Helping Develop America's Technological Workforce

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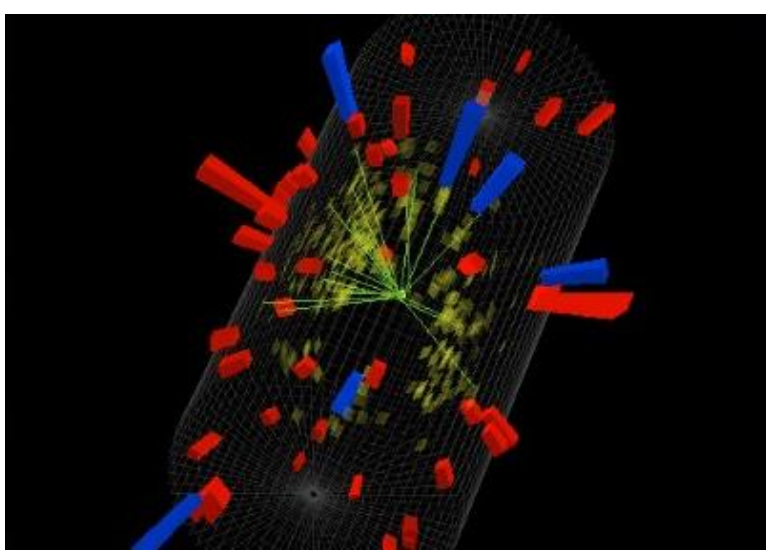
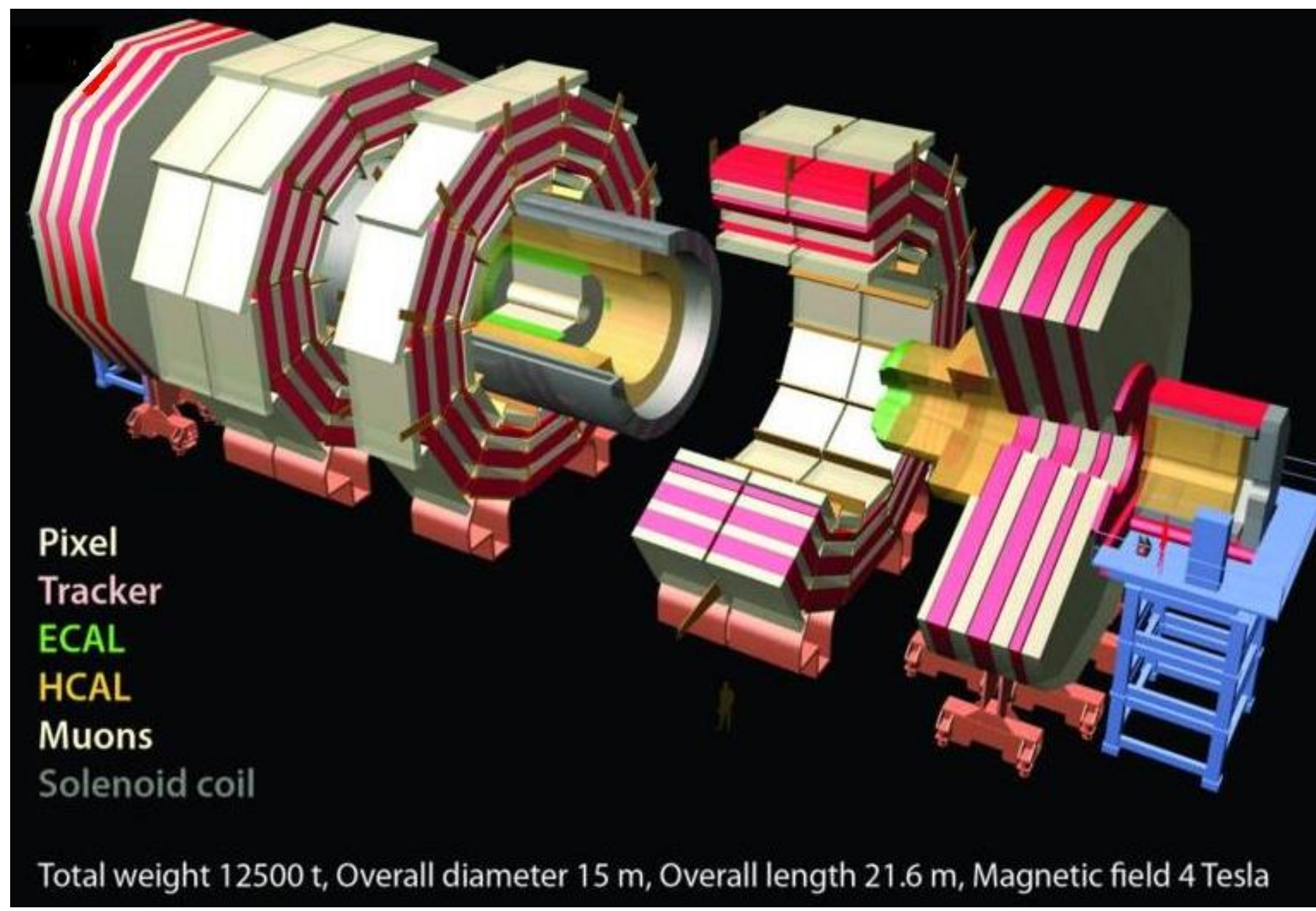
INTERNATIONAL MASTERCLASSES
hands on particle physics

CMS WZH Masterclass





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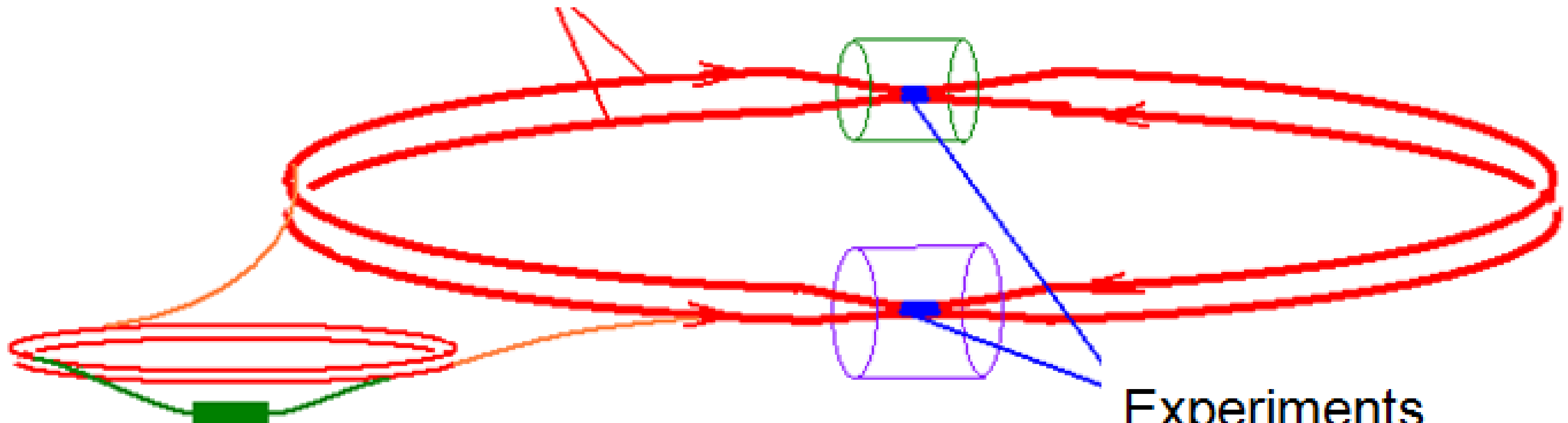
The LHC and New Physics

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.



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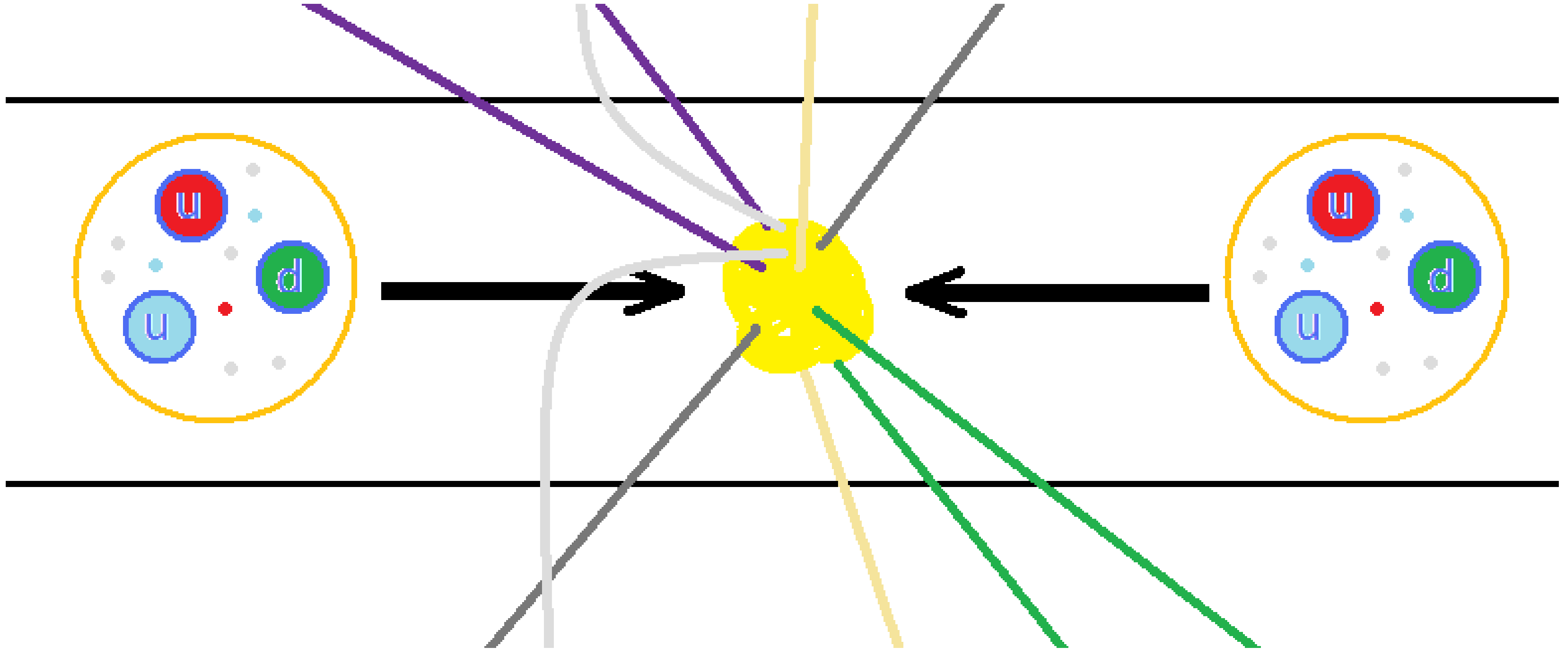
Energy & Particle Mass

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.

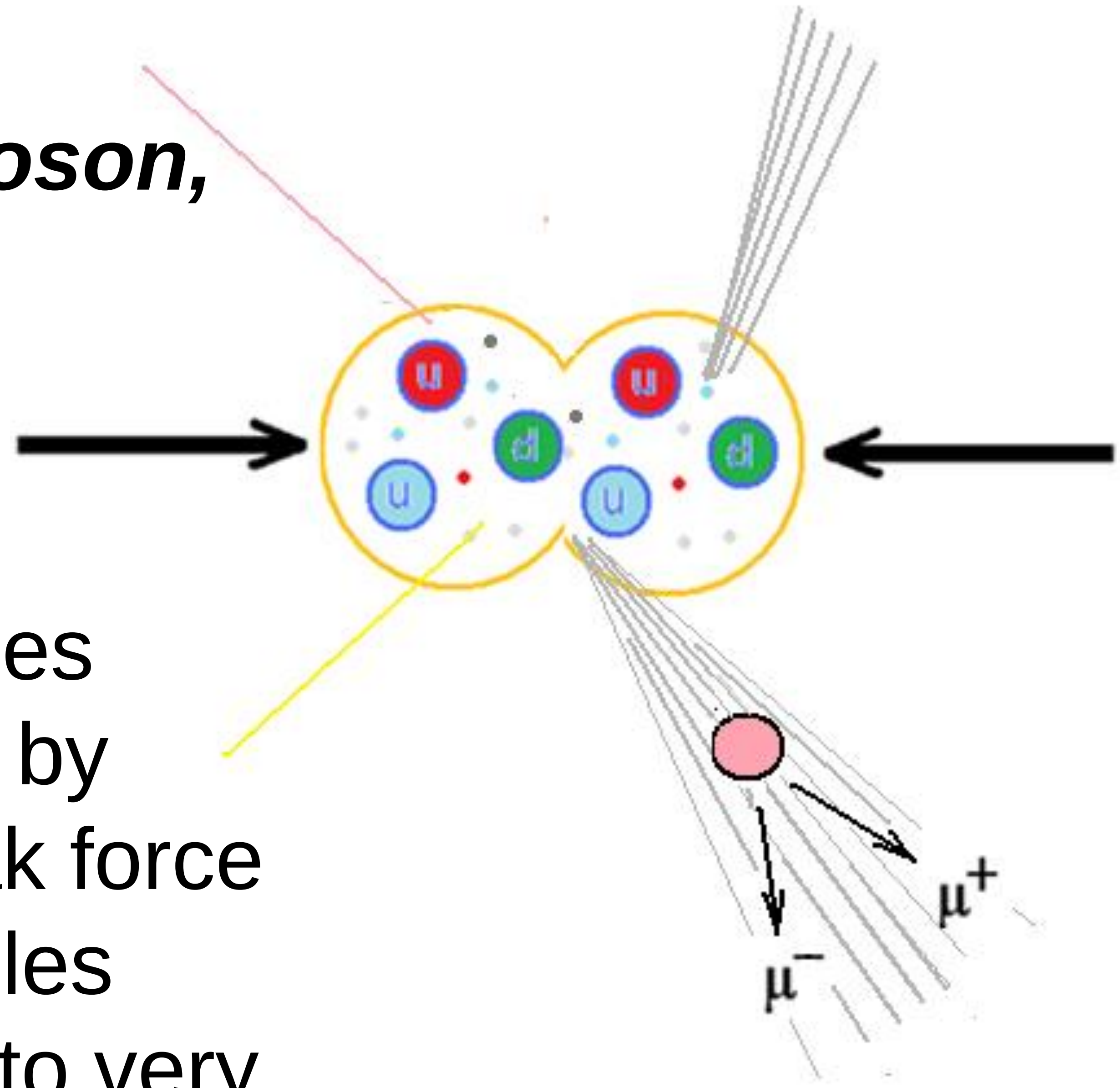
**In Run II, this was increased to 6.5 GeV!*



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***.



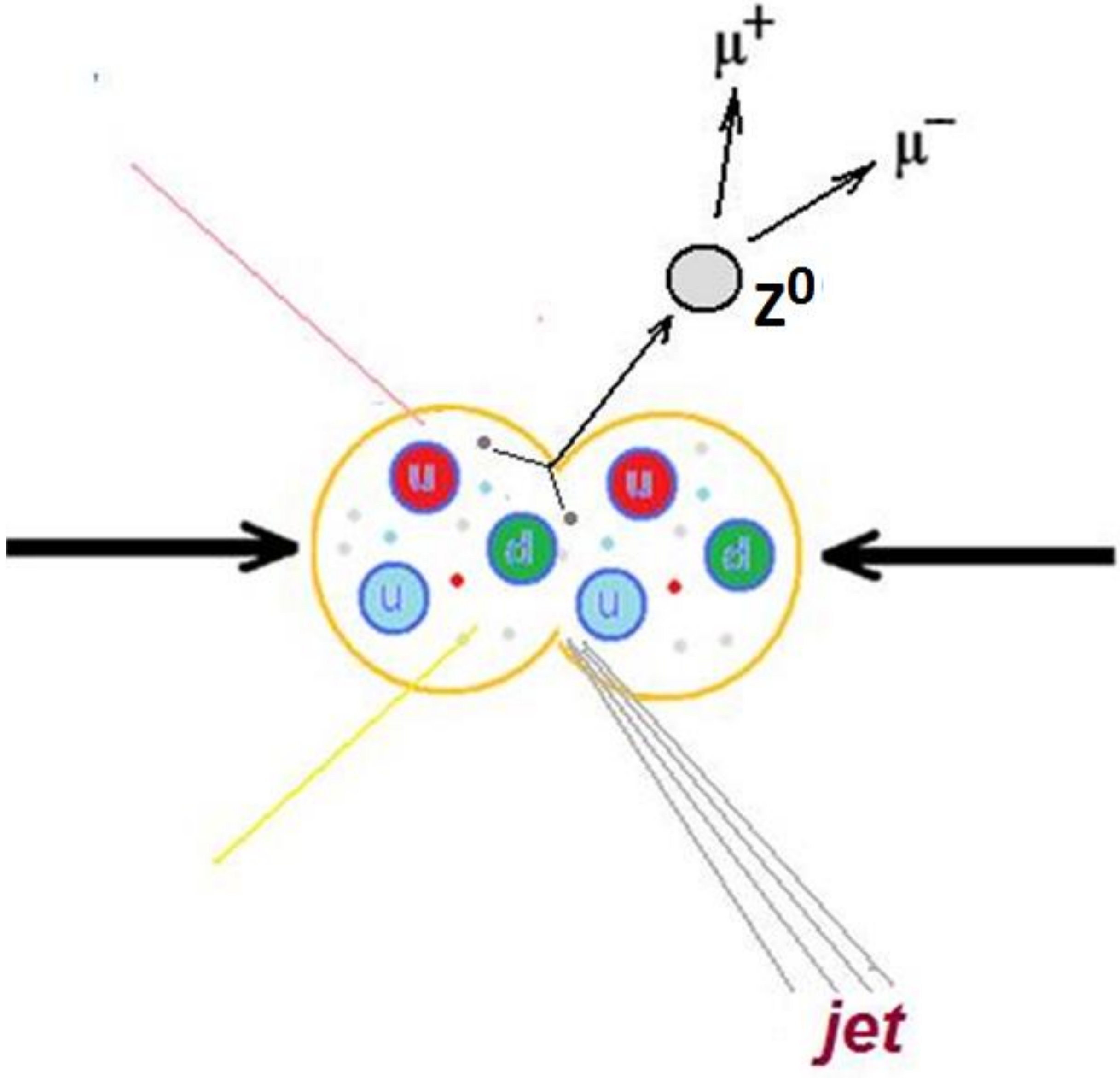
Unlike electromagnetic forces carried over long distances by massless photons, the weak force is carried by massive particles which restricts interactions to very tiny distances.

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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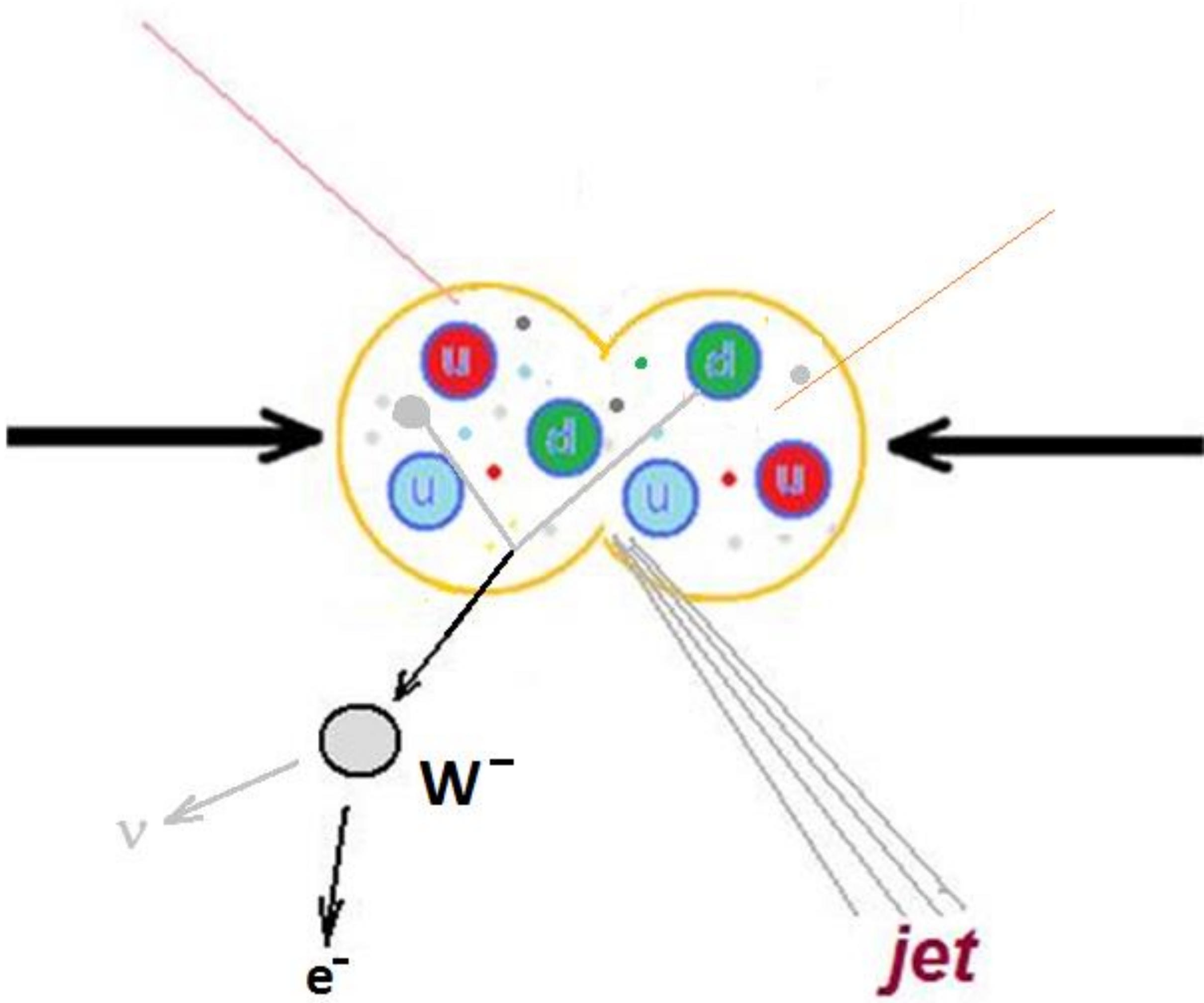

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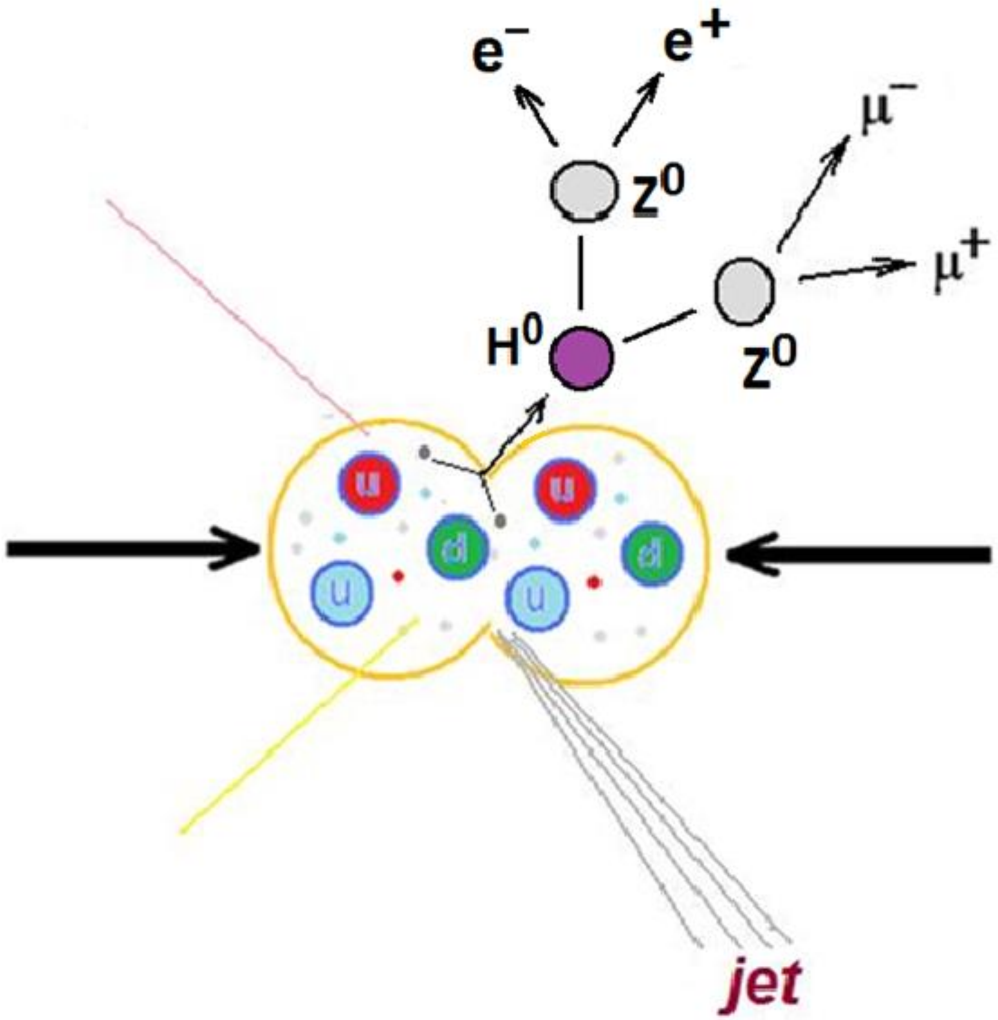
Higgs Particles

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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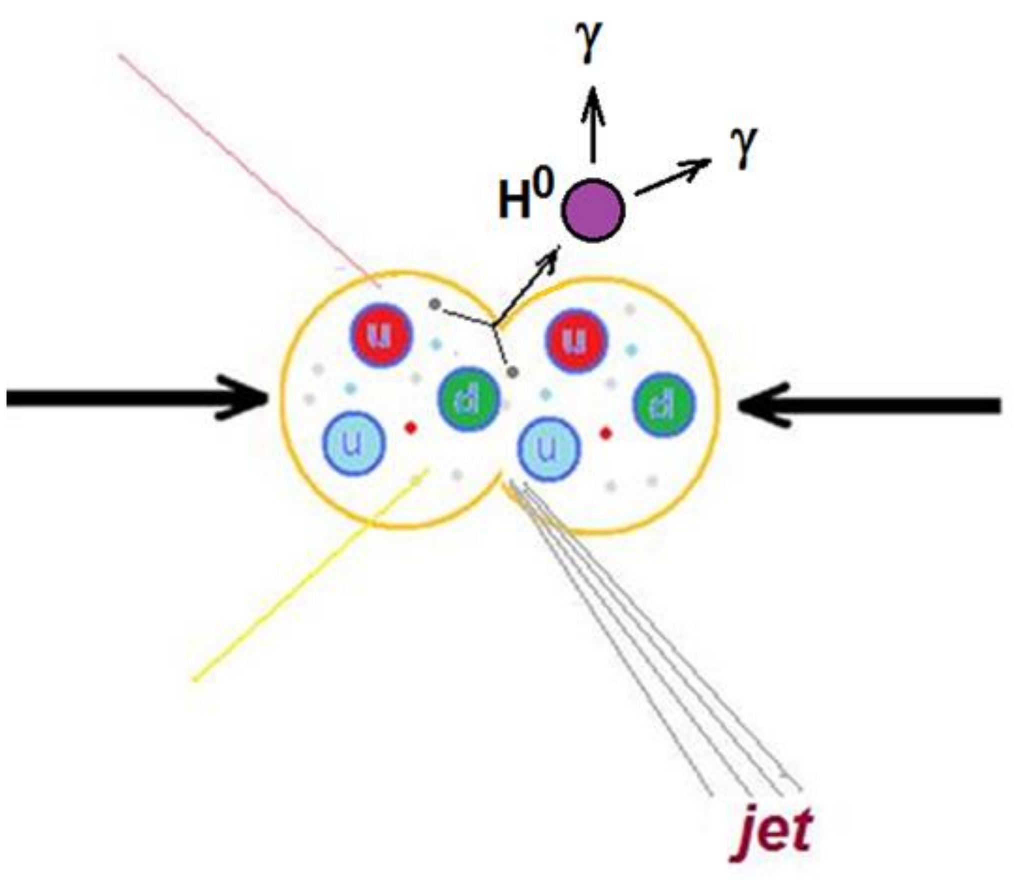
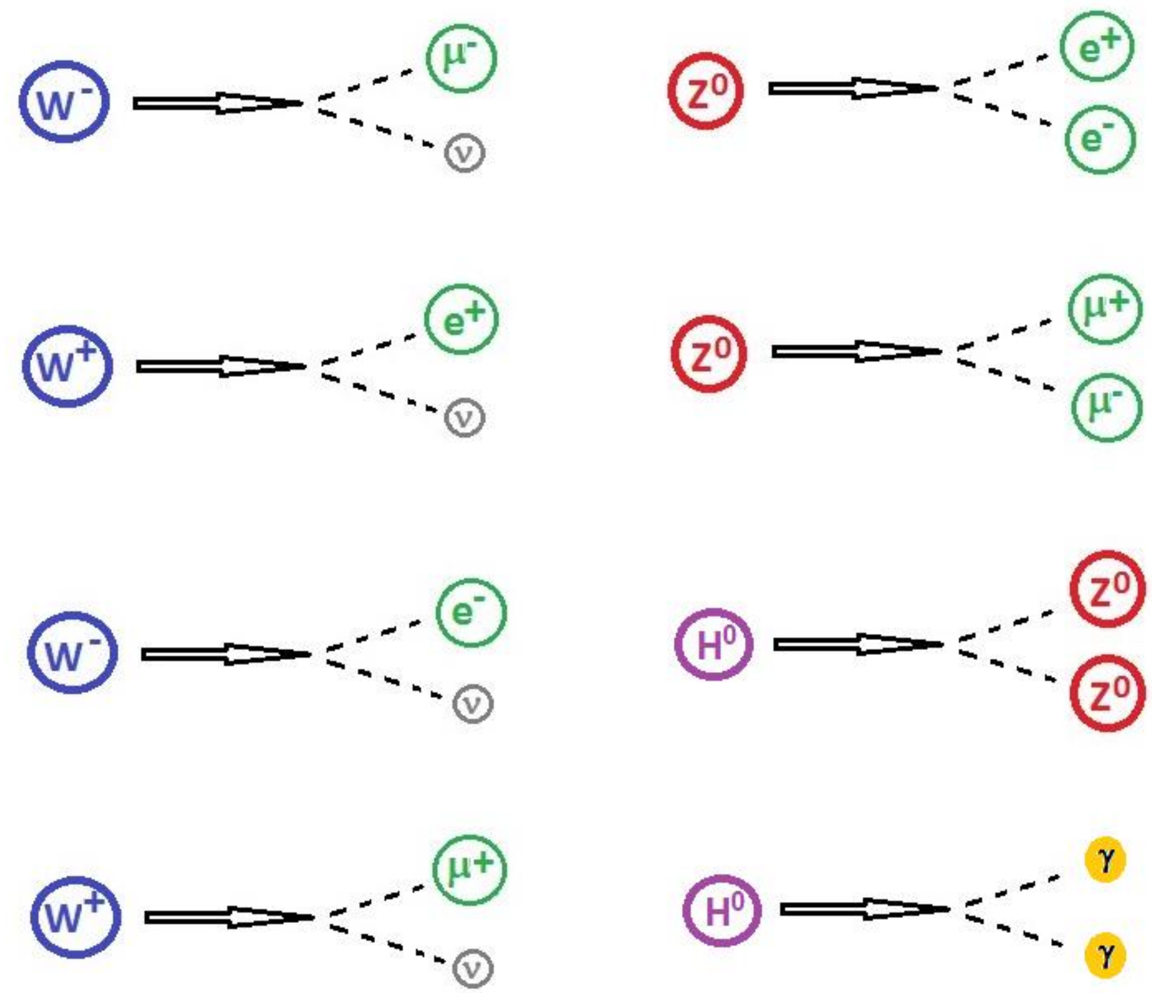


W and Z Decays

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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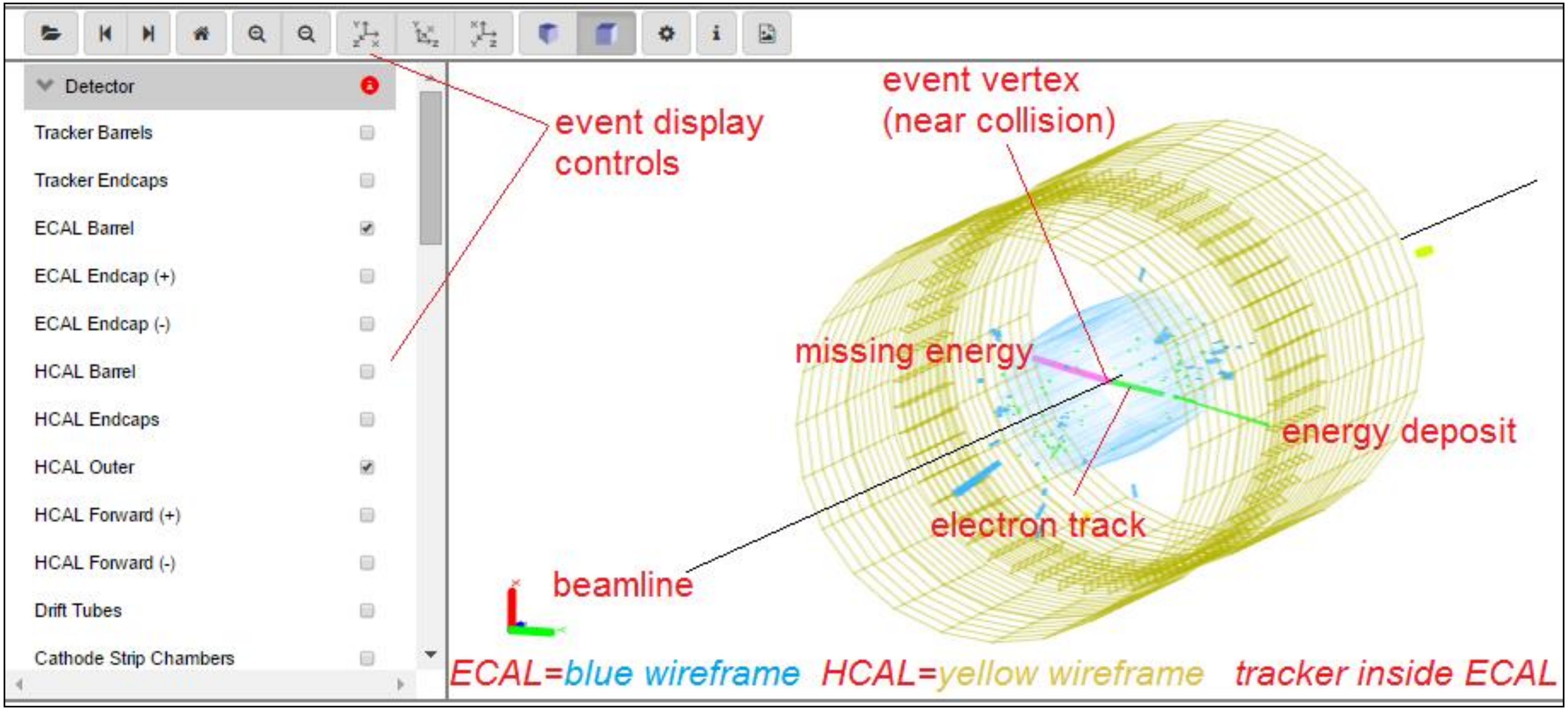
iSpy-webgl



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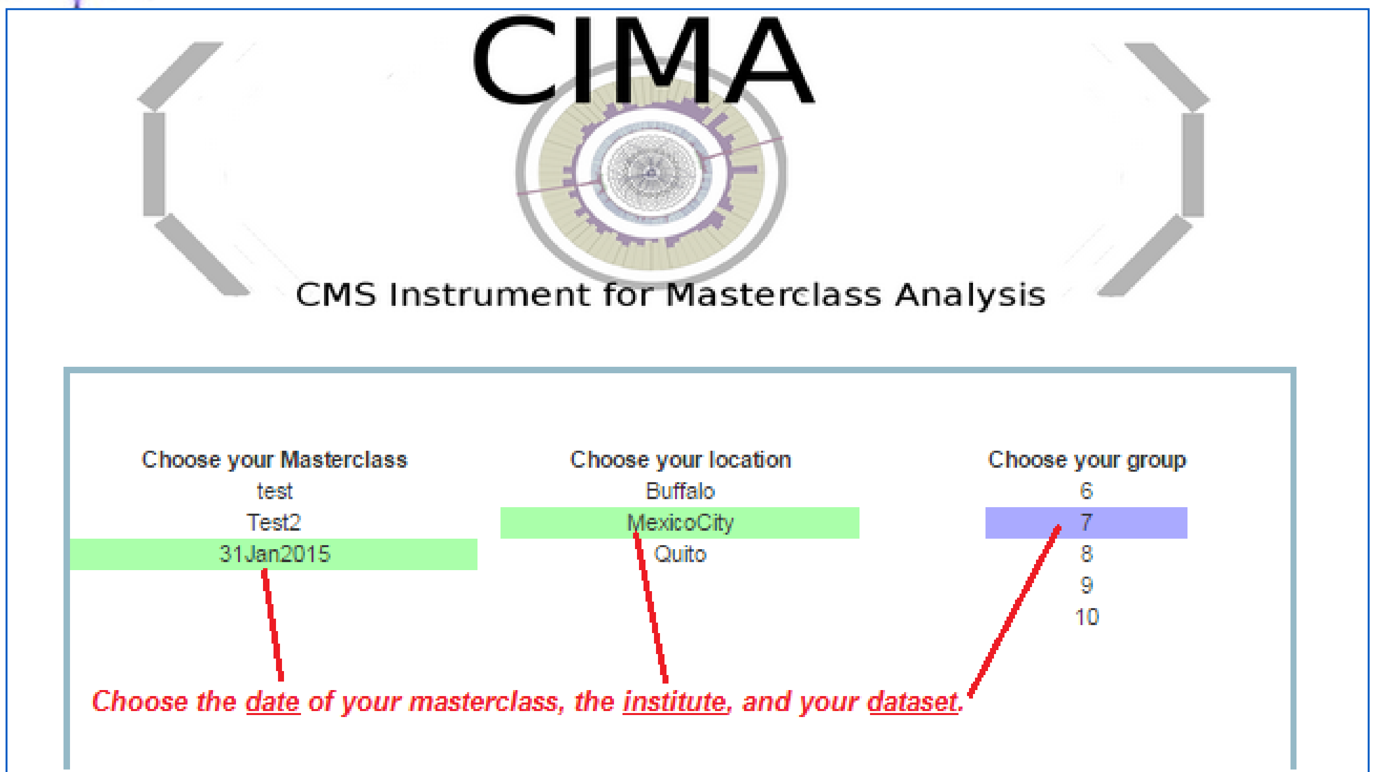
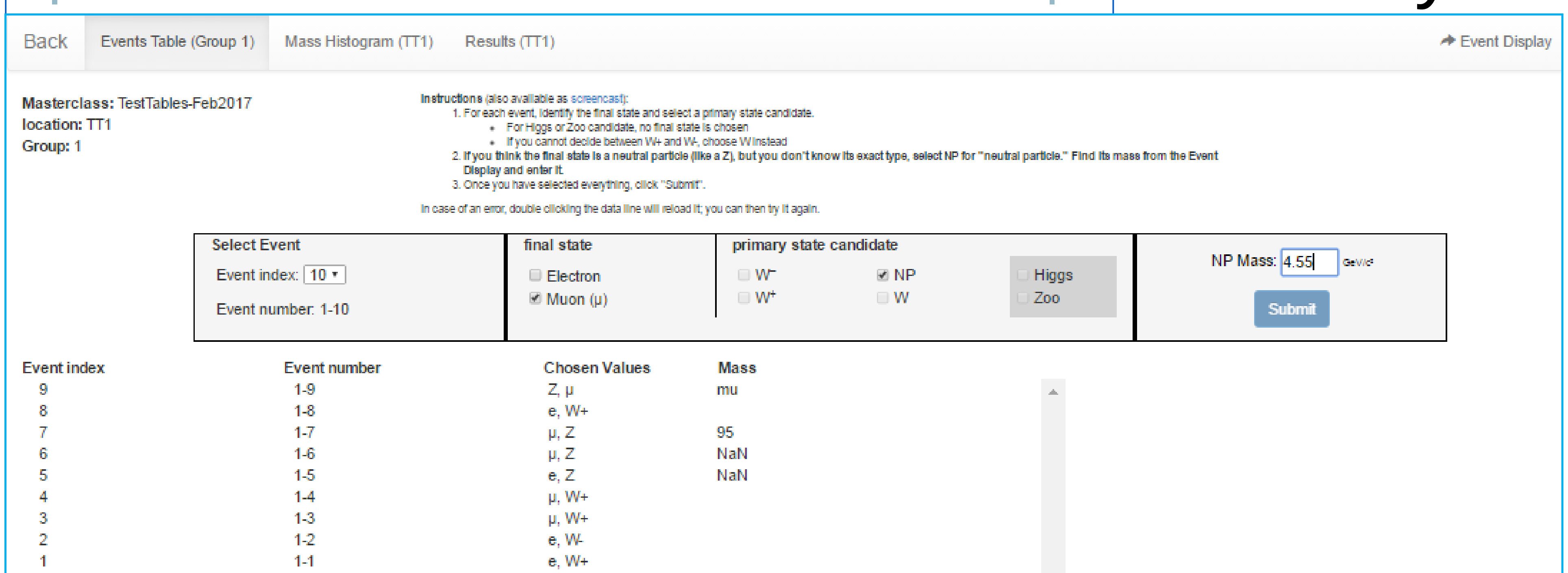
Recording event data





Find your dataset.

Record parent particles and decay modes.

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Recording event data

Mass Histogram and Results pages

Detector Design

Generic Design

Cylinders wrapped around the beam pipe

From inner to outer . . .

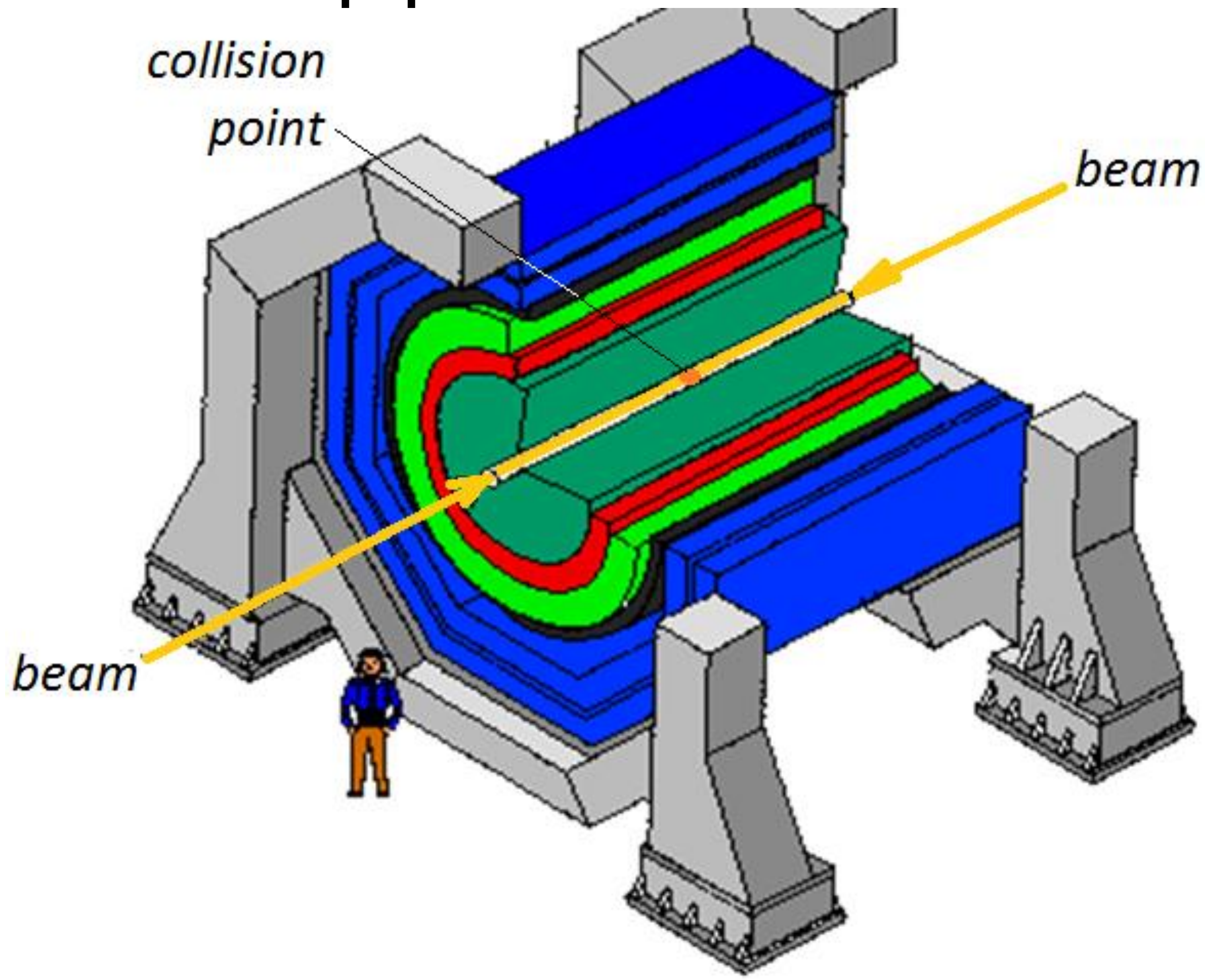
Tracking

Electromagnetic calorimeter

Hadronic calorimeter

Magnet*

Muon chamber



* *location of magnet depends on specific detector design*

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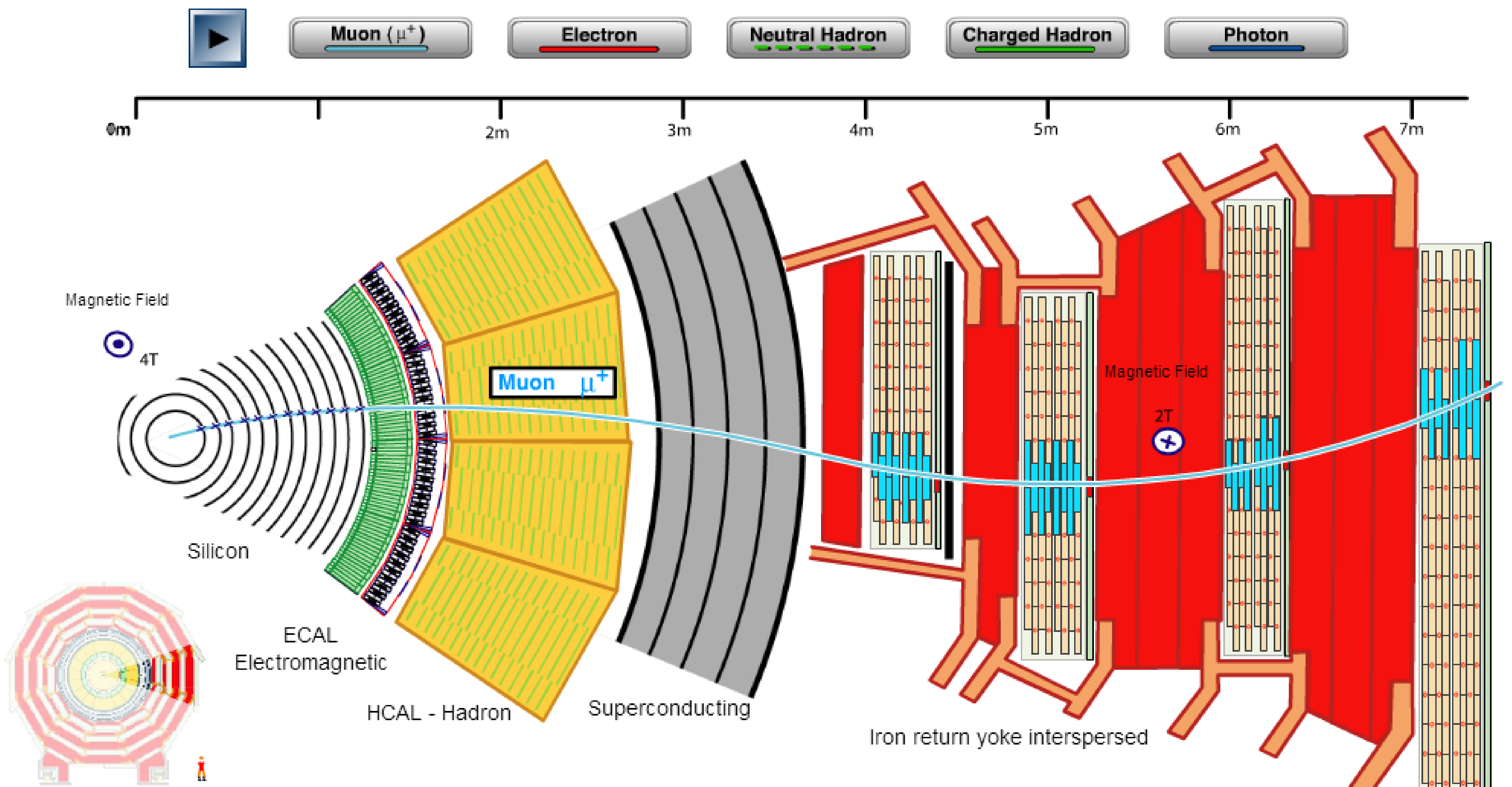
Detector Tracks

Web Version

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

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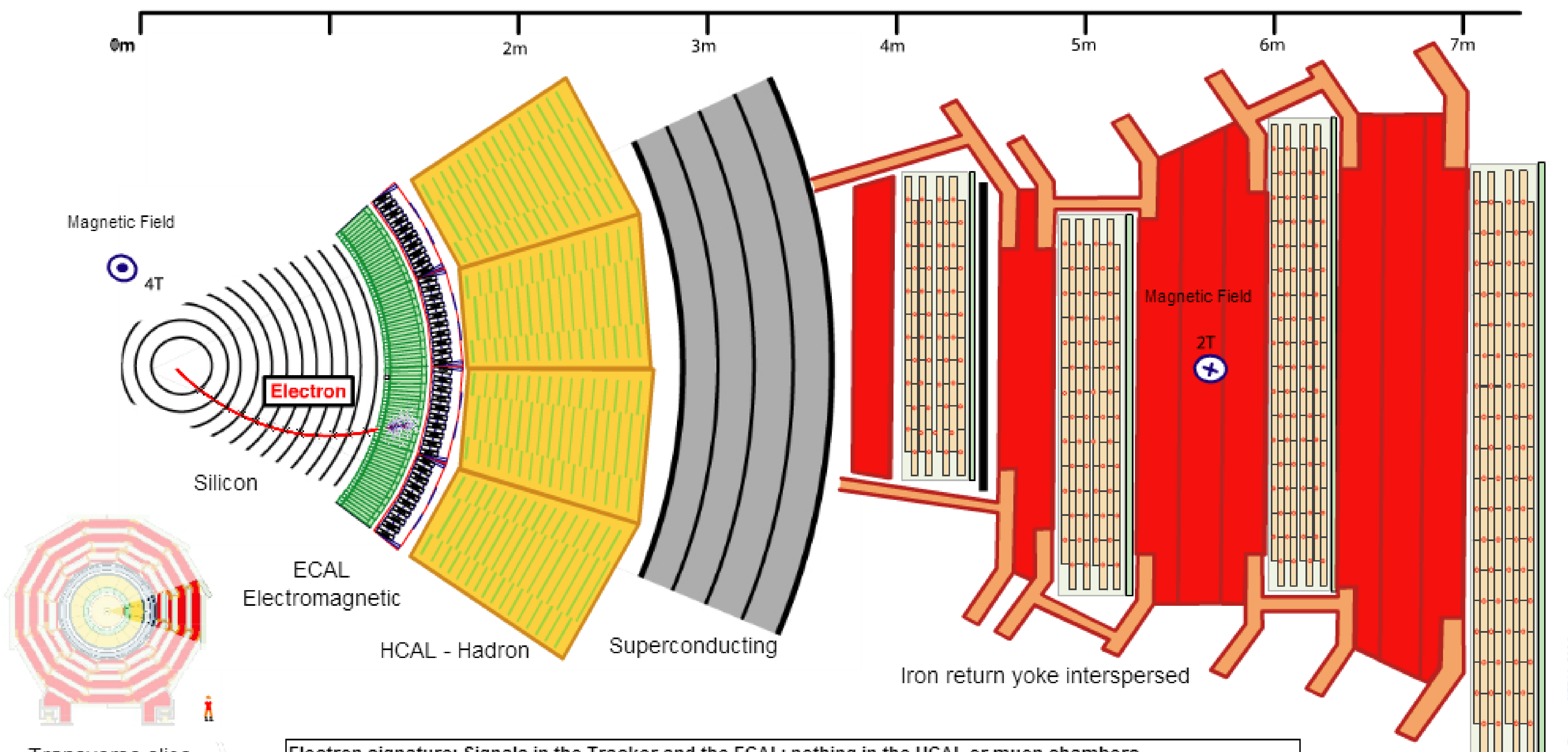
Detector Tracks

Web Version

Transverse Slice of the Compact Muon Solenoid (CMS) Detector

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



Transverse slice through CMS

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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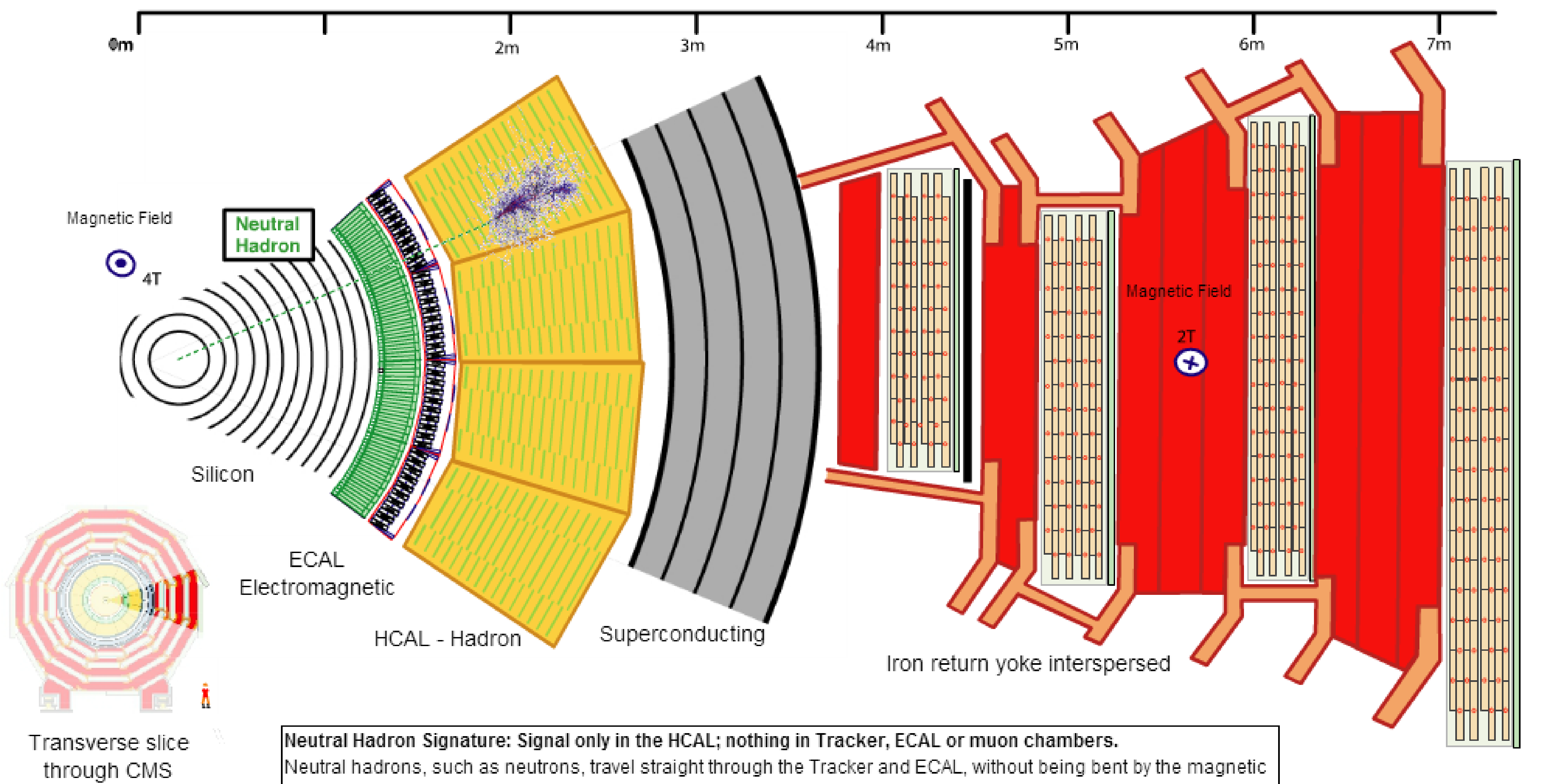

Neutral Hadron Signature: Signal only in the HCAL; nothing in Tracker, ECAL or muon chambers.
Neutral hadrons, such as neutrons, travel straight through the Tracker and ECAL, without being bent by the magnetic field or leaving any signals. Like charged hadrons, they are slowed to a stop in the HCAL, 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.

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Detector Tracks

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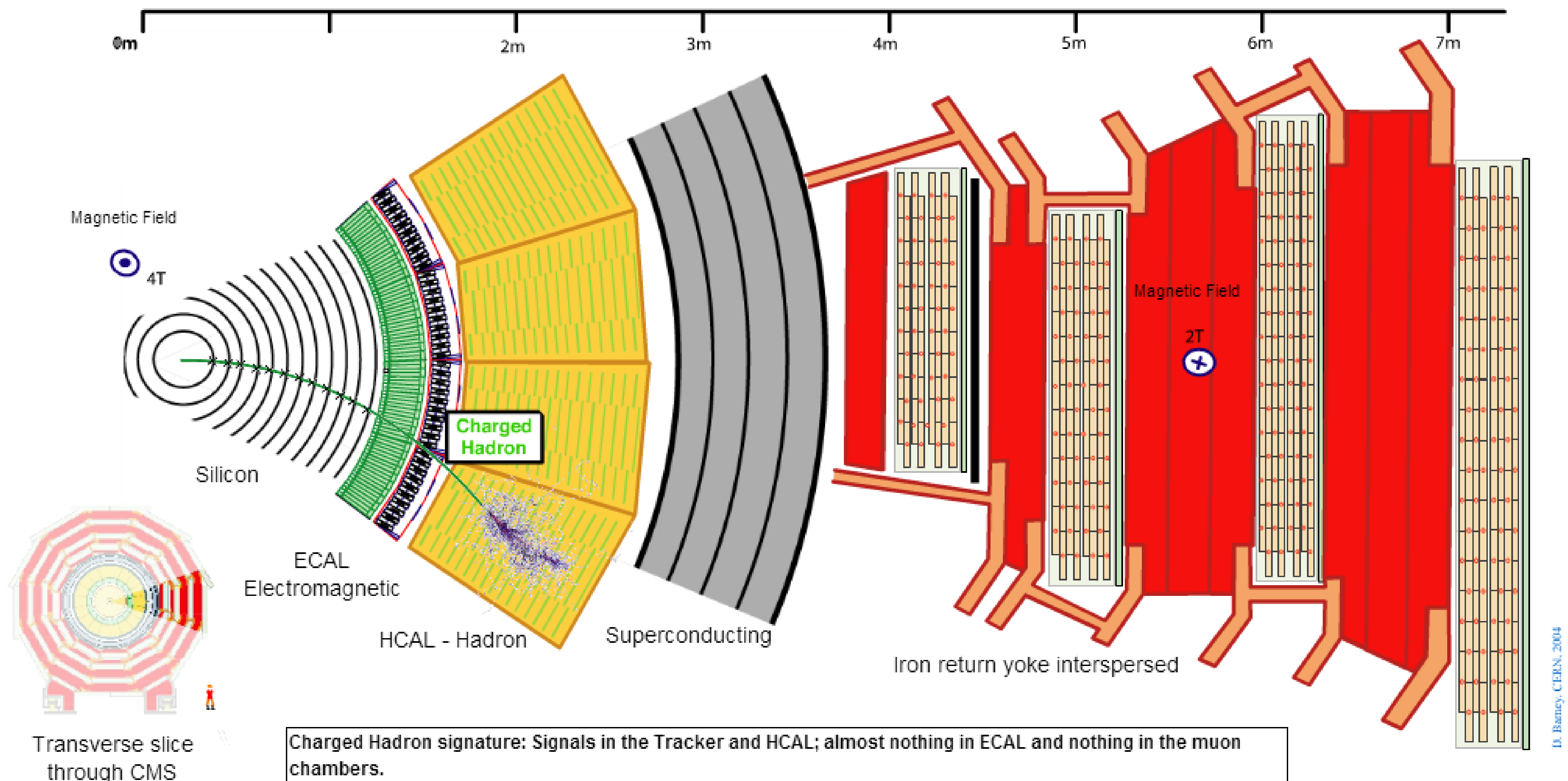

Charged Hadron signature: Signals in the Tracker and HCAL; almost nothing in ECAL and nothing in the muon chambers.

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

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Detector Tracks

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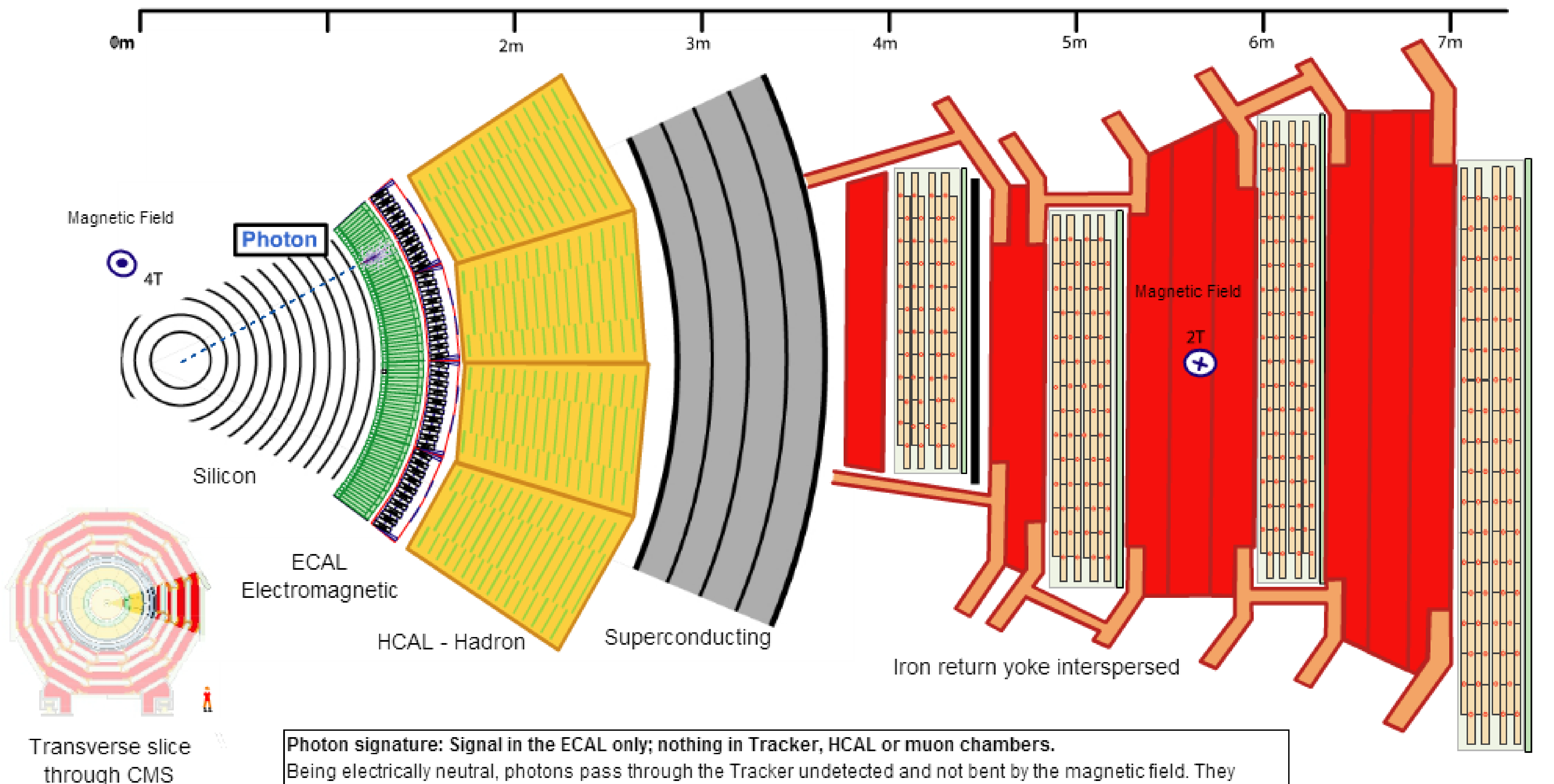
Transverse Slice of the Compact Muon Solenoid (CMS) Detector

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



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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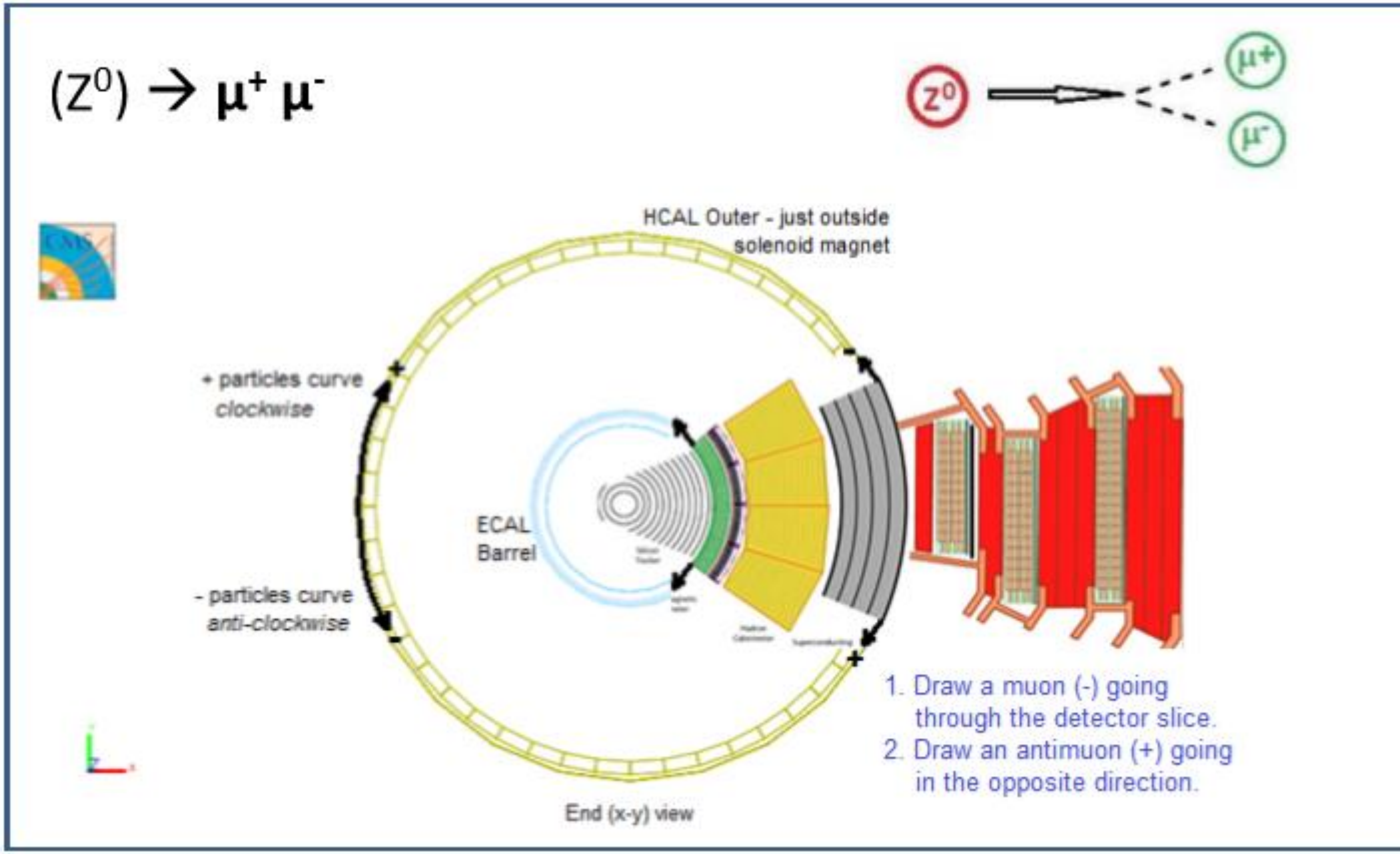
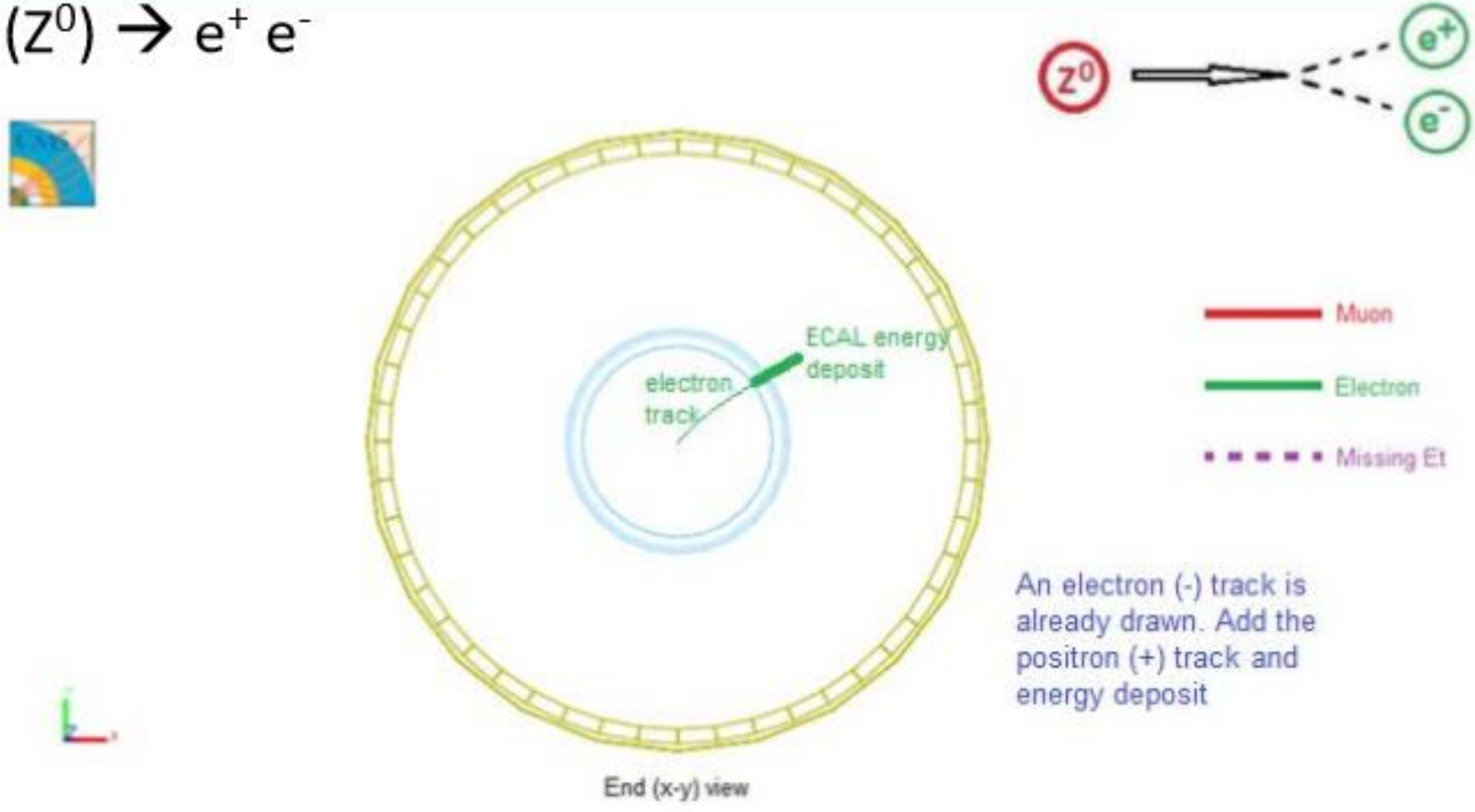
Sketch the tracks in CMS

Web Version



Sketch the tracks in CMS

$(Z^0) \rightarrow e^+ e^-$



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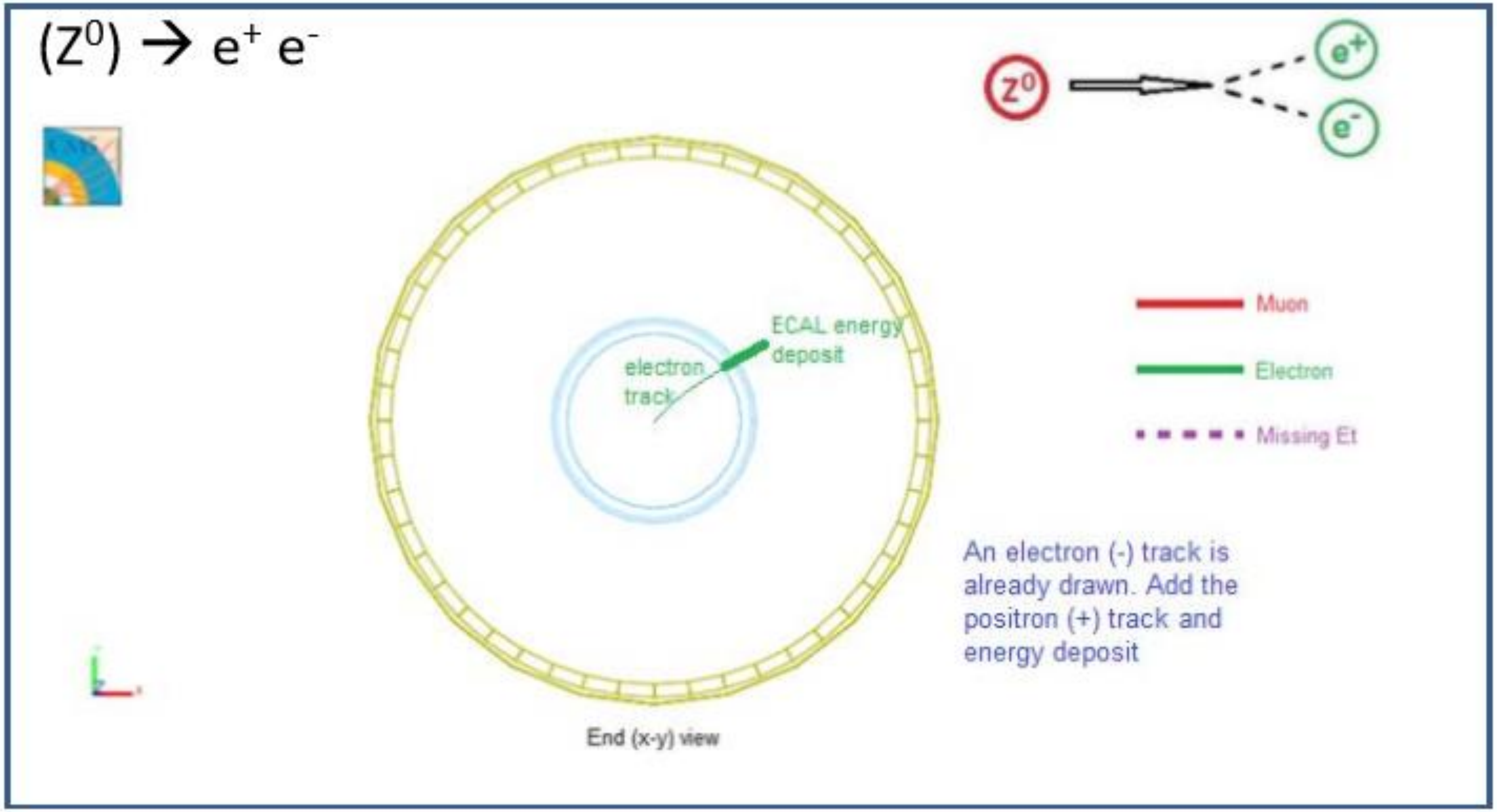

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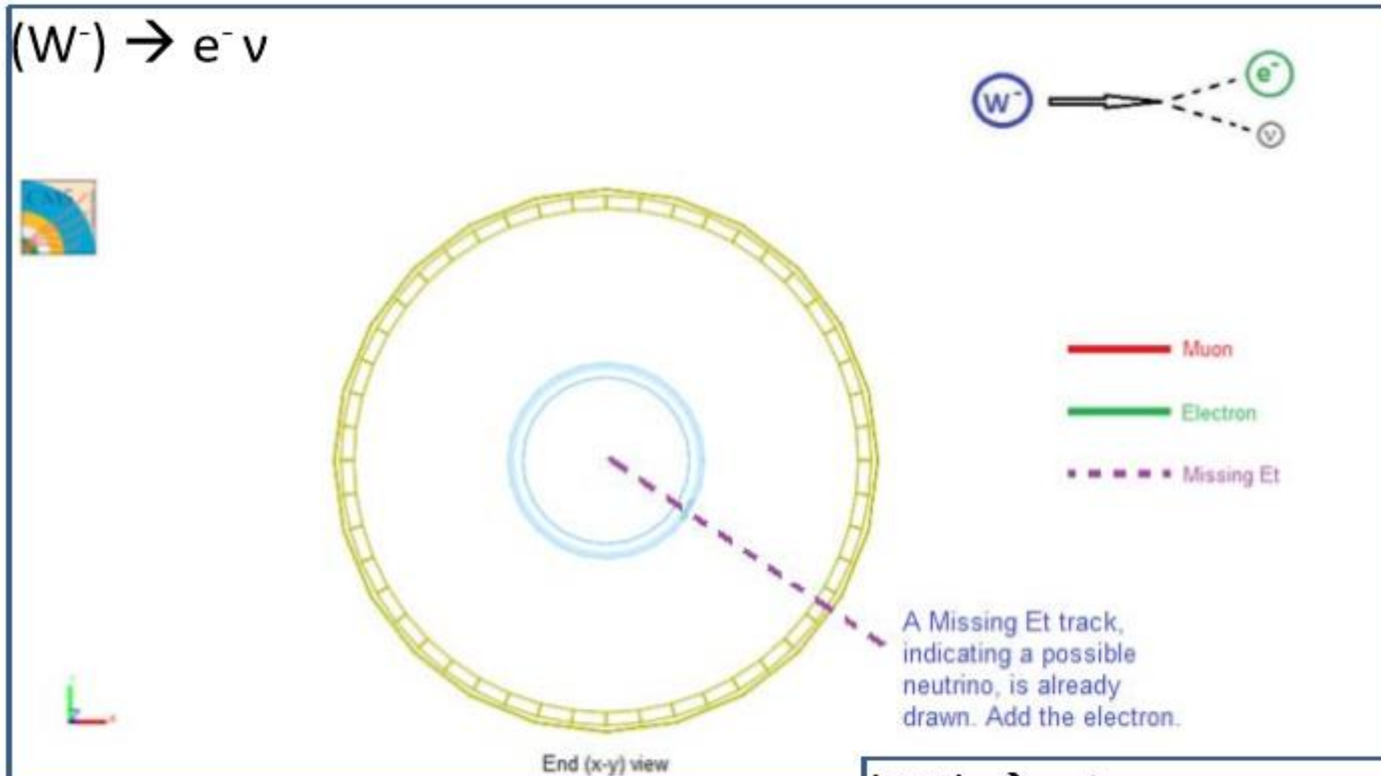

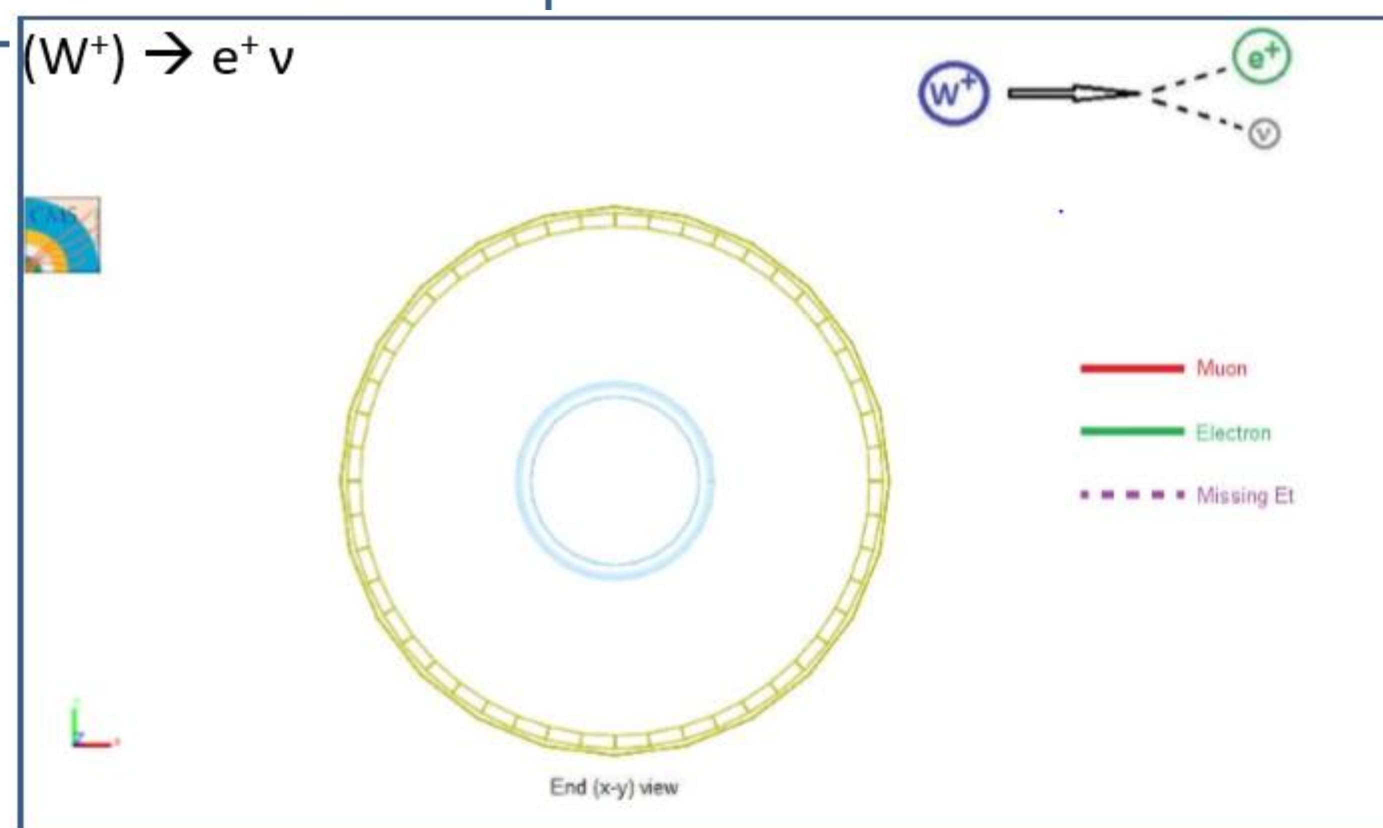

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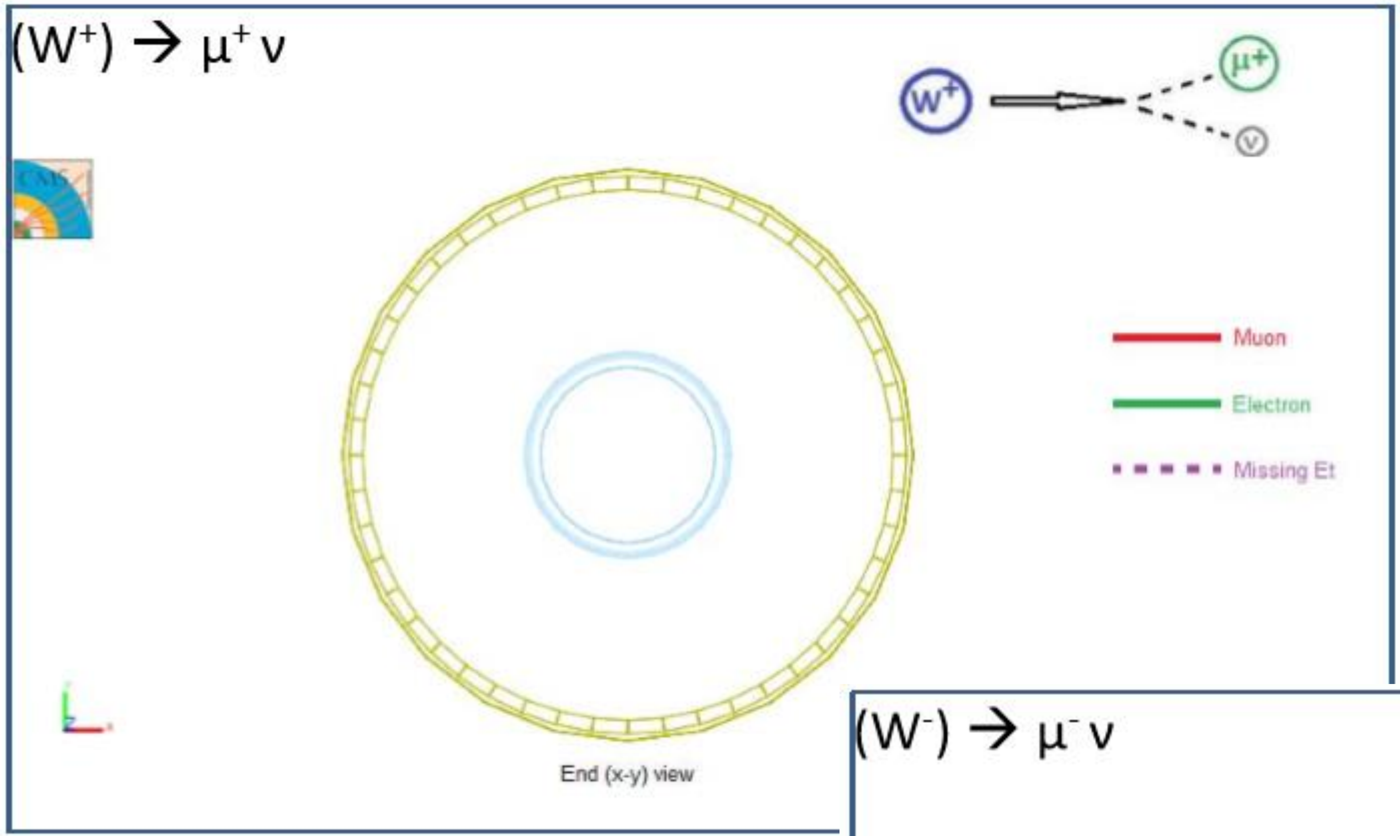

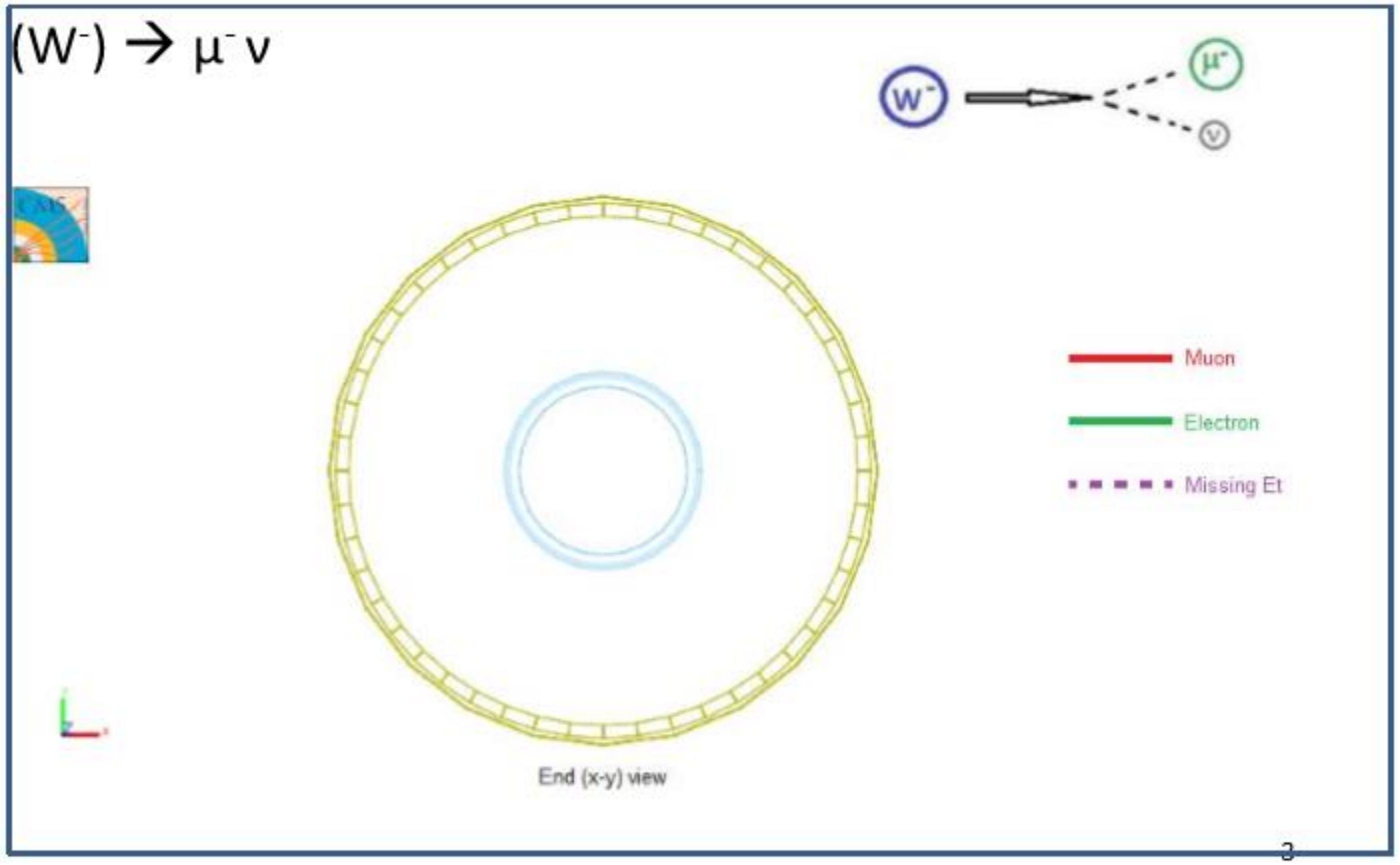

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