INTERNATIONAL MASTERCLASSES
hands on particle physics

BERKELEY LAB

ATLAS Masterclass

- Data Analysis techniques -

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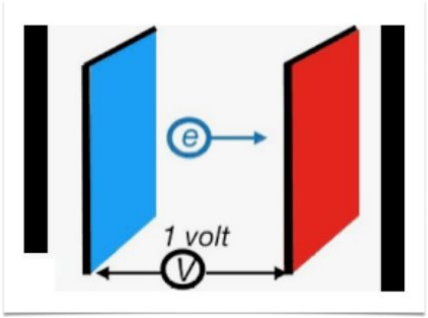
Units: "Electron Volt"

- At LHC, all particles are moving at speeds very close to light (0.99999999c).
  - C = 3 x 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".



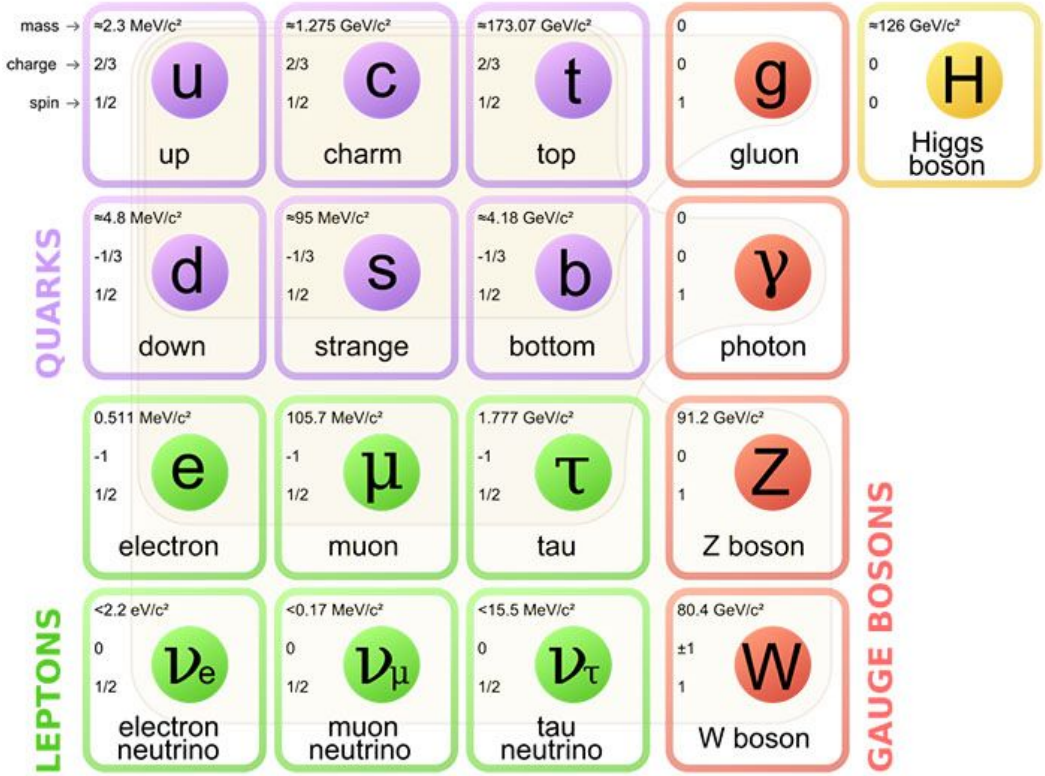
1 'electron Volt' or 1 eV:

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

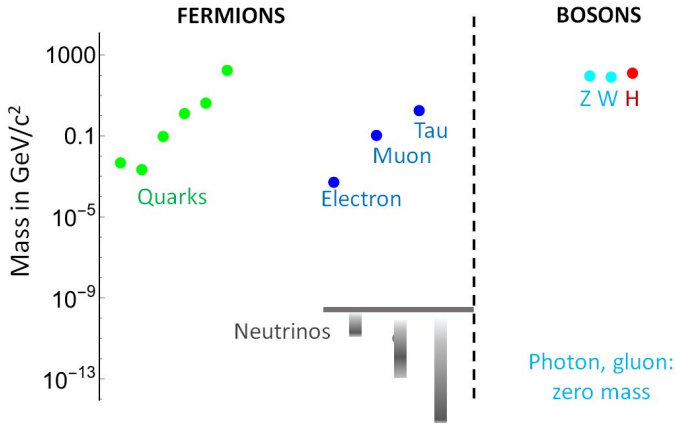
1 eV = 1.6 10^{-19} J

1 KeV = 1000 eV
1 MeV = 1000 KeV
1 GeV = 1000 MeV
1 TeV = 1000 GeV
13 TeV = Center-of-mass energy of protons in LHC collisions!!

Standard Model



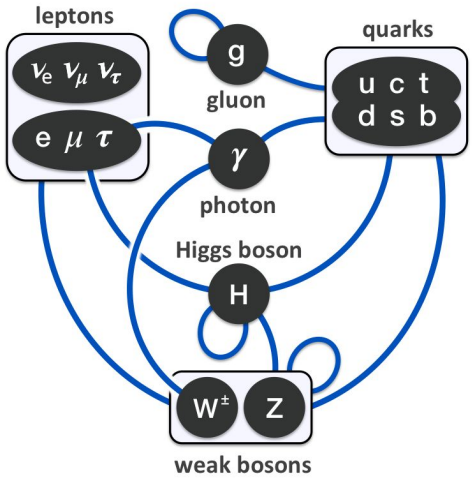
Scale of elementary particle masses



Standard Model

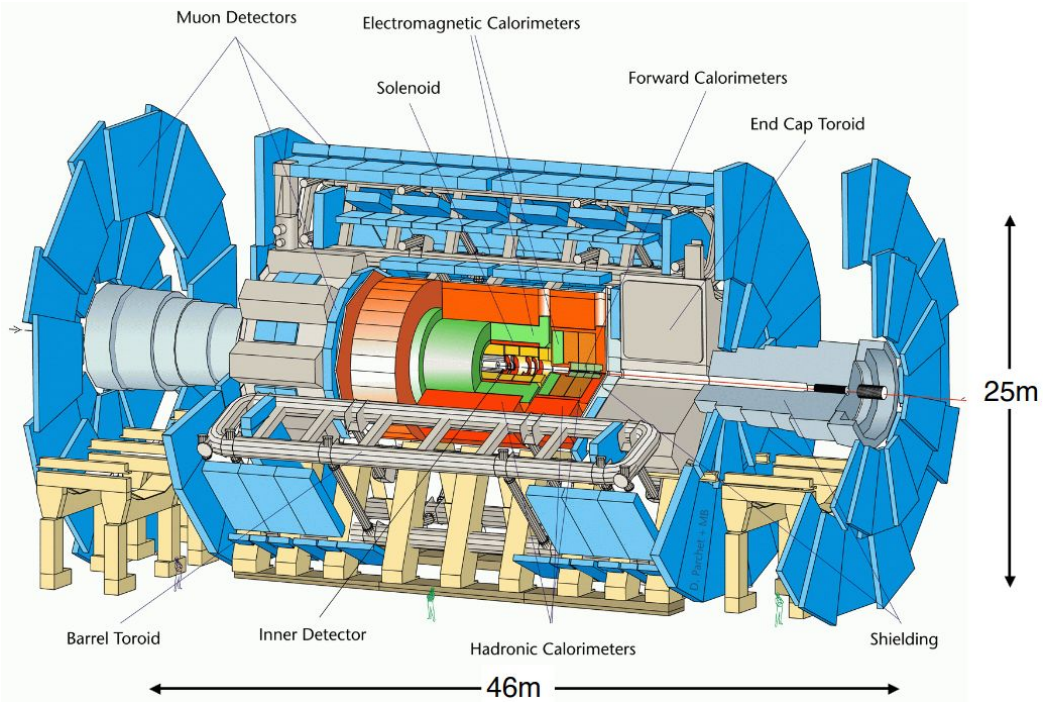
- Various fundamental particles.
- Unstable particles (e.g. bosons) -> decay at the interaction vertex.
- Stable particles -> “final-state” detectable.
  - E.g. electrons, muons, photons, charged and neutral hadrons.

What interacts with what?

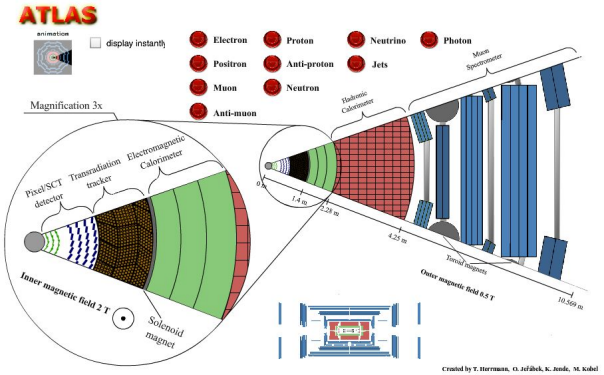


Tools of particle physics

ATLAS DETECTOR



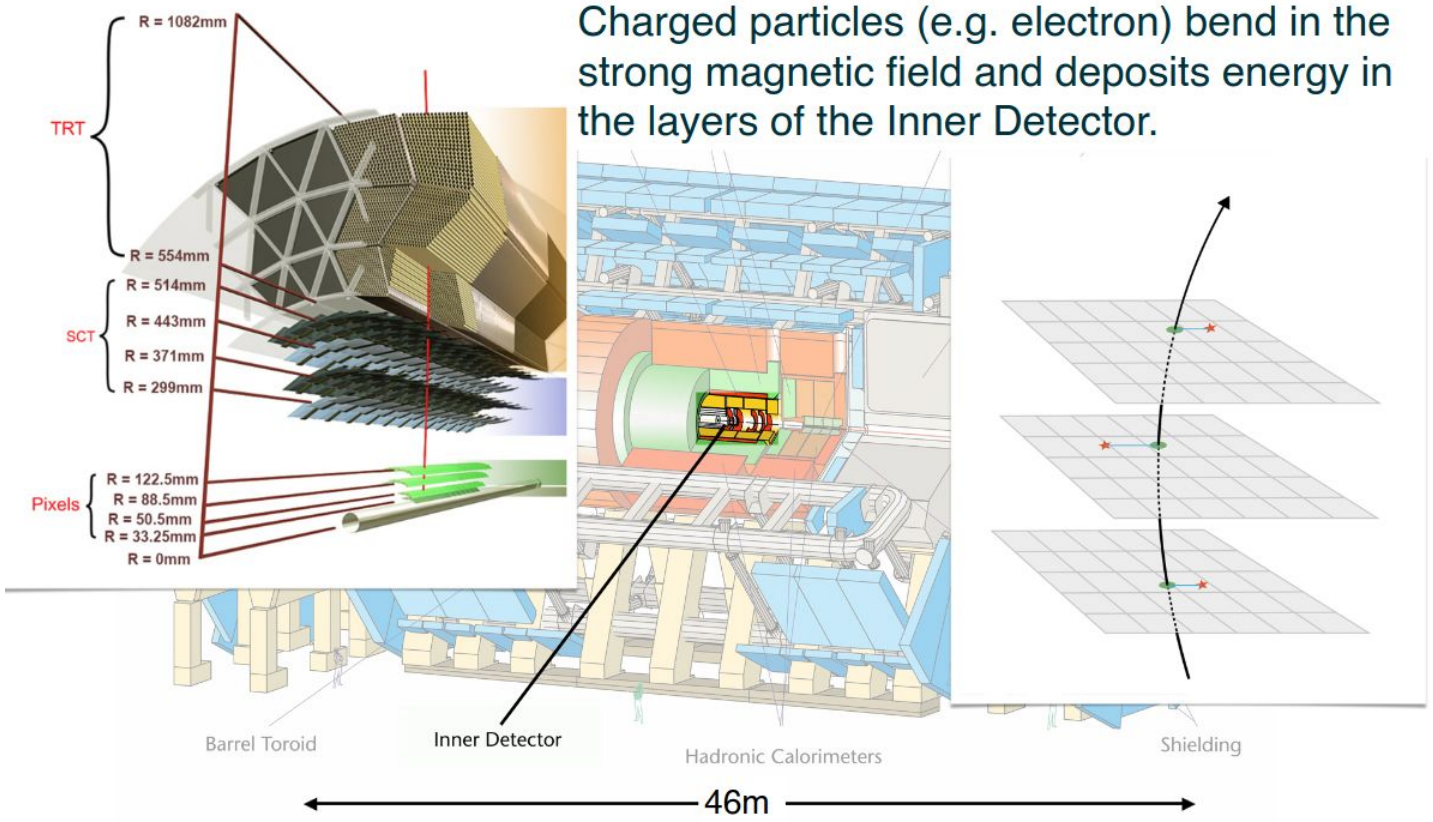
Longitudinal view



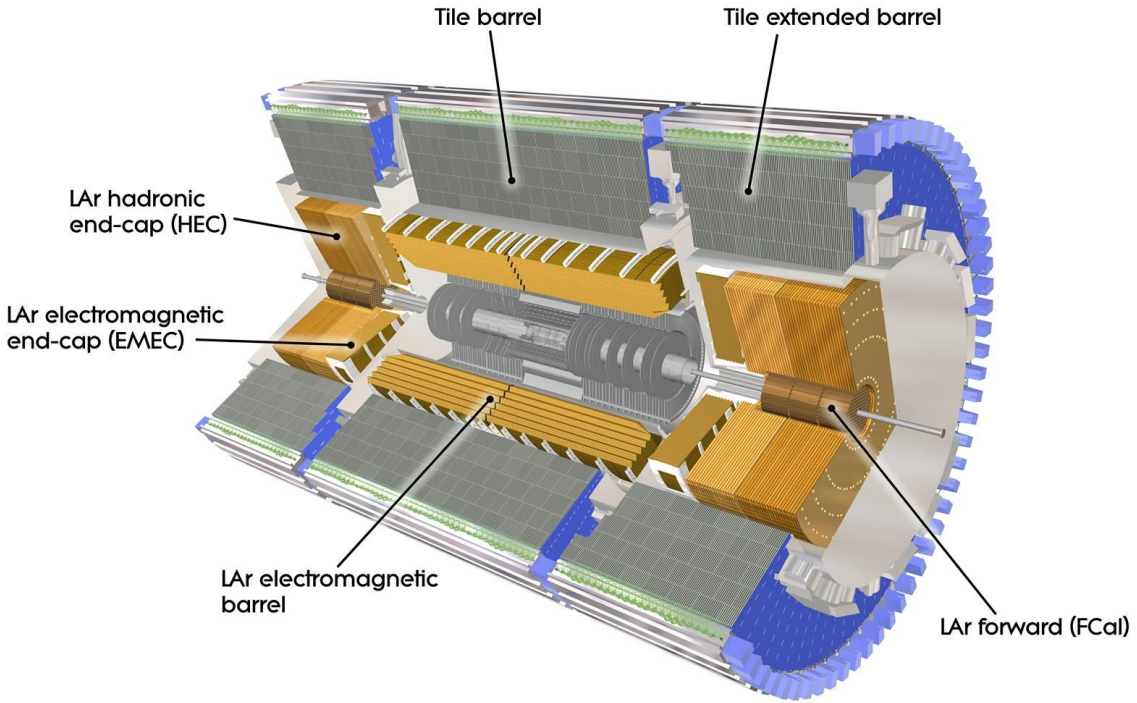
Transverse view

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

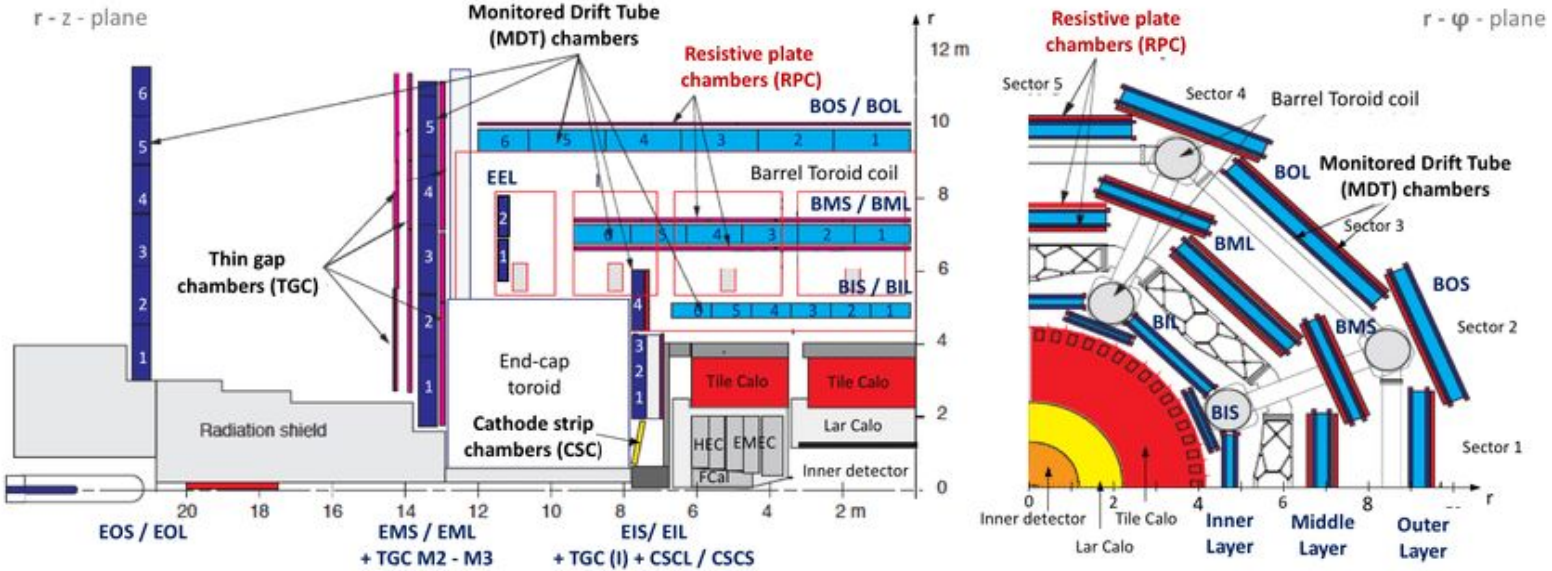
Neutron:

Leaves **no** track in Tracker

Muon detector

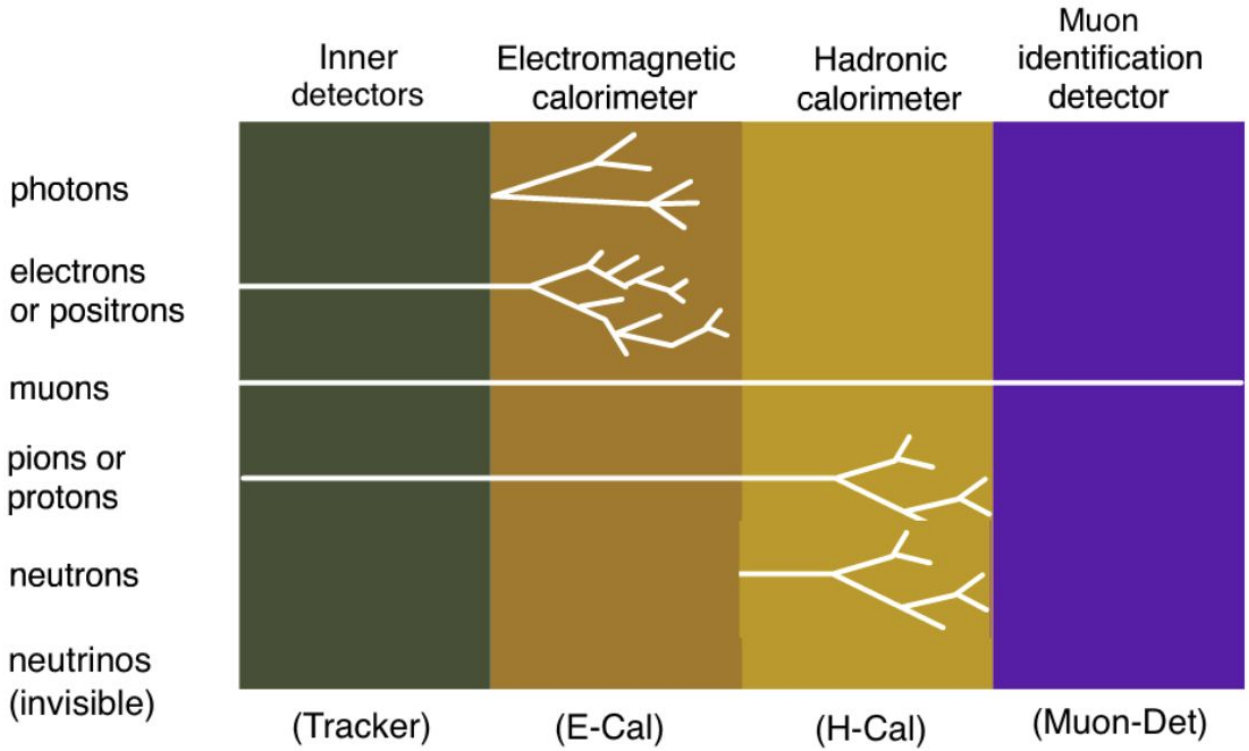
Muons:

- 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)

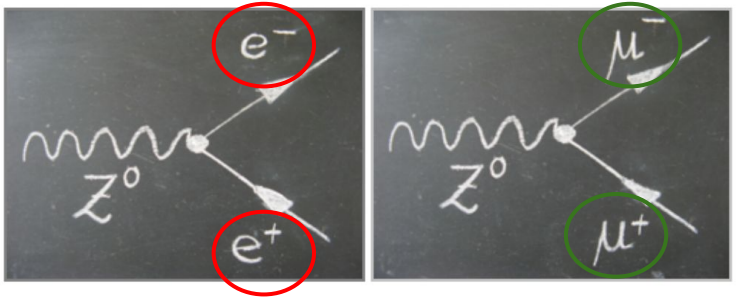


Q- Why invisible?

Today's exercises

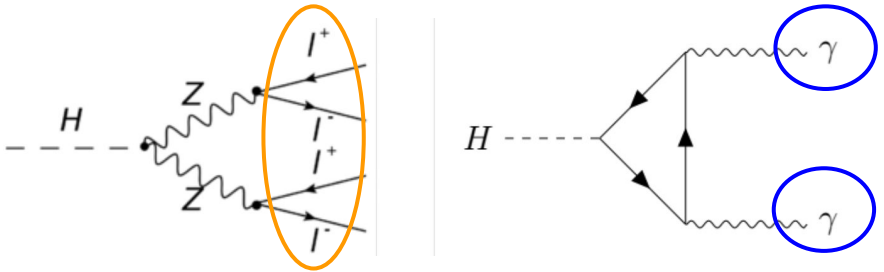
Search for Z-boson

- Via electrons
- Via muons



Search for higgs-boson

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



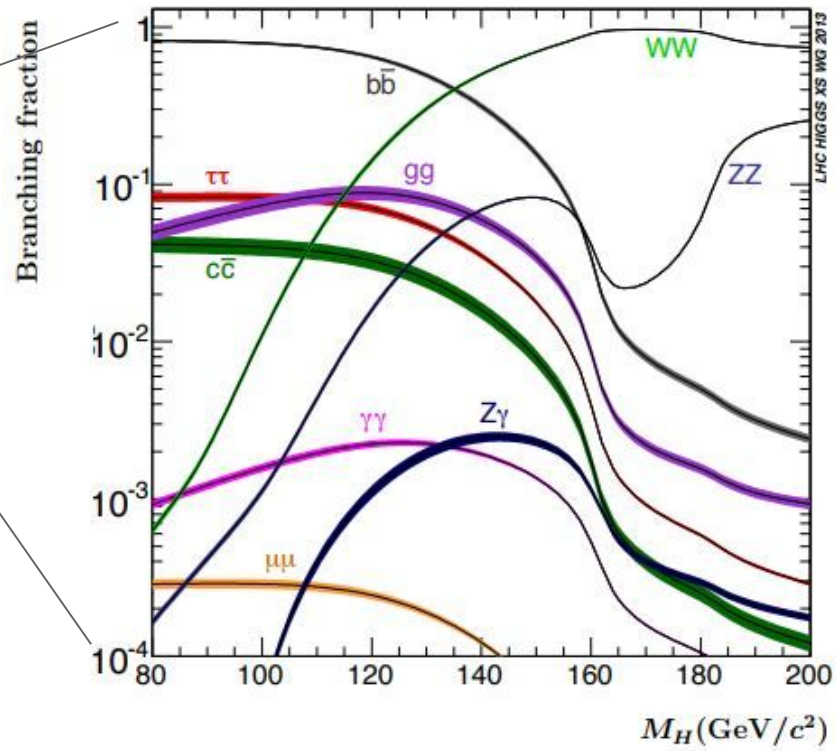
"Branching ratio" plot of HIGGS

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 γγ 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: (Px_1, Py_1, Pz_1, E_1)

  Particle 2: (Px_2, Py_2, Pz_2, E_2)

  ...

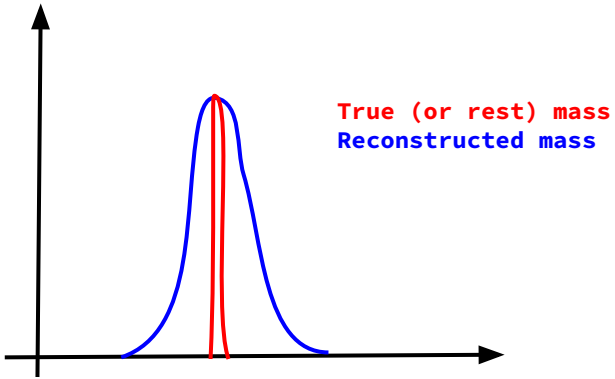
- Using these “4-momenta” of final-state particles, we can **reconstruct the invariant mass of the initial-state particle** i.e. Z-boson or higgs.

$$M = \sqrt{(E_2 - E_1)^2 - (Px_2 - Px_1)^2 - (Py_2 - Py_1)^2 - (Pz_2 - Pz_1)^2}$$

- 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)

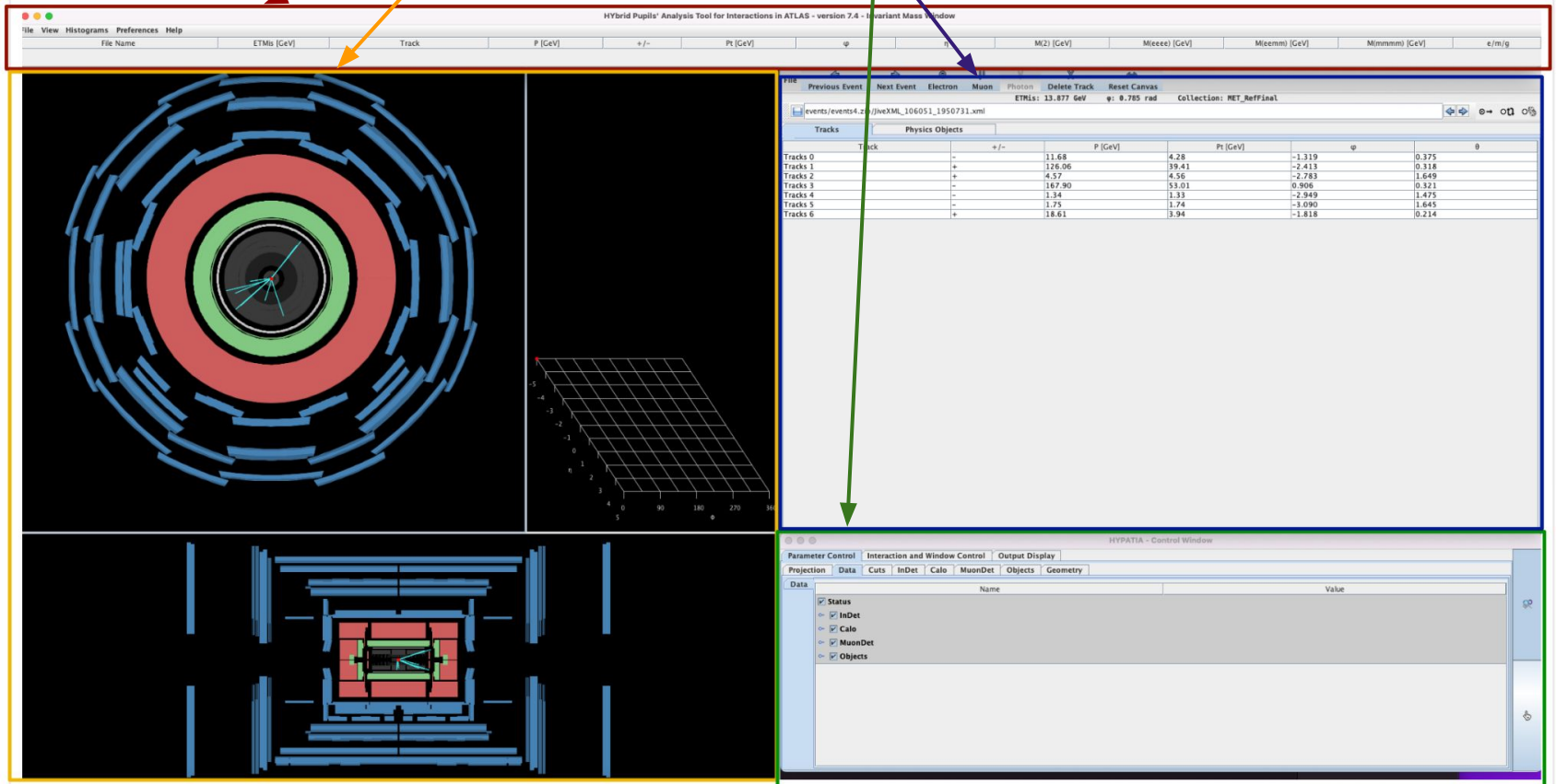
- Event display tool to visualize collision events, both data and simulation.
- Gives a very realistic image of the interaction between each proton bunch crossing (an event) at the vertex.
- Detector activity shown is post-reconstruction i.e. after digitizing the electrical signals and classifying them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

HYPATIA
(Launching the software)

THE GUI

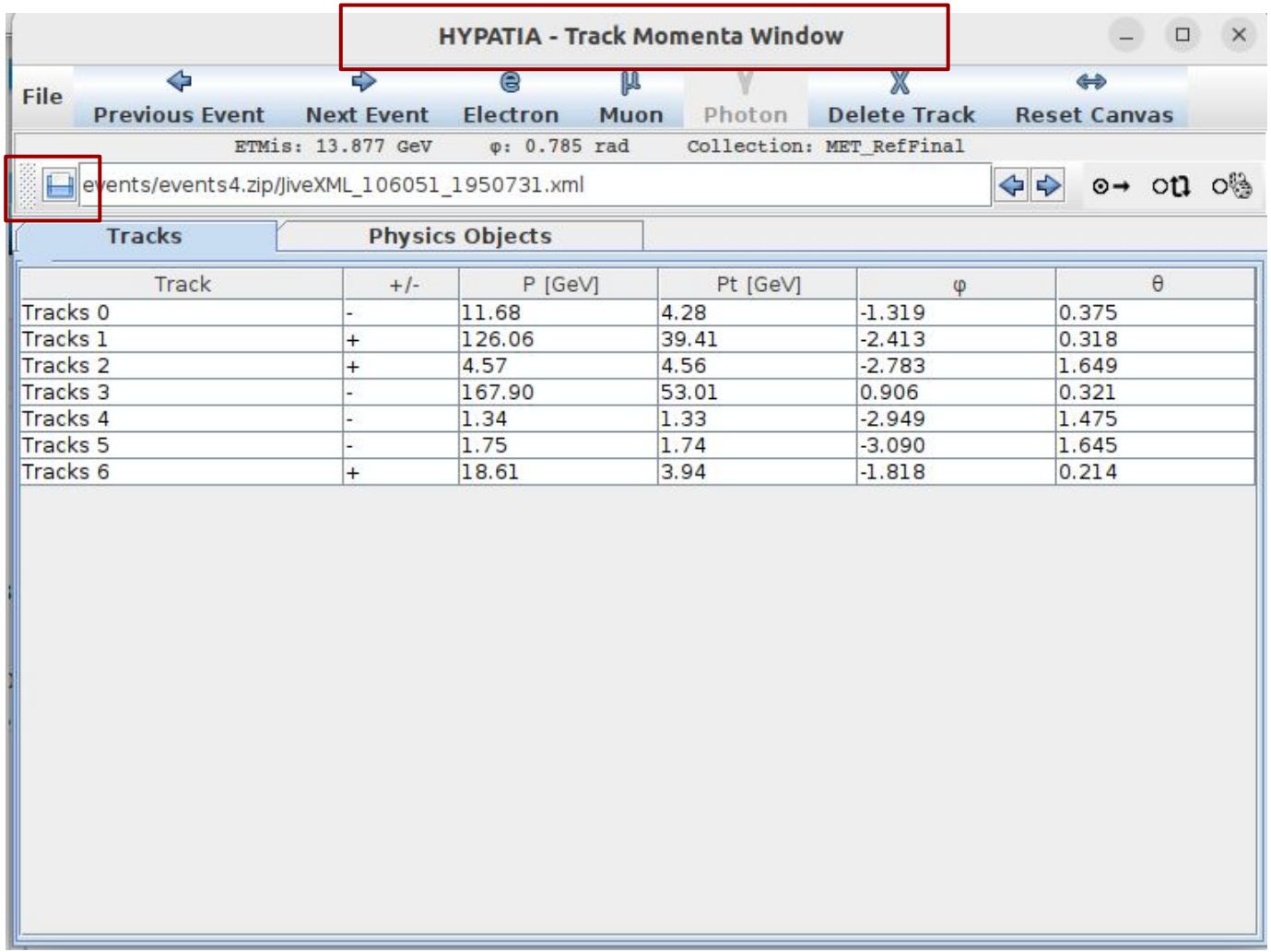
Four tabs

Invariant mass window
Event display window
Tracks/objects window
Control window

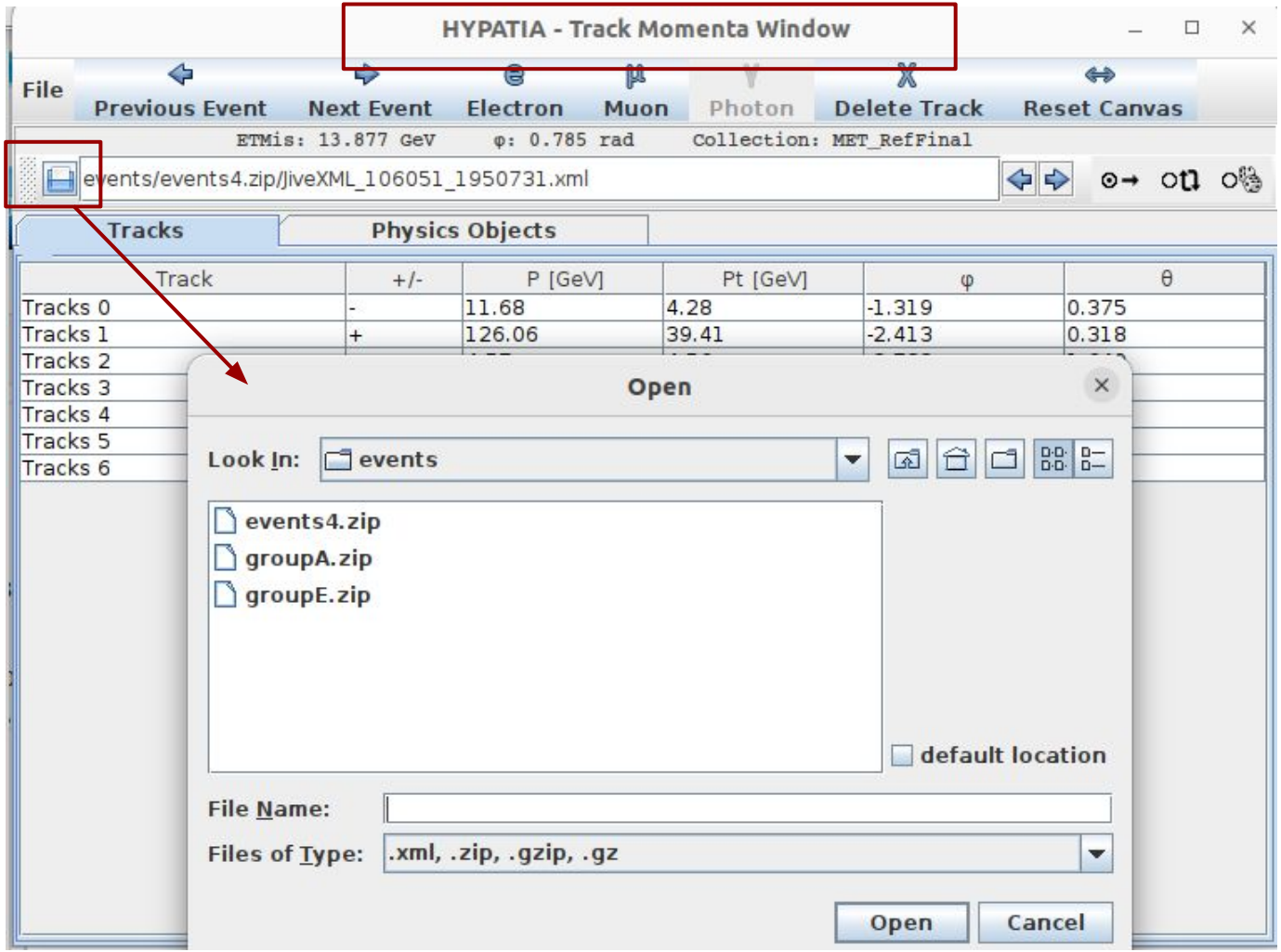


Hypatia software (loading the dataset)

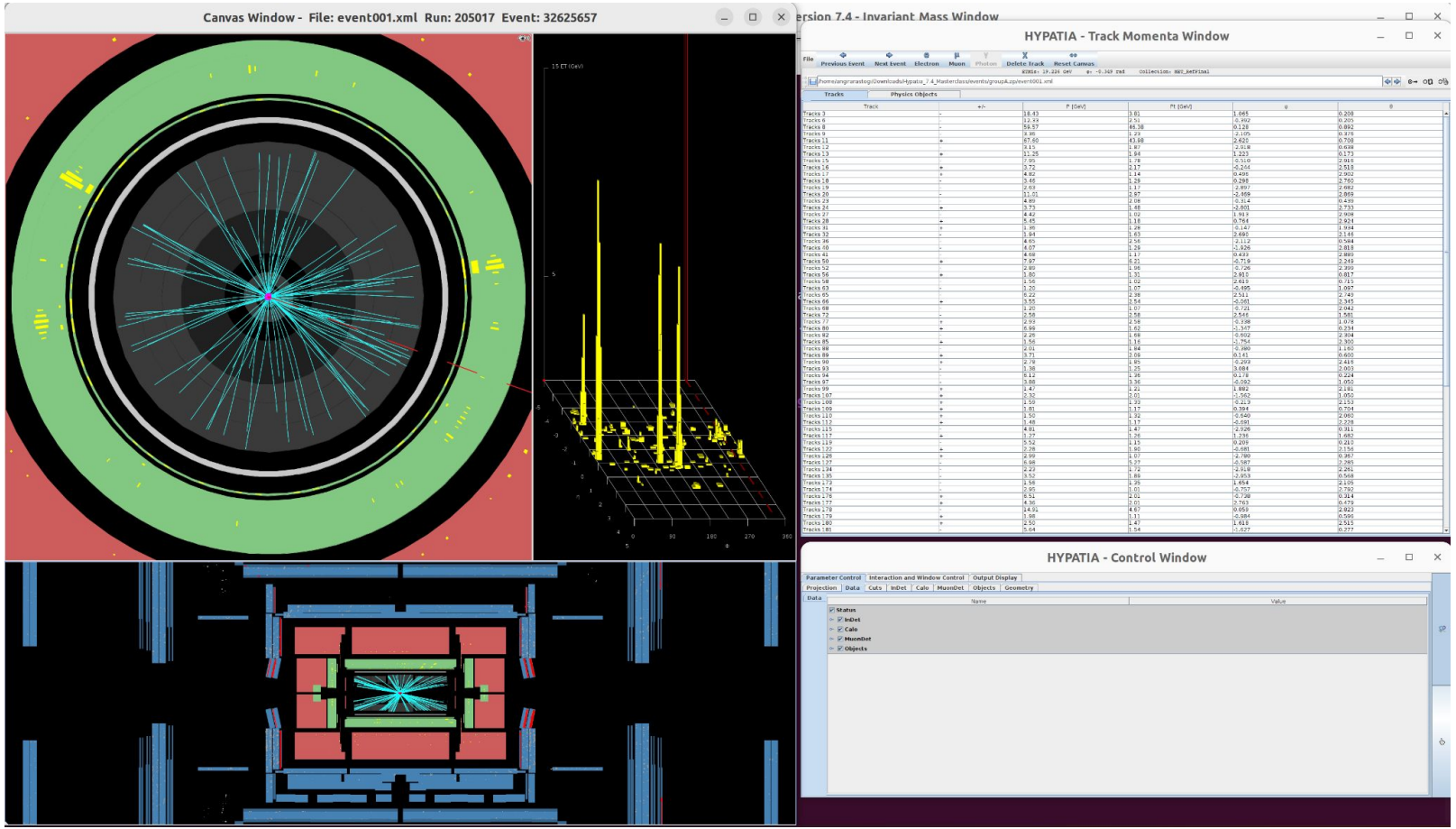
Datasets are downloaded and can be found inside “events” folder of the Hypatia software.



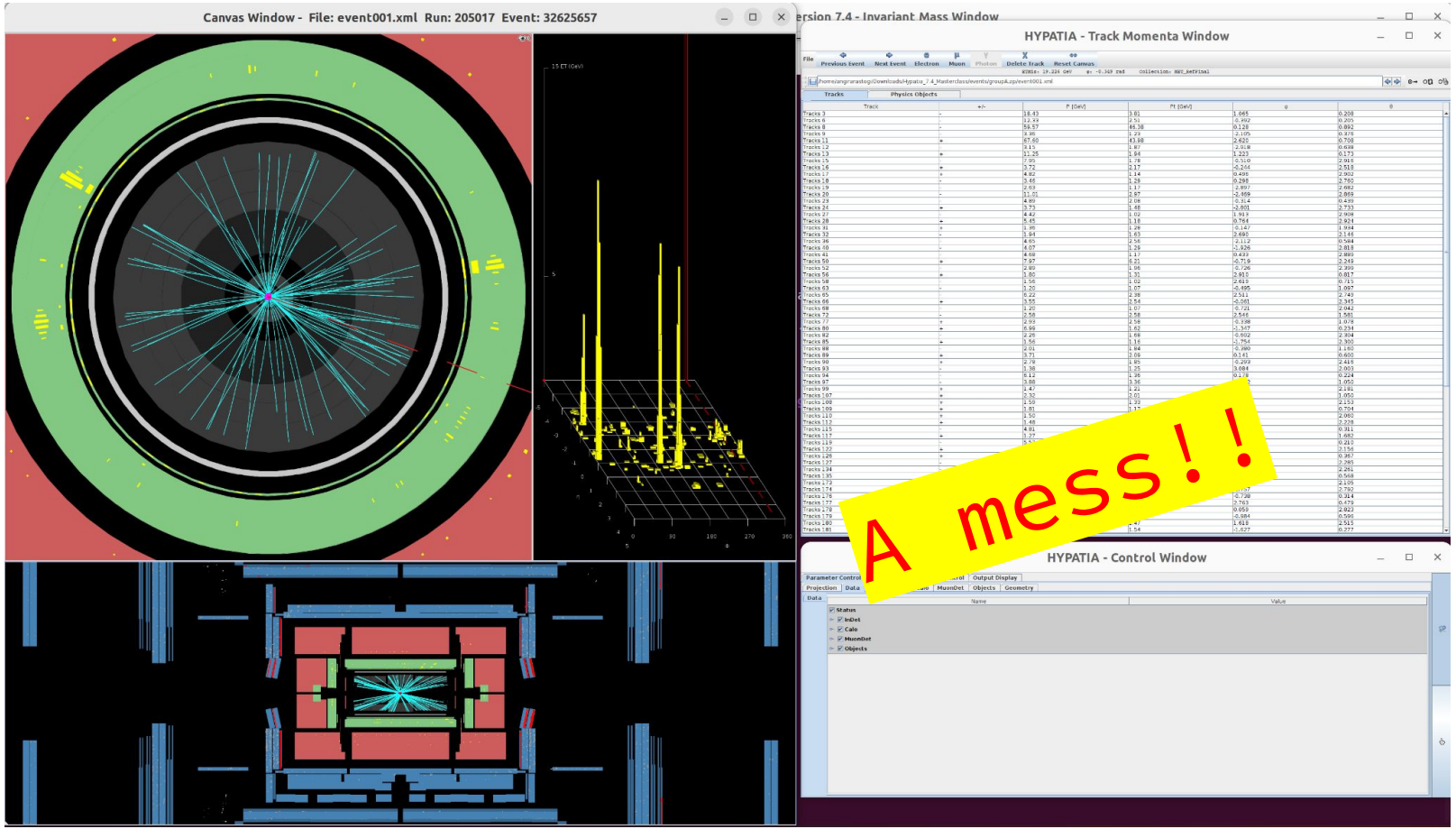
Track	+/-	P [GeV]	Pt [GeV]	φ	θ
Tracks 0	-	11.68	4.28	-1.319	0.375
Tracks 1	+	126.06	39.41	-2.413	0.318
Tracks 2	+	4.57	4.56	-2.783	1.649
Tracks 3	-	167.90	53.01	0.906	0.321
Tracks 4	-	1.34	1.33	-2.949	1.475
Tracks 5	-	1.75	1.74	-3.090	1.645
Tracks 6	+	18.61	3.94	-1.818	0.214


HYPATIA - Track Momenta Window
File
Previous Event
Next Event
Electron
Muon
Photon
Delete Track
Reset Canvas
ETMis: 13.877 GeV
φ: 0.785 rad
Collection: MET_RefFinal
events/events4.zip/JiveXML_106051_1950731.xml
Tracks
Physics Objects
Track
+/-
P [GeV]
Pt [GeV]
φ
θ
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
Open
Cancel

What will you see?

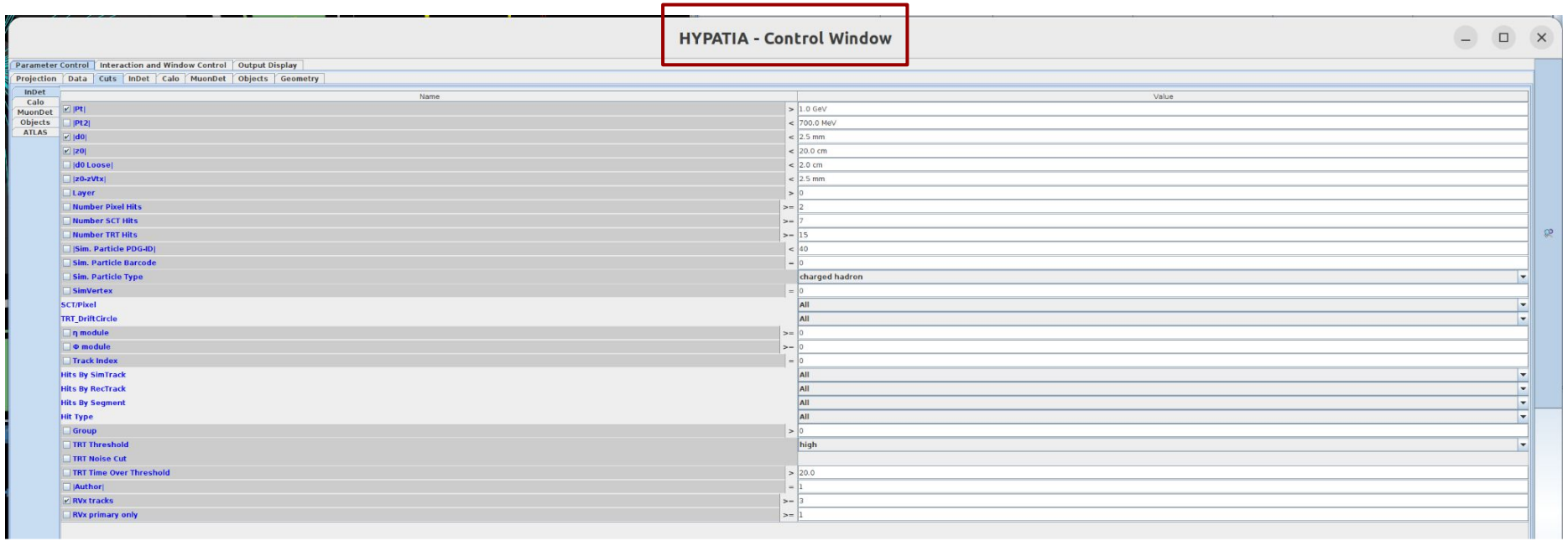


What will you see?

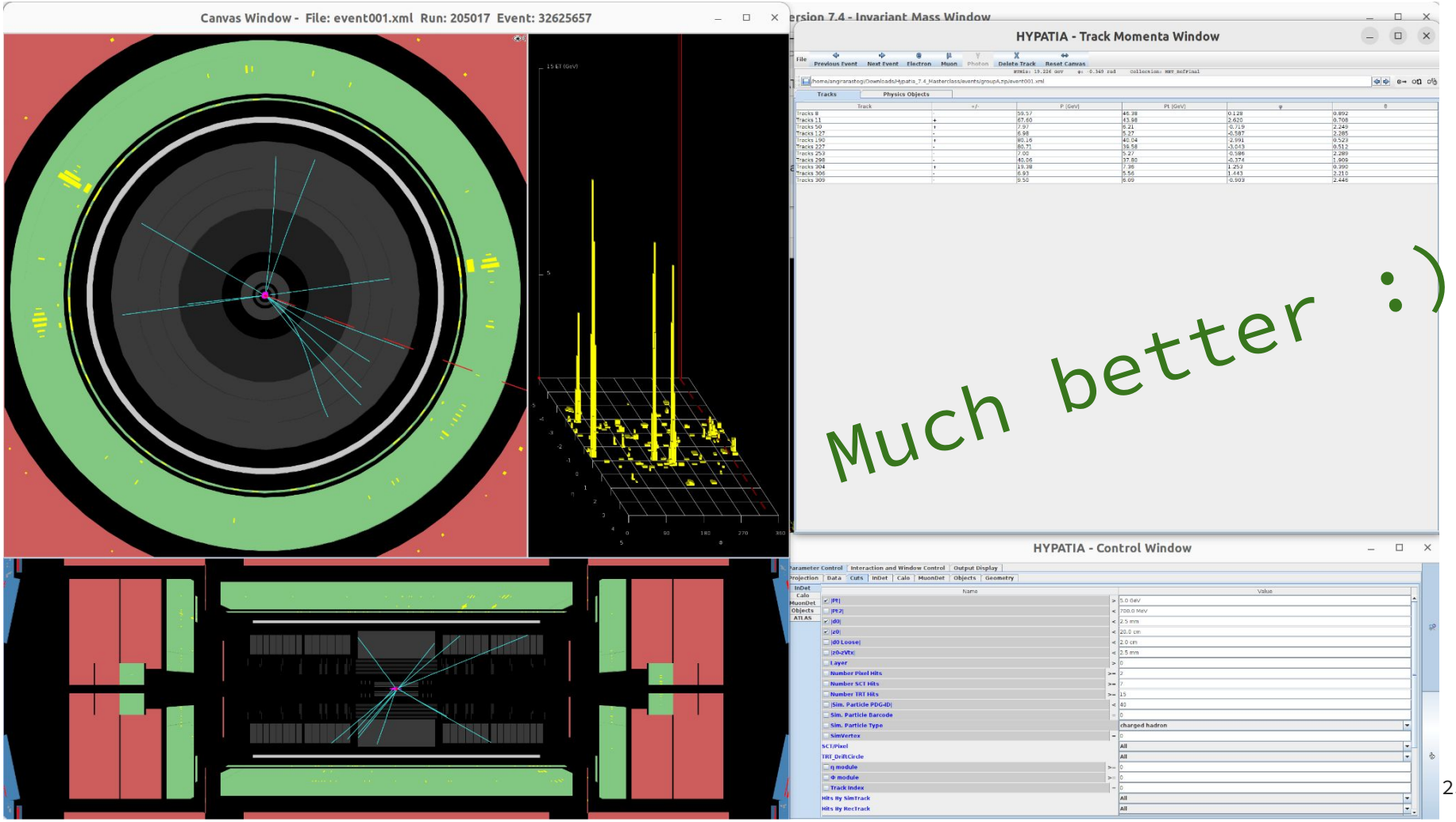


HYPATIA SOFTWARE (ADDING CUTS)

Default selections



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


Canvas Window - File: event001.xml Run: 205017 Event: 32625657
HYPATIA - Track Momenta Window
HYPATIA - Control Window
Much better :)

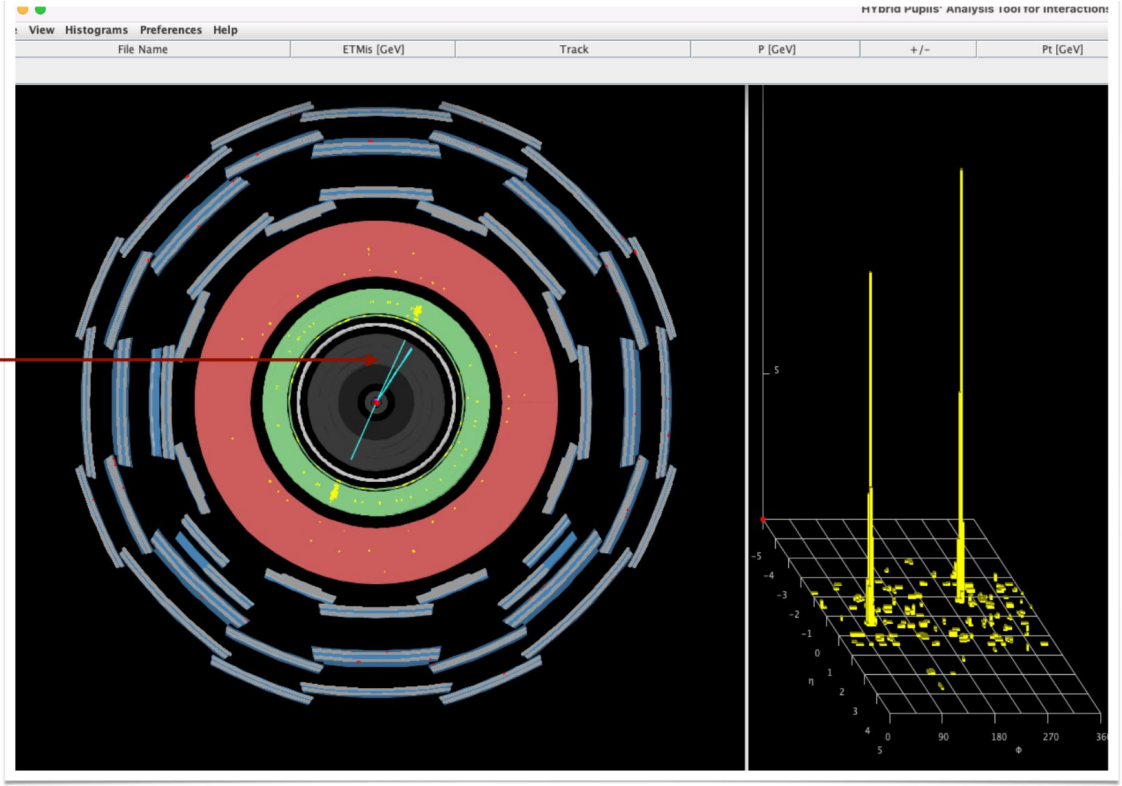
Now what?

Time to find the interesting events.

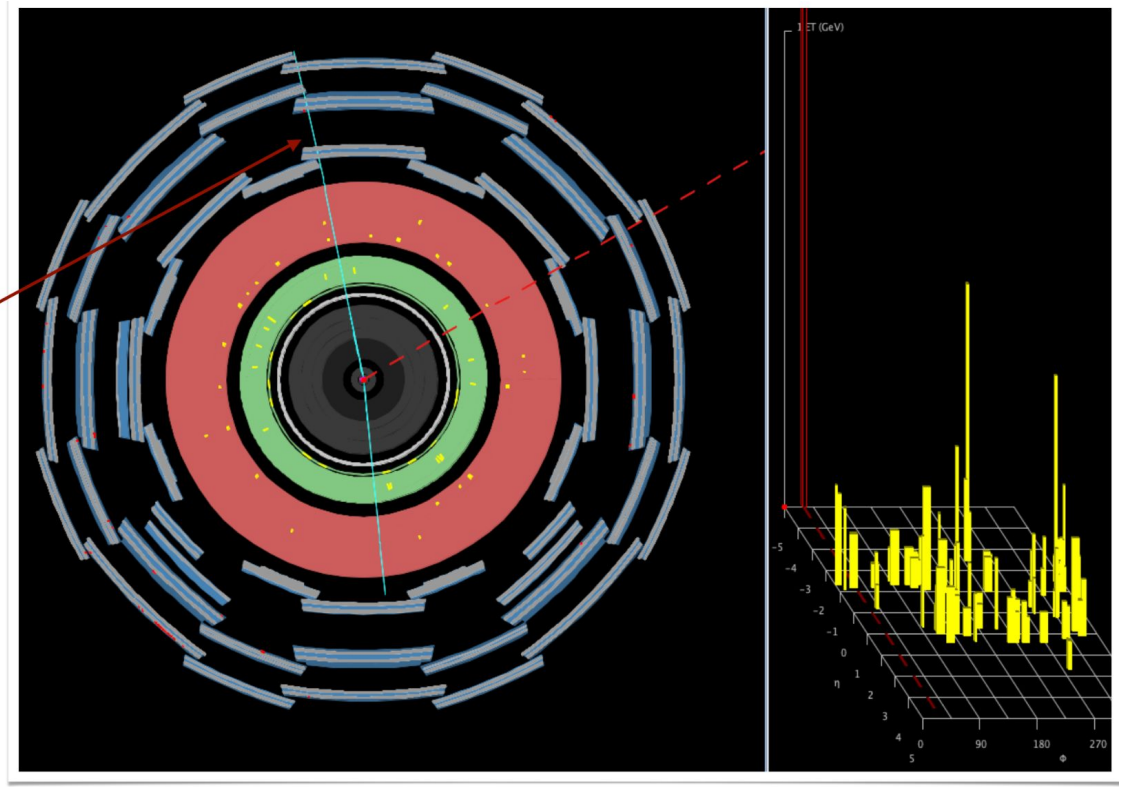
How? Look for evidence of their decays!!

HYPATIA SOFTWARE
(PARTICLE IDENTIFICATION)

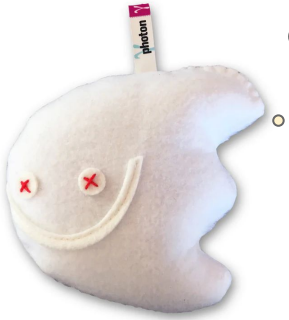
Electron:
- ID track
- Calo deposit



Muon:
- MS track

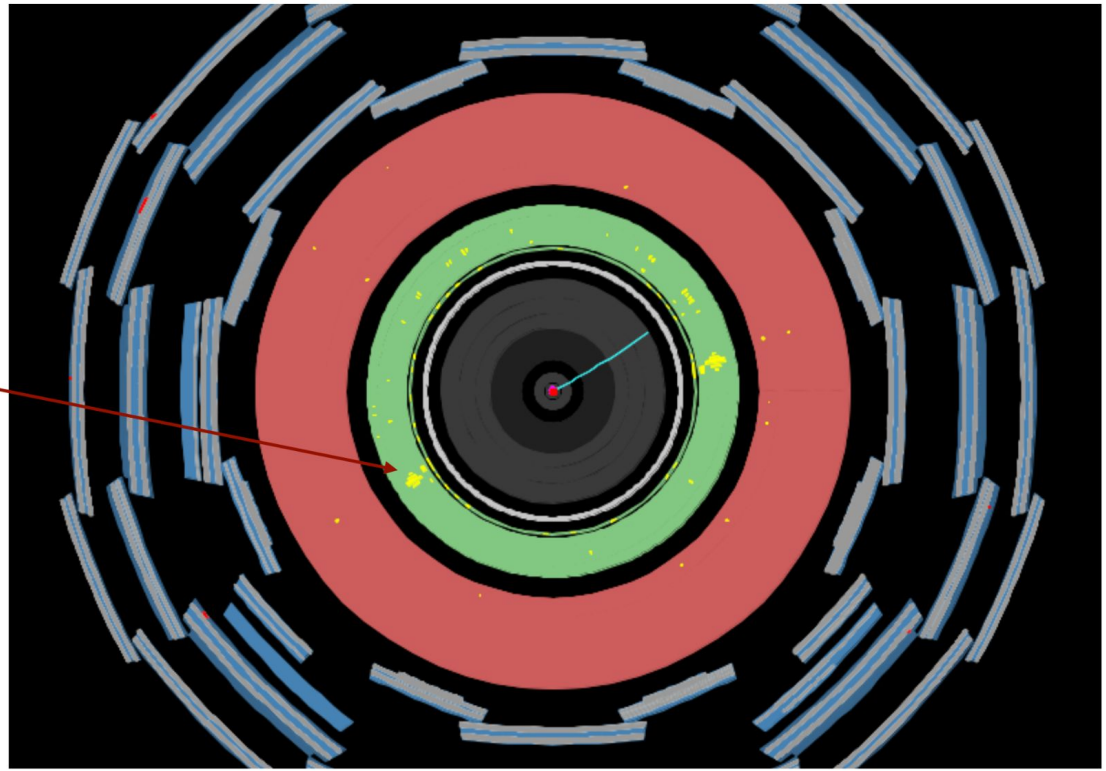


That's undoubtedly me!

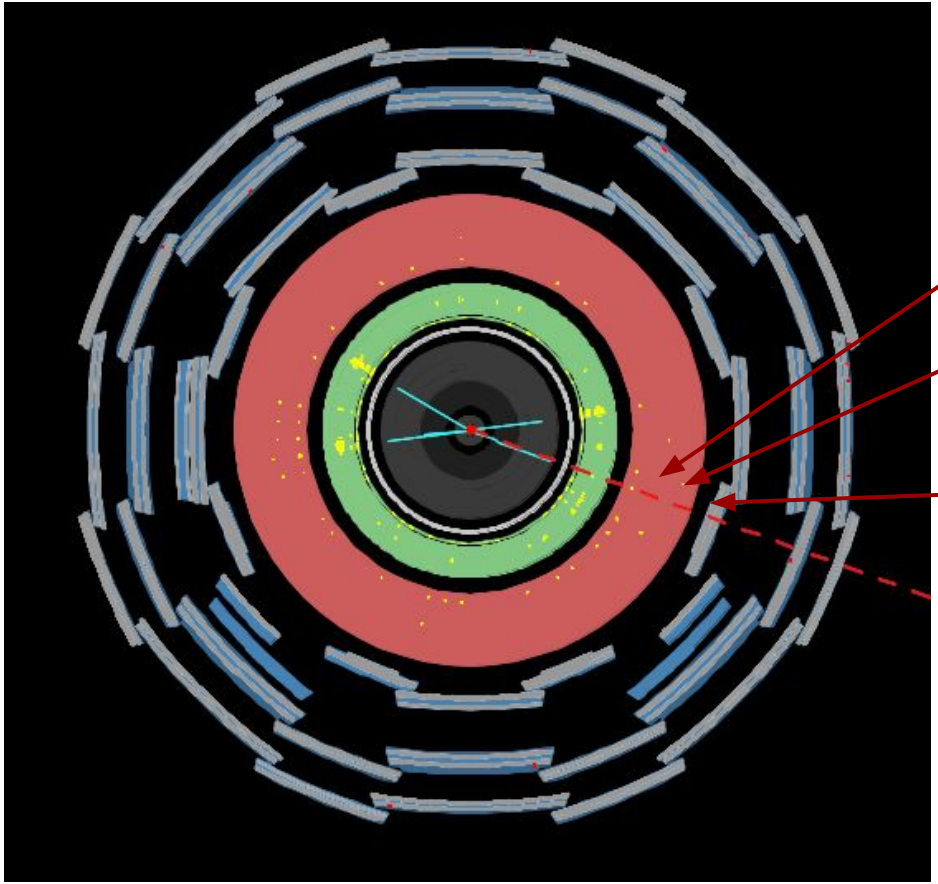


May not be that easy always!

Photon:
- Calo deposit
- No ID track



Neutrinos

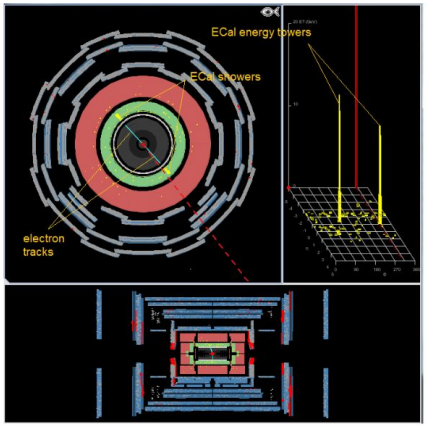


You can’t see us, but you can infer our presence…

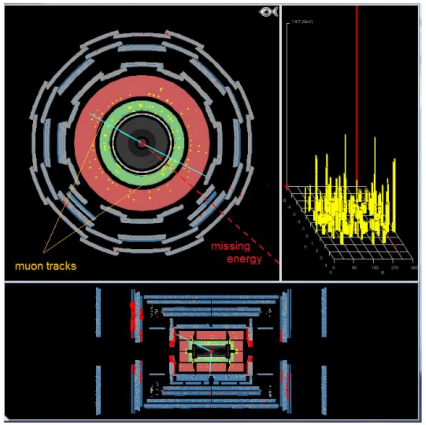
HYPATIA SOFTWARE
(FROM PARTICLES TO EVENTS)

Common scenarios

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



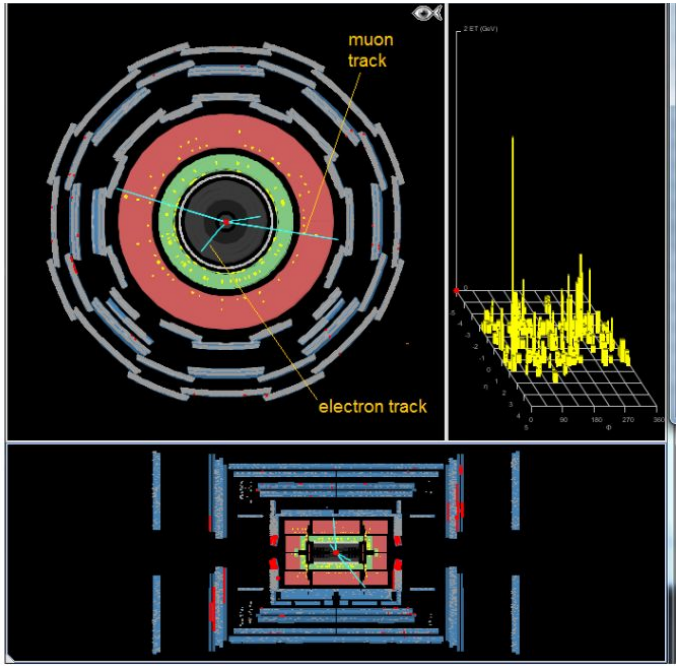
Dielectron or e^+e^- event.



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

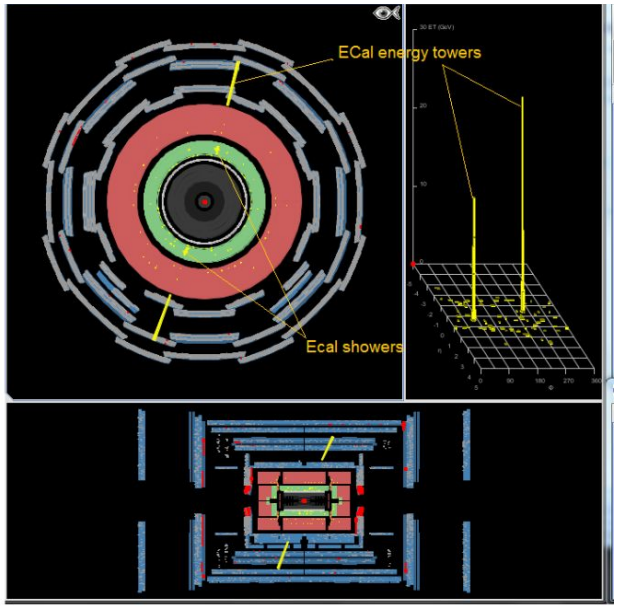
Common scenarios

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



Common scenarios

- Two unconverted photons (γγ)
  - Two calorimeter deposits without any associated tracks.



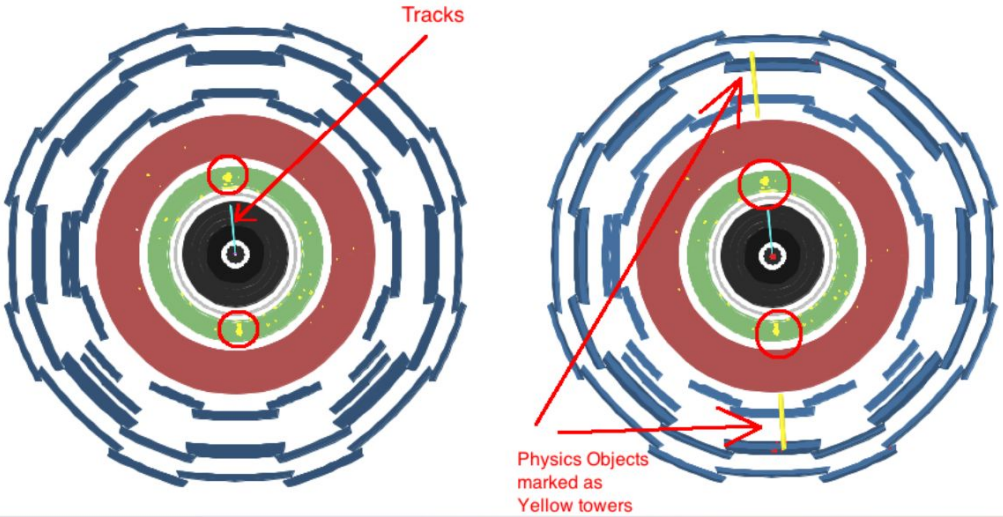
What's happening here?

ETMis: 14.969 GeV φ: -1.063 rad Collection: MET_RefFinal

…aikenp/Desktop/Hypatia_7-1-2/Hypatia_7-1/group1/event008.xml

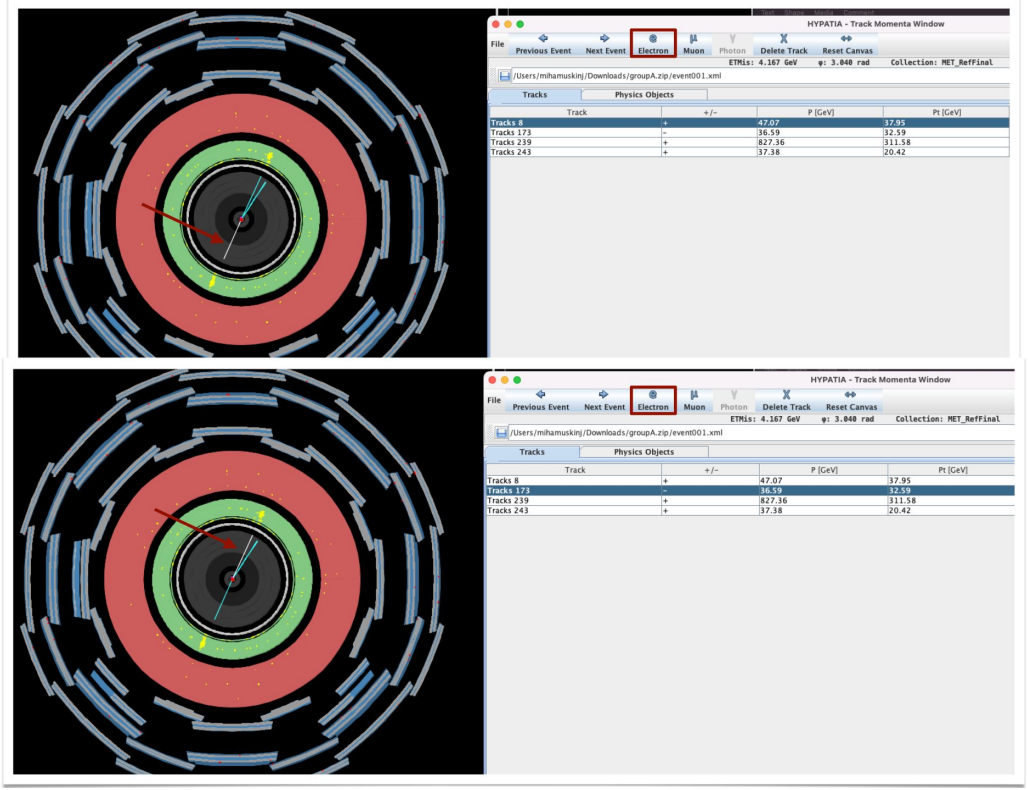
Tracks | Physics Objects

Track	P [GeV]	Pt [GeV]	φ	θ
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)

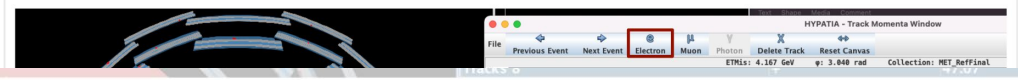
Events with 2-tracks



- 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

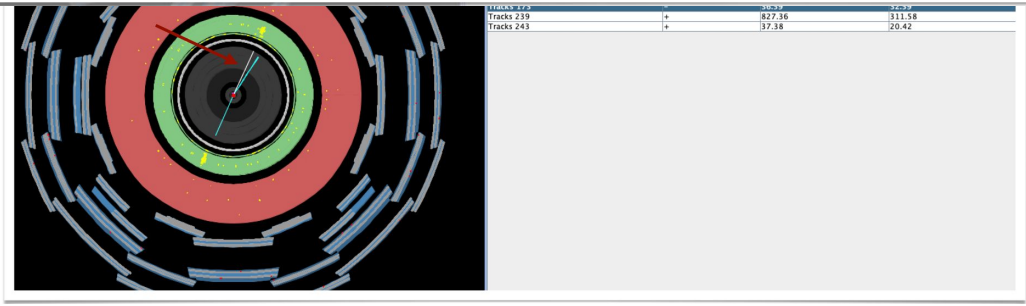


HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Windo

File View Histograms Preferences Help

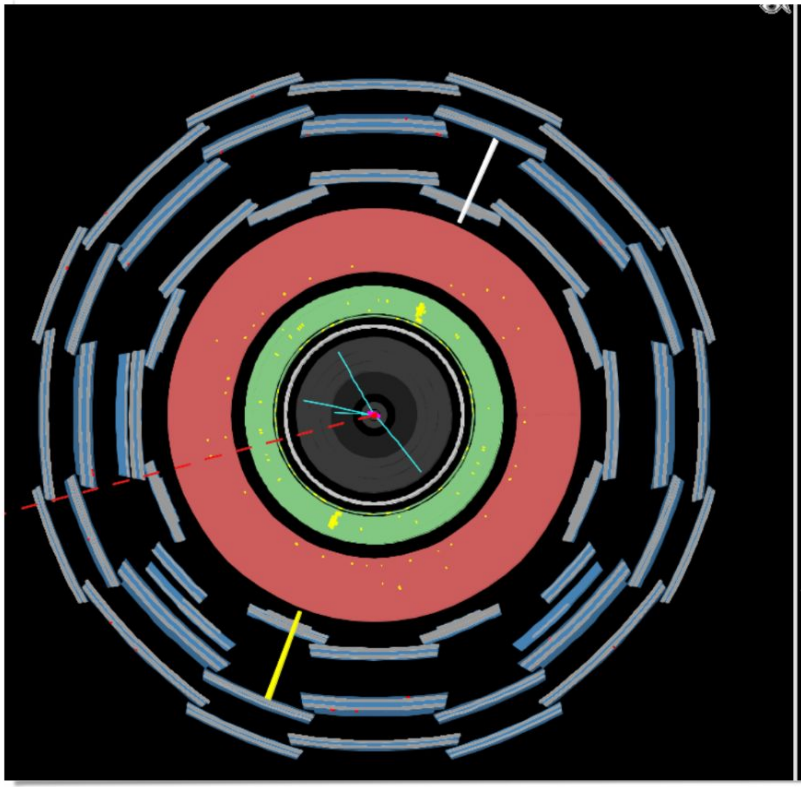
File Name	ETMis [GeV]	Track	P [GeV]	+...	Pt [GeV]	φ	η	M(2) [GeV]
event001.xml	4.167	Tracks 8	47.1	+	37.9	-1.978	-0.680	82.729
		Tracks 173	36.6	-	32.6	1.132	0.491	

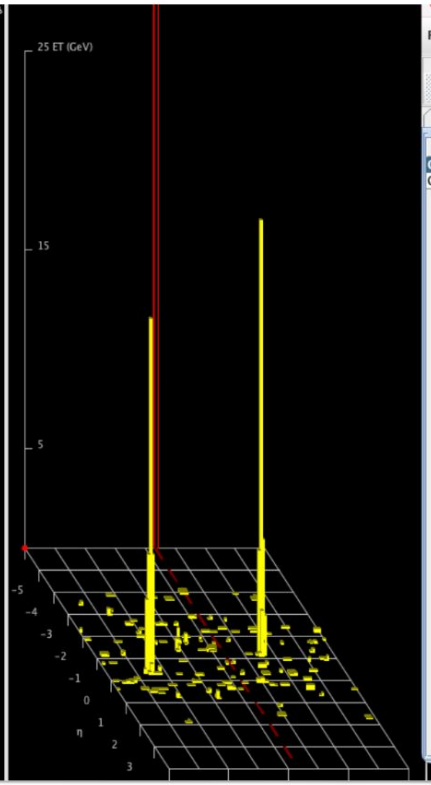
Probably Z → e+ e-

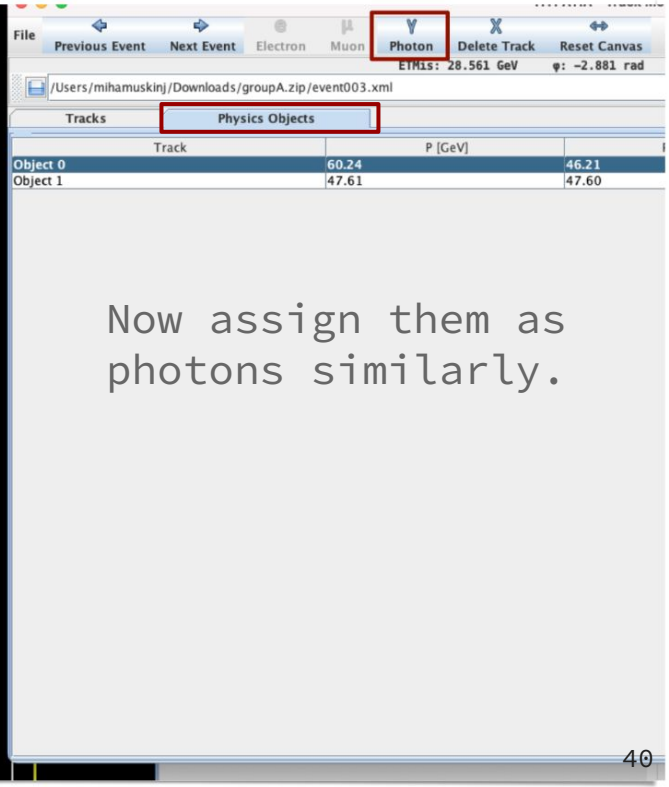


EVENTS WITH 2-CALO OBJECTS

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

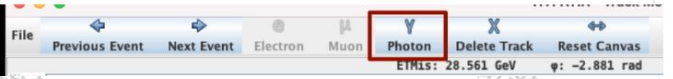






Now assign them as photons similarly.

Check the reconstructed initial-state object

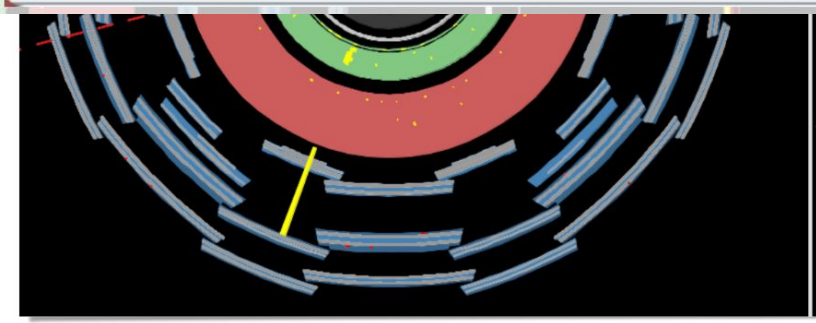


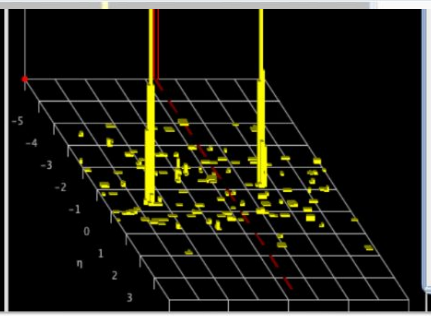
HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Windov

File View Histograms Preferences Help

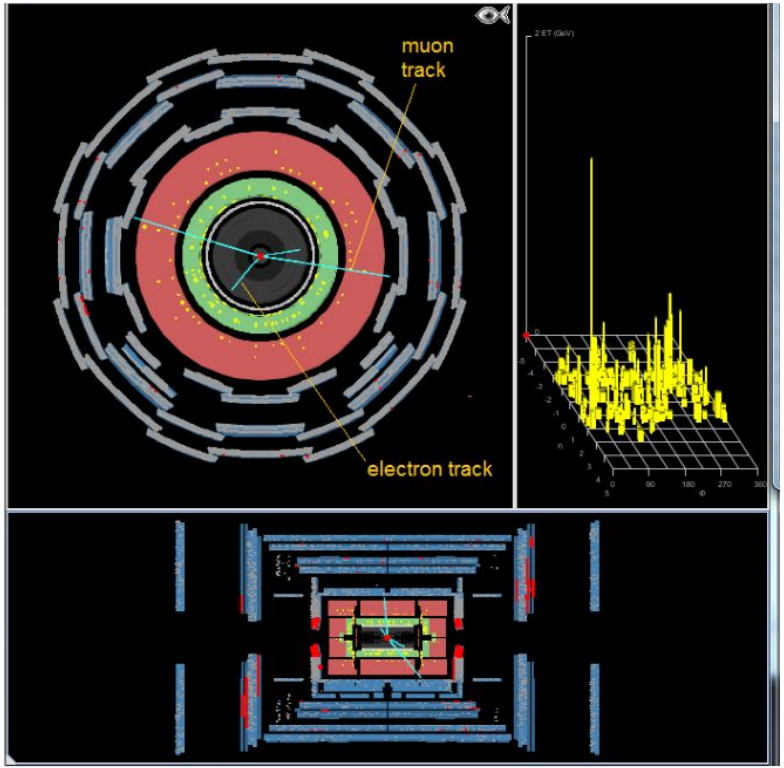
File Name	ETMis [GeV]	Track	P [GeV]	+...	Pt [GeV]	φ	η	M(2) [GeV]
event001.xml	4.167	Tracks 8	47.1	+	37.9	-1.978	-0.680	82.729
		Tracks 173	36.6	-	32.6	1.132	0.491	
event003.xml	28.561	Object 0	60.2		46.2	1.154	0.761	100.334
		Object 1	47.6		47.6	-1.931	0.017	

Probably $H \rightarrow \gamma\gamma$





What About Events with 4-tracks?

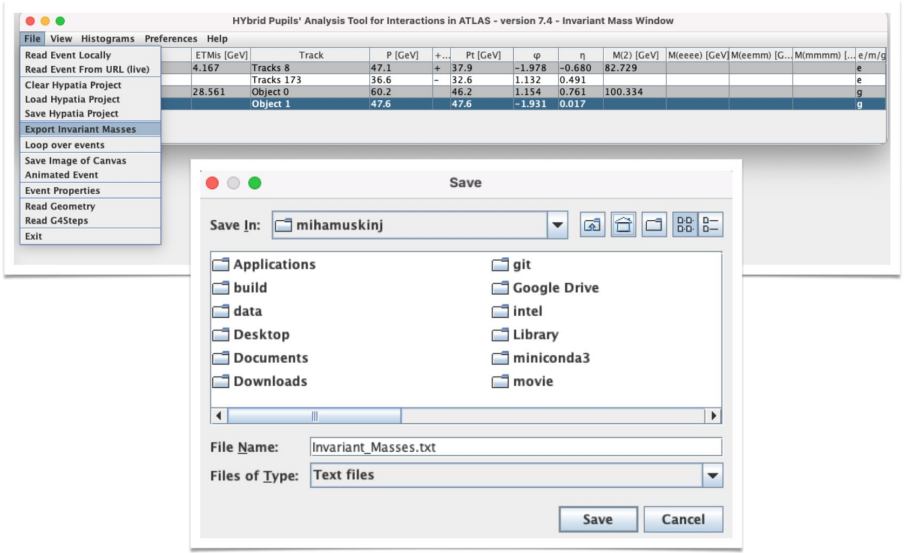


- How many pairs of tracks to form?
- Which two tracks belong in a pair?

HYPATIA SOFTWARE (EXPORTING DATA)

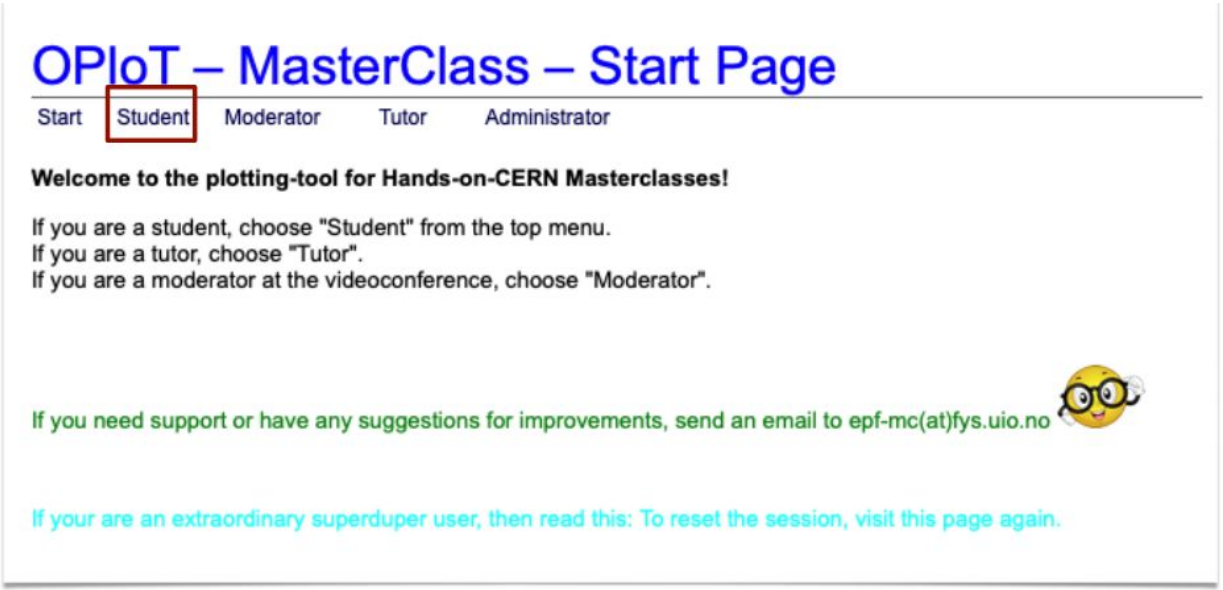
Saving the results

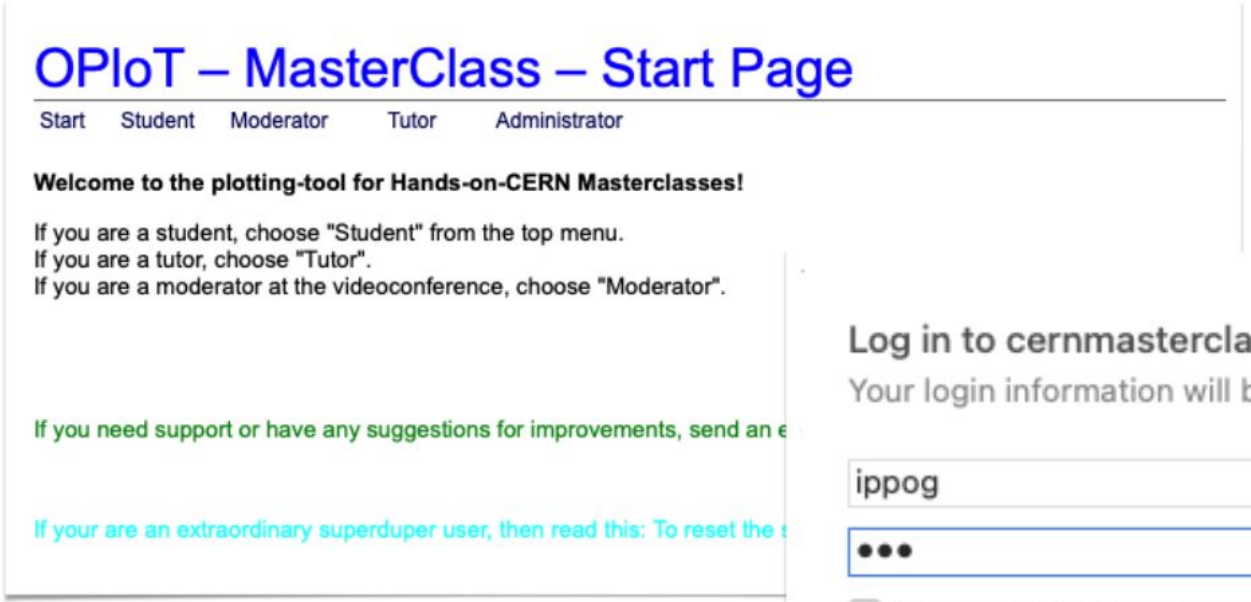
- The invariant mass data, analyzed from the given dataset, will be uploaded to a webpage and merged with the data from other students
- Invariant mass plots will be created automatically.
- Later merged also with other groups doing the event at the same time.

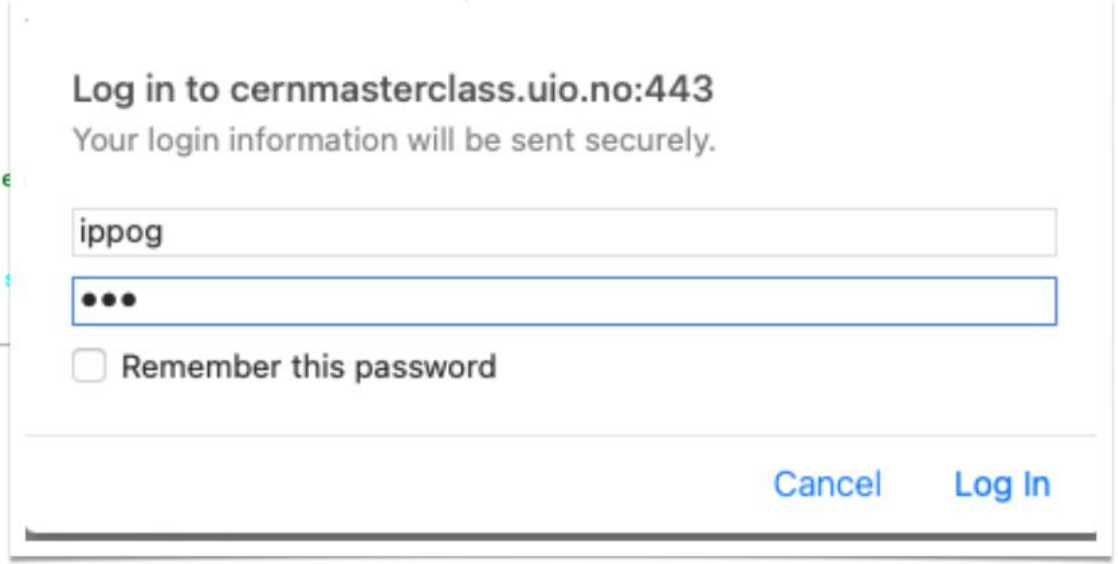


Uploading data to oplot

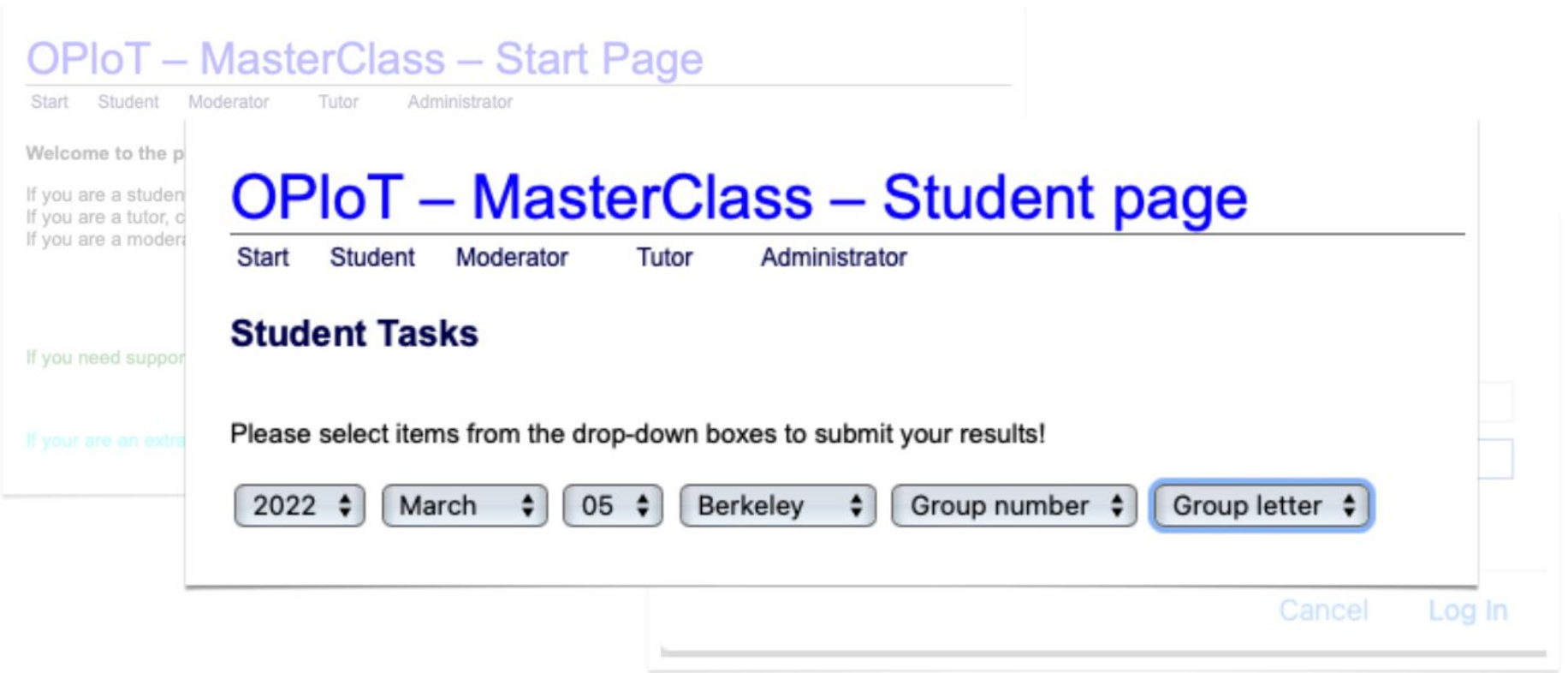
- Navigate to: https://cernmasterclass.uio.no/OPloT-US/OPloT/index.php
- Upload the data:







Account: ippog
Password: imc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