# Introduction to the LHC Hands on Session with MINERVA

Introduction

➢ **We are going to analysis real LHC data!**

➢ **We do this using a program called minerva to 'look' at recorded proton collision events to see what particles were made**

➢ **We are going to count the number of W+ and W- bosons produced and events were two Ws were made (WW)**

➢ **W bosons decay almost as soon as they are made**

➢ **We will look at how to detect them**

Different components in the ATLAS detector
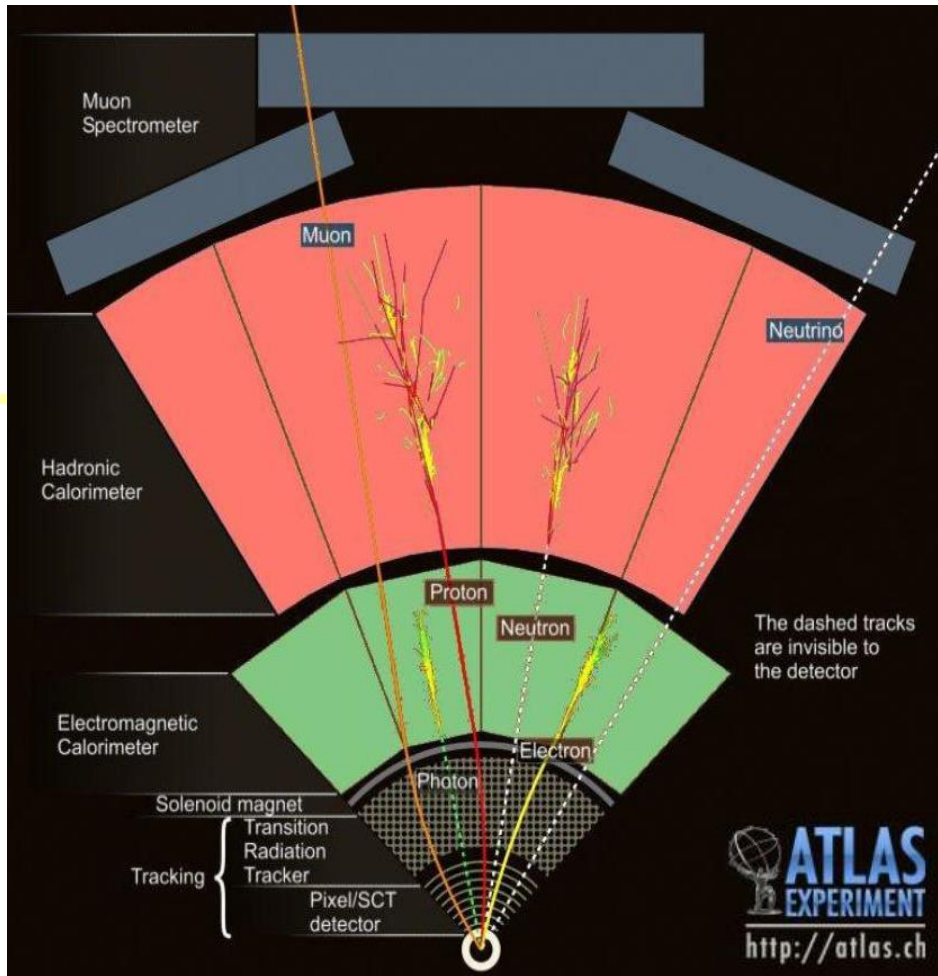
Neutrinos are only detected indirectly via 'missing energy' not recorded in the calorimeters

Muon detector

−Measure charge and momentum of muons and anti-muons in magnetic field (produced by toroids)

Hadronic calorimeter

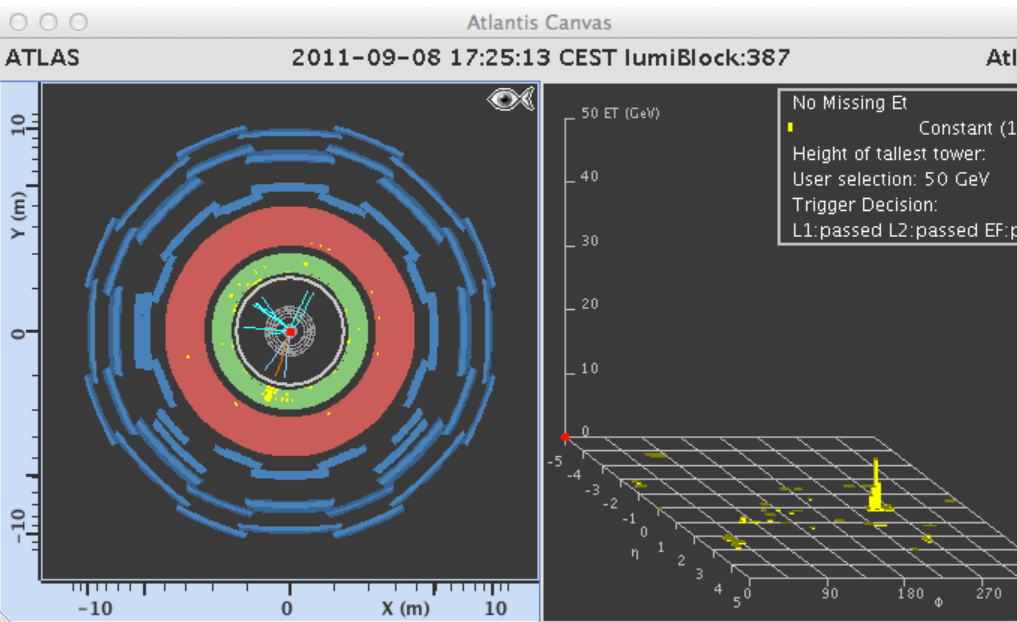−Measure energy of hadrons (particles containing quarks), such as protons, neutrons, pions, etc.

Electromagnetic calorimeter

−Measure energy of electrons, positrons and photons

Inner detector

−Measure charge and momentum of charged particles in magnetic field (produced by solenoid)

MINERVA Event Display

Muon detector

−Measure charge and momentum of muons and anti-muons in magnetic field (produced by toroids)
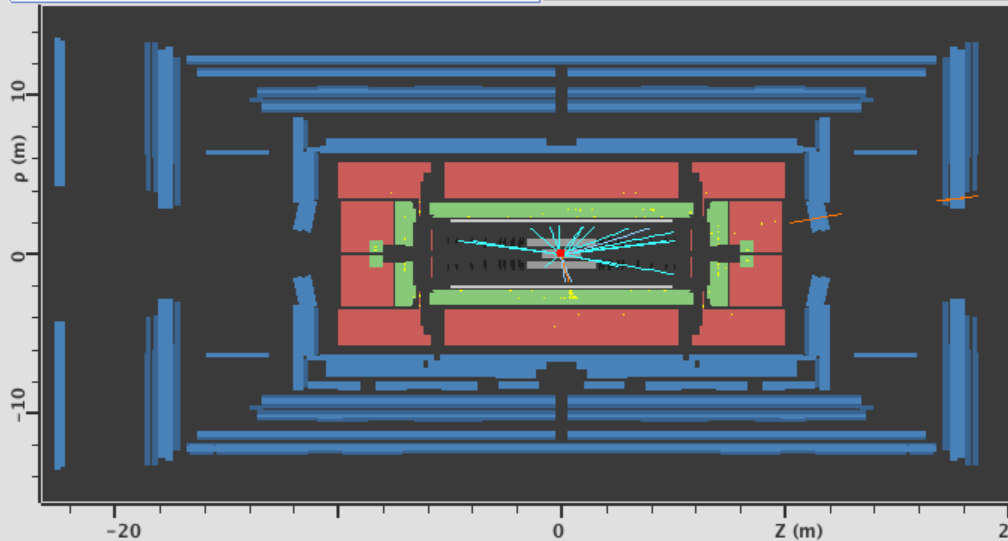
Hadronic calorimeter

−Measure energy of hadrons (particles containing quarks), such as protons, neutrons, pions, etc.
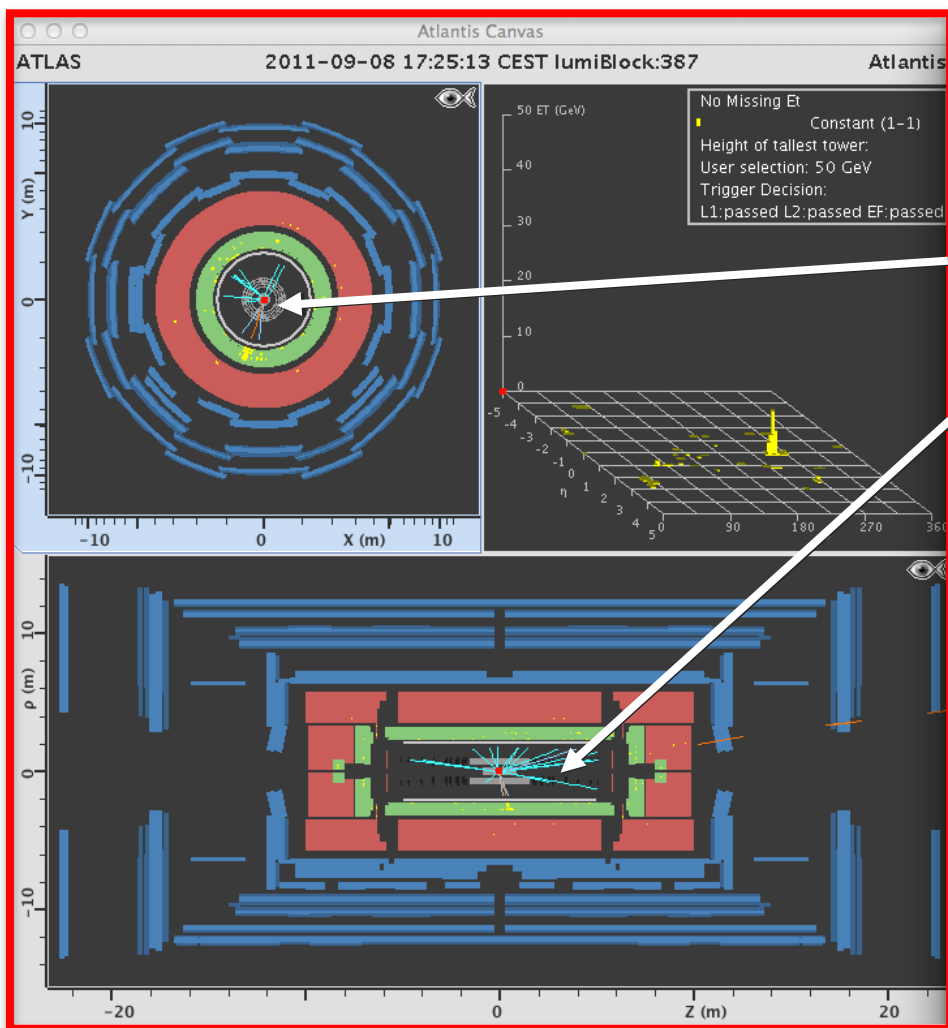
Electromagnetic calorimeter

−Measure energy of electrons, positrons and photons

Inner detector

−Measure charge and momentum of charged particles in magnetic field (produced by solenoid)

MINERVA Event Display – ATLANTIS Canvas
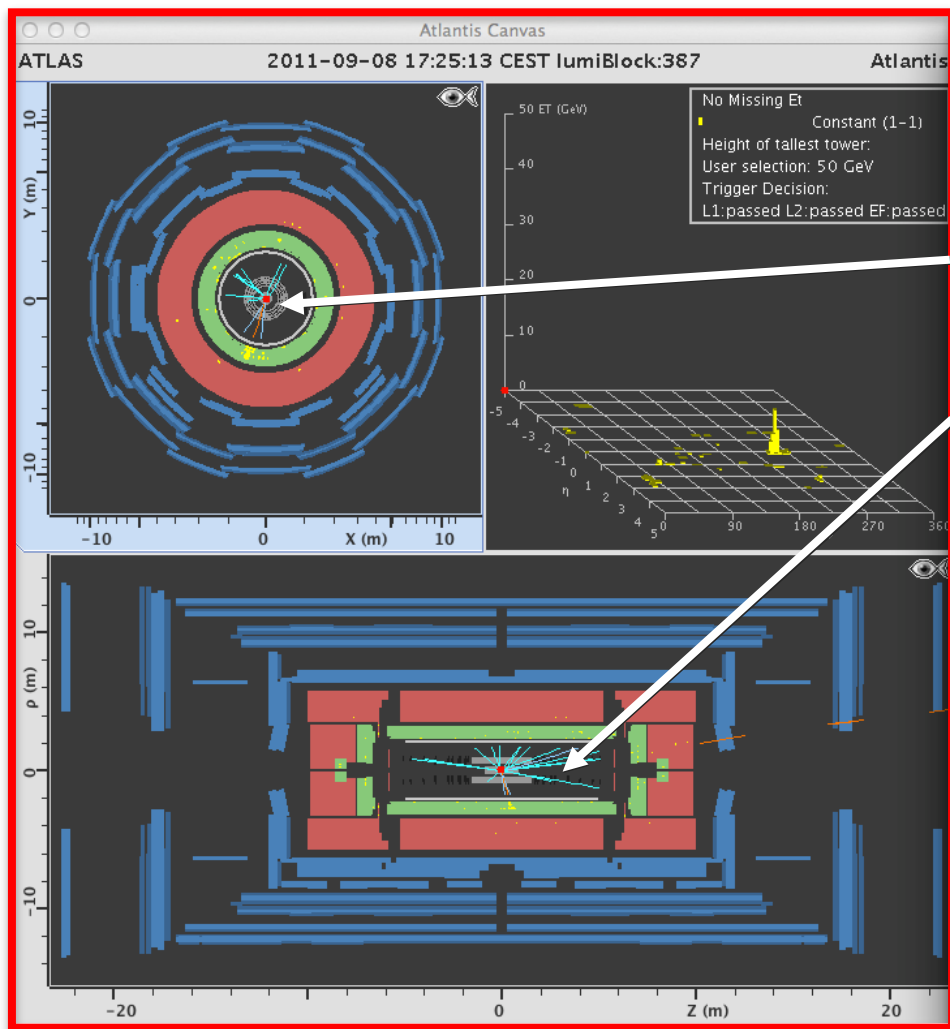
Can see all of the different detectors here

Tracking detector

Electromagnetic calorimeter

Hadronic calorimeter

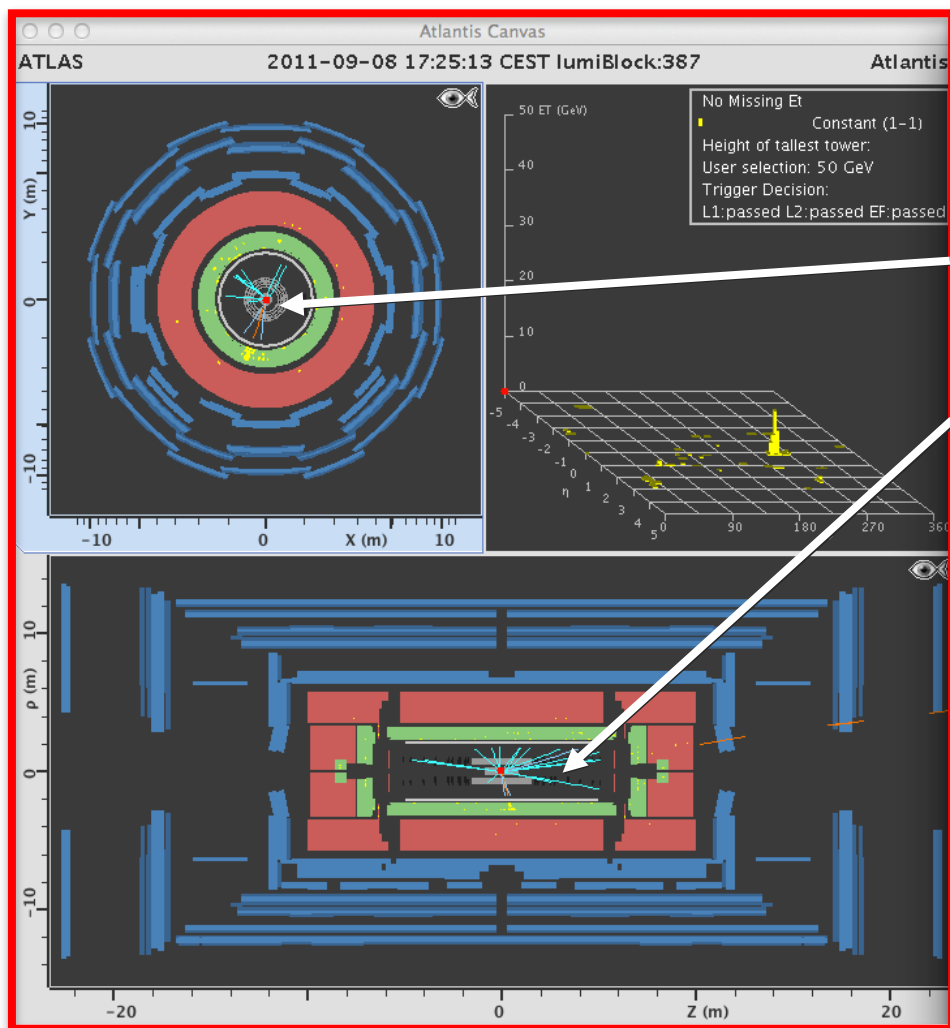Muon detectors

MINERVA Event Display – ATLANTIS Canvas

Can see all of the different detectors here

Tracking detector

Tracks the paths of CHARGED particles.. Such as?
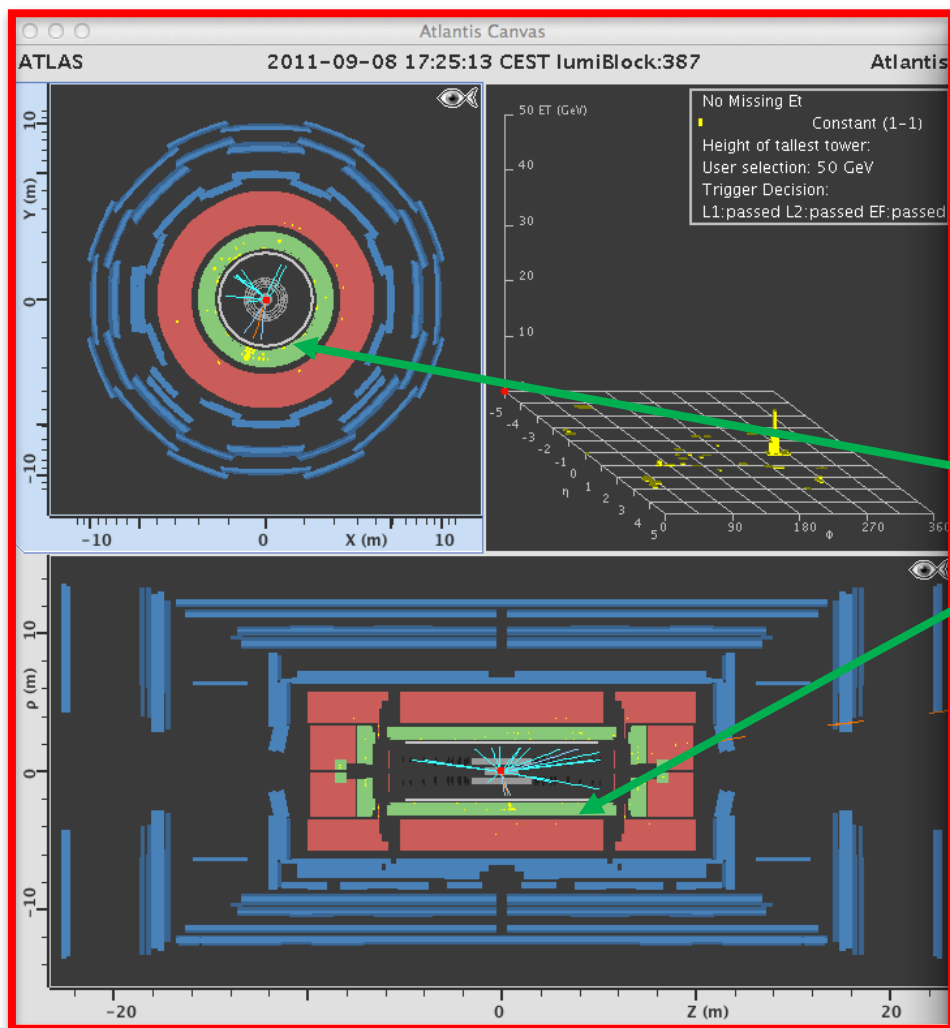
MINERVA Event Display – ATLANTIS Canvas

Can see all of the different detectors here

Tracking detector

Tracks the paths of CHARGED particles.. Such as?

Electrons

Muons

Jets

MINERVA Event Display – ATLANTIS Canvas

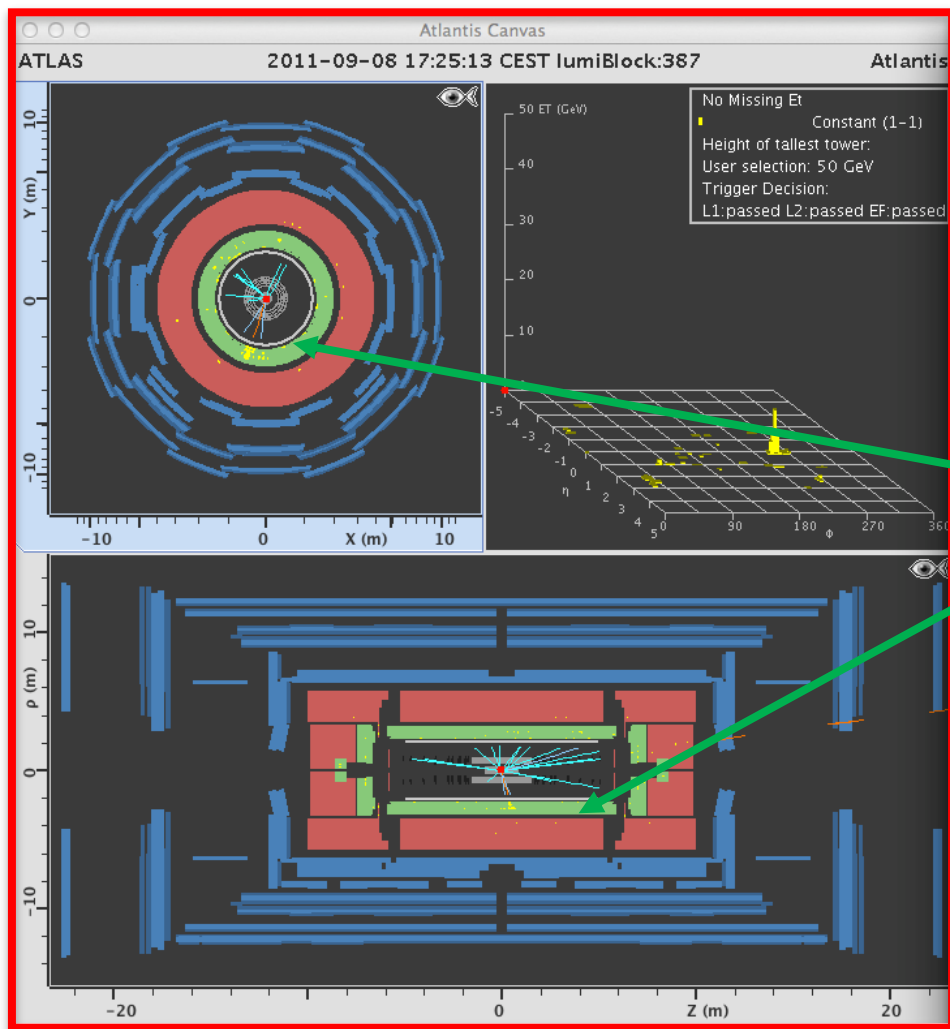Can see all of the different detectors here

Tracking detector

Electromagnetic calorimeter

Hadronic calorimeter

Muon detectors

MINERVA Event Display – ATLANTIS Canvas

Can see all of the different detectors here
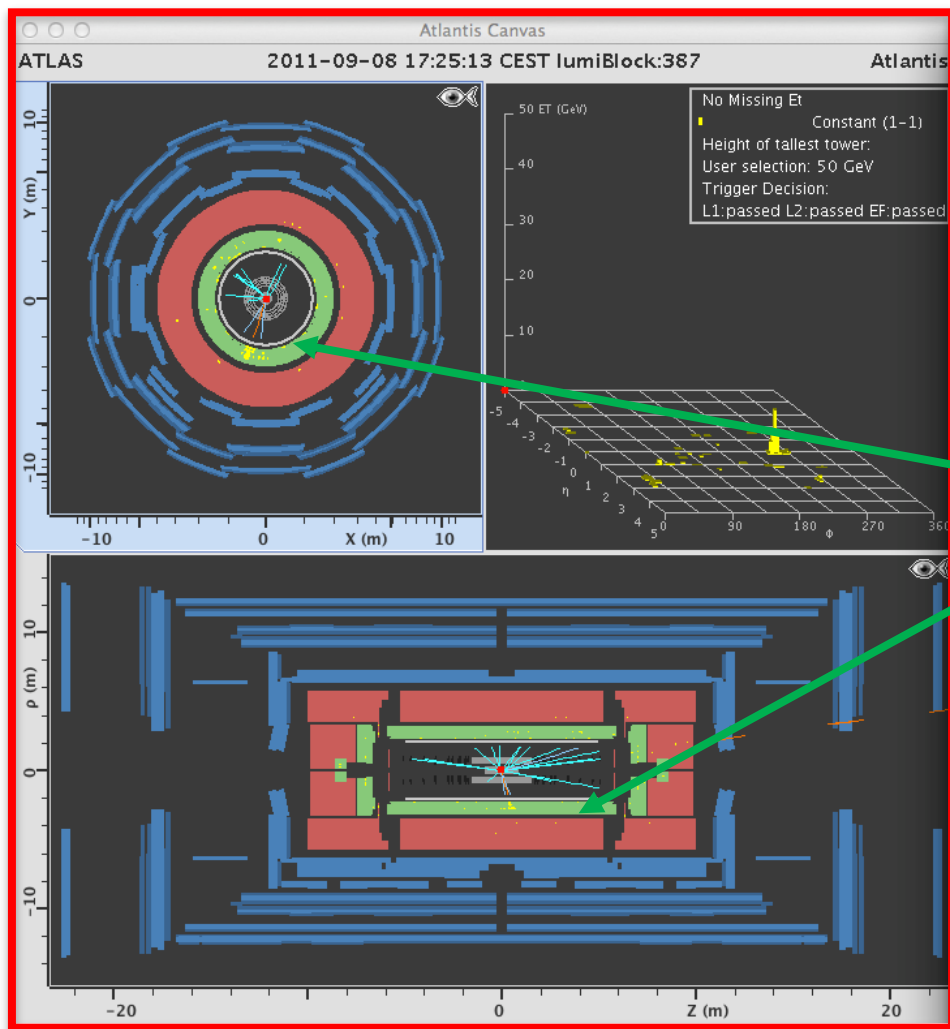
Tracking detector

Electromagnetic calorimeter

Absorbs energy of EM interacting particles

Absorbs?

Interacts with?

MINERVA Event Display – ATLANTIS Canvas

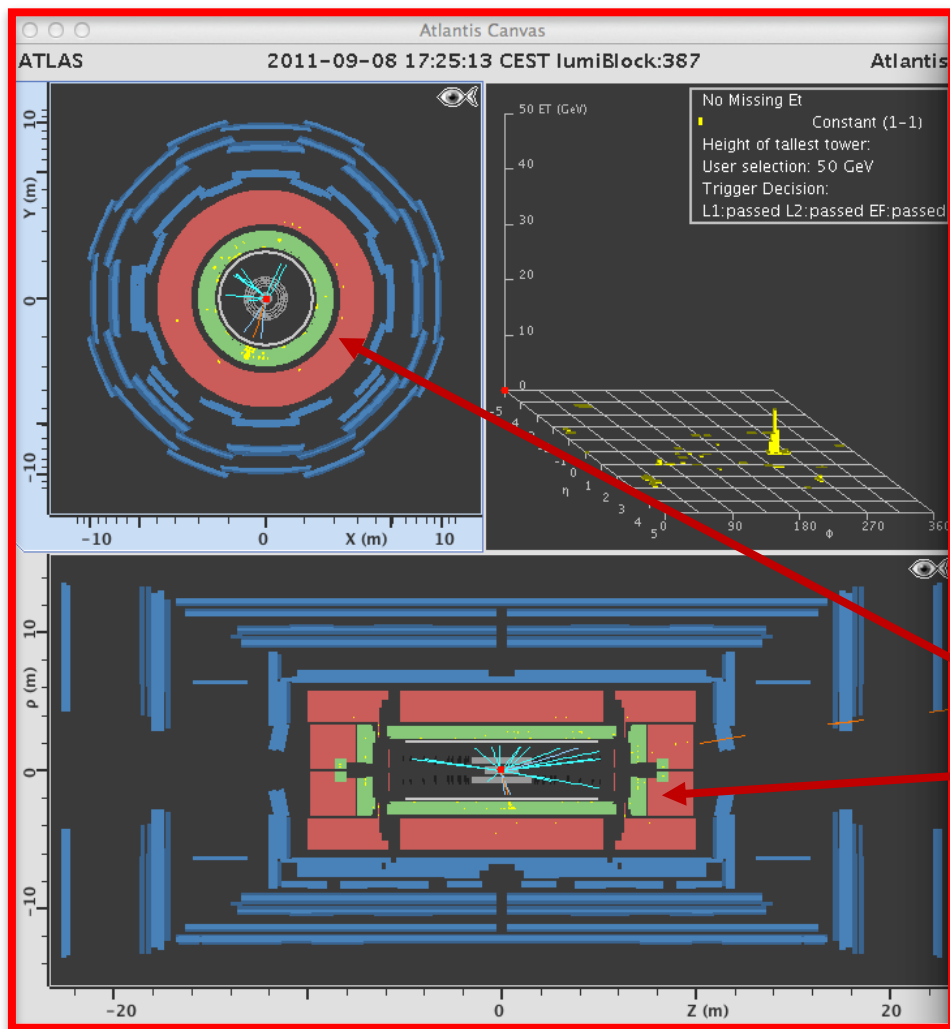Can see all of the different detectors here

Tracking detector

Electromagnetic calorimeter

Absorbs energy of EM interacting particles

Absorbs – e and photon

Interacts withs – jets, muons

MINERVA Event Display – ATLANTIS Canvas

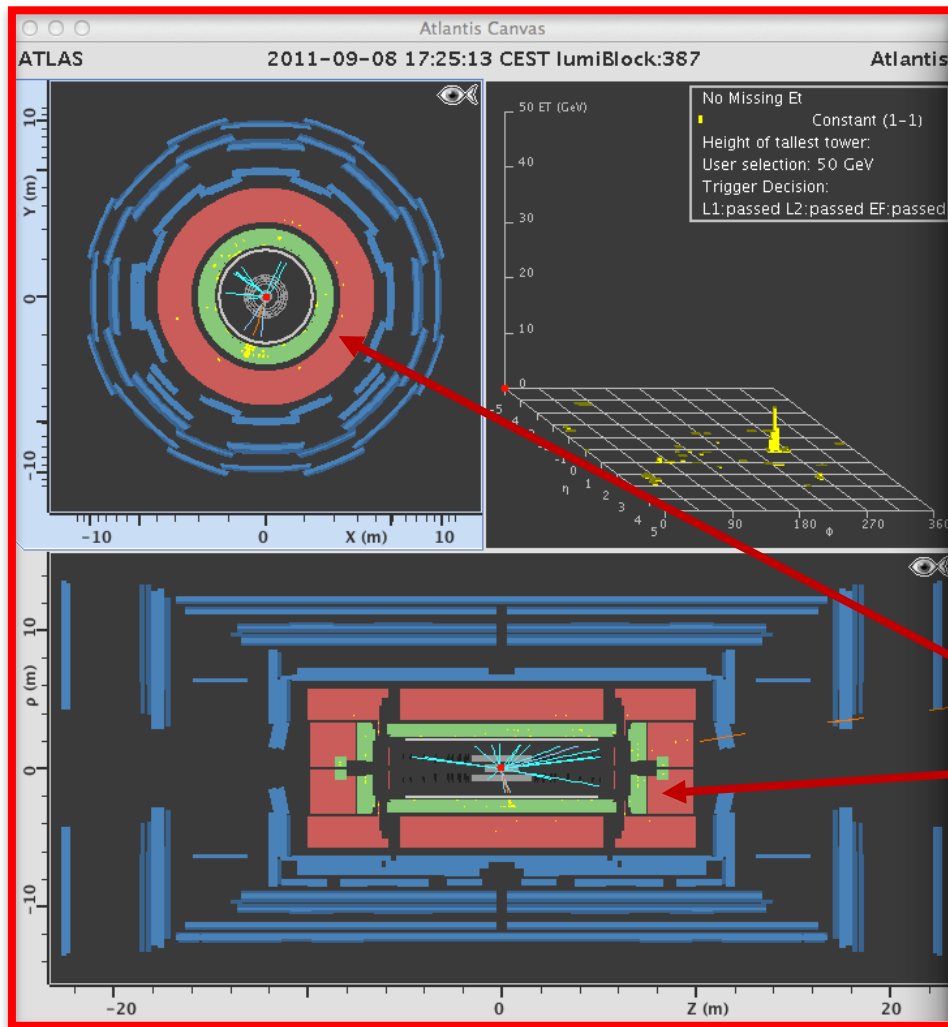Can see all of the different detectors here

Tracking detector

Electromagnetic calorimeter

Hadronic calorimeter

Absorbs hadronic particles, such as…

MINERVA Event Display – ATLANTIS Canvas

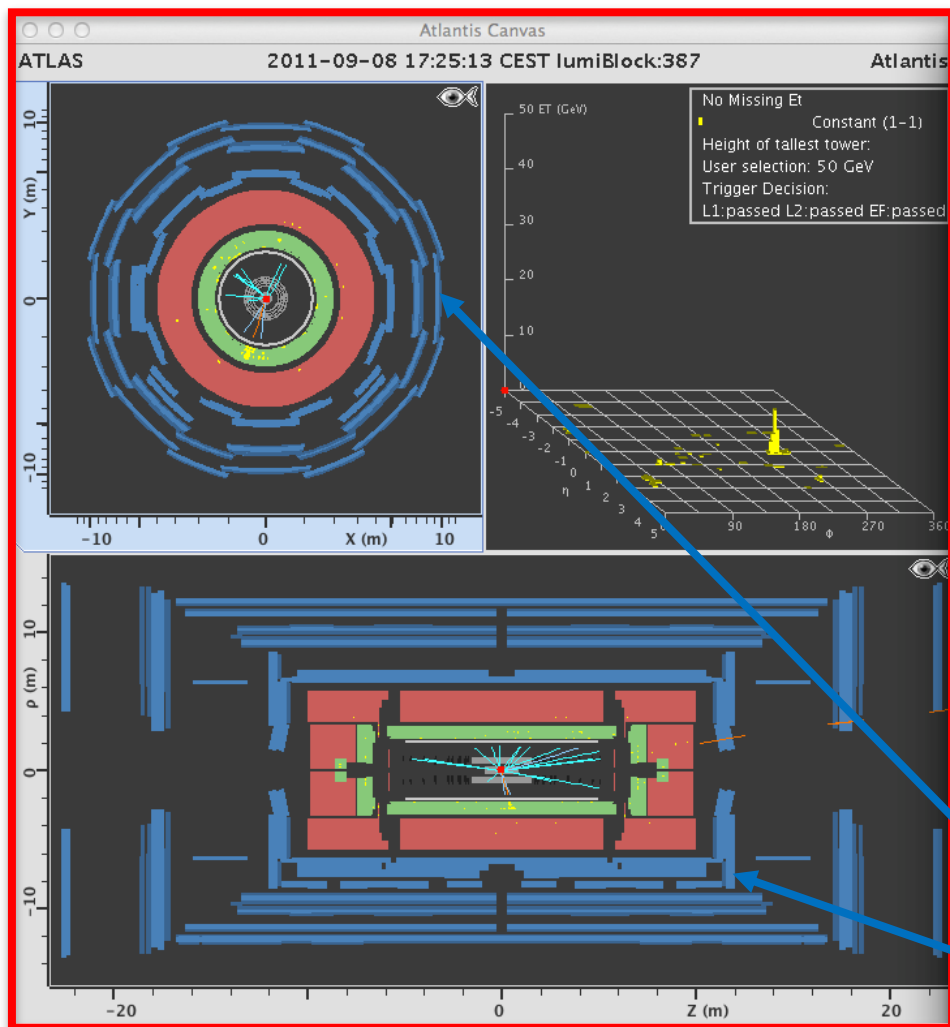
Can see all of the different detectors here

Tracking detector

Electromagnetic calorimeter

Hadronic calorimeter

Absorbs hadronic particles, such as Jets!

MINERVA Event Display – ATLANTIS Canvas

Can see all of the different detectors here
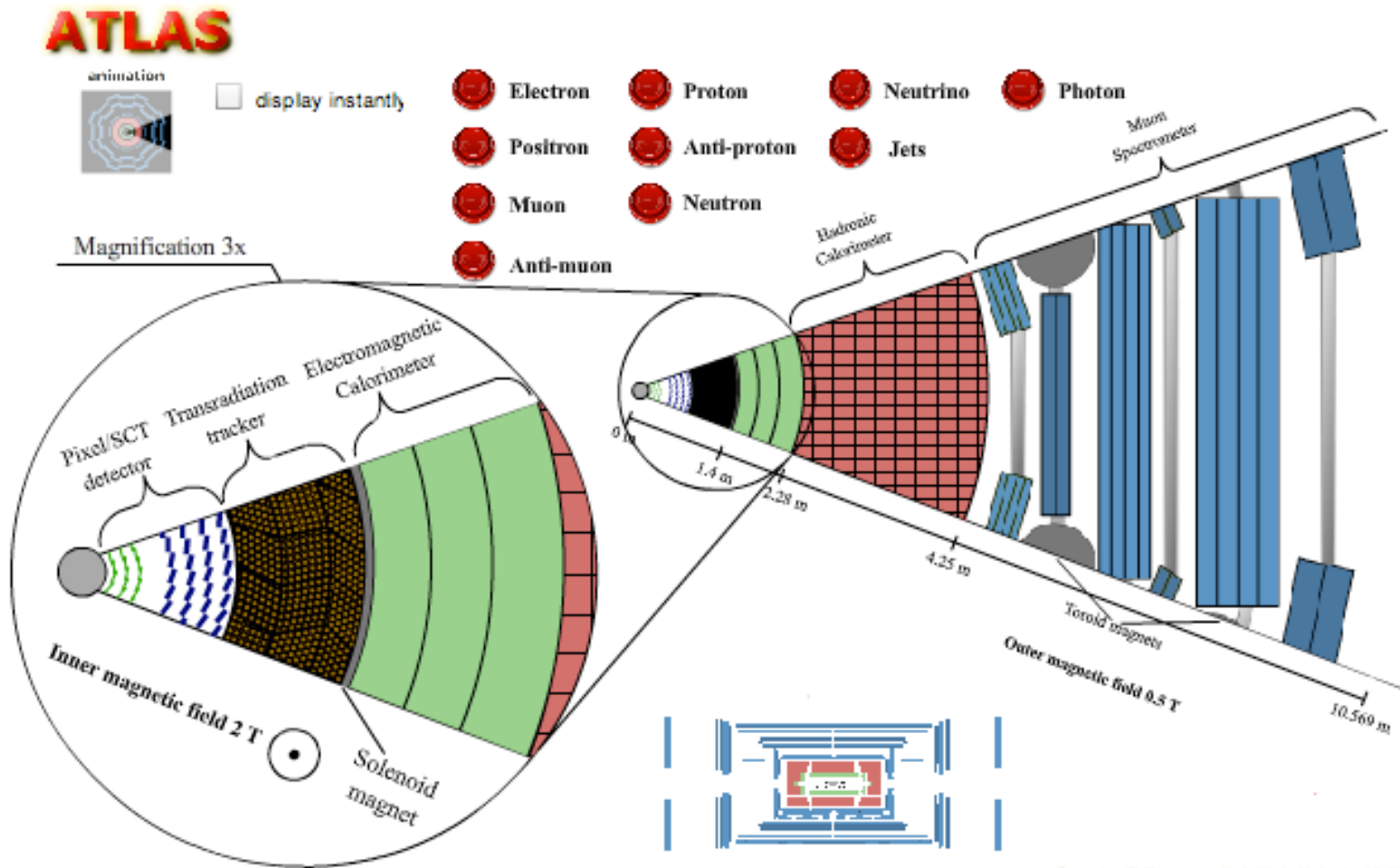
Tracking detector

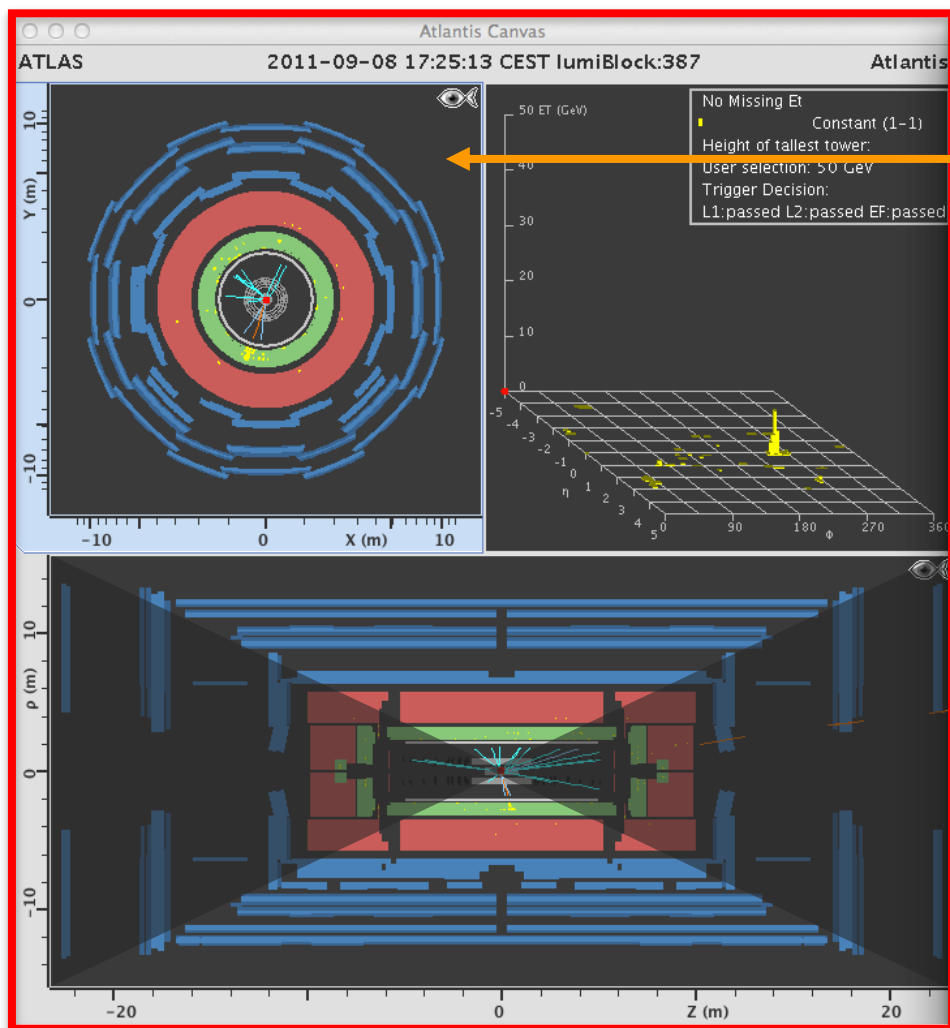Electromagnetic calorimeter

Hadronic calorimeter

Muon detectors

Detects charged particles – only muons left

Identifying particles

MINERVA Event Display – ATLANTIS Canvas

Top left

End-on view of the detector (*x-y* projection)

Warning: Only particles reconstructed in central region shown here (otherwise the particles in the forward would cover the view)!
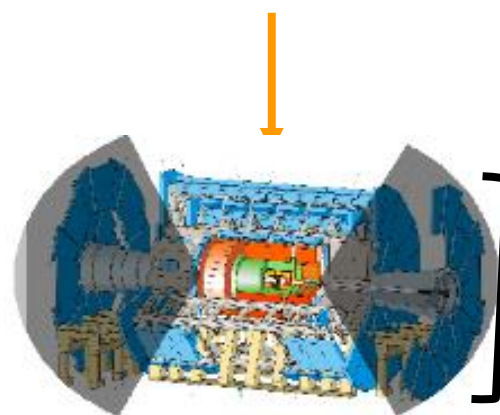
MINERVA Event Display – ATLANTIS Canvas
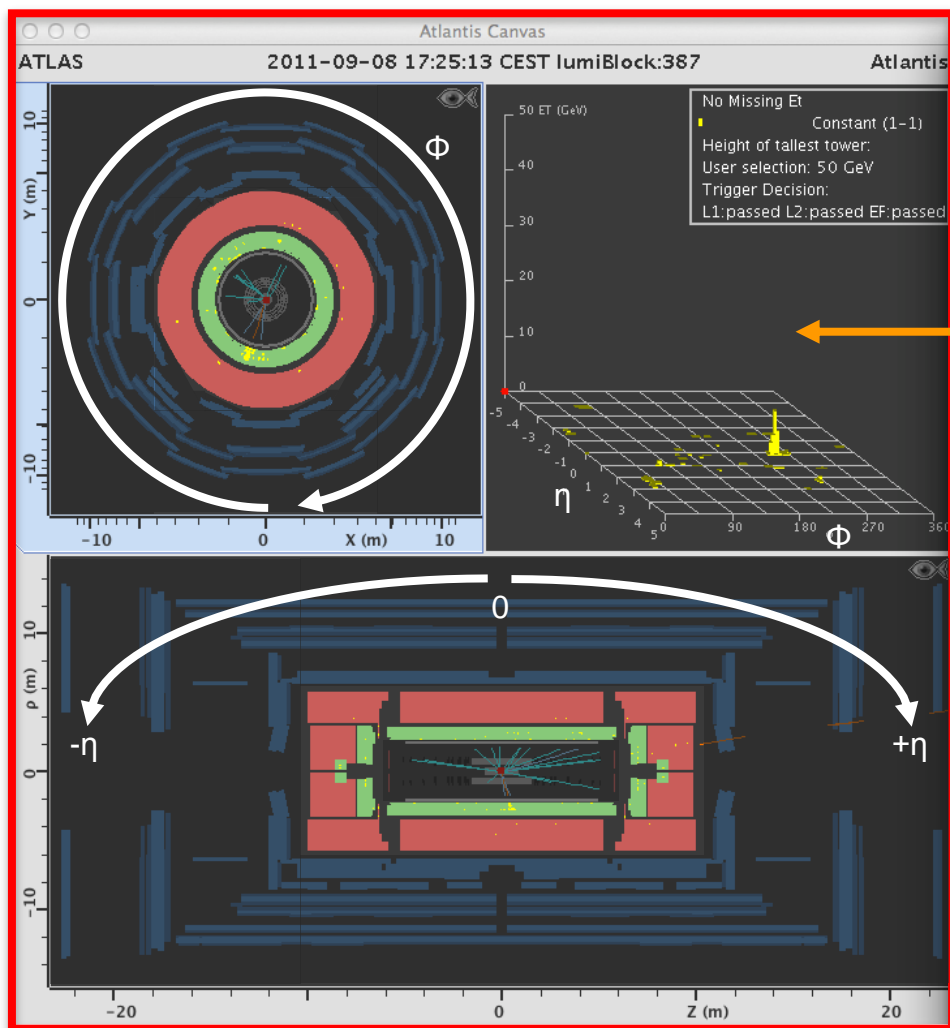
Top right

Lego plot ('rolled out' calorimeters)

Shows energy deposits seen by all regions of the electromagnetic and hadronic calorimeters as towers in eta (η) and phi (Φ) direction

Production of different W particles
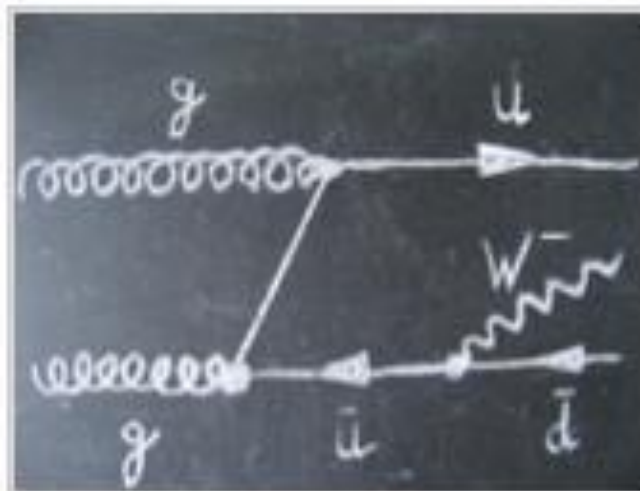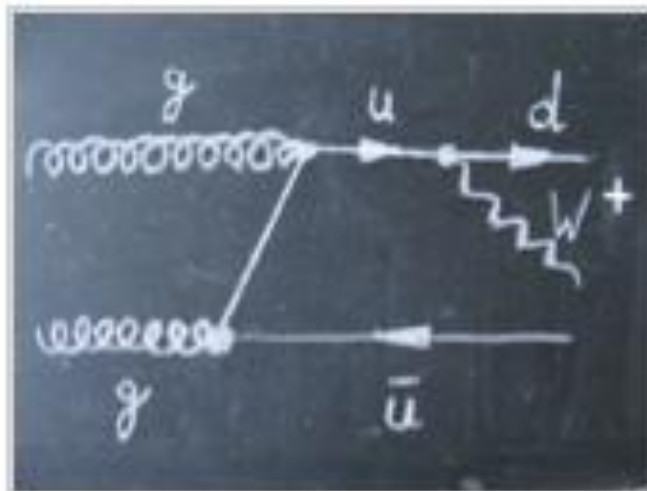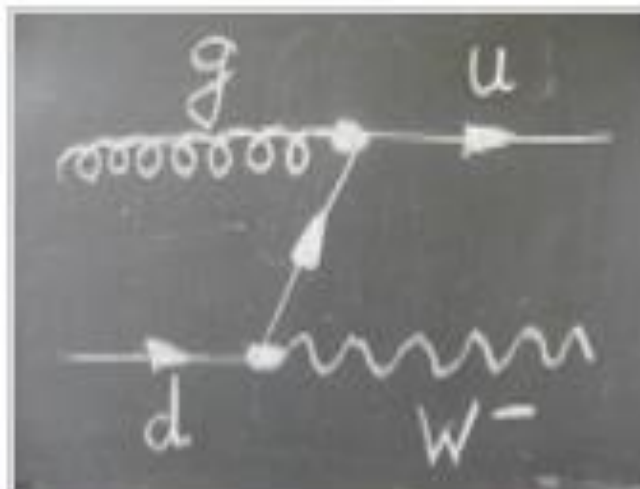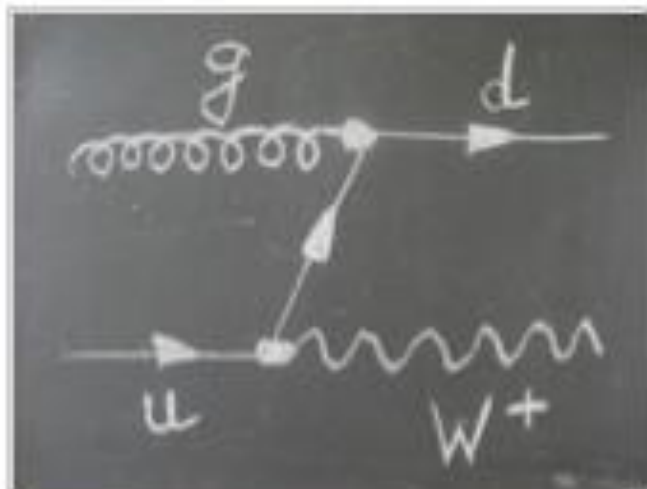
W boson decay
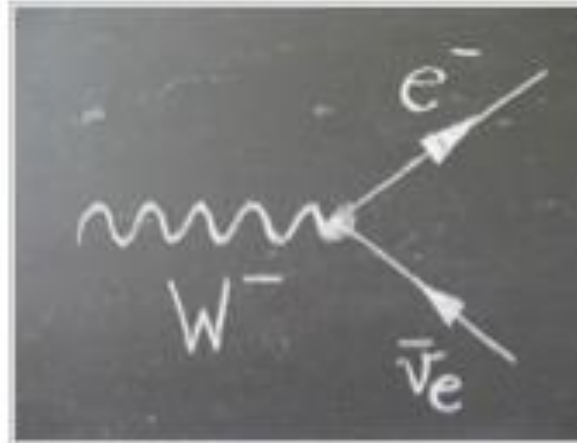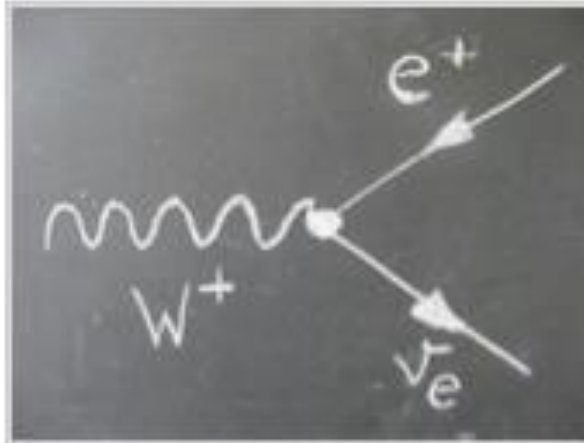
Electron channel
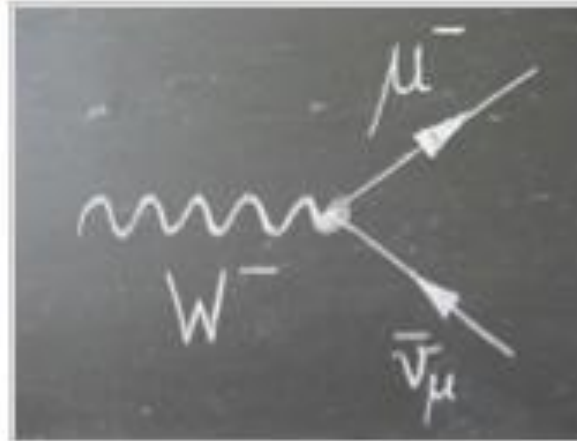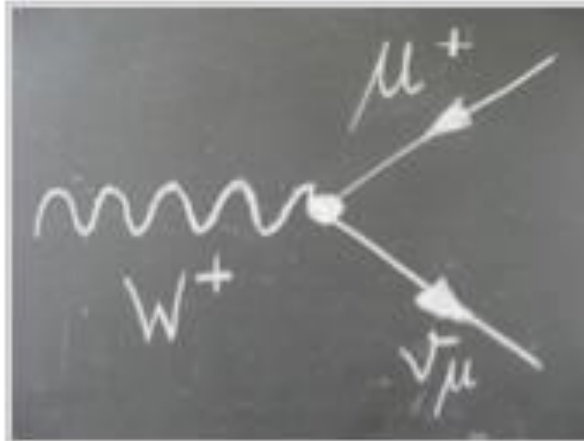
Muon channel

Background
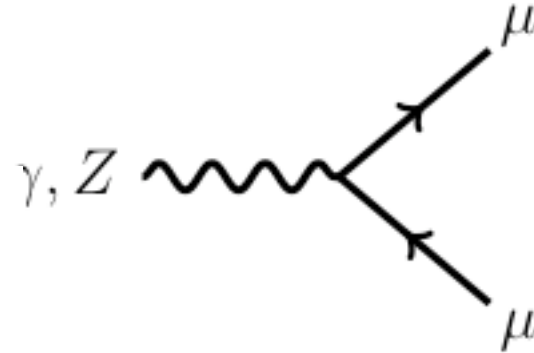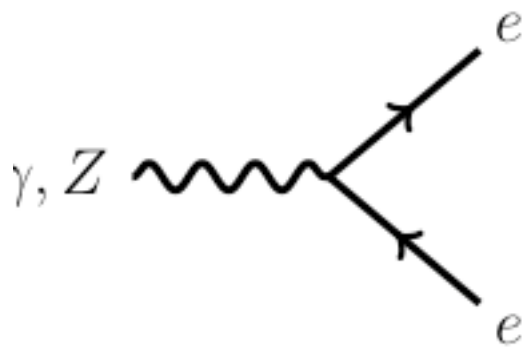
Z→μ⁻+μ⁺ (or Z→e⁻+e⁺)

there is TWO OPPOSITELY CHARGED Leptons (either an electron or a positron or a muon or an anti-muon),
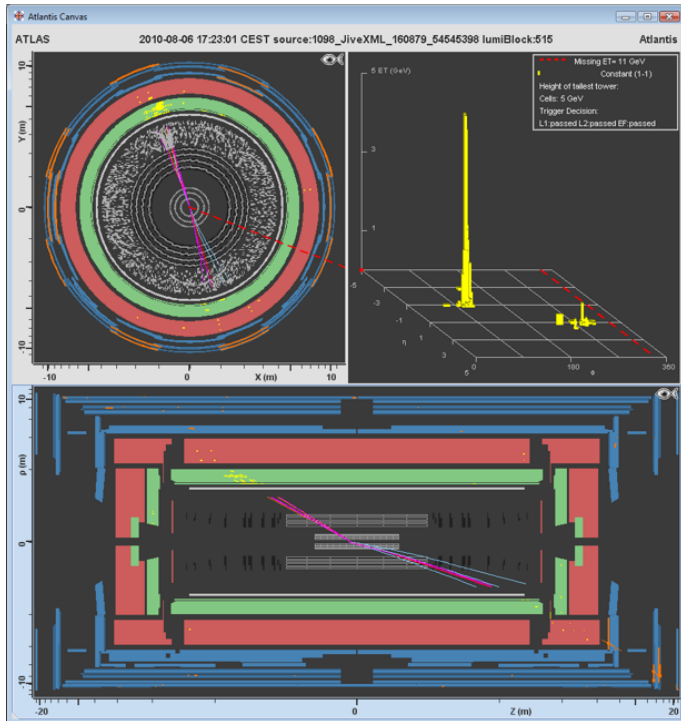
Multiple Jets

there are multiple jets (collections of hadrons particles)

MINERVA Event Display
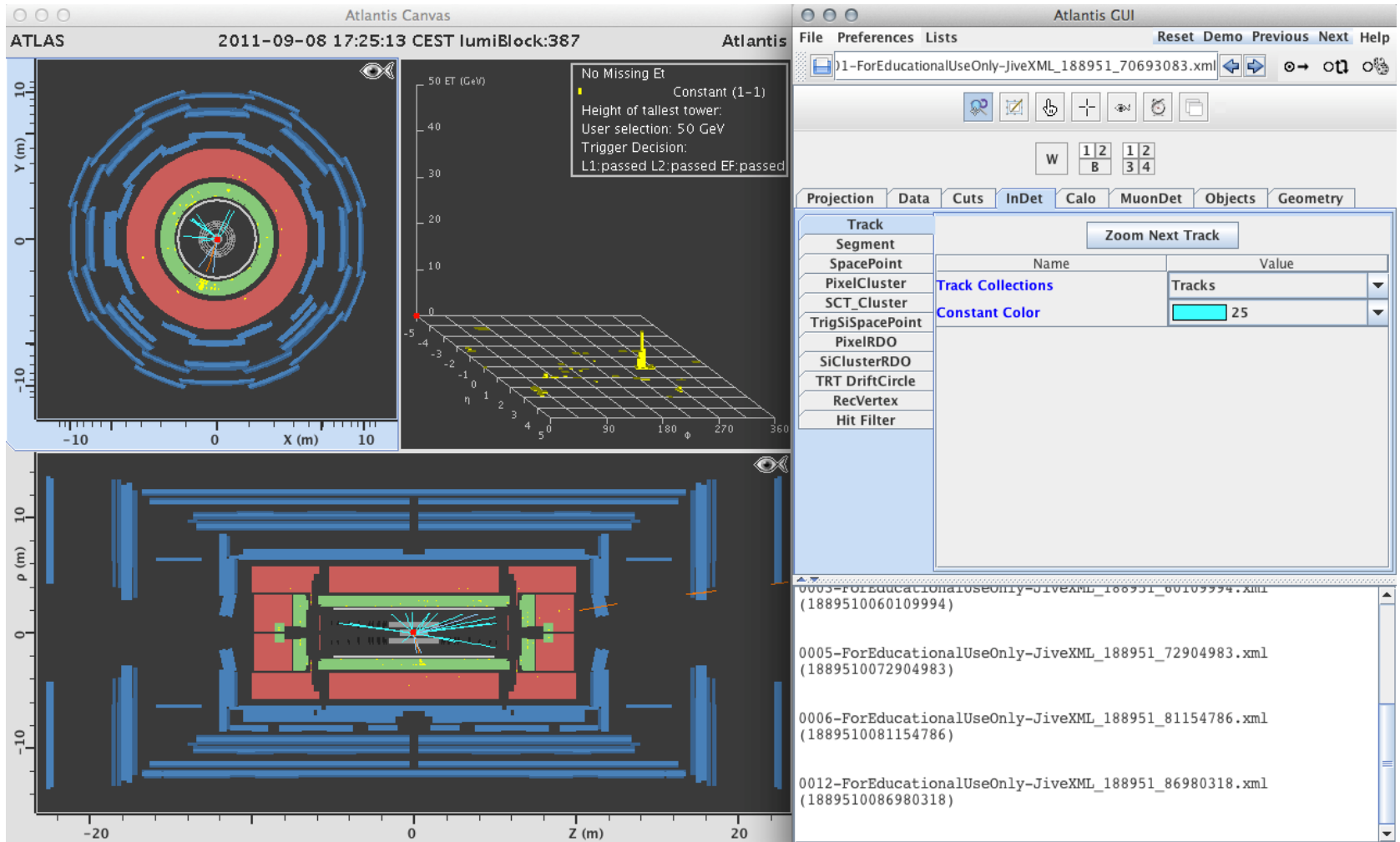
The Event Display – what you will use to identify particles and events

MINERVA – Particle Momentum & Charge

How to determine transverse momentum and electric charge?

InDetTrack index: 10
PT=24.268 GeV
η = 0.305
Φ = 59.827°
Px=12.198 GeV
Py=20.980 GeV
Pz=7.507 GeV
Charge = 1
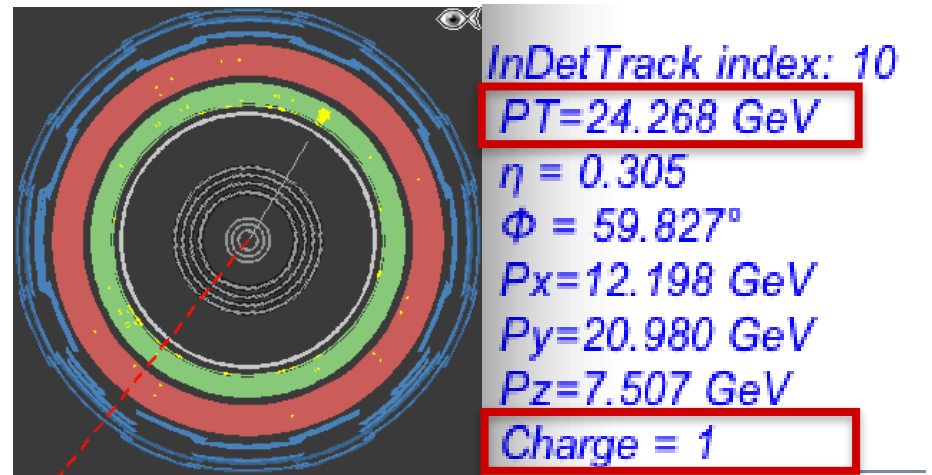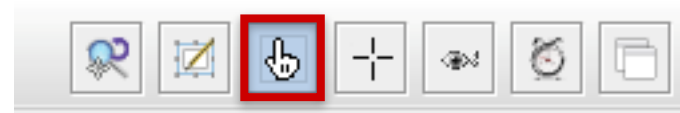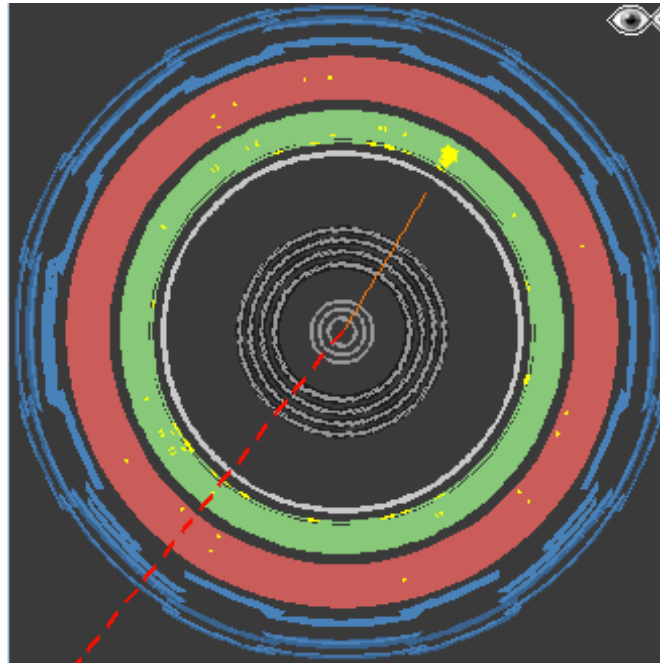
Here is the problem: determine the electric charge and momentum of the electron-like particle in this event display.

Click the Pick symbol from the tool box, select the track (colour turns into grey) and look at the output box …

Charge = 1 means positively electrically charged
Charge = -1 means negatively electrically charged

Particle/Object Identification
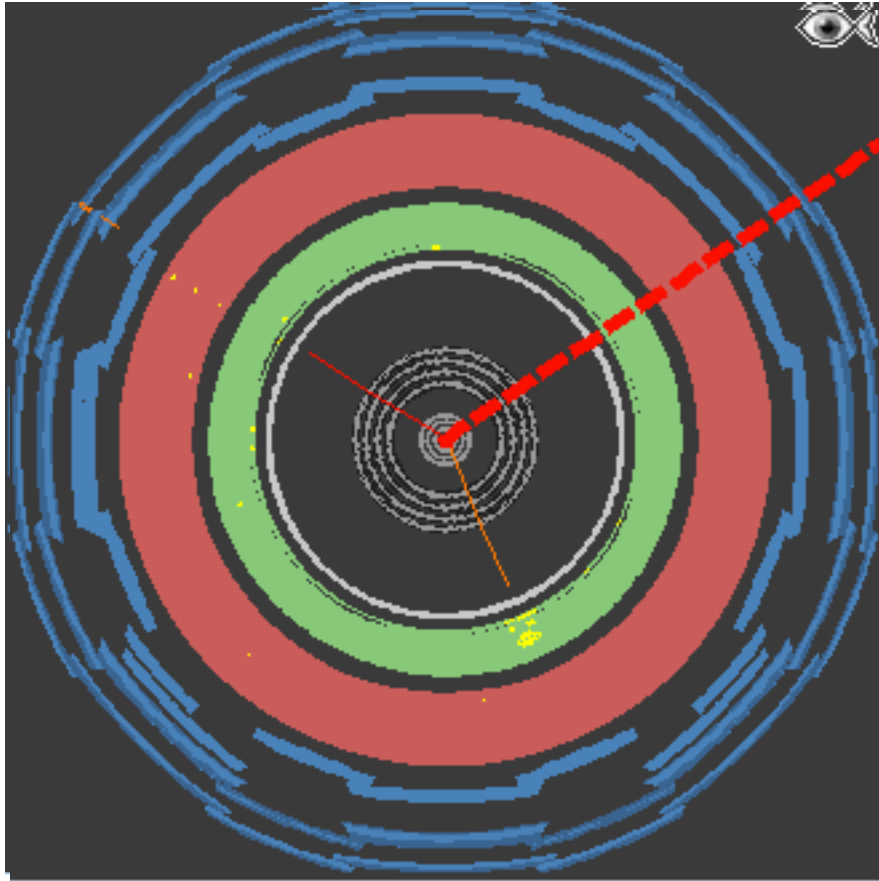
Electron:

- Track in inner detector

- Stopped inside electromagnetic calorimeter

Muon:

- Track in inner detector

- Only few interactions inside both calorimeters; cannot be stopped

- Orange tracks in outer muon chambers

Neutrino:

- Missing transverse momentum (dashed red line) – measured indirectly

Jets:

- Collection of tracks in inner detector

- Energy deposited in electromagnetic and hadronic calorimeters, stopped fully in hadronic calorimeter

Particle/Object Identification
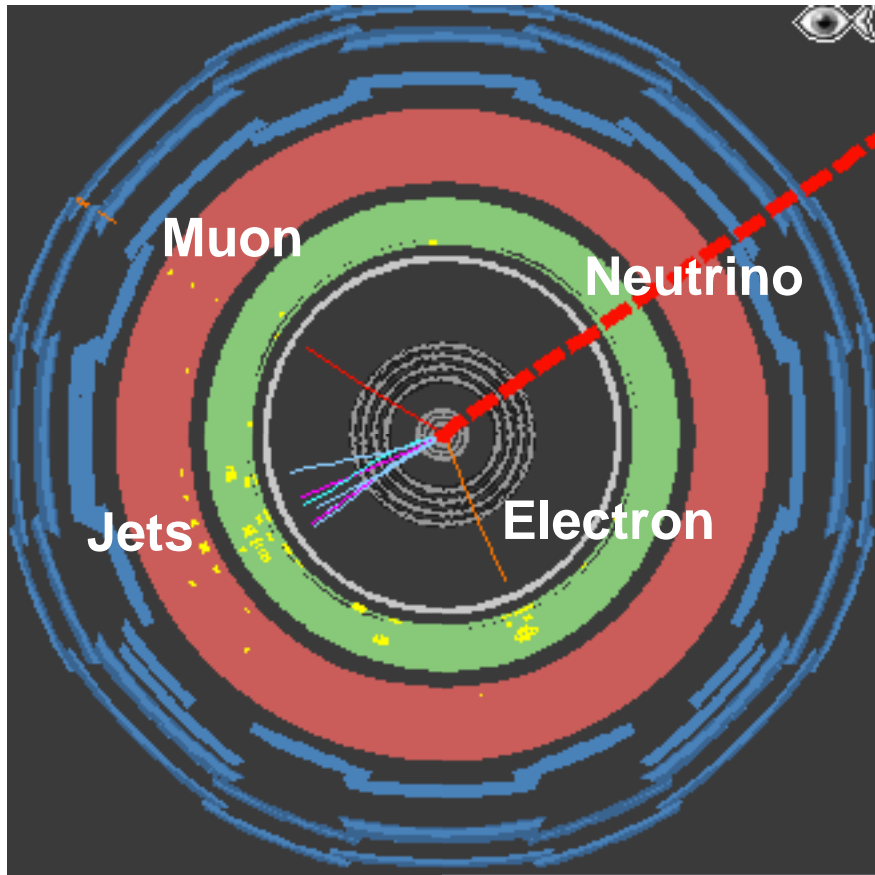
Electron:

•Track in inner detector

•Stopped inside electromagnetic calorimeter

Muon:

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•Only few interactions inside both calorimeters; cannot be stopped

•Orange tracks in outer muon chambers

Neutrino:

•Missing transverse momentum (dashed red line) – measured indirectly

Jets:

•Collection of tracks in inner detector

•Energy deposited in electromagnetic and hadronic calorimeters, stopped fully in hadronic calorimeter

Event Identification - Signal

$W^- \to \mu^- + \bar{v}_\mu$ or $W^+ \to \mu^+ + v_\mu$

there is EXACTLY ONE muon or an anti-muon,

which is isolated (meaning it DOES NOT appear inside a JET) and

has a transverse momentum (p_T) greater than 20 GeV. Furthermore

a missing transverse momentum (MET) of AT LEAST 25 GeV is required in the event

Remember to pick the muon-like track to find out its momentum and charge

Charge = -1 = muon
Charge = 1 = anti-muon

to work out if it came from W^+ or W^- boson

MuonTrack index: 0
PT=58.947 GeV
η = -2.372
Φ = 308.722°
Px=36.874 GeV
Py=-45.990 GeV
Pz=-313.191 GeV
Charge = -1
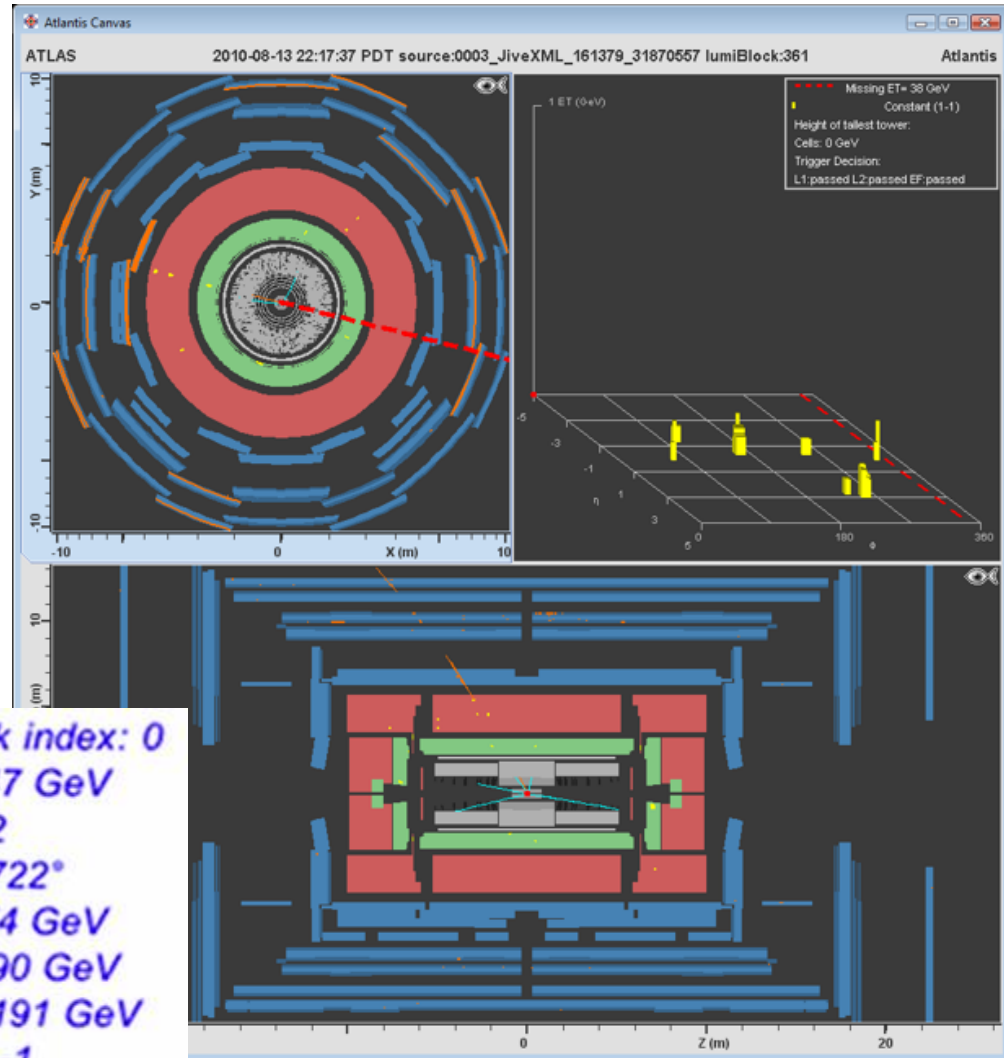
Event Identification - Signal

W⁻→e⁻+ν̄ₑ or W⁺→e⁺+νₑ

there is EXACTLY ONE electron or positron,

which is isolated (meaning it DOES NOT appear inside a JET) and

has a transverse momentum (p_T) greater than 20 GeV. Furthermore

a missing transverse momentum (MET) of AT LEAST 25 GeV is required in the event

Remember to pick the electron-like track to find out its momentum and charge

Charge = -1 = electron
Charge = 1 = positron

to work out if it came from
W⁺ or W⁻ boson

InDetTrack index: 5
PT=24.183 GeV
η = -0.416
Φ = 137.191°
Px=-17.741 GeV
Py=16.434 GeV
Pz=-10.364 GeV
Charge = -1
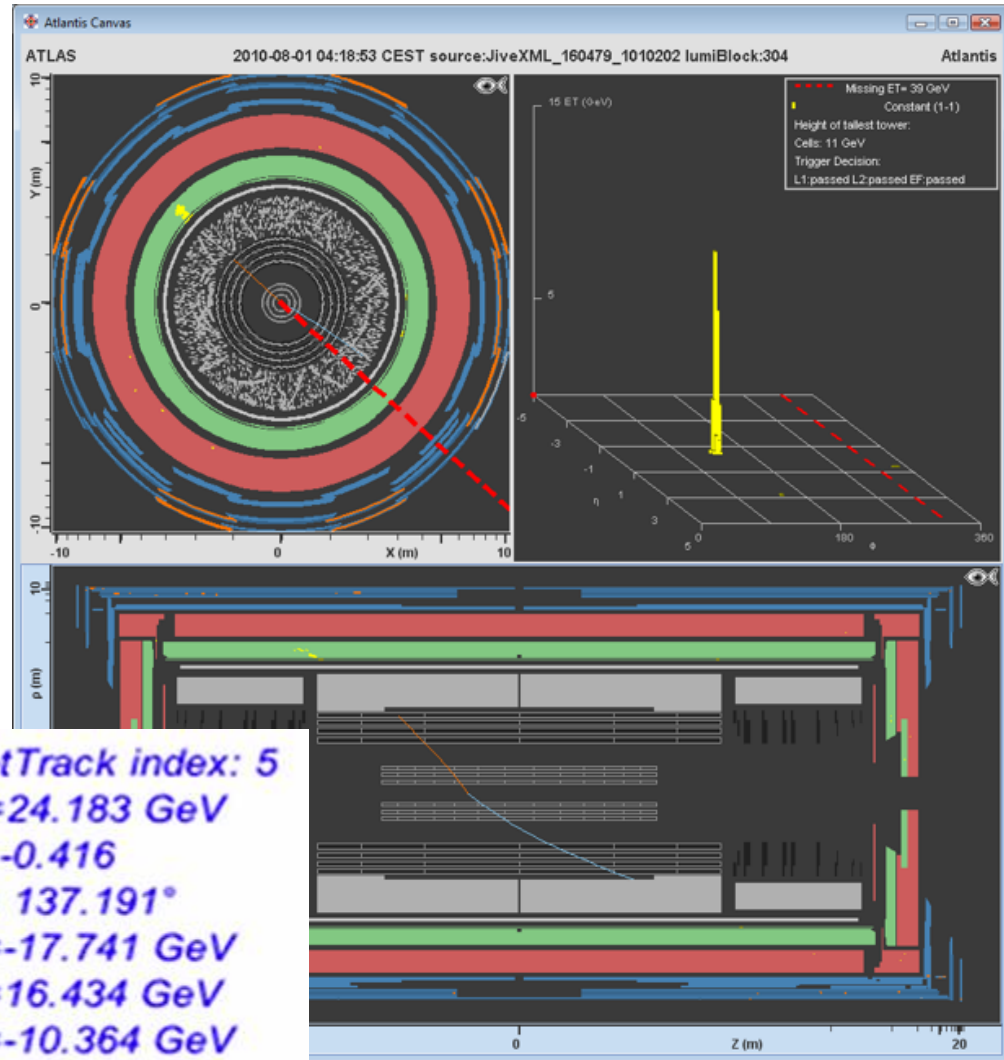
Event Identification - Signal

WW→*l*+ν*l*+*l*+ν*l*
(*l* can be electron, muon, positron, antimuon)

contain EXACTLY TWO leptons with OPPOSITE electric charges,

are isolated and

the lepton with higher transverse momentum needs to have pT of at least 25 GeV while the lepton with lower transverse momentum only needs to have at least 15 GeV.

Furthermore a missing transverse momentum is required depending on the kind of leptons involved:

of at least 40 GeV if both leptons are coming from the same family

of at least 25 GeV in the other case.
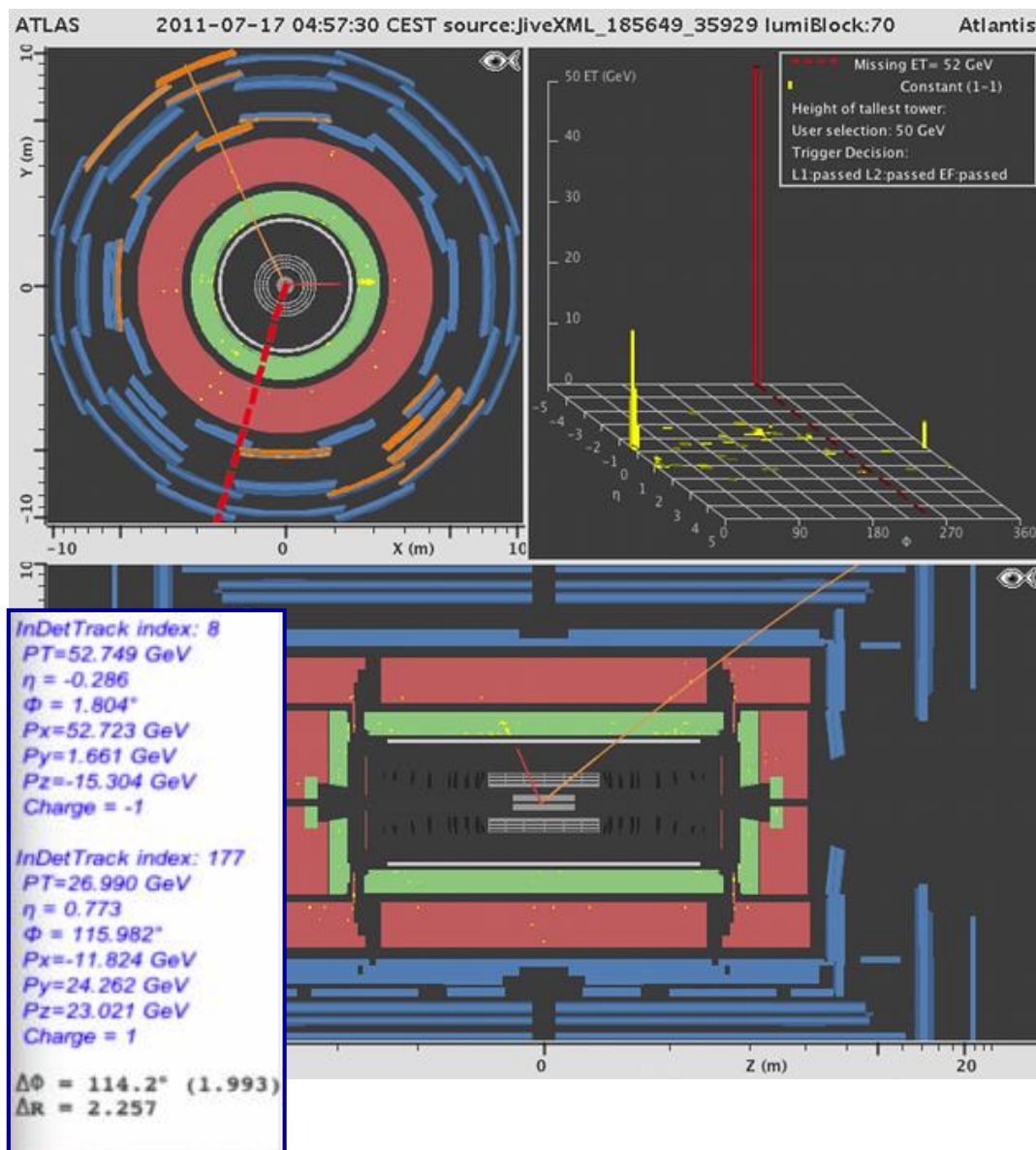
Event Identification - Background

Z→μ⁻+μ⁺ (or Z→e⁻+e⁺)

there is TWO OPPOSITELY CHARGED Leptons (either an electron or a positron or a muon or an anti-muon),

which appear isolated (meaning it DOES NOT appear inside a JET) and

the lepton with higher transverse momentum needs to have pT of at least 25 GeV while the lepton with lower transverse momentum only needs to have at least 15 GeV

a missing transverse momentum (MET) LESS THAN 25 GeV is required event (usually a lot smaller than this)

InDetTrack index: 2
PT=44.868 GeV
η = -1.047
Φ = 18.660°
Px=42.510 GeV
Py=14.356 GeV
Pz=-56.019 GeV
Charge = -1

InDetTrack index: 0
PT=40.762 GeV
η = -1.120
Φ = 205.003°
Px=-36.942 GeV
Py=-17.229 GeV
Pz=-55.794 GeV
Charge = 1
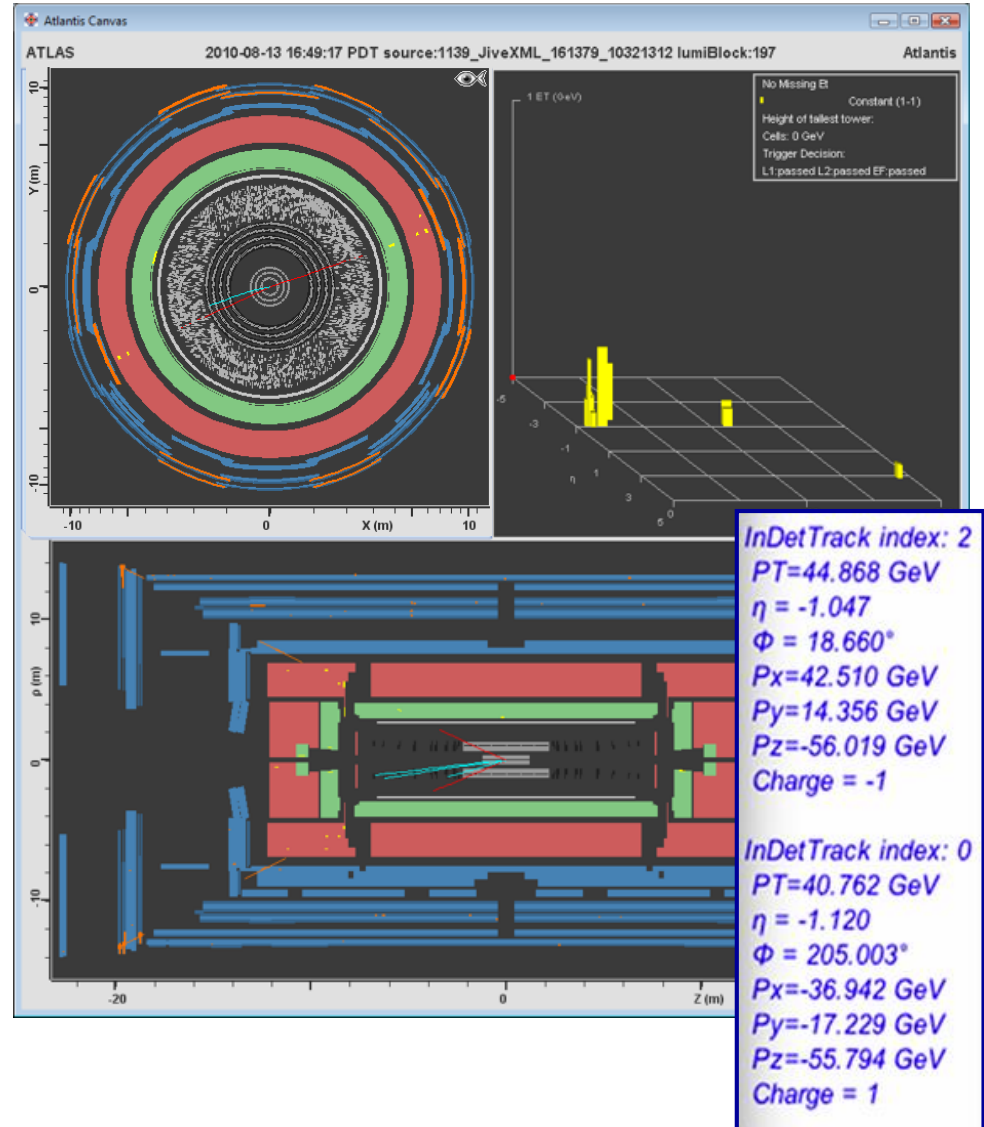
Event Identification - Background

Multiple Jets

there are multiple jets (collections of hadrons particles)

Lots of collected tracks in the tracking detector and lots of activity in the electromagnetic and hadronic calorimeter

a missing transverse momentum (MET) LESS THAN 25 GeV is required in the event (usually a lot smaller than this)
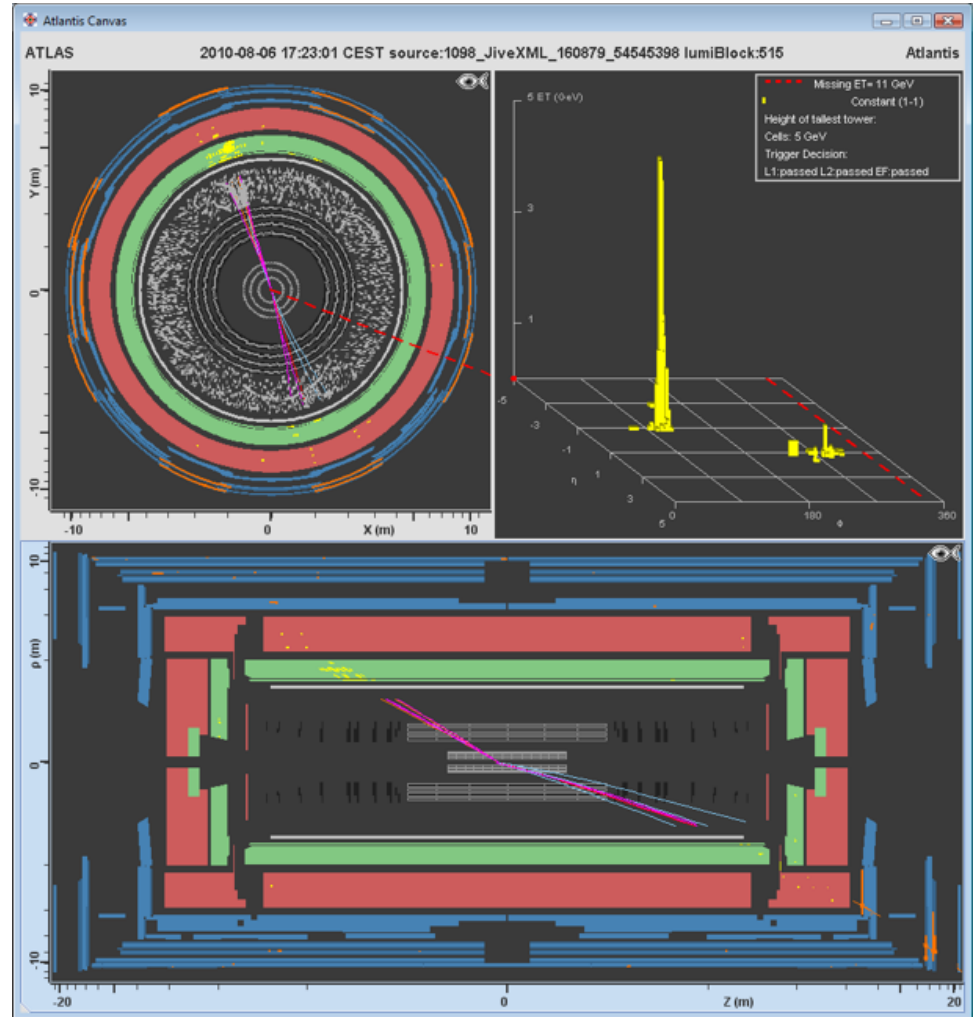
Exercise 2: Classify the Event

- Use the link online:
  http://kjende.web.cern.ch/kjende/en/wpath_exercise2.htm

- There are 10 events to look at – each of a different type
  - $W^+ \rightarrow e^+ + \nu_e$
  - $W^- \rightarrow e^- + \bar{\nu}_e$
  - $W^+ \rightarrow \mu^+ + \nu_\mu$
  - $W^- \rightarrow \mu^- + \bar{\nu}_\mu$
  - $WW^- \rightarrow l^- + \bar{\nu}_l + l^+ + \nu_l$
  - Background from jets, $Z \rightarrow e^+ e^-$, $Z \rightarrow \mu^+ \mu^-$

- Load up events from "exercise2.zip" in ATLANTIS
- Distinguish between background and signal events!
- Aim to correctly identify all of them

MET ≥ 20 GeV

no

yes

track(s) with transverse momentum $p_T ≥ 10$ GeV

no

yes

matching entries in the electromagnetic calorimeter (e^+, e^-) or muon chambers (μ^+, μ^-)

no

yes

load event and go through every step of the following flowchart in order to find out what kind of event it is

number of those tracks originating from one vertex (zoom in) is:

exactly 1 | **exactly 2** | **> 2**

yes | yes

$p_T ≥ 20$ GeV | **p_T (l_1) $≥ 20$ GeV p_T (l_2) $≥ 10$ GeV**

no | no

yes | yes

isolated? | **both isolated?**

no | no

yes | yes

opposite electric charge

no

yes

determine electric charge:

+1 | −1

W^+ candidate | **W^- candidate**

for leptons originating from the same family: MET $≥ 40$ GeV

no

yes

determine type of lepton:

e^+ μ^+ | e^- μ^-

measure angle between leptons in transverse plane

WW candidate

background

Exercise 2

Do 10 events

http://atlas.physicsmasterclasses.org/en/wpath_exercise2.htm

▪ Load up events from "exercise2.zip" in ATLANTIS

$W^- \rightarrow \mu^- + \nu_\mu$ or $W^+ \rightarrow \mu^+ + \nu_\mu$

$W^- \rightarrow e^- + \nu_e$ or $W^+ \rightarrow e^+ + \nu_e$

$WW \rightarrow l^- + \nu_l + l^+ + \nu_l$

Background $Z \rightarrow e^+ e^-$, $Z \rightarrow \mu^+ + \mu^-$

MINERVA Masterclass Resources

Main Minerva website
http://atlas-minerva.web.cern.ch/atlas-minerva/

ATLAS Experiment public website
http://atlas.cern