Higgs Implications on the SM validity

Nils Kristian Hüske
LPNHE Paris / Bielefeld University

DZero France, May 3-4 2010

Outline

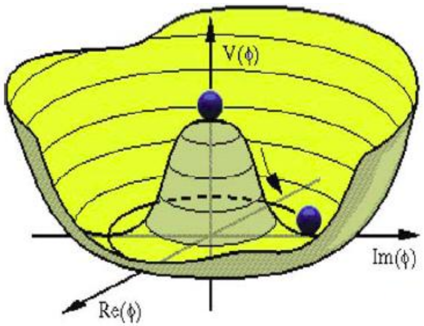
- Introduction / Standard Model
- The **Higgs** / **Validity** of the SM

The Standard Model

The $SU(2)_L \times U(1)_Y$ electroweak symmetry is not an exact symmetry of the vacuum, otherwise *particles* were *massless*.

From experiments we know: **particles have a mass!**

→ modify our theory



Introduction of the **Higgs mechanism**

Why?
Simplest model that conserves gauge invariance.

→ Introduces a new particle: the **Higgs boson**

But not the only solution, e.g. SUSY

The Higgs couples to massive particles. The coupling strength is a measure for the mass of the particle in question.

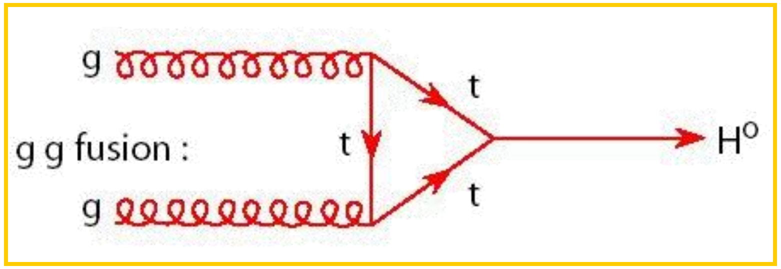
➔ Yukawa Couplings

This coupling strength varies with the energy scale at which we look at the theory

➔ Renormalization

Excerpt: Renormalization

Virtual particles can have arbitrary large momenta



→ Integrals diverge!!

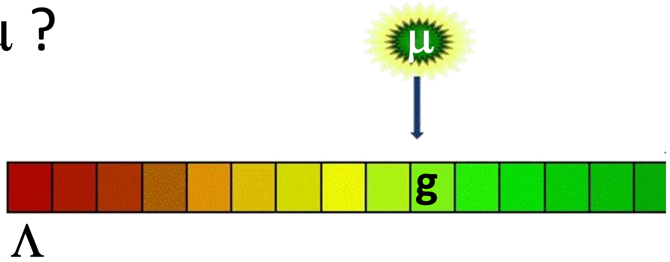
→ Introduce a *cutoff* scale Λ

→ Make the cutoff vanish: ***running couplings***

→ Renormalization

Important: *How* do the couplings behave with respect to the renormalization scale μ ?

→ Renormalization Group Equations



Excerpt: Renormalization

We know the RGEs for the Yukawa couplings g_t, g_b, g_c, g_s and the gauge couplings g, g', g_{QCD} analytically
but: *they are all coupled*

➔In total 7 coupled differential equations, to be solved simultaneously
→ *Runge-Kutta algorithm*

What is special about this work?

- This work takes into account the *bottom*, *charm* and *strange* Yukawa couplings!
- *Interesting to see how the quark Yukawa couplings behave at highest energy scales (~ M_{Pl}).*

Evolution of the Quark Yukawa Couplings

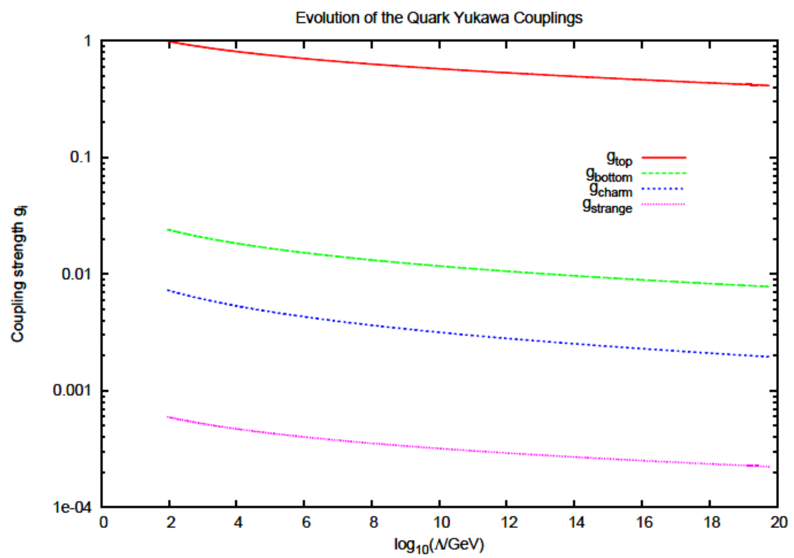
At the electroweak scale the ratio of the couplings is proportional to the ratio of the masses

Quark	Mass [GeV]	Mass ratio m_t / m_q	Couplings ratio g_t / g_q (at EW scale)
top	171.3	1.0	1.0
bottom	4.2	40.79	41.22
charm	1.27	134.88	136.32
strange	0.105	1631.43	1664.48

but at higher energies this is not obvious, looking at the RGE:

$$16\frac{\pi^2}{g_t}\frac{dg_t}{ds} = \frac{9}{2}g_t^2 + \left(3 - \frac{3}{2}(V_{tb})^2\right) g_b^2 + \left(3 - \frac{3}{2}(V_{ts})^2\right) g_s^2 - \left(\frac{9}{4}g^2 + \frac{17}{12}g'^2 + 8g_{QCD}^2\right)$$

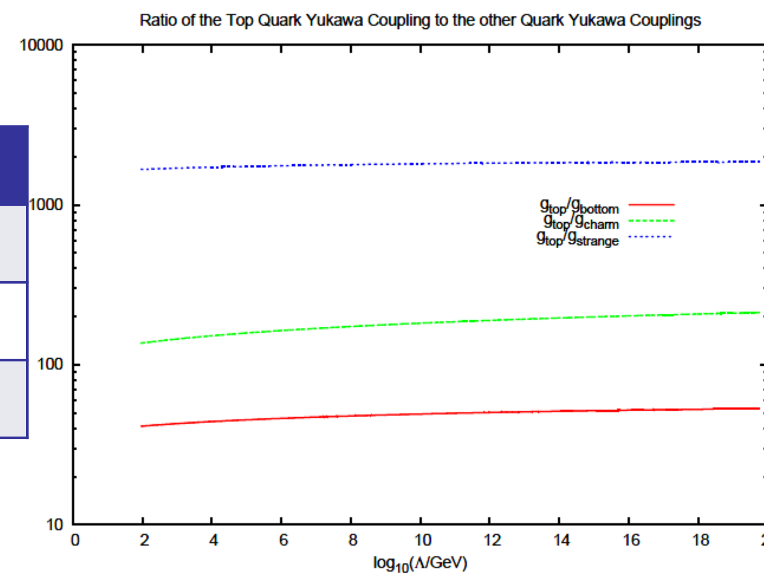
Evolution of the Quark Yukawa Couplings



Evolution of the
quark Yukawa couplings
(log-log scale)

Ratio of the top coupling to the other quark couplings

M_W
1664.48
136.32
41.22



M_{Pl}
1850.23
211.80
53.03

Consequences

1. The general assumption to only take into account g_t in calculations is justified

2. Even at high scales ~ M_{Pl} this assumption holds true

   ➔ Implications for cosmology:
   Models of cosmological inflation evolve around the Planck scale, simplified calculations neglecting everything but the top quark Yukawa coupling are justified

Validity of the Standard Model

Important quantity for the **validity of the SM**:

The quartic Higgs coupling λ

The Higgs potential:

$$V[\mu(s), g_i(s), \phi(s)] \equiv V_0 + V_1 + \ldots,$$

$$V_0 = -\frac{1}{2}m^2(s)\phi^2(s) + \frac{1}{4}\lambda(s)\phi^4(s)$$

$$V_1 = \sum_i \frac{n_i}{(8\pi)^2} M_i^4(\phi)\left[\log\frac{M_i^2(\phi)}{\mu^2} - c_i\right]$$

simplifies to:

$$V(\phi) = \frac{\lambda(\phi)}{4}\phi^4,$$

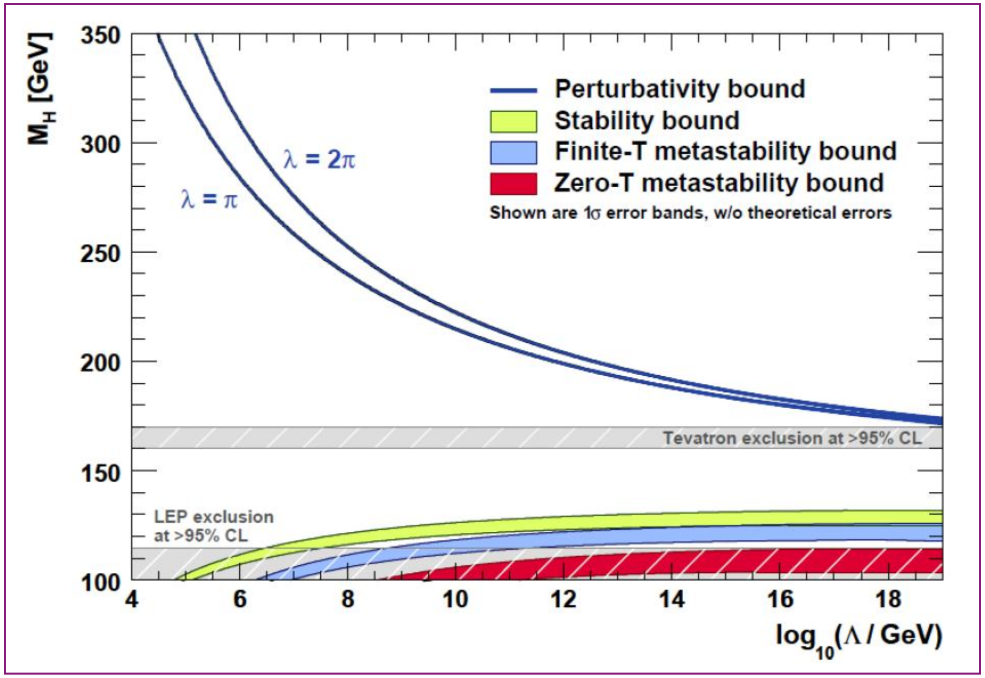
Validity of the Standard Model

$$16\pi^2 \frac{d\lambda}{ds} = \frac{27}{4} g^4 + \frac{9}{2} g'^2 g^2 - 9\lambda g^2 + \frac{9}{4} g'^4 - 36 g_t^4 + 4\lambda^2 - 3 g'^2 \lambda + 12 g_t^2 \lambda$$

The quartic Higgs coupling λ

a. If λ becomes negative, the vacuum could become unstable

b. If λ diverges, perturbation theory fails



John Ellis, Espinosa, J., Guidice, G., Hoecker, A., and Riotto, A. Phys. Lett. B 679(4), 369–375 August (2009).

Implications

1. If the **SM survives** up to the Planck scale (2 x 10^{18} GeV)
   - this could exclude GUTs!
   - this could make certain models for cosmological inflation work → Higgs as the inflaton!

2. If the **SM does not survive** up to very high scales
   - perturbativity bound: *new* non perturbative *physics* at Λ or new physics at some scale $\Lambda <$ that prevents λ from diverging
   - stability bound: another *minimum* of the EW vacuum at a scale Λ arises if not *new physics* at a scale $< \Lambda$ prevents this