HYPATIA

$E = mc^2$

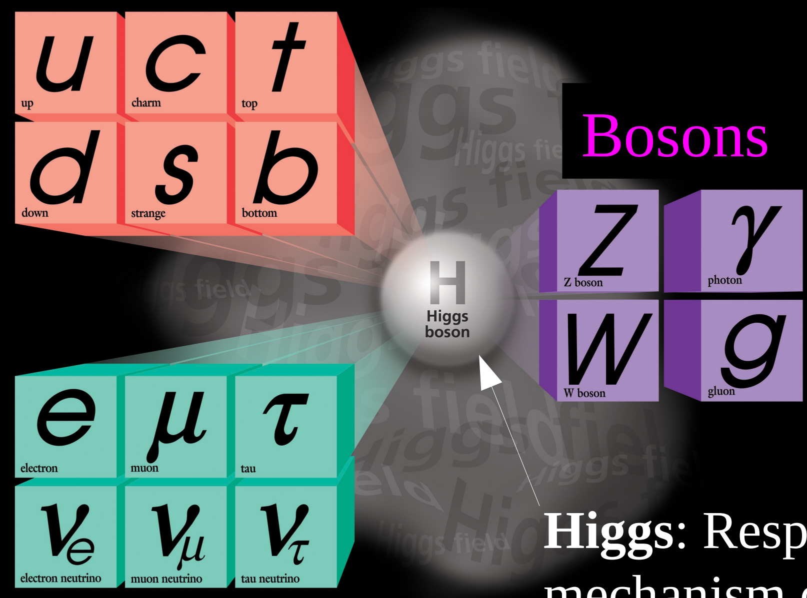
Helena Santos – Summer Internship, July 2019

The Standard Model of Elementary Particles

Fermions

Quarks

Leptões



Bosons

Mediate the fundamental interactions

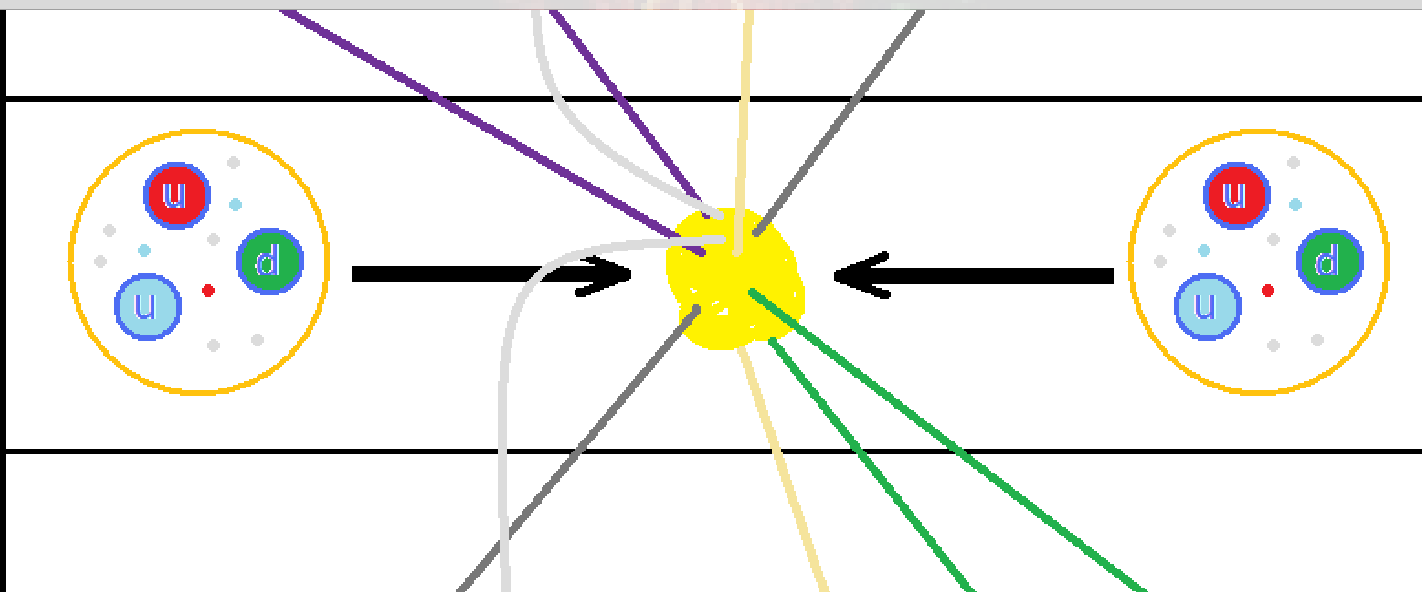
Higgs: Responsible for the mechanism of mass acquisition by the elementary particles

Proton-Proton interactions

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

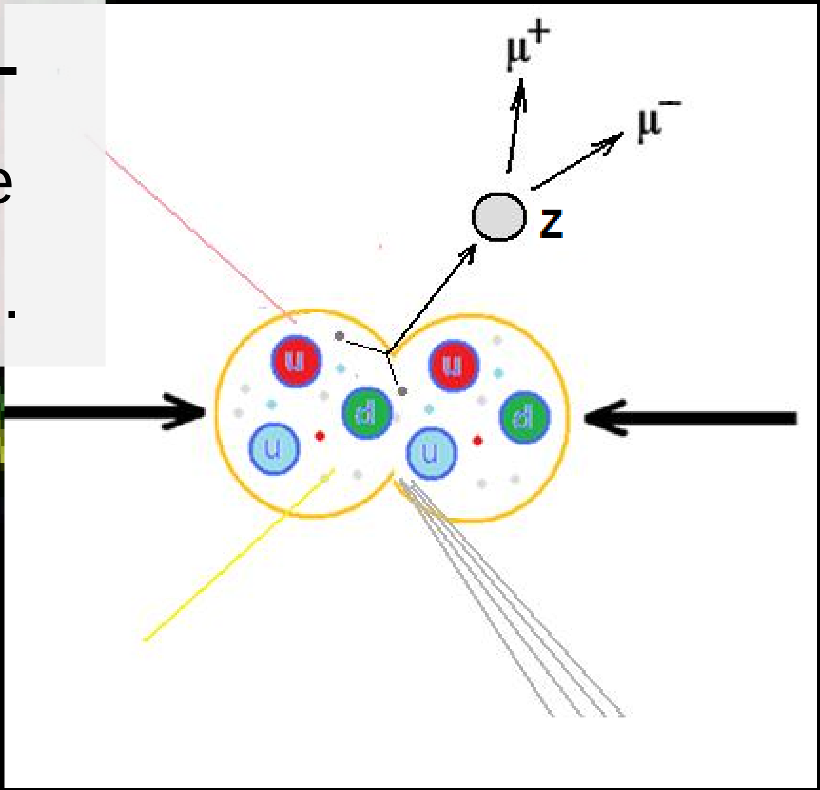
in the center of mass: 2 x 6.5 TeV = 13 TeV

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?).



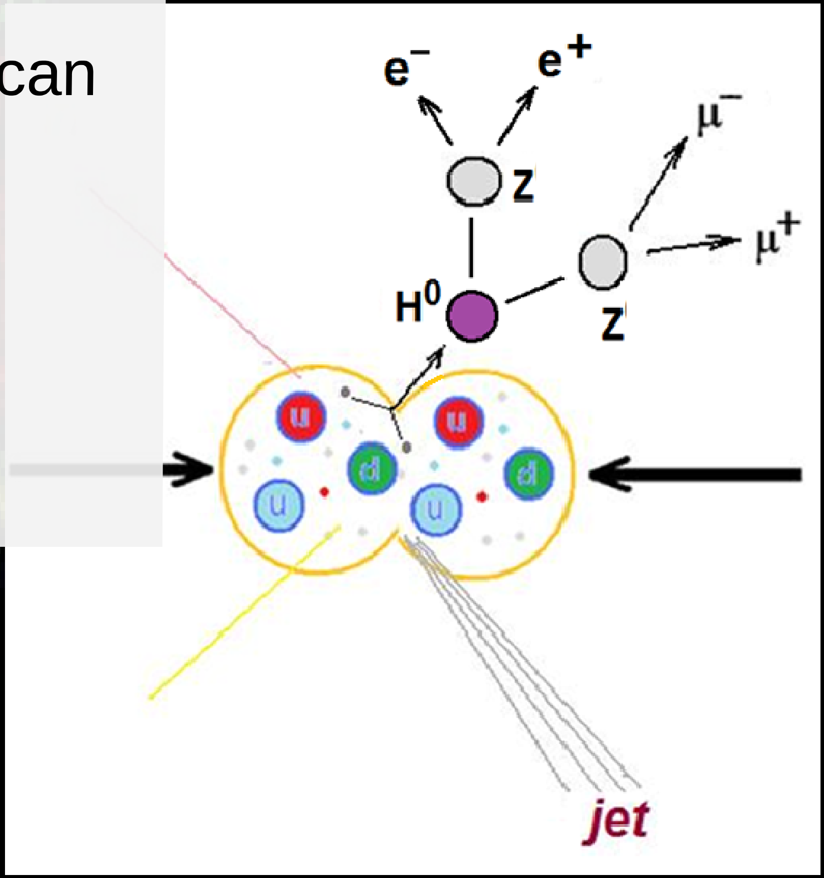
Production and particles decay

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 → ZZ* → 4 leptons

H → γγ (2 photons)

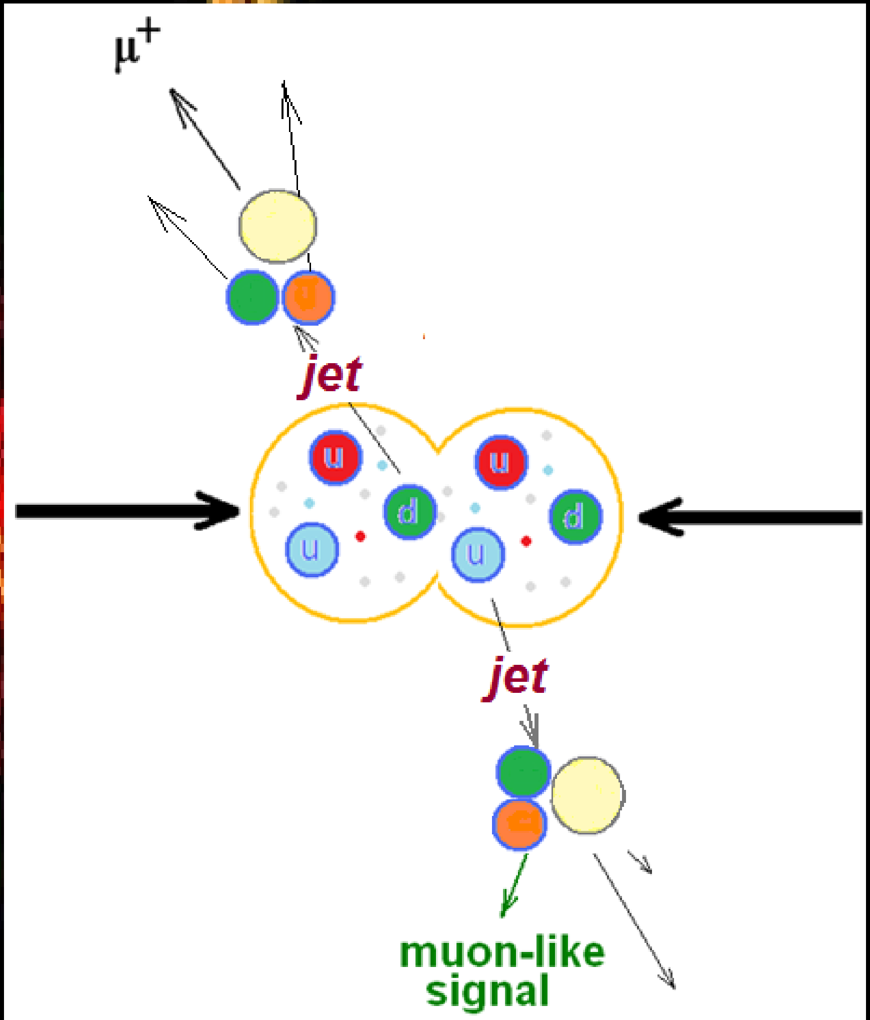


Production and particles decay

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**.



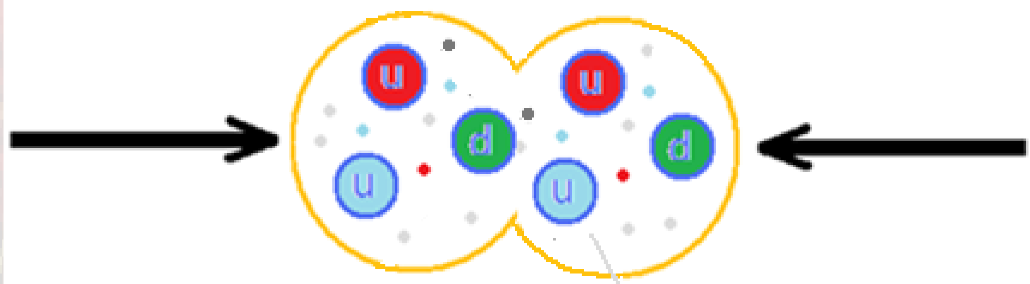
Production and particles decay

We will select several events with the **Z→μ⁺μ⁻** and **Z→e⁺e⁻** topologies and use the information of the invariant mass to know if they are Z boson candidates or other particles.

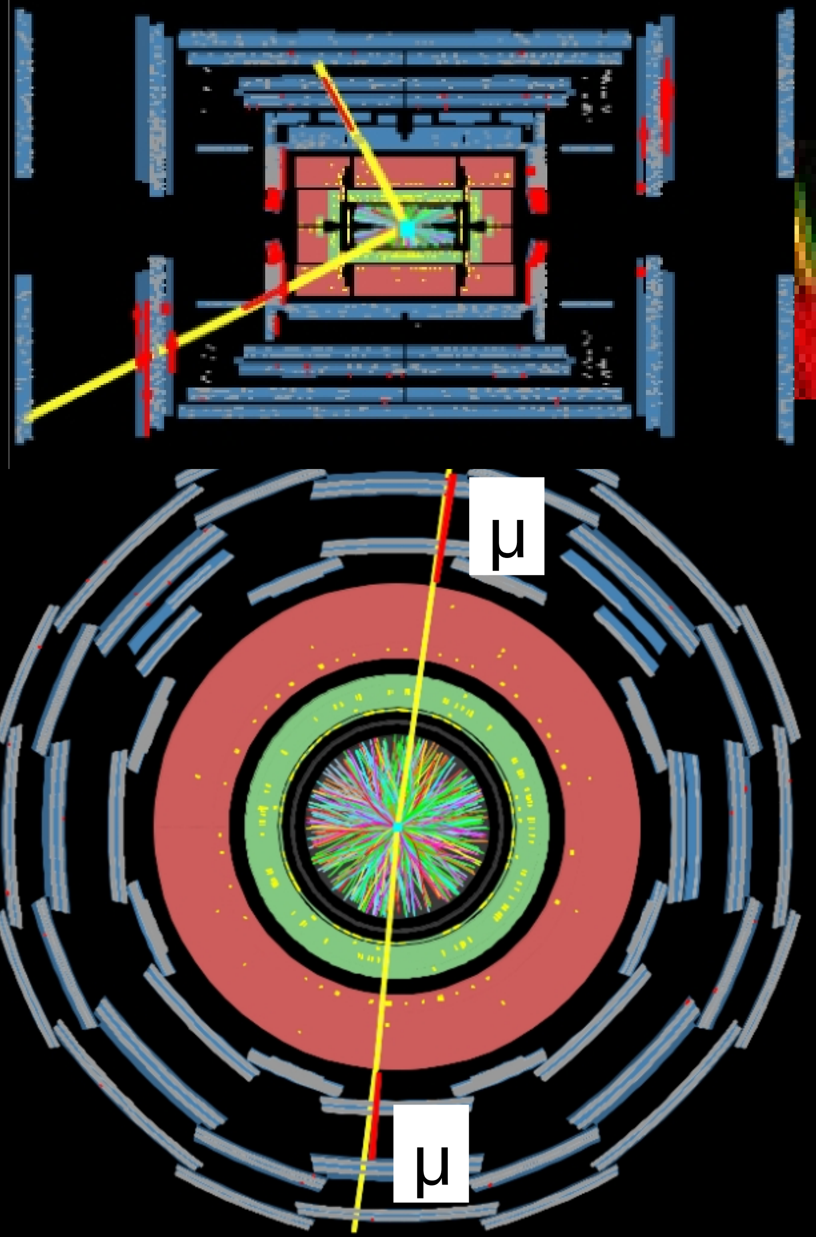
$$E^2 = m^2c^4 + c^2p^2$$

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

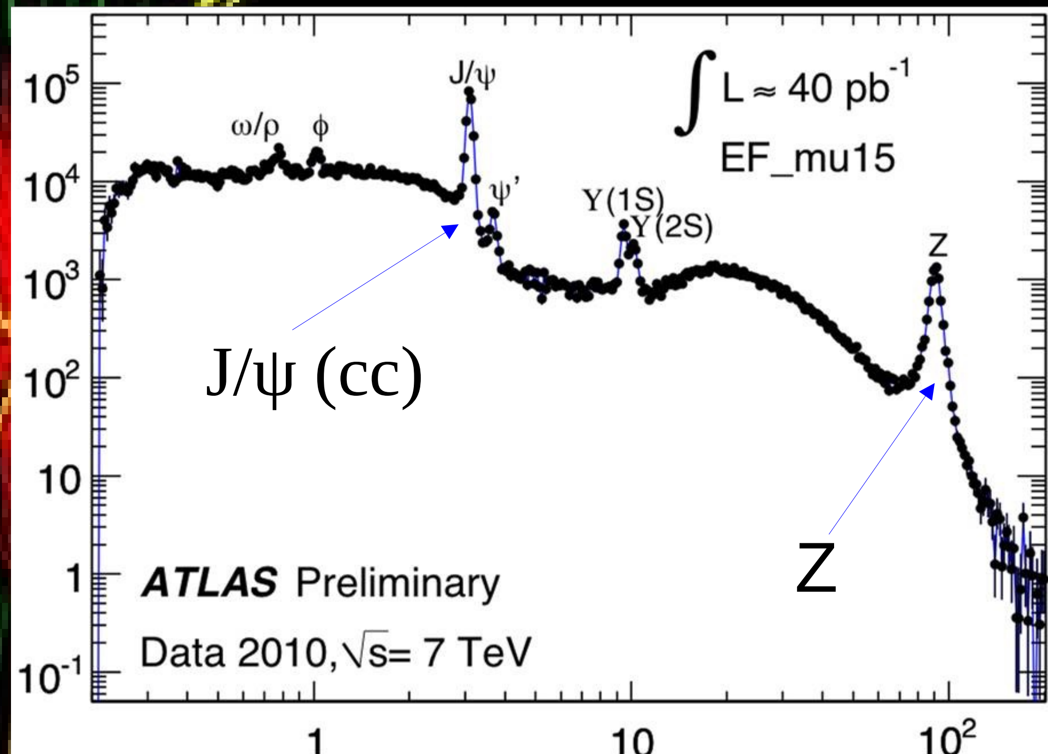
$$m = \sqrt{(E_1 + E_2)^2 - c^2(\vec{p}_1 + \vec{p}_2)^2}/c^2$$



After millions events...



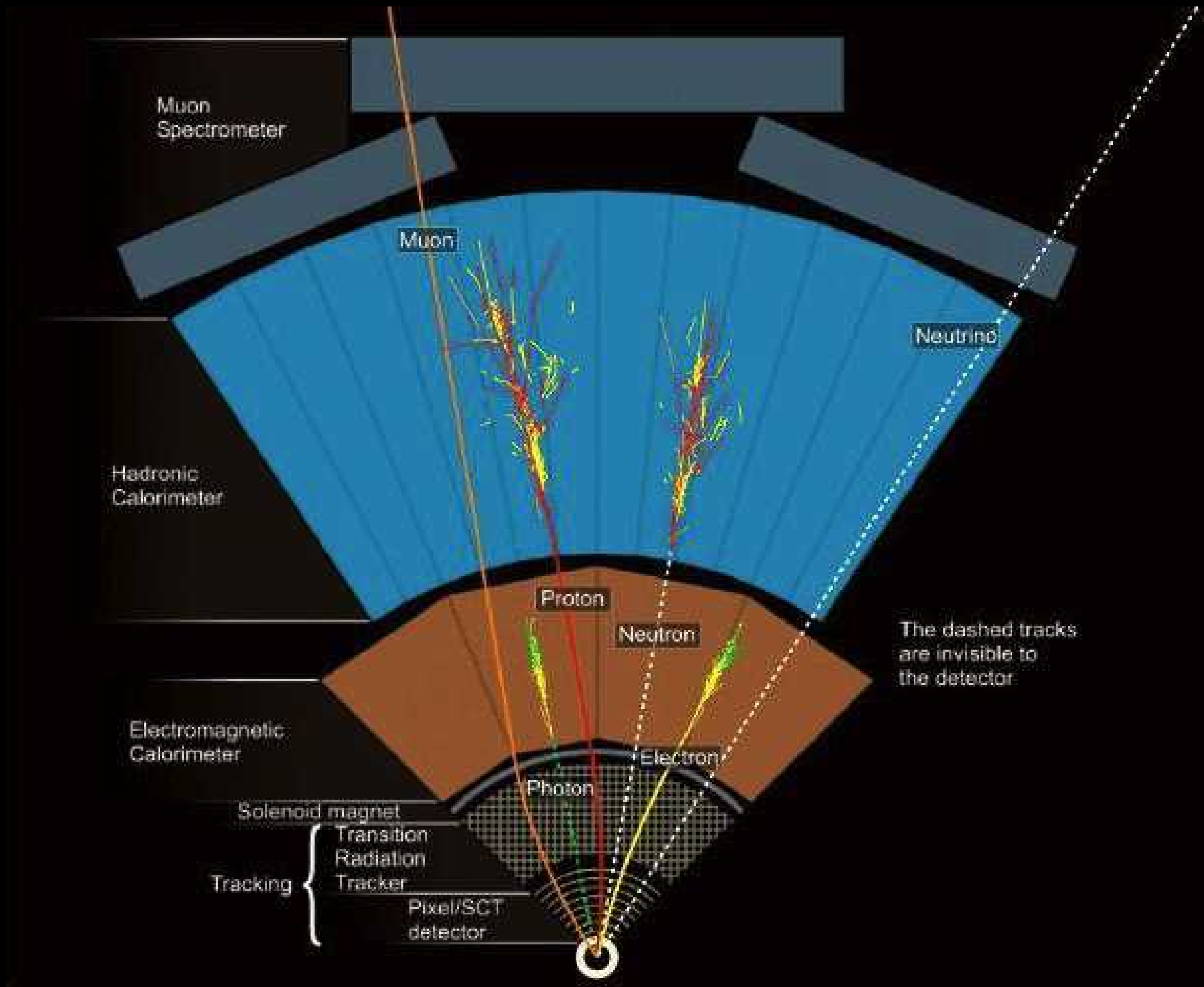
Dimuon invariant mass spectrum



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

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

Detecting Particles



Z Boson Properties

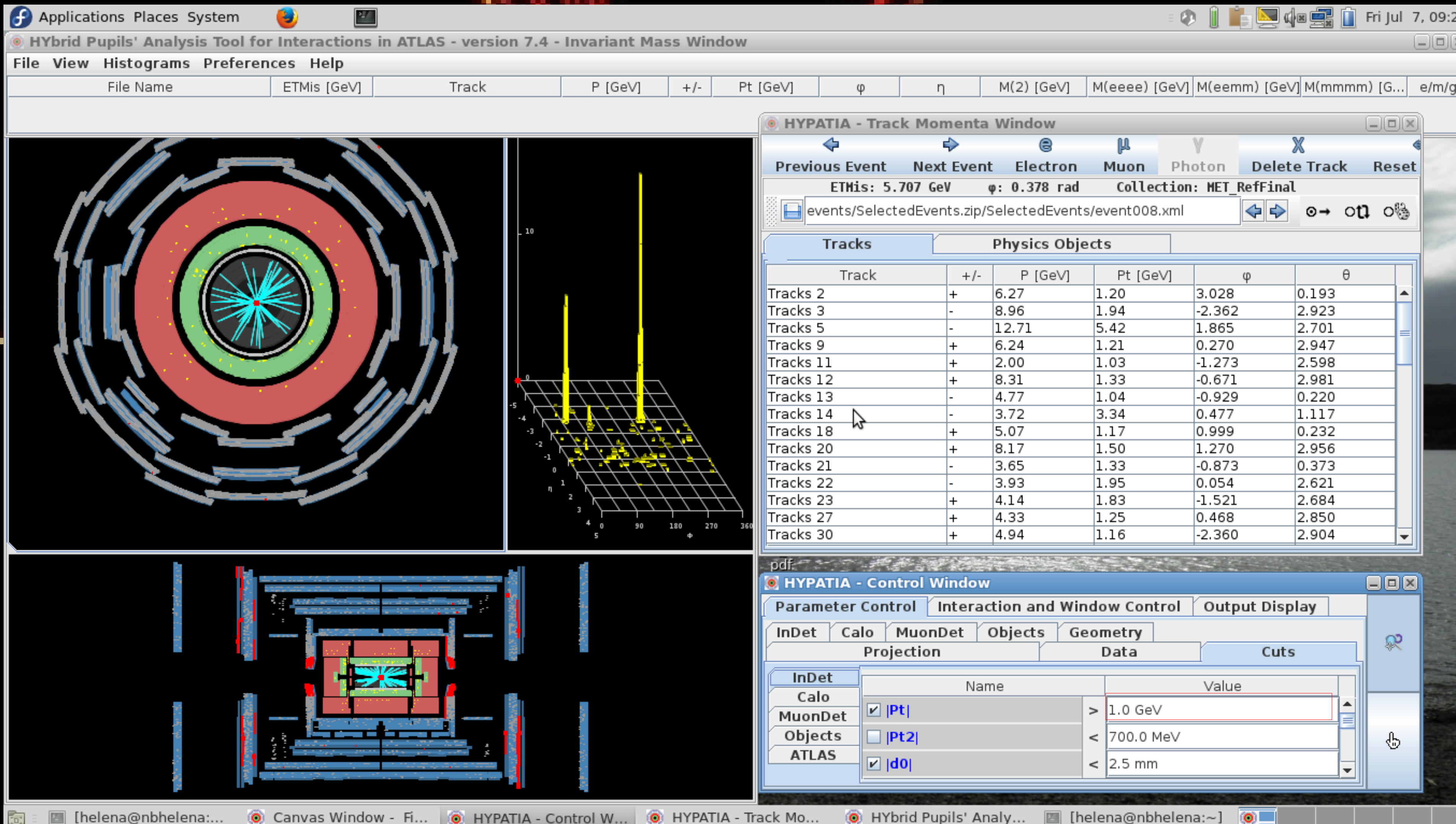
- The Z boson is heavy – mass: 91.2 GeV/c^2 – and its live timee is short: $4x10^{-25}$ s.
- The Z boson is neutral → The sum of the electric charges of the descendents is zero.
- It does decay to:

 - quark-antiquark pair (70%) → identified by jets in the calorimeter;

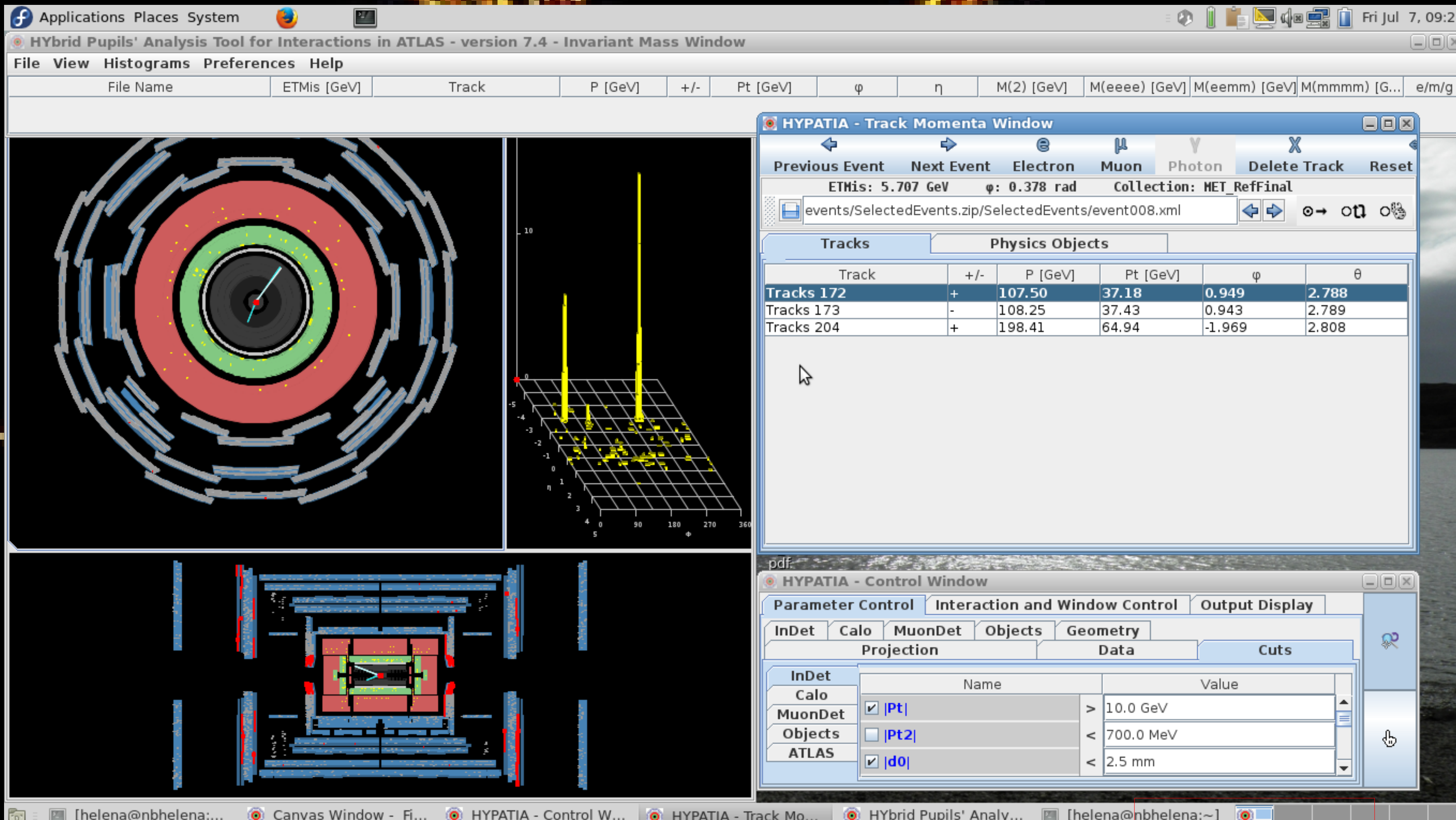
 - neutrino-antineutrino pair (20%). Neutrinos cross the entire detector untouched. They are infered from missing transverse momentum, MET.

 - leptão-antileptão (10%) pair. The three types of leptons (electron, muon and tau) are equally probable.

HYPATIA

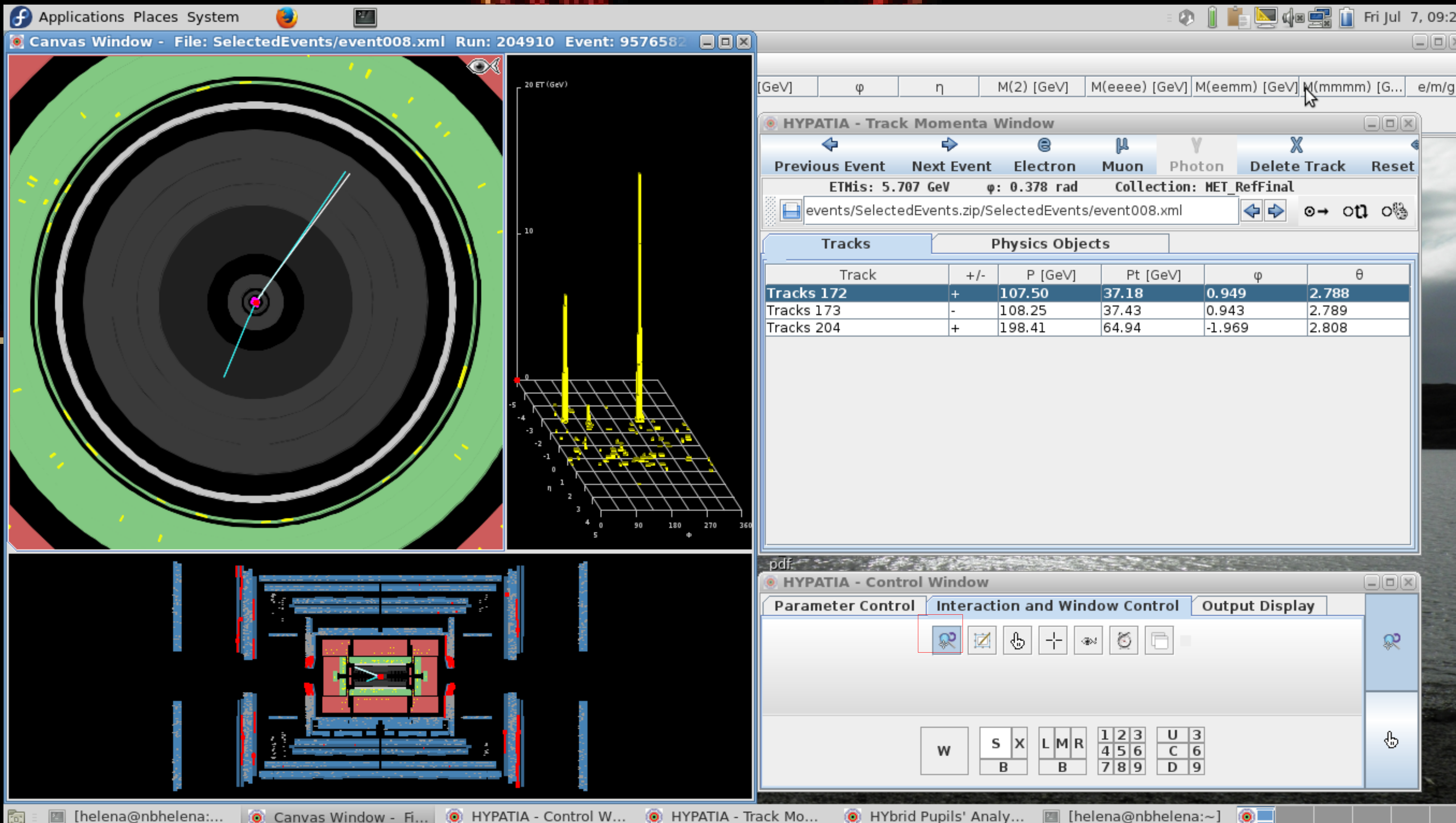

Applications Places System
Fri Jul 7, 09:20
HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window
File View Histograms Preferences Help
File Name ETMis [GeV] Track P [GeV] +/- Pt [GeV] φ η M(2) [GeV] M(eeee) [GeV] M(eemm) [GeV] M(mmmm) [G... e/m/g
HYPATIA - Track 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
Tracks
Physics Objects
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
InDet
Calo
MuonDet
Objects
ATLAS
Name Value
|Pt| > 1.0 GeV
|Pt2| < 700.0 MeV
|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 meomentum projected in the transverse plan of the detector) allows the low-p_T track removal, which helps to improve greatly the signal to background ratio.

Zoom


Applications Places System
Fri Jul 7, 09:23
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20 ET (GeV)
[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
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ETMis: 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
HYPATIA - Control Window
Parameter Control
Interaction and Window Control
Output Display
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Canvas Window - Fi...
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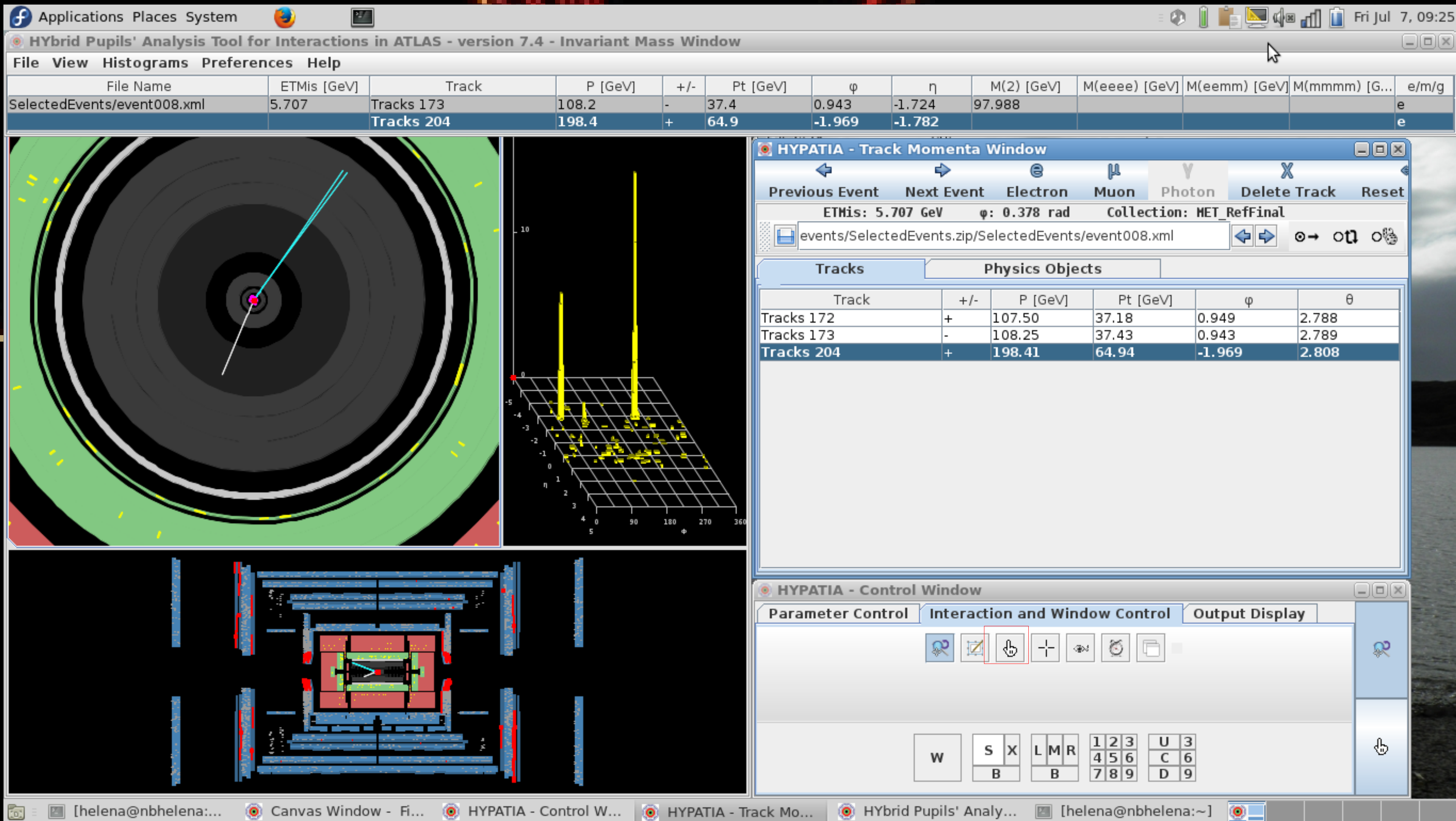
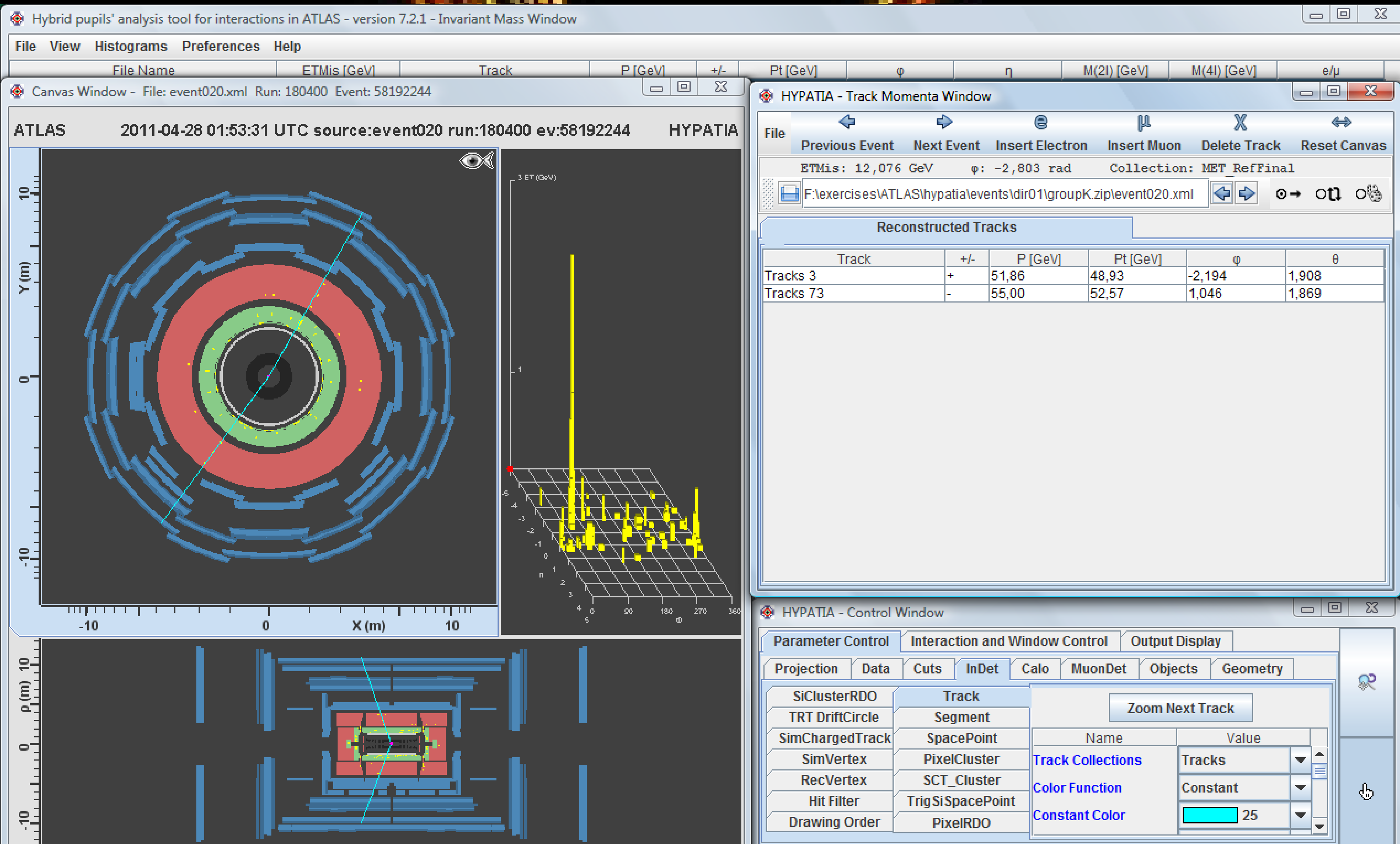
HYPATIA - Track Mo...
HYbrid Pupils' Analy...
[helena@nbhelena:~]

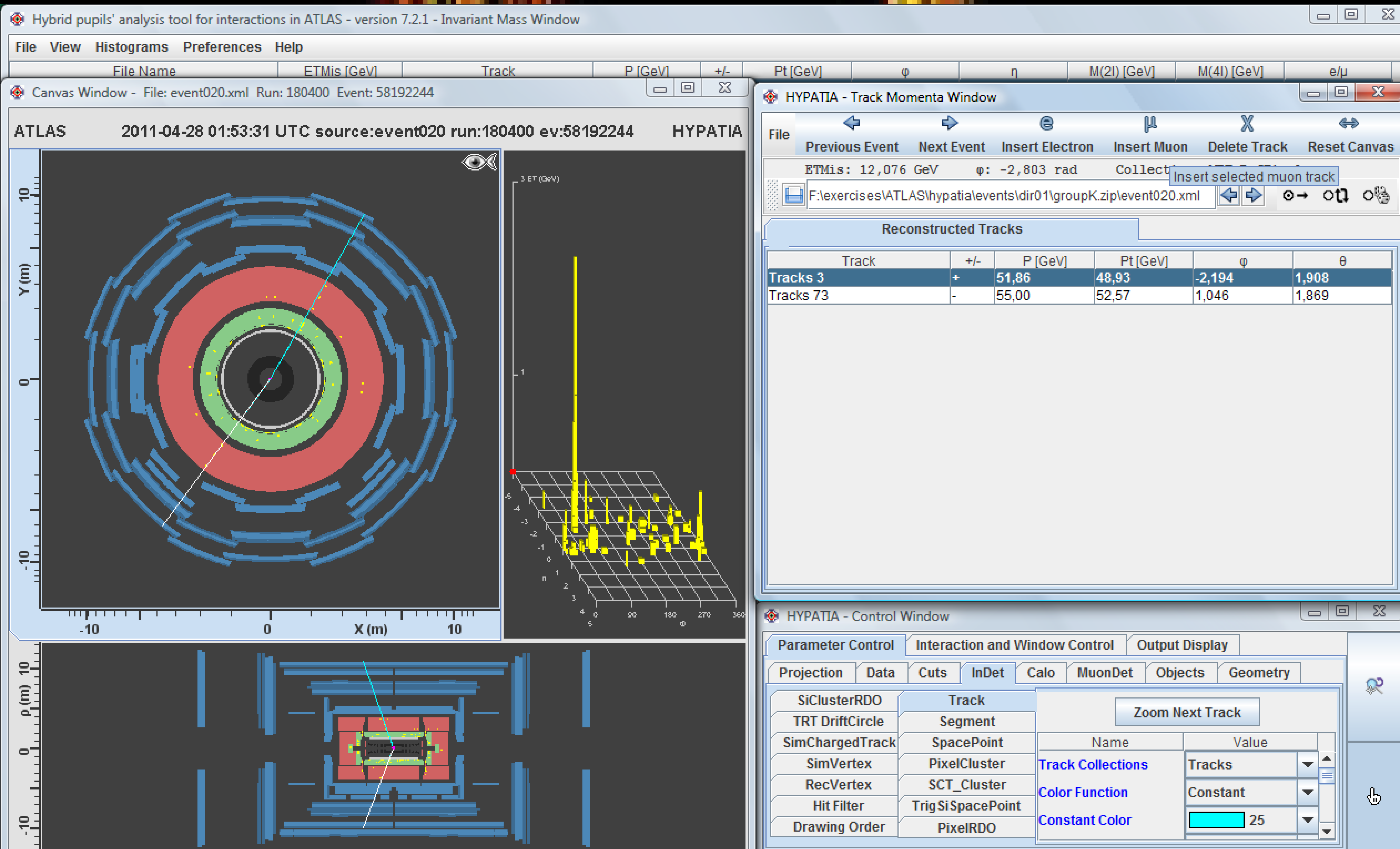
Track selection



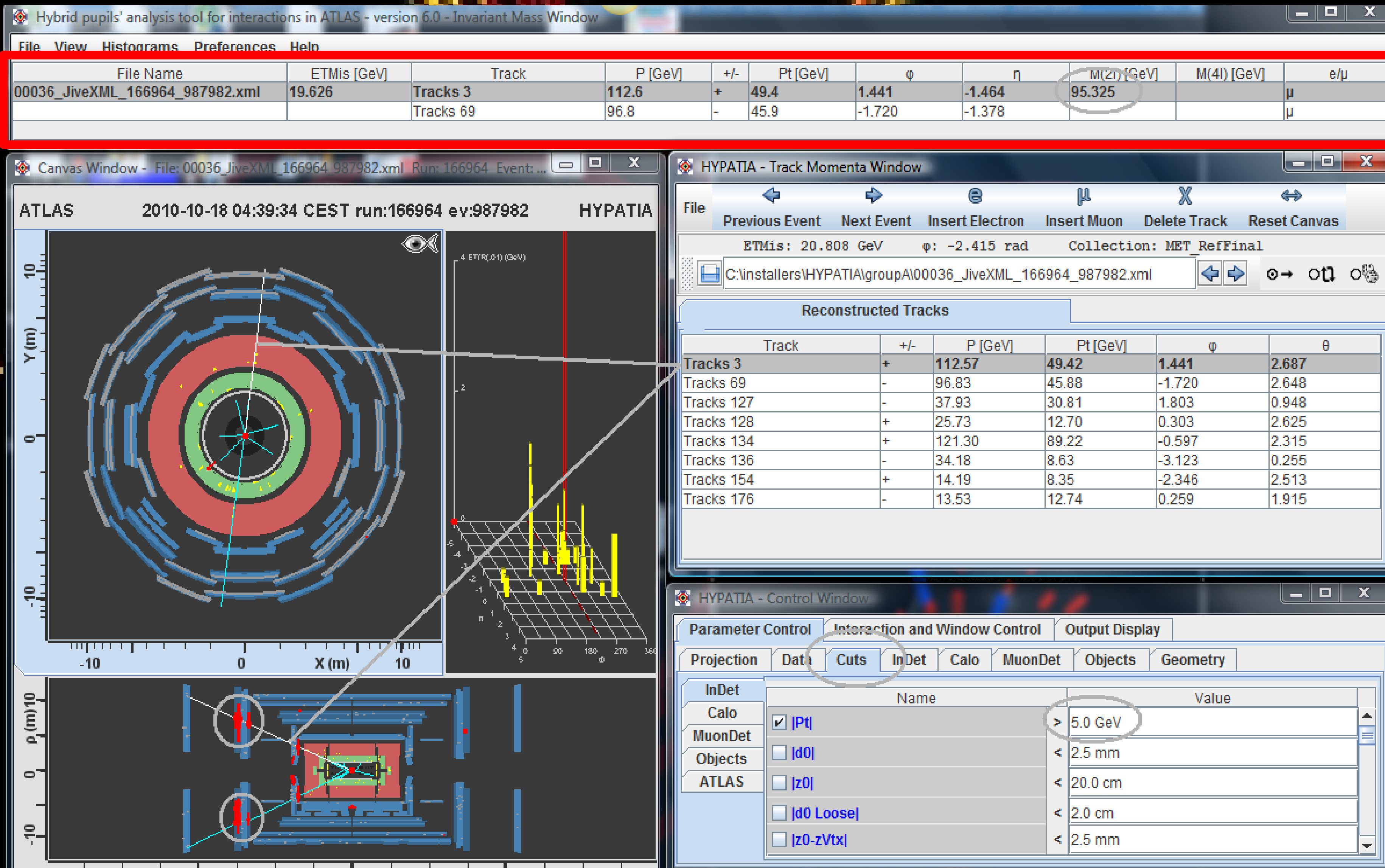
$Z \rightarrow \mu^+ \mu^-$



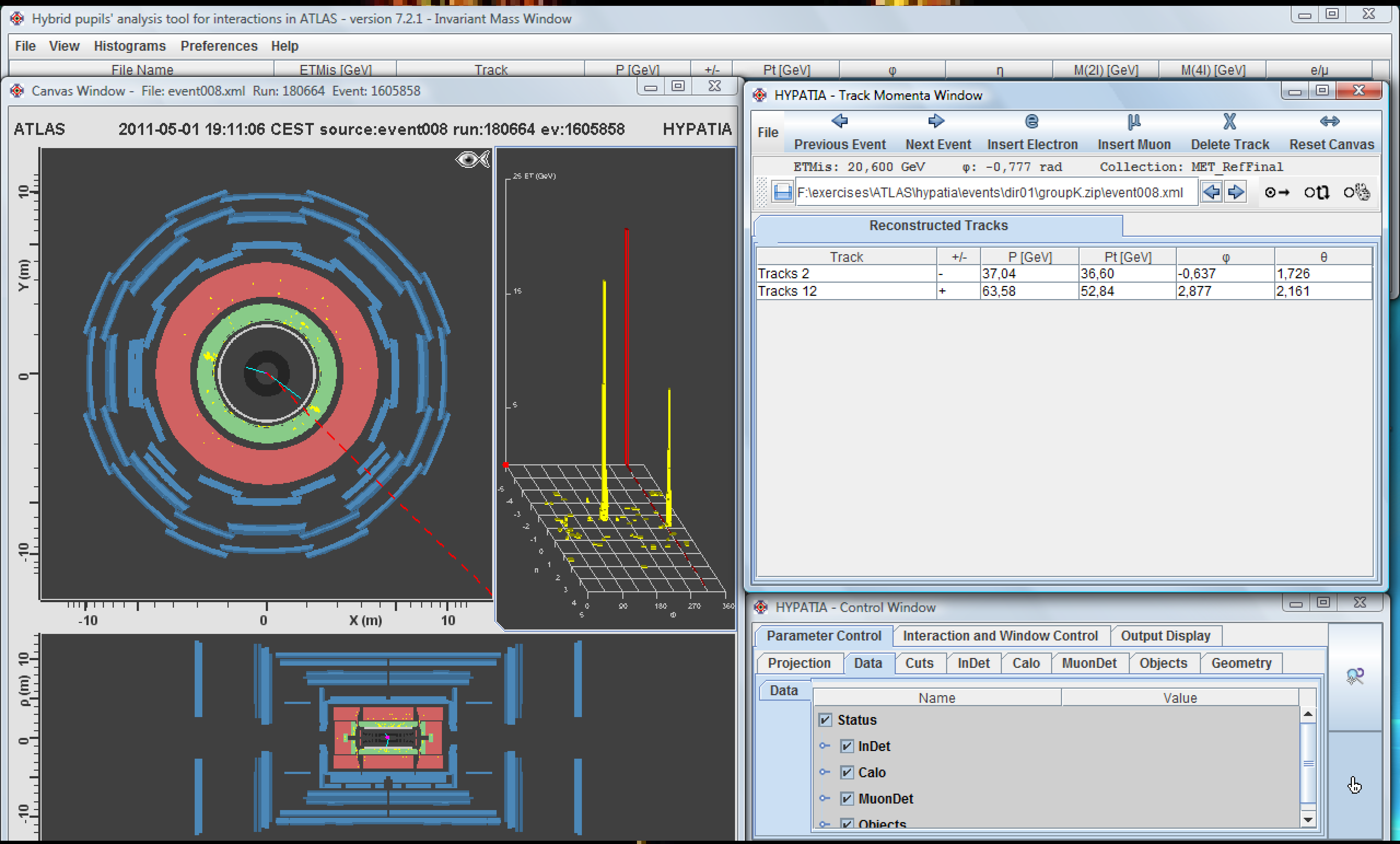
$Z \rightarrow \mu^{+} \mu^{-}$



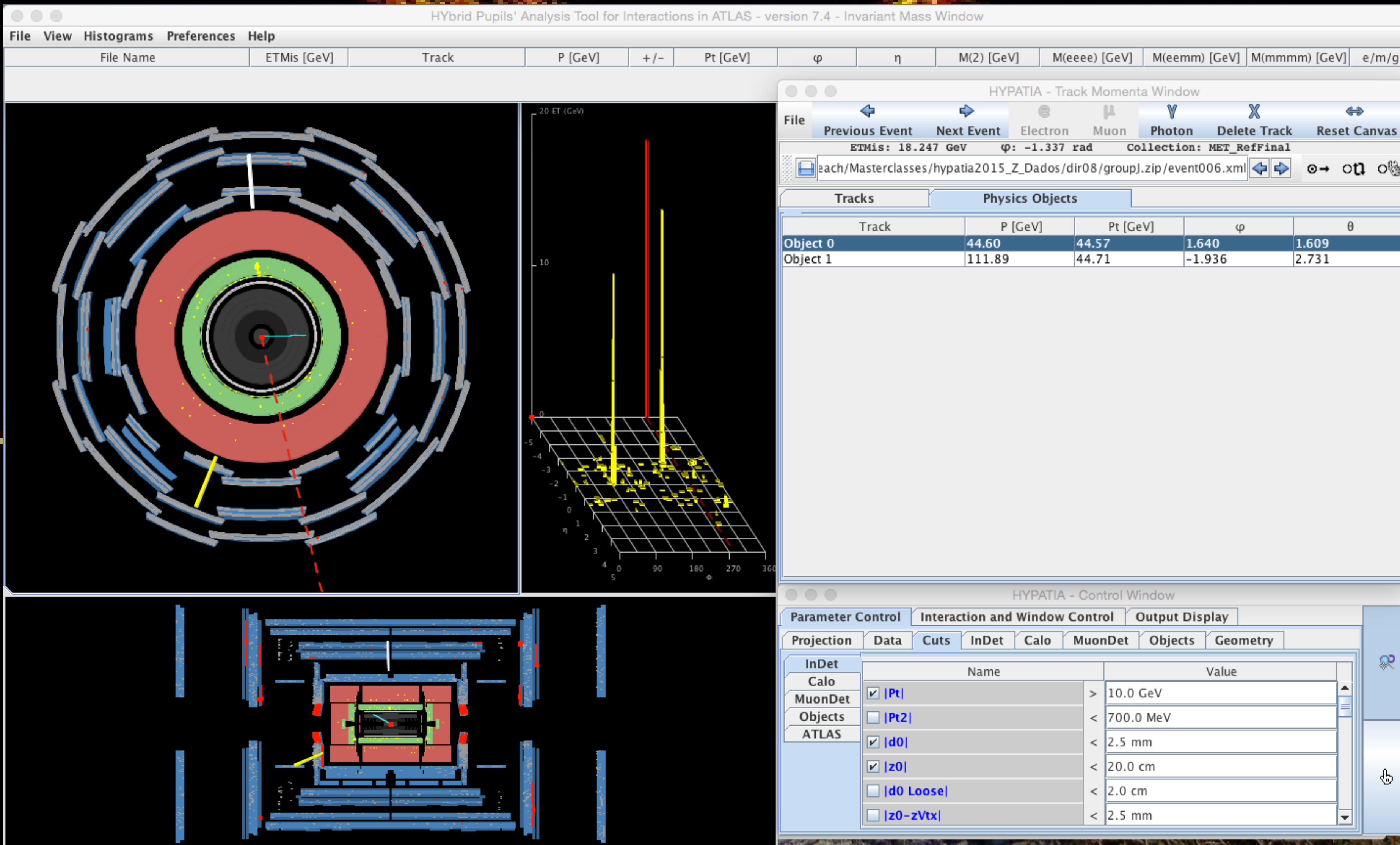
Invarian mass calculation



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

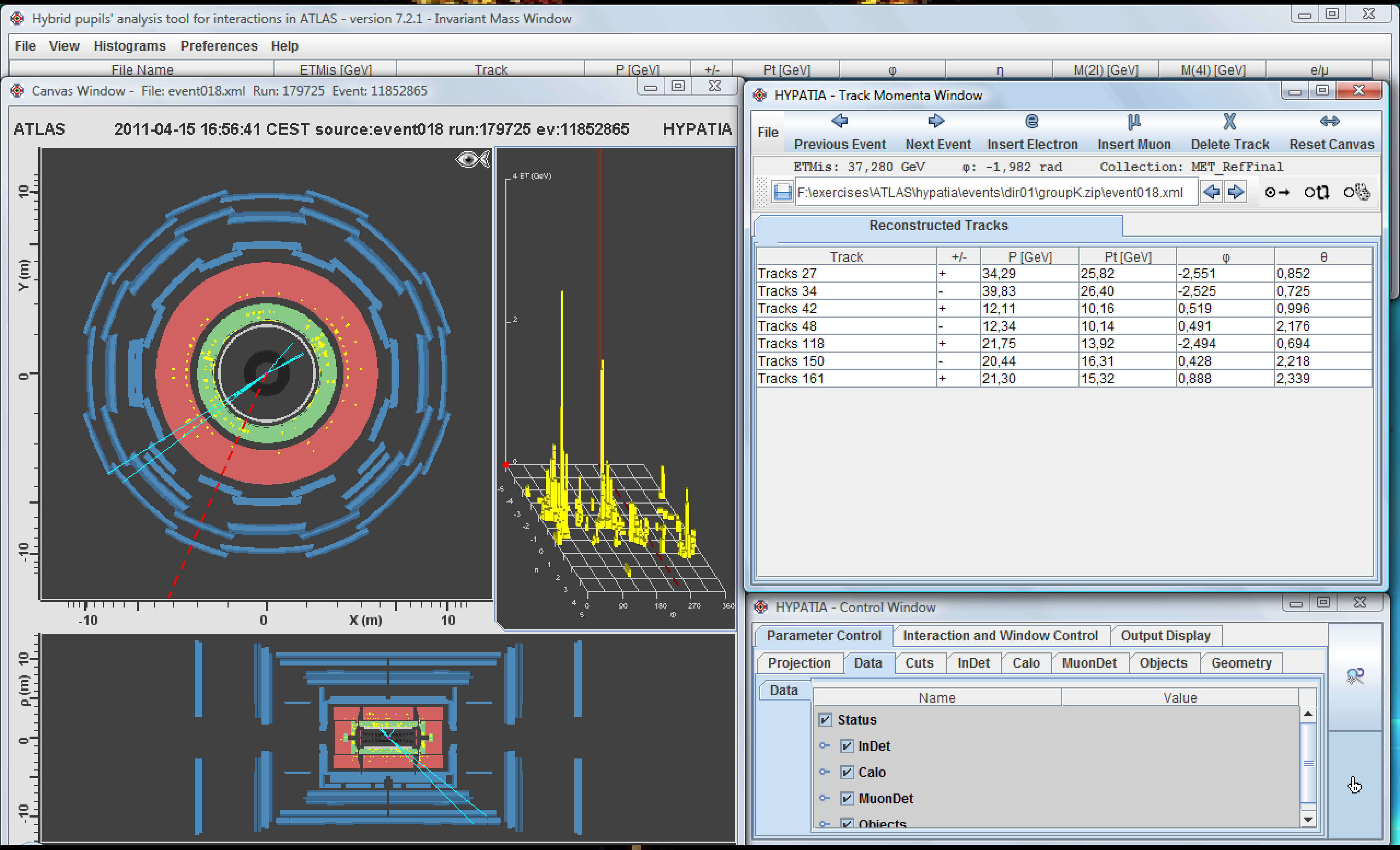


H → γγ



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

Z → jets (background)



- Download HYPATYA-Z in
- http://www.lip.pt/masterclasses/
- Download file with 10 events and make the exercise in
  https://atlas.physicsmasterclasses.org/en/zpath_exercise2.htm