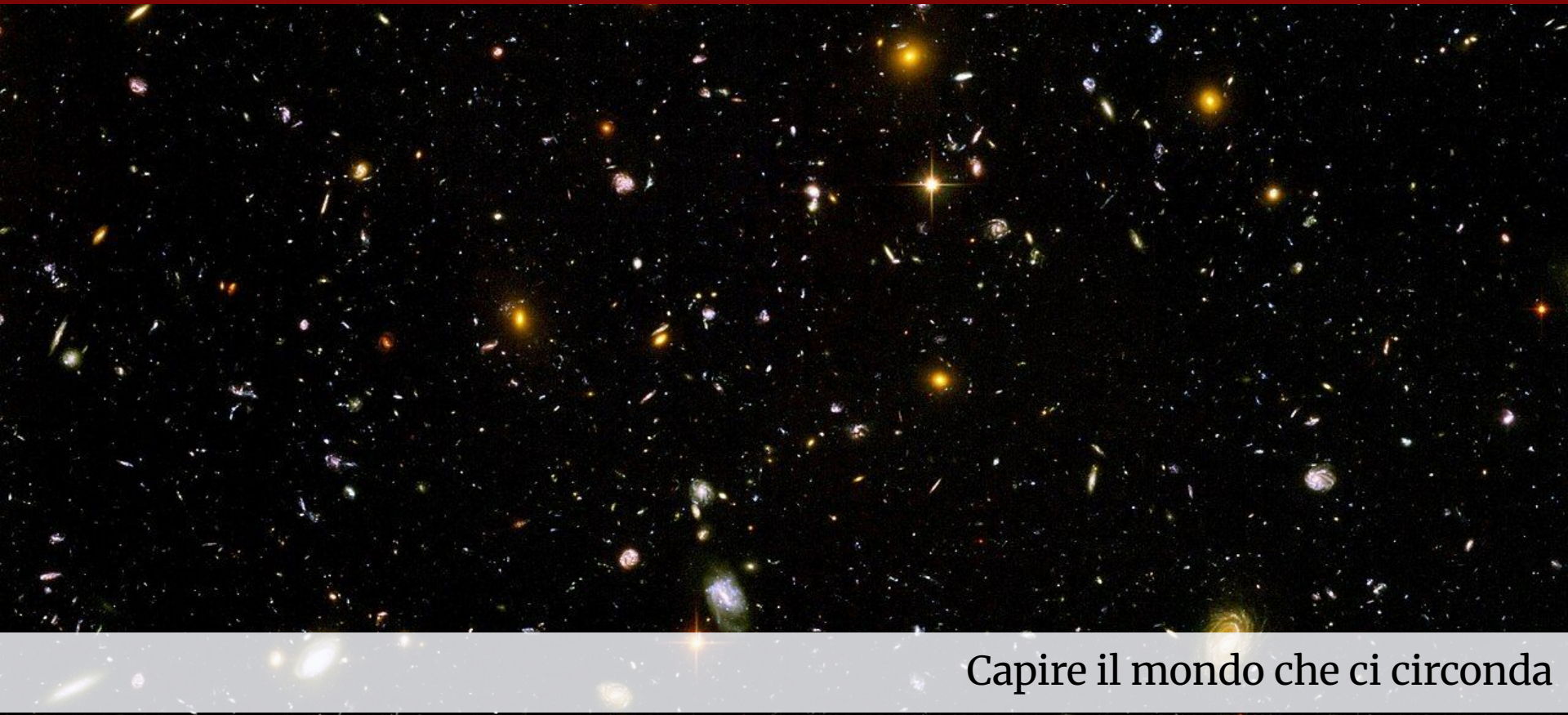
IL PUZZLE DELL'UNIVERSO:
alla ricerca dei pezzi mancanti a LHC



Sonia Carrà

ATLAS EXPERIMENT
UNIVERSITÀ DI PAVIA
INFN PAVIA

Il mestiere del fisico



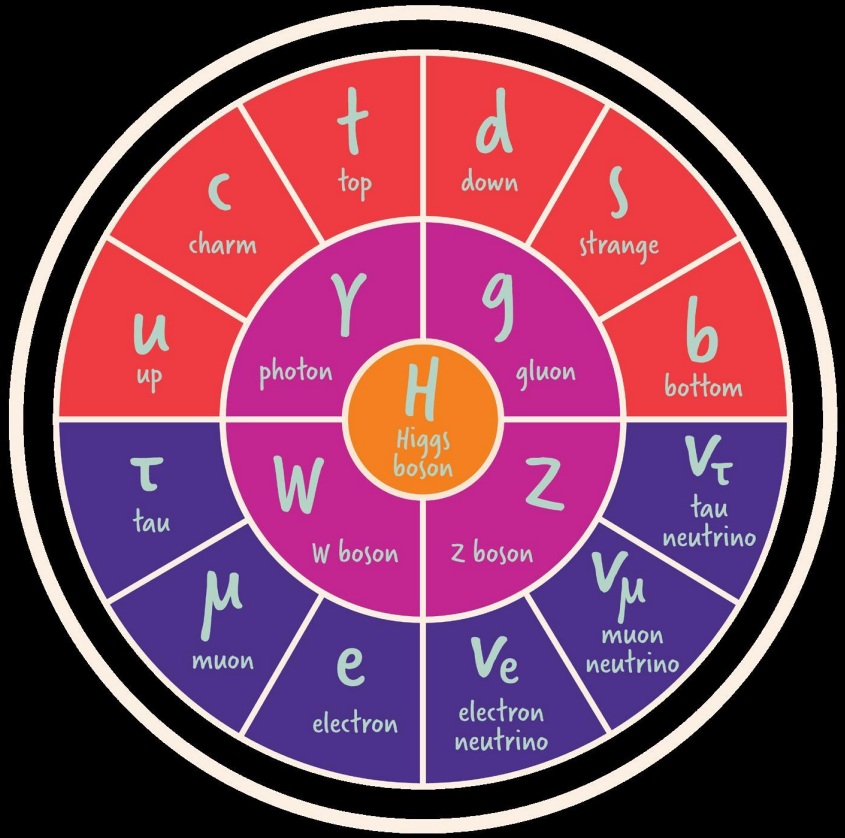
Capire il mondo che ci circonda

Da cosa è composto l'universo?

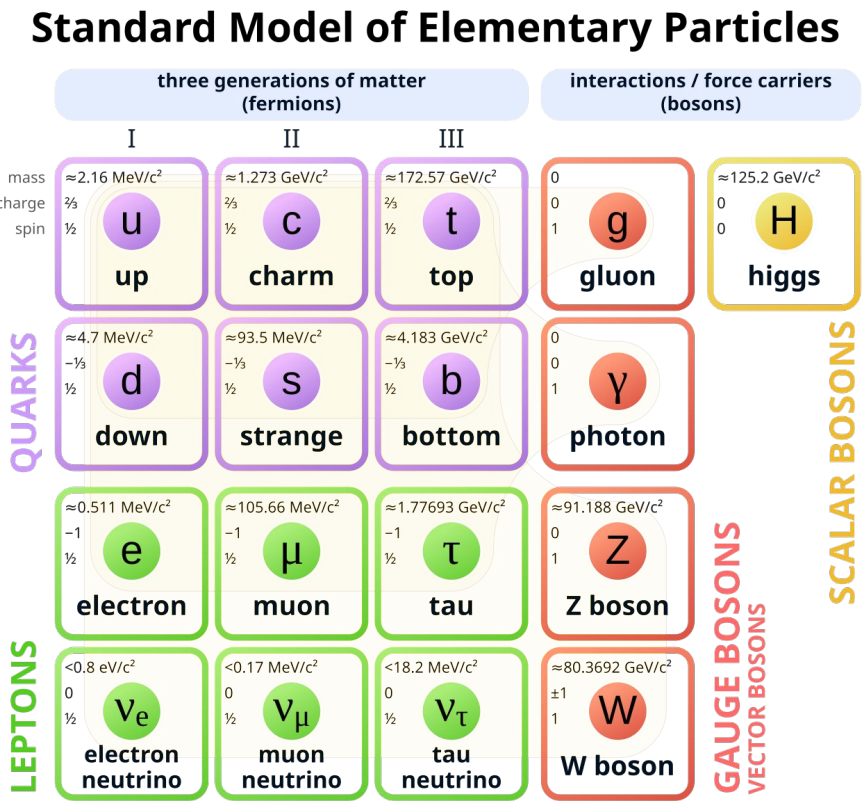


Comprendere il molto grande a partire dal molto piccolo

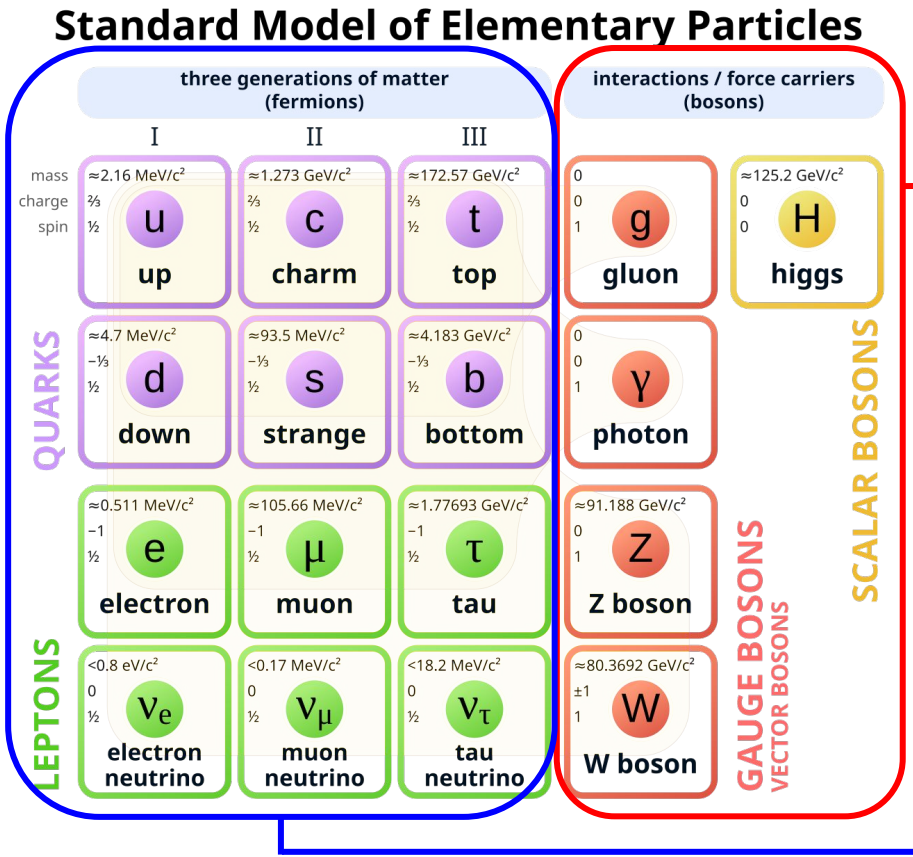
Particelle elementari...



… descritte dal Modello Standard



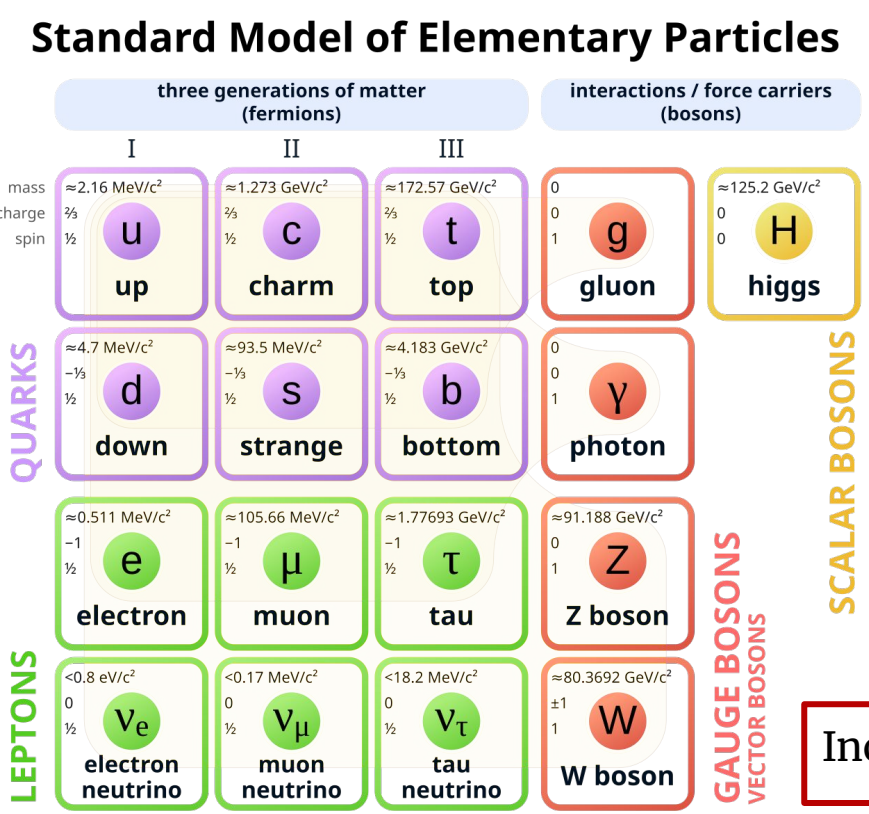
… descritte dal Modello Standard

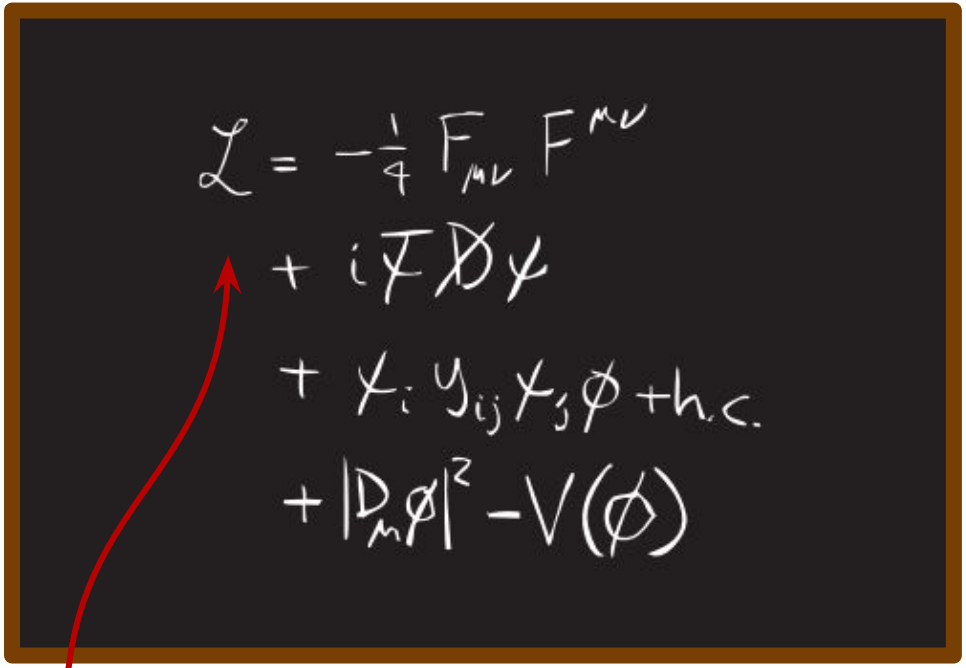


Spin 1 o 0, bosoni

Spin ½, fermioni

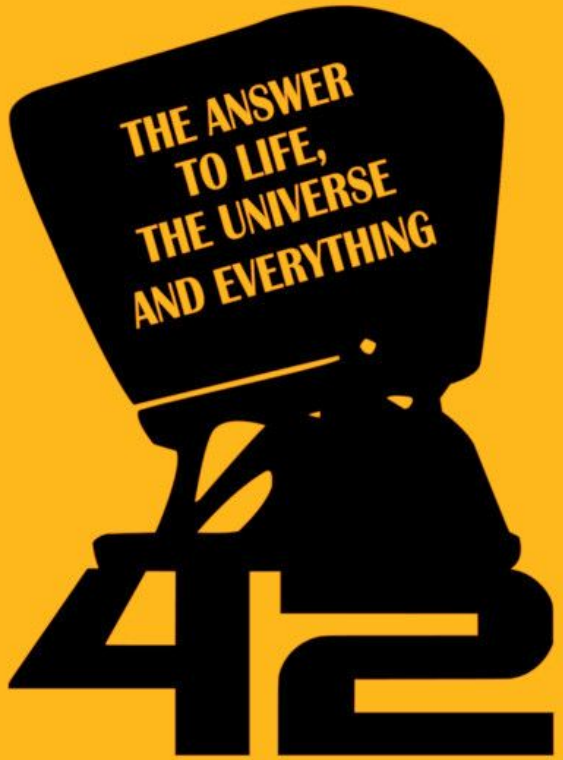
… descritte dal Modello Standard



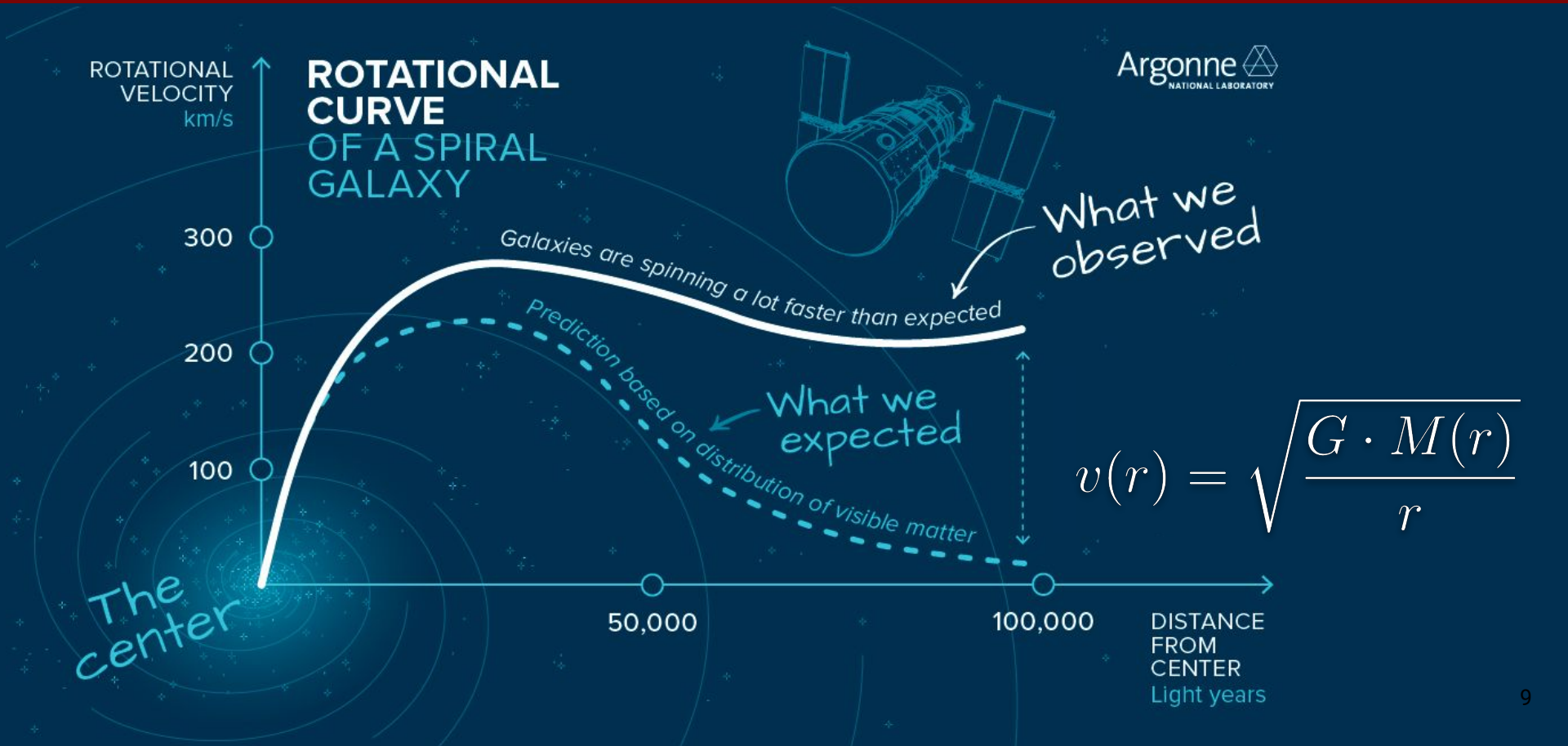


Include interazione forte, debole ed elettromagnetica!

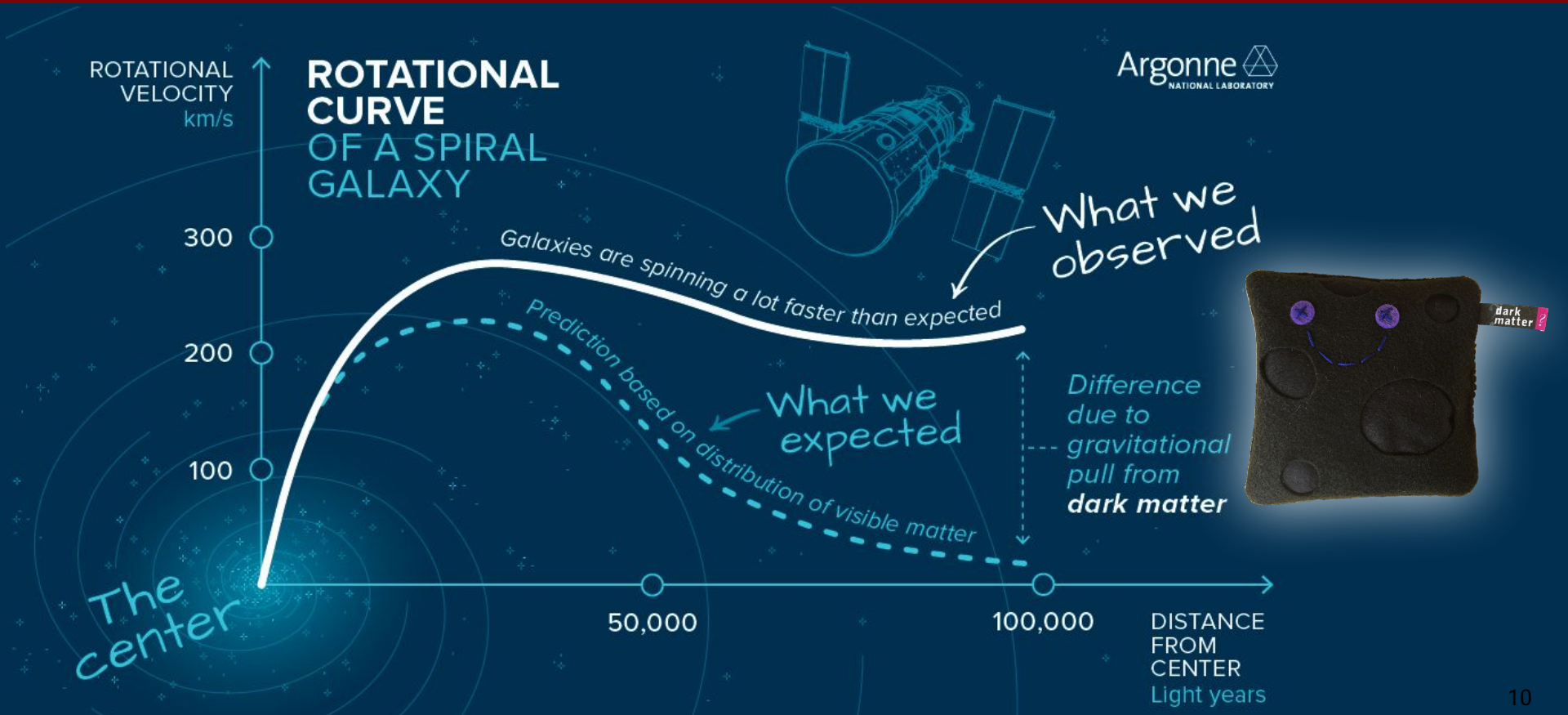
Siamo ora in grado di descrivere l’universo?



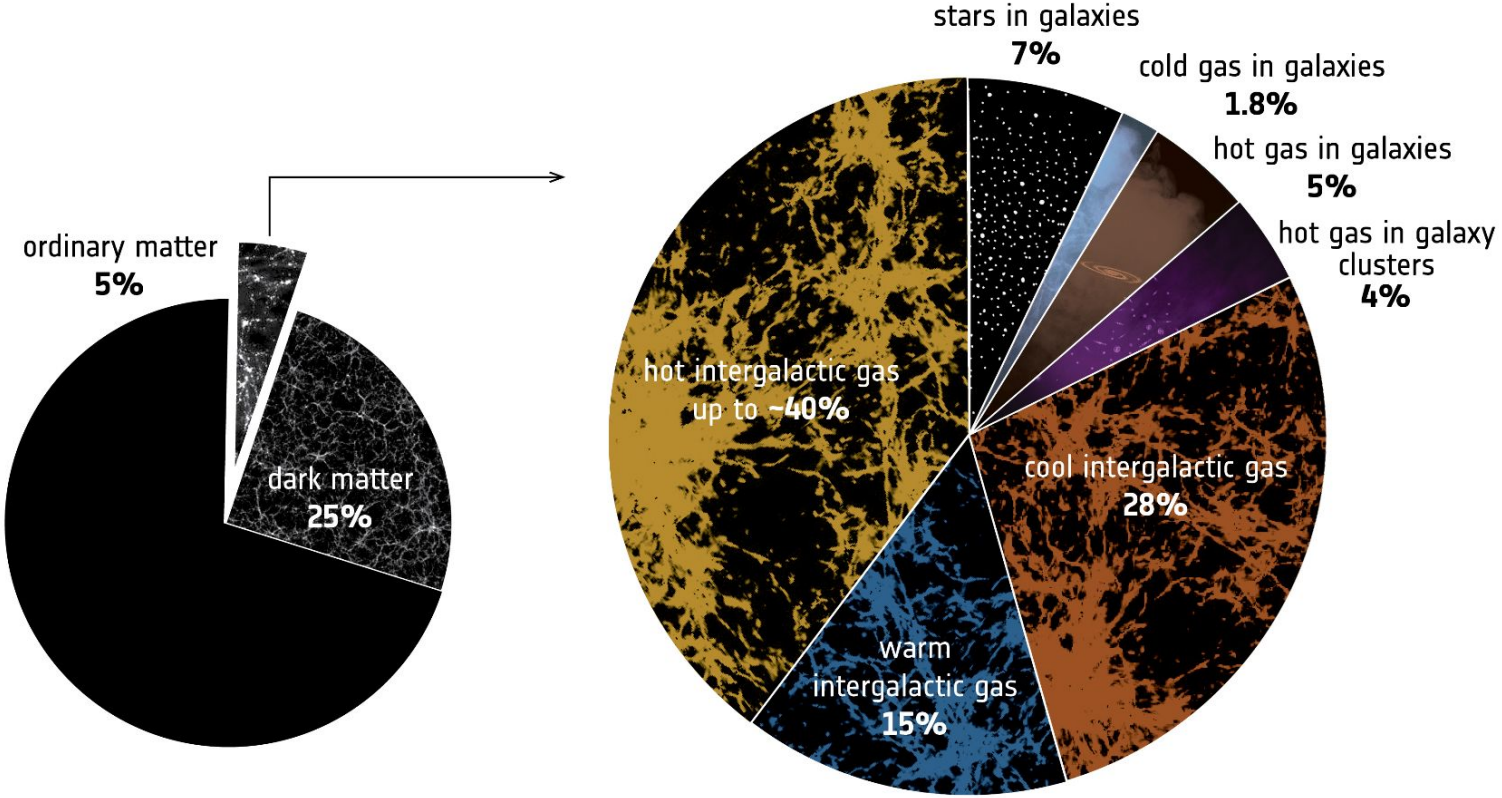
Purtroppo no!



Purtroppo no!

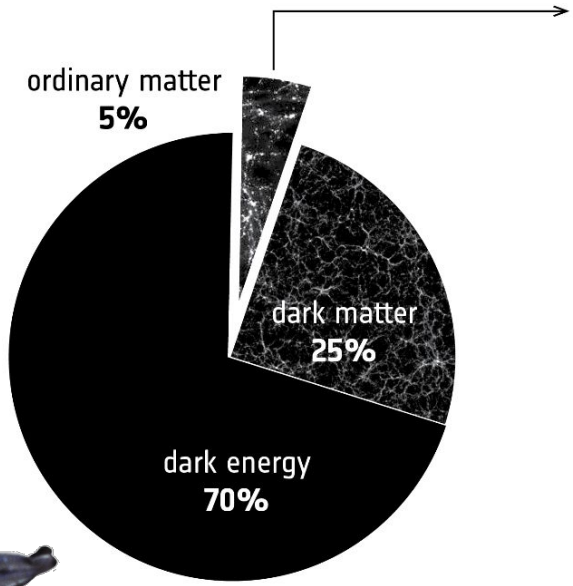


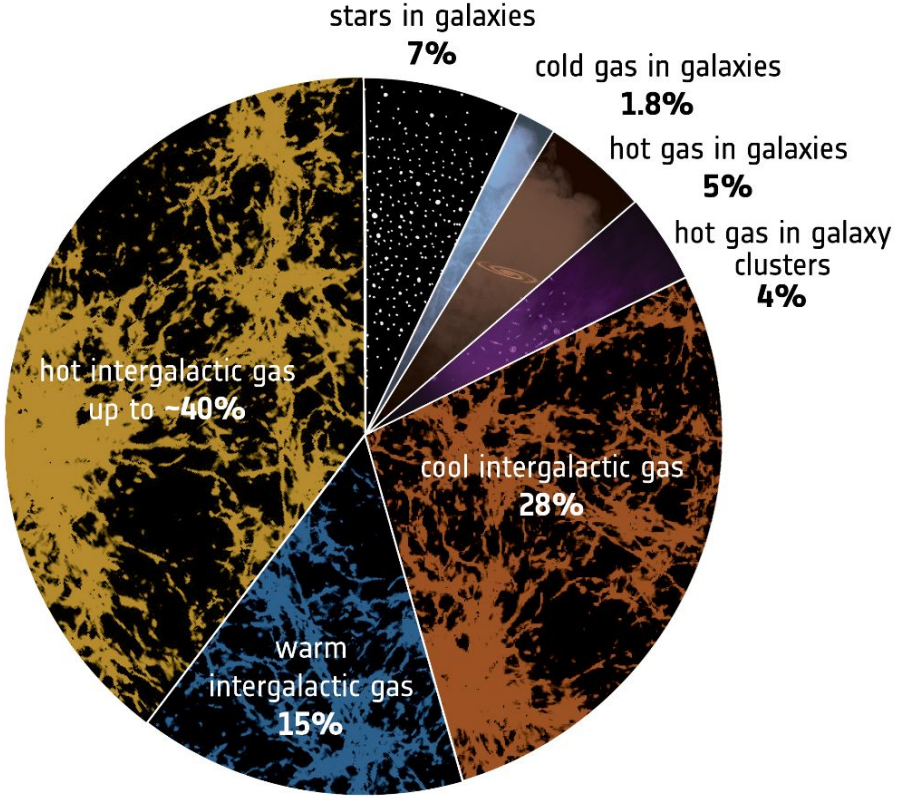
Materia oscura



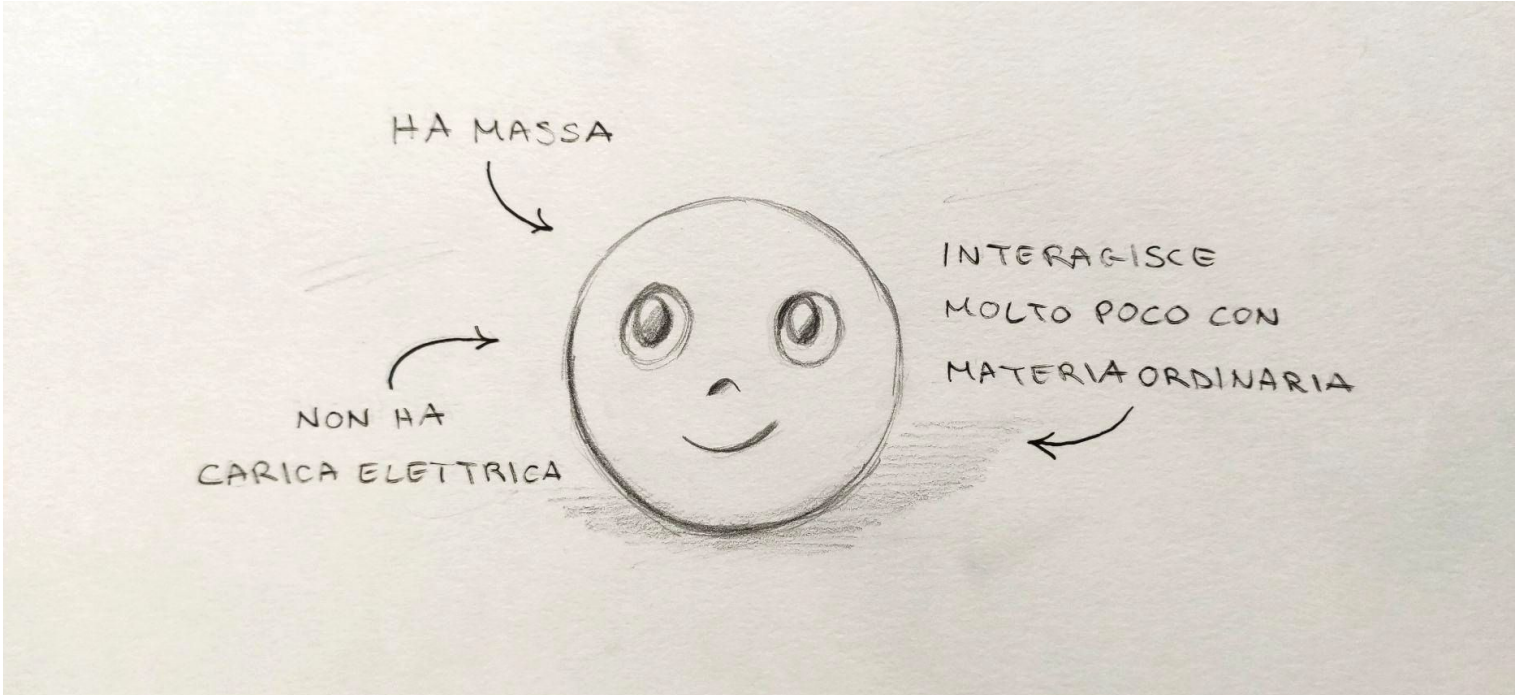
Materia oscura e energia oscura



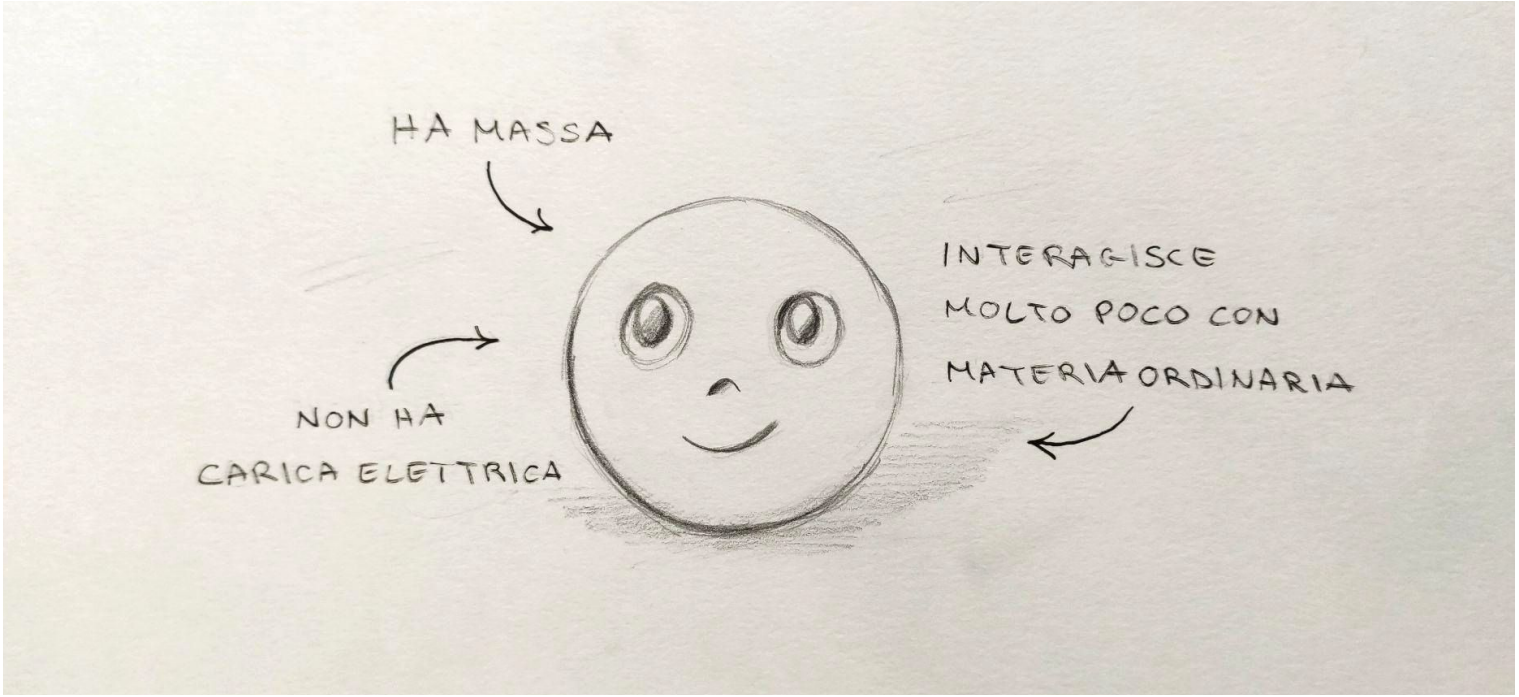




Materia oscura: identikit



Materia oscura: identikit



Non abbiamo una particella simile nel Modello Standard!

Domande aperte

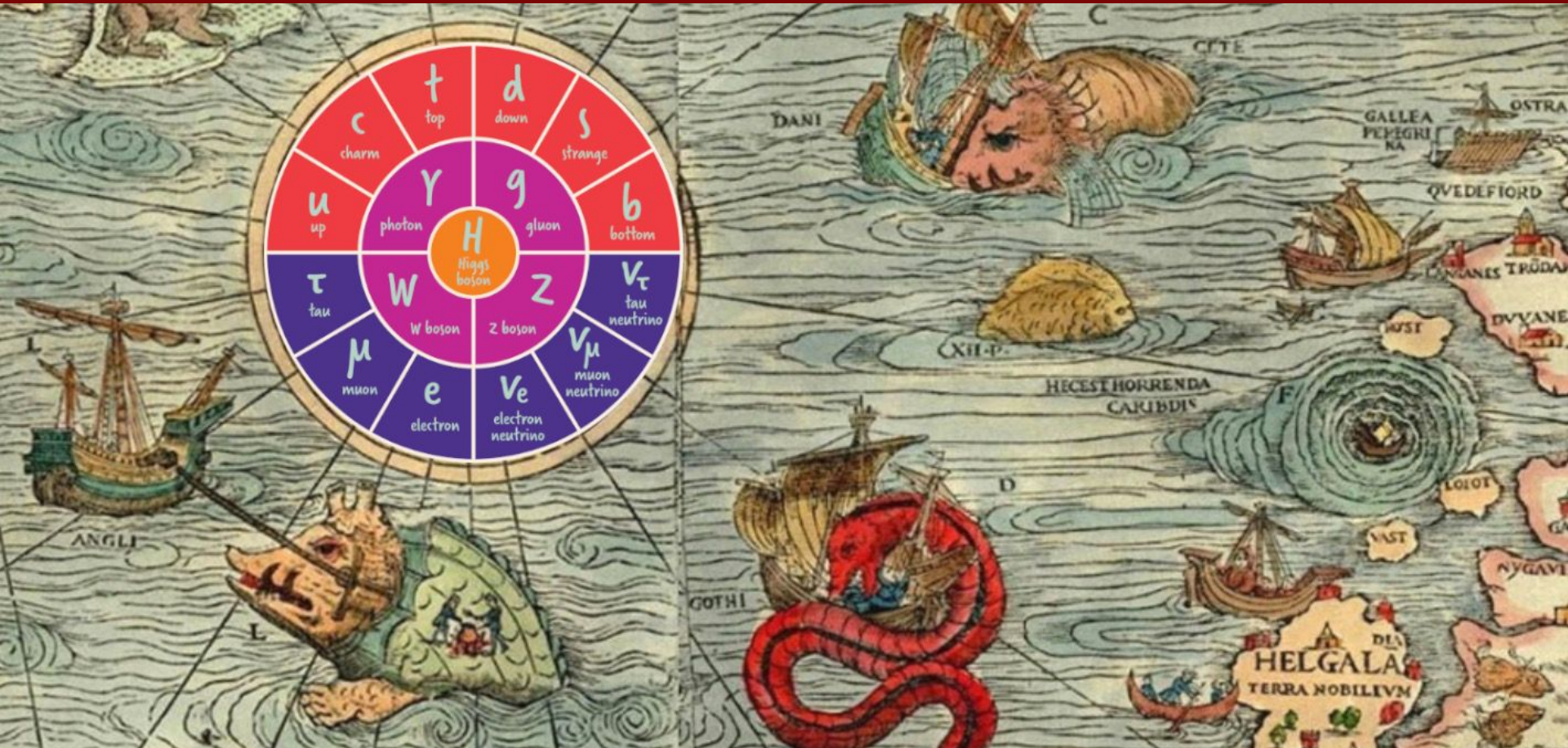
Il Modello Standard delle particelle **non** spiega:

- natura della materia oscura
- massa dei neutrini
- interazione gravitazionale
- … e altro!



→ Il nostro modello non è completo

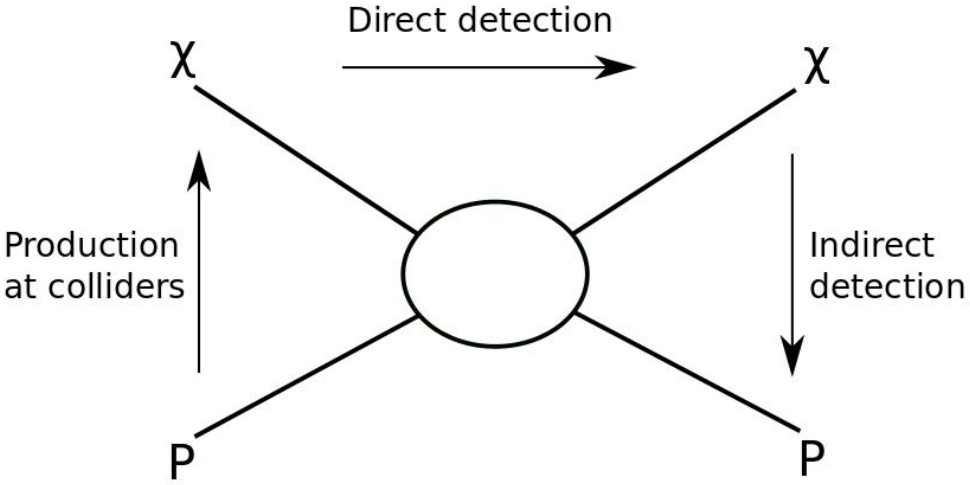
Hic sunt dracones



Che strumenti abbiamo per l'esplorazione?



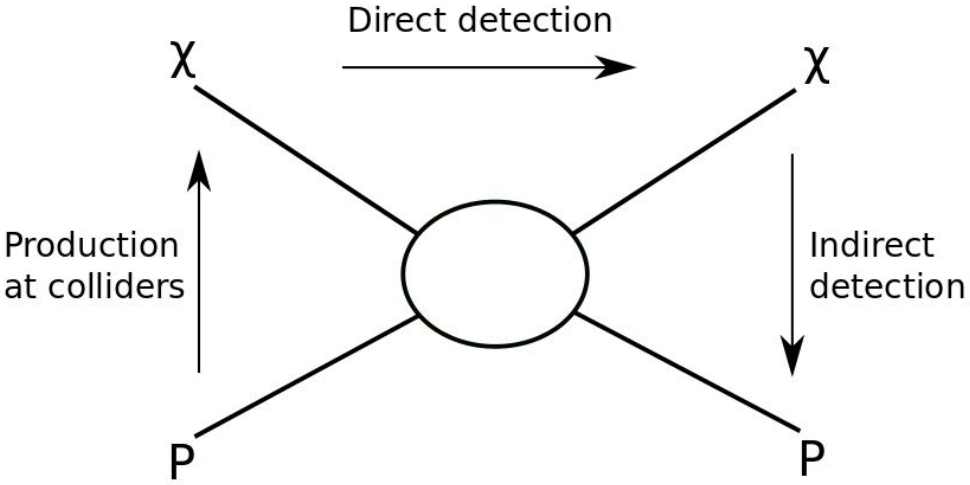
- Osservazione diretta di materia oscura che interagisce con materia ordinaria
- Osservazione indiretta di annichilazione di materia oscura



Che strumenti abbiamo per l'esplorazione?



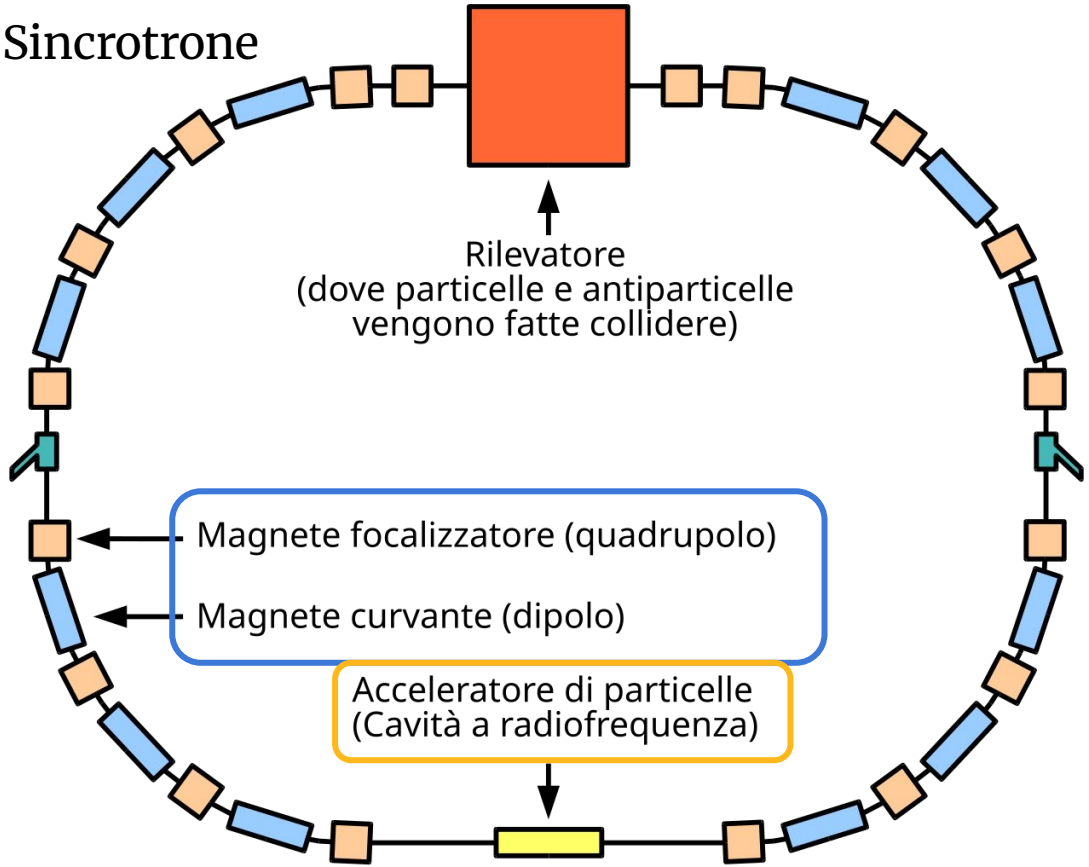
- Osservazione diretta di materia oscura che interagisce con materia ordinaria
- Osservazione indiretta di annichilazione di materia oscura



Produzione in laboratorio

→ acceleratori di particelle!

Acceleratori di particelle



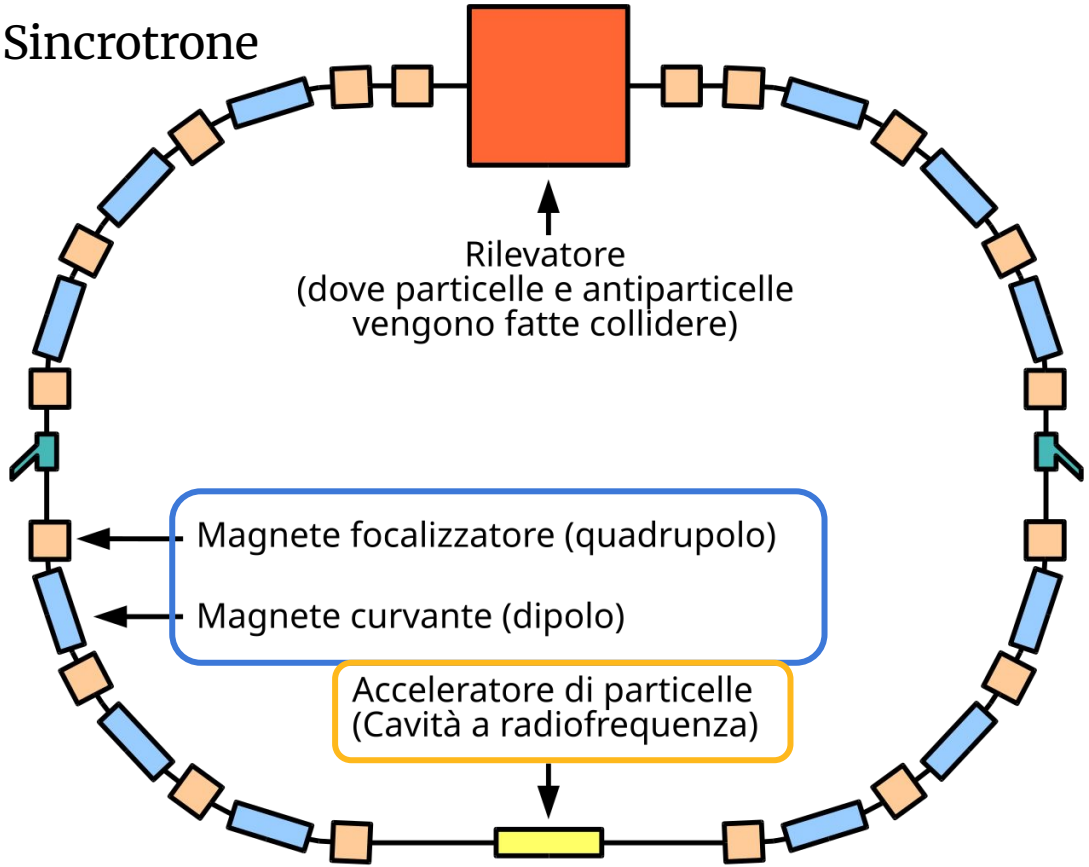
Forza di Lorentz:

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

Energia particelle:

$$E \sim q\,R\,B$$

Acceleratori di particelle



Forza di Lorentz:

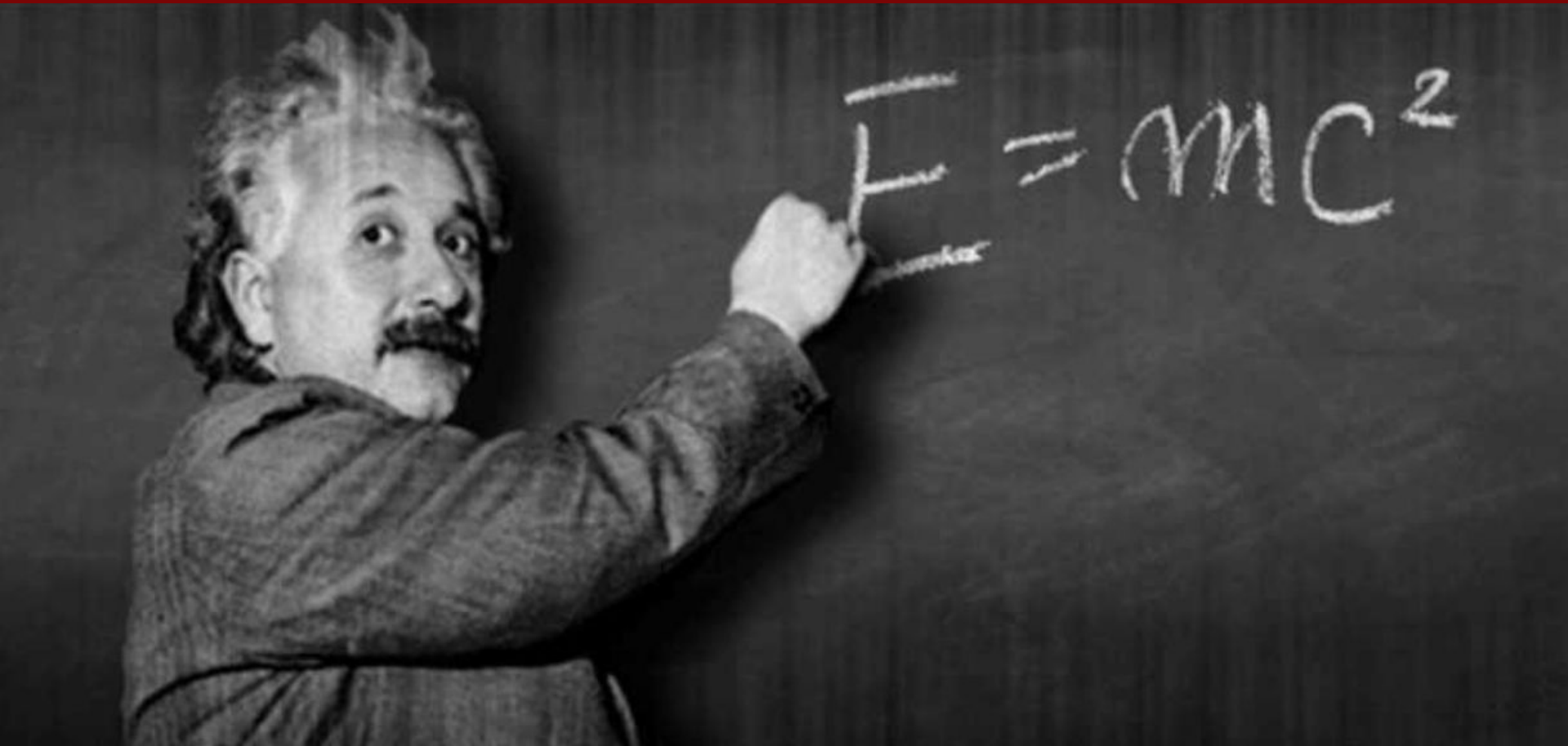
$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

Energia particelle:

$$E \sim q\,R\,B$$

Ma perchè alte energie?

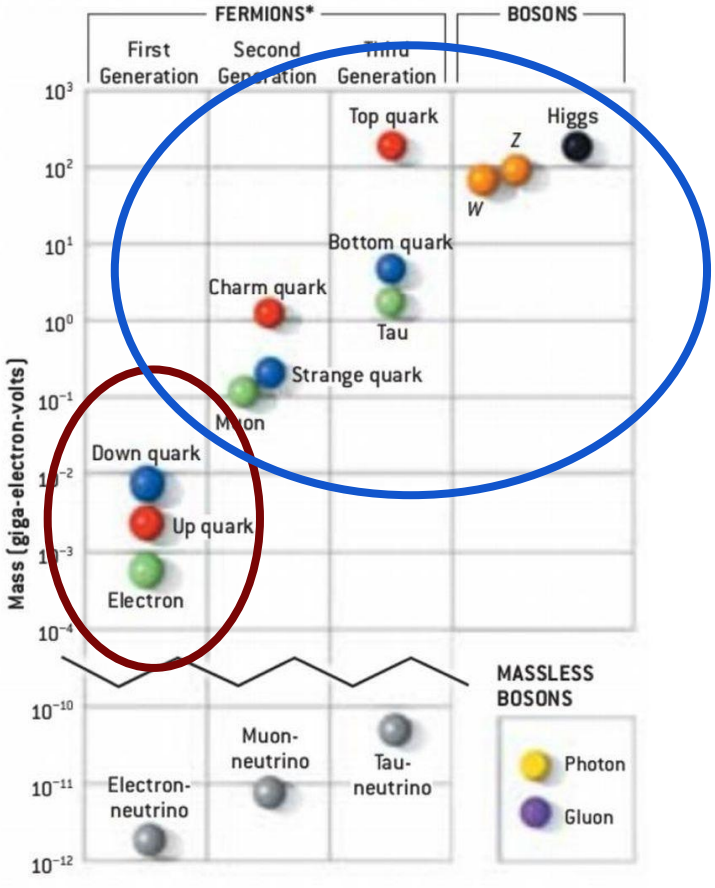
Fisica delle alte energie



Le masse del Modello Standard

Fisica delle alte energie:
massa espressa in eV

$1\ eV = 1.6 \times 10^{-19}\ J$

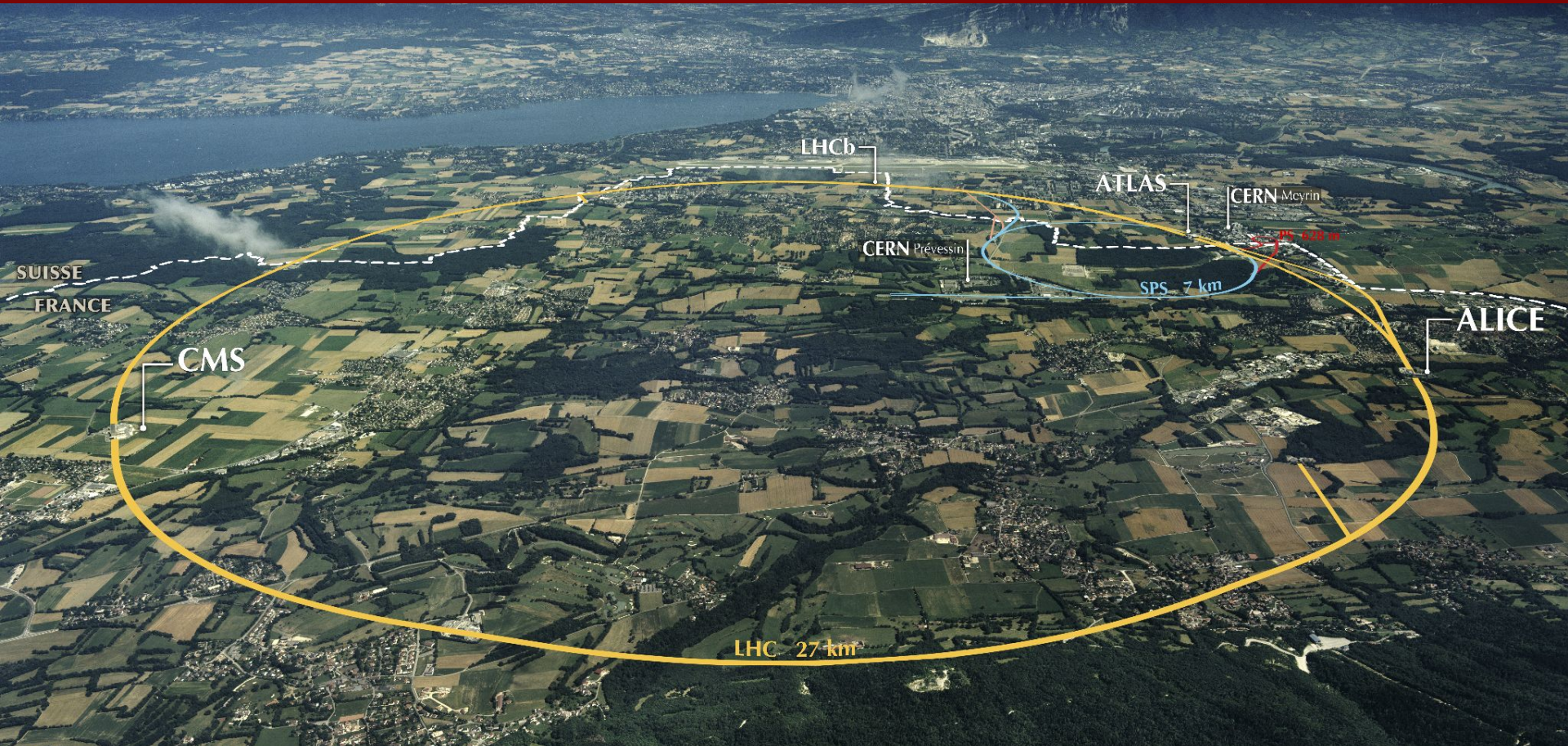


Particelle prodotte agli acceleratori

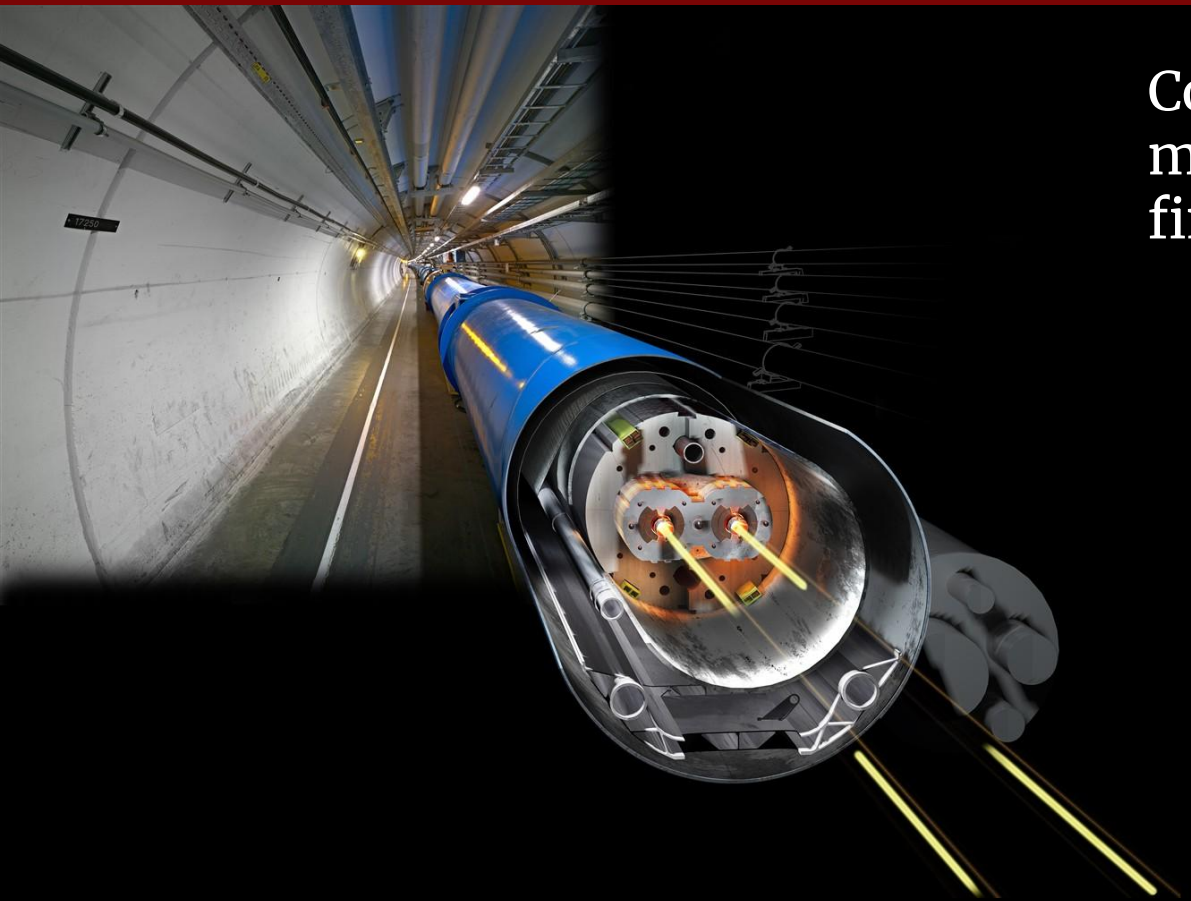
Bosone di Higgs
~ 125 GeV

Materia ordinaria
Protone ~ 1 GeV
Elettrone ~ 0.5 MeV

Large Hadron Collider @ CERN

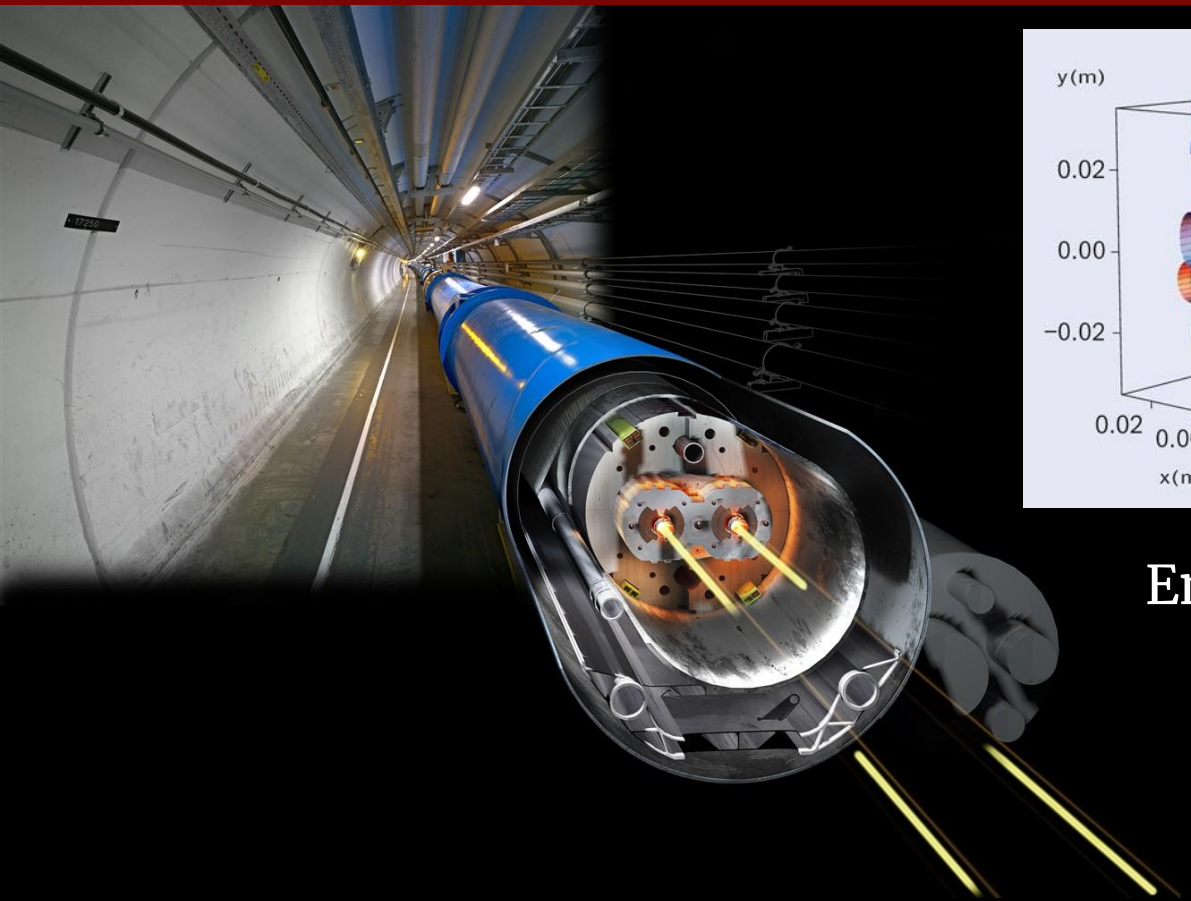


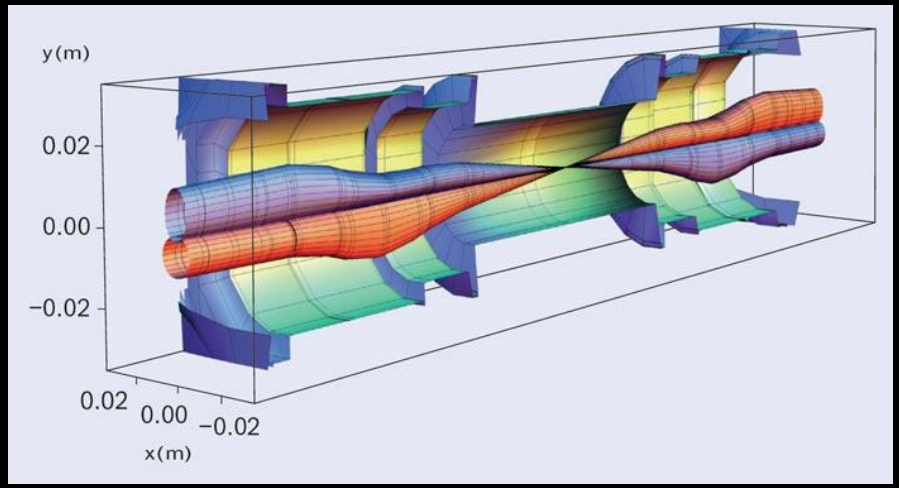
Large Hadron Collider @ CERN



Collisioni protoni-protoni,
ma anche di ioni pesanti,
fino al piombo!

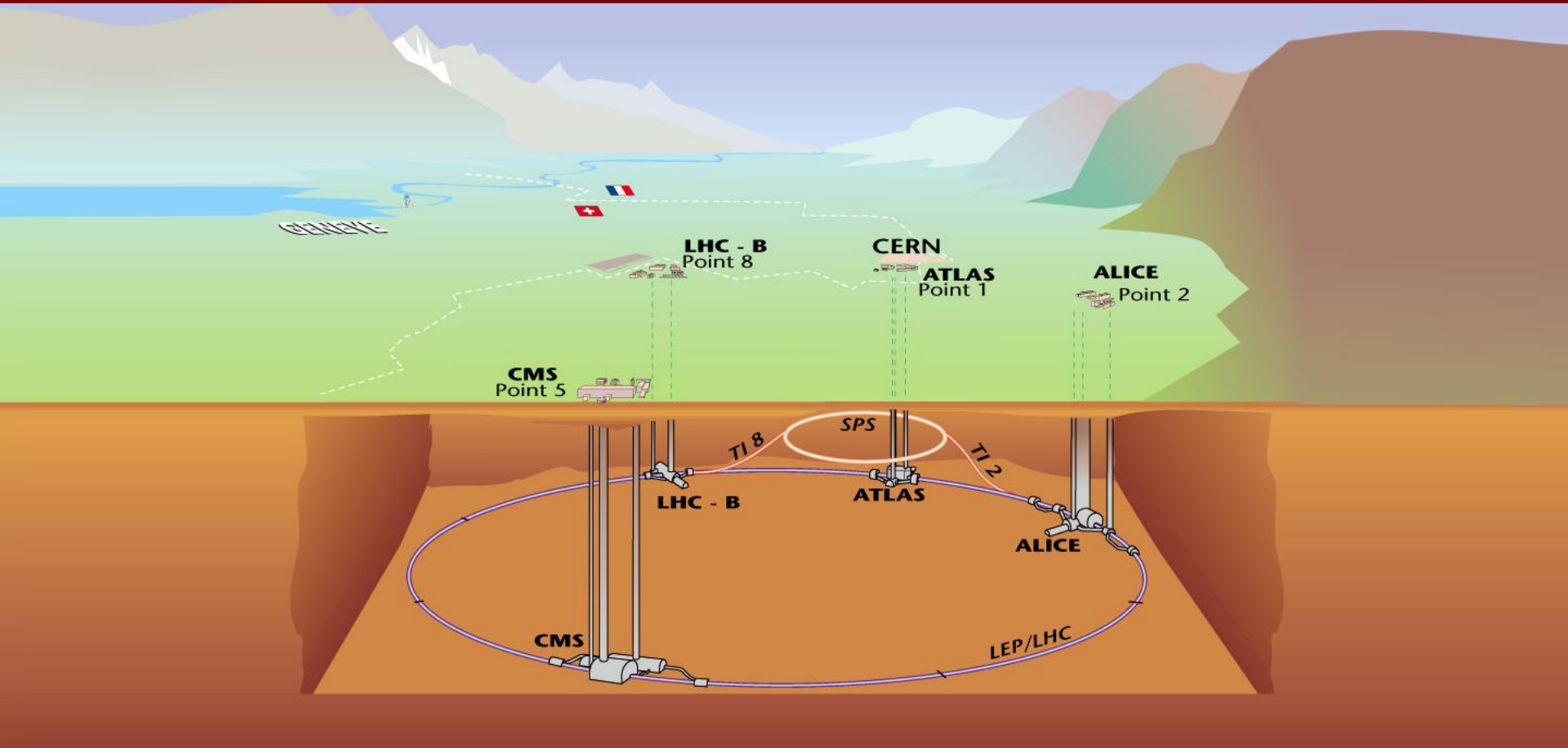
Large Hadron Collider @ CERN



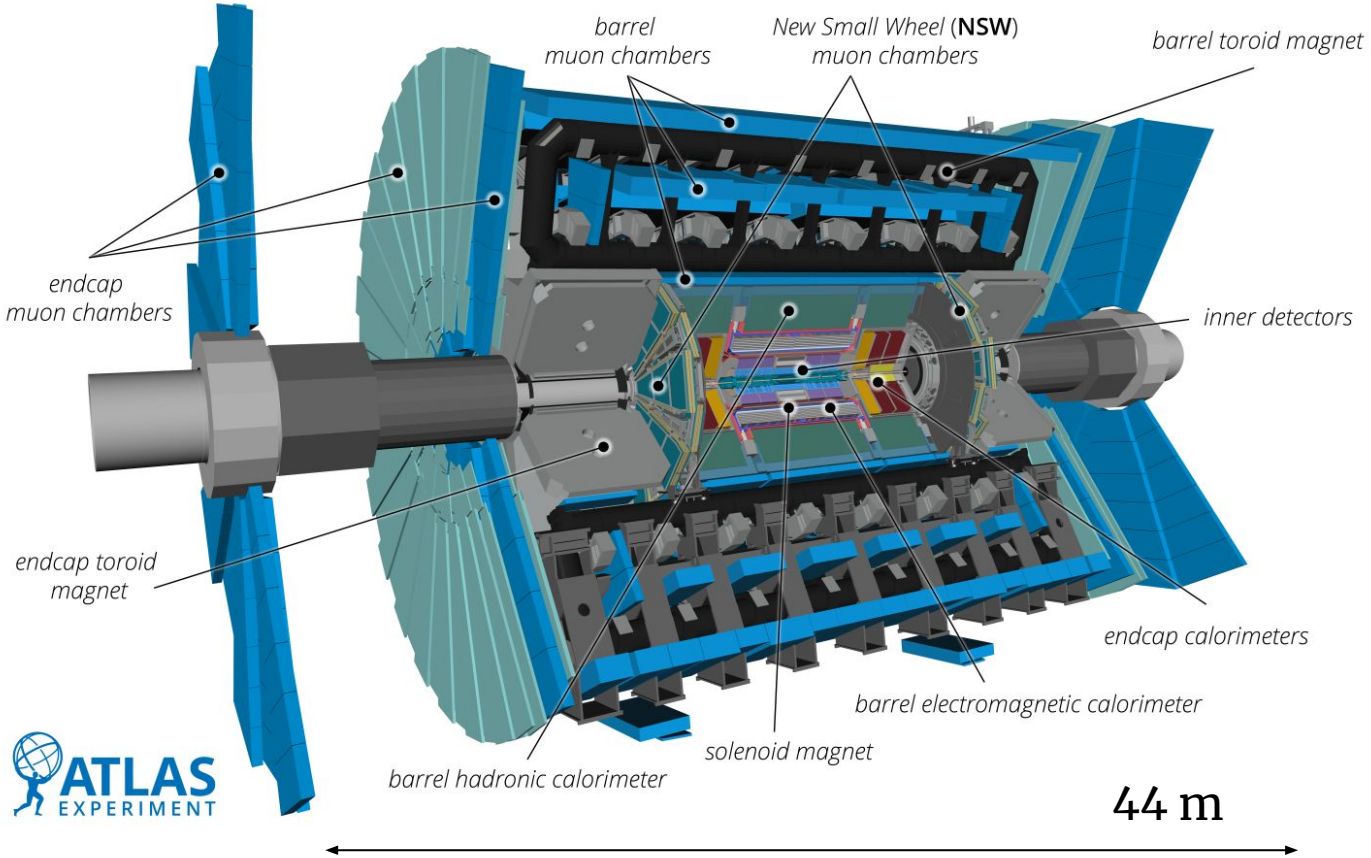


Energia nel centro di massa:
13.6 TeV

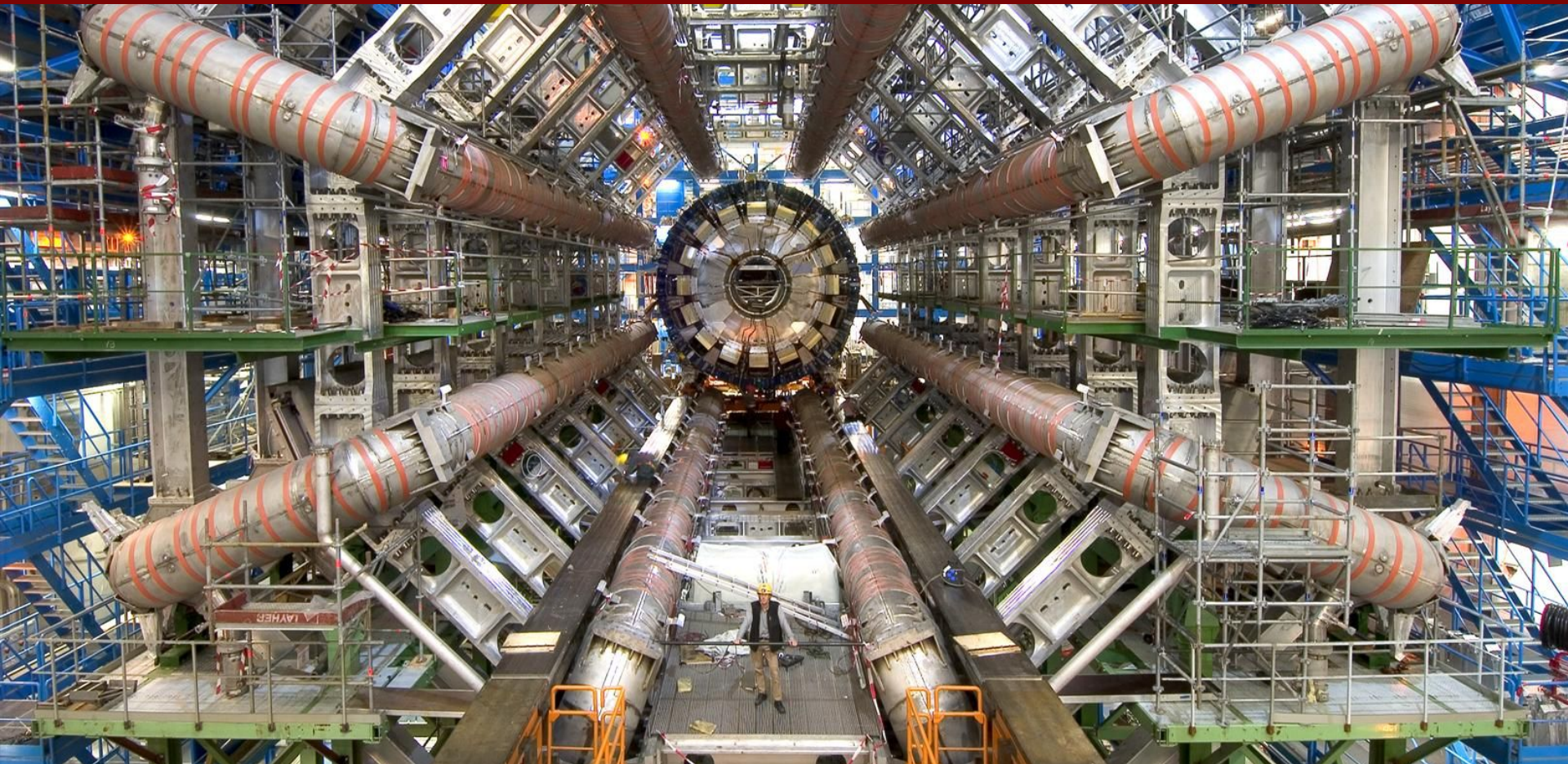
Punti di collisione dei fasci



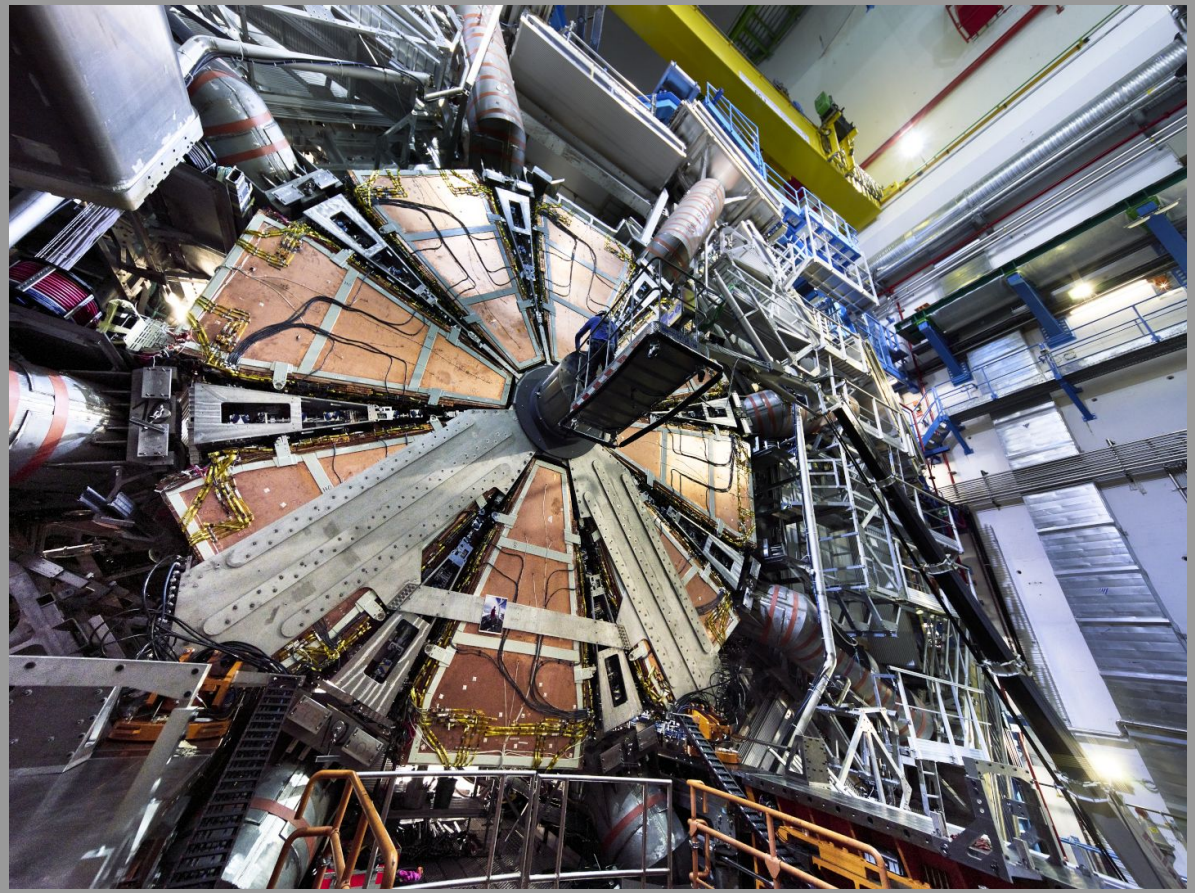
Esperimento ATLAS



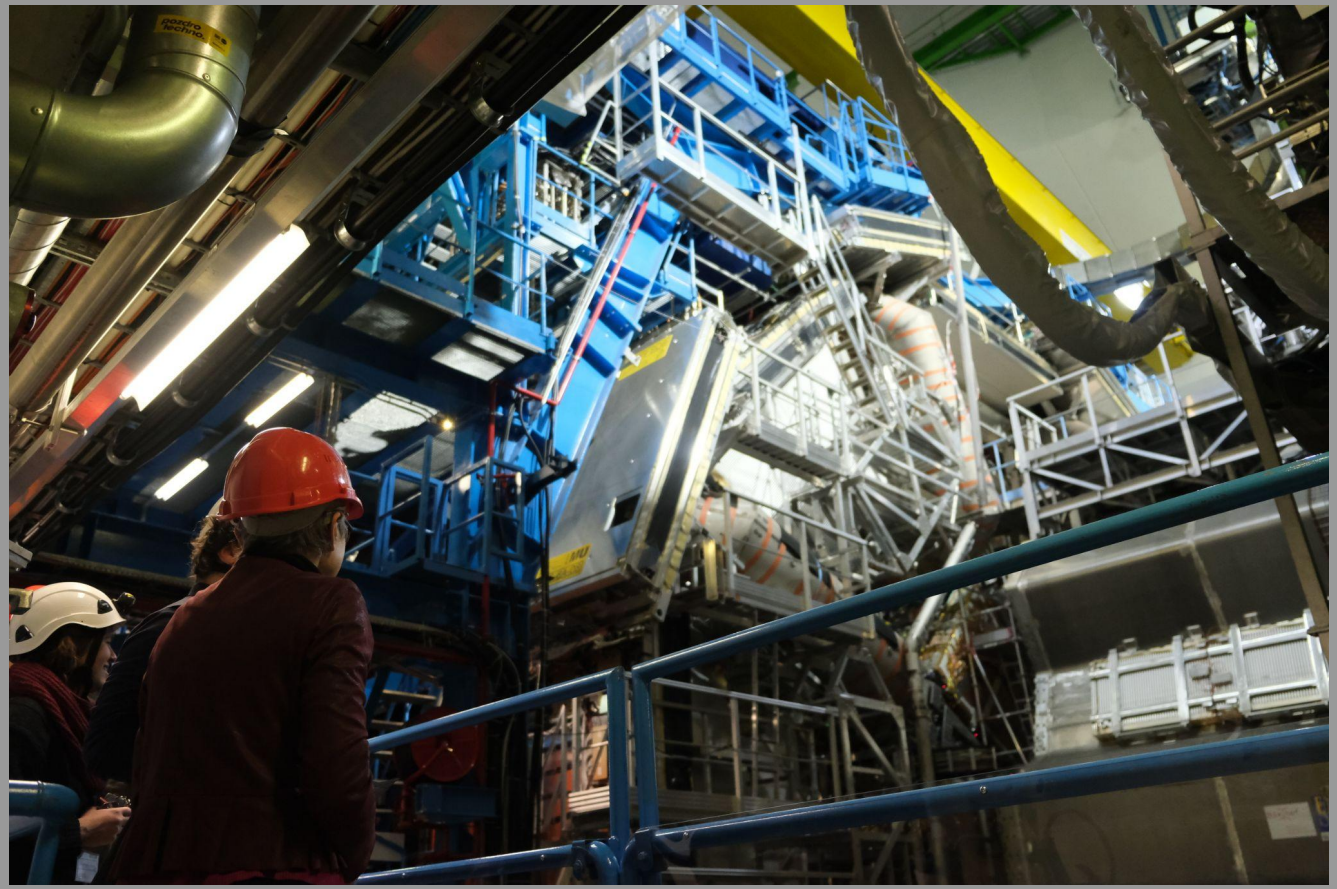
Esperimento ATLAS



Esperimento ATLAS



Esperimento ATLAS



Cosa cerchiamo?

Che caratteristiche ci aspettiamo abbiano le nuove particelle?

- possibili masse?
- carica elettrica?
- spin?
- e altro!

Servono modelli che prevedono le nuove particelle e le loro caratteristiche!





Nel 2012…

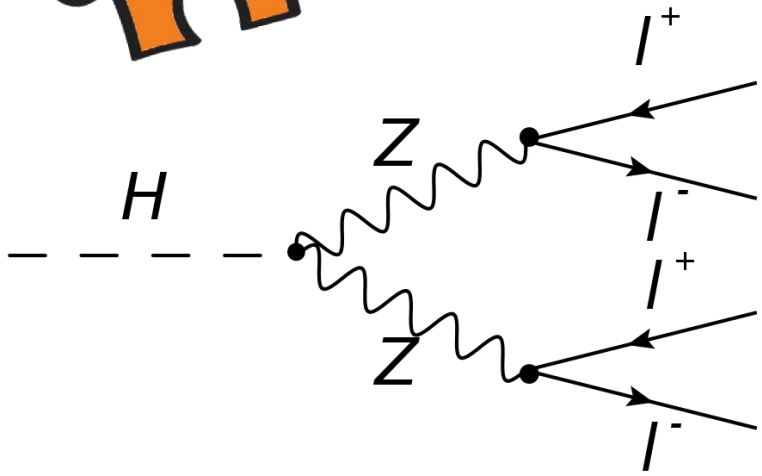


Predetto negli anni ‘60!



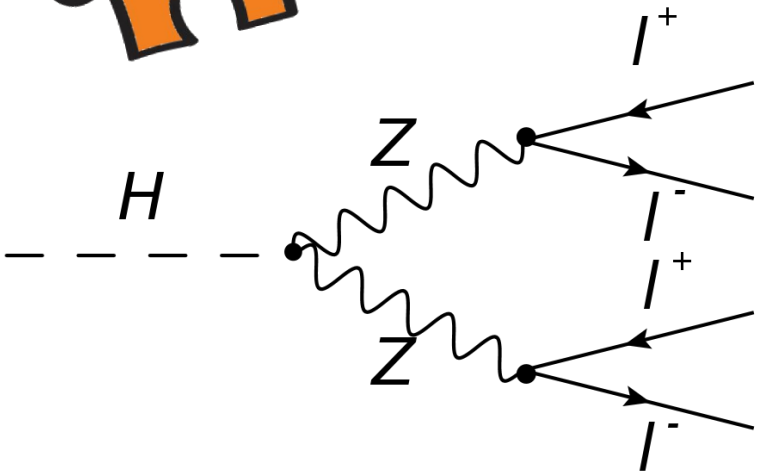
… scoperta del bosone di Higgs!

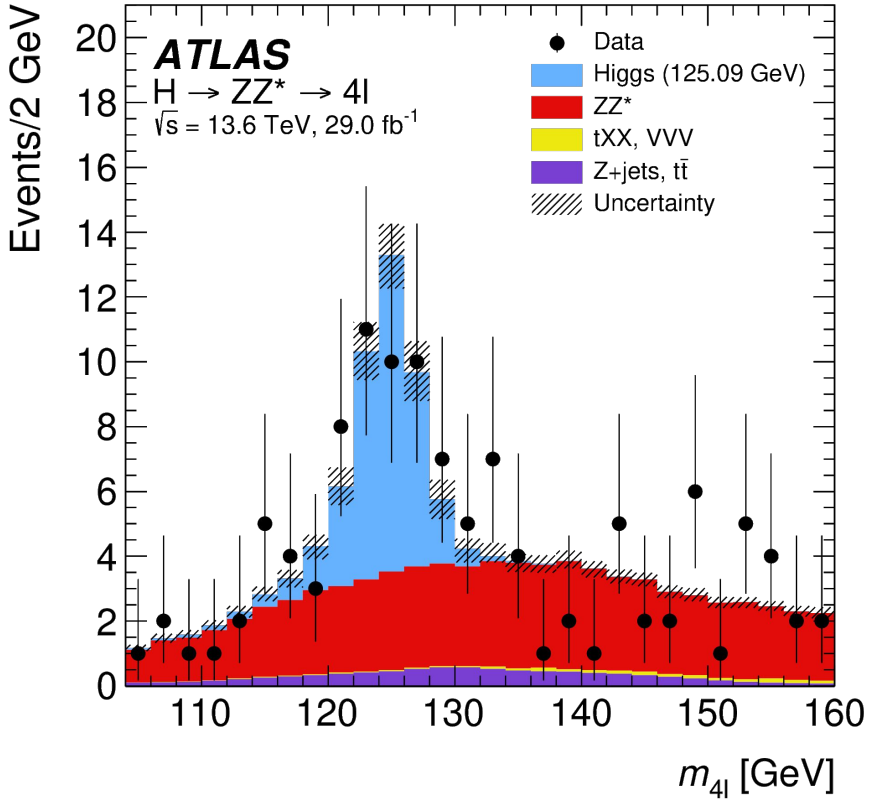




… scoperta del bosone di Higgs!





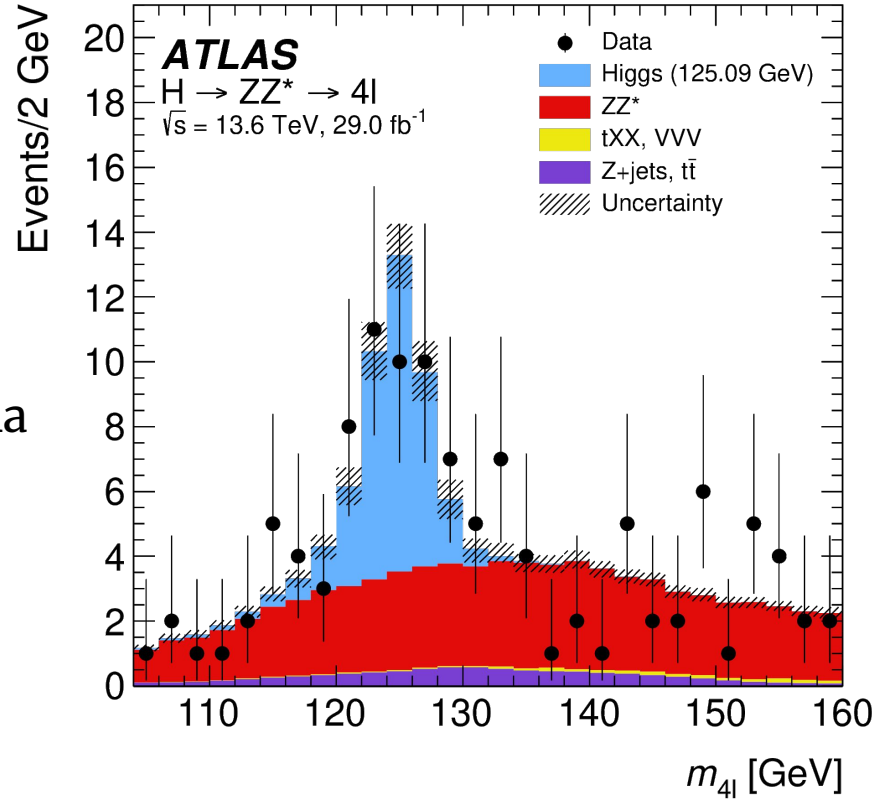


Eventi rari!

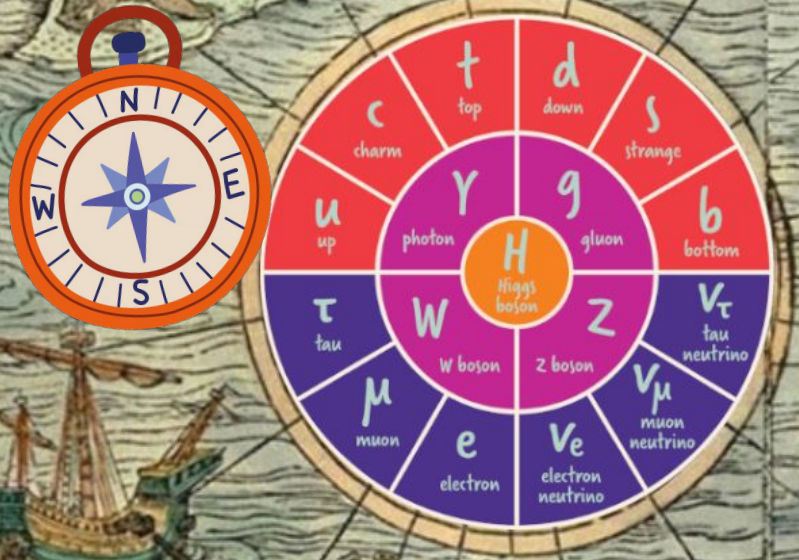


A LHC, si produce un bosone di Higgs una volta ogni cinque miliardi di collisioni!

→ prese dati durano anni per raccogliere abbastanza statistica



Cosa cerchiamo?



2HDM

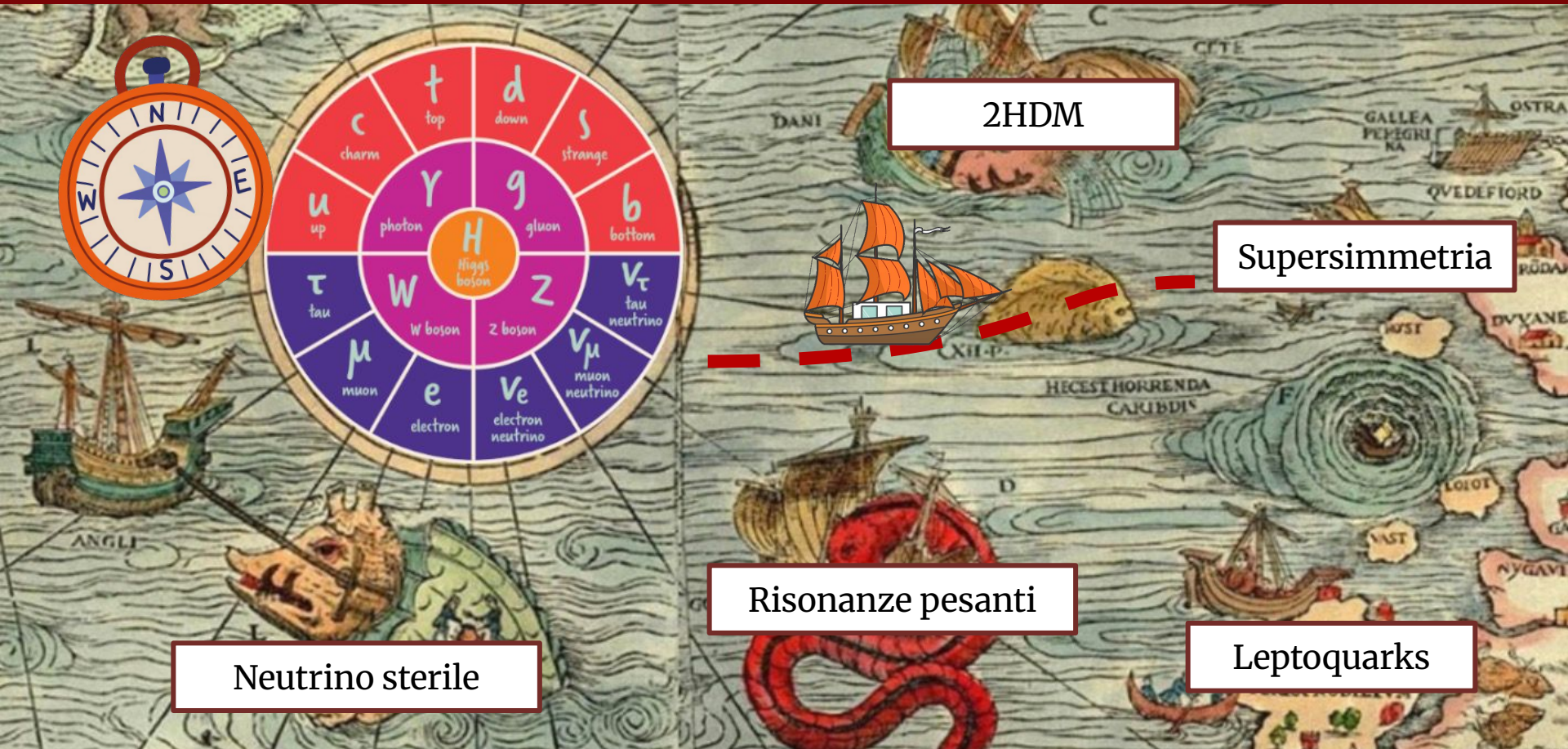
Supersimmetria

Risonanze pesanti

Leptoquarks

Neutrino sterile

Cosa cerchiamo?



Nuove simmetrie?

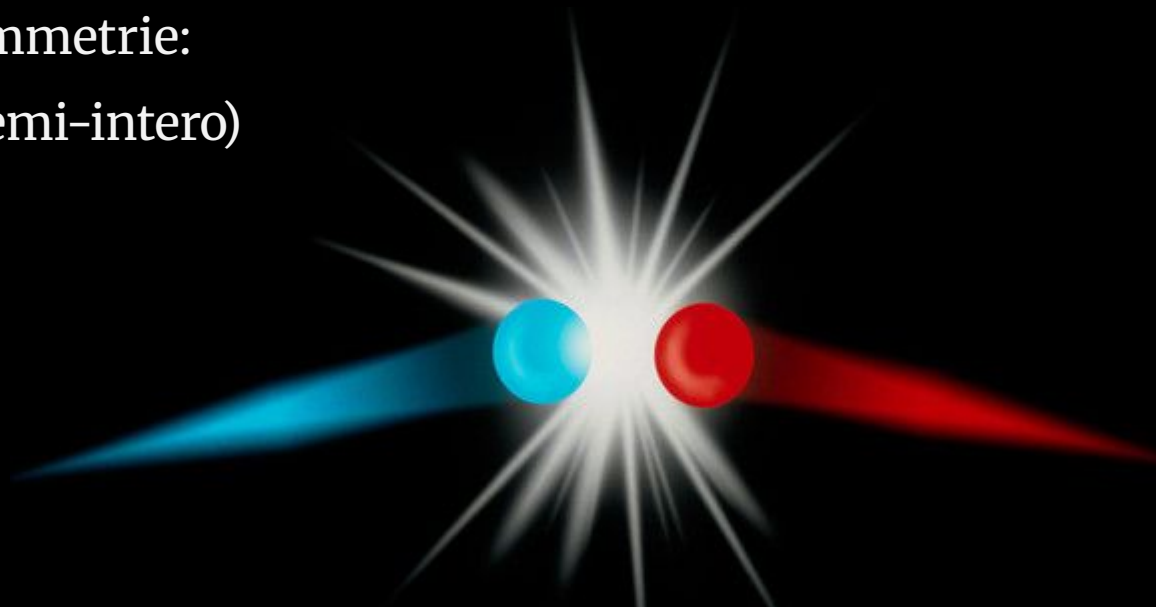
Modello Standard caratterizzato da simmetrie

→ ad esempio simmetria materia-antimateria

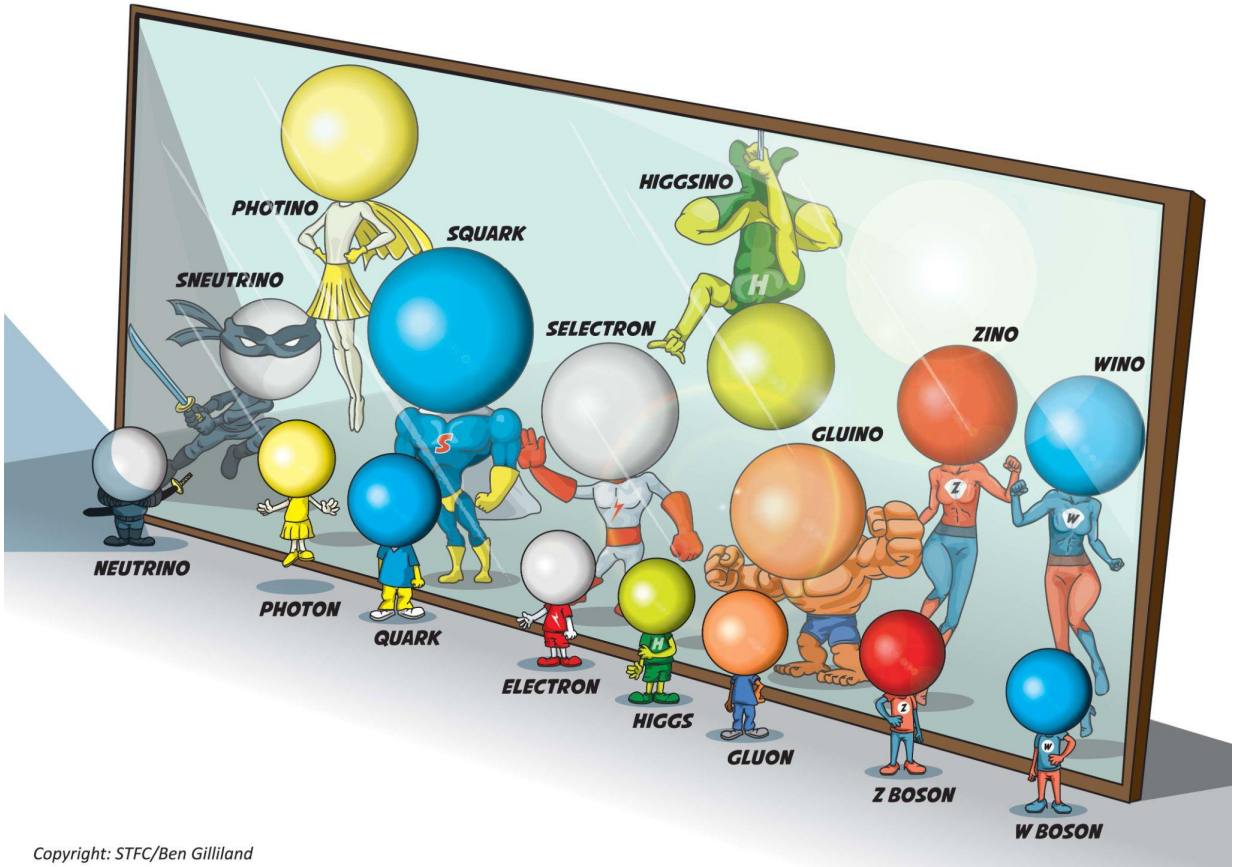
Possiamo teorizzare nuove simmetrie:

→ simmetria fermione (spin semi-intero)

e bosone (spin intero)

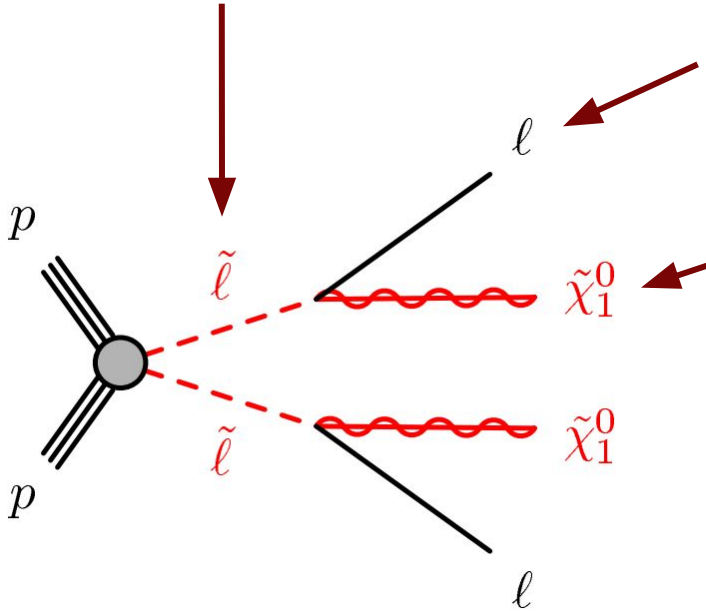


Supersimmetria



Un esempio

Partner di elettrone, instabile

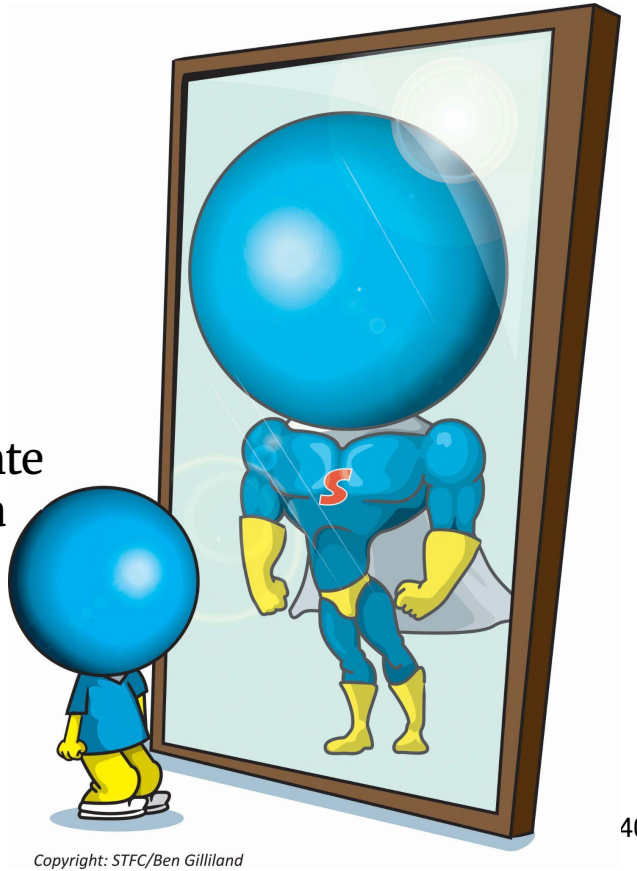


Elettrone, che possiamo rilevare

Nuova particella, con massa e stabile!

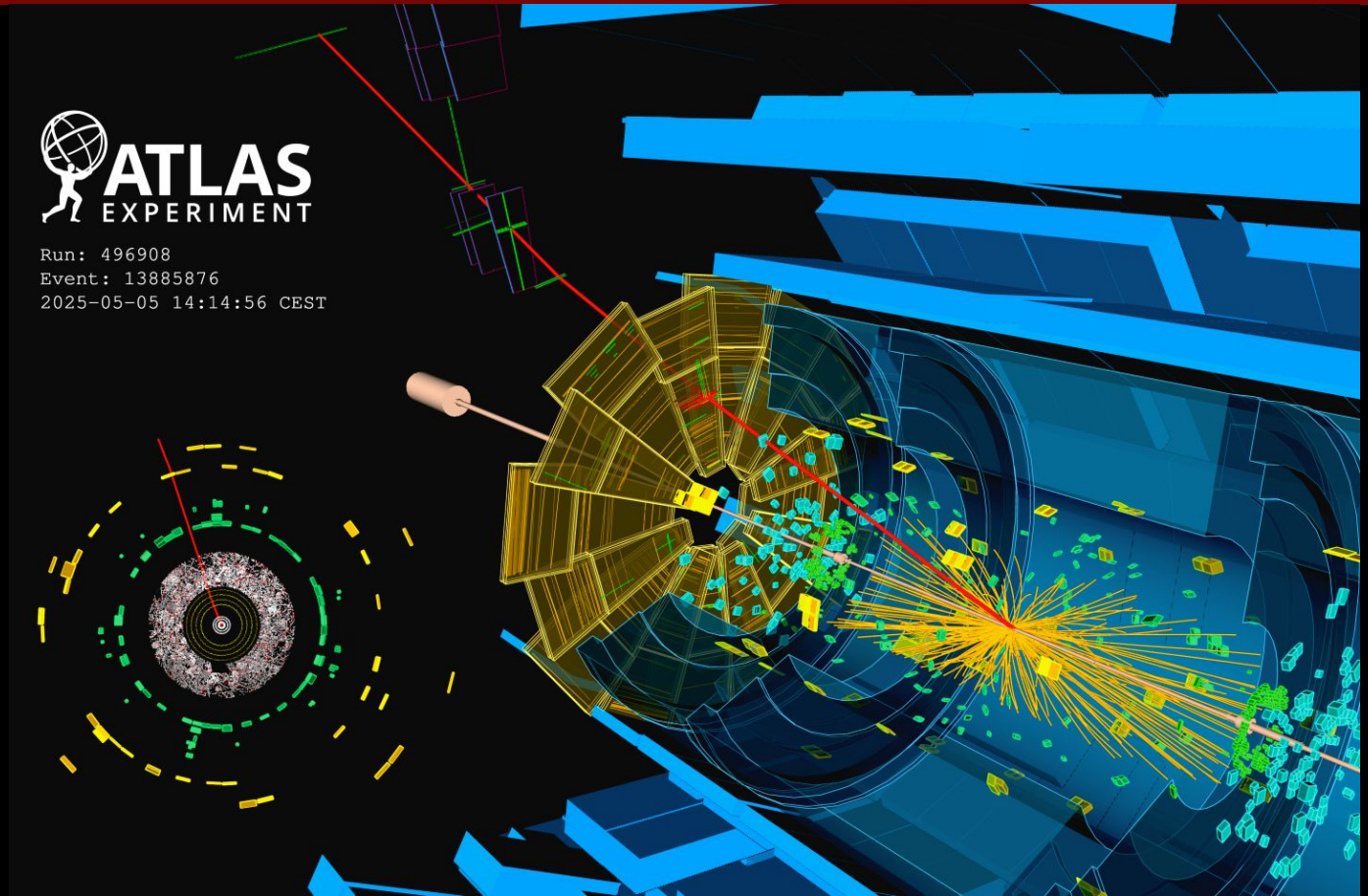
Interagisce debolmente con materia ordinaria

Candidato per materia oscura!



Copyright: STFC/Ben Gilliland

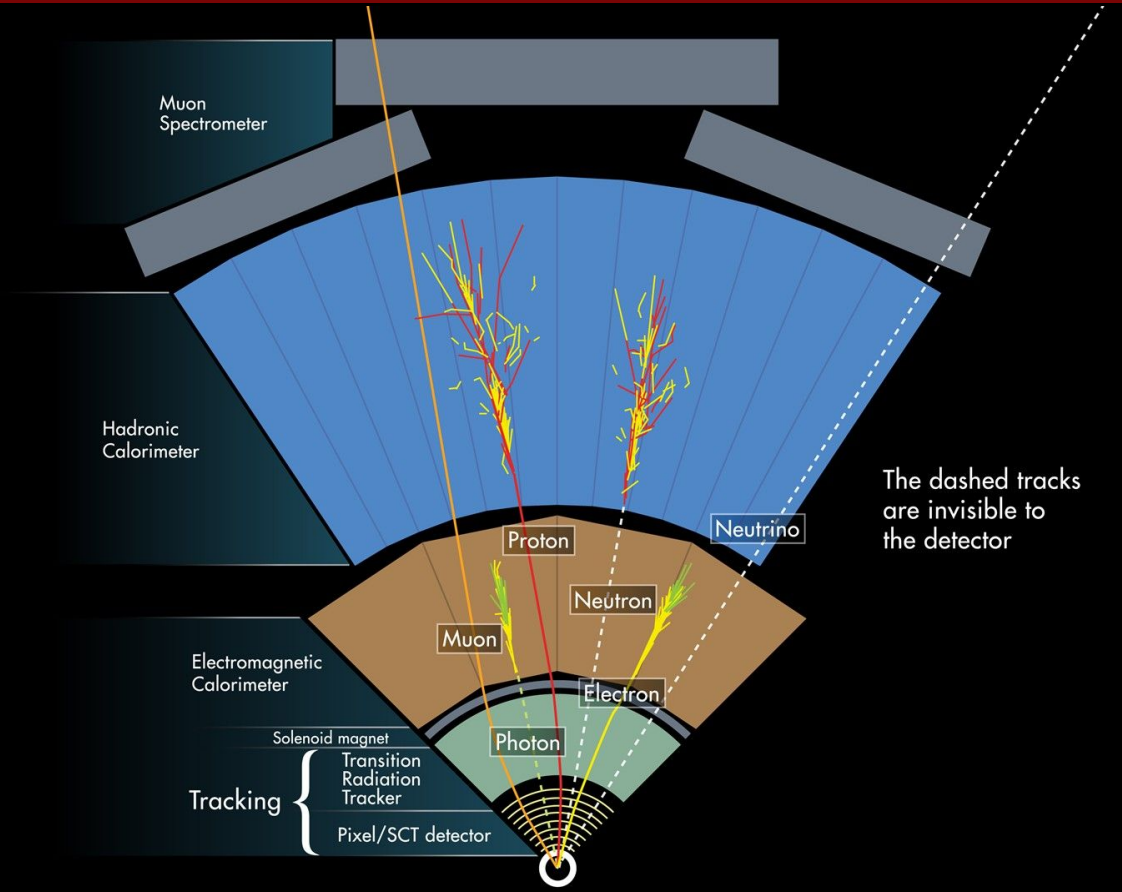
Come identifichiamo le particelle in ATLAS?



Ricostruzione

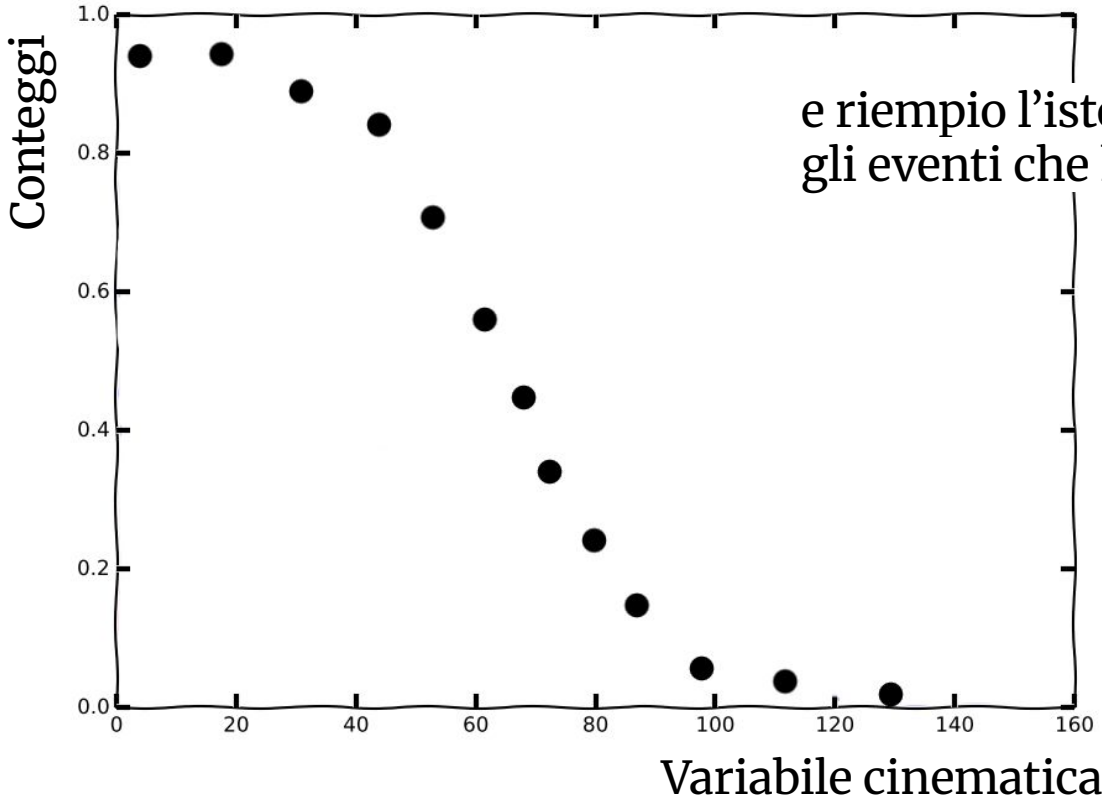
Particelle diverse interagiscono in modo diverso con la materia e con i nostri rivelatori

Diversi sotto detector per rilevare tipi di particelle diverse



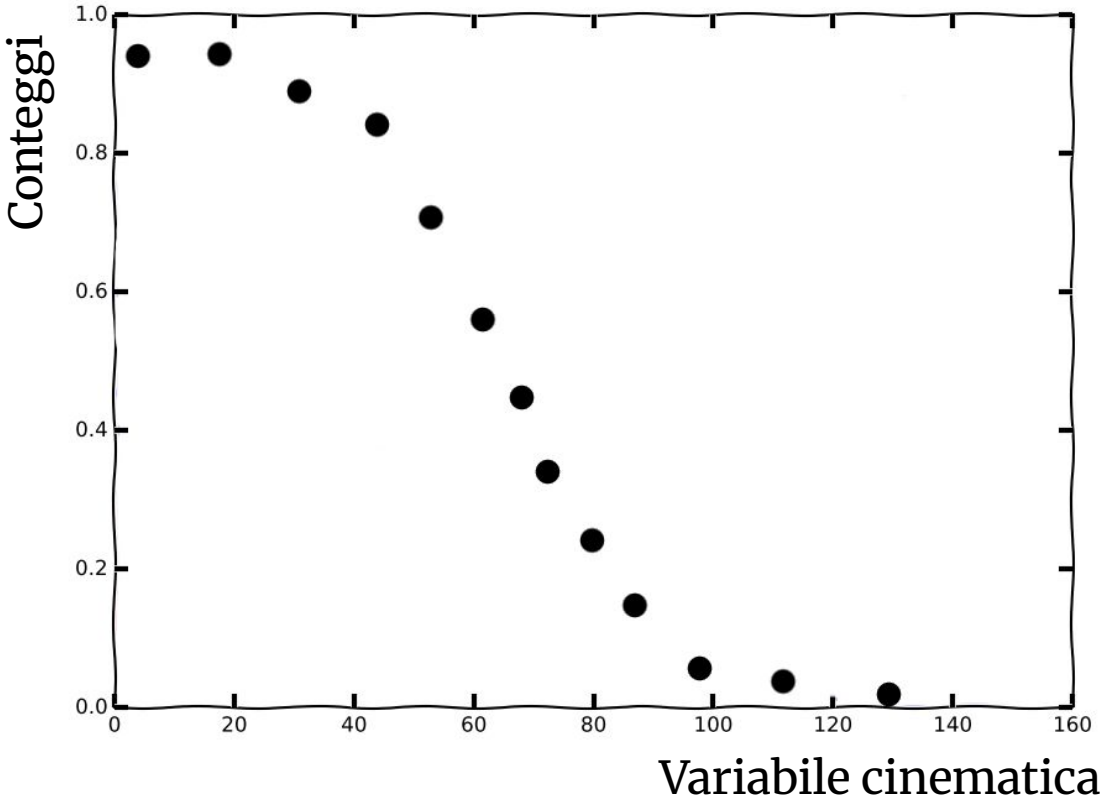
Raccolta dei dati!

Considero una variabile cinematica, ad es. energia, momento, massa invariante, ...

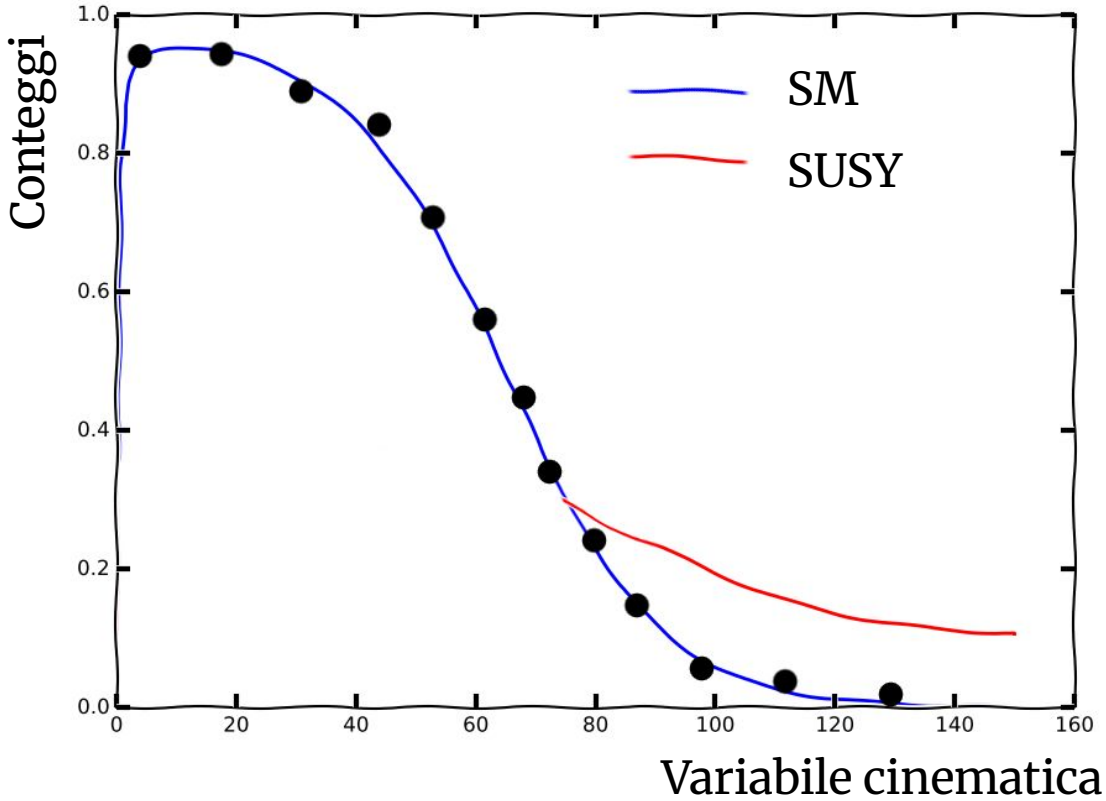


e riempio l'istogramma per tutti gli eventi che ho osservato

Nuova fisica?

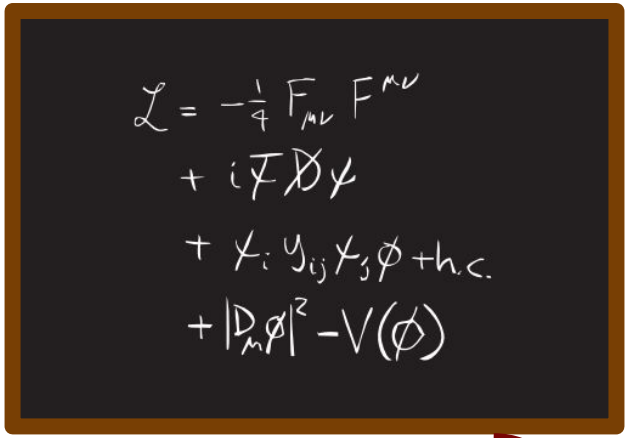


Confronto con predizione!

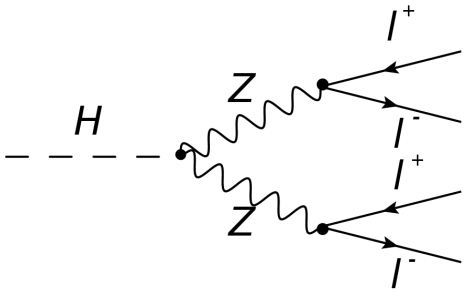


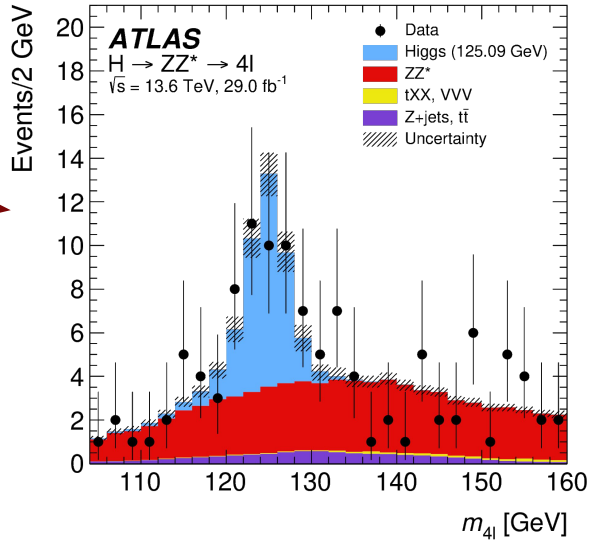


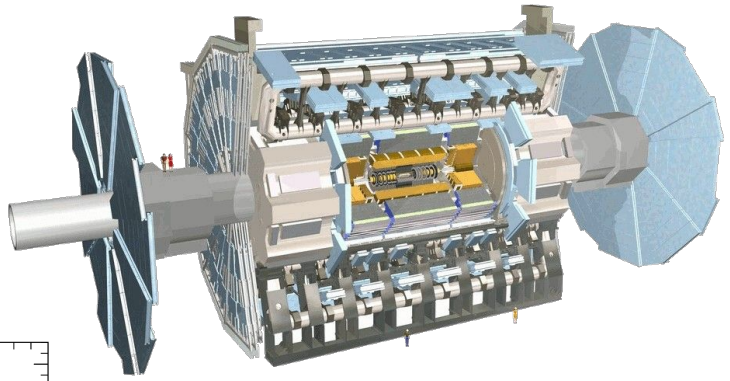
Confronto con predizione!



Modello teorico
(simulazioni Monte Carlo)

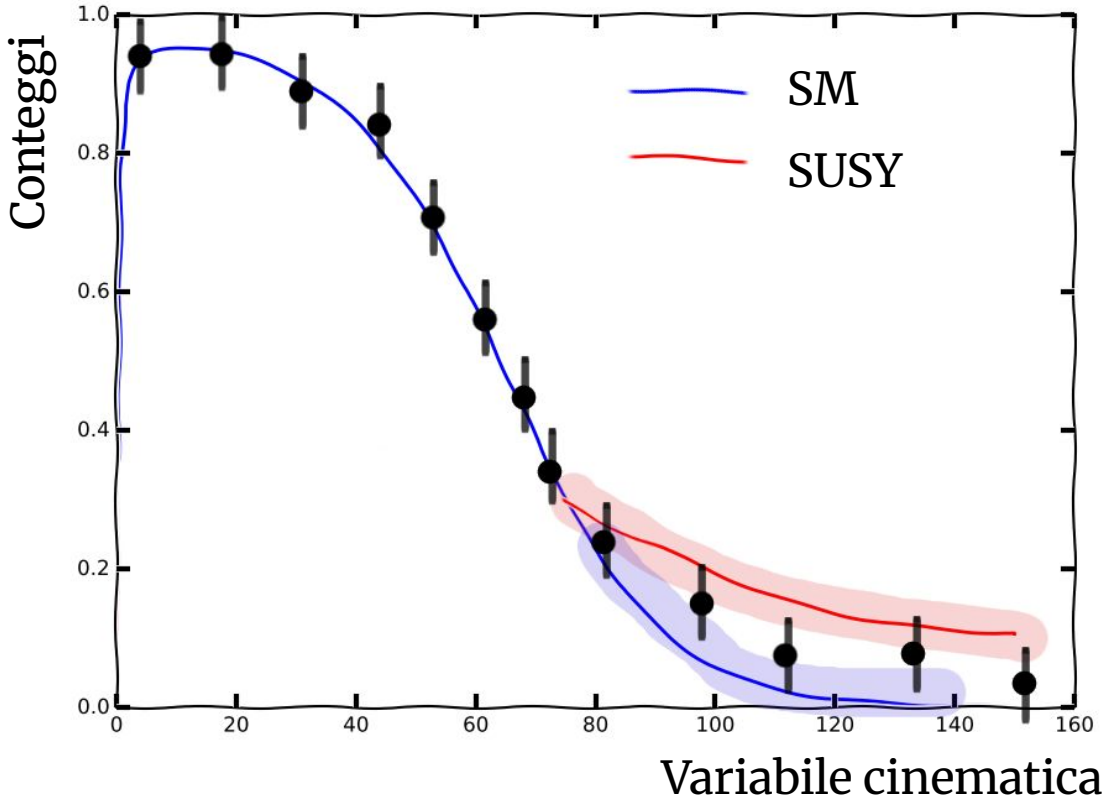






Dati sperimentali

Non dimentichiamo le incertezze!





Nuove particelle?

Nuove particelle elementari

osservate a LHC dal 2012?

O da altri esperimenti?

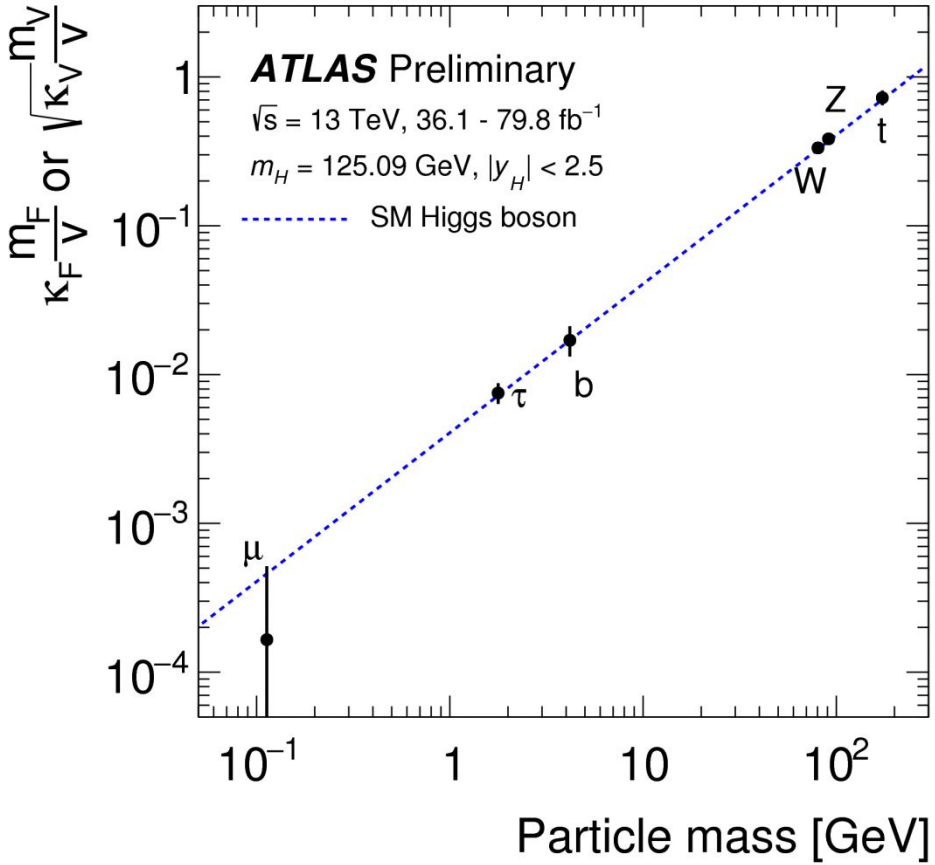
Nuove particelle?

Nuove particelle elementari osservate a LHC dal 2012?

O da altri esperimenti?

No…

Inoltre misure in accordo col Modello Standard!

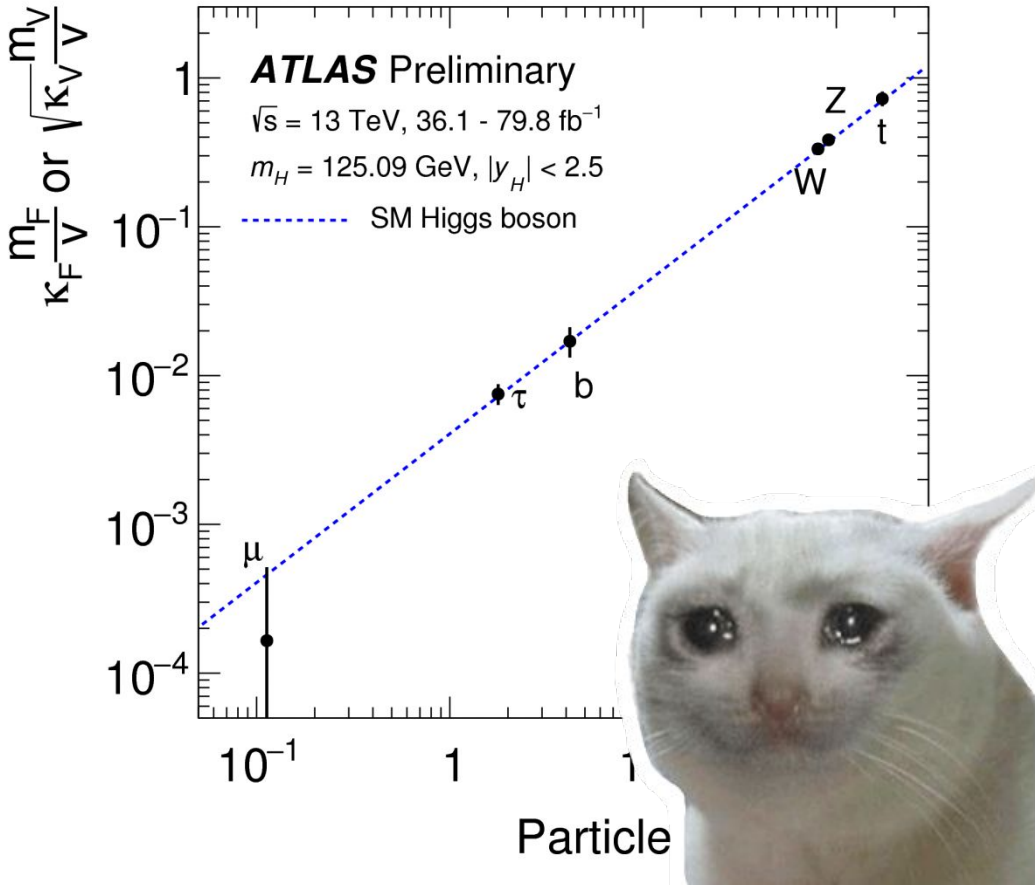


Nuove particelle?

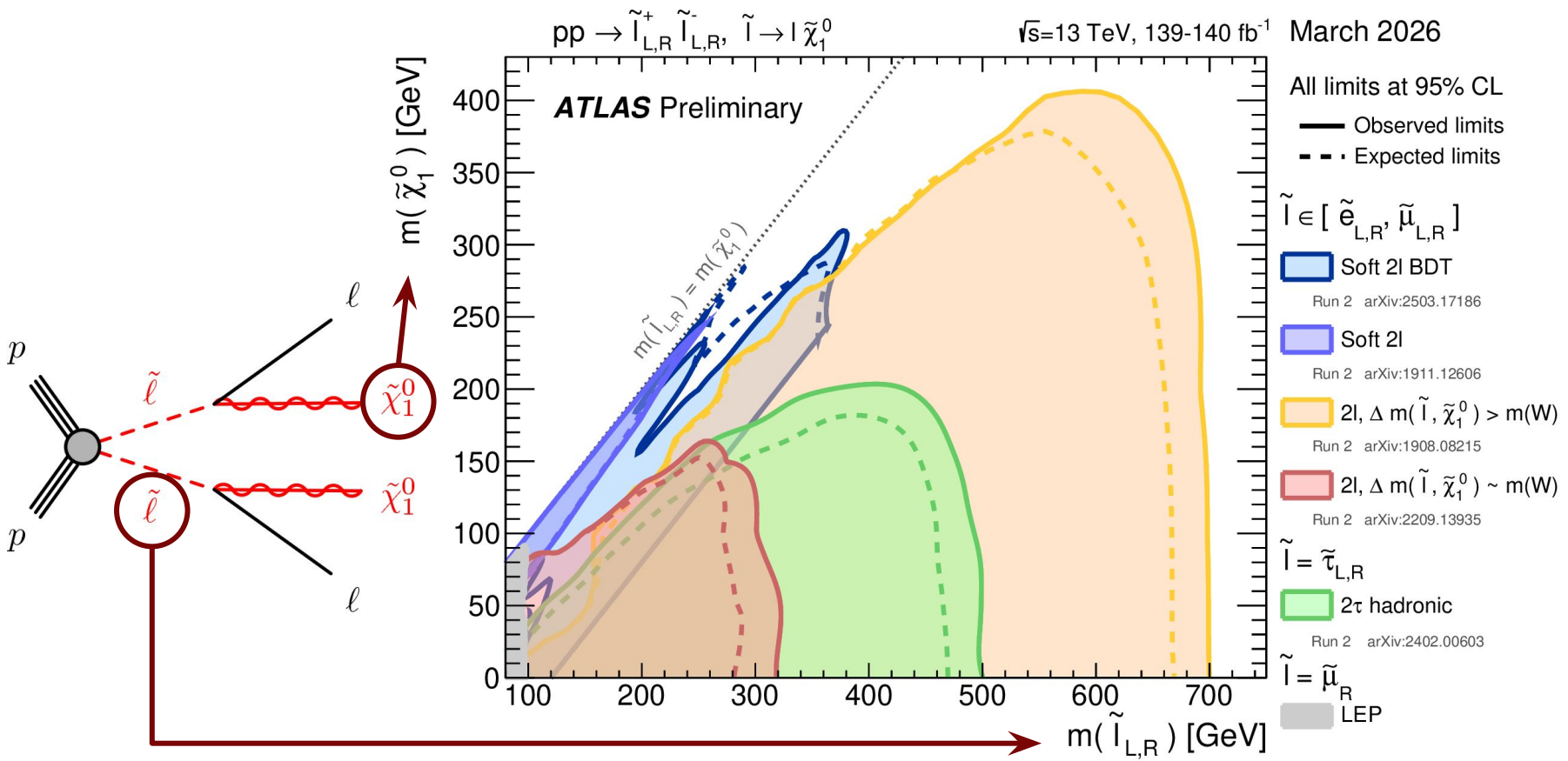
Nuove particelle elementari osservate a LHC dal 2012?
O da altri esperimenti?

No...

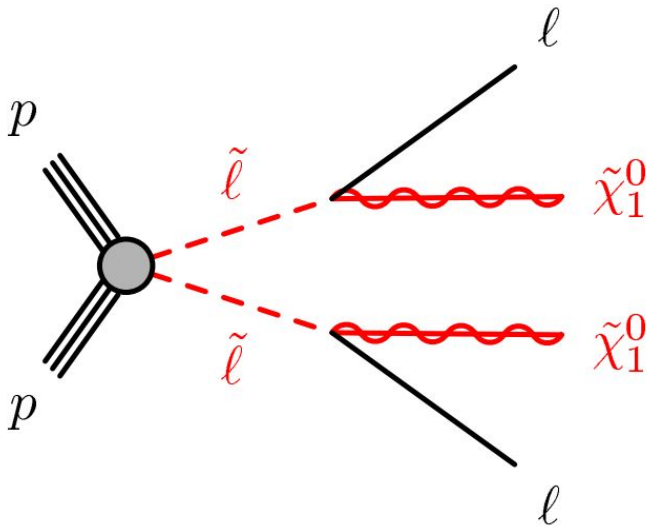
Inoltre misure in accordo col Modello Standard!



Cosa possiamo concludere in realtà?



Ed ora?

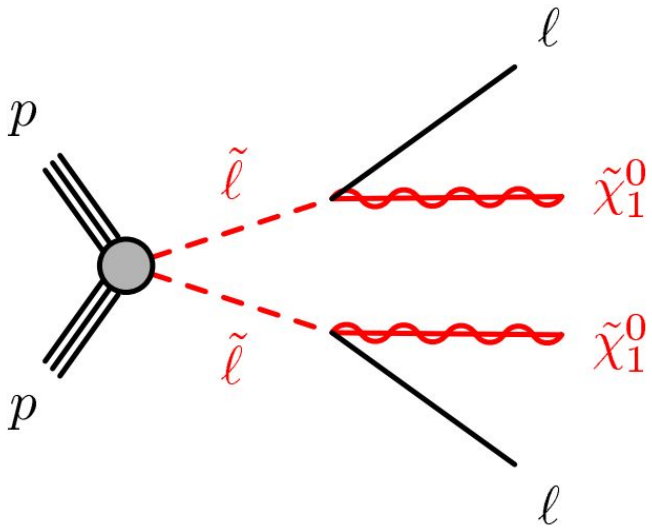


Eventi molto rari!

s-elettrone con massa di ~ 100 GeV
→ produzione è 100 volte più rara dell'Higgs

s-elettrone con massa di ~ 500 GeV
→ produzione è 10^5 volte più rara dell'Higgs

Ed ora?



Eventi molto rari!

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Le nuove particelle potrebbero essere ancora fuori dalla nostra portata!

Cosa ci riserva il futuro?



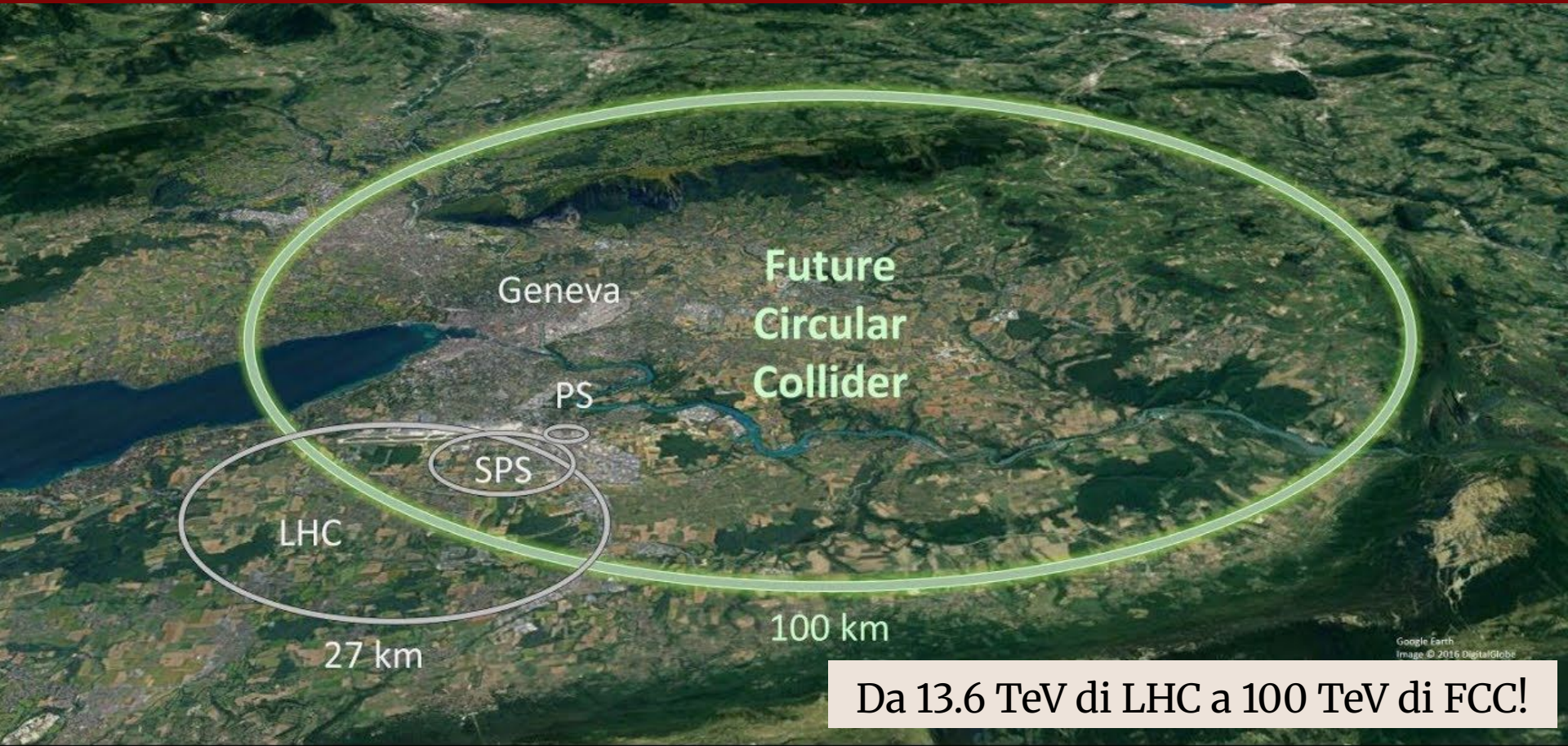
Cosa ci riserva il futuro?



Aumento della luminosità istantanea → **più dati raccolti!**

Molto importante per ricerca di eventi rari

Cosa ci riserva il futuro?



Da 13.6 TeV di LHC a 100 TeV di FCC!

Cosa concludiamo?



Ad oggi non abbiamo evidenza di nuove particelle che possano spiegare la materia oscura ...

Ma in caso di mancata scoperta non rimaniamo davvero a mani vuote!

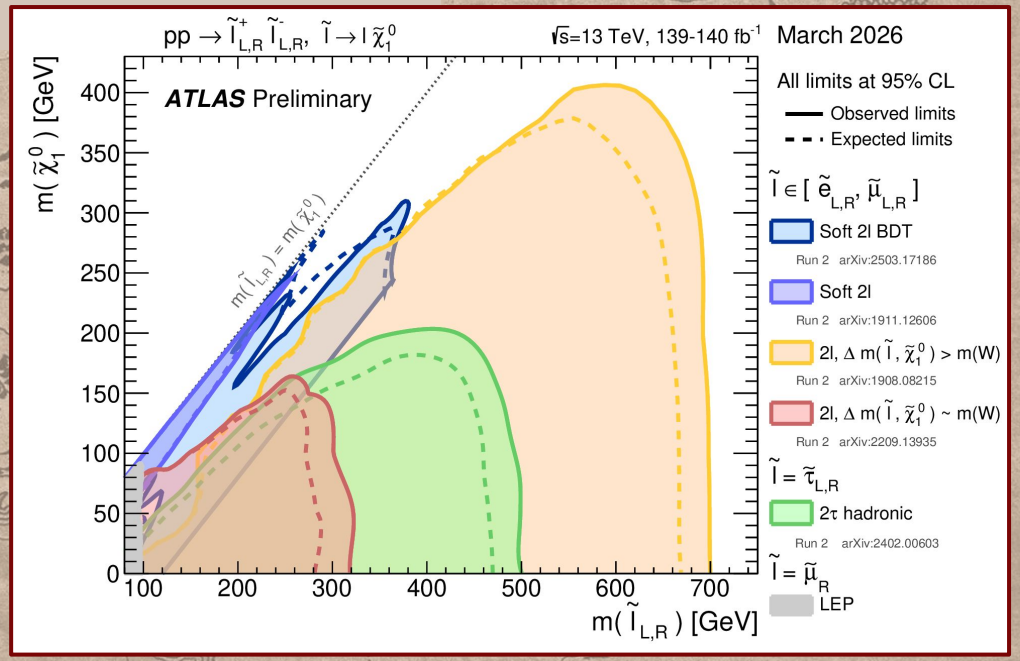




Cosa concludiamo?

Mancata scoperta di nuove particelle e nuovi fenomeni si traduce in limiti sulla nuova fisica:
→ importante guida per formulazione delle teorie e per ricerche future!





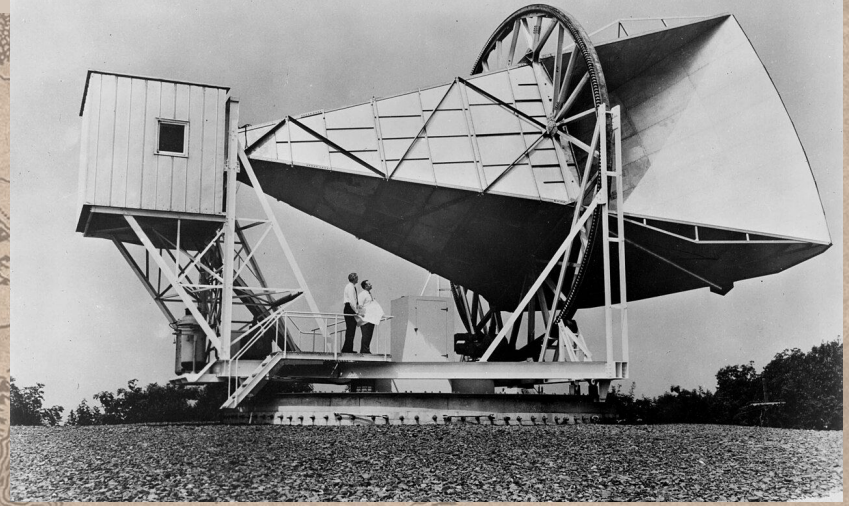
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Scoperte accidentali



Penzias e Wilson scoprono la CMB

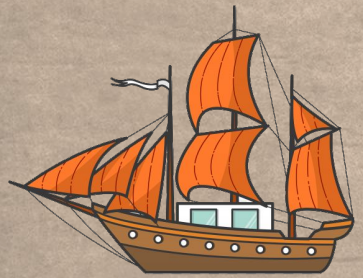


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Scoperte accidentali

Ricadute tecnologiche



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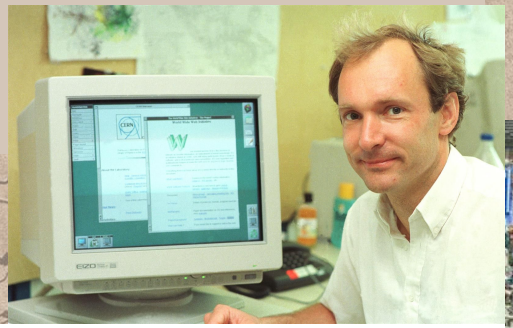


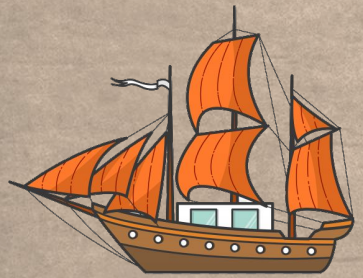
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Ricadute tecnologiche





- ➔ World Wide Web
- ➔ algoritmi di machine learning
- ➔ data management
- ➔ processori

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La ricerca continua!

