Why Higgs?

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- Experiments: $W^{\pm}$ and Z look like gauge bosons: only couple via covariant derivative
- They are massive
  - Break perturbative expansion
  - Break unitarity
  - Break renormalizability
- What about gauge?
  - Gauge invariance still present but hidden
  - Naive theory with massive gauge bosons = pre-chosen gauge

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- →Dirac mass breaks symmetry!

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- Field to "ignore": Higgs
- Problems:
  - Higgs is tricky to "ignore"
  - Higgs mass $\sim$ Weak interaction Energy
- $\rightarrow$Bad approximation!

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- We can only calculate with representations!

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- →Get “effective” terms like mass terms

Higgs: Extra field

Weak (complex) doublet with 4 (real) degrees of freedom:

$$\Phi = \begin{pmatrix} \phi_1 + i\phi_2 \\ \phi_3 + i\phi_4 \end{pmatrix}$$

With potential:

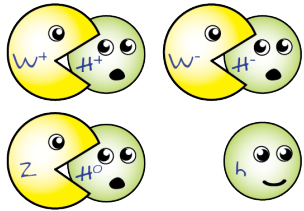
$$V(\Phi) = -\mu^2 \Phi^\dagger \Phi + \frac{\lambda}{2}(\Phi^\dagger \Phi)^2$$

With Minimum (vacuum):

$$vev = |\langle \Phi \rangle| = \sqrt{\frac{\mu^2}{\lambda}}$$

Where do the degrees of freedom go?

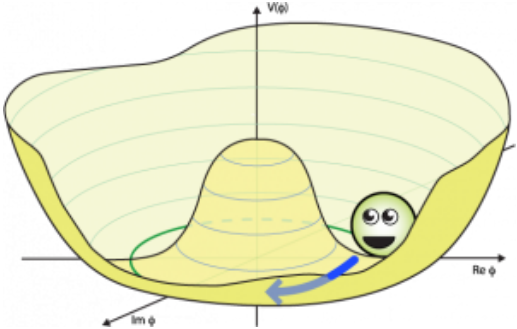
- Higgs doublet has 4 real degrees of freedom
- One is the Higgs particle
- What about the other 3?
- They are absorbed by the gauge bosons to give them mass and third polarization



Higgs: Potential

$$\Phi(x) = \begin{pmatrix} G^+(x) \\ v + H(x) + iG^0(x) \end{pmatrix}$$

$$\mathcal{L} \supset |D_\mu \Phi|^2 + y\bar{\Psi}_L \Phi \psi_R = |\partial_\mu \Phi - igA_\mu \Phi|^2 + y\bar{\Psi}_L \Phi \psi_R$$

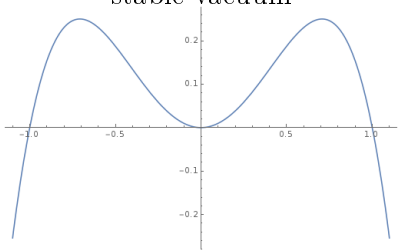


Source: http://www.quantumdiaries.org/2011/11/21/why-do-we-expect-a-higgs-boson-part-i-electroweak-symmetry-breaking/

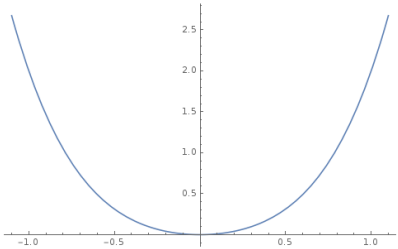
Constraints of Potential

$$V(\Phi) = \Phi^2 + \Phi^4$$

Bounded from below: stable vacuum



Non-zero minimum



Perturbativity & Unitarity

- Perturbativity & unitarity violated for gauge boson scattering
  This amplitude grows $\sim$ Energy
- New diagrams with Higgs: has exactly the right behavior that sum of both give a finite result for all energies.

- Renormalizability!

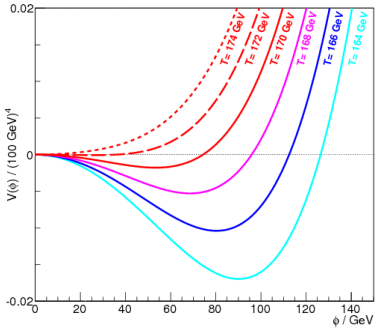
EW Phase Transition: Temperature vs. Energy

- Temperature is not just energy!
- Mental picture: plasma with temperature and number density "background"
- Large enough temperature: production and destruction processes give chemical potential
- Short free path of particle -> short free time
- →Adjust description (like path integral)
- →Effective terms in Lagrangian depending on temperature and number density

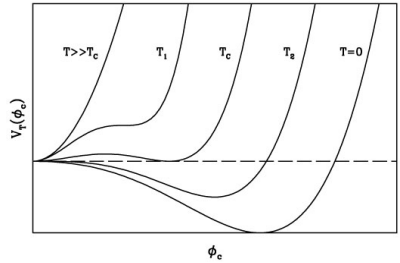
EW Phase Transition: Temperature dependence

- Temperature-dependent effective potential from plasma background
- Several phase transitions possible from hot → less hot
- Consequences for big bang & baryosynthesis

Smooth transition



Non-smooth: critical temperature & quantum tunneling



Conclusions

- Effective field theory doesn't work
- Higgs mechanism saves everything
- Group representations are a useful guide
- Spontaneous symmetry breaking
  - Lagrangian invariant under symmetry
  - Vacuum not invariant
  - Expand around vacuum
- Higgs potential restrictions
- Temperature $\neq$ energy
- EW phase transition $\rightarrow$cosmology