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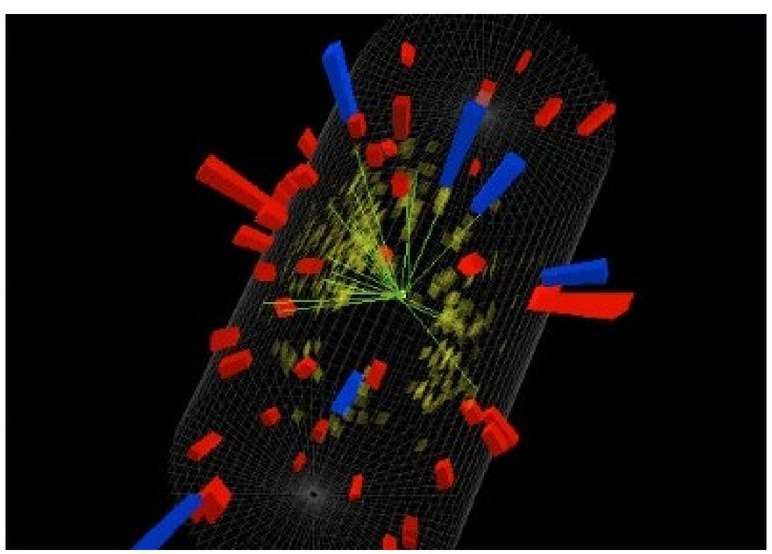
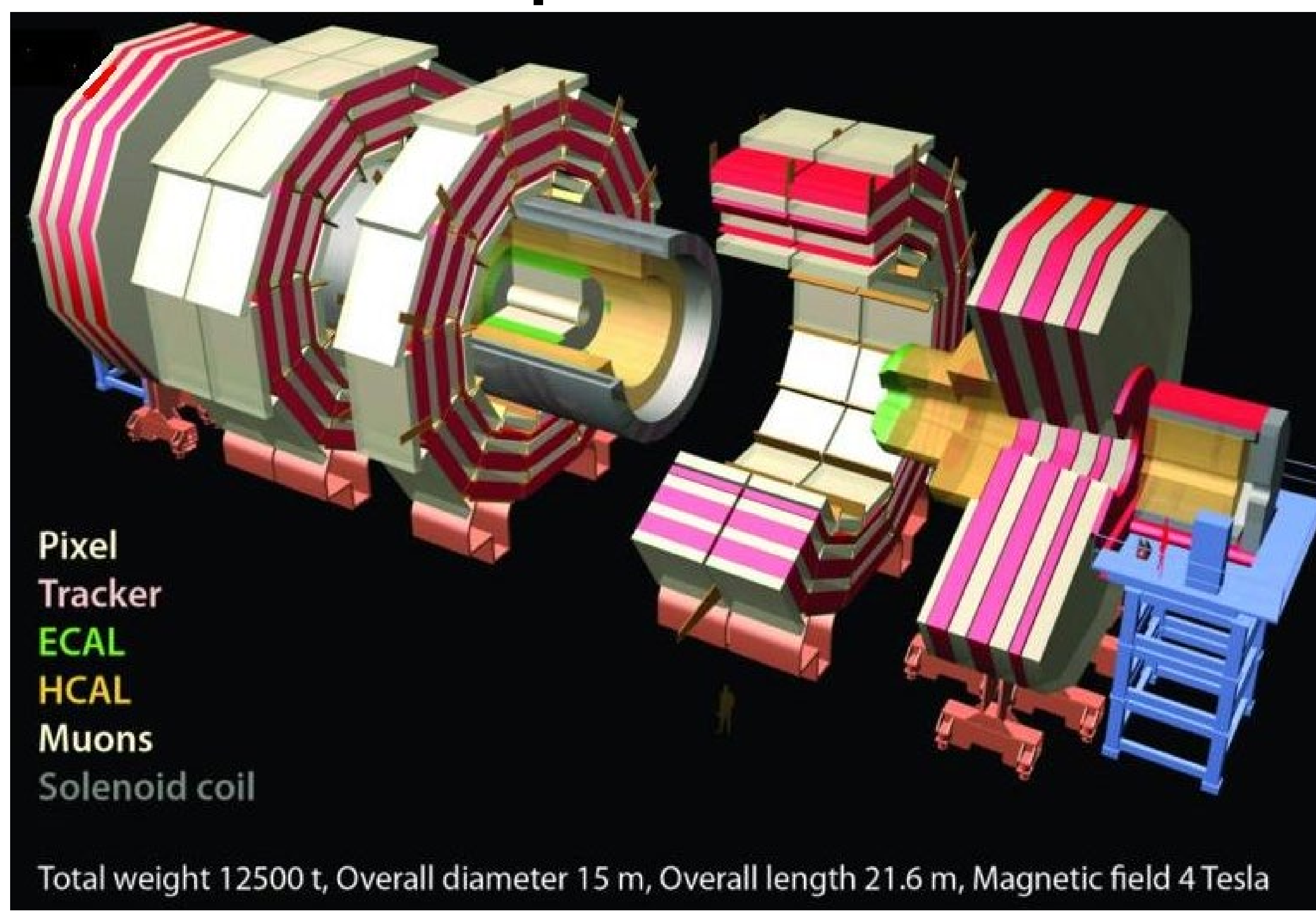
INTERNATIONAL MASTERCLASSES
hands on particle physics

DRAFT

CMS 2,4-lepton Masterclass





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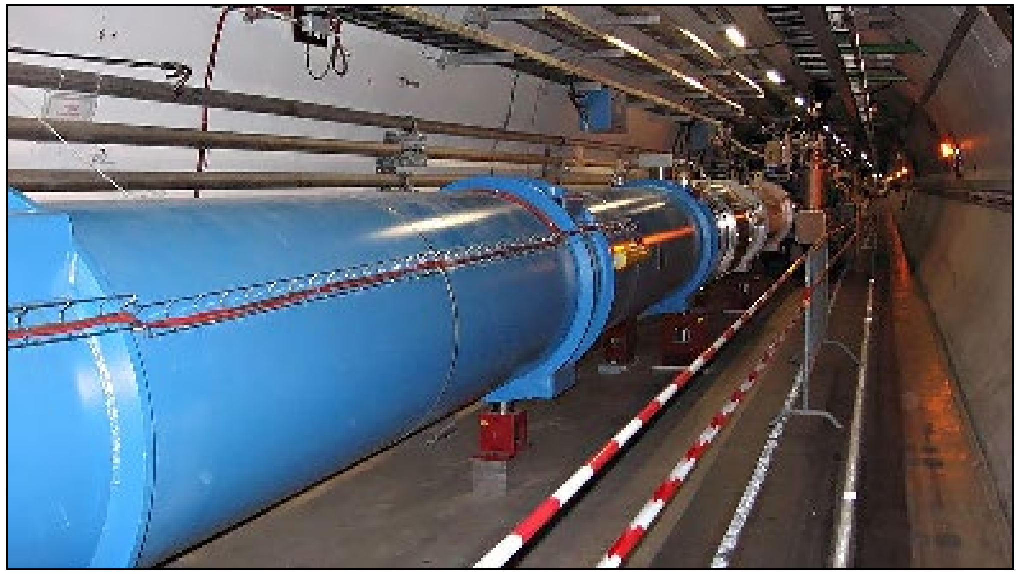
The LHC and New Physics

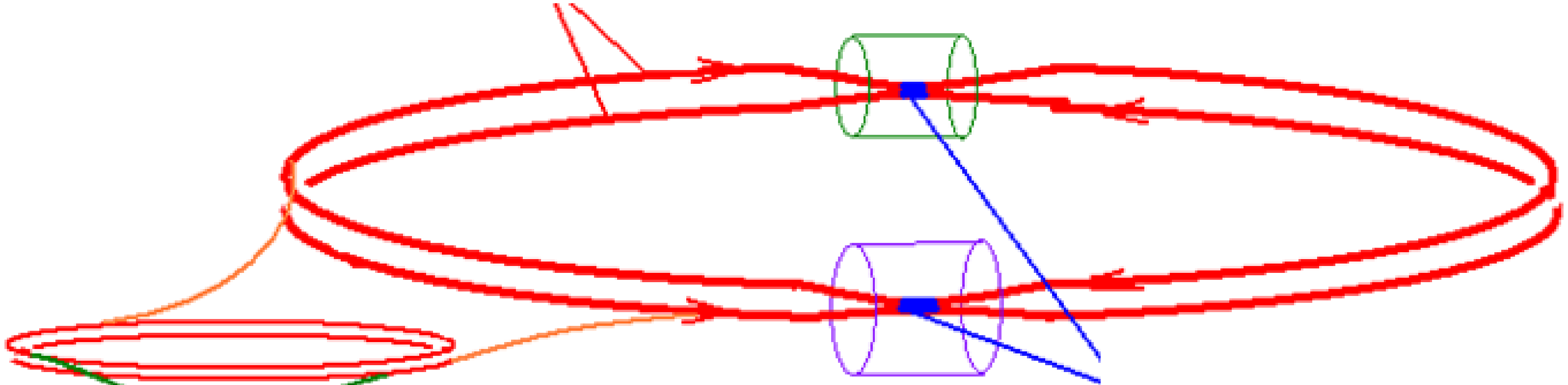
It's a time of exciting new discoveries in particle physics!



*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.*

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 . . .

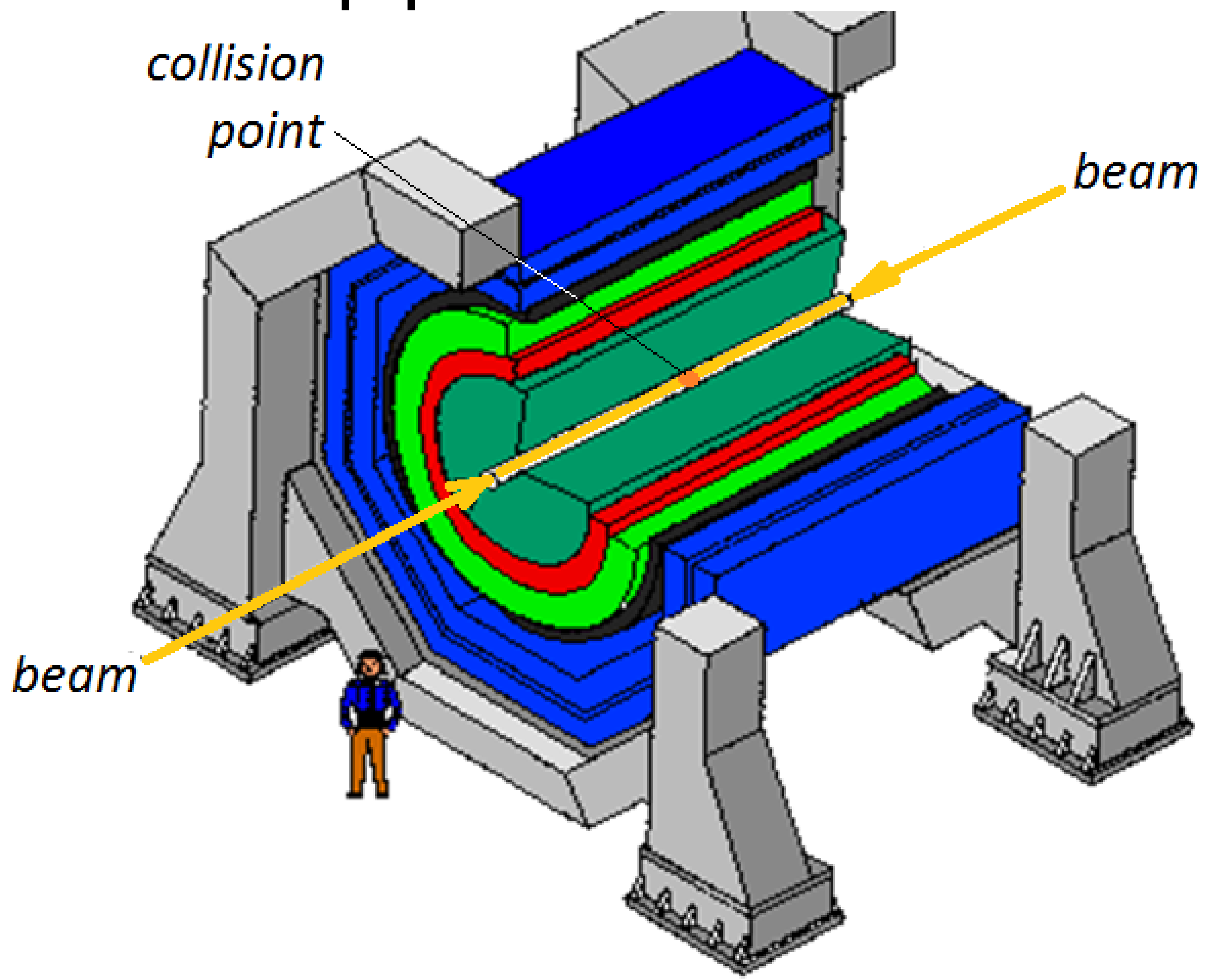
Tracking

Electromagnetic calorimeter

Hadronic calorimeter

Magnet*

Muon chamber

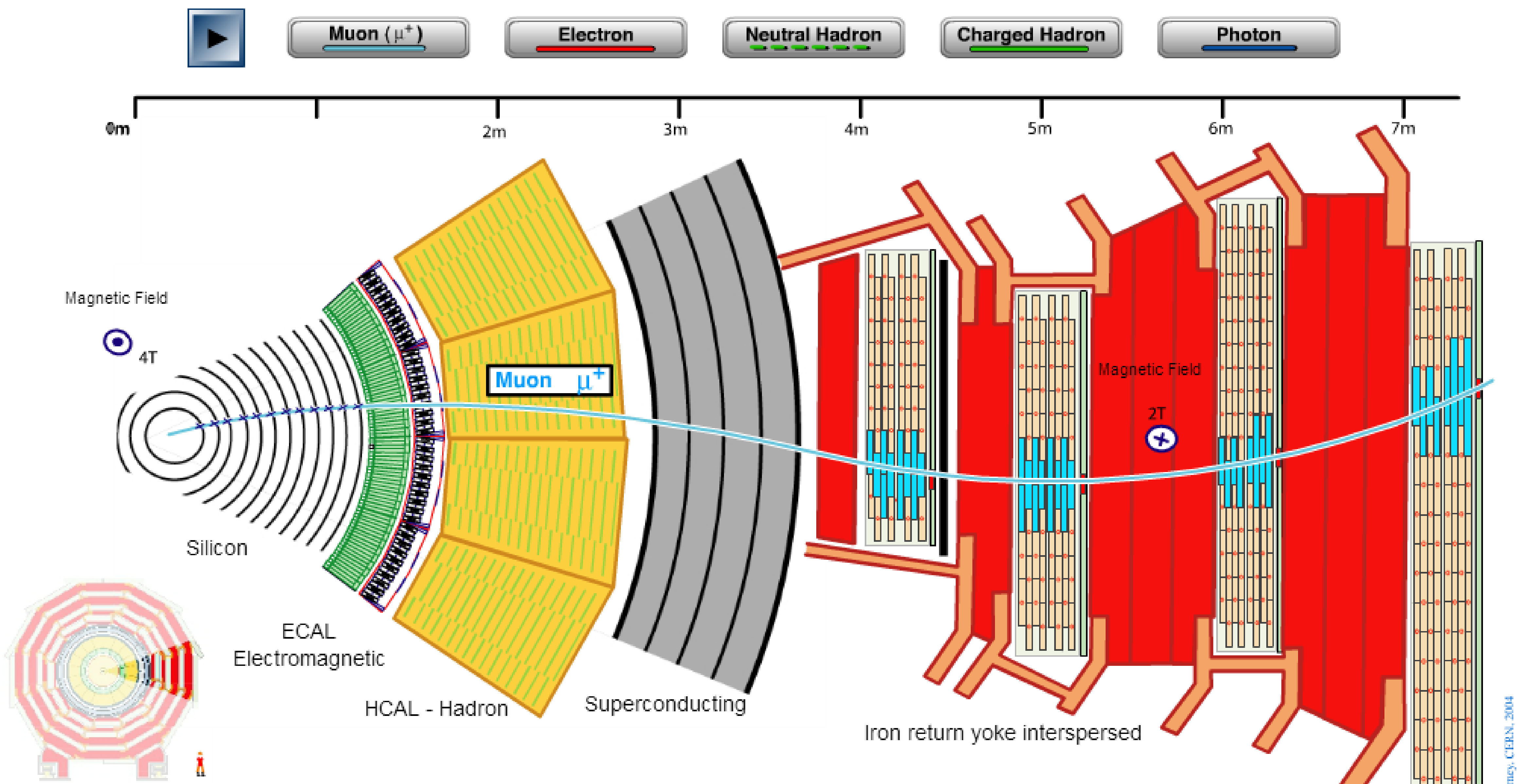


* *location of magnet depends on specific detector design*

Detector Tracks

Web Version

Transverse Slice of the Compact Muon Solenoid (CMS) Detector



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.

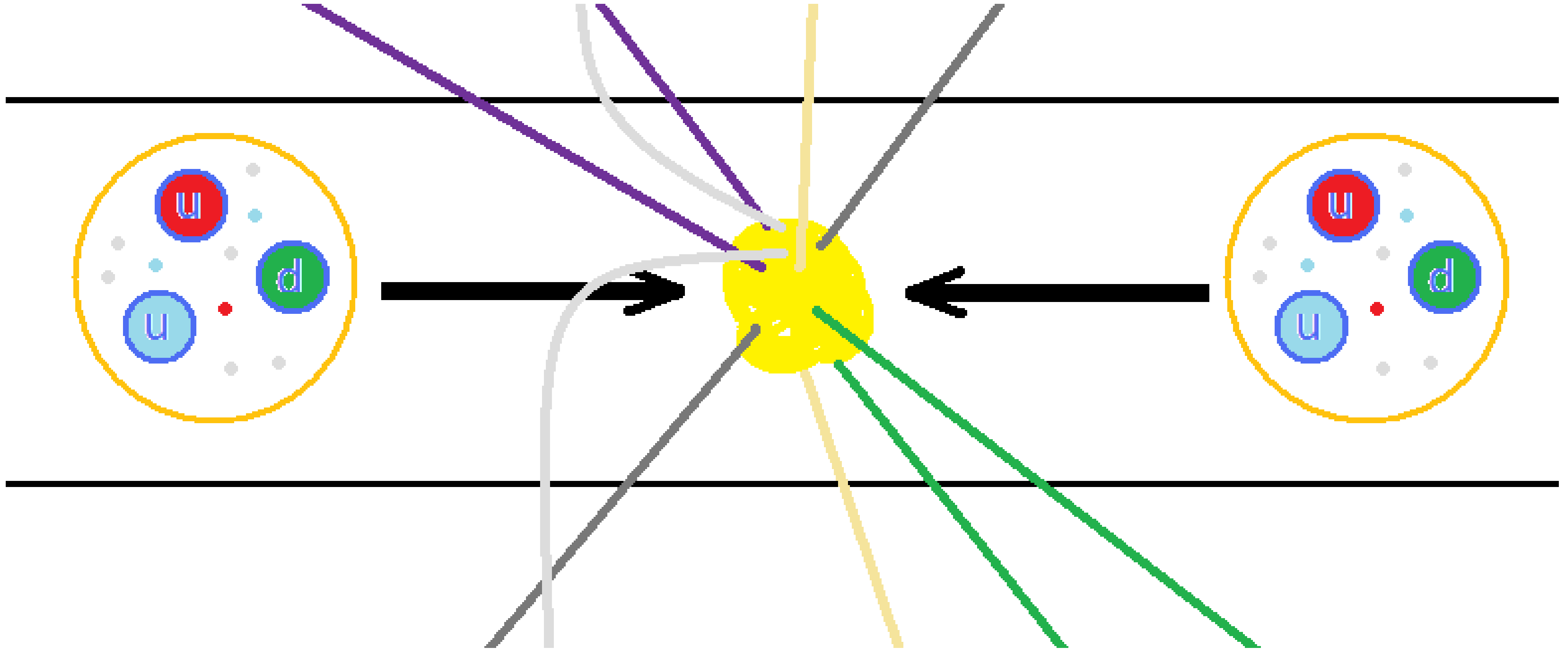
Derived from CMS Detector Slice from CERN

Energy & Particle Mass

We will look at data from 2 sets:

- Beam energy 4 TeV (collision energy 2 x 4 TeV =   8 TeV)
- Beam energy 7 TeV (collision energy 2 x 7 TeV = 14 TeV).

Each particle inside a proton shares only a portion of that energy and only a portion of the momentum of the proton.



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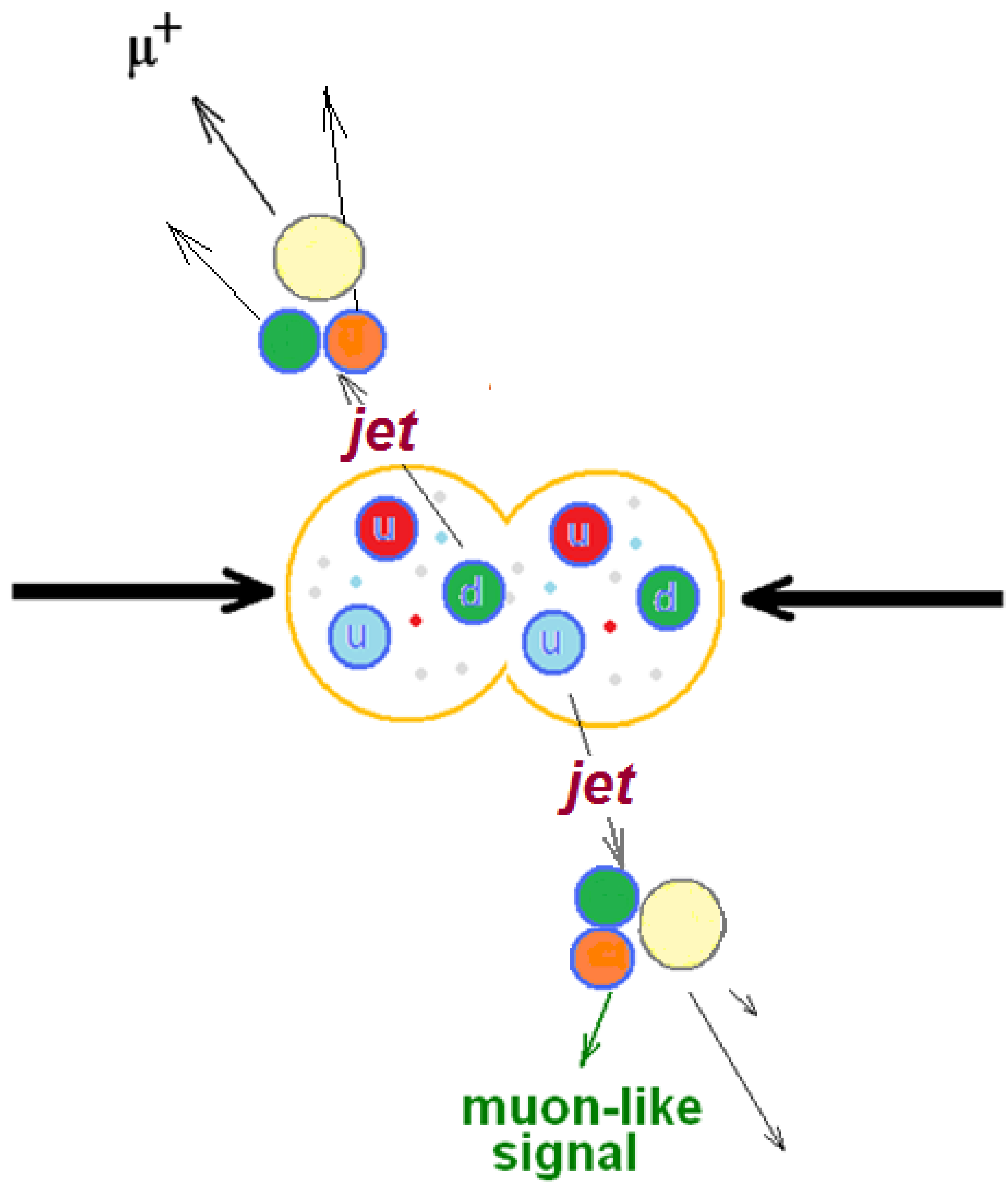
Background Events

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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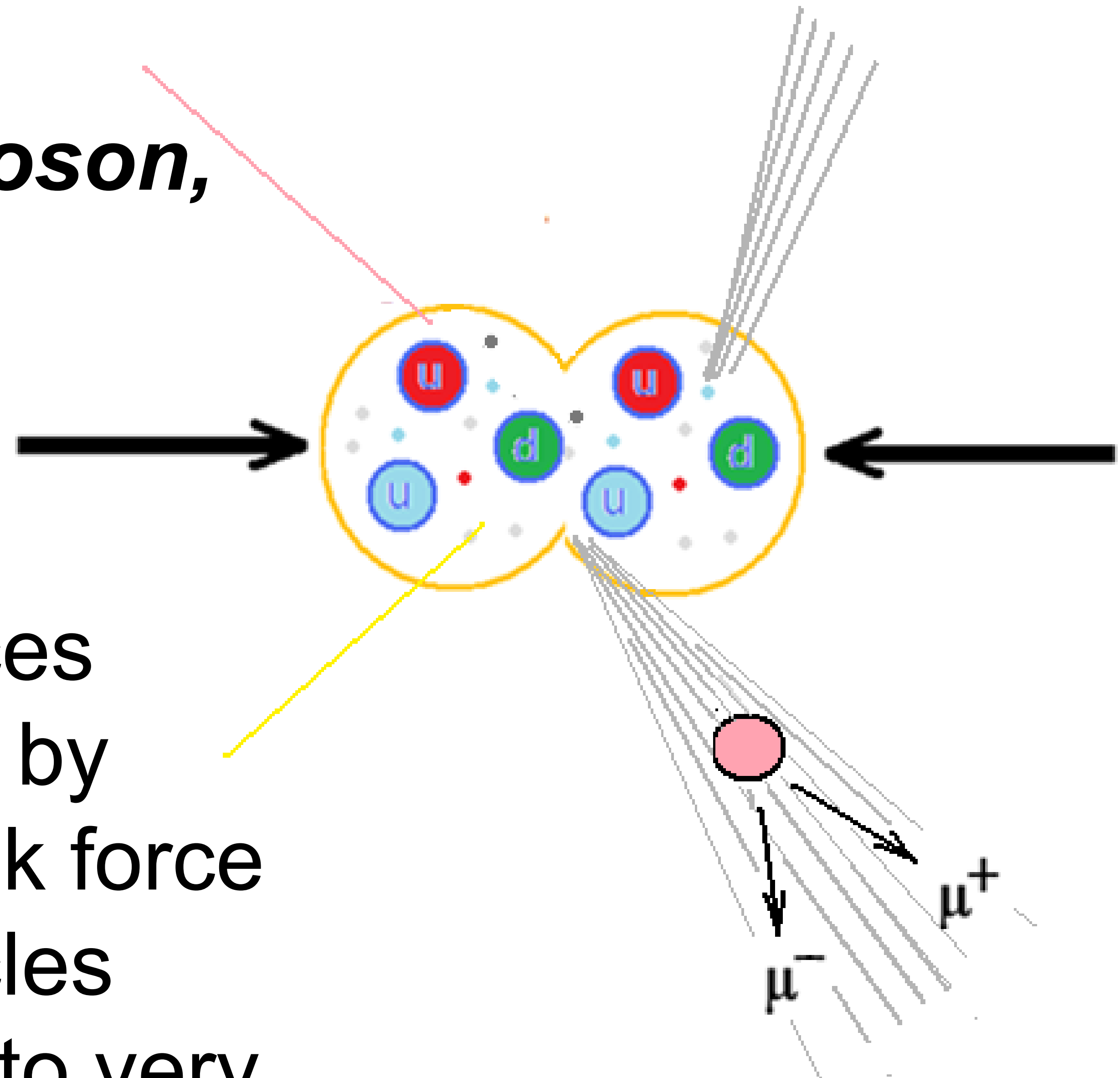
W and Z Particles

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

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



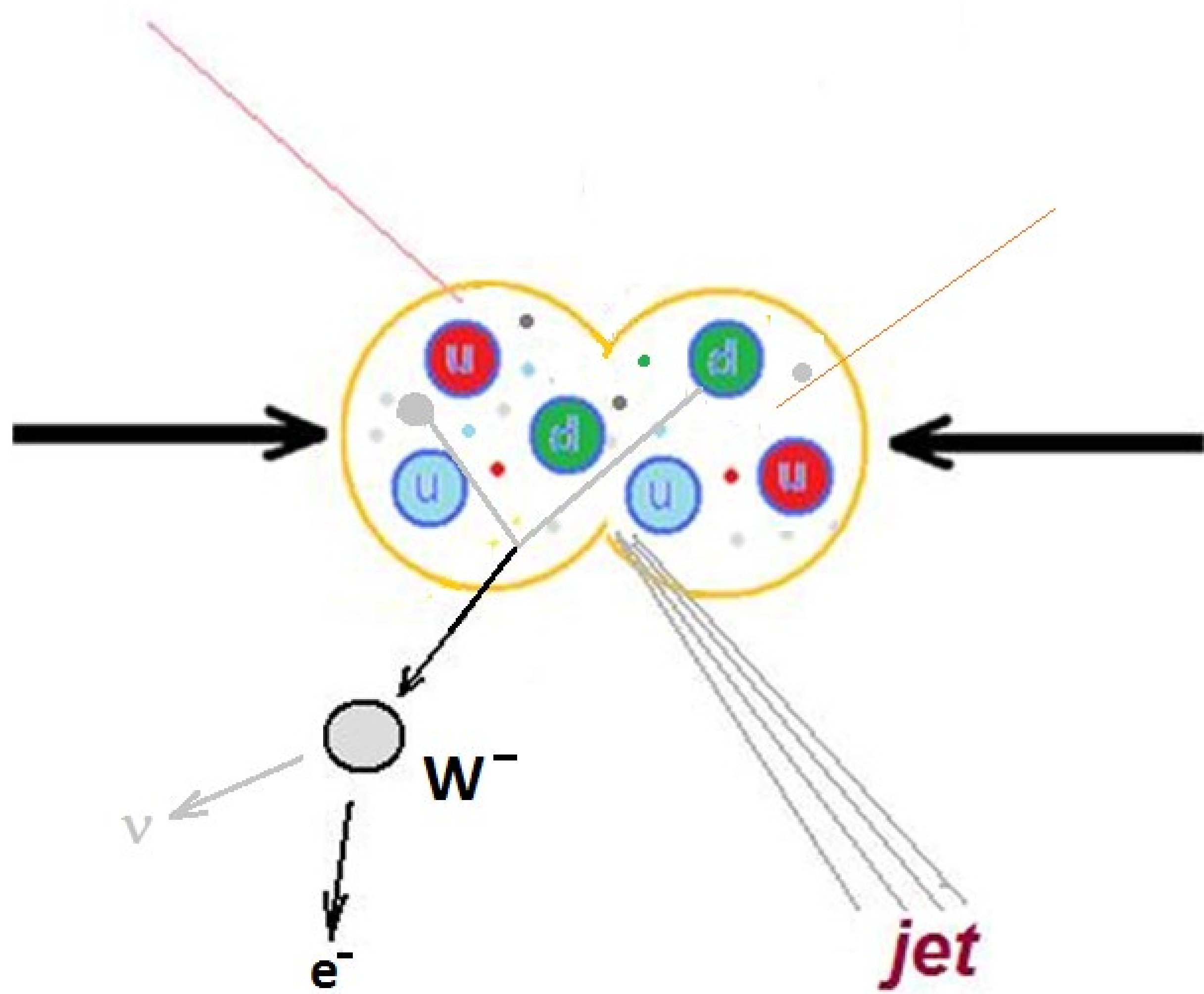
Unlike electromagnetic forces carried over long distances by massless photons, the weak force is carried by massive particles which restricts interactions to very tiny distances.

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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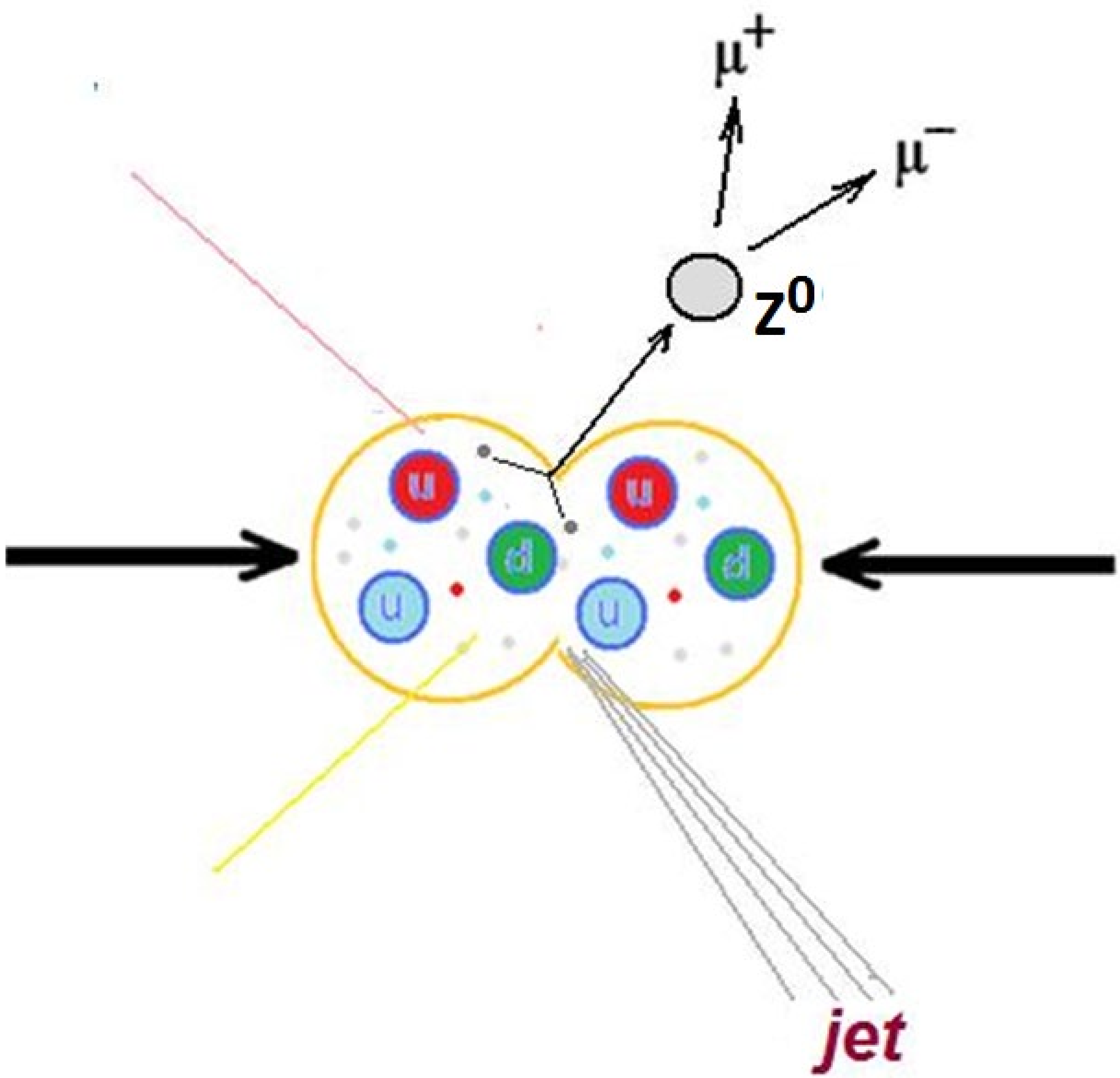
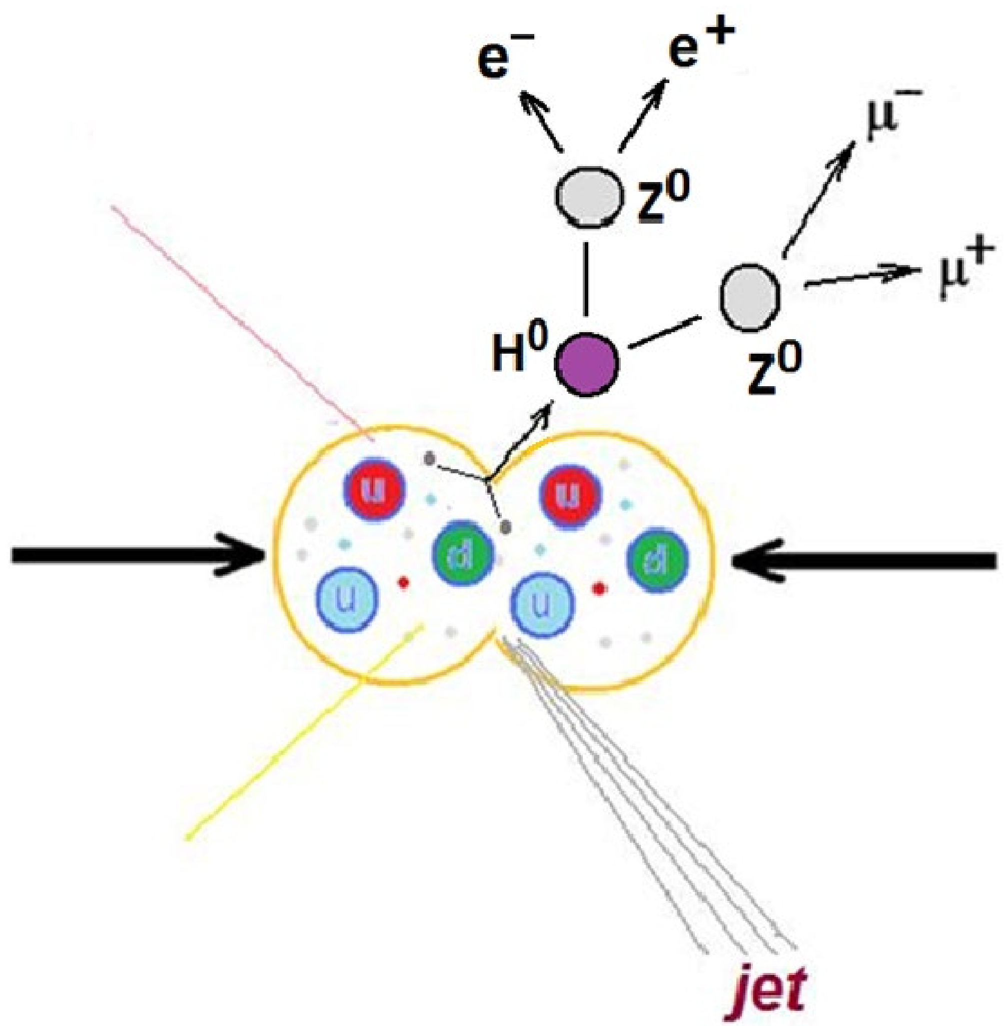


Higgs Particles

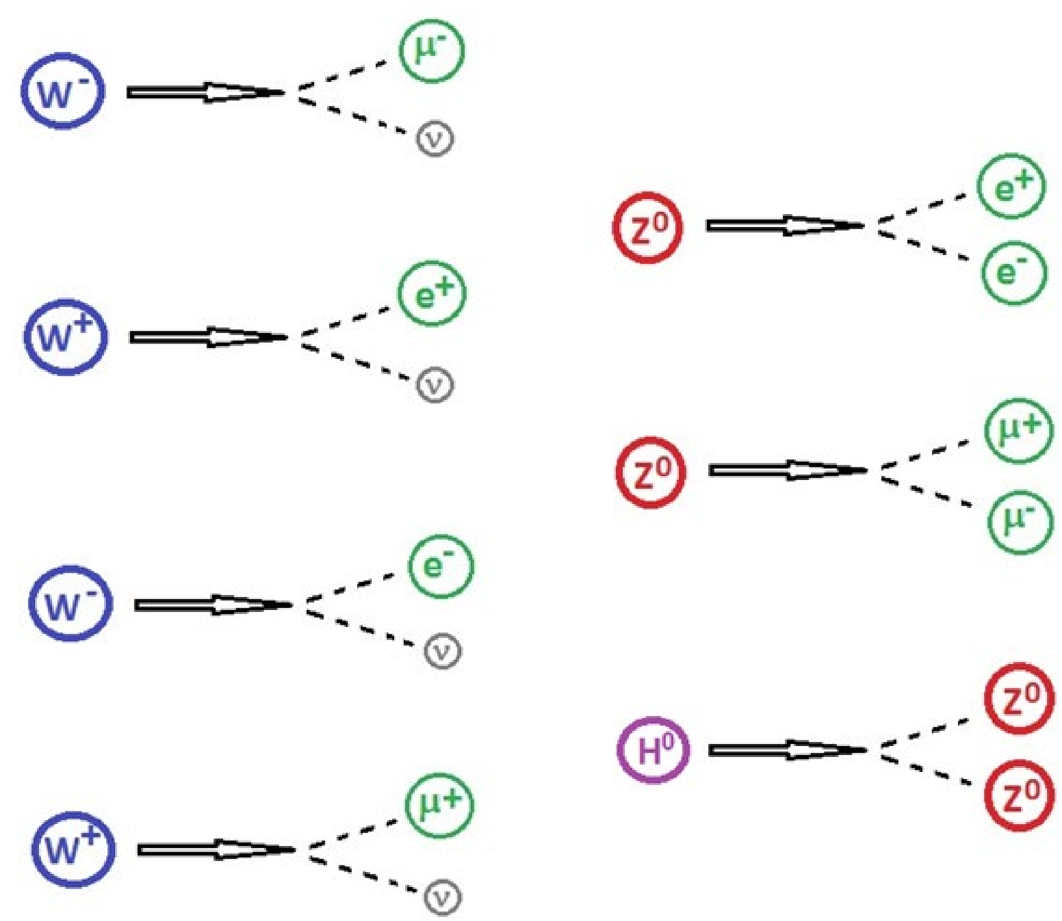
The Higgs boson was discovered by CMS and ATLAS and announced on July 4, 2012.



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

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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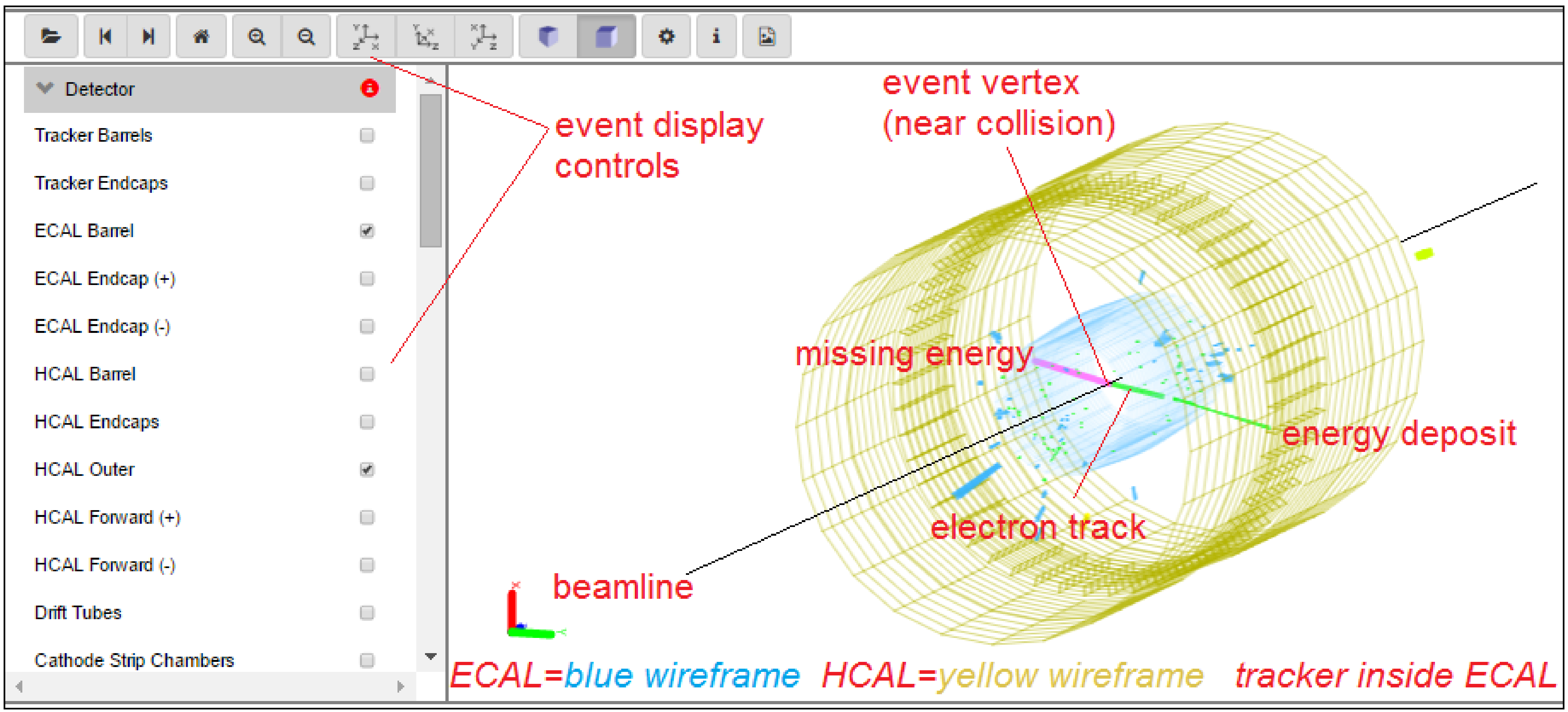
iSpy-webgl



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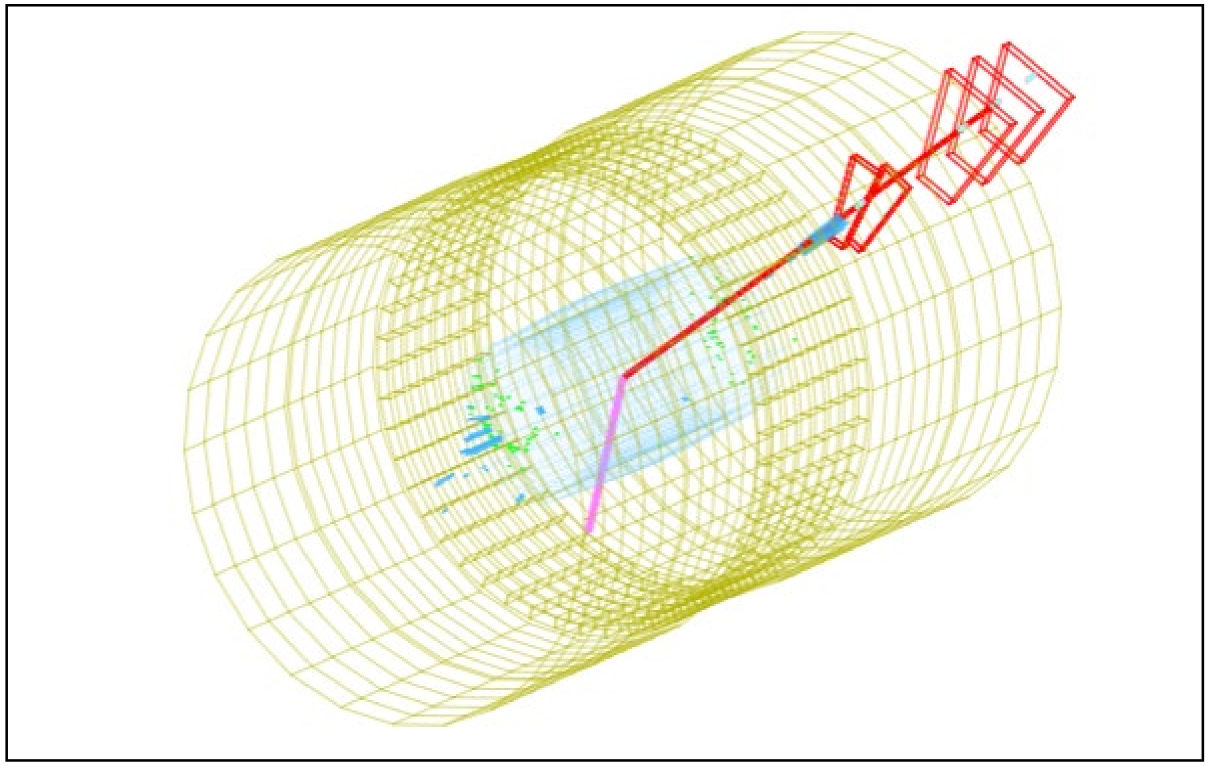
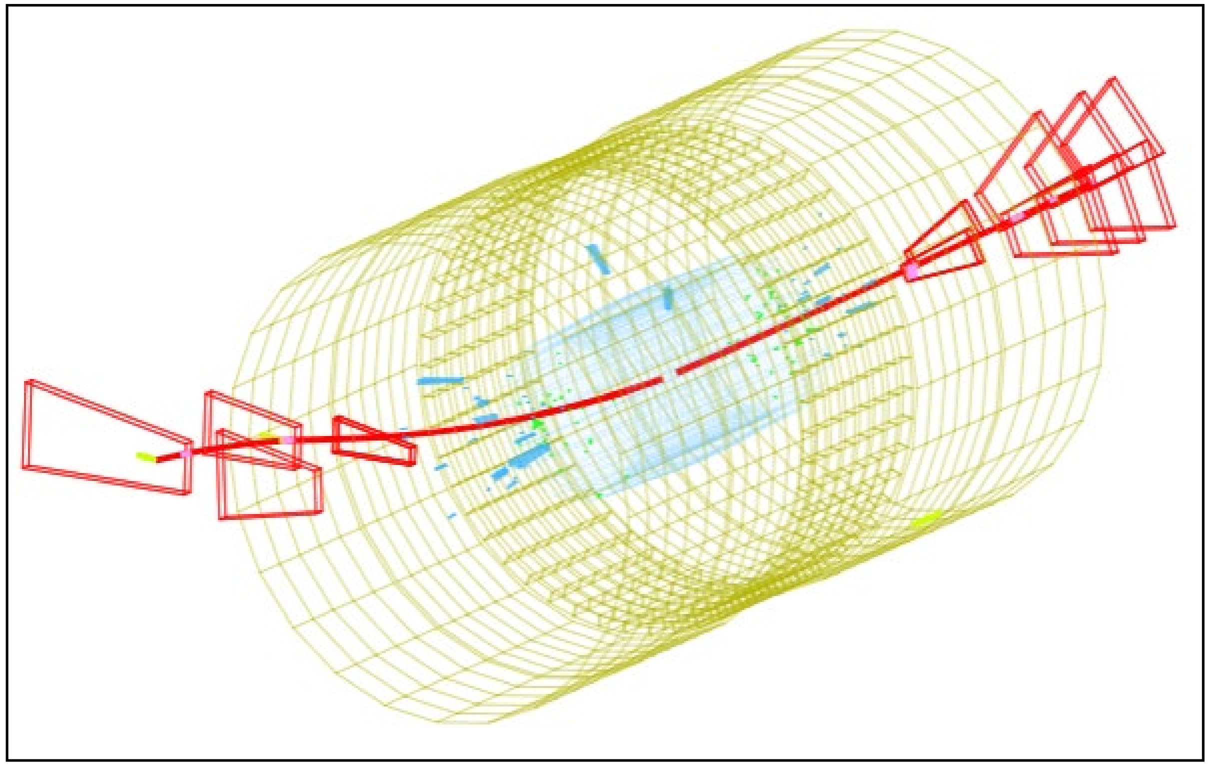
Today's Task

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

- Can we distinguish W from Z candidates?





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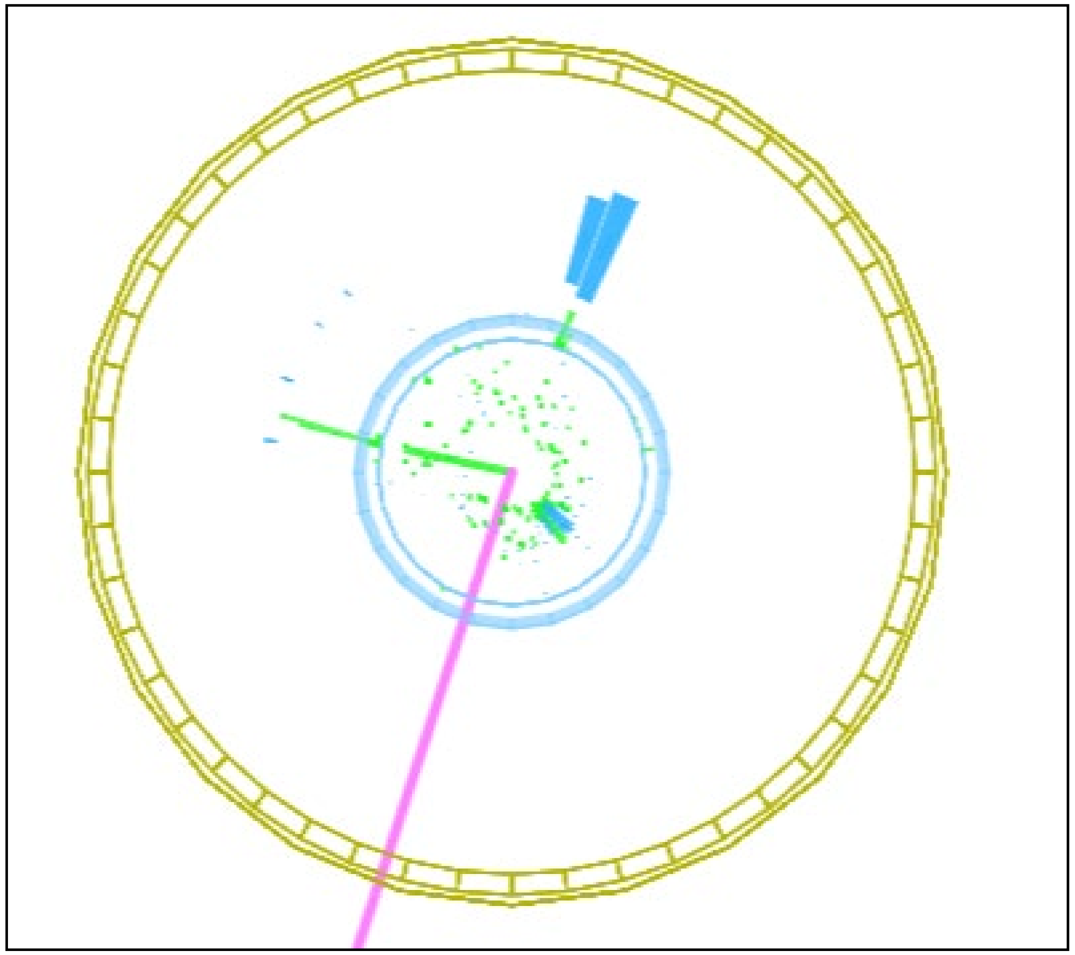
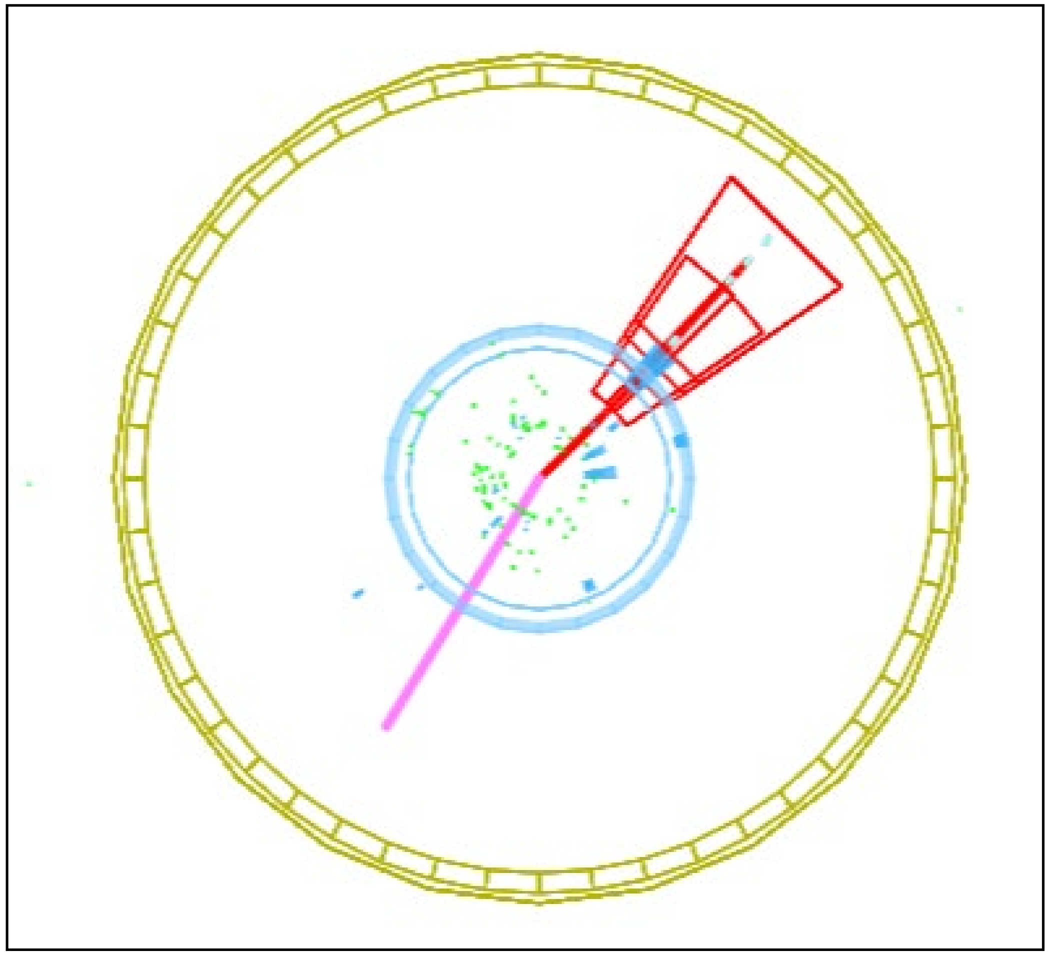
Today's Task

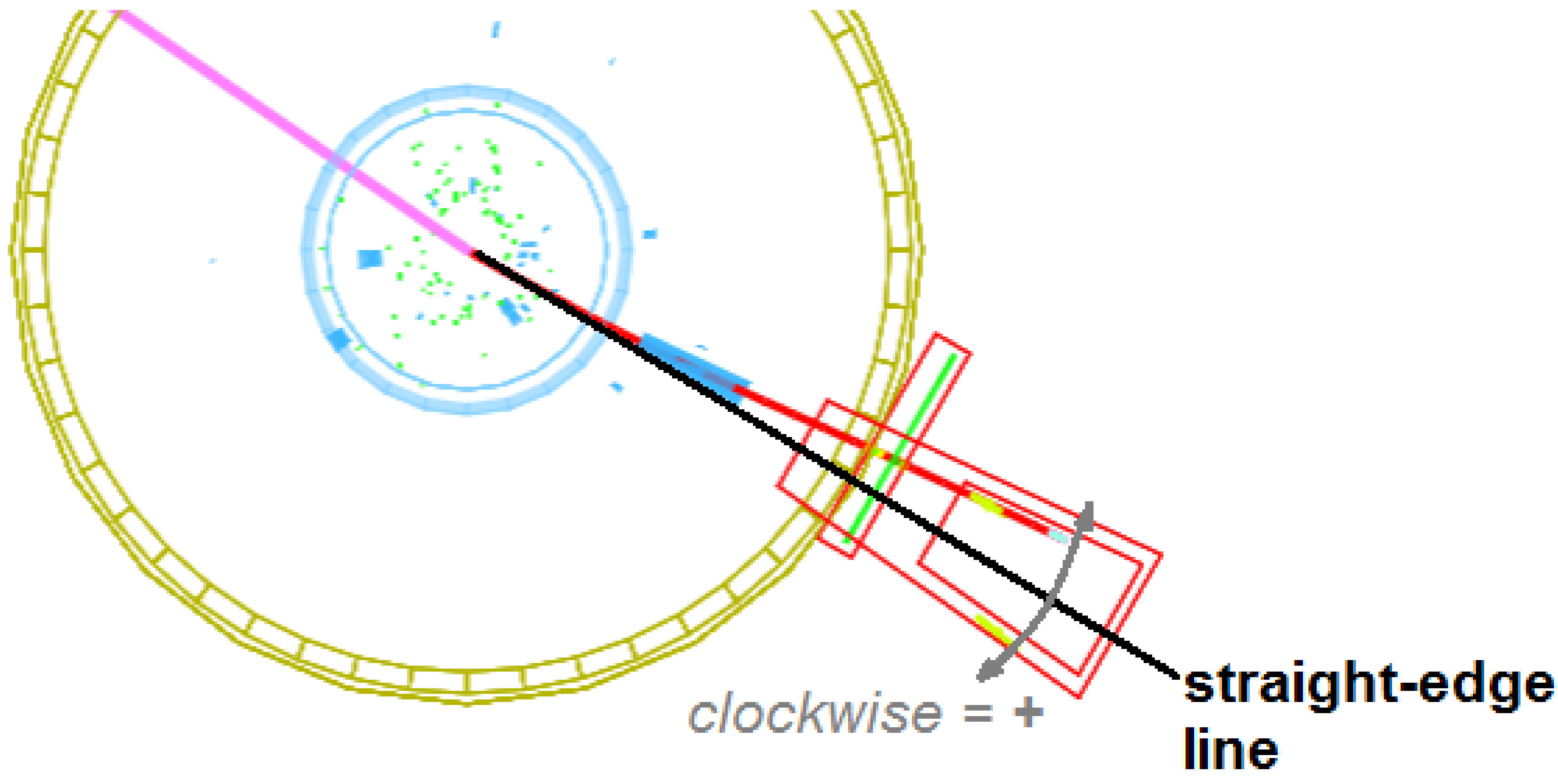
- Can we calculate the e/μ ratio?





Today's Task

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



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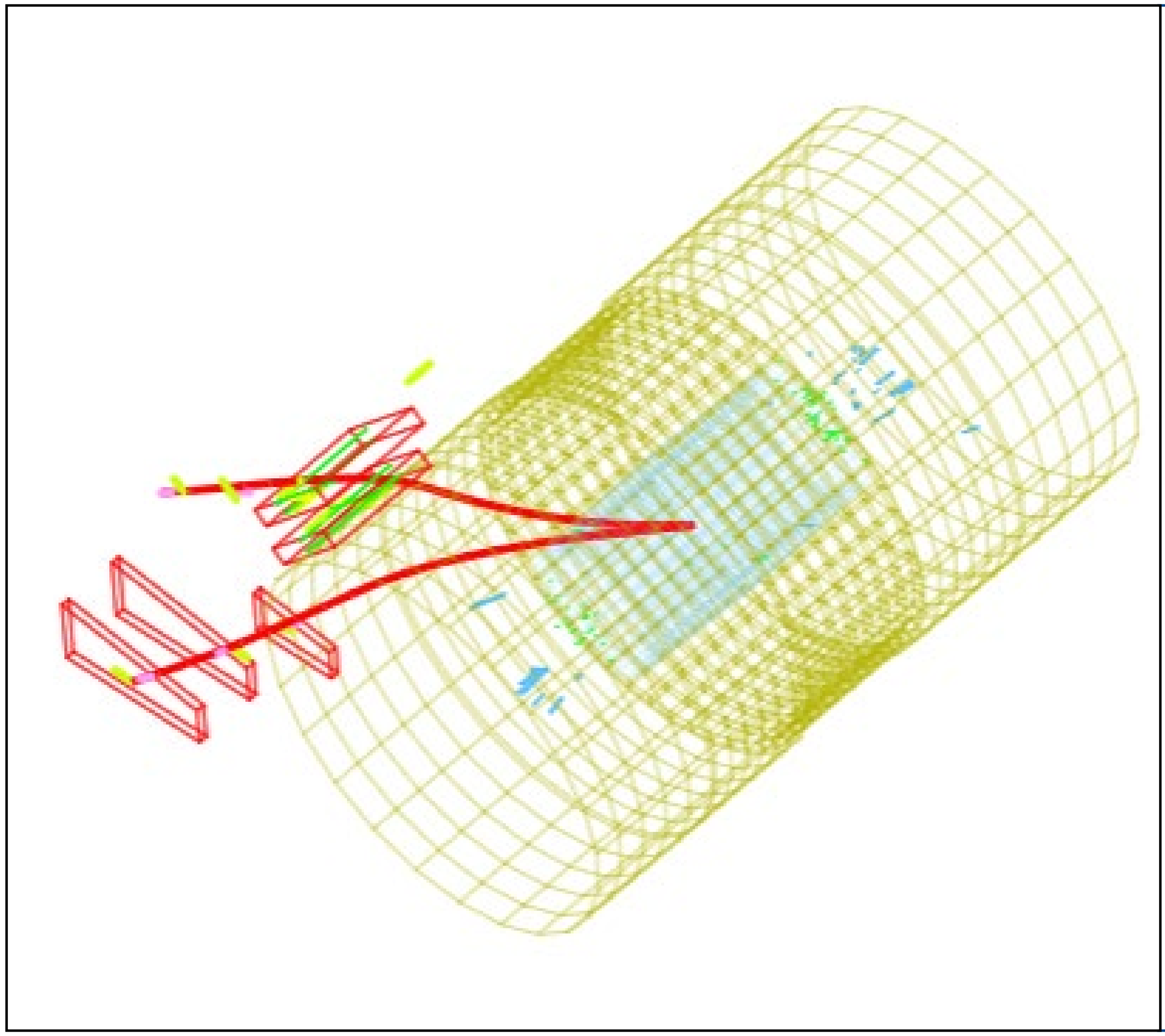
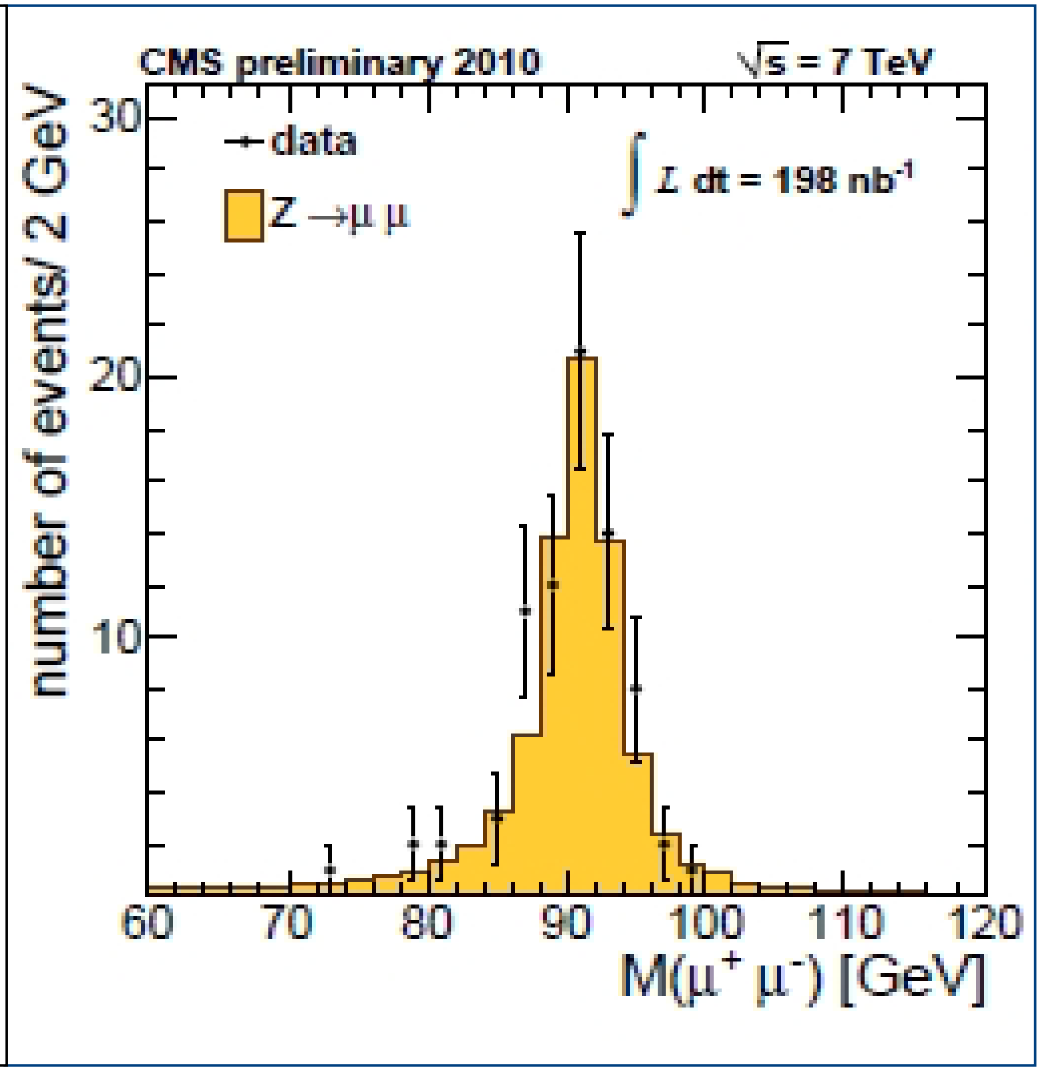
Today's Task

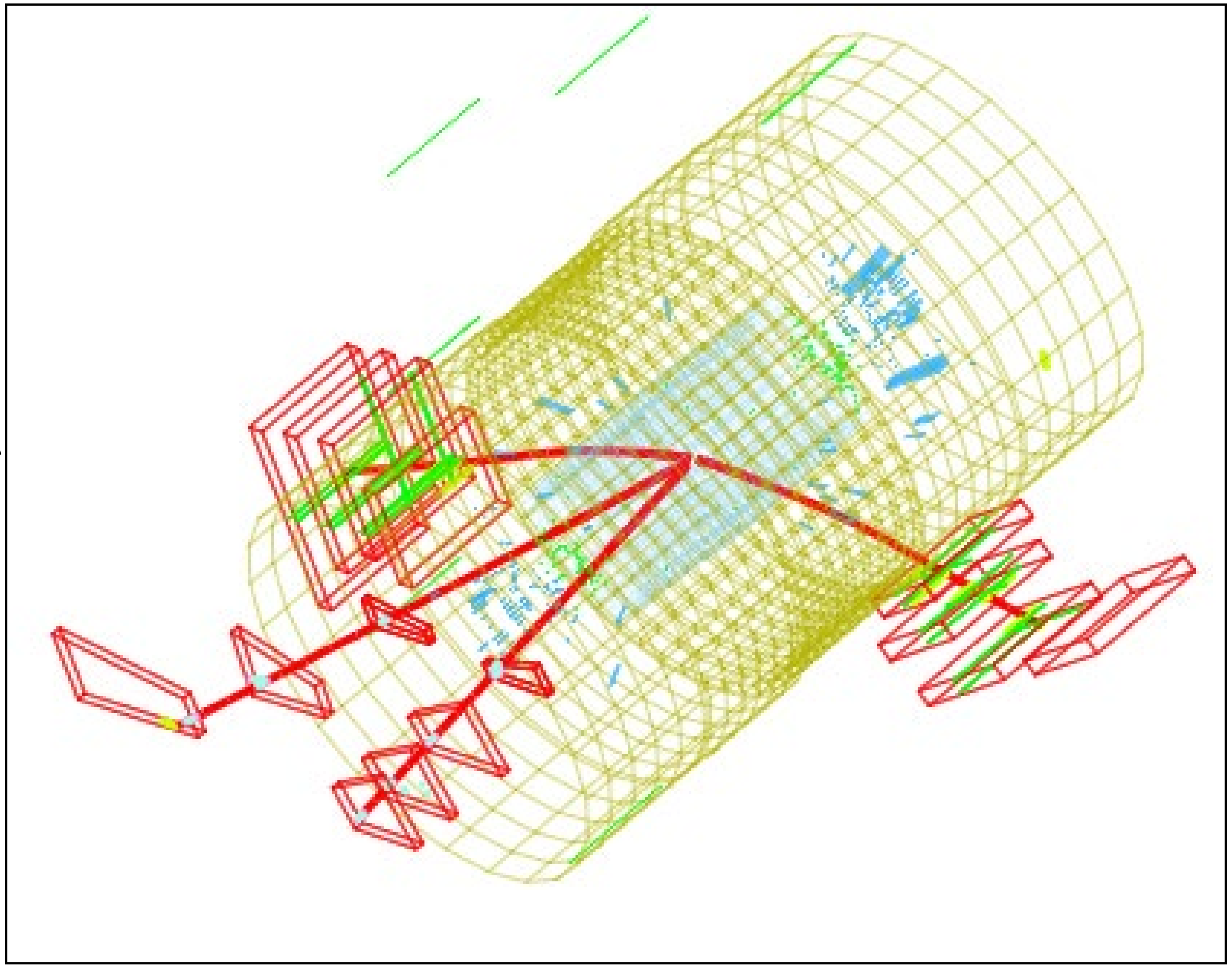
- Can we make dilepton (and more) mass plot?





Today's Task

- How about a 4-lepton mass plot?
  - $e^+e^-e^+e^-$
  - $\mu^+\mu^-\mu^+\mu^-$
  - $\mu^+\mu^-e^+e^-$



Can we pick out electrons and/or muons?

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

What sorts of 4-lepton events are there?

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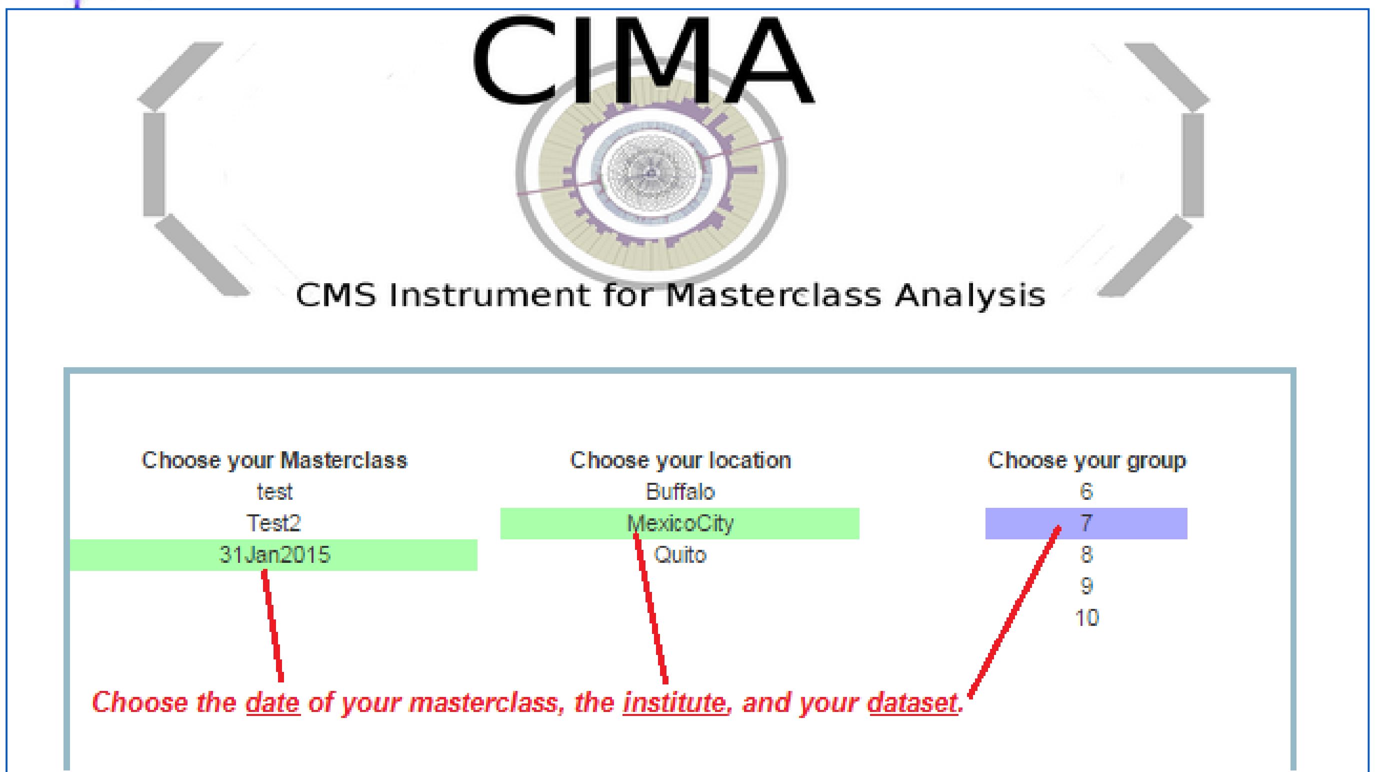
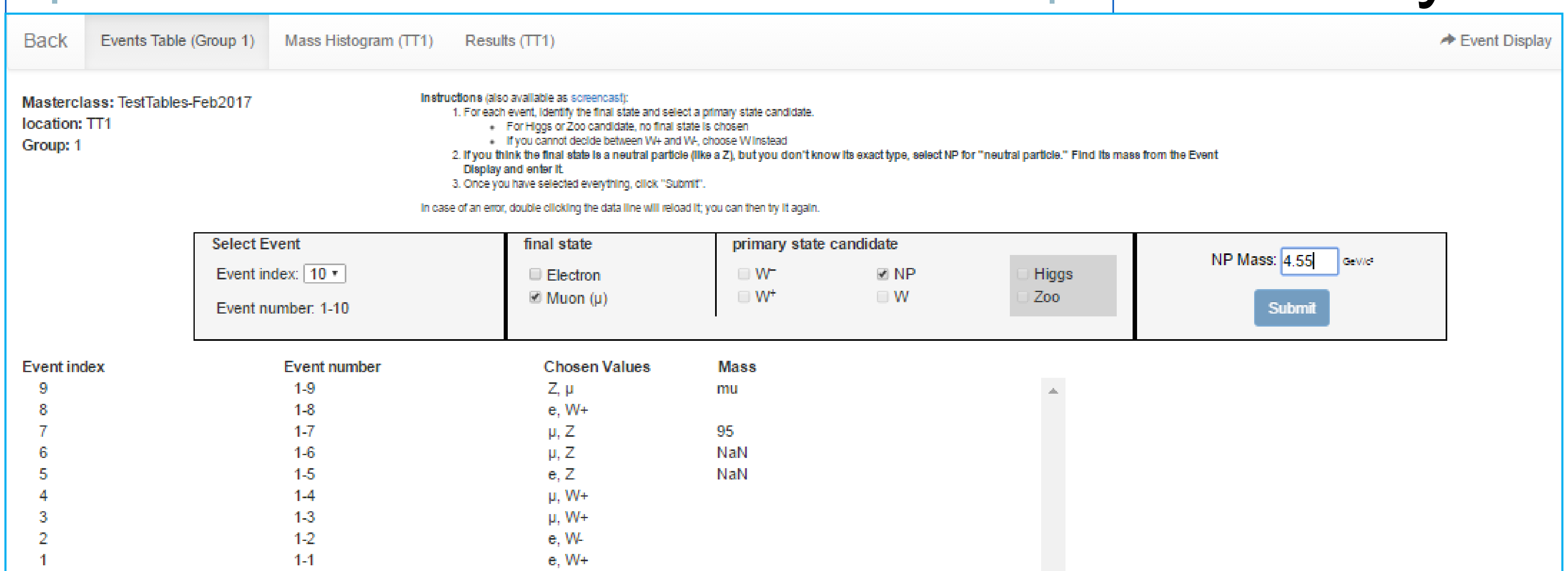
Recording event data





Find your dataset.

Record parent particles and decay modes.

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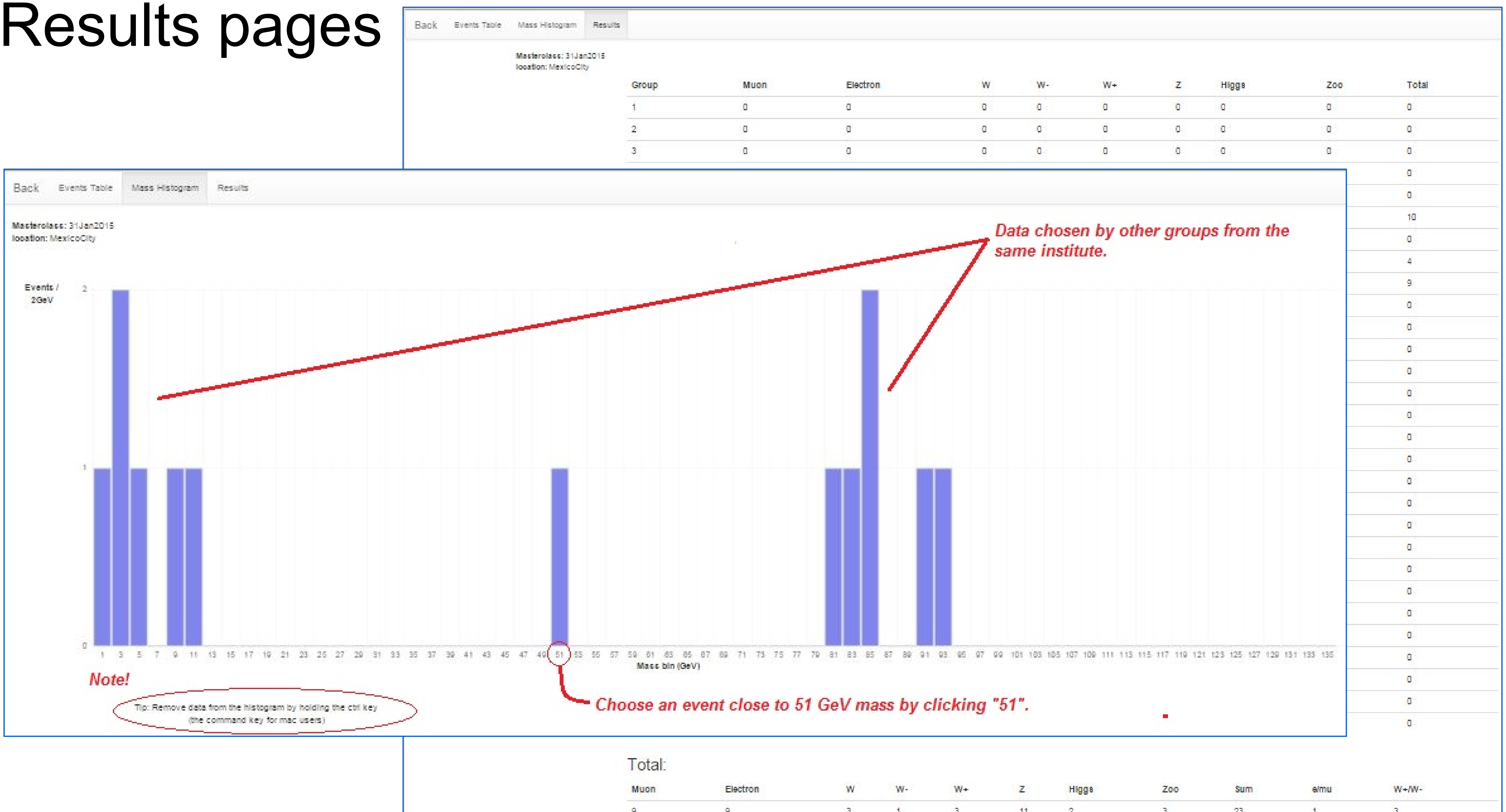
Recording event data

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: <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.

Form teams of two. Each team analyzes 100 events.

Talk with physicists about interpreting events. Pool results.