The W boson at the ATLAS experiment

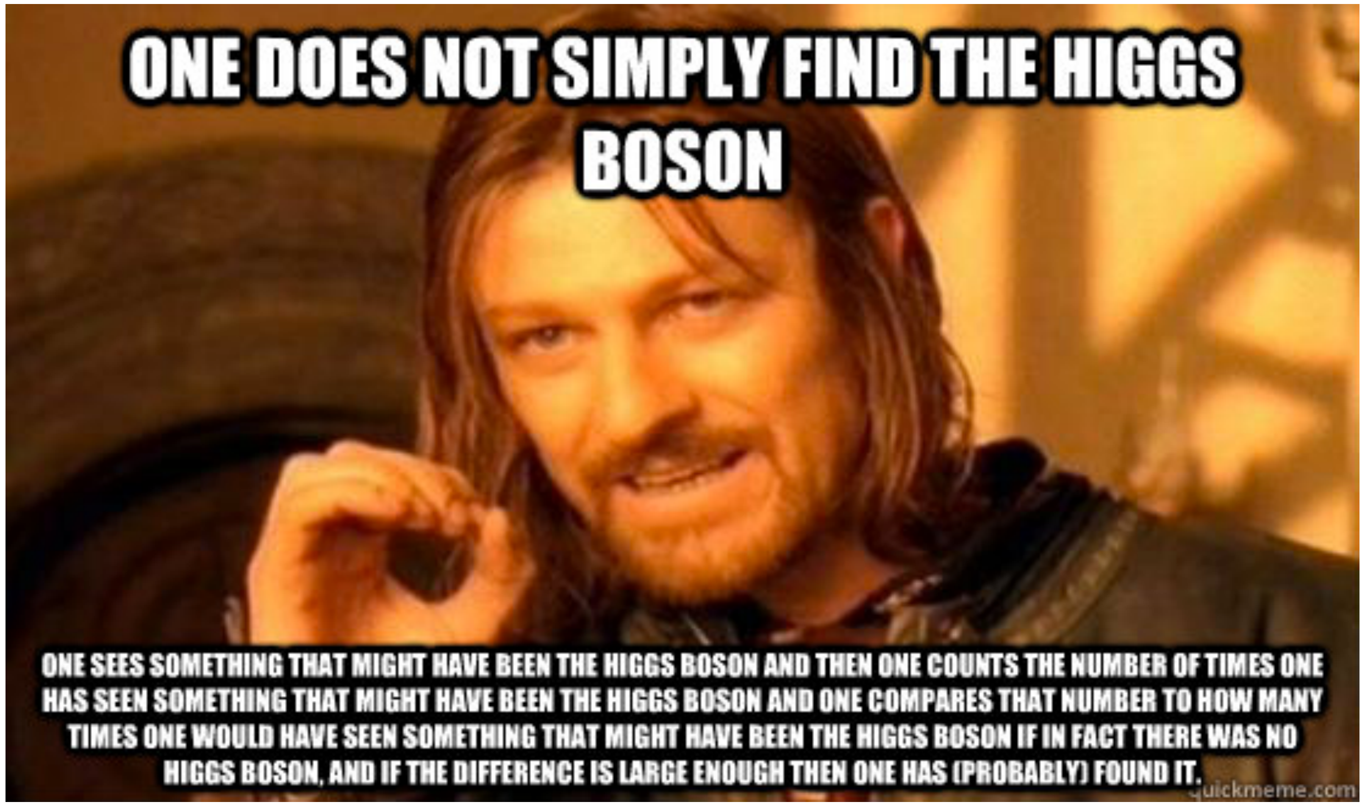
IP3

INTERNATIONAL MASTERCLASSES
hands on particle physics

Durham University

Today’s Activities

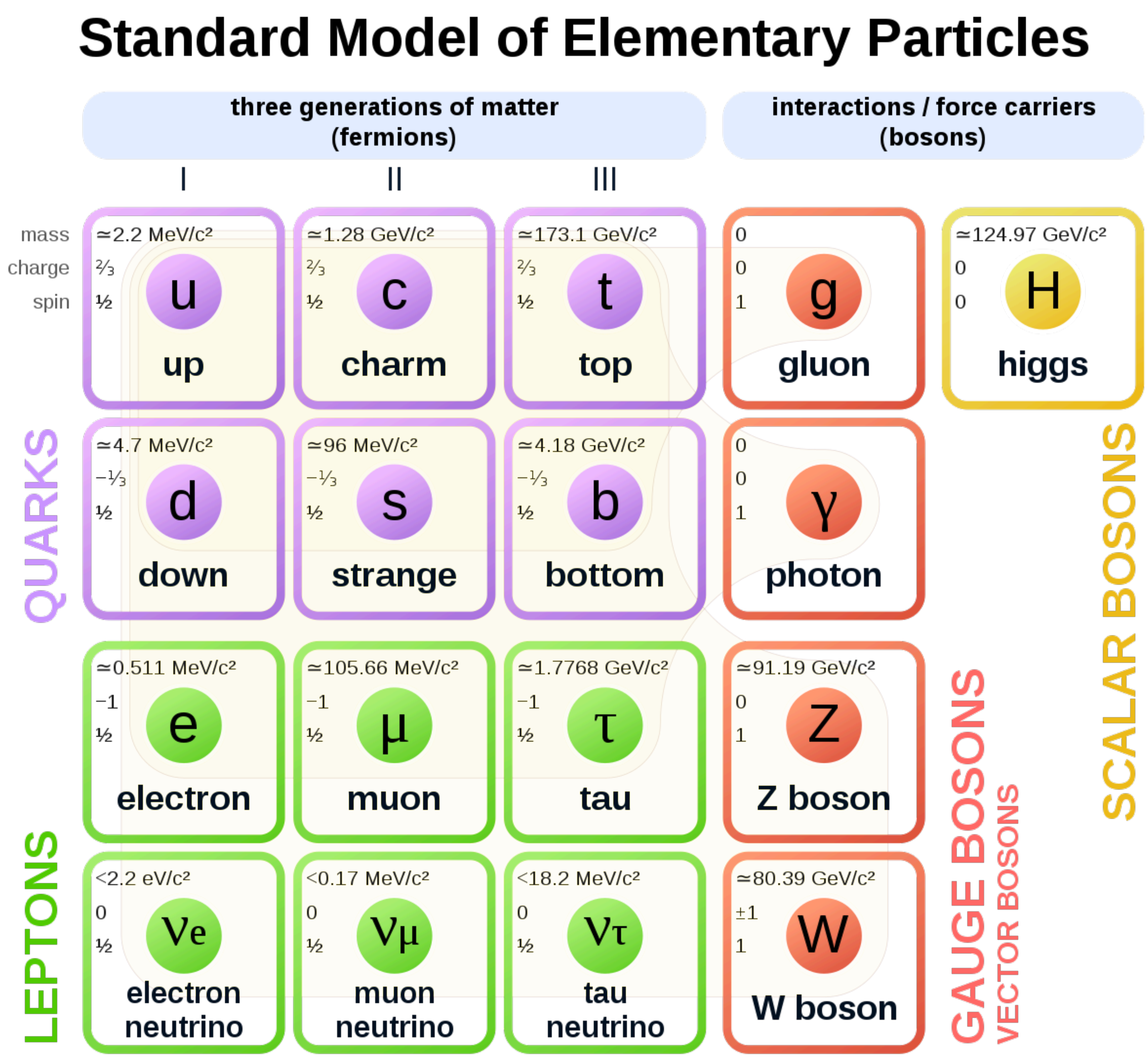
- We have two activities today, related to the W boson.
- 1) You will study the structure of the proton
- 2) You will search for the Higgs boson



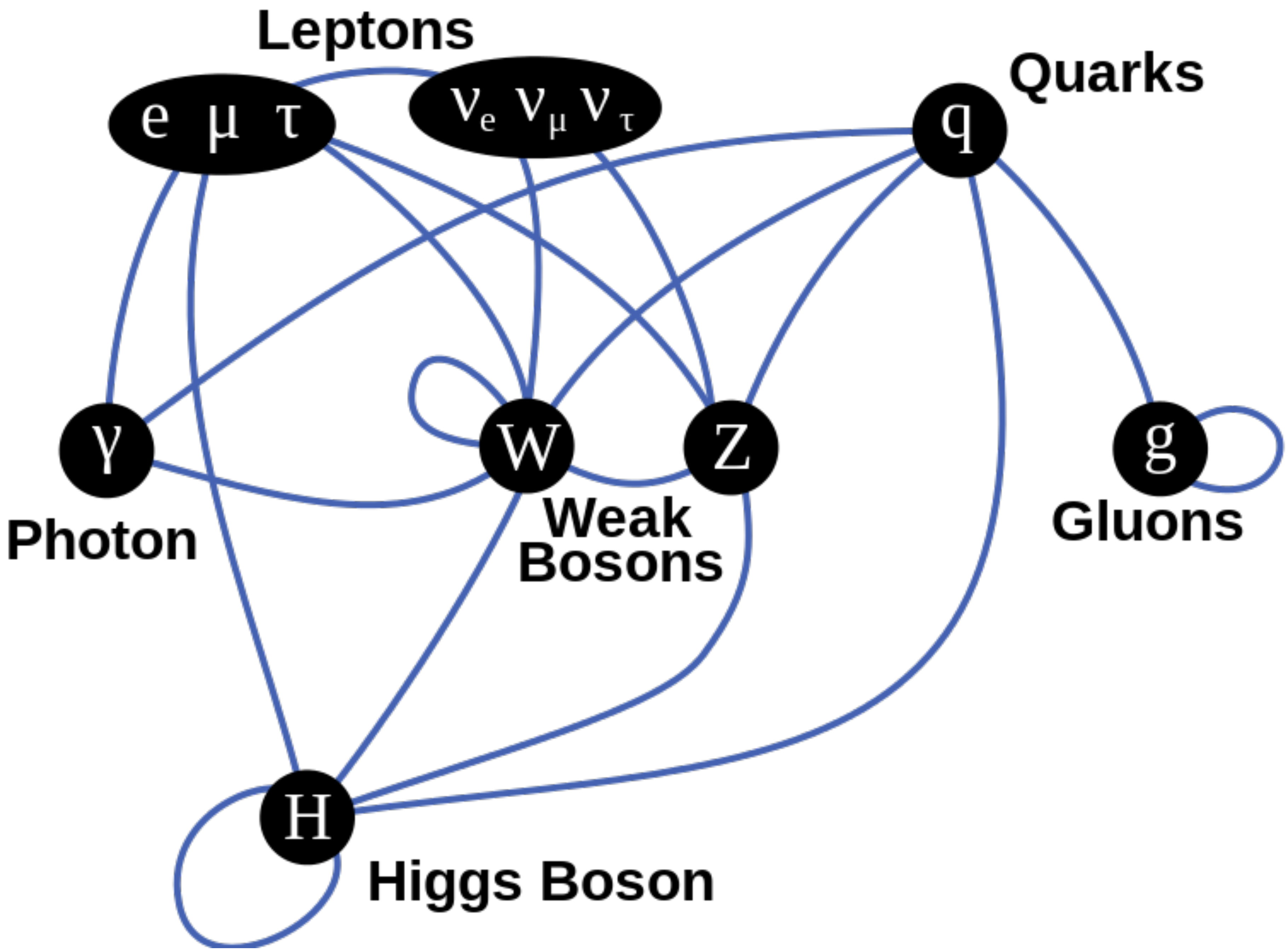
What is the W boson?

- As you heard in the first talk today, one of the four fundamental forces, is the weak nuclear force.
- As every other force it mediates through gauge bosons.
- Like electromagnetism uses photons, the weak force uses the W and Z bosons. In today's activity we'll mostly focus on the W but we'll still need some information about the Z as well.
- Unlike the Z, W boson is charged and thus there are two versions of it, one positively charged (identified by +) and one negatively charged (identified by -)

The Standard Model

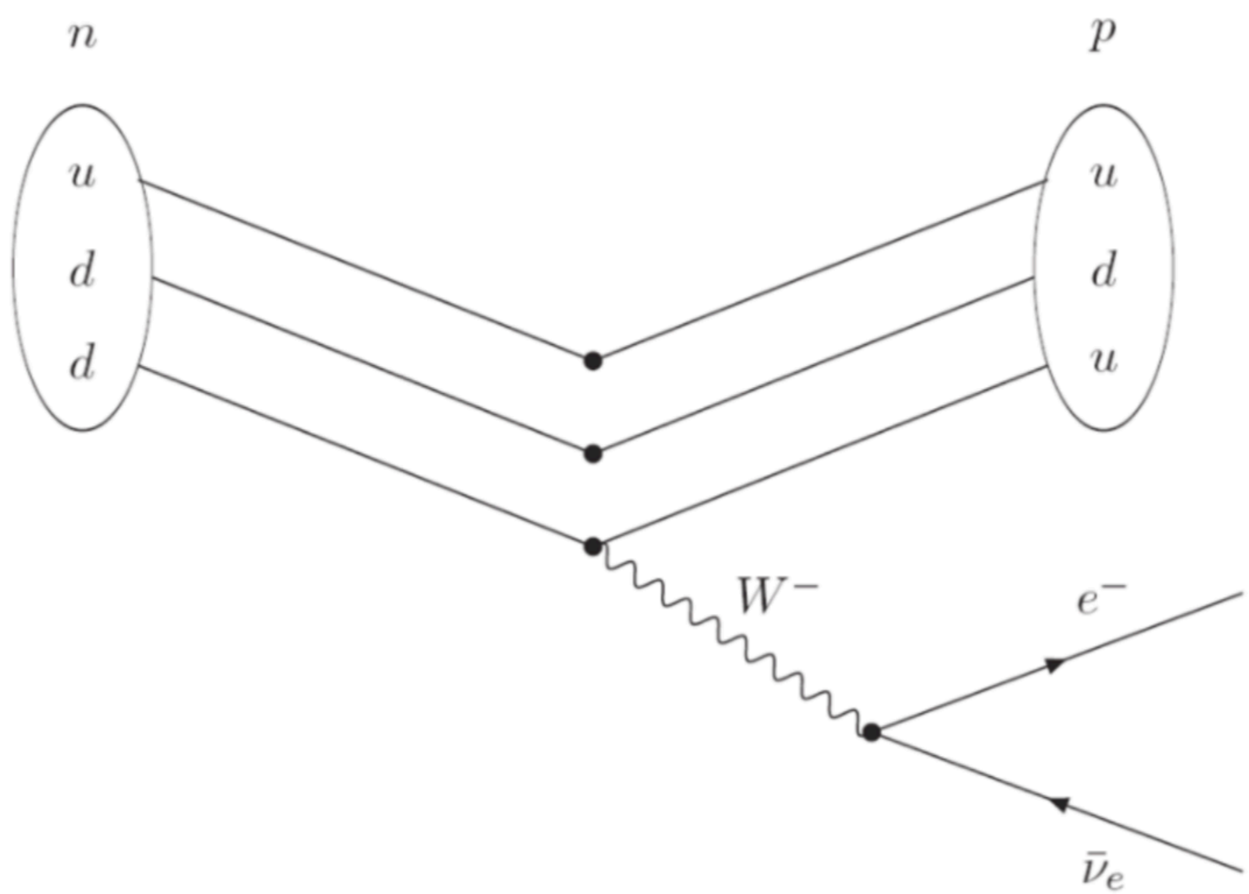


The Standard Model



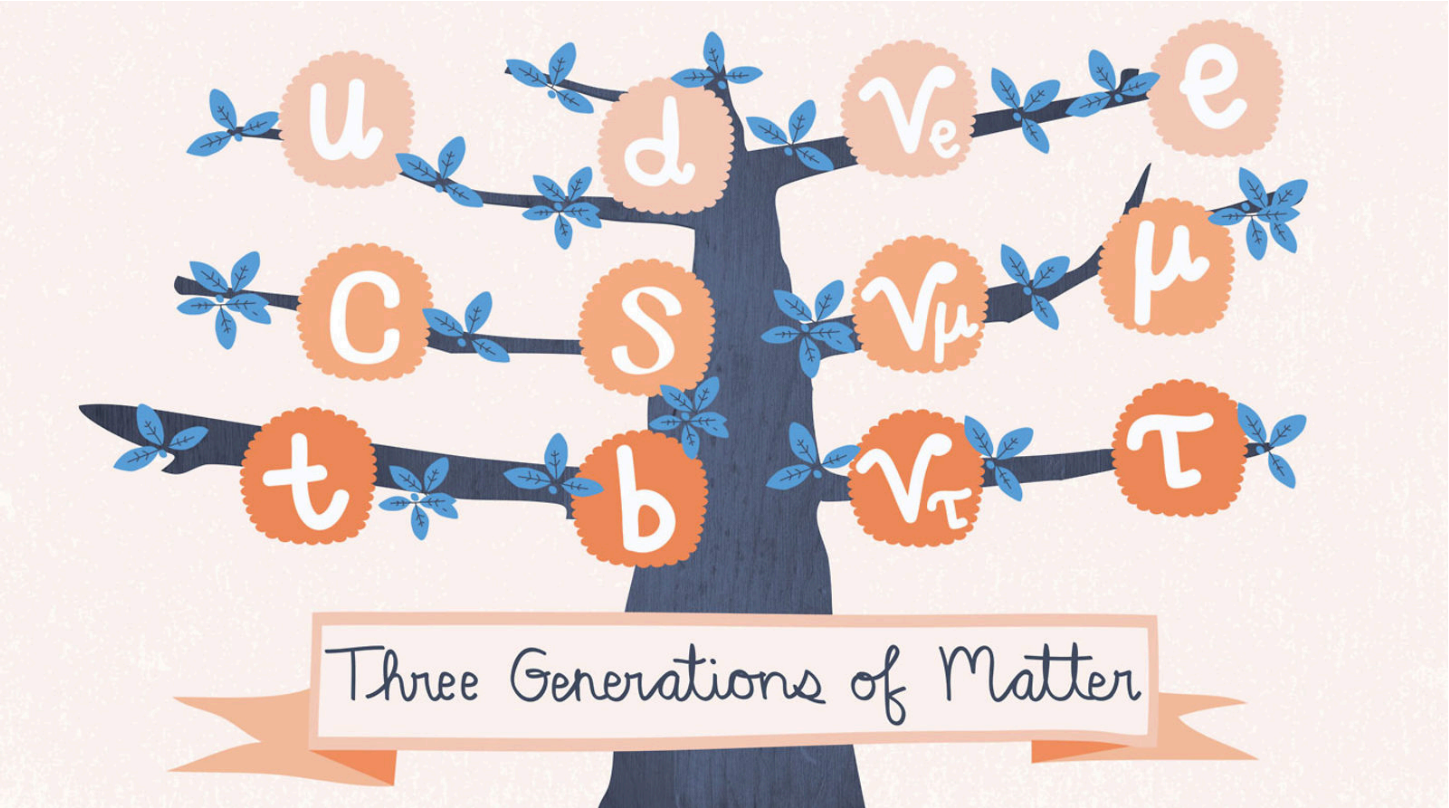
Weak Physics

- What is weak interaction responsible for?
- It is the force that drives radioactive decays and is responsible for the mechanism that powers our sun, and all other stars in general.



Why study the weak force?

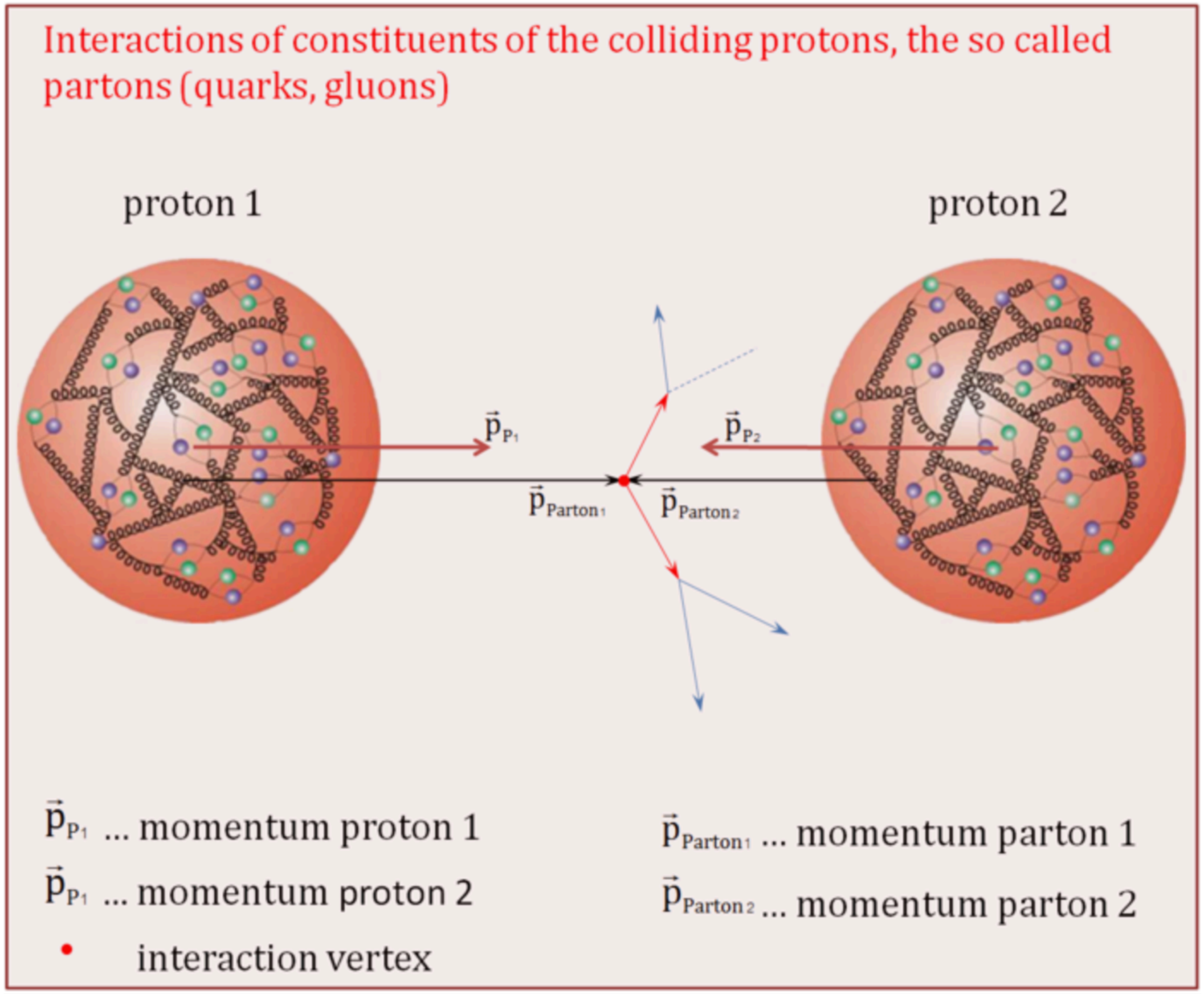
- As mentioned it is responsible for radioactive decays
- Its study can also help us understand the physics during the earliest stages of our universe.
- It is the only mechanism that allows different generations of fermions to interact.

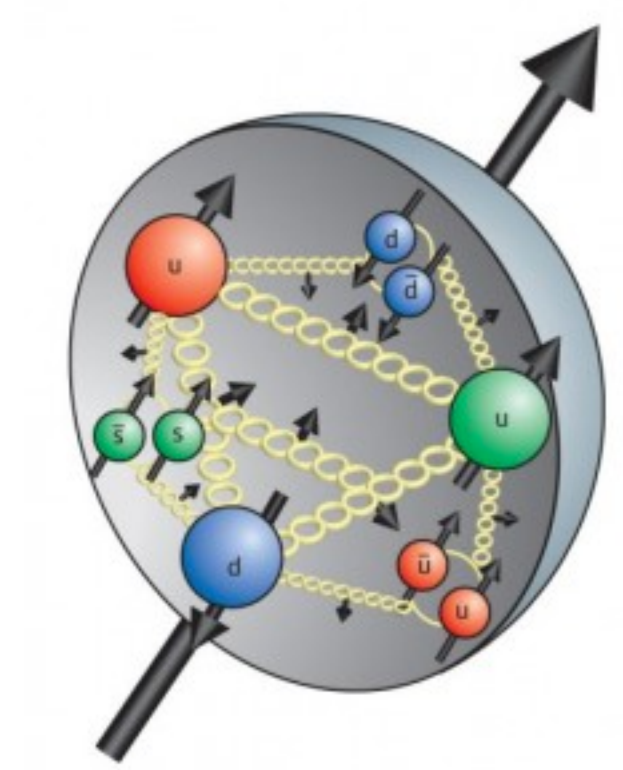


How do we find the W boson

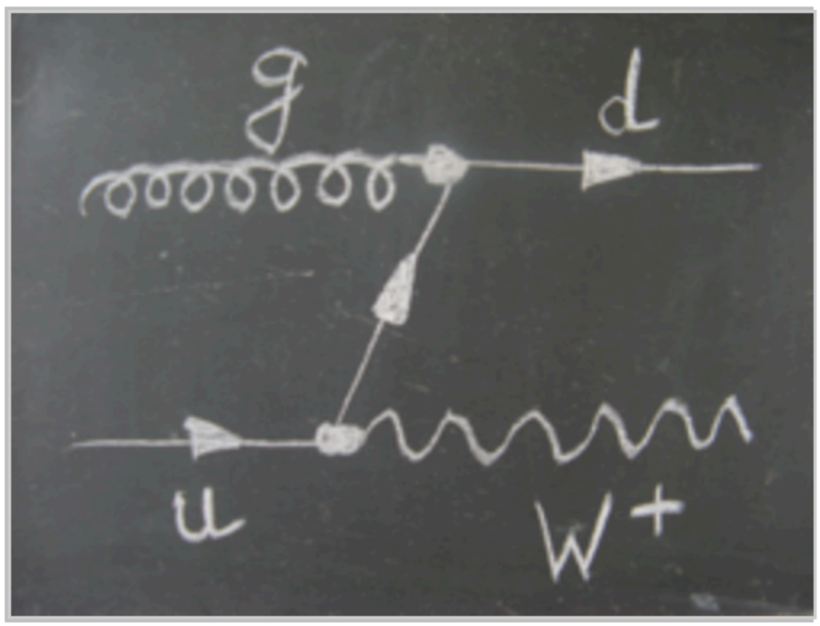
- Can we see the W or Z boson in our detectors?
- No. Unlike the photon, W and Z are massive particles and thus very unstable. That means they will decay into lighter particles before they reach our detectors.
- We identify them by looking for their products in the experiments.
- But in LHC it’s protons that collide with each other. How are W and all other particles created?
- Let’s see what are the production channels of W boson.

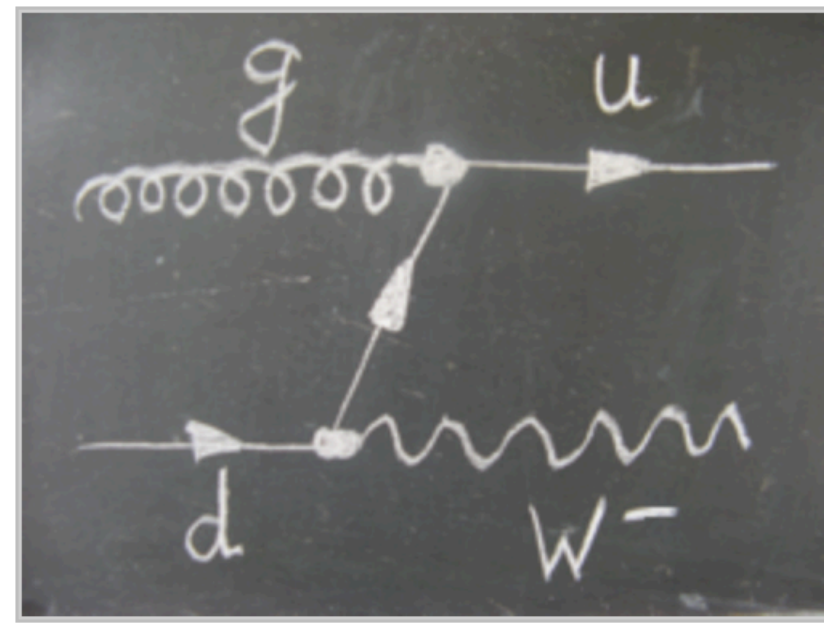
Proton Structure

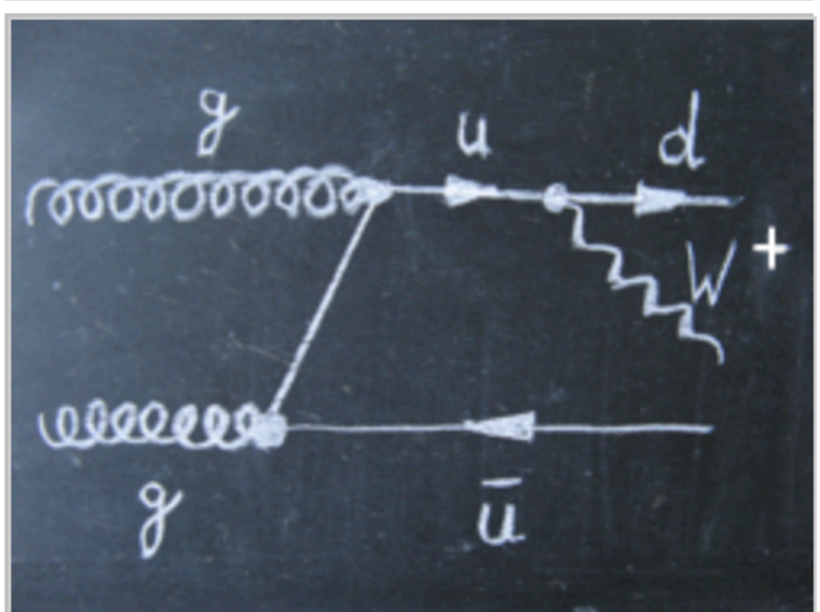


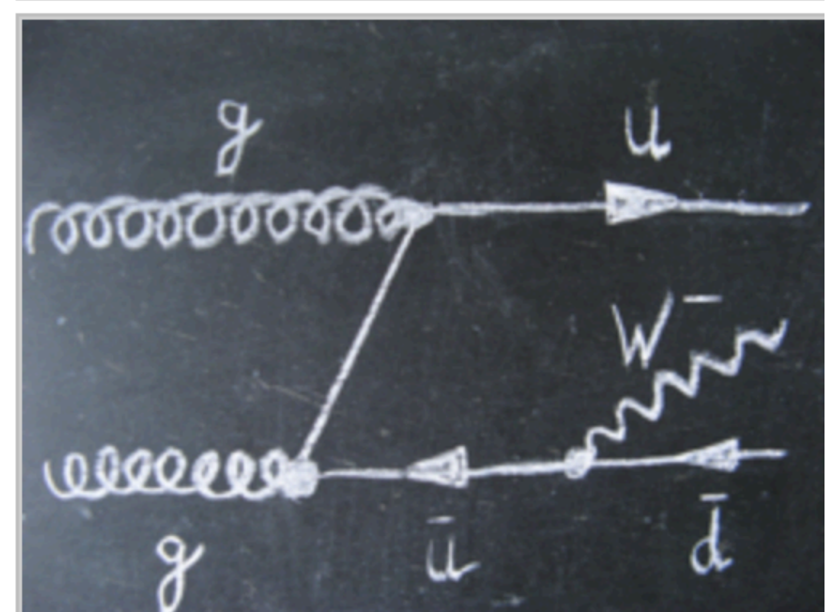


W production at LHC





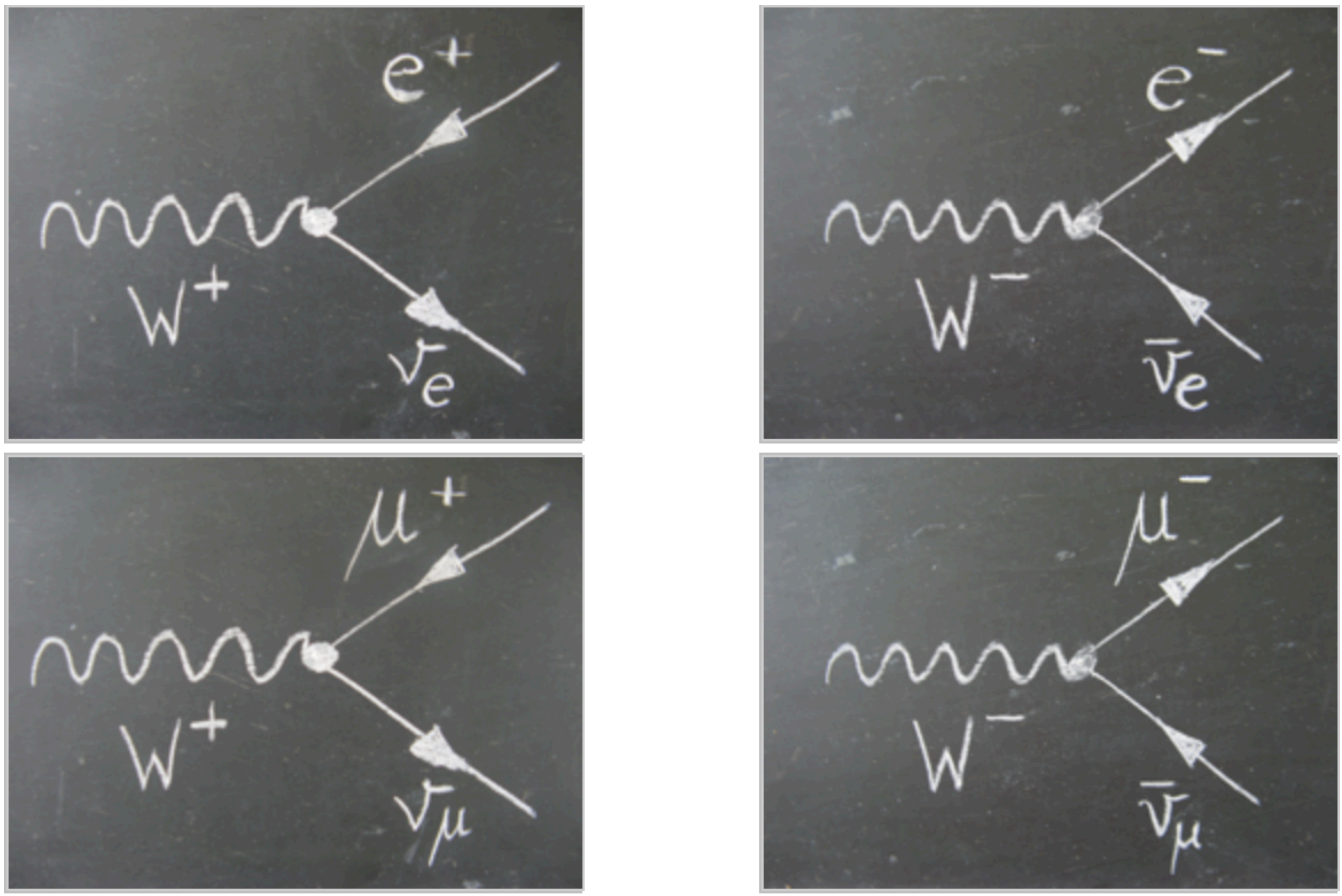




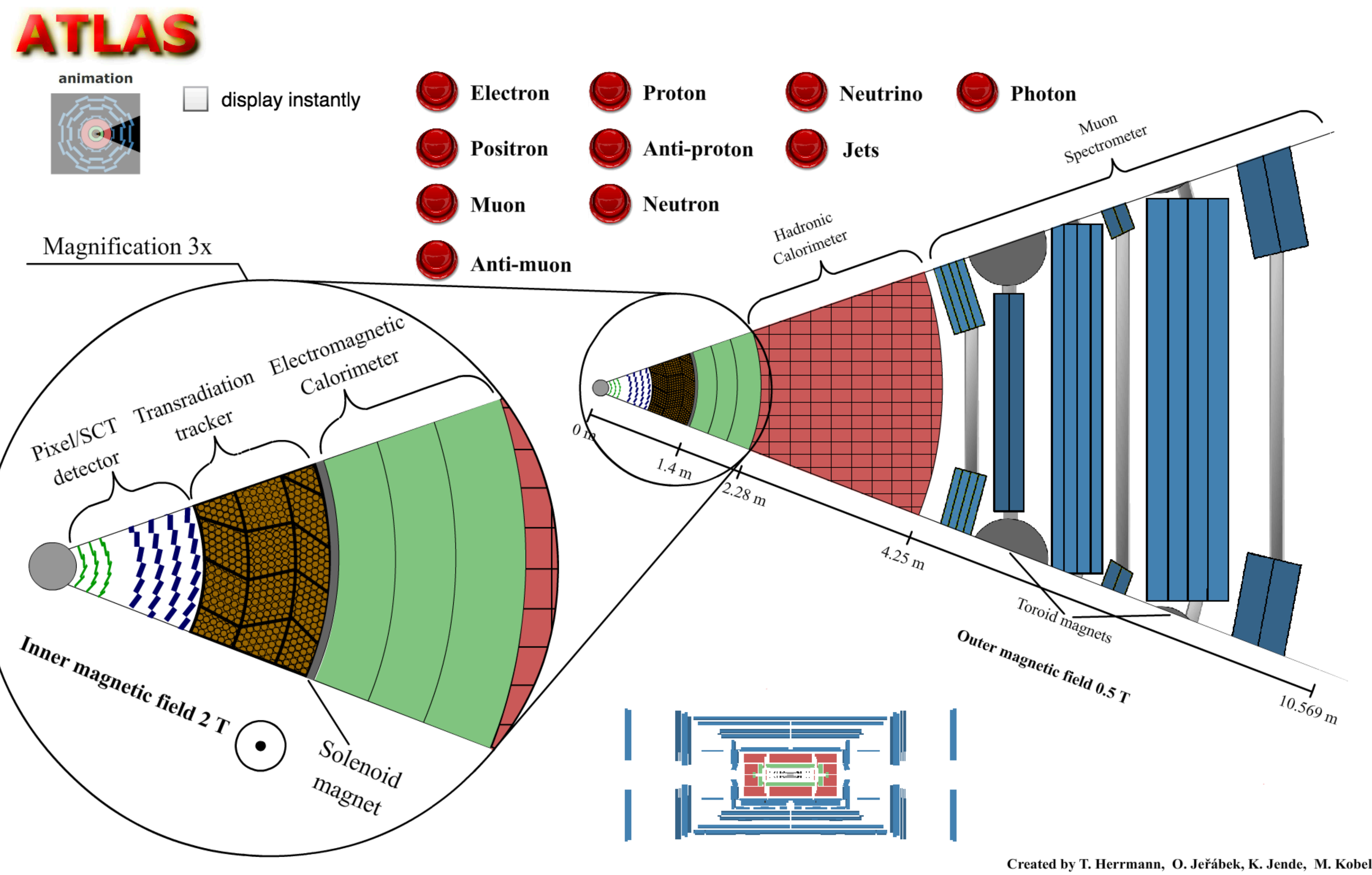
W boson decays

- The W bosons can decay either to charged lepton-neutrino or to a quark-antiquark pair.
- For the first case all 3 possibilities (electron/muon/tau) are equally likely and sum up to 1/3 of all W decays.
- In the quark case, the probability depends on the flavour of the produced quarks but it sums up to the remaining 2/3 of all W decays.
- Does it mean it’s better to look for this kind of signal while looking for W particles?
- Actually no, the background in this case is vast as quarks will evolve into jets, sprays of particles that can be produced by many other processes that will ruin our picture.
- So although it’s twice more probable for a W boson to decay in quark-antiquark, it is easier to detect it when it decays to leptonic pair because of the background difference.

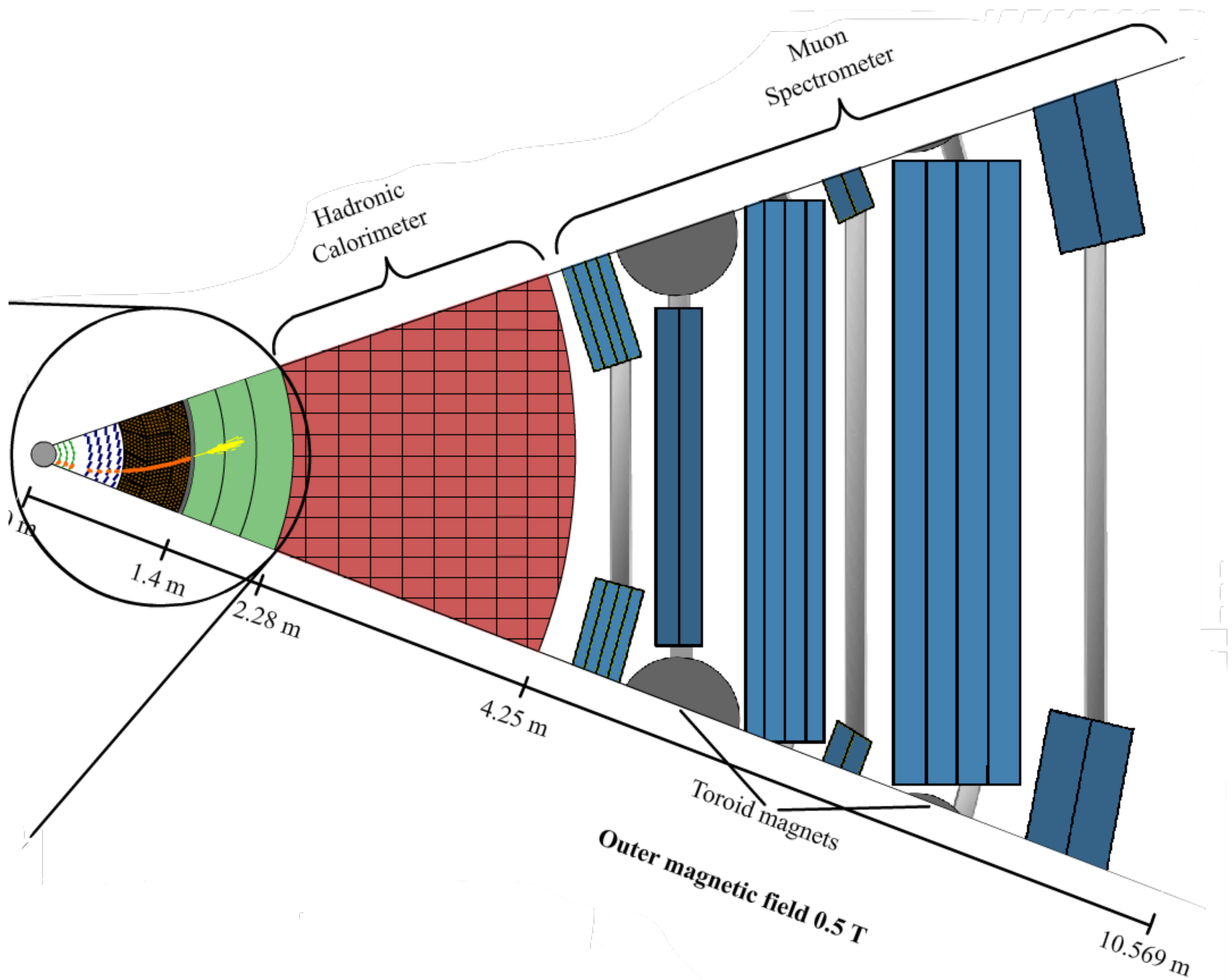
W boson decays

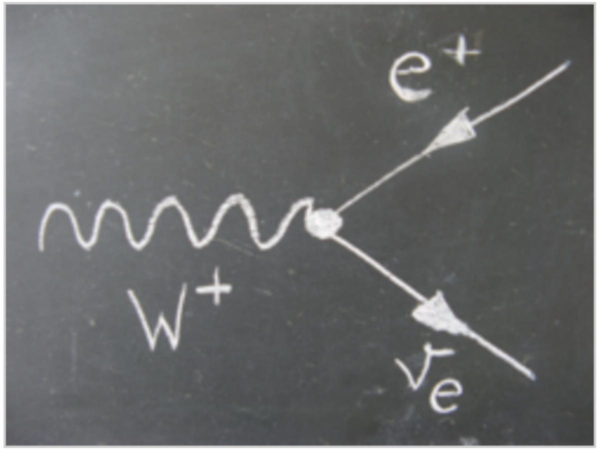


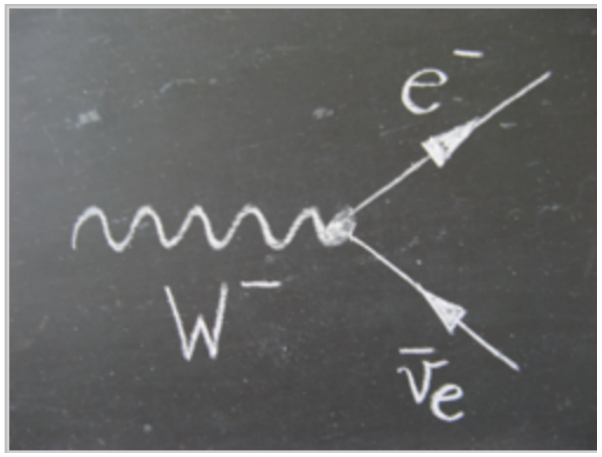
Detectors


ATLAS
animation
display instantly
Electron
Proton
Neutrino
Photon
Positron
Anti-proton
Jets
Muon
Neutron
Anti-muon
Magnification 3x
Pixel/SCT detector
Transradiation tracker
Electromagnetic Calorimeter
Hadronic Calorimeter
Muon Spectrometer
Inner magnetic field 2 T
Solenoid magnet
Toroid magnets
Outer magnetic field 0.5 T
0 m
1.4 m
2.28 m
4.25 m
10.569 m
Created by T. Herrmann, O. Jeřábek, K. Jende, M. Kobel

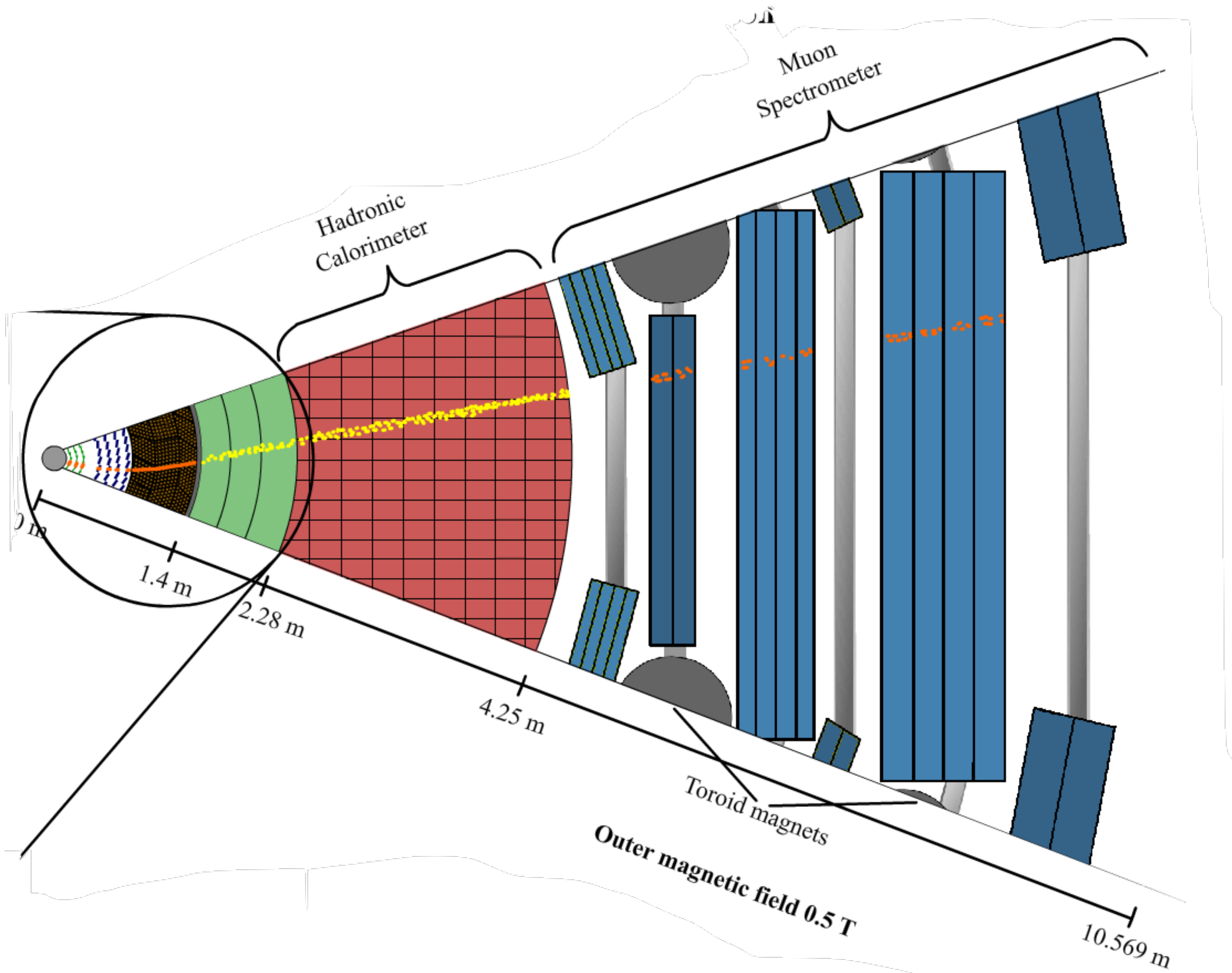
Signal at the detector

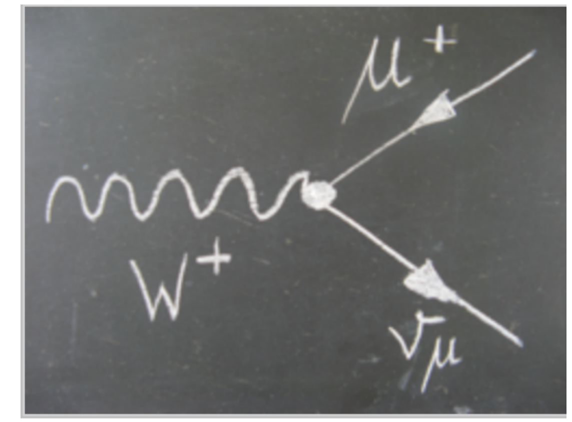


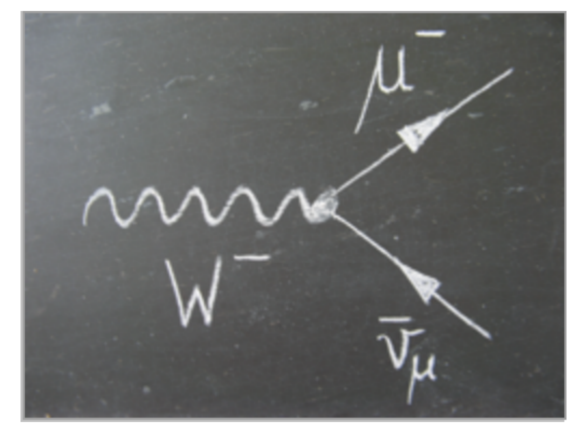




Signal at the detector



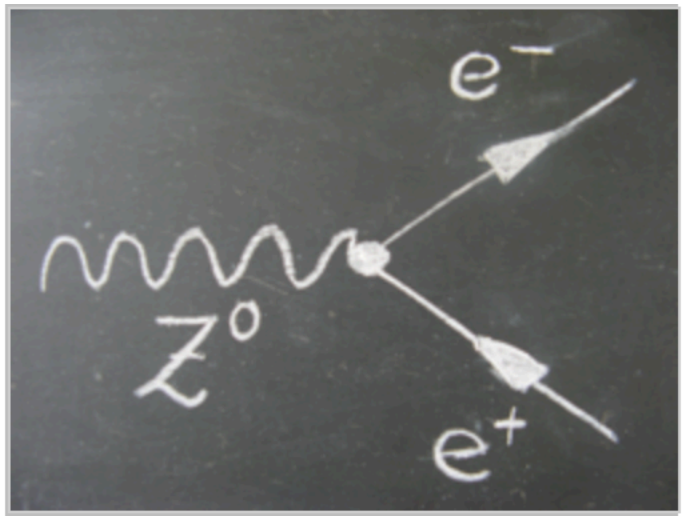


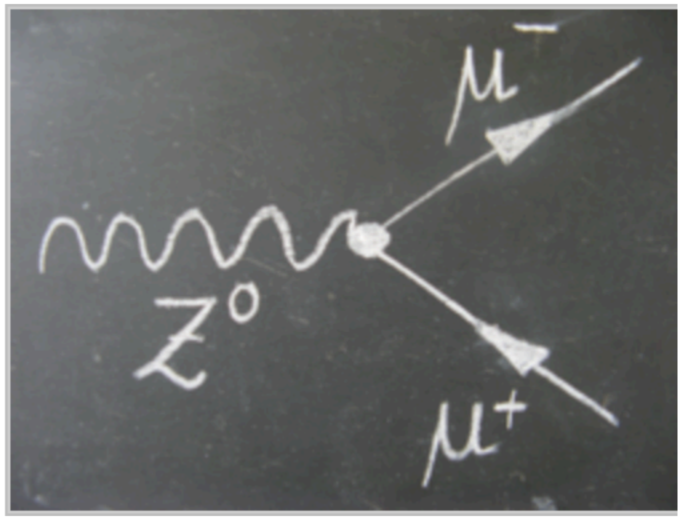


Background

- The trace of a W boson would be the produced lepton. Are we sure though that the lepton we observe in the detector comes from a W boson?

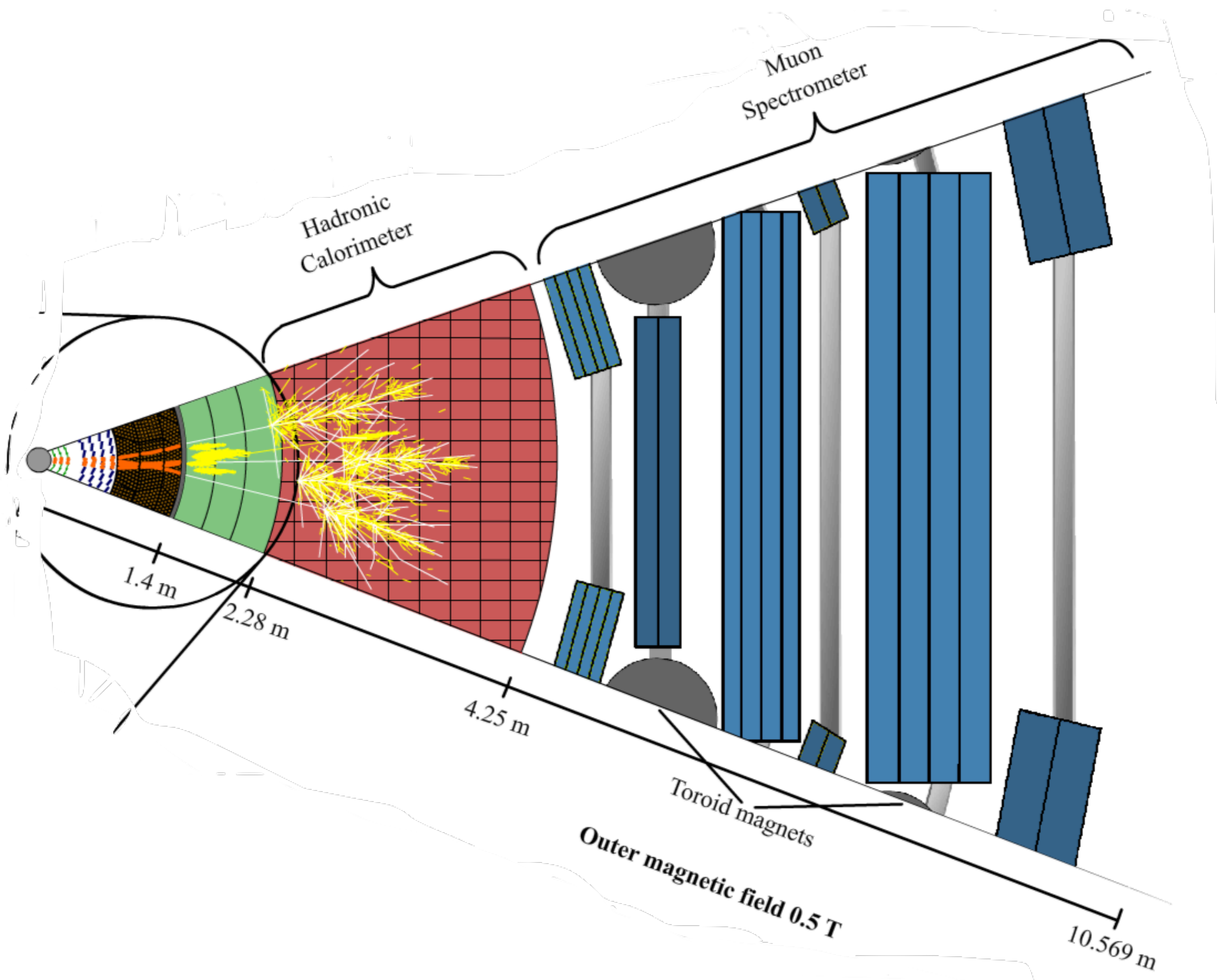
- The answer is no as there are other process that would give similar signals.



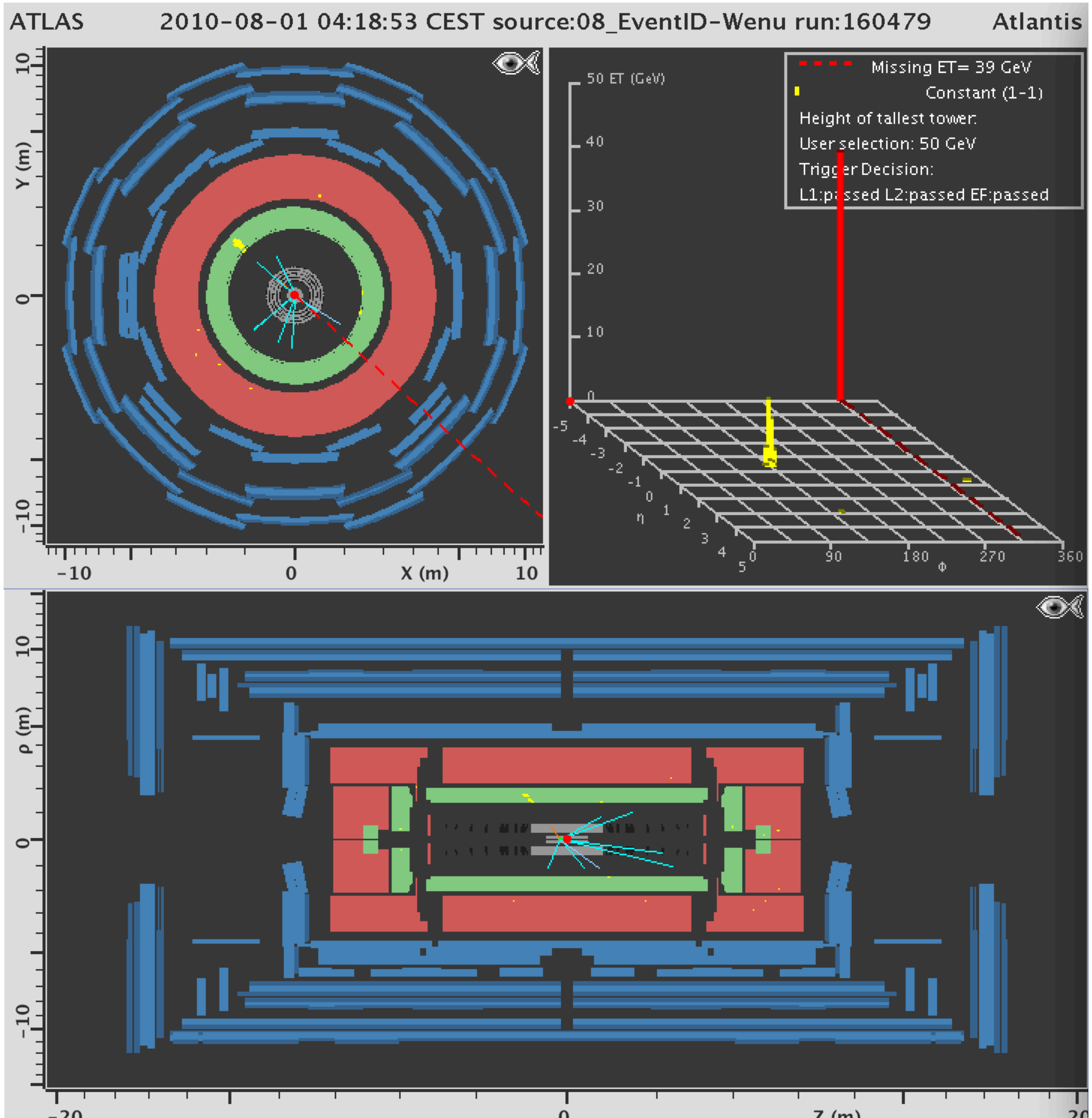


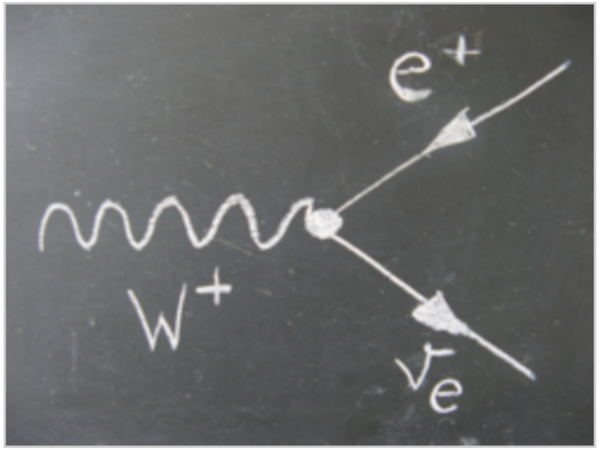
Background in the detector

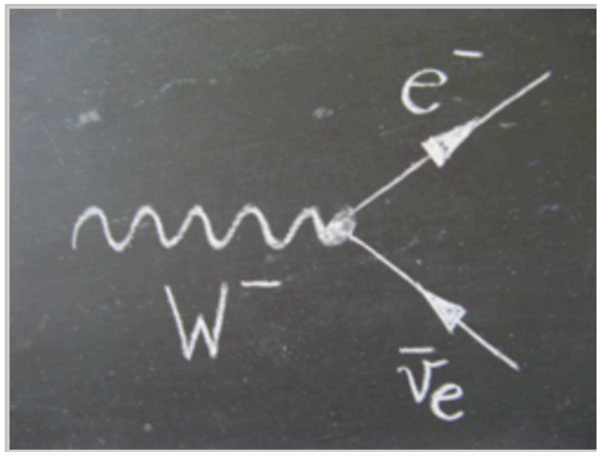
- Jet background as seen in the detector.



Signal in MINERVA



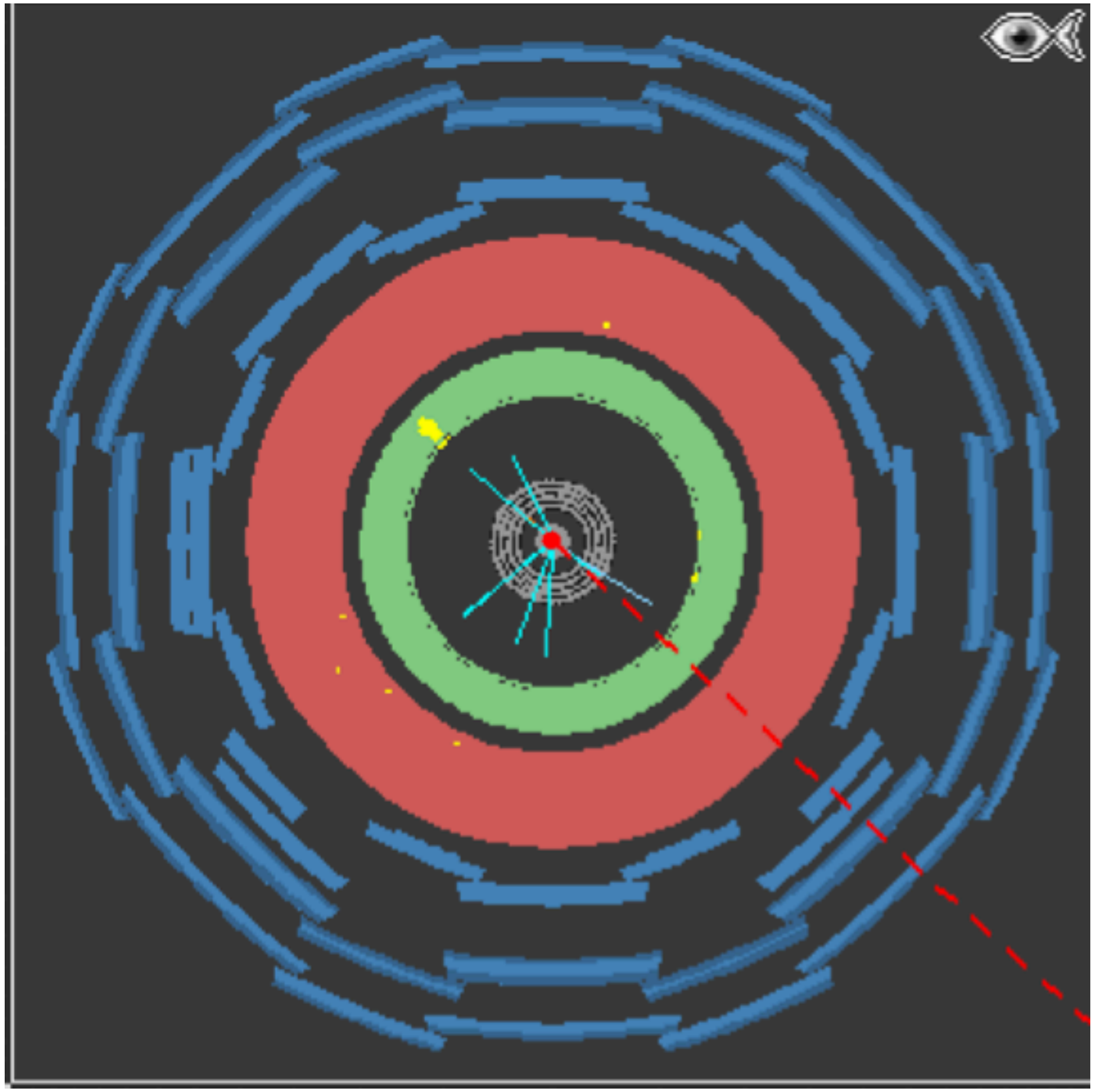


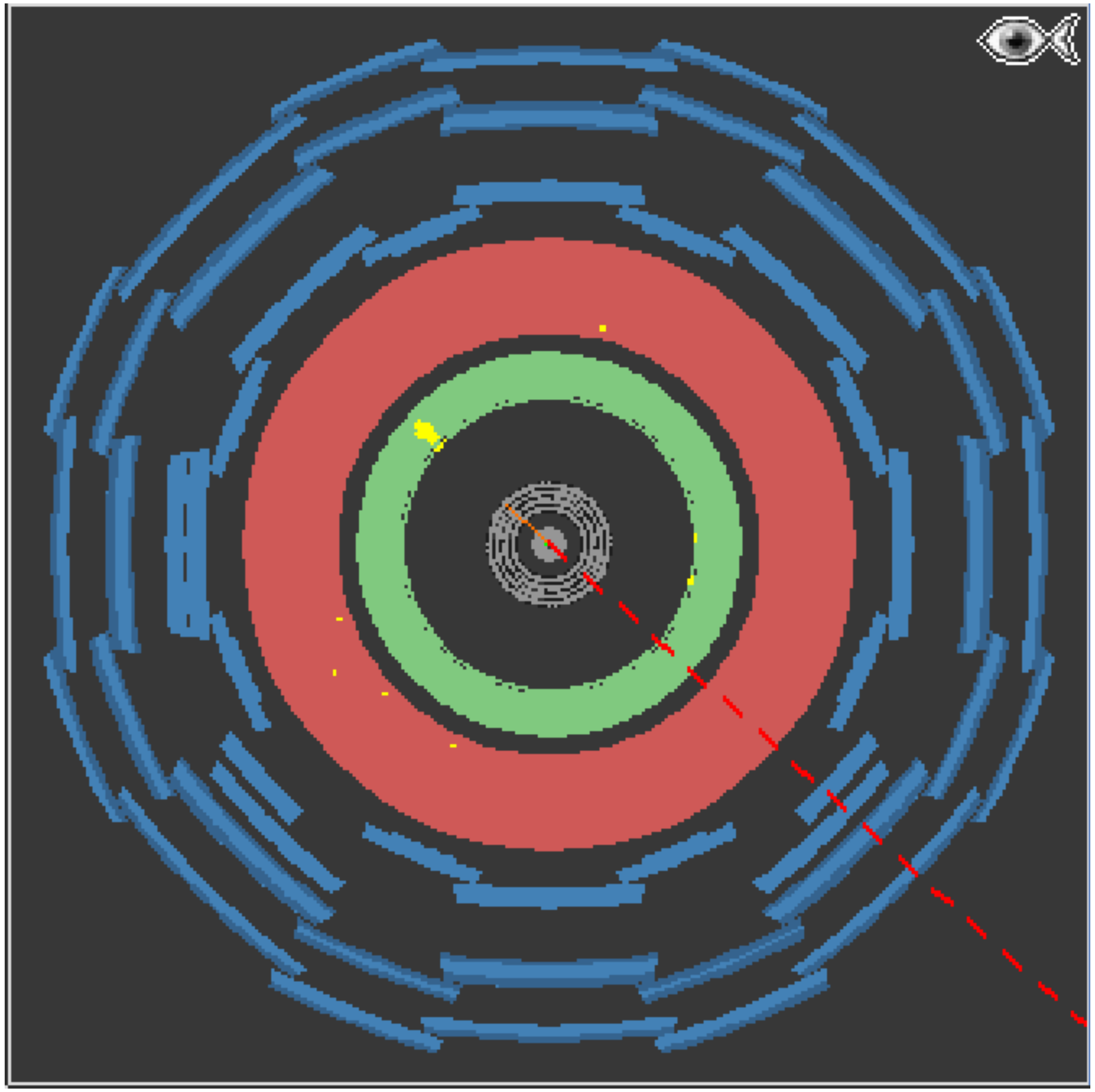


What are we looking for?

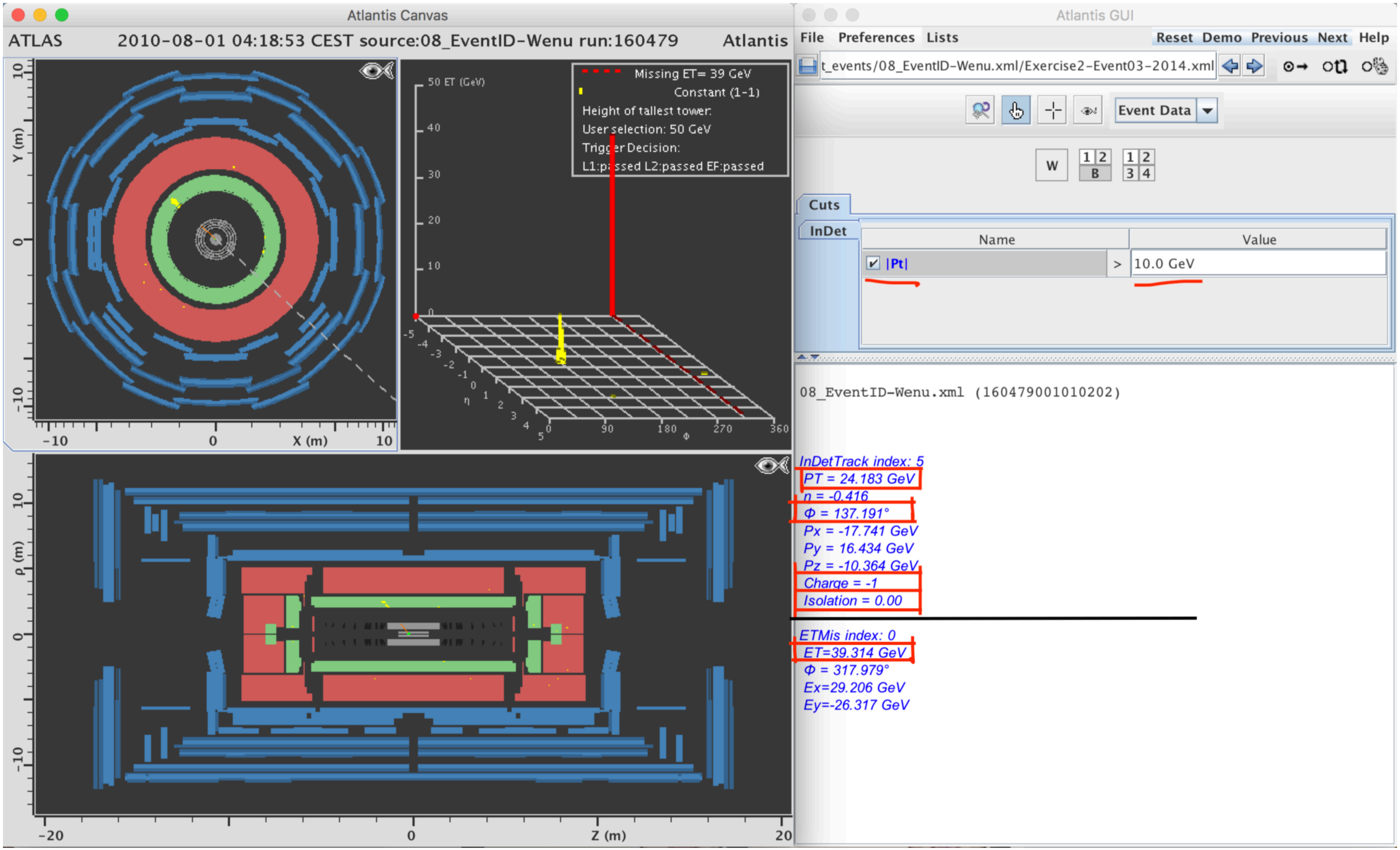
1. **Missing transverse energy (MET)**. Look for events with >20GeV MET
2. **Transverse momentum**. A general cut of >10GeV should be applied to recognise signal.
3. **Transverse angle Φ**. Necessary for Higgs search.
4. **Charge**. Separate electrons from positrons and muons from anti-muons.
5. **Isolation**. Leptons should be isolated enough from jets. A value <0.2 is appropriate.
6. **Finally, the ‘interesting’ tracks should originate from the same vertex**. Zoom in the side view and see if tracks come from the same green circle.

Signal in MINERVA

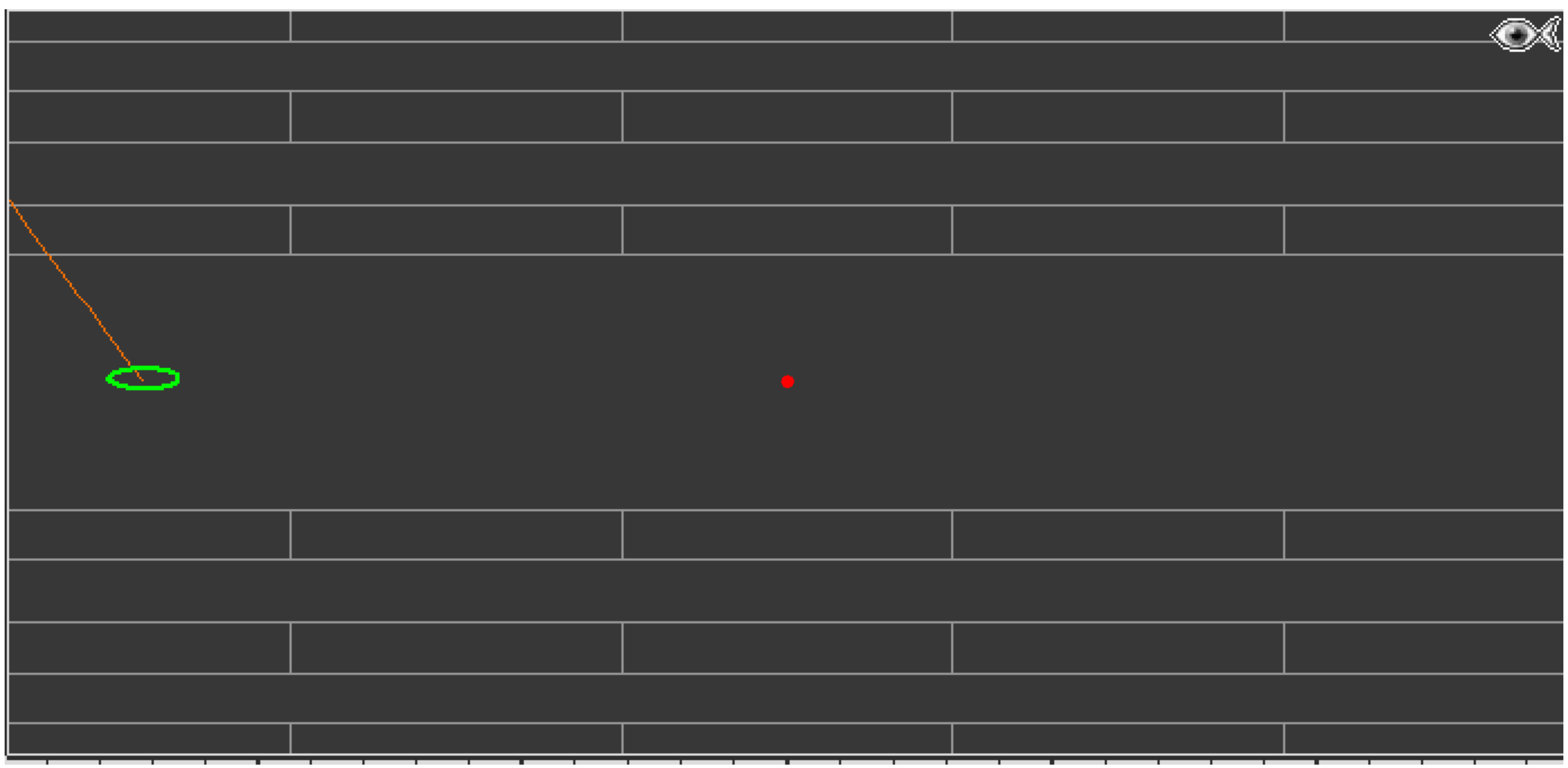




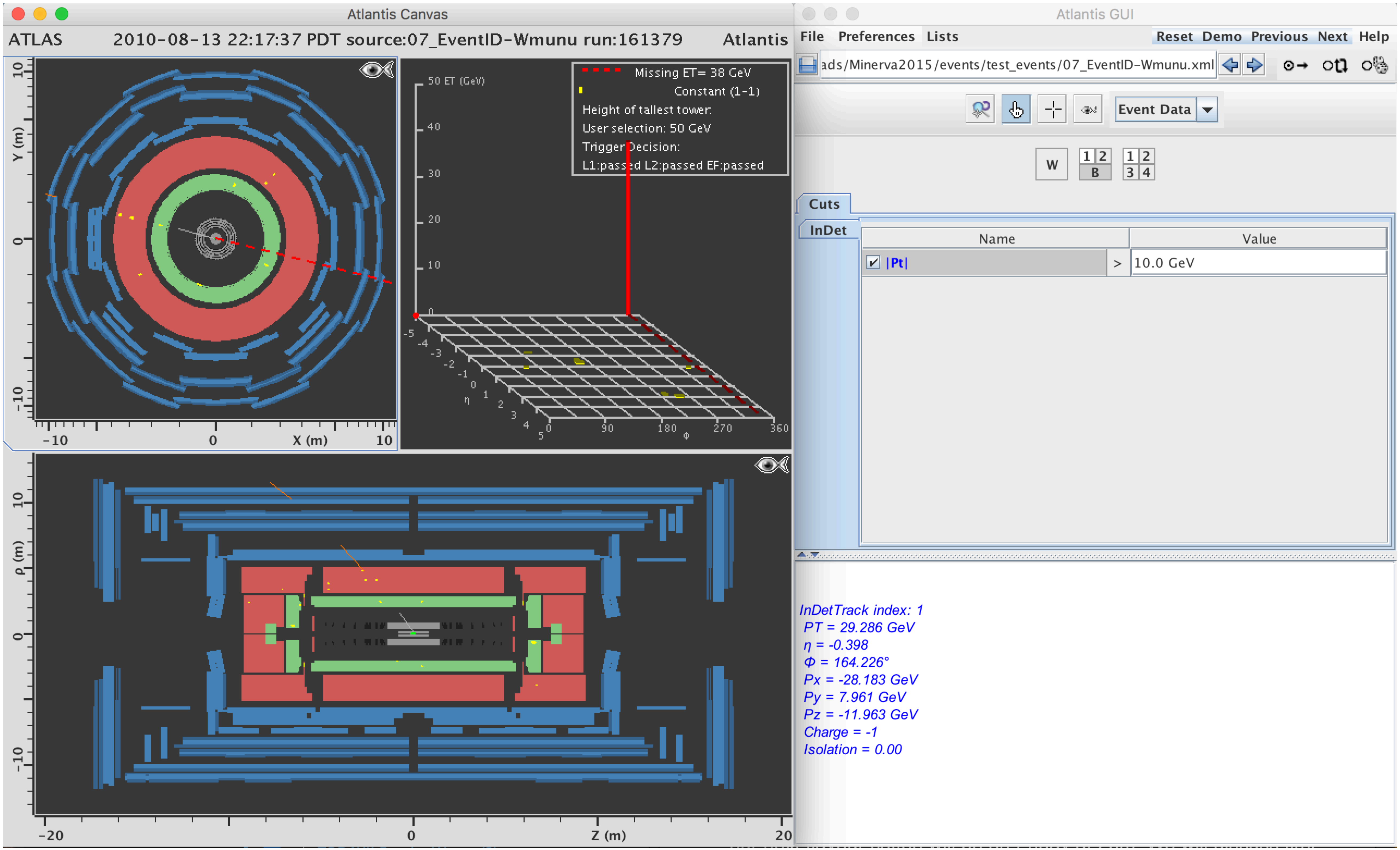
Signal in MINERVA



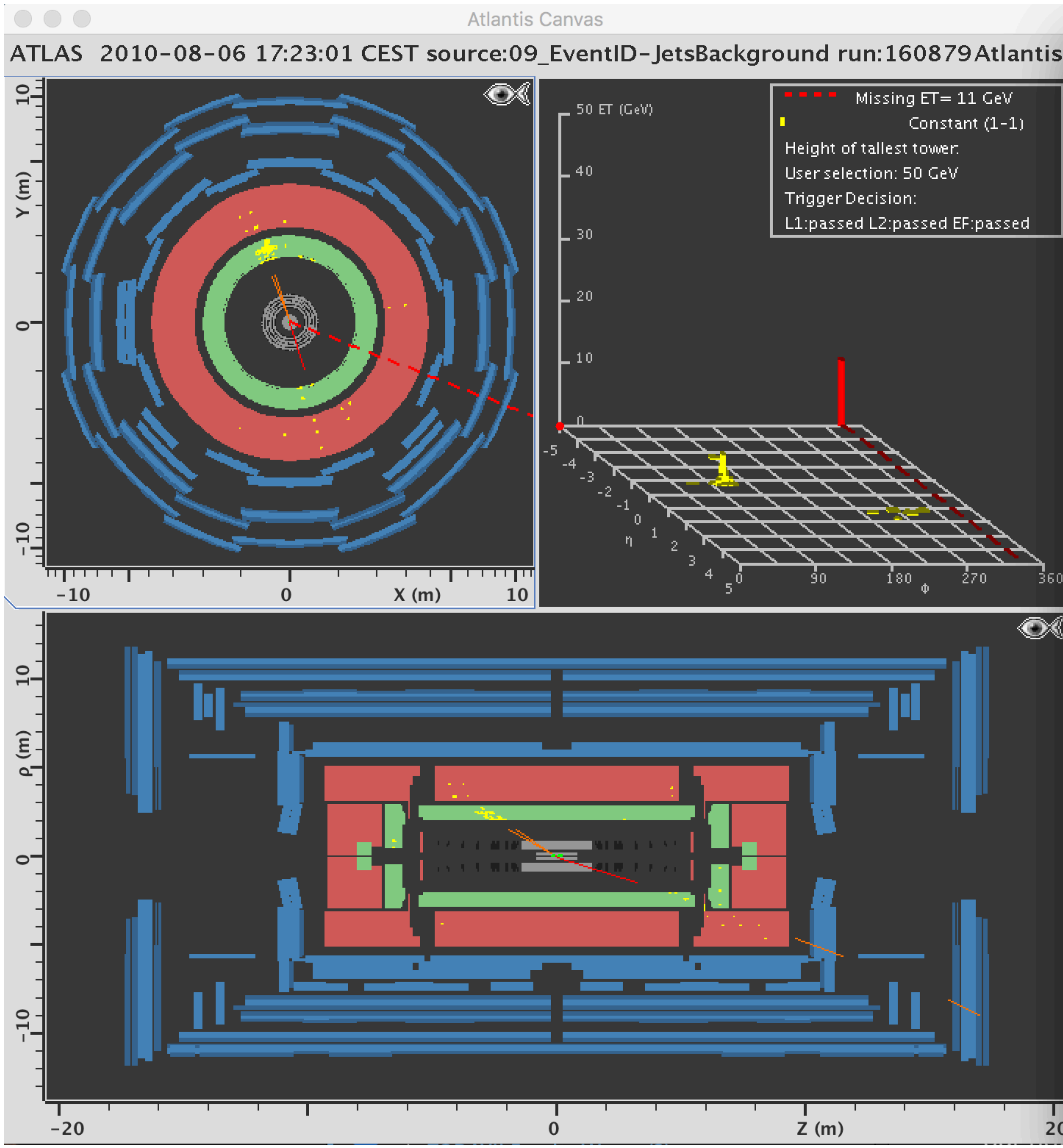
What are we looking for?

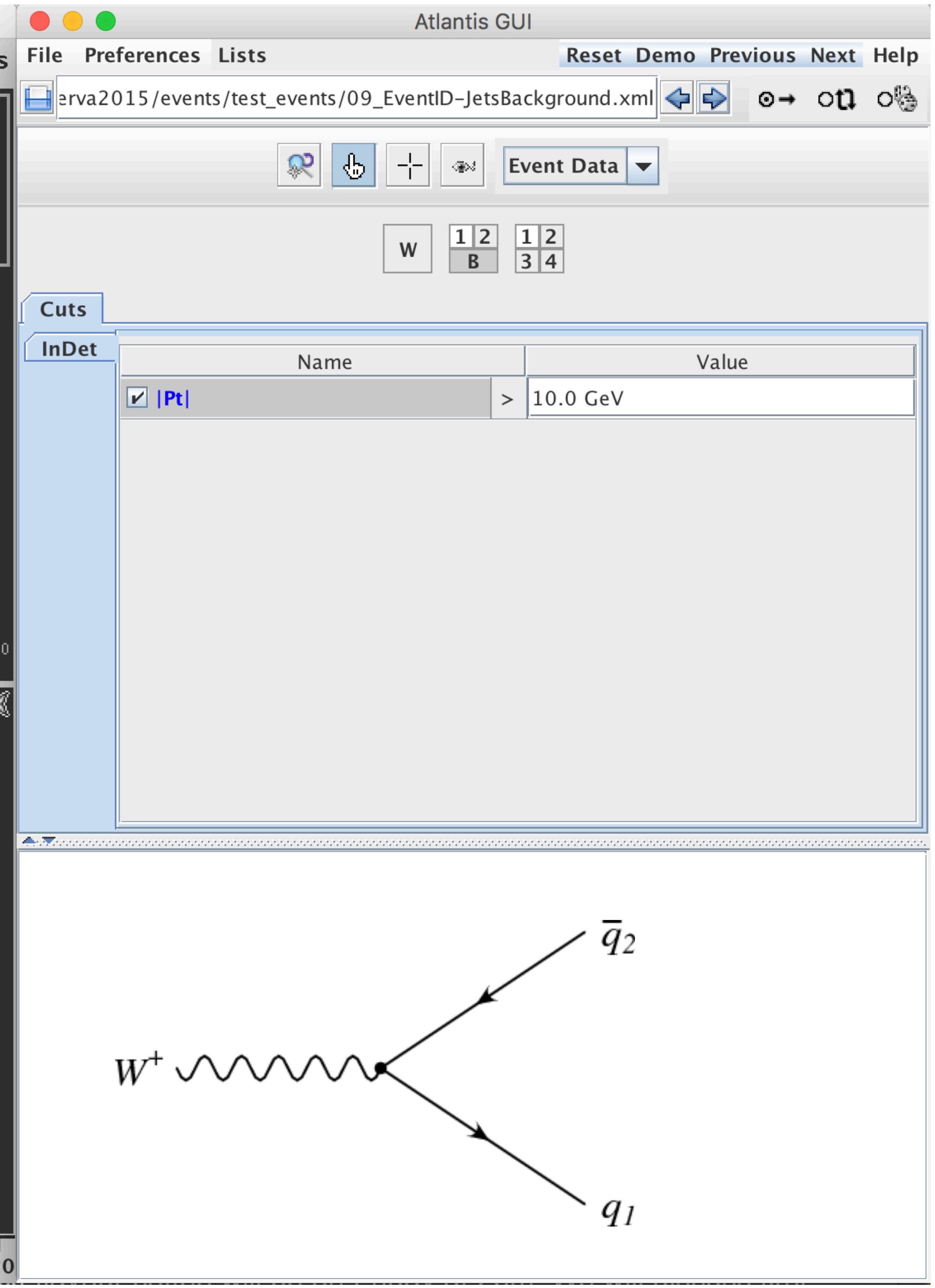


Signal in MINERVA

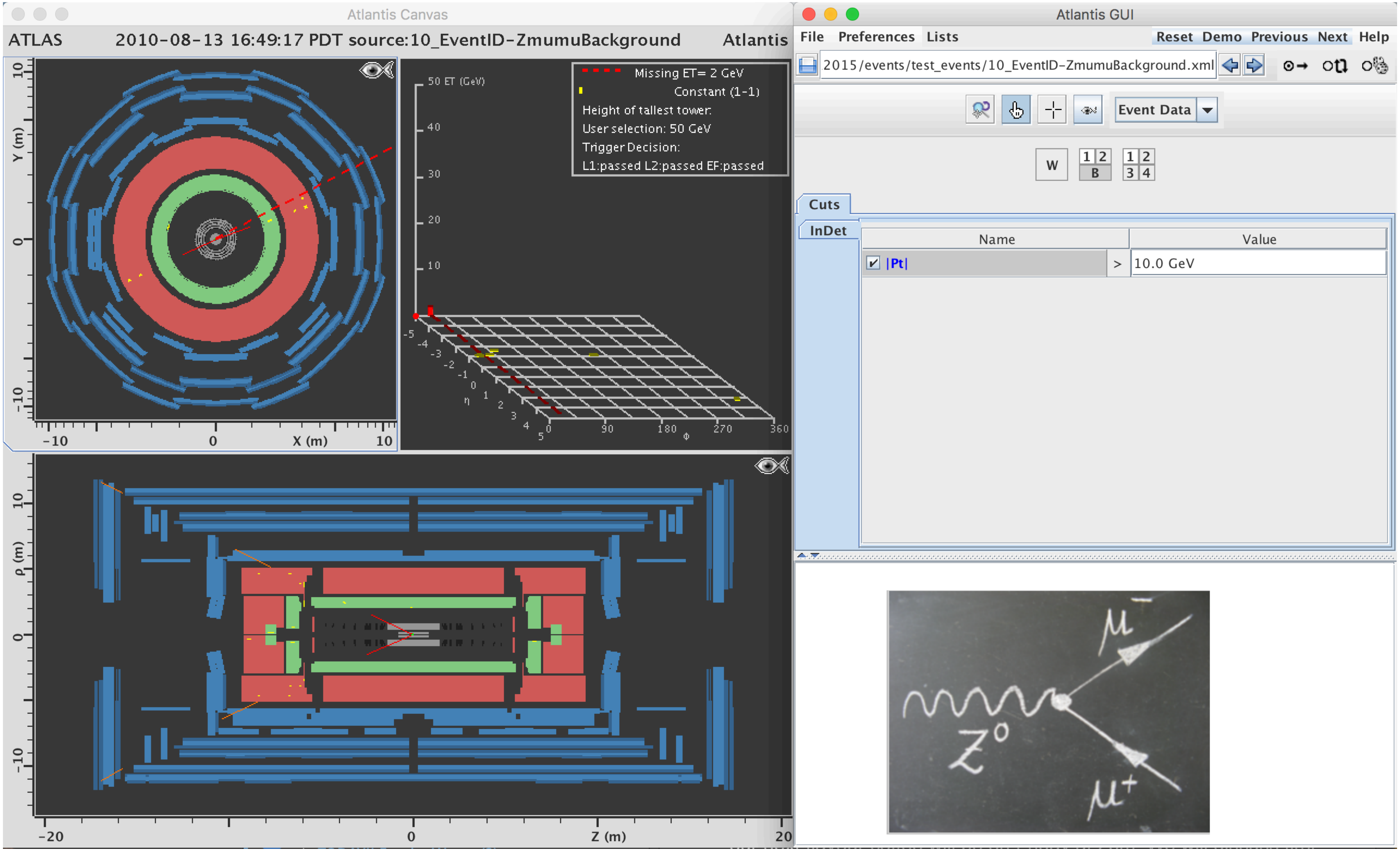


Background in MINERVA

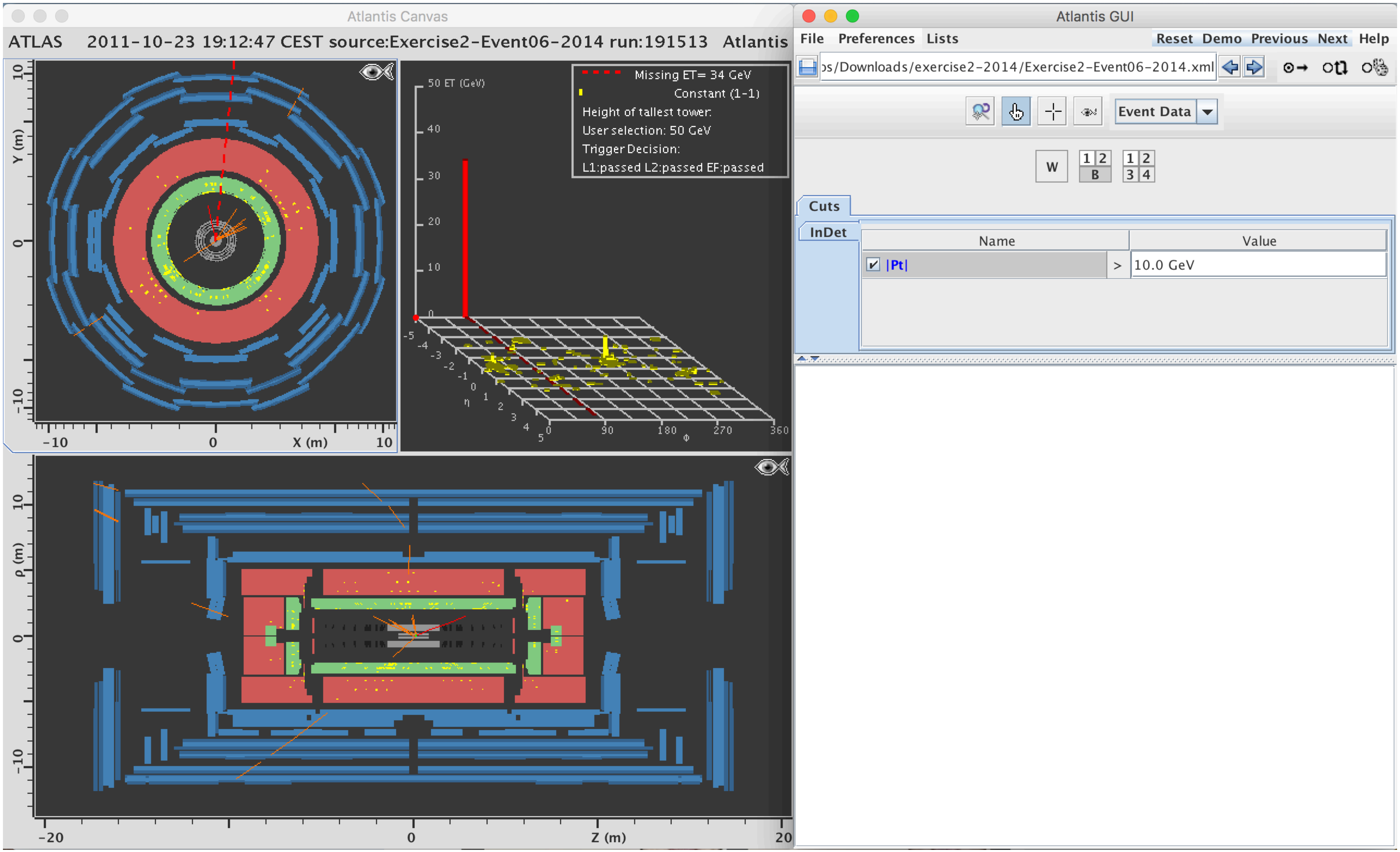




Background in MINERVA

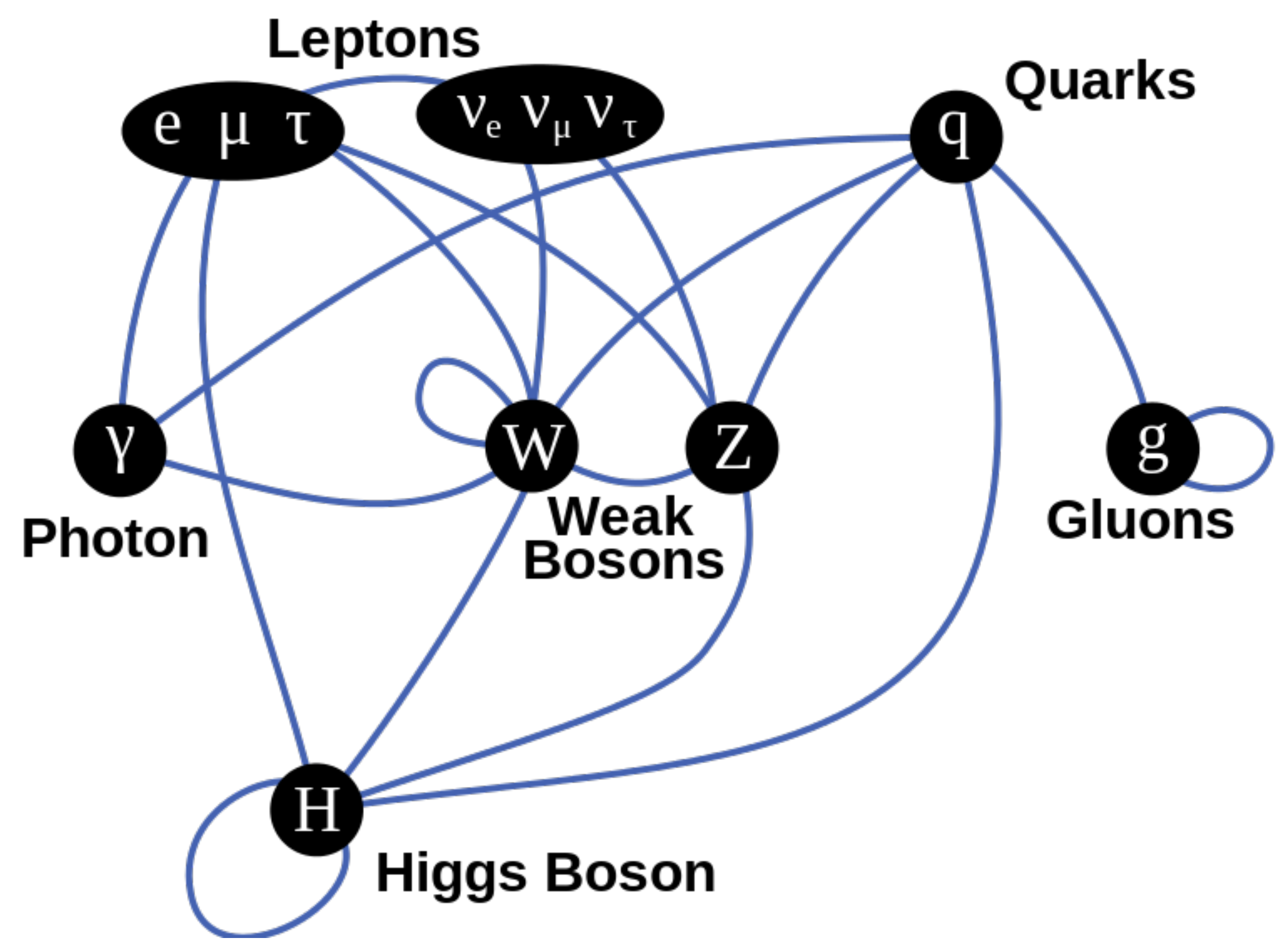


Background in MINERVA

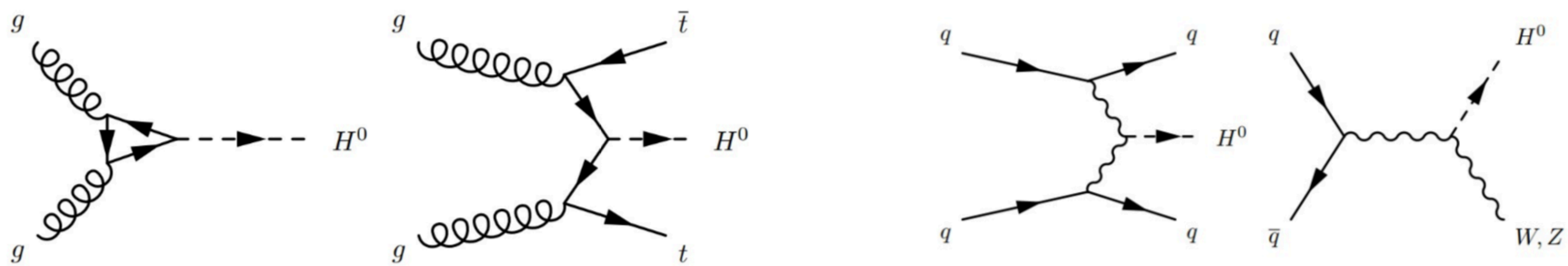


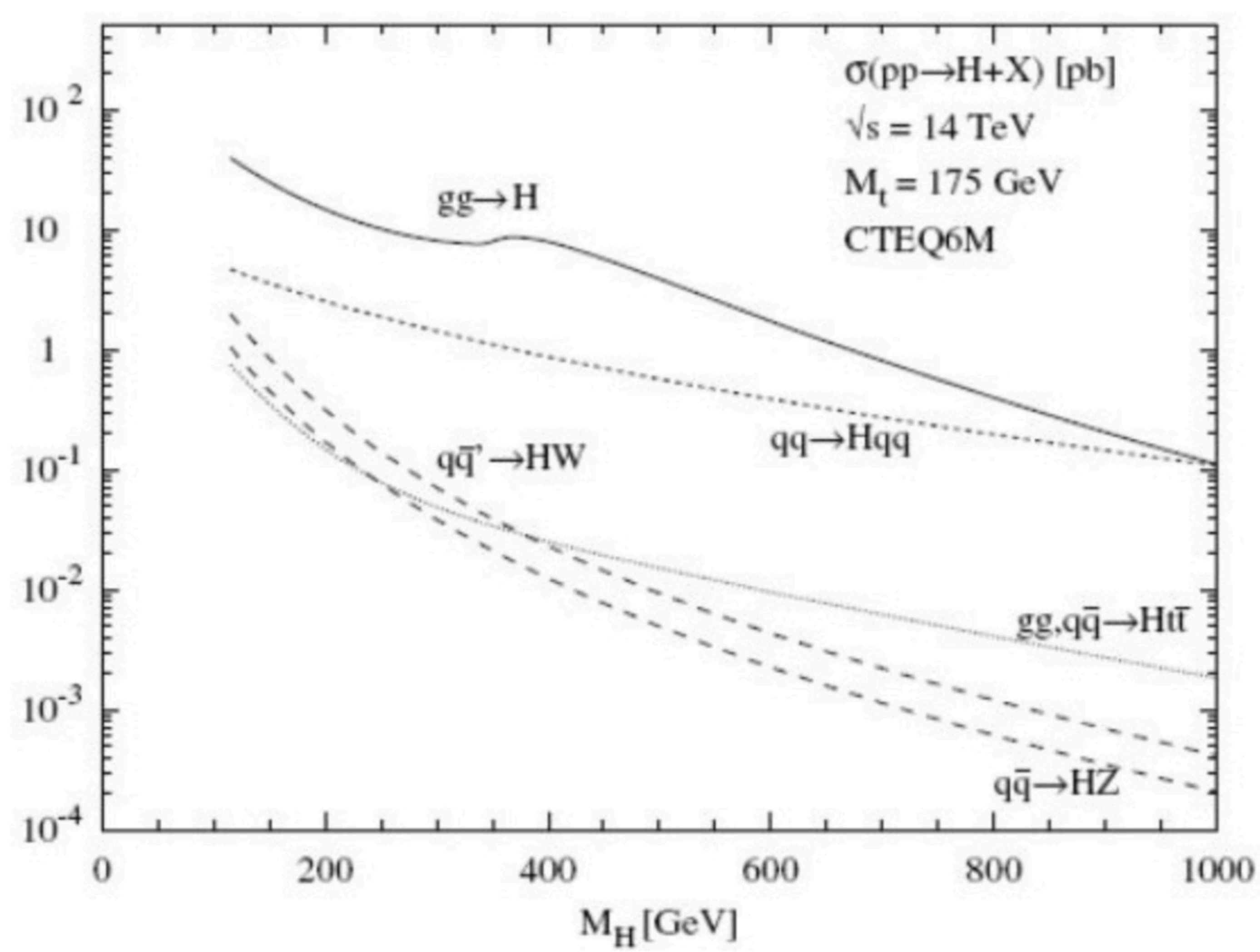
The Higgs Boson

- The Higgs boson is the elementary particle to be discovered (2012) and it was a missing piece of the Standard Model puzzle for over 50 years, since it was first proposed.
- From the Higgs boson originates the difference between the weak force and electromagnetism.
- It is essential in the mechanism that gives particles their mass. So only massive particles interact with it.



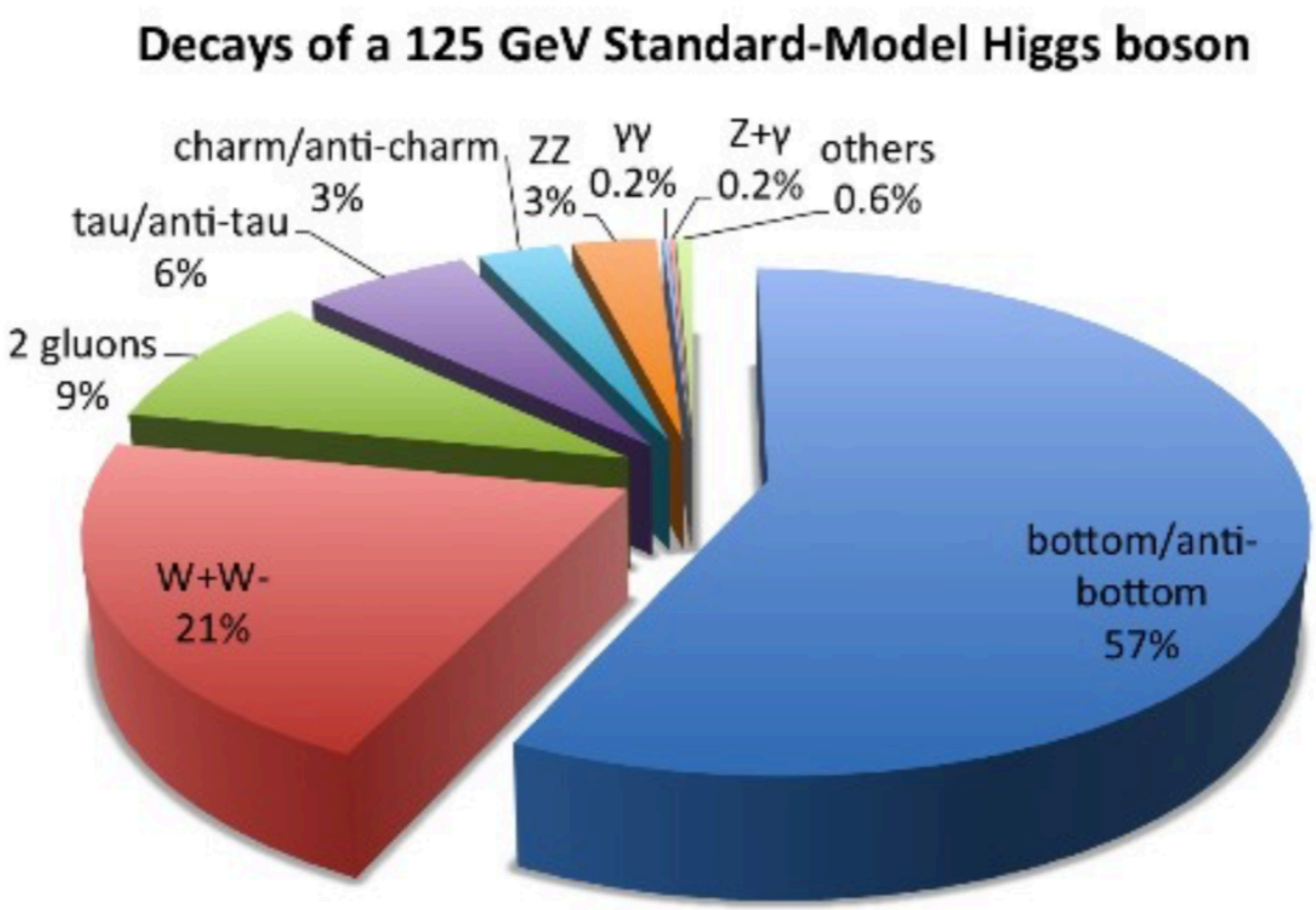
Higgs Production at LHC





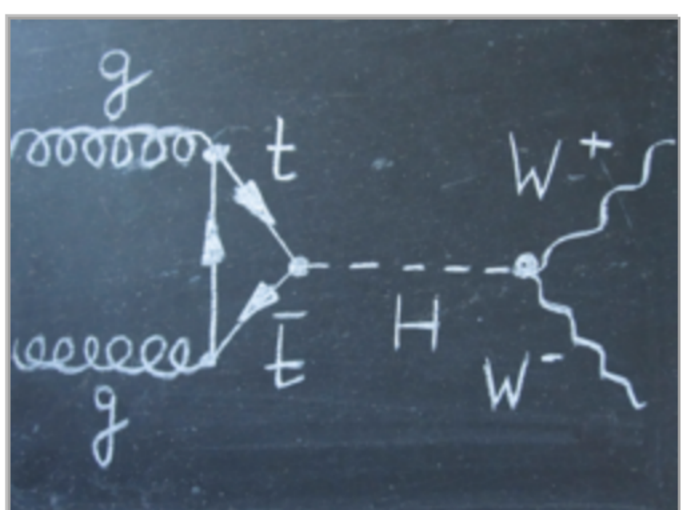
Higgs decays

- Higgs boson is massive (~125GeV) and so it decays before reaching the detector.
- Many decay channels.



Higgs decays

- Production of a bottom/anti-bottom pair seems the best choice, but the background of this signal is huge.
- Our choice will then be the decay to WW.
- Note that in order to conserve electric charge in this decay, the W bosons will have to be oppositely charged since Higgs is neutral.

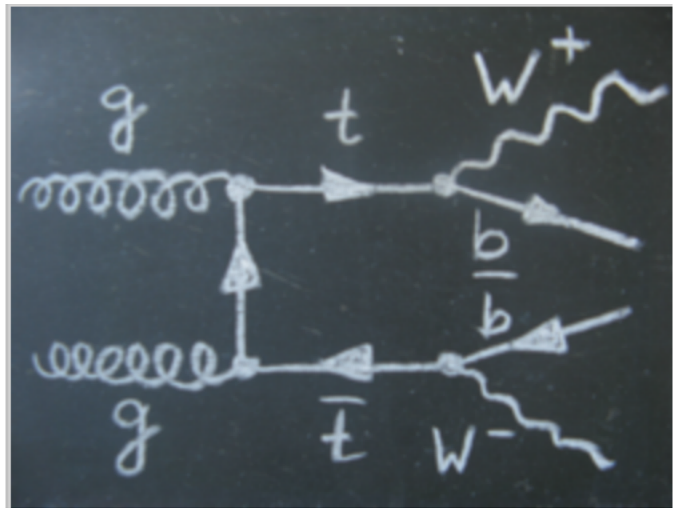


- Of course the W's can decay in any of the previously mentioned channels independently.

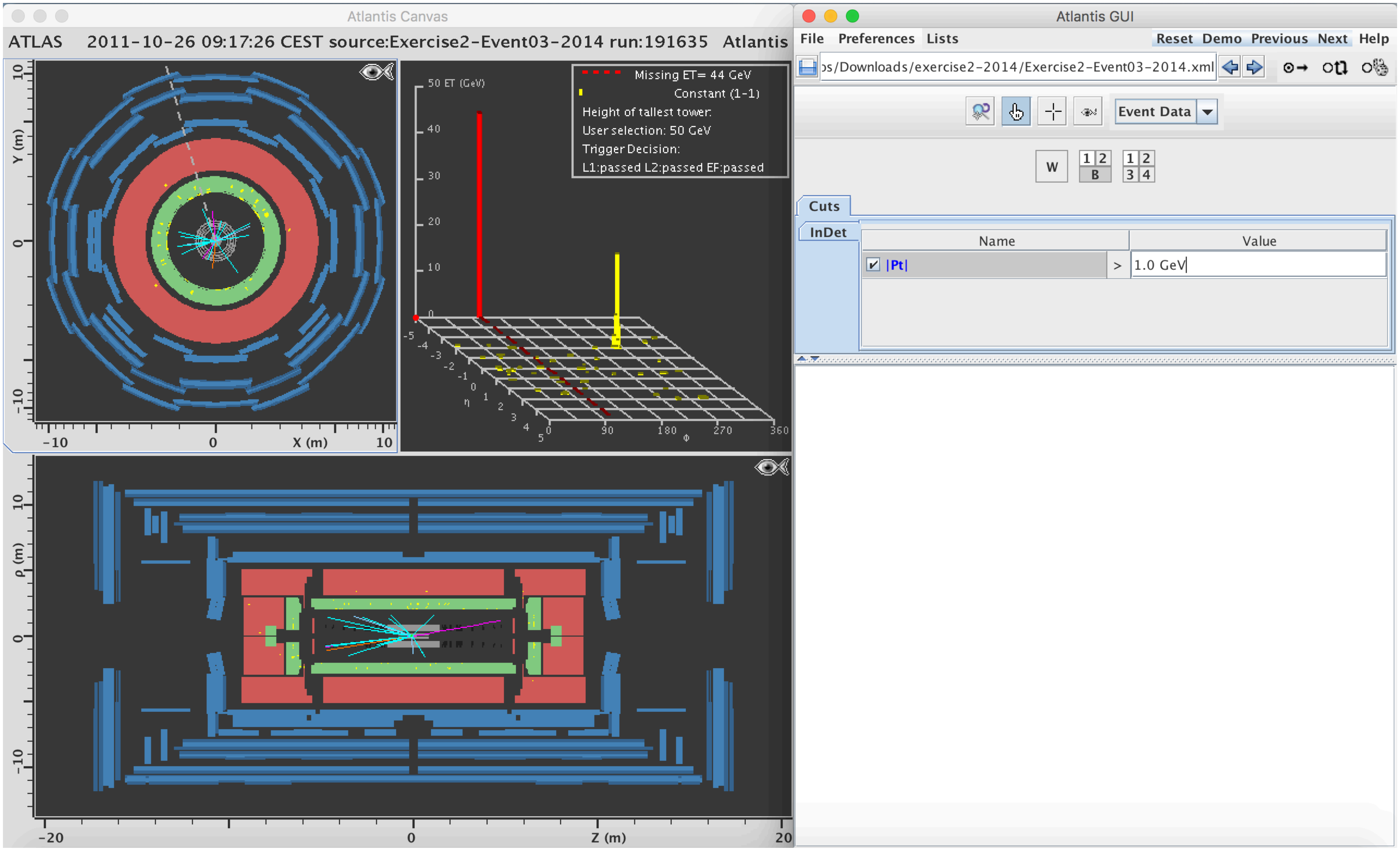
Higgs background

- The background in the Higgs decay to W bosons will be the production of heavy particles instead (like top quarks) that will decay to W's and b-jets.

- To increase the signal to background ratio today we'll look into the angle distribution of the produced leptons. In Higgs events we expect the angle to be less than 90 degrees. In Standard Model WW events the whole angle range is possible.



Example 1



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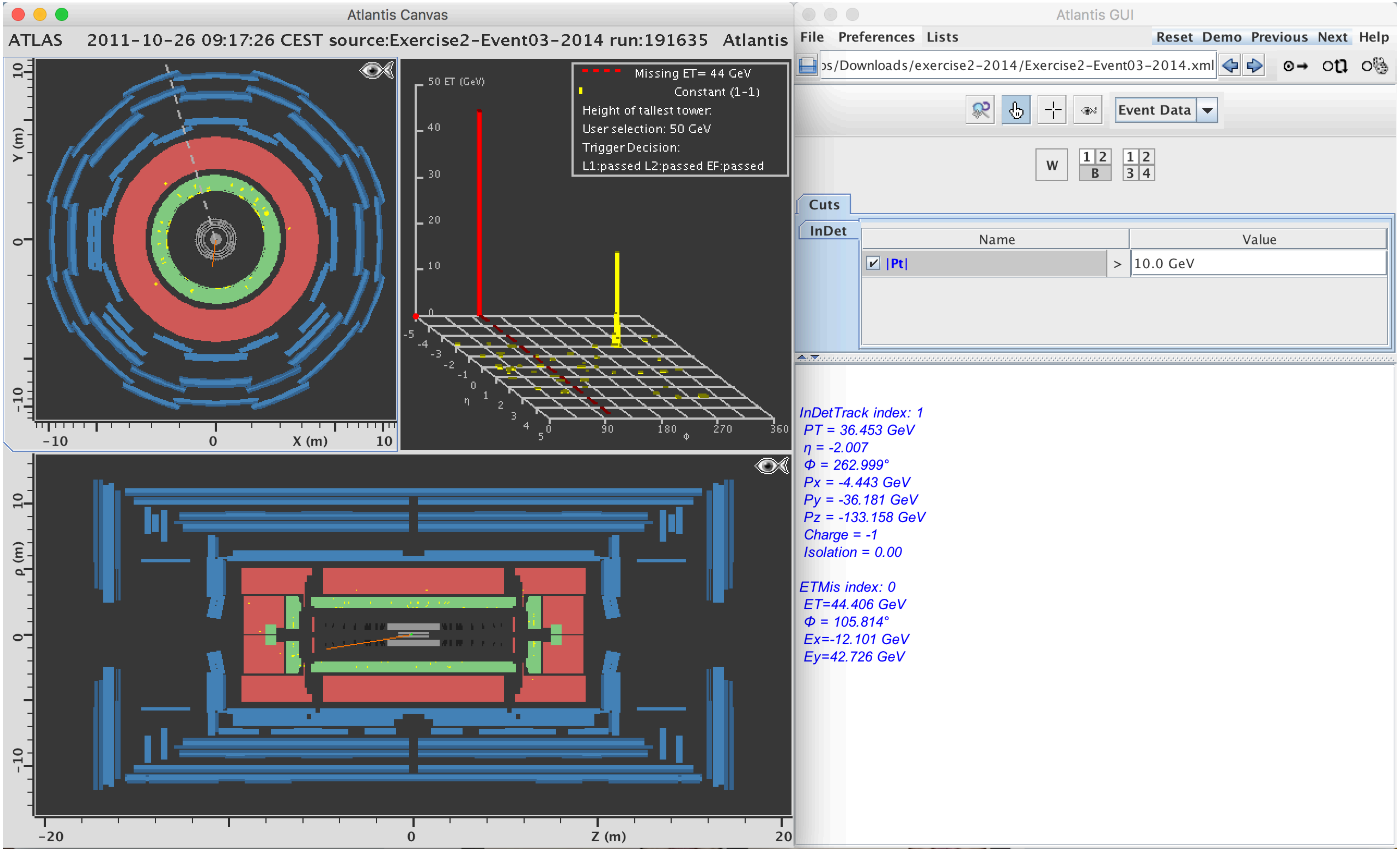
X (m)
Missing ET= 44 GeV
Constant (1-1)
Height of tallest tower:
User selection: 50 GeV
Trigger Decision:
L1:passed L2:passed EF:passed
50 ET (GeV)
η
φ
ρ (m)
Z (m)
Atlantis GUI
File Preferences Lists
Reset Demo Previous Next Help
os/Downloads/exercise2-2014/Exercise2-Event03-2014.xml
Event Data
W
Cuts
InDet
Name
Value
|Pt|
>
1.0 GeV

Example 1


Atlantis Canvas
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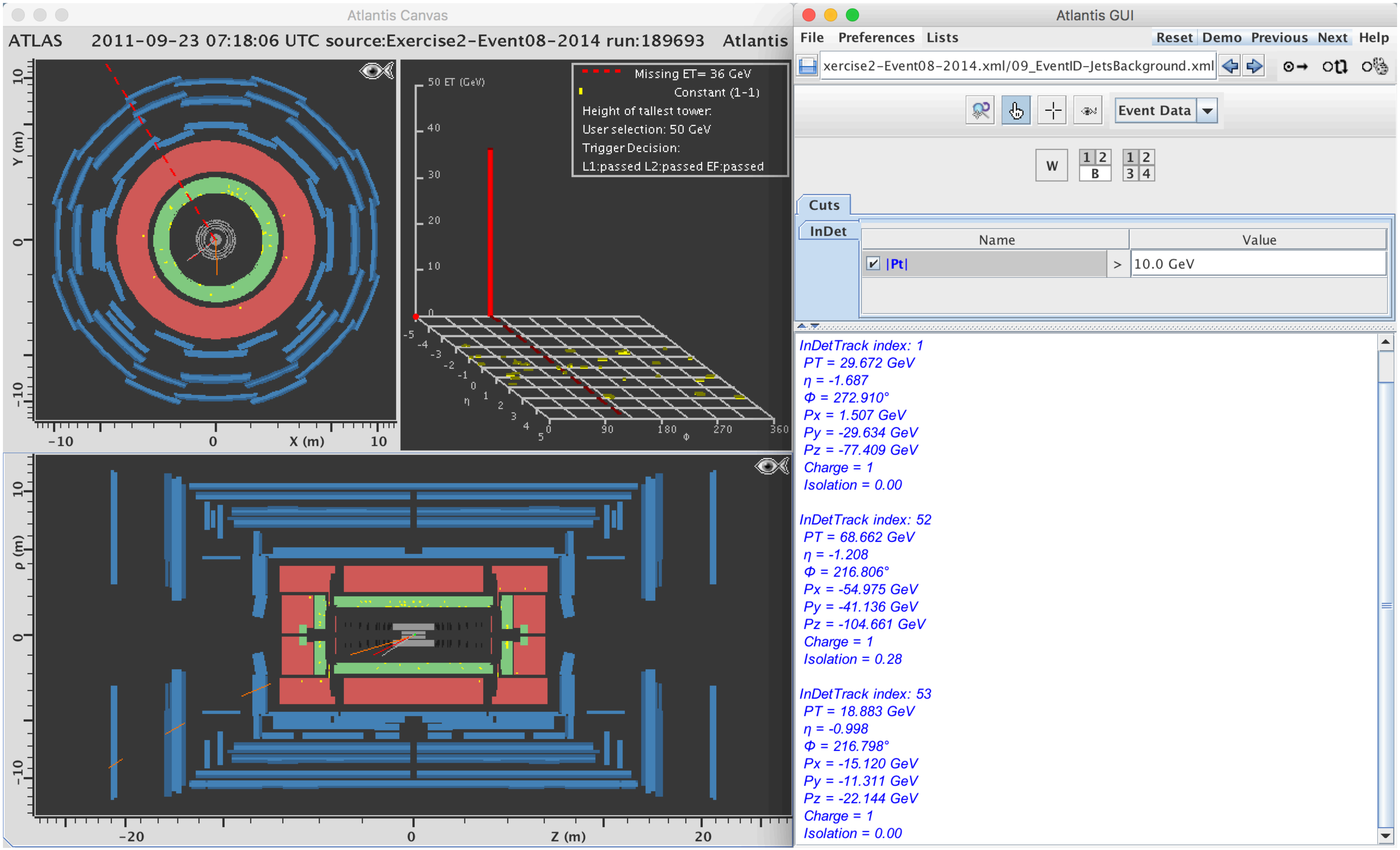
Constant (1-1)
Height of tallest tower:
User selection: 50 GeV
Trigger Decision:
L1:passed L2:passed EF:passed
Atlantis GUI
File Preferences Lists
Reset Demo Previous Next Help
Event Data
Cuts
InDet
Name
Value
|Pt|
10.0 GeV
InDetTrack index: 1
PT = 36.453 GeV
η = -2.007
Φ = 262.999°
Px = -4.443 GeV
Py = -36.181 GeV
Pz = -133.158 GeV
Charge = -1
Isolation = 0.00
ETMis index: 0
ET=44.406 GeV
Φ = 105.814°
Ex=-12.101 GeV
Ey=42.726 GeV

Example 2


Atlantis Canvas
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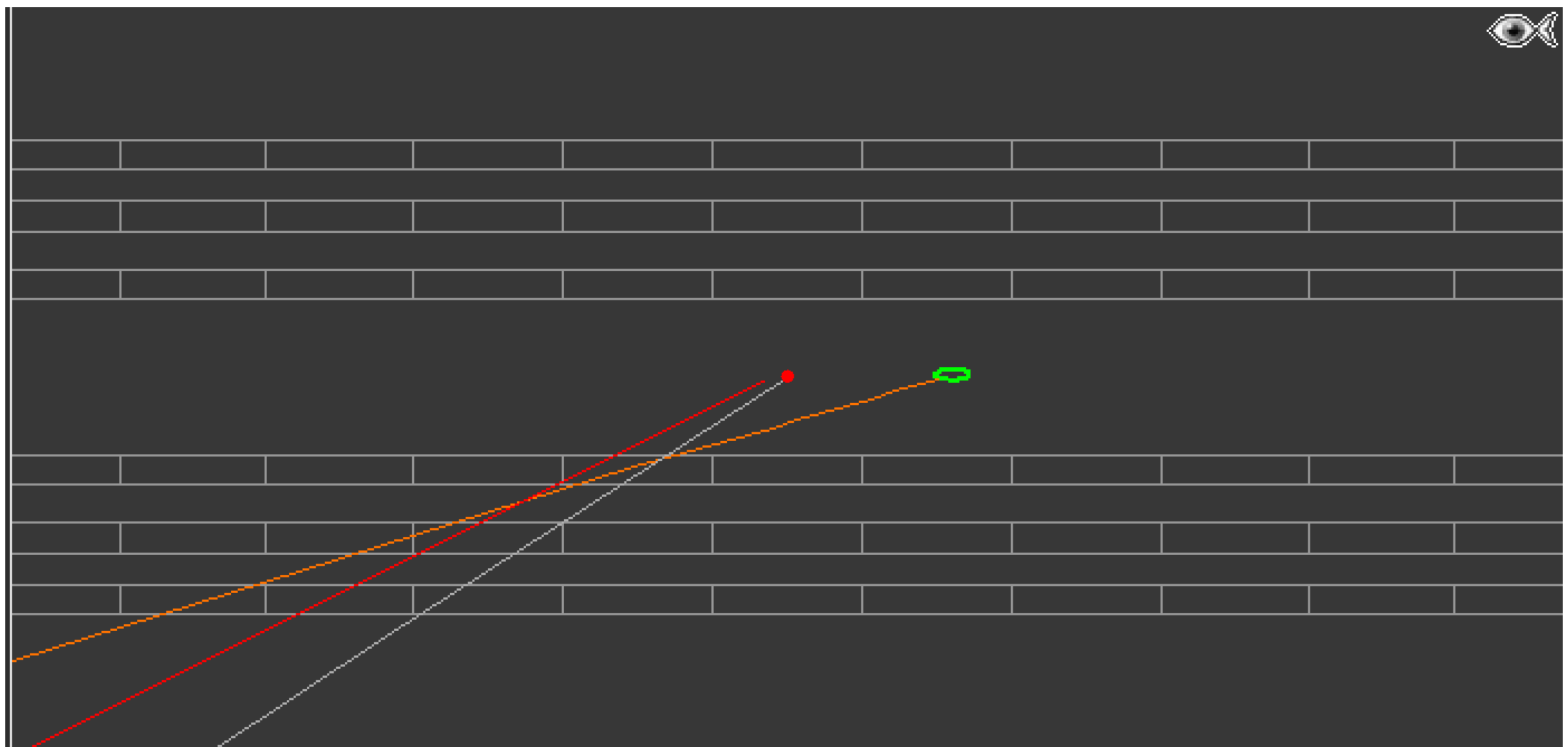
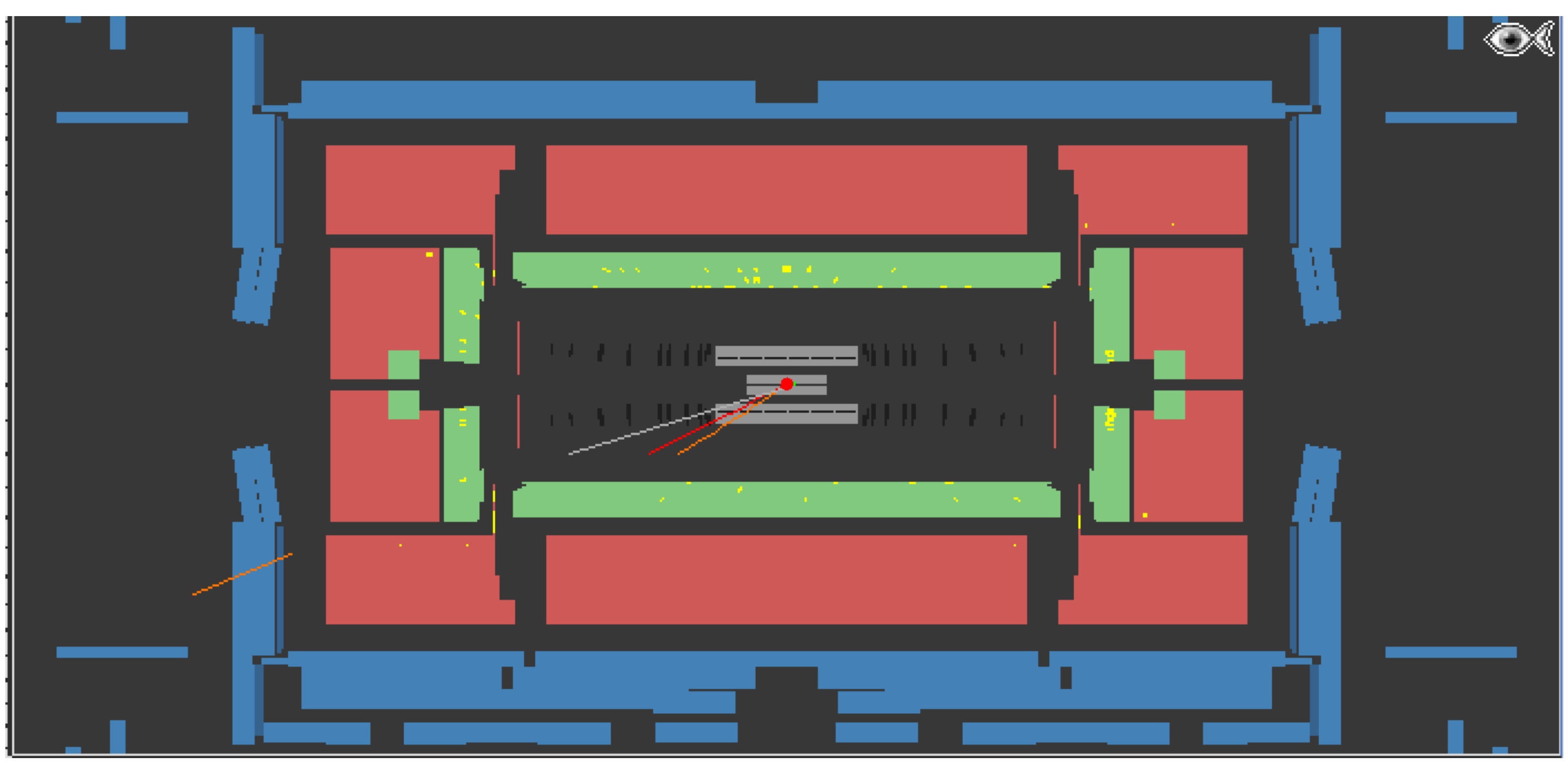
Constant (1-1)
Height of tallest tower:
User selection: 50 GeV
Trigger Decision:
L1:passed L2:passed EF:passed
Atlantis GUI
File Preferences Lists Reset Demo Previous Next Help
xercise2-Event08-2014.xml/09_EventID-JetsBackground.xml
Event Data
Cuts
InDet
Name Value
|Pt| > 10.0 GeV
InDetTrack index: 1
PT = 29.672 GeV
η = -1.687
Φ = 272.910°
Px = 1.507 GeV
Py = -29.634 GeV
Pz = -77.409 GeV
Charge = 1
Isolation = 0.00
InDetTrack index: 52
PT = 68.662 GeV
η = -1.208
Φ = 216.806°
Px = -54.975 GeV
Py = -41.136 GeV
Pz = -104.661 GeV
Charge = 1
Isolation = 0.28
InDetTrack index: 53
PT = 18.883 GeV
η = -0.998
Φ = 216.798°
Px = -15.120 GeV
Py = -11.311 GeV
Pz = -22.144 GeV
Charge = 1
Isolation = 0.00

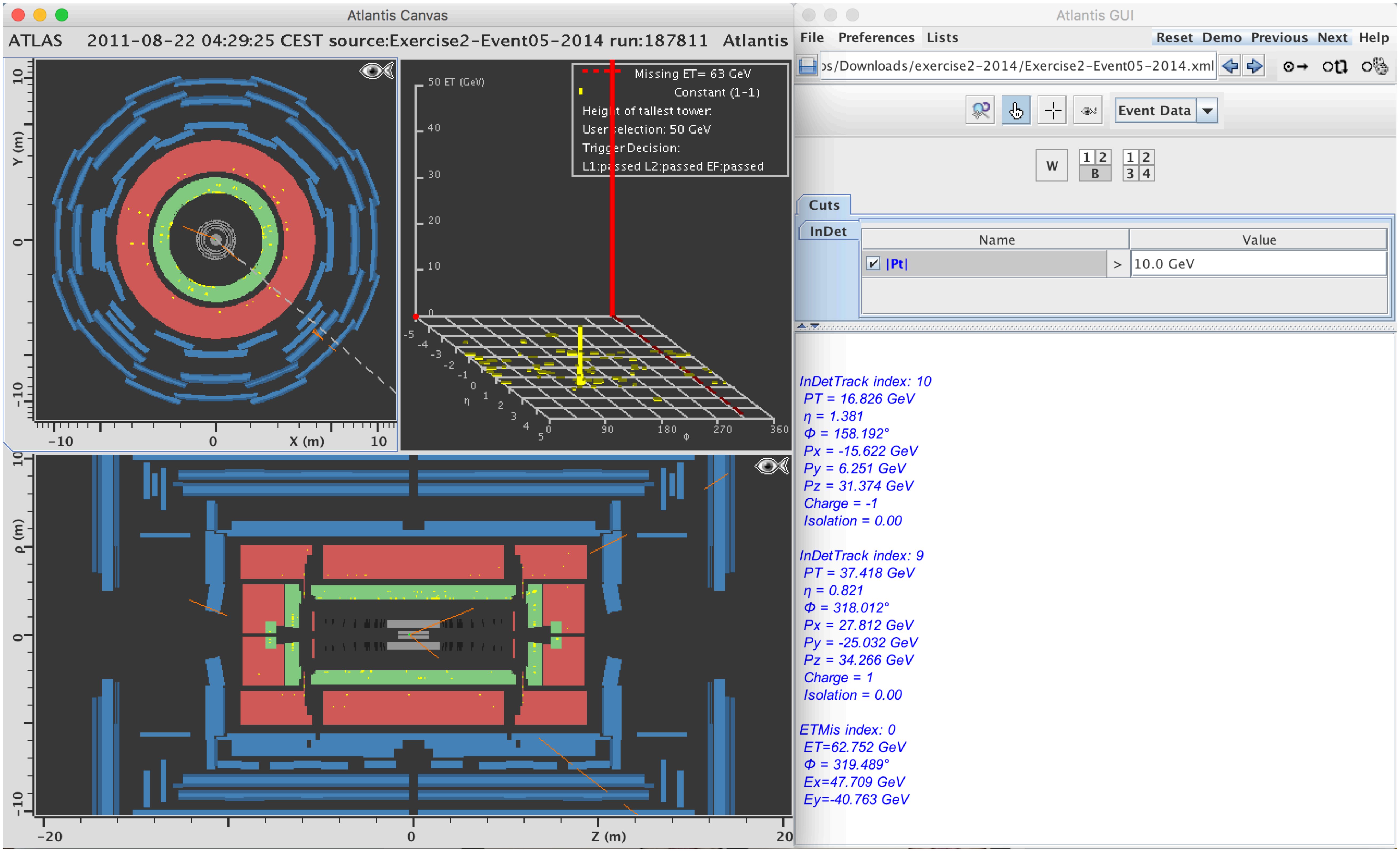
Example 2





InDetTrack index: 1
PT = 29.672 GeV
η = -1.687
Φ = 272.910°
Px = 1.507 GeV
Py = -29.634 GeV
Pz = -77.409 GeV
Charge = 1
Isolation = 0.00

WW example



Atlantis Canvas
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Y (m)
X (m)
50 ET (GeV)
Missing ET= 63 GeV
Constant (1-1)
Height of tallest tower:
User selection: 50 GeV
Trigger Decision:
L1:passed L2:passed EF:passed
η
ϕ
ρ (m)
Z (m)
Atlantis GUI
File
Preferences
Lists
Reset
Demo
Previous
Next
Help
os/Downloads/exercise2-2014/Exercise2-Event05-2014.xml
Event Data
W
Cuts
InDet
Name
Value
|Pt|
>
10.0 GeV
InDetTrack index: 10
PT = 16.826 GeV
η = 1.381
Φ = 158.192°
Px = -15.622 GeV
Py = 6.251 GeV
Pz = 31.374 GeV
Charge = -1
Isolation = 0.00
InDetTrack index: 9
PT = 37.418 GeV
η = 0.821
Φ = 318.012°
Px = 27.812 GeV
Py = -25.032 GeV
Pz = 34.266 GeV
Charge = 1
Isolation = 0.00
ETMis index: 0
ET=62.752 GeV
Φ = 319.489°
Ex=47.709 GeV
Ey=-40.763 GeV

WW example

- In the case you find a WW event, you'll need to calculate the transverse angle Φ between the two produced leptons.
- You can do that by holding down key P on the keyboard and click on the lepton tracks.
- Then the difference in their angles should appear on the window on the bottom left corner.

InDetTrack index: 10
PT = 16.826 GeV
η = 1.381
Φ = 158.192°
Px = -15.622 GeV
Py = 6.251 GeV
Pz = 31.374 GeV
Charge = -1
Isolation = 0.00

InDetTrack index: 9
PT = 37.418 GeV
η = 0.821
Φ = 318.012°
Px = 27.812 GeV
Py = -25.032 GeV
Pz = 34.266 GeV
Charge = 1
Isolation = 0.00

ΔΦ = 159.8° (2.789)
ΔR = 2.845

Activity details

- Each pair will be given a dataset with 50 events to identify.
- You will write down on the tally sheet given to you, what events you found and in the case of a Higgs event event you will also write down the angle difference.
- After you're finished you'll transfer your results to a CERN interface where an analysis will follow.
- The observables you want to calculate are: the ratio of W+/W- events, and based on that you will make some conclusions about the structure of the proton and the angle distribution in WW events, where you'll compare with background and Higgs predictions.