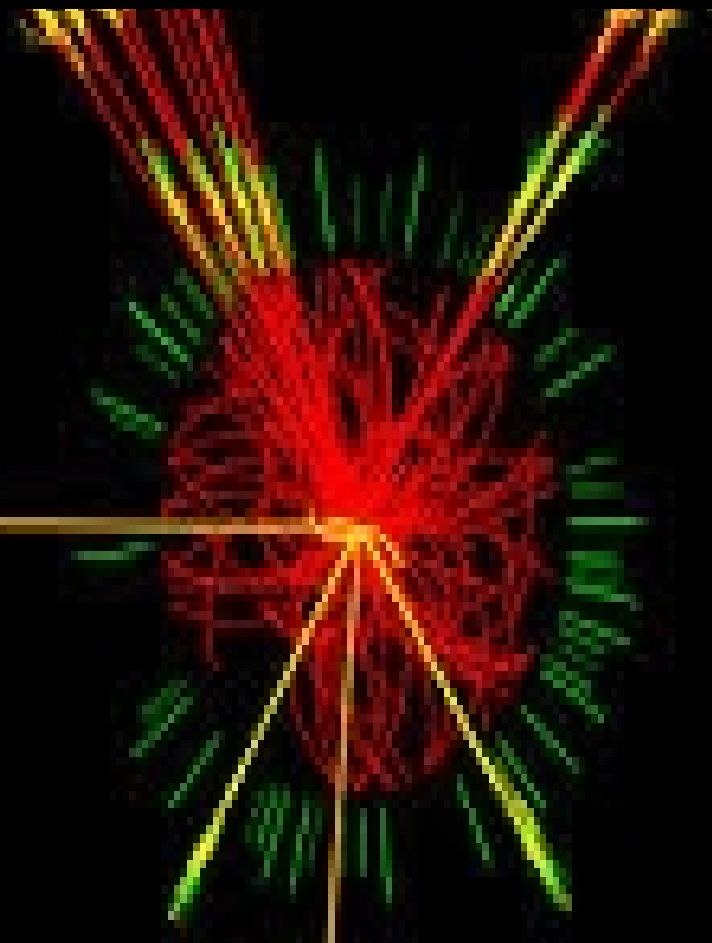


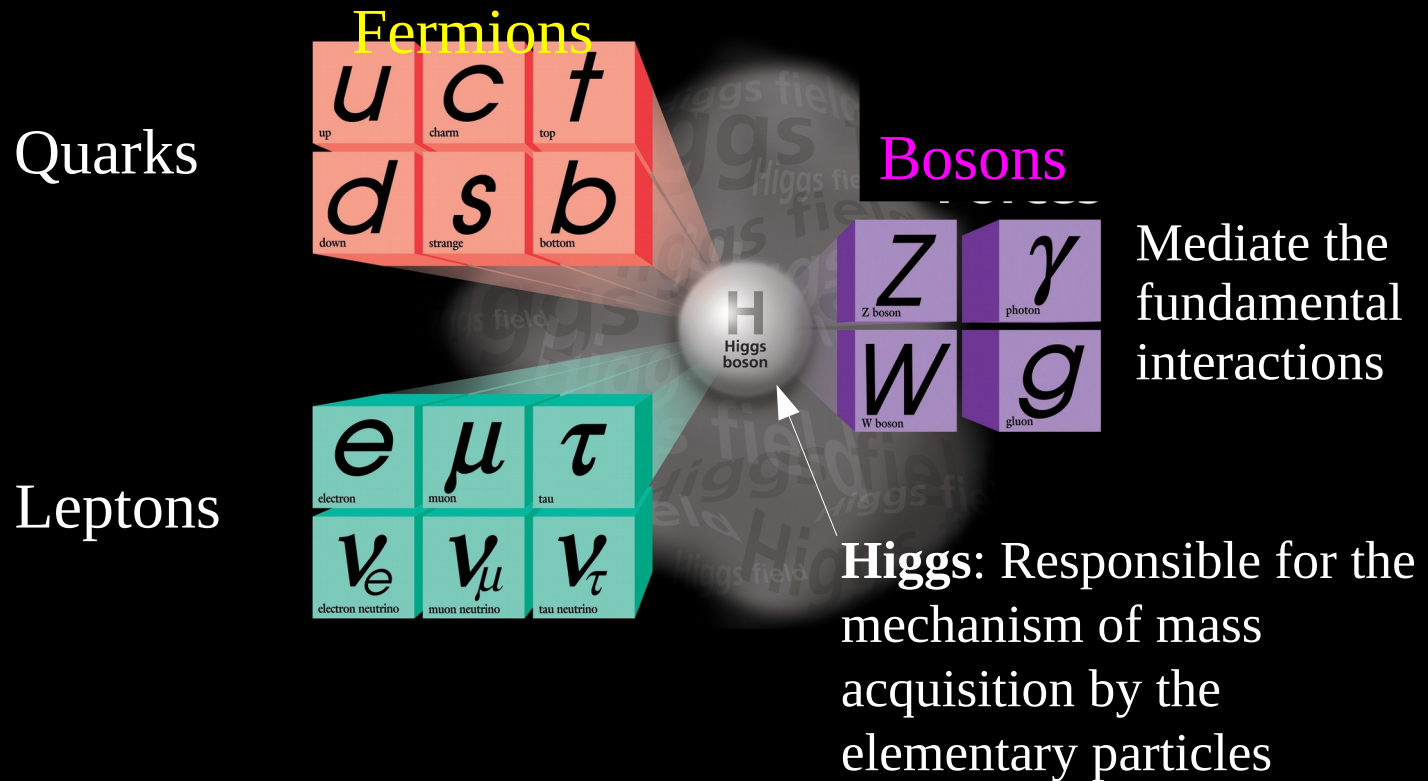


HYPATIA



$$E = mc^2$$

The Standard Model of Elementary Particles

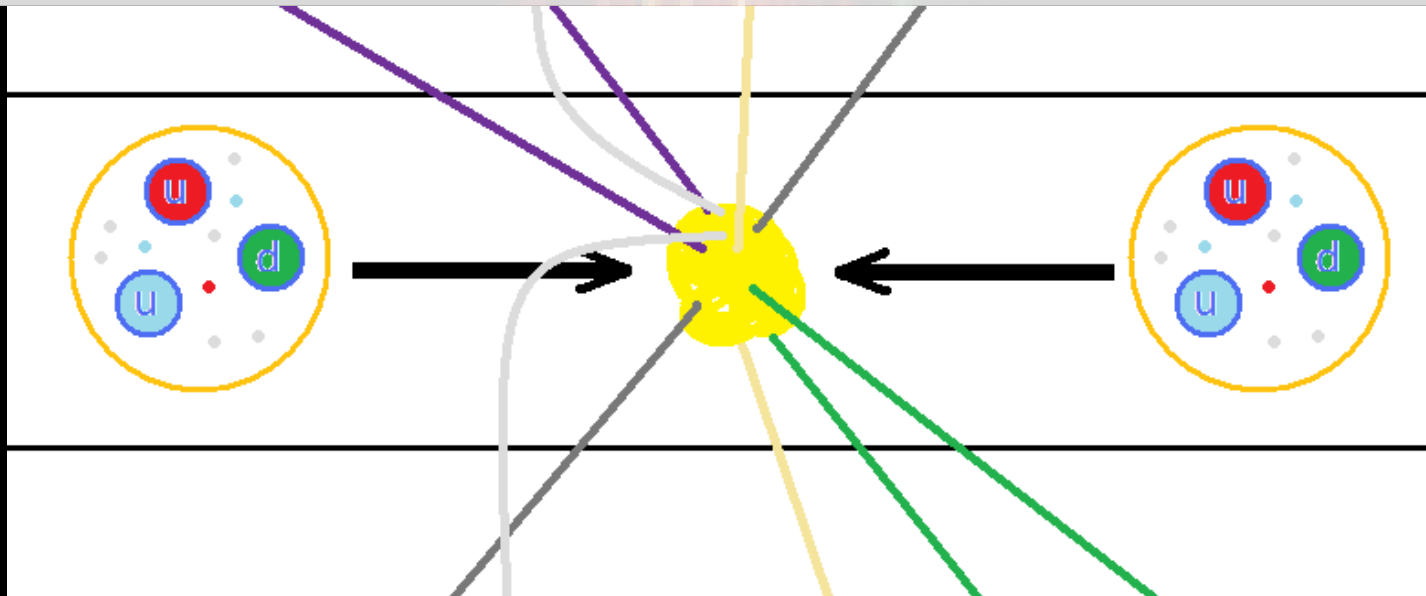


Proton-Proton interactions

At the LHC each proton in the beam is accelerated to 6.5 TeV:

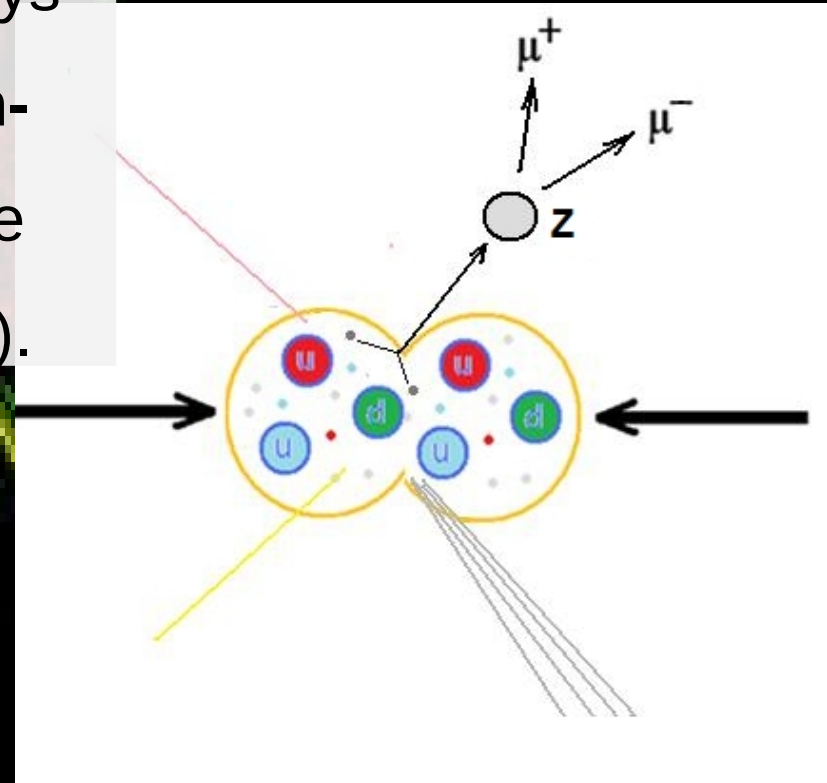
in the center of mass: $2 \times 6.5 \text{ TeV} = 13 \text{ TeV}$

Quarks and Gluons, the constituents of the proton, **share this energy**. The available energy (13 TeV) transforms in new particles as $E = mc^2$.



Production and particles decay

In HYPATIA we are primarily looking for the **Z boson**, which is a particle without **electric charge** and decays into **muon-antimuon**, or **electron-positron**, or **tau-antitau** pairs. We will ignore the later, though (why?).



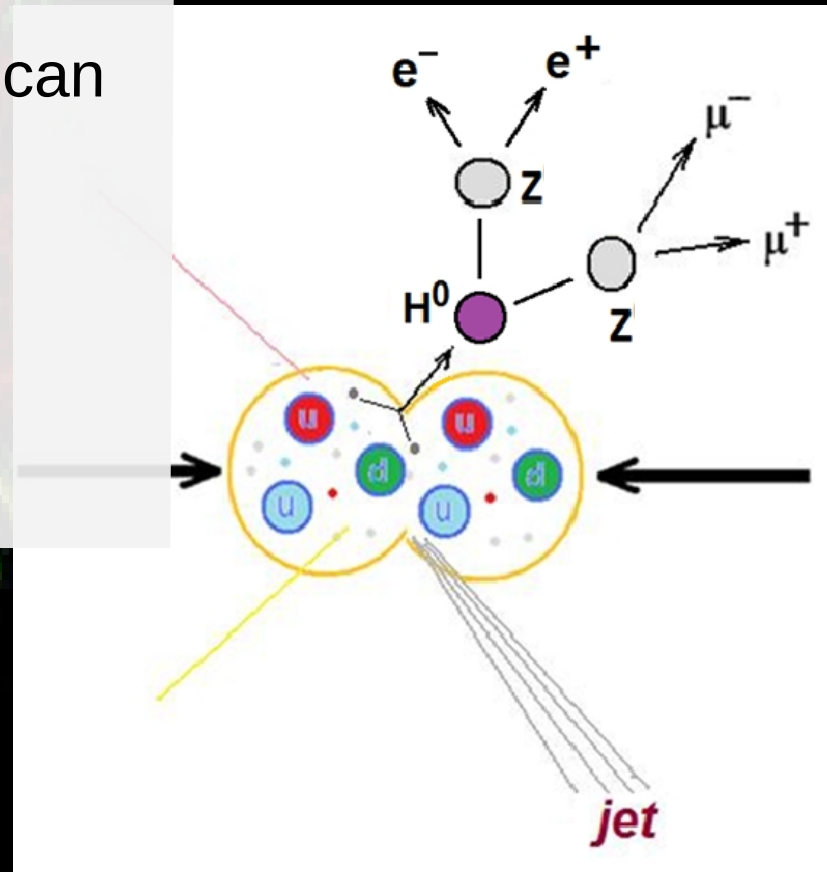
Production and particles decay

The **Higgs (H)** boson was discovered at ATLAS and CMS experiments at LHC/CERN in 2012.

Among many decay channels we can find Higgs bosons candidates in events like:

$H \rightarrow ZZ^* \rightarrow 4 \text{ leptons}$

$H \rightarrow \gamma\gamma$ (2 photons)



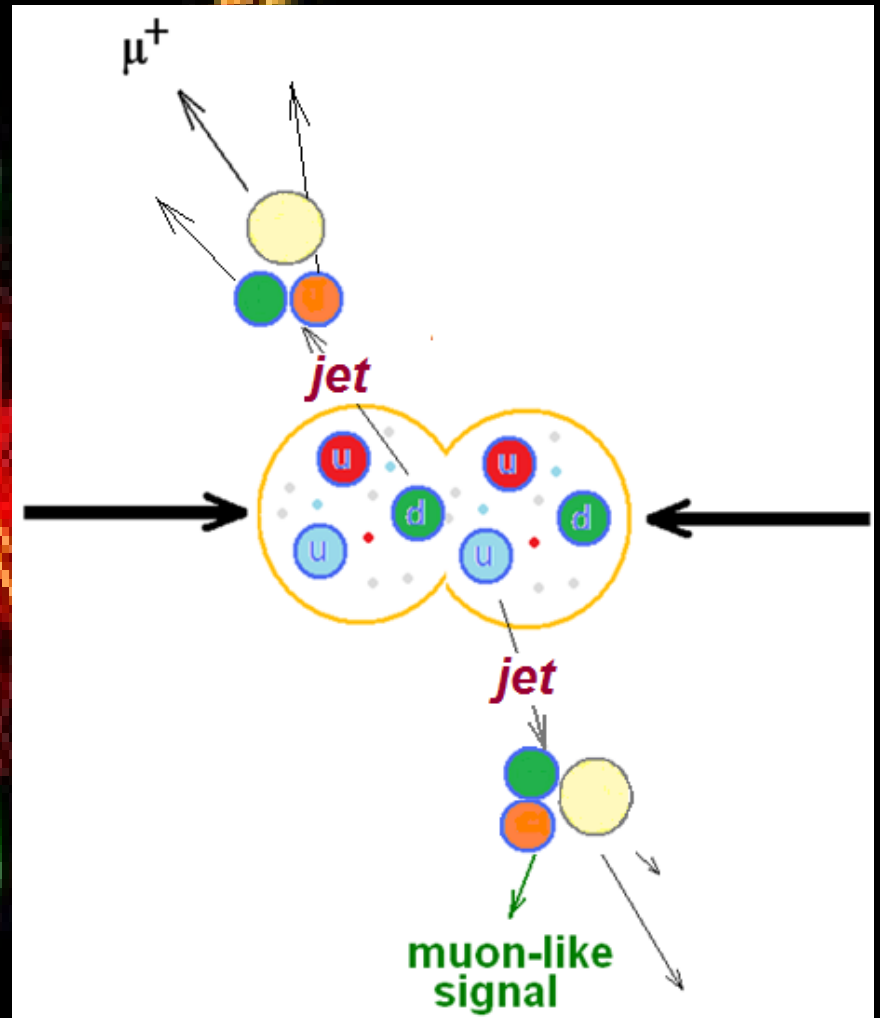
Production and particles decay

Quarks are scattered in the collisions very often.

These **quarks** fragment and originate **jets** (collimated sprays of particles)

Very interesting objects *per se*, but they are our “**background**”!

Low energy **muons** and **electrons** can be produced in jets and mimic those from **Z decay**.



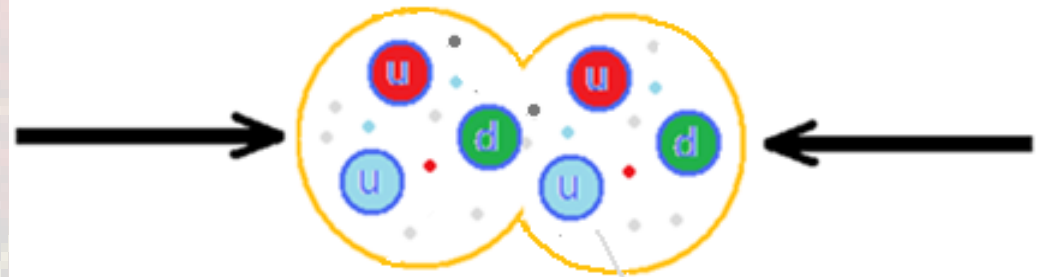
Production and particles decay

We will select several events with the $Z \rightarrow \mu^+ \mu^-$ and $Z \rightarrow e^+ e^-$ topologies and use the information of the invariant mass to know if they are Z boson candidates or other particles.

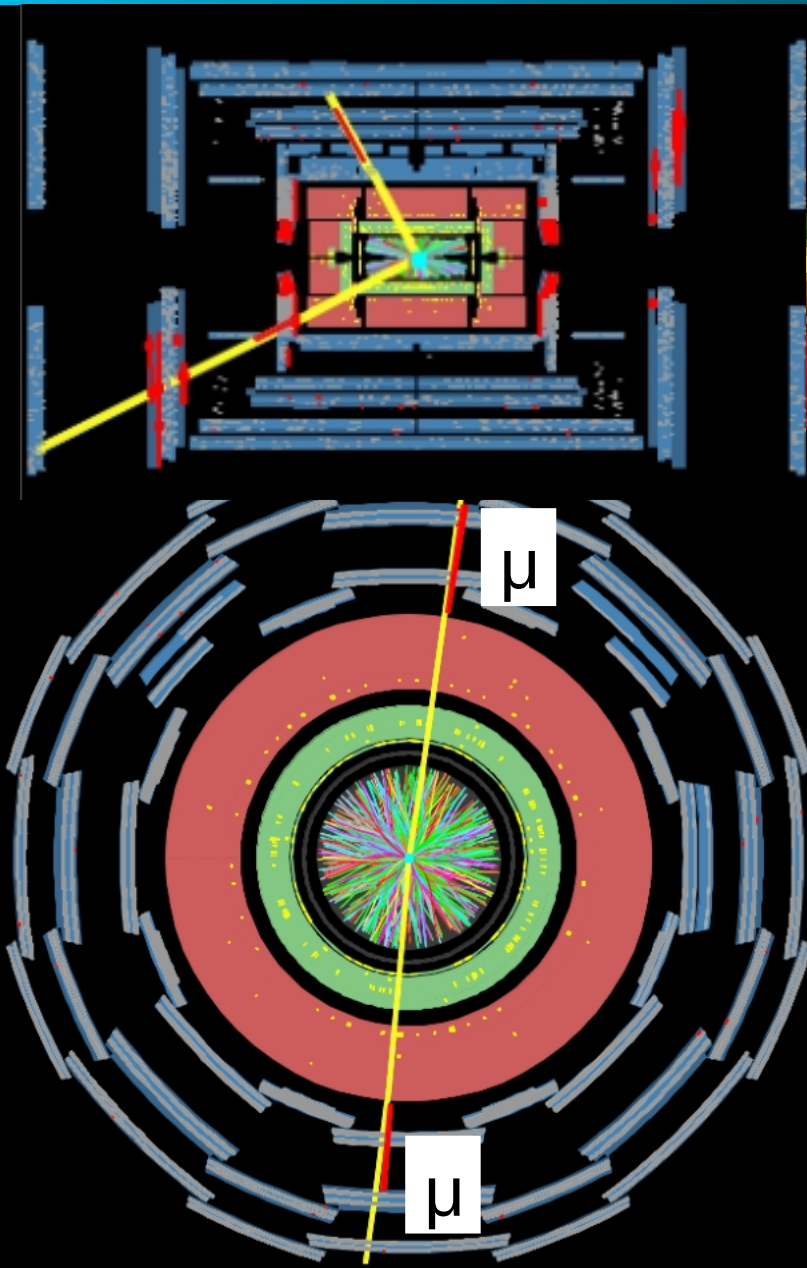
$$E^2 = m^2 c^4 + c^2 p^2$$

$$E = E_1 + E_2 \quad p = |\vec{p}| = |\vec{p}_1 + \vec{p}_2|$$

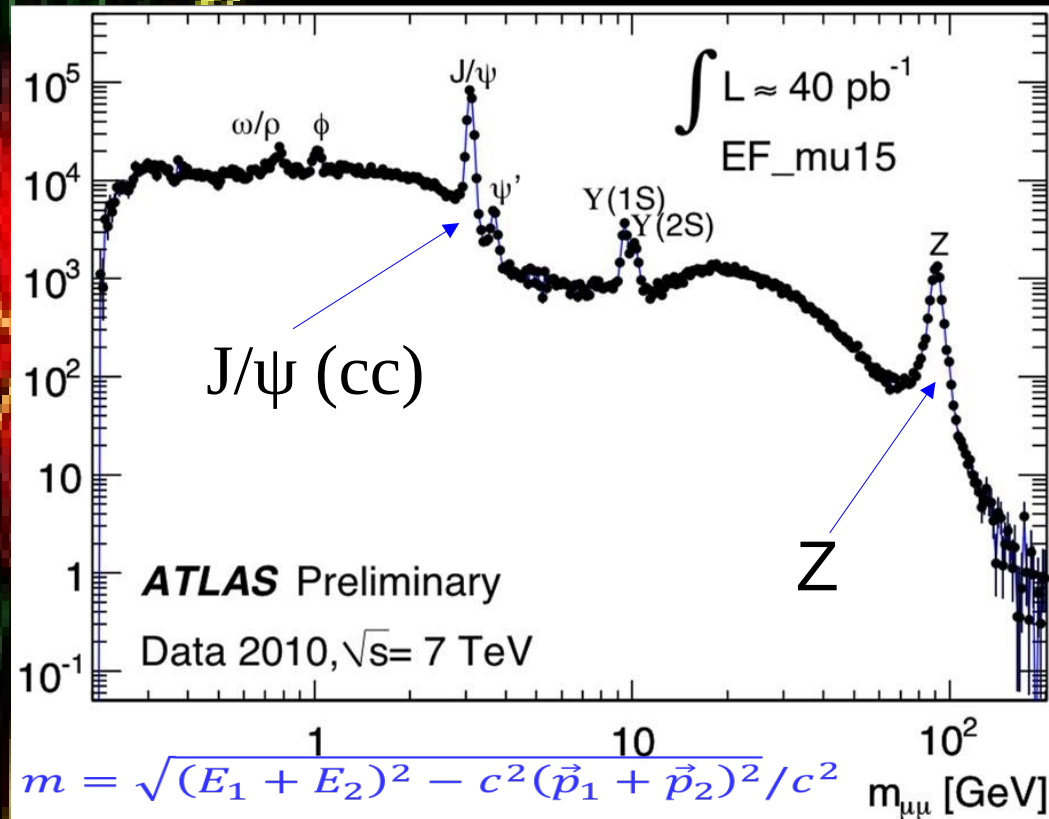
$$m = \sqrt{(E_1 + E_2)^2 - c^2(\vec{p}_1 + \vec{p}_2)^2} / c^2$$



After millions events...

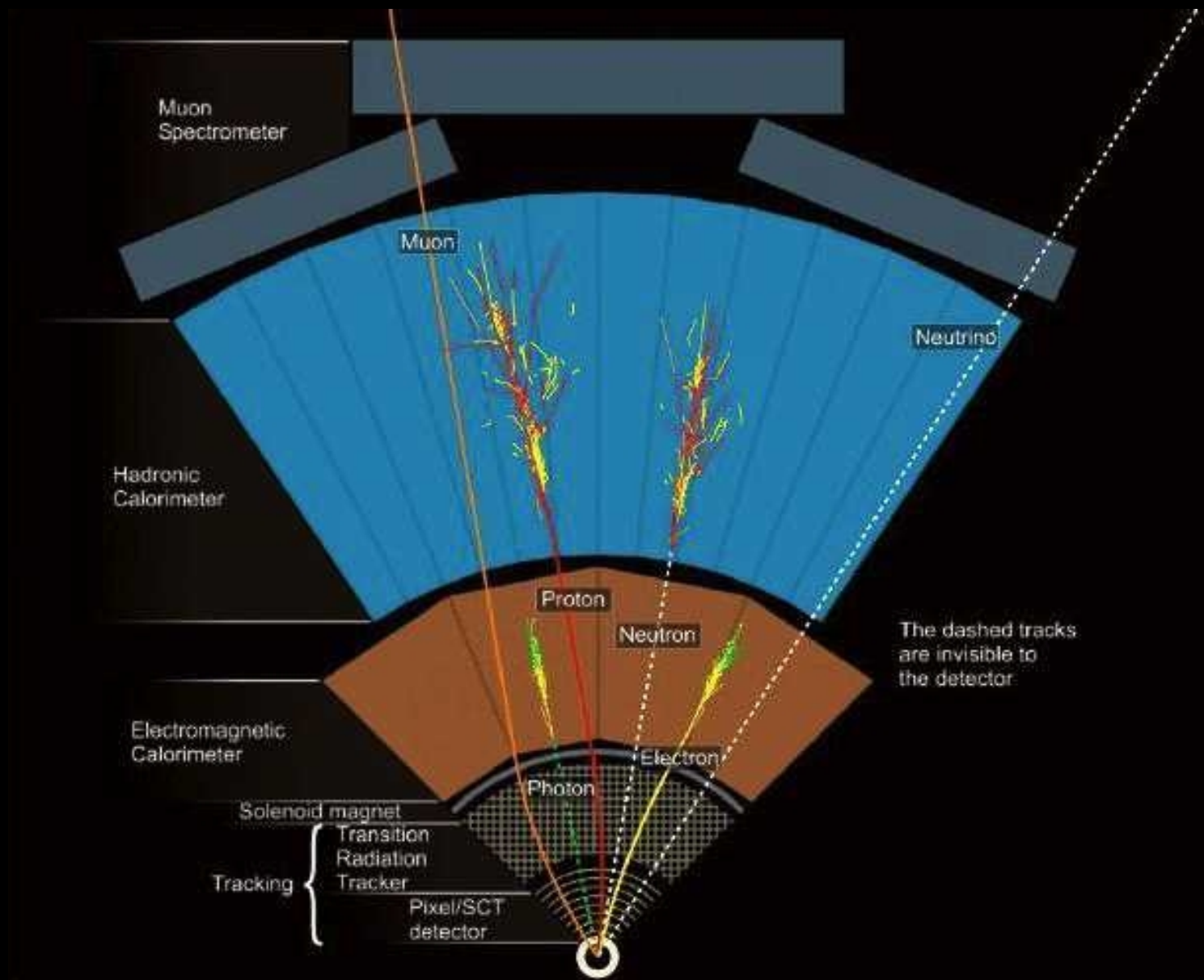


Dimuon invariant mass spectrum



We will consider the process $Z \rightarrow e^+e^-$ as well.

Detecting Particles



Z Boson Properties

■ The Z boson is heavy – mass: $91.2 \text{ GeV}/c^2$ – and its live time is short: $4 \times 10^{-25} \text{ s}$.

■ The Z boson is neutral → The sum of the electric charges of the descendents is zero.

■ It does decay to:

- quark-antiquark pair (70%) → identified by jets in the calorimeter;
- neutrino-antineutrino pair (20%). Neutrinos cross the entire detector untouched. They are inferred from missing transverse momentum, MET.
- **lepton-antilepton (10%) pair. The three types of leptons (electron, muon and tau) are equally probable.**

HYPATIA

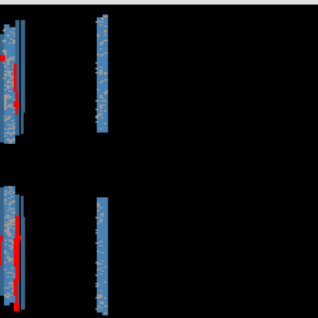
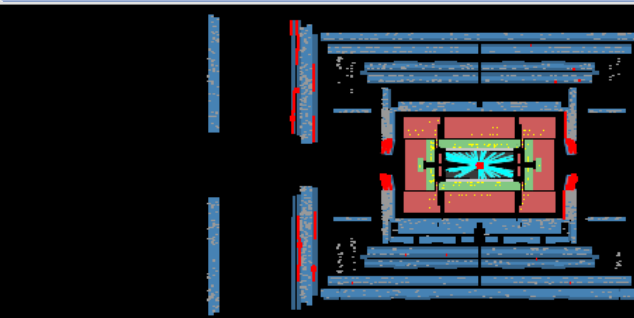
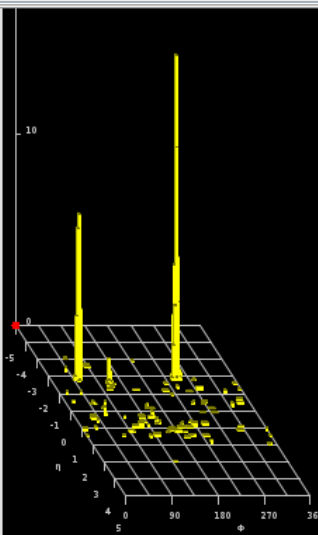
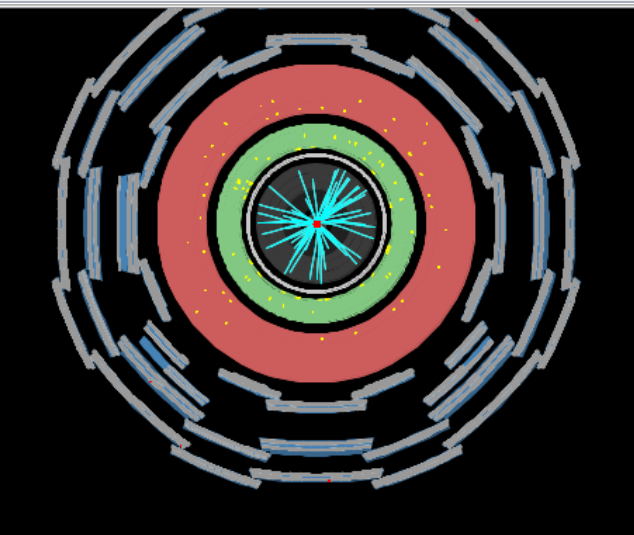


Applications Places System

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]	ϕ	η	M(2) [GeV]	M(eeee) [GeV]	M(eemm) [GeV]	M(mmmm) [G...	e/m/g
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HYPATIA - Track Momenta Window

Previous Event Next Event Electron Muon Photon Delete Track Reset

ETMis: 5.707 GeV ϕ : 0.378 rad Collection: MET_Reffinal

events/SelectedEvents.zip/SelectedEvents/event008.xml

Track	+/-	P [GeV]	Pt [GeV]	ϕ	θ
Tracks 2	+	6.27	1.20	3.028	0.193
Tracks 3	-	8.96	1.94	-2.362	2.923
Tracks 5	-	12.71	5.42	1.865	2.701
Tracks 9	+	6.24	1.21	0.270	2.947
Tracks 11	+	2.00	1.03	-1.273	2.598
Tracks 12	+	8.31	1.33	-0.671	2.981
Tracks 13	-	4.77	1.04	-0.929	0.220
Tracks 14	-	3.72	3.34	0.477	1.117
Tracks 18	+	5.07	1.17	0.999	0.232
Tracks 20	+	8.17	1.50	1.270	2.956
Tracks 21	-	3.65	1.33	-0.873	0.373
Tracks 22	-	3.93	1.95	0.054	2.621
Tracks 23	+	4.14	1.83	-1.521	2.684
Tracks 27	+	4.33	1.25	0.468	2.850
Tracks 30	+	4.94	1.16	-2.360	2.904

HYPATIA - Control Window

Parameter Control Interaction and Window Control Output Display

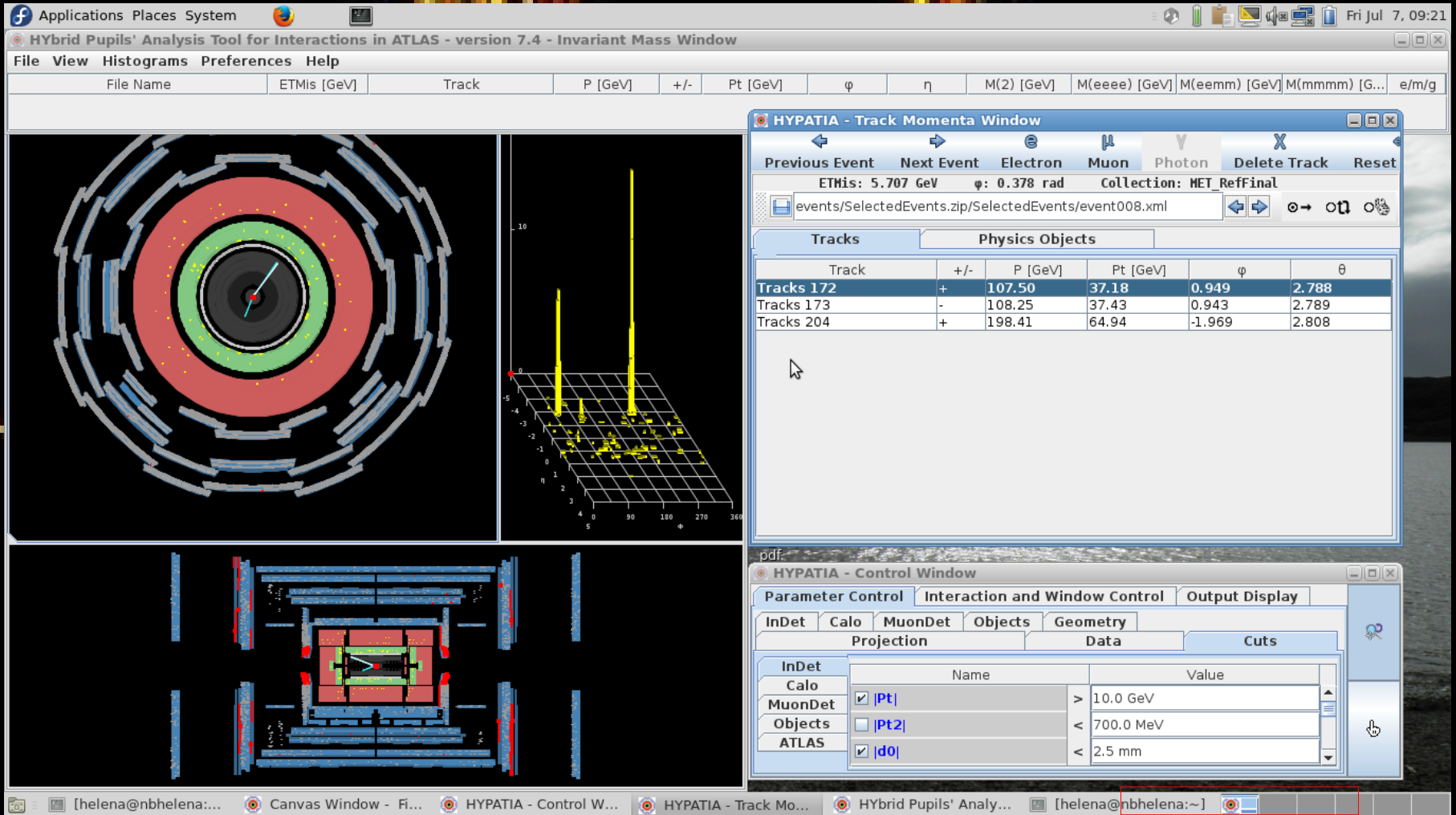
InDet Calo MuonDet Objects Geometry

Projection Data Cuts

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

[helena@nbhelena:~] Canvas Window - Fi... HYPATIA - Control W... HYPATIA - Track Mo... HYbrid Pupils' Analy... [helena@nbhelena:~]

Cut in the p_T variable



The cut in the p_T (transverse momentum - the linear momentum projected in the transverse plan of the detector – $p \cdot \sin\theta$) allows the low- p_T track removal, which helps to improve greatly the signal to background ratio.

Zoom



Applications Places System

Canvas Window - File: SelectedEvents/event008.xml Run: 204910 Event: 9576582

20 ET (GeV)

10

0

5

4 0 90 180 270 360

[GeV] ϕ η M(2) [GeV] M(eeee) [GeV] M(eemm) [GeV] M(mmmm) [G... e/m/g

HYPATIA - Track Momenta Window

Previous Event Next Event Electron Muon Photon Delete Track Reset

ETHis: 5.707 GeV ϕ : 0.378 rad Collection: MET_Reffinal

events/SelectedEvents.zip/SelectedEvents/event008.xml

Tracks Physics Objects

Track	+/-	P [GeV]	Pt [GeV]	ϕ	θ
Tracks 172	+	107.50	37.18	0.949	2.788
Tracks 173	-	108.25	37.43	0.943	2.789
Tracks 204	+	198.41	64.94	-1.969	2.808

pdf

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
7 8 9 D 9
B B

Track selection



Applications Places System

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]	ϕ	η	M(2) [GeV]	M(eeee) [GeV]	M(eemm) [GeV]	M(mmmm) [G...]	e/m/g
SelectedEvents/event008.xml	5.707	Tracks 173	108.2	-	37.4	0.943	-1.724	97.988				e
		Tracks 204	198.4	+	64.9	-1.969	-1.782					e

HYPATIA - Track Momenta Window

Previous Event Next Event Electron Muon Photon Delete Track Reset

ETMis: 5.707 GeV ϕ : 0.378 rad Collection: MET_Reffinal

events/SelectedEvents.zip/SelectedEvents/event008.xml

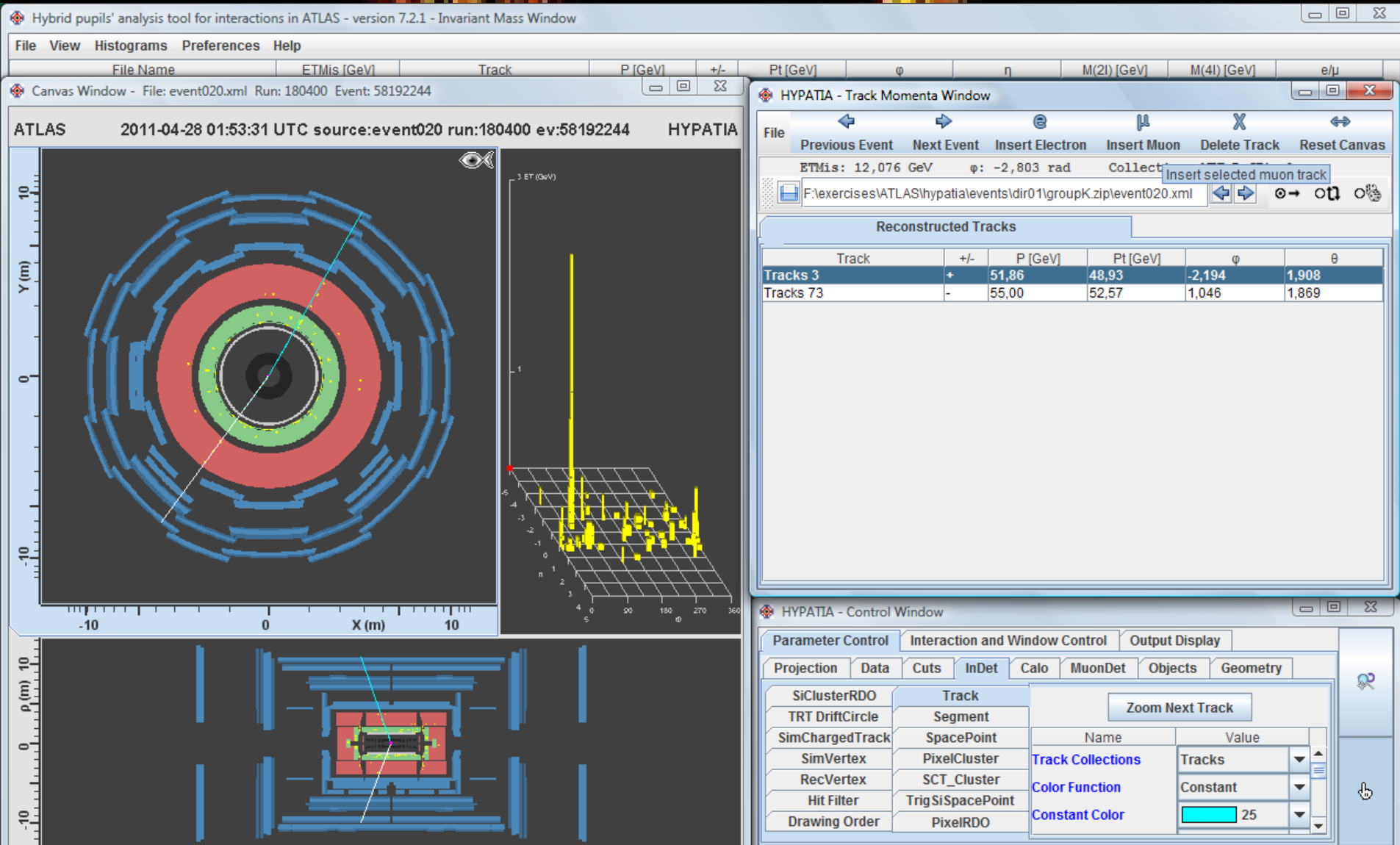
Track	+/-	P [GeV]	Pt [GeV]	ϕ	θ
Tracks 172	+	107.50	37.18	0.949	2.788
Tracks 173	-	108.25	37.43	0.943	2.789
Tracks 204	+	198.41	64.94	-1.969	2.808

HYPATIA - Control Window

Parameter Control Interaction and Window Control Output Display

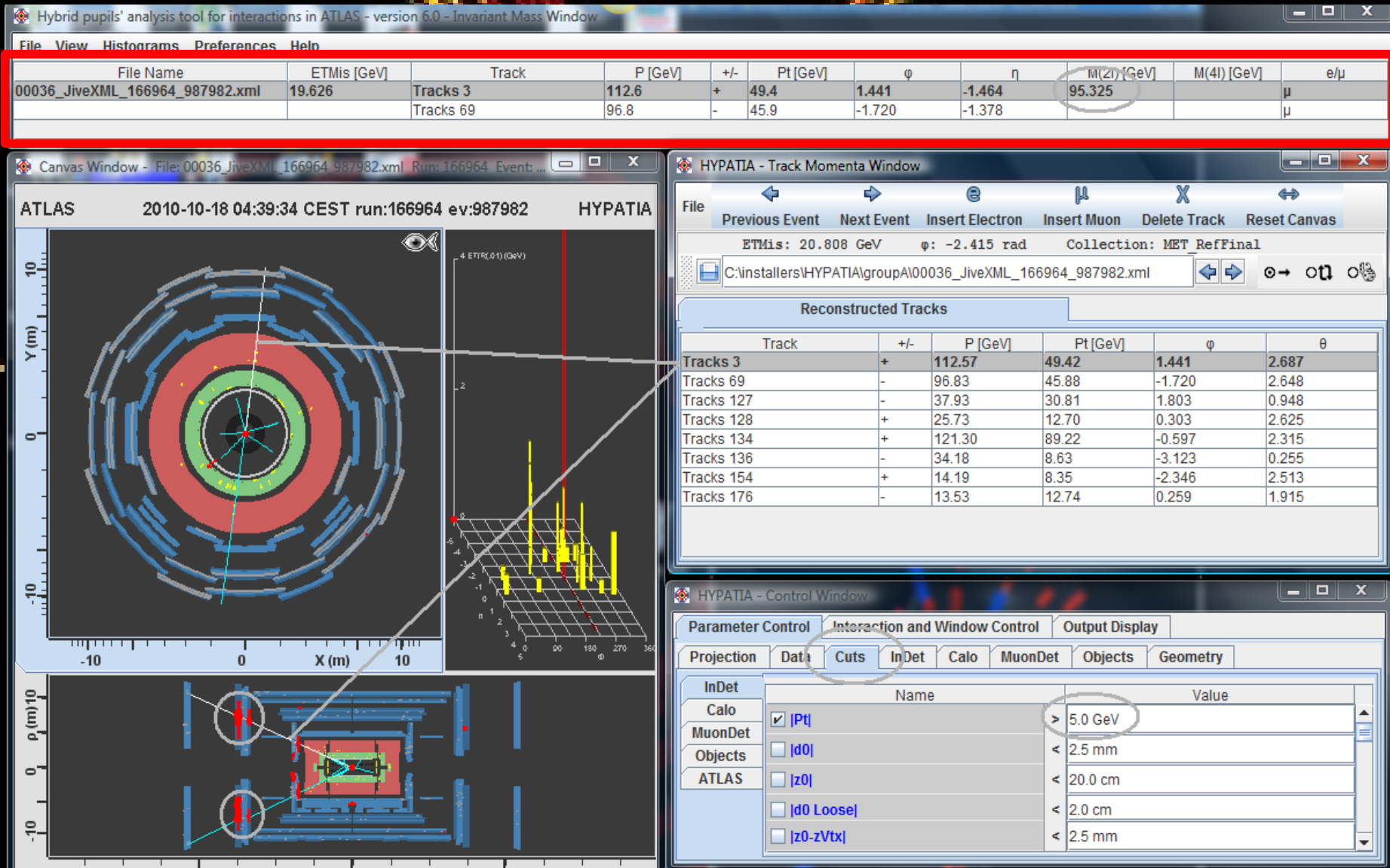
W S X L M R 1 2 3 U 3
B B 4 5 6 C 6
7 8 9 D 9

$$Z \rightarrow \mu^+ \mu^-$$

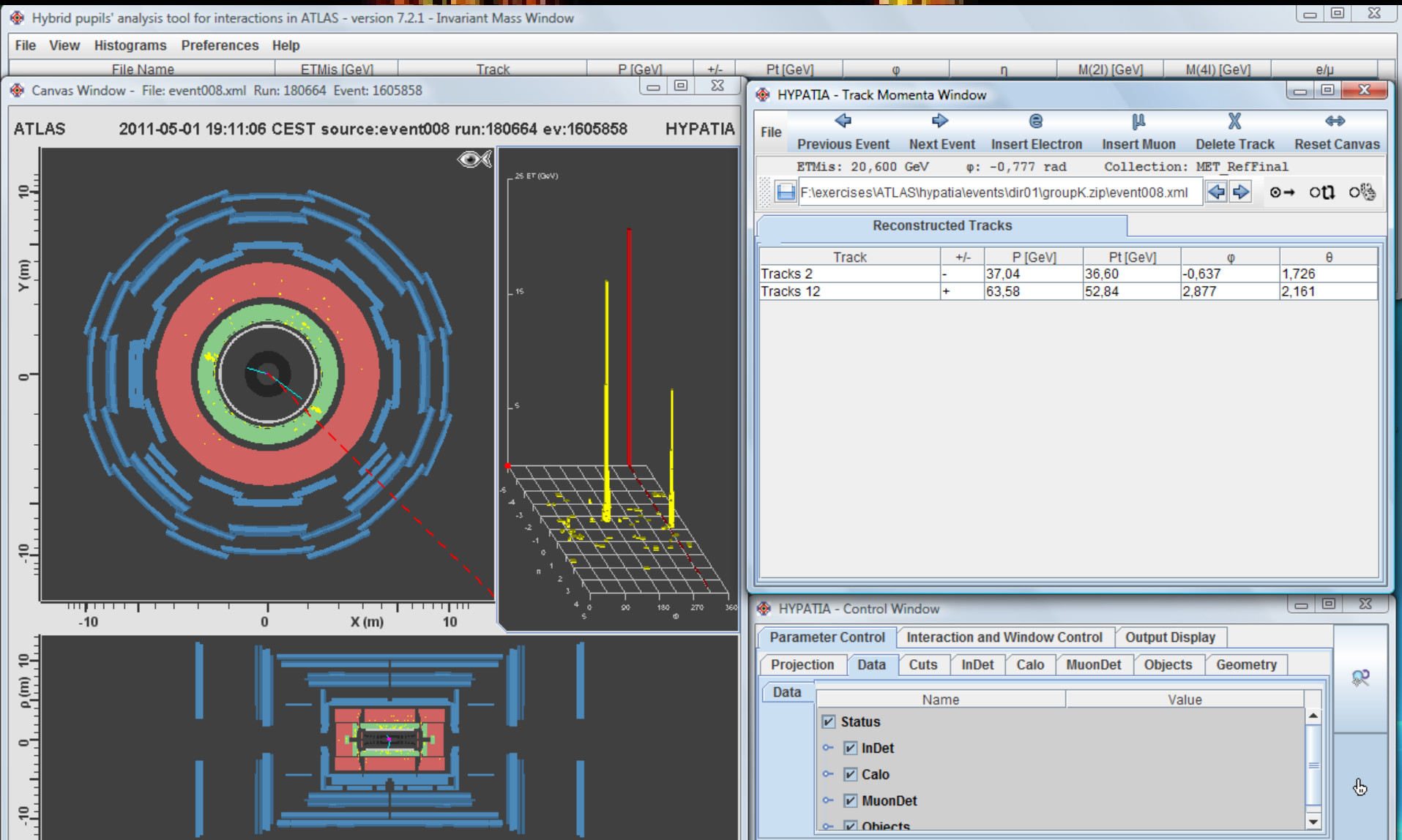


Only combinations of opposite charges are allowed

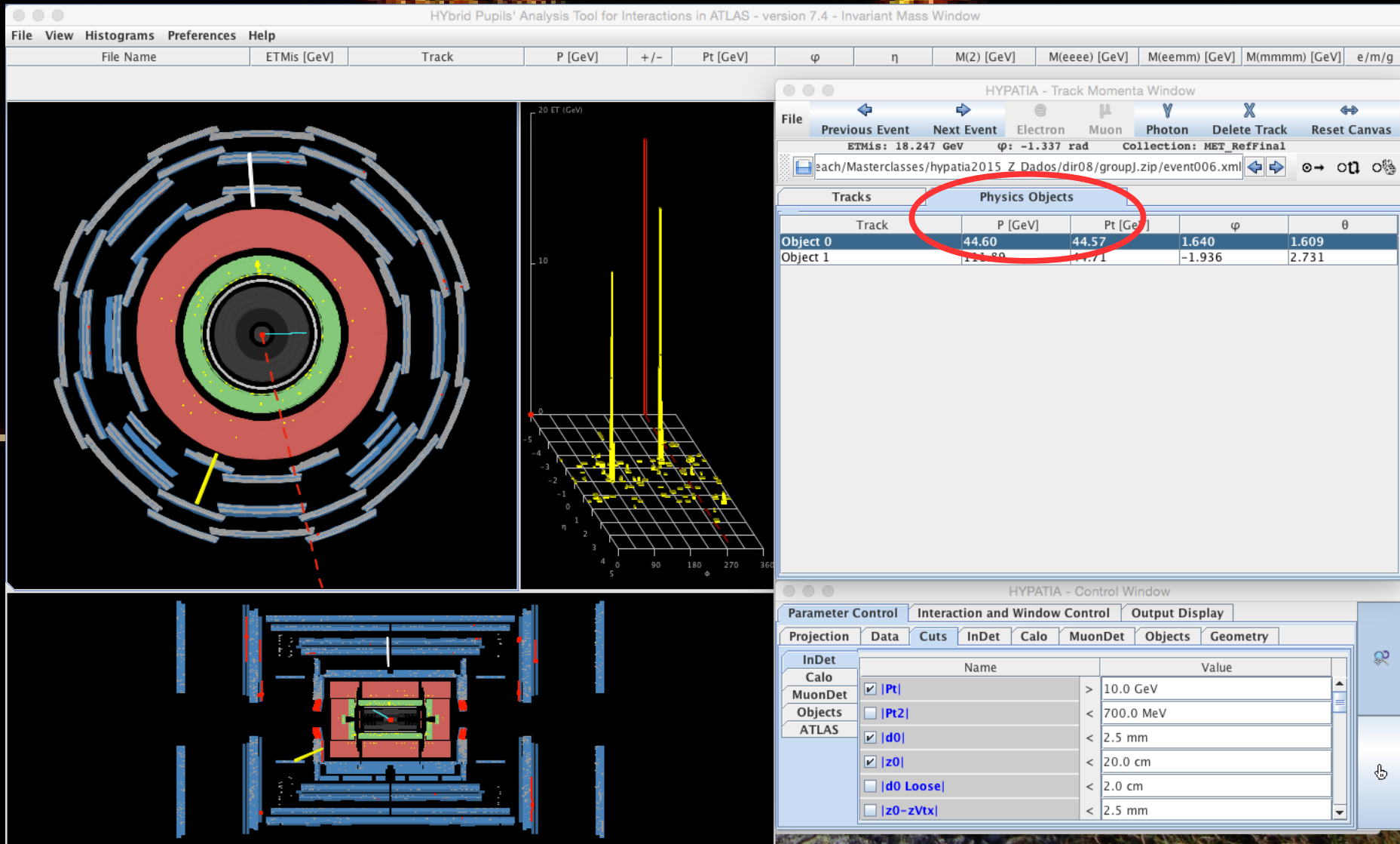
Invariant mass calculation



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

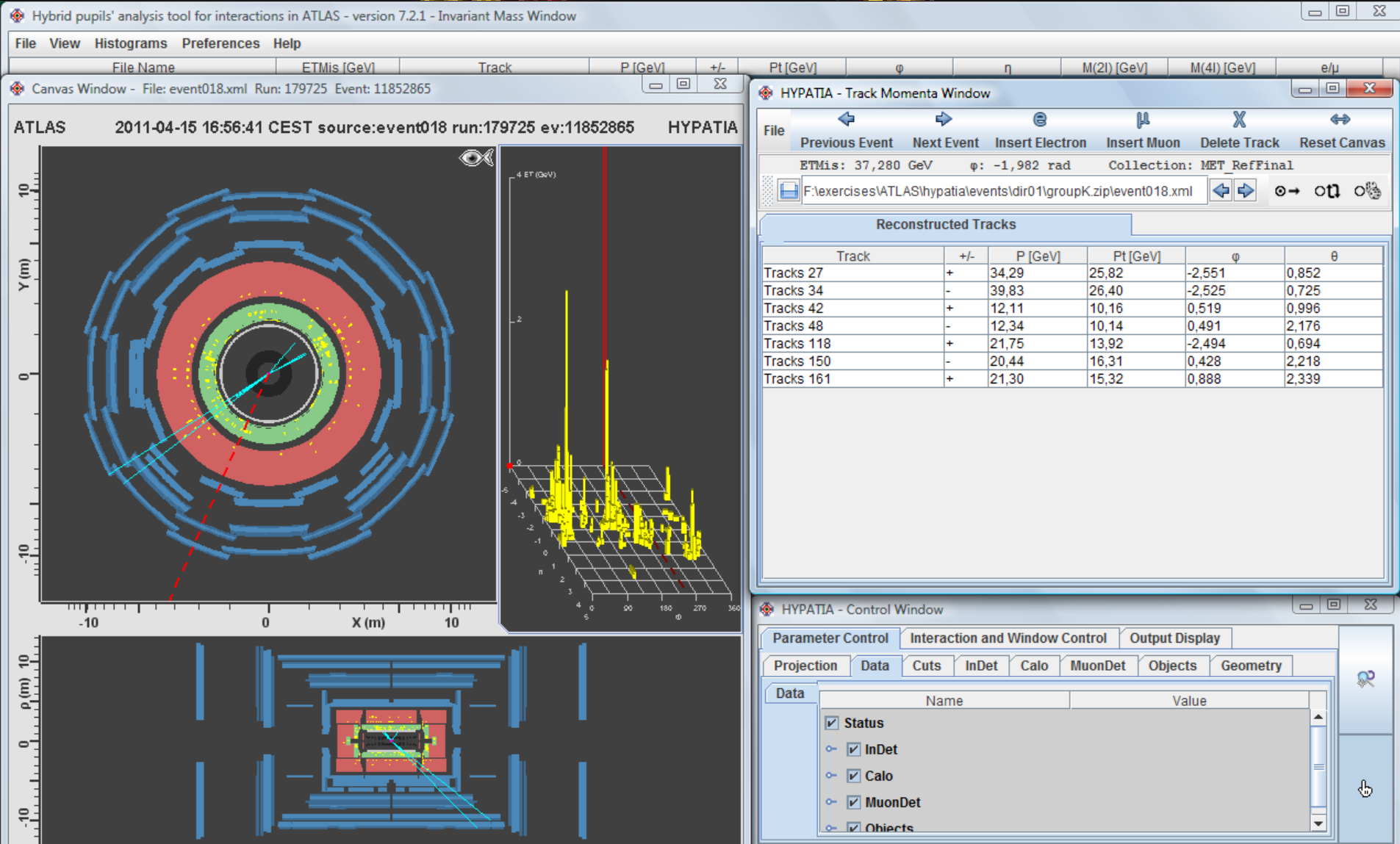


$$H \rightarrow \gamma\gamma$$



Photons are neutral particles; they do not leave tracks in the inner detector; only energy deposits in the electromagnetic calorimeter.

$Z \rightarrow$ jets (background)



- 
- A particle detector event visualization, likely from the ATLAS experiment, showing a central collision point with numerous tracks radiating outwards. The tracks are color-coded, with red and yellow tracks being more prominent. The background is black, and the tracks are set against a light gray rectangular area.
- Use script startHypatia.sh
 -
 - Get the file with 10 events and make the exercise in
https://atlas.physicsmasterclasses.org/en/zpath_exercise2.htm