

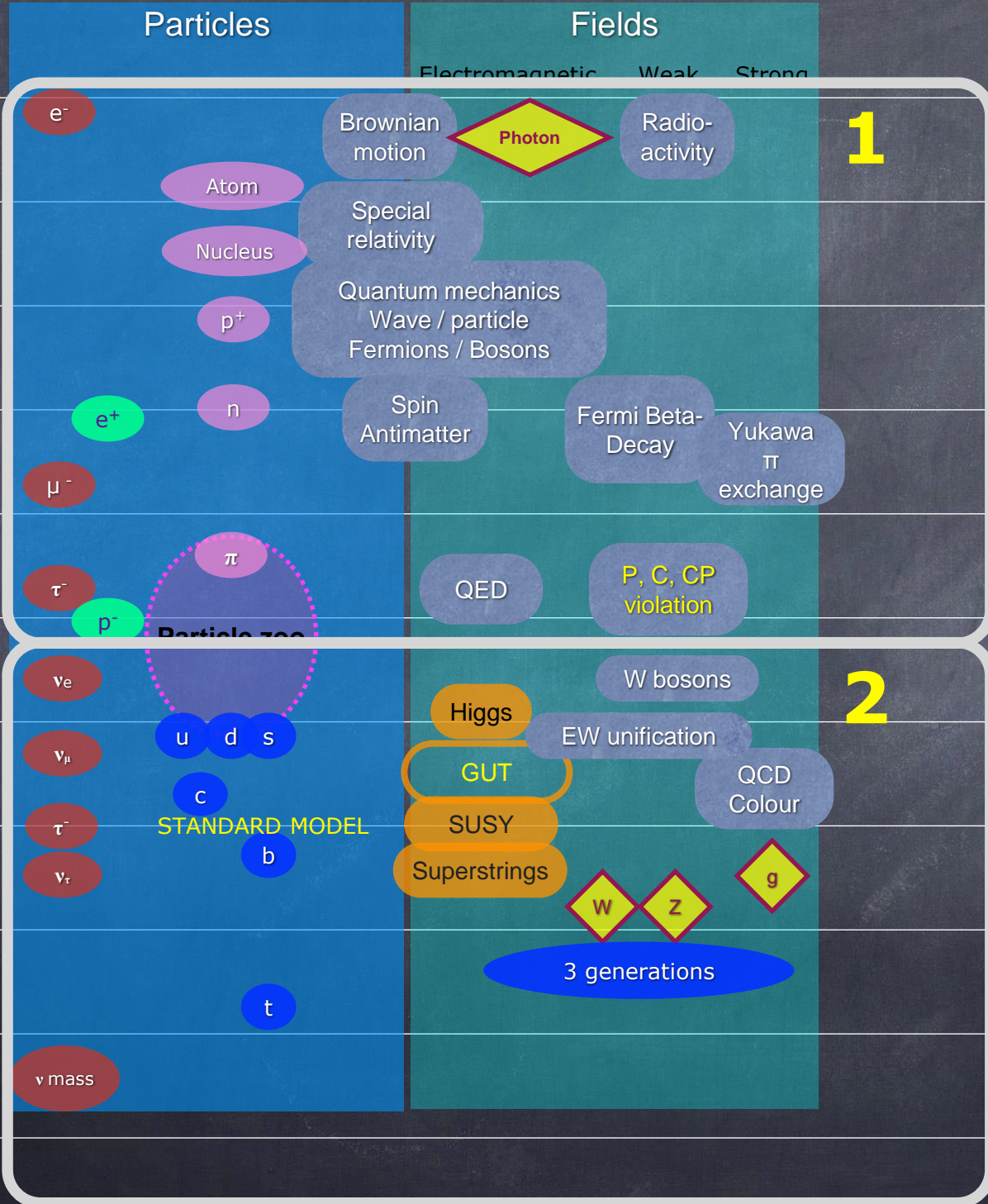
STRUCTURE OF MATTER

Discoveries and Mysteries

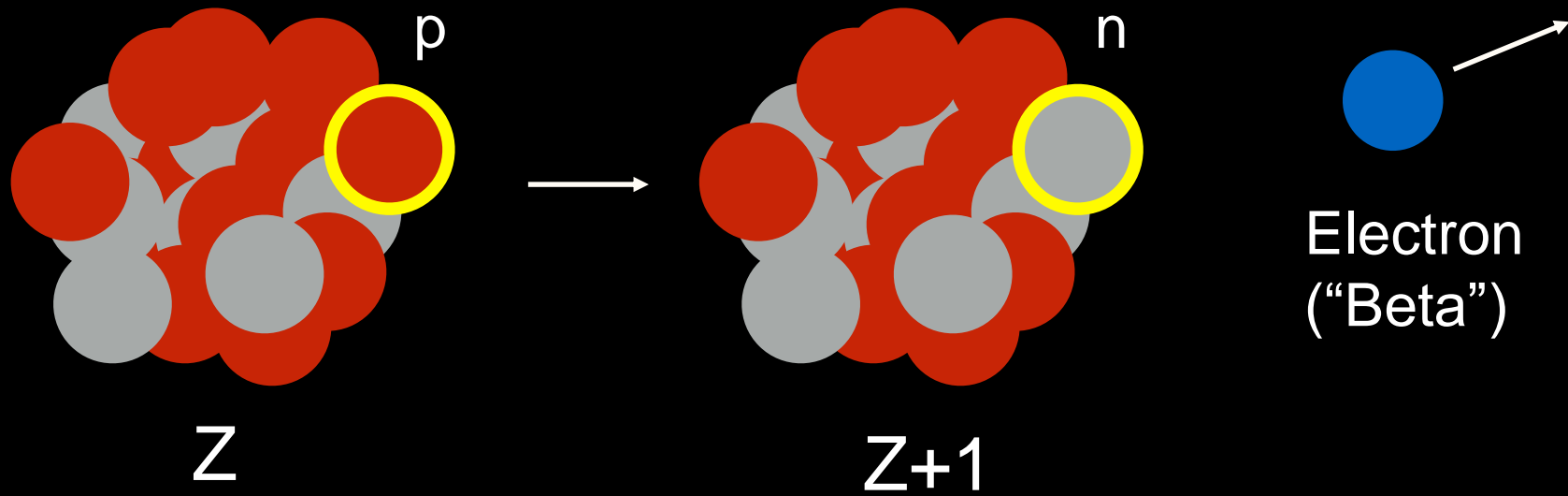
Part 2

Rolf Landua
CERN

1895
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
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1960
1965
1970
1975
1980
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2010

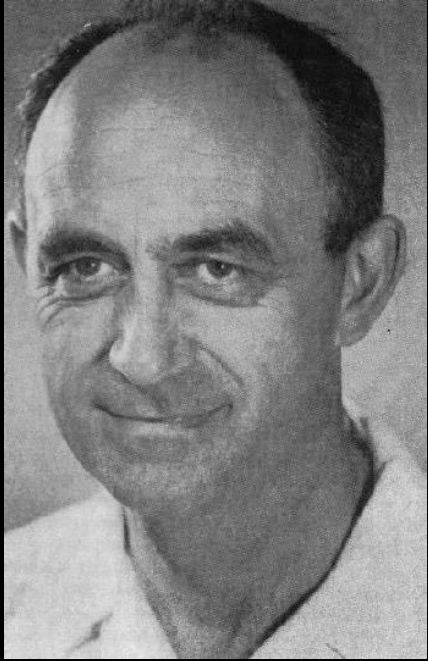


WEAK INTERACTION

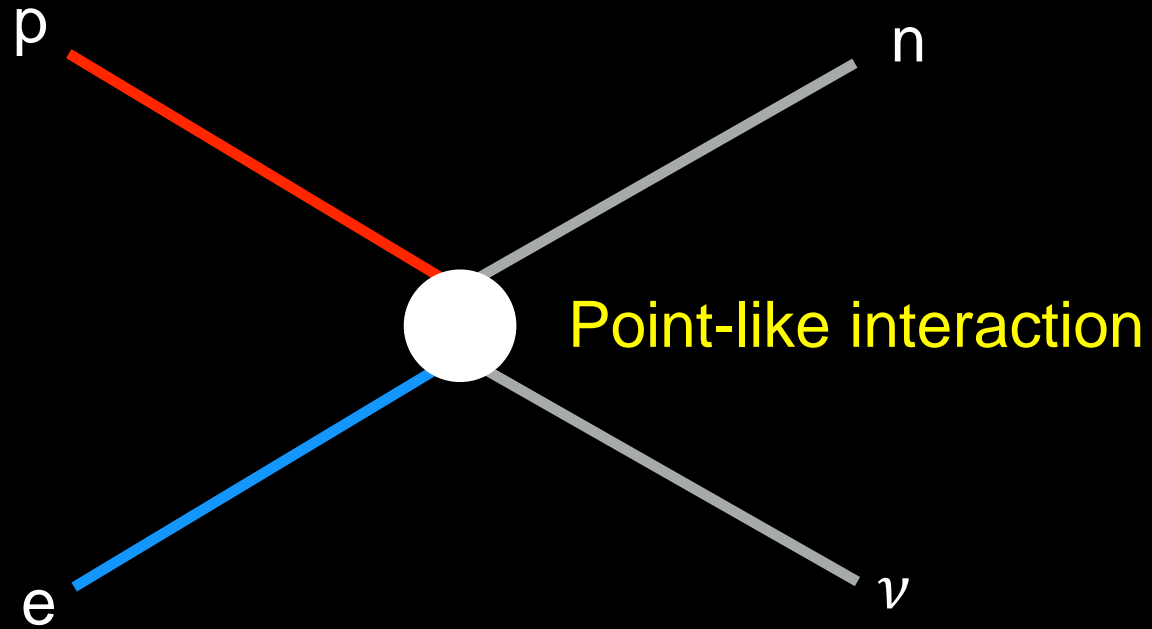


Henri Becquerel (1900): Beta-radiation = electrons

FERMI THEORY (1934)



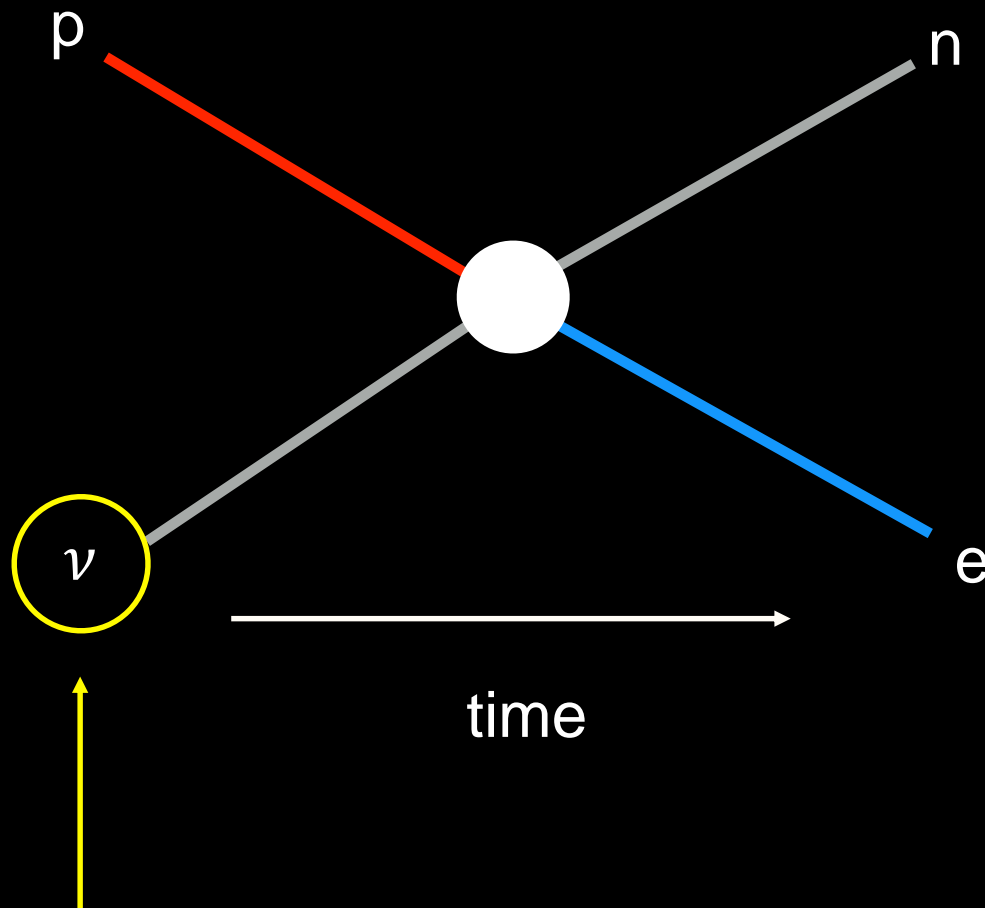
Enrico Fermi



$W = \text{Overlap of the four wave functions} \times \text{Universal constant } G$

$G \sim 10^{-5} / M_p^2 = \text{"Fermi constant"}$

FERMI: PREDICTION ABOUT NEUTRINO INTERACTIONS



$$\sigma = \frac{4}{\pi} G^2 E^2$$

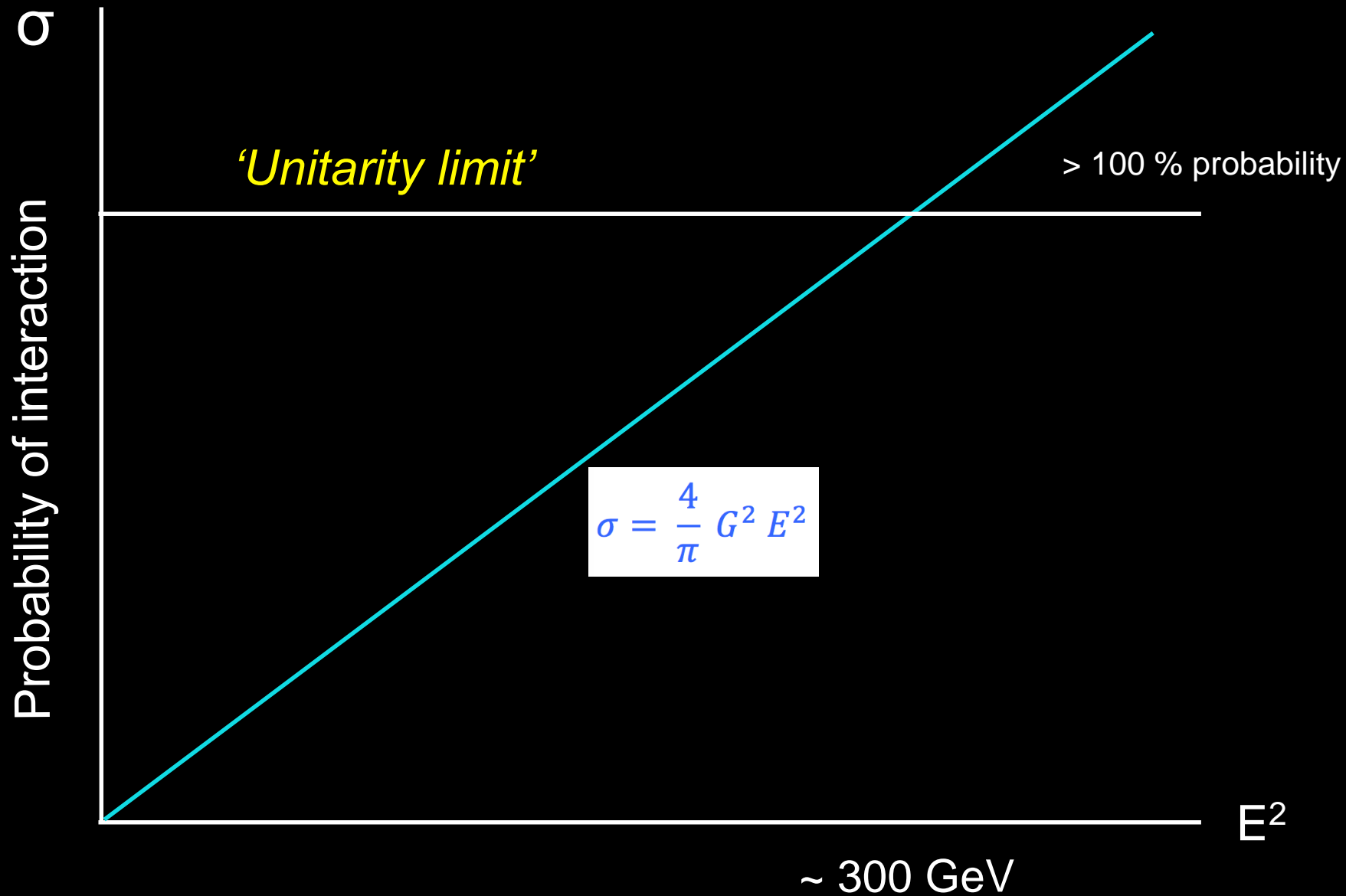
$$E = 1 \text{ MeV: } \sigma = 10^{-43} \text{ cm}^2$$

(Range: 10^{20} cm \sim 100 l.yr)

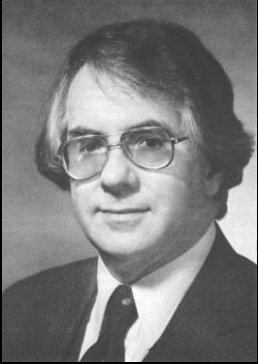
Reines, Cowan (1956):
Neutrino 'beam' from reactor

Reactions prove existence of neutrinos

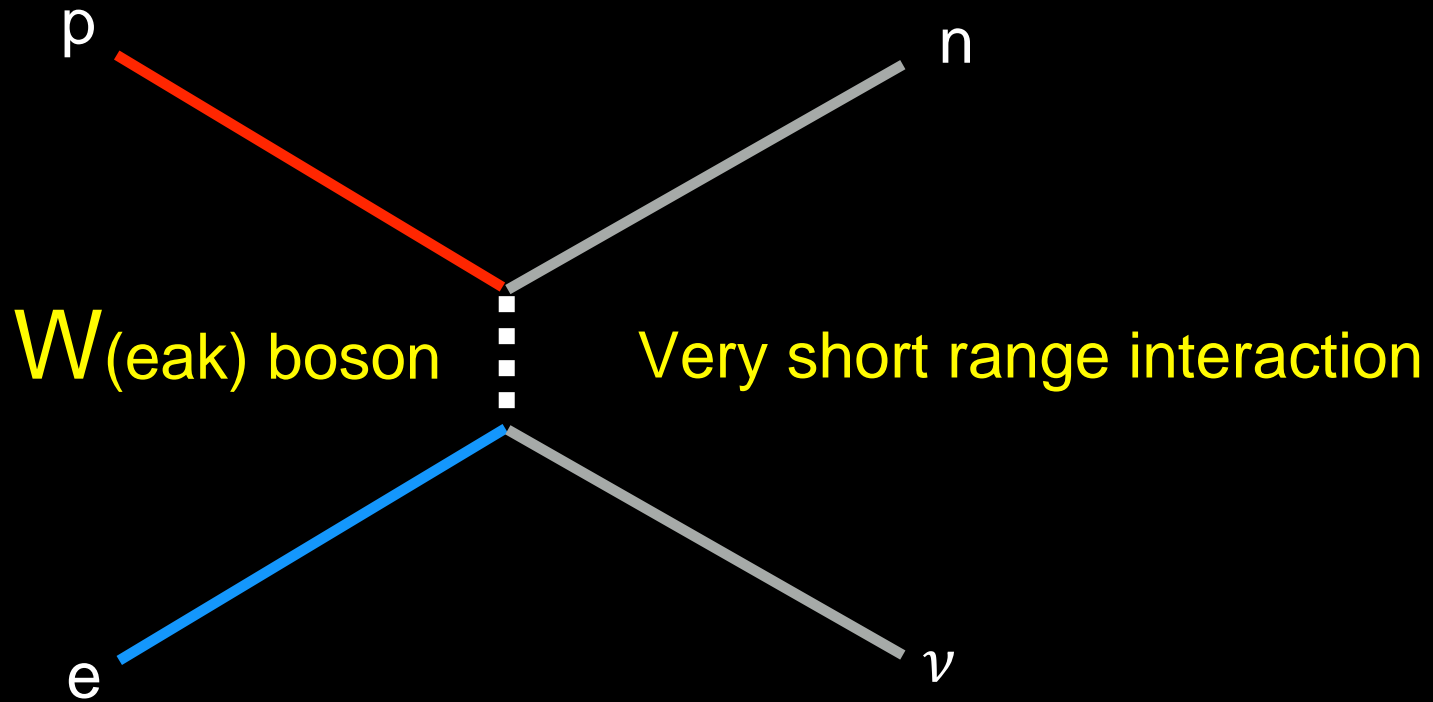
and then THE PREDICTION FAILED !!



GLASGOW REFORMULATES FERMIS THEORY (1958)

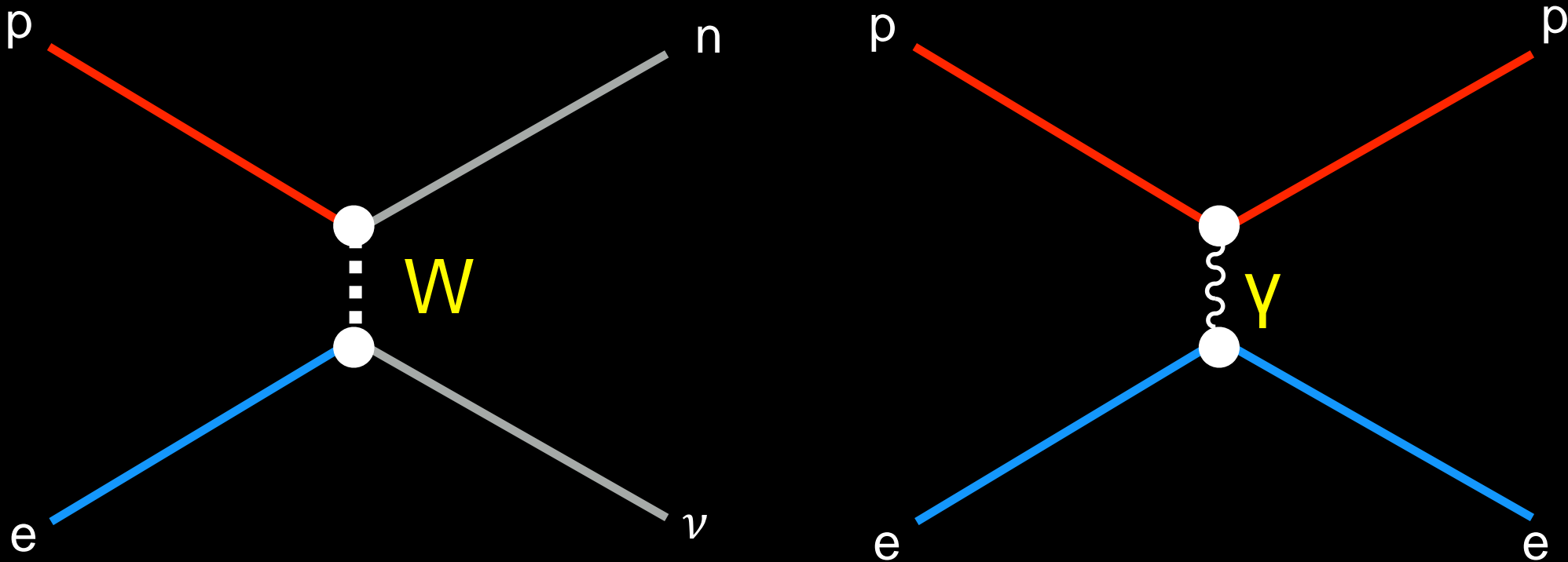


S. Glashow



If mass of W boson ~ 100 GeV : theory o.k.

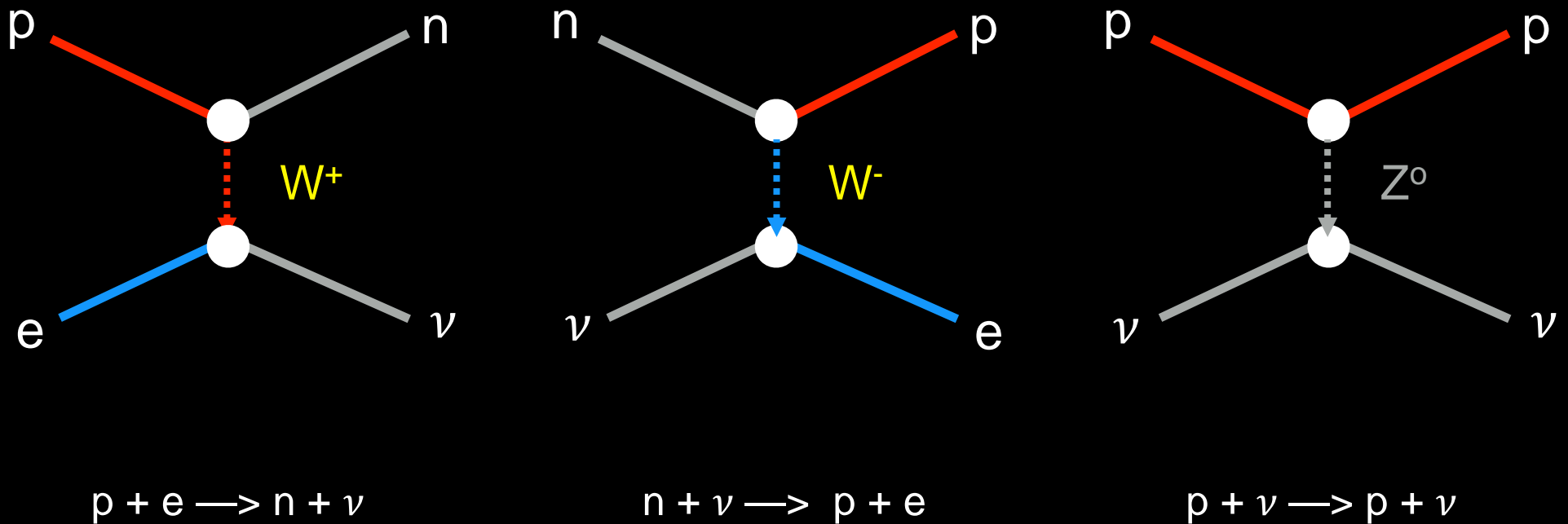
Interesting: at high energies, coupling of weak and e.m. interaction similar !



Leads to idea of ELECTRO-WEAK UNIFICATION
(Glashow, Salam, Weinberg)

ELECTRO-WEAK UNIFICATION

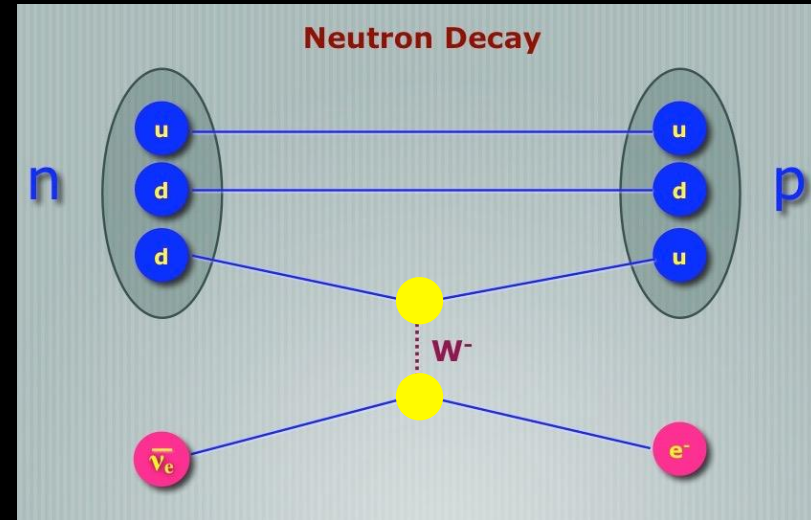
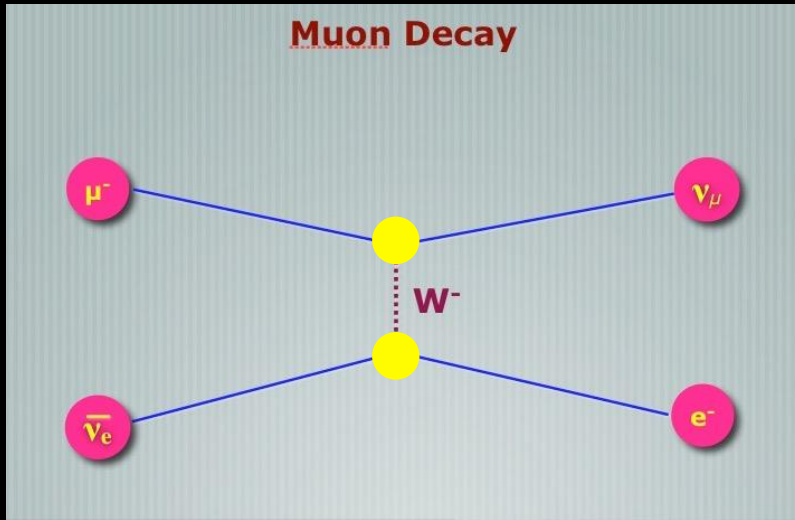
“Charged currents” (W^\pm) and “Neutral Current” (Z^0)



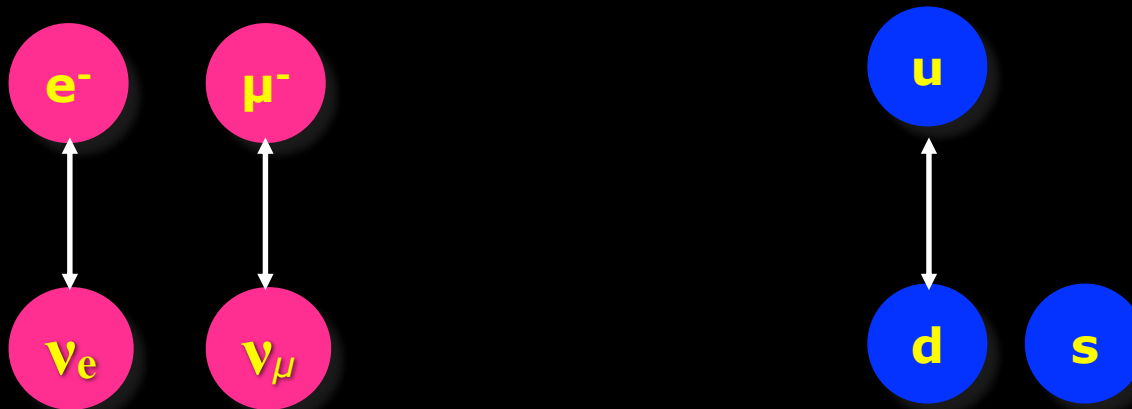
Z^0 is the ‘massive’ brother of the photon

Idea of “weak symmetry breaking” through ‘Higgs mechanism’

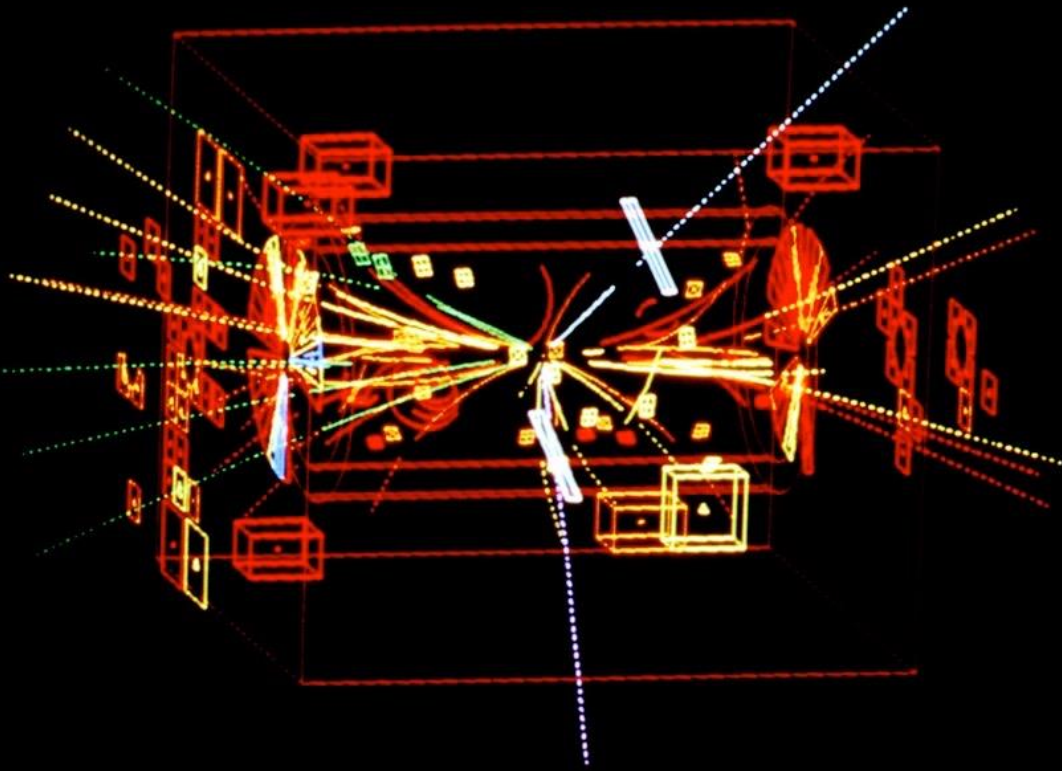
Interesting: electroweak interaction is (approx.) the same for leptons and quarks !



“Universality*” - transmitted by W, Z bosons, same strength!



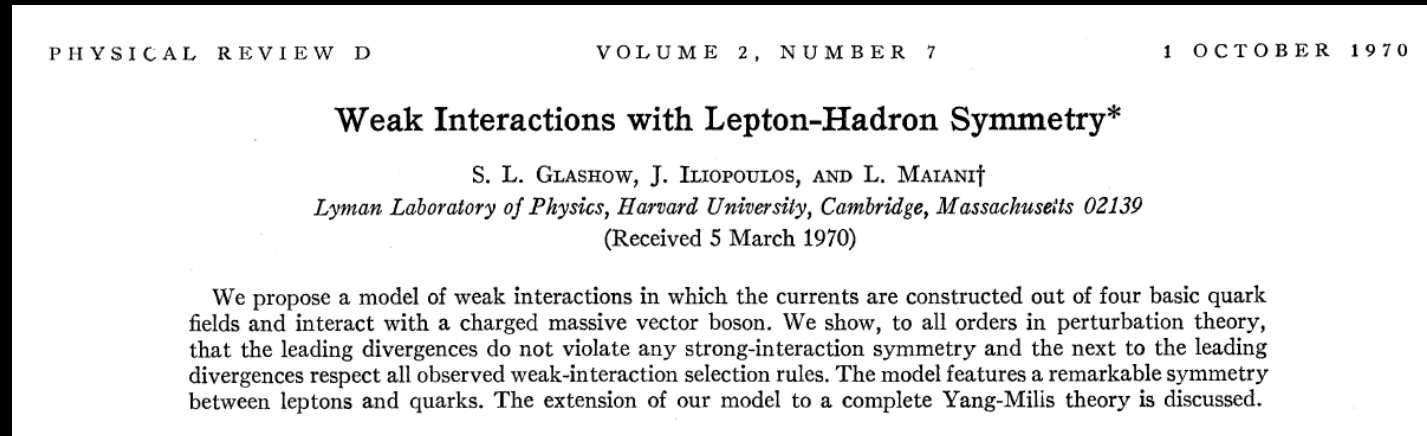
DISCOVERY OF THE WEAK BOSONS AT CERN (1983)



(C. Rubbia, S. van der Meer)

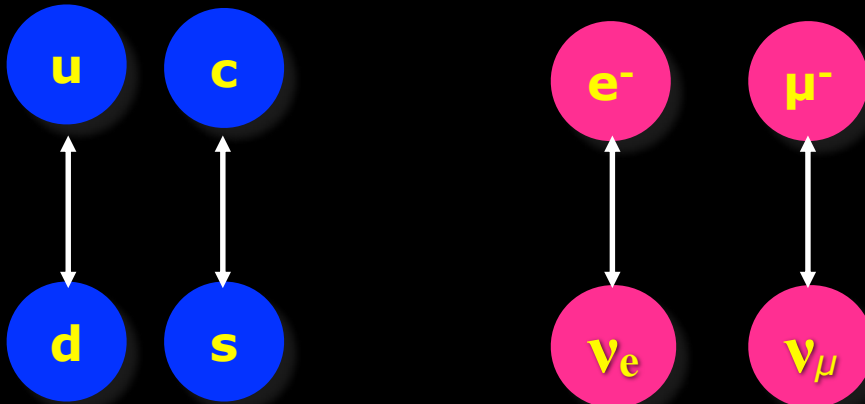
THE CHARM QUARK

A legendary paper, predicting the 'charm' quark (Glashow, Iliopoulos, Maiani)



Quarks

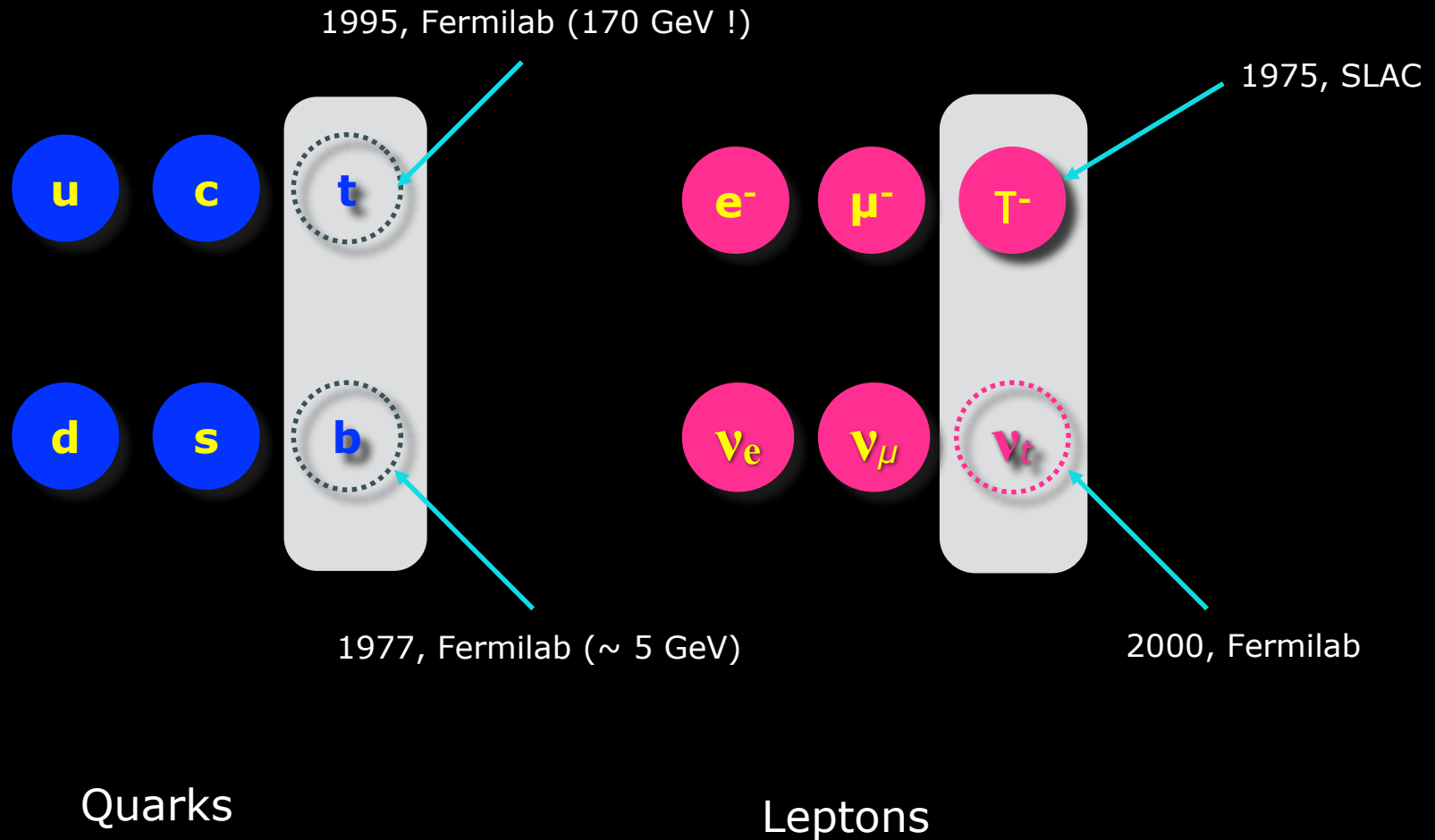
Leptons



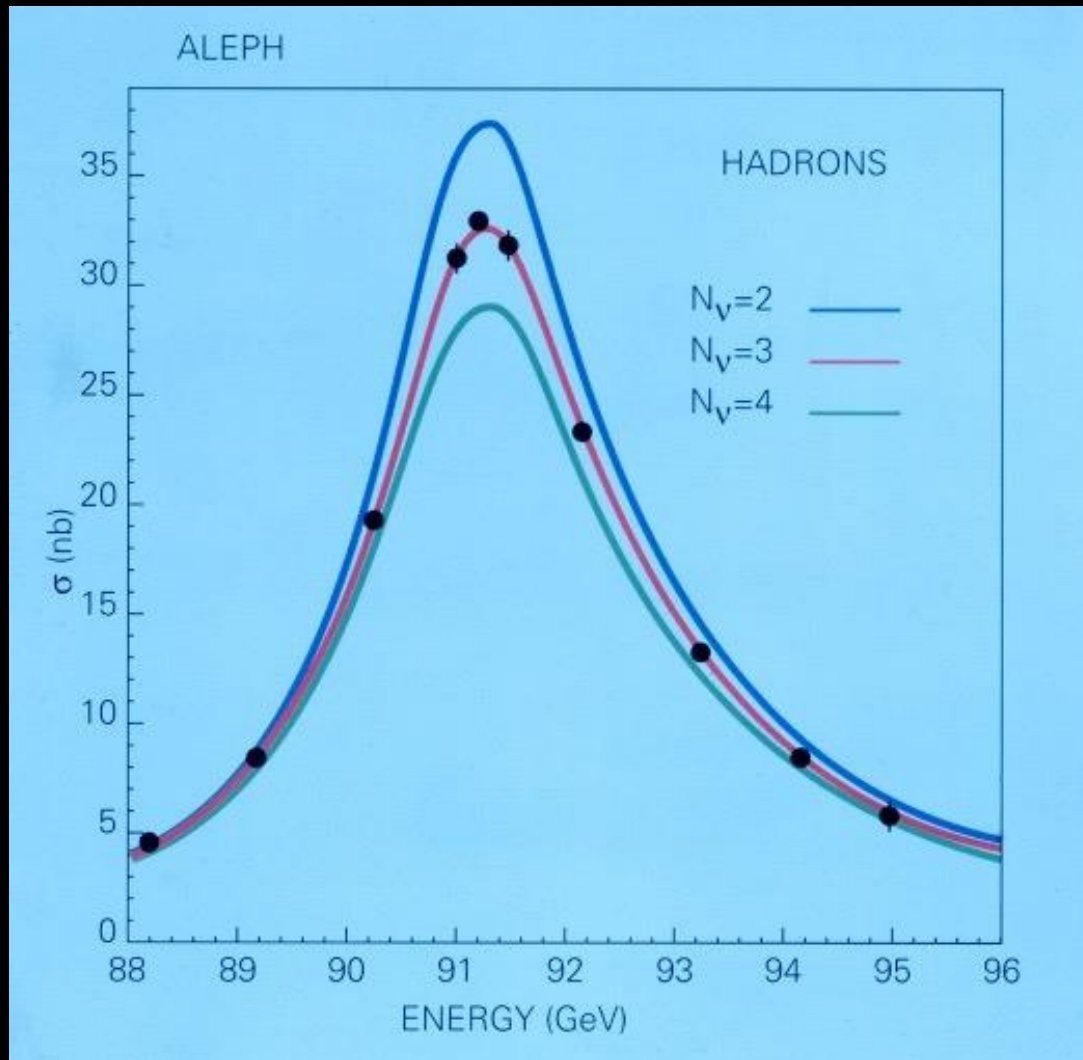
The charm quark was discovered (J/ψ meson = charm-anticharm bound state) in November 1974

Surprise, surprise: enter the THIRD FAMILY

A new lepton (called "tau") is discovered (heavy brother of e and μ)

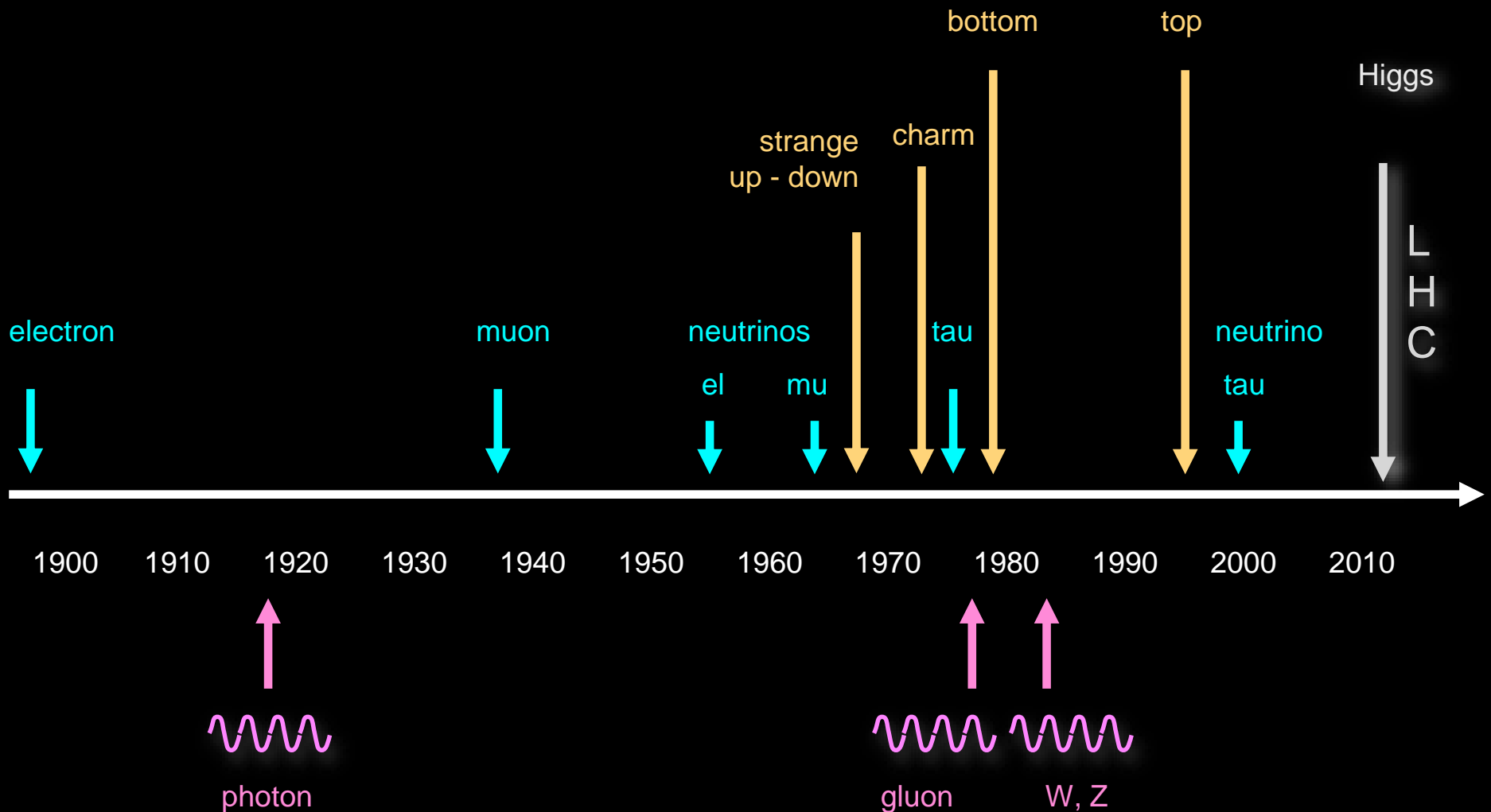


There are exactly 3 families



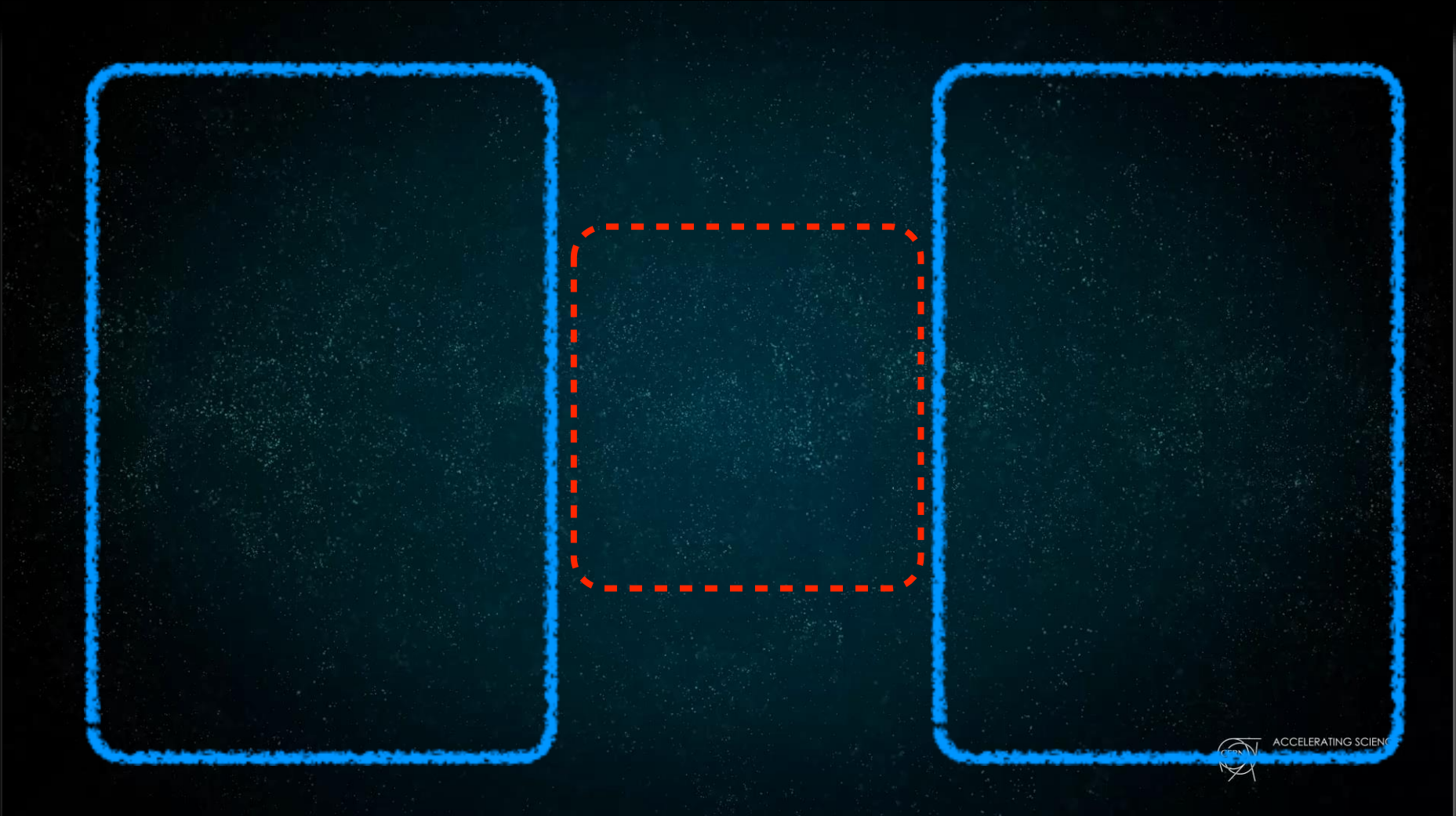
LEP measures the decay width of the Z^0 particle

Experiments at accelerators have discovered the whole set of fundamental particles



Particle physics of the 21st century

Standard model = 'periodic system' of elementary particles



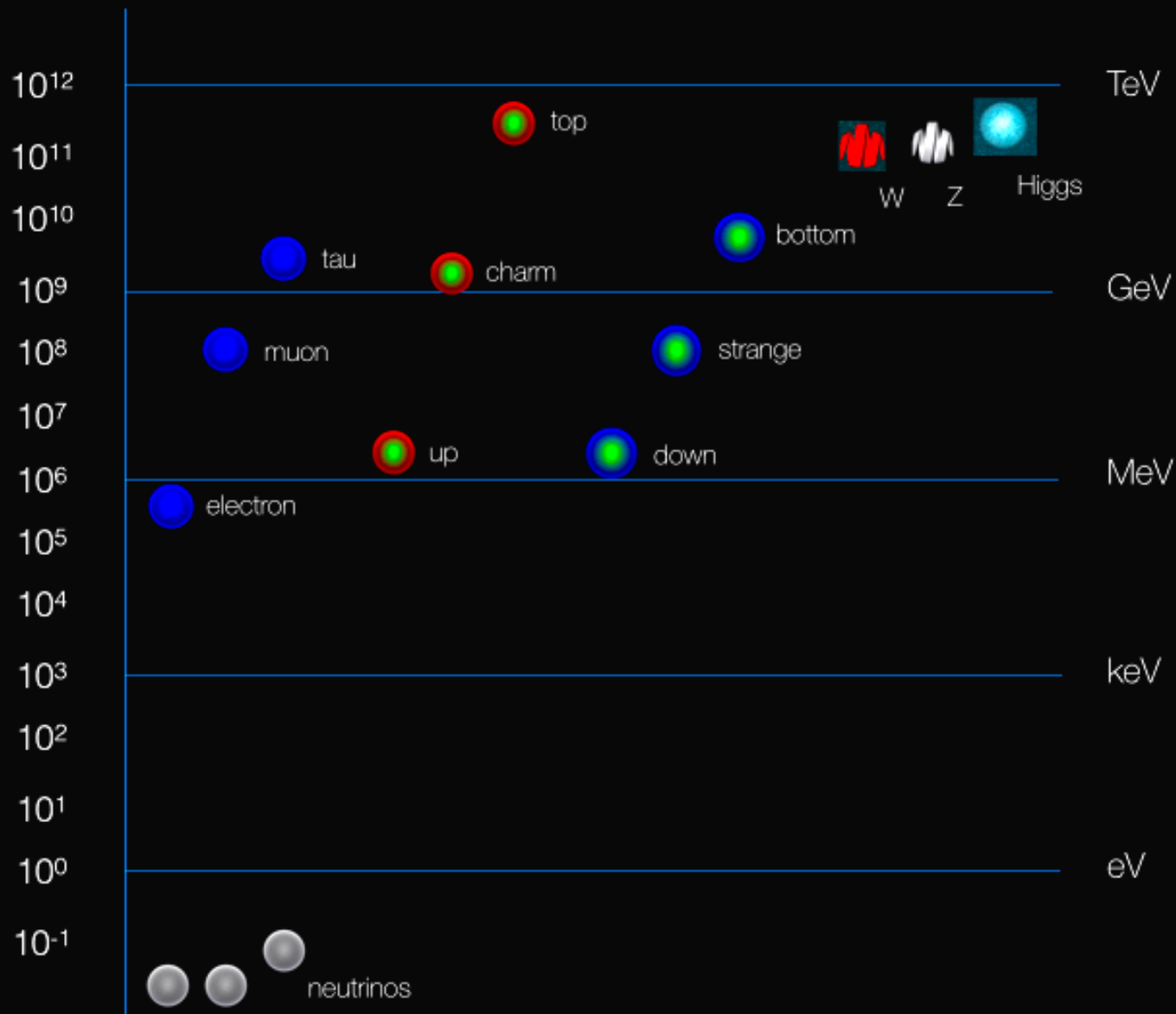
Particles

Higgs

Fields

How do particles obtain their mass ?

Mass of particles
[eV]

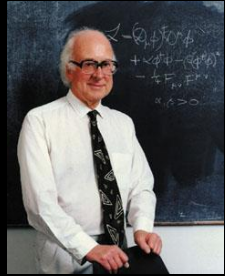


The mystery of mass

Massless particles have to move with the speed of light

THEY CANNOT FORM SOLID OBJECTS

The Brout-Englert-Higgs (BEH) field idea



the entire Universe is filled with a homogeneous field
particles interacting with this field obtain inertia (=rest mass)
the BEH field interaction is proportional to the mass of the particle

Sir Peter Higgs

The 'cocktail party' explanation of the Higgs mechanism



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'



A rumour is spreading among the guests ...

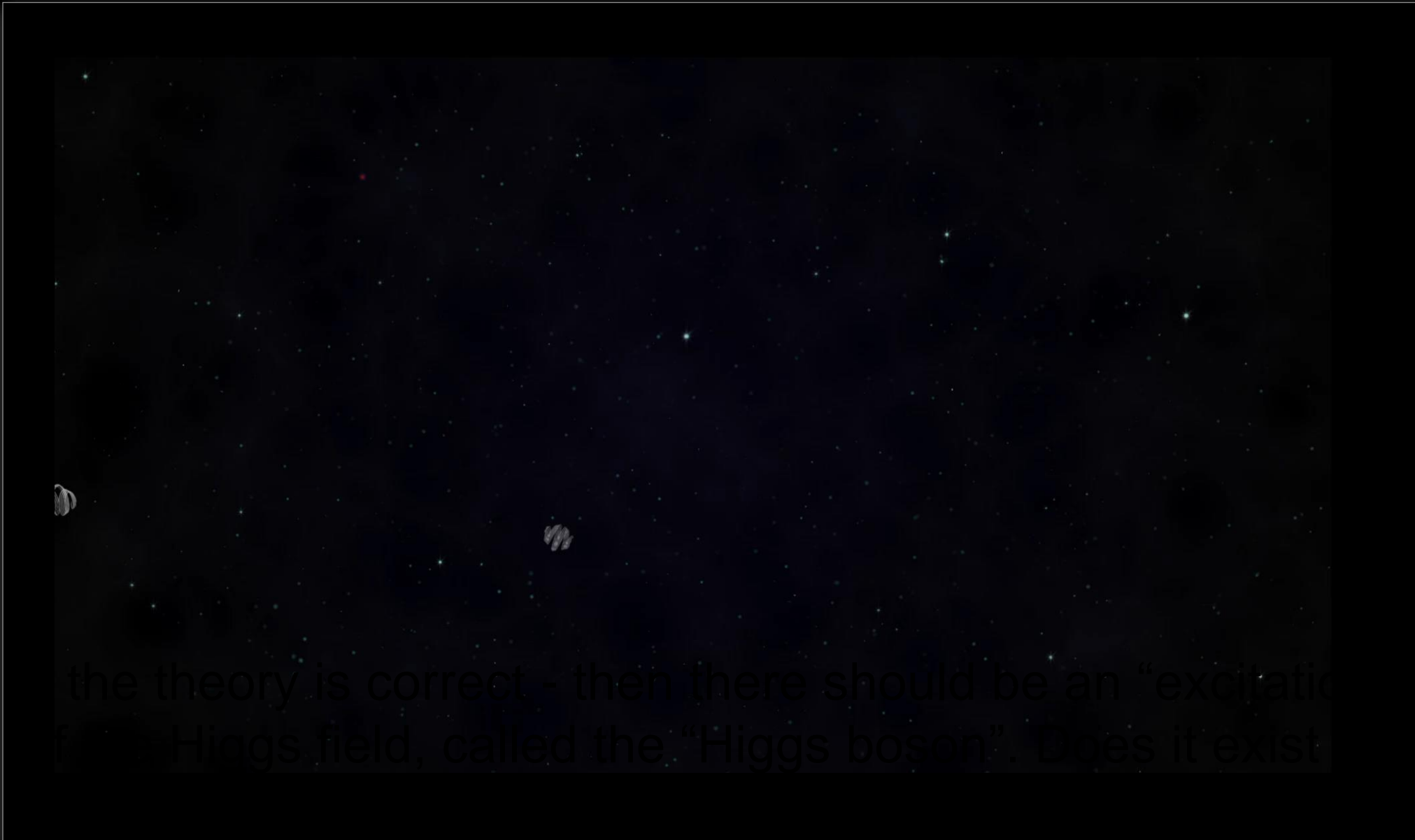


.. they cluster together to exchange the information among themselves...

The BEH field ...

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

Animation: the Higgs mechanism



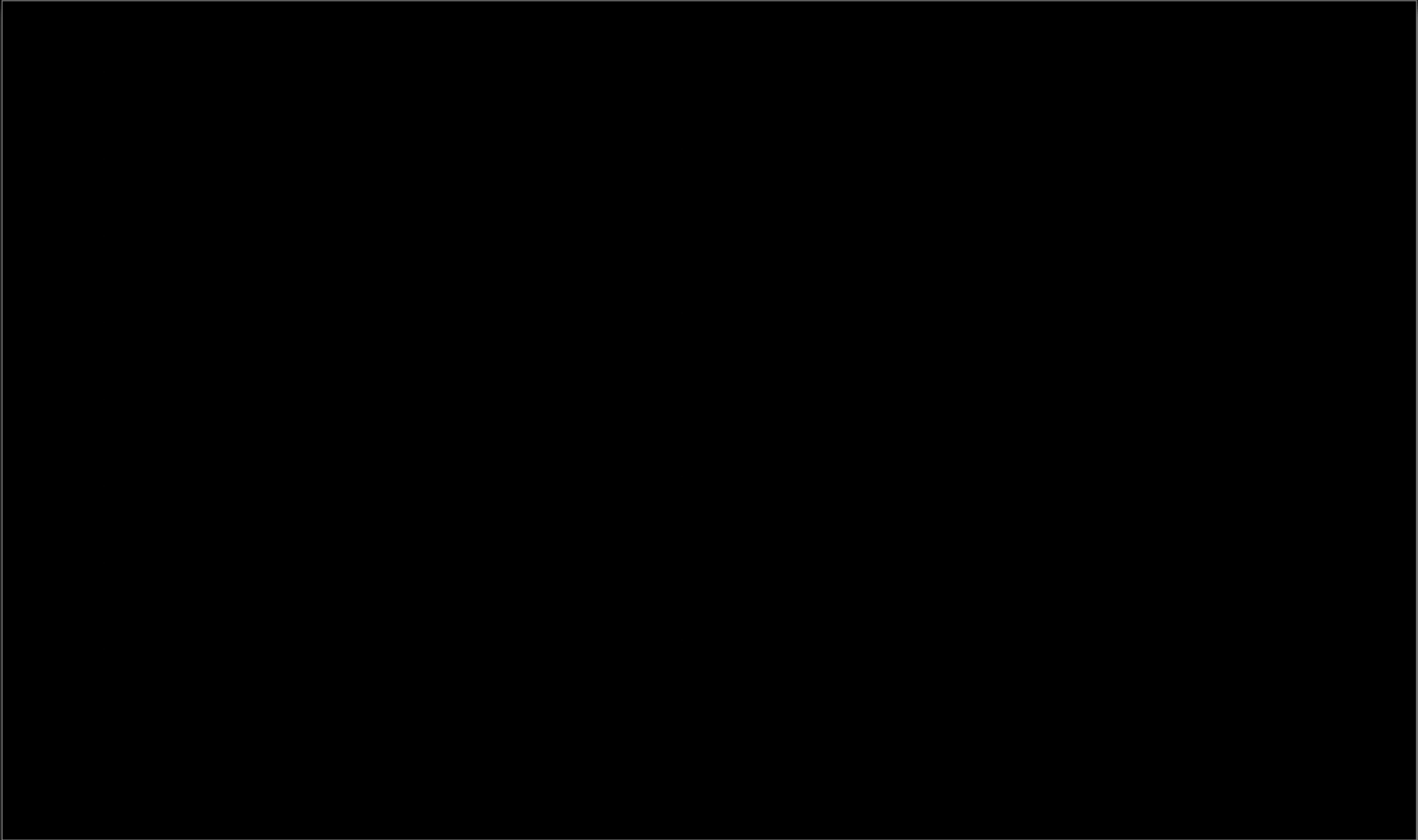
Exciting the Brout-Englert-Higgs field: the “Higgs boson”



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

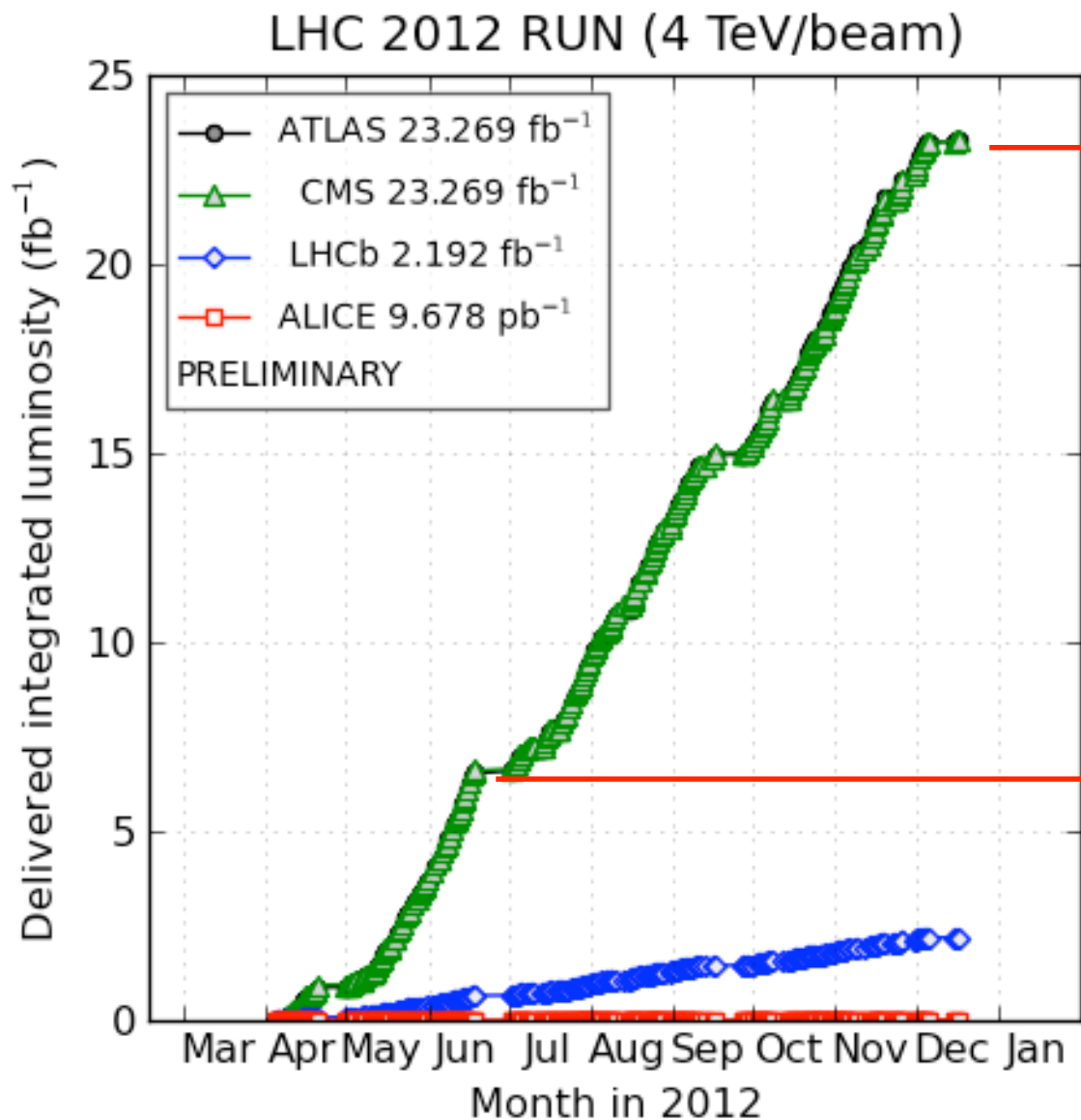
The Higgs boson can decay in two photons

...



but only with a probability of 0.2 %

The CERN hunt for the Higgs boson

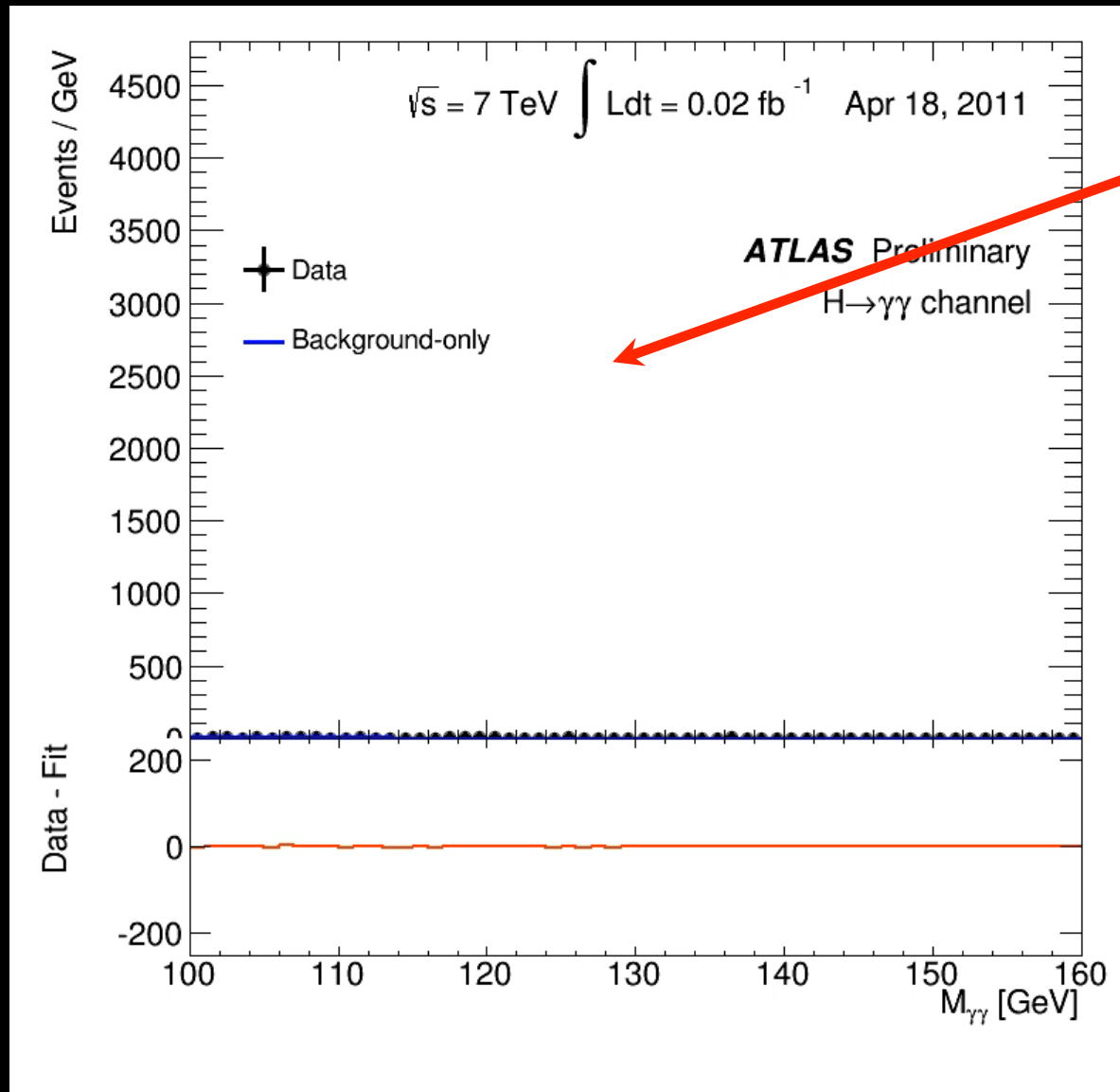


15.12.2012

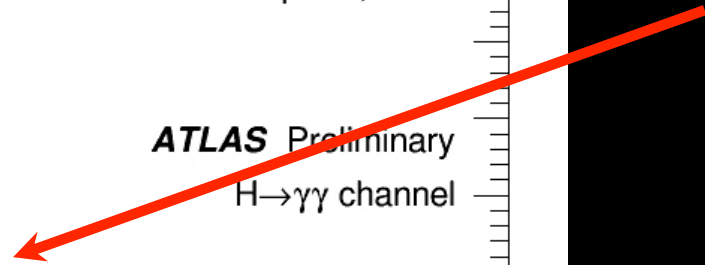
3,000,000,000,000,000 ($3 \cdot 10^{15}$)
(3000 trillion events !)

4.7.2012

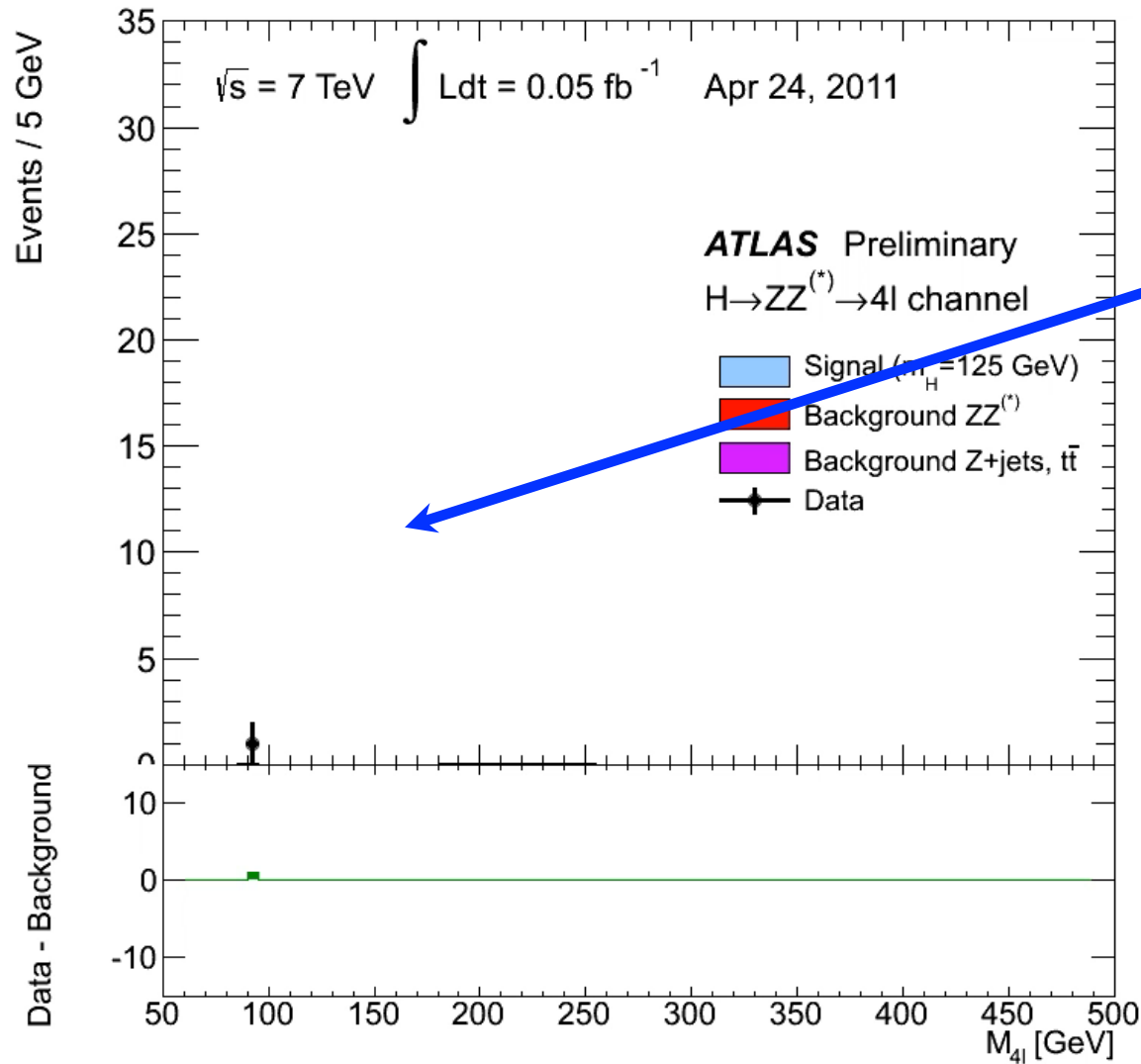
The evolution of the histogram with two-photon events



Higgs boson



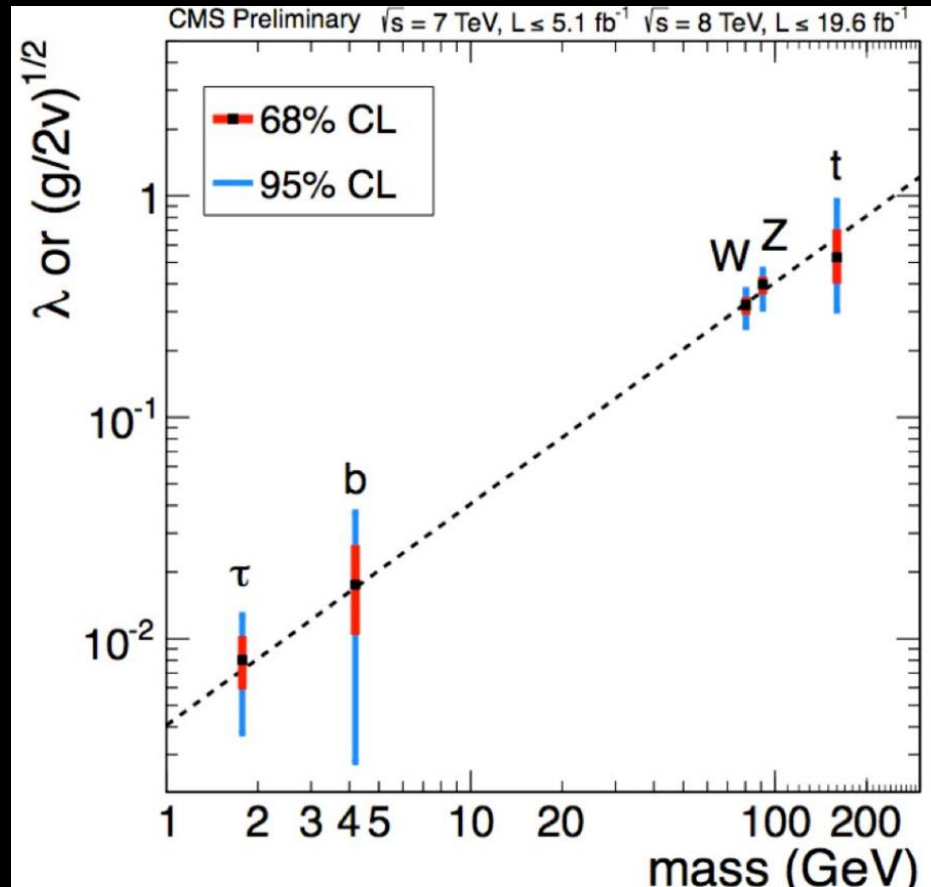
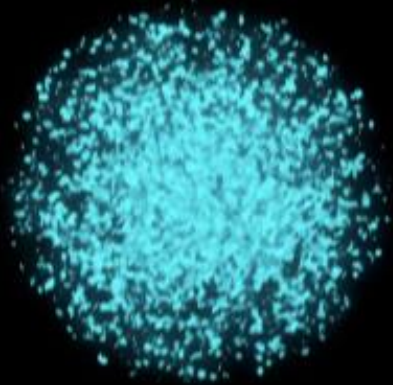
The evolution of the histogram with four leptons



Higgs boson

Status 2014: the new particle is the Higgs boson

Higgs boson decay probability is predicted to be proportional to the mass of the decay particles



Theoretical expectations compatible with observations

The
Economist

JULY 7TH - 13TH 2012

Economist.com

In praise of charter schools
Britain's banking scandal spreads
Volkswagen overtakes the rest
A power struggle at the Vatican
When Lonesome George met Nora

A giant leap for science



Finding the
Higgs boson

What does this mean?

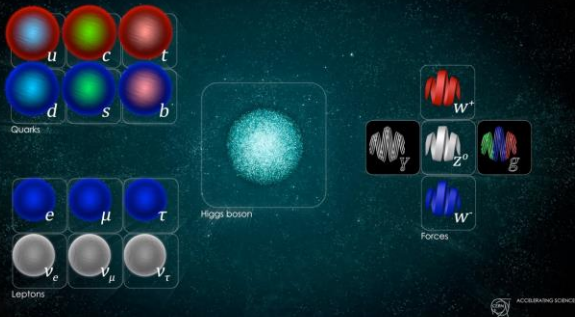
- the Higgs boson exists, therefore ...
- the Brout-Englert-Higgs field exists
- we know how particles obtain their mass
- the “Standard model” is complete

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

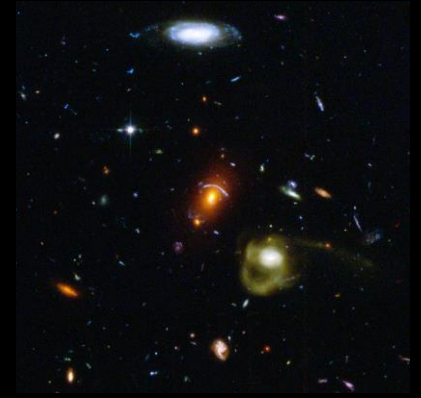
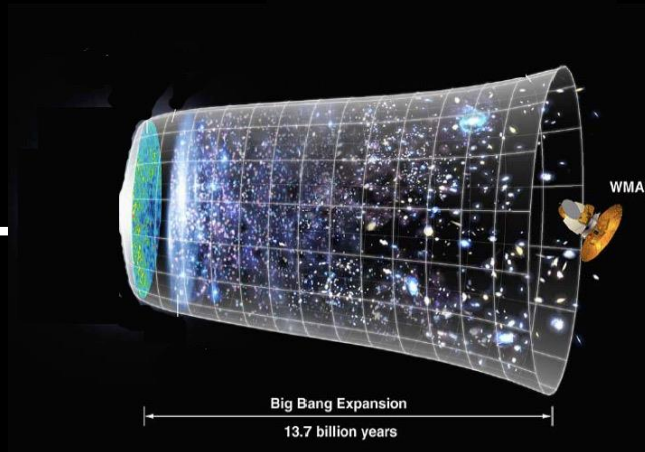
Even more:

Particle
physics

+ Cosmology = Universe ?



+



No !

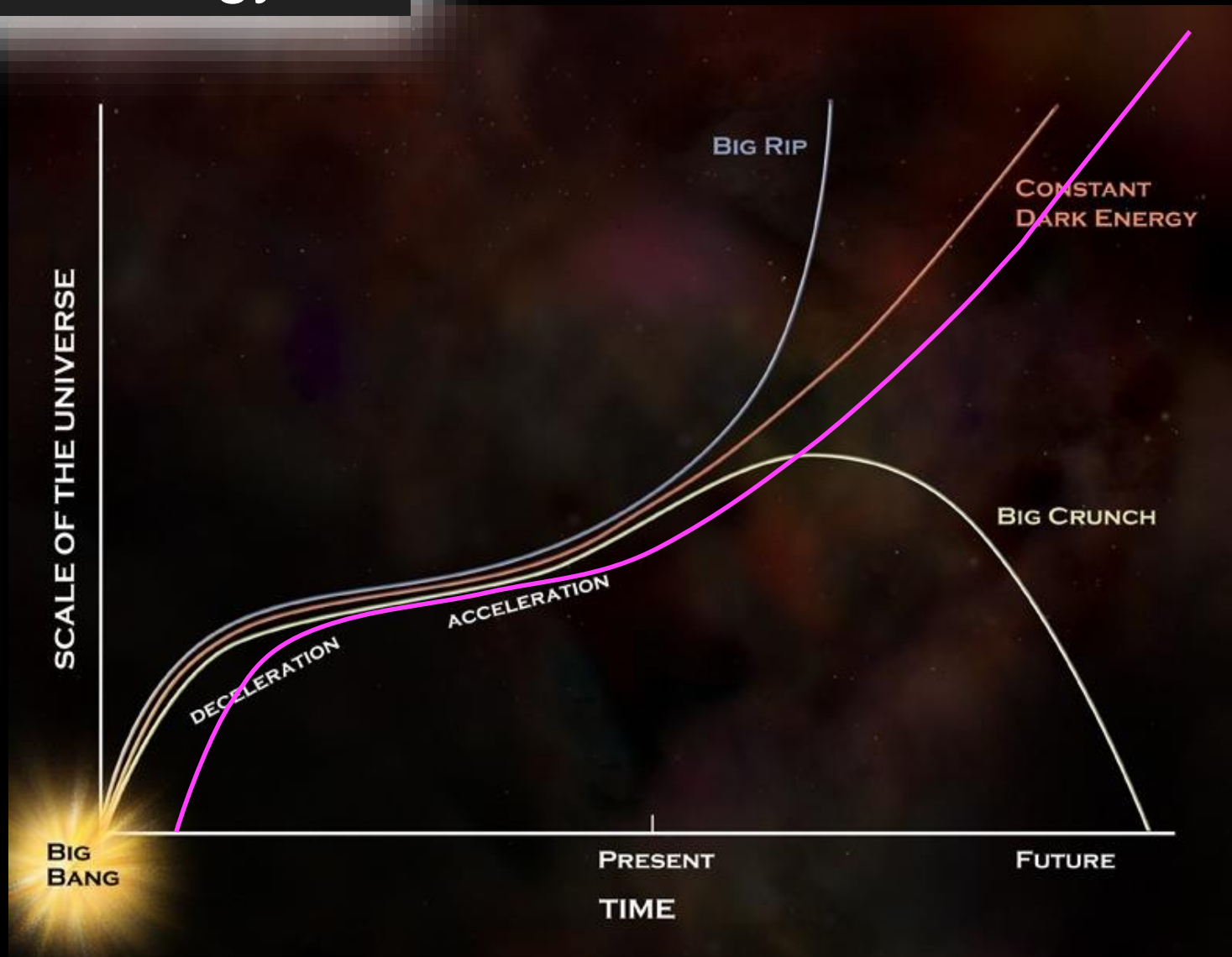
Less than 5% of the energy content of
the universe are understood!

Dark matter ...?



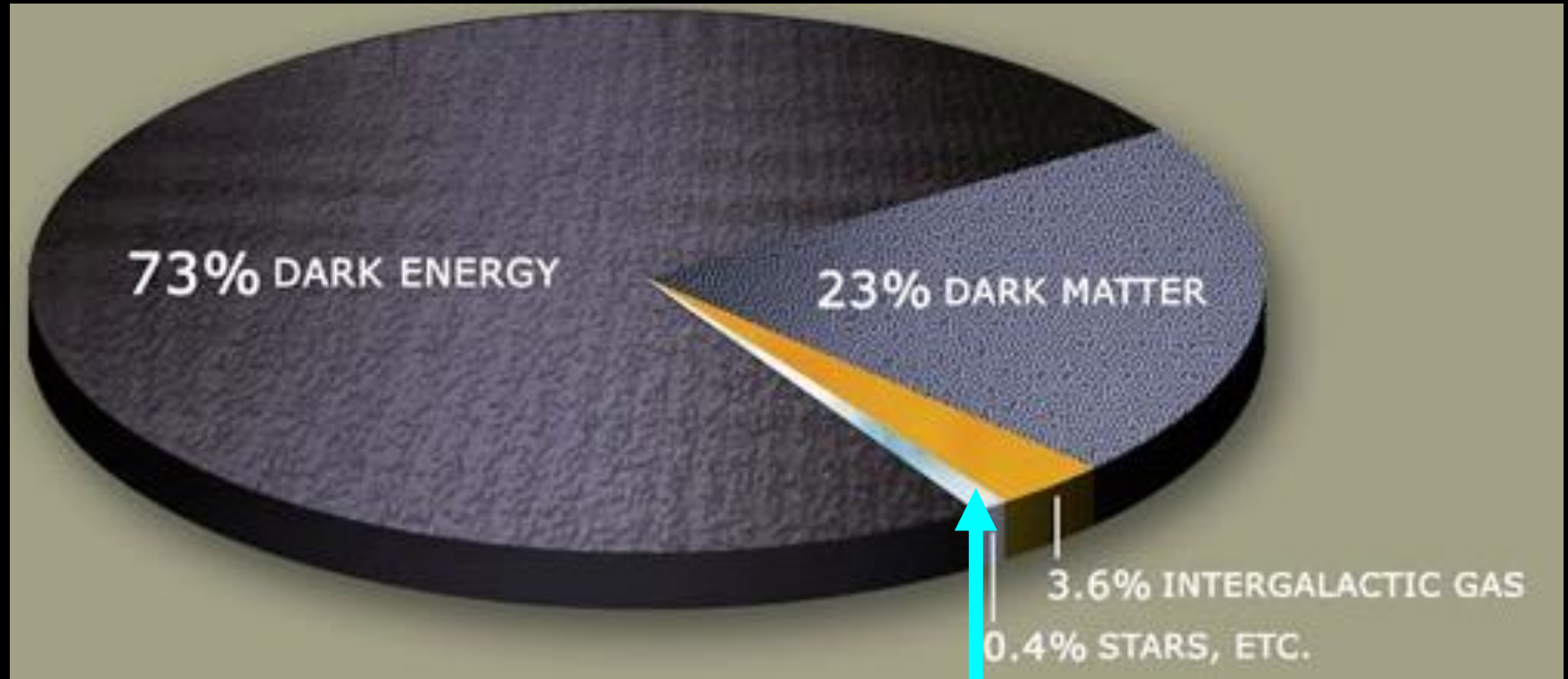
Galaxies rotate too fast

Dark energy ...?



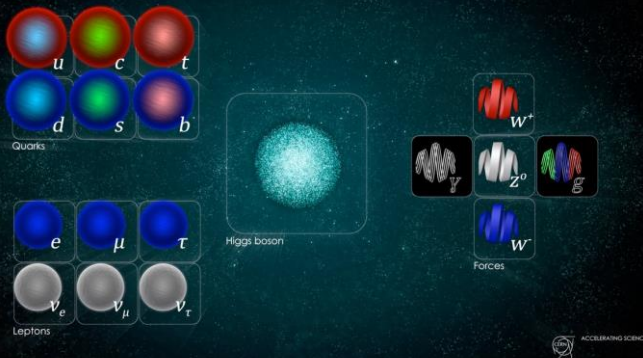
The expansion of the Universe accelerates ...

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



You are here

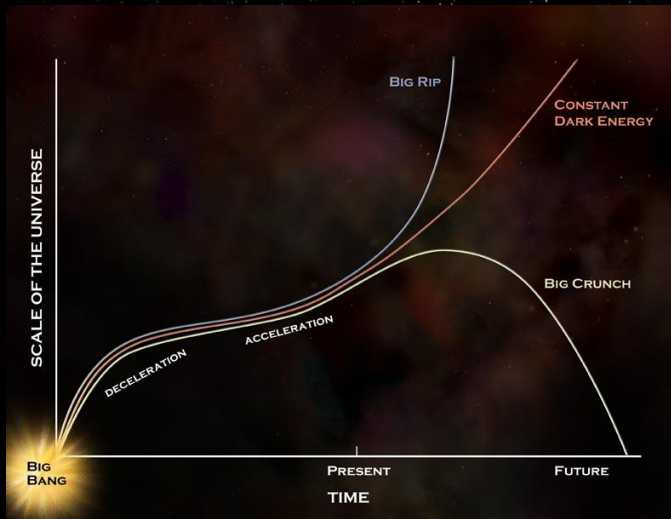
The big questions:



Is the Higgs boson alone?
Connection to 'dark energy' ?



What is dark matter?



What is dark energy?

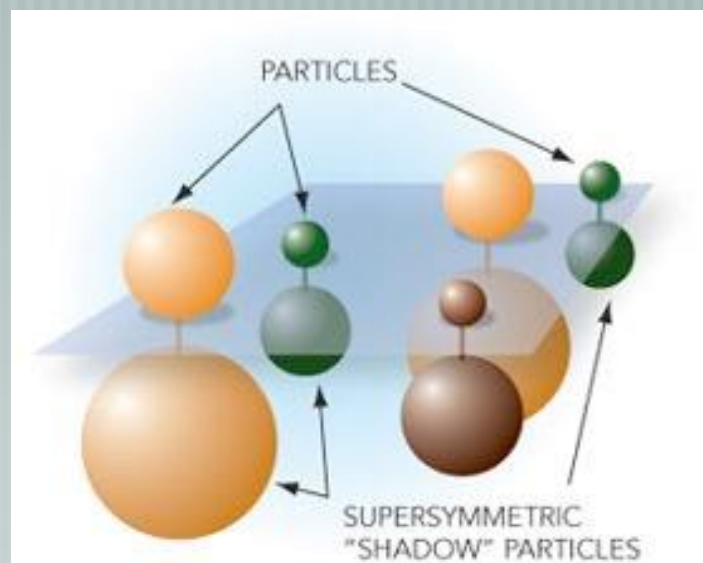
SUPERSYMMETRY - connection to Dark Matter ?

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)

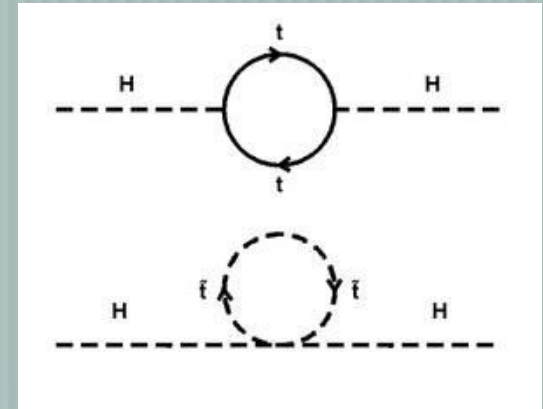


But: no such SUSY partner has ever been seen. So ... if they exist, they must have a large mass (> 1 TeV)

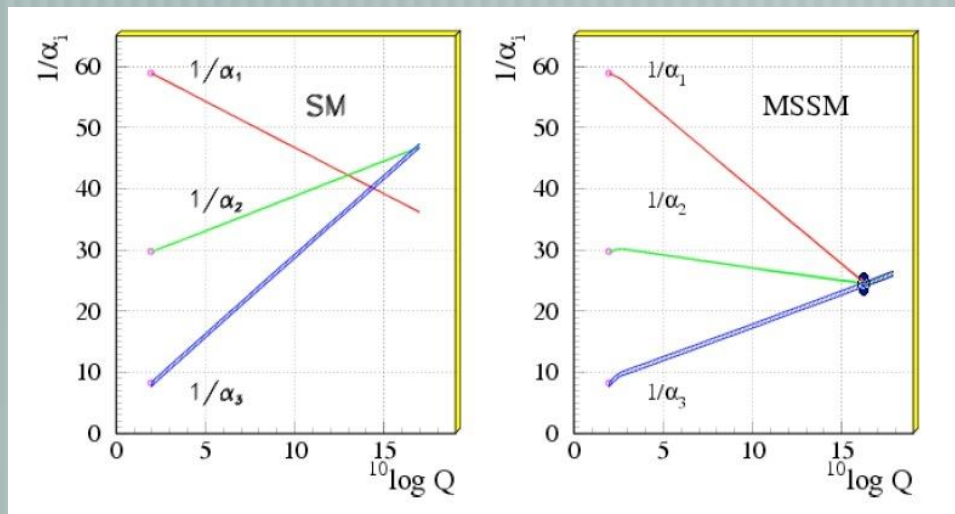
Why SUSY?

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

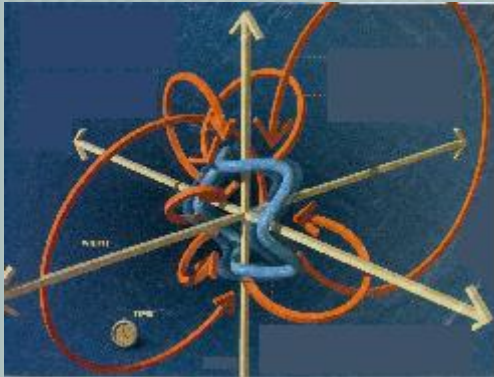


4) May explain the cosmological matter-antimatter asymmetry

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

MORE MYSTERIES

What is a particle?



Superstrings in 9+1 dimensions?

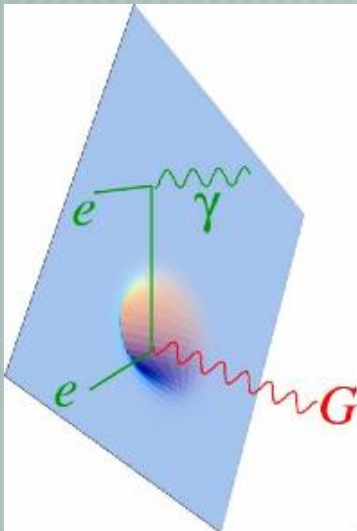
Little strings of string energy vibrating in a 9+1 dimensional space ?

$L \sim 10^{-35}$ 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?

Extra dimensions ?



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 !