ATLAS Z-Path
Masterclass 2018

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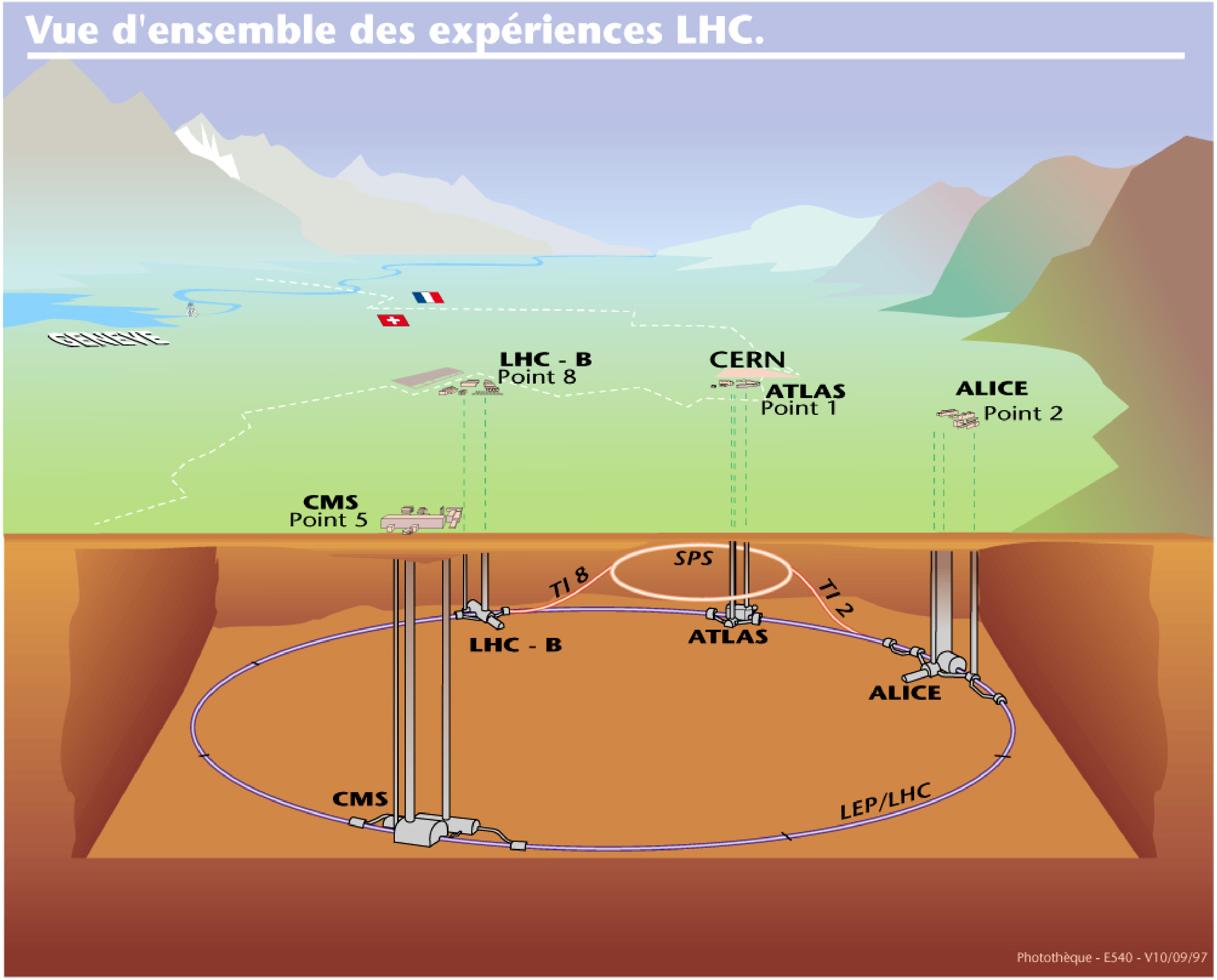
The LHC experiments

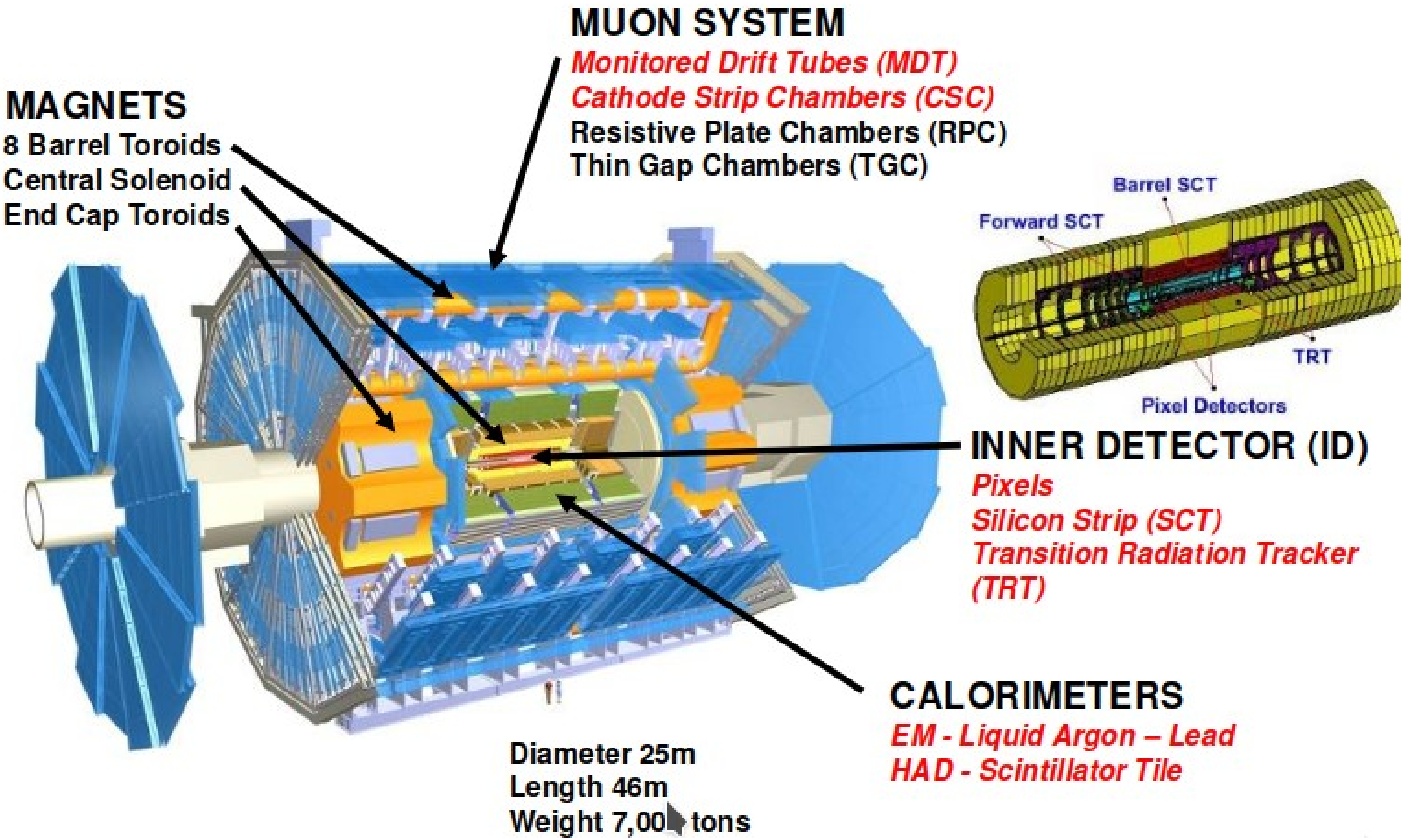


The scientific excitement at CERN

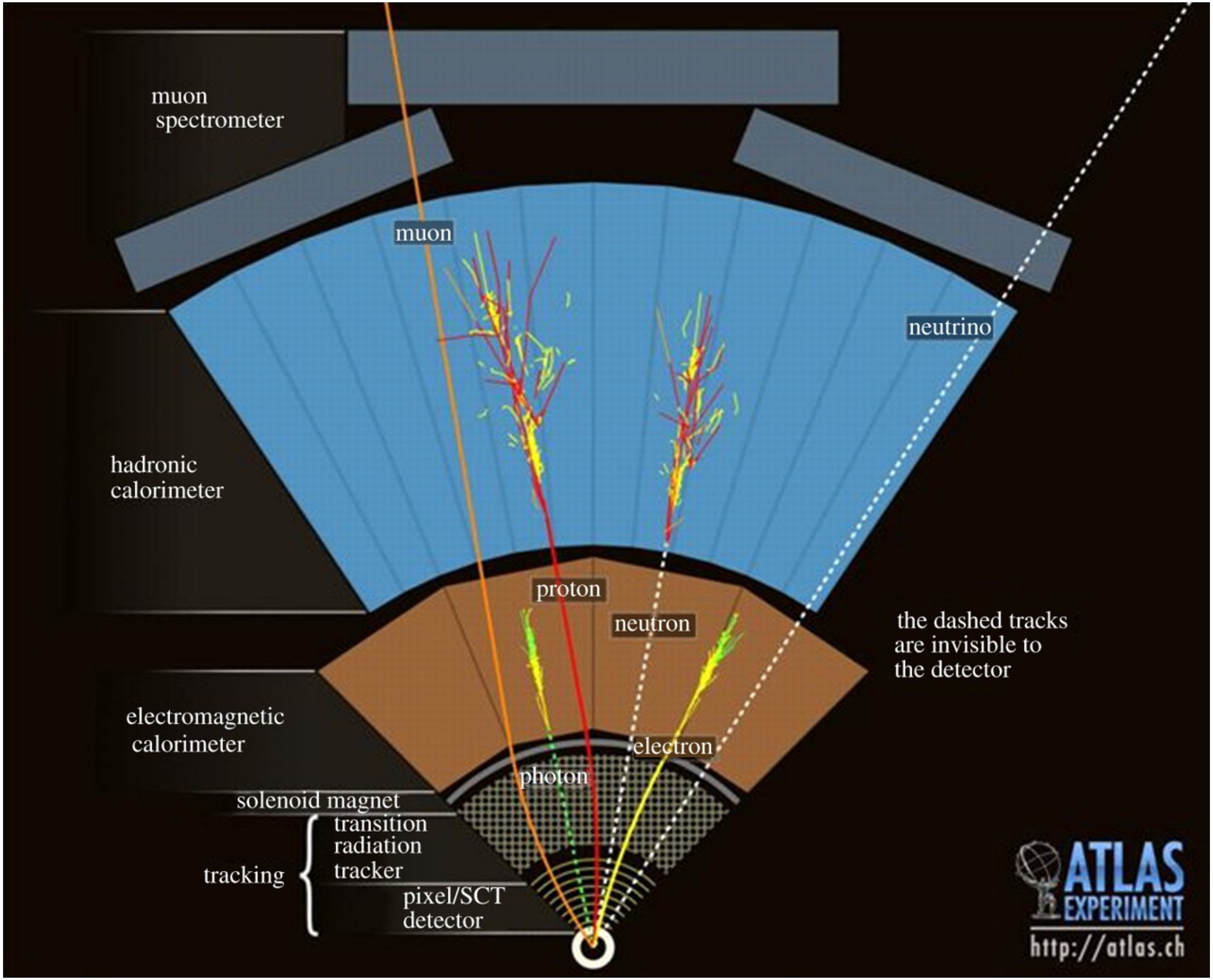
- We are at the threshold of a new era in fundamental science with the turn-on of the CERN Large Hadron Collider.

- Experiments have been built to probe some of the most puzzling questions about nature:

  - Testing speculations about the origin of mass
  - Identifying the character of dark matter
  - Searching for dimensions in space beyond those we observe in our 4-dimensional world
  - Exploring mechanisms for producing a matter-dominated universe

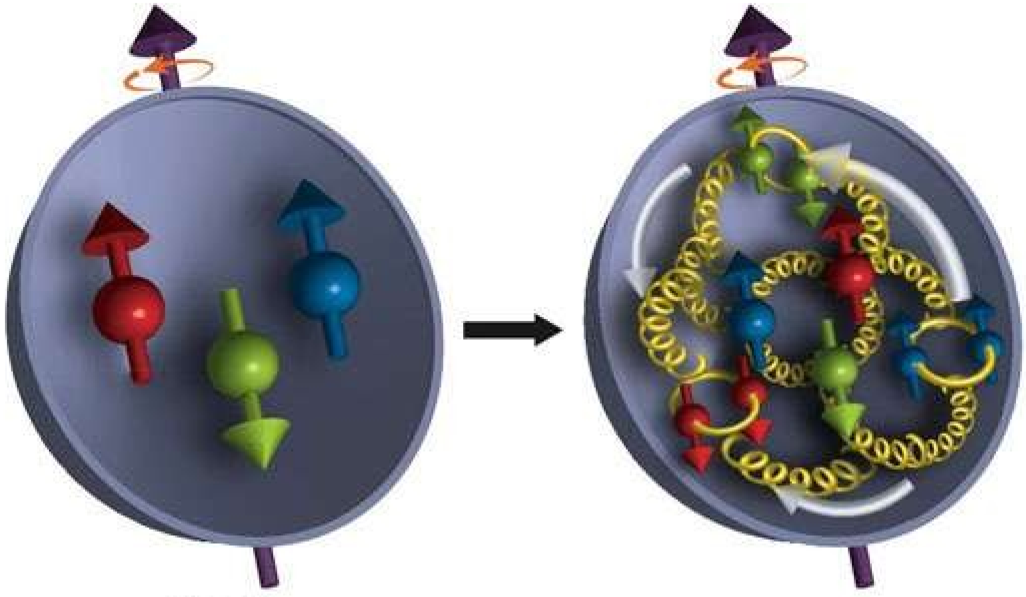

MUON SYSTEM
Monitored Drift Tubes (MDT)
Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)
Thin Gap Chambers (TGC)
MAGNETS
8 Barrel Toroids
Central Solenoid
End Cap Toroids
Barrel SCT
Forward SCT
TRT
Pixel Detectors
INNER DETECTOR (ID)
Pixels
Silicon Strip (SCT)
Transition Radiation Tracker
(TRT)
CALORIMETERS
EM - Liquid Argon – Lead
HAD - Scintillator Tile
Diameter 25m
Length 46m
Weight 7,000 tons

Particle detection in ATLAS



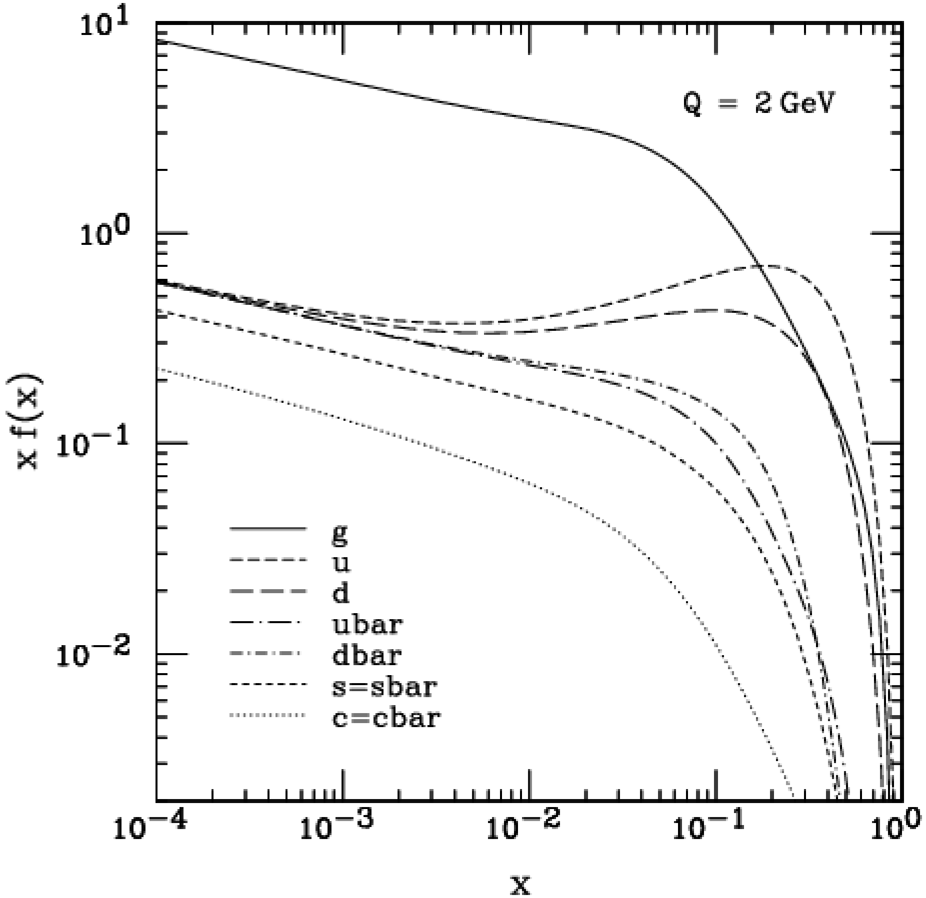
pp colisions

- The proton consists of three (valence) quarks bound together by the strong force
- These valence quarks are two up-quarks and one down-quark, giving the proton a total electric charge of +1
- But along with the valence quarks that contribute to their quantum numbers, they also contain virtual quark–antiquark pairs known as sea quarks. Sea quarks form when a gluon of the hadron's color field splits



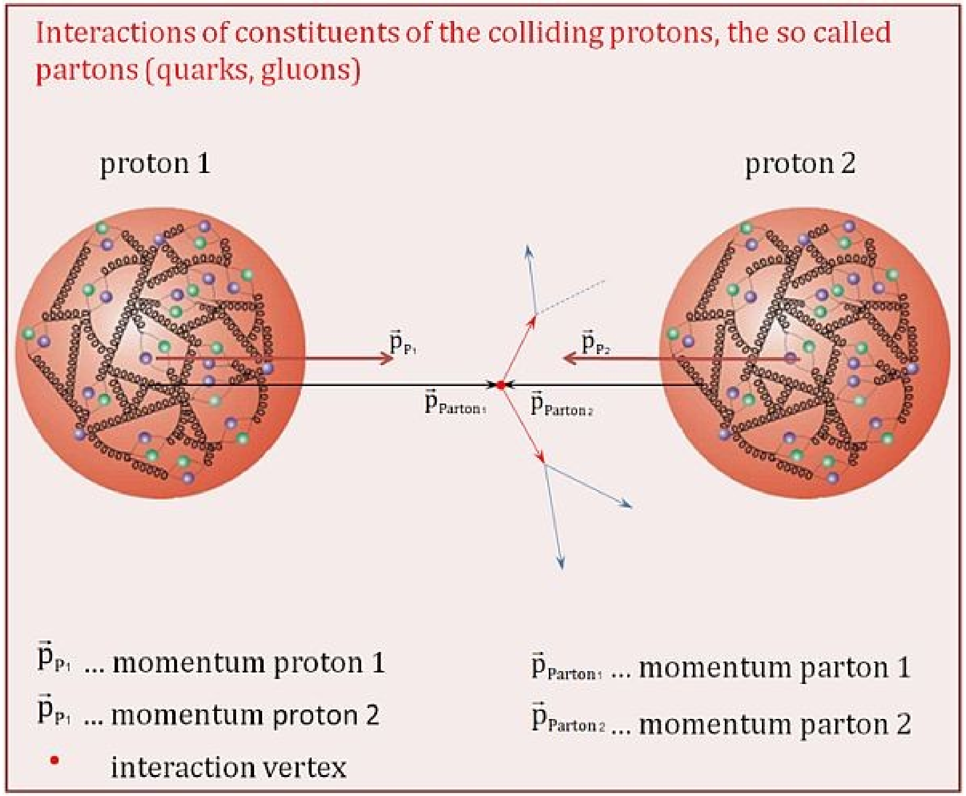
pp colisions – parton distribution

- The parton distribution functions (PDFs) describe how often the various proton constituents will go into a hard scattering with a given momentum fraction x (the fraction of the proton momentum carried by the constituent)
- They summarize the proton structure as seen on a given energy scale



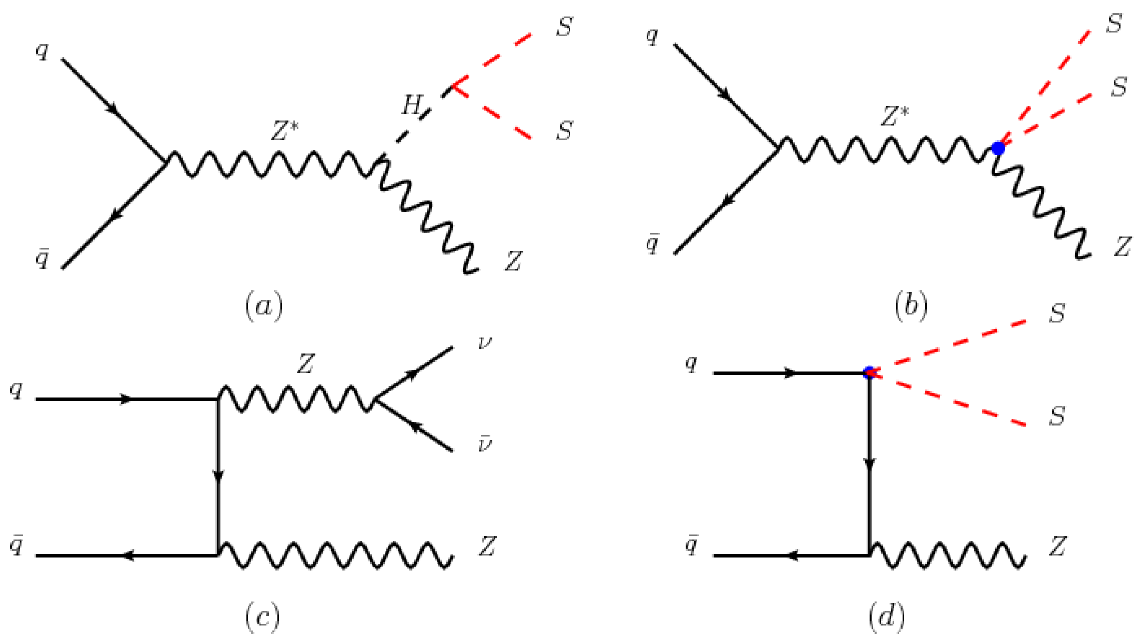
pp colisions – hard scattering

- In high energy collisions, such as at the LHC, we observe collisions between individual quarks, anti-quarks, and gluons from within the proton
- Such a collision is referred to as a hard scattering
- The individual particles that make up the proton only have a fraction of this energy. New particles made in the collision always have a mass smaller than that energy.



Z boson

- The W and Z bosons are the massive mediators of the weak force in the Standard Model
- The Z boson is its own antiparticle. Thus, all of its flavour quantum numbers and charges are zero.
- The exchange of a Z boson between particles, called a *neutral current interaction*, therefore leaves the interacting particles unaffected, except for a transfer of momentum.



Z boson properties:

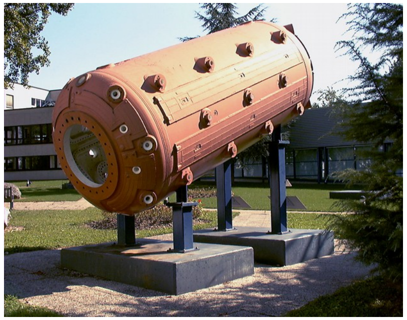
Mass:	*91.1876±0.0021 GeV/c²*
Lifetime:	*~3×10⁻²⁵ s*
Decay width:	*2.4952±0.0023 GeV/c²*
Spin:	*1*
Charges:	*0*

Discovery of neutral currents

- Charged current interactions is capable of changing the flavour of quarks: $d \to u + W^-$
- Neutral currents leave flavour unchanged $e^- \to e^- + Z^0$

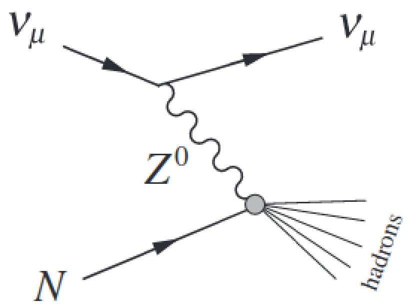
- Until 1973 all observed weak interactions were consistent with only a charged boson.
- CERN, 1973: first neutral current interaction observed:

$$\nu_\mu + N \to \nu_\mu + X$$



The Gargamelle detector

- Mechanism for neutral current reactions:

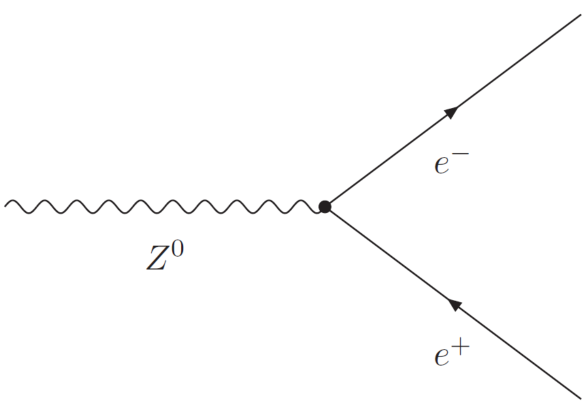


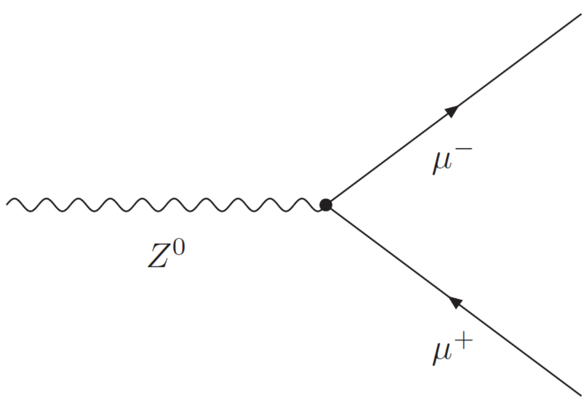
Discovery of the Z boson

- The Z boson was discovered at CERN in 1983 (UA1 and UA2 experiments)
- Z boson has 24 differnet decay possibilities:

hadronic	leptonic: visible	leptonic: invisible
$Z^\circ \rightarrow q\bar{q}$	$Z^\circ \rightarrow e^+e^-$	$Z^\circ \rightarrow \nu\bar{\nu}$
	$Z^\circ \rightarrow \mu^+\mu^-$	
	$Z^\circ \rightarrow \tau^+\tau^-$	

- Z decays to charged leptons are easiest to detect

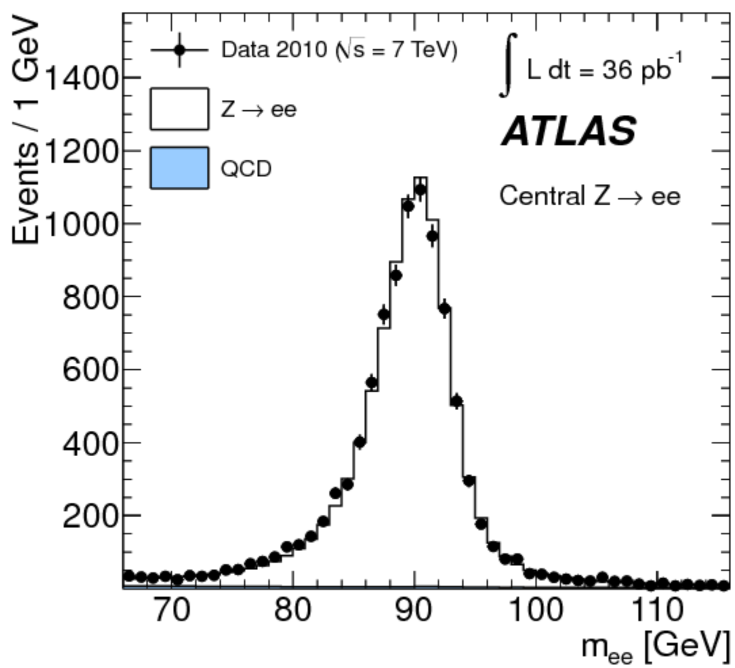




Invariant mass technique

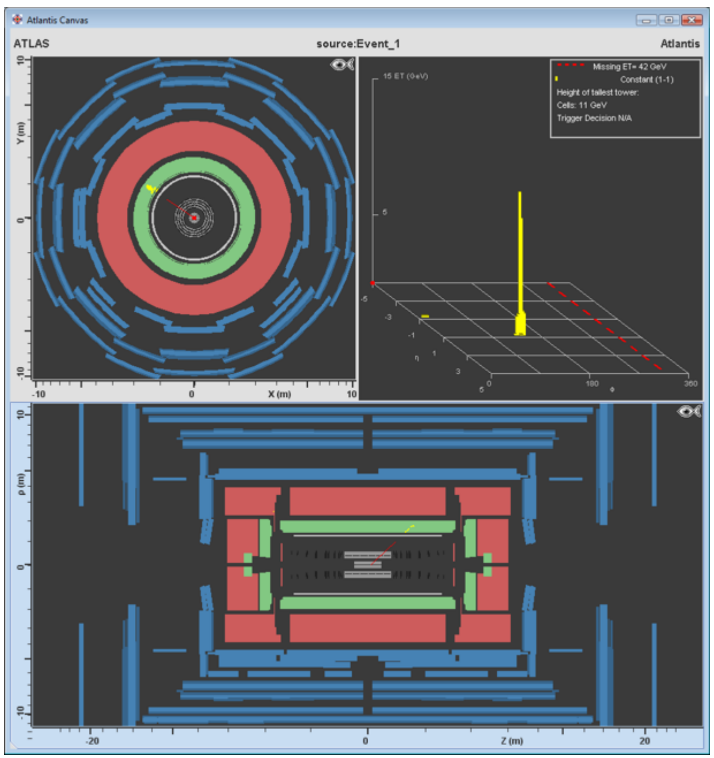
- The Einstein equation: $E = \sqrt{(\vec{p} \cdot c)^2 + (m_0 \cdot c^2)^2}$
- Invariant mass: $m_0 = \sqrt{\left(\frac{E}{c^2}\right)^2 - \left(\frac{\vec{p}}{c}\right)^2}$
- The energy of Z: $E_Z = E_{e^-} + E_{e^+}$
- The momentum of Z: $\vec{p}_Z = \vec{p}_{e^-} + \vec{p}_{e^+}$

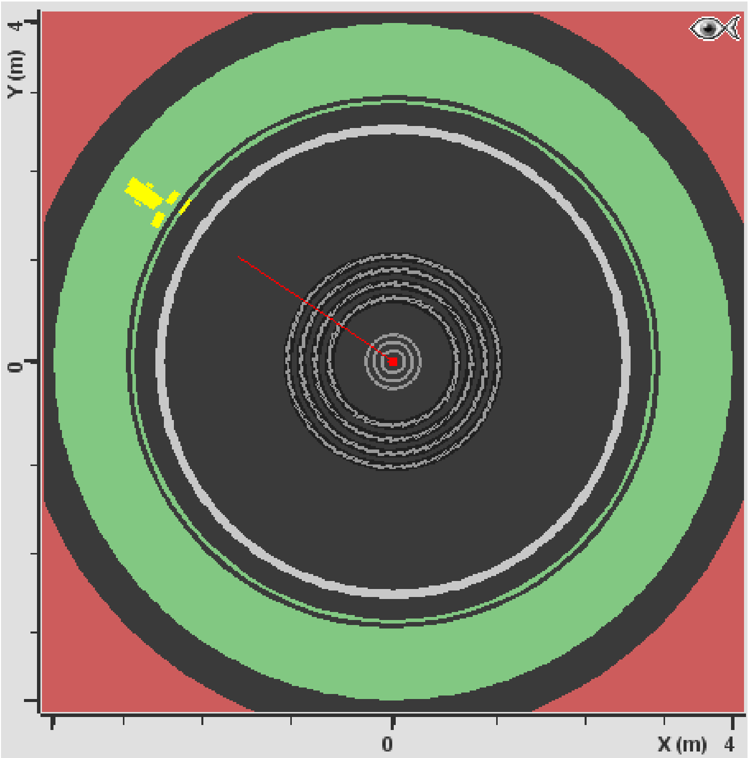
$$m_0^{(Z)} = \sqrt{\left(\frac{(E_{e^-} + E_{e^+})}{c^2}\right)^2 - \left(\frac{\vec{p}_{e^-} + \vec{p}_{e^+}}{c}\right)^2}$$



Particle footprint - Electrons

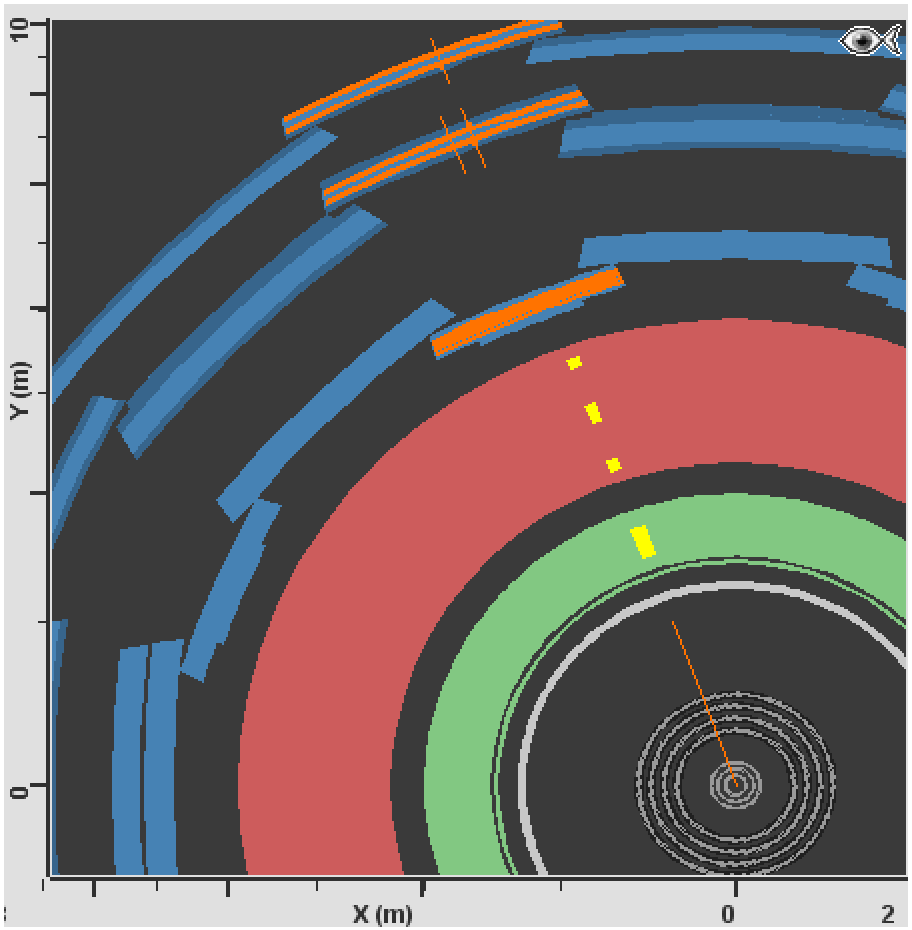
Electrons should have significant energy depositions in EM calorimeter and visible track in Inner Detector pointing at them

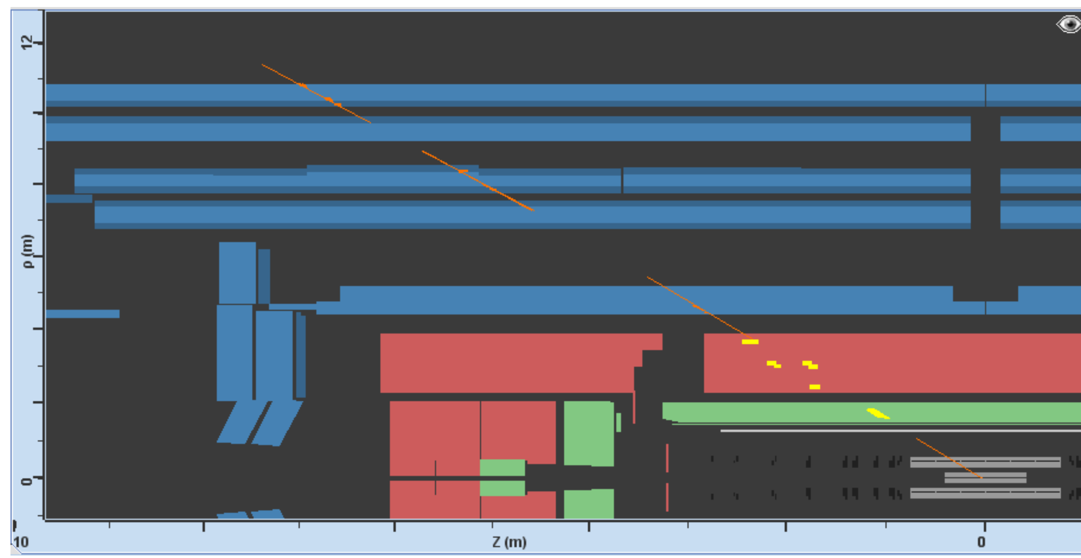




Particle footprint - Muons

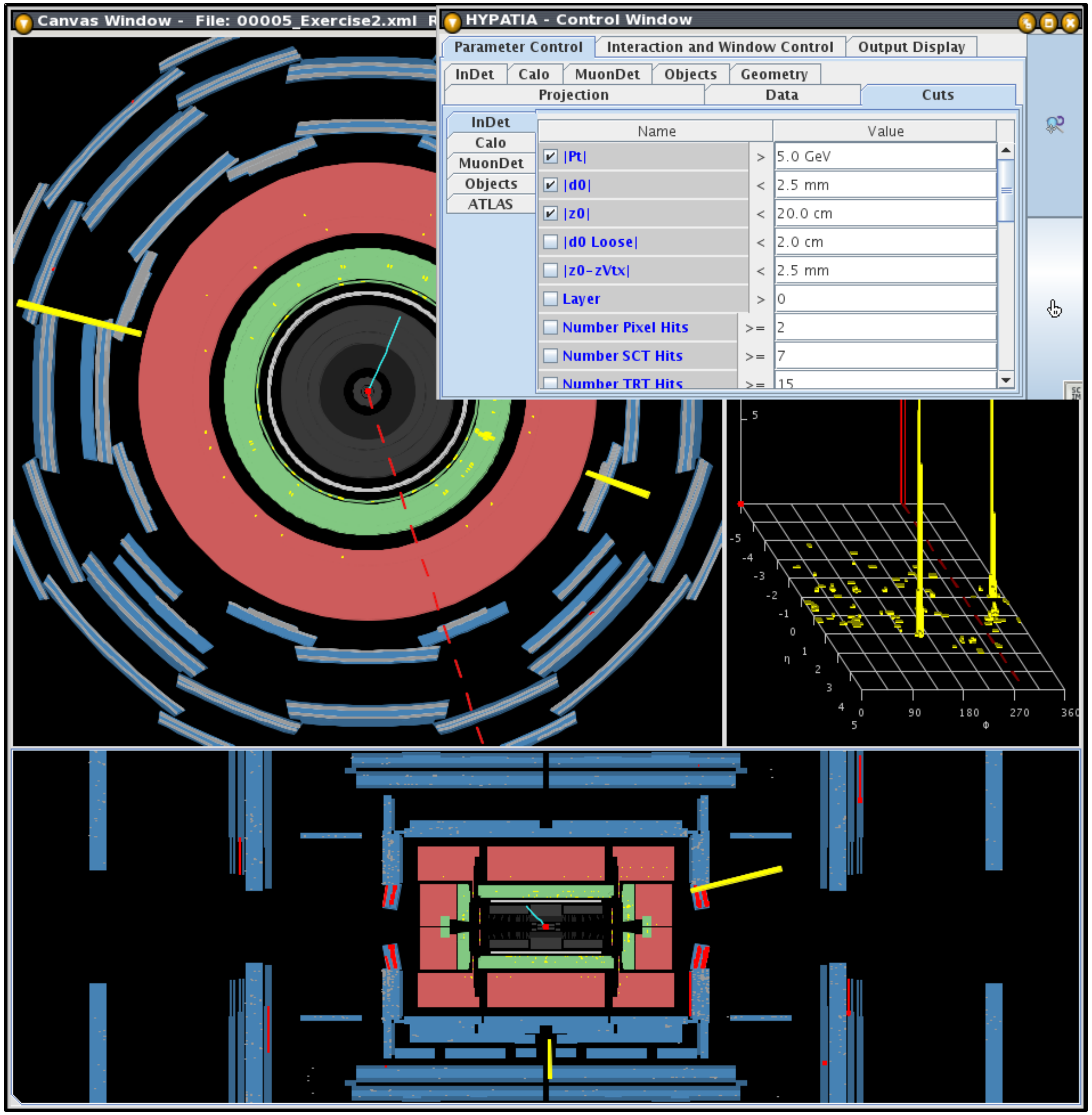
Muons go through the whole detector and thereby leaves signals in all shells.





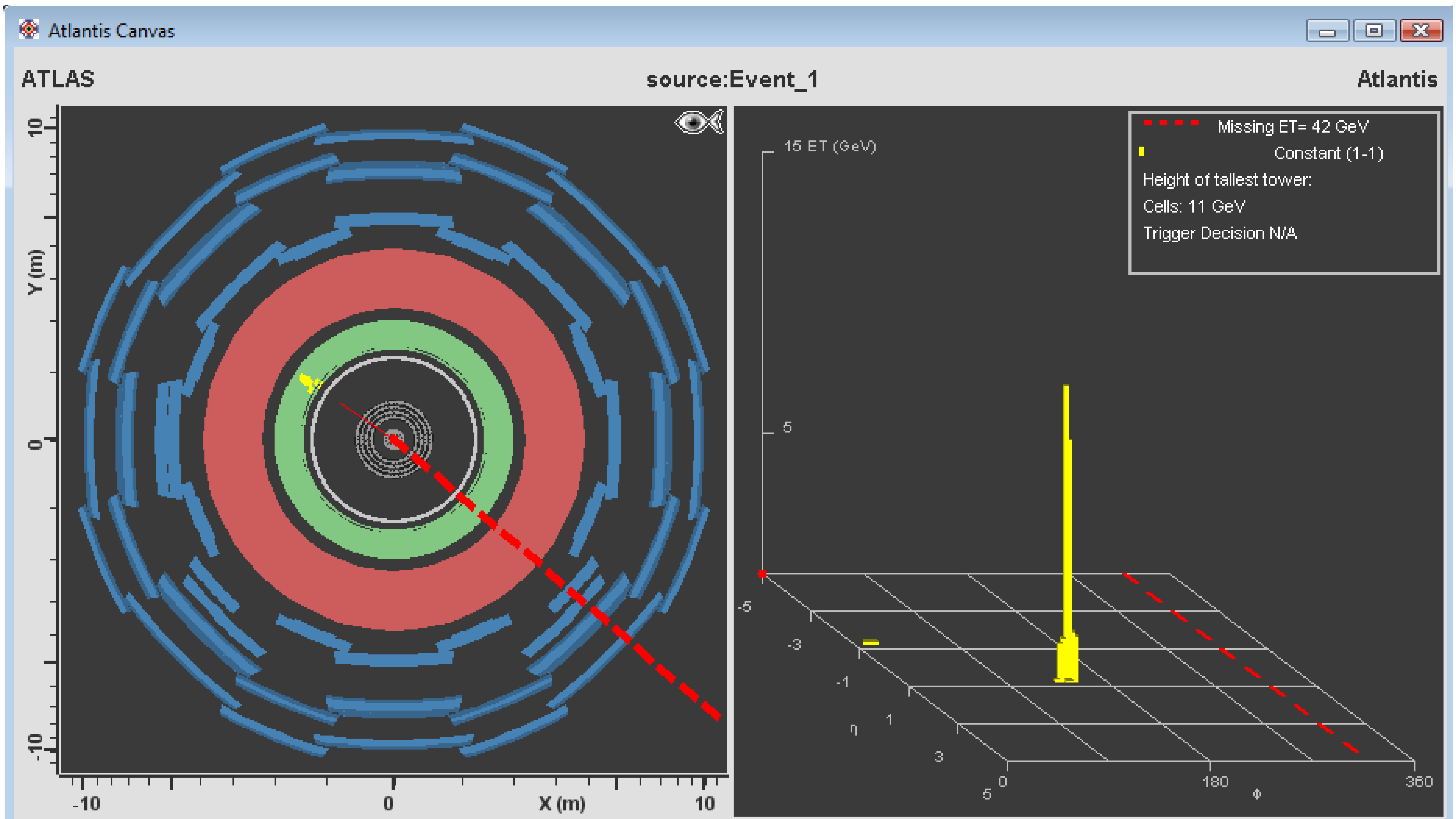
Particle footprint - Photons

Photons deposit energy in EM calorimeter without leaving tracks in Inner Detector

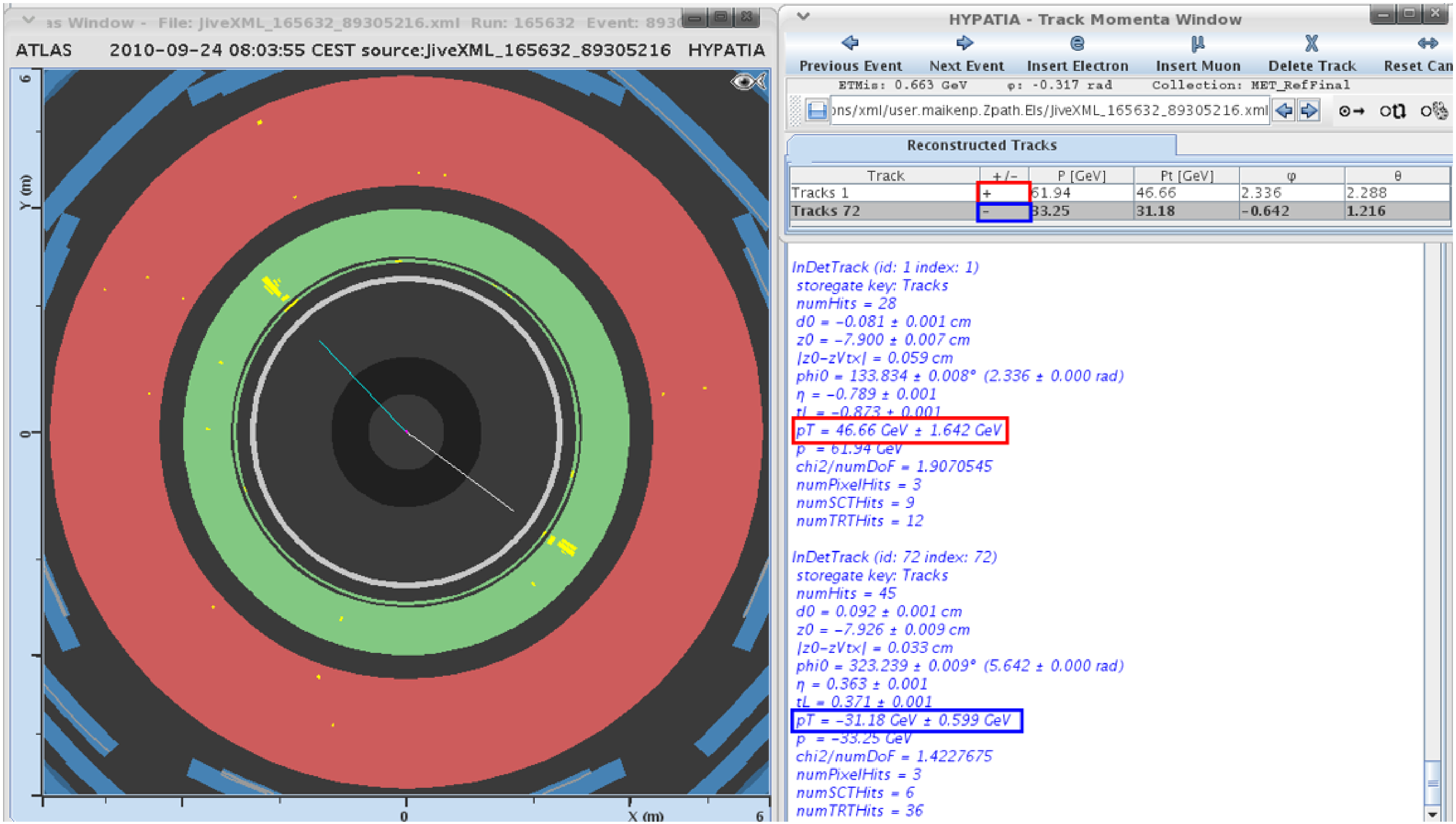


Particle footprint - Neutrinos

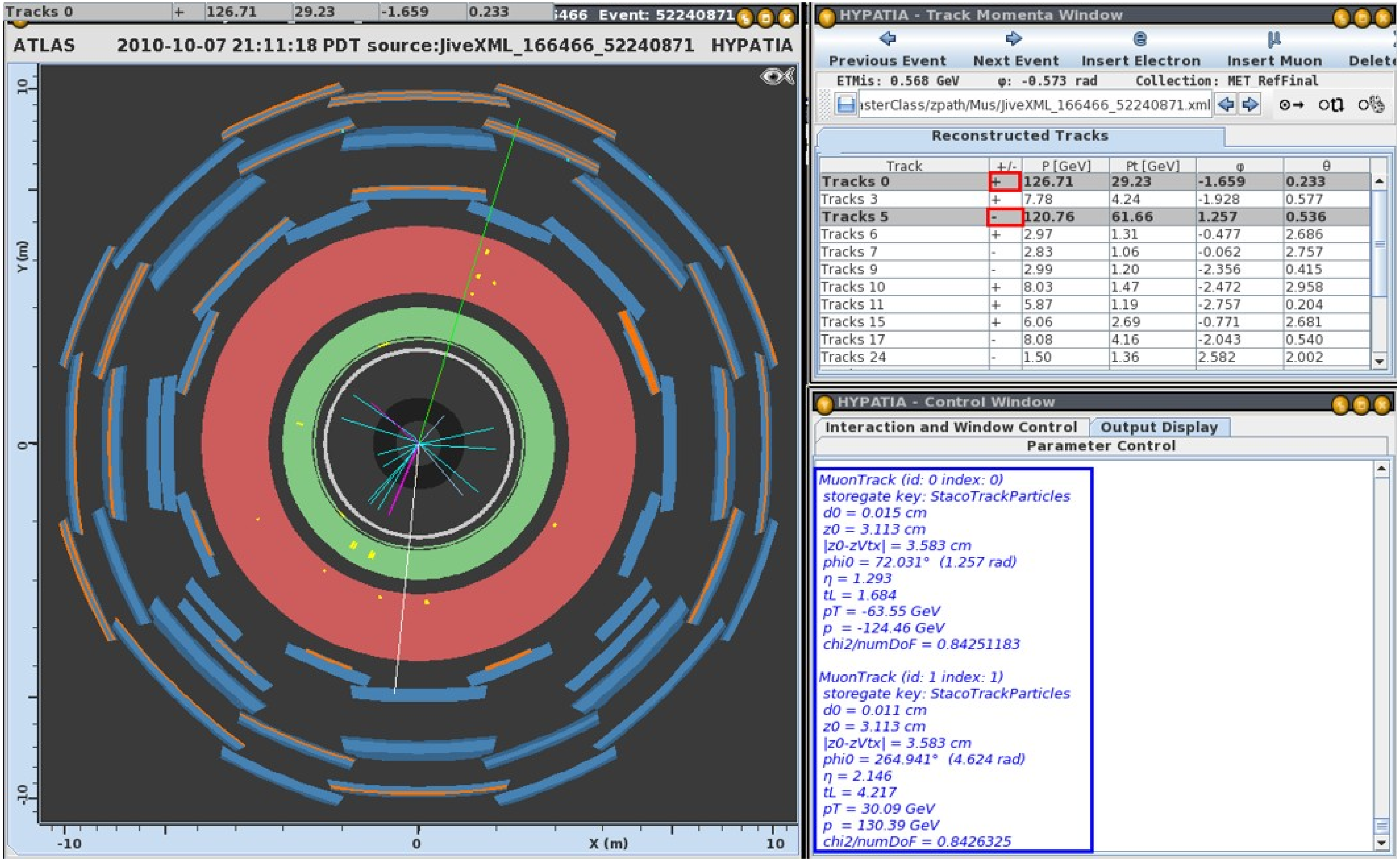
Neutrinos don't leave any track at all. Missing E_T is being measured and indicated as a red dashed line:



Examples

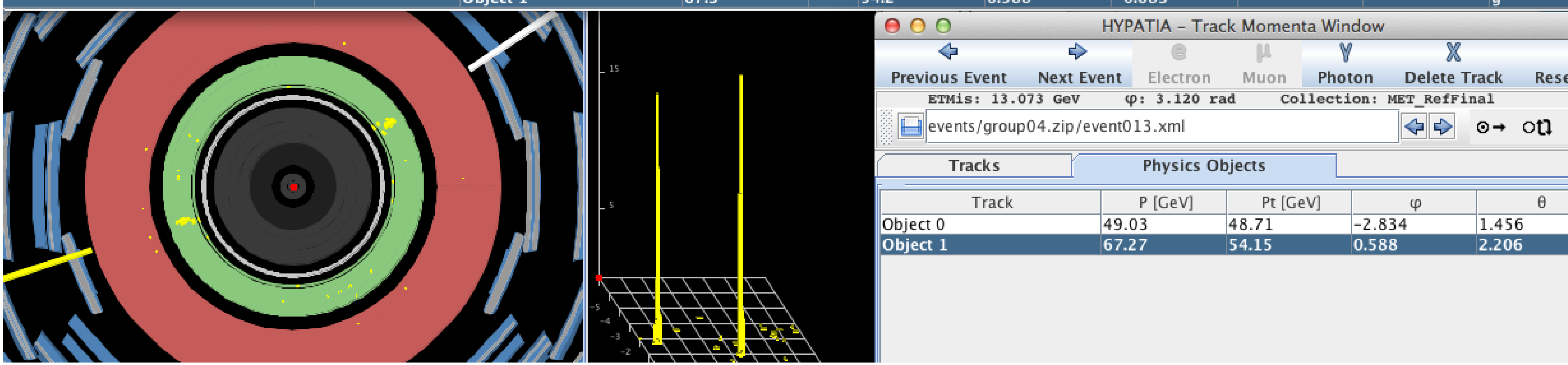

as Window - File: JiveXML_165632_89305216.xml Run: 165632 Event: 893
ATLAS 2010-09-24 08:03:55 CEST source:JiveXML_165632_89305216 HYPATIA
Y (m)
X (m)
HYPATIA - Track Momenta Window
Previous Event
Next Event
Insert Electron
Insert Muon
Delete Track
Reset Can
ETMis: 0.663 GeV φ: -0.317 rad Collection: MET_RefFinal
ons/xml/user.maikenp.Zpath.Els/JiveXML_165632_89305216.xml
Reconstructed Tracks
Track +/- P [GeV] Pt [GeV] φ θ
Tracks 1 + 61.94 46.66 2.336 2.288
Tracks 72 - 33.25 31.18 -0.642 1.216
InDetTrack (id: 1 index: 1)
storegate key: Tracks
numHits = 28
d0 = -0.081 ± 0.001 cm
z0 = -7.900 ± 0.007 cm
|z0-zVtx| = 0.059 cm
phi0 = 133.834 ± 0.008° (2.336 ± 0.000 rad)
η = -0.789 ± 0.001
tL = -0.873 ± 0.001
pT = 46.66 GeV ± 1.642 GeV
p = 61.94 GeV
chi2/numDoF = 1.9070545
numPixelHits = 3
numSCTHits = 9
numTRTHits = 12
InDetTrack (id: 72 index: 72)
storegate key: Tracks
numHits = 45
d0 = 0.092 ± 0.001 cm
z0 = -7.926 ± 0.009 cm
|z0-zVtx| = 0.033 cm
phi0 = 323.239 ± 0.009° (5.642 ± 0.000 rad)
η = 0.363 ± 0.001
tL = 0.371 ± 0.001
pT = -31.18 GeV ± 0.599 GeV
p = -33.25 GeV
chi2/numDoF = 1.4227675
numPixelHits = 3
numSCTHits = 6
numTRTHits = 36

Examples

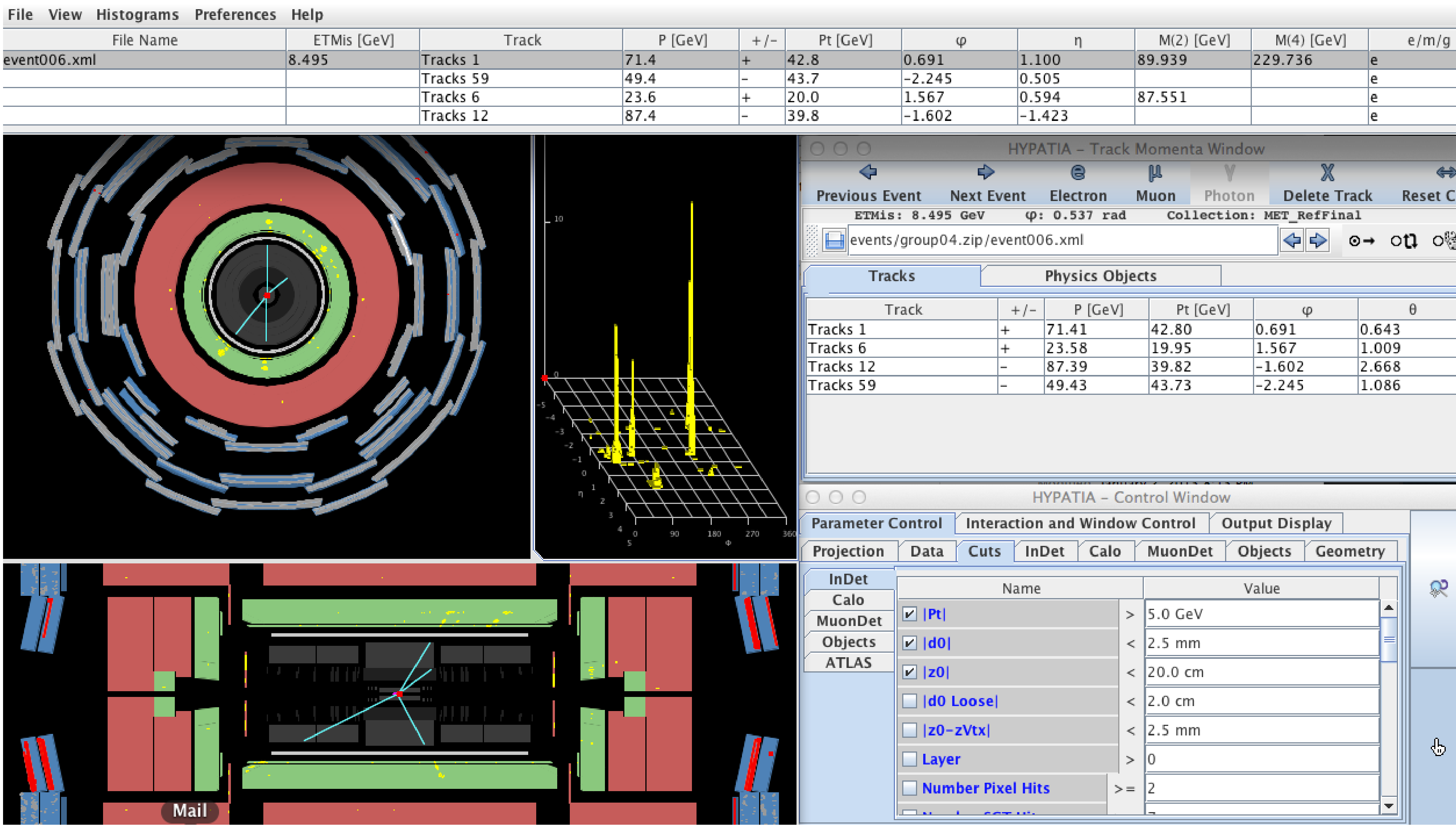

Tracks 0 + 126.71 29.23 -1.659 0.233
466 Event: 52240871
ATLAS 2010-10-07 21:11:18 PDT source:JiveXML_166466_52240871 HYPATIA
Y (m)
X (m)
HYPATIA - Track Momenta Window
Previous Event
Next Event
Insert Electron
Insert Muon
ETMis: 0.568 GeV φ: -0.573 rad Collection: MET_RefFinal
asterClass/zpath/Mus/JiveXML_166466_52240871.xml
Reconstructed Tracks
Track +/- P [GeV] Pt [GeV] φ θ
Tracks 0 + 126.71 29.23 -1.659 0.233
Tracks 3 + 7.78 4.24 -1.928 0.577
Tracks 5 - 120.76 61.66 1.257 0.536
Tracks 6 + 2.97 1.31 -0.477 2.686
Tracks 7 - 2.83 1.06 -0.062 2.757
Tracks 9 - 2.99 1.20 -2.356 0.415
Tracks 10 + 8.03 1.47 -2.472 2.958
Tracks 11 + 5.87 1.19 -2.757 0.204
Tracks 15 + 6.06 2.69 -0.771 2.681
Tracks 17 - 8.08 4.16 -2.043 0.540
Tracks 24 - 1.50 1.36 2.582 2.002
HYPATIA - Control Window
Interaction and Window Control
Output Display
Parameter Control
MuonTrack (id: 0 index: 0)
storegate key: StacoTrackParticles
d0 = 0.015 cm
z0 = 3.113 cm
|z0-zVtx| = 3.583 cm
phi0 = 72.031° (1.257 rad)
η = 1.293
tL = 1.684
pT = -63.55 GeV
p = -124.46 GeV
chi2/numDoF = 0.84251183
MuonTrack (id: 1 index: 1)
storegate key: StacoTrackParticles
d0 = 0.011 cm
z0 = 3.113 cm
|z0-zVtx| = 3.583 cm
phi0 = 264.941° (4.624 rad)
η = 2.146
tL = 4.217
pT = 30.09 GeV
p = 130.39 GeV
chi2/numDoF = 0.8426325

Examples

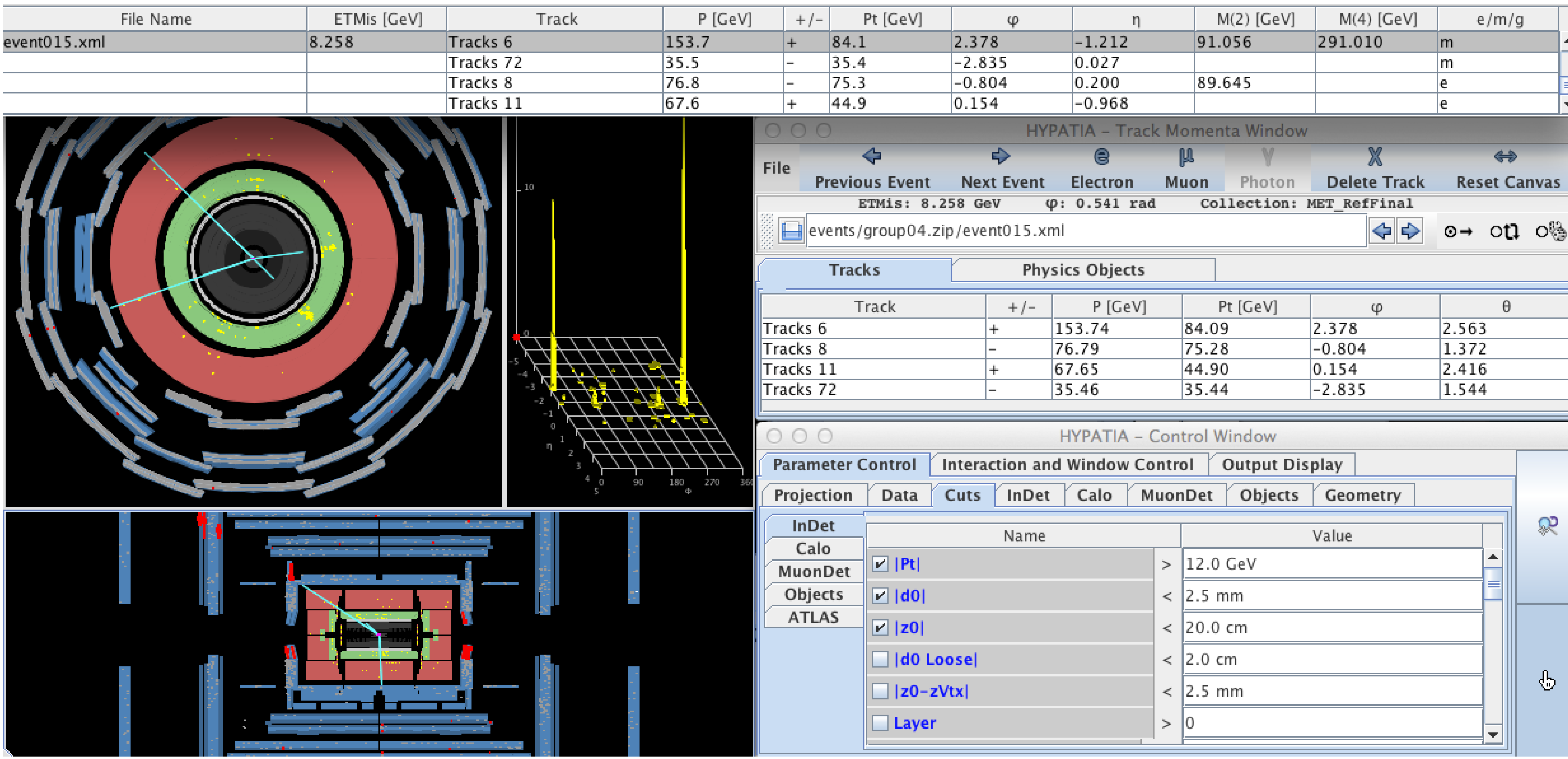
File Name	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	φ	η	M(2) [GeV]	M(4) [GeV]	e/m/g
event013.xml	13.073	Object 0	49.0		48.7	-2.834	0.115	110.062		g
		Object 1	67.3		54.2	0.588	-0.683			g



Examples


File View Histograms Preferences Help
File Name | ETMis [GeV] | Track | P [GeV] | +/- | Pt [GeV] | φ | η | M(2) [GeV] | M(4) [GeV] | e/m/g
event006.xml | 8.495 | Tracks 1 | 71.4 | + | 42.8 | 0.691 | 1.100 | 89.939 | 229.736 | e
Tracks 59 | 49.4 | - | 43.7 | -2.245 | 0.505 | e
Tracks 6 | 23.6 | + | 20.0 | 1.567 | 0.594 | 87.551 | e
Tracks 12 | 87.4 | - | 39.8 | -1.602 | -1.423 | e
HYPATIA – Track Momenta Window
Previous Event
Next Event
Electron
Muon
Photon
Delete Track
ETMis: 8.495 GeV φ: 0.537 rad Collection: MET_RefFinal
events/group04.zip/event006.xml
Tracks
Physics Objects
Track | +/- | P [GeV] | Pt [GeV] | φ | θ
Tracks 1 | + | 71.41 | 42.80 | 0.691 | 0.643
Tracks 6 | + | 23.58 | 19.95 | 1.567 | 1.009
Tracks 12 | - | 87.39 | 39.82 | -1.602 | 2.668
Tracks 59 | - | 49.43 | 43.73 | -2.245 | 1.086
HYPATIA – Control Window
Parameter Control
Interaction and Window Control
Output Display
Projection
Data
Cuts
InDet
Calo
MuonDet
Objects
Geometry
InDet
Calo
MuonDet
Objects
ATLAS
Name | Value
|Pt| > 5.0 GeV
|d0| < 2.5 mm
|z0| < 20.0 cm
|d0 Loose| < 2.0 cm
|z0-zVtx| < 2.5 mm
Layer > 0
Number Pixel Hits >= 2
Mail

Examples


File Name | ETMis [GeV] | Track | P [GeV] | +/- | Pt [GeV] | φ | η | M(2) [GeV] | M(4) [GeV] | e/m/g
event015.xml | 8.258 | Tracks 6 | 153.7 | + | 84.1 | 2.378 | -1.212 | 91.056 | 291.010 | m
Tracks 72 | 35.5 | - | 35.4 | -2.835 | 0.027 | m
Tracks 8 | 76.8 | - | 75.3 | -0.804 | 0.200 | 89.645 | e
Tracks 11 | 67.6 | + | 44.9 | 0.154 | -0.968 | e
HYPATIA - Track Momenta Window
File
Previous Event
Next Event
Electron
Muon
Photon
Delete Track
Reset Canvas
ETMis: 8.258 GeV φ: 0.541 rad Collection: MET_RefFinal
events/group04.zip/event015.xml
Tracks
Physics Objects
Track | +/- | P [GeV] | Pt [GeV] | φ | θ
Tracks 6 | + | 153.74 | 84.09 | 2.378 | 2.563
Tracks 8 | - | 76.79 | 75.28 | -0.804 | 1.372
Tracks 11 | + | 67.65 | 44.90 | 0.154 | 2.416
Tracks 72 | - | 35.46 | 35.44 | -2.835 | 1.544
HYPATIA - Control Window
Parameter Control
Interaction and Window Control
Output Display
Projection
Data
Cuts
InDet
Calo
MuonDet
Objects
Geometry
InDet
Calo
MuonDet
Objects
ATLAS
Name | Value
|Pt| > 12.0 GeV
|d0| < 2.5 mm
|z0| < 20.0 cm
|d0 Loose| < 2.0 cm
|z0-zVtx| < 2.5 mm
Layer > 0

What to do

- All of you will have dataset with 50 events to work with
- Look at all the events in HYPATHIA
- You are hunting for:
  - Z boson by hunting for an electron-positron pair or a muon-antimuon pair
  - a Higgs boson by hunting for a photon-photon pair
  - a Higgs boson by hunting for 2 lepton-pairs ($e^+e^-e^+e^-$, $e^+e^-\mu^+\mu^-$, $\mu^+\mu^-\mu^+\mu^-$)
  - Maybe you will discover something new too...
- If you believe you see the decay-products of one of the particles above, pick the corresponding tracks or objects and insert them into the HYPATIA invariant mass table.
- If you believe the collision resulted in a background event (no pair of leptons with opposite electric charges and nor pairs of photons), ignore the event and proceed to the next one.
- After analyzing all events, Export the Invariant Mass Table from HYPATIA: File-> Export Invariant Masses. The file is called Invariant_Masses.txt by default (do not change it). Place the file on your Desktop so you can easily find it.
- **Feel free to ask as many questions as you want!**
- Once you are done call the supervisor.

Thanks for attention