# Introduzione alle misure di fisica delle alte energie: ALLA SCOPERTA DEL BOSONE Z

Fabiola Raffaeli

03 Marzo 2023

"Hands on Particle Physics"
International Masterclasses

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

INFN Sezione di Roma Tor Vergata

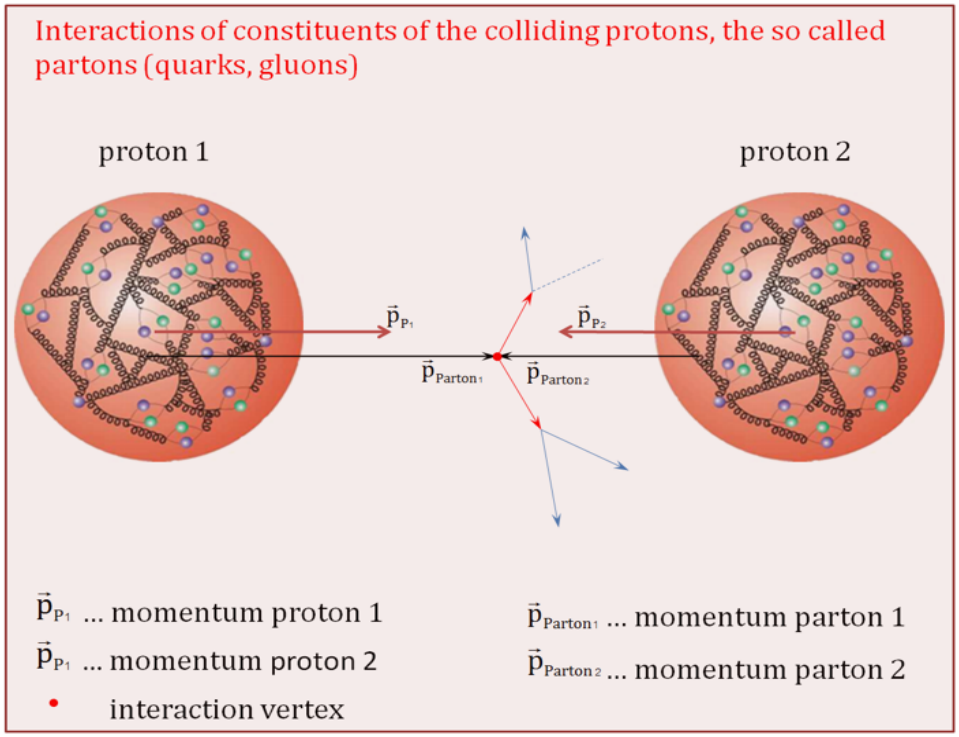
# Outline

- What is an “event”?
- Z boson: production and decays
- How one can identify the particles produced?
  - … in ATLAS
- The “Particle Physics Giant”: the ATLAS detector
- Example of a real analysis: signal and backgrounds
- Hands-on session

# The event

**Every time two beams collide in the Interaction Point, on average we have about 50 proton-proton collisions**

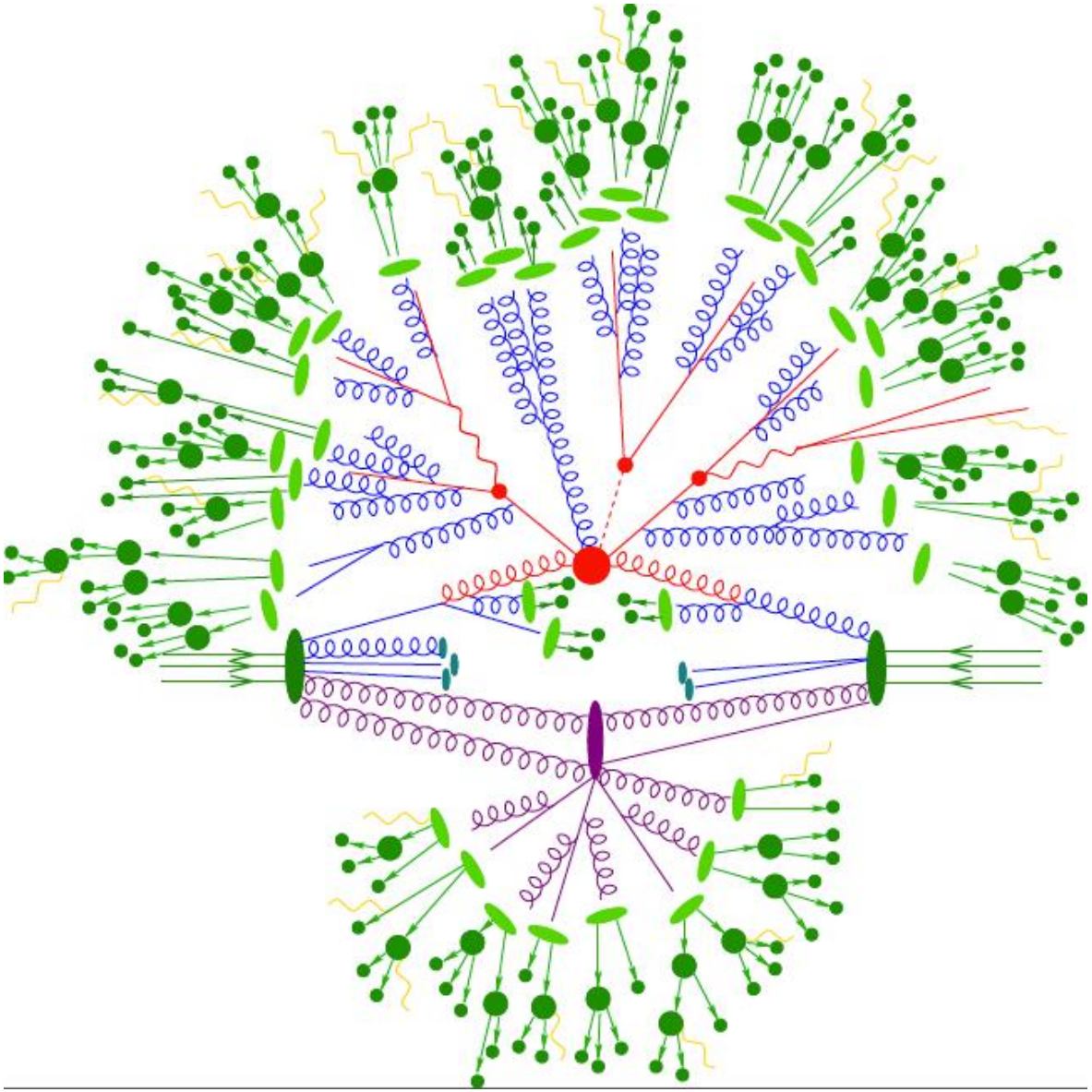
Almost all these collisions are not interesting (i.e. pp->pp)




**Protons collide with protons at high speed:**
lots of energy ($E_1+E_2 = mc^2$ ) which can be used to create **new particles**

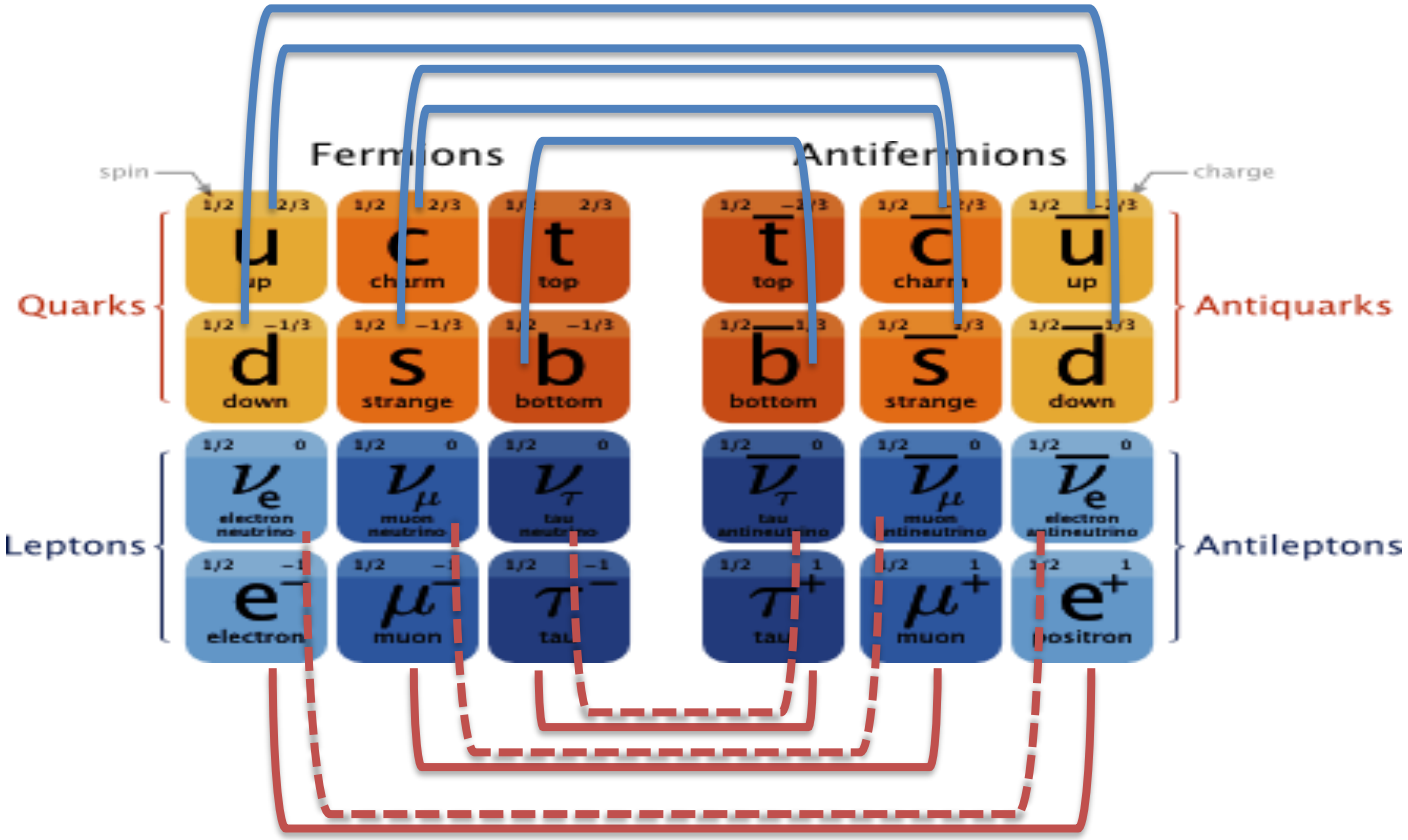
Sometimes a **Z boson** ( m = 91.2 GeV/$c^2$) or a **Higgs boson** ( m = 125.1 GeV/ $c^2$) is created

# Things are a bit more complex…



# The Z boson

- Responsible for mediating the weak interaction (with the W boson)
- It is not a stable particle – lifetime $3 \times 10^{-25}$ (0.0000000000000000000000003s) → no hope to measure the Z directly!
- Z bosons decay into a pair of fermion and anti-fermion



# The Z boson

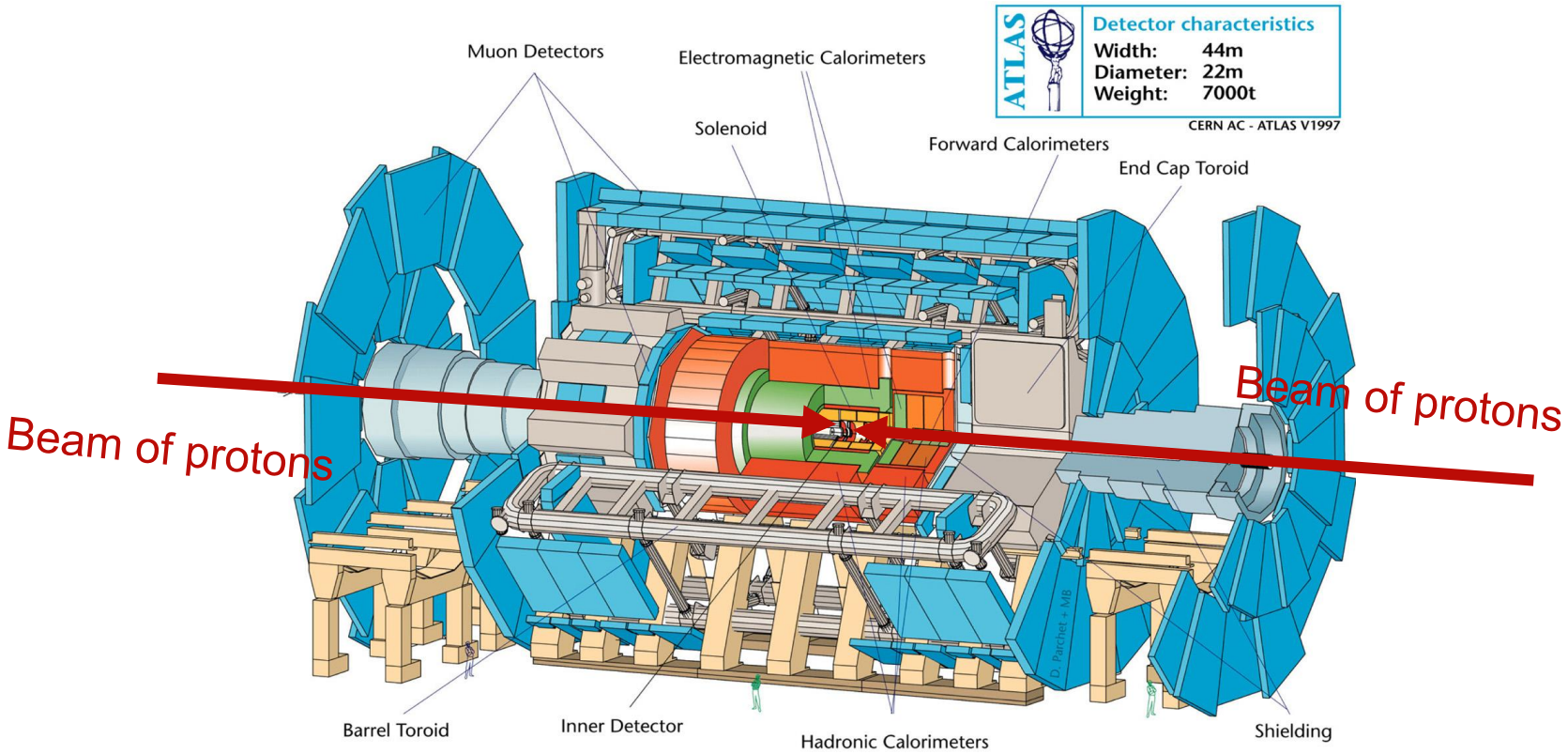


- The possible decays are:
  - 5 types of quark pairs (the top is too heavy to be produced)
  - A pair of taus
  - A pair of muons
  - An electon-positron pair
  - 3 types of neutrinos
- Quarks are not observed free in nature, they *hadronise* which means they produce a collimated "jet" of particles
- Leptons have unique signature which we will explore
  - Taus are more complex, so we only look at muons and electrons
- Neutrino do not interact* with matter, so they escape the detector
  - * they do interact, but the probability is so low we assume it is zero in ATLAS

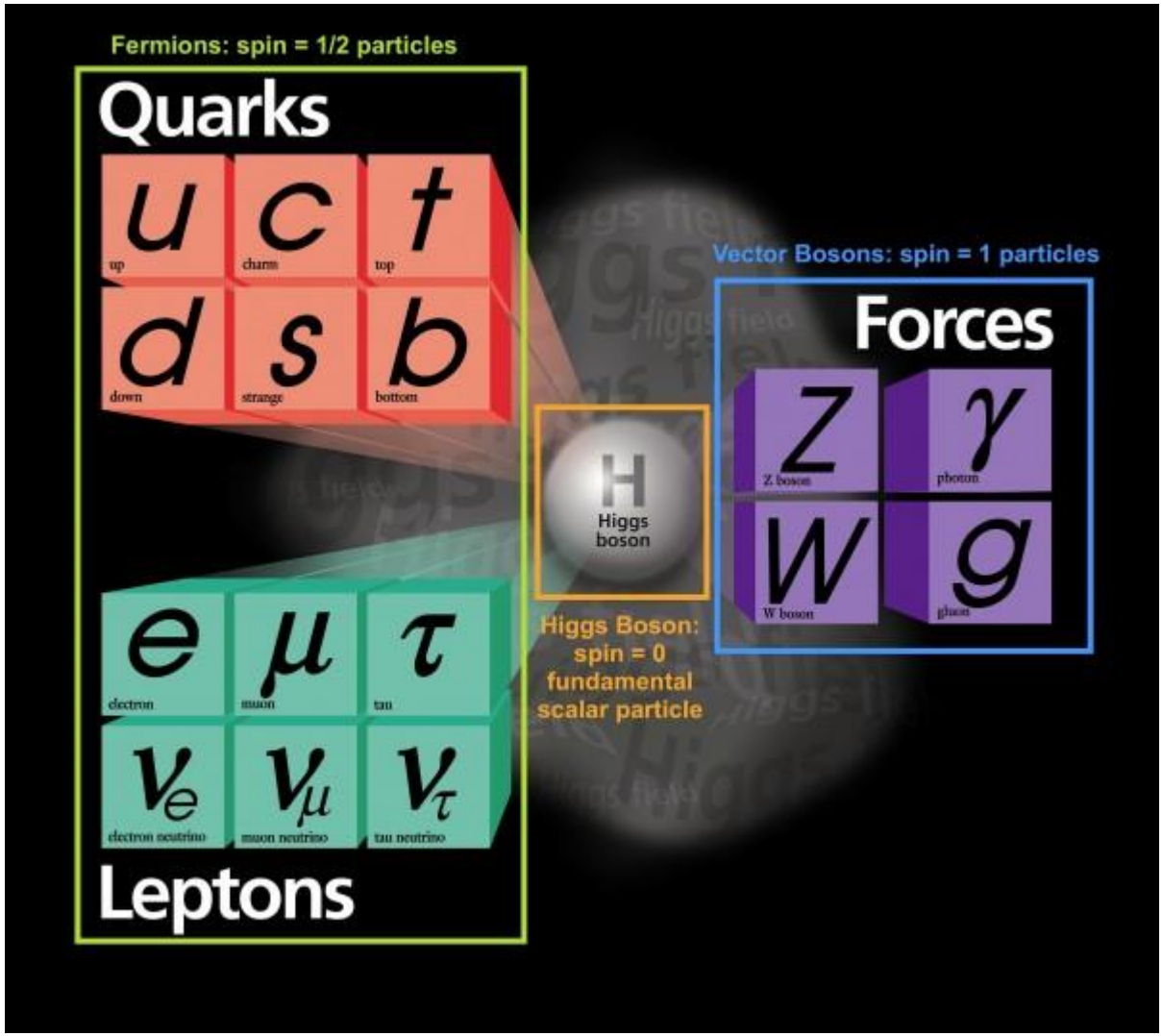
# ATLAS

We surround the place where particles collide with a set of detectors.

Different types of particles leave different signals in the various detectors

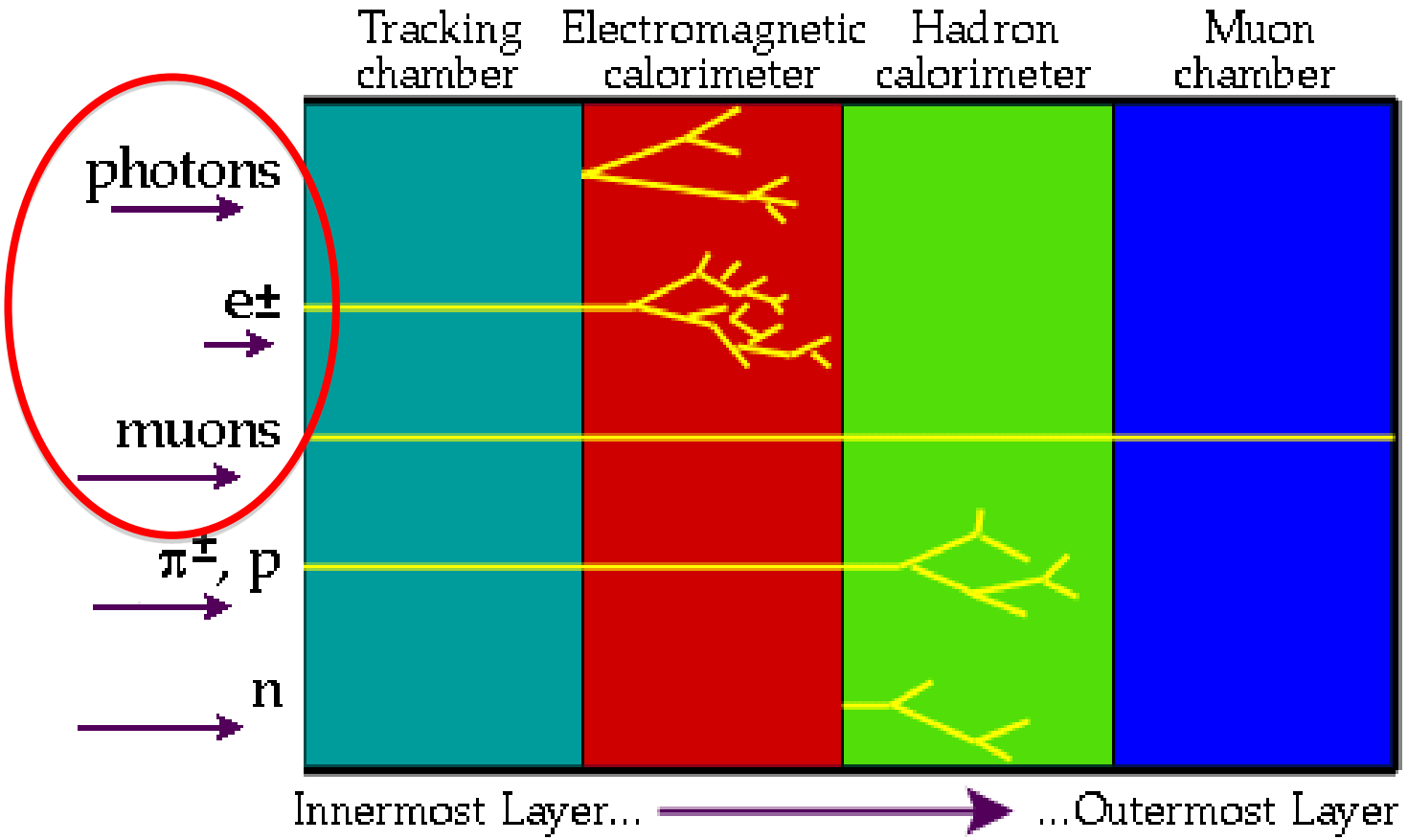


# Reminder: the Standard Model




Which of these is stable (i.e. can travel for ~100m) ?

# How particles interact with detectors

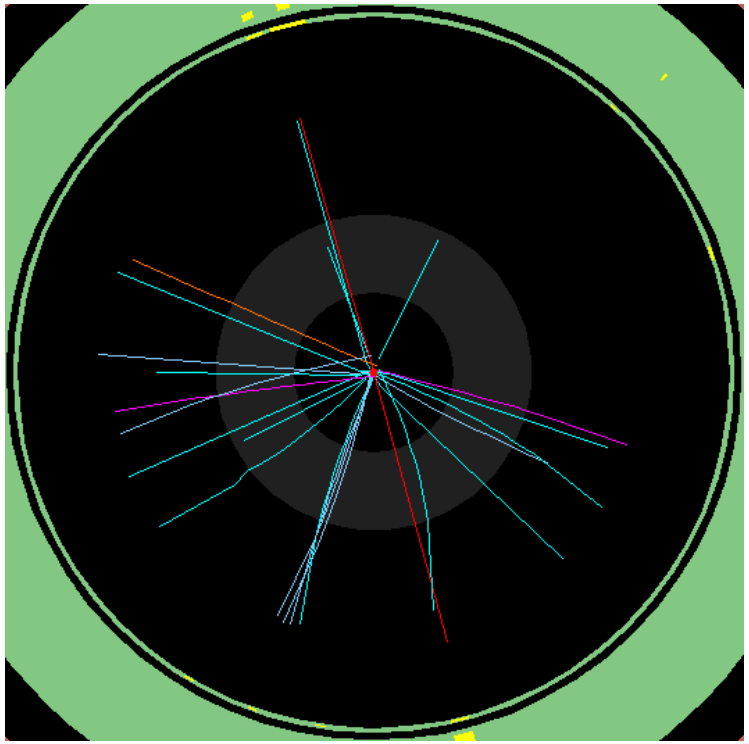


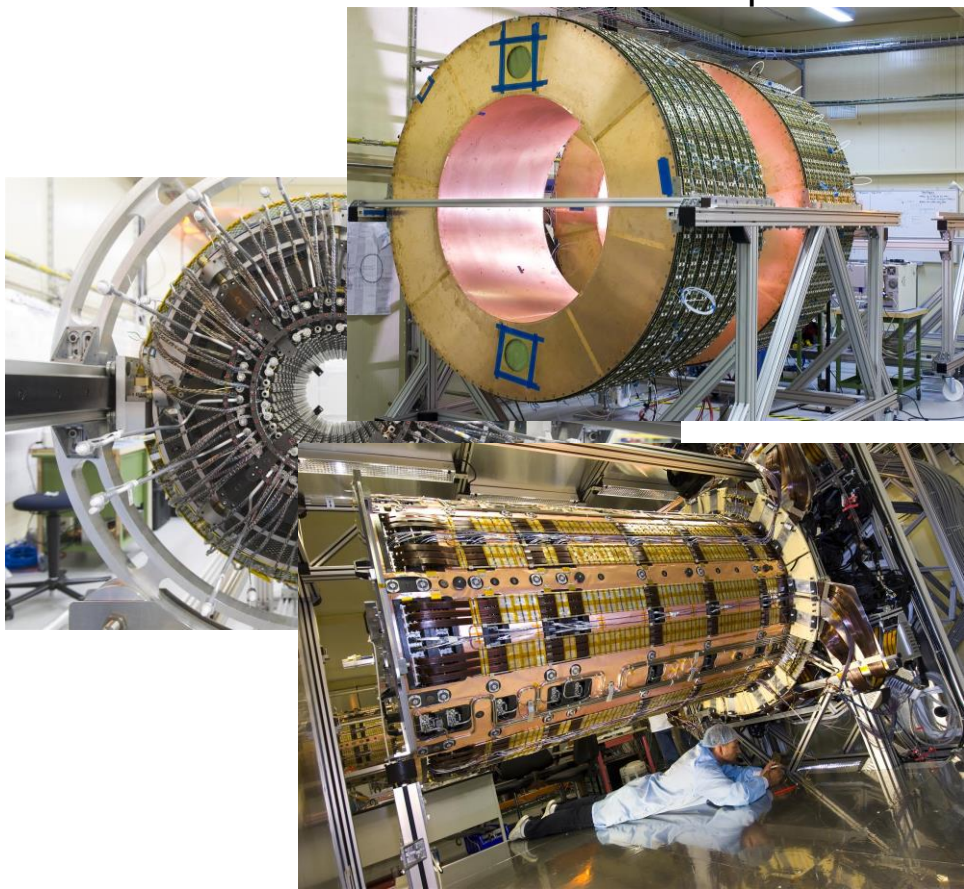
# The Inner Detector (tracking detector)



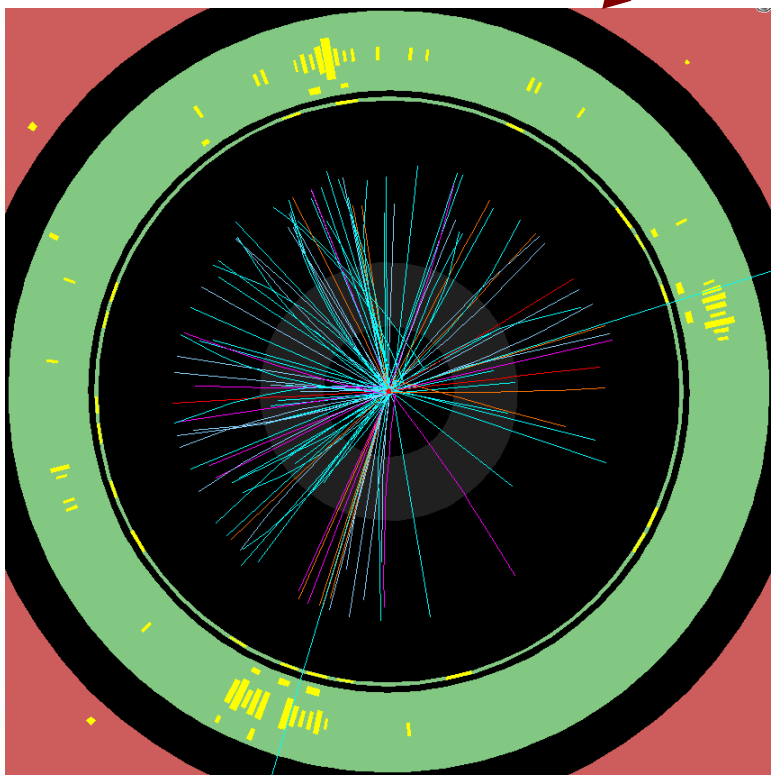
- detects electrically charged particles traversing the detector
  - electrons, muons, protons, quarks (jets) ...
- it is not sensitive to electrically neutral particles
  - photons, neutrons, neutrinos...

- the whole detector ″swims″ in a magnetic field, that deflects charged particles′ trajectories
  - Amount of deflection depends on mass and speed

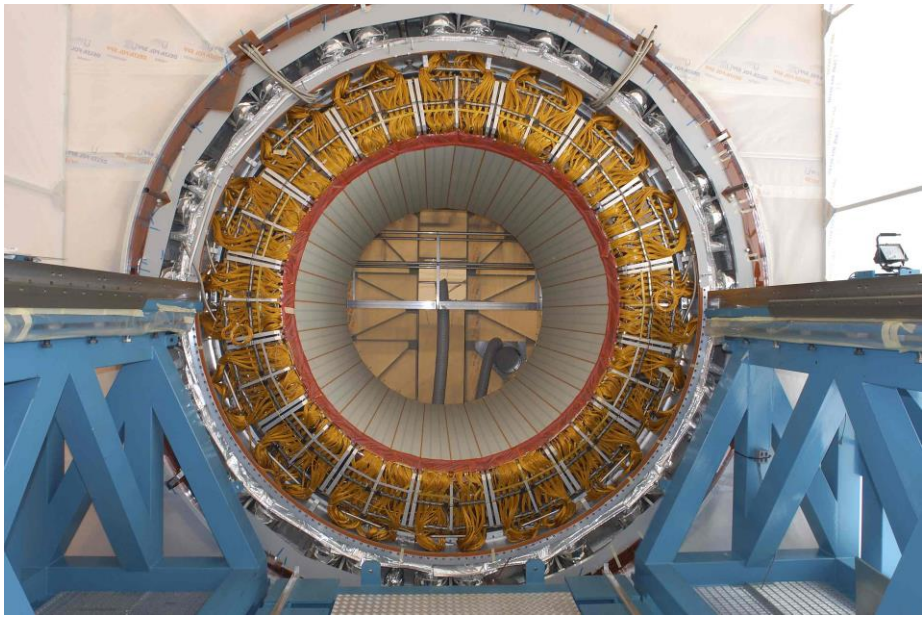




# Electromagnetic calorimeter (ECAL)

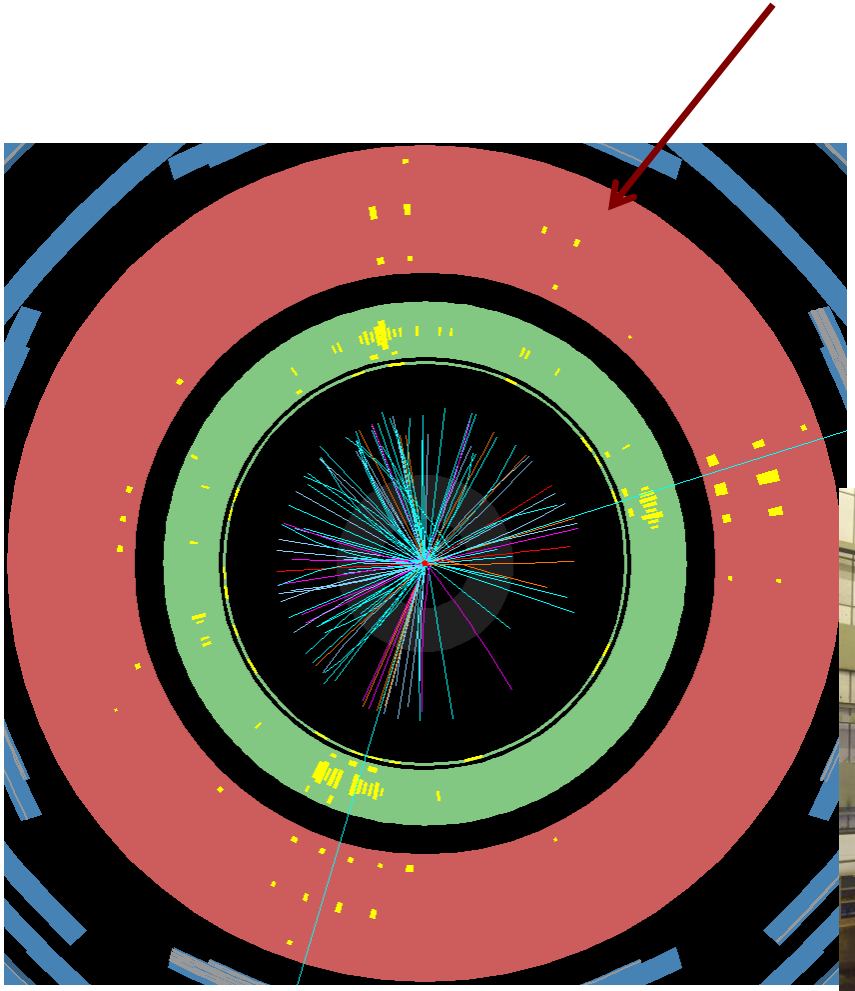


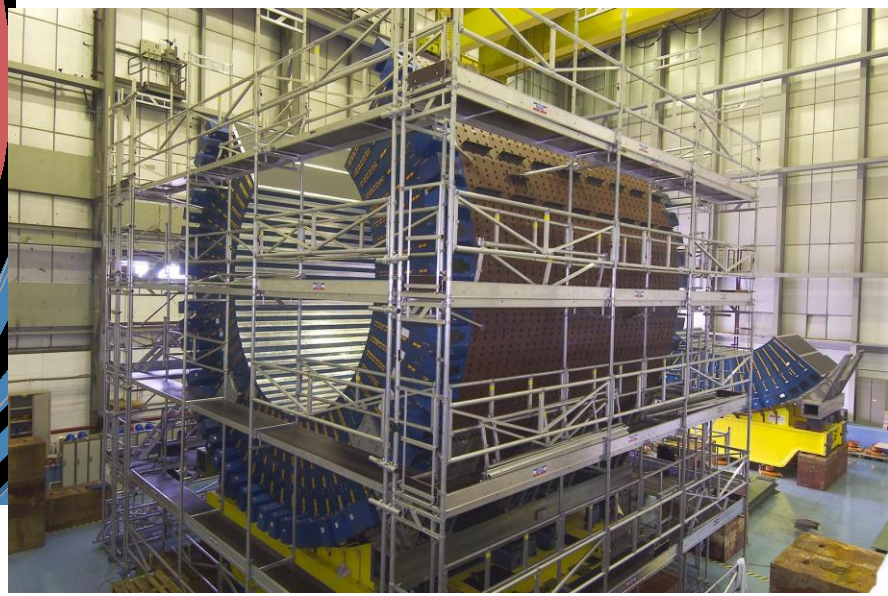
- **detects all particles interacting electromagnetically**
  - **such as electron, positron, photon, …**
  - **these particles deposit energy in the ECAL and this energy is measured**



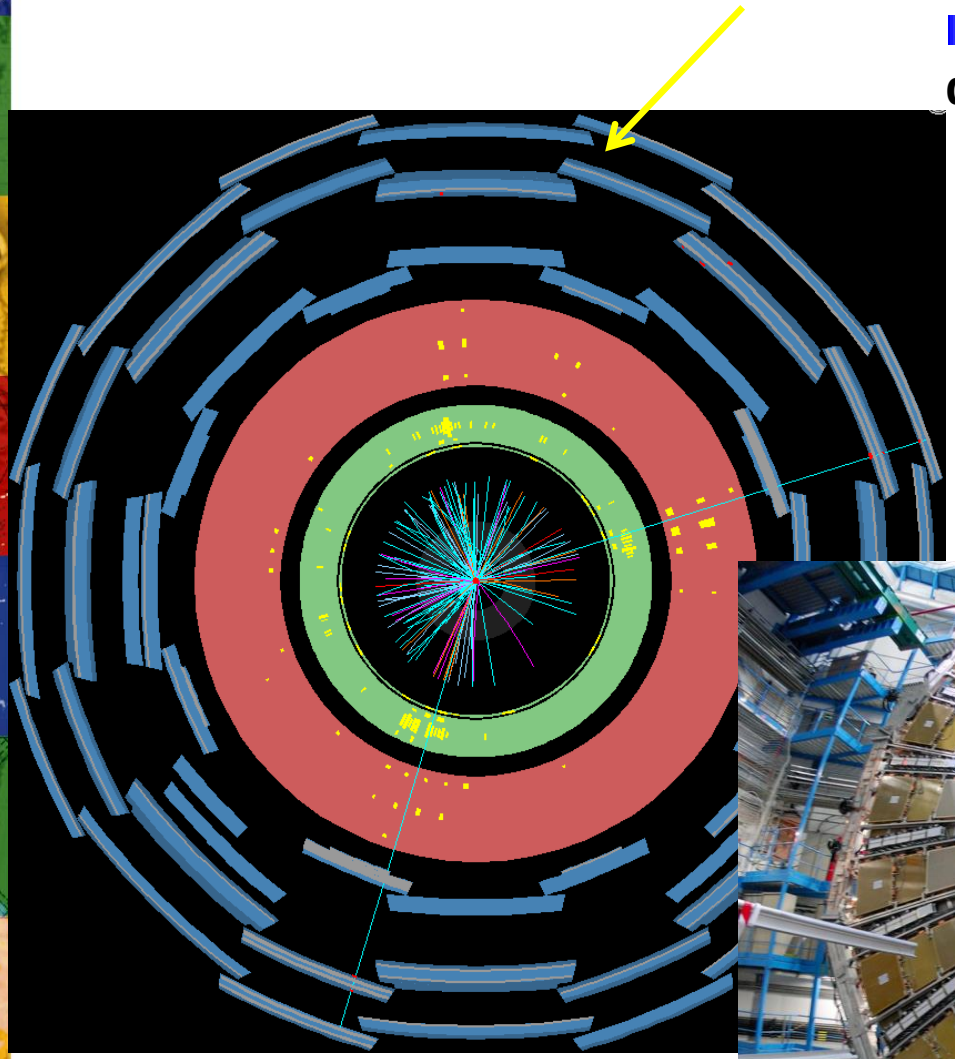
# Hadronic calorimeter (HCAL)

- **detects particles subject to strong interactions**
  - **mainly particles made of various flavours of quarks**

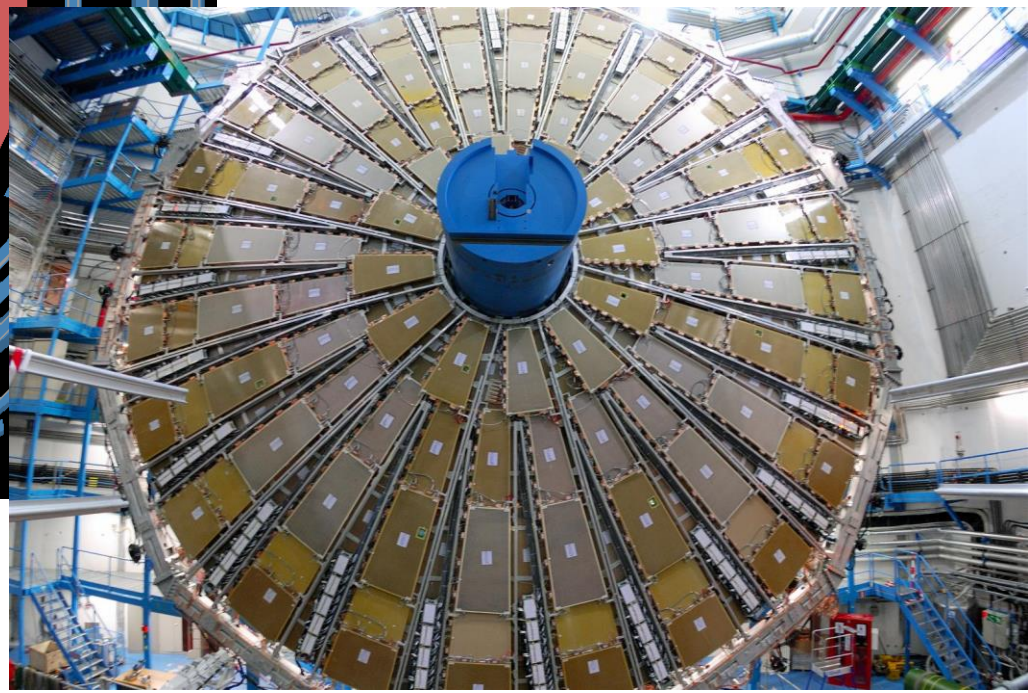


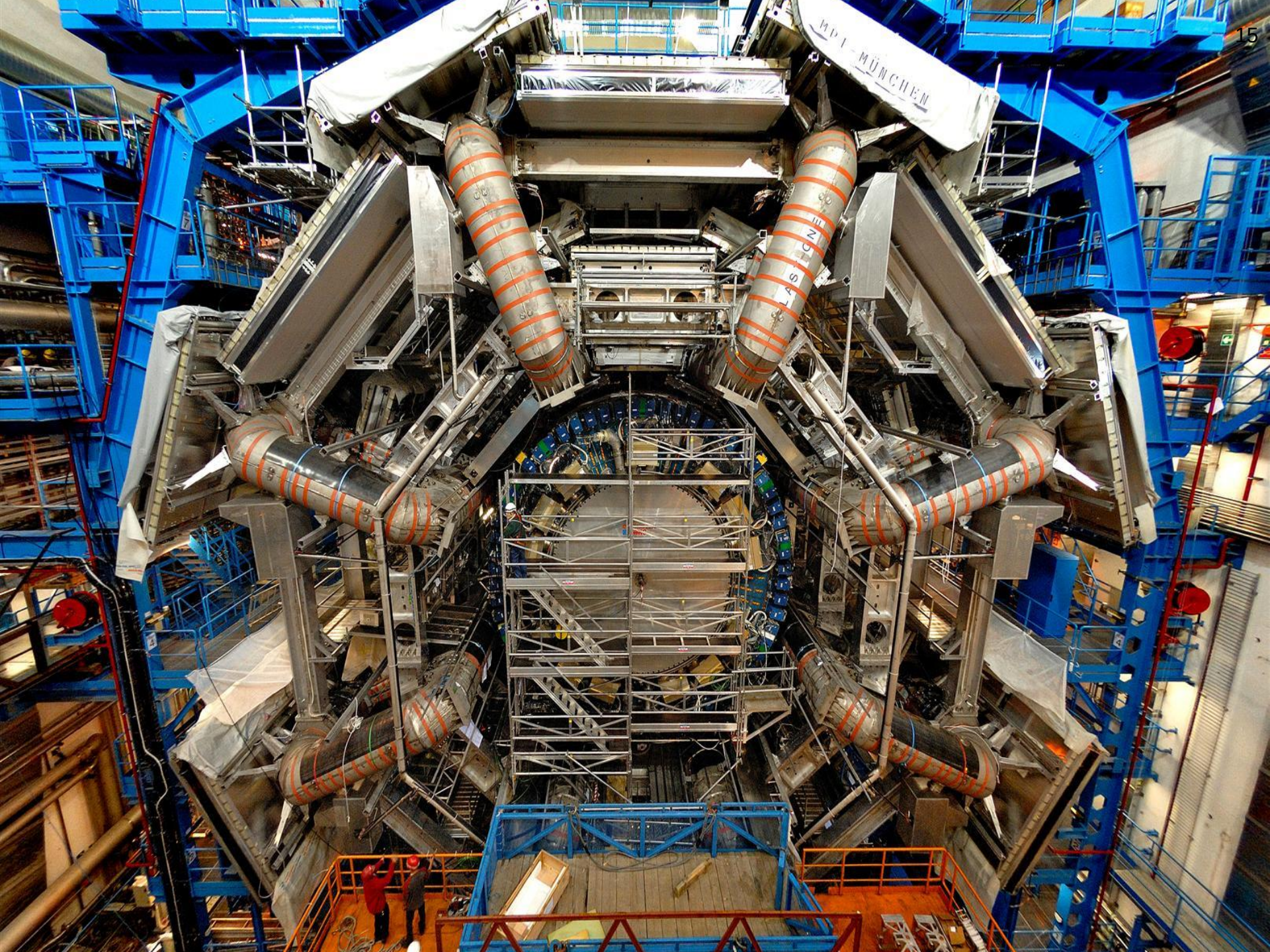


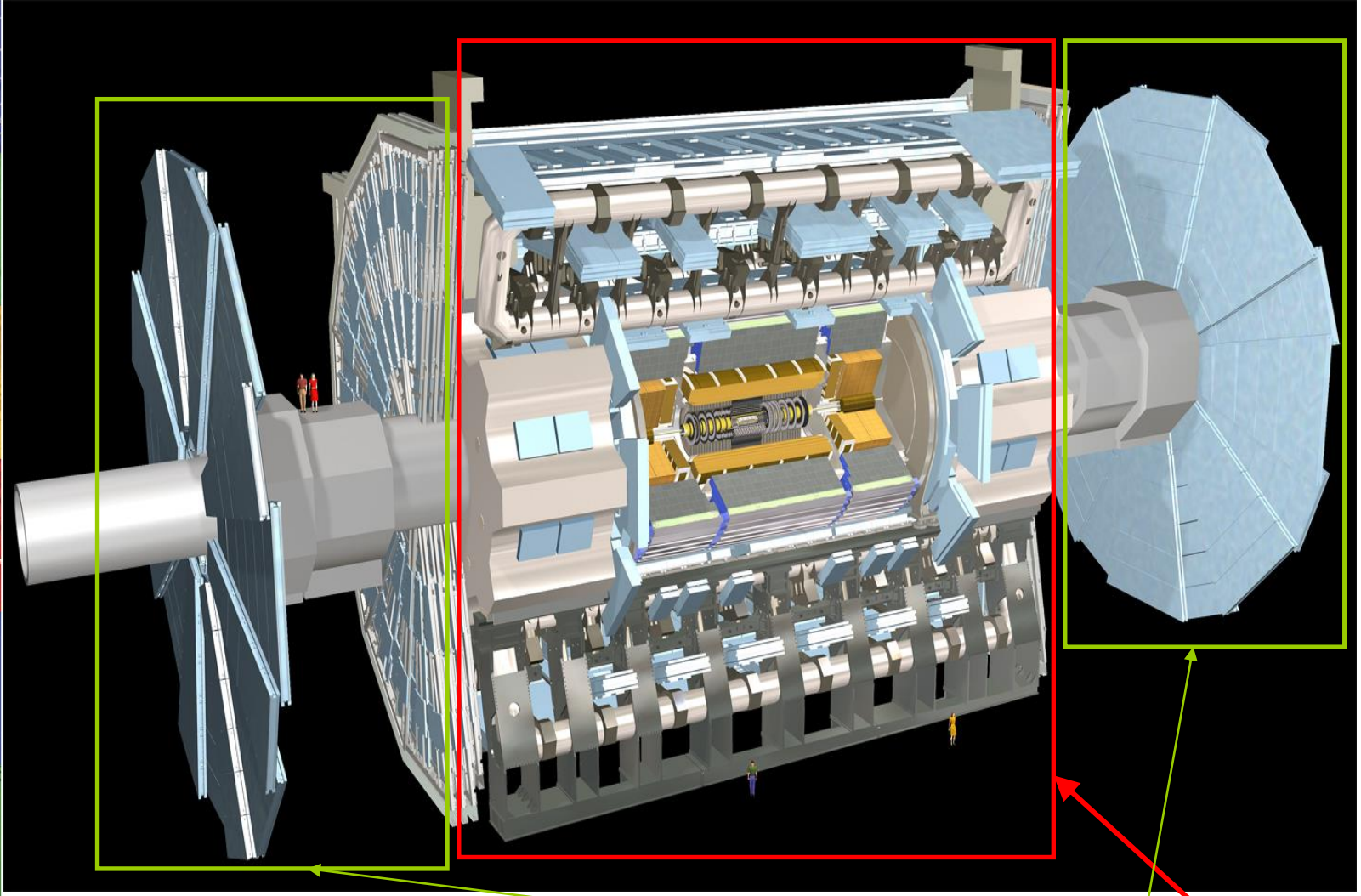
# Muon spectrometer (MS)



- **is the outermost part of the detector**
  - **detects muons**
  - **a strong magnetic field deflects the muon's trajectory allowing a measure of the momentum**

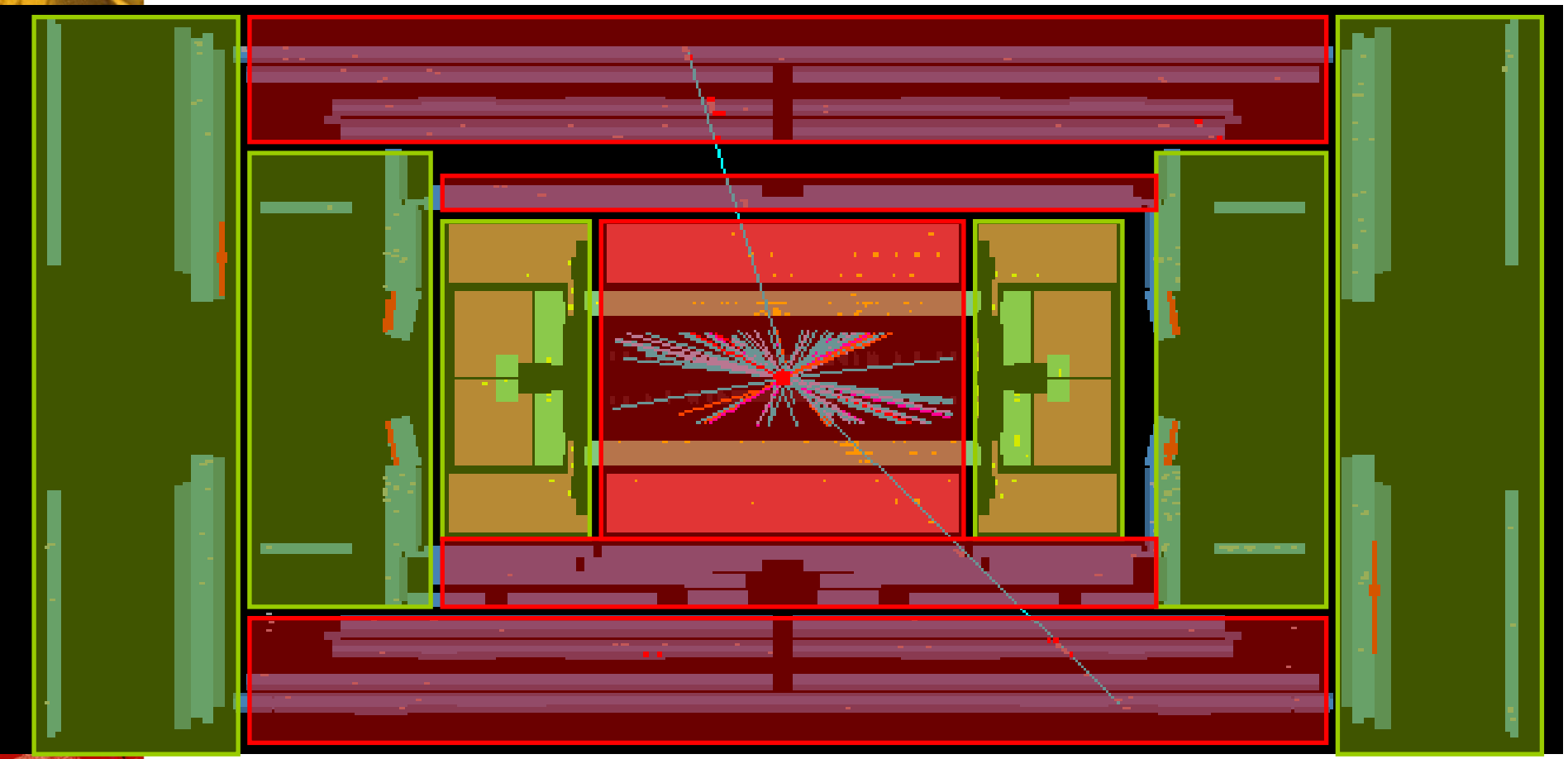



MPI - MÜNCHEN




- **In order to detect as many particles as possible after each collision, the detector is built such that it covers nearly the full solid angle**

# Endcap barrel



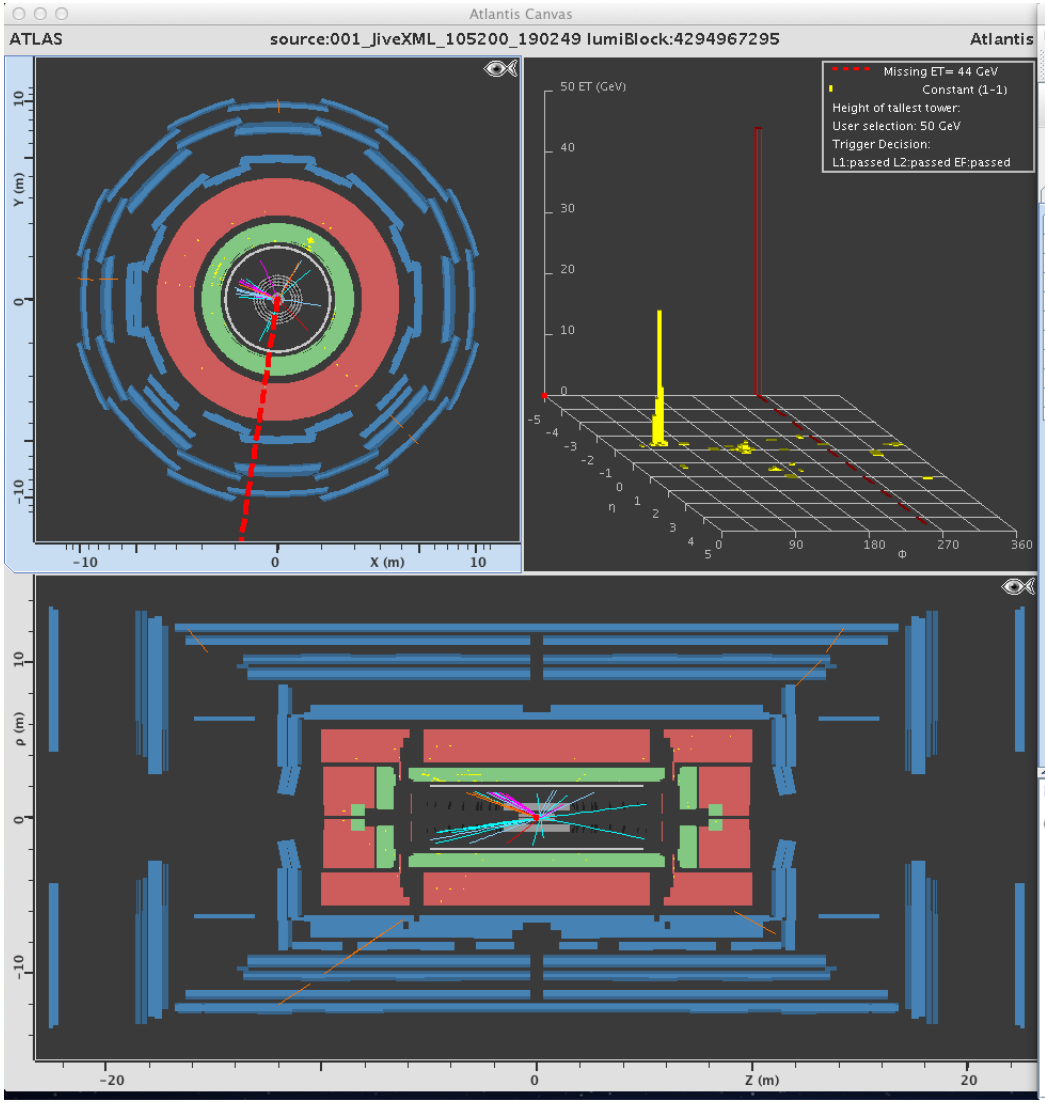
# You will:

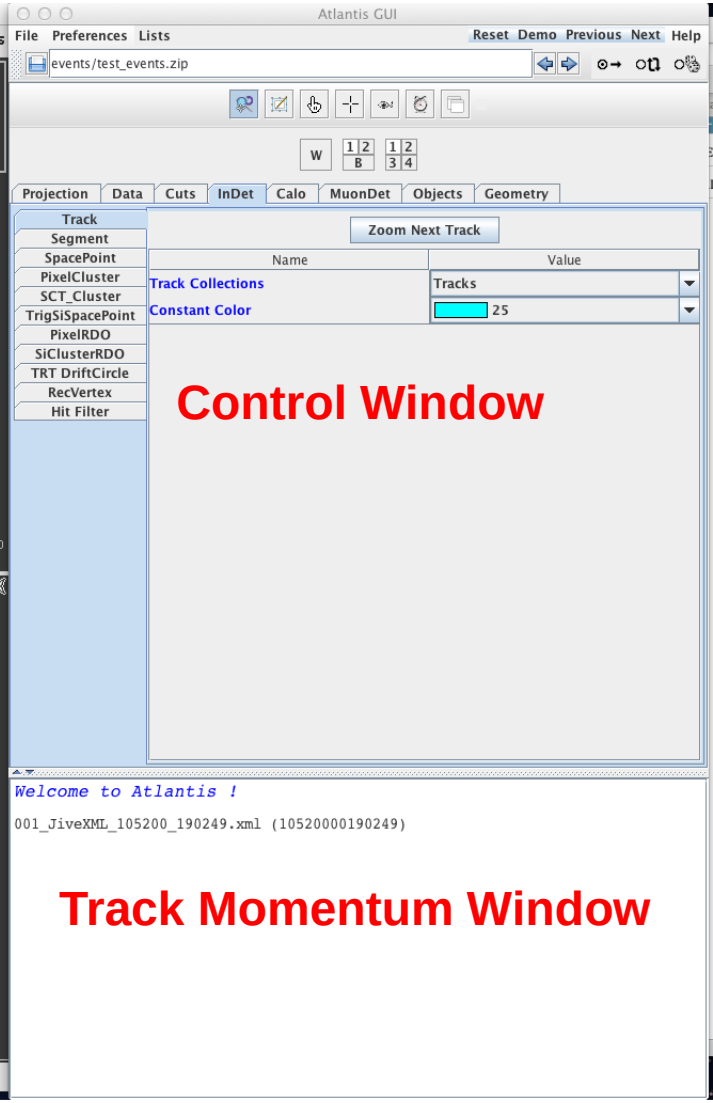
- 1. **Get to know the HYPATIA event display: a visualisation program for particle collisions in ATLAS**
  - Identify particles in a detector
  - Identify a decay process
  - Find as many correct answers as possible?

- 2. **Work with real data from LHC**
  - Identify decays of the Z boson from background

# How it looks like…

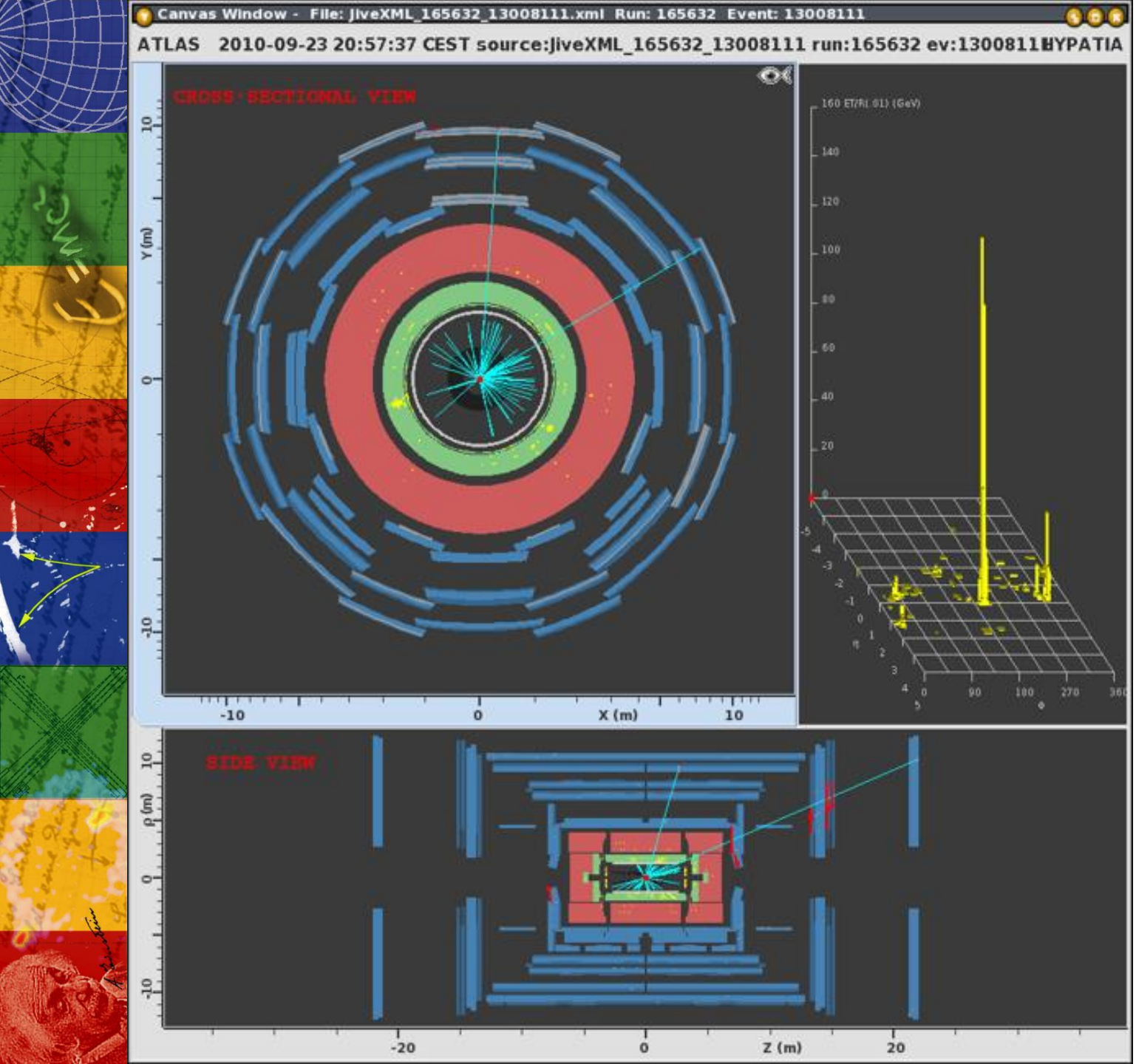
## Canvas Window




## Control Window

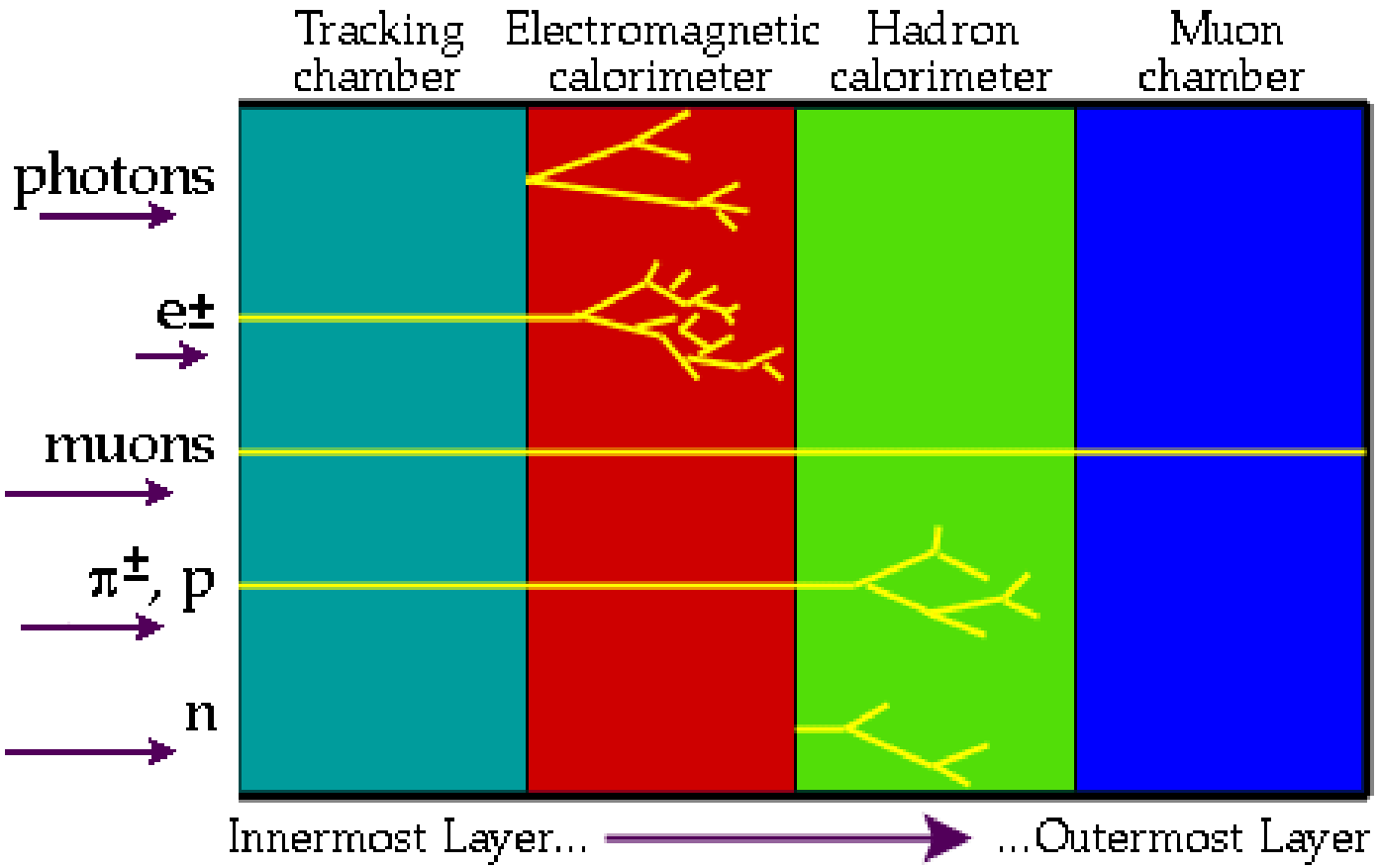
## Track Momentum Window



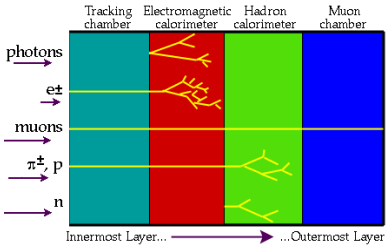

## Detector views

Four sub-detector types, depicted in different colors

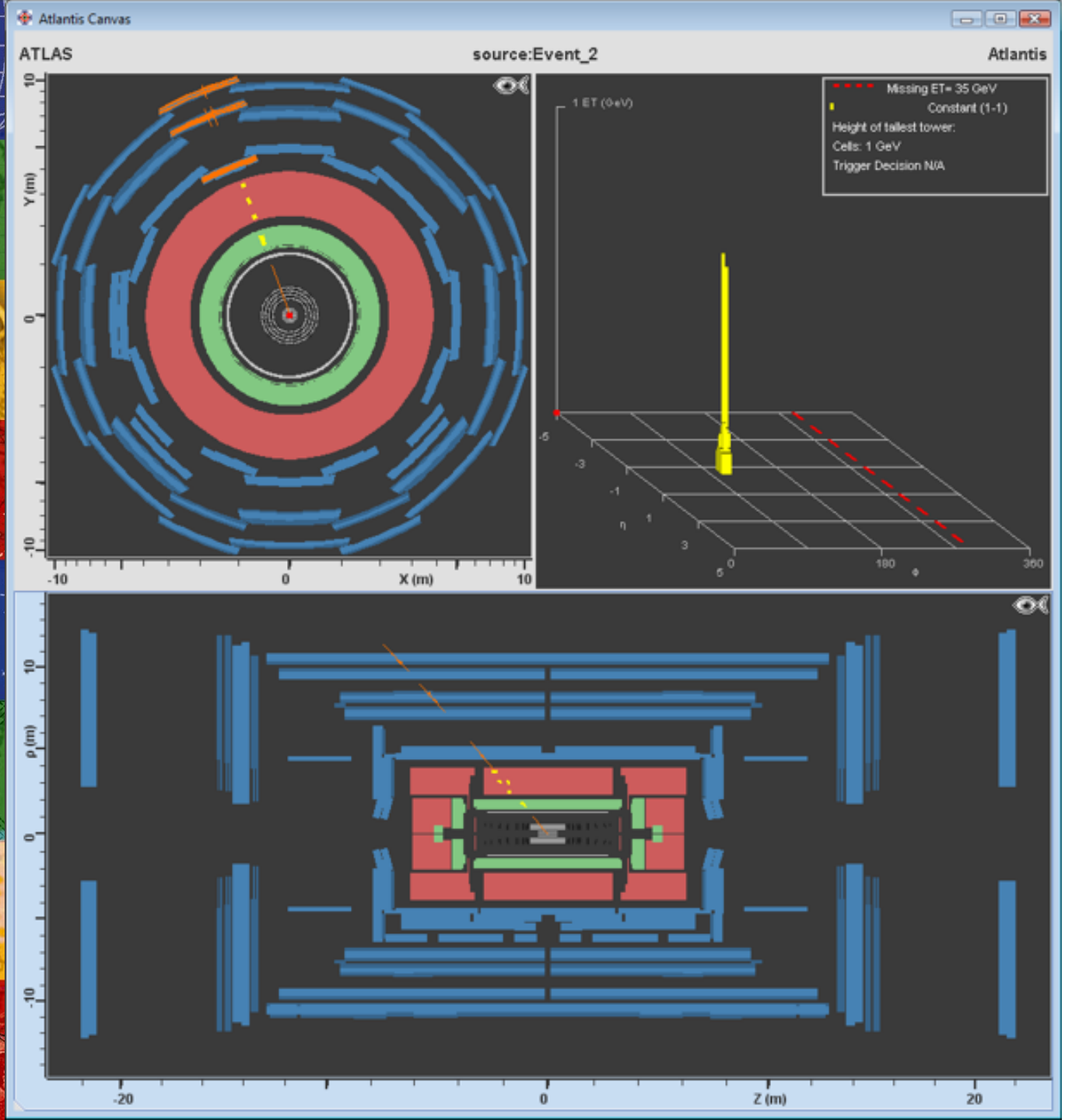
# How particles interact with detectors



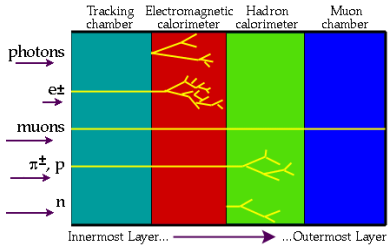
# Electron




Electron clusters in the EM calorimeter look like yellow “towers” over a green background

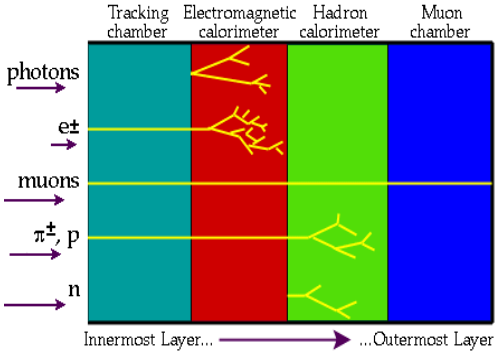



# Muon

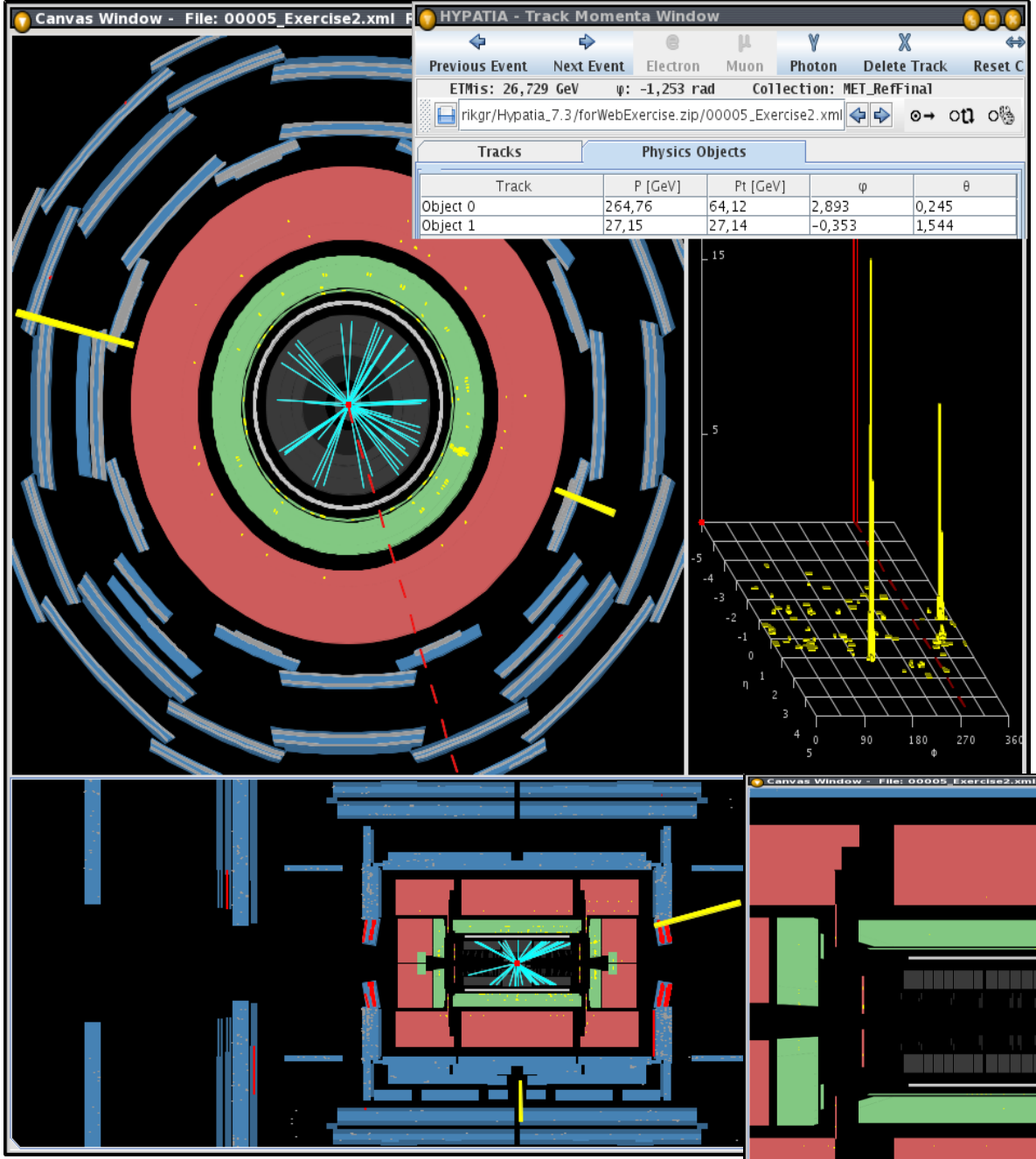



Muon chambers that are hit are colored orange

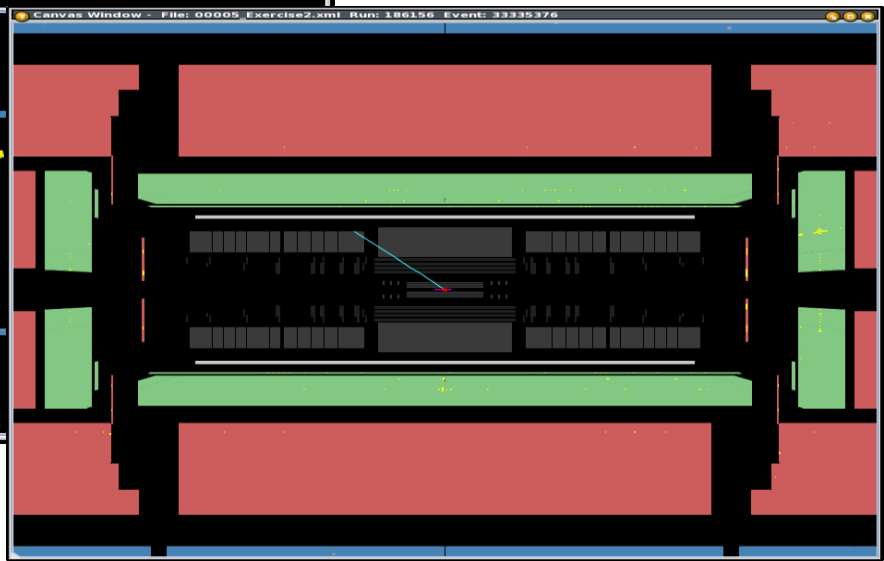
# Photon



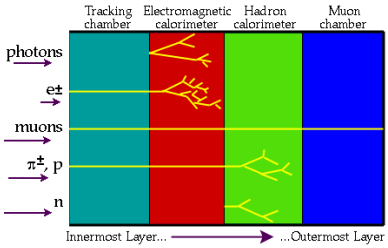

Electromagnetic calorimeter cells fired are marked in yellow



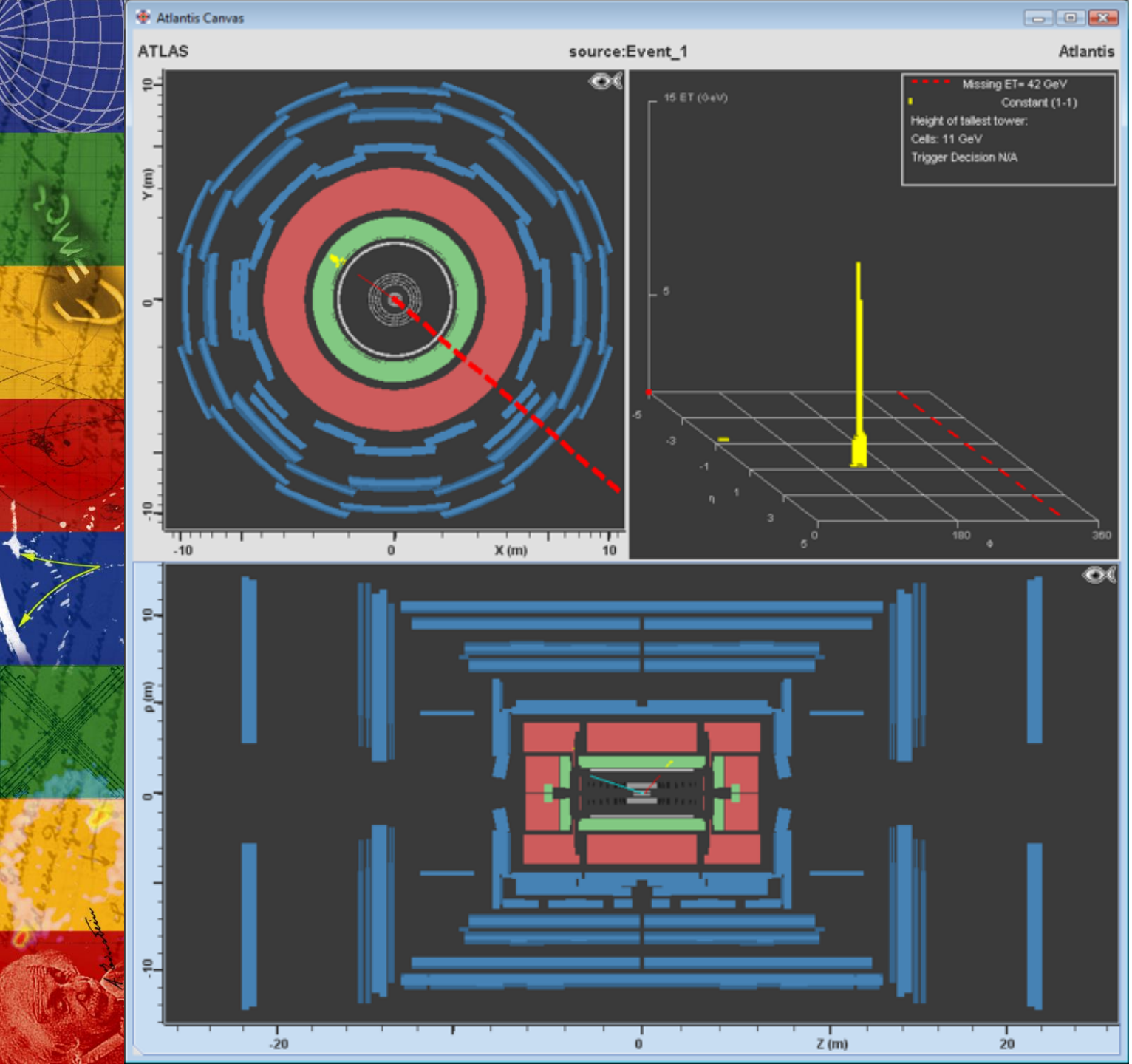


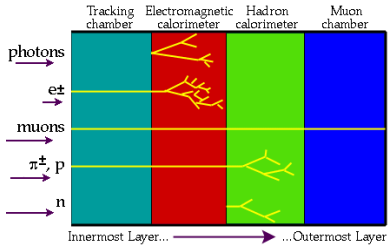
# Jets of hadrons




A bundle of several particles flying in one direction. It is the result of quark or gluons being ejected.




# Neutrino

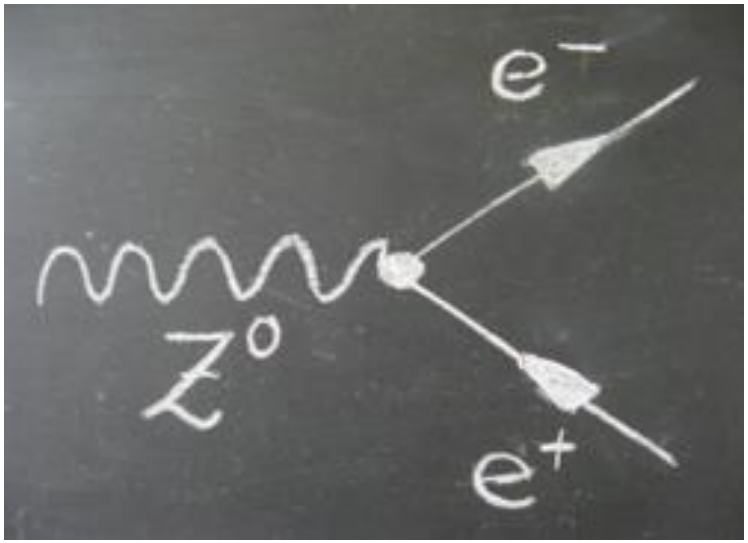


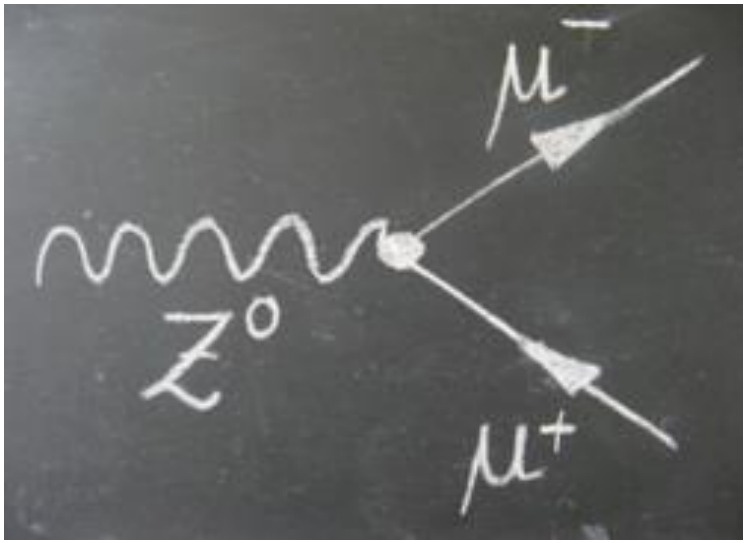

Neutrinos are not directly detected, but inferred from energy imbalance

Indicated by a dashed line, thicker line corresponds to larger missing energy

# The Z boson

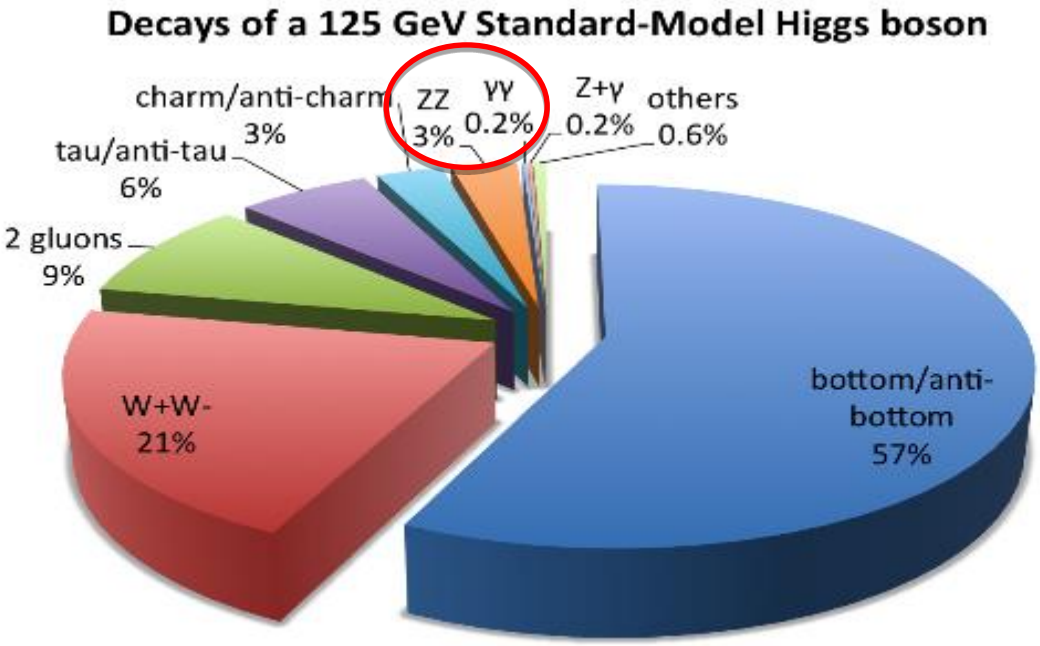
- Responsible for mediating the weak interaction (with the W boson)
- It is not a stable particle – lifetime $3 \times 10^{-25}$ (0.000000000000000000000003s) → no hope to measure the Z directly!
- Z bosons decay into a pair of fermion and anti-fermion

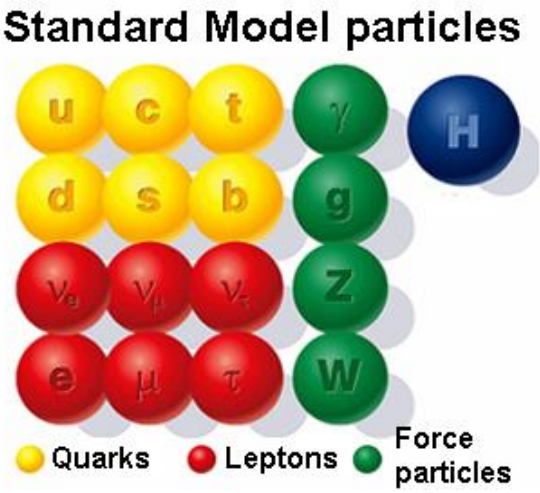


# The Higgs Boson

- Responsible for the mass of all particles
- It is not a stable particle – lifetime $1.5 \times 10^{-22}$ (0.000000000000000000000015s) → no hope to measure H directly!
- H bosons decay either into:
  - a pair of fermion and anti-fermion
  - a pair of gauge bosons ($W^+W^-$, ZZ, gg, γγ)



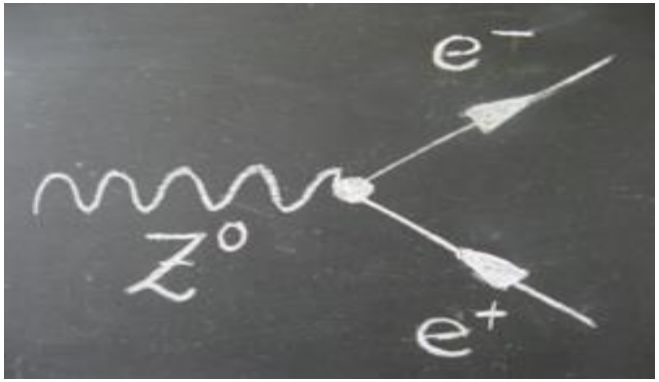



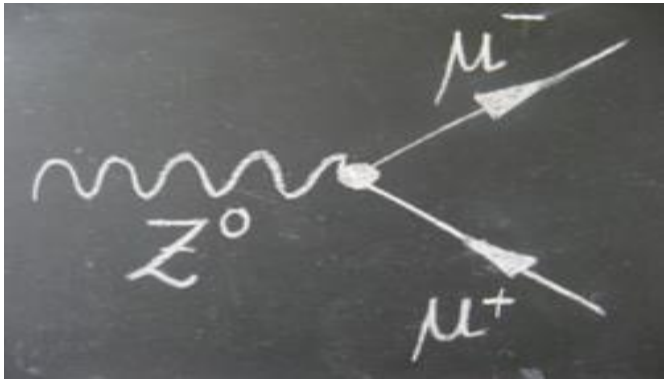

**Today we are interested only in two decays: ZZ (and γγ, if you want)**

# Signals summary

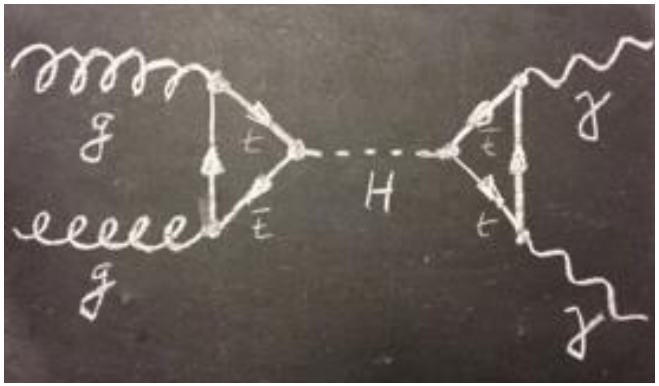


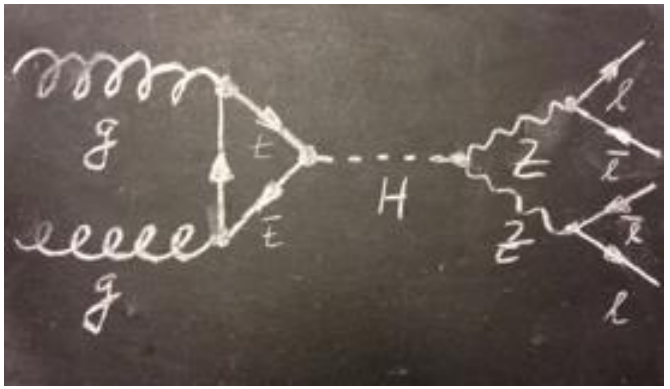
Z boson – electrically neutral mediator of the weak force



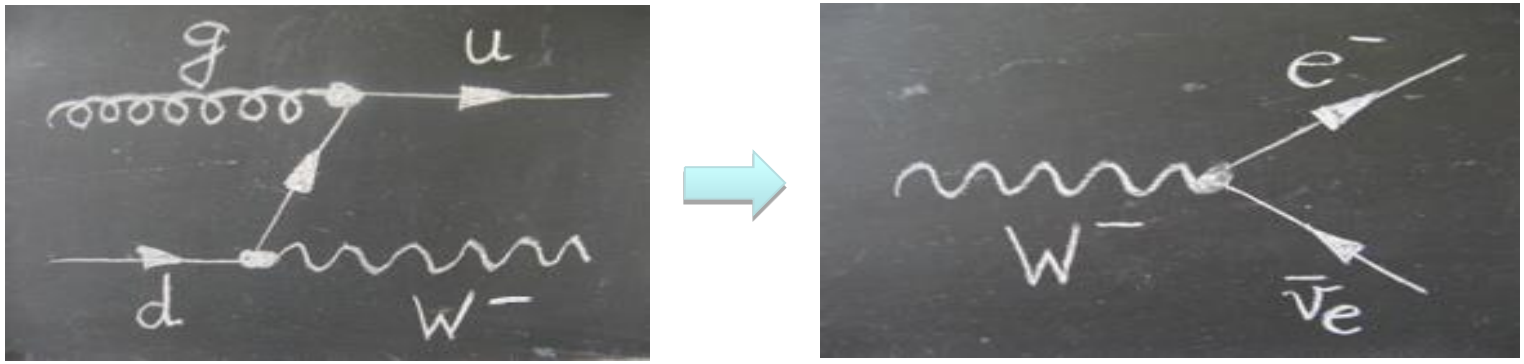

H boson – electrically neutral responsible of the mass of all elementary particles



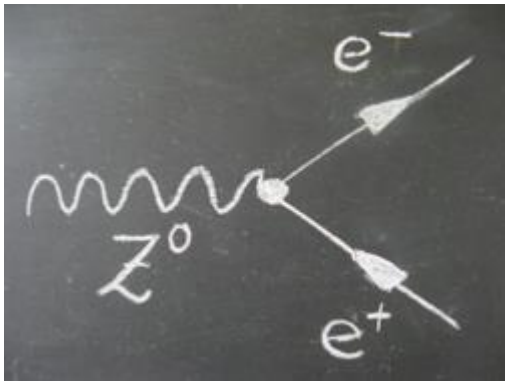



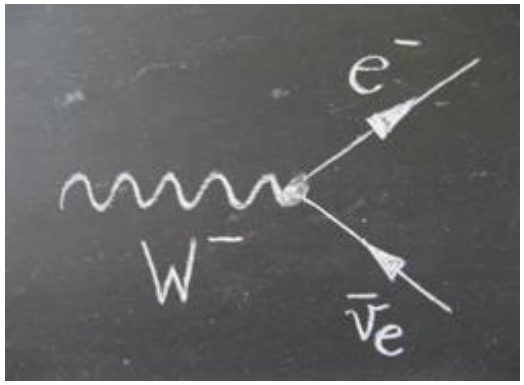
# Background (fondo) events

- In any pp collision, a lot of particles are produced! Not only Z and H…
- But we reconstruct Z and H (signals) based on their decay products: muons, electrons and photons
- All other physics processes producing muons, electrons and photons are called background events




- How can we distinguish background events from signal events?
- By looking at ALL particles we want in the final state!




Are they the same??

# And now

# Break!