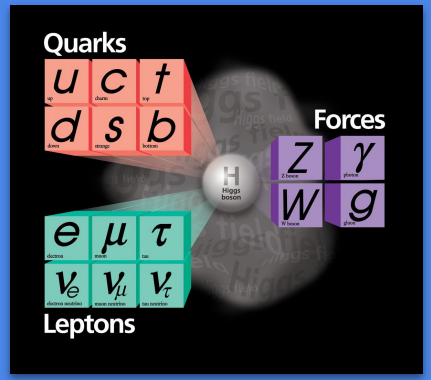
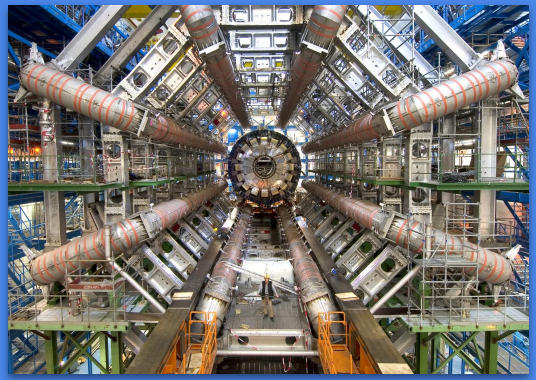
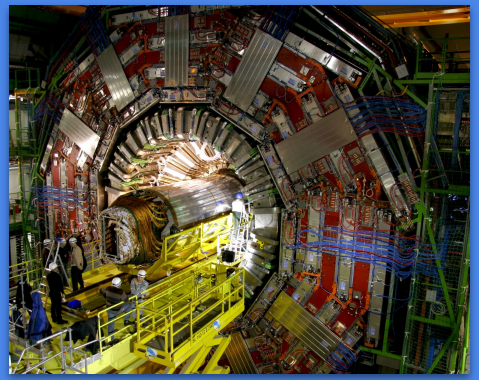
Il Modello Standard e gli esperimenti "general purpose" a LHC: ATLAS e CMS



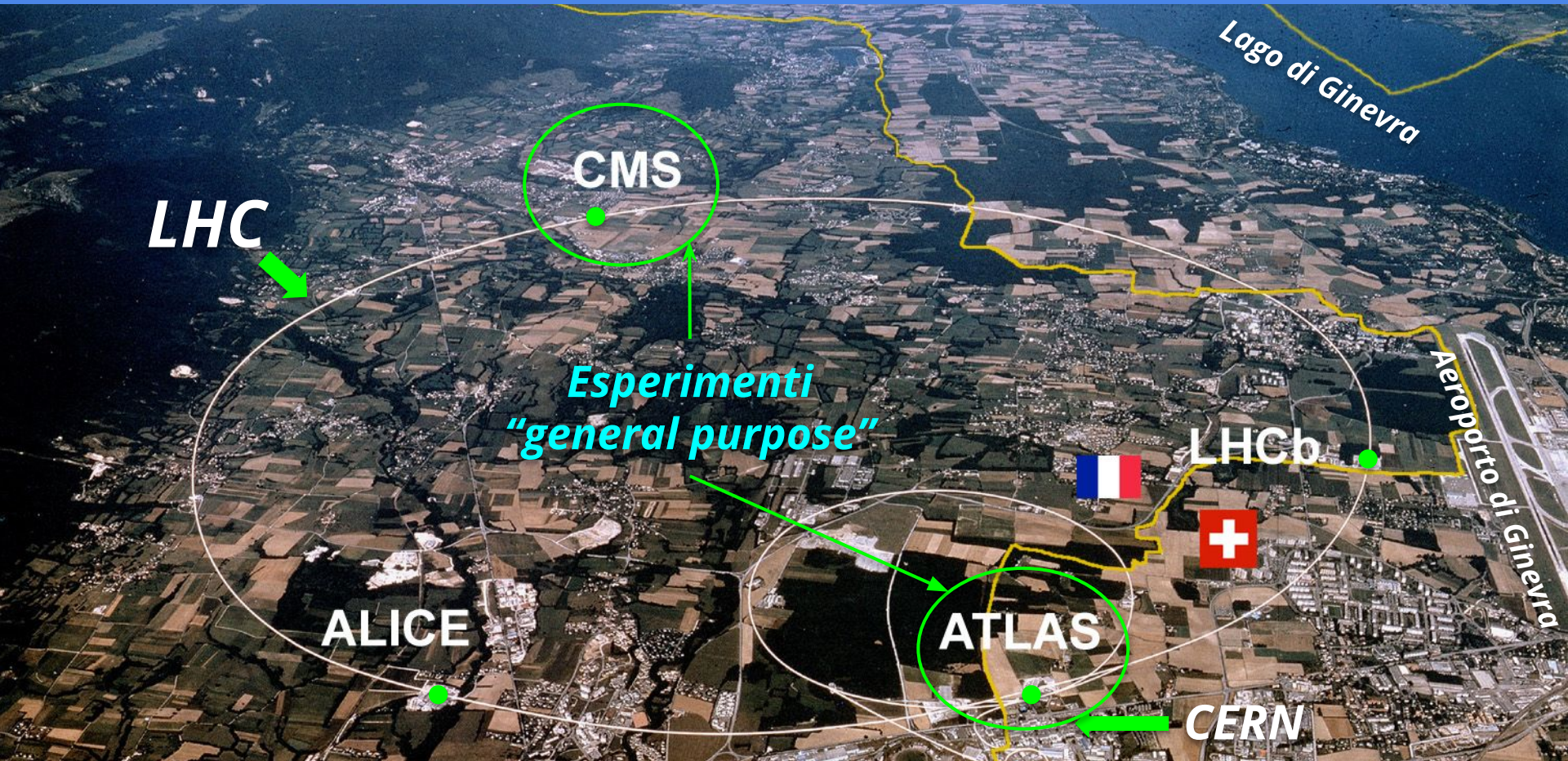




Michele Pinamonti (INFN Trieste)

UniTS / INFN Trieste - Seminario introduttivi visita CERN | 10 Febbraio 2023

LHC e i suoi esperimenti

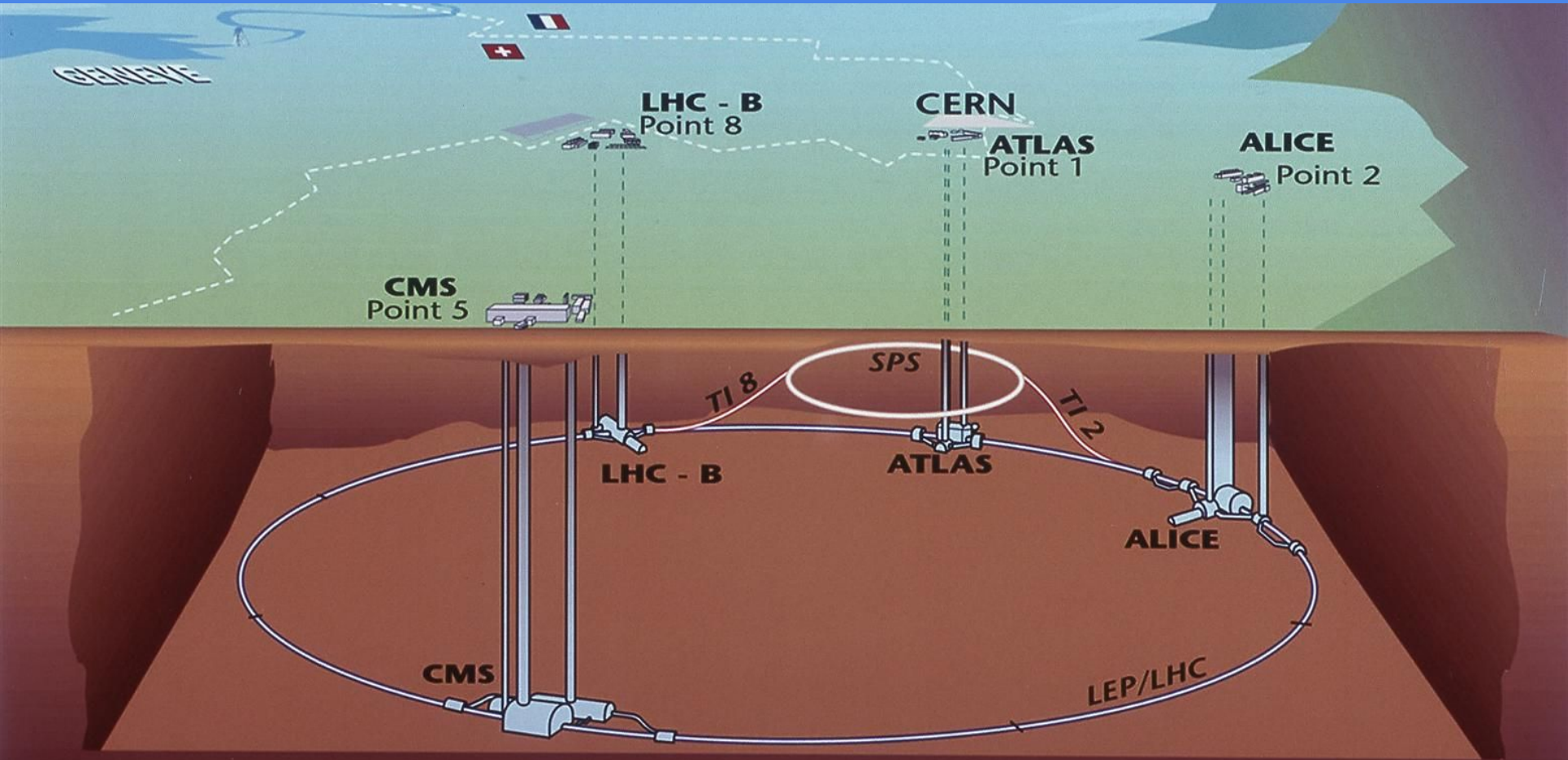


ATLAS @LHC

CMS @LHC

Lago di Ginevra
CMS
Sala controllo CMS
Rivelatore CMS...
Aeroporto di Ginevra
CERN

LHC underground

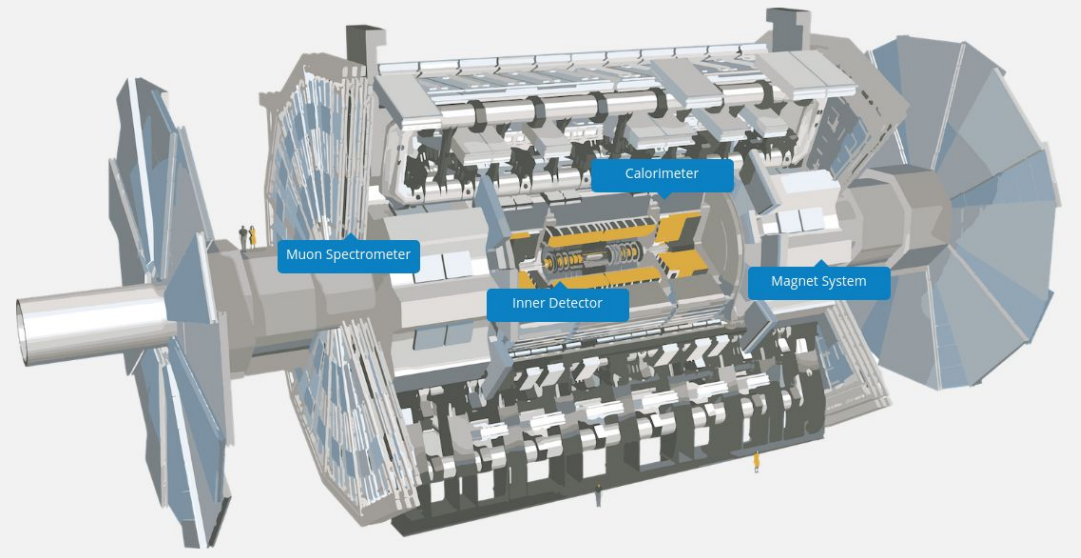


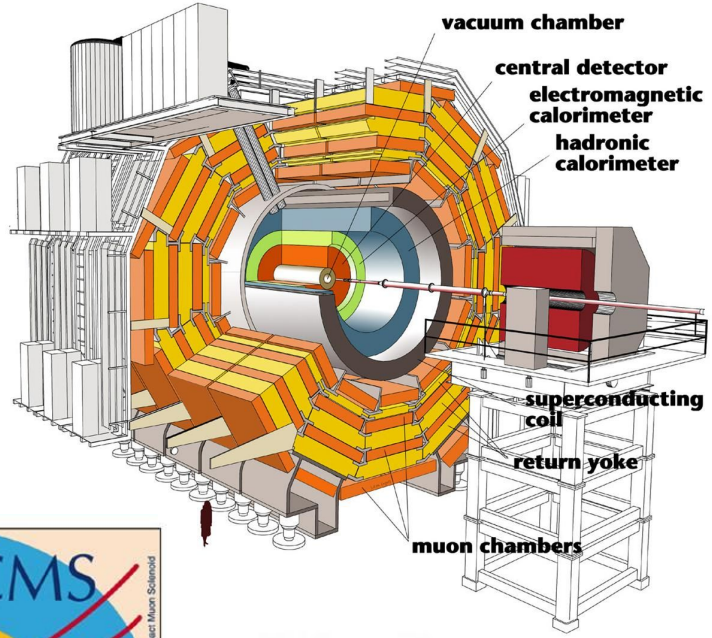
I rivelatori ATLAS e CMS

- Costruzione: 1995 - 2009
- Run 1: 2010 - 2012 → *pp* √s = 7 TeV, 8 TeV
- Upgrade Run 2: 2013 - 2014
- Run 2: 2015 - 2018 → *pp* √s = 13 TeV
- Upgrade Run 3: just finished
- Run 3: 2022 - 2025 → *pp* √s = 13.6 TeV

ATLAS EXPERIMENT

46	100	7000	1000000000
meters long & 25m of diameter	meters below ground	tonnes	collisions / second



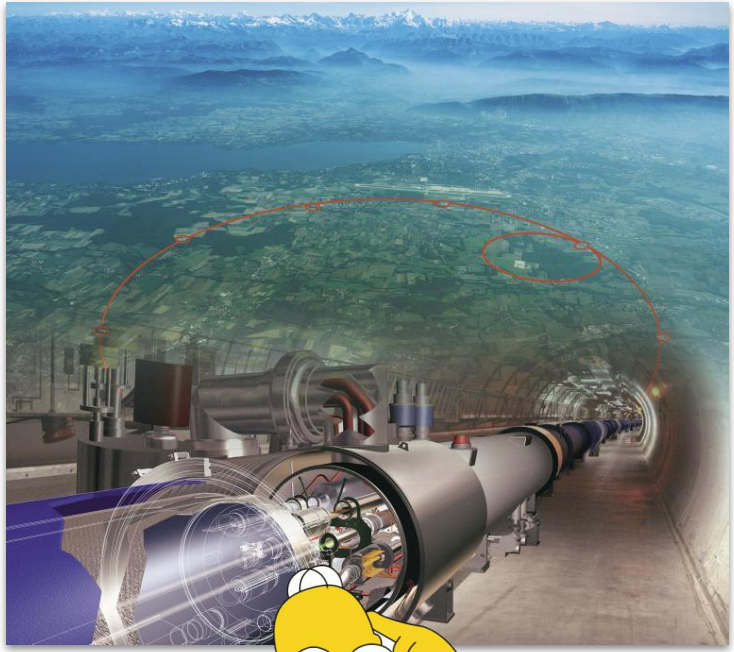


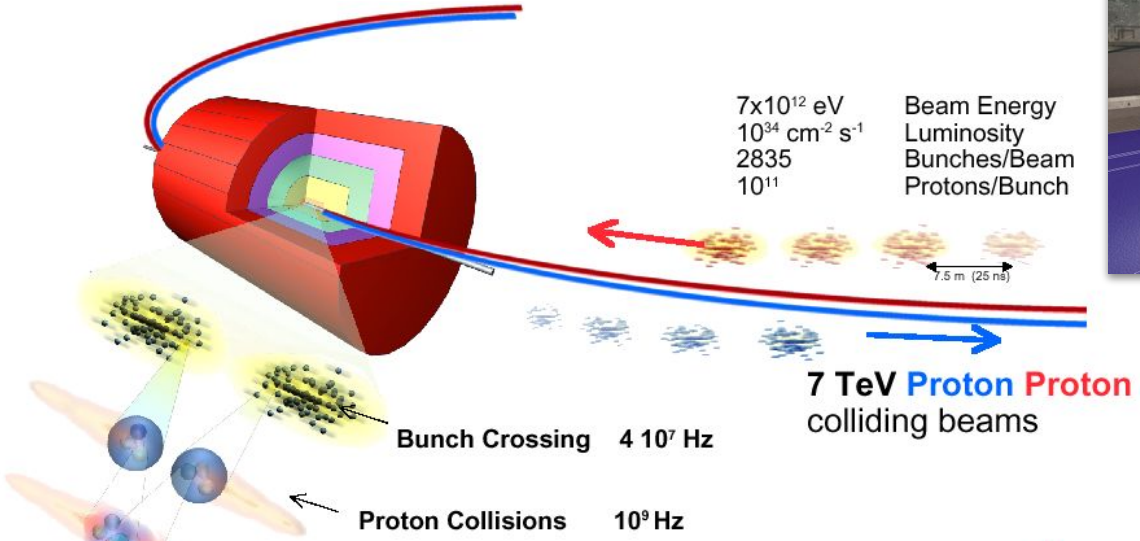
CMS Compact Muon Solenoid

Width: 22m
Diameter: 15m
Weight: 14'500t

Il Large Hadron Collider

- Anello di 27 km di circonferenza
- Fasci di **protoni** accelerati fino a energia (*cinetica*) di ~7 TeV (1 TeV = 10^{12} eV)
- 1 **fascio** = ~3k ***bunch*** (pacchetti) di protoni
  - 1 *bunch* = 10^{11} protoni

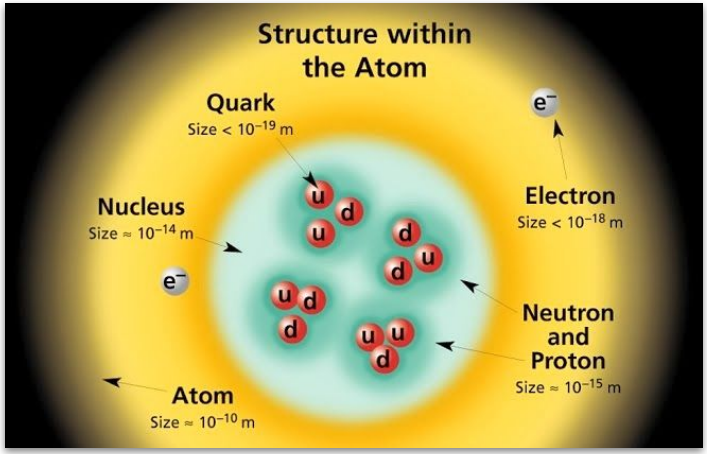




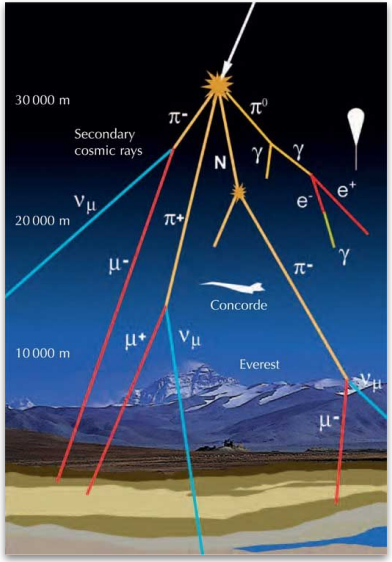
PERCHÈ?

...

Particelle...



- La **materia** che conosciamo è formata da **atomi**:
  - **elettroni**
  - **protoni** e **neutroni**
    = stati legati di **quark** (*up*, *down*)

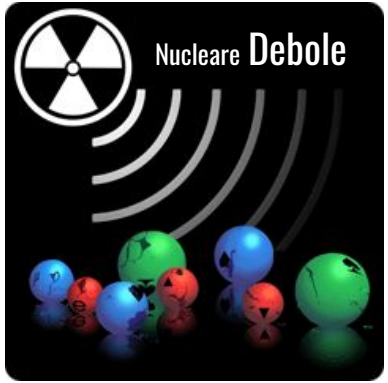


- **In aggiunta:**
  - **Antimateria**
  - Cucini **pesanti** (muoni, quark *strange*, *charm*...)
  - **Neutrini**
  - Molti altri stati legati di quark (**adroni**)

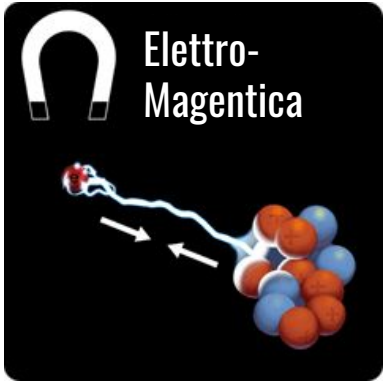
...e interazioni

- 4 **interazioni fondamentali**:

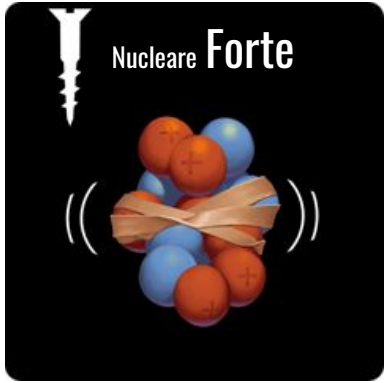
- molto debole
- solo attrattiva
- lungo raggio



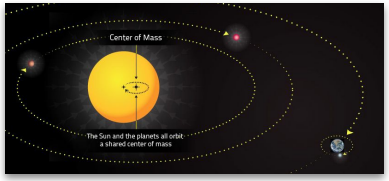
- decadimenti beta
- molto debole
- corto raggio

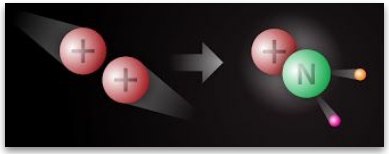


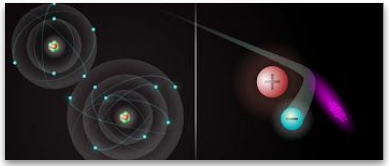
- legami atomici
- fenomeni elettrici
- fenomeni magnetici
- radiazione EM
- lungo raggio

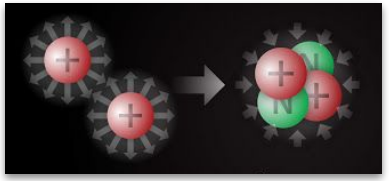


- legami tra nucleoni
- legami tra quark
- corto raggio







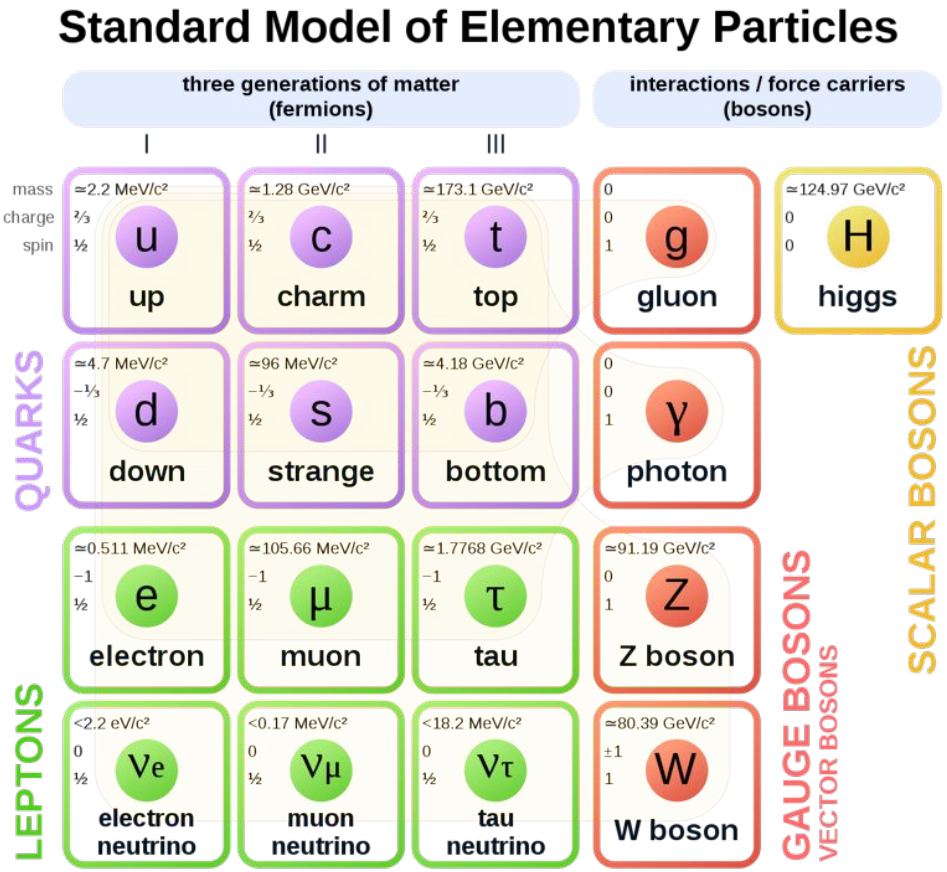


Il Modello Standard delle interazioni fondamentali

- Ogni **tipo** di particella elementare è descritto da un ***campo***

- A ogni **interazione** (*tranne la gravità*) associata una **particella portatrice** (*bosone di gauge*)

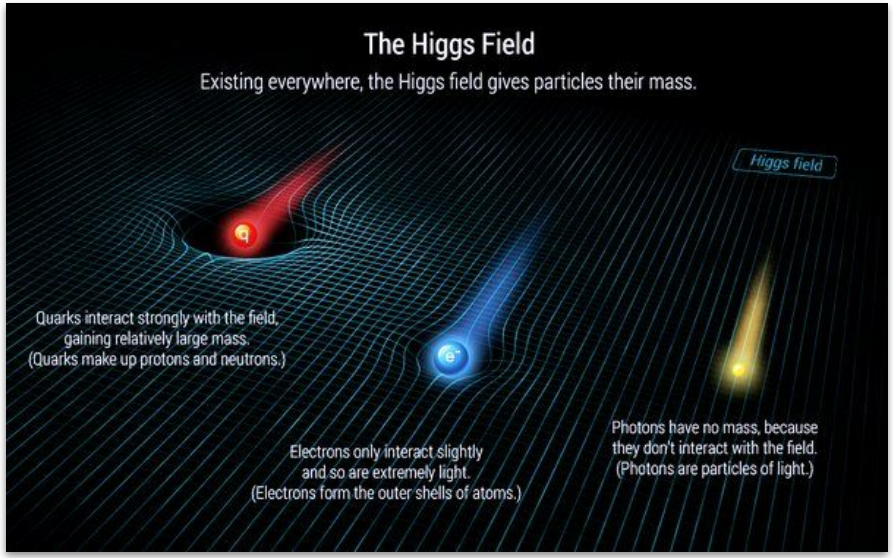
- In aggiunta, **campo di Higgs**...



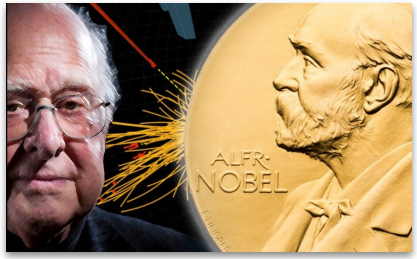
Campo di Higgs, bosone di Higgs

- Anni '60: il Modello Standard prevedeva un mondo fatto di particelle senza massa...

- **Soluzione**:
  - il *vuoto* è permeato da un **campo** (di Higgs) che interagisce con le particelle generando inerzia ⇒ **massa**



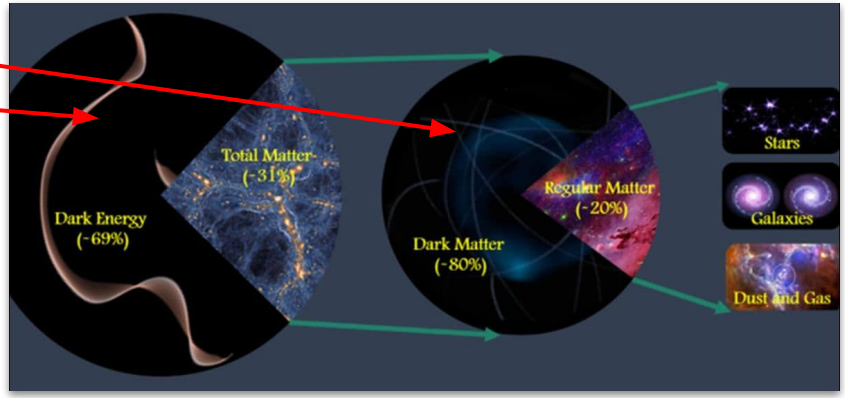
- Particella associata a campo di Higgs:
  - **bosone di Higgs**
    - cercato per 50 anni
    - scoperto nel 2012 grazie a LHC e ai suoi esperimenti CMS e ATLAS



Oltre il Modello Standard

- Ma il Modello Standard ***non*** descrive tutto quello che osserviamo in natura!

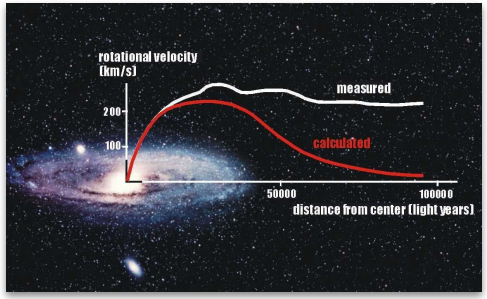
- Alcuni dei fenomeni non ancora compresi:
  - Gravità: *conciliazione tra relatività generale e meccanica quantistica*
  - **Materia Oscura**
  - **Energia Oscura**
  - Asimmetria materia/antimateria
  - ...

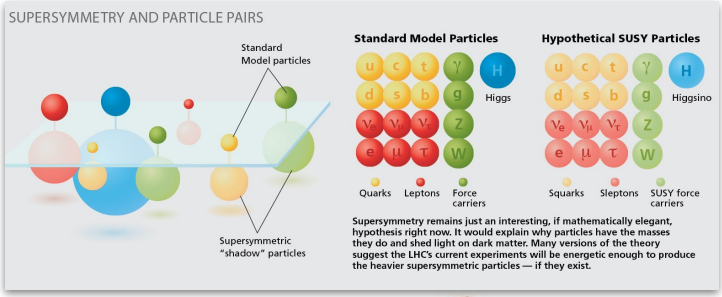


- **Modelli di nuova fisica**:
  - teorie che *estendono* il Modello Standard
    per spiegare alcuni dei fenomeni osservati non descritti

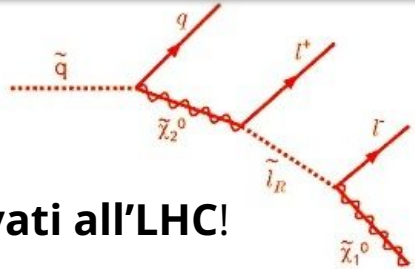
Esempio: Materia Oscura e Supersimmetria

- **<u>Materia Oscura</u>**:
  - ipotizzata per spiegare **rotazione galassie** e **collisioni** tra cluster di galassie
  - possibile spiegazione:
    - nuovo tipo di **particella** massiva e debolmente interagente **WIMP** (*weakly interacting massive particle*)



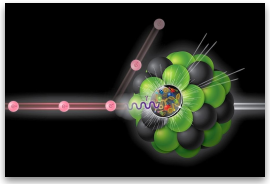


- **<u>Supersimmetria</u>** (SUSY):
  - classe di modelli con 1 nuova particella ∀ particella standard (*con massa maggiore*)
  - **particella SUSY** più leggera, se *neutra* elettricamente e non soggetta a interazione forte (eg. *neutralino*) → **candidato WIMP** perfetto
  - neutralini e altre particelle SUSY potrebbero essere **osservati all'LHC**!



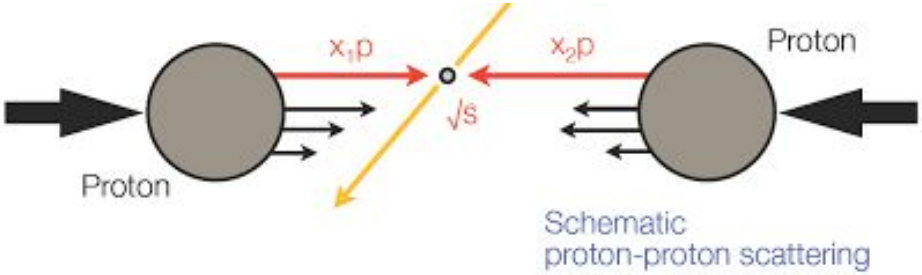
Collisioni tra protoni

- Particelle ≠ *p, n, e* → non facilmente reperibili in natura (***fortemente instabili***)



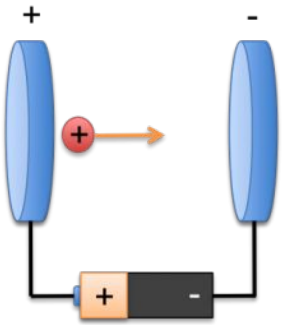
- Un modo per studiarle (*non è l'unico*):
  - **concentrazione di energia** in spazio circoscritto ⇒
    - **potere risolutivo** adatto a grandezze sub-nucleari
    - **creazione particelle** trasformando energia cinetica in massa

⇒ **collisioni** tra fasci altamente collimati di protoni ad alta energia!

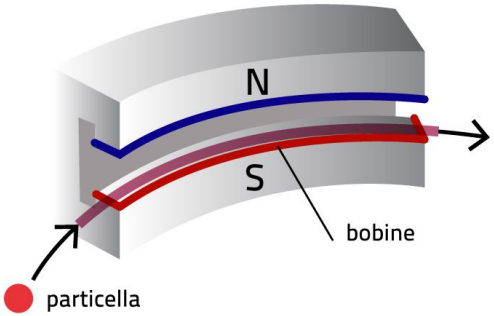


Accelerare particelle

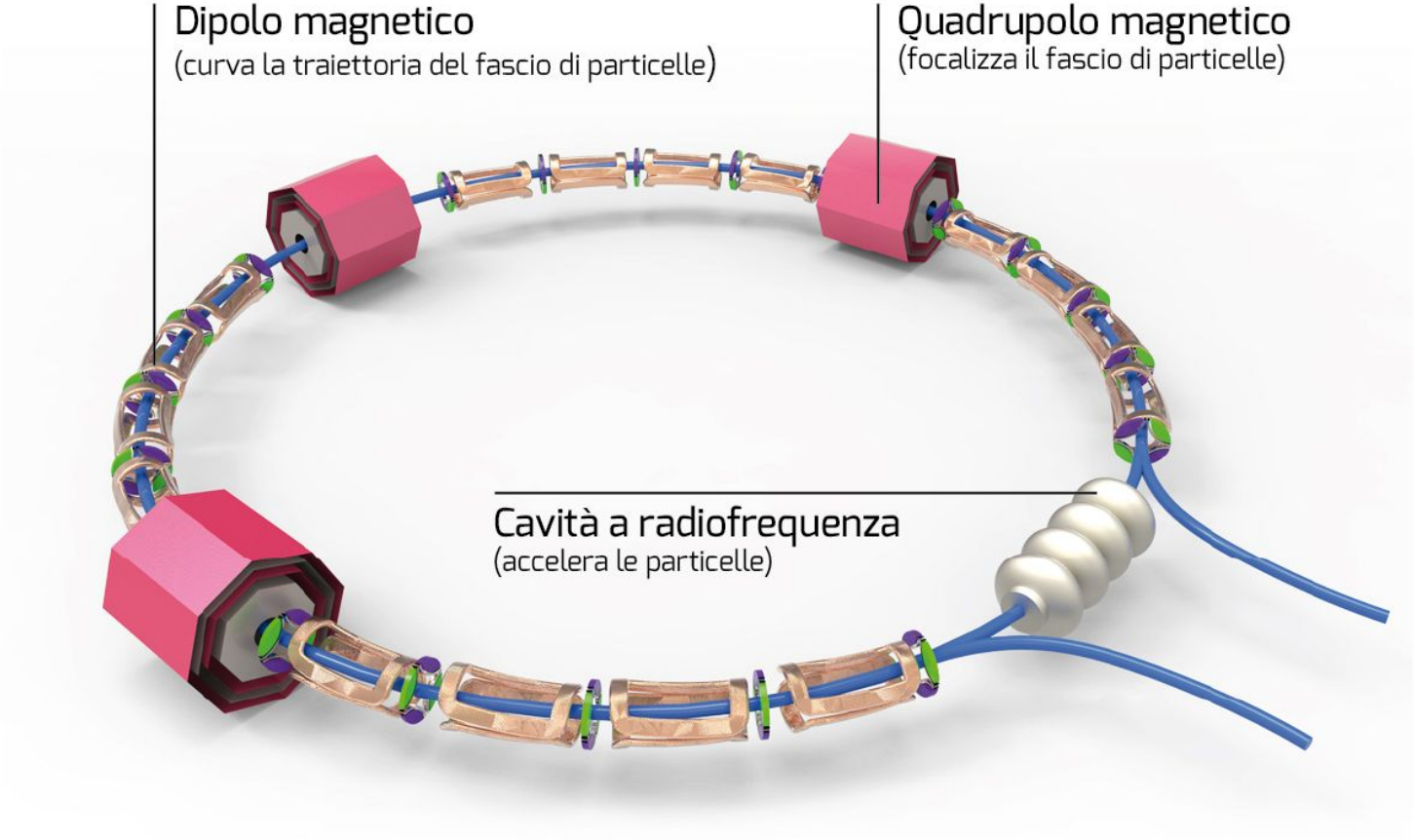
- Come accelerare particelle?
  - campo elettrico



- Come mantenerle in circolo?
  - campo magnetico



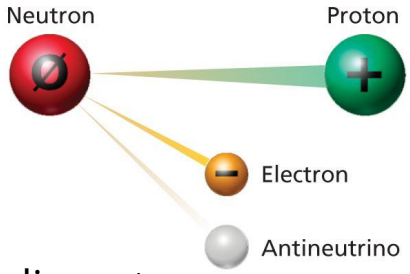
Collisionatori



Decadimenti

- Possiamo produrre ***particelle interessanti*** (pesanti) da collisioni ad alta energia

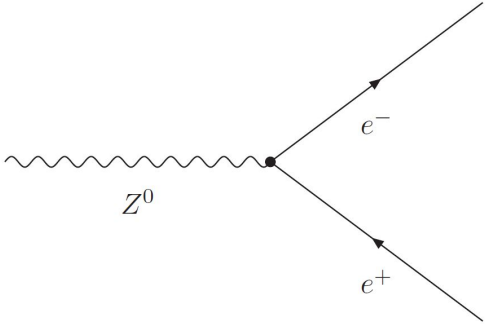
- Queste **decadono** *immediatamente* (= dopo 3×10^{-25}s !) in altre particelle…
  - decadimenti **conservano**:
    - **numeri quantici** (carica elettrica, numero leptonico e barionico, etc…)
    - **energia** e **quantità di moto** (“*quadri-momento*”)



⇒ Possiamo ***ricostruire*** particella madre dai prodotti di decadimento

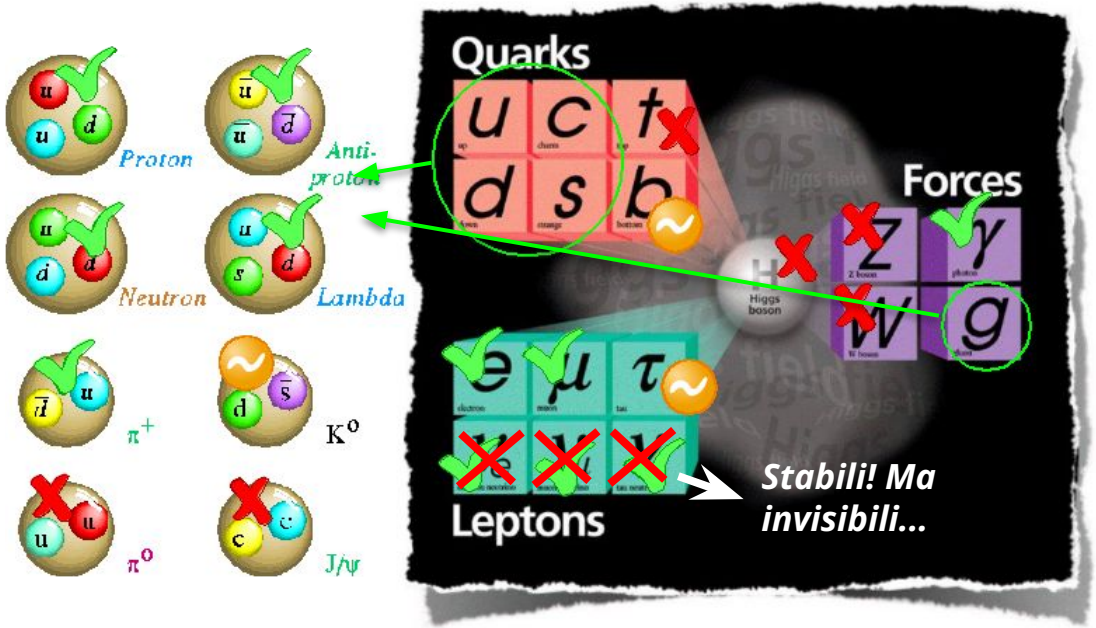
$$x_1 + x_2 = x_0$$

quadri-momenti



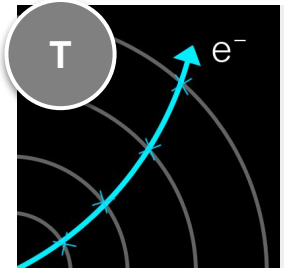
Cosa possiamo vedere?

- Solo poche particelle sono **stabili** o **quasi stabili**
  (i.e. possono percorrere distanze misurabili prima di decadere)



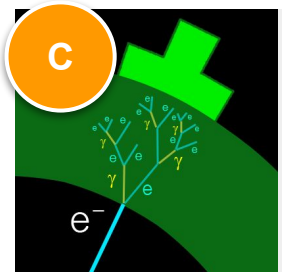
- I **rivelatori di particelle** puntano a identificare e misurare queste particelle

... e come?



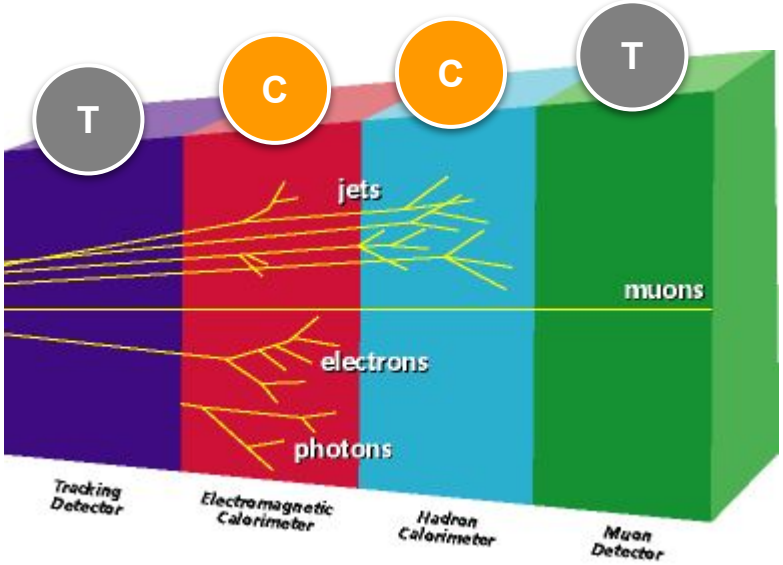
Tracciatori:

- idea = misurare la **traiettoria** (in campo magnetico) e estrarne ***quantità di moto***

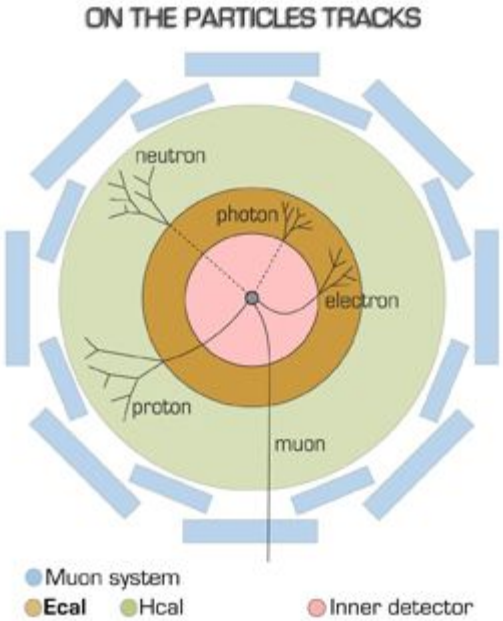


Calorimetri:

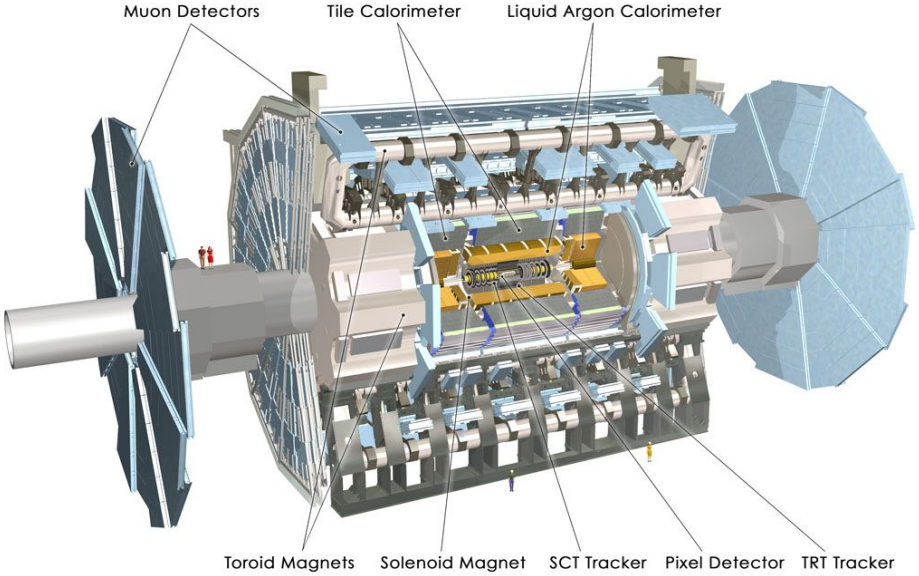
- idea = **fermare** particelle e misurarne l'***energia*** (cinetica)

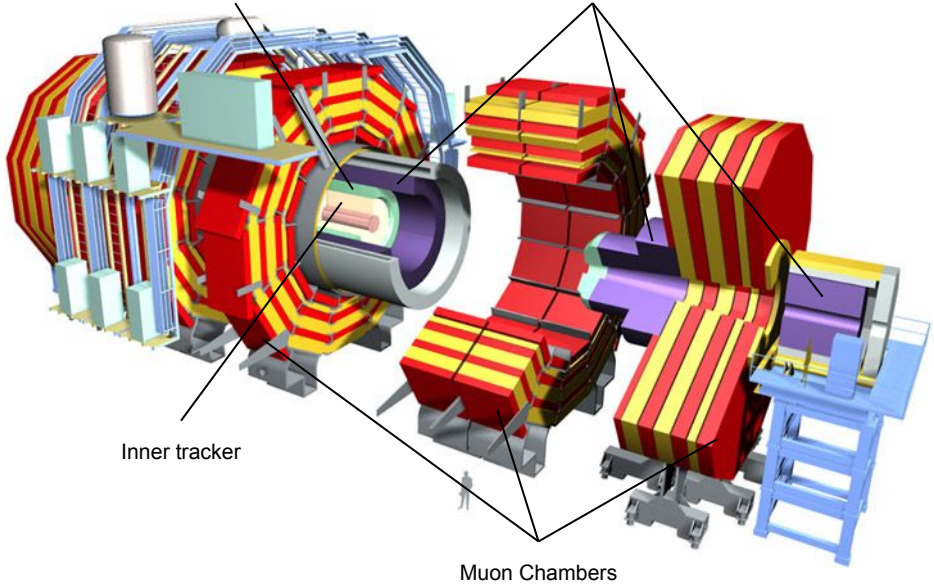


Struttura a cipolla!

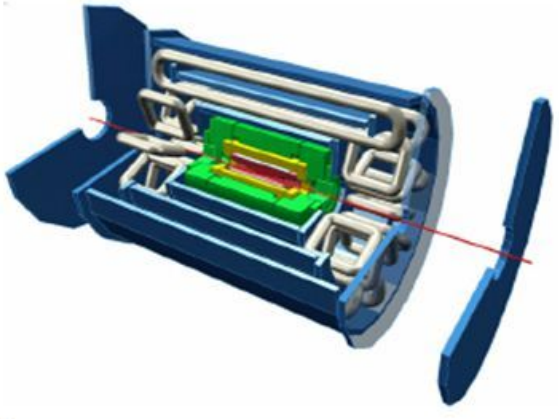


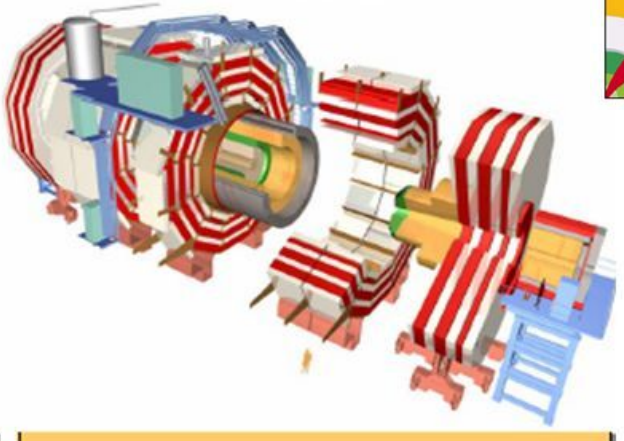
La struttura dei rivelatori

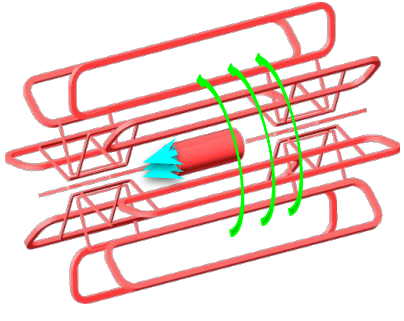


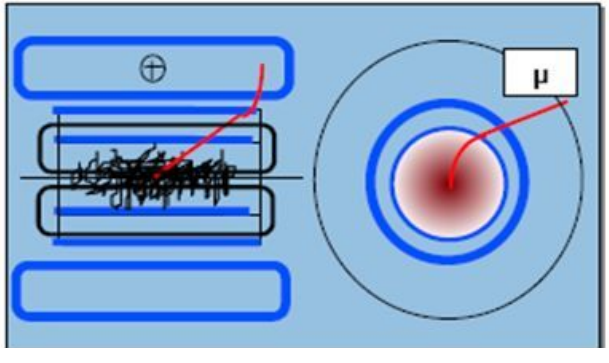


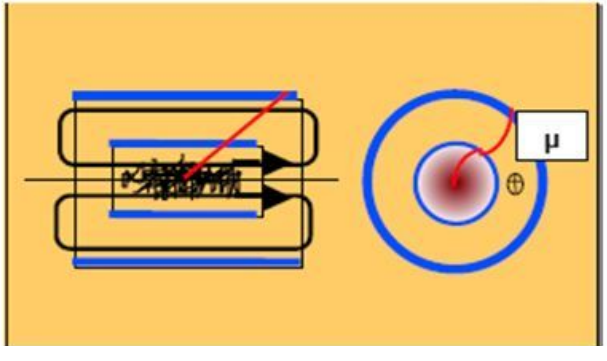
Sistema di Magneti



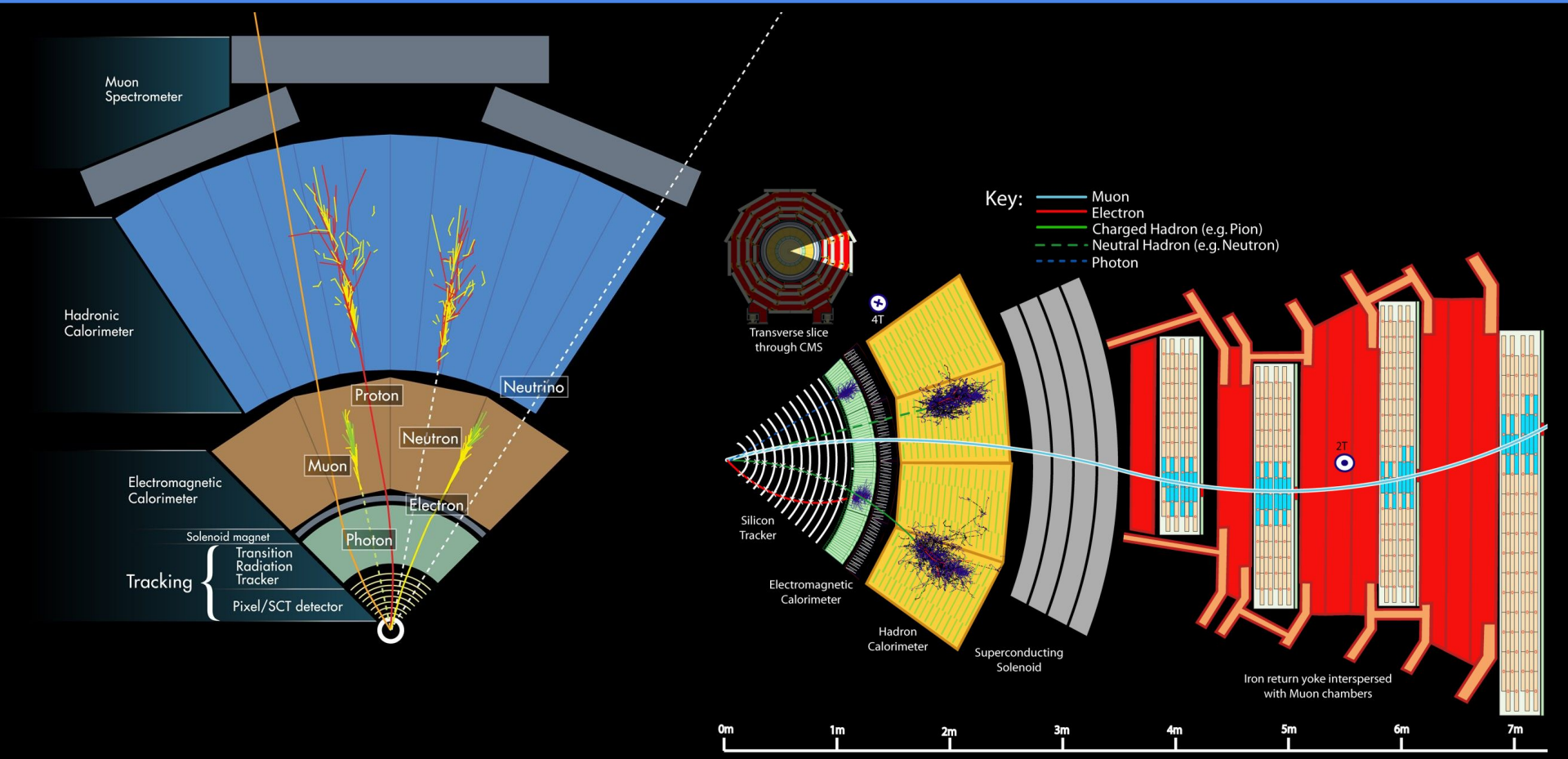




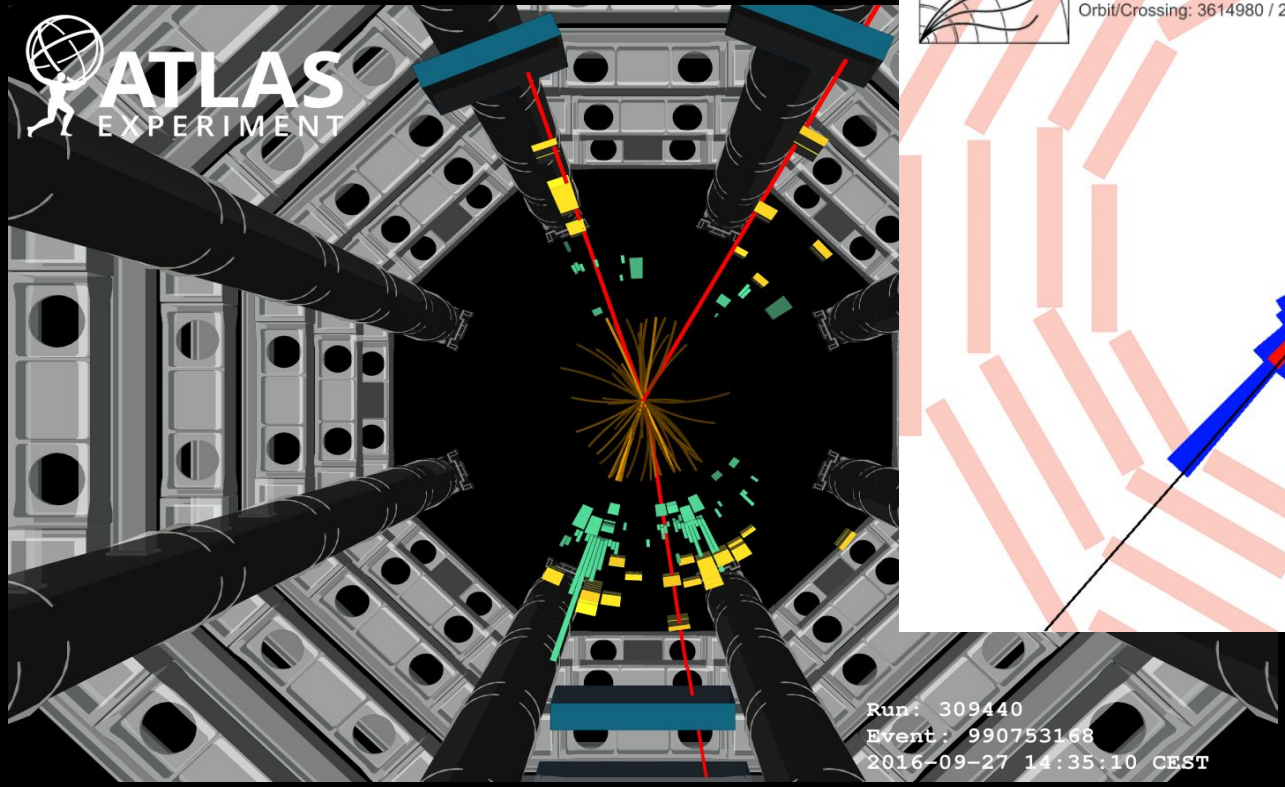


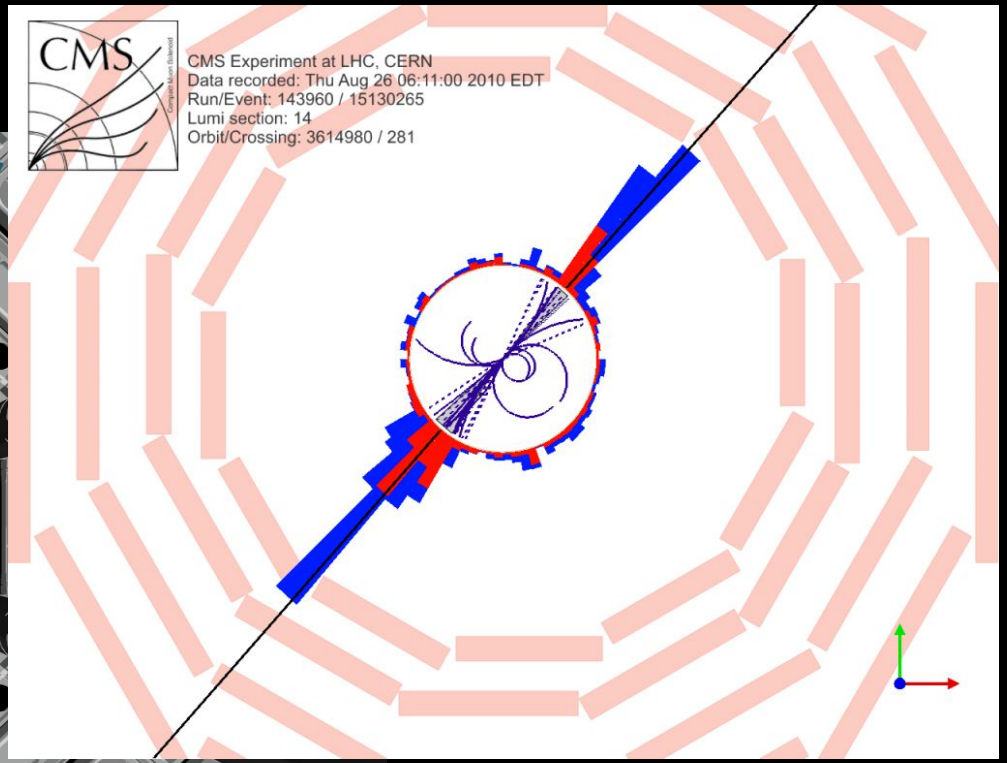


Identificazione delle particelle



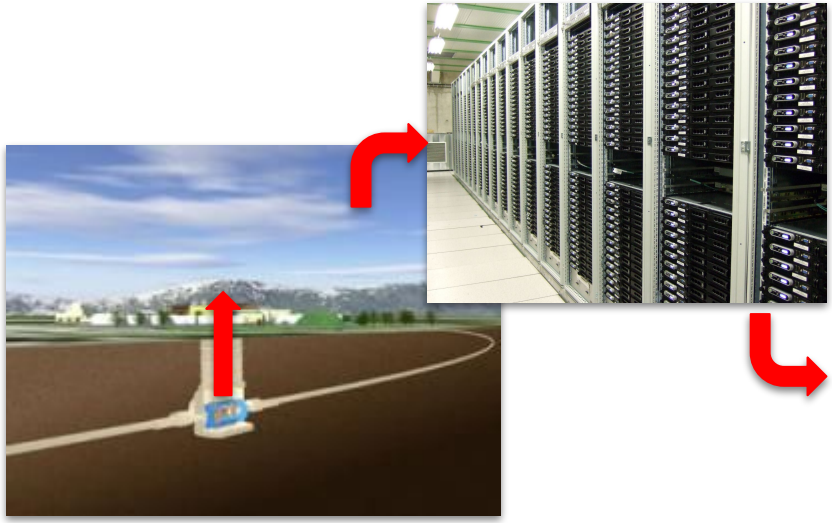
Eventi di collisione “ricostruiti”

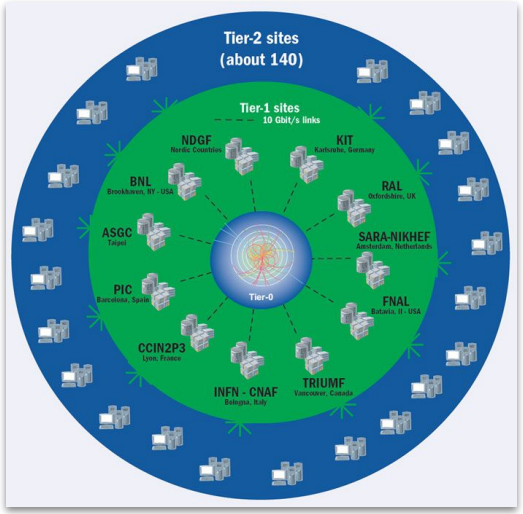


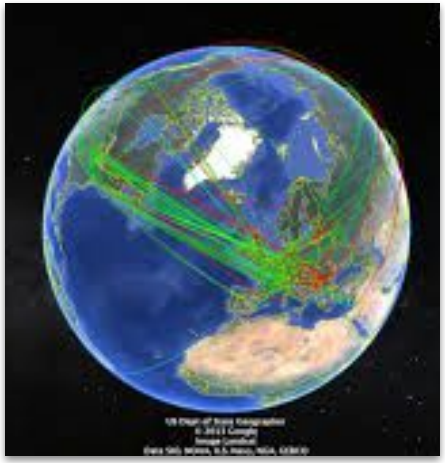


Trigger e flusso di dati

- Sistema di “**trigger**”:
  - seleziona in tempo reale solo i dati “**interessanti**”:
    ~1 miliardo di collisioni /sec (~60 TB/sec...) → ~1000 /sec
- Dati registrati e **distribuiti** tramite la “GRID”
  - per ricostruzione e analisi
    in > 100 centri di calcolo in tutto il mondo







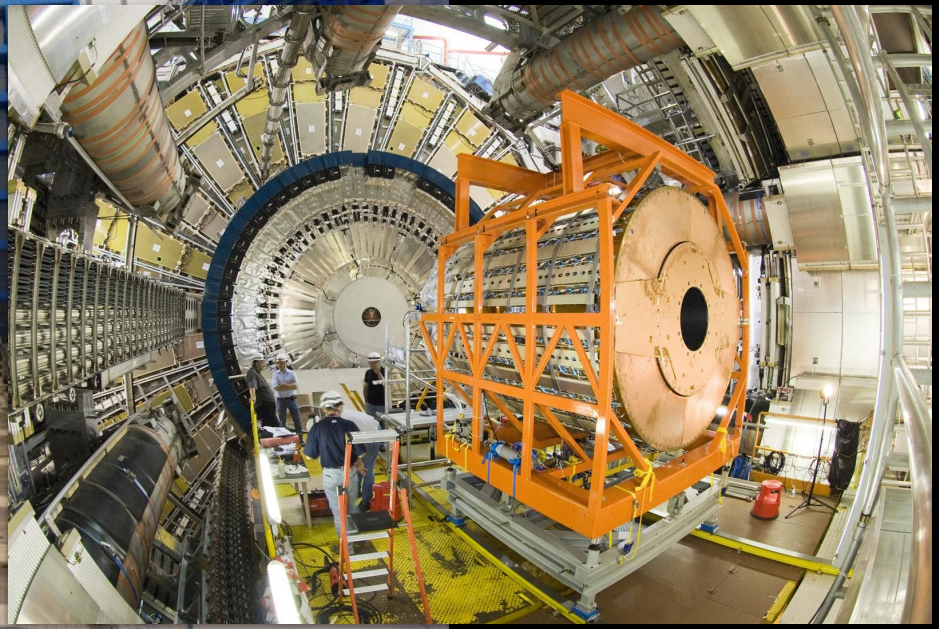
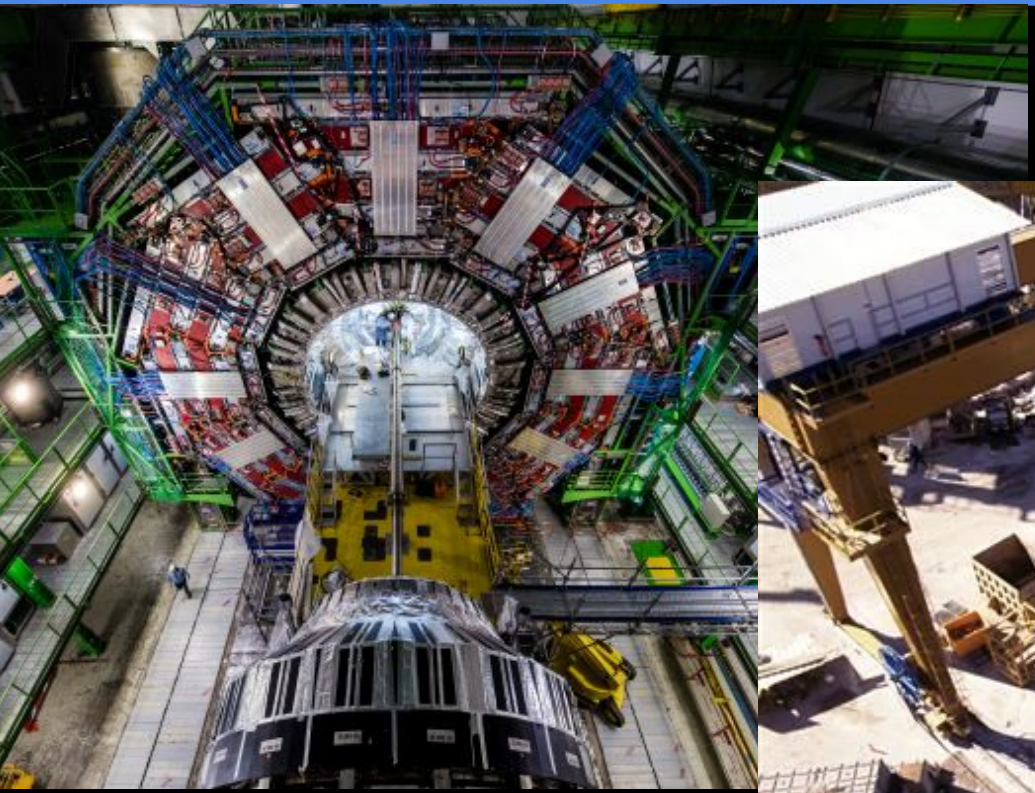
Le collaborazioni Sperimentali

ATLAS EXPERIMENT

3000	183	38	1200
Scientific authors	Institutions	Countries	Doctoral students

CMS

ATLAS in costruzione



CMS in costruzione