

Introduzione all'Esercizio

01/03/2024

A. Lapertosa

Uni
ct

FISICA E ASTRONOMIA
"ETTORE MAJORANA"

INFN
CATANIA

Fisica delle particelle: Modello Standard

Quark

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

Leptoni

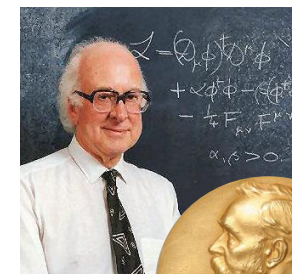
e elettrone	μ muone	τ tau
ν_e neutrino	ν_μ neutrino	ν_τ neutrino

Bosoni

W
Z
g gluone
γ fotone

H Higgs

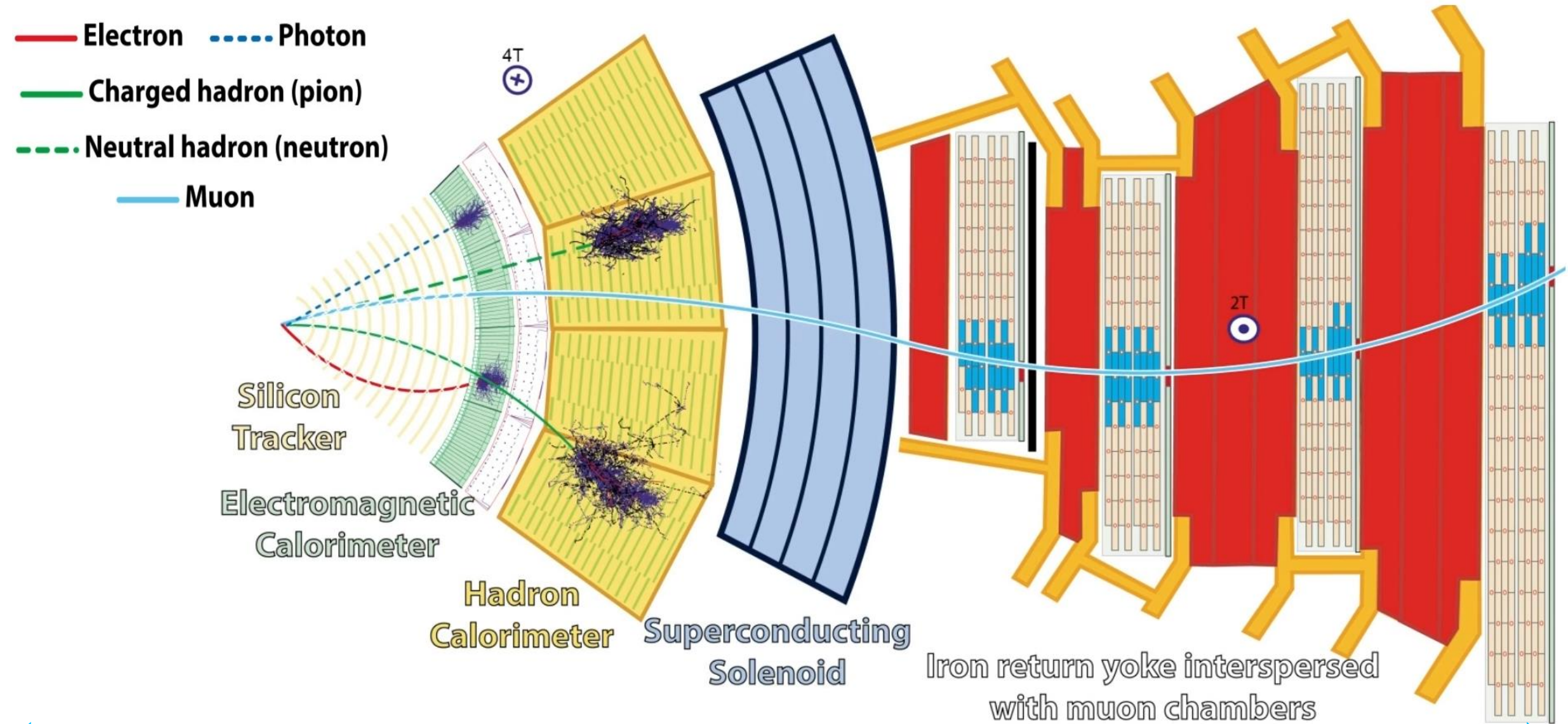
Higgs

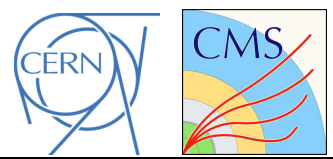


Una fetta di CMS



Rivelatori di particelle: l'esperimento CMS





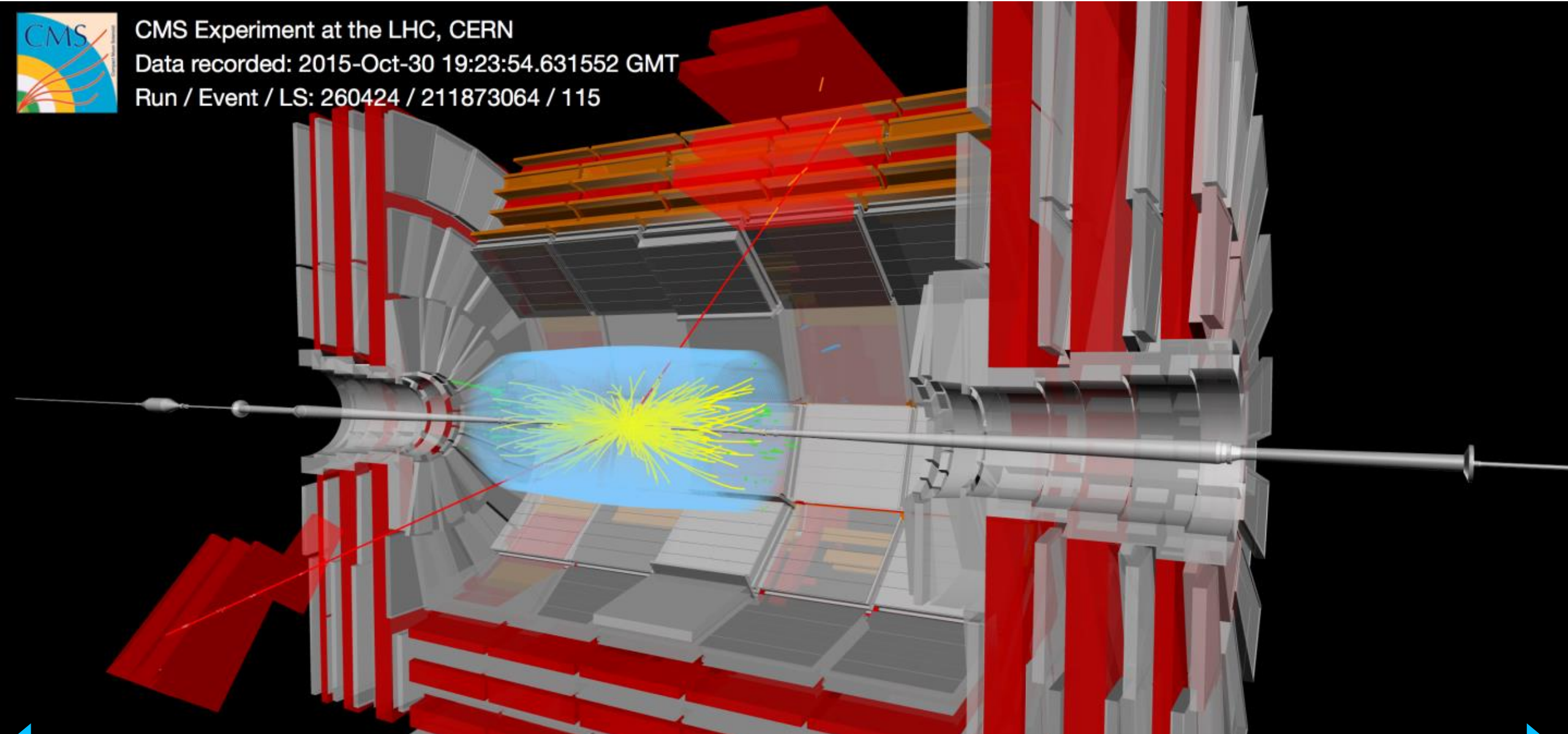
Le collisioni dentro l'esperimento CMS

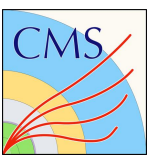


CMS Experiment at the LHC, CERN

Data recorded: 2015-Oct-30 19:23:54.631552 GMT

Run / Event / LS: 260424 / 211873064 / 115





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

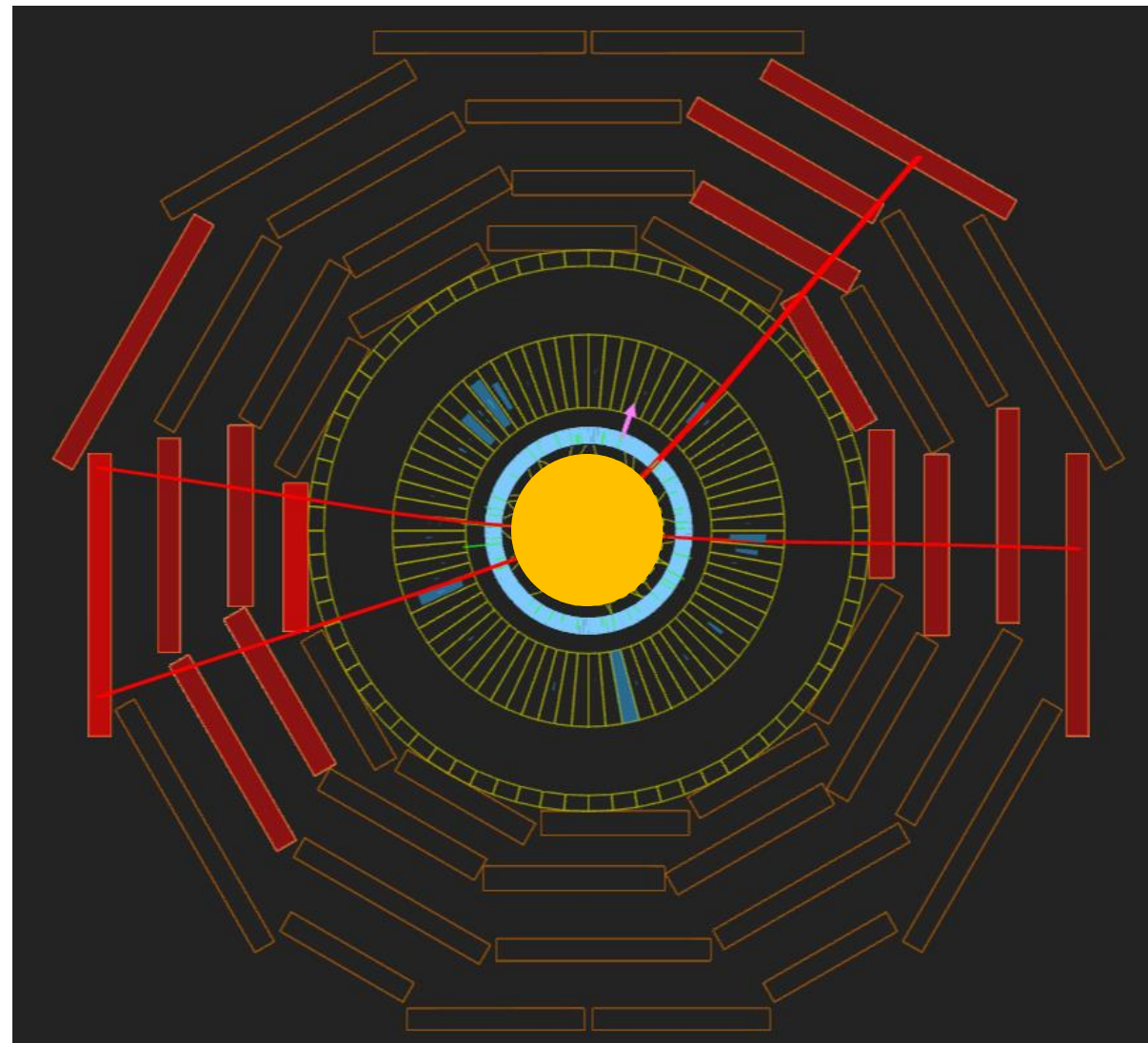
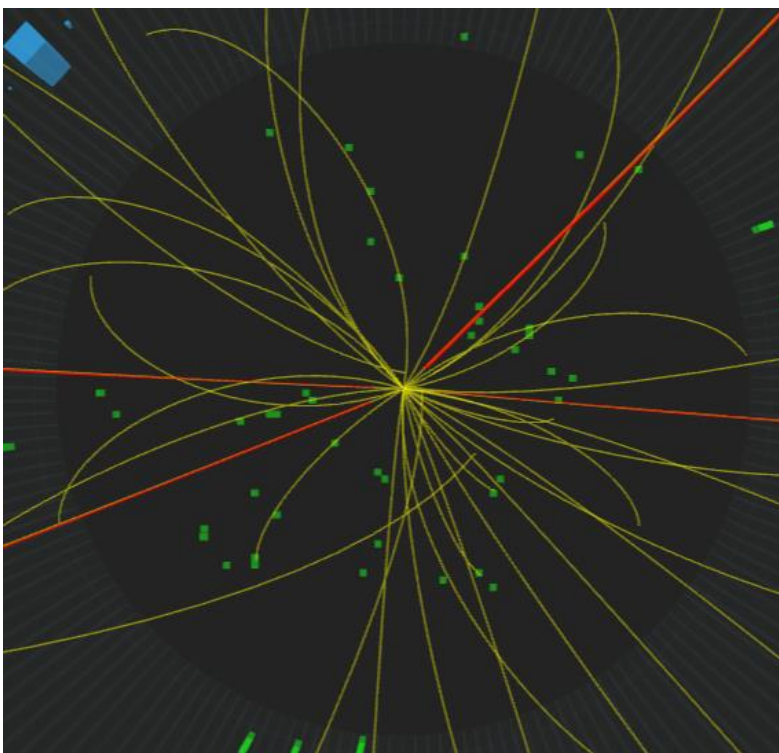
1. Tracciatore

2. Calorimetro Elettromagnetico

3. Calorimetro Adronico

4. Solenoide

5. Rivelatore di muoni



Segnali dentro l'esperimento CMS

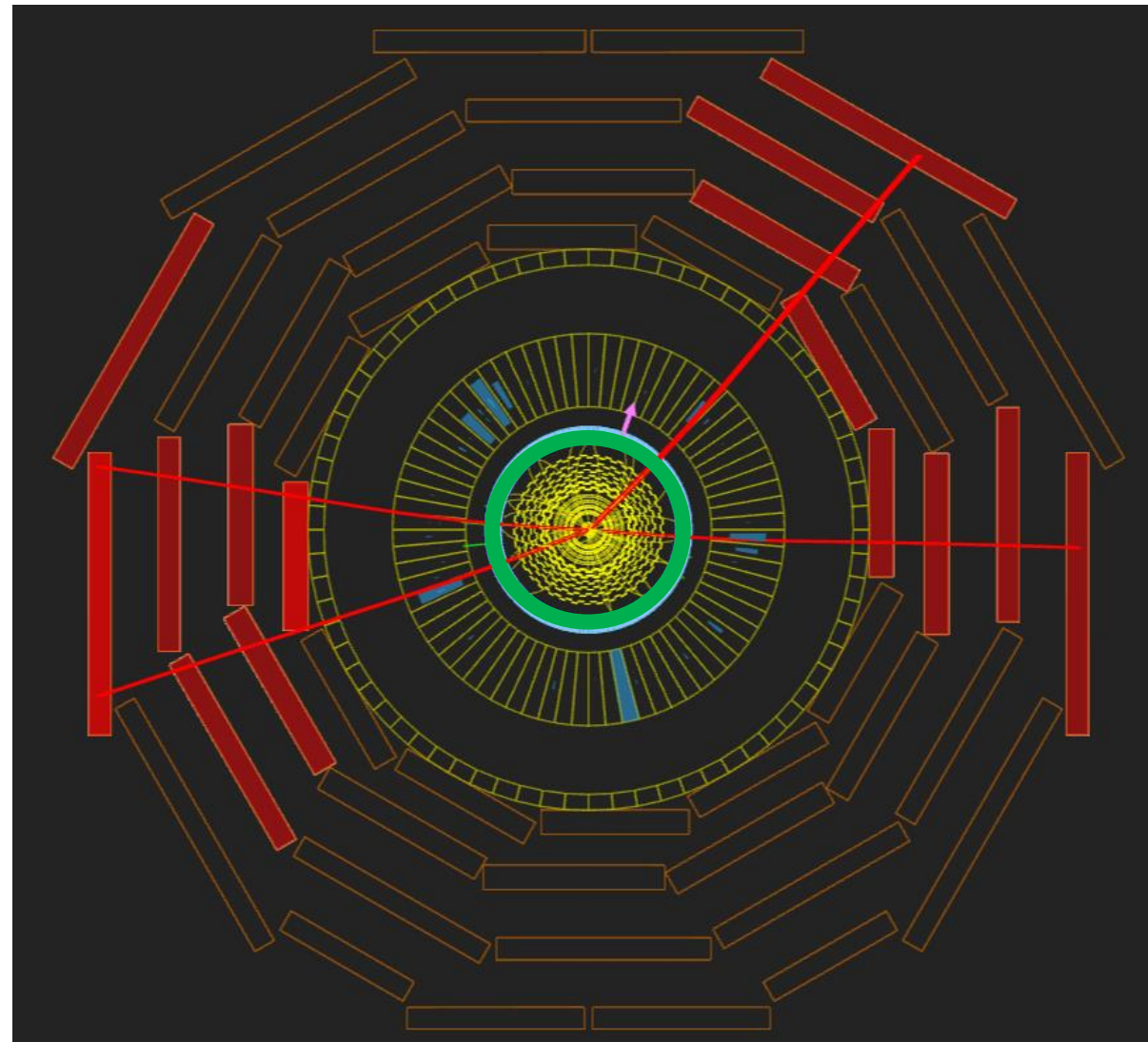
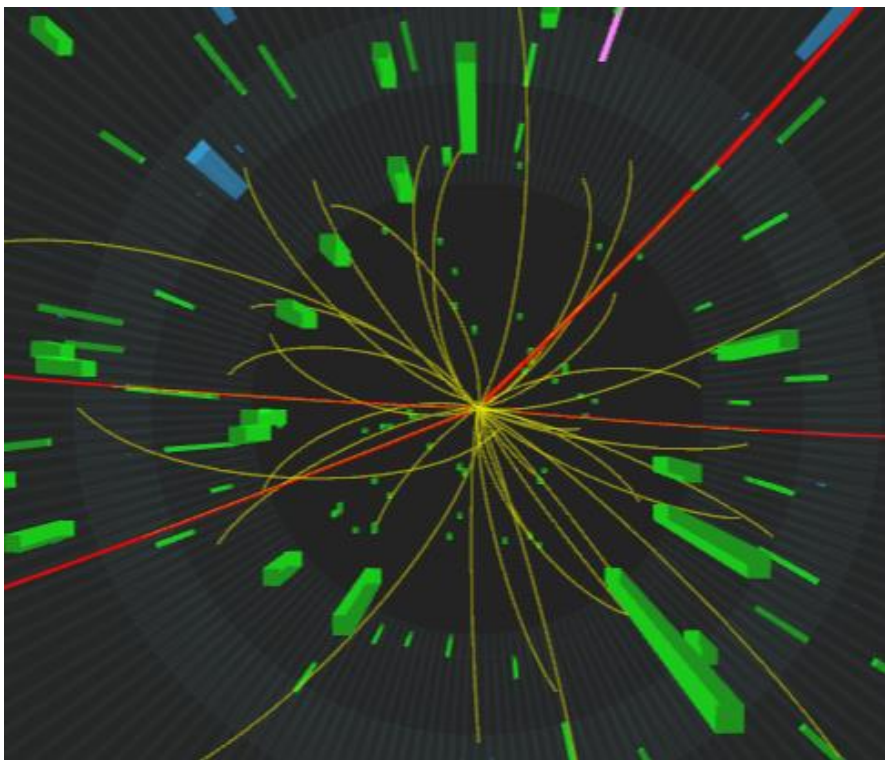
1. Tracciatore

2. Calorimetro Elettromagnetico

3. Calorimetro Adronico

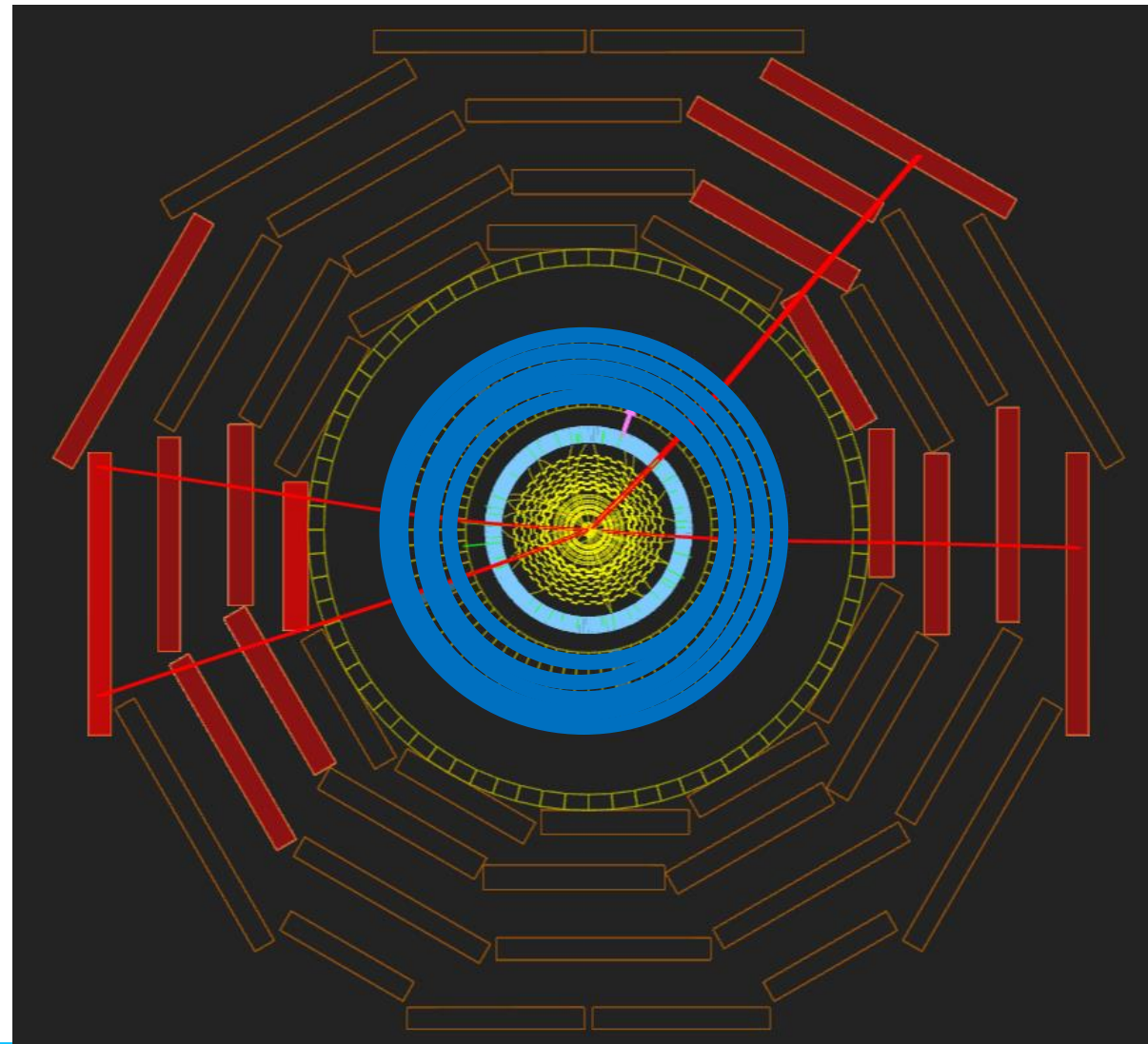
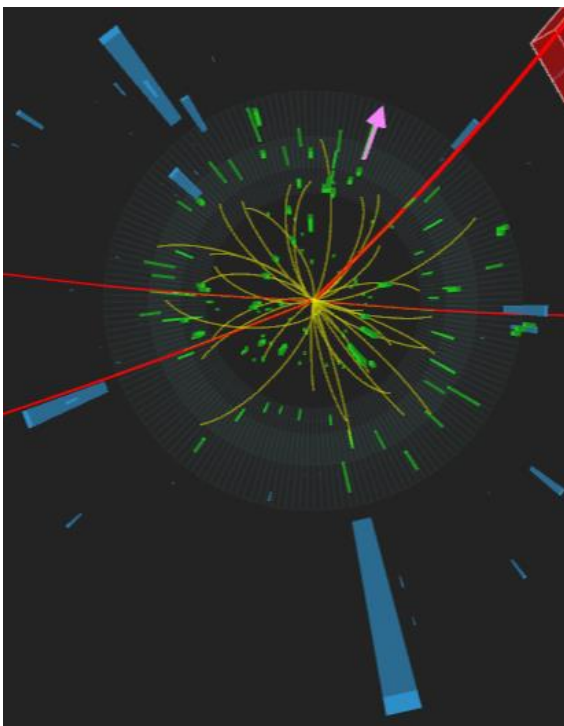
4. Solenoide

5. Rivelatore di muoni



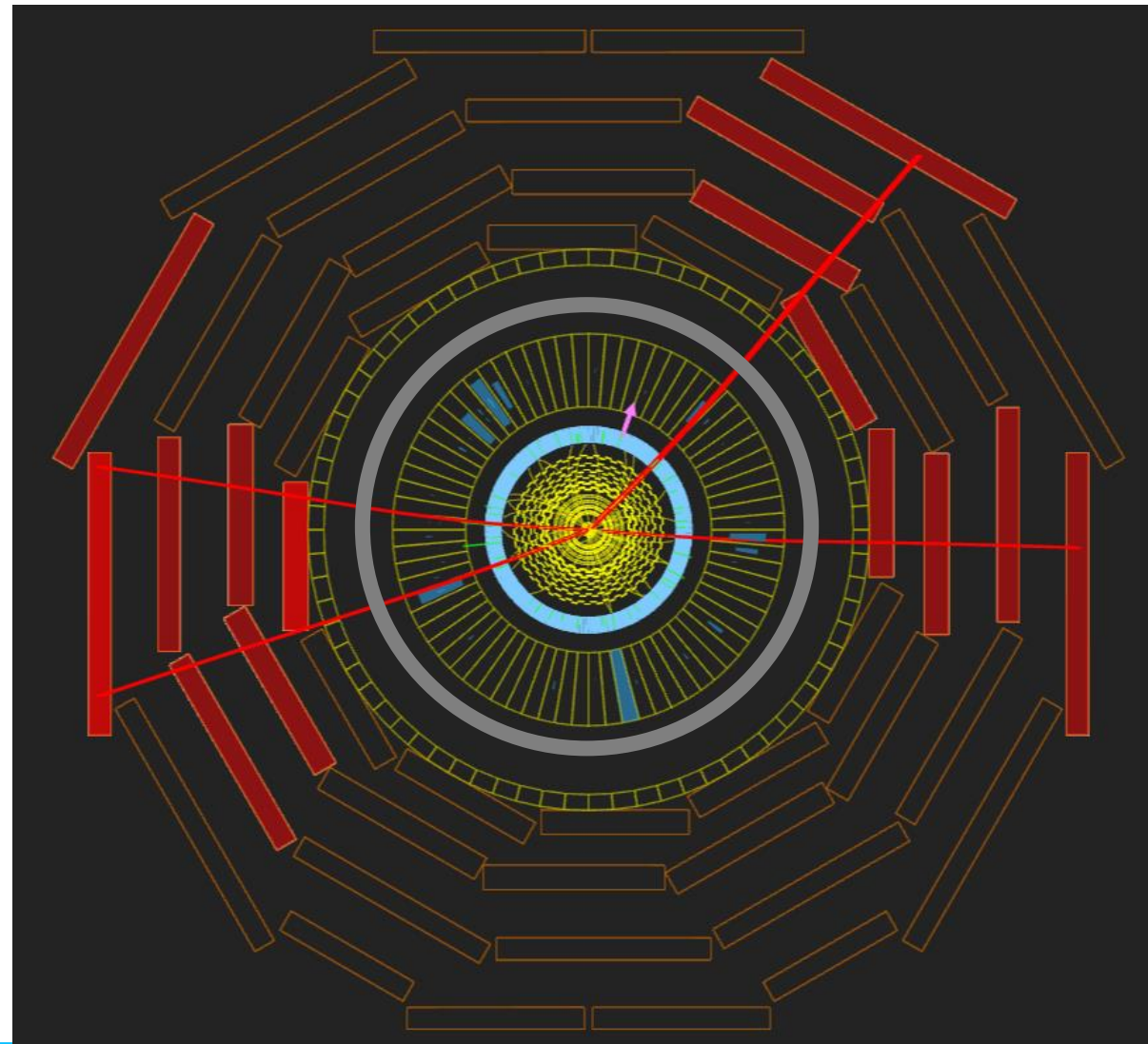
Segnali dentro l'esperimento CMS

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



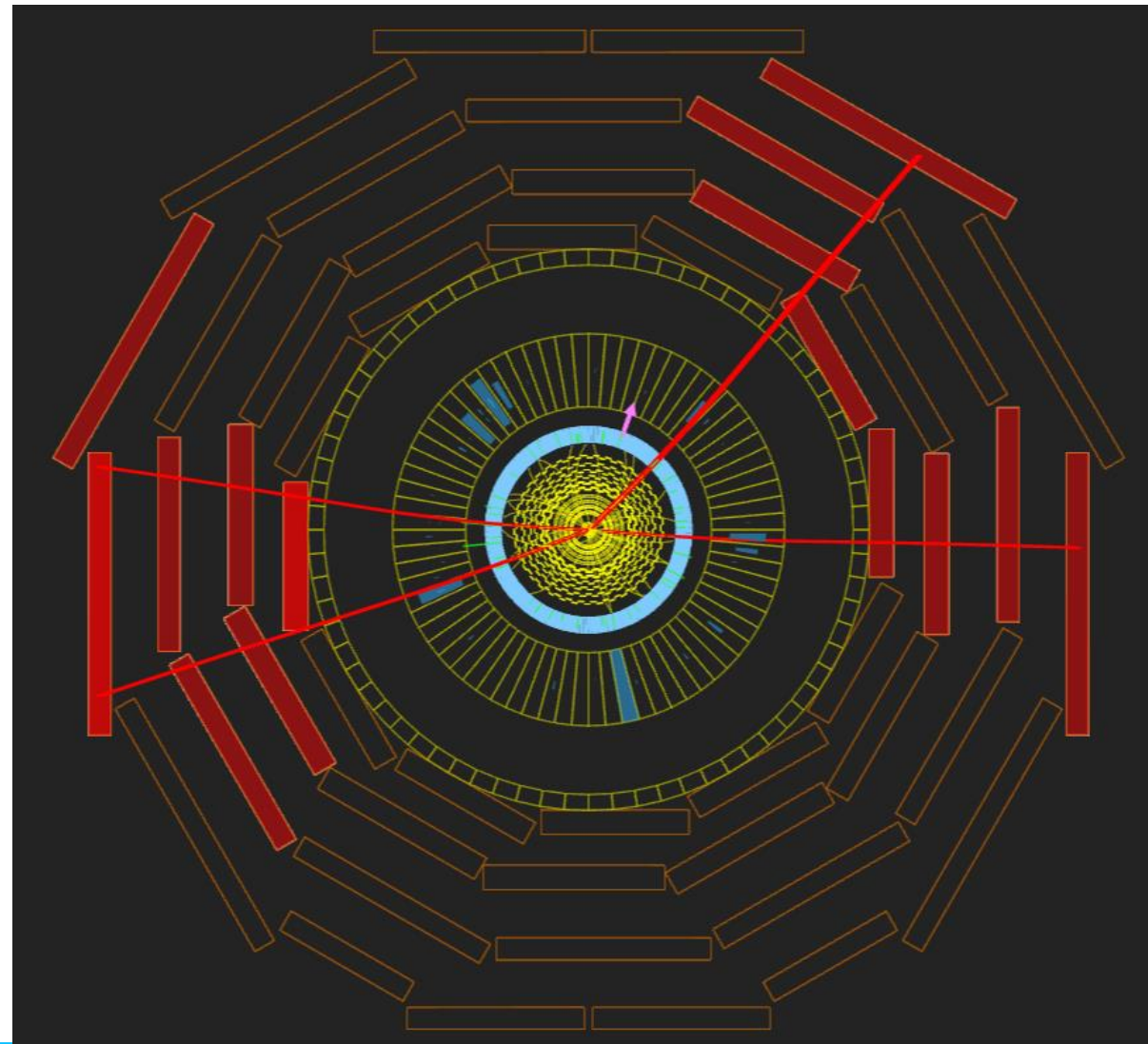
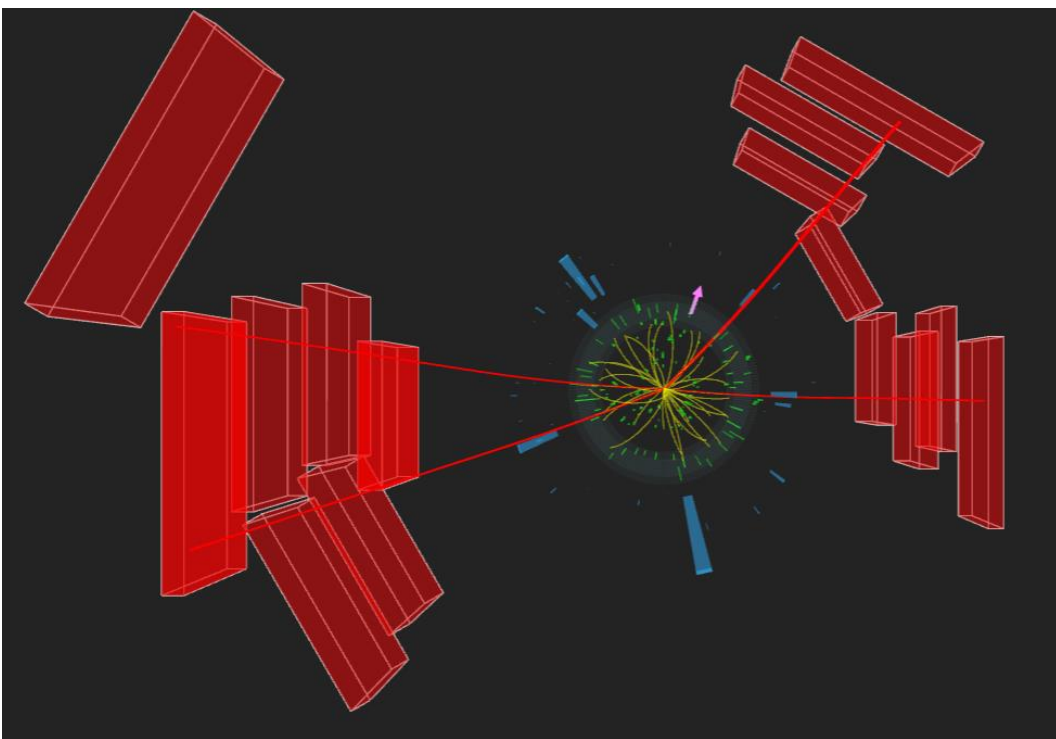
Segnali dentro l'esperimento CMS

1. Tracciatore
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Segnali dentro l'esperimento CMS

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



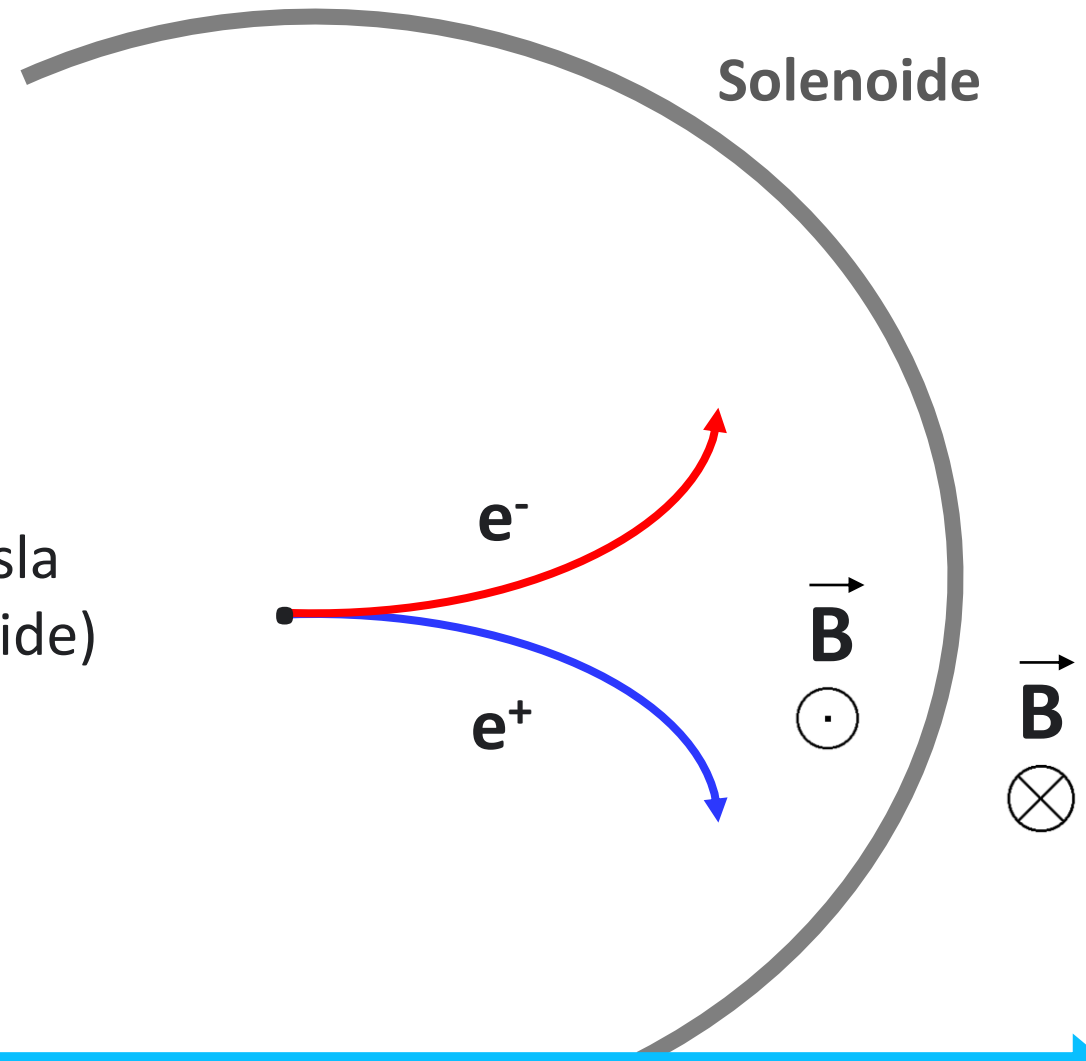
Forza di Lorentz

- 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

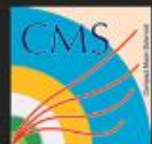
Numero dell'evento

iSpy WebGL

N25:Events/Run_2/Event_11 [11 of 100]



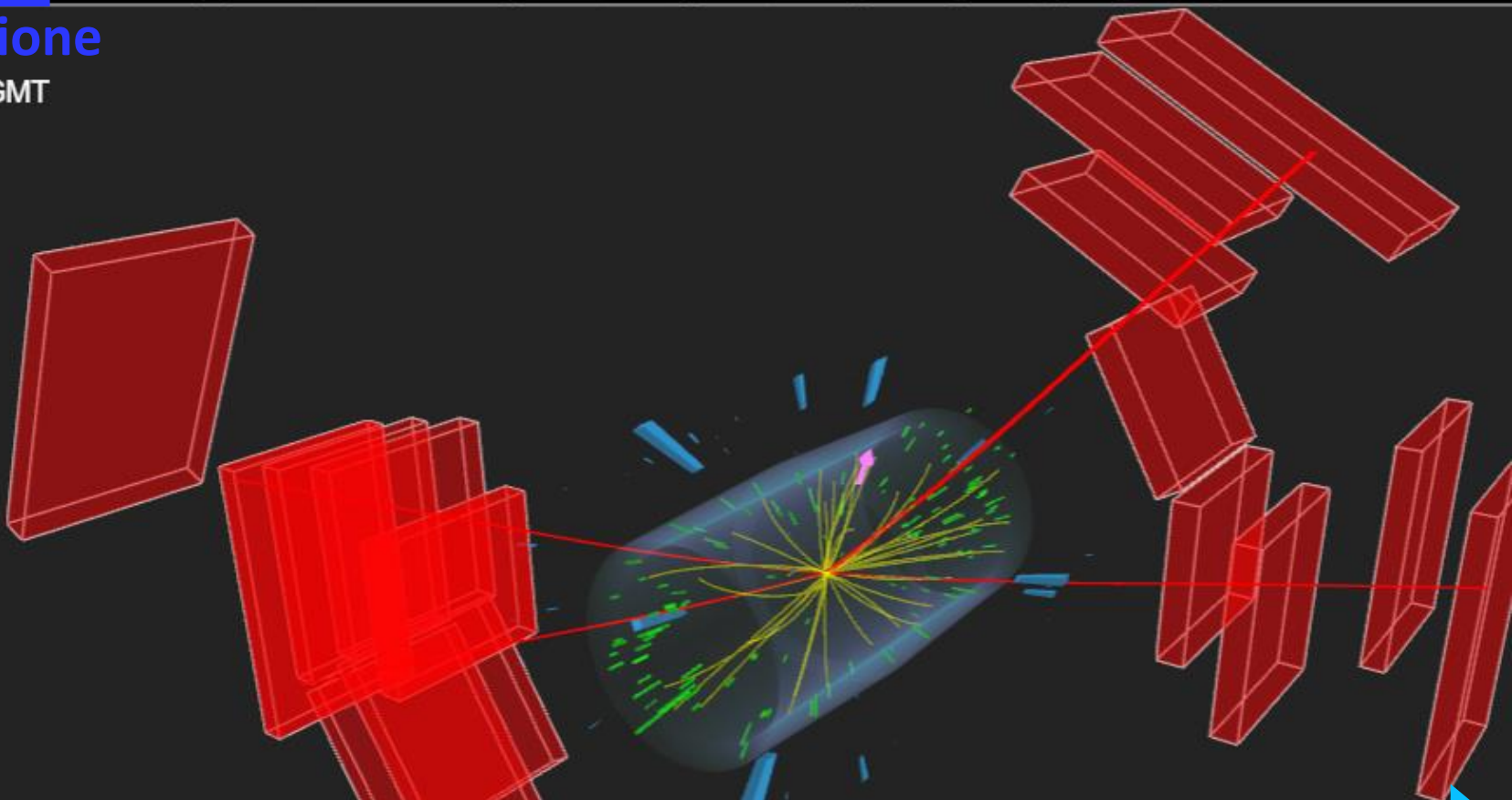
Visione



CMS Experiment at the LHC, CERN

Data recorded: 2012-Aug-25 07:54:49.462084 GMT

Run / Event / LS: 201668 / 114003150 / 121





iSpy: l'Event Display

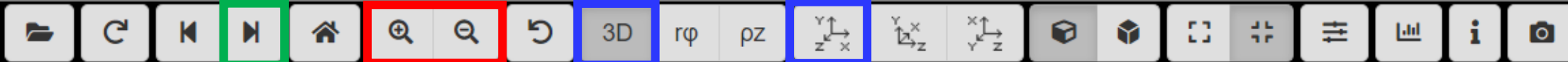
Prossimo
evento

Zoom

Numero dell'evento

iSpy WebGL

N25:Events/Run_2/Event_11 [11 of 100]



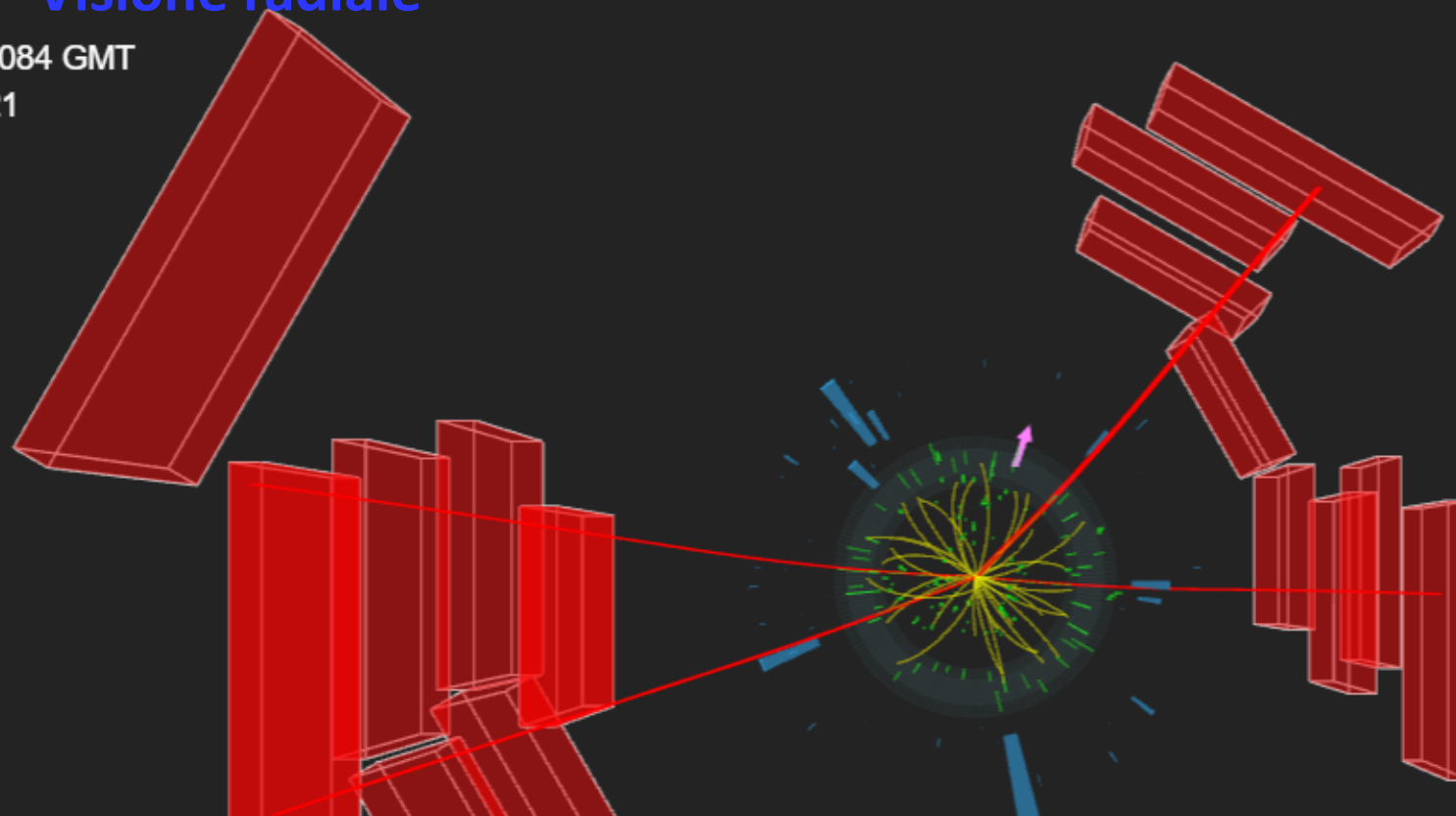
Visione radiale



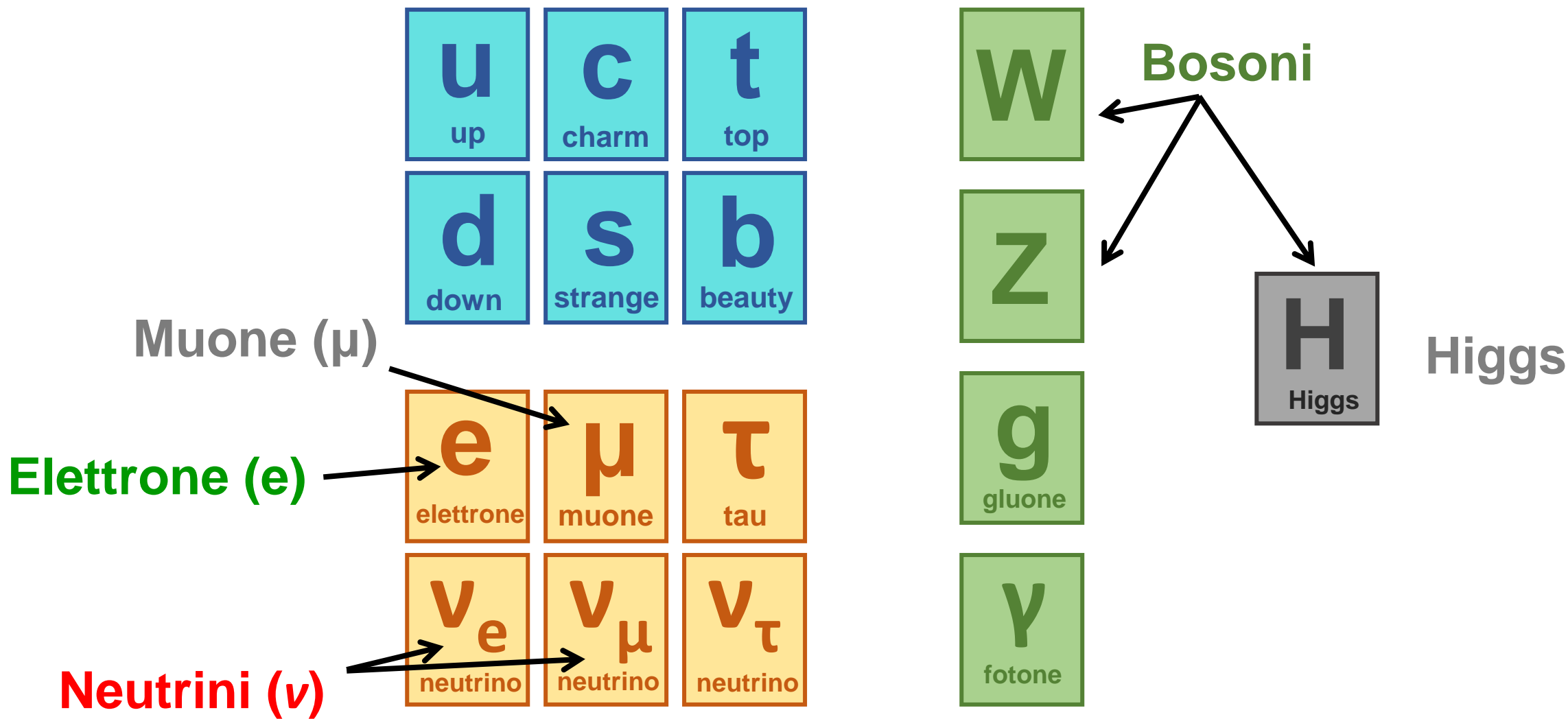
CMS Experiment at the LHC, CERN

Data recorded: 2012-Aug-25 07:54:49.462084 GMT

Run / Event / LS: 201668 / 114003150 / 121

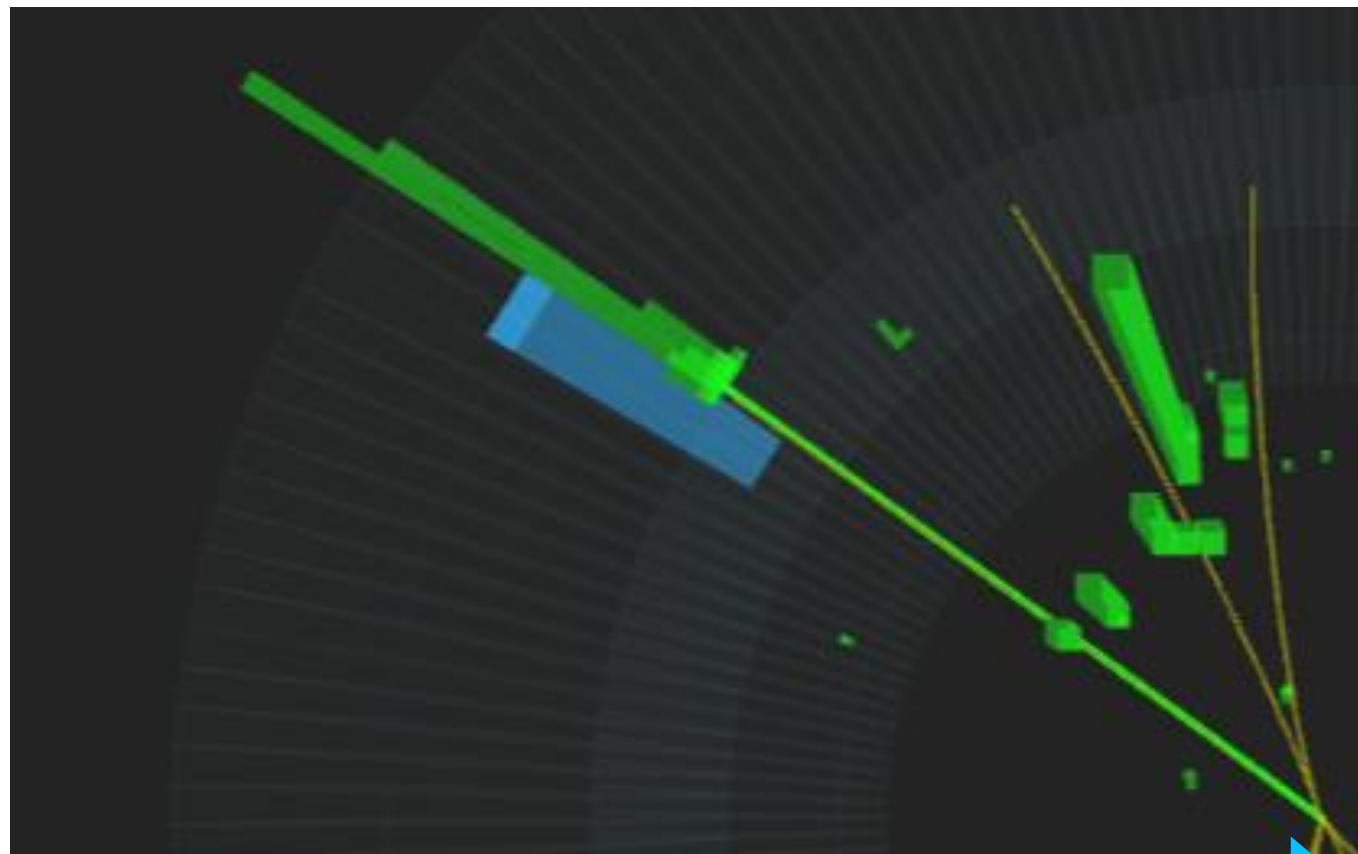


Cosa cerchiamo nei nostri eventi



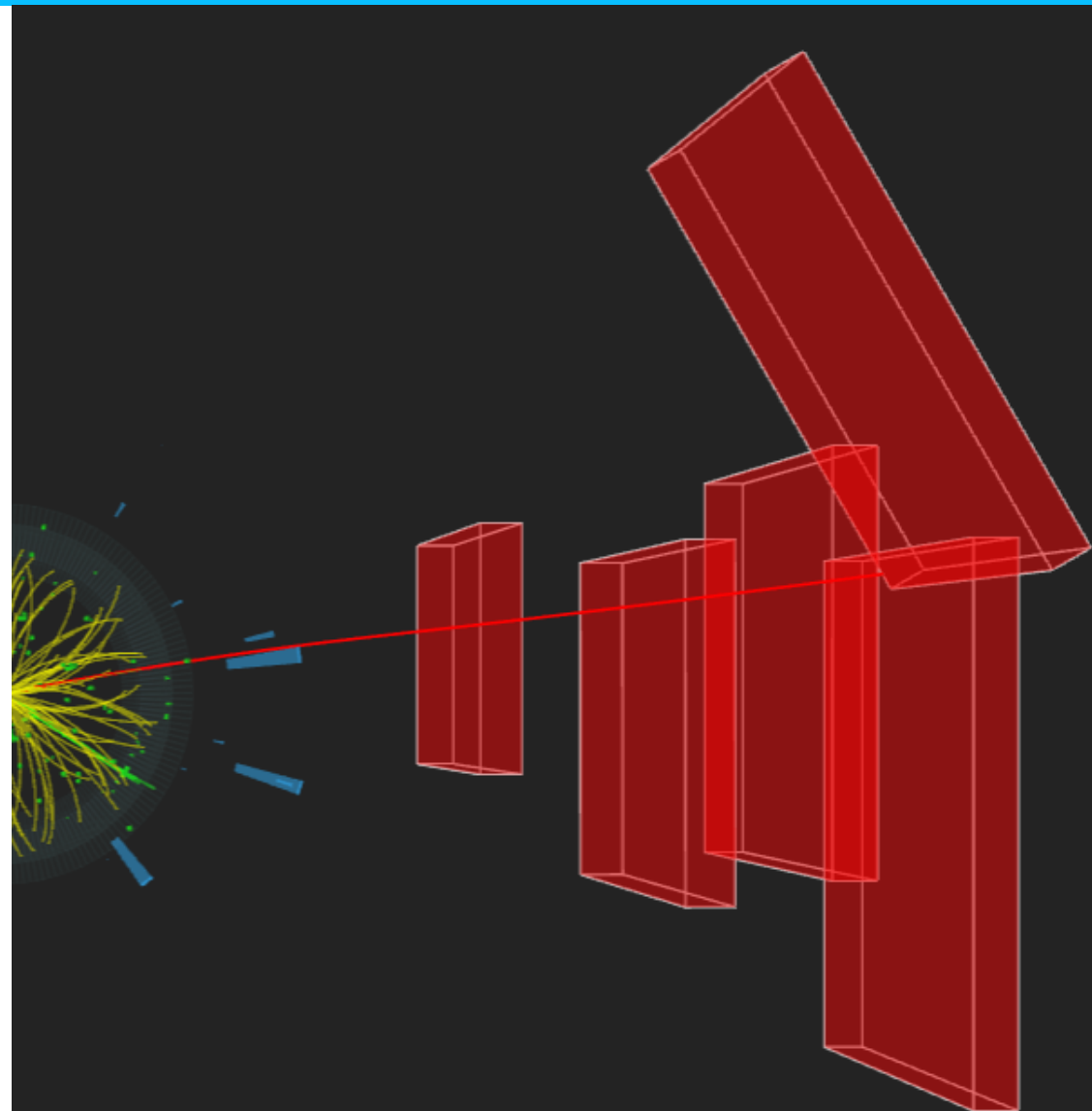
I segnali: elettrone (e)

- 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**



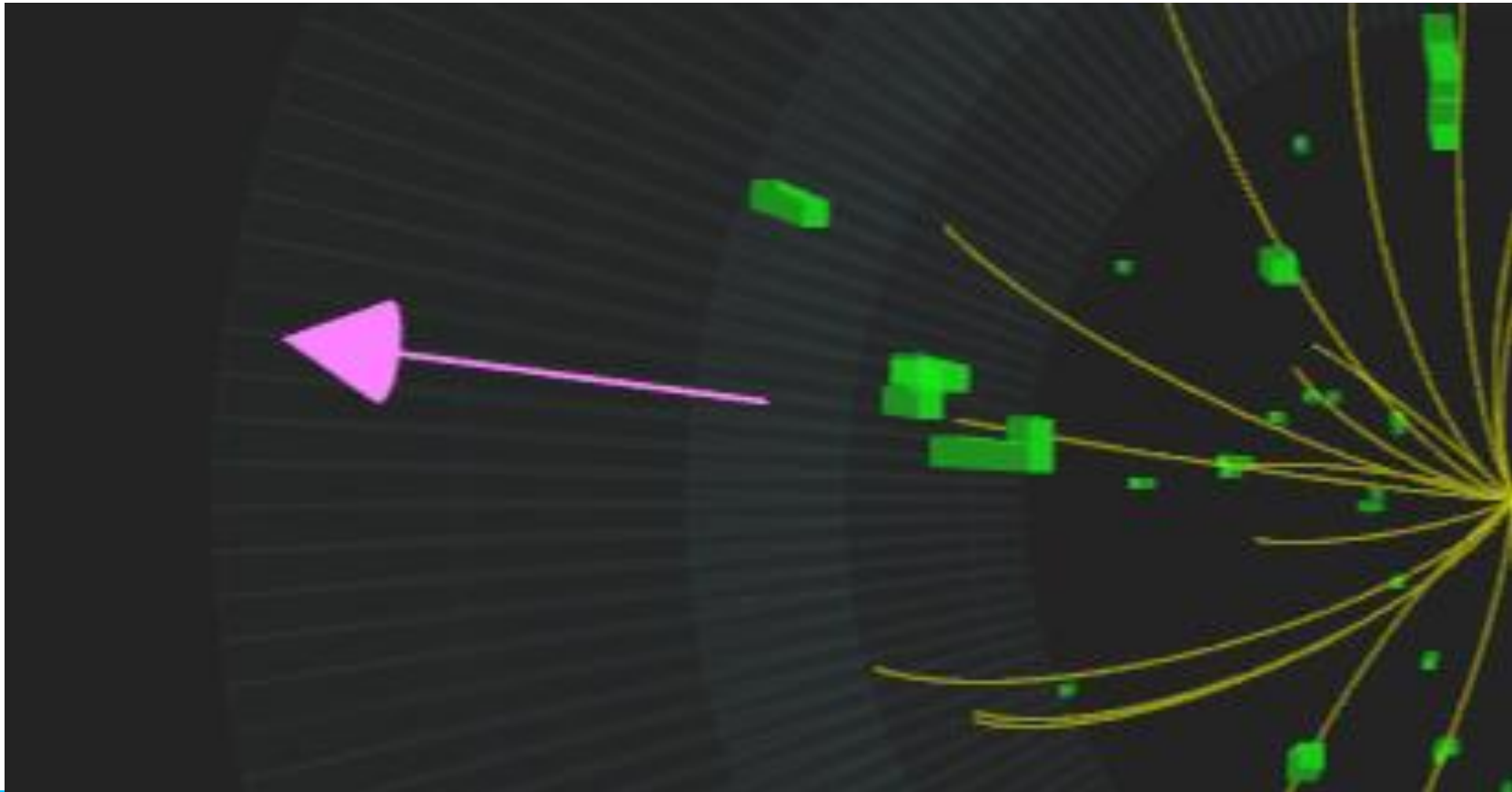
I segnali: muone (μ)

- 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**

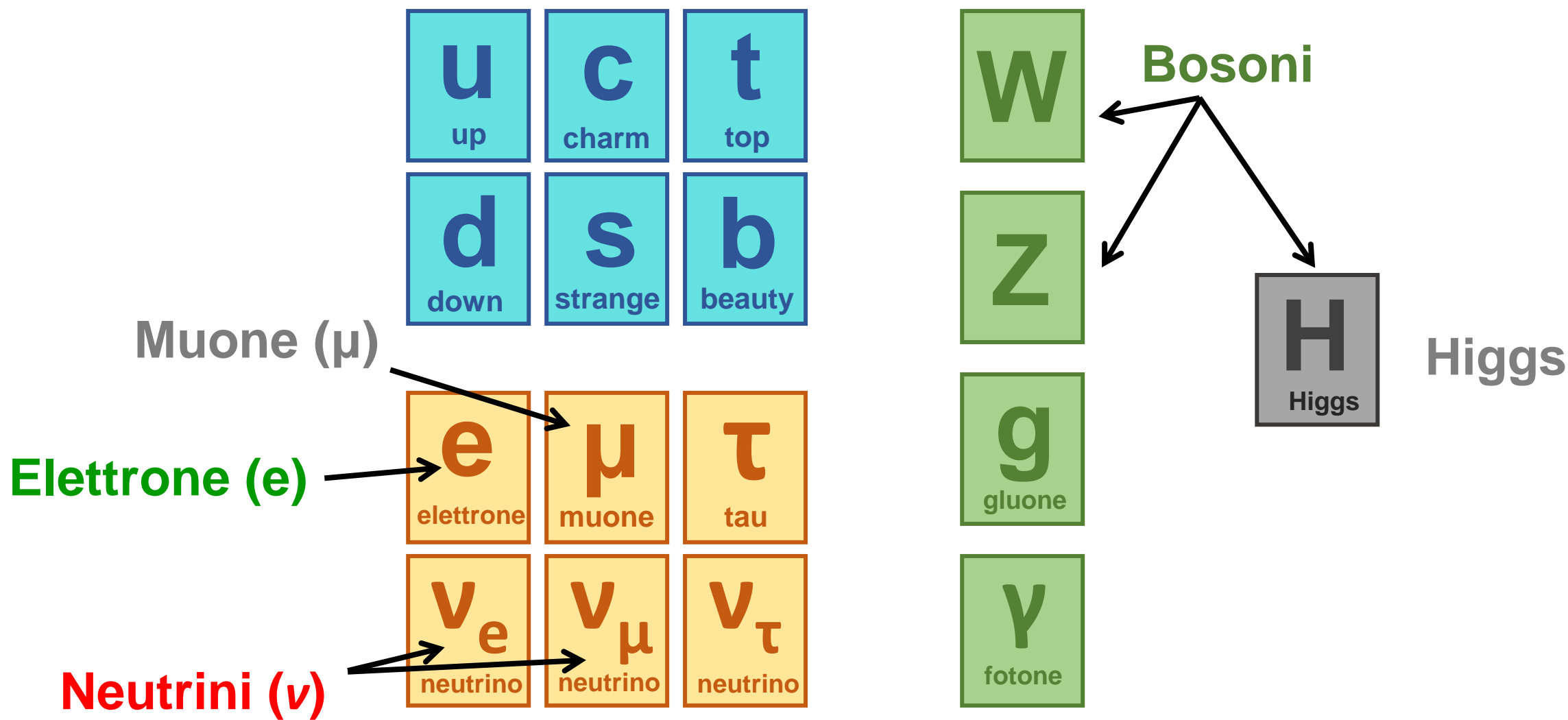


I segnali: neutrino (ν) ...energia mancante

- 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 \rightarrow “energia mancante”
-
- Caratteristiche del segnale:
 - **Freccia: rosa**



Cosa cerchiamo nei nostri eventi



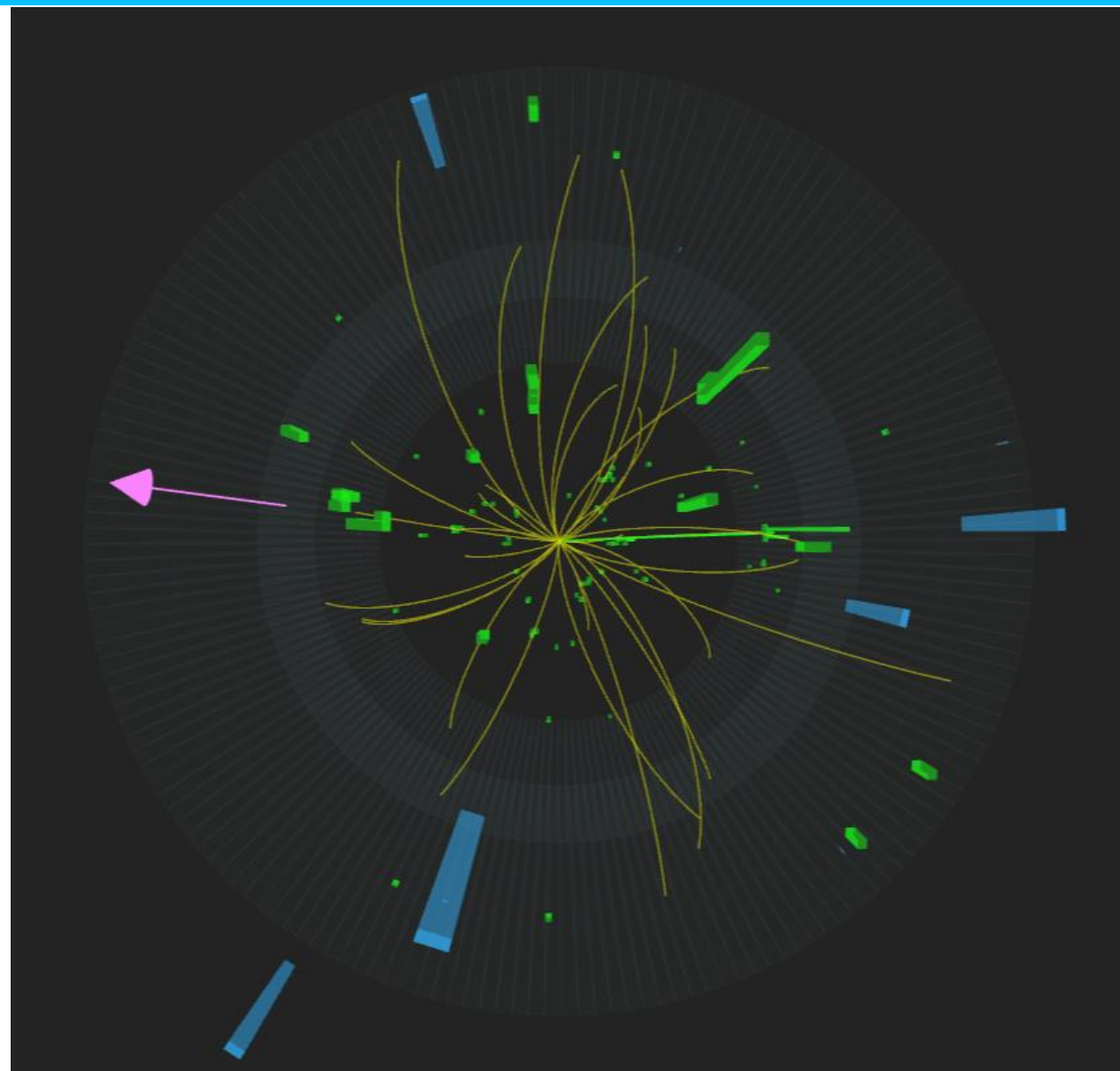
Le particelle: bosone W (e ν , μ ν)

- 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**

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

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

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

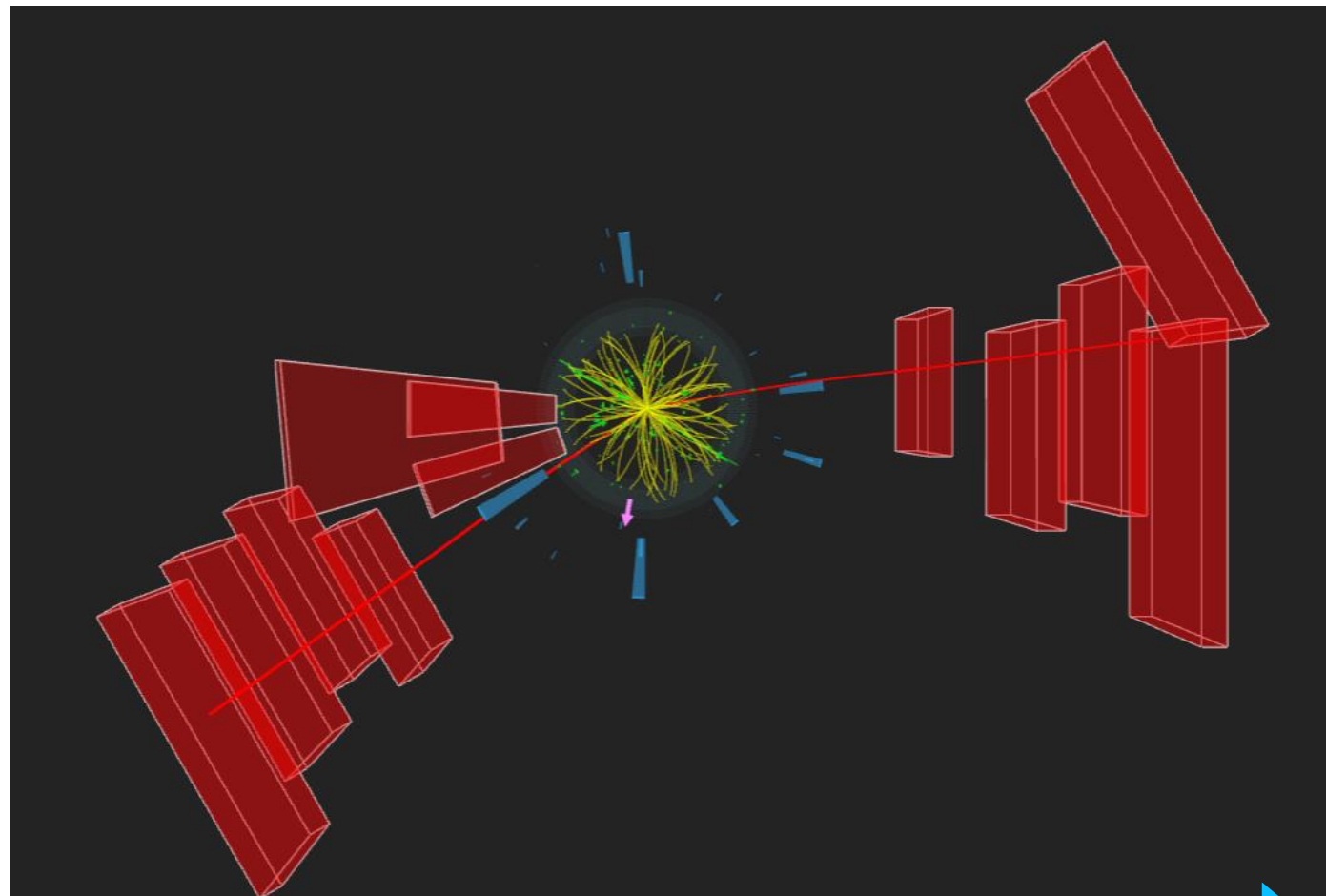


Le particelle: bosone Z (ee, $\mu\mu$)

- 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**

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

- Caratteristiche del segnale Z(ee):
 - **Traccia: verde**
 - **Traccia: verde**
- Caratteristiche del segnale Z($\mu\mu$):
 - **Traccia: rossa**
 - **Traccia: rossa**

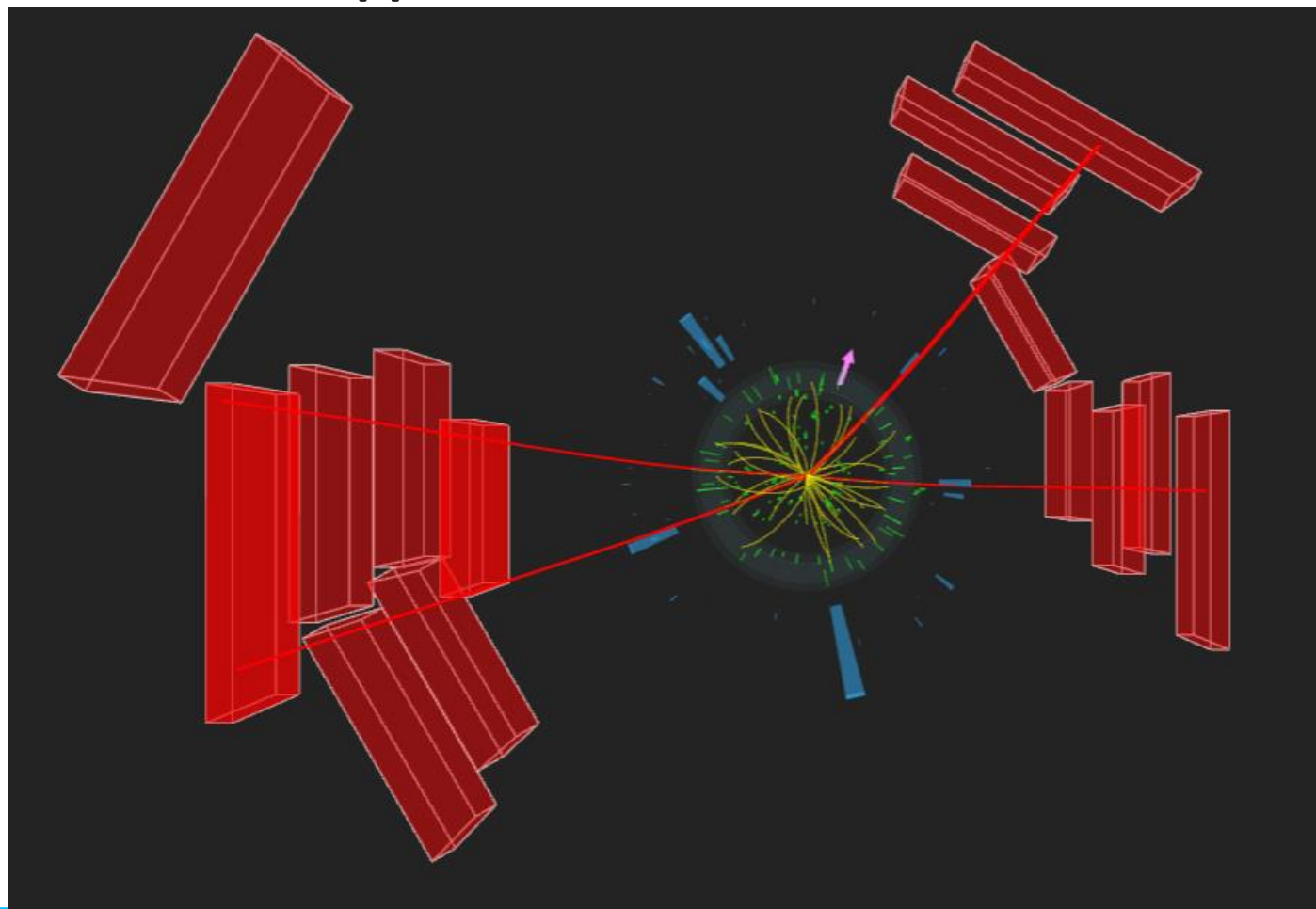


Le particelle: bosone H (ZZ)

- 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?

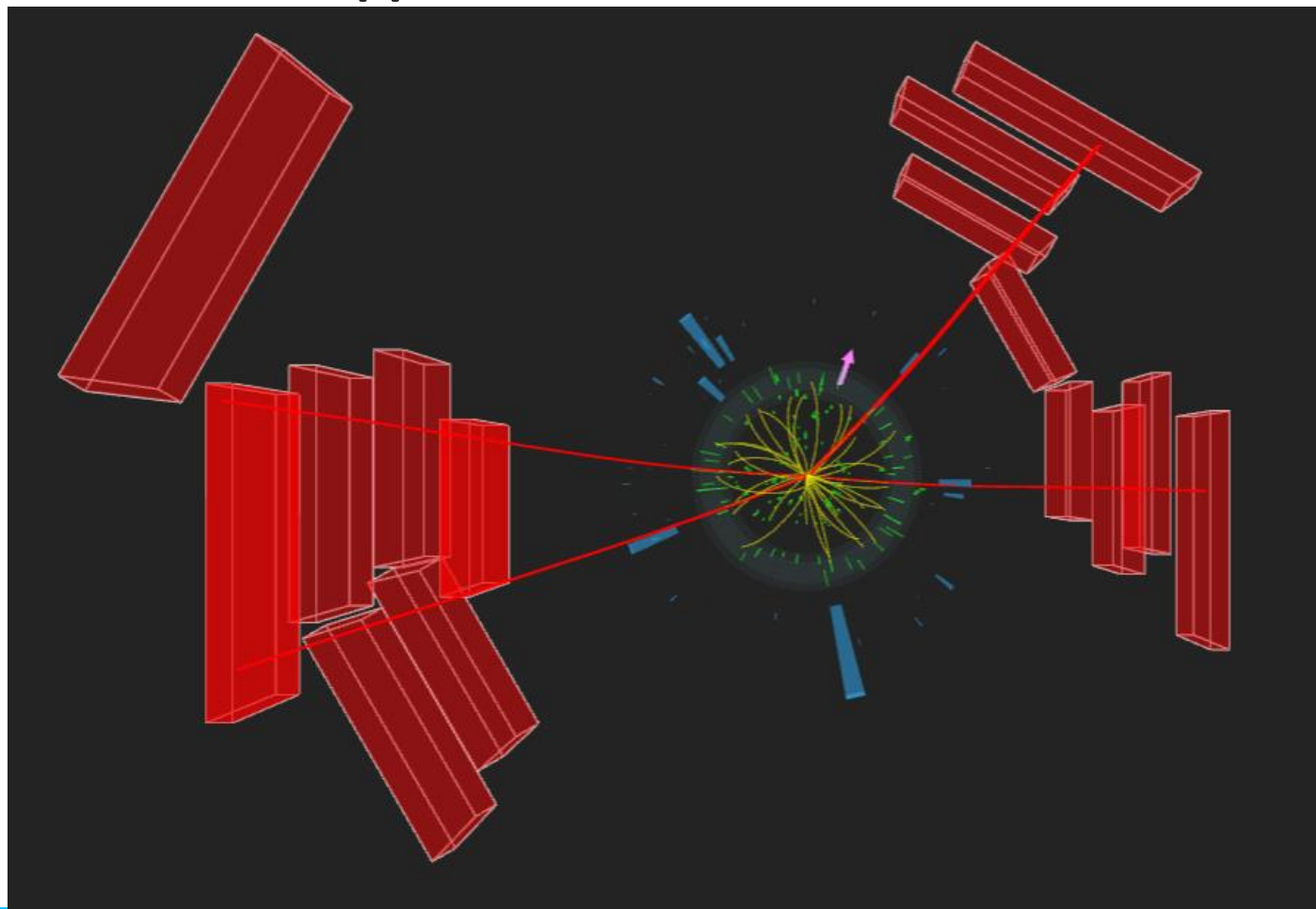


Le particelle: bosone H (ZZ)

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- Le trasformazioni più facili da identificare hanno **due coppie di elettroni o di muoni**

$H \rightarrow ZZ$

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

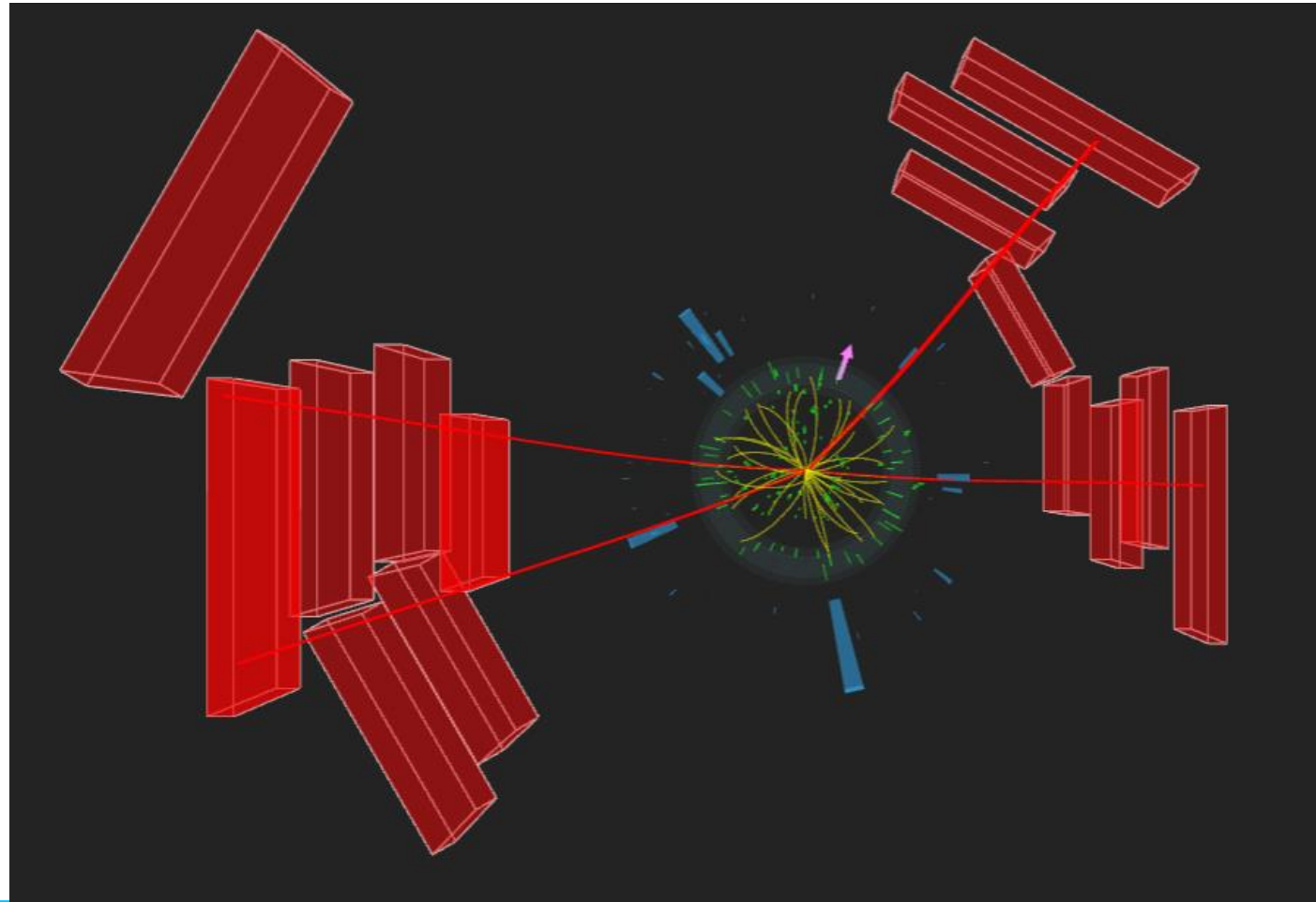


Le particelle: bosone H (ZZ)

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- 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:
 - $e^+ e^- e^+ e^-$
 - $\mu^+ \mu^- \mu^+ \mu^-$
 - $e^+ e^- \mu^+ \mu^-$
 - ...
 - $\nu_e \nu_e \nu_\mu \nu_\mu$





CIMA: selezione del file

- CERN → 1 Marzo 2024 → Catania



Choose your Masterclass	Choose your location	Choose your data file
TestEvents-01Jan2022	Constantine2024-A	10.1
Santander-13May2024	Catania2024	10.2
CERN-27Nov2023	Kharkiv2024	10.3
Salo-07Dec2023	Helsinki2024	10.4
Sofia-13Dec2023	SantiagoCampostela2024	10.5
CERN-LAMAP-08Dec2023		10.6
MP-15Jan2024		10.7
Cakovec-24Jan2024		10.8
Bristol-27Mar2024		10.9
CERN-09Feb2024		100.1
Sandbox-31Dec2023		100.11
CERN-20Feb2024		100.12
CERN-26Feb2024		100.13
CERN-29Feb2024		100.14
CERN-22Feb2024		100.15
CERN-01Mar2024		100.16
CERN-04Mar2024		100.17



Masterclass: CERN-01Mar2024

Location: Catania2024

Group: 10.1

Select Event

Event index:

Event number: 10.1-1

Final State

e ν $\mu \nu$

e e $\mu \mu$

4e 4 μ

2e 2 μ

Primary State

Charged Particle:

W⁺ W⁻ W \pm

Neutral Particle (Z, H)

Zoo

Enter Mass

GeV/c²

Next

Event index	Event number	Final state	Primary state	Mass

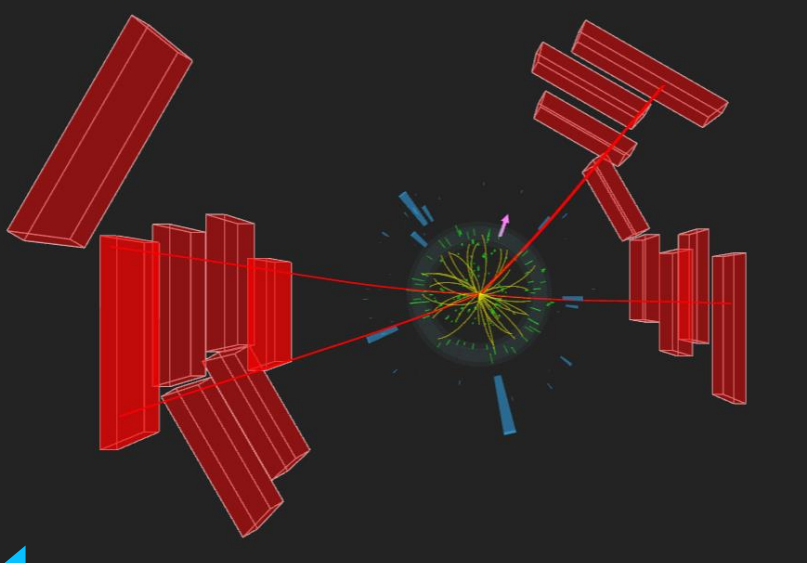
- Numero dell'evento: da 1 a 100
- Final State: quali segnali avete osservato
- Primary State: quale particella era stata prodotta
- Solo per "Neutral Particle (Z, H)" → Inserire il valore della massa "Enter Mass"

Esempio: $H \rightarrow ZZ \rightarrow \mu\mu\mu\mu$ (massa 182.95)

Select Event Event index: <input type="text" value="1"/> Event number: 10.1-1	Final State <input type="radio"/> e v <input type="radio"/> e e <input type="radio"/> 4e <input type="radio"/> 2e 2μ <input type="radio"/> μ ν <input type="radio"/> μ μ <input checked="" type="radio"/> 4μ	Primary State Charged Particle: <input type="radio"/> W+ <input type="radio"/> W- <input type="radio"/> W± <input type="radio"/> Neutral Particle (Z, H) <input type="radio"/> Zoo	Enter Mass <input type="text"/> GeV/c ² <input type="button" value="Next"/>
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Event index	Event number	Final state	Primary state	Mass
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1. Identificare i segnali e la particella

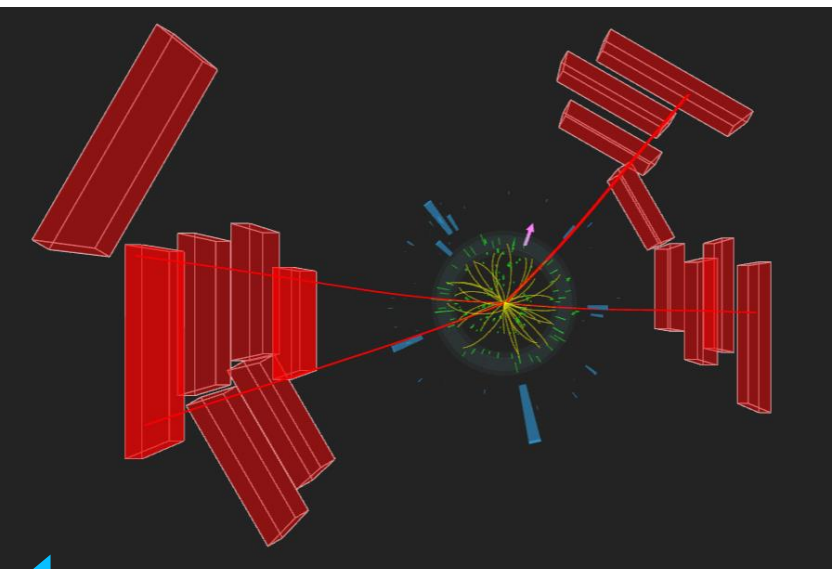


Esempio: $H \rightarrow ZZ \rightarrow \mu\mu\mu\mu$ (massa 182.95)

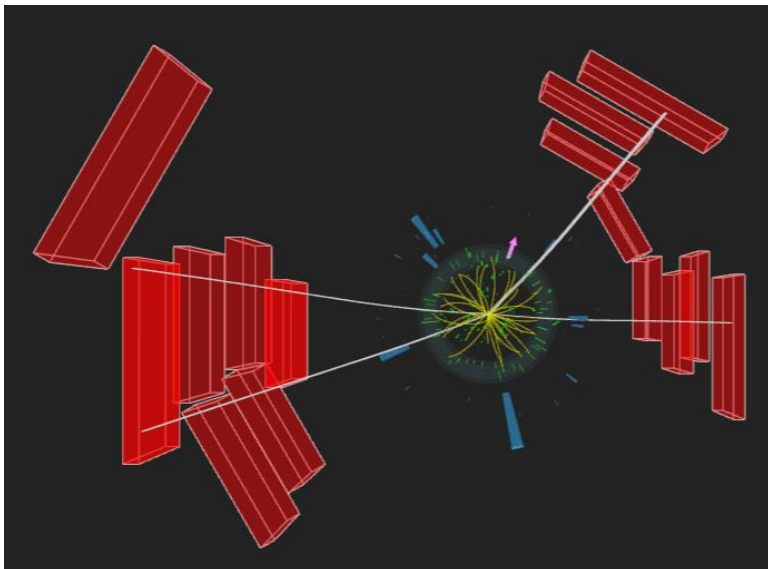
<p>Select Event</p> <p>Event index: <input type="text" value="1"/></p> <p>Event number: 10.1-1</p>	<p>Final State</p> <p><input type="radio"/> e v <input type="radio"/> μ v</p> <p><input type="radio"/> e e <input type="radio"/> μ μ</p> <p><input type="radio"/> 4e <input checked="" type="radio"/> 4μ</p> <p><input type="radio"/> 2e 2μ</p>	<p>Primary State</p> <p>Charged Particle:</p> <p><input type="radio"/> W⁺ <input type="radio"/> W⁻ <input type="radio"/> W\pm</p> <p><input checked="" type="radio"/> Neutral Particle (Z, H)</p> <p><input type="radio"/> Zoo</p>	<p>Enter Mass</p> <p><input type="text"/> GeV/c²</p> <p><input type="button" value="Next"/></p>
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Event index	Event number	Final state	Primary state	Mass
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1. Identificare i segnali e la particella



2. Selezionare le tracce col mouse

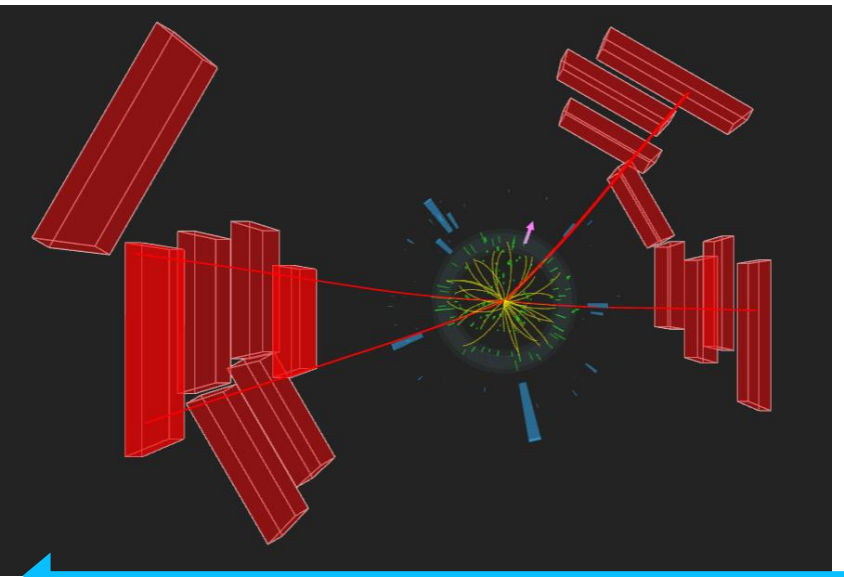


Esempio: $H \rightarrow ZZ \rightarrow \mu\mu\mu\mu$ (massa 182.95)

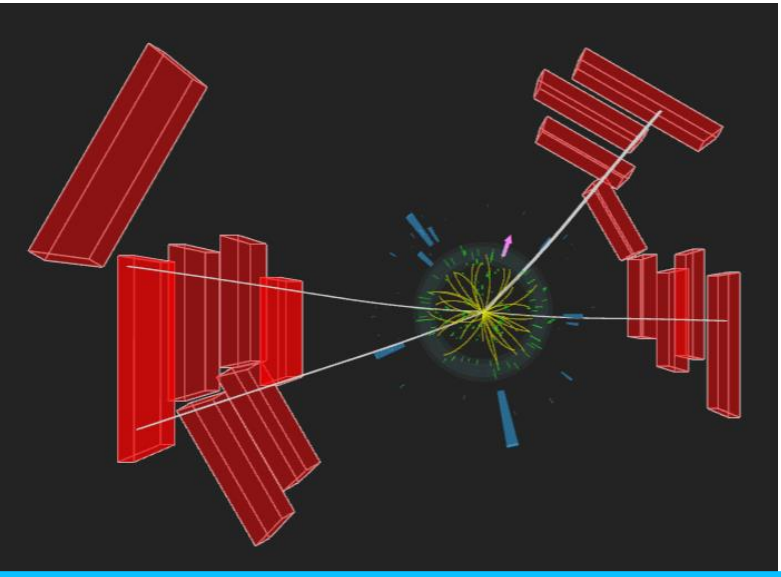
<p>Select Event</p> <p>Event index: <input type="text" value="1"/></p> <p>Event number: 10.1-1</p>	<p>Final State</p> <p> <input type="radio"/> e v <input type="radio"/> μ v <input type="radio"/> e e <input type="radio"/> μ μ <input type="radio"/> 4e <input checked="" type="radio"/> 4μ <input type="radio"/> 2e 2μ </p>	<p>Primary State</p> <p>Charged Particle:</p> <p> <input type="radio"/> W+ <input type="radio"/> W- <input type="radio"/> W\pm <input checked="" type="radio"/> Neutral Particle (Z, H) <input type="radio"/> Zoo </p>	<p>Enter Mass</p> <p><input type="text" value="182.95"/> GeV/c²</p> <p><input type="button" value="Next"/></p>
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Event index	Event number	Final state	Primary state	Mass
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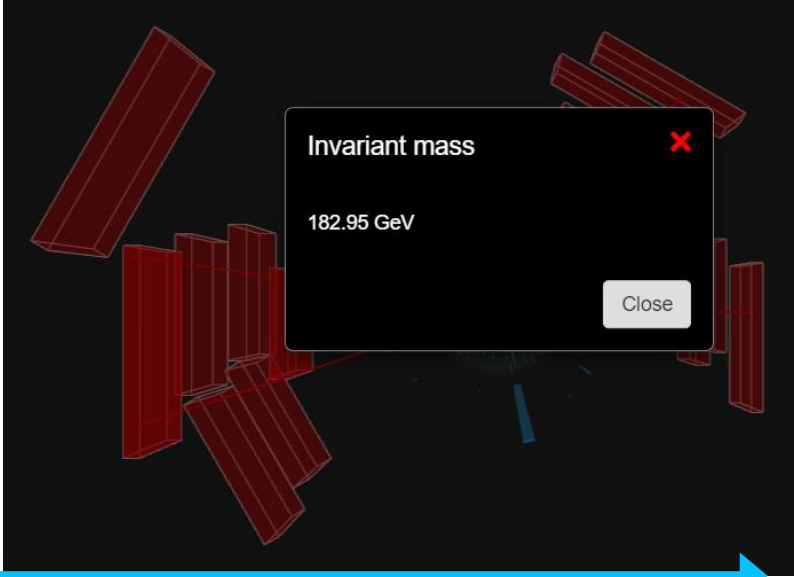
1. Identificare i segnali e la particella

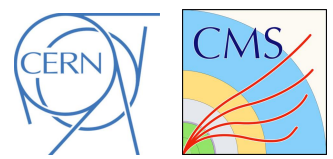


2. Selezionare le tracce col mouse



3. Premere "M" sulla tastiera





Esempio: $H \rightarrow ZZ \rightarrow \mu\mu\mu\mu$ (massa 182.95)

Select Event Event index: <input type="text" value="1"/> Event number: 10.1-1	Final State <input type="radio"/> e ν <input type="radio"/> $\mu \nu$ <input type="radio"/> e e <input type="radio"/> $\mu \mu$ <input type="radio"/> 4e <input checked="" type="radio"/> 4 μ <input type="radio"/> 2e 2 μ	Primary State Charged Particle: <input type="radio"/> W+ <input type="radio"/> W- <input type="radio"/> W \pm <input checked="" type="radio"/> Neutral Particle (Z, H) <input type="radio"/> Zoo	Enter Mass <input type="text" value="182.95"/> GeV/c ² <input type="button" value="Next"/>
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Event index	Event number	Final state	Primary state	Mass
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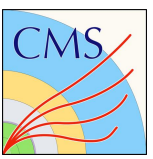
Esempio: $H \rightarrow ZZ \rightarrow \mu\mu\mu\mu$ (massa 182.95)

<p>Select Event</p> <p>Event index: <input type="text" value="1"/> ▼</p> <p>Event number: 10.1-1</p>	<p>Final State</p> <p> <input type="radio"/> e ν <input type="radio"/> $\mu \nu$ <input type="radio"/> e e <input type="radio"/> $\mu \mu$ <input type="radio"/> 4e <input checked="" type="radio"/> 4μ <input type="radio"/> 2e 2μ </p>	<p>Primary State</p> <p>Charged Particle:</p> <p> <input type="radio"/> W⁺ <input type="radio"/> W⁻ <input type="radio"/> W\pm <input checked="" type="radio"/> Neutral Particle (Z, H) <input type="radio"/> Zoo </p>	<p>Enter Mass</p> <p><input type="text" value="182.95"/> GeV/c²</p> <p><input type="button" value="Next"/></p>
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Event index	Event number	Final state	Primary state	Mass

<p>Select Event</p> <p>Event index: <input type="text" value="2"/> ▼</p> <p>Event number: 10.4-2</p>	<p>Final State</p> <p> <input type="radio"/> e ν <input type="radio"/> $\mu \nu$ <input type="radio"/> e e <input type="radio"/> $\mu \mu$ <input type="radio"/> 4e <input type="radio"/> 4μ <input type="radio"/> 2e 2μ </p>	<p>Primary State</p> <p>Charged Particle:</p> <p> <input type="radio"/> W⁺ <input type="radio"/> W⁻ <input type="radio"/> W\pm <input type="radio"/> Neutral Particle (Z, H) <input type="radio"/> Zoo </p>	<p>Enter Mass</p> <p><input type="text"/> GeV/c²</p> <p><input type="button" value="Next"/></p>
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Event index	Event number	Final state	Primary state	Mass
9001	10.4-1	4e	neutral	182.95



Programma delle attività del pomeriggio

- 14:00-15:30 – Ogni ricercatore identifica 100 eventi
 - iSPY
 - CIMA
- 15:30-16:00 – Discussione dei risultati: analisi statistica
- 16:00-17:00 – Collegamento in videoconferenza con CERN e altri 4 istituti
 - Presentazione
 - Discussione dei risultati
 - Quiz

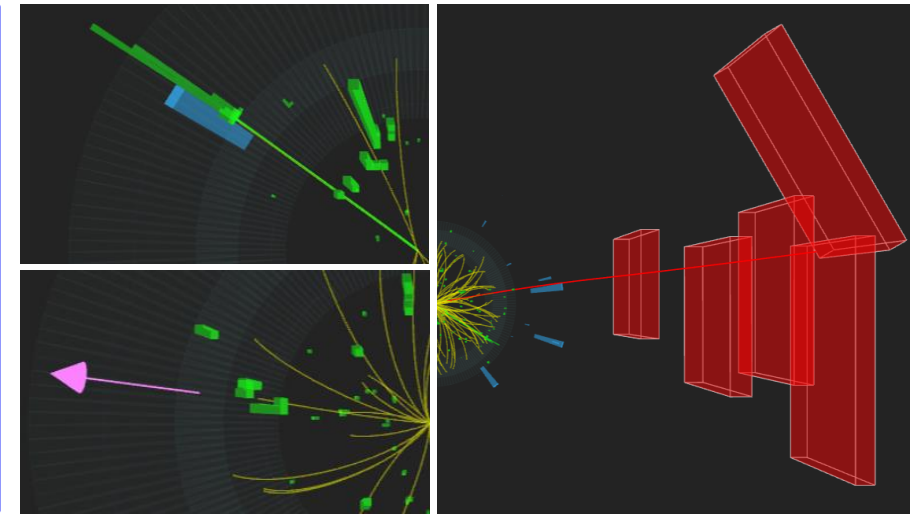
Legenda

- **Segnali:**

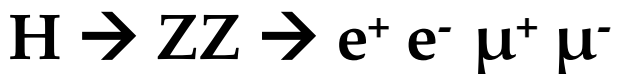
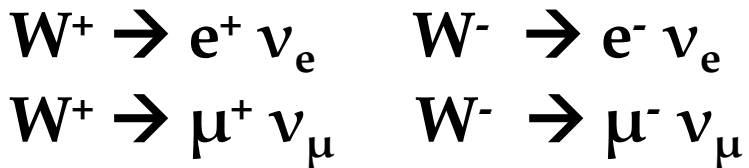
- Elettrone (e) : **traccia verde**
- Muone (μ) : **traccia rossa**
- Neutrino (ν) : **freccia rosa**

Final State

<input type="radio"/> $e \nu$	<input type="radio"/> $\mu \nu$
<input type="radio"/> $e e$	<input type="radio"/> $\mu \mu$
<input type="radio"/> $4e$	<input type="radio"/> 4μ
<input type="radio"/> $2e 2\mu$	



- **Particelle:**



Primary State

Charged Particle:

<input type="radio"/> W^+	<input type="radio"/> W^-
<input type="radio"/> Neutral Particle (Z, H)	
<input type="radio"/> Zoo	

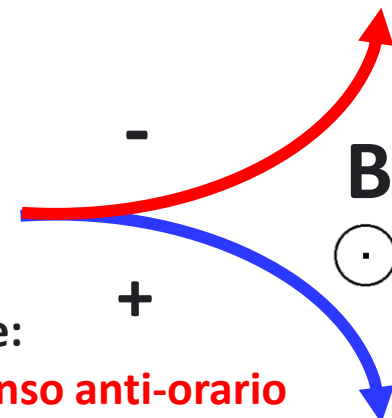
- Click su tracce verdi/rosse
- Premere "M" sulla tastiera

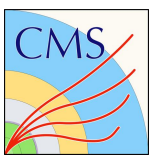
Enter Mass

GeV/c²

- **Curvatura tracce cariche:**

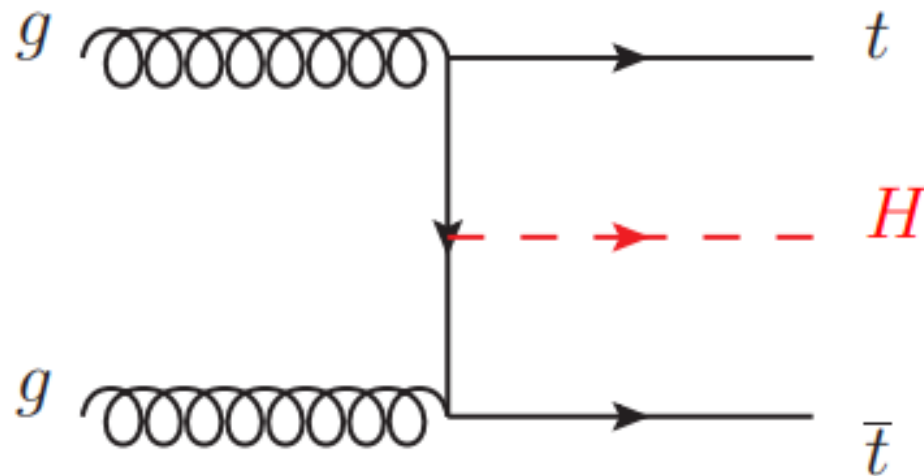
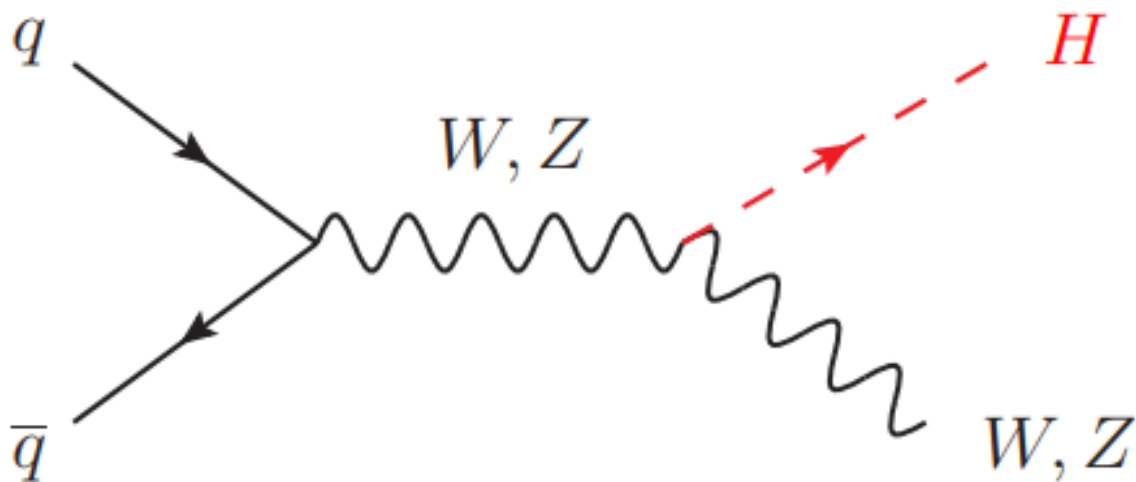
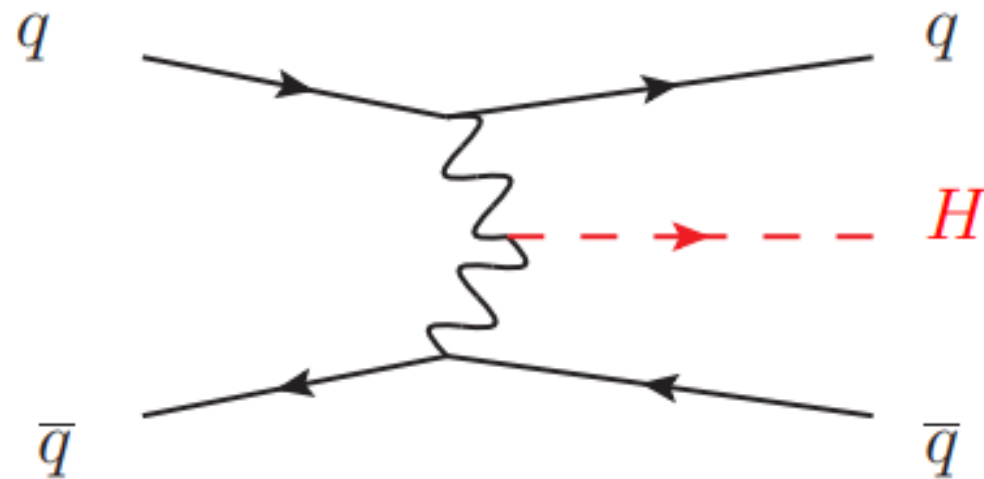
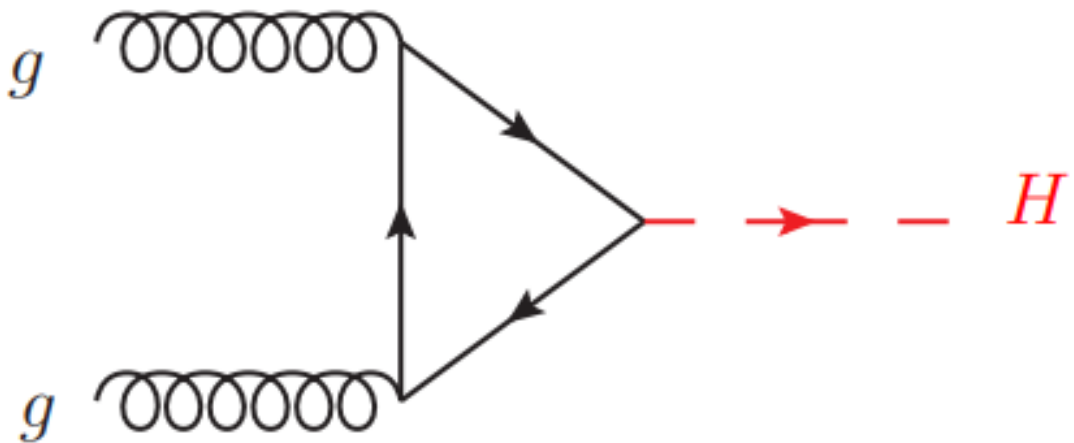
- **Carica negativa: senso anti-orario**
- **Carica positiva: senso orario**





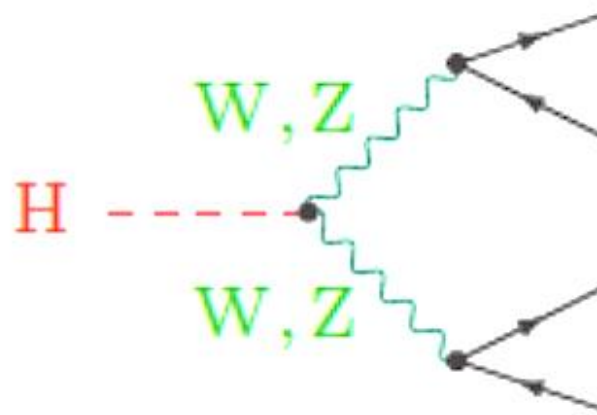
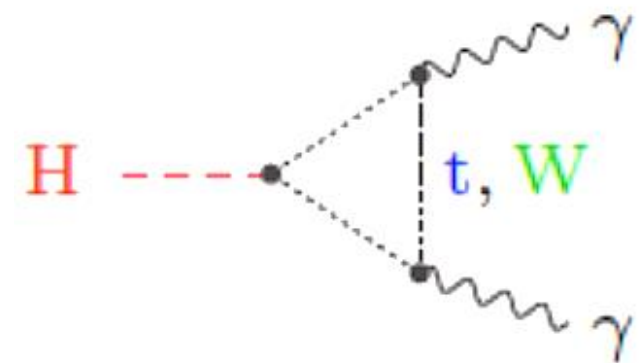
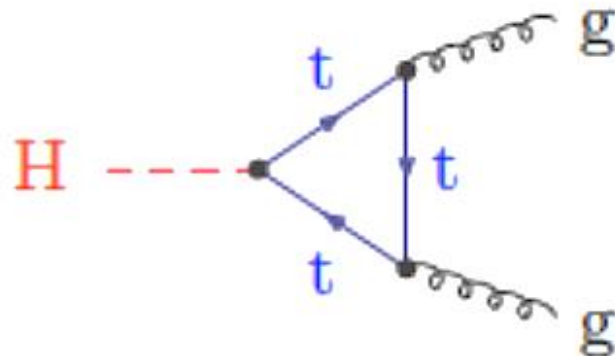
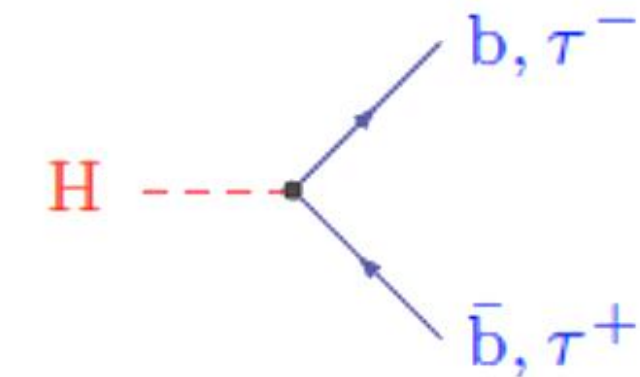
Backup

Processi di produzione del Bosone di Higgs



Canali di Decadimento del Bosone di Higgs

- Testo



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

