

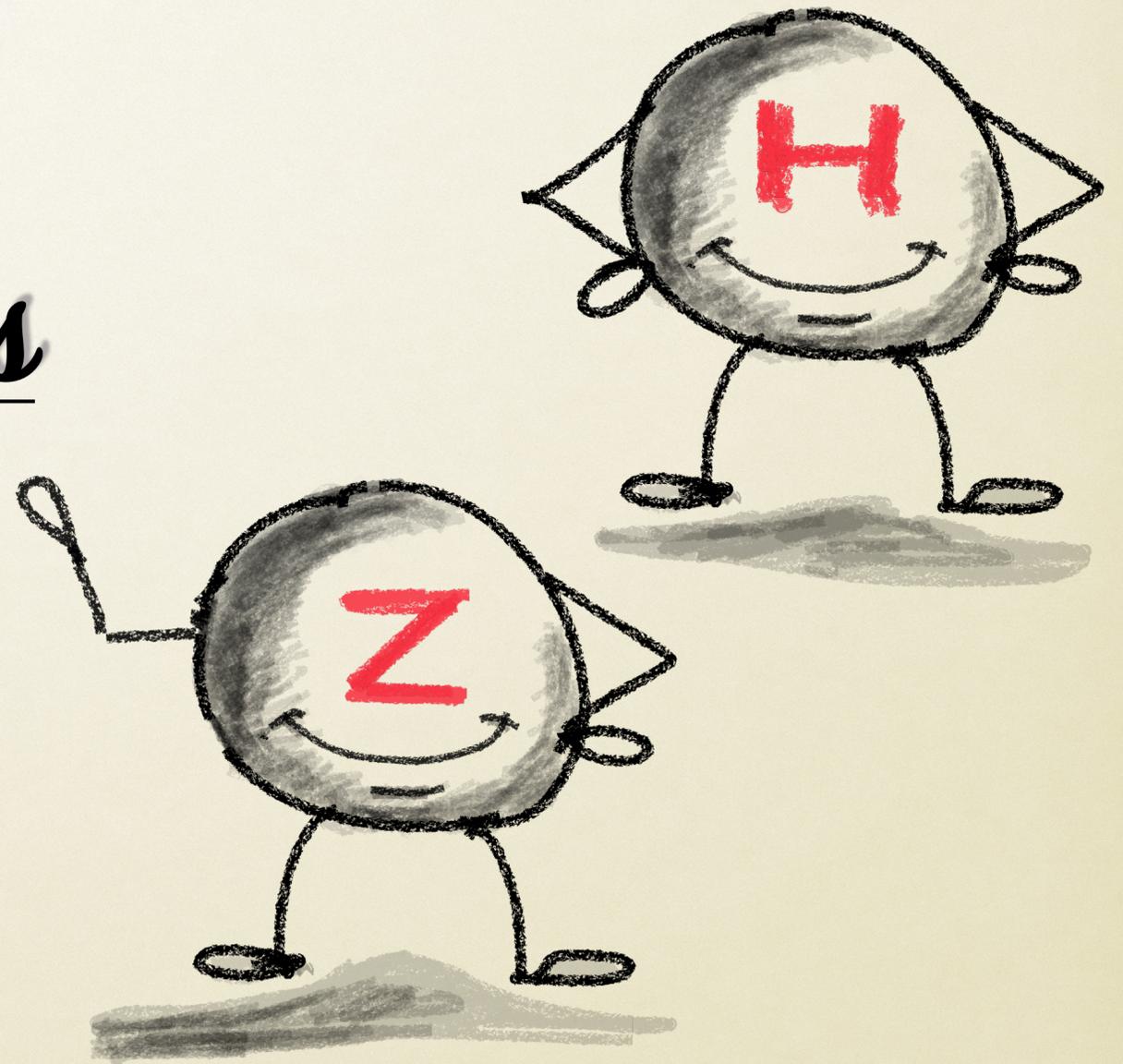


Cerchiamo le particelle: il bosone Z e il bosone di Higgs

MONICA VERDUCCI
monica.verducci@cern.ch

ATLAS PISA Università' e INFN di Pisa

ATLAS Z-Path - 11 Marzo 2021



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.

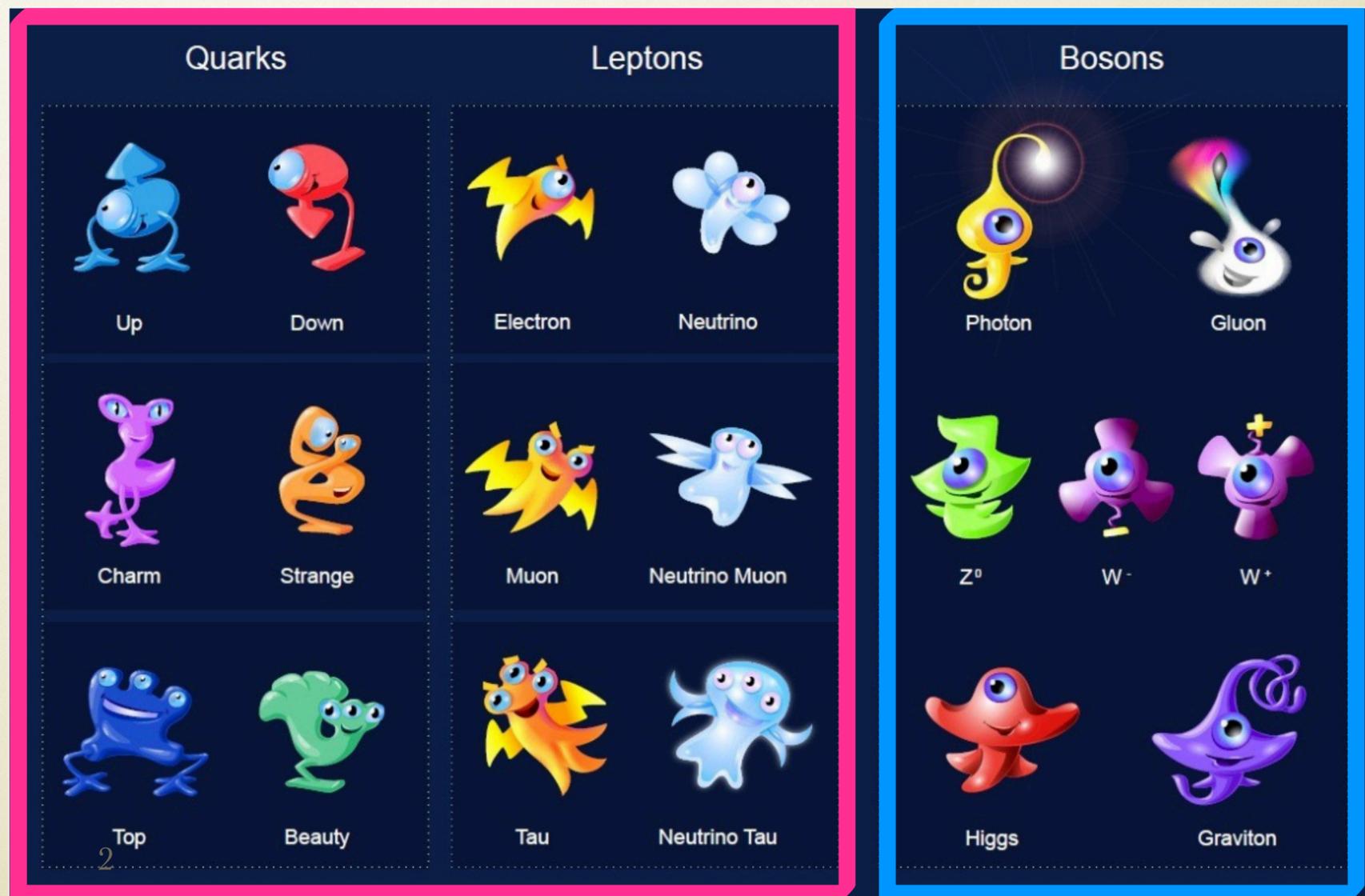


- L'interazione con il rivelatore comporta un rilascio di energia da parte della particella, che viene trasformata in un opportuno segnale elettrico (qualcosa di misurabile) analizzabile dal computer (come faremo oggi!!!)

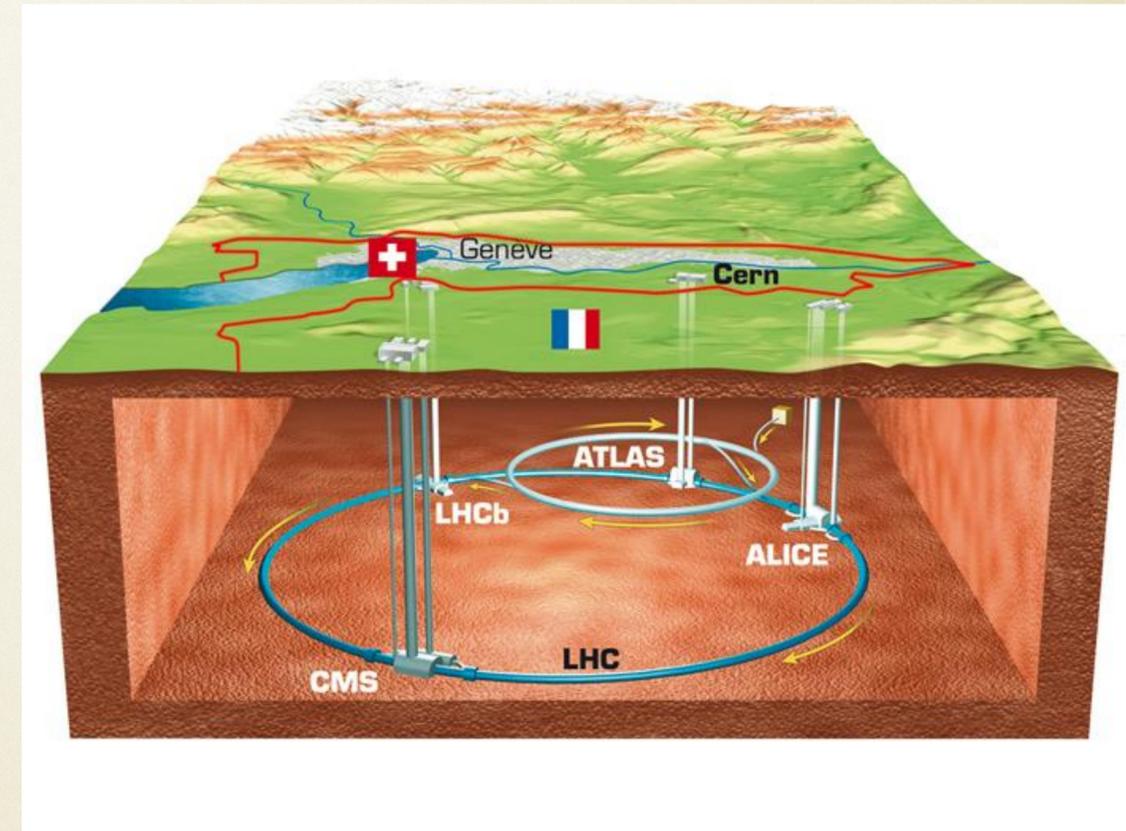
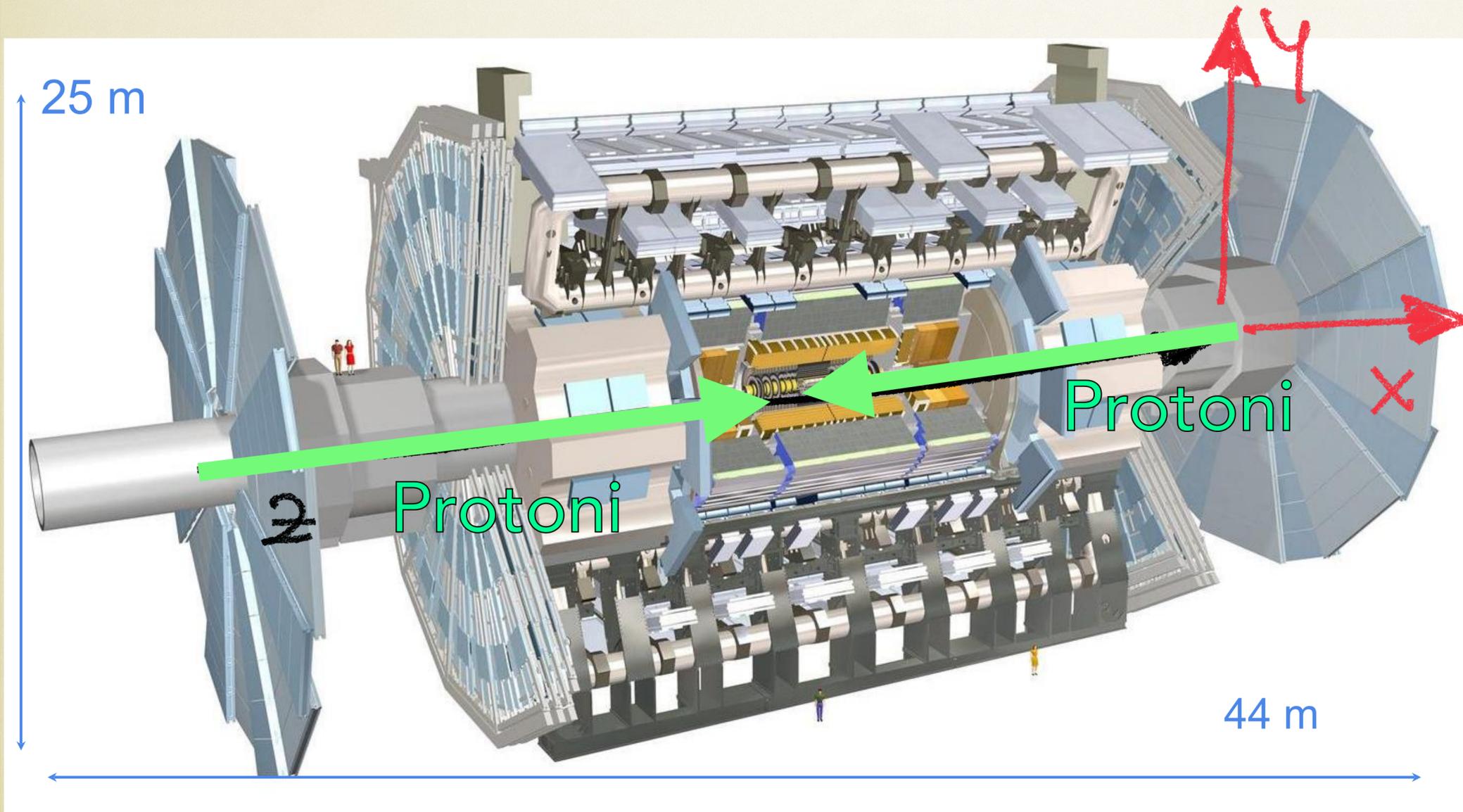


QUARK E LEPTONI: I COSTITUENTI ELEMENTARI DELLA MATERIA

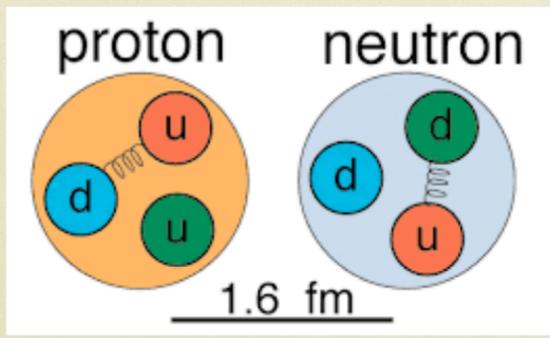
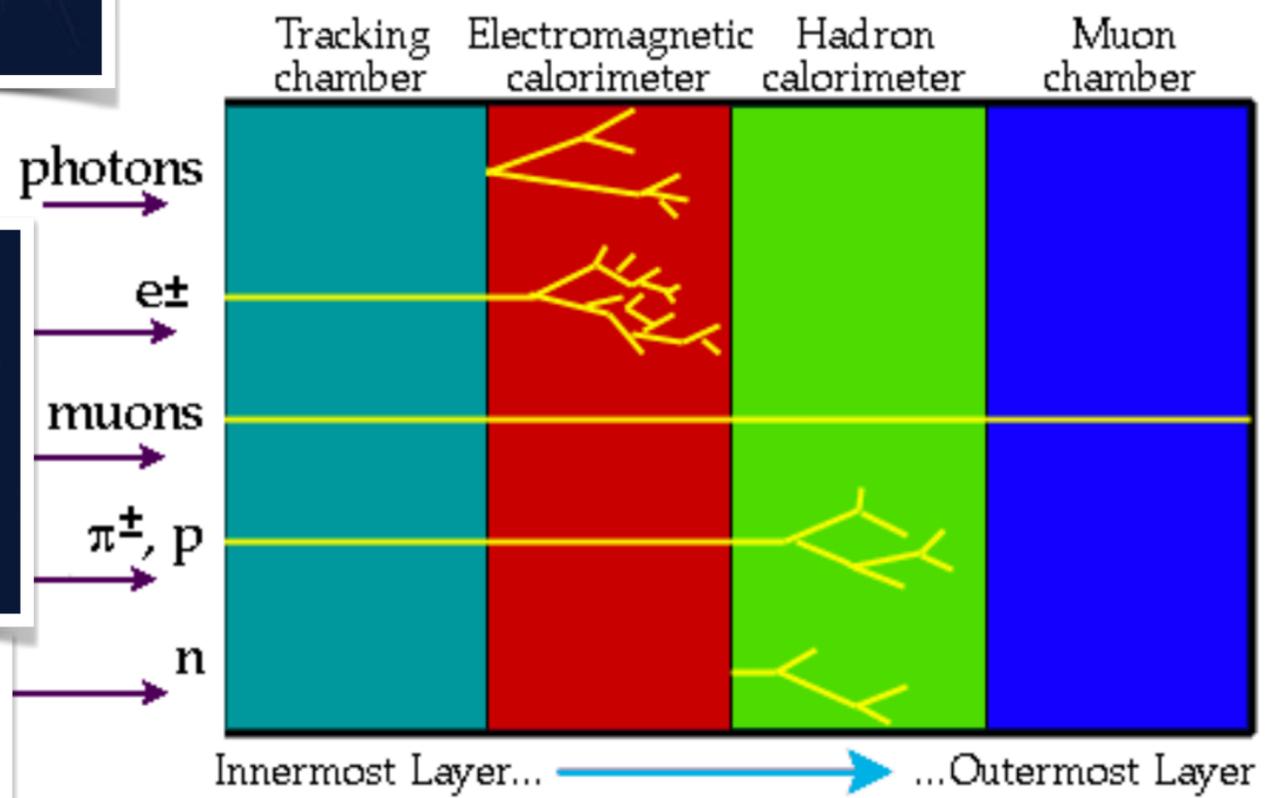
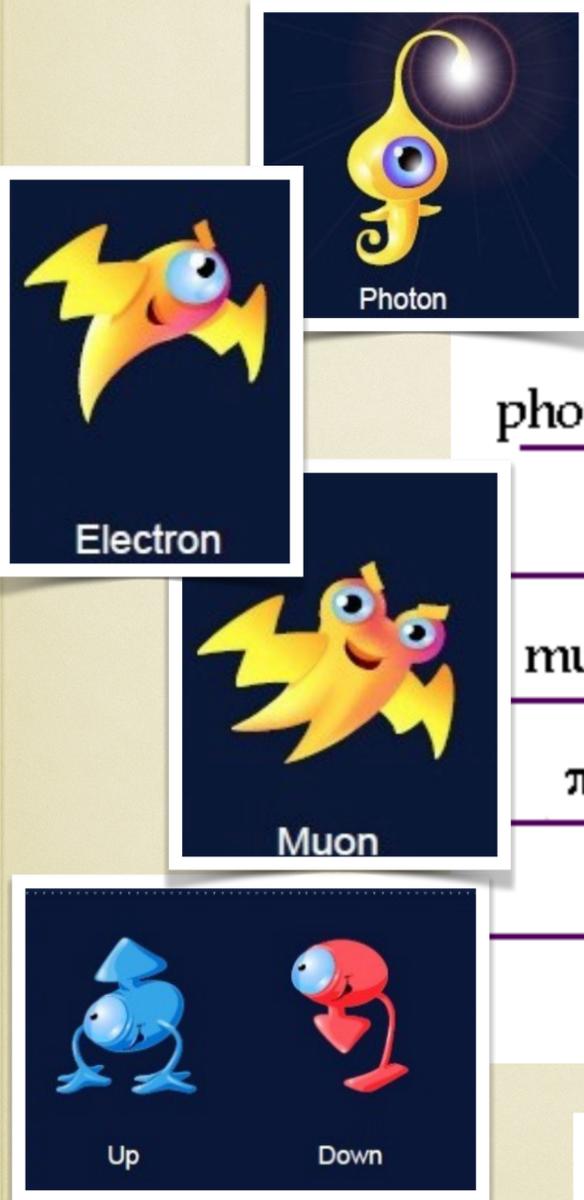
BOSONI: TRASMETTITORI DELLE INTERAZIONI



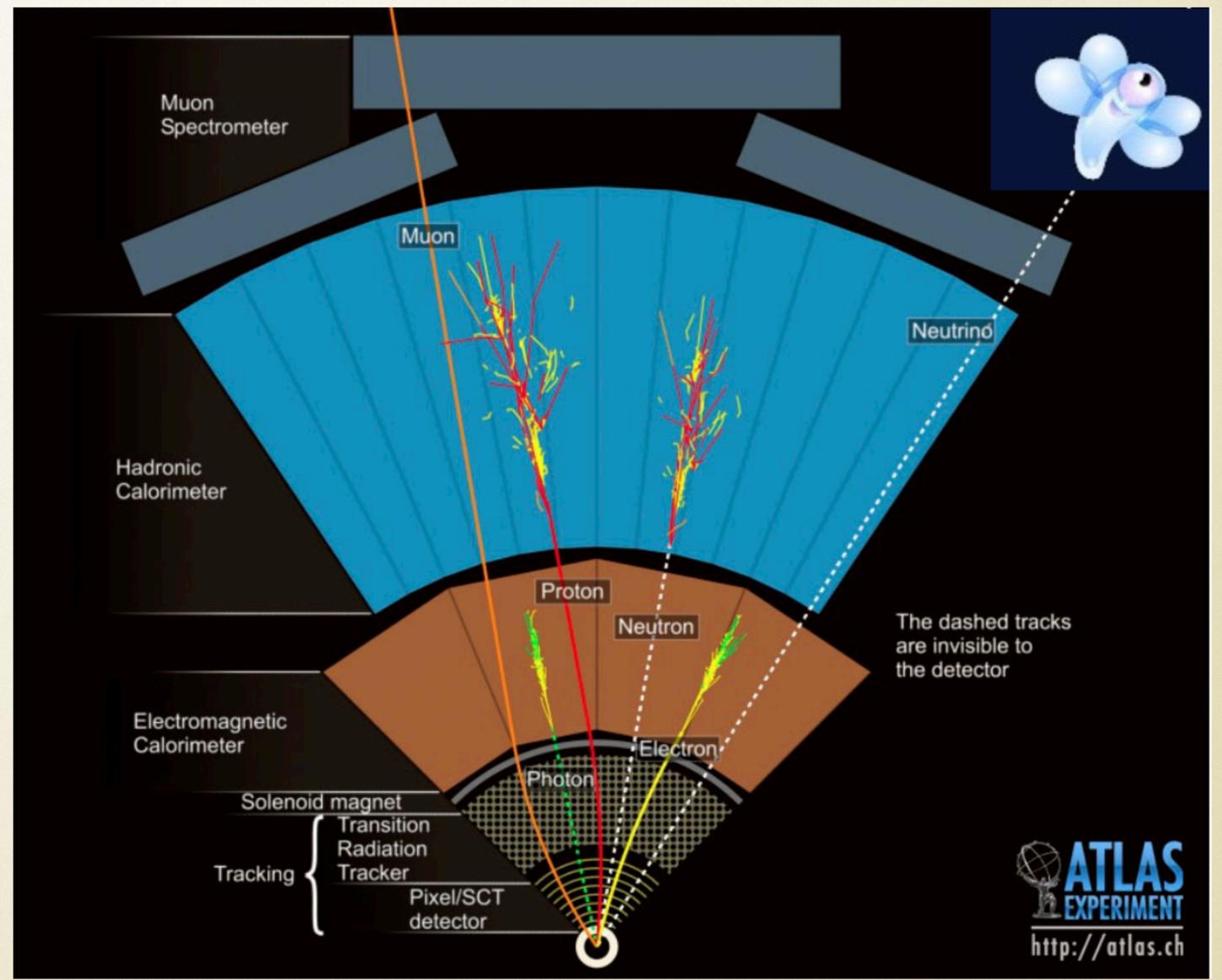
Come le cerchiamo? Con il rivelatore ATLAS



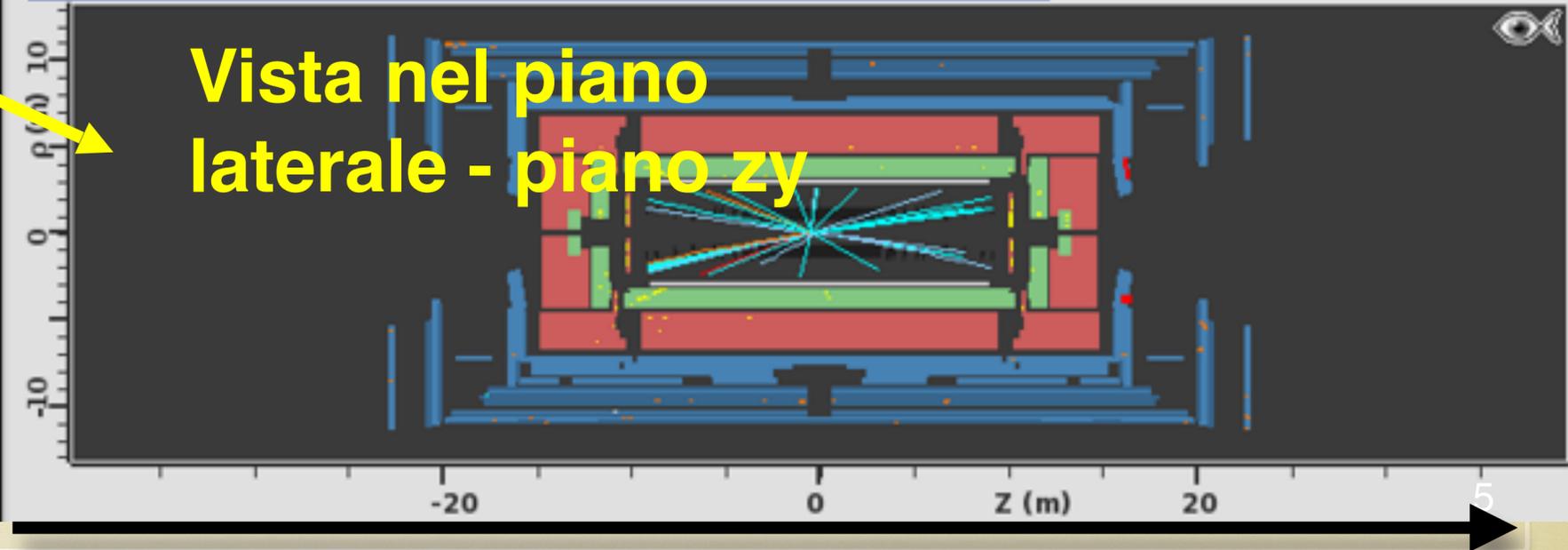
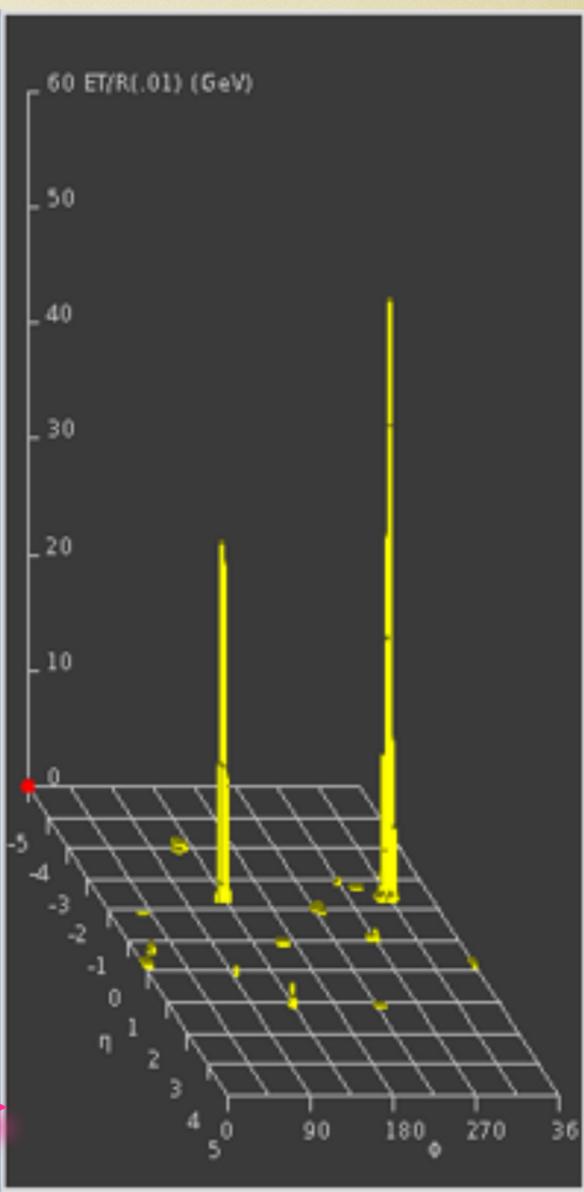
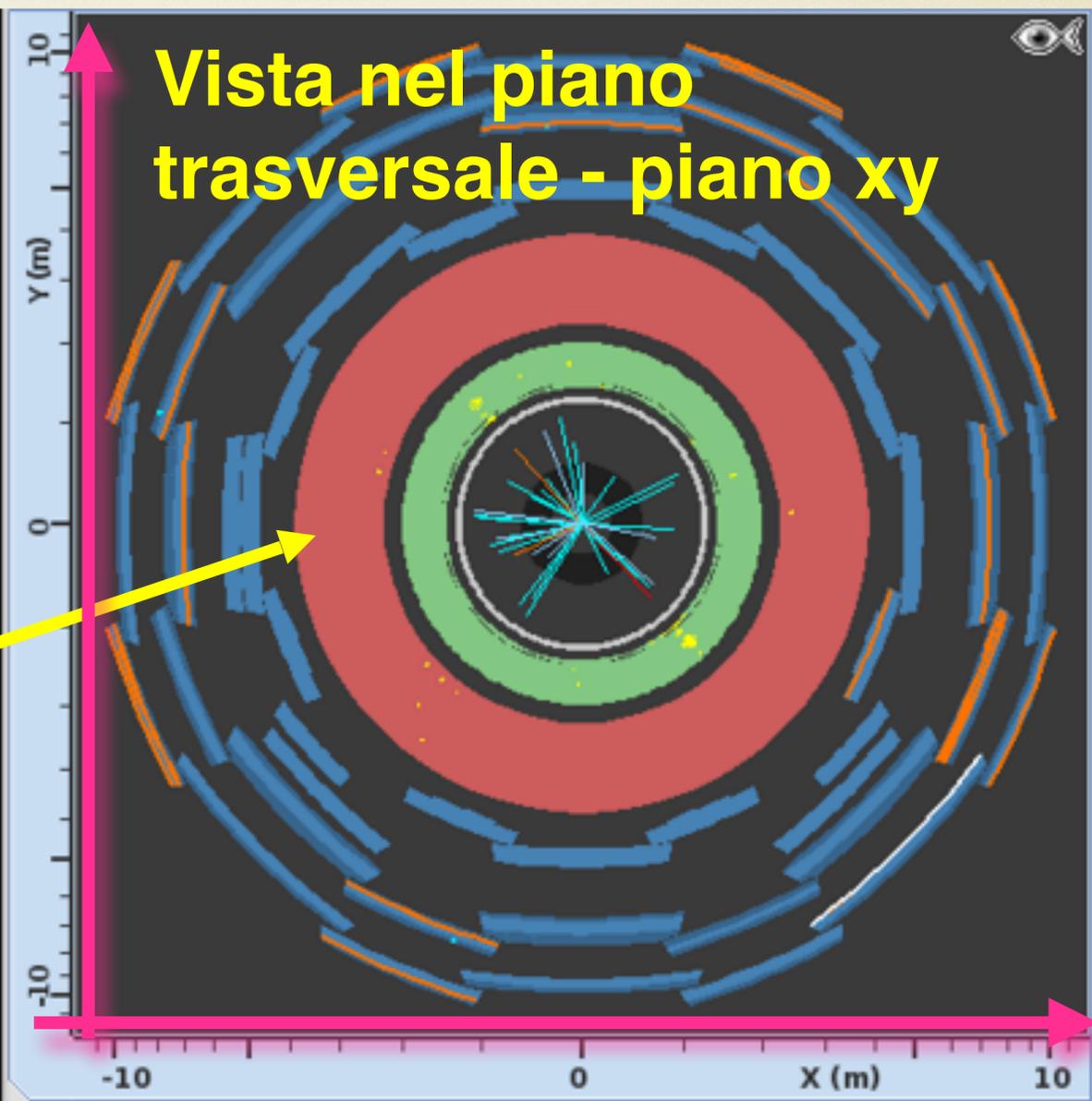
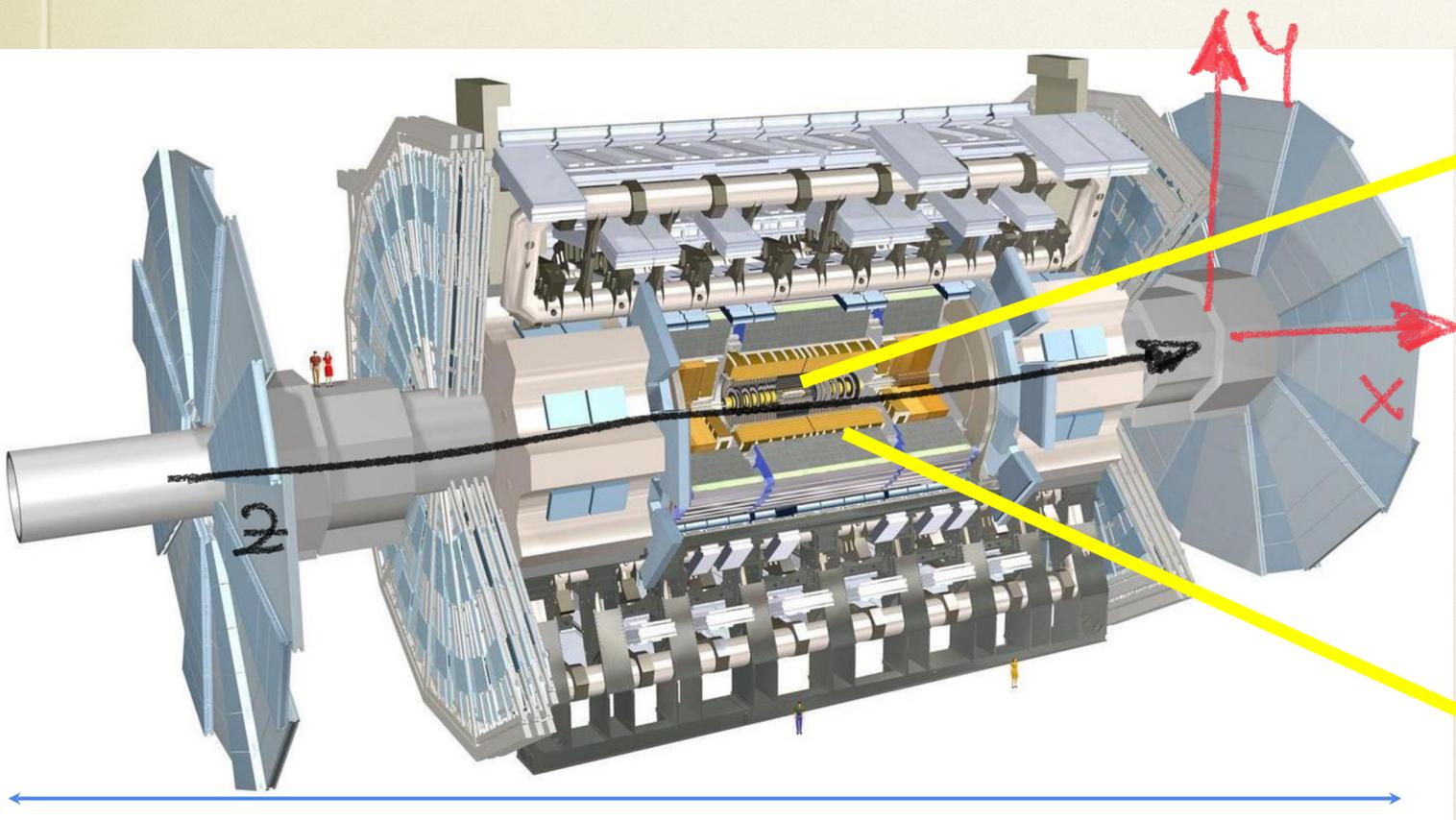
Strategia di rivelazione



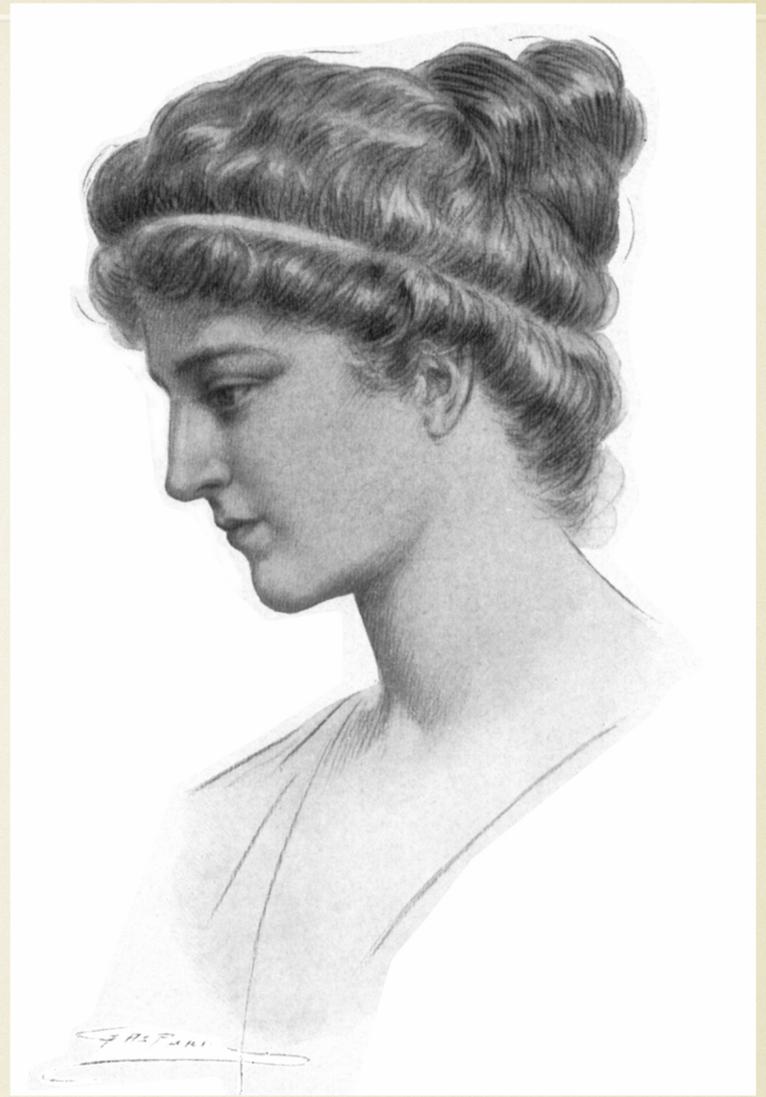
Il neutrone (n) e il protone (p) sono particelle formate da quarks up e down



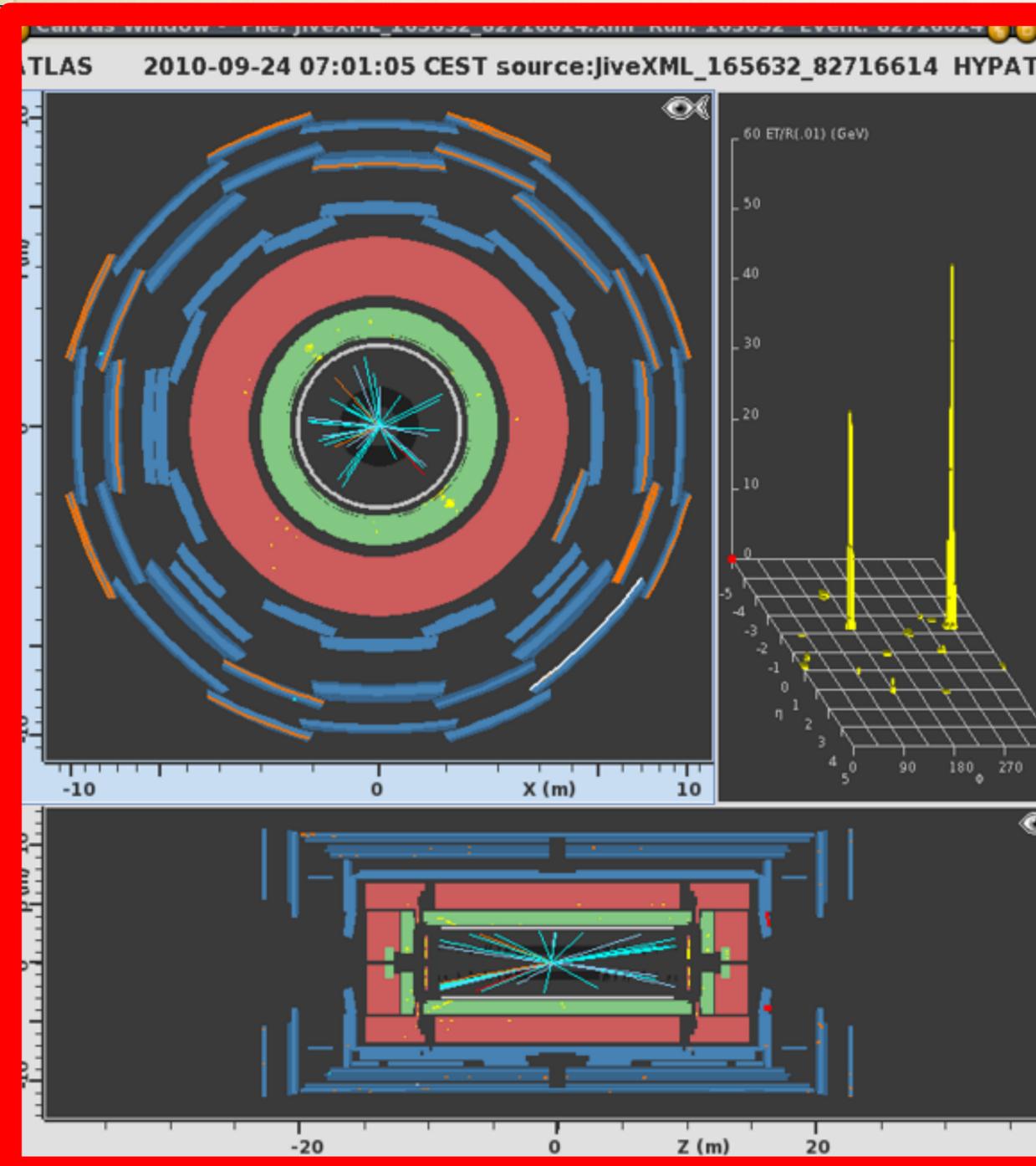
Come osserviamo le particelle in ATLAS



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



Ἰπάτια
(Ἰπάτια, [Alessandria d'Egitto](#),
[355/370](#) - [415](#))



Previous Event Next Event Insert Electron Insert Muon Dele

ETMis: 7.384 GeV ϕ : 2.227 rad Collection: MET RefFinal

masterClass/zpath/Els/jiveXML_165632_82716614.xml

Reconstructed Tracks

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

HYPATIA - Control Window

Interaction and Window Control Output Display

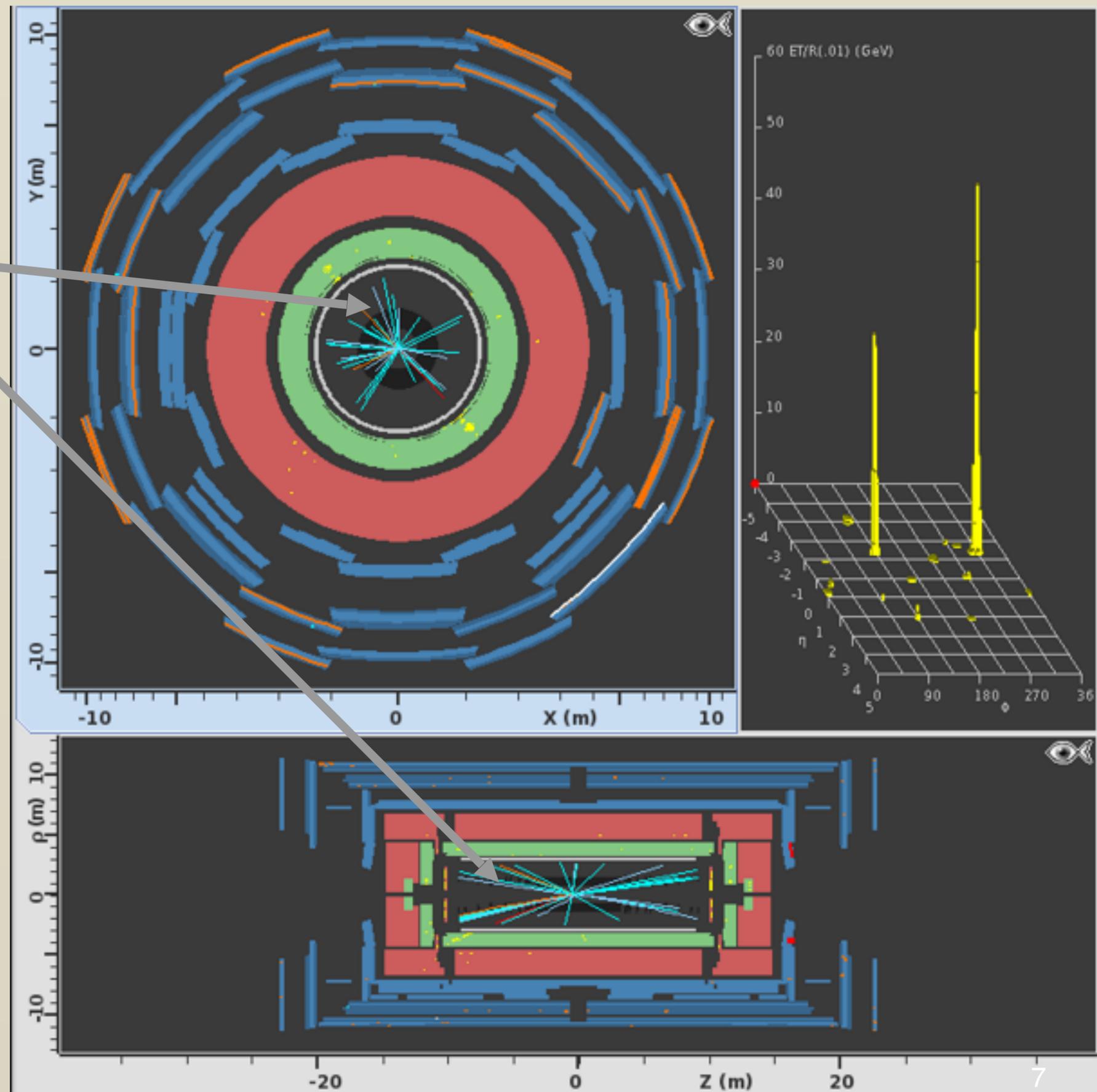
Parameter Control

InDet	Calo	MuonDet	Objects	Geometry
			Projection	Data
				Cuts

InDet	Name	Value
Calo	<input checked="" type="checkbox"/> Pt	> 1.0 GeV
MuonDet	<input checked="" type="checkbox"/> d0	< 6.5 mm
Objects	<input checked="" type="checkbox"/> z0	< 25.0 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
	<input type="checkbox"/> Number SCT Hits	>= 7
	<input type="checkbox"/> Number TRT Hits	>= 30
	<input type="checkbox"/> Sim. Particle PDG-ID	< 40
	<input type="checkbox"/> Sim. Particle Barcode	= 0
	<input type="checkbox"/> Sim. Particle Type	charged hadron

Event display

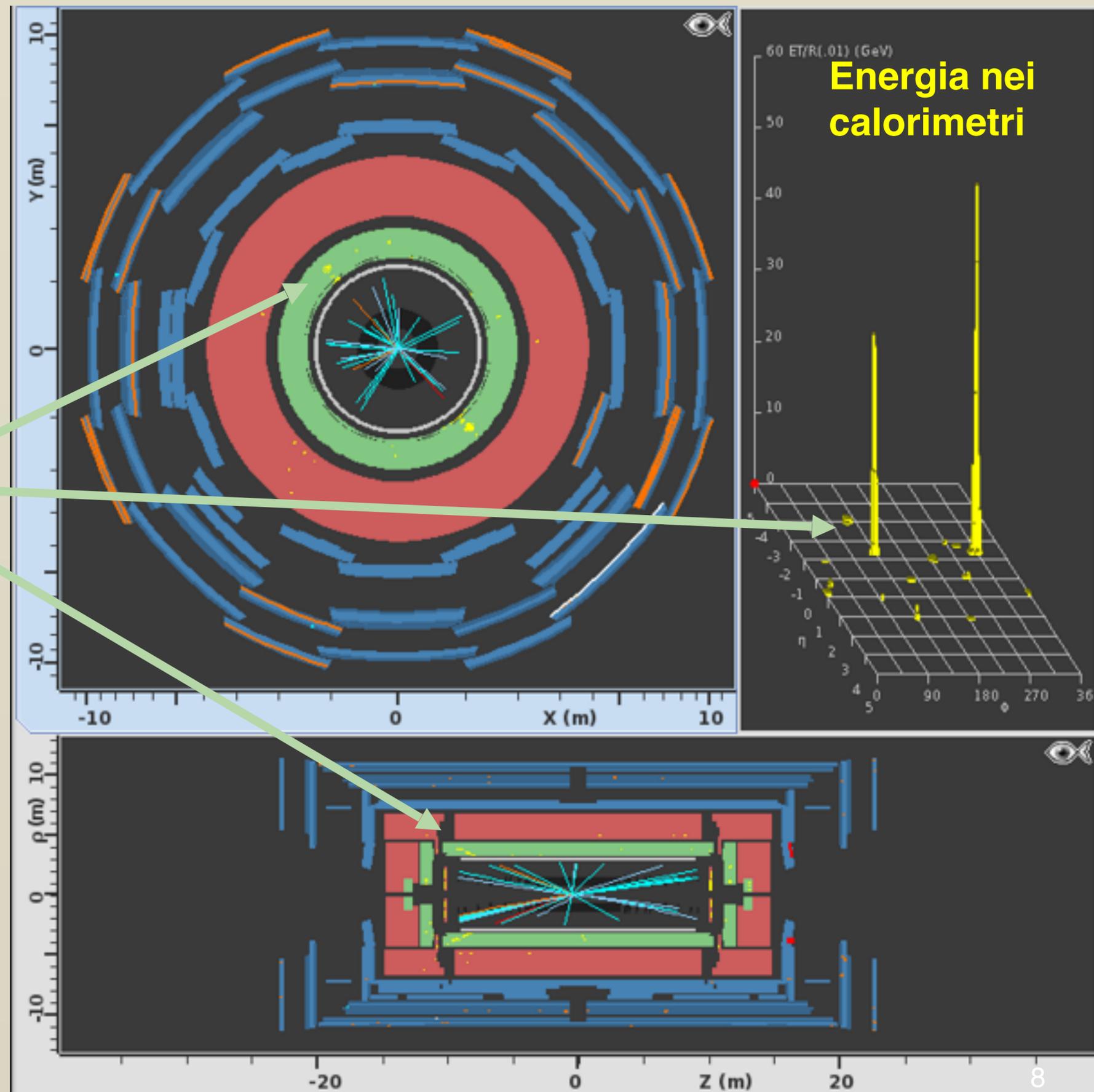
Tracciatore:
particelle cariche



Event display

Tracciatore:
particelle cariche

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

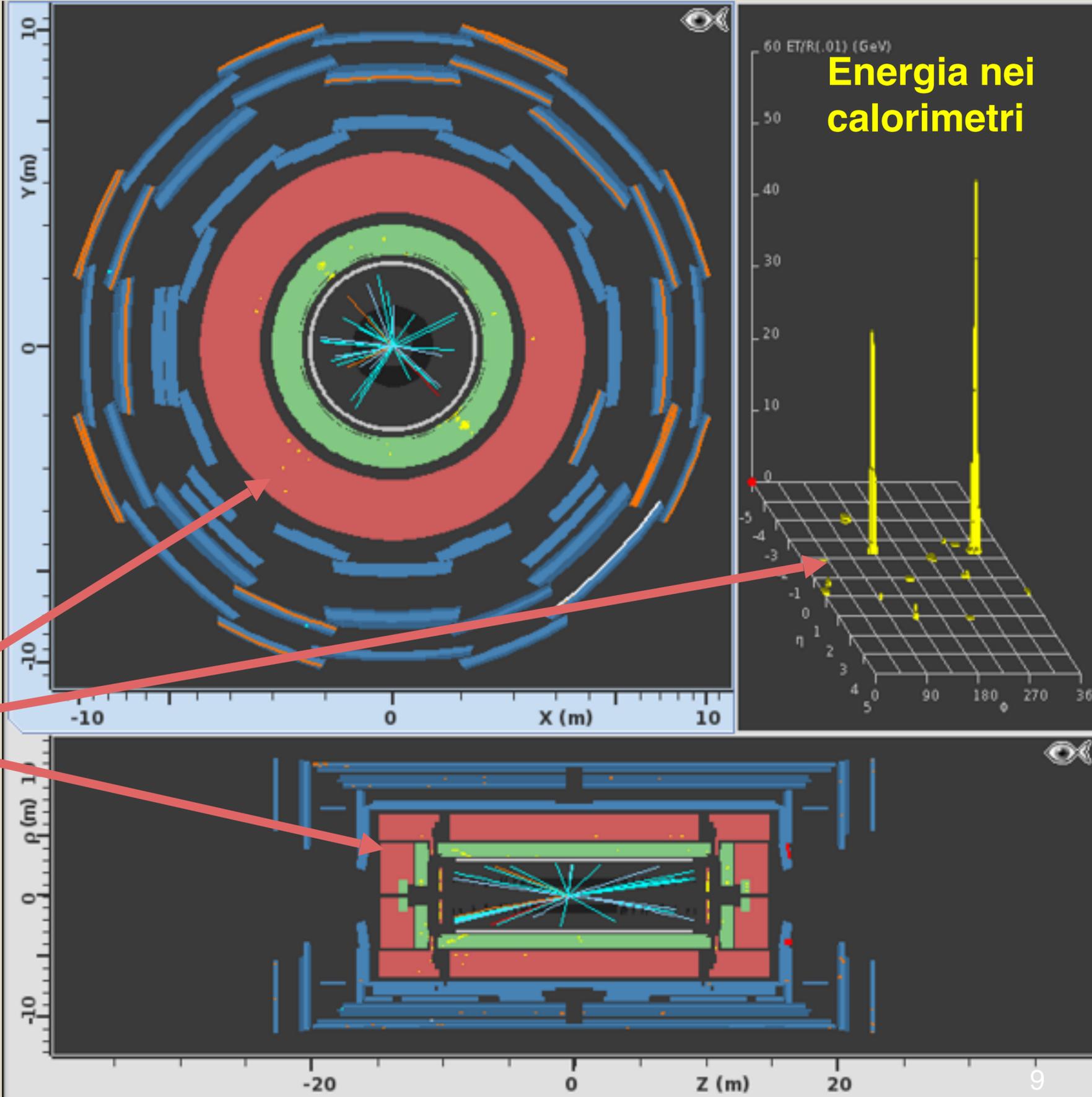


Event display

Tracciatore:
particelle cariche

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

Calorimetro adronico: adroni
(es: protoni, neutroni)



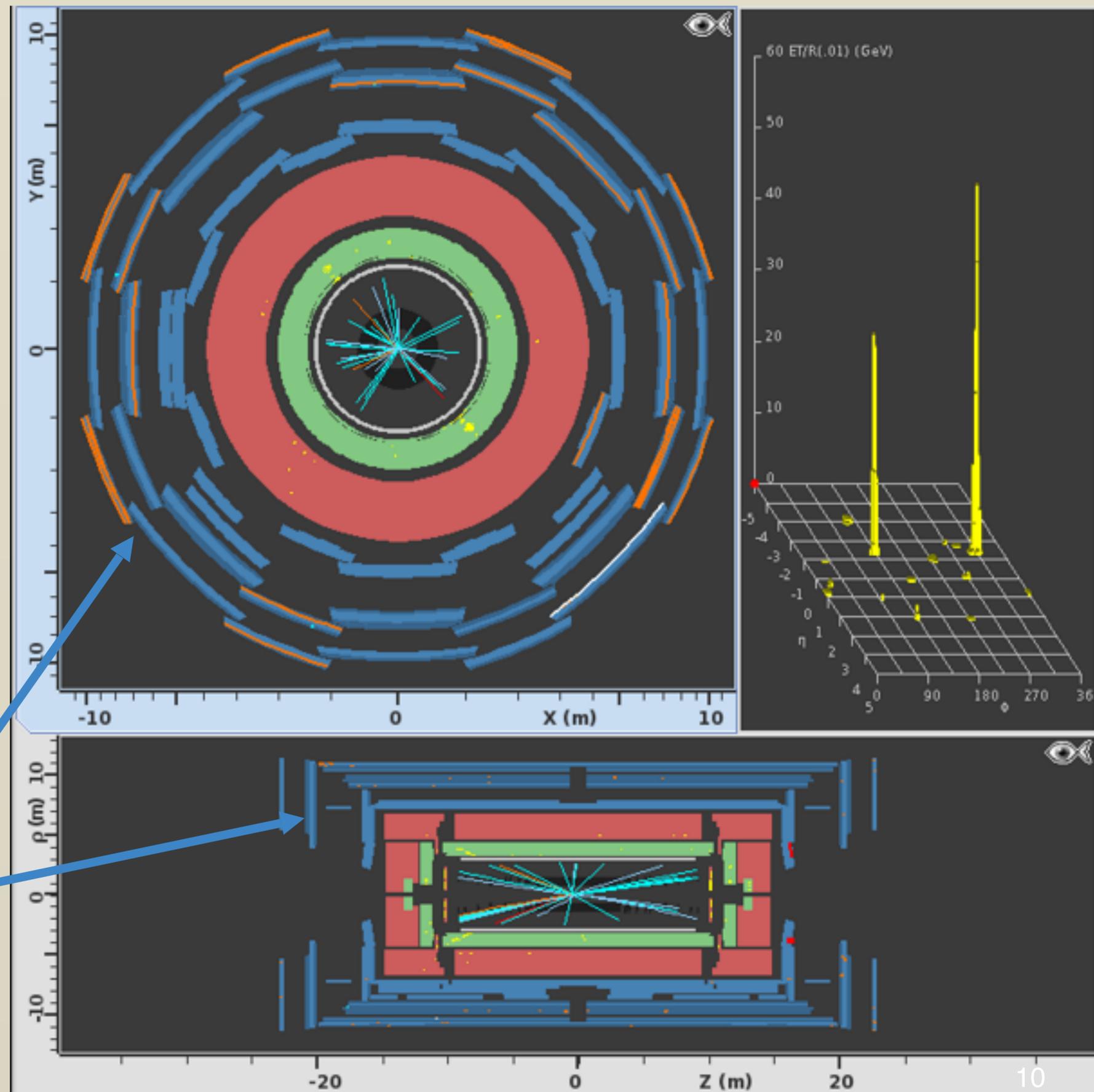
Event display

Tracciatore:
particelle cariche

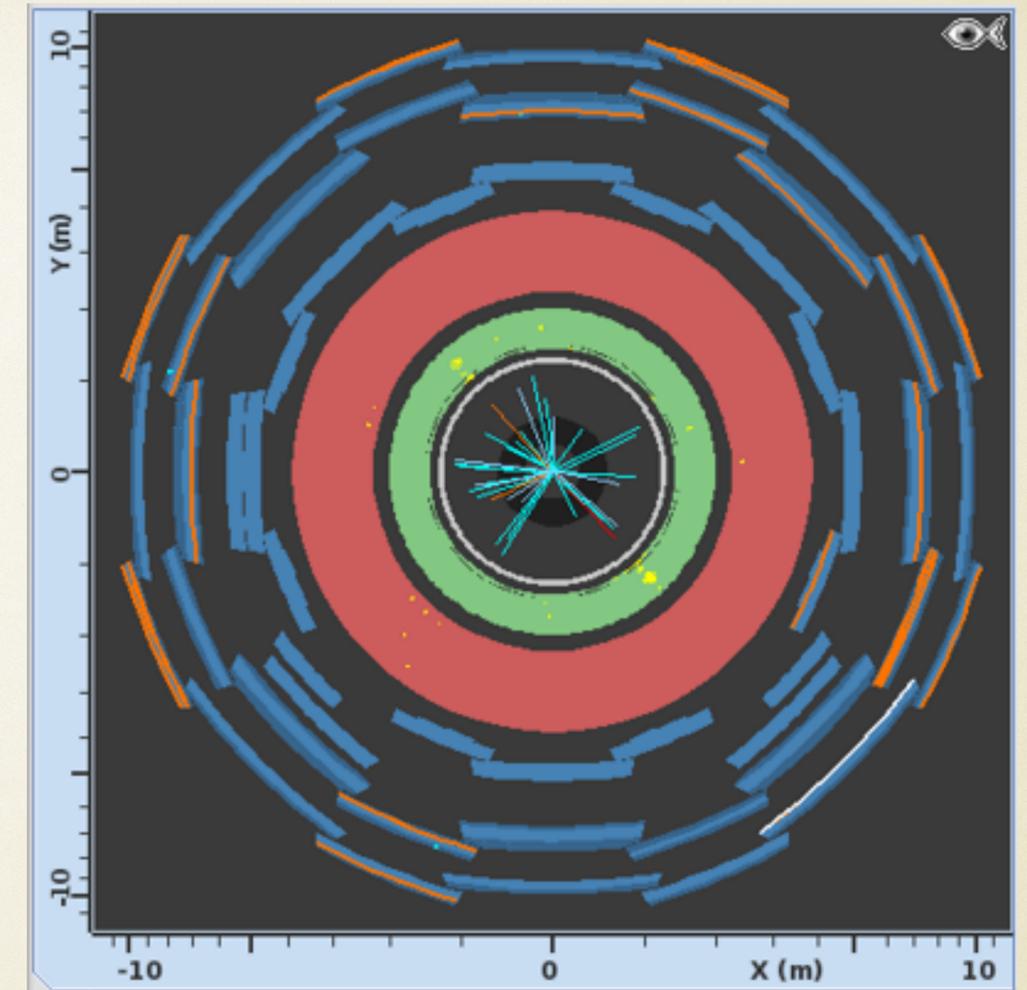
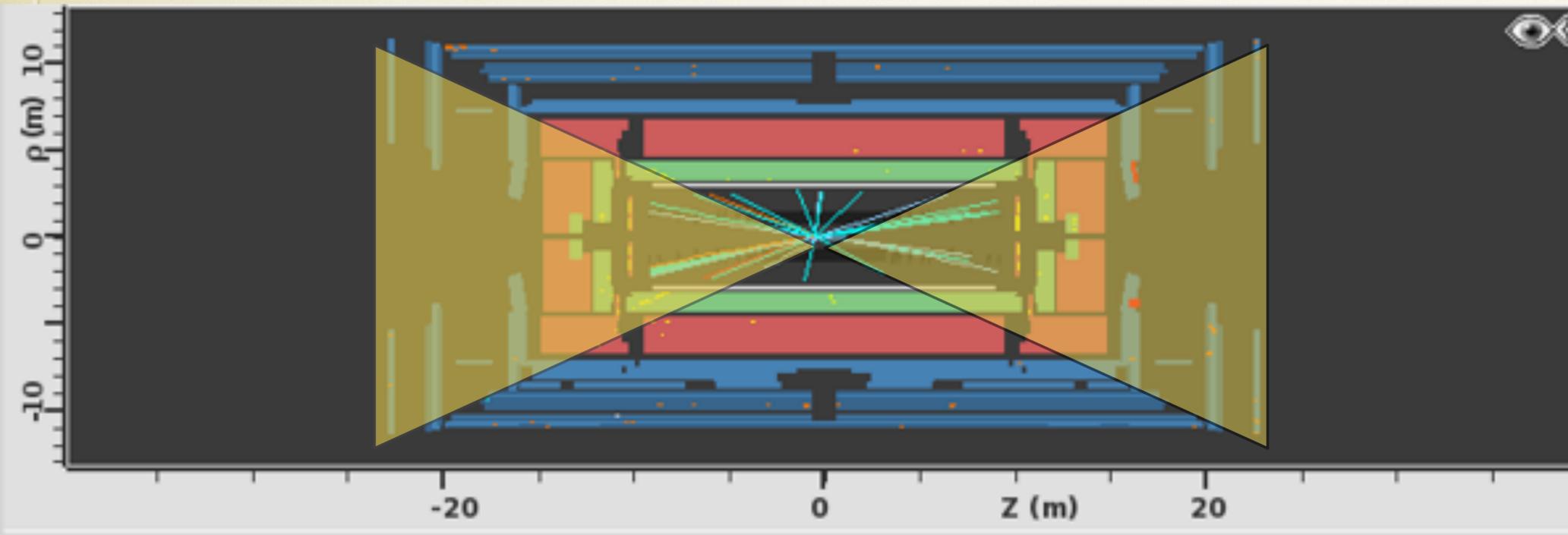
Calorimetro elettromagnetico:
elettroni (e^-), positroni (e^+) e
fotoni.

Calorimetro adronico: adroni
(es: protoni, neutroni)

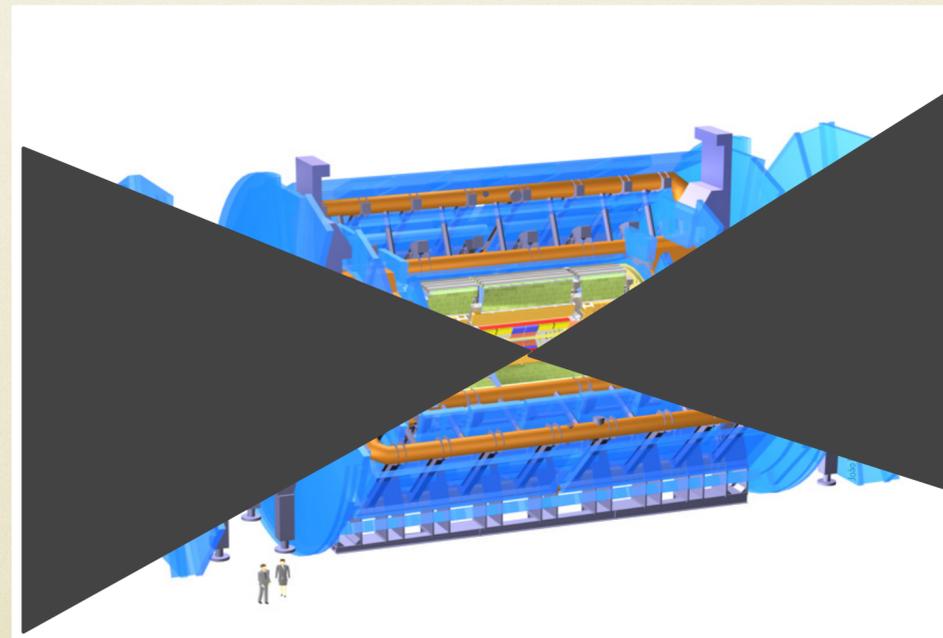
Rivelatori muoni



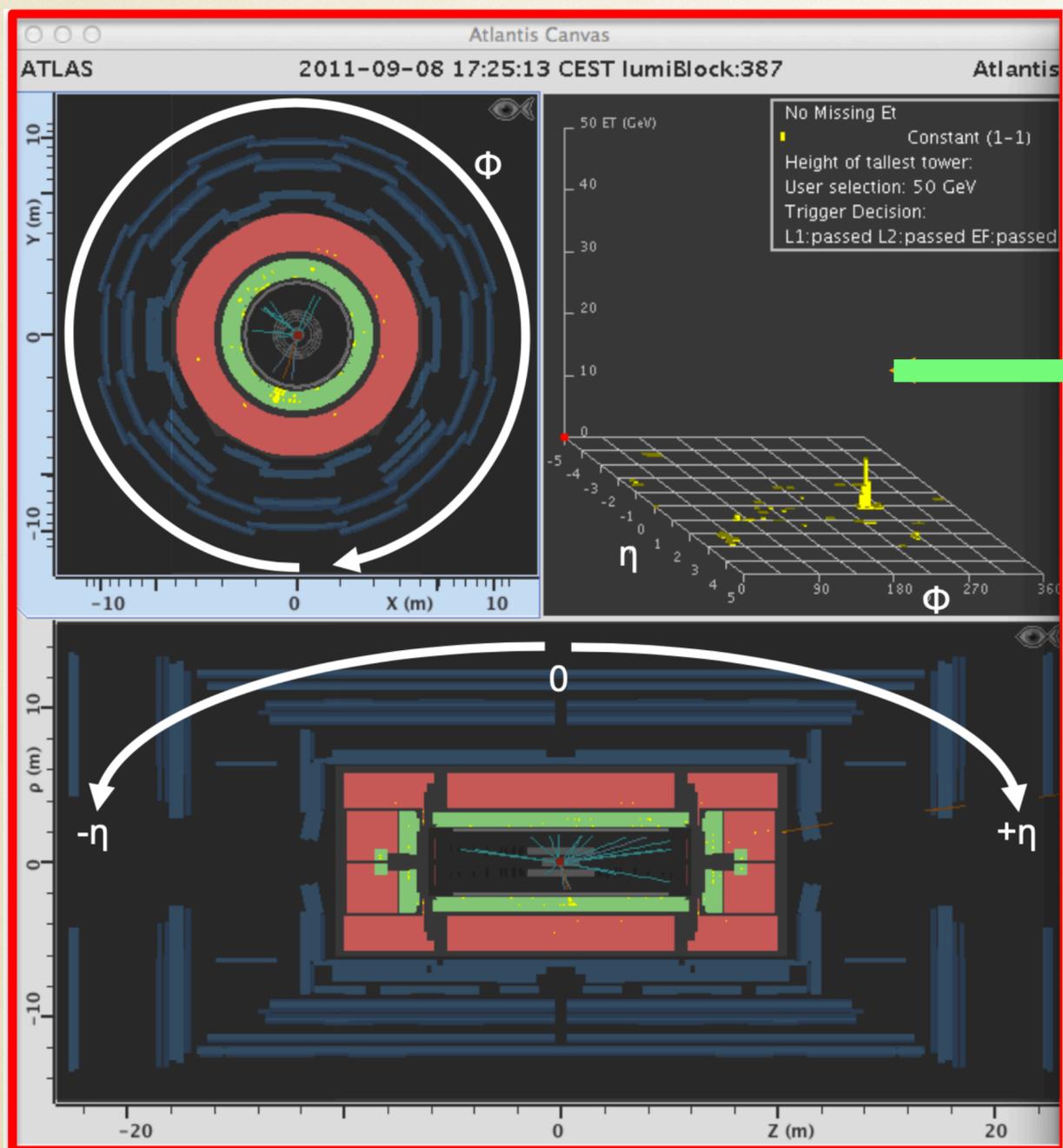
Event display



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



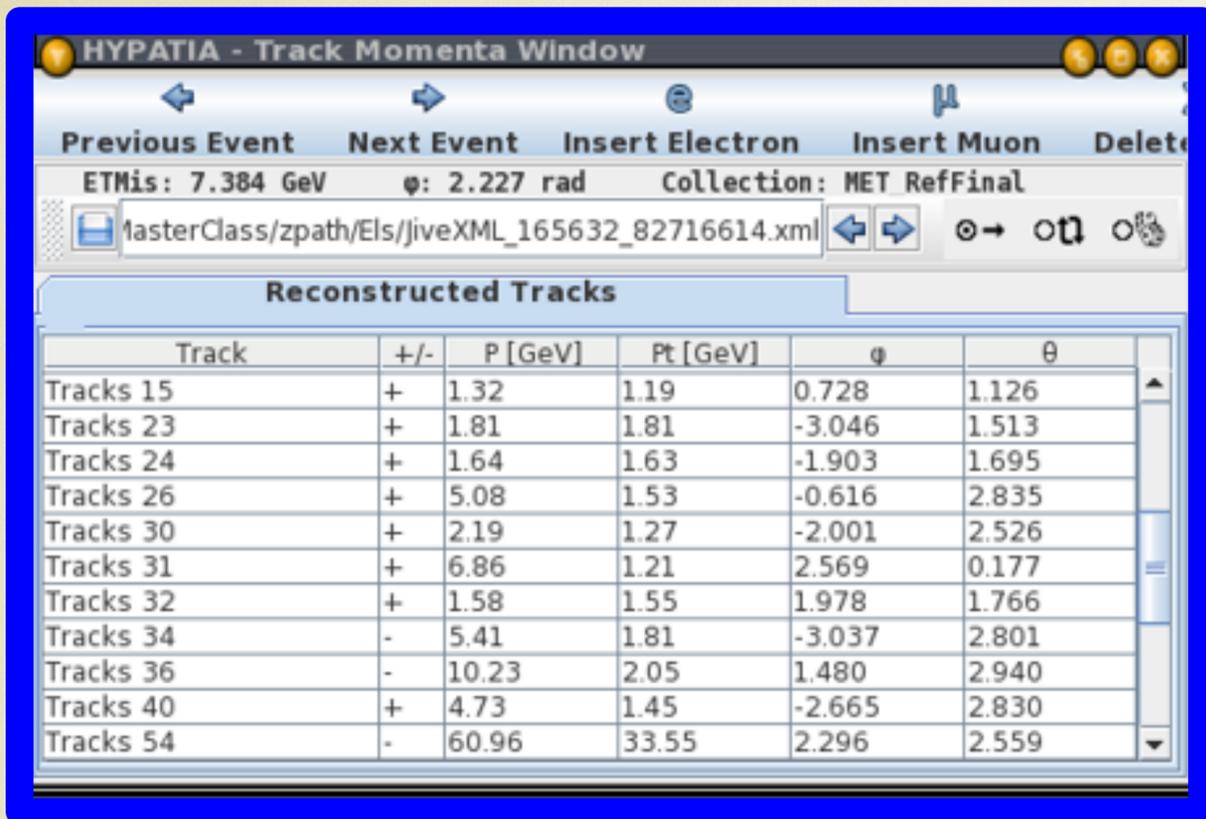
Event display



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

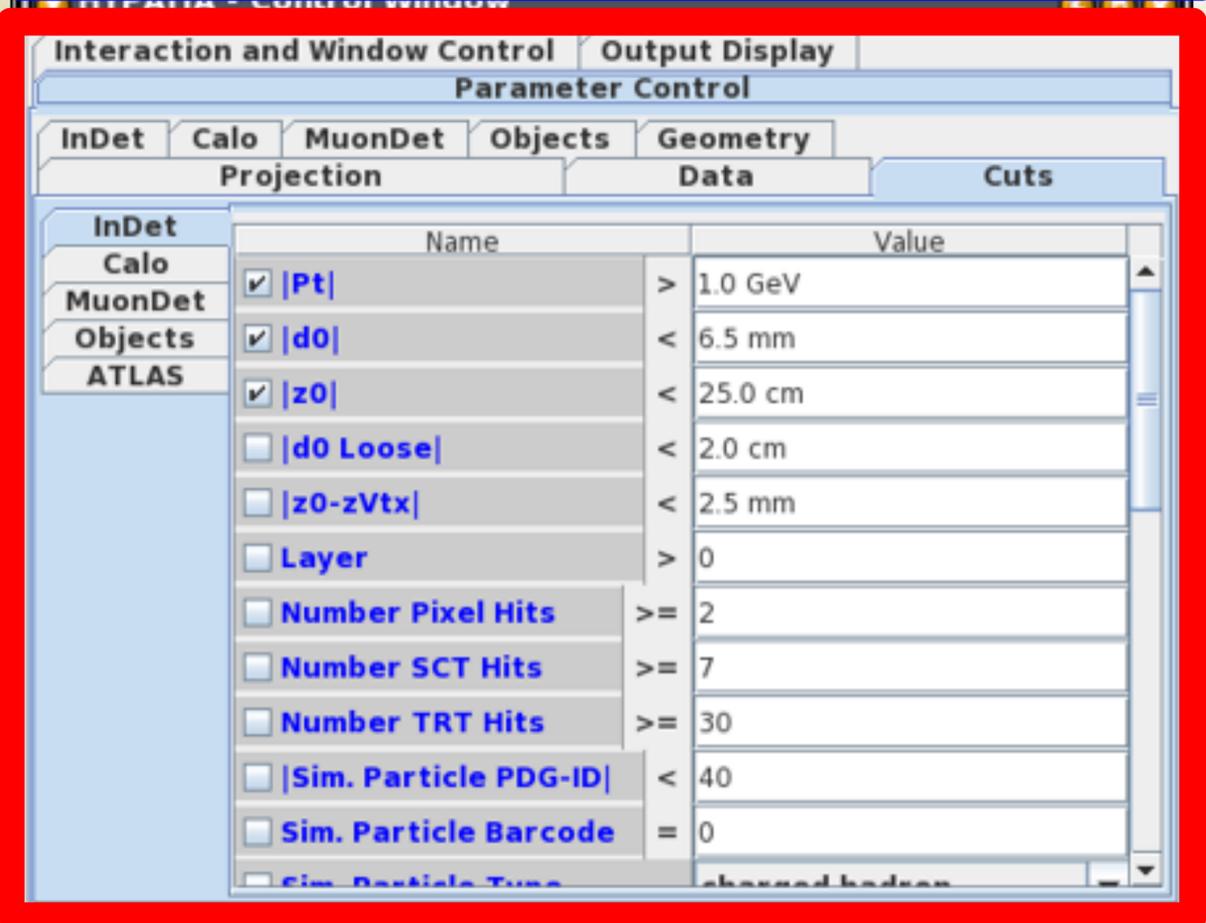
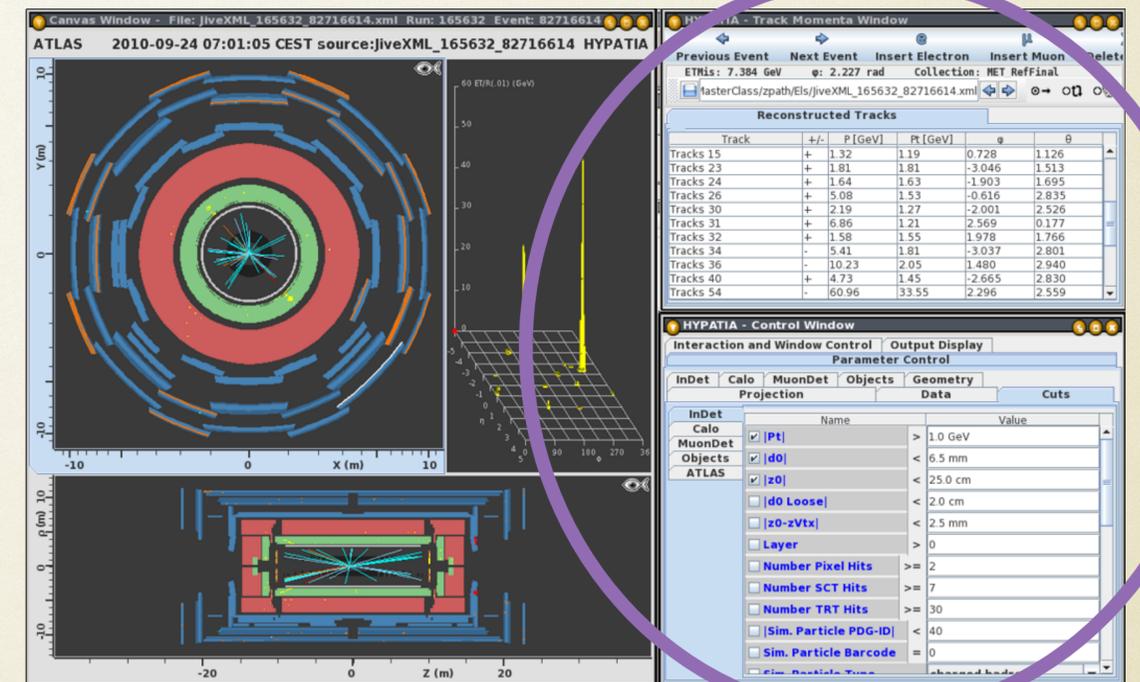
Selezione degli eventi

Particelle selezionate



Reconstructed Tracks

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



Interaction and Window Control

Parameter Control

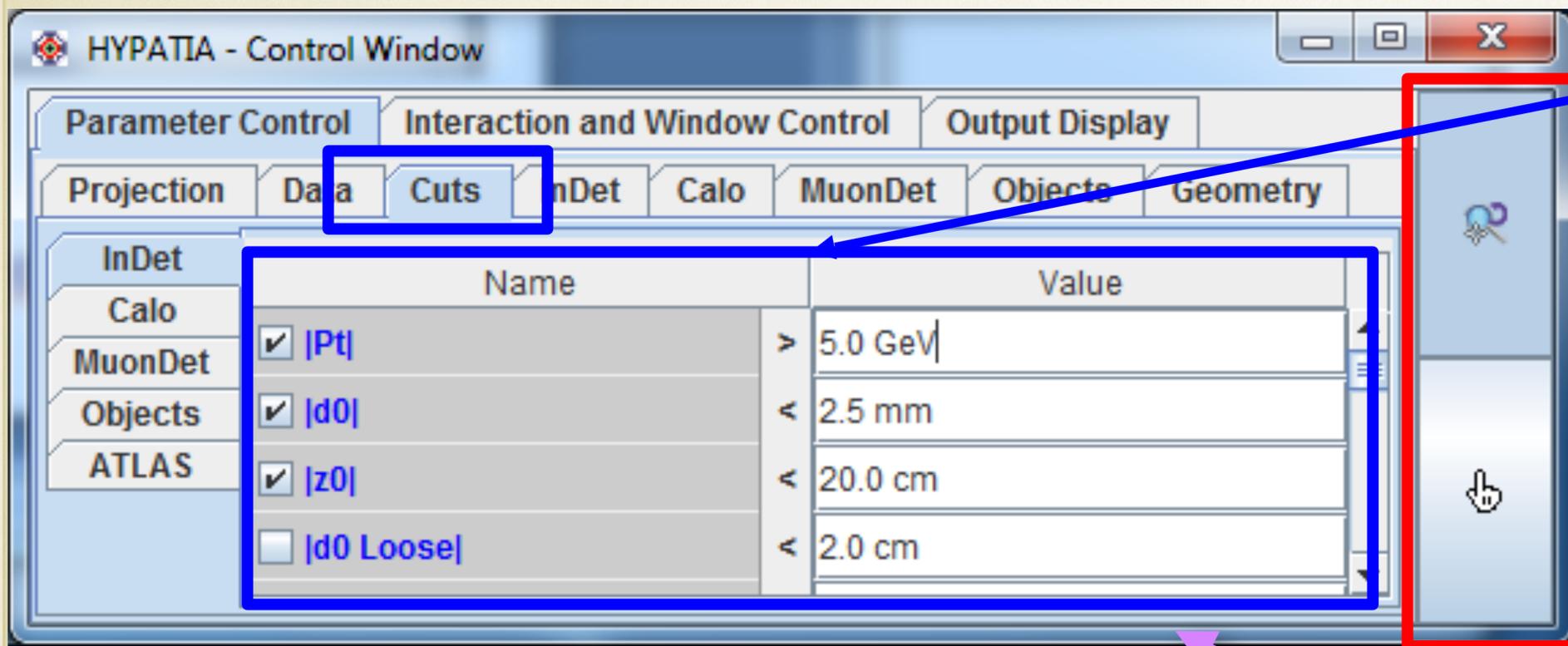
Projection	Name	Data	Cuts
InDet			
Calo	<input checked="" type="checkbox"/> Pt	>	1.0 GeV
MuonDet			
Objects	<input checked="" type="checkbox"/> d0	<	6.5 mm
ATLAS	<input checked="" type="checkbox"/> z0	<	25.0 cm
	<input type="checkbox"/> d0 Loose	<	2.0 cm
	<input type="checkbox"/> z0-zVtx	<	2.5 mm
	<input type="checkbox"/> Layer	>	0
	<input type="checkbox"/> Number Pixel Hits	>=	2
	<input type="checkbox"/> Number SCT Hits	>=	7
	<input type="checkbox"/> Number TRT Hits	>=	30
	<input type="checkbox"/> Sim. Particle PDG-ID	<	40
	<input type="checkbox"/> Sim. Particle Barcode	=	0
	<input type="checkbox"/> Sim. Particle Type		charged hadron

Tagli sull'impulso



impulso $P = \text{massa} \times \text{velocità}$ [vettore]
impulso trasverso $P_t = \text{proiezione nel piano } xy \text{ dell'impulso } p$

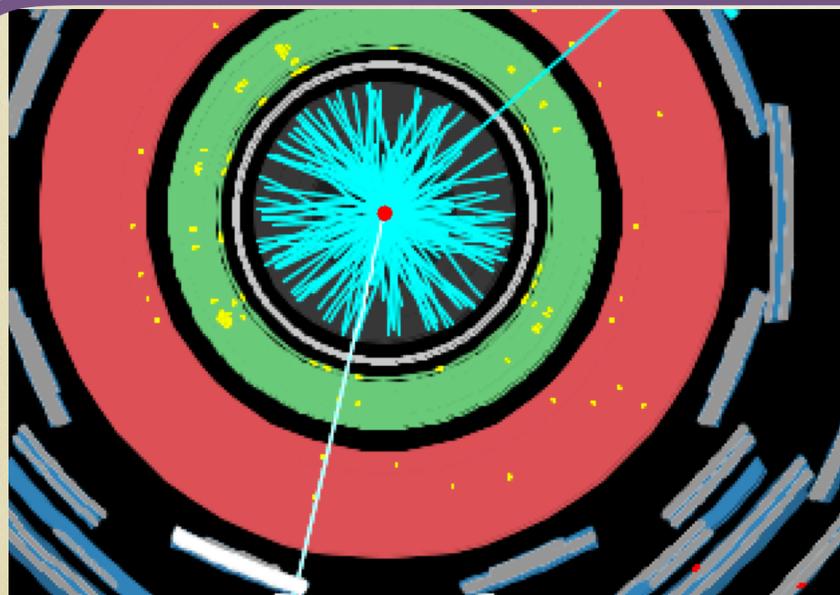
Selezione degli eventi



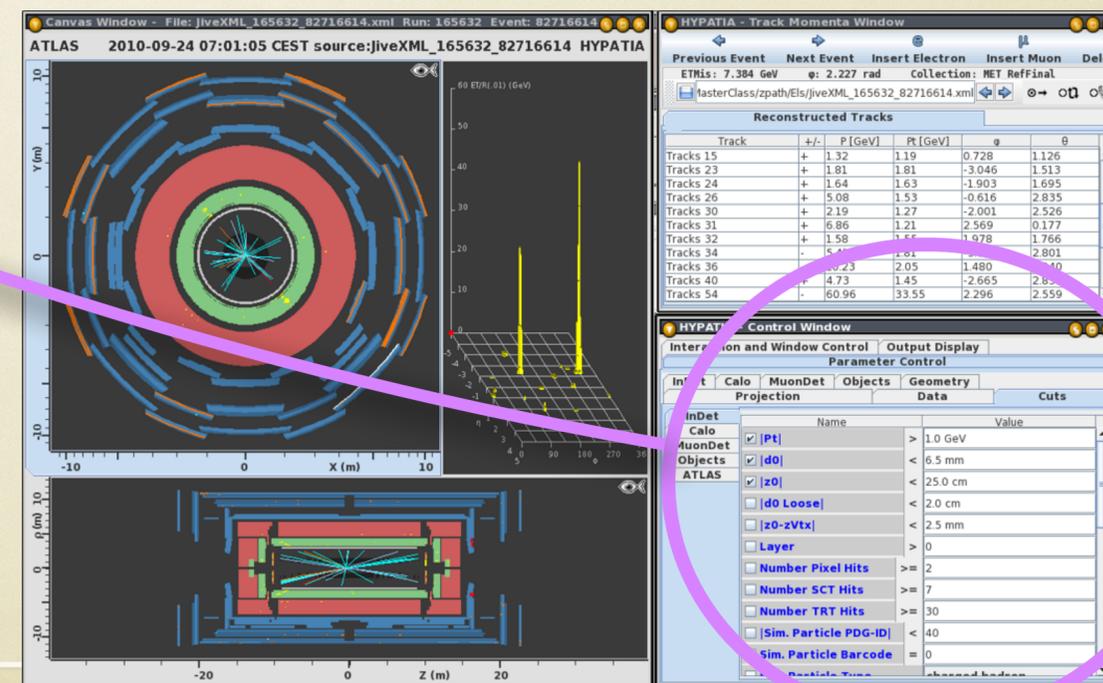
Tagli: criteri di selezione degli eventi

Zoom/Move/Rotate

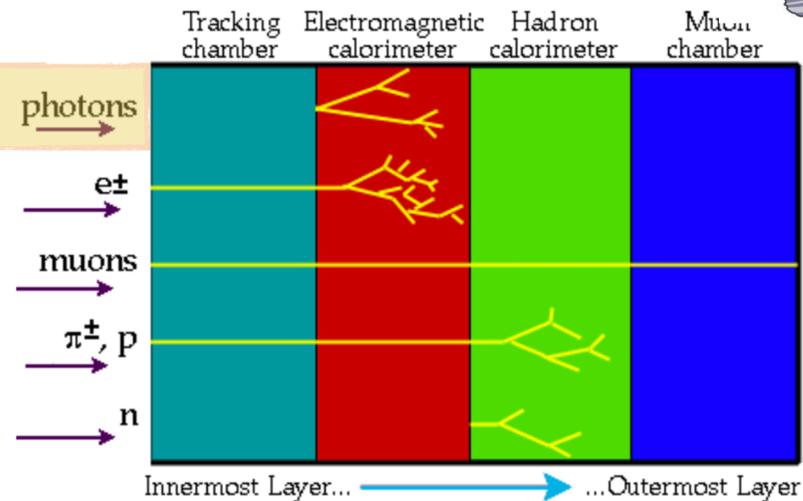
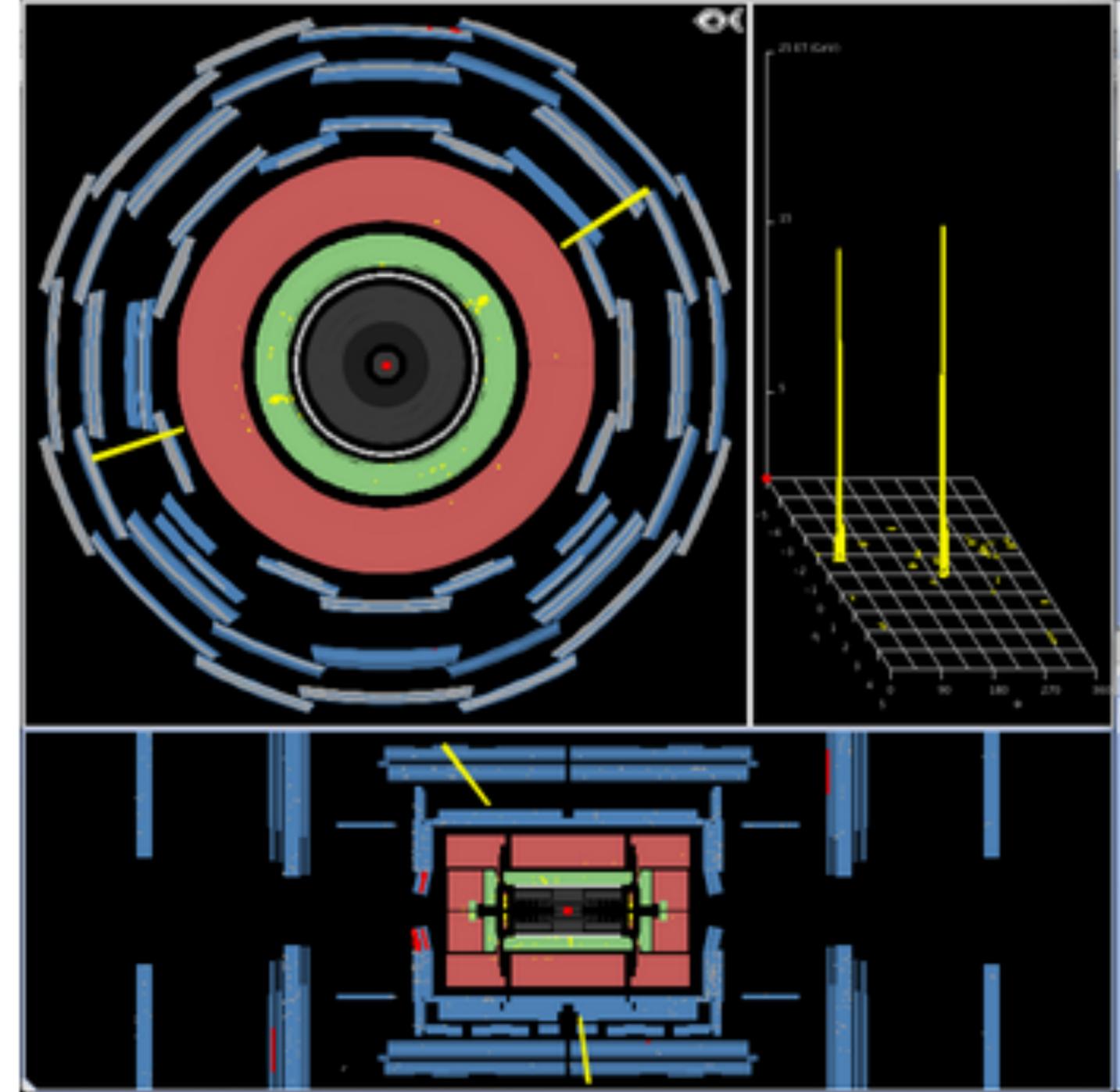
Mostra informazioni per l'oggetto selezionato



Evento senza tagli in Pt !!!



Carta di Identita' del FOTONE



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

Carta di Identita' dell' ELETTRONE



REPUBBLICA ITALIANA
MINISTERO DELL'INTERNO
CARTA DI IDENTITÀ / IDENTITY CARD
COMUNE / MUNICIPALITY

CA00000XX



Electron

COGNOME / SURNAME

Electrone

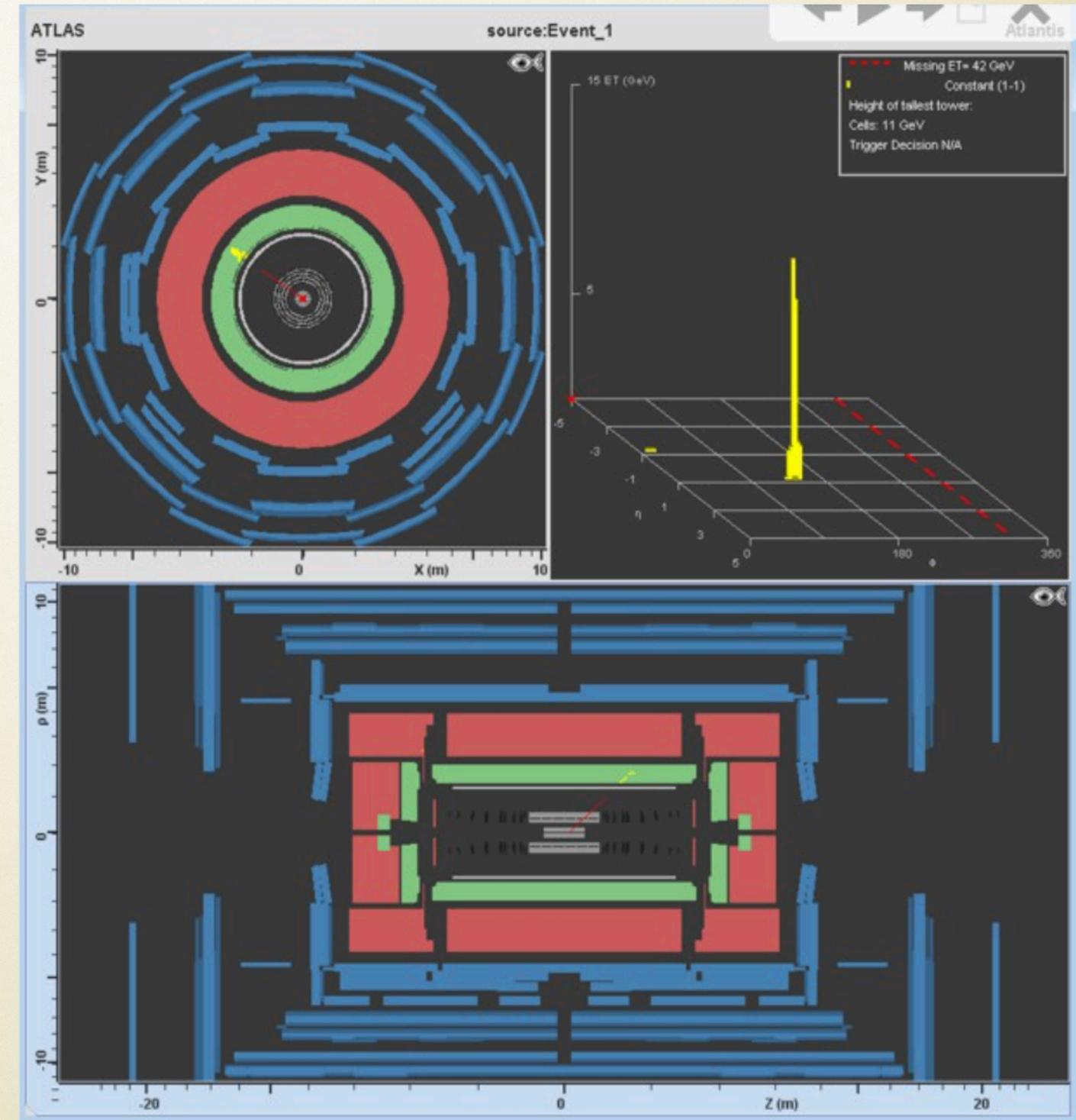
CITTADINANZA
NATIONALITY

SCADENZA / EXPIRY

00000

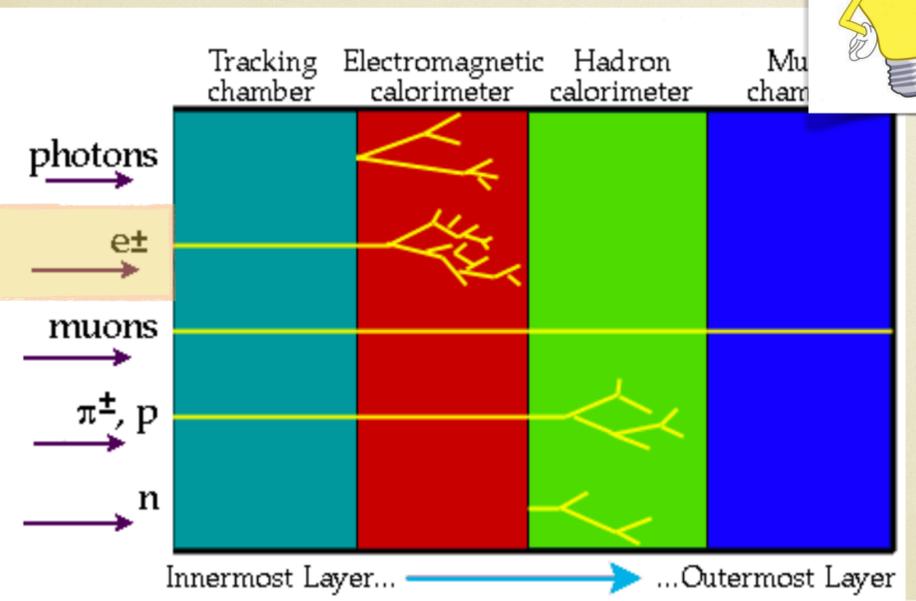
NON VALIDA PER L'ESPATRIO

Mass 0,5 MeV/c²
Charge -
Spin 1/2

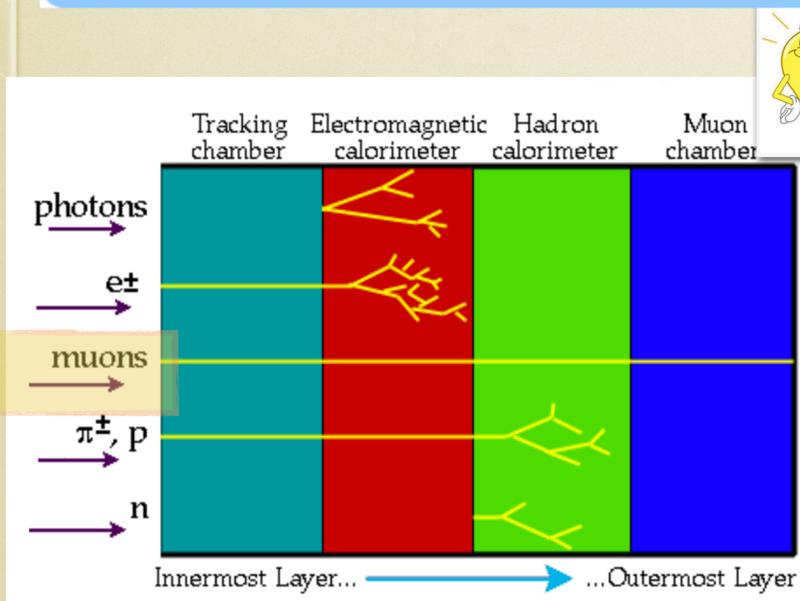
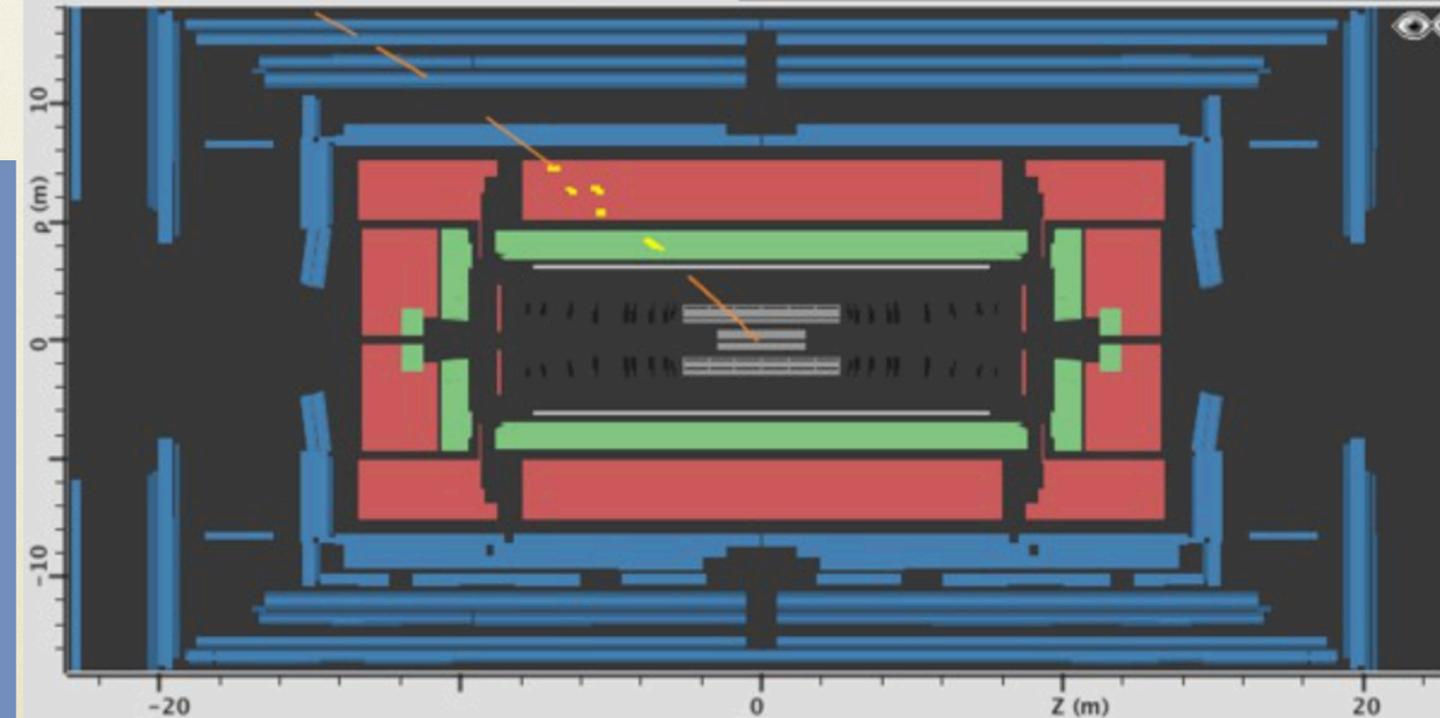
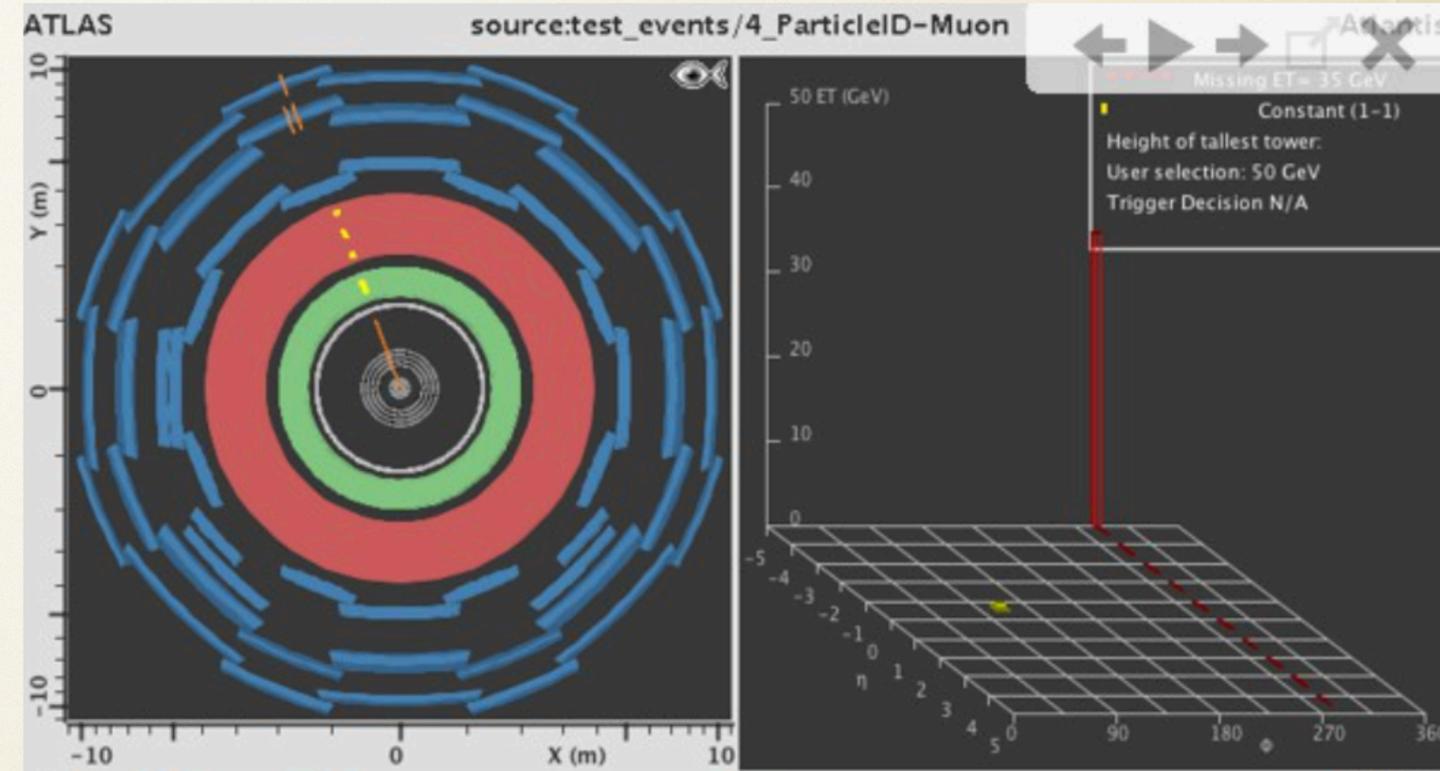


Lascia una traccia nel rivelatore interno

- Deposita tutta la sua energia nel Calorimetro Elettromagnetico



Carta di Identita' del MUONE



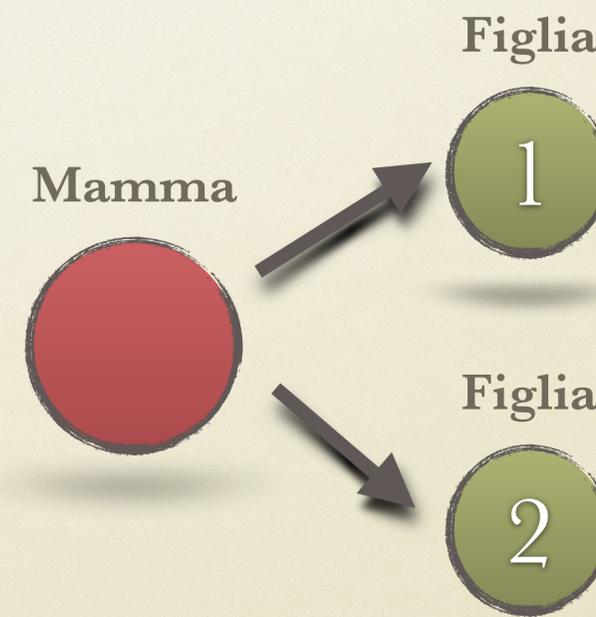
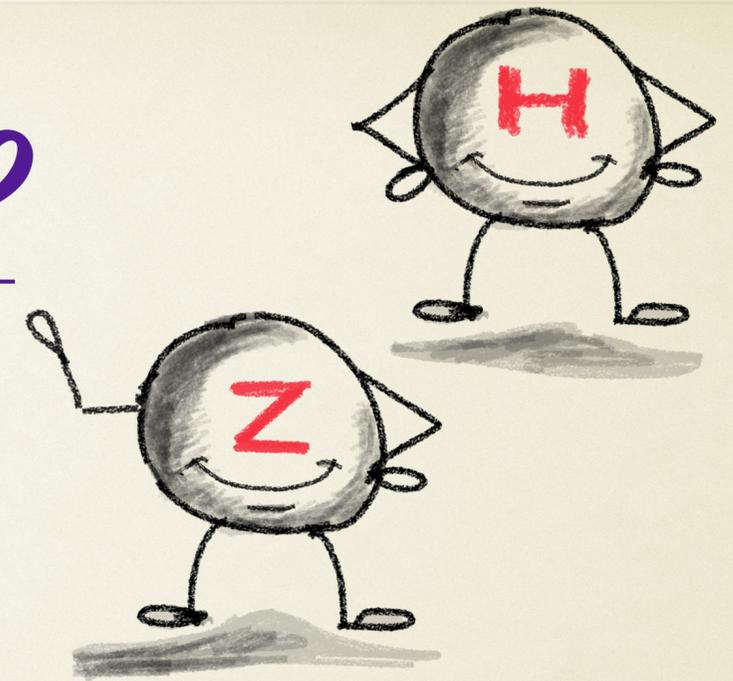
Lascia traccia nel rivelatore interno

- 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** per cui **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)**



Distribuzione della massa della particella mamma



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

Il Bosone Z

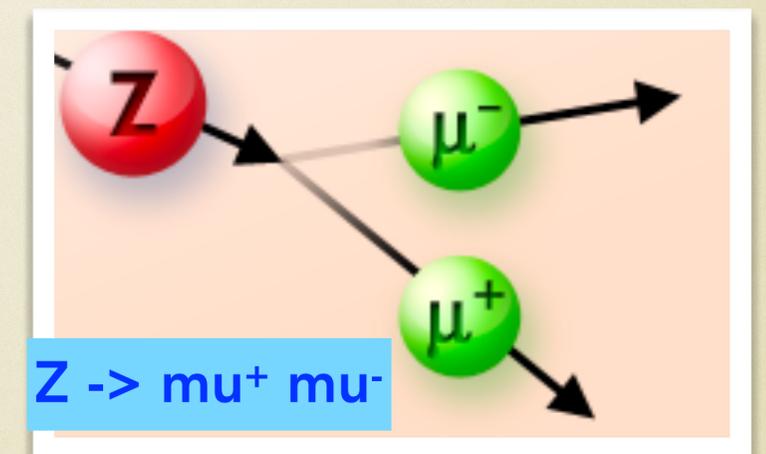
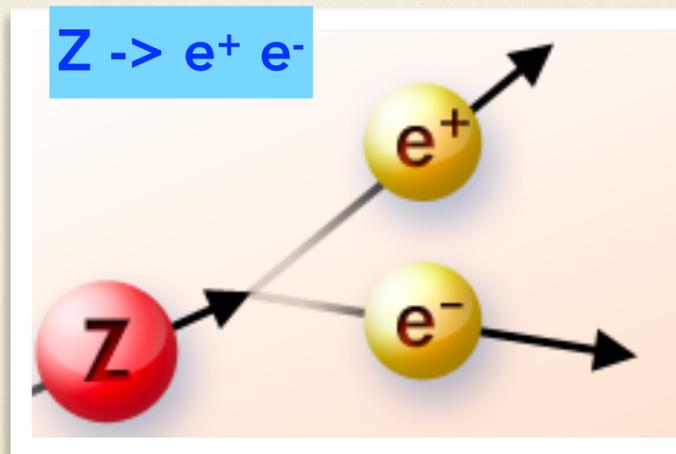


NB: Z e' neutro!
Le due particelle figlie devono avere carica opposta

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)

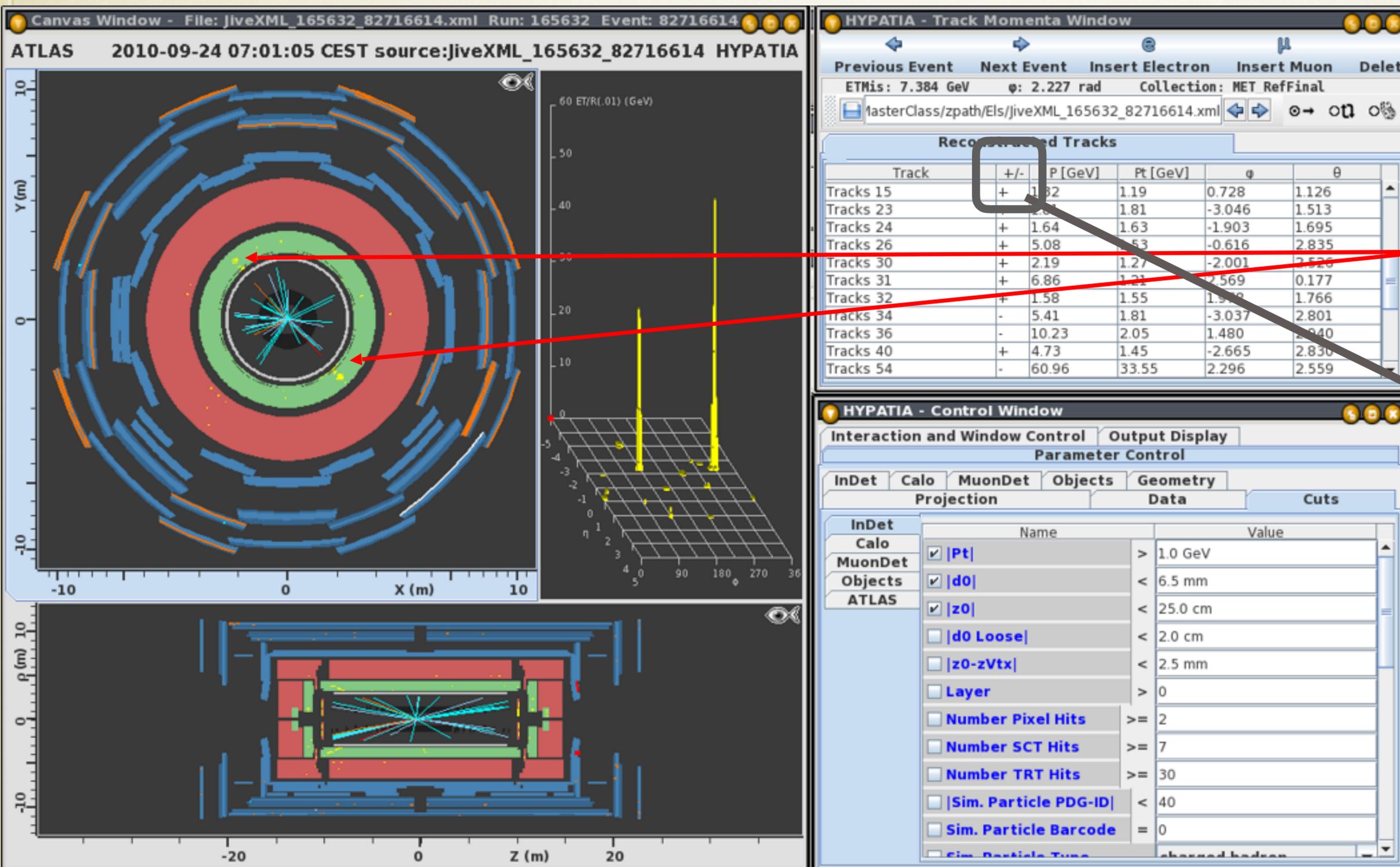


$$Z \rightarrow e^- e^+$$

Il bosone Z è neutro.

Elettrone e positrone

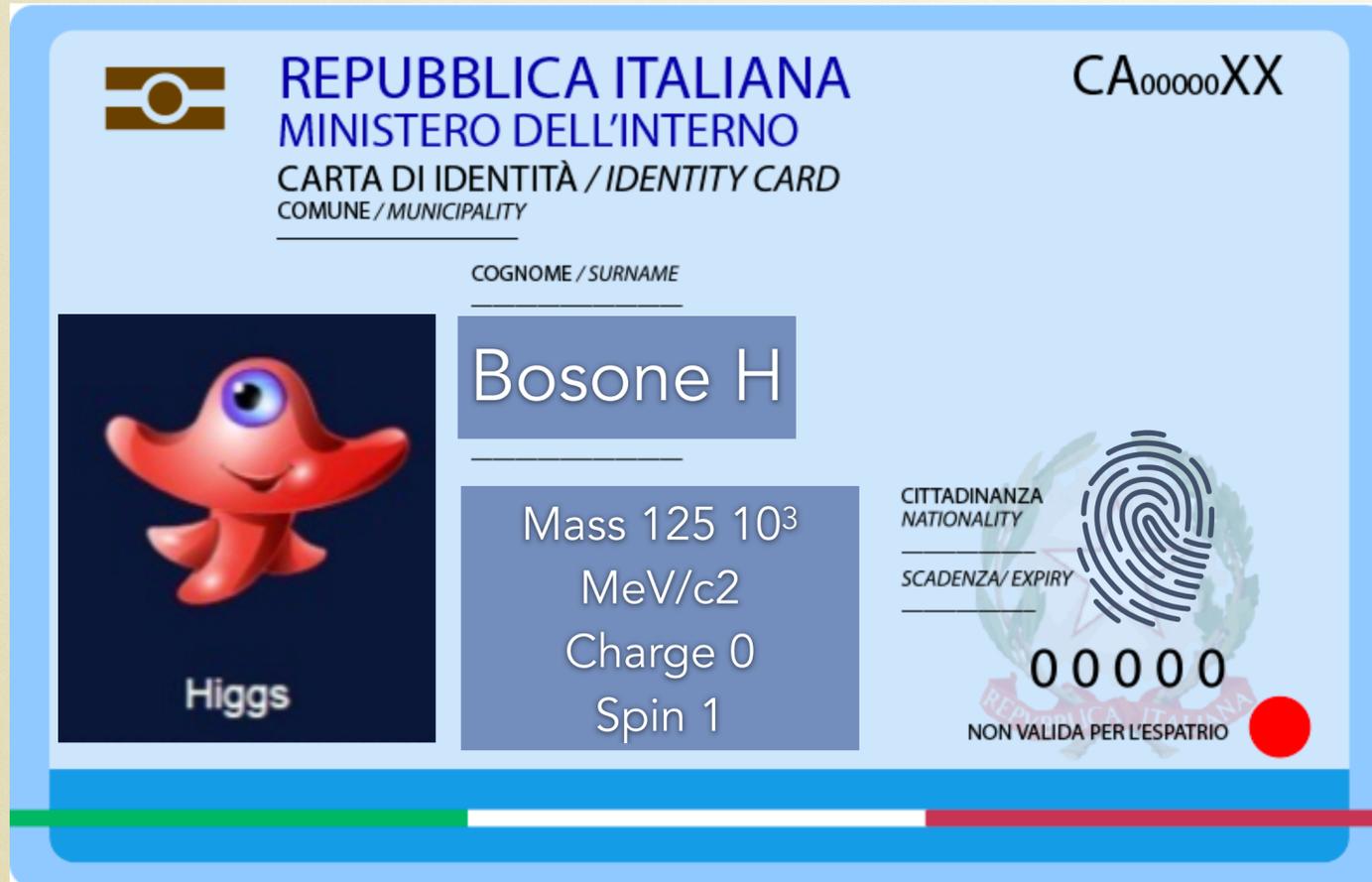
I segni delle due particelle devono essere opposti



Il Bosone H

NB: H e' neutro!

Le quattro particelle figlie devono avere carica totale zero!!!

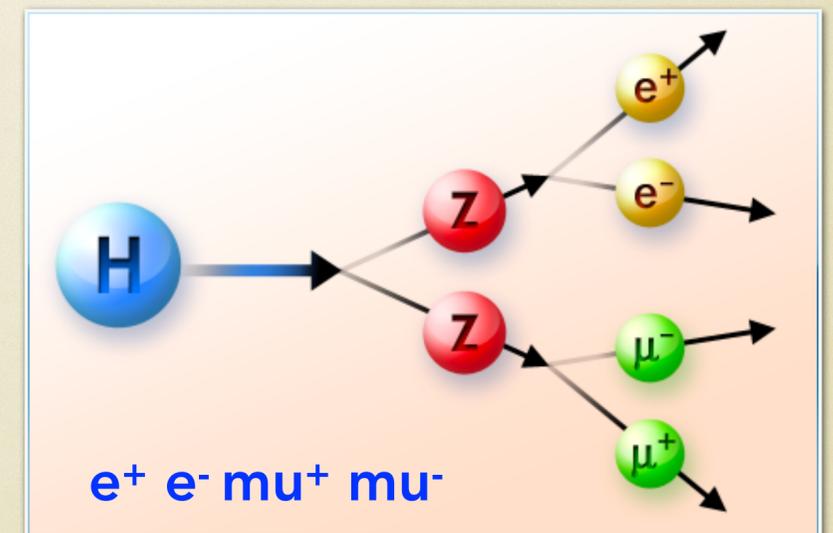


Il Bosone Higgs e' anche lui molto pesante e decade in coppie di fermione-antifermione e coppie di bosoni:

Nel nostro esercizio ci aspettiamo di "vedere":

- **Z Z (coppie di Z)**
 - Ricordiamoci che la Z a sua volta decade per cui questo decadimento dell'Higgs in coppie di Z può essere "visto" trovando:

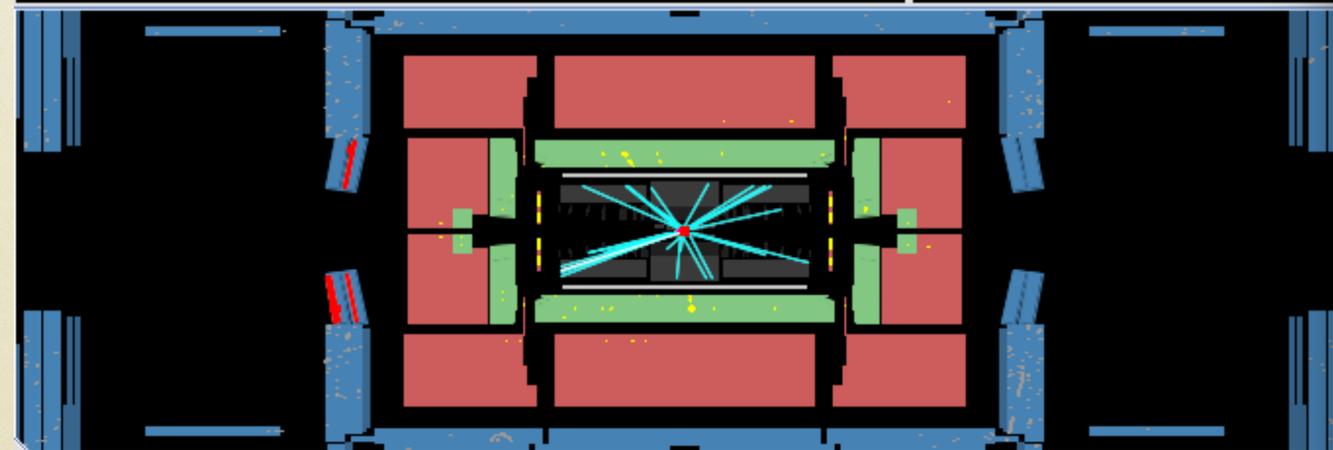
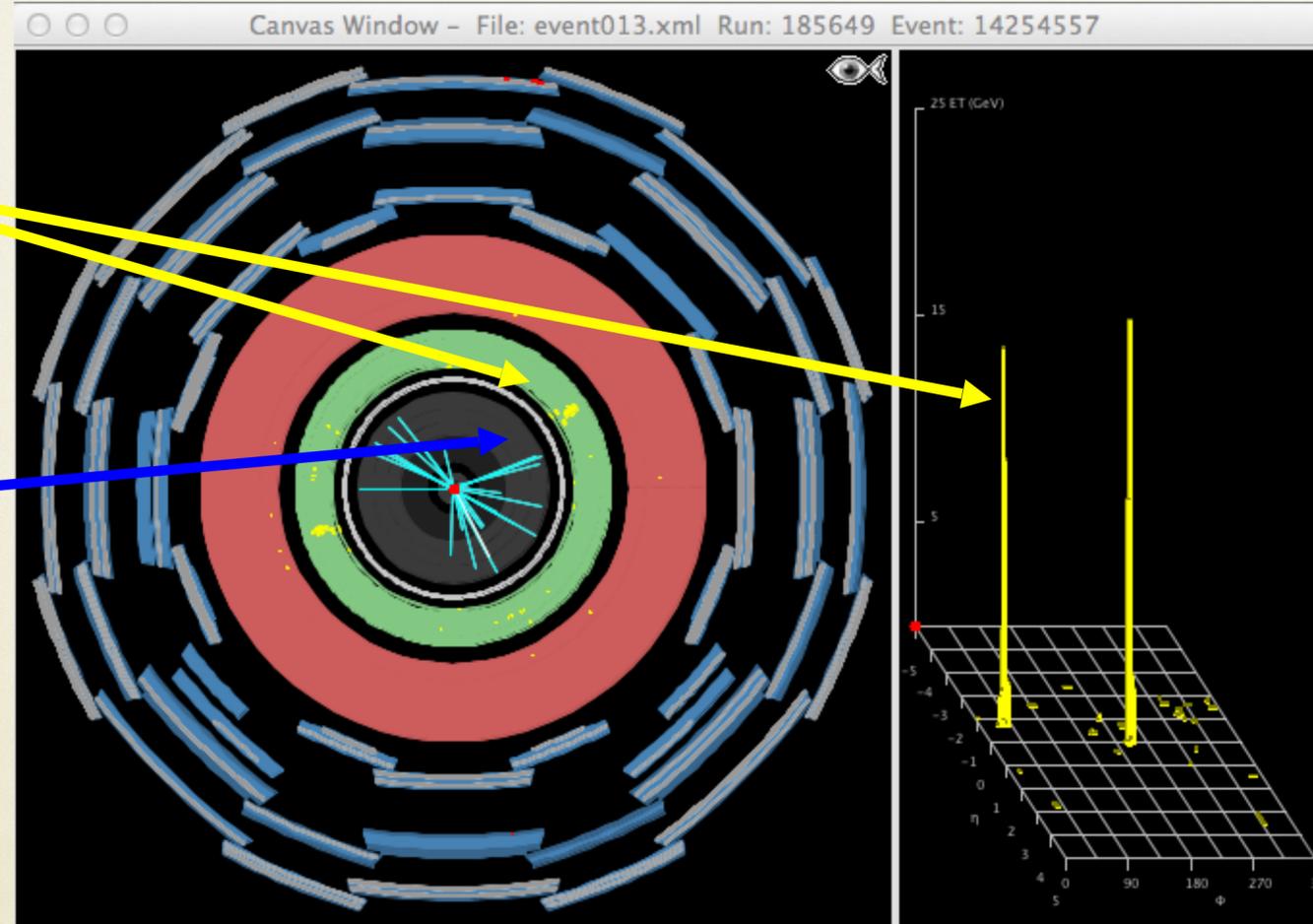
- $e^+ e^- e^+ e^-$
- $e^+ e^- \mu^+ \mu^-$
- $\mu^+ \mu^- \mu^+ \mu^-$
- **$\gamma\gamma$ (Coppie di fotoni)**



Higgs → fotone - fotone

Energia nel
**calorimetro
elettromagnetico**

No tracce vicino ai
depositi → non
sono elettroni



HYPATIA - Track Momenta Window

ETMis: 13.073 GeV ϕ : 3.120 rad Collection: MET_RefFinal

events/group04.zip/event013.xml

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

HYPATIA - Control Window

Parameter Control Interaction and Window Control Output Display

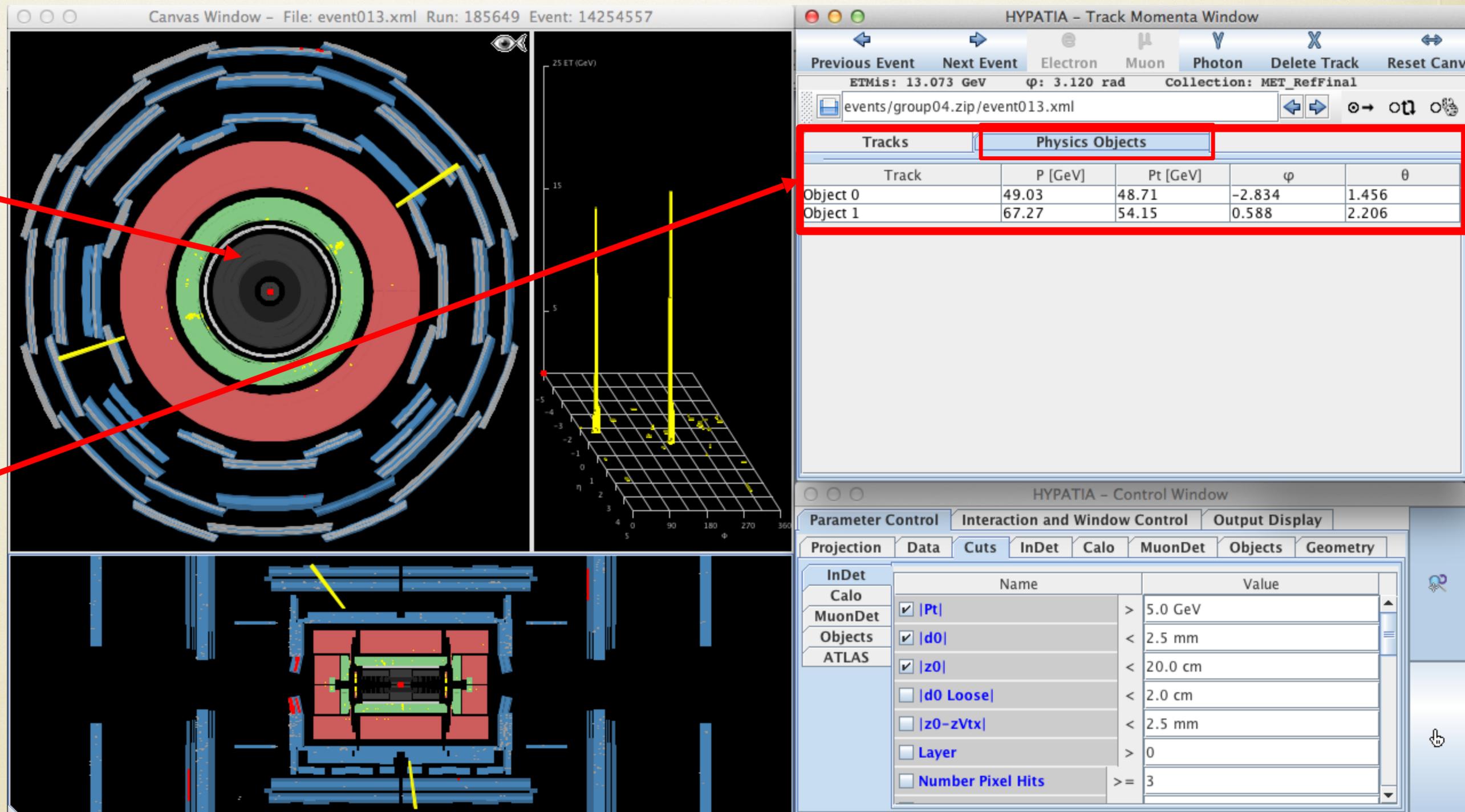
Projection Data Cuts InDet Calo MuonDet Objects Geometry

InDet	Name	Value
Calo	<input checked="" type="checkbox"/> Pt	> 1.0 GeV
Calo	<input checked="" type="checkbox"/> d0	< 2.5 mm
Calo	<input checked="" type="checkbox"/> z0	< 20.0 cm
Calo	<input type="checkbox"/> d0 Loose	< 2.0 cm
Calo	<input type="checkbox"/> z0-zVtx	< 2.5 mm
Calo	<input type="checkbox"/> Layer	> 0
Calo	<input type="checkbox"/> Number Pixel Hits	>= 3

Higgs → fotone - fotone

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

I fotoni sono fra i "Physics Objects"

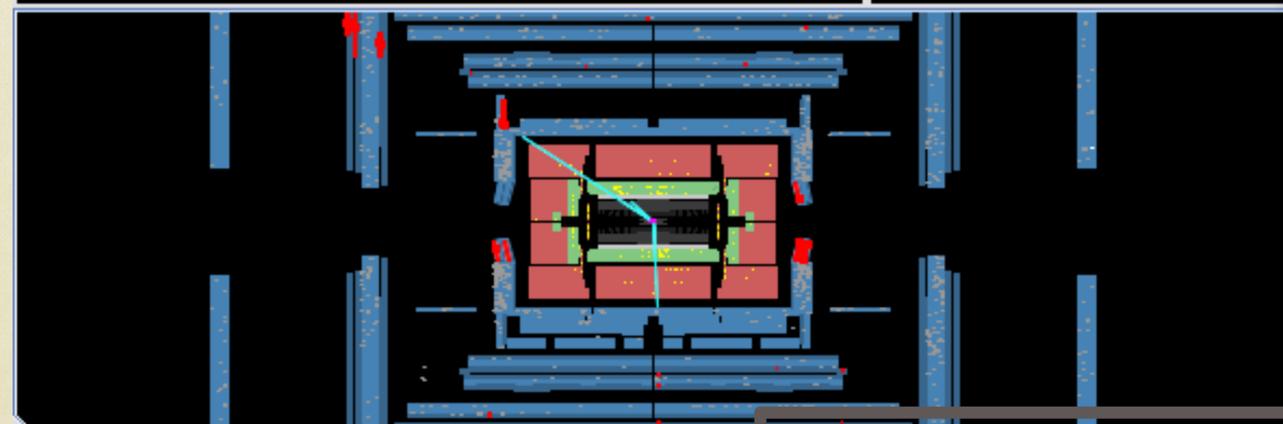
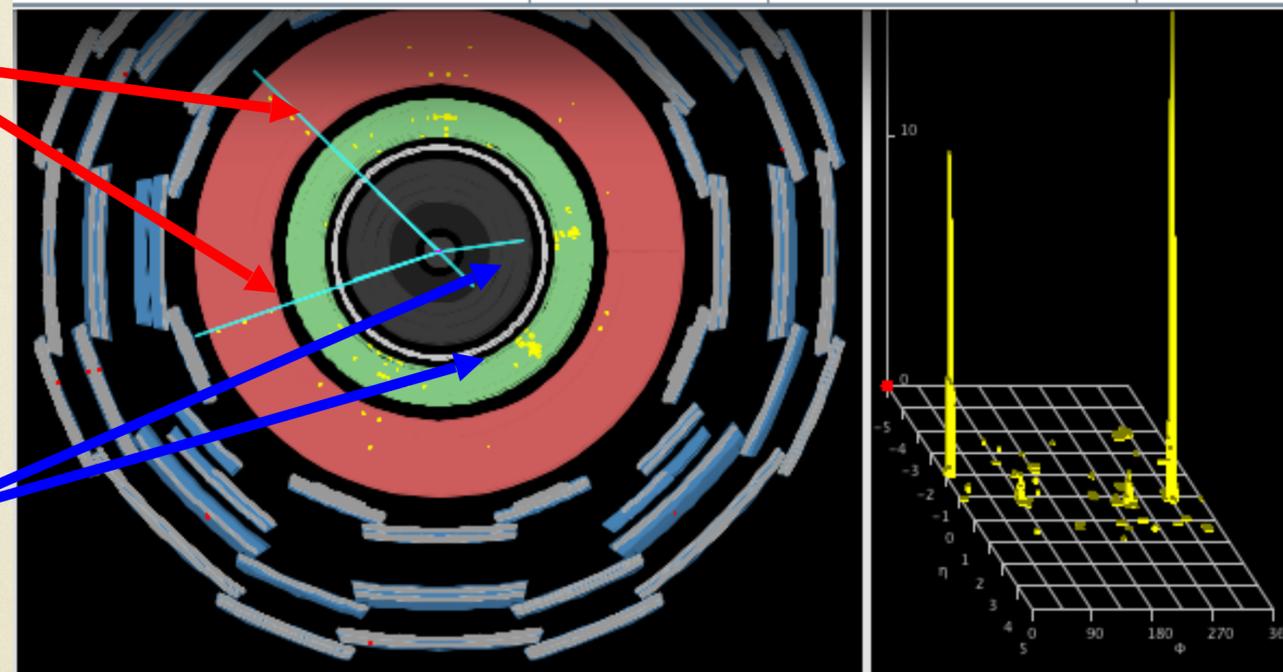


Higgs → 4 particelle cariche

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

Il bosone H è neutro.

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	-	75.79	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

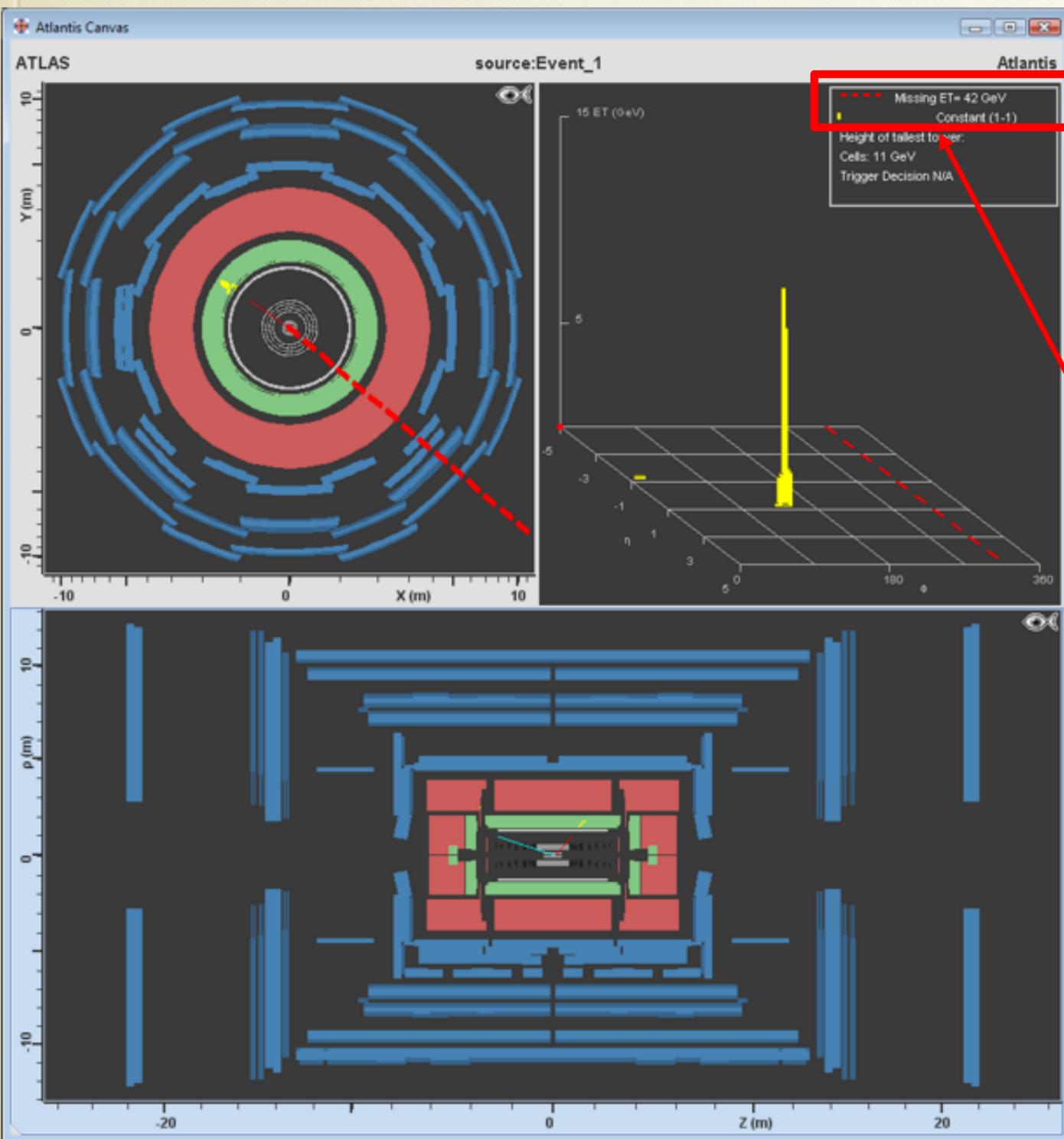
InDet	Name	Value
Calo	Pt	> 12.0 GeV
MuonDet	d0	< 2.5 mm
Objects	z0	< 20.0 cm
ATLAS	d0 Loose	< 2.0 cm
	z0-zVtx	< 2.5 mm
	Layer	> 0

$\mu^+\mu^-$

e^+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!

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

The screenshot displays the HYPATHIA software interface, which is used for analyzing particle interactions. The main window, titled "HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window", features a menu bar (File, View, Histograms, Preferences, Help) and a toolbar with various analysis options. The central area shows a detector simulation with tracks and physics objects. An "Open" dialog box is overlaid on the main window, showing the file selection process. The dialog box is set to the "MasterClass2021" directory and lists several files, including "groupM.zip". The "File Name" field is filled with "groupM.zip" and the "Files of Type" dropdown is set to ".xml, .zip, .gzip, .gz". The "Open" button is highlighted with a green arrow. Another green arrow points from the "Open" dialog box to the "HYPATHIA - Track Momenta Window", which shows the loaded event file "events/events4.zip/JiveXML_106051_1950731.xml" and a table of track parameters.

Track	+/-	P [GeV]	Pt [GeV]	φ	θ
Tracks 0	-	11.68	4.28	-1.319	0.375
Tracks 1	+	126.06	39.41	-2.413	0.318
Tracks 2	+	4.57	4.56	-2.783	1.649
Tracks 3	-	167.90	53.01	0.906	0.321
Tracks 4	-	1.34	1.33	-2.949	1.475
Tracks 5	-	1.75	1.74	-3.090	1.645
Tracks 6	+	18.61	3.94	-1.818	0.214

The "HYPATHIA - Control Window" at the bottom right shows the "Data" tab with a list of checked parameters: Status, InDet, Calo, MuonDet, and Objects.

Come Selezioniamo le tracce?

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

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

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 muone, 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 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

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

ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	ϕ	η	M(2) [GeV]	M(e)	M(eemm) [GeV]	M(mmmm) [GeV]	e/m/g
21.013	Object 0	58.2		42.5	2.252	0.837	145.215				g
	Object 1	98.9		35.2	-0.143	-1.692					g

HYPATIA - Track Momenta Window

Track	P [GeV]	Pt [GeV]	ϕ	θ
Object 0	58.25	42.49	2.252	0.817
Object 1	98.92	35.22	-0.143	2.778

Parameter Control

Name	Value
[d0 Loose]	< 2.0 cm
[z0-zVtx]	< 2.5 mm
Layer	> 0
Number Pixel Hits	>= 2
Number SCT Hits	>= 7
Number TRT Hits	>= 15

2

HYbrid Pupils' Analysis Tool for Interactions in ATLAS

File View Histograms Preferences Help

- Read Event Locally
- Read Event From URL (live)
- Clear Hypatia Project
- Load Hypatia Project
- Save Hypatia Project
- Export Invariant Masses**
- Loop over events
- Save Image of Canvas
- Animated Event
- Event Properties
- Read Geometry
- Read G4Steps
- Exit

3

HYbrid Pupils' Analysis Tool for Interactions in ATLAS

File View Histograms Preferences Help

File Name	ETMis [GeV]	Track	P [GeV]	+/-	Ge
event050.xml	21.013	Object 0	58.2		
		Object 1	98.9		

Save

Save In: MasterClass2021

- configuration
- events
- geometry
- help
- img
- lib

File Name: Invariant_Masses.txt

Files of Type: Text files

Save Cancel

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-US/index.php>

BACK UP