



International Masterclasses

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# ATLAS Z-Path Handbook

# Introduction

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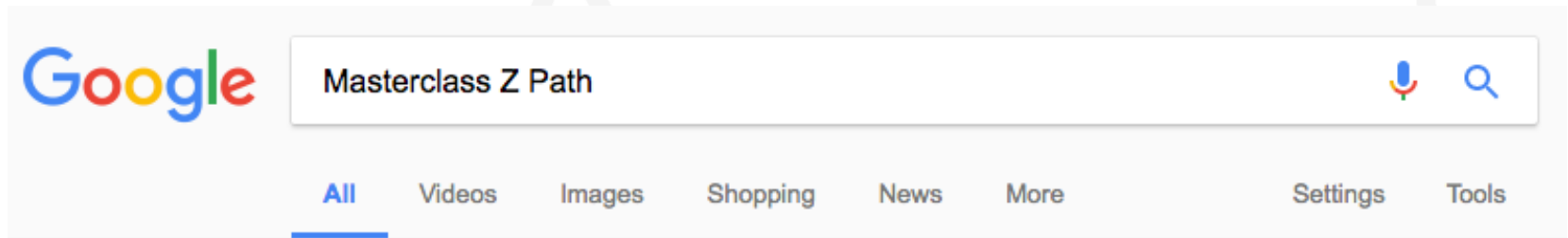
## Masterclass Ingredients

- Physicist
- Non-Physicist
- Real Data from an Experiment
- Tool to Visualise Data
- Method to Analyse Data
- Coffee

## Goal of the ATLAS Z-Path Masterclass

- Identify collisions in ATLAS that are Z-boson candidates
- Calculate their invariant mass
- Plot them in a histogram, present, and compare

# Getting Started



About 1.110.000 results (0,30 seconds)

**Z-Path - International Physics Masterclasses**

[atlas.physicsmasterclasses.org/en/zpath.htm](http://atlas.physicsmasterclasses.org/en/zpath.htm) ▼

Z-Path. Welcome to the Z-path! Here you will learn about some particles, such as the Z boson and the Higgs boson, and their importance to our understanding of ...

<http://atlas.physicsmasterclasses.org/en/zpath.htm>

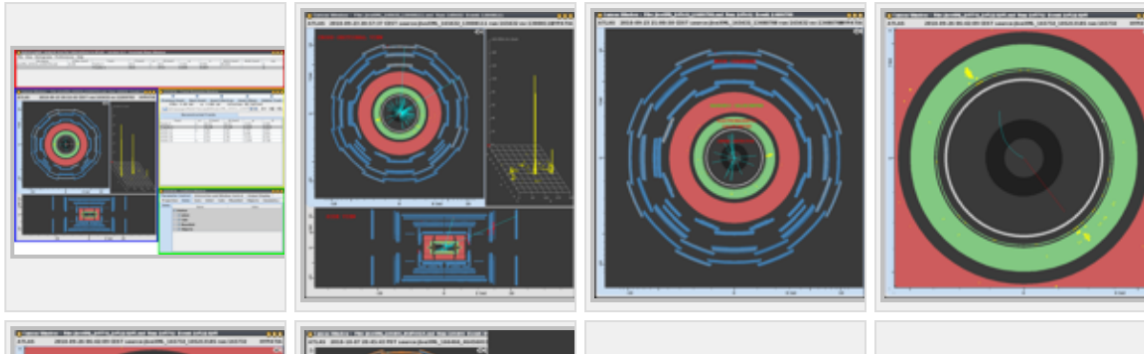
Link already in the Agenda "ATLAS Z-Path"

# Visualization with HYPATIA

*The footprints or electronic signals that are recorded by the detectors during a collision can be visualized in so-called “event displays”. These produce dynamic images showing how the particles travelled through the detector. You will use the event display program known as HYPATIA. In this section you will learn what possibilities and functions in HYPATIA will help you perform your measurement.*

First, start the program HYPATIA ([Download](#))

Use the following event-display gallery to get some insight into the functions of HYPATIA! Explore your own version of the program in parallel.



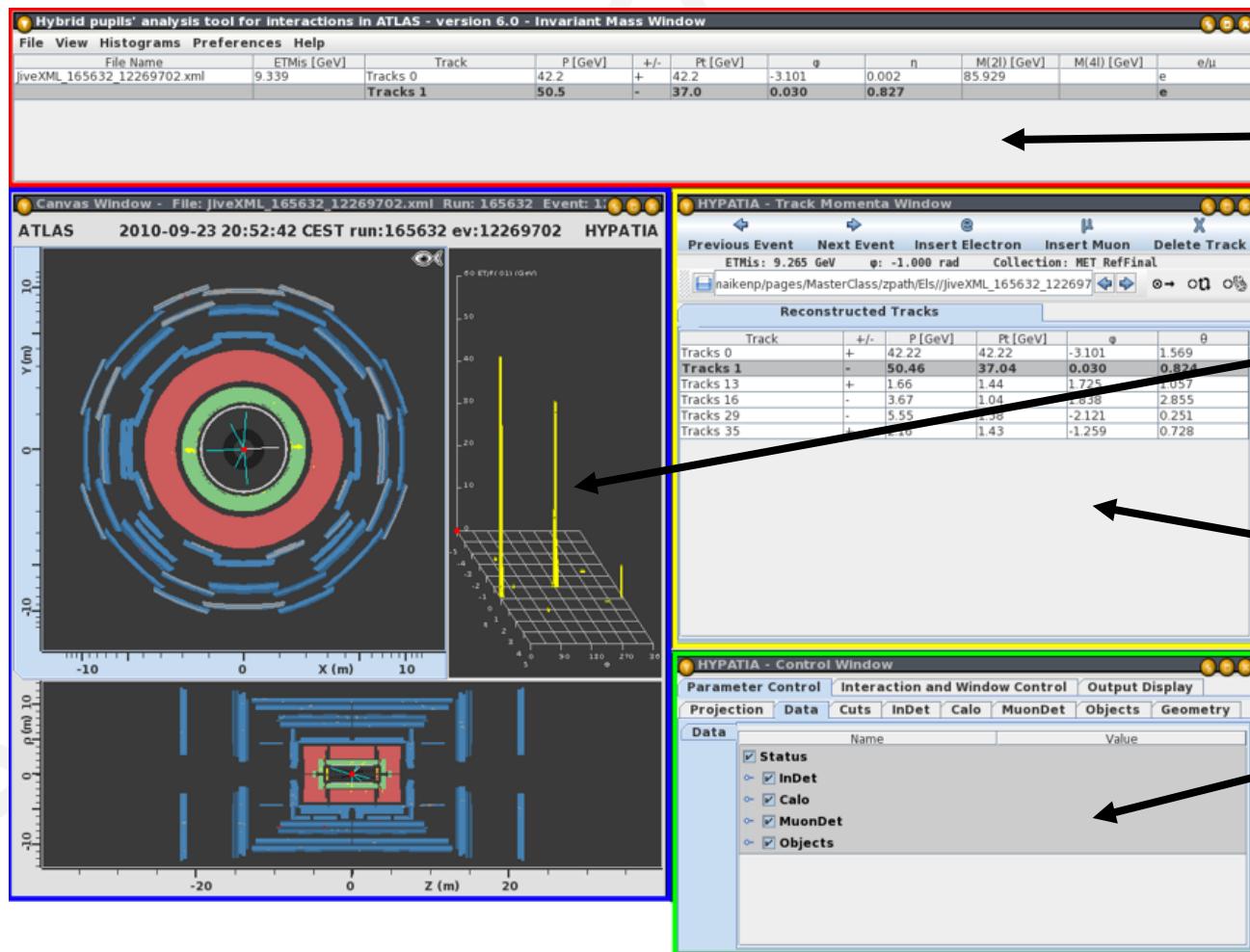
We will use HYPATIA to Identify Z bosons in proton collisions.  
It is already downloaded and installed on your notebook.

## Z-Path

Introducing the Z boson
Introducing the Higgs boson
New Physics
Identifying particles
ATLAS detector
Play!
<b>Visualization with HYPATIA</b>
Particle footprint visualization
Practice!
Identifying Events
Search and discover with mass
Get to work!



# Hypatia



Invariant Mass Window

Canvas Window

Track Momentum Window

Control Window

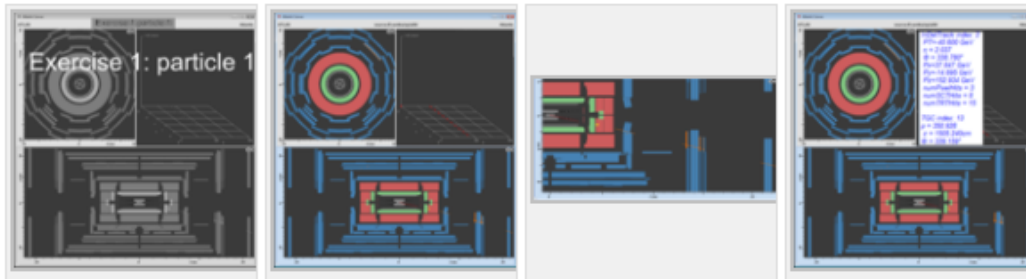
# Practice Identifying Particles

One can often see tracks of several different particles in each event.

You will do some detective work in this first exercise. Make use of the event display features to find all electrons, muons, photons, neutrinos, and jets in each displayed event.

Use the checkboxes below each exercise to record the type of particles you have just observed by clicking on 'Check'. The 'Hint' button helps you along the way! The 'Correct' button shows the right answer.

Good luck!



particle 1   electron   positron   muon   anti-muon   photon   neutrino-antineutrino   jet

check

correct answer

Try this for 10 minutes. Hints on the next page...

## Z-Path

Introducing the Z boson

Introducing the Higgs boson

New Physics

Identifying particles

ATLAS detector

Play!

Visualization with HYPATIA

Particle footprint visualization

Practice!

Identifying Events

Search and discover with mass

Get to work!

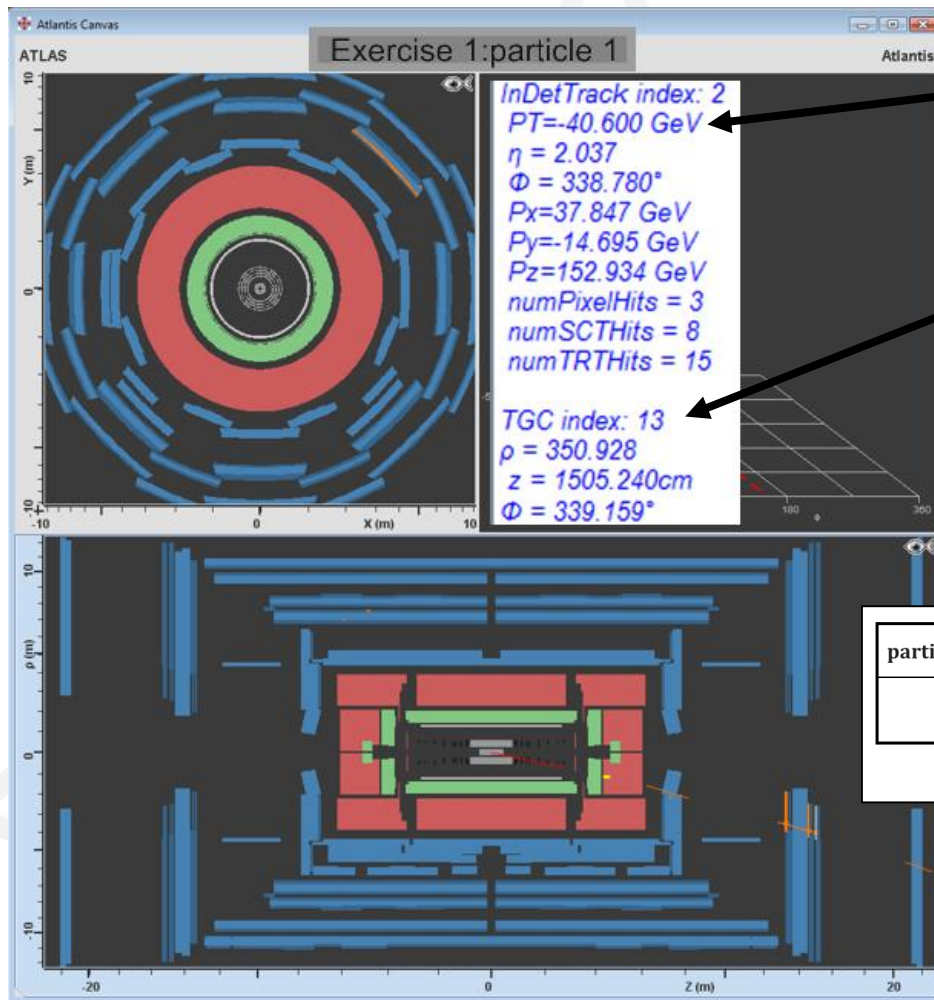


## Knowledge Center

Research at the LHC

The Standard Model

# Identifying Particles: Hints

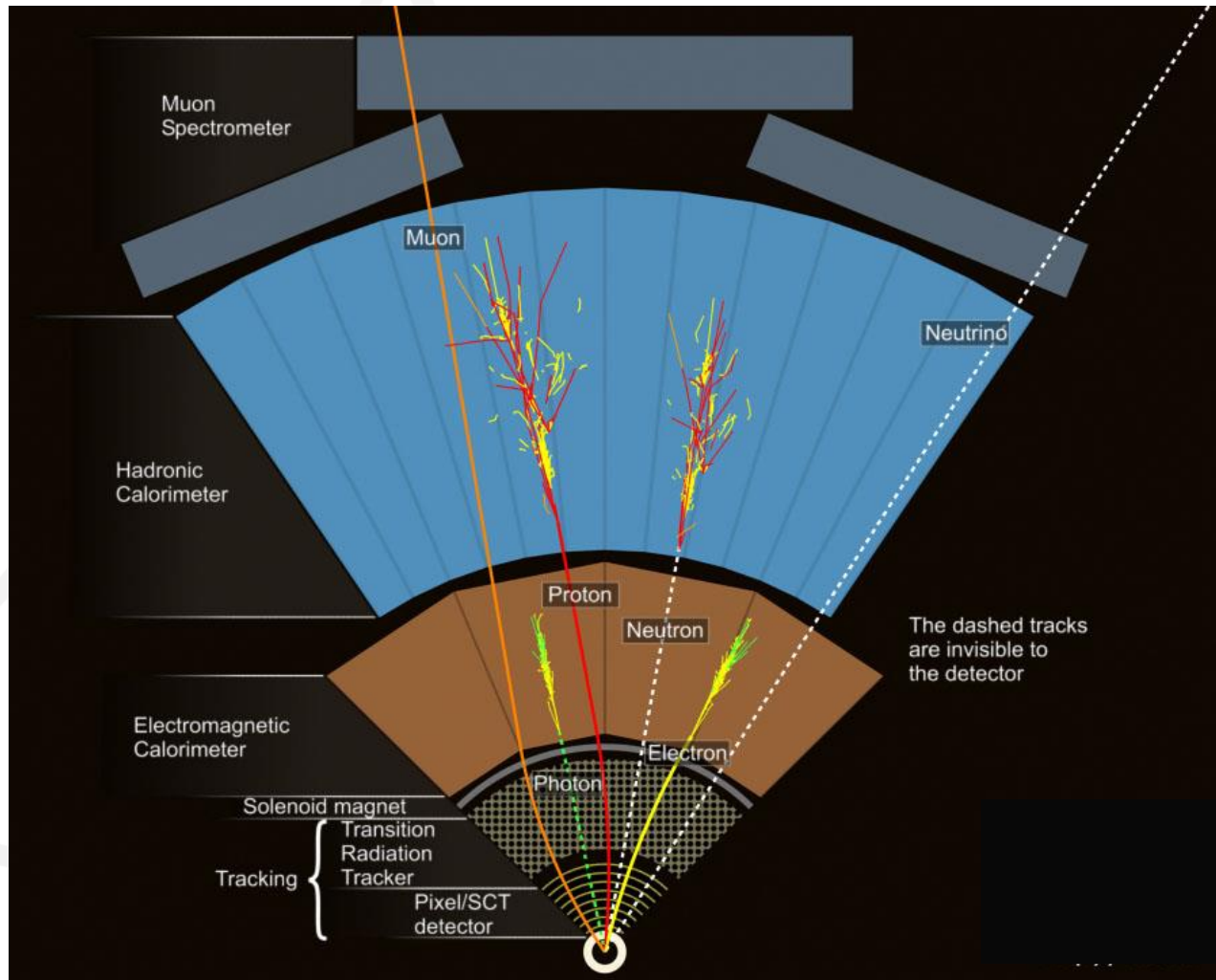


**Hint:** PT = -40.600 GeV  
Means charge is **negative**.

**Hint:** Only muons make it  
to the TGC.

particle 1	electron	positron	muon	anti-muon	photon	neutrino-antineutrino	jet
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

# Particle ID in ATLAS

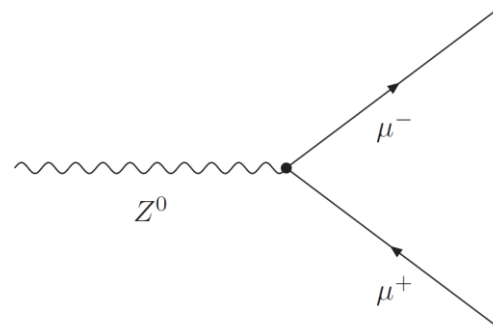
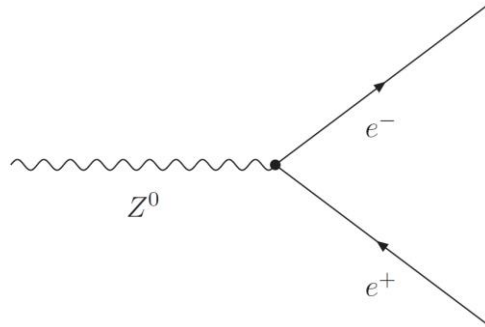


# How to spot a Z boson

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Z boson lifetime =  $10^{-25}$  seconds

- We identify it by its decay products



Z boson mass = 91 GeV

- And by the mass reconstructed from the two leptons

$$m_X = \sqrt{2E_1 E_2 (1 - \cos\theta)}$$

Expect lepton momenta to be roughly half the Z mass

# Removing Background

In a typical LHC collision, around 20-30 protons collide at the same time, producing many tracks. We only want to look at the tracks that come from Z boson decays.

Track	+/-	P [GeV]	Pt [GeV]	$\phi$	$\theta$
Tracks 0	-	11.68	4.28	-1.319	0.375
Tracks 1	+	126.06	39.41	-2.413	0.318
Tracks 2	+	4.57	4.56	-2.783	1.649
Tracks 3	-	167.90	53.01	0.906	0.321
Tracks 4	-	1.34	1.33	-2.949	1.475
Tracks 5	-	1.75	1.74	-3.090	1.645
Tracks 6	+	18.61	3.94	-1.818	0.214

Under the **Parameter Control** tab:

Change the **cut** for the track **Pt** (transverse momentum):

- Try 2.0 GeV
- Try 10.0 GeV

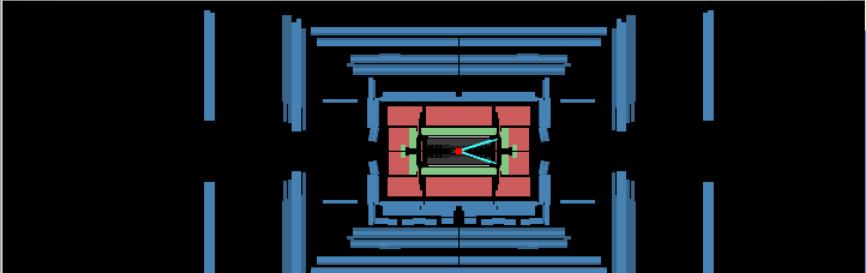
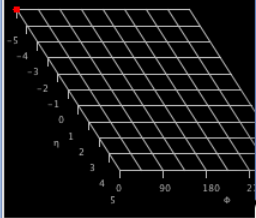
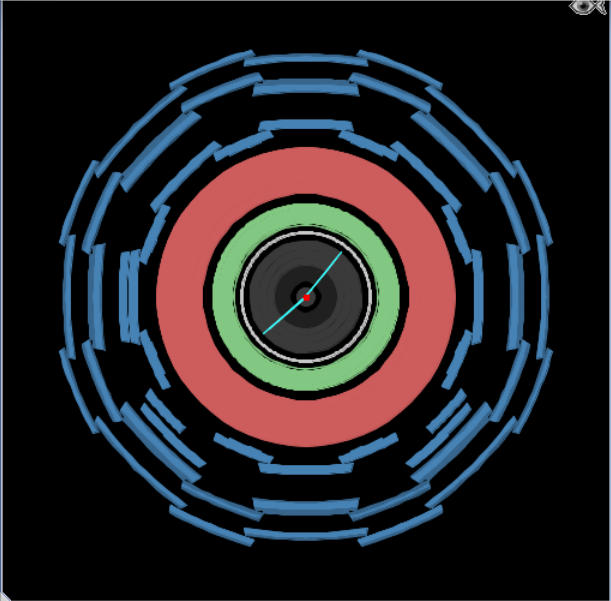
Which will help us to find tracks from Z bosons?

# Viewing the Tracks

HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window

View Histograms Preferences Help

File Name	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	$\varphi$	$\eta$	M(2) [GeV]	M(eeee) [GeV]	M(eemm) [GeV]	M(mmmm) [GeV]	e/m/g
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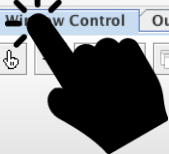
File Previous Event Next Event Electron Muon Photon Delete Track Reset Canvas  
ETMis: 13.877 GeV  $\varphi$ : 0.785 rad Collection: MET\_Reffinal  
events/events4.zip/jiveXML\_106051\_1950731.xml

Tracks	Physics Objects					
Track	+/-	P [GeV]	Pt [GeV]	$\varphi$	$\theta$	
Tracks 1		+	126.06	39.41	-2.413	0.318
Tracks 3		-	167.90	53.01	0.906	0.321

A Pt cut of 10 GeV appears sensible. Set that, then click on the **Interaction and Window Control** Tab

HYPAIA - Control Window

Parameter Control Interaction and Window Control Output Display



W	S	X	L	M	R	1	2	3	U	3
			4	5	6	4	5	6	C	6
	B		B			7	8	9	D	9

# Viewing the Tracks

HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window

View Histograms Preferences Help

File Name	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	$\varphi$	$\eta$	M(2) [GeV]	M(eeee) [GeV]	M(eemm) [GeV]	M(mmmm) [GeV]	e/m/g
-----------	-------------	-------	---------	-----	----------	-----------	--------	------------	---------------	---------------	---------------	-------

File: Previous Event Next Event Electron Muon Photon Delete Track Reset Canvas  
ETMis: 13.877 GeV  $\varphi$ : 0.785 rad Collection: MET\_ReFinal  
events/events4.zip/jiveXML\_106051\_1950731.xml

Track	+/-	P [GeV]	Pt [GeV]	$\varphi$	$\theta$
Tracks 1	+	126.06	39.41	-2.413	0.318
Tracks 3	-	167.90	53.01	0.906	0.321

Now click on the **magnifying glass** to make it possible to zoom the image in and out with your cursor. Practice.

HYPATIA - Control Window

Parameter Control Interaction and Window Control Output Display

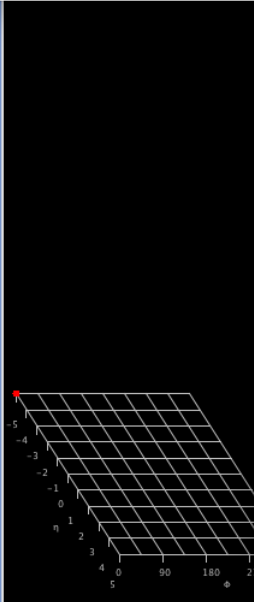
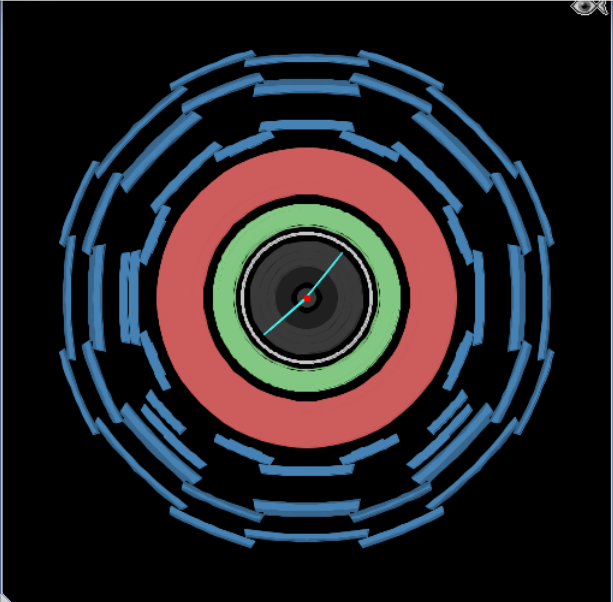
W S X L M R 1 2 3 U 3  
4 5 6 C 6  
B B 7 8 9 D 9

# Viewing the Tracks

HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window

View Histograms Preferences Help

File Name	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	$\varphi$	$\eta$	M(2) [GeV]	M(eeee) [GeV]	M(eemm) [GeV]	M(mmmm) [GeV]	e/m/g
-----------	-------------	-------	---------	-----	----------	-----------	--------	------------	---------------	---------------	---------------	-------



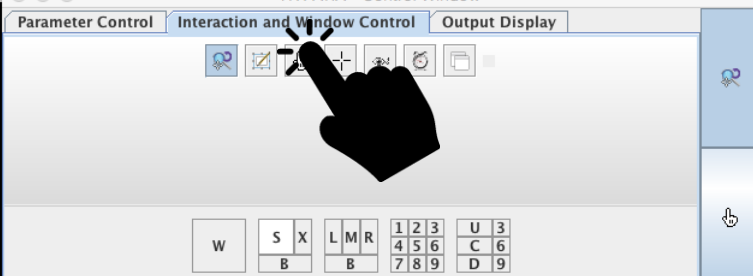
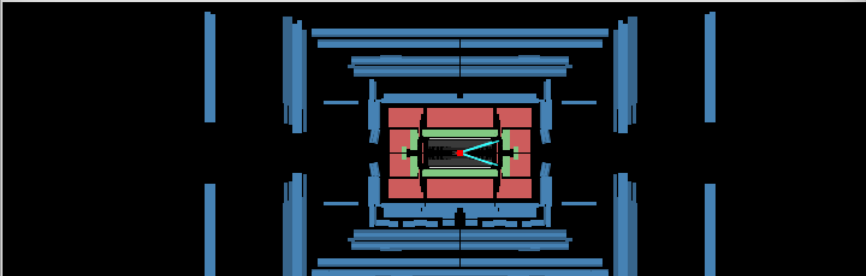
File Previous Event Next Event Electron Muon Photon Delete Track Reset Canvas  
ETMis: 13.877 GeV  $\varphi$ : 0.785 rad Collection: MET\_ReFinal  
events/events4.zip/jiveXML\_106051\_1950731.xml

Tracks	Physics Objects					
Track	+/-	P [GeV]	Pt [GeV]	$\varphi$	$\theta$	
Tracks 1		+	126.06	39.41	-2.413	0.318
Tracks 3		-	167.90	53.01	0.906	0.321

Now click on the **finger** to make it possible to select tracks with your cursor. When a track is selected, it will be **highlighted** above and the track in the event display will **turn white**.

HYPATIA - Control Window

Parameter Control Interaction and Window Control Output Display



W	S	X	L	M	R	1	2	3	U	3
	B		B			4	5	6	C	6
						7	8	9	D	9

# Photons

The screenshot displays the HYPATIA software interface. The top menu bar includes "ew", "Histograms", "Preferences", and "Help". Below the menu is a toolbar with various icons and labels: "File Name", "ETMis [GeV]", "Track", "P [GeV]", "+/-", "Pt [GeV]", " $\phi$ ", " $\eta$ ", "M(2) [GeV]", "M(eeee) [GeV]", "M(eemm) [GeV]", "M(mmmm) [GeV]", and "e/m/g".

The main interface is divided into several panels:

- Top Left:** A circular detector view showing concentric layers of calorimeters. Two yellow bars indicate energy deposits in the electromagnetic calorimeter.
- Top Right:** A 3D plot of energy deposits (yellow bars) on a grid. The vertical axis is labeled "35 ET (GeV)".
- Center:** The "HYPATIA - Track Momenta Window". It features a menu bar with "Previous Event", "Next Event", "Electron", "Muon", "Photon", "Delete Track", and "Reset Canvas". Below the menu, it shows event information: "ETMis: 13.556 GeV", " $\phi$ : -2.942 rad", and "Collection: MET Refinial". A file path is also visible: "top/Hypatia\_7.4\_Masterclass/events/exercise2\_Z/00001\_Exercise2.xml". Below this is a table with two tabs: "Tracks" and "Physics Objects". The "Physics Objects" tab is active, showing a table with columns: "Track", "P [GeV]", "Pt [GeV]", " $\phi$ ", and " $\theta$ ".
- Bottom Left:** A detailed detector view showing the internal structure of the calorimeters and the location of the energy deposits.
- Bottom Right:** The "HYPATIA - Control Window". It has tabs for "Parameter Control", "Interaction and Window Control", and "Output Display". Under "Parameter Control", there are sub-tabs for "Projection", "Data", "Cuts", "InDet", "Calo", "MuonDet", "Objects", and "Geometry". The "Cuts" sub-tab is active, showing a list of parameters and their values:

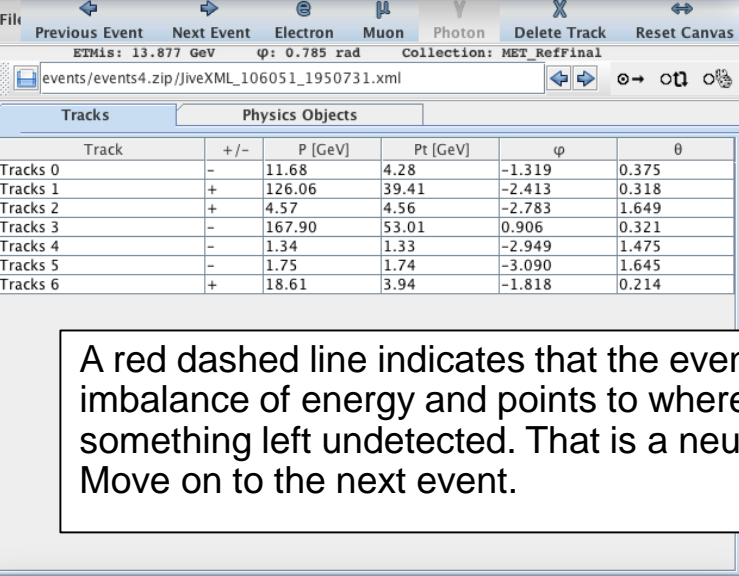
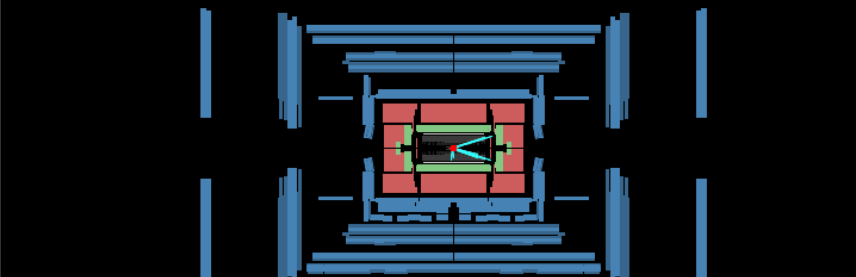
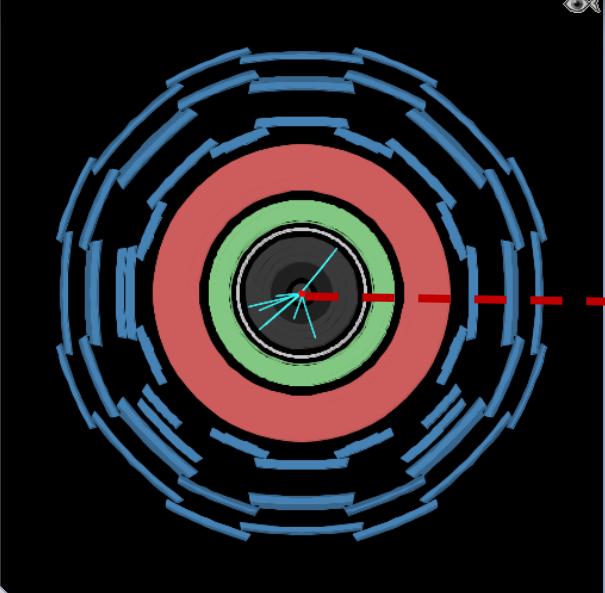
Name	Value
<input checked="" type="checkbox"/>  Pt	> 10.0 GeV
<input type="checkbox"/>  Pt2	< 700.0 MeV
<input checked="" type="checkbox"/>  d0	< 2.5 mm
<input checked="" type="checkbox"/>  z0	< 20.0 cm
<input type="checkbox"/>  d0 Loose	< 2.0 cm
<input type="checkbox"/>  z0-zVtx	< 2.5 mm

If you see **energy deposits** (yellow bars) in the electromagnetic calorimeter with no tracks pointing to them, they are **photons**. You see their information under "**Physics Objects**." We will ignore them for this exercise, as we are only looking for pairs of electrons or muons. Move on to the next event.

# Neutrinos

HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window

File Name | ETMis [GeV] | Track | P [GeV] | +/- | Pt [GeV] |  $\phi$  |  $\eta$  | M(2) [GeV] | M(eeee) [GeV] | M(eemm) [GeV] | M(mmmm) [GeV] | e/m/g



Track	+/-	P [GeV]	Pt [GeV]	$\phi$	$\theta$
Tracks 0	-	11.68	4.28	-1.319	0.375
Tracks 1	+	126.06	39.41	-2.413	0.318
Tracks 2	+	4.57	4.56	-2.783	1.649
Tracks 3	-	167.90	53.01	0.906	0.321
Tracks 4	-	1.34	1.33	-2.949	1.475
Tracks 5	-	1.75	1.74	-3.090	1.645
Tracks 6	+	18.61	3.94	-1.818	0.214

File | Previous Event | Next Event | Electron | Muon | Photon | Delete Track | Reset Canvas

ETMis: 13.877 GeV  $\phi$ : 0.785 rad Collection: MET\_RefFinal

events/events4.zip/liveXML\_106051\_1950731.xml

Tracks | Physics Objects

HYPATIA - Control Window

Parameter Control | Interaction and Window Control | Output Display

Projection | Data | Cuts | InDet | Calo | MuonDet | Objects | Geometry

InDet	Name	Value
Calo	<input checked="" type="checkbox"/>  Pt	> 1.0 GeV
MuonDet	<input type="checkbox"/>  Pt2	< 700.0 MeV
Objects	<input type="checkbox"/>  d0	< 2.5 mm
ATLAS	<input checked="" type="checkbox"/>  z0	< 20.0 cm
	<input type="checkbox"/>  d0 Loose	< 2.0 cm
	<input type="checkbox"/>  z0-zVtx	< 2.5 mm

A red dashed line indicates that the event had an imbalance of energy and points to where something left undetected. That is a neutrino. Move on to the next event.

# Exercise 2

The screenshot displays the HYPATIA software interface, which is used for analyzing particle detector data. The main window is divided into several panels:

- Top Left:** A circular detector simulation view showing concentric layers of detector components. Two yellow lines represent tracks originating from the center.
- Top Right:** A 3D plot of track momenta. The vertical axis is labeled "35 ET [GeV]" and ranges from 0 to 25. The horizontal axes are labeled "η" and "φ". The plot shows a distribution of yellow points representing tracks.
- Bottom Left:** A detailed view of the detector simulation, showing the internal structure of the detector layers.
- Top Center:** A menu bar with options: File Name, ETMis [GeV], Track, P [GeV], +/-, Pt [GeV], φ, η, M(2) [GeV], M(eeee) [GeV], M(eemm) [GeV], M(mmmm) [GeV], e/m/g.
- Bottom Center:** A "Physics Objects" table with the following data:

	P [GeV]	Pt [GeV]	φ	θ
Object	73.60	73.48	0.132	1.627
Object 1	74.22	65.20	2.981	2.069
- Bottom Right:** A "Control Window" with tabs for "Parameter Control", "Interaction and Window Control", and "Output Display". The "Parameter Control" tab is active, showing a list of parameters and their values:

Name	Value
<input checked="" type="checkbox"/>  Pt	> 10.0 GeV
<input type="checkbox"/>  Pt2	< 700.0 MeV
<input checked="" type="checkbox"/>  d0	< 2.5 mm
<input checked="" type="checkbox"/>  z0	< 20.0 cm
<input type="checkbox"/>  d0 Loose	< 2.0 cm
<input type="checkbox"/>  z0-zVtx	< 2.5 mm

Open the dataset in the ESADE folder on your Desktop. It has a name like groupX. This is the data you will be analysing.

## Exercise 2

With the following exercise, you can test how good your sense of event selection and particle identification is.

Therefore we have chosen ten examples of events which are stored [here](#) in electronic form for you to download. They have to be opened in the program HYPATIA (with “Read Event Locally”).

The picture gallery will guide you through this task.

- Di-lepton signal events are only events, where a Z boson, a  $J/\psi$  or  $\Upsilon$  particles are produced. In signal events you also determine whether these particles have decayed into an electron-positron pair or into a muon-antimuon pair.
- Higgs candidate events contain either 2 photons or 2 pairs of leptons.
- Events with jets, W bosons, top-quark pairs and are background events.

You can check your results using the table below. For each event, choose which process you are seeing. By clicking “Confirm Task”, you can find out the number of events guessed correctly. By clicking “Correct Answers”, you can see the solution.

Good luck!

event	$e^+e^-$	$\mu^+\mu^-$	$\gamma\gamma$	$l^+l^-l^+l^-$	Backgrounds
1	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

## Z-Path

Introducing the Z boson
Introducing the Higgs boson
New Physics
Identifying particles
Identifying Events
When protons collide
Z events
Higgs events
Background events
Visualization
<b>Practice!</b>
Search and discover with me
Get to work!

Open Exercise 2 in your browser (under Identifying Events, Practice!).

Try classifying the events according to the categories specified below.

## Knowledge Center

Research at the LHC
The Standard Model
More about the Z boson
Extra Space Dimensions and Gravity
Supersymmetry

# Identifying Events

The screenshot displays the HYPATIA software interface, which is used for analyzing particle interactions. The main window is titled "HYBRID PUPILS' ANALYSIS TOOL FOR INTERACTIONS IN ATLAS - version 7.4 - Invariant Mass Window". It features a menu bar with "File", "Histograms", "Preferences", and "Help". Below the menu bar is a table with columns for "File Name", "ETMis [GeV]", "Track", "P [GeV]", "+/-", "Pt [GeV]", " $\varphi$ ", " $\eta$ ", "M(2) [GeV]", "M(eeee) [GeV]", "M(eemm) [GeV]", "M(mmmm) [GeV]", and "e/m/g".

The interface is divided into several panels:

- Top Left:** A circular detector layout diagram with concentric rings representing different detector layers. Two yellow lines indicate the paths of particles.
- Top Right:** A 2D histogram showing the distribution of events. The vertical axis is labeled "35 ET [GeV]" and ranges from 0 to 25. The horizontal axis is labeled " $\eta$ " and ranges from -4 to 4. A 3D plot below it shows the distribution of events in a 3D space.
- Bottom Left:** A detailed view of the detector layout, showing the central region and the surrounding layers.
- Bottom Right:** A "Control Window" with tabs for "Parameter Control", "Interaction and Window Control", and "Output Display". It contains a table of parameters and their values:

Category	Name	Value
InDet		
Calo	<input checked="" type="checkbox"/>  Pt	> 10.0 GeV
MuonDet	<input checked="" type="checkbox"/>  Pt2	< 700.0 MeV
Objects	<input checked="" type="checkbox"/>  d0	< 2.5 mm
ATLAS	<input checked="" type="checkbox"/>  z0	< 20.0 cm
	<input type="checkbox"/>  d0 Loose	< 2.0 cm
	<input type="checkbox"/>  z0 -zVtx	< 2.5 mm

The "Track Momenta Window" is also visible, showing a table of track data:

Track	Pt [GeV]	$\varphi$	$\theta$	
Object 0	73.60	73.48	0.132	1.627
Object 1	74.22	65.20	2.981	2.069

A hand icon points to the "Next Event" button in the "Track Momenta Window" menu.

Take 10 minutes to classify the 10 events. Check the boxes in your browser accordingly. Use the **Next Event** button to advance.

# Answers to Exercise 2

Event	Classification	Notes
1	$\gamma\gamma$	Energy deposits without tracks are photons
2	$\gamma\gamma$	Energy deposits without tracks are photons
3	$e^+e^-$	Tracks pointing to electromagnetic energy deposits
4	$\mu^+\mu^-$	Tracks making it into the muon chambers
5	$\gamma\gamma$	Energy deposits without tracks are photons
6	$e^+e^-$	Tracks pointing to electromagnetic energy deposits
7	$\mu^+\mu^-$	Tracks making it into the muon chambers
8	$l^+l^+l^-l^-$	<b><i>Reduce the Pt cut to 5 GeV to see all four leptons</i></b>
9	$e^+e^-$	Tracks pointing to electromagnetic energy deposits
10	$l^+l^+l^-l^-$	Four leptons

Refer to [http://atlas.physicsmasterclasses.org/en/zpath\\_lhcphysics3.htm](http://atlas.physicsmasterclasses.org/en/zpath_lhcphysics3.htm) for help.

# The Competition

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## Get the data

- From Hypatia open the data file in the ESADE folder

## Select the Events

1. Set your track Pt cut to 10 GeV
2. Select  $e^+e^-$  and  $\mu^+\mu^-$  events
3. For each pair, **double click** on the tracks to record them in the invariant mass window

## Save Each Measurement

- Record **Event Number** and **Mass** in the Spreadsheet

## Plot the Mass Spectrum

- Use the plotting tool in Spreadsheet

## Combine ATLAS Groups

- Make final plot for conference