Le boson de Brout-Englert-Higgs
Point de vue théorique

LAURA LOPEZ HONOREZ

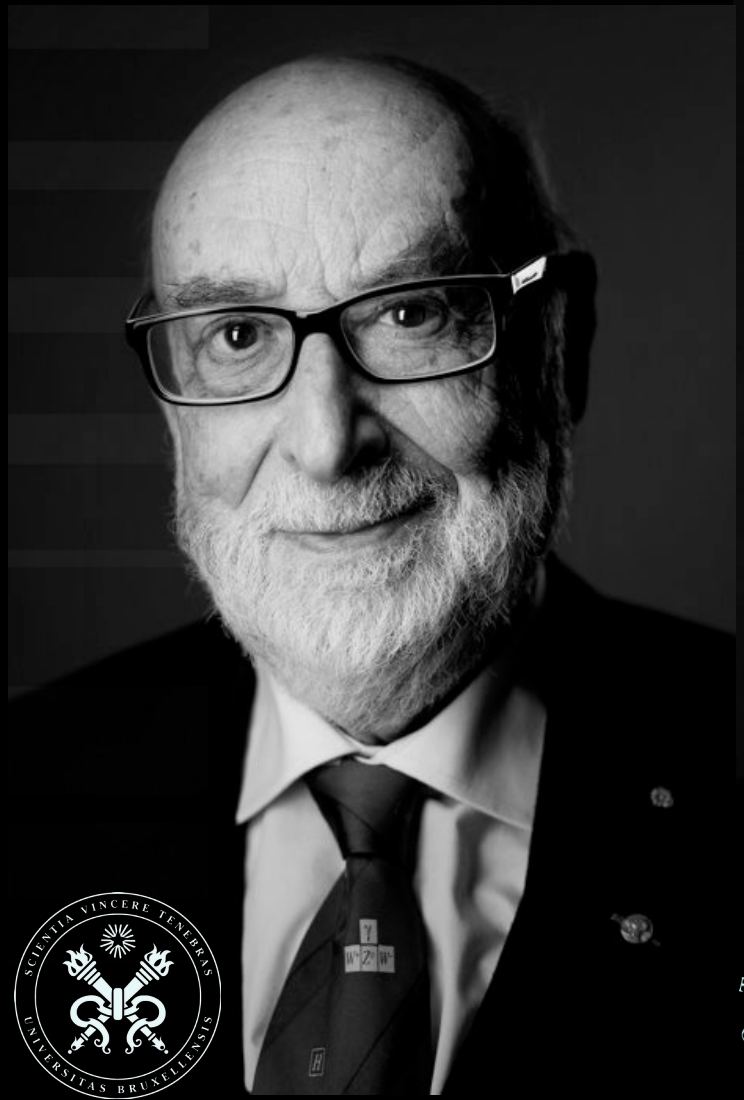
Université Libre de Bruxelles

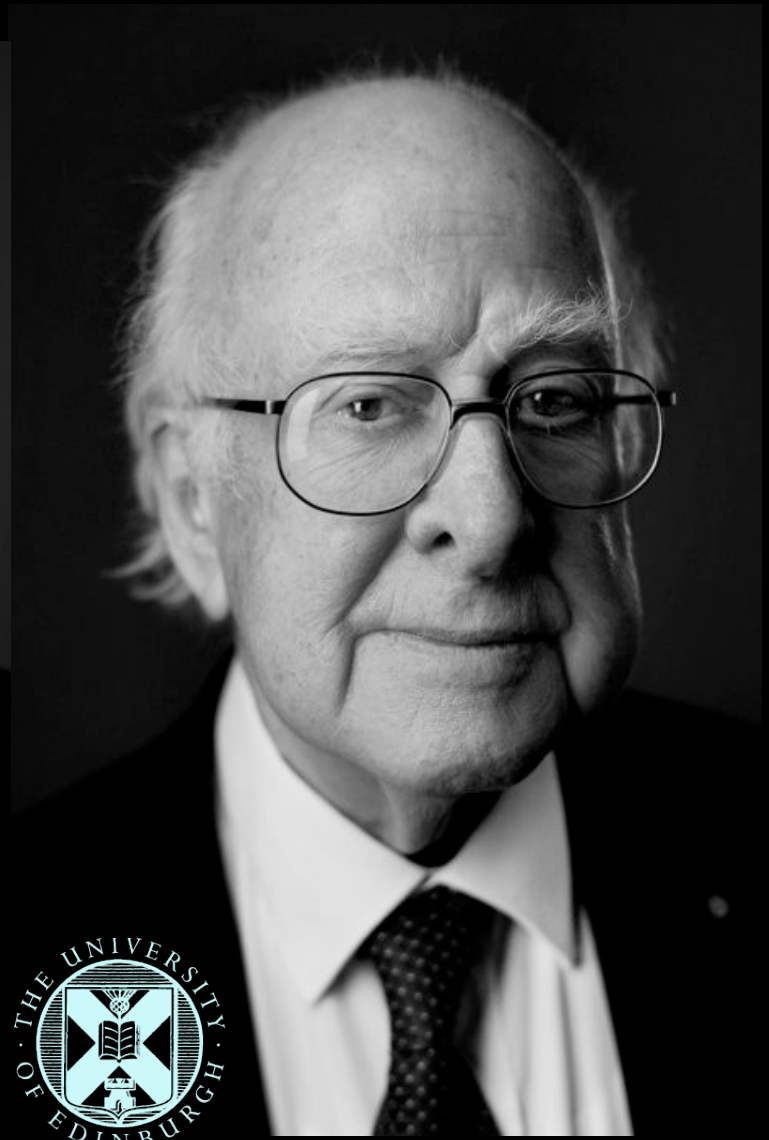
ULB, Solvay Room

29 Septembre, 2023

The Nobel Prize in Physics 2013

François Englert and Peter W. Higgs





"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"

1964

VOLUME 13, NUMBER 9 PHYSICAL REVIEW LETTERS 31 AUGUST 1964

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout
Faculté des Sciences, Université Libre de Bruxelles, Bruxelles, Belgium
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The interaction between the φ and the A_μ fields is

$$H_{\text{int}} = ieA_\mu \varphi^* \overleftrightarrow{\partial}_\mu \varphi - e^2 \varphi^* \varphi A_\mu A_\mu, \qquad (1)$$

where $\varphi = (\varphi_1 + i\varphi_2)/\sqrt{2}$. We shall break the symmetry by fixing $\langle \varphi \rangle \neq 0$ in the vacuum

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« The Mechanism »

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« The boson »

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where $\varphi = (\varphi_1 + i\varphi_2)/\sqrt{2}$. We shall break the symmetry by fixing $\langle \varphi \rangle \neq 0$ in the vacuum

Tous les détails,

FIG. 1. Broken-symmetry diagram leading to a mass for the gauge field. Short-dashed line, $\langle\varphi_1\rangle$; long-dashed line, φ_2 propagator; wavy line, A_μ propagator. (a) $\rightarrow (2\pi)^4 ie^2 g_{\mu\nu}\langle\varphi_1\rangle^2$, (b) $\rightarrow -(2\pi)^4 ie^2(q_\mu q_\nu/q^2)\times\langle\varphi_1\rangle^2$.

Tous les détails, au cours de

PHYS-F422

Modèle standard des interactions fondamentales

ANNÉE ACADÉMIQUE 2022-2023 2023-2024

Titulaire(s) du cours
Thomas HAMBYE (Coordonnateur) et Laura LOPEZ HONOREZ

Crédits ECTS
5

1982 : Prix Francqui

1997 : High Energy and Particle Physics Prize of the European Physical Society

2004 : Wolf Prize in Physics

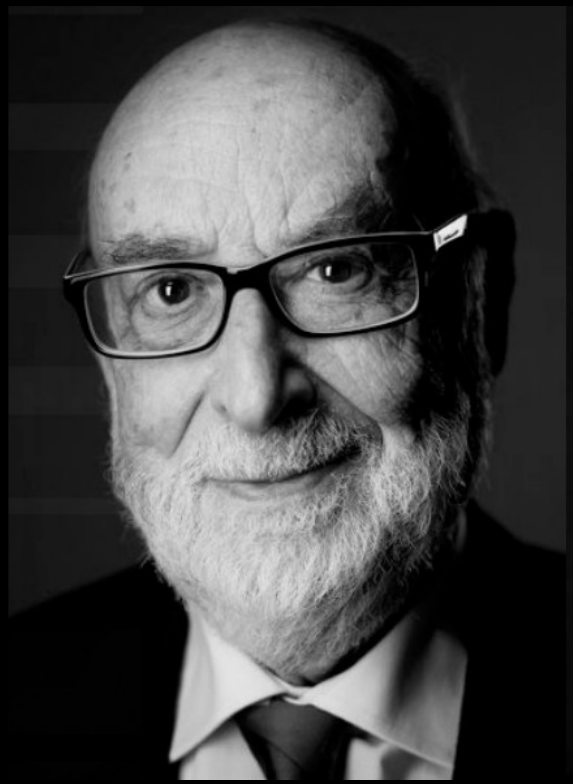
2013 : Prince of Asturias Award for Technical and Scientific Research

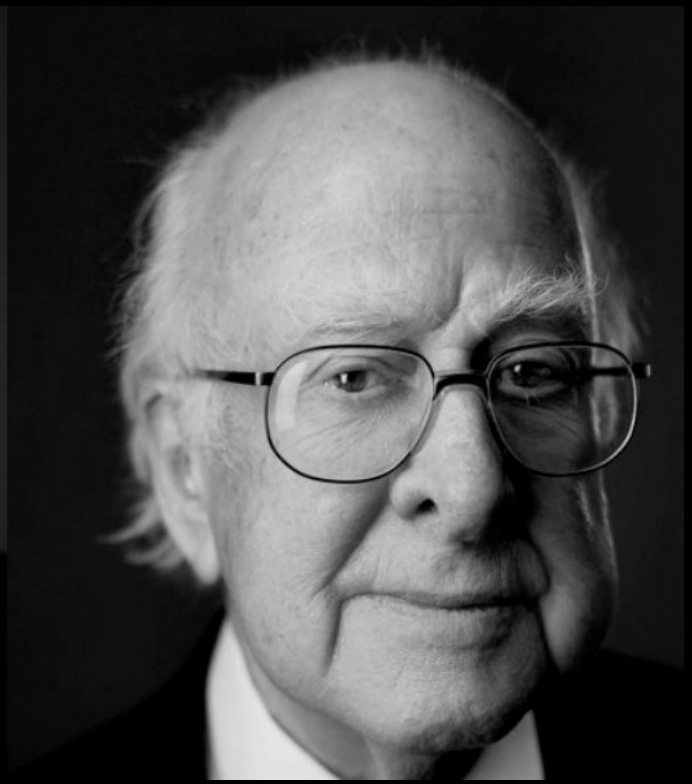
Plus tard
en
1964

Brout and
Englert

Higgs

Guralnik
Hagen
Kibble





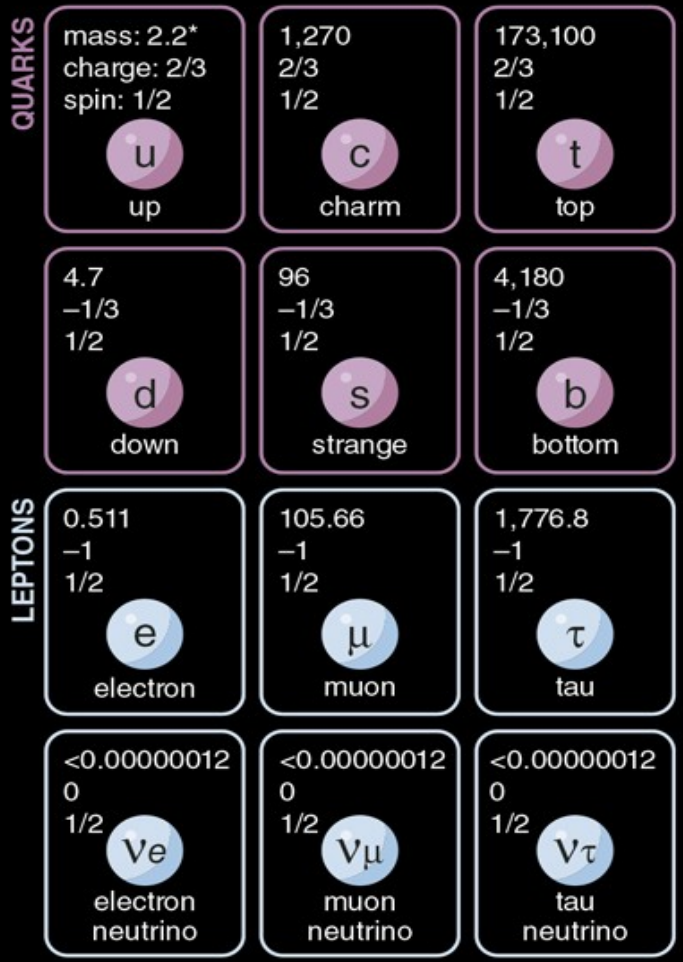
Englert - Higgs

Brout - Englert - Higgs Boson and Mechanism

"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"

Subatomic Particles

Particules de Matière


QUARKS
mass: 2.2*
charge: 2/3
spin: 1/2
u
up
1,270
2/3
1/2
c
charm
173,100
2/3
1/2
t
top
4.7
–1/3
1/2
d
down
96
–1/3
1/2
s
strange
4,180
–1/3
1/2
b
bottom
LEPTONS
0.511
–1
1/2
e
electron
105.66
–1
1/2
μ
muon
1,776.8
–1
1/2
τ
tau
<0.00000012
0
1/2
νe
electron neutrino
<0.00000012
0
1/2
νμ
muon neutrino
<0.00000012
0
1/2
ντ
tau neutrino

QUARKS

mass: 2.2*
charge: 2/3
spin: 1/2

u

up

4.7
–1/3
1/2

d

down

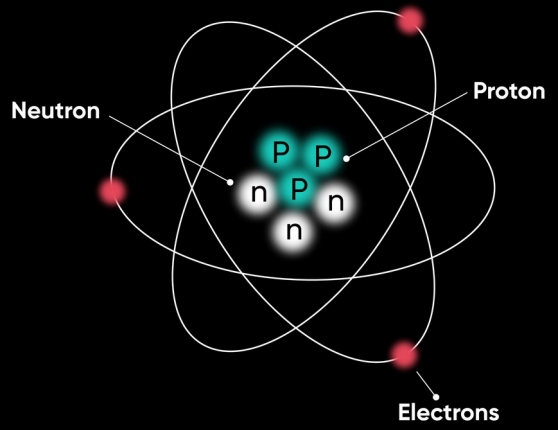
LEPTONS

0.511
–1
1/2

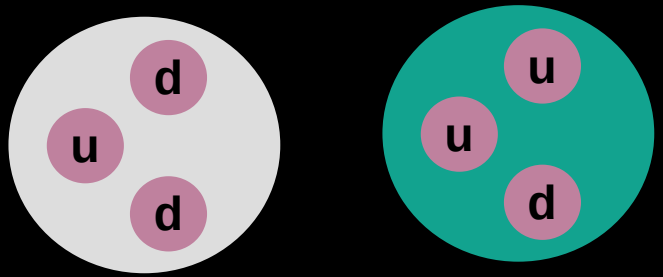
e

electron

Composants des atomes



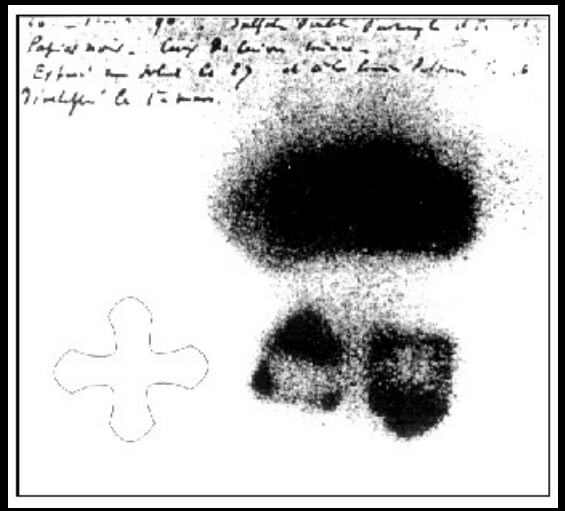
et des neutrons & protons

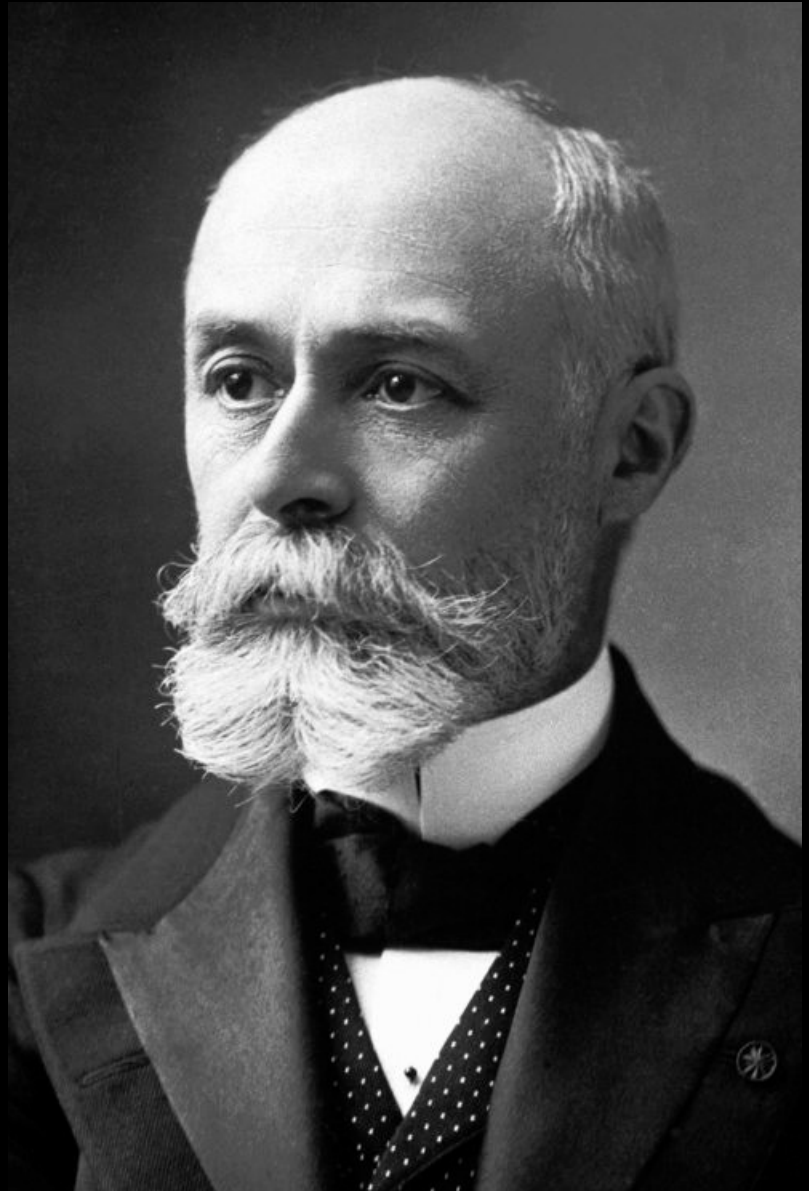


1896 : Henry Becquerel

discovers
radioactivity

$N \rightarrow N' + \beta$

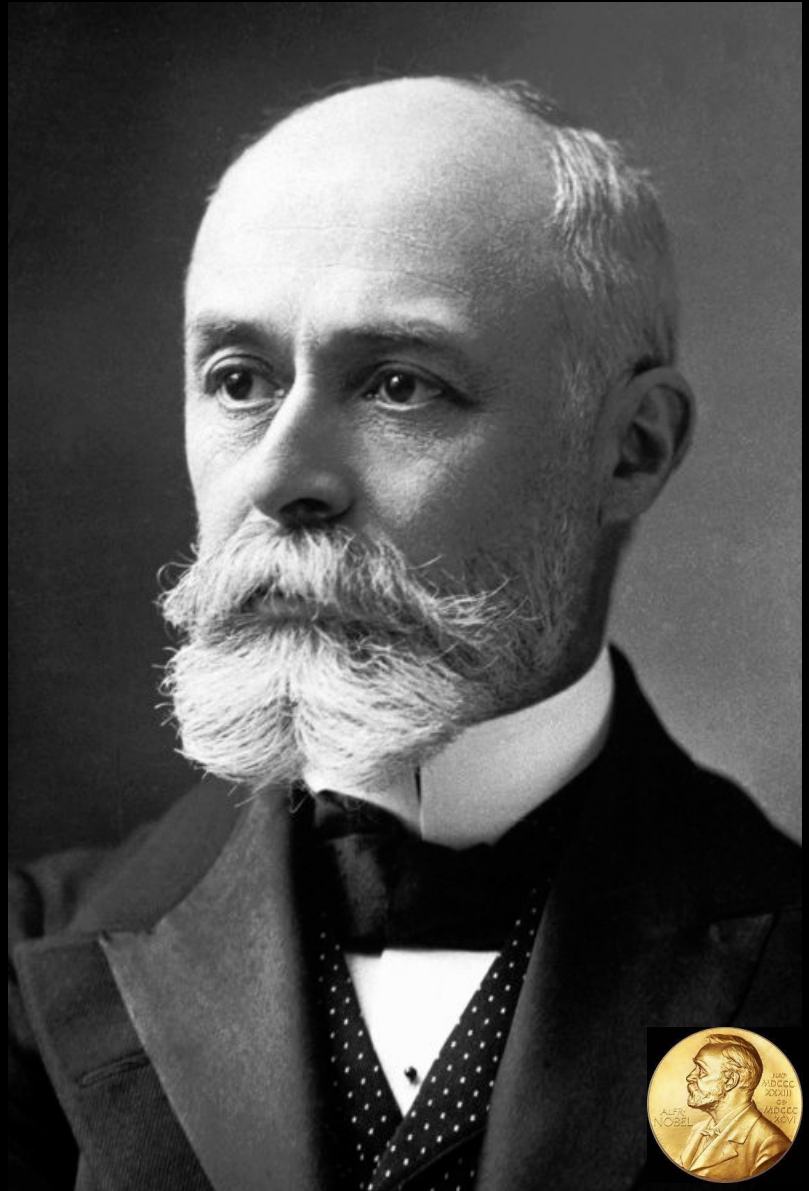




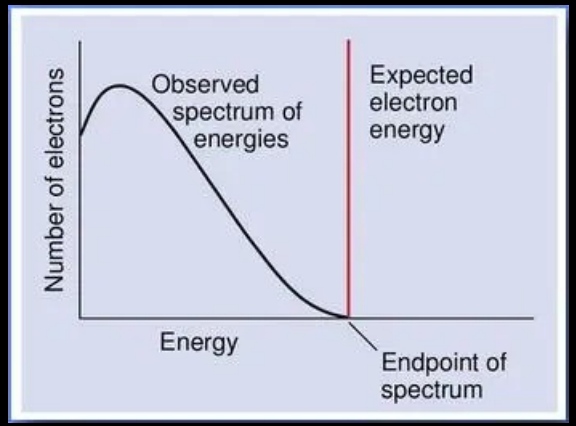
1896 : Henry Becquerel

Nobel in Physics avec Pierre Curie & Marie Skłodowska-Curie (1903)

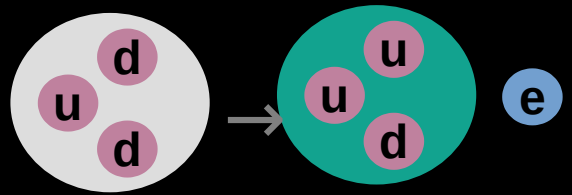
The Nobel Prize in Physics 1903 was divided, one half awarded to Antoine Henri Becquerel "in recognition of the extraordinary services he has rendered by his discovery of spontaneous radioactivity", the other half jointly to Pierre Curie and Marie Curie, née Sklodowska "in recognition of the extraordinary services they have rendered by their joint researches on the radiation phenomena discovered by Professor Henri Becquerel"



1911 : Lise Meintner & Otto Hahn



$$N \rightarrow N' + e$$



1911 : Otto Hahn, & Lise Meintner

Nobel in Chemistry pour O. Hahn (1944)

The Nobel Prize in Chemistry 1944 was awarded to Otto Hahn "for his discovery of the fission of heavy nuclei" $n+N \rightarrow N'+N''+3n$

1930 : Wolfgang Pauli

propose
une nouvelle
particule neutre ‘n’

Offener Brief an die Gruppe der Radioaktiven bei der Gauvereins-Tagung zu Tübingen.

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Des. 1930
Gloriastrasse

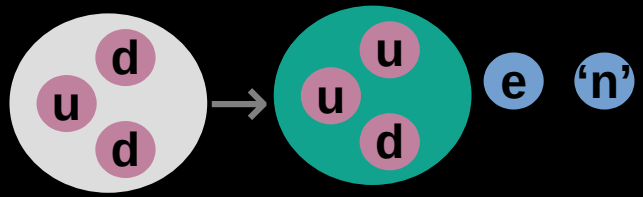
Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen

Dear Radioactive Ladies and Gentlemen, As the bearer of these lines, for whom I pray the favor of a hearing will explain in more detail, I have... hit upon a desperate remedy for rescuing the "alternation law".. This is the possibility that there might exist in the nuclei electrically neutral particles, which I call neutrons.

1930 : Wolfgang Pauli

propose
une nouvelle
particule neutre ‘n’

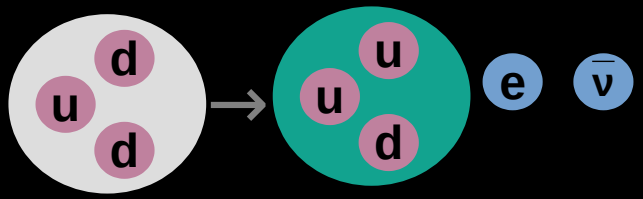


1945 : Nobel in physics

The Nobel Prize in Physics 1945 was awarded to Wolfgang Pauli "for the discovery of the Exclusion Principle, also called the Pauli Principle" (1925 : which proposed that no two electrons in an atom could have identical sets of quantum numbers)

1934 : Enrico Fermi

théorie de l'emission beta incluant le « neutrino » de Pauli



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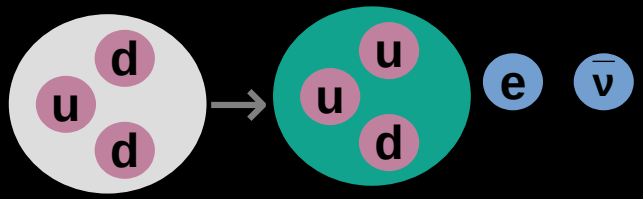


Nobel in physics (1938)

The Nobel Prize in Physics 1938 was awarded to Enrico Fermi "for his demonstrations of the existence of new radioactive elements produced by neutron irradiation, and for his related discovery of nuclear reactions brought about by slow neutrons"

QUARKS

mass: 2.2*
charge: 2/3
spin: 1/2

u

up

4.7
−1/3
1/2

d

down

LEPTONS

0.511
−1
1/2

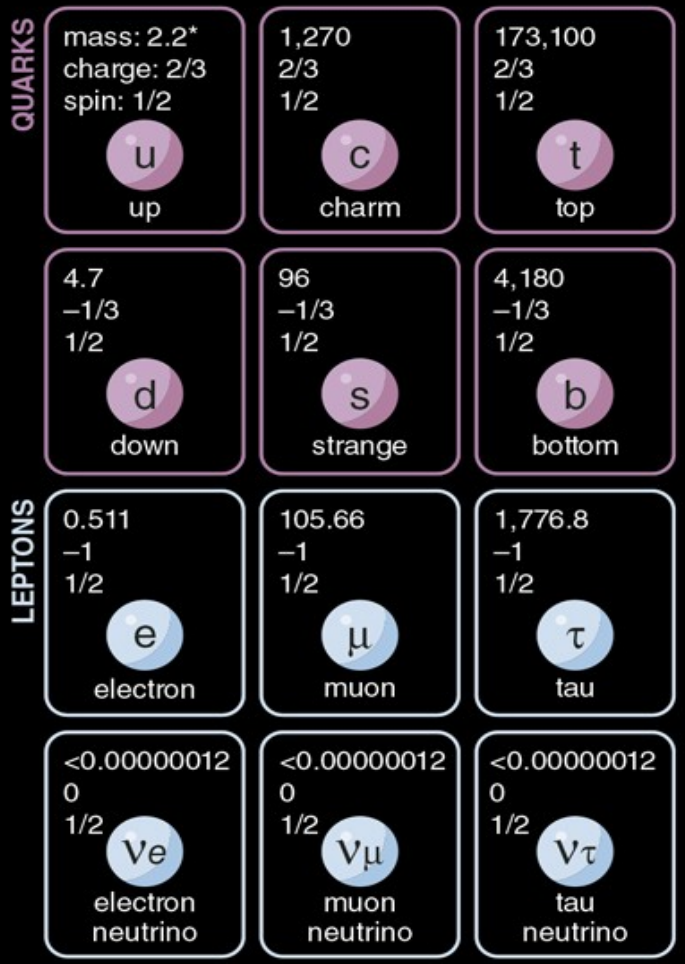
e

electron

<0.00000012
0
1/2

νe

electron
neutrino

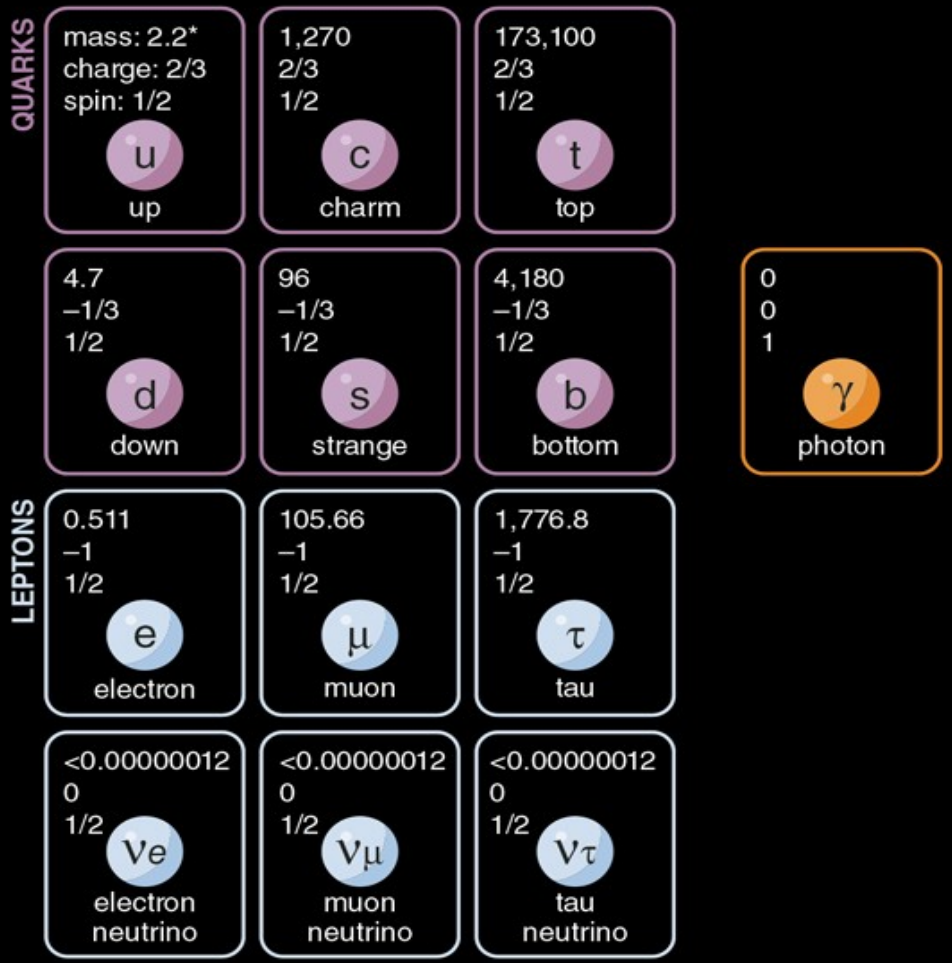


Subatomic Particles

Particules de Matière

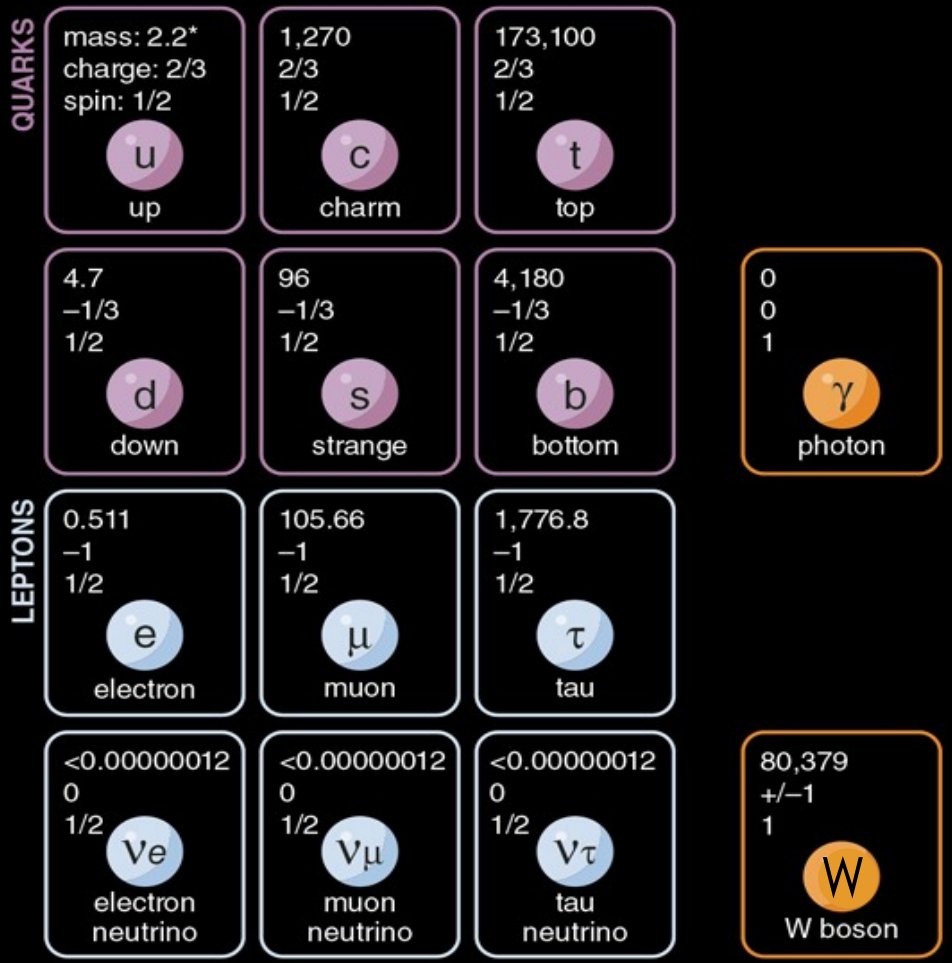
Subatomic Particles

Médiateurs d’interactions



Photons

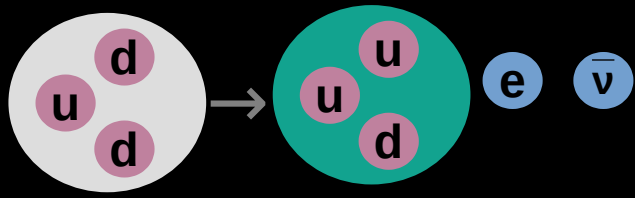
Médiateurs des interactions Électro-magnetiques

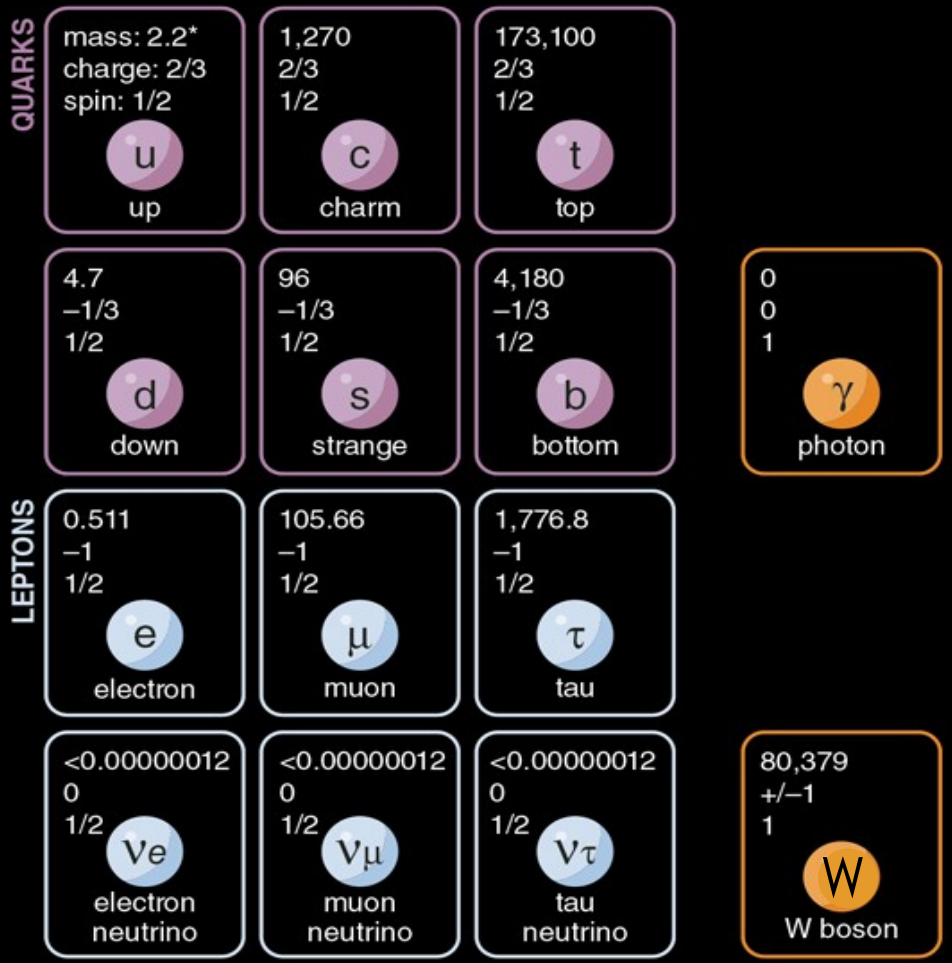


Boson W

Médiateurs des désintégrations

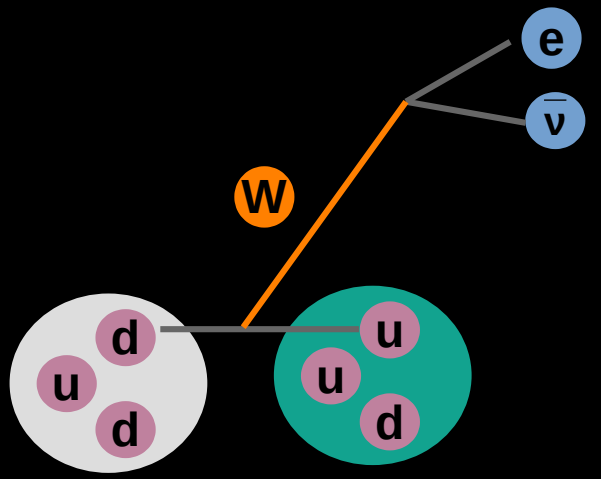
désintégrations β

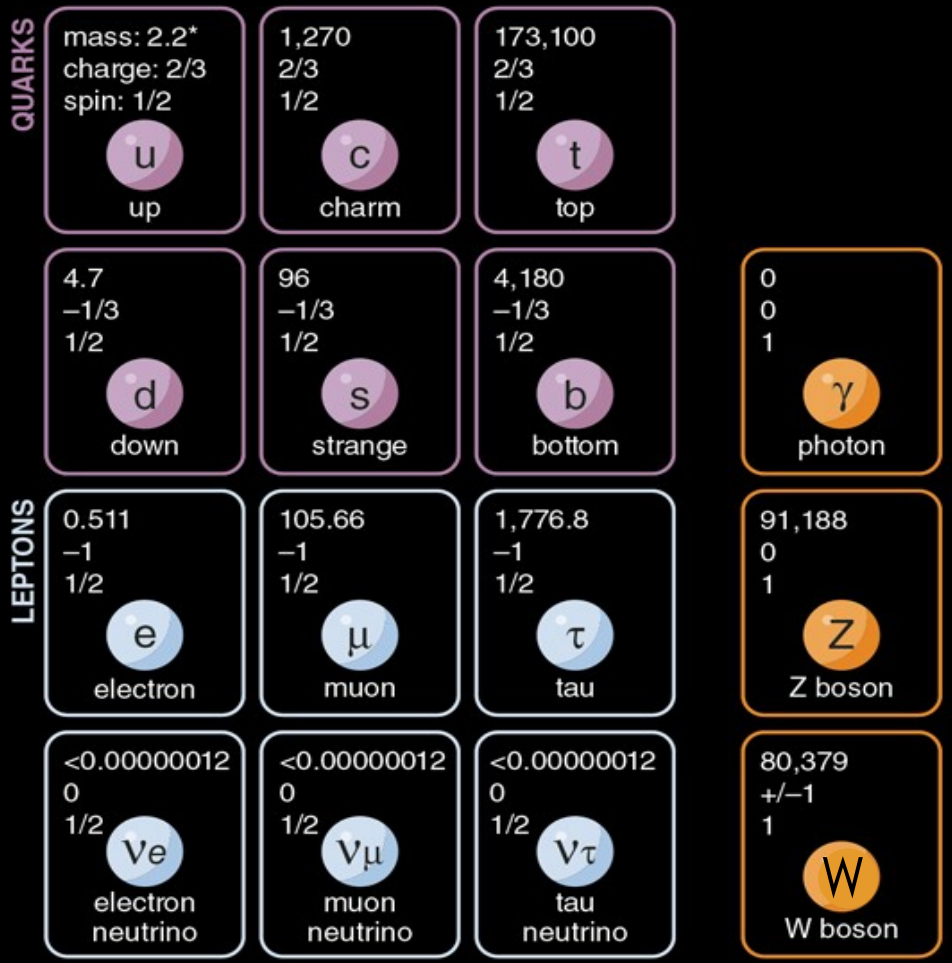




Boson W

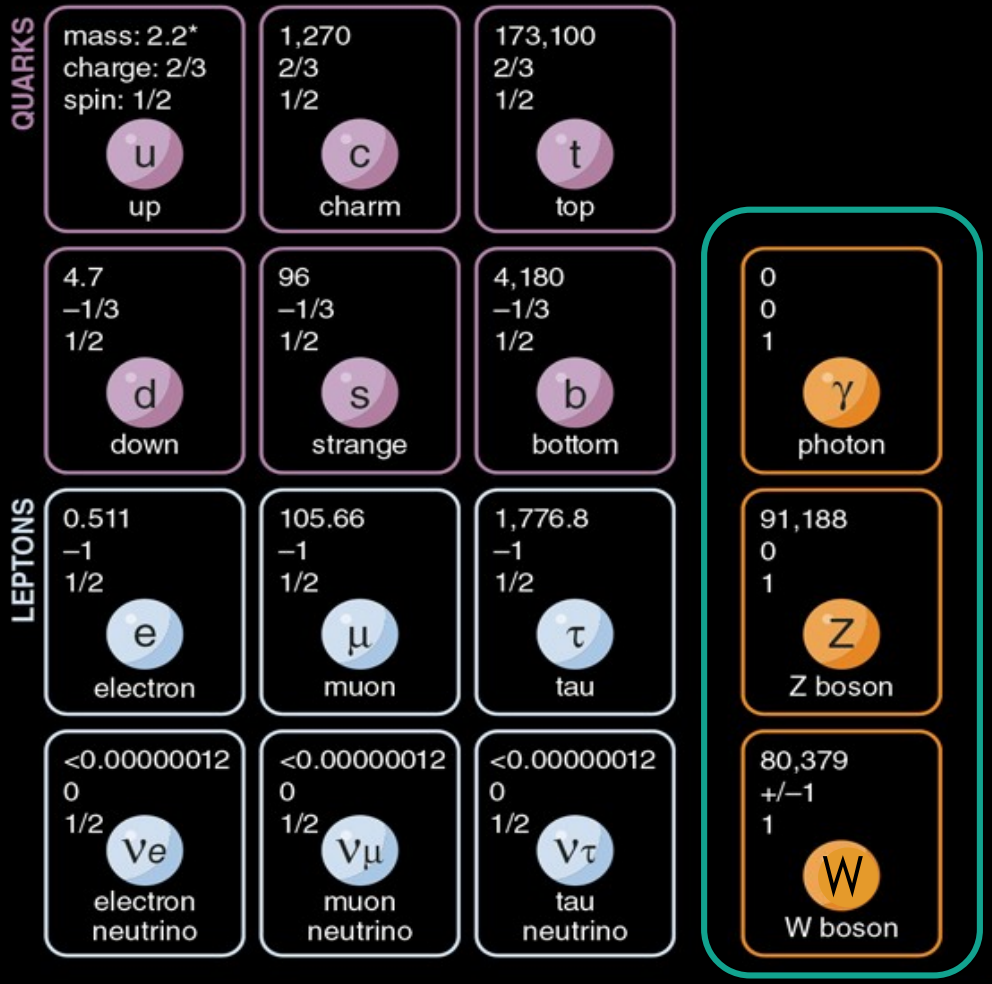
Médiateurs des désintégrations
désintégrations β
(interaction faible)





Boson Z

2eme médiateur d'interactions faibles

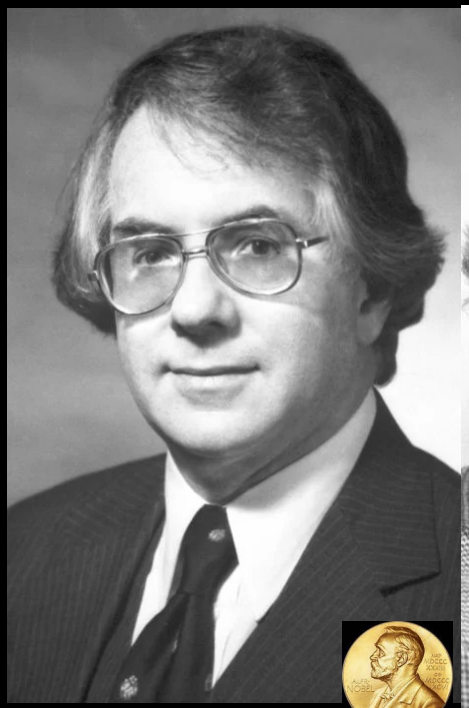


Boson Z

2eme médiateur d'interactions faibles

prédit dans la Théorie Electrofaible

=Unification Interactions Electromagnétiques & faible



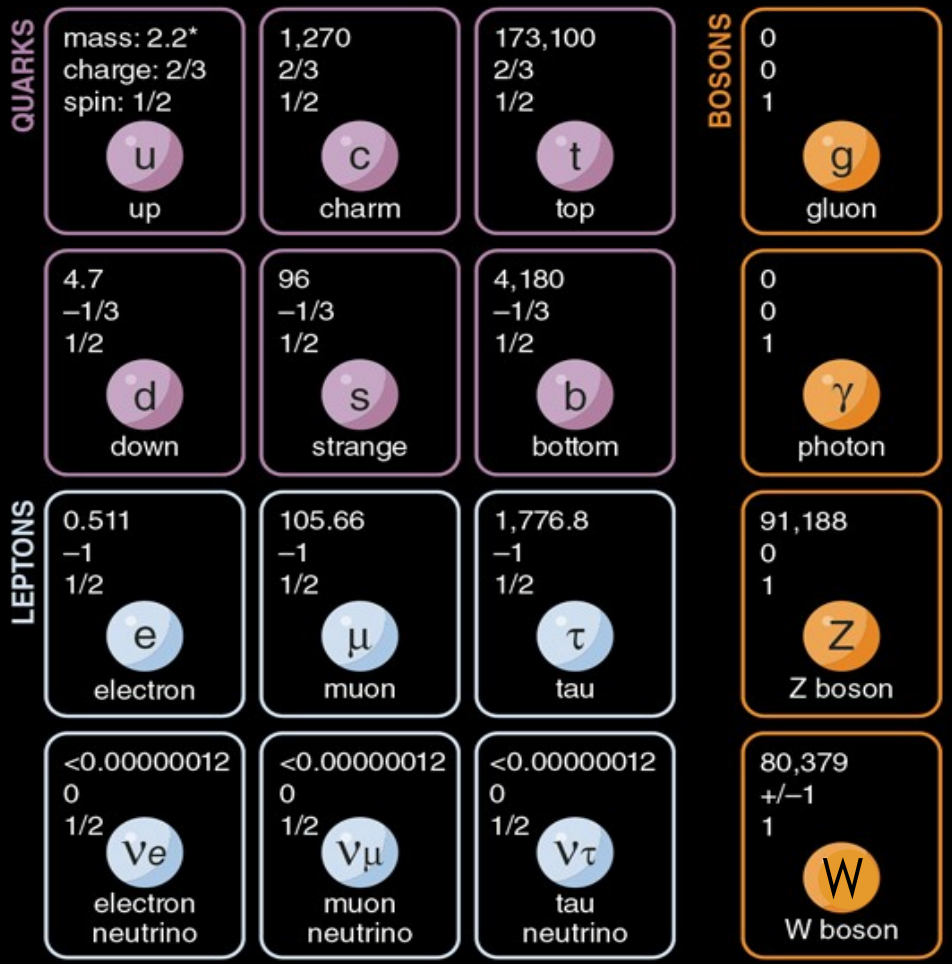
1967 :Théorie
Glashow-Weinberg-Salam

Théorie Electrofaible

= Unification
Interactions
Electromagnétiques
& faible

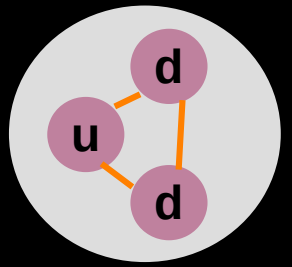
Nobel in physics (1979)

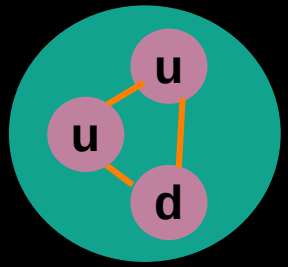
The Nobel Prize in Physics 1979 was awarded jointly to Sheldon Lee Glashow, Abdus Salam and Steven Weinberg "for their contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including, inter alia, the prediction of the weak neutral current"



Gluon

médiateur d'interactions fortes





the origin
of mass of
subatomic particles

- l'électromagnetisme
- les interactions faibles
- les interactions fortes

sont régis par des
principes de symétries

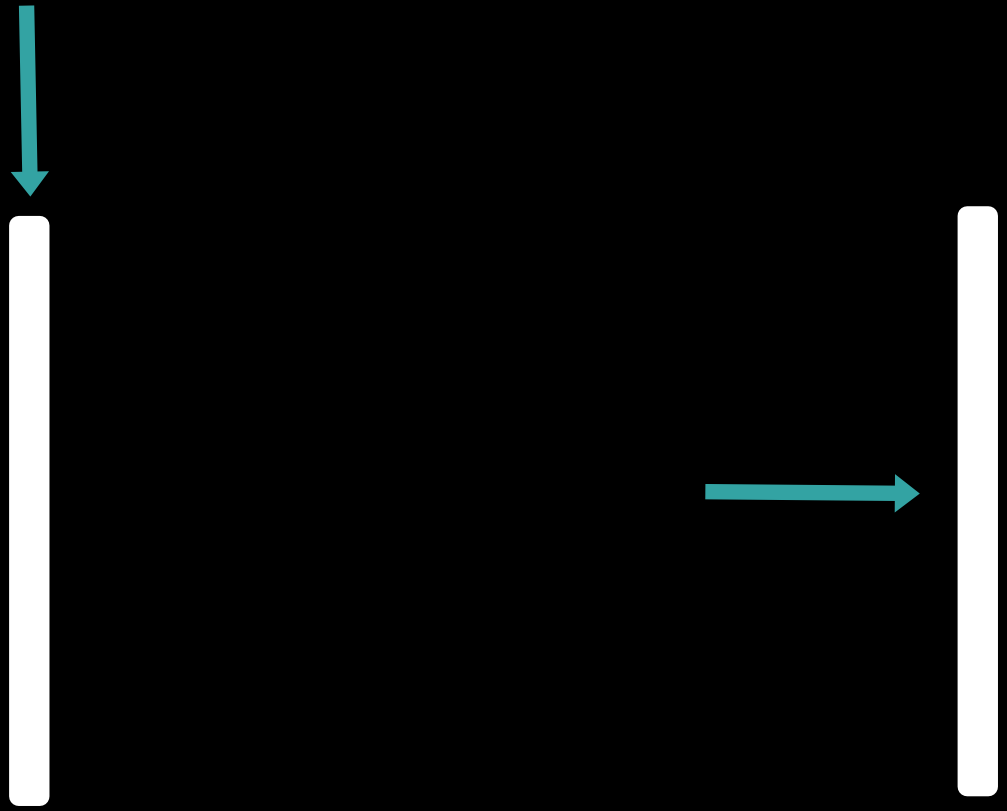
- l'électromagnetisme
- les interactions faibles
- les interactions fortes

sont régis par des
principes de symétries
→ conservation
de charges

=théorème de Emmy
Nœther (1915)

Ecrire une masse
aux médiateurs W,Z
brise la symétrie
électrofaibe
Explicitement

Brout, Englert, Higgs (Hagen,Guralnik, Kibble)
Proposenten 1964 un mécanisme de brisure
Spontanée
de symétrie pour donner une masse aux
médiateurs d'interactions de jauge



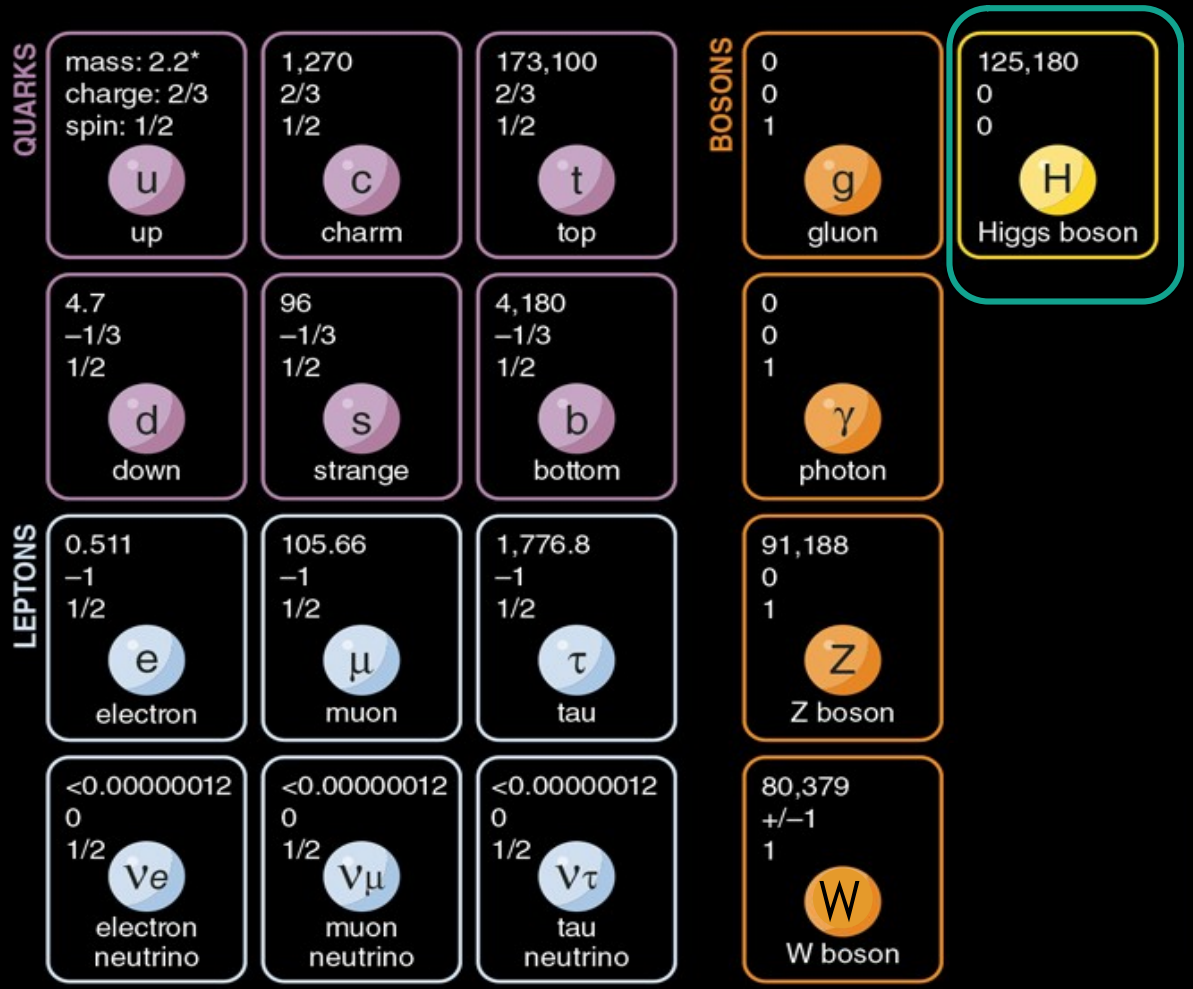
Brisure spontanée

Malgré une symétrie originale du système

Au delà d'un point critique

la symétrie est brisée dans une direction particulière

Plusieurs directions de brisures auraient été tout aussi probables

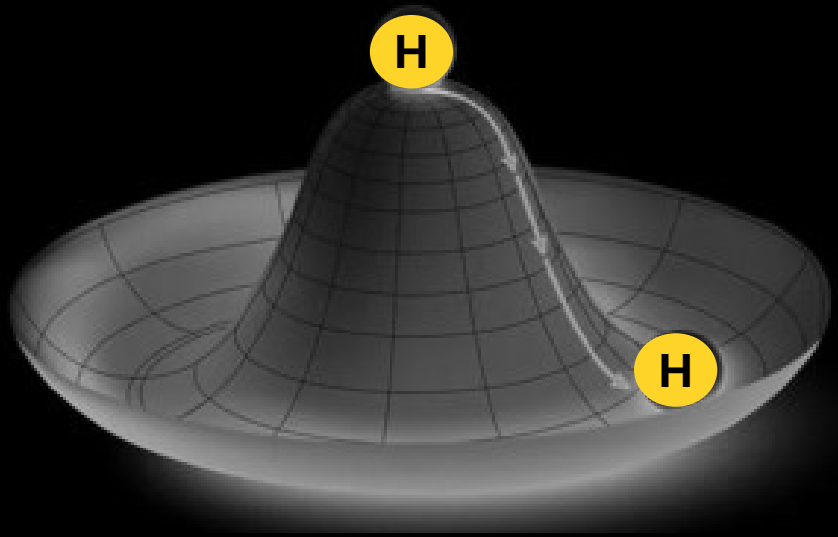


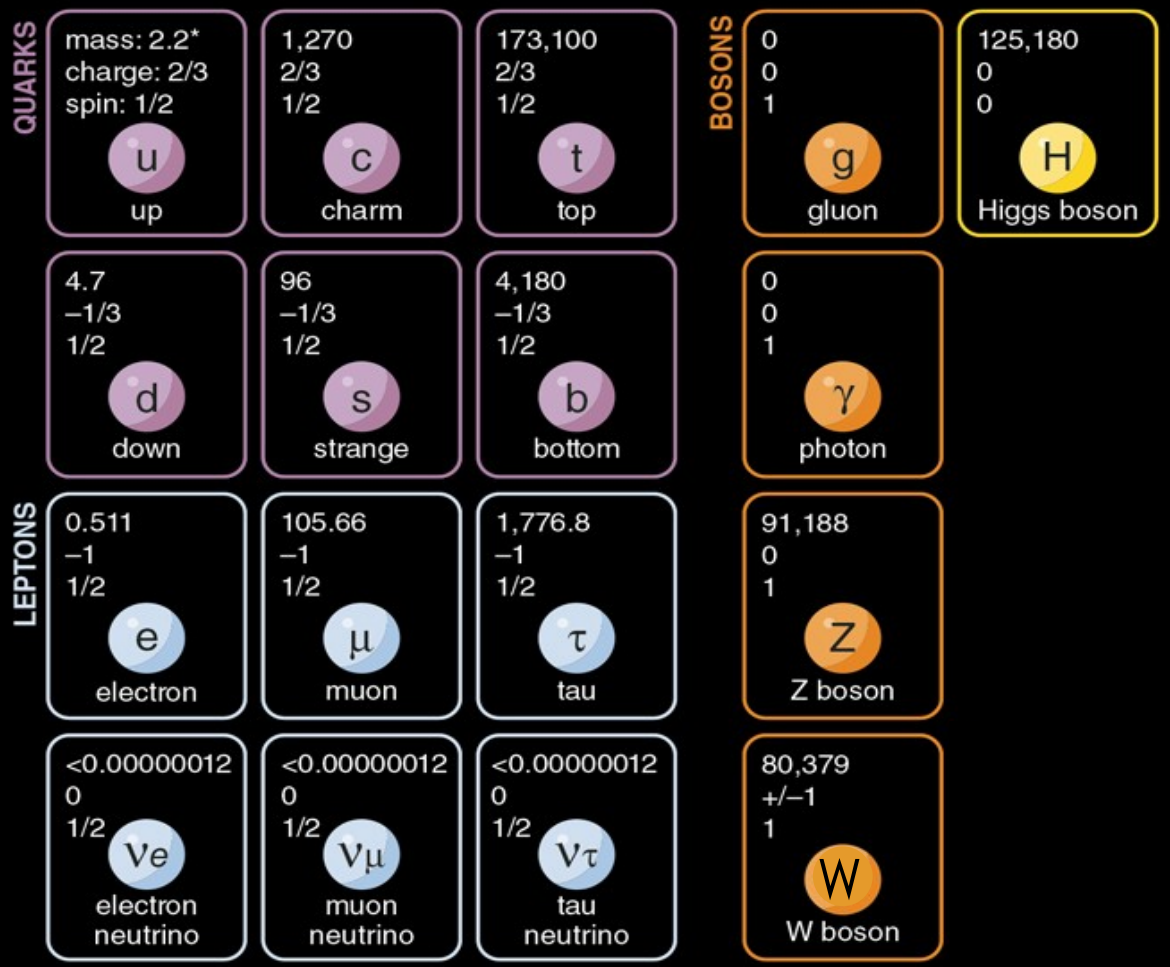
Dans le « Modèle Standard »

c'est le boson de Brout-Englert-Higgs

qui brise le symmétrie électrofaible spontanément dû à la forme de son potentiel

QUARKS	mass: 2.2* charge: 2/3 spin: 1/2 u up	1,270 2/3 1/2 c charm	173,100 2/3 1/2 t top	BOSONS	0 0 1 g gluon	125,180 0 0 H Higgs boson
	4.7 −1/3 1/2 d down	96 −1/3 1/2 s strange	4,180 −1/3 1/2 b bottom		0 0 1 γ photon	
LEPTONS	0.511 −1 1/2 e electron	105.66 −1 1/2 μ muon	1,776.8 −1 1/2 τ tau		91,188 0 1 Z Z boson	
	<0.00000012 0 1/2 νe electron neutrino	<0.00000012 0 1/2 νμ muon neutrino	<0.00000012 0 1/2 ντ tau neutrino		80,379 +/−1 1 W W boson	

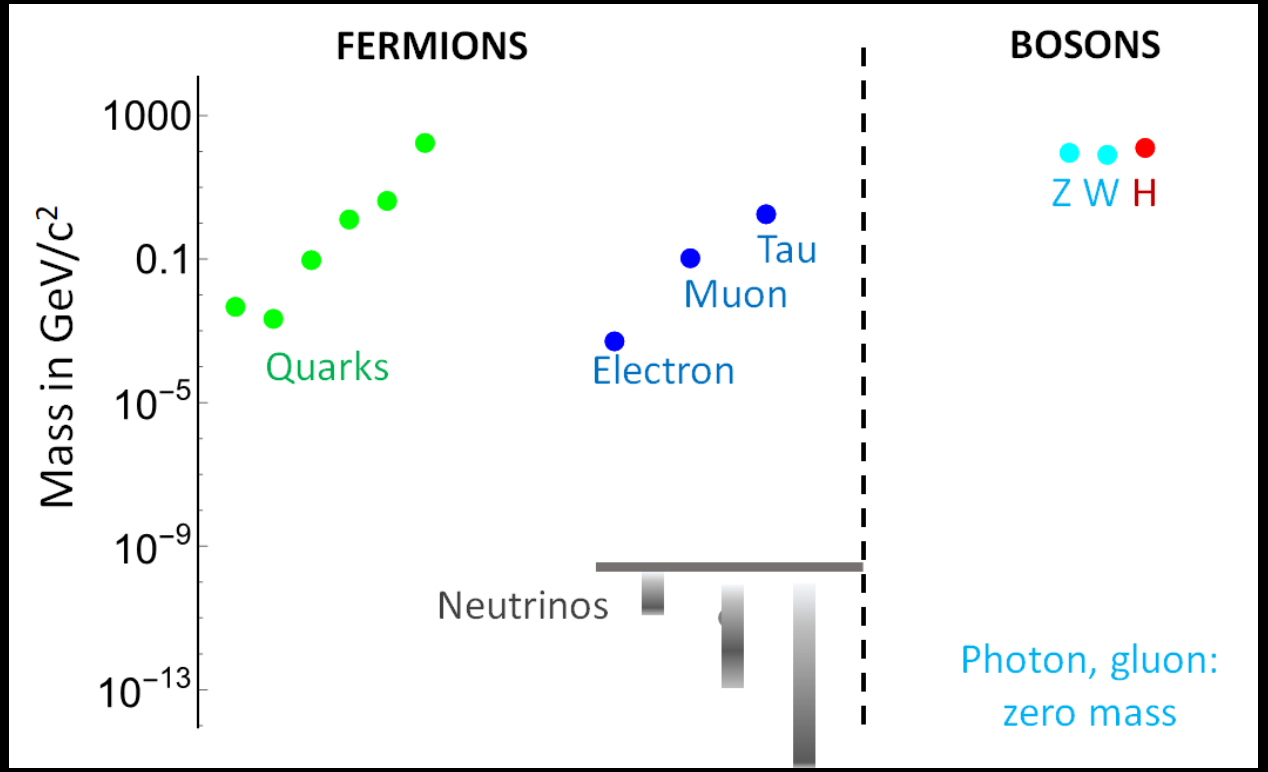




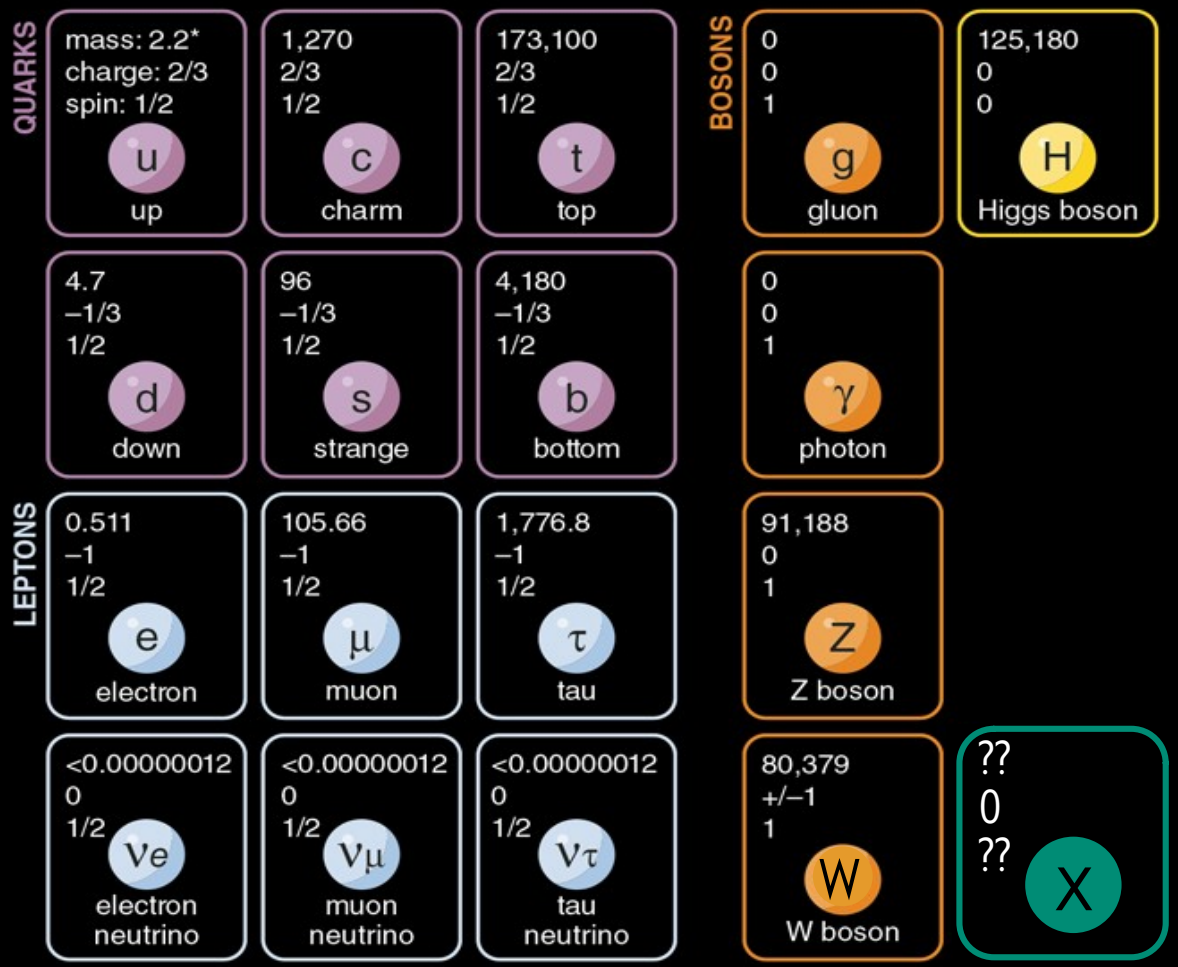
De part ses interactions plus ou moins fortes avec les particules du modèle standard

Le boson BEH donne une masse plus ou moins importante aux particules

Quelques questions ouvertes



- Nature du boson BEH ? (composite, fondamentale, etc)
- D'autres bosons scalaires ? (susy, axions, etc)
- D'autres médiateurs, interactions ?
- Pourquoi ces masses?
- Pourquoi des charges fractionnelles ?
- Grande unification ?
-



- Origine de la faible masse des neutrinos
- Origine de l 'asymétrie matière antimatière
- Origine de la matière noire ?
- ...

Merci

Pour votre attention!

Extra

QUARKS

mass: 2.2*
charge: 2/3
spin: 1/2
u
up

4.7
–1/3
1/2
d
down

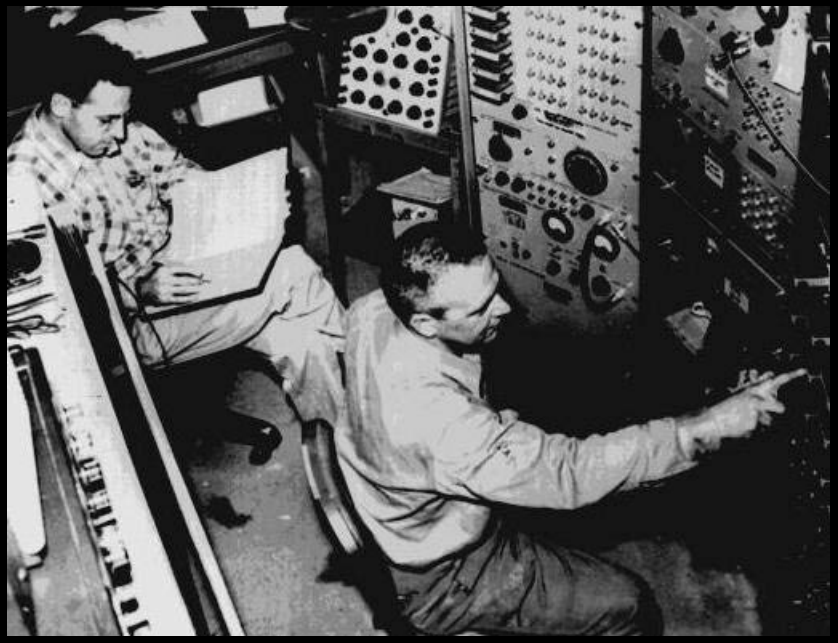
LEPTONS

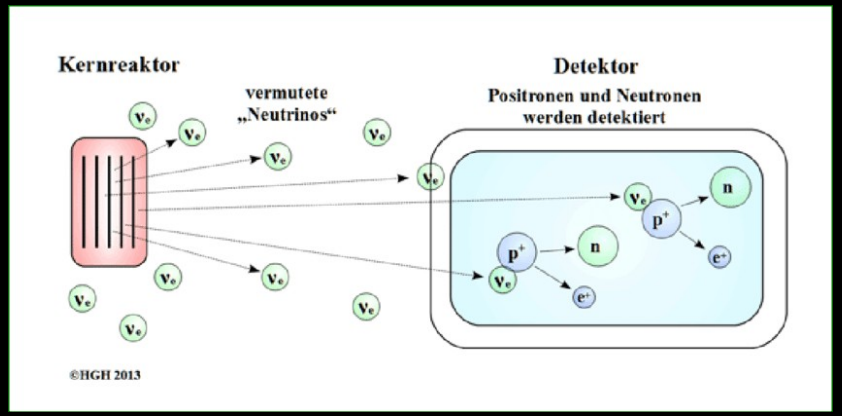
0.511
–1
1/2
e
electron

<0.00000012
0
1/2
νe
electron neutrino

1956 : F. Reines & C. Cowan

Observed electron neutrinos from a reactor at Hanford, Washington





QUARKS

mass: 2.2*
charge: 2/3
spin: 1/2
u
up

4.7
−1/3
1/2
d
down

LEPTONS

0.511
−1
1/2
e
electron

<0.00000012
0
1/2
νe
electron neutrino

1956 : F. Reines & C. Cowan

Observed electron neutrinos from a reactor at Hanford, Washington

Nobel in Physics for F. Reines (1995)

The Nobel Prize in Physics 1995 was awarded for one half to Frederick Reines "for the detection of the neutrino"