



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

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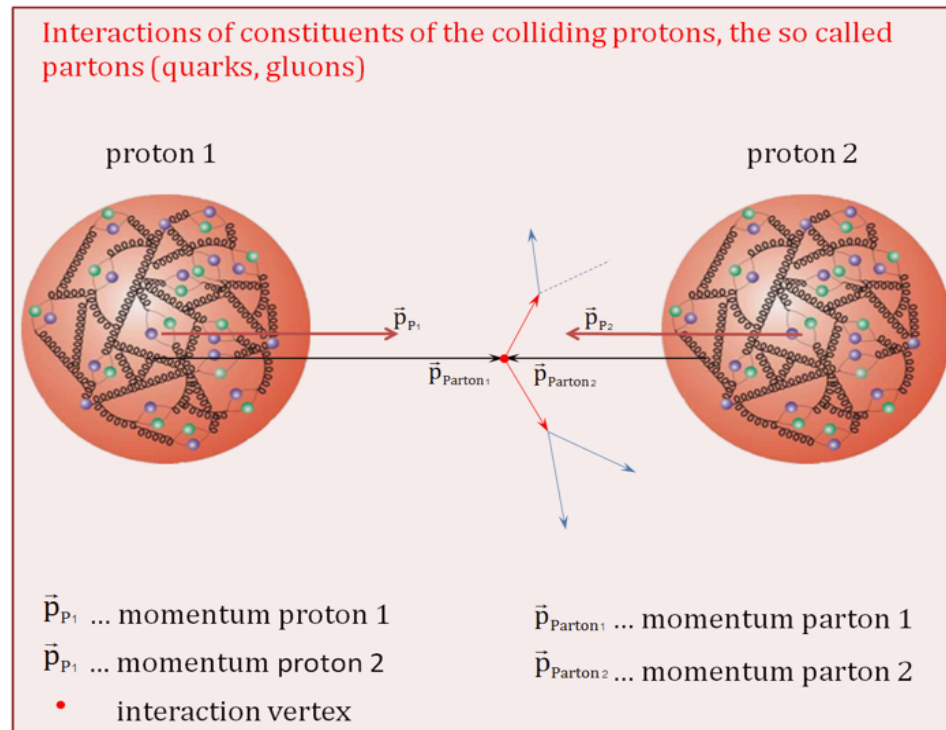
Outline

- **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. $pp \rightarrow pp$)

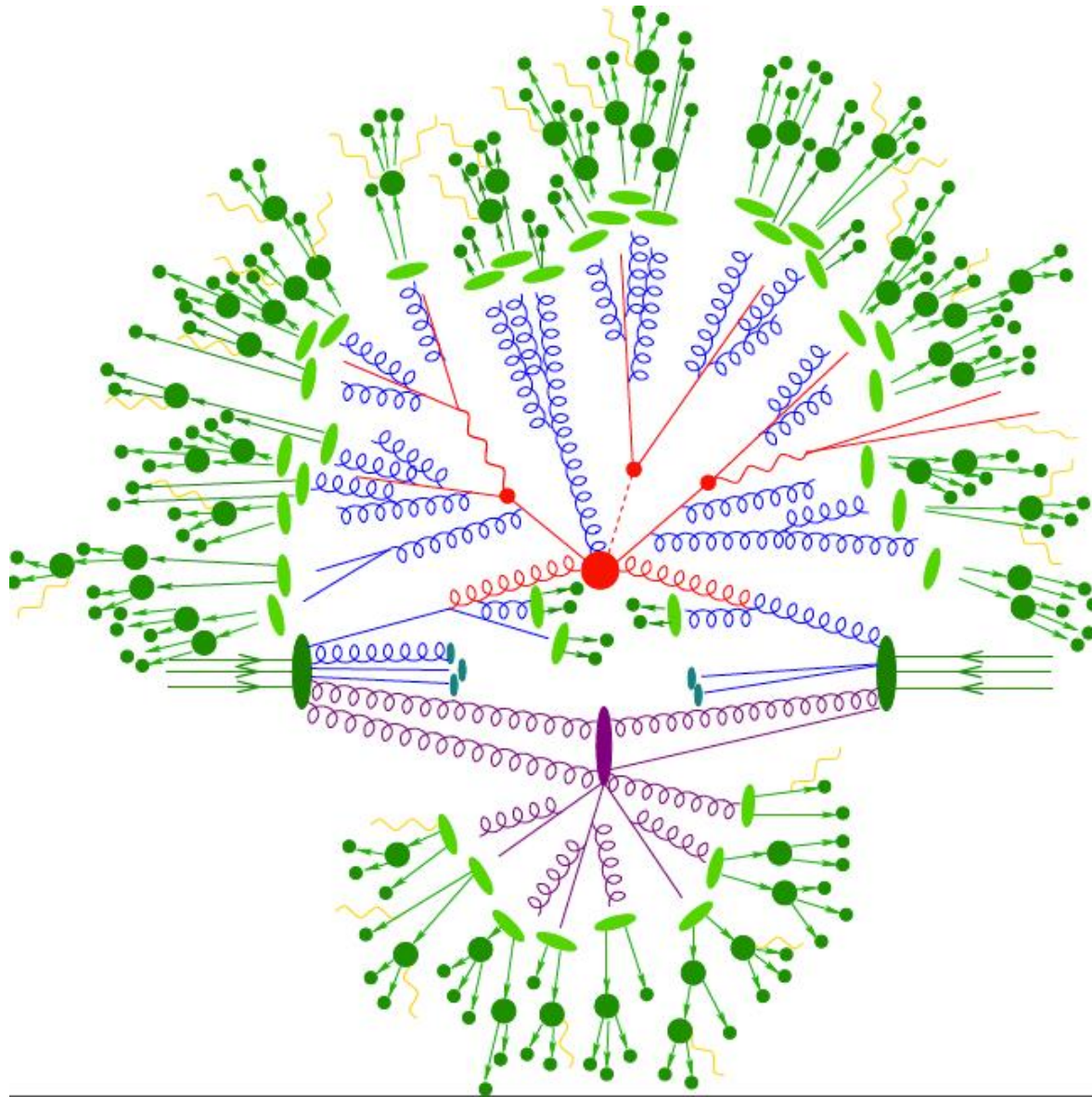


Protons collide with protons at high speed:

lots of energy ($E_1 + E_2 = mc^2$) which can be used to create **new particles**

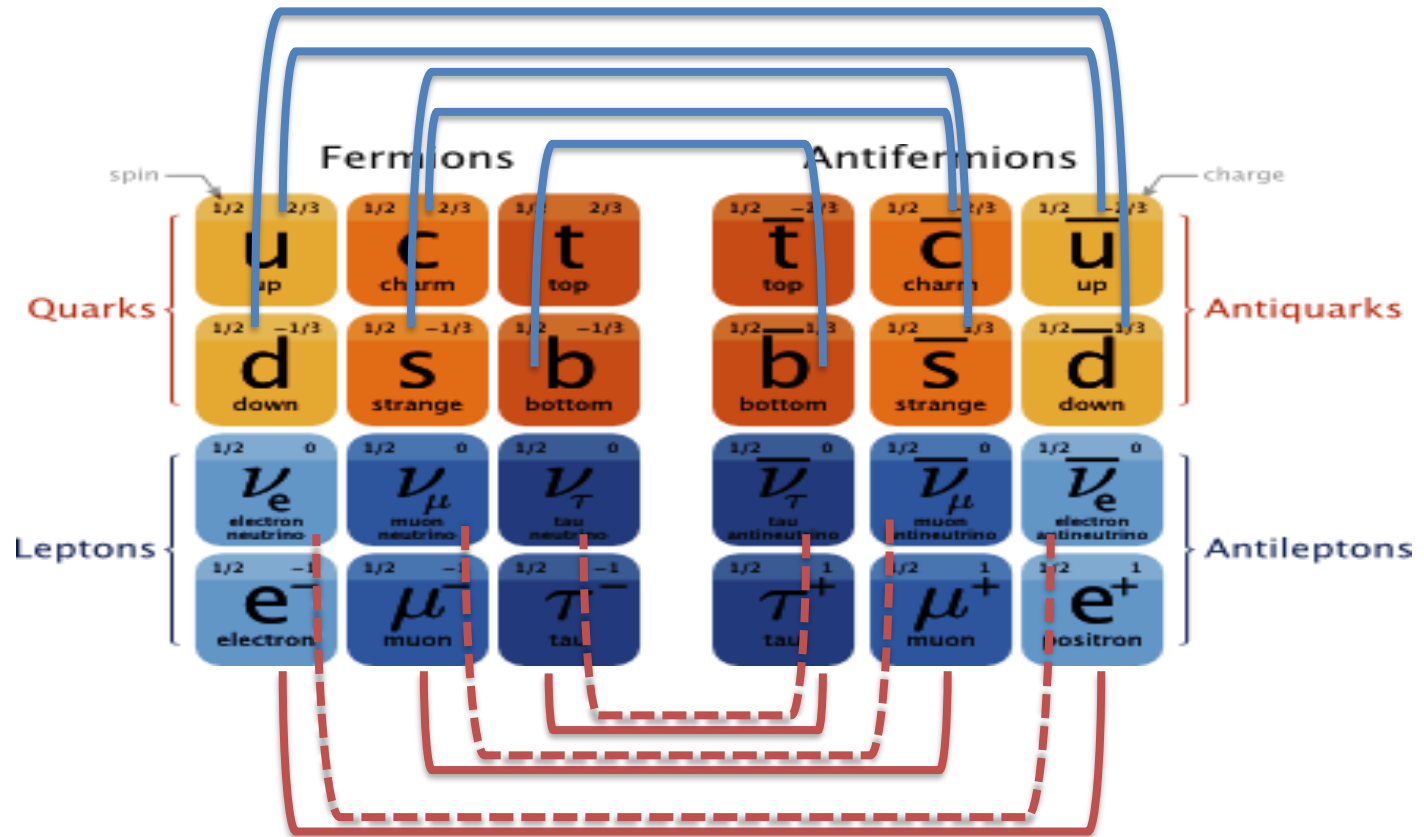
Sometimes a **Z boson** ($m = 91.2 \text{ GeV}/c^2$) or a **Higgs boson** ($m = 125.1 \text{ GeV}/c^2$) is created

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 3×10^{-25} (0.0000000000000000000000003s) → no hope to measure the Z directly!
- Z bosons decay into a pair of fermion and anti-fermion



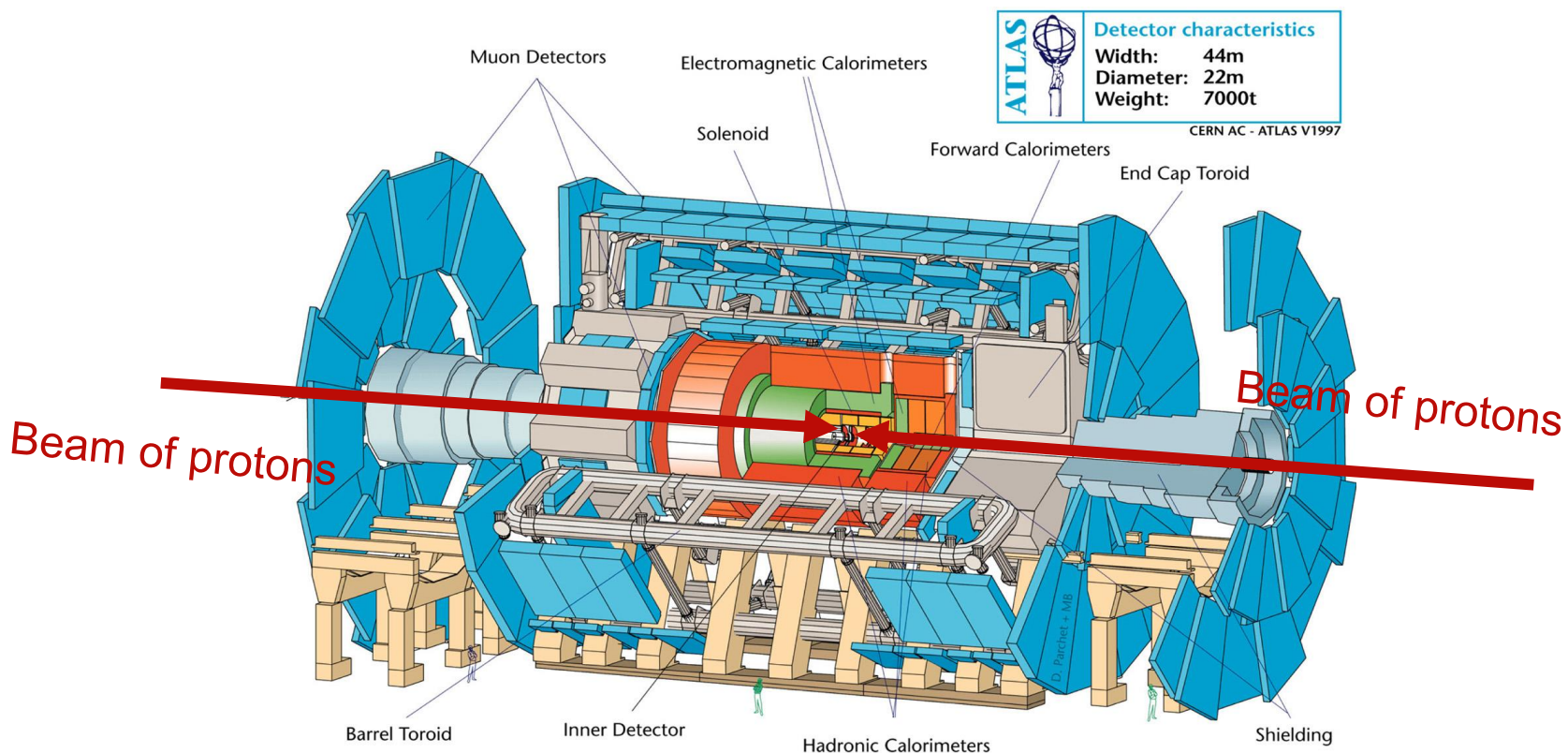
The Z boson

- 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 electron-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
- Neutrinos 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

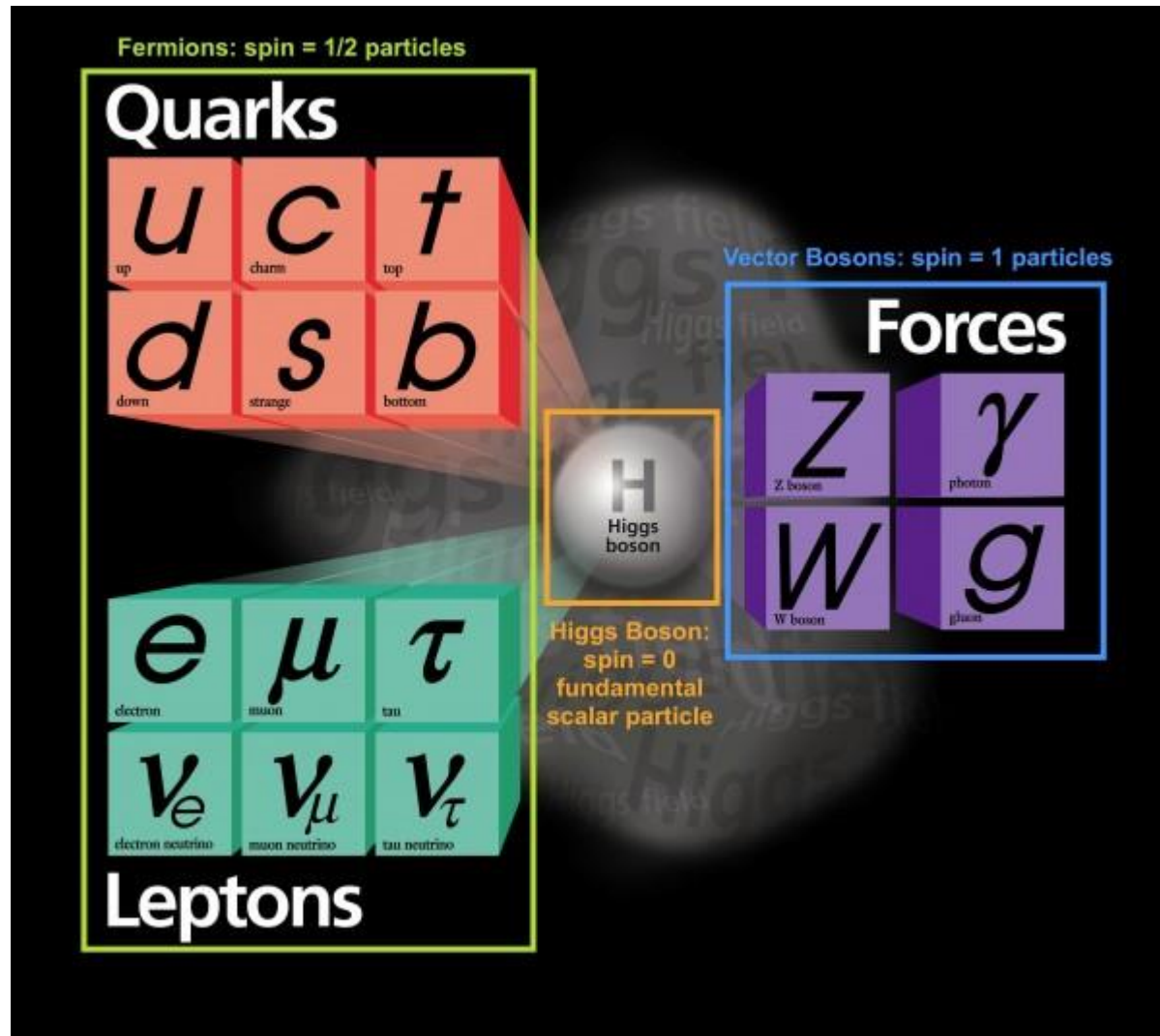
ATLAS

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

Different types of particles leave different signals in the various detectors

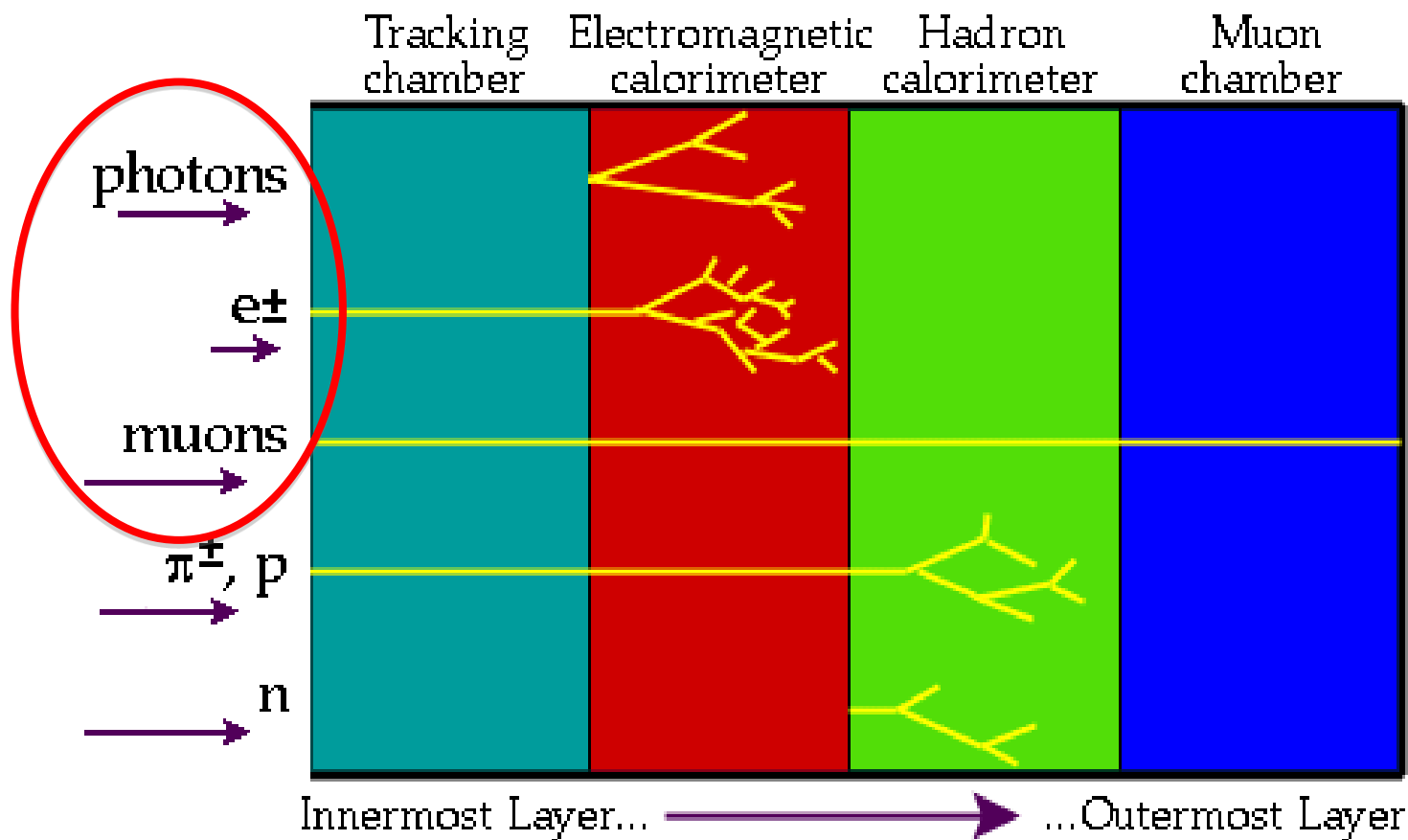


Reminder: the Standard Model



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

How particles interact with detectors



The Inner Detector (tracking detector)

10

- detects electrically charged particles traversing the detector

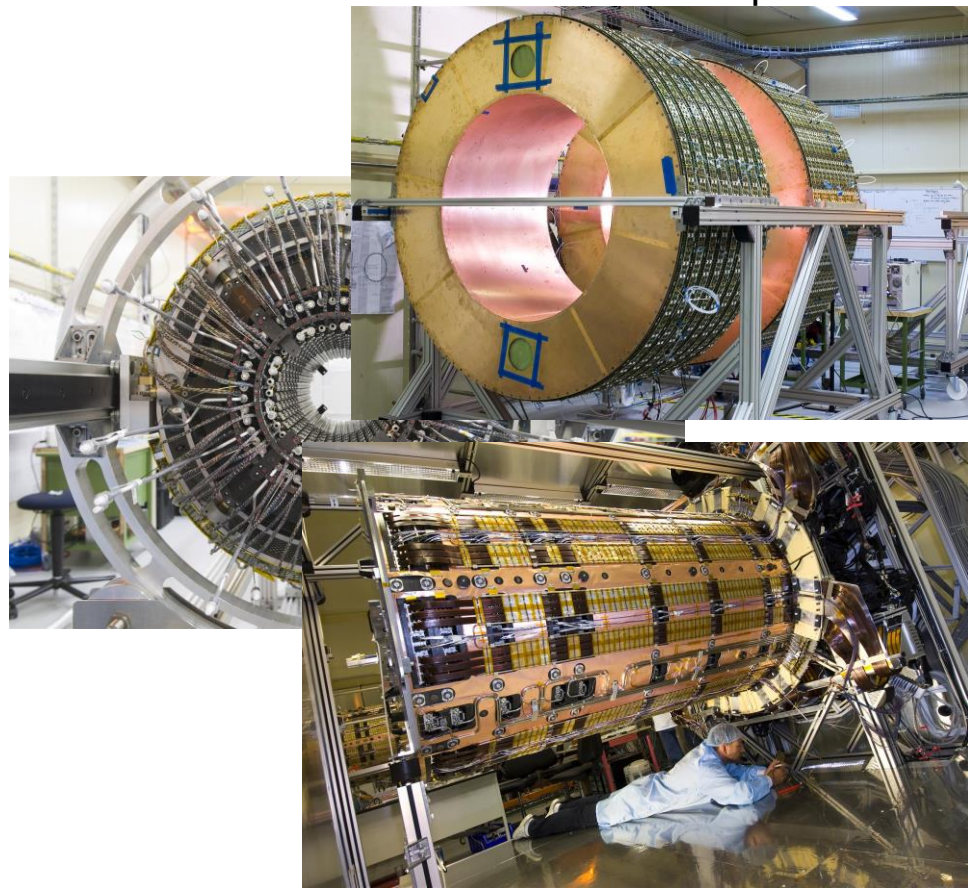
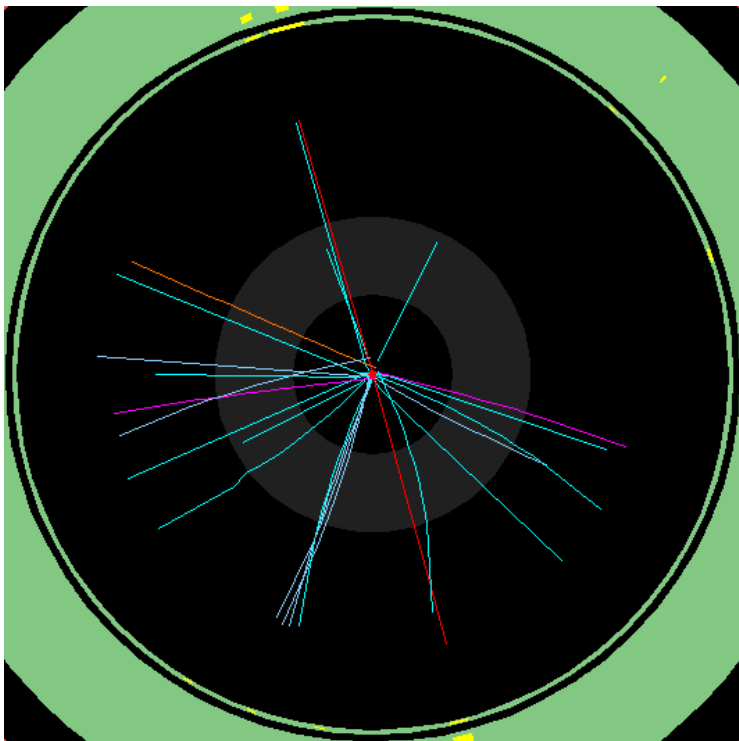
- electrons, muons, protons, quarks (jets) ...

- it is not sensitive to electrically neutral particles

- photons, neutrons, neutrinos...

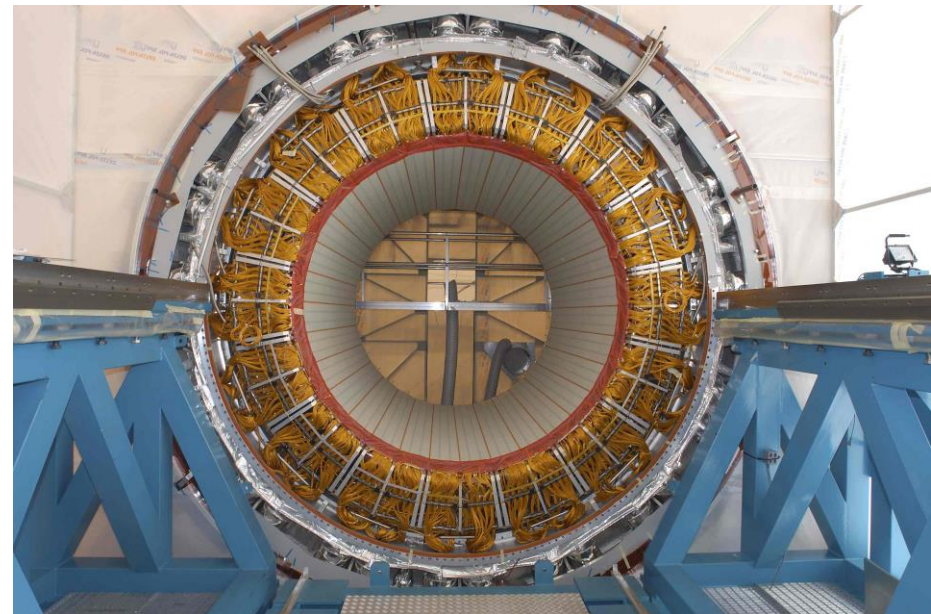
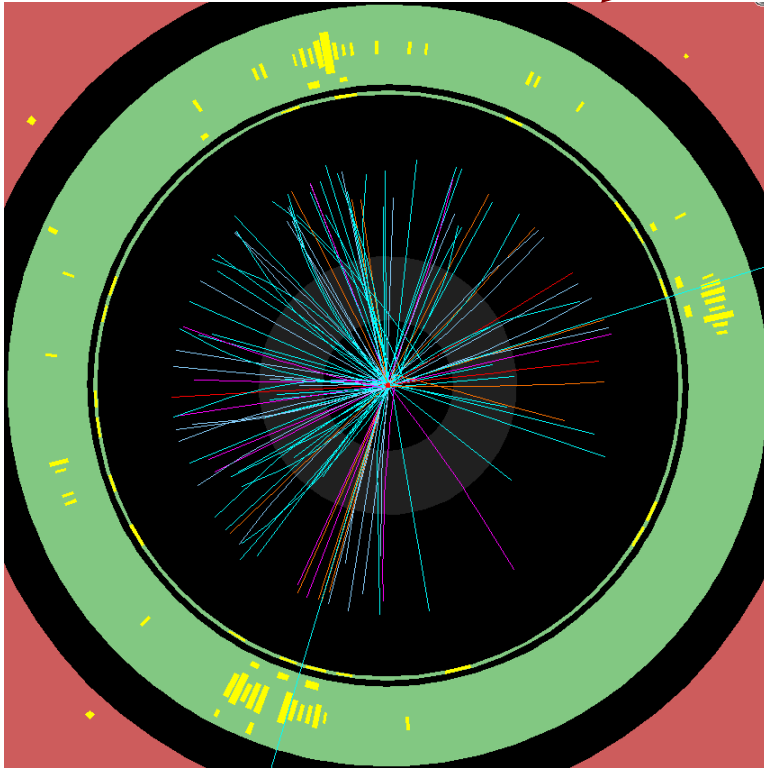
- the whole detector "swims" in a magnetic field, that deflects charged particles' trajectories

- Amount of deflection depends on mass and speed



Electromagnetic calorimeter (ECAL)

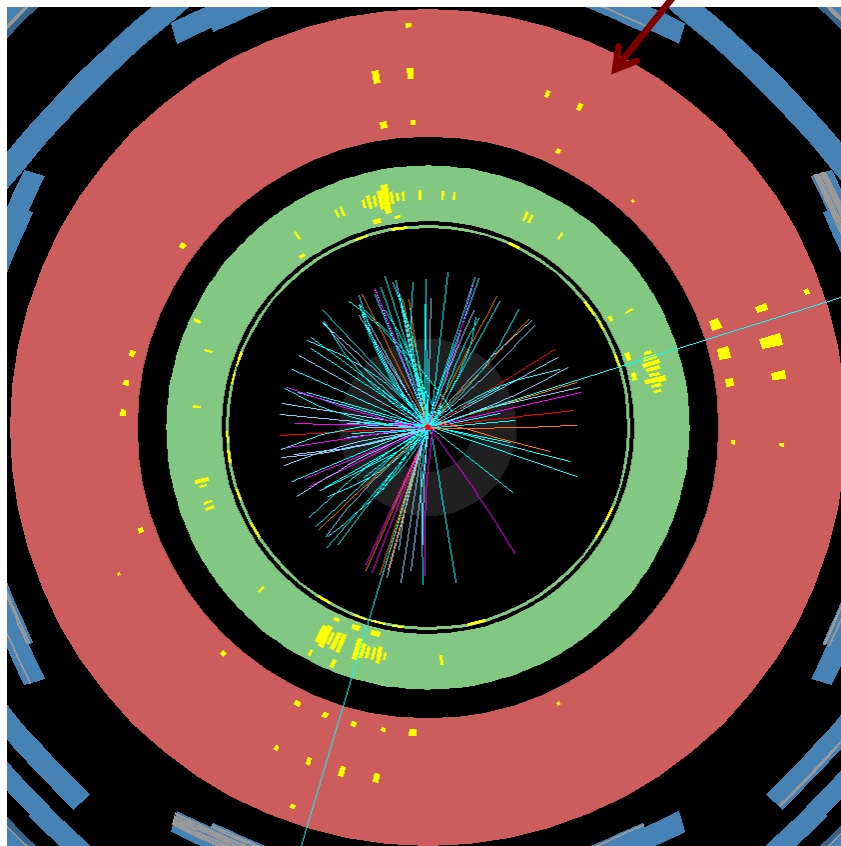
- detects all particles interacting electromagnetically
 - such as electron, positron, photon, ...
 - these particles deposit energy in the ECAL and this energy is measured





Hadronic calorimeter (HCAL)

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

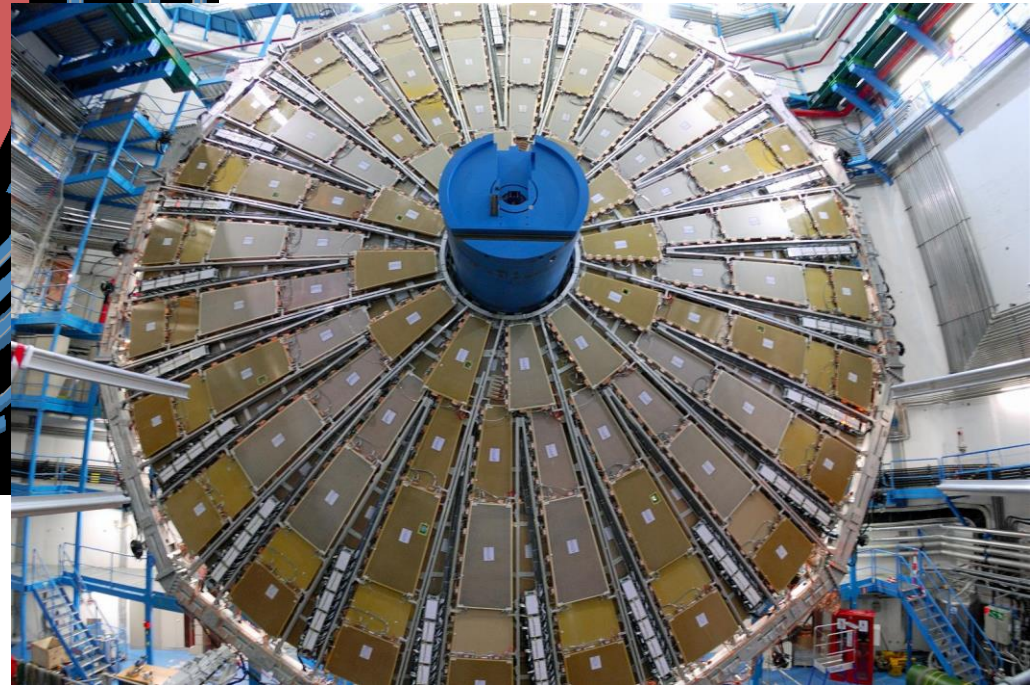
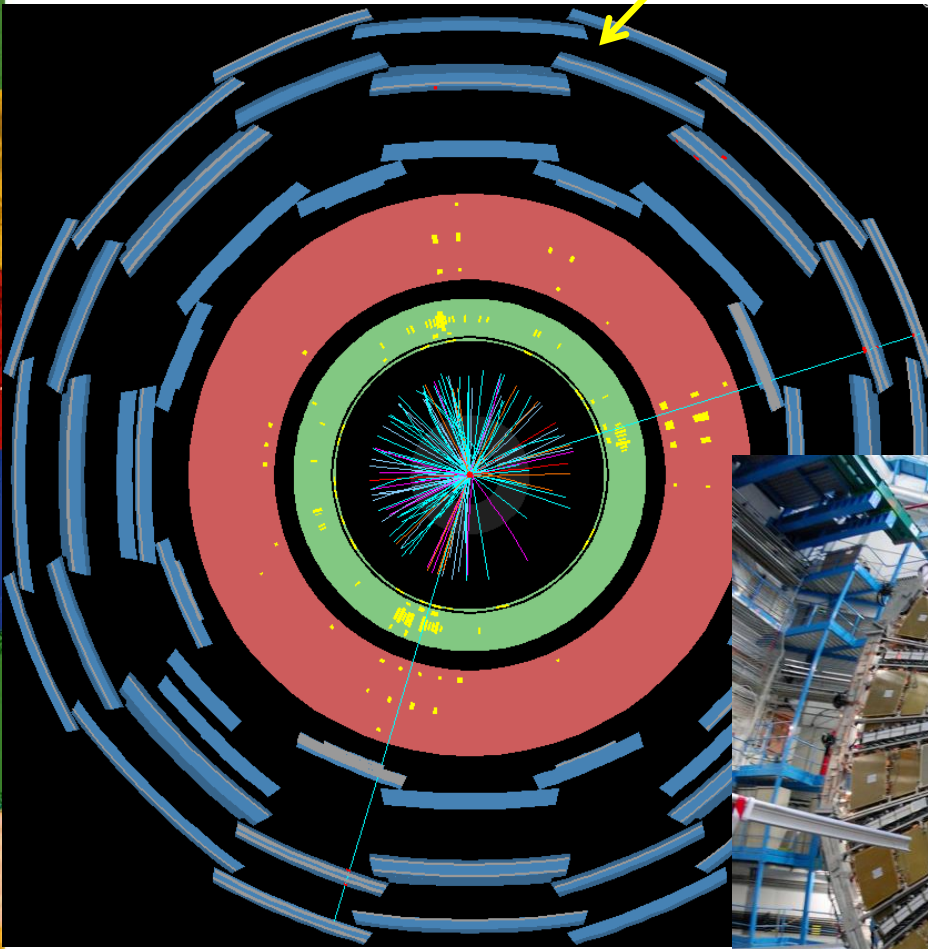


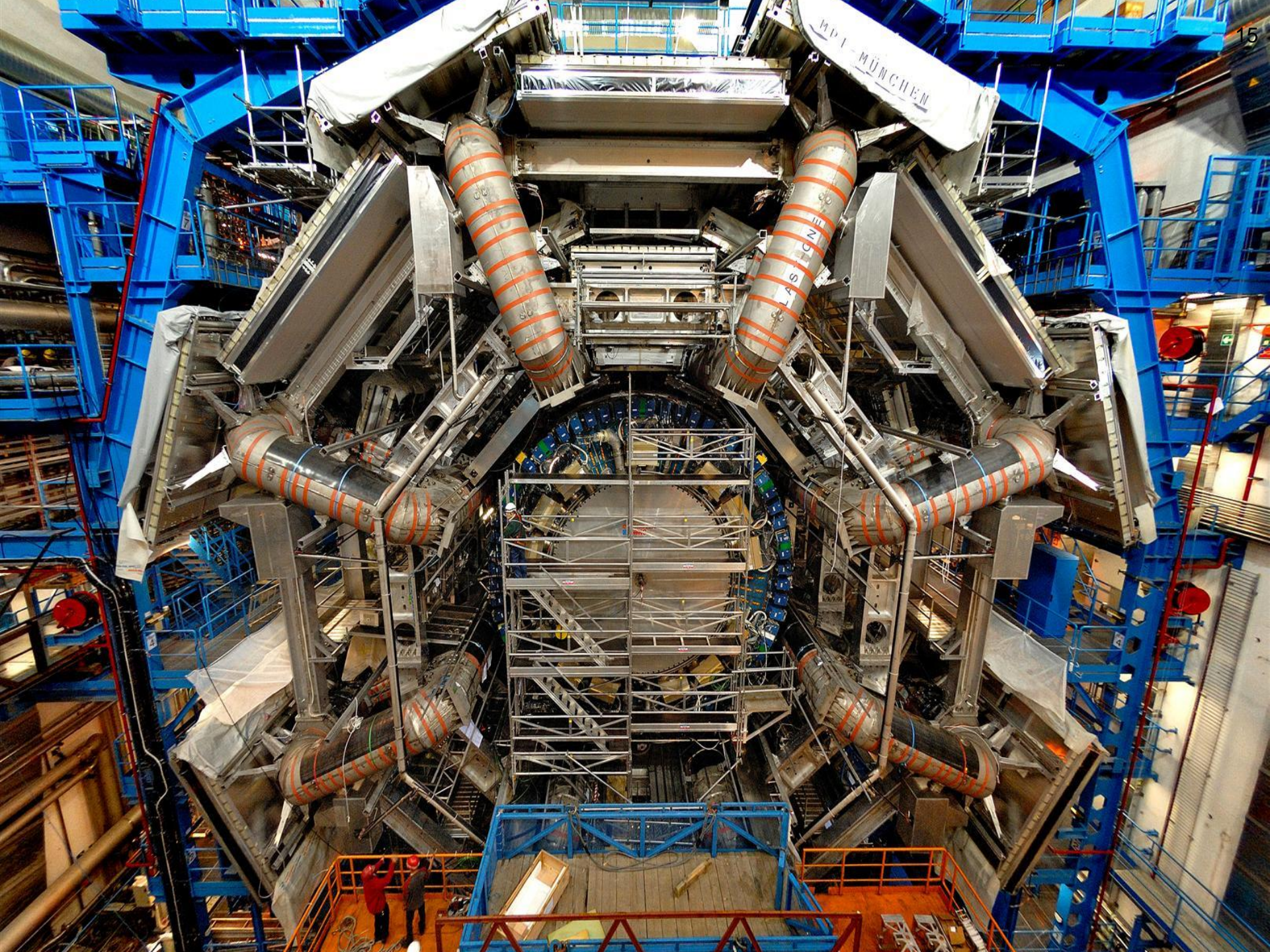
Muon spectrometer (MS)

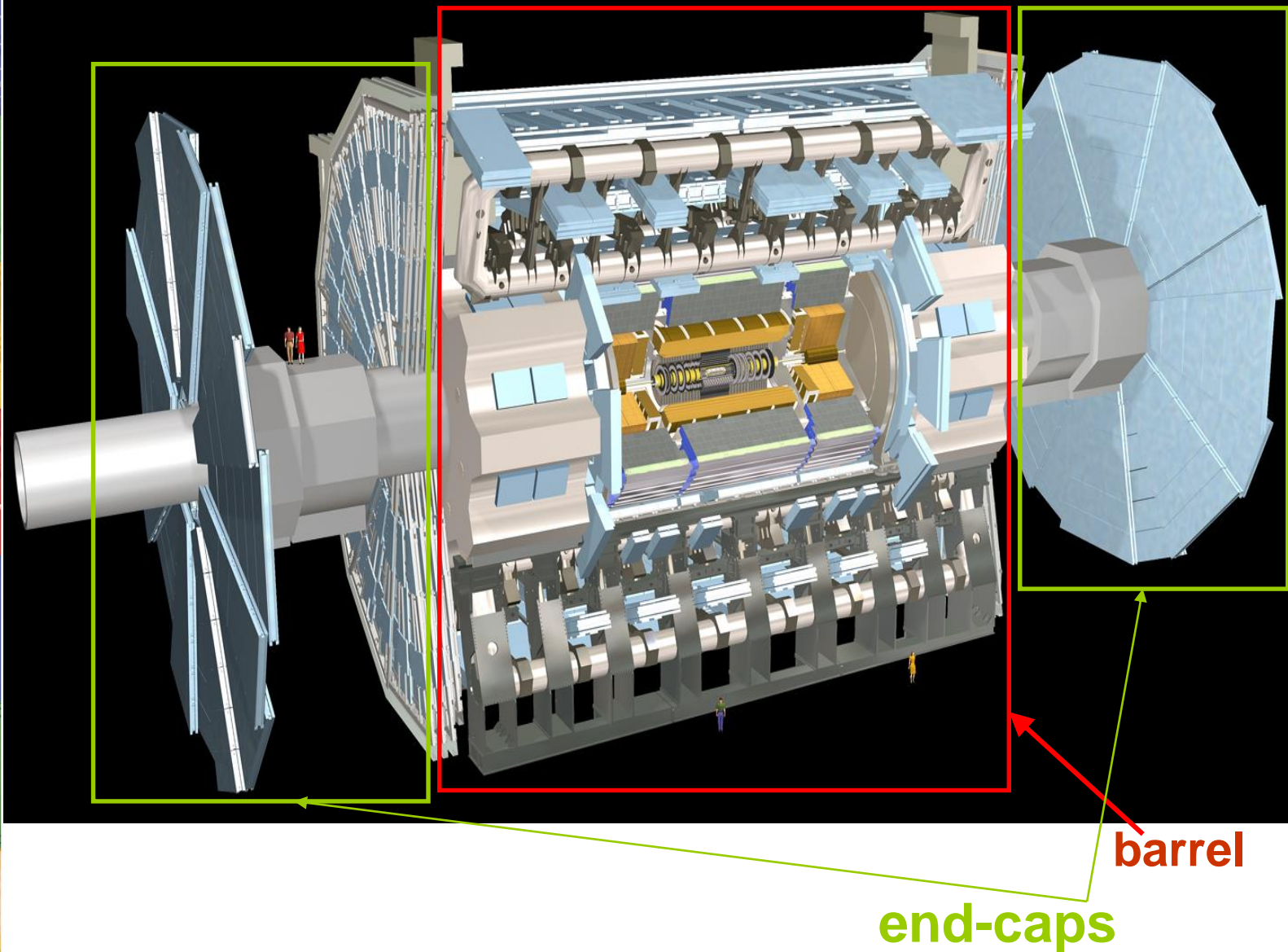
■ is the outermost part of the detector

■ detects muons

■ a strong magnetic field deflects the muon's trajectory allowing a measure of the momentum

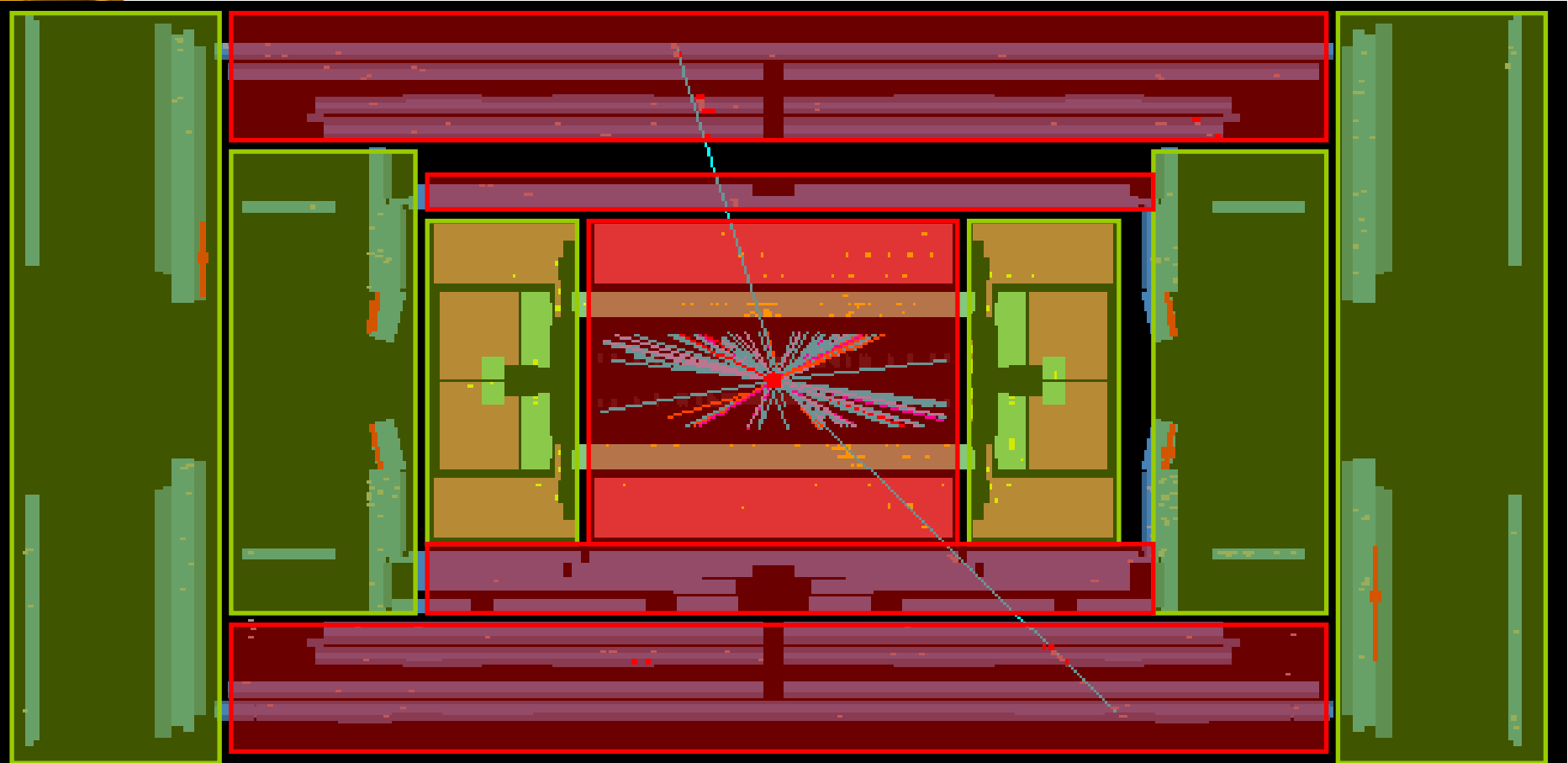






■ In order to detect as many particles as possible after each collision, the detector is built such that it covers nearly the full solid angle

Endcap barrel

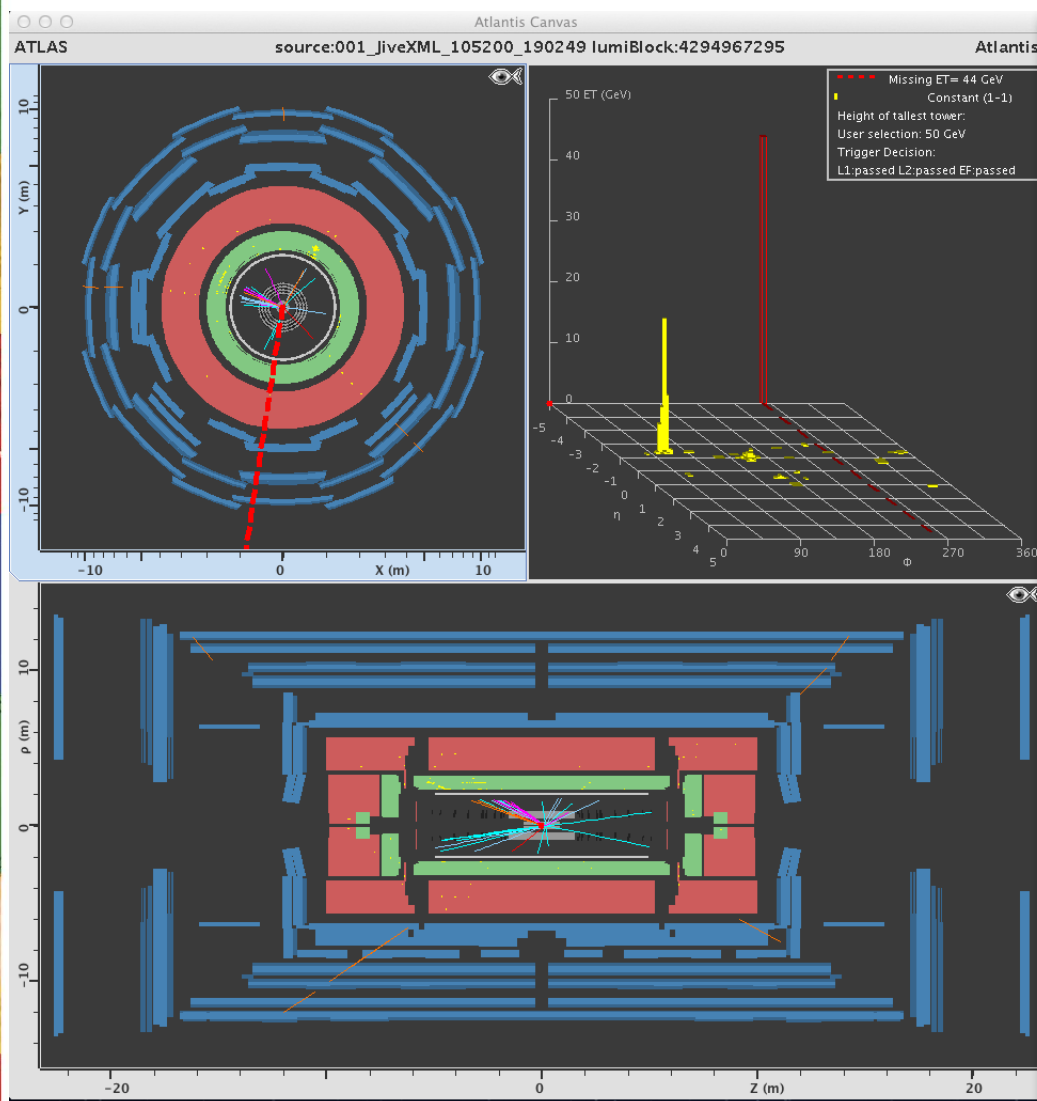


You will:

- **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

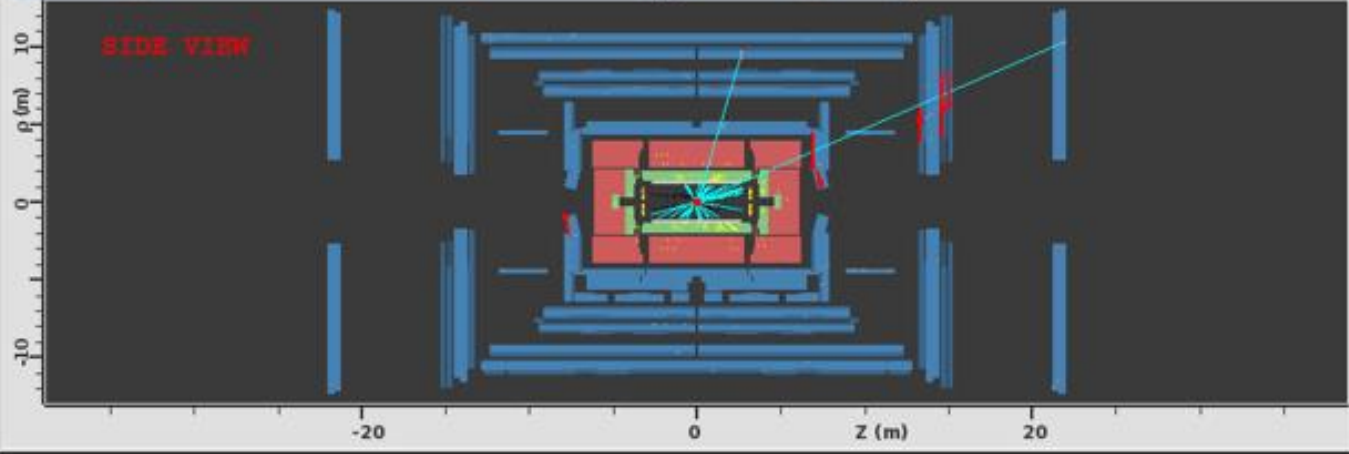
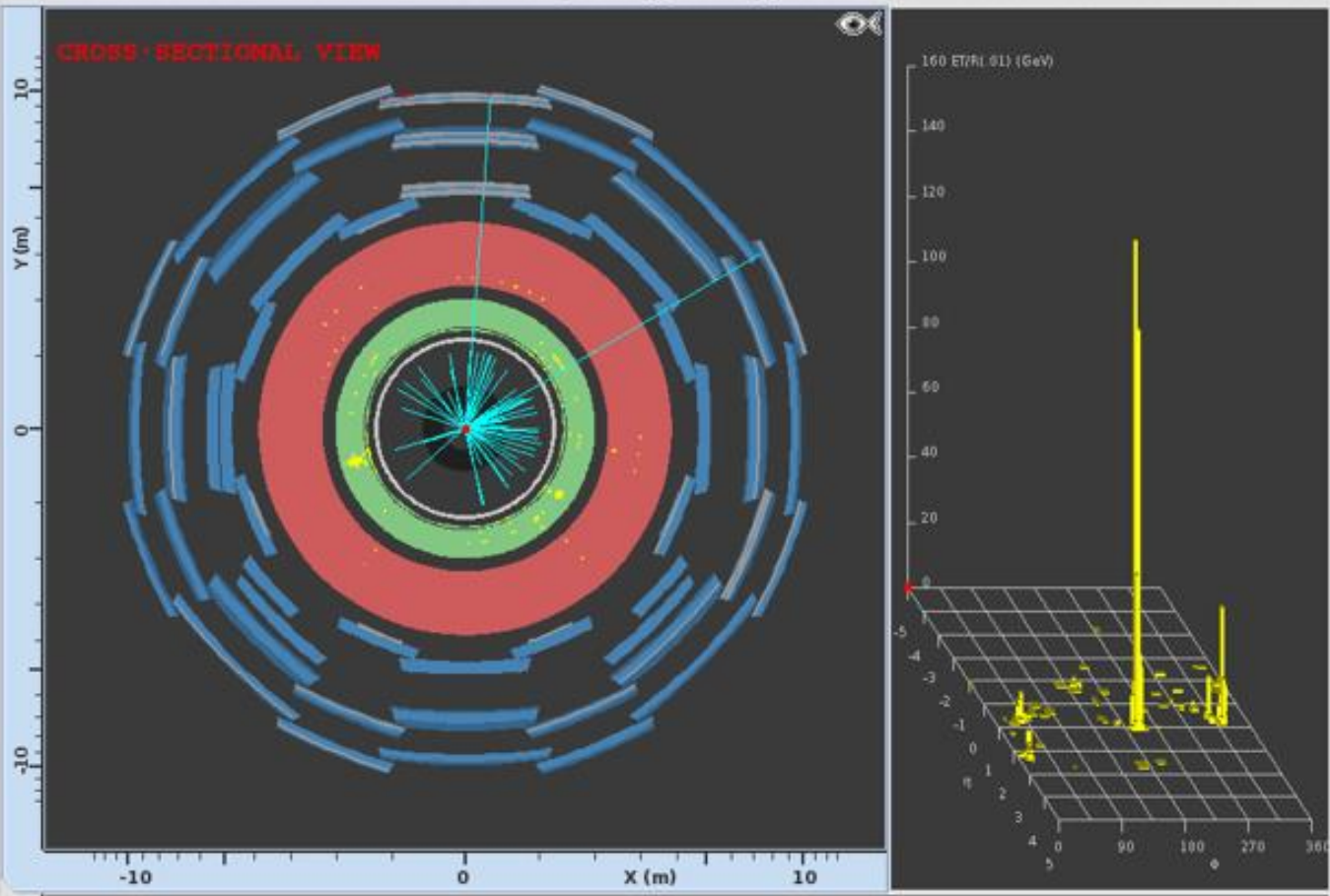


The Atlantis GUI Control Window shows the following components:

- File Preferences Lists:** Includes options like "Reset Demo Previous Next Help" and a file path "events/test_events.zip".
- Projection Data Cuts InDet Calo MuonDet Objects Geometry:** A set of tabs for different detector components.
- Track Segment SpacePoint PixelCluster SCT_Cluster TrigSISpacePoint PixelRDO SiClusterRDO TRT DriftCircle RecVertex Hit Filter:** A list of track-related objects.
- Zoom Next Track:** A button to zoom into the next track.
- Track Collections:** A table with columns "Name" and "Value".

Name	Value
Tracks	25
- Constant Color:** A dropdown menu showing a cyan color and the value 25.
- Welcome to Atlantis !** A message box.
- 001_JiveXML_105200_190249.xml (10520000190249)** A file path.

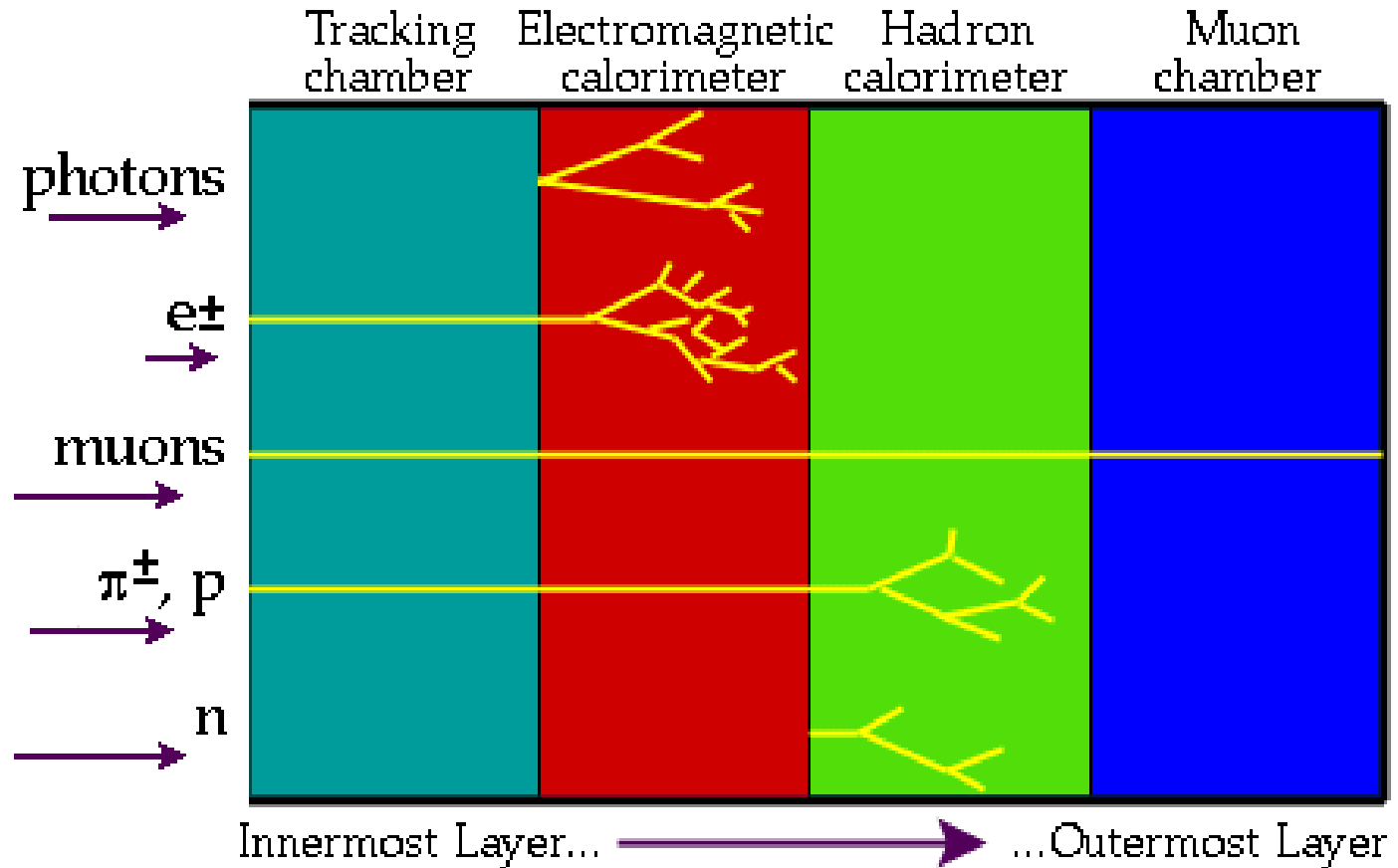
Track Momentum Window

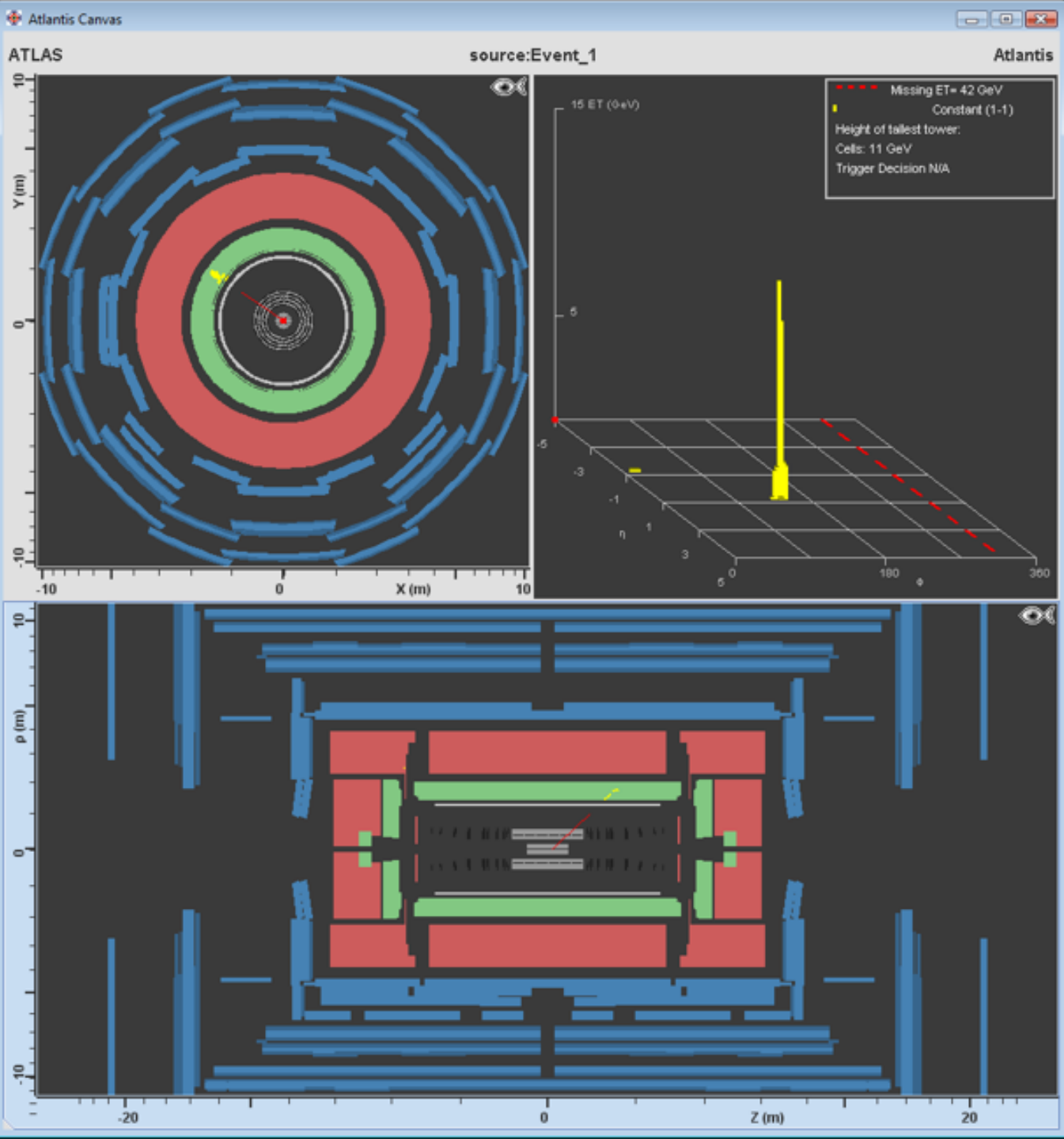


Detector views

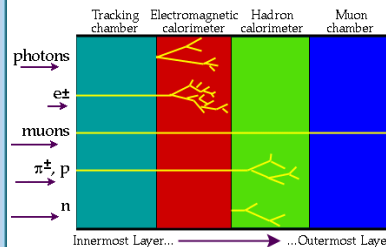
Four sub-detector types, depicted in different colors

How particles interact with detectors



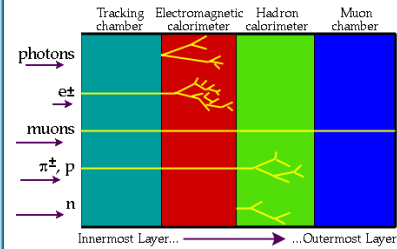


Electron

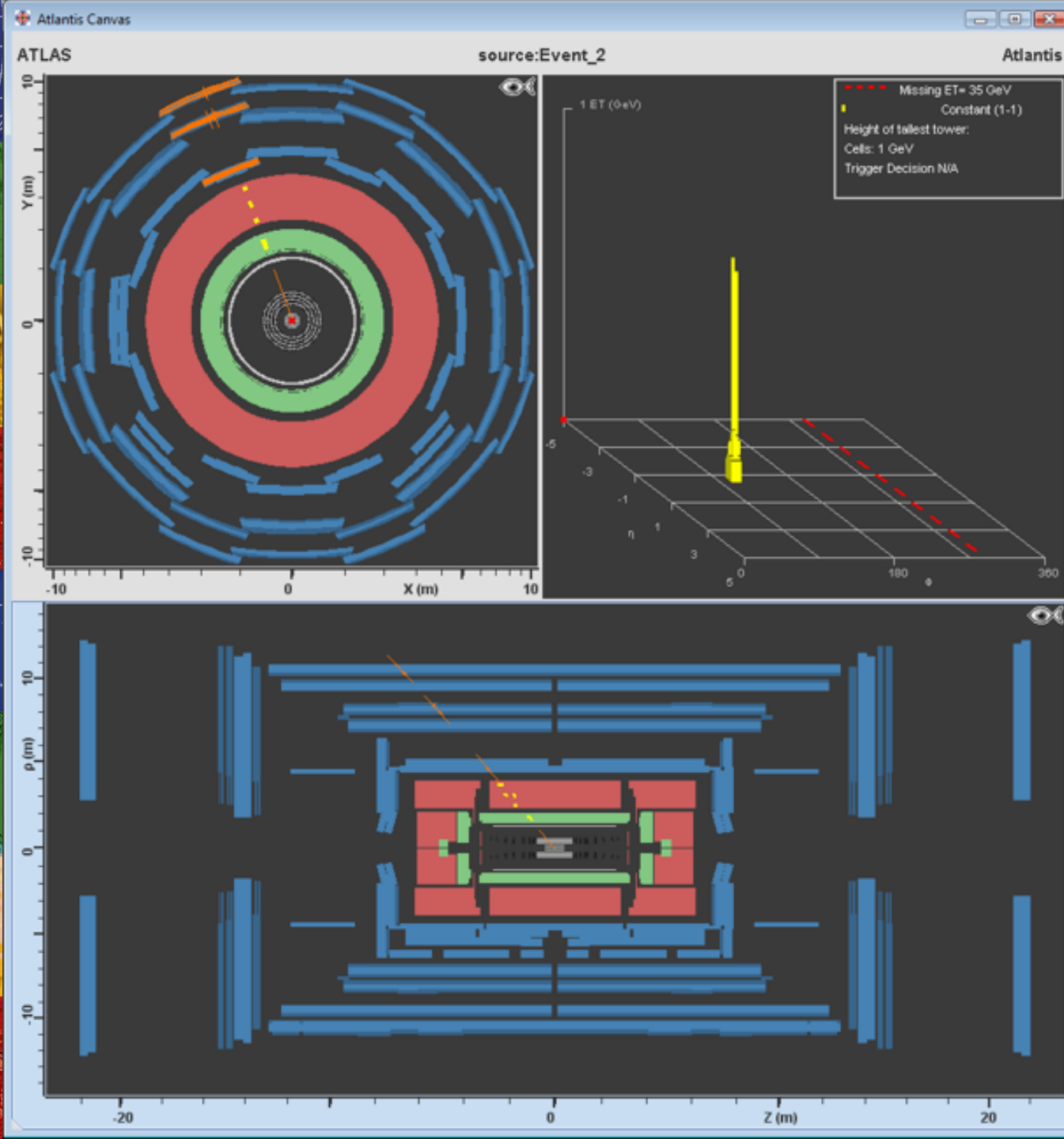


Electron clusters in the EM calorimeter look like yellow “towers” over a green background

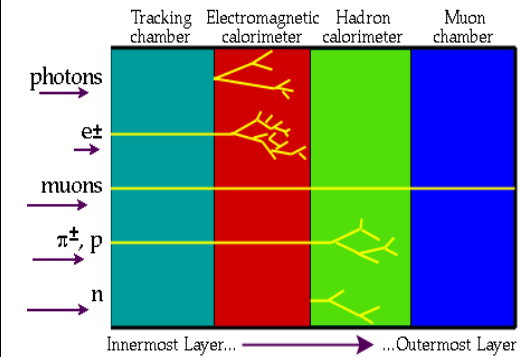
Muon



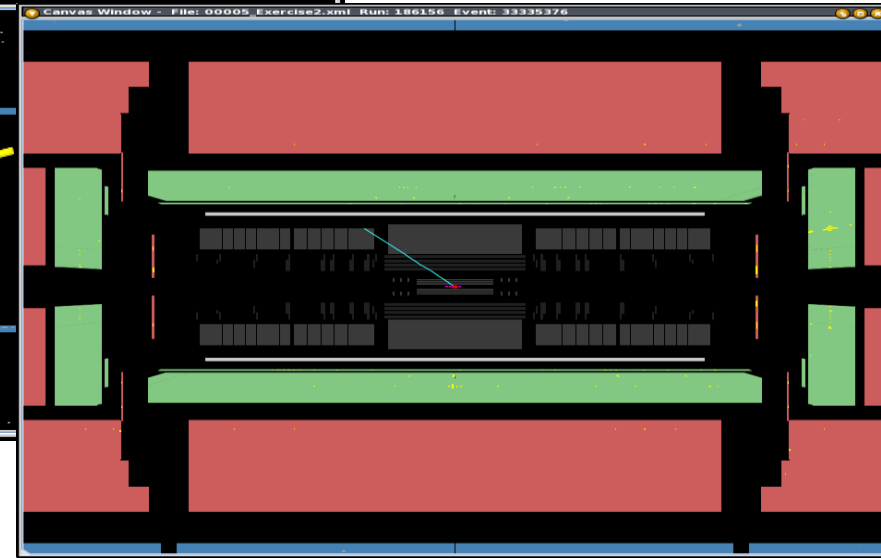
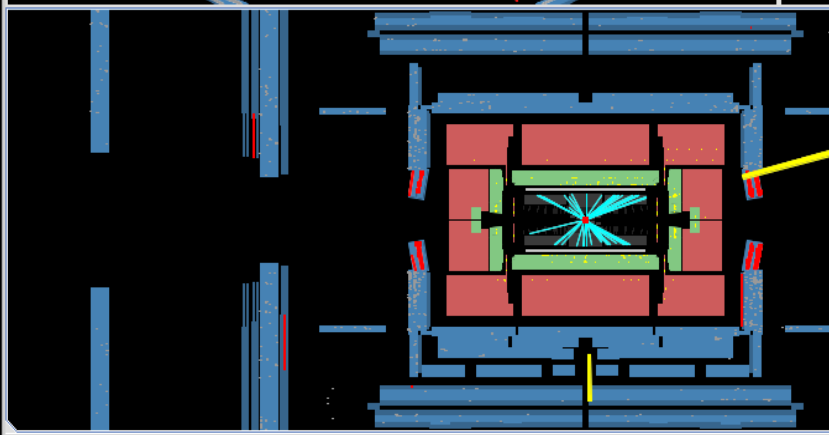
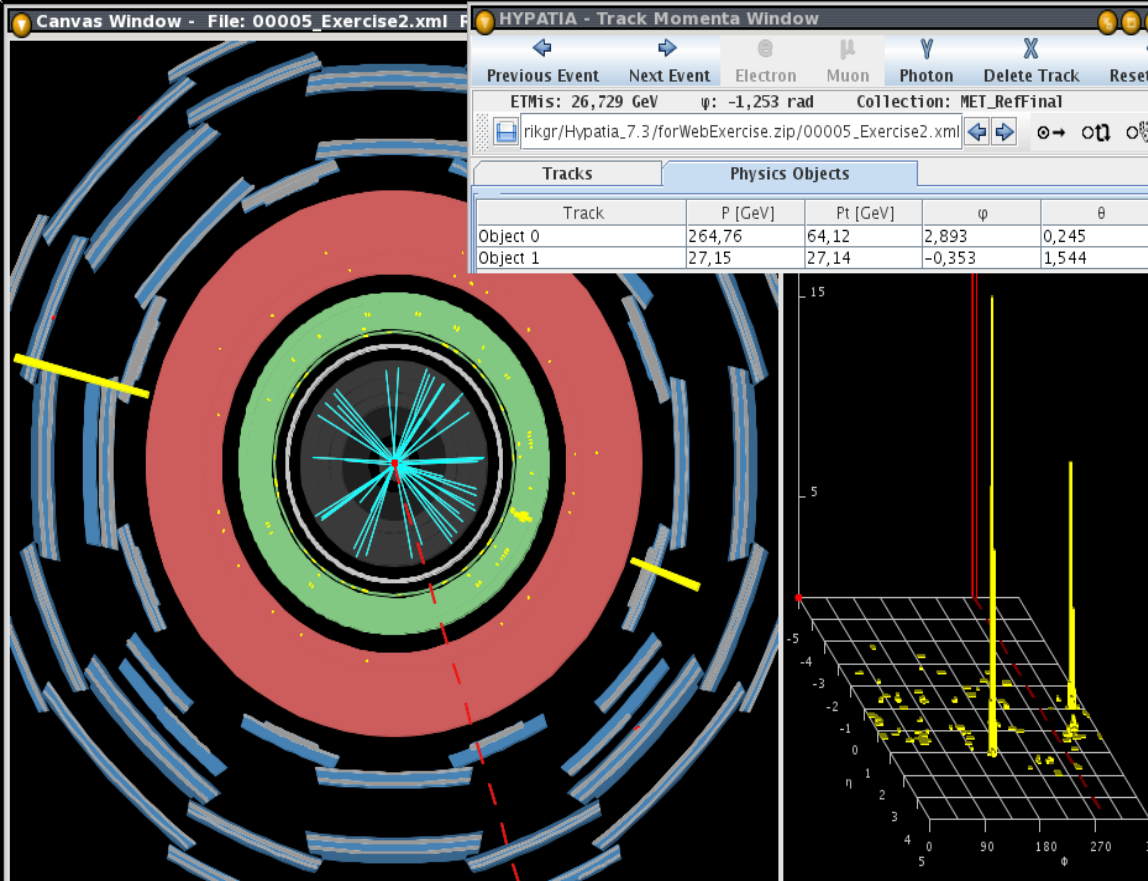
Muon chambers that are hit are colored orange

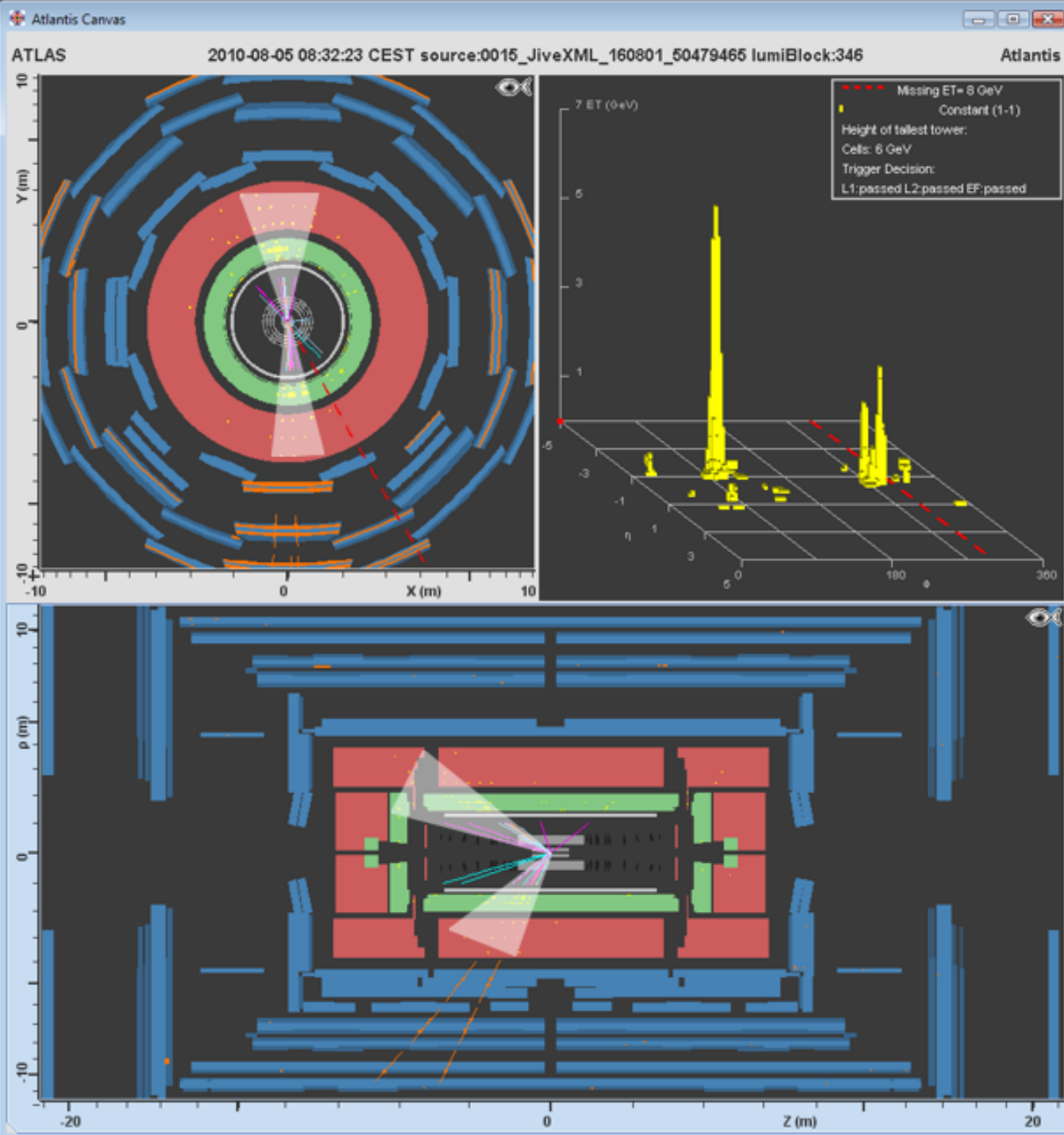


Photon

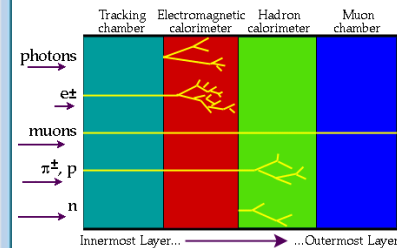


Electromagnetic
calorimeter cells
fired are
marked in yellow



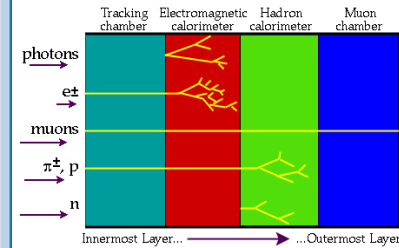


Jets of hadrons



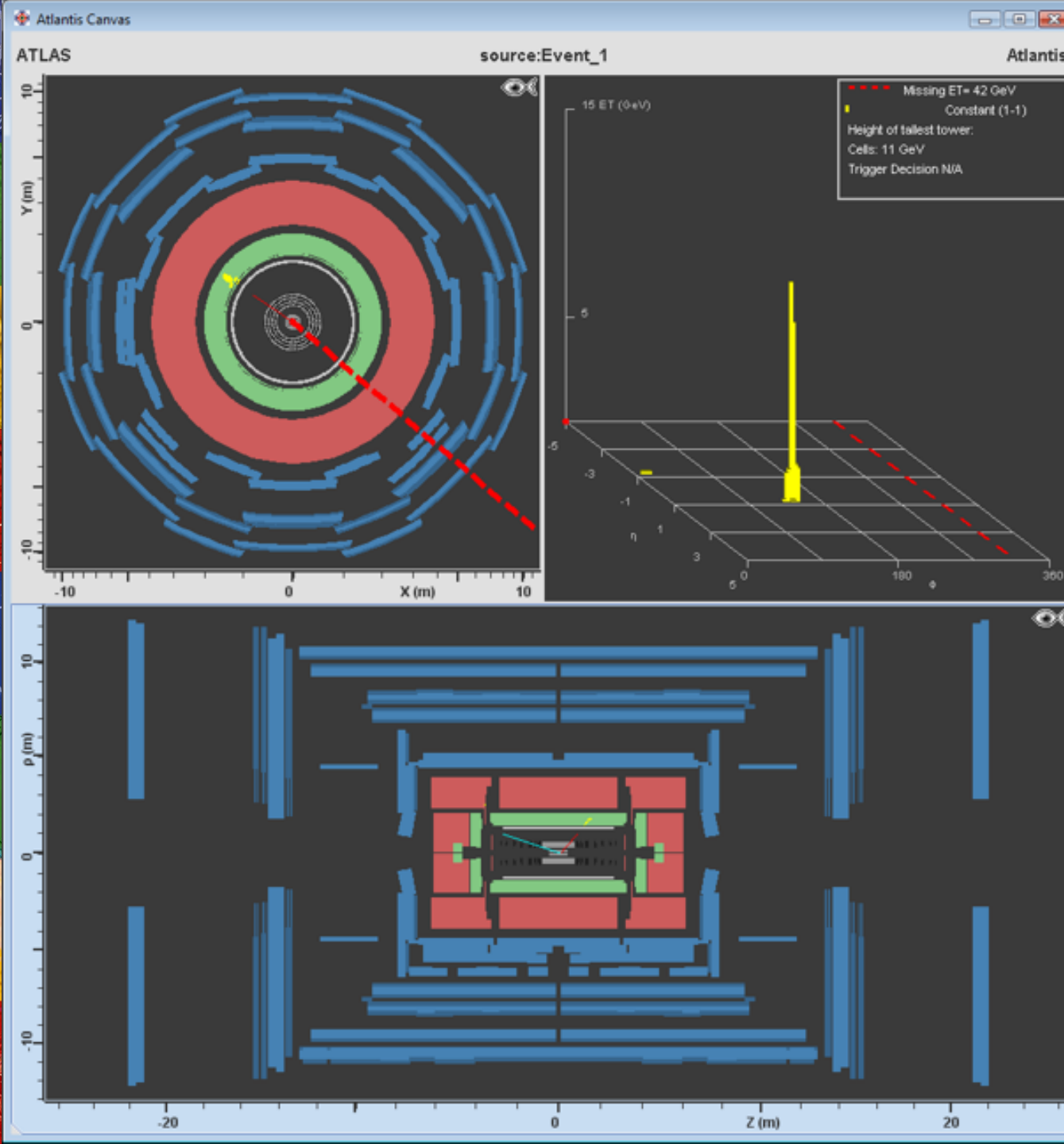
A bundle of several particles flying in one direction. It is the result of quark or gluons being ejected.

Neutrino



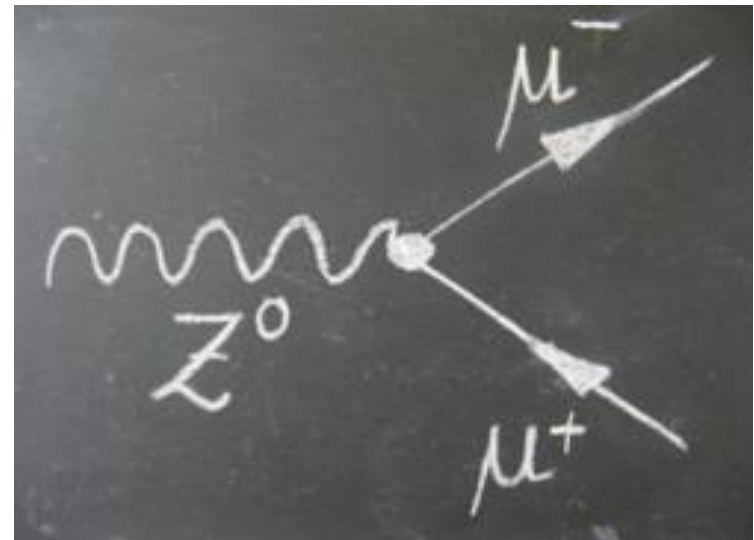
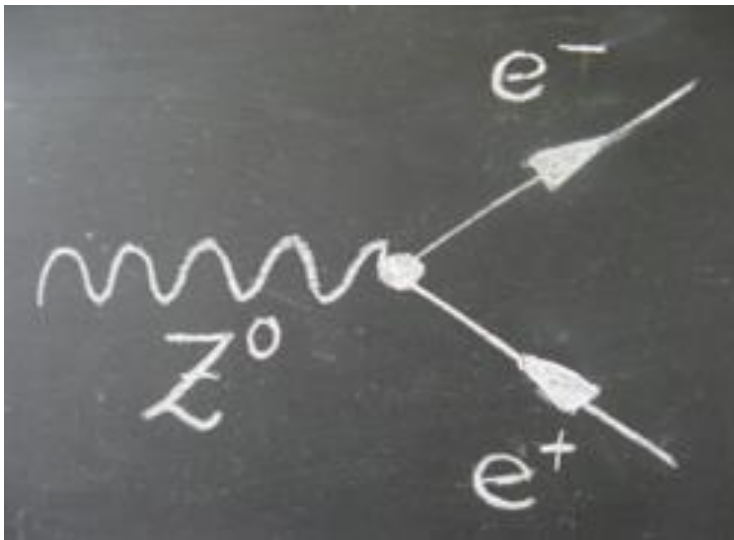
Neutrinos are not directly detected, but inferred from energy imbalance

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



The Z boson

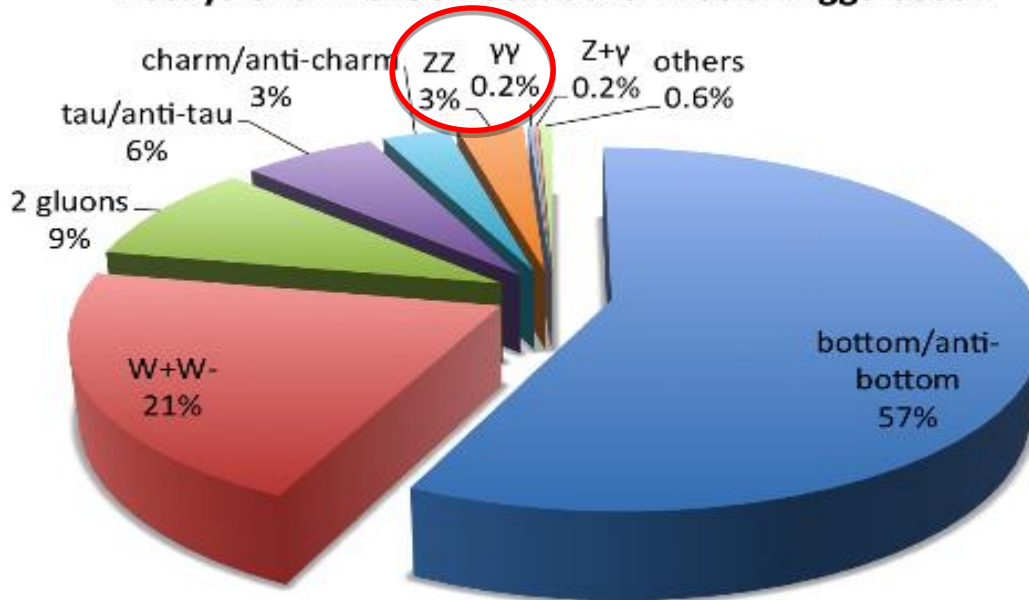
- Responsible for mediating the weak interaction (with the W boson)
- It is not a stable particle – lifetime 3×10^{-25} (0.00000000000000000000000003s) → no hope to measure the Z directly!
- Z bosons decay into a pair of fermion and anti-fermion



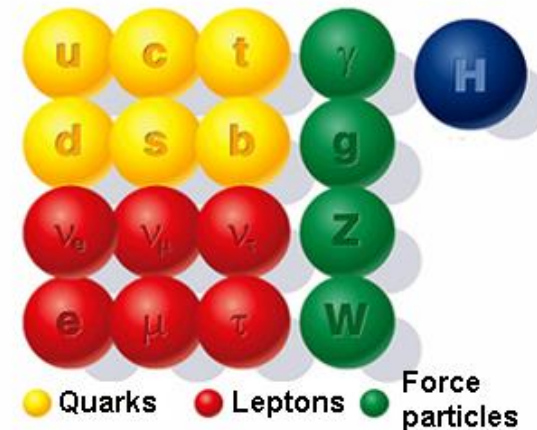
The Higgs Boson

- Responsible for the mass of all particles
- It is not a stable particle – lifetime 1.5×10^{-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, $\gamma\gamma$)

Decays of a 125 GeV Standard-Model Higgs boson



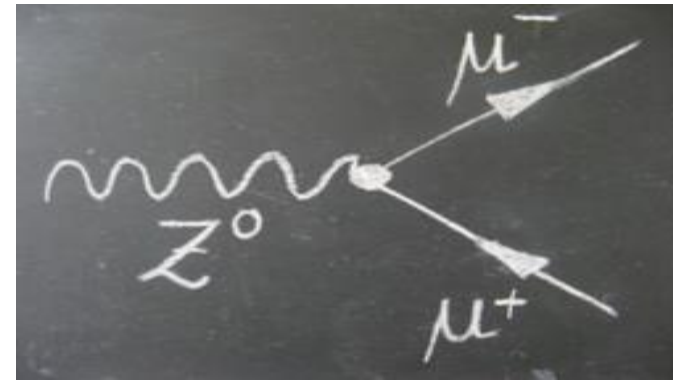
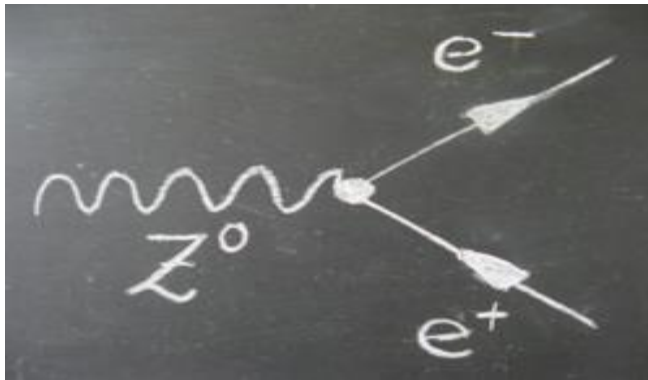
Standard Model particles



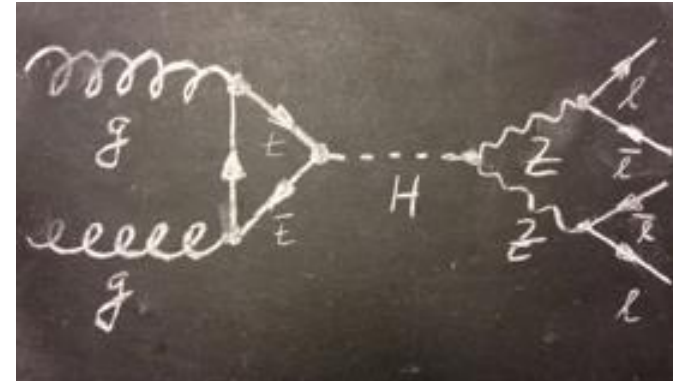
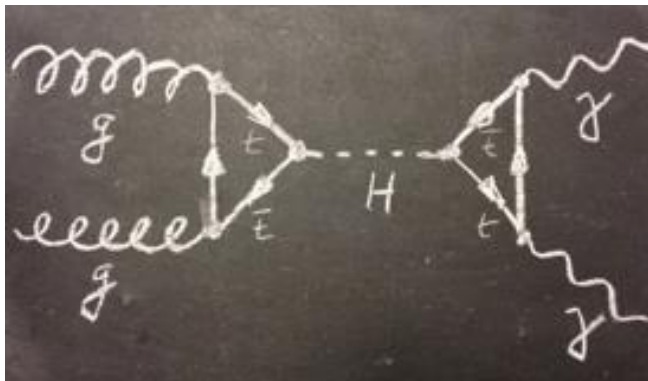
Today we are interested only in two decays: ZZ (and $\gamma\gamma$, if you want)

Signals summary

Z boson – electrically neutral mediator of the weak force

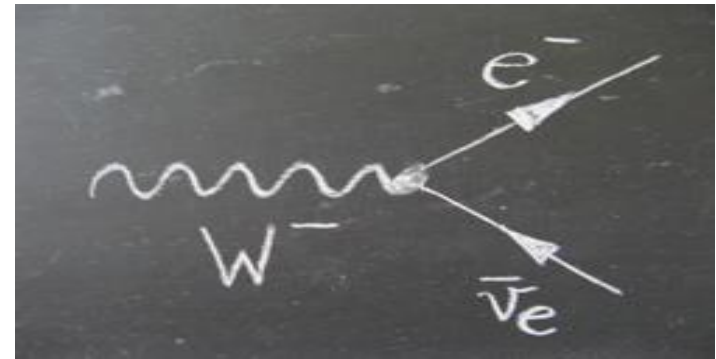
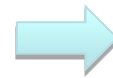
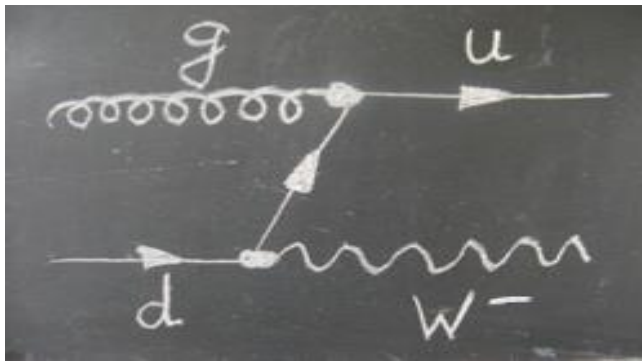


H boson – electrically neutral responsible of the mass of all elementary particles

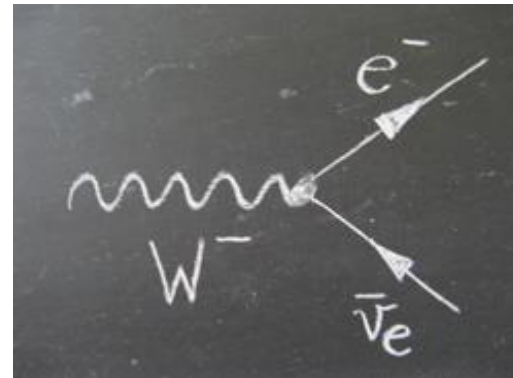
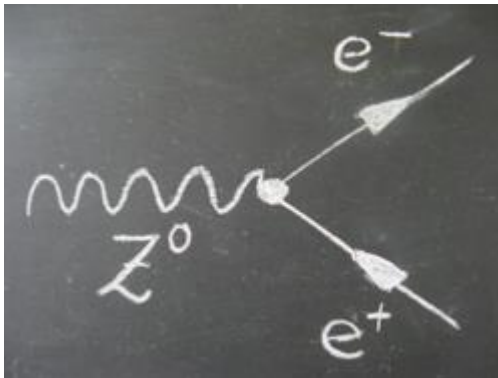


Background (fondo) events

- 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!