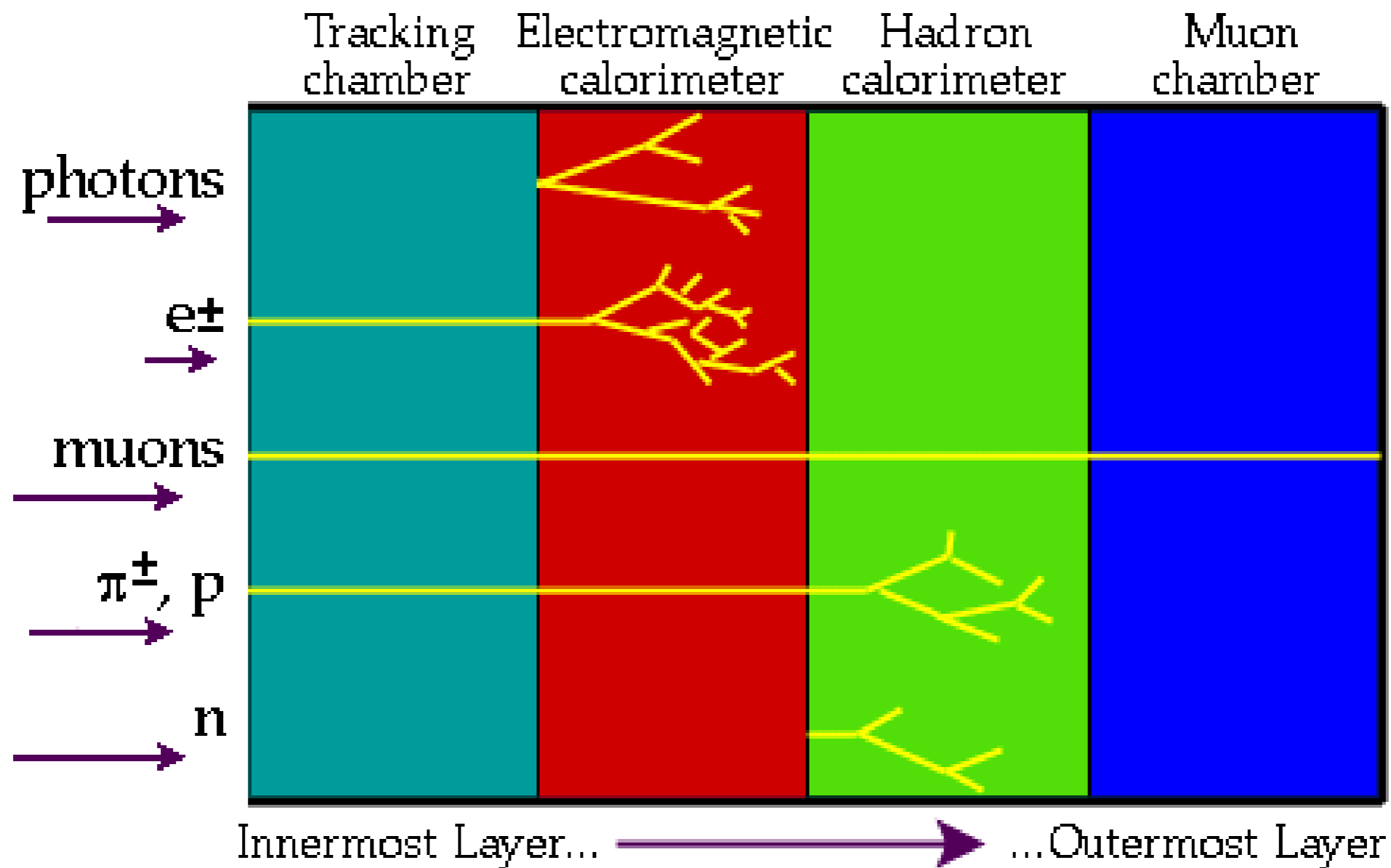
From inner to outer...

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



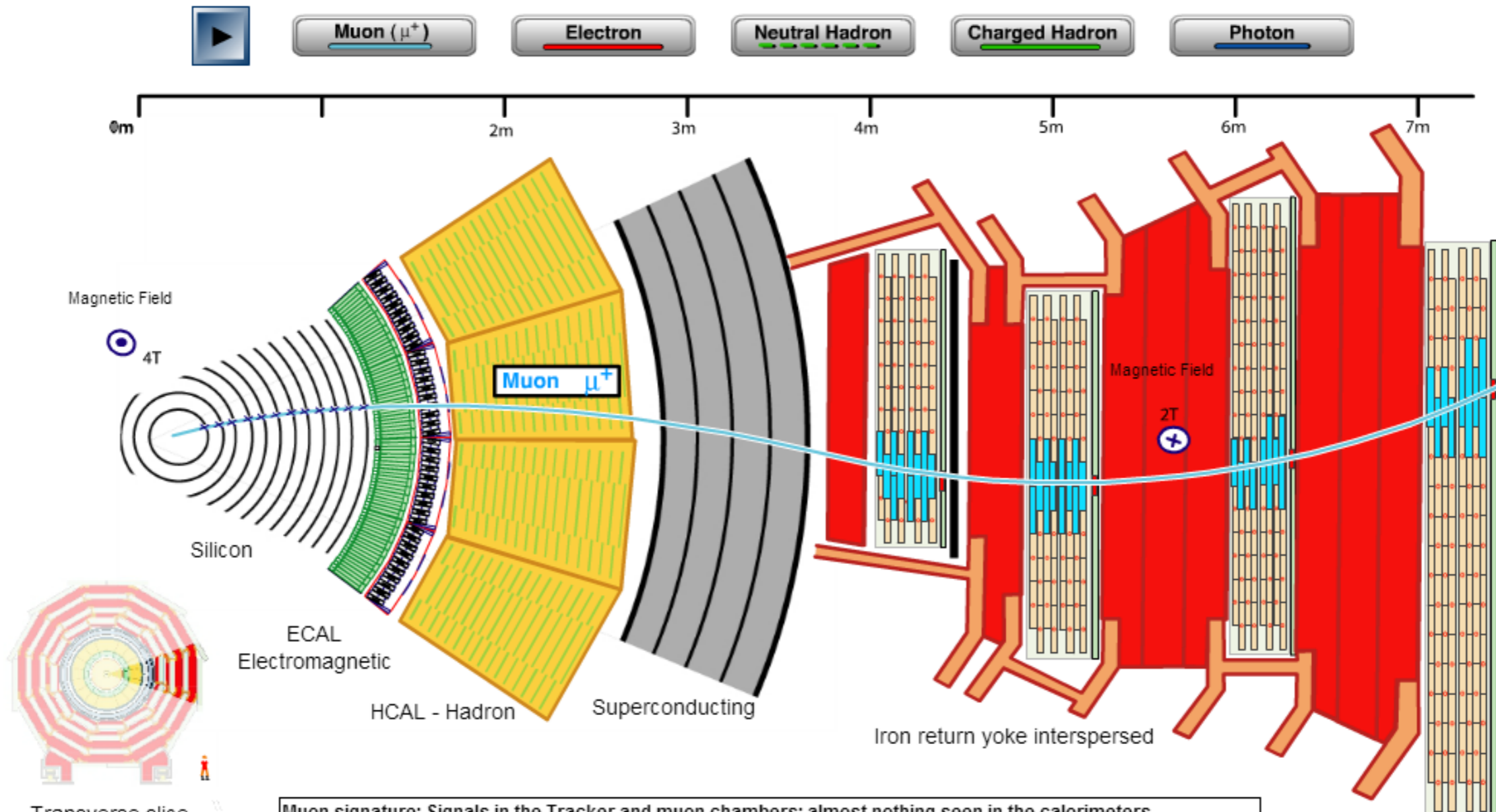
* Localization of magnet depends of specific detector design

Detectors





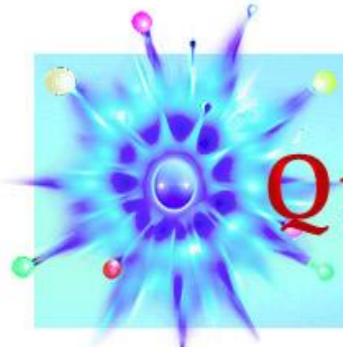
Transverse Slice of the Compact Muon Solenoid (CMS) Detector



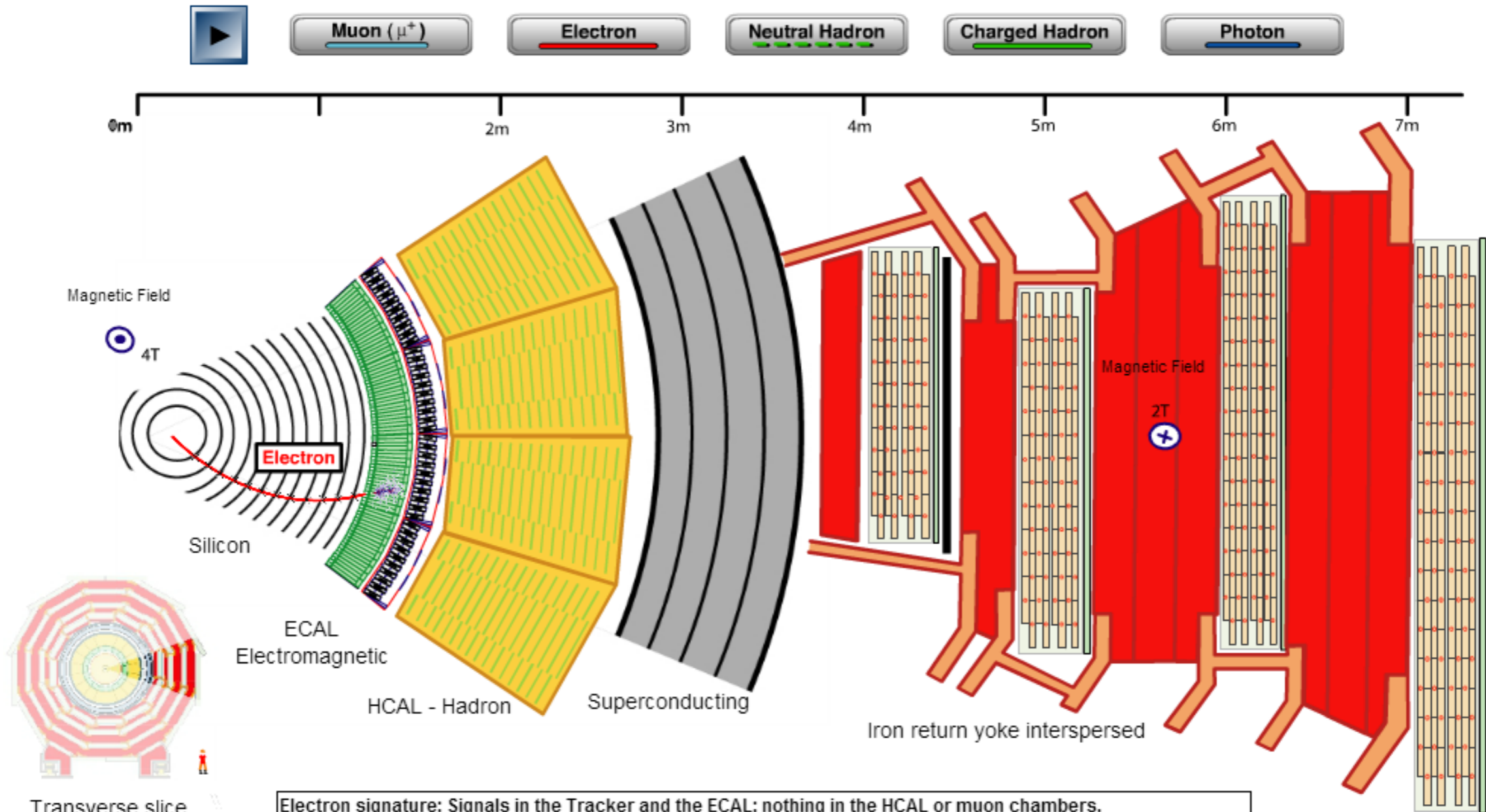
Muon signature: Signals in the Tracker and muon chambers; almost nothing seen in the calorimeters. Muons are perhaps the easiest particles to identify in CMS: no other charged particle traverses the whole detector. Being charged, they are bent by the field in one direction inside the solenoid and in 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

D. Barney, CERN, 2004

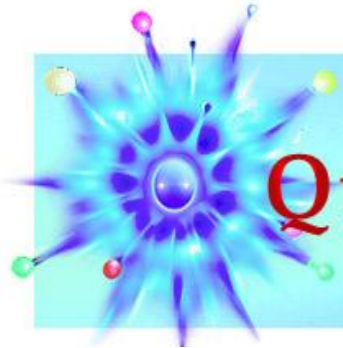


Transverse Slice of the Compact Muon Solenoid (CMS) Detector

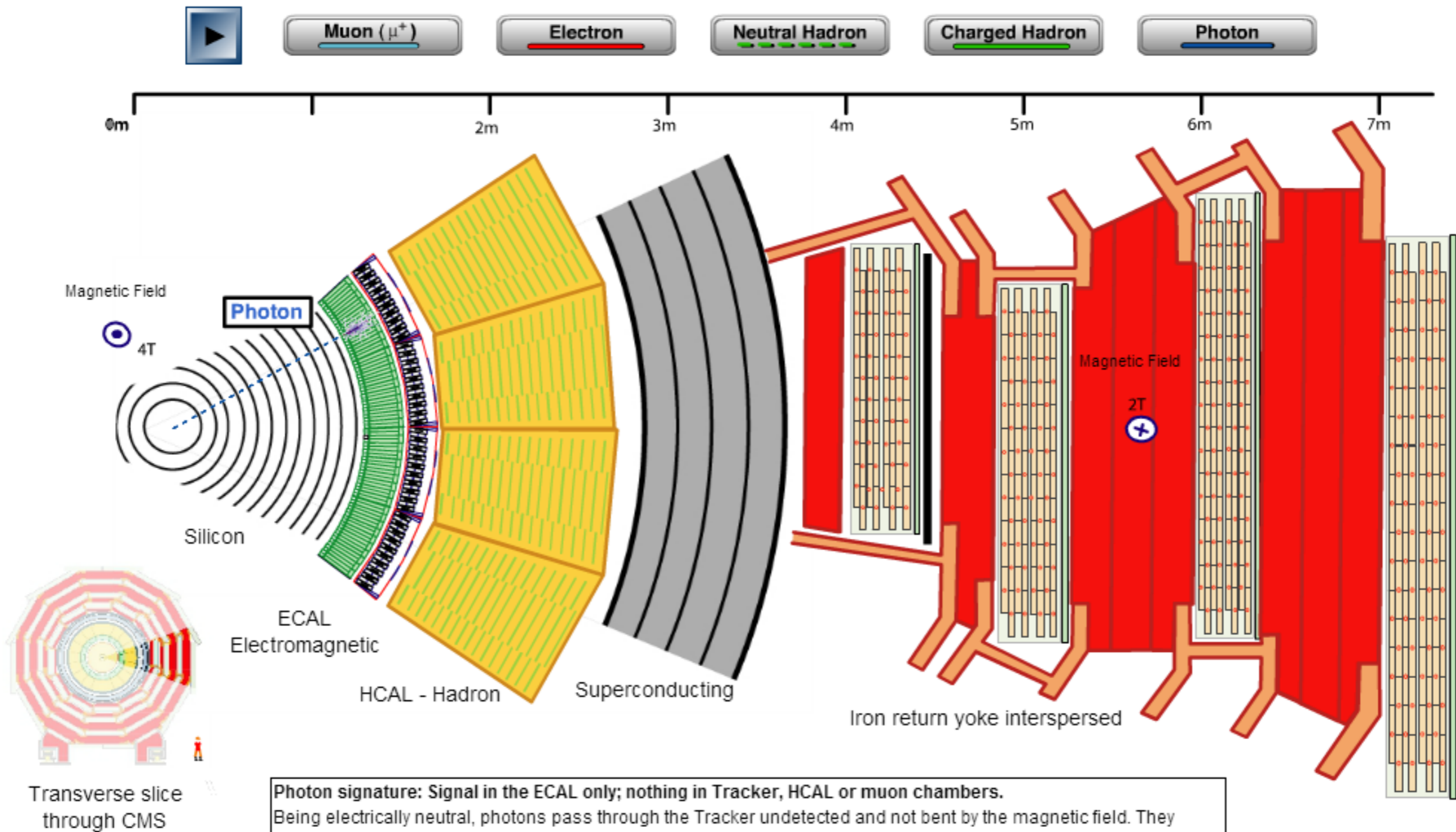


Electron signature: Signals in the Tracker and the ECAL; nothing in the HCAL or muon chambers.
 These electrically charged particles bend in the field and leave signals in the Tracker, enabling their paths to be reconstructed. The amount of bend depends on the momentum they carry, with the radius of curvature, r , being given by the momentum, p , divided by $0.3 \times B$, 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

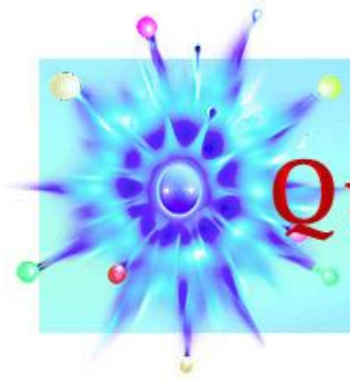


Transverse Slice of the Compact Muon Solenoid (CMS) Detector



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.

D. Barney, CERN, 2004



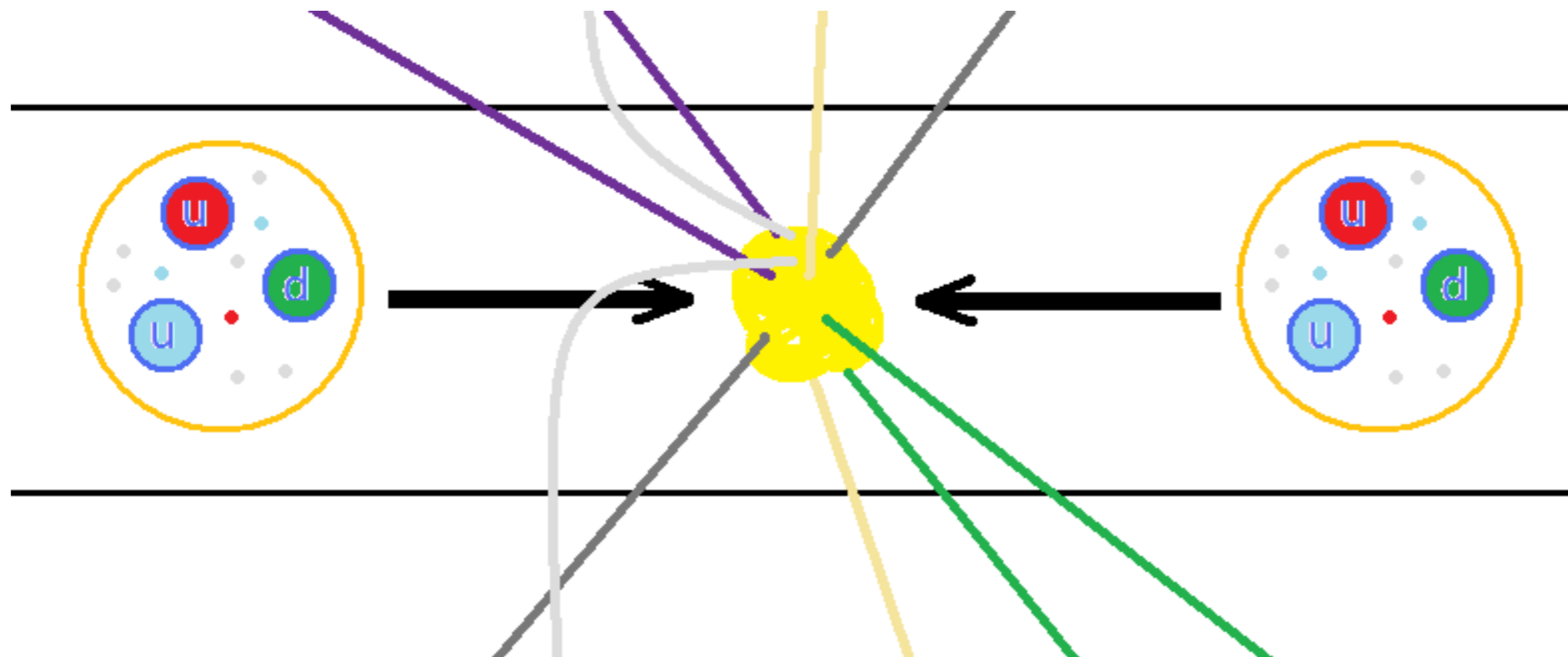
QuarkNet

Energy & Particle Mass

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

- The total collision energy is $2 \times 4 \text{ TeV} = 8 \text{ TeV}$.
- 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!*



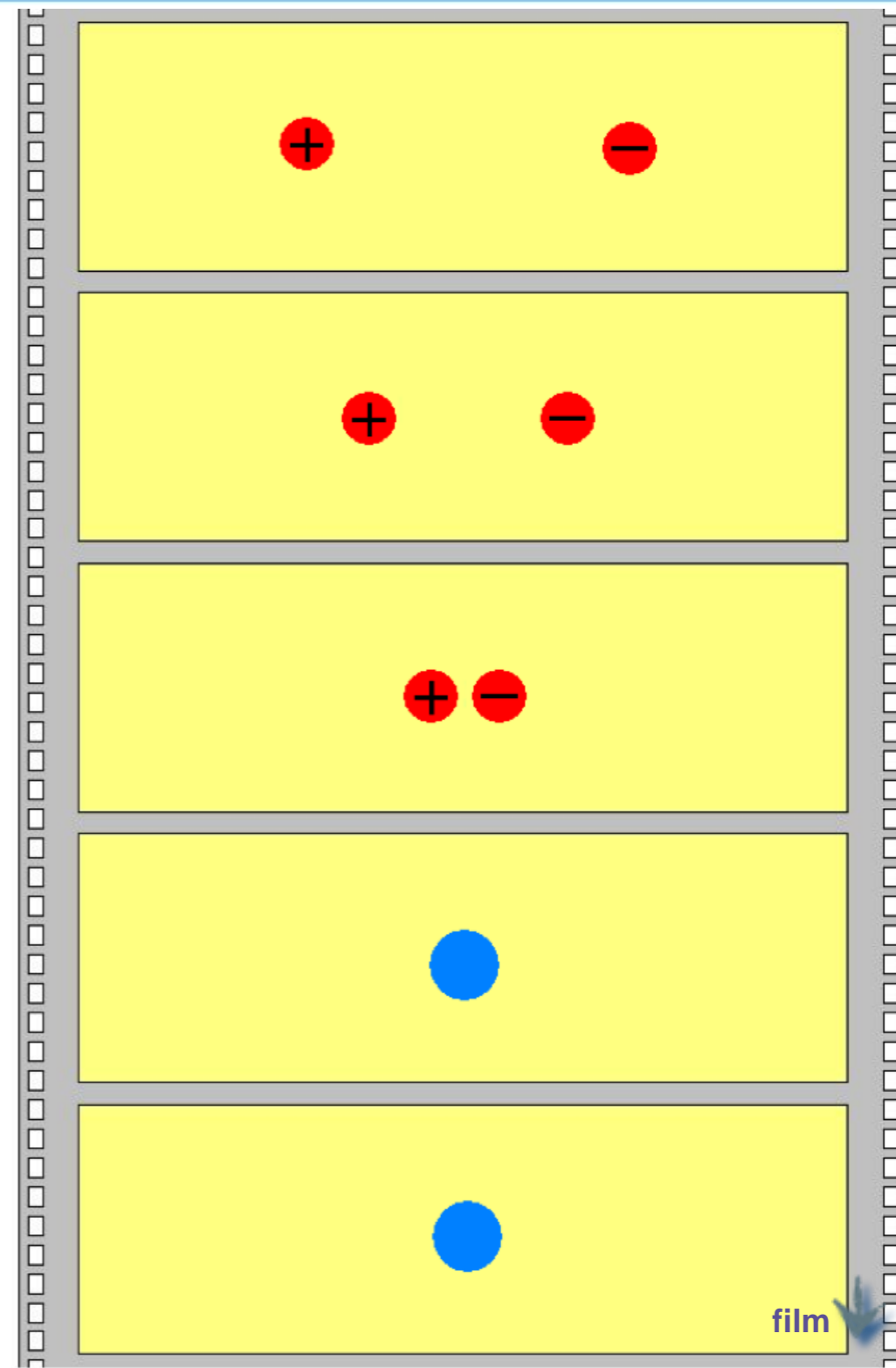


Particle Decays

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.



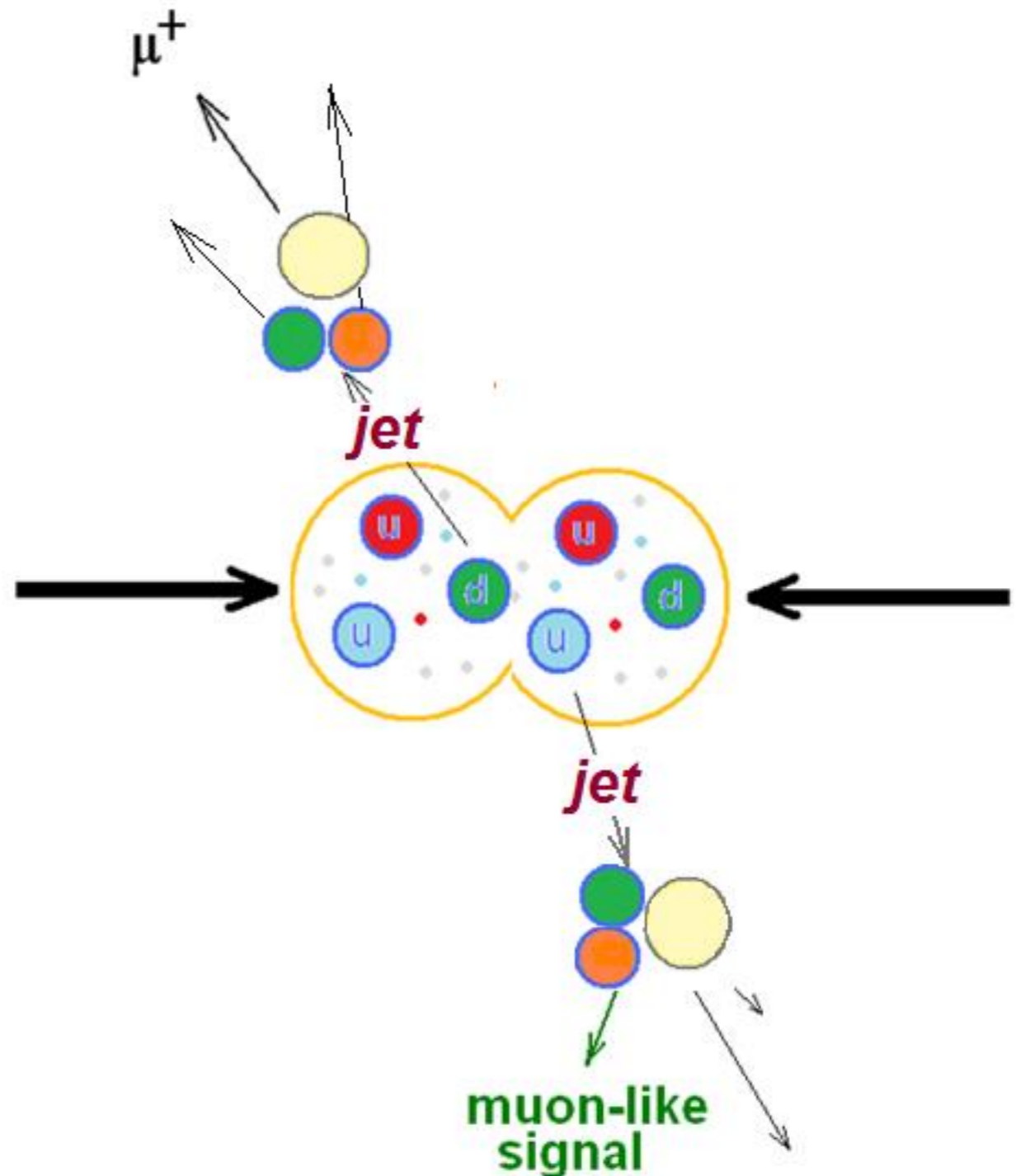


Background Events

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.



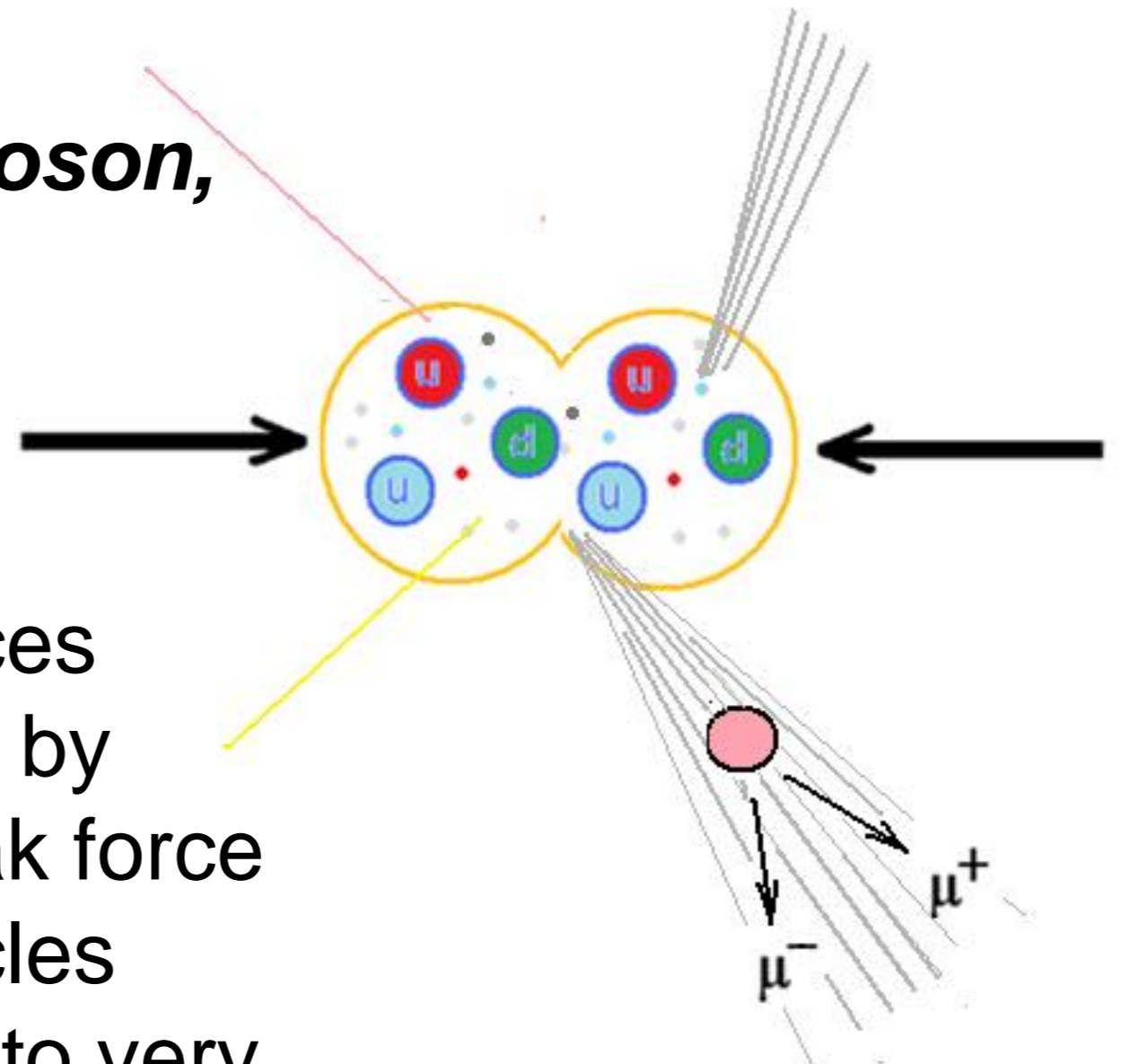


W and Z Particles

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.



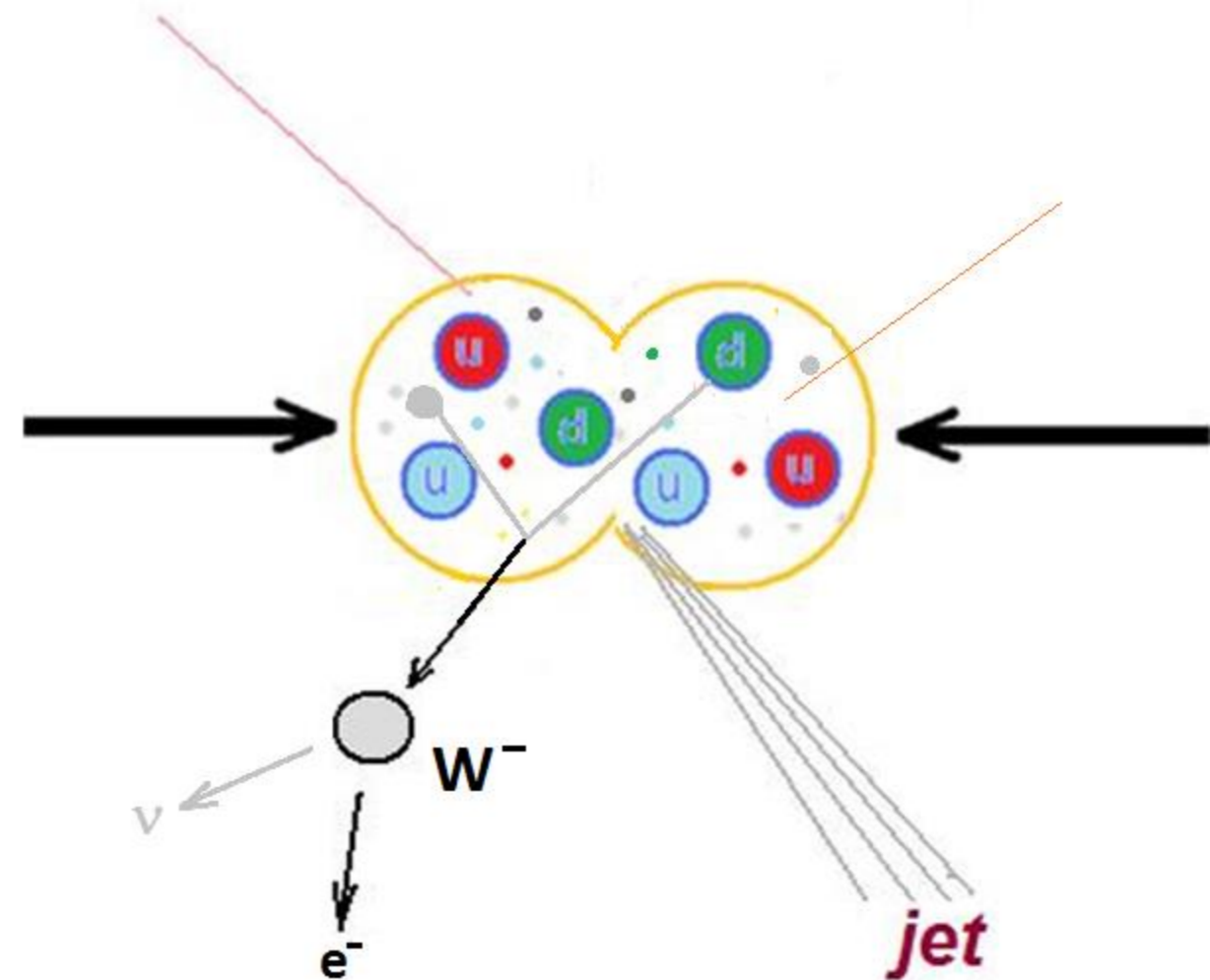


W and Z Particles

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.



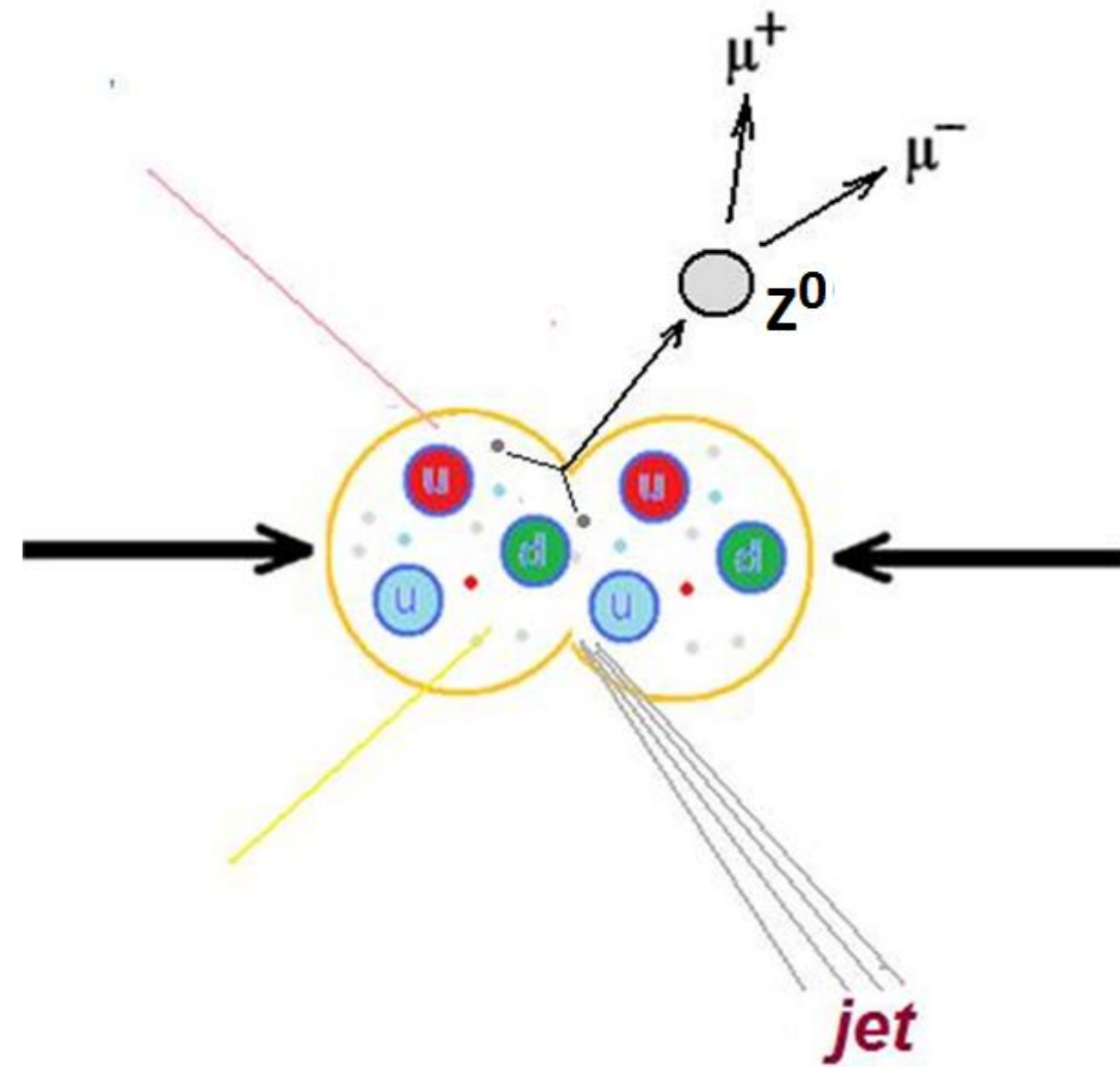


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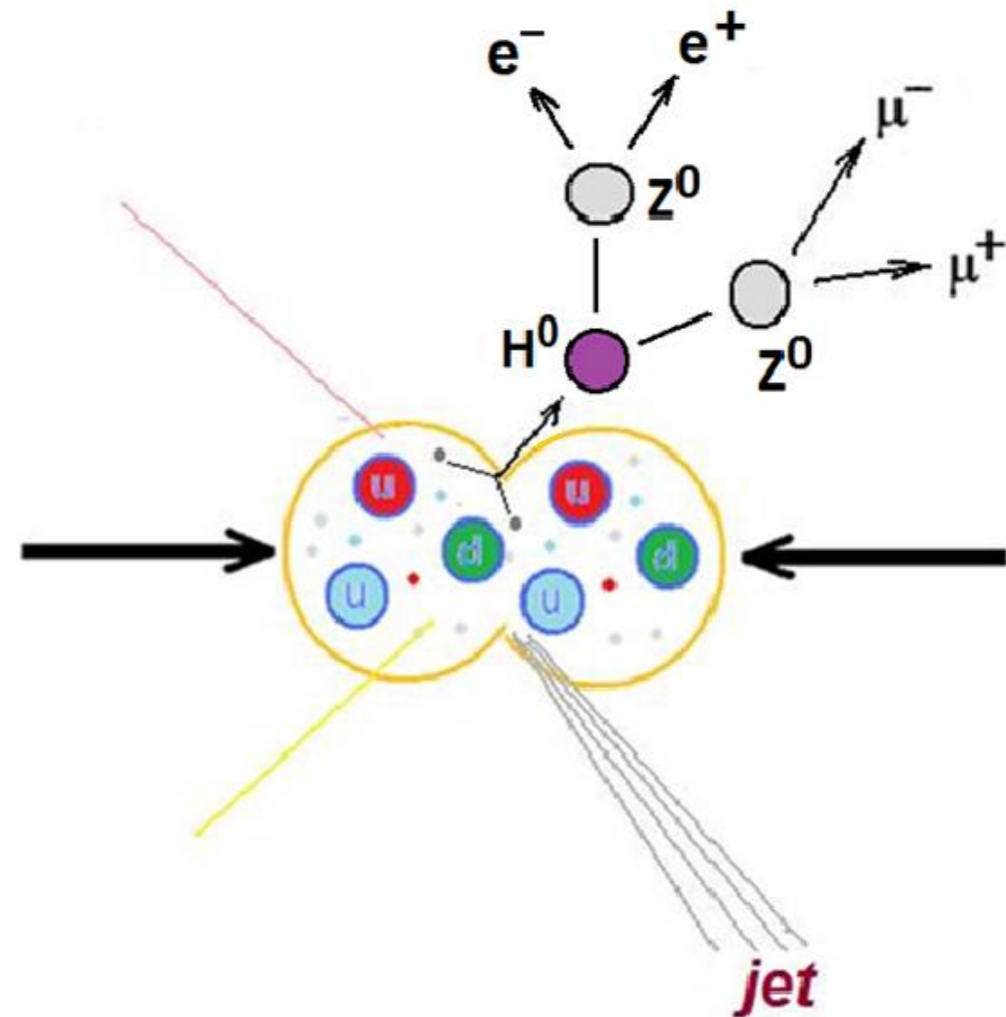




Higgs Particles

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.

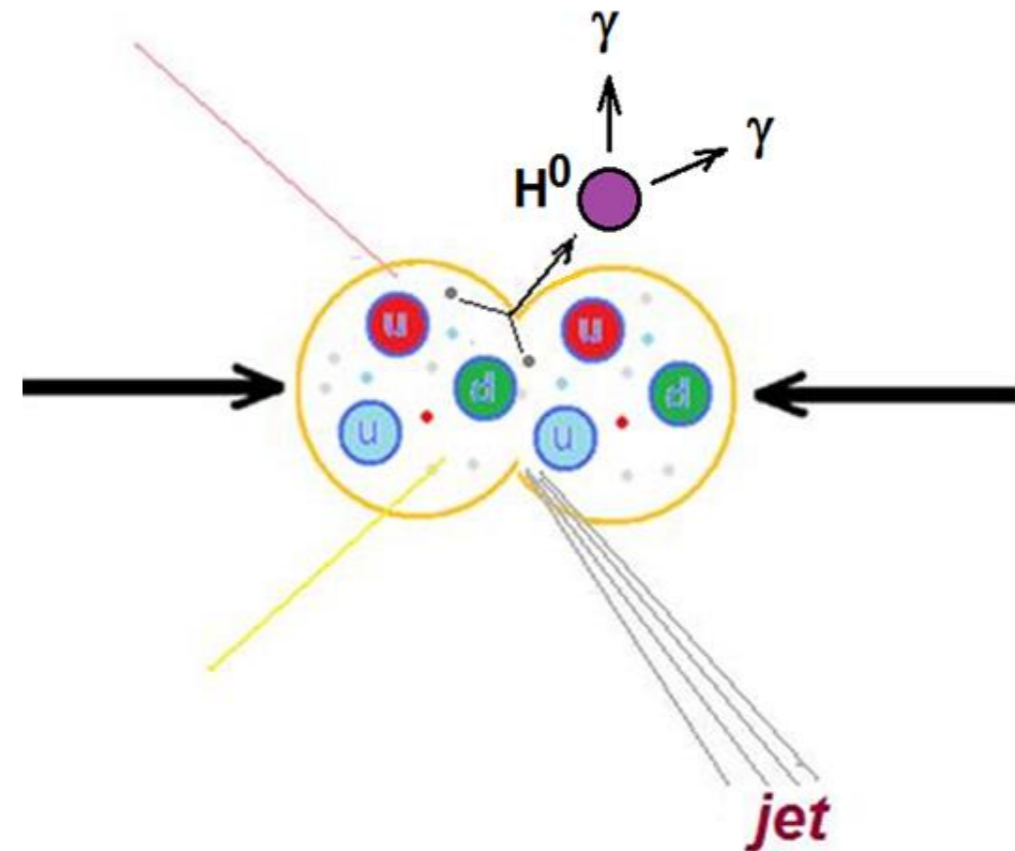




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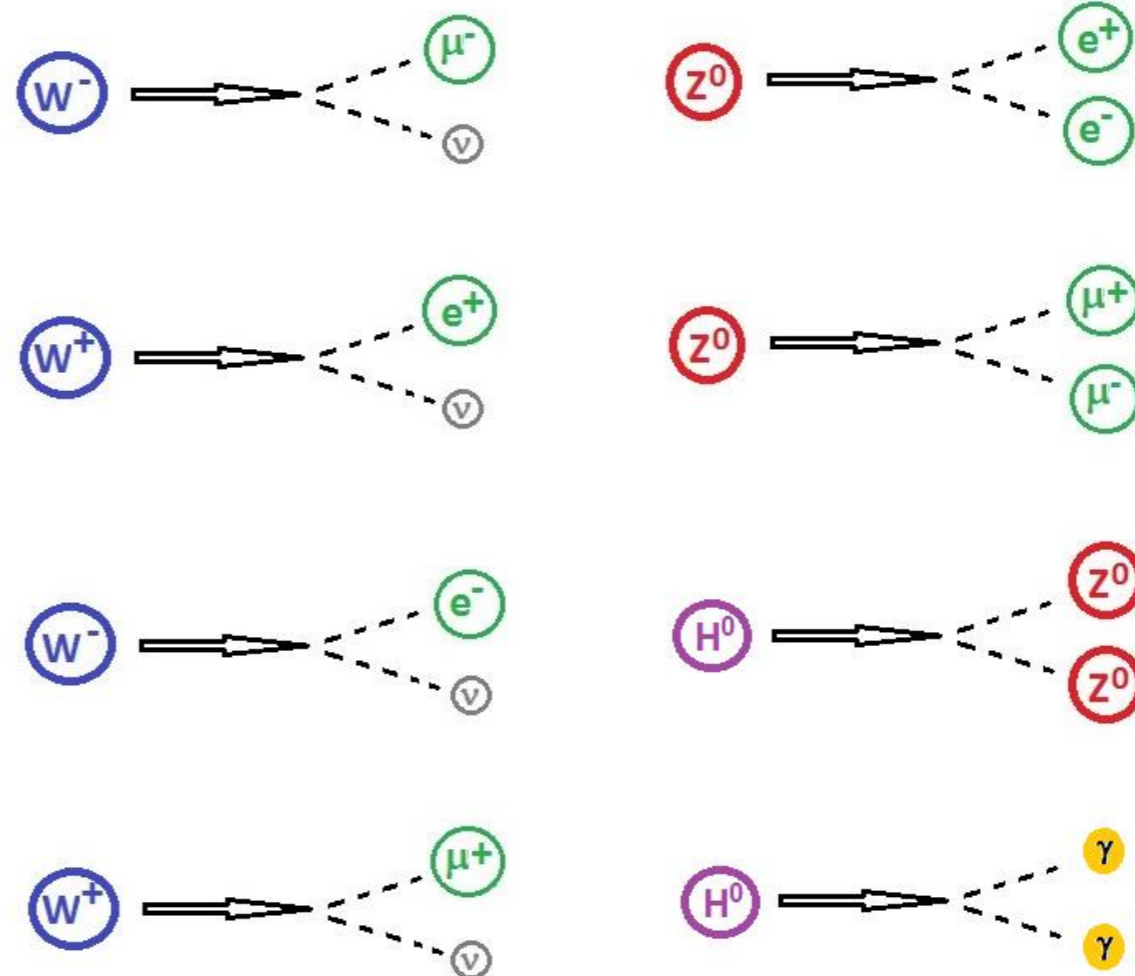


W and Z Decays

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

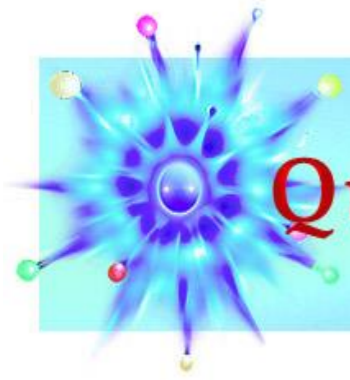
CMS *can* detect :

- electrons
- muons
- photons



CMS can infer:

- neutrinos from “missing energy”



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iSpy-webgl

event display controls

event vertex (near collision)

missing energy

energy deposit

electron track

beamline

ECAL=blue wireframe HCAL=yellow wireframe tracker inside ECAL

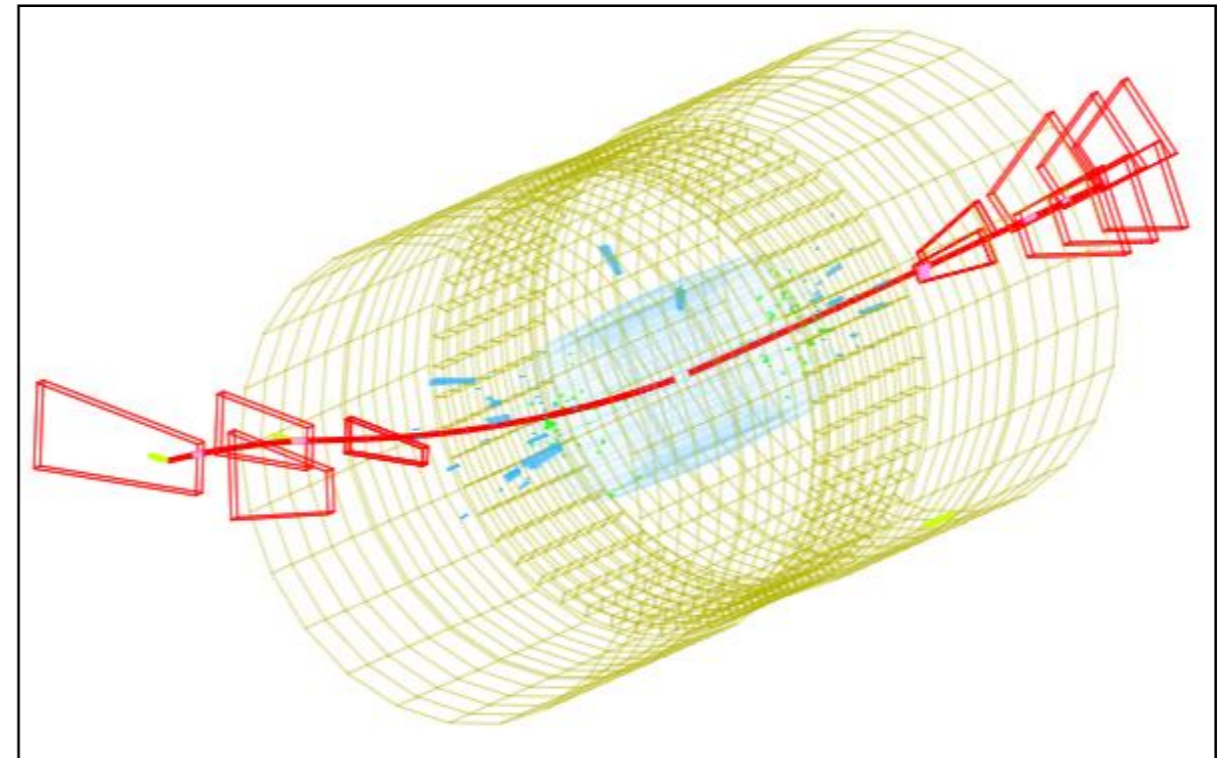
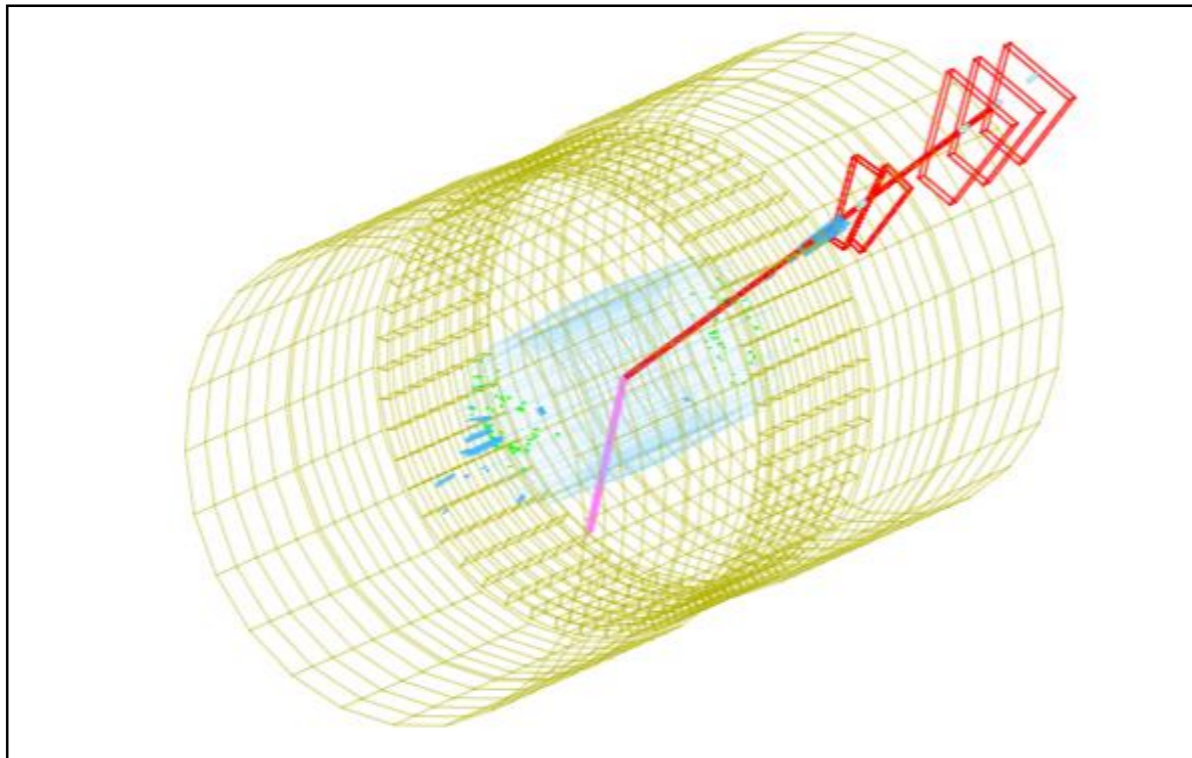
- Detector
- Tracker Barrels
- Tracker Endcaps
- ECAL Barrel
- ECAL Endcap (+)
- ECAL Endcap (-)
- HCAL Barrel
- HCAL Endcaps
- HCAL Outer
- HCAL Forward (+)
- HCAL Forward (-)
- Drift Tubes
- Cathode Strip Chambers

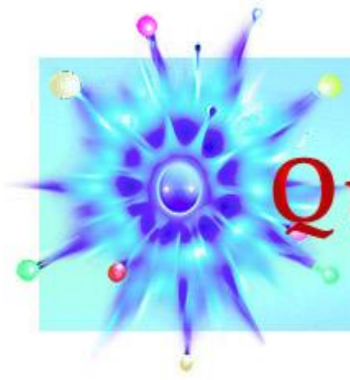


Today's Task

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

- Can we distinguish W from Z candidates?

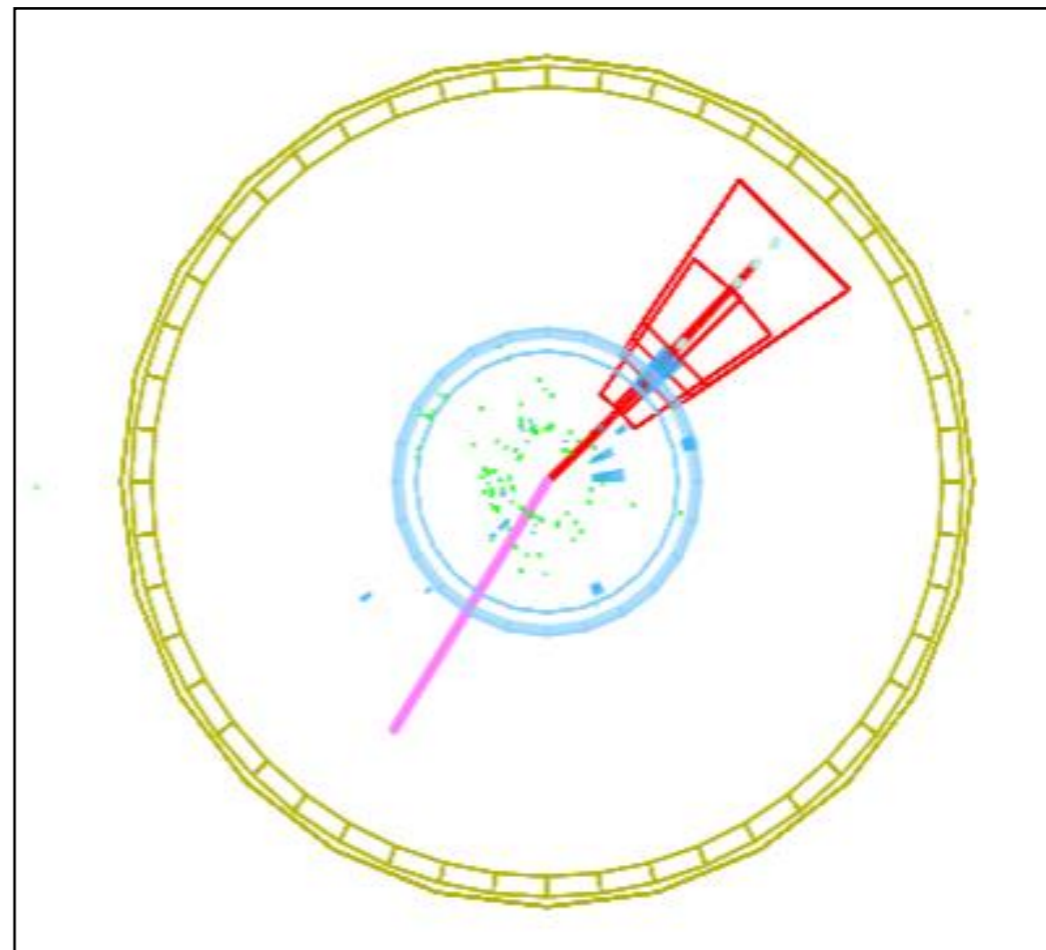
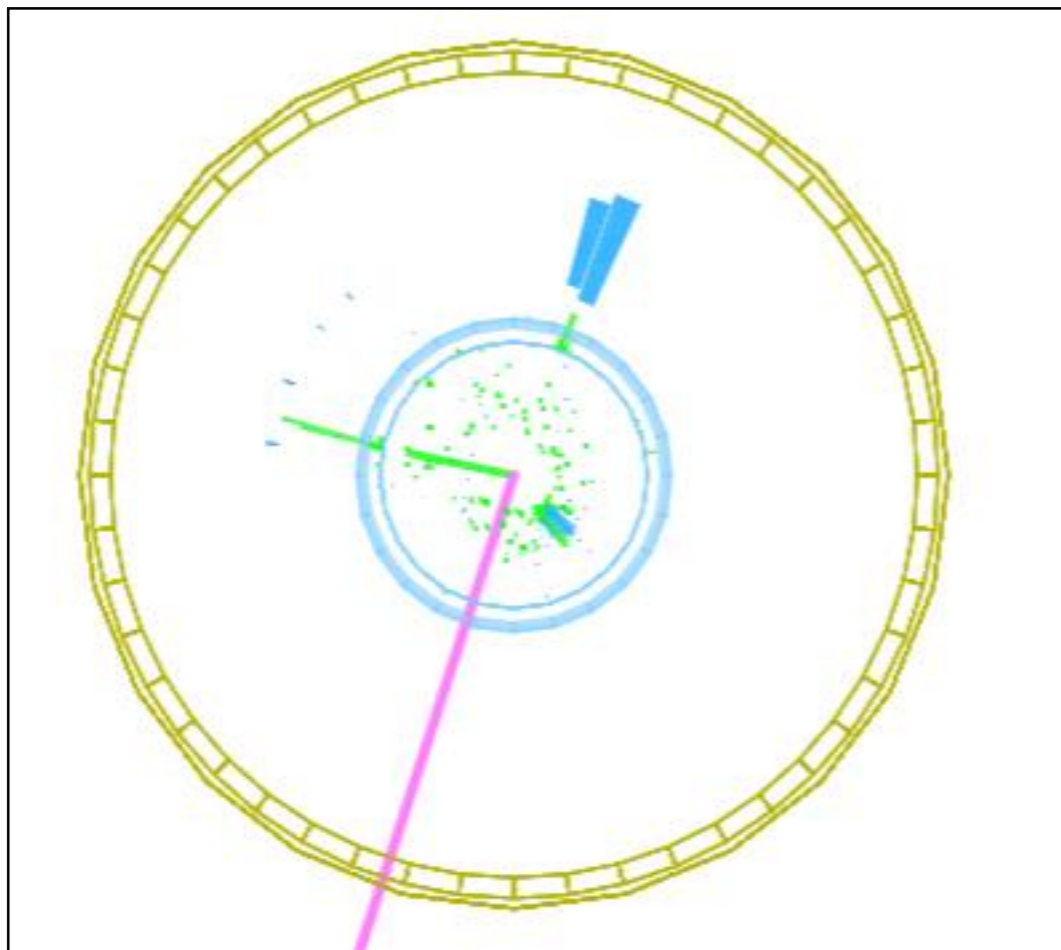


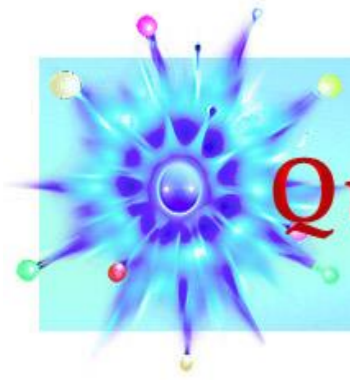


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Today's Task

- Can we calculate the e/μ ratio?

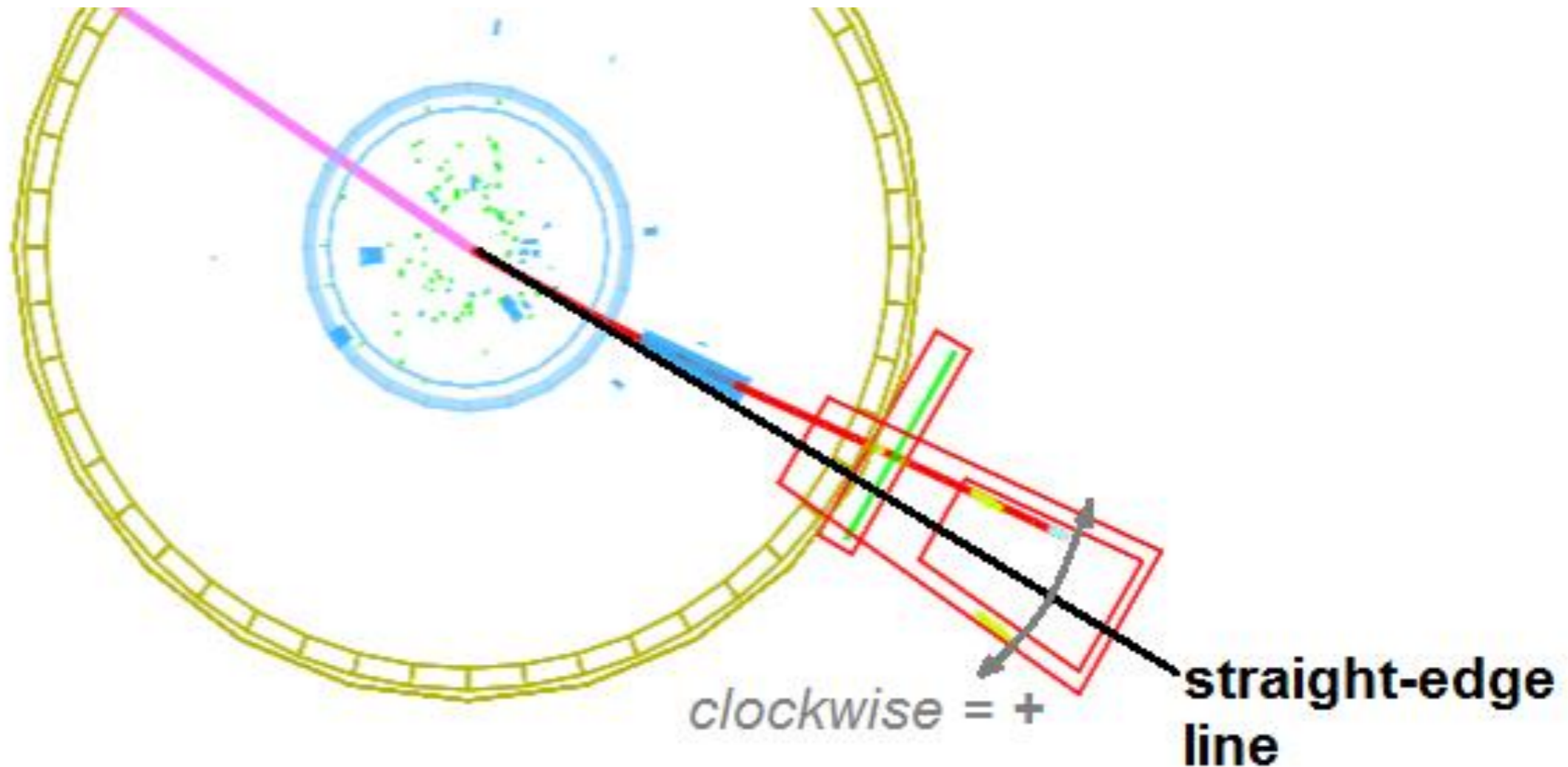




QuarkNet

Today's Task

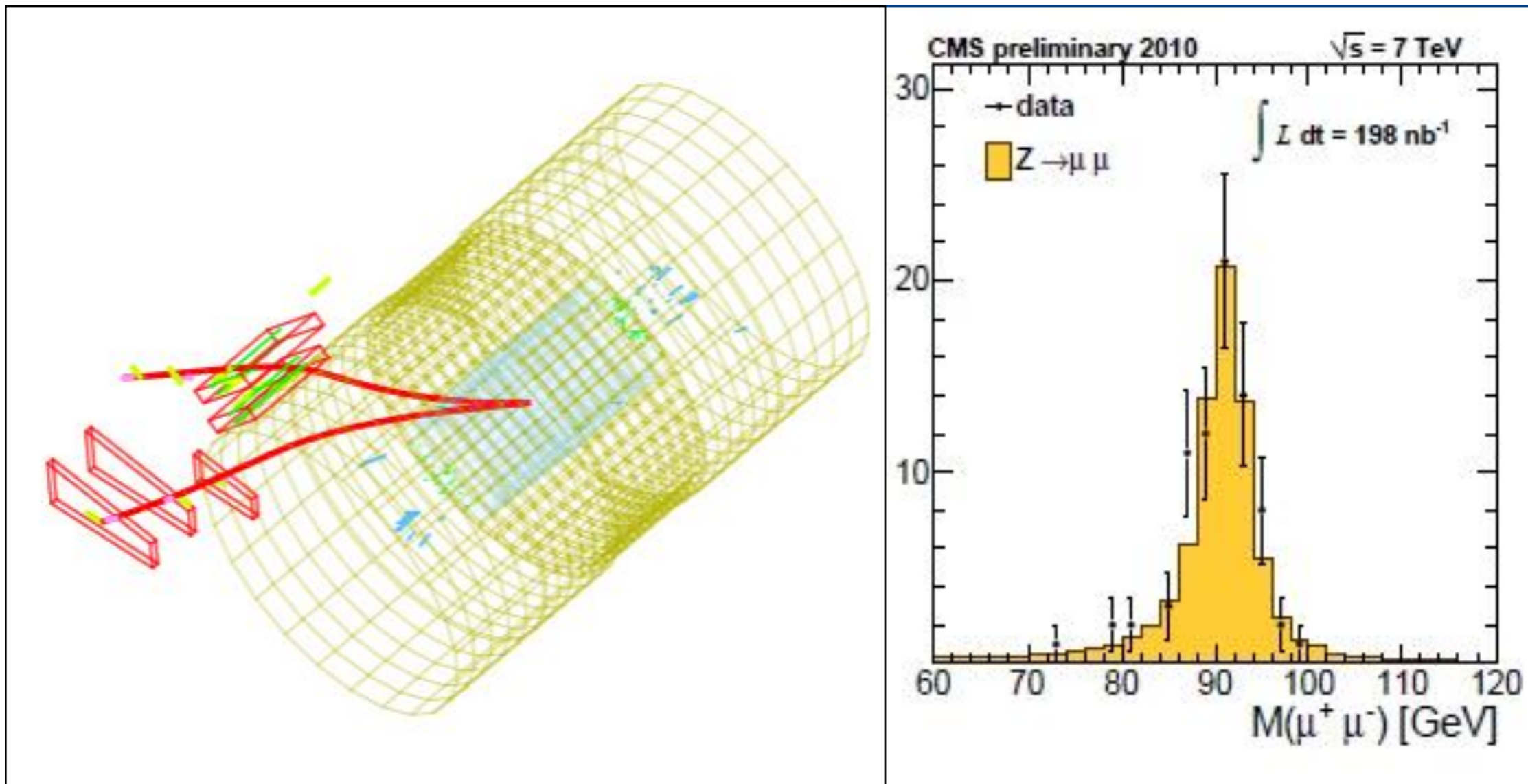
- Can we calculate a W^+/W^- ratio for CMS?





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

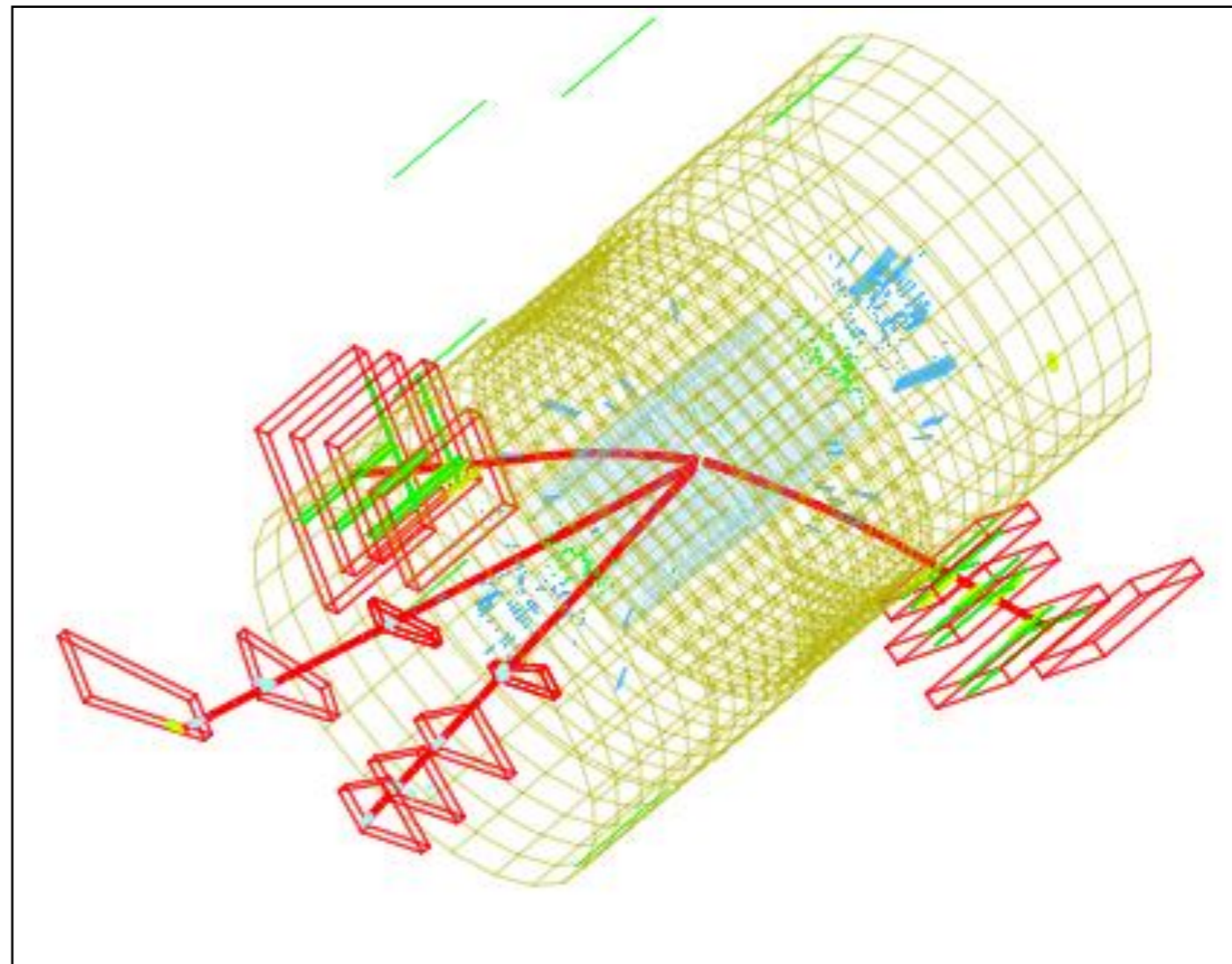
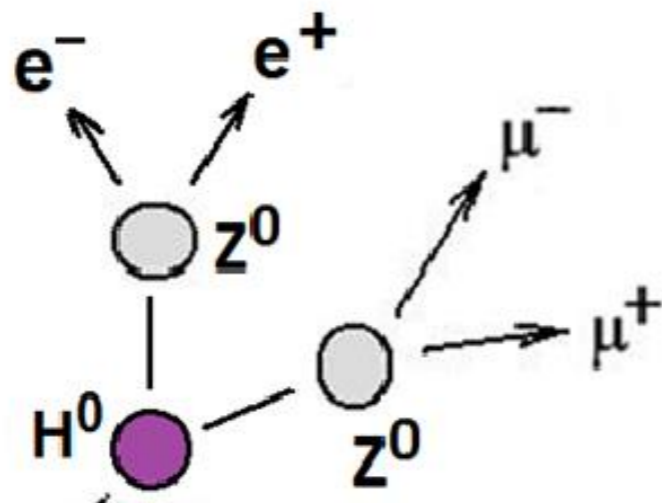


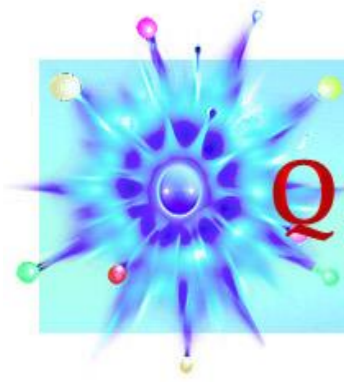
Today's Task

- Can we find rare $H \rightarrow ZZ$ events?
 - $Z \rightarrow e^+e^-$
 - $Z \rightarrow \mu^+\mu^-$

Can we pick out electrons and/or muons?

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

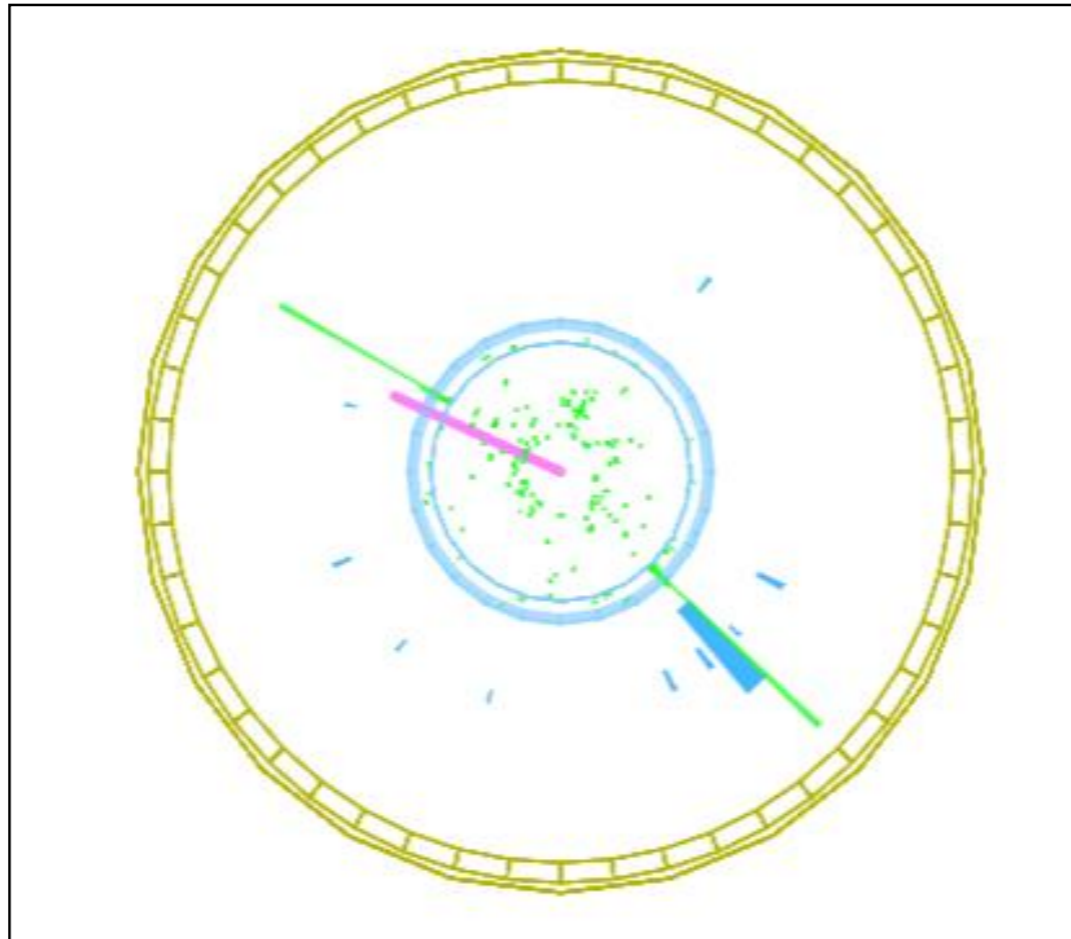




QuarkNet

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?



Recording event data

CIMA
CMS Instrument for Masterclass Analysis

Choose your Masterclass

test
Test2
31Jan2015

Choose your location

Buffalo
MexicoCity
Quito

Choose your group

6
7
8
9
10

Choose the date of your masterclass, the institute, and your dataset.

Find your dataset.

Record parent particles and decay modes.

Back Events Table (Group 1) Mass Histogram (TT1) Results (TT1) ➔ Event Display

Masterclass: TestTables-Feb2017
location: TT1
Group: 1

Instructions (also available as screencast):

- For each event, identify the final state and select a primary state candidate.
 - For Higgs or Zoo candidate, no final state is chosen
 - If you cannot decide between W^+ and W^- , choose W instead
- If you think the final state is a neutral particle (like a Z), but you don't know its exact type, select NP for "neutral particle." Find its mass from the Event Display and enter it.
- Once you have selected everything, click "Submit".

In case of an error, double clicking the data line will reload it; you can then try it again.

Select Event Event index: 10 Event number: 1-10	final state <input type="checkbox"/> Electron <input checked="" type="checkbox"/> Muon (μ)	primary state candidate <input type="checkbox"/> W^- <input checked="" type="checkbox"/> NP <input type="checkbox"/> Higgs <input type="checkbox"/> W^+ <input type="checkbox"/> W <input type="checkbox"/> Zoo	NP Mass: 4.55 GeV/c ² <input type="button" value="Submit"/>
--	---	--	---

Event index	Event number	Chosen Values	Mass
9	1-9	Z, μ	mu
8	1-8	e, W^+	
7	1-7	μ , Z	95
6	1-6	μ , Z	NaN
5	1-5	e, Z	NaN
4	1-4	μ , W^+	
3	1-3	μ , W^+	
2	1-2	e, W^-	
1	1-1	e, W^+	



Recording event data

Mass Histogram and Results pages

Back Events Table Mass Histogram Results

Masterclass: 31Jan2015
location: MexicoCity

Group	Muon	Electron	W	W-	W+	Z	Higgs	Zoo	Total
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0



Total:

Muon	Electron	W	W-	W+	Z	Higgs	Zoo	Sum	amu	W+W-
9	9	3	1	3	11	2	3	23	1	3



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.