Il Large Hadron Collider e l'esperimento CMS

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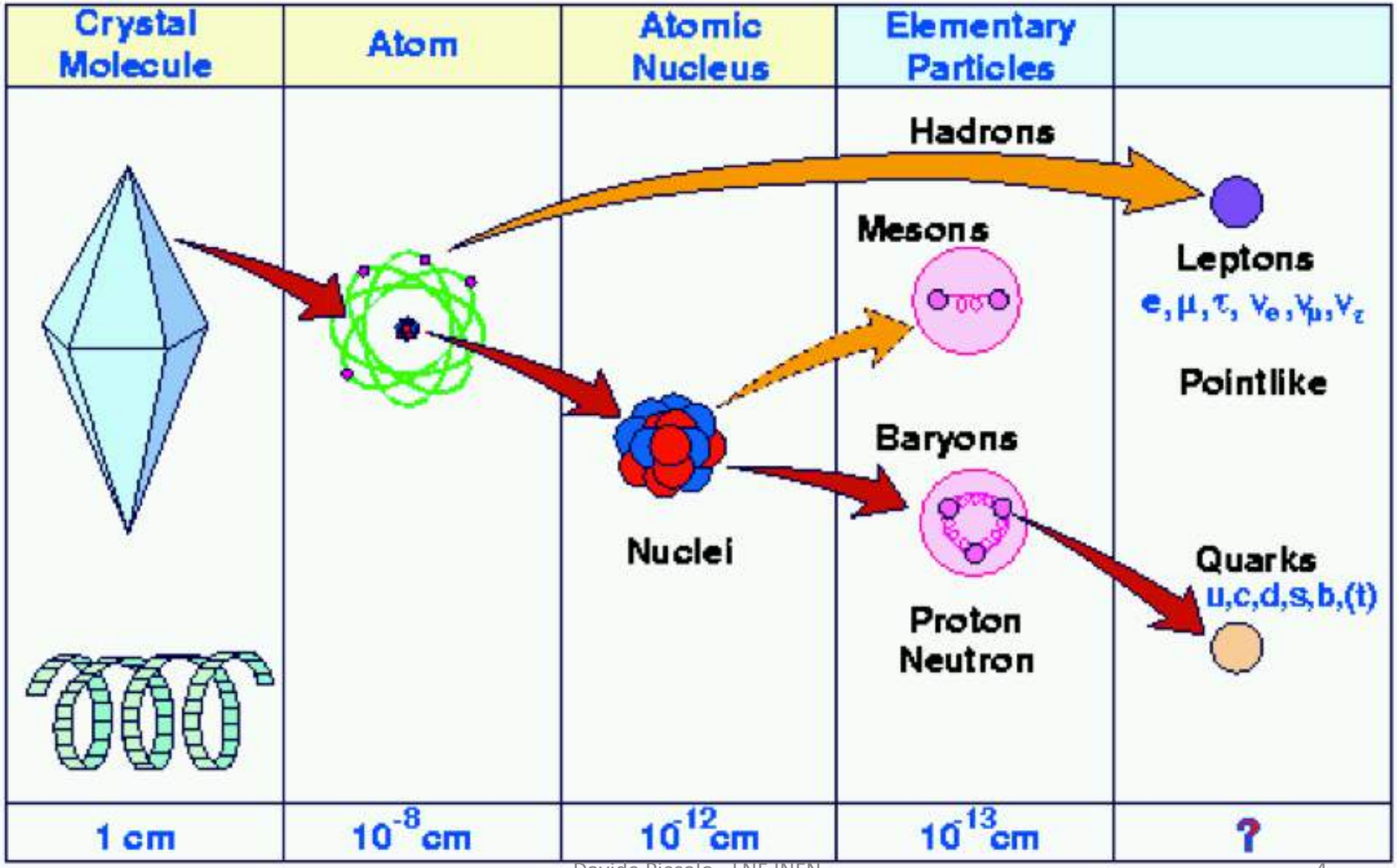
LHC

A cosa serve? Quali problemi di fisica vogliamo affrontare ?

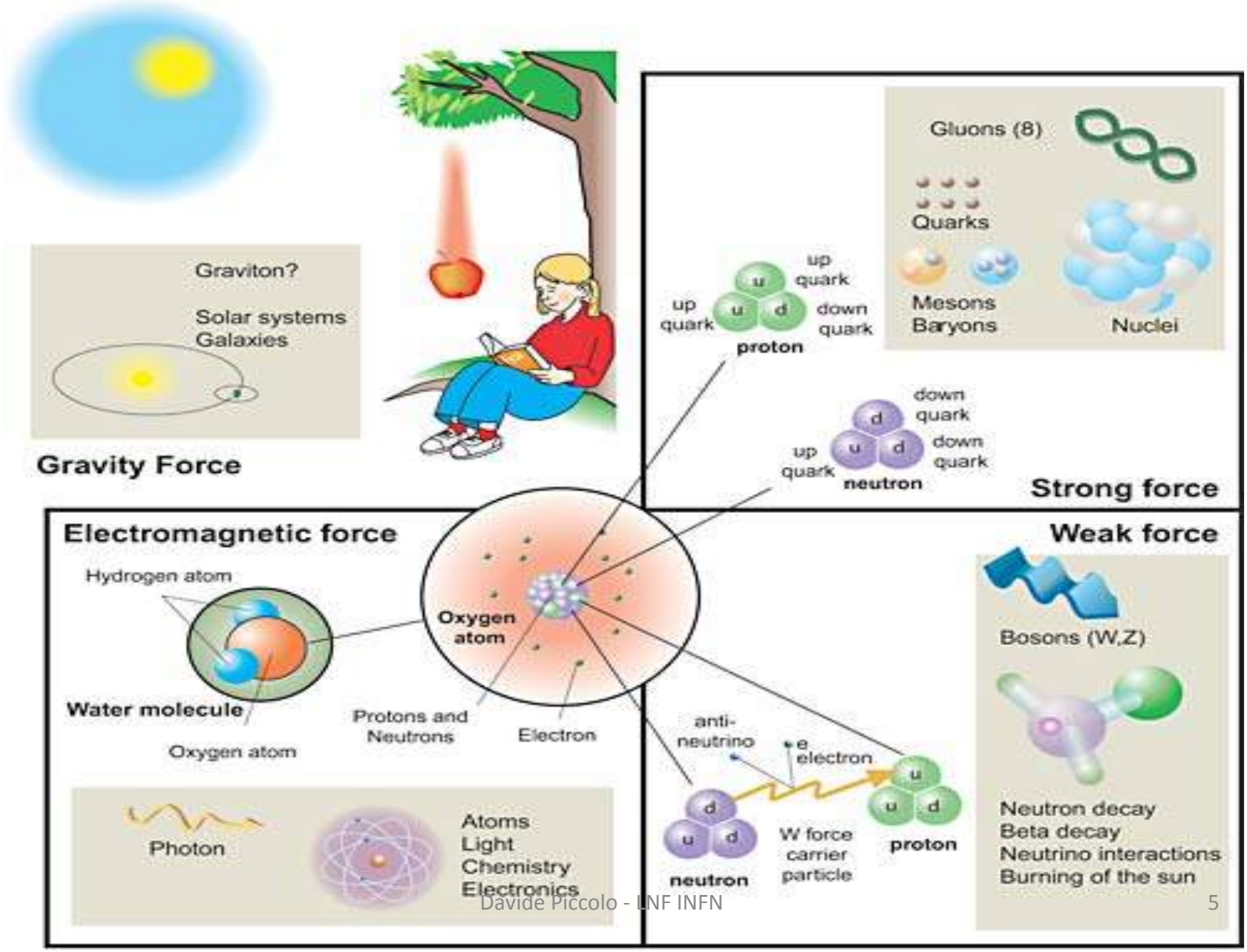
Cosa studiano i fisici delle particelle

1. Come e' nato l'Universo ?
2. Da cosa e' composta la materia ?
3. Quali sono I mattoni fondamentali della materia ?
4. Quali forze tengono assieme l'universo ?
5. Esistono forze ancora sconosciute ?
6. Che cosa e' la materia oscura ?
7. ….. Ed altro ancora

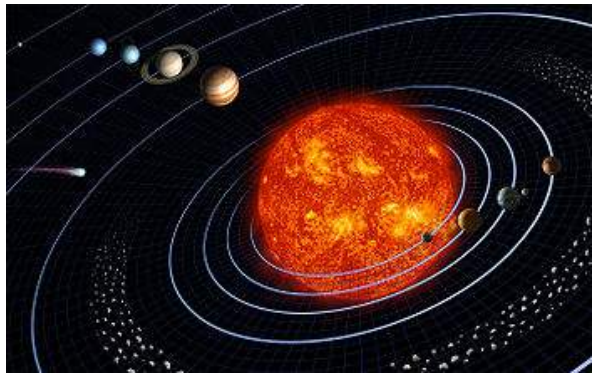
Di cosa e' fatta la materia ?



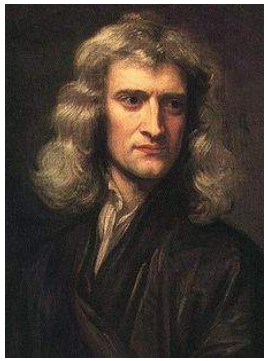
Quali sono le forze della natura?

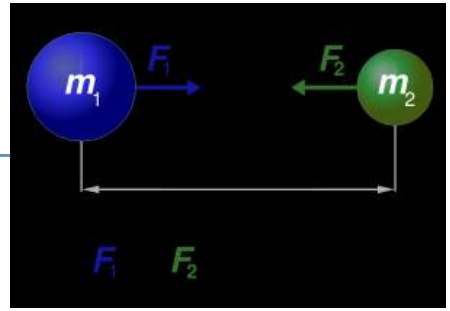


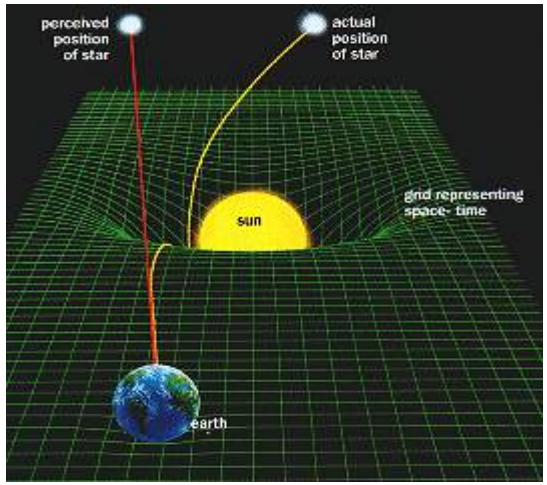
Le forze – Interazione Gravitazionale



Mantiene i pianeti attorno al sole







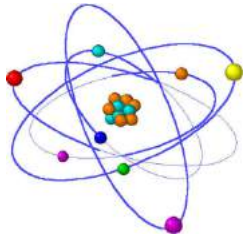
Responsabile della caduta dei gravi

Si deve a Newton L'intuizione che I due fenomeni siano regolati dalla stessa legge
La legge di Gravitazione universale

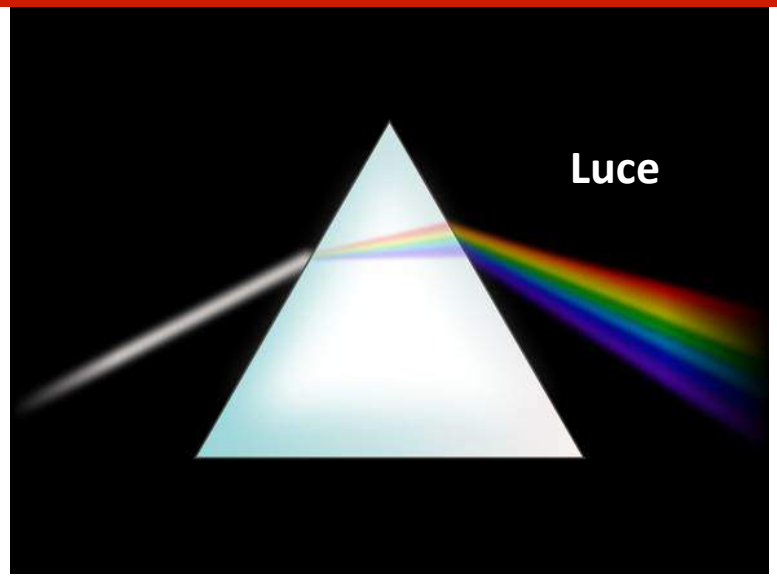
Si deve ad Einstein aver interpretato la gravita come curvaura dello spazio-tempo
Teoria della Relativita' Generale

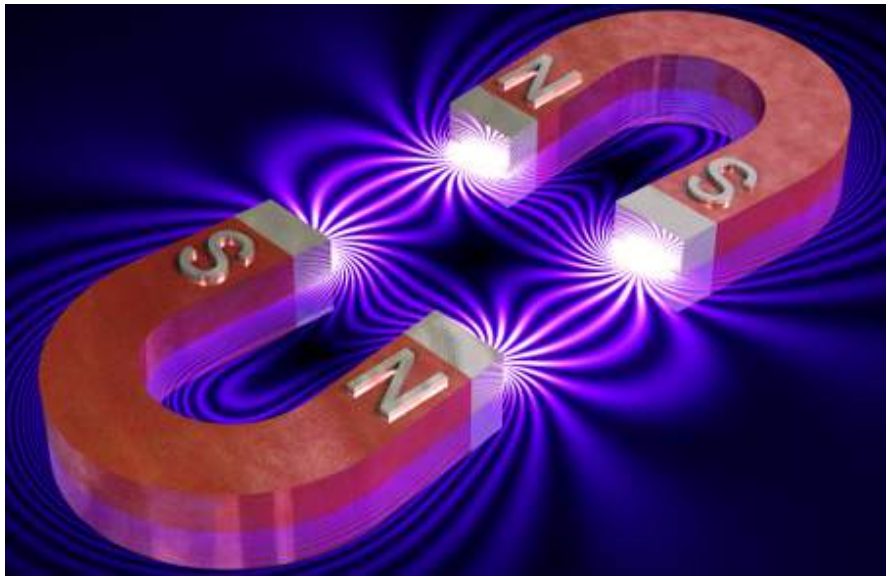
Le forze – Interazione Elettromagentica

Elettricita'

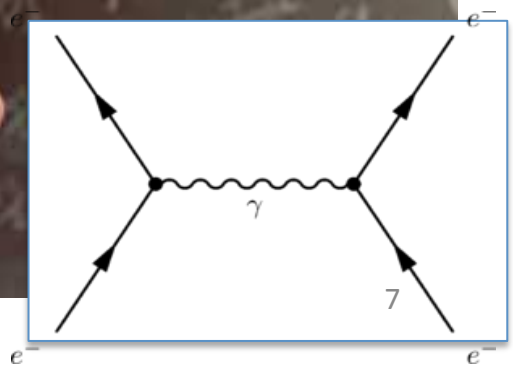


chimica



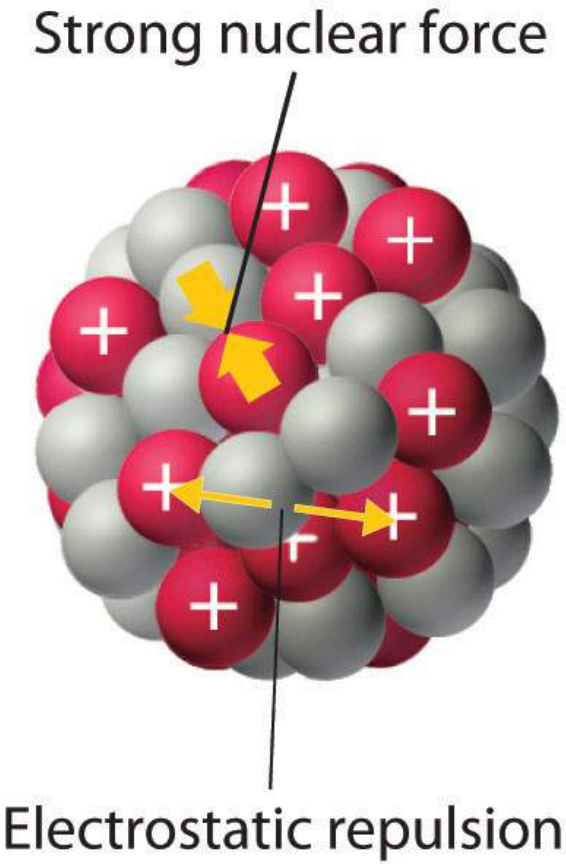


Magnetismo

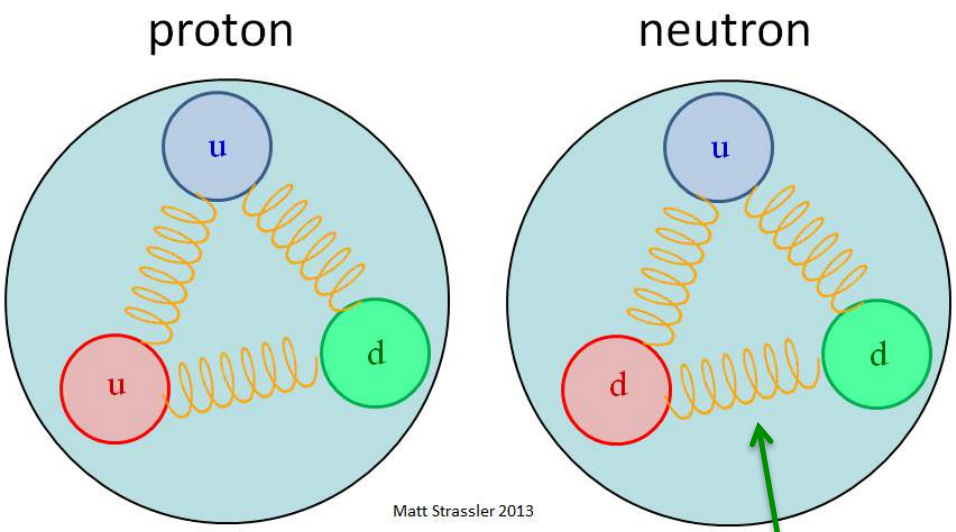


Le forze – L'interazione Nucleare Forte

Ma cosa tiene assieme I protoni e I neutroni nel nucleo ……



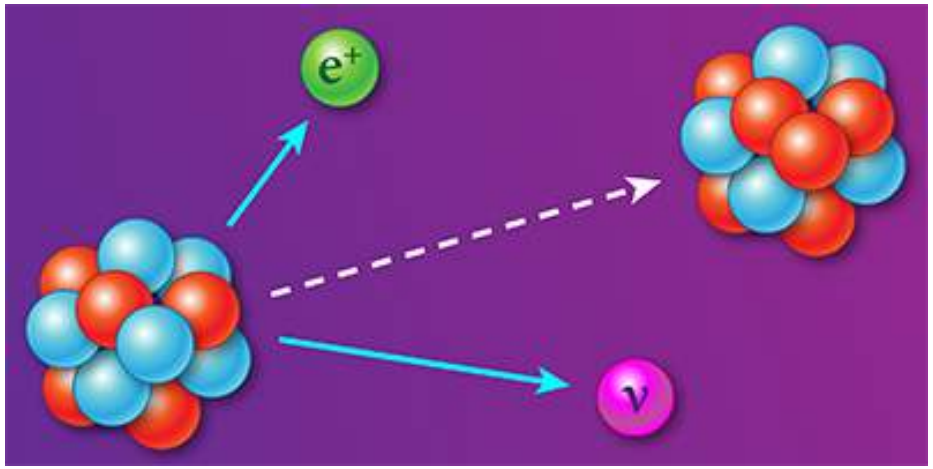
…… e I quark all'interno di neutroni e protoni ?

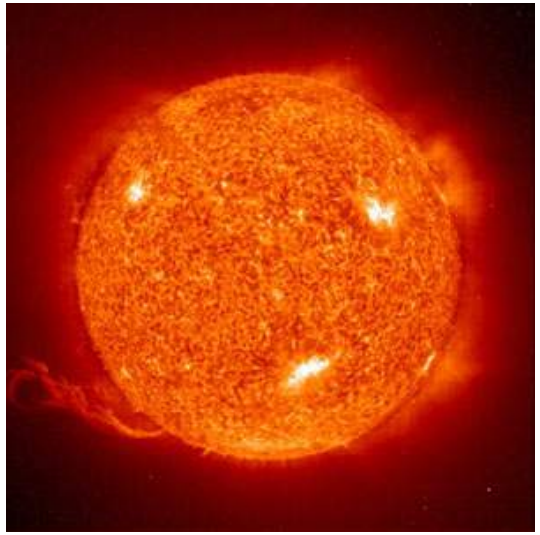


Nella teoria quantistica dei campi, l'interazione forte e' mediata dai GLUONI

Le forze – L'interazione debole

E' l'interazione meno immediata da comprendere, ma e' fondamentale per il ciclo delle stelle

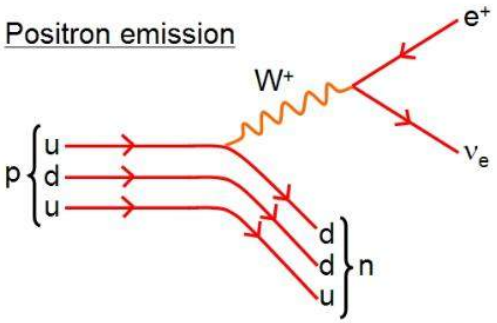




… ha un ruolo fondamentale nelle reazioni che avvengono nelle stelle

Radioattivita': decadimento β del neutrone

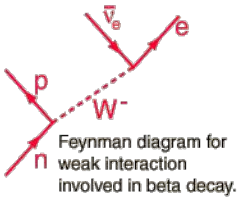
Nella teoria quantistica dei campi, l'interazione debole e' mediata dai bosoni W^+W^- e Z^0



$p \rightarrow n + e^+ + \nu_e$

W^+ W^- 80.4 GeV

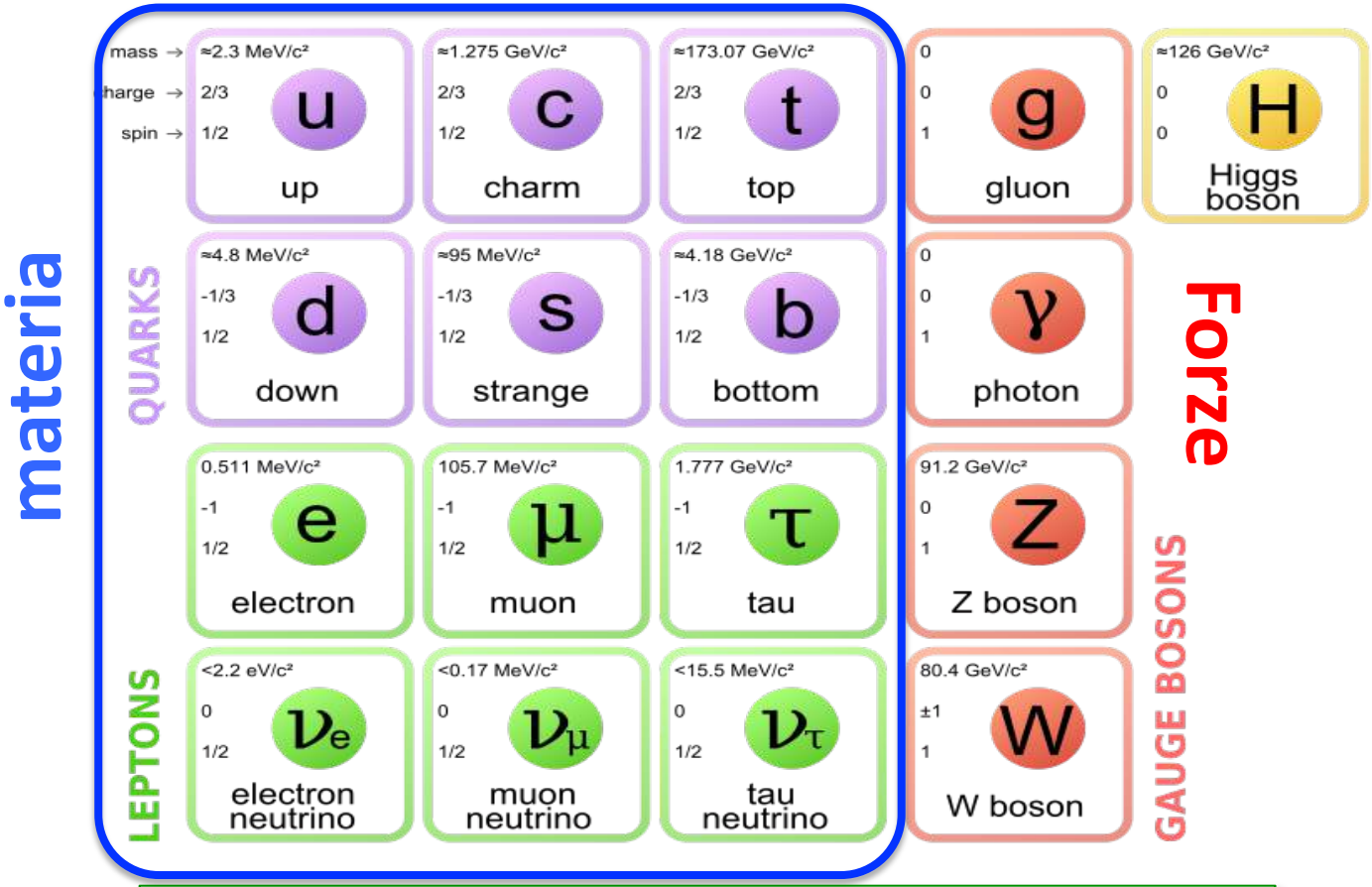
Z^0 91.2 GeV



Feynman diagram for weak interaction involved in beta decay.

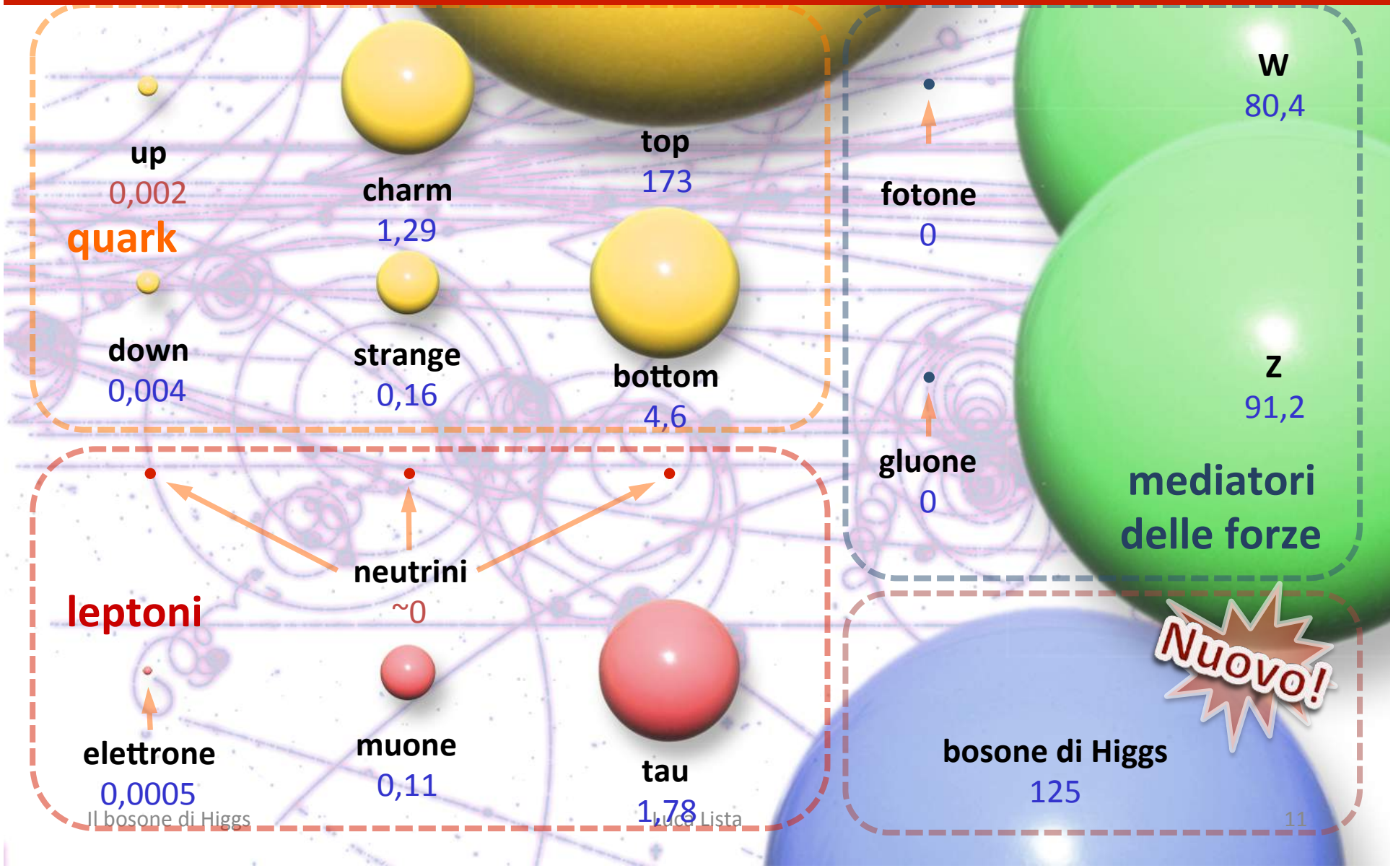
Il Modello Standard

Il Modello Standard fornisce una descrizione completa (o quasi) delle particelle e delle forze

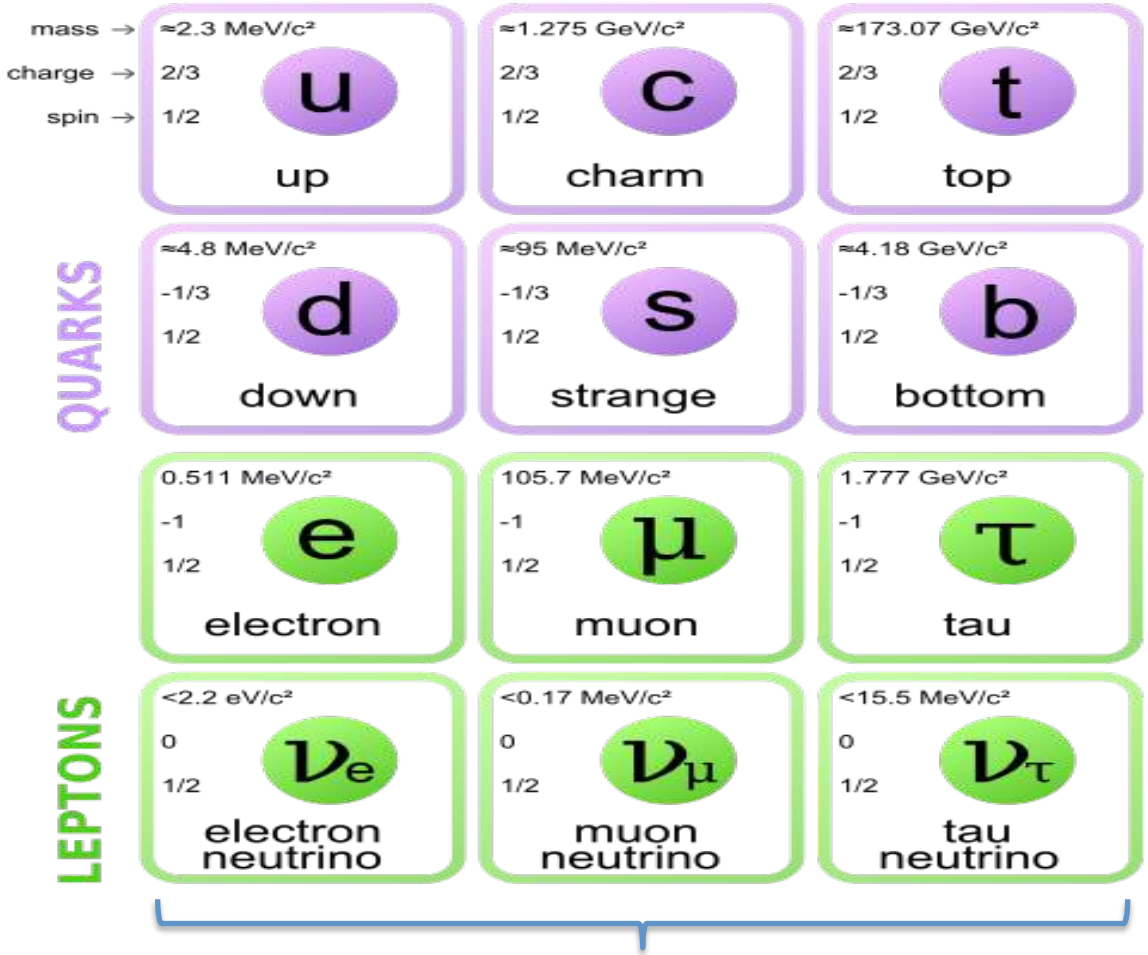


Materia e forze in un unica tabella

Le particelle elementari hanno masse molto diverse tra di loro, anche se sono tutte "puntiformi"!

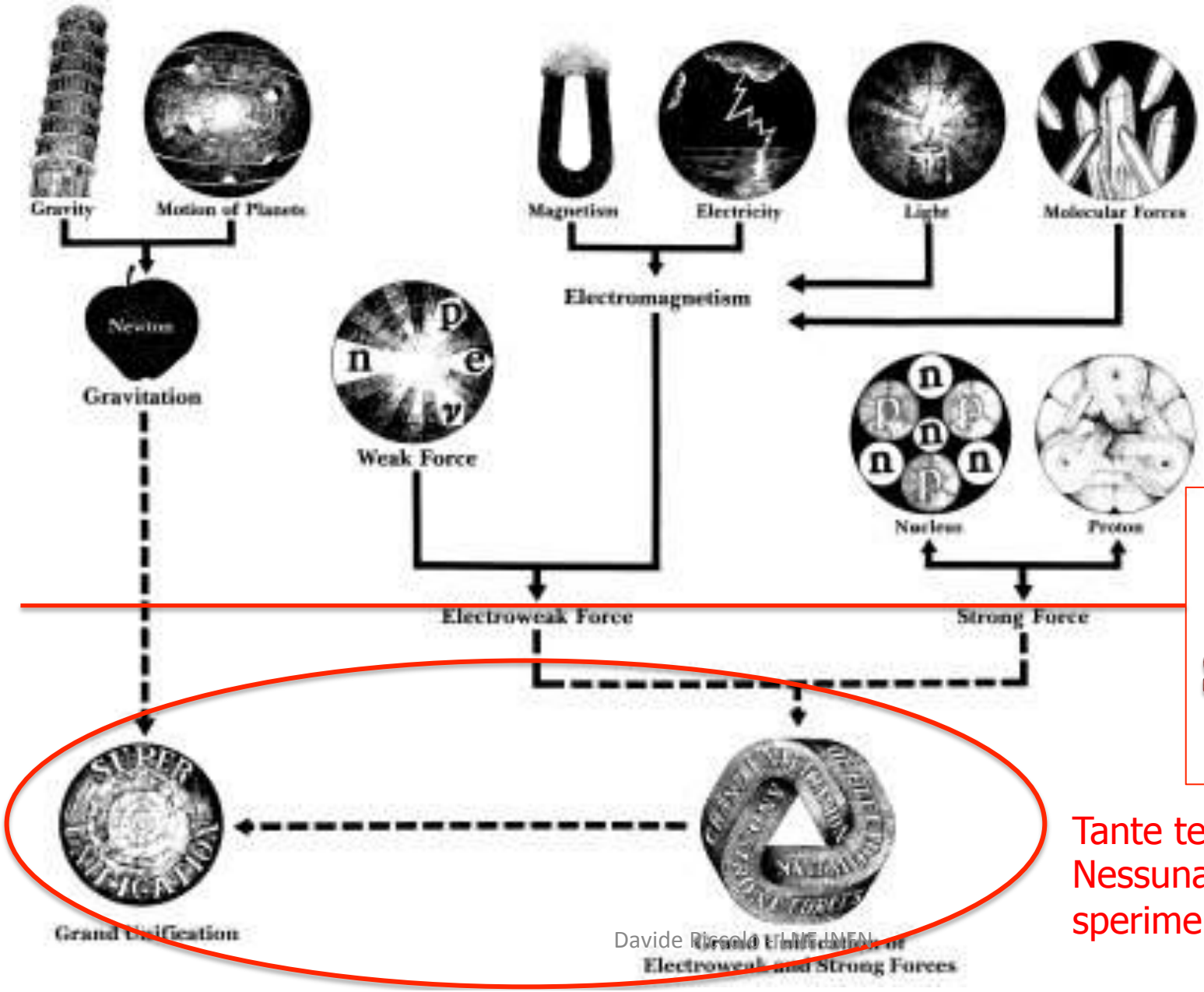


FERMIONI



Perche' ci sono 3 famiglie ? Nessuno lo sa !

Alla ricerca dell'unificazione



Le teorie Attuali Spiegano Fin qui

Tante teorie,
Nessuna prova sperimentale

Il modello Standard e il bosone di Higgs

Le equazioni del Modello Standard

$$
\begin{aligned}
&\mathcal{L}_{SM} = -\tfrac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \tfrac{1}{4}g_s^2 f^{abc} f^{cde} g^b_\mu g^c_\nu g^d_\mu g^e_\nu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu - \\
&M^2 W^+_\mu W^-_\mu - \tfrac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \tfrac{1}{2c_0^2} M^2 Z^0_\mu Z^0_\mu - \tfrac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - igc_w(\partial_\nu Z^0_\mu(W^+_\mu W^-_\nu - \\
&W^+_\nu W^-_\mu) - Z^0_\nu(W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu(W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)) - \\
&igs_w(\partial_\nu A_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu(W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + A_\mu(W^+_\nu \partial_\nu W^-_\mu - \\
&W^-_\nu \partial_\nu W^+_\mu)) - \tfrac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \tfrac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c_w^2(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - \\
&Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2 s_w^2(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w(A_\mu Z^0_\mu(W^+_\mu W^-_\nu - \\
&W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu) - \tfrac{1}{2}\partial_\mu H \partial_\mu H - 2M^2\alpha_h H^2 - \partial_\mu\phi^+\partial_\mu\phi^- - \tfrac{1}{2}\partial_\mu\phi^0\partial_\mu\phi^0 - \\
&\beta_h\left(\tfrac{2M^2}{g^2} + \tfrac{2M}{g}H + \tfrac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)\right) + \tfrac{2M^4}{g^2}\alpha_h - \\
&g\alpha_h M(H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-) - \\
&\tfrac{1}{8}g^2\alpha_h(H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2H^2) - \\
&gMW^+_\mu W^-_\mu H - \tfrac{1}{2}g\tfrac{M}{c_0^2}Z^0_\mu Z^0_\mu H - \\
&\tfrac{1}{2}ig\left(W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)\right) + \\
&\tfrac{1}{2}g\left(W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) + W^-_\mu(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)\right) + \tfrac{1}{2}g\tfrac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) + \\
&M(\tfrac{1}{c_w}Z^0_\mu\partial_\mu\phi^0 + W^+_\mu\partial_\mu\phi^- + W^-_\mu\partial_\mu\phi^+) - ig\tfrac{s_0^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) + igs_w MA_\mu(W^+_\mu\phi^- - \\
&W^-_\mu\phi^+) - ig\tfrac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) + igs_w A_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \\
&\tfrac{1}{4}g^2 W^+_\mu W^-_\mu(H^2 + (\phi^0)^2 + 2\phi^+\phi^-) - \tfrac{1}{8}g^2\tfrac{1}{c_w^2}Z^0_\mu Z^0_\mu(H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2\phi^+\phi^-) - \\
&\tfrac{1}{2}g^2\tfrac{s_0^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) - \tfrac{1}{2}ig^2\tfrac{s_0^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \tfrac{1}{2}g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- + \\
&W^-_\mu\phi^+) + \tfrac{1}{2}ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\tfrac{s_w}{c_w}(2c_w^2 - 1)Z^0_\mu A_\mu\phi^+\phi^- - \\
&g^2 s_w^2 A_\mu A_\mu\phi^+\phi^- + \tfrac{1}{2}ig_s\lambda^a_{ij}(\bar{q}^i_\sigma\gamma^\mu q^\sigma_j)g^a_\mu - \bar{e}^\lambda(\gamma\partial + m^\lambda_e)e^\lambda - \bar{\nu}^\lambda(\gamma\partial + m^\lambda_\nu)\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + \\
&m^\lambda_u)u^\lambda_j - \bar{d}^\lambda_j(\gamma\partial + m^\lambda_d)d^\lambda_j + igs_w A_\mu\left(-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \tfrac{2}{3}(\bar{u}^\lambda_j\gamma^\mu u^\lambda_j) - \tfrac{1}{3}(\bar{d}^\lambda_j\gamma^\mu d^\lambda_j)\right) + \\
&\tfrac{ig}{4c_w}Z^0_\mu\{(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s_w^2 - 1 - \gamma^5)e^\lambda) + (\bar{d}^\lambda_j\gamma^\mu(\tfrac{4}{3}s_w^2 - 1 - \gamma^5)d^\lambda_j) + \\
&(\bar{u}^\lambda_j\gamma^\mu(1 - \tfrac{8}{3}s_w^2 + \gamma^5)u^\lambda_j)\} + \tfrac{ig}{2\sqrt{2}}W^+_\mu\left((\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)U^{lep}_{\lambda\kappa}e^\kappa) + (\bar{u}^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)\right) + \\
&\tfrac{ig}{2\sqrt{2}}W^-_\mu\left((\bar{e}^\kappa U^{lep\dagger}_{\kappa\lambda}\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\kappa\lambda}\gamma^\mu(1+\gamma^5)u^\lambda_j)\right) + \\
&\tfrac{ig}{2M\sqrt{2}}\phi^+\left(-m^\kappa_e(\bar{\nu}^\lambda U^{lep}_{\lambda\kappa}(1-\gamma^5)e^\kappa) + m^\lambda_\nu(\bar{\nu}^\lambda U^{lep}_{\lambda\kappa}(1+\gamma^5)e^\kappa)\right) + \\
&\tfrac{ig}{2M\sqrt{2}}\phi^-\left(m^\lambda_e(\bar{e}^\lambda U^{lep\dagger}_{\lambda\kappa}(1+\gamma^5)\nu^\kappa) - m^\kappa_\nu(\bar{e}^\lambda U^{lep\dagger}_{\lambda\kappa}(1-\gamma^5)\nu^\kappa)\right) - \tfrac{g}{2}\tfrac{m^\lambda_\nu}{M}H(\bar{\nu}^\lambda\nu^\lambda) - \\
&\tfrac{g}{2}\tfrac{m^\lambda_e}{M}H(\bar{e}^\lambda e^\lambda) + \tfrac{ig}{2}\tfrac{m^\lambda_\nu}{M}\phi^0(\bar{\nu}^\lambda\gamma^5\nu^\lambda) - \tfrac{ig}{2}\tfrac{m^\lambda_e}{M}\phi^0(\bar{e}^\lambda\gamma^5 e^\lambda) - \tfrac{1}{4}\bar{\nu}_\lambda M^R_{\lambda\kappa}(1-\gamma_5)\hat{\nu}_\kappa - \\
&\tfrac{1}{4}\overline{\nu_\lambda M^R_{\lambda\kappa}(1-\gamma_5)\hat{\nu}_\kappa} + \tfrac{ig}{2M\sqrt{2}}\phi^+\left(-m^\kappa_d(\bar{u}^\lambda_j C_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) + m^\lambda_u(\bar{u}^\lambda_j C_{\lambda\kappa}(1+\gamma^5)d^\kappa_j)\right) + \\
&\tfrac{ig}{2M\sqrt{2}}\phi^-\left(m^\lambda_d(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m^\kappa_u(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1-\gamma^5)u^\kappa_j)\right) - \tfrac{g}{2}\tfrac{m^\lambda_u}{M}H(\bar{u}^\lambda_j u^\lambda_j) - \\
&\tfrac{g}{2}\tfrac{m^\lambda_d}{M}H(\bar{d}^\lambda_j d^\lambda_j) + \tfrac{ig}{2}\tfrac{m^\lambda_u}{M}\phi^0(\bar{u}^\lambda_j\gamma^5 u^\lambda_j) - \tfrac{ig}{2}\tfrac{m^\lambda_d}{M}\phi^0(\bar{d}^\lambda_j\gamma^5 d^\lambda_j) + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu\bar{G}^a G^b g^c_\mu + \\
&\bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 - \tfrac{M^2}{c_0^2})X^0 + \bar{Y}\partial^2 Y + igc_w W^+_\mu(\partial_\mu\bar{X}^0 X^- - \\
&\partial_\mu\bar{X}^+ X^0) + igs_w W^+_\mu(\partial_\mu\bar{Y}X^- - \partial_\mu\bar{X}^+ Y) + igc_w W^-_\mu(\partial_\mu\bar{X}^- X^0 - \\
&\partial_\mu\bar{X}^0 X^+) + igs_w W^-_\mu(\partial_\mu\bar{X}^- Y - \partial_\mu\bar{Y}X^+) + igc_w Z^0_\mu(\partial_\mu\bar{X}^+ X^+ - \\
&\partial_\mu\bar{X}^- X^-) + igs_w A_\mu(\partial_\mu\bar{X}^+ X^+ - \\
&\partial_\mu\bar{X}^- X^-) - \tfrac{1}{2}gM\left(\bar{X}^+ X^+ H + \bar{X}^- X^- H + \tfrac{1}{c_0^2}\bar{X}^0 X^0 H\right) + \tfrac{1-2c_0^2}{2c_w}igM(\bar{X}^+ X^0\phi^+ - \bar{X}^- X^0\phi^-) + \\
&\tfrac{1}{2c_w}igM(\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-) + igMs_w(\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-) + \\
&\tfrac{1}{2}igM(\bar{X}^+ X^+\phi^0 - \bar{X}^- X^-\phi^0)\,.
\end{aligned}
$$

Modello Standard verificato sperimentalmente con una precisione di una parte su 10000 gia negli anni 90'
Ma per funzionare ha bisogno del meccanismo di HIggs

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

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(Received 26 June 1964)

It is of interest to inquire whether gauge vector mesons acquire mass through interaction[1]; by a gauge vector meson we mean a Yang-Mills field[2] associated with the extension of a Lie group from global to local symmetry. The importance of this problem resides in the possibility that strong-interaction physics originates from massive gauge fields related to a system of conserved currents.[3] In this note, we shall show that in certain cases vector mesons do indeed acquire mass when the vacuum is degenerate with respect to a compact Lie group.

Theories with degenerate vacuum (broken symmetry) have been the subject of intensive study since their inception by Nambu.[4-6] A

those vector mesons which are coupled to currents that "rotate" the original vacuum are the ones which acquire mass [see Eq. (6)].

We shall then examine a particular model based on chirality invariance which may have a more fundamental significance. Here we begin with a chirality-invariant Lagrangian and introduce both vector and pseudovector gauge fields, thereby guaranteeing invariance under both local phase and local γ_5-phase transformations. In this model the gauge fields themselves may break the γ_5 invariance leading to a mass for the original Fermi field. We shall show in this case that the pseudovector field acquires mass.

In the last paragraph we sketch a simple argument which renders these results reason-

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

In a recent note[1] it was shown that the Goldstone theorem,[2] that Lorentz-covariant field theories in which spontaneous breakdown of symmetry under an internal Lie group occurs contain zero-mass particles, fails if and only if the conserved currents associated with the internal group are coupled to gauge fields. The purpose of the present note is to report that, as a consequence of this coupling, the spin-one quanta of some of the gauge fields acquire mass; the longitudinal degrees of freedom of these particles (which would be absent if their mass were zero) go over into the Goldstone bosons when the coupling tends to zero. This phenomenon is just the relativistic analog of the plasmon phenomenon to which Anderson[3] has drawn attention: that the scalar zero-mass excitations of a superconducting neutral Fermi gas become longitudinal plasmon modes of finite mass when the gas is charged.

about the "vacuum" solution $\varphi_1(x) = 0$, $\varphi_2(x) = \varphi_0$:

$$\partial^\mu\{\partial_\mu(\Delta\varphi_1) - e\varphi_0 A_\mu\} = 0, \qquad (2a)$$

$$\{\partial^2 - 4\varphi_0^2 V''(\varphi_0^2)\}(\Delta\varphi_2) = 0, \qquad (2b)$$

$$\partial_\nu F^{\mu\nu} = e\varphi_0\{\partial^\mu(\Delta\varphi_1) - e\varphi_0 A_\mu\}. \qquad (2c)$$

Equation (2b) describes waves whose quanta have (bare) mass $2\varphi_0\{V''(\varphi_0^2)\}^{1/2}$; Eqs. (2a) and (2c) may be transformed, by the introduction of new variables

$$B_\mu = A_\mu - (e\varphi_0)^{-1}\partial_\mu(\Delta\varphi_1),$$
$$G_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu = F_{\mu\nu}, \qquad (3)$$

into the form

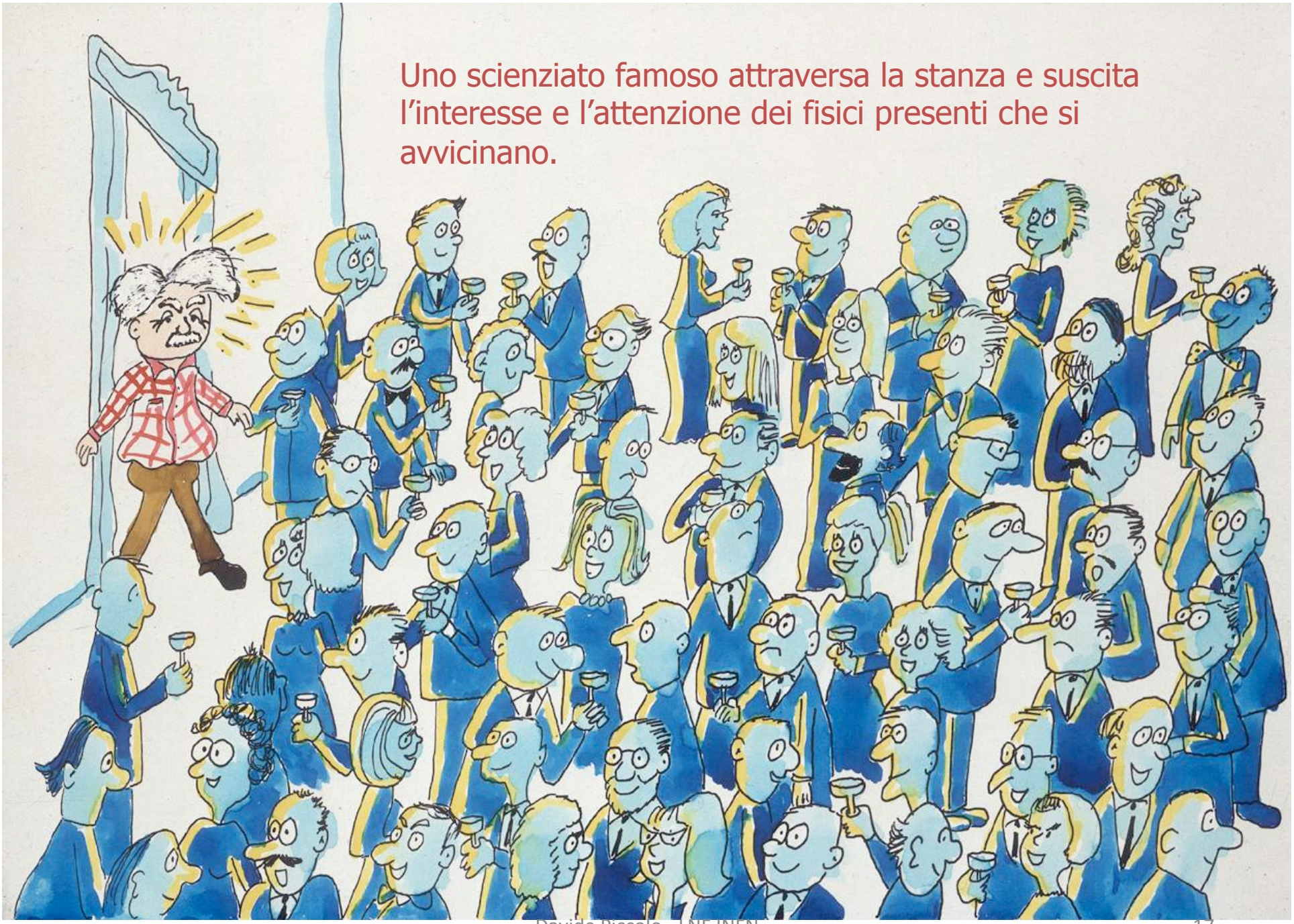
$$\partial_\mu B^\mu = 0, \quad \partial_\nu G^{\mu\nu} + e^2\varphi_0^2 B^\mu = 0. \qquad (4)$$

Ma cosa e' il meccanismo di Higgs ?

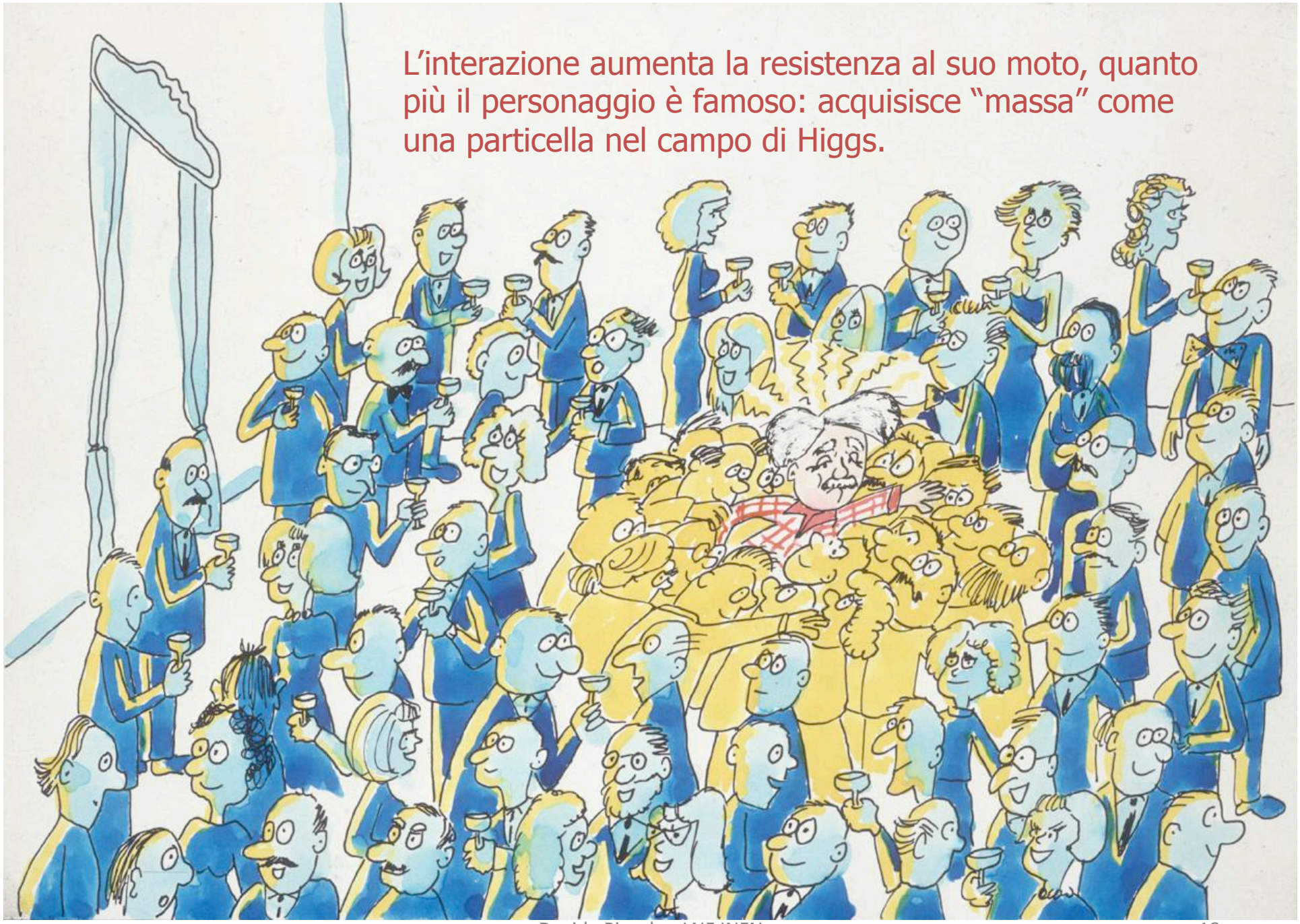
Lo spazio e' permeato da un campo (campo di Higgs) che permette di dare massa alle particelle.
Immaginiamo una stanza piena di fisici ....

David Miller, UCL
premio 1993 per la miglior spiegazione del bosone di Higgs

Uno scienziato famoso attraversa la stanza e suscita l'interesse e l'attenzione dei fisici presenti che si avvicinano.



L'interazione aumenta la resistenza al suo moto, quanto più il personaggio è famoso: acquisisce "massa" come una particella nel campo di Higgs.



Anche un pettegolezzo può attraversare la sala.

… e causa raggruppamenti di fisici: le particelle di Higgs.

Perche' abbiamo costruito LHC ?

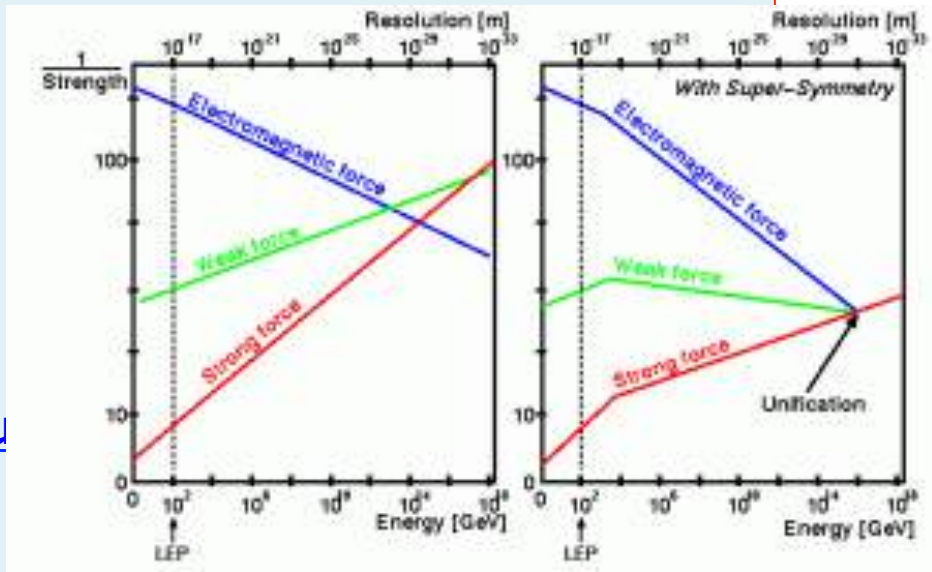
Scoprire il Bosone di Higgs

•Il Modello Standard funziona benissimo, ma se non si fosse trovato il Bosone di Higgs, non poteva essere corretto

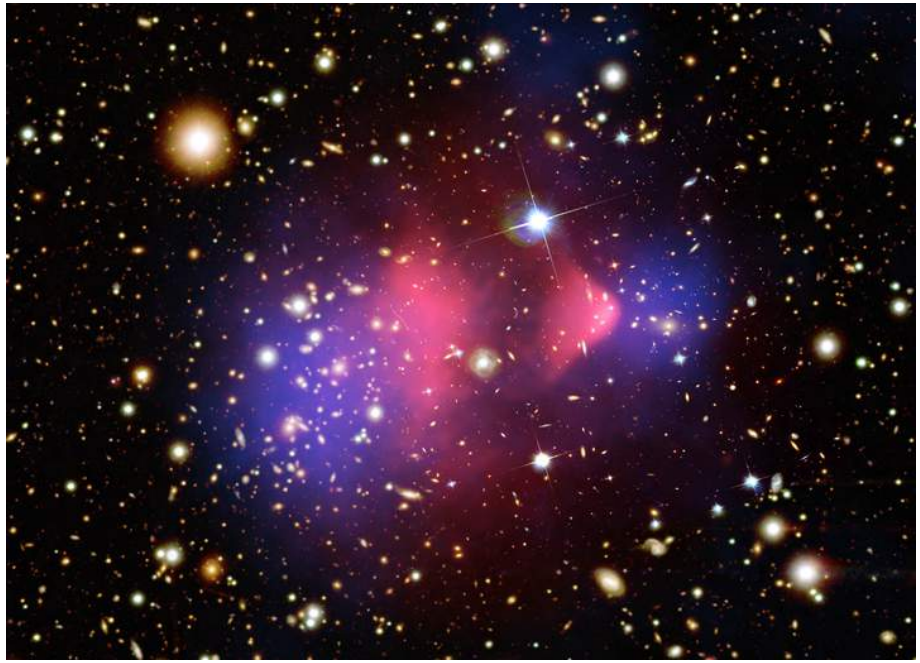
Grande Unificazione e SuperSimmetria

Le interazioni elettromagnetiche, deboli e forti non si unificano esattamente ad alta energia.
La Superimmetria modifica la Teoria in maniera da unificarle Esattamente

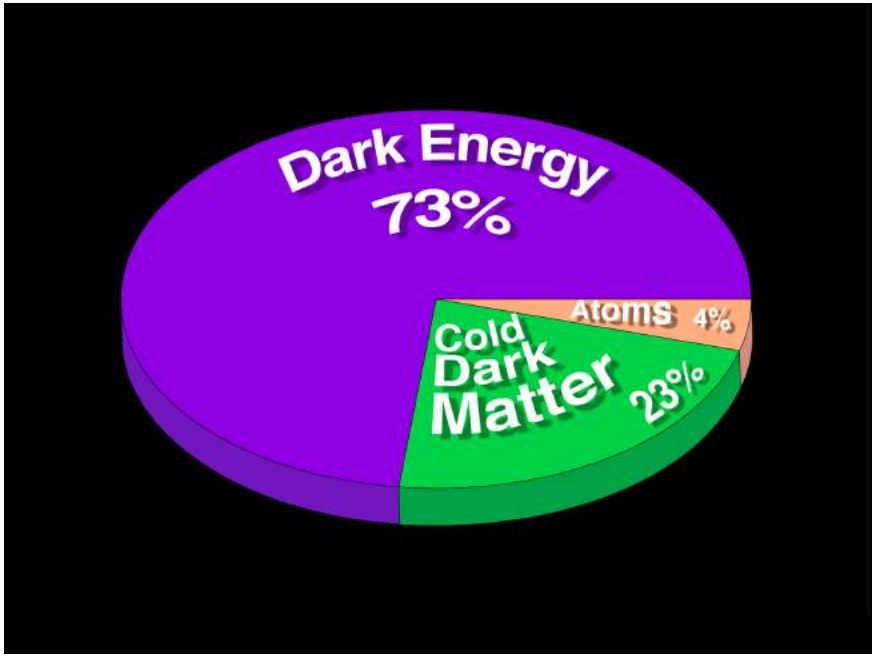
Inoltre da una spiegazione piu natu
All'esistenza del Bosone di Higgs



… altri misteri – La materia oscura



Il cluster Bullet (1E 0657-56). Due galassie in collisione. In rosso la concentrazione di materia visibile. In blue la materia oscura dedotta dall'effetto della lente gravitazionale

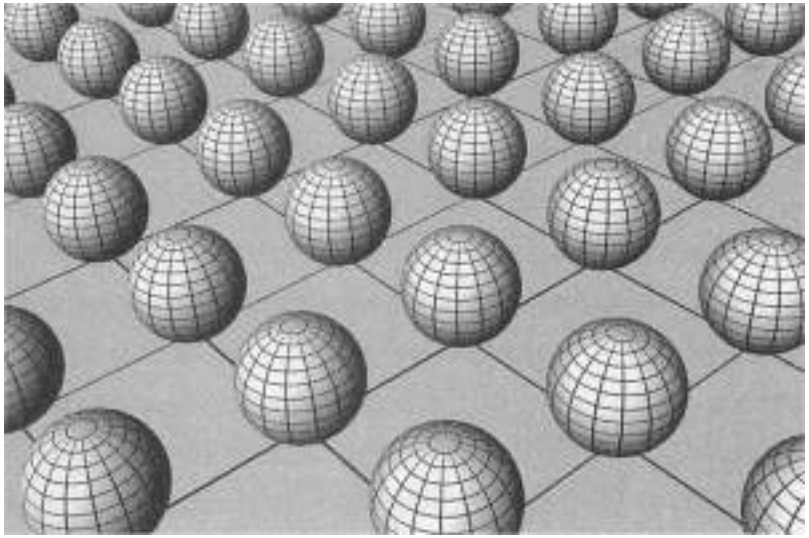


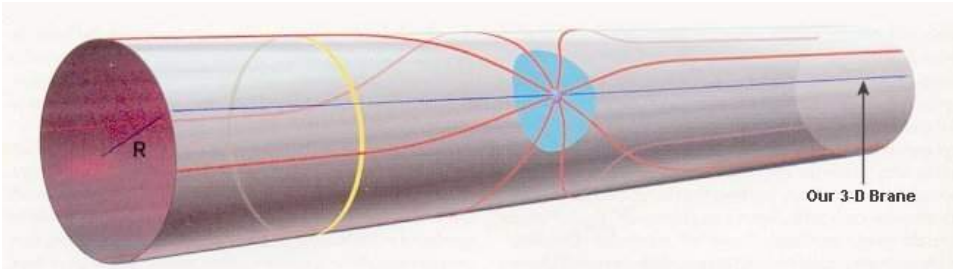
La materia ordinaria e' solo il 4%. Cio' che NON sappiamo e' molto piu' di cio' che sappiamo

Da cosa e' formata la materia oscura ?

Le particelle Supersimmetriche che potrebbero essere scoperte ad LHC rappresentano dei possibili candidati

Esistono dimensioni extra ? Ma soprattutto … qualcosa che non sospettiamo minimamente ?





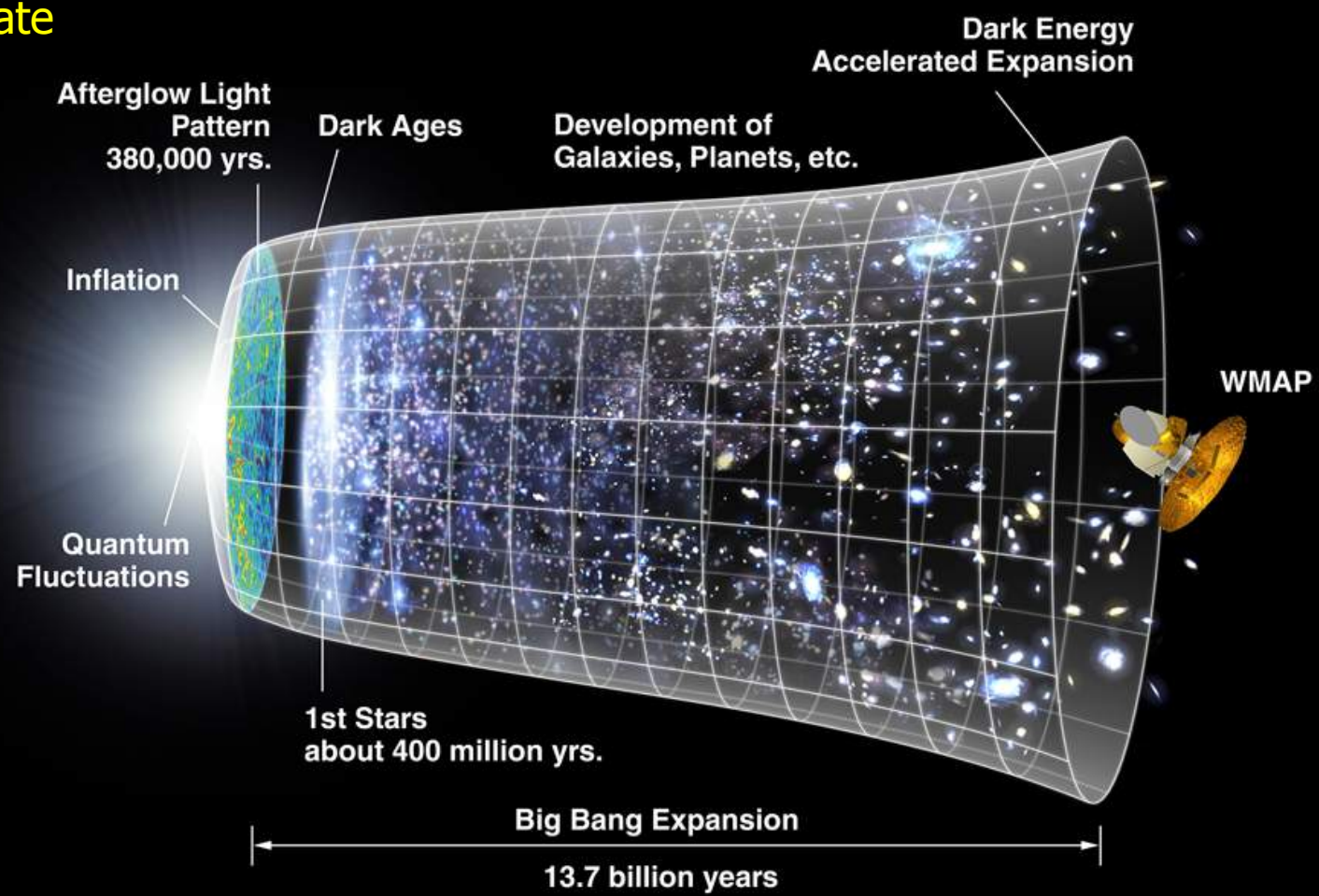
SMALL EXTRA DIMENSION wrapped in a circle (*circumference of tube*) modifies how gravity (*red lines*) spreads in space. At distances smaller than the circle radius (*blue patch*), the lines of force spread apart rapidly through all the dimensions. At much larger distances (*yellow circle*), the lines have filled the extra dimension, which has no further effect on the lines of force.

La cosa piu eccitante sarebbe scoprire qualcosa di completamente inatteso

Obiettivo di LHC

Riprodurre le condizioni dell'universo ~10^{-6} secondi dopo il big-bang per studiare fenomeni fisici mai osservati.

Esplorare I primi Istanti dell'universio, vuol dire esplorare le energie piu elevate

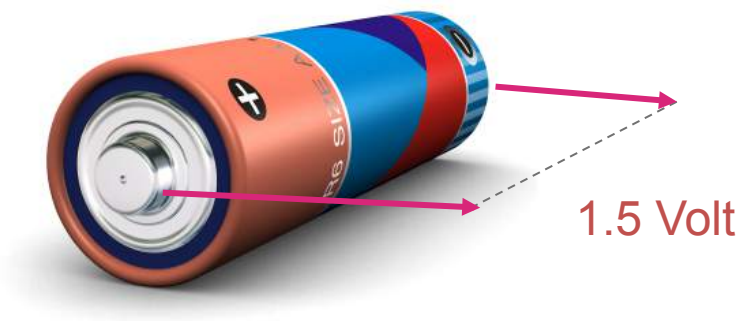


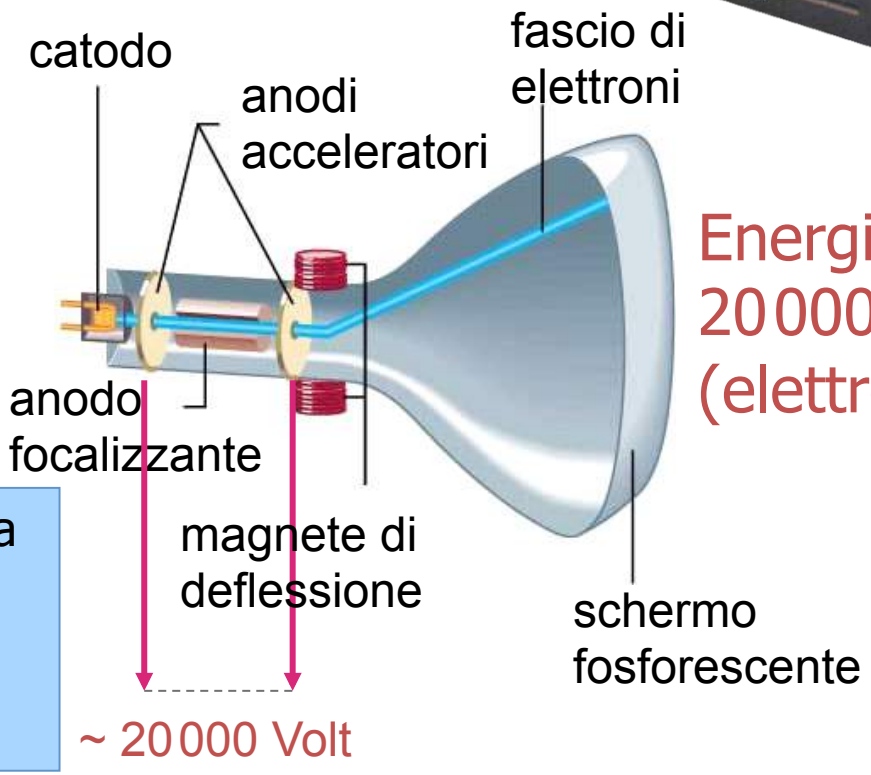
Gli strumenti per esplorare Il microcosmo

CERN – European Centre for Nuclear Research

Gli acceleratori

- Anche un vecchio televisore col tubo catodico è un acceleratore di elettroni!





Energia ≈ 20 000 eV (elettron×Volt)

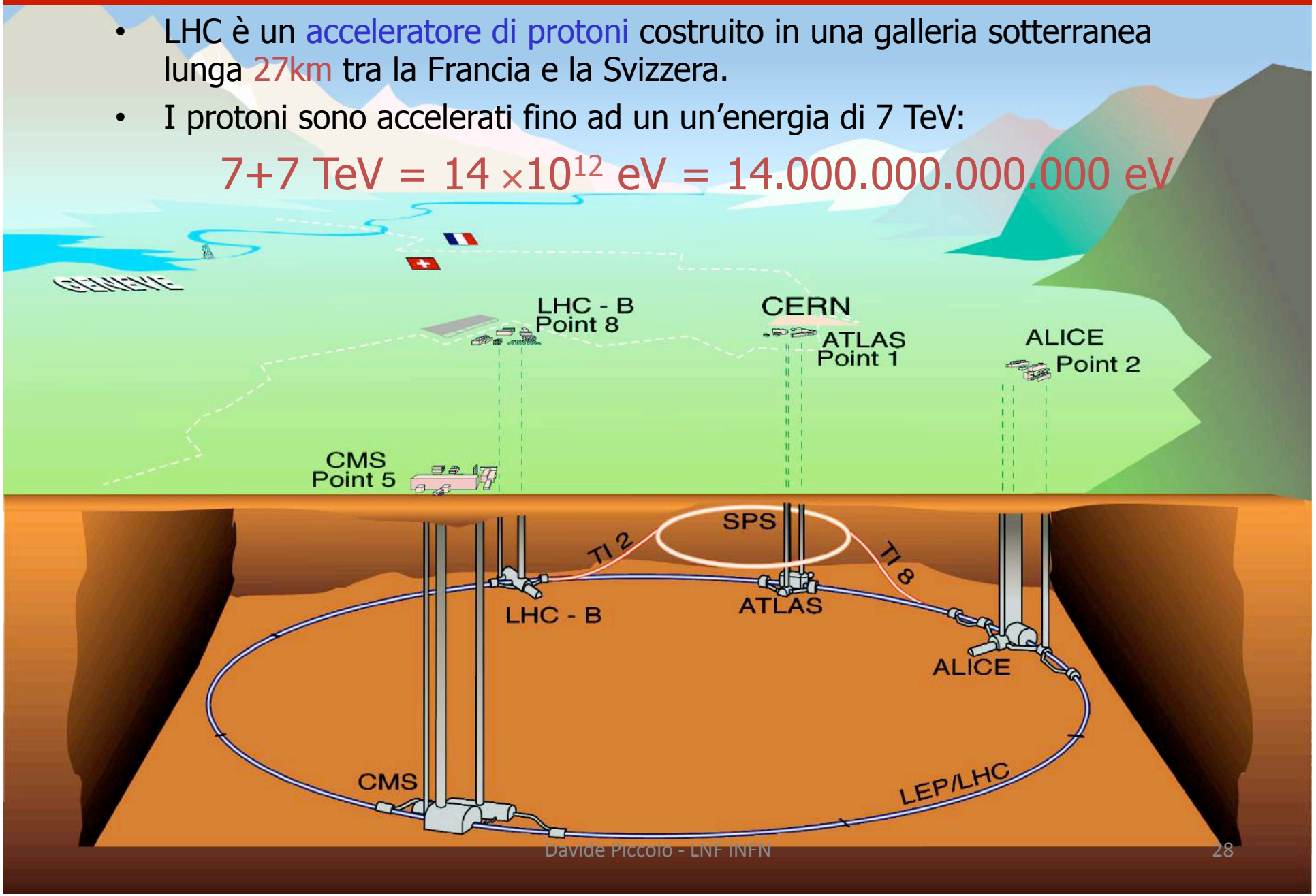
1 eV = Energia cinetica acquistata da un elettrone accelerato in un campo elettrostatico di potenziale 1 Volt

$$1\ \text{eV} = 1.6\times10^{-19}\ \text{J}$$

Il Large Hadron Collider

- LHC è un acceleratore di protoni costruito in una galleria sotterranea lunga 27km tra la Francia e la Svizzera.
- I protoni sono accelerati fino ad un un'energia di 7 TeV:

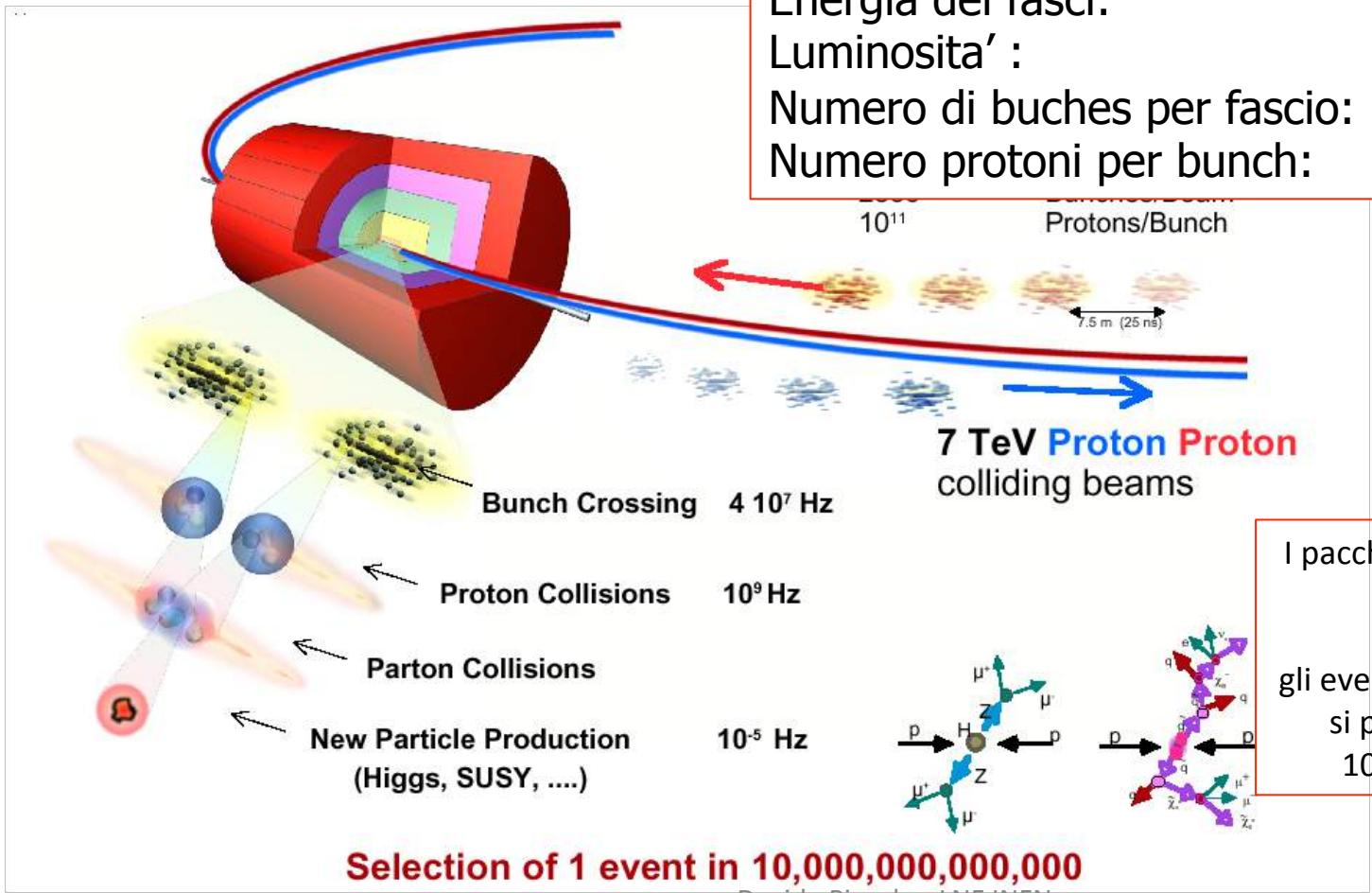
$$7+7 \text{ TeV} = 14 \times 10^{12} \text{ eV} = 14.000.000.000.000 \text{ eV}$$



LHC in numeri

LHC fa collidere protoni che vengono accelerati nel tunnel di 27 km ad una velocita pari al 99.999999% di quella della luce

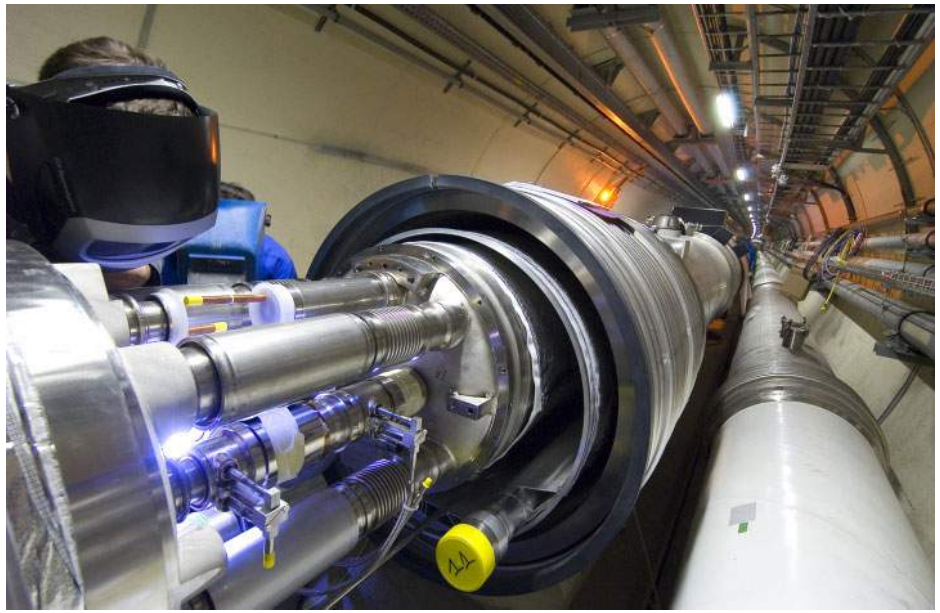
Energia dei fasci:	7×10^{12} eV
Luminosita' :	10^{34} cm^{-2} s^{-1}
Numero di buches per fascio:	2835
Numero protoni per bunch:	100 miliardi

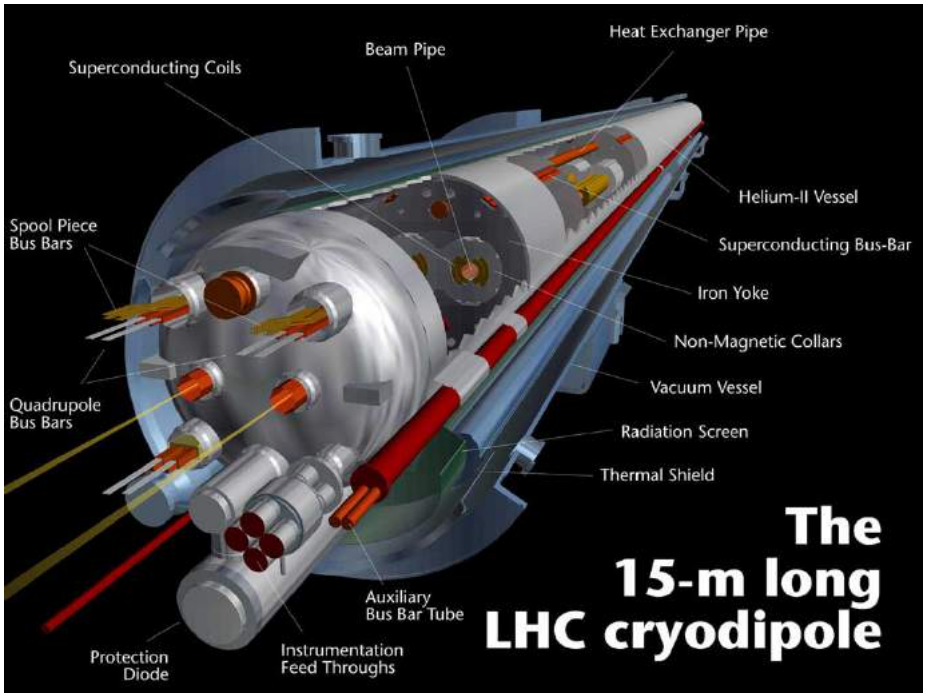


I pacchetti si incrociano 40 milioni di volte al secondo
MA
gli eventi interessanti (Higgs- Susy) si producono una volta ogni 10mila milardi di collisioni

LHC estremo - 1

LHC e' il luogo piu vuoto dell'universo





Per evitare che nel loro viaggio i protoni colpiscano molecole di aria , all'interno dell'acceleratore viene prodotto un vuoto piu spinto di quello presente nello spazio interstellare

LHC estremo - 2

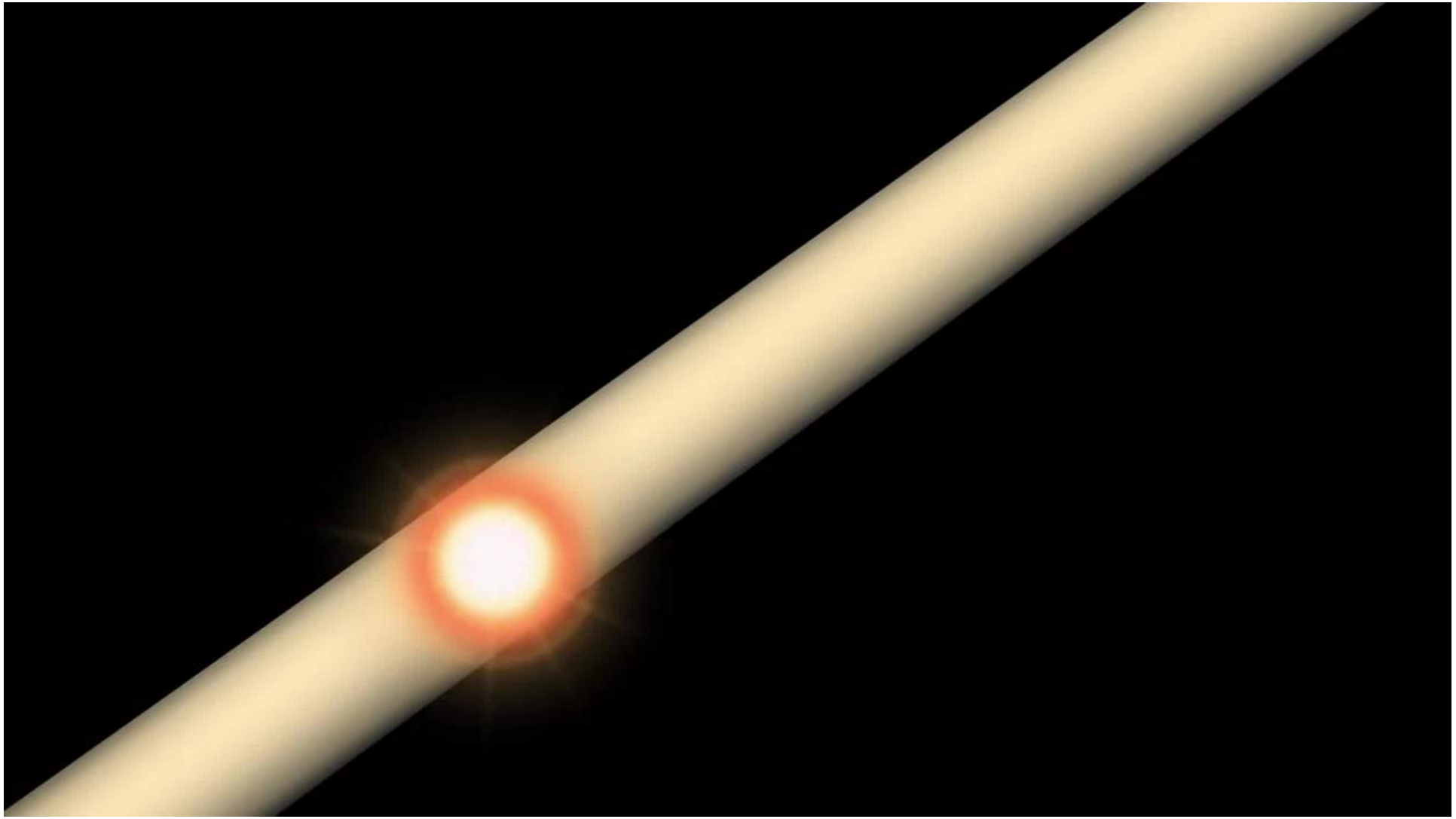
LHC e' il luogo piu freddo dell'universo

Per permettere di mantenere i fasci di protoni in circolo, vengono usati 1600 magneti superconduttori che producono campi magnetici 80000 volte piu intensi di quello terrestre.

Essi devono essere raffreddati da elio liquido superfluido mantenuto a -271.3 C (1.9 K)

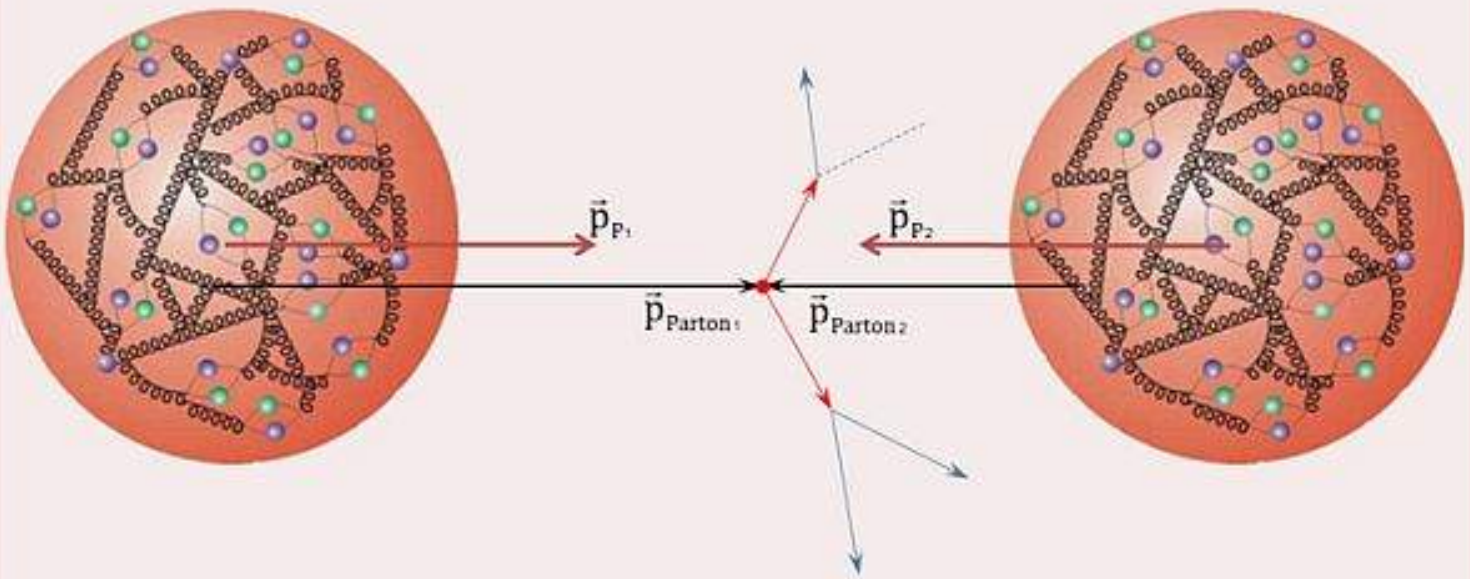
Questa e' una temperatura leggermente piu bassa di quella che si misura nello spazio interstellare

Il viaggio dei protoni dentro LHC



Collissione tra protoni

Il protone e' un oggetto molto piu complicato di una semplice pallina.
Sono I suoi costituenti base ossia quark e gluoni (chiamati genericamente partoni) che collidono



$\vec{p}_{P_1}$ ... momentum proton 1

$\vec{p}_{P_1}$ ... momentum proton 2

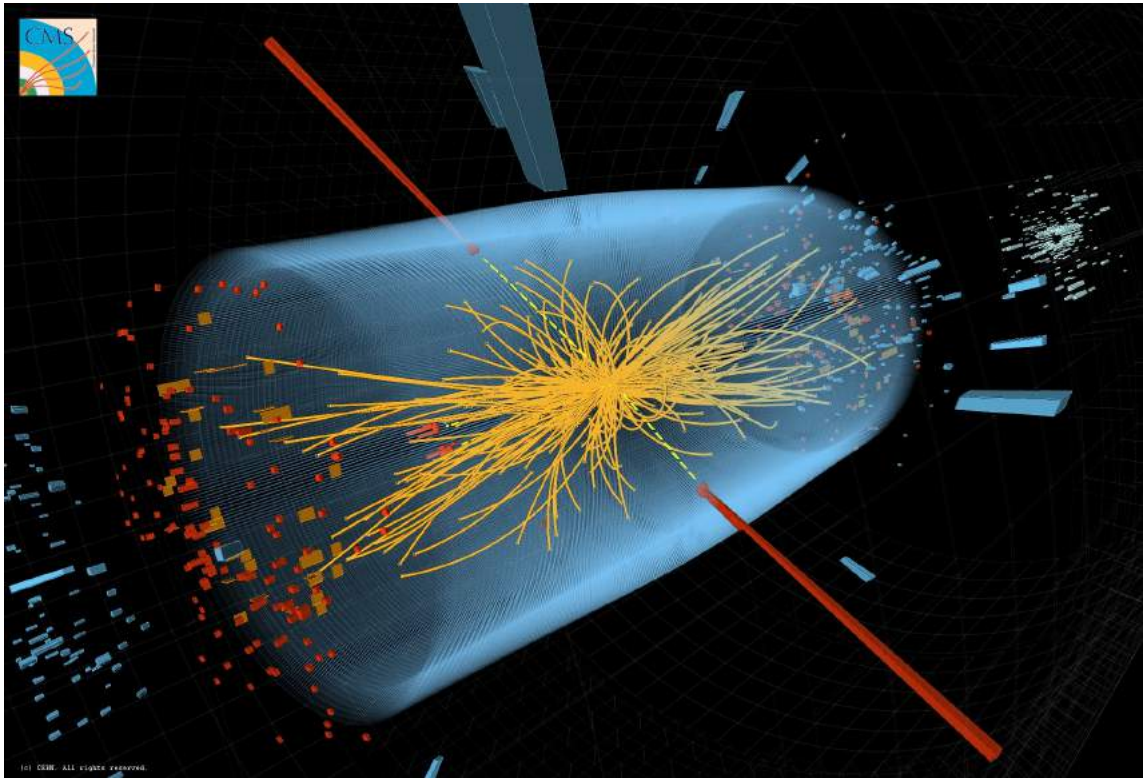
• interaction vertex

$\vec{p}_{Parton_1}$ ... momentum parton 1

$\vec{p}_{Parton_2}$ ... momentum parton 2

$E = mc^2$ ma anche $m = E/c^2$

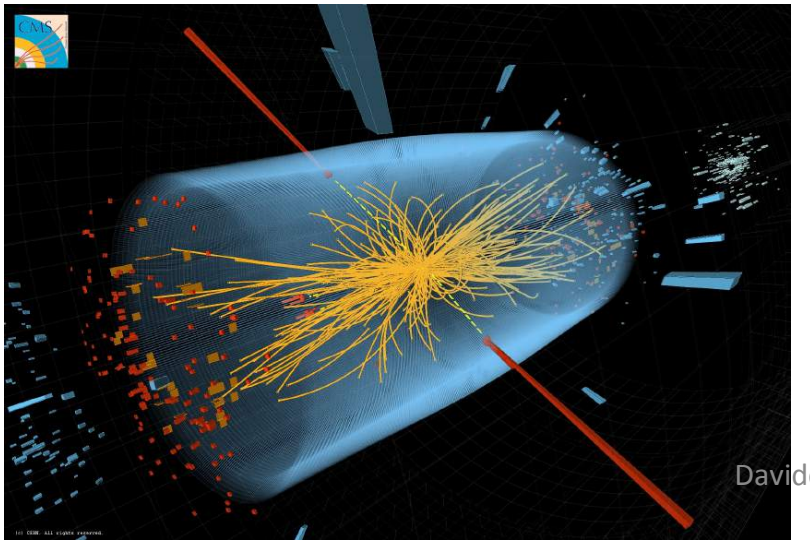
L'energia della collisione si puo' trasformare in massa. Particelle di massa molto elevate Possono essere prodotte (Higgs, susy)



Le nuove particelle generate non vivono abbastanza per essere identificate, ma decadono in altre particelle stabili che possiamo rivelare e fotografare

La nostra macchina fotografica: I rivelatori

Abbiamo bisogno
Di una potente macchina fotografica



rivelatori di particelle

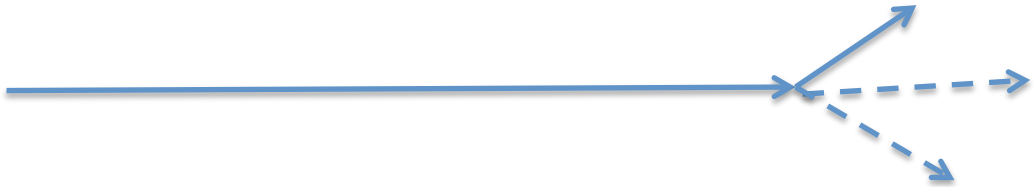
Quali particelle posso rivelare ?

Elettrone

fotone

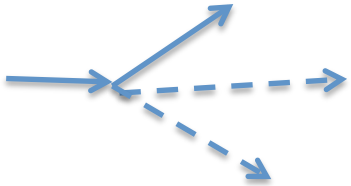
Partcielle stabili

Muone



Vita media 2.2 us
~ 600 m

tau

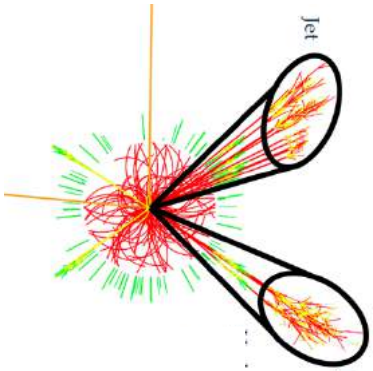


Vita media 0.3 ps
~ 0.1 mm

neutrini

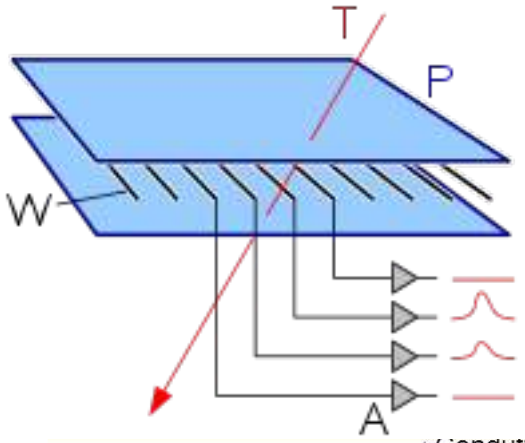
Interagiscono debolmente.
Energia mancante nel rivelatore

quarks

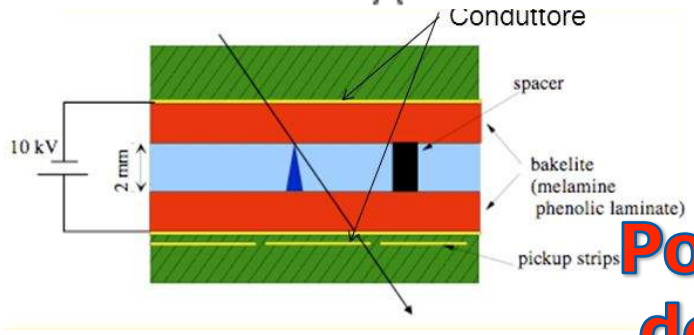


I quark non esistono isolati.
Adronizzano e si presentano sotto forma di "Getti" di particelle

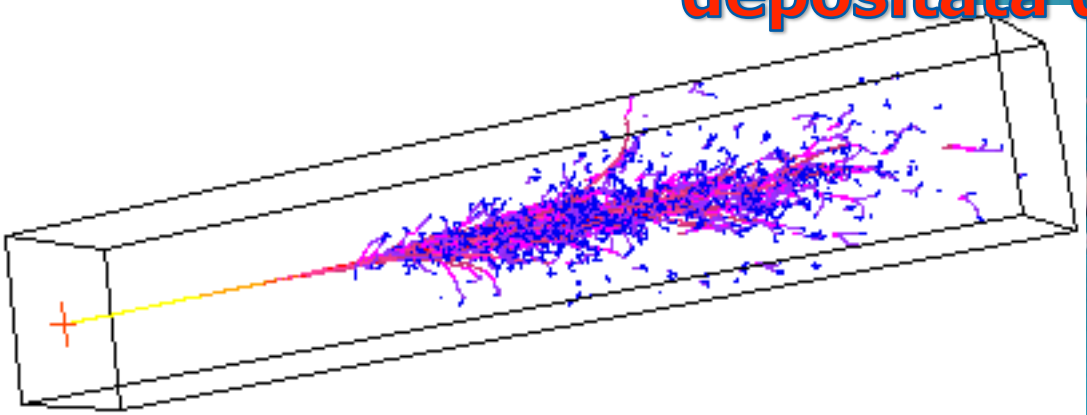
Cosa sono i rivelatori di particelle ?



Possono misurare la posizione di passaggio della particella



Possono misurare l'energia depositata dalla particella



Misurare la quantita' di moto

$\vec{F} = q * (\vec{v} \times \vec{B})$

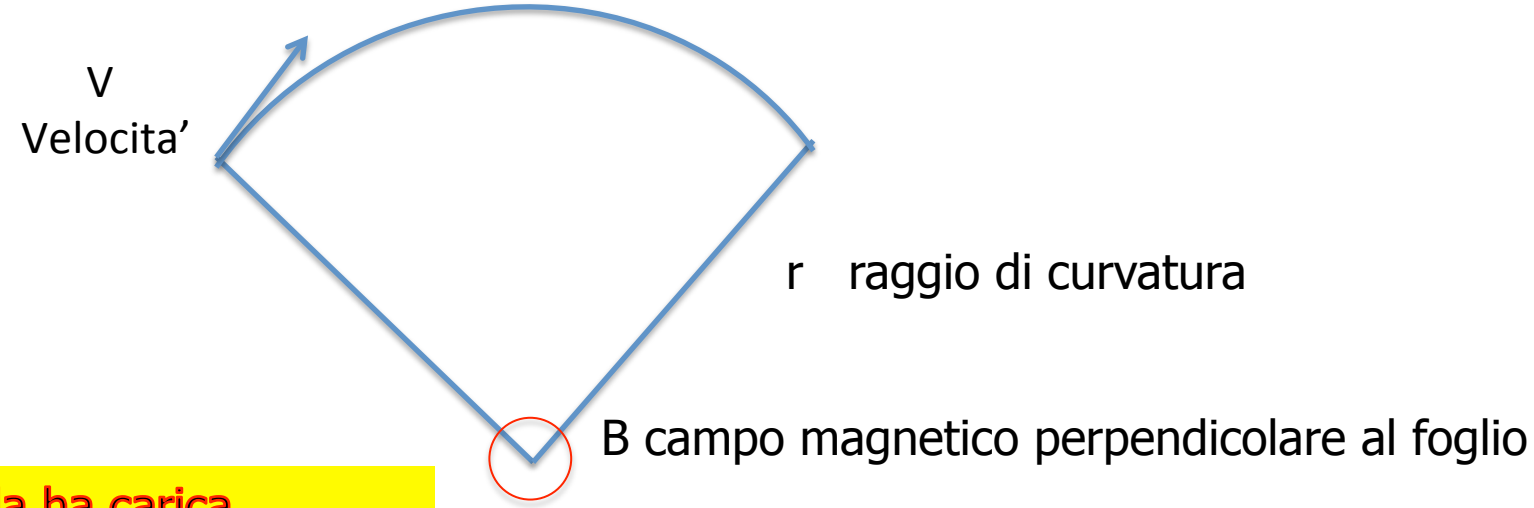
Nel piano perpendicolare al campo magneticom una particella carica percorre una traiettoria circolare

$F = m v^2/r$

Forza centripeta

$$P_T = mv = q\, r\, B$$

$$r = P_T/qB$$

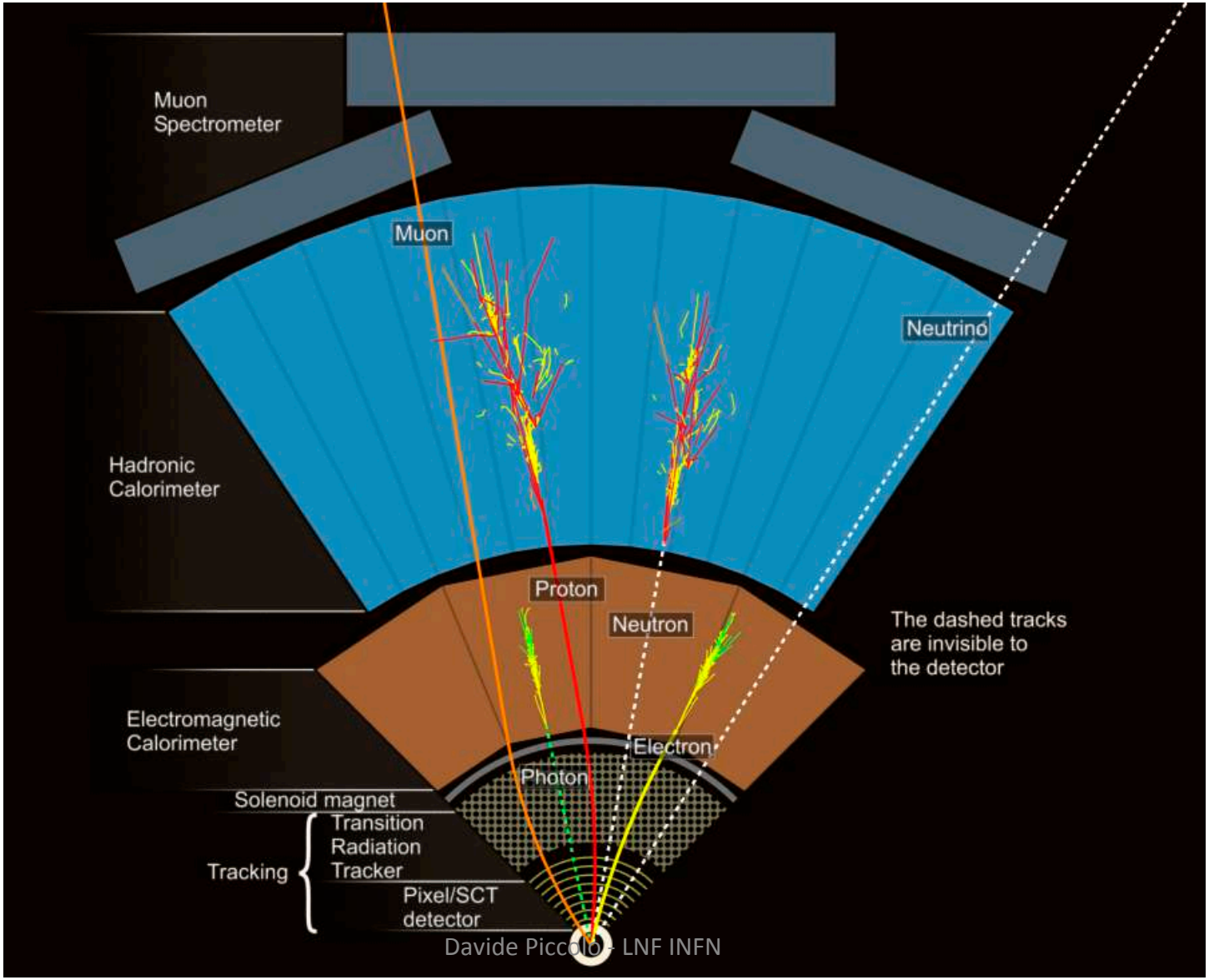


Se la partciella ha carica positiva si muove in senso orario altrimenti in senso antiorario

Maggiore e' la quantita di moto della particella
Maggiore il raggio di curvatura

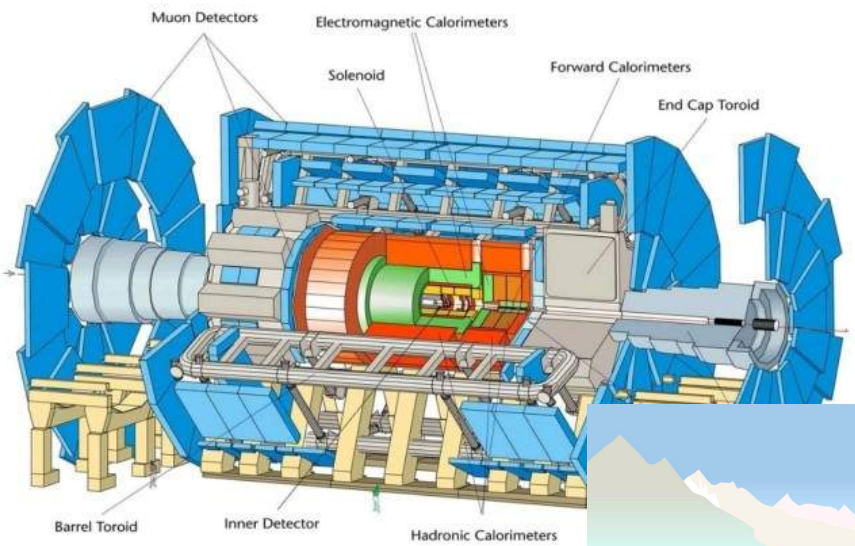
Organizzare i rivelatori

CMS come esempio generale

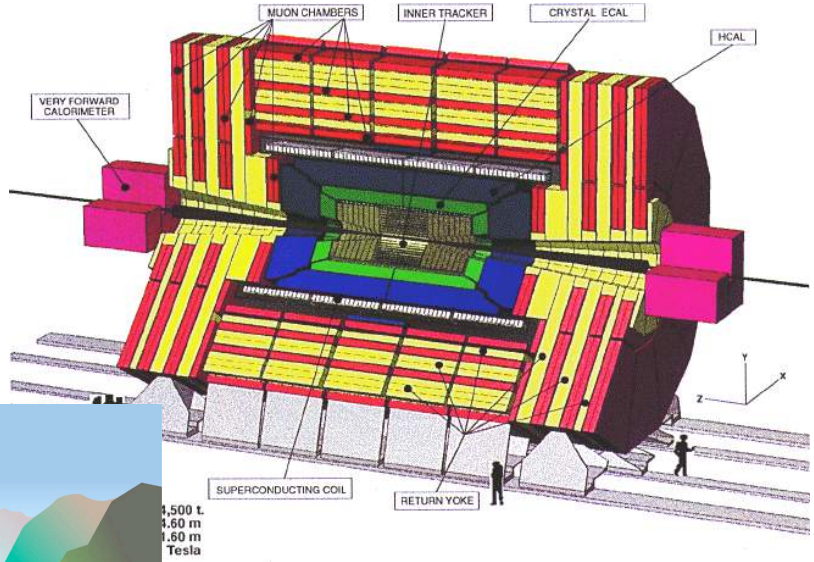


https://www.i2u2.org/elab/cms/graphics/CMS_Slice_elab.swf

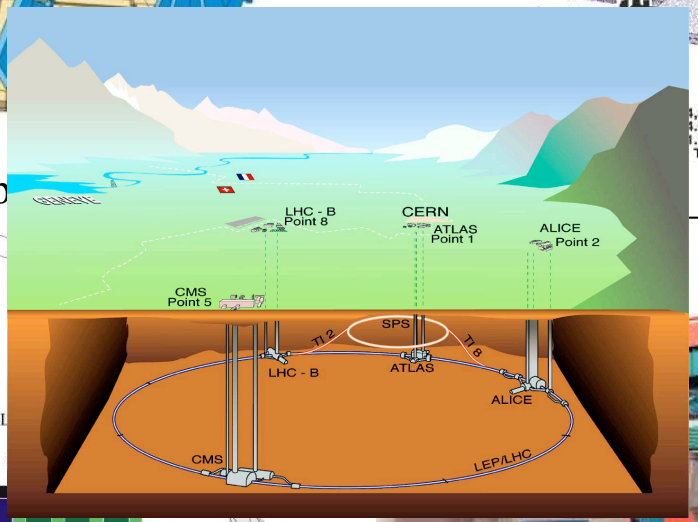
ATLAS, CMS, ALICE ed LHCb

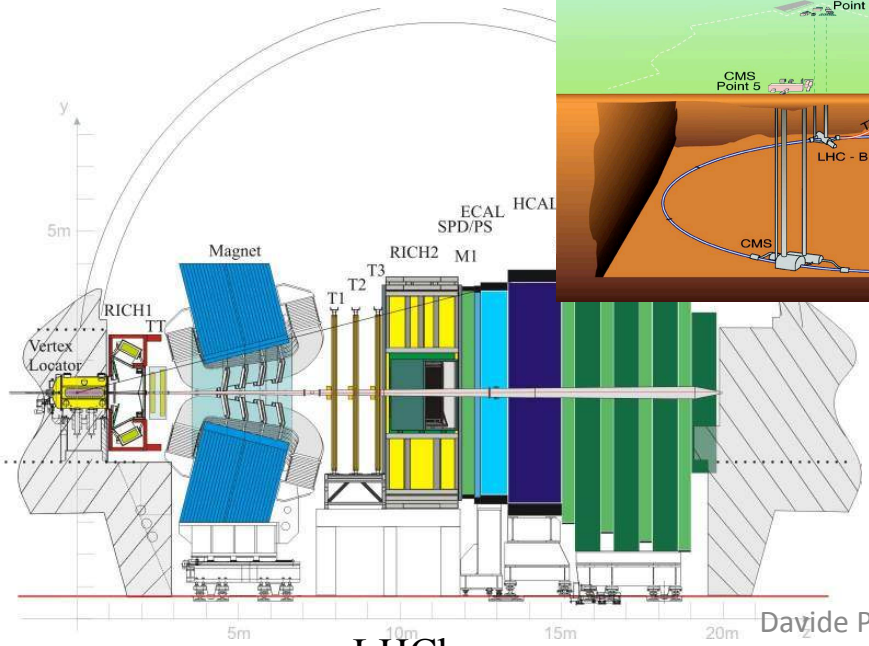


ATLAS – A Toroidal LHC Ap



– Compact Muon Solenoid





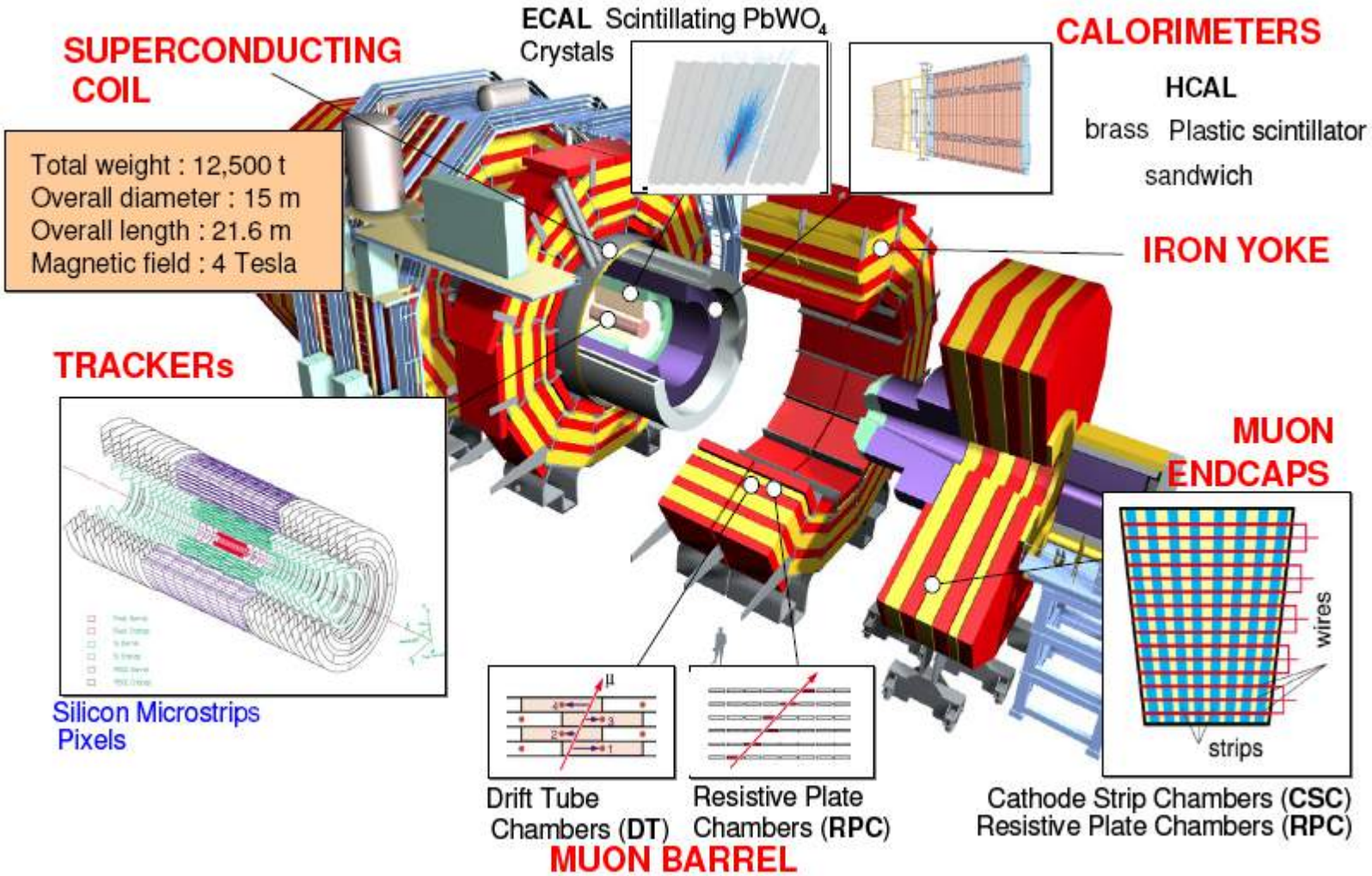
LHCb

ALICE – A Large Ion Collider Experiment

CMS una macchina fotografica molto complessa

Un rivelatore con 140 milioni di canali
che scatta 40 milioni di foto al secondo

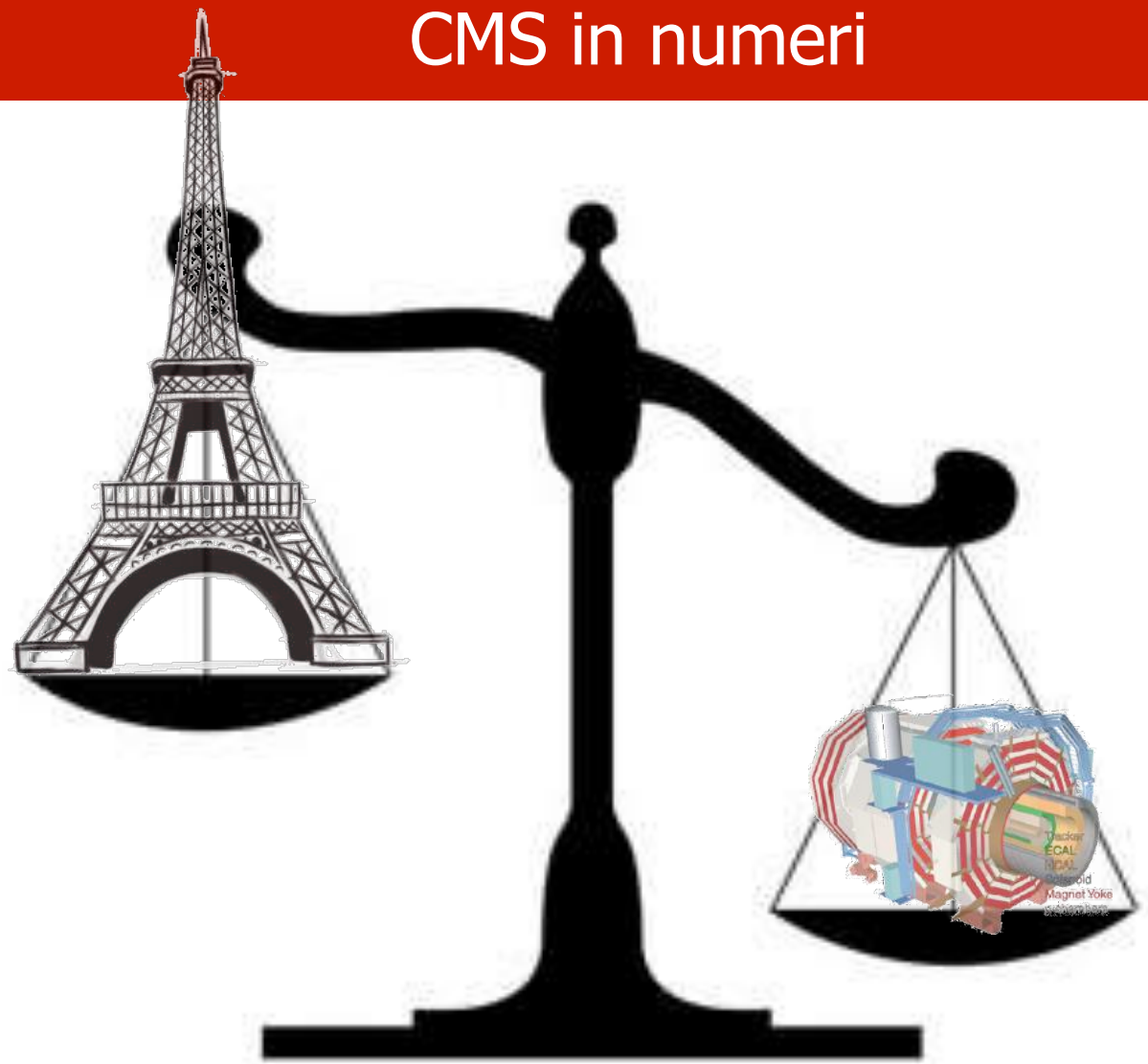
CMS


SUPERCONDUCTING COIL
Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla
ECAL Scintillating PbWO4 Crystals
CALORIMETERS
HCAL
brass Plastic scintillator sandwich
IRON YOKE
TRACKERs
Silicon Microstrips
Pixels
MUON ENDCAPS
wires
strips
Drift Tube Chambers (DT)
Resistive Plate Chambers (RPC)
Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)
MUON BARREL

Il sito di CMS nel 1999

Il sito di CMS nel 2000

CMS in numeri

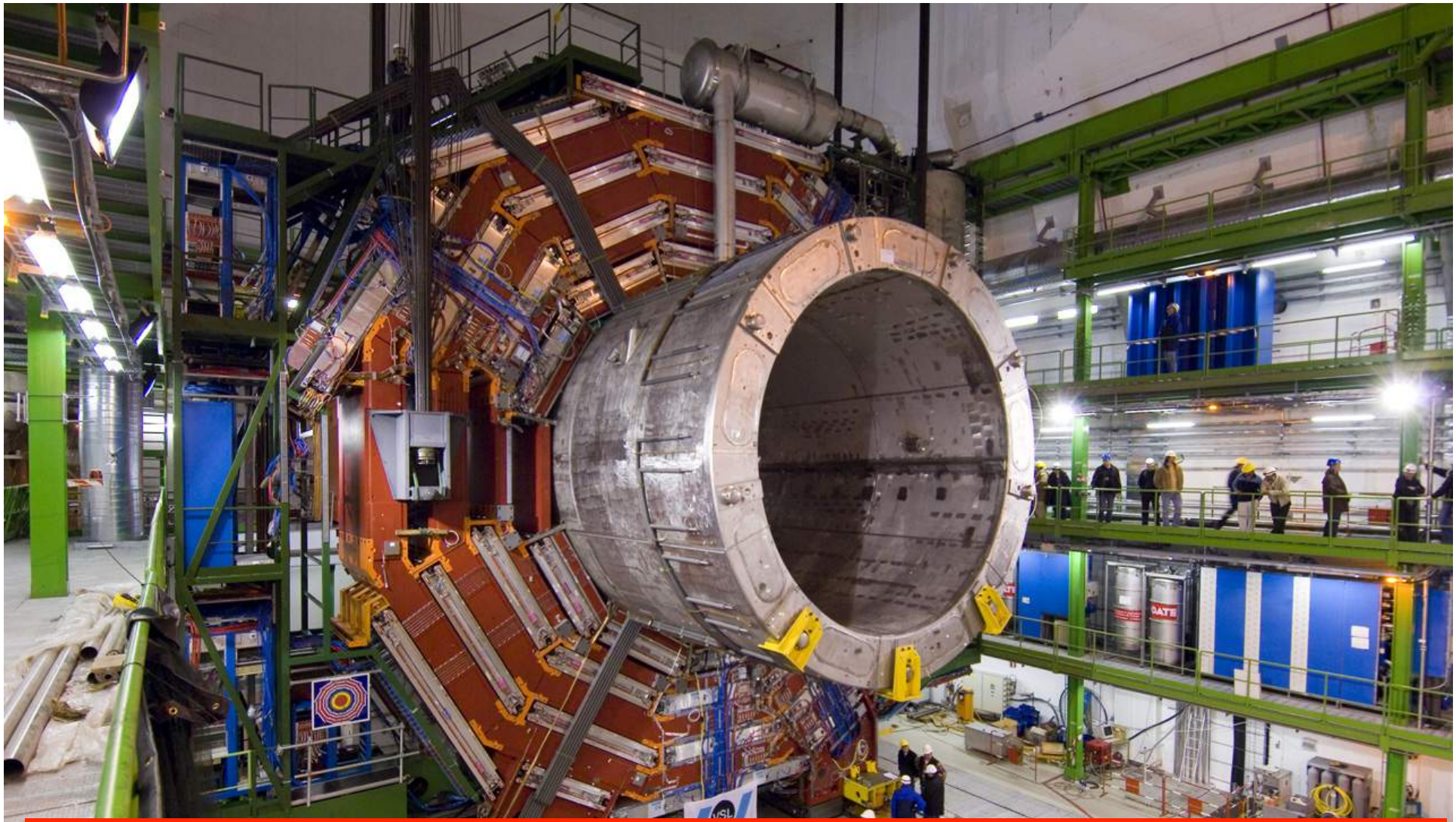


CMS con le sue quasi 14000 tonnellate e` l'esperimento piu` pesante dell'LHC. Pesa quasi il doppio della Torre Eiffel ma, misurando 15 metri di diametro e 21.5 metri di lunghezza, occupa un volume 400 volte piu' piccolo

CMS e` stato costruito in 15 grandi sezioni e molti altri pezzi piu` piccoli. Ogni parte dell'esperimento forma uno strato attorno al tubo del fascio

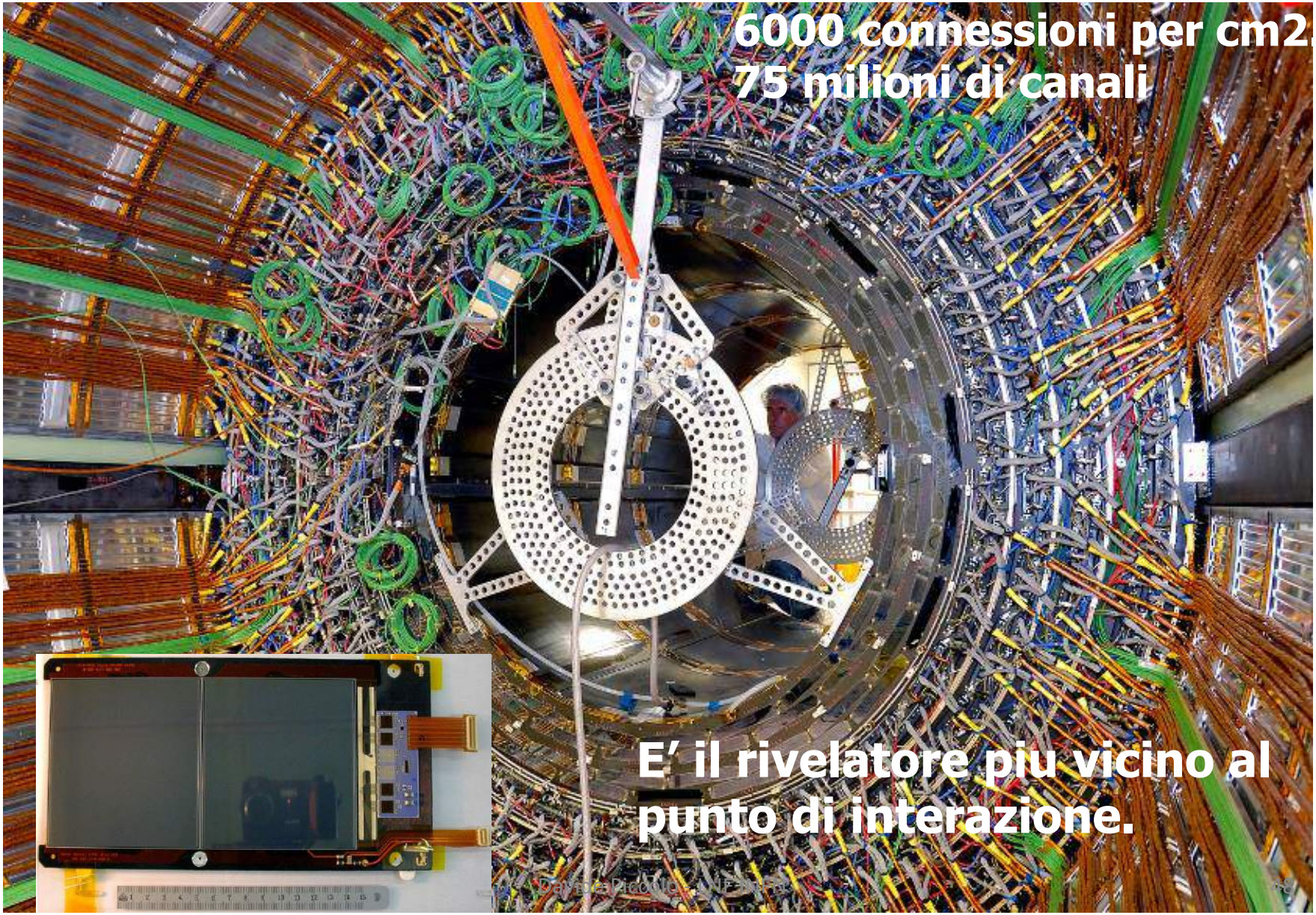
Ogni pezzo e' assemblato in superfice e poi calato nel pozzo a 100 mt di profondita'

Il pezzo più grande è giù (2006)



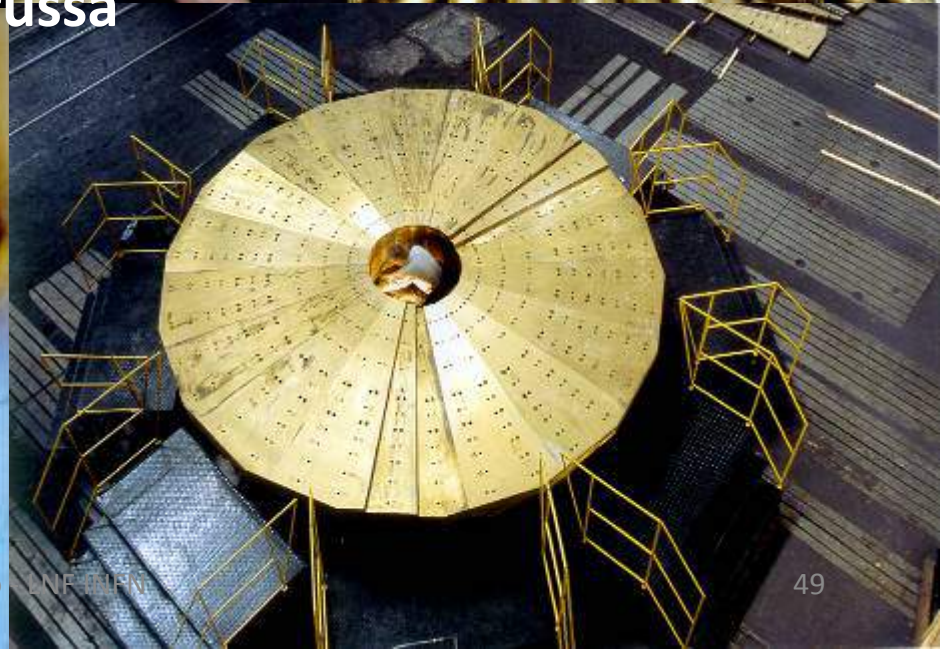
La sezione piu` pesante arriva a quasi 2000 tonnellate e ci sono volute 12 ore per farla scendere dal momento che c'erano solo 10 centimetri di margine con le pareti del pozzo.

Il tracciatore a silici

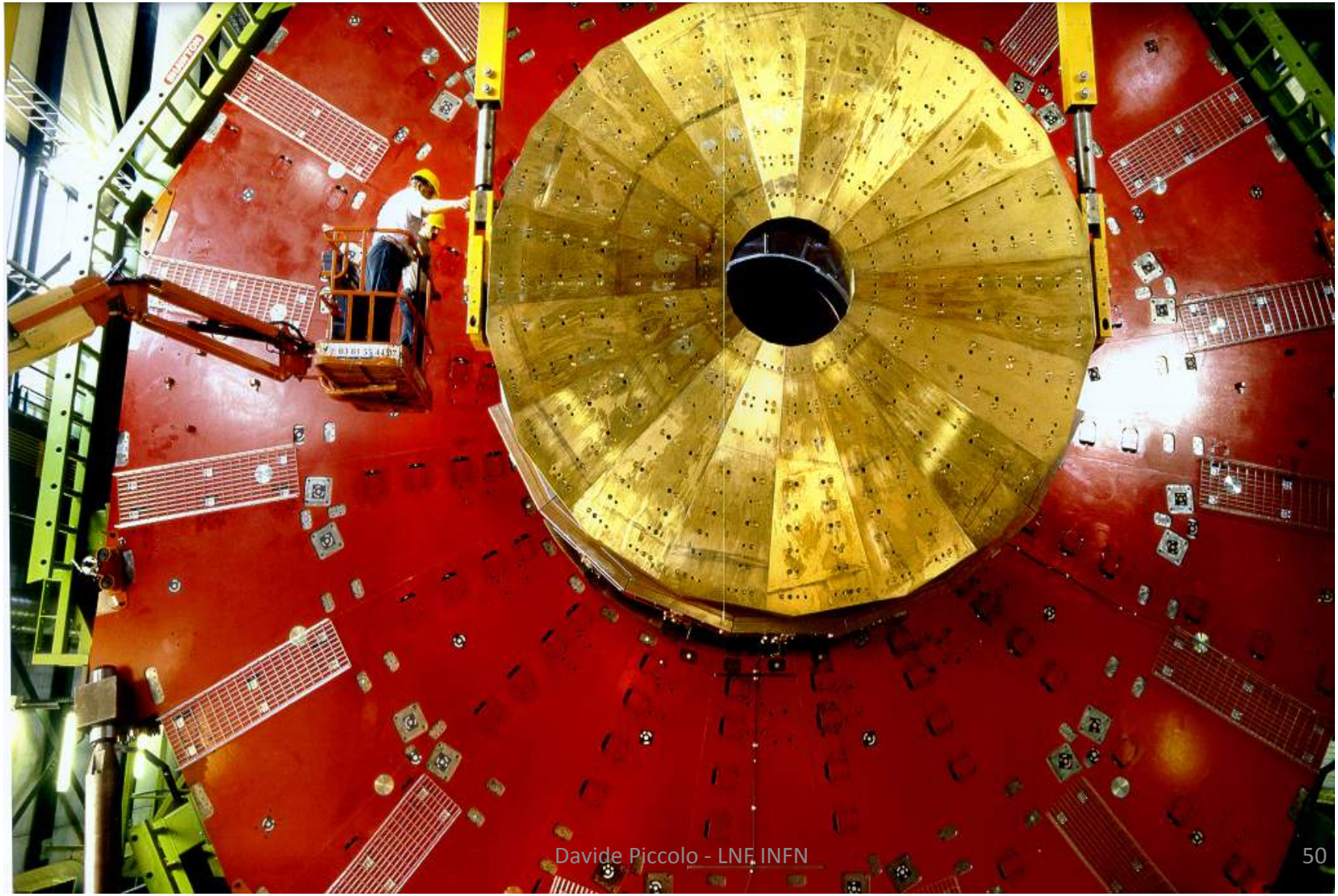


Il calorimetro adronico e l'iniziativa dei fisici

Un milione di bossoli di ottone della marina russa

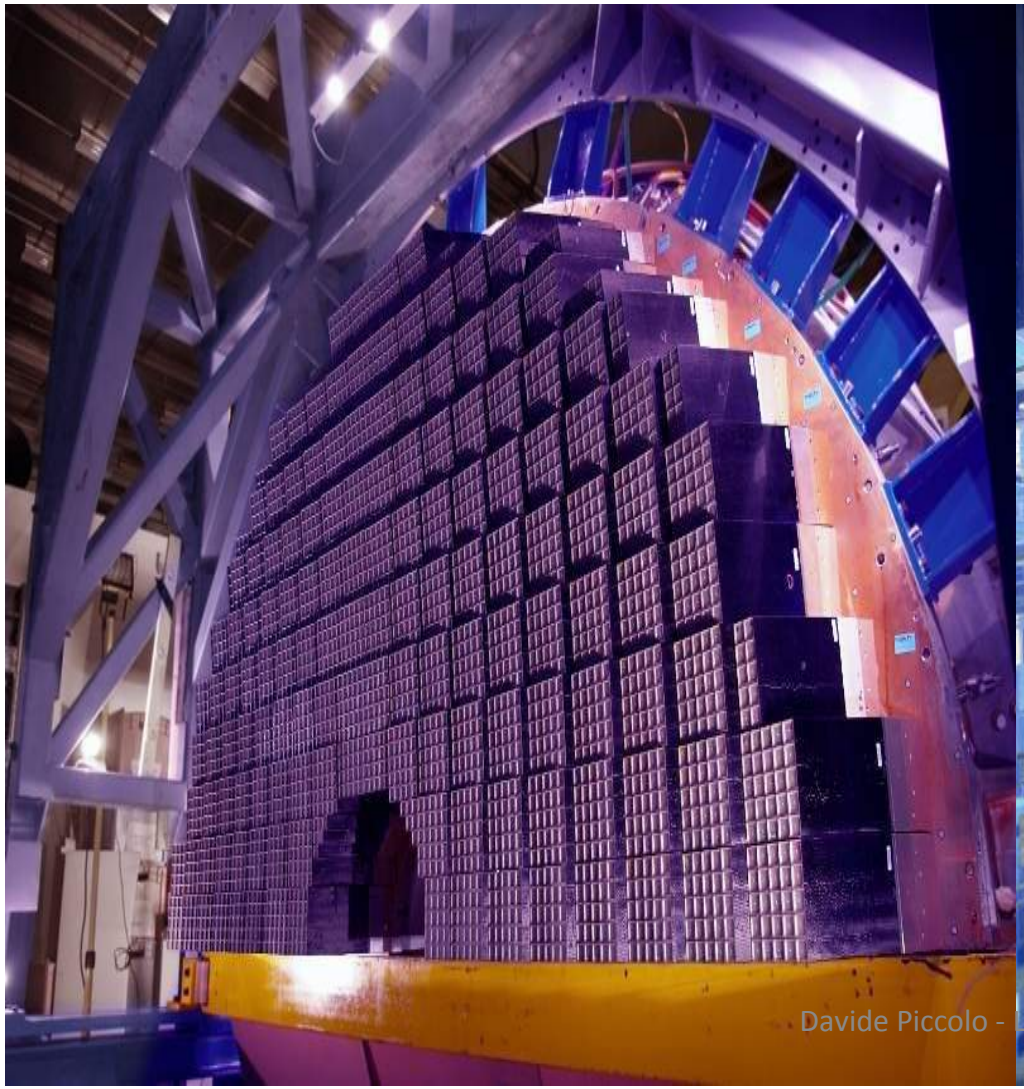


Il calorimetro adronico endcap



CMS – il calorimetro elettromagnetico

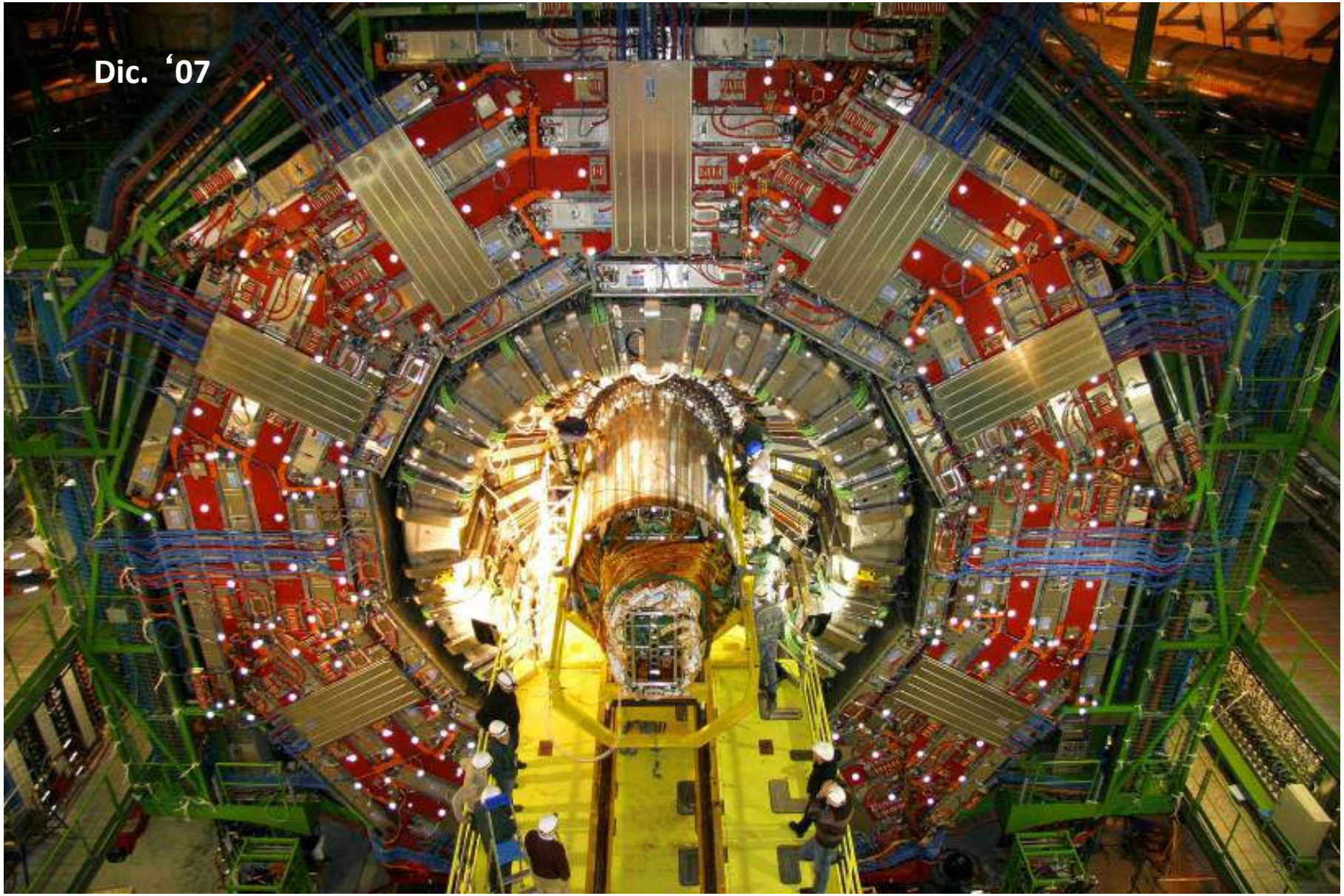
75648 cristalli di tungstato di piombo.
Nonostante siano costituiti per l'86% da metallo, sono perfettamente trasparenti



Il sistema dei Muoni

1400 camere di rivelazione:
2 milioni di fili sottilissimi come un capello che misurano la posizione del passaggio delle particelle con una precisione inferiore al millimetro.
~ 200000 canali che individuano il passaggio delle particelle con una precisione di pochi miliardesimi di secondo

Ora è tutto completo !

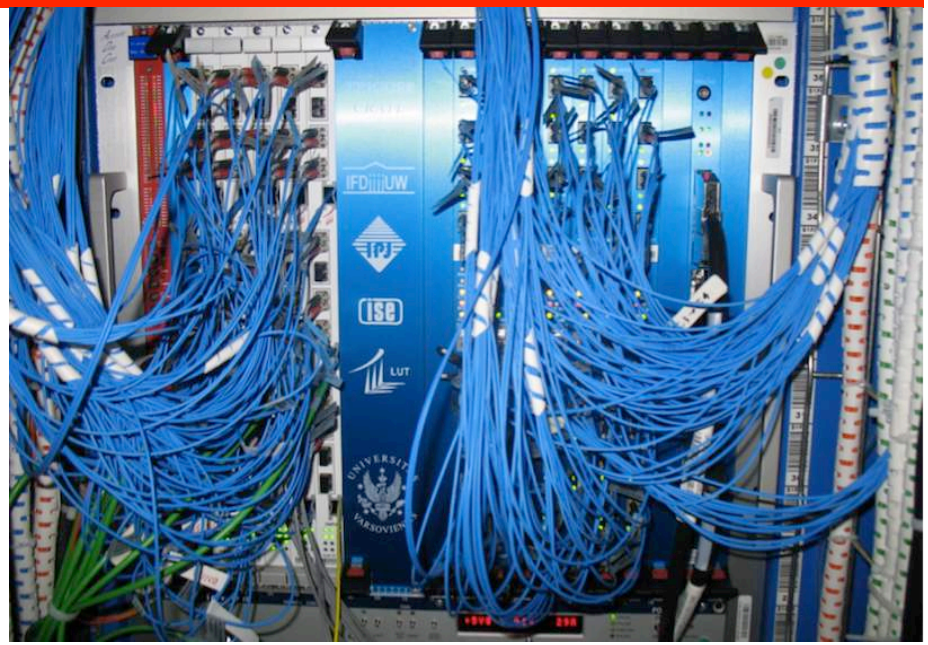


Il trigger di CMS

CMS e' una macchina fotografica che deve acquisire immagini 3-dimensionali di 100 Mpixel ciascuna delle collisioni dei protoni.

1 Miliardo di collisioni al secondo.

CMS deve capire quali siano di interesse in pochi miliardesimi di secondo



Elettronica sofisticatissima permette
di identificare solo 100 eventi al secondo
Che vengono poi memorizzati su disco

Conservare I dati e analizzarli: La griglia

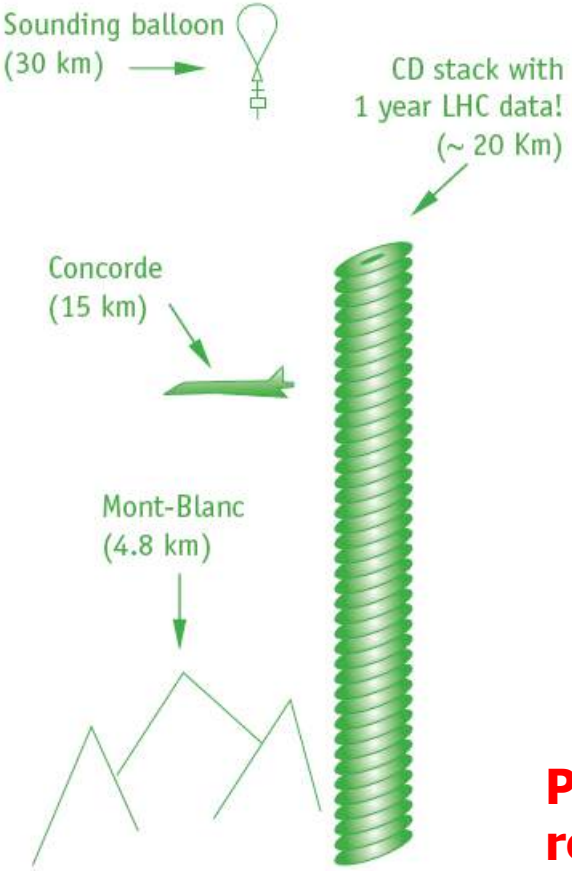
100 eventi/ sec:

~ 30000 Enciclopedia Britannica ogni secondo

15 milioni di GB per anno:

una pila di 20 km di CD ogni anno

La Griglia



Per analizzare una tale quantita; di dati, occorre una rete di PC a livello mondiale

E alla fine

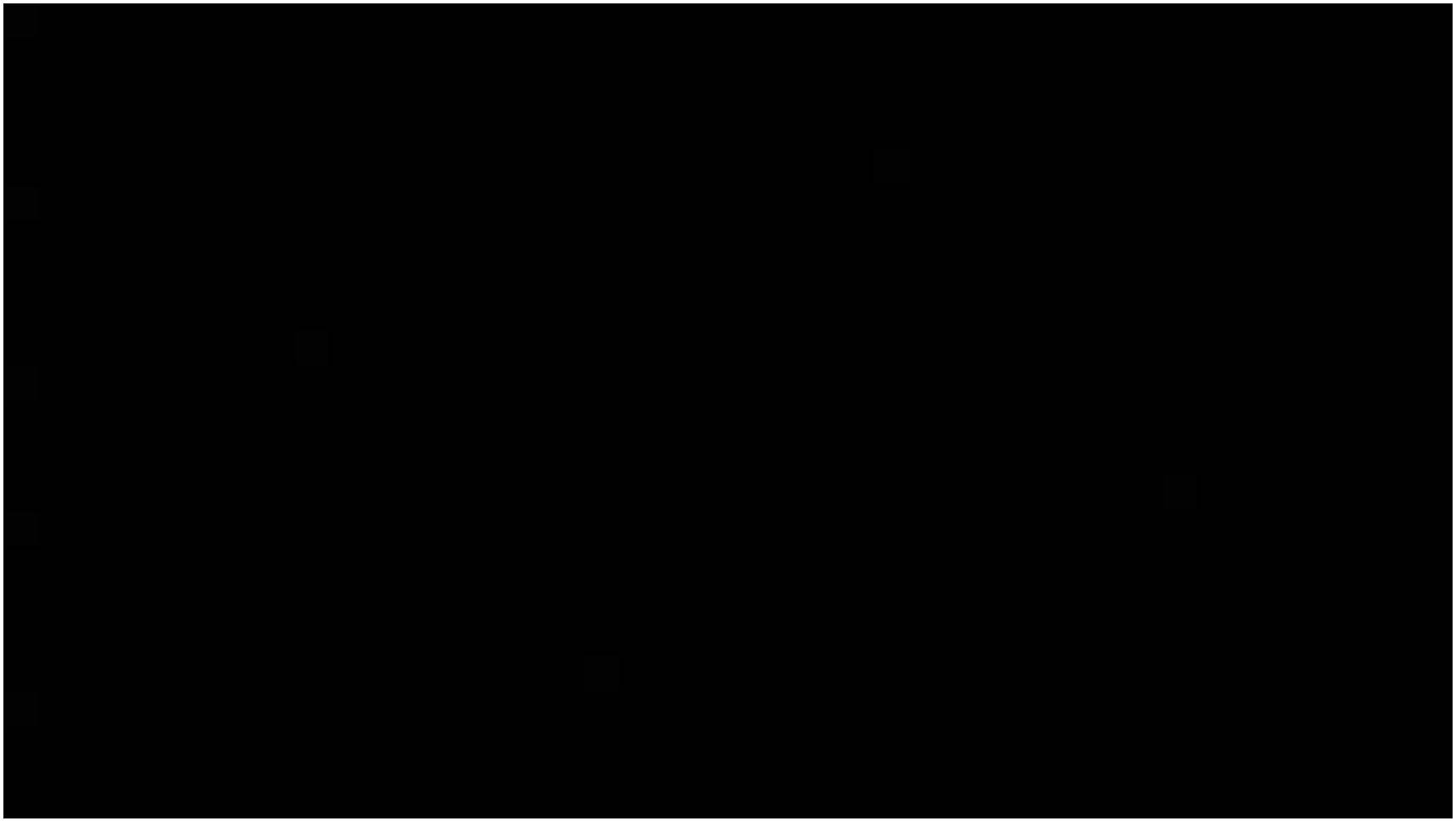
Abbiamo l'acceleratore di particelle piu potente al mondo: **LHC**

Abbiamo apparati sperimentali di altissimo livello: **CMS e ATLAS**

Abbiamo un sistema di computer potentissimo

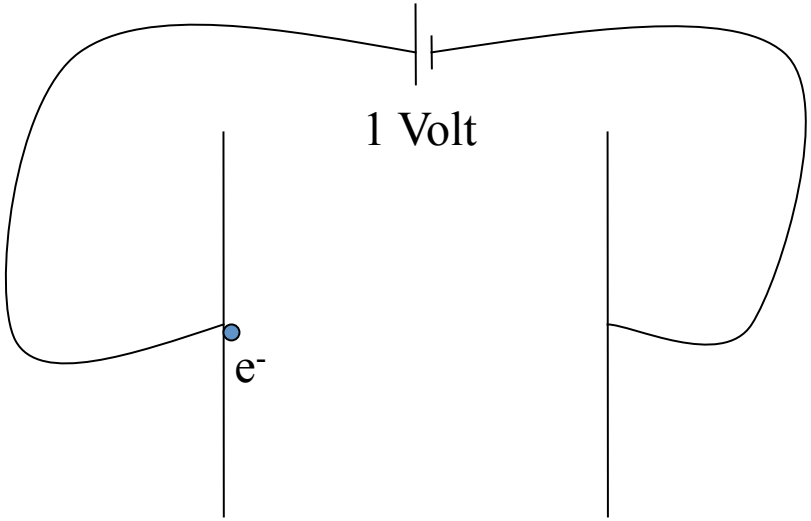
Abbiamo collaborazioni di fisici motivati, entusiasti, preparati e organizzati

4 luglio 2012
Annuncio della scoperta del bosone di Higgs



SPARES

Mass and Energy in Electron Volts



1 eV = kinetic energy gained by an electron when it accelerates through an electrostatic potential of 1 volt

$$1 \text{ eV} = 1.6\times10^{-19} \text{ J}$$

Einstein's mass-energy equivalence allows us to quote mass in terms of energy.

The mass of subatomic particles are quoted in eV, MeV (million electron volts), GeV (billion electron volts) and TeV (thousand billion electron volts).

$$\text{mass of a proton} = 1.67\times10^{-27} \text{ kg} = 938 \text{ MeV/c}^2 \approx 1 \text{ GeV}$$