W-Path Data Analysis with MINERvA Used for the ISP220 Honors Project

International Masterclass, CERN

31st March 2012

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Outline

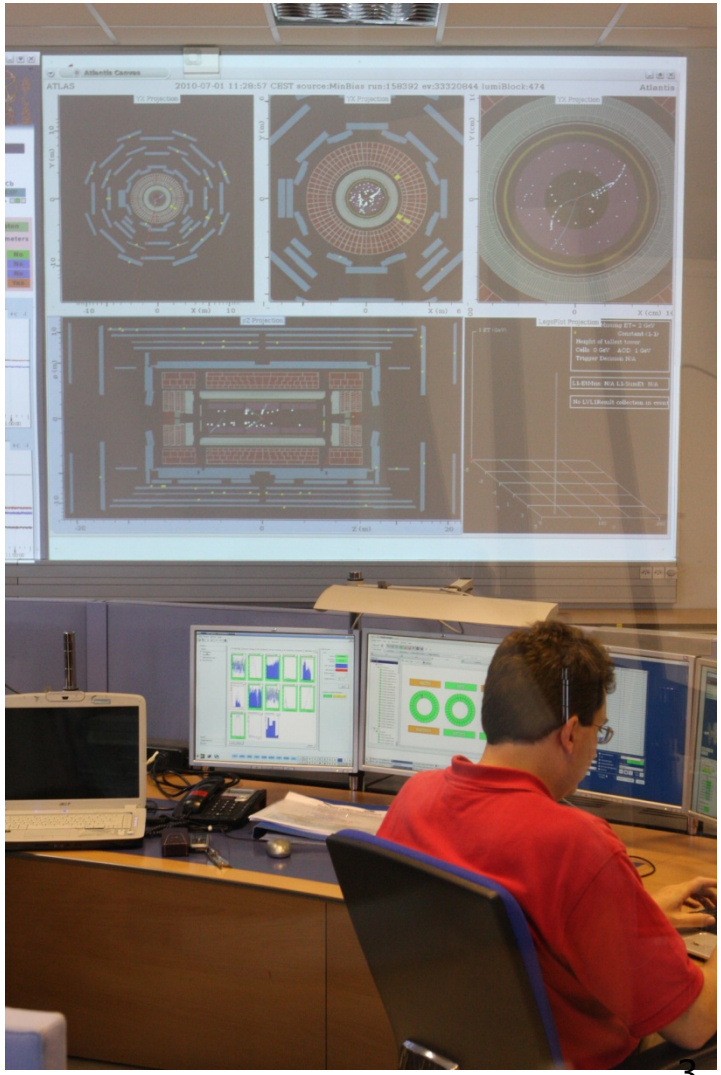
- MINERVA Event Display
- Particle Identification in ATLAS
- Events Classification (“particles produced in one collision”)
- Data Analysis
  - Structure of Proton
  - Searching for the Higgs
- Discussion of results

Introduction to MINERVA

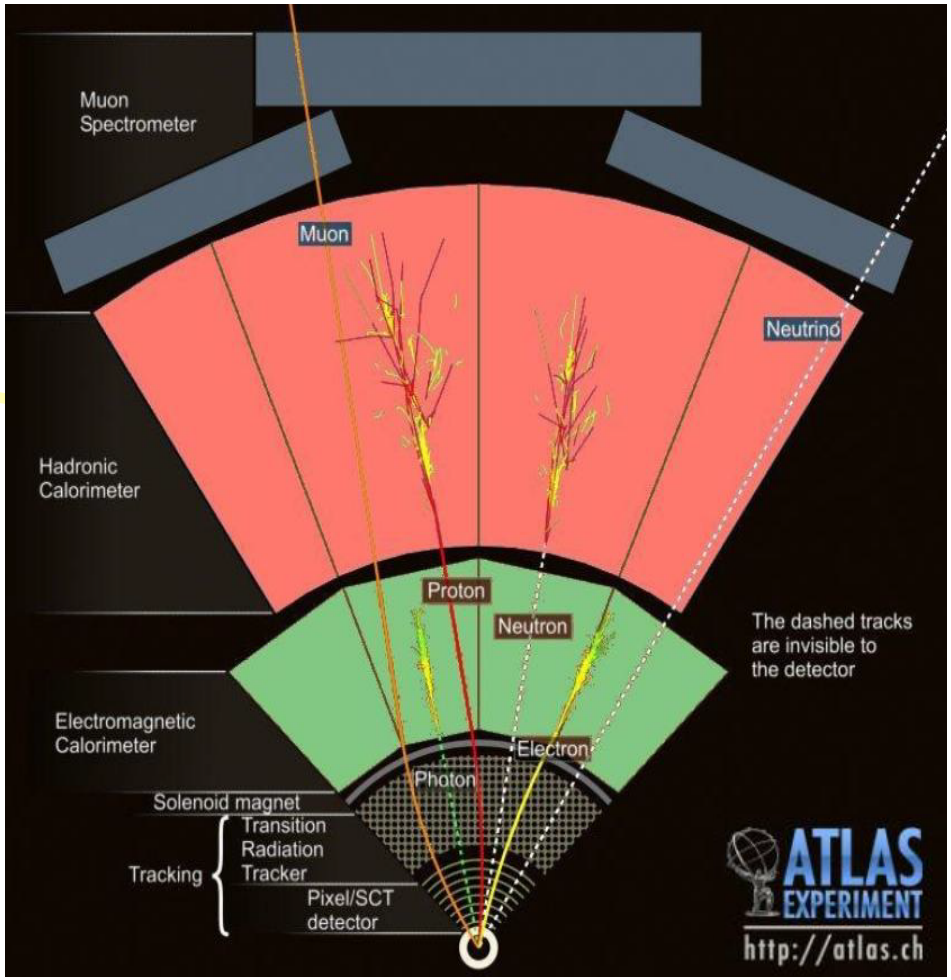
MINERVA

Masterclass INvolving Event Recognition Visualised with Atlantis

- A masterclass tool for students to learn about the ATLAS Experiment at CERN
- Motivates identification of individual particles and events from the signatures seen in the ATLAS detector
- Based on the ATLAS event display – Atlantis



Different components in the ATLAS detector



Neutrinos are only detected indirectly via 'missing energy' not recorded in the calorimeters

Tracking detector

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

Electromagnetic calorimeter

−Measure energy of electrons, positrons and photons

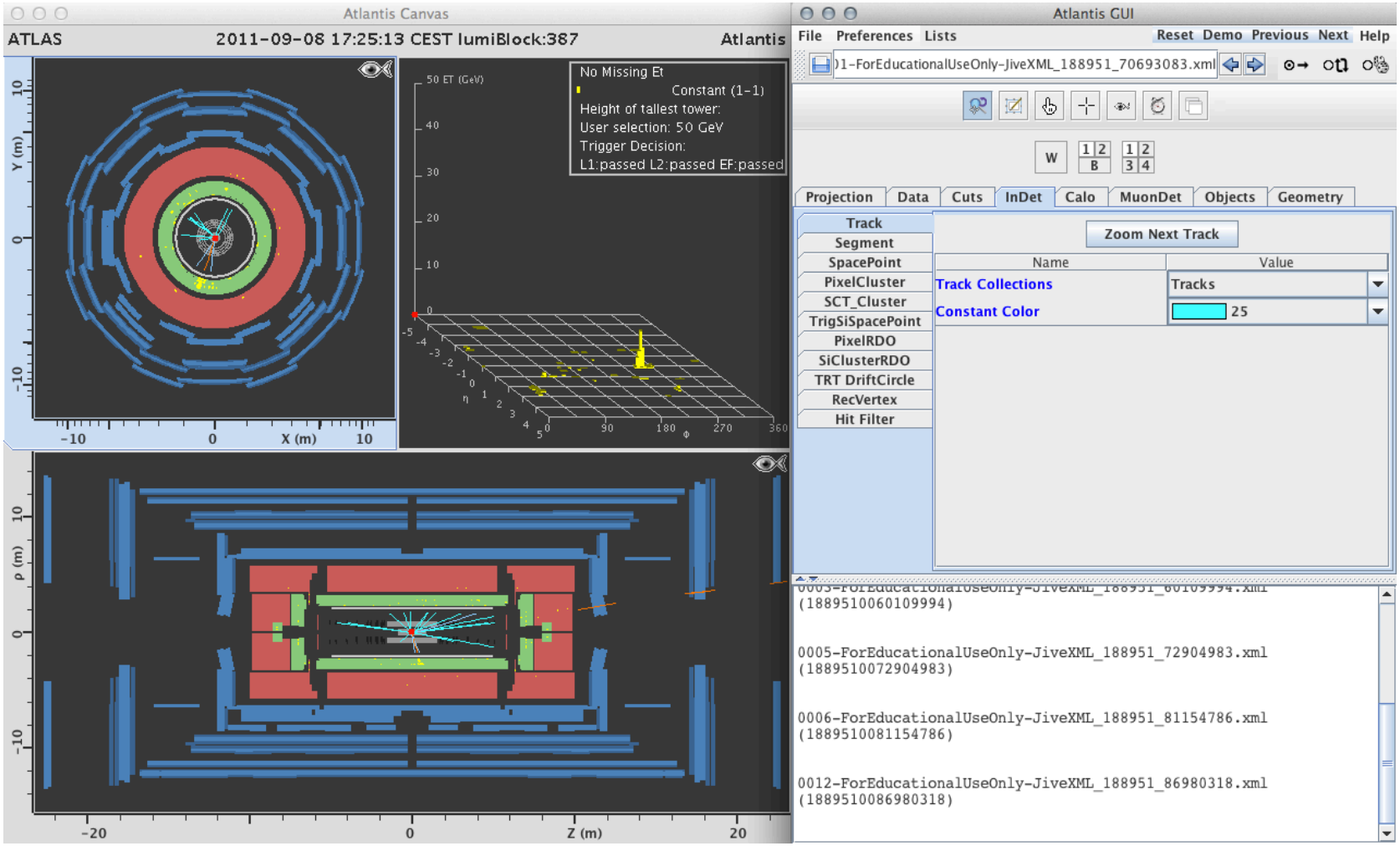
Hadronic calorimeter

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

Muon detector

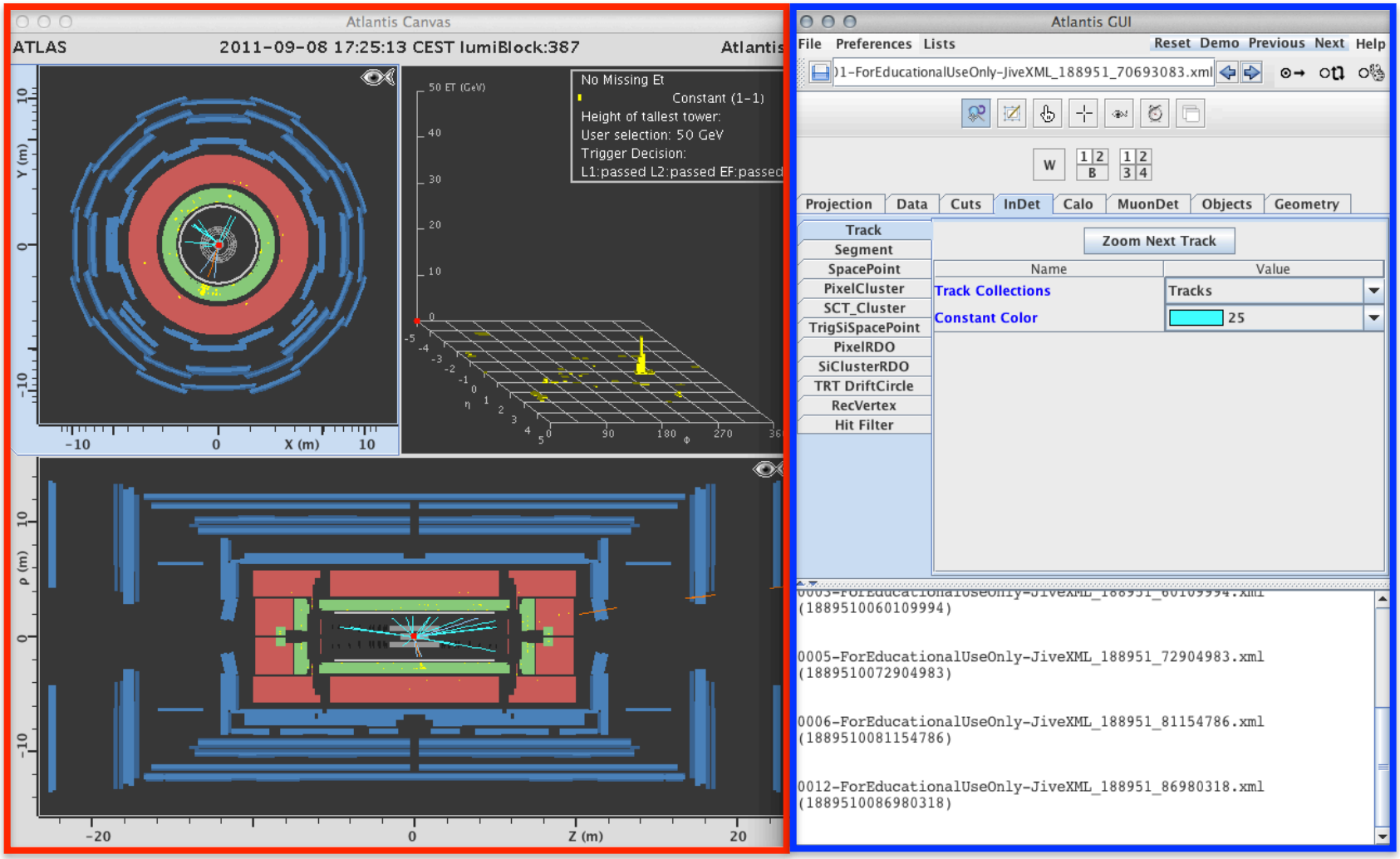
−Measure charge and momentum of muons and anti-muons in magnetic field (produced by toroids)

MINERVA Event Display



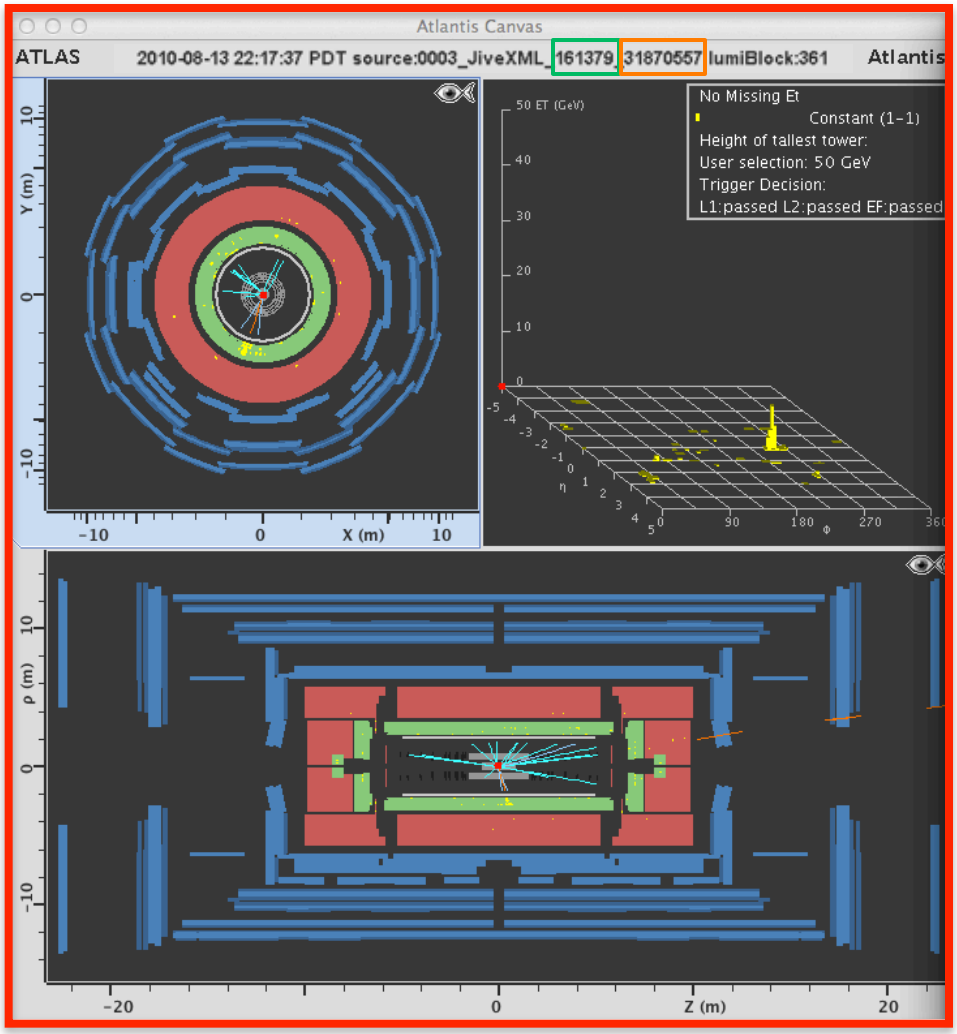
The Event Display – what you will use to identify particles and events

MINERVA Event Display



ATLANTIS Canvas Window (**red** frame) and ATLANTIS GUI Window (**blue** frame)

MINERVA Event Display – ATLANTIS Canvas

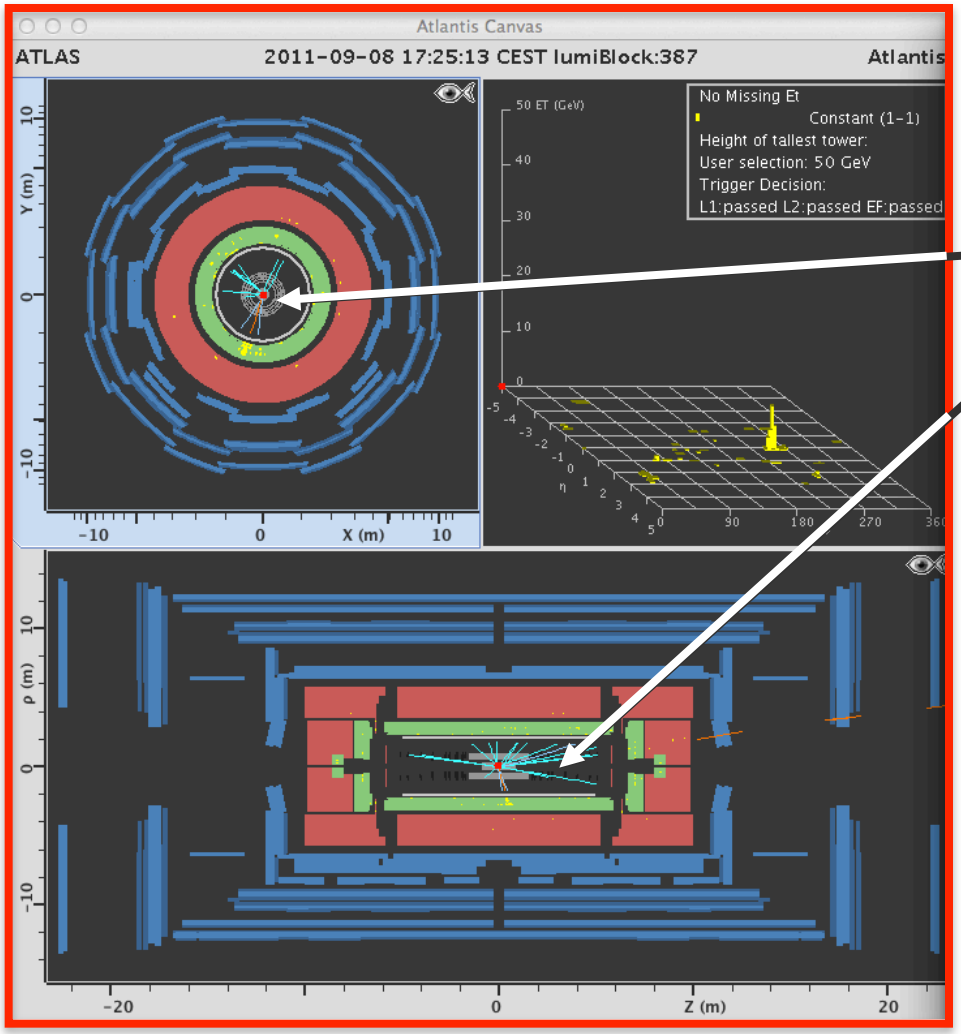


ATLANTIS Canvas displays event as seen in ATLAS detector in a number of ways

Use all views to get the complete picture of what particles are in the detector!

Also get Run Number and Event Number of event in ATLAS

MINERVA Event Display – ATLANTIS Canvas



Can see all of the different detectors here

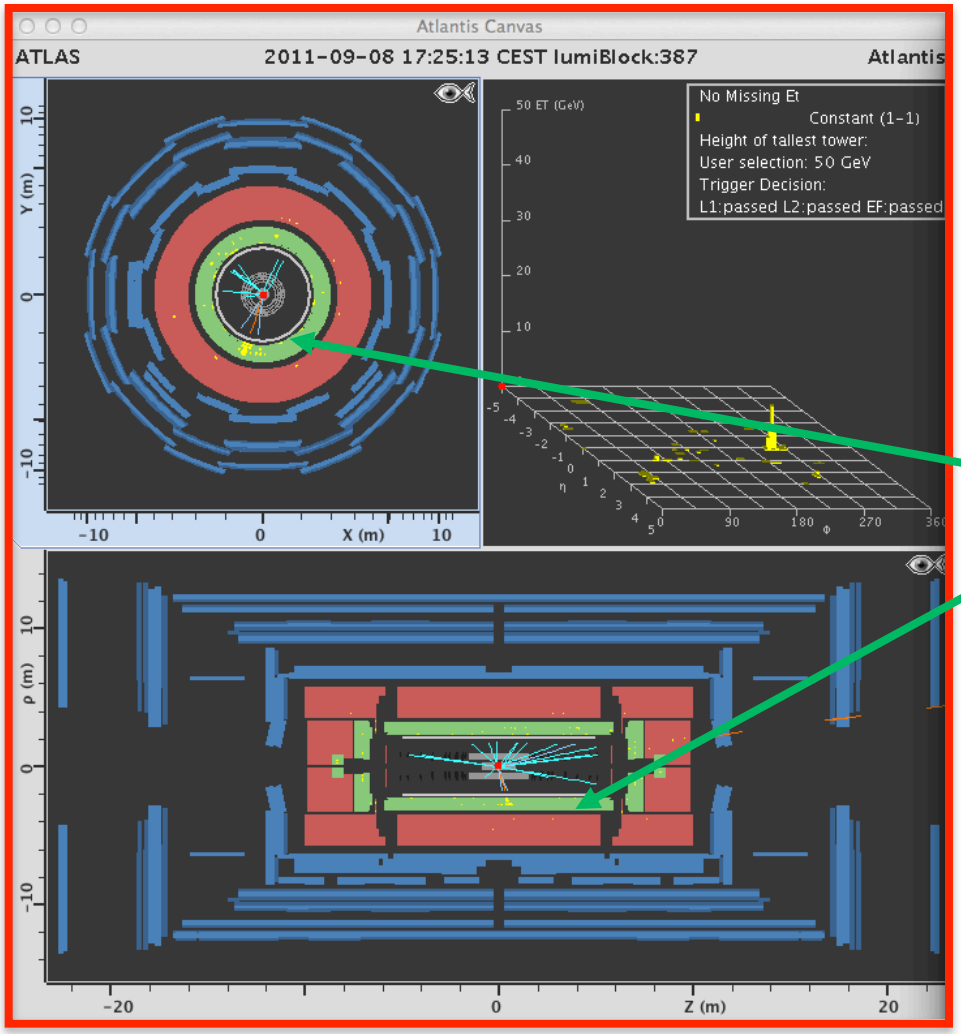
Tracking detector

Electromagnetic calorimeter

Hadronic calorimeter

Muon detectors

MINERVA Event Display – ATLANTIS Canvas



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Muon detectors

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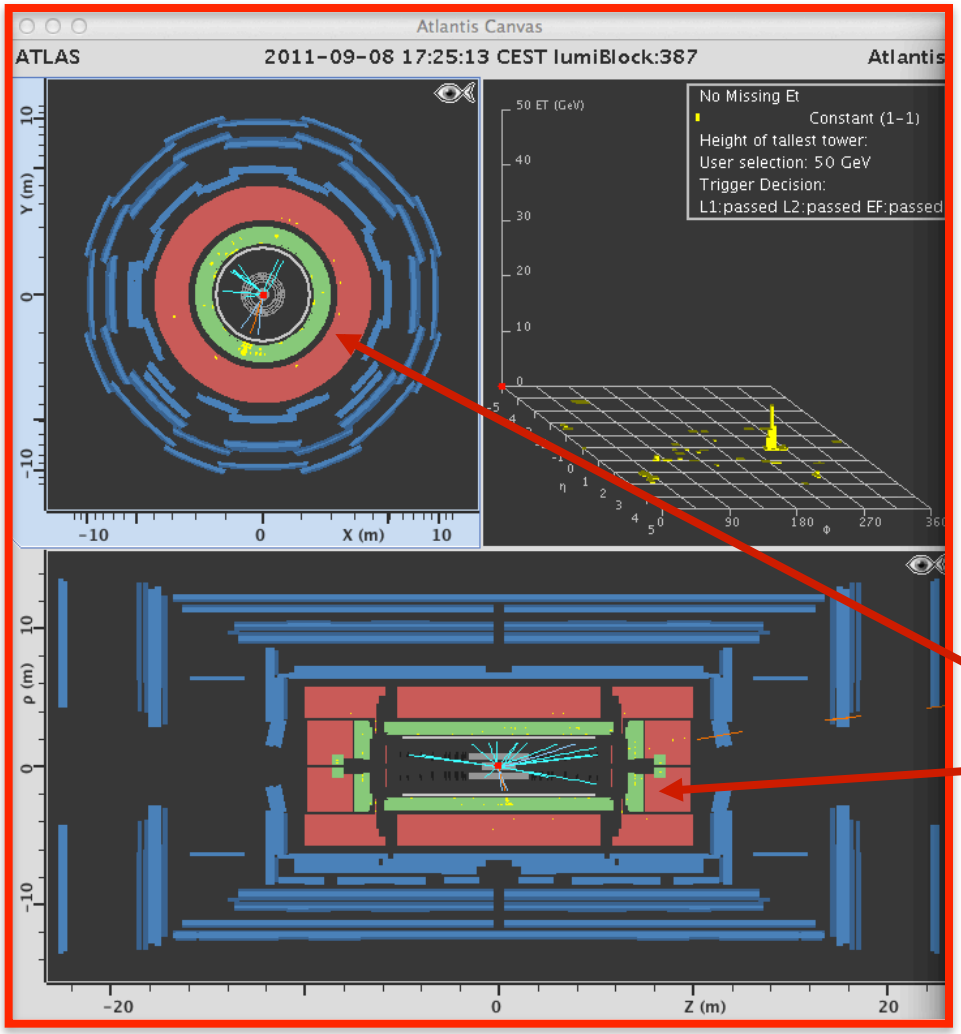

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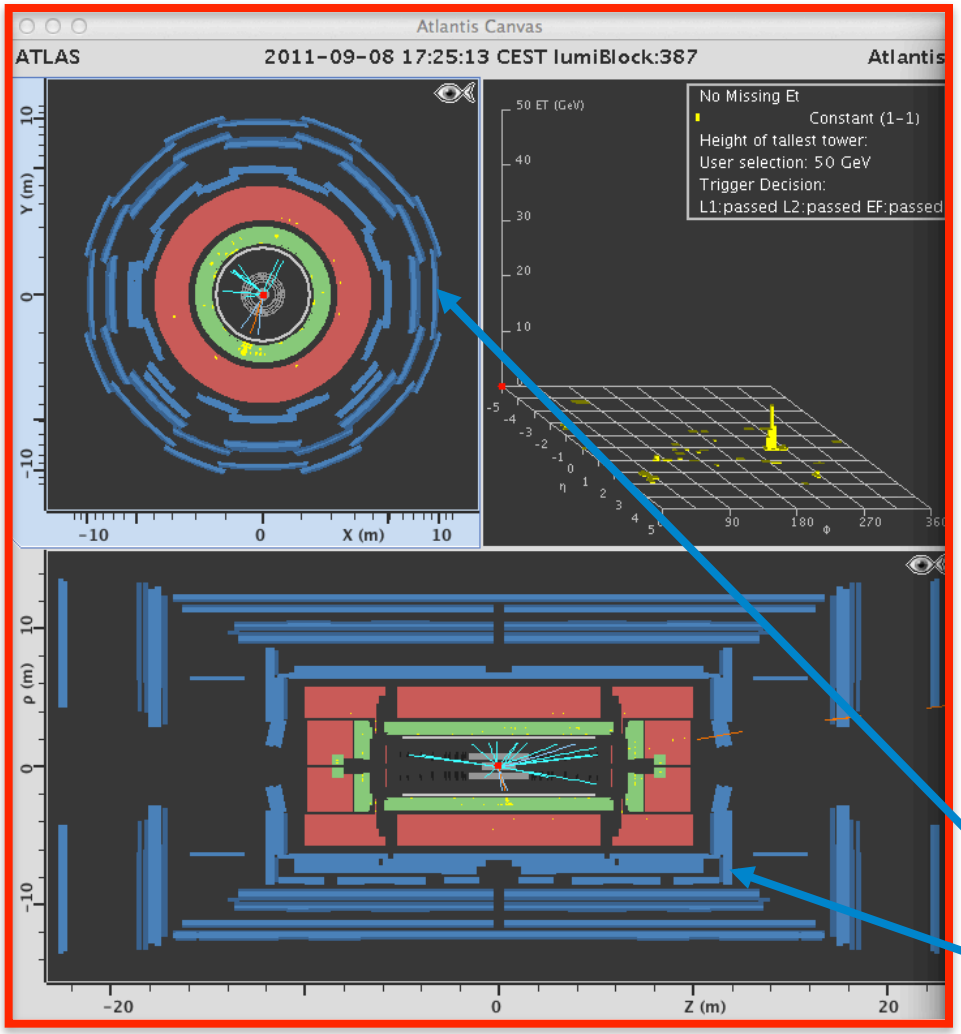
Tracking detector

Electromagnetic calorimeter

Hadronic calorimeter

Muon detectors

MINERVA Event Display – ATLANTIS Canvas



Can see all of the different detectors here

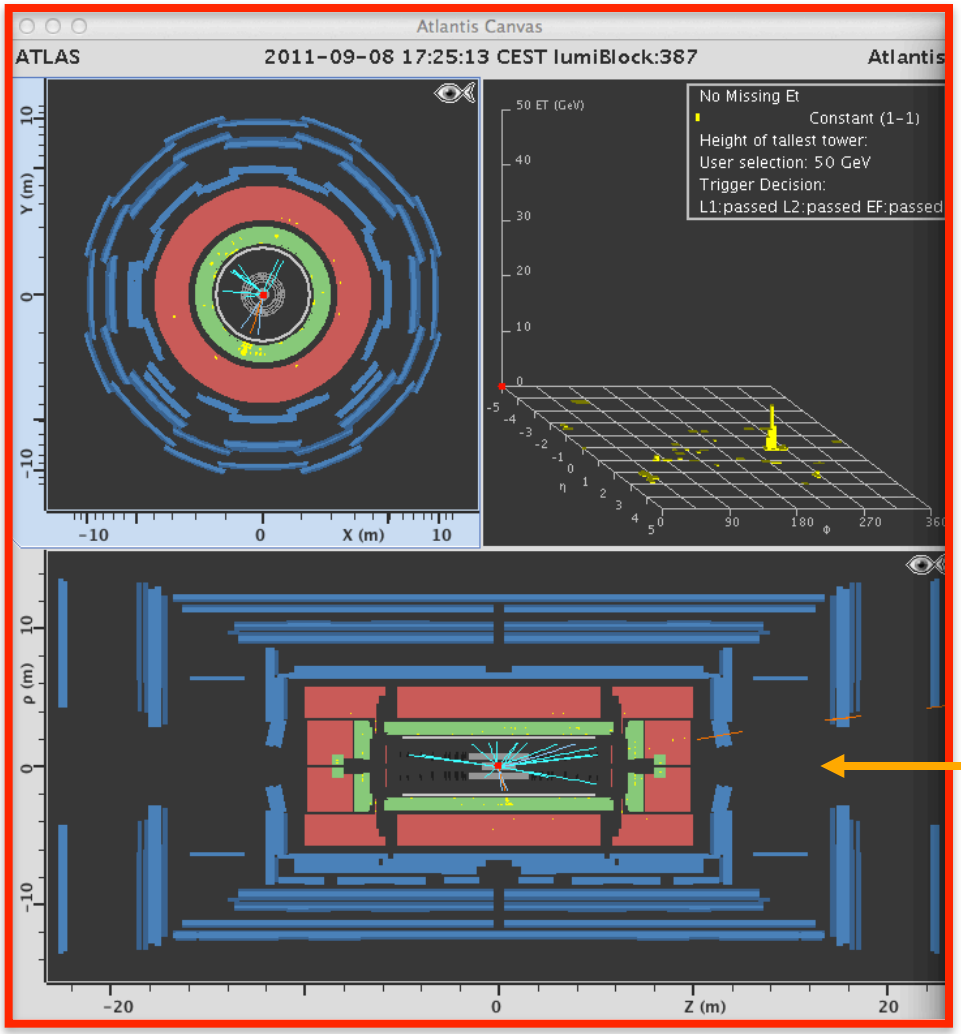
Tracking detector

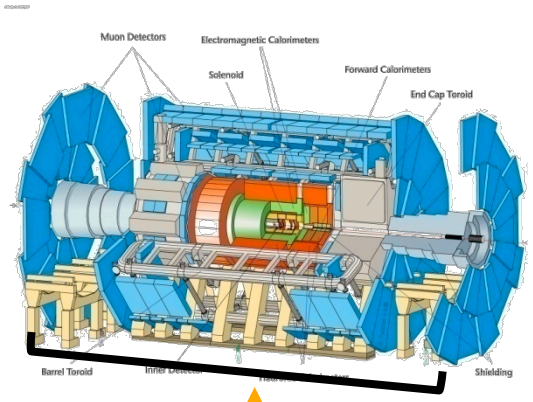
Electromagnetic calorimeter

Hadronic calorimeter

Muon detectors

MINERVA Event Display – ATLANTIS Canvas



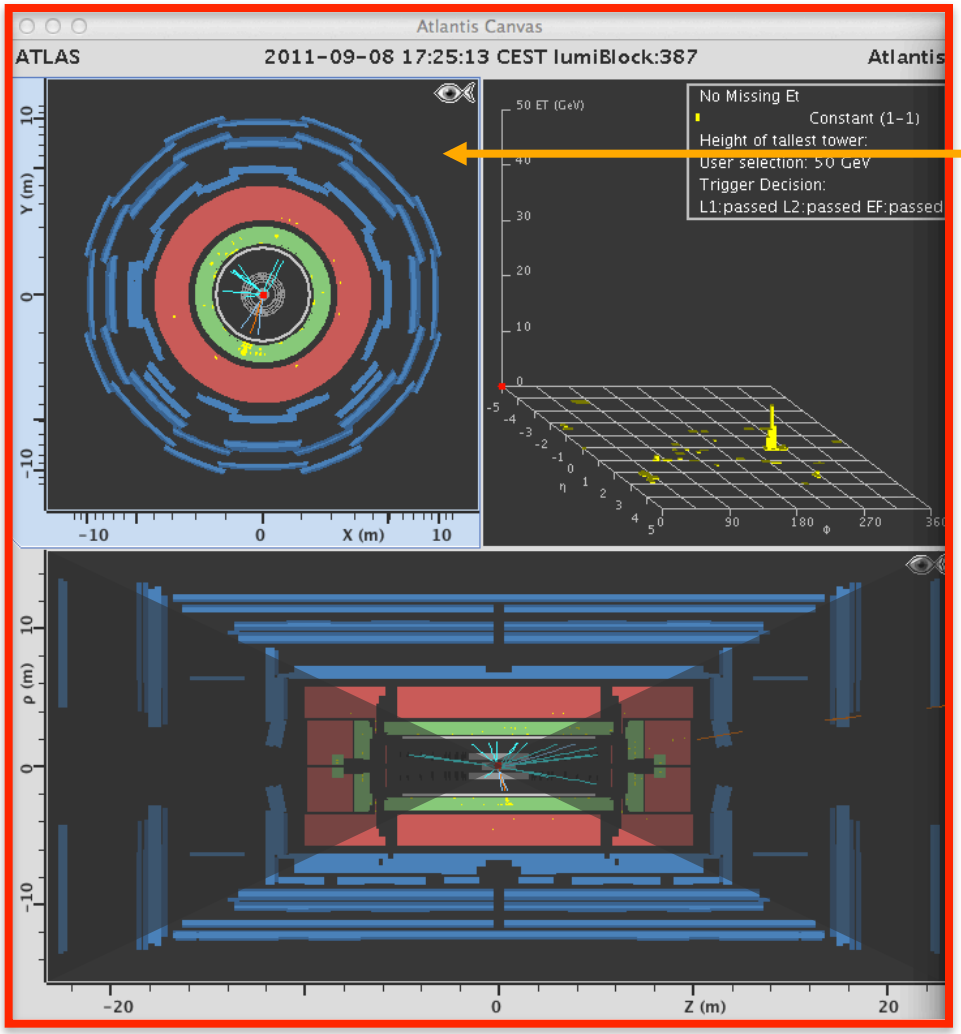


Bottom

Side view of the detector (*R-z* projection)

- Particles in all regions of detector are shown

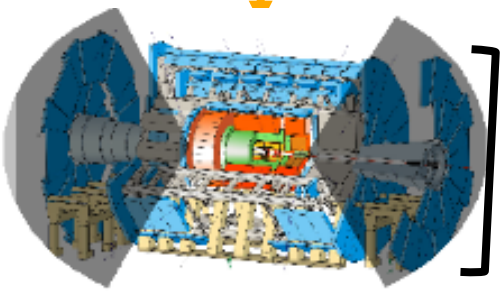
MINERVA Event Display – ATLANTIS Canvas



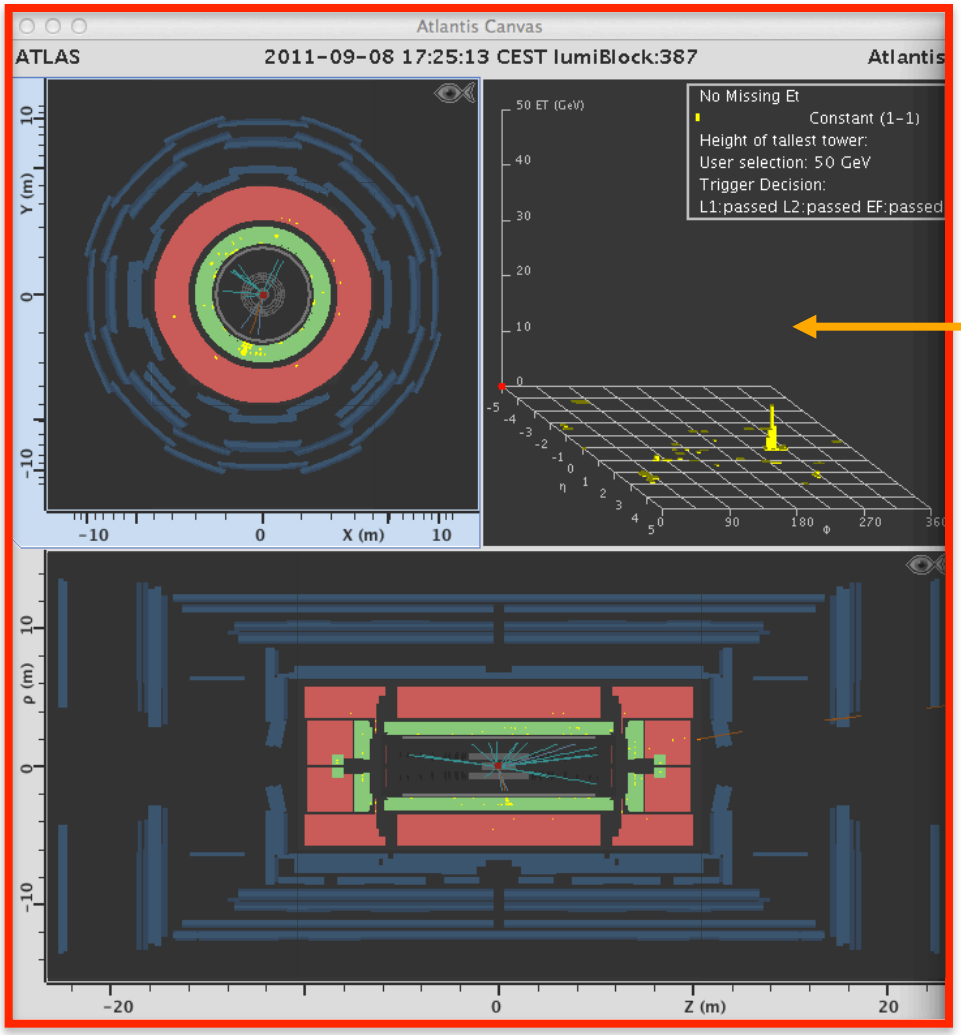
Top left

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

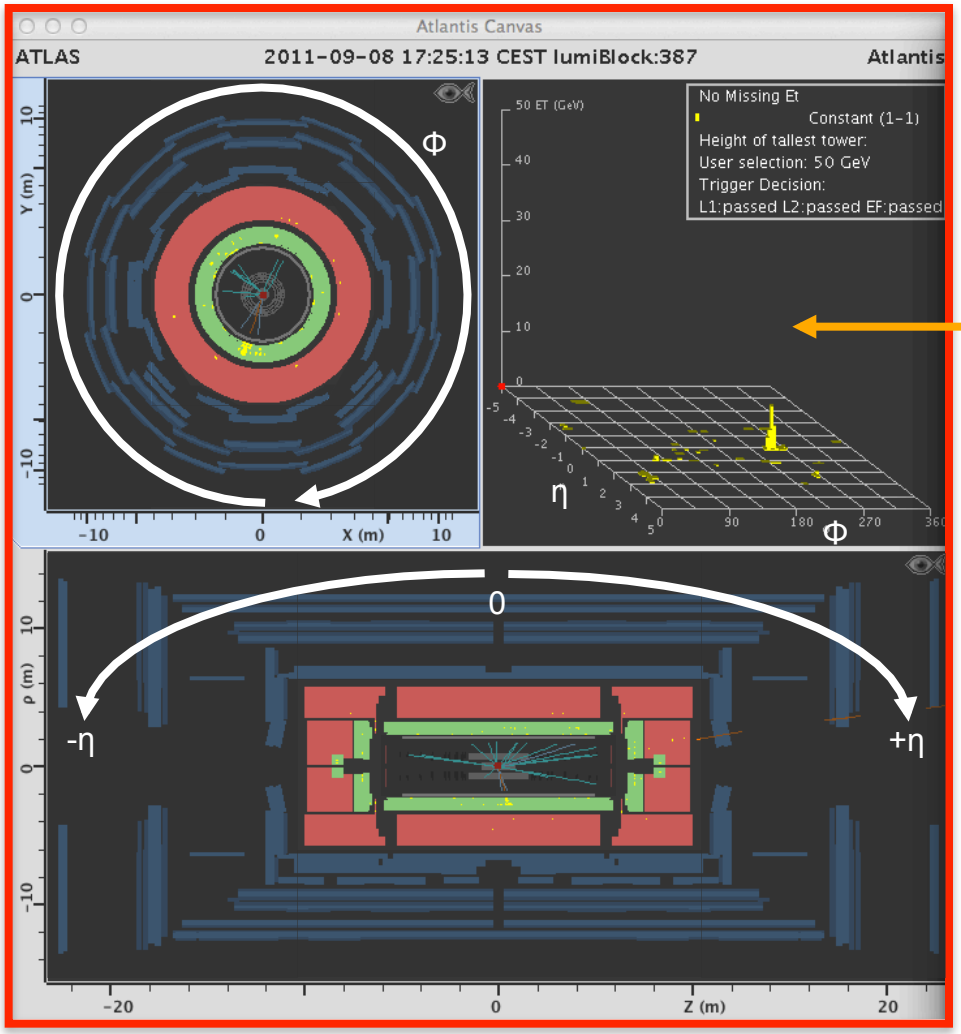


Top right

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

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

MINERVA Event Display – ATLANTIS GUI

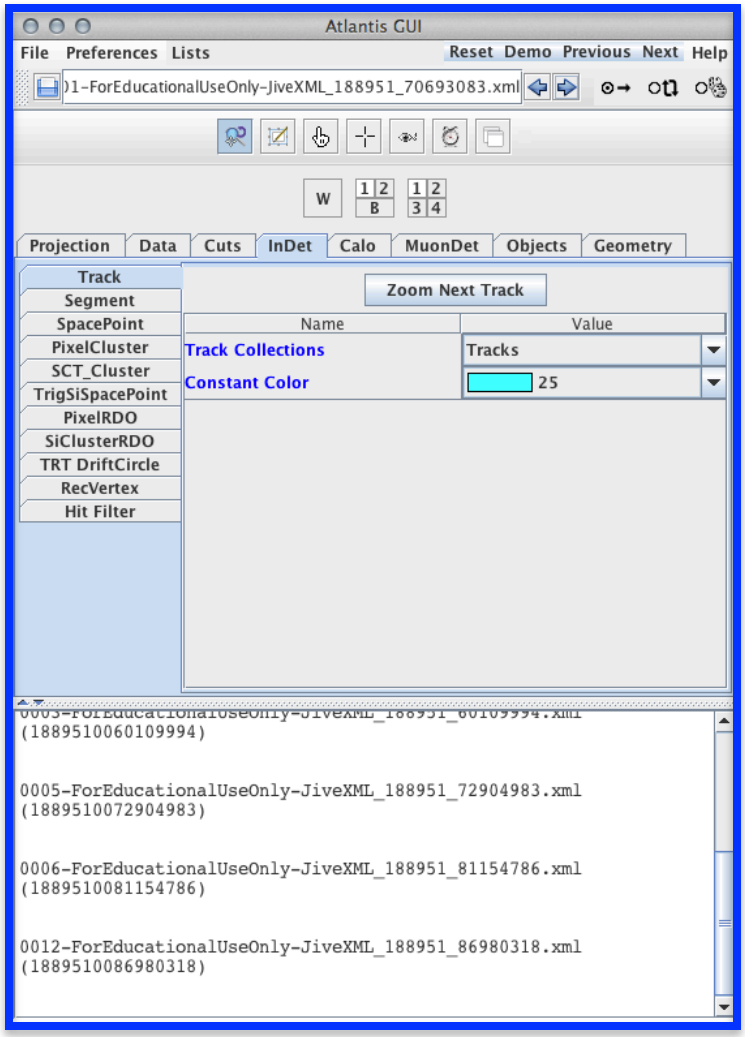
ATLANTIS GUI (**blue** frame) allows to change settings and appearance of the event and can provide with information on tracks and calorimeter hits.

File management & event selection

Tool box to interact with current event on Canvas

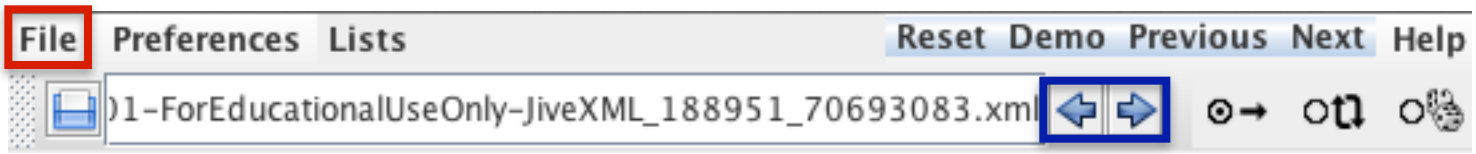
Selection cards

Output box for more information



MINERVA Event Display – ATLANTIS GUI

File management



Click 'File' and 'Read events locally' in the appearing drop down menu to load events

Click on the blue arrows right next to the file name information to steer through events

Tool box

Zoom/Move/Rotate Views

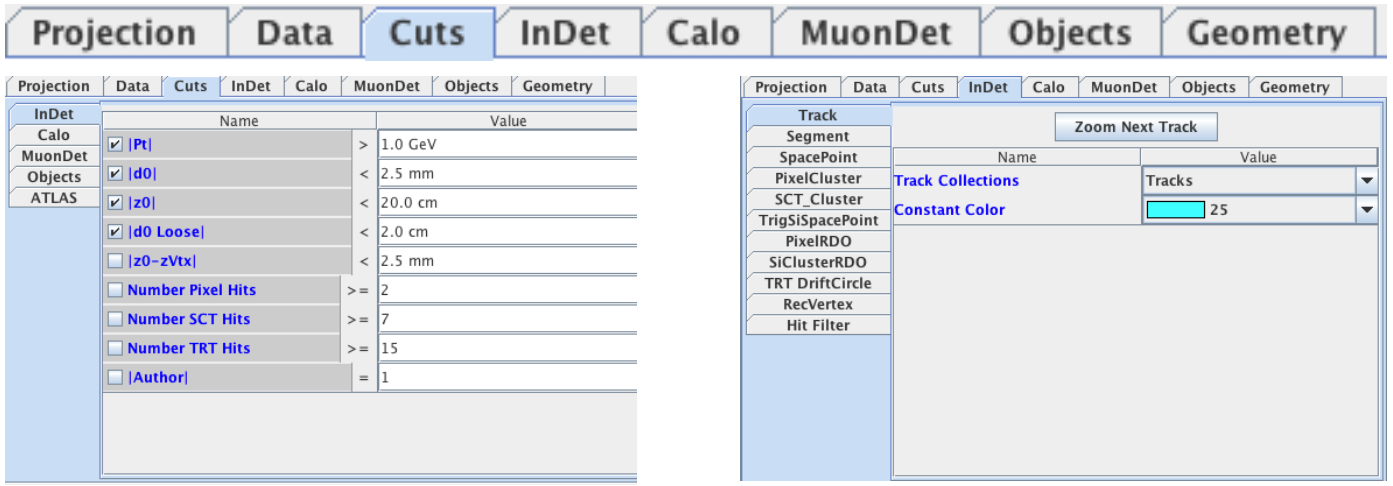
Rubberband selection

Show info for picked item

FishEye Transformation (better view of inner detector)

MINERVA Event Display – ATLANTIS GUI

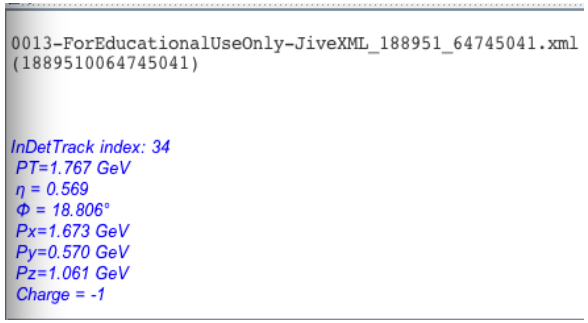
Settings cards



Apply cut criteria to the events

Important settings (various detector parts)

Output box

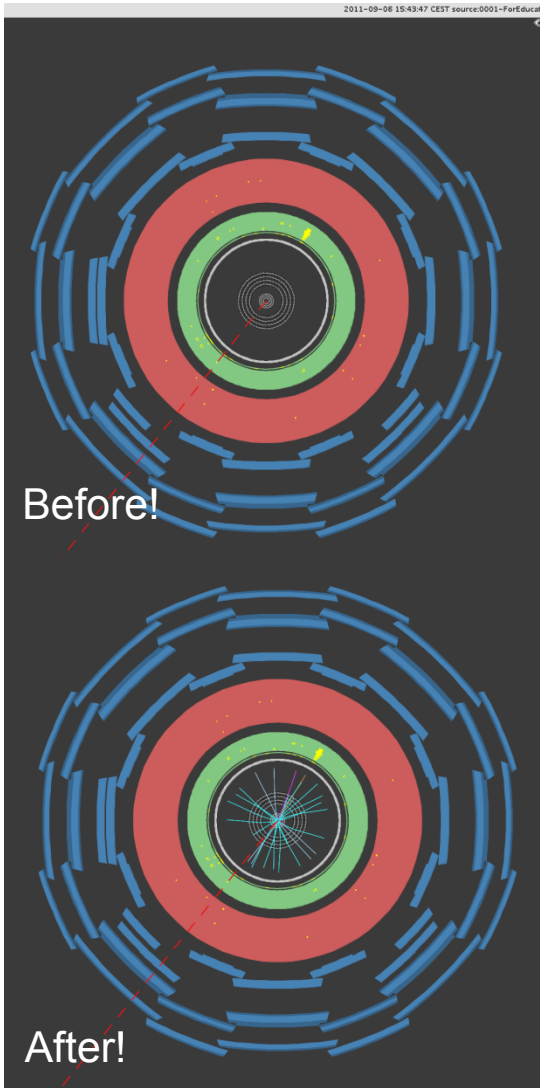


Displays the file name of the event and information on picked item (e.g. tracks of particles)

Allows to determine electric charge, transverse momentum, …

MINERVA Event Display – ATLANTIS GUI

Important setting at the beginning!

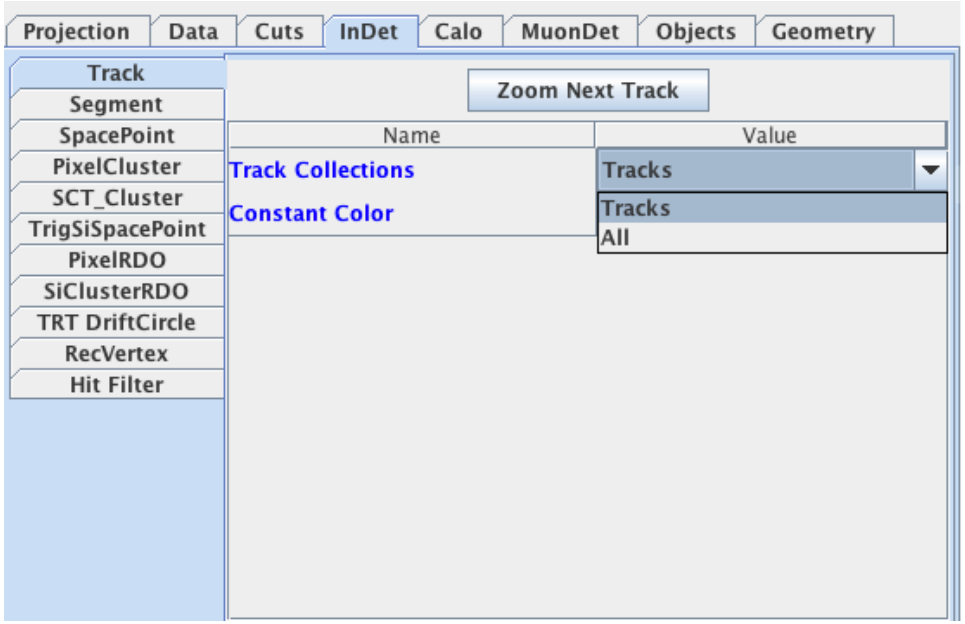


Open up the MINERVA software

Open the ‘Courses’ folder

Click on the ‘ATLAS’ application

Go to the ‘InDet’ Settings card and choose ‘Tracks’ from the ‘Track Collections’ drop down menu in order to display tracks properly!

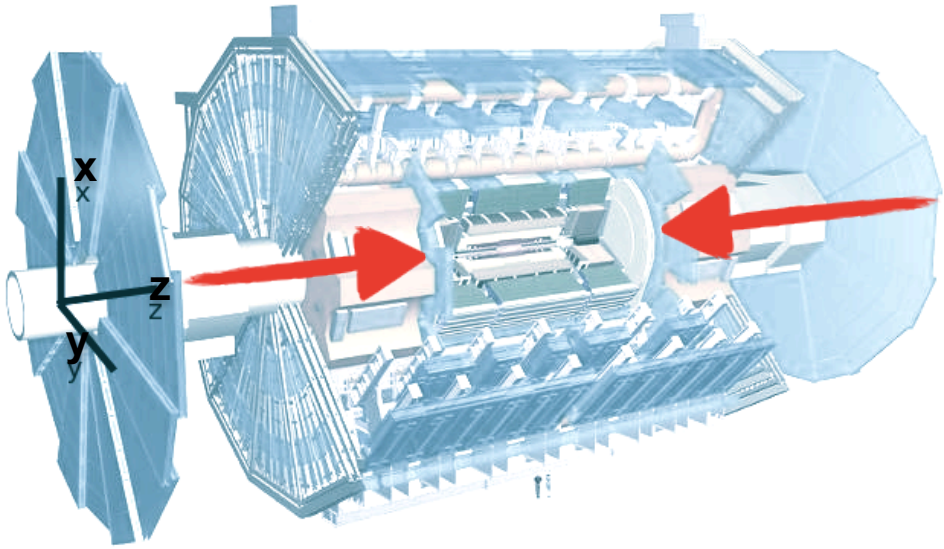


Otherwise the rest of the tasks will be difficult …

Explanation: Transverse Energy and Momentum

- Before colliding, the protons in ATLAS move in the z-direction
- So we know that in x and y, the momentum is zero and this must be conserved after the collision

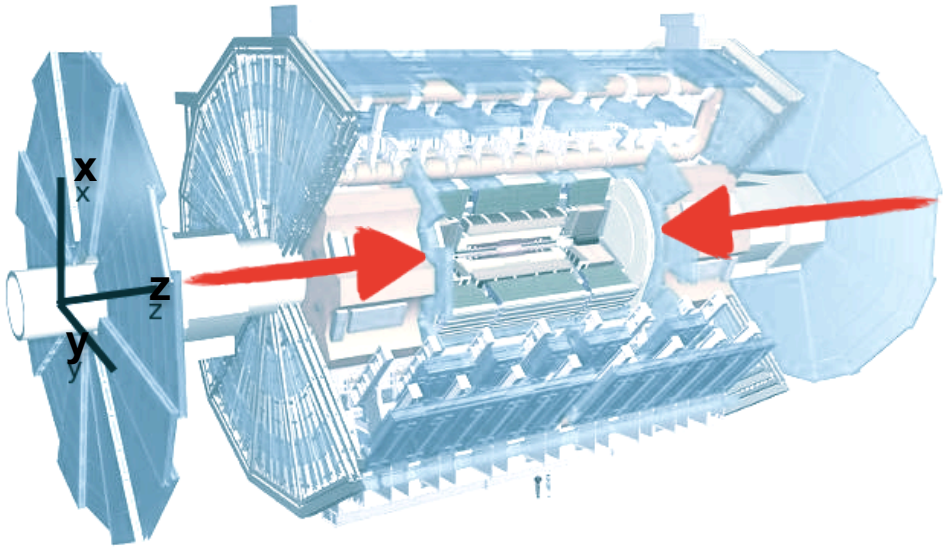
- We cannot measure the whole event energy because energy is lost in very forward region (beam-pipe)
  - Better measurement: transverse or "side-ways" component (x-y)
- Typically "interesting" collisions contain particles with big transverse energies (E_T) and momenta (p_T)



Explanation: Missing Energy

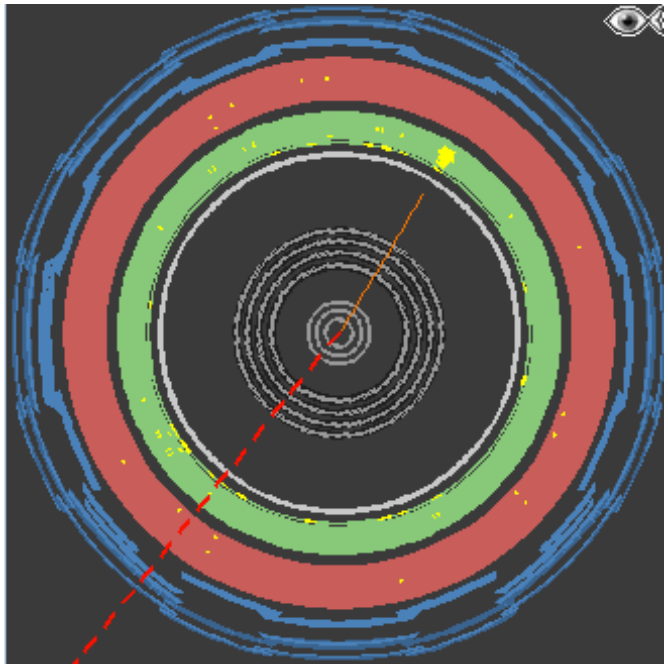
- Before colliding, the protons in ATLAS move in the z-direction
- So we know that in x and y, the momentum is zero and this must be conserved after the collision

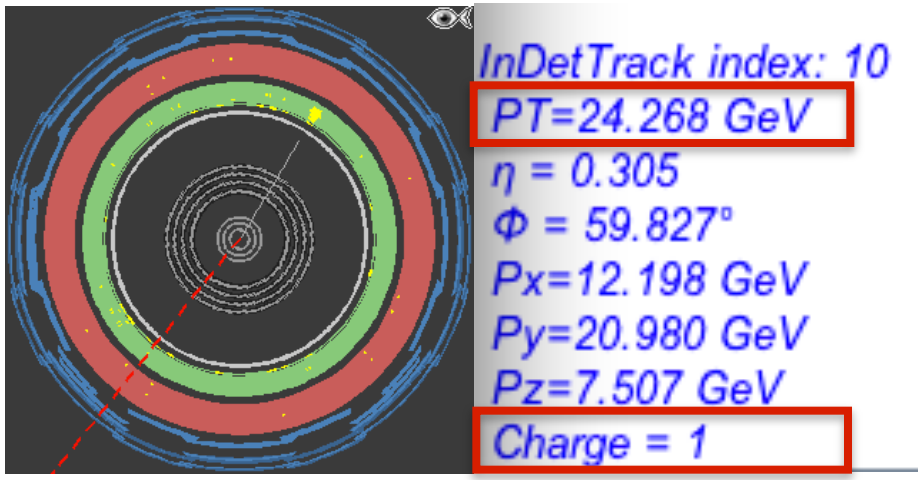
- If a neutrino is created, the detector does not see it, so when we add up the momenta of all the particles we see, there is a deficit - this is Missing (Transverse) Energy



MINERVA – Particle Momentum & Charge

How to determine transverse momentum and electric charge?





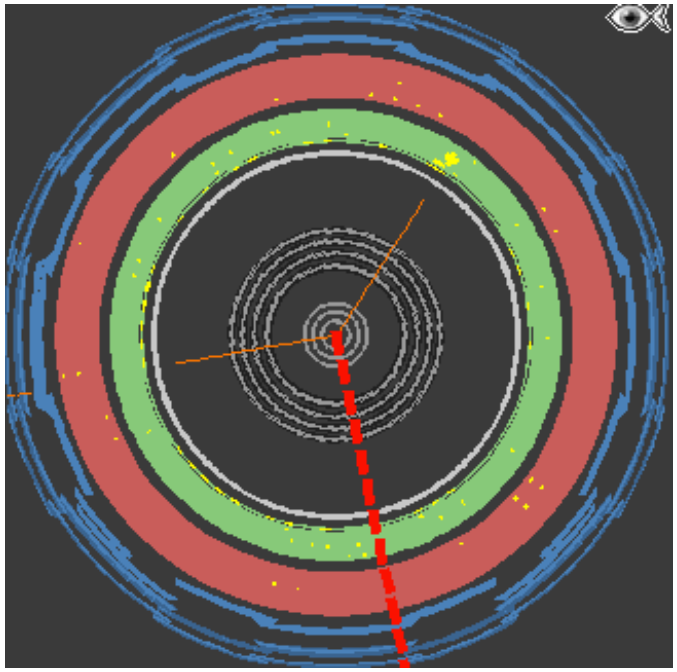
Here is the problem: determine the electric charge and momentum of the electron-like particle in this event display.

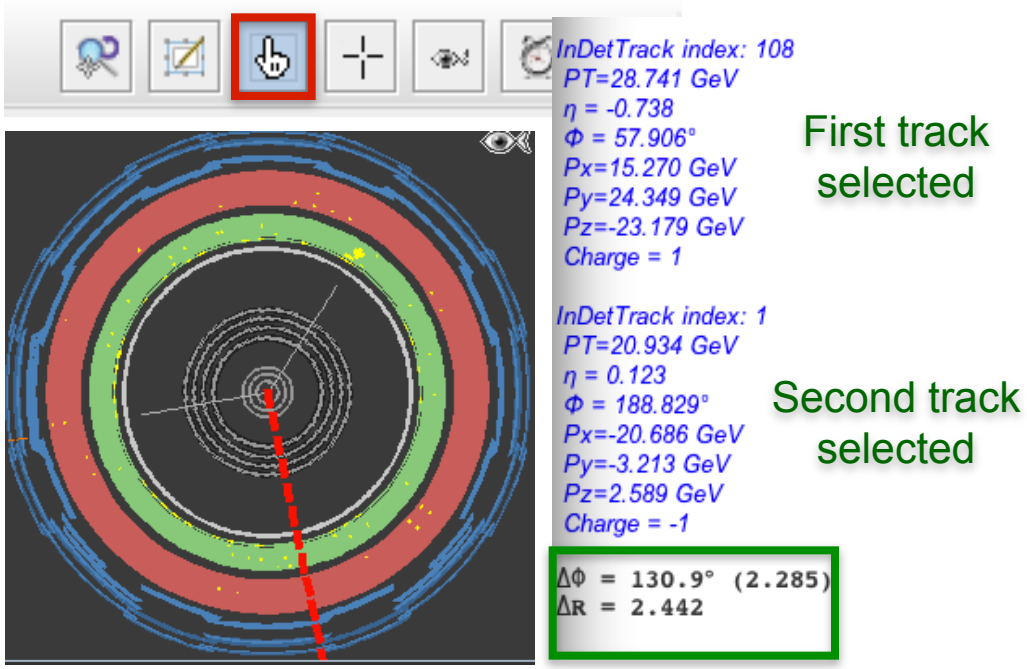
Click the Pick symbol from the tool box, select the track (colour turns into grey) and look at the output box …

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

MINERVA – Measuring Angles

How to measure angles between particles with MINERVA?





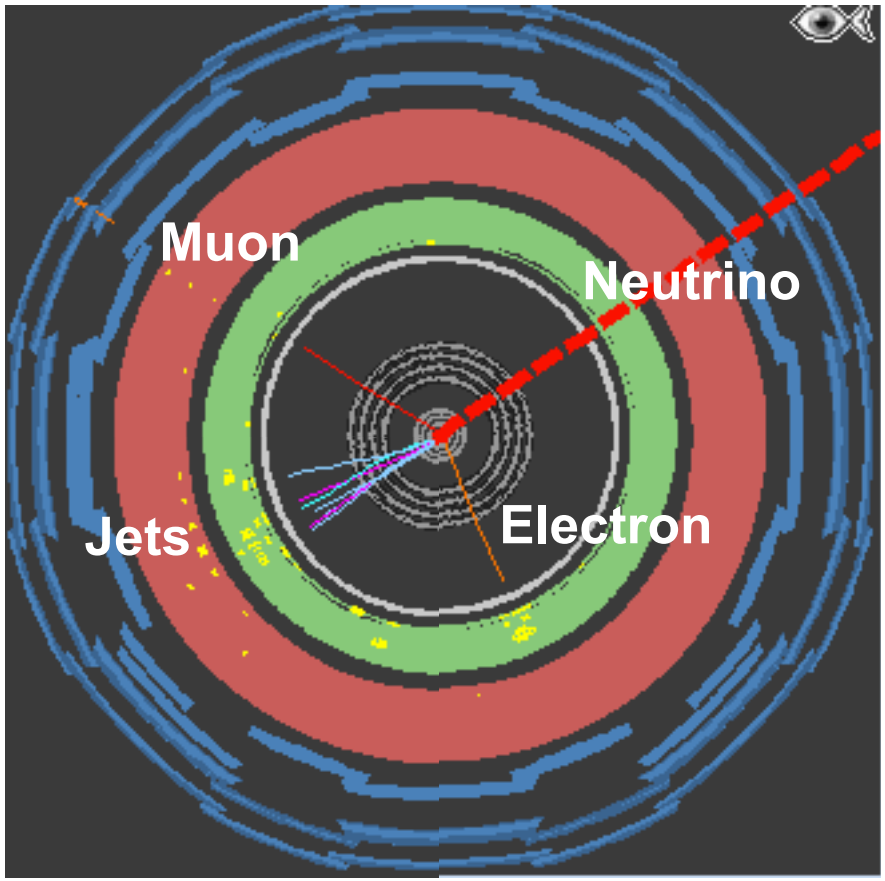
First track selected

Second track selected

Here is another problem: determine the angle between two tracks.

Hold the P key on the keyboard down and click on the two tracks (both turn into grey). The angle between both tracks in transverse plane is displayed in the Output box (green frame).

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

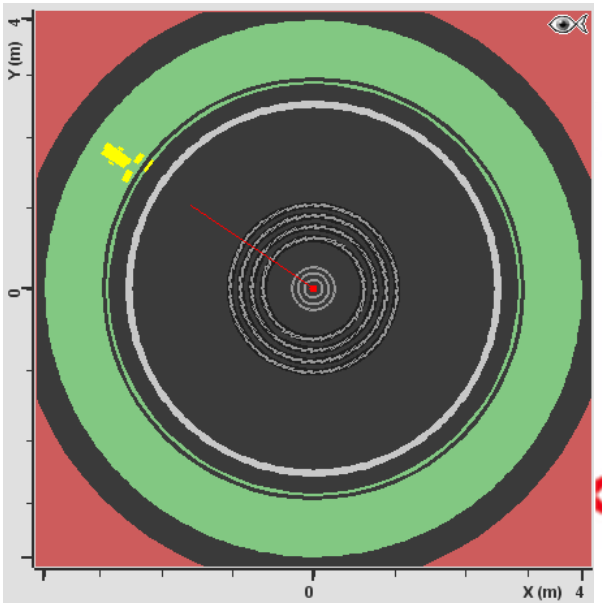
•Energy deposited in electromagnetic and hadronic calorimeters, stopped fully in hadronic calorimeter

Use animation on the following website to see for yourself:

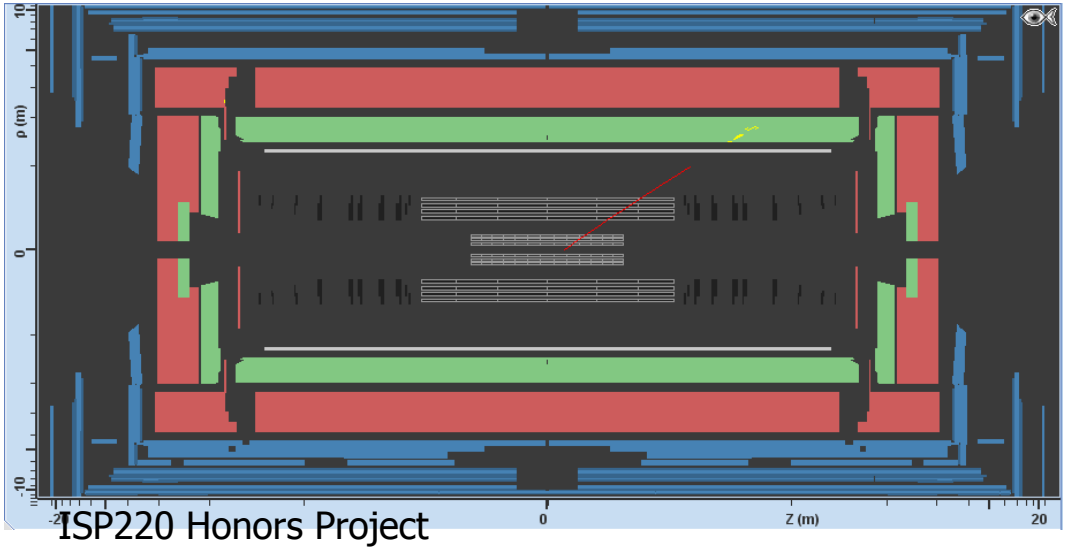
http://kjende.web.cern.ch/kjende/en/wpath_teilchenid1.htm

Try both the side view and end view!

Particle Identification – Electrons / Positrons



InDetTrack index: 2
PT=42.530 GeV
η = 0.753
Φ = 145.560°
Px=-35.075 GeV
Py=24.052 GeV
Pz=35.162 GeV
Charge = -1



Track in the tracking detector

Lots of activity in the electromagnetic calorimeter (Energy deposits stop here)

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

Charge = -1 = electron
Charge = 1 = positron

Particle Identification – Muons / Antimuons

Track in the tracking detector

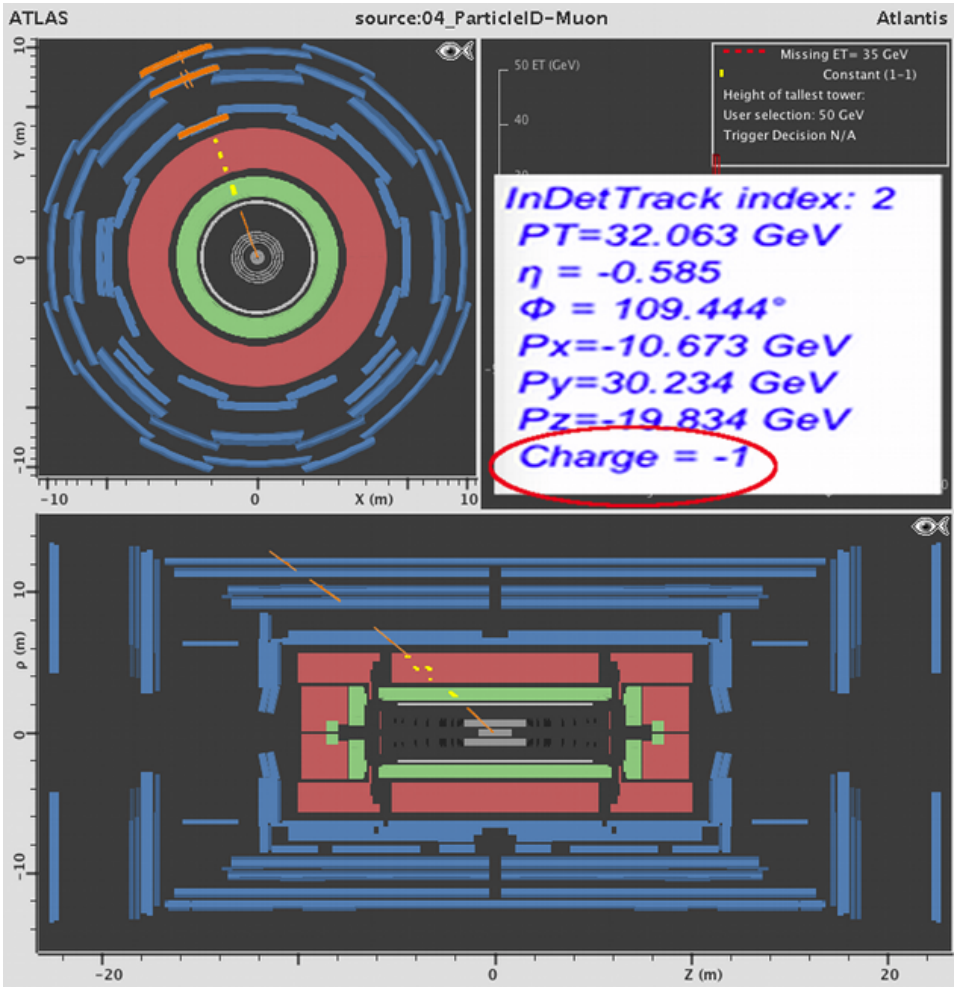
Track in the muon detectors

(occasionally algorithms may connect tracks)

Very little activity in the electromagnetic and hadronic calorimeters (energy deposits line up well with tracks)

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

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



Particle Identification – Neutrinos / Antineutrinos

Neutrinos found indirectly from missing energy calculation

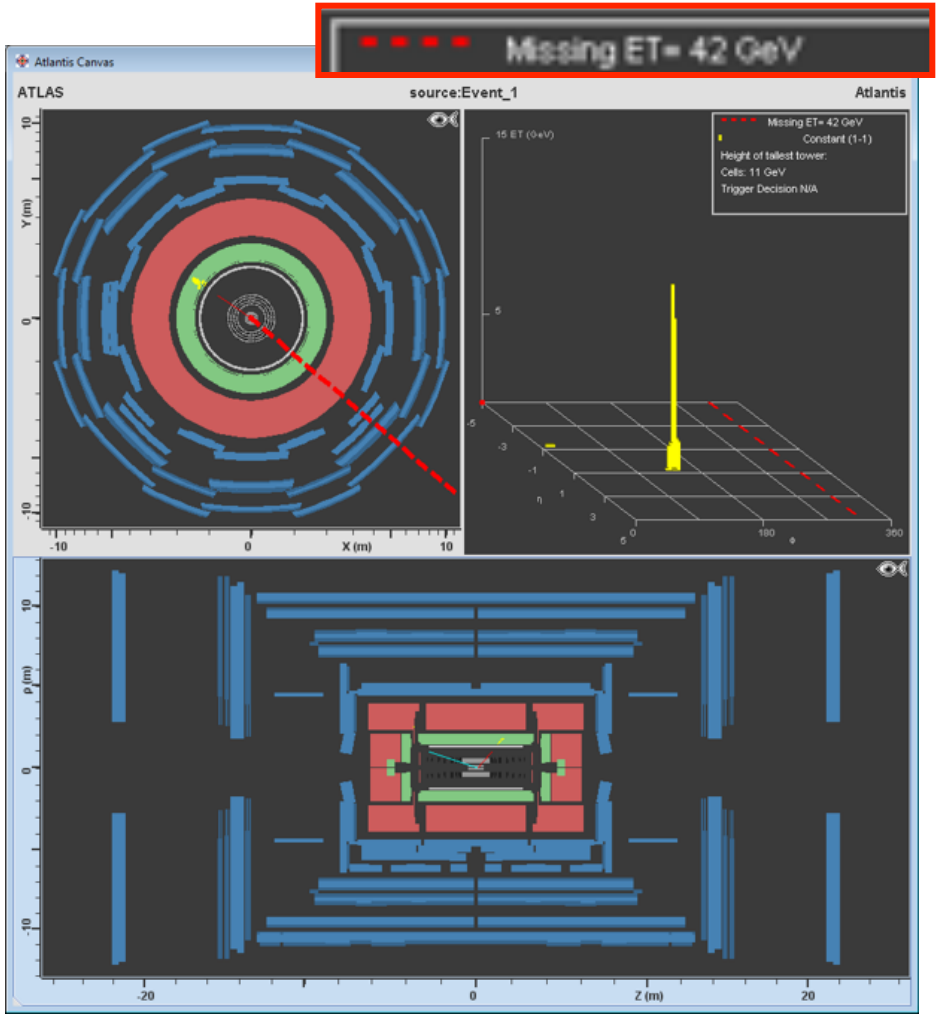
Shown with dotted red line

Thickness of line represents magnitude of missing energy

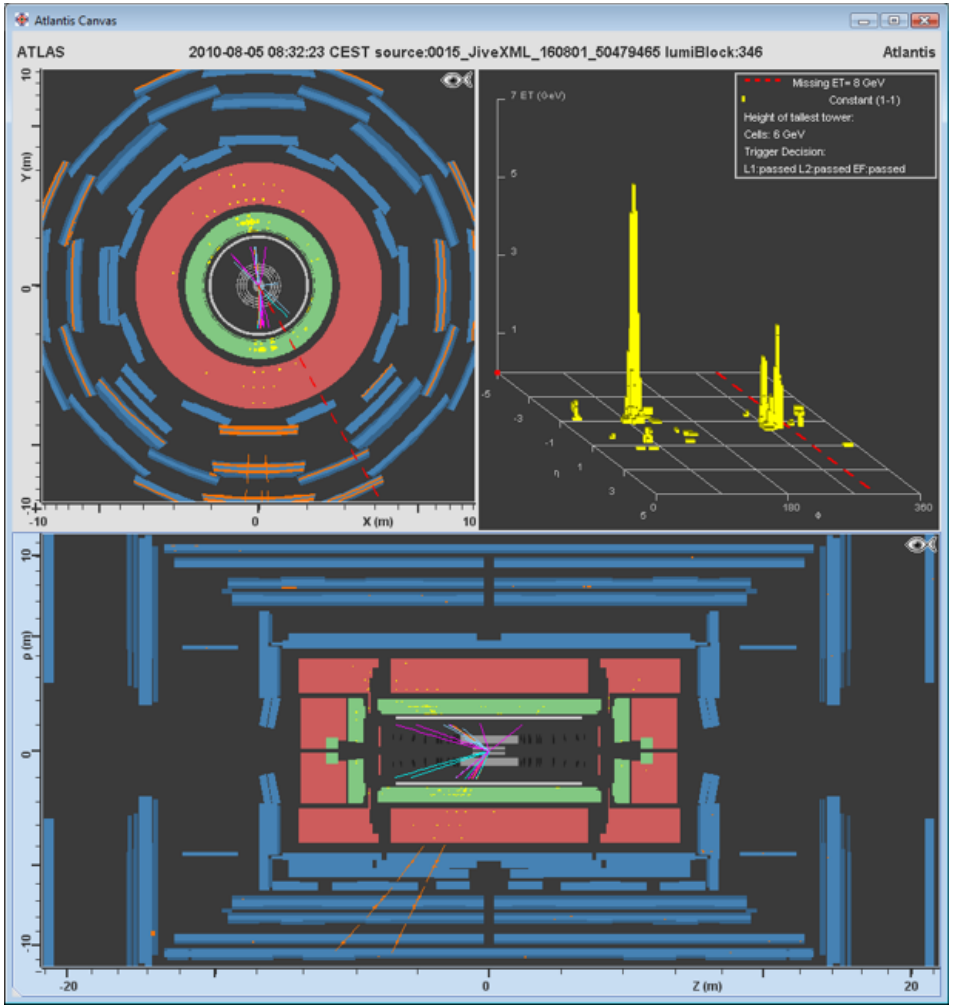
Amount easily obtained using information on Lego Plot

If Missing ET at least 25 GeV then have good candidate

Chargeless so have to work out if neutrino or antineutrino based on particles elsewhere in event



Particle Identification – Jets



This is due to the production of streams of hadrons (known as jets)

Spray of particles in tracking detector (lots of tracks)

Lots of activity in electromagnetic calorimeter

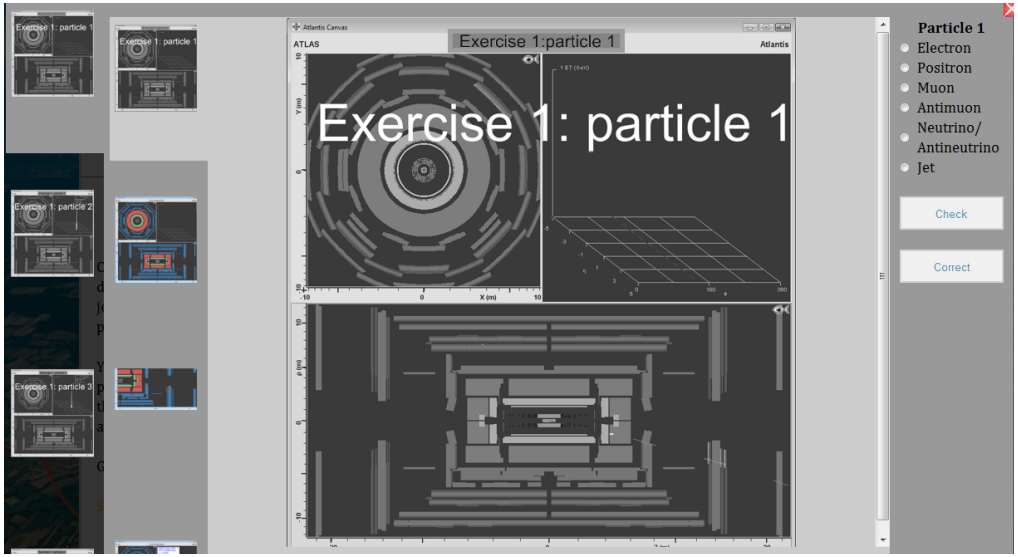
But also a lot of hadronic calorimeter activity

May get some muon hits if the odd particle escapes out of the calorimeters (not too common)

Exercise 1: Identify the Particles

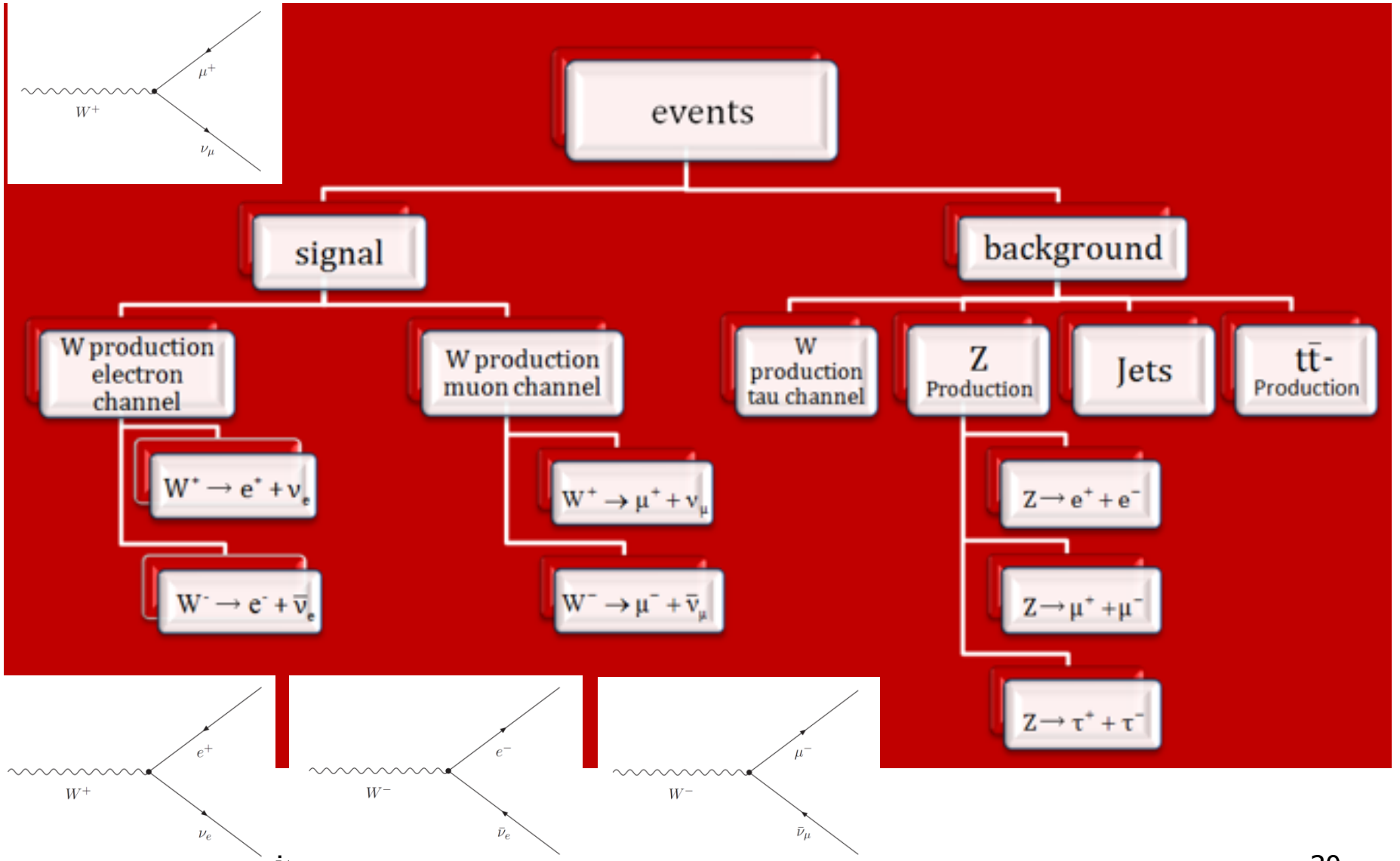
- Use the link online:

  http://kjende.web.cern.ch/kjende/en/wpath_exercise1.htm



- There are 4 events to look at – each with a set of particles to identify
- Use all 4 pictures in each set to identify the particles:
- Can you observe muons, antimuons, electrons, positrons, neutrinos/ antineutrinos or jets?
- Tick the boxes for each particle you see in the event then press 'Check'
- If you get stuck there are hints available!

Event Identification - Background and signal

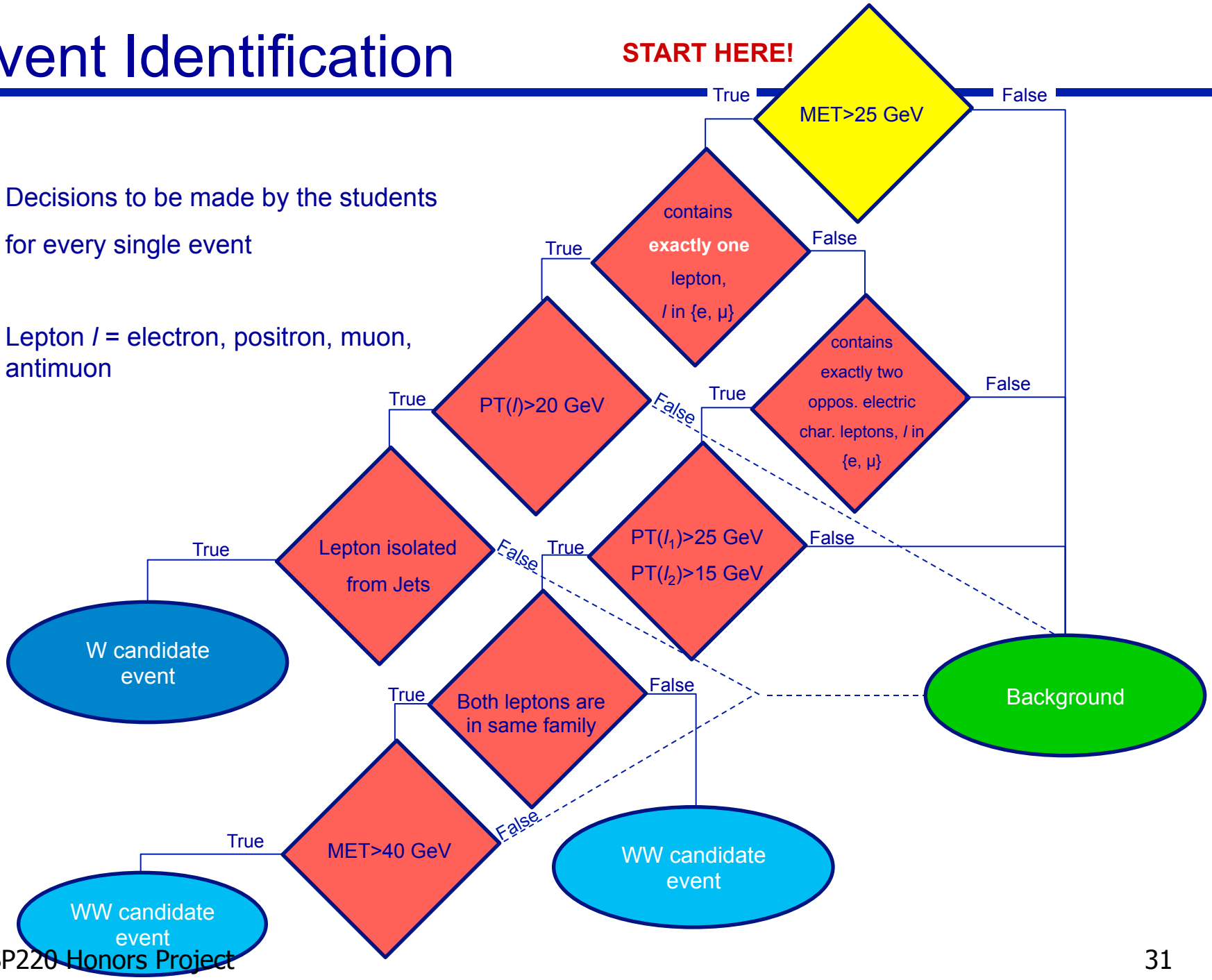


Event Identification

Decisions to be made by the students

for every single event

Lepton *l* = electron, positron, muon, antimuon



Event Identification - Signal

$W^- \rightarrow \mu^- + \bar{\nu}_\mu$ or $W^+ \rightarrow \mu^+ + \nu_\mu$

there is EXACTLY ONE muon or an anti-muon,

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

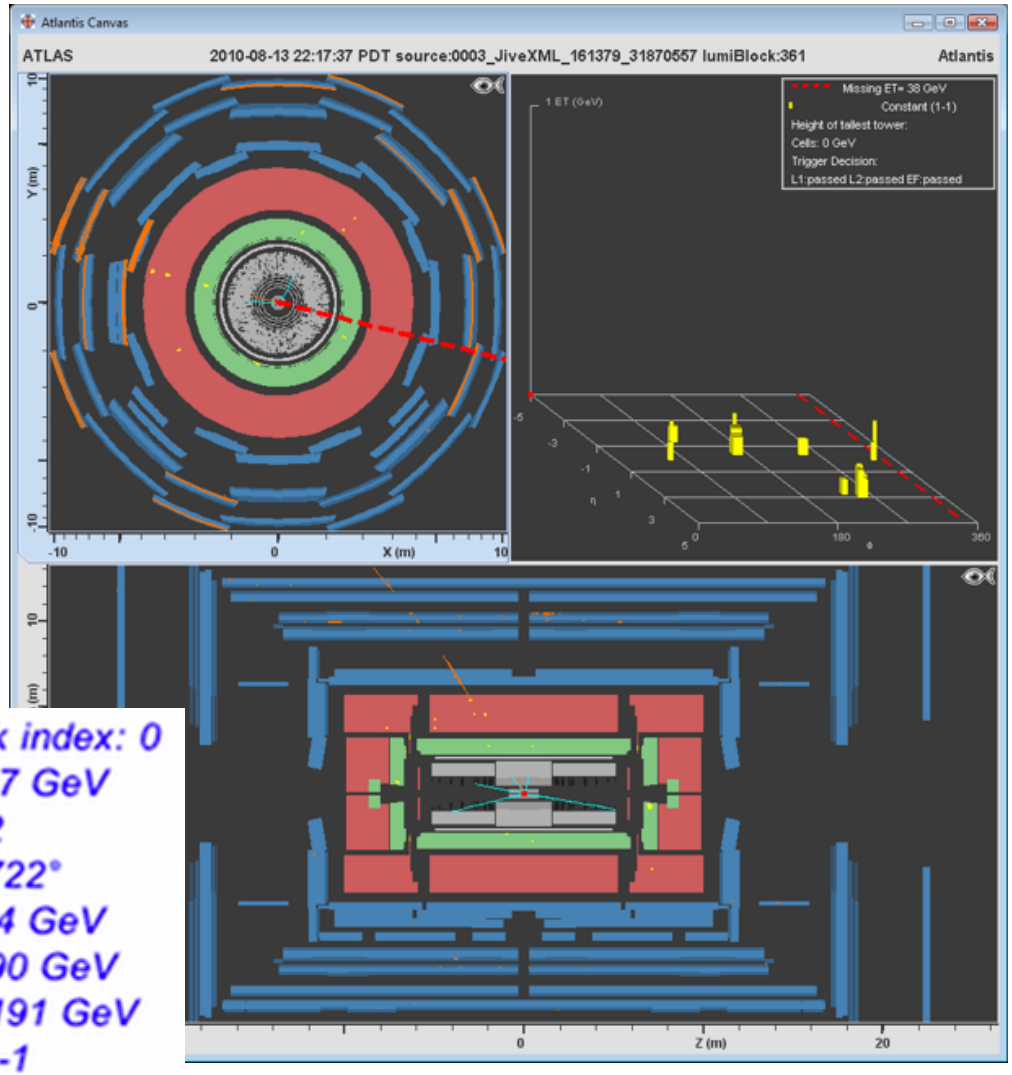
has a transverse momentum (p_T) greater than 20 GeV. Furthermore

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



Event Identification - Signal

$W^- \rightarrow e^- + \bar{\nu}_e$ or $W^+ \rightarrow e^+ + \nu_e$

there is EXACTLY ONE electron or positron,

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

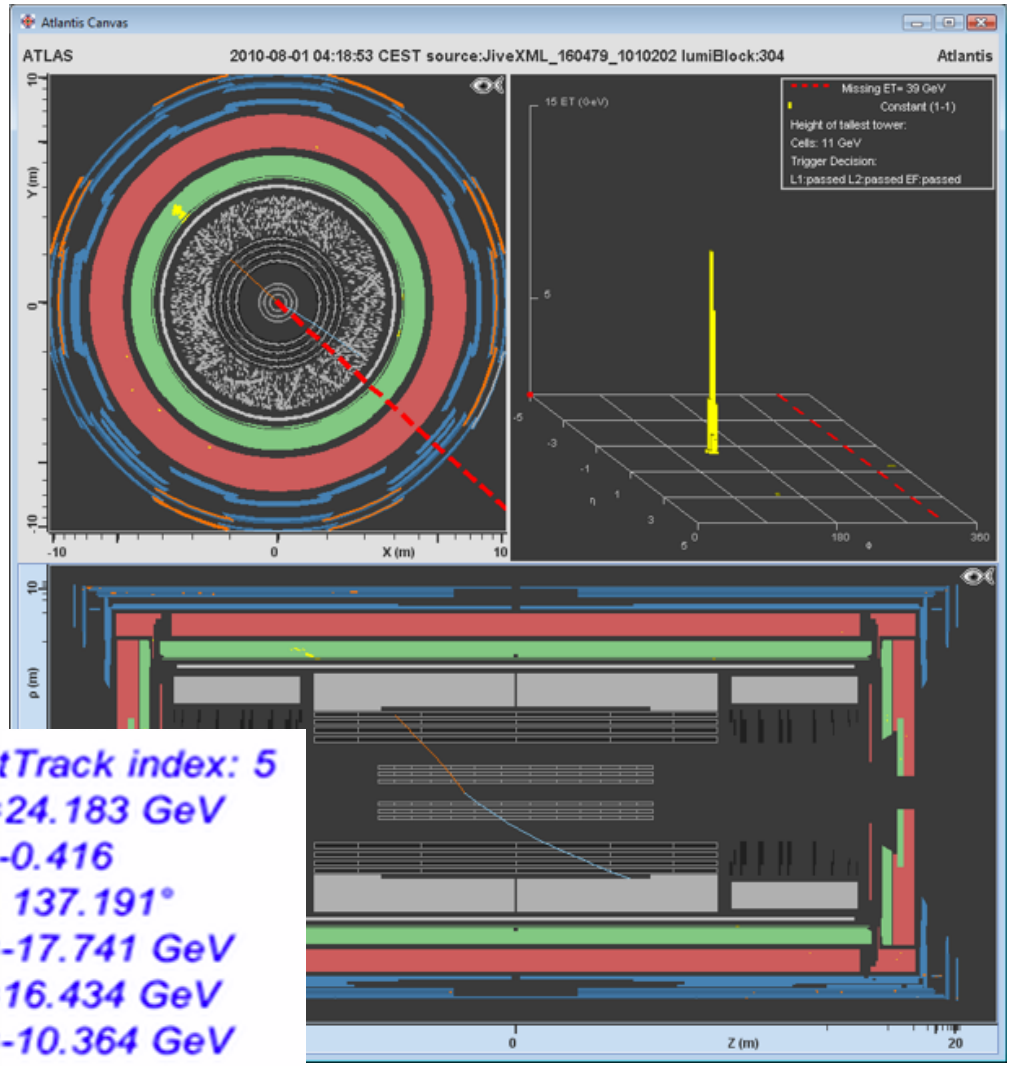
has a transverse momentum (p_T) greater than 20 GeV. Furthermore

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



Event Identification - Signal

$WW \rightarrow l^- + \nu_l + l^+ + \nu_l$
(*l* can be electron, muon, positron, antimuon)

contain EXACTLY TWO leptons with OPPOSITE electric charges,

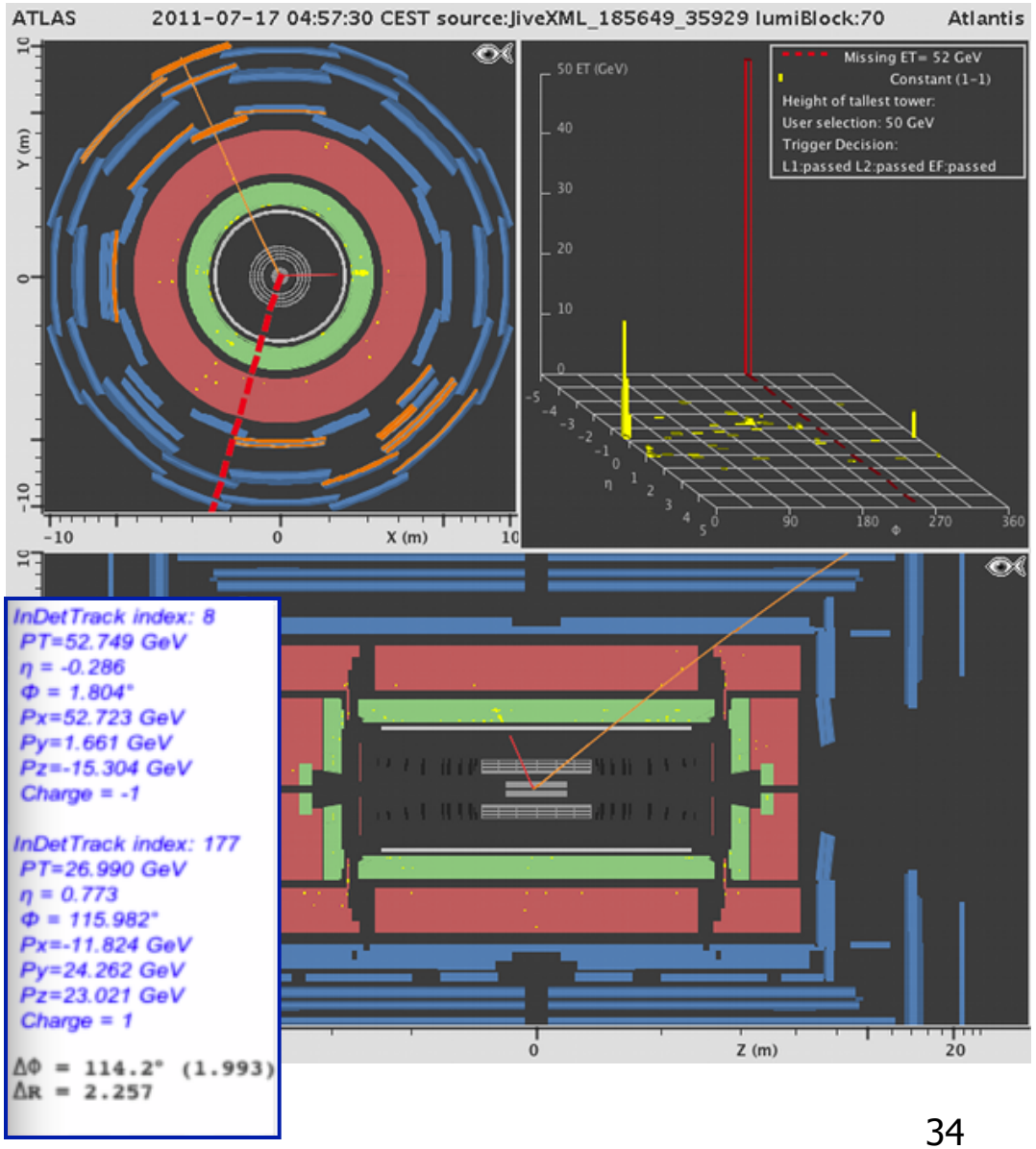
are isolated and

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

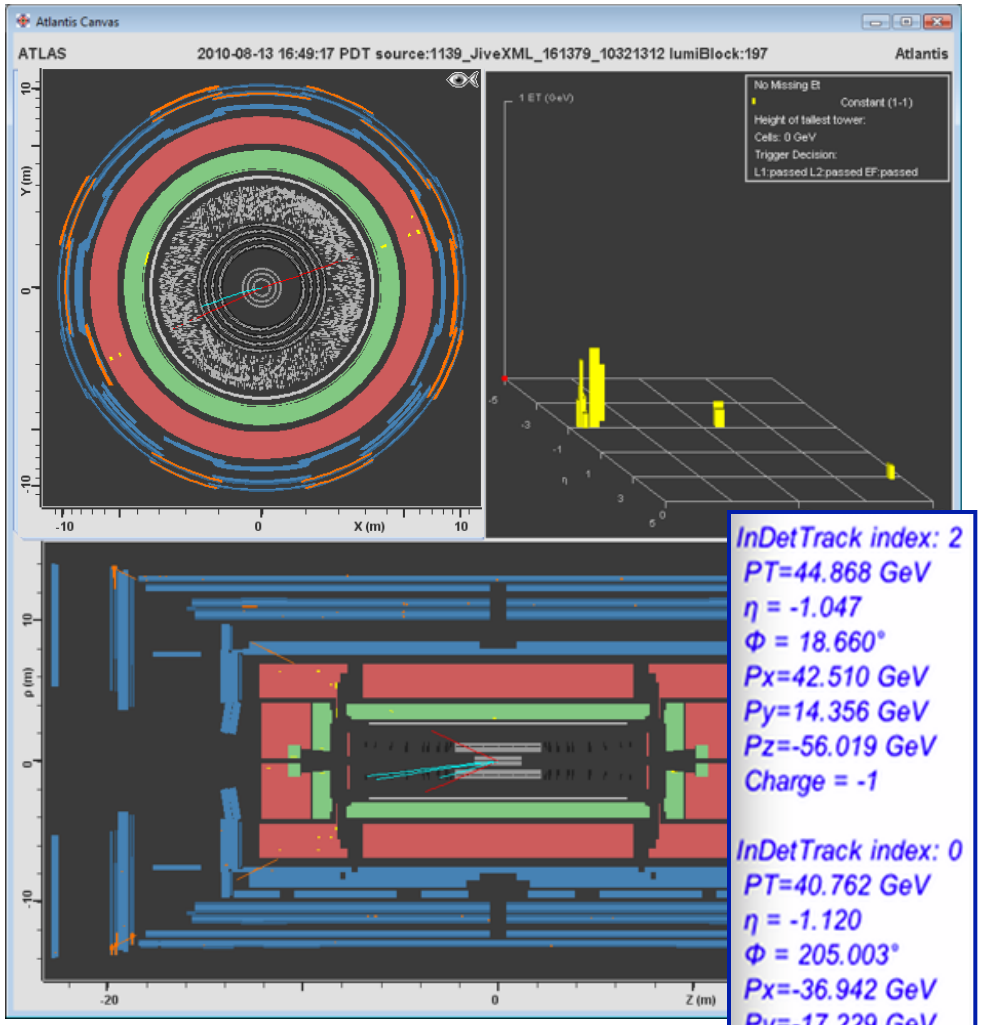
$Z \rightarrow \mu^- + \mu^+$ (or $Z \rightarrow e^- + e^+$)

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)



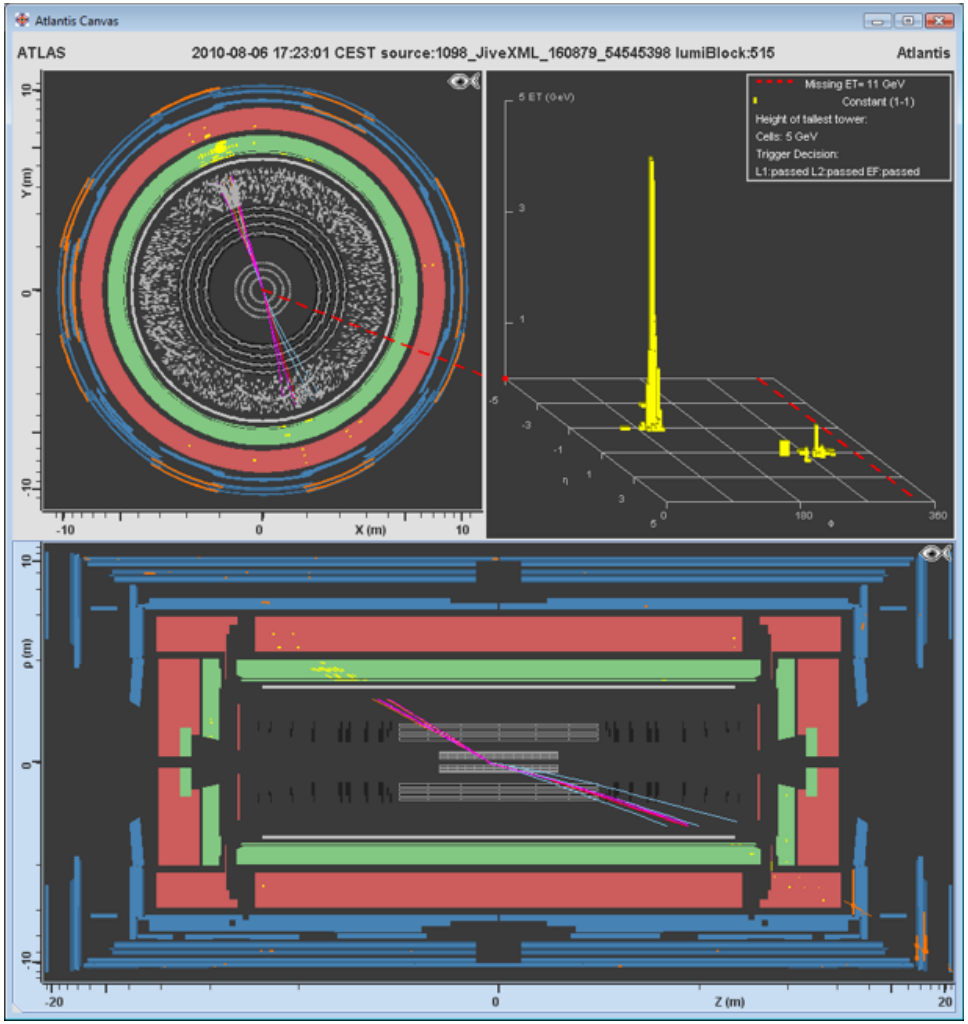
Event Identification - Background

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

Data Analysis: Structure of Proton & Higgs searches

Task 1 - Discover the structure of the proton!

- Select all the signal events (events producing a W particle) from the 50 events of your data sample.
- Determine the electric charge of the W particle.
- Count numbers of W^+ and W^- events and determine the ratio of the number of positively charged W particles to the number of negatively charged W particles ($R\pm$). Keep track of this on your tally sheet.

Task 2 - Identify the Higgs particle!

- See how the Higgs particle could be identified using simulated WW events mixed between the real data events.
- Pick them out and measure the angle between the two leptons (that arise from the W's) in the transverse plane, $\Delta\Phi_{ll}$.
- Fill your tally sheet and write down the event number and angle.
- Strongly recommend checking over your WW events again

Data Analysis

How the data sample is structured …

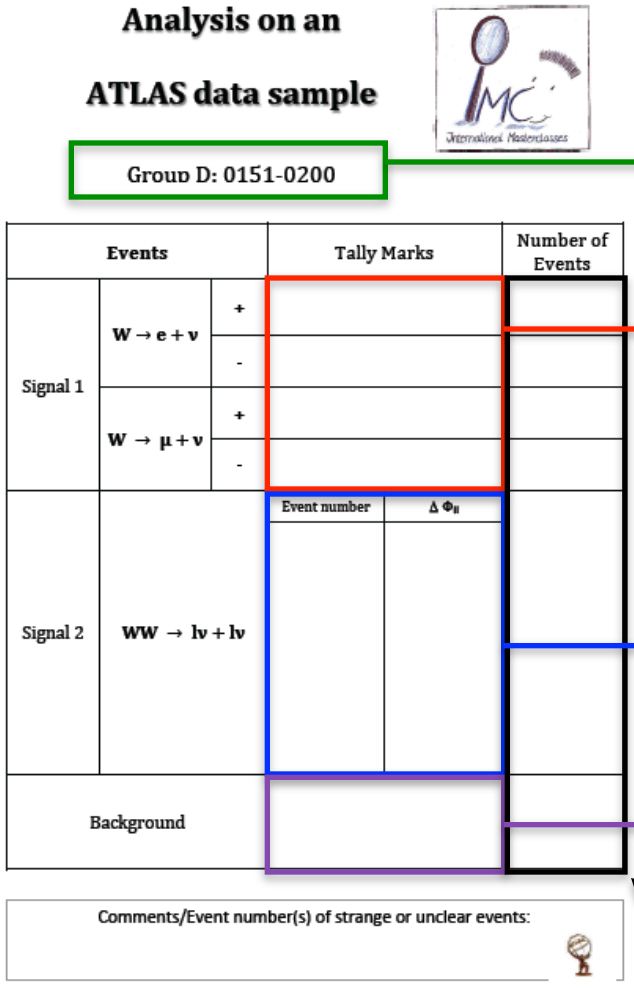
- CERN analyzes W data sample no. 6 (containing 1000 events)
- Each data sample is split into 20 sub samples, labeled from A to T, each containing 50 events
- Distribute sub samples over our two subgroups:
  - English Groups: 6A-6J
  - French Groups: 6K-6T

What you need…

- Event display (installed on the PC's)
  - Run 'ATLAS' from 'Courses' folder on Desktop
- Data sample
  - Load corresponding data sample from 'events' folder
- Tally sheet (printed)
- Help sheet (printed)
- Link to online spread sheet
  - https://www.editgrid.com/user/masterclass/Analysis_2012

Data Analysis – Tally sheet

What to enter on the tally sheet …



Analysis on an

ATLAS data sample

Group D: 0151-0200

Events			Tally Marks	Number of Events
Signal 1	$W \rightarrow e + \nu$	+		
		-		
	$W \rightarrow \mu + \nu$	+		
		-		
Signal 2	$WW \rightarrow l\nu + l\nu$		Event number | $\Delta\Phi_{ll}$	
Background				

Comments/Event number(s) of strange or unclear events:

Corresponding letter of the data sample to be analyzed

To be filled with tallies for each W candidate events (corresponding to the electric charge and family where the leptons come from)

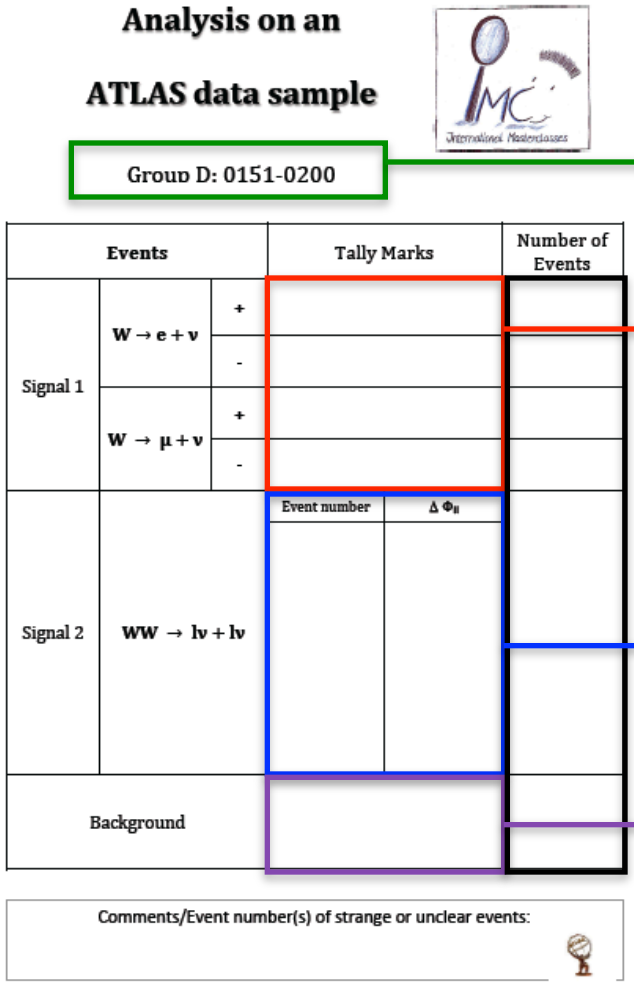
Event number and angle between leptons in transversal plane has to be entered for WW candidate events

Space for tallies for background events

Last column is for counting up

Data Analysis – Tally sheet

What to enter on the tally sheet …



Analysis on an

ATLAS data sample

Group D: 0151-0200

Events			Tally Marks	Number of Events
Signal 1	$W \rightarrow e + \nu$	+		
		-		
	$W \rightarrow \mu + \nu$	+		
		-		
Signal 2	$WW \rightarrow l\nu + l\nu$		Event number / $\Delta\Phi_{ll}$	
Background				

Comments/Event number(s) of strange or unclear events:

Corresponding letter of the data sample to be analyzed

To be filled with tallies for each W candidate events (corresponding to the electric charge and family where the leptons come from)

Event number and angle between leptons in transversal plane has to be entered for WW candidate events

Space for tallies for background events

When complete, enter results into spreadsheet (details on help sheet)

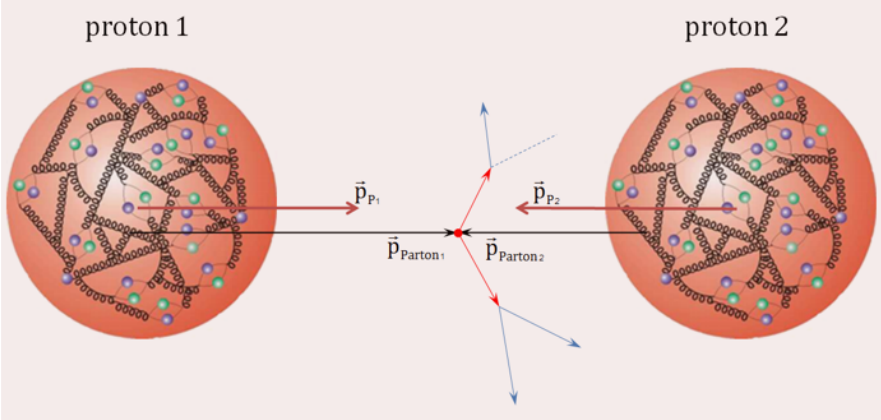
Data Analysis: Almost done!

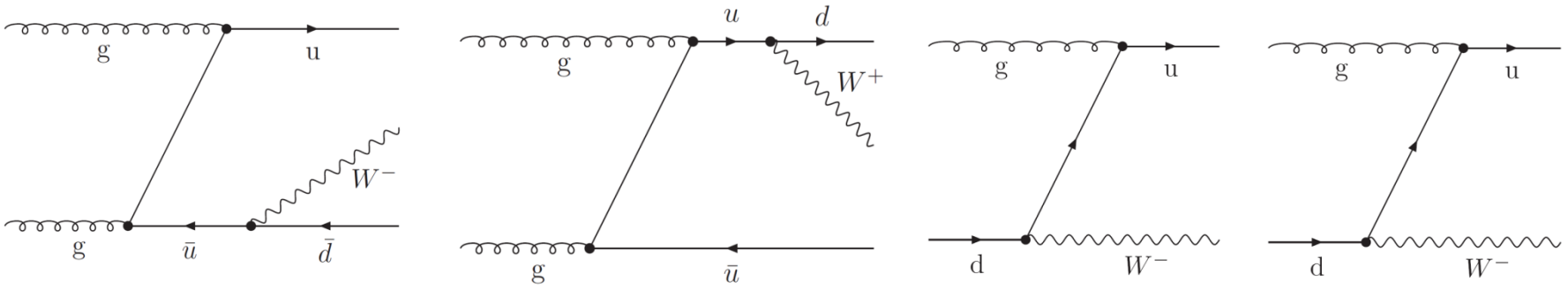
- Now capable of identifying different types of events
  - $W \rightarrow e\nu, W \rightarrow \mu\nu$, background, $WW \rightarrow \ell\nu\ell\nu$
- Understand the structure of the proton
  - Only worked with a small sample of events
  - Many more W's are produced compared to Z events
  - Note: in reality there many more background events than W or Z events compared to this sample
- Studied the Higgs boson
- Discussed the results

Thank you for your participation!

Data Analysis: Discussion of Proton Structure

- Proton does not react as a whole
- Different methods of production of

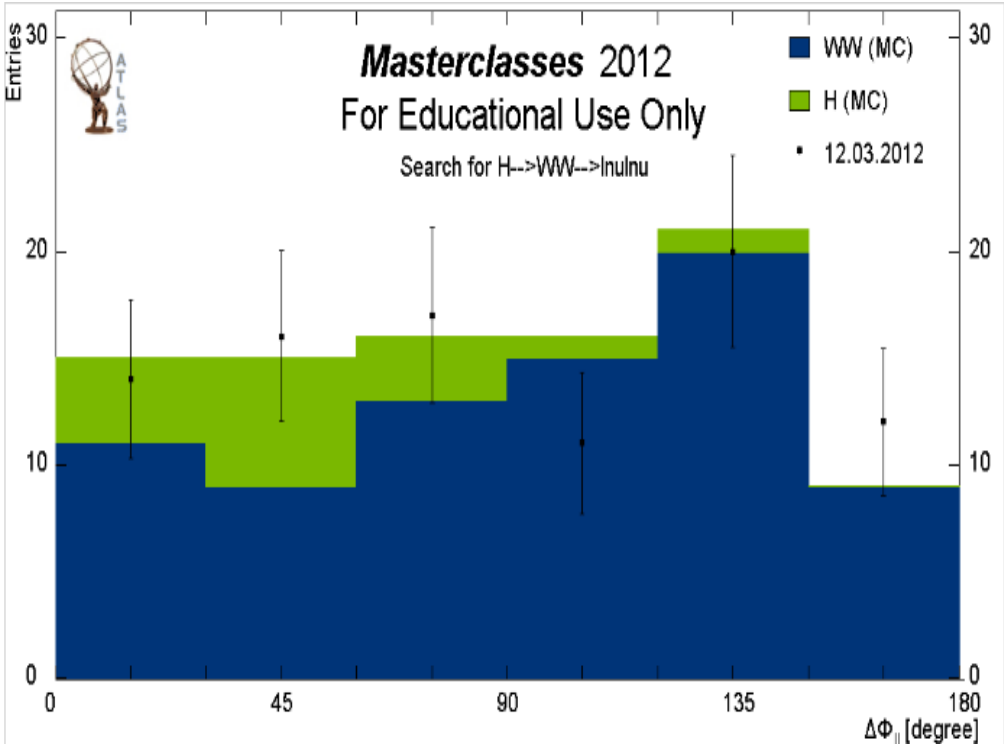




- Decays – 1/3 of the time W decays into a lepton and neutrino (electron, muon or tau)
- Protons are complicated at high energies!

Data Analysis: Discussion of Higgs Search

- Histogram
- H→WW
- Background-to-signal
- Additional variables
- Agreement
- Uncertainty & effects on discovery
- What to do better?



MINERVA Masterclass Resources

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

ATLAS Experiment public website
http://atlas.ch/

Learning with ATLAS@CERN
http://www.learningwithatlas-portal.eu/en

The Particle Adventure (Good introduction to particle physics)
http://www.particleadventure.org/

LHC@InternationalMasterclasses
http://kjende.web.cern.ch/kjende/en/index.htm