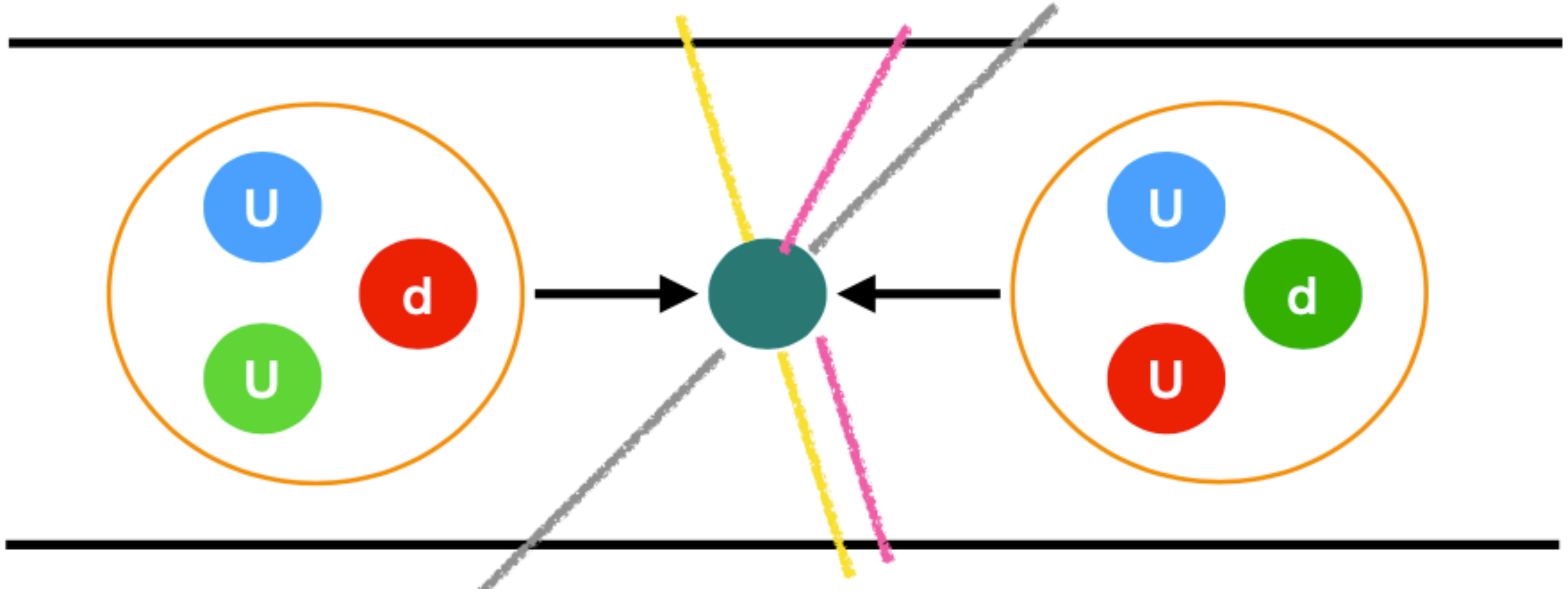
ATLAS Masterclass
Data Analysis Techniques

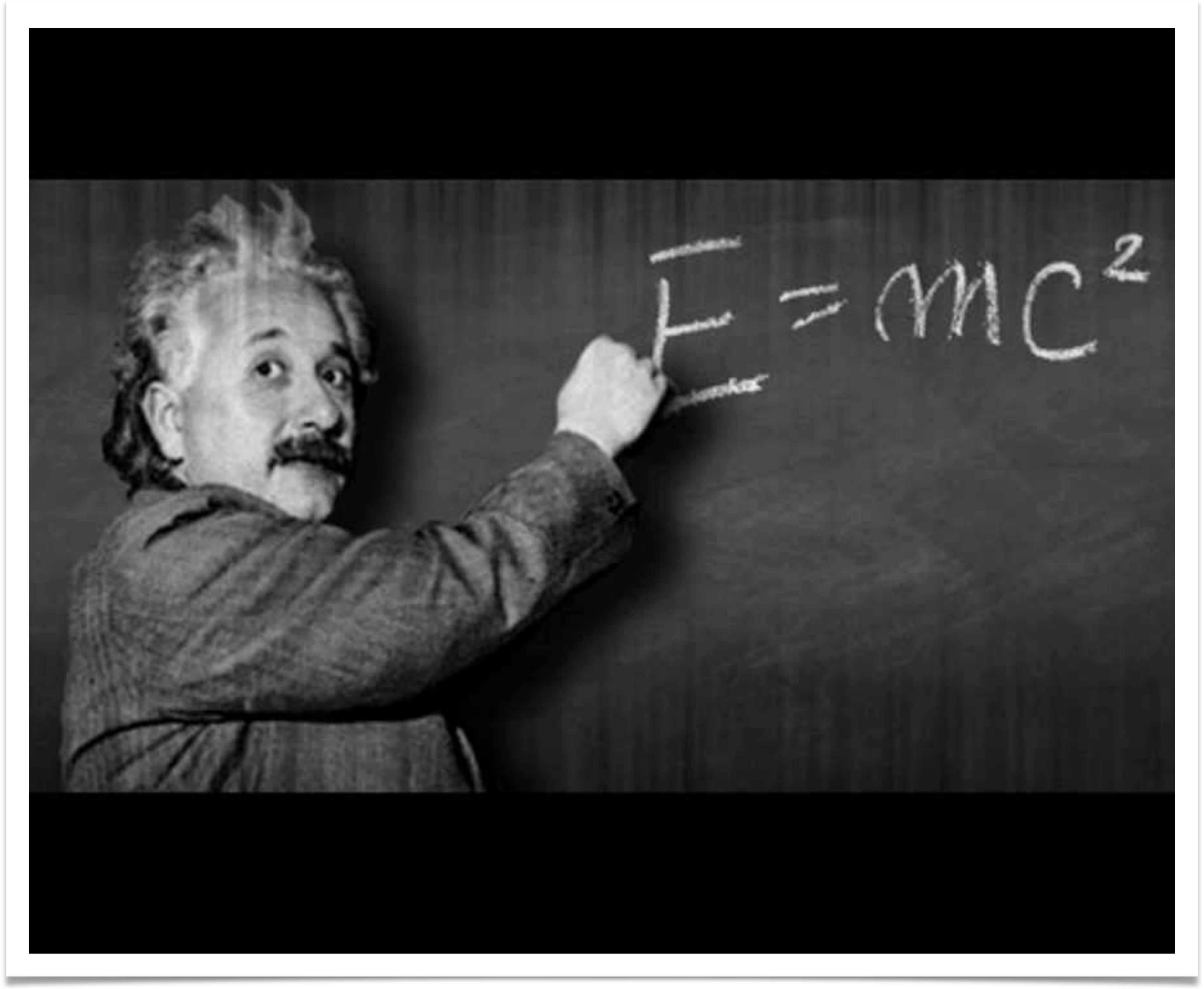
Miha Muškinja

ATALS Masterclass
Saturday, April 22, 2023

BERKELEY LAB

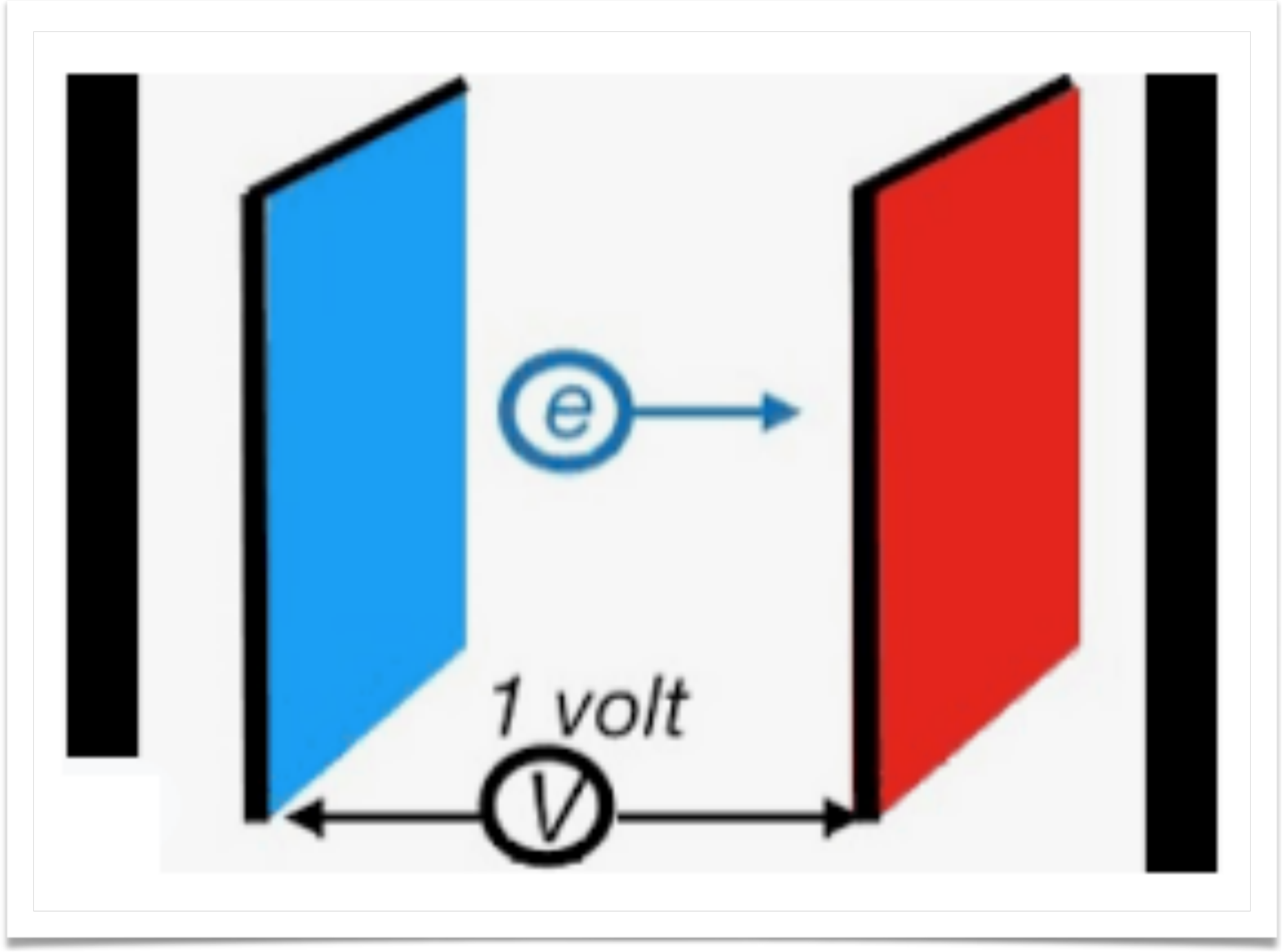
ATLAS EXPERIMENT





- Einstein: energy and mass are equivalent!
- Colliding particles with high energy produces many new particles,
- We use the Large Hadron Collider (LHC) to accelerate protons to 0.99999999 times the speed of light and collide them,
  - Between 2015 and 2018, we produced about 8,000,000 Higgs bosons in ATLAS.

- “0.99999999 times the speed of light”— inconvenient,
  - Instead of quoting the speed, we rather talk about the kinetic energy,
- Energy: ‘Joules’. However we rather use the ‘electron Volt’ unit:



1 ‘electron Volt’ or **1 eV**:

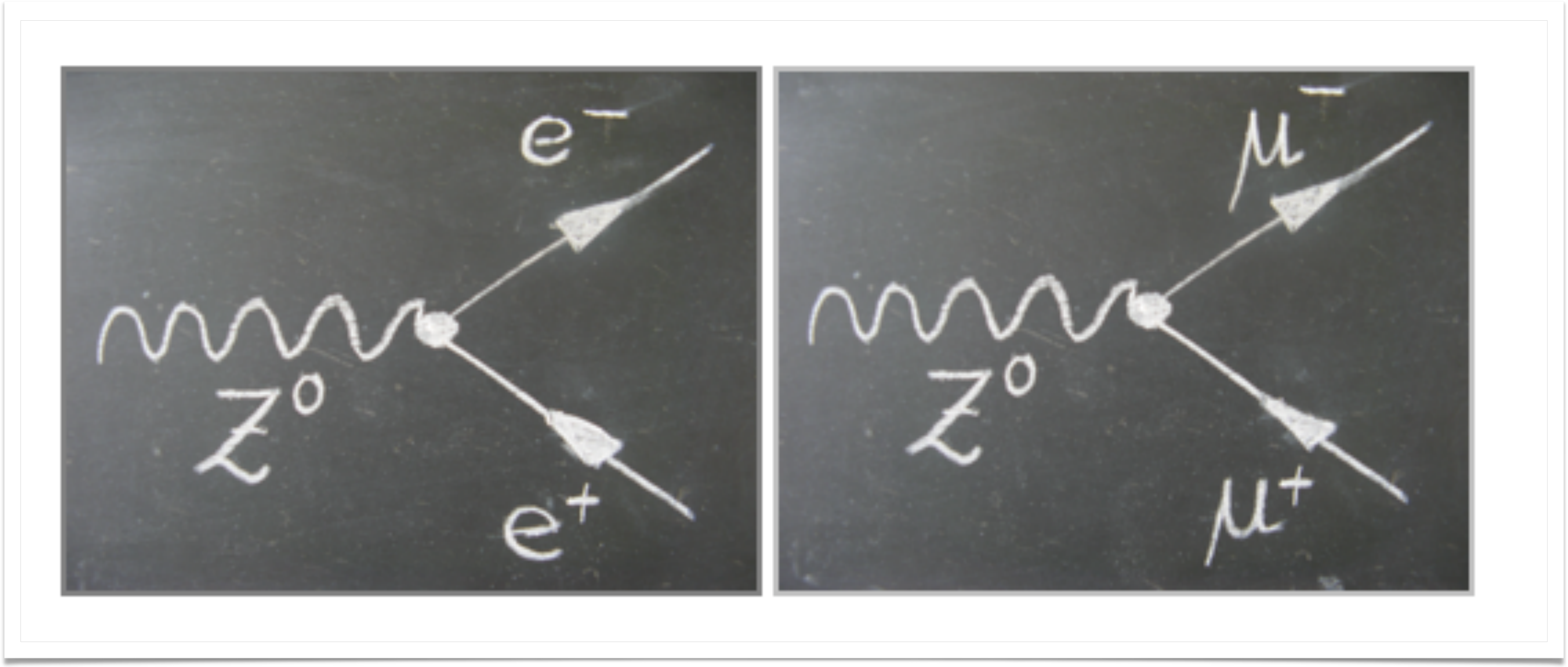
Energy gained by an electron accelerated by an electrical potential of one Volt.

1 eV = 1.6 10^{-19} J

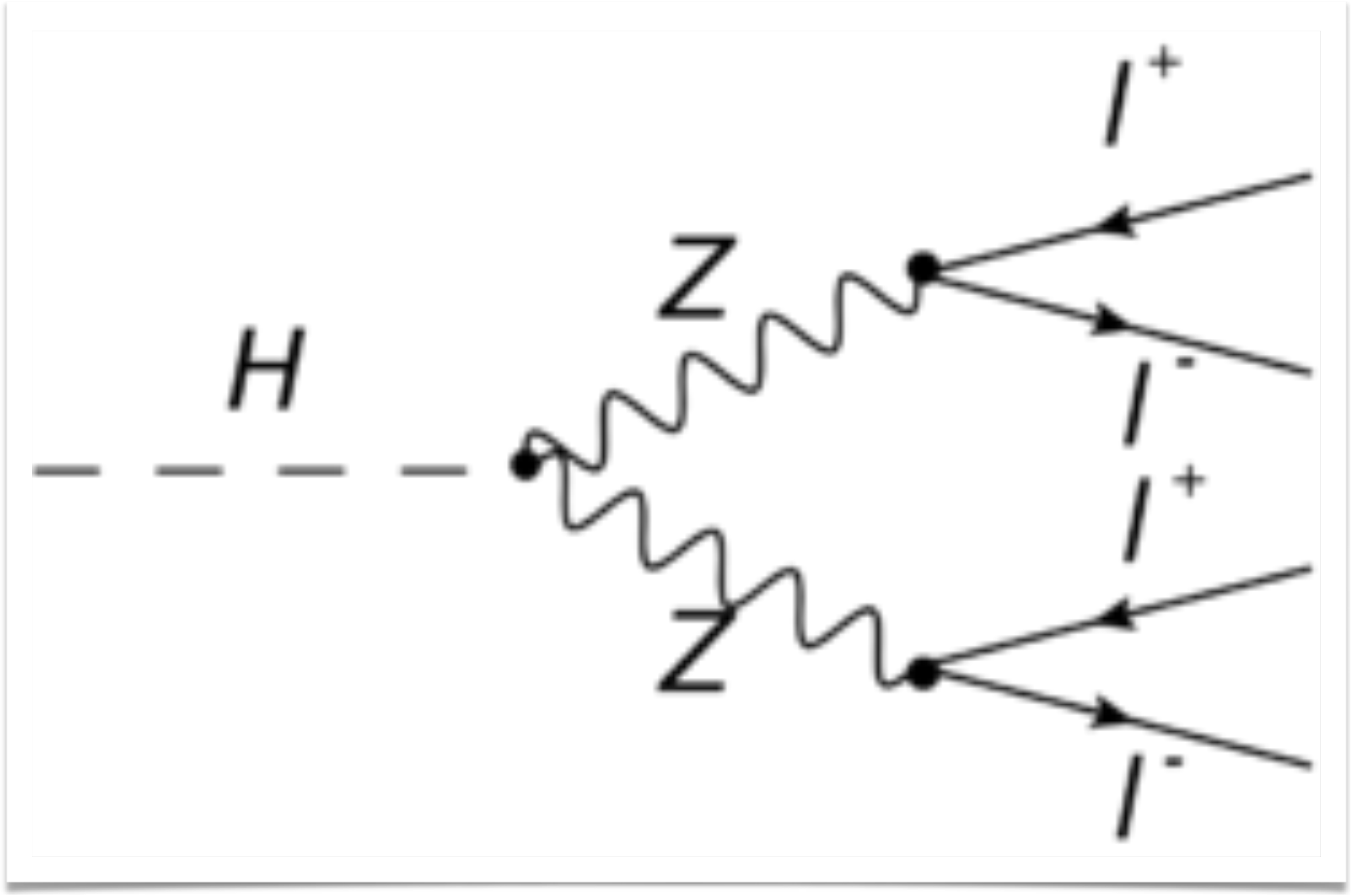
- At the LHC, we collide protons with the energy of 13 TeV = 13,000,000,000 eV,
- New particles created in these collisions typically have energy around 1—100 GeV.

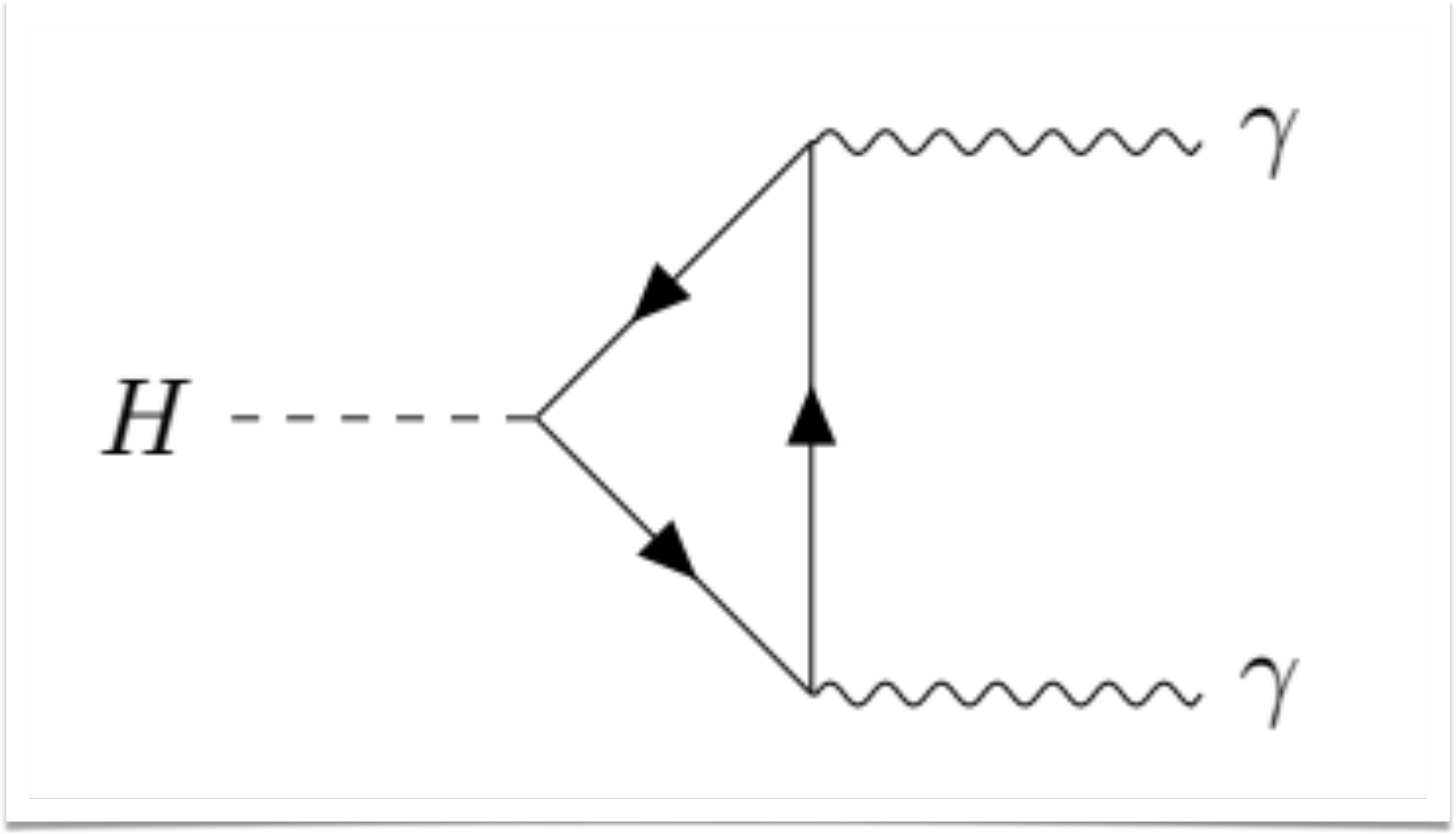
What we will be searching for today

- Today, you will be searching for the Z boson decays:

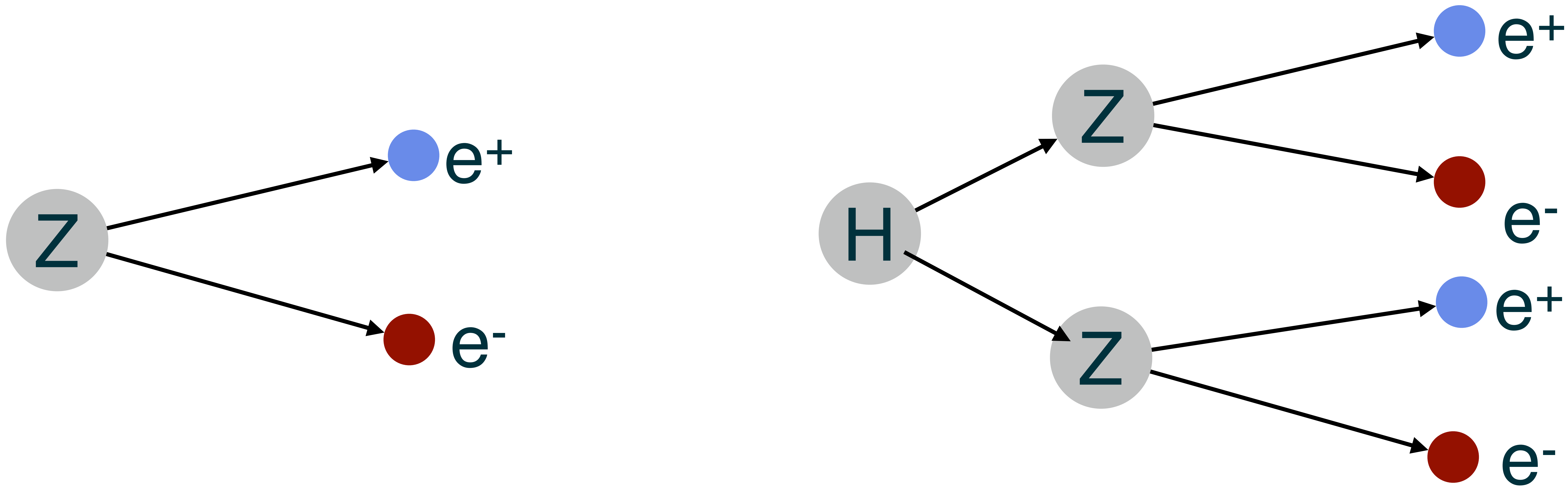


- The Z boson decays either into to two electrons or two muons,
- The Z boson has no charge. Due to charge conservation, outgoing particles have the opposite charge: e- and e+.



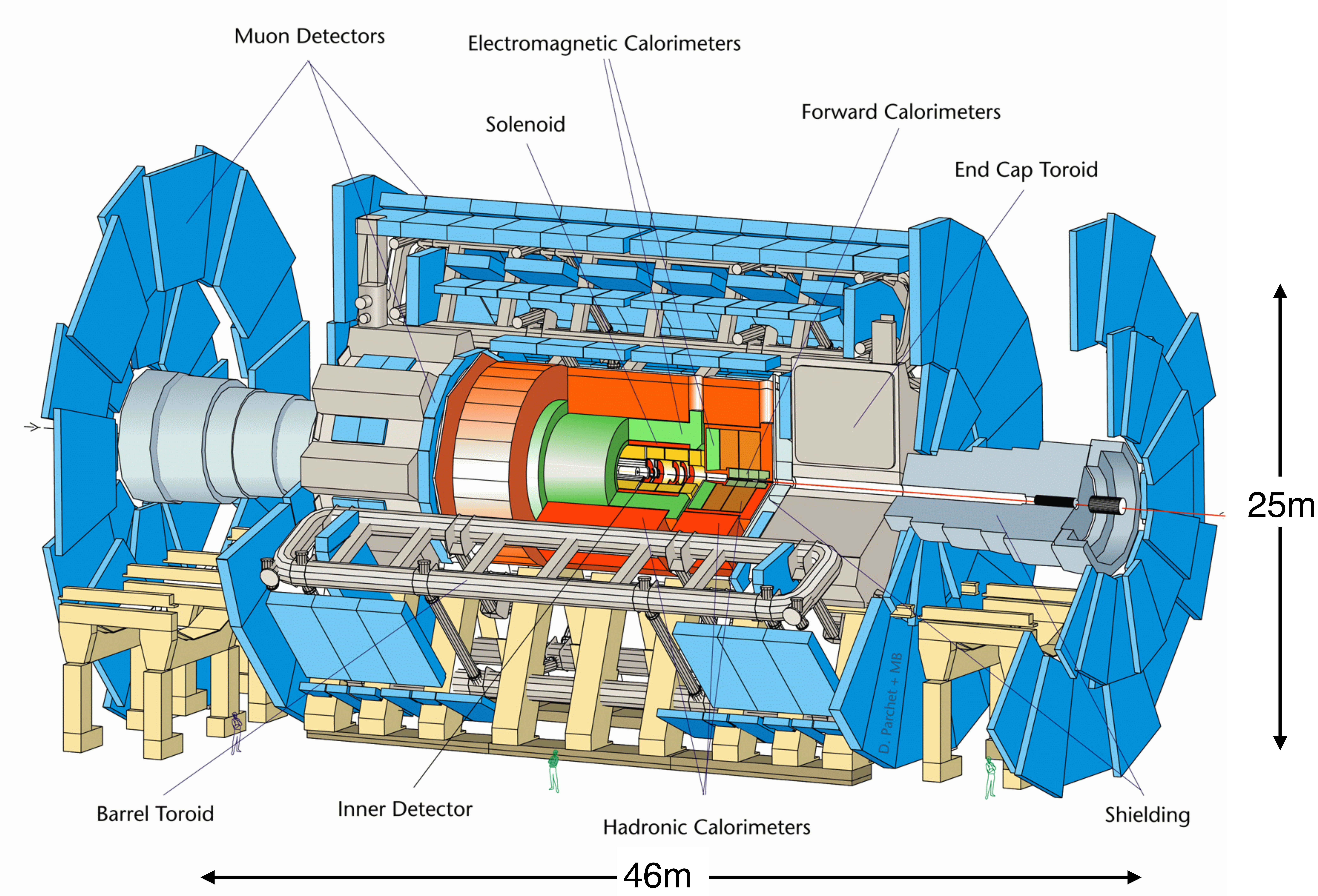


- You will also be searching for Higgs boson decays:
  - H → ZZ → 4 leptons (electrons or muons),
  - H → ɣɣ (2 photons),
- By correctly identifying the Z bosons, you will be able to reconstruct the Higgs boson!

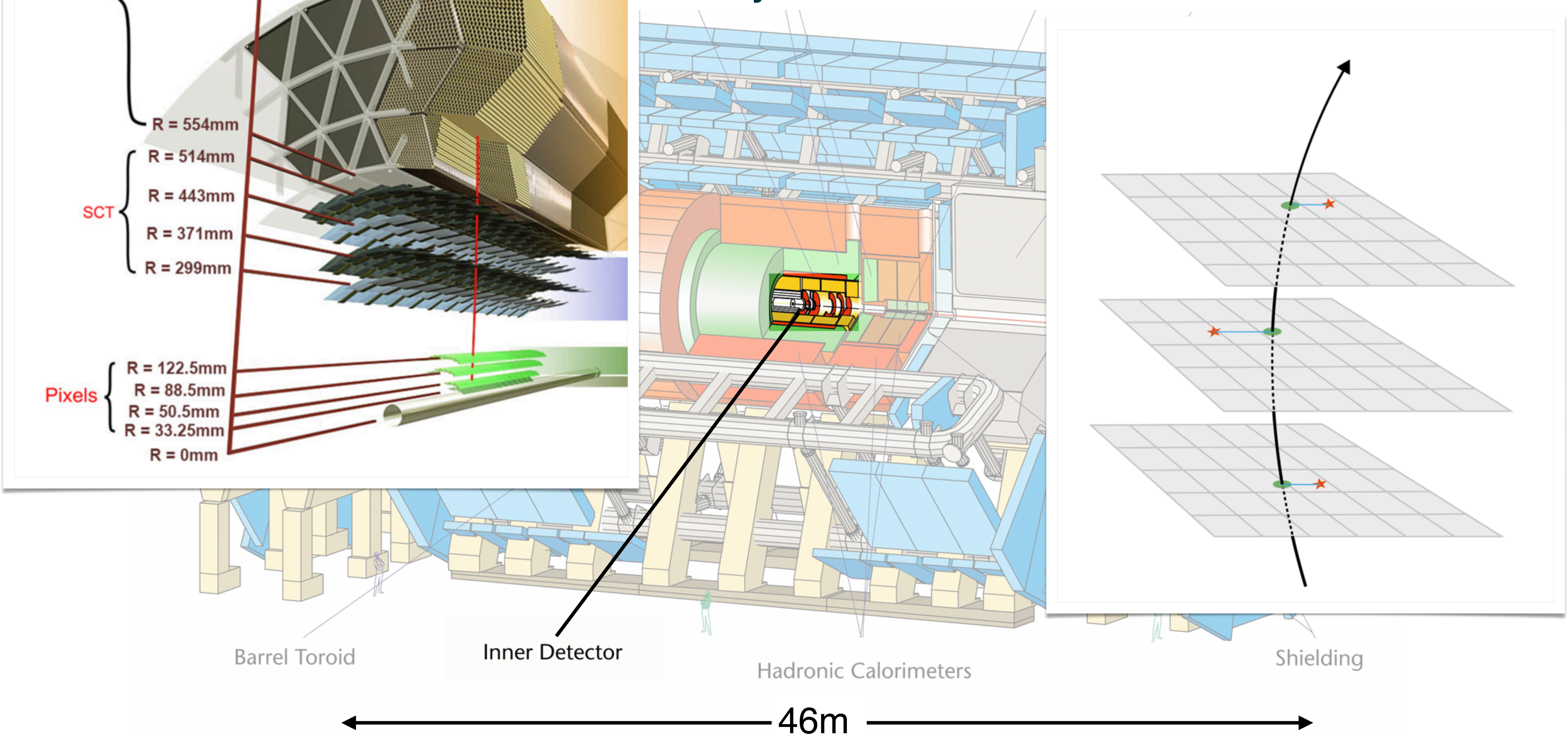


- The ATLAS detector measures the momentum of final particles only (e, μ, ɣ, …),
- With these we can reconstruct the **mass** of the initial particle (Z boson or H boson),
  - Z boson: 90 GeV,
  - H boson: 125 GeV,
- However, because the detector has some measurement error, the reconstructed mass will be scattered around the true mass.

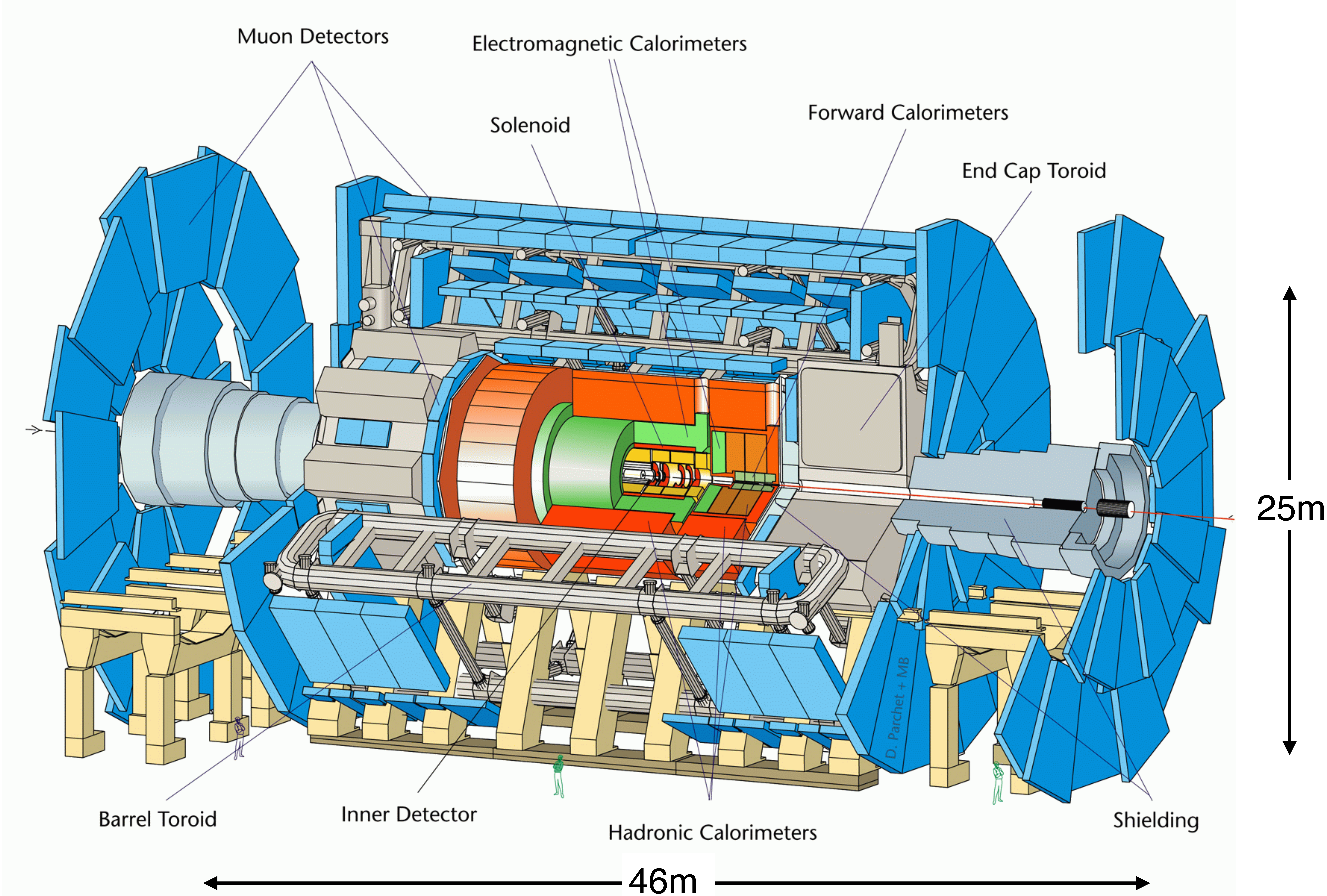
The ATLAS detector

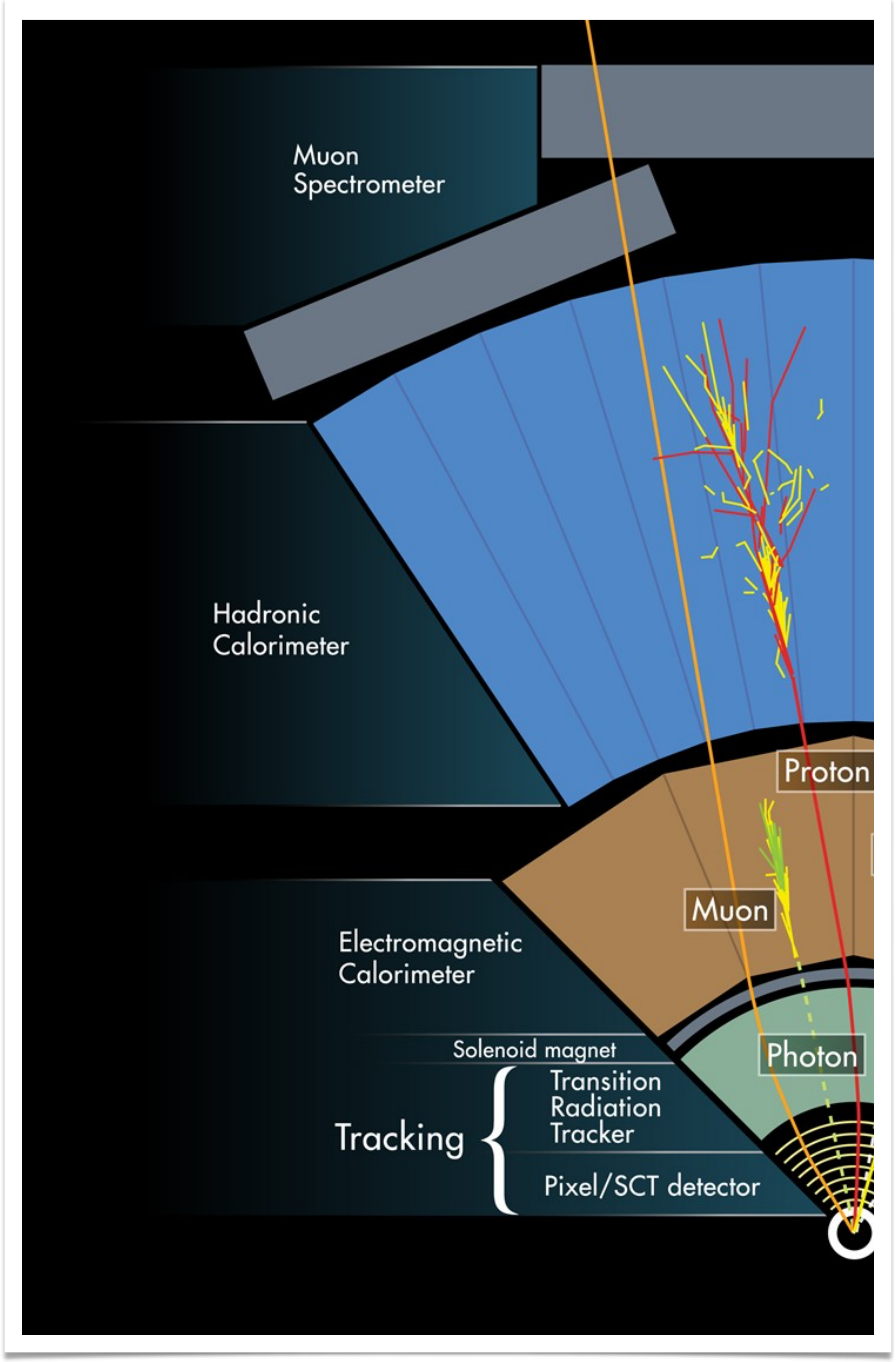


Charged particles (e.g. electron) bend in the strong magnetic field and deposits energy in the layers of the Inner Detector.

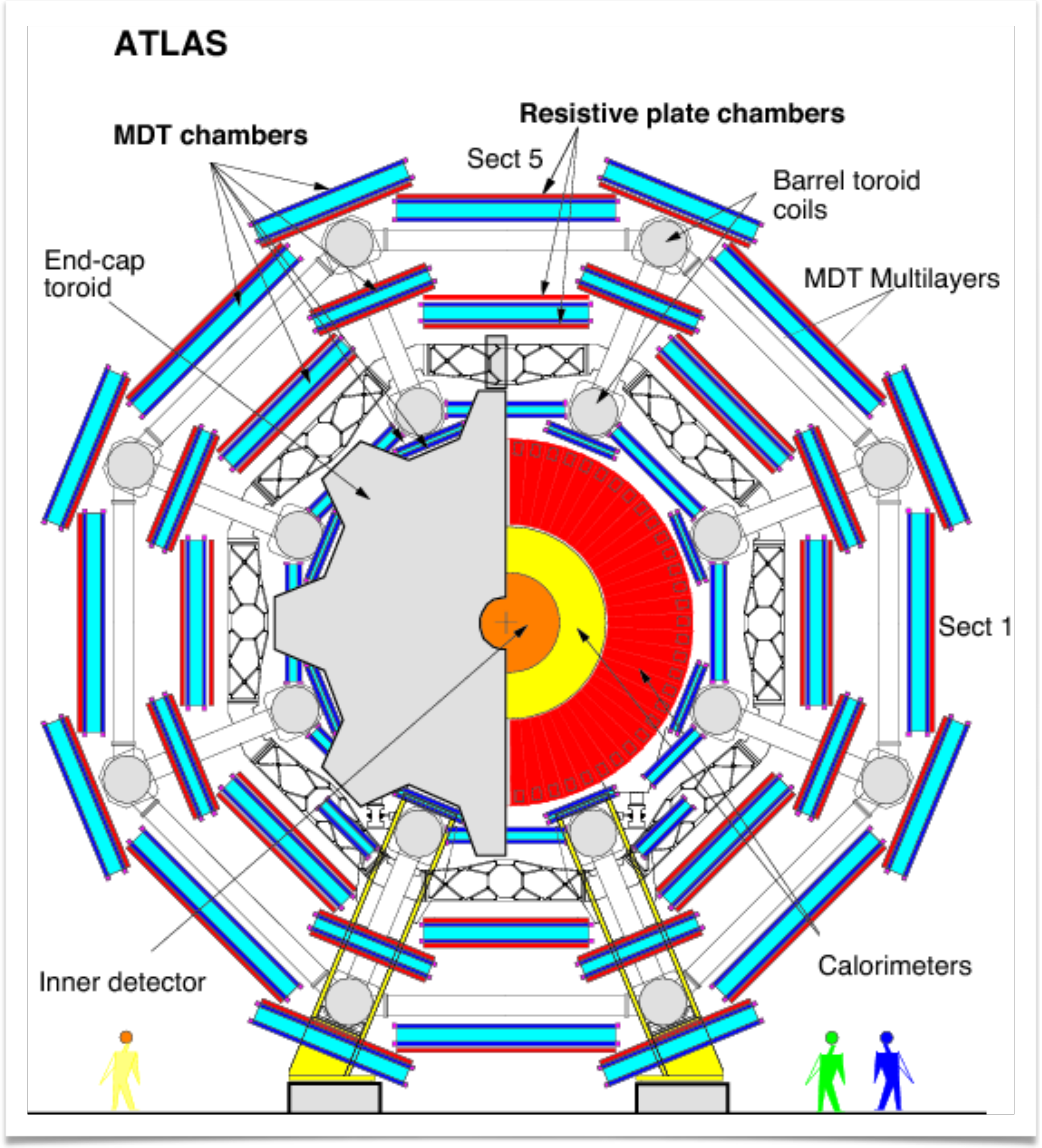


Muon Detectors



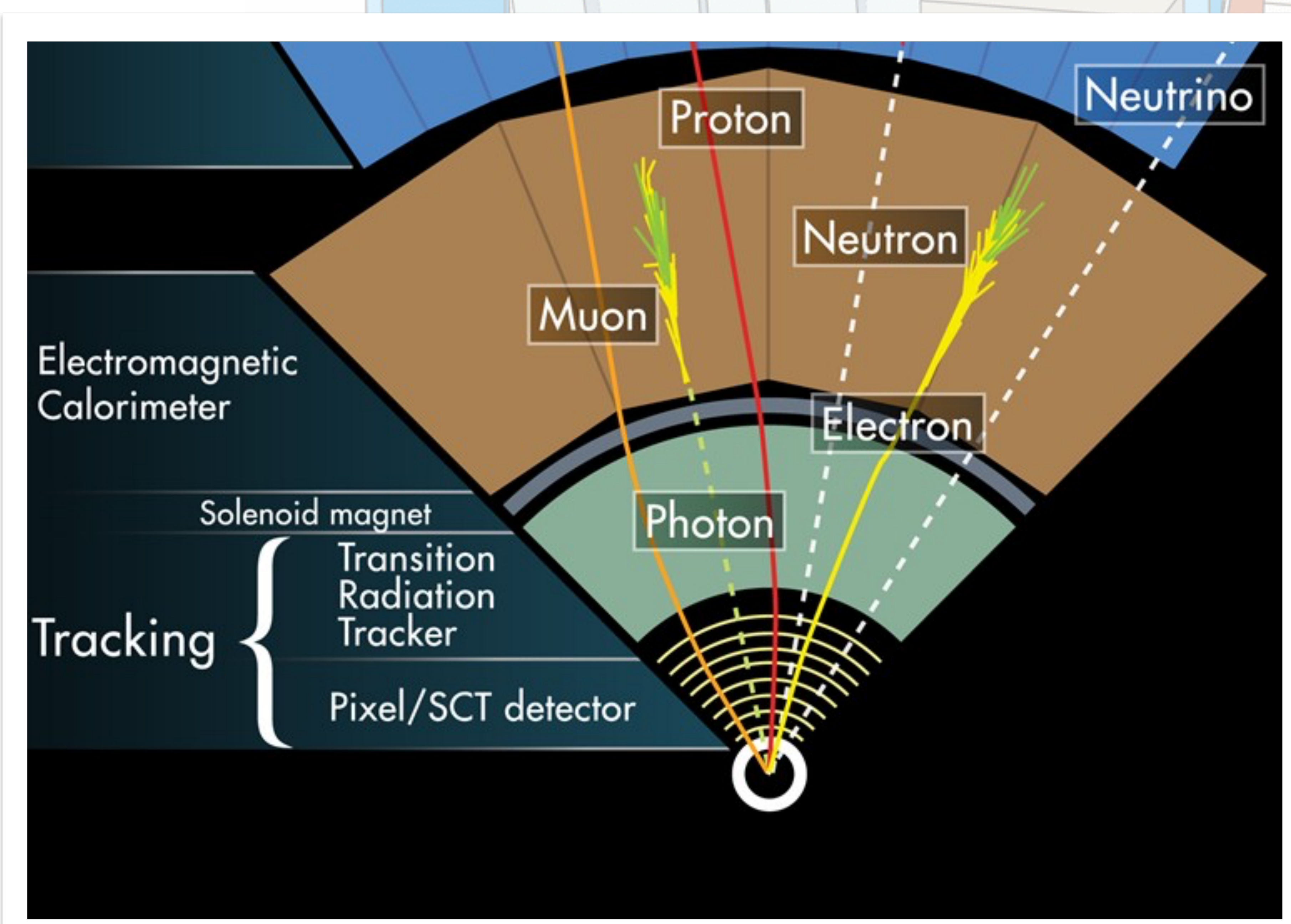


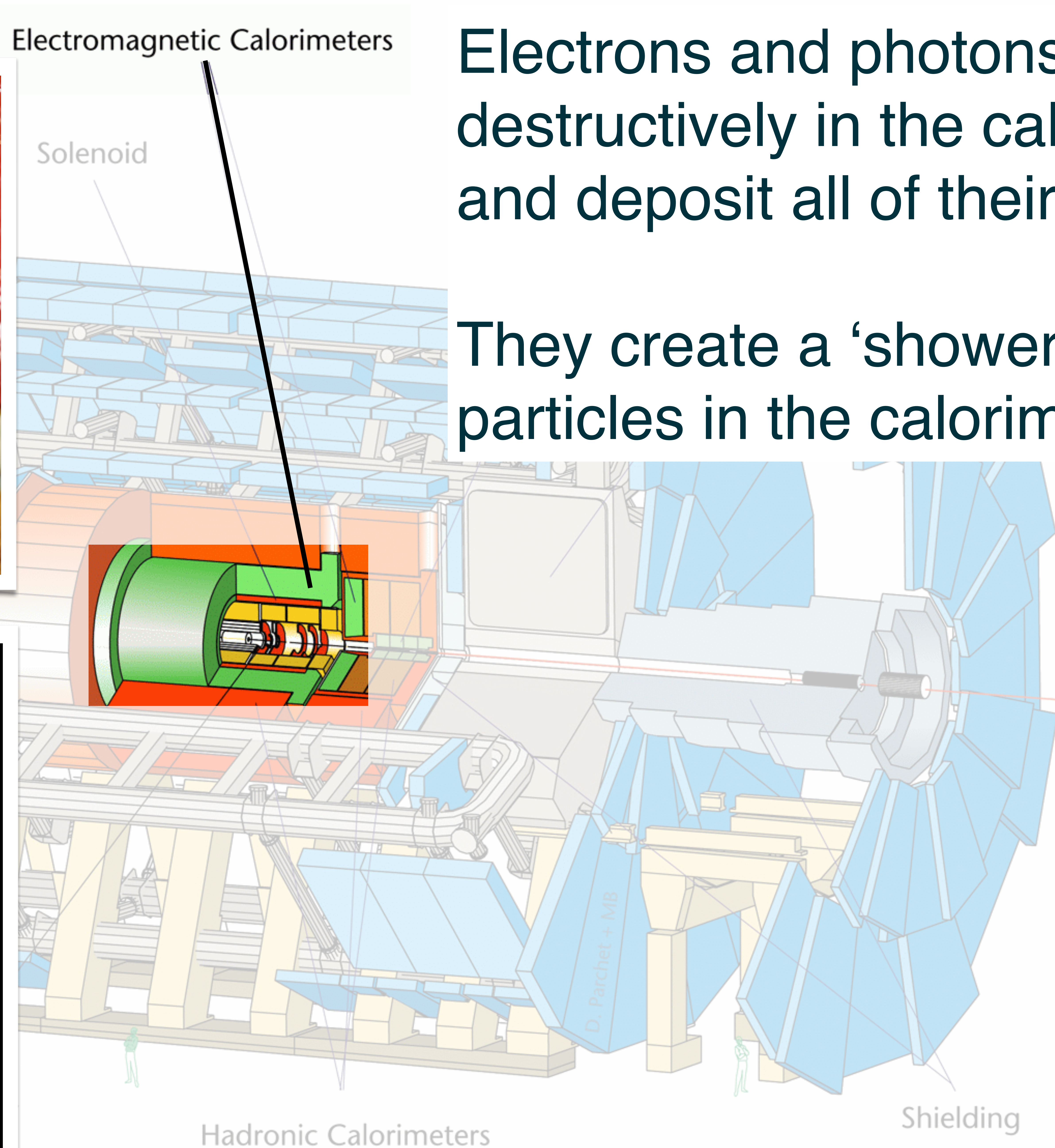
Muons are the heavier siblings of electrons. They interact with the detector material less frequently and travel all the way through. We catch them with the outer Muon Detectors.



Electrons and photons stop destructively in the calorimeter and deposit all of their energy.

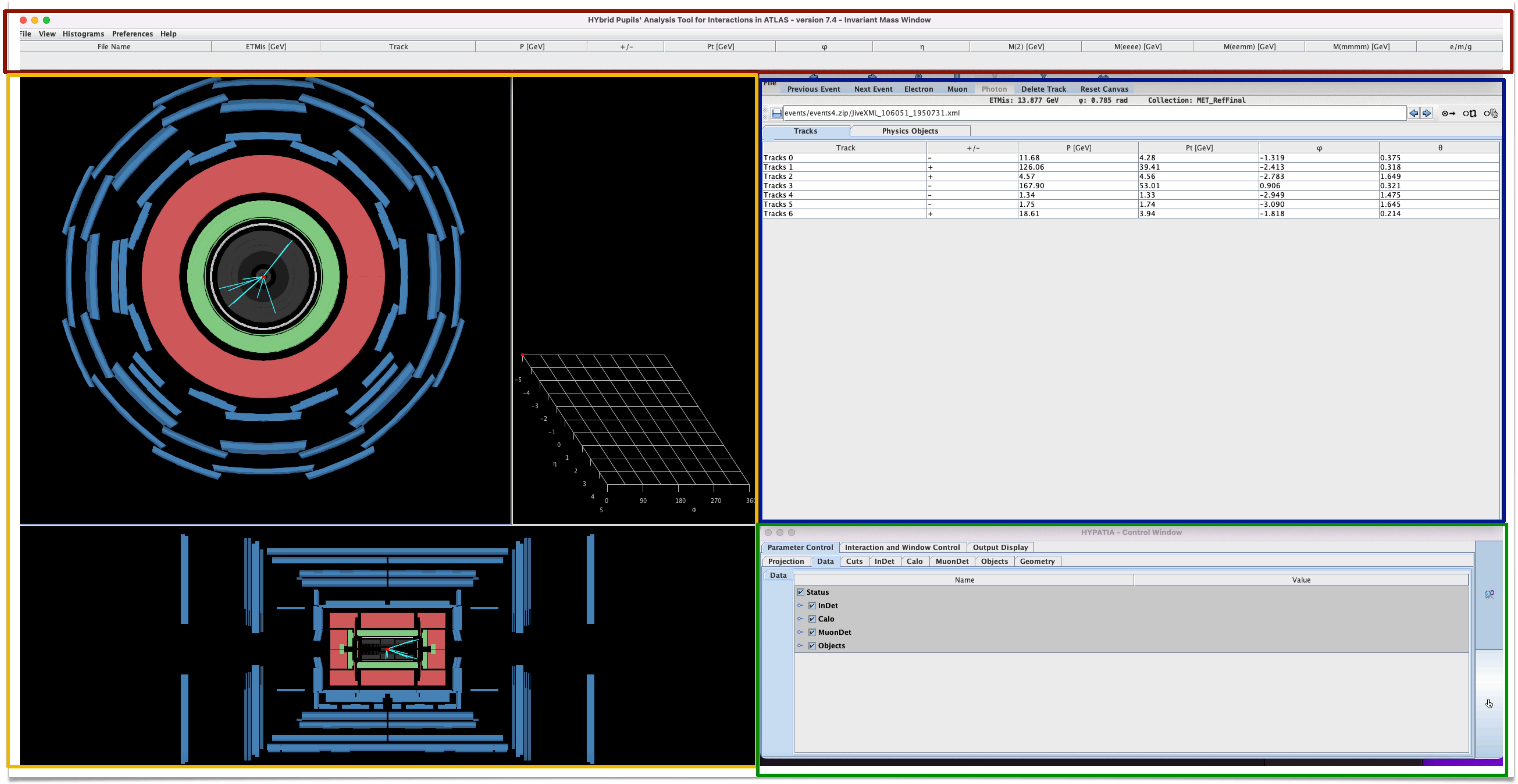
They create a ‘shower’ of particles in the calorimeter.





Hypathia software

- Four screens— 'invariant mass' window, event display, control panels.



Name	Dataset	Name	Dataset
Jia Mohan	12-A	Carlos Fernandez	12-M
Talon Joe	12-B	Claire Palmer	12-N
Adrian Womack	12-C	Andrea Torres	12-O
Zachary Capote	12-D	Jocelin Ramos	12-P
Elsie Scott	12-E	Abhiraj Jalagekar	12-Q
Ryan Tonkovich	12-F	Miya Takeuchi	12-R
Benite Bazinga	12-G	Rigby Shaw	12-S
Xenia Gomez Iñiguez	12-H	Jaden Patel	12-T
Hagan Sum	12-I	Jadin Mom	13-A
Vincent Vazquez	12-J	Isaac Wong	13-B
Nora Weltman	12-K	karina pablo calmo	13-C
Michael Lac	12-L		

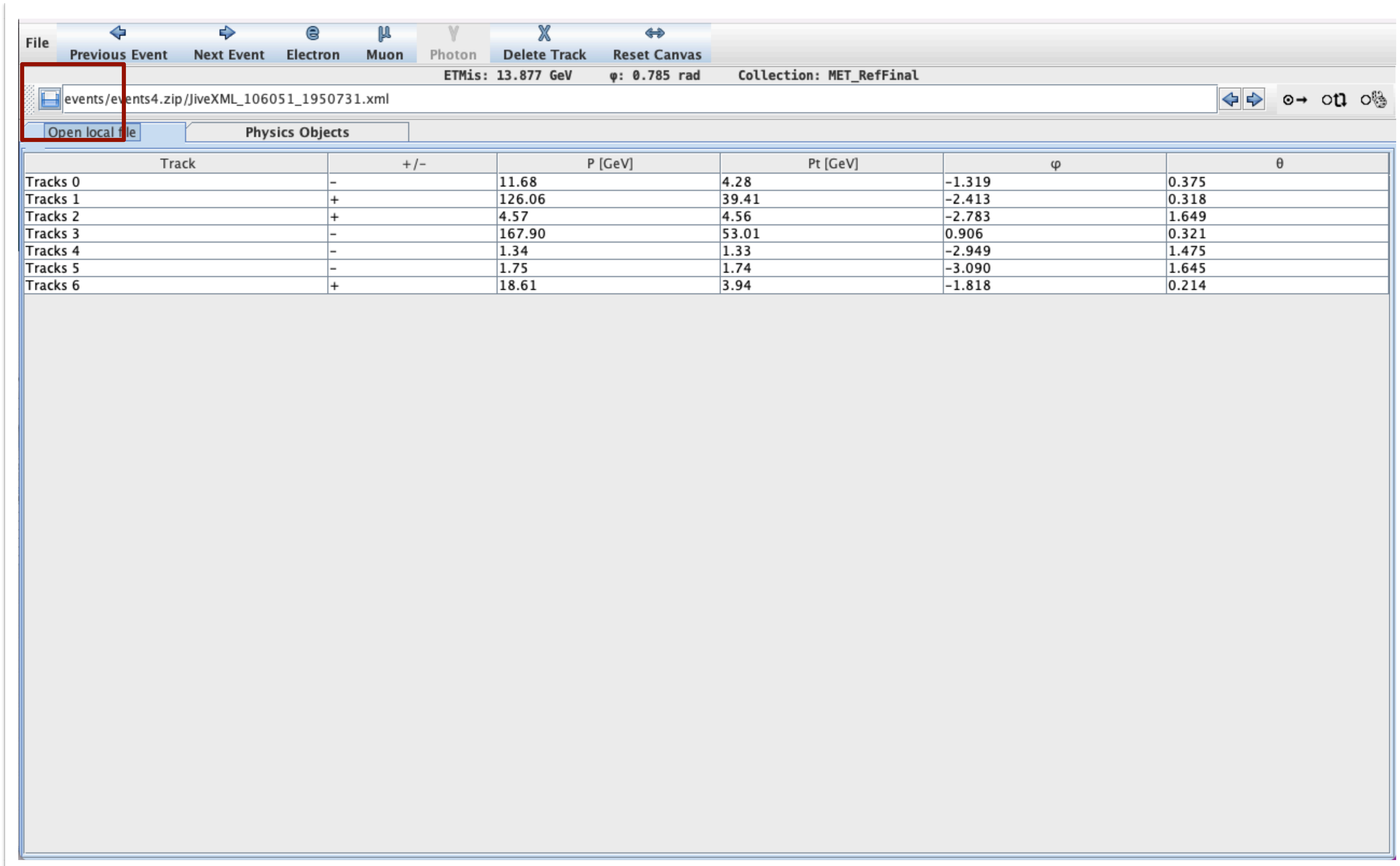
- https://quarknet.org/content/atlas-z-path-measurement

Data assignments for CERN masterclass institutes

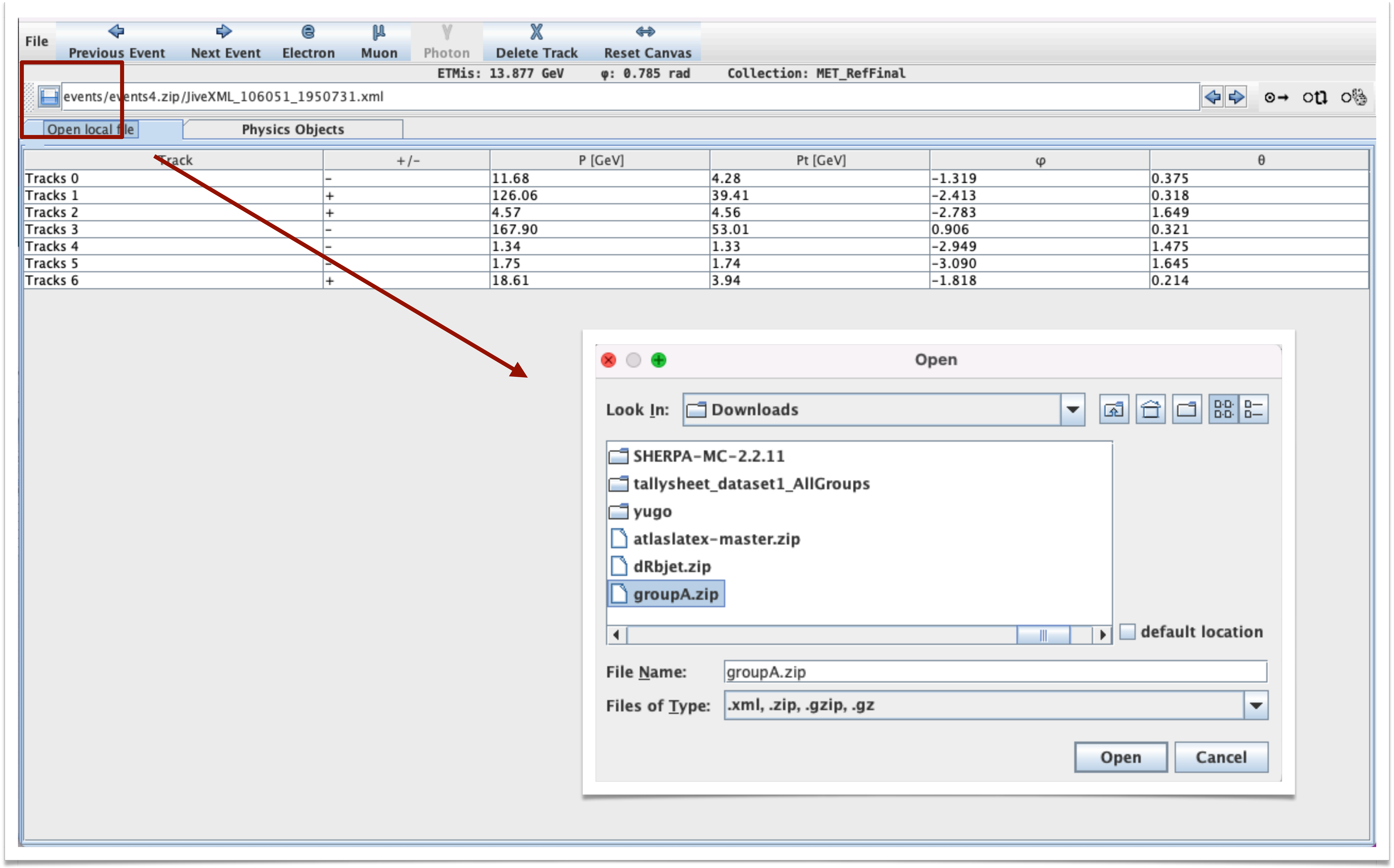
Table of data assignments for Fermilab 2023 masterclass institutes.

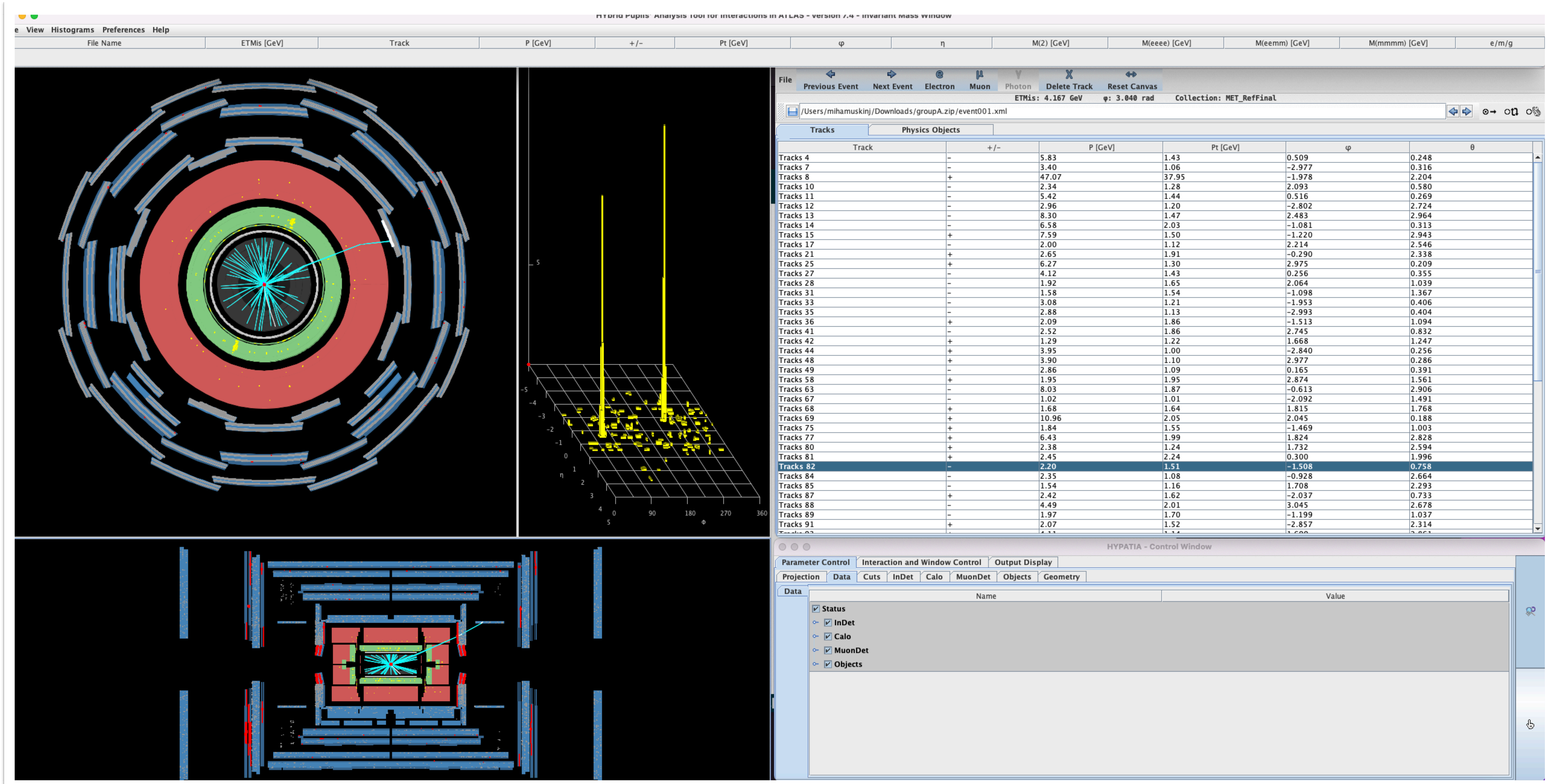
Date	**Institute, data groups**	**Institute, data groups**	**Institute, data groups**
Sat 25 Feb	LisboaUni, **1** and **2**		
Fri 03 Mar	Stillwater A, **1** and **2**	Ruston, **3** and **4**	
Sat 04 Mar	Santa Cruz, **5** and **6**		
Thu 09 Mar	Dallas, **7** and **8**		
Tue 14 Mar	DeKalb, **10** and **11**		
Fri 24 Mar	Stillwater B, **13** and **14**		
Sat 25 Mar AM	LisboaLIP, **1**. **2**, and **3**	Coimbra, **4**, **5**, **10**, and **11**	Evora, **6** and **7**
Sat 25 Mar PM	Stillwater C, **8** and **9**		
Fri 31 Mar	Stillwater D, **10** and **11**		
Thu 06 Apr	Accra, **1** and **2**		
Sat 22 Apr	Berkeley, **12** and **14**		

E-mail for data login and password.


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
Open local file
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 + 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

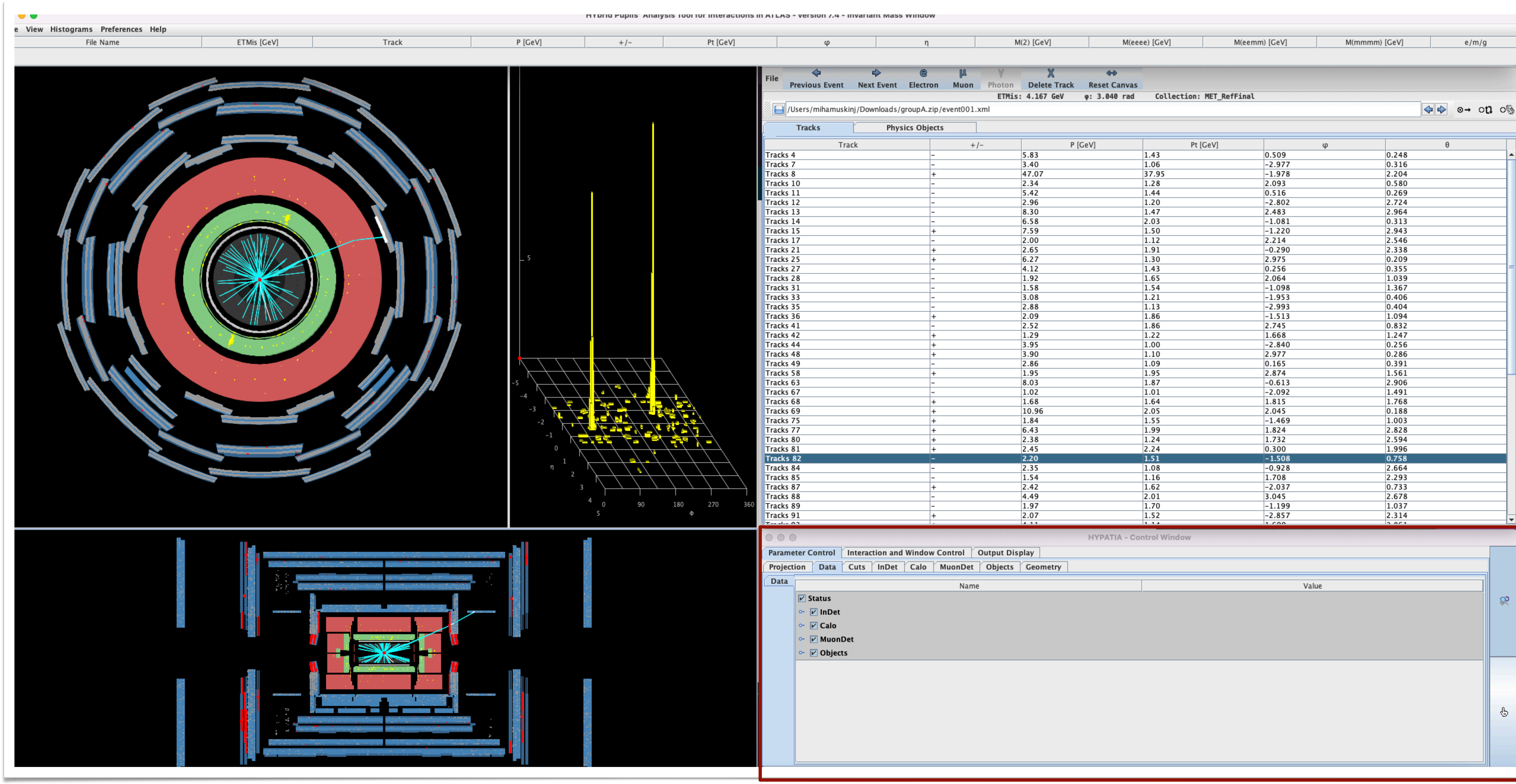
Hypathia navigation: Loading the data




View Histograms Preferences Help
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
File
Previous Event Next Event Electron Muon Photon Delete Track Reset Canvas
ETMis: 4.167 GeV φ: 3.040 rad Collection: MET_RefFinal
/Users/mihamuskinj/Downloads/groupA.zip/event001.xml
Tracks Physics Objects
Track +/- P [GeV] Pt [GeV] φ θ
Tracks 4 - 5.83 1.43 0.509 0.248
Tracks 7 - 3.40 1.06 -2.977 0.316
Tracks 8 + 47.07 37.95 -1.978 2.204
Tracks 10 - 2.34 1.28 2.093 0.580
Tracks 11 - 5.42 1.44 0.516 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 0.209
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 + 2.09 1.86 -1.513 1.094
Tracks 41 - 2.52 1.86 2.745 0.832
Tracks 42 + 1.29 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 0.165 0.391
Tracks 58 + 1.95 1.95 2.874 1.561
Tracks 63 - 8.03 1.87 -0.613 2.906
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
Tracks 77 + 6.43 1.99 1.824 2.828
Tracks 80 + 2.38 1.24 1.732 2.594
Tracks 81 + 2.45 2.24 0.300 1.996
Tracks 82 - 2.20 1.51 -1.508 0.758
Tracks 84 - 2.35 1.08 -0.928 2.664
Tracks 85 - 1.54 1.16 1.708 2.293
Tracks 87 + 2.42 1.62 -2.037 0.733
Tracks 88 - 4.49 2.01 3.045 2.678
Tracks 89 - 1.97 1.70 -1.199 1.037
Tracks 91 + 2.07 1.52 -2.857 2.314
HYPATIA - Control Window
Parameter Control Interaction and Window Control Output Display
Projection Data Cuts InDet Calo MuonDet Objects Geometry
Data
Name Value
Status
InDet
Calo
MuonDet
Objects

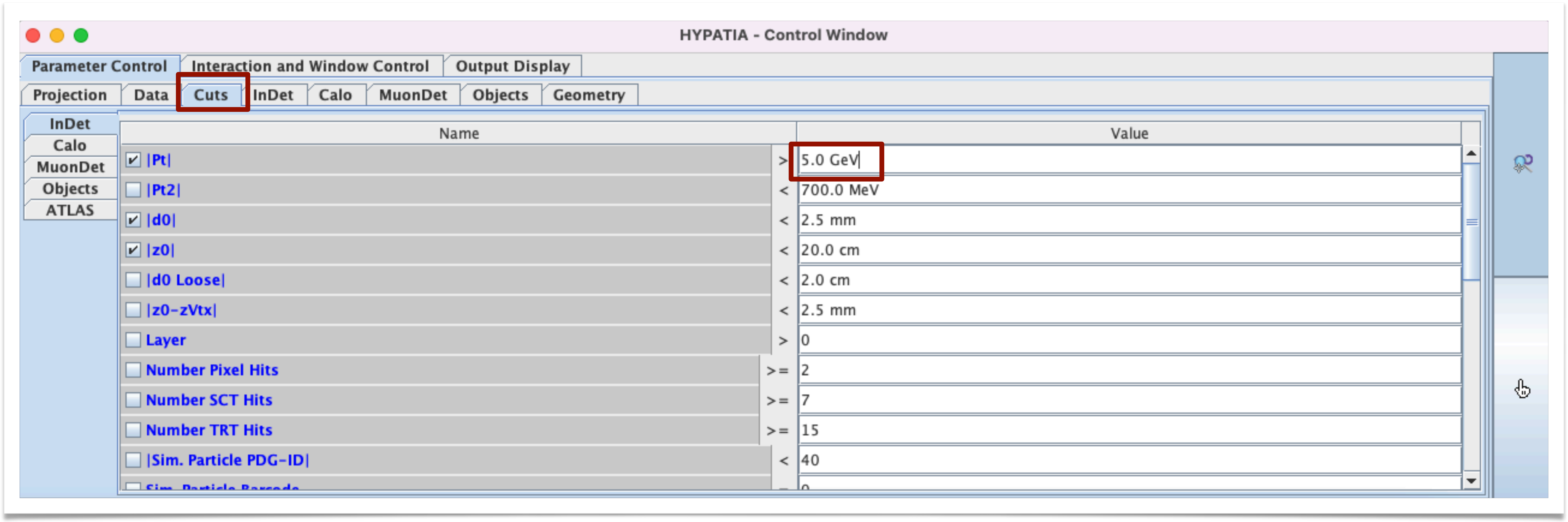
Adding cuts

Hypathia navigation: Adding cuts

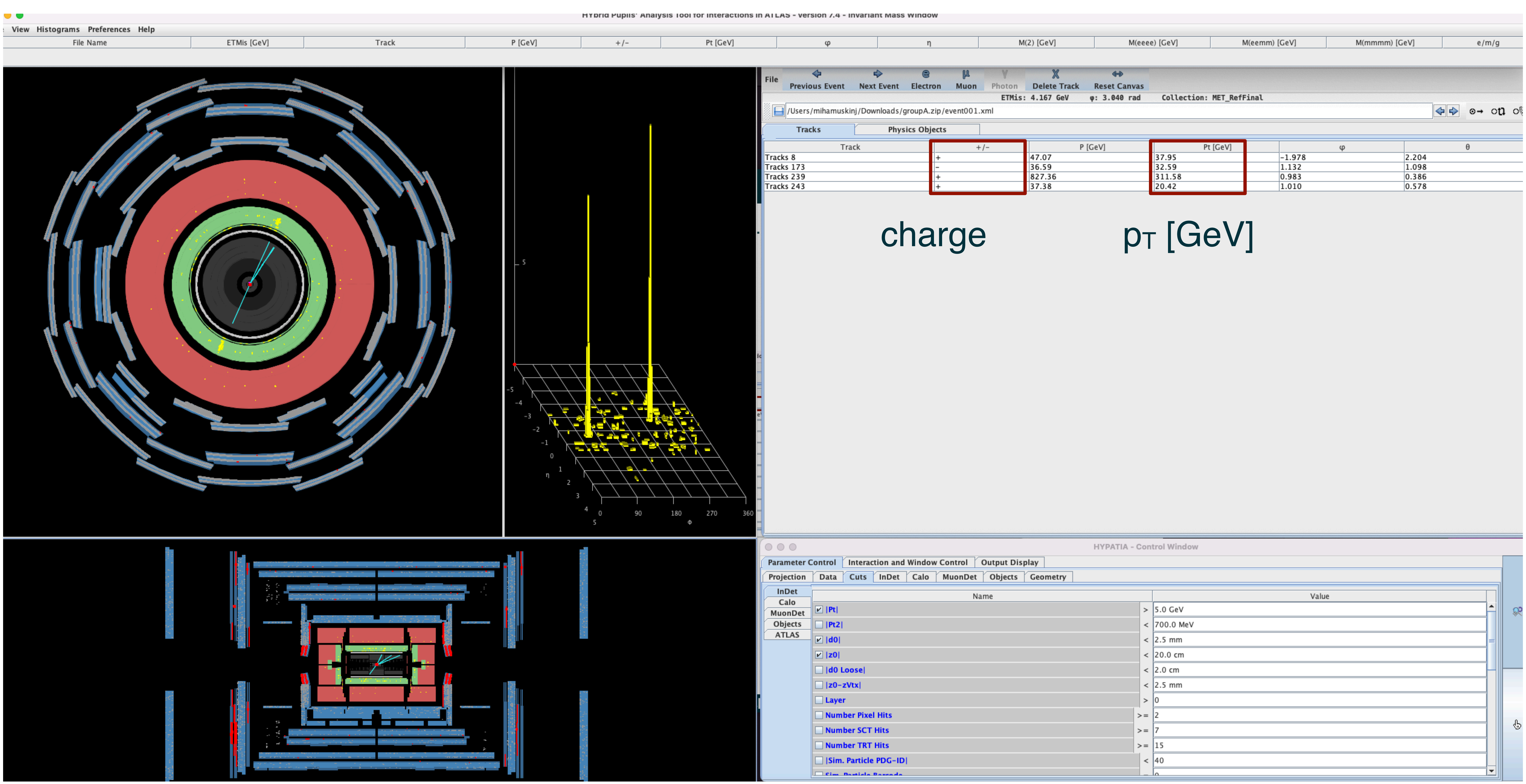


Hypathia navigation: Adding cuts

- Change the track p_T cut to 10 GeV to remove fake tracks…

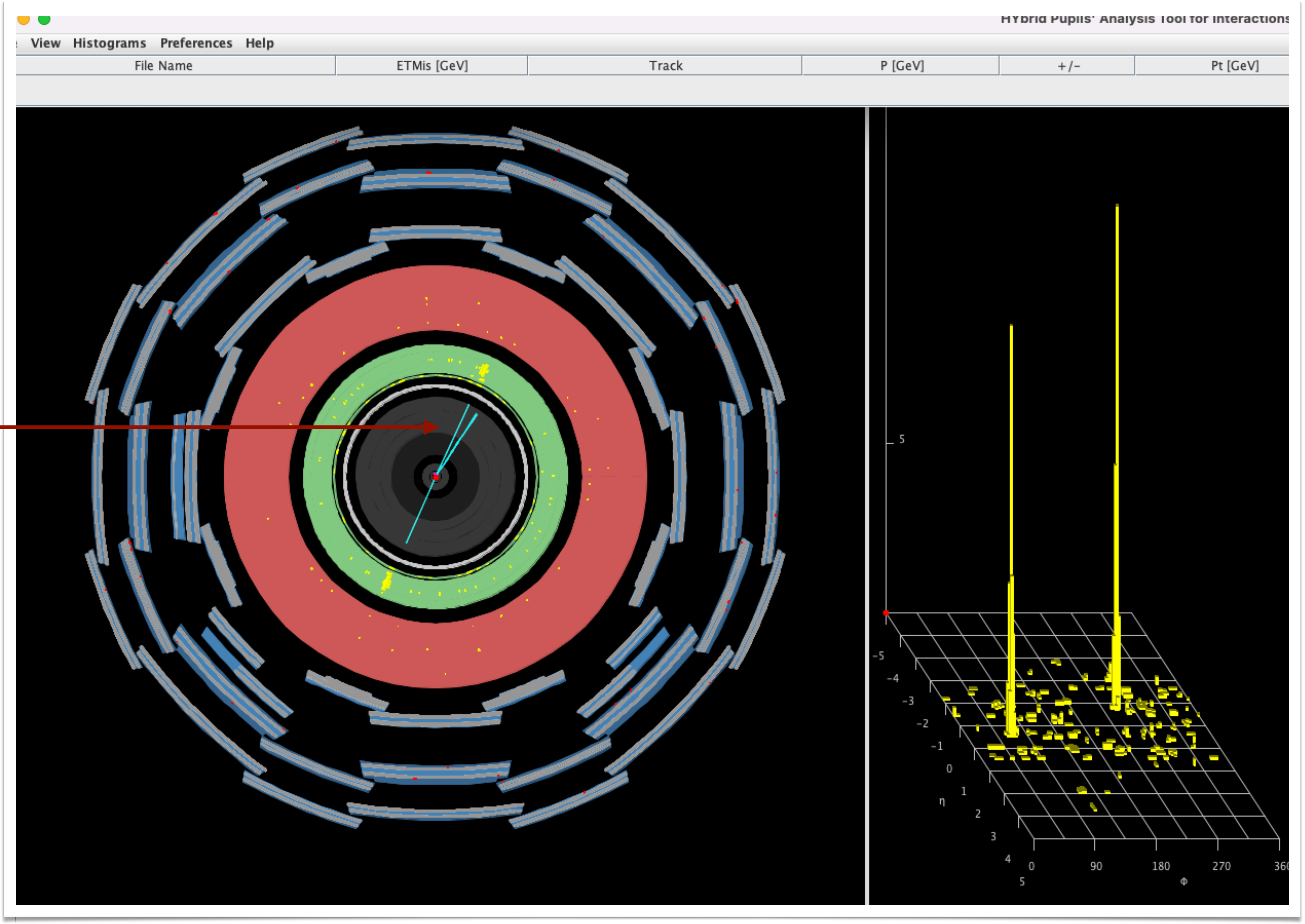


Hypathia navigation: Adding cuts

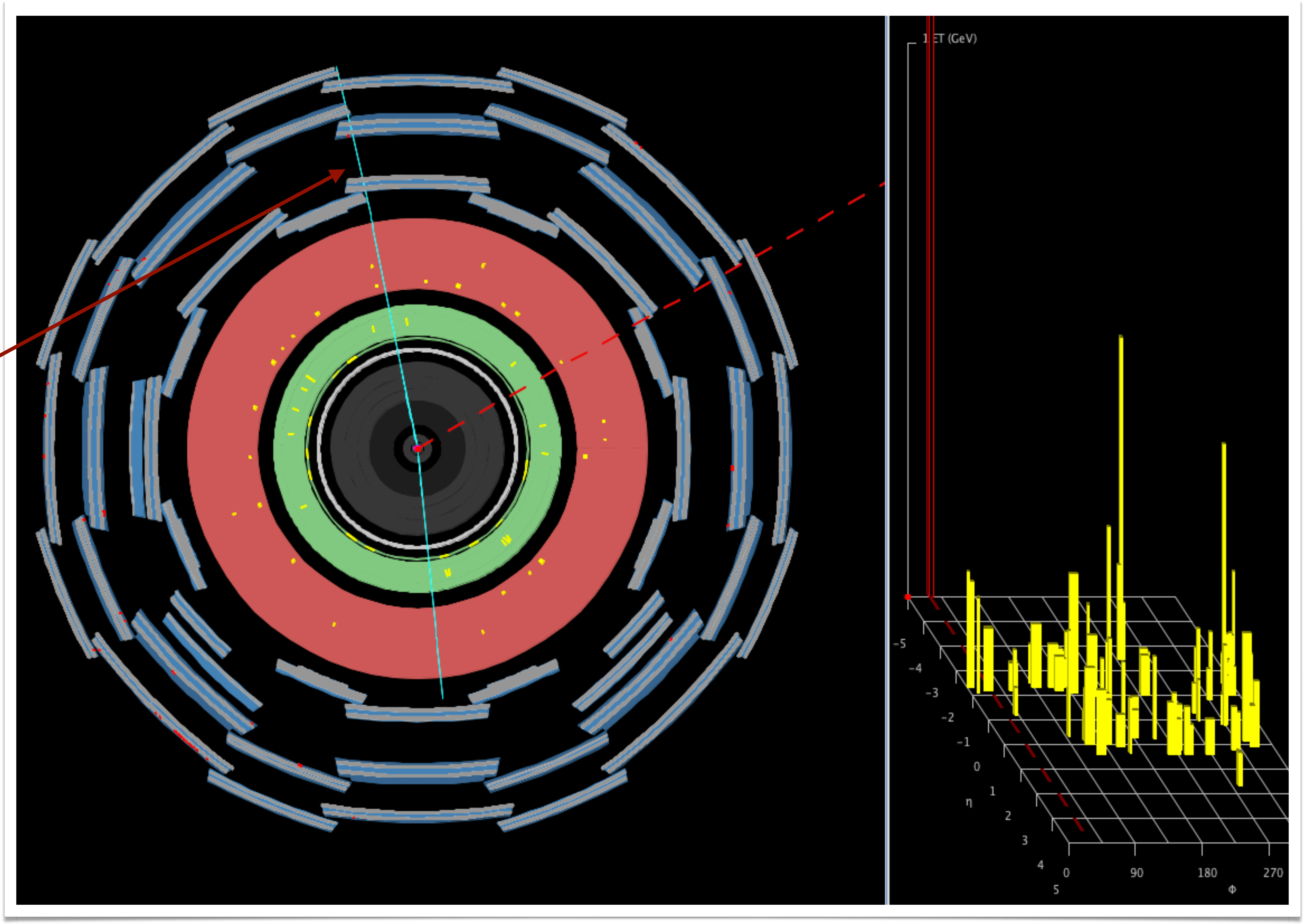


Particle identification

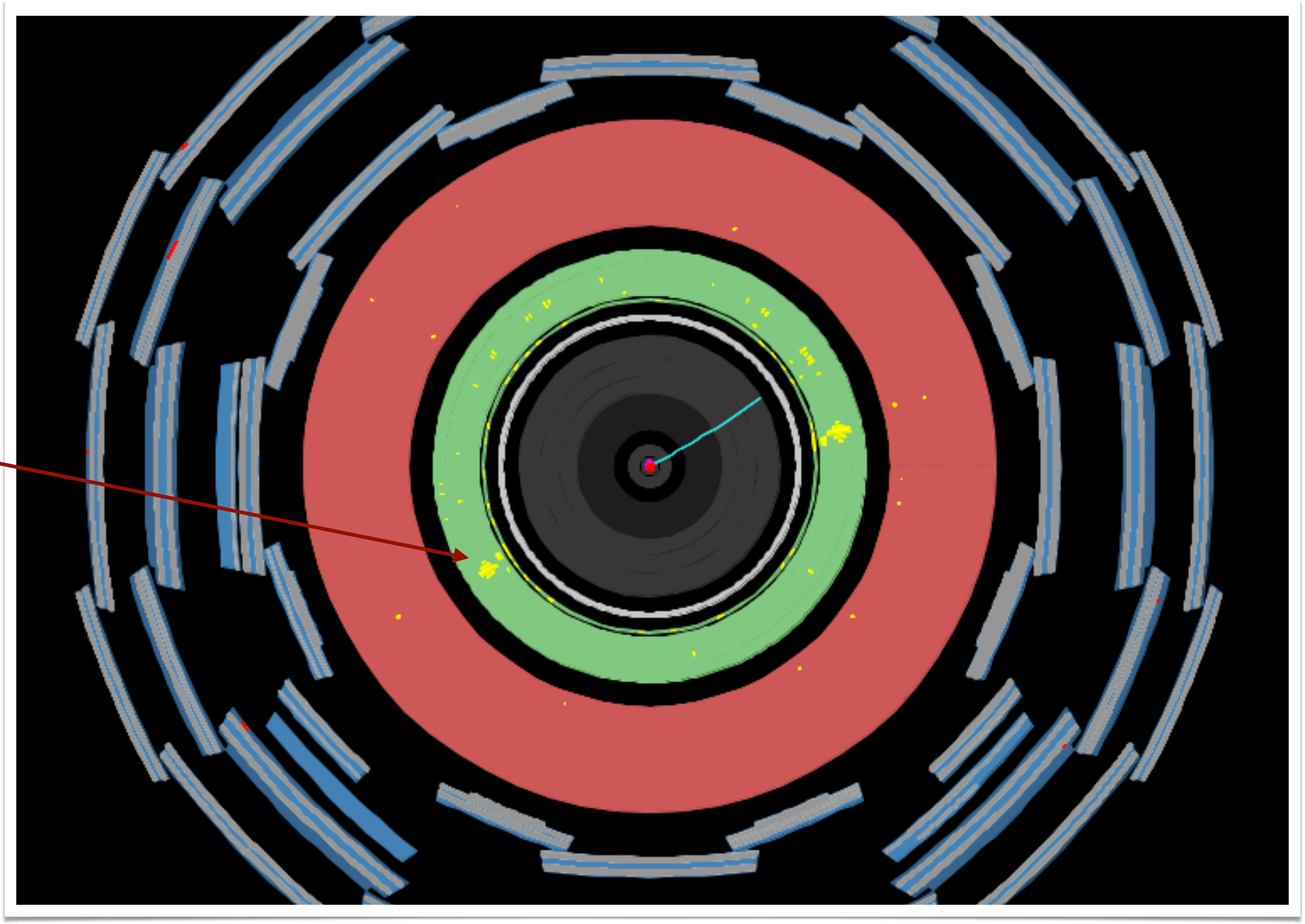
Electron:
- ID track
- Calo deposit

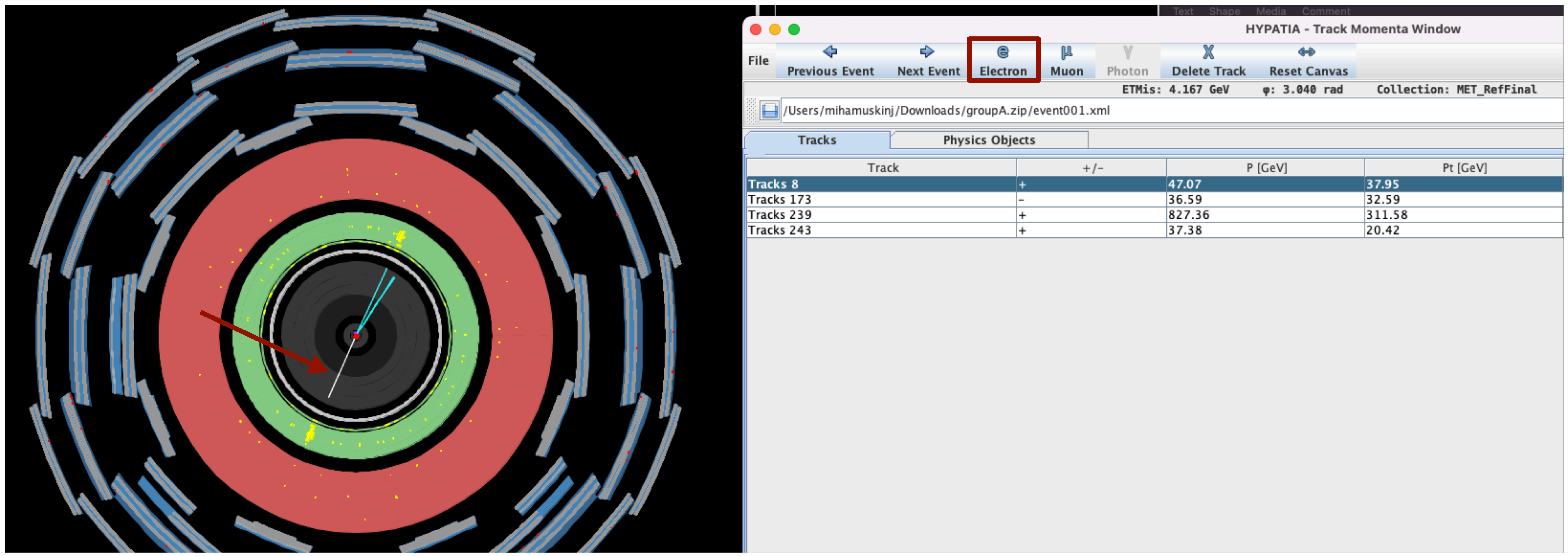


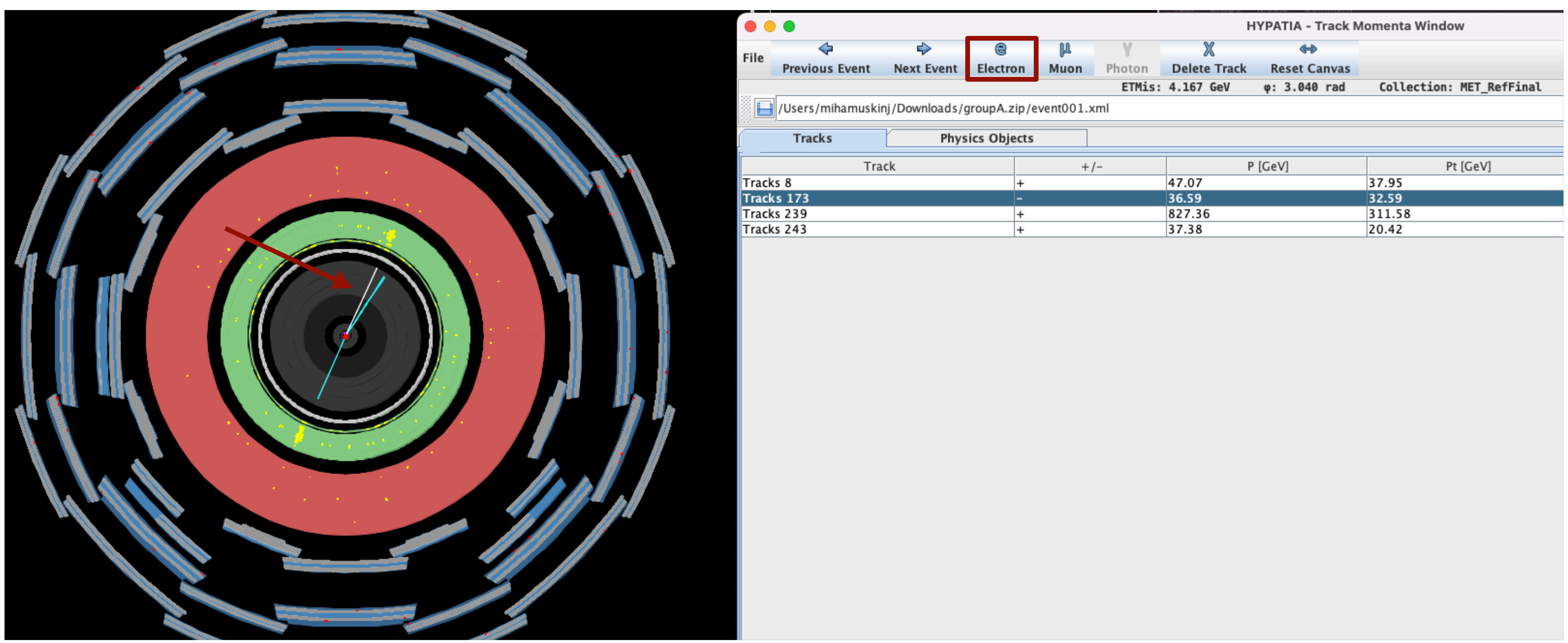
Muon:
- MS track



Photon:
- Calo deposit
- No ID track




HYPATIA - Track Momenta Window
File
Previous Event
Next Event
Electron
Muon
Photon
Delete Track
Reset Canvas
ETMis: 4.167 GeV φ: 3.040 rad Collection: MET_RefFinal
/Users/mihamuskinj/Downloads/groupA.zip/event001.xml
Tracks
Physics Objects
Track | +/- | P [GeV] | Pt [GeV]
Tracks 8 | + | 47.07 | 37.95
Tracks 173 | - | 36.59 | 32.59
Tracks 239 | + | 827.36 | 311.58
Tracks 243 | + | 37.38 | 20.42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File
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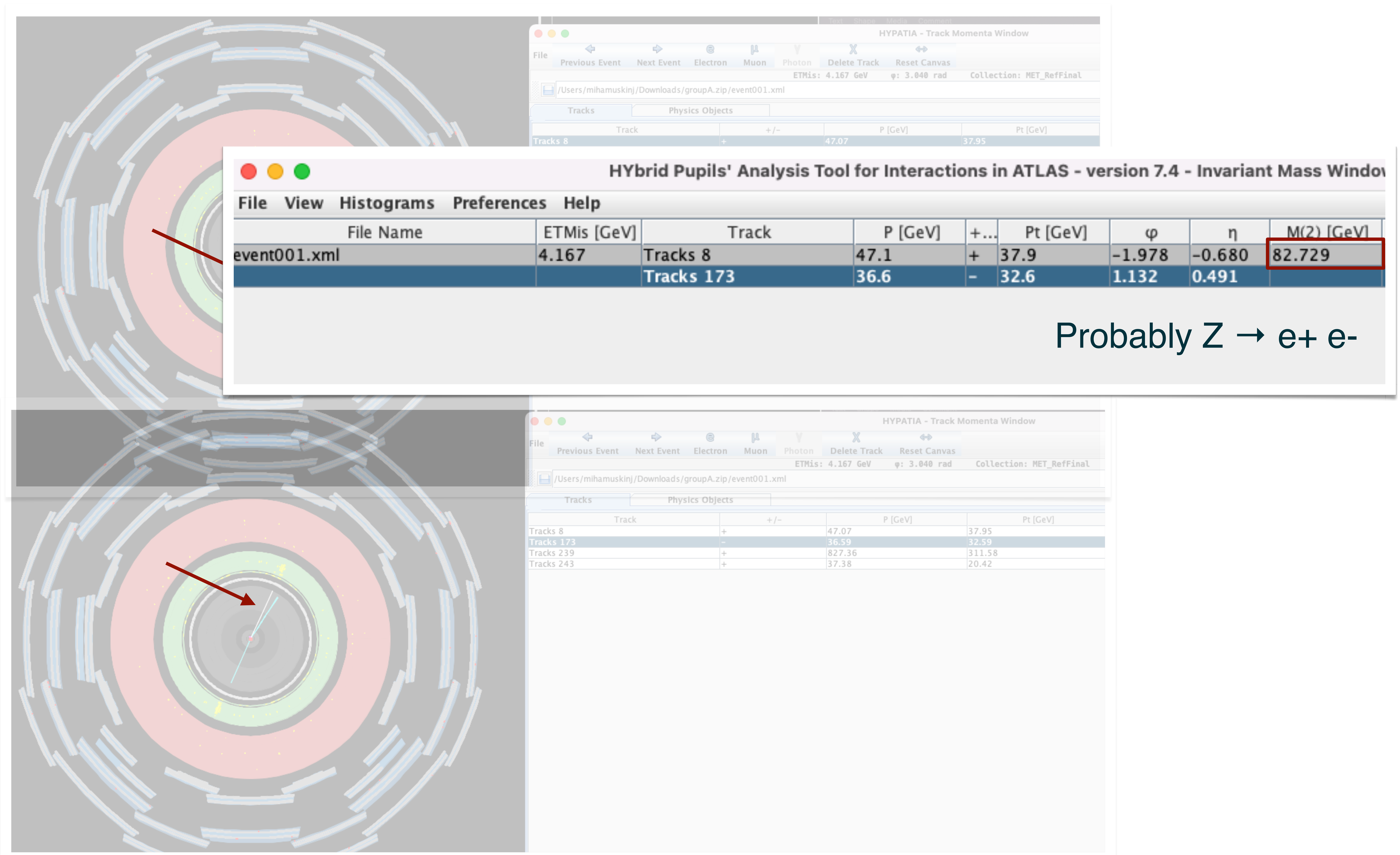
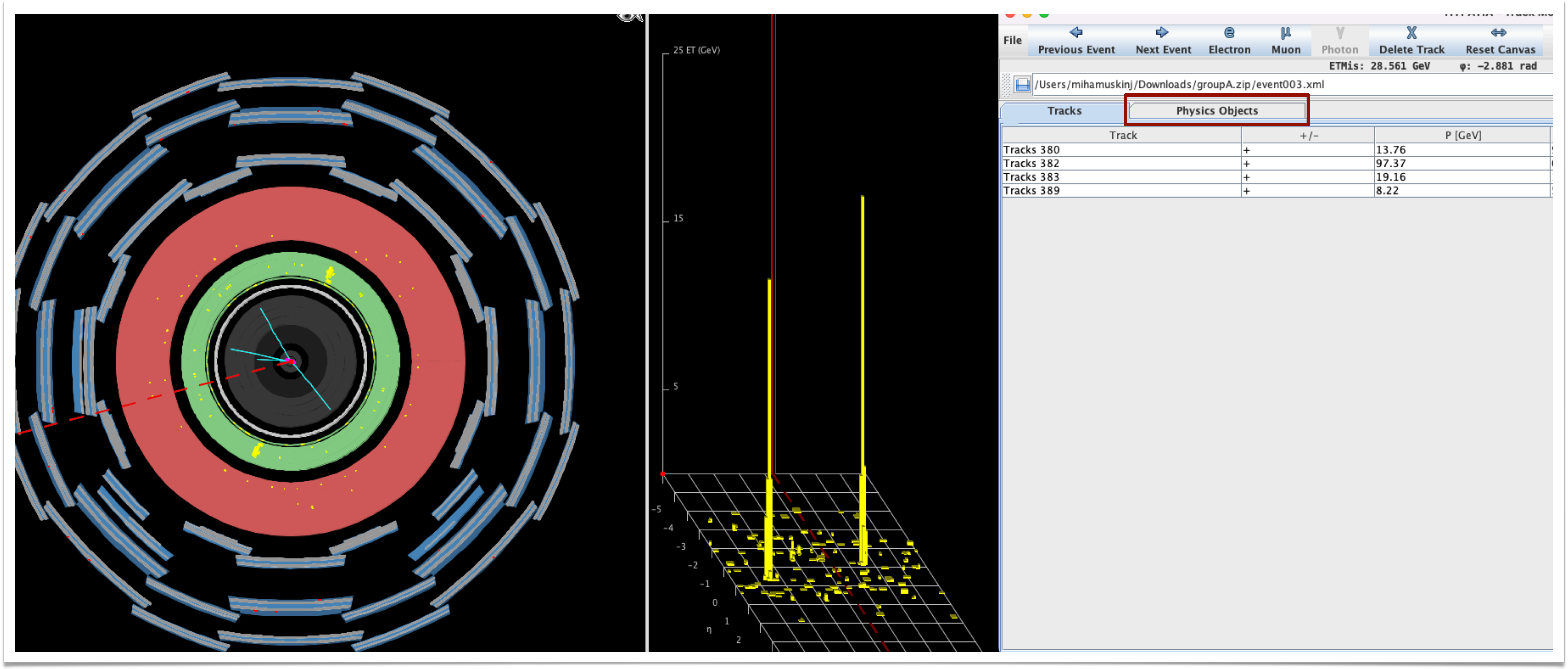


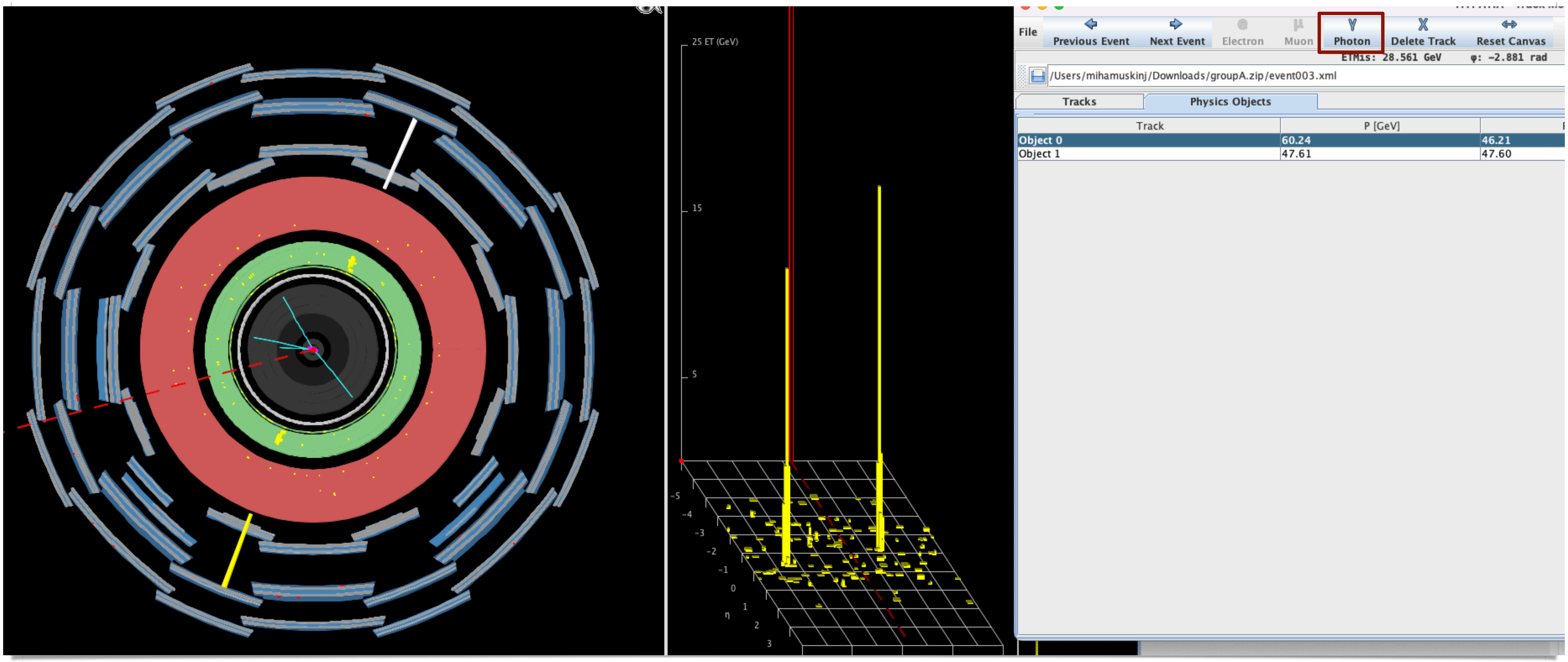
Probably Z → e+ e-

- For photons, need to click on the “**Physics Objects**” tab.

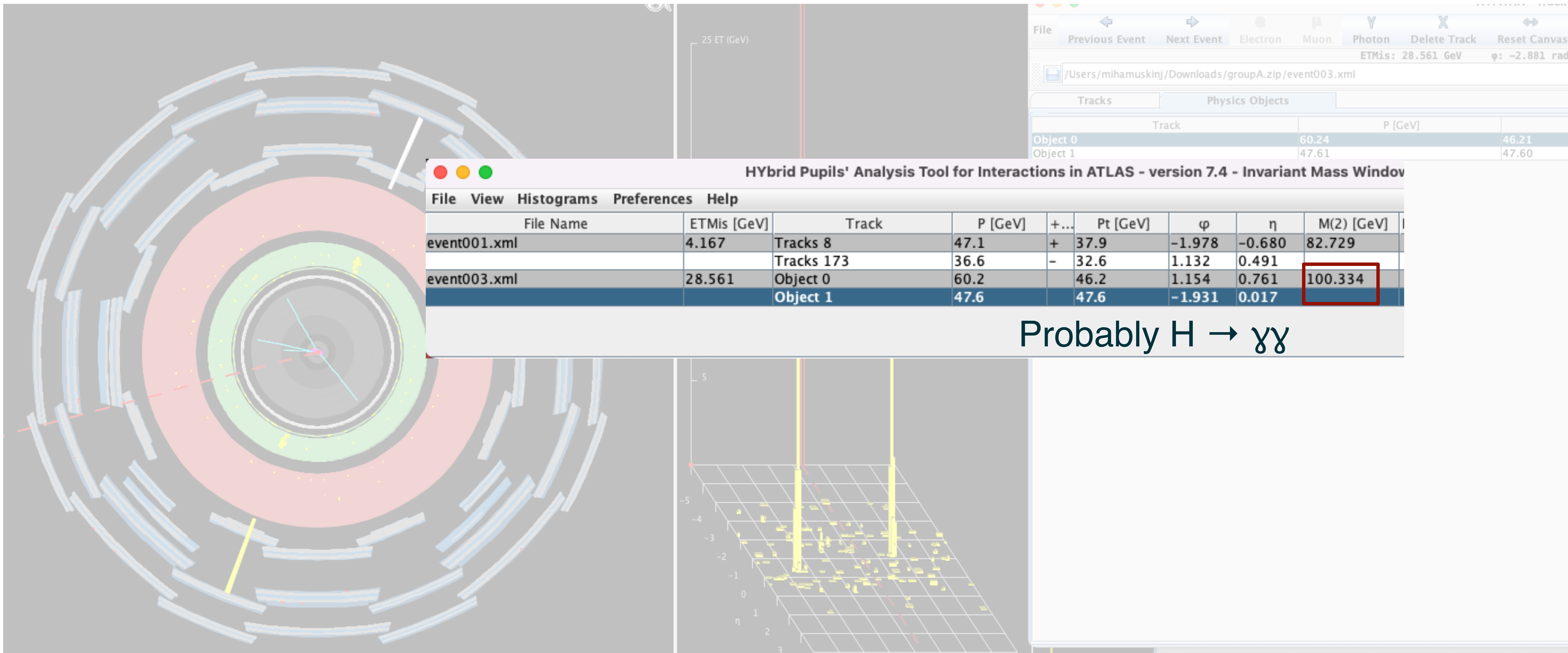


Hypathia navigation: Selecting particles

- For photons, need to click on the "**Physics Objects**" tab,
- Now select them…



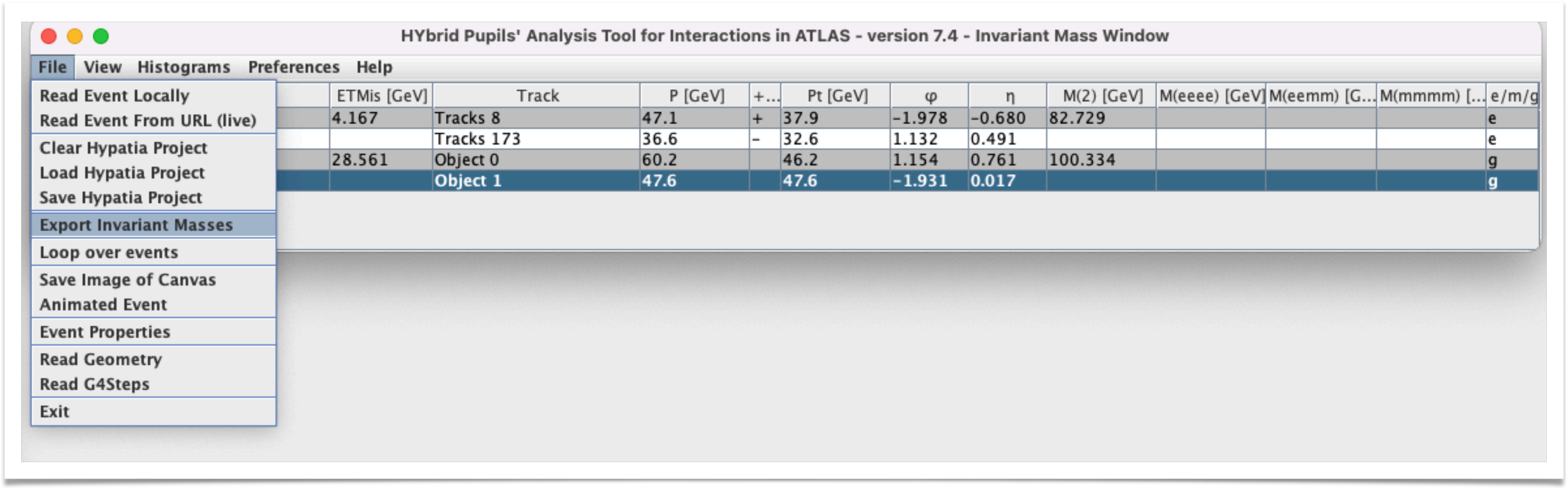
- For photons, need to click on the “**Physics Objects**” tab,
- Now select them…



Exporting data

Exporting data

- The data 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.



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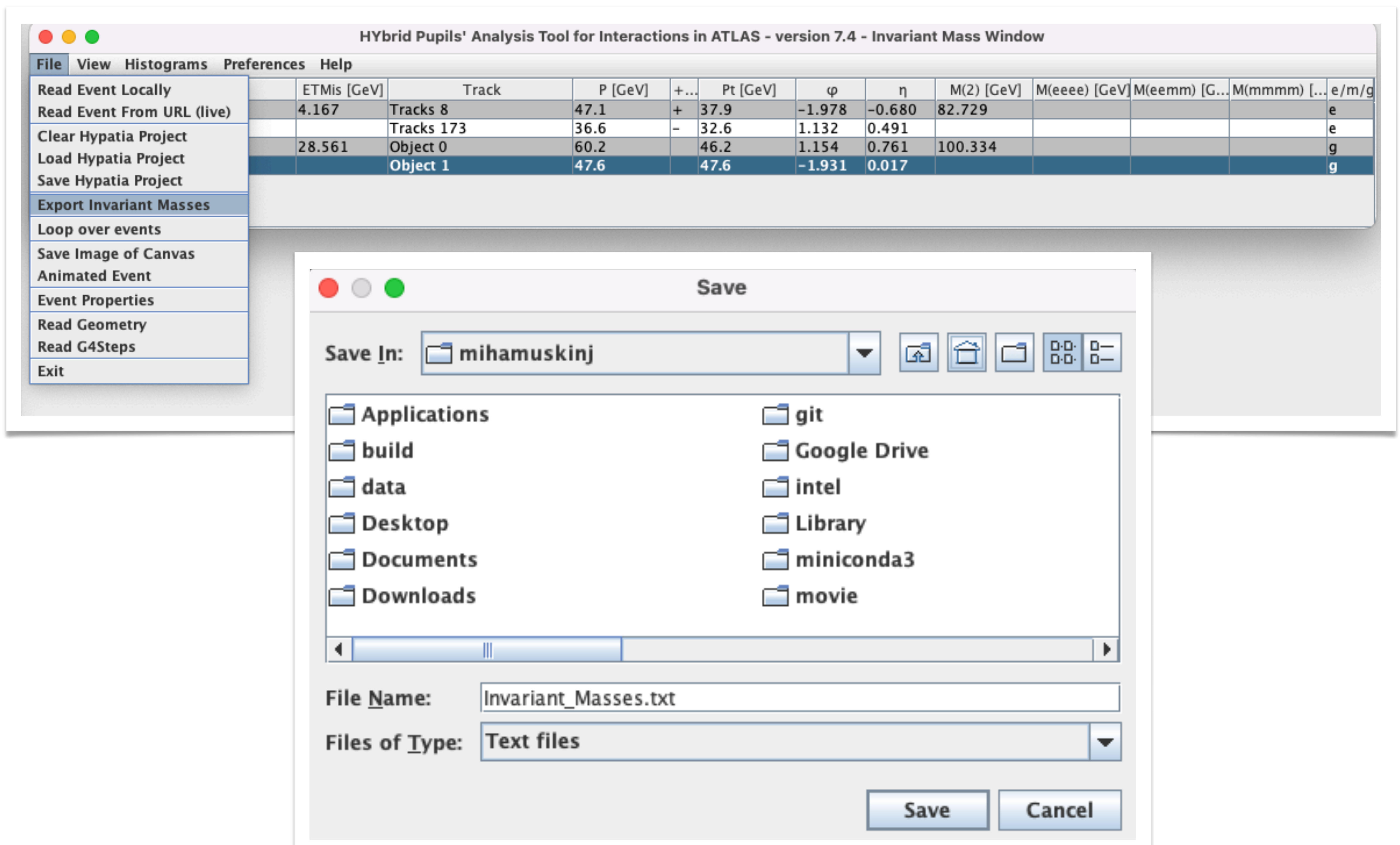
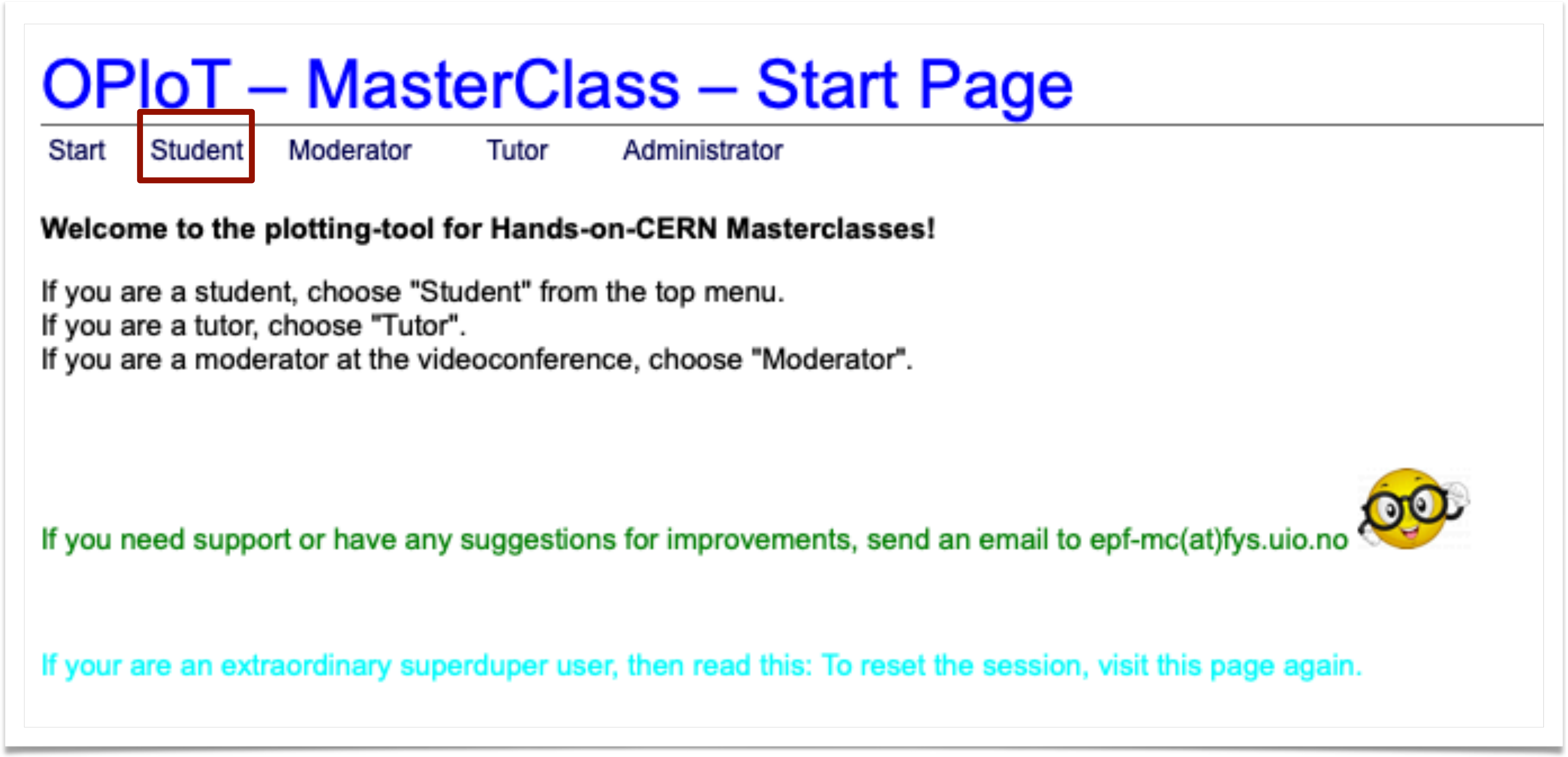
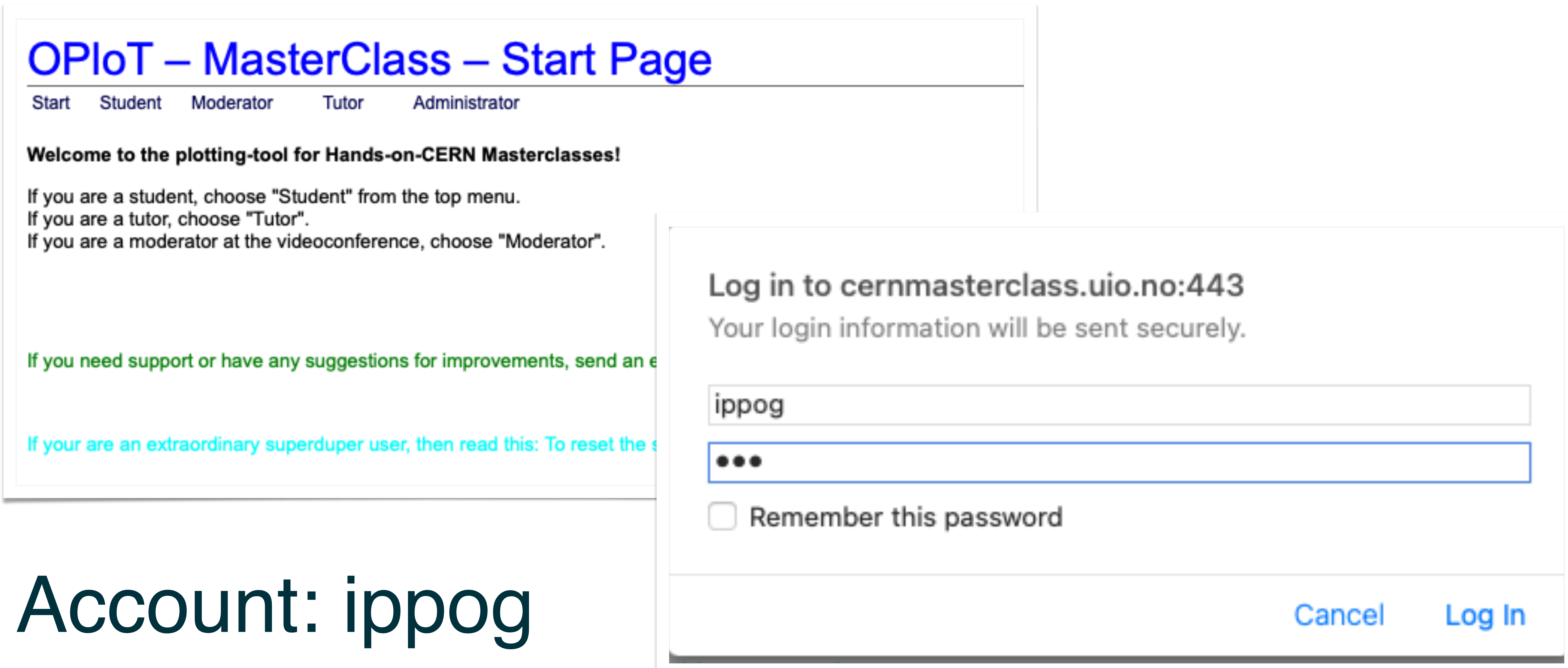


Uploading the data to OPIoT

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

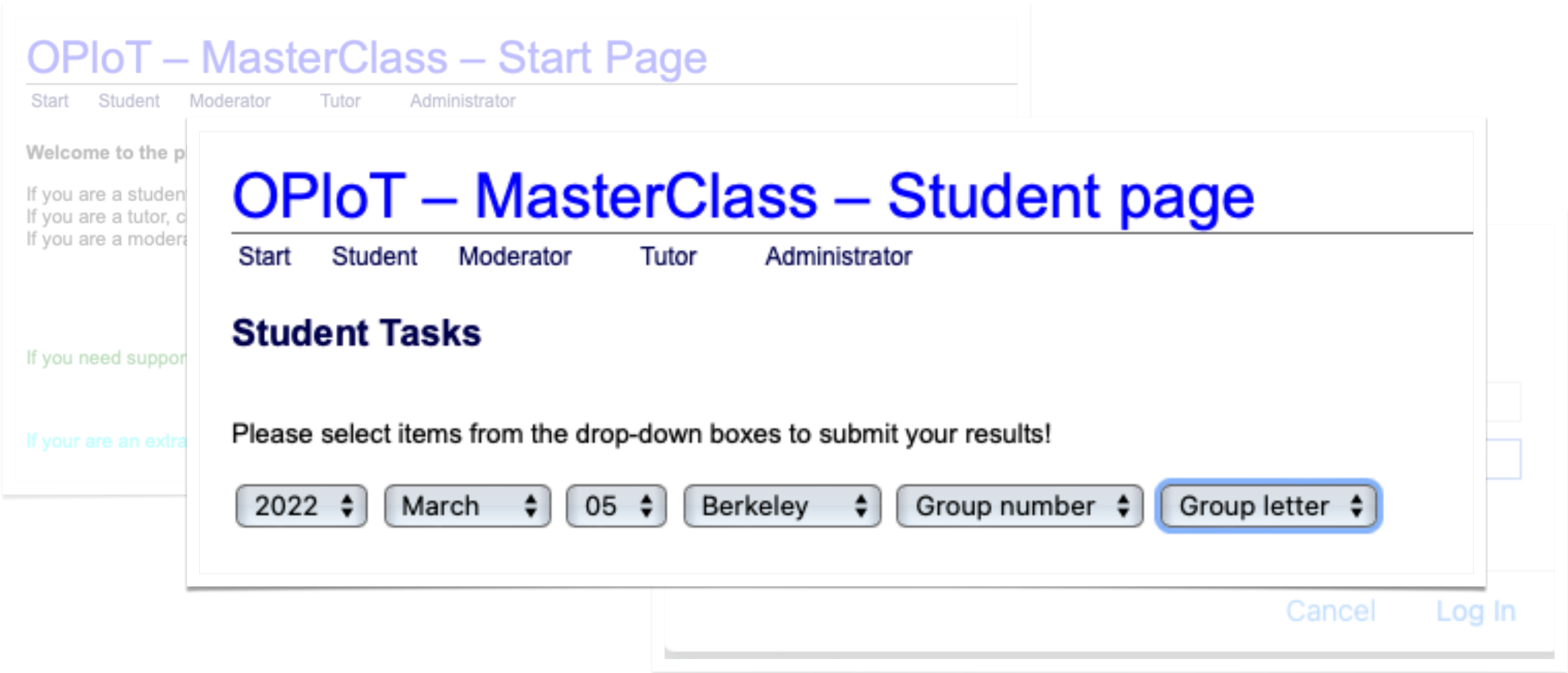


- Navigate to: https://cernmasterclass.uio.no/OPIoT-US/OPIoT/index.php,
- Upload the data:



Account: ippog
Password: imc

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



- For reference:

11:00 → 12:00 **Hands-on part: Data Analysis**

🕐 1h

You and your group, along with your mentors, will solve a task using LHC data

Cheat Sheet | Particle Identificati...

GET STARTED ON THE WEB WITH HYPATIA AND OPloT

You will now analyze up to 50 particle collisions (events) by using the visualization application HYPATIA.

From these collisions, you shall try to find the footprints from heavy neutral particles, like for instance the Z-boson or the Higgs boson.

All you need can be found at
http://atlas.physicsmasterclasses.org/en/zpath_measurement.htm (replace /en/ with your language)

This is:

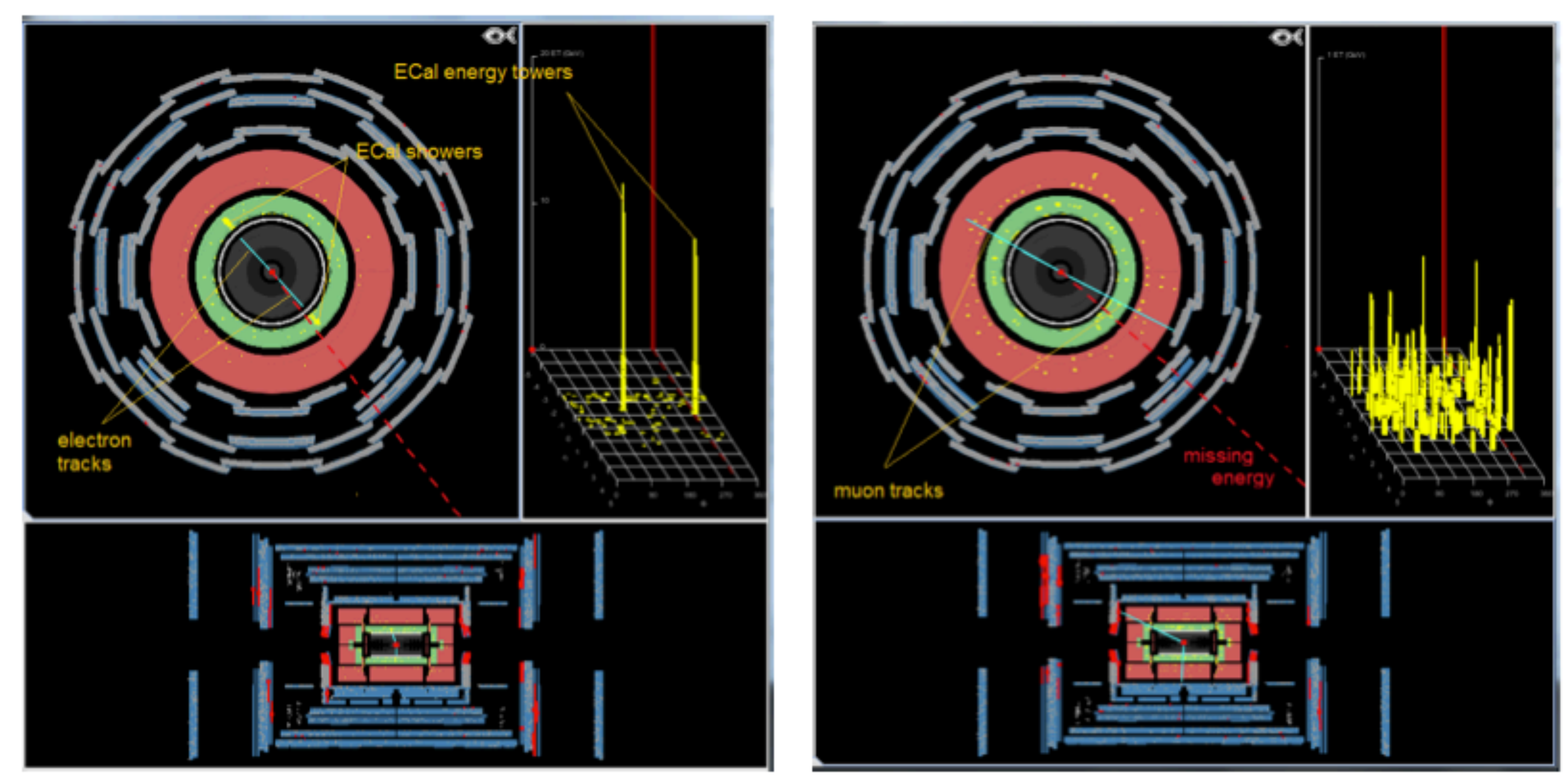
1. The HYPATIA application and instructions
2. Your unique dataset - ask your tutor if you need help
3. The web plotting tool OPloT: http://cernmasterclass.uio.no/OPloT/
   - username: ippog
   - password: imc

Do the following:
Go to the Z-Path: http://atlas.physicsmasterclasses.org/en/zpath_measurement.htm

1. Instructions of what to do can be found under the sub-menu items of **"Get to work"**:
   - Get to work→Data samples and tools
   - Get to work→Do it!
   - Get to work→Analyze your result (together with rest of students and tutors)
2. Find and download your data sample - follow instructions found at **"Data samples and tools"**.
   - To start HYPATIA
     - On a Windows or Mac:
       - Double-click the file Hypatia_7.4_Masterclass.jar
     - On Linux:
       - Right-click the file: HYPATIA_for_Linux.sh
       - Change the permissions to make it executable
       - Double-click the HYPATIA_for_Linux.sh file
   - Unzip data sample
   - Load events in HYPATIA with File→Read Events Locally - Navigate to your downloaded and unzipped data sample

ATLAS Z-path Masterclass "Cheat Sheet"

2-lepton events



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

Backup