Introduzione alle misure di fisica delle alte energie:

La ricerca del bosone Z e del bosone di Higgs

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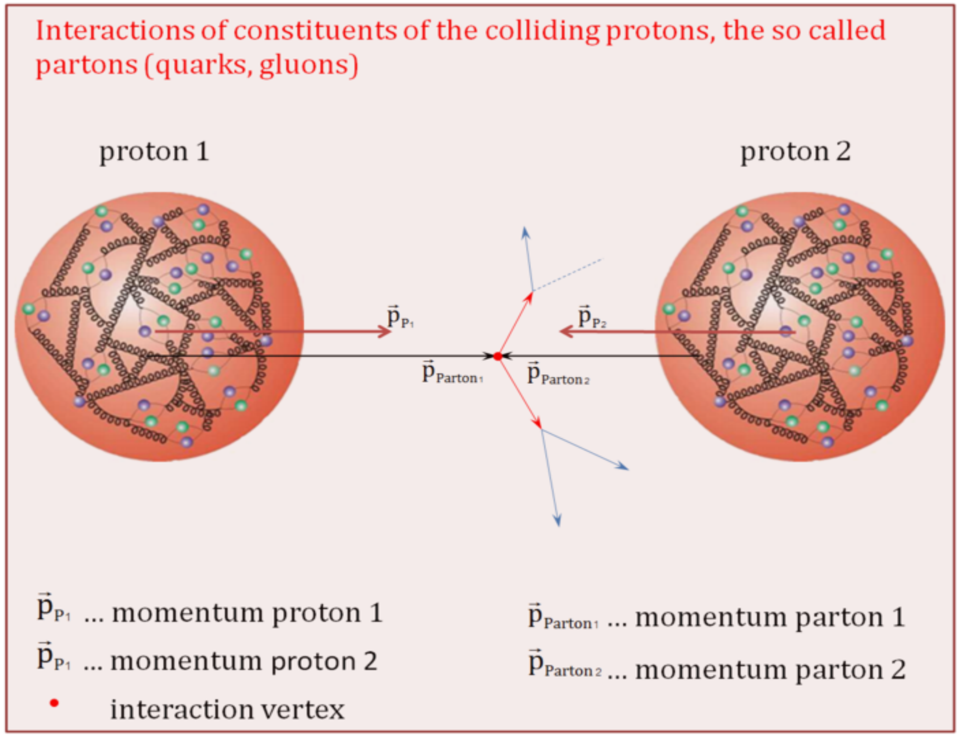
Outline

- 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

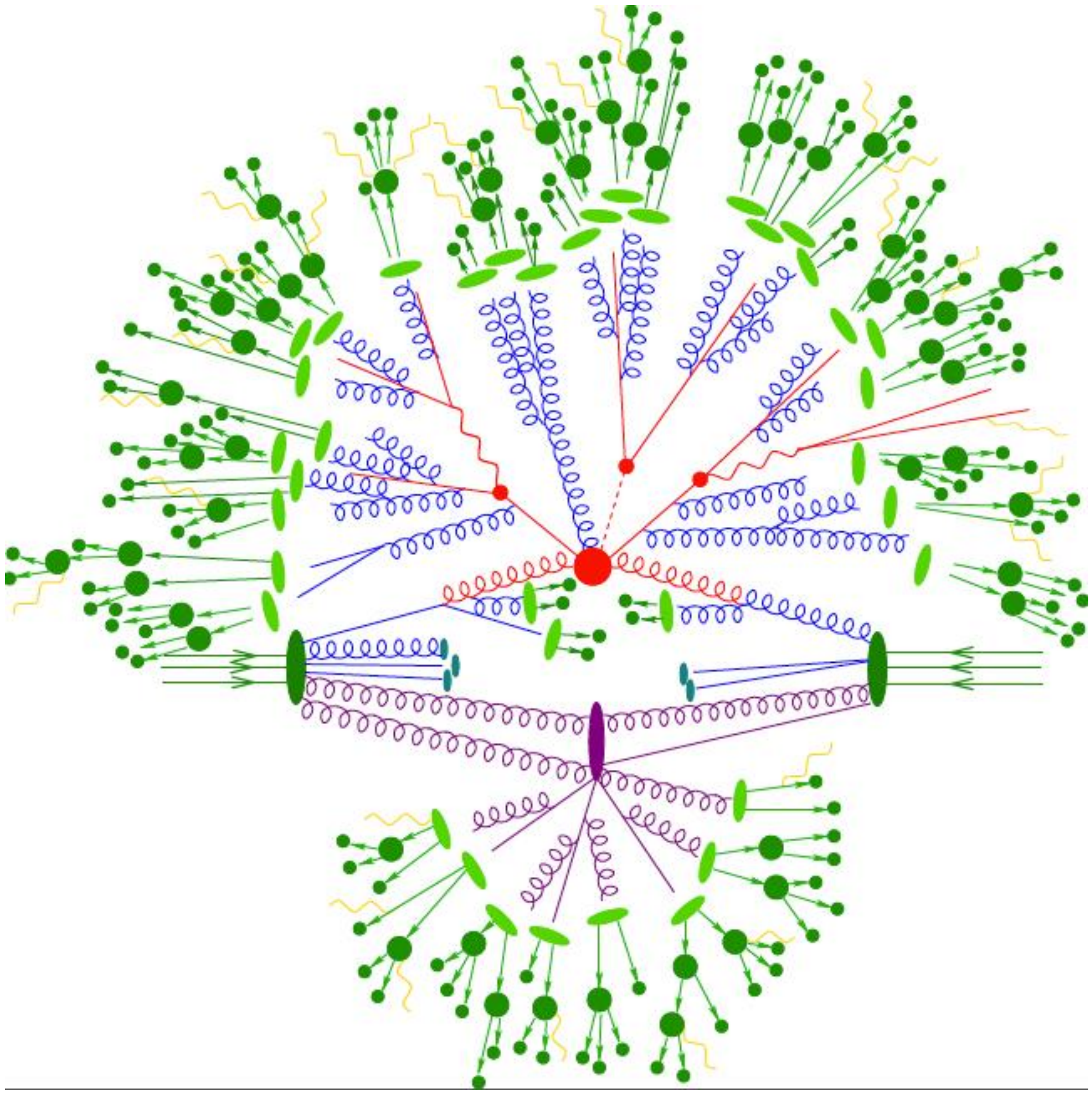
Every time two beams collide in the Interaction Point, on average we have about 50 proton-proton collisions
Almost all these collisions are not interesting (i.e. pp->pp)



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

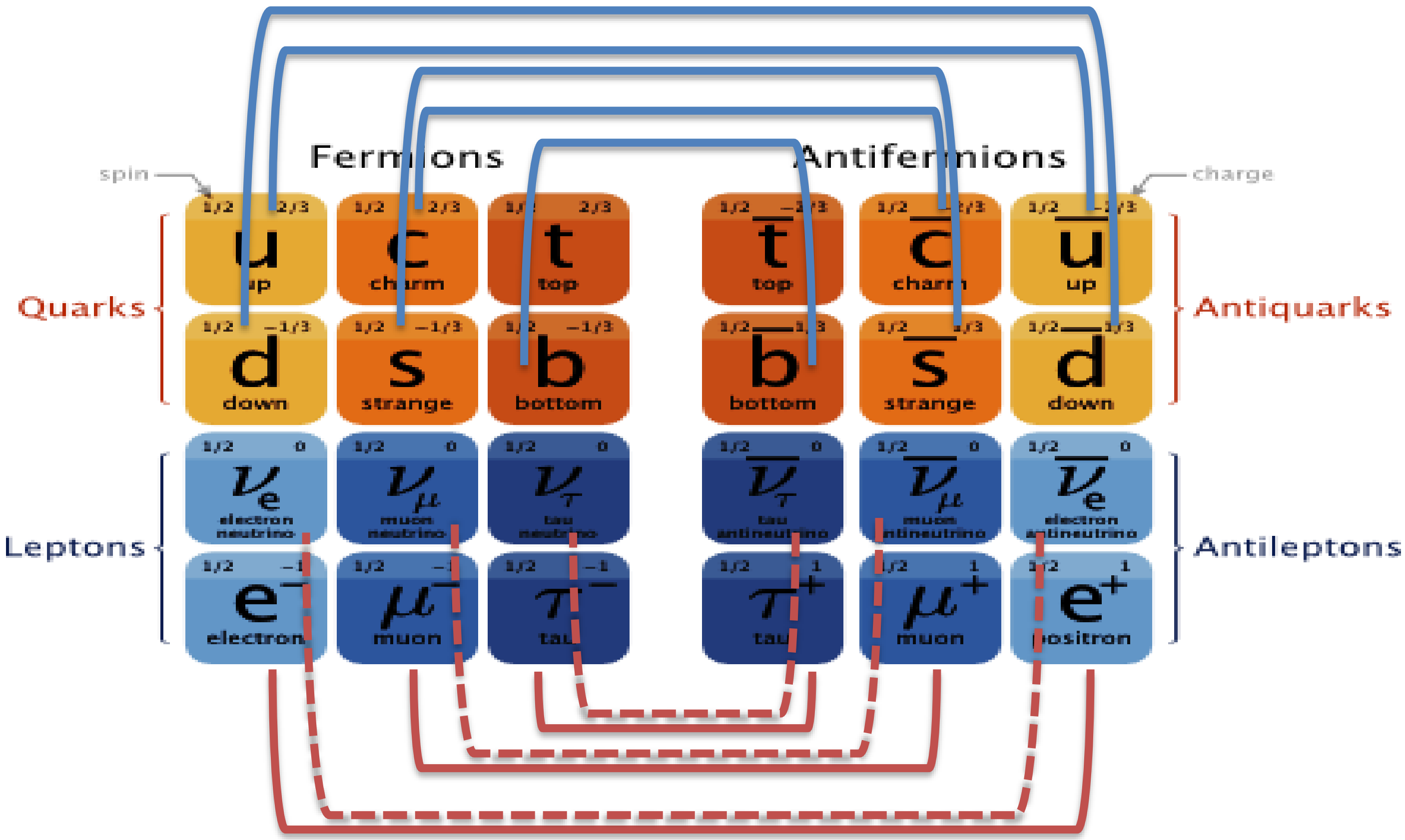
Sometimes a **Z boson** (m = 91.2 GeV/c^2) or a **Higgs boson** (m = 125.1 GeV/ c^2) is created

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 $3x10^{-25}$ (0.0000000000000000000000003s) → no hope to measure the Z directly!
- Z bosons decay into a pair of fermion and anti-fermion



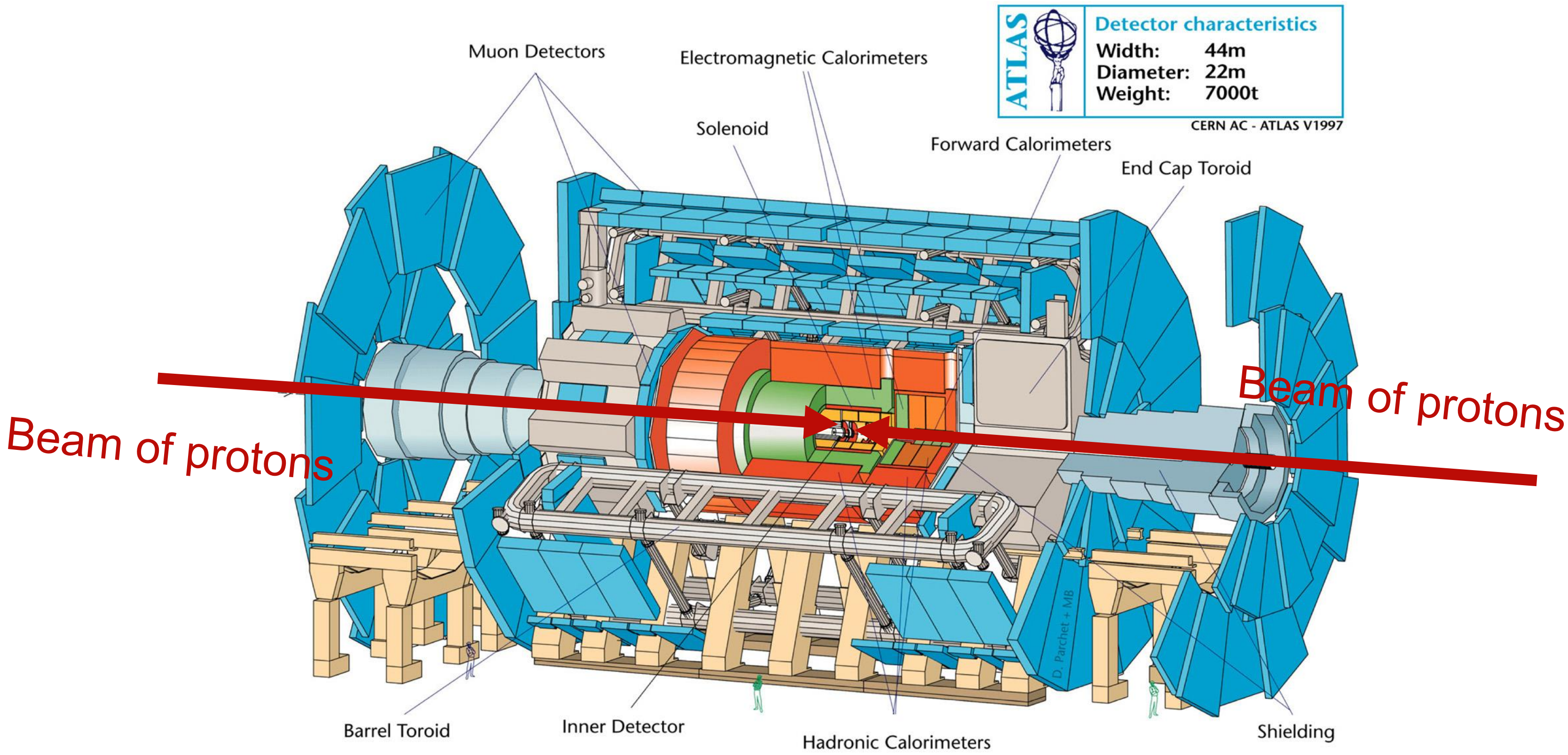
The Z boson

- 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

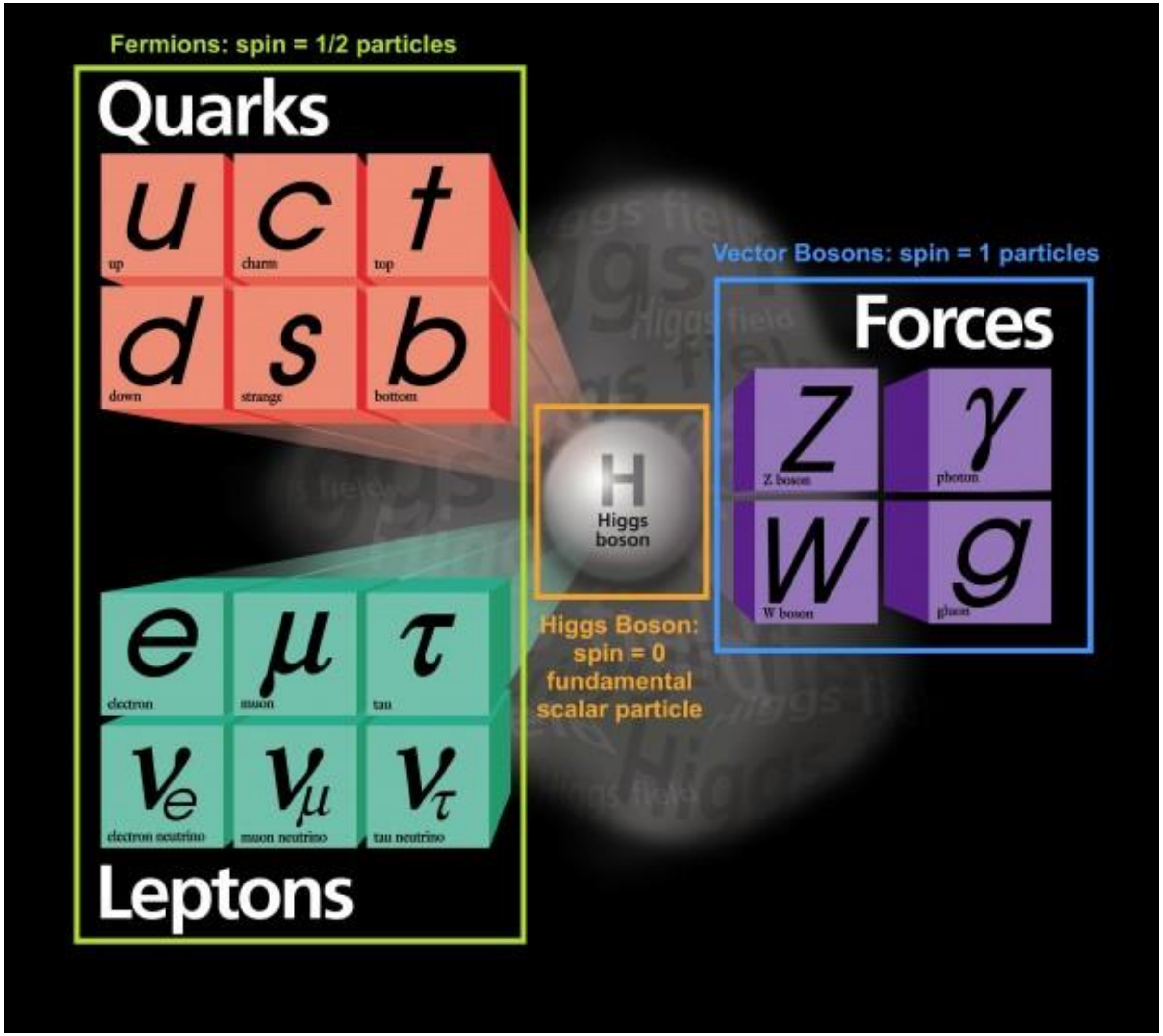
ATLAS

We <u>surround</u> the place where particles collide with a set of detectors.

Different types of particles leave different signals in the various detectors

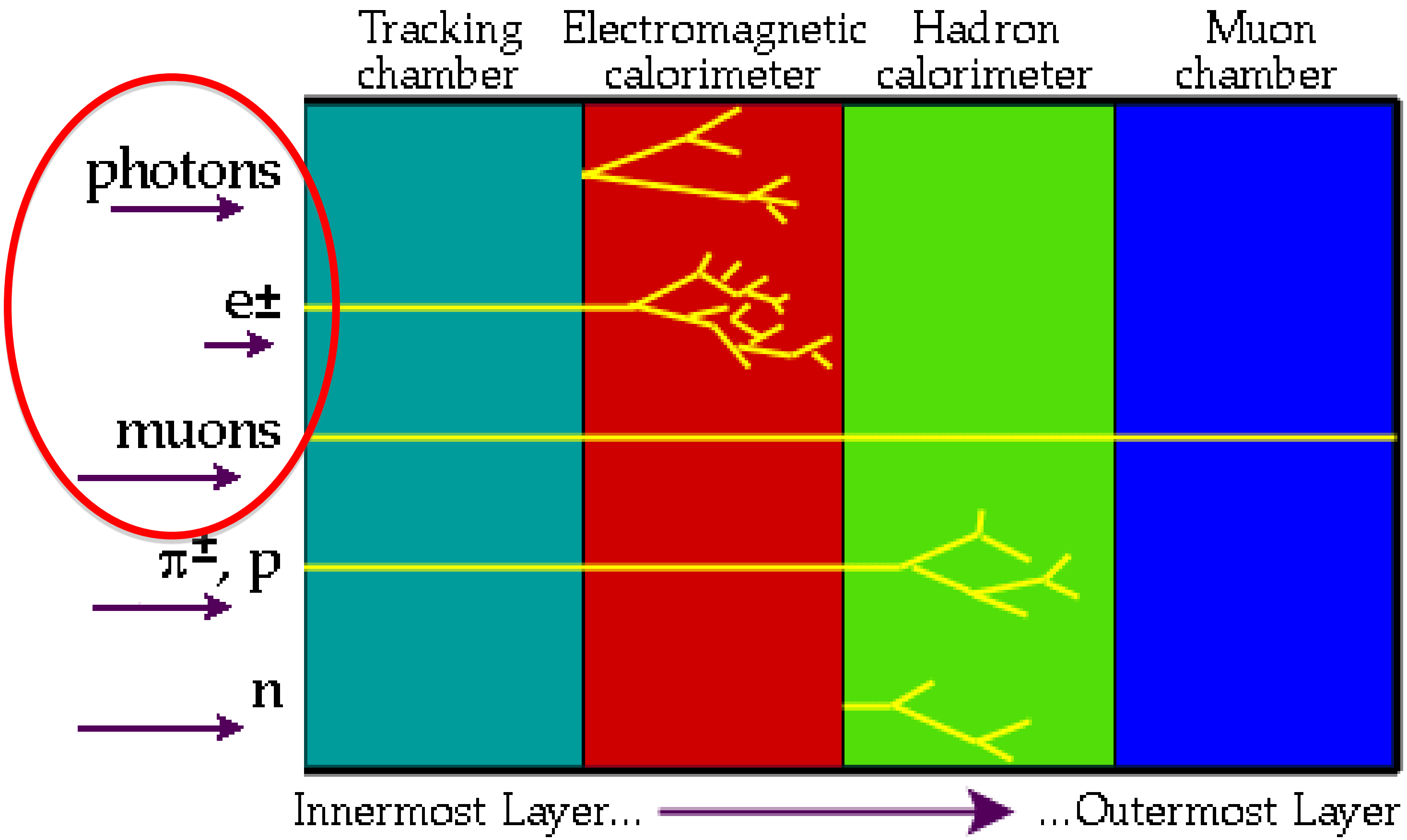


Reminder: the Standard Model



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

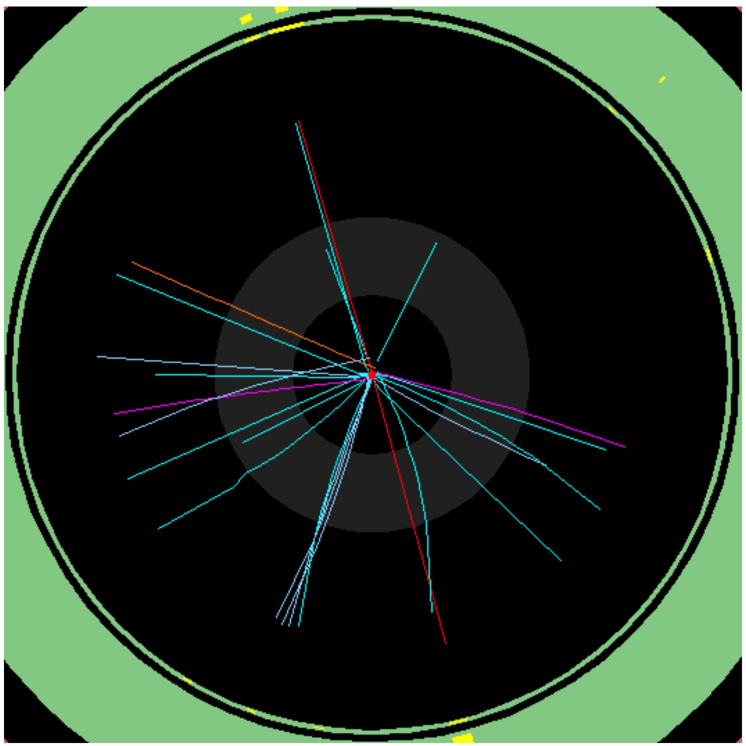
How particles interact with detectors

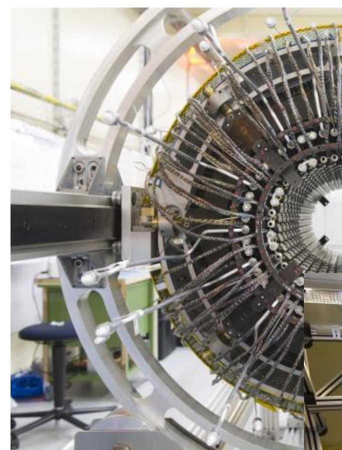


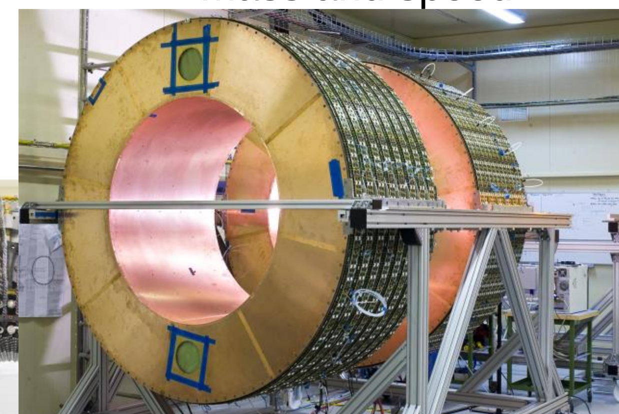
The Inner Detector (tracking detector)

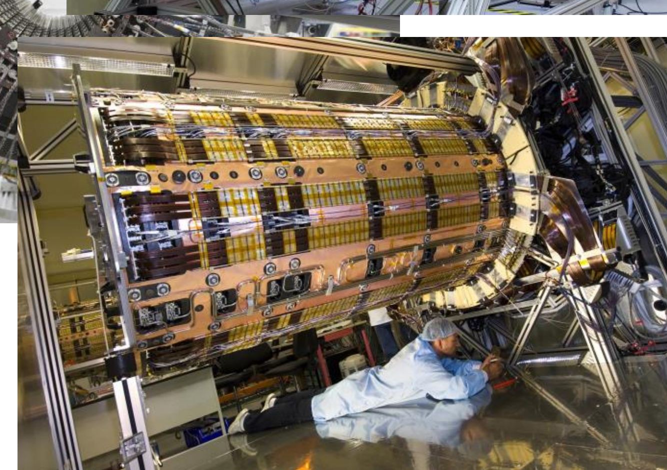
- detects electrically charged particles traversing the detector
    - electrons, muons, protons, quarks (jets) ...
- it is not sensitive to electrically neutral particles
    - photons, neutrons, neutrinos...

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

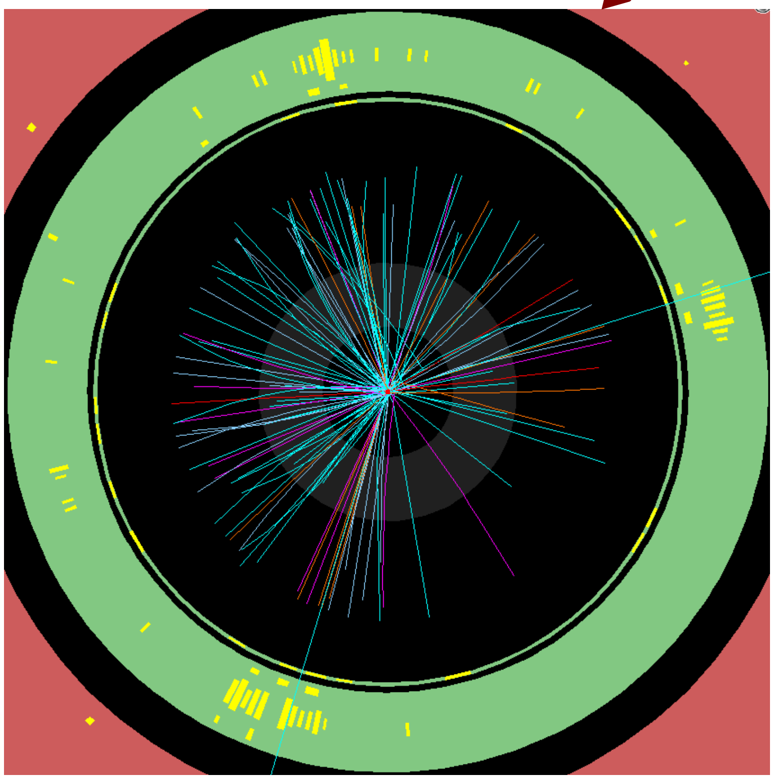




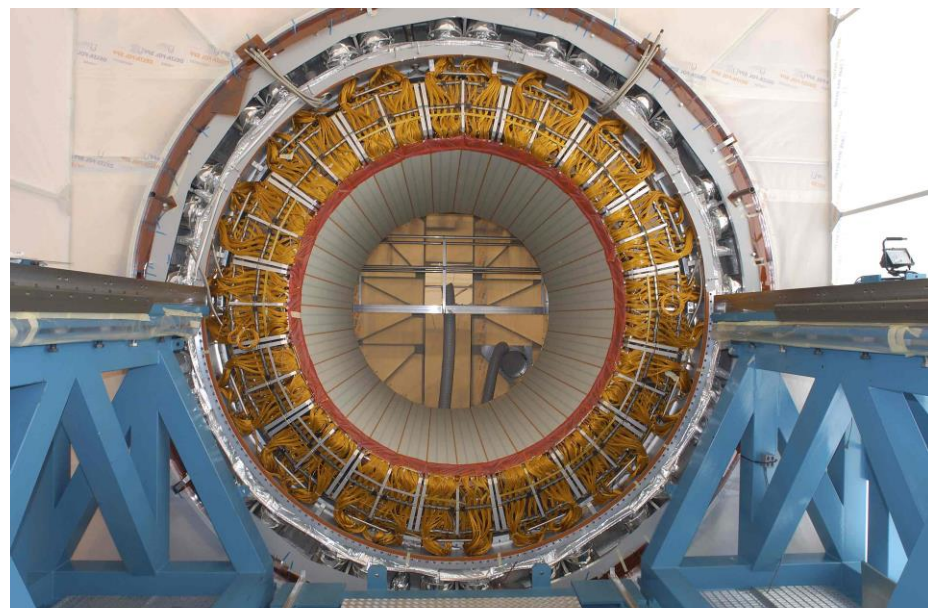




Electromagnetic calorimeter (ECAL)

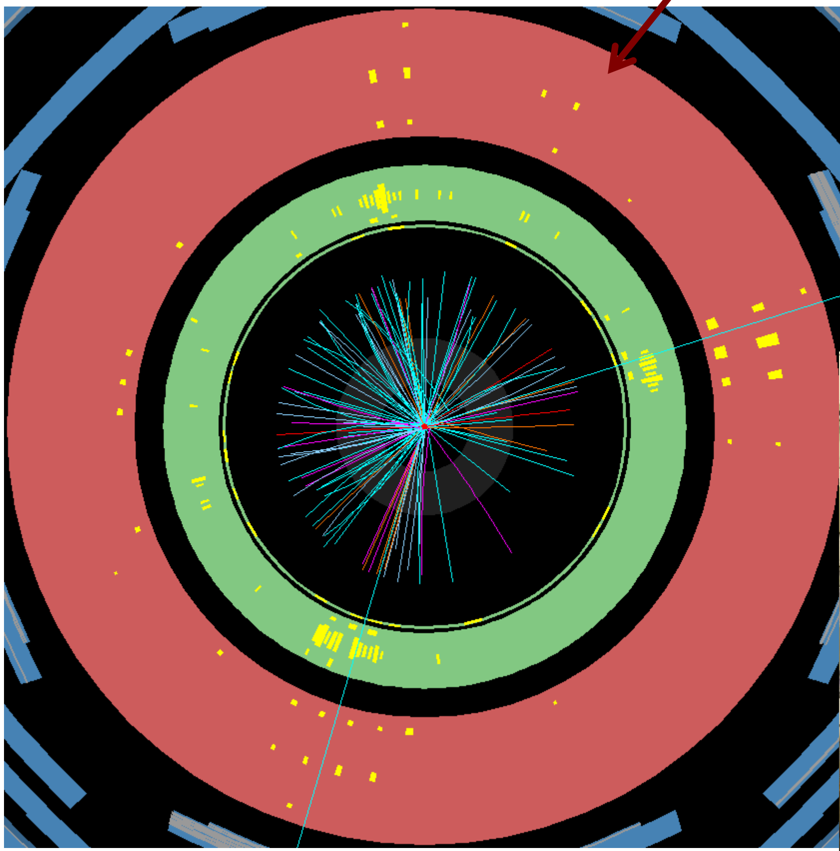


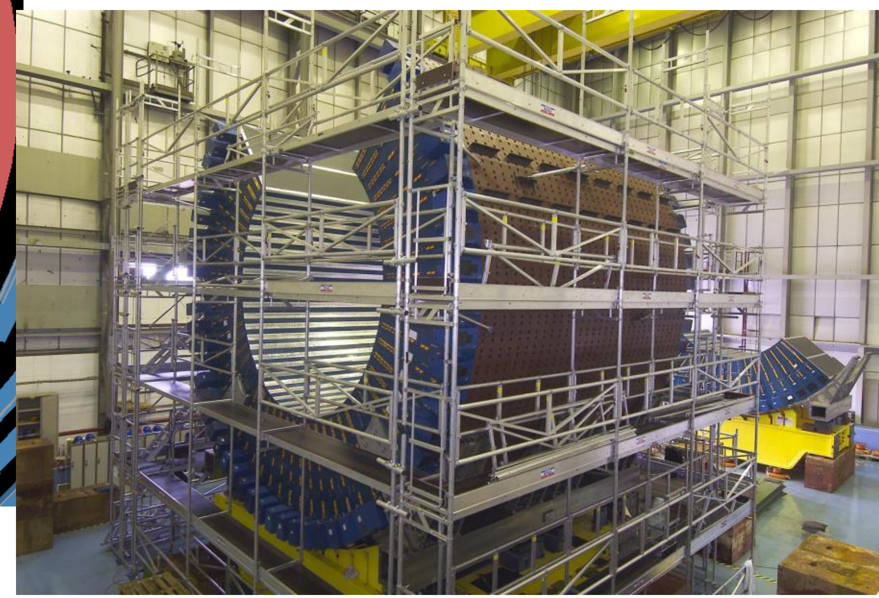
- **detects all particles interacting electromagnetically**
    - **such as electron, positron, photon, …**
    - **these particles deposit energy in the ECAL and this energy is measured**



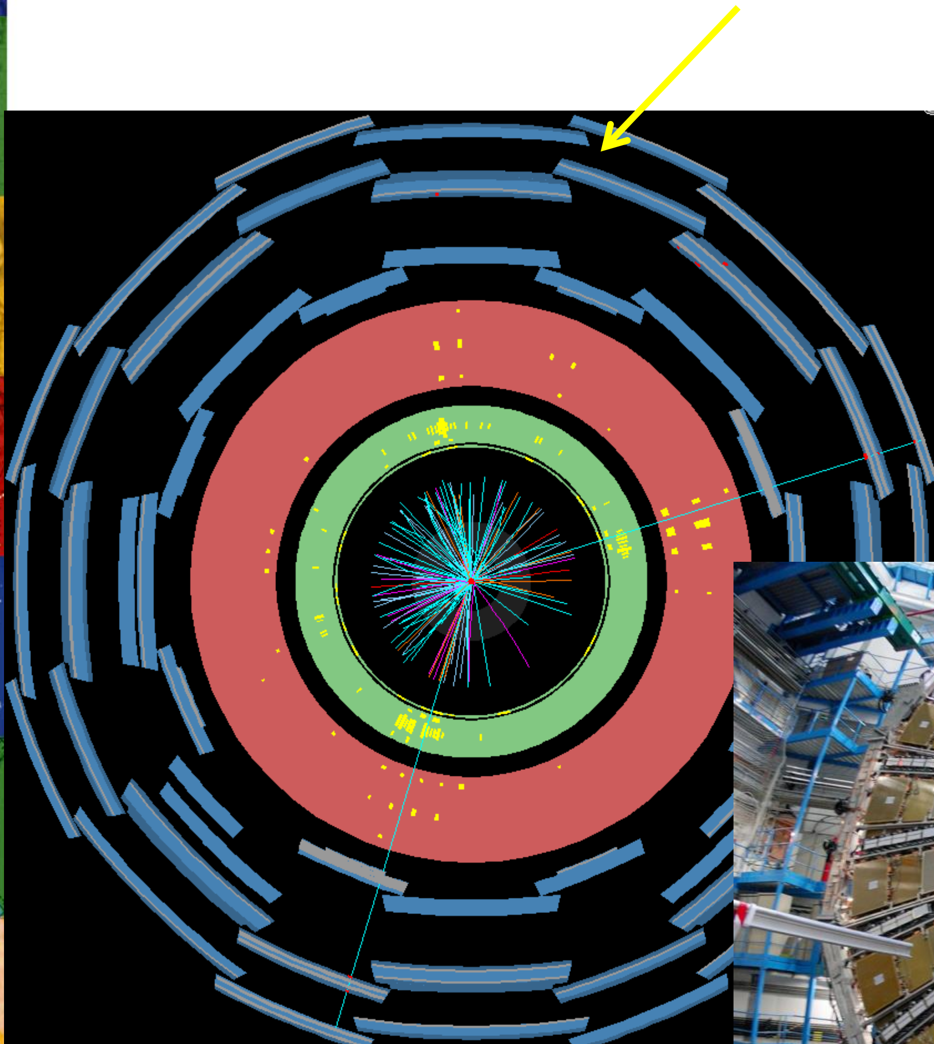
Hadronic calorimeter (HCAL)

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

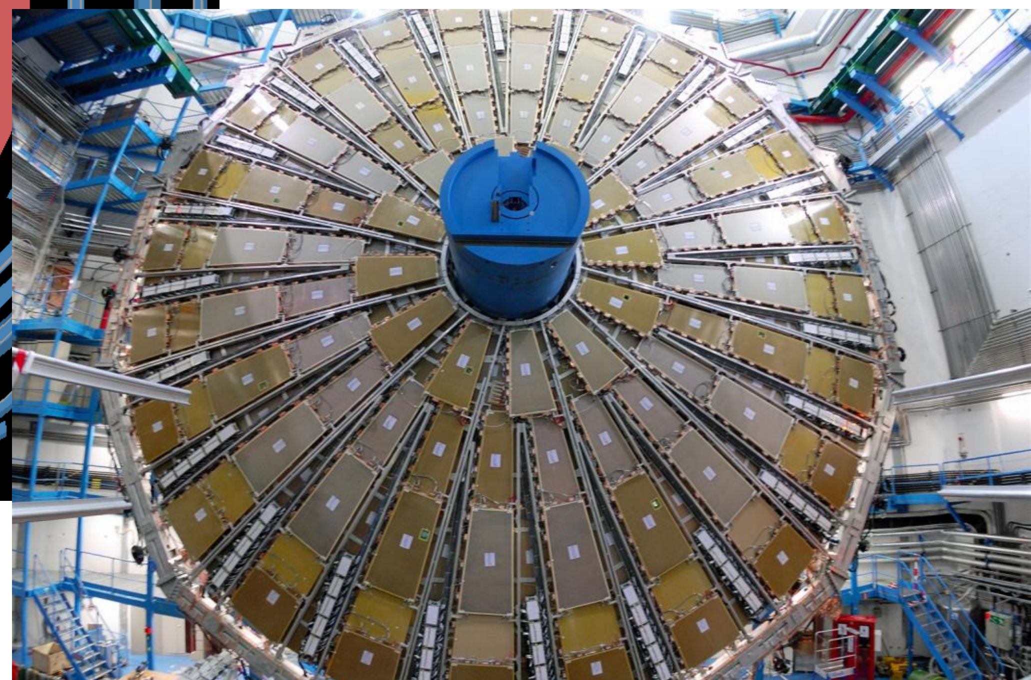


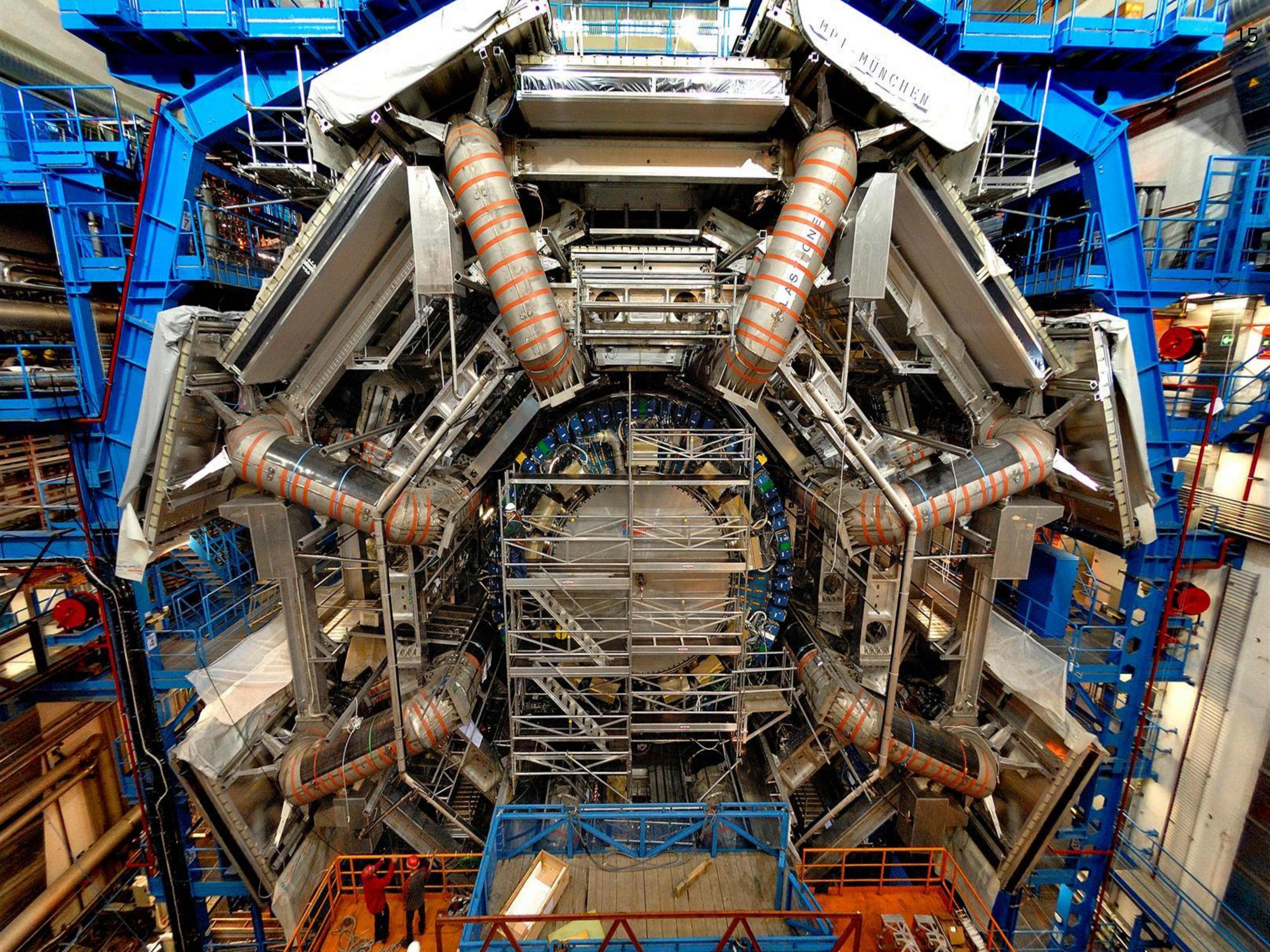


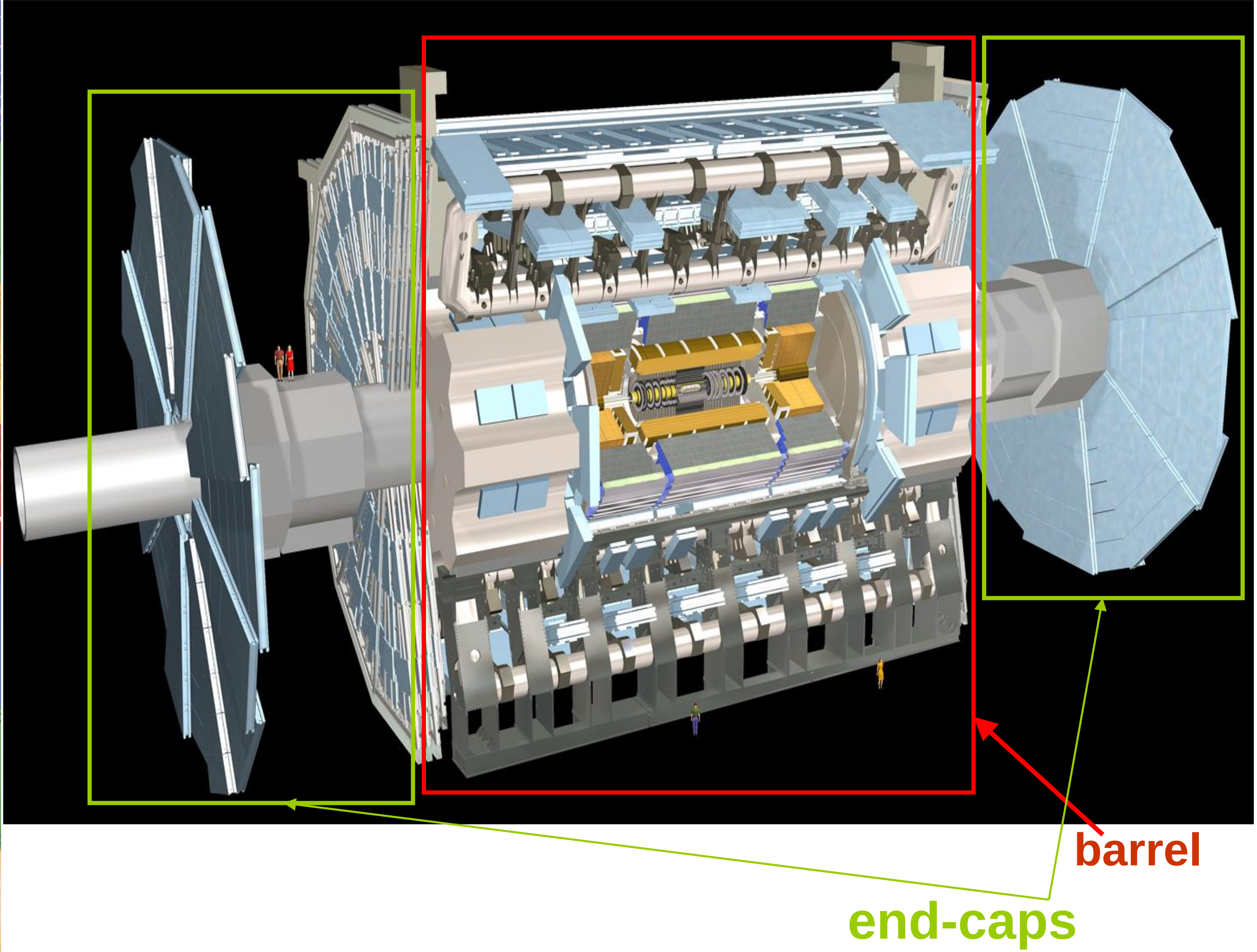
Muon spectrometer (MS)



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

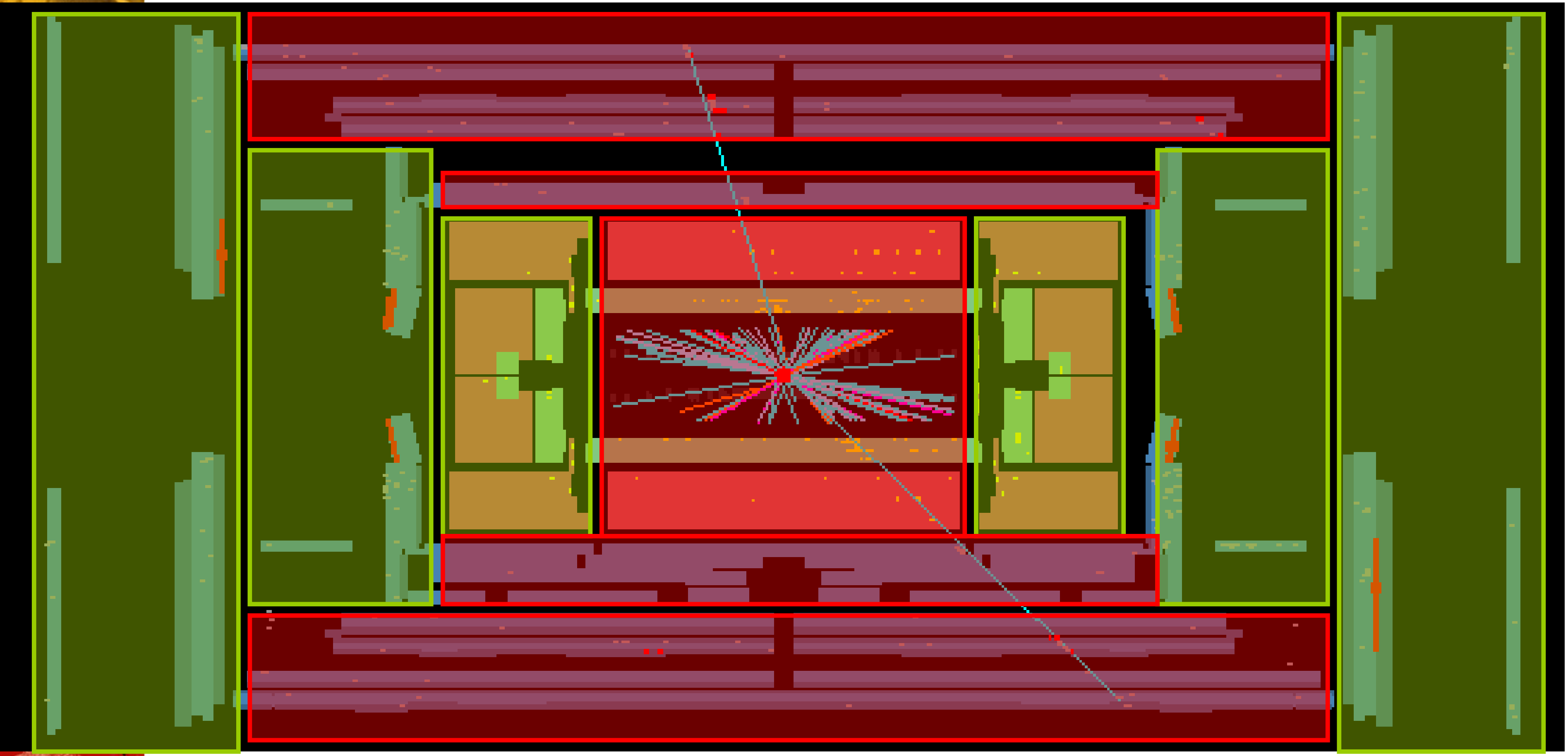


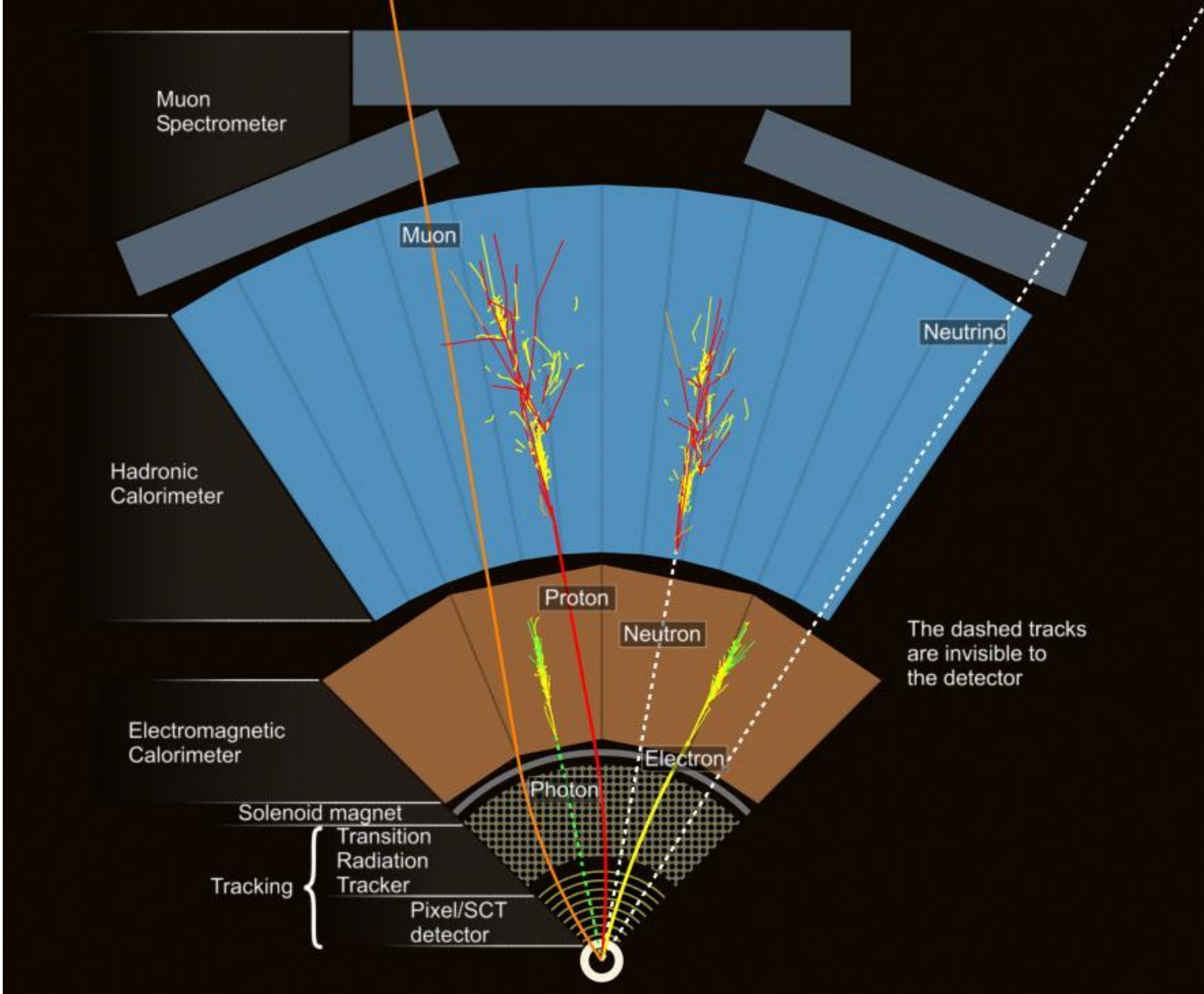

MPI-MÜNCHEN



- 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




Muon
Spectrometer
Muon
Hadronic
Calorimeter
Neutrino
Proton
Neutron
The dashed tracks
are invisible to
the detector
Electromagnetic
Calorimeter
Electron
Photon
Solenoid magnet
Tracking
Transition
Radiation
Tracker
Pixel/SCT
detector

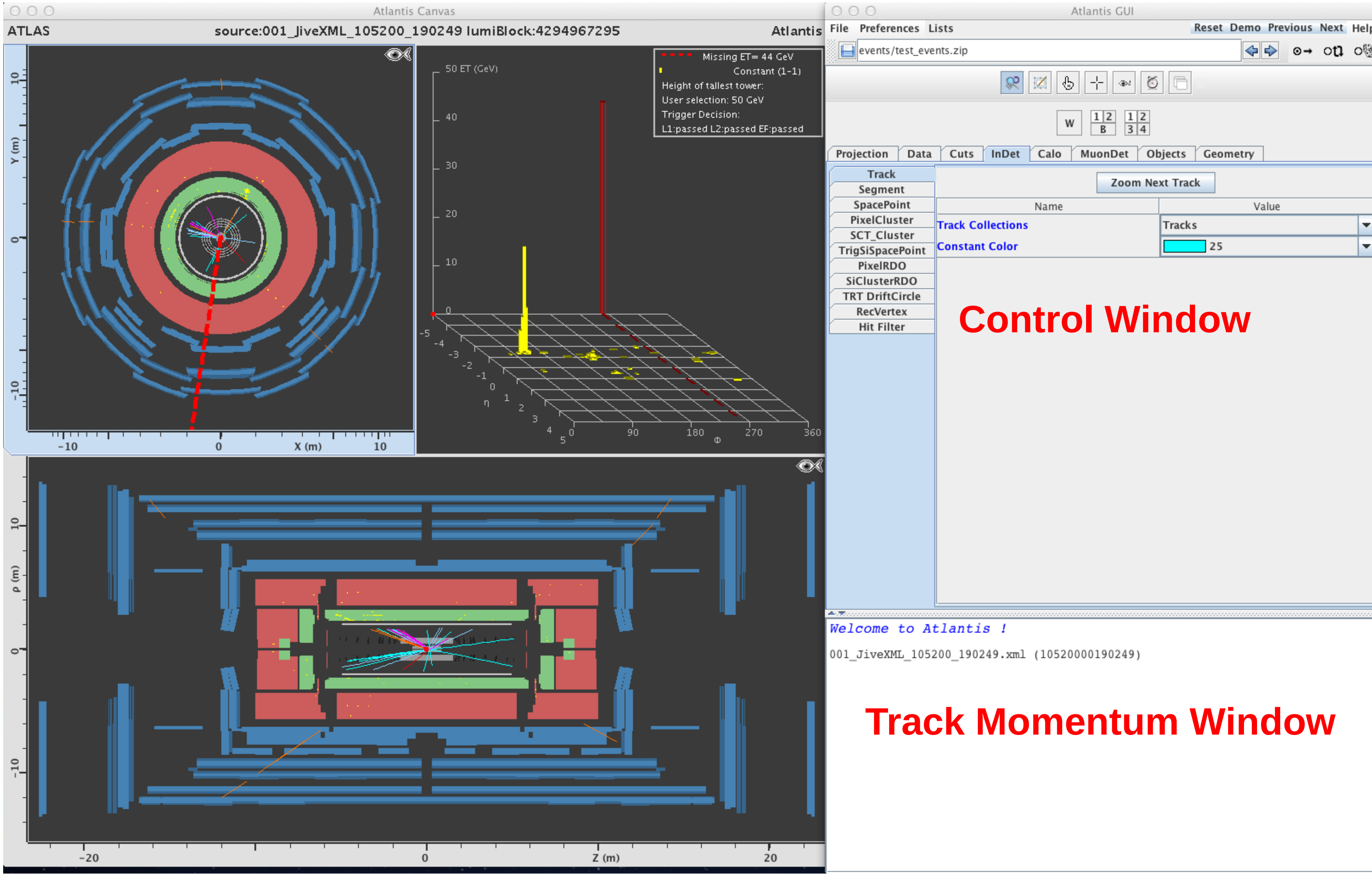
You will:

- 1. **Get to know the ATLANTIS 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

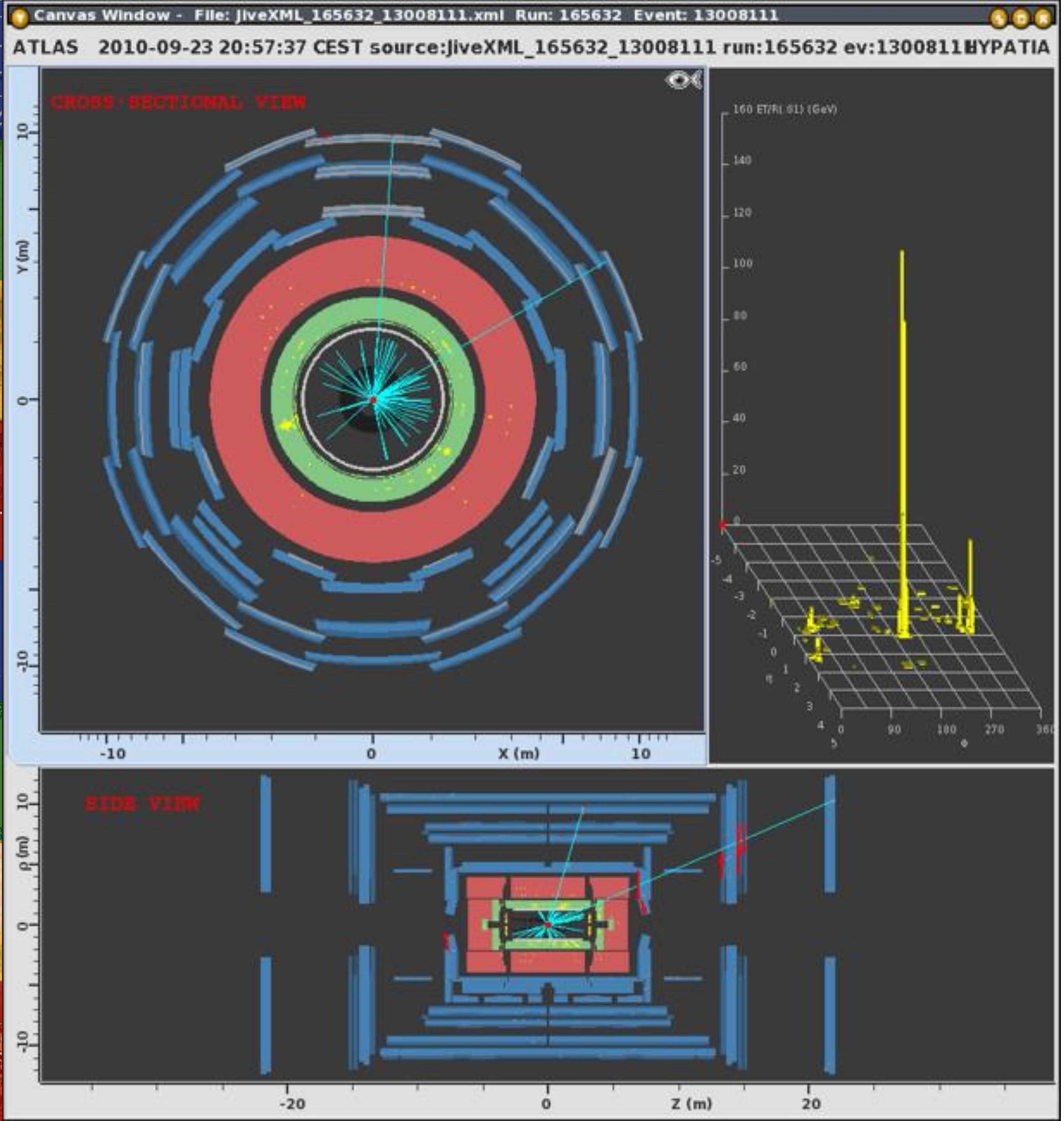
*: Can we answer this? What about for real data?

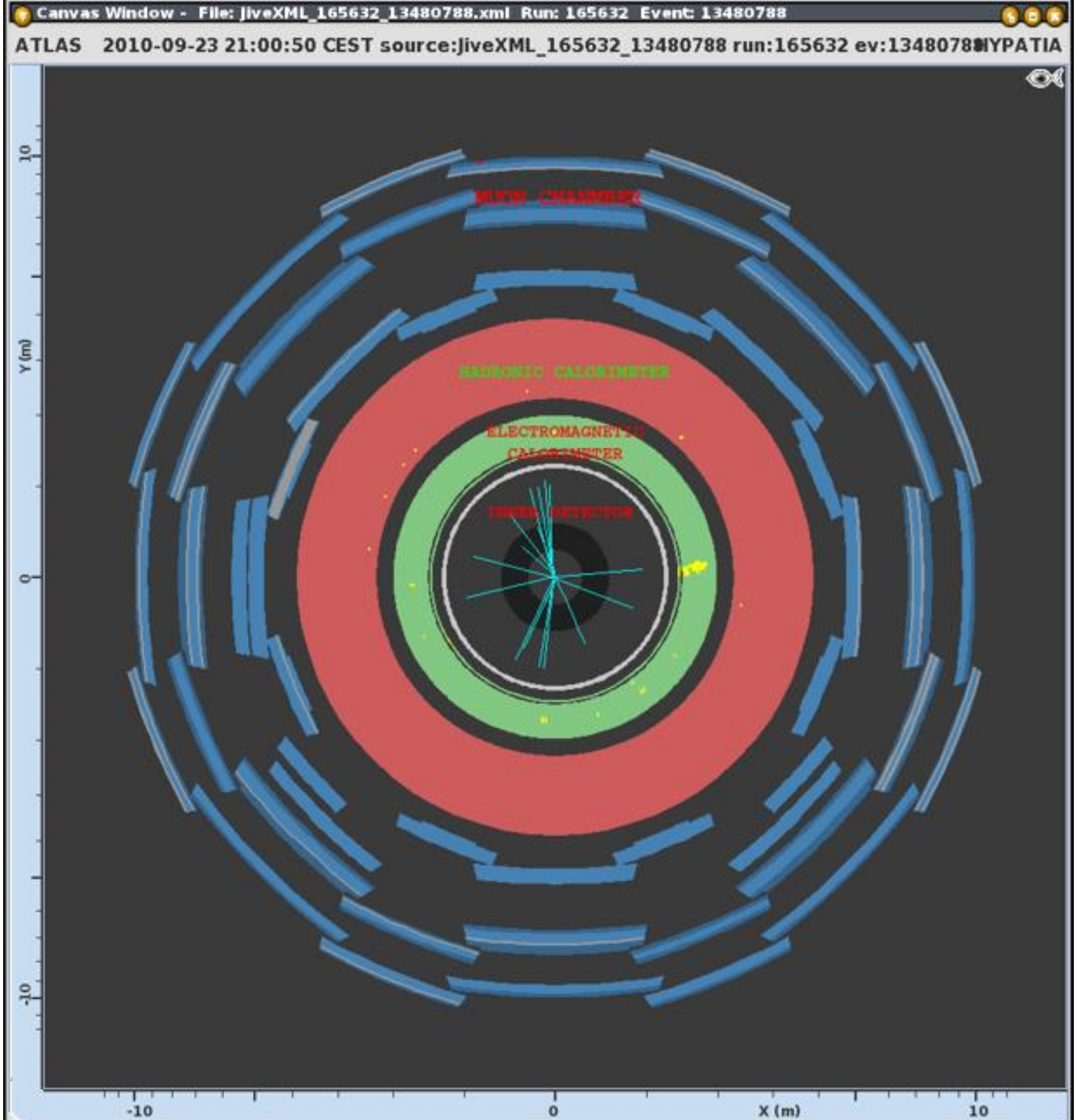
How it looks like…

Canvas Window

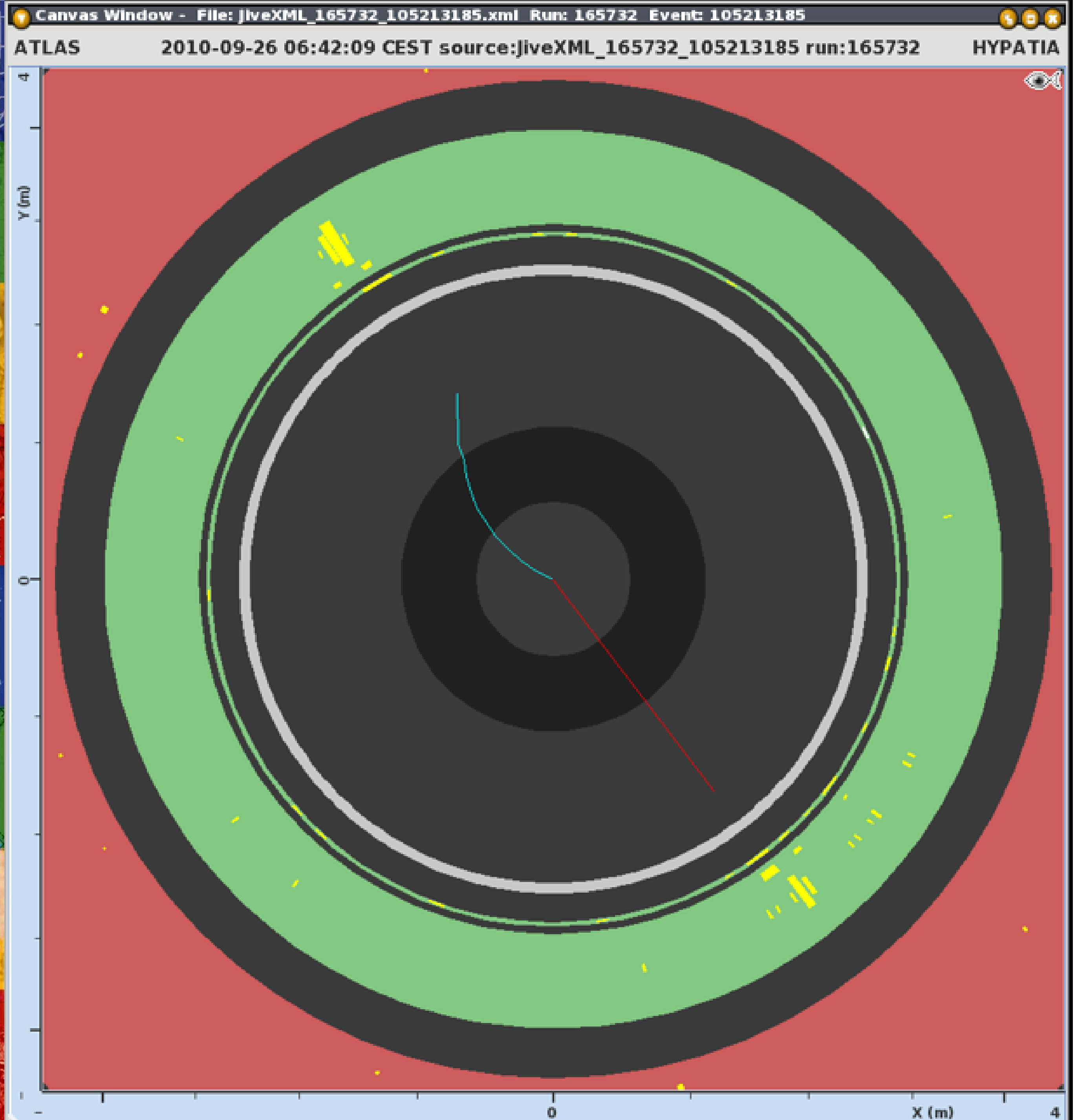


Detector views





Four sub-detector types, depicted in different colors

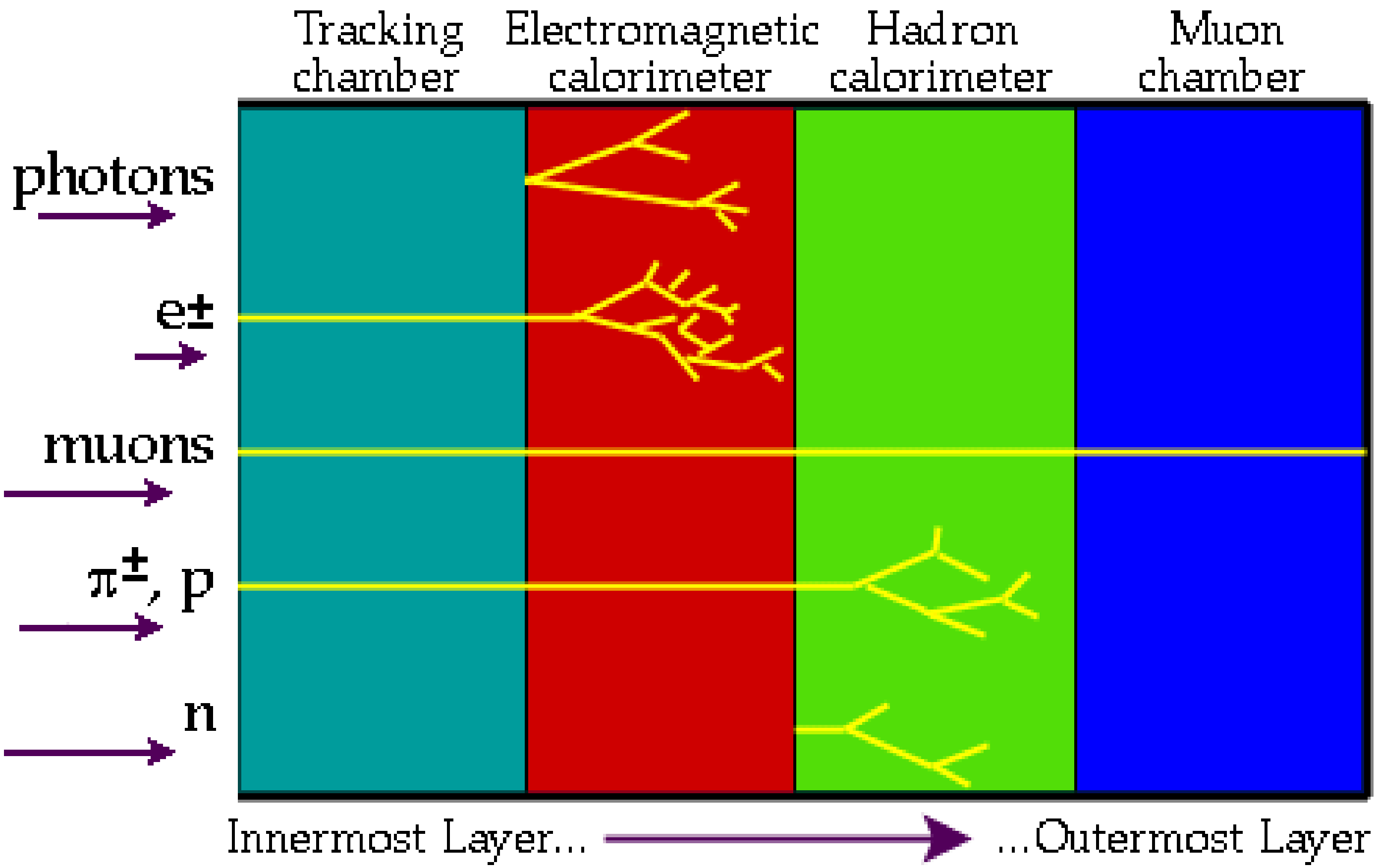


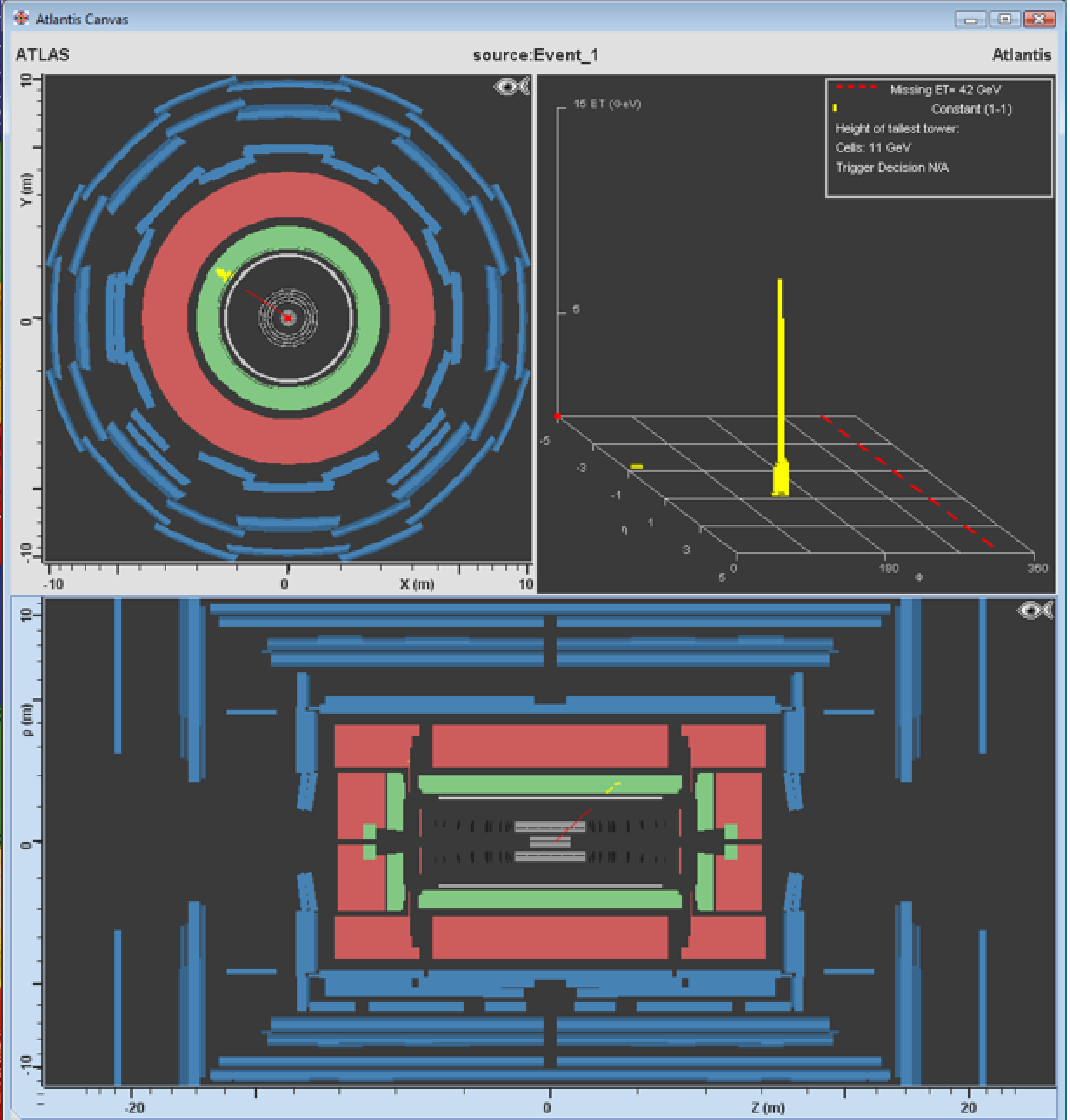
Charged tracks in inner detector and energy deposits.

The color of the tracks encodes the transverse momentum (p_T). Sign of p_T indicates the electric charge

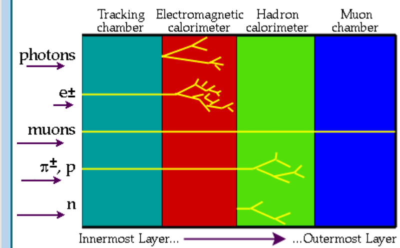
Energy deposits are shown are yellow cell entries in both EM and HAD calo

How particles interact with detectors



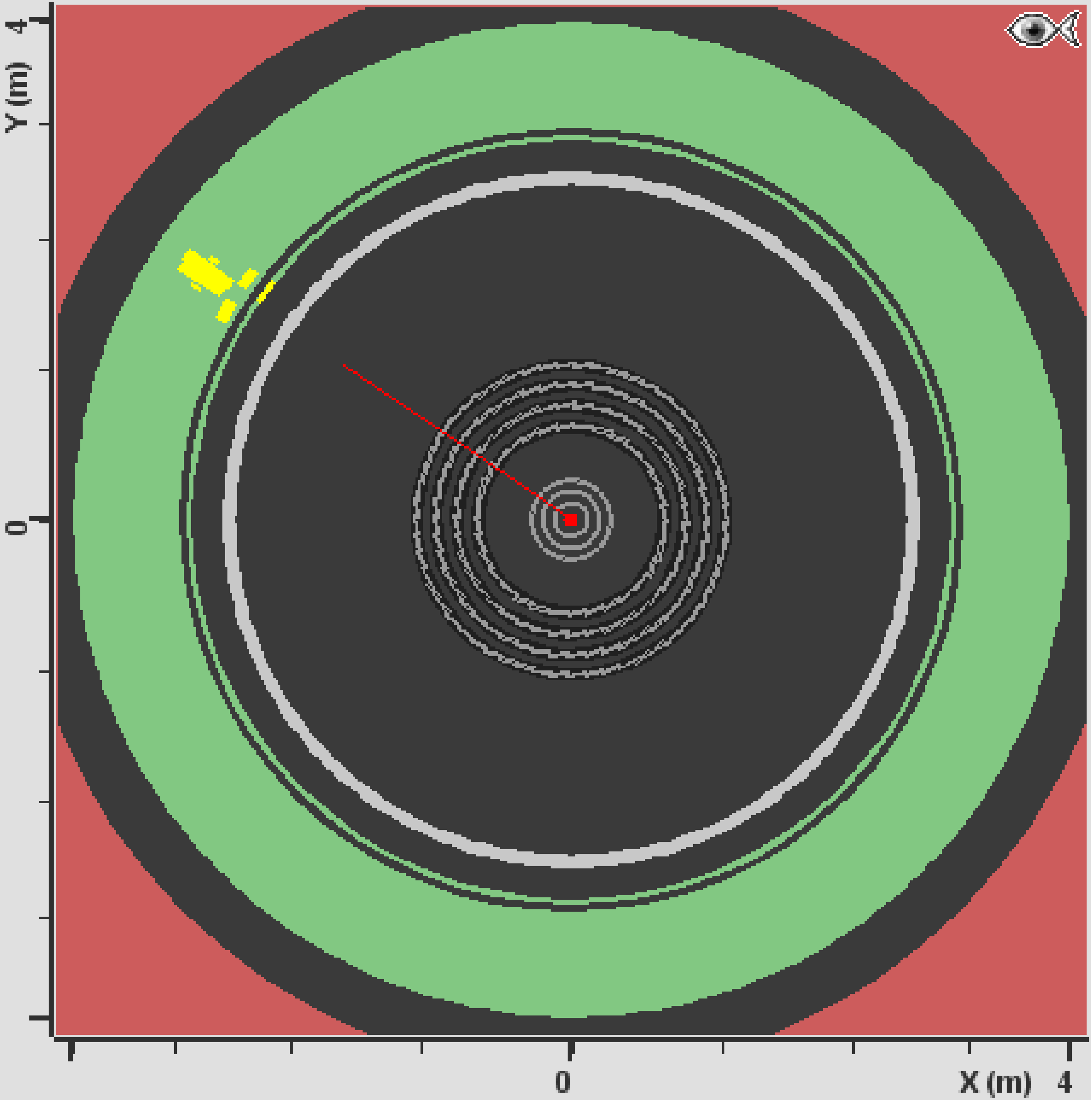


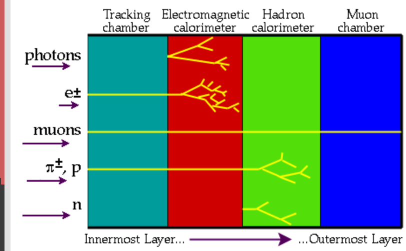
Electron

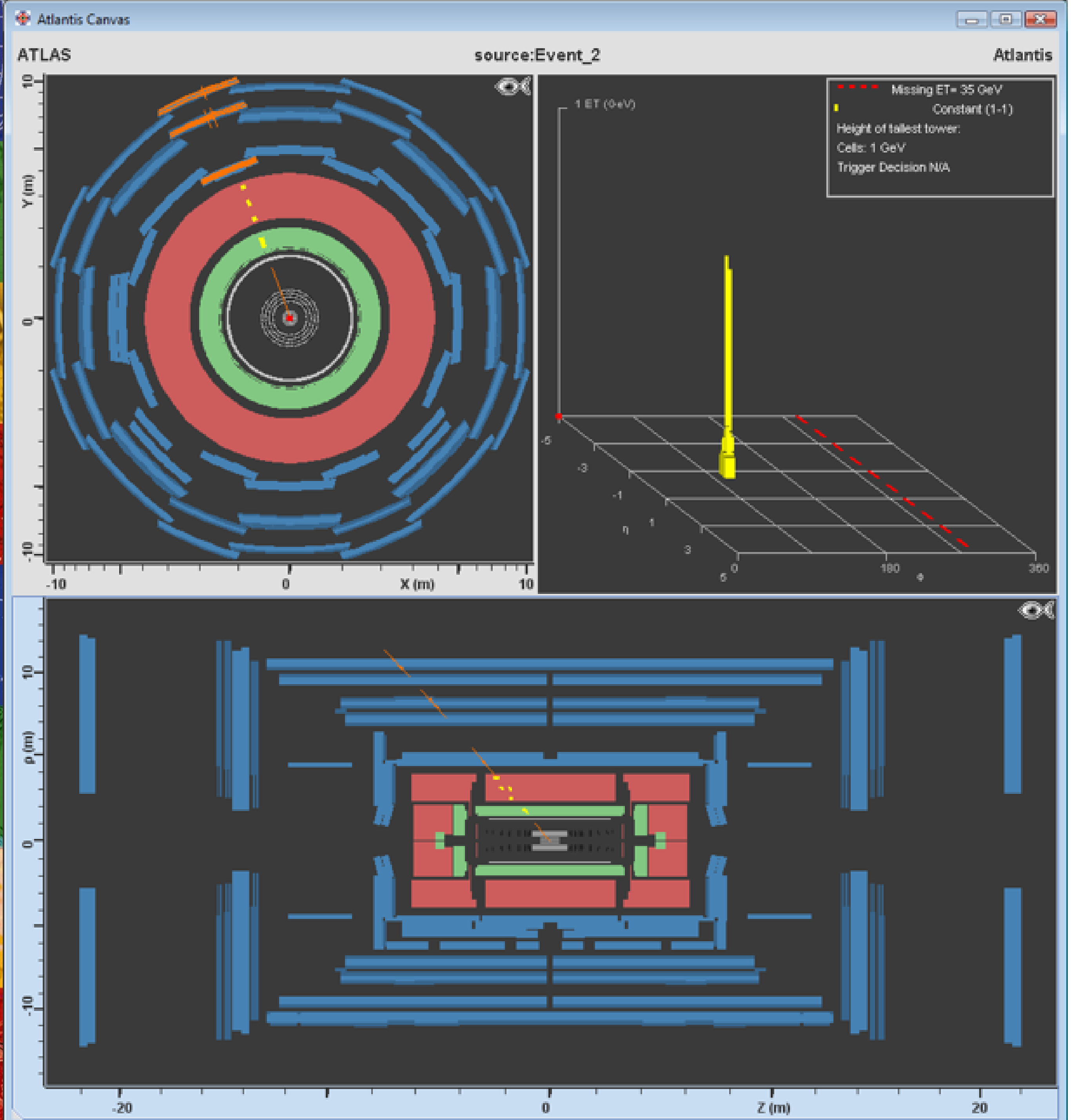


Electron clusters in the EM calorimeter look like yellow “towers” over a green background

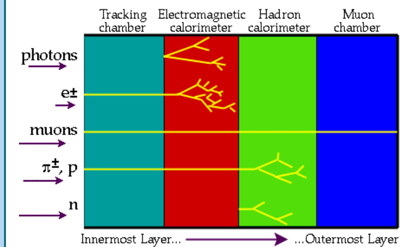
Electron


Y (m)
4
0
0
X (m)
4


Tracking chamber
Electromagnetic calorimeter
Hadron calorimeter
Muon chamber
photons
e±
muons
π±, p
n
Innermost Layer...
...Outermost Layer



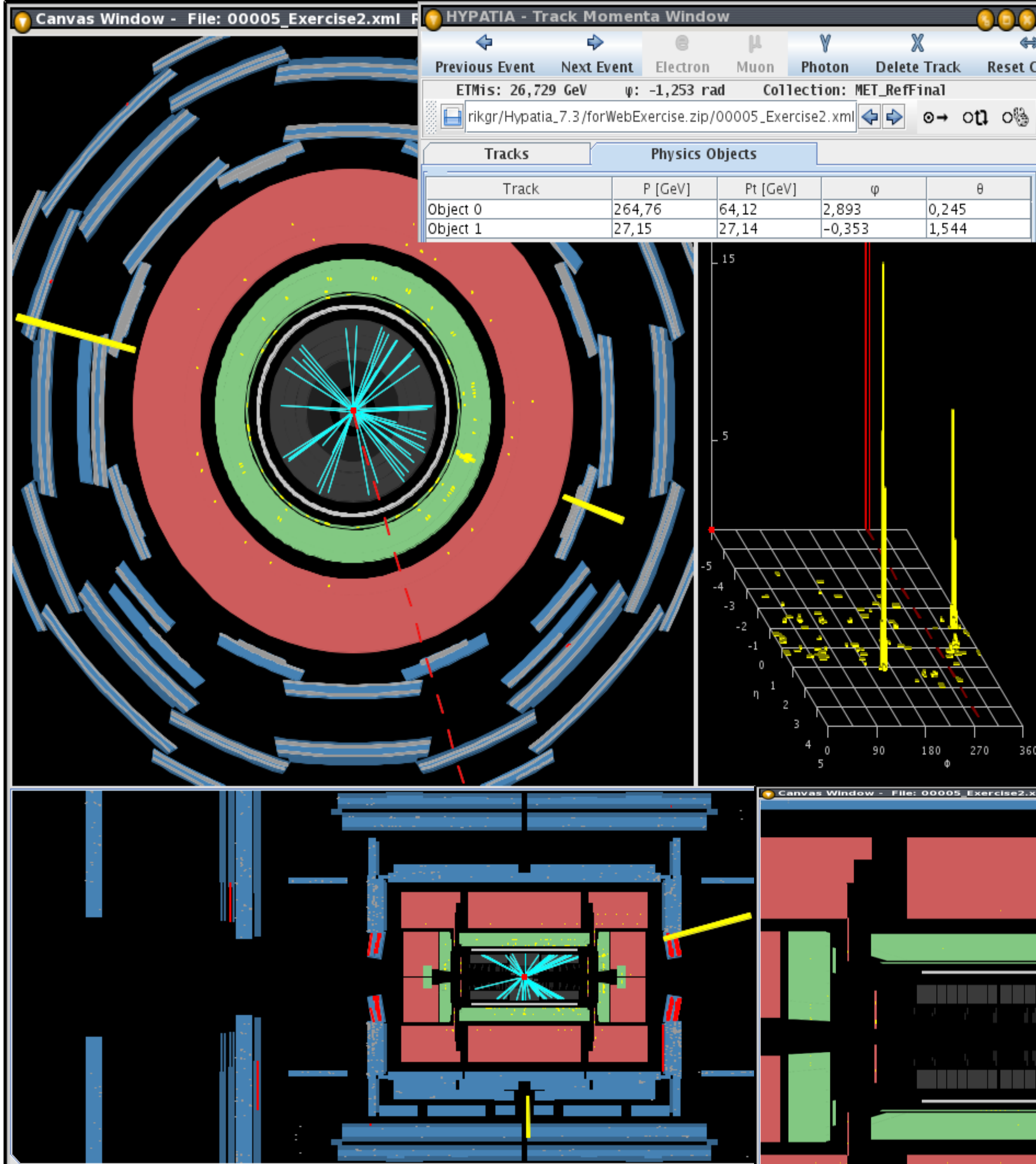
Muon

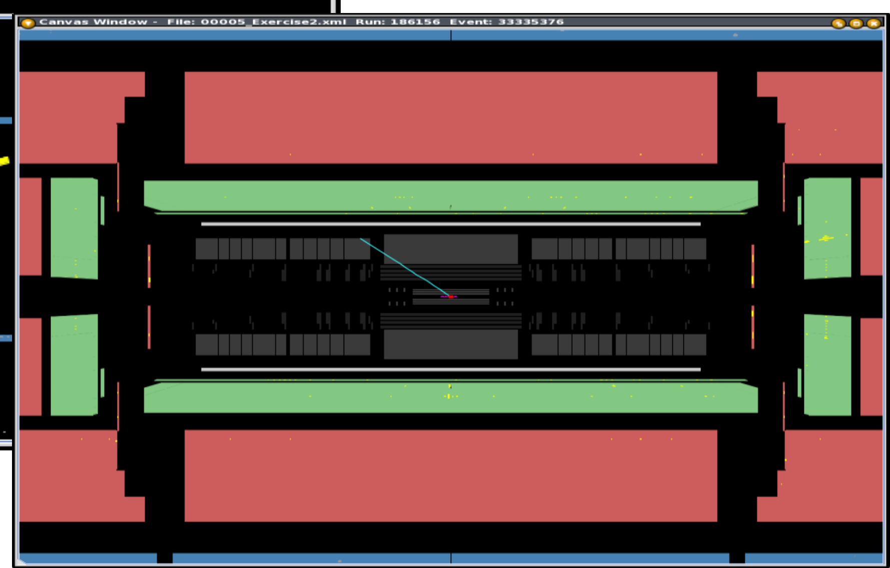


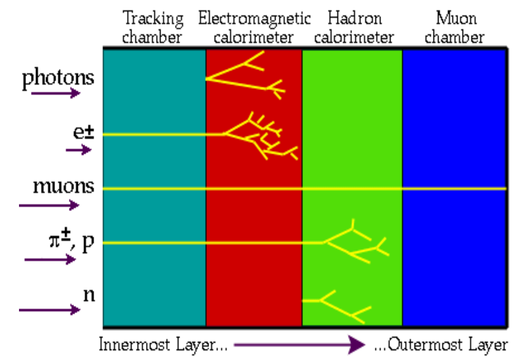
Muon chambers that are hit are colored orange

Some of the hits in the outer muon chambers are due to particles in the cavern

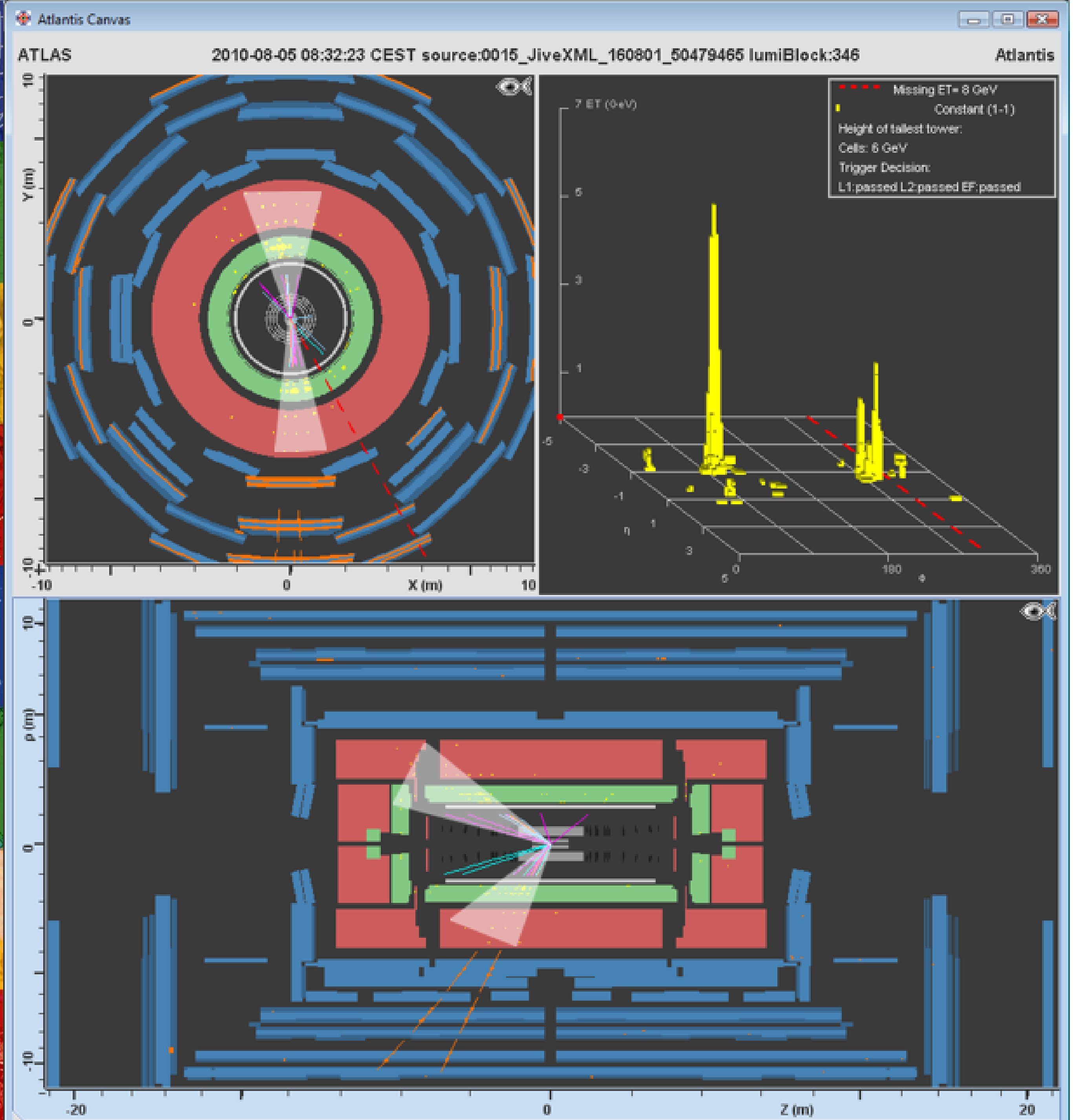
Photon



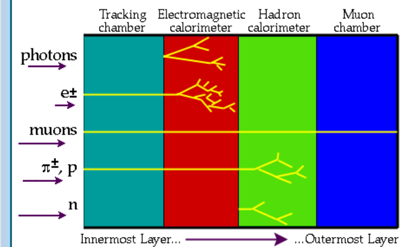




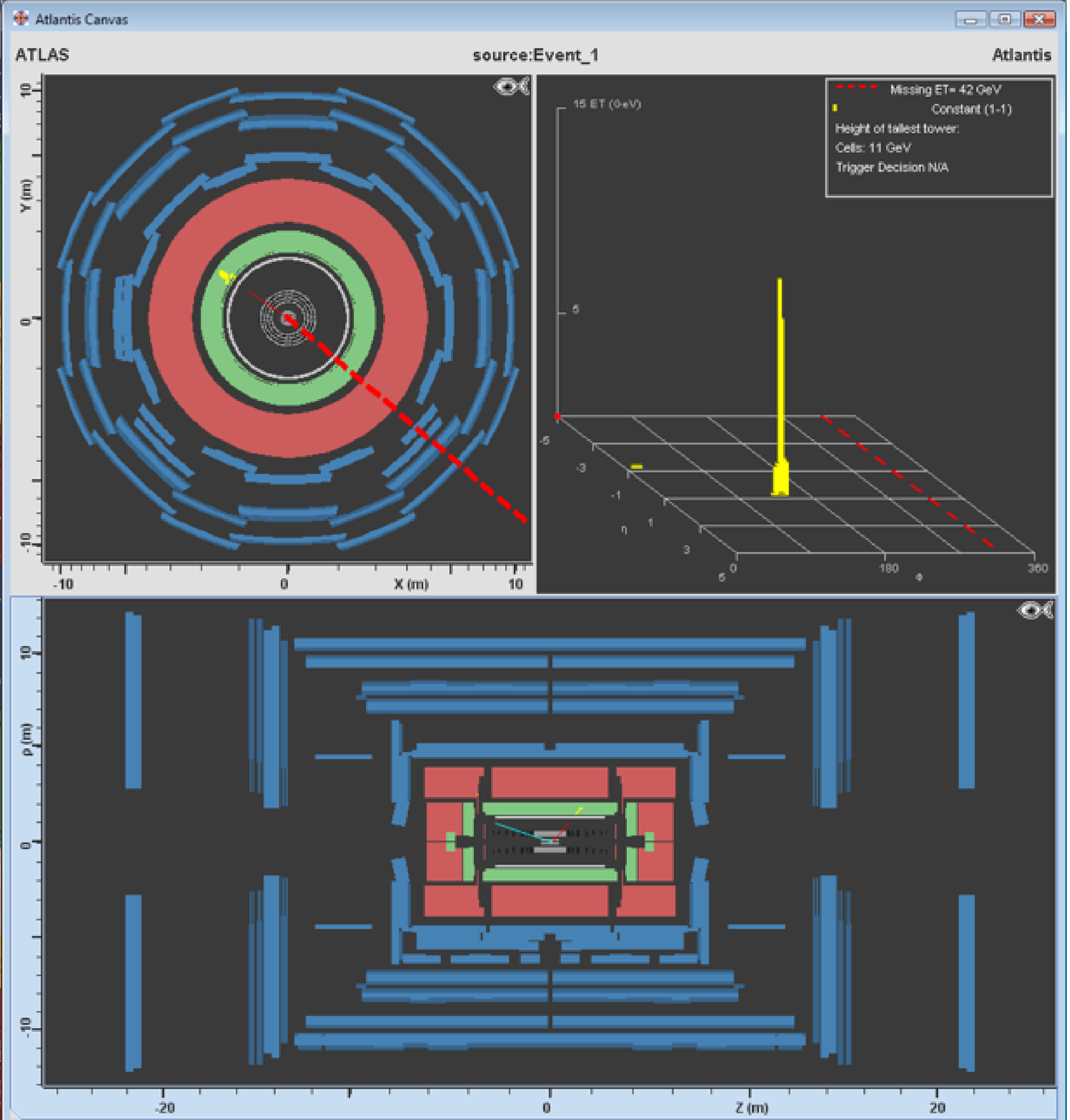
Electromagnetic calorimeter cells fired are marked in yellow



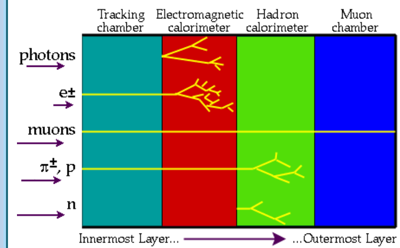
Jets of hadrons



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



Neutrino

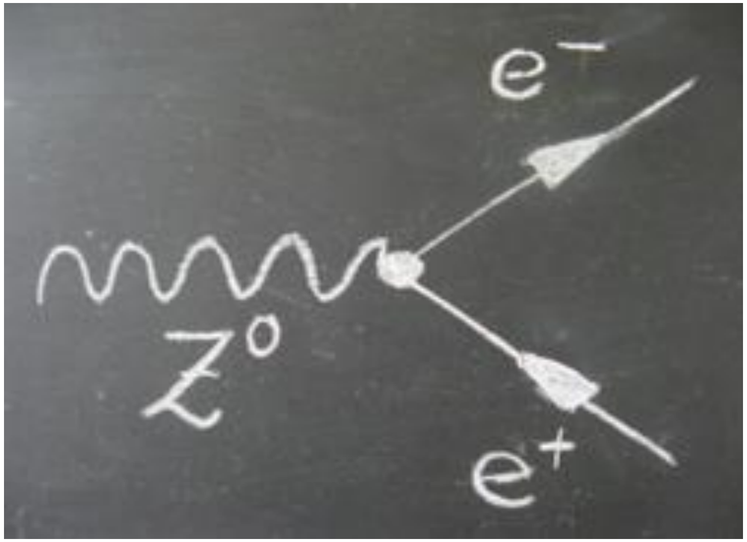


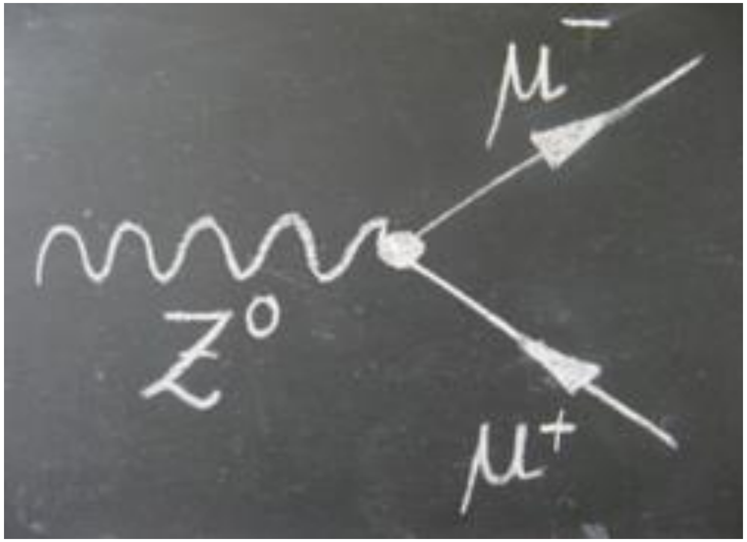
Neutrinos are not directly detected, but inferred from energy imbalance

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

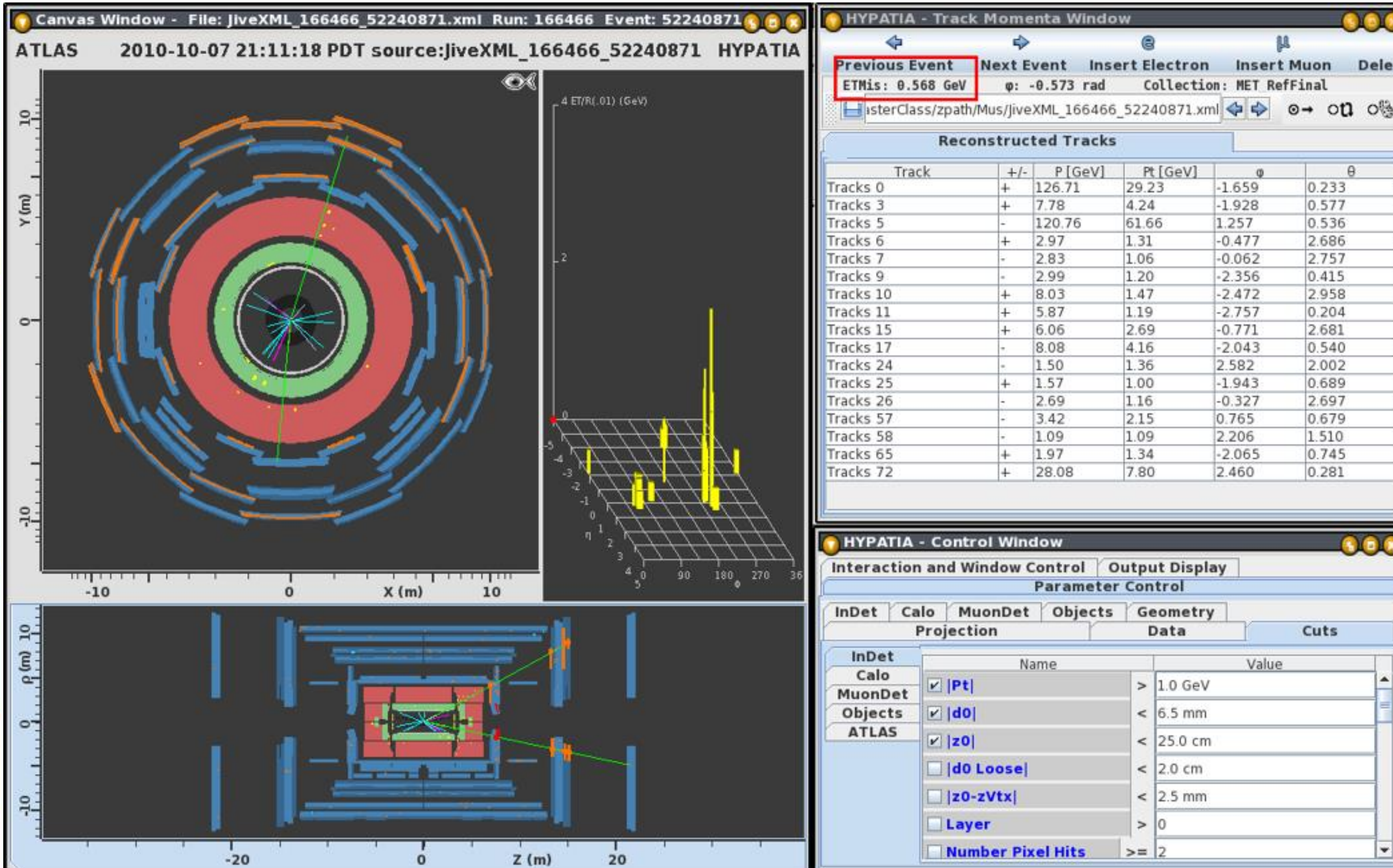
The Z boson

- Responsible for mediating the weak interaction (with the W boson)
- It is not a stable particle – lifetime $3x10^{-25}$ (0.0000000000000000000000003s) → no hope to measure the Z directly!
- Z bosons decay into a pair of fermion and anti-fermion



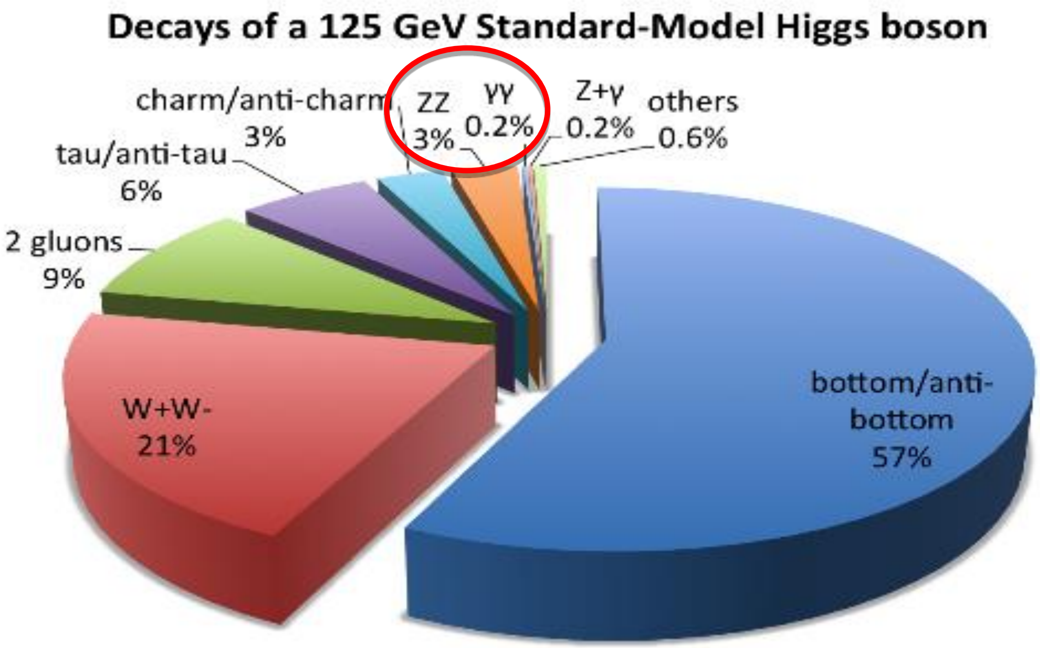


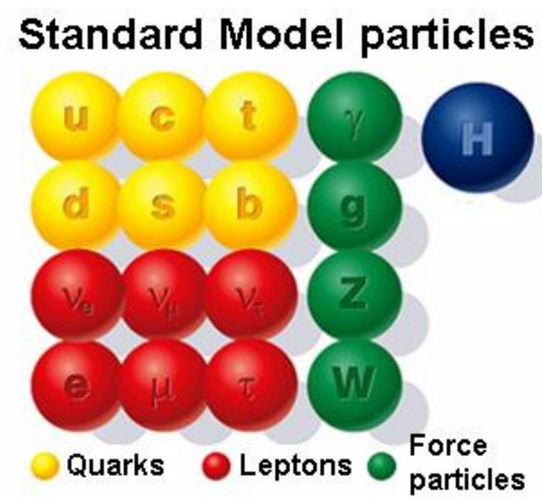
Signal: Z->$\mu^+\mu^-$



The Higgs Boson

- **Responsible for the mass of all particles**
- **It is not a stable particle – lifetime 1.5×10^{-22} (0.00000000000000000000015s) → 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)**



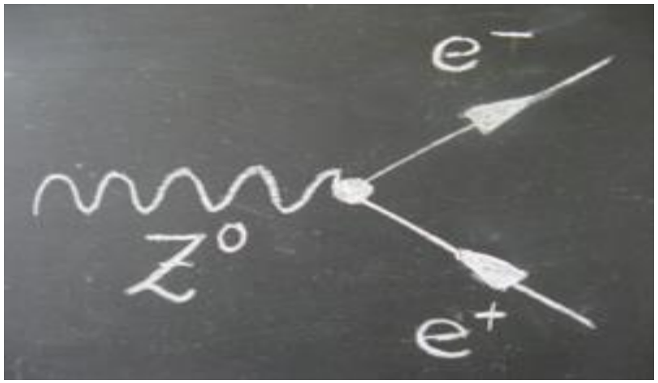


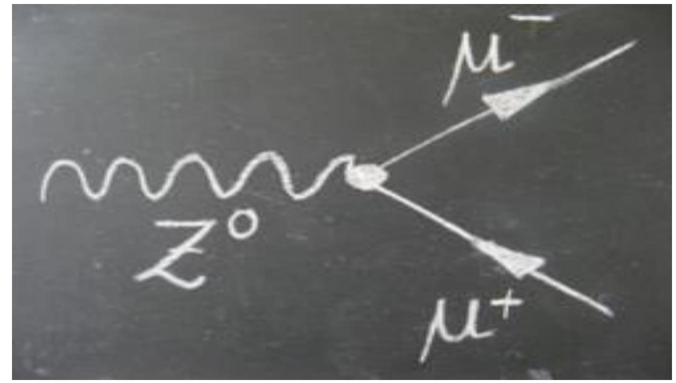
Today we are interested only in two decays: ZZ (and γγ, if you want)

Why these two decays and not the most probable one in bb?

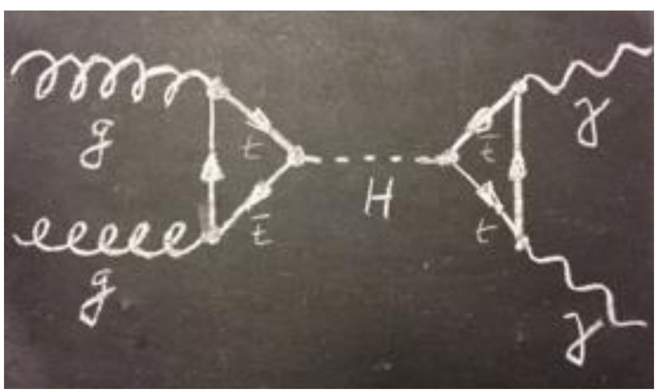
Signals summary

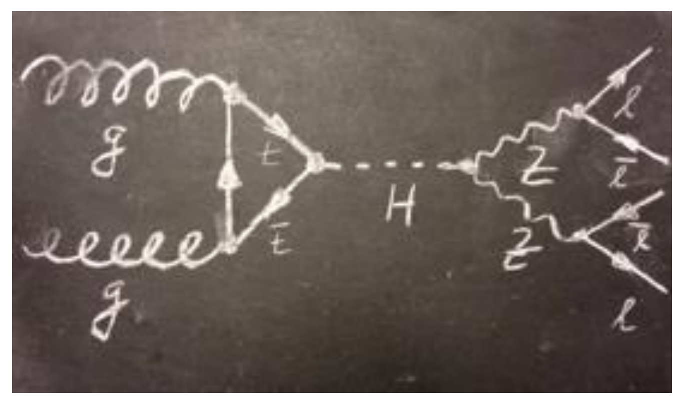
Z boson – electrically neutral mediator of the weak force





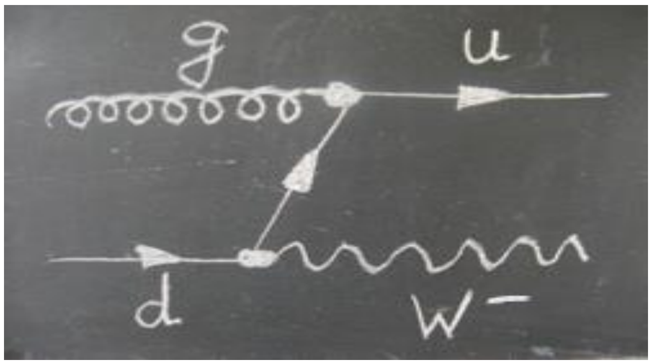
H boson – electrically neutral responsible of the mass of all elementary particles

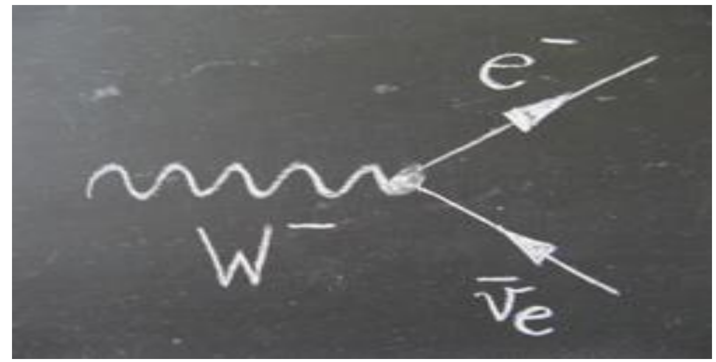




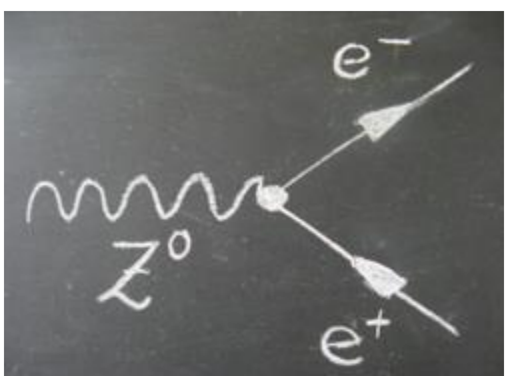
Background (fondo) events

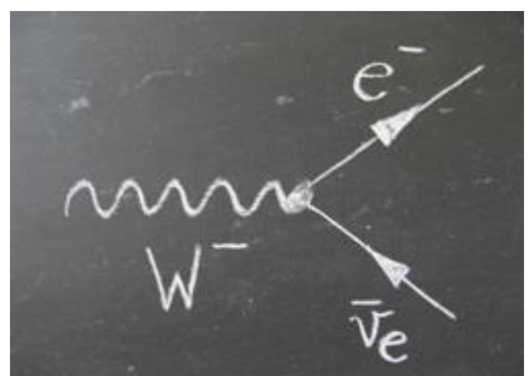
- In any pp collision, a lot of particles are produced! Not only Z and H…
- But we reconstruct Z and H (signals) based on their decay products: muons, electrons and photons
- All other physics processes producing muons, electrons and photons are called background events





- 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!