



L'universo in fiore

*«L'astronomia costringe l'anima a guardare oltre
e ci conduce da un mondo ad un altro»
La Repubblica - Platone*

*Corso di astronomia 2013-2014
Osservatorio Astronomico di Brera*



Il bosone di Higgs: che cosa è? Come funziona? E a che cosa serve?

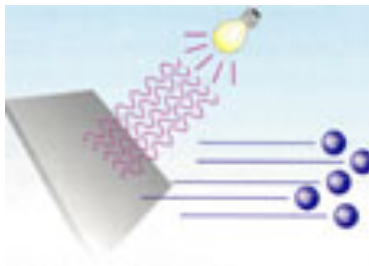
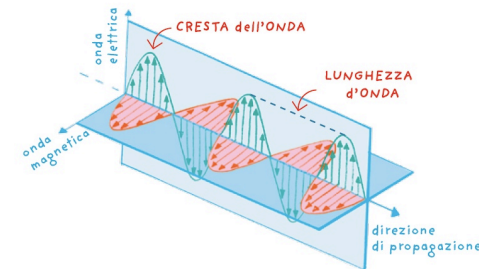
Stefano Sandrelli
INAF – Osservatorio Astronomico di Brera



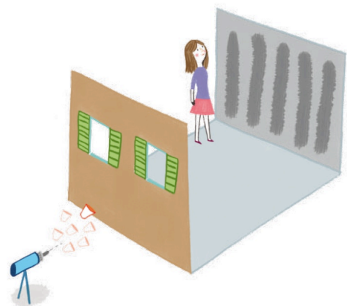
Riassunto: che cosa è la luce?

Onda o particella? Il fotone. Natura ondulatoria del fotone

Fisica classica: → onde elettromagnetiche



Effetto fotoelettrico: energia “a pacchetti”. Nasce il fotone.



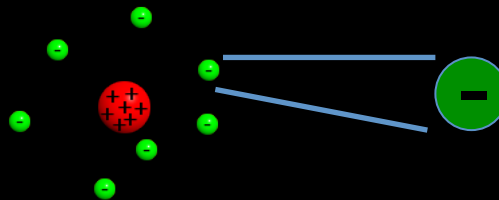
Esperimento con le due fessure: sovrapposizione dei fotoni.



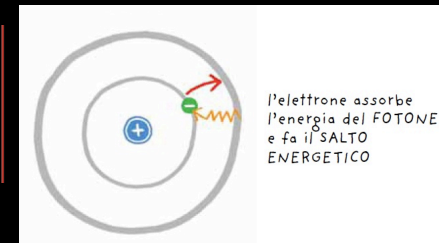
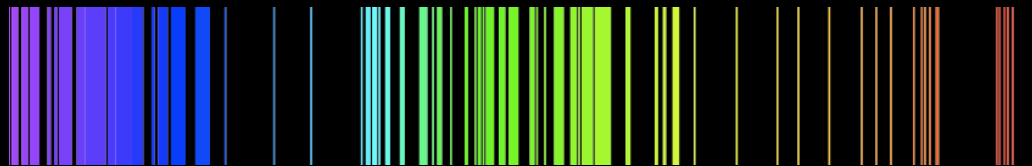
Riassunto: che cosa è un elettrone?

elettroni: onda o particella? Natura ondulatoria delle particelle

Fisica classica: → particelle elementari, con *raggio*, *massa*, *carica*

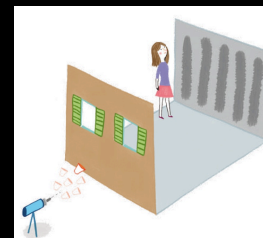


Emissioni atomiche: atomo di Bohr. Energie “quantizzate”



Esperimento con le due fessure: sovrapposizione degli elettroni

$$\lambda = \frac{h}{mv}$$



Fotone vs elettrone

fotone

Massa = 0

Carica = 0

Spin = 1

BOSONE

elettrone

Massa = $9 \cdot 10^{-31}$ Kg
0,511 MeV

Carica (e) = $-1,6 \cdot 10^{-19}$ C

Spin = 1/2

FERMIONE



La massa e l'energia: equivalenza

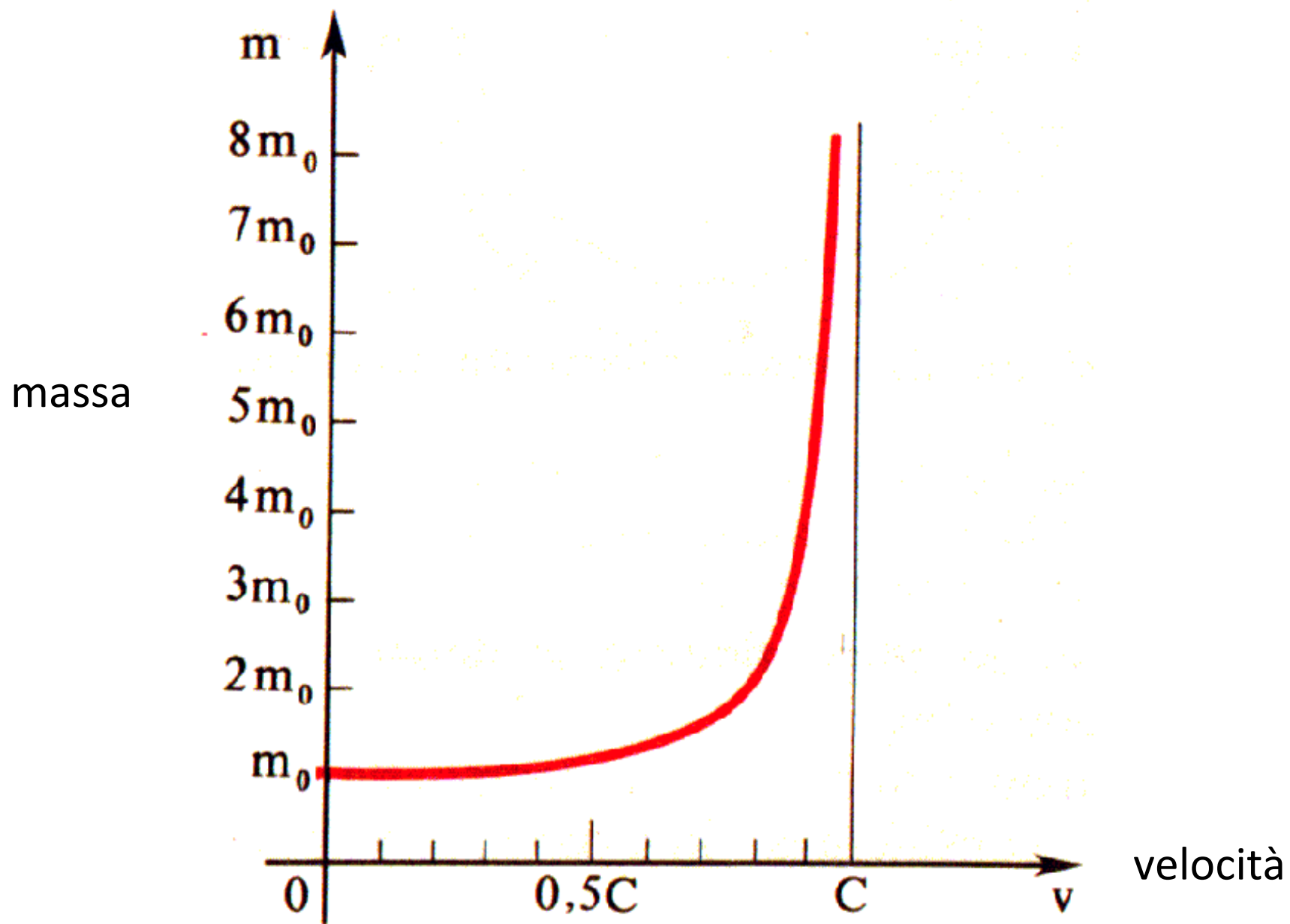
$$**E = mc^2**$$

A ogni particella che trasporta un'energia E si può associare una massa m tale che:

$$m = \frac{E}{c^2}$$

In generale, la massa di una particella che si muove non coincide con la massa che si misura quando la particella è ferma

La massa e l'energia: equivalenza



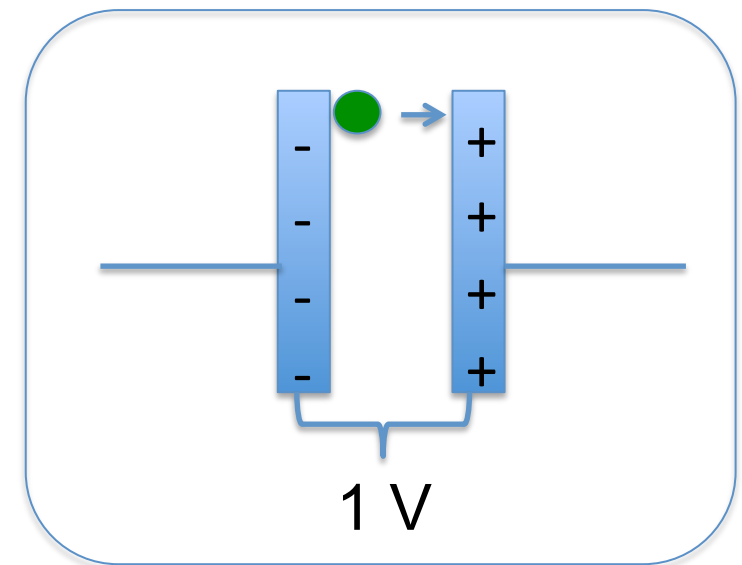
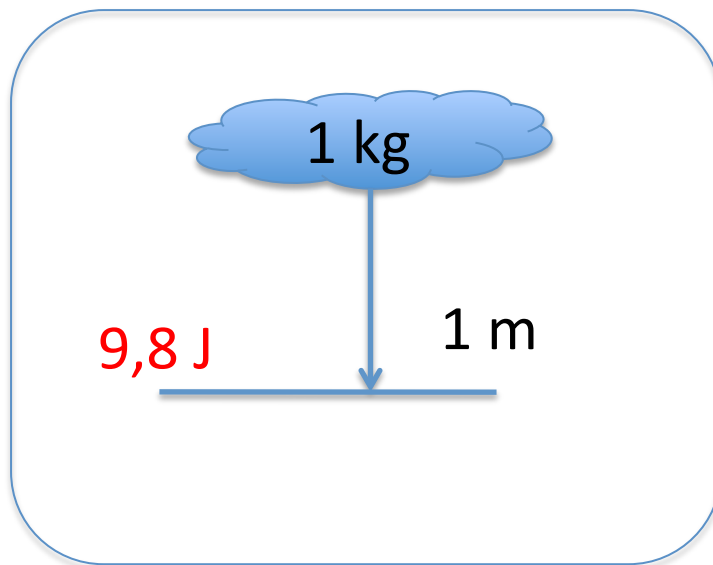


Joule ed elettronVolt

Joule

$$1 \text{ J} = 6,2 \cdot 10^{18} \text{ eV}$$

elettronVolt



1 J è l'energia di un etto di pasta
che cade da un metro

Il modello standard

$$\begin{aligned} \mathcal{L} = & -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\ & + i \bar{\psi} \not{D} \psi + \text{h.c.} \\ & + \bar{\psi}_i \gamma_{ij} \psi_j \phi + \text{h.c.} \\ & + |D_\mu \phi|^2 - V(\phi) \end{aligned}$$

Le forze fondamentali in natura

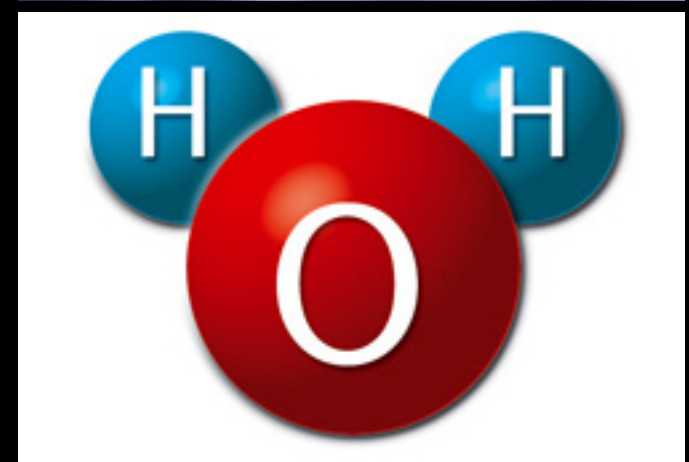
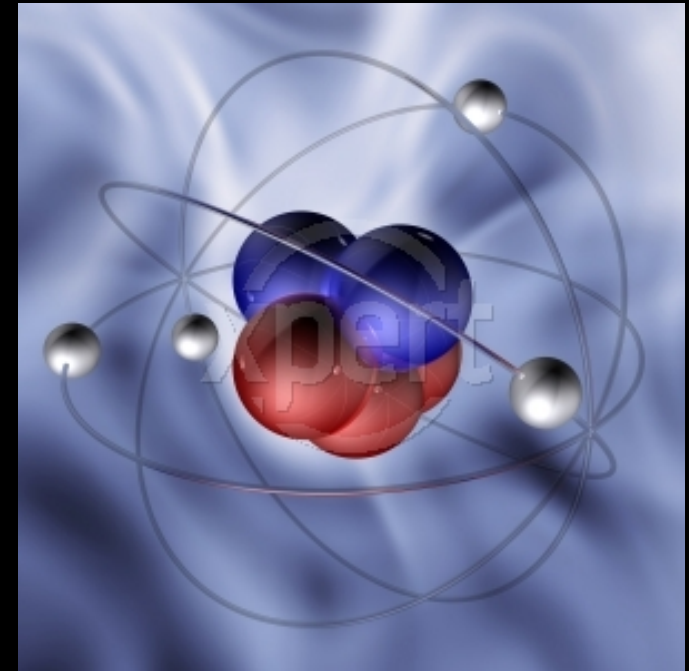
gravitazionale

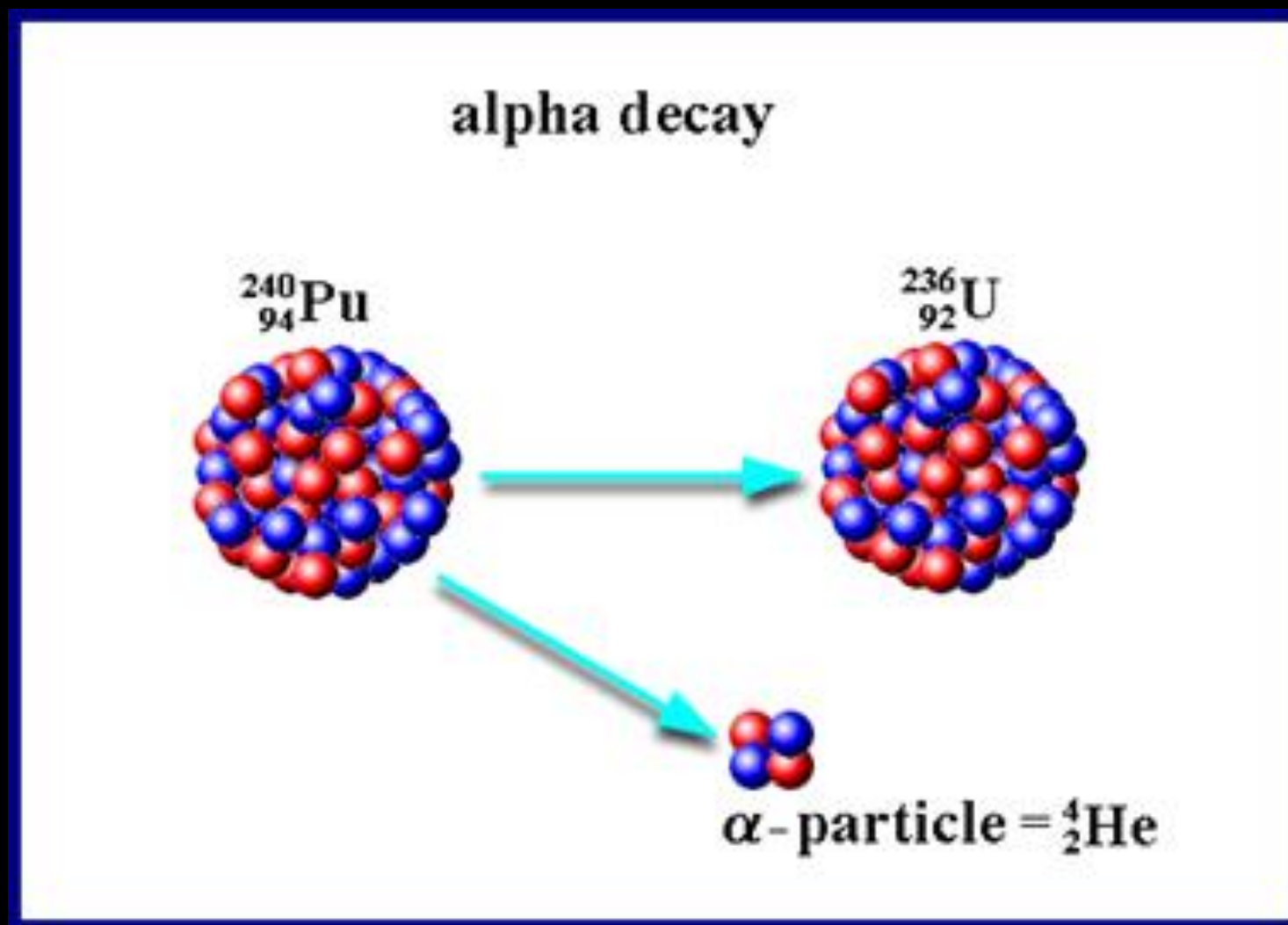


Le forze fondamentali in natura



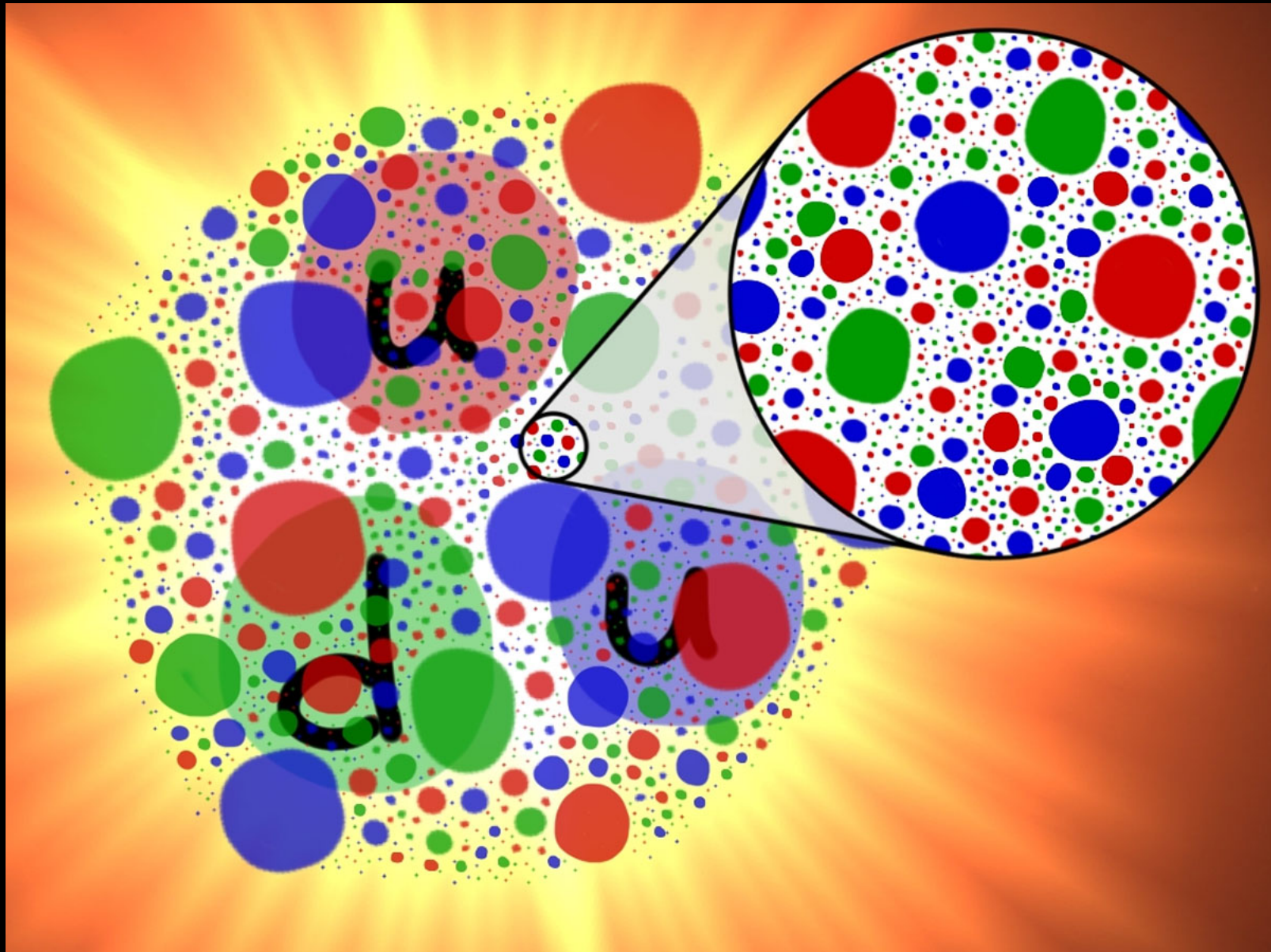
elettromagnetica

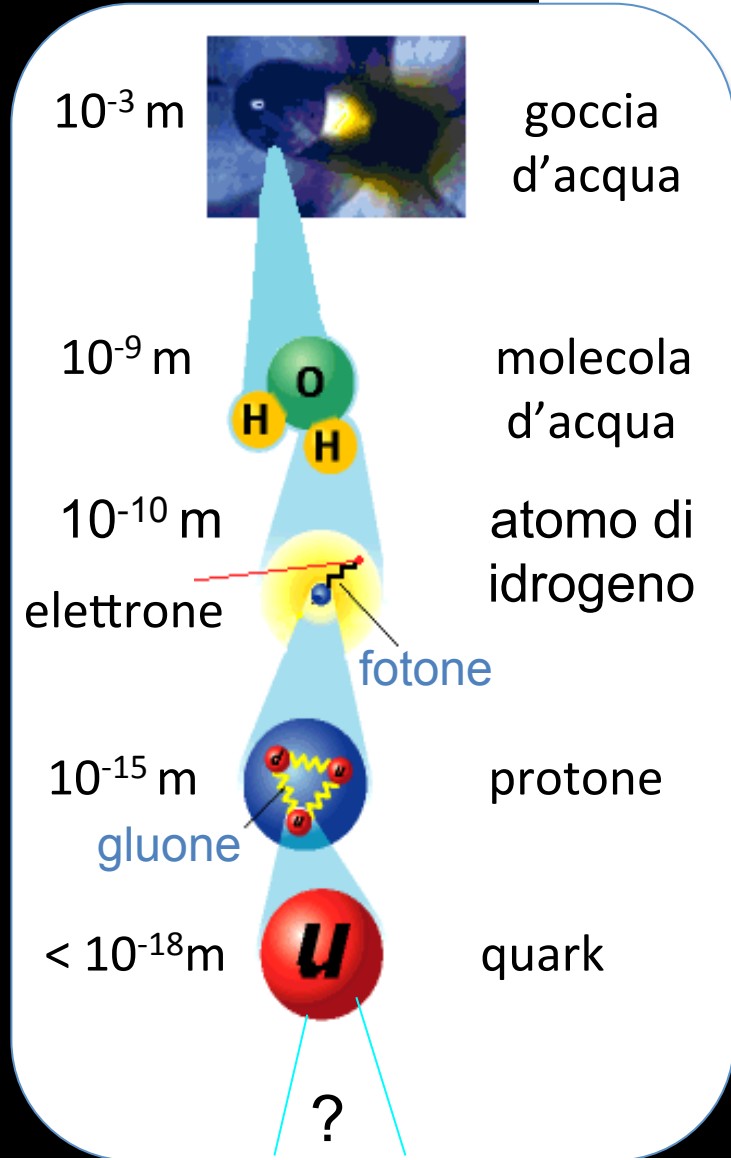




Le forze fondamentali in natura

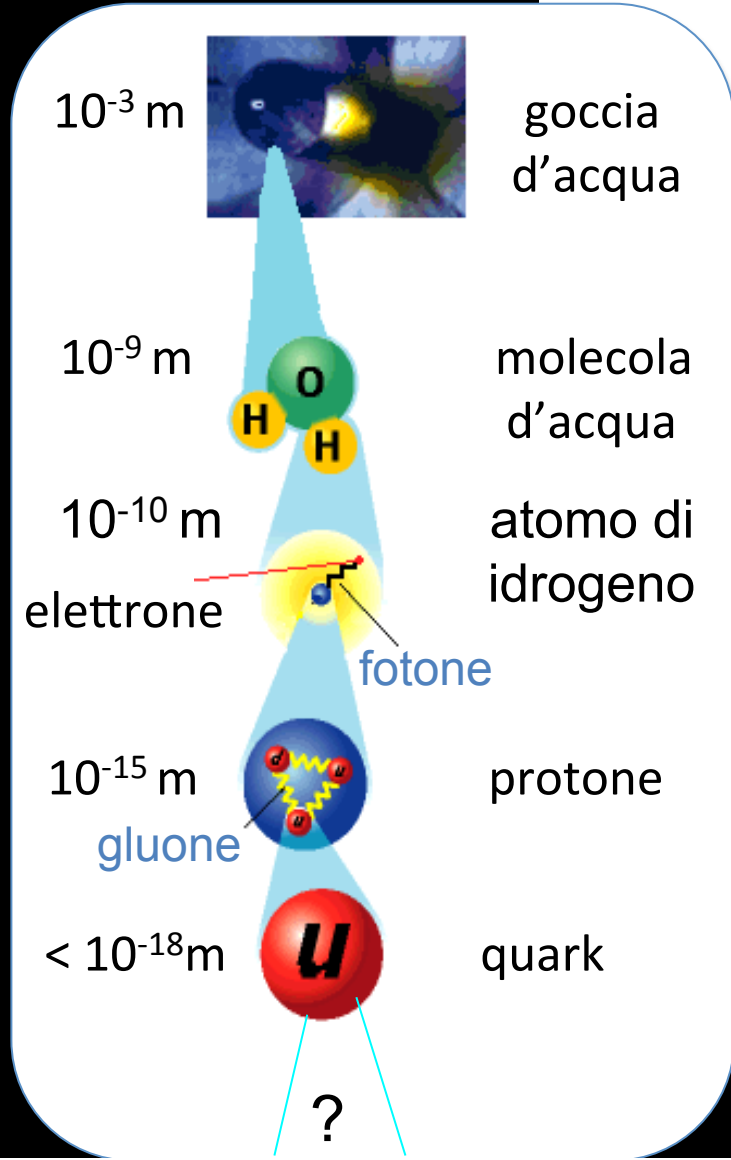
Nucleare forte: il nucleo





massa → 2,4 MeV carica → $\frac{2}{3}$ spin → $\frac{1}{2}$ nome → u up	0 0 1 γ fotone
4,8 MeV $-\frac{1}{3}$ $\frac{1}{2}$ d down	0 0 1 g gluone
$< 2,2 \text{ eV}$ 0 $\frac{1}{2}$ ν_e neutrino elettronico	91,2 GeV 0 1 Z^0 forza debole
0,511 MeV -1 $\frac{1}{2}$ e elettrone	80,4 GeV ± 1 1 $W^{\pm}$ forza debole

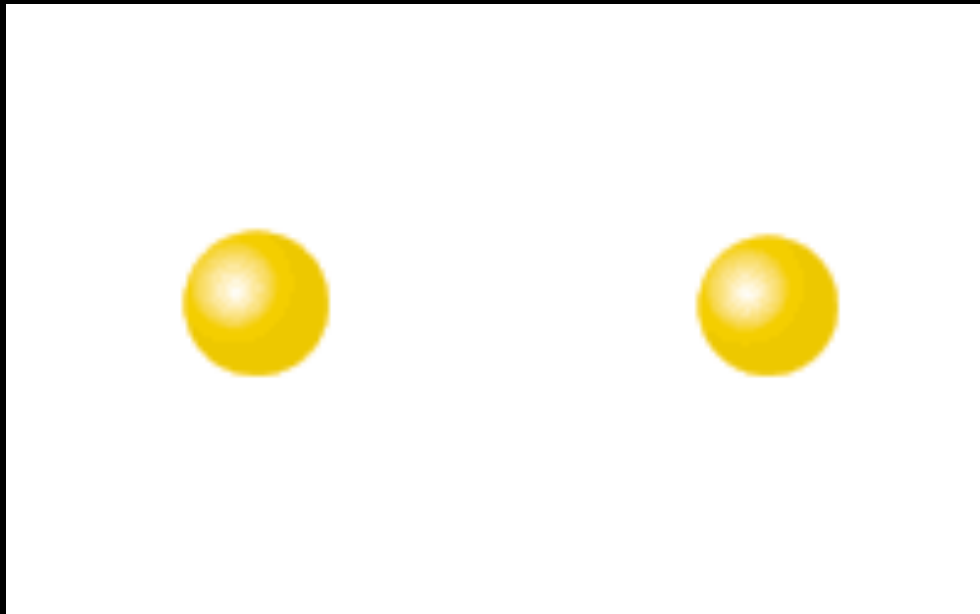
Bosoni di gauge



massa→ carica→ spin→ nome→	2,4 MeV $\frac{2}{3}$ $\frac{1}{2}$ u up	1,27 GeV $\frac{2}{3}$ $\frac{1}{2}$ c charm	171,2 GeV $\frac{2}{3}$ $\frac{1}{2}$ t top	0 0 1 γ fotone
	4,8 MeV $-\frac{1}{3}$ $\frac{1}{2}$ d down	104 MeV $-\frac{1}{3}$ $\frac{1}{2}$ s strange	4,2 GeV $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	0 0 1 g gluone
	<2,2 eV 0 $\frac{1}{2}$ ν_e neutrino elettronico	<0,17 MeV 0 $\frac{1}{2}$ ν_μ neutrino muonico	<15,5 MeV 0 $\frac{1}{2}$ ν_τ neutrino tauonico	91,2 GeV 0 1 Z^0 forza debole
	0,511 MeV -1 $\frac{1}{2}$ e elettrone	105,7 MeV -1 $\frac{1}{2}$ μ muone	1,777 GeV -1 $\frac{1}{2}$ τ tauone	80,4 GeV ± 1 1 $W^\pm$ forza debole

Bosoni di gauge

L'idea di
bosone



Le questioni aperte del modello standard

Come conciliare la gravità con la meccanica quantistica?

Perché le particelle hanno massa?

Perché le particelle hanno esattamente *quella* massa?

Di quale massa si parla?

$$P = m \cdot g$$

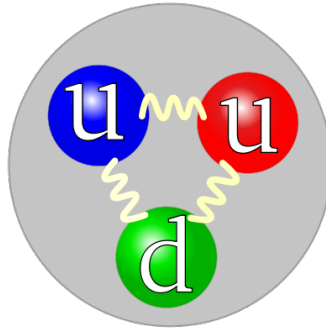


Di quale massa si parla?

$$F = m \cdot a$$



Di quale massa si parla?



Massa di 1 protone
=
938,27 MeV

Massa di 1 up = 2,4 MeV

Massa di 1 down = 4,8 MeV

Massa di 2 up + 1 down = 9,6 MeV

Il problema non è
la massa delle “cose”
di tutti i giorni non è

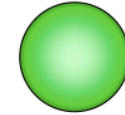
$\Delta m \approx 928 \text{ MeV} \approx \text{massa di un 1 protone}$

Di quale massa si parla?



massa→ 2,4 MeV
carica→ $\frac{2}{3}$
spin→ $\frac{1}{2}$
nome→ **u**
up

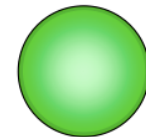
2,4 MeV



Quark

4,8 MeV
 $-\frac{1}{3}$
 $\frac{1}{2}$
d
down

4,8 MeV



<2,2 eV
0
 $\frac{1}{2}$
 ν_e
neutrino
elettronico

< 2,2 eV



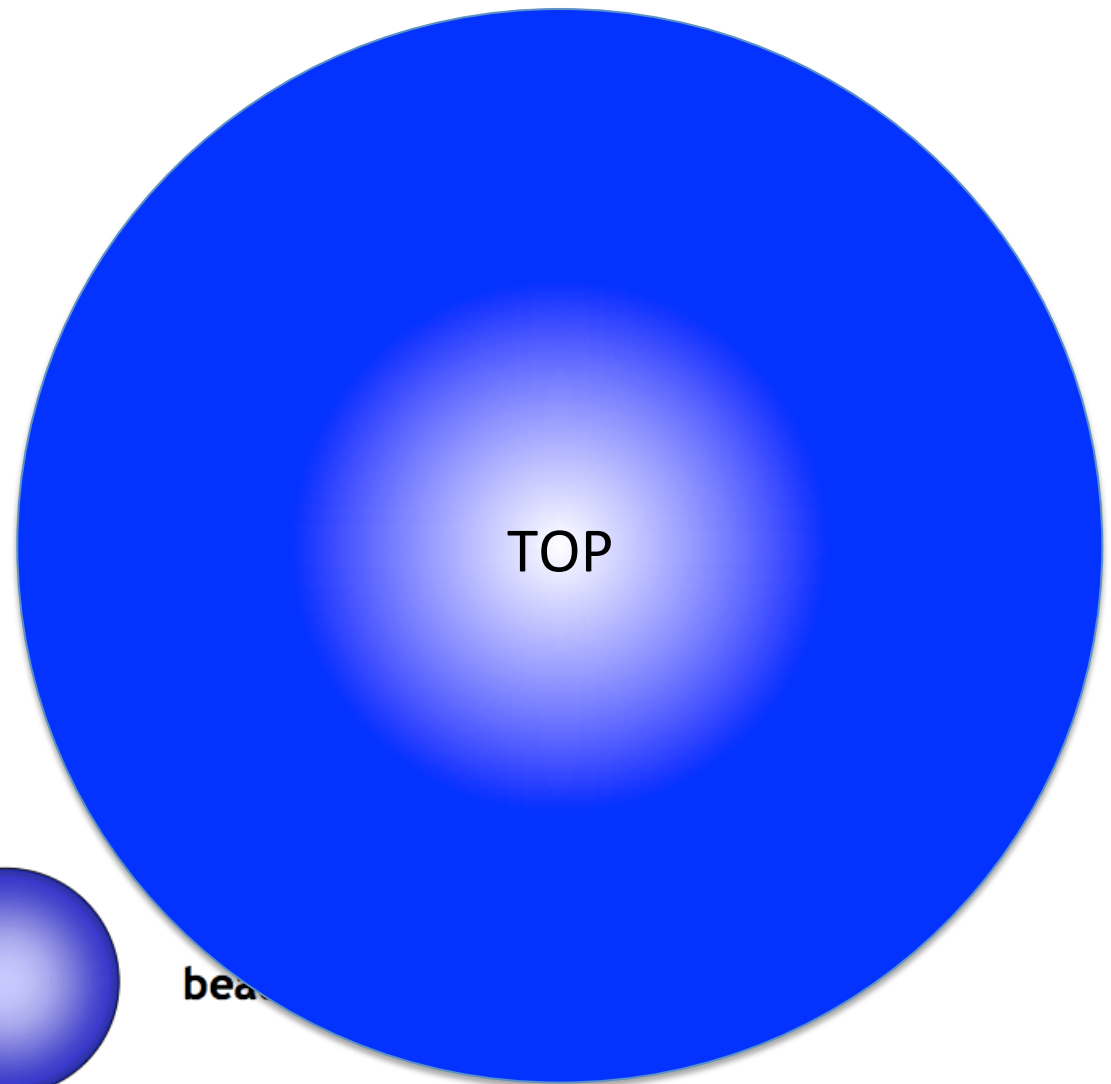
Leptoni

0,511 MeV
-1
 $\frac{1}{2}$
e
elettrone

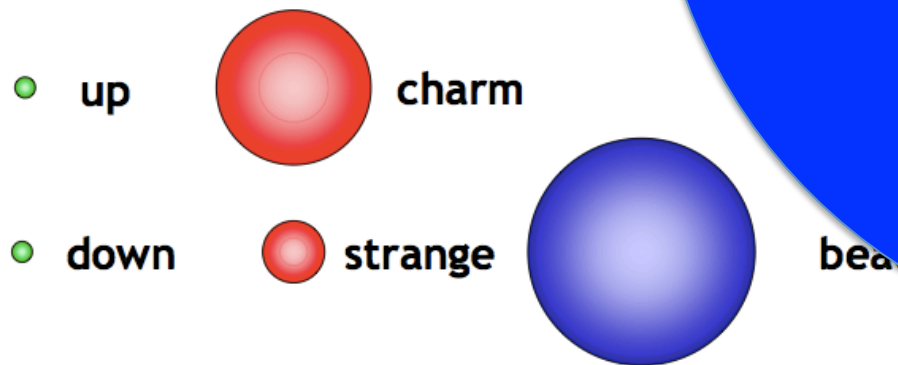
0,511 MeV



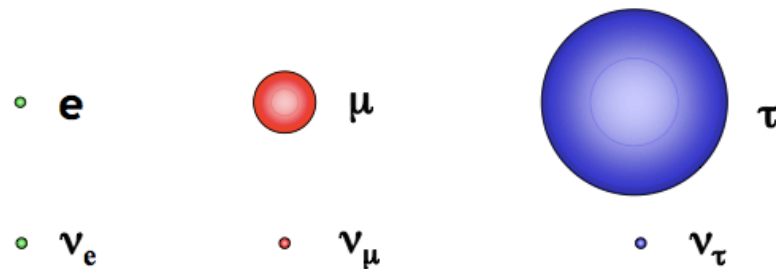
2,4 MeV $\frac{2}{3}$ $\frac{1}{2}$ u up	1,27 GeV $\frac{2}{3}$ $\frac{1}{2}$ c charm	171,2 GeV $\frac{2}{3}$ $\frac{1}{2}$ t top
4,8 MeV $-\frac{1}{3}$ $\frac{1}{2}$ d down	104 MeV $-\frac{1}{3}$ $\frac{1}{2}$ s strange	4,2 GeV $-\frac{1}{3}$ $\frac{1}{2}$ b bottom



quarks



leptoni



Fe 52 GeV

Quark top 171 GeV

Ag 197 GeV

Au 192 GeV

Ir 183 GeV

1 H Hydrogen 1.00794																	2 He Helium 4.003						
3 Li Lithium 6.941	4 Be Beryllium 9.012182																	5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050																	13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80						
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29						
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)						
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 Ds Darmstadtium (269)	111 Rg Roentgenium (272)	112 Cn Copernicium (277)	113	114										

Ag

Au

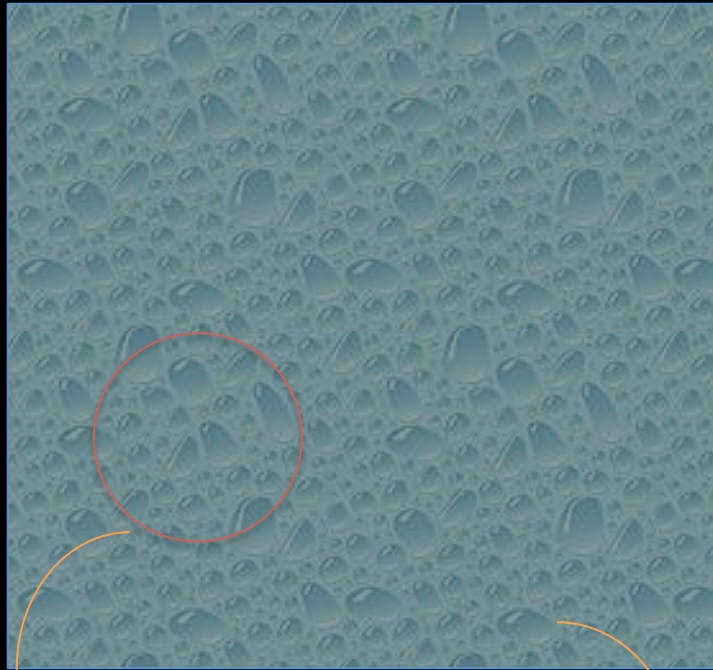
Ir

197 GeV

192 GeV

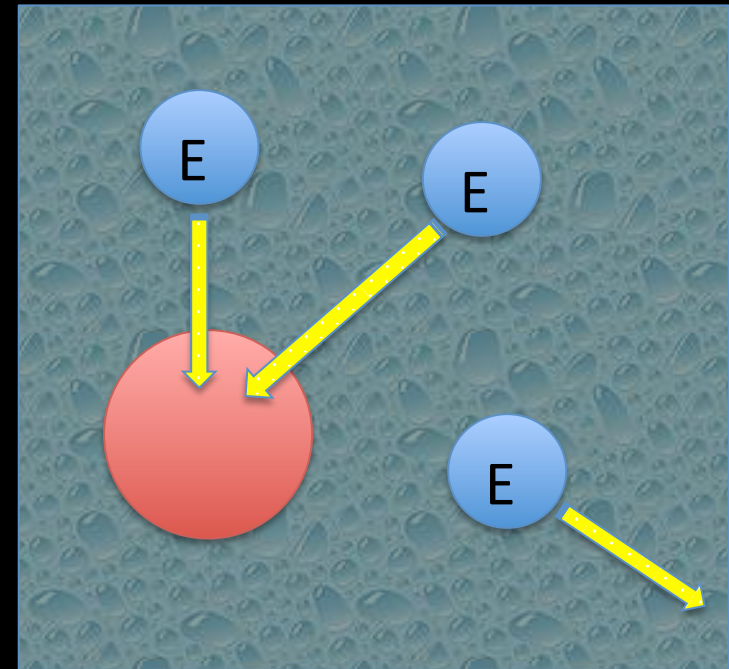
183 GeV

Il bosone di Higgs è un “vettore” di energia, che trasferisce energia tra il campo di Higgs e altre particelle



Particella senza massa

Campo
di Higgs



L'energia assorbita dalla
particella diviene la massa
della particella

□

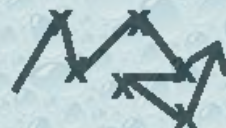
e →



w →



t →



**La massa e' una misura di
quanto sia difficile accelerare
un oggetto ($F=ma$)**

Analogia del meccanismo
di Higgs, proposta da David J. Miller
dell'University College di Londra.



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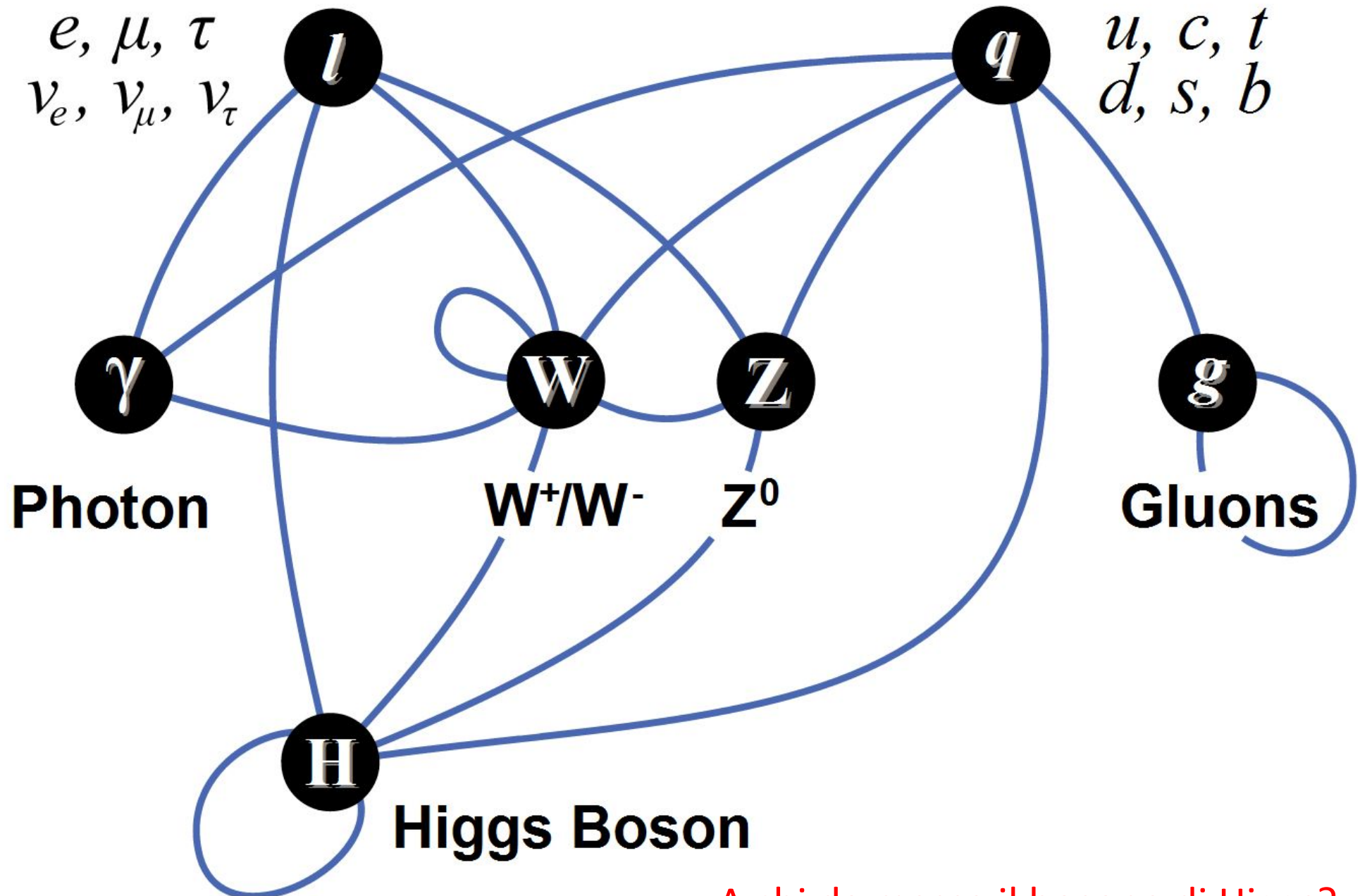


Leptons

e, μ, τ
 ν_e, ν_μ, ν_τ

Quarks

u, c, t
 d, s, b



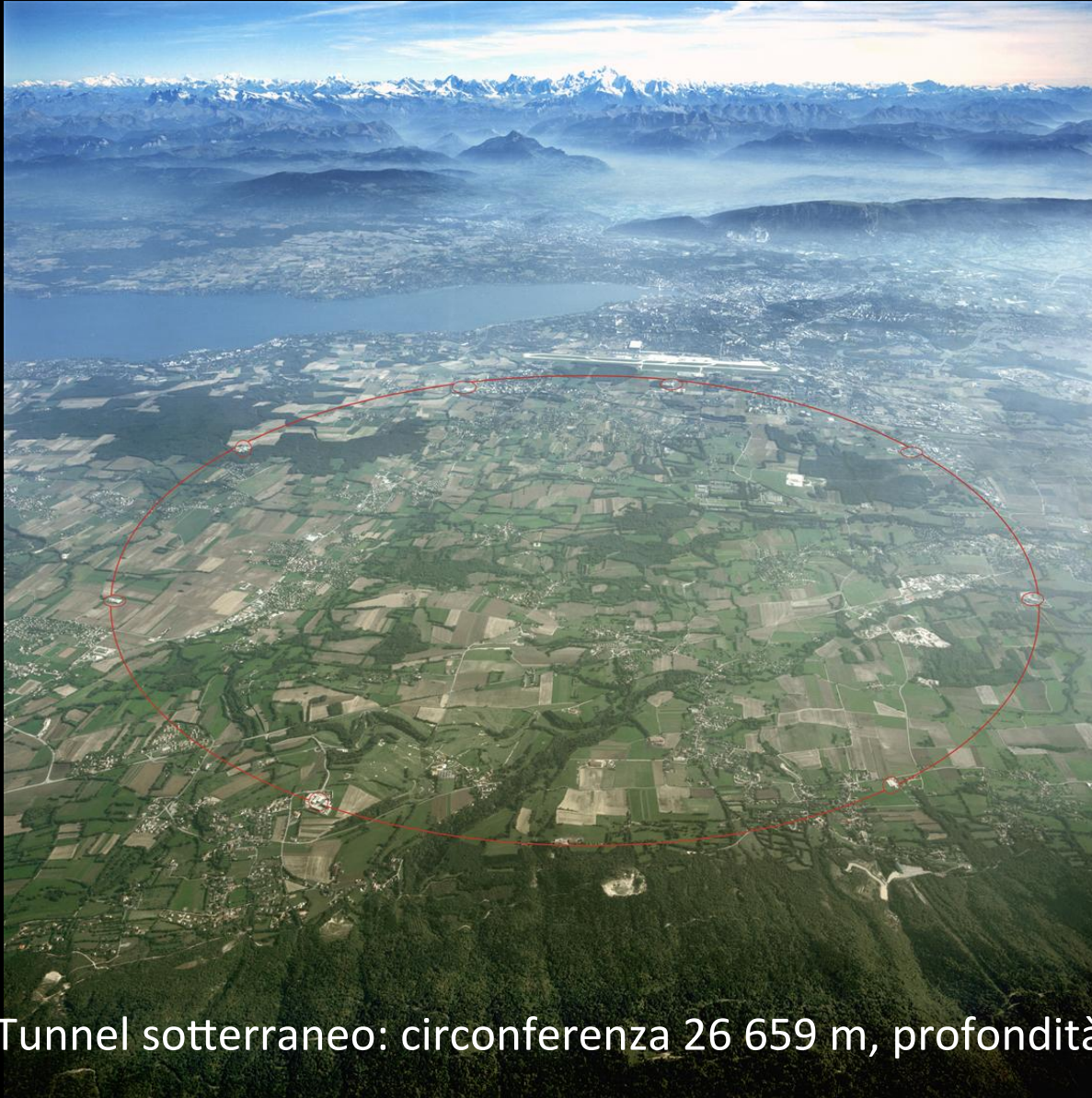
A chi da massa il bosone di Higgs?

La scoperta



Annuncio del 4 luglio 2012

I luoghi della scoperta



Large
Hadronic
Collider

CERN

Ginevra

Tunnel sotterraneo: circonferenza 26 659 m, profondità 100 m

CERN - Large Hadronic Collider

Tunnel sotterraneo: circonferenza 26 659 m, profondità 100 m

Collisioni p-p: velocità dei protoni 99.9999991% velocità luce

Collisione nuclei di piombo

$$E_{p-p} = 14 \text{ TeV} = 14 \cdot 10^{12} \text{ eV} \rightarrow 22,4 \cdot 10^{-7} \text{ J}$$

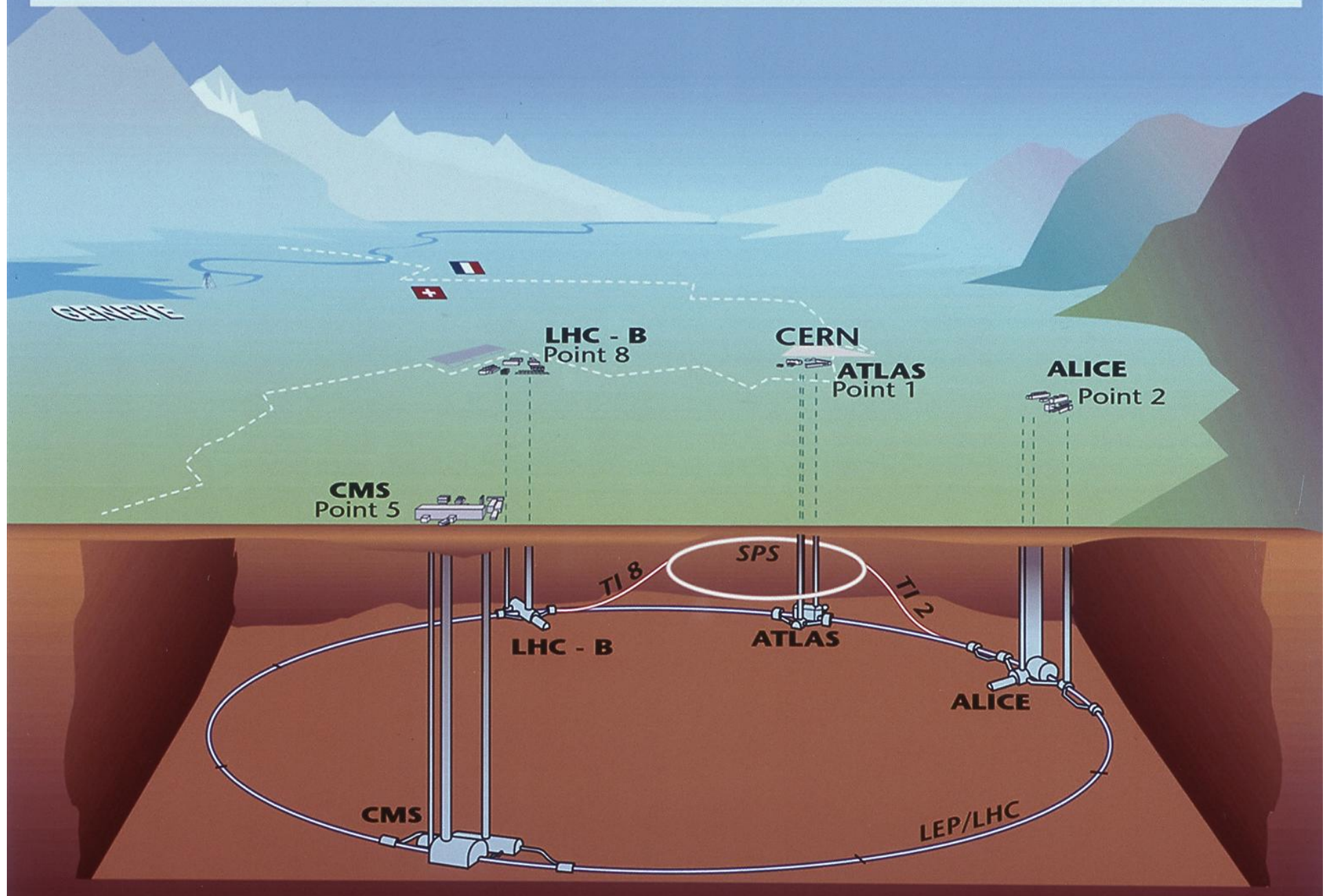
$$T = \text{diecimila volte più alta del nucleo del sole} = 10^5 \cdot 15 \cdot 10^6 \text{ K}$$

600 milioni di collisioni al secondo

$$P = 10^{-13} \text{ atm}$$

$$T = -271,3 \text{ K}$$

Overall view of the LHC experiments.



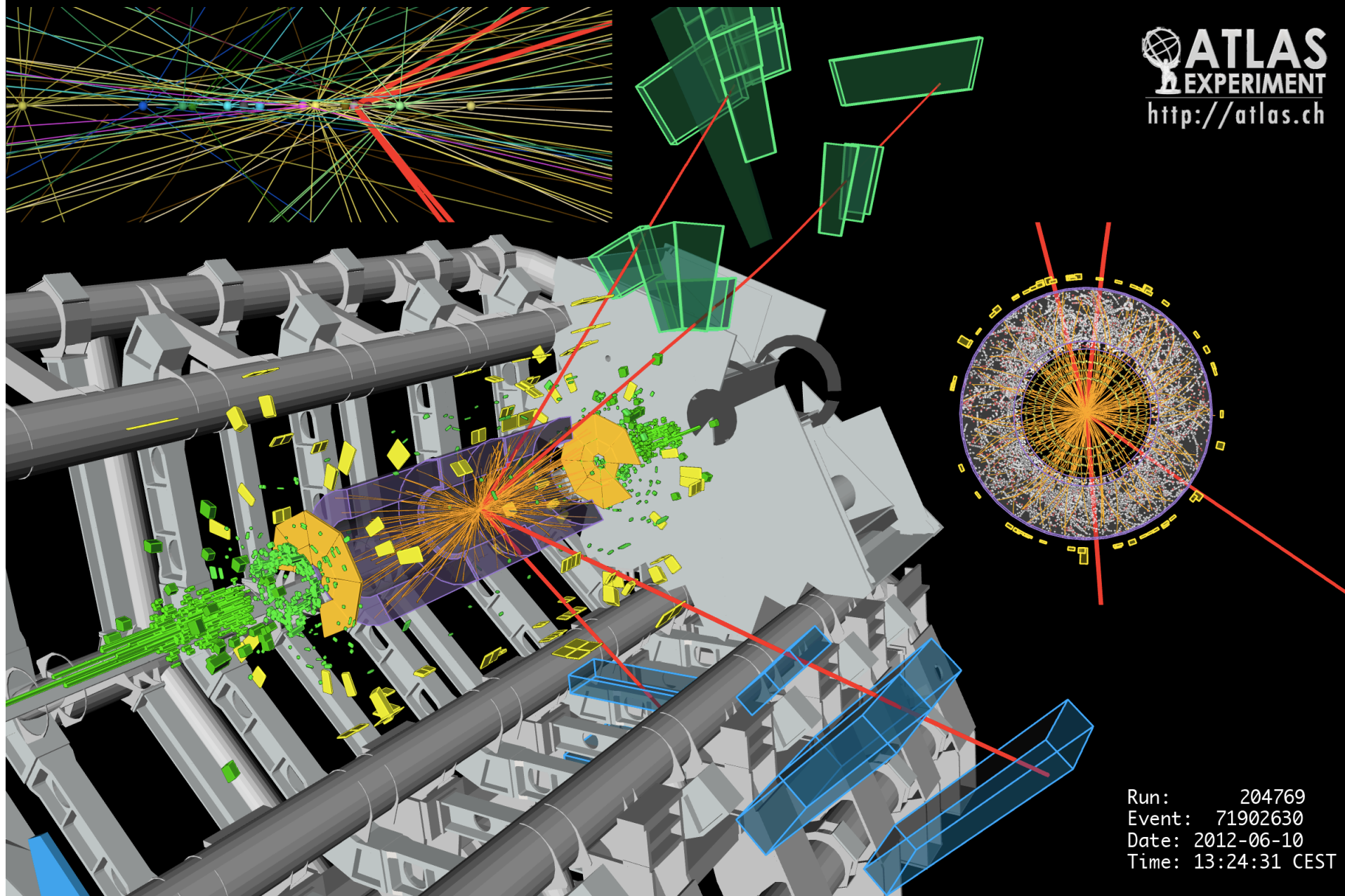
ATLAS

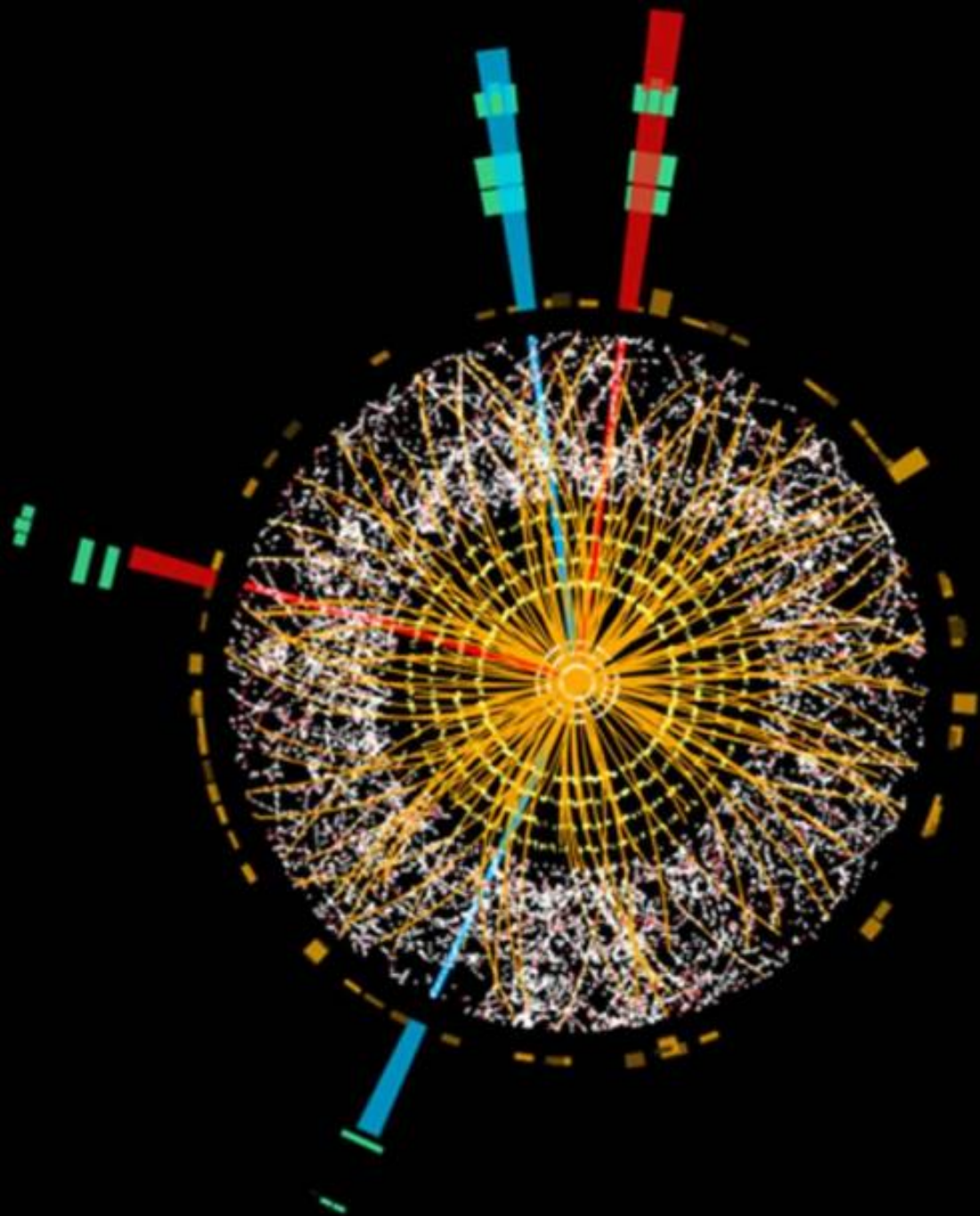
A Toroidal LHC Apparatus

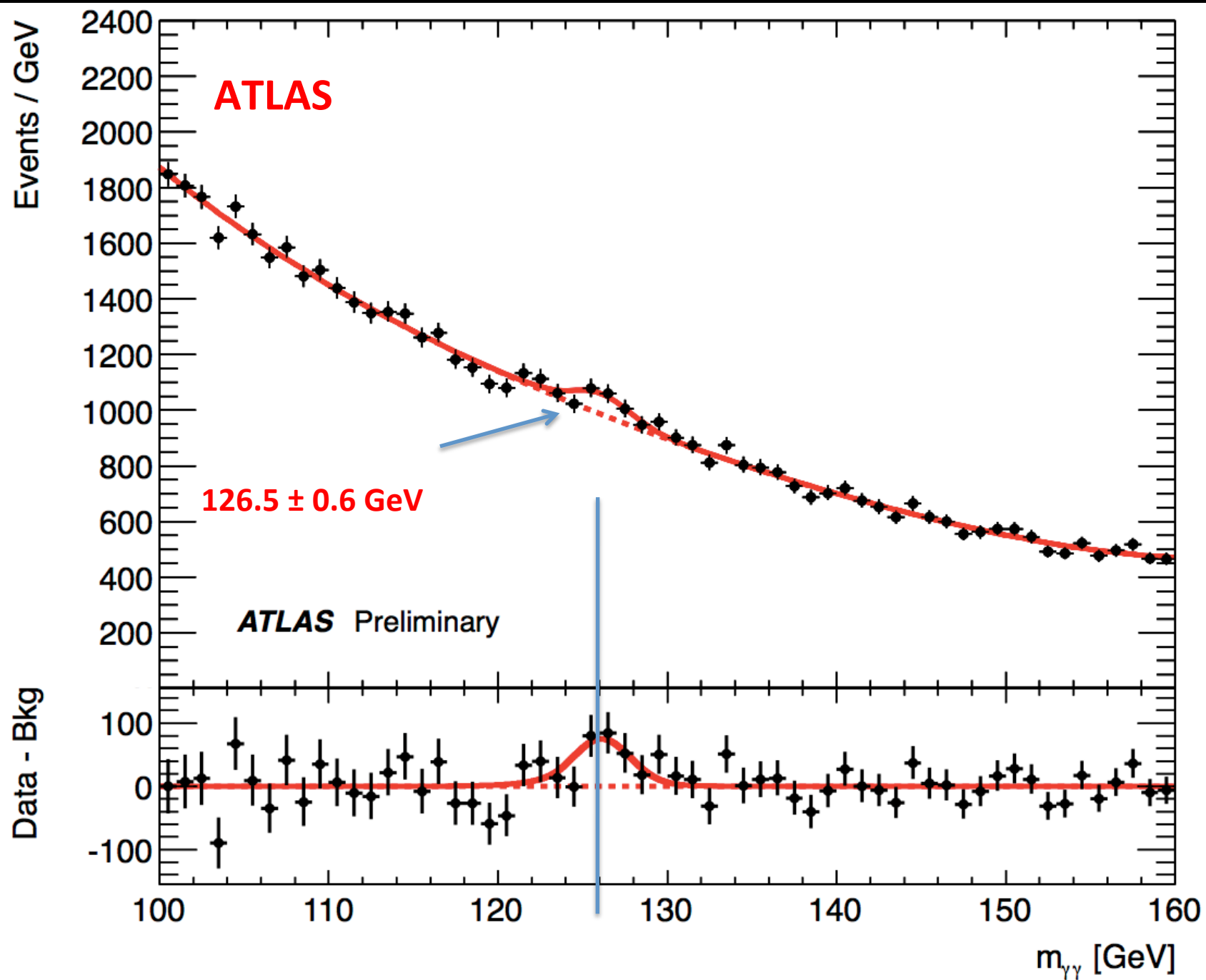
CMS

Compact Muon Solenoid

- lo studio della fisica delle particelle sulla scala dei TeV (10^{12} eV)
- la ricerca del bosone di Higgs
- la ricerca di un'evidenza dell'esistenza della supersimmetria
- la ricerca di nuove dimensioni spazio-temporali

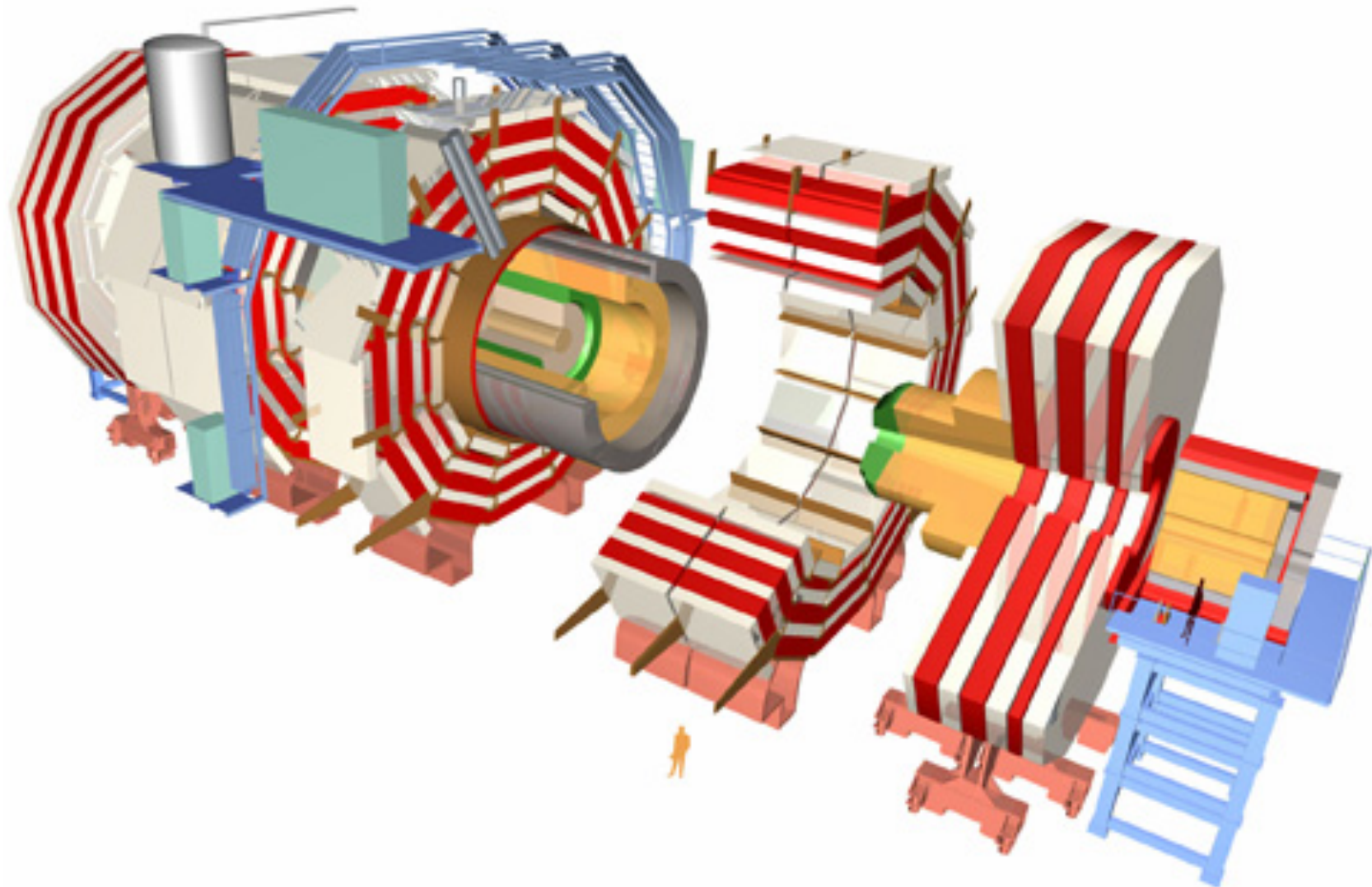


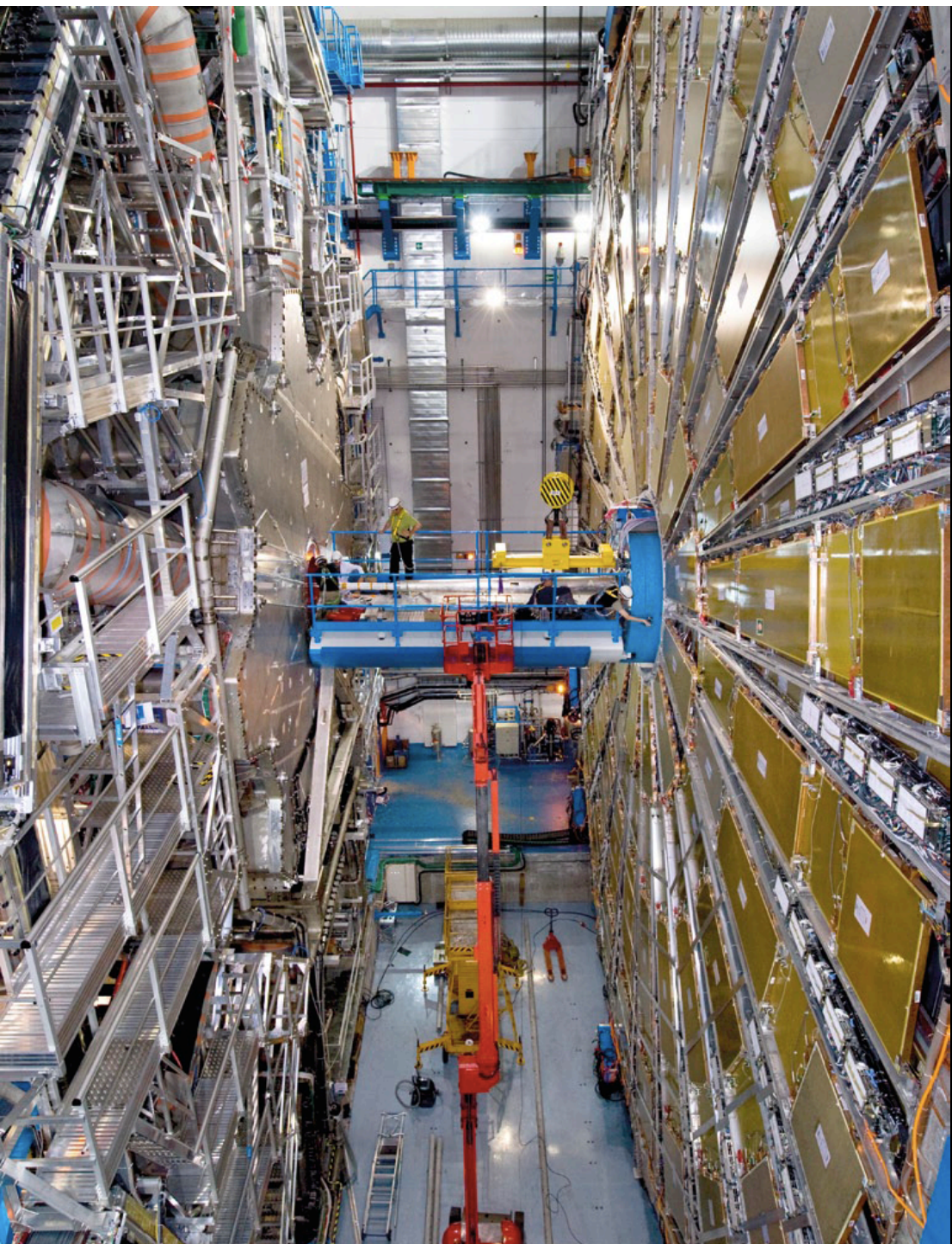


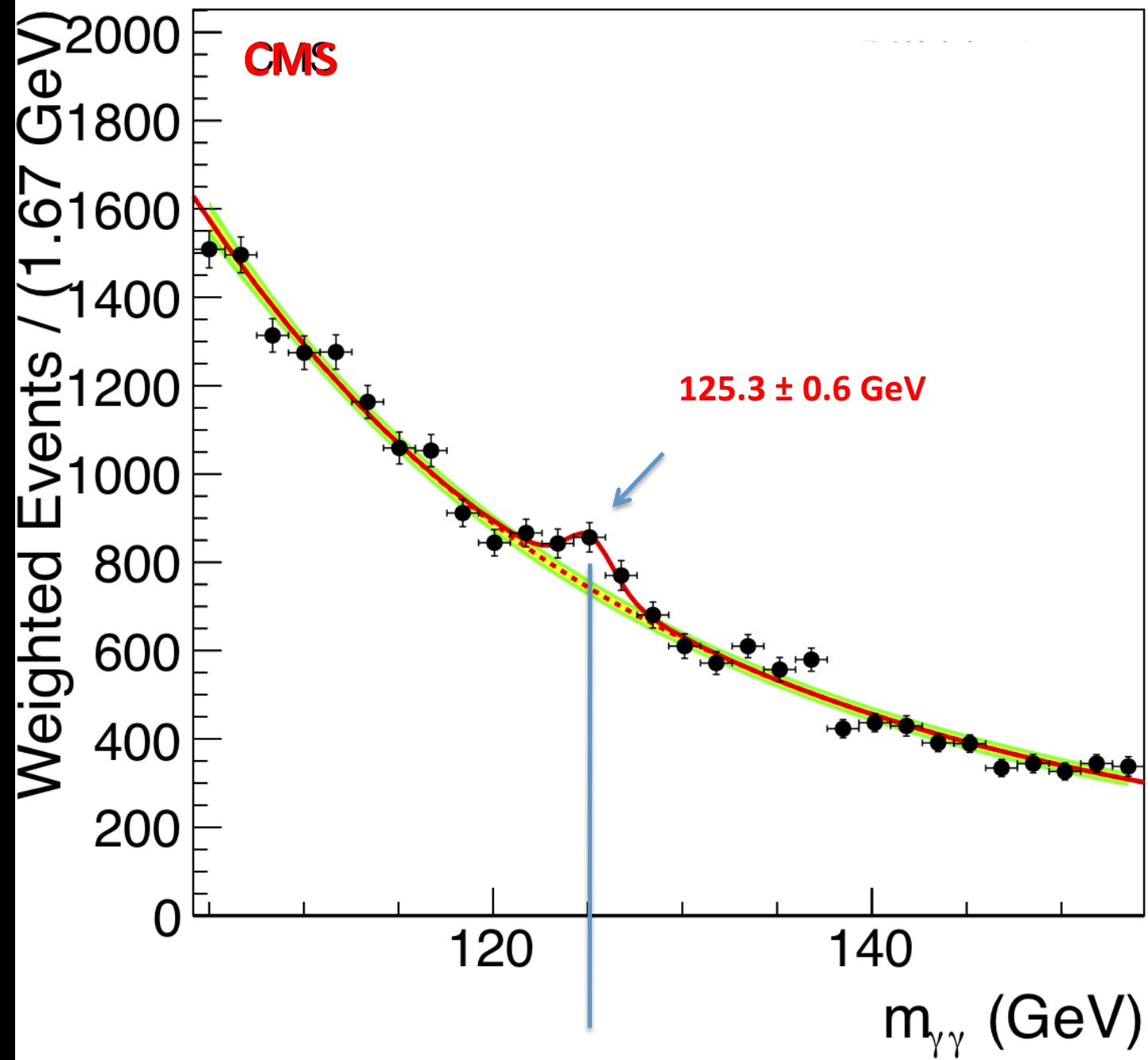


Compact Muon Solenoid

$p - p$ at 8 TeV



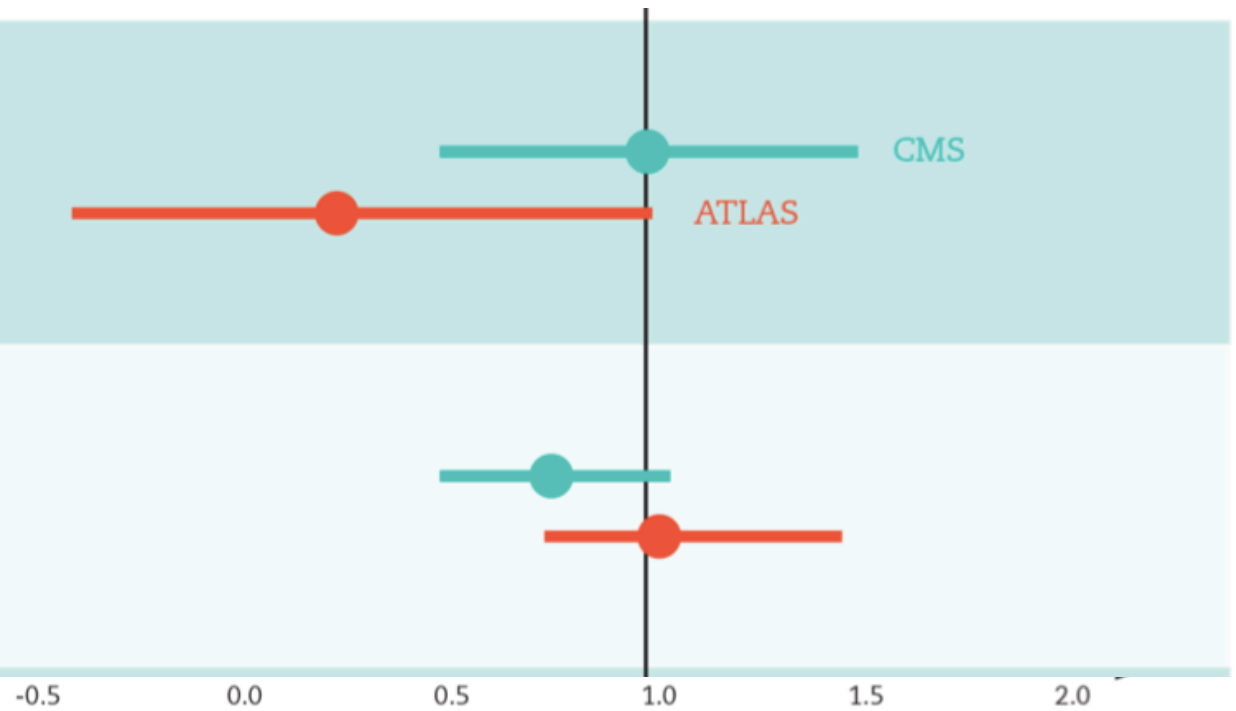




Higgs decay to two bottom quarks

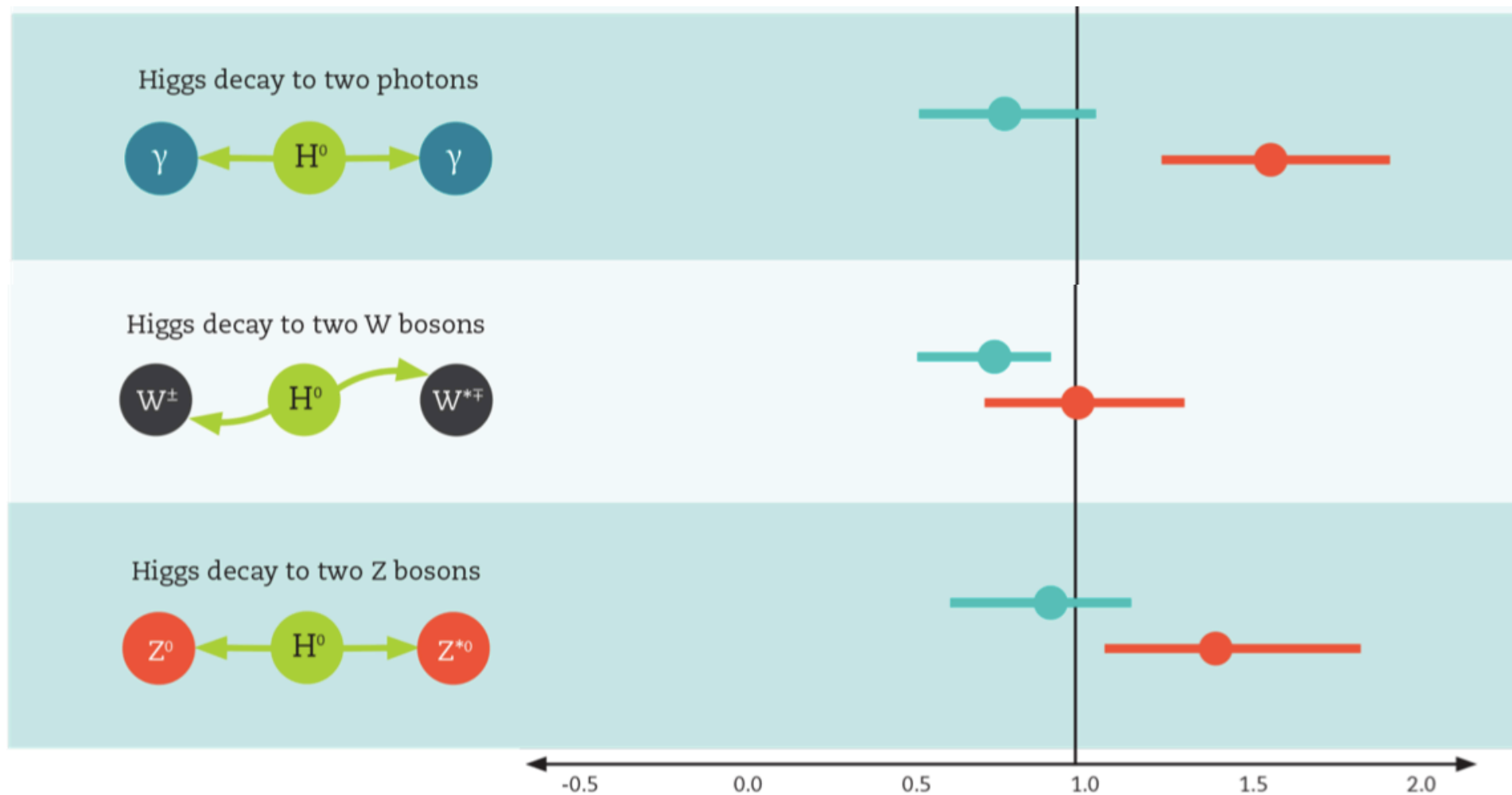


Higgs decay to two tau leptons



measured rate / rate expected from Standard Model

Preliminary results from the ATLAS and CMS experiments, 2014



measured rate / rate expected from Standard Model

Preliminary results from the ATLAS and CMS experiments, 2014



The Nobel Prize in Physics 2013
François Englert, Peter Higgs

The Nobel Prize in Physics 2013



Photo: A. Mahmoud
François Englert

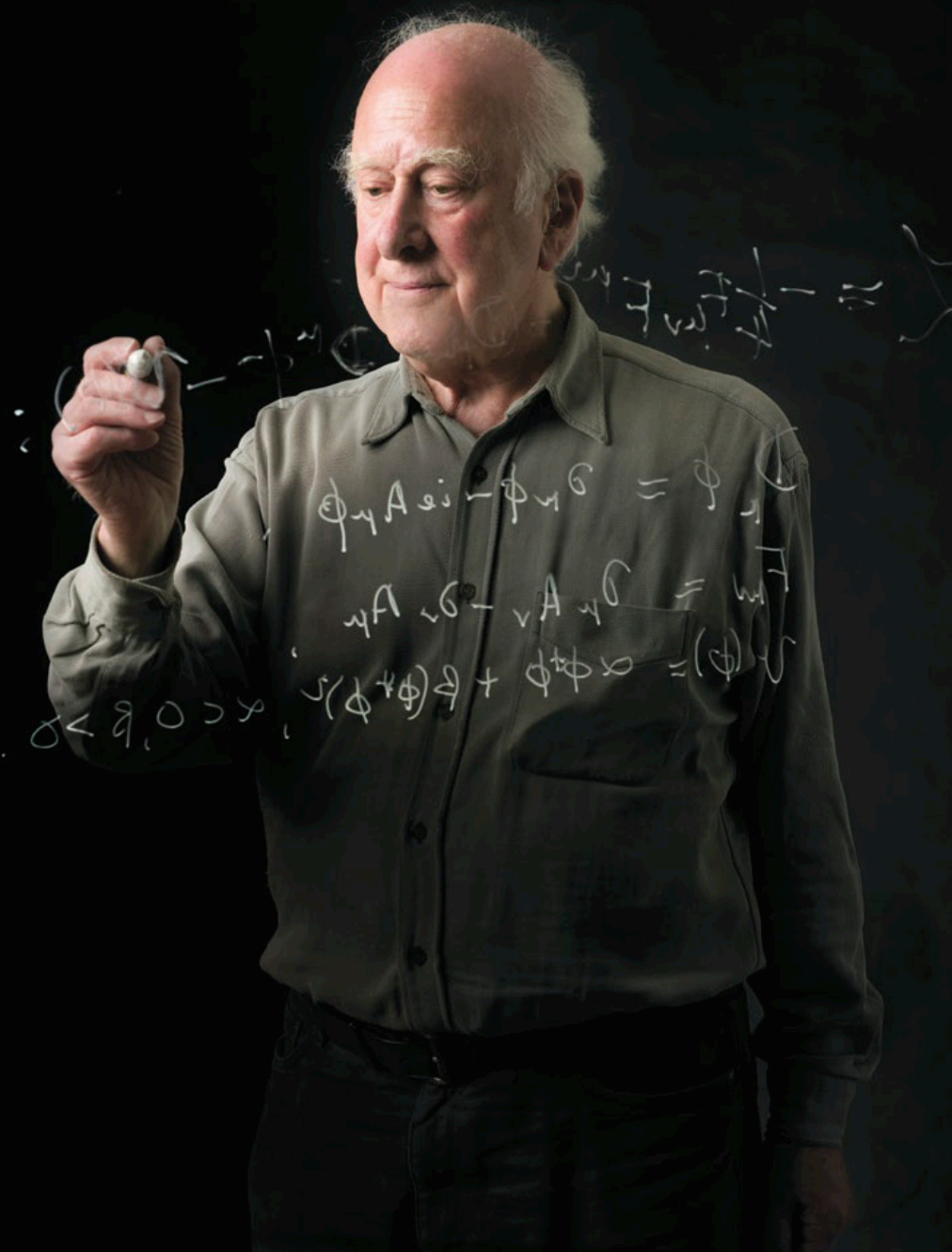


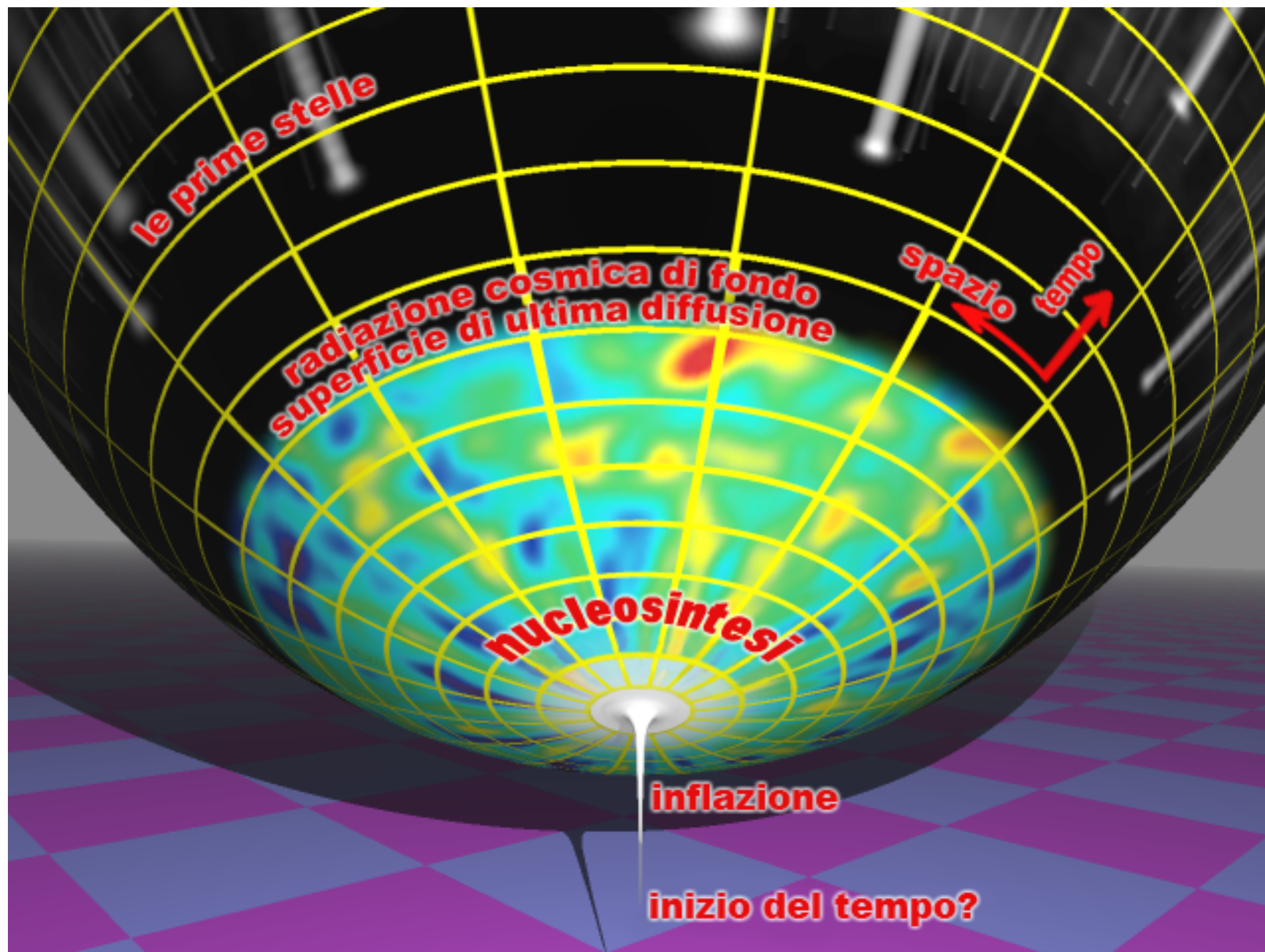
Photo: A. Mahmoud
Peter W. Higgs

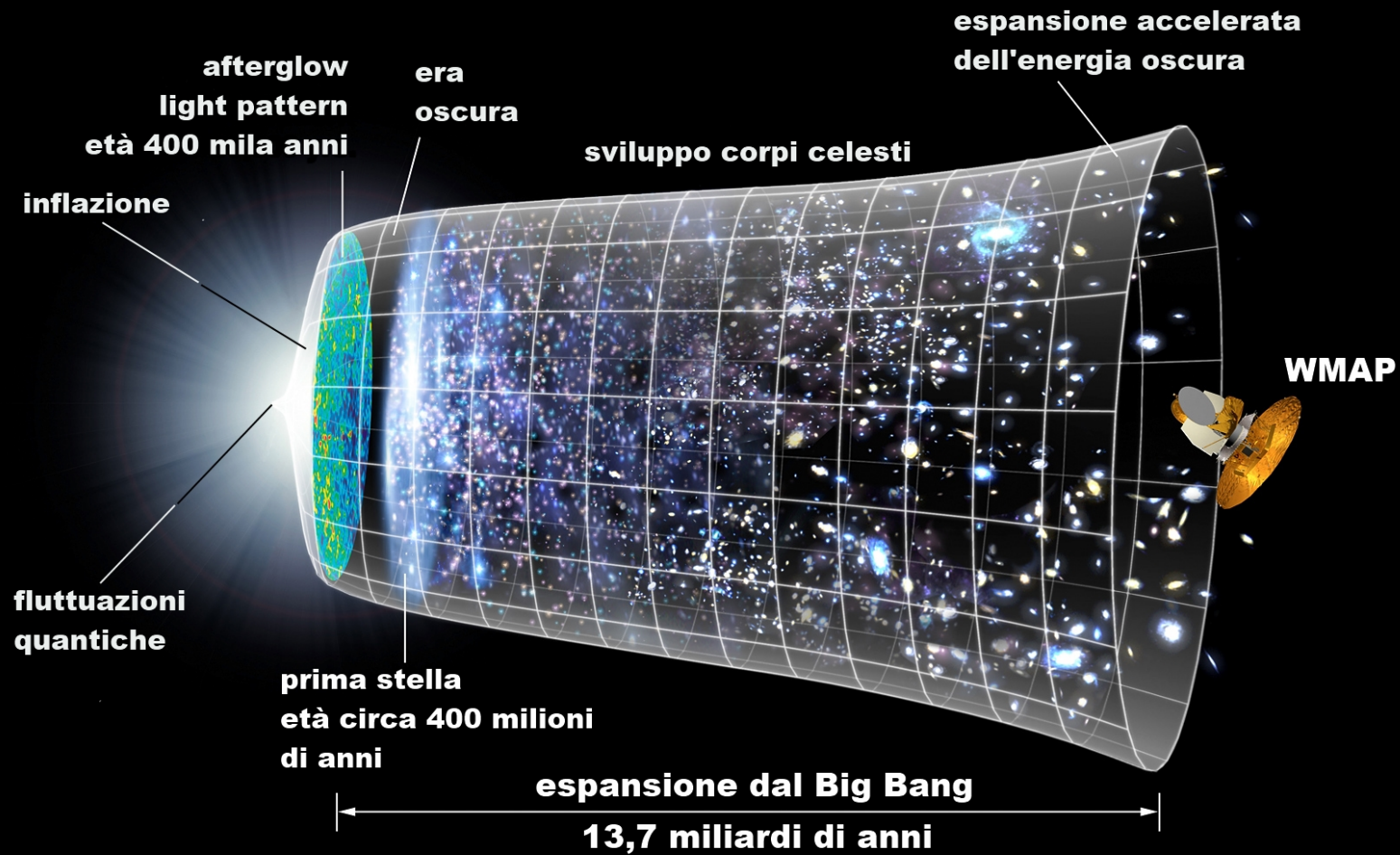
The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

Photos: Copyright © The Nobel Foundation

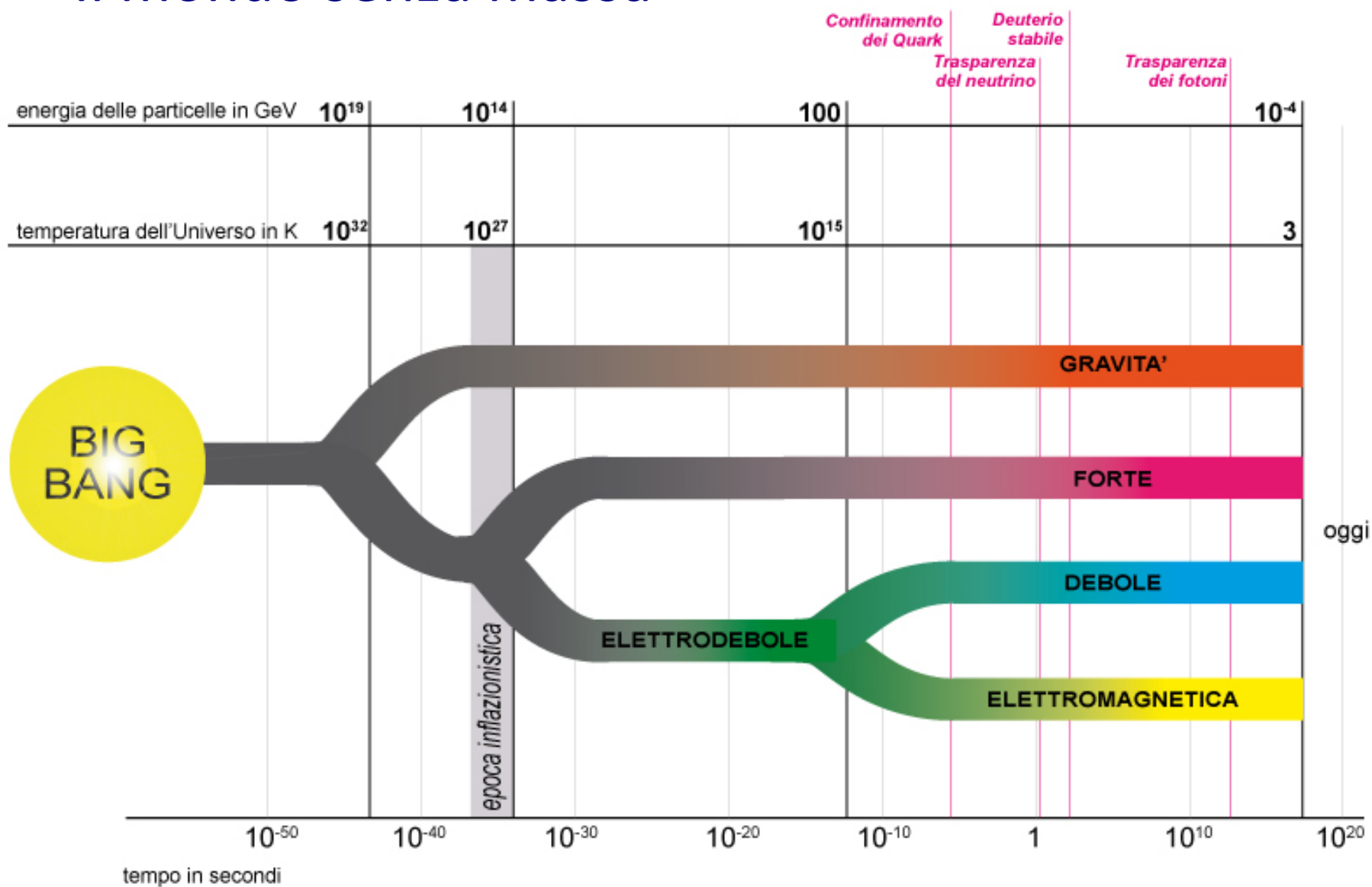
“(...) per la scoperta teorica di un meccanismo che contribuisce alla nostra comprensione dell’origine della massa delle particelle subatomiche e che è stato recentemente confermato attraverso la scoperta della particella fondamentale predetta, dagli esperimenti ATLAS e CMS al Large Hadron Collider del CERN”







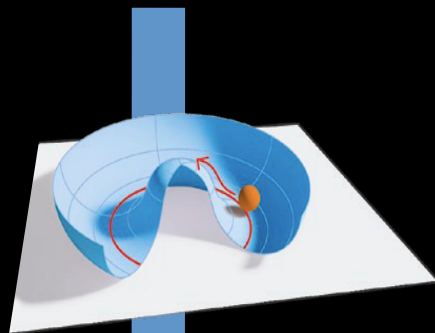
Il mondo senza massa



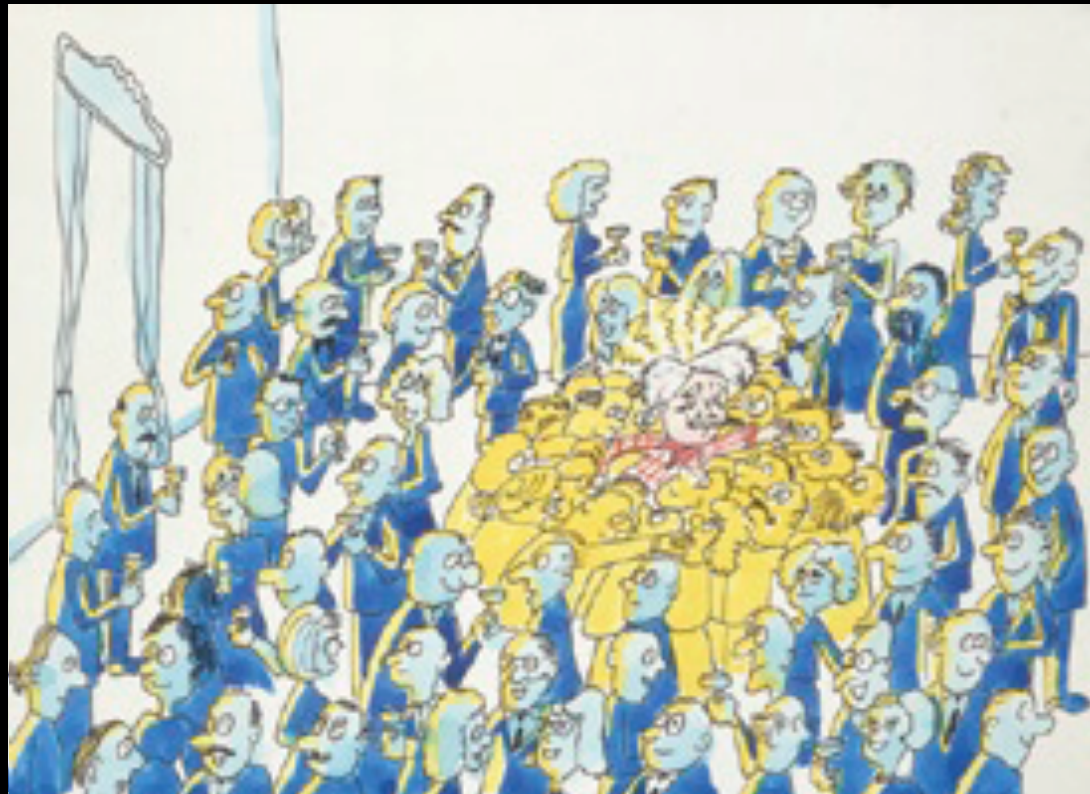
Tempo dopo il Big Bang: 10^{-32} secondi

Diametro dell'Universo: 10 metri

Temperatura: 10^{27} K



Rottura di simmetria



Tempo dopo il Big Bang: 10^{-9} secondi

Diametro dell'Universo: 10^{12} metri

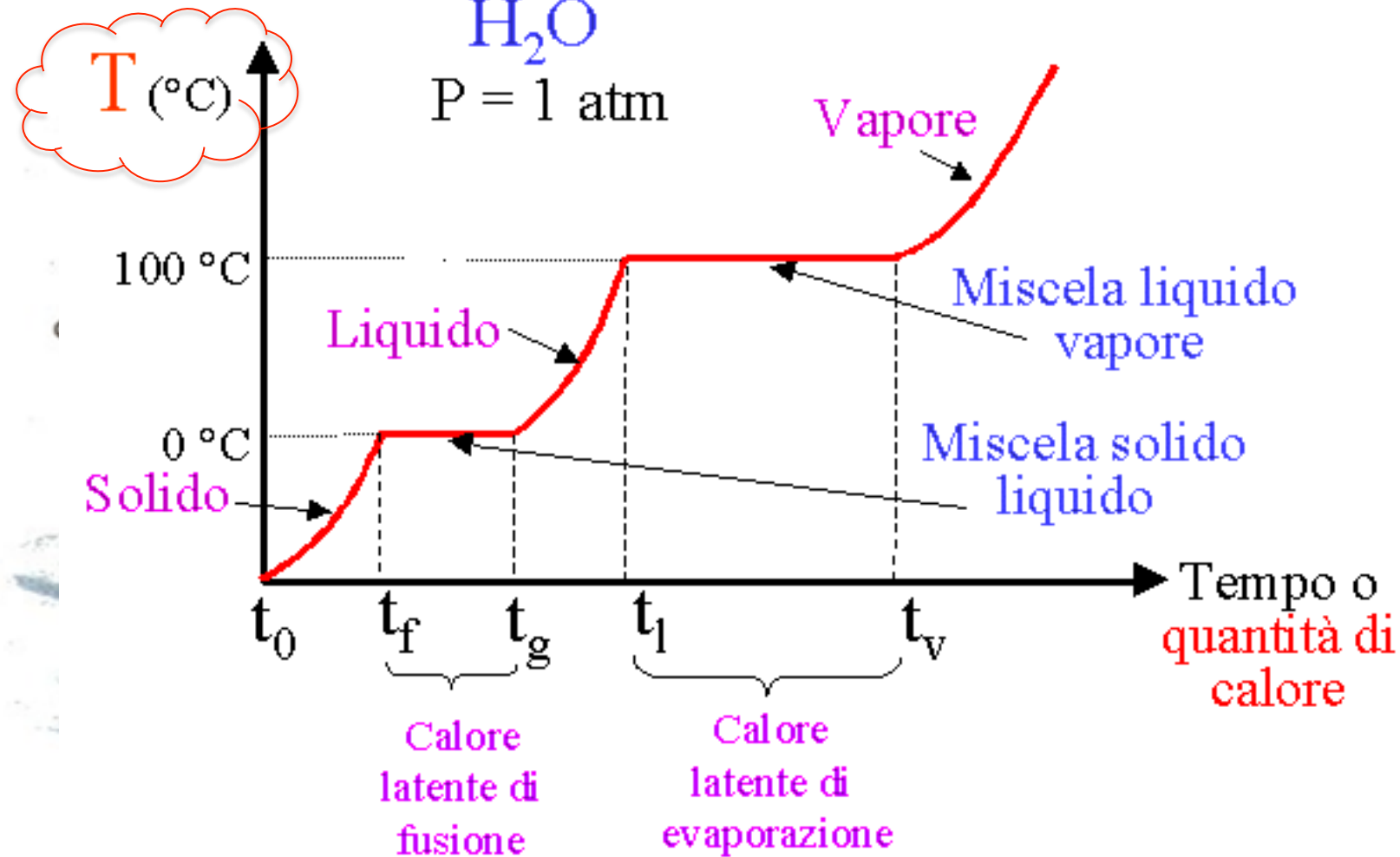
Temperatura: 10^{15} K

Stato
gassoso

Vapore
acqueo

H_2O

$P = 1 \text{ atm}$





Un'idea di Felix

