

Filippo Errico¹

1. INFN Roma Sapienza

05/04/2023

Liceo Bachelet, Roma

Dove tutto ha inizio...



...scelta quasi obbligata...



...One small travel for a student, one giant leap for a dreamer ...

☰ 🏠 🚗 🚆 🚶 🚲 ✈️ ✕

📍 Ginevra Aeroporto, 1215 Le Grand-Saco

📍 Bari, Città Metropolitana di Bari

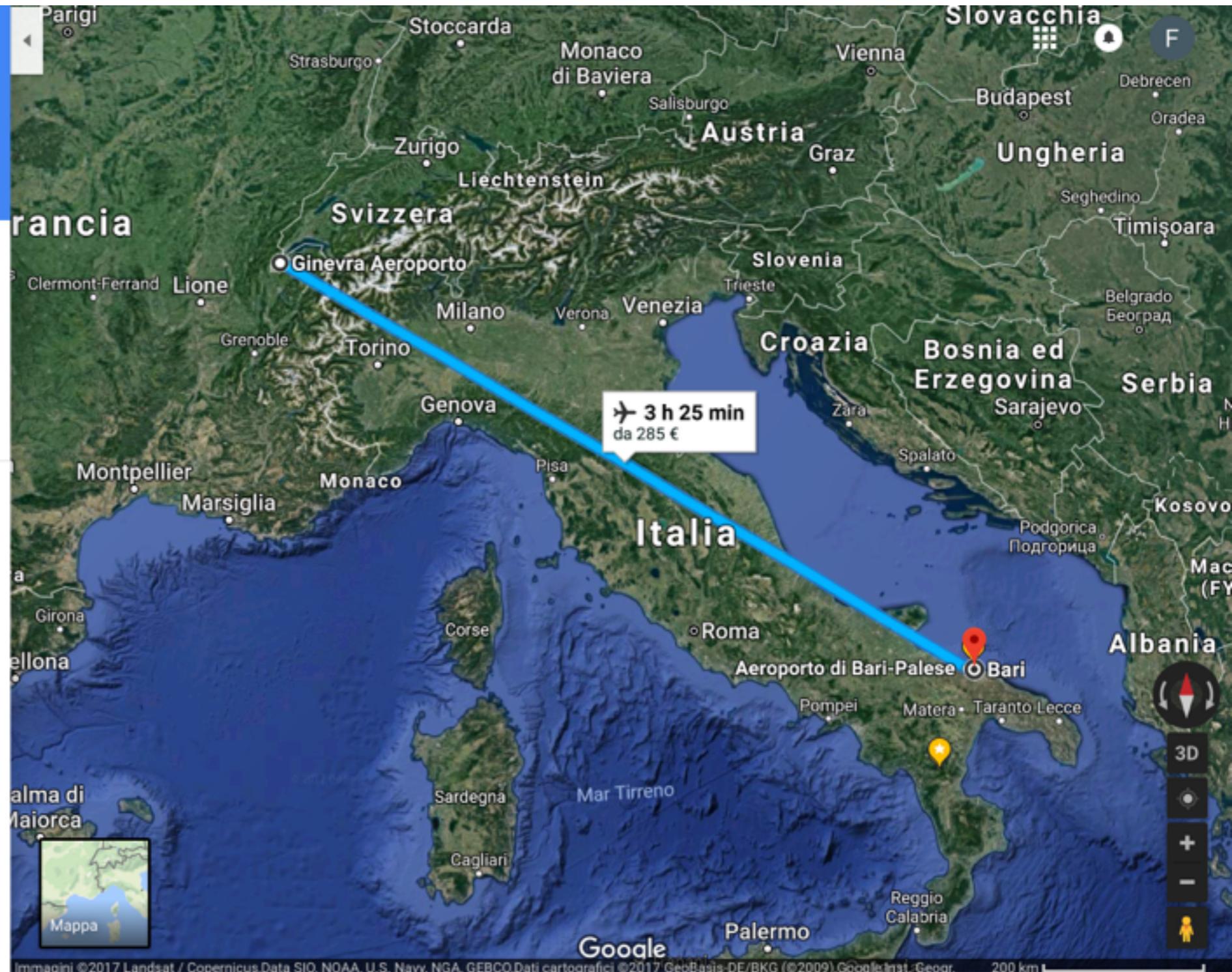
✈️ **Ginevra, Svizzera—Bari, Italia**

Volo in coincidenza (1 o più fermate) 3 h 25 min+

Prezzo andata e ritorno, 04–08 gen da 285 €

Lufthansa, KLM, Alitalia...

🔍 [Visualizza i risultati in Google Ricerca Voli](#) Sponsorizzato ⓘ



...welcome to CERN



Lavori in Svizzera ma abiti in Francia...



LHC: Large Hadron Collider

LHC: Large Hadron Collider



**E' il più lungo al mondo:
27 km**

LHC: Large Hadron Collider



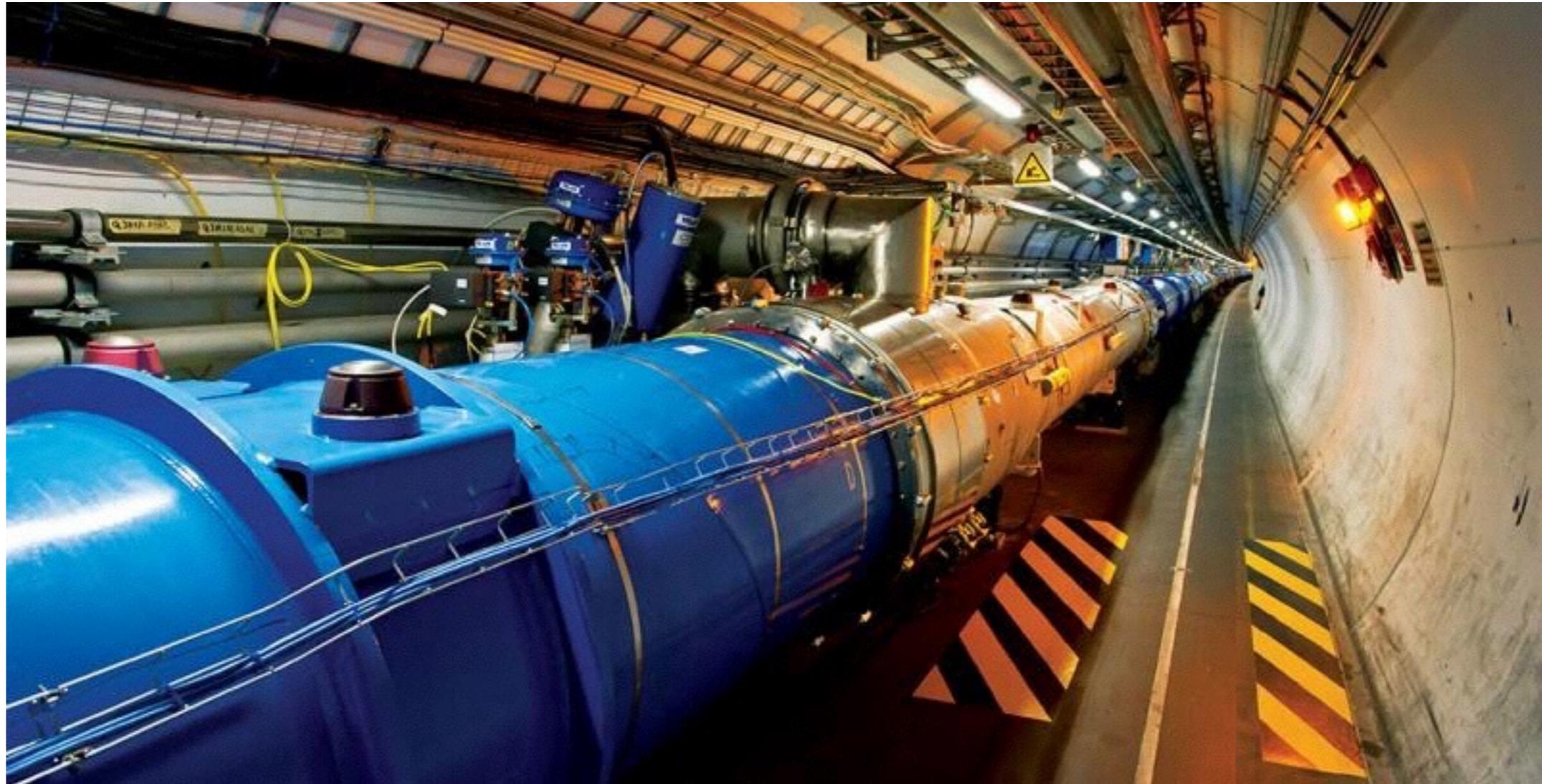
Adroni: particolari tipi di particelle

LHC: Large Hadron Collider

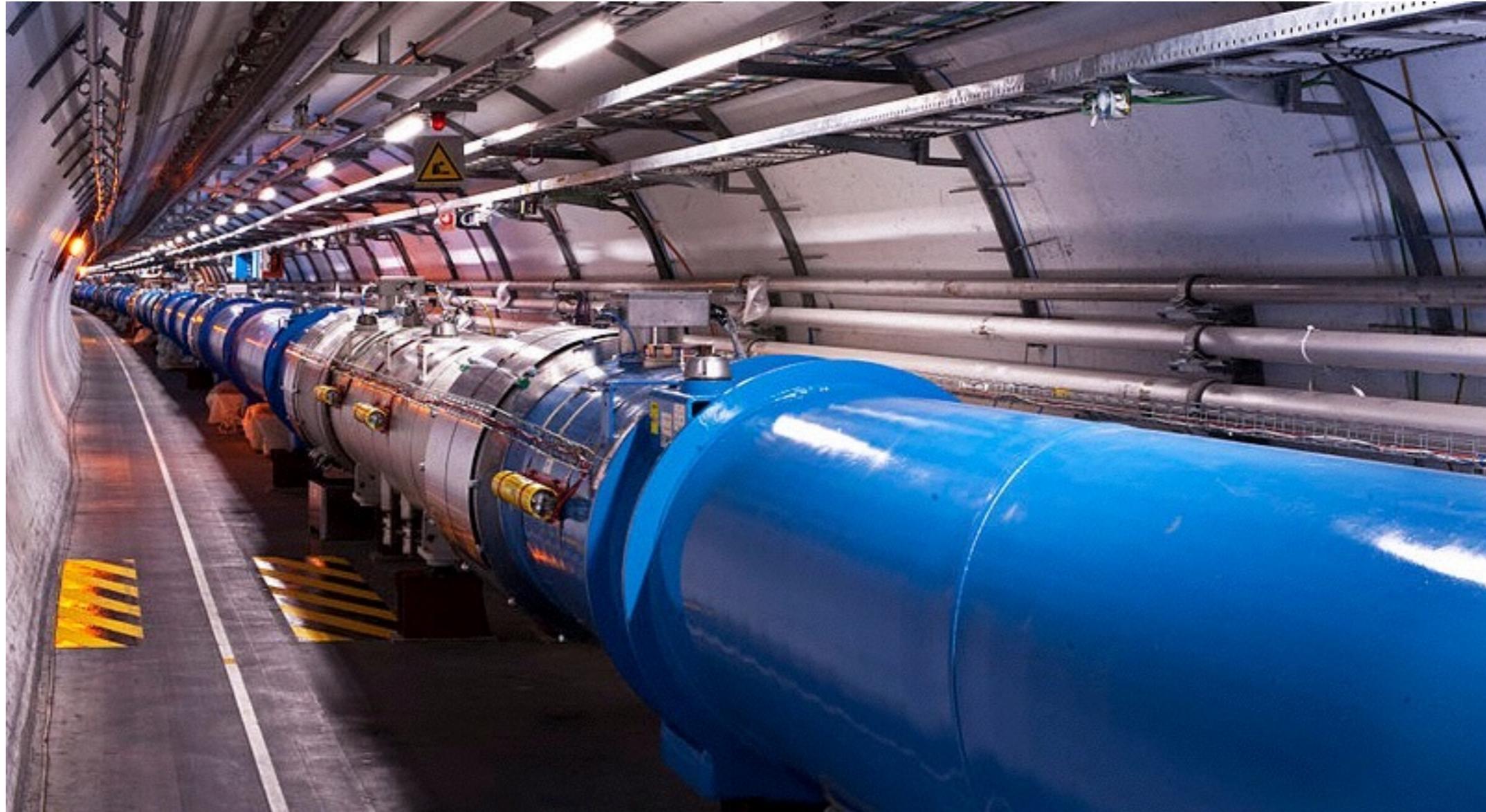


**Fa collidere adroni
(No, non produce buchi neri)**

LHC: Large Hadron Collider



LHC: Large Hadron Collider

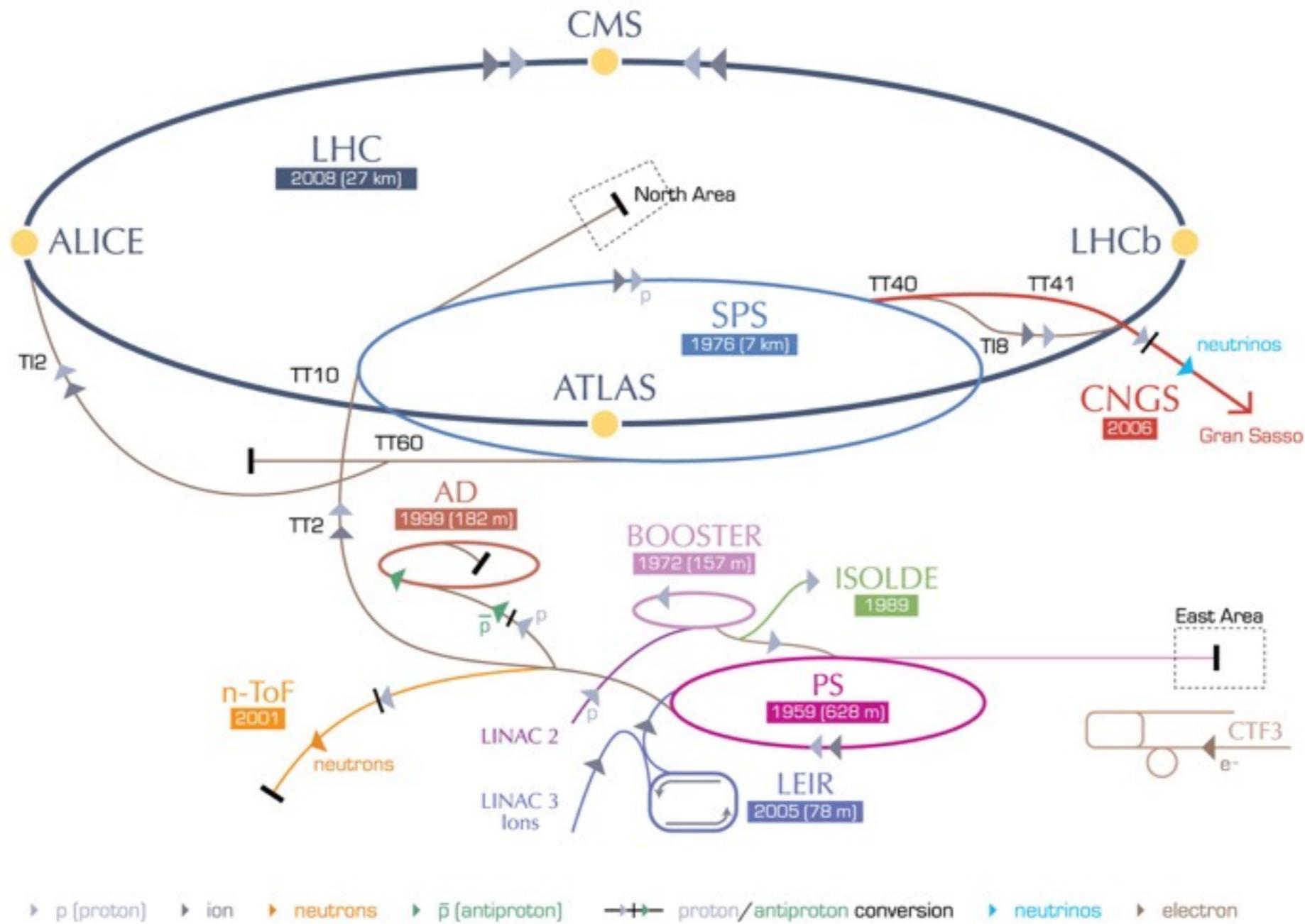


LHC: Large Hadron Collider



Che vi aspettavate da un tubo???

CERN's accelerator complex

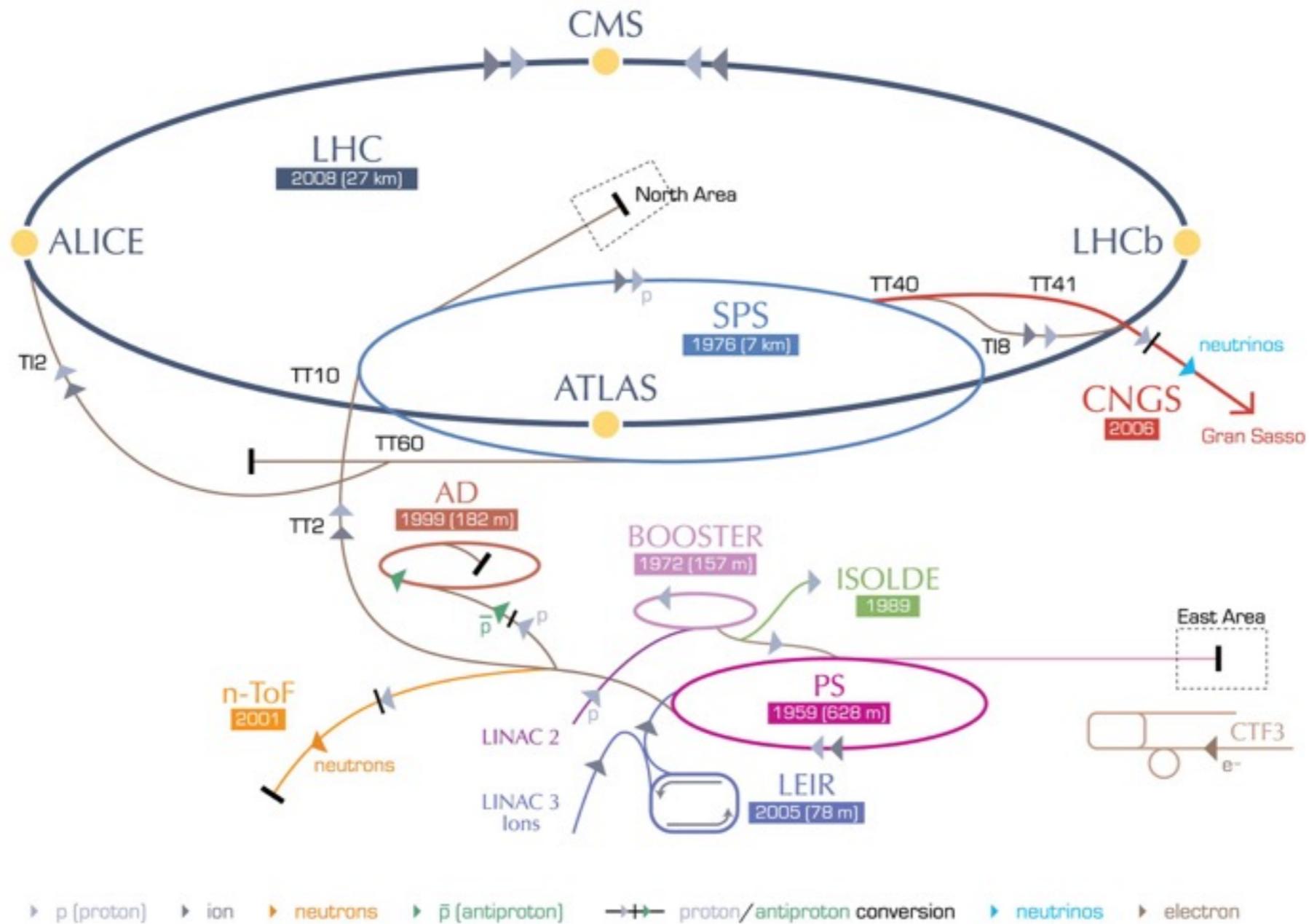


LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

AD Antiproton Decelerator CTF3 Clic Test Facility CNGS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice
 LEIR Low Energy Ion Ring LINAC LINEar ACcelerator n-ToF Neutrons Time Of Flight



CERN's accelerator complex



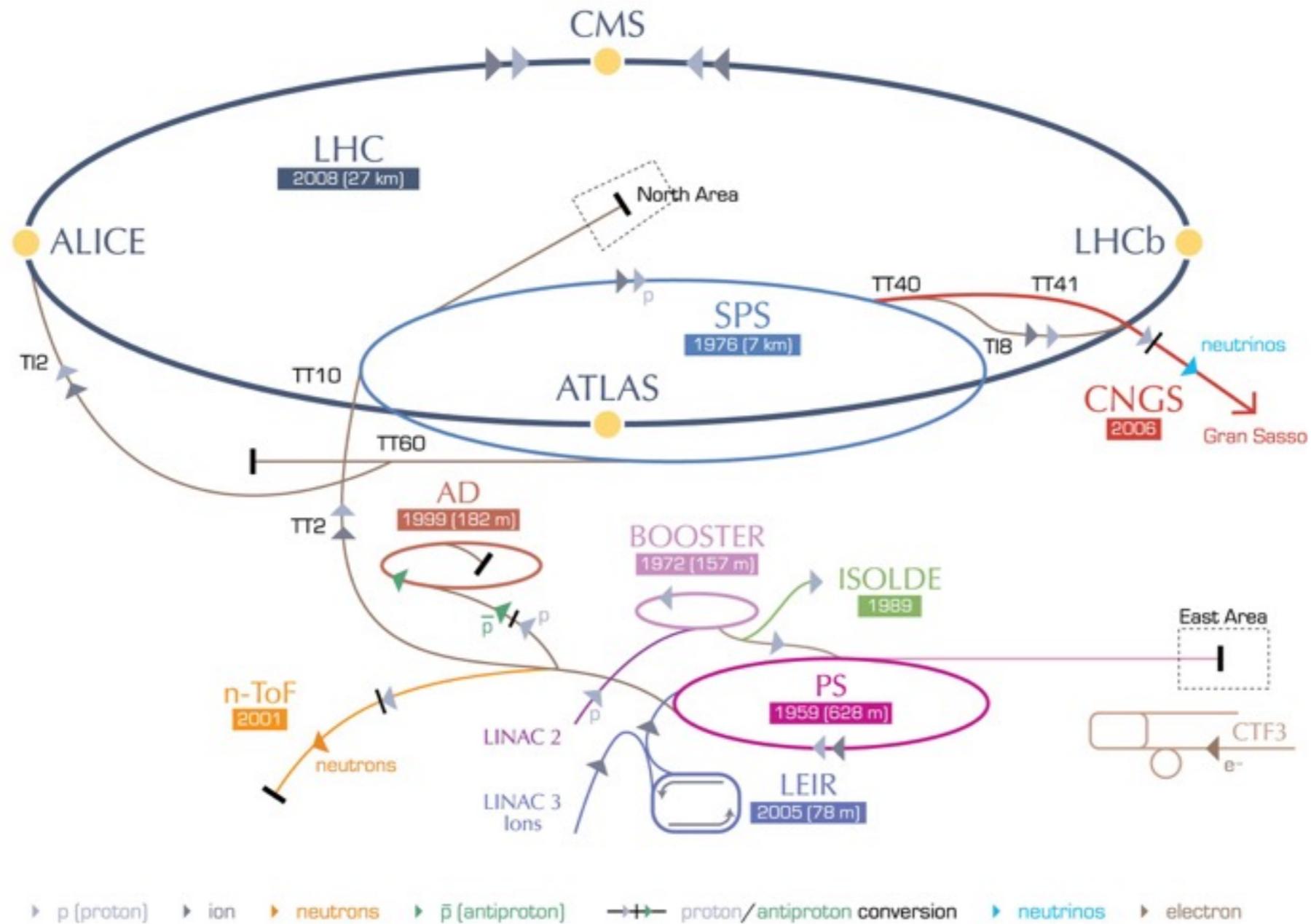
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$$1 \text{ eV} = 1,602176565 \times 10^{-19} \text{ J}$$

LINAC II = 50 MeV

CERN's accelerator complex PS = 25 GeV



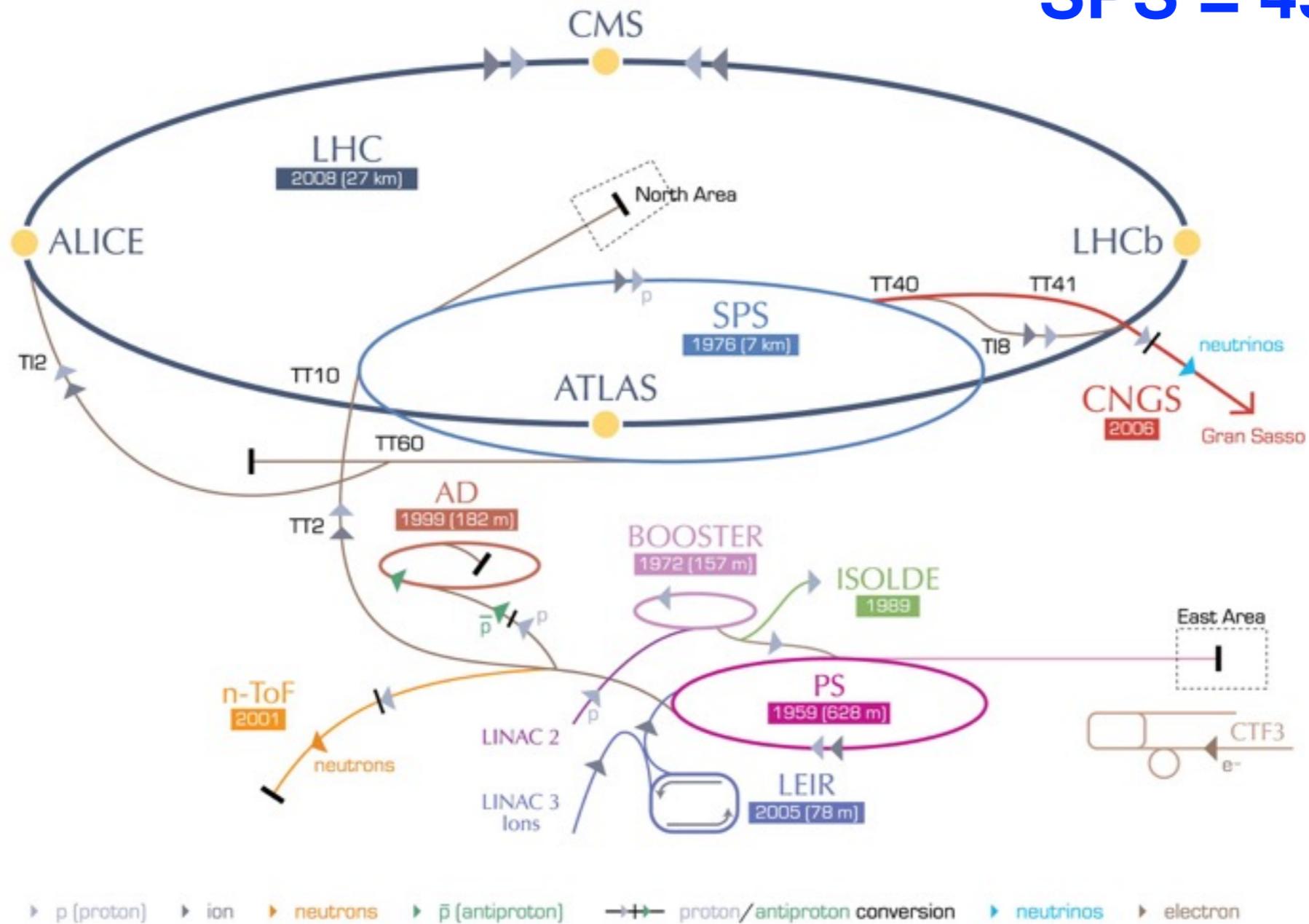
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LINAC II = 50 MeV
PS = 25 GeV
SPS = 450 GeV

CERN's accelerator complex



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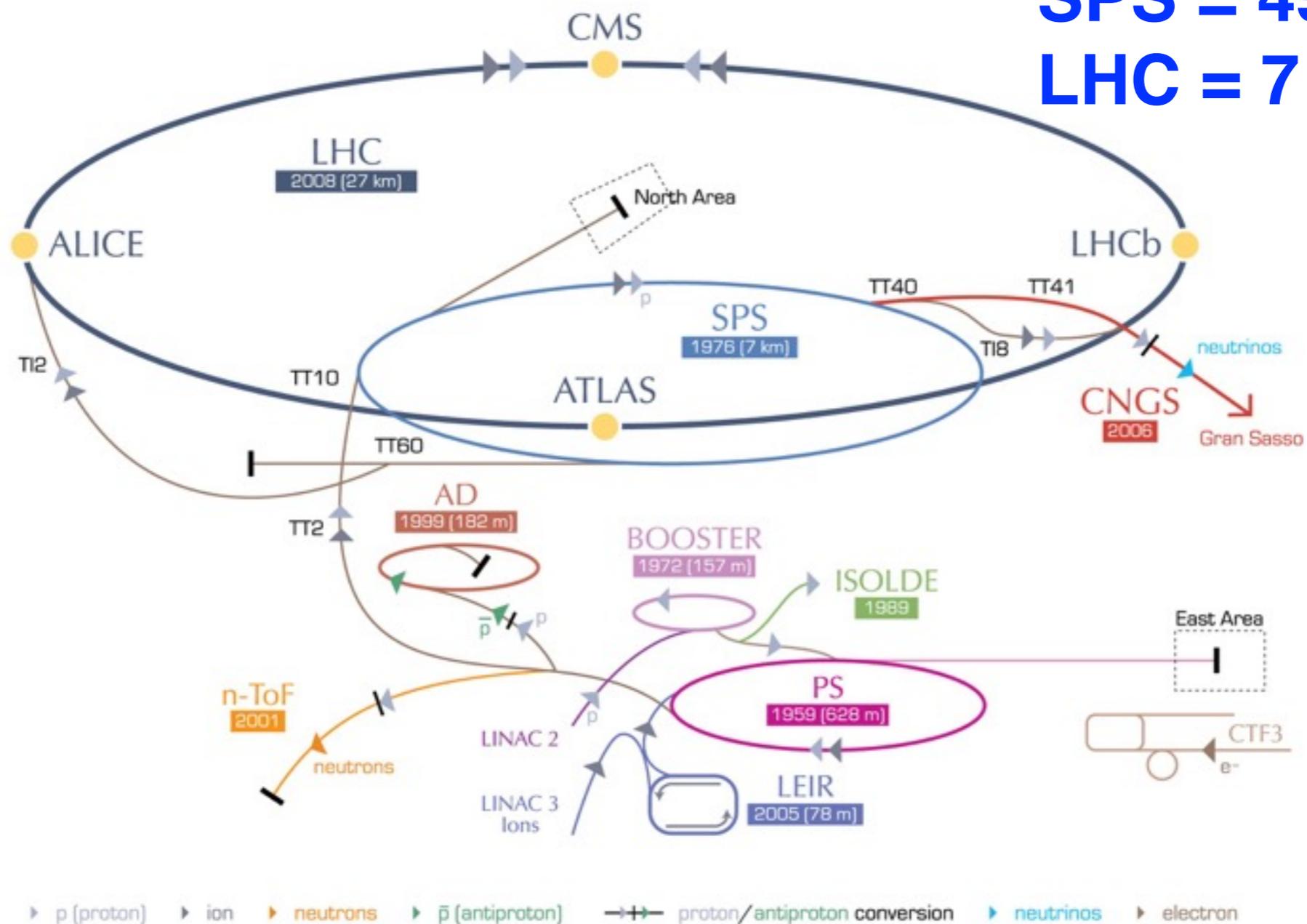
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Si va bene, ma che fa?

CERN's accelerator complex

LINAC II = 50 MeV
PS = 25 GeV
SPS = 450 GeV
LHC = 7 TeV



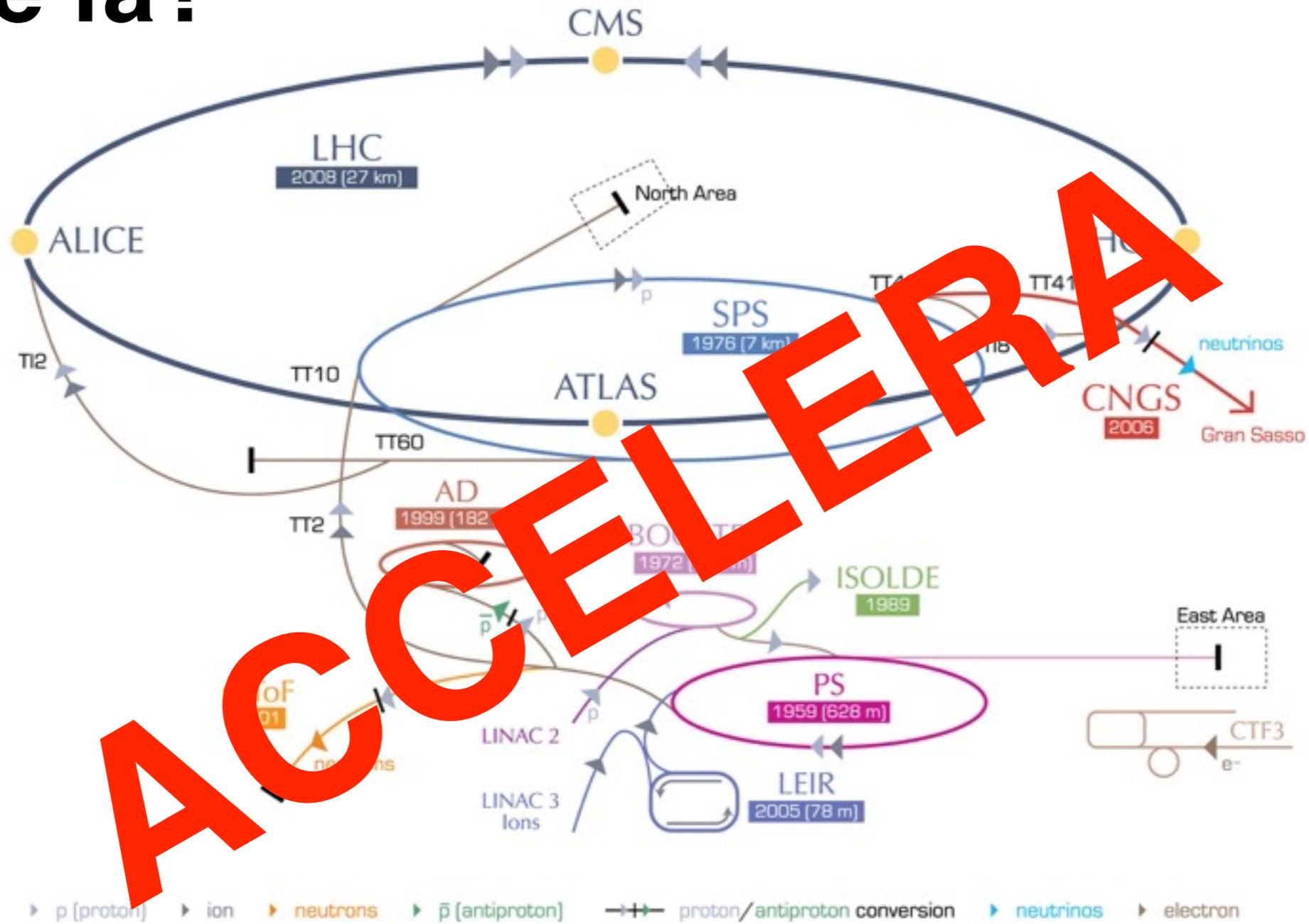
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Si va bene, ma che fa?

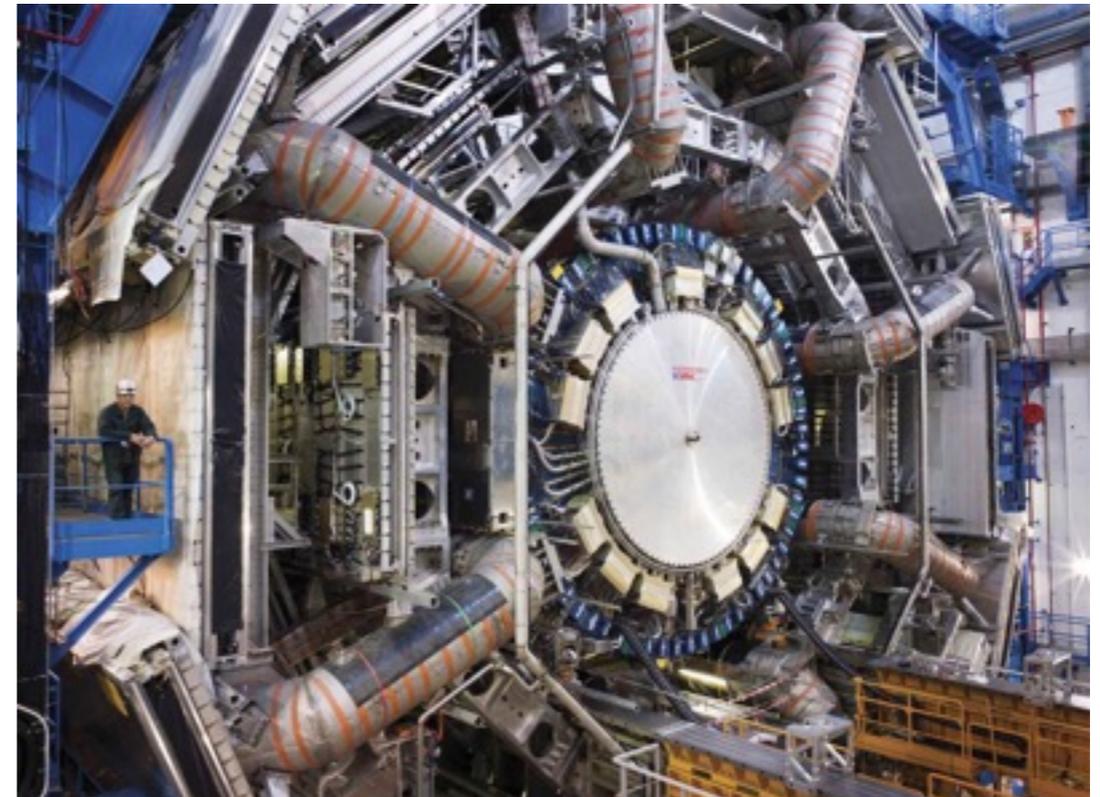
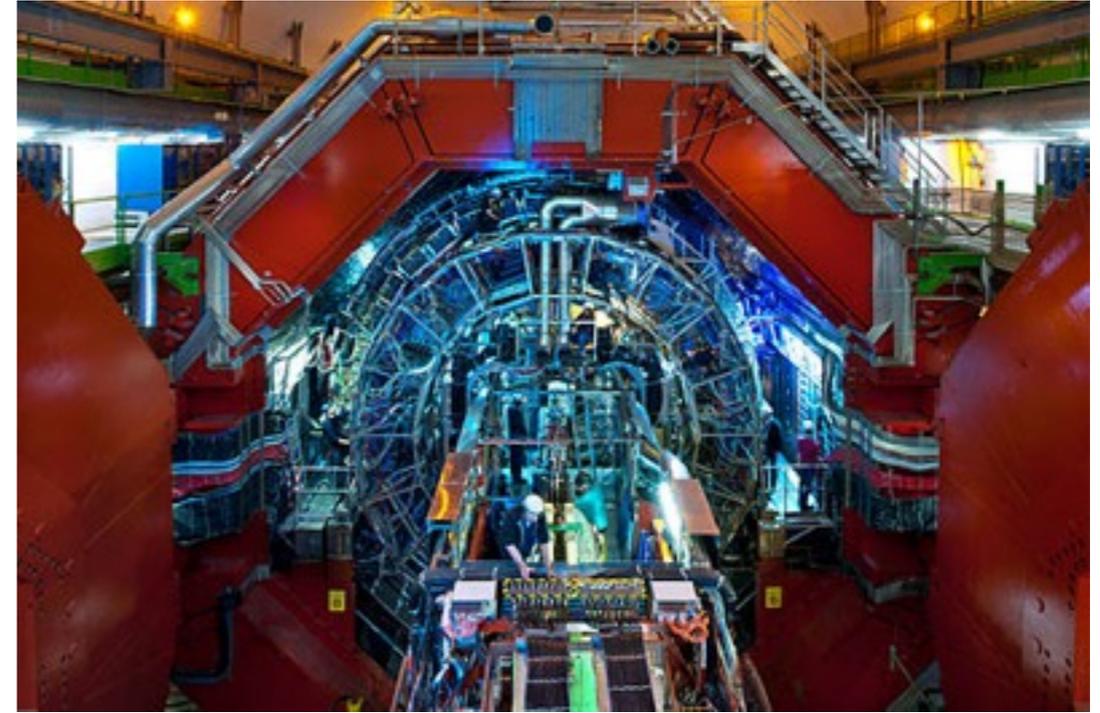
CERN's accelerator complex



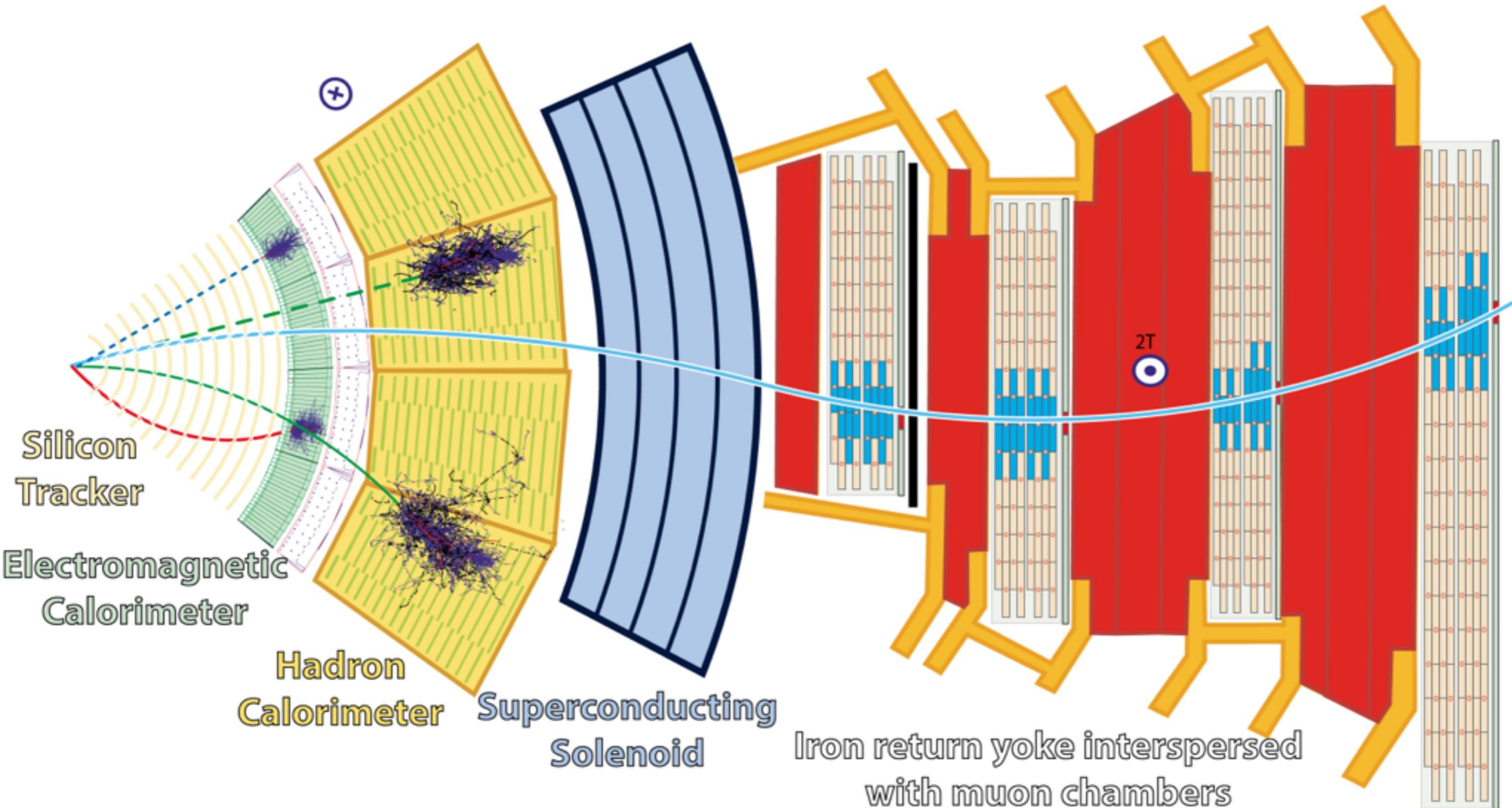
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I grandi esperimenti



I grandi esperimenti: CMS



— Muon

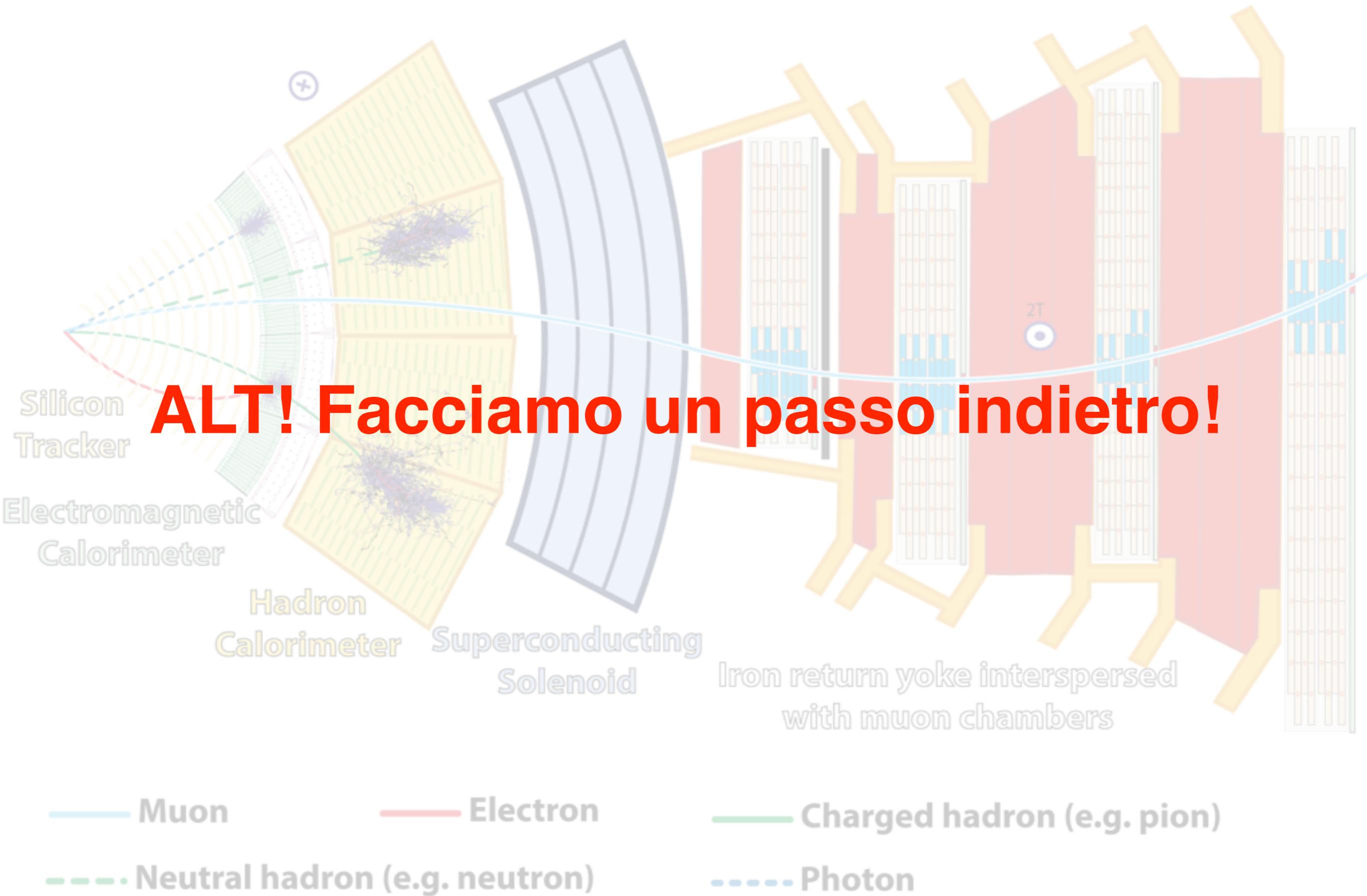
— Electron

— Charged hadron (e.g. pion)

- - - Neutral hadron (e.g. neutron)

- - - Photon

I grandi esperimenti: CMS



Un pò di fisica delle particelle...

Particella elementare: particella, **indivisibile**
caratterizzata da ben **precisi numeri quantici**

Un pò di fisica delle particelle...

Particella elementare: particella, **indivisibile**
caratterizzata da ben **precisi numeri quantici**

Protone?

Un pò di fisica delle particelle...

Particella elementare: particella, **indivisibile**
caratterizzata da ben **precisi numeri quantici**

Protone? **NO**

Un pò di fisica delle particelle...

Particella elementare: particella, **indivisibile**
caratterizzata da ben **precisi numeri quantici**

Protone? **NO**

Neutrone?

Un pò di fisica delle particelle...

Particella elementare: particella, **indivisibile**
caratterizzata da ben **precisi numeri quantici**

Protone? **NO**

Neutrone? **NO**

Un pò di fisica delle particelle...

Particella elementare: particella, **indivisibile**
caratterizzata da ben **precisi numeri quantici**

Protone? **NO**

Neutrone? **NO**

Elettrone?

Un pò di fisica delle particelle...

Particella elementare: particella, **indivisibile**
caratterizzata da ben **precisi numeri quantici**

Protone? **NO**

Neutrone? **NO**

Elettrone? **SI**

Un pò di fisica delle particelle...

Particella elementare: particella, **indivisibile**
caratterizzata da ben **precisi numeri quantici**

Protone? **NO**

Neutrone? **NO**

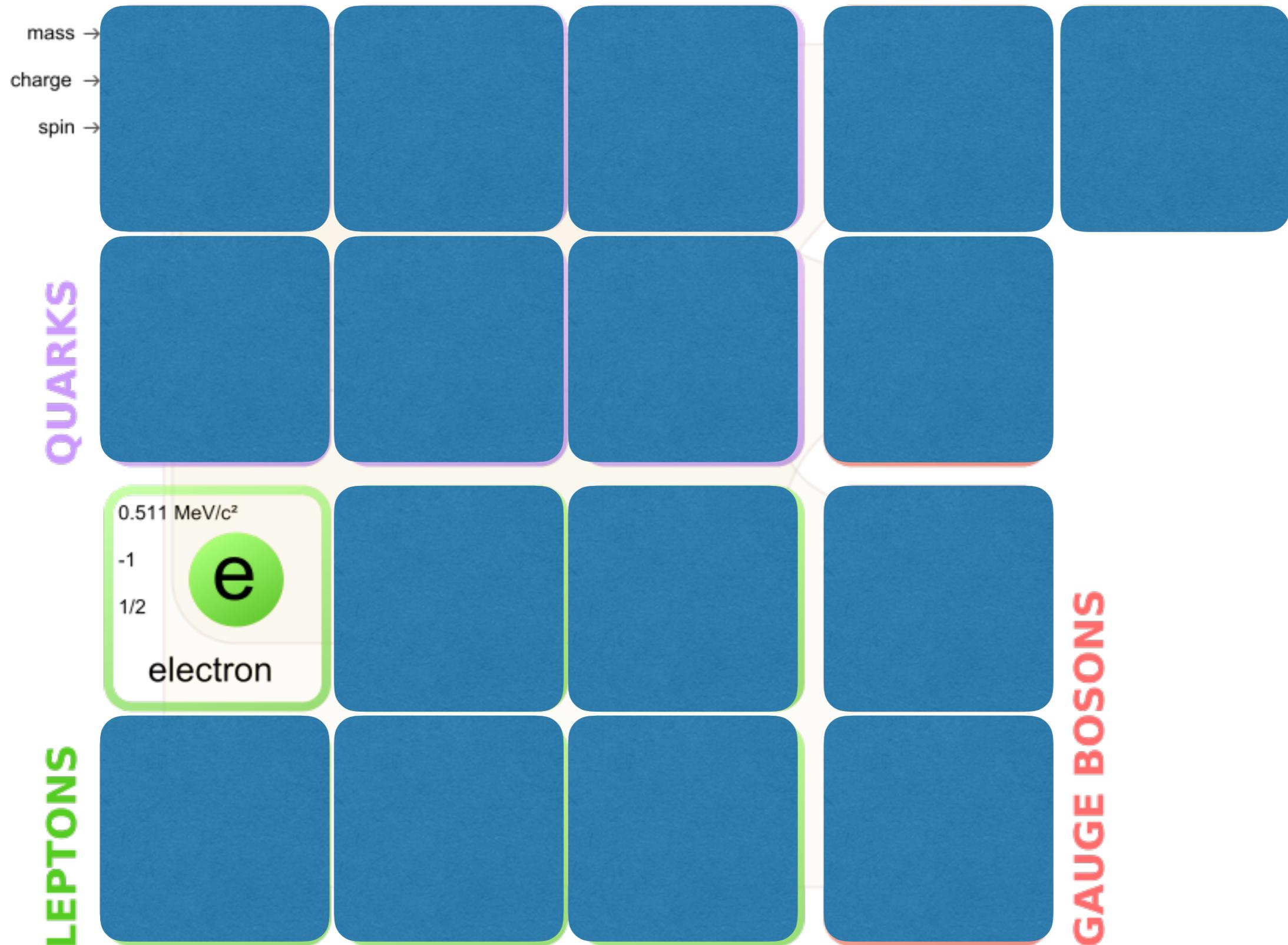
Elettrone? **SI**

Solo queste sono le particelle in natura?

Ovviamente no...

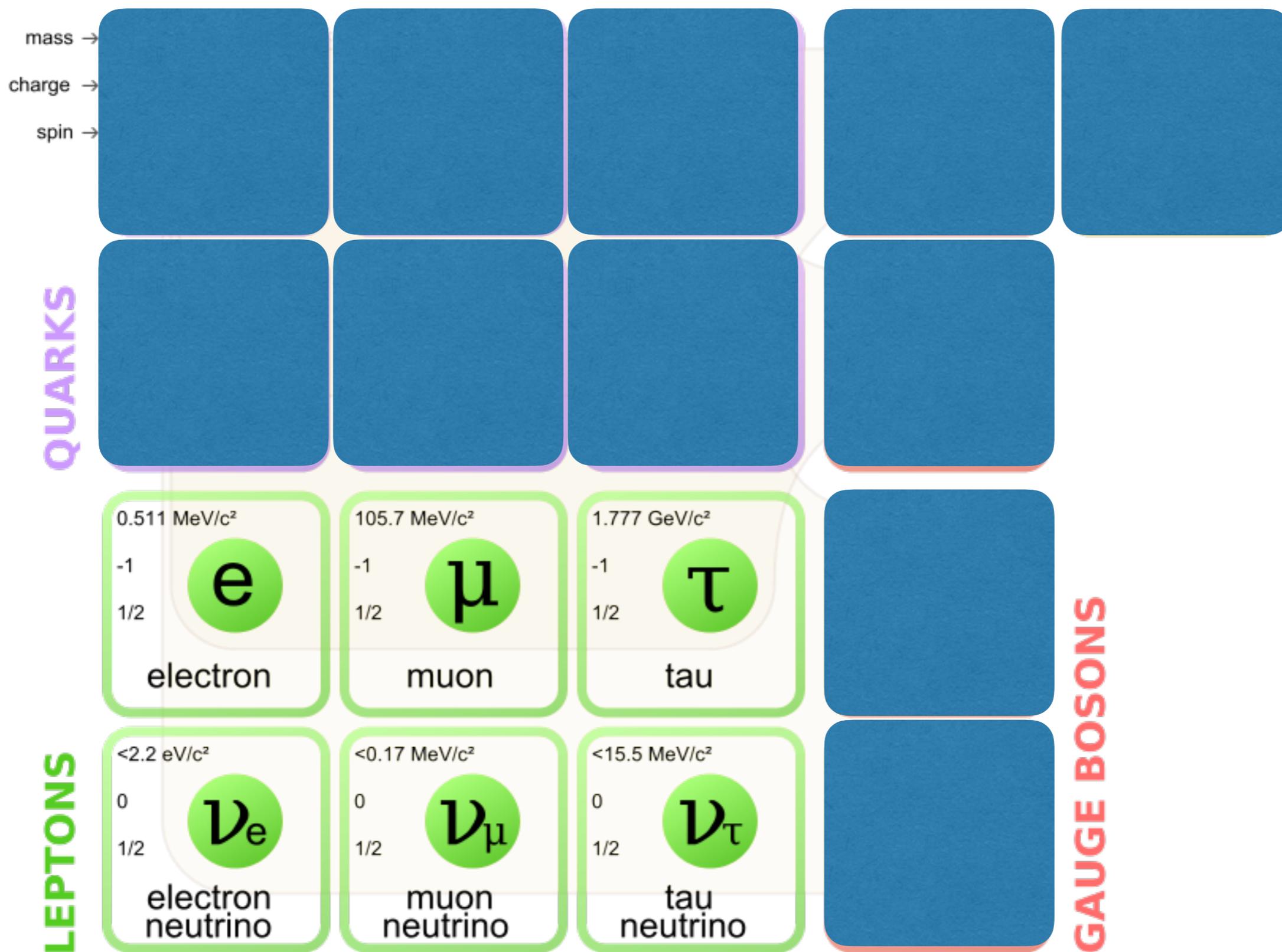
...i costituenti elementari della materia...

(no, non sono gli atomi)



...i costituenti elementari della materia...

(no, non sono gli atomi)

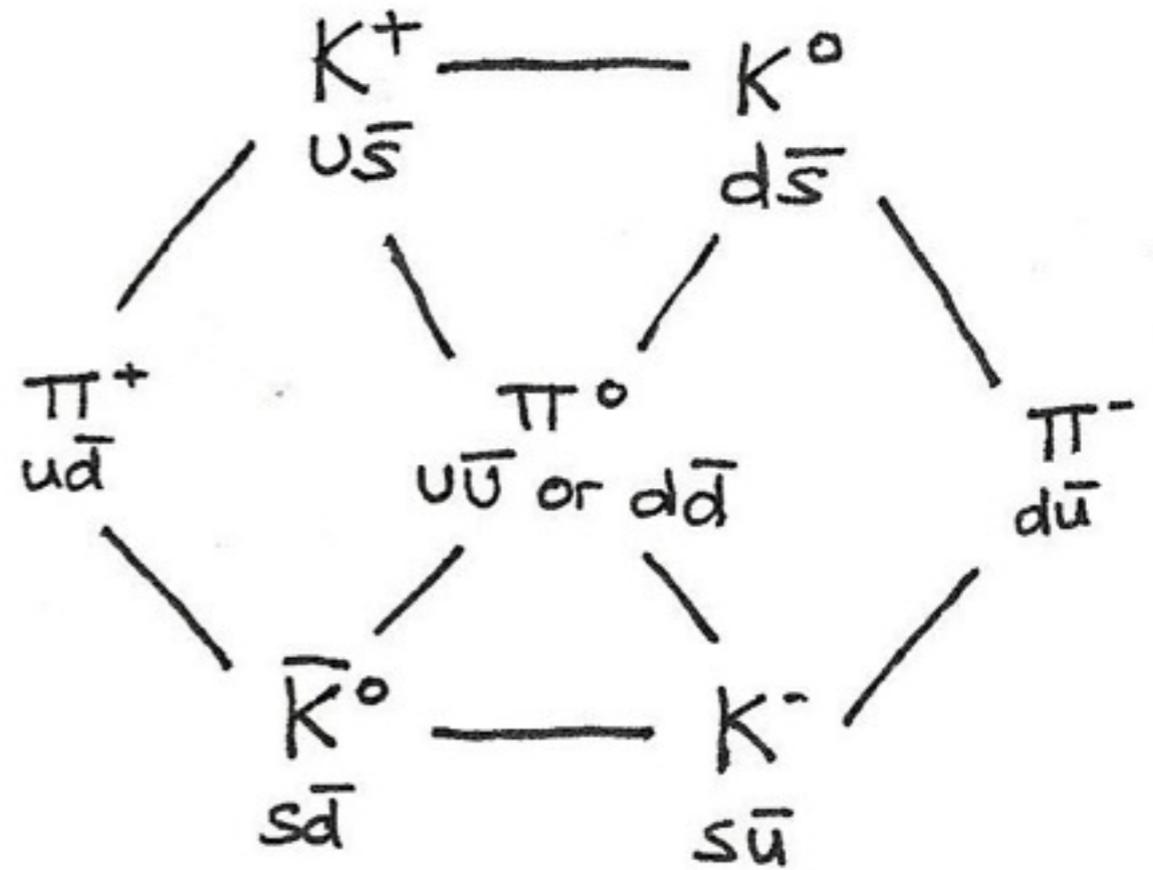


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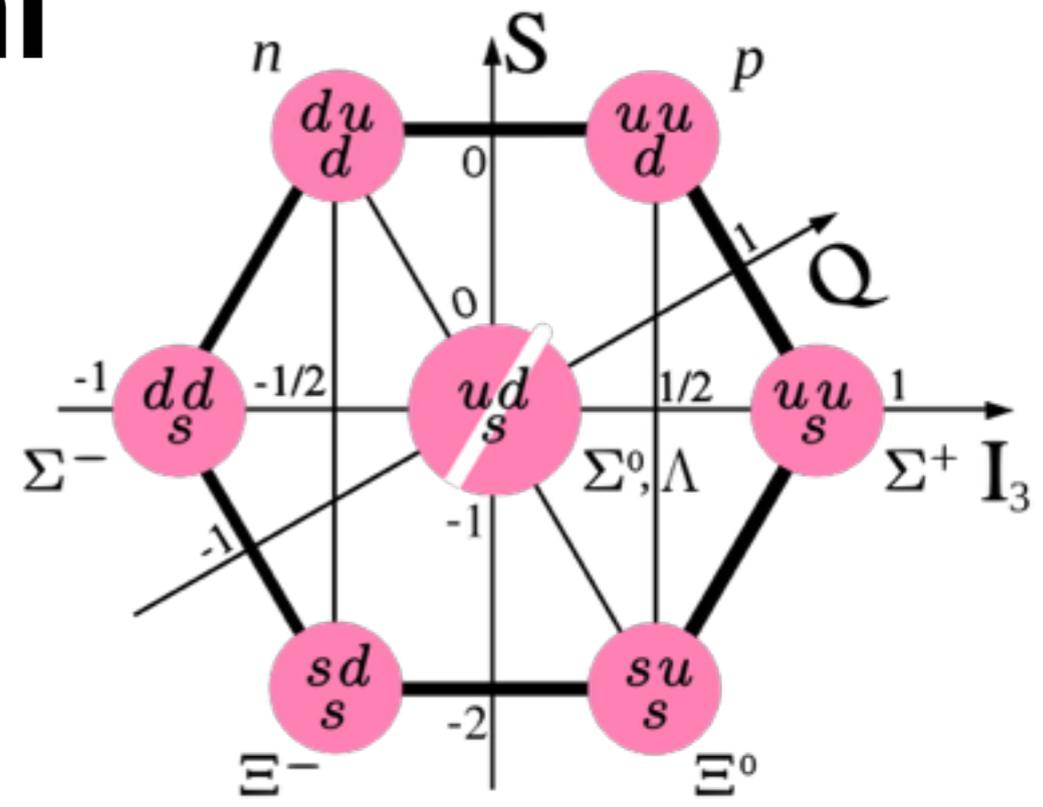
| | | | | | |
|----------------|--|--|--|--|---------------------|
| mass → | $\approx 2.3 \text{ MeV}/c^2$ | $\approx 1.275 \text{ GeV}/c^2$ | $\approx 173.07 \text{ GeV}/c^2$ | | |
| charge → | $2/3$ | $2/3$ | $2/3$ | | |
| spin → | $1/2$ | $1/2$ | $1/2$ | | |
| | u up | c charm | t top | | |
| QUARKS | $\approx 4.8 \text{ MeV}/c^2$ $-1/3$ $1/2$ d down | $\approx 95 \text{ MeV}/c^2$ $-1/3$ $1/2$ s strange | $\approx 4.18 \text{ GeV}/c^2$ $-1/3$ $1/2$ b bottom | | |
| | $0.511 \text{ MeV}/c^2$ -1 $1/2$ e electron | $105.7 \text{ MeV}/c^2$ -1 $1/2$ μ muon | $1.777 \text{ GeV}/c^2$ -1 $1/2$ τ tau | | |
| LEPTONS | $< 2.2 \text{ eV}/c^2$ 0 $1/2$ ν_e electron neutrino | $< 0.17 \text{ MeV}/c^2$ 0 $1/2$ ν_μ muon neutrino | $< 15.5 \text{ MeV}/c^2$ 0 $1/2$ ν_τ tau neutrino | | |
| | | | | | GAUGE BOSONS |

Gli adroni

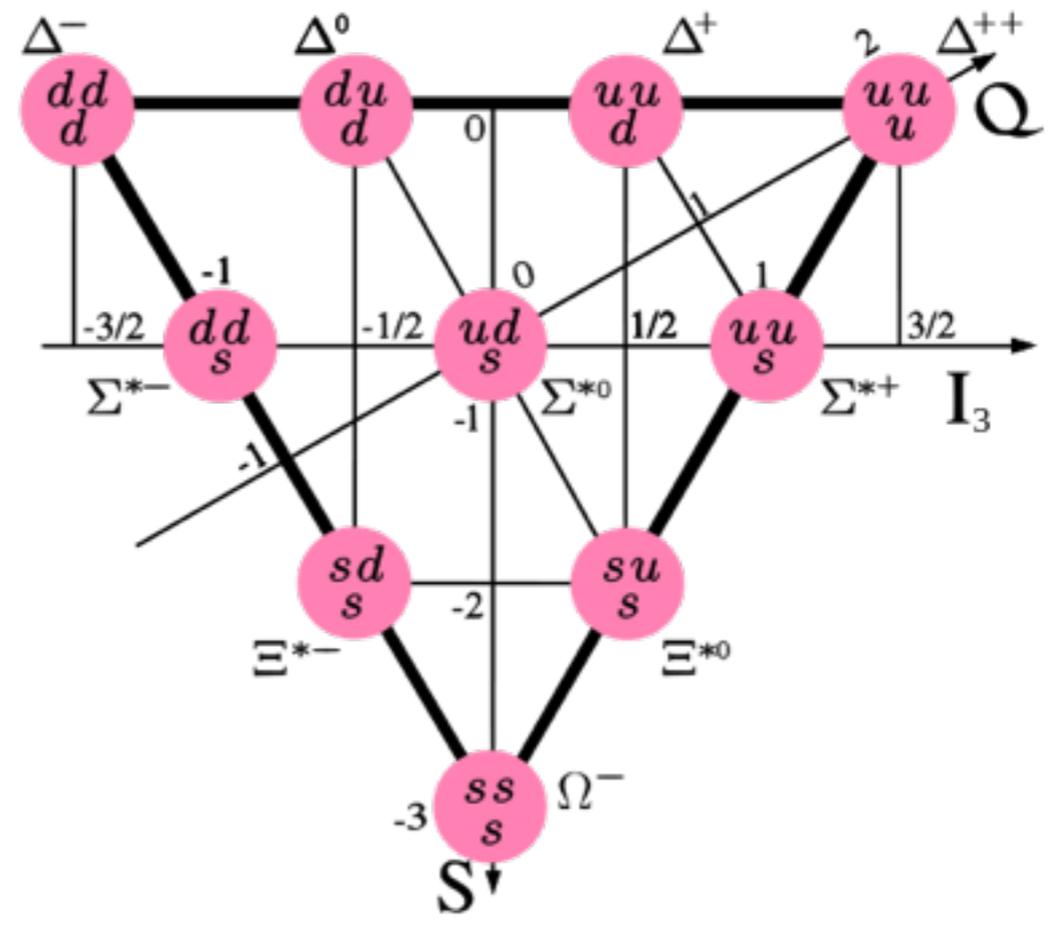
Mesoni = $q + \text{anti-}q$



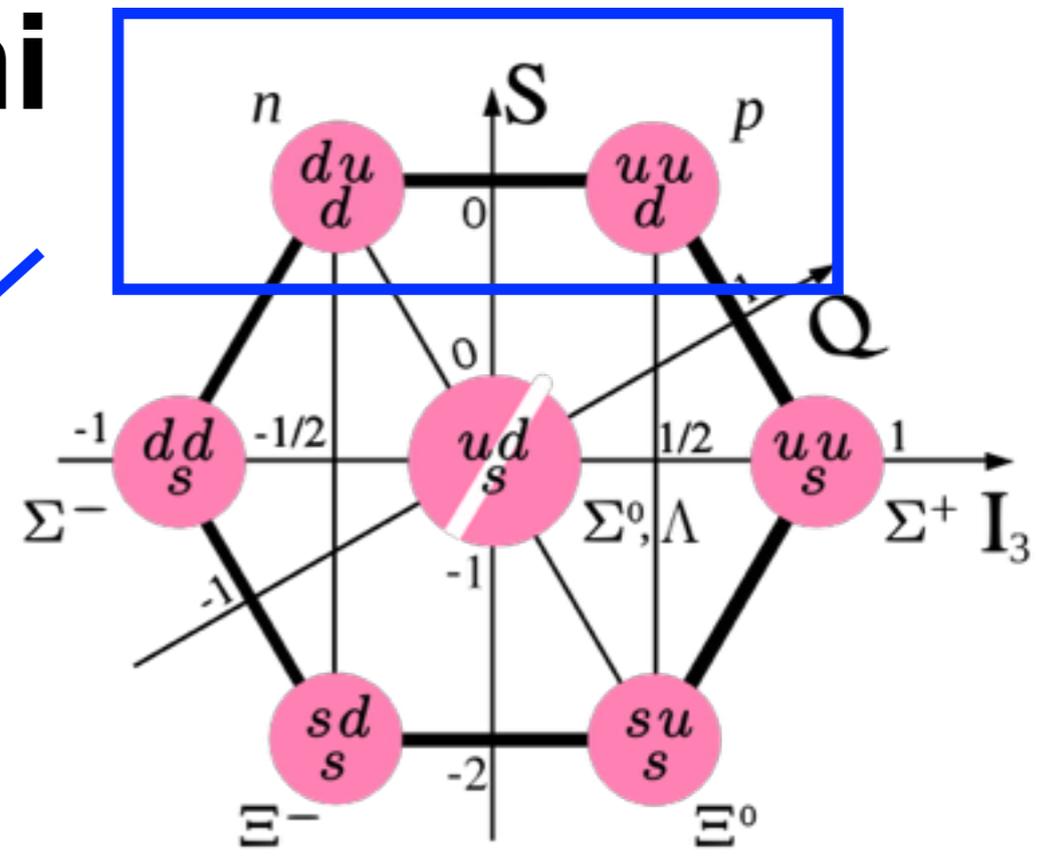
Gli adroni



Barioni = $q + q + q$

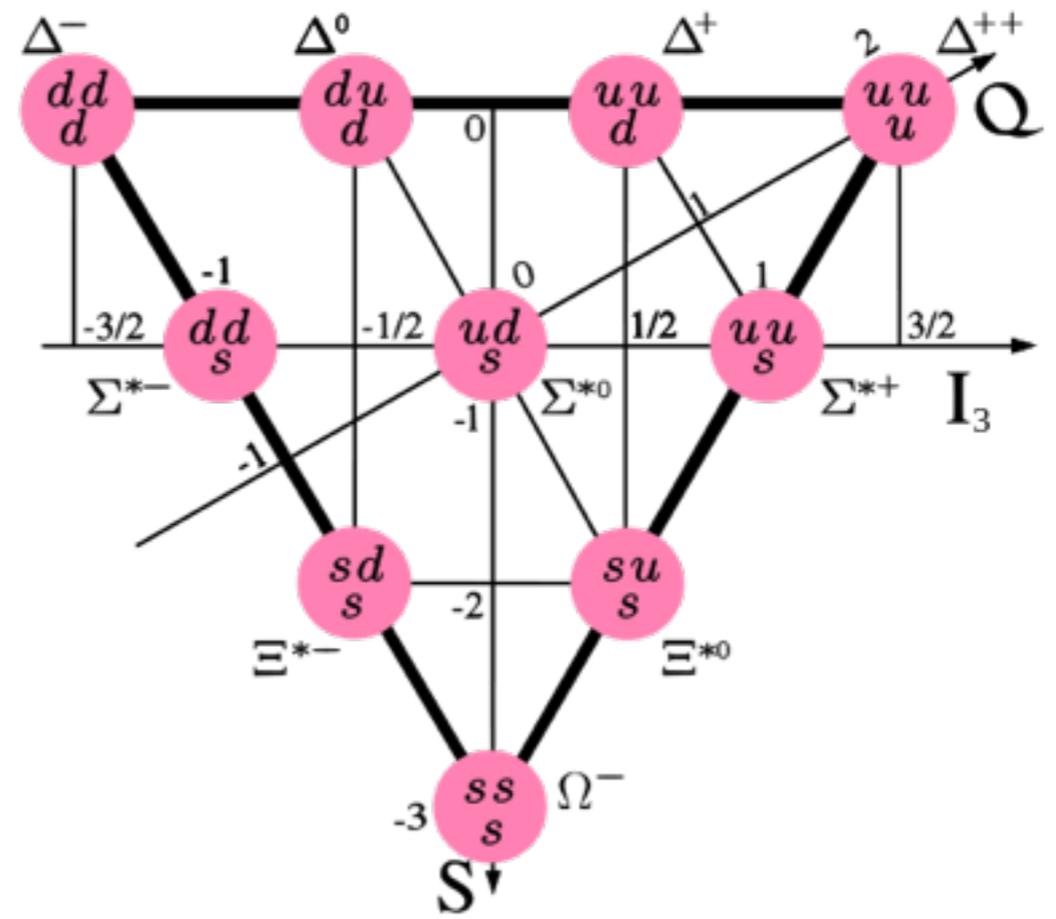


Gli adroni



Protoni e neutroni sono barioni composti da 3 quarks

Barioni = $q + q + q$



...i costituenti elementari della materia... (no, non sono gli atomi)

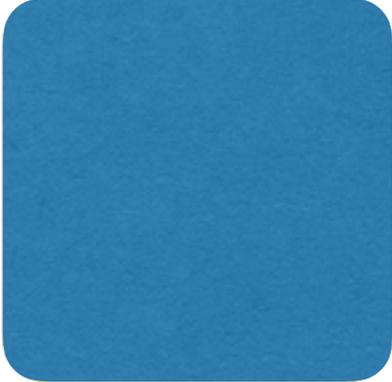
| | | | | | |
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| mass → | $\approx 2.3 \text{ MeV}/c^2$ | $\approx 1.275 \text{ GeV}/c^2$ | $\approx 173.07 \text{ GeV}/c^2$ | | |
| charge → | $2/3$ | $2/3$ | $2/3$ | | |
| spin → | $1/2$ | $1/2$ | $1/2$ | | |
| | u up | c charm | t top | | |
| | d down | s strange | b bottom | | |
| | e electron | μ muon | τ tau | | |
| | ν_e electron neutrino | ν_μ muon neutrino | ν_τ tau neutrino | | |

QUARKS

LEPTONS

GAUGE BOSONS

...i costituenti elementari della materia... (no, non sono gli atomi)

| | | | | | |
|----------------|--|--|--|------------------------|---|
| mass → | $\approx 2.3 \text{ MeV}/c^2$ | $\approx 1.275 \text{ GeV}/c^2$ | $\approx 173.07 \text{ GeV}/c^2$ | 0 |  |
| charge → | $2/3$ | $2/3$ | $2/3$ | 0 | |
| spin → | $1/2$ | $1/2$ | $1/2$ | 1 | |
| | u up | c charm | t top | g gluon | |
| QUARKS | $\approx 4.8 \text{ MeV}/c^2$ | $\approx 95 \text{ MeV}/c^2$ | $\approx 4.18 \text{ GeV}/c^2$ | 0 | |
| | $-1/3$ | $-1/3$ | $-1/3$ | 0 | |
| | $1/2$ | $1/2$ | $1/2$ | 1 | γ photon |
| | d down | s strange | b bottom | | |
| | $0.511 \text{ MeV}/c^2$ | $105.7 \text{ MeV}/c^2$ | $1.777 \text{ GeV}/c^2$ | $91.2 \text{ GeV}/c^2$ | |
| | -1 | -1 | -1 | 0 | |
| | $1/2$ | $1/2$ | $1/2$ | 1 | |
| | e electron | μ muon | τ tau | Z Z boson | |
| LEPTONS | $< 2.2 \text{ eV}/c^2$ | $< 0.17 \text{ MeV}/c^2$ | $< 15.5 \text{ MeV}/c^2$ | $80.4 \text{ GeV}/c^2$ | GAUGE BOSONS |
| | 0 | 0 | 0 | ± 1 | |
| | $1/2$ | $1/2$ | $1/2$ | 1 | |
| | ν_e electron neutrino | ν_μ muon neutrino | ν_τ tau neutrino | W W boson | |

Le forze fondamentali

Forza gravitazionale \longrightarrow gravitone (???)
[**teorizzato ma non trovato**]

Forza elettromagnetica \longrightarrow fotone

Forza nucleare debole \longrightarrow bosone W^+ , W^- , Z

Forza nucleare forte \longrightarrow gluone

...i costituenti elementari della materia... (no, non sono gli atomi)

| | | | | | |
|----------------|--|--|--|--------------------------------------|-------------------------------|
| mass → | $\approx 2.3 \text{ MeV}/c^2$ | $\approx 1.275 \text{ GeV}/c^2$ | $\approx 173.07 \text{ GeV}/c^2$ | 0 | $\approx 126 \text{ GeV}/c^2$ |
| charge → | $2/3$ | $2/3$ | $2/3$ | 0 | 0 |
| spin → | $1/2$ | $1/2$ | $1/2$ | 1 | 0 |
| | u up | c charm | t top | g gluon | H Higgs boson |
| QUARKS | $\approx 4.8 \text{ MeV}/c^2$ | $\approx 95 \text{ MeV}/c^2$ | $\approx 4.18 \text{ GeV}/c^2$ | 0 | |
| | $-1/3$ | $-1/3$ | $-1/3$ | 0 | |
| | $1/2$ | $1/2$ | $1/2$ | 1 | |
| | d down | s strange | b bottom | γ photon | |
| | $0.511 \text{ MeV}/c^2$ | $105.7 \text{ MeV}/c^2$ | $1.777 \text{ GeV}/c^2$ | $91.2 \text{ GeV}/c^2$ | |
| | -1 | -1 | -1 | 0 | |
| | $1/2$ | $1/2$ | $1/2$ | 1 | |
| | e electron | μ muon | τ tau | Z Z boson | |
| LEPTONS | $< 2.2 \text{ eV}/c^2$ | $< 0.17 \text{ MeV}/c^2$ | $< 15.5 \text{ MeV}/c^2$ | $80.4 \text{ GeV}/c^2$ | |
| | 0 | 0 | 0 | ± 1 | |
| | $1/2$ | $1/2$ | $1/2$ | 1 | |
| | ν_e electron neutrino | ν_μ muon neutrino | ν_τ tau neutrino | W W boson | |
| | | | | | GAUGE BOSONS |

Il bosone di Higgs

Particella di Dio? **NO**

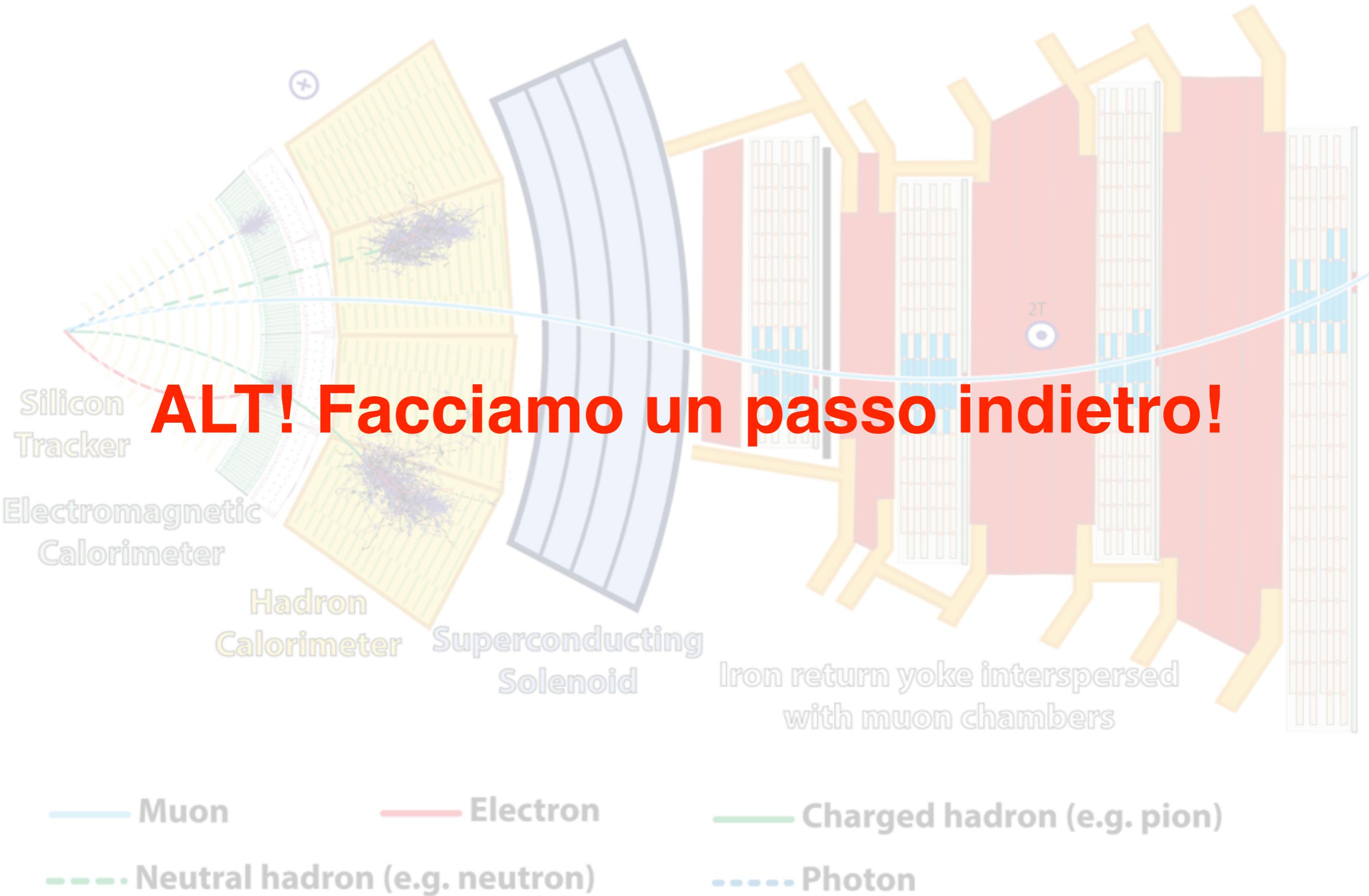
Compare per la prima volta nel titolo del libro di Leon Lederman "*The God Particle: If the Universe Is the Answer, What Is the Question?*"

Tale titolo derivò da un cambiamento da parte dell'editore del soprannome di "**Goddamn particle**" (**particella maledetta**), originalmente scelto dall'autore in riferimento alla difficoltà della sua individuazione.

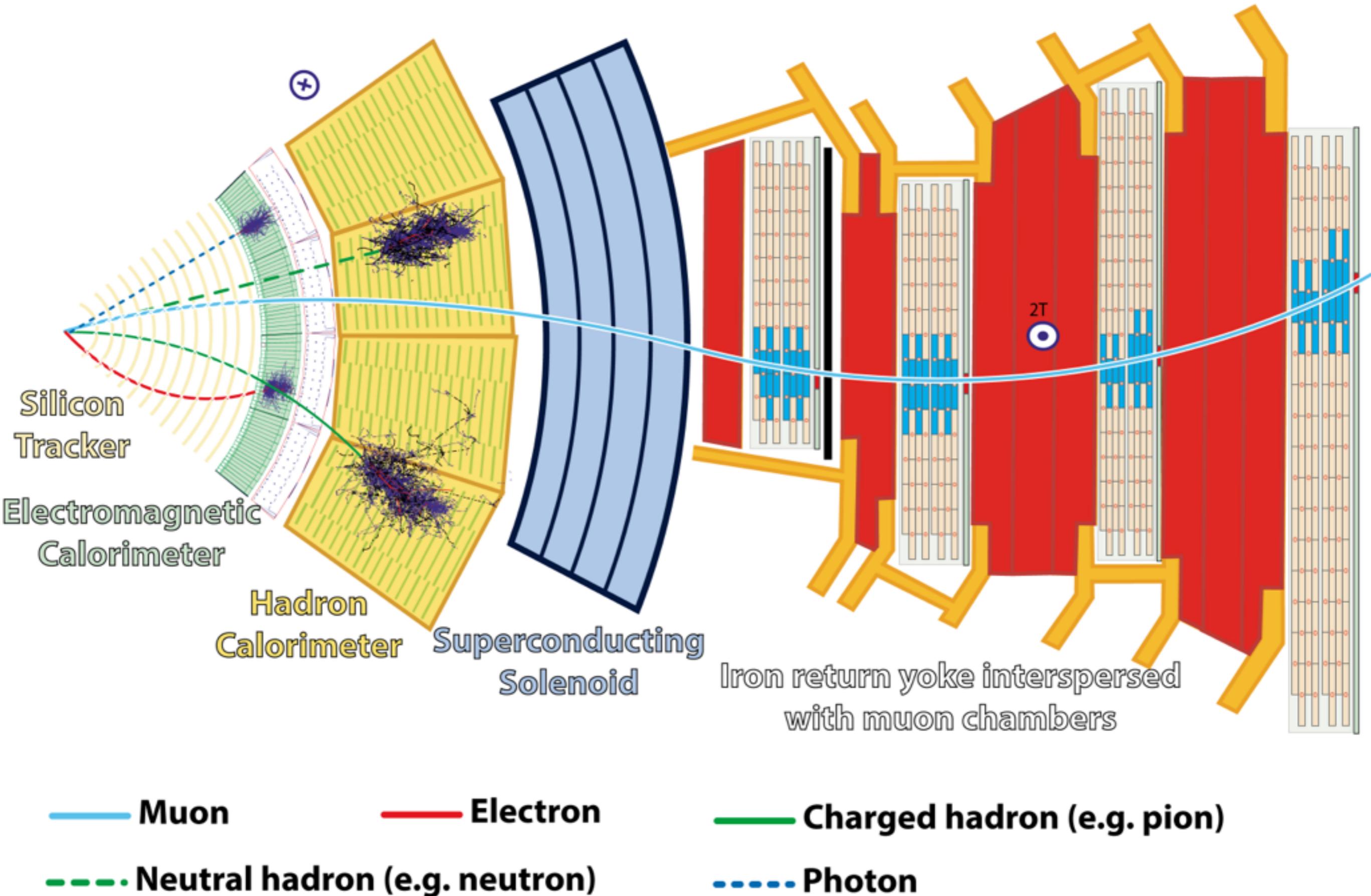
Il bosone di Higgs è la particella associata al campo di Higgs (come il fotone al campo elettromagnetico):

le particelle interagendo con questo campo acquisiscono massa.

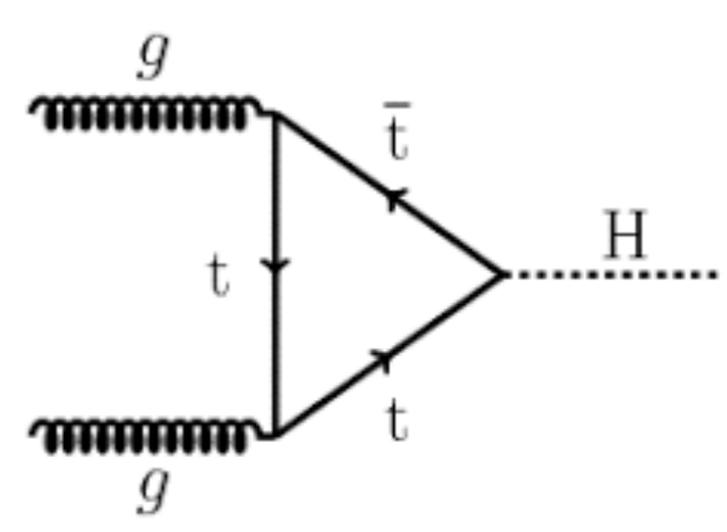
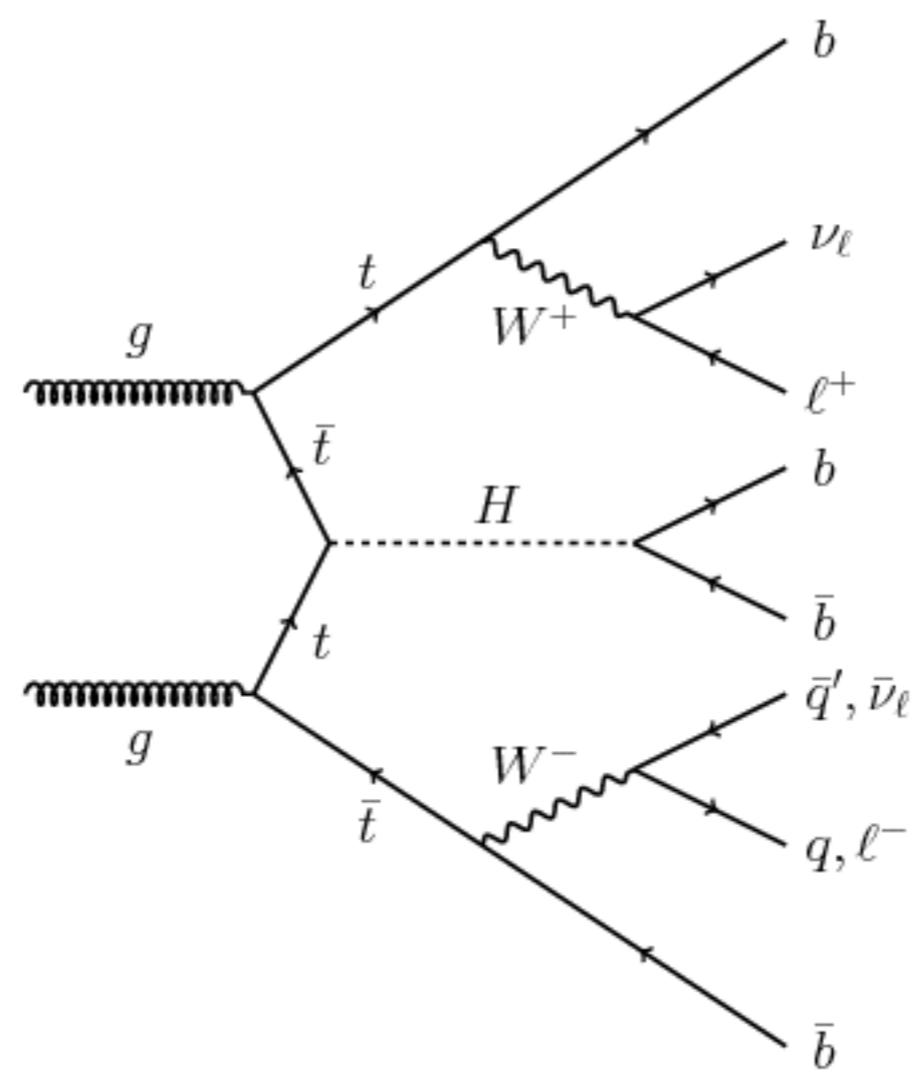
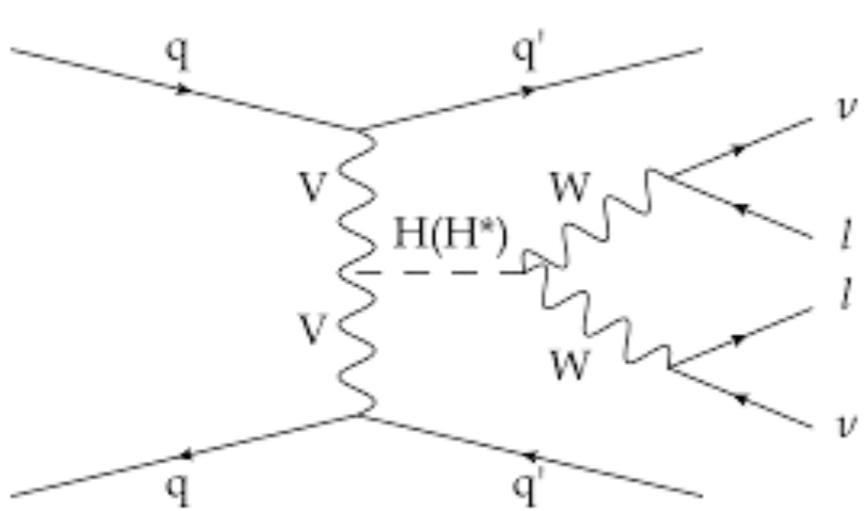
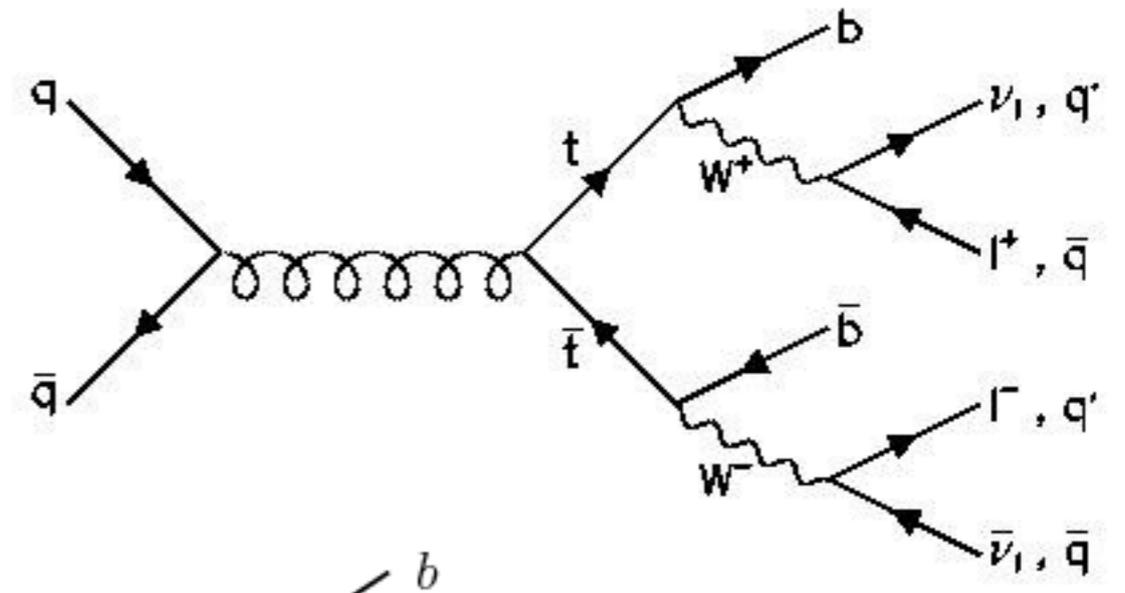
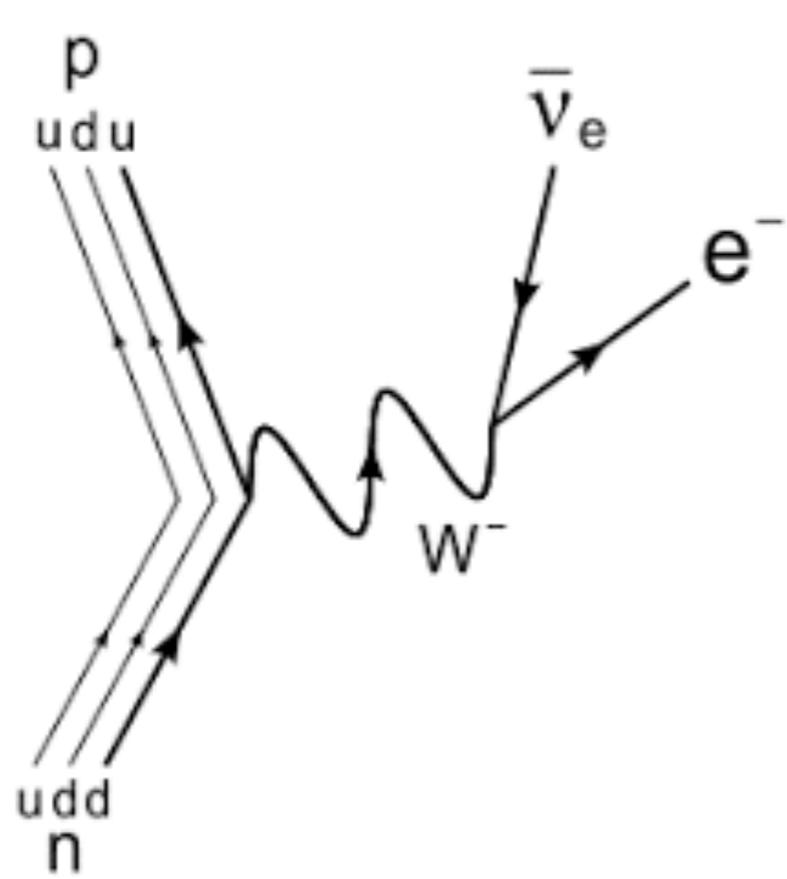
I grandi esperimenti: CMS



I grandi esperimenti: CMS



Diagrammi di Feynman



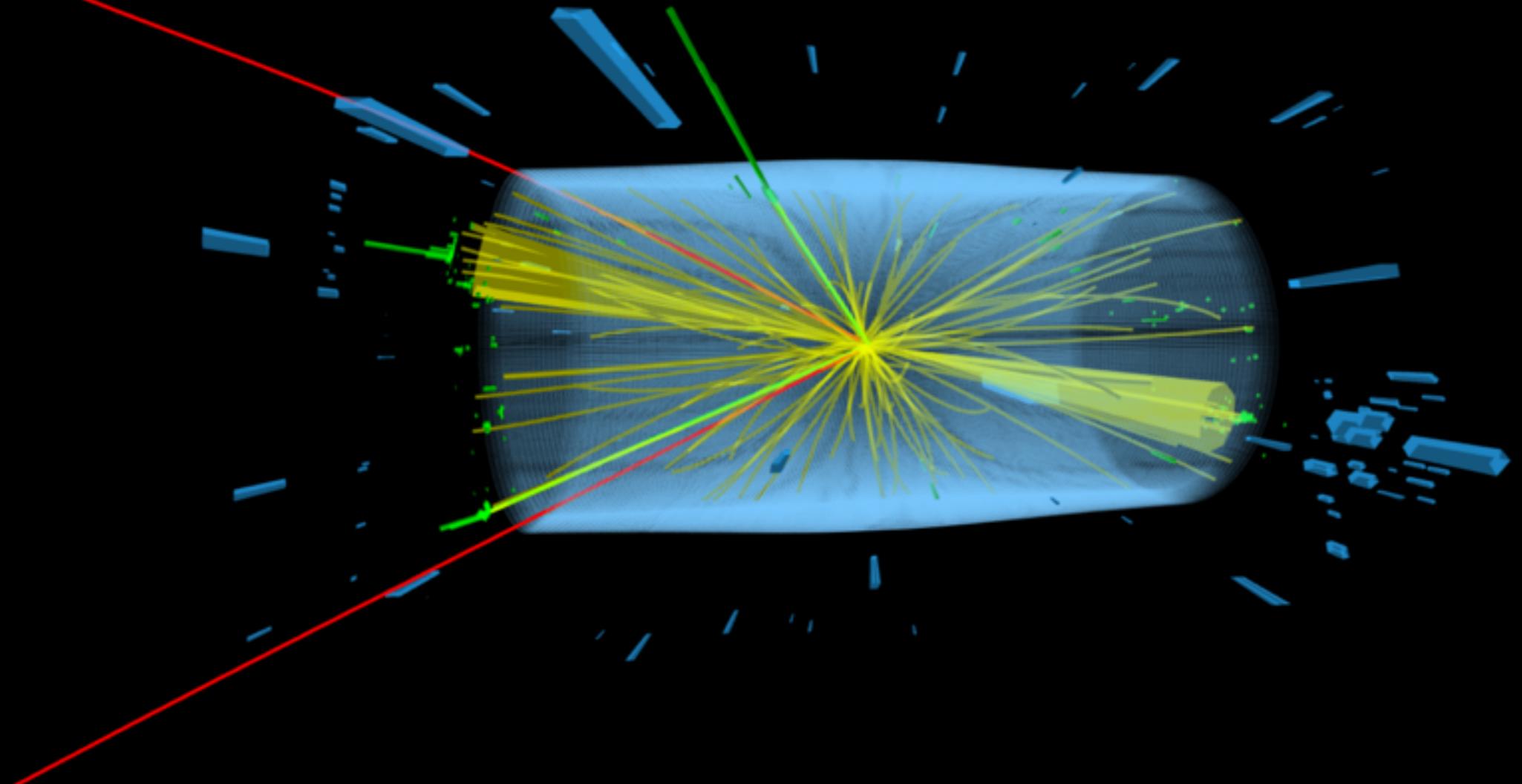
Le collisioni



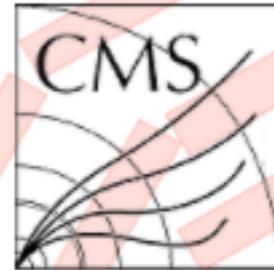
CMS Experiment at the LHC, CERN

Data recorded: 2016-Jul-08 23:47:39.259242 GMT

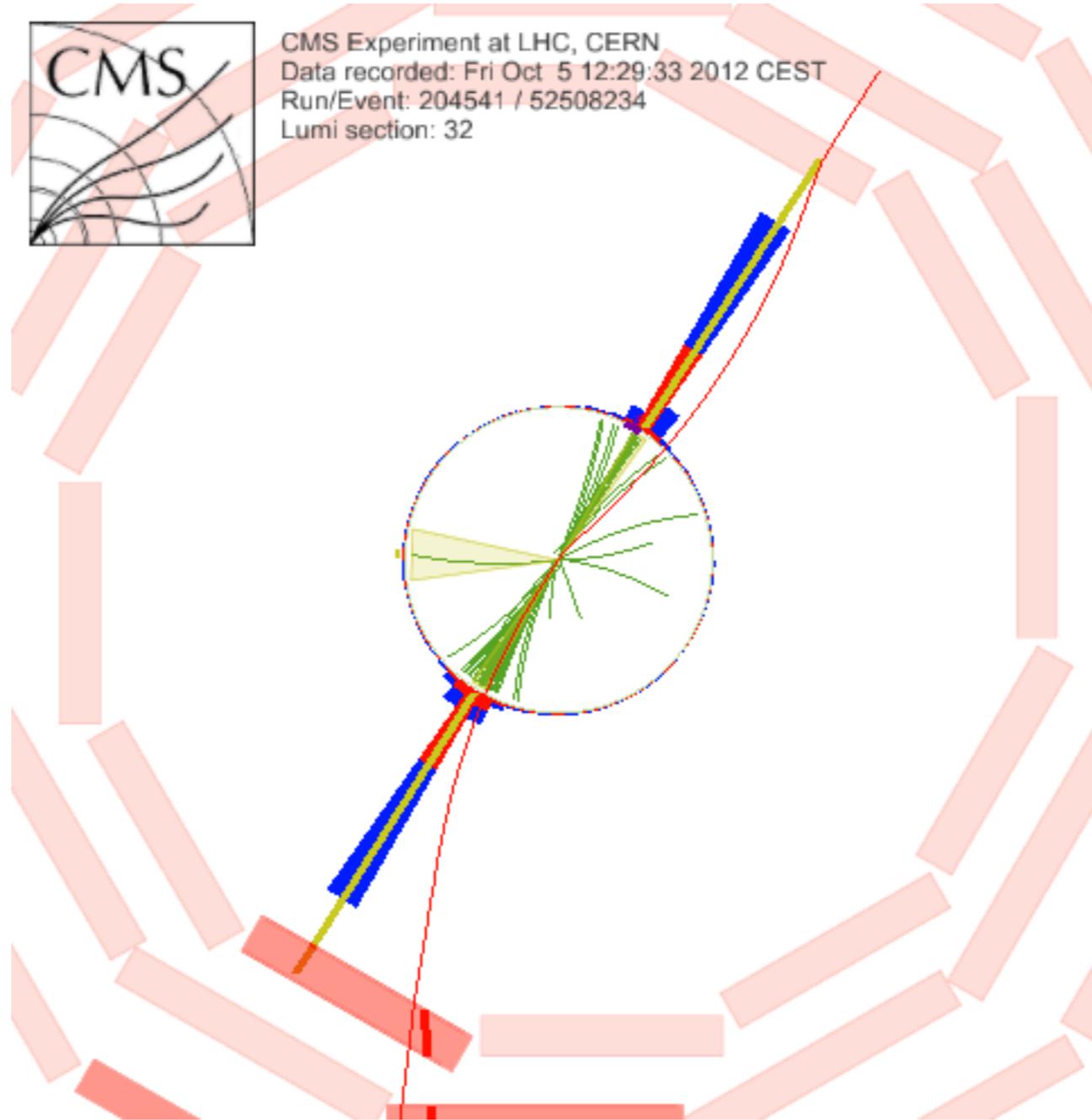
Run / Event / LS: 276525 / 2665335317 / 1561



Le collisioni



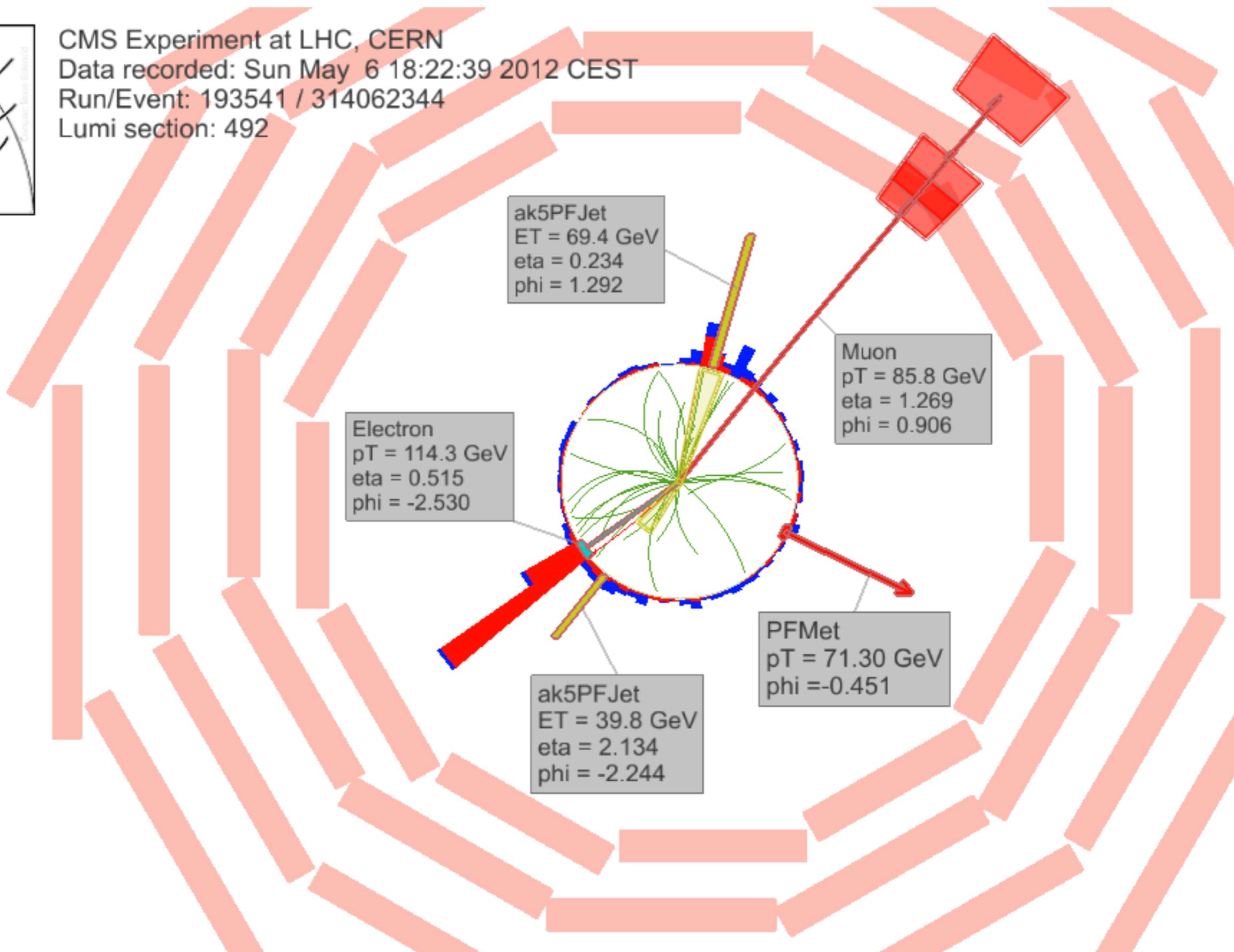
CMS Experiment at LHC, CERN
Data recorded: Fri Oct 5 12:29:33 2012 CEST
Run/Event: 204541 / 52508234
Lumi section: 32



Le collisioni



CMS Experiment at LHC, CERN
Data recorded: Sun May 6 18:22:39 2012 CEST
Run/Event: 193541 / 314062344
Lumi section: 492



ak5PFJet
ET = 69.4 GeV
eta = 0.234
phi = 1.292

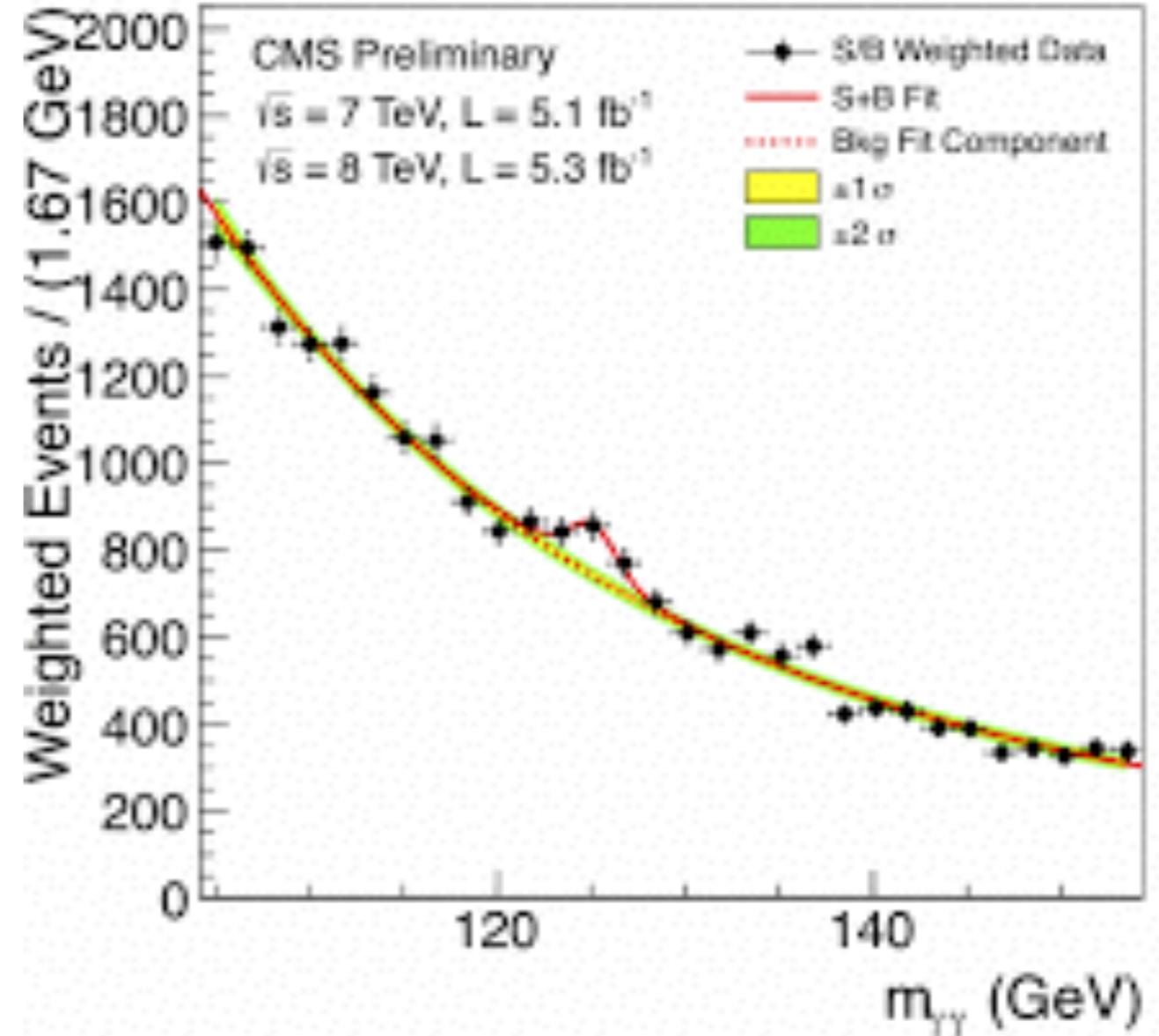
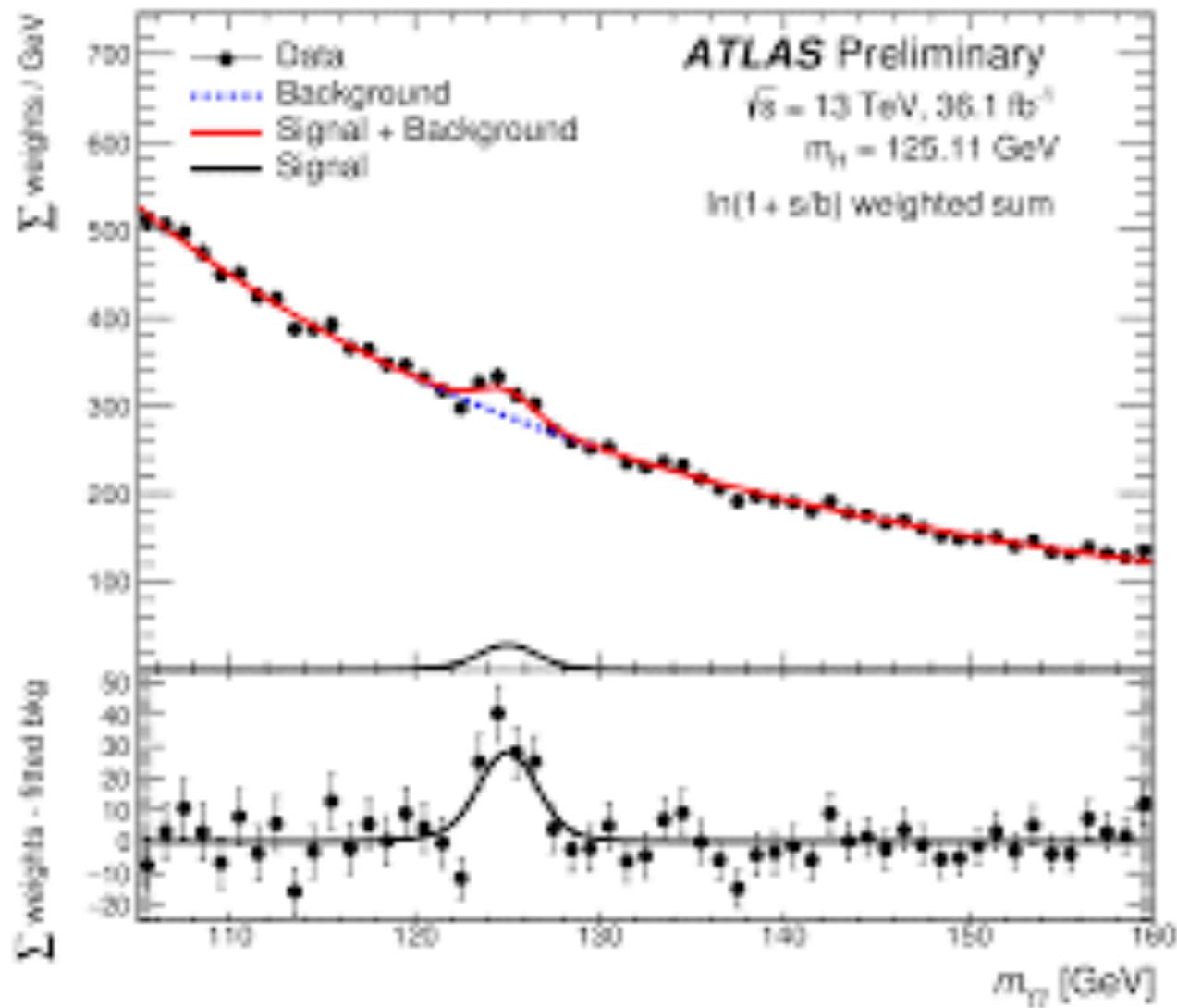
Muon
pT = 85.8 GeV
eta = 1.269
phi = 0.906

Electron
pT = 114.3 GeV
eta = 0.515
phi = -2.530

PFMet
pT = 71.30 GeV
phi = -0.451

ak5PFJet
ET = 39.8 GeV
eta = 2.134
phi = -2.244

4 Luglio 2012: finalmente lo hanno trovato



4 Luglio 2012: finalmente lo hanno trovato



E ora?

Vari problemi legati al modello che descrive attualmente la Fisica delle Particelle (Modello Standard):

- ◆ non include la forza di Gravità
- ◆ prevede neutrini senza massa
- ◆ problema legato alle costanti di accoppiamento

Vari modelli sviluppati per ovviare a queste problematiche:

- Supersimmetrie
- Teoria della Grande Unificazione
- Extra - dimensioni

**Si va bene,
ma a che serve?**

A che serve?

La ricerca e la curiosità sono alla base della natura dell'essere umano.

Spinge l'uomo a porsi degli obiettivi e a superarli.

La scoperta dell'Higgs non ha in se stessa una ricaduta nella vita quotidiana delle persone ma ha permesso lo sviluppo di tecnologie che hanno rivoluzionato la nostra vita.

A che serve?

Parte I: **INTERNET**



A che serve?

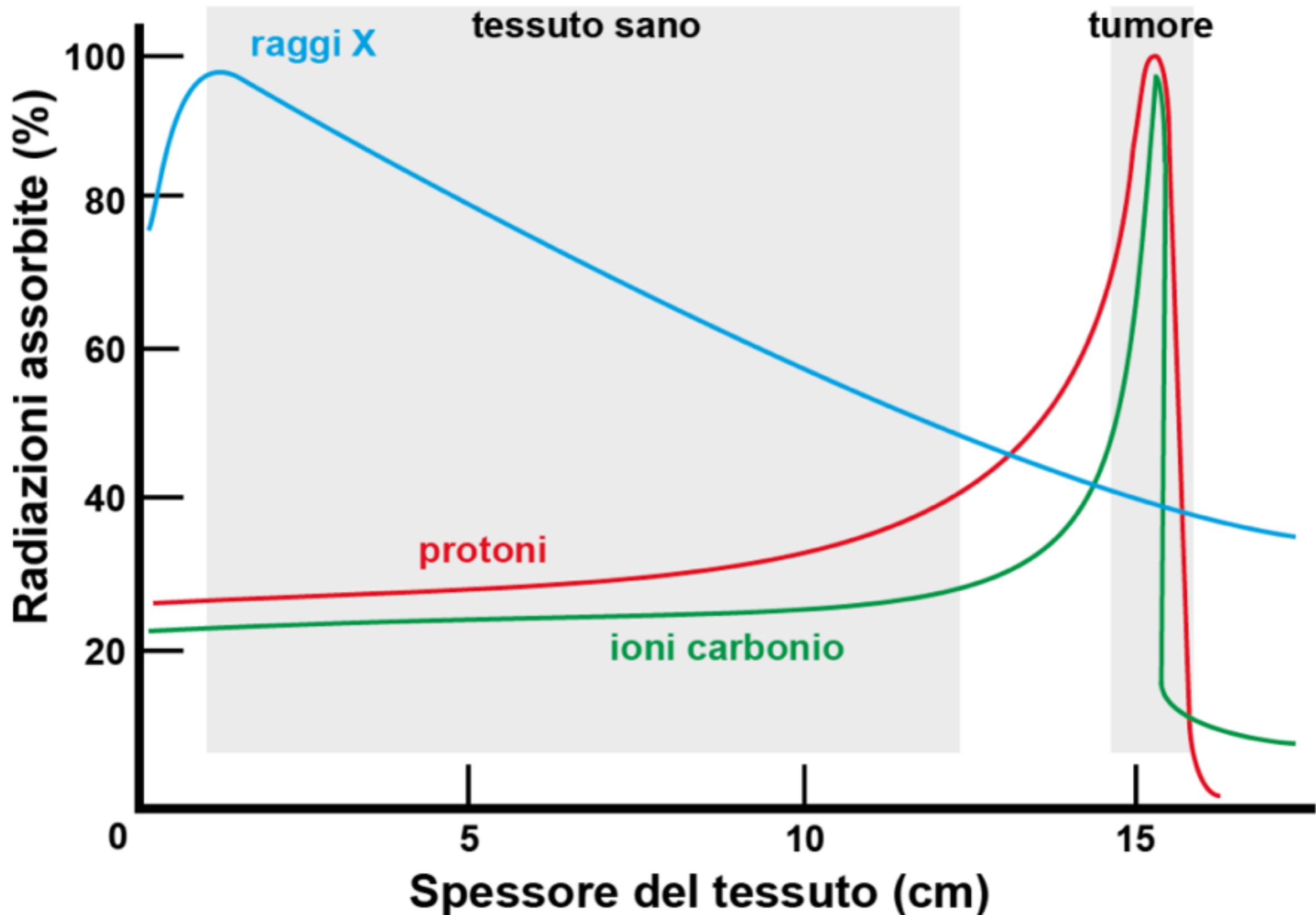
Parte II: **Adroterapia**



CNAO a Pavia

A che serve?

Parte II: Adroterapia



Grazie per l'attenzione

**Se avete domande:
chiamate il mio avvocato**