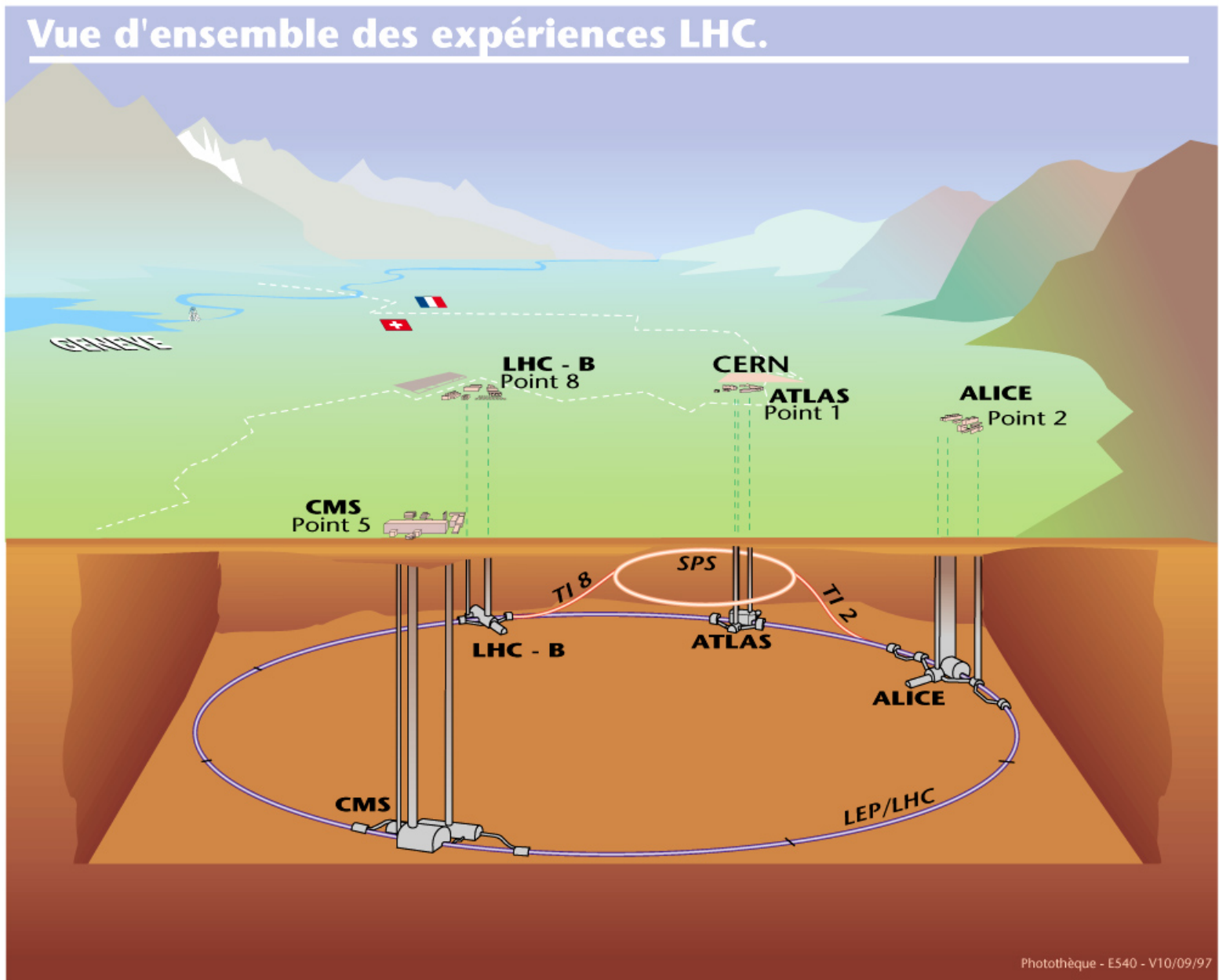


ATLAS Z-Path Masterclass 2019

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(HEPI TSU)

14 March 2019

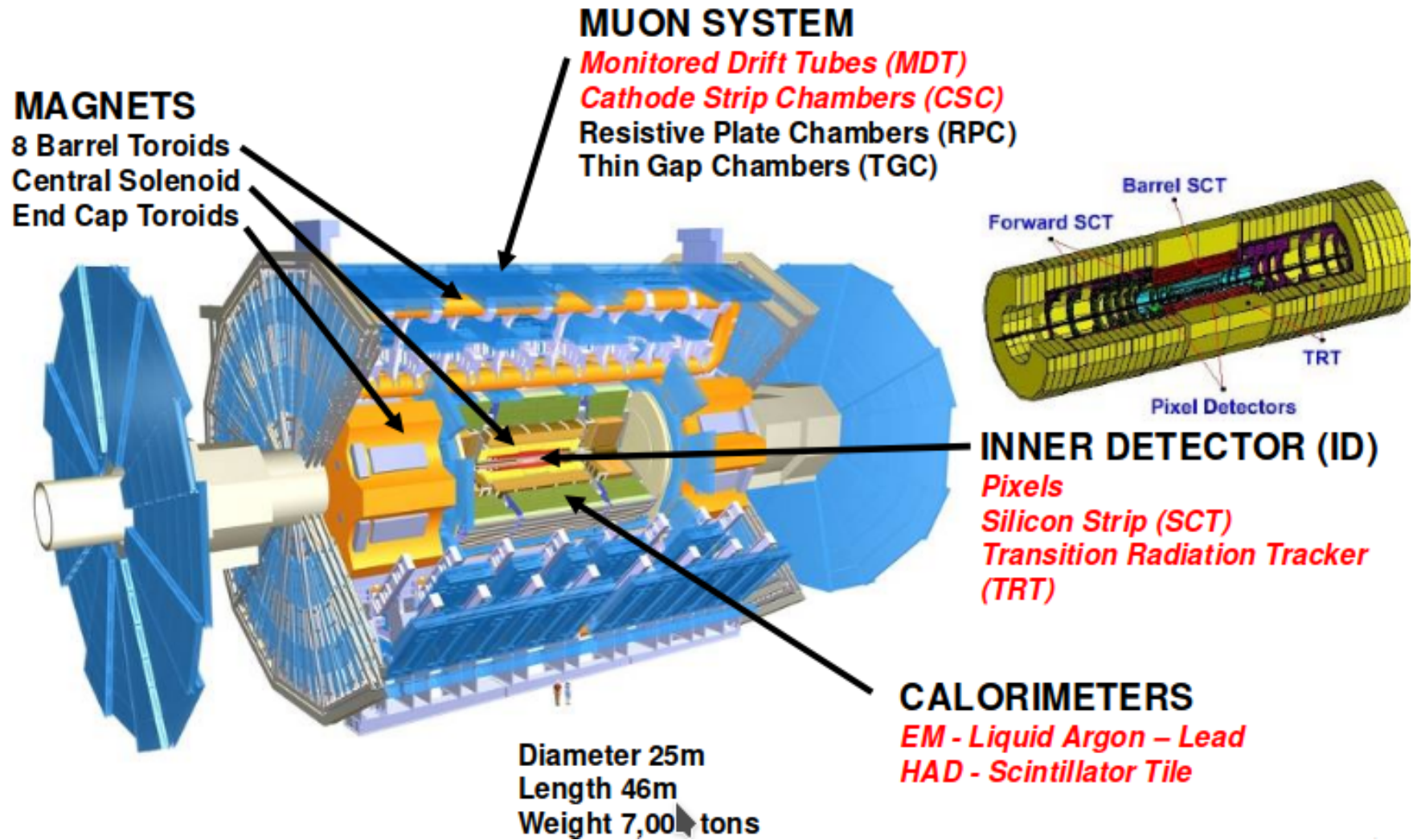
The LHC experiments



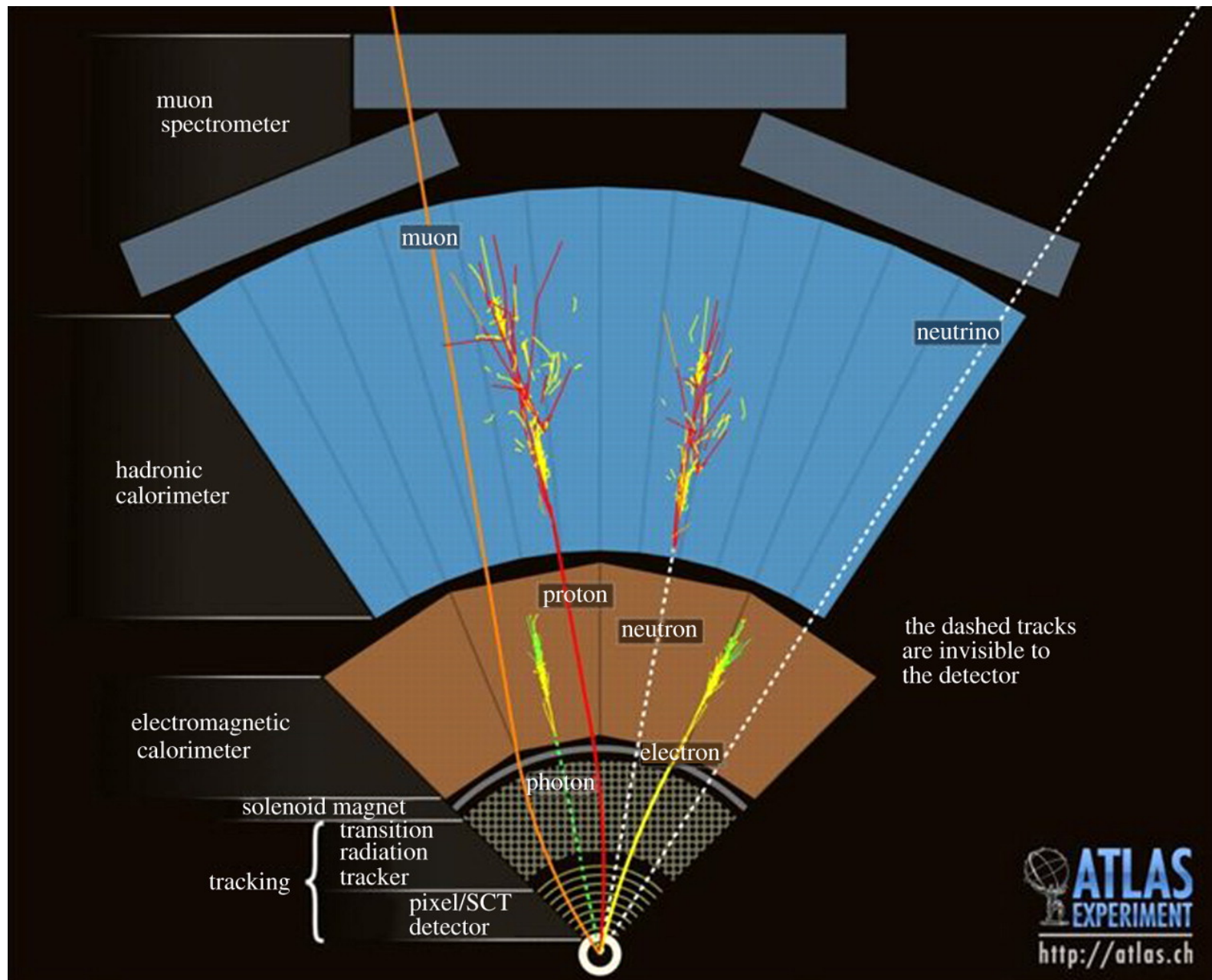
The scientific excitement at CERN

- 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

The ATLAS detector

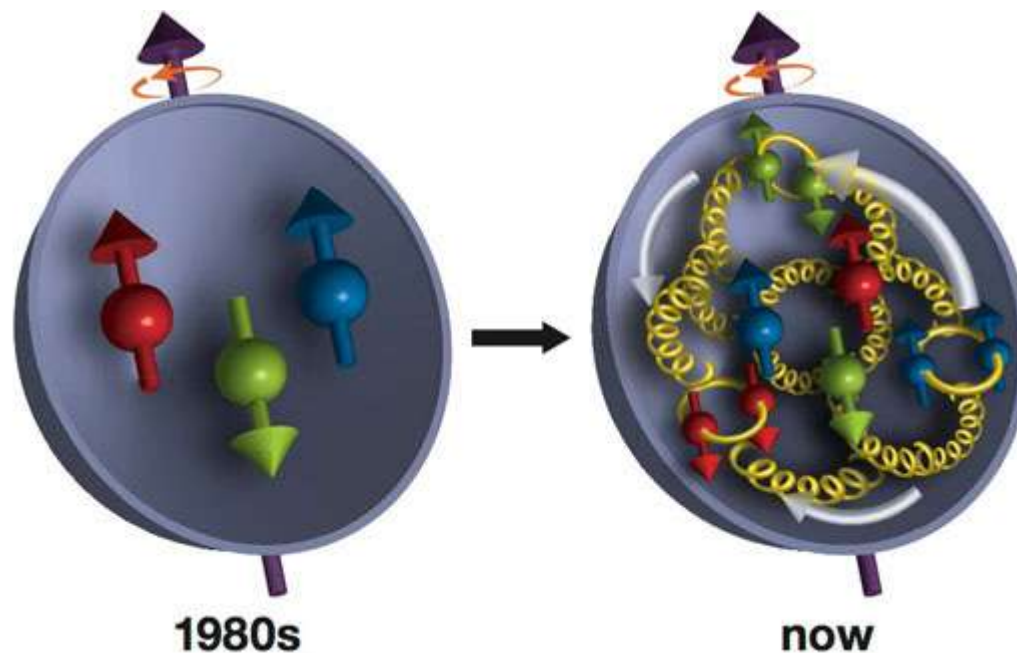


Particle detection in ATLAS



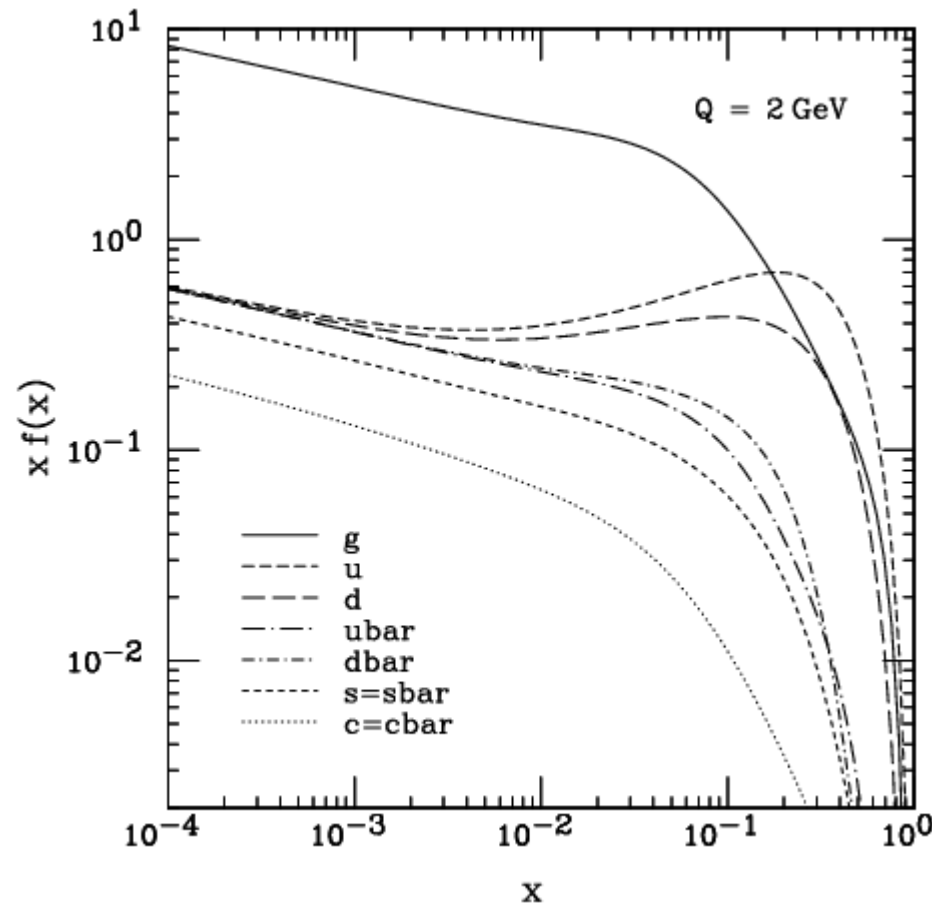
pp collisions

- 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



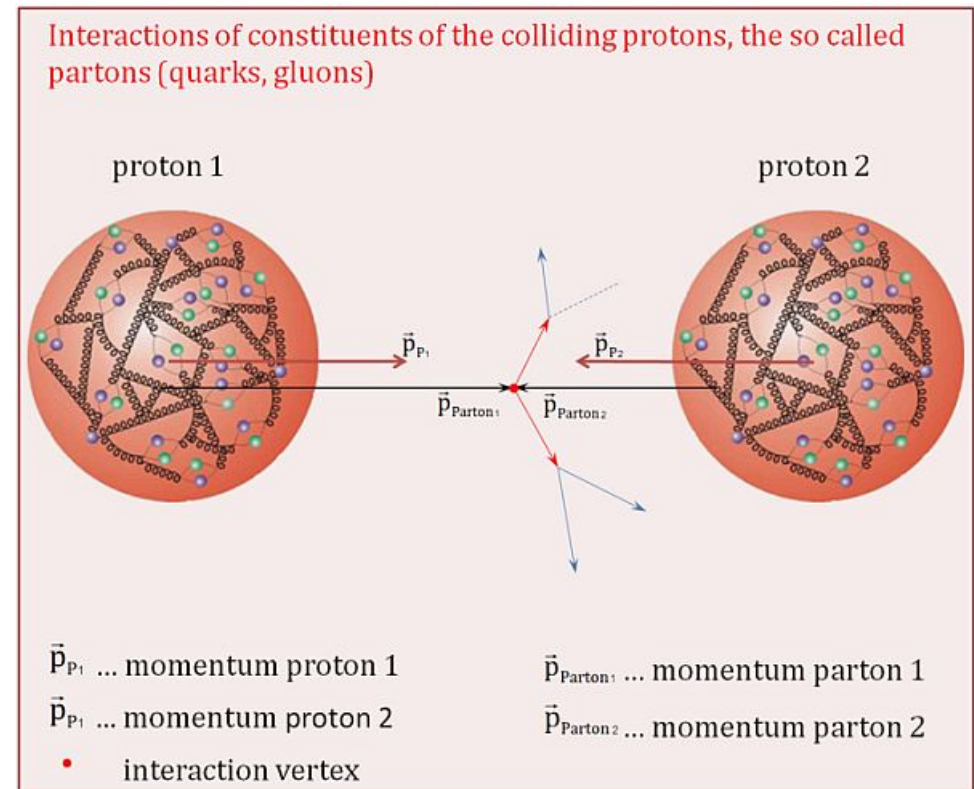
pp collisions – parton distribution

- 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



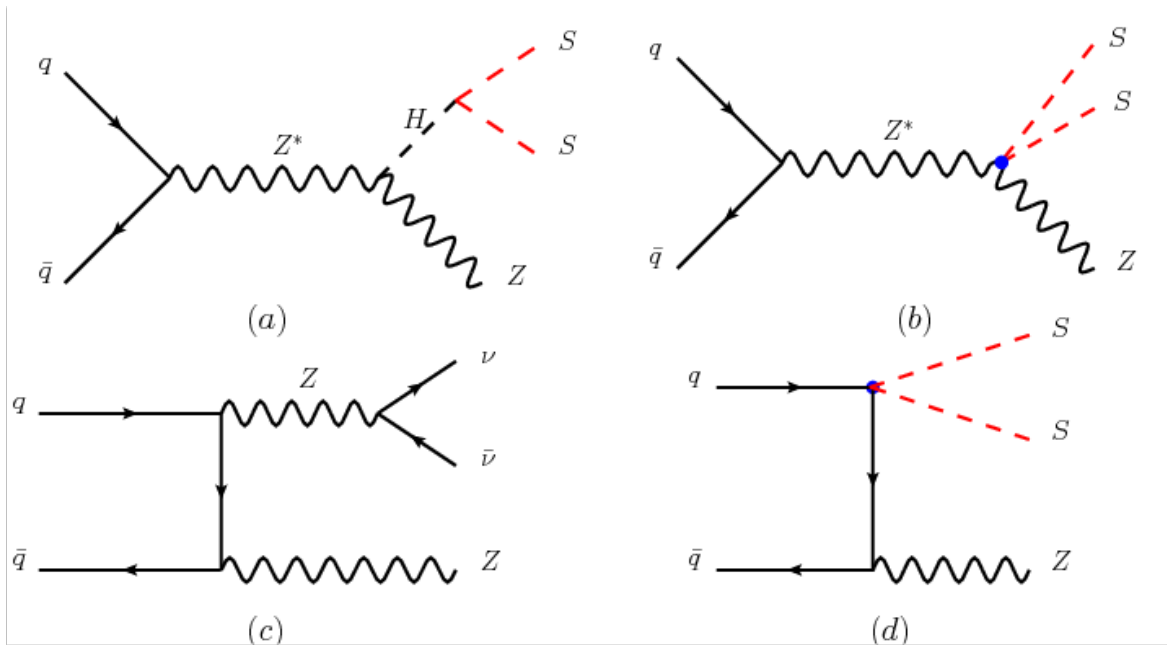
pp collisions – hard scattering

- 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: $91.1876 \pm 0.0021 \text{ GeV}/c^2$

Lifetime: $\sim 3 \times 10^{-25} \text{ s}$

Decay width: $2.4952 \pm 0.0023 \text{ GeV}/c^2$

Spin: 1

Charges: 0

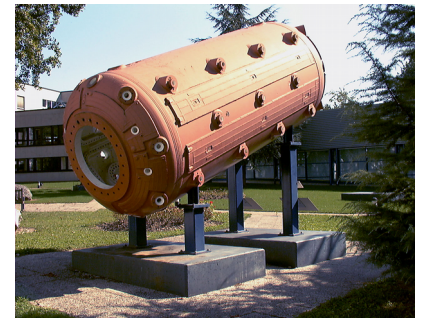
Discovery of neutral currents

- Charged current interactions is capable of changing the flavour of quarks:
- Neutral currents leave flavour unchanged
- Until 1973 all observed weak interactions were consistent with only a charged boson.
- CERN, 1973: first neutral current interaction observed:

$$d \rightarrow u + W^-$$

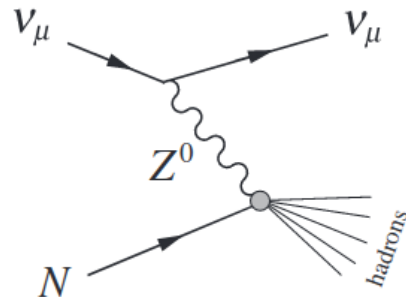
$$e^- \rightarrow e^- + Z^0$$

$$\nu_\mu + N \rightarrow \nu_\mu + X$$



The Gargamelle detector

- Mechanism for neutral current reactions:

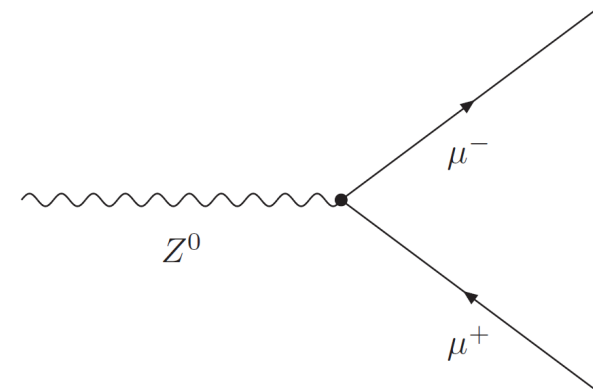
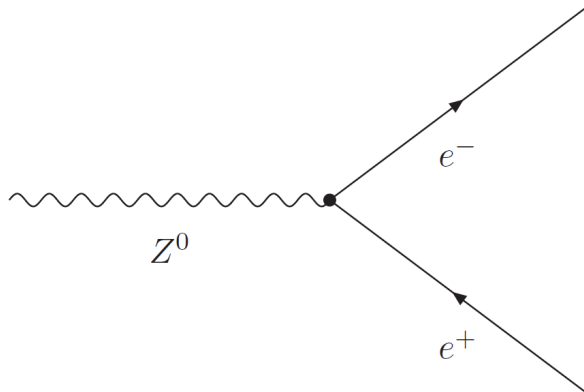


Discovery of the Z boson

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

hadronic	leptonic	
	visible	invisible
$Z^0 \rightarrow q\bar{q}$	$Z^0 \rightarrow e^+e^-$	$Z^0 \rightarrow \nu\bar{\nu}$
	$Z^0 \rightarrow \mu^+\mu^-$	
	$Z^0 \rightarrow \tau^+\tau^-$	

- Z decays to charged leptons are easiest to detect



Invariant mass technique

- The Einstein equation:
- Invariant mass:
- The energy of Z:
- The momentum of Z:

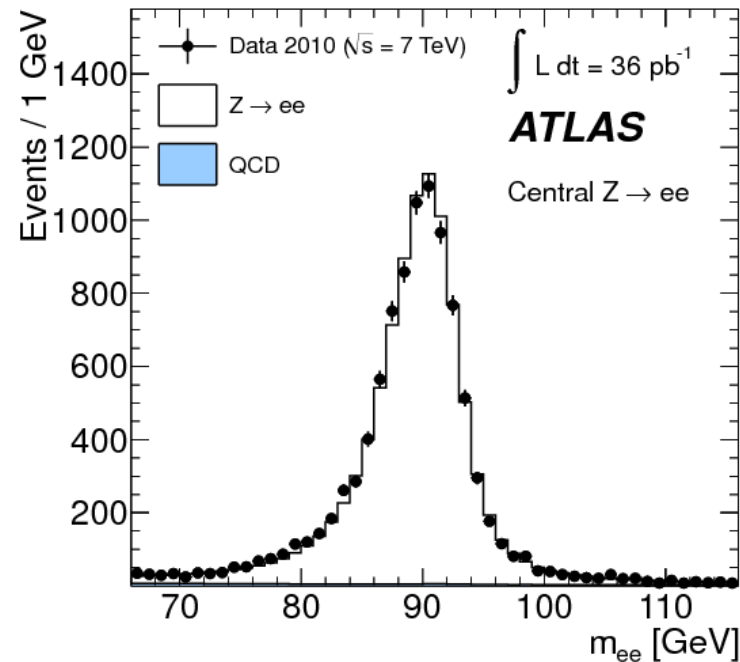
$$E = \sqrt{(\vec{p} \cdot c)^2 + (m_0 \cdot c^2)^2}$$

$$m_0 = \sqrt{\left(\frac{E}{c^2}\right)^2 - \left(\frac{\vec{p}}{c}\right)^2}$$

$$E_Z = E_{e^-} + E_{e^+}$$

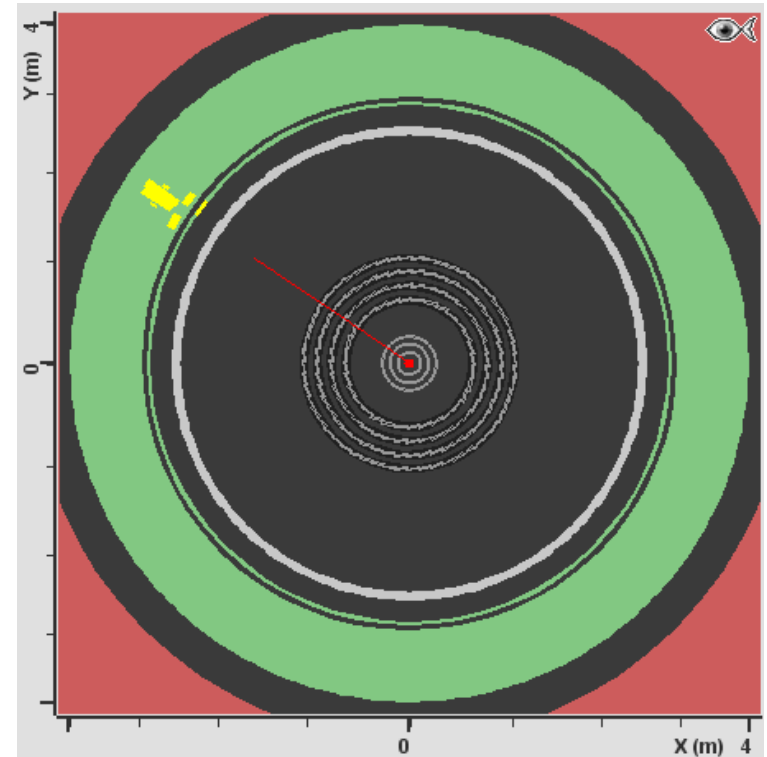
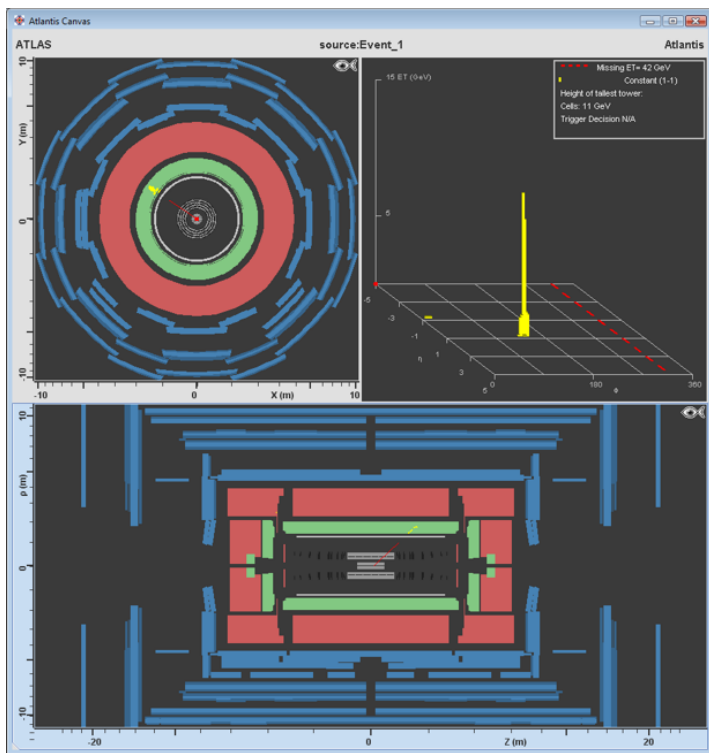
$$\vec{p}_Z = \vec{p}_{e^-} + \vec{p}_{e^+}$$

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



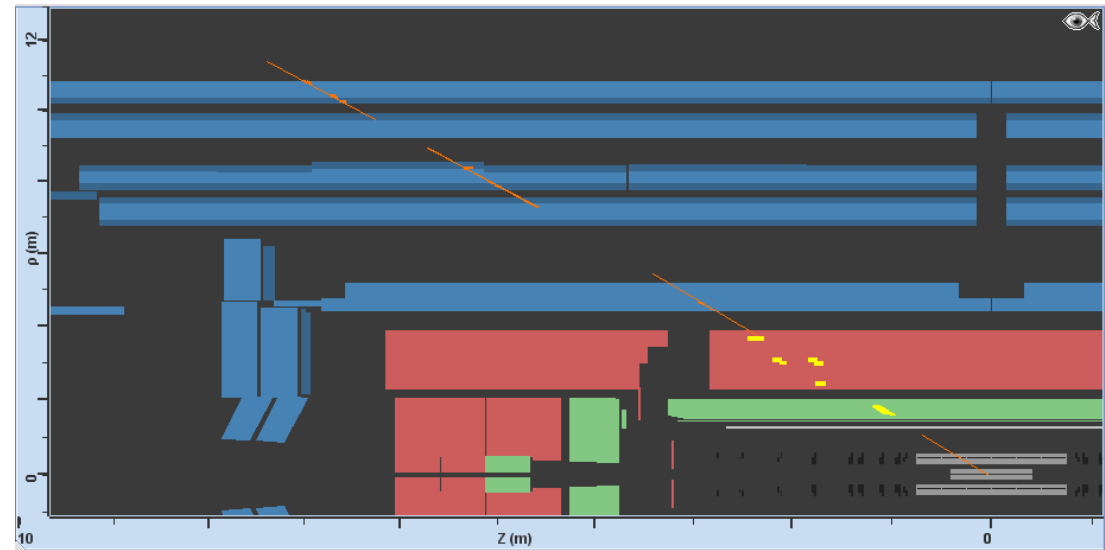
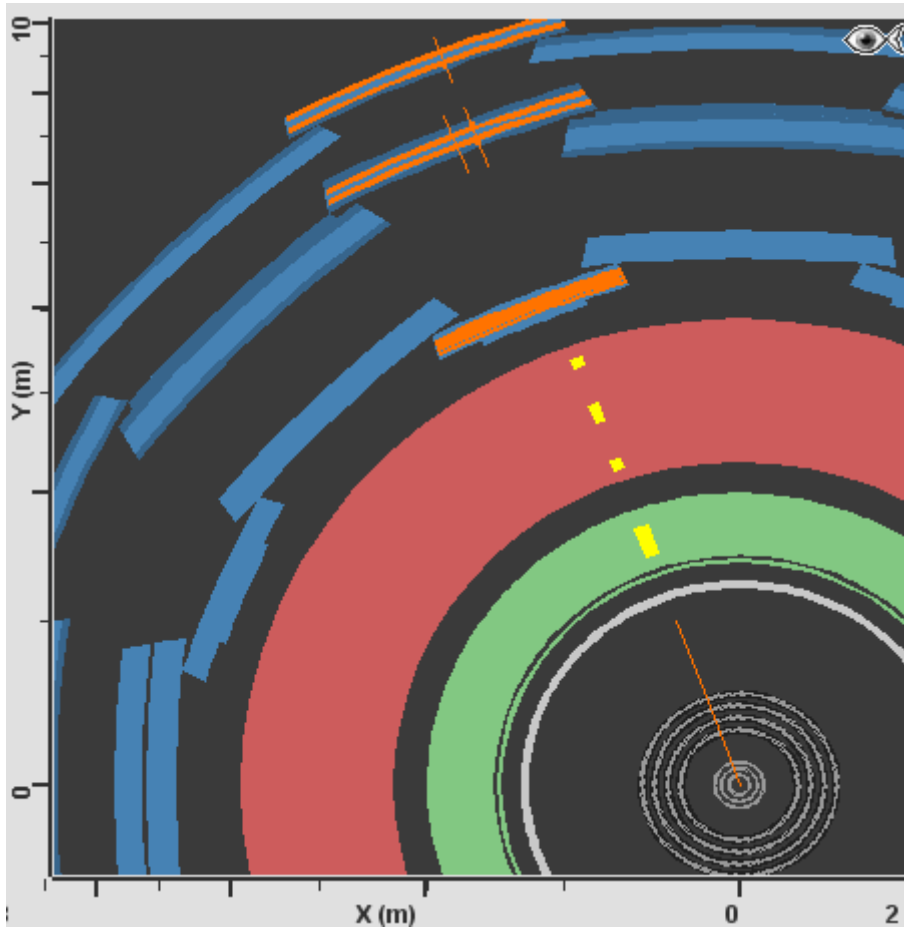
Particle footprint - Electrons

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



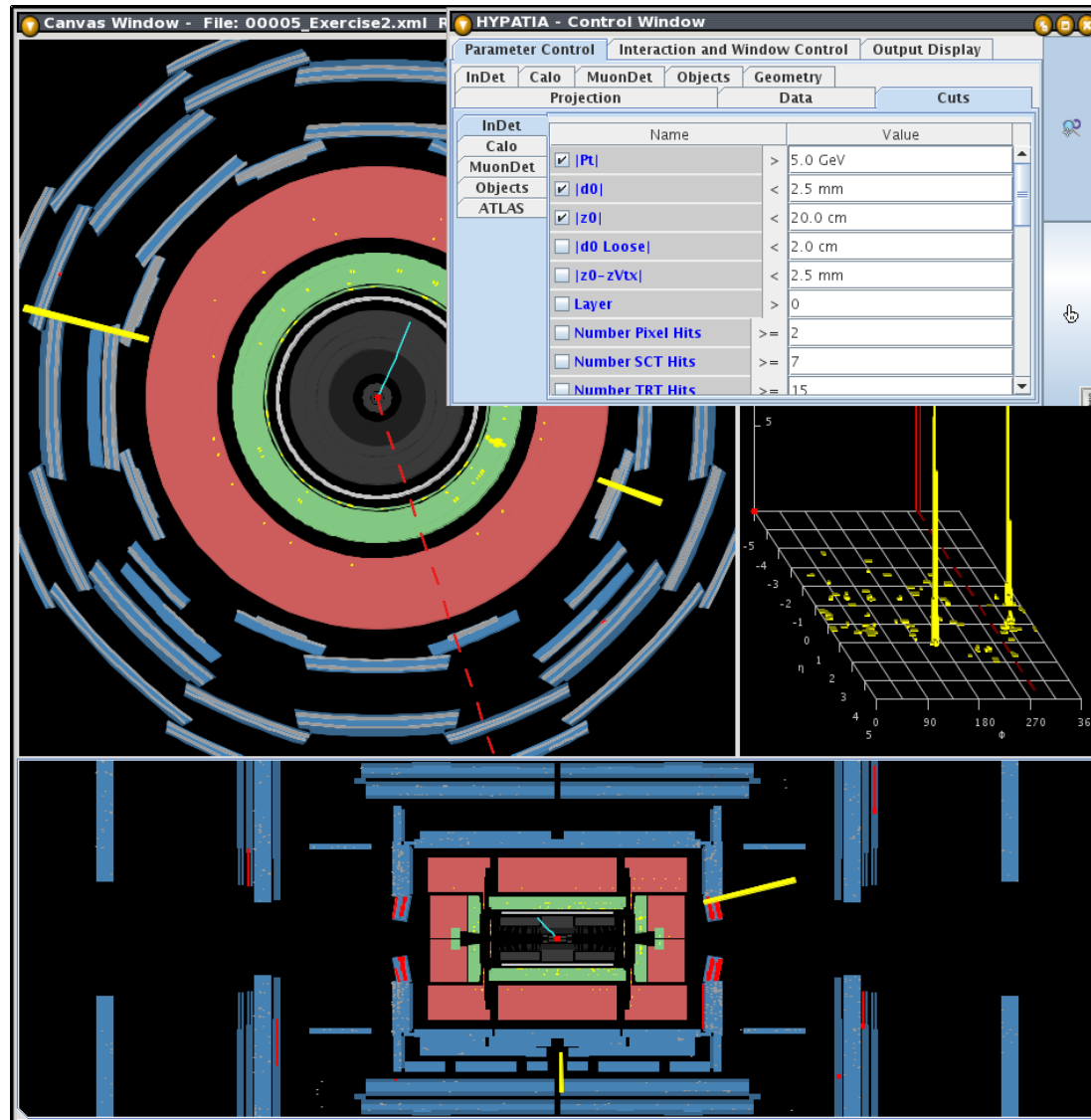
Particle footprint - Muons

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



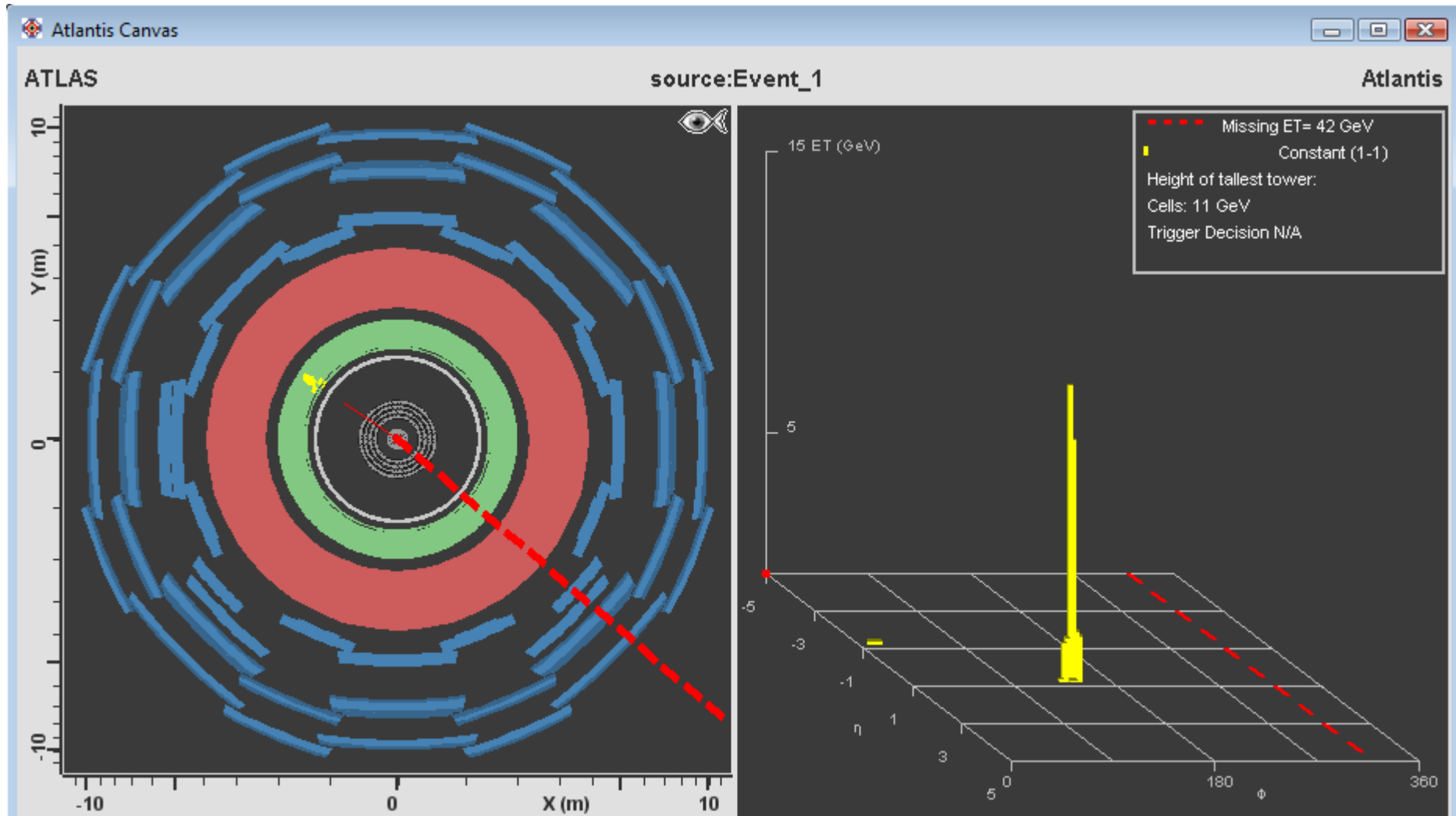
Particle footprint - Photons

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

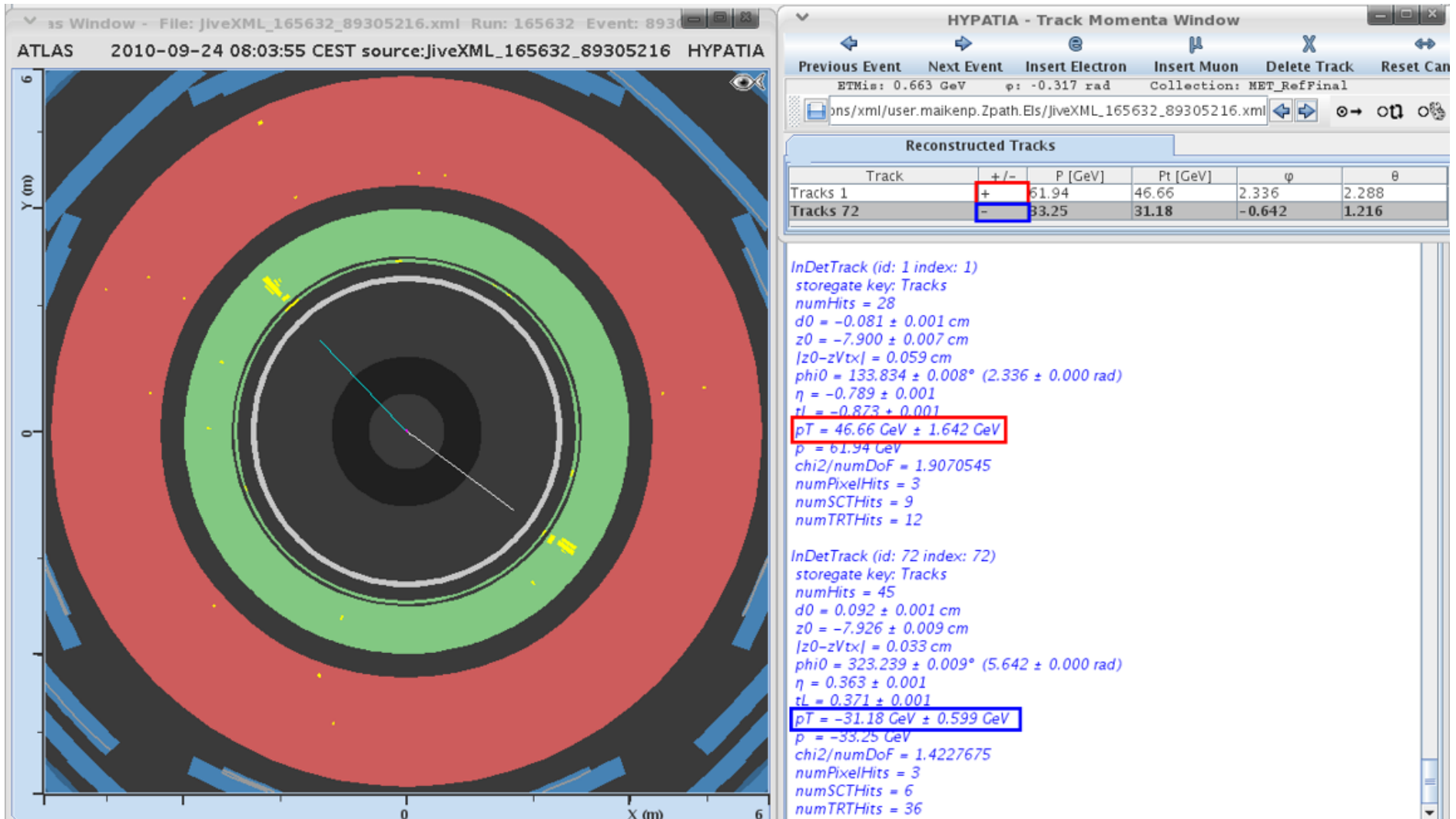


Particle footprint - Neutrinos

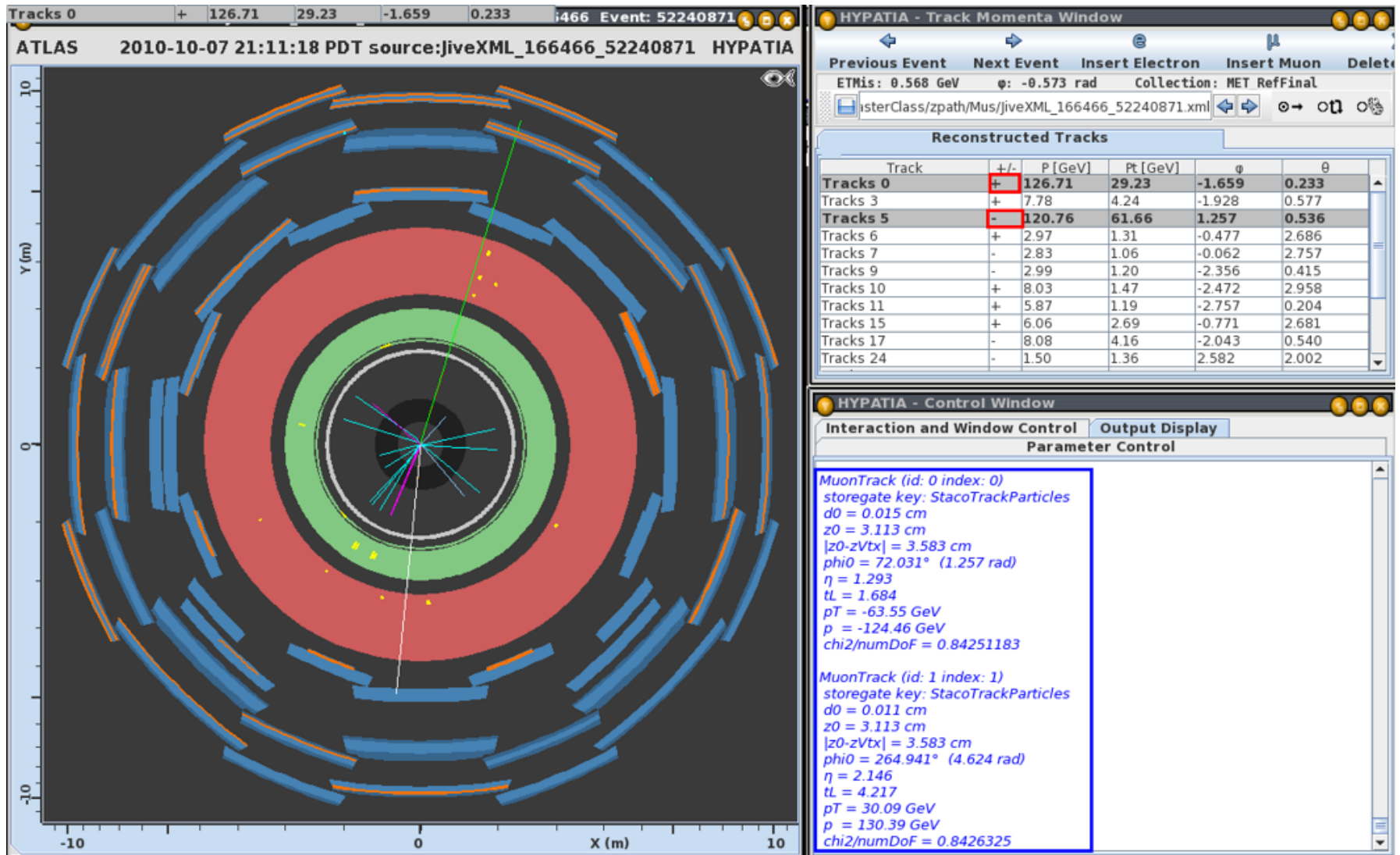
Neutrinos don't leave any track at all. Missing E_T is being measured and indicated as a red dashed line:



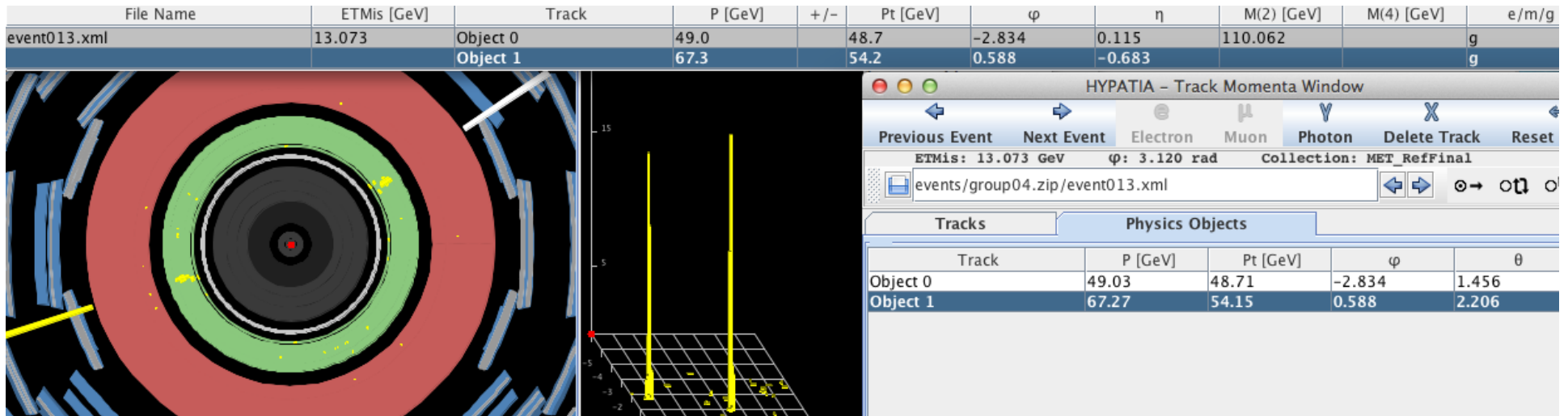
Examples



Examples



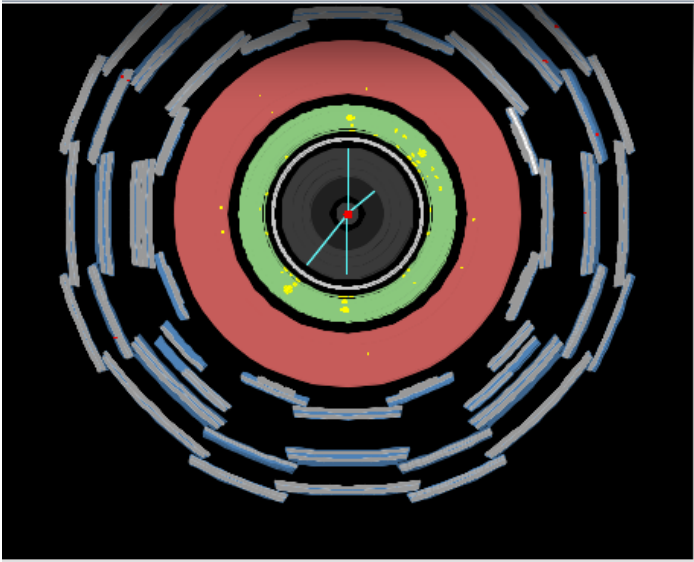
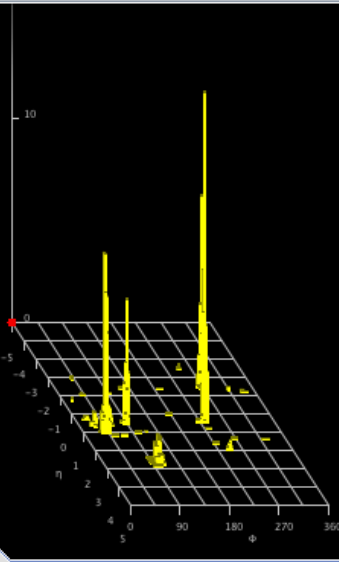
Examples



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 Reset Car

ETMis: 8.495 GeV ϕ : 0.537 rad Collection: MET_RefFinal

events/group04.zip/event006.xml

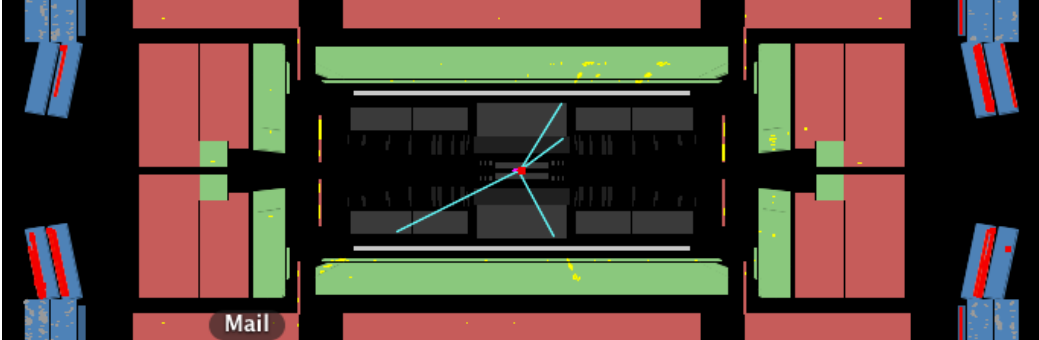
Track	+/-	P [GeV]	Pt [GeV]	ϕ	θ
Tracks 1	+	71.41	42.80	0.691	0.643
Tracks 6	+	23.58	19.95	1.567	1.009
Tracks 12	-	87.39	39.82	-1.602	2.668
Tracks 59	-	49.43	43.73	-2.245	1.086

HYPATIA - Control Window

Parameter Control Interaction and Window Control Output Display

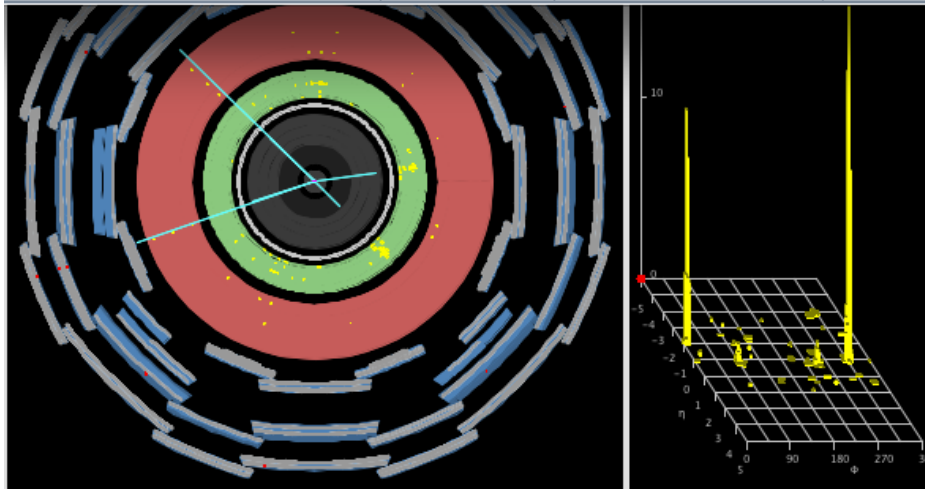
Projection Data Cuts InDet Calo MuonDet Objects Geometry

InDet	Name	Value
Calo	<input checked="" type="checkbox"/> Pt	> 5.0 GeV
MuonDet	<input checked="" type="checkbox"/> d0	< 2.5 mm
Objects	<input checked="" type="checkbox"/> z0	< 20.0 cm
ATLAS	<input type="checkbox"/> d0 Loose	< 2.0 cm
	<input type="checkbox"/> z0-zVtx	< 2.5 mm
	<input type="checkbox"/> Layer	> 0
	<input type="checkbox"/> Number Pixel Hits	>= 2



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		



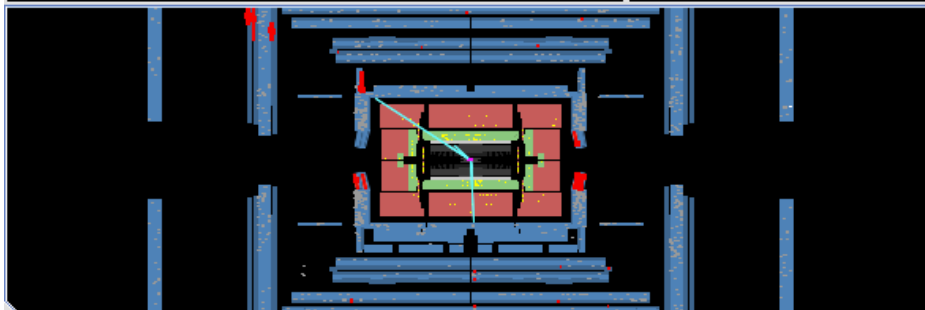
HYPATIA - Track Momenta Window

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

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



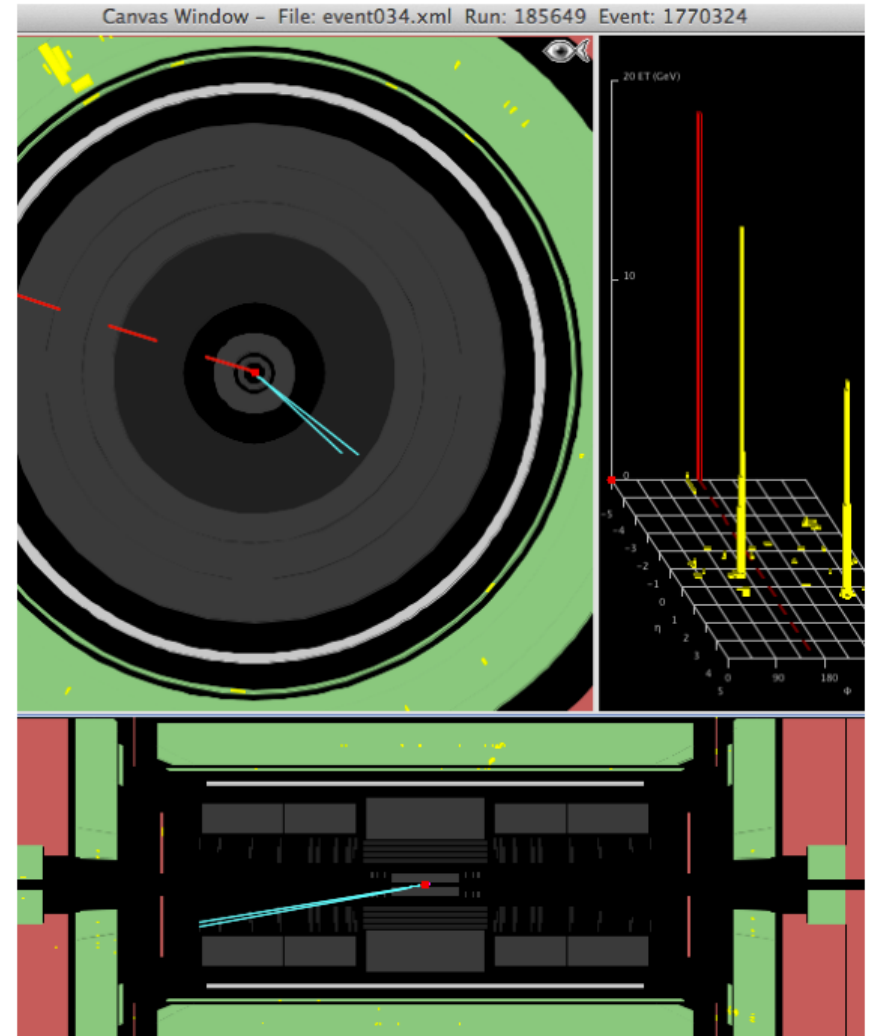
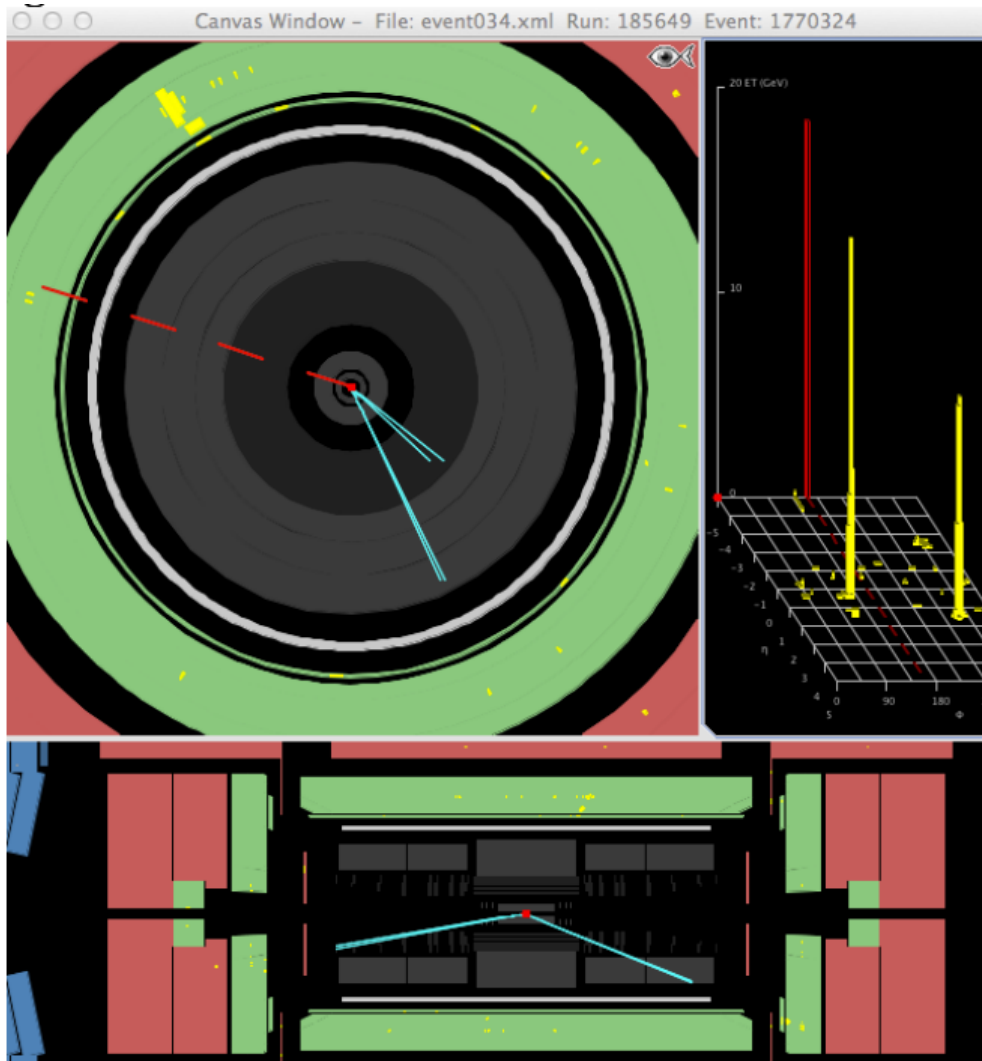
HYPATIA - Control Window

Parameter Control Interaction and Window Control Output Display

Projection Data Cuts InDet Calo MuonDet Objects Geometry

InDet	Name	Value
Calo	<input checked="" type="checkbox"/> Pt	> 12.0 GeV
MuonDet	<input checked="" type="checkbox"/> d0	< 2.5 mm
Objects	<input checked="" type="checkbox"/> z0	< 20.0 cm
ATLAS	<input type="checkbox"/> d0 Loose	< 2.0 cm
	<input type="checkbox"/> z0-zVtx	< 2.5 mm
	<input type="checkbox"/> Layer	> 0

Examples



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