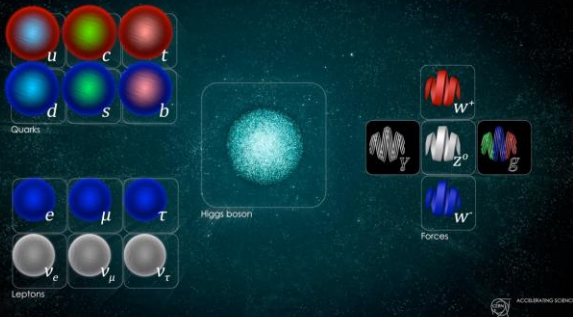


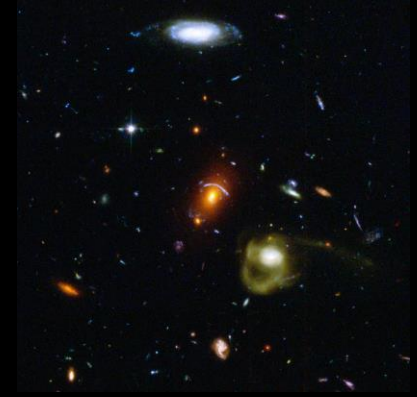
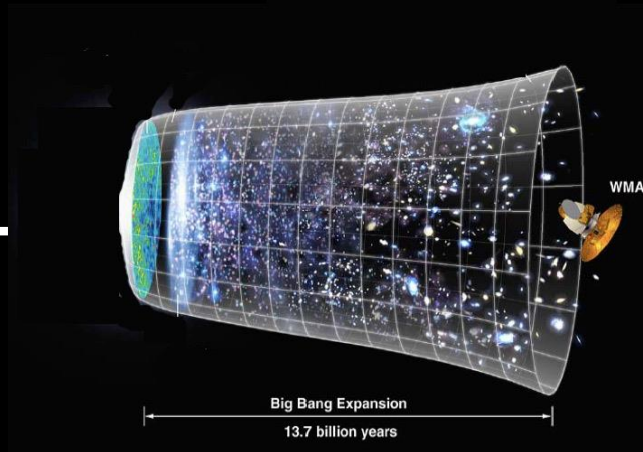
Particle physics of the 21st century

Particle
physics

+ Cosmology = Universe ?



+



No !

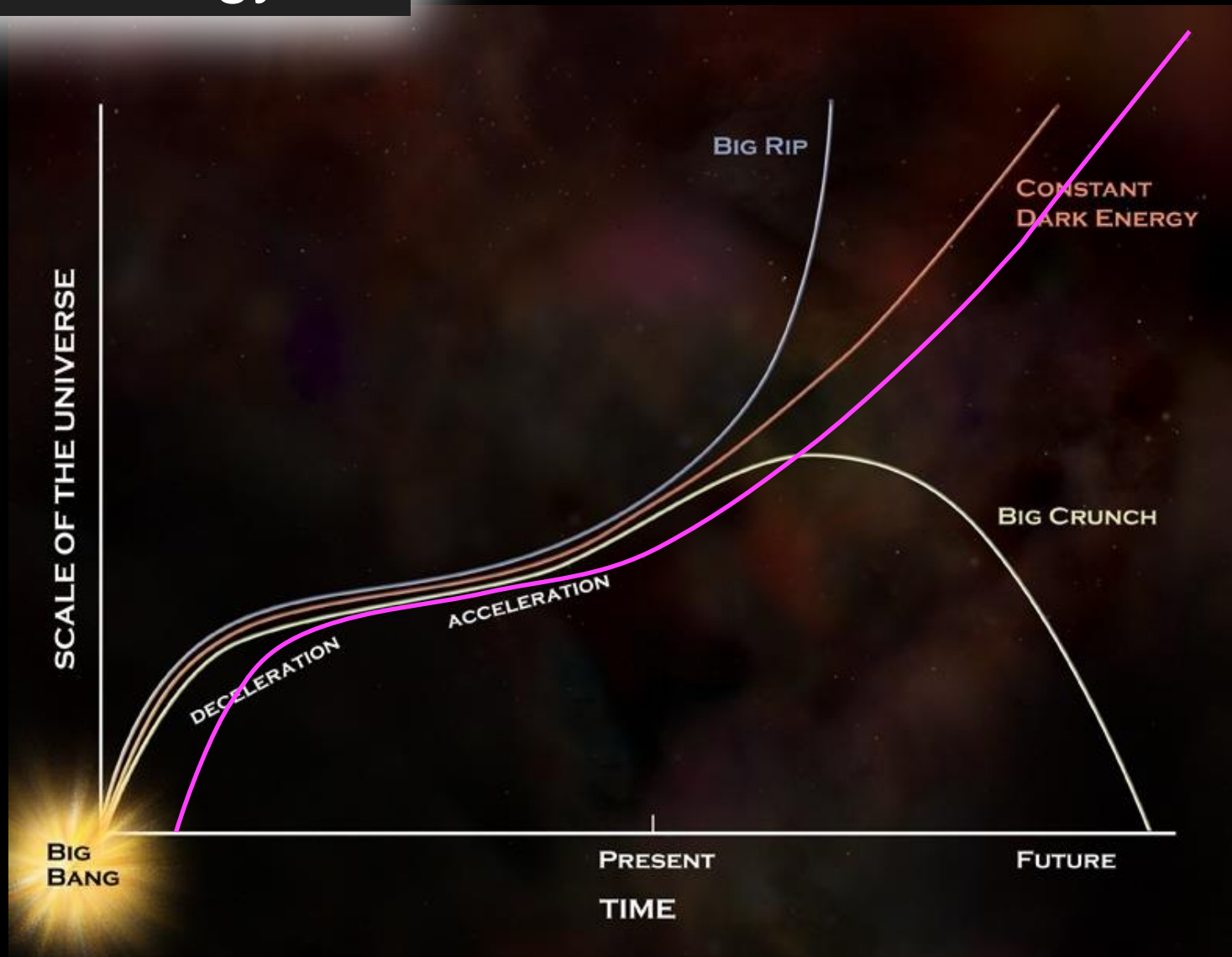
Less than 5% of the energy content of
the universe are understood!

Dark matter ...?



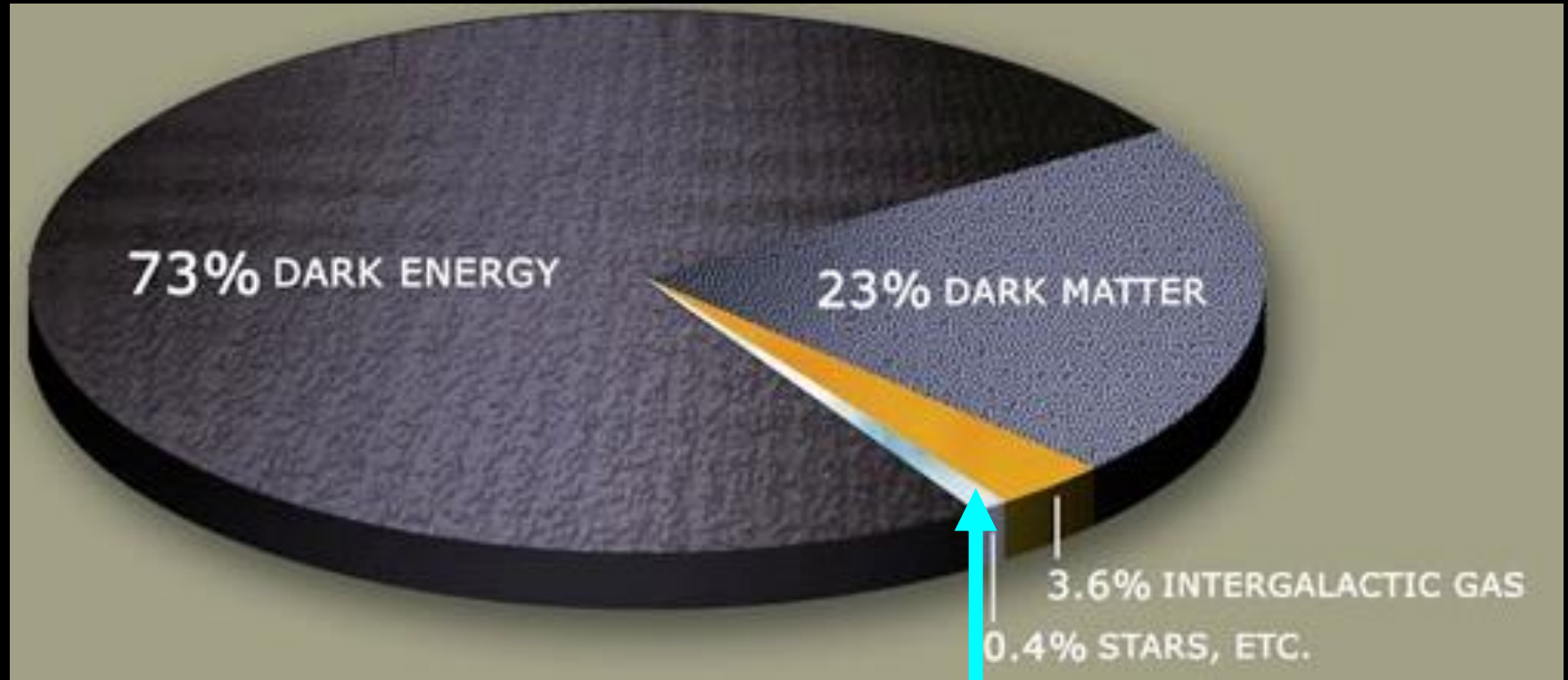
Galaxies rotate too fast

Dark energy ...?



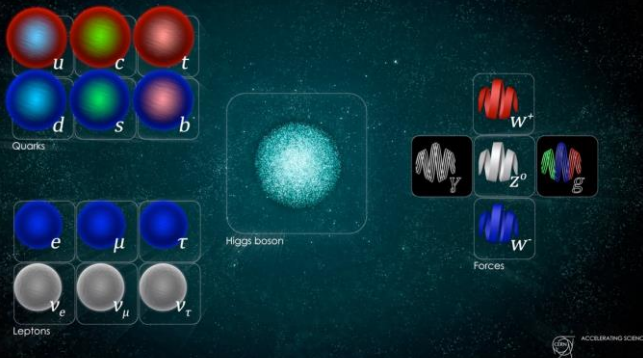
The expansion of the Universe accelerates ...

The “dark Universe”: 96 % of its energy content are hidden in ‘dark energy’ and ‘dark matter’



You are here

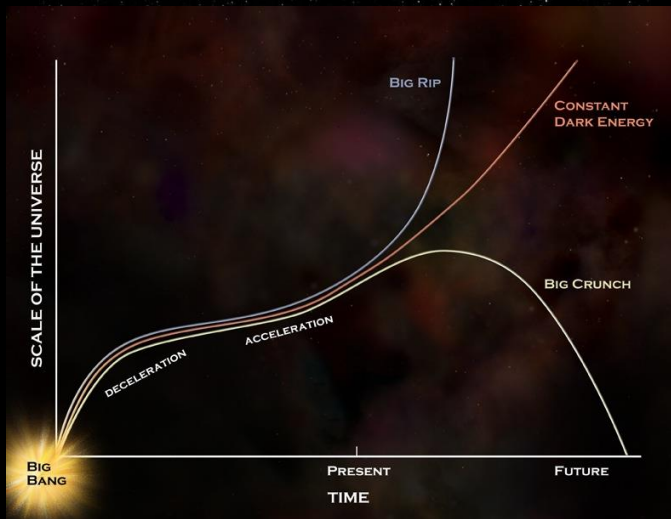
The big questions:



How do particles obtain their mass?



What is dark matter?



What is dark energy?

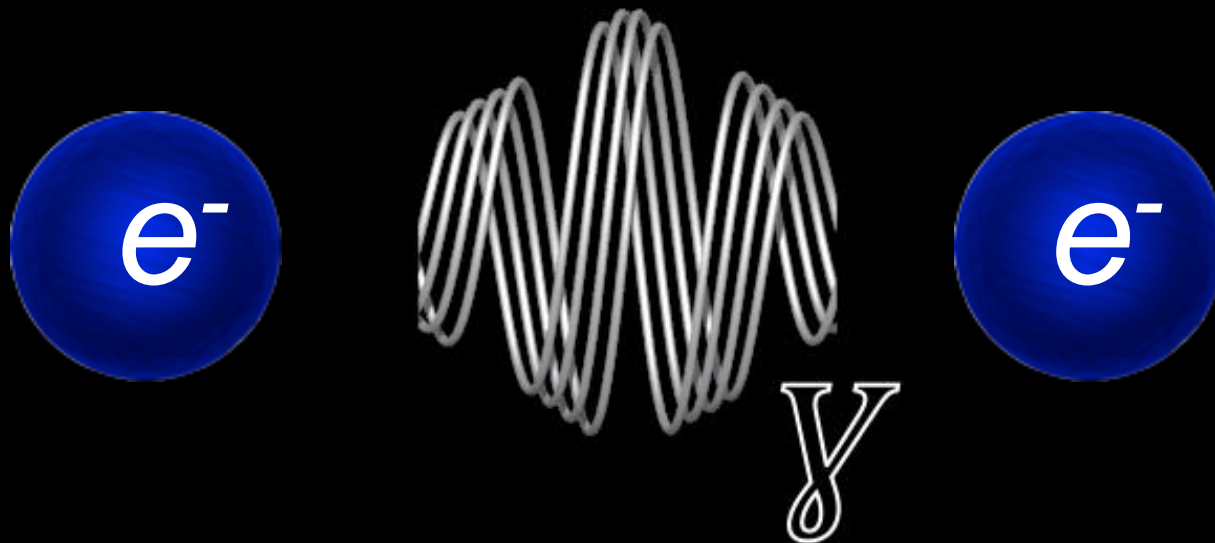
Voyage to the smallest scales of matter



Anything you can see and touch is made of three particles:

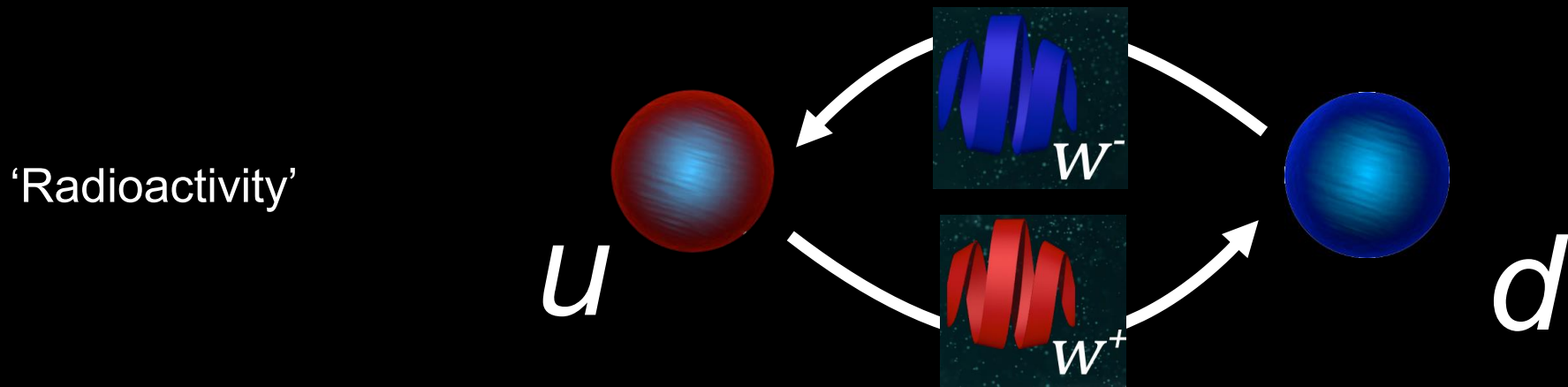
Up-Quark, Down-Quark, Electron.

Forces are transmitted by the exchange of messenger particles ('bosons', spin = 1)

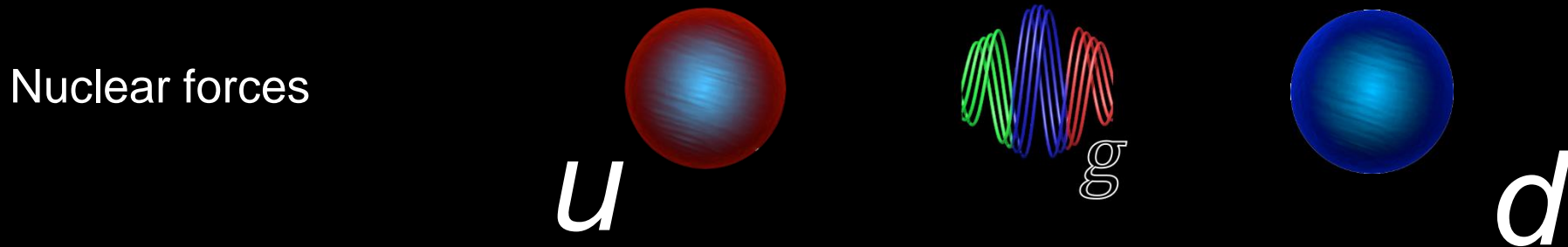


Electromagnetic interaction: Photons

Two forces have a very short range:



Weak force: **W-** and **Z-bosons**



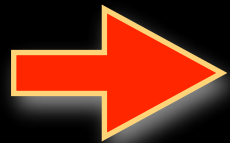
Strong force: **gluons**

How do we know?

$$E=mc^2$$

Energy can become matter

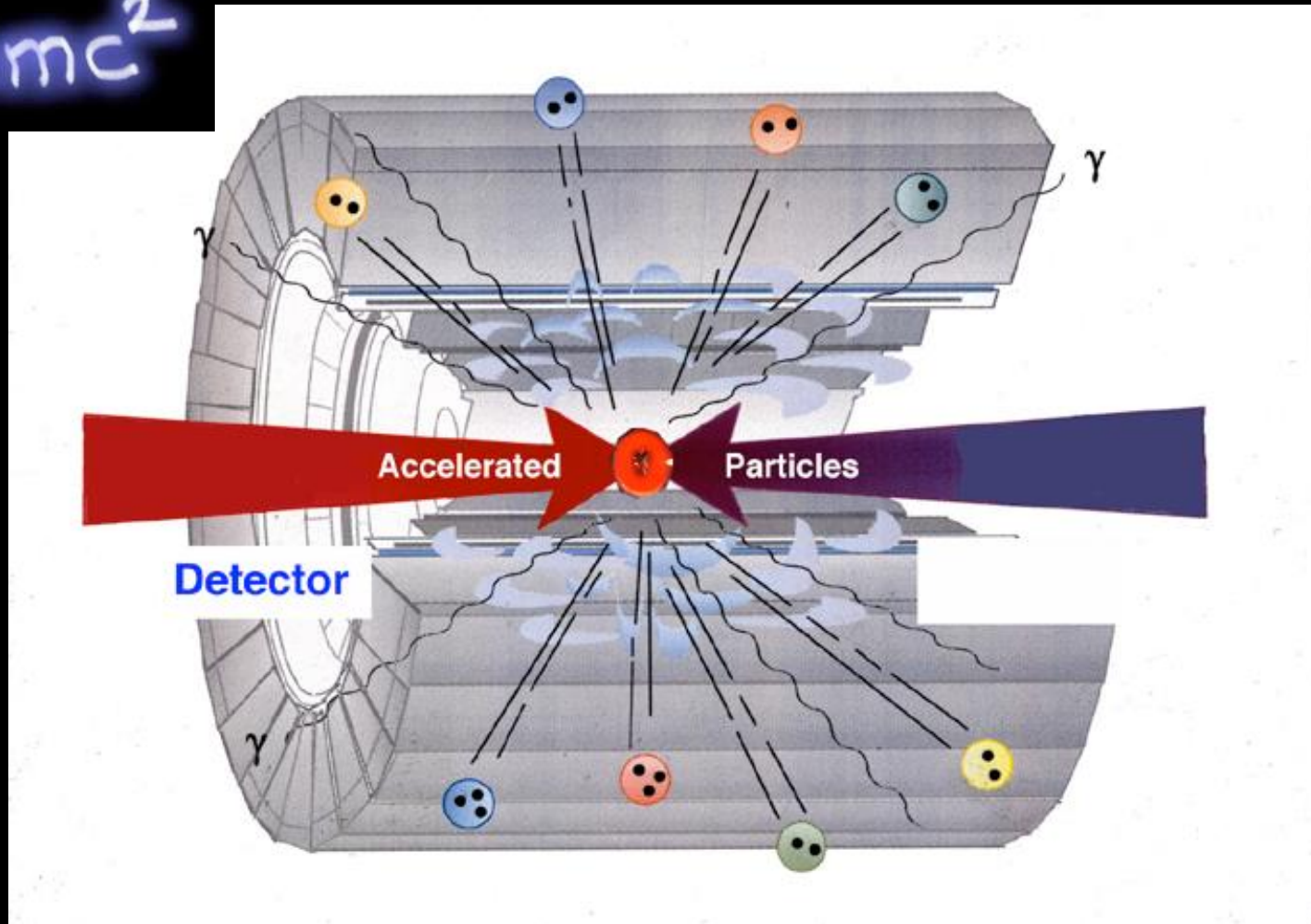
How? Concentrate lots of energy on small scale



Particle collision at high kinetic energy

Energy becomes matter

$$E=mc^2$$

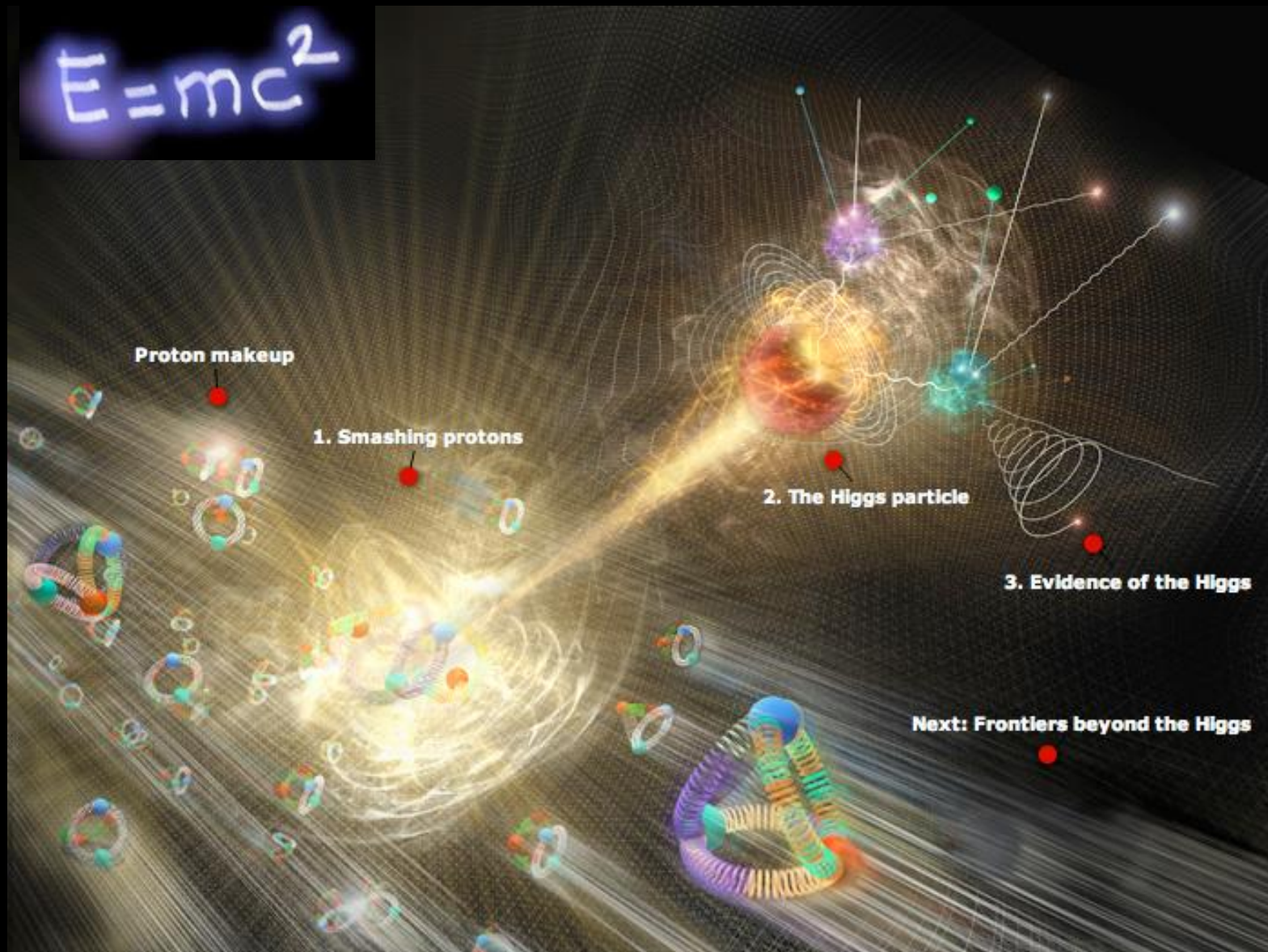


Simple analogy

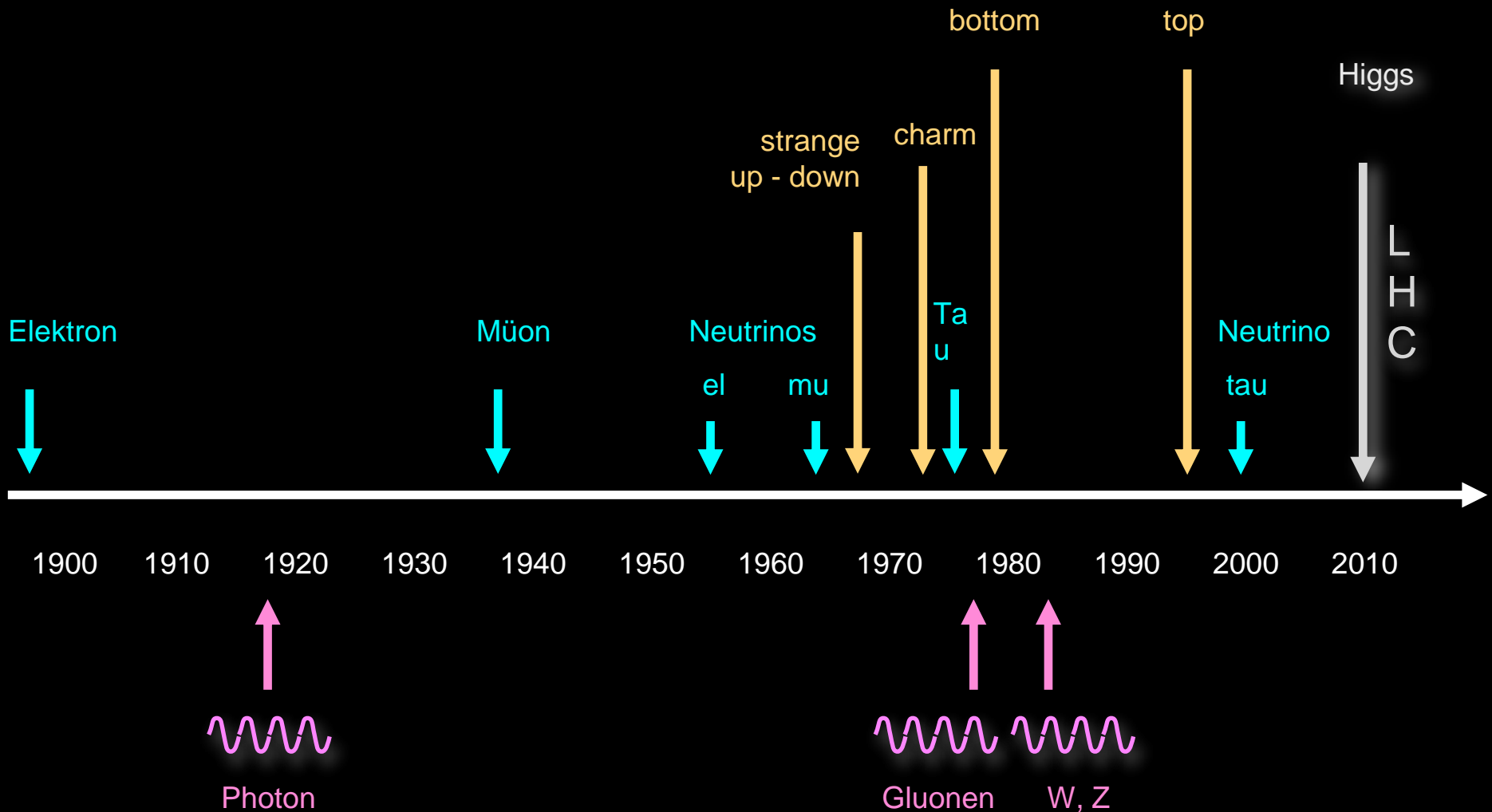
$$E=mc^2$$



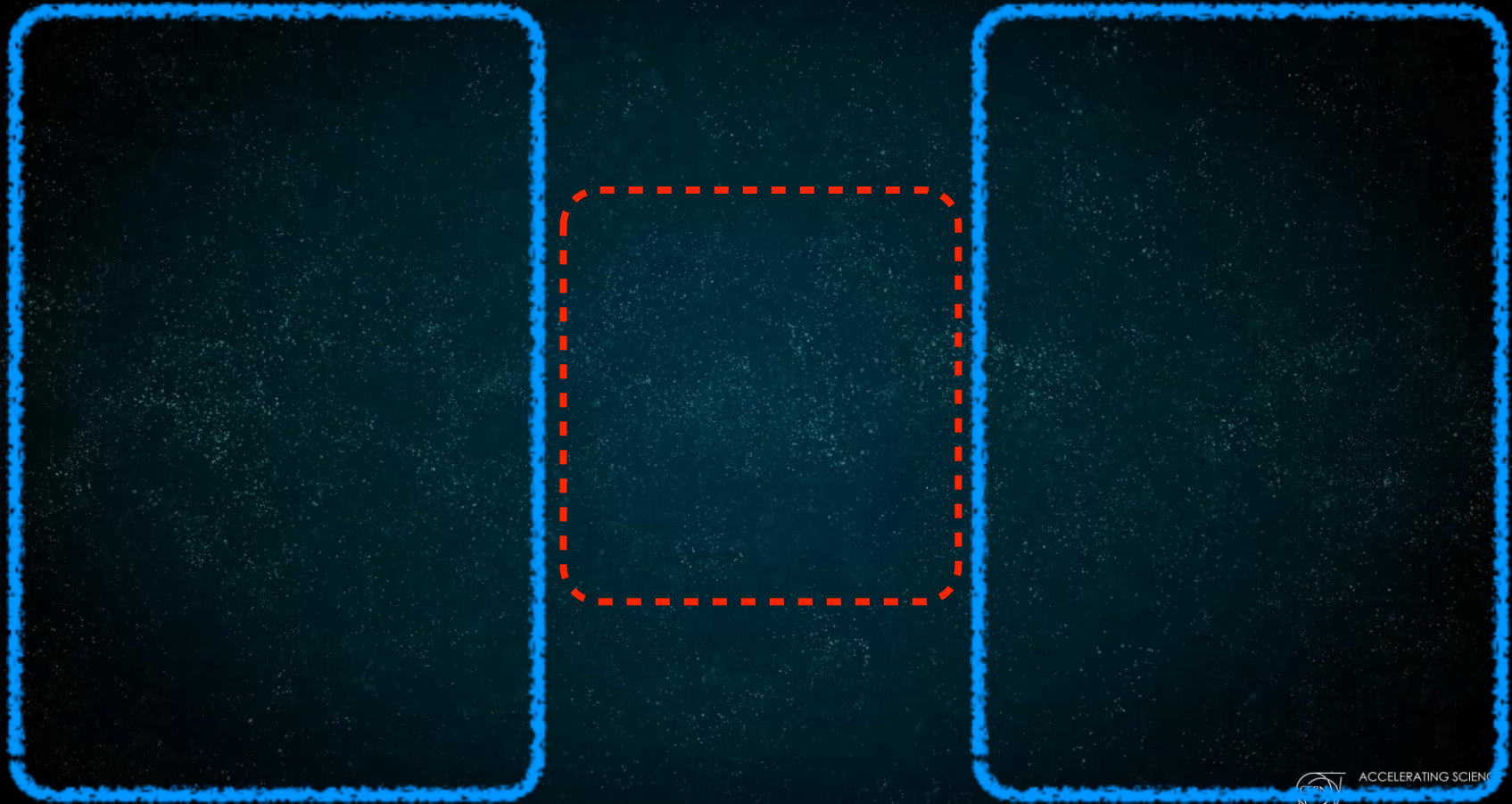
Produce short-lived particles and observe their decay products



Experiments at accelerators have discovered all particles of the “Standard Model”



Standard model = 'periodic system' of elementary particles



Particles

Higgs

Fields

How do particles obtain their respective masses?

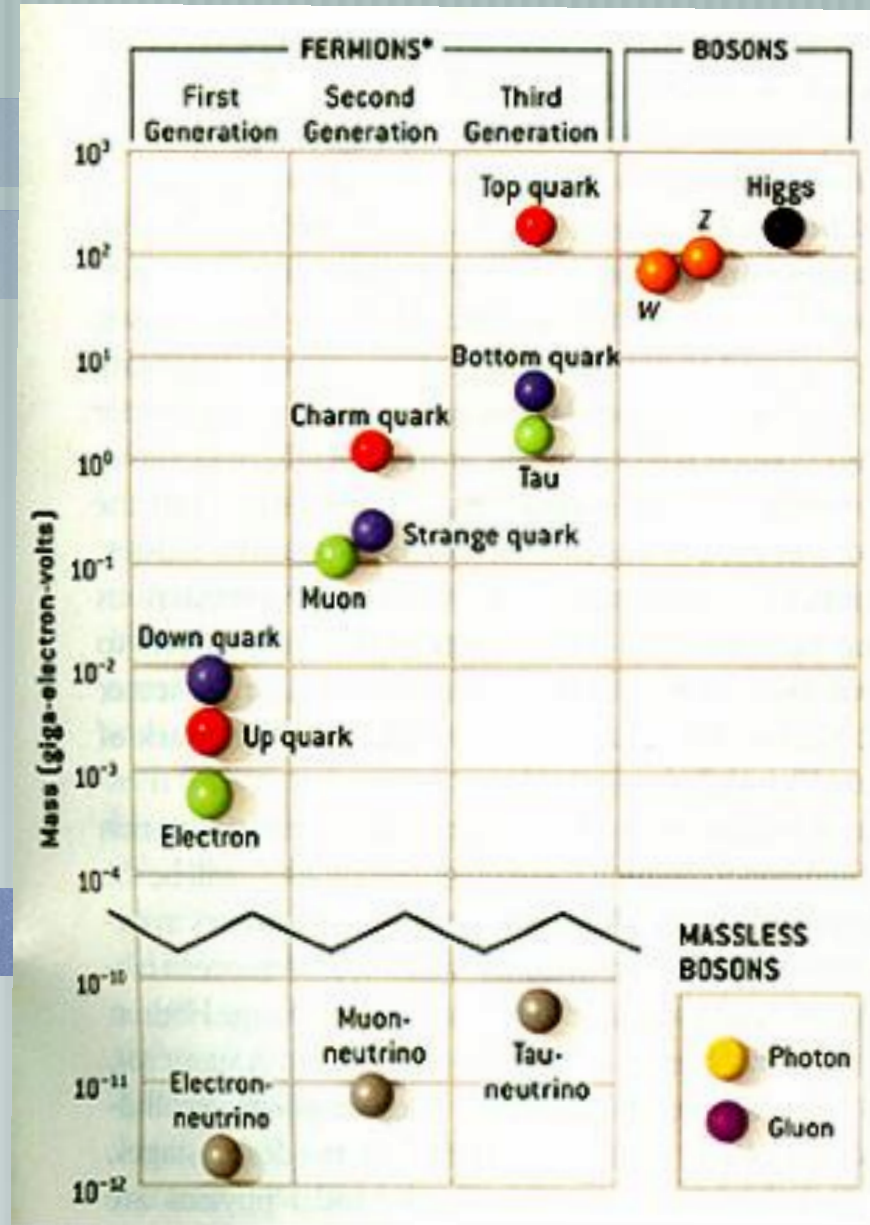
1 TeV →

100 GeV →

1 GeV →

1 MeV →

0.01 eV →



The mystery of mass

Massless particles have to move with the speed of light

THEY CANNOT FORM SOLID OBJECTS

The Brout-Englert-Higgs field idea

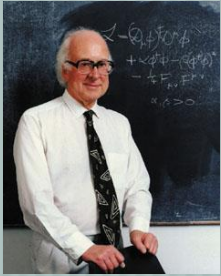
The Brout-Englert-Higgs field idea:

the entire Universe is filled with a homogeneous field

massless particles interacting with this field obtain inertia (=rest mass)

the BEH field interaction is proportional to the mass of the particle

The 'cocktail party' explanation of the Higgs mechanism



Sir Peter Higgs



A cocktail party ...

The BEH field



.. a famous person wants to traverse the room...

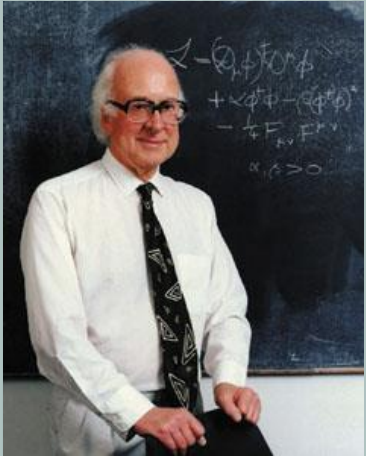
... a massless particle enters...



.. but the guests cluster around and slow down its movement...

... the interaction with the BEH field produces the inertia of the particle ...

The 'Higgs boson'



Sir Peter Higgs



A rumour is spreading among the guests ...

The BEH field ...



.. they cluster together to exchange the information among themselves...

... is excited by an energy concentration and forms an excitation by self-interaction ...

Animation: the Higgs mechanism



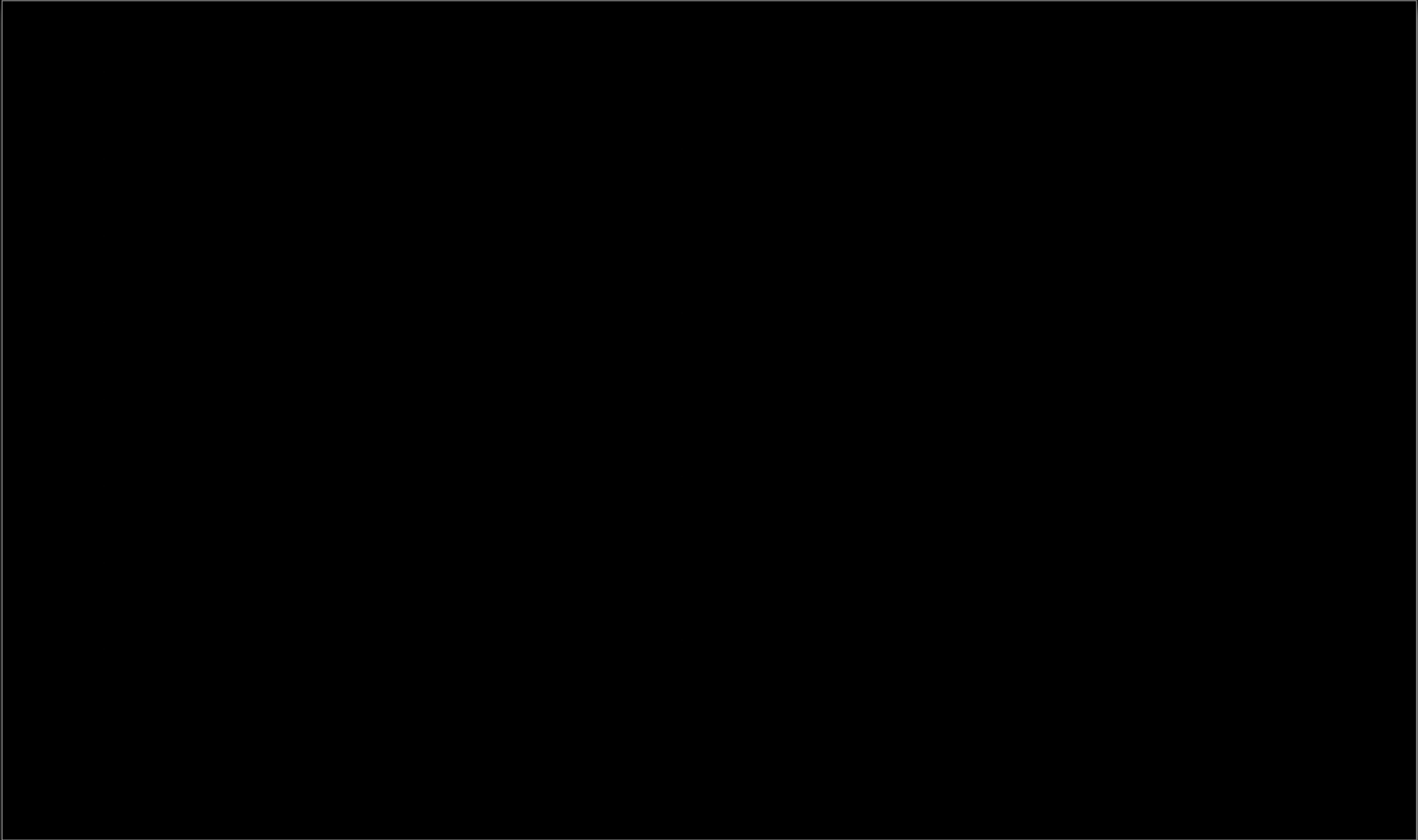
Exciting the Brout-Englert-Higgs field: the “Higgs boson”



... but this happens on average once per 10,000,000,000 (10^{10}) collisions !

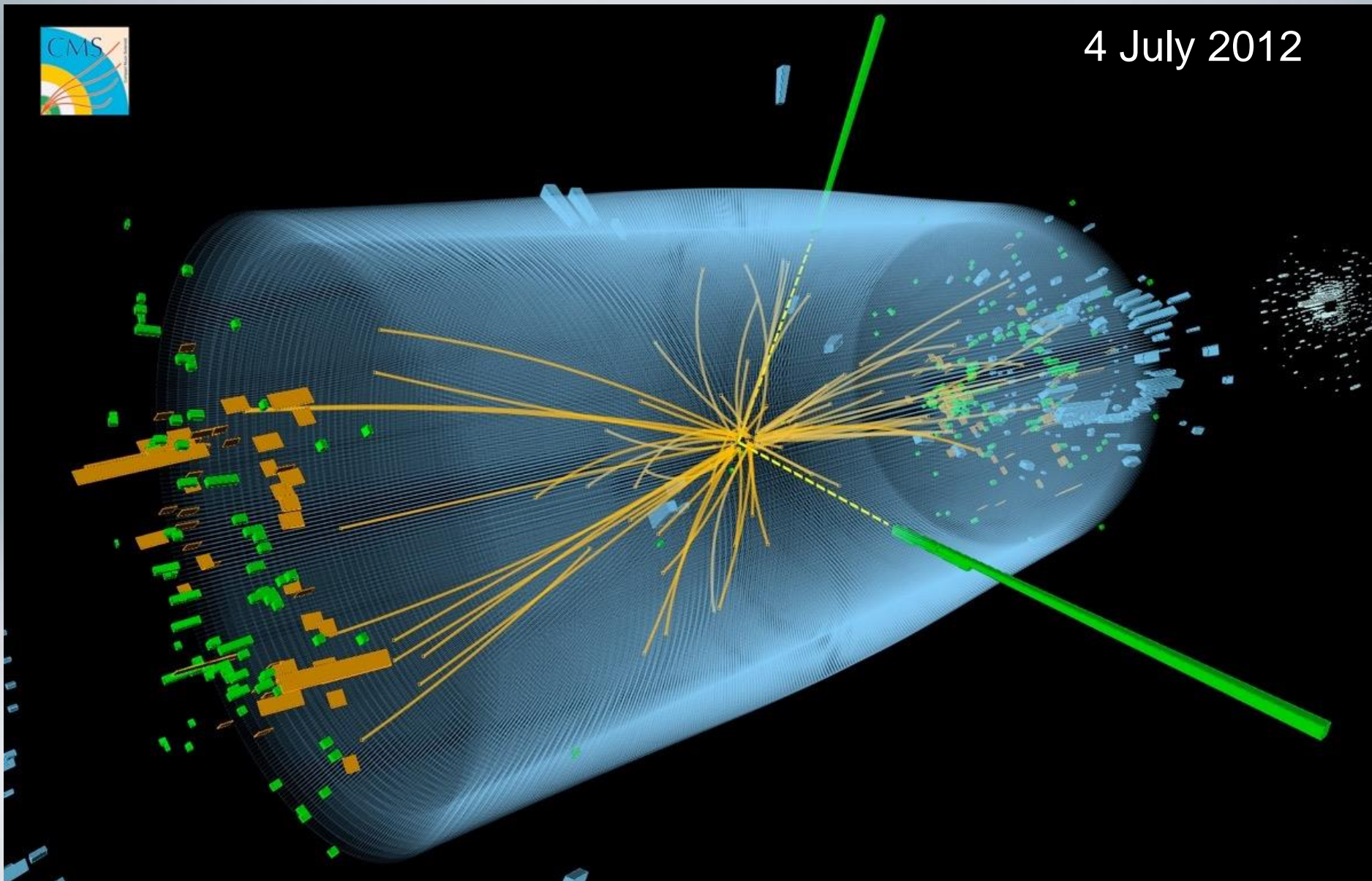
The Higgs boson can decay in two photons

...

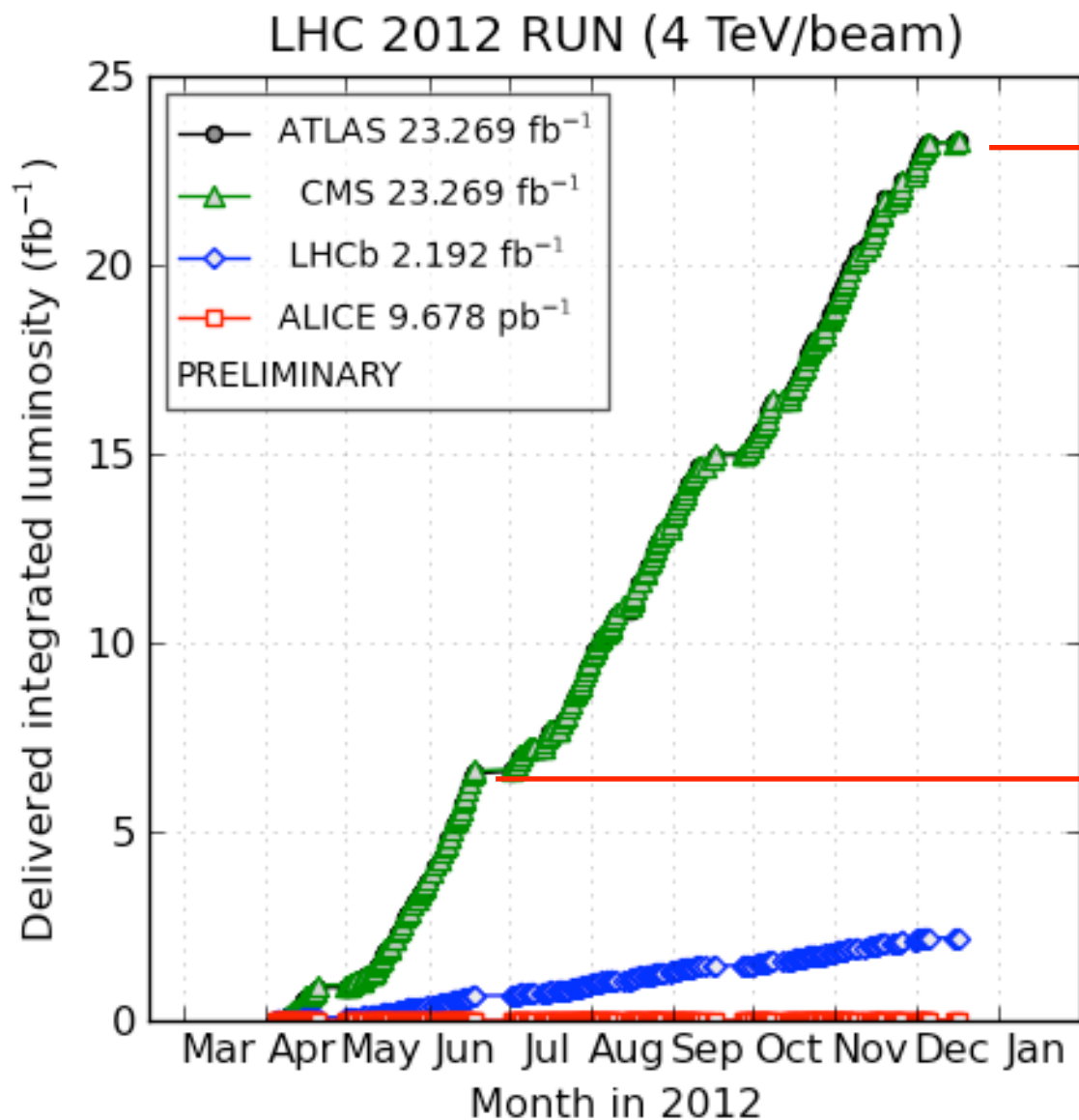


but only with a probability of 0.2 %

How do we know that it is the Higgs boson ?



2011 - 2012 : Data taking with LHC

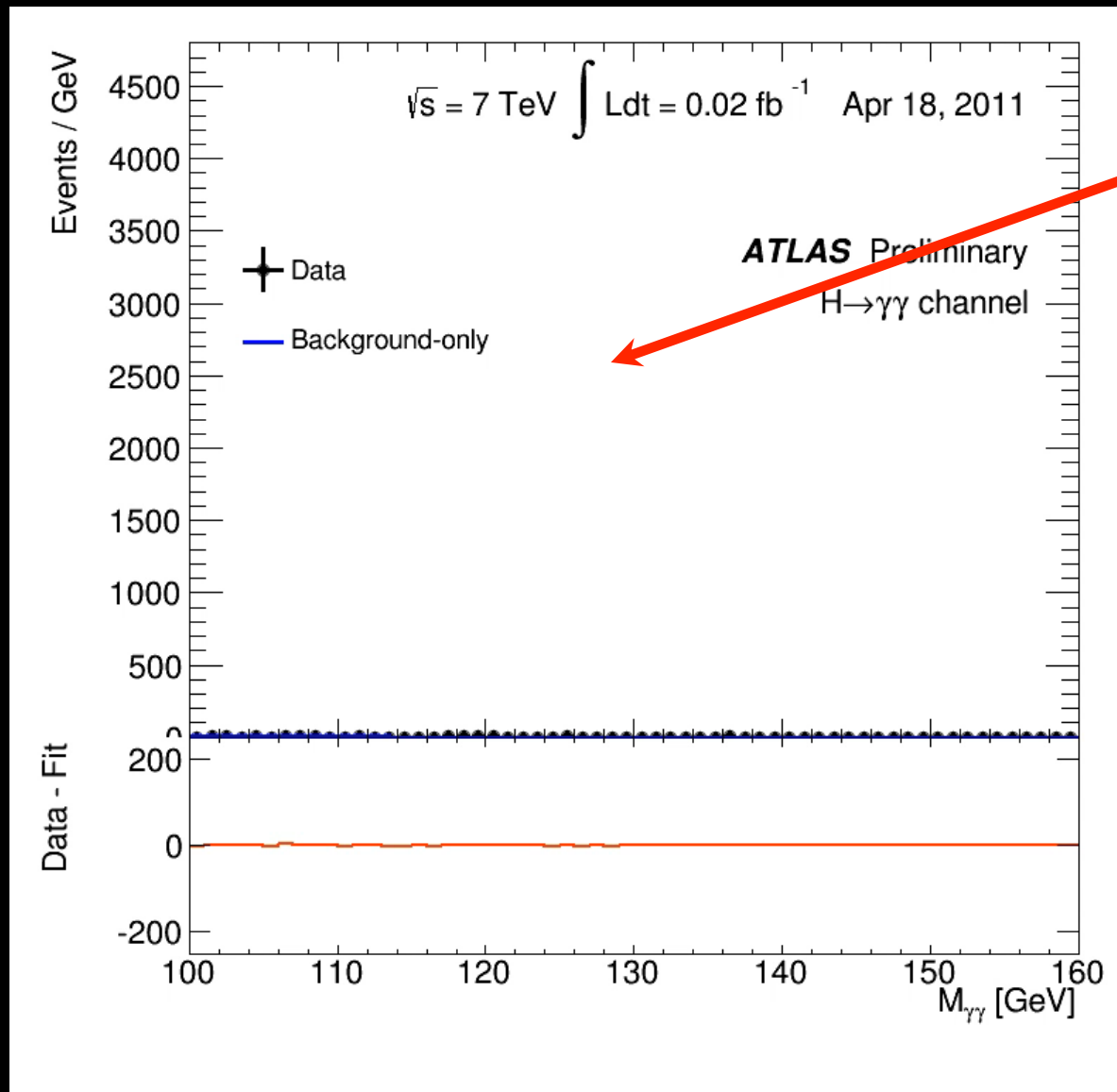


15.12.2012

3,000,000,000,000,000 ($3 \cdot 10^{15}$)
(3000 trillion events !)

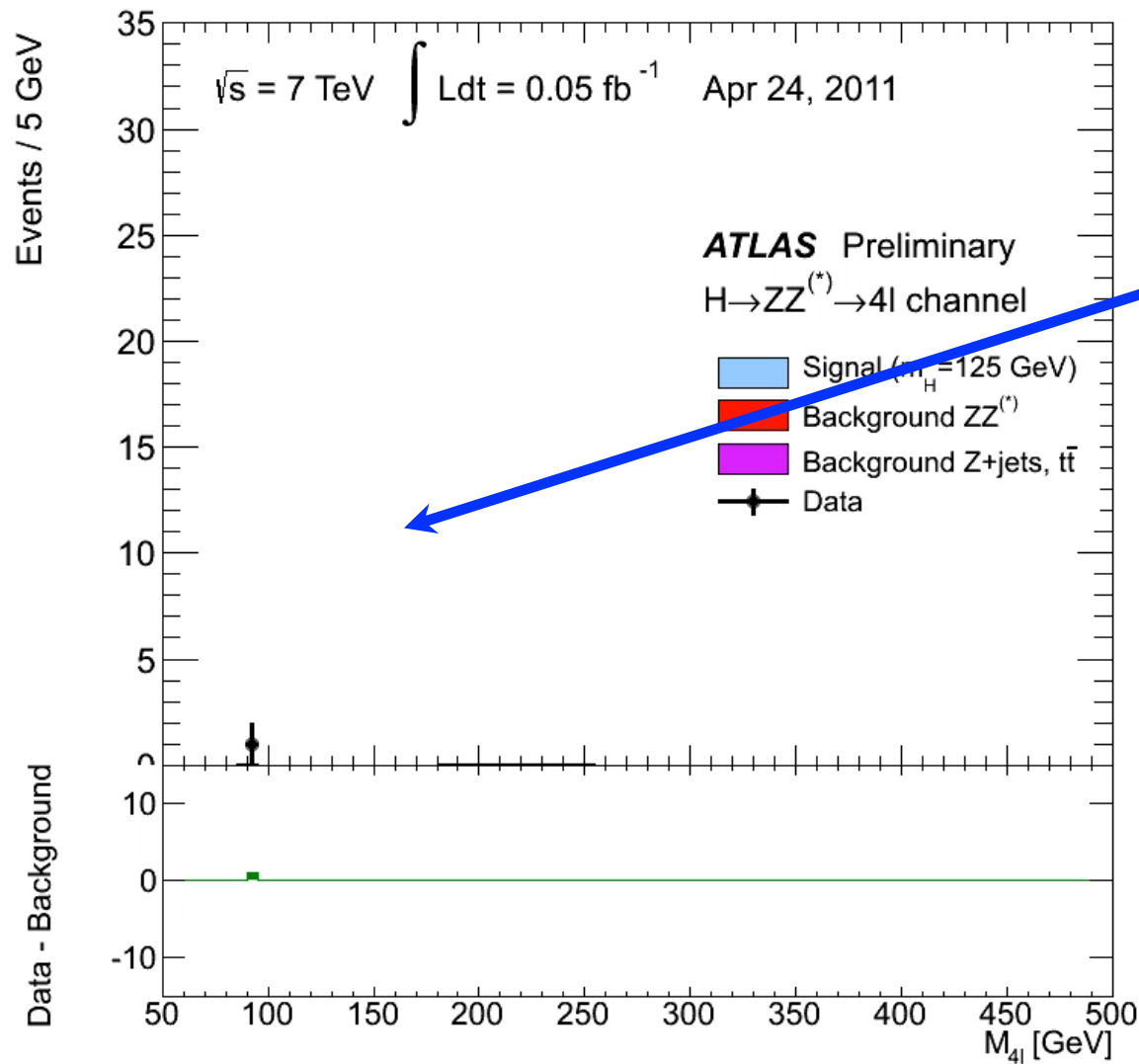
4.7.2012

The evolution of the histogram with two-photon events



Higgs boson

The evolution of the histogram with four leptons

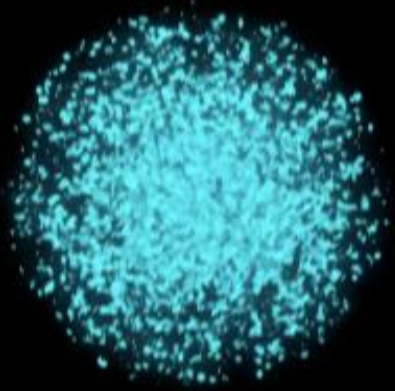


Higgs boson

Update 14.3.2013: CERN Press Release

More data confirm: new particle = Higgs boson

Higgs boson decay



$\gamma\gamma$



$Z^0 - Z^0$



Tau- Antitau



Bottom - Antibottom

Theoretical expectations compatible with observations



What does this mean?

- the Higgs boson exists, therefore ...
- the Brout-Englert-Higgs field exists
- we know how particles obtain their mass
- the “Standard model” is complete

Even more:

- empty space is not ‘empty’
- perhaps a connection to ‘dark energy’ ?

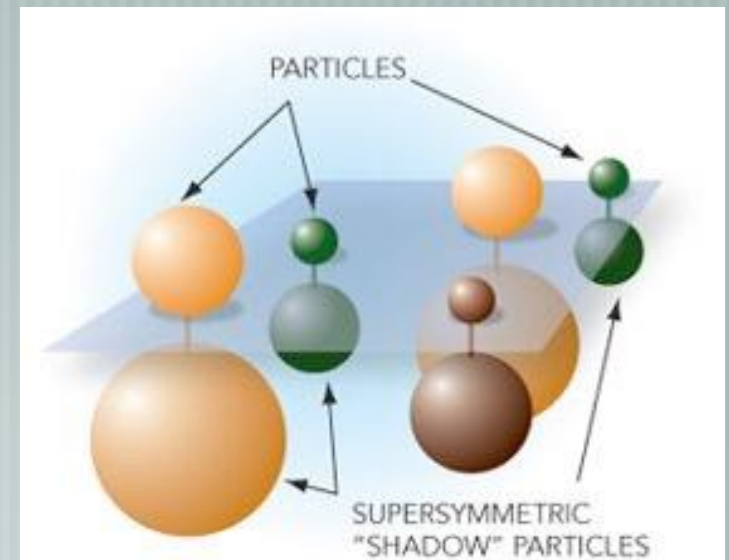
SUPERSYMMETRY

A connection between particles (spin 1/2) and fields (spin 1) ?

FERMIONS (quarks, electrons, neutrinos) interact through the exchange of BOSONS (gluons, photon, W/Z bosons)

“SUPERSYMMETRY” predicts a complete symmetry between FERMIONS AND BOSONS: each fermion has a boson partner, and vice versa:

Spin 1/2	Spin 0, Spin 1
electron	selectron (S=0)
quark	squark (S=0)
photino	photon (S=1)
gluino	gluon (S=1)
gaugino (Wino, Zino)	W, Z (S=1)

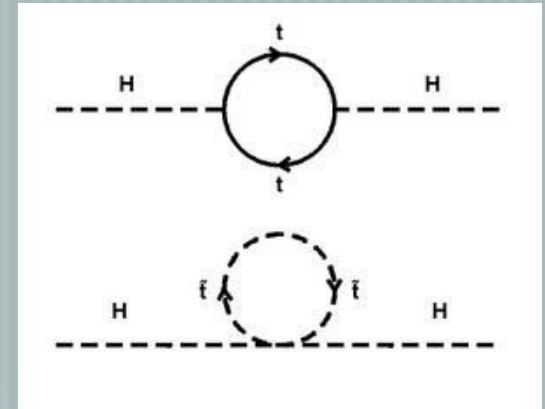


But: no such SUSY partner has ever been seen. So ... if they exist, they must have a large mass (> 1 TeV)

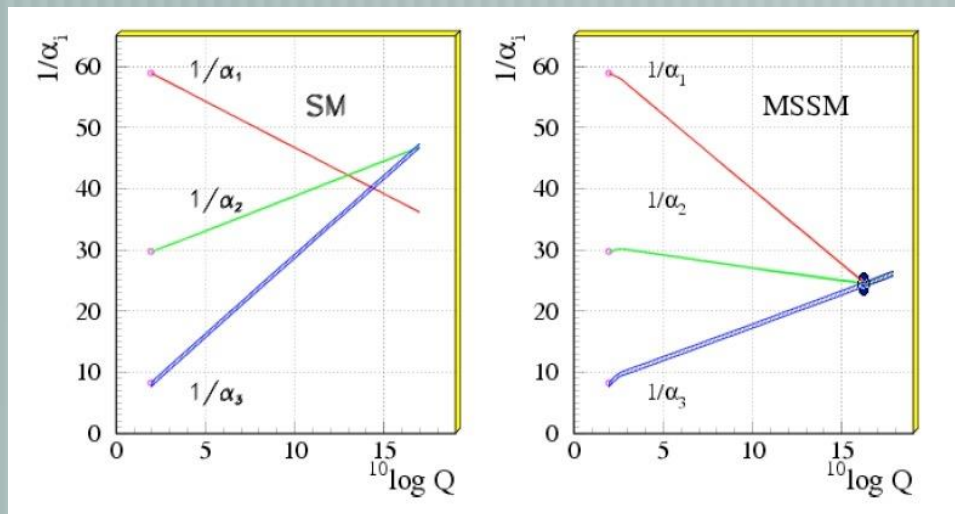
Why SUSY?

1) A fundamental space-time-symmetry

2) "Protection of the Higgs boson mass ($M \sim 10^2$ GeV) from vacuum fluctuations up to Planck mass ($\sim 10^{19}$ GeV)



3) Predicts unification of electroweak and strong interaction at $\sim 10^{17}$ GeV

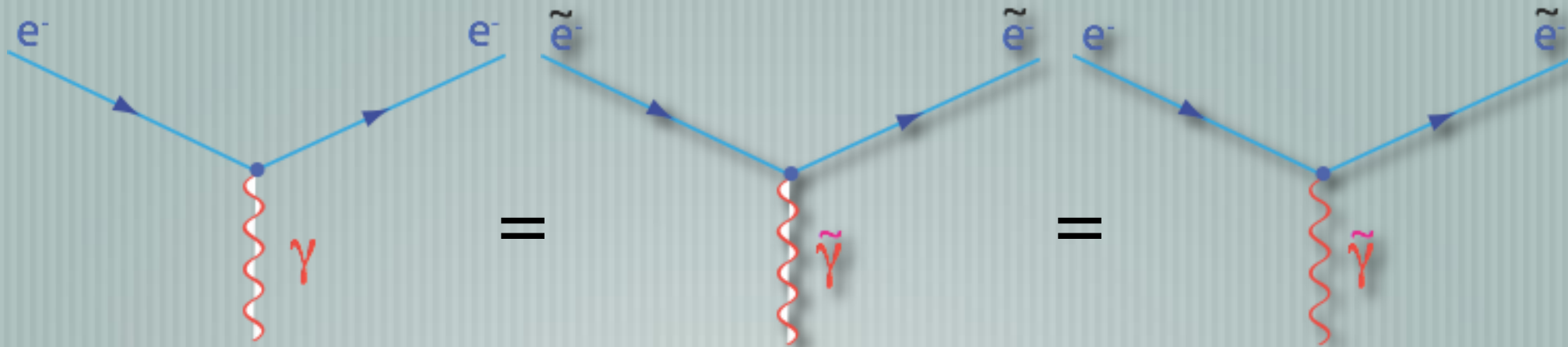


4) May explain the cosmological matter-antimatter asymmetry

5) **Lightest supersymmetric particle = dark matter ??**

Supersymmetry - easy to calculate:

Particles and 'Super-Partners' can simply be exchanged



e = electron

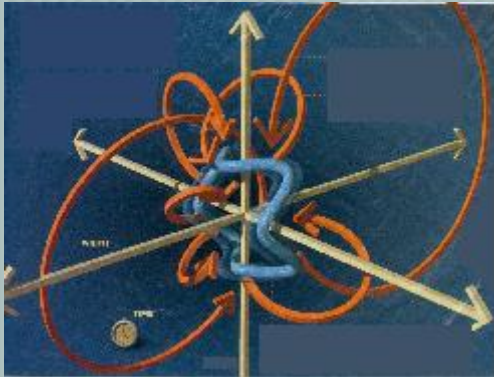
\odot = photon

\tilde{e} = selectron

$\tilde{\odot}$ = photino

MORE MYSTERIES

What is a particle?



Superstrings in 9+1 dimensions?

Little strings of string energy vibrating in a 9+1 dimensional space ?

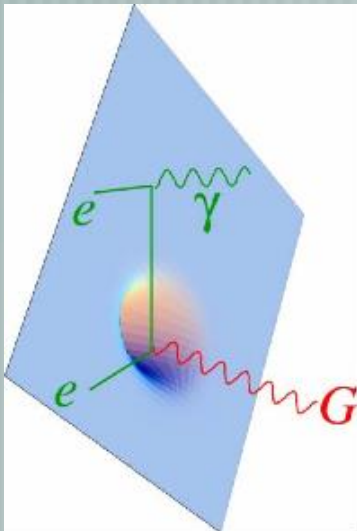
$L \sim 10^{-35}$ m (Planck length)

Standard model particles: different vibration modes, open/closed strings

GRAVITON-like particle contained (unification of SM and gravity?)

BUT: why did 6 dimensions disappear? how did they disappear?
is there a unique way to go from 10 to 4 dimensions?

Quantum Gravitation



More than 3 macroscopic dimensions of space?

Is the graviton propagating in 4- or more dimensions of space?

Micro-black holes ?

Mysteries of the 21st century

1900 - 2000: Phantastic progress in understanding matter and the Universe

We know what matter is made of.

We know the principle steps in the evolution of the Universe.

Some of the big physics questions of the 21st century

What is the structure of empty space: the BEH field? dark energy?

What is dark matter?

What is the origin/nature of particle families? Why three? What are particles?

Where is the connection between quarks and leptons (identical electroweak charges!!)

How did the antimatter disappear?

The origin and value of the constants of Nature? Is life in the Universe an 'accident' ?

The Large Hadron Collider - 2015



New discoveries are waiting !