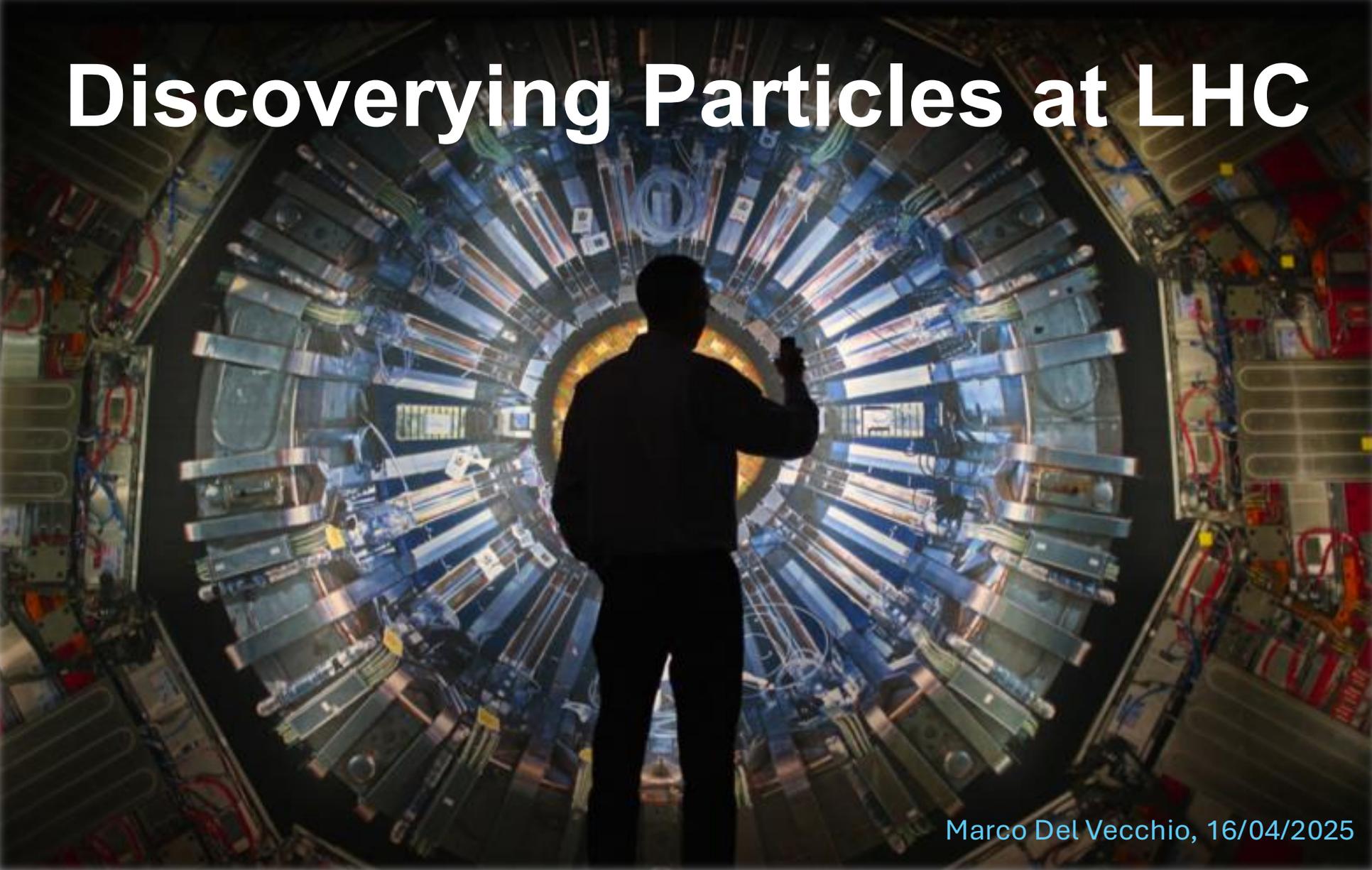


# Discovering Particles at LHC



Marco Del Vecchio, 16/04/2025



**Istituto Nazionale di Fisica Nucleare**

Sezione di Roma



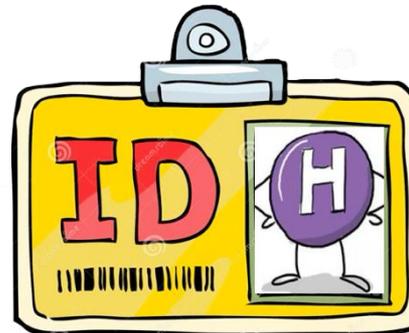
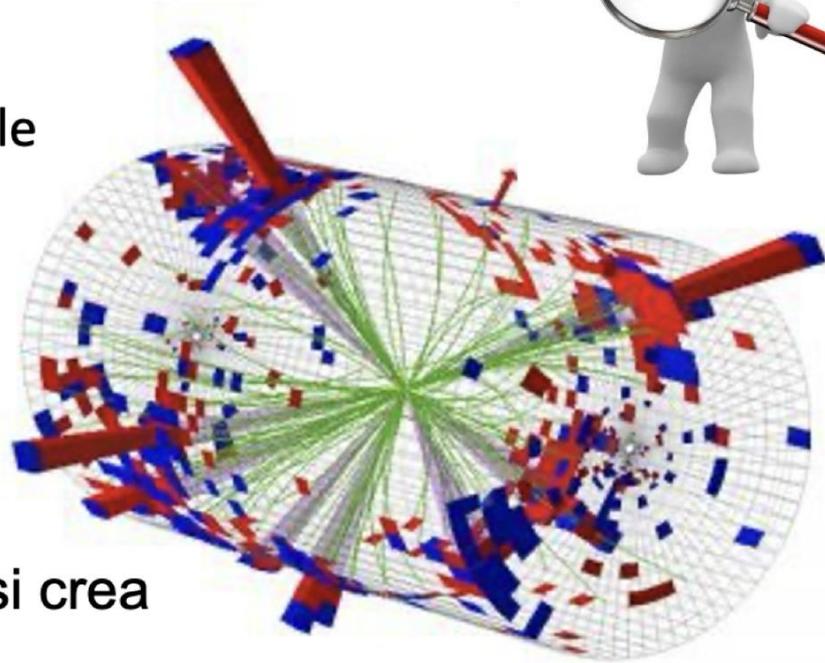
# Particle identikit

Nelle collisioni si producono  
diversi tipi di particelle

Ogni particella lascia un segnale  
caratteristico diverso

Per ciascuna particella che si crea  
vogliamo misurare:

- La direzione
- L'energia
- La carica elettrica
- Sapere che particella e'



CMS Experiment at LHC, CERN  
Data recorded: Mon May 23 21:46:26 2011 EDT  
Run/Event: 195567 / 347495624  
Lumi section: 280  
Orbit/Crossing: 73256863 / 3161

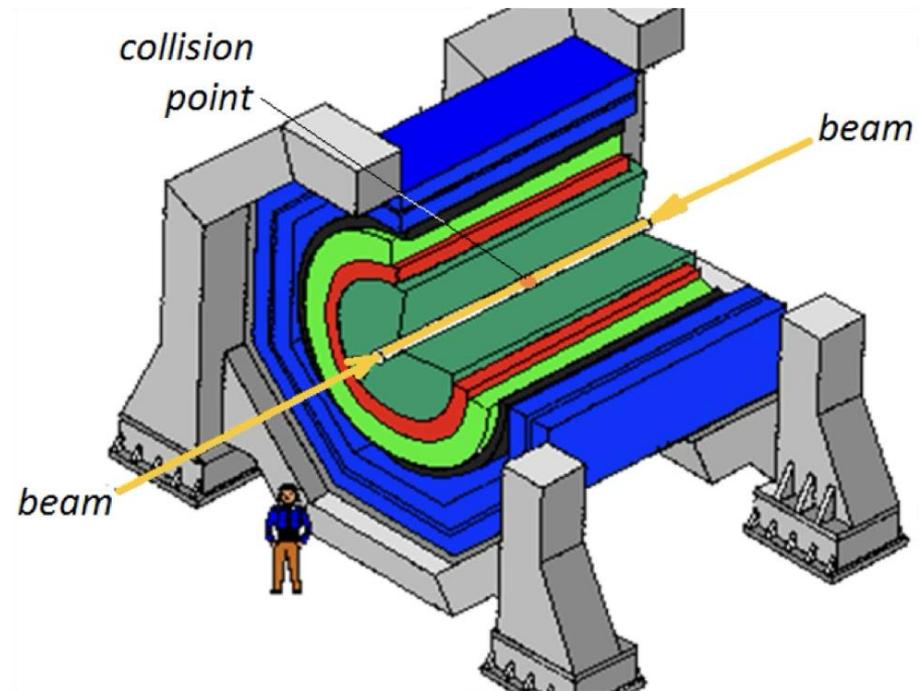
# Come e' fatto un esperimento all'LHC

Un disegno generico di Atlas o CMS e' fatto cosi':

→ **Forma cilindrica** attorno al tubo del fascio

dall'interno verso l'esterno:

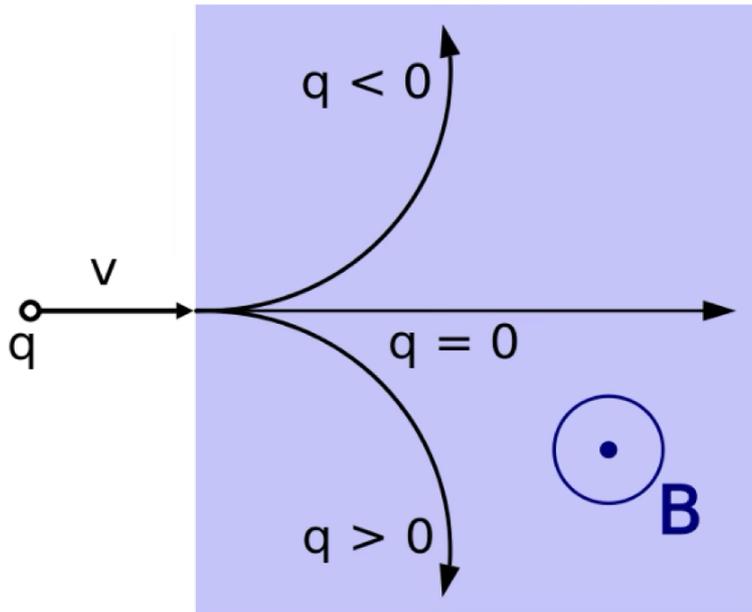
- Tracciatore
- **Calorimetro elettromagnetico**
- **Calorimetro adronico**
- Magnete
- **Camere per muoni**



# Magnete

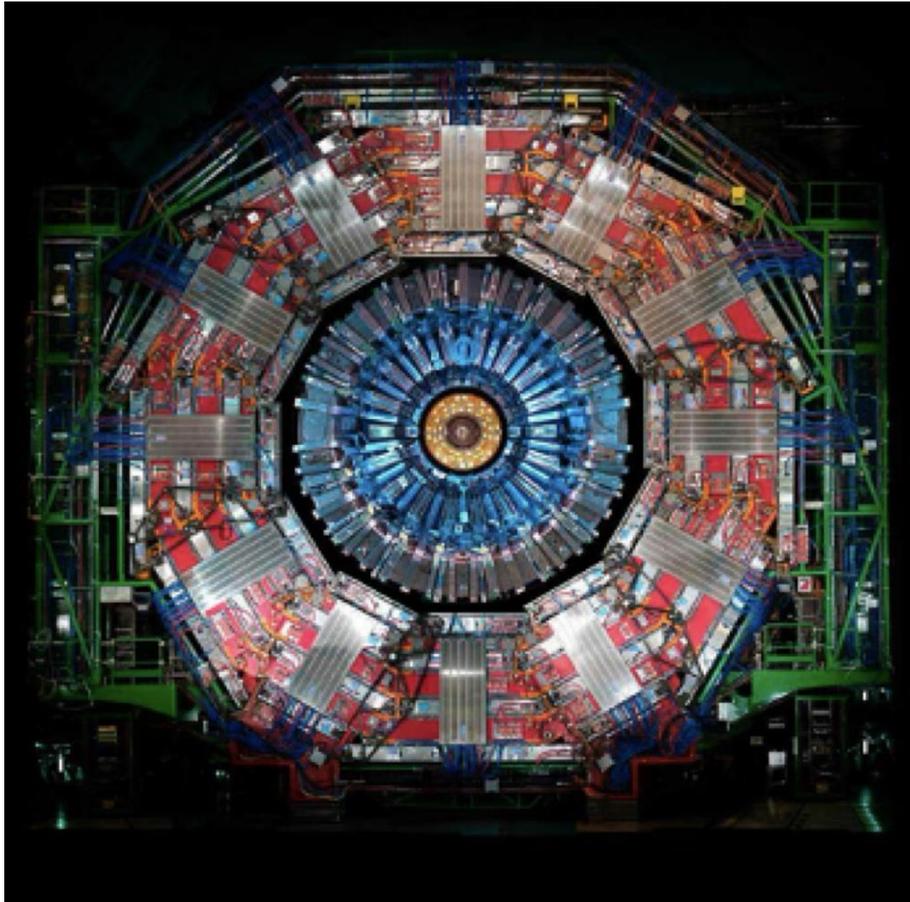
Il tracciatore e' immerso in un campo magnetico.

Usando la Forza di Lorentz:  $\vec{F} = q\vec{v} \times \vec{B}$

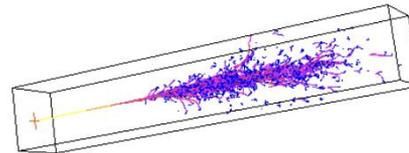
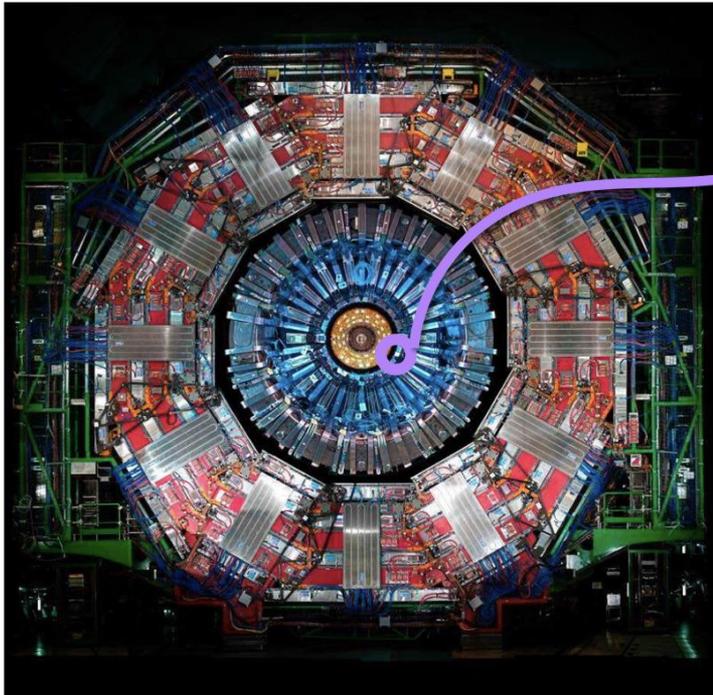


possiamo misurare la carica delle particelle

# CMS: Our sophisticated camera

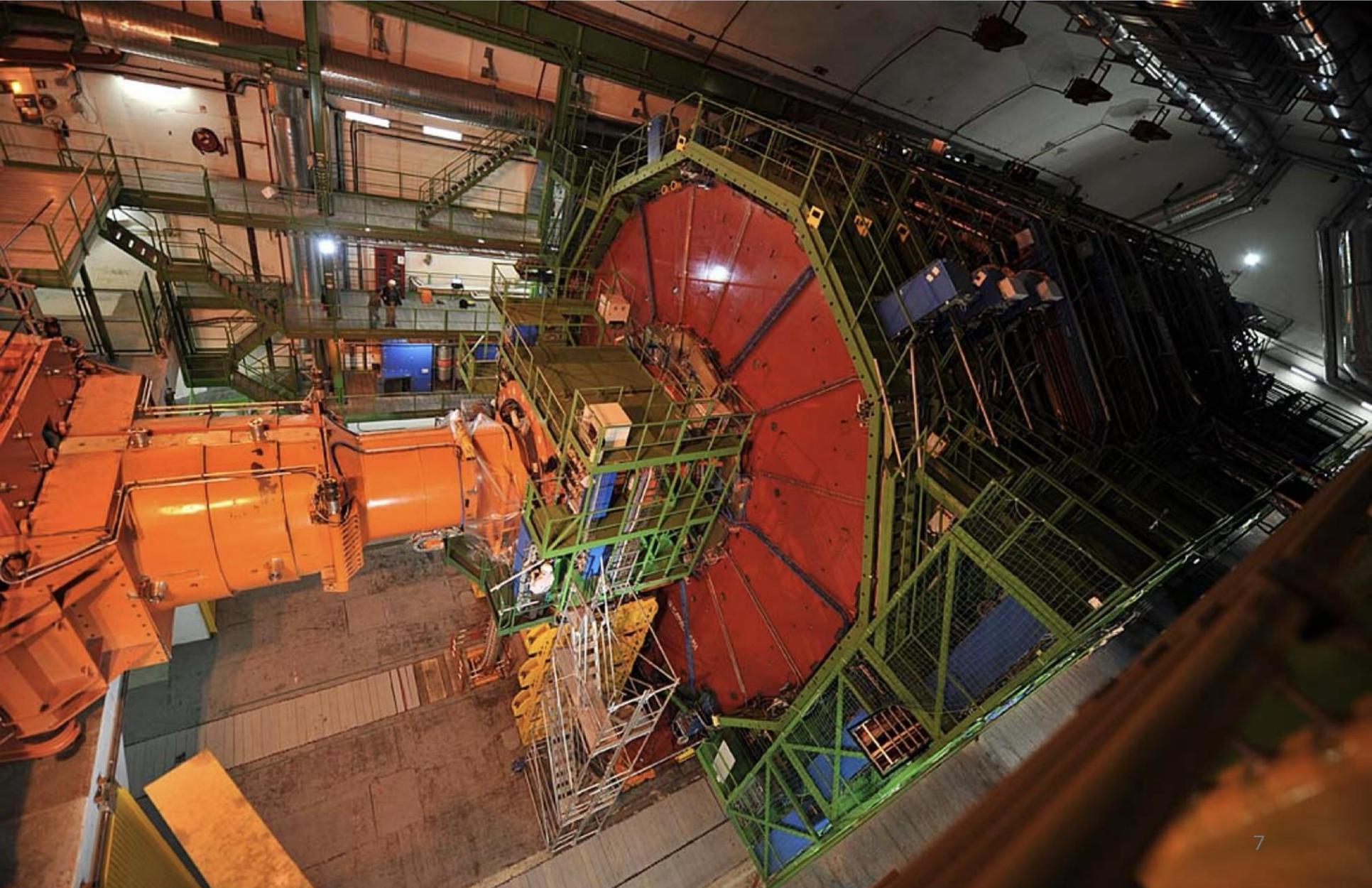


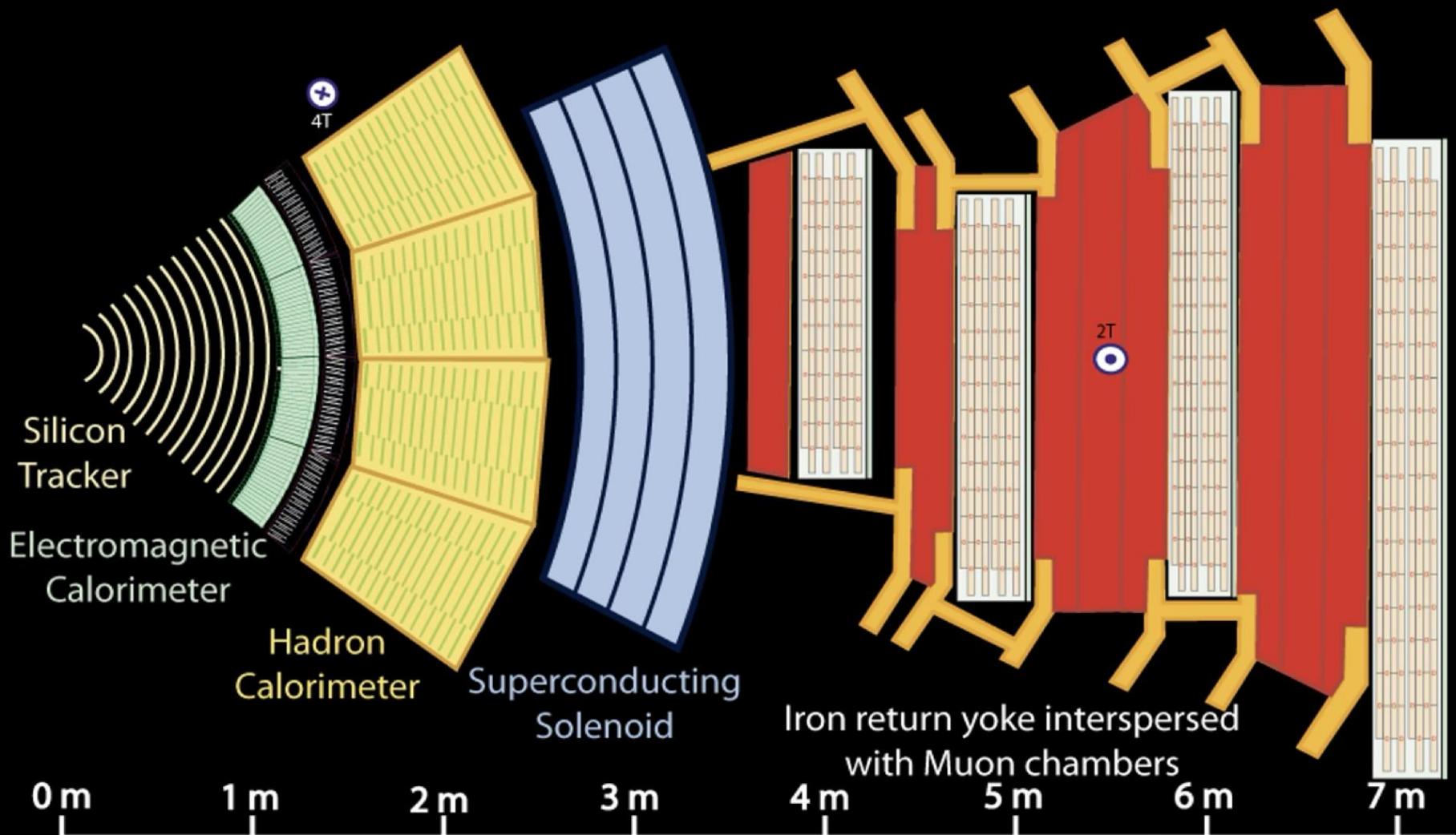
# Cristallo DI ECAL (calorimetro elettromagnetico)



Fotoni ed elettroni interagiscono con il materiale, frammentandosi in una cascata di particelle. Misurando l'energia depositata da questi prodotti secondari, è possibile risalire all'energia del fotone o dell'elettrone iniziale.

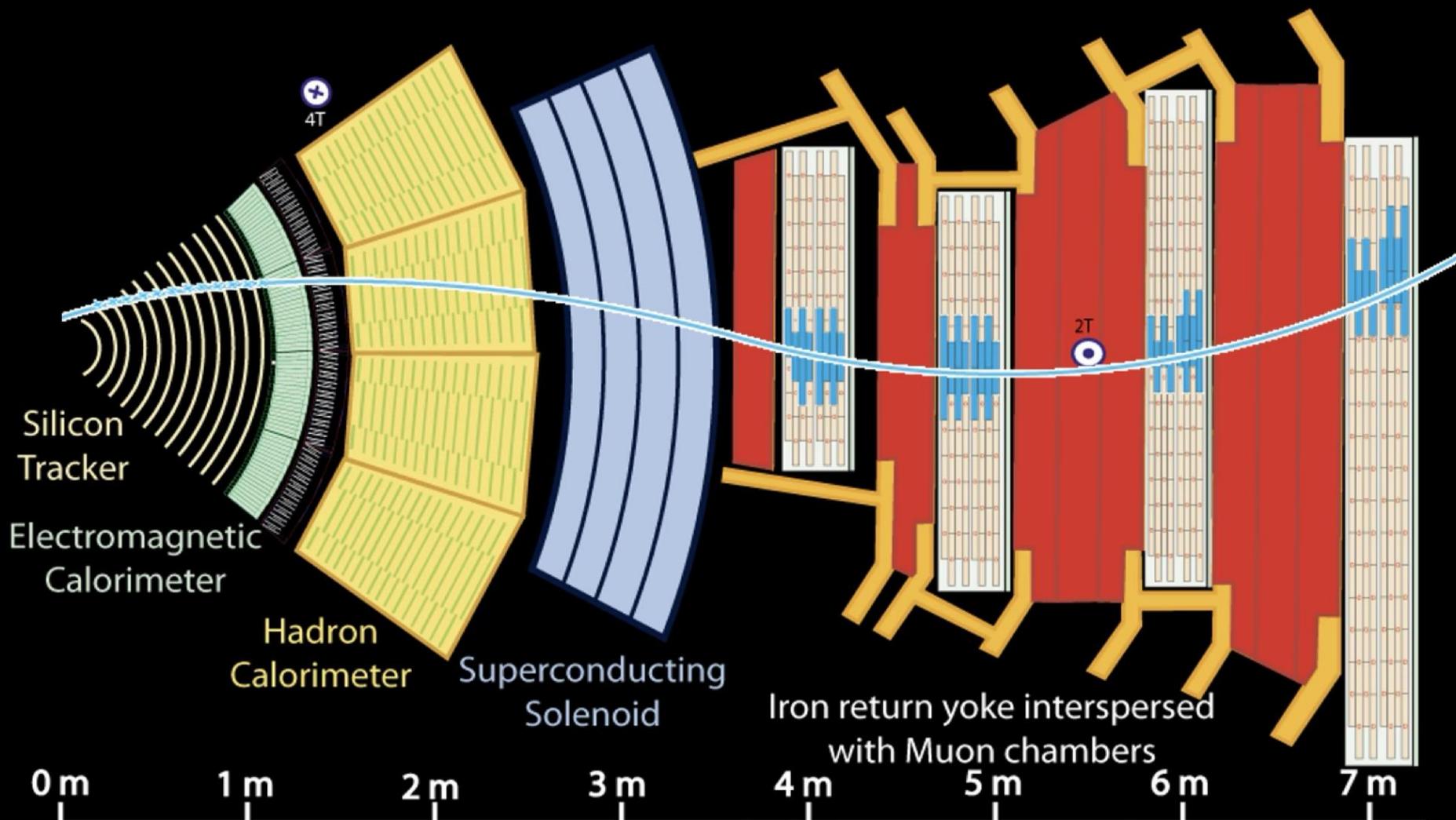
# La caverna di CMS (Settembre 2008)





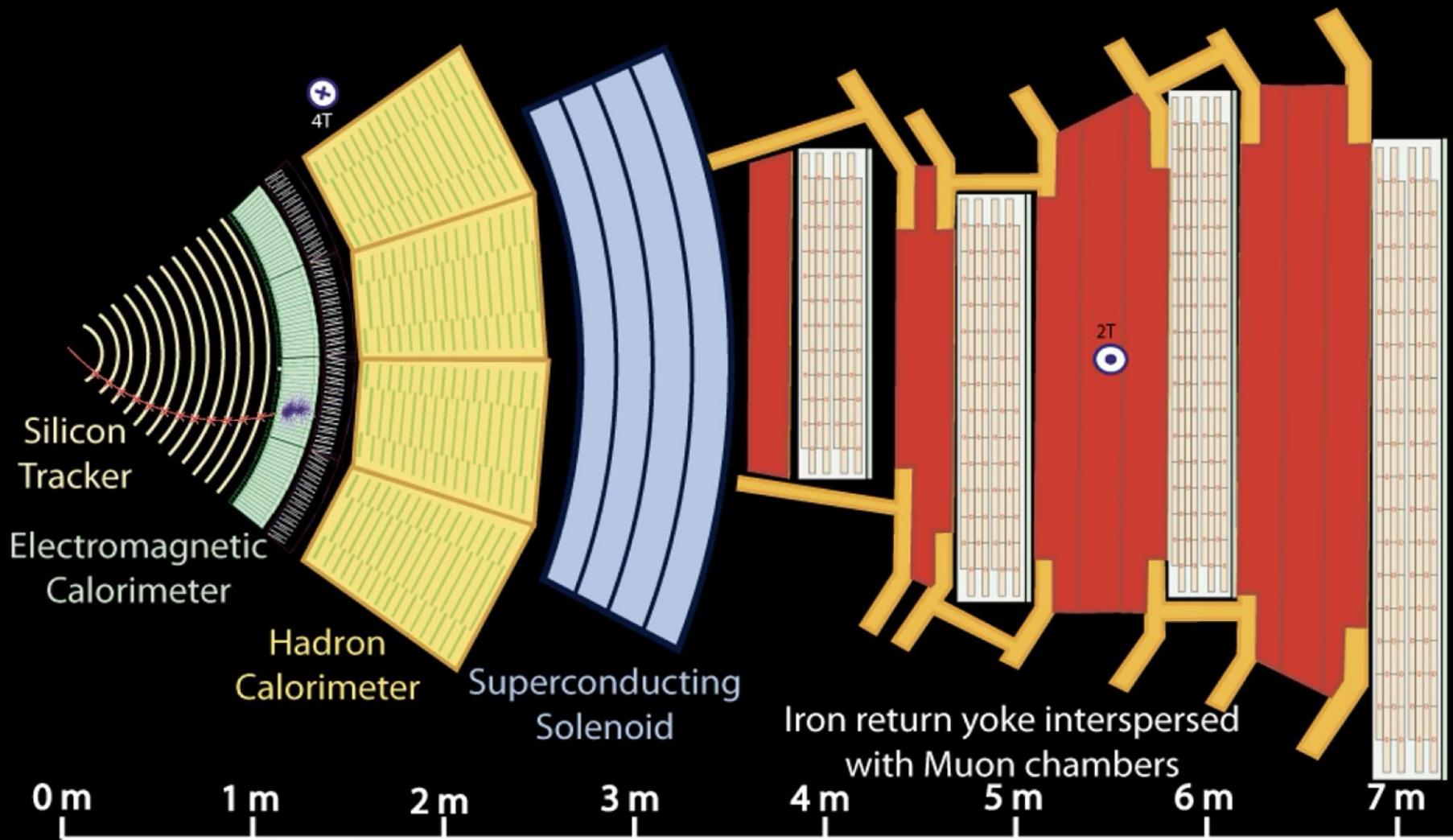
Key:

- Muon
- Electron
- Charged Hadron (e.g. Pion)
- - - Neutral Hadron (e.g. Neutron)
- - - Photon



Key:

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Key:

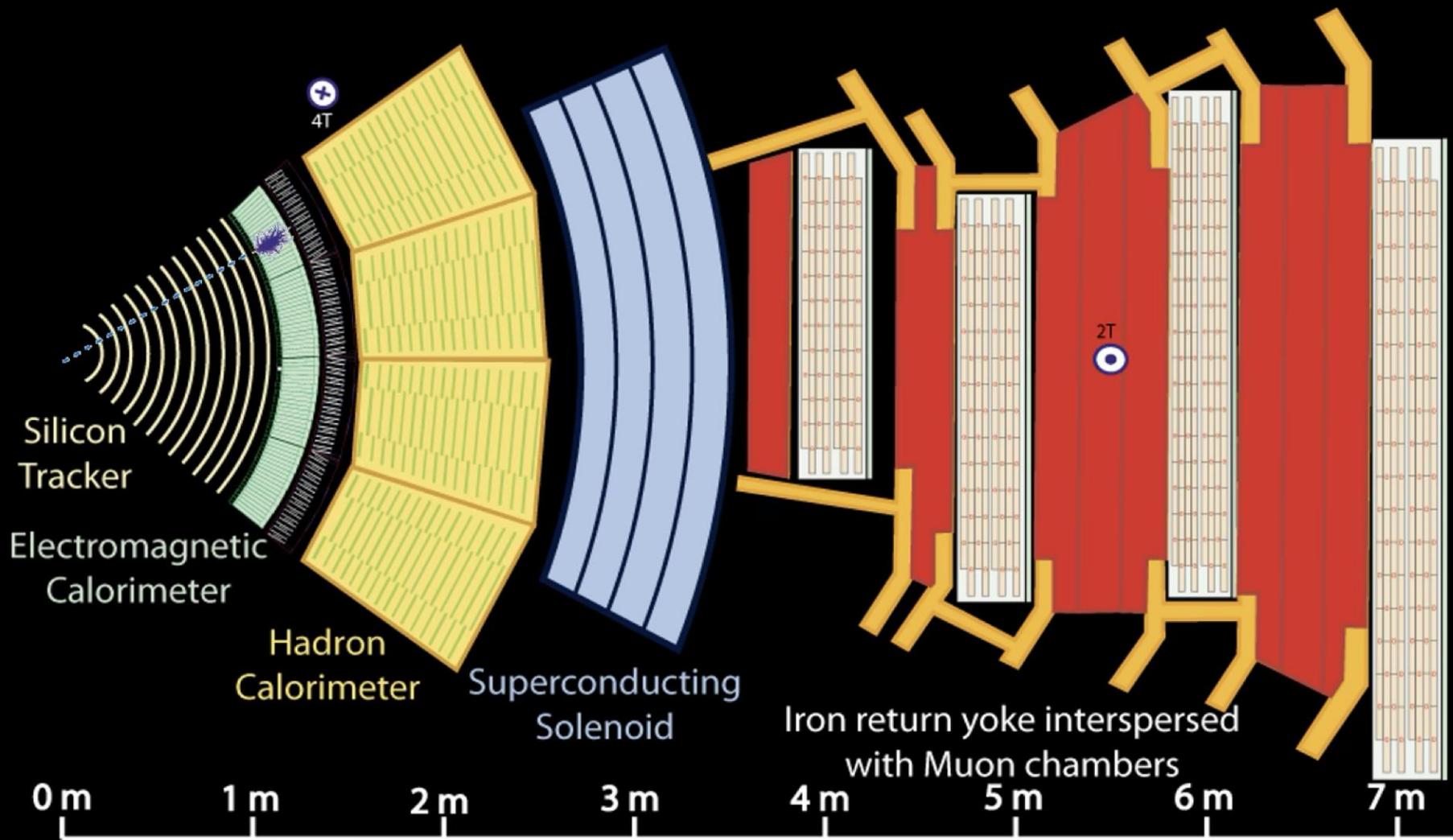
— Muon

— Electron

— Charged Hadron (e.g. Pion)

- - - Neutral Hadron (e.g. Neutron)

- - - Photon



Key:

— Muon

— Electron

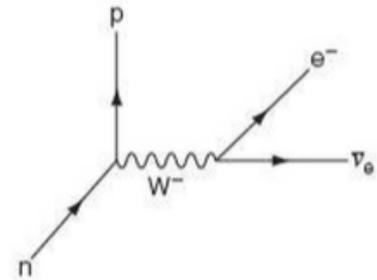
— Charged Hadron (e.g. Pion)

- - - Neutral Hadron (e.g. Neutron)

- - - Photon

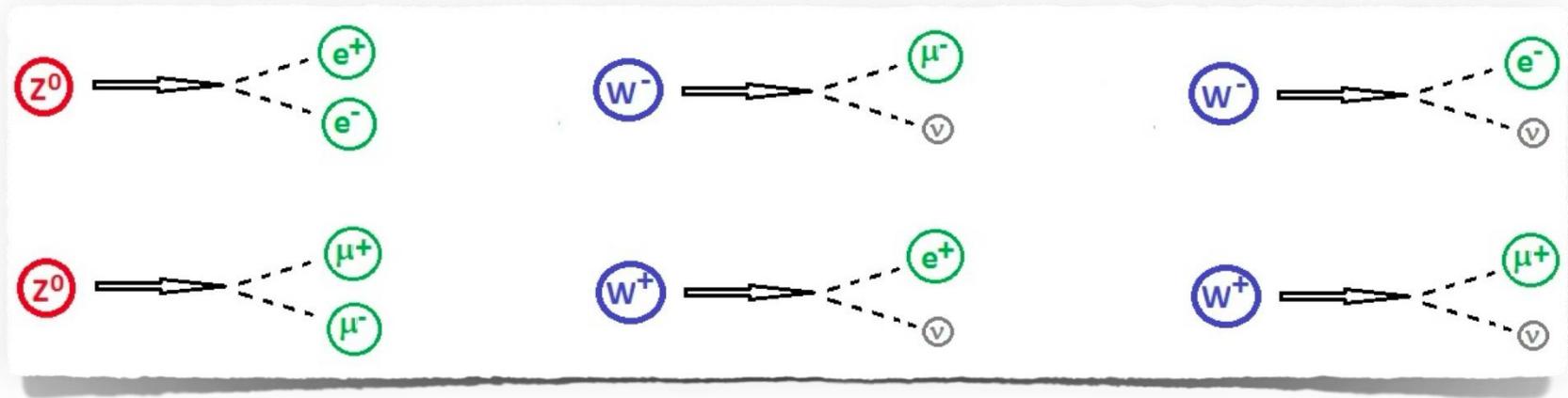
# The W and Z bosons

- **W** and **Z bosons** are the particles **mediator** of the **weak force**
- They have been **predicted** in the **1960's** to explain the “**beta**” **decays** observed well before by **Fermi**
- Theory predicted **W** and **Z masses** around **100 GeV** and physicists at **CERN** built in early **1980's** the first most powerful collider able to reach such high energies: the **SppS**



# Discovery of a new particle

- The **Z and W bosons** produced at LHC do not live long, but **decay immediately to other elementary particles that can be measured by the CMS and ATLAS detectors**



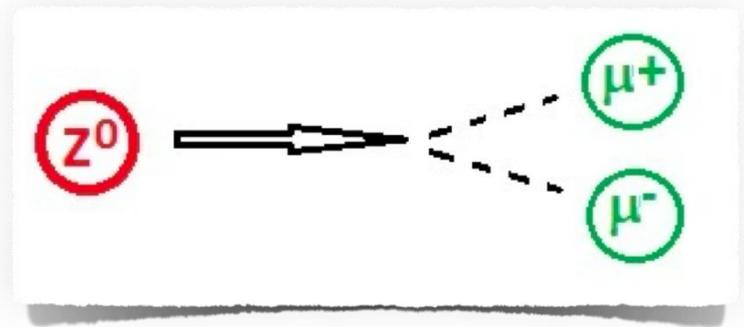
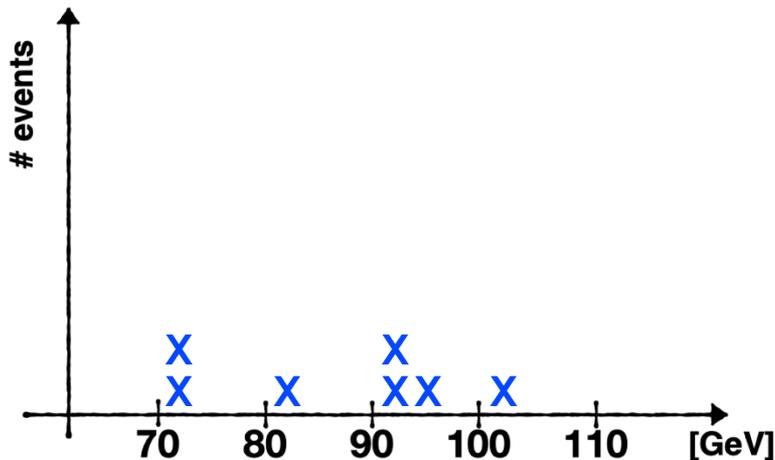
- So when in an LHC collision we produce a Z or W particle, **what we detect in the our experiments are only electrons and muons!**

# The Z boson mass reconstruction

- Measuring the **energies** and the **direction of production** of the two electrons or muons, we can compute the mass of the particle that have produced them in its decays:

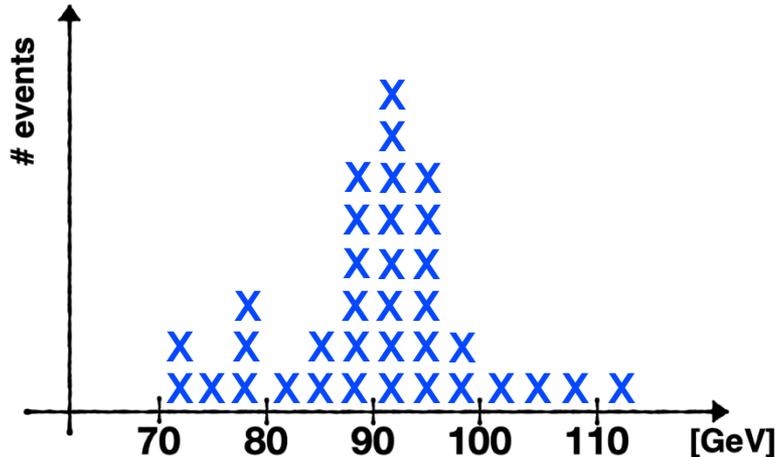
$$m_X = \sqrt{2E_1E_2(1 - \cos\theta)}$$

- In each **event** where we have **two electrons**/or **muons** we compute the Z mass with this formula and we fill an histogram of events:



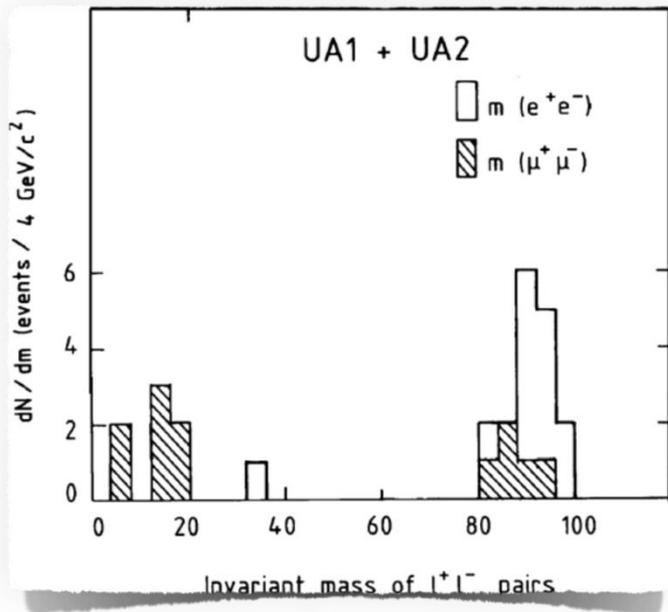
# The Z boson mass reconstruction

- A **peak of events** will appear **close to the true value** of the **mass** of the **Z boson** if the **Z exists**
- If the **“excess”** of events is **significantly big** → we discovered a **new particle**



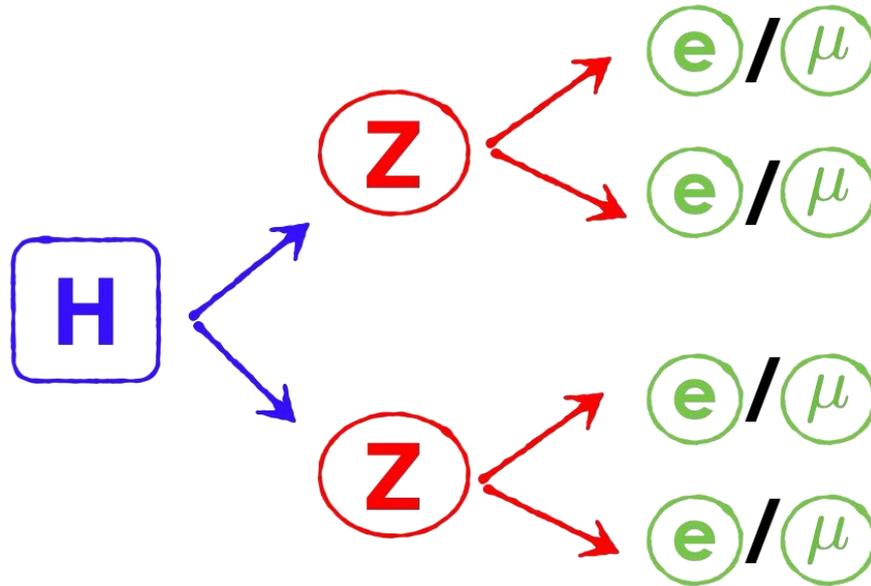
# The Z boson Nobel Prize

- A **peak of events** will appear **close to the true value** of the **mass** of the **Z boson** if the **Z exists**
- If the **“excess”** of events is **significantly big** → we discovered a **new particle**
- In **1983** the **UA1** and **UA2** experiments at CERN: **discovery** of the **W** and **Z boson**



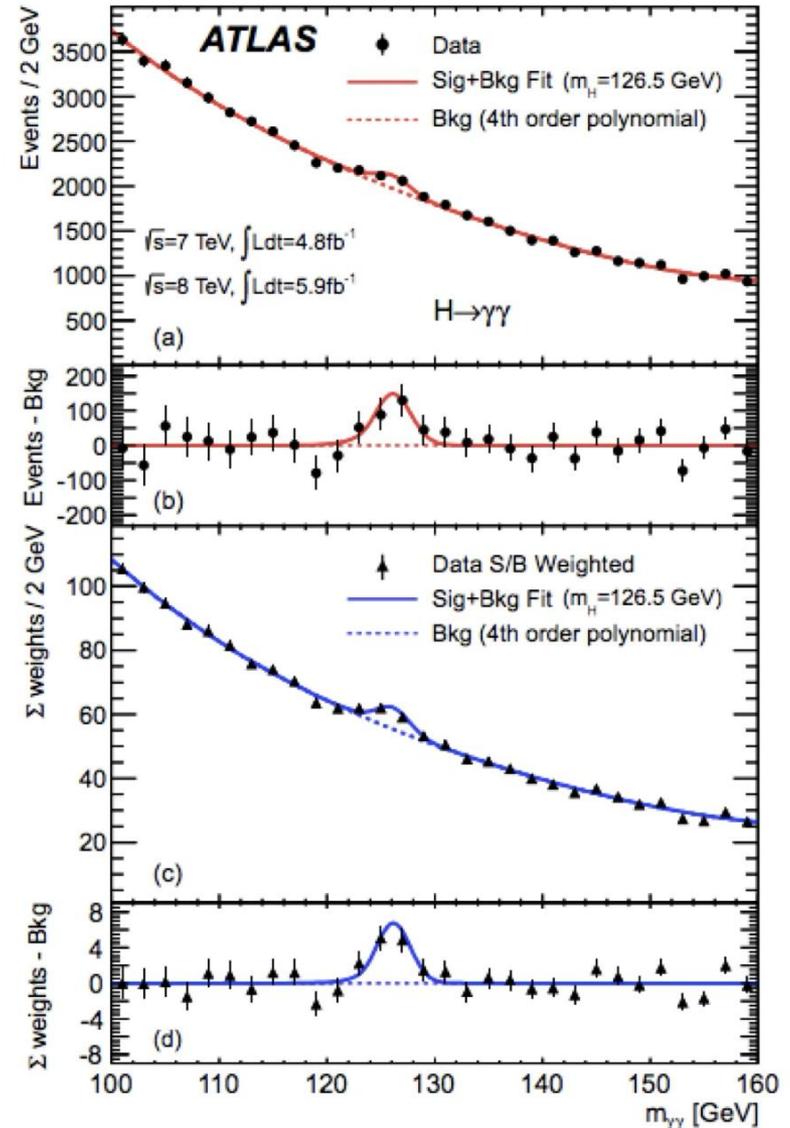
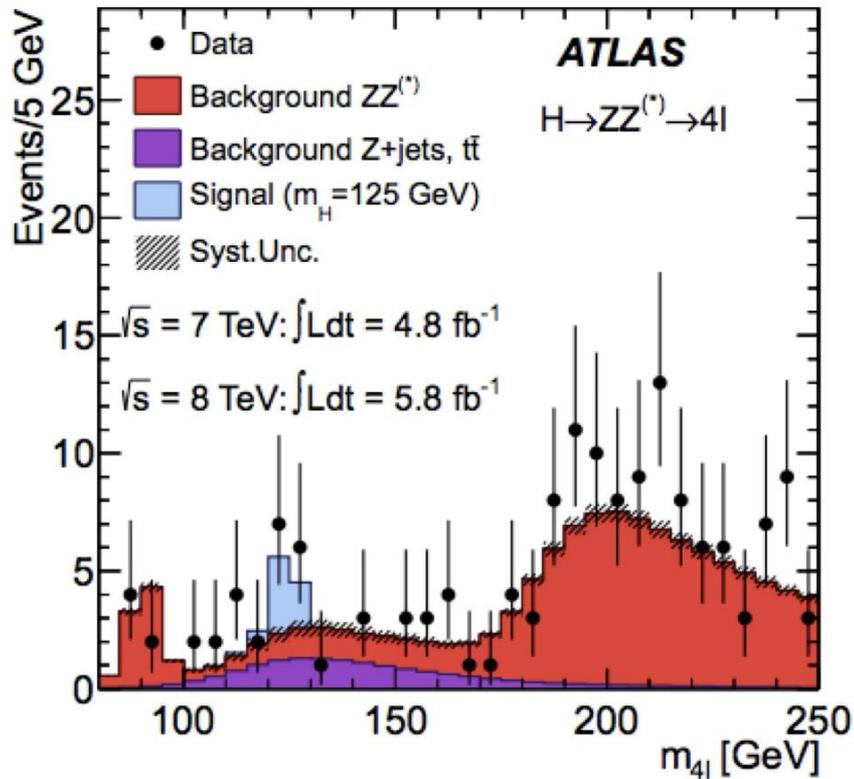
# The Z role in the Higgs discovery

- The discovery of the Z boson opened the opportunity to “use” the recently discovered particle for the quest of the **Higgs boson**:



- Either decays of the **Z** to **electrons/muons** are considered

# The Higgs discovery



# Now it's your turn!

- Today we will look at the **REAL DATA** collected by **CMS** at LHC and we will try to “**RE-DISCOVER**” the **Z** and the **W boson**
  
- We will learn how to **work in team** in **data analysis** and how to **present our own results** like in a **major physics conference!**

# iSpy tool – CMS event

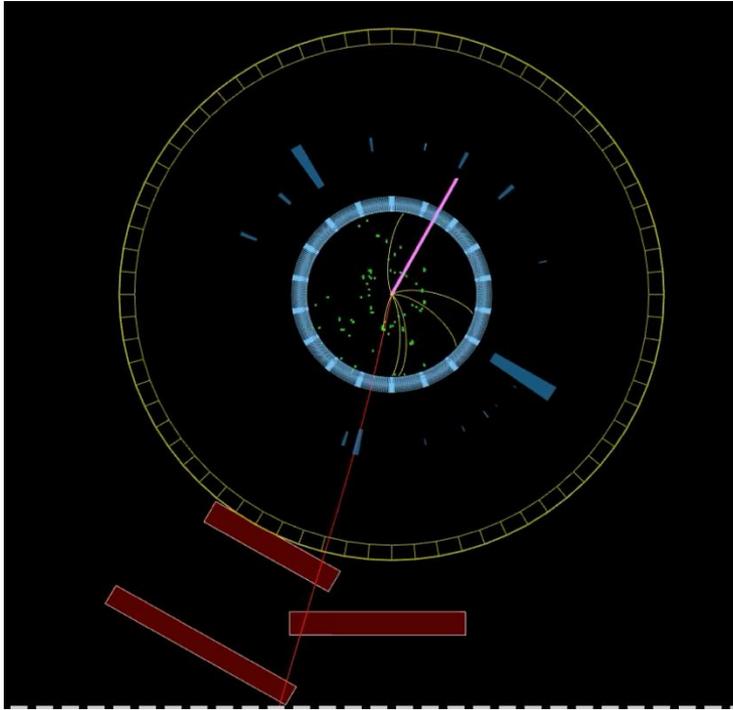
Different planes views

The screenshot displays the iSpy tool interface for a CMS event. The top toolbar contains icons for file operations, navigation, and view controls. The left sidebar shows a tree view of event components, including Detector, Imported, Provenance, Event, Tracking, Tracks (reco.) [179], ECAL, Barrel Rec. Hits [530], Preshower Rec. Hits [18], Endcap Rec. Hits [389], SuperClusters [7], and HCAL. The central 3D visualization area shows a wireframe model of the CMS detector with a central event vertex and tracks. A yellow arrow points to the 'HCAL' component in the sidebar. The bottom table displays physics objects with columns for pt, charge, rp, phi, eta, and calo\_energy.

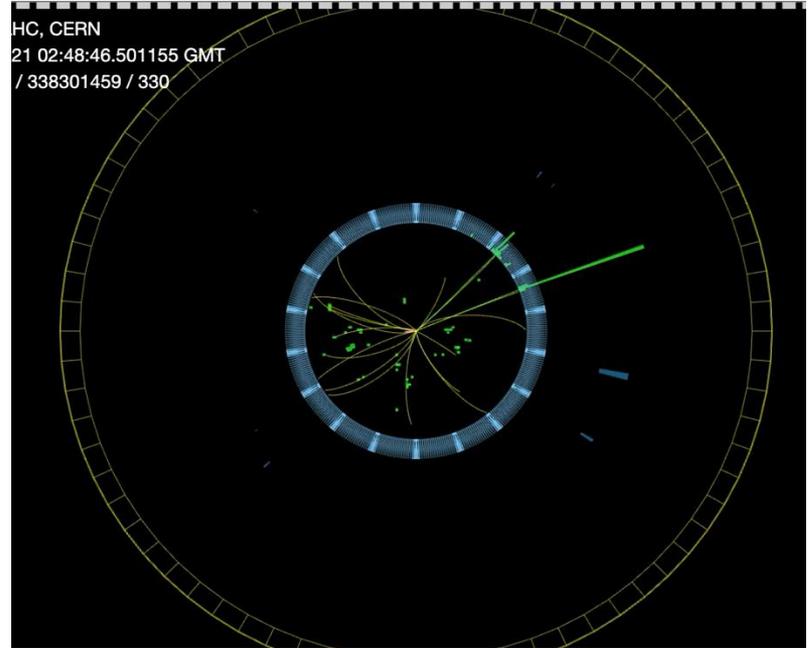
pt	charge	rp	phi	eta	calo_energy
17.226		0.000687702,0.00069938,-0.100233	0.344044	0.205445	0
126.97		0.000703579,0.000671055,-0.100225	2.0224	-0.887451	0

Subdetectors and physics objects visualization

# Particles Identification

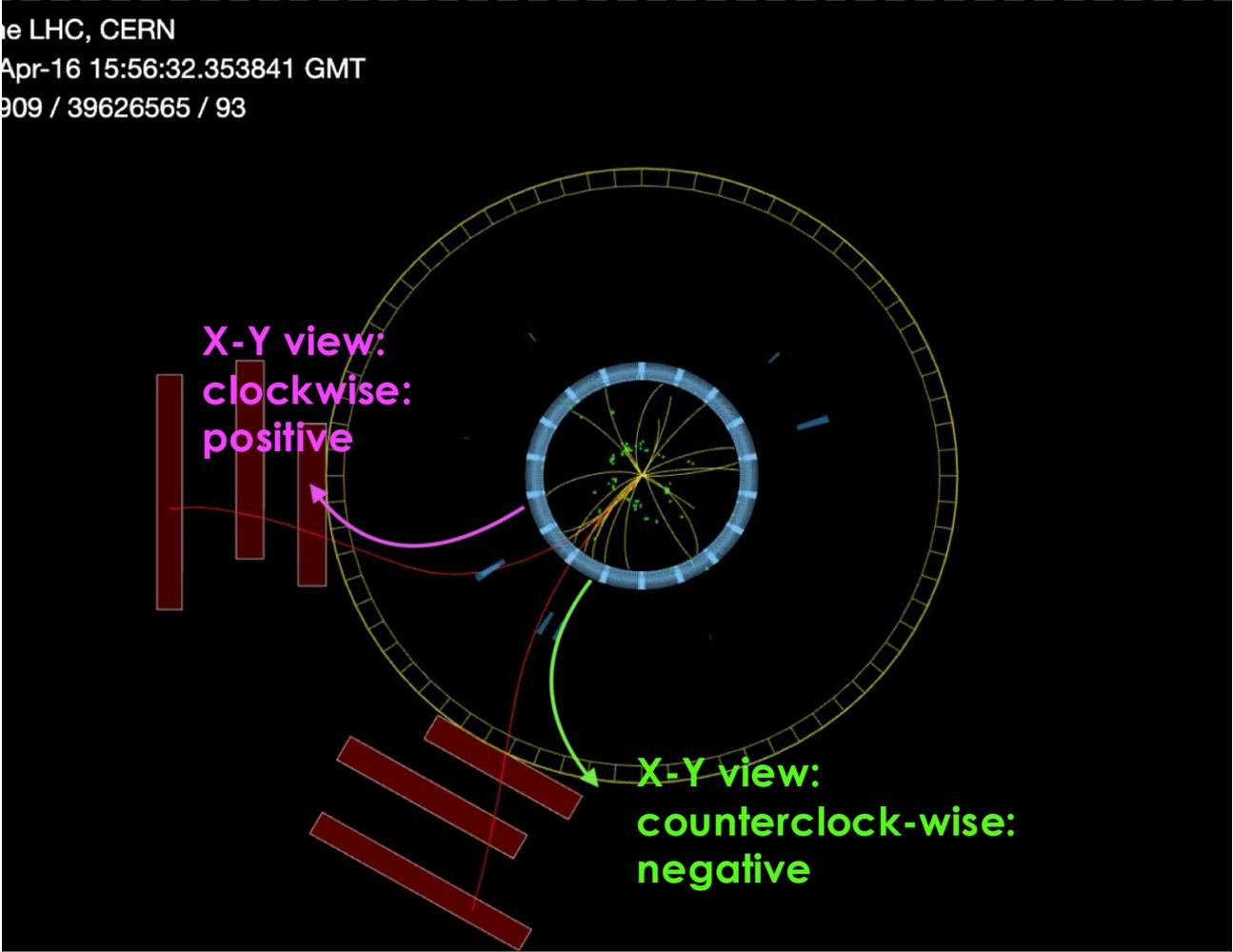


**Muon  $\mu$**   
Neutrino  $\nu$



**Electron  $e$**

# Charge Identification

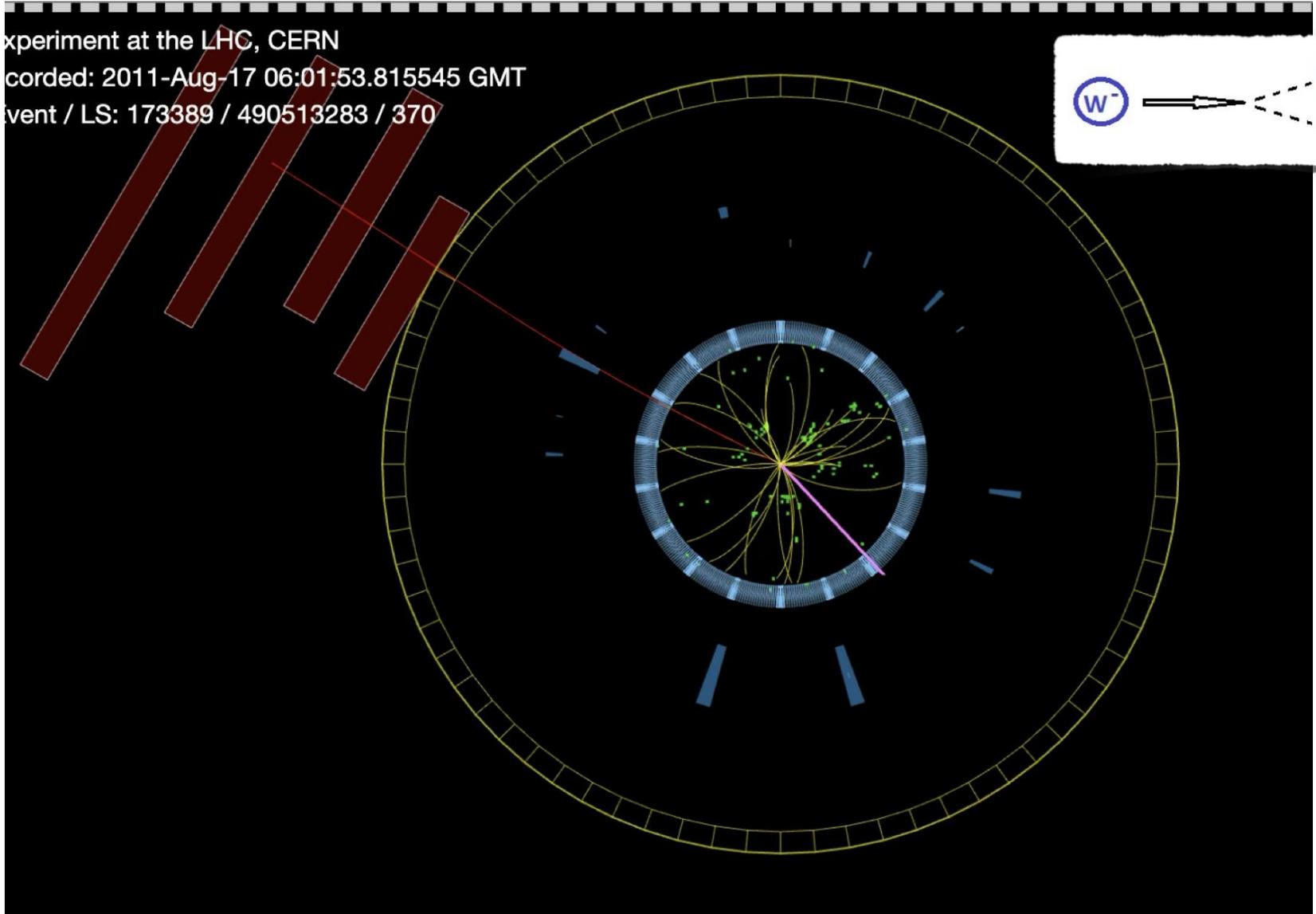
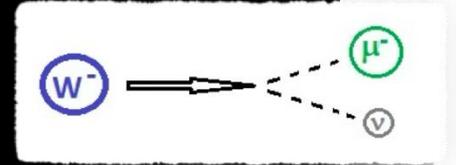


$$W \rightarrow \mu + \nu$$

Experiment at the LHC, CERN

Recorded: 2011-Aug-17 06:01:53.815545 GMT

Event / LS: 173389 / 490513283 / 370

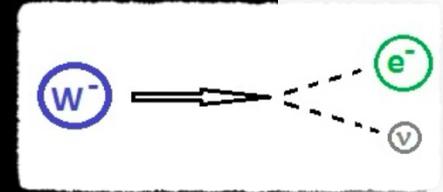
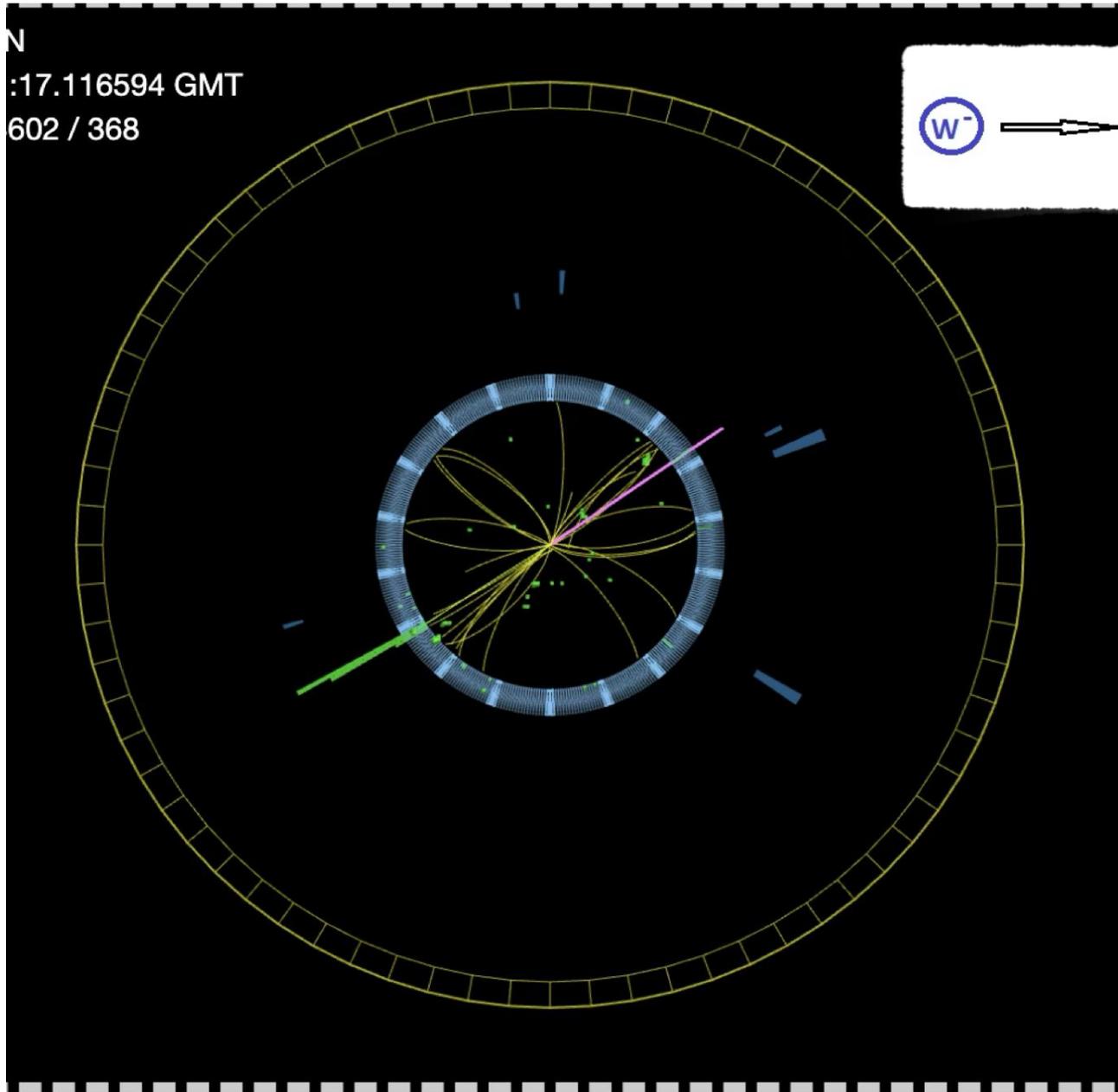


$$W \rightarrow e + \nu$$

N

:17.116594 GMT

602 / 368

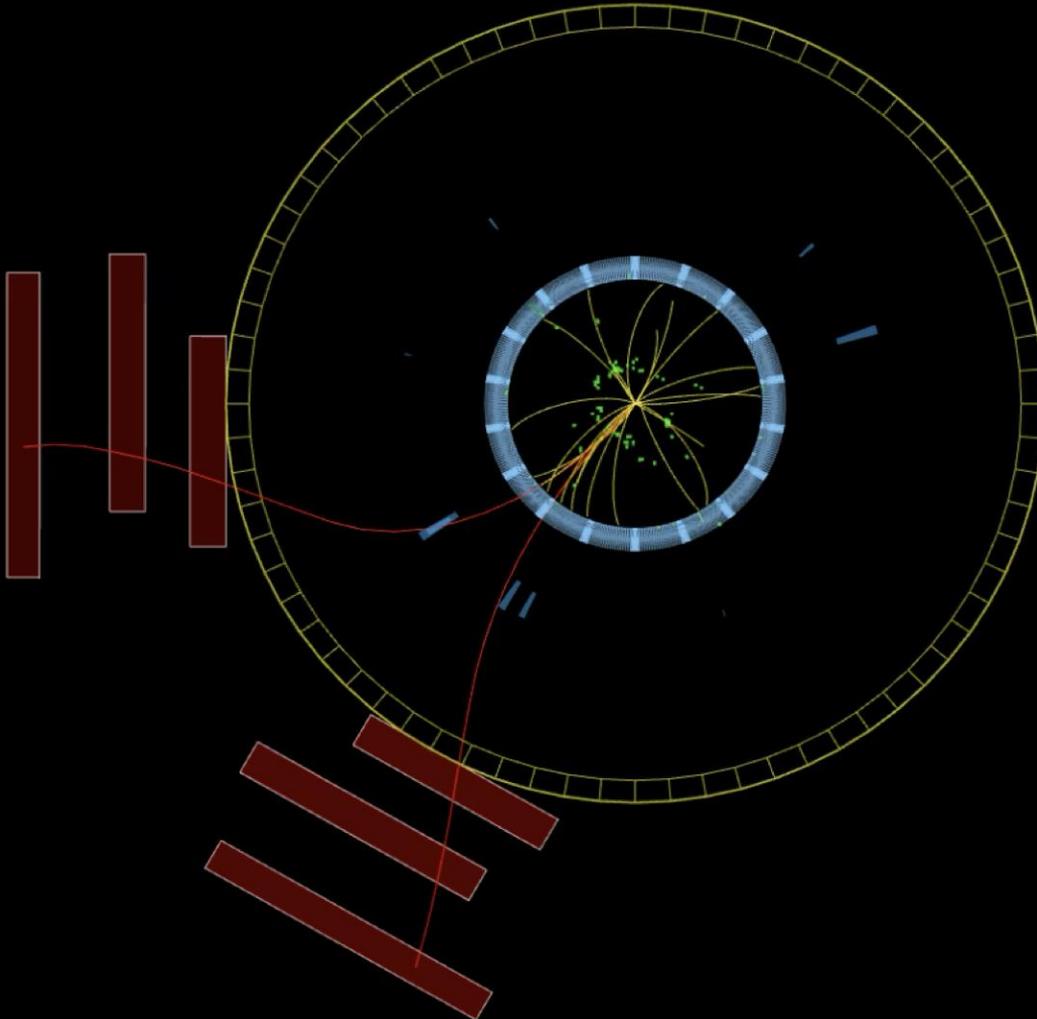
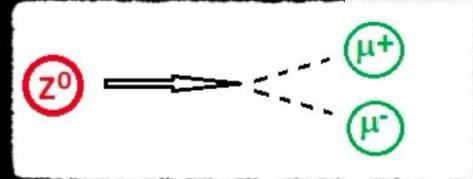


$$Z \rightarrow \mu^+ + \mu^-$$

the LHC, CERN

Apr-16 15:56:32.353841 GMT

909 / 39626565 / 93

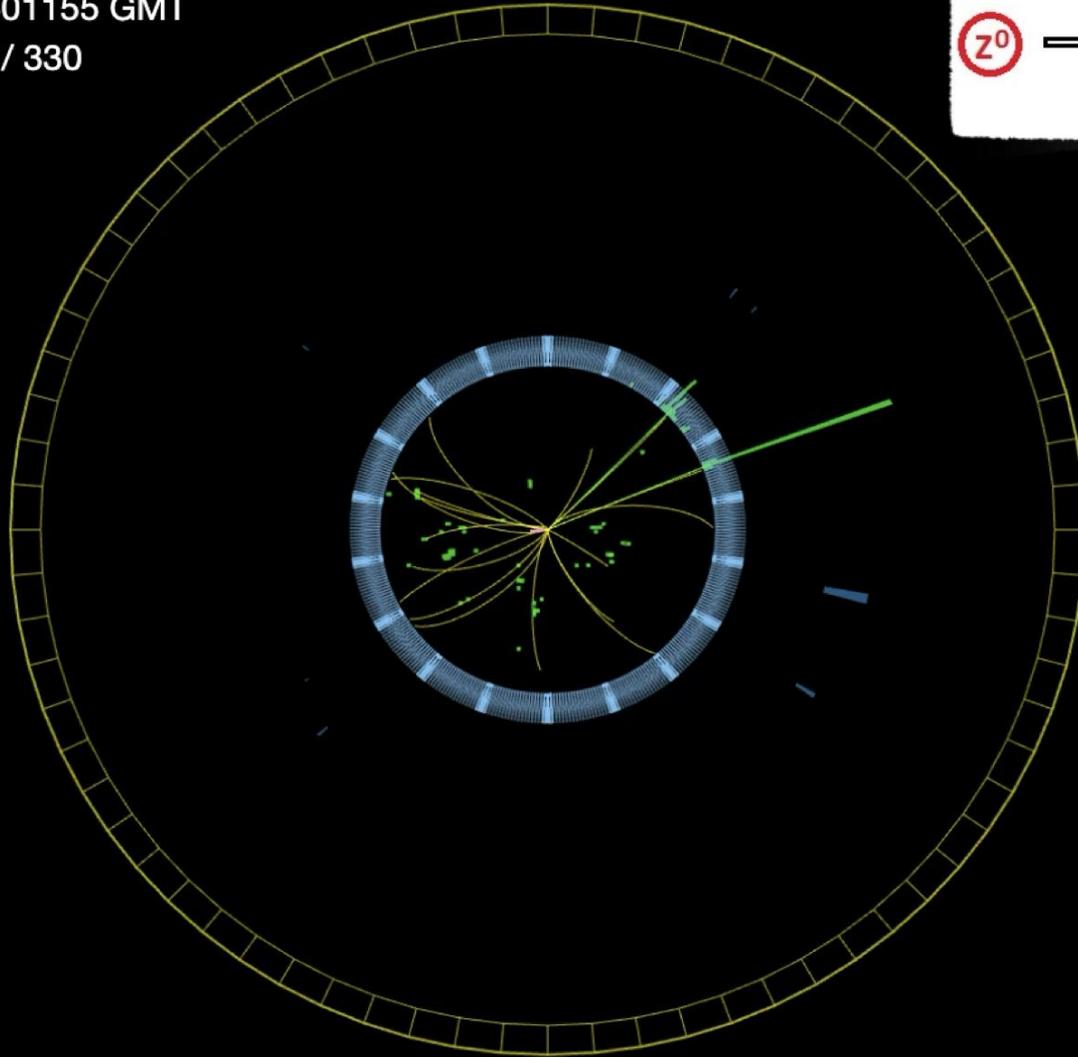
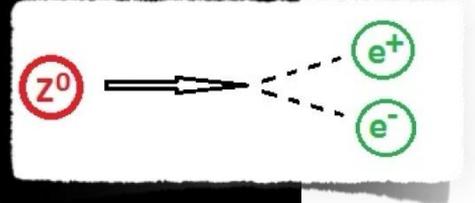


$$Z \rightarrow e + e$$

C, CERN

02:48:46.501155 GMT

338301459 / 330



**BACKUP**

# Many resonances around!

