

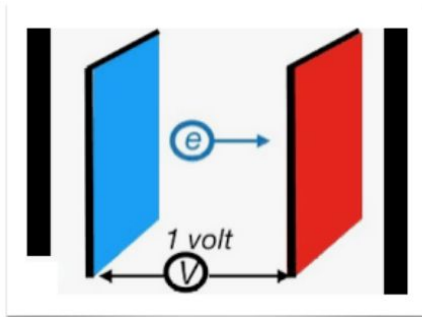
# ATLAS MASTERCLASS

- Data Analysis techniques -

Angira Rastogi  
April 27, 2024

# UNITS: "ELECTRON VOLT"

- At LHC, all particles are moving at speeds very close to light ( $0.999999999c$ ).
  - $c = 3 \times 10^8$  m/s
- For our convenience, we rather talk in terms of energy of particles.
- Common unit of Energy: Joules.
  - But, we use a different metric of energy: "electron-Volt" or "eV".



**1 'electron Volt' or 1 eV:**

Energy gained by an electron accelerated by an electrical potential of one Volt.

$$1 \text{ eV} = 1.6 \cdot 10^{-19} \text{ J}$$

$$1 \text{ KeV} = 1000 \text{ eV}$$

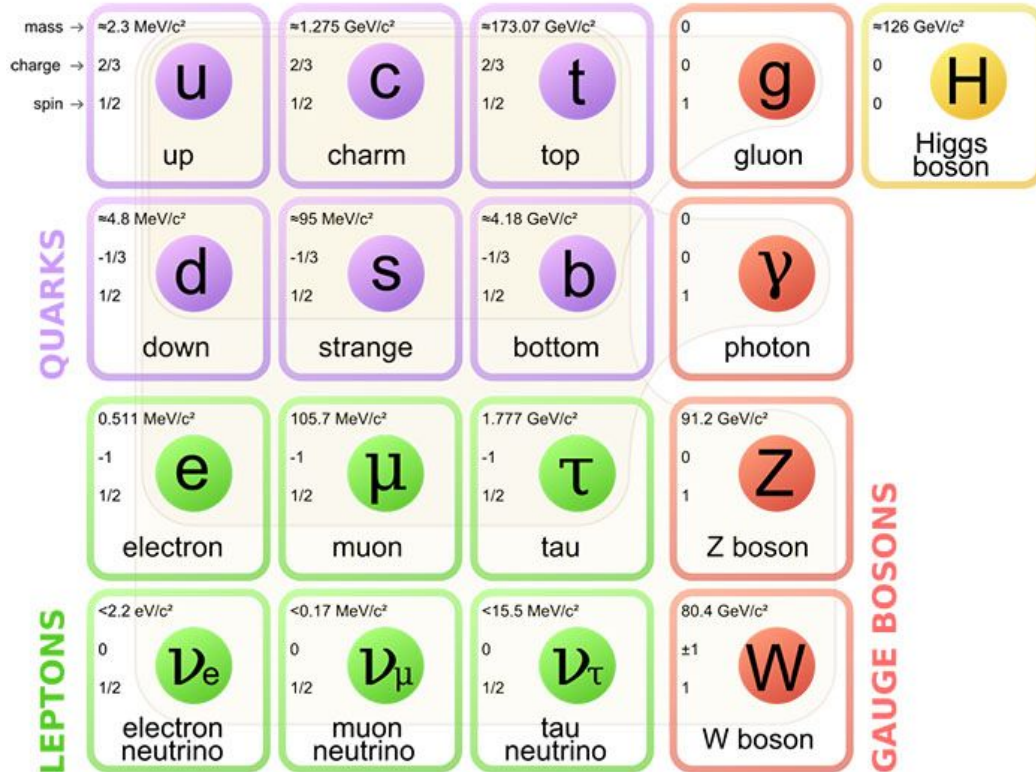
$$1 \text{ MeV} = 1000 \text{ KeV}$$

$$1 \text{ GeV} = 1000 \text{ MeV}$$

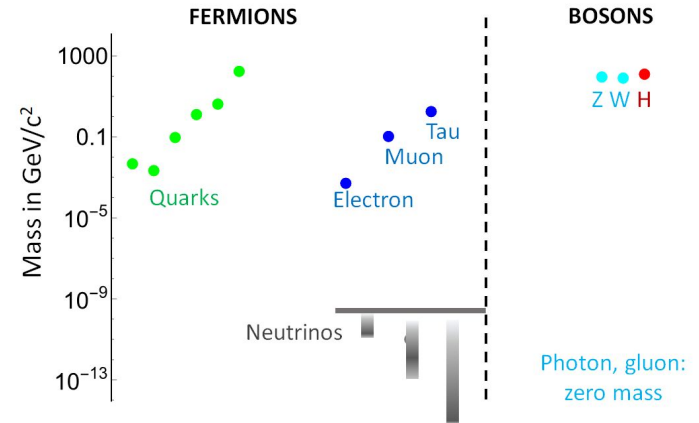
$$1 \text{ TeV} = 1000 \text{ GeV}$$

13 TeV = Center-of-mass energy of protons in LHC collisions!!

# STANDARD MODEL



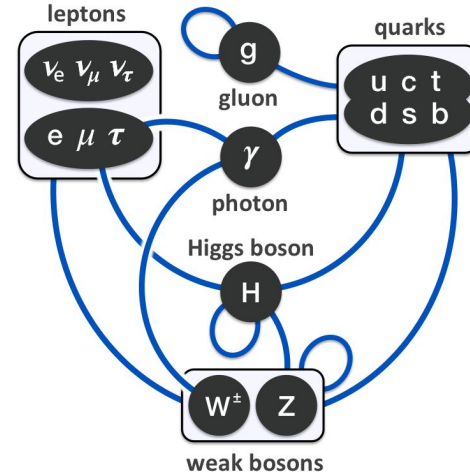
Scale of elementary particle masses



# STANDARD MODEL

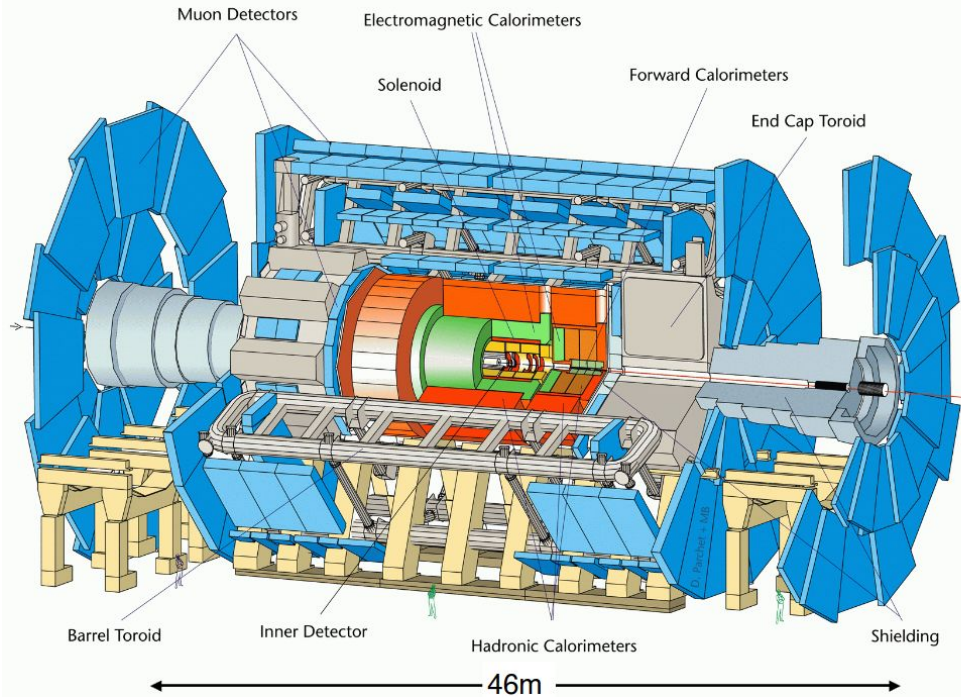
- Various fundamental particles.
- Unstable particles (e.g. bosons)  $\rightarrow$  decay at the interaction vertex.
- Stable particles  $\rightarrow$  “final-state” detectable.
  - E.g. electrons, muons, photons, charged and neutral hadrons.

What interacts with  
what?  $\longrightarrow$



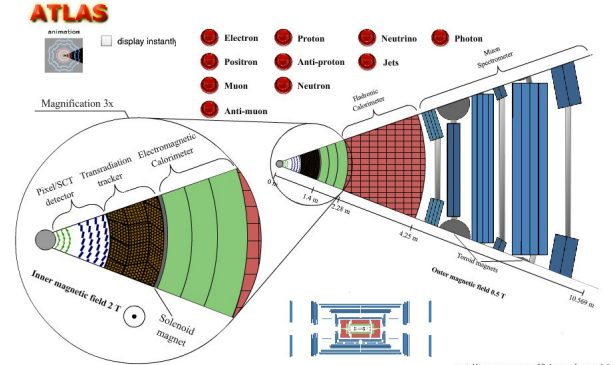
# TOOLS OF PARTICLE PHYSICS

# ATLAS DETECTOR



Longitudinal view

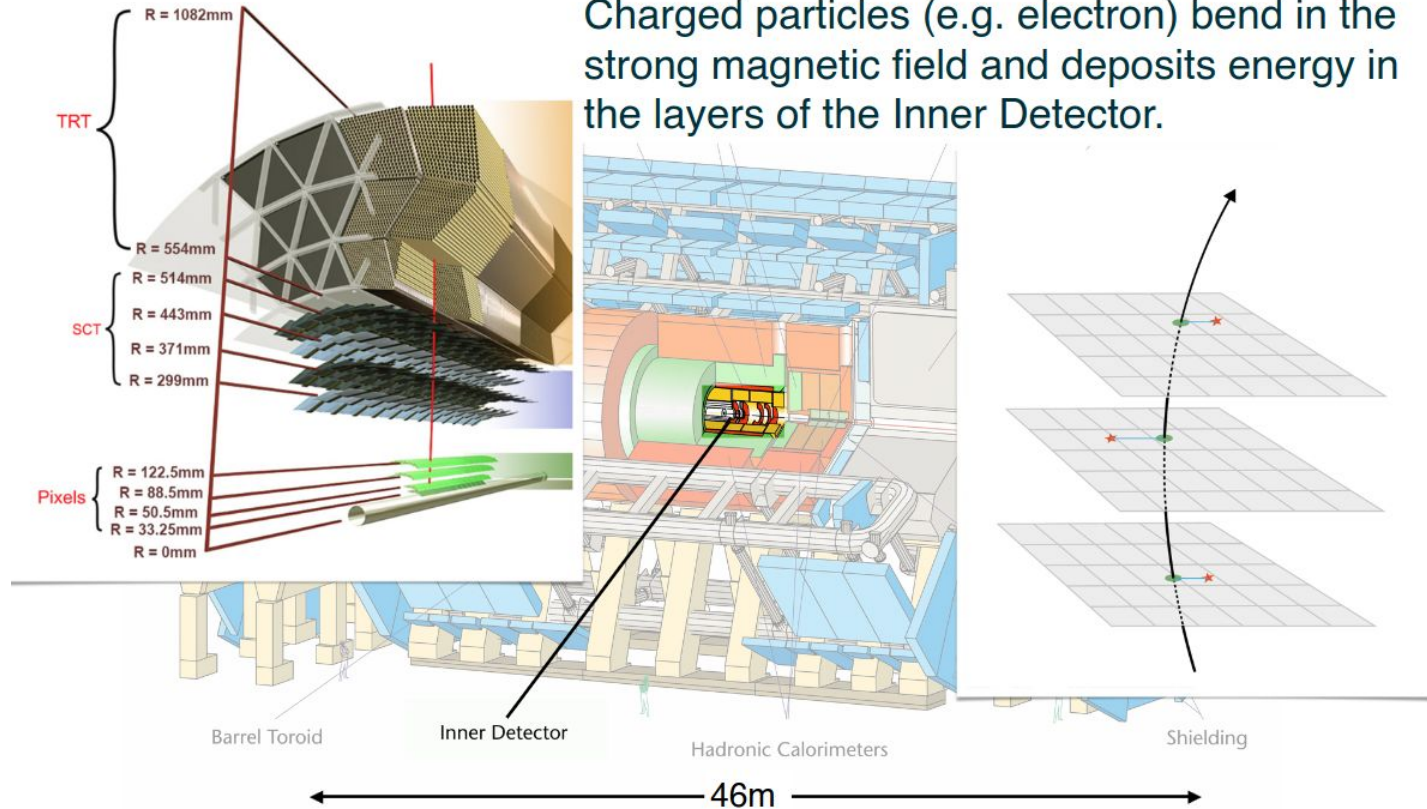
25m



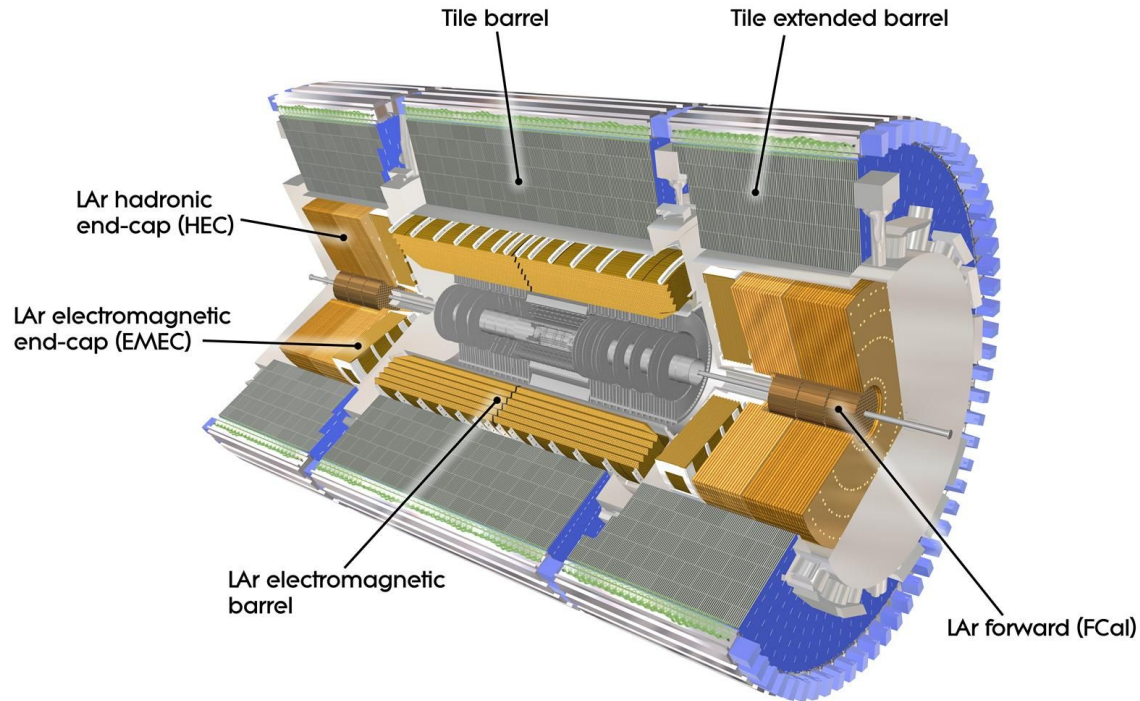
Transverse view

Like a giant camera taking snapshots of the collisions at interaction vertex.

# INNER DETECTOR



# ELECTROMAGNETIC & HADRONIC CALORIMETER



## Electrons and photons:

- Leave energy-deposit in E-Cal
- Stop in E-Cal

Electron:

Leaves a track in Tracker

Photon:

Leaves **no** track in Tracker

## Protons and neutrons:

- Leave energy deposit in H-Cal (and possibly a little in E-Cal)
- Stop in H-Cal

Proton:

Leaves track in Tracker

Neutron:

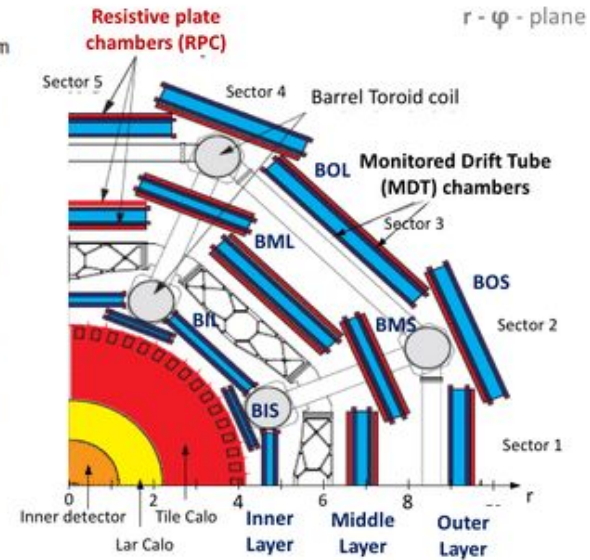
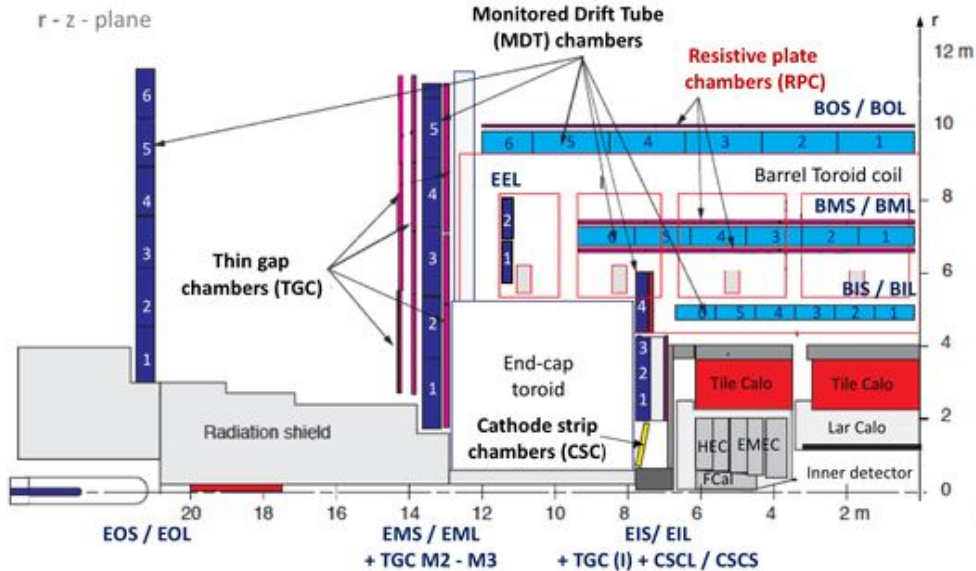
Leaves **no** track in Tracker



# MUON DETECTOR

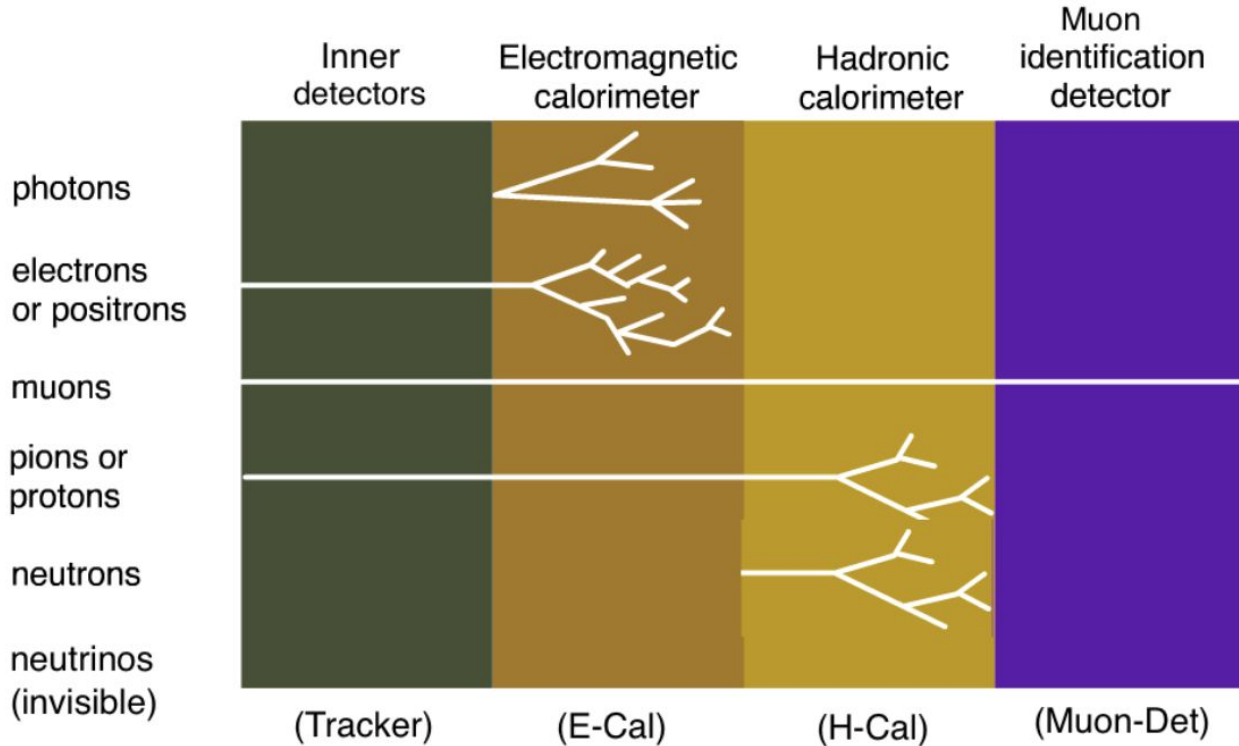
## Muons:

- Leave track in Tracker
- Reach all the way out to the MuonDet
- Leave little energy deposit in E-Cal and H-Cal



# PARTICLE SIGNATURE IN THE DETECTOR

(For a typical detector layout)

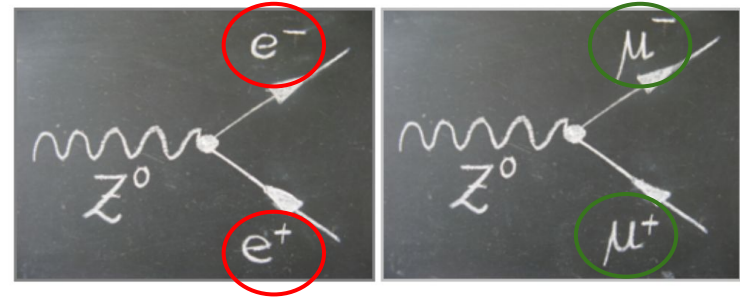


Q- Why invisible?

# TODAY'S EXERCISES

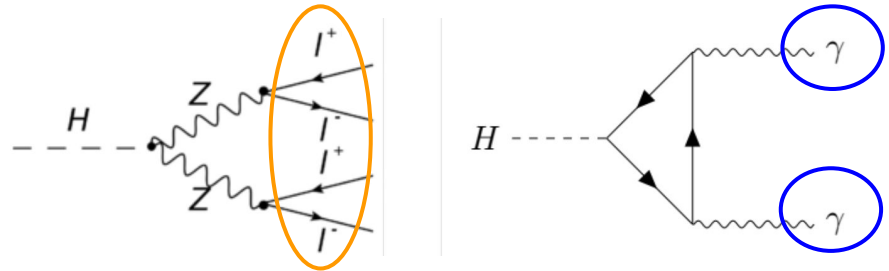
## Search for Z-boson

- Via electrons
- Via muons



## Search for higgs-boson

- Via two Z-boson decays (i.e. 4 leptons)
- Via photons



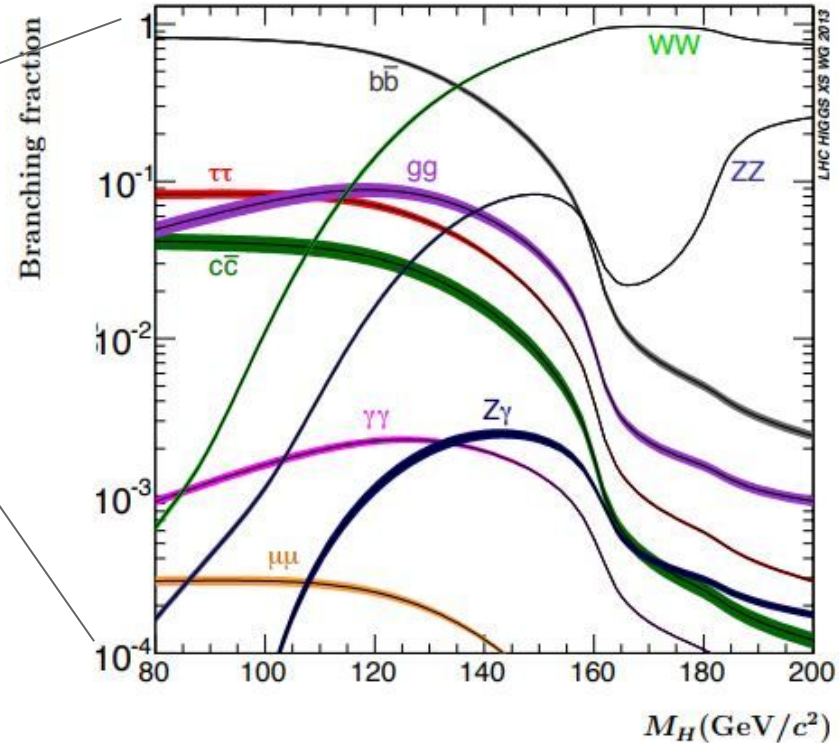
# "BRANCHING RATIO" PLOT OF HIGGS

All possible ways in which higgs boson can decay

Q - What is the most probable decay mode?

Q - What is the least probable mode? Why?

Q - Why are we detecting only higgs decays to ZZ and  $\Upsilon\Upsilon$  today?



# RECONSTRUCTING THE MASS

- The ATLAS detector measures the **momentum (energy) of final particles only e.g. electrons, muons, charged hadrons (photons, neutral hadrons)**.

Particle 1:  $(P_{x_1}, P_{y_1}, P_{z_1}, E_1)$

Particle 2:  $(P_{x_2}, P_{y_2}, P_{z_2}, E_2)$

...

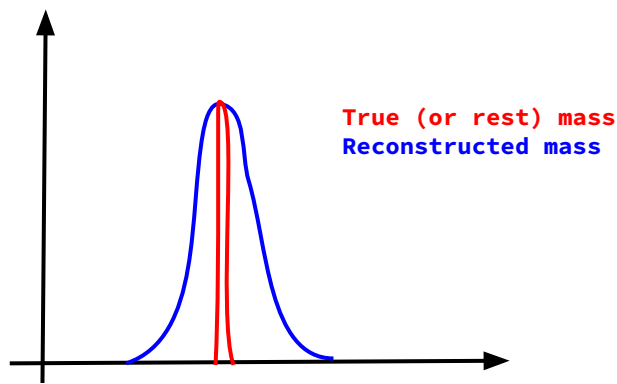
- Using these “4-momenta” of final-state particles, we can **reconstruct the invariant mass of the initial-state particle** i.e. Z-boson or higgs.

$$M = \text{sqrt}[(E_2 - E_1)^2 - (P_{x_2} - P_{x_1})^2 - (P_{y_2} - P_{y_1})^2 - (P_{z_2} - P_{z_1})^2]$$

- Invariant mass may or may not be equal to the rest mass of the particle.

# RECONSTRUCTING THE MASS

- However, due to the detector resolution (how precisely it can measure the four-momenta of various physics objects) and also the “real-ness” of the initial propagator particle, the reconstructed mass will be smeared around the true mass.
  - Mass distribution will appear as a bell curve.



# HYPATIA SOFTWARE



## (HYBRID PUPIL'S ANALYSIS TOOL FOR INTERACTIONS IN ATLAS)

- Event display tool to visualize collision events, both data and simulation.
- Gives a very realistic image of the interaction between each proton bunch crossing (an event) at the vertex.
- Detector activity shown is post-reconstruction i.e. after digitizing the electrical signals and classifying them into various physics objects (tracks and calo deposits).

HYPATIA  
(LAUNCHING THE SOFTWARE)



# THE GUI

## Four tabs

Invariant mass window  
Event display window

Tracks/objects window  
Control window

The screenshot displays the HYBRID Pupils' Analysis Tool interface. The main window is titled "Invariant Mass Window" and contains a menu bar (File, View, Histograms, Preferences, Help) and a toolbar with various analysis options. The interface is divided into four main panels:

- Top Left:** A circular detector layout visualization with concentric rings in blue, red, and green, and a central black region.
- Bottom Left:** A 3D grid visualization of the detector geometry, showing a grid of points in a 3D coordinate system.
- Top Right:** The "Tracks/objects window" displaying a table of physics objects. The table has columns for Track, +/-, P [GeV], Pt [GeV], and  $\eta$ . The data is as follows:

Track	+/-	P [GeV]	Pt [GeV]	$\eta$
Tracks 0	-	11.68	4.28	-1.119
Tracks 1	+	126.06	39.41	-2.413
Tracks 2	+	4.57	4.56	-2.783
Tracks 3	+	167.90	53.01	0.906
Tracks 4	-	3.34	1.33	-2.949
Tracks 5	-	1.75	1.74	-3.090
Tracks 6	+	18.61	3.94	-1.818
- Bottom Right:** The "Control window" titled "HYPATIA - Control Window" with tabs for Parameter Control, Interaction and Window Control, and Output Display. It includes sub-tabs for Projection, Data, Cuts, InDet, Calo, MuonDet, Objects, and Geometry. A table with columns "Name" and "Value" is visible, containing checked items: Status, InDet, Calo, MuonDet, and Objects.

# HYPATIA SOFTWARE (LOADING THE DATASET)

Datasets are downloaded and can be found inside “events” folder of the Hypatia software.

# HYPATIA - Track Momenta Window

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/jiveXML\_106051\_1950731.xml

Tracks

Physics Objects

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

**HYPATIA - Track Momenta Window**

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

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					
Tracks 3					
Tracks 4					
Tracks 5					
Tracks 6					

**Open**

Look In: events

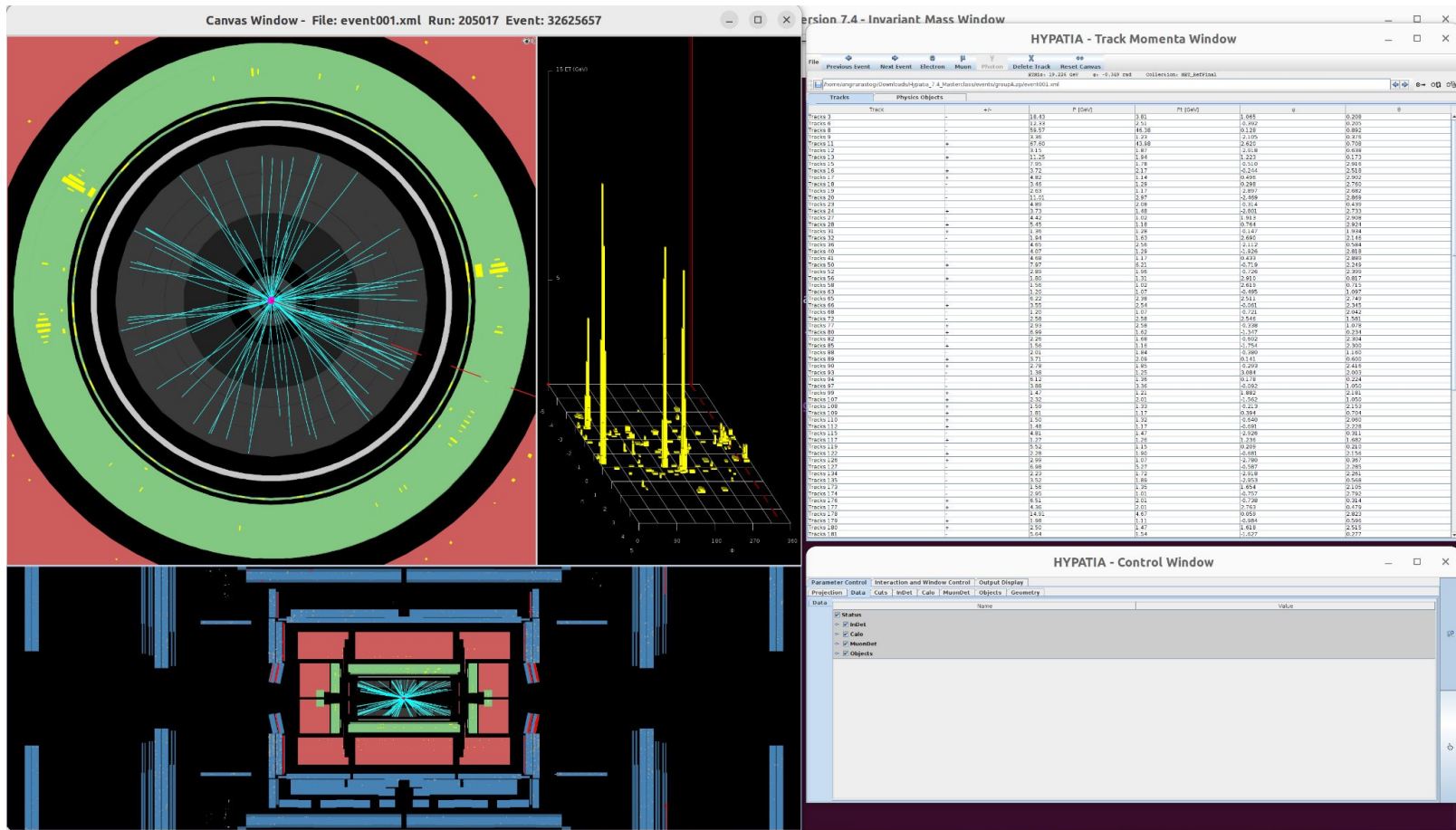
- events4.zip
- groupA.zip
- groupE.zip

default location

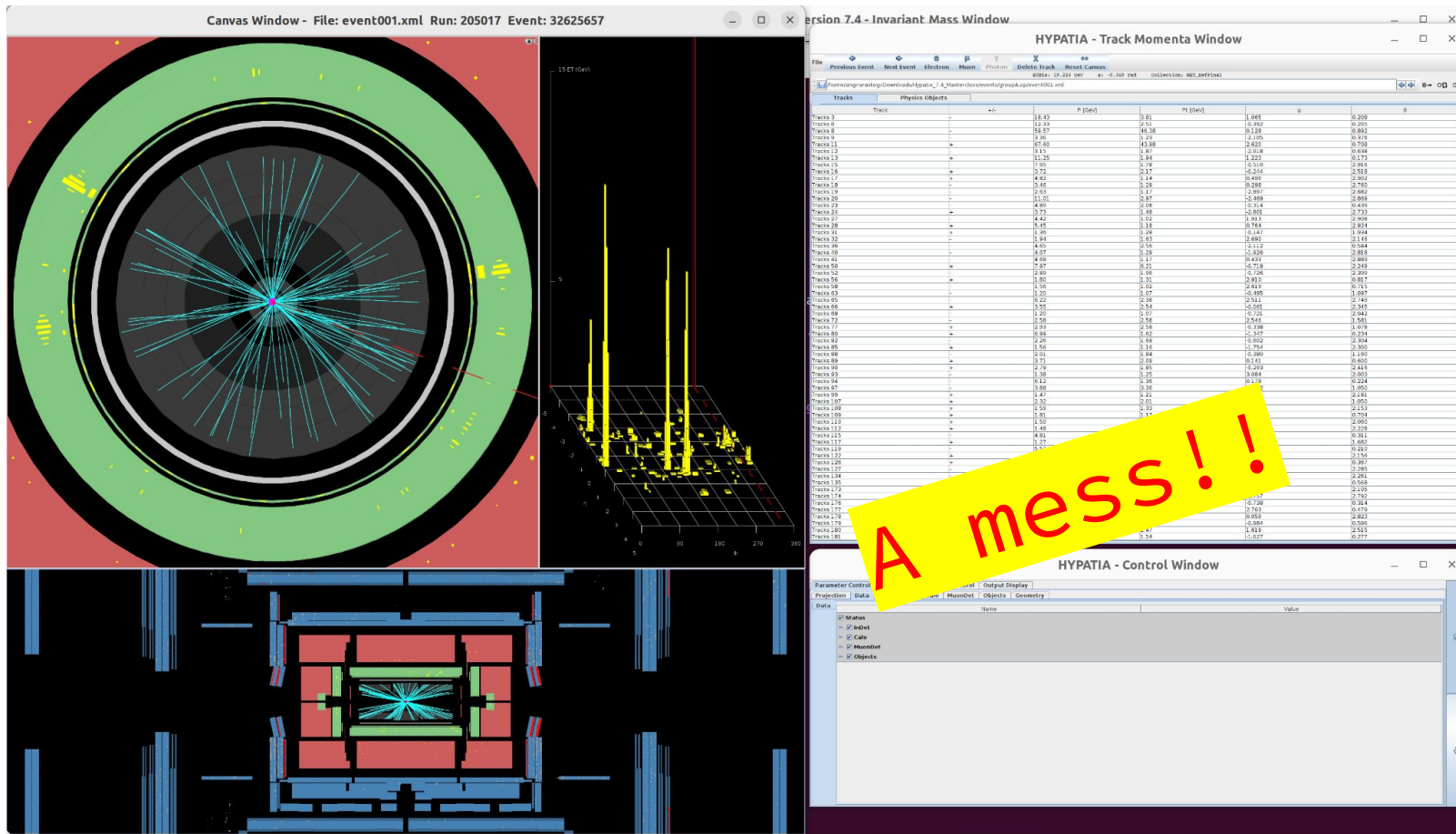
File Name:

Files of Type: .xml, .zip, .gzip, .gz

# WHAT WILL YOU SEE?



# WHAT WILL YOU SEE?



# HYPATIA SOFTWARE (ADDING CUTS)

# DEFAULT SELECTIONS

**HYPATIA - Control Window**

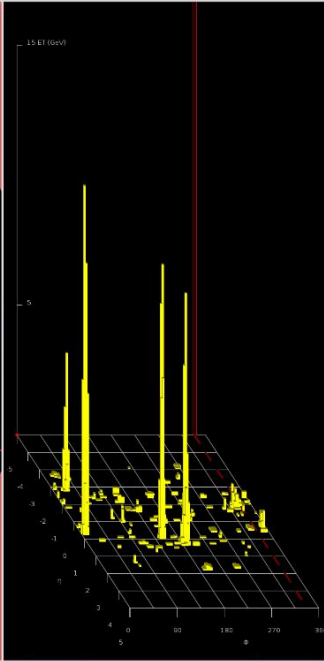
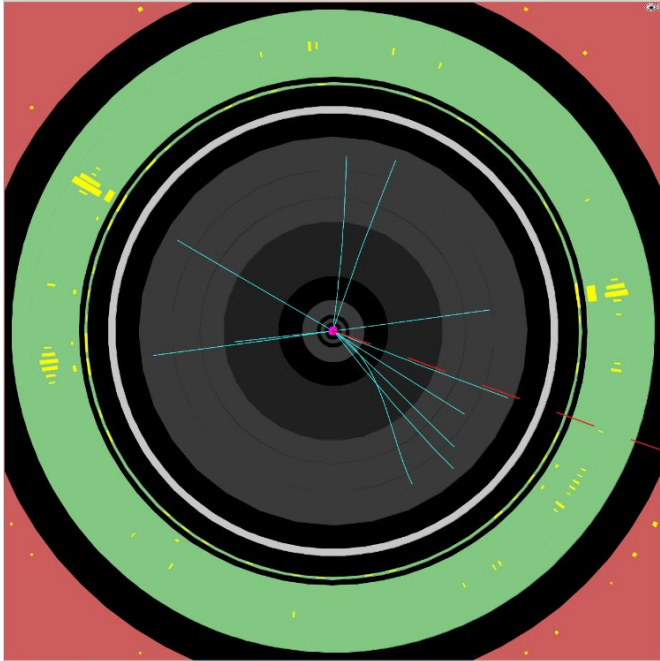
The screenshot shows the HYPATIA Control Window interface. The window title is "HYPATIA - Control Window". The interface is divided into several sections:

- Parameter Control:** Includes tabs for "Interaction and Window Control" and "Output Display".
- Projection:** Includes tabs for "Data", "Cuts", "InDet", "calo", "MuonDet", "Objects", and "Geometry".
- InDet:** A tree view on the left showing various detector components and their selection status (checked/unchecked).
- Value:** A table on the right showing the current values for the selected parameters.

Name	Value
Calo	> 1.0 GeV
MuonDet	< 700.0 MeV
Objects	< 2.5 mm
ATLAS	< 20.0 cm
Pt	< 2.0 cm
d0	< 2.5 mm
z0	> 0
d0 Loose	>= 2
z0-zVtx	>= 7
Layer	>= 15
Number Pixel Hits	< 40
Number SCT Hits	= 0
Number TRT Hits	charged hadron
Sim. Particle PDG-ID	= 0
Sim. Particle Barcode	All
Sim. Particle Type	All
SimVertex	All
SCT/Pixel	All
TRT_DriftCircle	All
η module	0
φ module	0
Track Index	0
Hits by SimTrack	All
Hits by RecTrack	All
Hits by Segment	All
HIT Type	All
Group	0
TRT Threshold	high
TRT Noise Cut	
TRT Time Over Threshold	> 20.0
Author	= 1
RVx tracks	>= 3
RVx primary only	>= 1

Try changing tracks  $|Pt|$  to 5 GeV or 10 GeV.  
Look at the highest  $p_T$  tracks first.





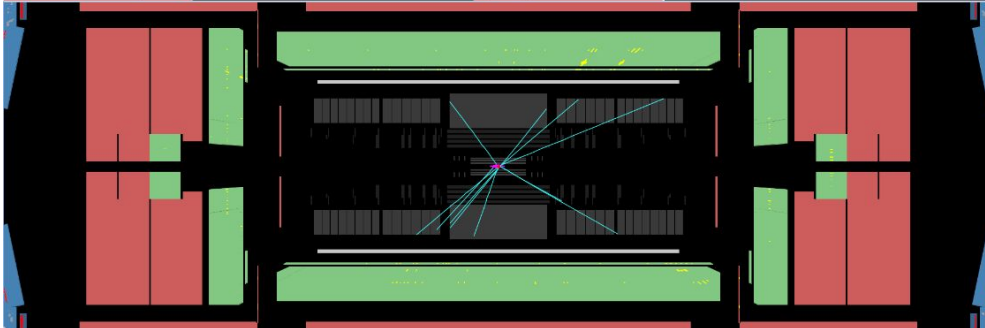
### HYPATIA - Track Momenta Window

File: Previous Event Next Event Electron Muon Photon Delete Track Reset Canvas  
 amis: 15.226 GeV pr: 0.340 rad callocsim: wpy adrenal

Download: /home/ingram/stog/Downloads/hypatia\_7\_4\_MatterClass/EventGroup/npavevent001.xml

Tracks	Physics Objects								
Track		z/	P (GeV)	P1 (GeV)					
Tracks 8			55.57	46.58	0.128		0.802		
Tracks 11			87.60	43.58	2.625		0.708		
Tracks 508	*		7.97	0.21	0.119		2.240		
Tracks 127	-		6.98	0.27	-0.587		2.285		
Tracks 180	*		80.18	40.58	2.591		0.525		
Tracks 227	-		80.71	36.58	-3.613		0.512		
Tracks 252			7.00	0.27	0.386		2.289		
Tracks 268			46.50	37.60	-0.374		1.609		
Tracks 288	*		13.38	0.28	1.203		0.200		
Tracks 308	*		6.93	0.26	1.443		2.210		
Tracks 309	-		0.50	0.00	-0.609		2.446		

Much better :) )



### HYPATIA - Control Window

Parameter Control | Interaction and Window Control | Output Display |

Projection: Data | Curs | InDet | Calo | MuonDet | Objects | Geometry

name	Value
InDet	
Calo	
MuonDet	
Objects	
ATLAS	
IP1	> 0.0 GeV
IP2	< 700.0 MeV
IP3	< 2.5 mm
IP4	< 20.5 cm
IP5	< 2.0 cm
IP6	< 2.5 mm
Layer	> 0
Number Pixel HES	>> 0
Number SCT HES	>> 7
Number ITT HES	>> 15
Sim. Particle PDG-ID	< 40
Sim. Particle Barcode	> 0
Sim. Particle Type	charged hadron
SimVertex	> 0
SCTInDet	All
ITT_DeclCircle	All
IP module	> 0
IP module	> 0
Track Index	> 0
HES By SimTrack	All
HES By RecTrack	All

# NOW WHAT?

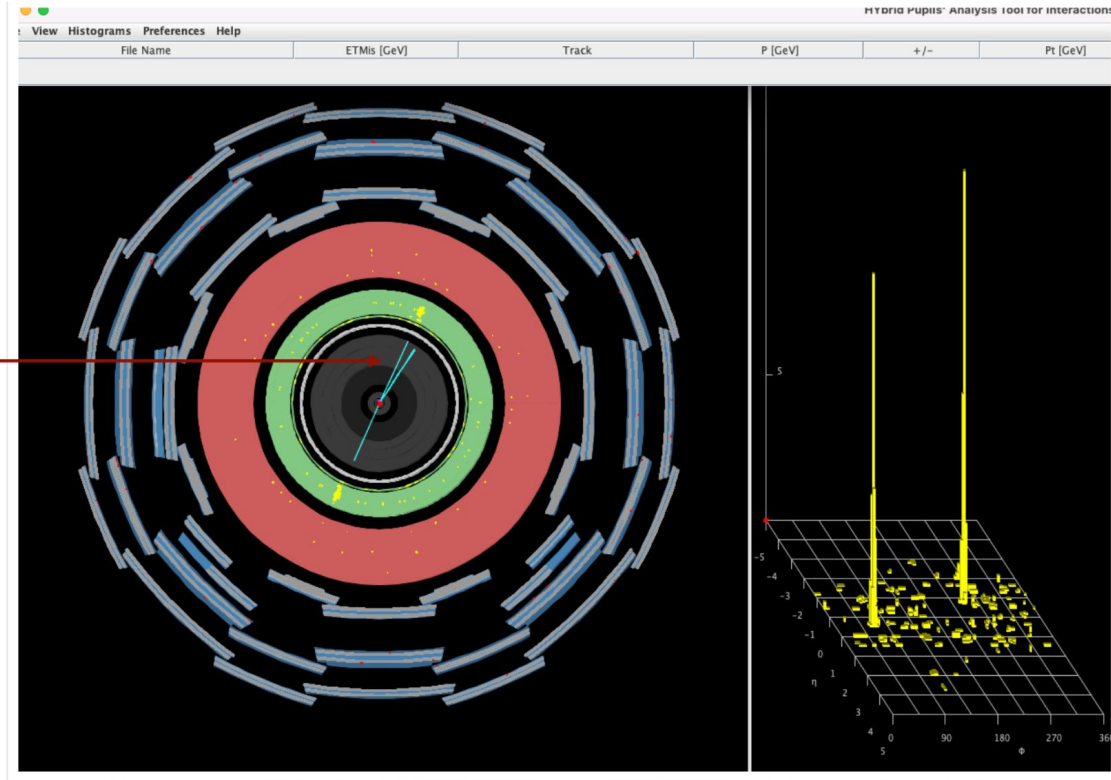


Time to find the interesting events.

How? Look for evidence of their decays!!

HYPATIA SOFTWARE  
(PARTICLE IDENTIFICATION)

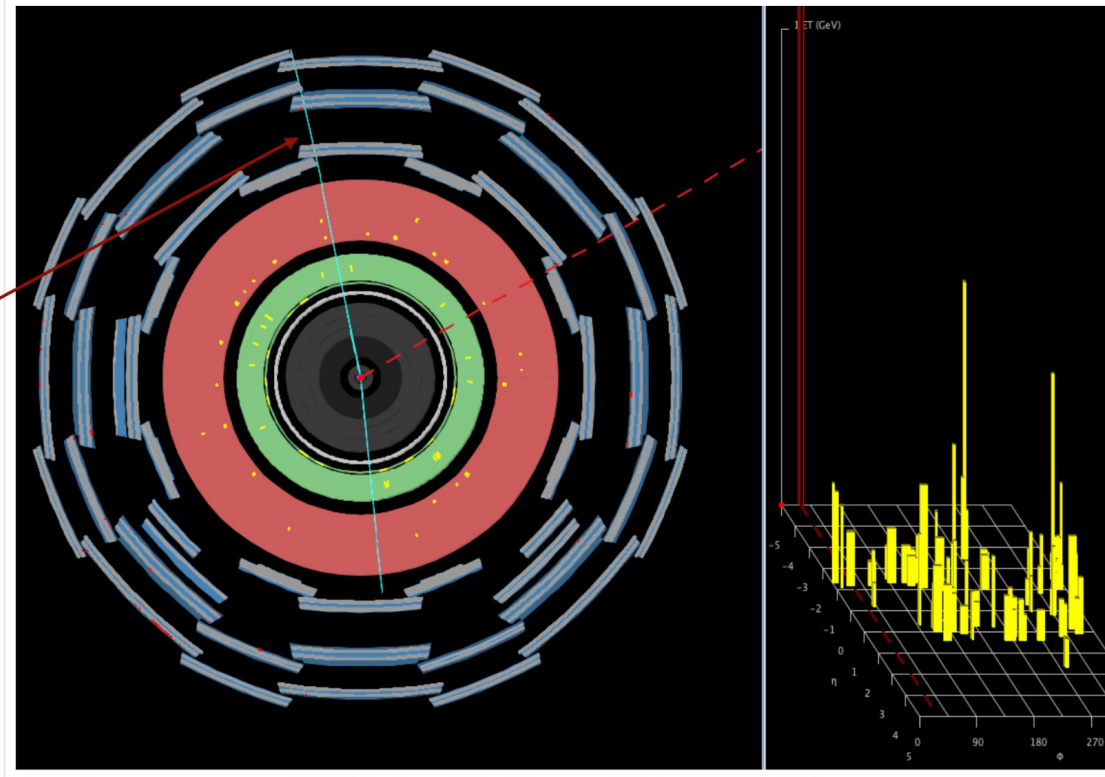
**Electron:**  
- ID track  
- Calo deposit



That's undoubtedly me!



**Muon:**  
- MS track

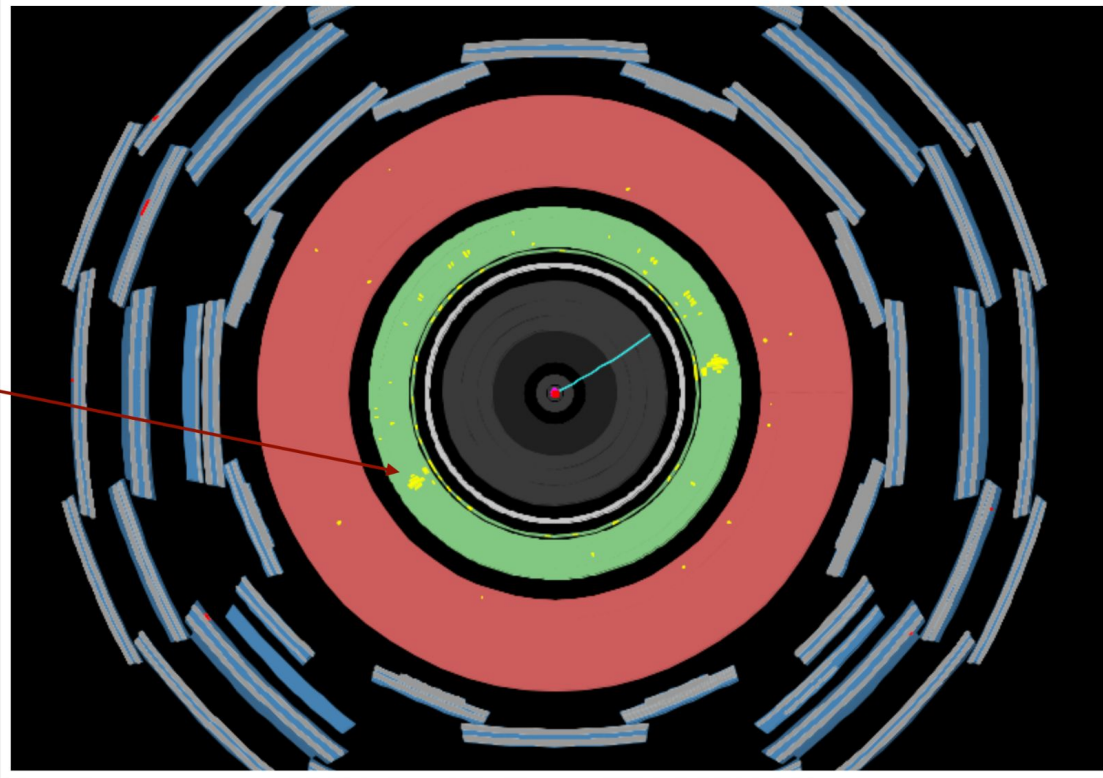




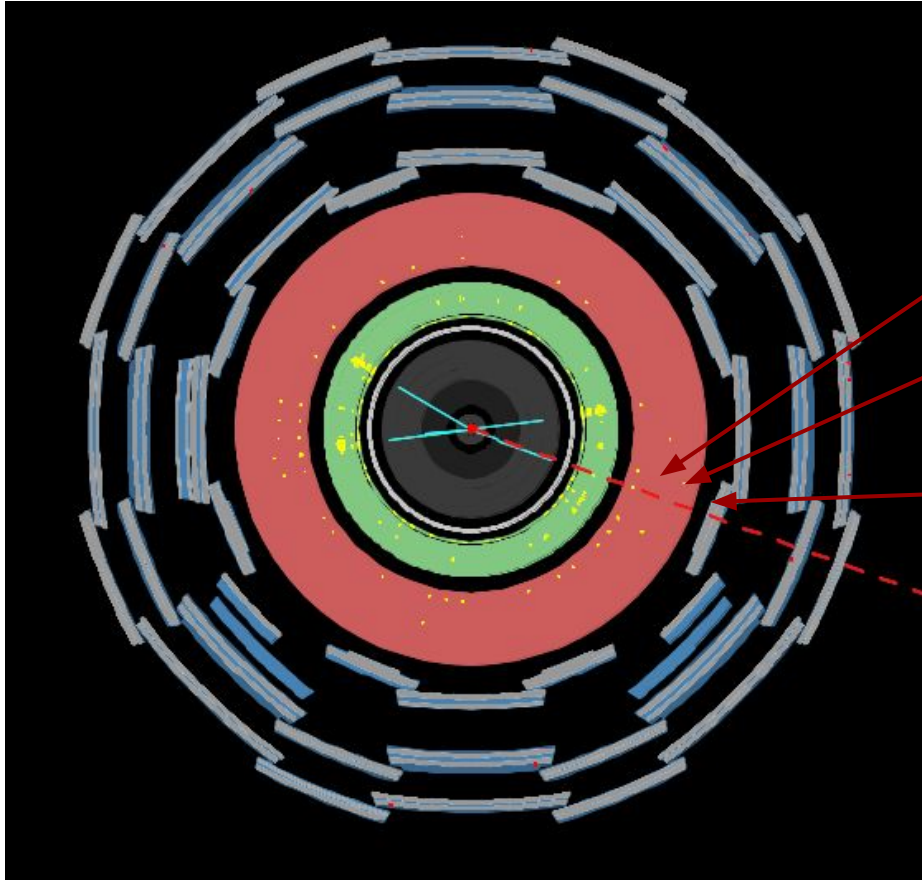
May not be that  
easy always!

**Photon:**

- Calo deposit
- No ID track



# Neutrinos



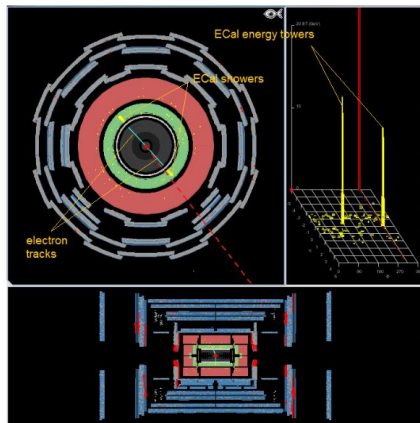
You can't see us, but you can infer our presence...

HYPATIA SOFTWARE  
(FROM PARTICLES TO EVENTS)

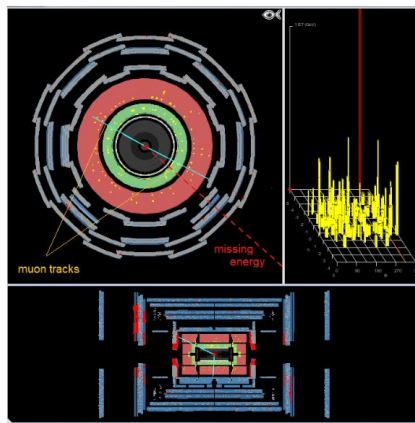


# COMMON SCENARIOS

- Two electrons opposite-sign ( $e^+e^-$ )
  - Two tracks pointing to two calo deposit.
- Two muons, opposite-sign ( $\mu^+\mu^-$ )
  - Two tracks going all the way up to muon detectors.



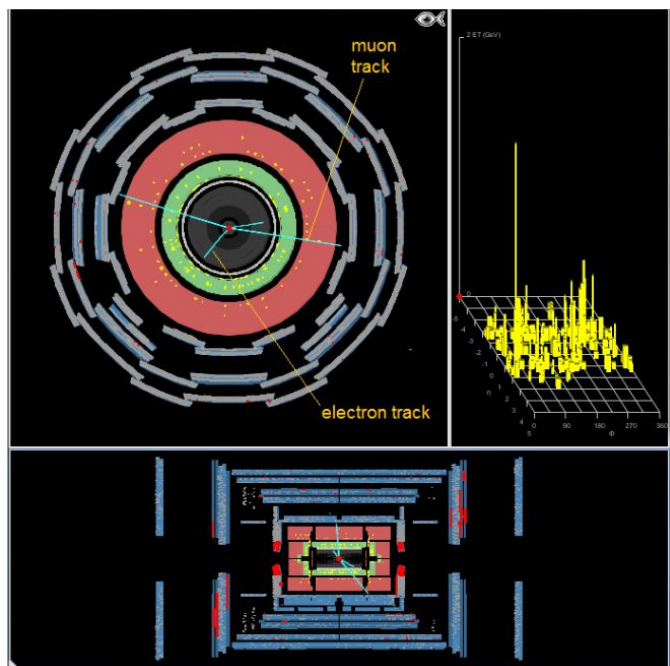
*Dielectron or  $e^+e^-$  event.*



*Dimuon or  $\mu^+\mu^-$  event.*

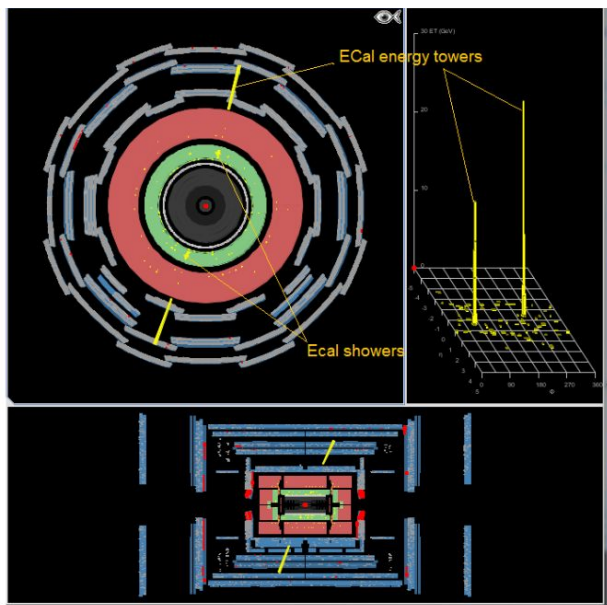
# COMMON SCENARIOS

- Four leptons ( $e^+e^-e^+e^-$ ,  $e^+e^-\mu^+\mu^-$ ,  $\mu^+\mu^-\mu^+\mu^-$ )



# COMMON SCENARIOS

- Two unconverted photons ( $\Upsilon\Upsilon$ )
  - Two calorimeter deposits without any associated tracks.



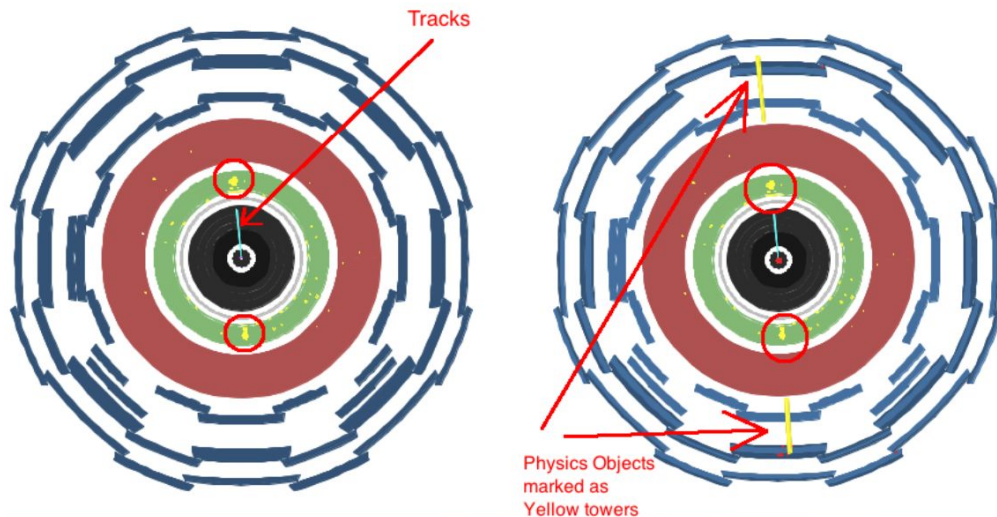
# WHAT'S HAPPENING HERE?

ETMis: 14.969 GeV     $\phi$ : -1.063 rad    Collection: MET\_Reffinal

\\aikerp\Desktop\Hypatia\_7-1-2\Hypatia\_7-1\group1\event008.xml

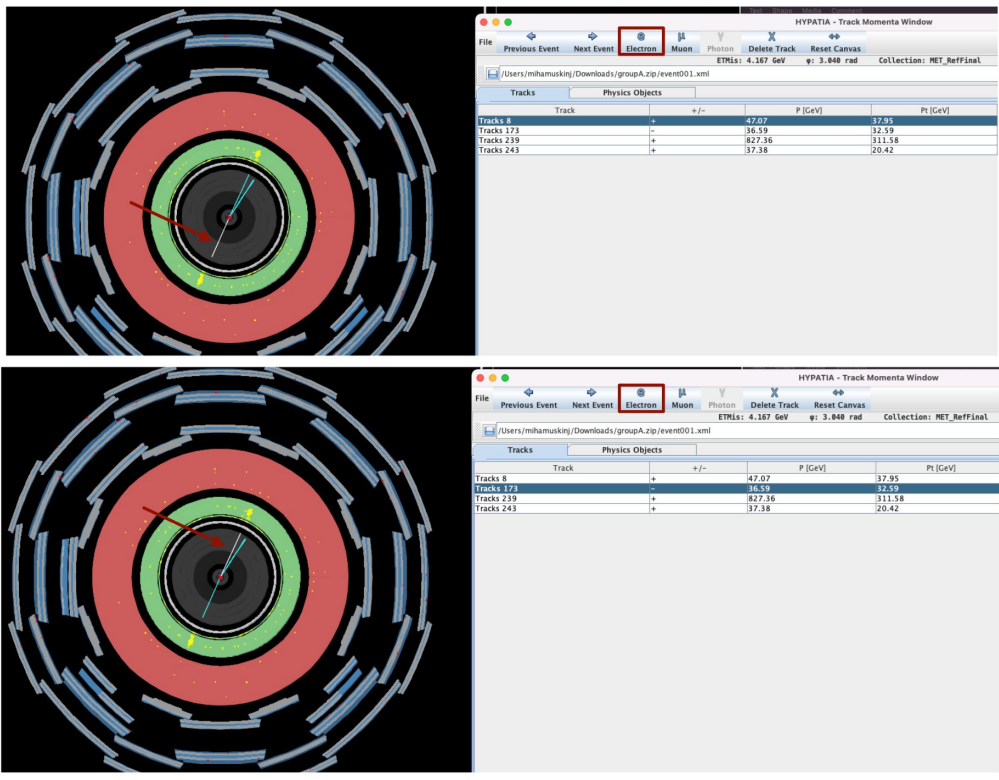
Tracks    **Physics Objects**

Track	P [GeV]	Pt [GeV]	$\phi$	$\theta$
Object 0	106.15	52.96	1.673	0.522
Object 1	53.31	41.32	-1.512	2.255



HYPATIA SOFTWARE  
(RECONSTRUCTING THE INVARIANT MASS)

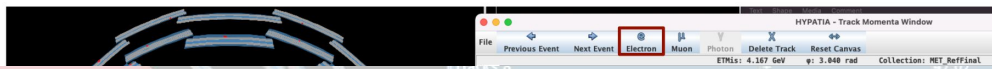
# EVENTS WITH 2-TRACKS



- Click on the track and see it on the event display tab
- If it looks like an electron (or muon), click on the electron (or muon) on the tab above.
- This will insert the objects in the invariant mass tab.
- **Make sure to select tracks with opposite charge but same type (electron or muon).**

Q- Why?

# CHECK THE RECONSTRUCTED INITIAL-STATE OBJECT

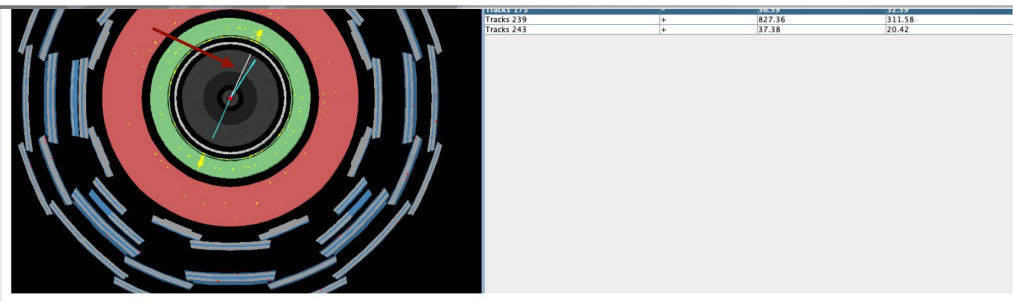


HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window

File View Histograms Preferences Help

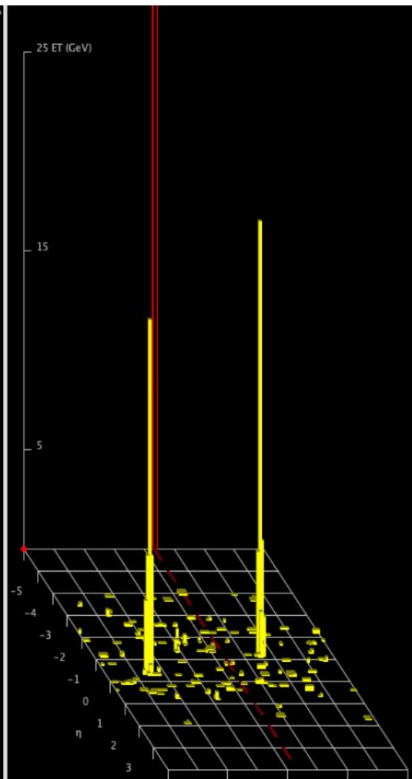
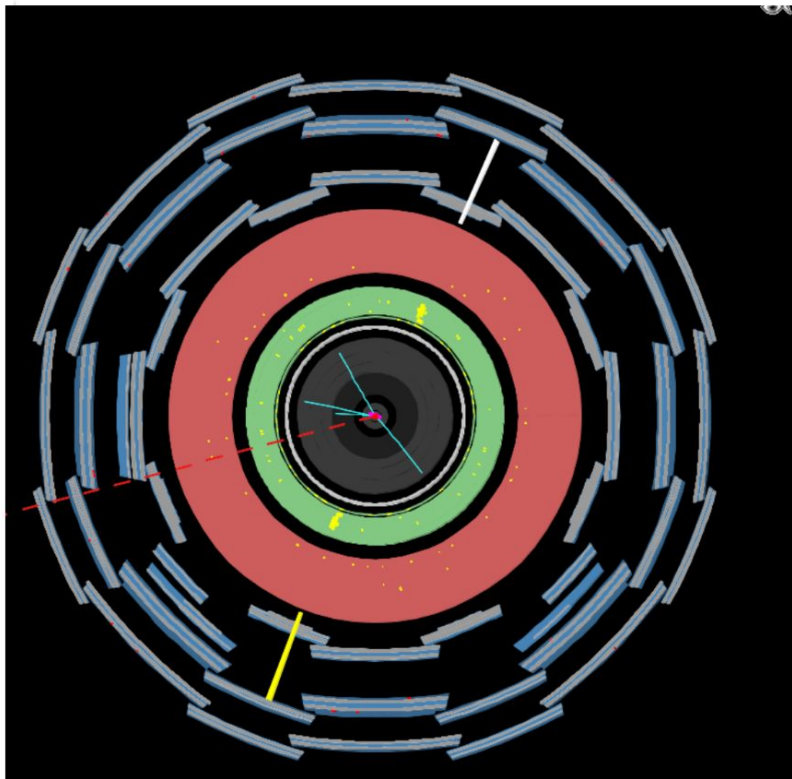
File Name	ETMis [GeV]	Track	P [GeV]	+...	Pt [GeV]	$\varphi$	$\eta$	M(2) [GeV]
event001.xml	4.167	Tracks 8	47.1	+	37.9	-1.978	-0.680	82.729
		Tracks 173	36.6	-	32.6	1.132	0.491	

Probably  $Z \rightarrow e^+ e^-$



# EVENTS WITH 2-CALO OBJECTS

Note: For photons, need to click on the “Physics objects” tab.



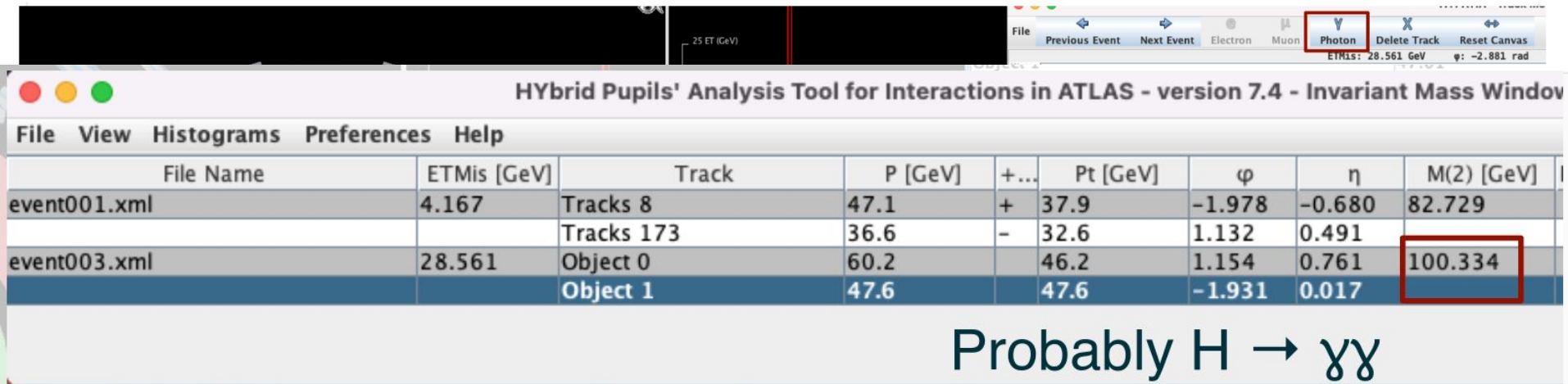
A screenshot of a software interface showing the "Physics Objects" tab. The interface includes a menu bar with "File", "Previous Event", "Next Event", "Electron", "Muon", "Photon", "Delete Track", and "Reset Canvas". The "Photon" menu item is highlighted with a red box. Below the menu bar, the file path is shown as "/Users/mihamuskinj/Downloads/groupA.zip/event003.xml". The "Physics Objects" table is displayed below the menu bar, with the following data:

Track	P [GeV]
Object 0	60.24
Object 1	47.61

Now assign them as photons similarly.



# CHECK THE RECONSTRUCTED INITIAL-STATE OBJECT

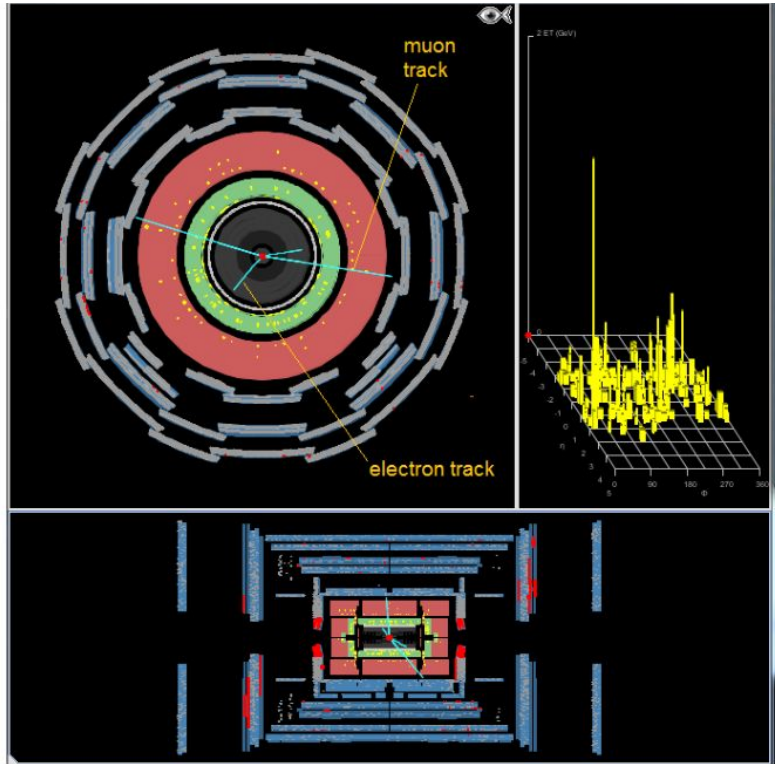


The screenshot displays the 'HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window'. The interface includes a menu bar (File, View, Histograms, Preferences, Help) and a toolbar with buttons for 'Previous Event', 'Next Event', 'Electron', 'Muon', 'Photon', 'Delete Track', and 'Reset Canvas'. The 'Photon' button is highlighted with a red box. Below the toolbar is a table with the following data:

File Name	ETMis [GeV]	Track	P [GeV]	+...	Pt [GeV]	$\varphi$	$\eta$	M(2) [GeV]
event001.xml	4.167	Tracks 8	47.1	+	37.9	-1.978	-0.680	82.729
		Tracks 173	36.6	-	32.6	1.132	0.491	
event003.xml	28.561	Object 0	60.2		46.2	1.154	0.761	100.334
		Object 1	47.6		47.6	-1.931	0.017	

The value '100.334' in the M(2) column for Object 0 is highlighted with a red box. Below the table, the text 'Probably  $H \rightarrow \gamma\gamma$ ' is displayed in a large blue font. At the bottom of the screenshot, there are two plots: a top-down view of the ATLAS detector with a yellow track highlighted, and a 3D plot showing the distribution of tracks in the  $\eta$ - $\varphi$ -P space.

# WHAT ABOUT EVENTS WITH 4-TRACKS?

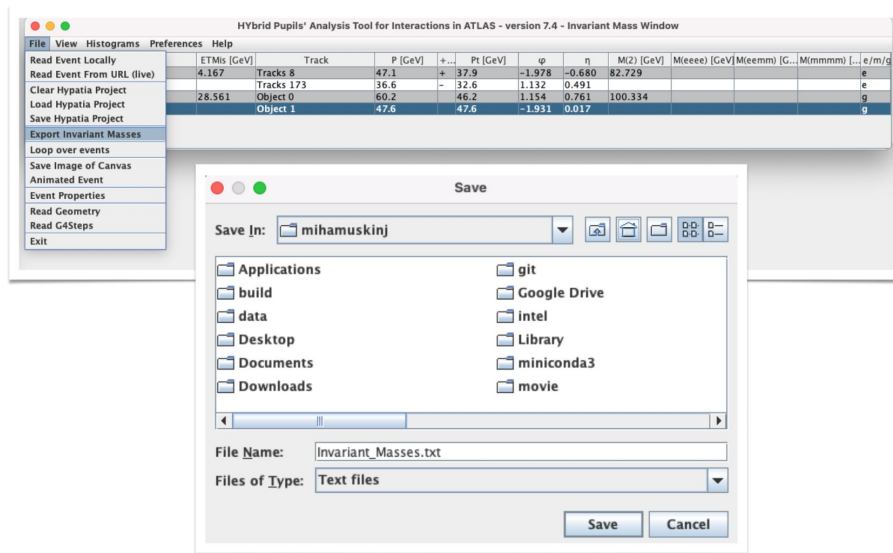


- How many pairs of tracks to form?
- Which two tracks belong in a pair?

# HYPATIA SOFTWARE (EXPORTING DATA)

# SAVING THE RESULTS

- The invariant mass data, analyzed from the given dataset, will be uploaded to a webpage and merged with the data from other students
- Invariant mass plots will be created automatically.
- Later merged also with other groups doing the event at the same time.



# UPLOADING DATA TO OPLOT


- Navigate to:  
<https://cernmasterclass.uio.no/OPloT-US/OPloT/index.php>
- Upload the data:

## OPloT – MasterClass – Start Page

Start **Student** Moderator Tutor Administrator

**Welcome to the plotting-tool for Hands-on-CERN Masterclasses!**

If you are a student, choose "Student" from the top menu.  
If you are a tutor, choose "Tutor".  
If you are a moderator at the videoconference, choose "Moderator".

If you need support or have any suggestions for improvements, send an email to [epf-mc\(at\)fys.uio.no](mailto:epf-mc(at)fys.uio.no) 

If your are an extraordinary superduper user, then read this: [To reset the session, visit this page again.](#)

# OPlOT – MasterClass – Start Page

Start Student Moderator Tutor Administrator

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Account: ippog  
Password: imc

## Log in to cernmasterclass.uio.no:443

Your login information will be sent securely.

Remember this password

Cancel

Log In

## OPIoT – MasterClass – Start Page

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## OPIoT – MasterClass – Student page

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### Student Tasks

Please select items from the drop-down boxes to submit your results!

2022 ▾ March ▾ 05 ▾ Berkeley ▾ Group number ▾ **Group letter ▾**

[Cancel](#)

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