Brout-Englert-Higgs Mechanism and Beyond

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- Physicists knew the Quantum Electrodynamics (QED) and tried to build a theory to explain the β-decay based on similar ideas
- This theory agreed with experiments AT LOW ENERGY, but had BAD HIGH ENERGY BEHAVIOR

A quick revision (continued..)

- To solve this a theory of ‘weak interactions’ was put forward adding $W^{\pm}$ bosons as the force carriers of the weak force

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- To cancel certain 'badly behaving interactions' a third neutral W^0 boson was added
- Three matrices ($T^{1,2,3}$) were required for this cancellation with a condition
  $[T^a, T^b] = T^a T^b \; - \; T^b T^a = i \; \sum_c \epsilon^{abc} T^c$
  $\Rightarrow SU(2)$ group symmetry !

A quick revision (continued..)

- Construct Lagrangian of (Weak + QED) $\rightarrow$ ELECTROWEAK THEORY ($SU(2) \times U(1)$ symmetry)

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  W^{μ} and A^{μ} combine to give $W\pm$, Z^0 and photon γ
- Meaning of having a symmetry: If the 'Fields' associated with all particles undergo transformation under the symmetry group (something like multiplication by $Exp(i \sum_a T^a \alpha^a)$),
  the Lagrangian of the theory remains invariant

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- If we want a freedom of performing such transformations at a point in space-time without affecting fields at other space-time points (LOCAL SYMMETRY: $\alpha \rightarrow \alpha(x)$),

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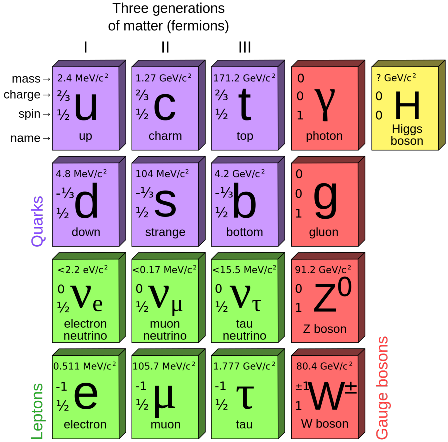
- Same for mass terms like $m_f \bar{\Psi}_f \Psi_f$ of fermions (electron, neutrinos, muon etc.)
- Because these particles MUST be massive some other mechanism is needed to give these particles their masses

BROUT-ENGLERT-HIGGS MECHANISM

In 1964 by 3 groups: Robert Brout and François Englert; by Peter Higgs; and by Gerald Guralnik, C. R. Hagen, and Tom Kibble

Incorporated in the Standard Model by Steven Weinberg (1967) and Abdus Salam (1968)

Introduction to the Standard Model



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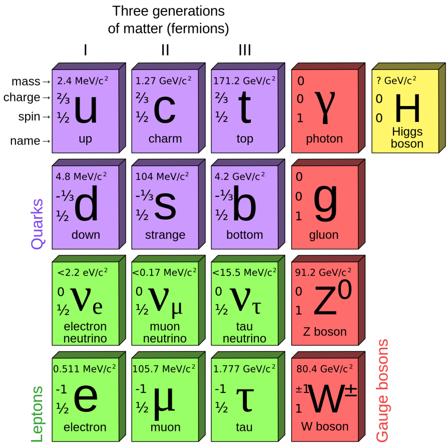

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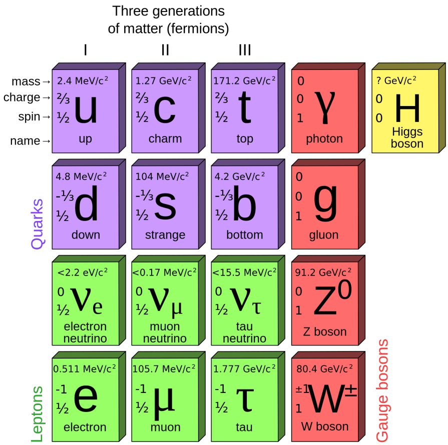

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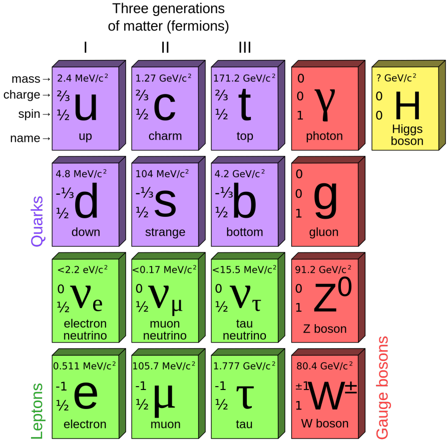

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- $SU(3) \times SU(2) \times U(1)$ LOCAL GAUGE SYMMETRY
- It is important to understand how all these elementary particles get their masses or massless-ness

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- This means that in the stable state of the universe that we are in, $SU(2) \times U(1)$ is broken
- Thus, $SU(2) \times U(1)$ symmetry must have existed right after the Big Bang and soon after that
  THE SYMMETRY WAS BROKEN *SPONTANEOUSLY*

SOME CONCEPTS

Perturbation Theory

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  the fields need to have small values i.e.
  average value zero + quantum fluctuations

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- Hereafter, we'll use the covariant derivative in the kinetic terms

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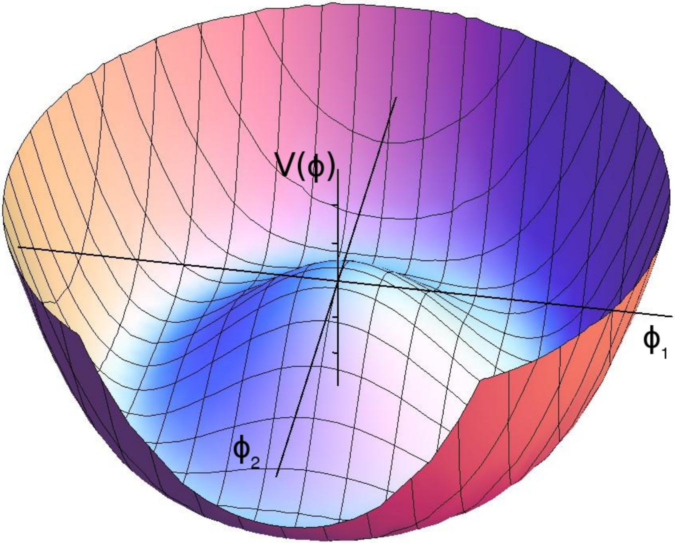
- No higher orders of ϕ to ensure that all infinite interactions/diagrams can be cancelled (*Renormalizability!*)

Only case of interest: $\mu^2 > 0$ ($\mu^2 < 0$ does not have the 'valley')



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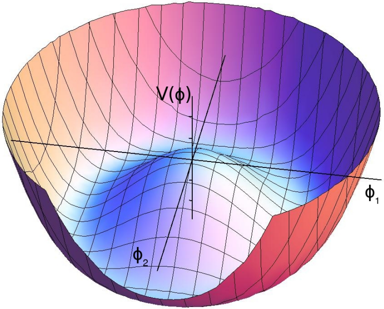

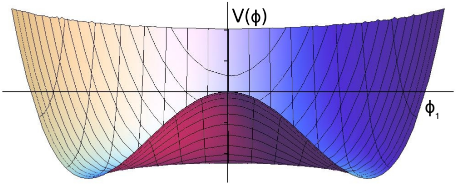

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- This is the state that all the 'Expectation (like average) values' (e.g. $< \phi >$) are seen to be in

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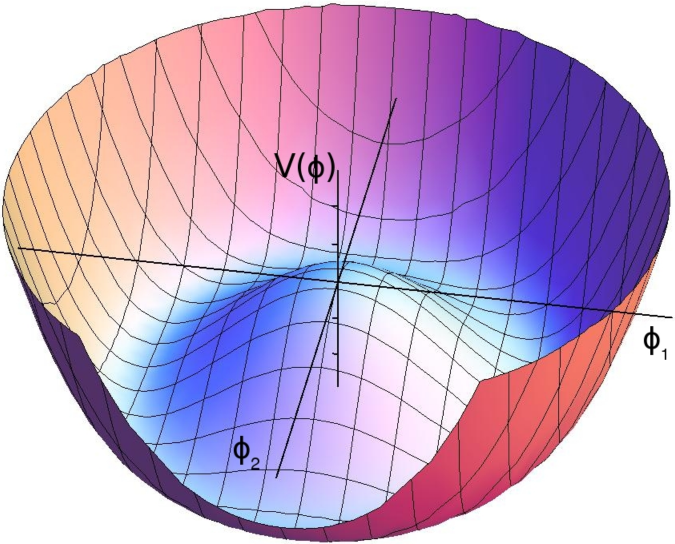

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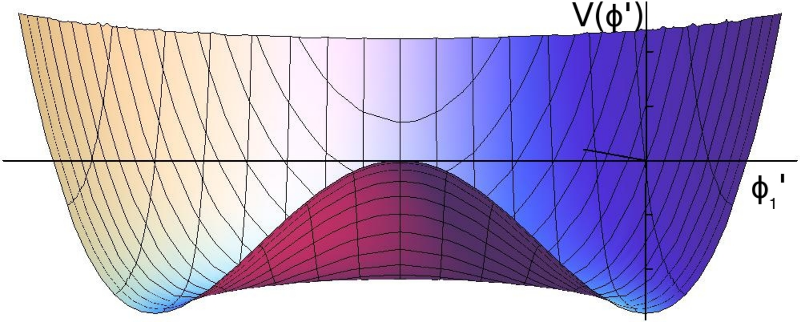
- One problem in working with these fields: We want to use perturbation theory

  And perturbation theory requires smallness of the terms in the expansion (much like Taylor expansion)
- So the fields must have average value zero in the ground state

- Define: $\phi_1' = \phi_1 - v$. Thus, $< \phi_1' >= 0$



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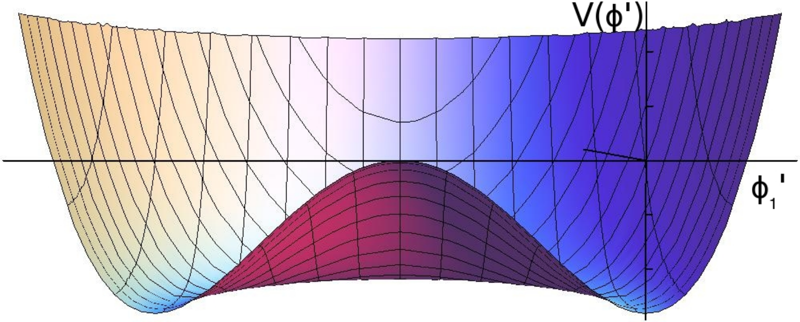

- The symmetry OF THE GROUND STATE is broken SPONTANEOUSLY

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- Try polar coordinates:
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- $\phi(x) \approx \frac{1}{\sqrt{2}}\ (\ v\ +\ \eta(x)\ +\ i\ \theta(x))$ and

$$= \frac{1}{\sqrt{2}}(\ v\ +\ \phi_1'(x)\ +\ i\ \phi_2(x))$$

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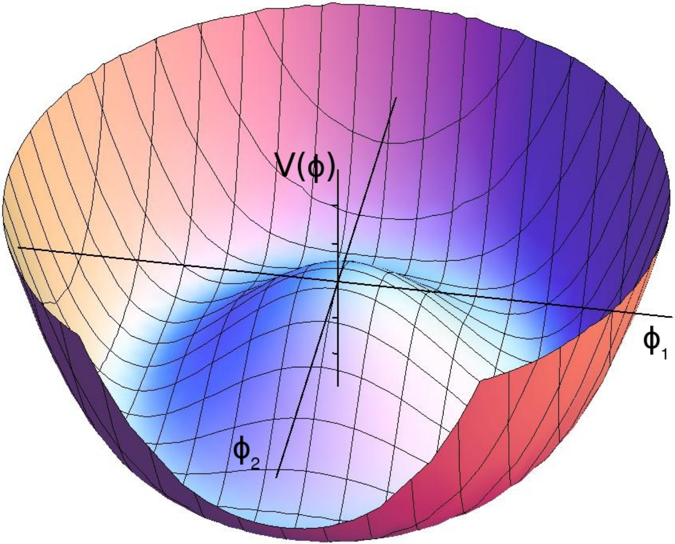
- AND a scalar particle associated with ϕ'_1 has appeared having mass $(\sqrt{2} \ \mu)$
  $\rightarrow$ BROUT-ENGLERT-HIGGS BOSON :-)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ϕ1
ϕ2

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- Higgs field interacts with the fermions through Yukawa interaction

  $$\sim \; g_f \; \phi \; \bar{\psi}_f \; \psi_f \; = \; \frac{g_f \; v}{\sqrt{2}} \bar{\psi}_f \; \psi_f \; + \text{(interaction with } \phi')$$

  $\rightarrow$ masses of fermions (Neutrinos are still massless)

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- IT IS NOT RESPONSIBLE FOR MASS OF ALL THE MATTER IN THE UNIVERSE

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- Higgs boson (particle) DOES NOT give mass to the particles but the interaction with the HIGGS FIELD is responsible for that
- Mass of the Higgs boson cannot be predicted theoretically even if g and v are known (this is where LHC discovery comes in)
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  and/or there can be (pleeeeaaase be there) something else BEYOND

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- Many Grand Unified Theories (GUT) postulate right-handed neutrinos at mass $\sim\ 10^{16-17}\ \mathrm{GeV}$!!
  Cannot be detected at LHC or near future colliders

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YES, the Electroweak-scale Right-handed Neutrino (EWν_R) Model

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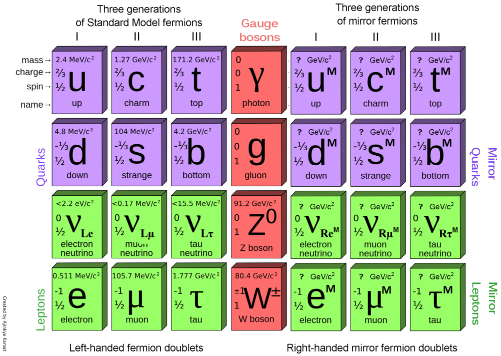

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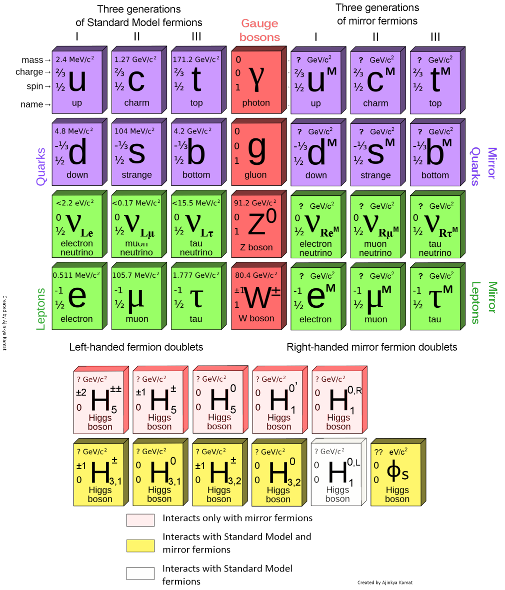

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- Our calculations also show that the a Higgs boson in this model can show properties of the Standard Model Higgs boson as seen at LHC experiments (paper under preparation)
- Many exciting possibilities in this model as well as others.
  Stay tuned!

Thank You :-)