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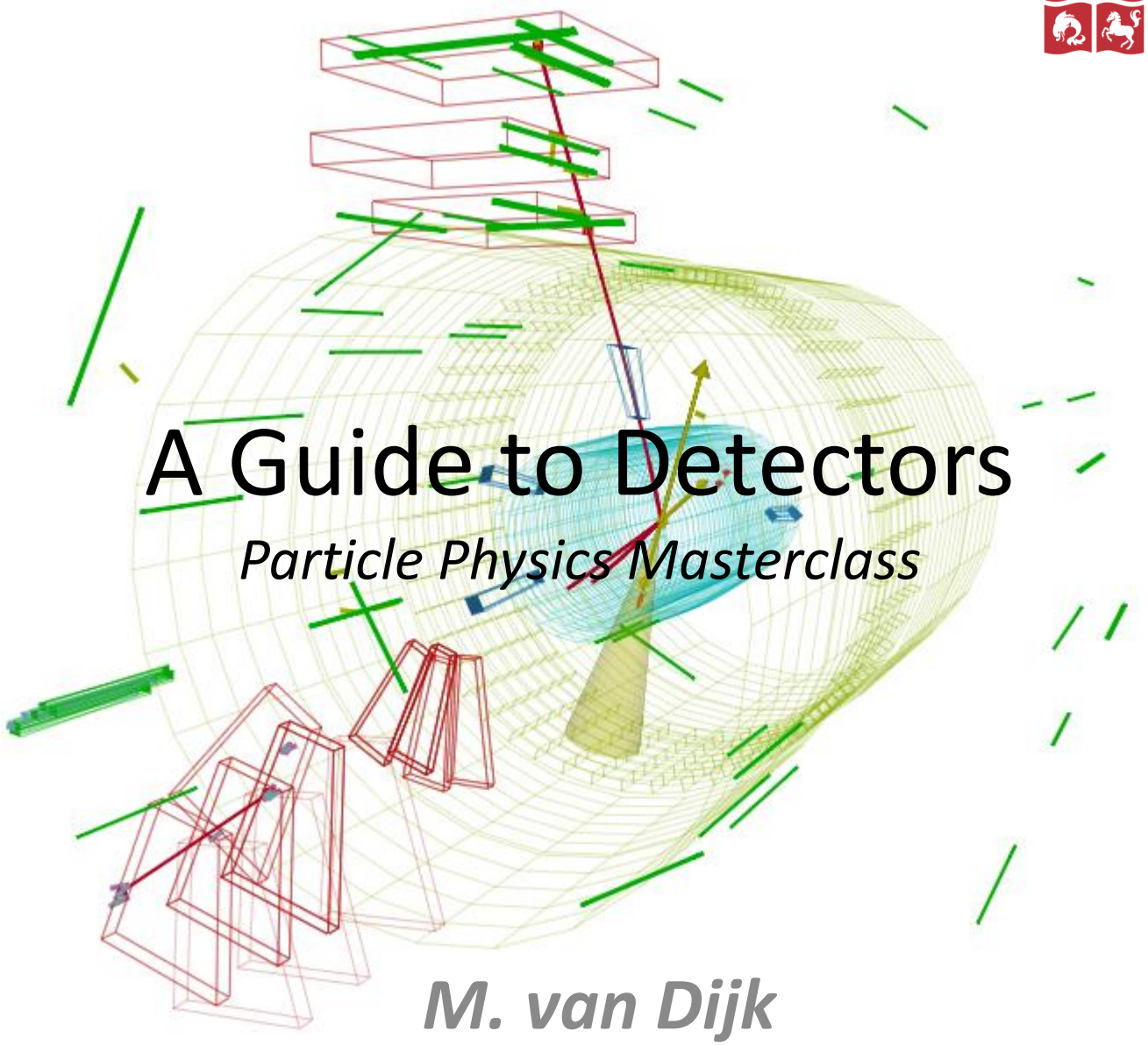

A Guide to Detectors

Particle Physics Masterclass

M. van Dijk

Introduction

- Introduction

- How detectors work
  - Scintillation
  - Ionization
- Particle identification
  - Tracking
  - Calorimetry
- Data Analysis
  - W & Z bosons

- Summary

Reconstructing collisions

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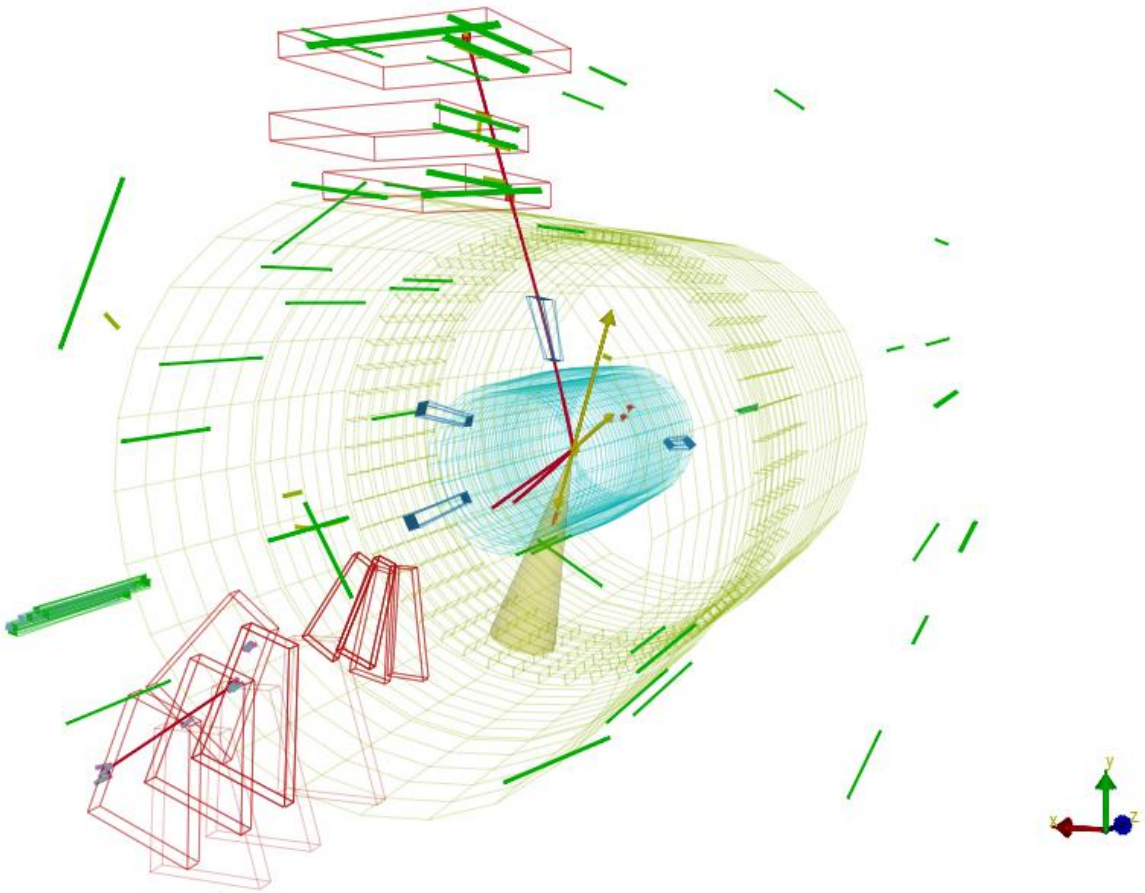
- What just happened?
- Not possible to view actual collision
- View collision debris
- Identify particles
- Reconstruct what happened



Reconstructing collisions

Reconstructing outgoing particles

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- What do we want to know about particles?
  - Where are they produced?
  - Where do they fall apart?
  - What are the parent particles?

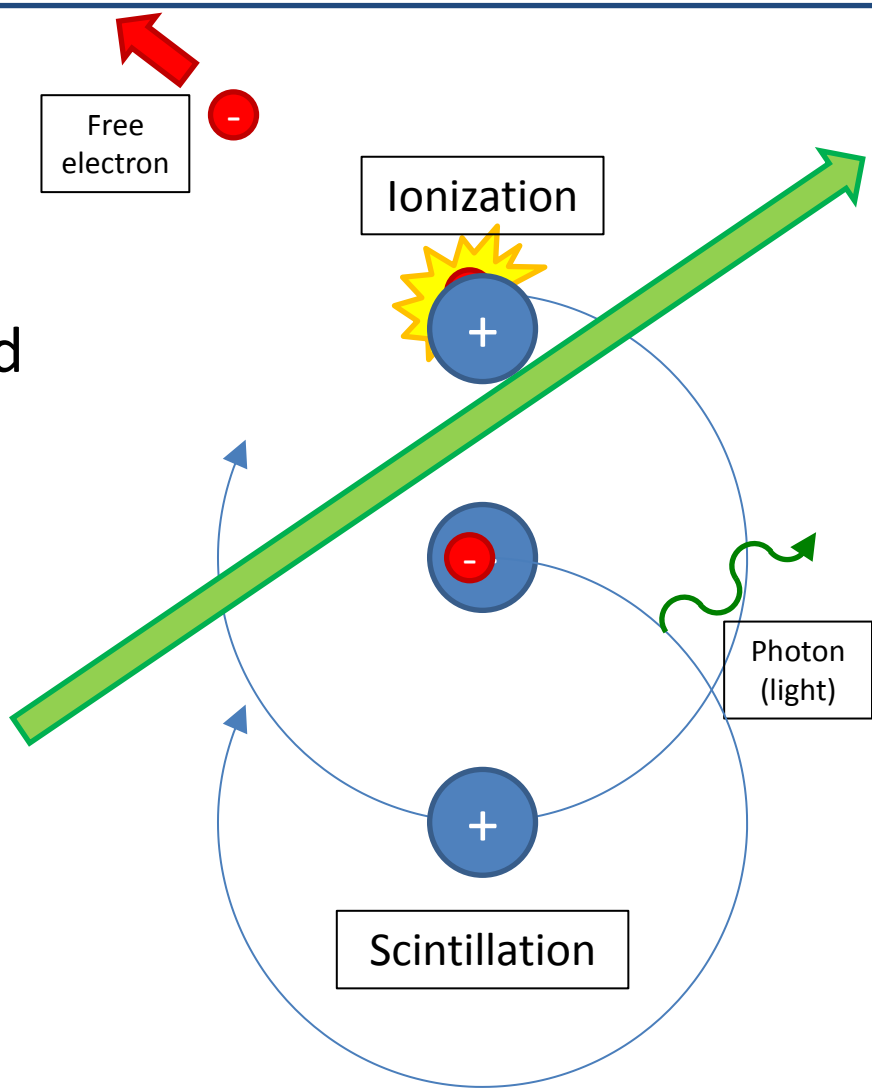
- To figure this out we use detectors to measure:
  - Charge
  - Mass
  - … etc.

  } • But how?

- Measure where the particles go **tracking**
- Measuring their energy **calorimetry**

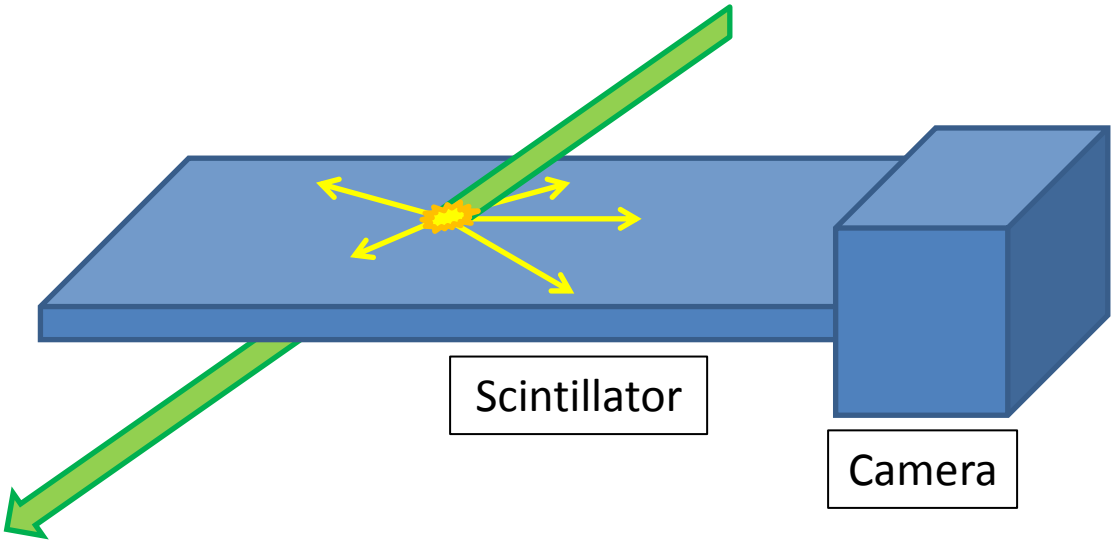
Charged particles in matter

- Electrons are orbiting the nucleus
- When a charged particle passes through, some energy is transferred (*Coulomb interactions*)
- This excites the electrons:
  - Some get so much energy that they escape: **ionization**
  - Some simply gain some energy. They can fall back and emit light: **scintillation**



Scintillation detector

- Charged particle passes through scintillator
- Light is emitted
- Light is detected
- Simples
- Used for **calorimetry**

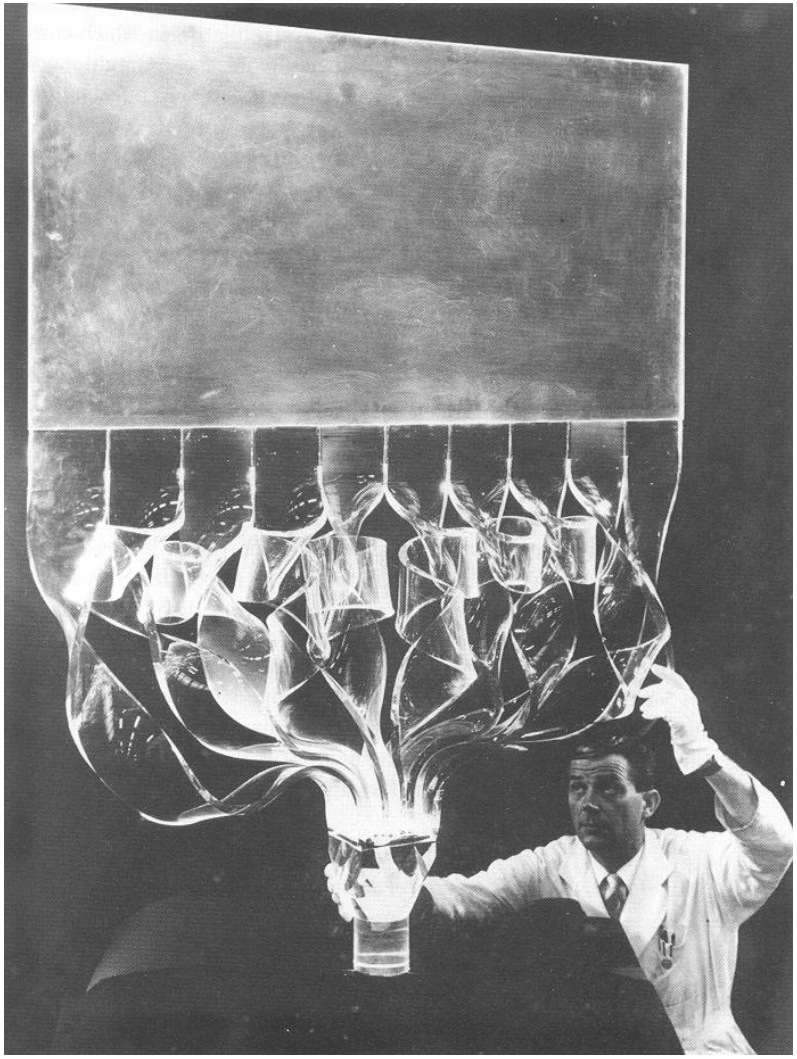


Scintillation detectors

Scintillator

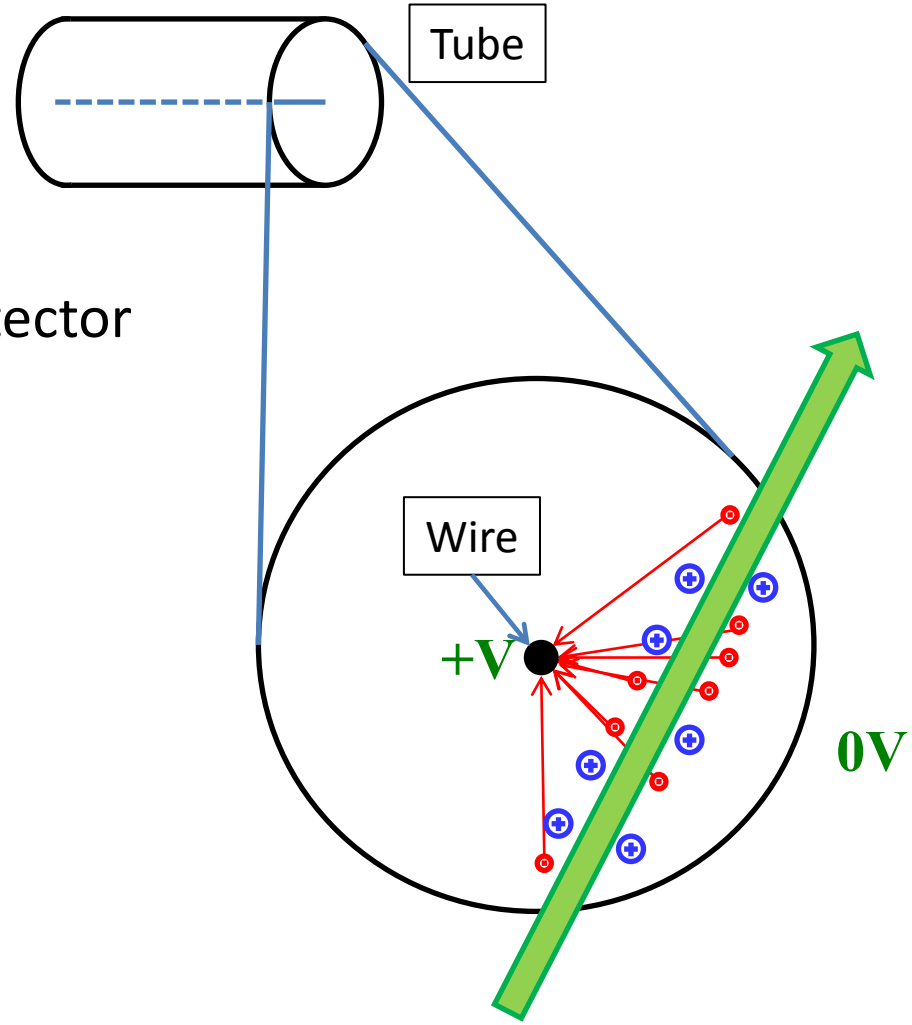
Light guide

Camera



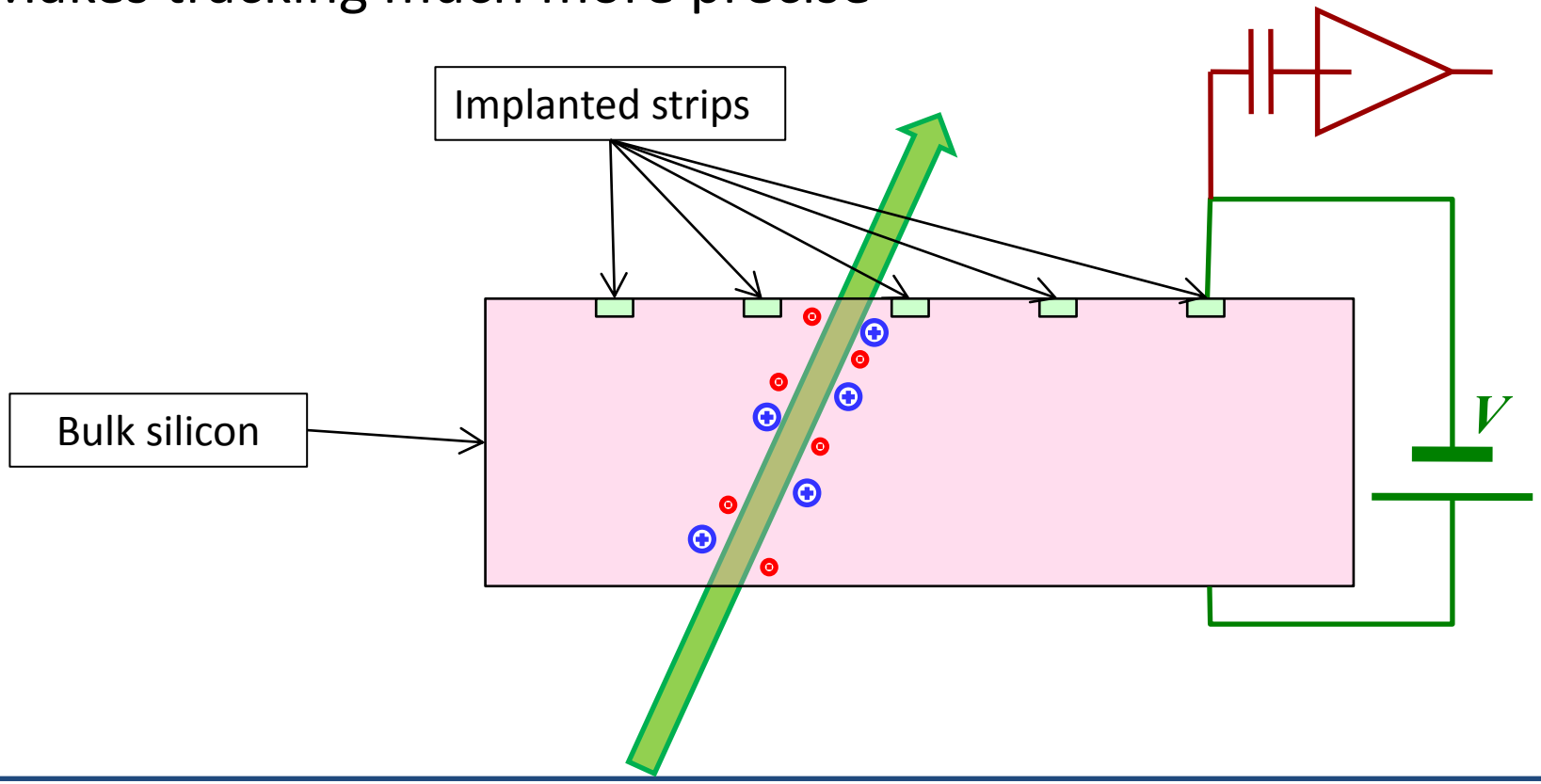
Detecting electrons

- Tube with wire: wire chamber
- Ionizing track passes through
- Gas in tube is ionized
- Electrons collect on wire
- Pulse of current goes through detector
- Used for **tracking**



Silicon detectors

- Making lots of wires is hard
- On silicon they can be spaced 50µm apart
- Makes tracking much more precise



Particle ID introduction

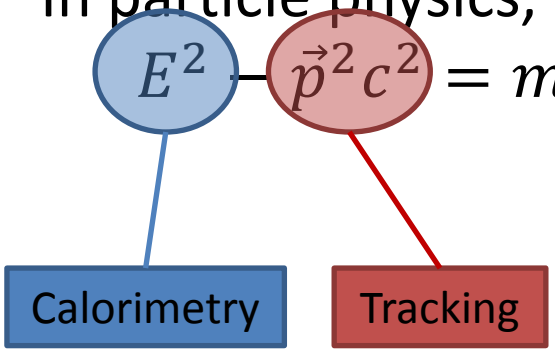
- Info we need per particle
  - What particle is it?
  - How fast is it going?
  - Which direction is it headed?

- But how do we get this information?
- Need to combine different detectors
  - Tracking
  - Calorimetry

Particle identification

- You might remember
  $E = mc^2$

- In particle physics, we use an adapted version (relativistic)

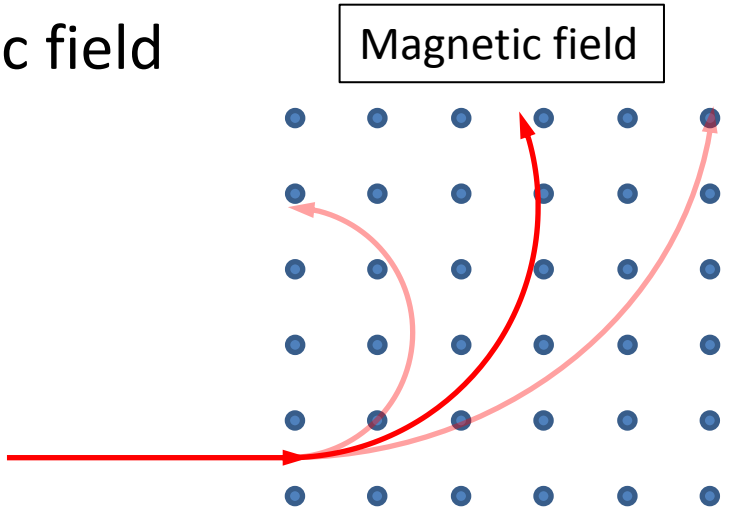


  - Combine calorimetry and tracking
  - Extract mass, velocity and direction

- Separate detectors used for these purposes – as described before

Tracking

- Charged particles bend in a magnetic field
- Used to extract extra information



- Lorentz force:

$$F_L = qvB = \frac{mv^2}{r}$$

- Use magnetic field to determine
  - Charge
  - Velocity

- Case in point: electrons

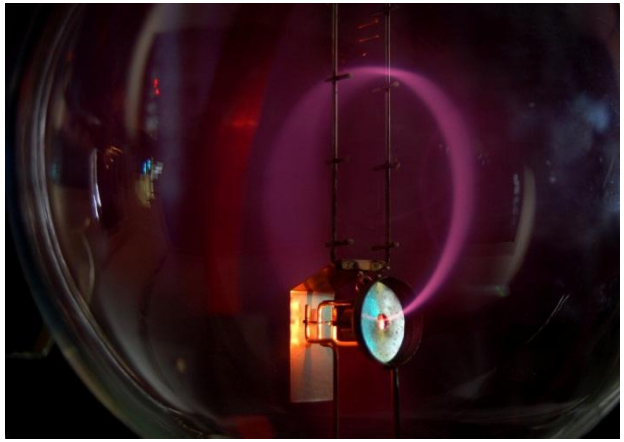
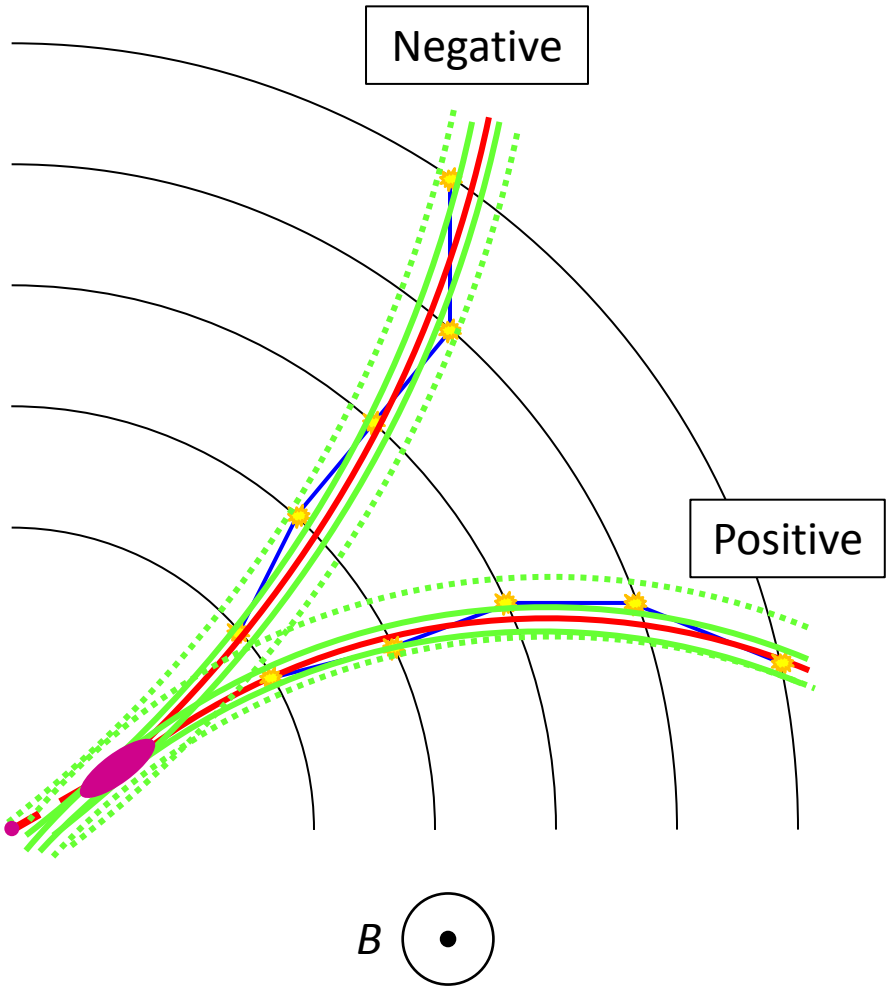


Image taken from: http://en.wikipedia.org/wiki/Lorentz_force

Tracking

- Particles go through consecutive layers of detectors
- Keep track of where they go
- Reconstruct path
- Use information to extract
  - Point of origin
  - Velocity
  - Charge

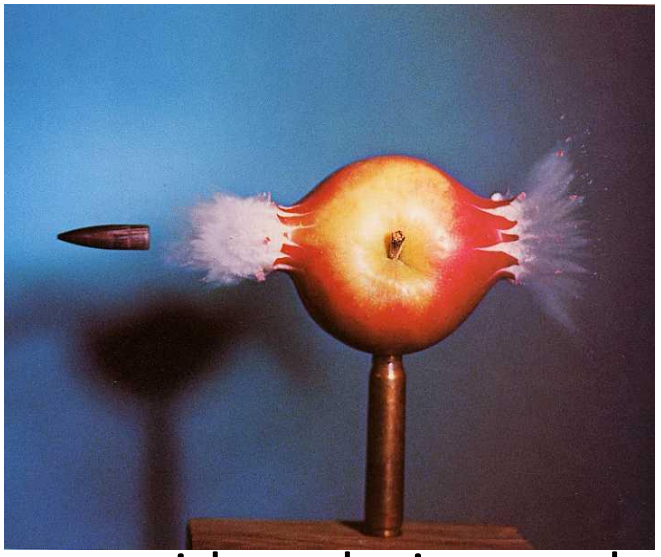


Calorimetry

- Aim is to fully stop the particle flying through so all its energy is absorbed into the material

Image taken from:
http://2.bp.blogspot.com/_6q-f-zD4xPY/TFu5QrVGmMI/AAAAAAAAYe8/DLNaU0OZwo4/s1600/EdgertonBullet.jpg

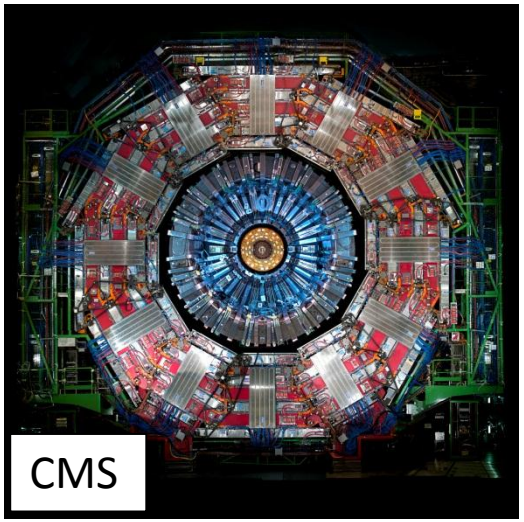
- Particles can be roughly qualified as being “light” or “heavy”
- Two different calorimeters used
  - Electromagnetic calorimeter (catches the ping-pong balls)
    - Thin, often single crystal
  - Hadronic calorimeter (catches the bullets)
    - Thick, sandwich design

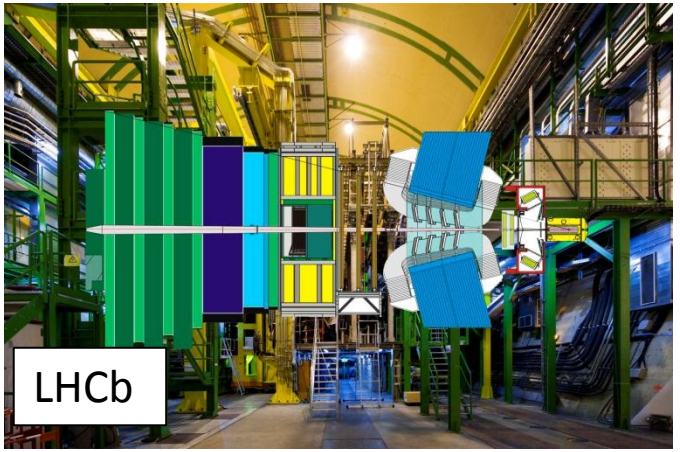


- Heavy particles pass through the first calorimeter without losing much energy

Big, fancy detectors

- What you want to measure determines how to build the detector
- Detector is a combination of a lot of subdetectors
  - Tracking
  - Calorimetry
- CMS
- LHCb
- So what are we going to be looking at with these?





Images taken from: http://cdsmedia.cern.ch

Standard Model Particles

- Particles are made of smaller particles
- There seems to be a smallest level
- Particles fall apart

Unstable / short lived

- Some particles we cannot see at all
  - Found through missing energy

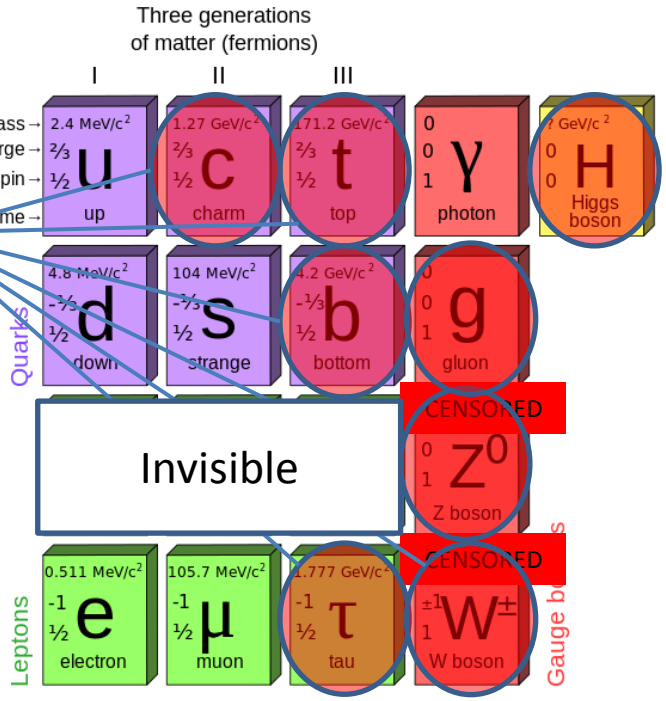


Image taken from:
http://en.wikipedia.org/wiki/Elementary_particle

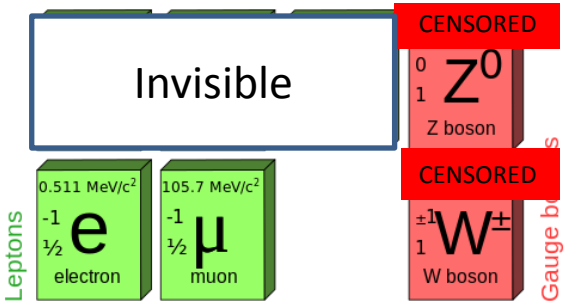
CMS Data Analysis

- Today: Focus on only part of the Standard Model

- Ignore top half
- Also ignore τ-lepton

- Look at “leptonic decays” of W and Z
  - These are still the most important channels

- Neutrino’s are invisible but they still show
  - Missing ET (transverse energy)



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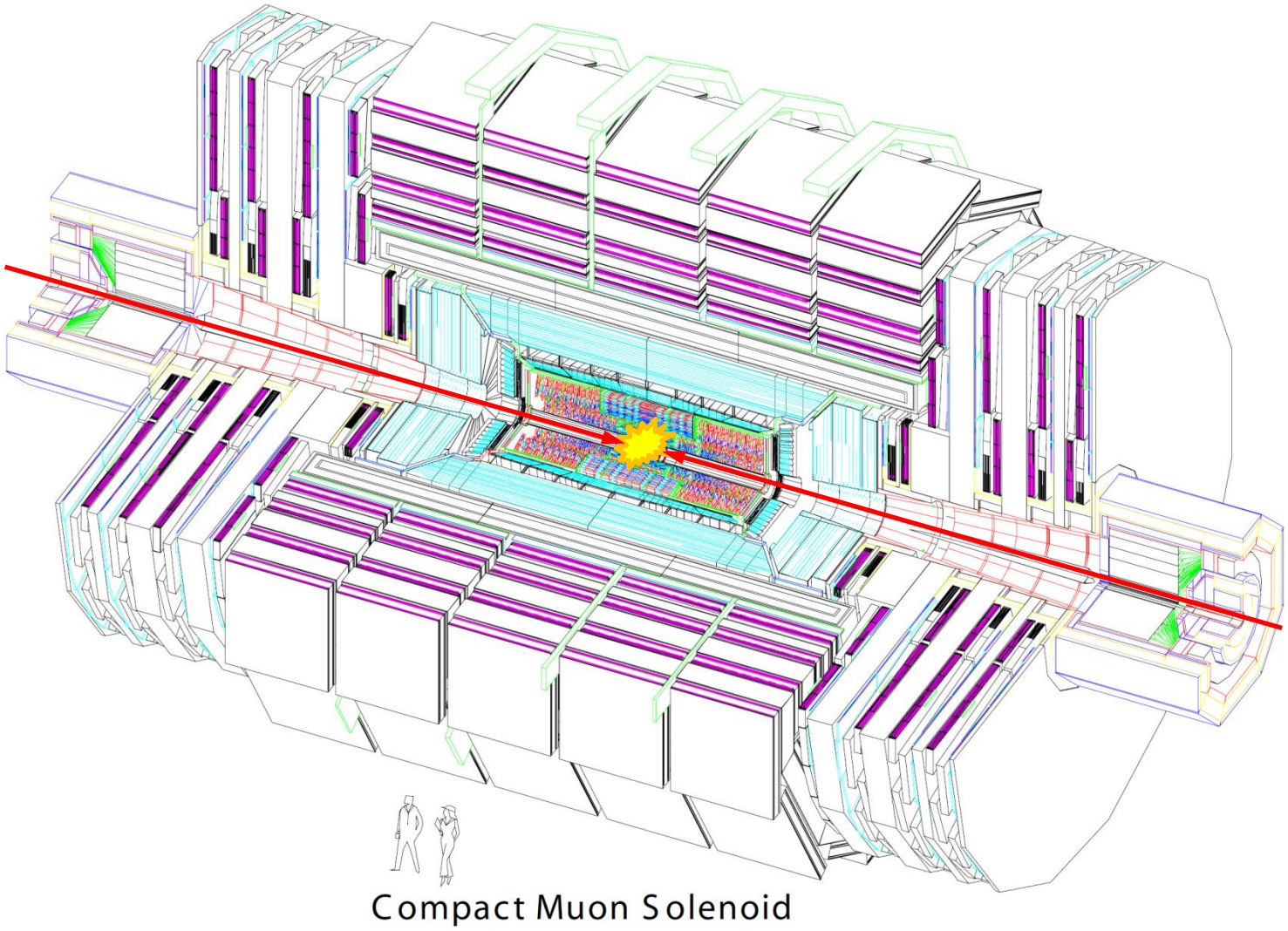
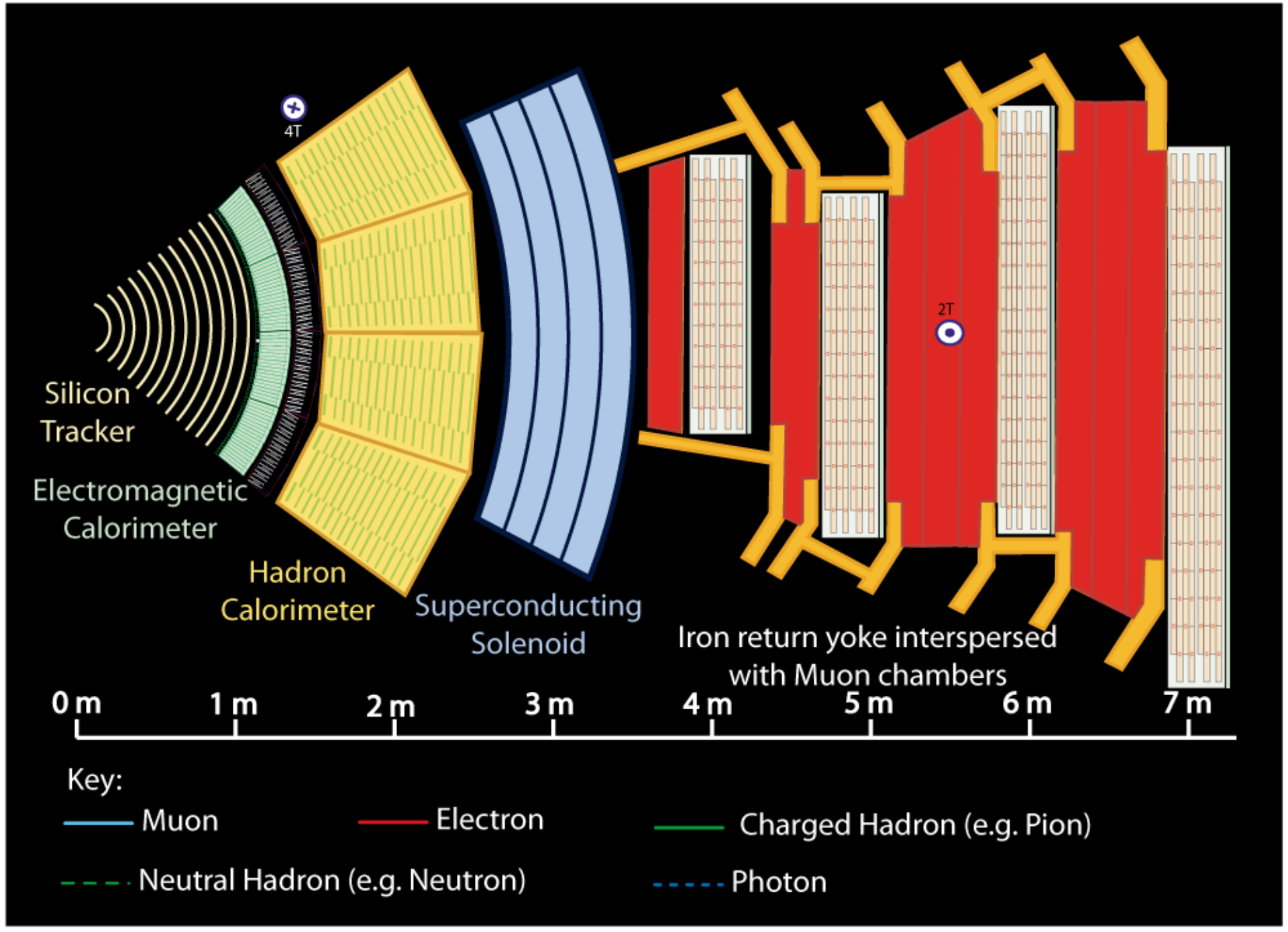
CMS Detector

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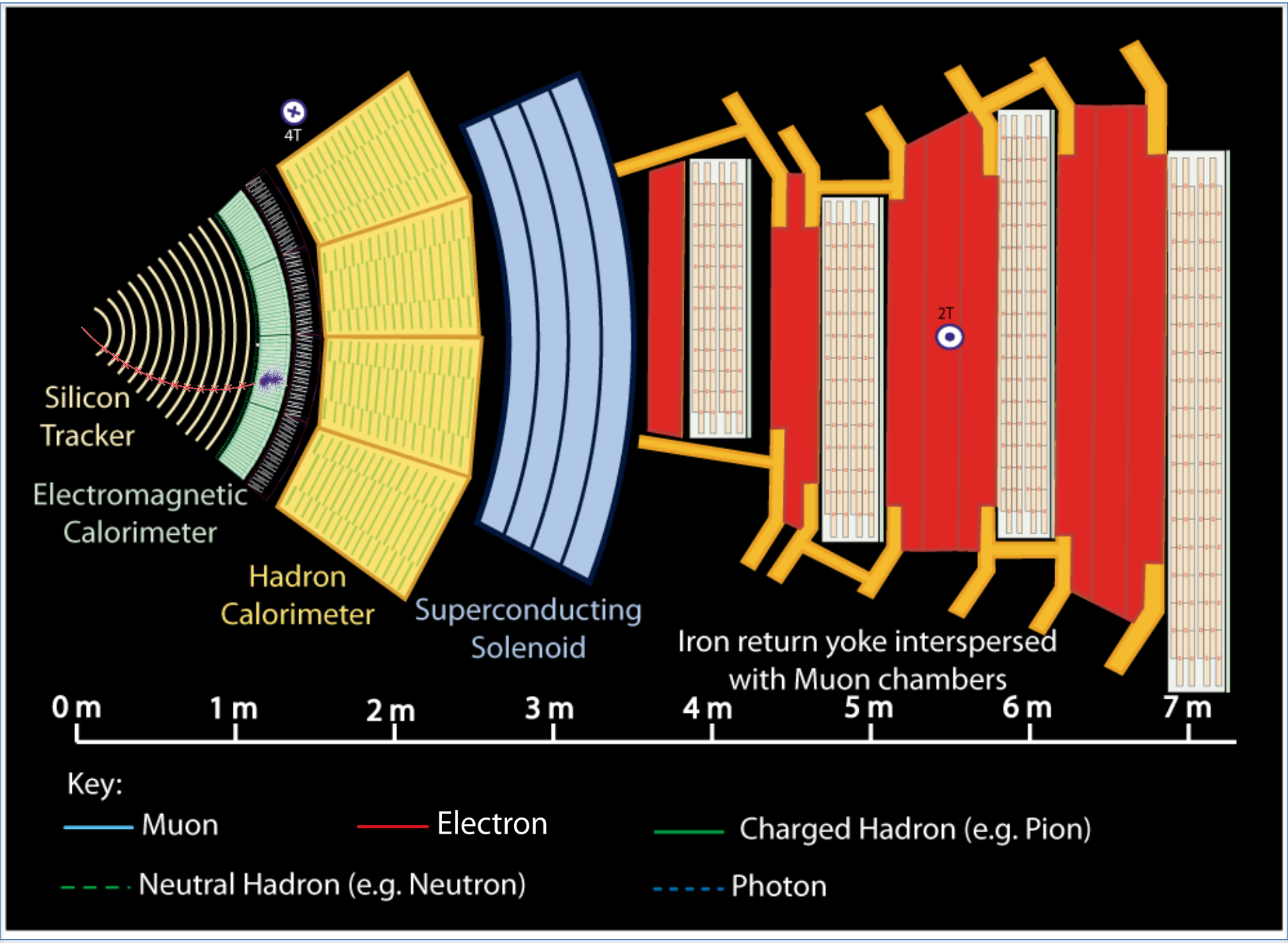
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
0 m
1 m
2 m
3 m
4 m
5 m
6 m
7 m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon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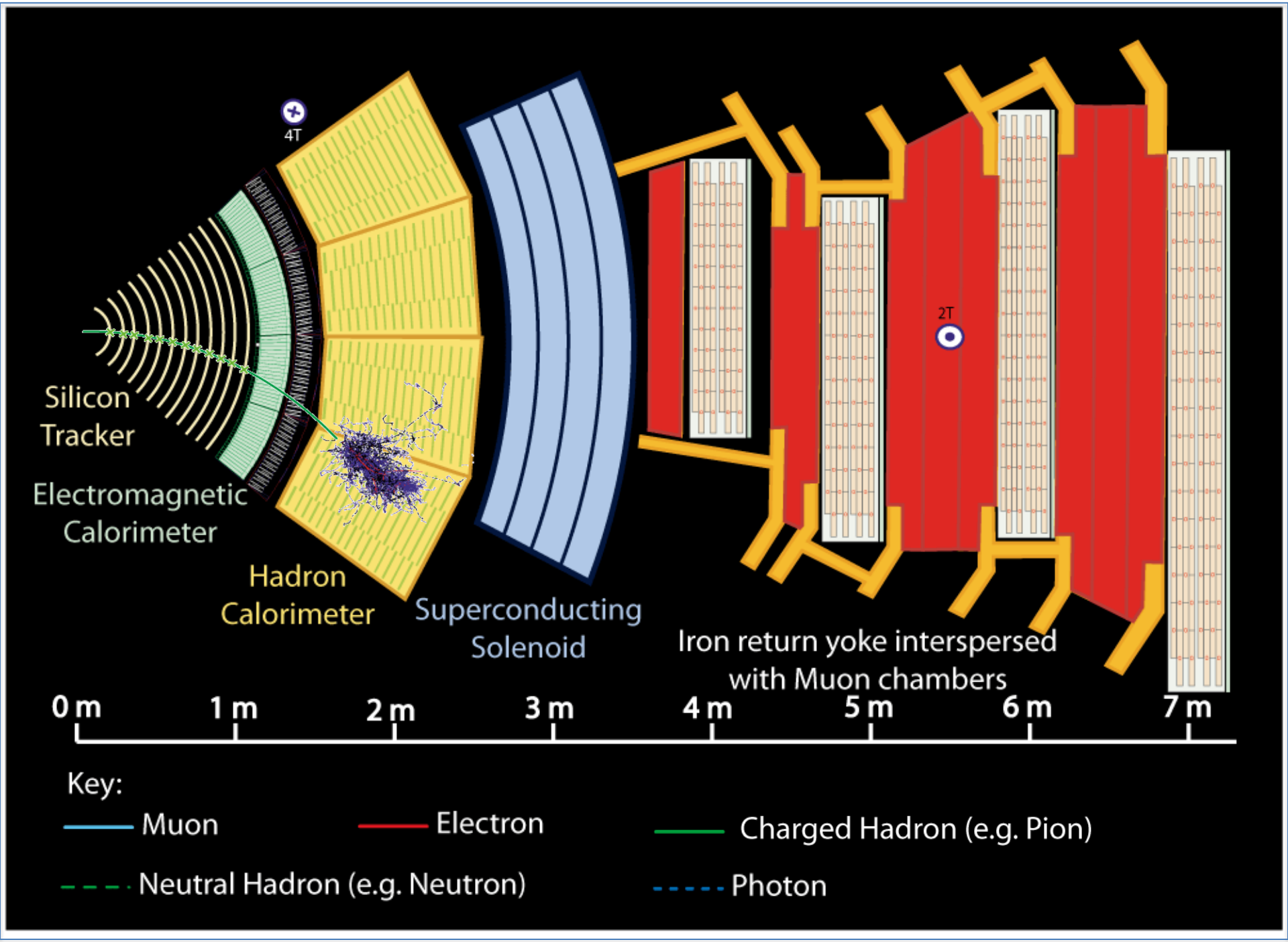
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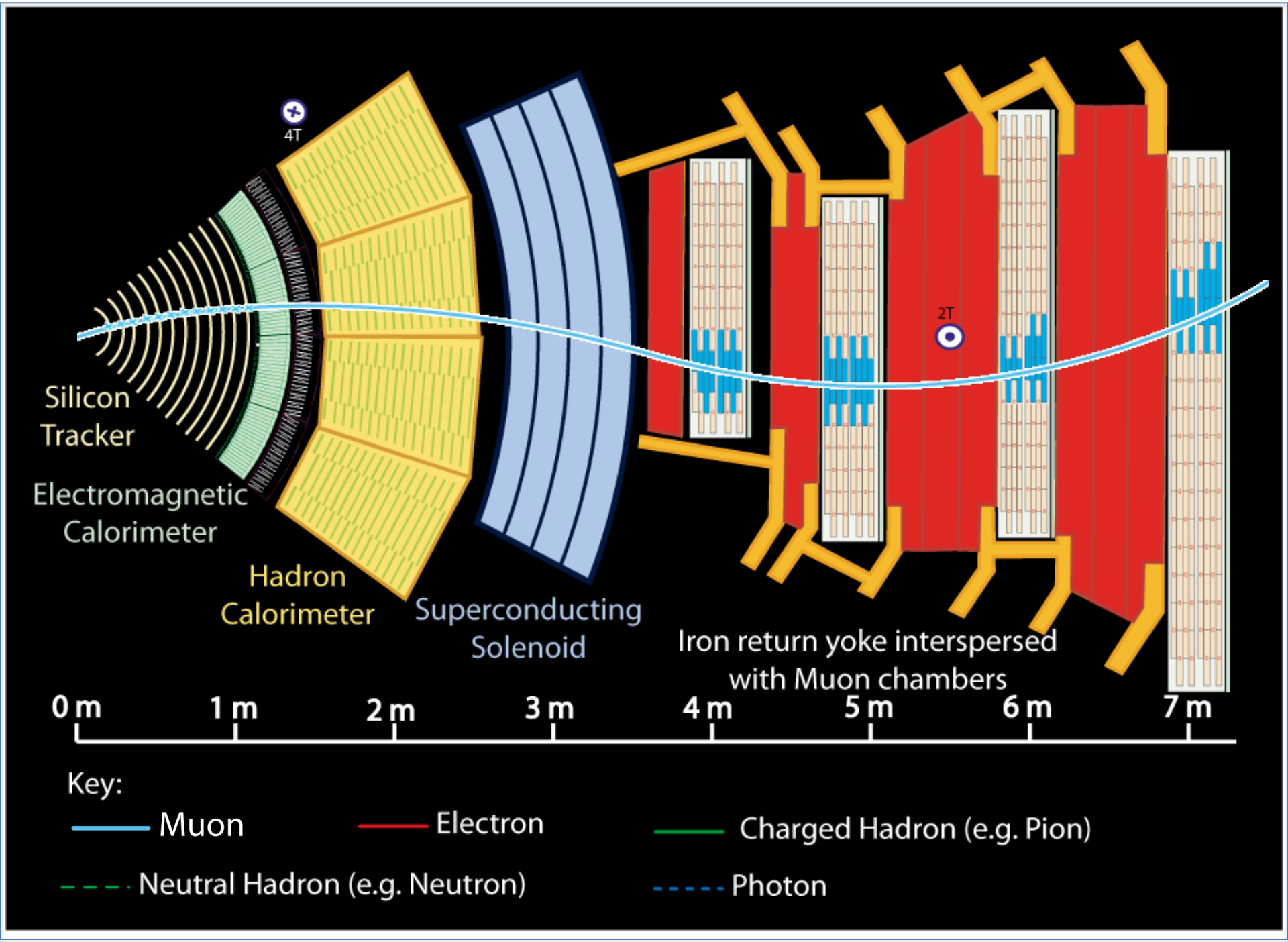
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Particle signatures in CMS

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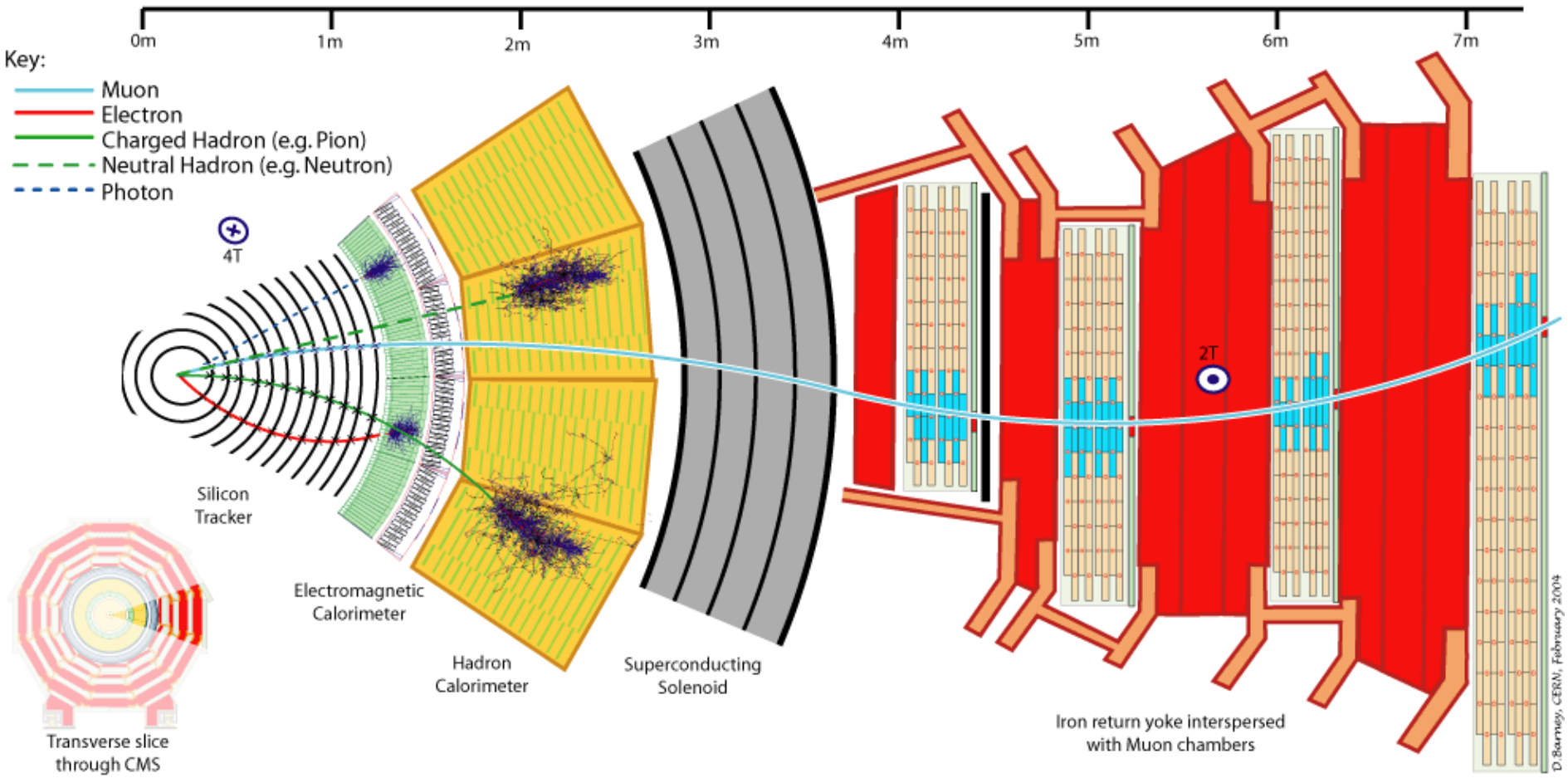
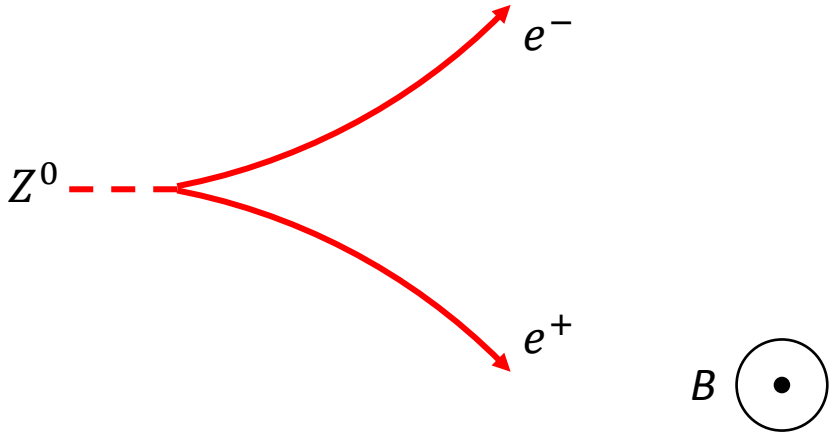
- Different particles leave a different signature in the detector



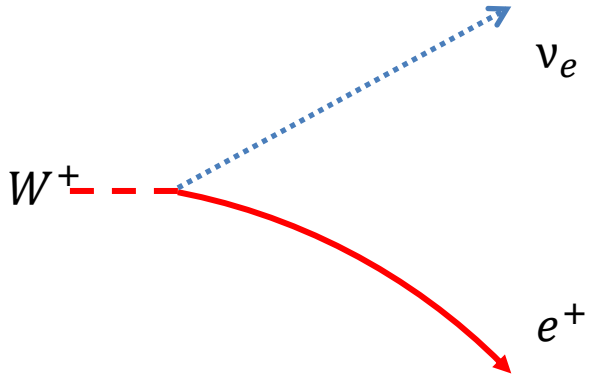
Data Analysis Exercise

- Focus today on leptonic decays of W and Z bosons

- Z is always neutral
  - Signature decays $Z^0 \to e^+e^-$
    $Z^0 \to \mu^+\mu^-$

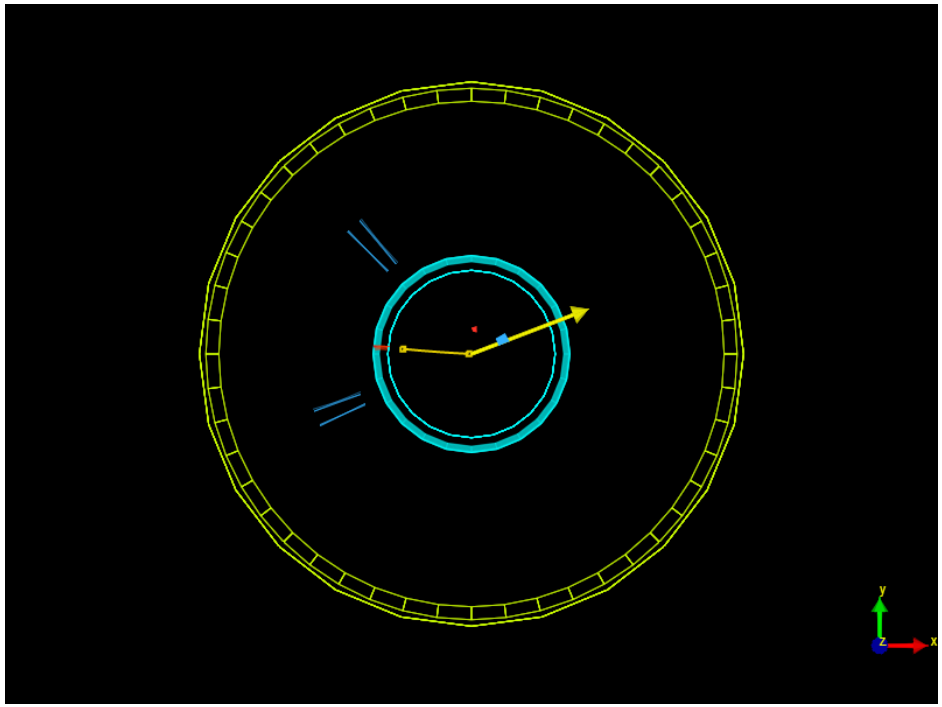


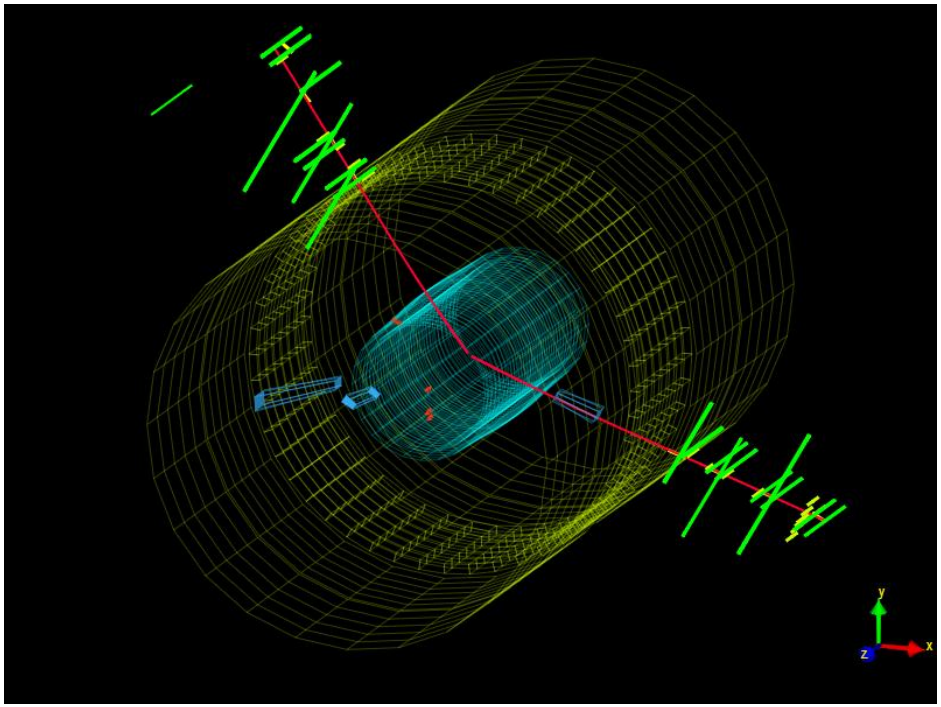
- W comes in W^+ and W^-
  - Signature decays $W^+ \to e^+\nu_e$
    $W^+ \to \mu^+\nu_\mu$



- Real data from CMS!

So – what does this look like?





- $W \rightarrow e\ \nu$ (but what kind?)
- Clockwise bend
- $W^+ \rightarrow e^+ \nu_e$
- $Z^0 \rightarrow \mu^+ \mu^-$

Summary

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- Particle identification is difficult – but doable
- Different detectors are good at different things
  → combine detectors to do it all

- What particles am I seeing?
  - Muons
  - Electrons
- What particles am I NOT seeing?
  - Neutrinos (but – missing ET)

- Was it a W or a Z boson?
- How did it decay?

- Put information together and find out what is going on

Have fun!

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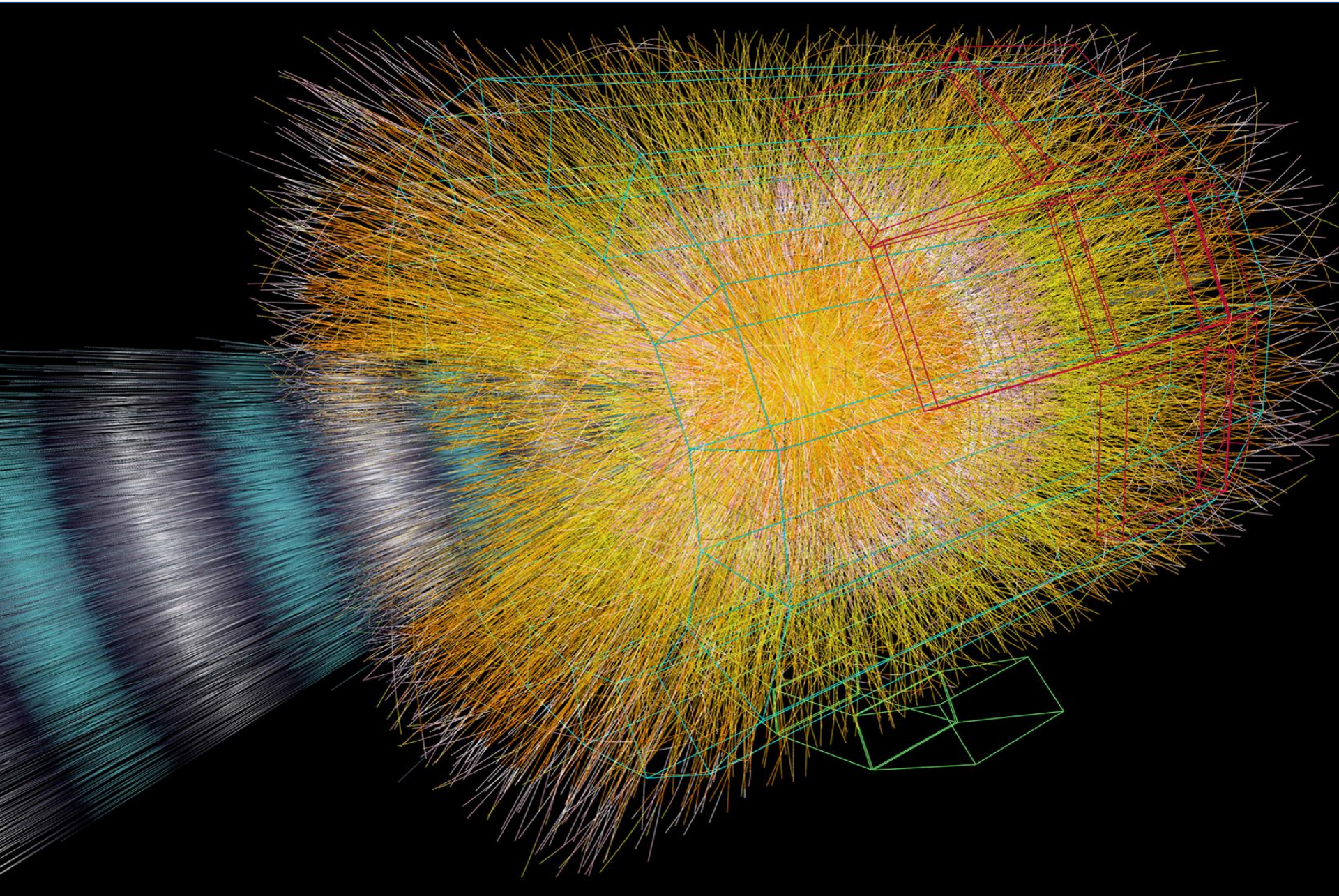

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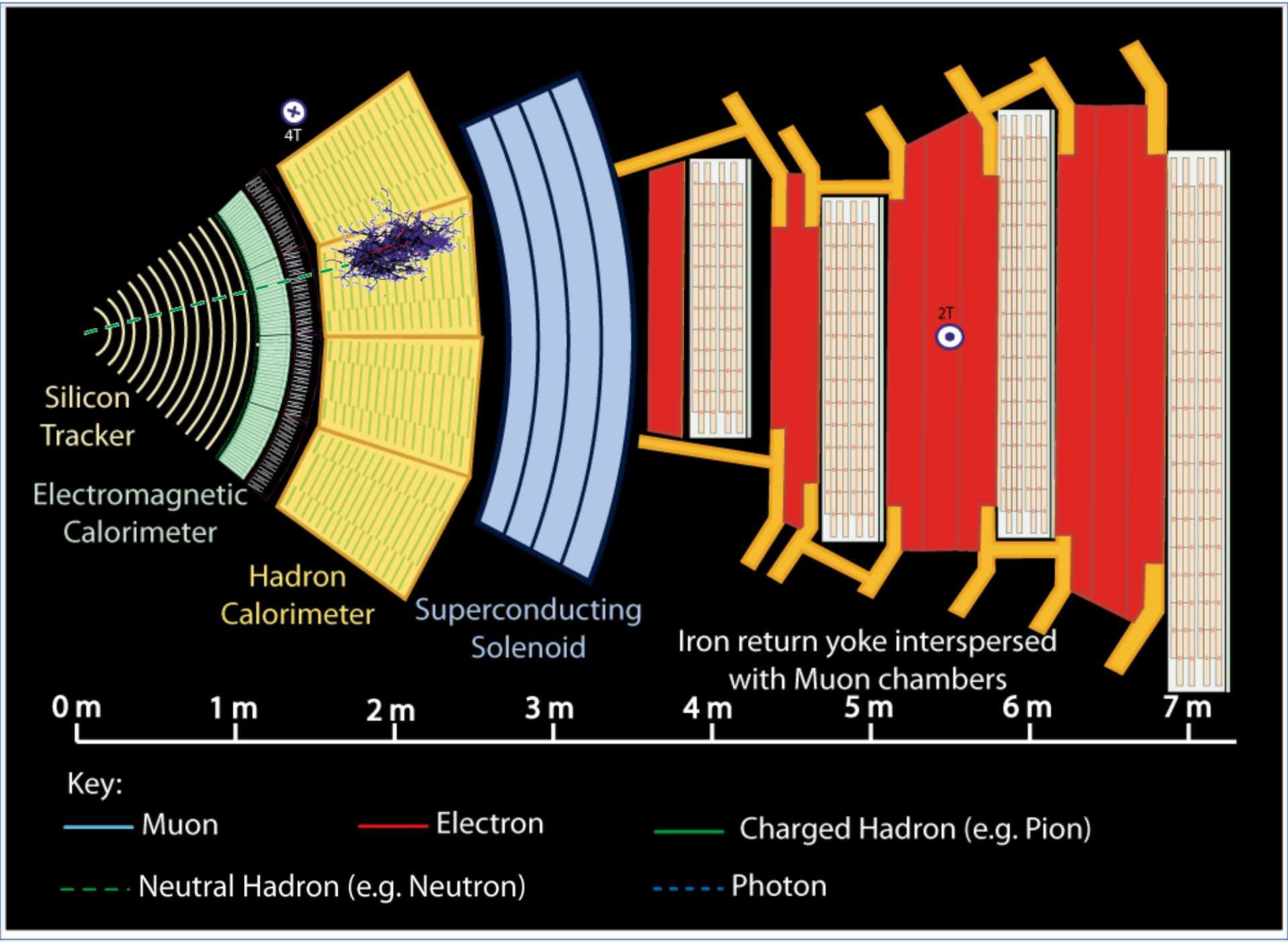
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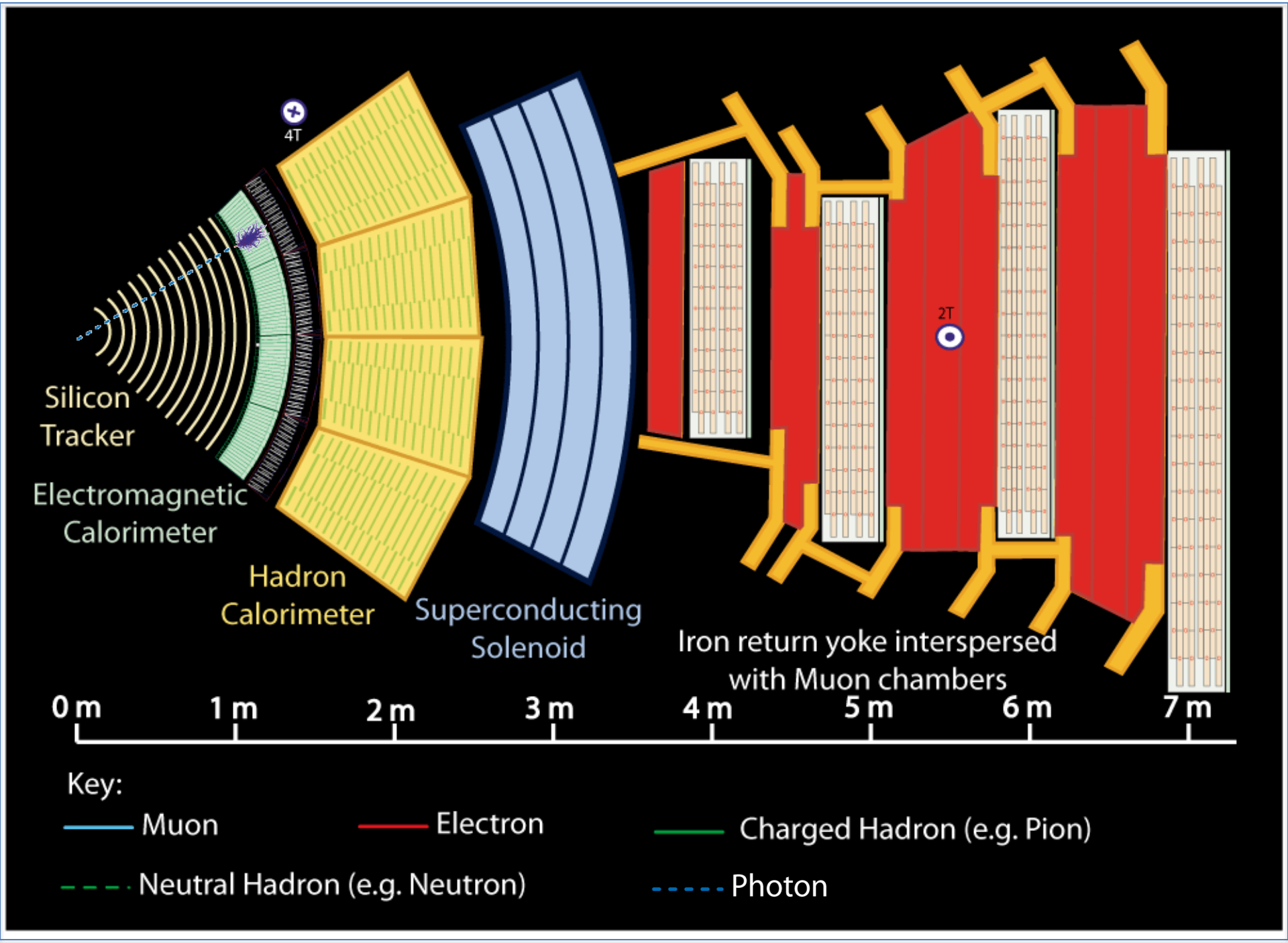
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