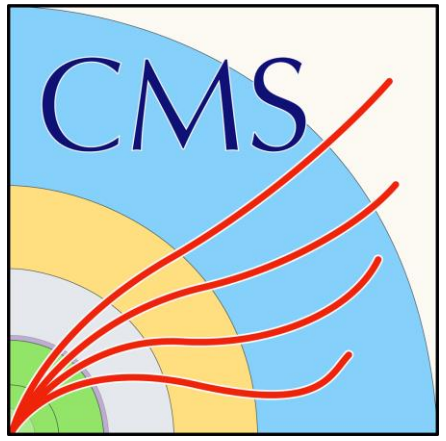


Introduzione all'Esercizio

25/02/2025

A. Lapertosa

Fisica delle particelle: Modello Standard

Quark

u up	c charm	t top
d down	s strange	b beauty

Leptoni

e elettrone	μ muone	τ tau
ν_e neutrino	ν_μ neutrino	ν_τ neutrino

Bosoni

W

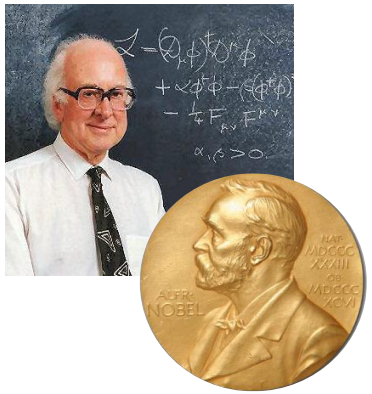
Z

g gluone

γ fotone

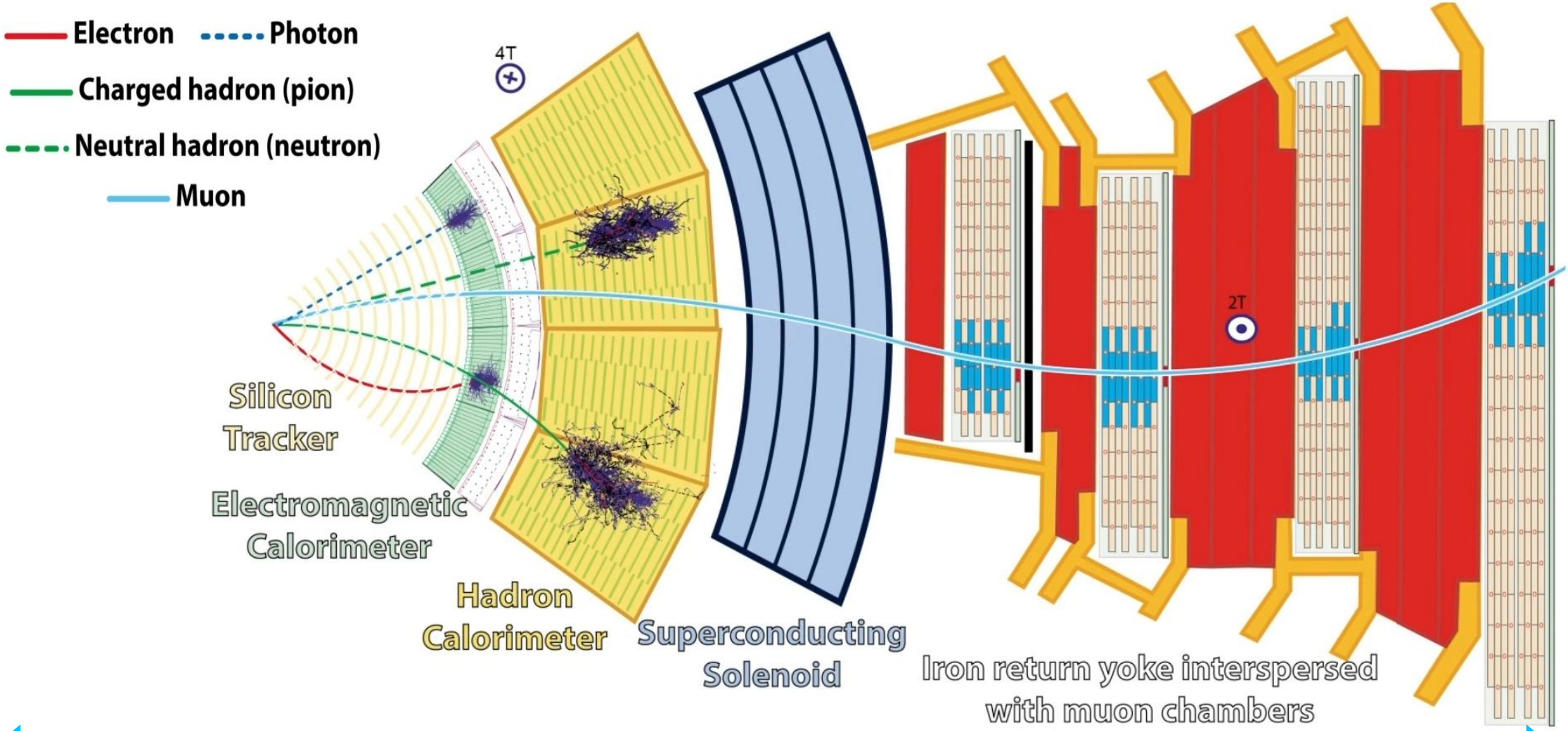
H Higgs

Higgs

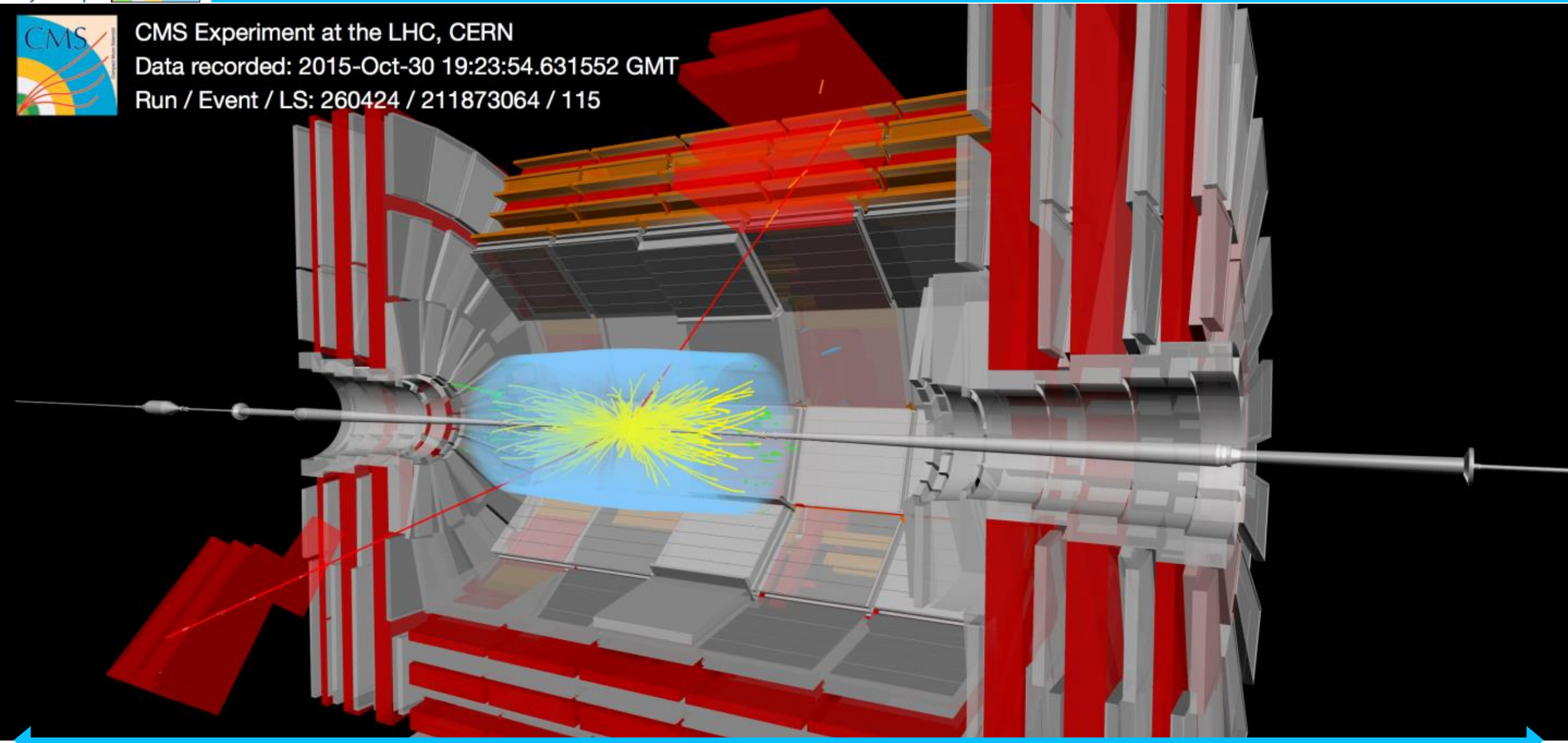


Una fetta di CMS

Rivelatori di particelle: l'esperimento CMS



Le collisioni dentro l'esperimento CMS



Le collisioni

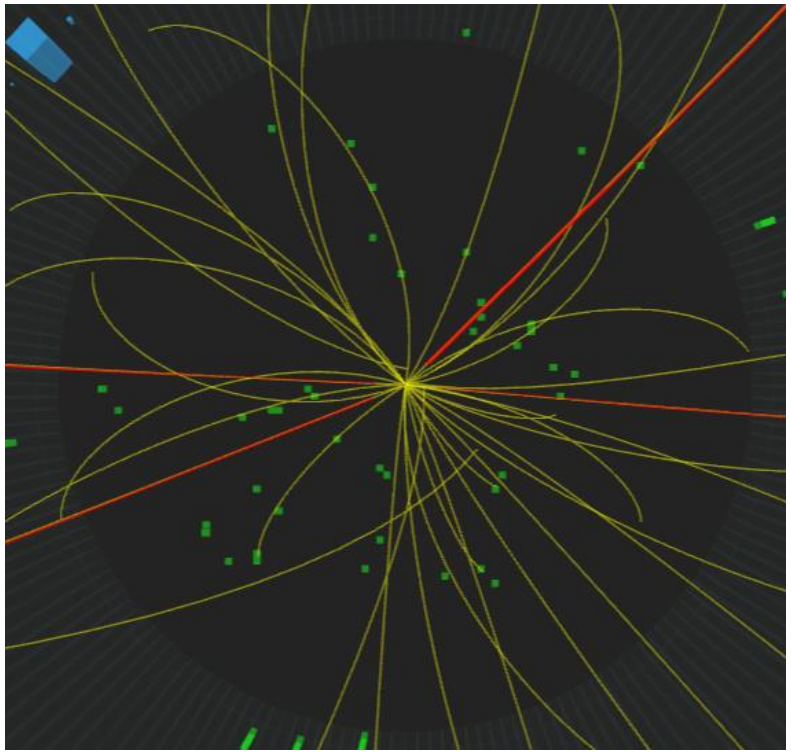
- Al centro del rivelatore CMS, i pacchetti di protoni (100 miliardi) si attraversano ogni 25 ns
- Qualche decina di protoni si ‘‘scontra’’ ogni 25 ns
- Vengono registrate circa 1000 collisioni al secondo

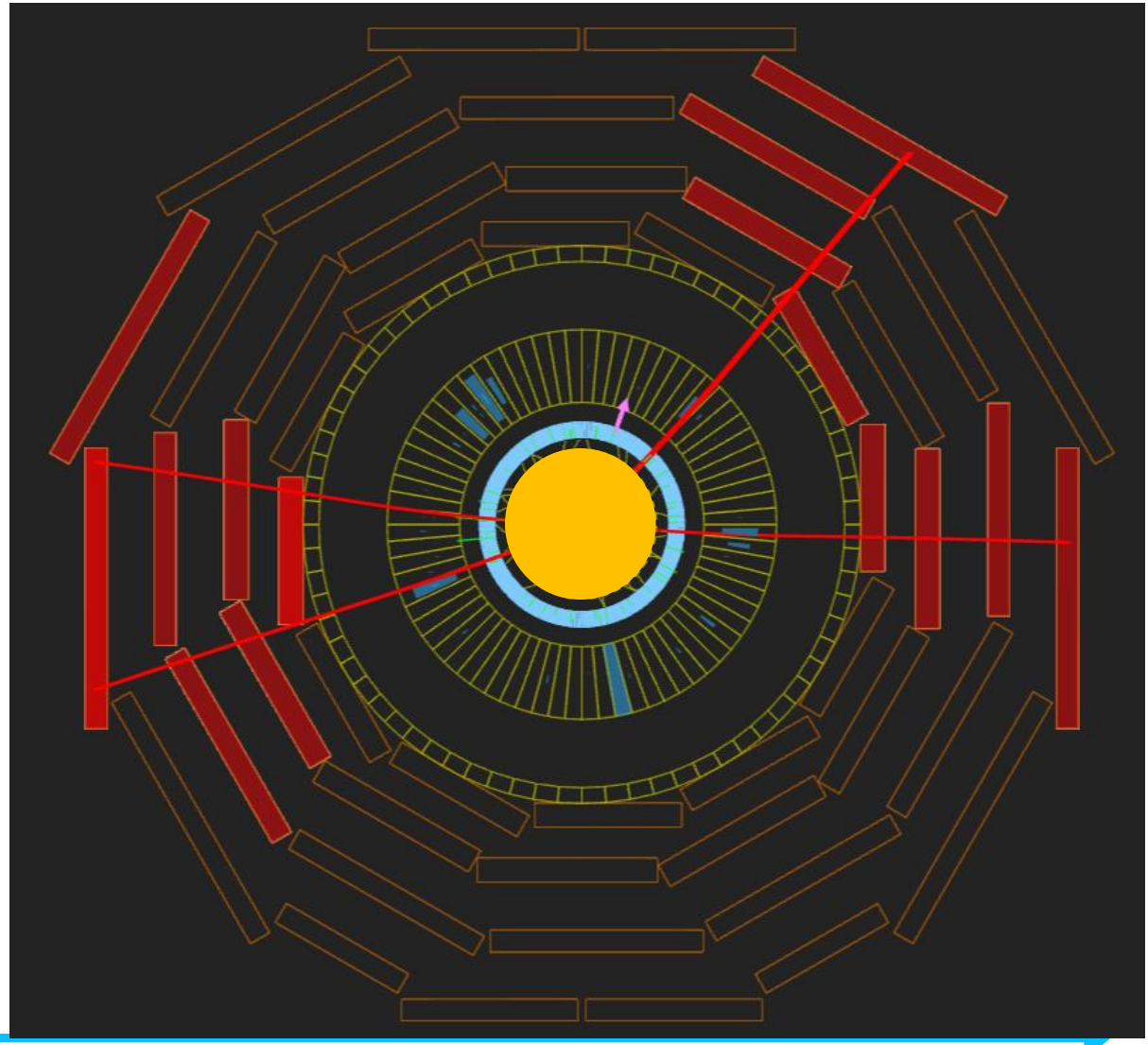
- L’obiettivo dell’esercizio di oggi: **identificare le particelle a partire dalle loro tracce**

  - Ingredienti:
    - **100 collisioni reali** registrate da CMS
    - **iSpy ‘‘Event Display’’:** visualizzare le tracce lasciate dalle particelle
    - **CIMA ‘‘Catalogatore’’:** registrare la tipologia di particelle osservata

Segnali dentro l'esperimento CMS

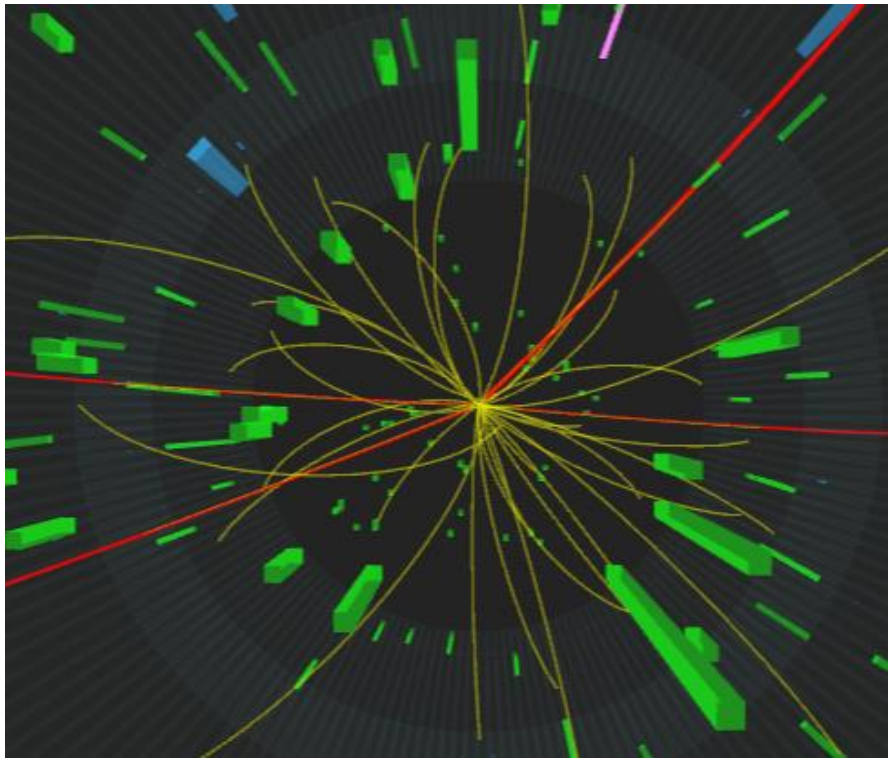
1. Tracciatore
2. Calorimetro Elettromagnetico
3. Calorimetro Adronico
4. Solenoide
5. Rivelatoree di muoni

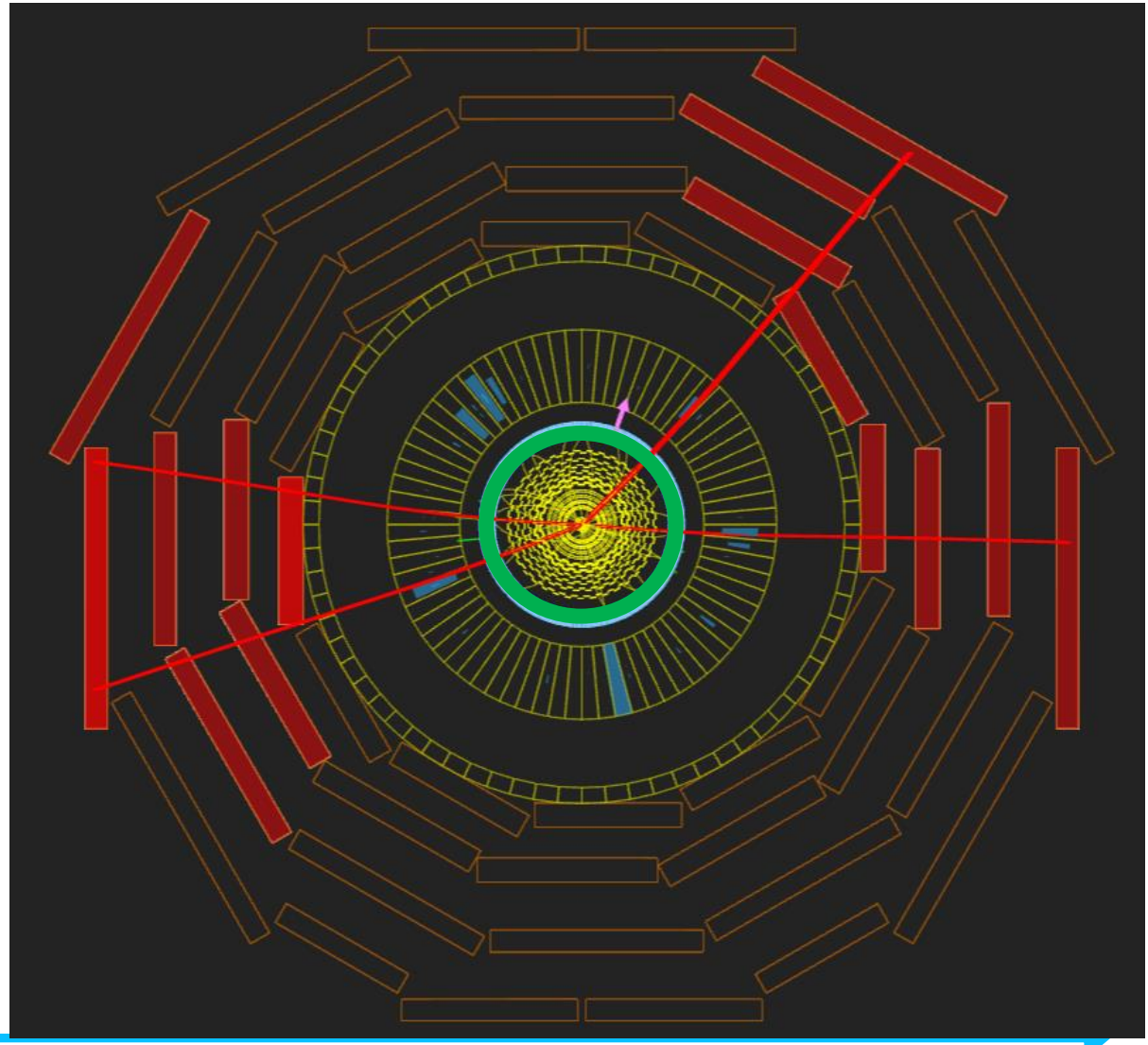




Segnali dentro l'esperimento CMS

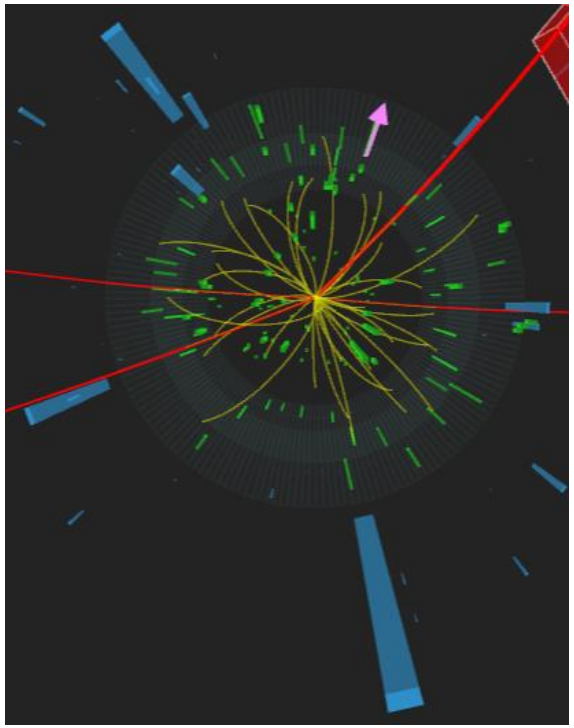
1. Tracciatore
2. **Calorimetro Elettromagnetico**
3. Calorimetro Adronico
4. Solenoide
5. Rivelatoree di muoni

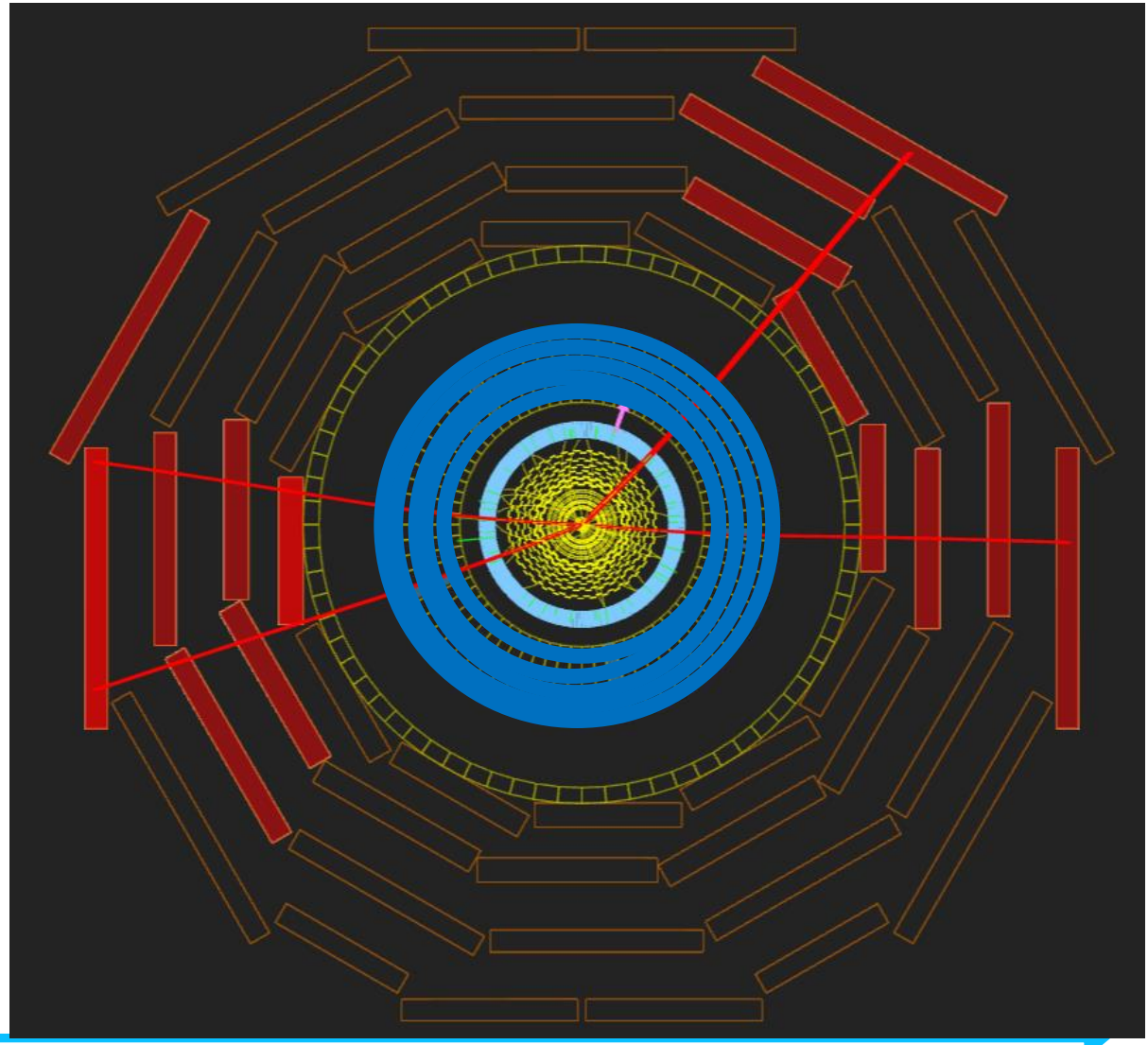




Segnali dentro l'esperimento CMS

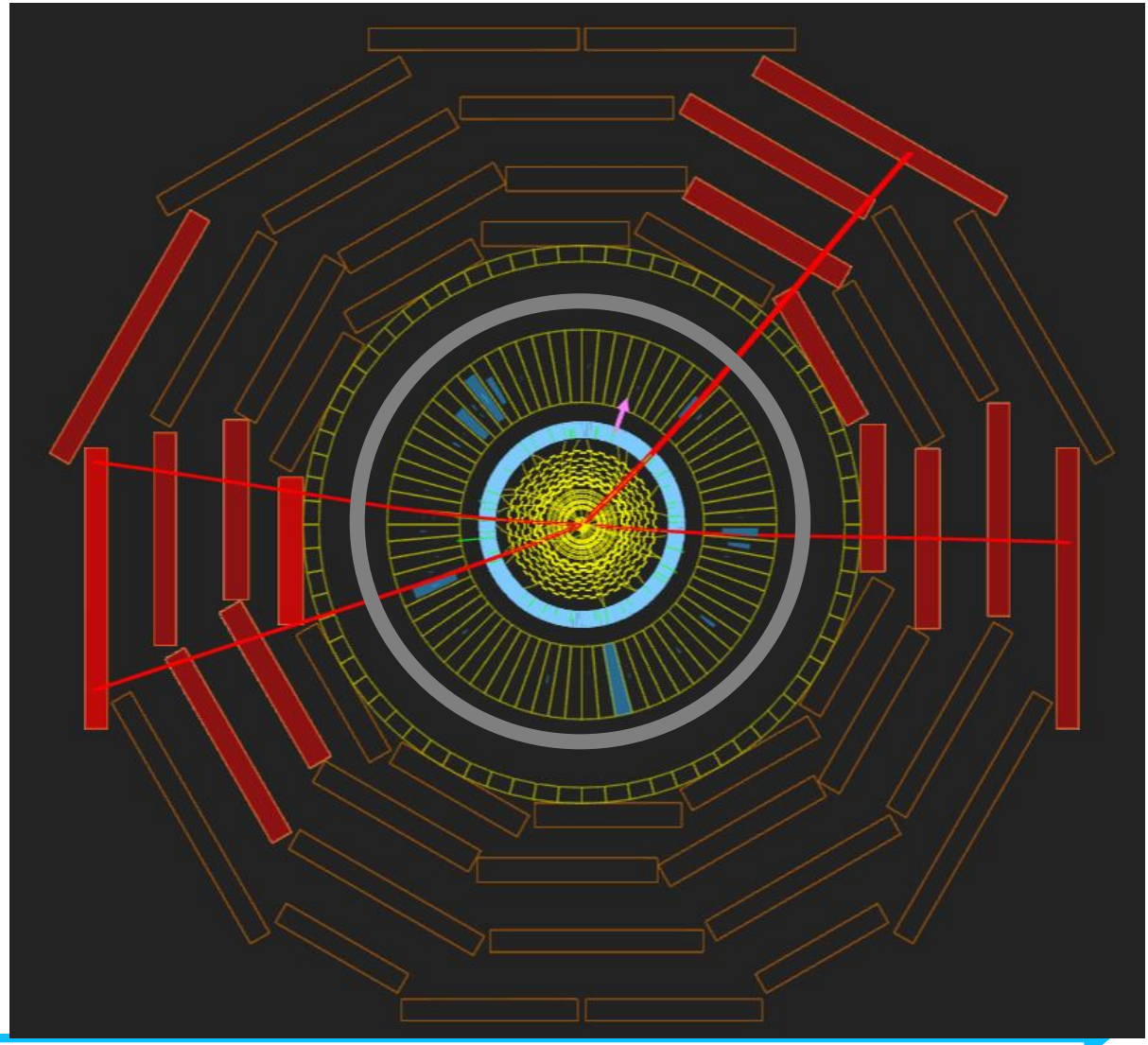
1. Tracciatore
2. Calorimetro Elettromagnetico
3. Calorimetro Adronico
4. Solenoide
5. Rivelatoree di muoni





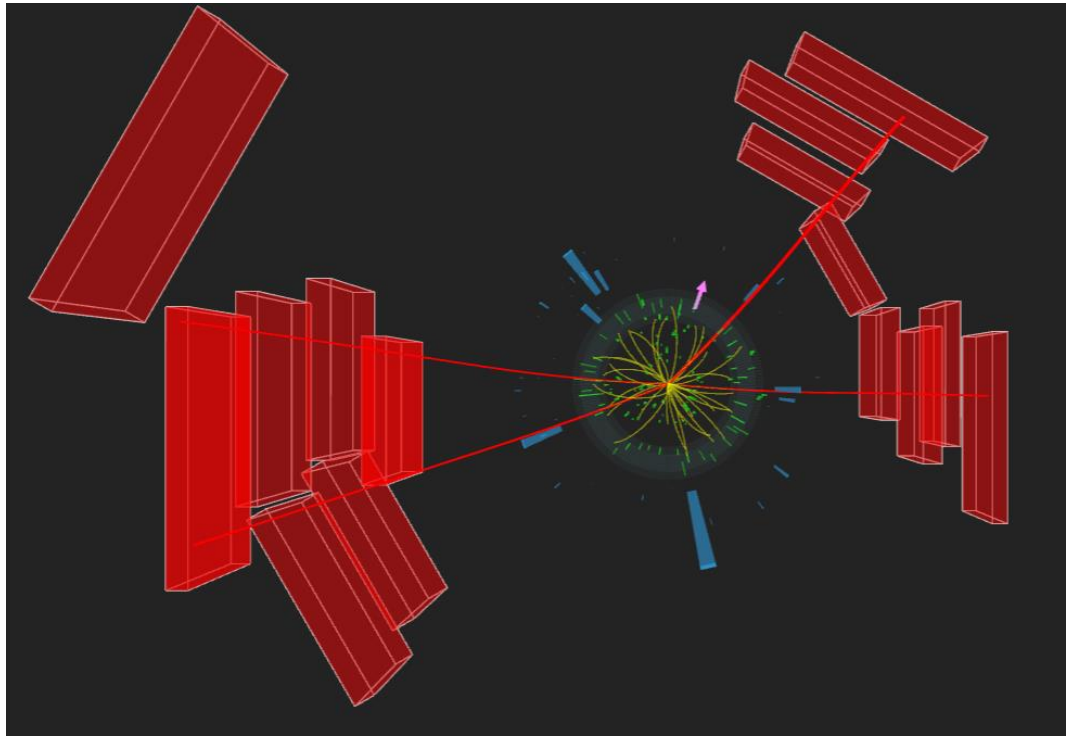
Segnali dentro l'esperimento CMS

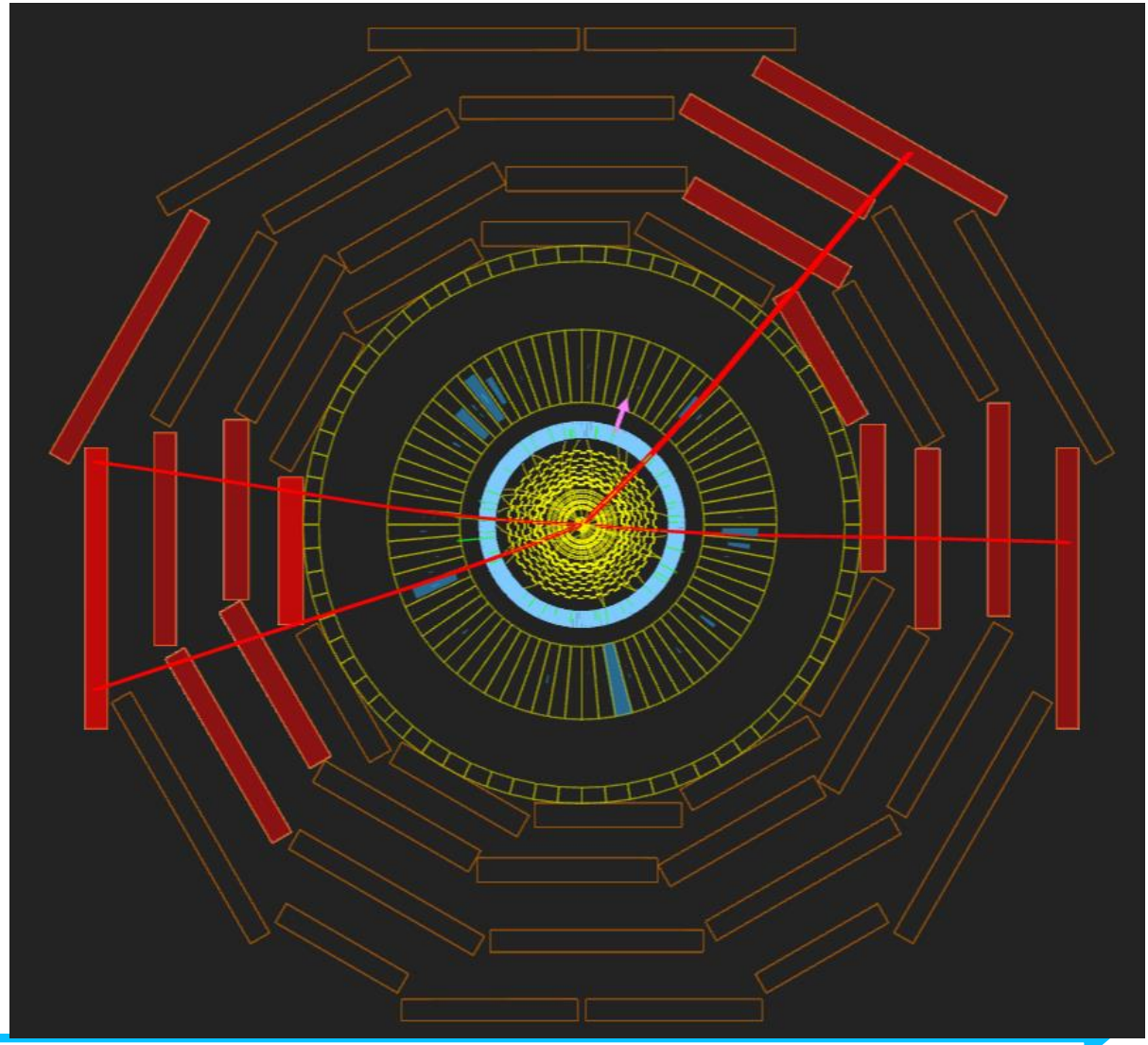
1. Tracciatore
2. Calorimetro Elettromagnetico
3. Calorimetro Adronico
4. **Solenoide**
5. Rivelatoree di muoni



Segnali dentro l'esperimento CMS

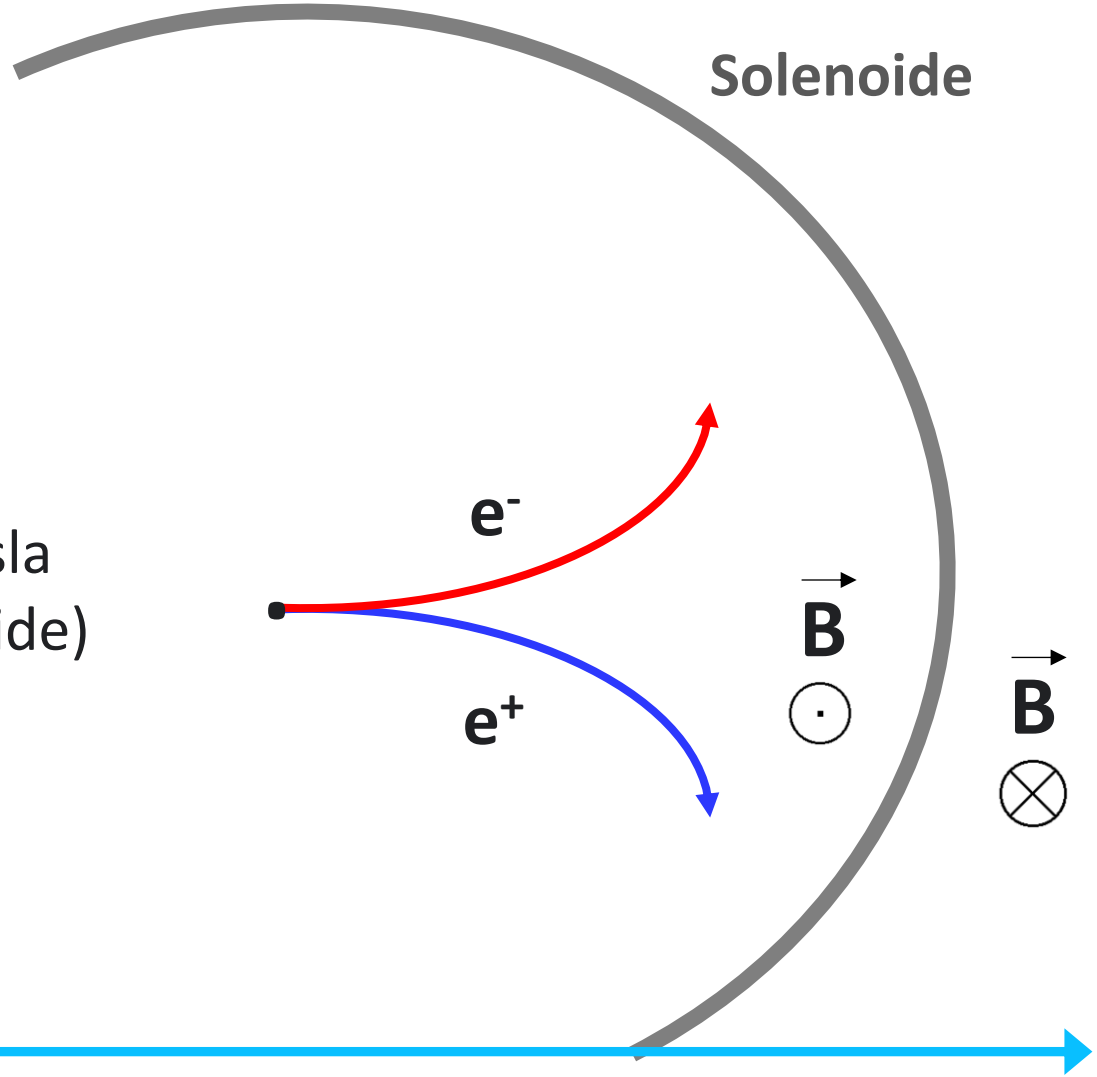
1. Tracciatore
2. Calorimetro Elettromagnetico
3. Calorimetro Adronico
4. Solenoide
5. **Rivelatoree di muoni**





Forza di Lorentz

- La traiettoria di una particella carica viene deviata in presenza di campo magnetico
  - $\vec{F} = q\,\vec{v} \times \vec{B}$
    - **F: Forza**
    - q: carica
    - **v: velocità**
    - **B: Campo magnetico**
- Il Solenoide al centro di CMS ha un campo di 3.8 Tesla
- Le particelle cariche curvano (all'interno del Solenoide)
  - Carica negativa: curva in senso anti-orario
  - Carica positiva: curva in senso orario

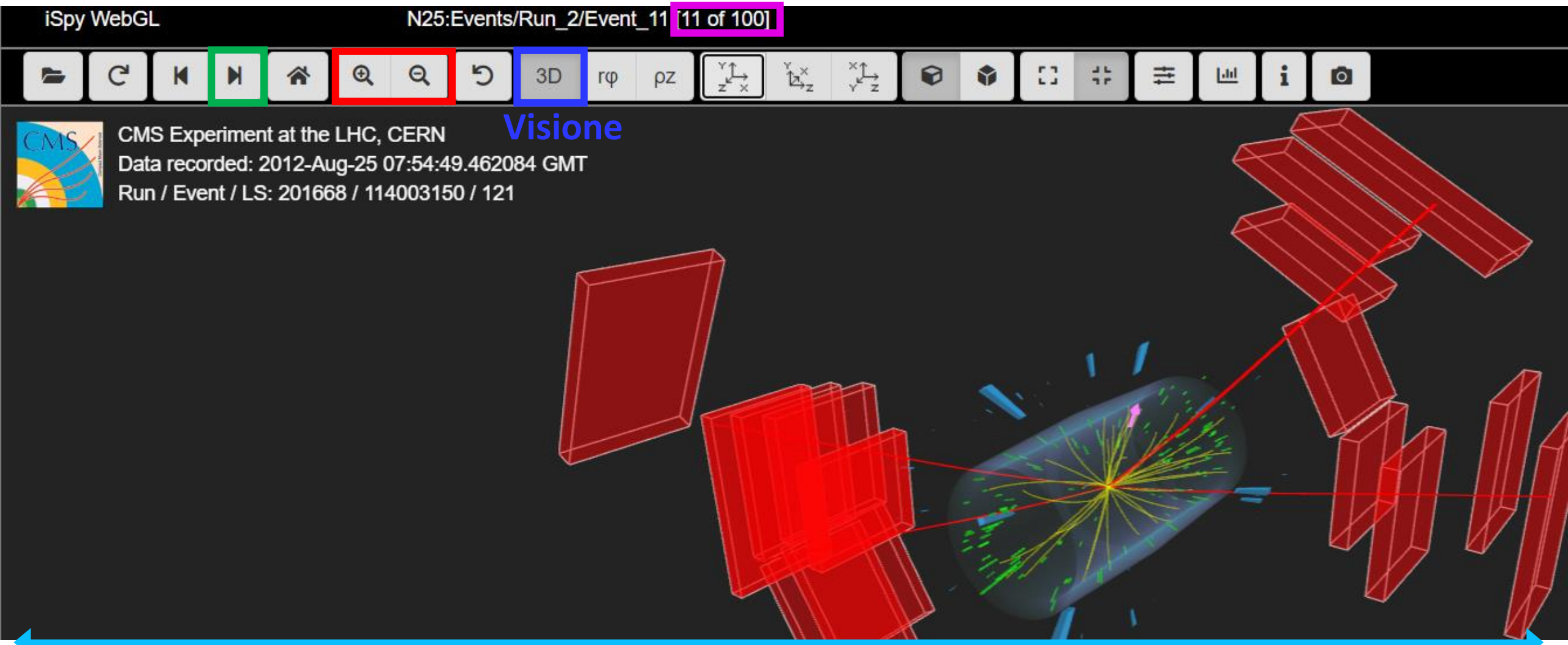


iSpy: l'Event Display

Prossimo evento

Zoom

Numero dell'evento

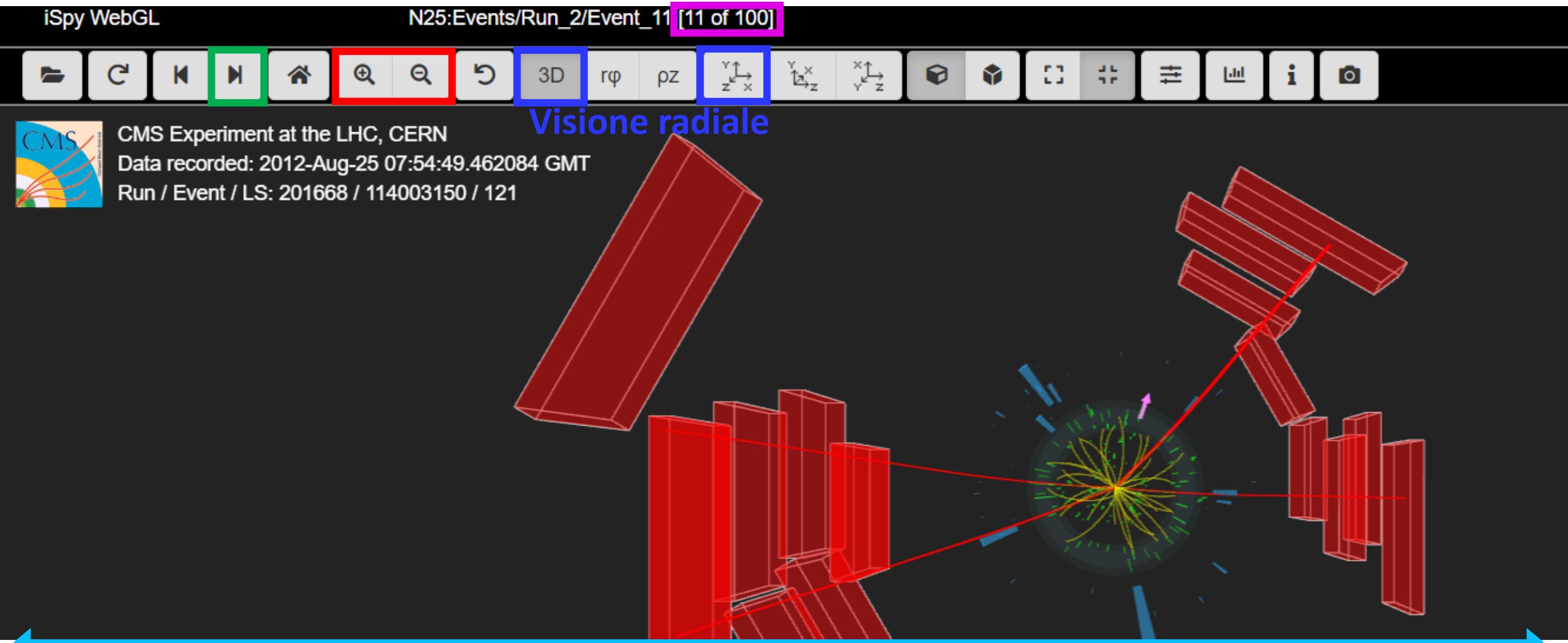


iSpy: l'Event Display

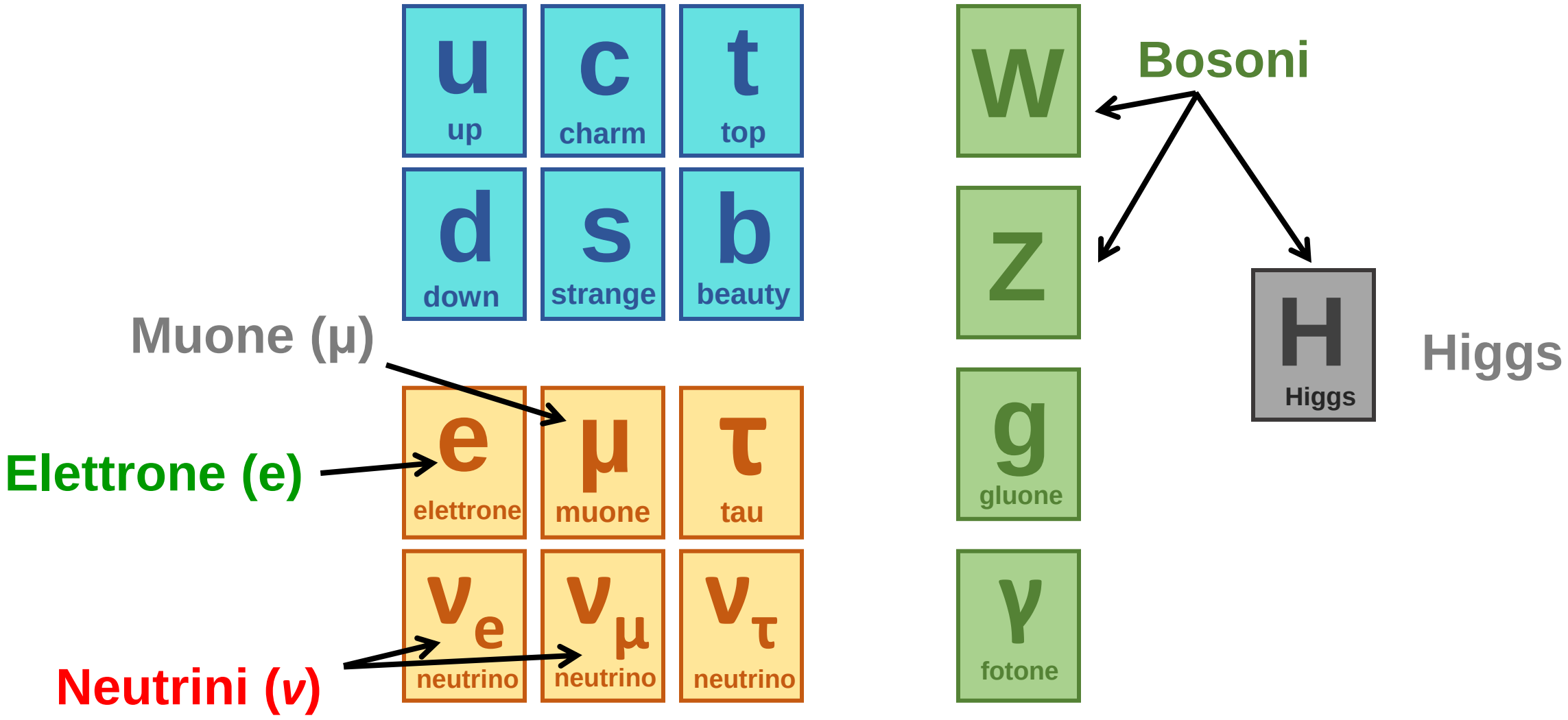
Prossimo evento

Zoom

Numero dell'evento



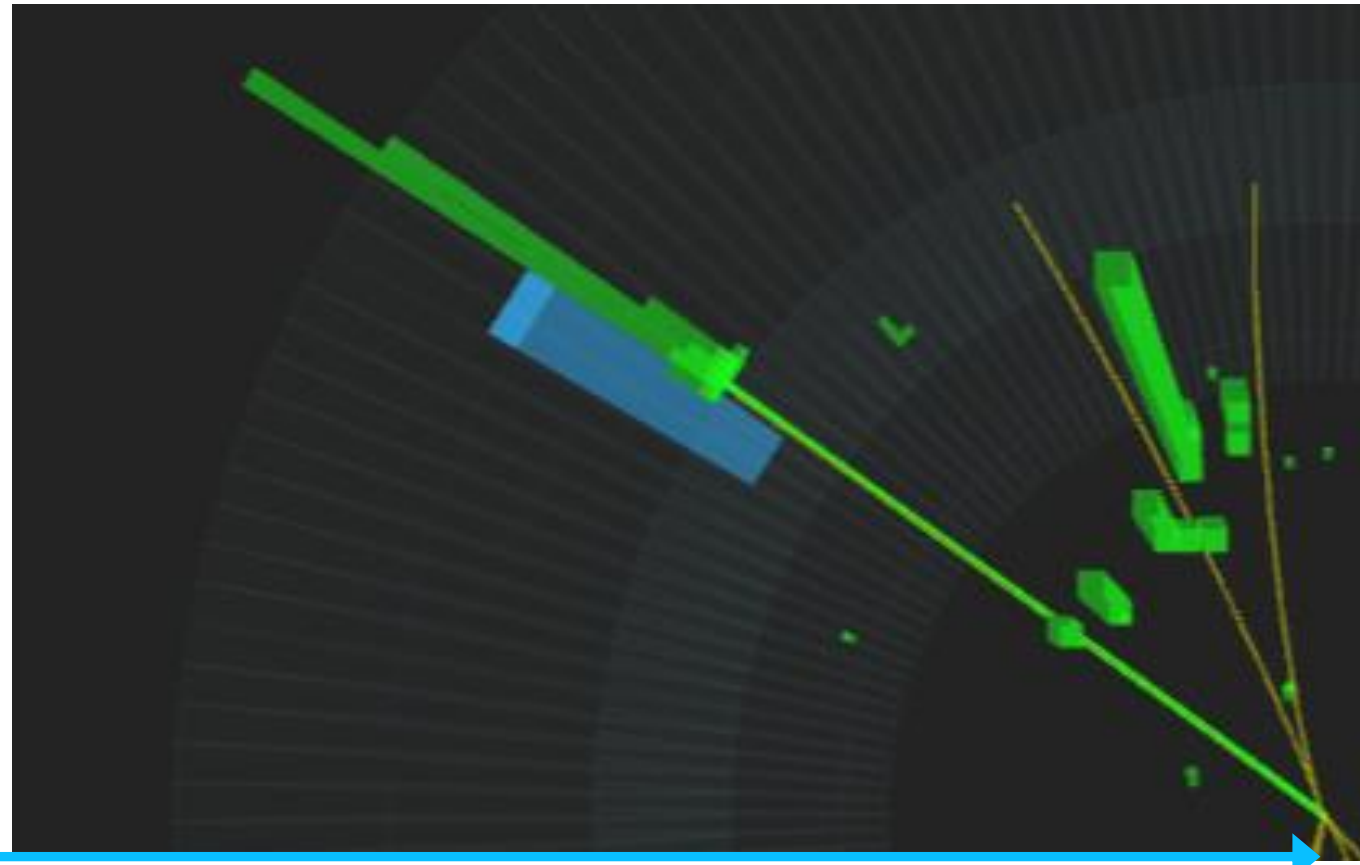
Cosa cerchiamo nei nostri eventi



I segnali: elettrone (e)

- L'elettrone (o positrone) è una particella carica
- La traiettoria viene deviata dal campo magnetico
- La traccia viene ricostruita dal tracciatore
- L'energia viene rilasciata nel Calorimetro Elettromagnetico

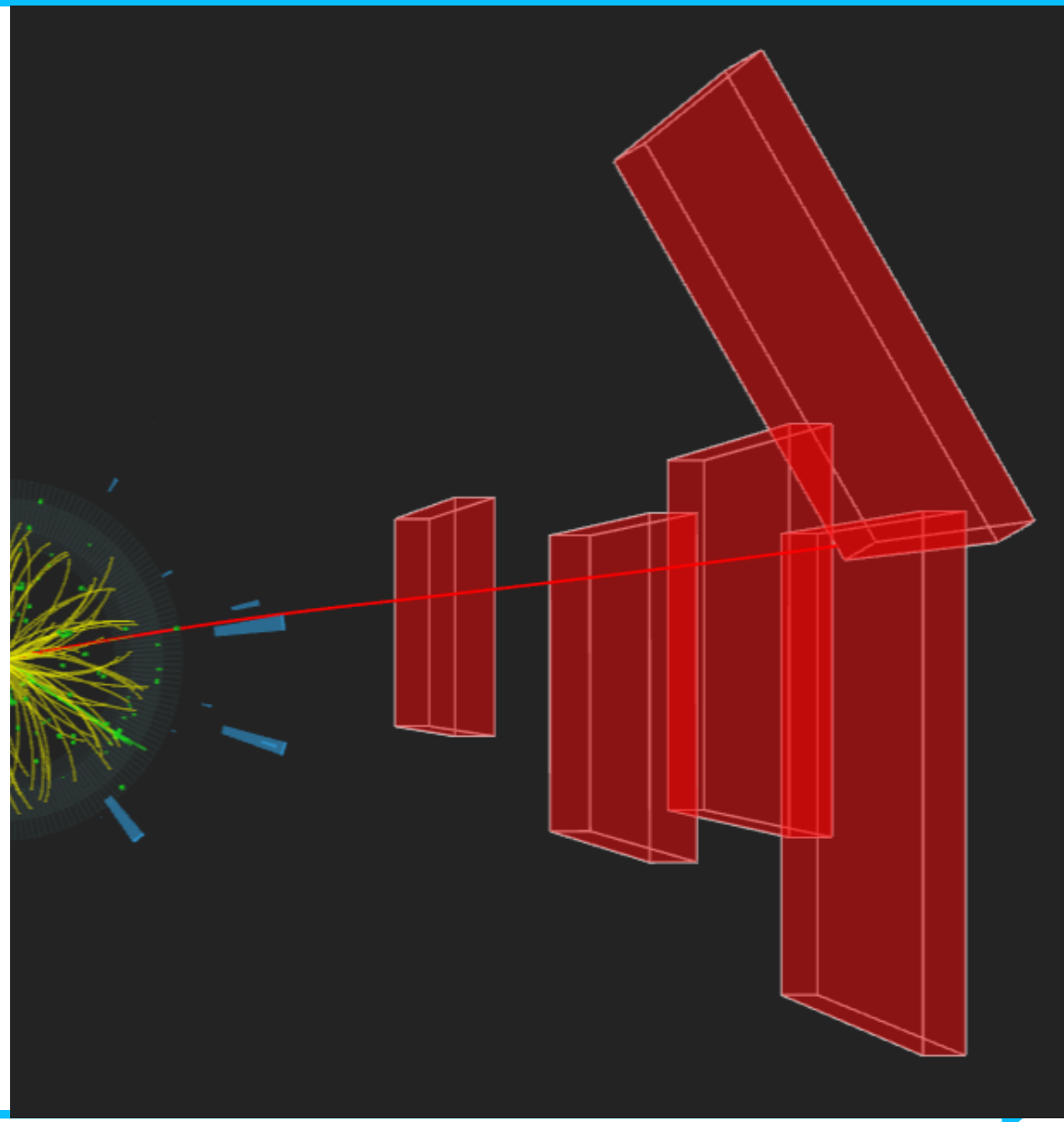
- Caratteristiche del segnale:
  - **Traccia: verde**
  - **Blocco di energia: verde**



I segnali: muone (μ)

- Il muone (o anti-muone) è una particella carica
- La traiettoria viene deviata dal campo magnetico
- La traccia viene ricostruita dal tracciatore
- La particella attraversa i due Calorimetri
- La traccia continua nel rivelatore di muoni

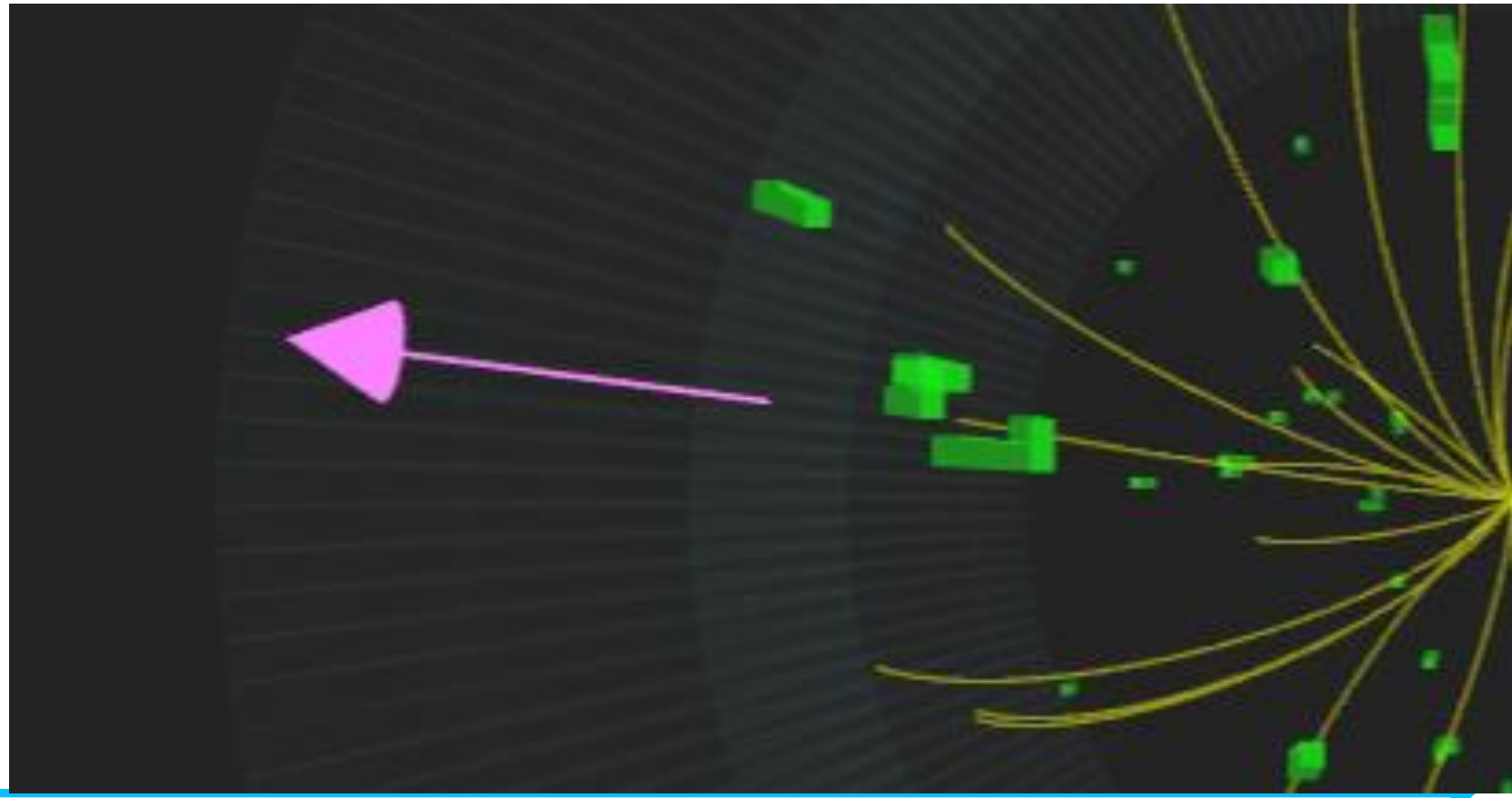
- Caratteristiche del segnale:
  - **Traccia: rossa**
  - **Camere a muoni colpite: rosse**



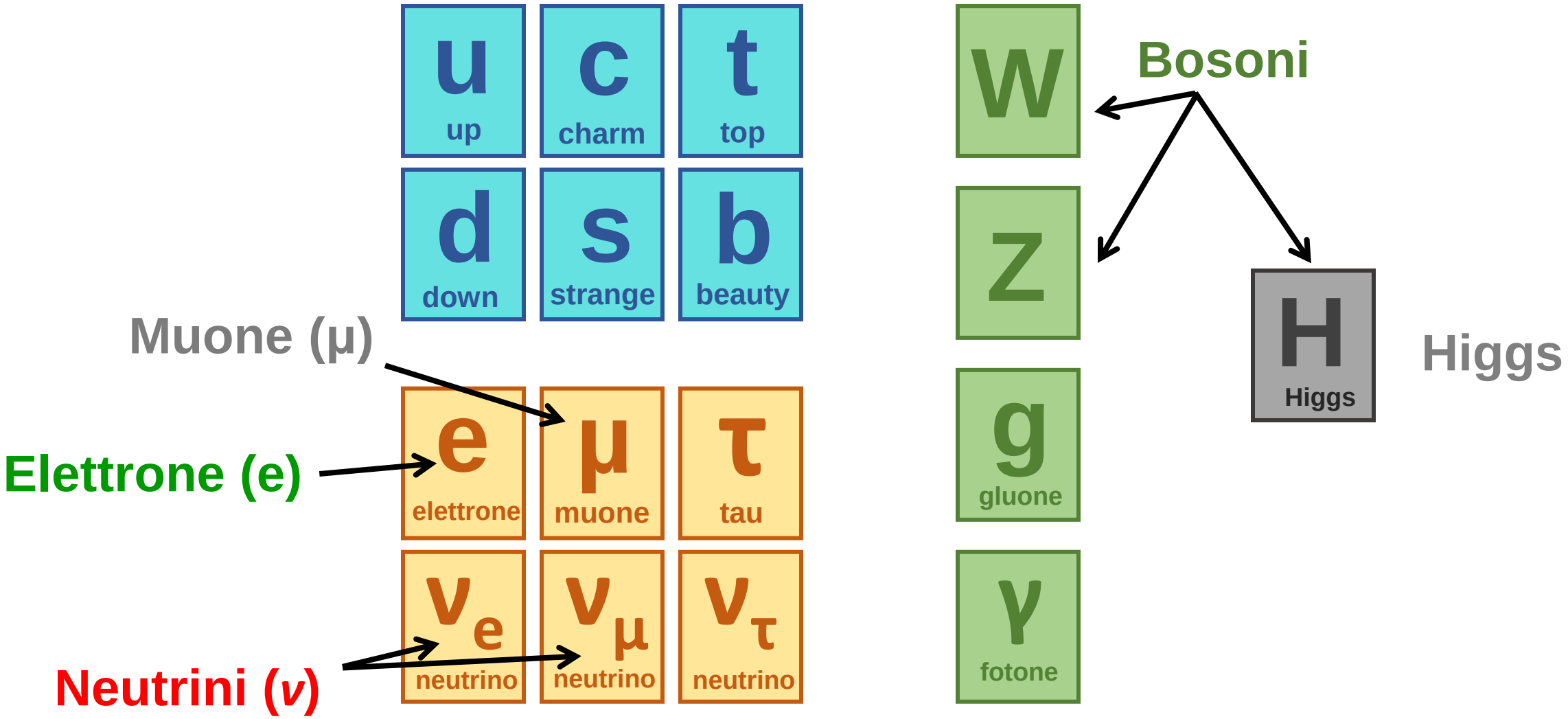
I segnali: neutrino (ν) …energia mancante

- Il neutrino (o anti-neutrino) è una particella neutra
- La particella interagisce solamente tramite Interazione Nucleare Debole
- Tipicamente attraversa il rivelatore CMS senza interagire
- Lascia un ‘‘buco’’ nella ricostruzione dell’energia → ‘‘energia mancante’’

- Caratteristiche del segnale:
  - **Freccia: rosa**



Cosa cerchiamo nei nostri eventi

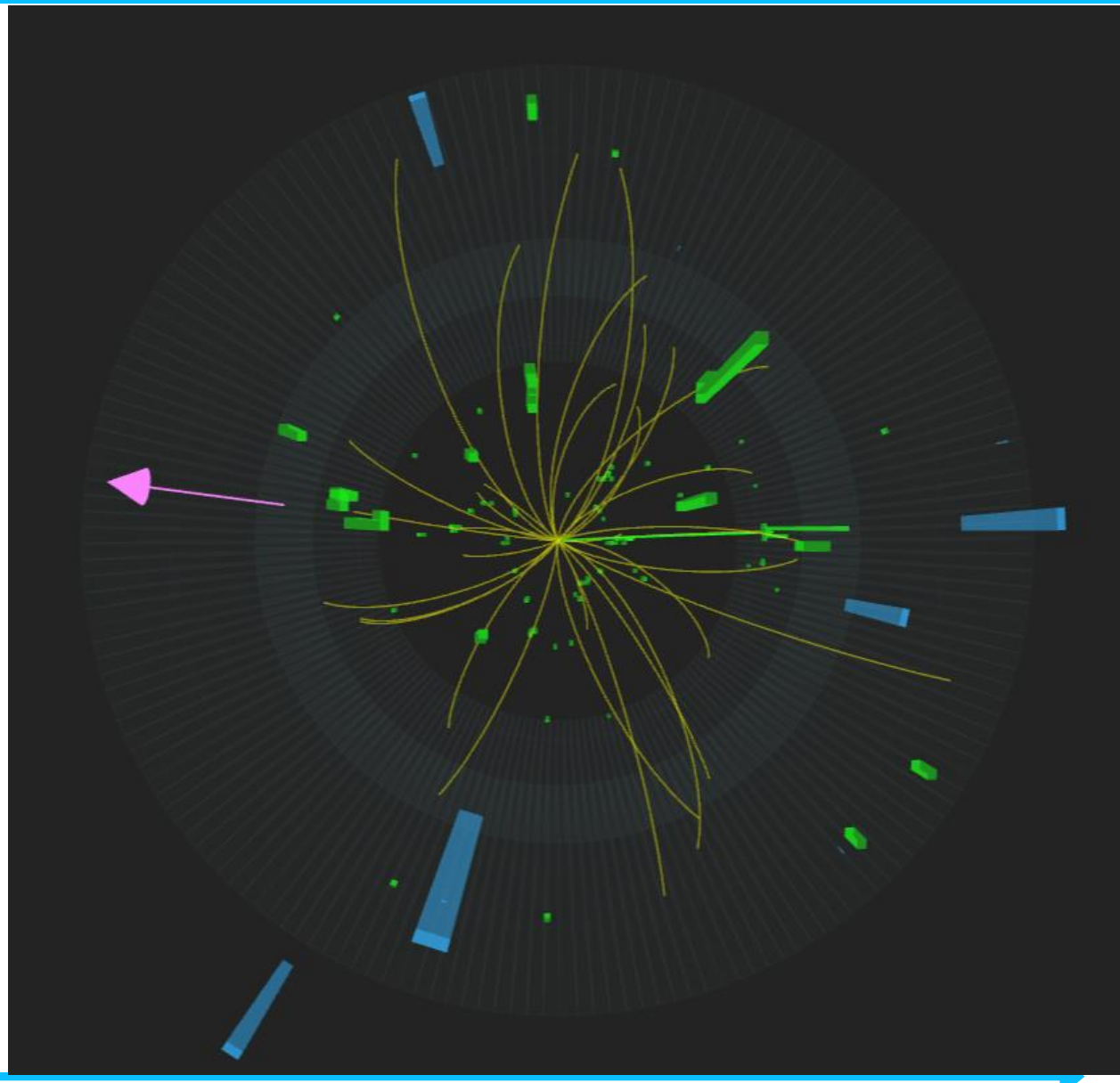


Le particelle: bosone W (e ν, μ ν)

- Il bosone W è una particella carica (W^+, W^-)
- Il bosone W può ‘‘decadere’’ in tanti modi…
- Le trasformazioni più facili da identificare hanno: **elettroni e neutrini, muoni e neutrini**

$$W^+ \rightarrow e^+ \nu_e \qquad W^- \rightarrow e^- \nu_e$$
$$W^+ \rightarrow \mu^+ \nu_\mu \qquad W^- \rightarrow \mu^- \nu_\mu$$

- Caratteristiche del segnale W(e ν):
  - **Traccia: verde**
  - **Freccia: rosa**
- Caratteristiche del segnale W(μ ν):
  - **Traccia: rossa**
  - **Freccia: rosa**

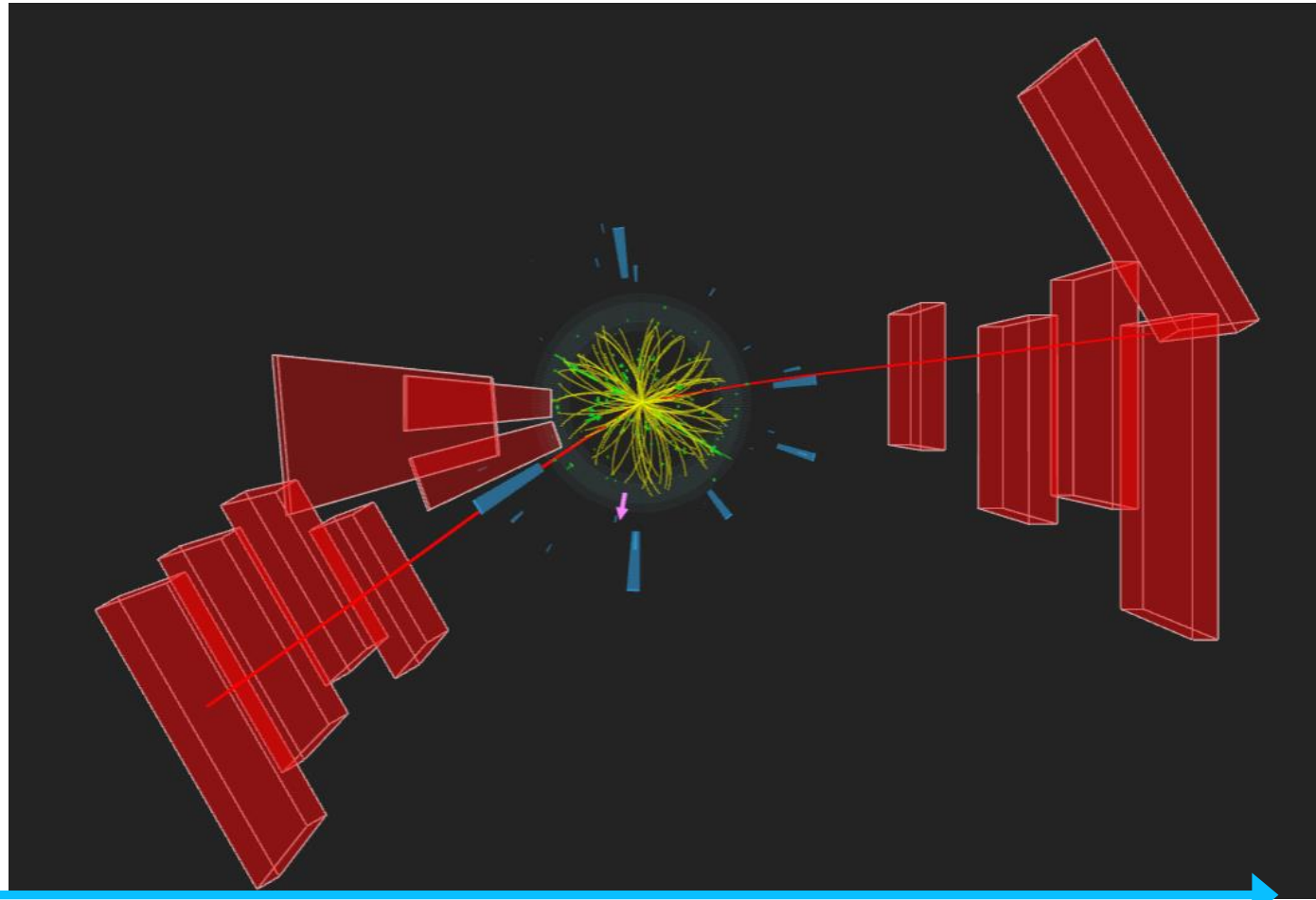


Le particelle: bosone Z (ee, μμ)

- Il bosone Z è una particella neutra (Z^0)
- Il bosone Z può ‘‘decadere’’ in tanti modi…
- Le trasformazioni più facili da identificare hanno **coppie di elettroni o di muoni**

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

- Caratteristiche del segnale Z(ee):
  - **Traccia: verde**
  - **Traccia: verde**
- Caratteristiche del segnale Z(μμ):
  - **Traccia: rossa**
  - **Traccia: rossa**

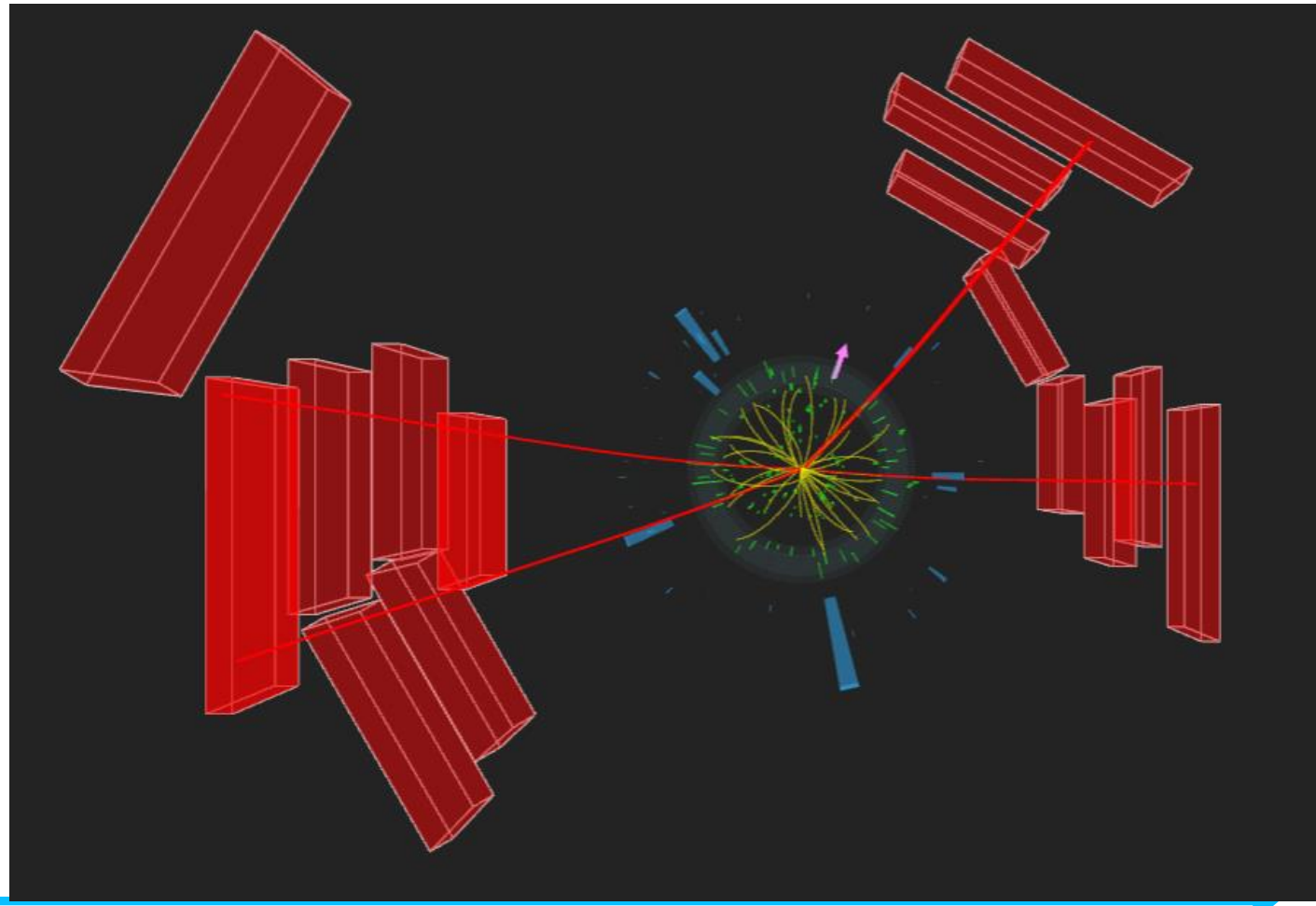


Le particelle: bosone H (ZZ)

- Il bosone H è una particella neutra (H^0)
- Il bosone H può ‘‘decadere’’ in tanti modi…
- Le trasformazioni più facili da identificare hanno **due coppie di elettroni o di muoni**

$$H \rightarrow ZZ$$

- Possibili segnali?

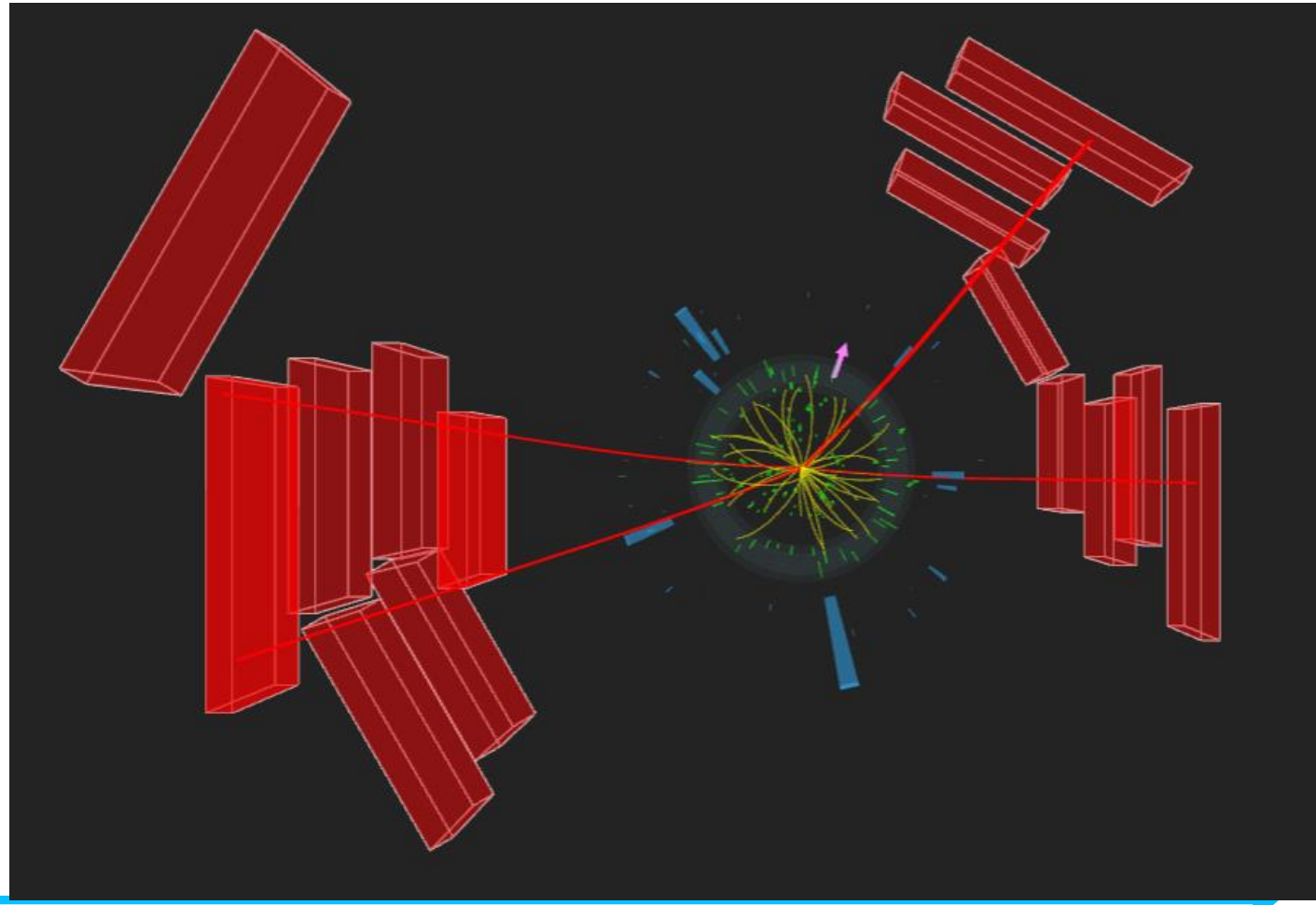


Le particelle: bosone H (ZZ)

- Il bosone H è una particella neutra (H^0)
- Il bosone H può ‘‘decadere’’ in tanti modi…
- Le trasformazioni più facili da identificare hanno **due coppie di elettroni o di muoni**

$$H \rightarrow ZZ$$

- Possibili segnali:
  - $e^+ e^-$ $e^+ e^-$
  - $\mu^+ \mu^-$ $\mu^+ \mu^-$
  - $e^+ e^-$ $\mu^+ \mu^-$



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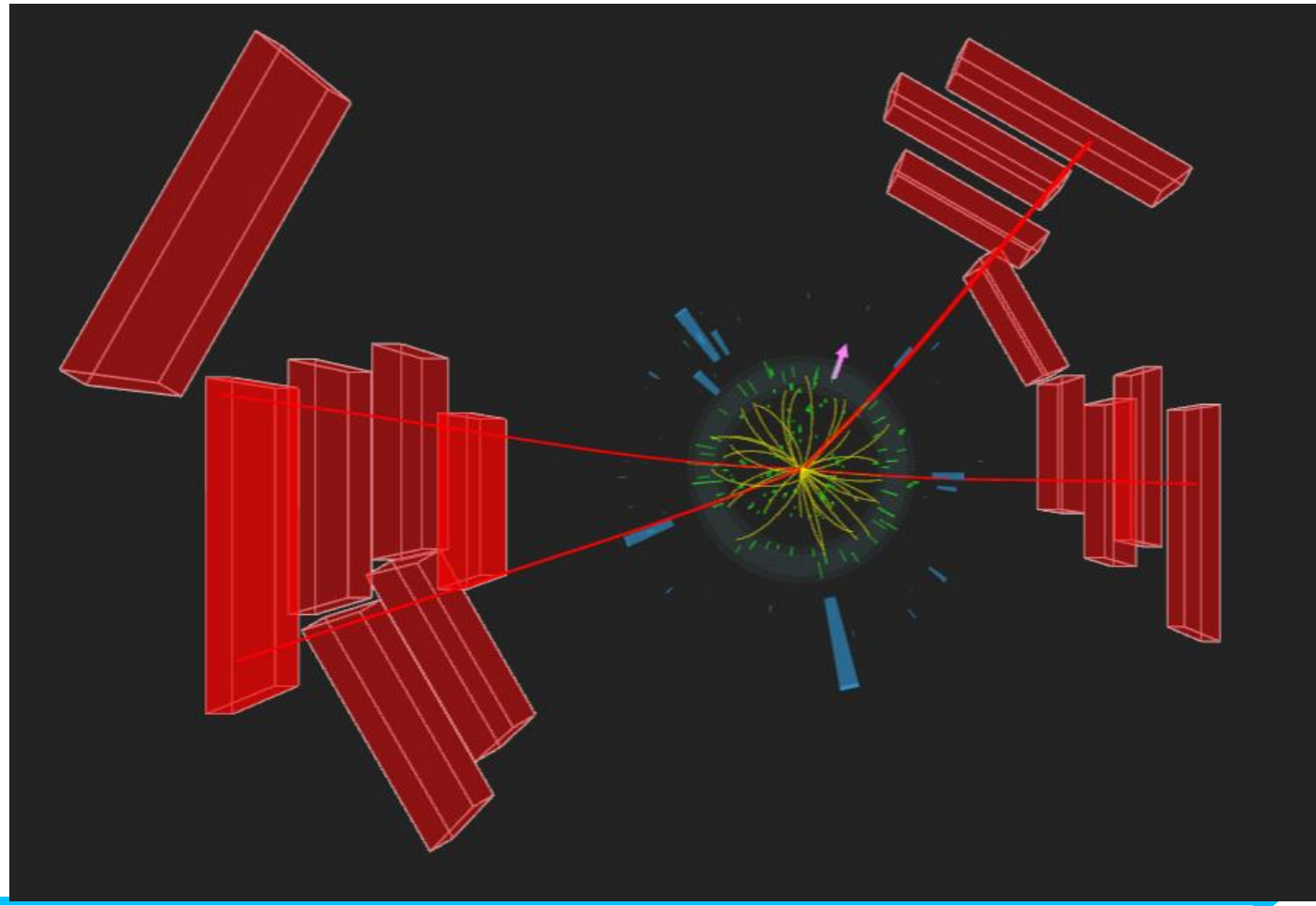
- Possibili segnali:
  - $e^+ e^-$ $e^+ e^-$
  - $\mu^+ \mu^-$ $\mu^+ \mu^-$
  - $e^+ e^-$ $\mu^+ \mu^-$

  …
  - $\nu_e \nu_e \nu_\mu \nu_\mu$

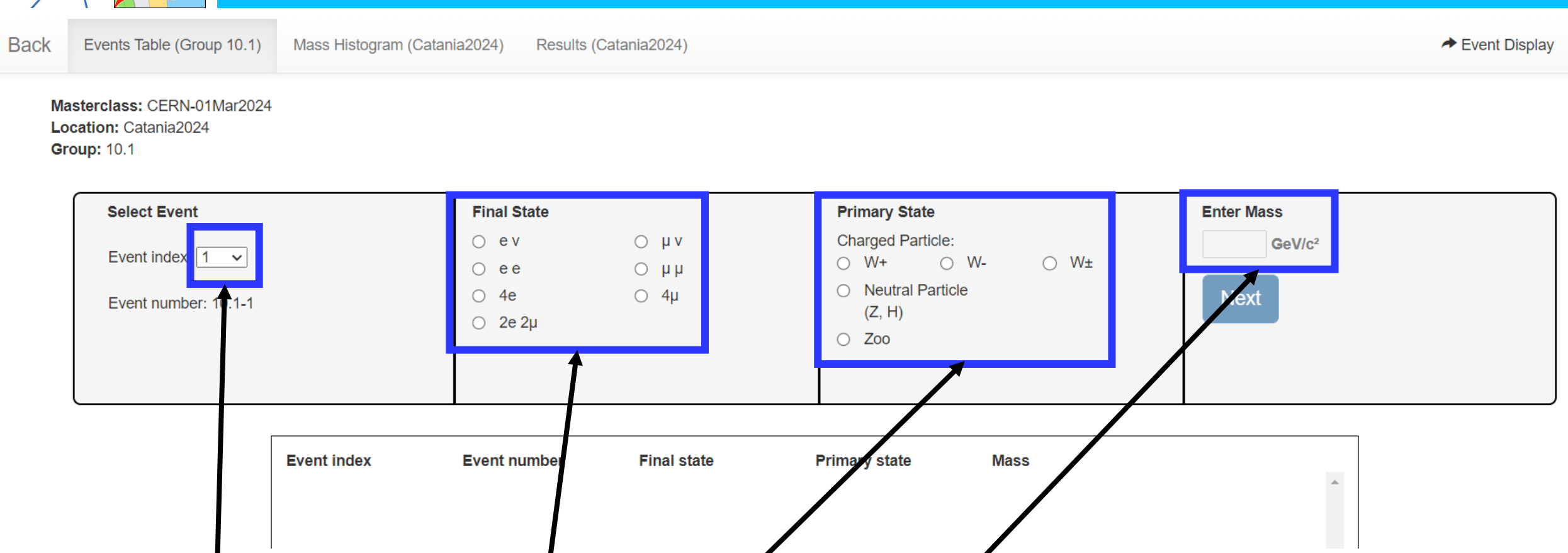


CIMA: selezione del file

- CERN → 25 Febbraio 2025 → Catania

Choose your Masterclass	Choose your location	Choose your data file
TestEvents-01Jan2022	Firenze_25feb25	10.1
Santander-13May2024	Podgorica_25feb25	10.2
MP-15Jan2024	Pavia_25feb25	10.3
Cakovec-24Jan2024	Catania_25feb25	10.4
Bristol-27Mar2024	MSila_25feb25	10.5
Sandbox-31Dec2023	Helsinki_25feb25	10.6
Belgrade-FF		10.7
Osijek_17Jan2025		10.8
Sofia-13Jan2025		10.9
Chilton-29Jan2025		100.31
CERN-19Feb2025		100.32
CERN-IDWGS-11Feb2025		100.33
RAL-11to14Mar2025		100.34
CERN-25Feb2025		100.35
CERN-01Mar2025		100.36
CERN-05Mar2025		100.37
CERN-07Mar2025		100.38

CIMA: il catalogatore



- Numero dell'evento: da 1 a 100
- Final State: quali segnali avete osservato
- Primary State: quale particella era stata prodotta
- <u>Solo per ''Neutral Particle (Z, H)''</u> → Inserire il valore della massa ''Enter Mass''

Esempio: H → ZZ → μμμμ (massa 182.95)

Select Event

Event index: 1

Event number: 10.1-1

Final State

- e ν
- e e
- 4e
- 2e 2μ
- μ ν
- μ μ
- 4μ

Primary State

Charged Particle:

- W+
- W-
- W±
- Neutral Particle (Z, H)
- Zoo

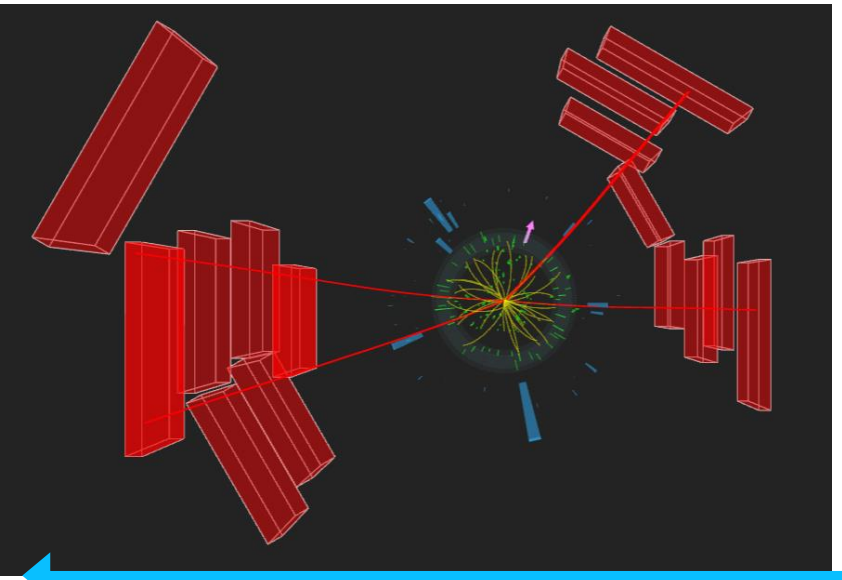
Enter Mass

GeV/c²

Next

Event index	Event number	Final state	Primary state	Mass

1. **Identificare i segnali e la particella**



Esempio: H → ZZ → μμμμ (massa 182.95)

Select Event

Event index: 1

Event number: 10.1-1

Final State

- e ν
- e e
- 4e
- 2e 2μ
- μ ν
- μ μ
- 4μ

Primary State

Charged Particle:

- W+
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GeV/c²

Next

Event index	Event number	Final state	Primary state	Mass

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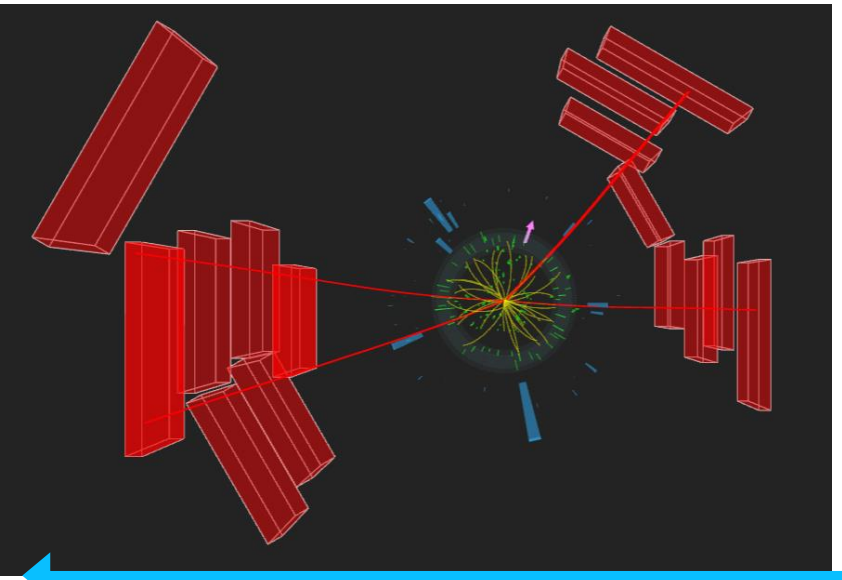
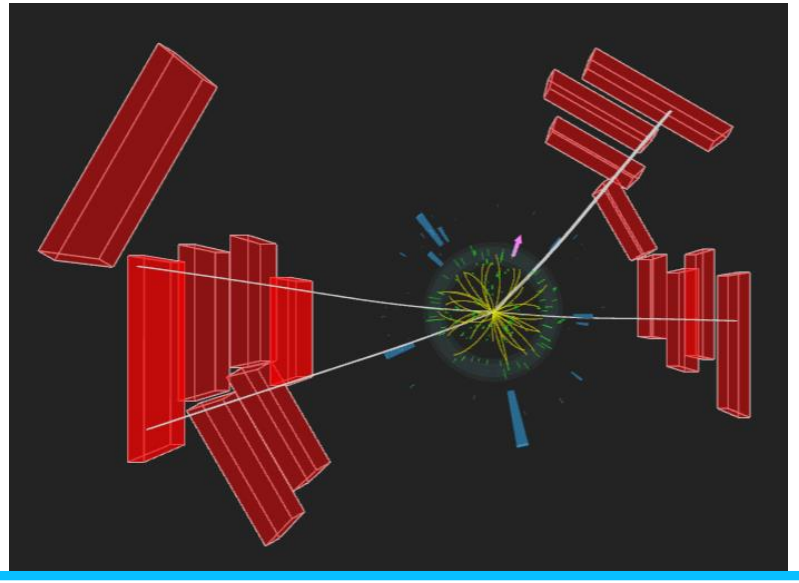
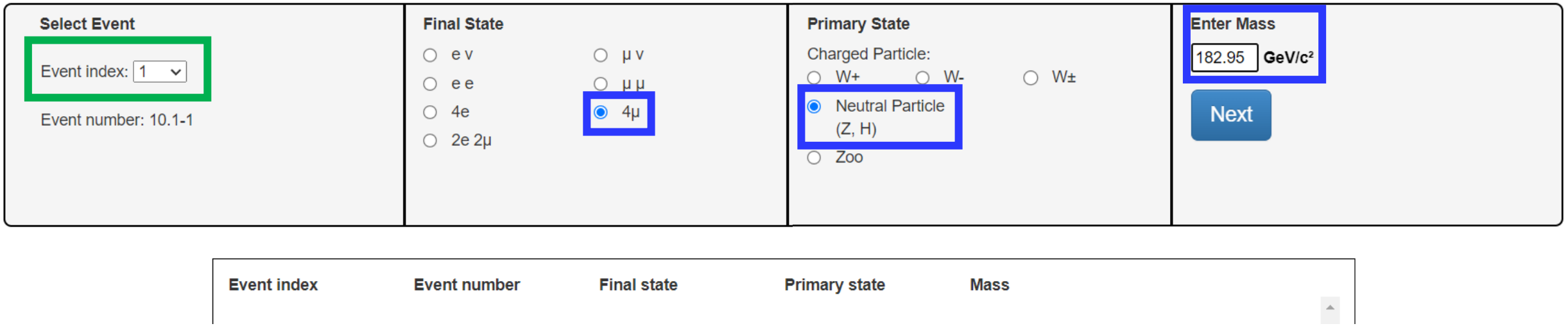


2. Selezionare le tracce col mouse



Esempio: H → ZZ → μμμμ (massa 182.95)



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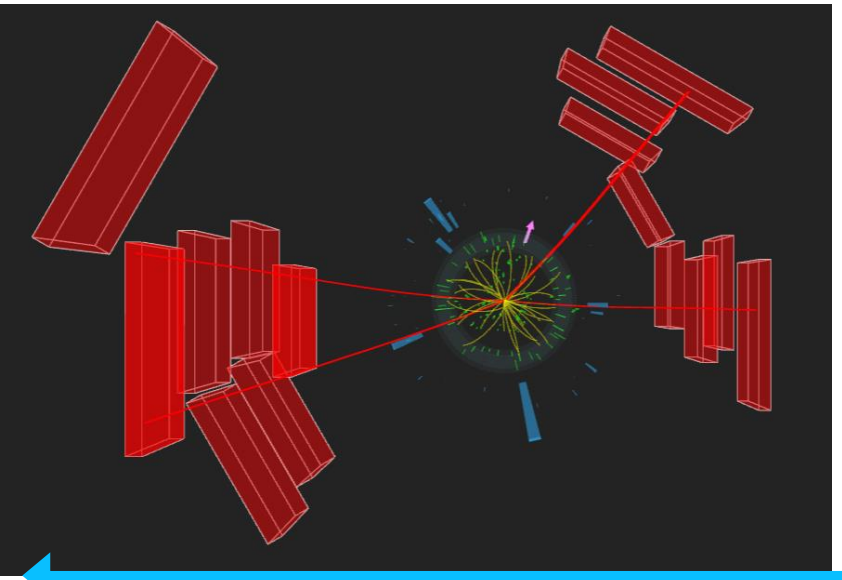

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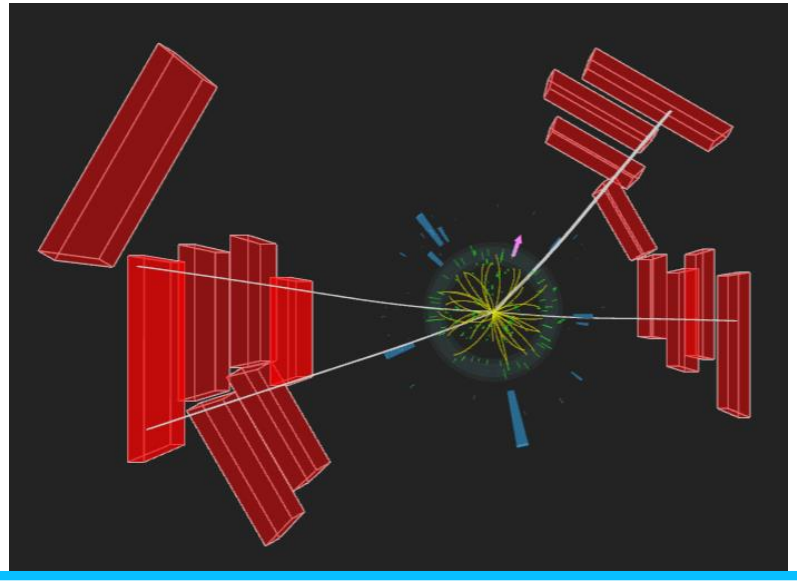
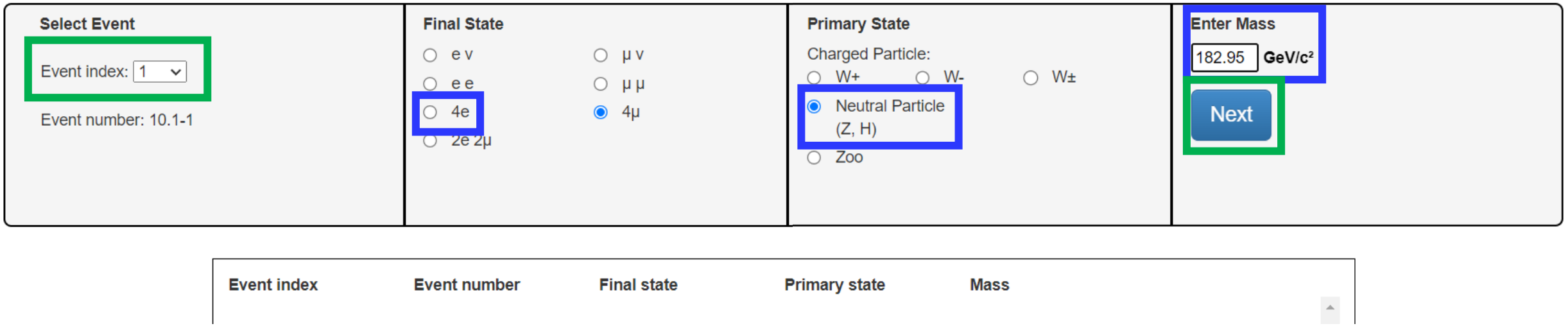


3. Premere "M" sulla tastiera

Esempio: H → ZZ → μμμμ (massa 182.95)



Esempio: H → ZZ → μμμμ (massa 182.95)

Select Event

Event index: 1

Event number: 10.1-1

Final State

- e ν
- e e
- 4e
- 2e 2μ
- μ ν
- μ μ
- 4μ

Primary State

Charged Particle:

- W+
- W-
- W±
- Neutral Particle (Z, H)
- Zoo

Enter Mass

182.95 GeV/c²

Next

Event index	Event number	Final state	Primary state	Mass

Select Event

Event index: 2

Event number: 10.4-2

Final State

- e ν
- e e
- 4e
- 2e 2μ
- μ ν
- μ μ
- 4μ

Primary State

Charged Particle:

- W+
- W-
- W±
- Neutral Particle (Z, H)
- Zoo

Enter Mass

GeV/c²

Next

Event index	Event number	Final state	Primary state	Mass
9001	10.4-1	4e	neutral	182.95

Programma delle attività del pomeriggio

- 14:00-15:00 – Ogni ricercatore identifica almeno 50 eventi
  - iSPY
  - CIMA

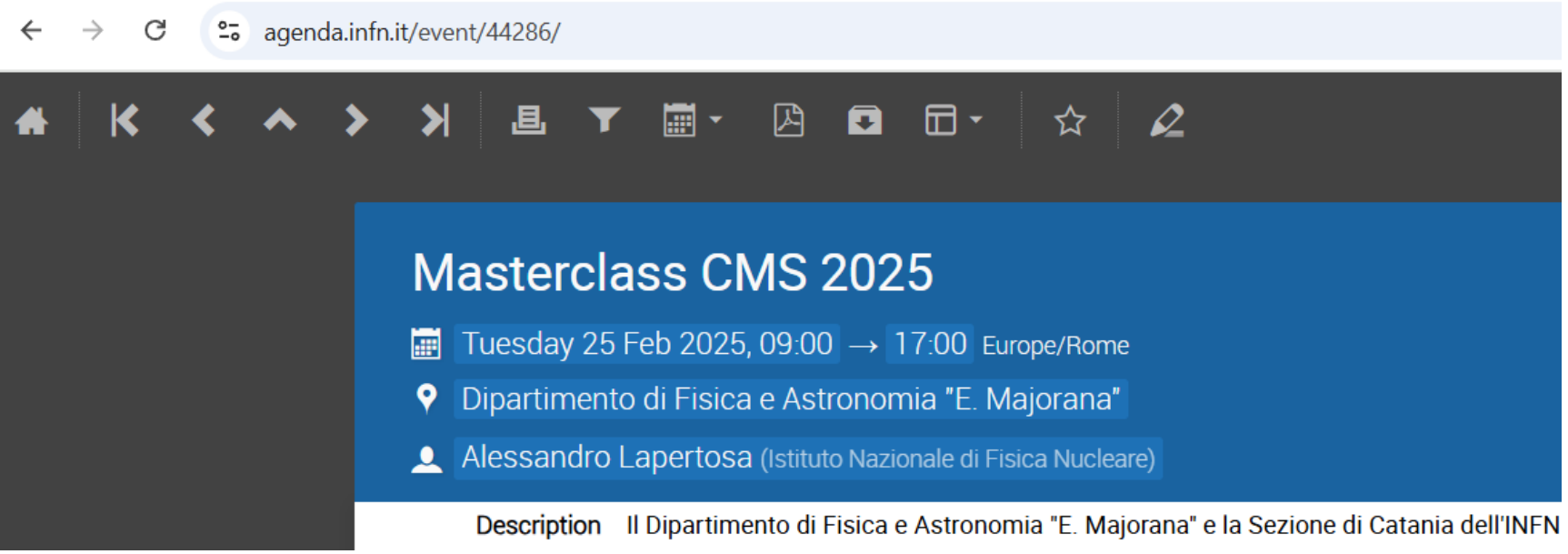
- 15:00-15:30 – Discussione dei risultati: analisi statistica

- 15:30-16:00 – Pausa

- 16:00-17:00 – Collegamento in videoconferenza con CERN e altri 5 istituti
  - Saluti
  - Introduzione
  - Discussione dei risultati
  - Quiz

Seconda parte

Da Firefox → aprire CIMA e iSpy



… Scorrere in giù …

CIMA: CERN-25Feb25 → Catania_25feb25

CIMA

CMS Instrument for Masterclass Analysis

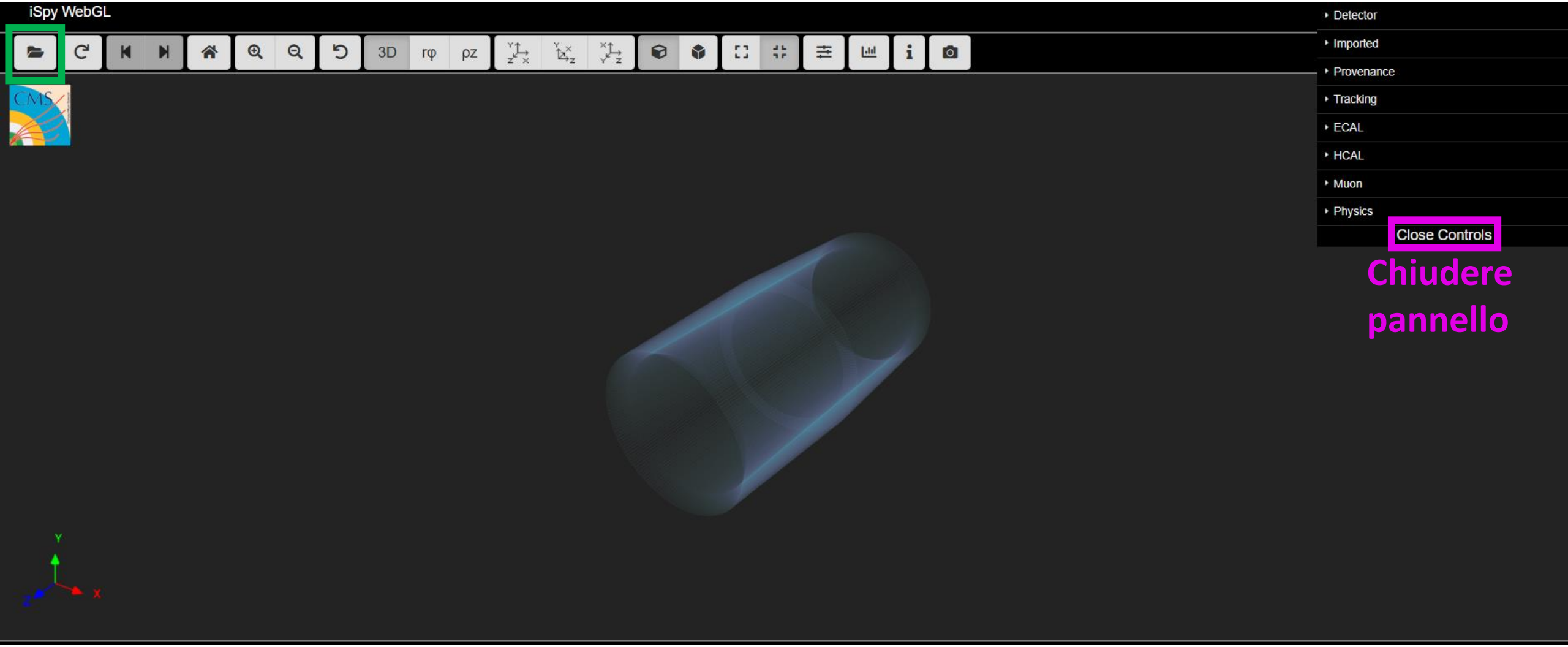
Choose your Masterclass	Choose your location	Choose your data file
TestEvents-01Jan2022	Firenze_25feb25	10.1
Santander-13May2024	Podgorica_25feb25	10.2
MP-15Jan2024	Pavia_25feb25	10.3
Cakovec-24Jan2024	Catania_25feb25	10.4
Bristol-27Mar2024	MSila_25feb25	10.5
Sandbox-31Dec2023	Helsinki_25feb25	10.6
Belgrade-FF		10.7
Osijek_17Jan2025		10.8
Sofia-13Jan2025		10.9
Chilton-29Jan2025		100.31
CERN-19Feb2025		100.32
CERN-IDWGS-11Feb2025		100.33
RAL-11to14Mar2025		100.34
CERN-25Feb2025		100.35
CERN-01Mar2025		100.36
CERN-05Mar2025		100.37
CERN-07Mar2025		100.38

Postazioni → cartella.file

10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8
100.31	100.32	100.33	100.34	100.35	100.36	100.37	100.38
100.41	100.42	100.43	100.44	100.45	100.46	100.47	100.48
100.51	100.52	100.53	100.54	100.55	100.56	100.57	100.58
10.9	100.39	100.49	100.59				

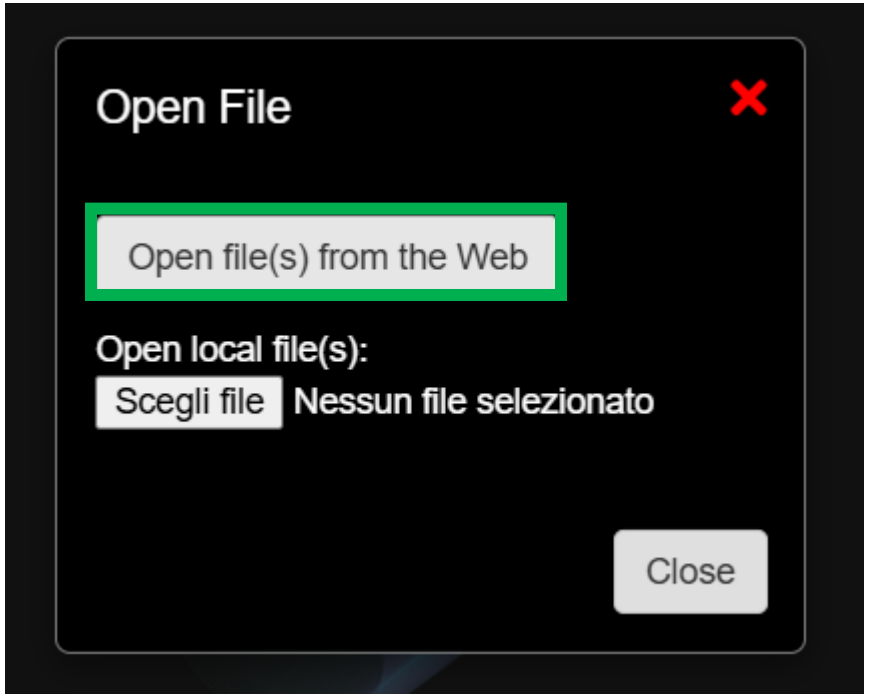
iSpy: chiudere pannello e aprire file

Aprire file



iSpy: selezionare file

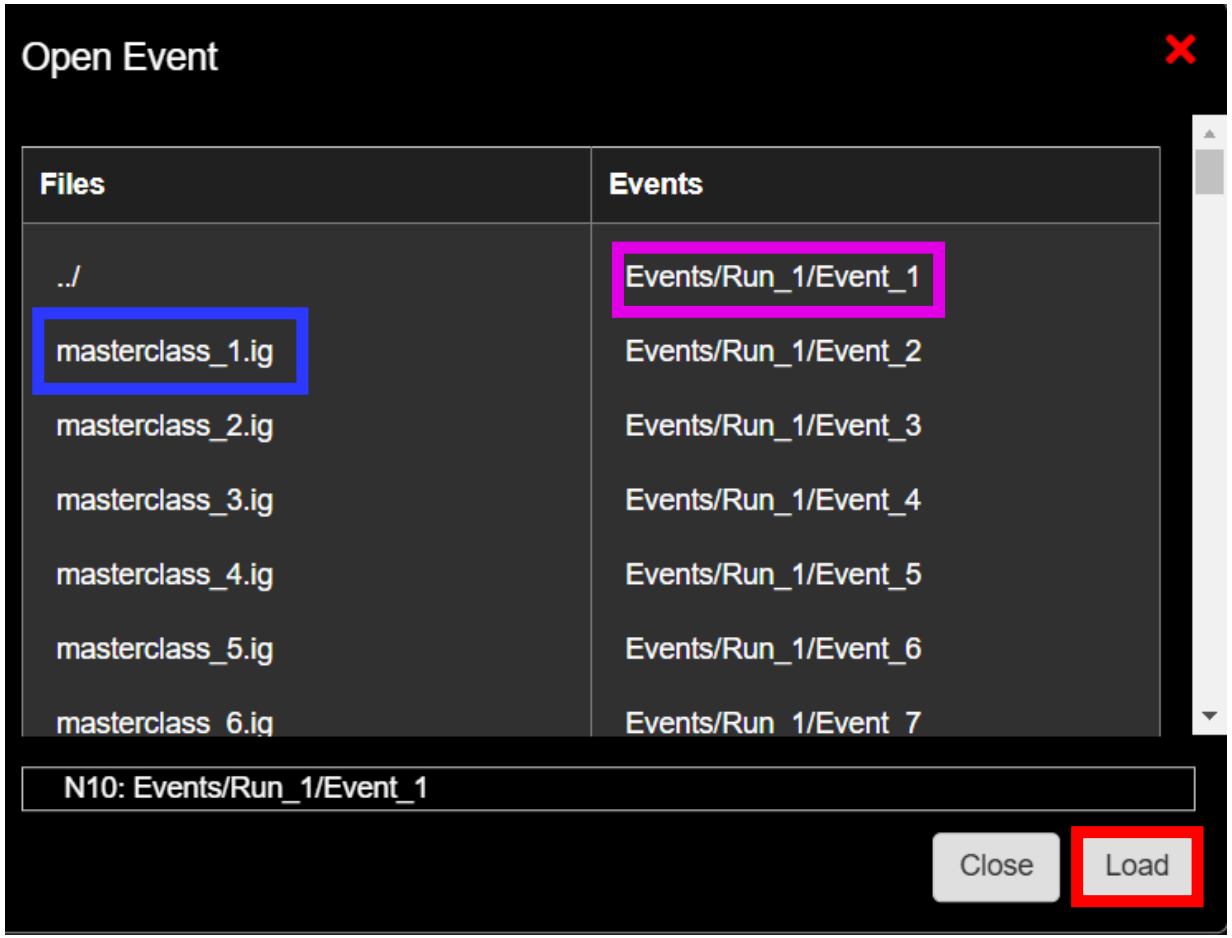
Seleziona file



Cartella 10 oppure 100

File 1 … 9

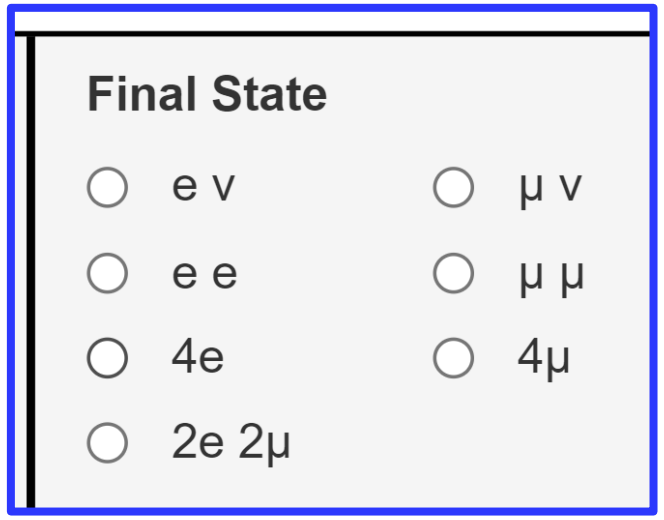
Primo evento

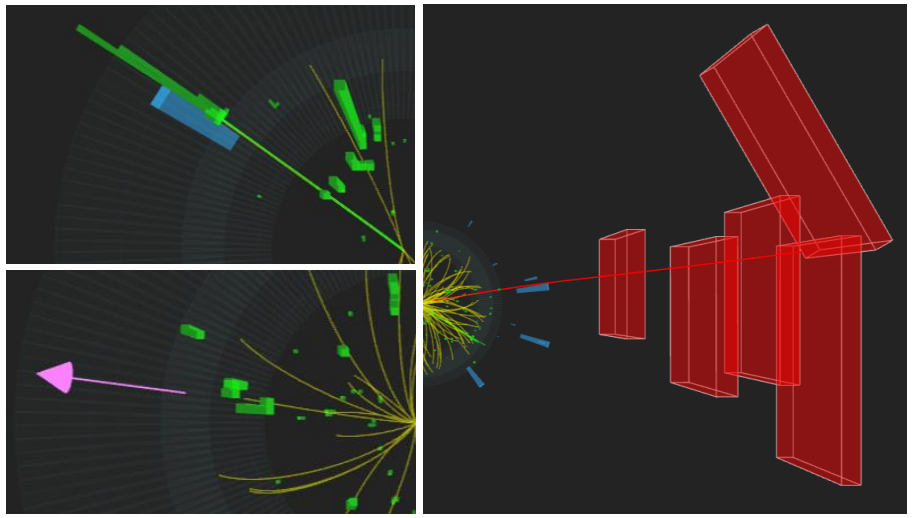


Carica

Legenda

- **Segnali:**
  - Elettrone (e) : **traccia verde**
  - Muone (μ) : **traccia rossa**
  - Neutrino (ν) : **freccia rosa**





- **Particelle:**

$W^+ \rightarrow e^+ \nu_e$ $W^- \rightarrow e^- \nu_e$

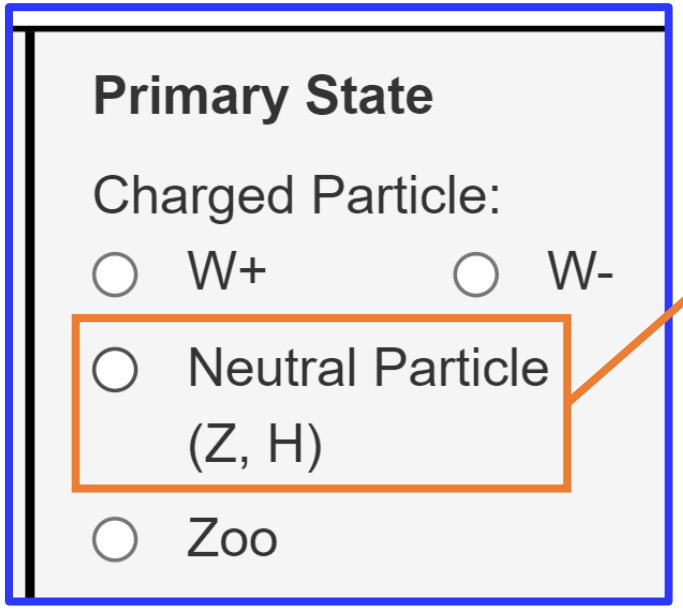
$W^+ \rightarrow \mu^+ \nu_\mu$ $W^- \rightarrow \mu^- \nu_\mu$

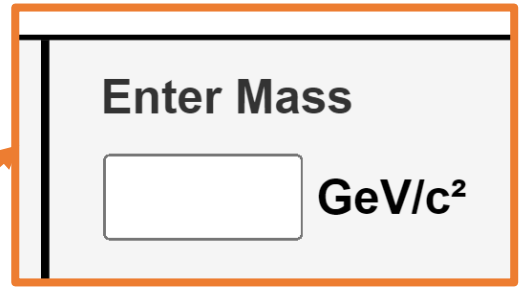
$Z \rightarrow e^+ e^-$ $Z \rightarrow \mu^+ \mu^-$

$H \rightarrow ZZ \rightarrow e^+ e^- e^+ e^-$

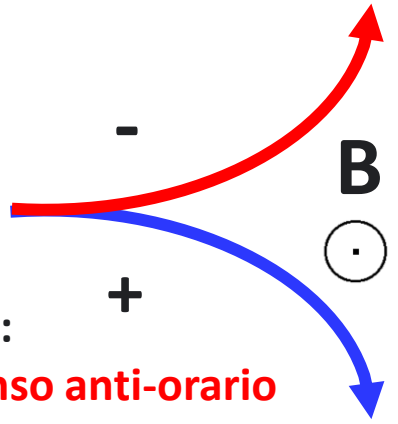
$H \rightarrow ZZ \rightarrow \mu^+ \mu^- \mu^+ \mu^-$

$H \rightarrow ZZ \rightarrow e^+ e^- \mu^+ \mu^-$





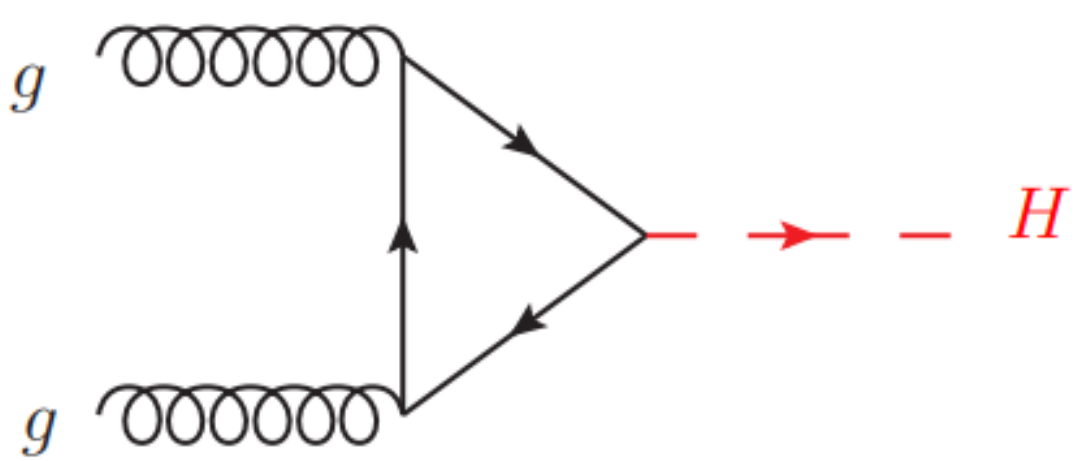
- **Click su tracce verdi/rosse**
- **Premere "M" sulla tastiera**

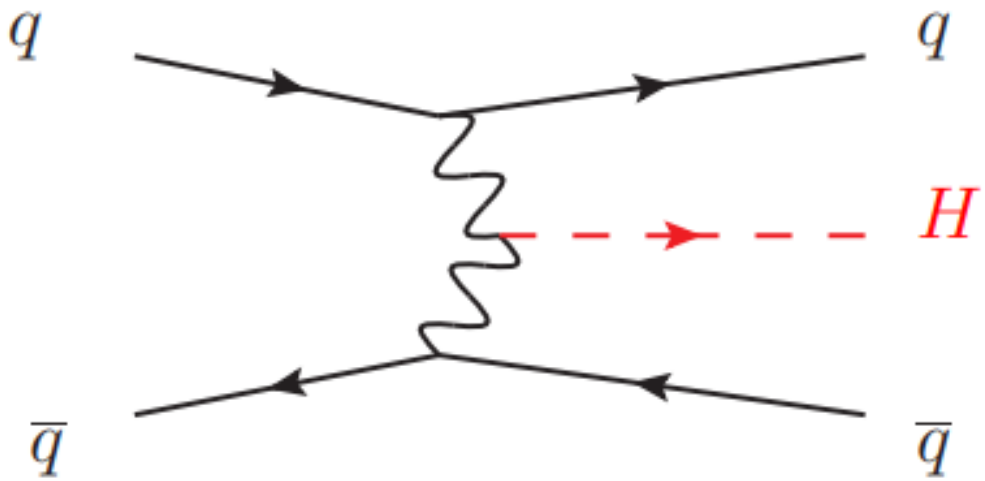


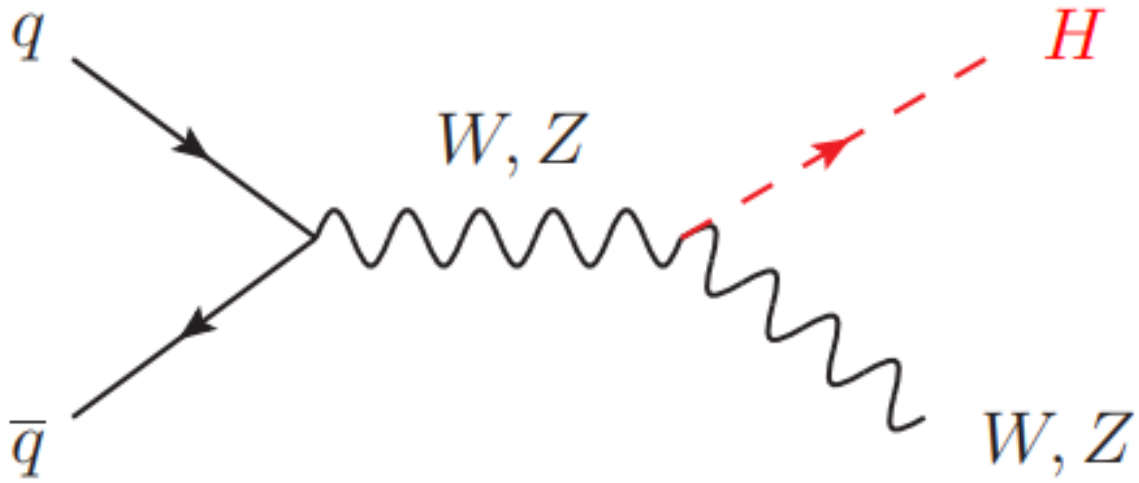
- **Curvatura tracce cariche:**
  - **Carica negativa: senso anti-orario**
  - **Carica positiva: senso orario**

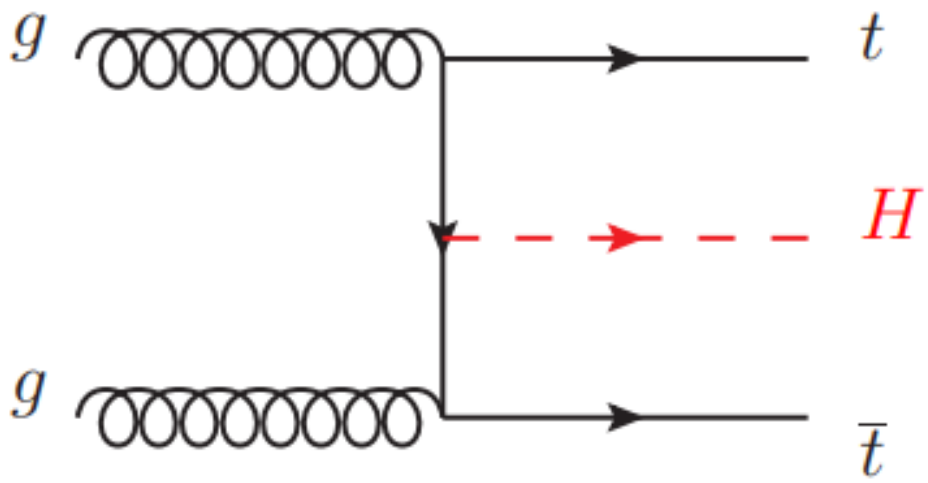
Backup

Processi di produzione del Bosone di Higgs



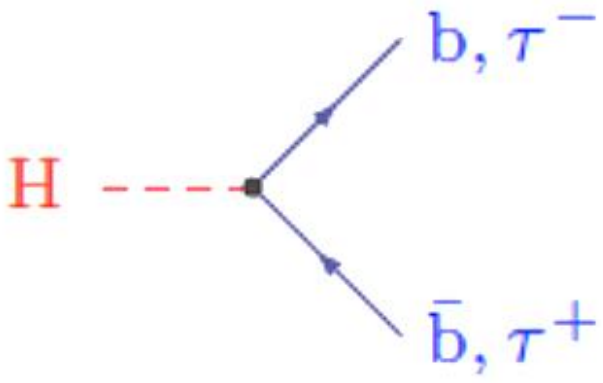


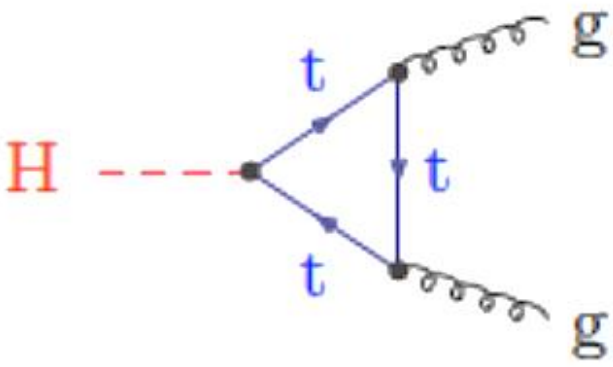


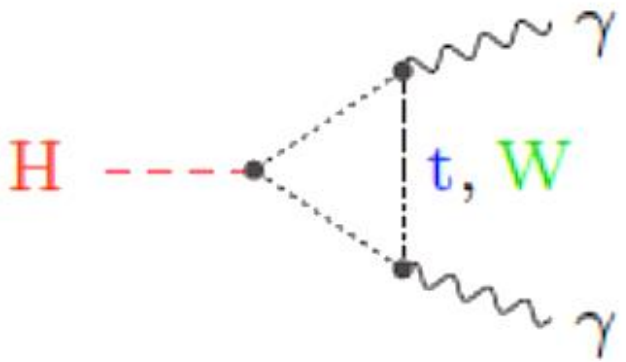


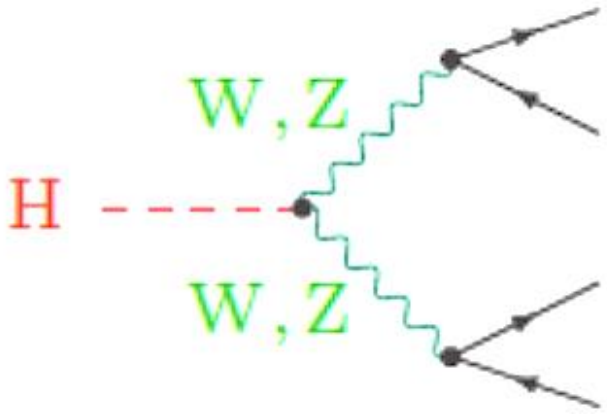
Canali di Decadimento del Bosone di Higgs

- Testo

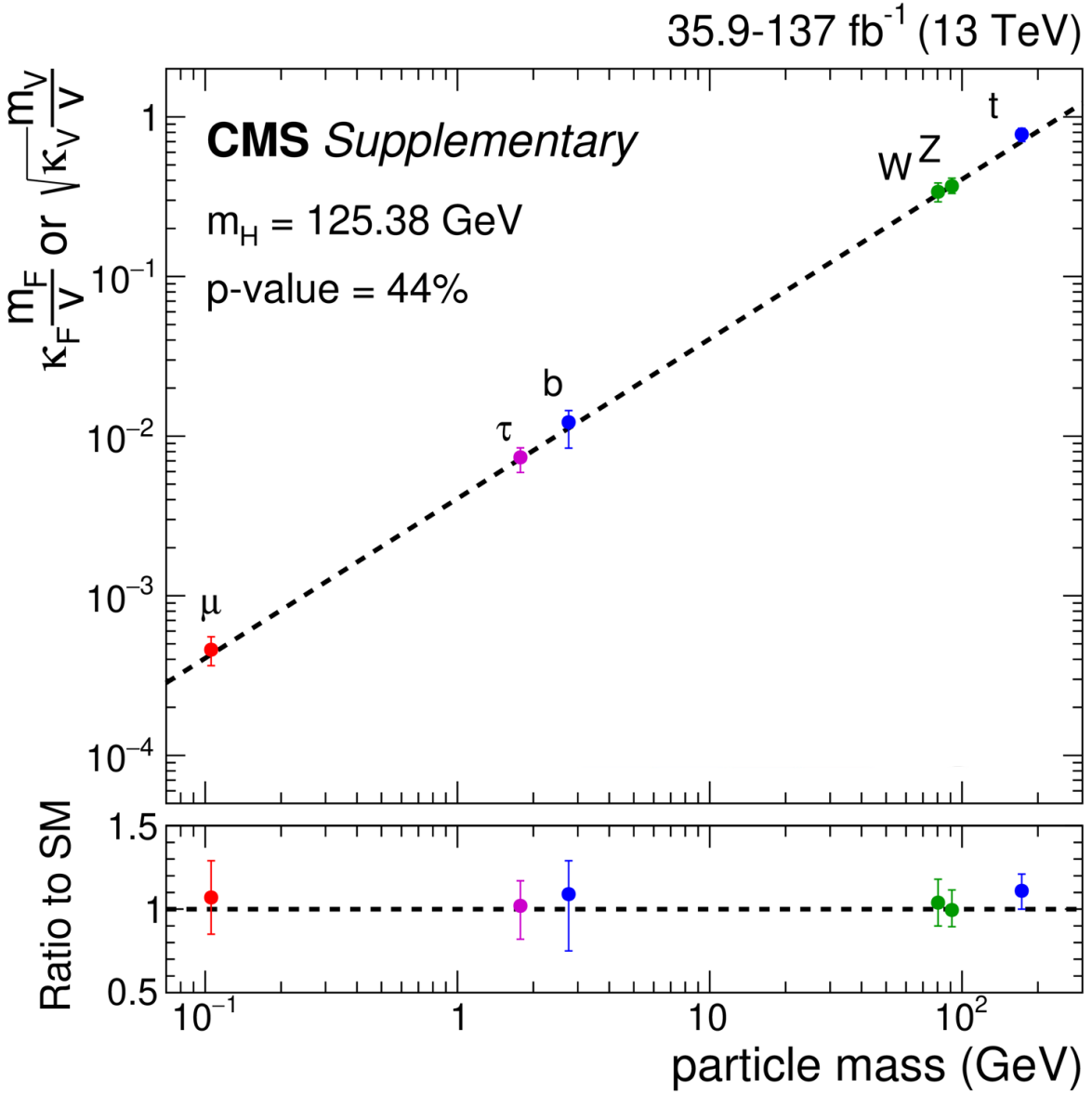








Decadimento	Probabilità [%]
$H \to b\bar{b}$	57.5 ± 1.9
$H \to WW$	21.6 ± 0.9
$H \to gg$	8.56 ± 0.86
$H \to \tau\tau$	6.30 ± 0.36
$H \to c\bar{c}$	2.90 ± 0.35
$H \to ZZ$	2.67 ± 0.11
$H \to \gamma\gamma$	0.228 ± 0.011
$H \to Z\gamma$	0.155 ± 0.014
$H \to \mu\mu$	0.022 ± 0.001

Meccanismo di Higgs: la massa

- Interazione con bosone di Higgs proporzionale alla massa!
  - t: 173 GeV
  - Z: 90 GeV
  - W: 80 GeV
  - b: 4 GeV
  - τ: 2 GeV
  - μ: 0.1 GeV