What we do not know about the Universe and how to know a bit more

1. Elementary particles
2. The Higgs Boson
3. What we don’t know
4. Experimental techniques

INFN: Istituto Nazionale di Fisica Nucleare

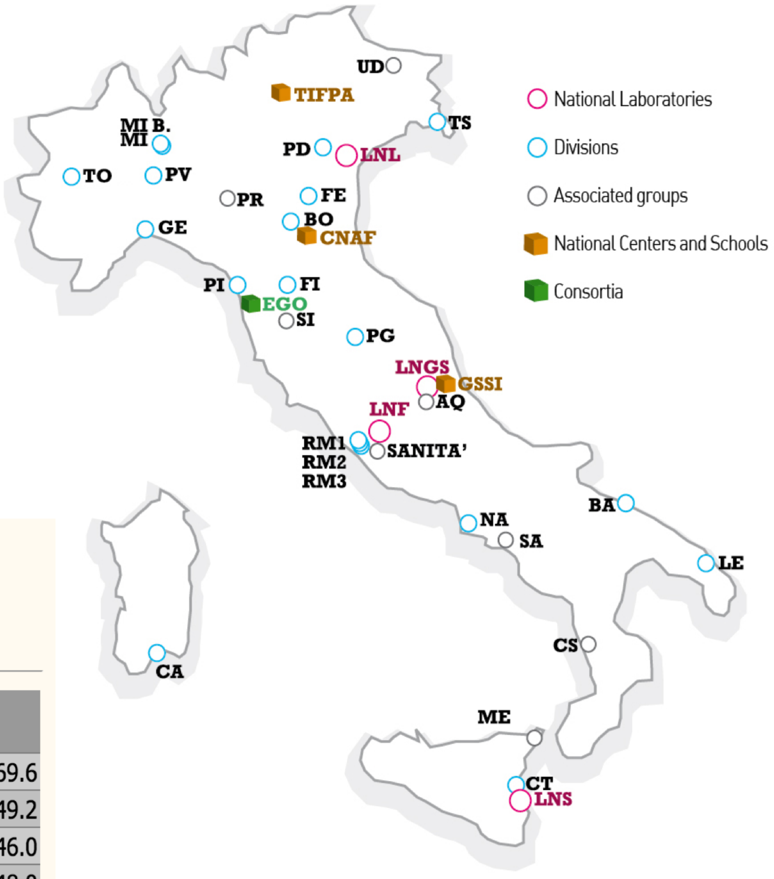


Table 1 - The Top 50 research Institutes in Italy.
The Institutes are ranked according to the Sum of H-index of their affiliated TIS.
Those fundamentally private or independent are highlighted in yellow.
Please note, this table is updated in real-time, based on the TIS database.

Rank	Italian Institution	Sum of H-Index	N. of TIS	Average H-Index
1	INFN	**10161**	146	69.6
2	Bologna	**8608**	175	49.2
3	Roma	**8289**	180	46.0
4	Padova	**7541**	157	48.0
5	Milano	**7347**	158	46.5
6	CNR	**5921**	134	44.2
7	Firenze	**5644**	121	46.6
8	Torino	**5410**	116	46.6
9	INAF	**4700**	91	51.6
10	Napoli	**4659**	104	44.8

Problem: how to deal with a very complex system

What surrounds us is extremely complex, often the result of many overlapping factors.

Think of this classroom: there are lots of things that happen right now and write the laws of physics to describe them is virtually impossible.

Solution: reduce the problem to its simpler parts

Reductionism

the basic process used in physics to understand reality

The properties of a complex system can be interpreted in terms of the properties of its simpler parts

Reductionism in the kitchen

Let's suppose you are eating these foods, and you need to identify their components

A good theory: these foods are made of eggs, flavor , sugar, salt

→ Complex and diverse foods are made of simple ingredients

Reductionism in music

Imagine you are listening to these songs, and you need to understand the elementary components

7 note ed ottave, diesis, bemolle

Riduzionismo in natura

INFORMAZIONI NUTRIZIONALI

	Per 100g	Per porzione da 30g
VALORE ENERGETICO	1604 kJ 378 kcal	481 kJ 113 kcal
GRASSI	0,9 g	0,3 g
di cui saturi	0,2 g	0,1 g
CARBOIDRATI	84 g	25 g
di cui zuccheri	8 g	2,4 g
FIBRE	3 g	0,9 g
PROTEINE	7 g	2,1 g
SALE	1,13 g	0,34 g
VITAMINE:	(%NRV)	(%NRV)
D	4,2 µg (83)	1,3 µg (25)
B1	0,91 mg (83)	0,28 mg (25)
B2	1,2 mg (83)	0,35 mg (25)
NIACINA	13 mg (83)	4,0 mg (25)
B6	1,2 mg (83)	0,35 mg (25)
ACIDO FOLICO	166 µg (83)	50,0 µg (25)
B12	2,1 µg (83)	0,63 µg (25)
MINERALI:		
FERRO	8,0 mg (57)	2,4 mg (17)

Where these iron atoms come from?

Now, let's look around… lot's of different things, is there a common origin? Why they are made the way they are made…

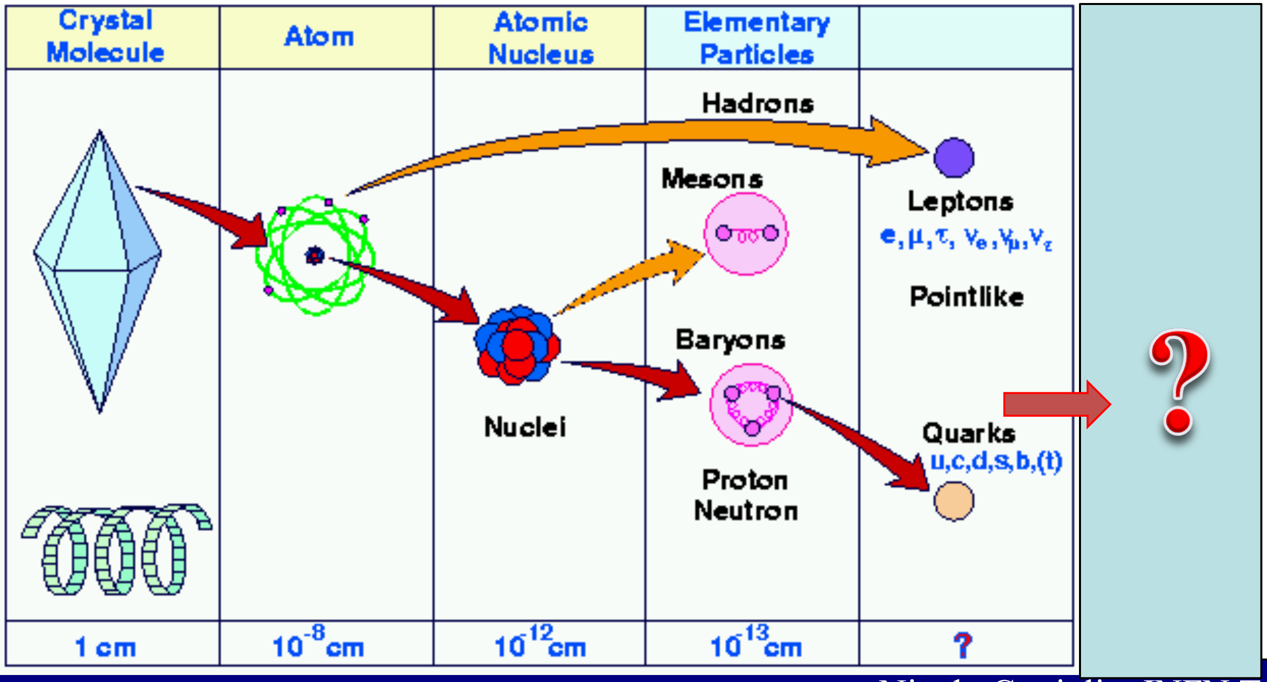
Elementary particles, forces…

What is "particle physics"?

The reductionist approach in particle physics has led to many advances.

The passage from one level to the next takes place through the study of symmetries that indicate the presence of a sub-structure

Today we talk about what we do not know ... the next level



What is an “elementary particle”?

We can define a particle as "elementary" if we think that it does not have substructure.

This means that you can not break into smaller pieces.

Elementary particles are of 3 types:

1. Particles that transmit forces (4)

2. Particles that form the matter (12)

1. The Higgs particle (1+?)

How do we find the elements composing things? We order them

How do we make new particles in the lab?

We smash particles together, and we make new ones

Einstein: $E=mc^2$

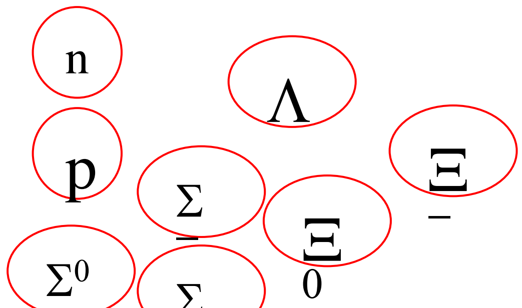
Energy can become mass (what we do).

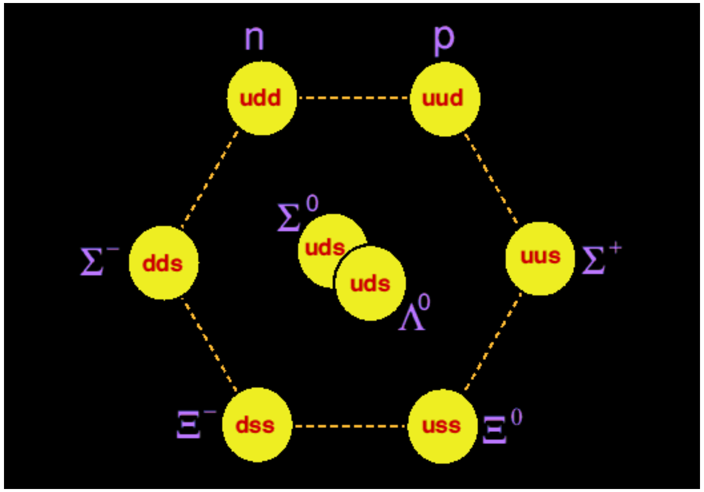
Bombs: mass become energy (what we don't do!)

~ 1970: lot's of particles were created in the labs, which one are elementary ?

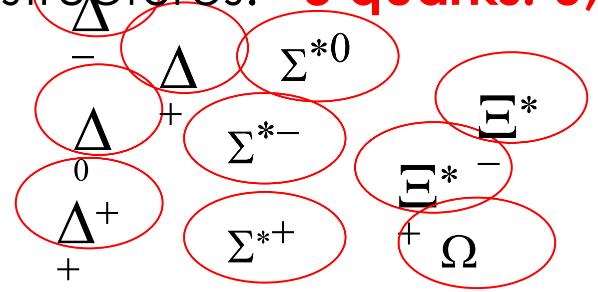
The zoo of particles

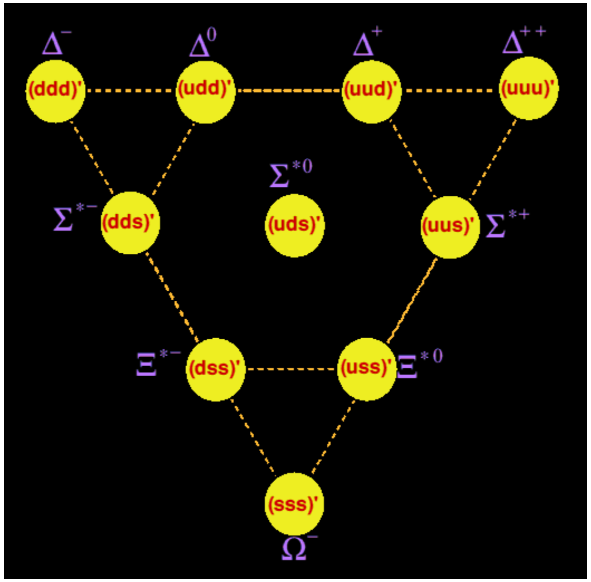
Can we make orders in the particles created in thelabs?





Ordering the particles have allowed physicists to identify sub-structures: **3 quarks: u, d, s**





A zoo made of composite particles

In the interaction many composite particles are created

Barions (made of 3 quarks, qqq): p,n
Mesons (made of a q-anti q): pions, kaons, rho…

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	–1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	–1	1.672	3/2

Mesons $q\bar{q}$

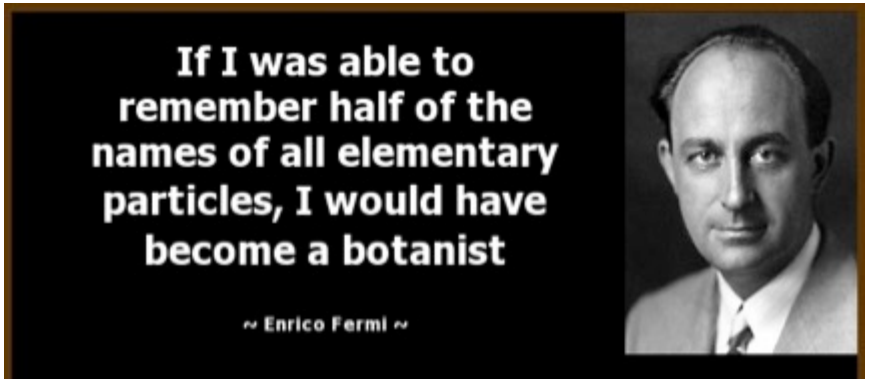
Mesons are bosonic hadrons.
There are about 140 types of mesons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	–1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

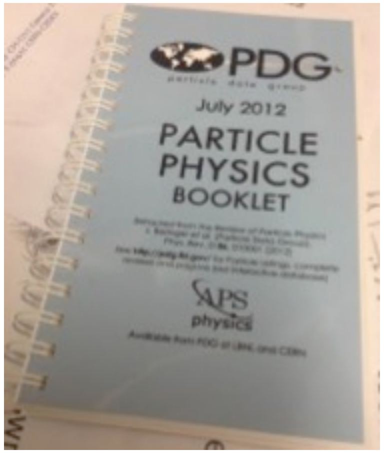
A book full of particles

How do you remember the name of all composite particles?

You don't!!



But you can use a book, that lists them all



For example…

$\omega(782)$ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi^+\pi^-\pi^0$		(89.2 ± 0.7) %		327
$\pi^0\gamma$		(8.28 ± 0.28) %	S=2.1	380
$\pi^+\pi^-$		$(1.53^{+0.11}_{-0.13})$ %	S=1.2	366
neutrals (excluding $\pi^0\gamma$)		$(8\ ^{+8}_{-5}) \times 10^{-3}$	S=1.1	–
$\eta\gamma$		$(4.6 \pm 0.4) \times 10^{-4}$	S=1.1	200
$\pi^0 e^+ e^-$		$(7.7 \pm 0.6) \times 10^{-4}$		380
$\pi^0 \mu^+ \mu^-$		$(1.3 \pm 0.4) \times 10^{-4}$	S=2.1	349
$e^+ e^-$		$(7.28 \pm 0.14) \times 10^{-5}$	S=1.3	391
$\pi^+\pi^-\pi^0\pi^0$		$< 2 \times 10^{-4}$	CL=90%	262
$\pi^+\pi^-\gamma$		$< 3.6 \times 10^{-3}$	CL=95%	366
$\pi^+\pi^-\pi^+\pi^-$		$< 1 \times 10^{-3}$	CL=90%	256
$\pi^0\pi^0\gamma$		$(6.6 \pm 1.1) \times 10^{-5}$		367
$\eta\pi^0\gamma$		$< 3.3 \times 10^{-5}$	CL=90%	162
$\mu^+\mu^-$		$(9.0 \pm 3.1) \times 10^{-5}$		377
3γ		$< 1.9 \times 10^{-4}$	CL=95%	391
Charge conjugation (C) violating modes				
$\eta\pi^0$	C	$< 2.1 \times 10^{-4}$	CL=90%	162
$2\pi^0$	C	$< 2.1 \times 10^{-4}$	CL=90%	367
$3\pi^0$	C	$< 2.3 \times 10^{-4}$	CL=90%	330

$\eta'(958)$ $\quad I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 957.78 \pm 0.06$ MeV
Full width $\Gamma = 0.198 \pm 0.009$ MeV

$\eta'(958)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\pi^+\pi^-\eta$	(42.9 ± 0.7) %		232
$\rho^0\gamma$ (including non-resonant $\pi^+\pi^-\gamma$)	(29.1 ± 0.5) %		165
$\pi^0\pi^0\eta$	(22.2 ± 0.8) %		239
$\omega\gamma$	(2.75 ± 0.23) %		159
$\gamma\gamma$	(2.20 ± 0.08) %		479
$3\pi^0$	$(2.14 \pm 0.20) \times 10^{-3}$		430
$\mu^+\mu^-\gamma$	$(1.08 \pm 0.27) \times 10^{-4}$		467
$\pi^+\pi^-\mu^+\mu^-$	$< 2.9 \times 10^{-5}$	90%	401
$\pi^+\pi^-\pi^0$	$(3.8 \pm 0.4) \times 10^{-3}$		428
$\pi^0\rho^0$	< 4 %	90%	111
$2(\pi^+\pi^-)$	$< 2.4 \times 10^{-4}$	90%	372

HTTP://PDG.LBL.GOV Page 5 Created: 8/25/2014 17:06

Citation: K.A. Olive et al. (Particle Data Group), Chin. Phys. C38, 090001 (2014) (URL: http://pdg.lbl.gov)

$f_0(500)$ or σ [g] was $f_0(600)$ $\quad I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = (400–550)$ MeV
Full width $\Gamma = (400–700)$ MeV

$f_0(500)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\pi$	dominant	–
$\gamma\gamma$	seen	–

$\rho(770)$ [h] $\quad I^G(J^{PC}) = 1^+(1^{--})$

Mass $m = 775.26 \pm 0.25$ MeV
Full width $\Gamma = 149.1 \pm 0.8$ MeV
$\Gamma_{ee} = 7.04 \pm 0.06$ keV

$\rho(770)$ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi\pi$		~ 100 %		363
$\rho(770)^\pm$ decays				
$\pi^\pm\gamma$		$(4.5 \pm 0.5) \times 10^{-4}$	S=2.2	375
$\pi^\pm\eta$		$< 6 \times 10^{-3}$	CL=84%	152
$\pi^\pm\pi^+\pi^-\pi^0$		$< 2.0 \times 10^{-3}$	CL=84%	254
$\rho(770)^0$ decays				
$\pi^+\pi^-\gamma$		$(9.9 \pm 1.6) \times 10^{-3}$		362
$\pi^0\gamma$		$(6.0 \pm 0.8) \times 10^{-4}$		376
$\eta\gamma$		$(3.00 \pm 0.20) \times 10^{-4}$		194
$\pi^0\pi^0\gamma$		$(4.5 \pm 0.8) \times 10^{-5}$		363
$\mu^+\mu^-$	[i]	$(4.55 \pm 0.28) \times 10^{-5}$		373
e^+e^-	[i]	$(4.72 \pm 0.05) \times 10^{-5}$		388
$\pi^+\pi^-\pi^0$		$(1.01^{+0.54}_{-0.36} \pm 0.34) \times 10^{-4}$		323
$\pi^+\pi^-\pi^+\pi^-$		$(1.8 \pm 0.9) \times 10^{-5}$		251
$\pi^+\pi^-\pi^0\pi^0$		$(1.6 \pm 0.8) \times 10^{-5}$		257
$\pi^0 e^+ e^-$		$< 1.2 \times 10^{-5}$	CL=90%	376

$\omega(782)$ $\quad I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 782.65 \pm 0.12$ MeV (S = 1.9)
Full width $\Gamma = 8.49 \pm 0.08$ MeV
$\Gamma_{ee} = 0.60 \pm 0.02$ keV

HTTP://PDG.LBL.GOV Page 4 Created: 8/25/2014 17:06

It's 500 pages long!!

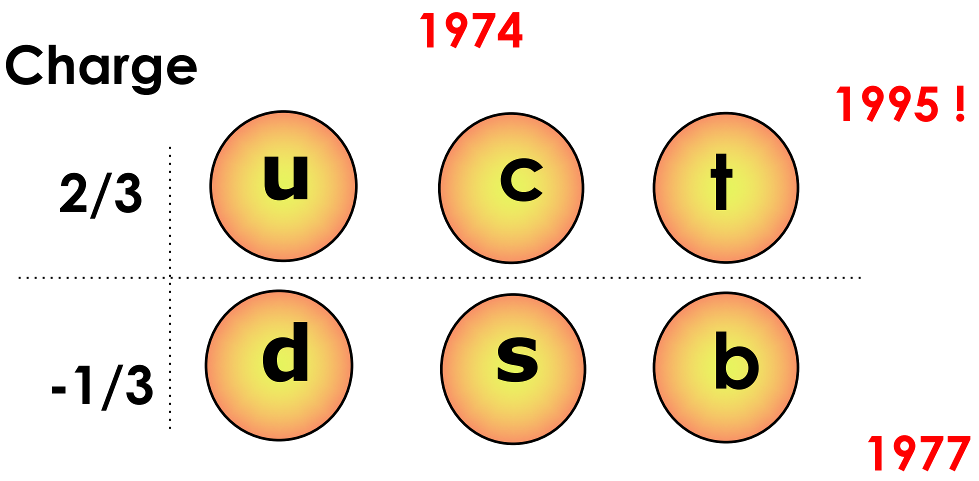
Symmetries in particle physics

Symmetries are

a guide in the search for new phenomena

The discovery of the quark family is an example::

Initial condition:

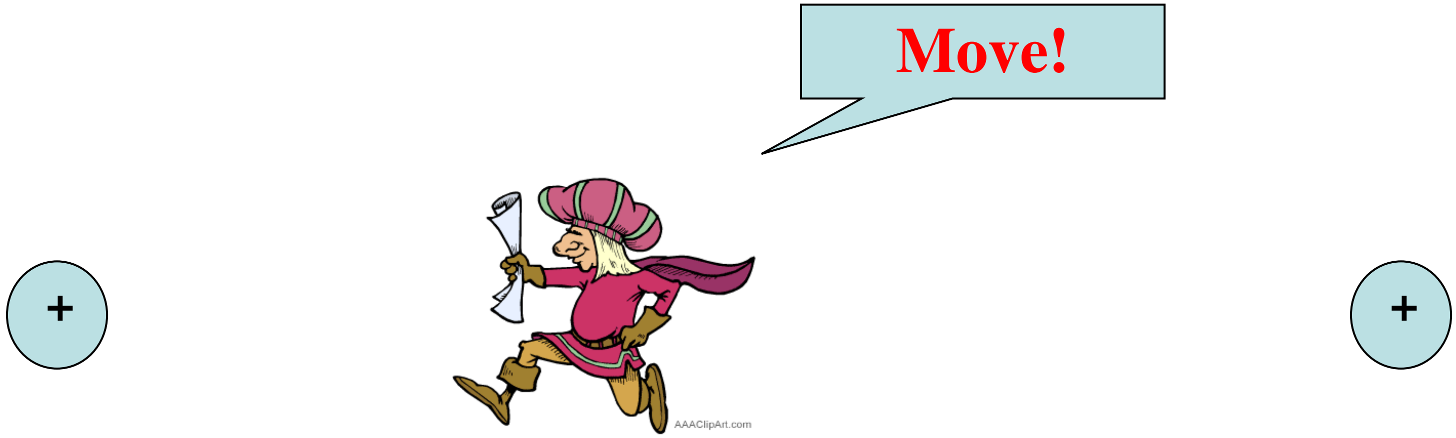


Matter and messangers

Elementary particles are of two different kinds:

1. Particles that form matter (12)

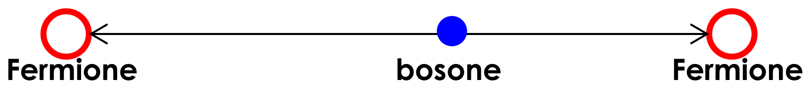
2. Particles that transfer a force (3+1)

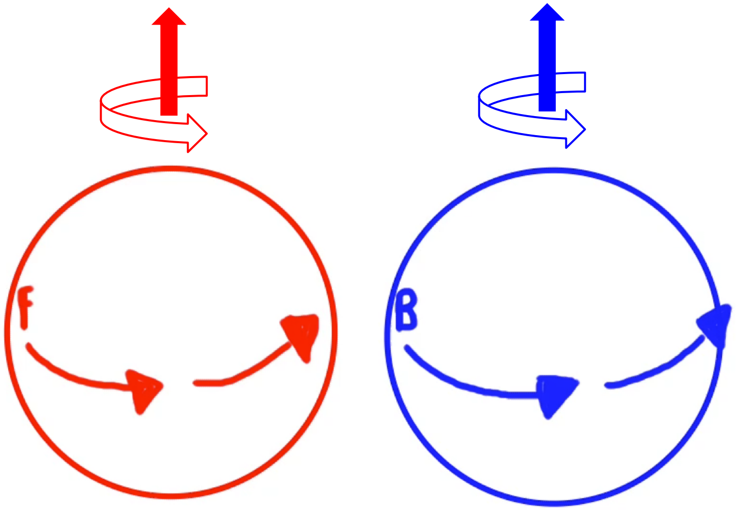


The spin of elementary particles

Particles spin on themselves..
We call this rotation spin.

Se lo spin è
- ½,3/2,5/2 si chiamano fermioni
- 0,1,2.. si chiamano bosoni



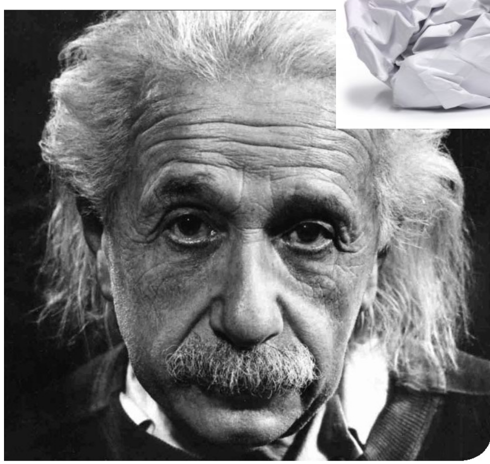


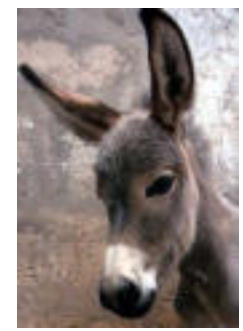
Elementary particles:
Messengers have spin 1
Matter has spin ½

This difference has very profound consequences

Examples: physics exam in the classromm

Piece of paper with the solution:
Boson, spin = 1

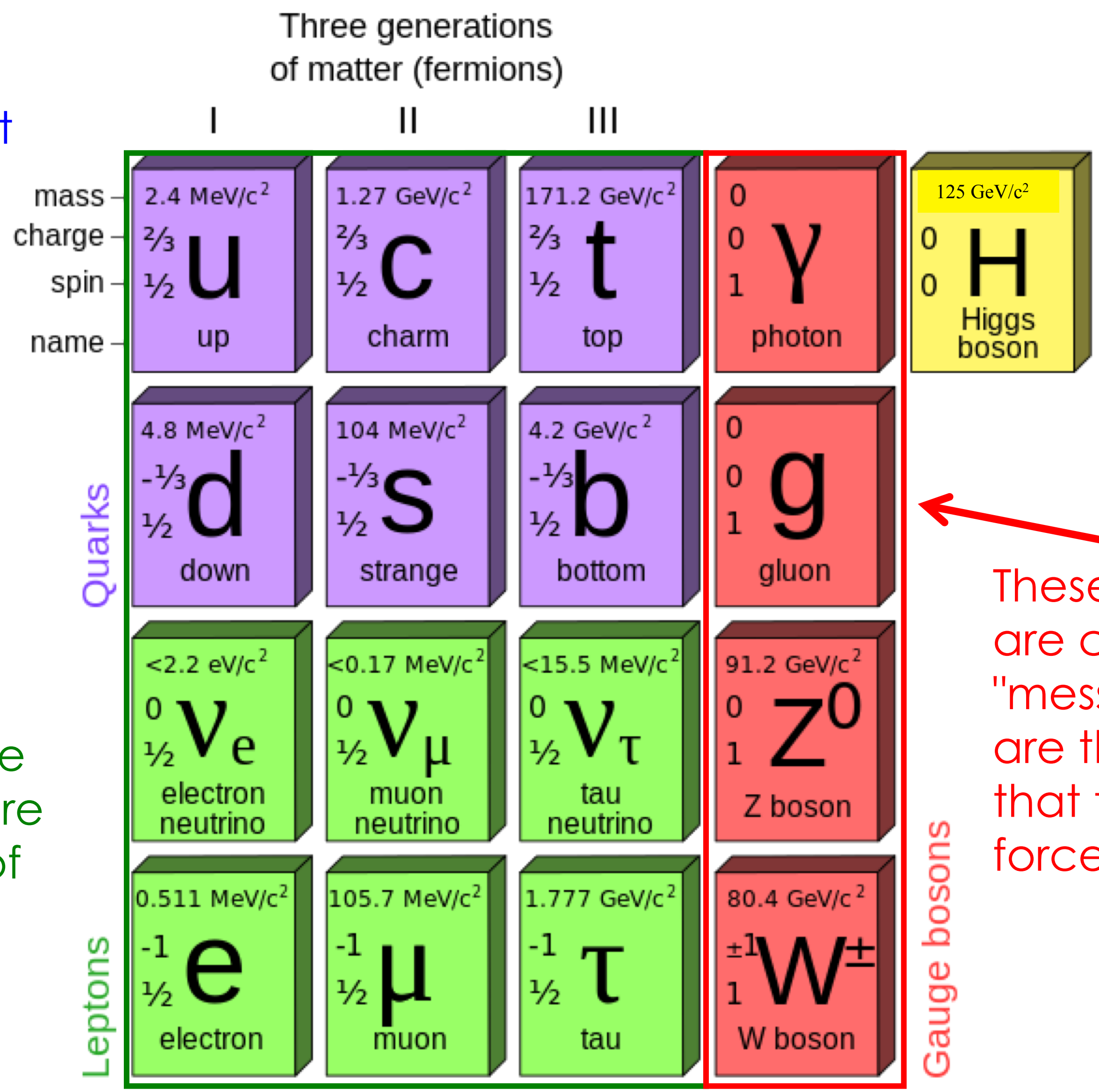




Good student
(matter particle)
Fermion, spin = 1/2

Less good student
(matter particles)
Fermione, spin = 1/2

Elementary: These particles are considered without internal structure (although not excluded)

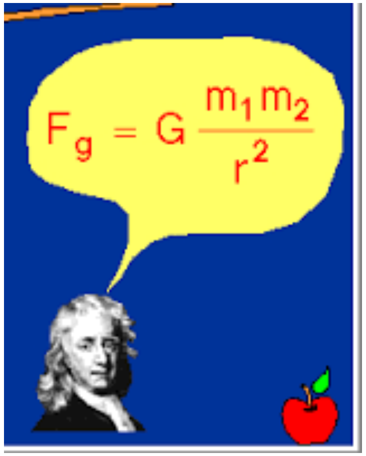


These particles are called "matter", are the constituents of matter

These particles are called "messengers", are the ones that transmit forces

Digression: what is gravity?

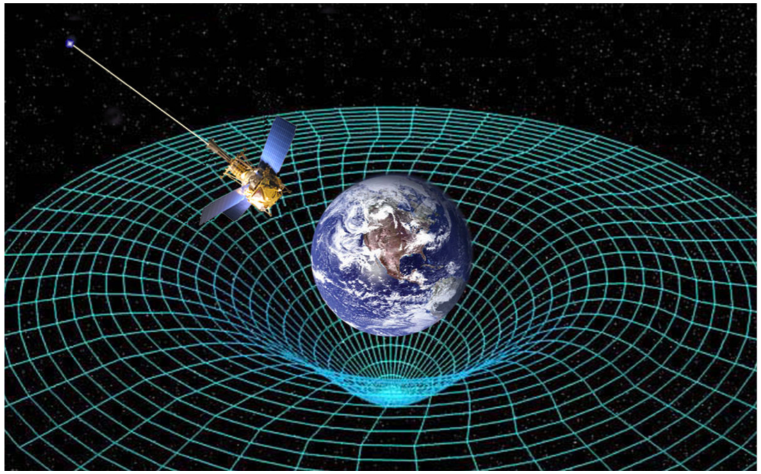
Why do planets attract each others?



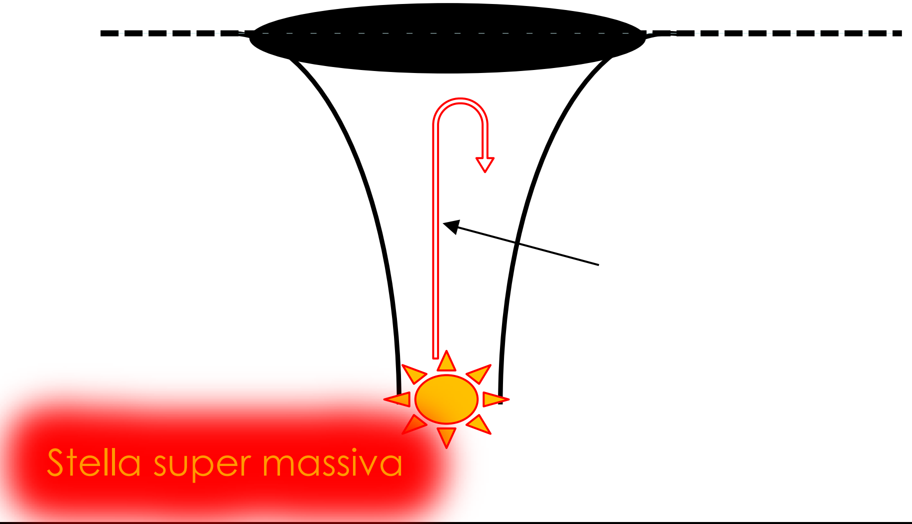
We are told that gravity is a force, but actually we have not found a messenger so far.

The only theory that works (General relativity) has not particles in it, it is about the geometry of space

Nobody knows how to write a theory of gravity with a messenger…



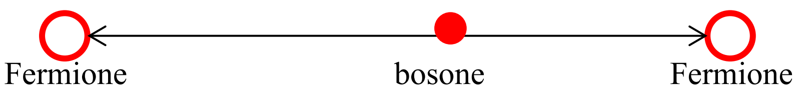
Balck holes, not even light comes out

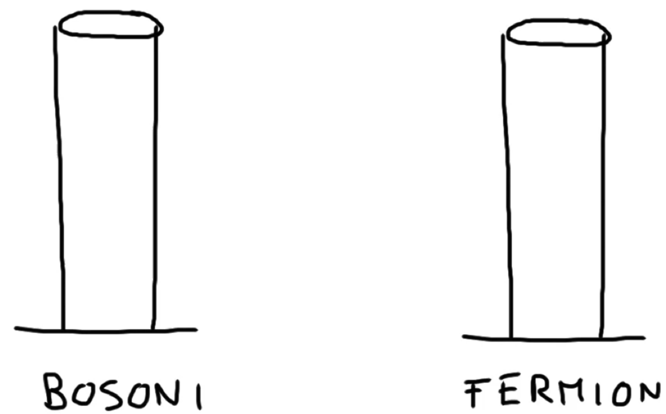


Spin: bosons and fermions

Matter particles has spin ½ : FERMIONS
Messangers have integer spins (0, 1 o 2): BOSONS

Fermions interact among themselves exchanging bosons





Bosonic particles can be all in the same place:

- 1) In a class of bosonic students there is only one chair
- 2) The parking place for bosonic cars has a single place
- Lovers are often bosons, they use one chair, stay very close to each other…

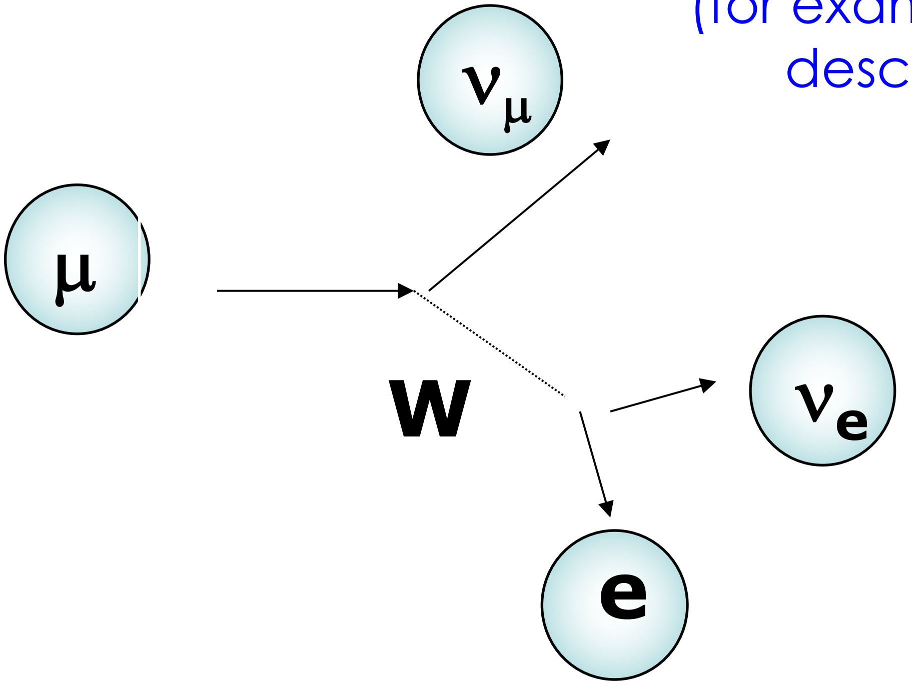
Cars are clearly not bosons…

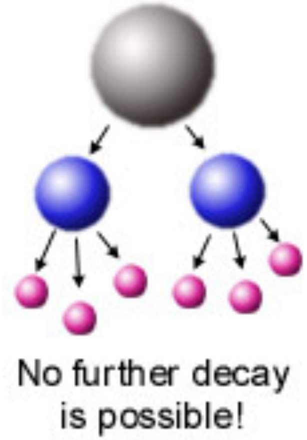
Coherence effects such as superconductivity and the laser are due to this fact

Particle decays

Heavier particles decay into lighter ones

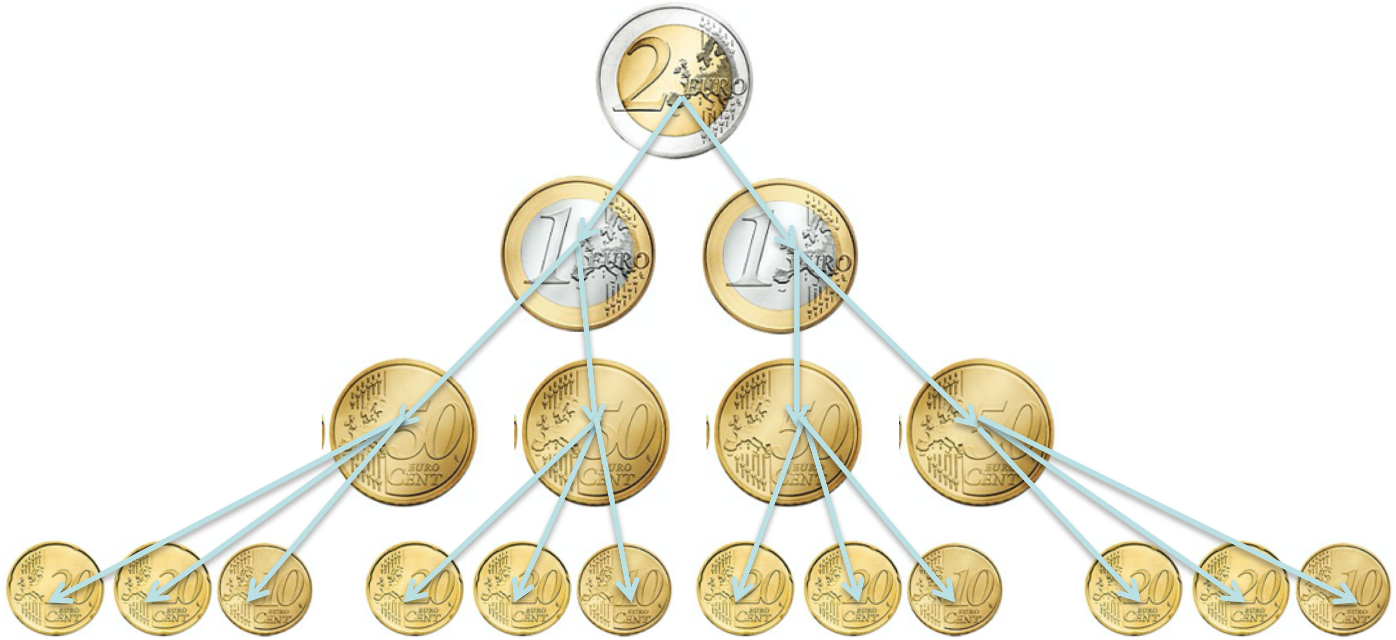
The decays occur following the rules
(for example, the conservation of charge)
described by the Standard Model





What does it mean: decay?

A single particle becomes several particles, however many of the properties of the initial particles are conserved



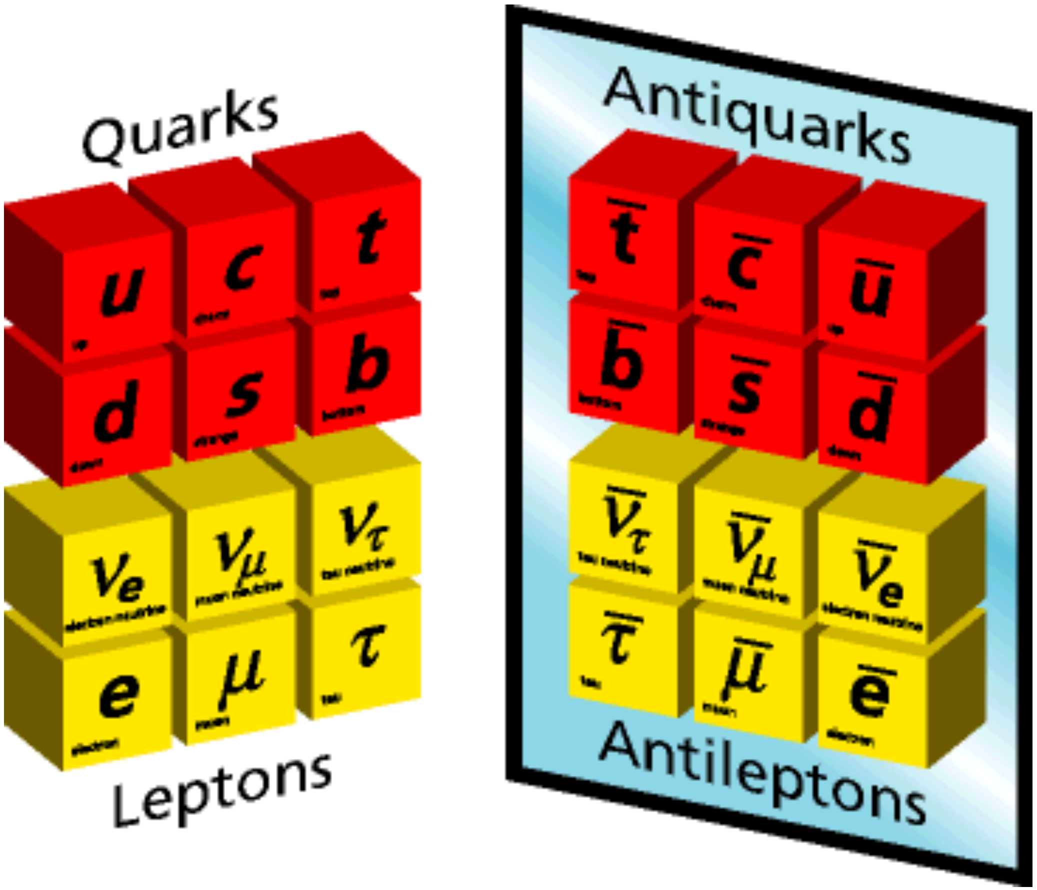
Conservazione del valore, non conservazione del peso

Matter and anti-matter

Every matter particle has its own anti-particle.

- **The mediators** don't have antiparticles: there are no anti-gluons or anti-photons!

- The anti-particles have opposite charges to those of the particles



Rule:
if in the laboratory you make a matter particle, then you make also its antiparticles,

Matter and anti-matter come together

How do you make anti-matter?

Bananas produce antimatter:
releasing one positron—the antimatter equivalent of an electron—about every 75 minutes.

This occurs because bananas contain a small amount of potassium-40, a naturally occurring isotope of potassium.

As potassium-40 decays, it occasionally spits out a positron in the process.

There are also other methods to make anti-matters

Are hidden symmetries in nature that can help us identify substructures?

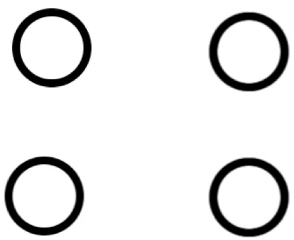
Hidden symmetries

Symmetries in nature are often hidden, “broken” by other effects that overlap and make the situation unclear

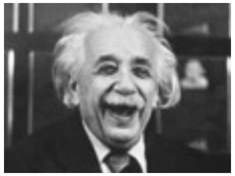
Example:

Laws of physics are symmetric under rotation. On land however, because of gravity, this is not true.

It is said then that the symmetry is hidden (or broken) by gravity.

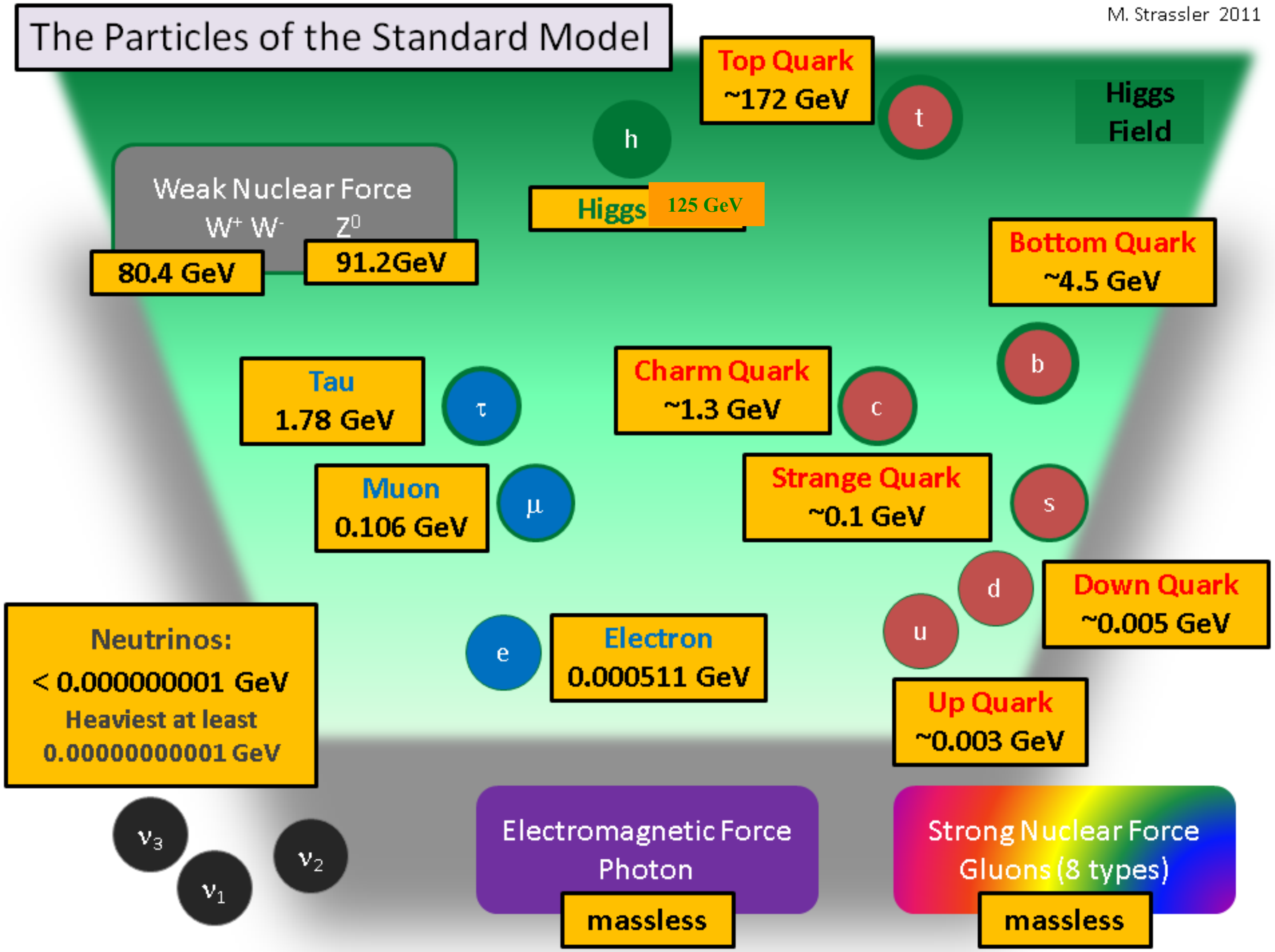


The search for hidden symmetry is the job of theoretical physicists …



The mass of elementary particles

What symmetry can we find using the values of mass we measure?



Mr. Higgs big idea

Elementary particles do not have mass

This symmetry is "hidden" (broken) by the interaction of the particles with the Higgs boson, which makes the particles massive

BROKEN SYMMETRIES, MASSLESS PARTICLES AND GAUGE FIELDS

P. W. HIGGS
Tait Institute of Mathematical Physics, University of Edinburgh, Scotland

Received 27 July 1964 !!!!!!

Recently a number of people have discussed
he Goldstone theorem [1,2]: that any solution of a
orentz-invariant theory which violates an inter-
al symmetry operation of that theory must con-
ain a massless scalar particle. Klein and Lee [3]
howed that this theorem does not necessarily ap-
ly in non-relativistic theories and implied that
heir considerations would apply equally well to
orentz-invariant field theories. Gilbert [4], how-
ever, gave a proof that the failure of the Goldstone theorem in the nonrelativistic case is of a type which cannot exist when Lorentz invariance is imposed on a theory. The purpose of this note is to show that Gilbert's argument fails for an important class of field theories, that in which the conserved currents are coupled to gauge fields.

Following the procedure used by Gilbert [4], let us consider a theory of two hermitian scalar fields

This idea opens the door to the mathematical description of the interactions between particles, called the STANDARD MODEL, which is possible only if:

all elementary particles have no mass

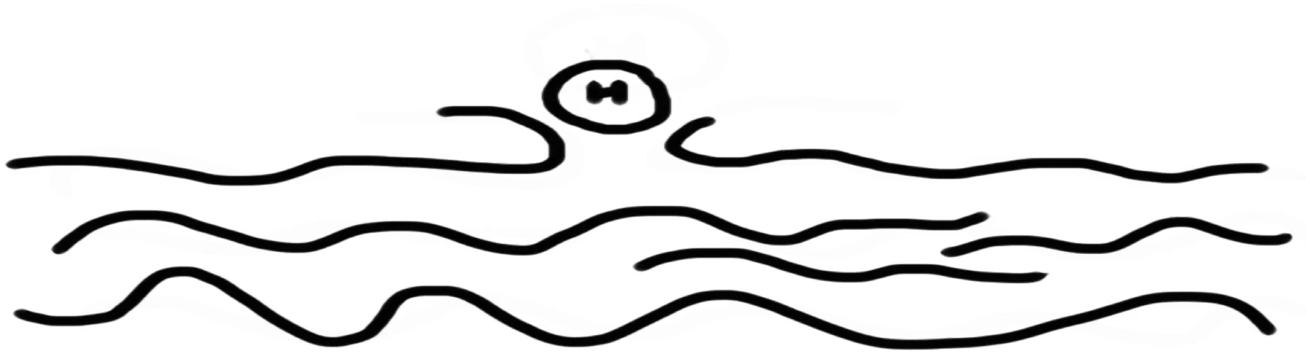
There is a particle absolutely special, which is neither matter nor a messenger of forces, which explains why the particles are massive:

The Higgs boson

The Higgs boson and the Higgs field

Think about the Electric field:
➔ The photon is the "proof" of the electric field

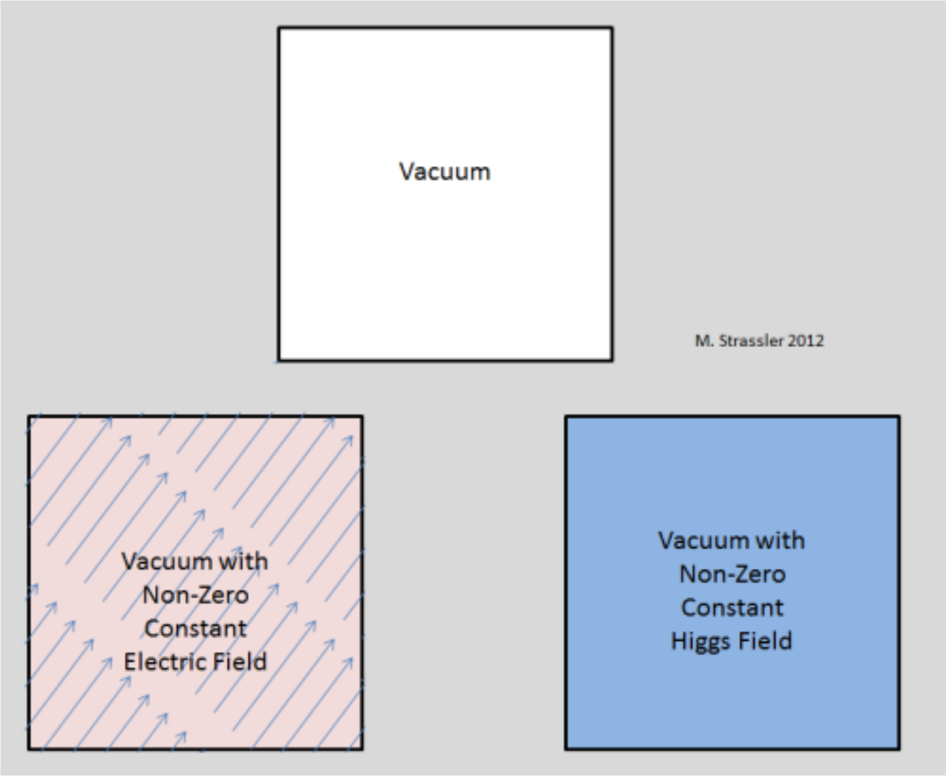
➔ The Higgs particle is the proof on the Higgs field



The Higgs field

The concept of "field" is pretty common in physics, think at the electric field in a parallel plate capacitor. Note: the electric field has a direction

The Higgs field is similar, but it's a scalar, it does not have a direction, It's like the temperature in a room.



Similarly to the inside of a capacitor, filled with the electric field, empty space is not empty: it's filled with the Higgs field.

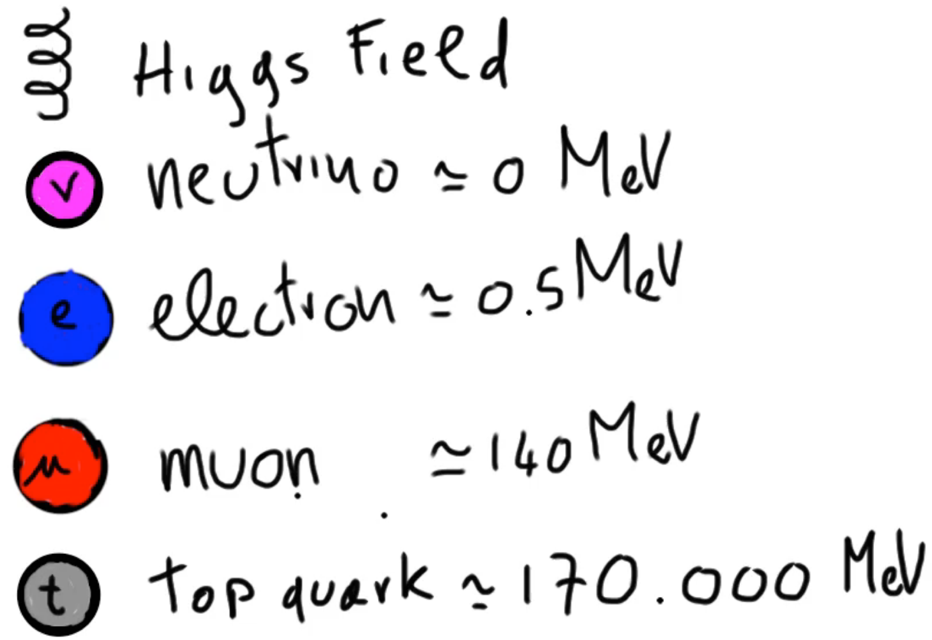
Vacuum does not exist!!

The mass of leptons and quarks

The Higgs field interacts with the massless particles, and makes them massive

Mass is therefore a property that does not belong to the particle, but it's due to the interaction with the Higgs field.

Particles look like having mass simply because they interact with the Higgs field



The Higgs mechanism

Let’s look at the relationship between Energy, mass and momentum:

$$E^2 = (mc^2)^2 + (pc)^2$$

In the absence of a Higgs field, the energy is pure momentum:

$$E^2 = (p_1 c)^2$$

Higgs mechanism

$$\Downarrow$$

In the presence of the Higgs field, the particles slow down and acquire mass:

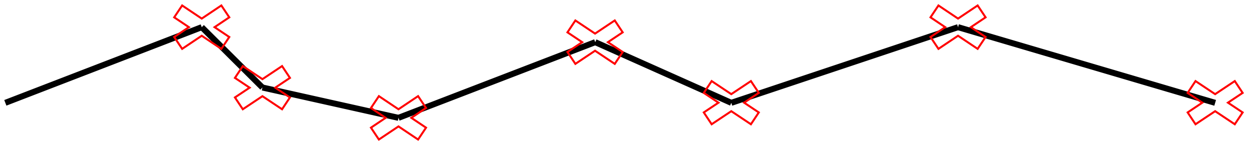
$$E^2 = (mc^2)^2 + (p_2 c)^2$$

$$p_1 > p_2$$

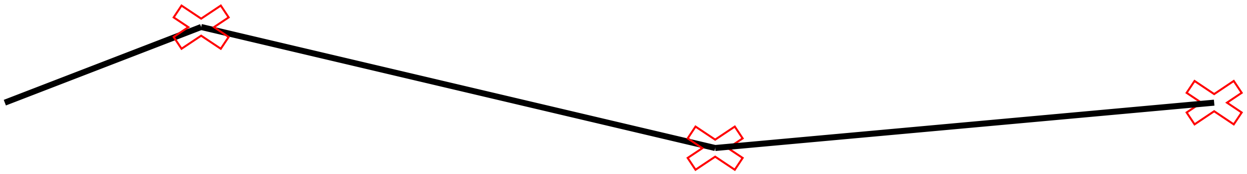
Why some particles are more massive?

Bumping against the Higgs field produces the mass

Heavy particle:



Light particle:



The hunt for the Higgs Boson

Since 1964, year of the publication of the paper by Mr Higgs, the Higgs particle has been the Holy grail of particle physics.

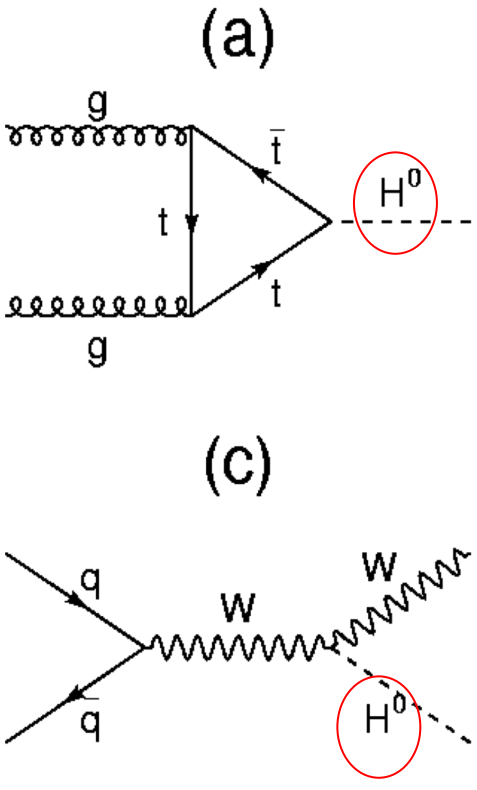
Rivers of ink, thousands of sleepless night, broken weddings, new weddings, tons of money, hope and dear disappointments...

Everything changed on July 4th 2012 ….

How do we make a Higgs boson?

The theory is telling us how to make it:

- You start from two protons
- 2 of the proton constituents combine and make an Higgs boson



For the inquisitive mind

$$
\begin{aligned}
\sigma^1_{\mathrm{H}}(\mathrm{pp}\to\mathrm{H}) &= \sum_{ab}\int_{\tau}^{1}\mathrm{d}x_a\int_{\tau/x_a}^{1}\mathrm{d}x_b\int\frac{\mathrm{d}\omega_1}{2\pi}\int\frac{\mathrm{d}\omega_2}{2\pi}\int\mathrm{d}z\,\delta\left(x_a x_b-\frac{M_{\mathrm{BH}}^2}{s}\right)2\pi\delta(zM_{\mathrm{BH}}-\omega_1-\omega_2)2\pi\delta(M_{\mathrm{H}}-\omega_1-\omega_2)\\
&\quad\times f_{a/\mathrm{A}}(x_a,\mu^2)f_{b/\mathrm{B}}(x_b,\mu^2)L^{ab\to\mathrm{BH}\to\mathrm{gg}}(\omega_1,\omega_2)p_{\mathrm{g}}(\omega_1)p_{\mathrm{g}}(\omega_2)L^{\mathrm{gg}\to\mathrm{H}}(\omega_1,\omega_2)\\
&= \sum_{ab}\int_{\tau}^{1}\mathrm{d}x_a\int_{\tau/x_a}^{1}\mathrm{d}x_b\int\frac{\mathrm{d}\omega_1}{2\pi}\int\frac{\mathrm{d}\omega_2}{2\pi}\int\mathrm{d}z\,\delta\left(x_a x_b-\frac{M_{\mathrm{BH}}^2}{s}\right)2\pi\delta(zM_{\mathrm{BH}}-\omega_1-\omega_2)2\pi\delta(M_{\mathrm{H}}-\omega_1-\omega_2)\\
&\quad\times f_{a/\mathrm{A}}(x_a,\mu^2)f_{b/\mathrm{B}}(x_b,\mu^2)\frac{\mathrm{e}^{-8\pi M_{\mathrm{BH}}\omega_1}}{1-\mathrm{e}^{-8\pi M_{\mathrm{BH}}\omega_1}}\frac{\mathrm{e}^{-8\pi M_{\mathrm{BH}}\omega_2}}{1-\mathrm{e}^{-8\pi M_{\mathrm{BH}}\omega_2}}\frac{1}{M_{\mathrm{P}}^2}\left\{\frac{\omega_1+\omega_2}{zM_{\mathrm{P}}}\left[\frac{4\Gamma(7/2)}{3}\right]\right\}^{2/5}\frac{1}{\omega_1^2}\frac{1}{\omega_2^2}\\
&\quad\times\sum_{C=1}^{8}(T^C T^C)_{mn}\left(\frac{\alpha_S}{\pi}\right)^2\frac{\pi}{288\sqrt{2}}\left(\frac{6M_{\mathrm{t}}^2}{(\omega_1+\omega_2)^2}\left\{1+\left[1-\frac{4M_{\mathrm{t}}^2}{(\omega_1+\omega_2)^2}\right]\arcsin^2\left[\sqrt{\frac{(\omega_1+\omega_2)^2}{4M_{\mathrm{t}}^2}}\right]\right\}\right)^2\\
&\approx C_{\mathrm{F}}\delta_{mn}\left(\frac{s}{M_{\mathrm{BH}}^2}\right)^{1.2}\left[1+3\frac{M_{\mathrm{BH}}^2}{s}\ln\left(\frac{s}{M_{\mathrm{BH}}^2}\right)\right]\left(\frac{\alpha_S}{\pi}\right)^2\frac{\pi}{288\sqrt{2}}\left\{\frac{6M_{\mathrm{t}}^2}{M_{\mathrm{H}}^2}\left[1+\left(1-\frac{4M_{\mathrm{t}}^2}{M_{\mathrm{H}}^2}\right)\arcsin^2\left(\sqrt{\frac{M_{\mathrm{H}}^2}{4M_{\mathrm{t}}^2}}\right)\right]\right\}^2\\
&\quad\times\frac{1}{M_{\mathrm{P}}^2}\left\{\frac{M_{\mathrm{BH}}}{M_{\mathrm{P}}}\left[\frac{4\Gamma(7/2)}{3}\right]\right\}^{2/5}\frac{\mathrm{e}^{-8\pi M_{\mathrm{BH}}^2}}{1-\mathrm{e}^{-8\pi M_{\mathrm{BH}}^2}}\left[\frac{1}{M_{\mathrm{t}}^2}-\frac{1}{M_{\mathrm{H}}^2}+\ln\left(\frac{M_{\mathrm{t}}}{M_{\mathrm{H}}}\right)\right]
\end{aligned}
$$

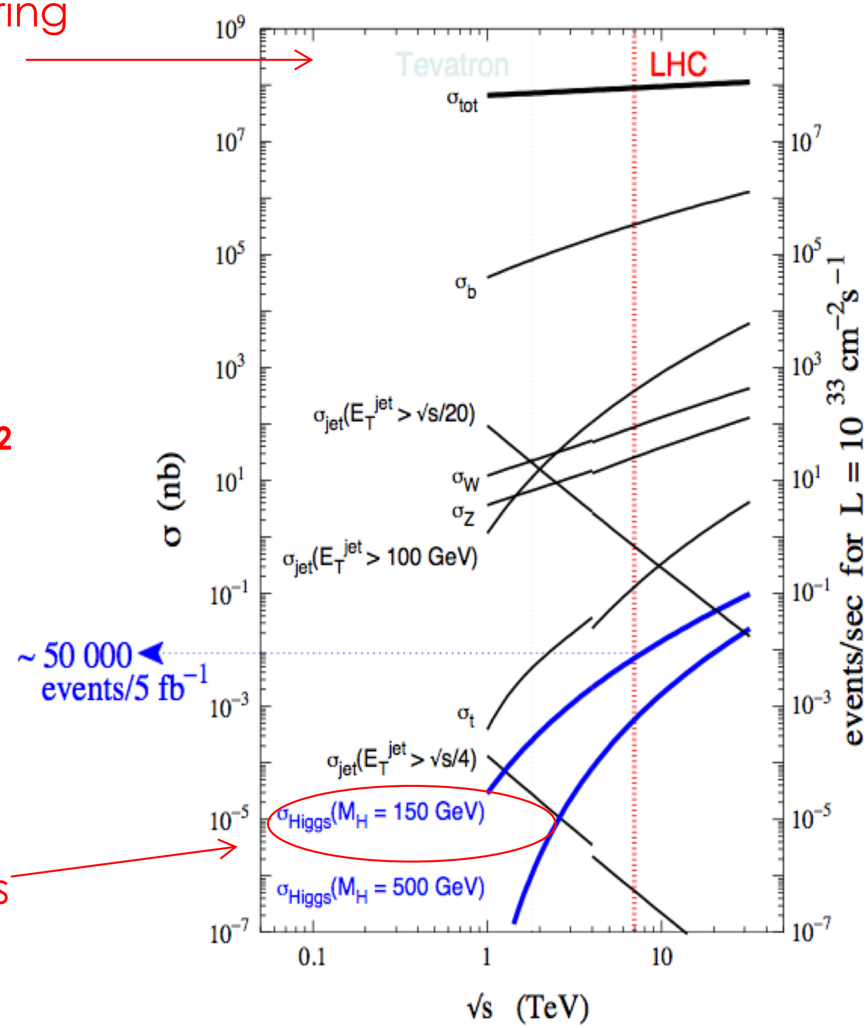
What is the probability to make a Higgs boson?

Probability of proton-proton scattering

You make one Higgs particle every 10^{12} scattering..

At LHC, we make a few Higgs each hour

10^{-12}

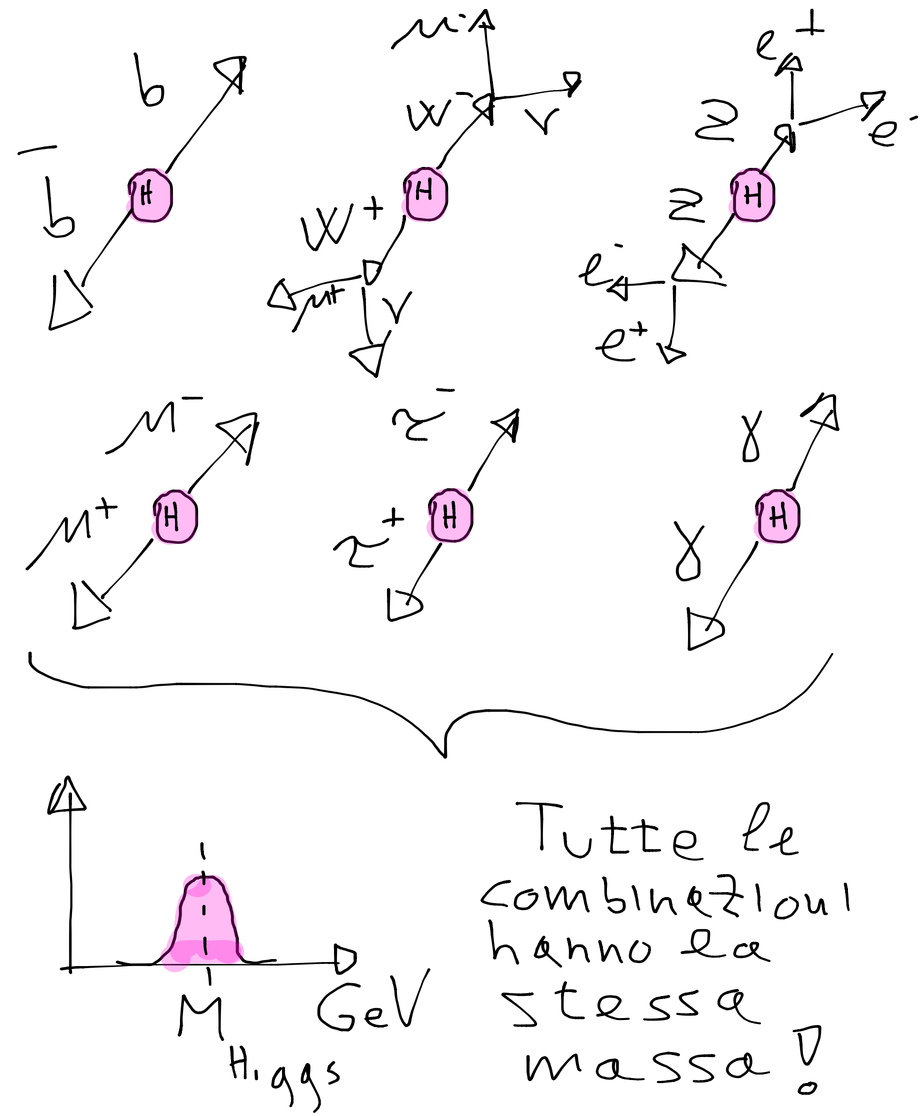


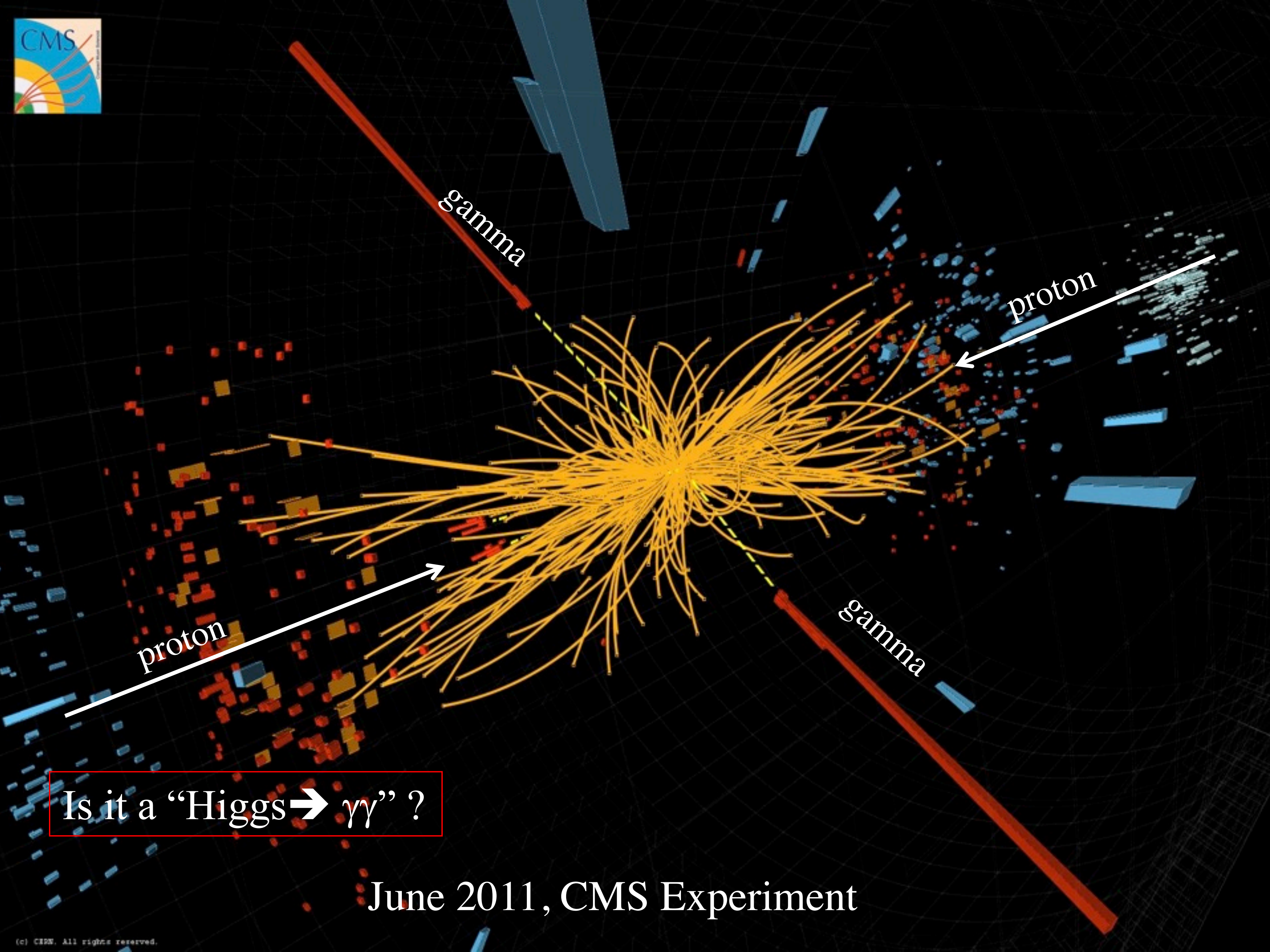
Probability to make a Higgs

How can we see a Higgs boson?

The Higgs boson does not live long enough to be seen, so we need to measure its decay products.

For example, we need to measure the mass of pairs of bb, or WW, ZZ, …, gg, and see if it's the same one

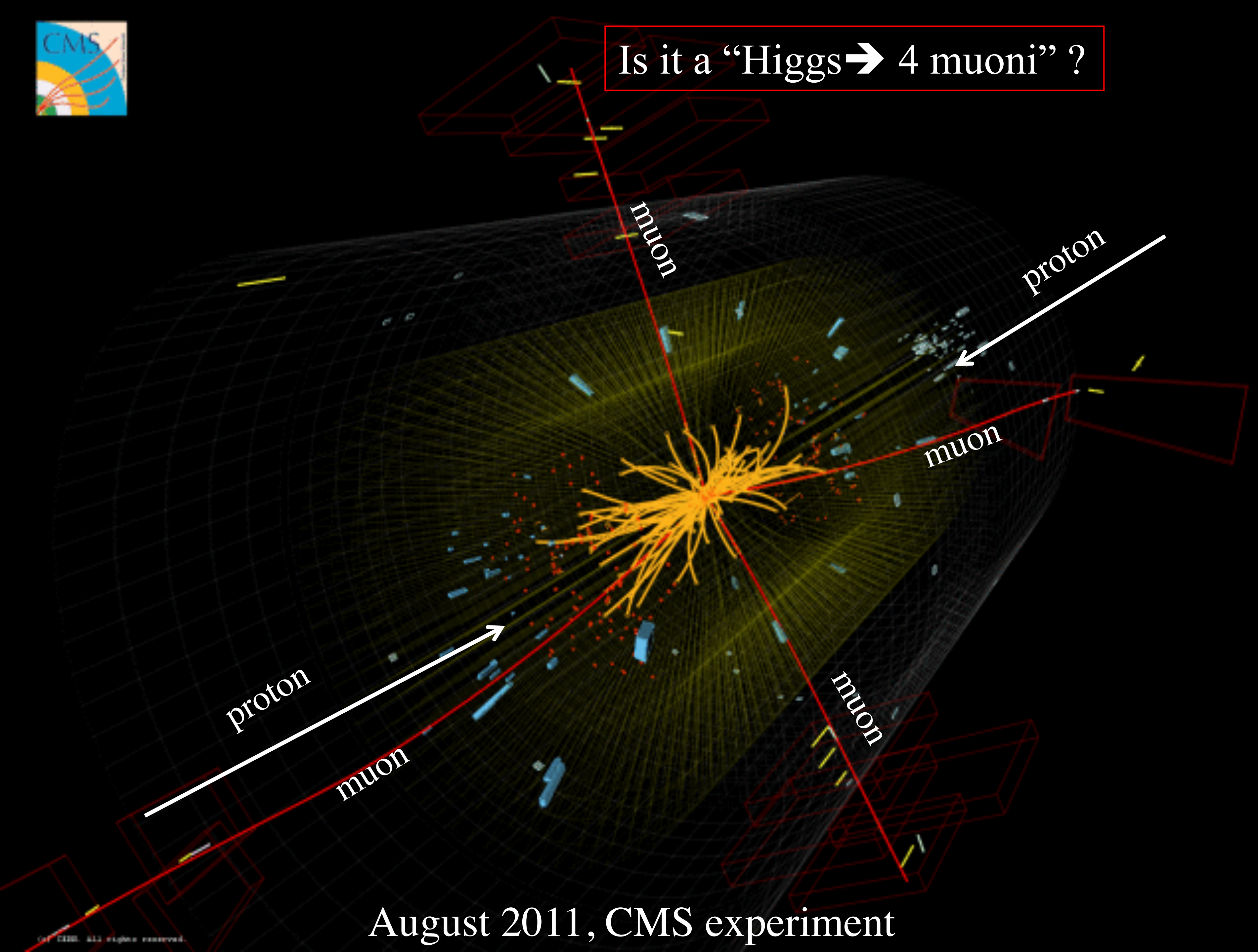




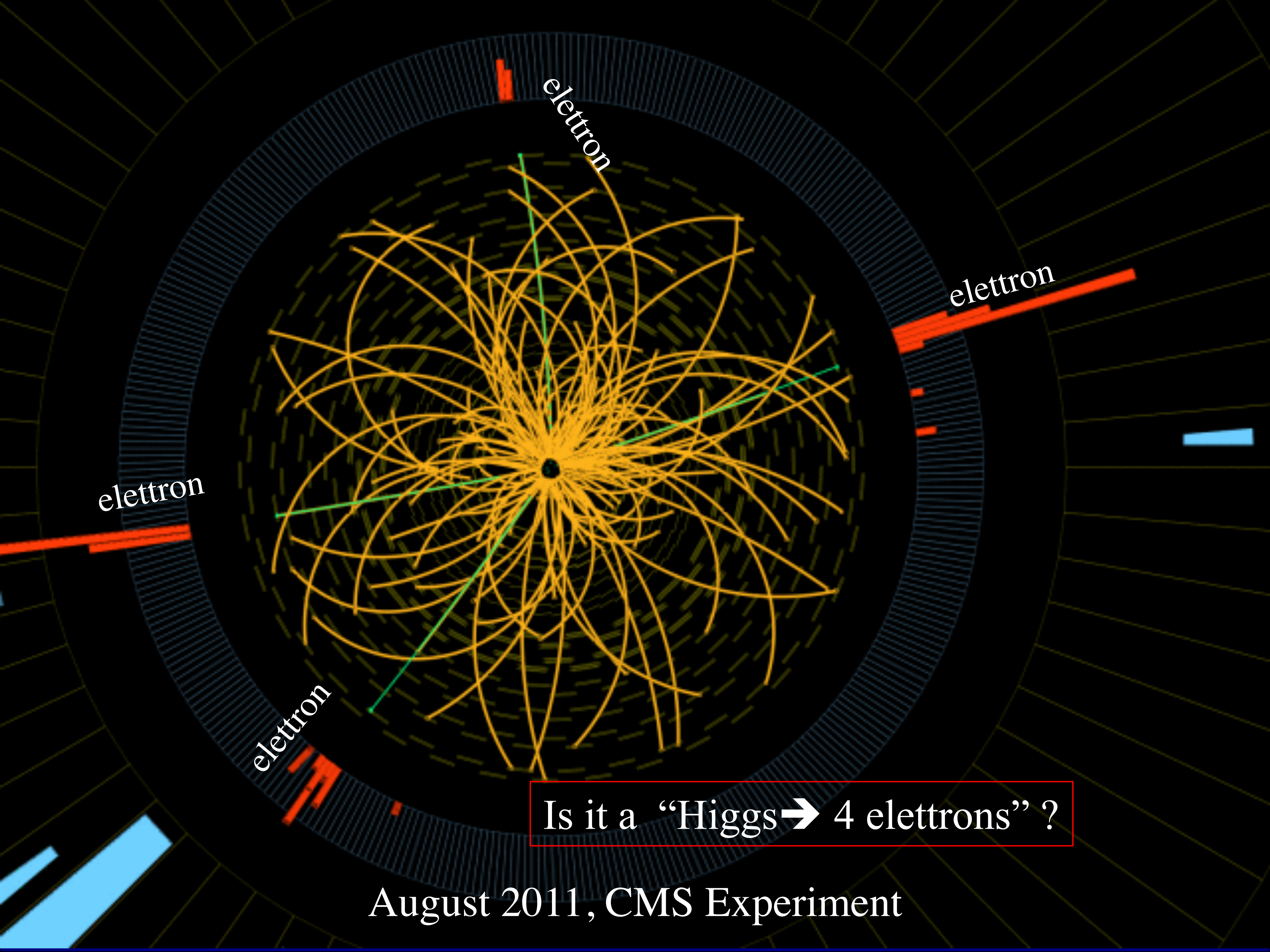
Is it a “Higgs➔ $\gamma\gamma$” ?

June 2011, CMS Experiment

Is it a “Higgs→ 4 muoni” ?



August 2011, CMS experiment



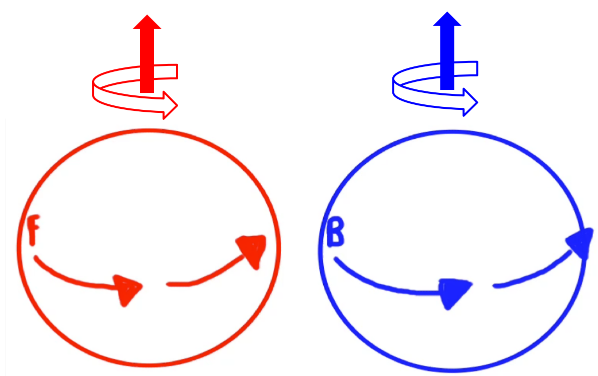
Is it a "Higgs➔ 4 elettrons" ?

August 2011, CMS Experiment

Why the Higgs particle is so special?

1. We don't know how to write a theory without it
2. It is everywhere, in every part of the universe
3. It is a new kind of force
4. It is the first elementary particle that does not rotate..

- Maybe it is not elementary…



Composite Higgs?

The mass of the Higgs boson

We can also calculate the mass of the Higgs boson using the theories that we have, and the results is

1) according to theory:

Theory: Higgs Mass = **10^{16} GeV ~ infinite**

2) while we measured:

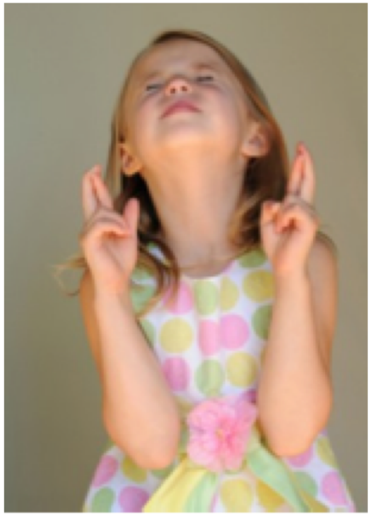
Measured: Higgs Mass = 125 GeV (~125 protons)

This is of course wrong!

Solution: you need additional particles to be able to calculate the mass of the Higgs boson correctly.

And now, what do we do?

There are fundamental questions to which we do not know the answer, we have theories that suggest solutions.



We have to find new particles to prove which of the theories is proposed the right one.

LHC starts in a few months with higher energy, we hope to find new things ...

Now, to understand the laws of physics,
we look at the sky ...

First let's exam the mass of the Higgs boson

1) according to theory:

Theory: Higgs Mass = **10^{16} GeV ~ infinite**

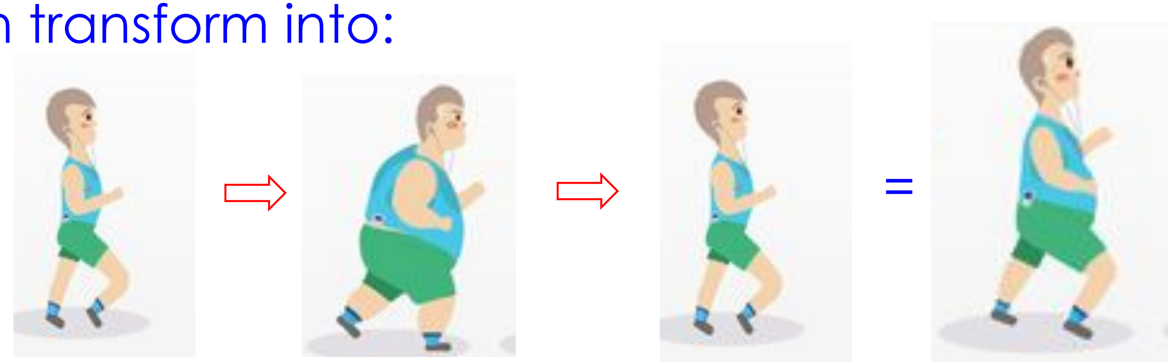
2) while we measured:

Measured: Higgs Mass = 125 GeV (~125 protons)

Loop corrections (for theorist..)

The mass of the Higgs boson is the combination of its own mass, plus the states it can transform into:

If it were a man:



Skinny not skinny medium

In the calculation of the Higgs mass , we need to include all the virtual state

Skinny: Self coupling

Energy violation for a short time:

$$\Delta E \, \Delta t \sim h$$

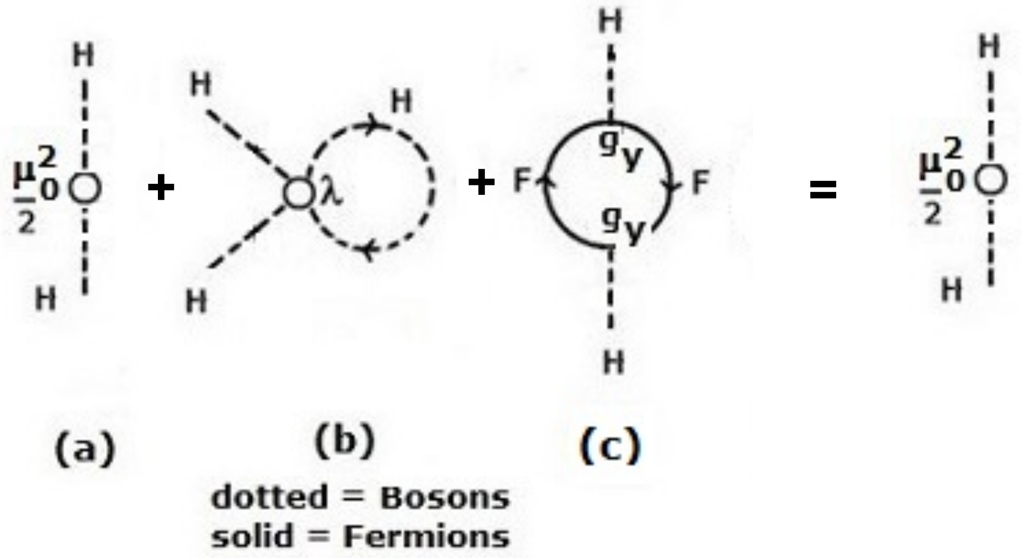
The idea…

'loop corrections' contribute to the mass:

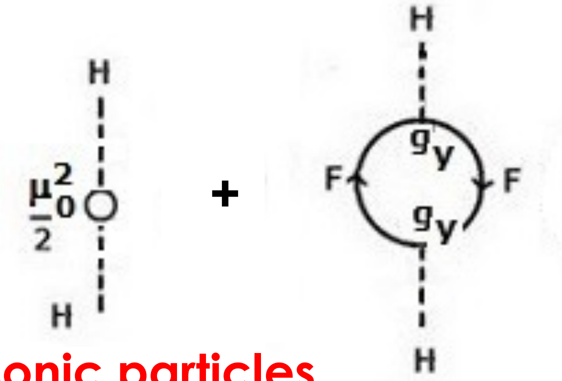
- negative for bosons
- positive for fermions

Fermions: positive contribution = + infinity

Bosons: negative contribution = - infinity

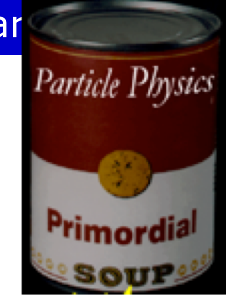


Now we have only:



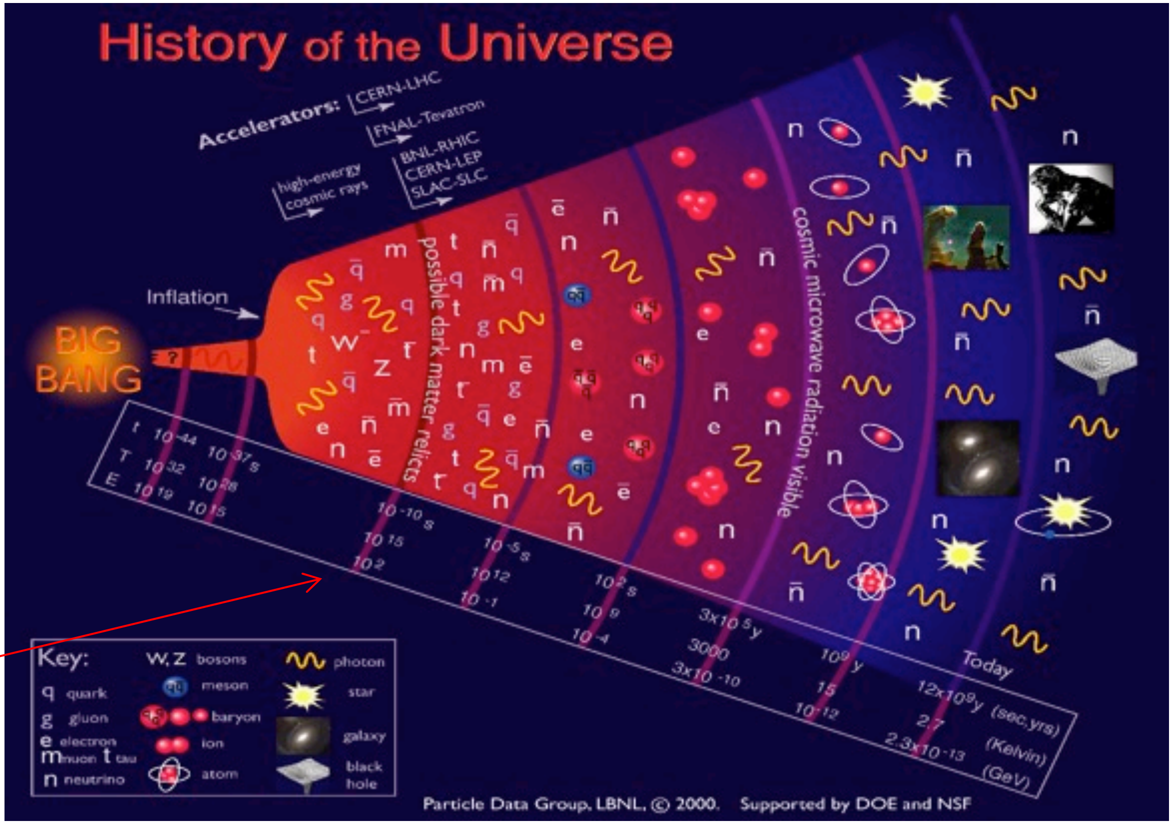
= infinity

We are missing new bosonic particles



The connection between astronomy and particle physics

The initial moments of our universe were governed by the same forces we study in accelerators, so it is natural to look at the stars to understand what has happened ..



Study the laws that have governed the evolution of the universe is equivalent to making a huge experiment.

There is evidence that:

1) there was a big bang
2) That there was a time of rapid expansion (inflation)

The physics of the LHC is to 10^{-11} seconds after the big bang

Far away = back in time

We need a fundamental concept, always used in astrophysics:

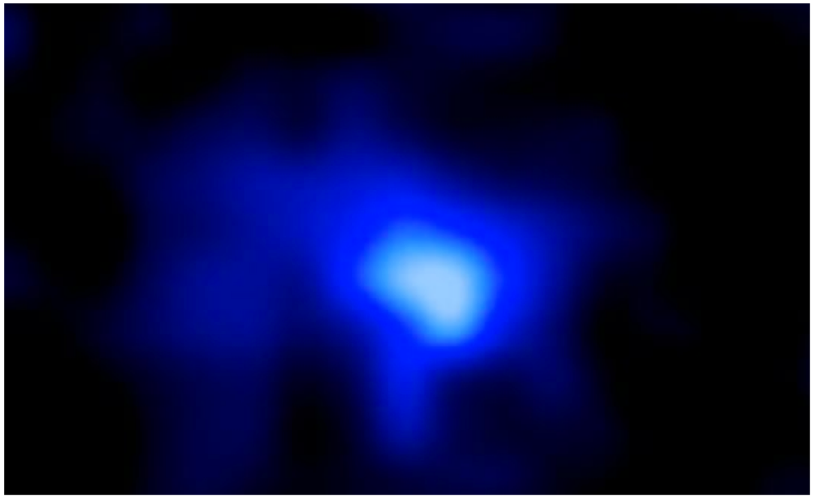
Looking at very far away objects means looking back in time.

The light from a distant galaxy takes a long time to arrive, and it shows us how the galaxy was when the light left.

1) We see the moon as it was 1.3 seconds ago
2) We see the sun as it was 500 seconds ago
3) The stars at the edge of our galaxy as they were 100,000 years ago

This is the image of the furthest galaxy (EGS-zs8-1) ever recorded

- The light has travelled 13 billion years
- The age of the galaxy is 670 million years



Expansion speed of the Universe

Consider a fire engine with the siren on.
Watching and listening we can learn two things:

1) As we know its real size, from its apparent size we can understand the position
2) As we know its true frequency, from its apparent frequency we can calculate the speed (Doppler effect)

In the universe, the fire engines are the type 1A supernova: we know very well the brightness and frequency.

From the apparent brightness and frequency of 1A supernova, we can derive their position, speed and age.

Distant supernovae stars move slower than closer supernova

Dark Energy

Remember:

Distant Supernovae ➔ oldest supernovae
Closer Supernovae ➔ newer supernovae

Fact: the expansion rate of older supernovae is slower than the newer ones

Conclusion:

In the past, the expansion of the universe was slower
➔ the universe is accelerating.

(Nobel Prize for physics in 2011)

➔ There is a form of energy that exerts a repulsive force:
DARK ENERGY

We have absolutely no idea what it is ....
(according to the BigBang expansion is expected to slow down due to gravity)

Dark matter and the rotational speed of galaxies

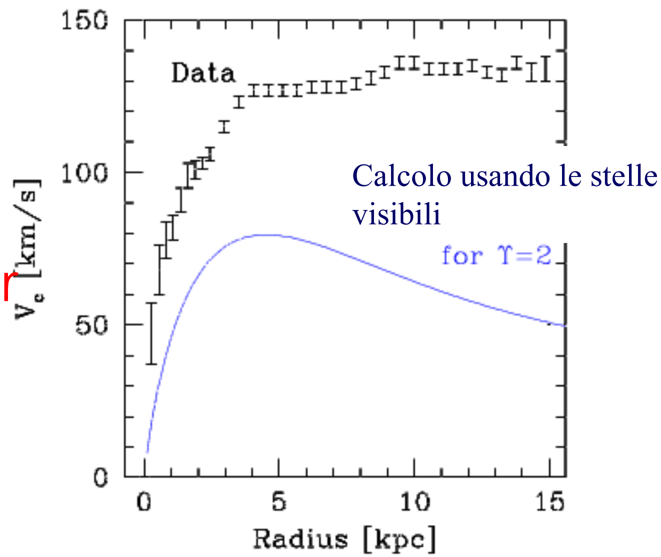
Consider a galaxy: the stars revolve around its center, like the planets around the sun.

Using Newton's laws, it can be shown that the stars at the periphery must move slower: where there is less matter the stars rotate more slowly.

However, in reality, the speed of rotation is constant. How can this happen?

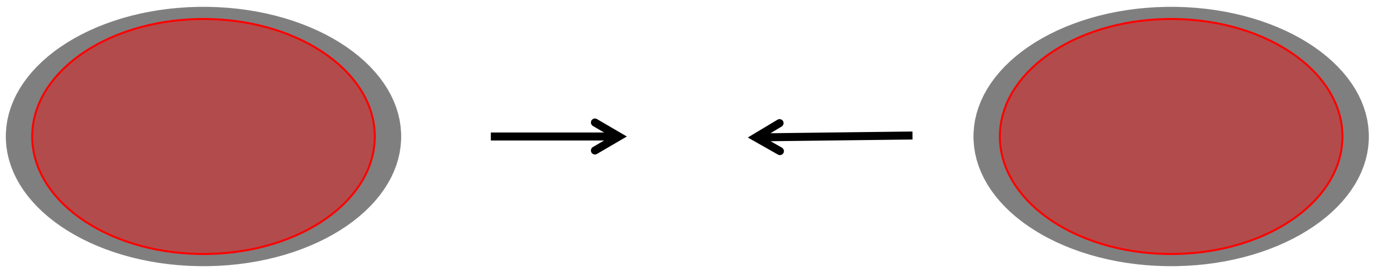
This is possible only if there is a lot more matter uniformly distributed in the galaxy

Dark matter = 500% normal matter



Do we know anything else about Dark matter?

If we consider two two galaxy crossing each other



We have seen that after collition (Hubble, Chandra data) matters had change shape, while dark matter didn't.

Dark matter interacts very weakly, it does not scatter against normal matter neither againts antimatter

What's the universe made of?

(I) 4-5% is made from the material that we know

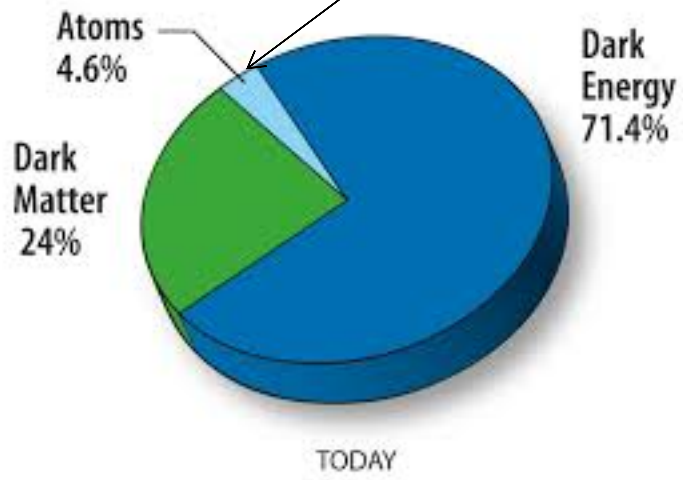
(II) The 22-25% consists of 'Dark Matter':

1) It does not emit any type of electromagnetic radiation.
2) Rotates the galaxies faster
3) One possibility is that it contains 'super-symmetrical particles'

(III) The 70-73% consists of 'Dark Energy'

1) Uniformly fills all space
2) Increase the speed of expansion of the universe

Up to now, we discussed this small piece

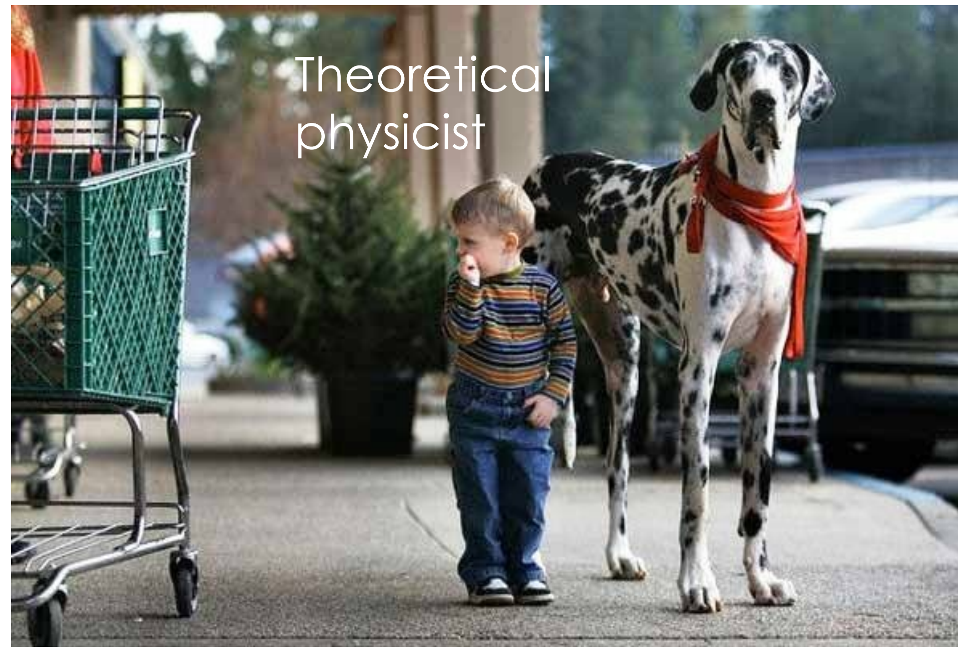


Theory – Experiments relationship in the LHC era

pre - LHC

Experimental physicist

post - LHC

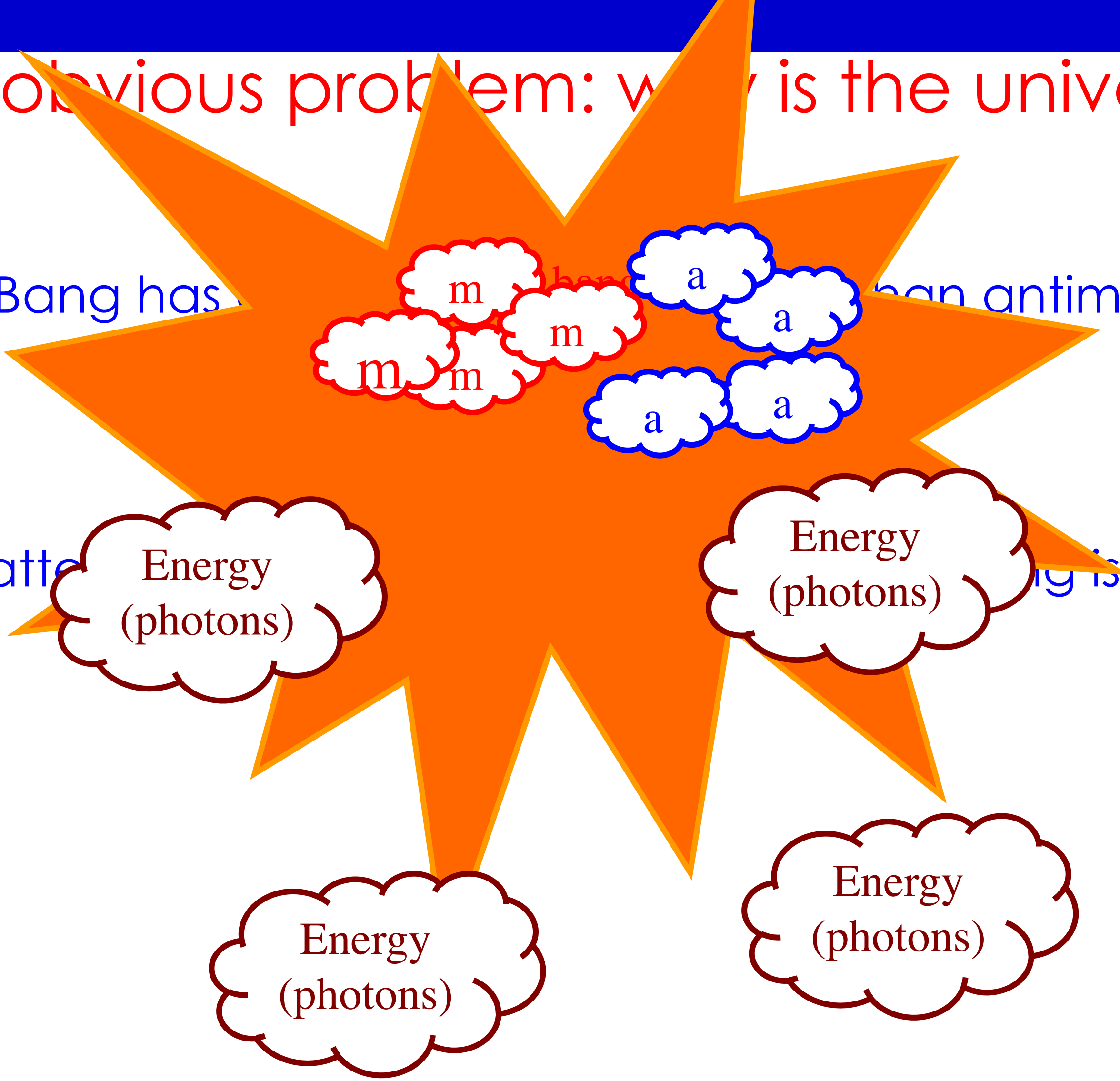


Experimental physicist

An obvious problem: why is the universe there?

The Big-Bang has … han antimatter

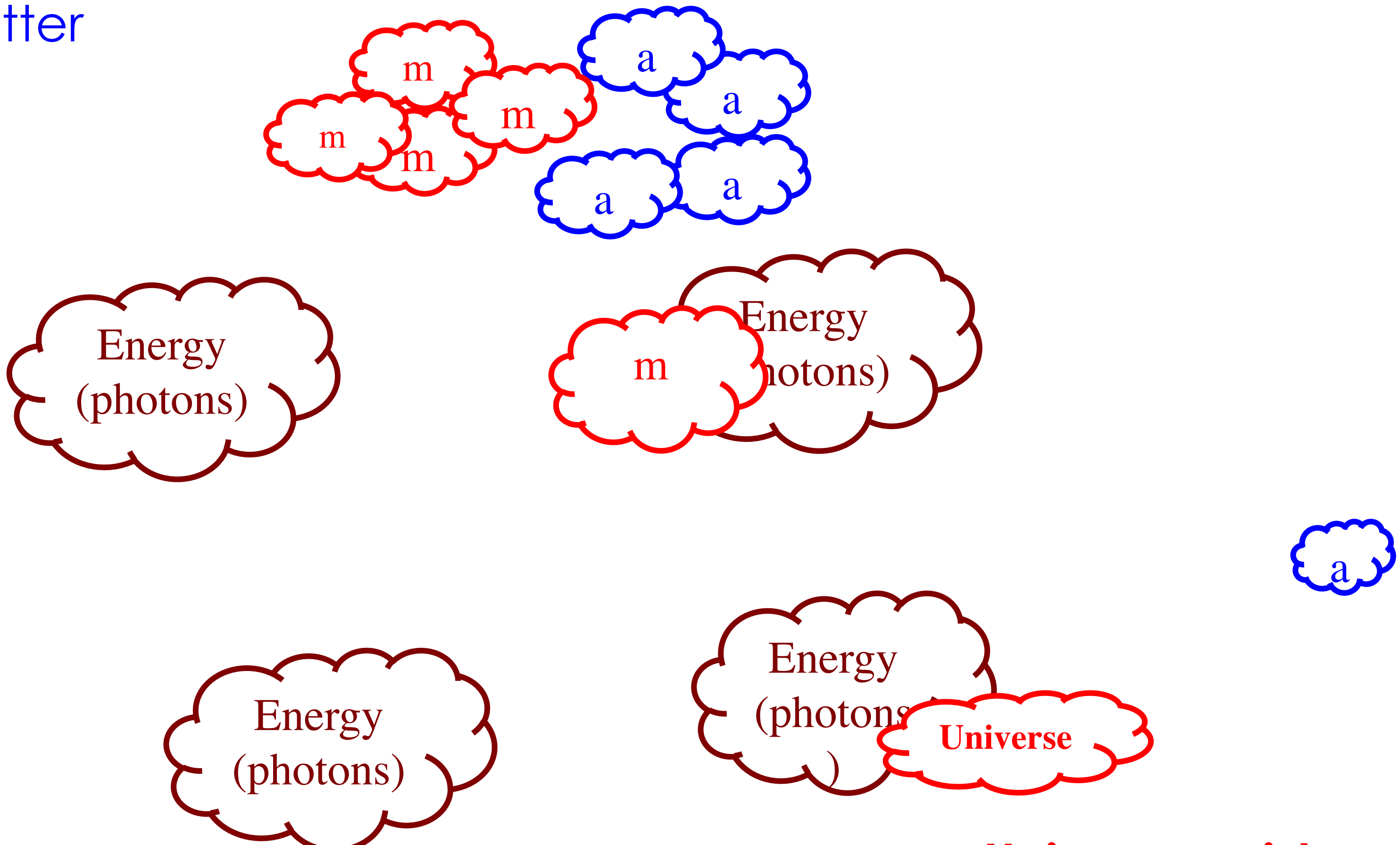
Then matte… g is left…



But we know this is not true: the universe in there!

An obvious problem: why is the universe there?

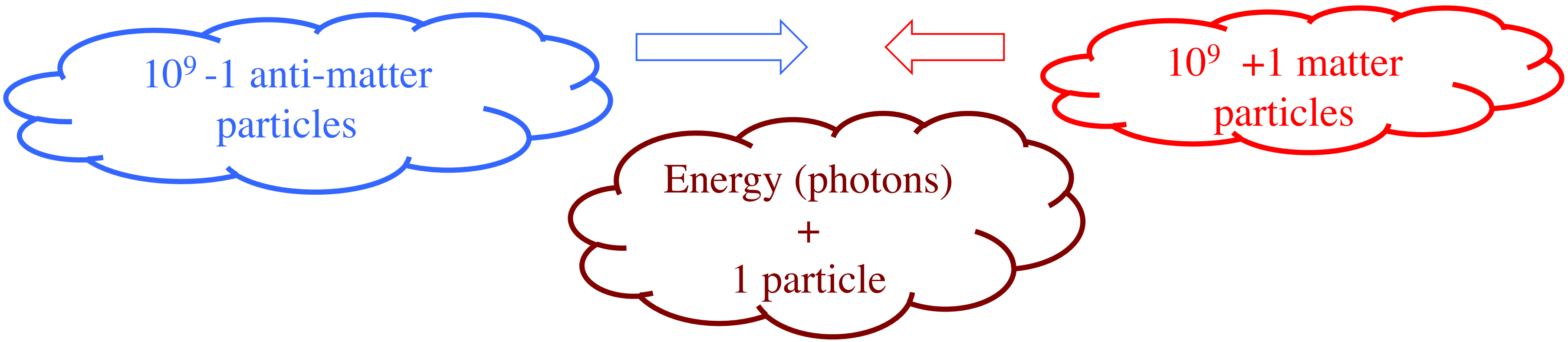
Suppose again the Big-Bang has created as much matter than antimatter



Universe exists

For some reason, antimatter decreases and matter increases , there is a violation in the matter-antimatter symmetry

Universe is what is left over



There is one billion photons for every particle

This photon ocean is called "background radiation"
(Nobel prize 1978 (discovered), 2006 (measured)

Most likely this effect is true also for dark matter: it's mostly gone, only a small part is left

One solution for many problems?

We know we need to find other particles to make the Higgs theory work well

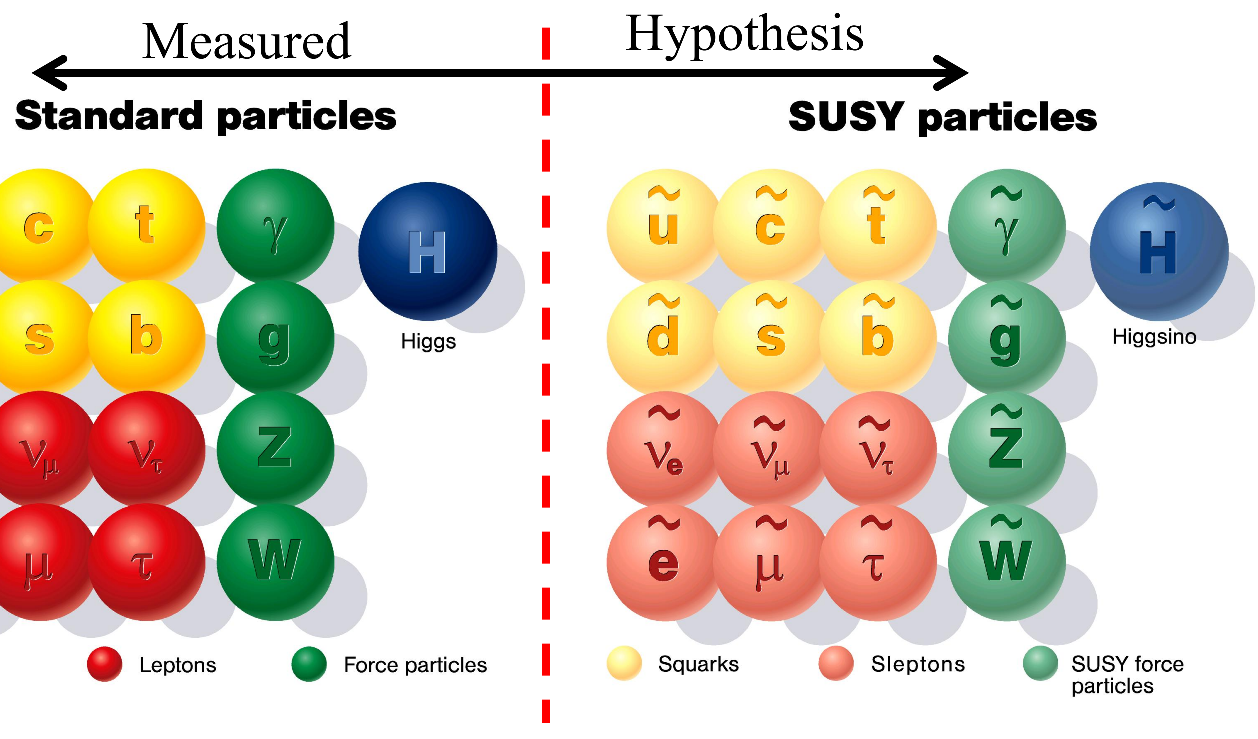
We know there is dark matter in the Universe

Is it possible that the same particles will solve both problems?

Yes, theories such as SUPERSYMMETRY propose these solutions

SUperSYmmetry

SUSY is an extension of the Standard Model:
every fermion has a bosonic counterpart (and viceversa)
it's a broken symmetry as we know that the SUSY particles don't have the same mass as their symmetric partner



It solves the problems related to the Higgs boson
It makes the connection between fermions and bosons

Nature: 2 hidden symmetries

The universe is possibily composed of supersymmetric particles, all massless.
This means that every particle is present as a boson and as a fermion
(there is an elettron with spin = 0 ed ½).

??

Supersymmetry is clearly broken by some force we don't know, which makes the bosonic particles very heavy

On the other hand, fermions are not affected by this process and remain massless

Hypothesis

Higgs

This second symmetry is broken by the Higgs Boson

Measured

So we end up with two grups of particles:
Fermions, with small masses due to the Higgs boson mechanism(<200 GeV)
Bosons, with large masses due to some unknown mechanism (~ 500-1000 GeV)
Is this true?

What does it happen now?

Our theoretical colleagues in discussions pre-LHC were very sure of themselves:

"We understood everything: at LHC you will find the Higgs and other particles…"

We found the Higgs, but nothing else !!!!

Every theory we know forecasts that we should find additional particles besides the Higgs

1) Multiply the mass of the Higgs by 10^{-16}
2) Find new particles in the coming years (LHC in Geneva will start working in a month !!)
3) The theories are wrong

Summary and outlook

After 50 years, we have finally found the Higgs boson!

We have not found other particles, so we are missing some crucial aspects of the theory

LHC is about to begin at the highest energy ever reached.
We hope to find the missing particles soon.

We lack the 96% of the universe ....

We have a secret weapon: you!

Come and join the research