



International Particle Physics Outreach Group

INTERNATIONAL



hands on particle physics

# International Masterclasses 2022

## Il Bosone Z

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# Z-Path

Analisi di dati sperimentali prodotti ad LHC: collisioni pp a 7 TeV (2011)

Effettuare una vera misura di fisica delle particelle, con veri dati del rivelatore ATLAS: identificare il bosone Z(91 GeV) e misurare la sua massa e non solo...

Ci sono anche la  $J/\psi$ (3 GeV),  $Y$  (10GeV) e il Bosone di Higgs con altre particelle esotiche:  $Z'$ (1000 GeV) e  $G$  (1500 GeV)!

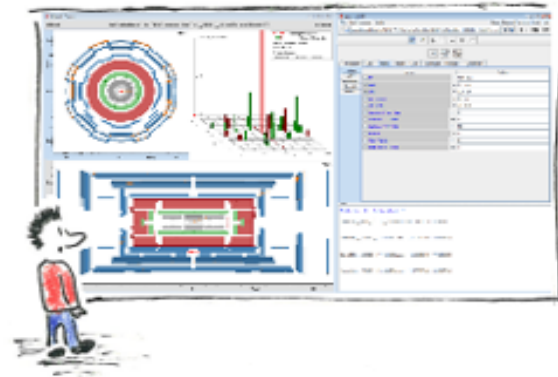
Categorie:  $e^+e^-$ ,  $\mu^+\mu^-$ ,  $\gamma\gamma$ , 4-leptoni

A noi interessano solo  $Z \rightarrow e^+e^-$ ,  $\mu^+\mu^-$

# Educational Software Hypatia



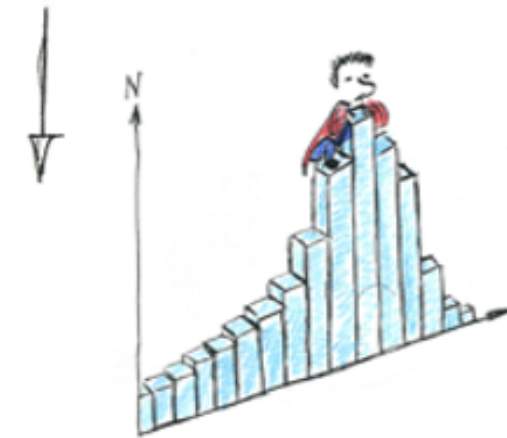
Identifying particles



Identifying events



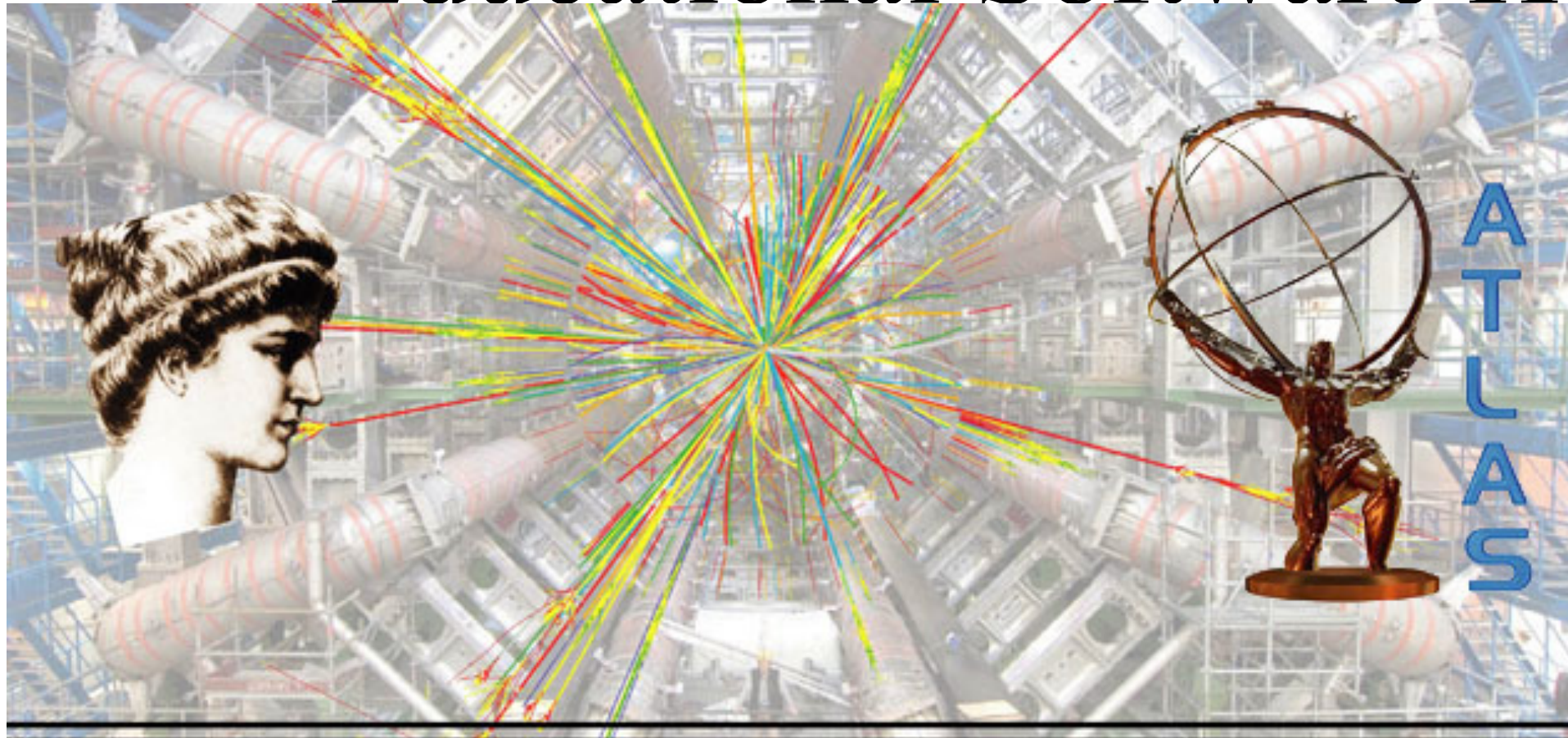
Get to work



Rediscover the Z boson



# Educational Software Hypatia



UNIVERSITY  
OF  
ATHENS



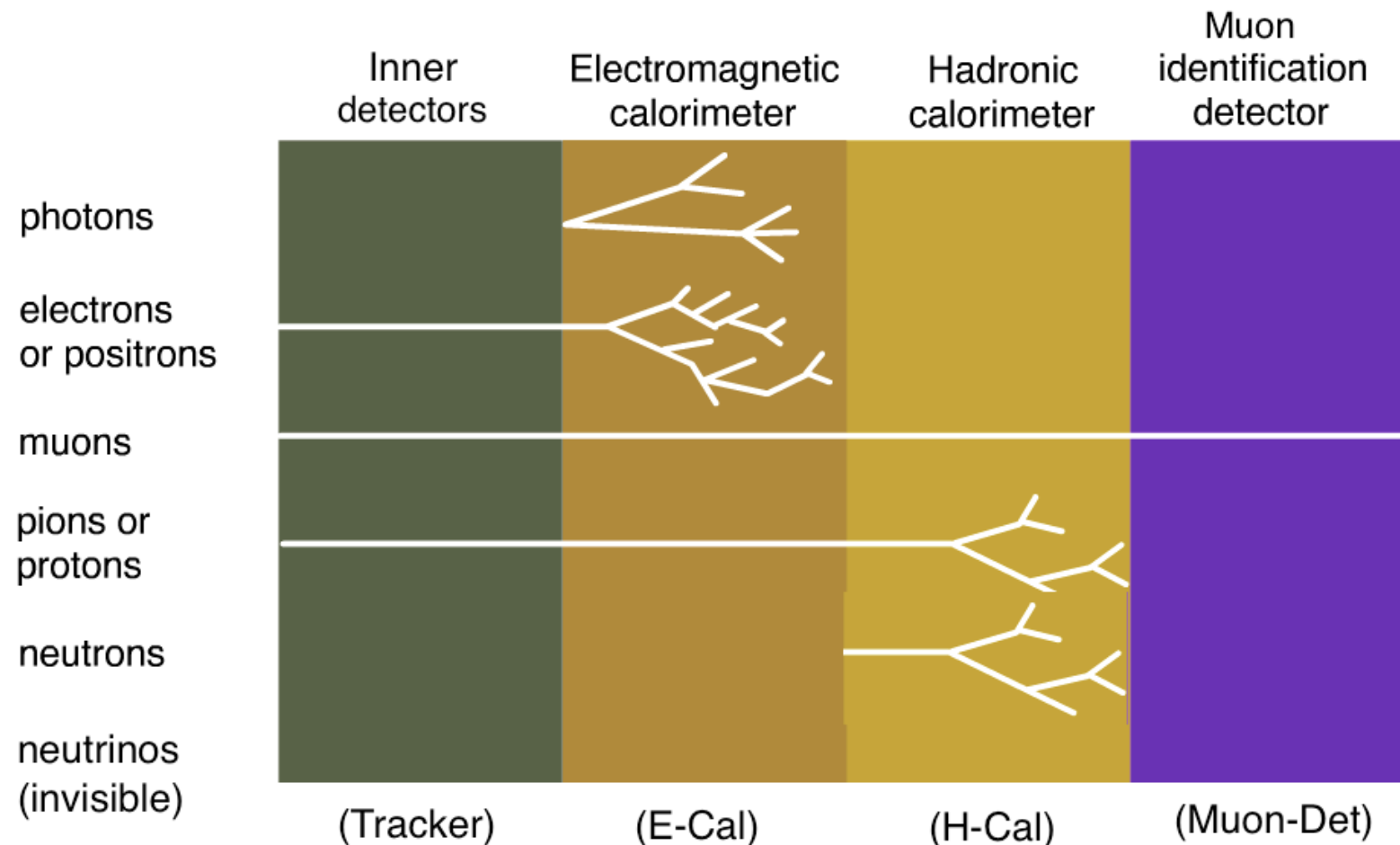
INSTITUTE  
OF PHYSICS  
BELGRADE

H Y P A T I A

HYbrid Pupil's Analysis Tool for Interactions in ATLAS

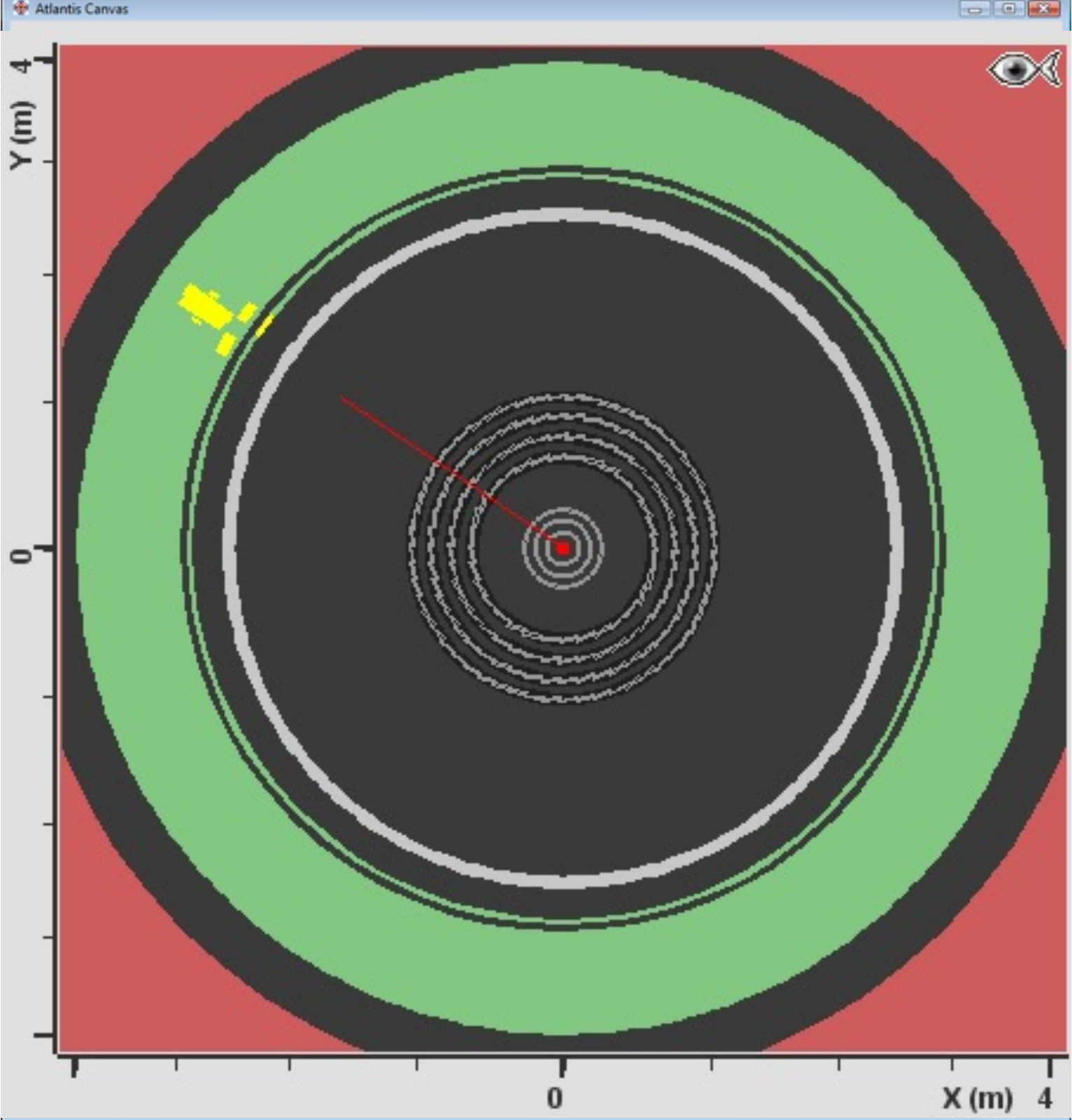
# Educational Software Hypatia

Le impronte delle particelle nei rivelatori: [segnali](#)



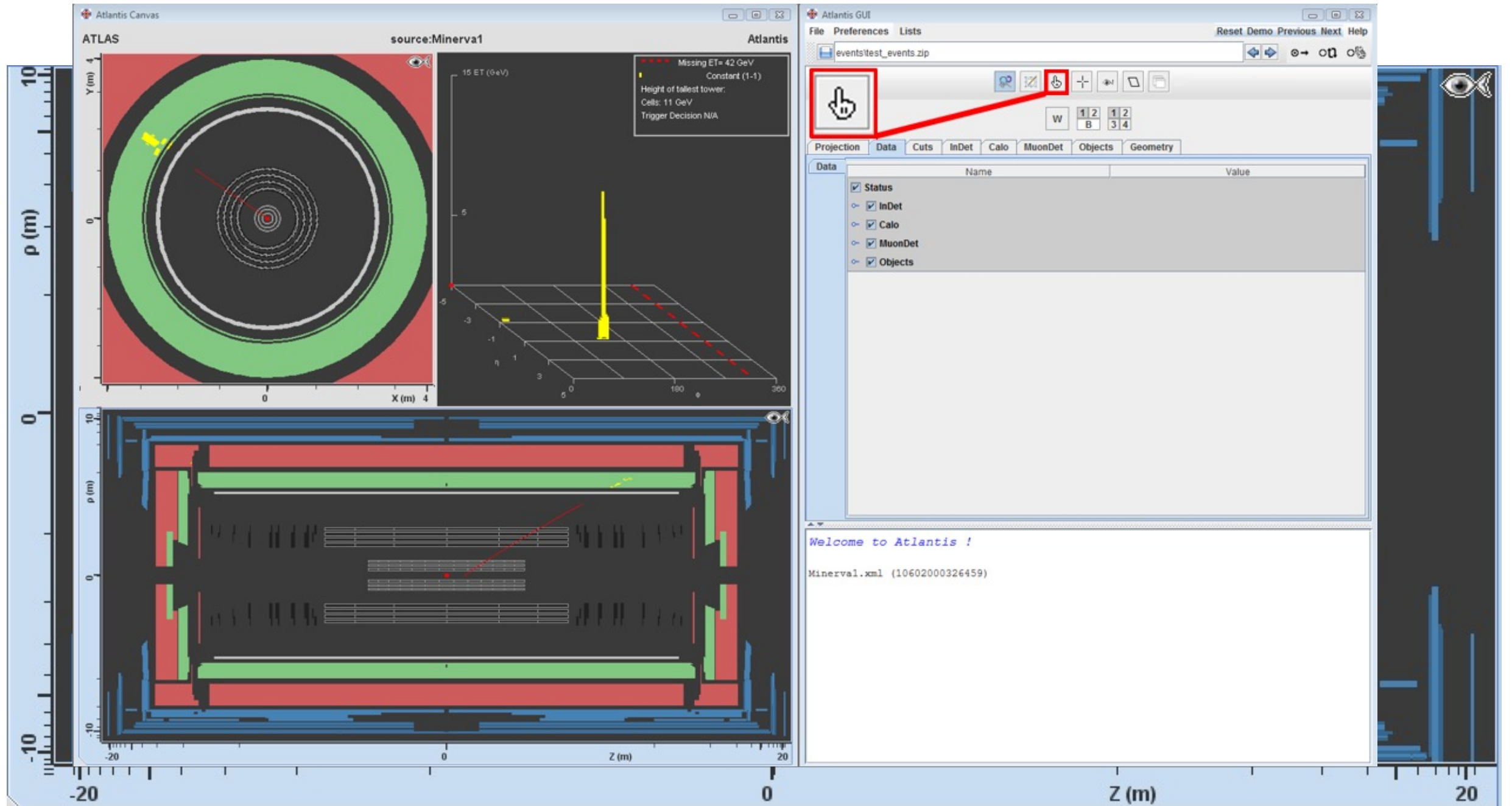
# Cosa Cerchiamo?

- Bosone Z: coppie  $e^+e^-$ ,  $\mu^+\mu^-$
- Bosone di Higgs: coppie  $\gamma\gamma$
- Bosone di Higgs: coppie Z, quindi coppie di due leptoni
  - $e^+e^-e^+e^-$ ,  $\mu^+\mu^-\mu^+\mu^-$ ,  $\mu^+\mu^-e^+e^-$
- Fondo: evento che NON appartiene alle categorie indicate; ignoratelo e andate avanti!
- **Attenzione!!!! Ricorda che la somma delle cariche di ogni coppia DEVE essere zero**

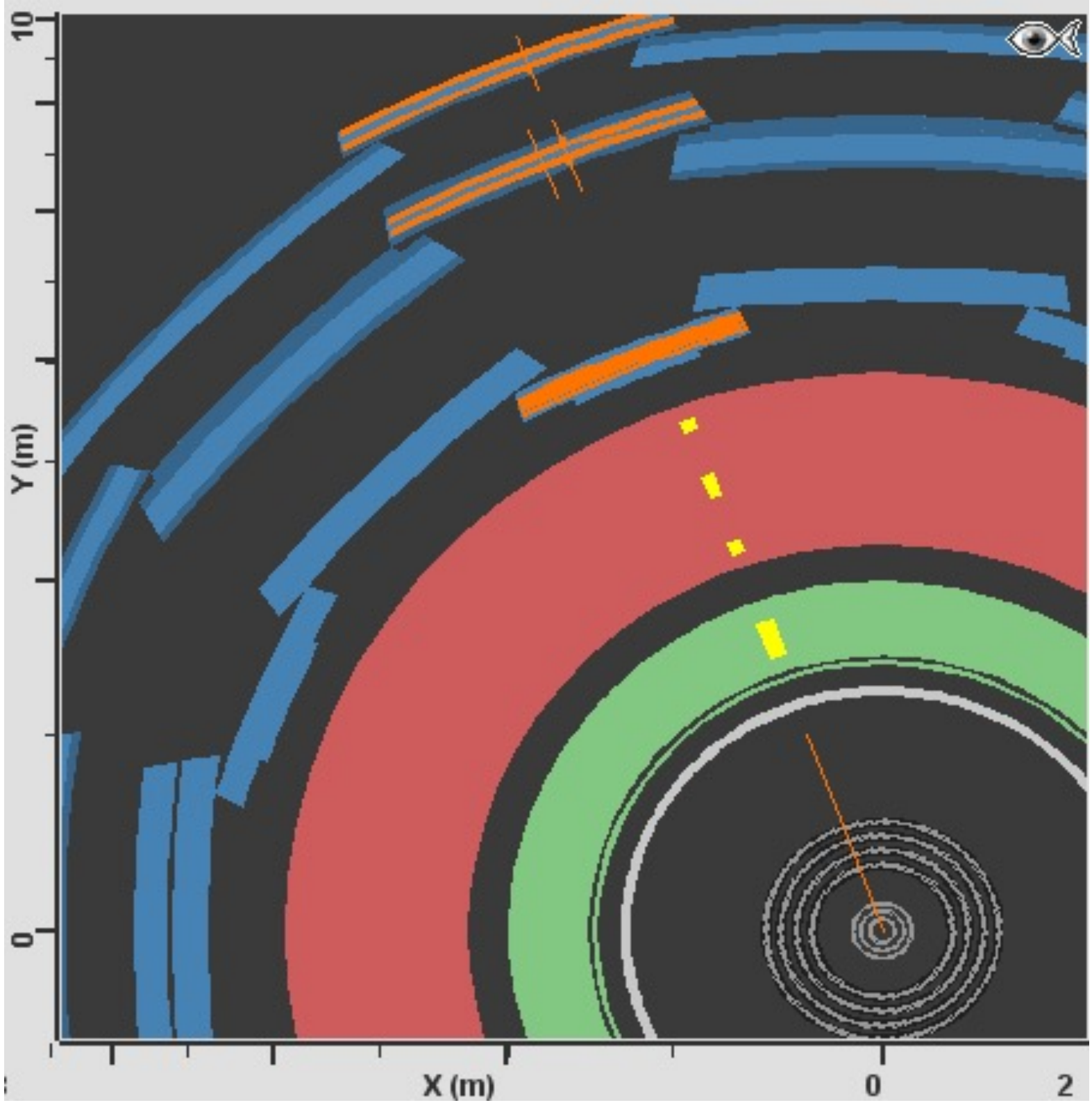


Eletrone

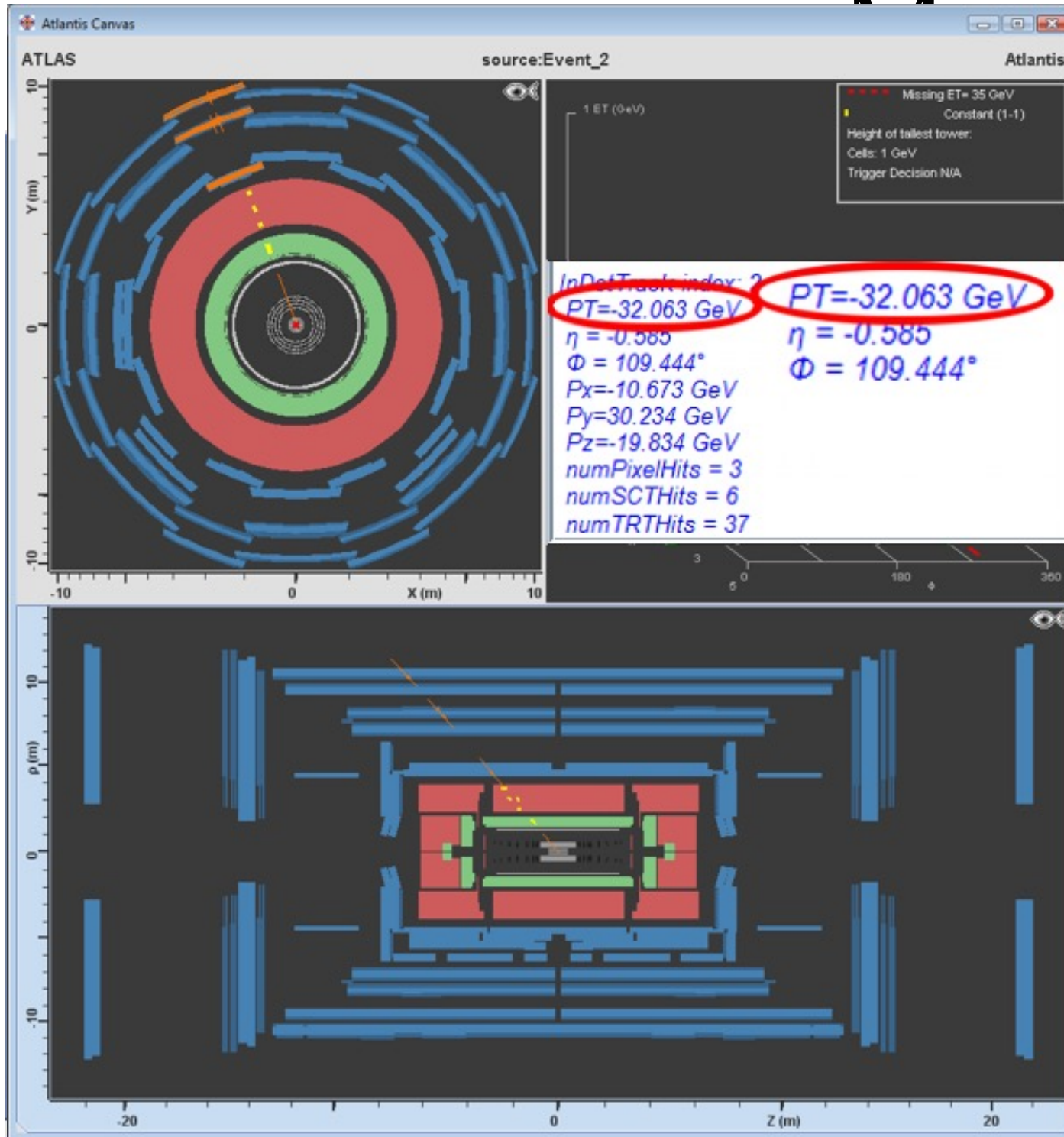
# Elettrone



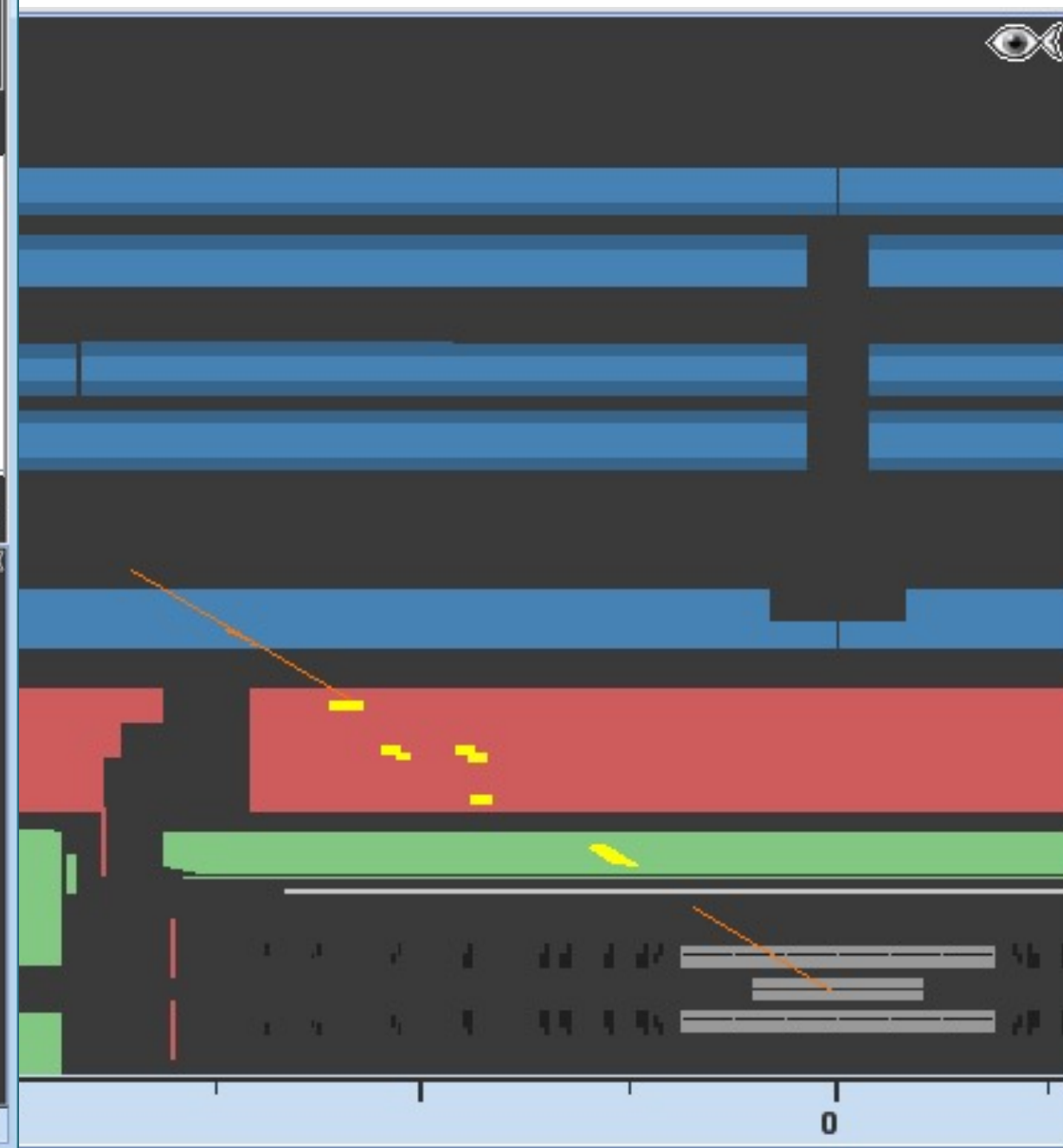




Muone



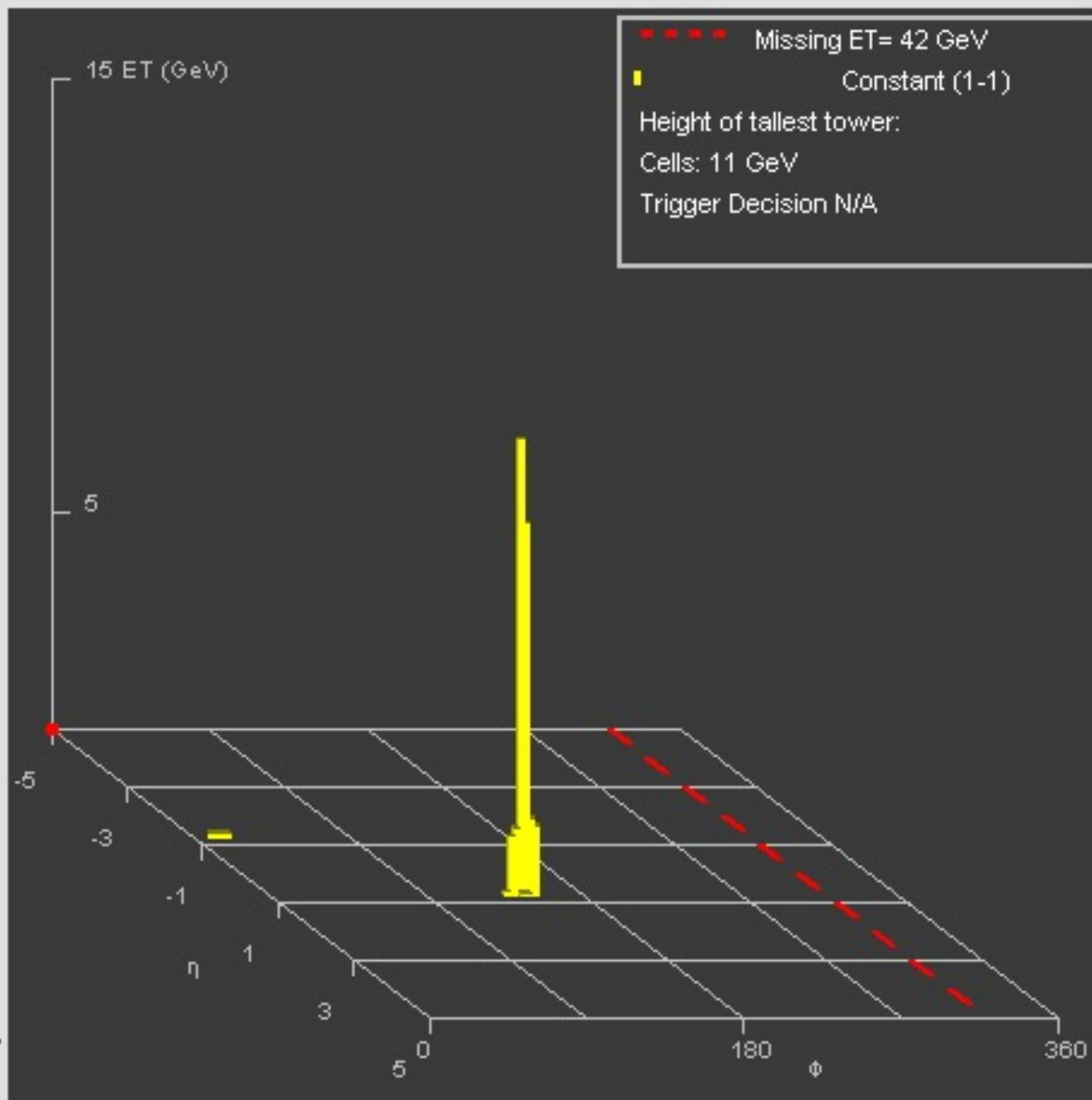
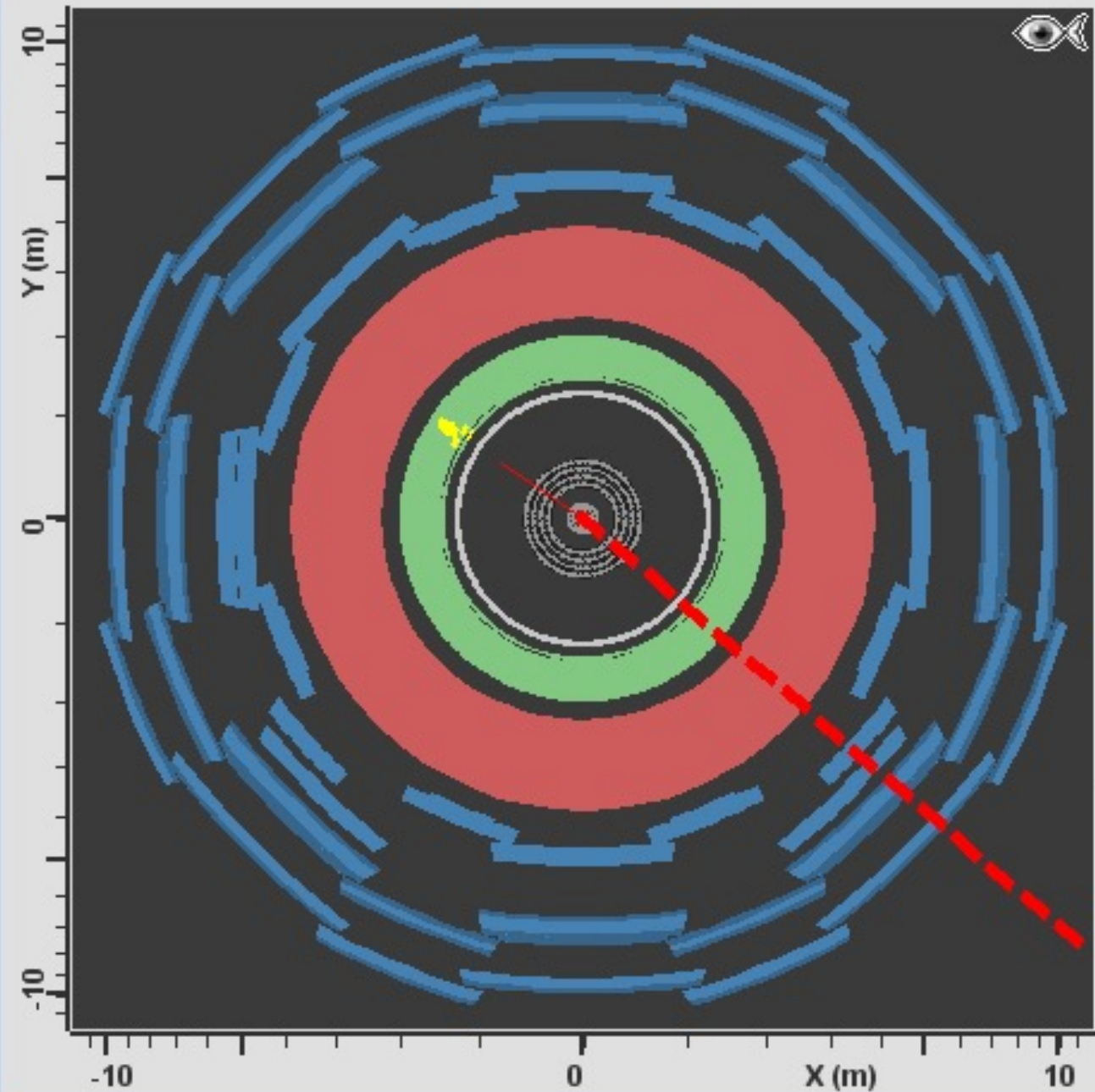
ne

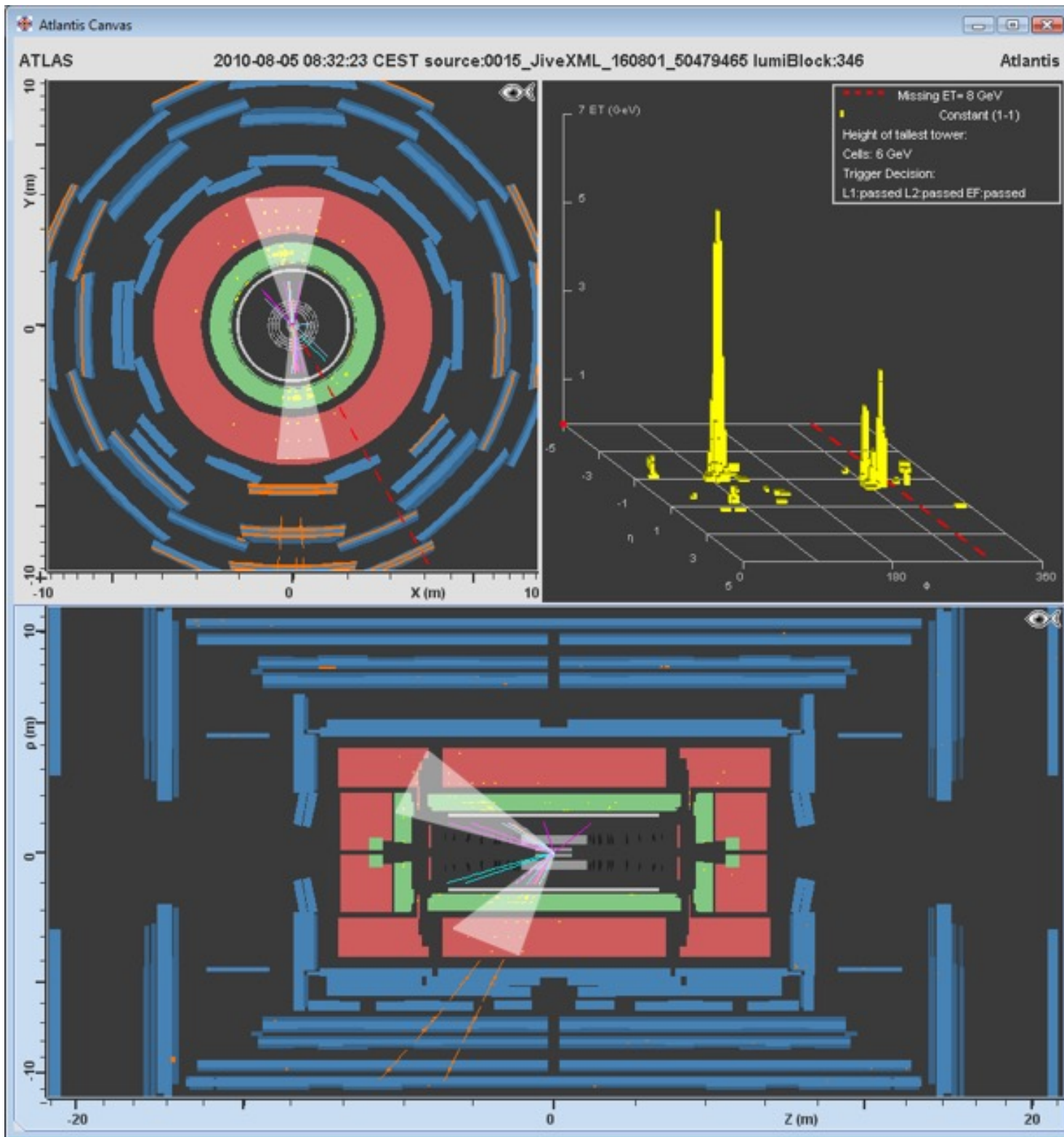


ATLAS

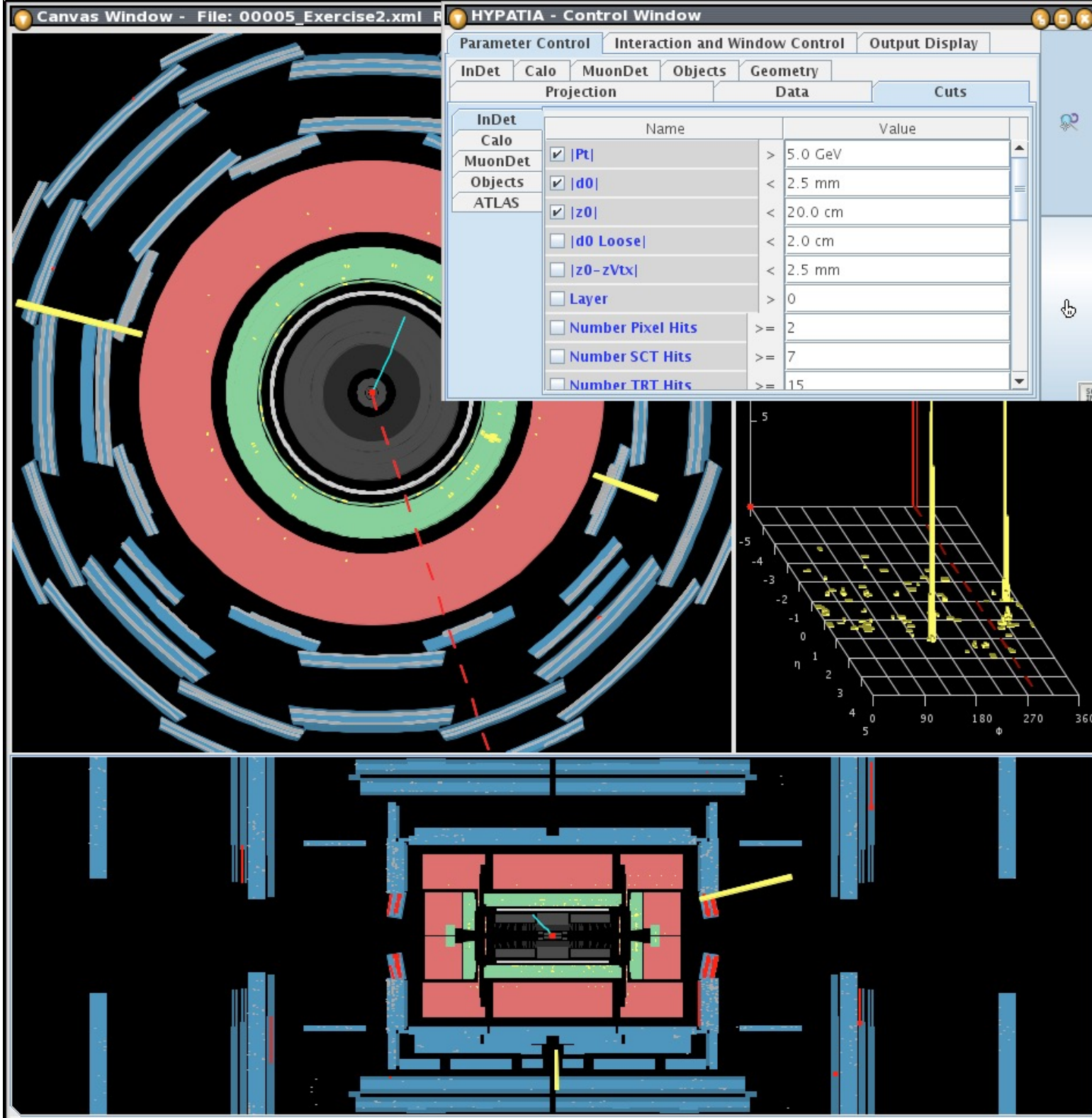
source:Event\_1

Atlantis

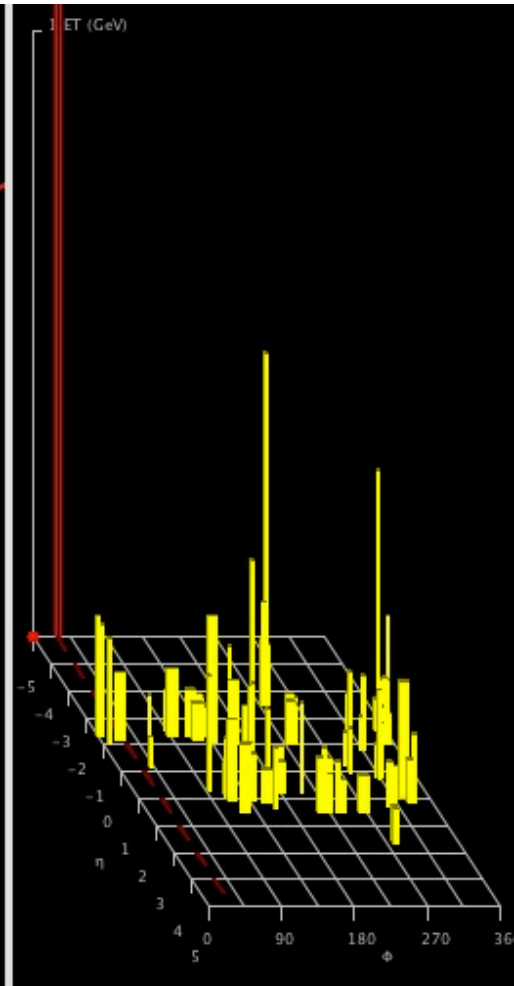
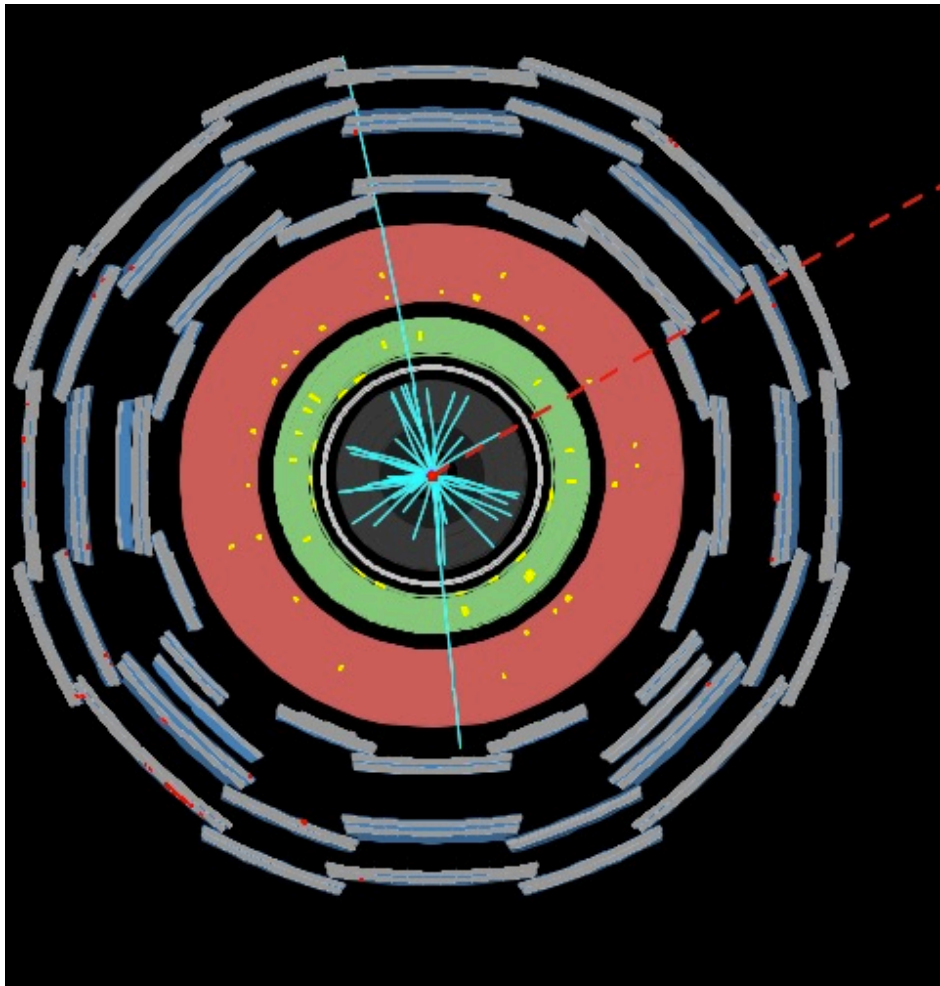




Jets



Fotone



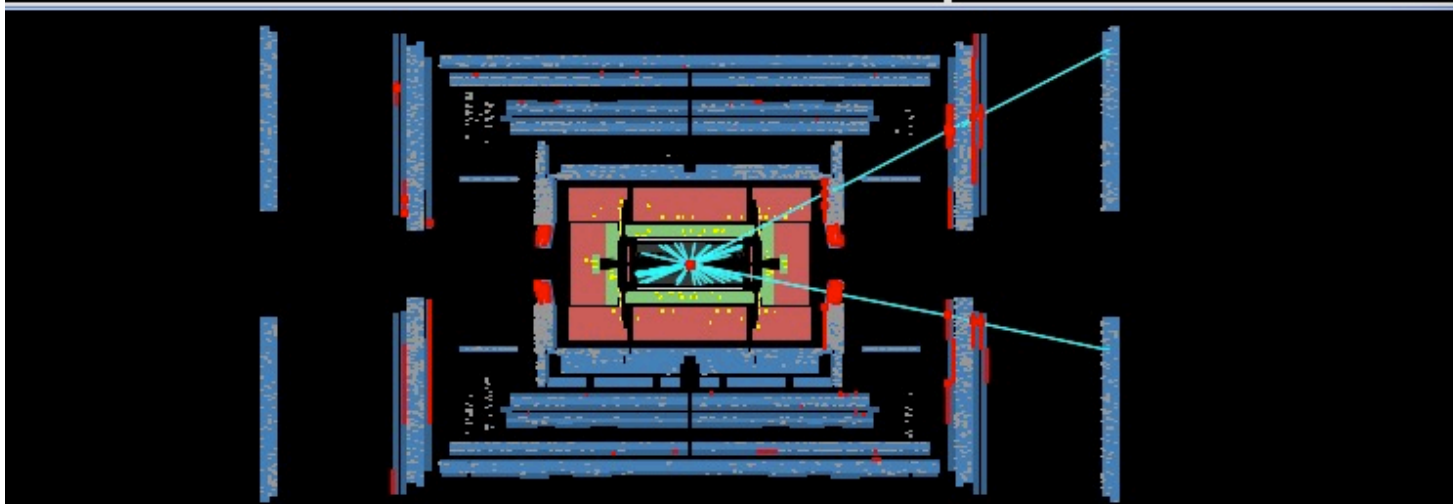
HYPATIA - Track Momenta Window

File Previous Event Next Event Electron Muon Photon

ETMis: 23,199 GeV φ: 0,516 rad Collection:

/Users/paolomassarotti/Desktop/Hypatia\_7/events/groupA/event0

Track	+/-	P [GeV]	Pt [GeV]
Tracks 0	-	216,96	42,63
Tracks 1	-	18,48	3,21
Tracks 2	-	7,35	1,58
Tracks 3	+	2,98	1,25
Tracks 4	+	1,51	1,02
Tracks 6	+	3,25	1,34
Tracks 9	-	4,64	1,51
Tracks 10	+	4,16	1,06
Tracks 11	-	3,04	2,98
Tracks 16	-	1,59	1,01
Tracks 17	-	9,38	1,53
Tracks 18	+	5,25	1,35
Tracks 19	+	3,99	1,00
Tracks 21	-	1,64	1,19
Tracks 24	-	1,16	1,10
Tracks 35	+	14,92	2,55
Tracks 38	-	1,39	1,02
Tracks 40	-	2,23	1,91
Tracks 41	-	10,32	1,76
Tracks 42	-	1,80	1,16



HYPATIA - Control Window

Parameter Control Interaction and Window Control Output Dis

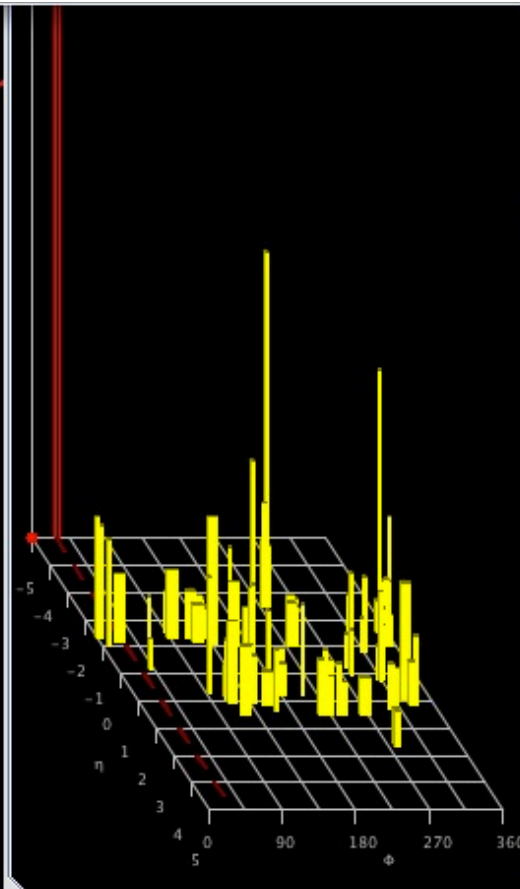
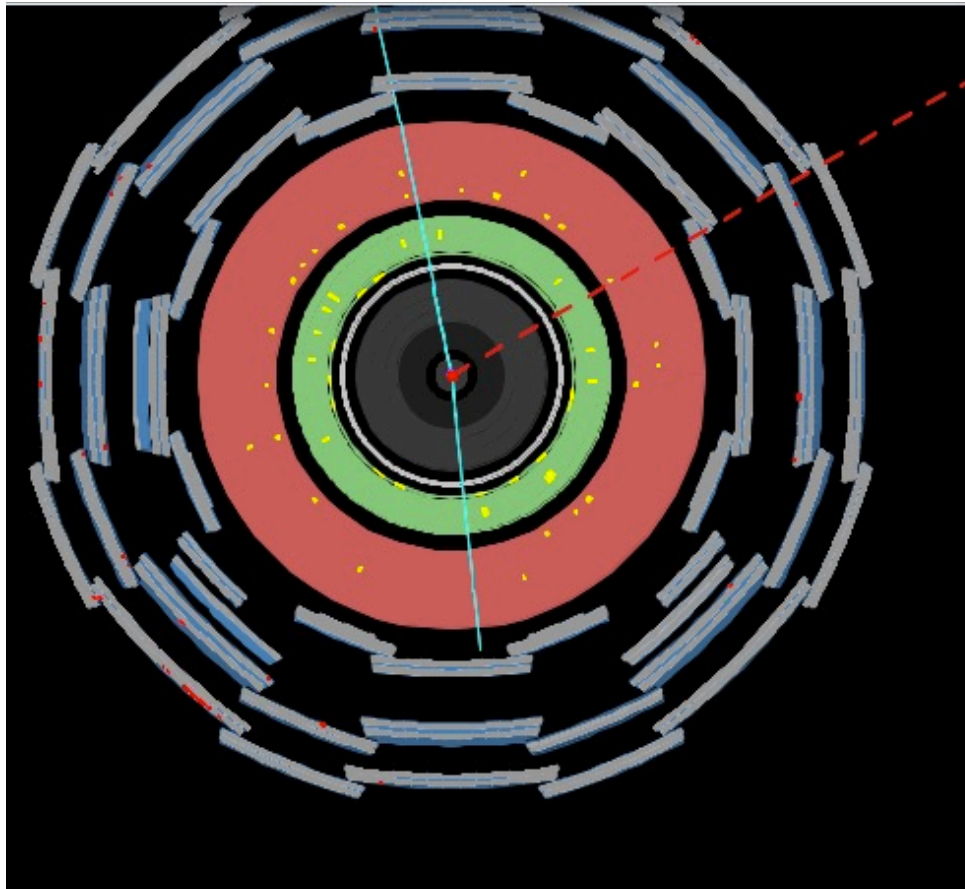
Projection Data Cuts InDet Calo MuonDet Objects

	Name	
InDet		
Calo	<input checked="" type="checkbox"/>  Pt	> 1.0 GeV
MuonDet	<input type="checkbox"/>  Pt2	< 700.0 MeV
Objects	<input checked="" type="checkbox"/>  d0	< 2.5 mm
ATLAS	<input checked="" type="checkbox"/>  z0	< 20.0 cm
	<input type="checkbox"/>  d0 Loose	< 2.0 cm

Resear...etwork

# Cosa Fare, step by step

Applichiamo dei tagli, ovvero richiediamo dei requisiti agli eventi:  $P_t > 10 \text{ GeV}$

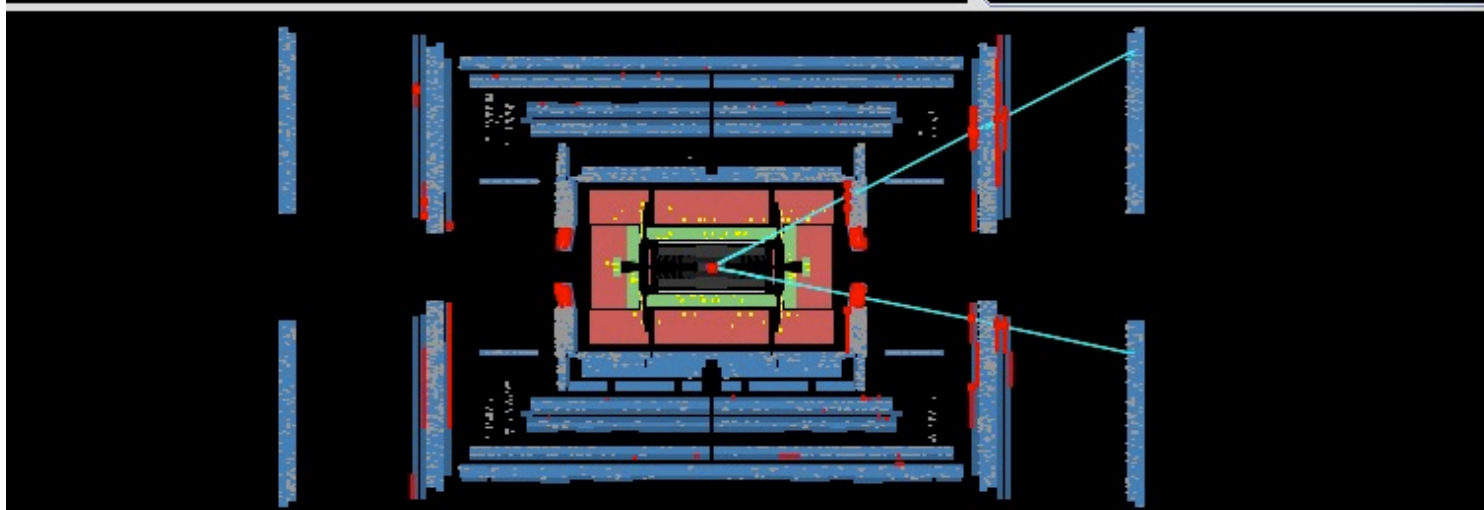


File    Previous Event    Next Event    Electron    Muon    Photon

ETMis: 23,199 GeV     $\phi$ : 0,516 rad    Collection:

/Users/paolomassarotti/Desktop/Hypatia\_7/events/groupA/eventC

Tracks		Physics Objects	
Track	+/-	P [GeV]	Pt [GeV]
Tracks 0	-	216,96	42,63
Tracks 76	+	93,33	42,90



HYPATIA - Control Window

Parameter Control    Interaction and Window Control    Output Di

Projection    Data    Cuts    InDet    Calo    MuonDet    Objects

	Name		
<input checked="" type="checkbox"/>	Pt	>	25.0 GeV
<input type="checkbox"/>	Pt2	<	700.0 MeV
<input checked="" type="checkbox"/>	d0	<	2.5 mm
<input checked="" type="checkbox"/>	z0	<	20.0 cm
<input type="checkbox"/>	d0 Loose	<	2.0 cm



# Cosa Fare, step by step

Per ogni evento cercate un segnale tipo:

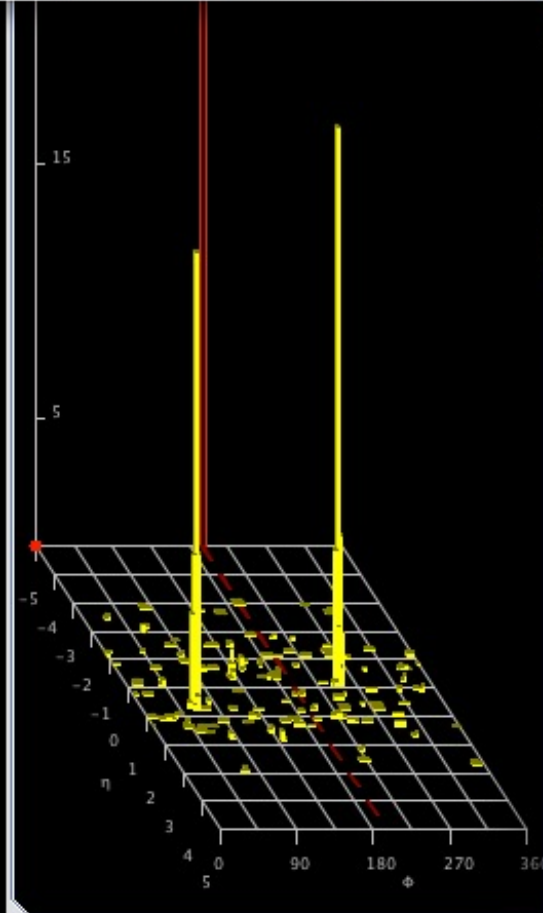
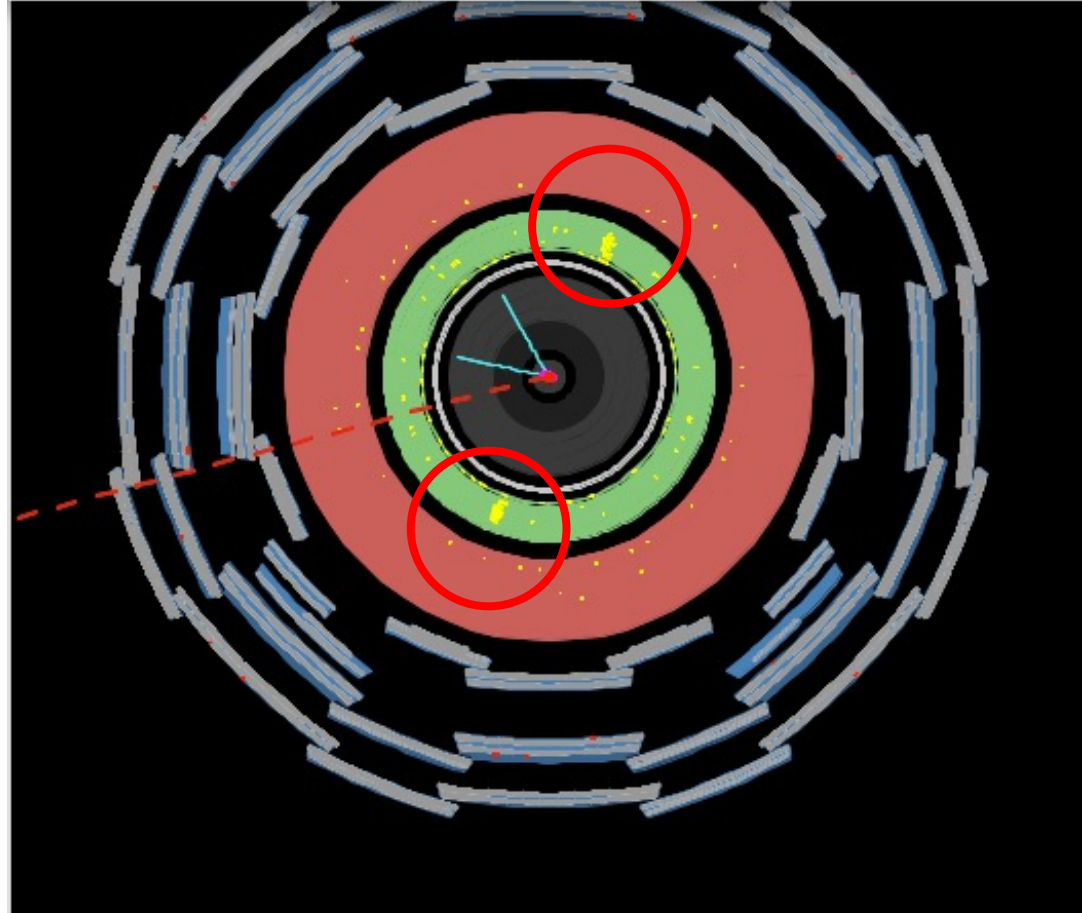
- Bosone Z: coppie  $e^+e^-$ ,  $\mu^+\mu^-$
- Bosone di Higgs: coppie  $\gamma\gamma$
- Bosone di Higgs: coppie di due leptoni
  - $e^+e^-e^+e^-$ ,  $\mu^+\mu^-\mu^+\mu^-$ ,  $\mu^+\mu^-e^+e^-$
- Fondo: evento che NON appartiene alle categorie indicate; ignoratelo e andate avanti!
- **Attenzione!!!! Ricorda che la somma delle cariche di ogni coppia DEVE essere zero**

# Fotoni

Ci sono eventi di soli fotoni o di tracce e fotoni

Per selezionare i fotoni bisogna passare da Tracks a  
Physics Objects

event003.xml	28,561	Tracks 261	49,6	-2,215	-0,071	49,5	1,154	0,761	100,334
		Object 0	60,2			46,2			
		Object 1	47,6			47,6	-1,931	0,017	



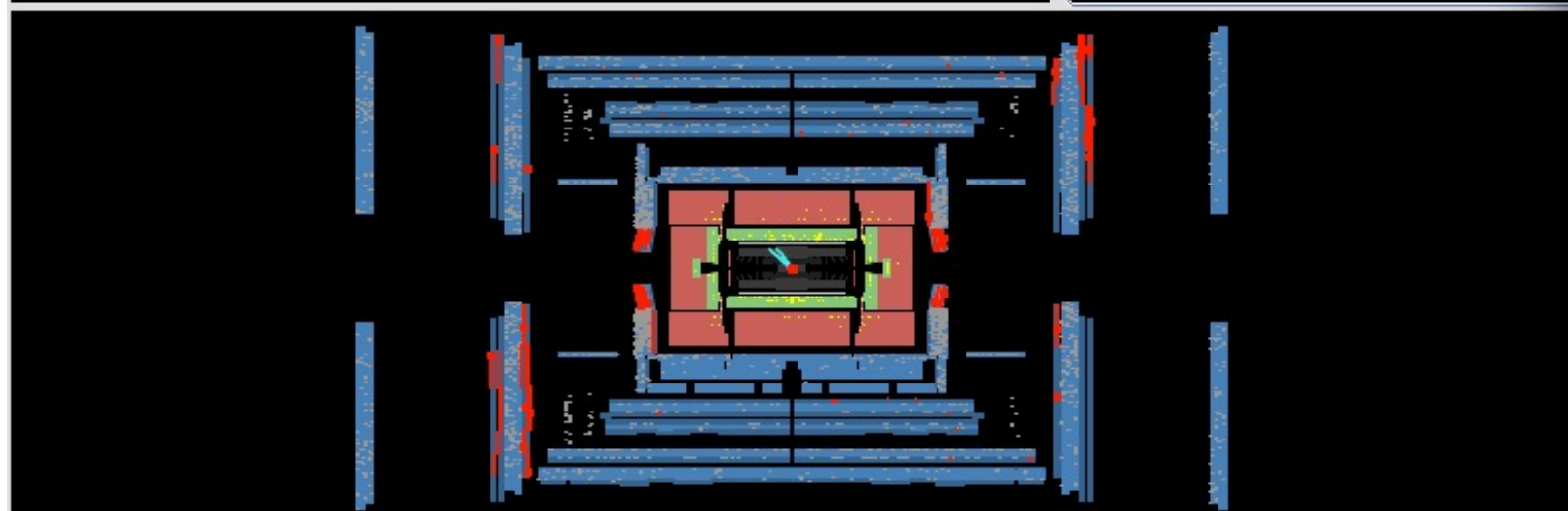
HYPATIA - Track Momenta Window

File    Previous Event    Next Event    Electron    Muon    Photon

ETMis: 28,561 GeV     $\varphi$ : -2,881 rad    Collection

/Users/paolomassarotti/Desktop/Hypatia\_7/events/groupA/event

Tracks		Physics Objects	
Track	+/-	P [GeV]	Pt [GeV]
Tracks 382	+	97,37	63,27
Tracks 383	+	19,16	15,56



Parameter Control    Interaction and Window Control    Output D

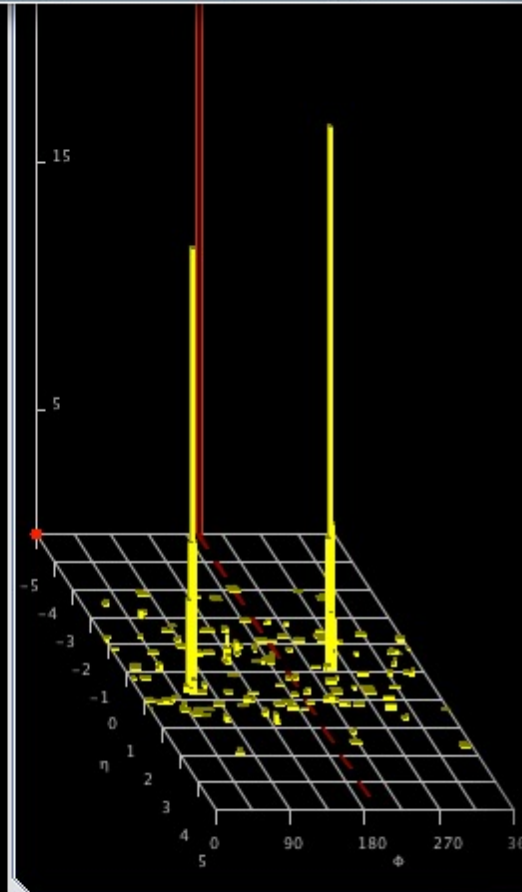
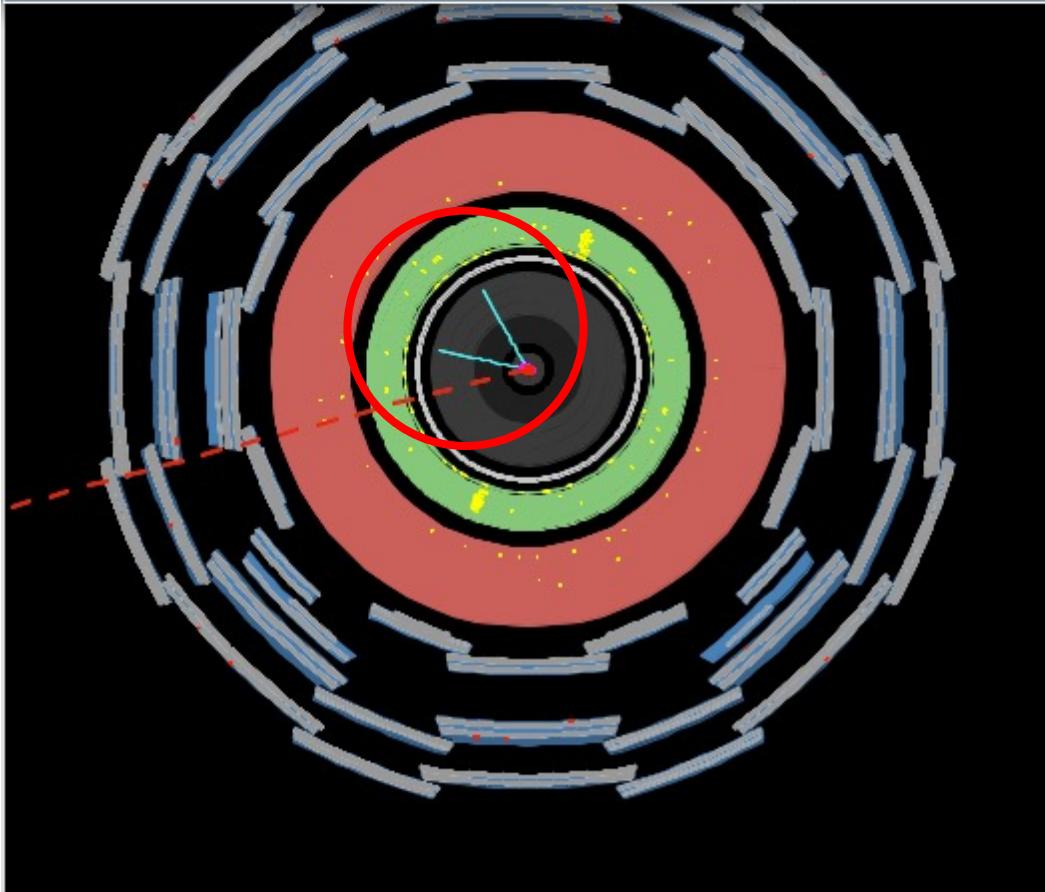
Projection    Data    Cuts    InDet    Calo    MuonDet    Object

InDet	Name		
Calo	<input checked="" type="checkbox"/>  Pt	>	10.0 GeV
MuonDet	<input type="checkbox"/>  Pt2	<	700.0 MeV
Objects	<input checked="" type="checkbox"/>  d0	<	2.5 mm
ATLAS	<input checked="" type="checkbox"/>  z0	<	20.0 cm
	<input type="checkbox"/>  d0 Loose	<	2.0 cm

3    2015-...1.28.00



File Name	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	$\phi$	$\eta$	M(2) [GeV]	M(eeee) [GeV]	M(eemm)
		Tracks 281	49,6	-	49,5	-2,215	-0,071			
event003.xml	28,561	Object 0	60,2		46,2	1,154	0,761	100,334		
		Object 1	47,6		47,6	-1,931	0,017			



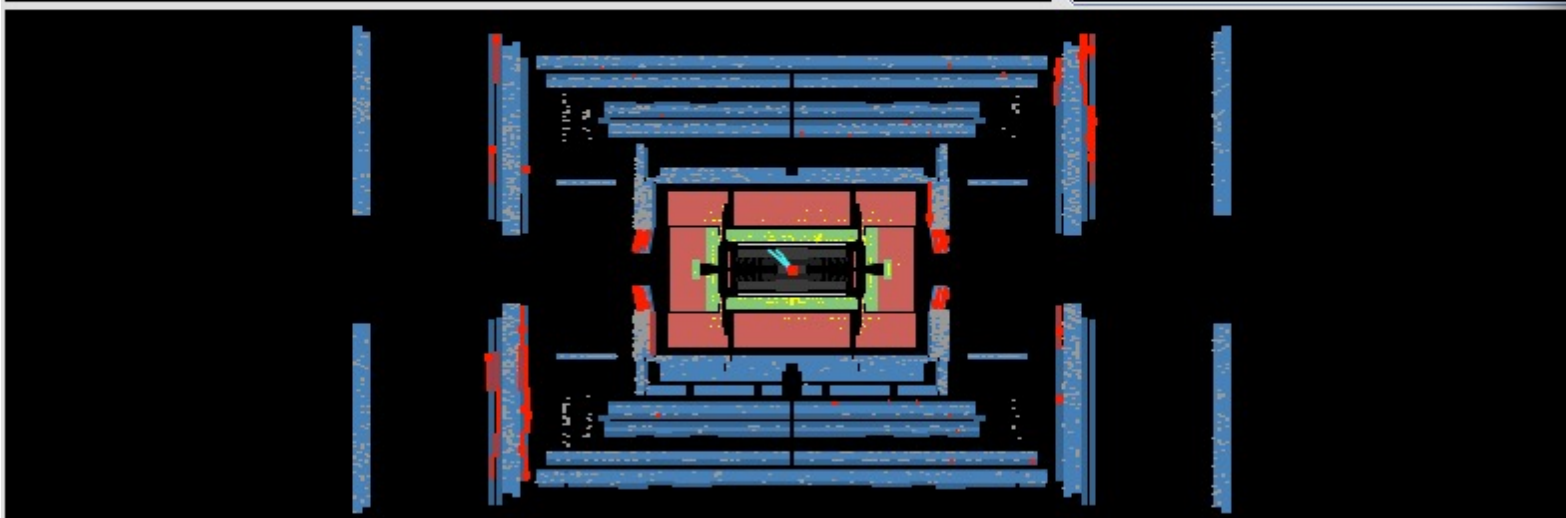
HYPATIA - Track Momenta Window

File    Previous Event    Next Event    Electron    Muon    Photon

ETMis: 28,561 GeV     $\phi$ : -2,881 rad    Collection

/Users/paolomassarotti/Desktop/Hypatia\_7/events/groupA/event

Track	+/-	P [GeV]	Pt [GeV]
Tracks 382	+	97,37	63,27
Tracks 383	+	19,16	15,56



Parameter Control    Interaction and Window Control    Output D

Projection    Data    Cuts    InDet    Calo    MuonDet    Object

InDet	Name	Value
Calo	<input checked="" type="checkbox"/>  Pt	> 10.0 GeV
MuonDet	<input type="checkbox"/>  Pt2	< 700.0 MeV
Objects	<input checked="" type="checkbox"/>  d0	< 2.5 mm
ATLAS	<input checked="" type="checkbox"/>  z0	< 20.0 cm
	<input type="checkbox"/>  d0 Loose	< 2.0 cm

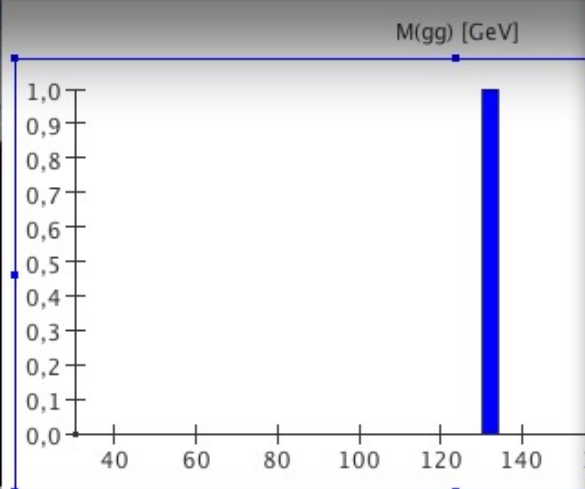
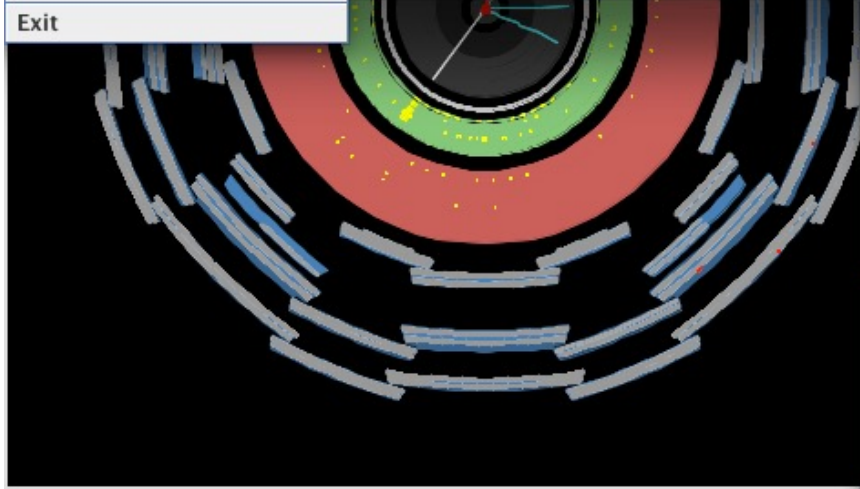
3    2015-... 1.28.00

# Gli eventi sono finiti?

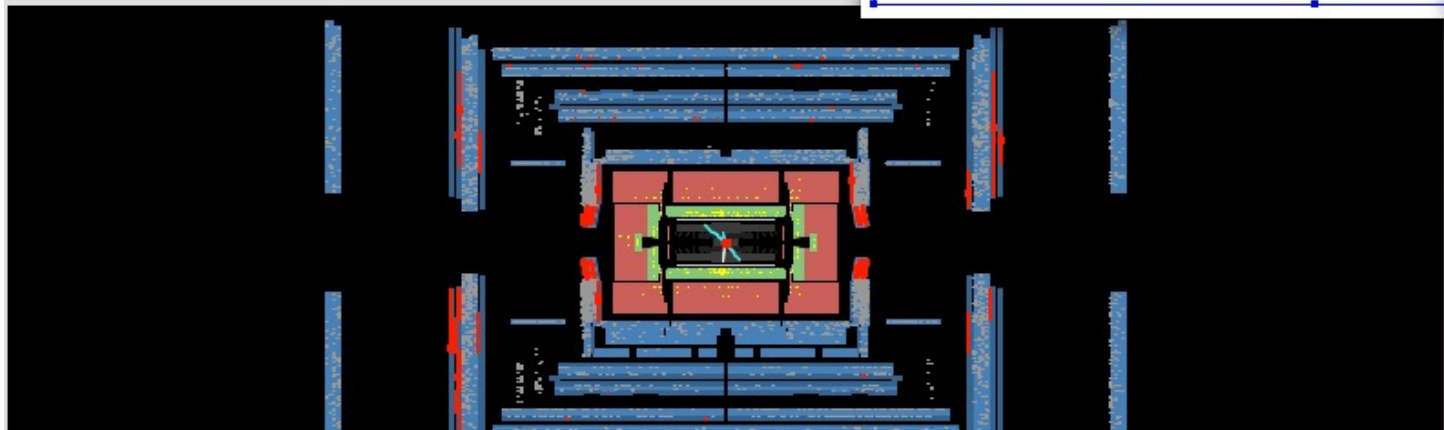
Export Invariant Mass Table:

- HYPATHIA: File->Export Invariant Masses
  - Salvate sul desktop il file “Invariant\_Masses\_3A.txt”

	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	$\phi$	$\eta$	M(2) [GeV]	M(eeee) [GeV]	M(eemm) [GeV]
Read Event Locally		Object 1	63,5		46,1	-2,568	0,843			
Read Event From URL (live)	11,123	Tracks 22	44,0	-	36,4	-0,772	0,634	90,930		
Clear Hypatia Project		Tracks 227	53,9	+	53,5	2,248	0,129			
Load Hypatia Project	4,167	Tracks 173	36,6	-	32,6	1,132	0,491	82,729		
Save Hypatia Project		Tracks 8	47,1	+	37,9	-1,978	-0,680			
Export Invariant Masses	29,106	Tracks 11	87,0	+	27,5	-1,813	1,820	68,420		
Loop over events		Tracks 0	202,0	-	40,3	1,286	2,295			
Save Image of Canvas	22,805	Tracks 184	449,7	+	423,3	-1,090	-0,352	994,430		
Animated Event	28,020	Tracks 247	567,5	-	434,3	2,080	0,764			
Event Properties		Tracks 168	189,2	-	31,2	3,130	-2,487	95,647		
Read Geometry	57,128	Tracks 184	65,9	+	44,3	0,484	-0,953			
Read G4Steps	29,794	Tracks 451	224,3	+	100,9	2,291	1,437			
	29,794	Tracks 4	43,8	+	43,6	1,082	-0,104	92,582		
		Tracks 281	49,6	-	49,5	-2,215	-0,071			



Tracks	M(2) [GeV]	M(eeee) [GeV]	M(eemm) [GeV]
360	-	44,13	28,47



HYPATIA – Control Window

Parameter Control | Interaction and Window Control | Output Disp

Projection | Data | Cuts | InDet | Calo | MuonDet | Objects

Category	Name	Value
InDet		
Calo	<input checked="" type="checkbox"/>  Pt	> 25.0 GeV
MuonDet	<input type="checkbox"/>  Pt2	< 700.0 MeV
Objects	<input checked="" type="checkbox"/>  d0	< 2.5 mm
ATLAS	<input checked="" type="checkbox"/>  z0	< 20.0 cm
	<input type="checkbox"/>  d0 Loose	< 2.0 cm

Salva

Salva in: Hypatia\_7

- config
- events
- geome
- help
- img
- lib

Nome file: Invariant\_Masses.txt

Tipo file: Text files

Salva Annulla

Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant

	P [GeV]	+/-	Pt [GeV]	$\phi$	n
	63,5		46,1	-2,568	0,843
	44,0	-	36,4	-0,772	0,634
	53,9	+	53,5	2,248	0,129
	36,6	-	32,6	1,132	0,491
	47,1	+	37,9	-1,978	-0,680
	87,0	+	27,5	-1,813	1,820
	202,0	-	40,3	1,286	2,295
	449,7	+	423,3	-1,090	-0,352
	567,5	-	434,3	2,080	0,764
	189,2	-	31,2	3,130	-2,487
	65,9	+	44,3	0,484	-0,953
	224,3	+	100,9	2,291	1,437
	43,8	+	43,6	1,082	-0,104
	49,6	-	49,5	-2,215	-0,071

M(gg) [GeV]

Tracks 360

Parameter Control

Projection Data

InDet

Calo

MuonDet  | Pt



**Cosa abbiamo visto?**

# Analisi dei Risultati

## Misura con due leptoni

- Confronta gli istogrammi delle coppie elettrone-positrone e muone-antimuone
  - Noti delle differenze/somiglianze?
  - Con che frequenza il bosone  $Z$  decade in coppie elettrone-positrone? E in coppie muone-antimuone?
  - Cosa ti aspettavi? Perché?
  - Osservi altre particelle? Con che valori di massa?
- Qual'è la massa più probabile del bosone  $Z$ ?
  - Perché non si ottiene un valore esatto per la massa?
  - Quale può essere la spiegazione per una larghezza così grande?
- Hai scoperto il bosone  $Z'$ ?
  - Se pensi di sì, quanto vale la massa del bosone  $Z'$ ?
- Perché è utile combinare i tuoi risultati con quelli ottenuti da altri gruppi?

# Analisi dei Risultati

## Misura con due fotoni

- Hai osservato qualche traccia di un decadimento di un bosone di Higgs in 2 fotoni:  $H \rightarrow \gamma\gamma$ ?
  - In caso negativo, quale può esserne la ragione?
  - Ricorda che il campione che hai analizzato include effettivamente qualche candidato Higgs reale.

## Misura con 4 leptoni

- Hai osservato qualche traccia di un decadimento di un bosone di Higgs in 4 leptoni:  $H \rightarrow ZZ \rightarrow llll$ ?
  - In caso negativo, quale può esserne la ragione?
  - In caso affermativo, a quale massa si osserva l'Higgs? Il campione che hai analizzato contiene un evento candidato Higgs reale in quattro leptoni.