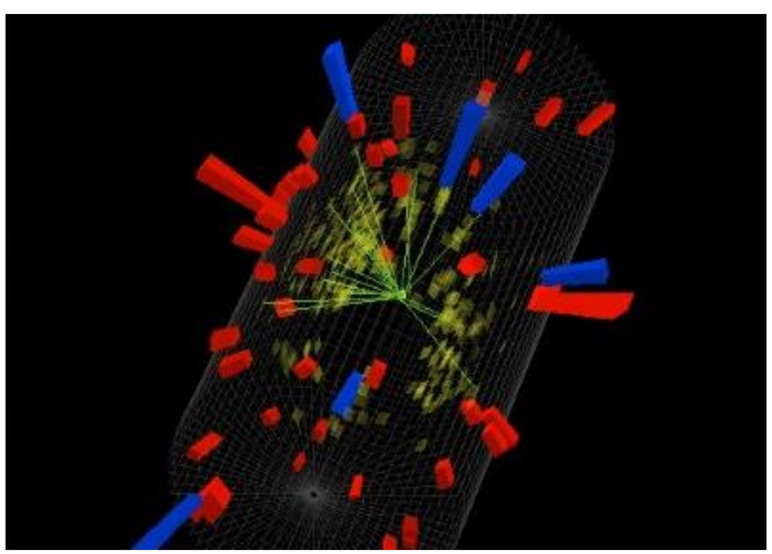
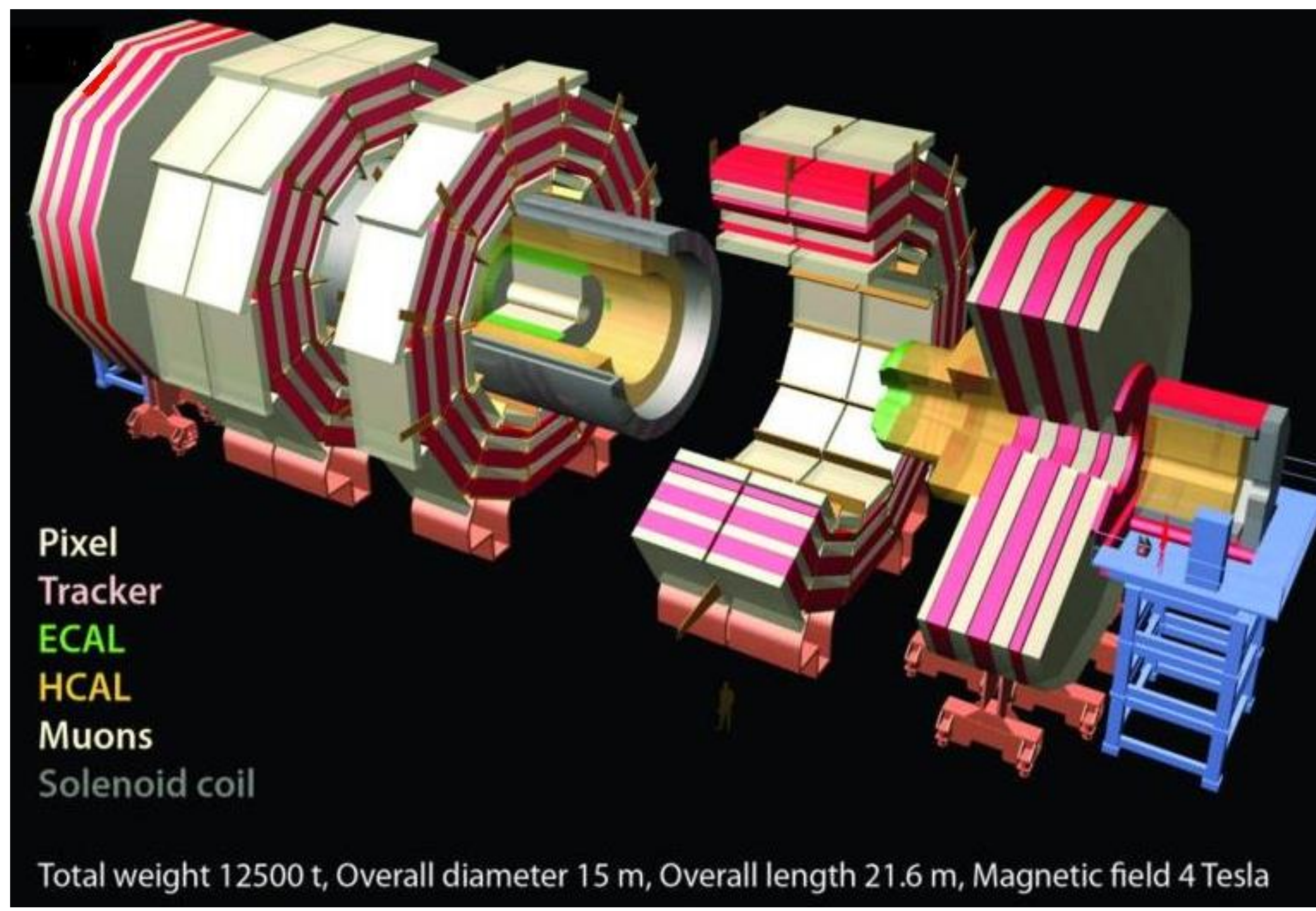
QuarkNet

Helping Develop America's Technological Workforce

INTERNATIONAL MASTERCLASSES
hands on particle physics

# CMS Masterclass 2017

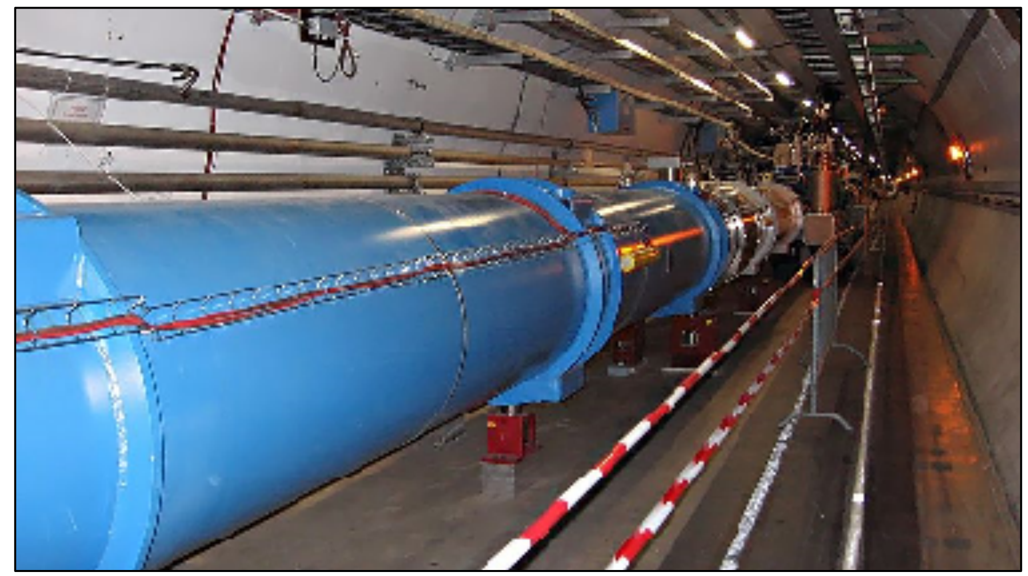




QuarkNet

# 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.*

# QuarkNet Enduring Understandings

Points students should remember long after masterclass:

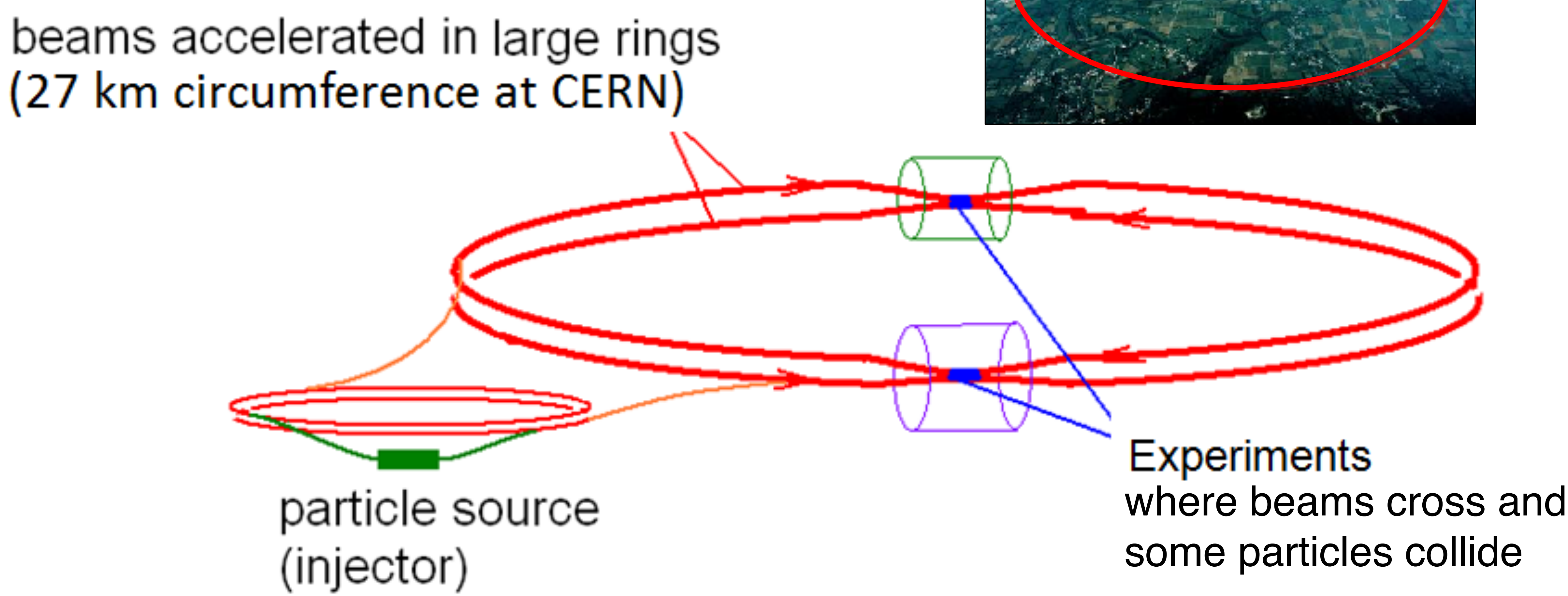
1. Particle physics research requires the use of indirect evidence to support claims.
2. The Standard Model is the current theoretical framework for our understanding of matter.
3. The behavior of particles is governed by conservation laws and mass-energy conversion.

Helping Develop America's Technological Workforce

QuarkNet

# The LHC and New Physics

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



Helping Develop America's Technological Workforce

QuarkNet

# Detector Design

**Generic Design**

Cylinders wrapped around the beam pipe

From inner to outer . . .

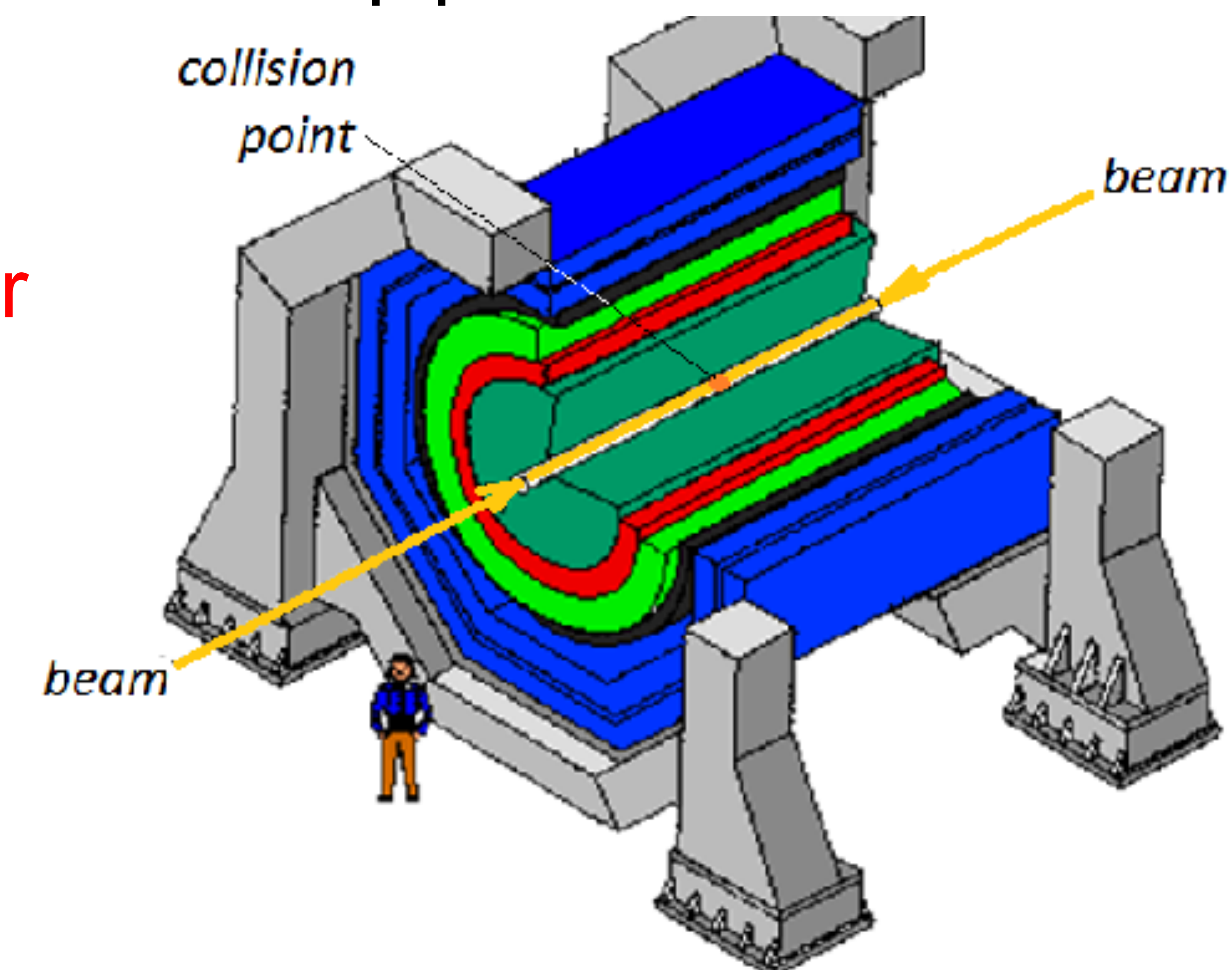
Tracking

Electromagnetic calorimeter

Hadronic calorimeter

Magnet*

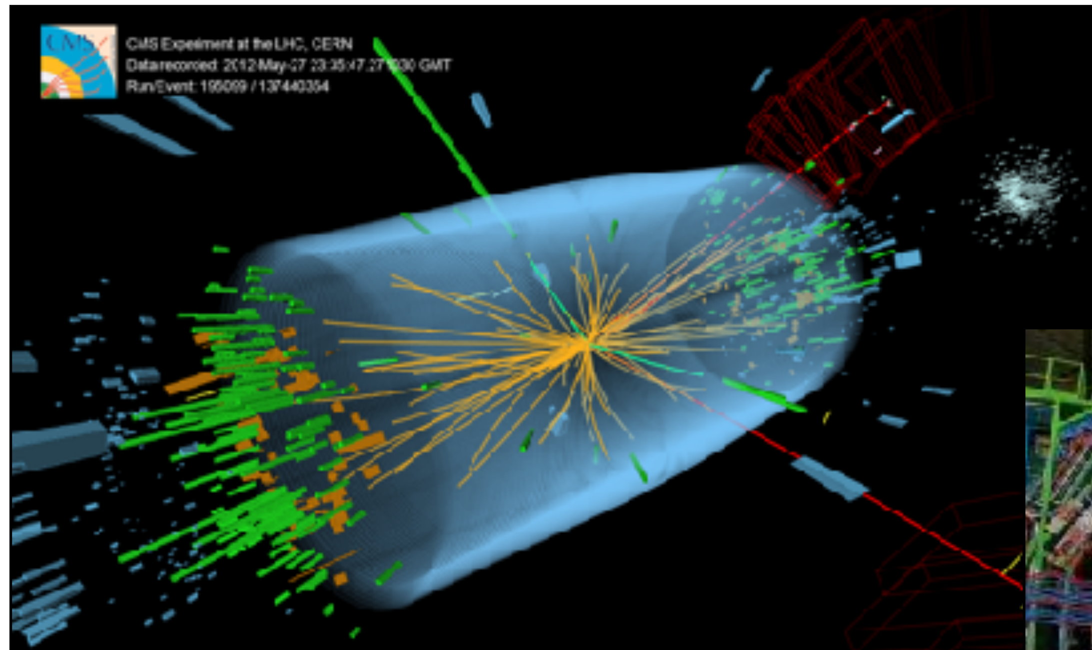
Muon chamber

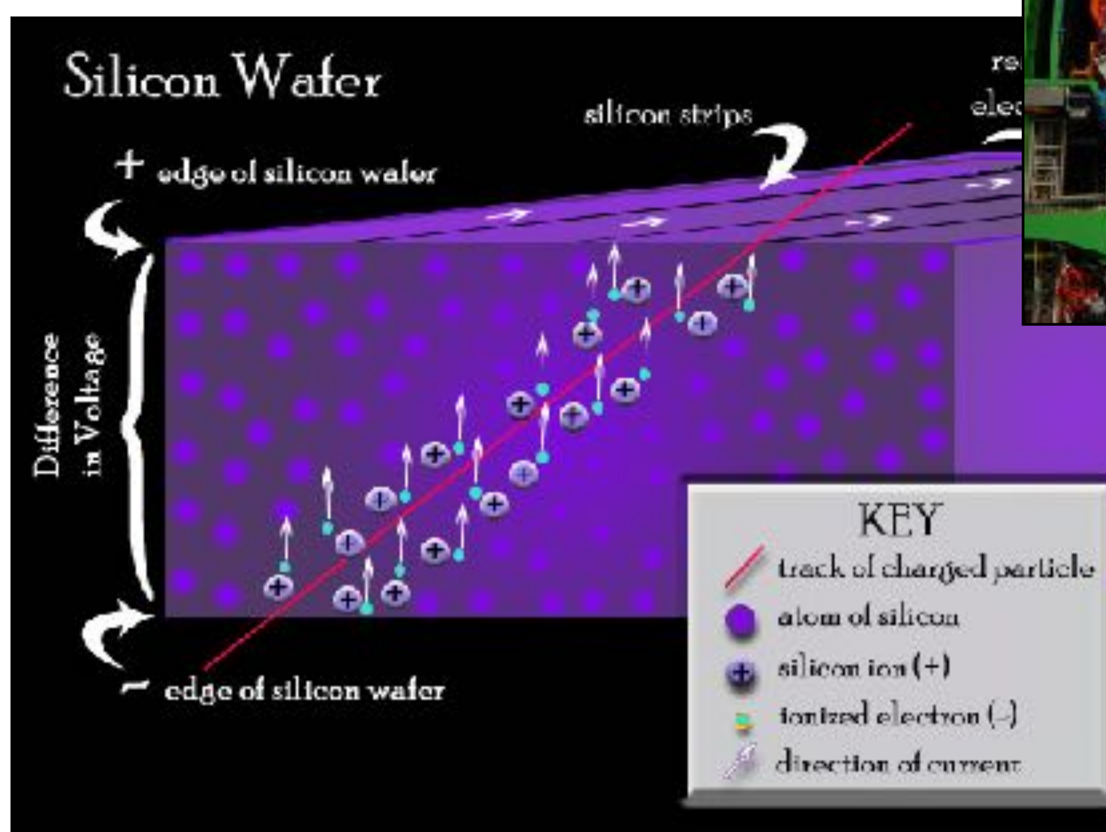


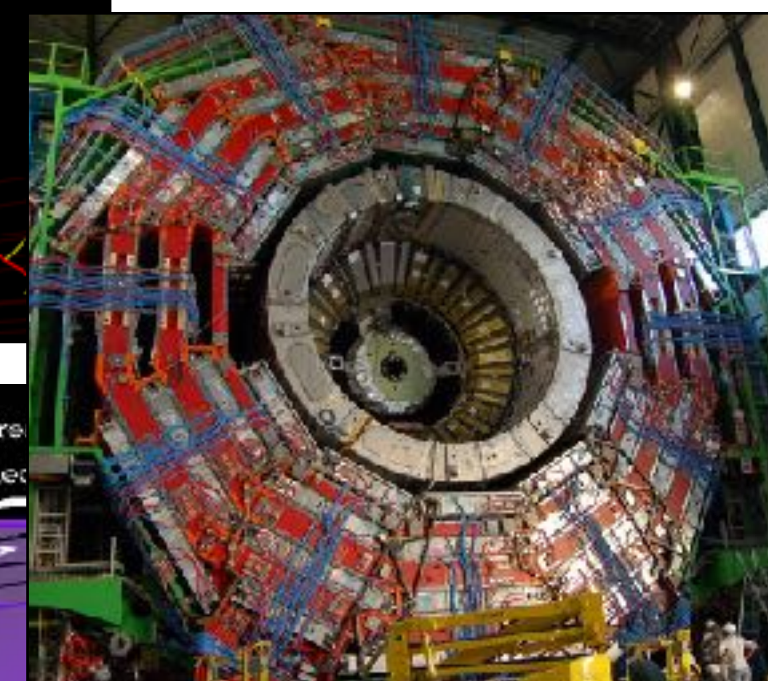

* *location of magnet depends on specific detector design*

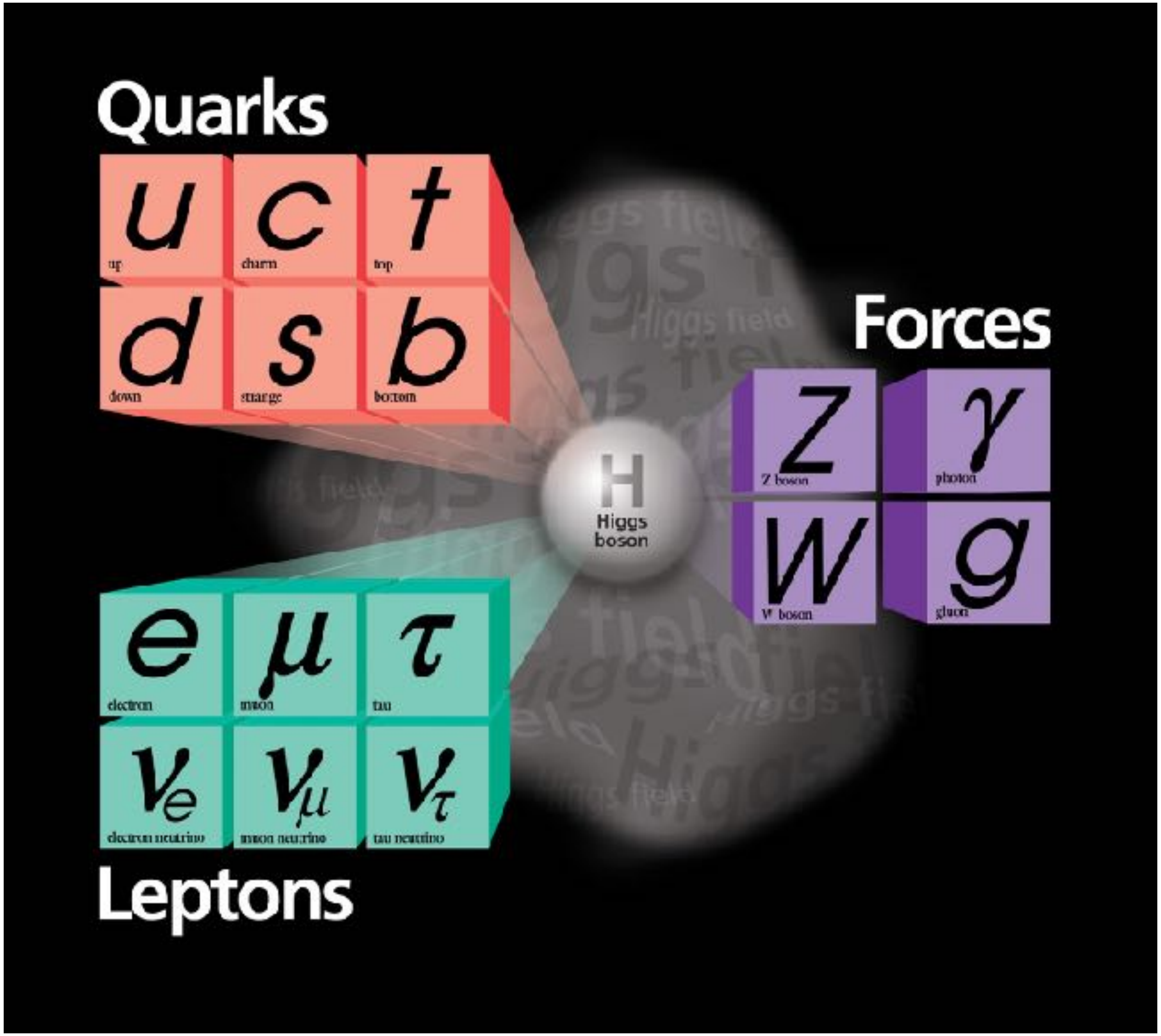
# QuarkNet Observations and Inferences

Similar to inferring a plane left the trail in the sky, we can infer much by observing particle tracks left behind.



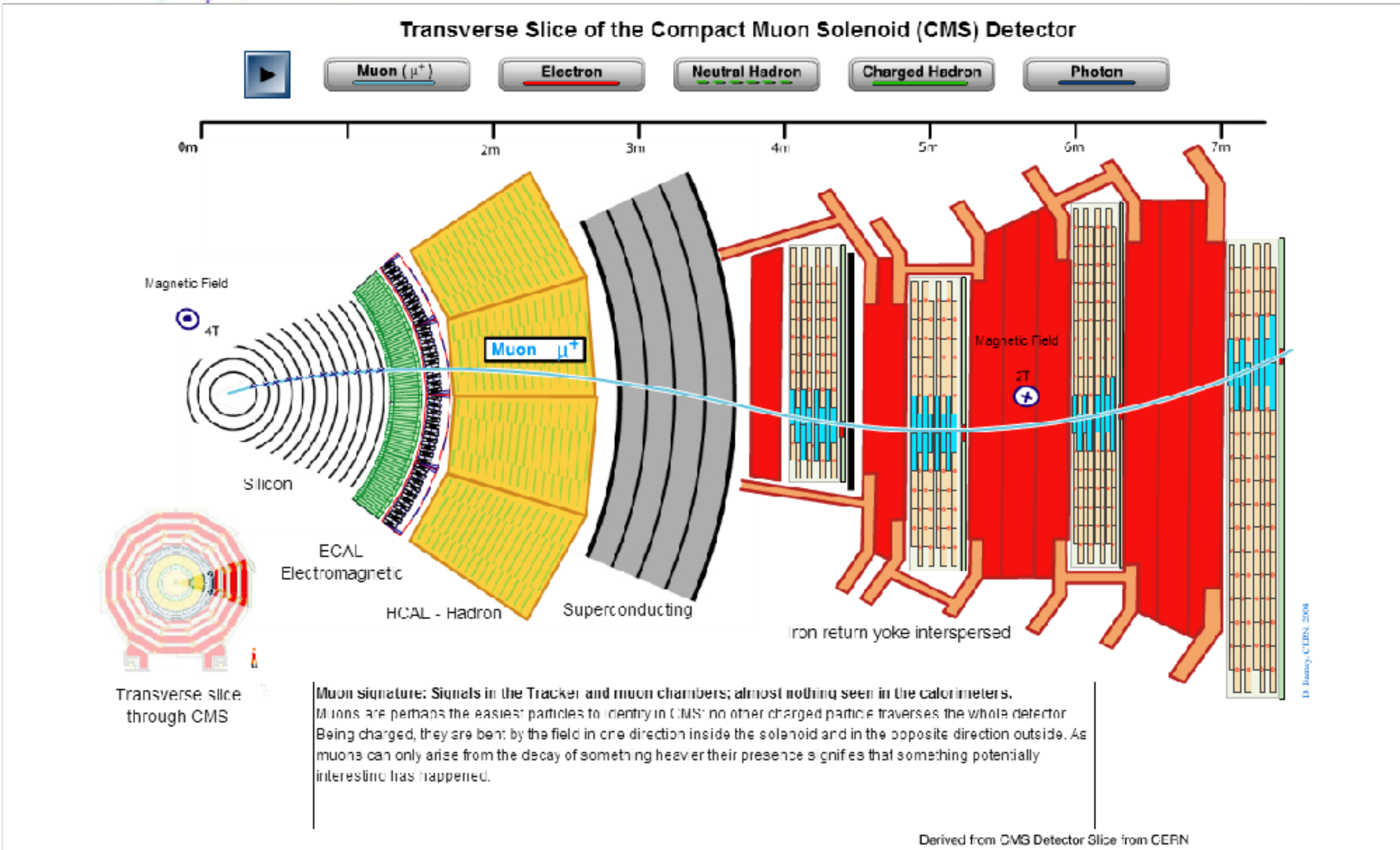

Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Forces
Z
Z boson
γ
photon
W
W boson
g
gluon
H
Higgs boson
e
electron
μ
muon
τ
tau
$\nu_e$
electron neutrino
$\nu_\mu$
muon neutrino
$\nu_\tau$
tau neutrino
Leptons

Helping Develop America's Technological Workforce

QuarkNet

# Detector Tracks

Web Version

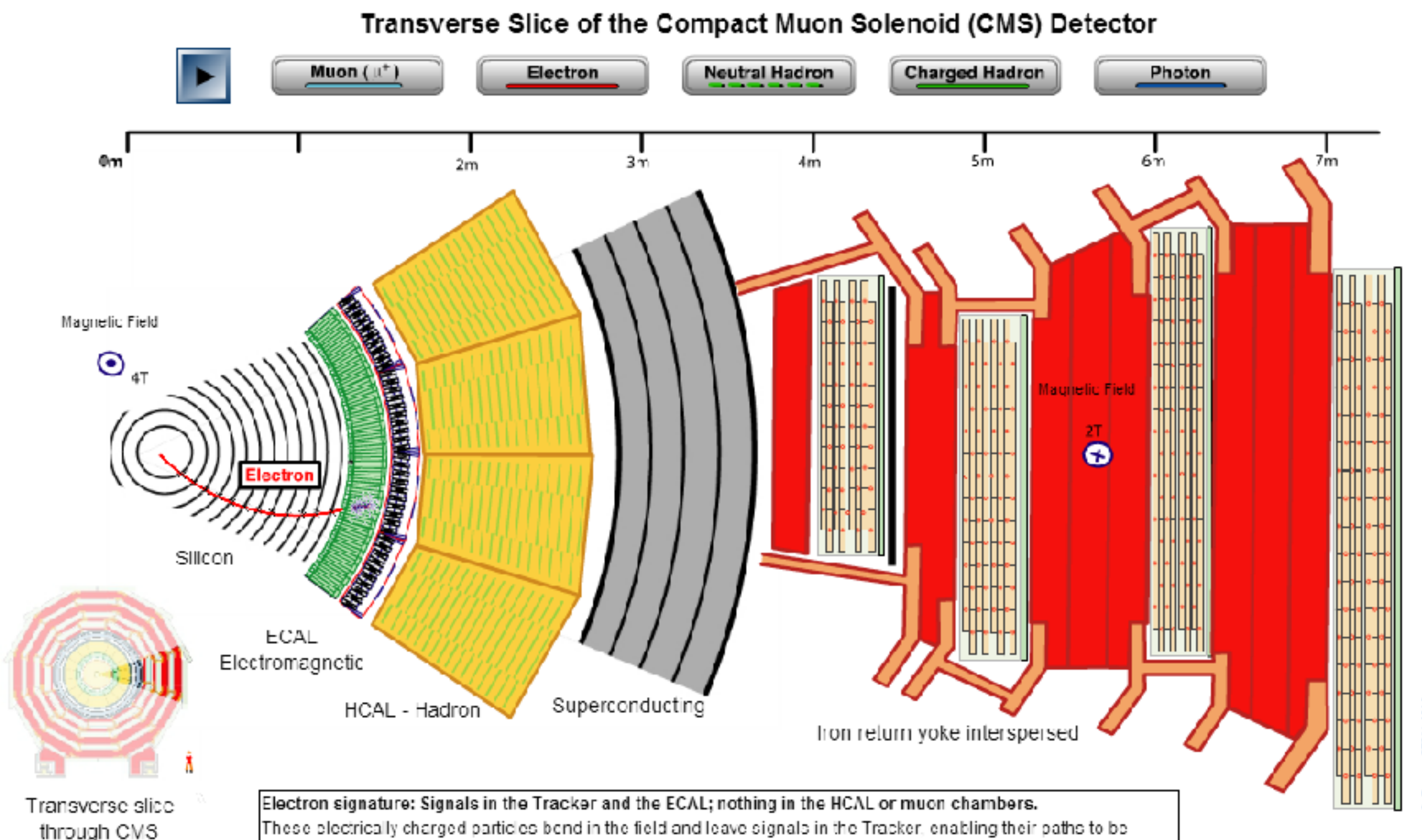


Helping Develop America's Technological Workforce

QuarkNet

# 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

Helping Develop America's Technological Workforce

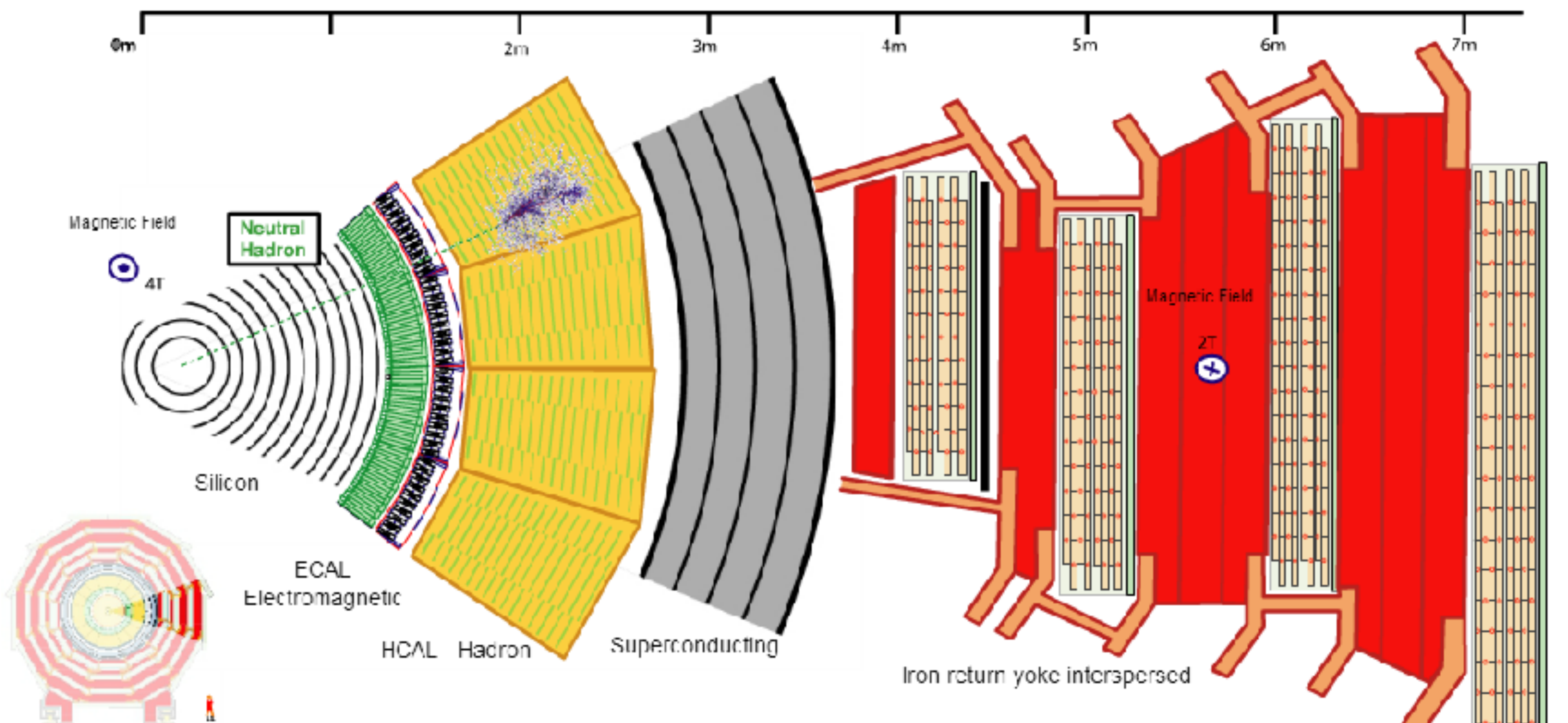
QuarkNet

# Detector Tracks

Web Version

## Transverse Slice of the Compact Muon Solenoid (CMS) Detector

Muon ($\mu^+$) | Electron | Neutral Hadron | Charged Hadron | Photon




**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.

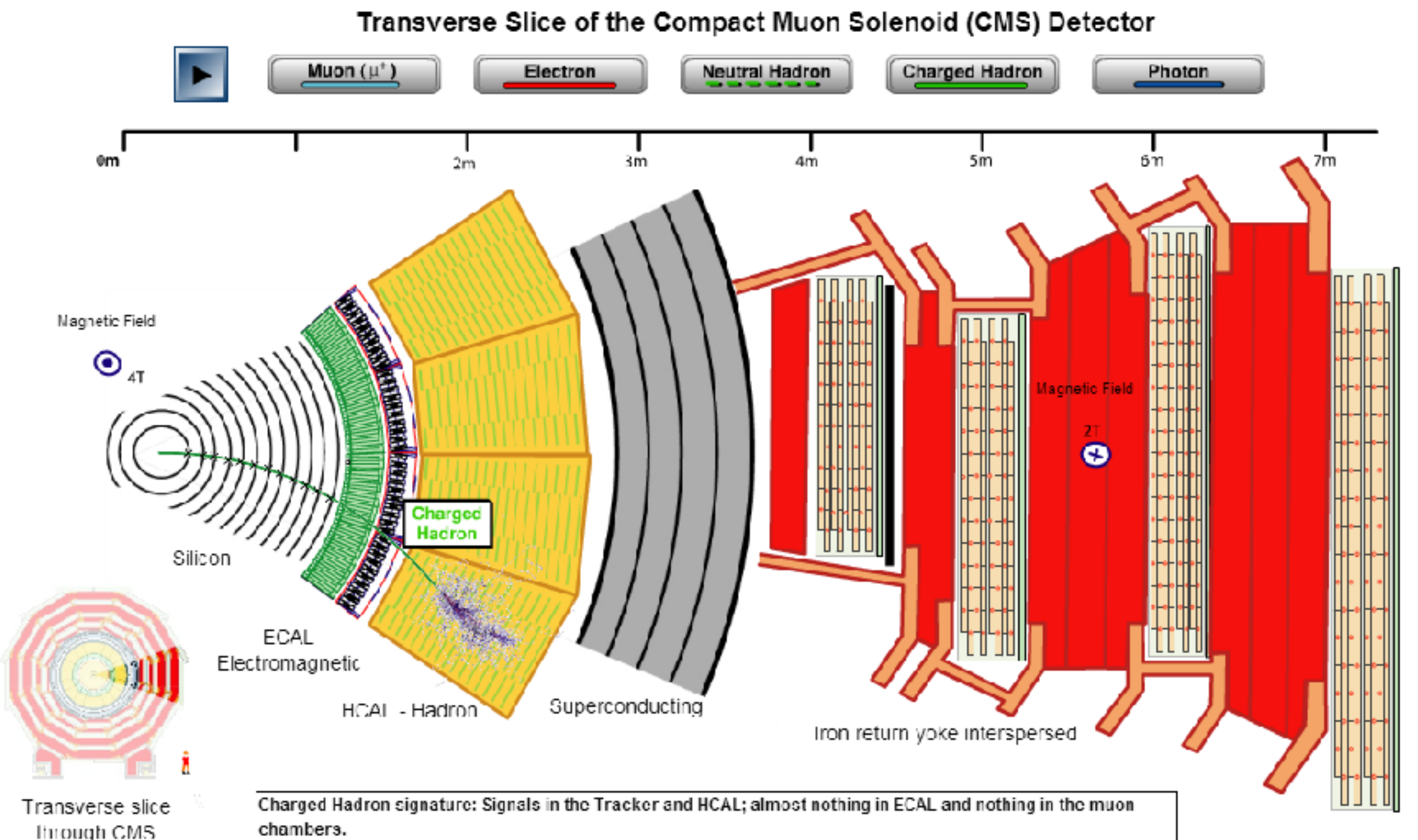
Derived from CMS Detector Slice from CERN

Helping Develop America's Technological Workforce

QuarkNet

# Detector Tracks

Web Version




**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

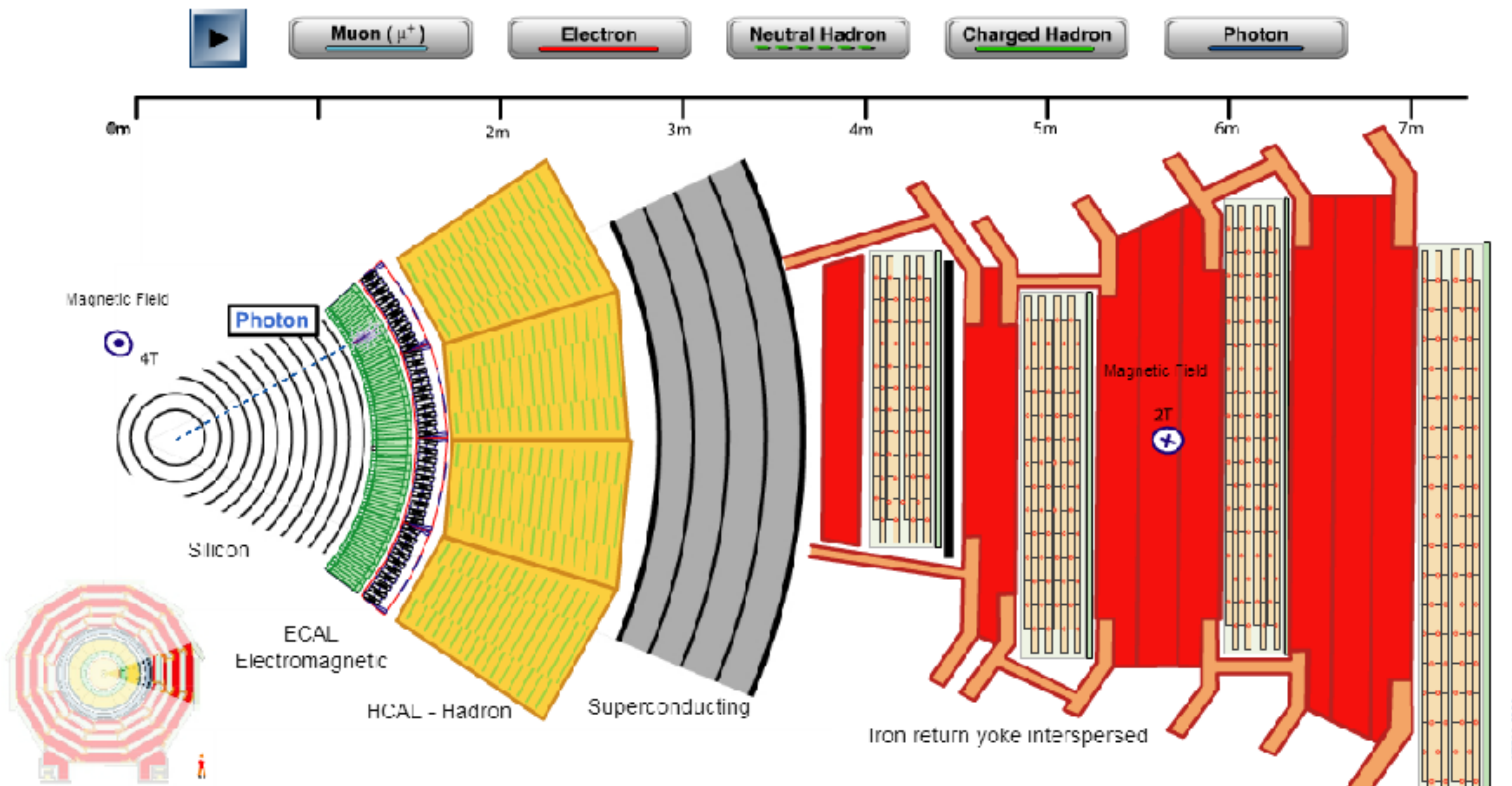
Helping Develop America's Technological Workforce

QuarkNet

# Detector Tracks

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

Helping Develop America's Technological Workforce

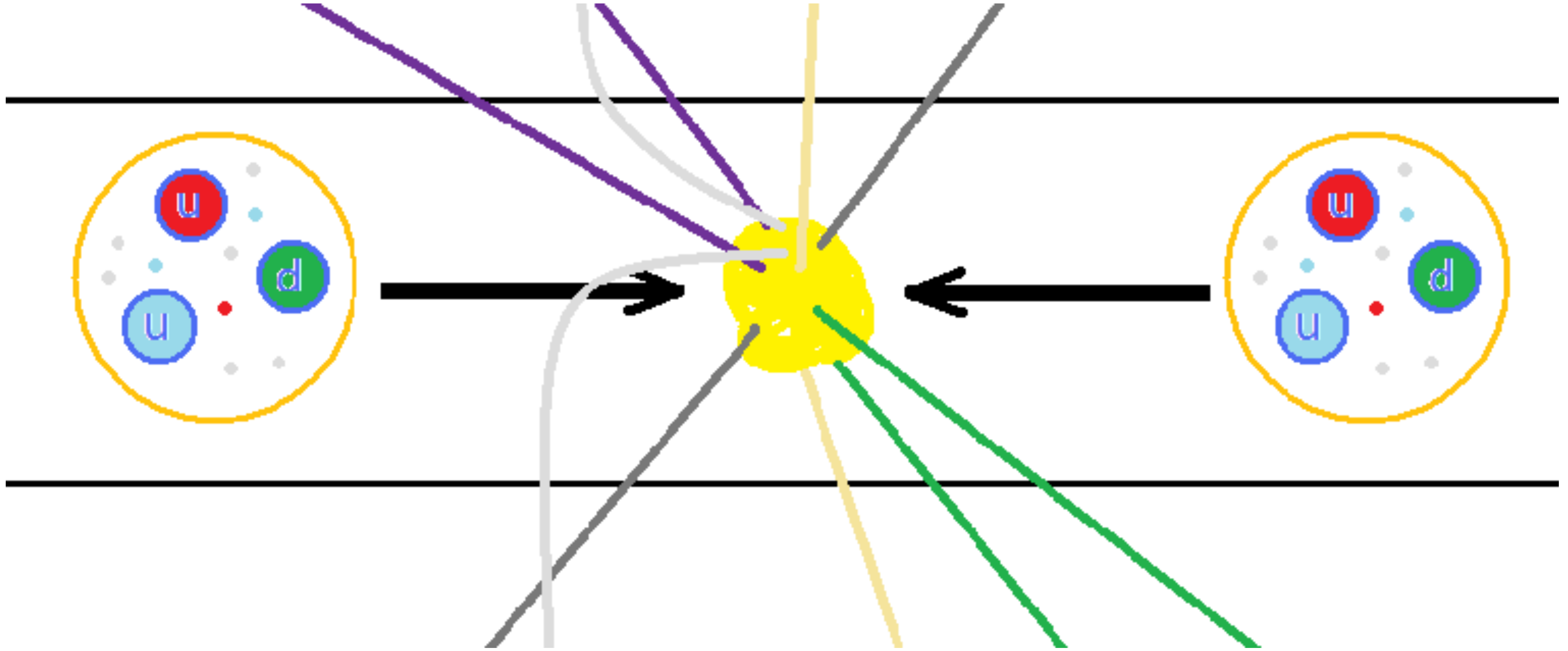
QuarkNet

# 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.

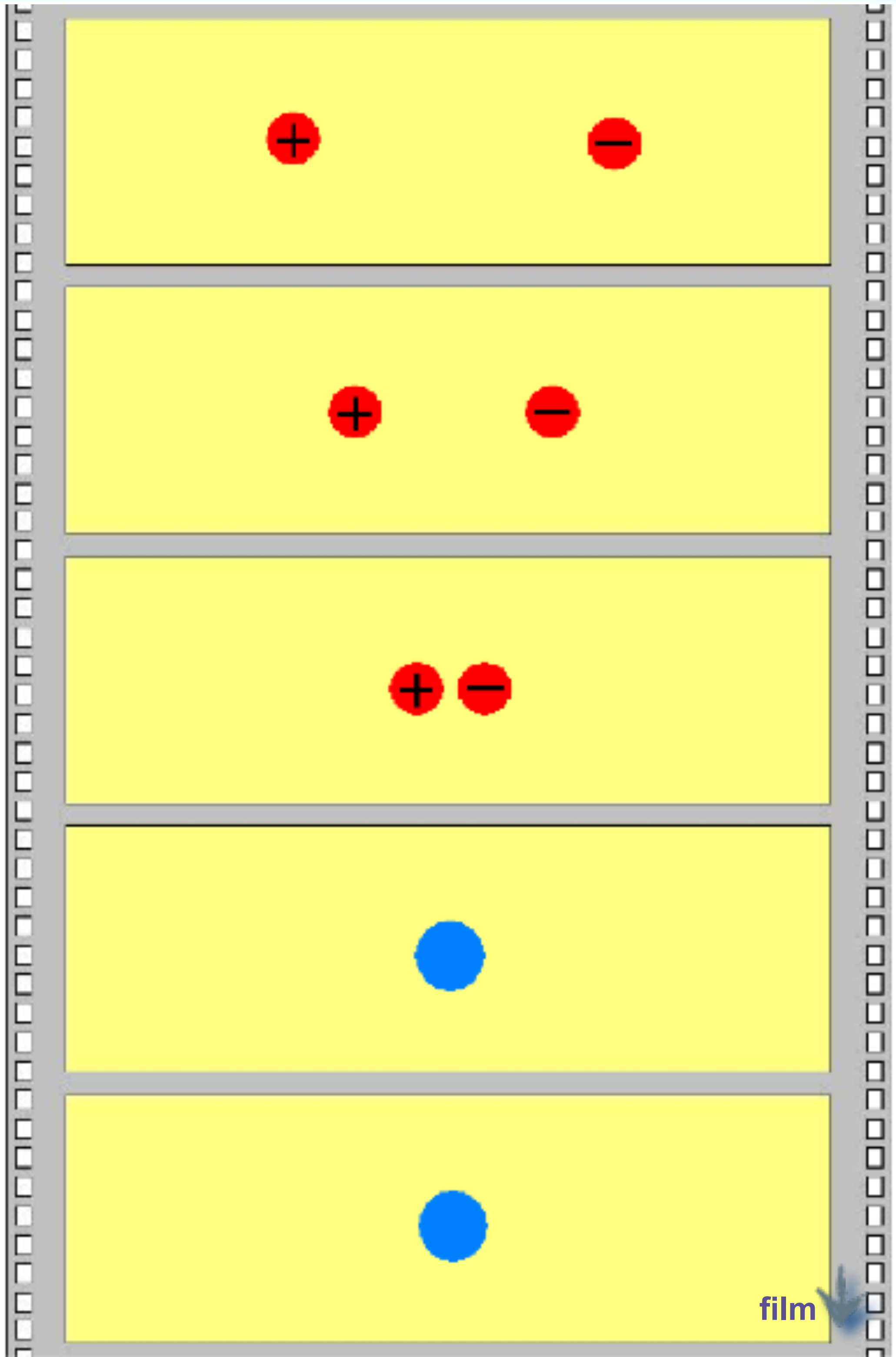
**In Run II, this was increased to 6.5 GeV!*



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.



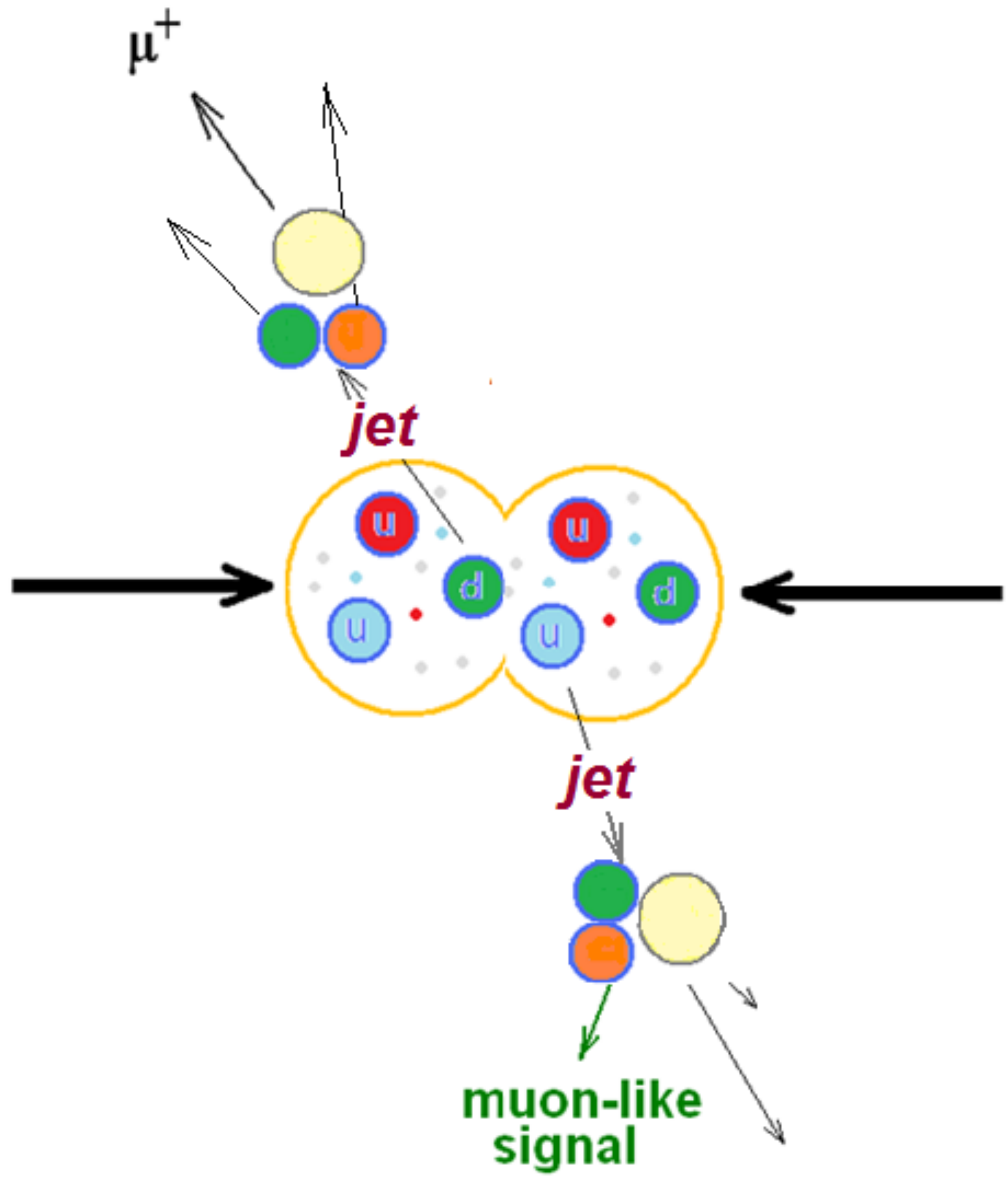
QuarkNet

# 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.

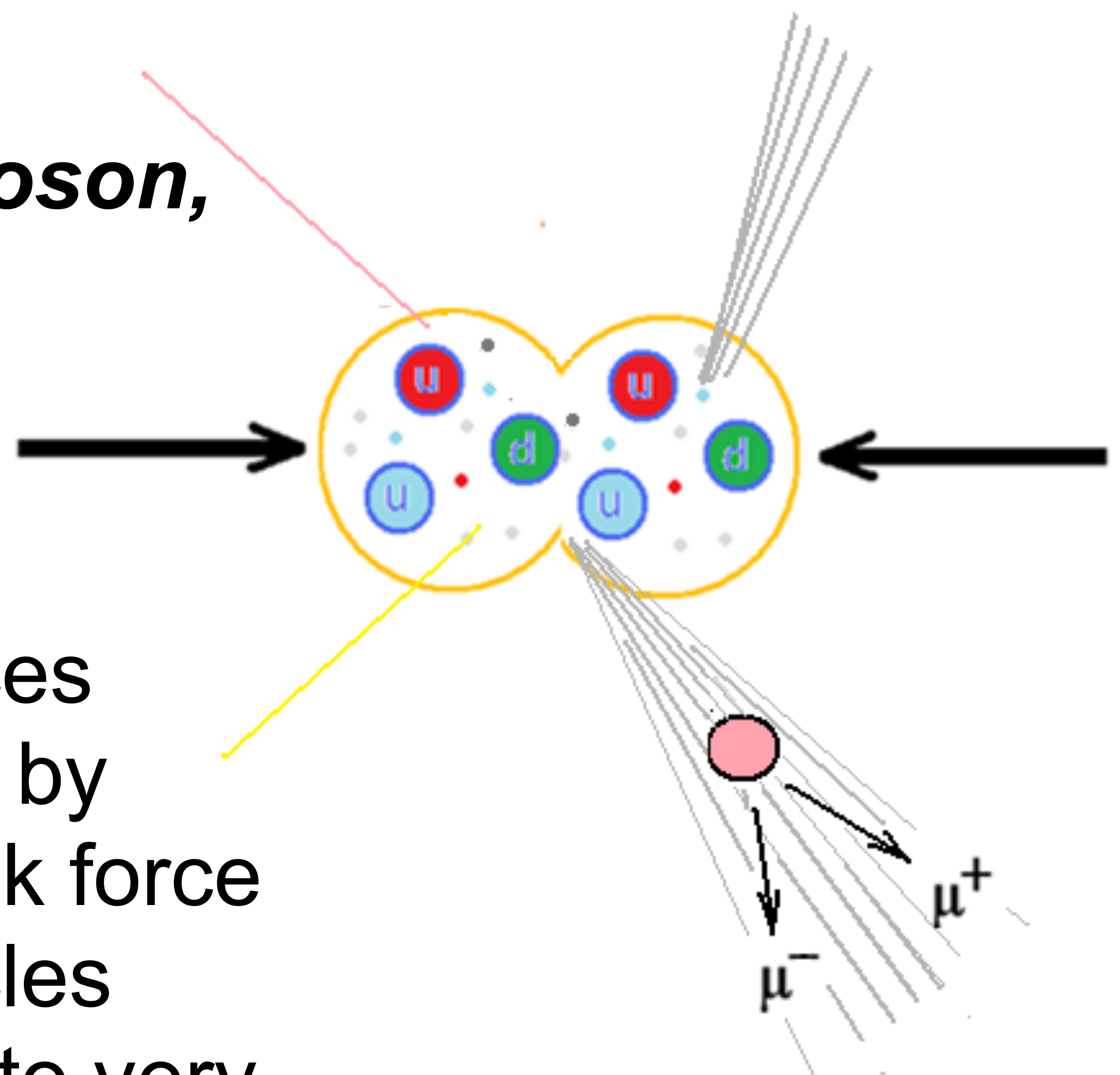
Software can filter out events with jets beyond our current interest.



# 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.

Helping Develop America's Technological Workforce

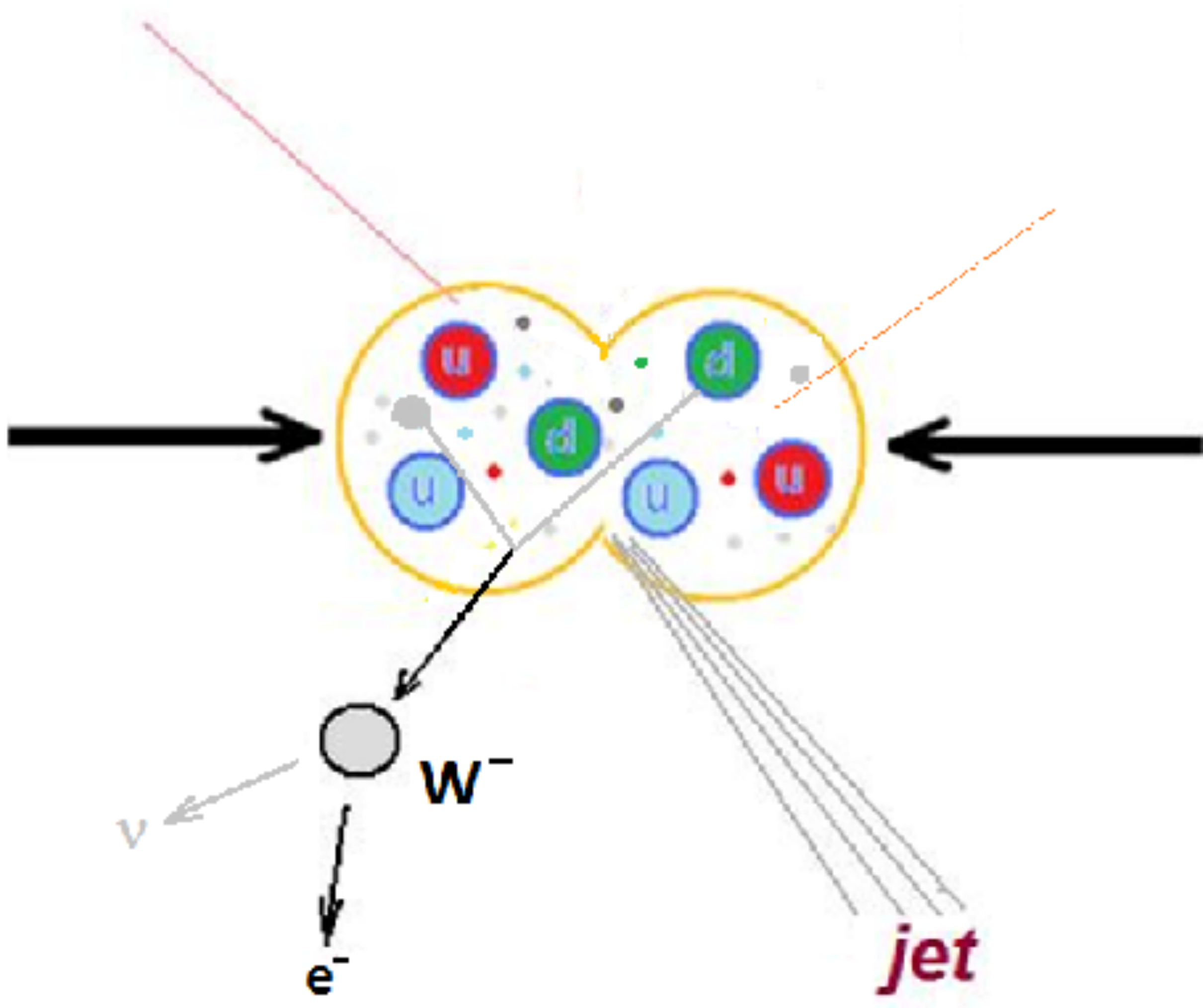
QuarkNet

# 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.

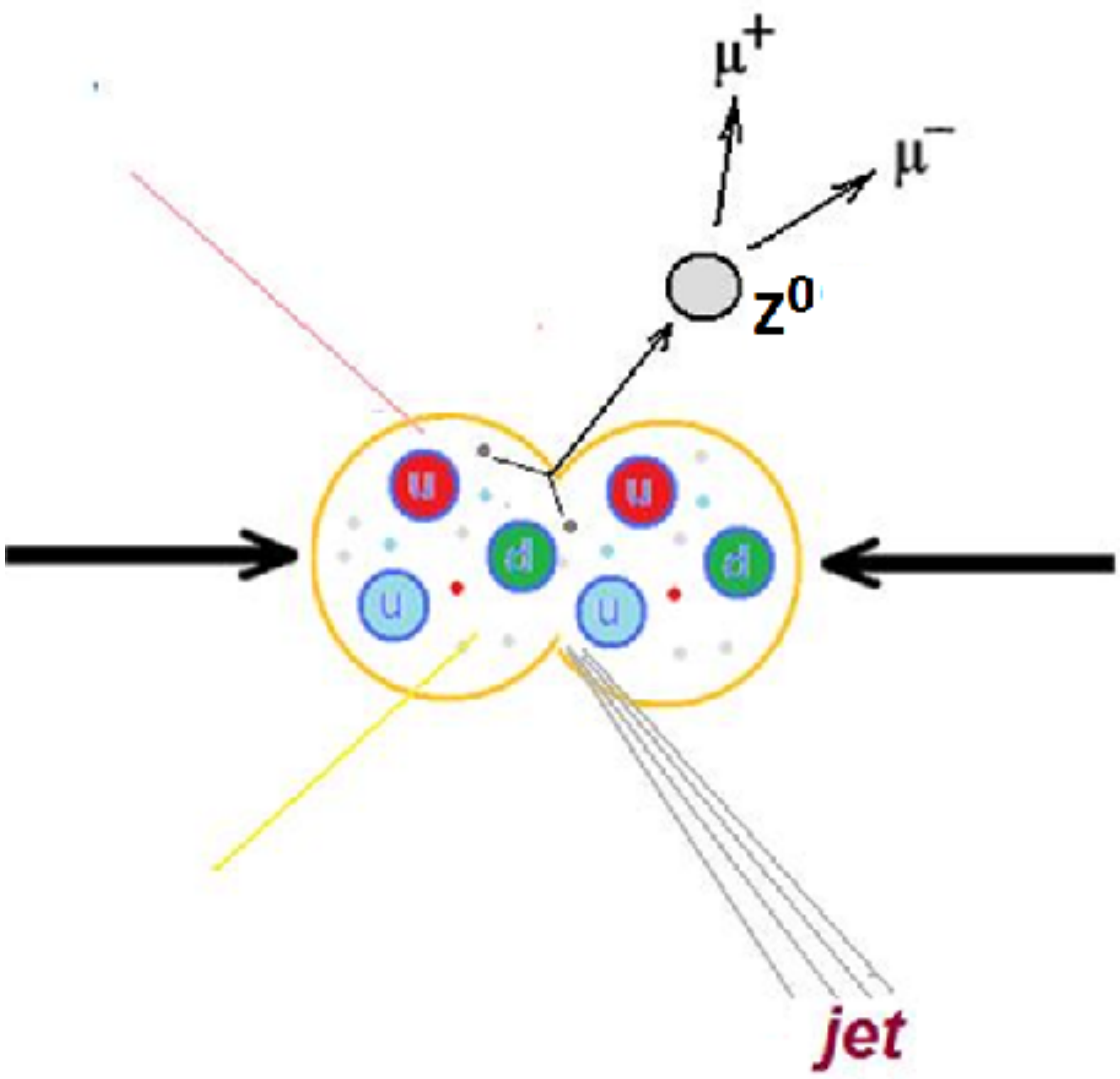


# W and Z Particles

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.



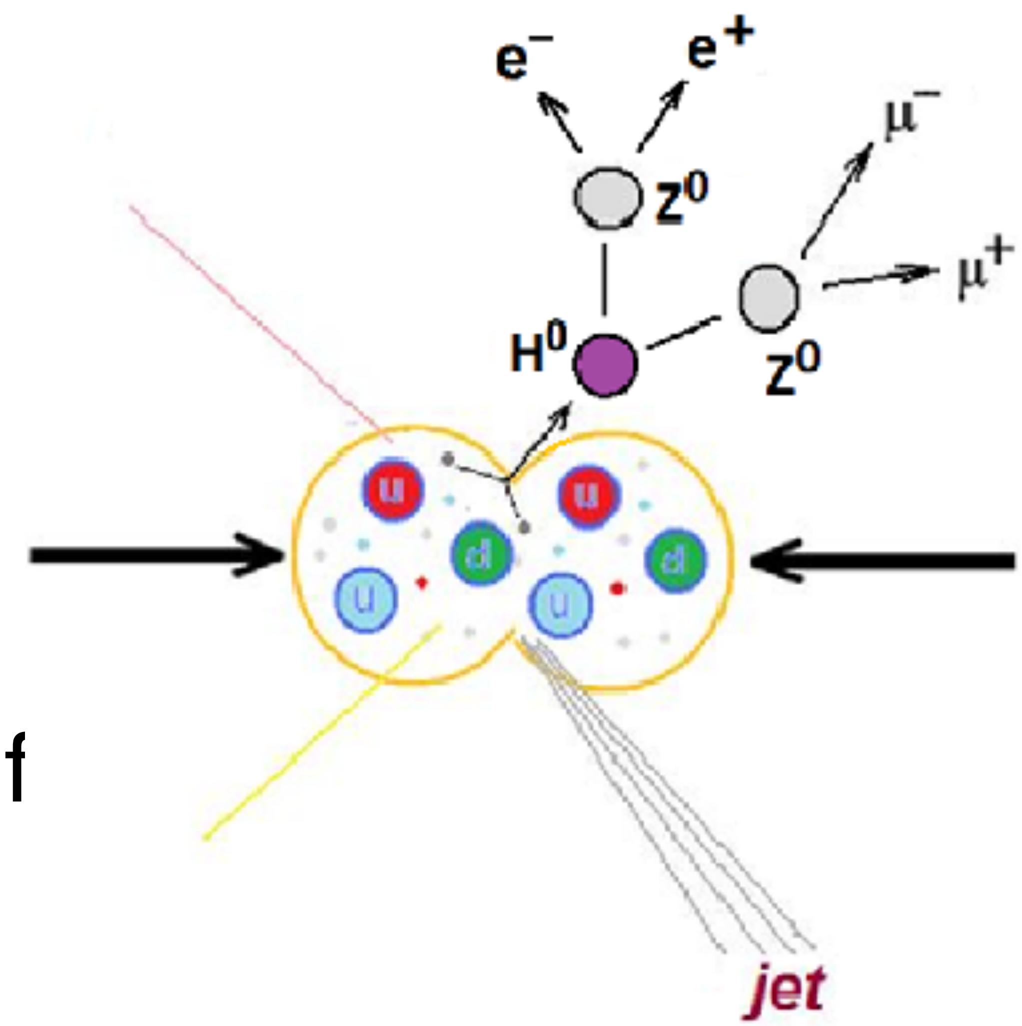
Helping Develop America's Technological Workforce

QuarkNet

# Higgs Particles

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

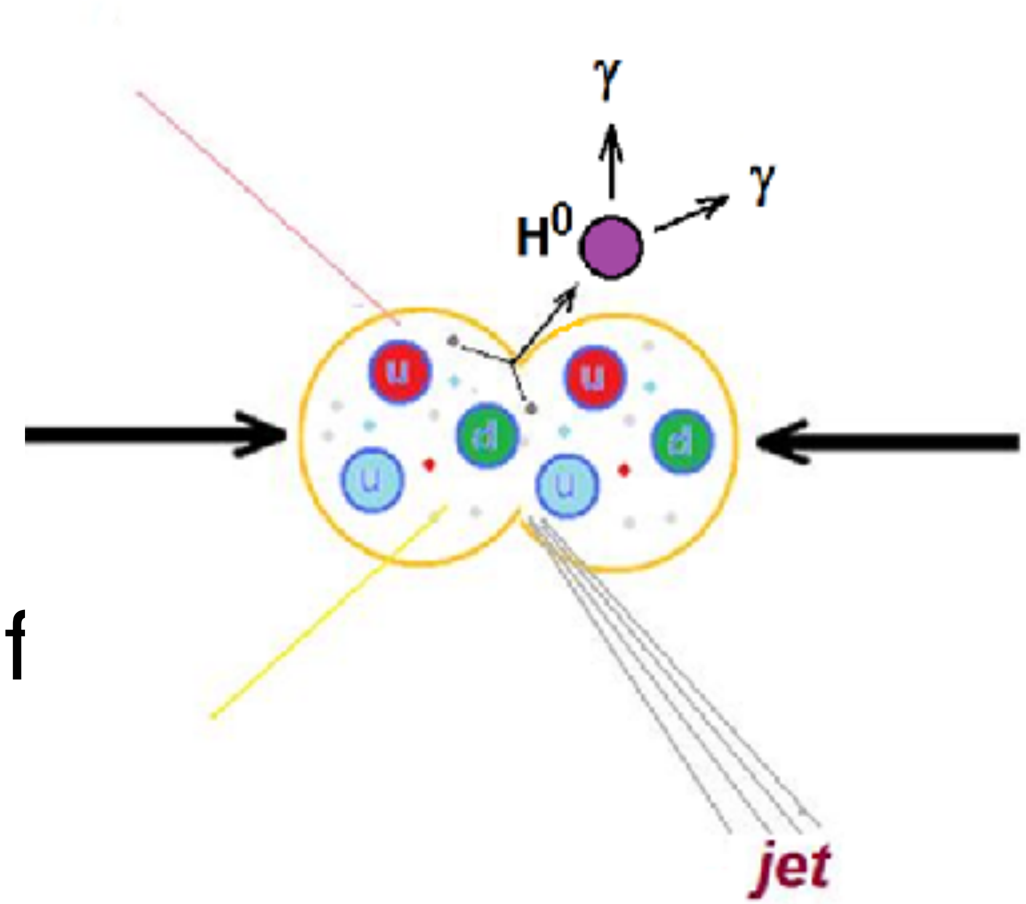
This long-sought particle is part of the "Higgs mechanism" that accounts f other particle having mass.



# Higgs Particles

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

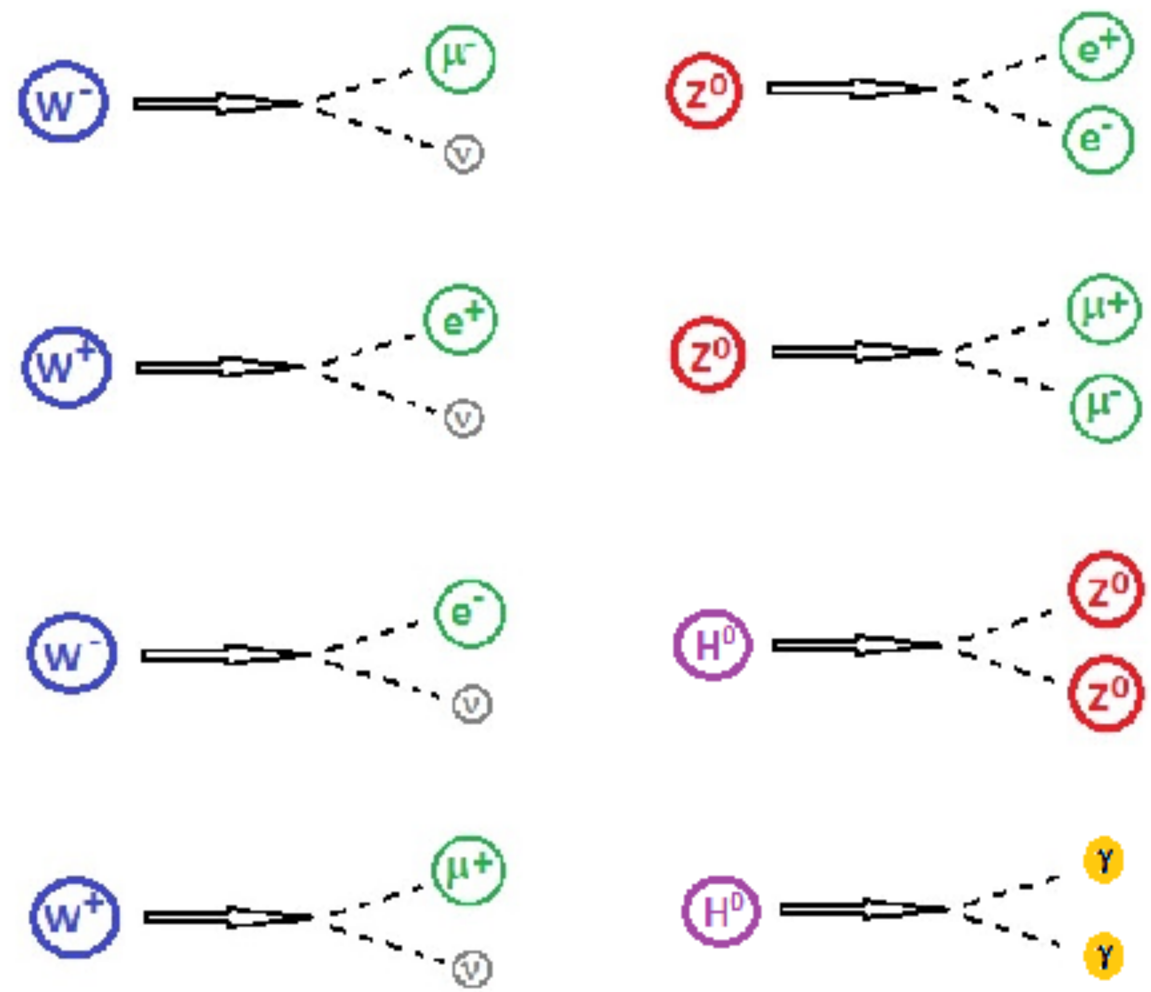
This long-sought particle is part of the "Higgs mechanism" that accounts f other particle having mass.



# 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

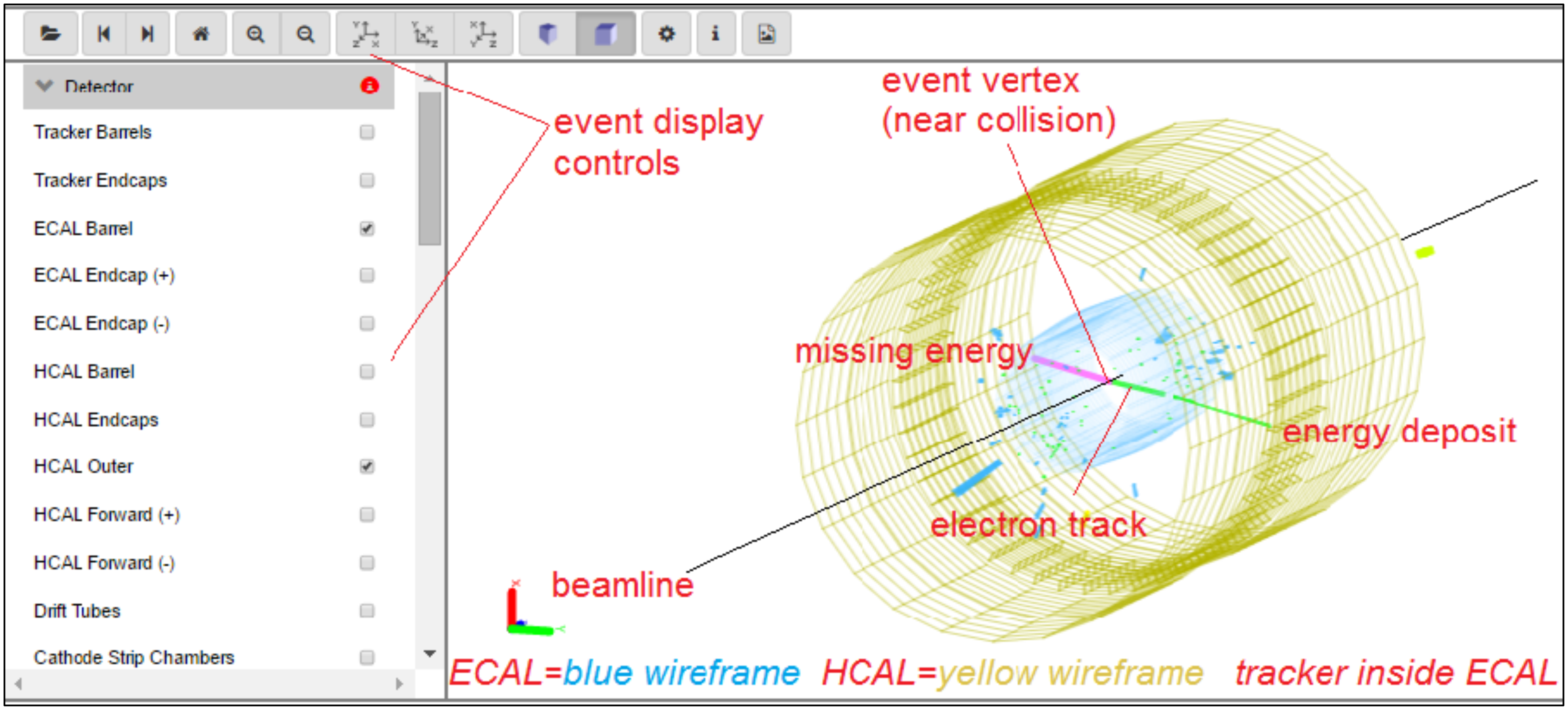



CMS can infer:
- neutrinos from “missing energy”

Helping Develop America's Technological Workforce

QuarkNet

# iSpy-webgl



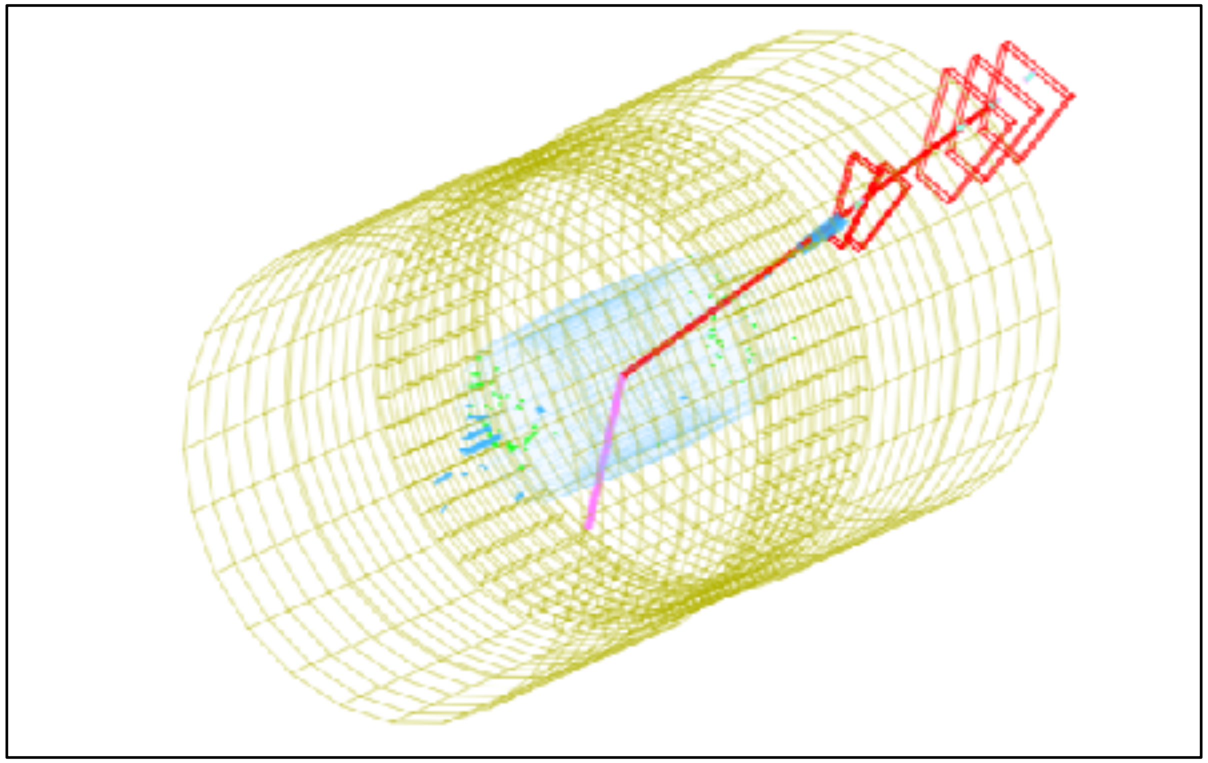
Helping Develop America's Technological Workforce

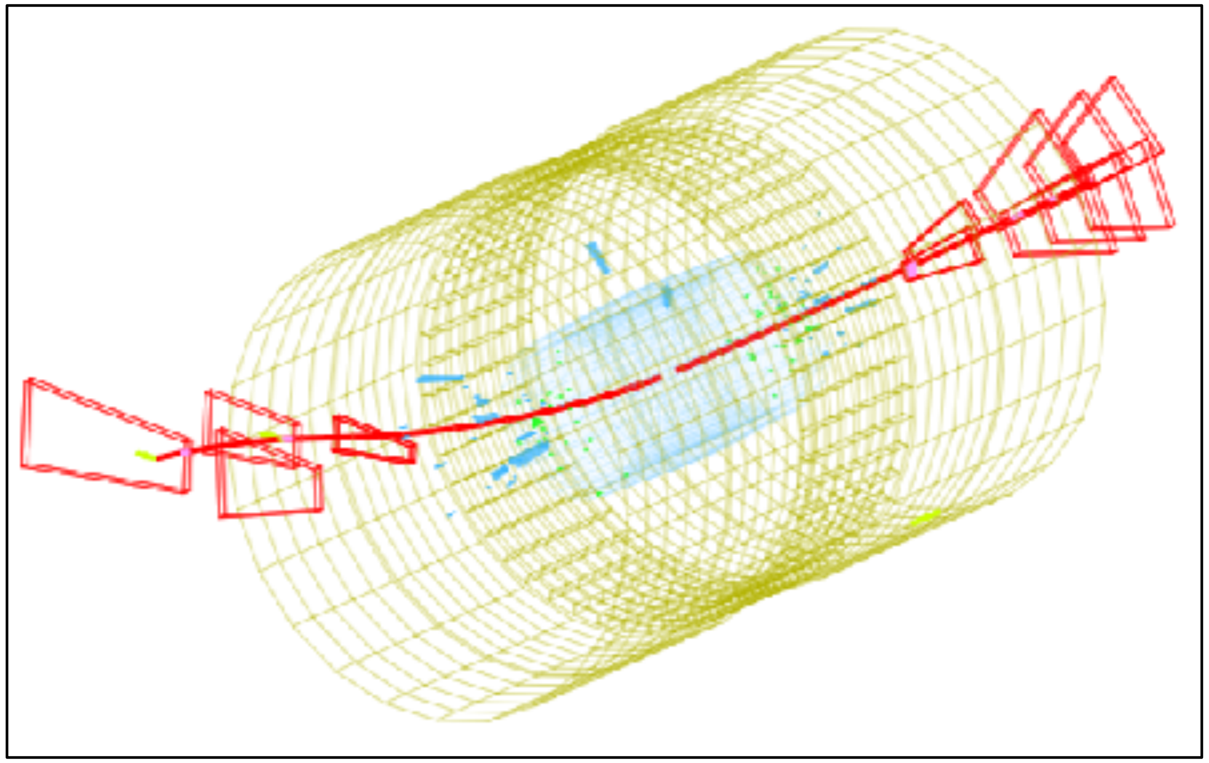
QuarkNet

# Today's Task

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

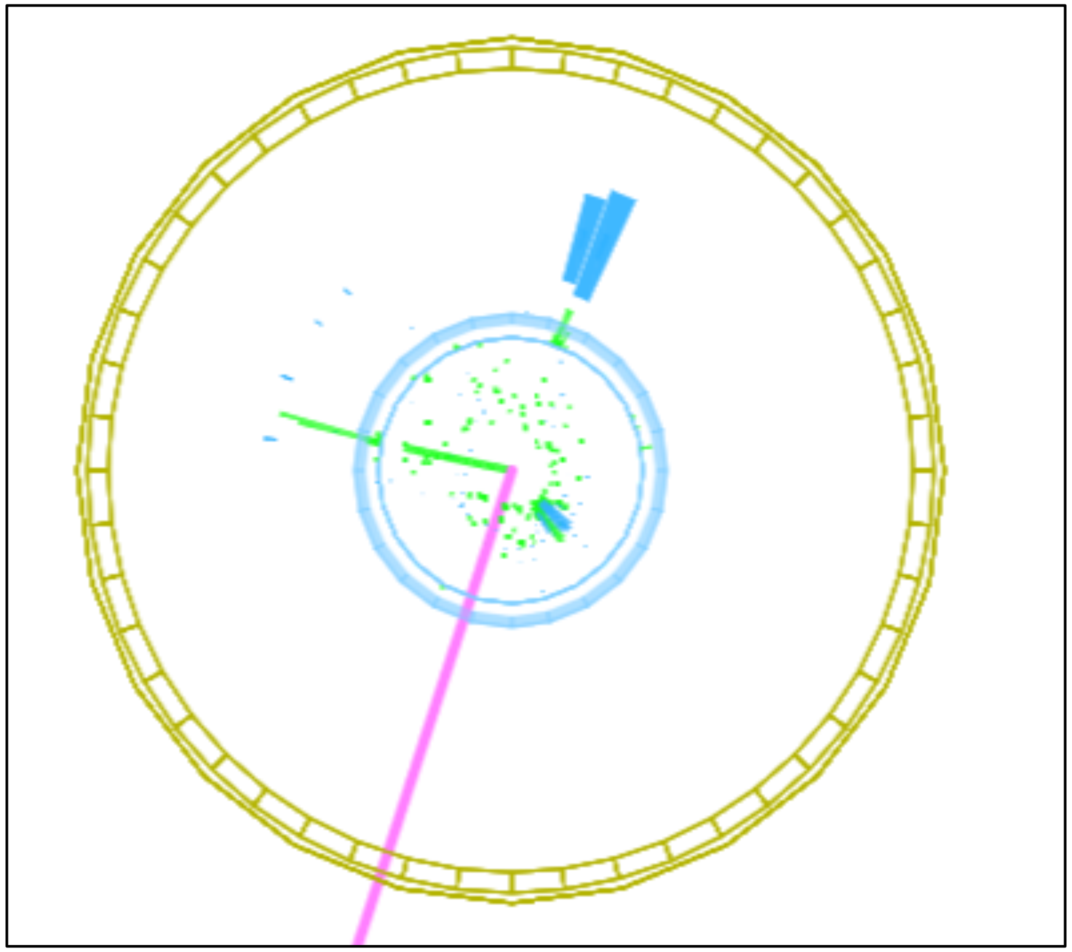
- Can we distinguish W from Z candidates?

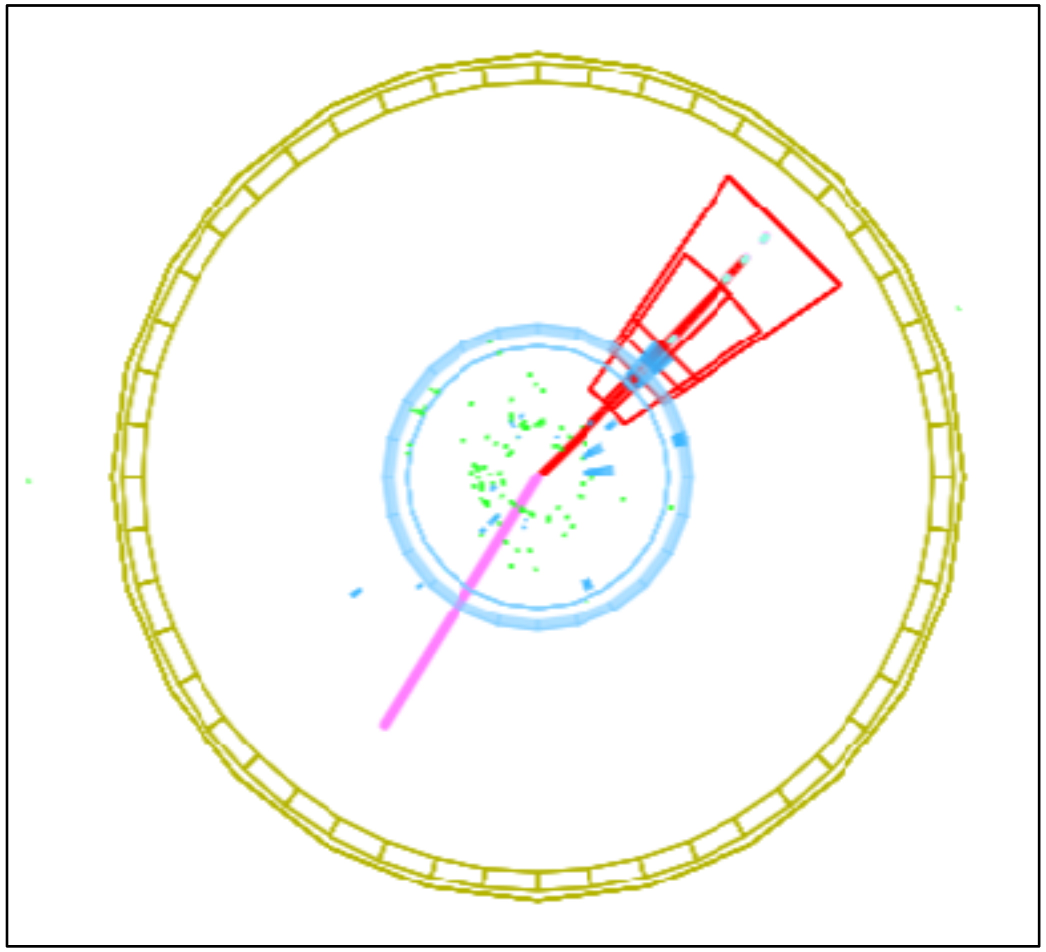




# Today's Task

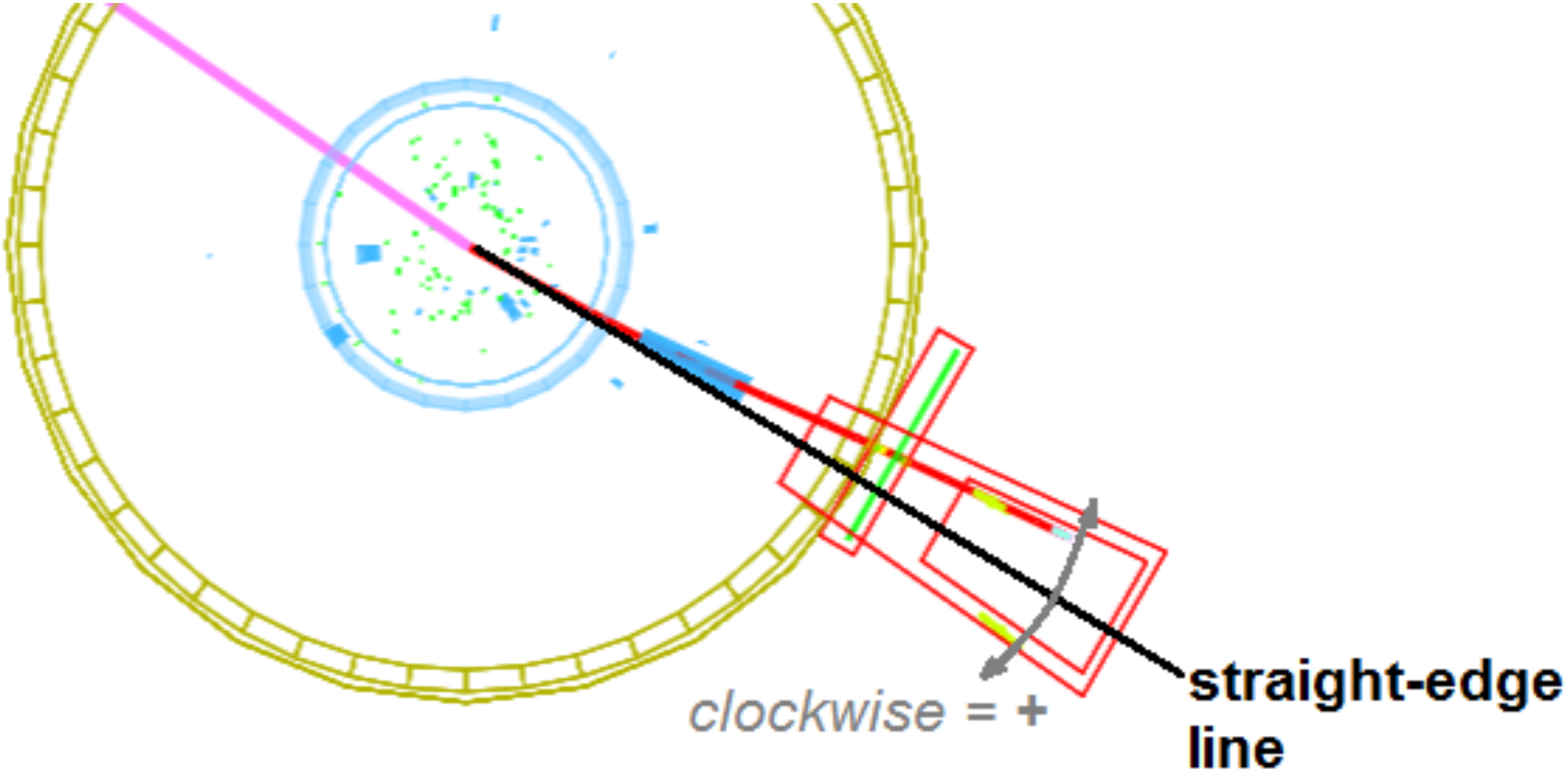
- Can we calculate the e/μ ratio?





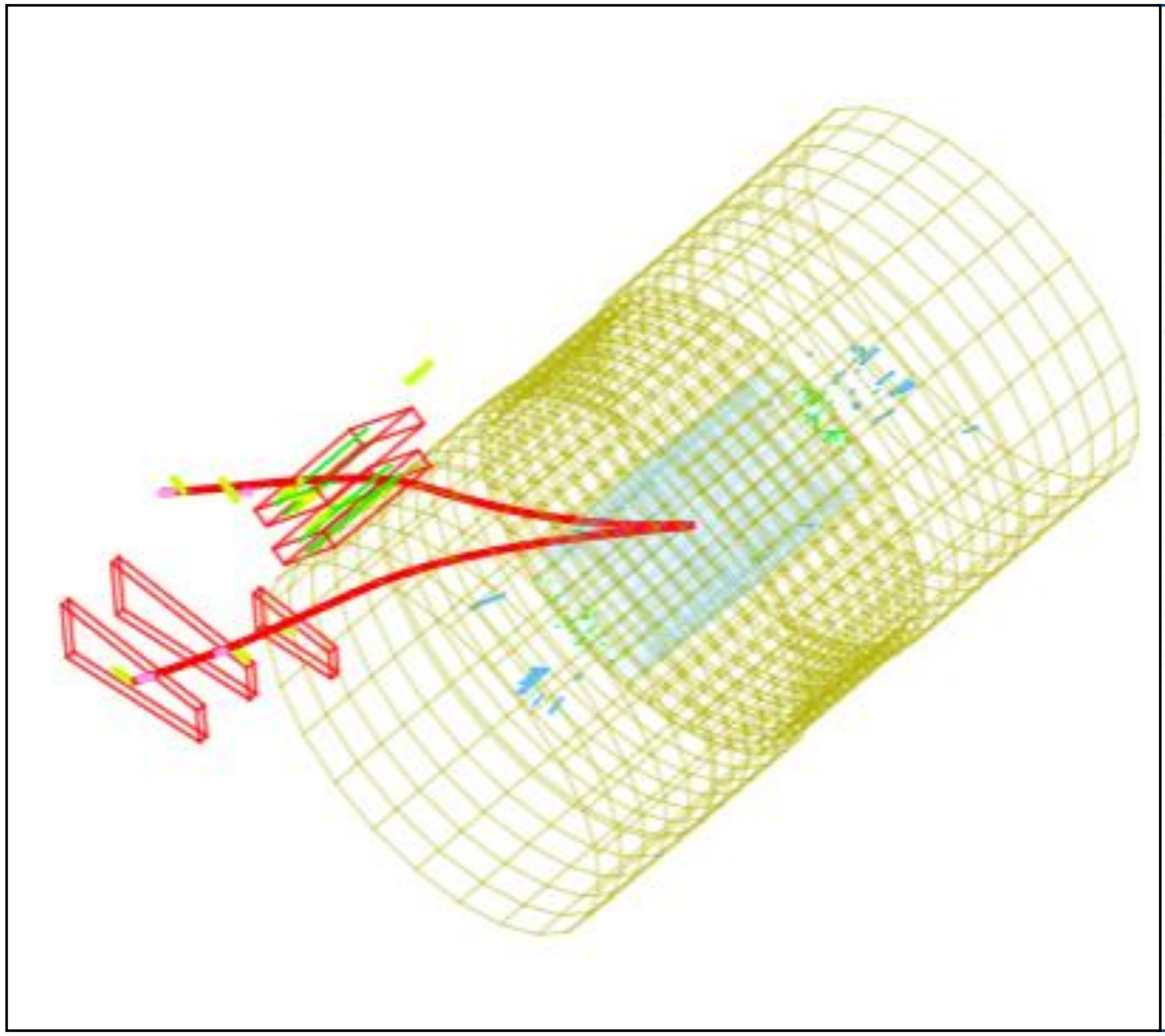
# Today's Task

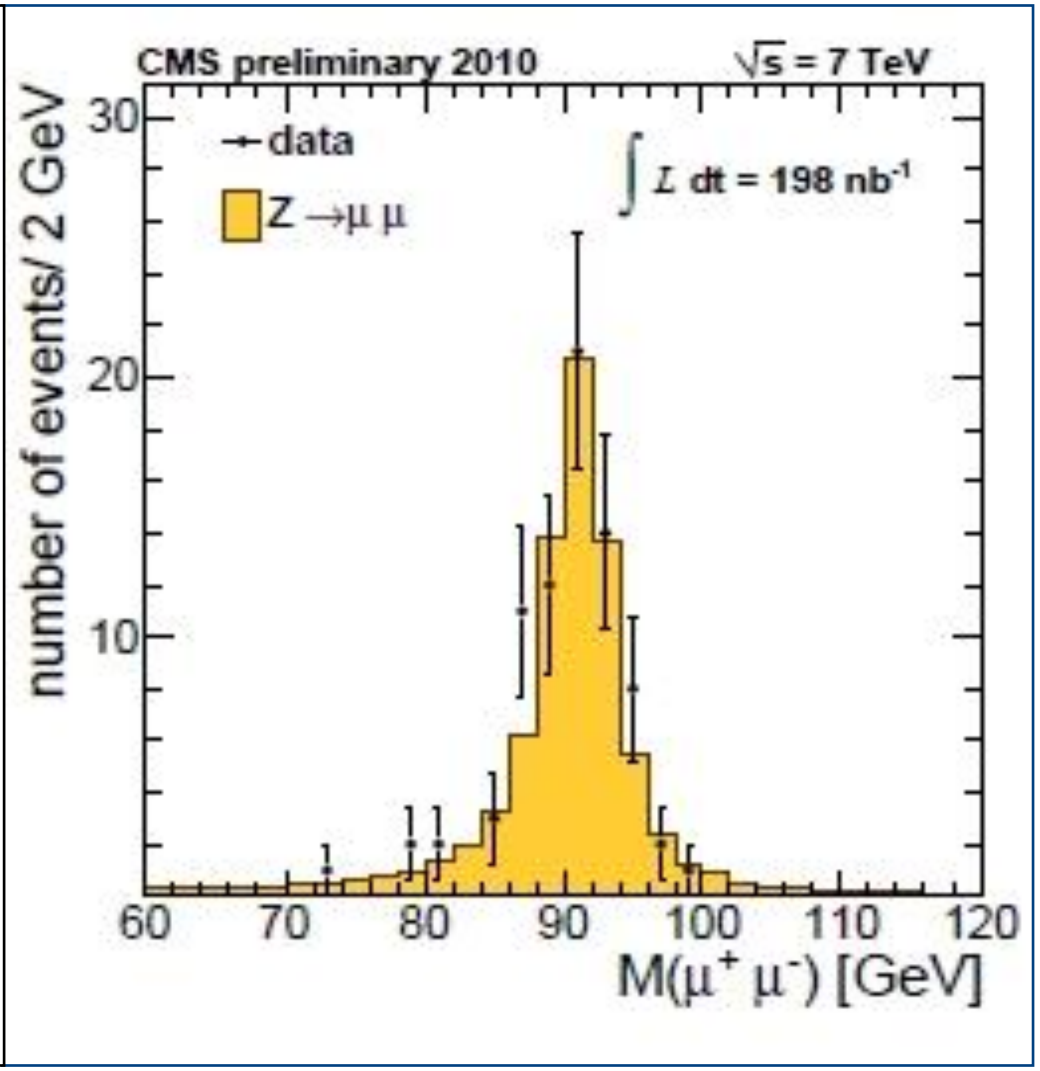
- Can we calculate a W+/W- ratio for CMS?



# Today's Task

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



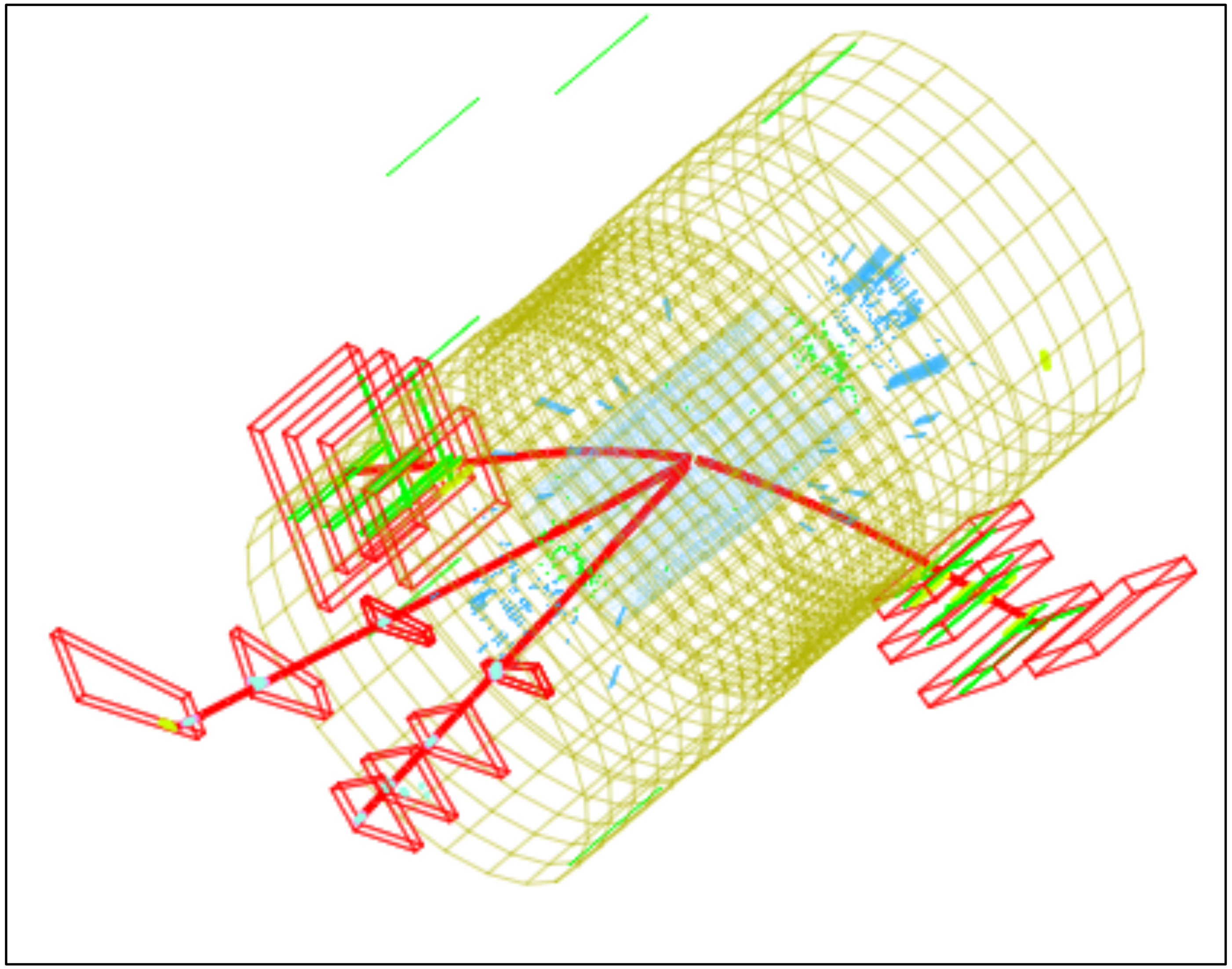


Helping Develop America's Technological Workforce

QuarkNet

# Today's Task

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



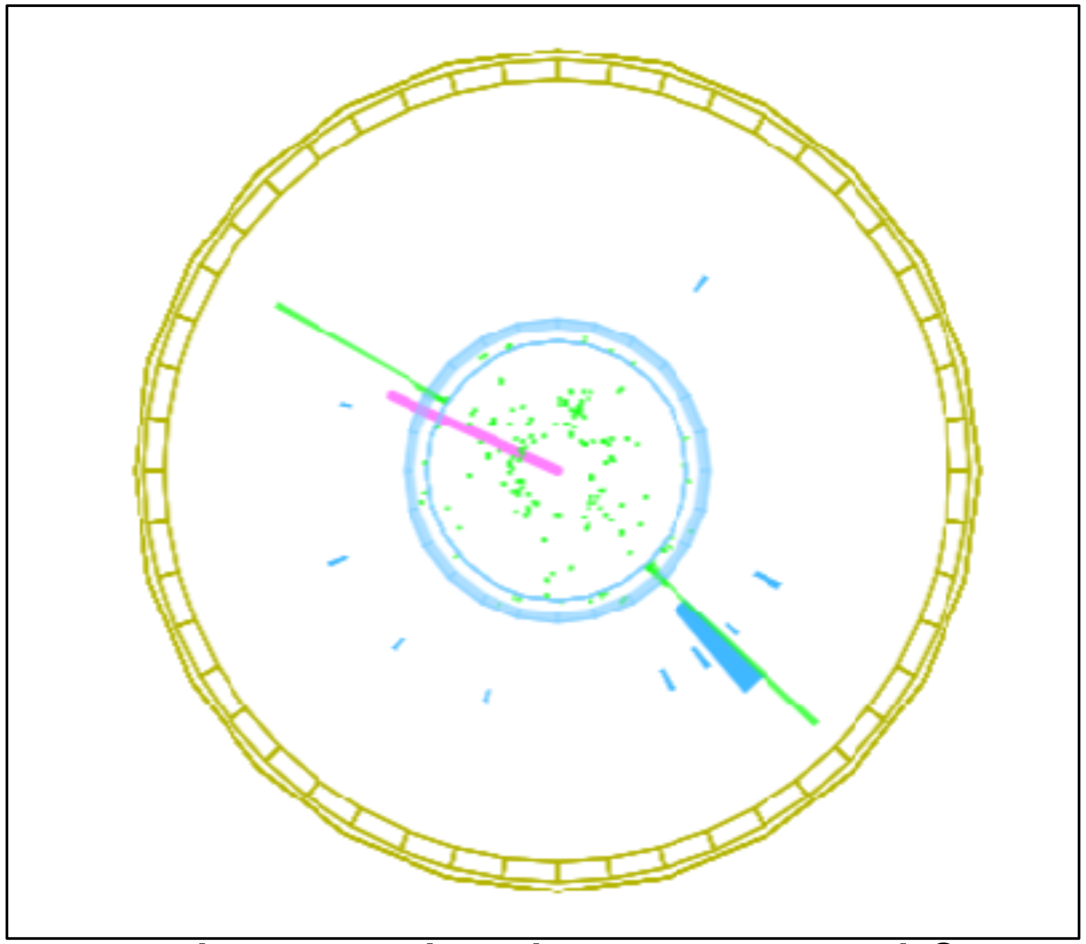
*Can we pick out electrons and/or muons?*

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

QuarkNet

# Today's Task

- Can we find some H→γγ events?

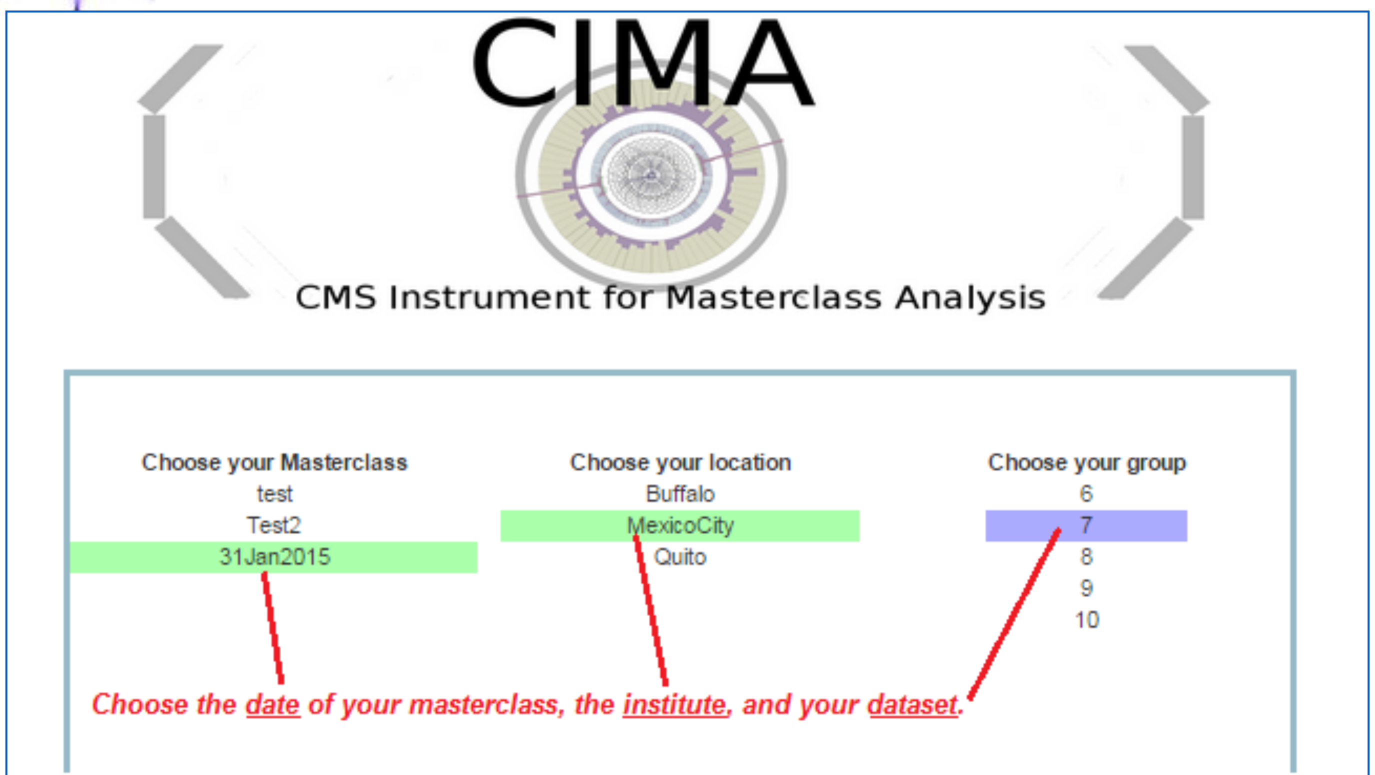


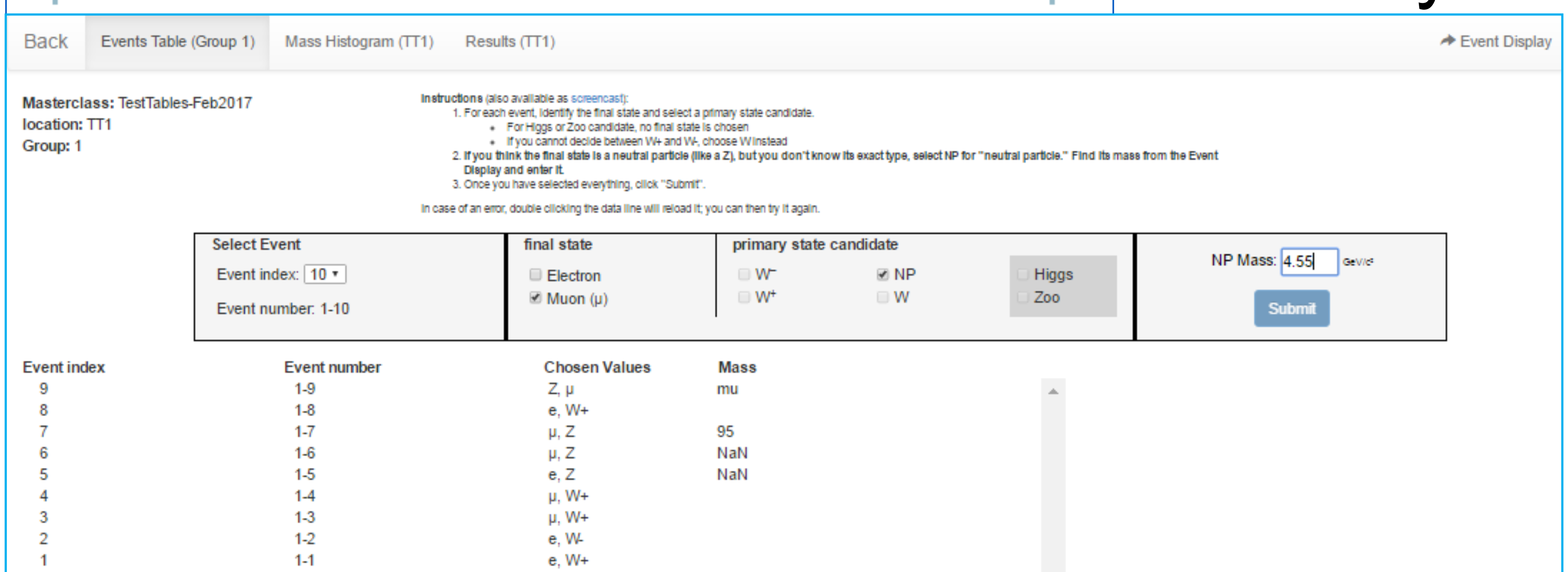
*How do we spot photons that leave no track?*

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

QuarkNet

# Recording event data




Find your dataset.

Record parent particles and decay modes.

Helping Develop America's Technological Workforce

QuarkNet

# Recording event data

Mass Histogram and Results pages

QuarkNet — Helping Develop America's Technological Workforce

# 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.**