

HYPATIA Tutorial



ATLAS Masterclass (27/04/2024)

Charlie Chen & Adrienne Scott (UVIC)



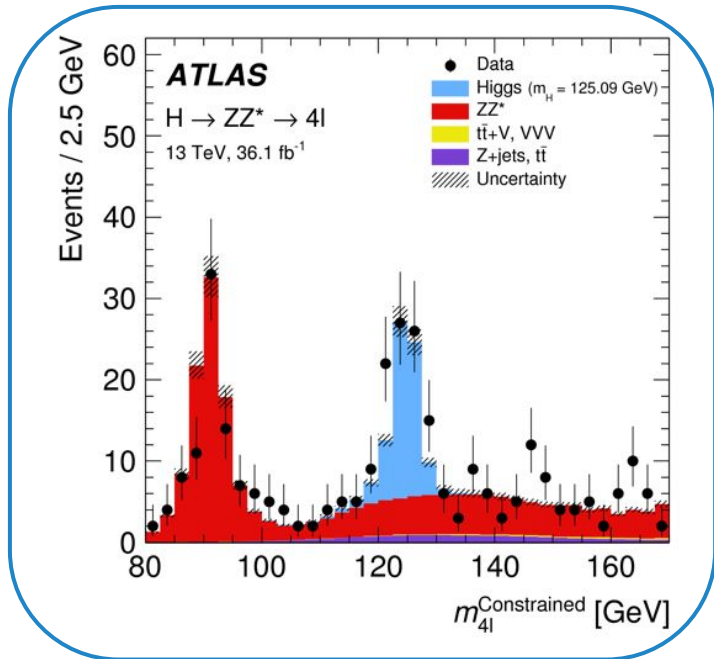
**University
of Victoria**

Overview of HEP Analyses

- Remember that most High-Energy Physics (HEP) analyses are “counting experiments”: they count number of good **physics objects** that pass a certain set of cuts.
- We plot each of the variables (e.g. momentum, energy, mass, position, etc.) that we are interested in as **histograms**.

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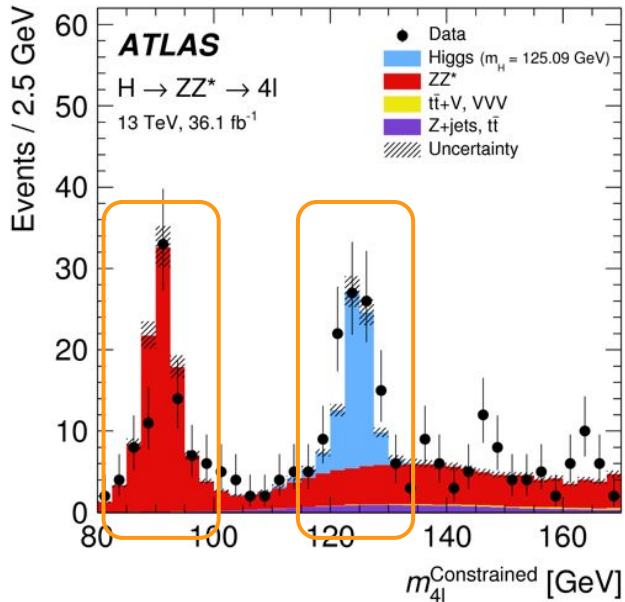
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→ Are there any distinct patterns that we can see?

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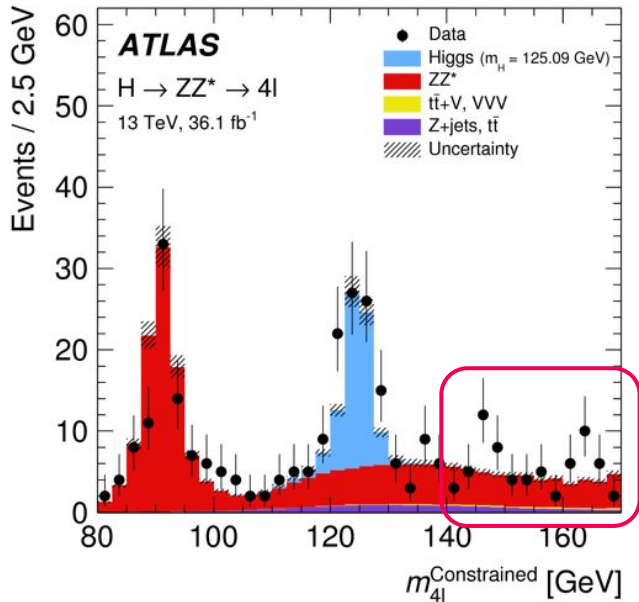


- Here we see an example of a Higgs boson analysis which plots the the combined mass of four particles (leptons) → Are there any distinct patterns that we can see?

- There are two distinct peaks in this histogram, implying that there we have successfully reconstructed two parent particles → Which standard model particles do these peaks correspond to?

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- Here we see an example of a Higgs boson analysis which plots the the combined mass of four particles (leptons) → Are there any distinct patterns that we can see?

- There are two distinct peaks in this histogram, implying that there we have successfully reconstructed two parent particles → Which standard model particles do these peaks correspond to?

- There are other smaller peaks elsewhere in the histogram, do these correspond to any particles that we are aware of? Are 12 events enough to say that we've discovered a new particle?

Intro to HYPATIA

- We will try to perform a similar analysis using the analysis tool **HYPATIA**.
- This tool is a simplified version of the same tools that would be used in a standard ATLAS analysis and gives good consistent results.
- When you open HYPATIA for the first time, you will see 4 separate windows. Let's go through each of these windows.

The screenshot displays the HYPATIA software interface, titled "HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window". The interface is divided into several windows:

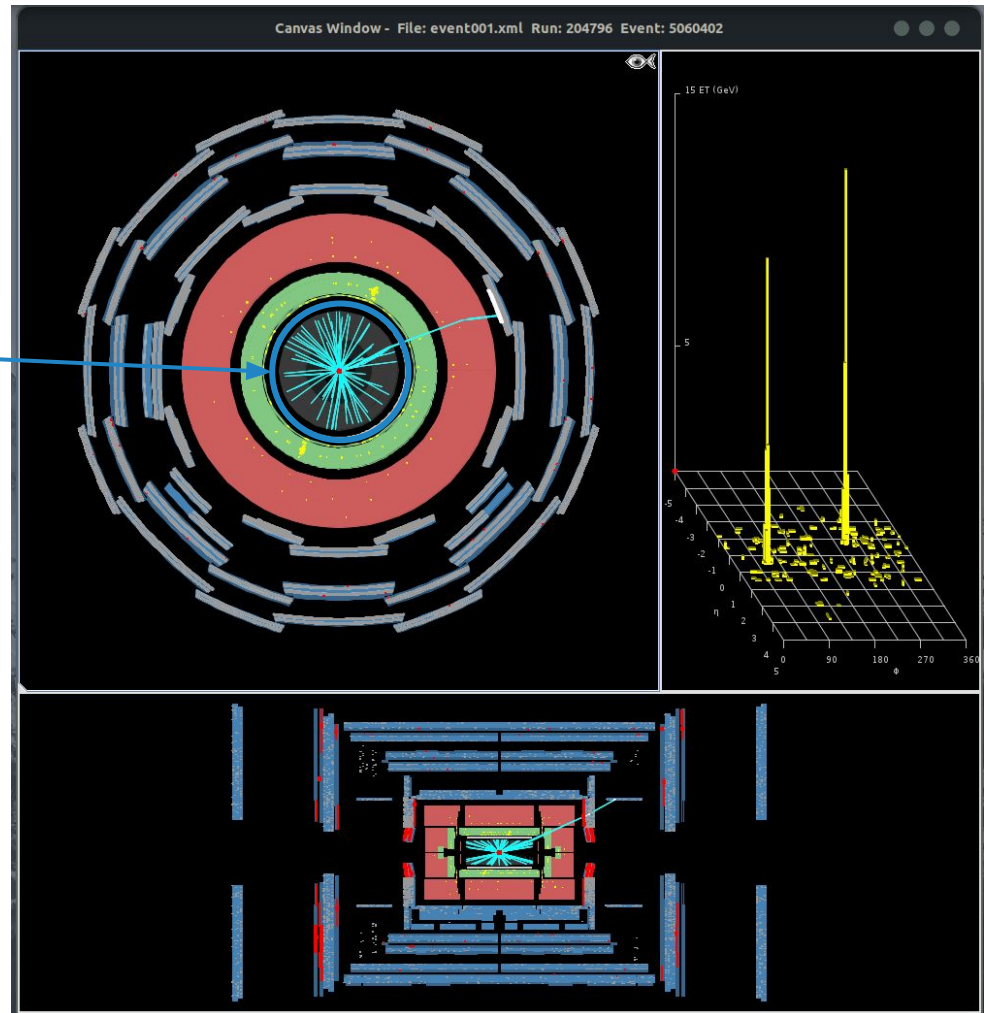
- Control Window:** Contains tabs for "Parameter Control", "Interaction and Window Control", and "Output Display". It includes a "Data" table with columns for Name and Value, and a tree view for "Status" (InDet, Calo, MuonDet, Objects).
- Track Momenta Window:** Shows a table of physics objects with columns for Track, +/-, P [GeV], PT [GeV], ψ , and θ . The table lists tracks 4 through 75 with their respective kinematic values.
- Canvas Window:** Displays a 2D visualization of the ATLAS detector geometry with tracks overlaid. A 3D plot on the right shows the tracks in a 3D coordinate system.
- Physics Objects Window:** A table listing track parameters for tracks 4 through 75.

Track	+/-	P [GeV]	PT [GeV]	ψ	θ
Tracks 4	-	5.83	1.43	0.509	0.248
Tracks 7	-	3.40	1.06	2.977	0.316
Tracks 9	*	47.07	37.95	-1.979	2.204
Tracks 10	-	2.34	1.28	2.093	0.580
Tracks 11	-	5.42	1.44	0.316	0.269
Tracks 12	-	2.96	1.20	2.802	2.724
Tracks 13	-	8.30	1.47	2.483	2.964
Tracks 14	-	6.58	2.03	-1.081	0.313
Tracks 15	*	7.59	1.50	-1.220	2.943
Tracks 17	-	2.00	1.12	2.214	2.546
Tracks 21	+	2.65	1.91	-0.290	2.338
Tracks 25	-	6.27	1.30	2.975	0.269
Tracks 27	-	4.12	1.43	0.256	0.355
Tracks 28	-	1.92	1.65	2.064	1.039
Tracks 31	-	1.58	1.54	1.098	1.367
Tracks 33	-	3.08	1.21	-1.953	0.406
Tracks 35	-	2.88	1.13	-2.993	0.404
Tracks 36	+	2.08	1.86	1.513	1.094
Tracks 41	-	2.52	1.86	2.745	0.892
Tracks 42	+	1.39	1.22	1.668	1.247
Tracks 44	+	3.95	1.00	-2.840	0.256
Tracks 48	+	3.90	1.10	2.977	0.286
Tracks 49	-	2.86	1.09	0.185	0.391
Tracks 58	+	1.95	1.95	2.874	1.561
Tracks 63	-	8.03	1.87	-0.613	2.966
Tracks 67	-	1.02	1.01	-2.092	1.491
Tracks 68	+	1.68	1.64	1.815	1.768
Tracks 69	+	10.96	2.05	2.045	0.188
Tracks 75	+	1.84	1.55	-1.469	1.003

Main Detector

- This is the main detector window, which shows the main sub-detectors and the various tracks and energy deposits.

Inner detector: responsible for precise tracking of charged particles

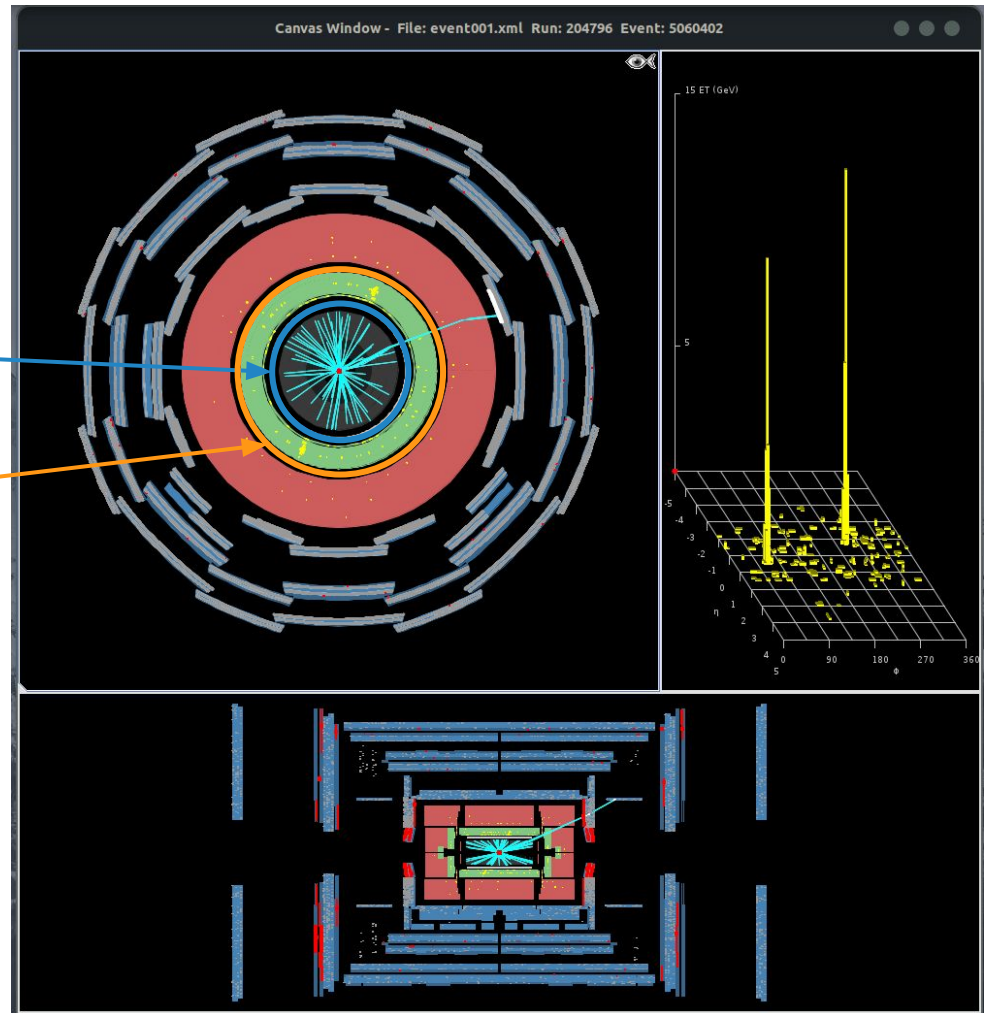


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EM calorimeter: measures energy of electrons and photons



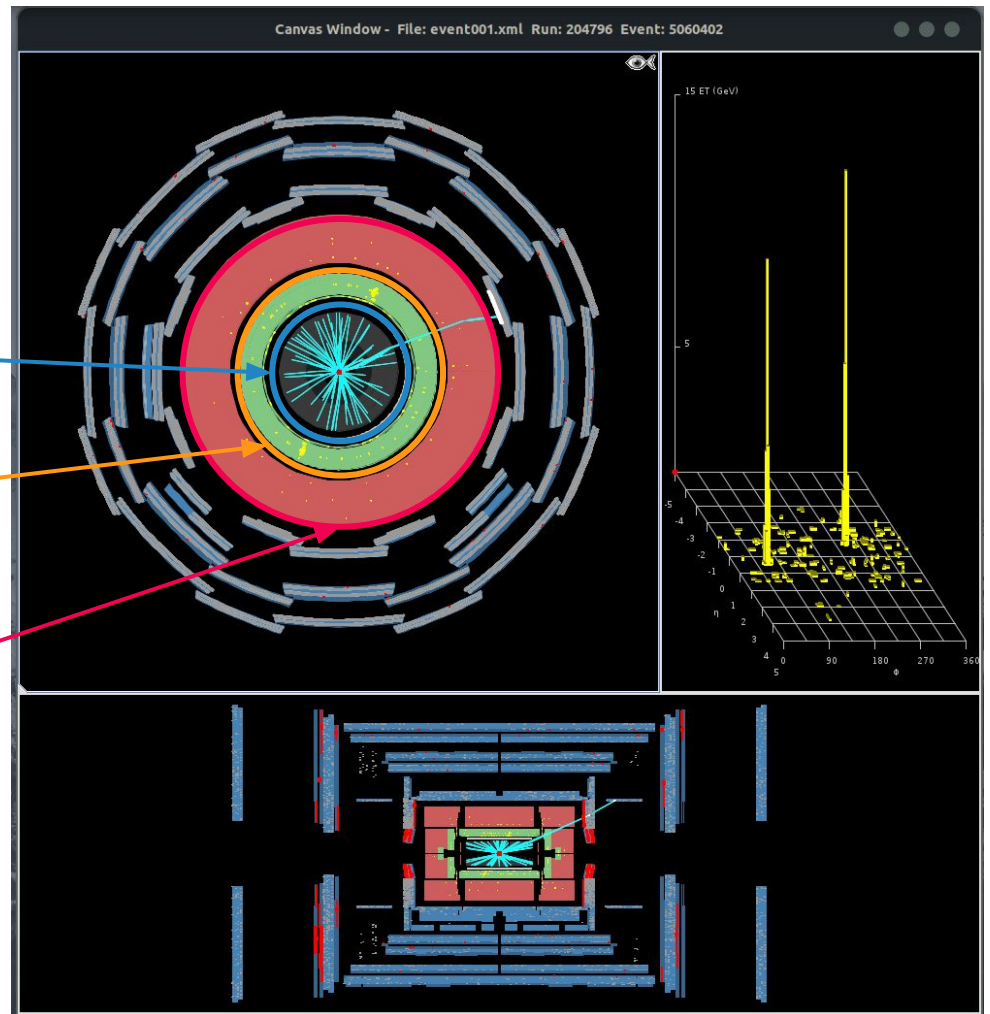
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Hadronic calorimeter: energies of hadrons (i.e. particles that are made of quarks and gluons), and of quark and gluon 'jets'



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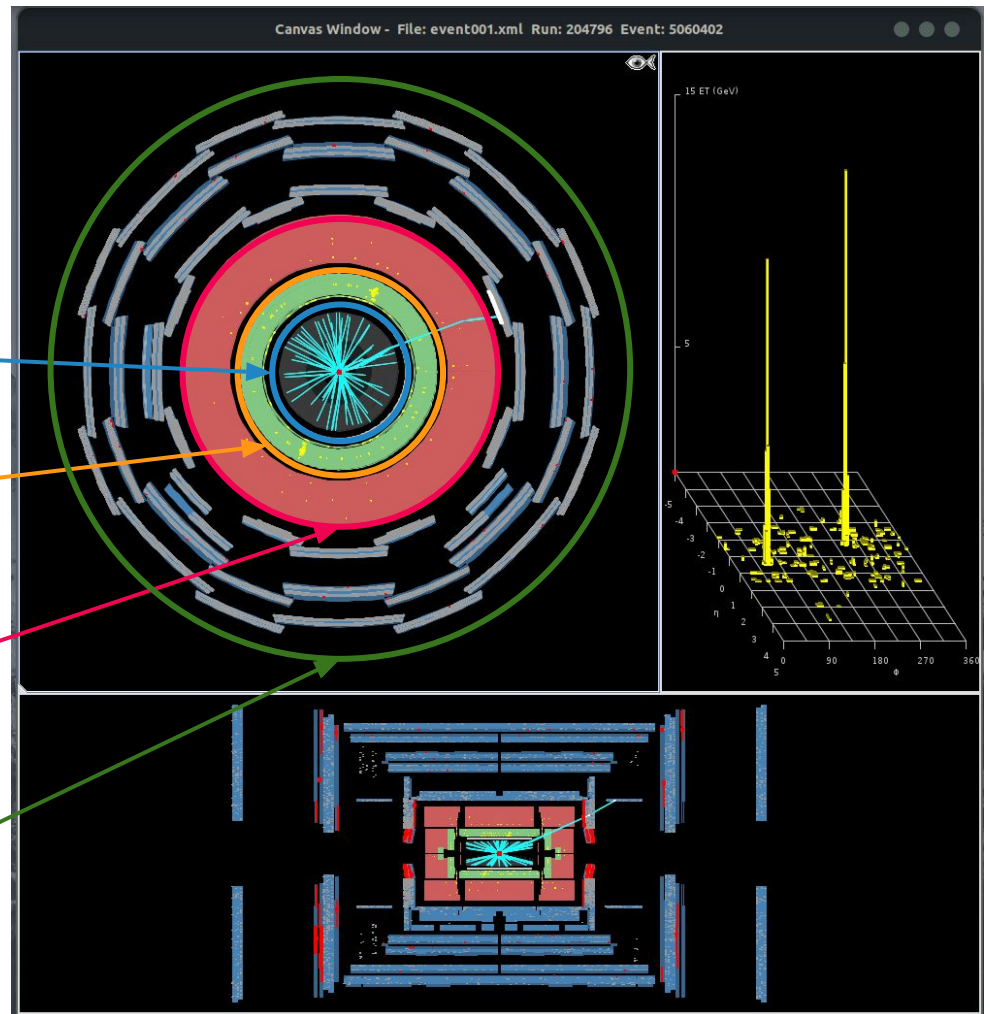
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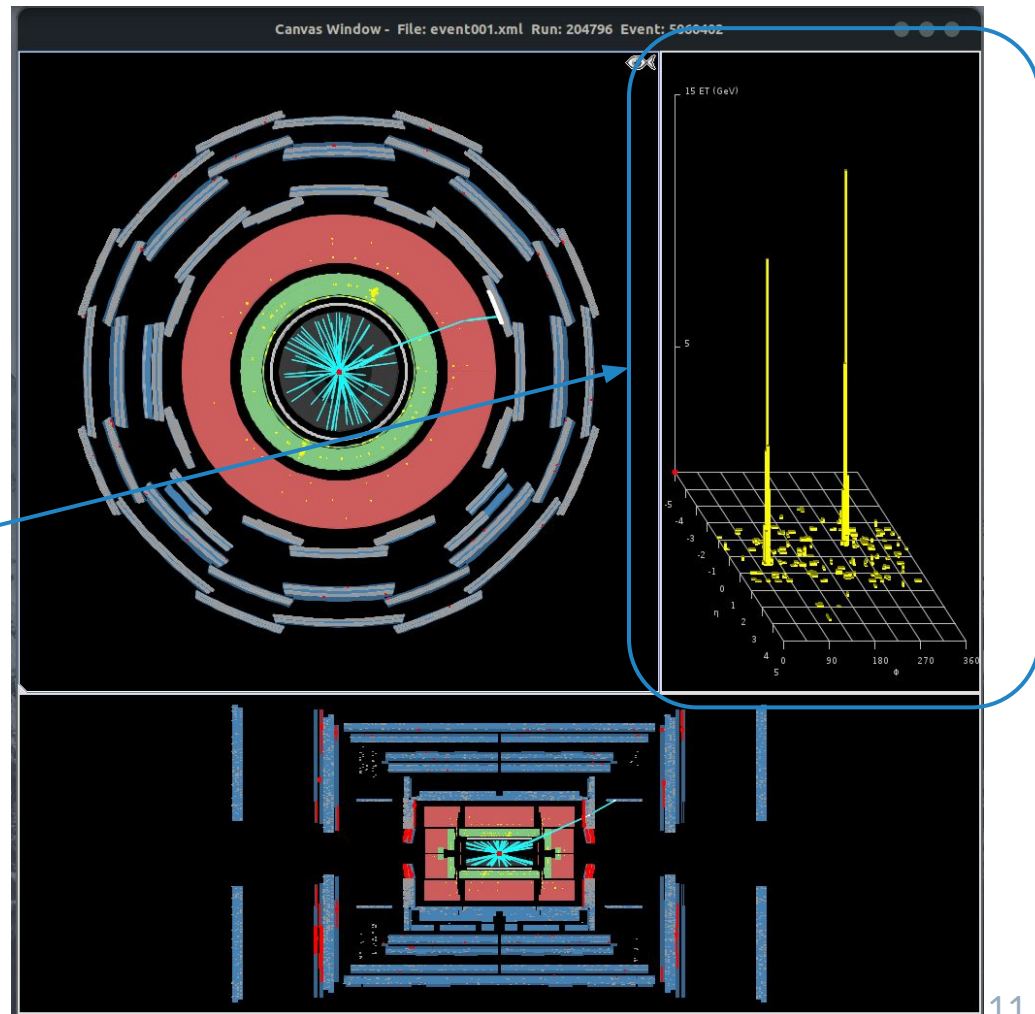
Hadronic calorimeter: energies of hadrons (i.e. particles that are made of quarks and gluons), and of quark and gluon 'jets'

Muon spectrometer: measures passages of muons



Main Detector

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- This window shows where energy deposits occurred in the calorimeter.



Particle Measurements

- This is a complete list of tracks and physics objects that were recorded in the event.

We will use this interface to identify tracks/physics objects with electrons, muons and photons.

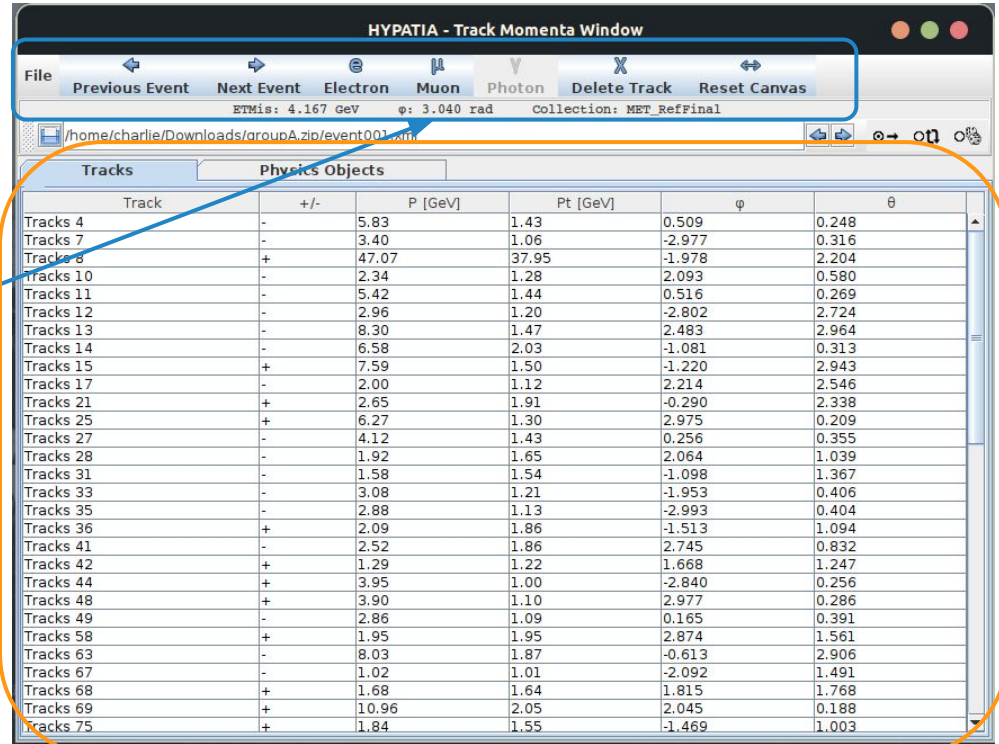
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We will use this interface to identify tracks/physics objects with electrons, muons and photons.

This is the full list of tracks and physics objects. There are a lot of tracks, do we need all of these tracks? How do we determine which tracks to keep?



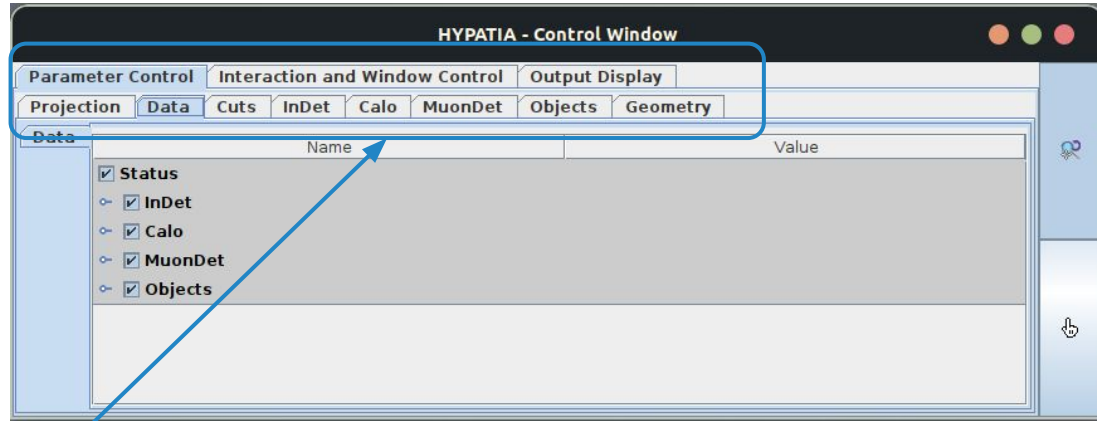
The screenshot shows the HYPATIA - Track Momenta Window interface. The window title is "HYPATIA - Track Momenta Window". The menu bar includes "File", "Previous Event", "Next Event", "Electron", "Muon", "Photon", "Delete Track", and "Reset Canvas". The status bar shows "ETMis: 4.167 GeV", "φ: 3.040 rad", and "Collection: MET_RefFinal". The main content area is divided into two tabs: "Tracks" and "Physics Objects". The "Tracks" tab is active, displaying a table with the following columns: Track, +/-, P [GeV], Pt [GeV], φ, and θ. The table contains 28 rows of data, with track numbers ranging from 4 to 75.

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Control Window

- This window is where we will control which cuts we will apply to our tracks to determine which tracks we will keep for our analysis.

There are many different cuts that you can use to control your analysis. But for our purposes, we will mainly use the “Cuts” tab to select physics objects.



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The cuts tab allows you to enter different requirements for your physics objects, we will use this (demo) to reduce the list of physics objects.

The screenshot shows the HYPATIA - Control Window interface. The 'Cuts' tab is selected, displaying a table of physics objects and their values. An orange arrow points from the 'Cuts' tab label to the table.

Name	Value
<input checked="" type="checkbox"/> Pt	1.0 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
Layer	0
<input type="checkbox"/> Number Pixel Hits	2
<input type="checkbox"/> Number SCT Hits	7
<input type="checkbox"/> Number TRT Hits	15
<input type="checkbox"/> Sim. Particle PDG-ID	40
<input type="checkbox"/> Sim. Particle Barcode	0
<input type="checkbox"/> Sim. Particle Type	charged hadron
<input type="checkbox"/> SimVertex	0
SCT/Pixel	All
TRT_DriftCircle	All
<input type="checkbox"/> η module	0
<input type="checkbox"/> Φ module	0
<input type="checkbox"/> Track Index	0
Hits By SimTrack	All
Hits By RecTrack	All
Hits By Segment	All
Hit Type	All
<input type="checkbox"/> Group	0
<input type="checkbox"/> TRT Threshold	high
<input type="checkbox"/> TRT Noise Cut	
<input type="checkbox"/> TRT Time Over Threshold	20.0
<input type="checkbox"/> Author	1
<input checked="" type="checkbox"/> RVx tracks	3
<input type="checkbox"/> RVx primary only	1

Invariant Mass

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
event001.xml	4.167	Tracks 173	36.6	-	32.6	1.132	0.491	122.275				e
		Tracks 239	827.4	+	311.6	0.983	1.632					e

- When we begin to assign tracks to particles, we will see them being populated in the invariant mass window.

Here, as an example, I've added two tracks which I've assigned to be electrons. HYPATIA then calculates the invariant mass of those two tracks.

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event002.xml	32.423	Tracks 3	52.6	-	11.5	1.483	2.204	25.782		104.969		m
		Tracks 12	10.6	+	10.2	0.533	0.300					m
		Tracks 65	9.2	-	8.3	-3.043	0.470	40.364				e
		Tracks 214	45.0	+	37.7	-0.144	-0.612					e

- As I go through more events and label tracks, the list begins to grow.

For the second event, I've added four tracks with 2 muons and 2 electrons.

Invariant Mass

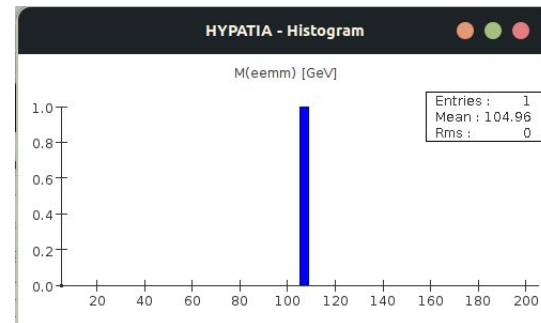
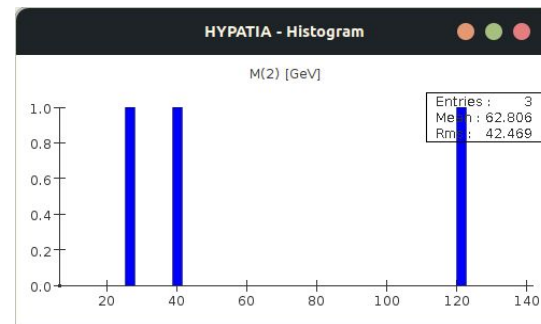
Hybrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window

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
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Histograms Preferences

- M(1) Histogram
- M(2) Histogram
- M(III) Histogram
- M(ee) Histogram
- M(mm) Histogram
- M(gg) Histogram
- M(eeee) Histogram
- M(eemm) Histogram
- M(mmmm) Histogram
- ETMis Histogram
- P Histogram
- Pt Histogram
- φ Histogram
- cot θ Histogram
- η Histogram

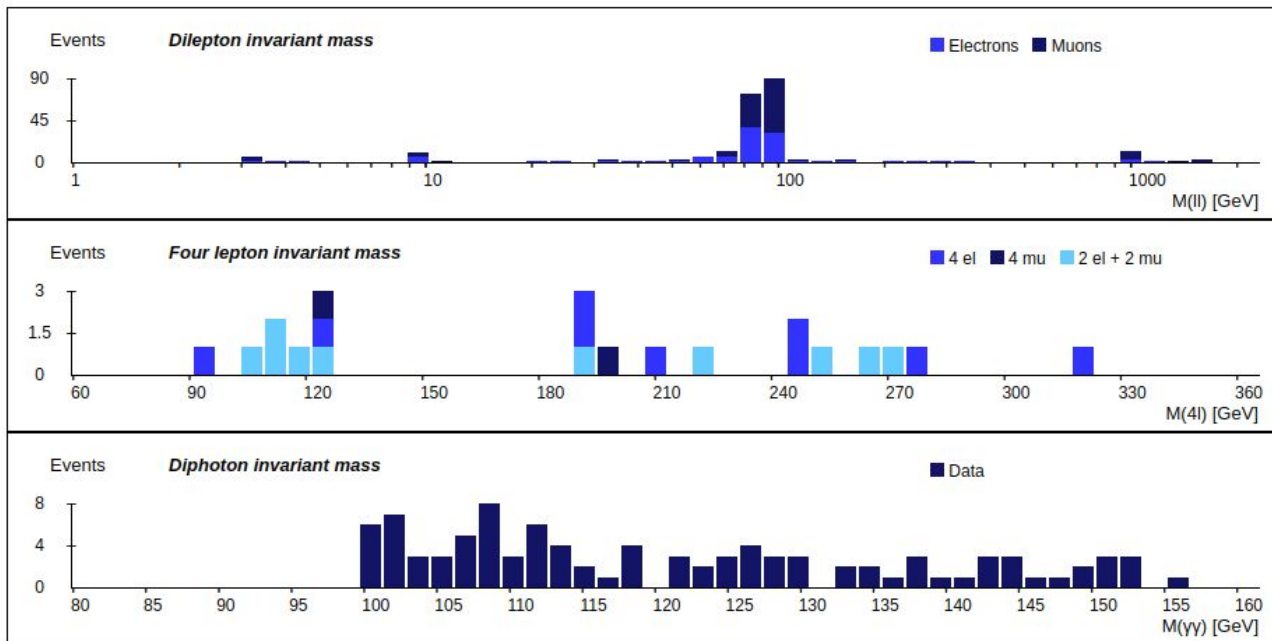
- After we've completed assigning tracks in all of the events, then HYPATIA will automatically plot histograms of the different invariant mass quantities.



More Data = Better Results

- As good scientists, we know that when we collect **more data** we get **better results**. At the end of the session we will compile everyone's data into a single histogram and see if we've accomplished our goal of finding a new particle!

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Plot type:

Dilepton statistics

Region	Electrons			
	R1	R2	R3	R4
Events	6	9	67	4
Mean	3.20	10.11	89.77	994.22
Width	0.54	1.09	3.95	30.21

Region	Muons			
	R1	R2	R3	R4
Events	4	5	93	8
Mean	3.05	9.54	90.43	1,013.91
Width	0.08	0.52	3.20	28.34

Number of events

	Student distribution	Expected
ll	270	585
4l	25	40
γγ	98	270
Sum	393	895