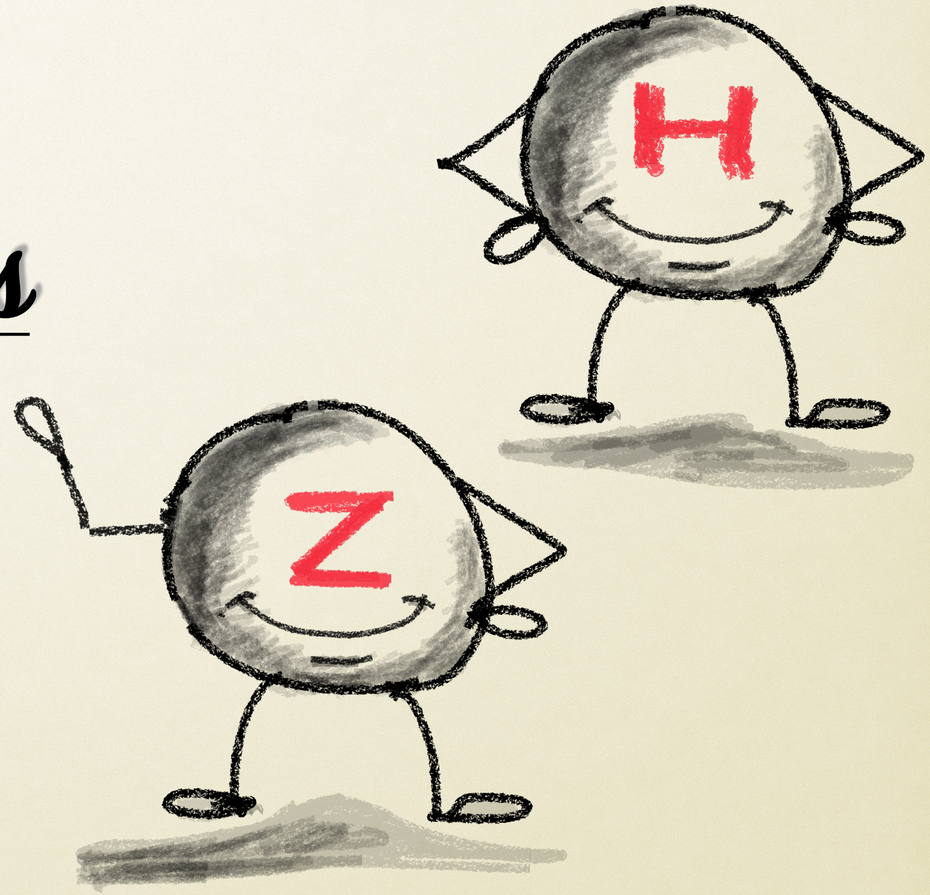
Cerchiamo le particelle: il bosone Z e il bosone di Higgs



MONICA VERDUCCI

monica.verducci@cern.ch

ATLAS PISA Universita' e INFN di Pisa

ATLAS Z-Path - 28 Febbraio 2025

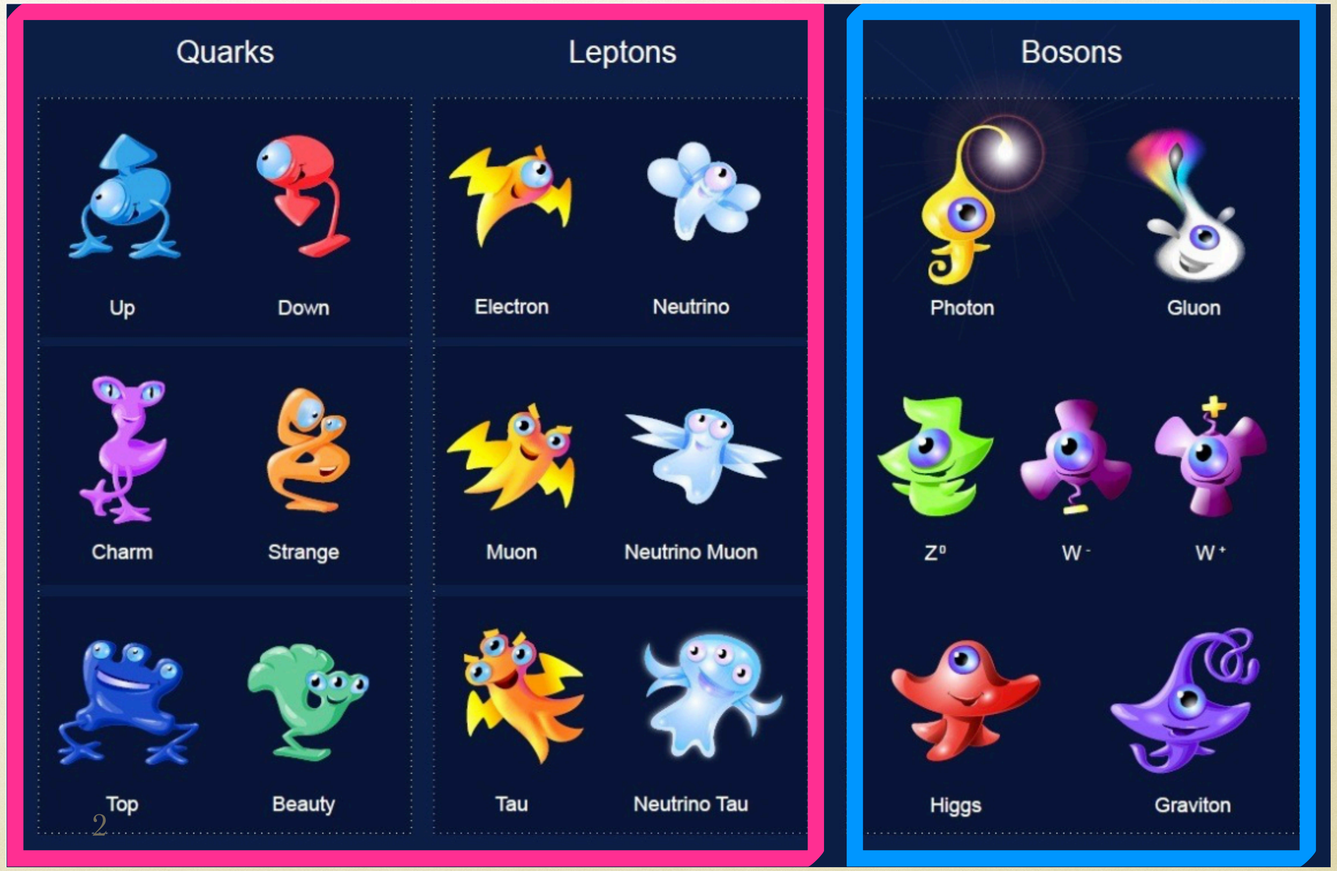
Quali particelle cerchiamo? Come le cerchiamo?

- Molte di queste particelle attraversando il rivelatore (materia) interagendo con esso e lasciando quindi "tracce" visibili e misurabili del loro passaggio.

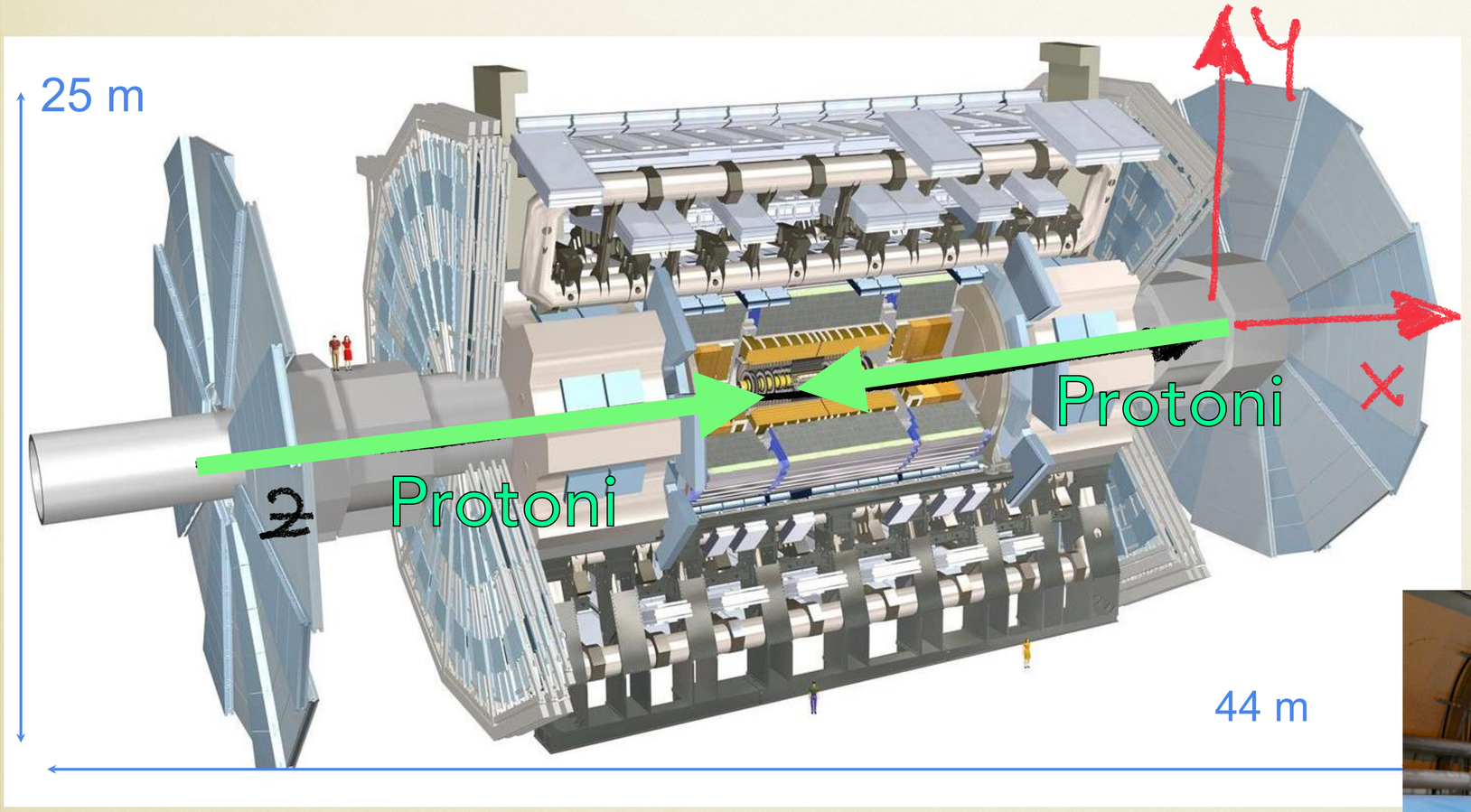
- L'interazione con il rivelatore comporta un rilascio di energia da parte della particella, che viene trasformata in un opportuno segnale elettrico (qualcosa di misurabile) analizzabile dal computer (come faremo oggi!!!)

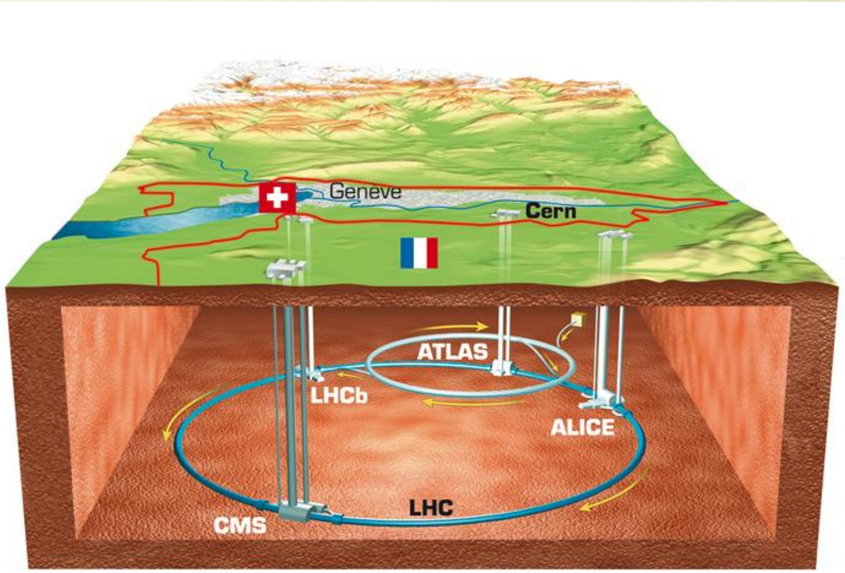
QUARK E LEPTONI: I COSTITUENTI ELEMENTARI DELLA MATERIA

BOSONI: TRASMETTITORI DELLE INTERAZIONI

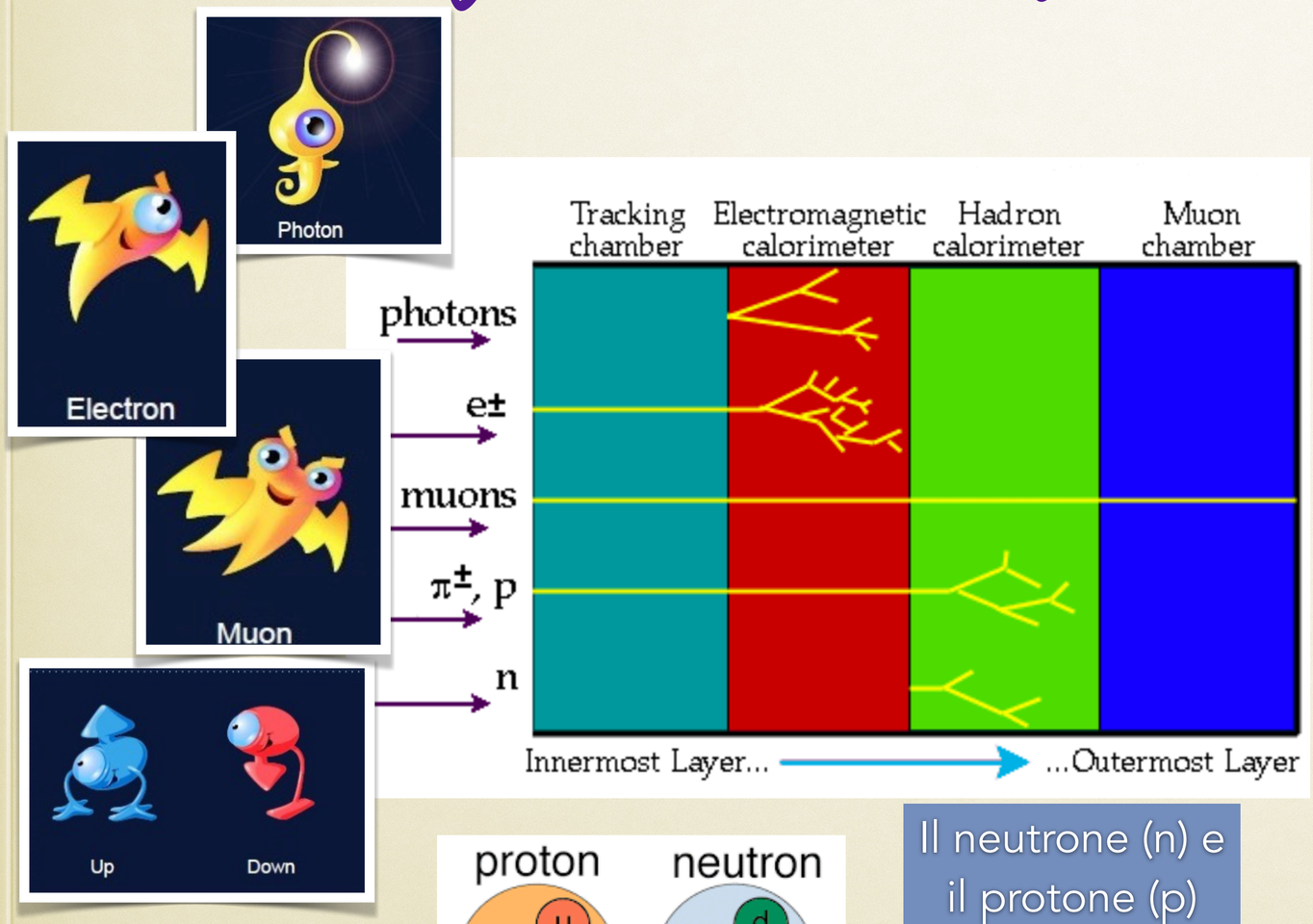


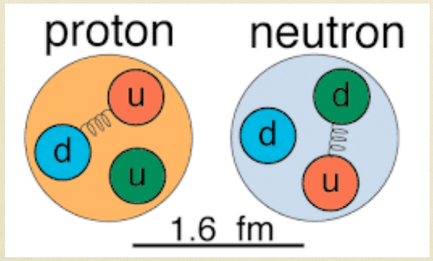
Come le cerchiamo? Con il rivelatore ATLAS



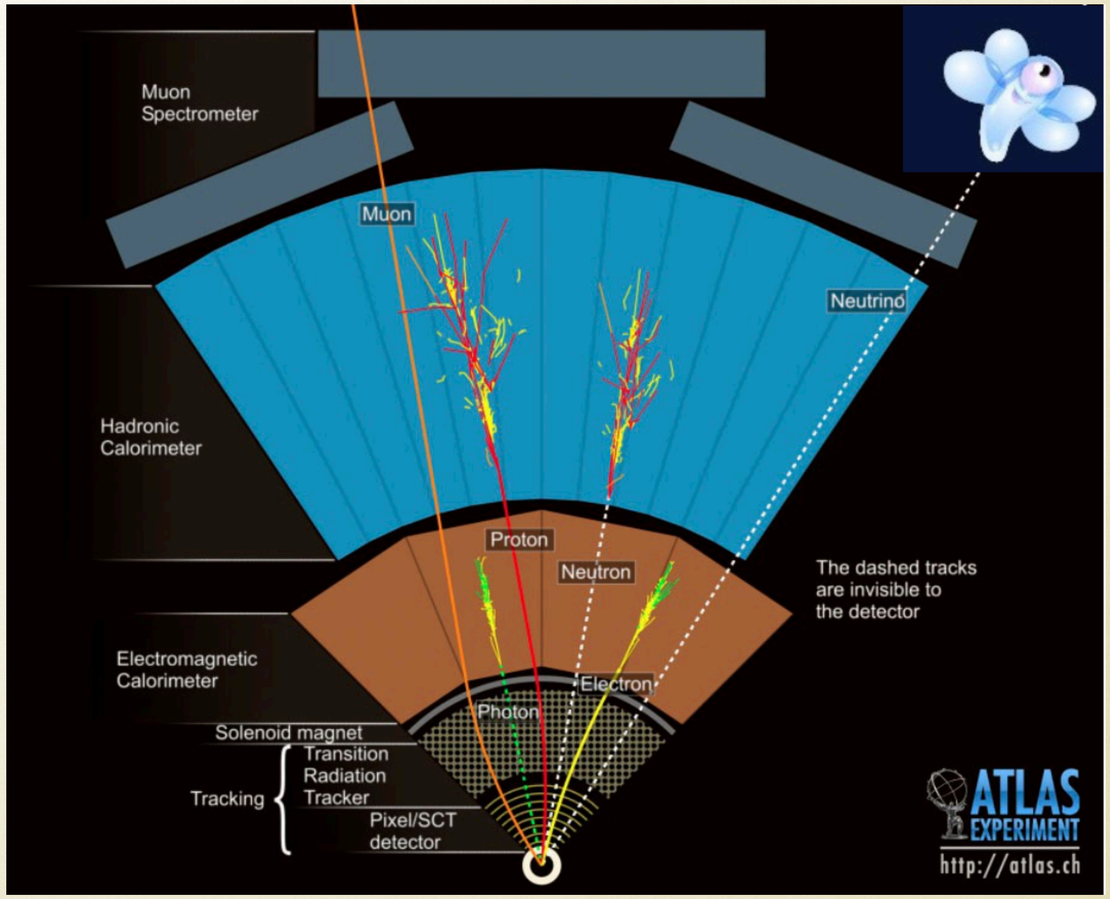


Strategia di rivelazione

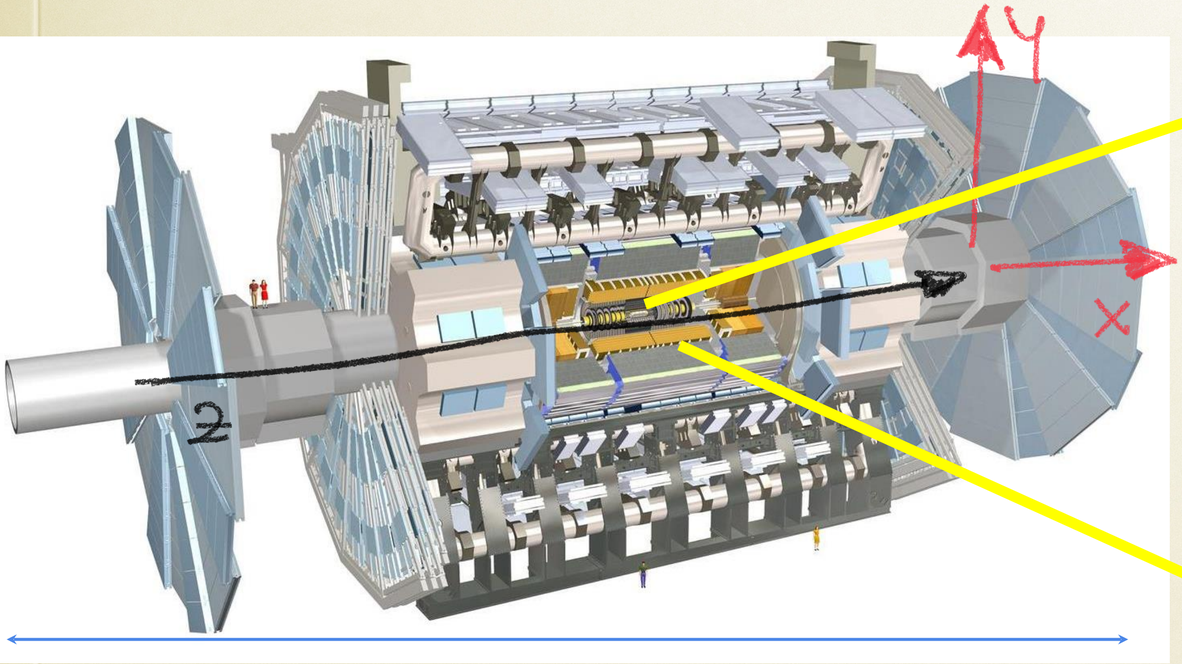


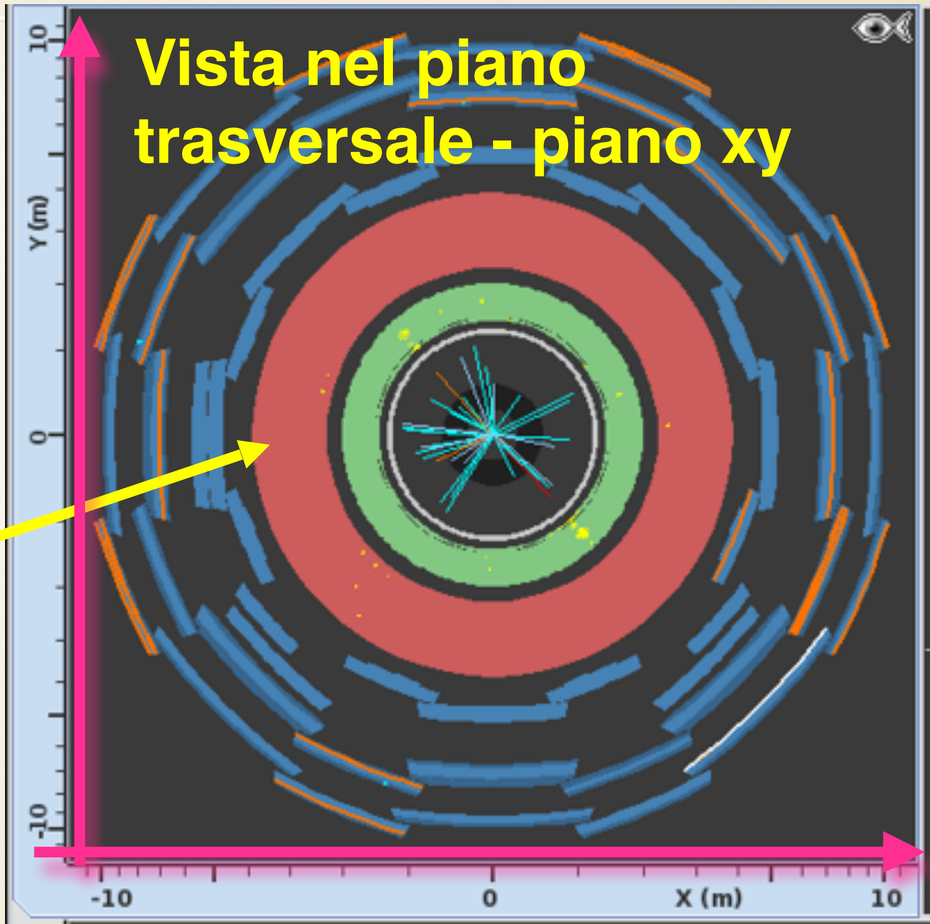


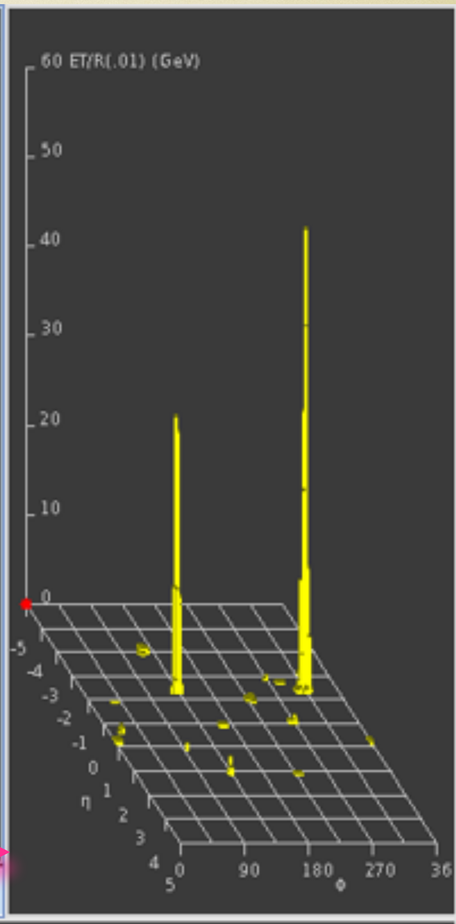
Il neutrone (n) e il protone (p) sono particelle formate da quarks up e down

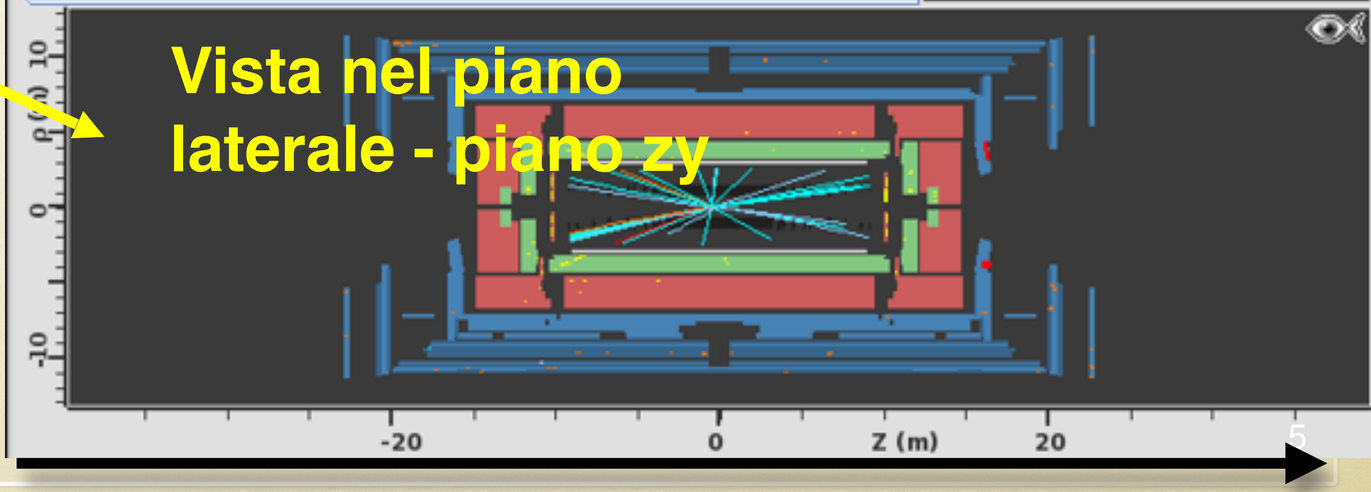


Come osserviamo le particelle in ATLAS

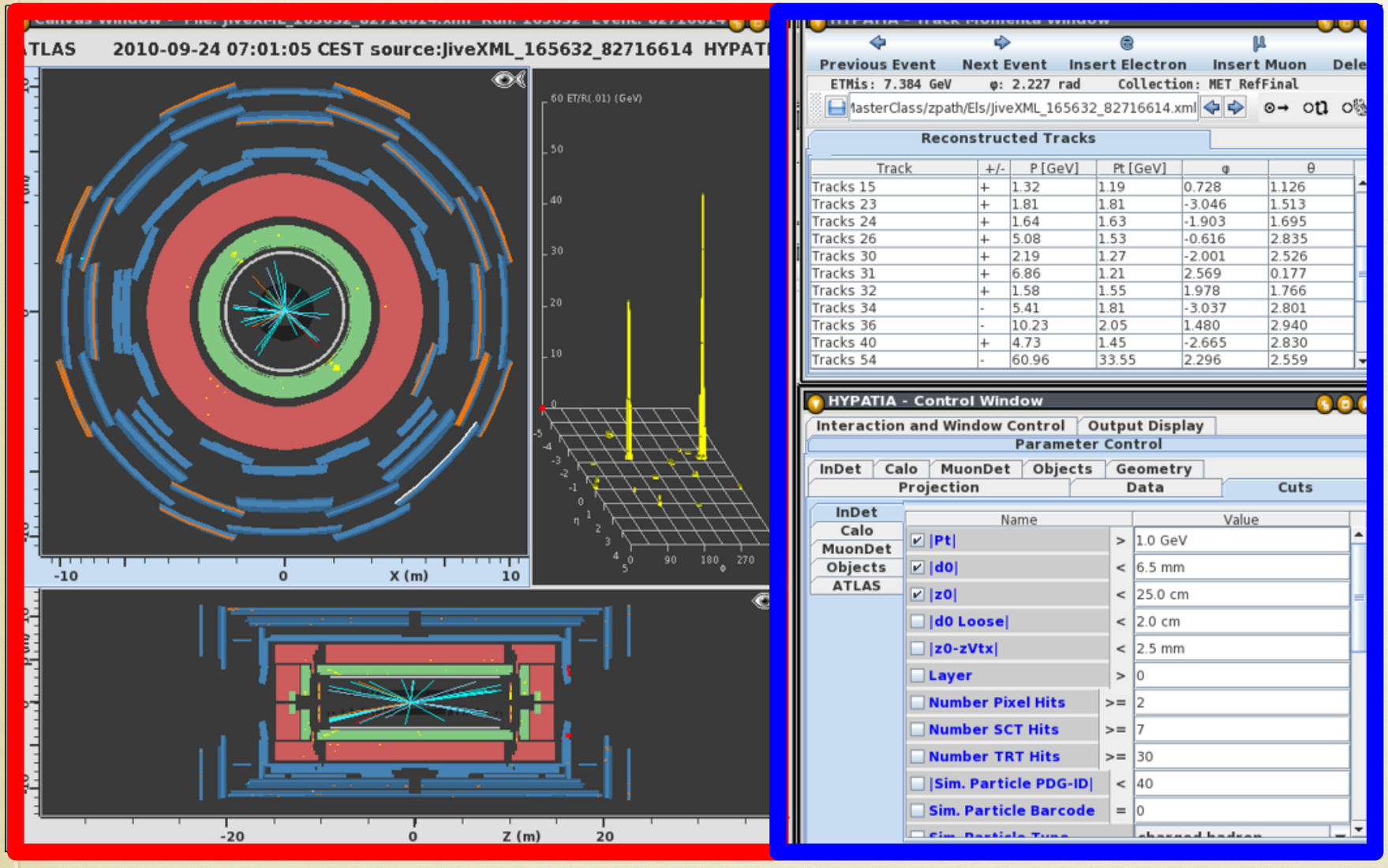








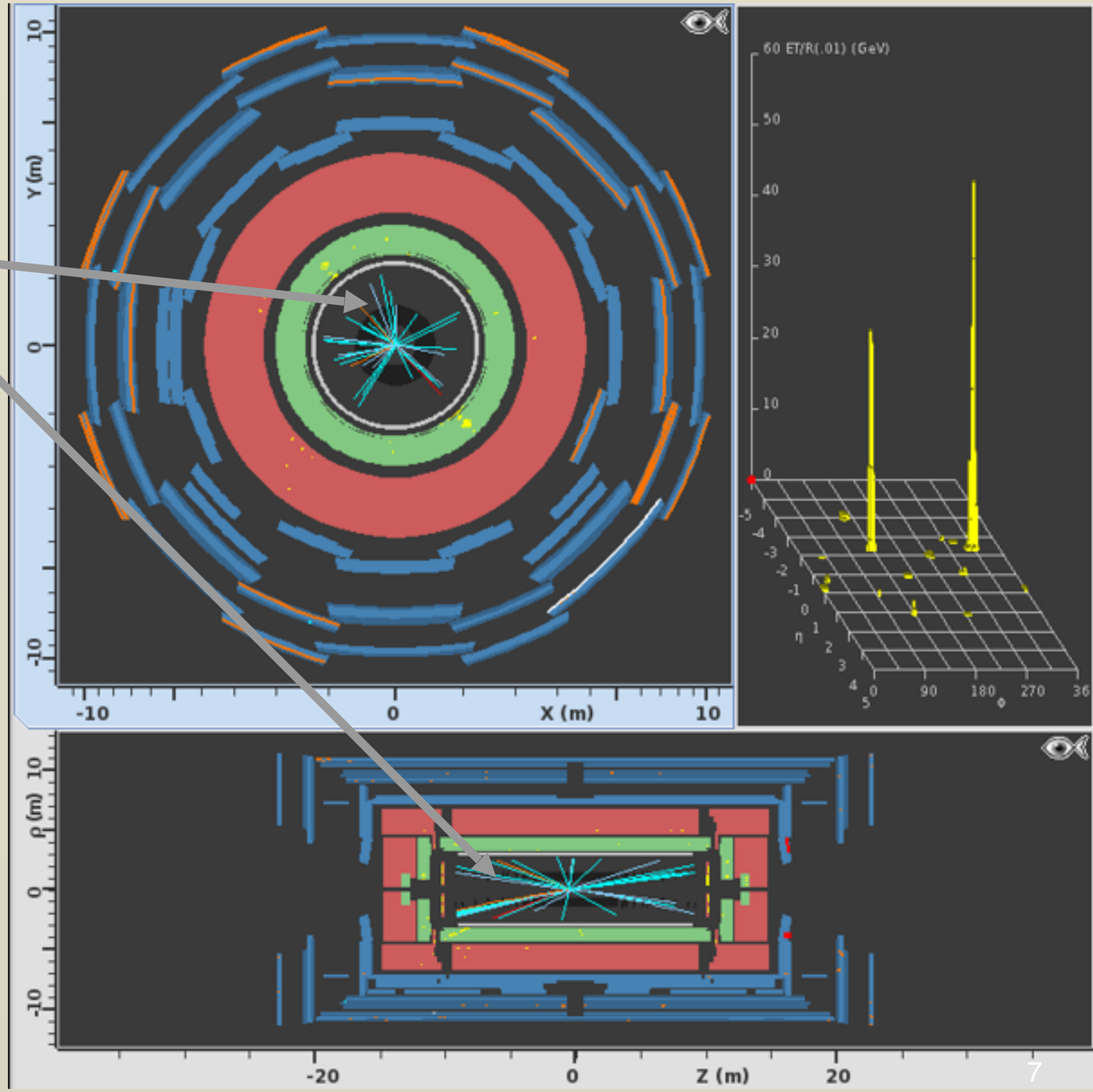
HYPATIA (Hybrid Pupil's Analysis Tool for Interactions in Atlas)



Ipàzia
(Ὑπατία, Alessandria d'Egitto, 355/370 - 415)

Event display

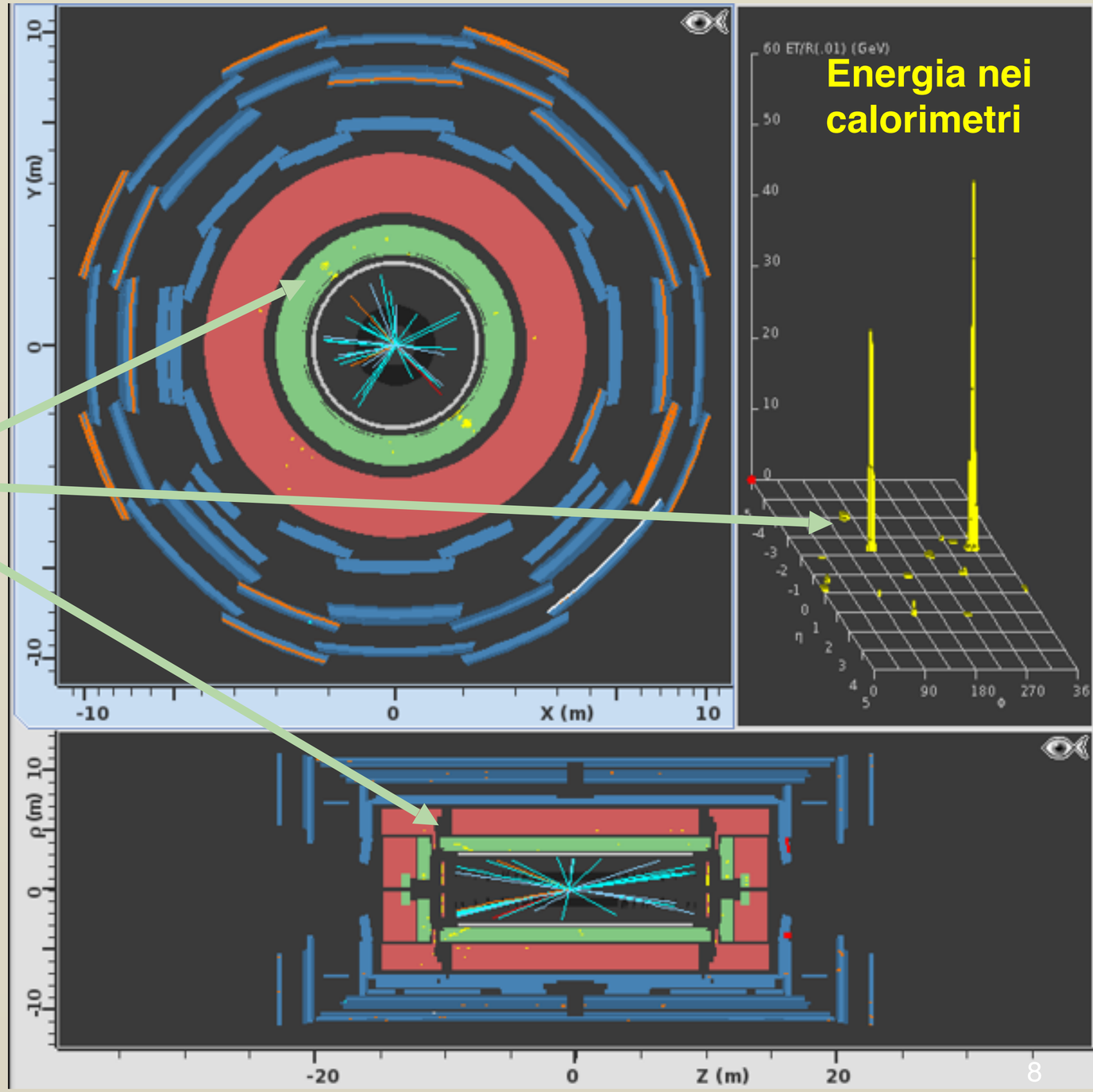
Tracciatore:
particelle cariche



Event display

Tracciatore:
particelle cariche

Calorimetro elettromagnetico:
elettroni (e-), positroni (e+) e fotoni.

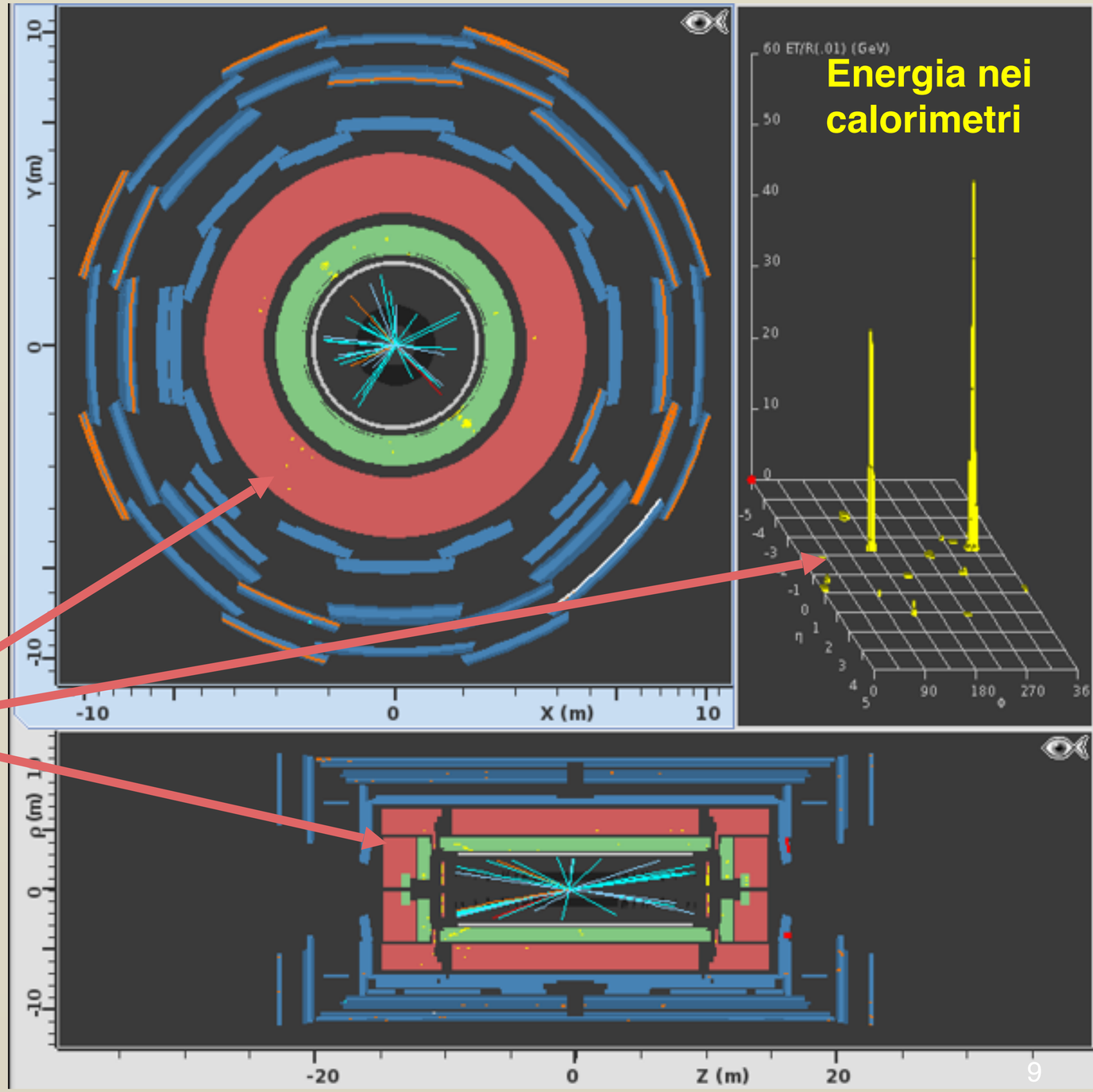


Event display

Tracciatore:
particelle cariche

Calorimetro elettromagnetico: elettroni (e-), positroni (e+) e fotoni.

Calorimetro adronico: adroni (es: protoni, neutroni)



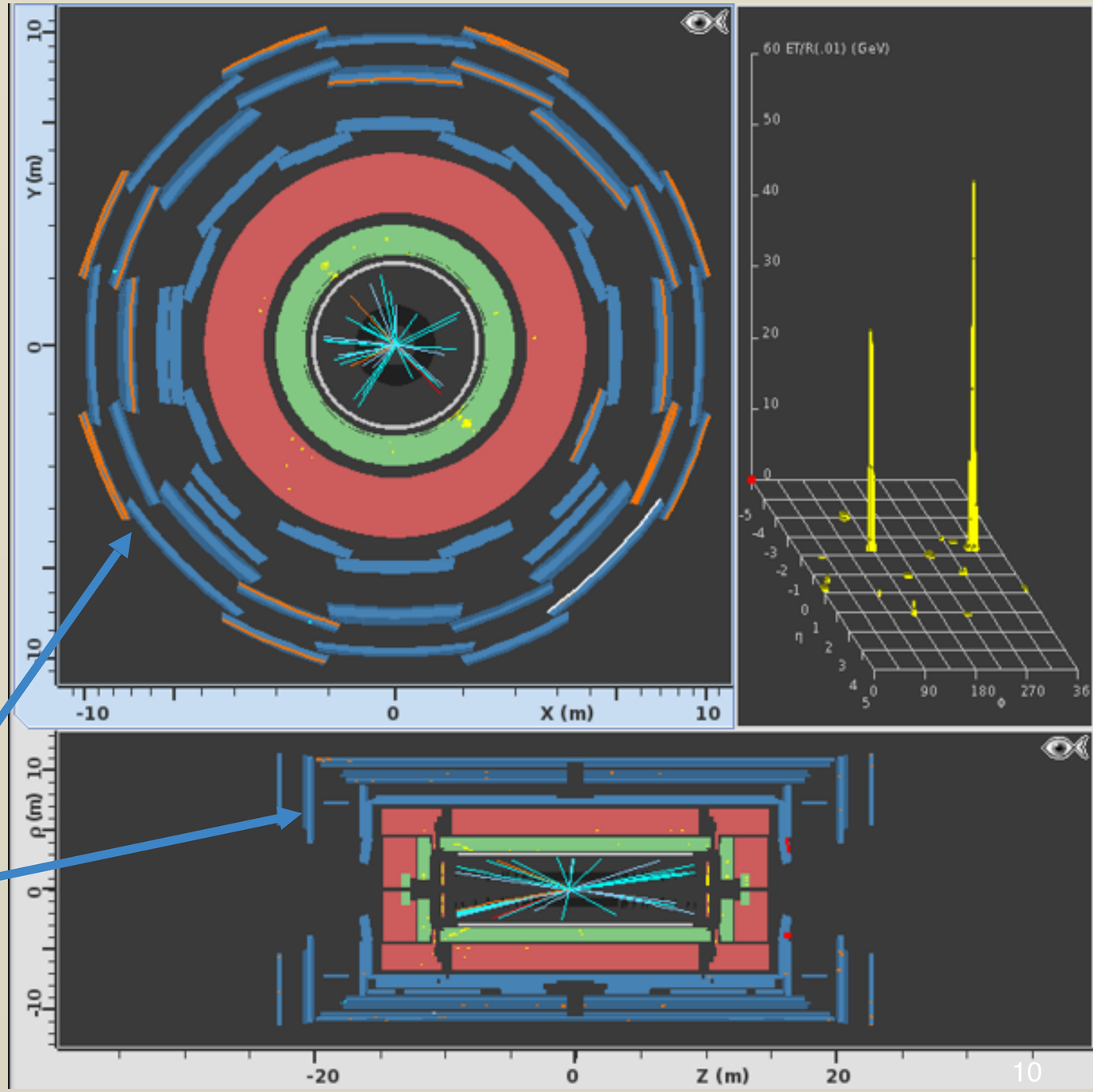
Event display

Tracciatore:
particelle cariche

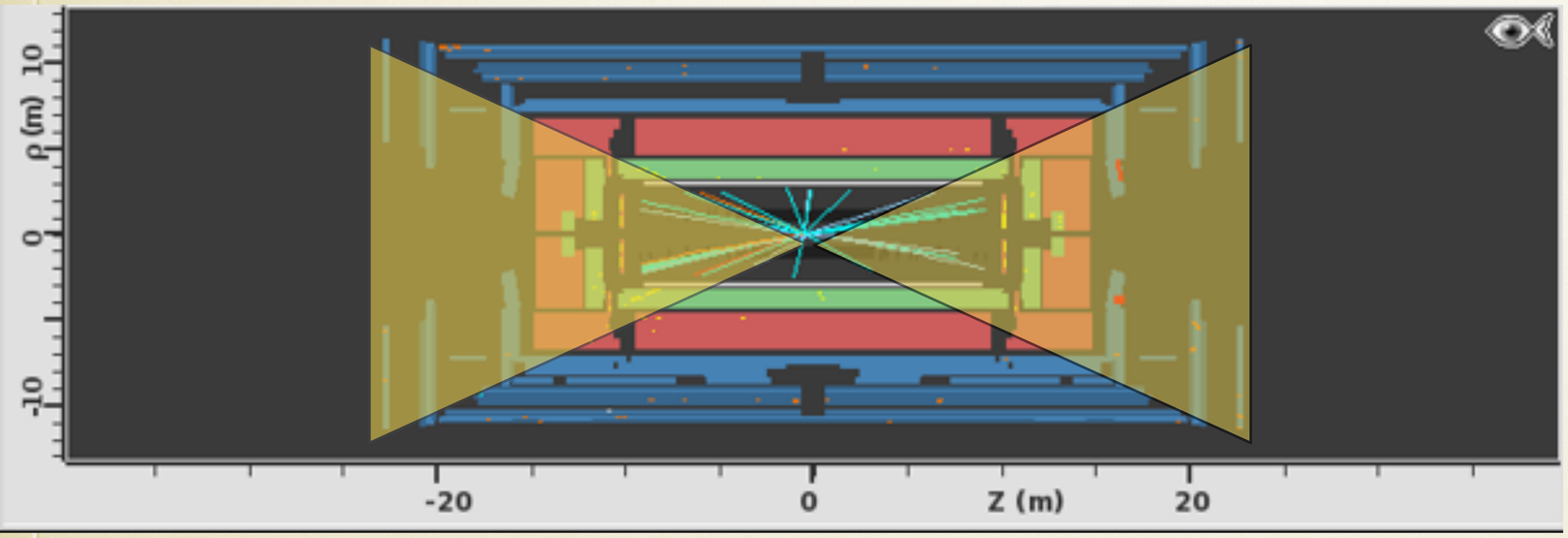
Calorimetro elettromagnetico: elettroni (e-), positroni (e+) e fotoni.

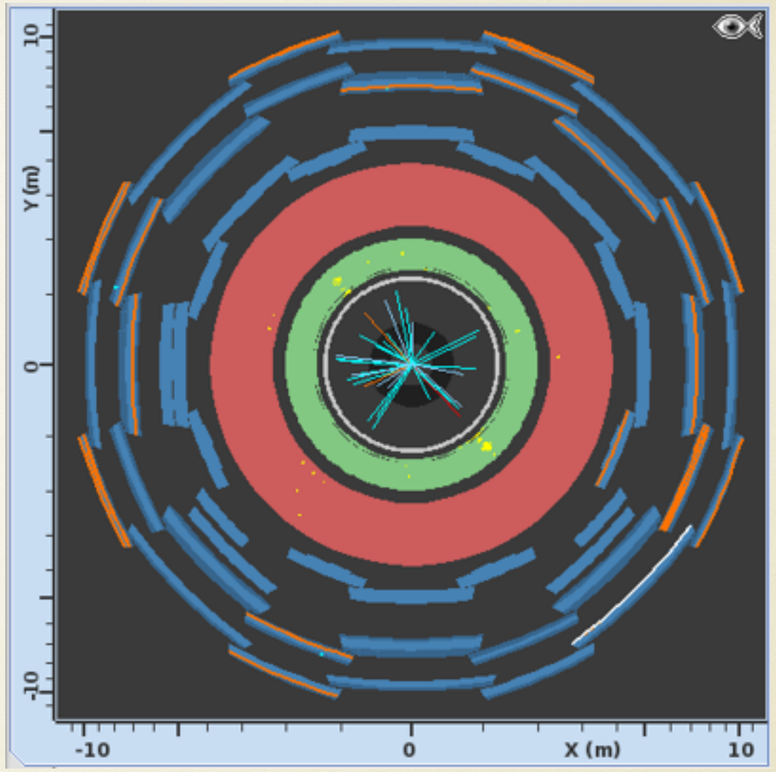
Calorimetro adronico: adroni (es: protoni, neutroni)

Rivelatori muoni

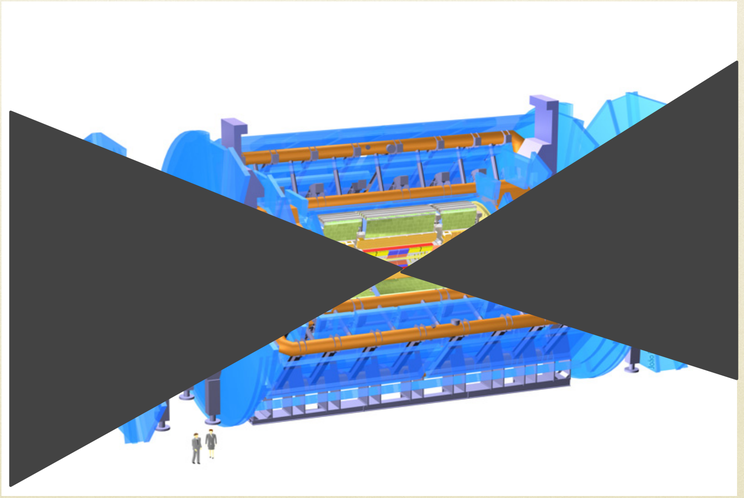


Event display

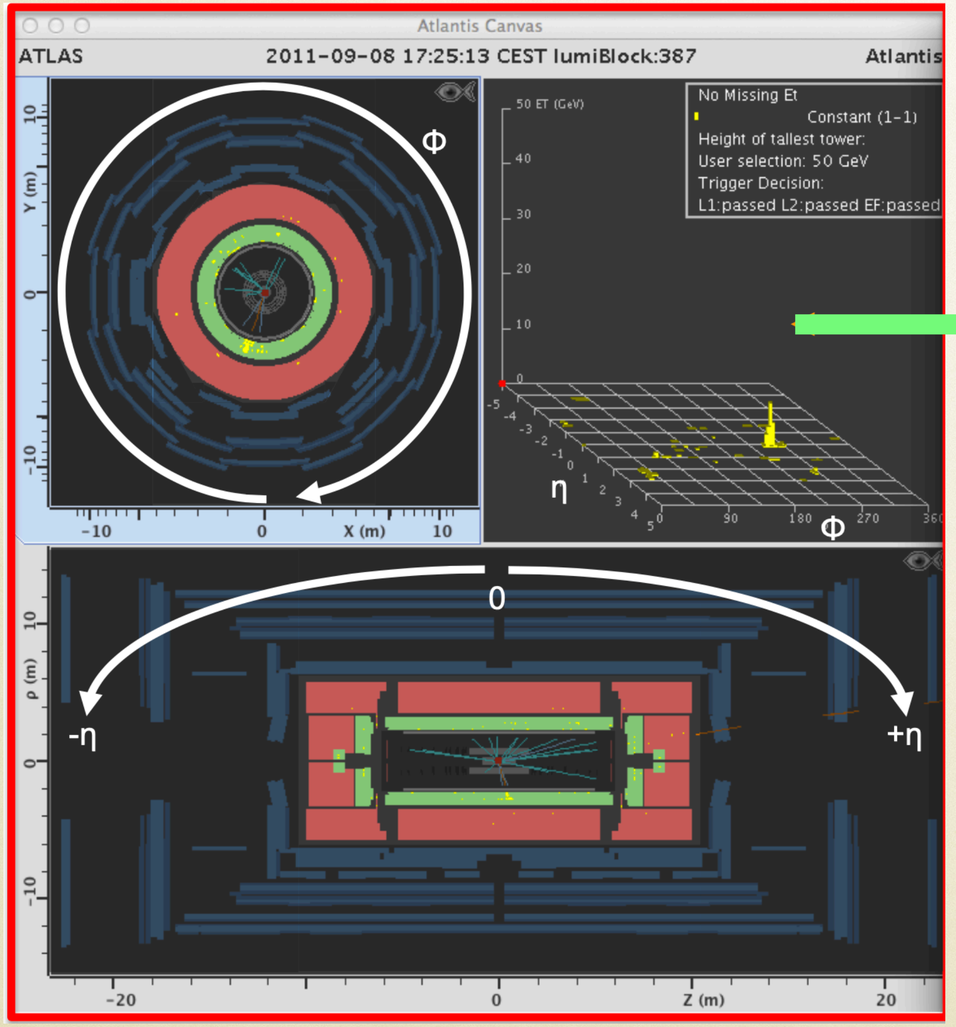




Solo le particelle ricostruite nella **regione centrale** sono visibili nella visione **trasversale**

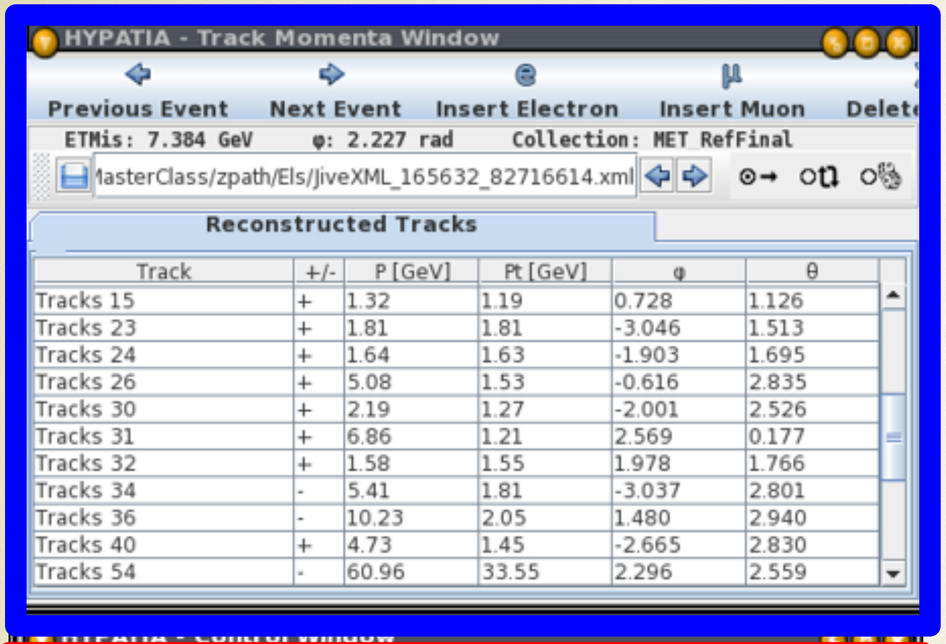


Event display



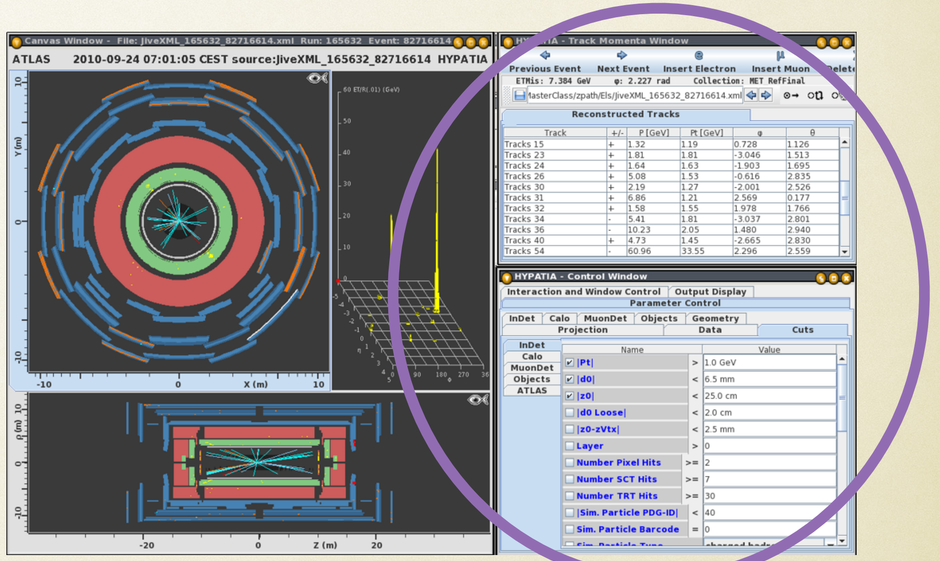
Lego plot : Mostra l'entita` dei depositi di energia visti da tutte le regioni dei calorimetri elettromagnetico ed adronico in **eta (η) e phi (Φ)**

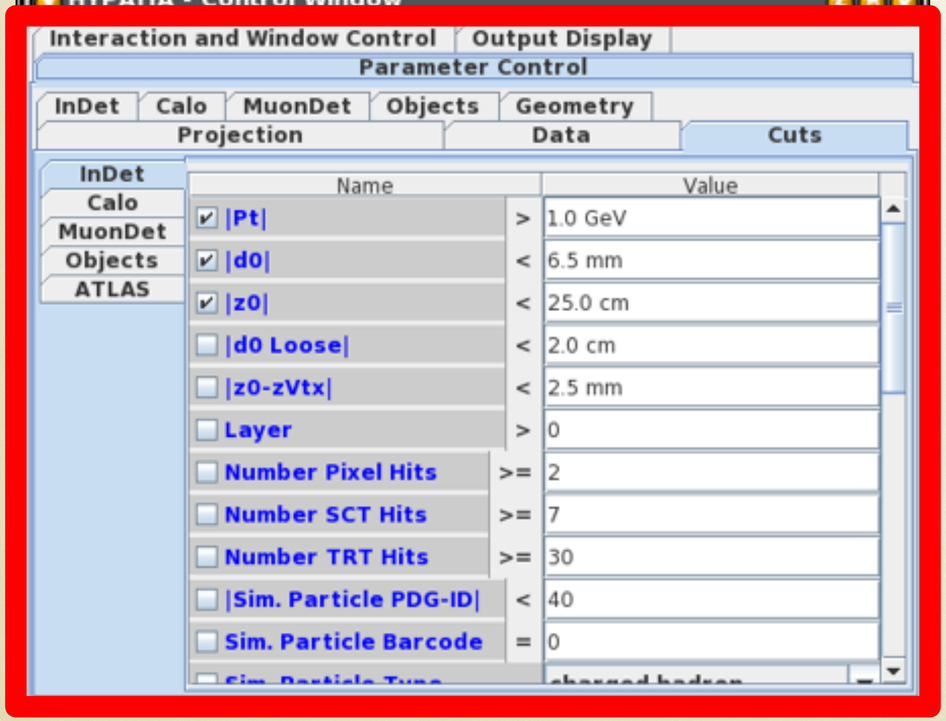
Selezione degli eventi



Track	+/-	P [GeV]	Pt [GeV]	φ	θ
Tracks 15	+	1.32	1.19	0.728	1.126
Tracks 23	+	1.81	1.81	-3.046	1.513
Tracks 24	+	1.64	1.63	-1.903	1.695
Tracks 26	+	5.08	1.53	-0.616	2.835
Tracks 30	+	2.19	1.27	-2.001	2.526
Tracks 31	+	6.86	1.21	2.569	0.177
Tracks 32	+	1.58	1.55	1.978	1.766
Tracks 34	-	5.41	1.81	-3.037	2.801
Tracks 36	-	10.23	2.05	1.480	2.940
Tracks 40	+	4.73	1.45	-2.665	2.830
Tracks 54	-	60.96	33.55	2.296	2.559

Particelle selezionate



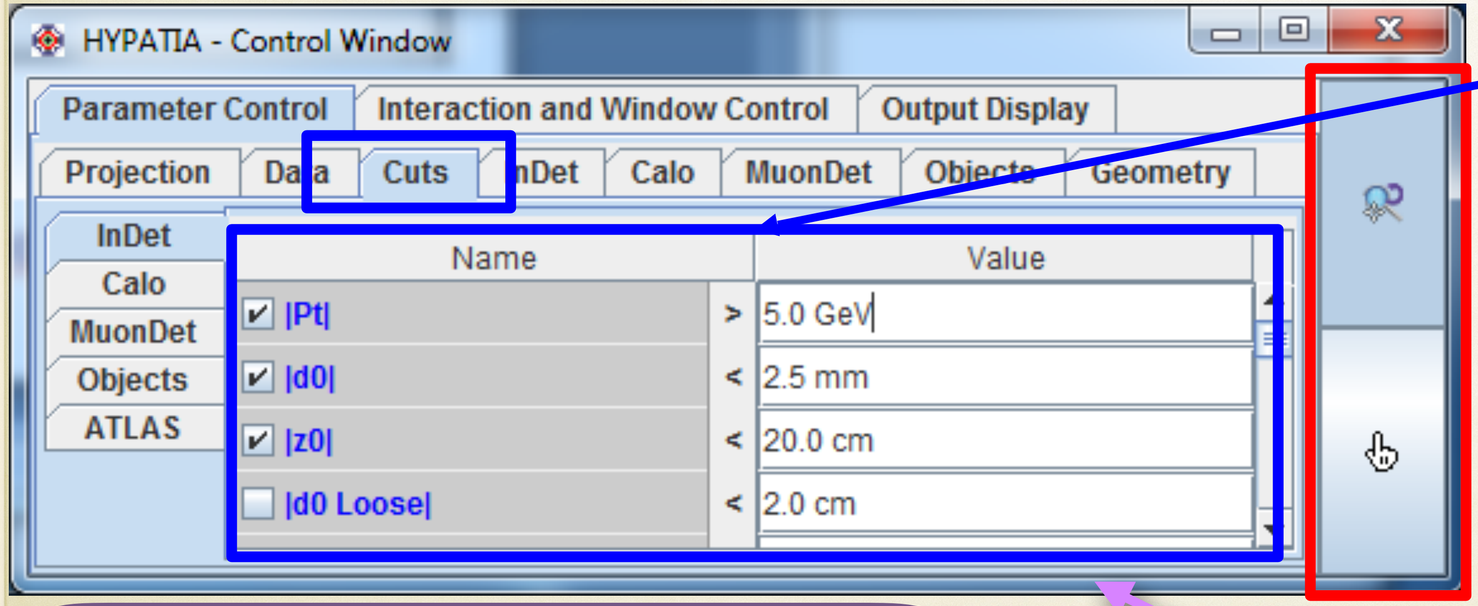


Name		Value
✔ |Pt|	>	1.0 GeV
✔ |d0|	<	6.5 mm
✔ |z0|	<	25.0 cm
|d0 Loose|	<	2.0 cm
|z0-zVtx|	<	2.5 mm
Layer	>	0
Number Pixel Hits	>=	2
Number SCT Hits	>=	7
Number TRT Hits	>=	30
|Sim. Particle PDG-ID|	<	40
Sim. Particle Barcode	=	0

Tagli sull'impulso

impulso P = massa x velocità [vettore]
impulso trasverso Pt = proiezione nel piano xy dell'impulso p

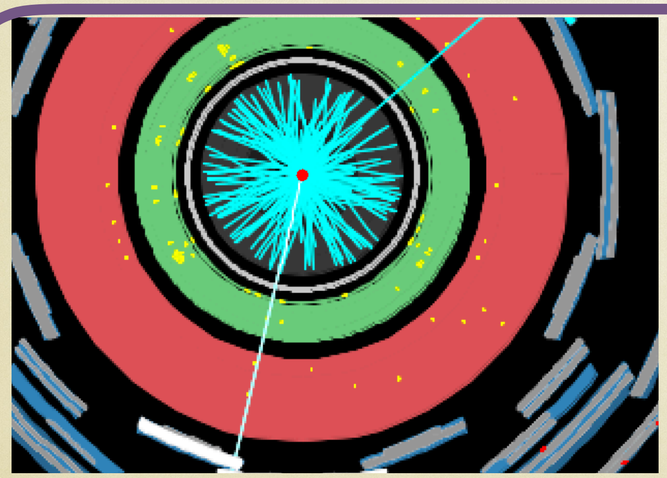
Selezione degli eventi



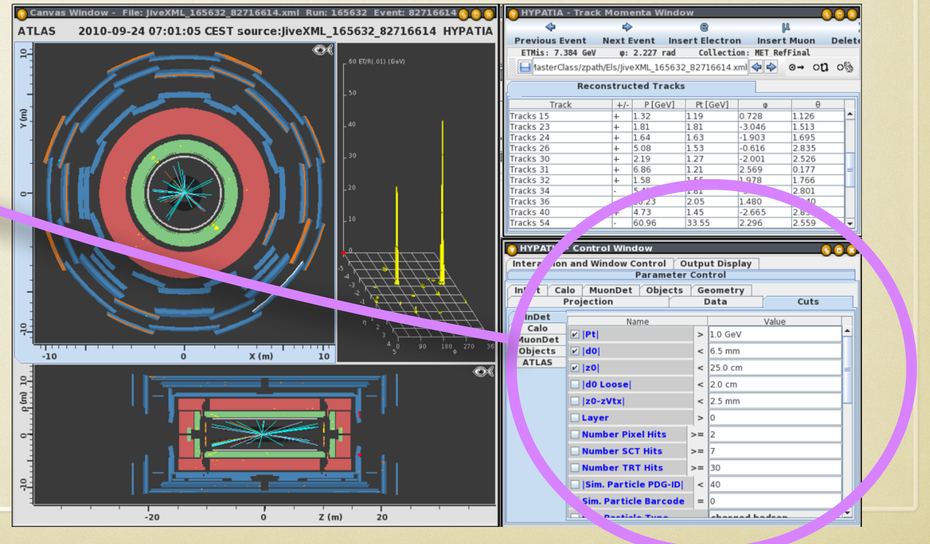
Tagli:criteri di selezione degli eventi

Zoom/Move/Rotate

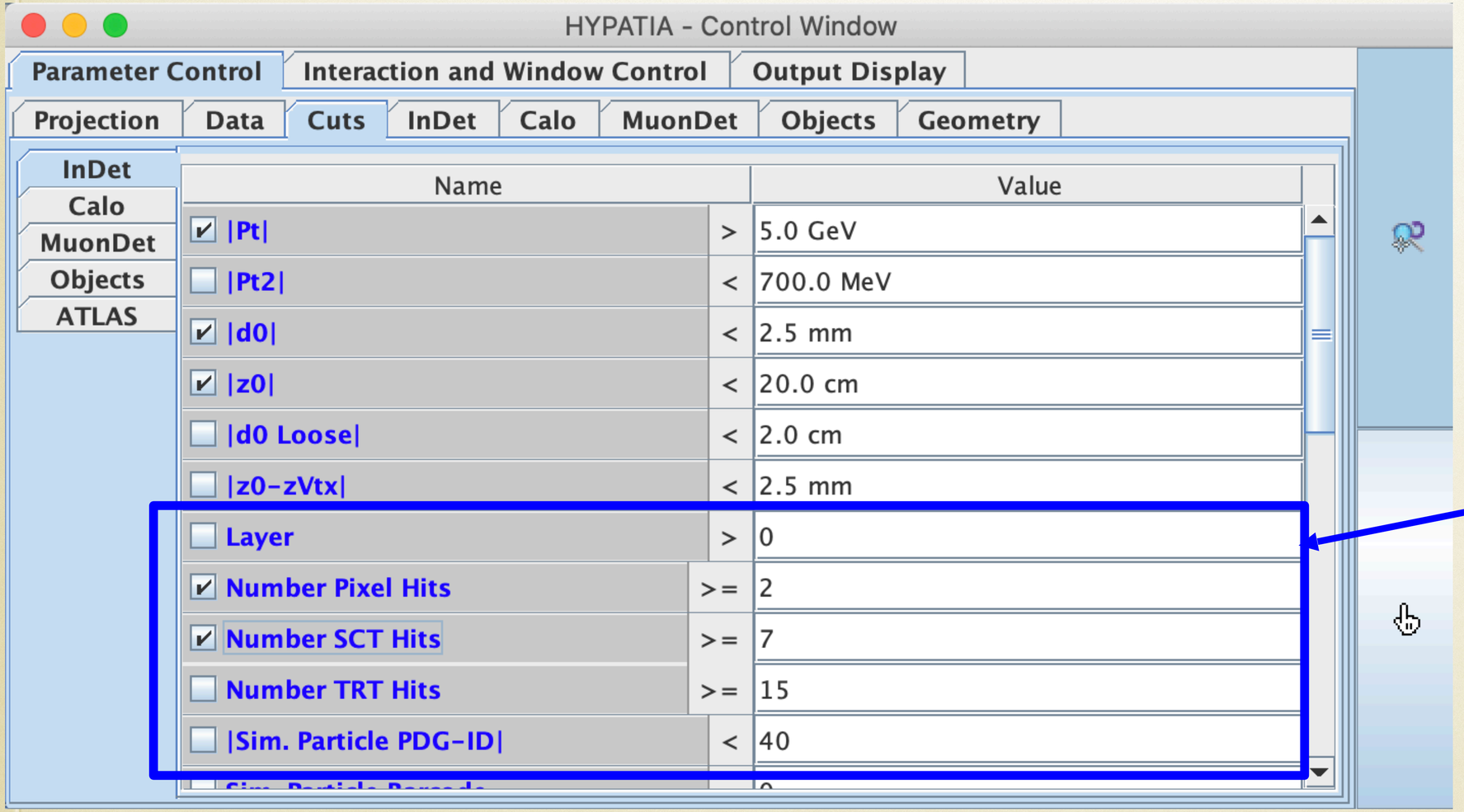
Mostra informazioni per l'oggetto selezionato



Evento senza tagli in Pt !!!



Selezione degli eventi

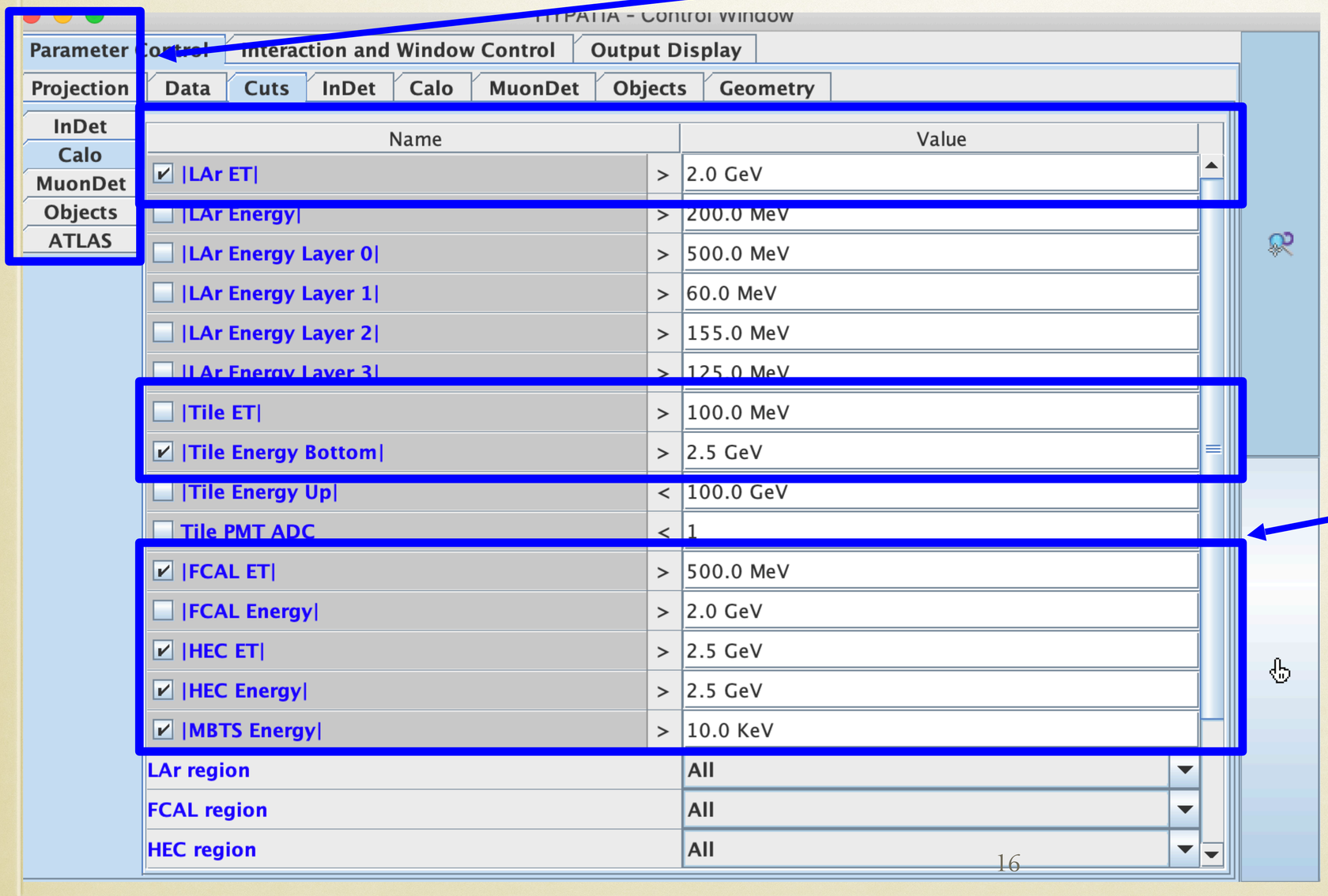


Click sul:
Number of Pixel Hits
Number of SCT Hits

In questo modo eliminiamo le tracce non perfettamente ricostruite

Selezione degli eventi

Click CALO (diventa celeste come nella figura)



Mettere

LAr ET 2000

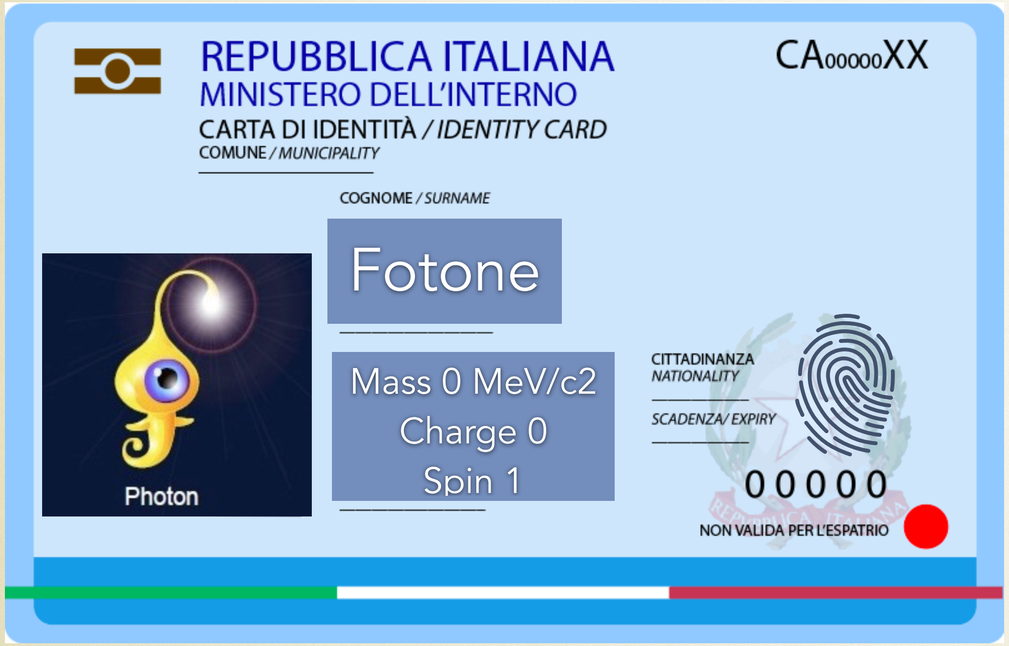
Tile Energy Bottom 2500

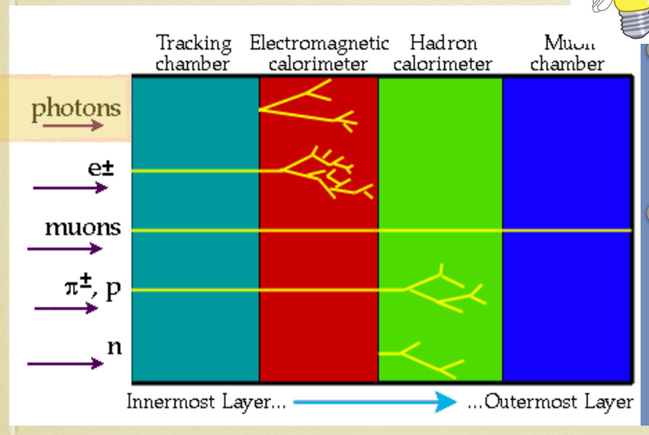
HEC ET 2500

HEC Energy 2500

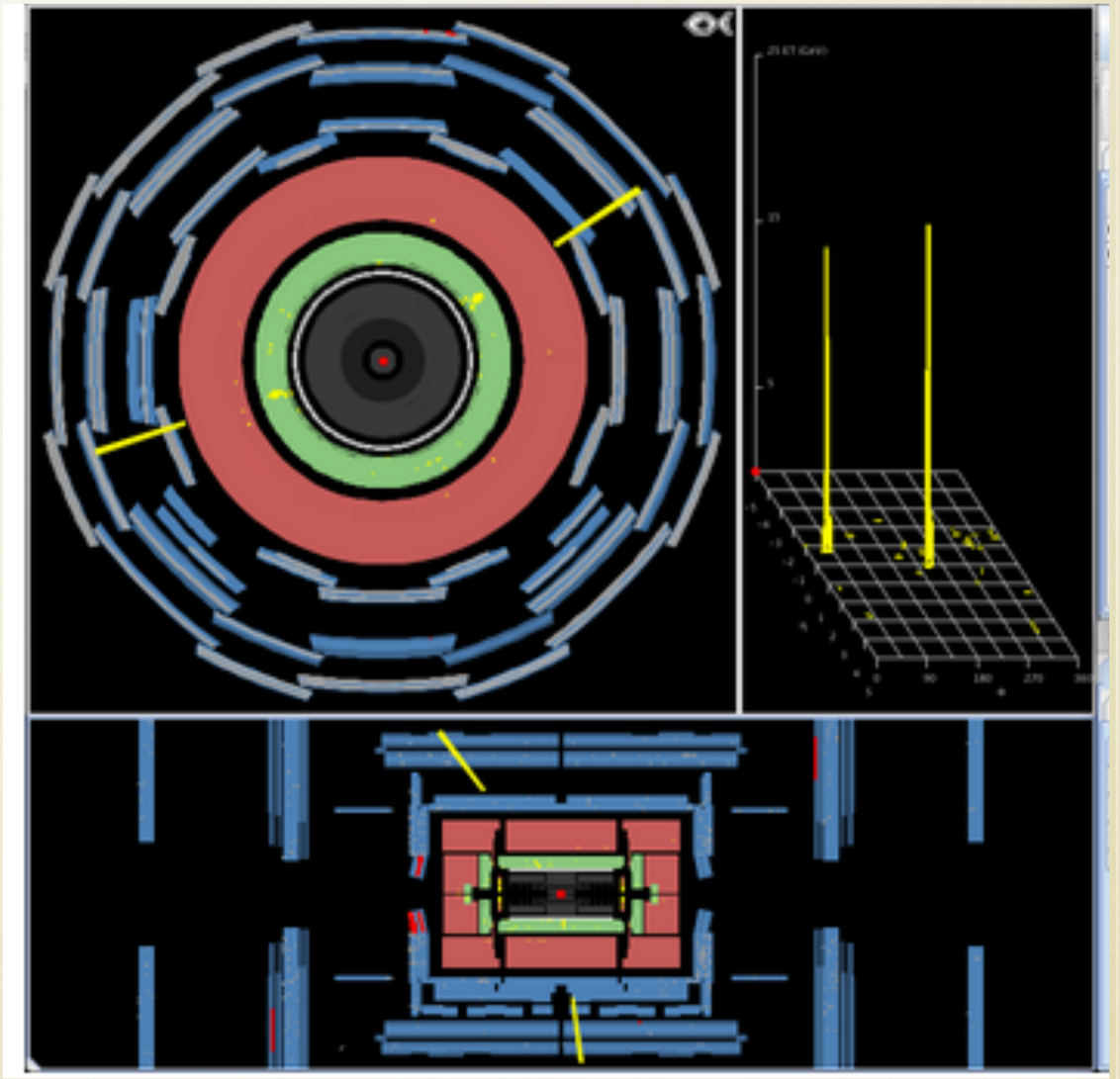
In questo modo eliminiamo depositi di energia non perfettamente ricostruiti

Carta di Identita' del FOTONE

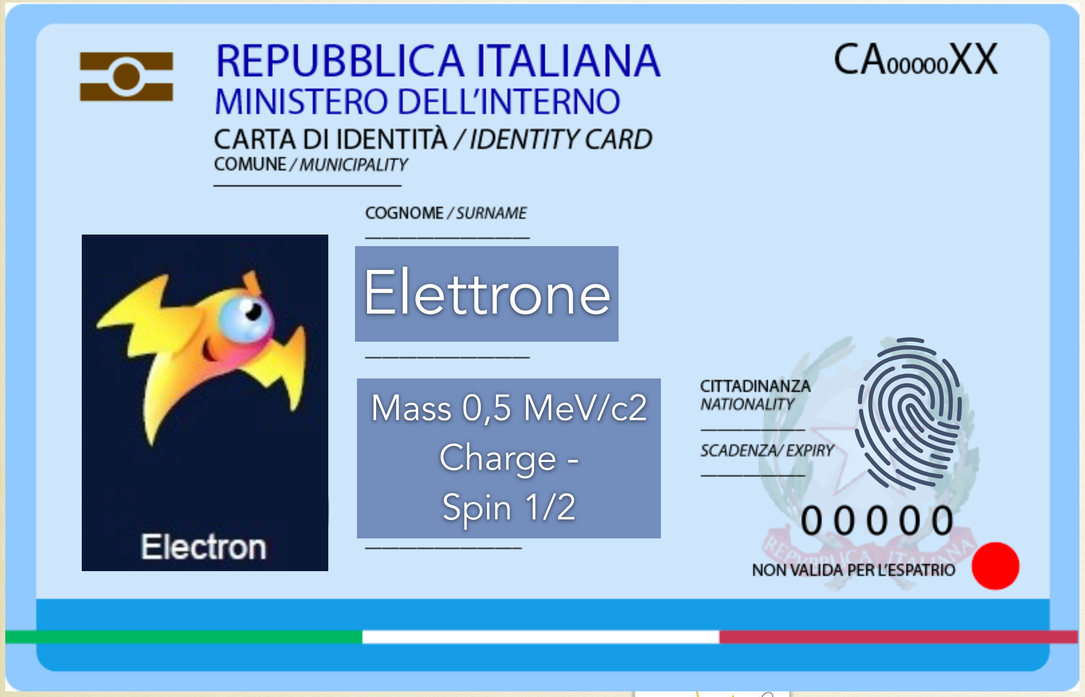


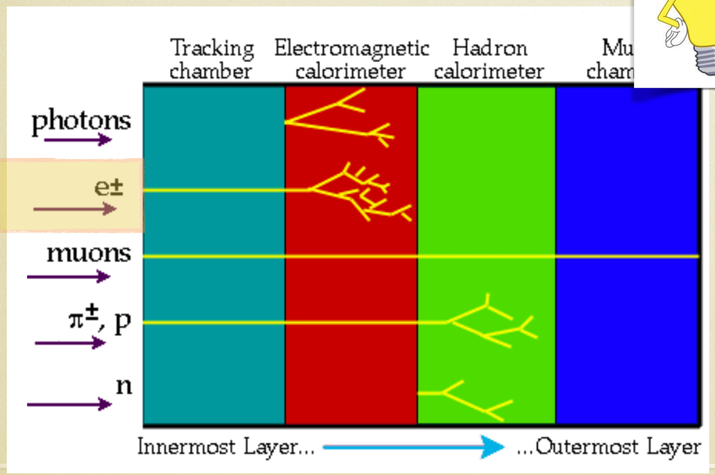


- Non lascia traccia nel rivelatore interno
- Deposita tutta la sua energia nel Calorimetro Elettromagnetico

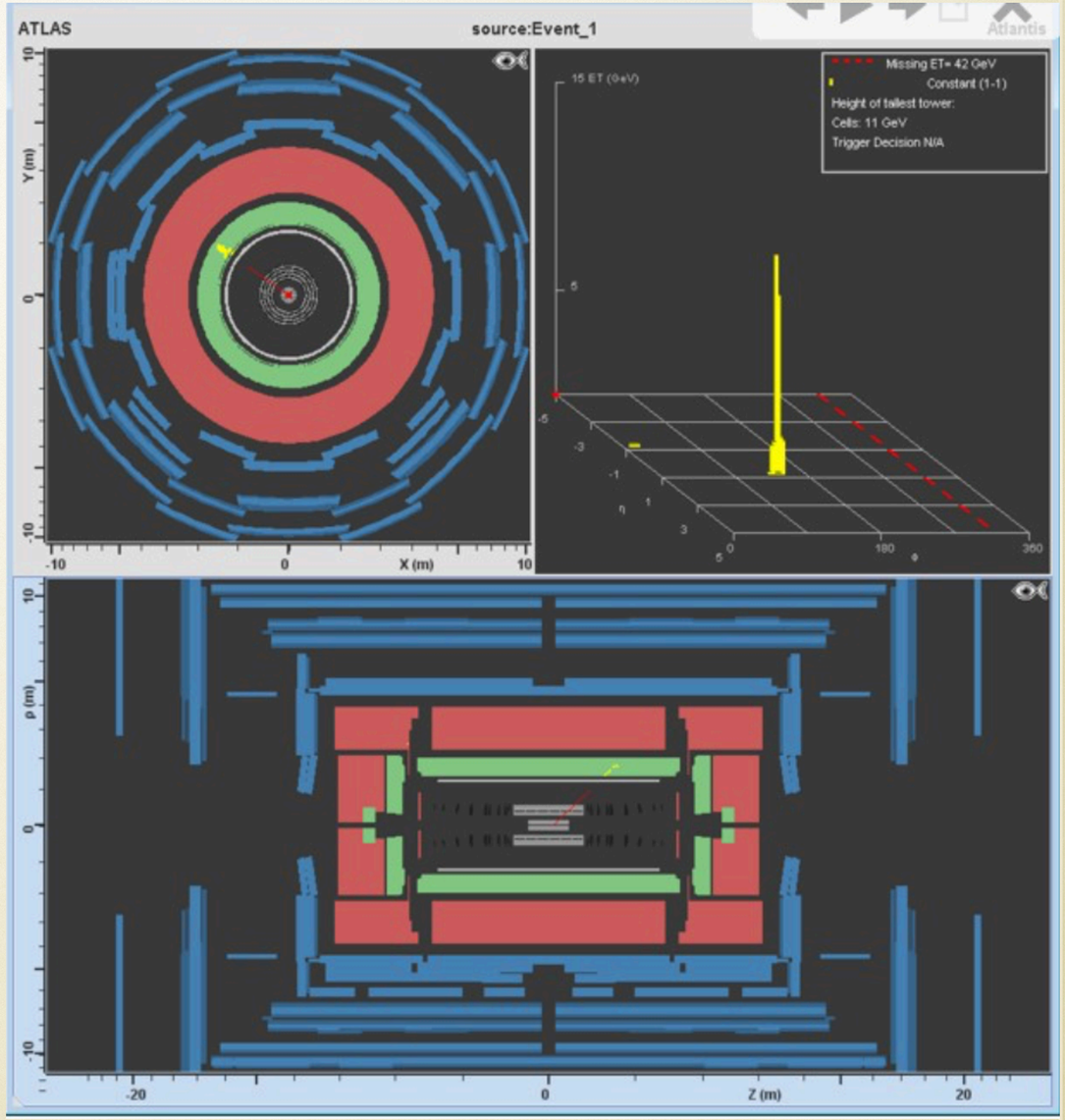


Carta di Identita' dell' ELETTRONE

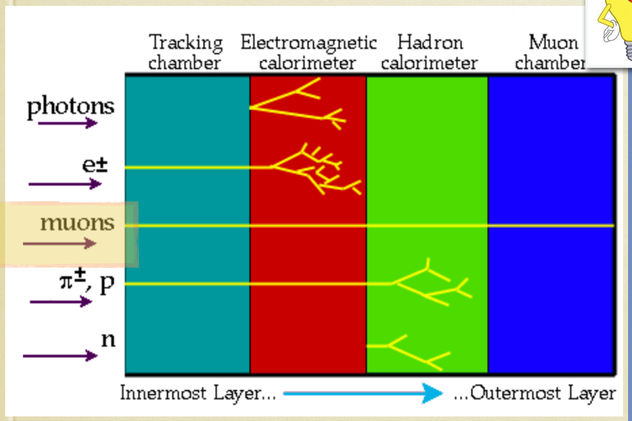




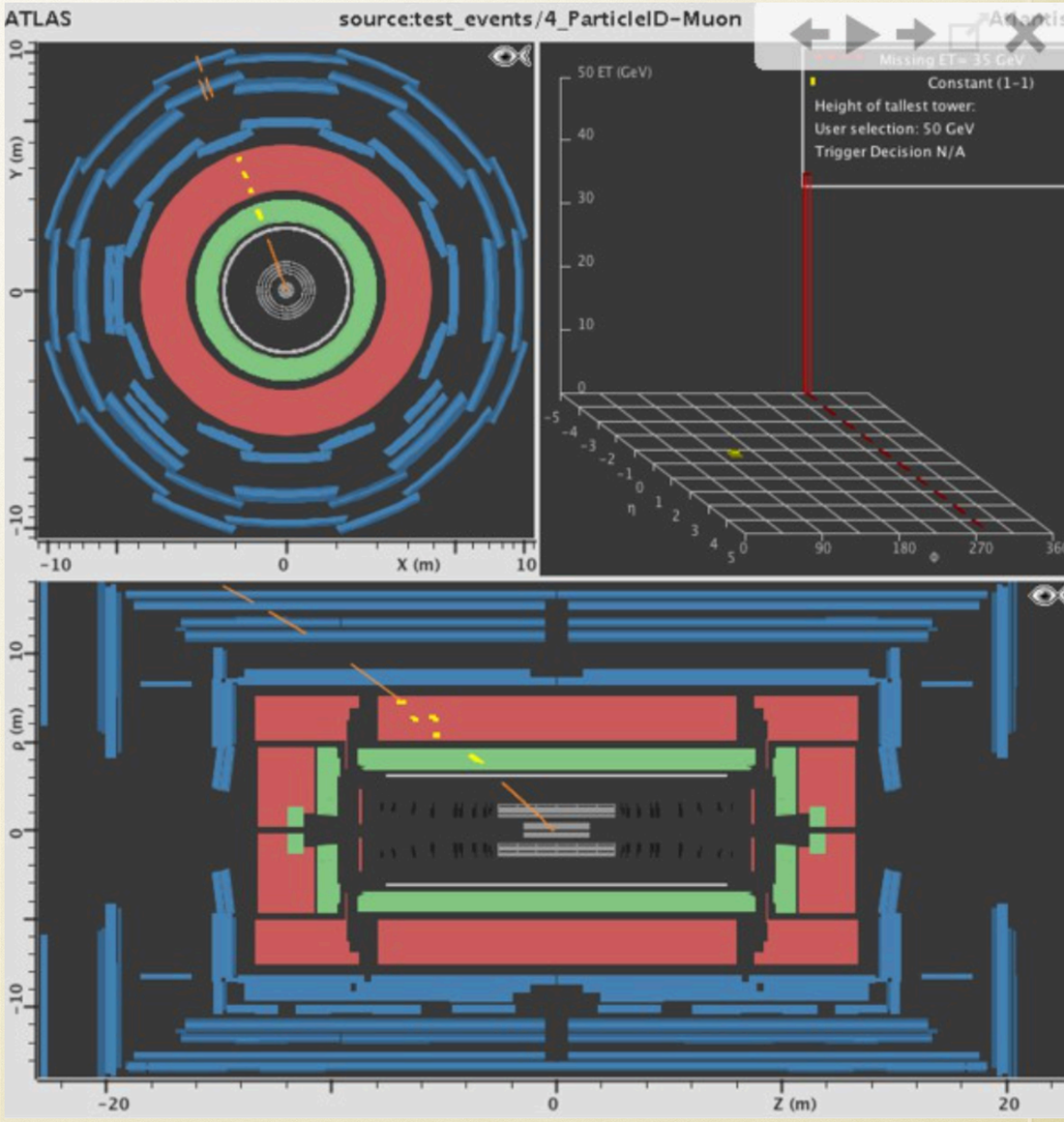
- Lascia una traccia nel rivelatore interno
- Deposita tutta la sua energia nel Calorimetro Elettromagnetico



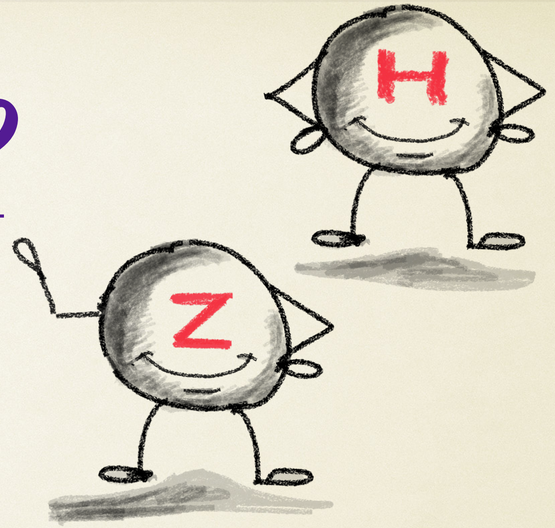
Carta di Identita' del MUONE



- Lascia traccia nel rivelatore interno
- Deposita pochissima energia nei Calorimetri
- Raggiunge Il rivelatore più' esterno dove lascia un'altra traccia

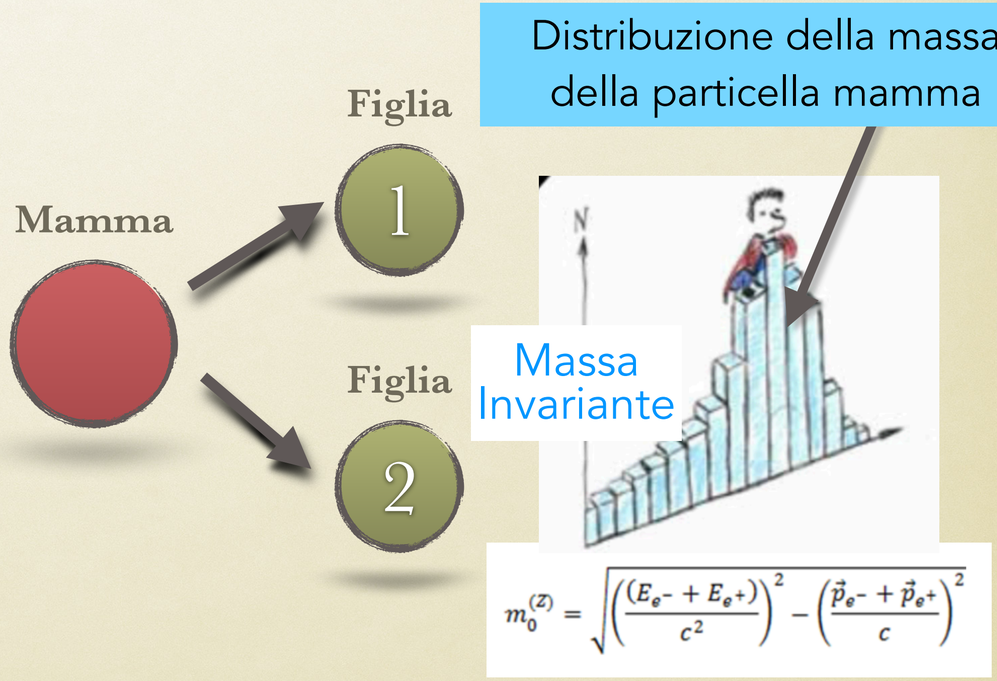


… ma il Bosone Z e il Bosone H ?!?



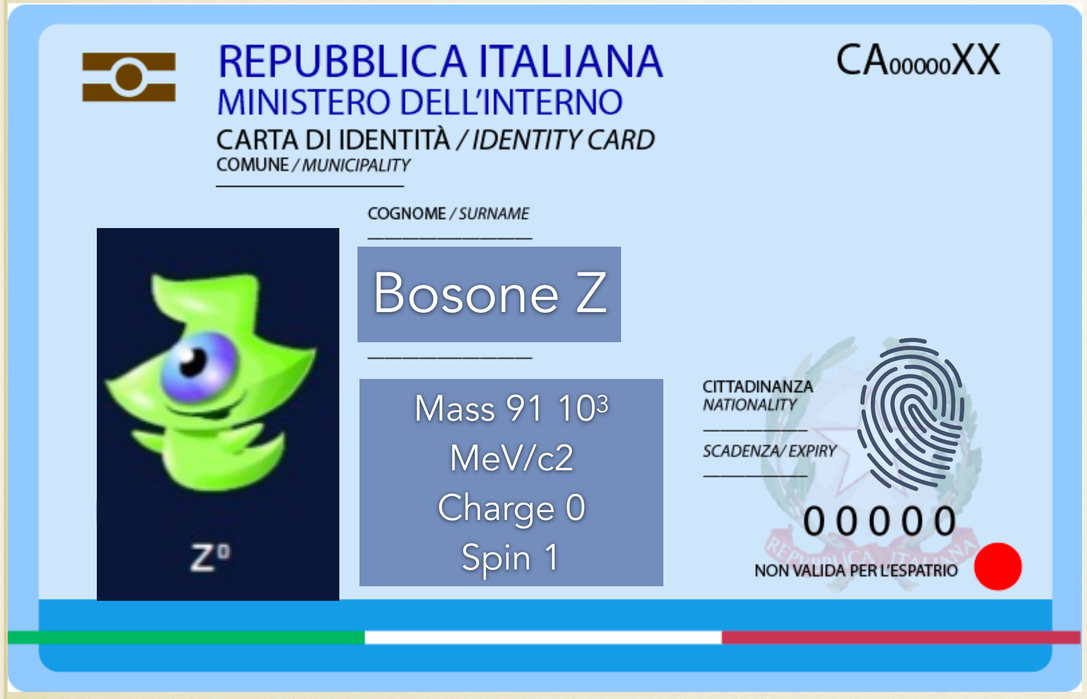
Come identifico il Bosone Z e il Bosone Higgs?

- Queste particelle decadono (ovvero creano altre particelle disintegrandosi) in altre particelle, rispettando tutte le leggi di conservazione (carica elettrica, energia, momento angolare…).
- Quando questo decadimento e' molto probabile avviene su tempi brevissimi percui non riusciamo a "vedere direttamente" mai il Bosone Z o il Bosone Higgs.
- **I rivelatori registrano solo i prodotti finali (le particelle prodotte dal decadimento - figlie del decadimento)**
  - "Sommando" tutte le masse delle particelle finali e le loro energie si trova la massa (massa invariante) della particella iniziale (particella mamma)



Il Bosone Z

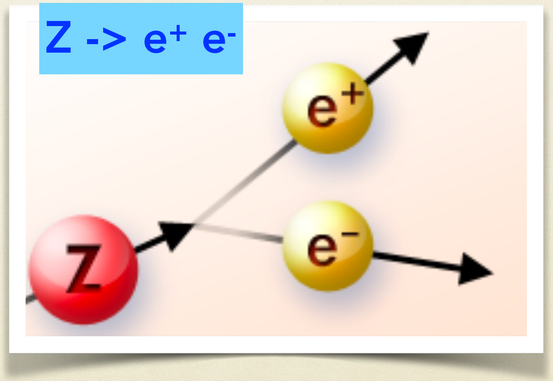
NB: Z e' neutro!
Le due particelle figlie devono avere carica opposta

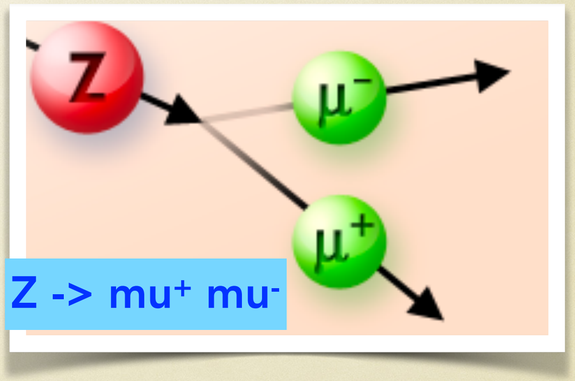


Il Bosone Z e' molto pesante e decade in coppie di fermione-antifermione:

Nel nostro esercizio ci aspettiamo di "vedere":

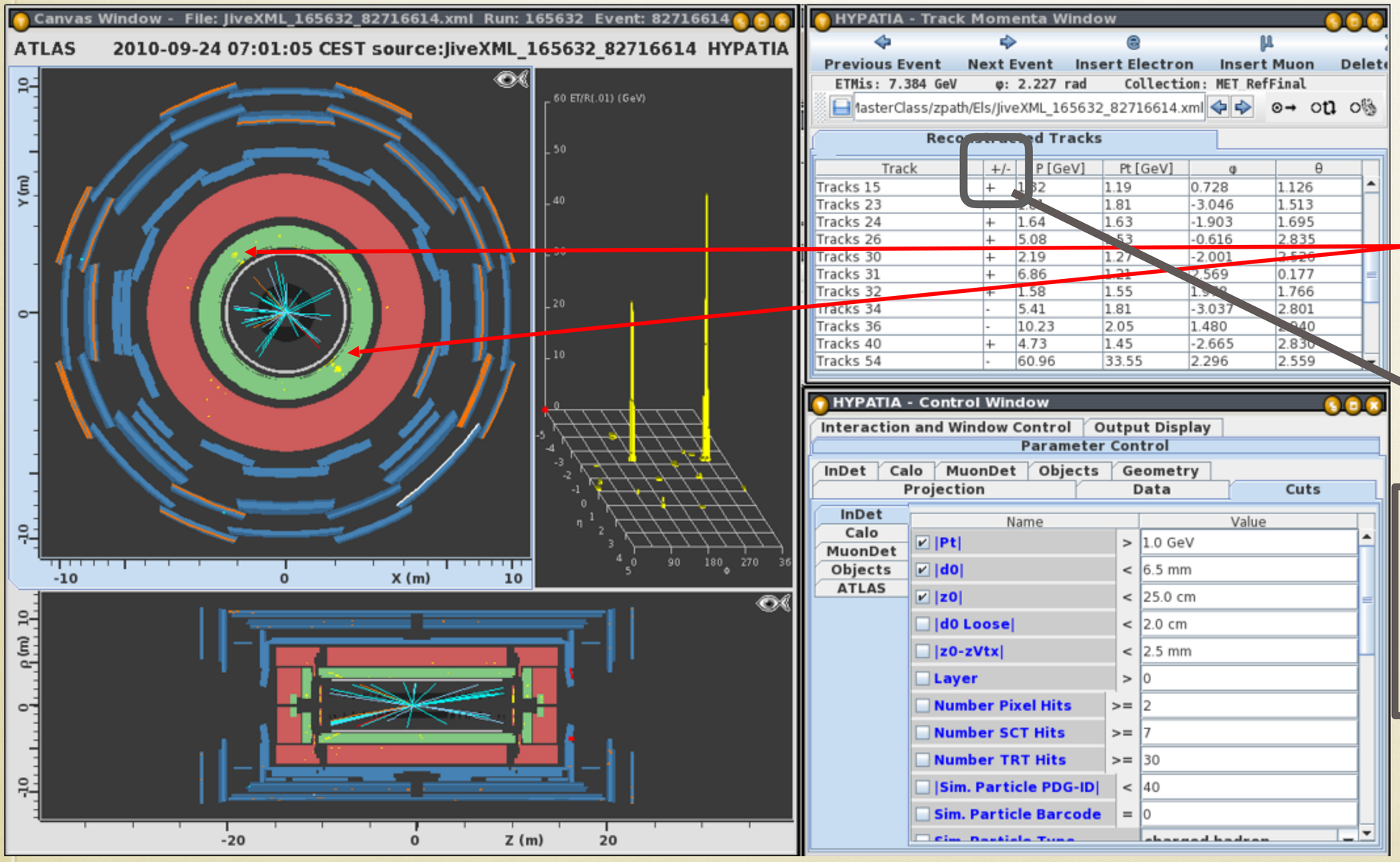
- **e^+ e^- (positrone ed elettrone)**
- **mu^+ mu^- (muone positivo e muone negativo)**





$Z \rightarrow e^- e^+$

Il bosone Z è **neutro**.



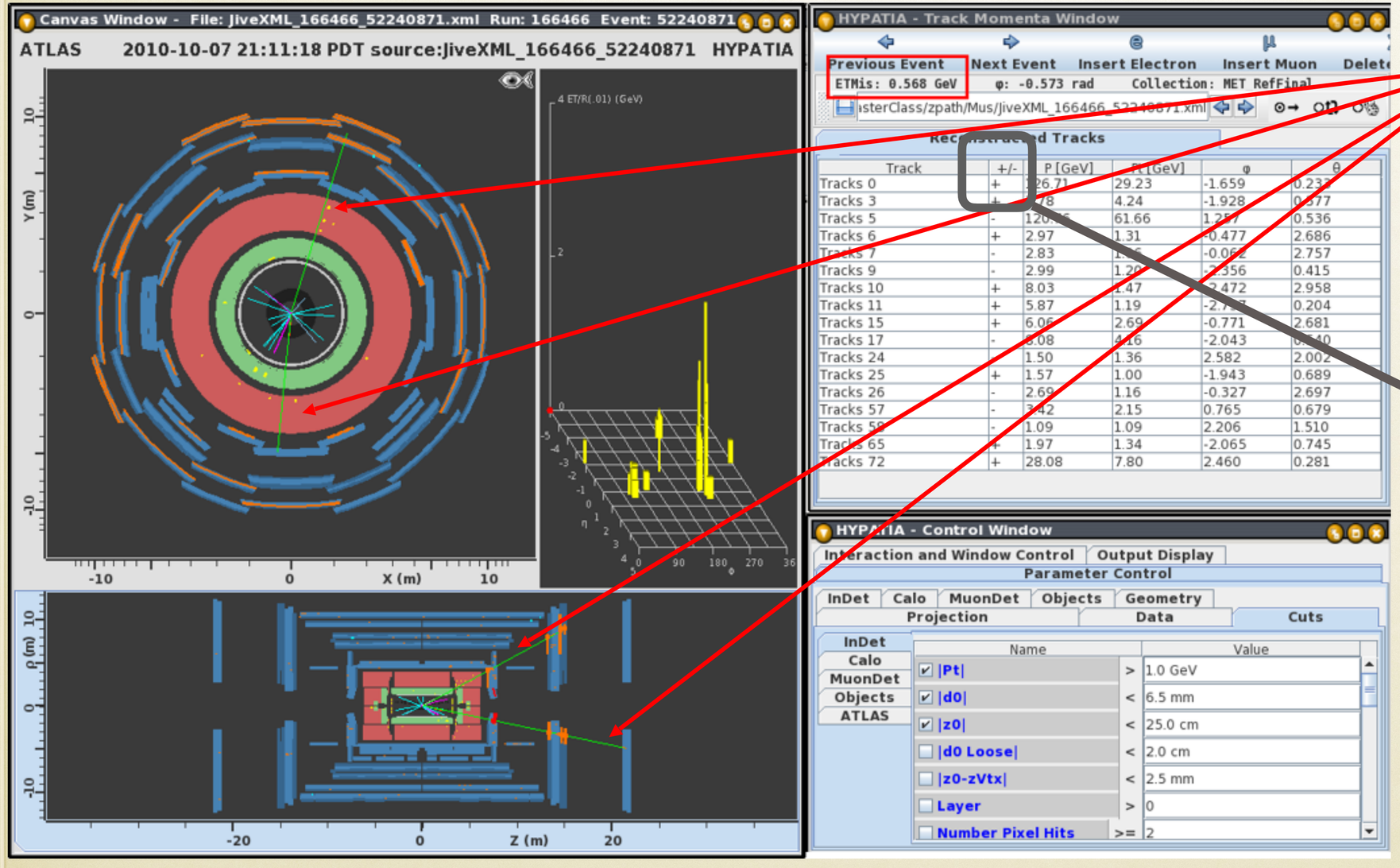
Track	+/-	P [GeV]	Pt [GeV]	φ	θ
Tracks 15	+	1.32	1.19	0.728	1.126
Tracks 23	-	1.84	1.81	-3.046	1.513
Tracks 24	+	1.64	1.63	-1.903	1.695
Tracks 26	+	5.08	4.53	-0.616	2.835
Tracks 30	+	2.19	1.27	-2.001	2.526
Tracks 31	+	6.86	1.21	2.569	0.177
Tracks 32	+	1.58	1.55	1.948	1.766
Tracks 34	-	5.41	1.81	-3.037	2.801
Tracks 36	-	10.23	2.05	1.480	2.840
Tracks 40	+	4.73	1.45	-2.665	2.830
Tracks 54	-	60.96	33.55	2.296	2.559

Name		Value
|Pt|	>	1.0 GeV
|d0|	<	6.5 mm
|z0|	<	25.0 cm
|d0 Loose|	<	2.0 cm
|z0-zVtx|	<	2.5 mm
Layer	>	0
Number Pixel Hits	>=	2
Number SCT Hits	>=	7
Number TRT Hits	>=	30
|Sim. Particle PDG-ID|	<	40
Sim. Particle Barcode	=	0

Elettrone e positrone

I segni delle due particelle devono essere opposti

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

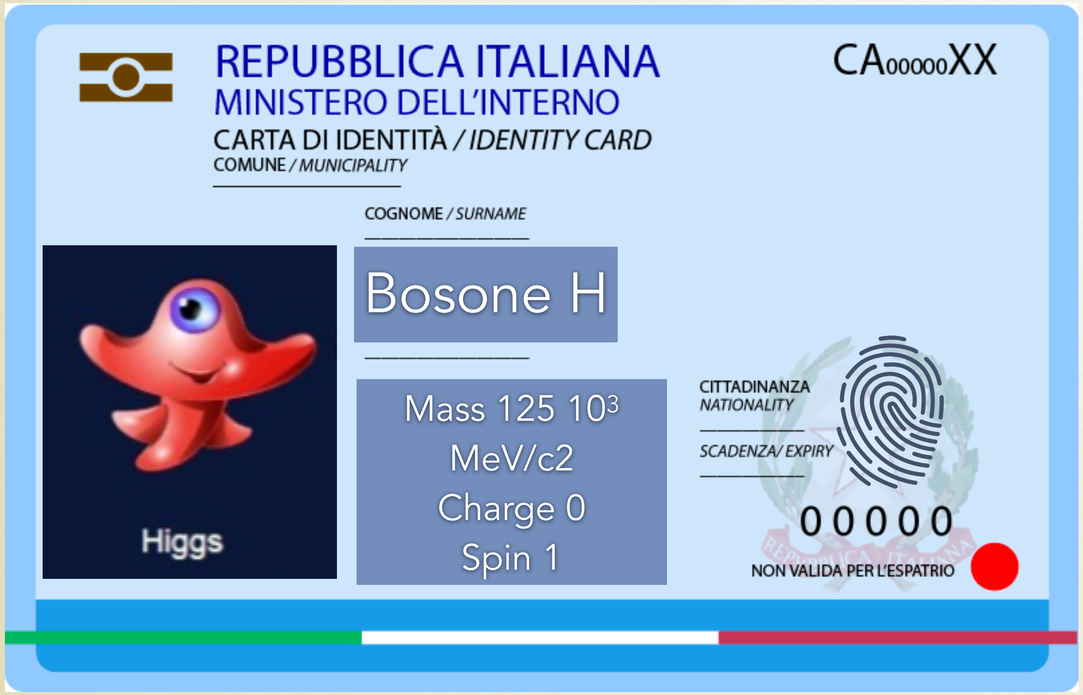


Muone e anti-muone

I segni delle due particelle devono essere opposti

Il Bosone H

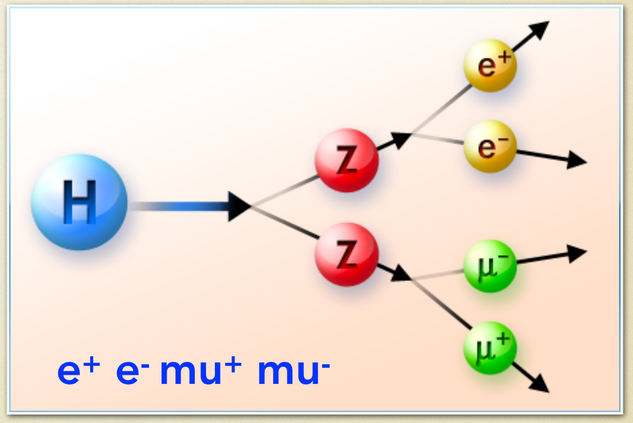
NB: H e' neutro!
Le quattro particelle figlie devono avere carica totale zero!!!



Il Bosone Higgs e' anche lui molto pesante e decade in coppie di fermione-antifermione e coppie di bosoni:

Nel nostro esercizio ci aspettiamo di "vedere":

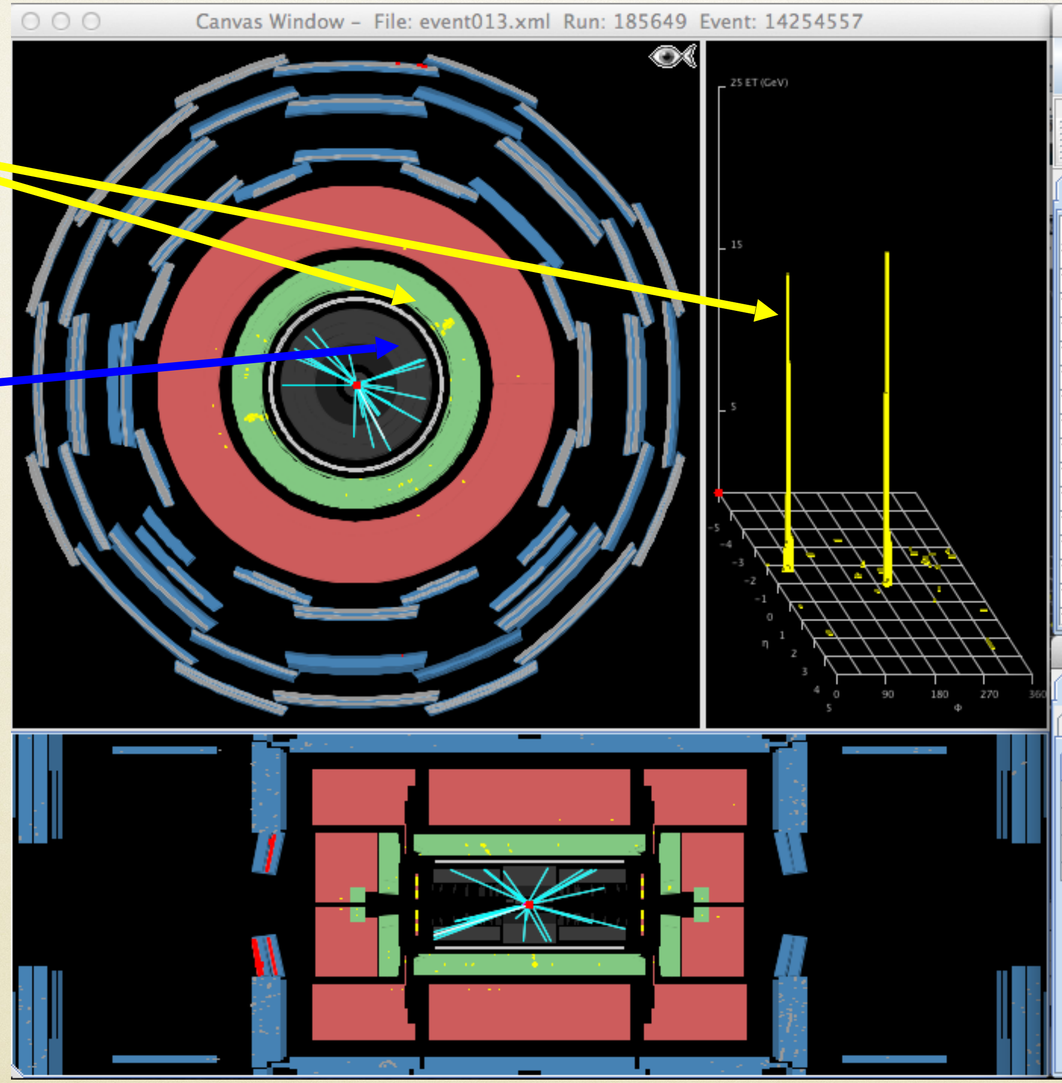
- **Z Z (coppie di Z)**
  - Ricordiamoci che la Z a sua volta decade percui questo decadimento dell'Higgs in coppie di Z può essere "visto" trovando:
    - $e^+ e^- e^+ e^-$
    - $e^+ e^- mu^+ mu^-$
    - $mu^+ mu^- mu^+ mu^-$
- $\gamma\gamma$ **(Coppie di fotoni)**

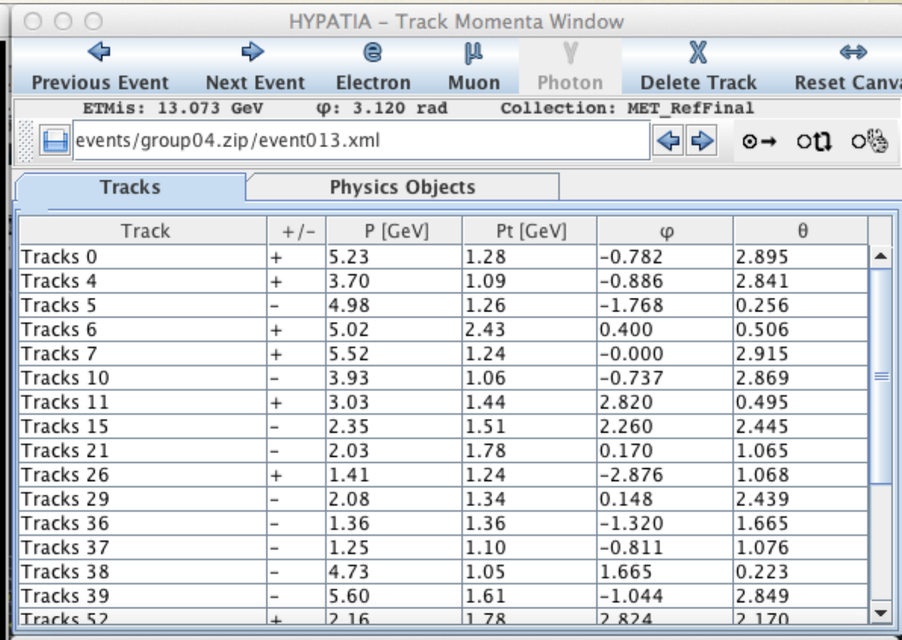


Higgs → fotone - fotone

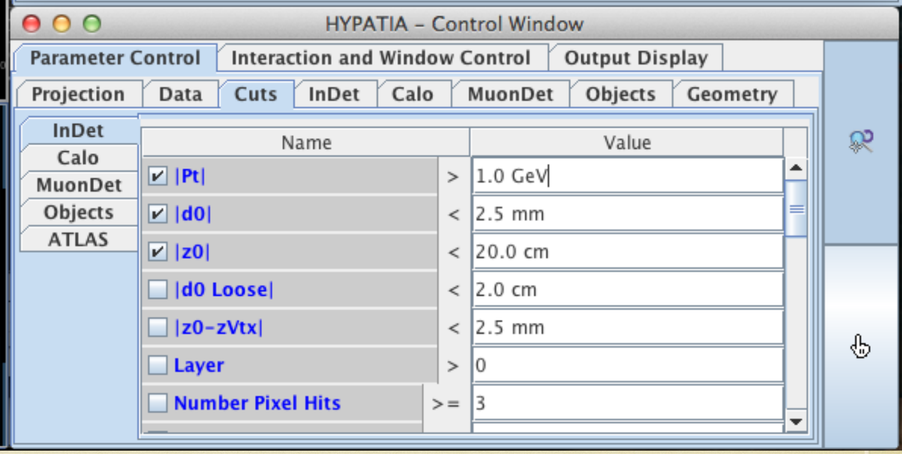
Energia nel **calorimetro elettromagnetico**

No tracce vicino ai depositi → non sono elettroni





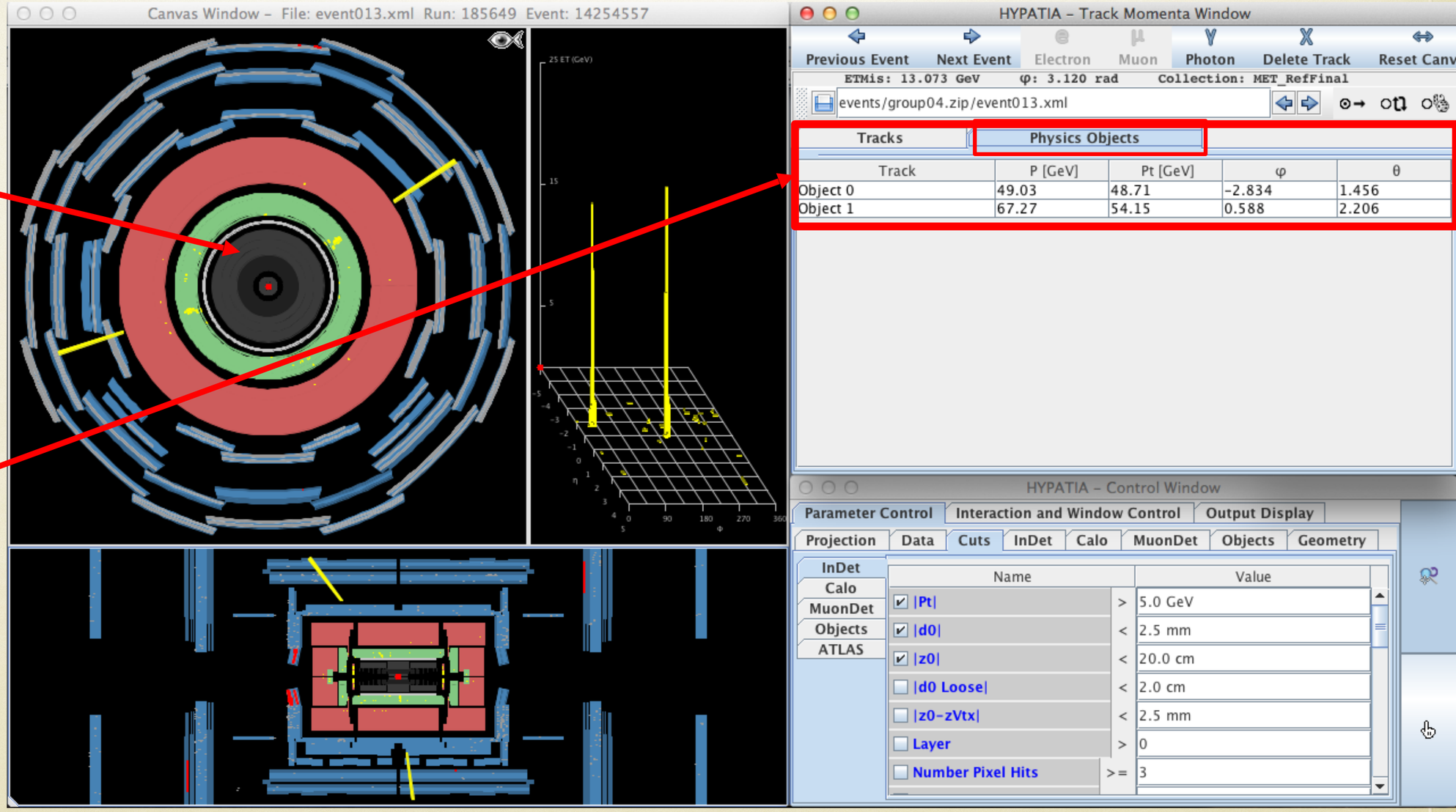
Track	+/-	P [GeV]	Pt [GeV]	φ	θ
Tracks 0	+	5.23	1.28	-0.782	2.895
Tracks 4	+	3.70	1.09	-0.886	2.841
Tracks 5	-	4.98	1.26	-1.768	0.256
Tracks 6	+	5.02	2.43	0.400	0.506
Tracks 7	+	5.52	1.24	-0.000	2.915
Tracks 10	-	3.93	1.06	-0.737	2.869
Tracks 11	+	3.03	1.44	2.820	0.495
Tracks 15	-	2.35	1.51	2.260	2.445
Tracks 21	-	2.03	1.78	0.170	1.065
Tracks 26	+	1.41	1.24	-2.876	1.068
Tracks 29	-	2.08	1.34	0.148	2.439
Tracks 36	-	1.36	1.36	-1.320	1.665
Tracks 37	-	1.25	1.10	-0.811	1.076
Tracks 38	-	4.73	1.05	1.665	0.223
Tracks 39	-	5.60	1.61	-1.044	2.849
Tracks 52	+	2.16	1.78	2.824	2.170



Higgs → fotone - fotone

Applicando un taglio p_T>5 GeV non vedo più le tracce nel **tracciatore**

I fotoni sono fra i "**Physics Objects**"



Higgs → 4 particelle cariche

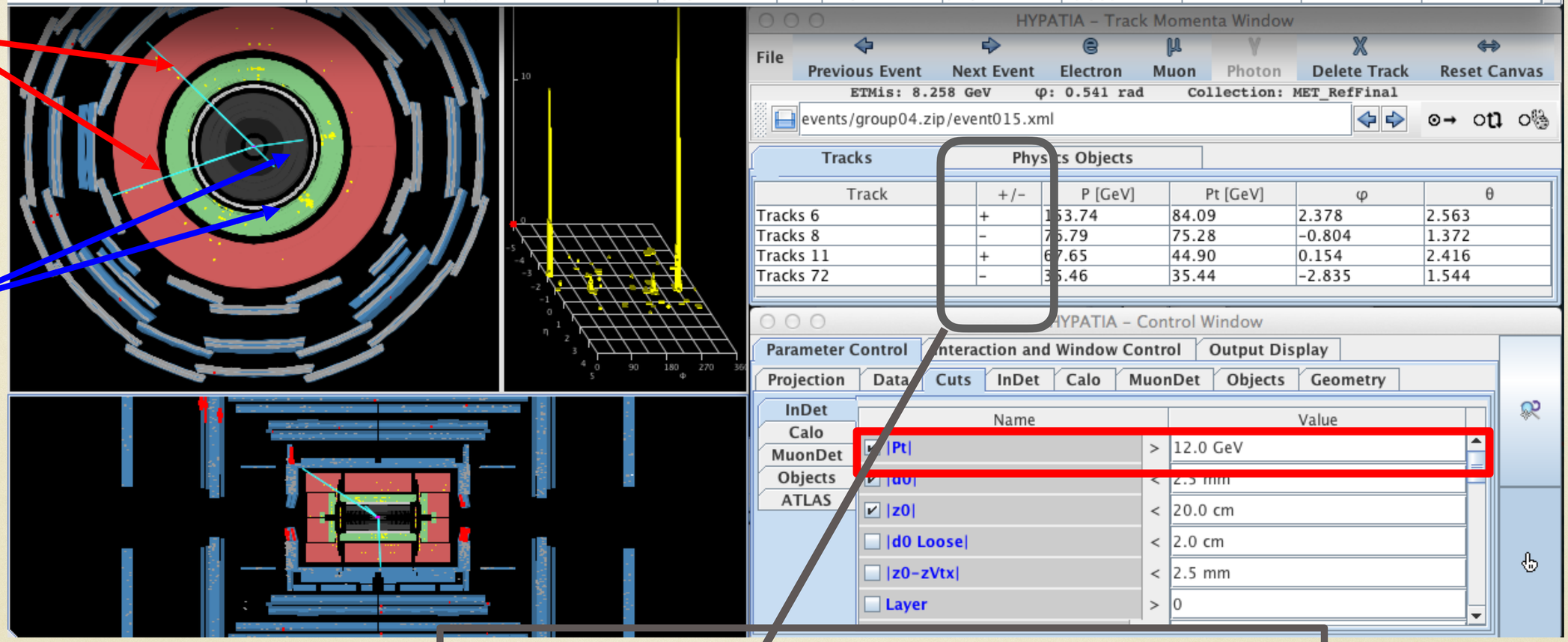
(es: $H \rightarrow e^+e^-\mu^+\mu^-$)

Il bosone H è **neutro**.

$\mu^+\mu^-$

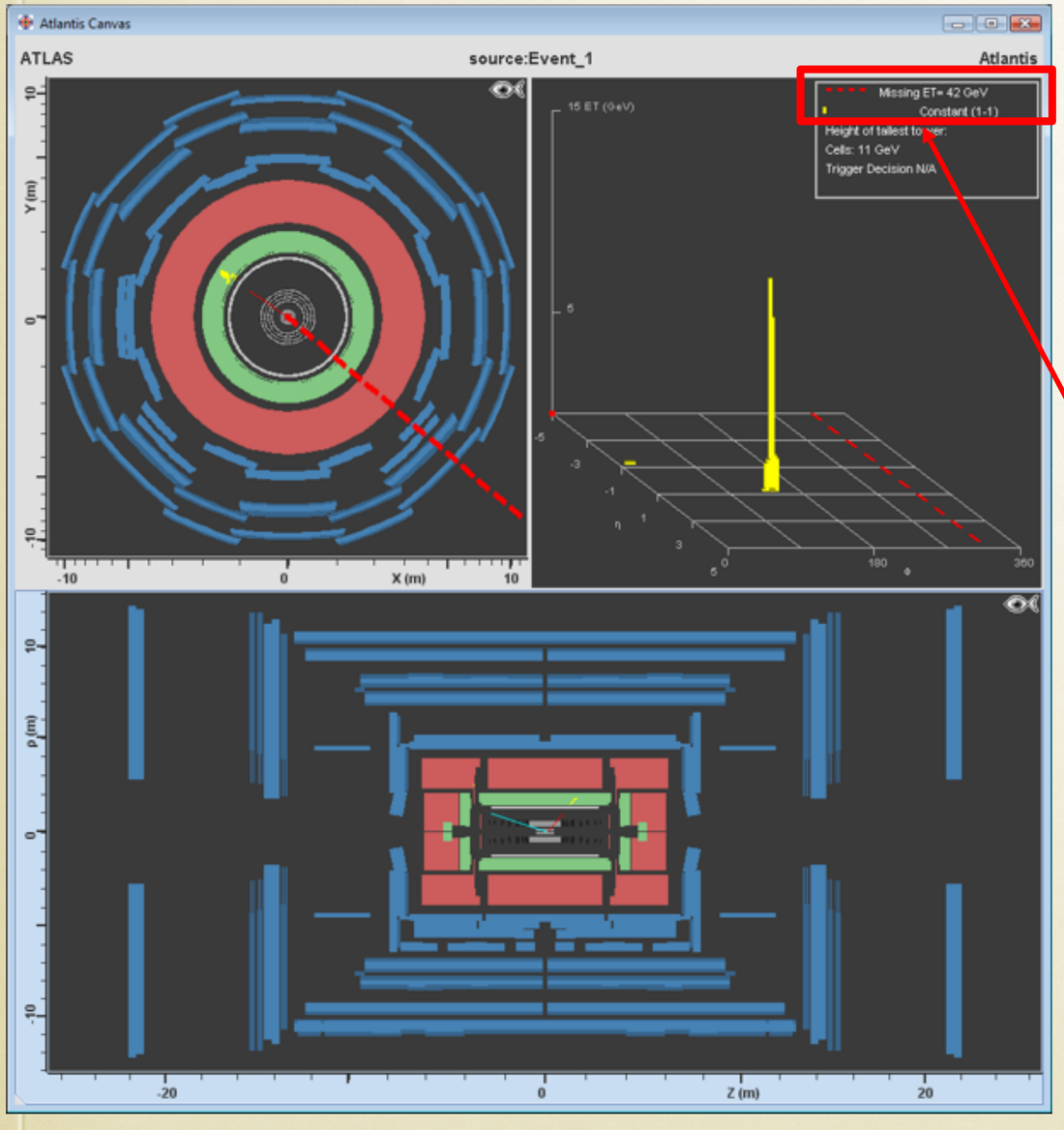
e^+e^-

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



due particelle positive e due negative!

Eventi da scartare



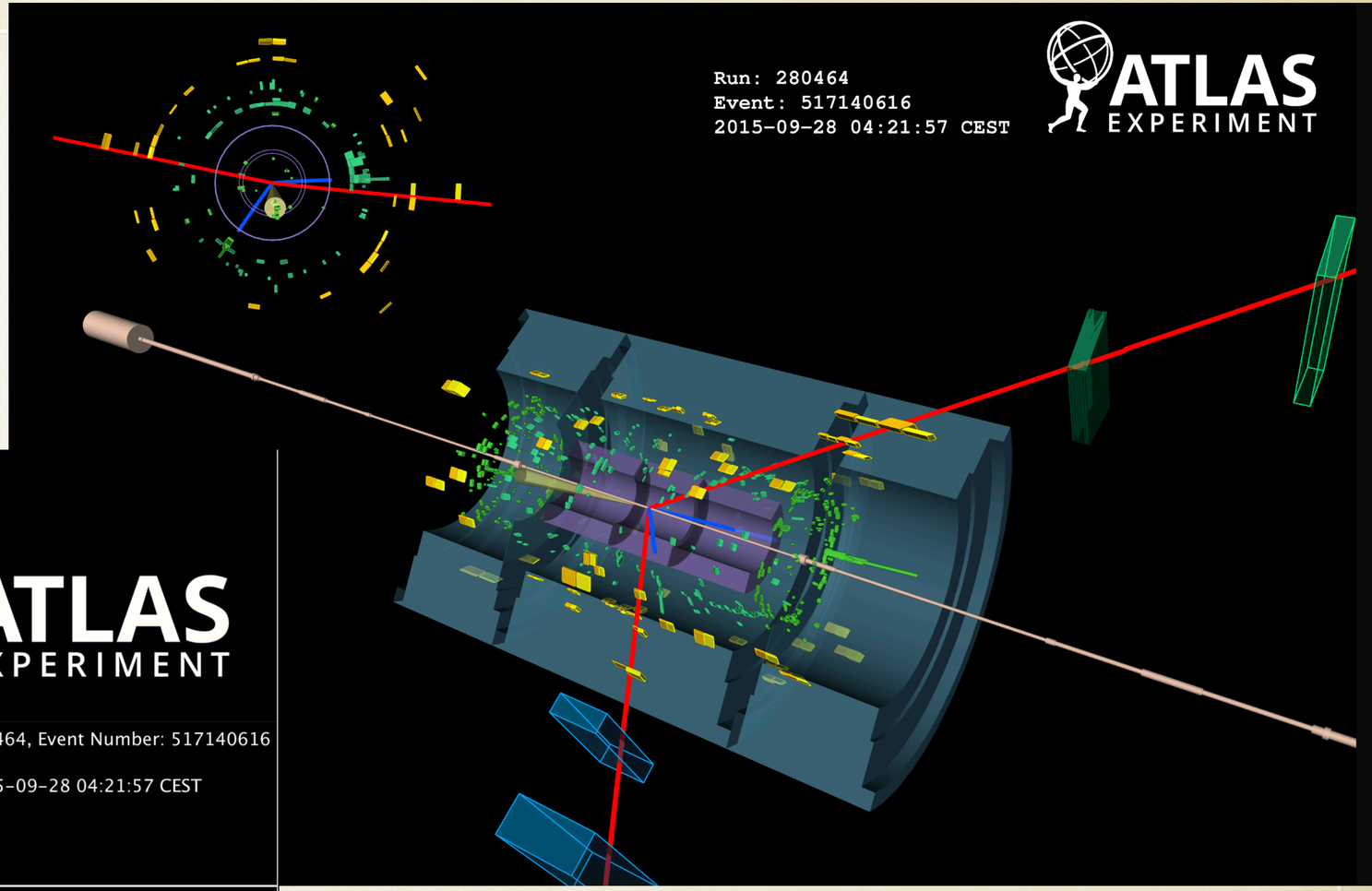
Identificazione dei Neutrini

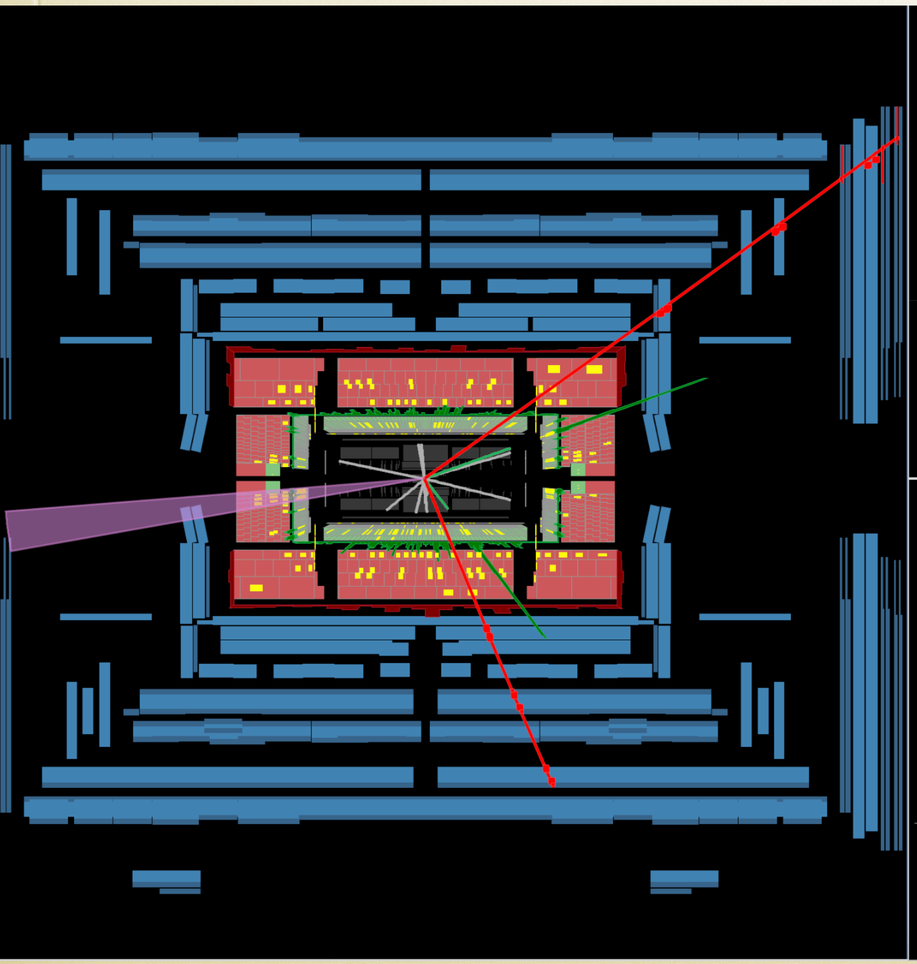
Trovati dal calcolo dell' "**impulso mancante**" sul piano trasverso

Valore dell'impulso del neutrino (Missing ET)

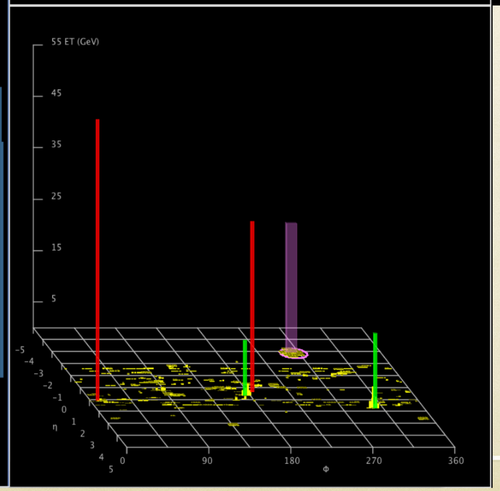
Eventi con la presenza di linea rossa tratteggiata (Missing ET) vanno scartati!

Higgs -> μμee

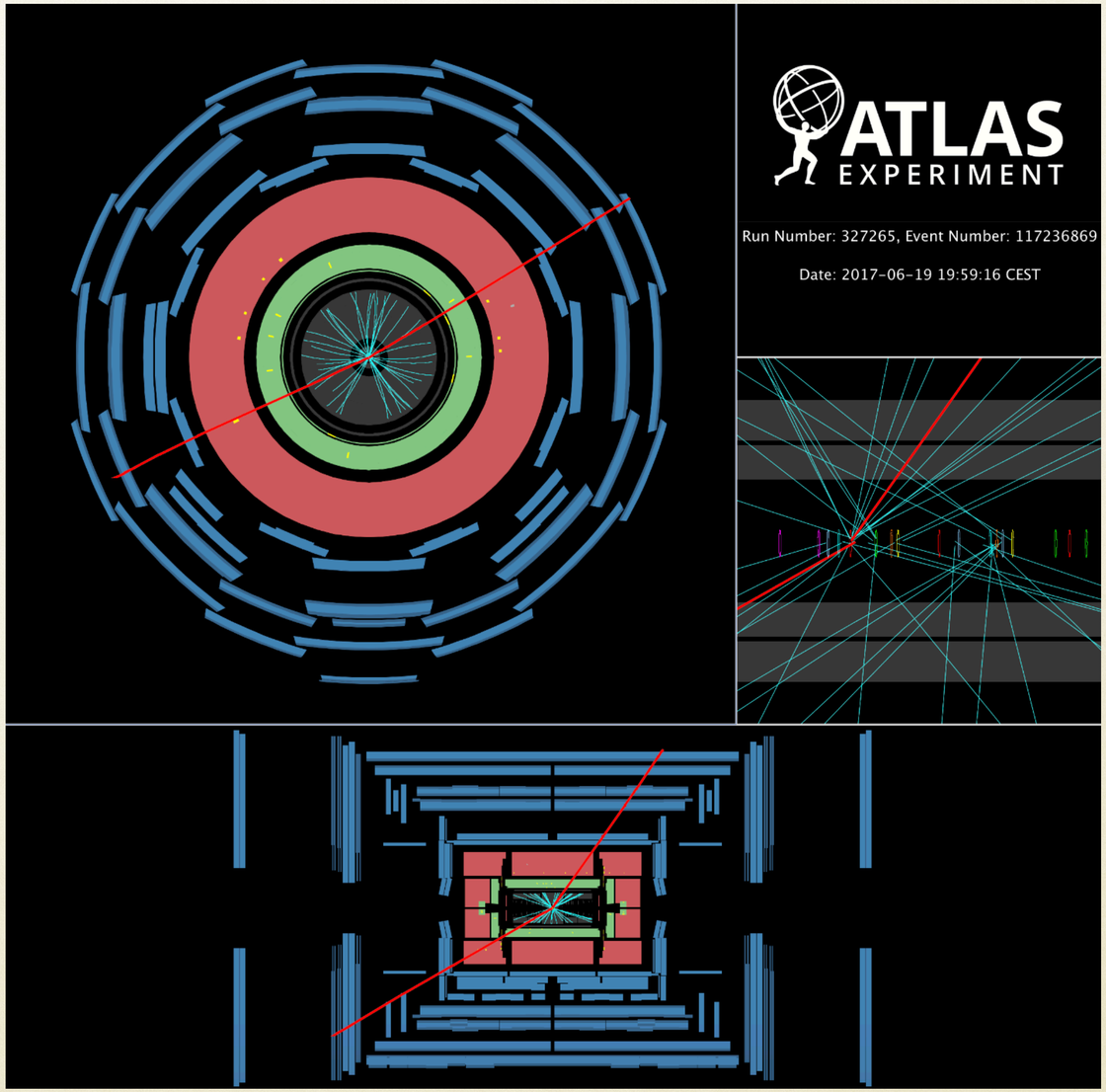

Run: 280464
Event: 517140616
2015-09-28 04:21:57 CEST
ATLAS
EXPERIMENT




ATLAS
EXPERIMENT
Run Number: 280464, Event Number: 517140616
Date: 2015-09-28 04:21:57 CEST


55 ET (GeV)
45
35
25
15
5
-5
-4
-3
-2
-1
0
1
2
3
4
5
η
0
90
180
270
360
Φ

$Z \to \mu\mu$


ATLAS
EXPERIMENT
Run Number: 327265, Event Number: 117236869
Date: 2017-06-19 19:59:16 CEST

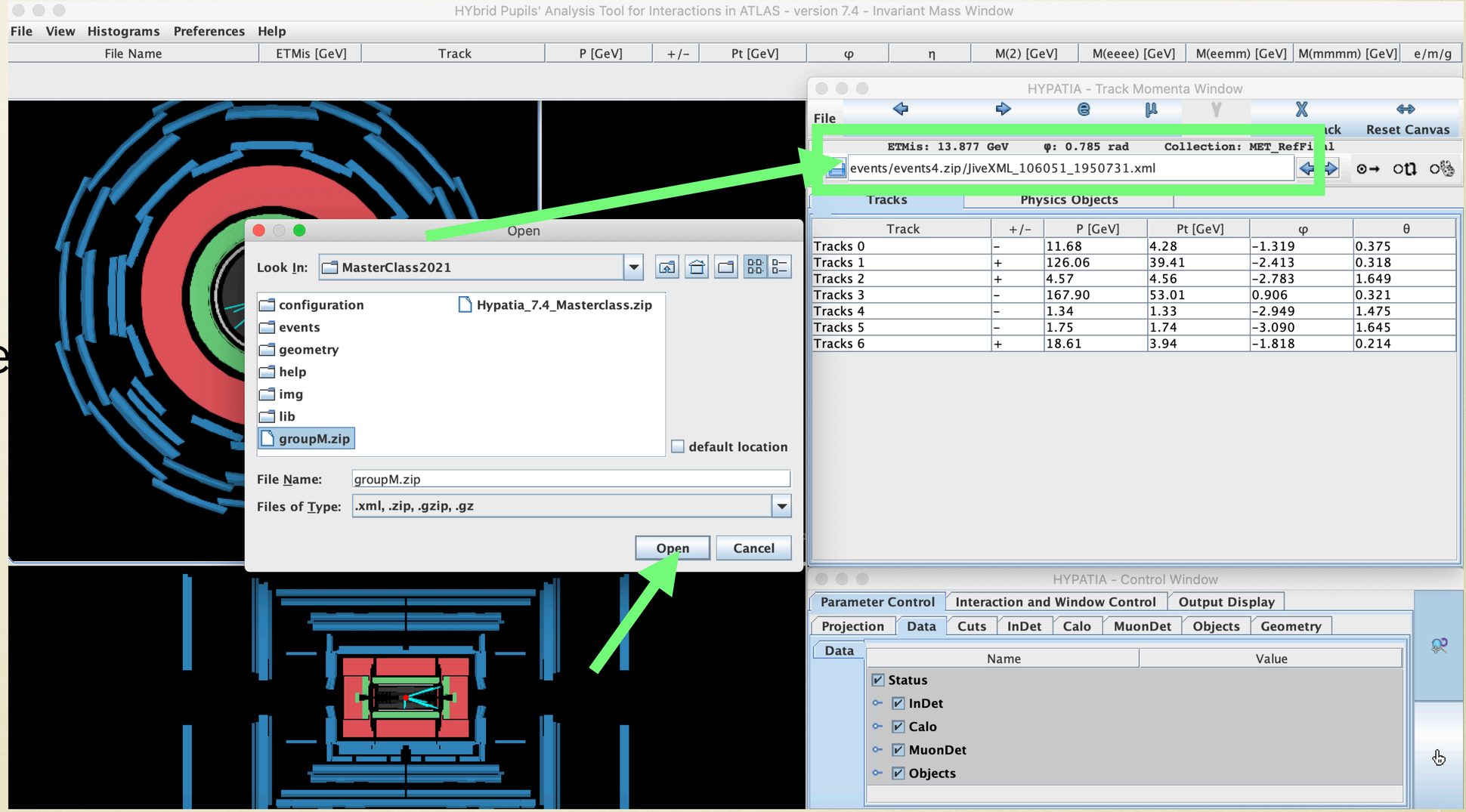
Cominciamo...

Obiettivo: Misurare la massa del bosone Z e di eventuali altre particelle presenti nel campione di dati (compreso il bosone di Higgs).

1. Identificare eventi con Z (da salvare) nei decadimenti:
   A. Elettrone (e^-) -positrone (e^+)
   B. Muone (μ^-)-antimuone (μ^+)
2. Identificare eventi con Higgs (da salvare) nei decadimenti:
   A. Due coppie di particelle cariche (e^+e^- e^+e^-, e^+e^- $\mu^+\mu^-$, $\mu^+\mu^-$ $\mu^+\mu^-$)
   B. fotone - fotone

Apriamo Hypathia e carichiamo i file di eventi

1. Apriamo Hypathia e carichiamo il file scelto per gli eventi

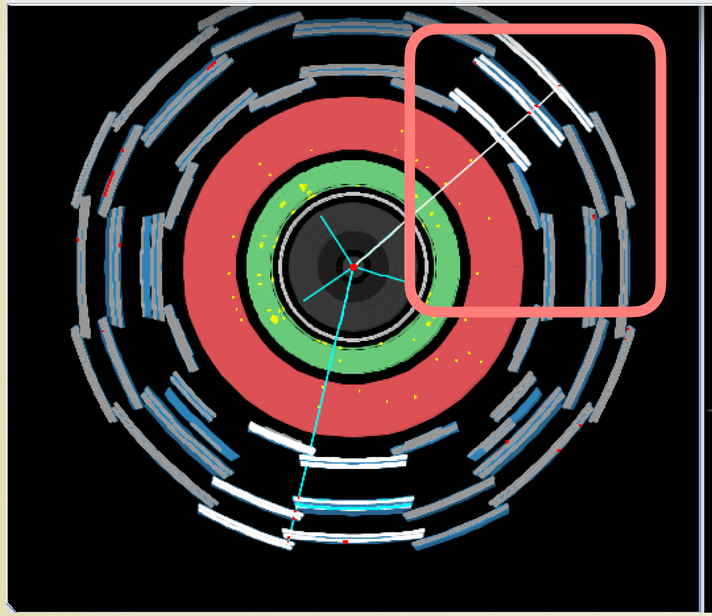


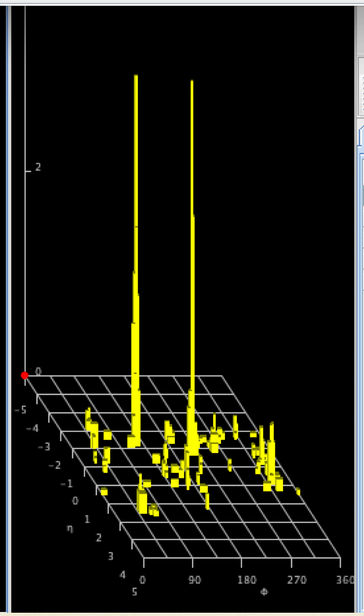
Come Selezioniamo le tracce?

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) [GeV]	e/m/g
event003.xml	26.783	Tracks 3	58.2	-	37.7	0.707	-1.001					m





File Previous Event Next Event Electron Muon Photon Delete Track Reset Canvas

ETMis: 26.783 GeV φ: 2.200 rad Collection: MET_RefFinal

/Users/monica/Desktop/MasterClass2021/groupM.zip/event003.xml

Tracks | Physics Objects

Track	+/-	P [GeV]	Pt [GeV]	φ	θ
Tracks 3	-	58.21	37.68	0.707	2.438
Tracks 4	+	79.66	57.03	-1.794	2.344
Tracks 13	+	14.52	11.66	-2.513	2.209
Tracks 118	-	28.78	15.80	2.114	2.561
Tracks 180	-	9.84	9.27	-0.295	1.912

2.Analizzo gli eventi

1.Mi sembra un muon

2.Click sulla traccia quindi su "Muon"

3.La traccia mi appare sopra

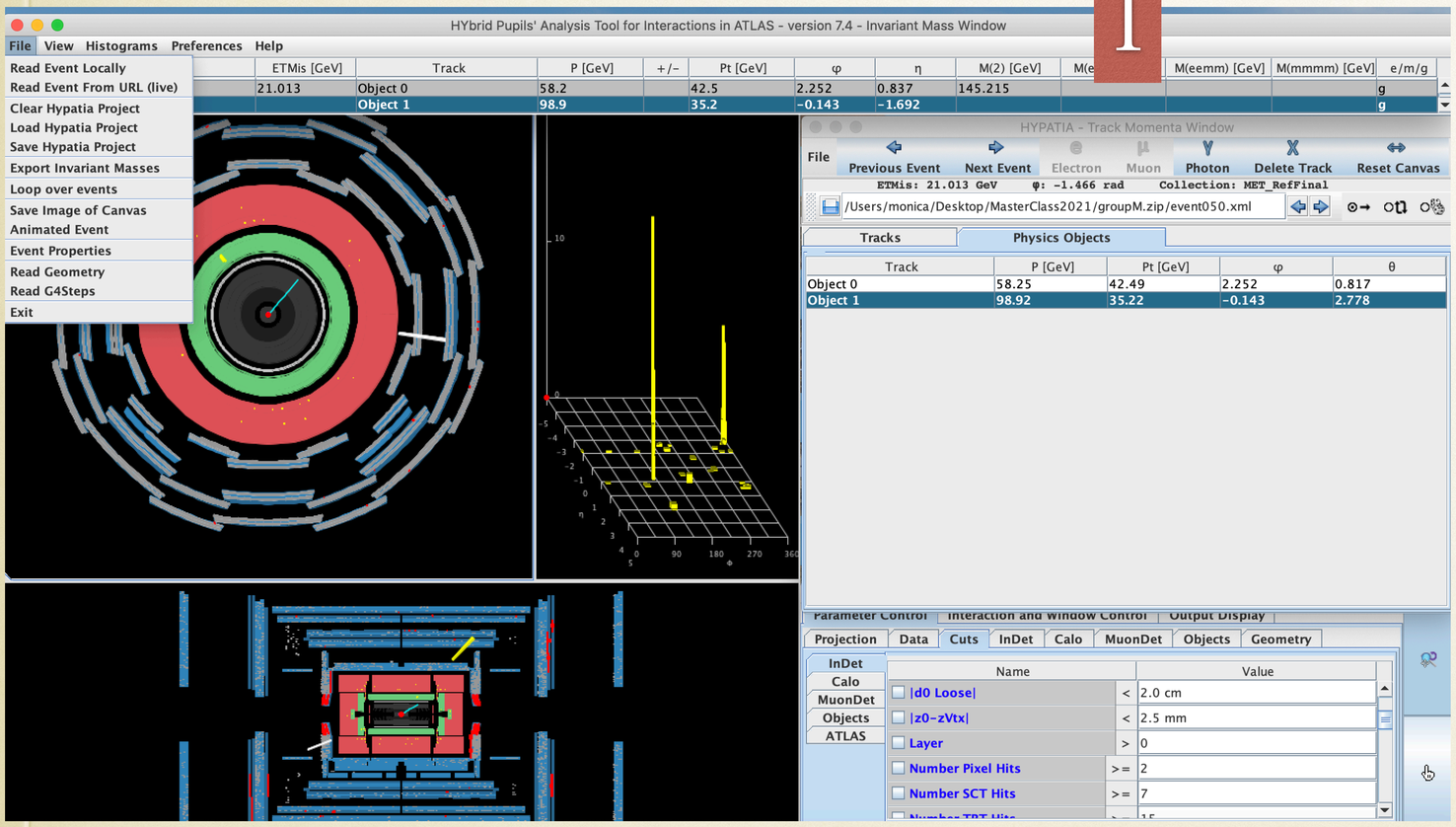
4.Vedo un altro muore, lo aggiungo click su "muon" e mi appare la massa invariante dei due.

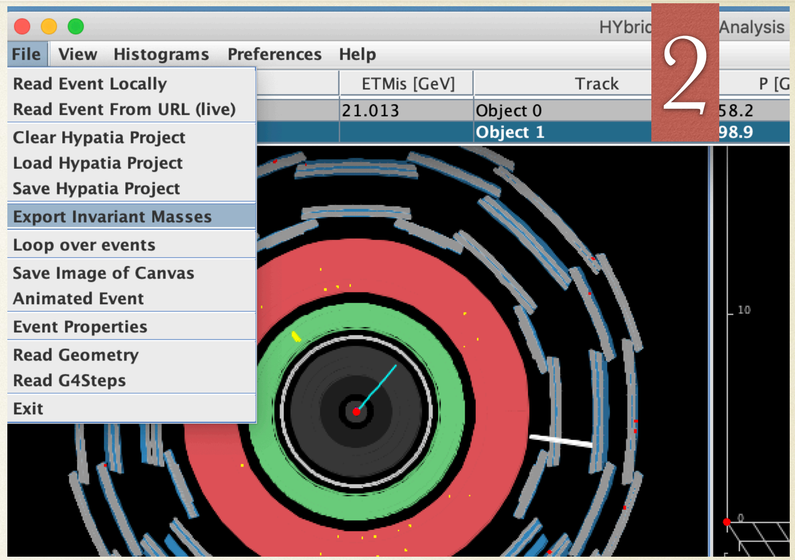
HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window

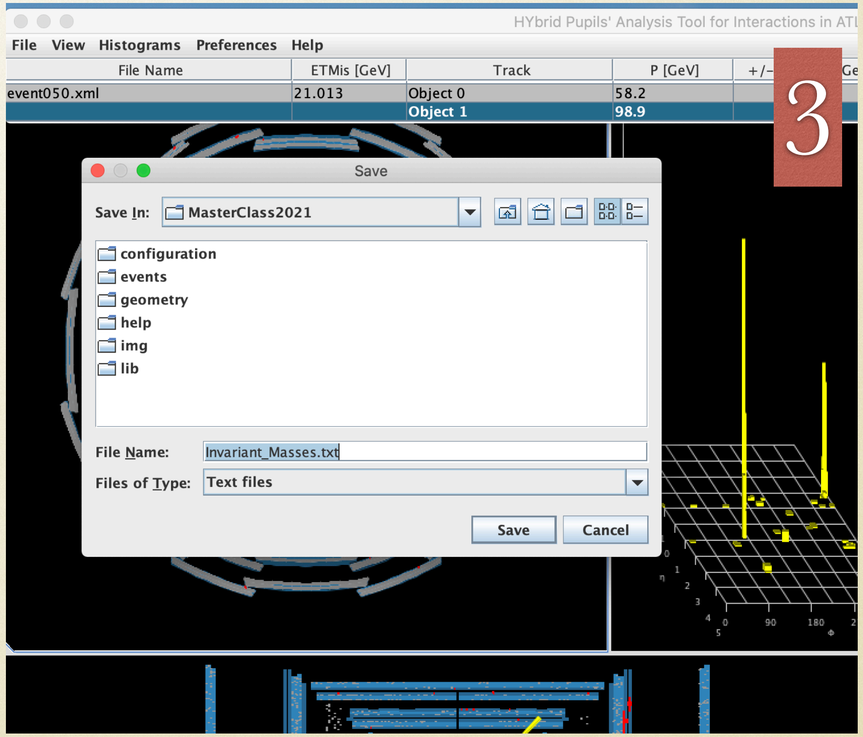
File View Histograms Preferences Help

File Name	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	φ	η	M(2) [GeV]	M(eeee) [GeV]	M(eemm) [GeV]	M(mmmm) [GeV]	e/m/g
event003.xml	26.783	Tracks 3	58.2	-	37.7	0.707	-1.001	88.235				m
		Tracks 4	79.7	+	57.0	-1.794	-0.864					m

Esportare i dati







1. Al passo 3 avete ora salvato il file Invariant_Mass.txt
2. Inseriamo questo file su OPloT dalla pagina web per fare un grafico e confrontarci con gli altri gruppi
3. https://cernmasterclass.uio.no/OPloT/index.php

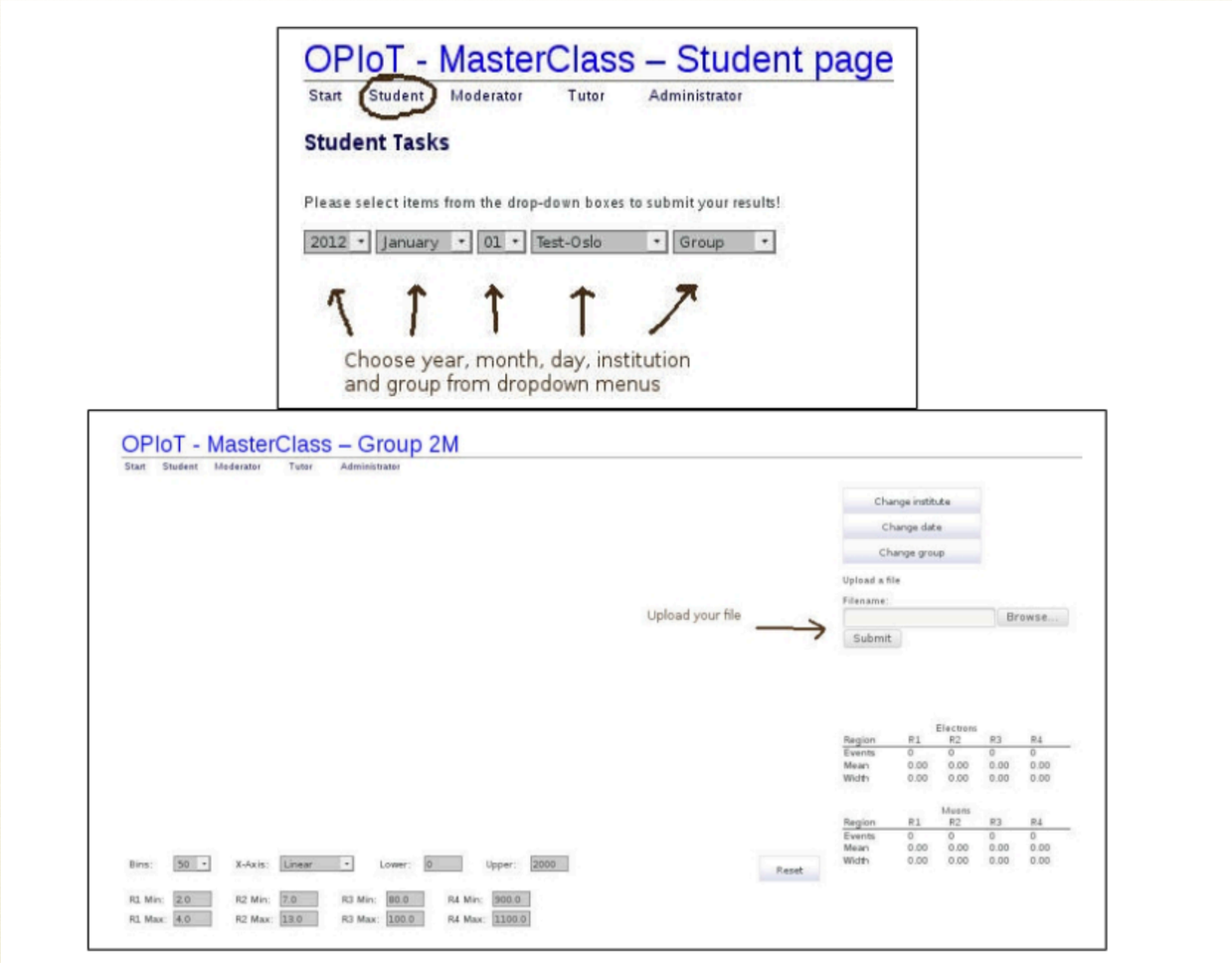
Carichiamo i risultati

Selezionate “Student” dal menu-item
* username: ippog
* password: imc

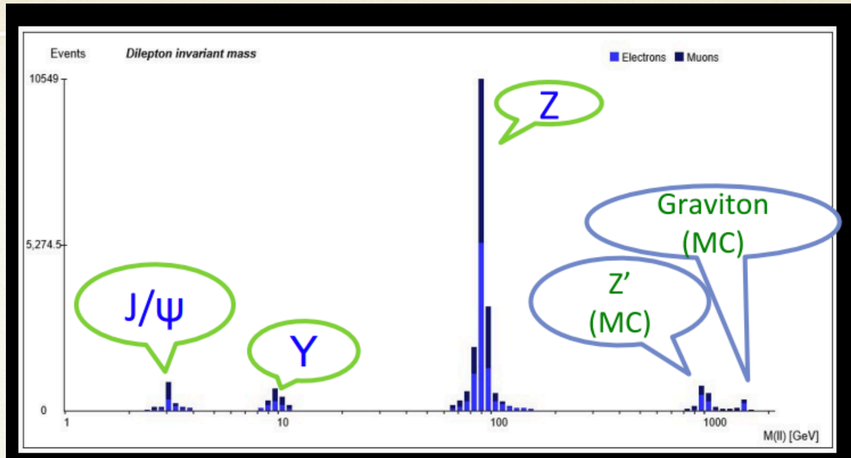
2. Selezionate la data e l’istituto (PISA) dal menu

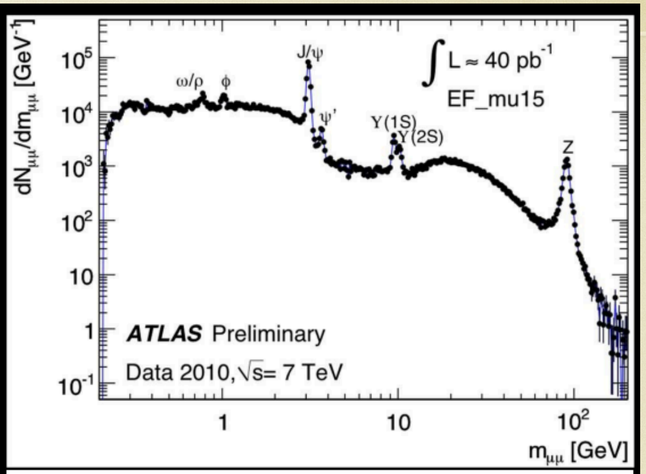
3. Selezionate il groupX del file di dati usato dal menu

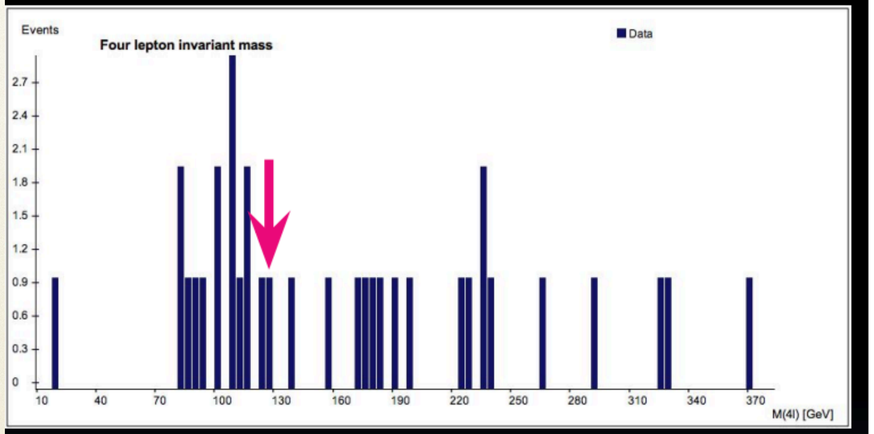
4. Caricate quindi il vostro file “Invariant_Masses.txt”.

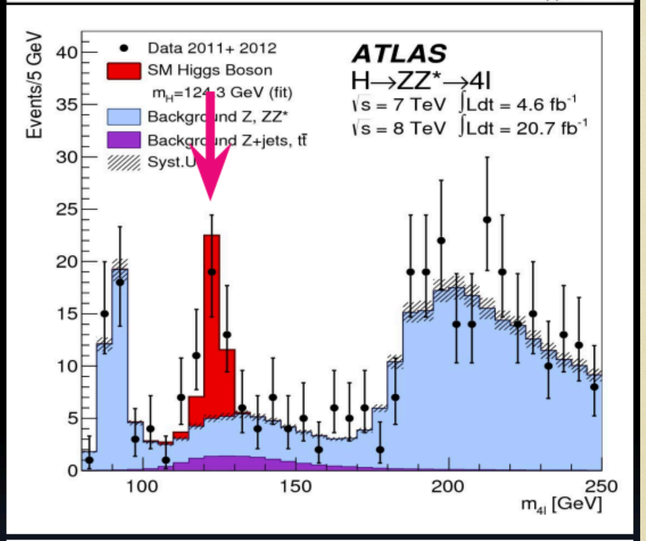


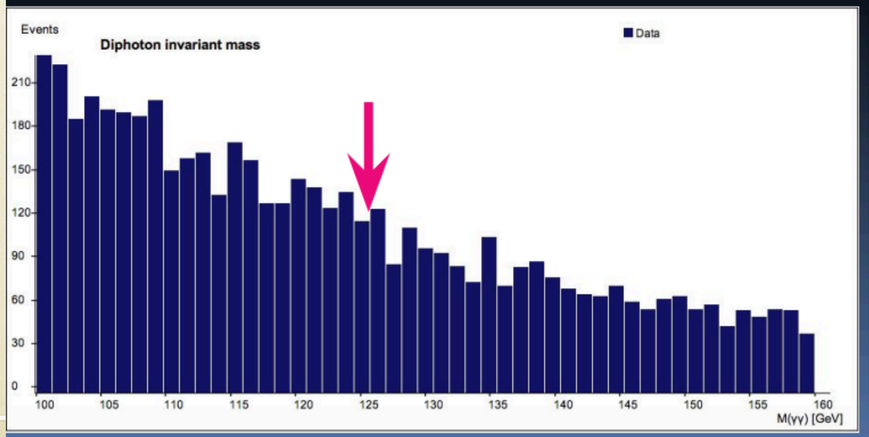
Commentiamo i Risultati

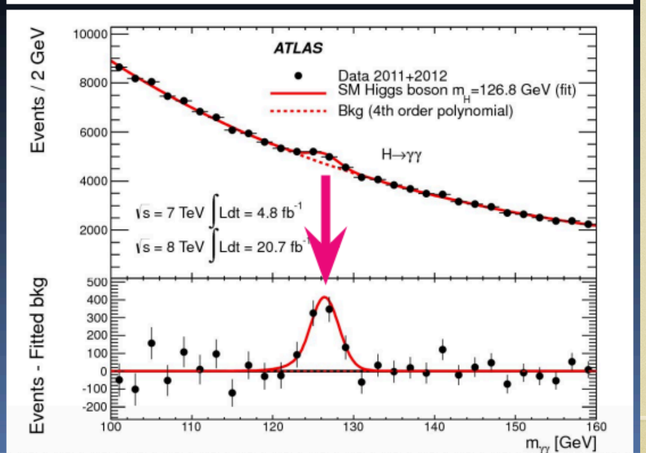












XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Masterclass 01 is inviting you to a scheduled Zoom meeting.

Topic: ATLAS International Masterclass
Time: Feb 28, 2025 15:30 Zurich
Join Zoom Meeting
https://cern.zoom.us/j/67339850490?pwd=WusneBsMfBvKWyEQmmn77nucm8QISK.1

Meeting ID: 673 3985 0490
Passcode: 430371

BACK UP