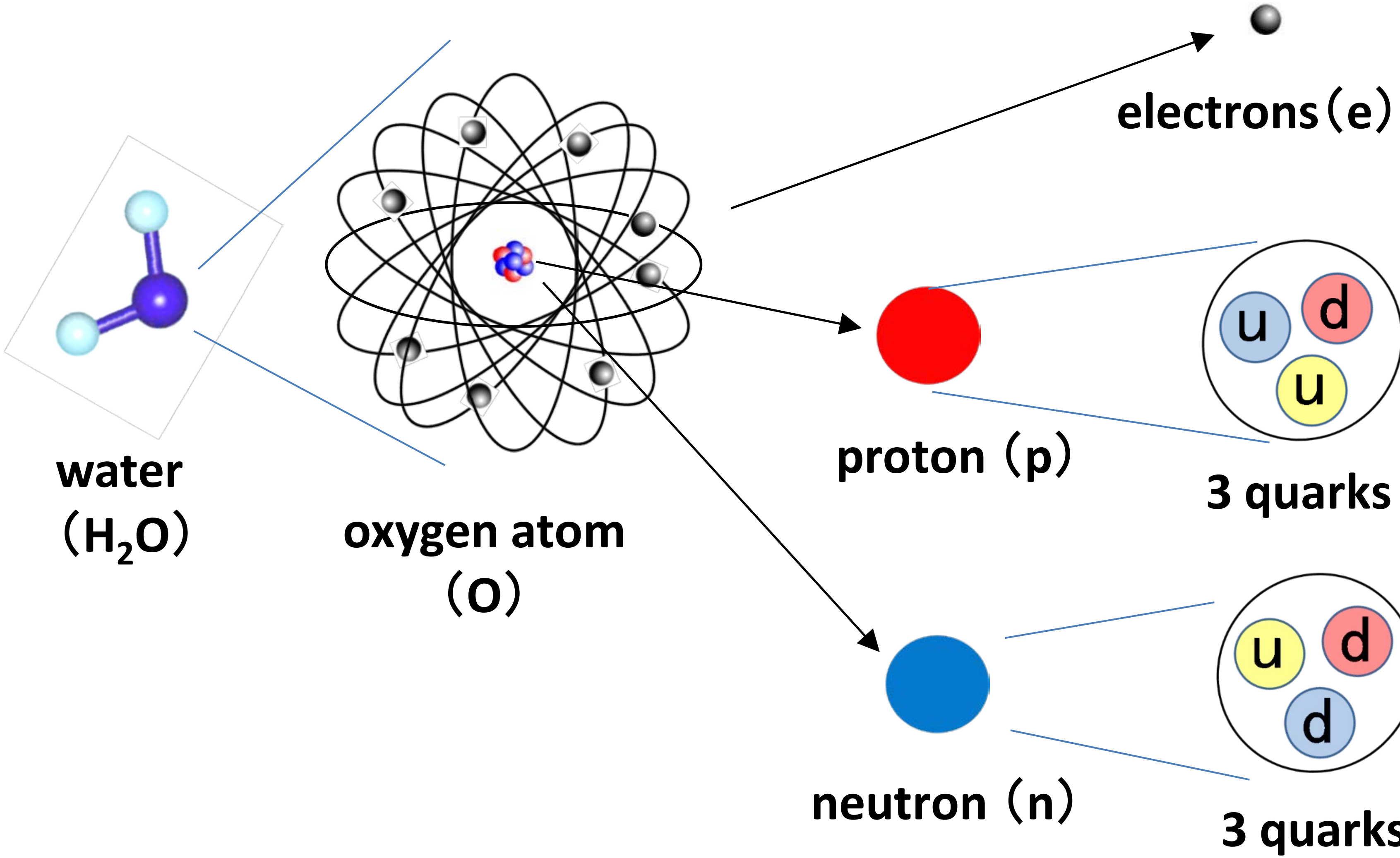
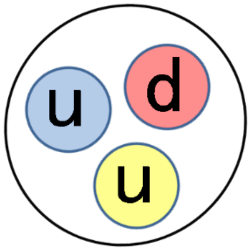
What the matters are made out of ?

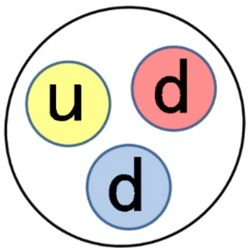


http://atlas.kek.jp/public/HiggsCERNOpenDays_A4.pdf (or _each.pdf or _each.pptx)

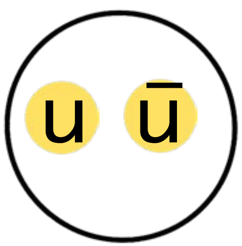
Quarks are very strange !!



proton



neutron



pion

- Single quark never come out.

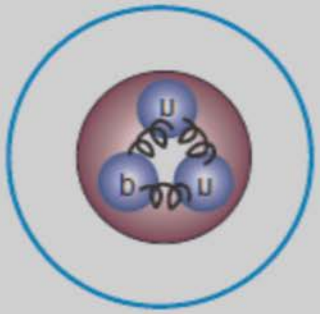
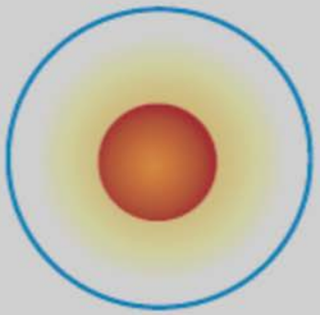
- They have fractional charges:

  u up quarks $+\frac{2}{3}e$

  d down quarks $-\frac{1}{3}e$

- Strong forces between quarks.

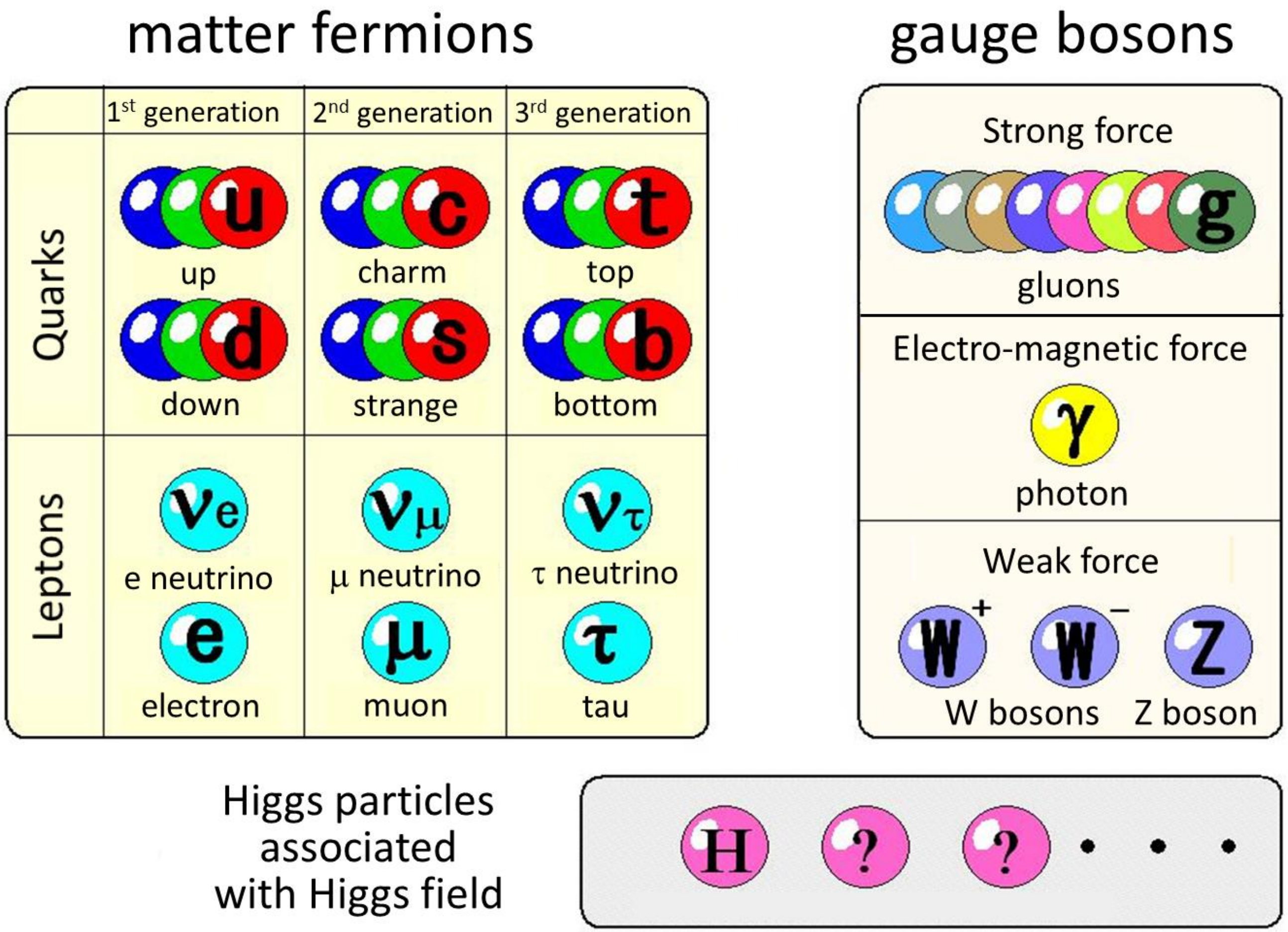
There are 4 forces in Nature

Strong	>	Electro-magnetic	>	Weak	>>>	Gravity
						
Bind quarks and making nucleus		Light, atom, crystal, radio, TV, phone, car, rain, thunder,.....		Sun/star energy, radio activities.. ……		Falling apples, planet motions, satellite…….

These forces are carried by

Gluons	Photons	W, Z bosons	Gravitons

Elements of the Standard Model



Mass

$m_g = 0$

$m_\gamma = 0$

$m_W = 80\,\mathrm{GeV}$

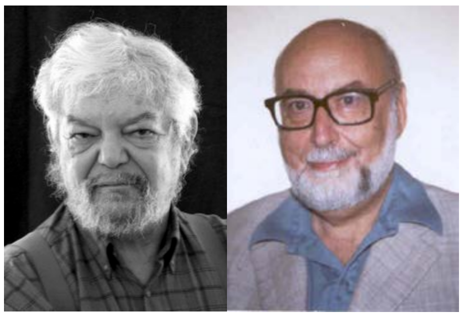
$m_Z = 91\,\mathrm{GeV}$

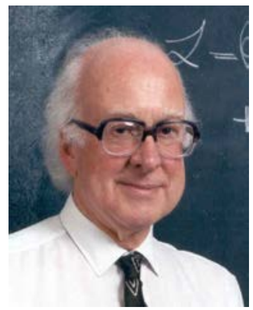
2008

Y. Nambu

Introduced Spontaneous Symmetry Breakdown (1959)

2013

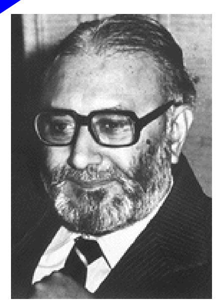




R. Brout & F. Englert , P. Higgs

Found BEH mechanism (1964)

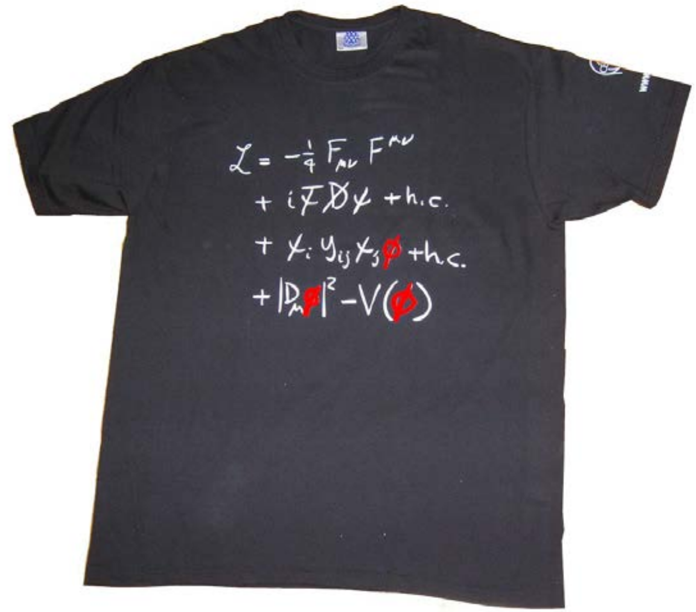
1979



S. Weinberg A. Salam

Proposed Electro-weak theory (1967)

CERN T-shirt



Standard Model

Higgs field ϕ must exist to generate particle masses.

QCD of strong interactions (1973)

Glashow-Weinberg-Salam Model

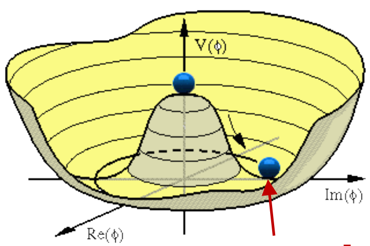
Φ=Higgs field free motion

Potential Energy by Higgs field

$$\mathcal{L} = \bar{L} i\gamma^{\mu} D_{\mu} L + \bar{R} i\gamma^{\mu} D_{\mu} R - \frac{1}{4}\vec{W}^{\mu\nu}\cdot\vec{W}_{\mu\nu} - \frac{1}{4} B^{\mu\nu}B_{\mu\nu} + \left|D_{\mu}\Phi\right|^2 - \left\{\mu^2\Phi^{\dagger}\Phi + \lambda\left(\Phi^{\dagger}\Phi\right)^2\right\} - G_e\left[\bar{R}\Phi^{\dagger}L + \bar{L}\Phi R\right]$$

where $D_{\mu} \equiv \partial_{\mu} + ig\vec{W}_{\mu}\cdot\frac{\vec{\tau}}{2} + ig'\frac{1}{2}B_{\mu}Y$, $B_{\mu\nu} \equiv \partial_{\nu}B_{\mu} - \partial_{\mu}B_{\nu}$, $L \equiv \begin{pmatrix}\nu_e \\ e^-\end{pmatrix}_L$, $R \equiv e_R^-$

Higgs-electron coupling



We are here

Symmetry Breakdown

$$SU(2)_L \times U(1)_Y \rightarrow U(1)_Q\,, \quad \Phi(x) = \frac{1}{\sqrt{2}}\begin{pmatrix}0 \\ \upsilon + h(x)\end{pmatrix}$$

$$\mathcal{L}_{\Phi} = \frac{1}{2}(\partial h)^2 + \frac{1}{4}g_2^2 W^+W^-(\upsilon+h)^2 + \frac{1}{8}\frac{g_2^2}{\cos^2\theta_W}ZZ(\upsilon+h)^2 - \frac{1}{2}\left(-2\mu^2\right)h^2 + \frac{1}{4}\mu^2\upsilon^2\left[-1 + \frac{4h^3}{\upsilon^3} + \frac{h^4}{\upsilon^4}\right] - \frac{G_e\upsilon}{\sqrt{2}}\bar{e}e - \frac{G_e}{\sqrt{2}}h\bar{e}e$$

Therefore

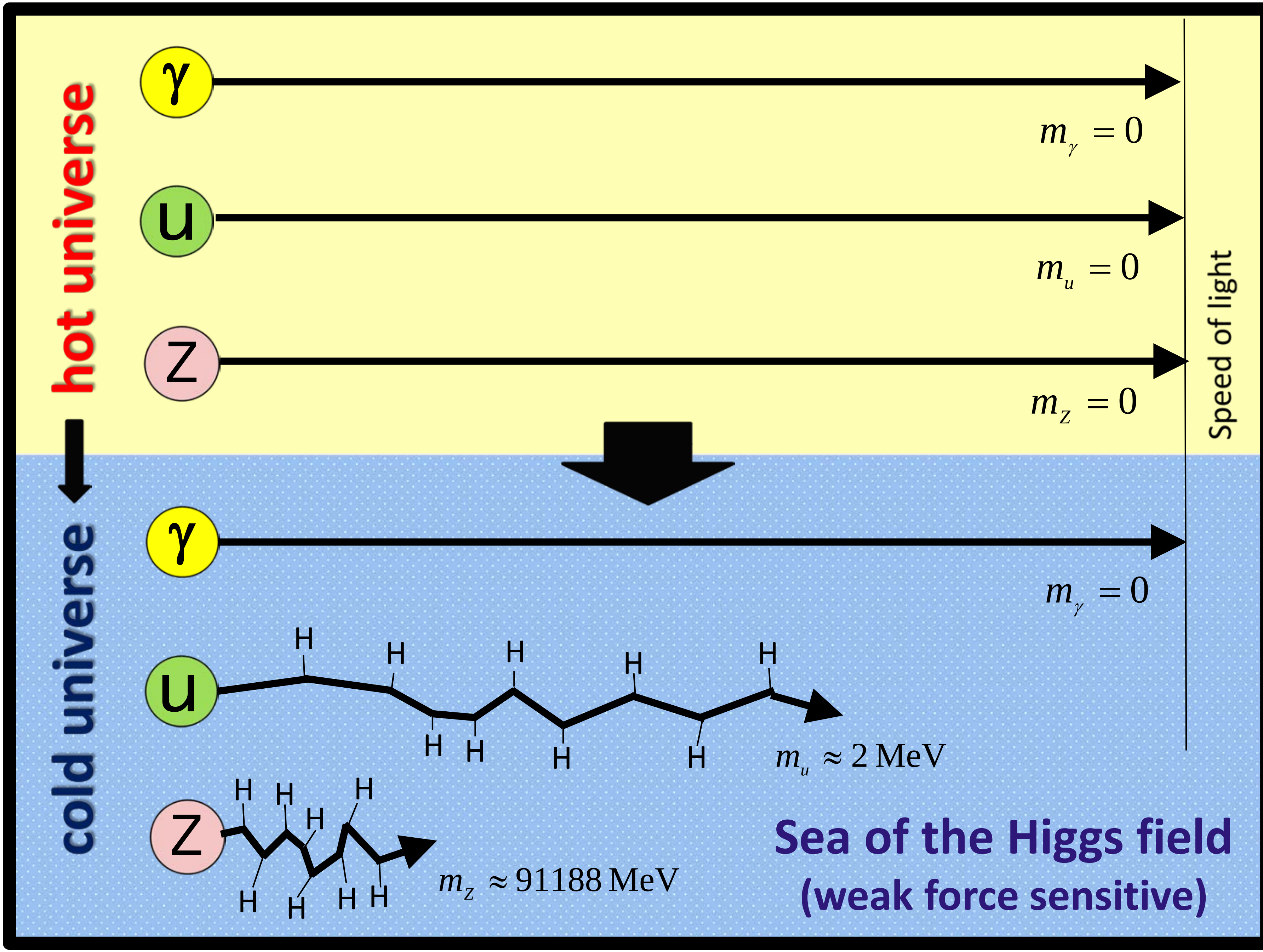
$$M_W = \frac{1}{2}g_2\upsilon, \quad M_Z = \frac{1}{2}\frac{g_2}{\cos\theta_W}\upsilon = \frac{M_W}{\cos\theta_W}, \quad M_H == \sqrt{-2\mu^2}\,, \quad M_e = \frac{G_e\upsilon}{\sqrt{2}}, \quad \upsilon = \frac{1}{\sqrt{\sqrt{2}G_F}} = 246\ \text{GeV}$$

h= wave function of Higgs particle

Mass of Higgs

Mass of electron

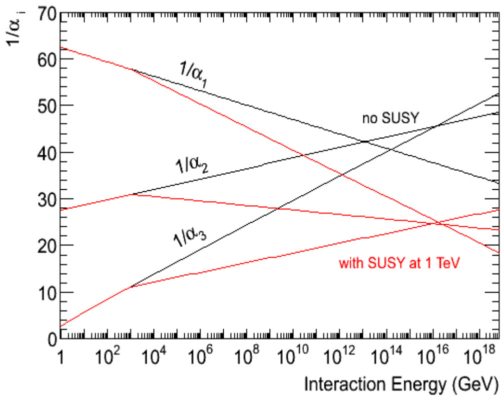
Vacuum expectation value



hot universe
γ
$m_\gamma = 0$
u
$m_u = 0$
Z
$m_Z = 0$
Speed of light
cold universe
γ
$m_\gamma = 0$
u
H H H H H
H H H H
$m_u \approx 2\,\mathrm{MeV}$
Z
H H H H
H H H H
$m_Z \approx 91188\,\mathrm{MeV}$
Sea of the Higgs field
(weak force sensitive)

SUSY particles may exist ?

SUSY = symmetry between Bosons and Fermions.
Spins of SUSY particles differ $\pm 1/2$ from those of SM.



If SUSY particles exist at ~1 TeV, then

a. 3 forces can unify at high energy.

b. It avoids quantum divergence of Higgs particle mass.

c. Some SUSY particles can be dark matters.