LITTLE CONFORMAL SYMMETRY

arXiv: 1603.00030

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Chicago

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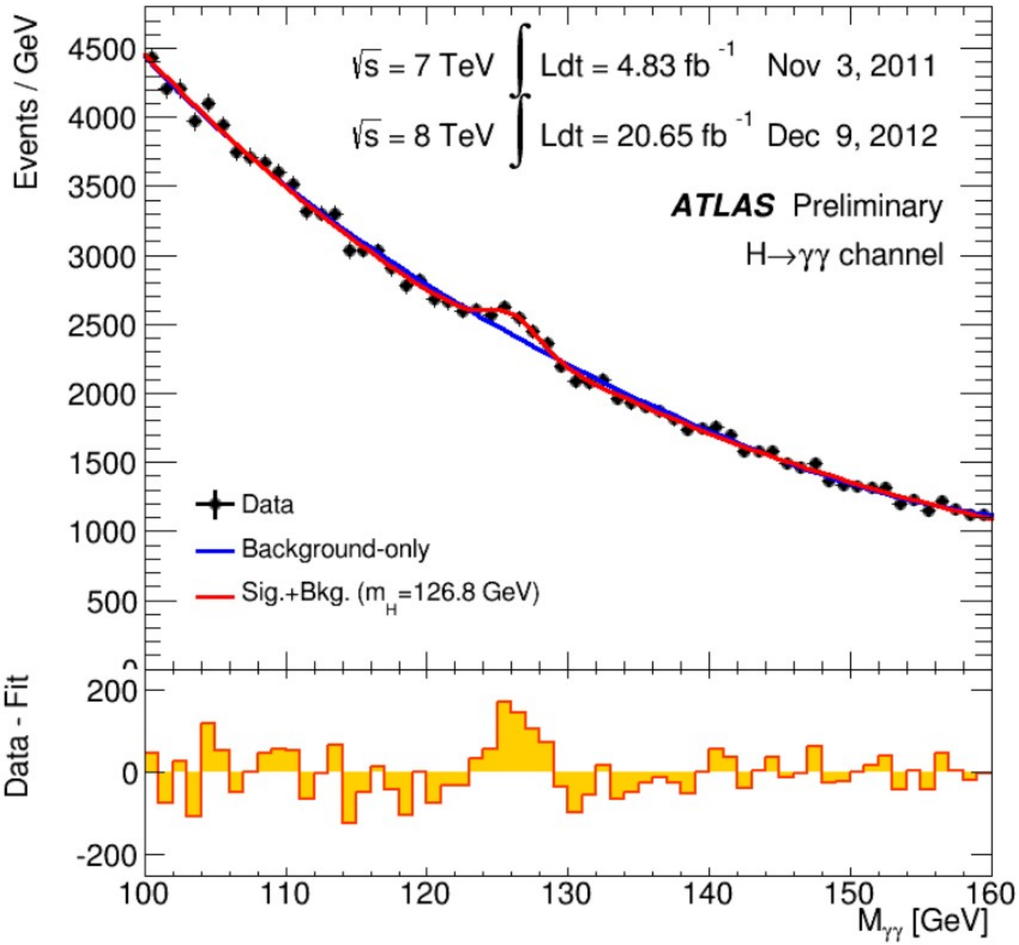
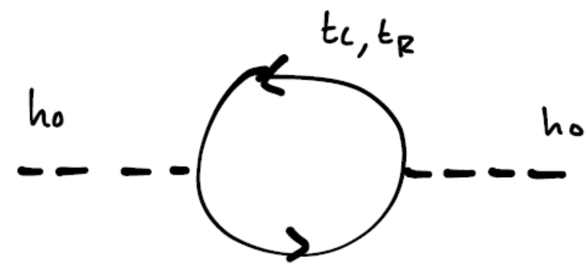
125 GeV Higgs



Amazing!

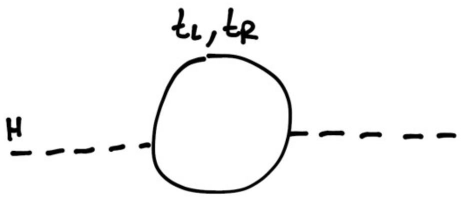
except...



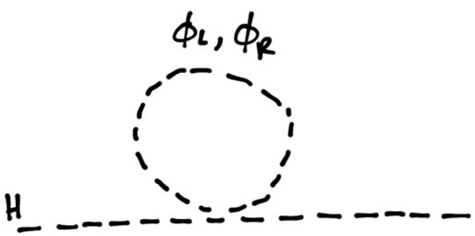
$$\delta m_h^2 = -\frac{N_C}{16\pi^2}|y_t|^2 \times \left[2\Lambda^2 - 6m_t^2 \ln\left(\frac{\Lambda^2 + m_t^2}{m_t^2}\right) + \cdots\right]$$

Cancelling the Divergence

SUSY's Claim to Fame



$$\delta m_h^2 = -\frac{N_C}{16\pi^2}|y_t|^2 \times \left[2\Lambda^2 - 6m_t^2 \ln\left(\frac{\Lambda^2 + m_t^2}{m_t^2}\right) + \cdots\right]$$

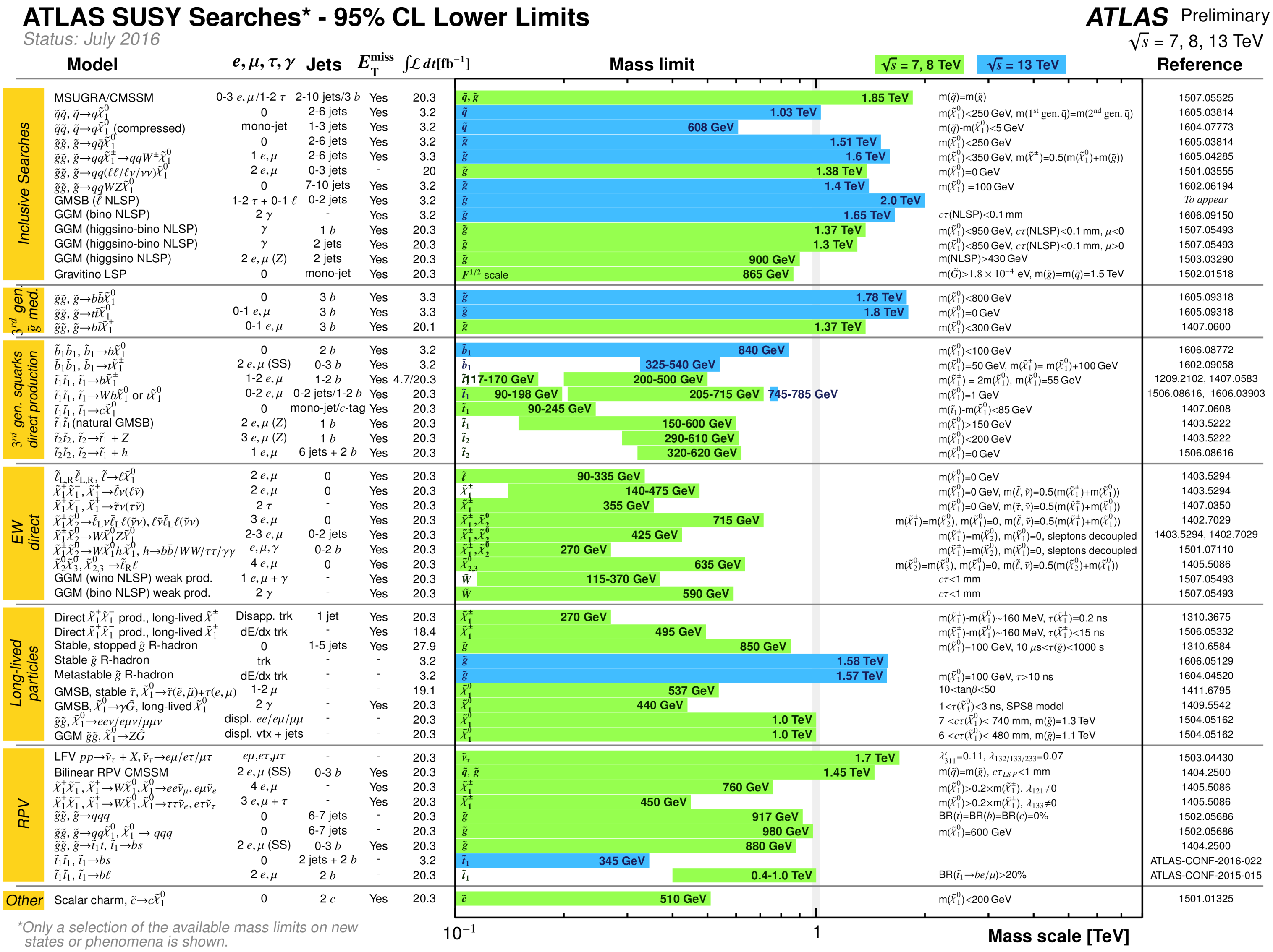


$$\delta m_h^2 = \frac{\lambda N}{16\pi^2}\left[2\Lambda^2 - m_L^2 \ln\left(\frac{\Lambda^2 + m_L^2}{m_L^2}\right) - m_R^2 \ln\left(\frac{\Lambda^2 + m_R^2}{m_R^2}\right) + \cdots\right]$$

SUSY guarantees such a cancellation

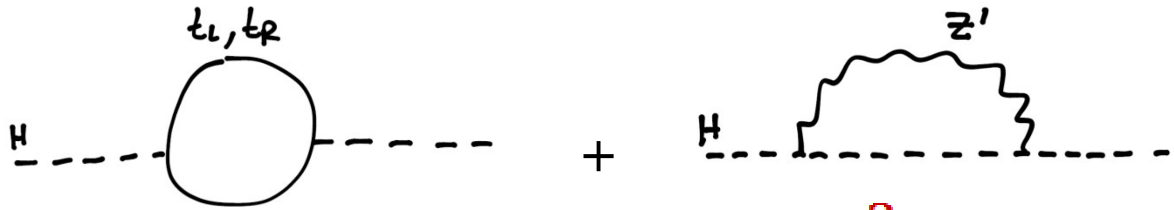
Terning. *Modern Supersymmetry: Dynamics and Duality.* Oxford University Press USA, 2006.

Where are the superpartners?



Alternative Theory: Introduce a new Gauge Boson

$\delta m_h \ni$



$$\delta m_h \ni \left(-2N_C y_t^2 + 3C_2(S) g_N^2\right) \frac{\Lambda^2}{16\pi^2}$$

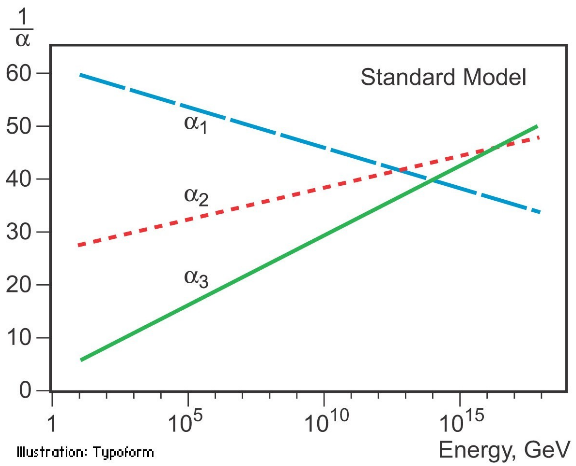
$$0 = -2N_C y_t^2 + 3C_2(S) g_N^2$$

A cancellation is possible if y_t and g_N satisfy this relationship.

Some Problems....

1) How is this not just different fine tuning?

$$0 = -2N_C y_t^2 + 3C_2(S) g_N^2$$



www.nobelprize.org/nobel_prizes/physics/laureates/2004/

2) y_t and g_N run, so a cancellation at one scale will be spoiled

$$\delta m_h \ni (-2N_C y_t^2 + 3C_2(S) g_N^2)\frac{\Lambda^2}{16\pi^2} \Longrightarrow \delta m_h^2 \ni -2N_C y_t^2 \Lambda_t^2 + 3C_2(S) g_N^2 \Lambda_N^2$$

3) Why would the cutoffs for both loops be the same?

-Depends on high energy theory

Solution:
Little Conformal Symmetry

What if this relation is the result of an underlying symmetry?

$$0 = -2N_C y_t^2 + 3C_2(S) g_N^2$$

M. J. G. Veltman, “The Infrared-Ultraviolet Connection,” Acta Phys. Polon. B **12** (1981) 437.

- Impose Conformal Symmetry to derive this relationship between couplings
- Allows for a naturally small Higgs mass with superpartners >10 TeV, similar to Little Higgs models

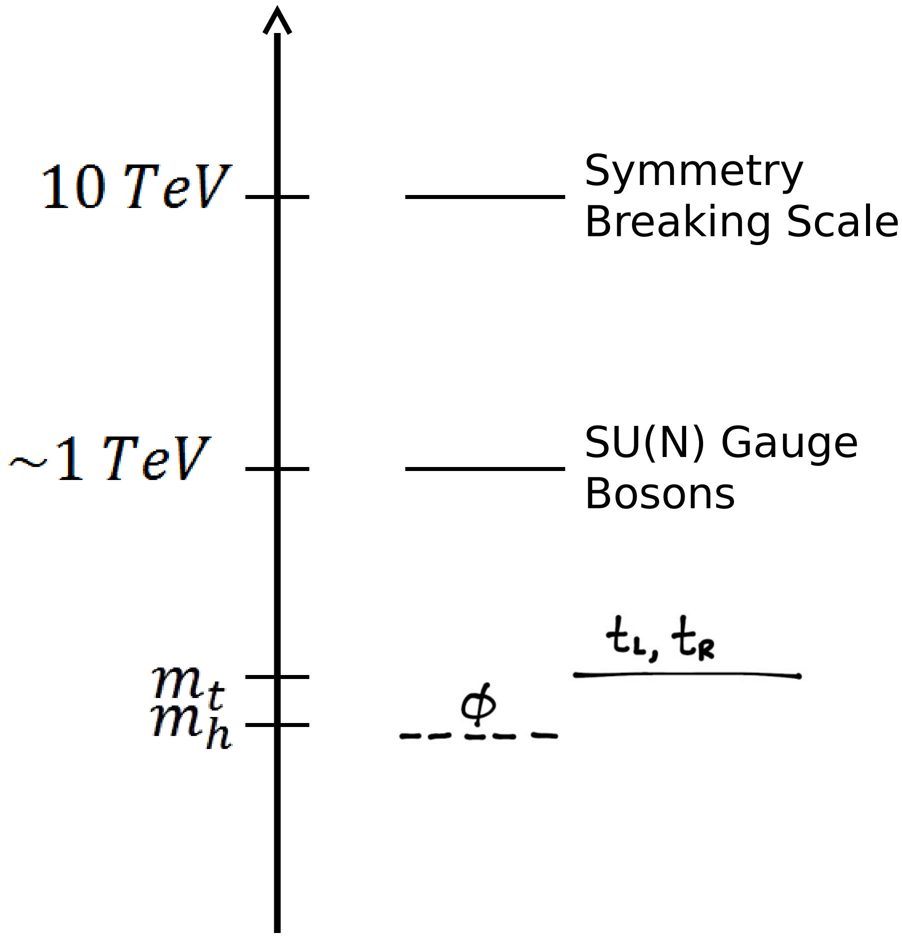
N. Arkani-Hamed, A. G. Cohen, T. Gregoire, and J. G. Wacker, *Phenomenology of electroweak symmetry breaking from theory space, hep-ph/0202089*

Little Conformal Symmetry: A Simple Toy Model

$$\mathcal{L} \ni -y_t \bar{t}_R \phi t_L$$

$$\alpha_N = \frac{g_N^2}{4\pi} \qquad \alpha_t = \frac{y_t^2}{4\pi}$$

	copies	SU(N)
t_L	$2 \times N_c$	$\mathbb{1}$
t_R	N_c	$\square$
ϕ	2	$\square$



Top Yukawa Fixed Point

$$\cancel{\beta(\alpha_t)} = \frac{1}{2\pi}(\alpha_t^2 - b_N \alpha_N \alpha_t)$$

$$\boxed{\alpha_t = \frac{b_N}{a}\alpha_N}$$

Quadratic Divergence Cancellation

$$\cancel{\delta m_h^2} \ni -2N_C \alpha_t + 3C_2(\phi)\alpha_N$$

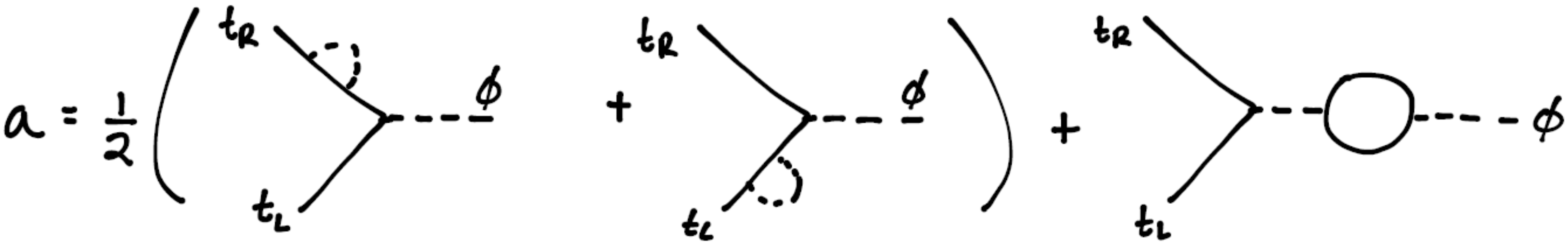
$$\boxed{\alpha_t = \frac{3C_2(\phi)}{2N_C}\alpha_N}$$

Symmetry Condition

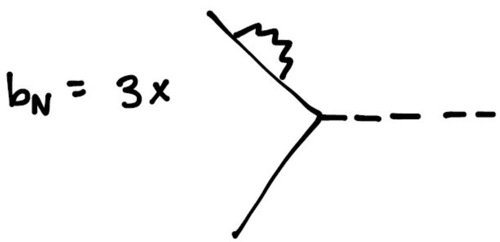
$$\frac{b_N}{a} = \frac{3C_2(S)}{2N_C}$$

Ensures that both the quadratic divergence is cancelled and the top Yukawa coupling is at a fixed point.

Top Yukawa Fixed point



M E. Machacek and M. T. Vaughn, Nucl Phys. B 236. 221 (1983)



$$\Longrightarrow a = \frac{1}{2}N + 4 \quad \& \quad b_N = 3C_2(t_R)$$

Symmetry Condition

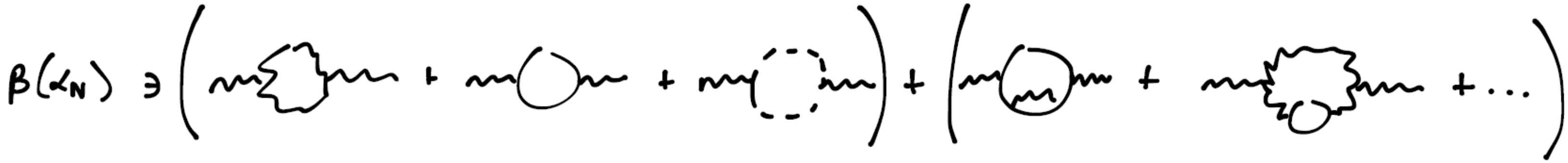
$$\frac{b_N}{a} = \frac{3C_2(S)}{2N_C} \Longrightarrow \boxed{N = 4}$$

$$\alpha_t = \frac{15}{16}\alpha_N$$

- Quadratic Divergence Cancelled
- Top Yukawa at a fixed point
- New Gauge coupling at a fixed point.

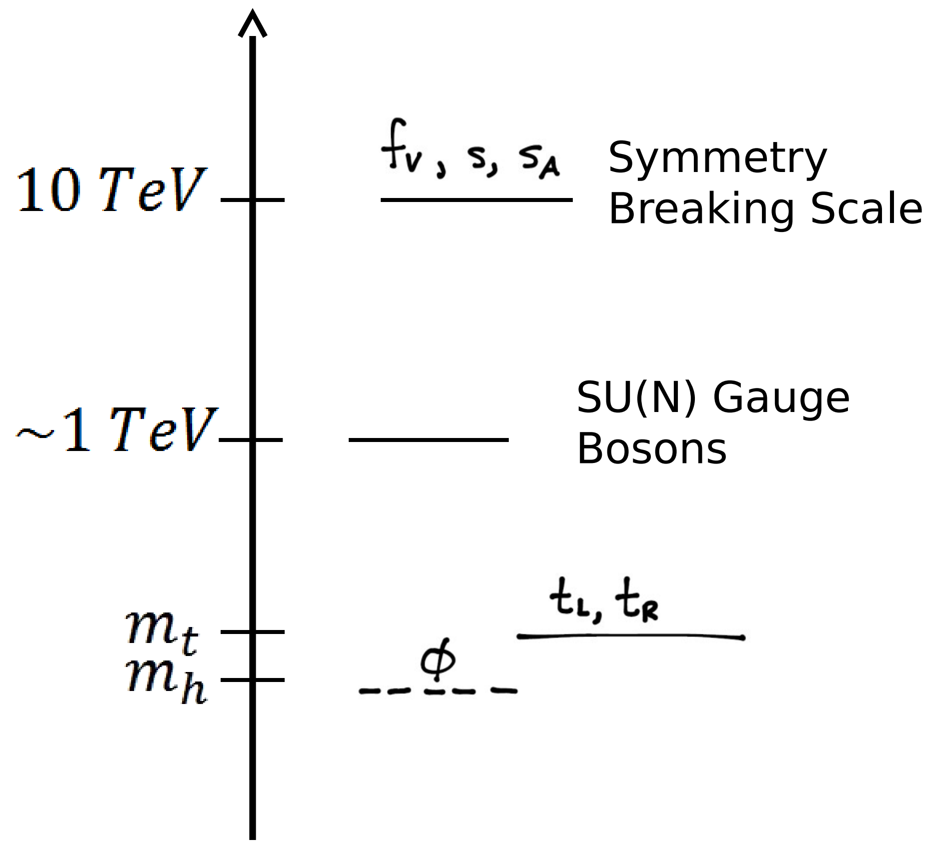
Gauge Coupling Banks-Zaks Fixed Point

M E. Machacek and M. T. Vaughn, Nucl Phys. B 222. 83 (1983)



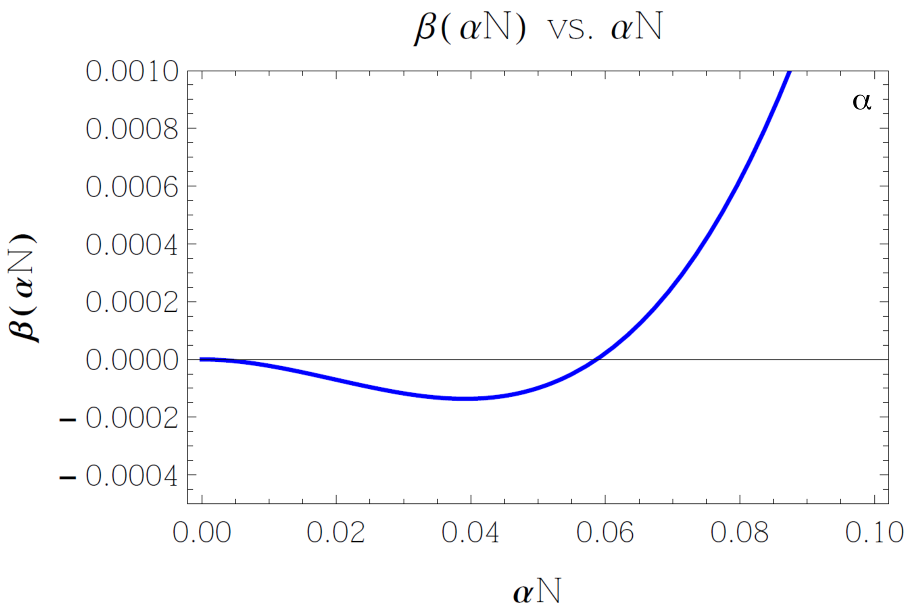
β –function coefficients depend on the matter content of the UV theory

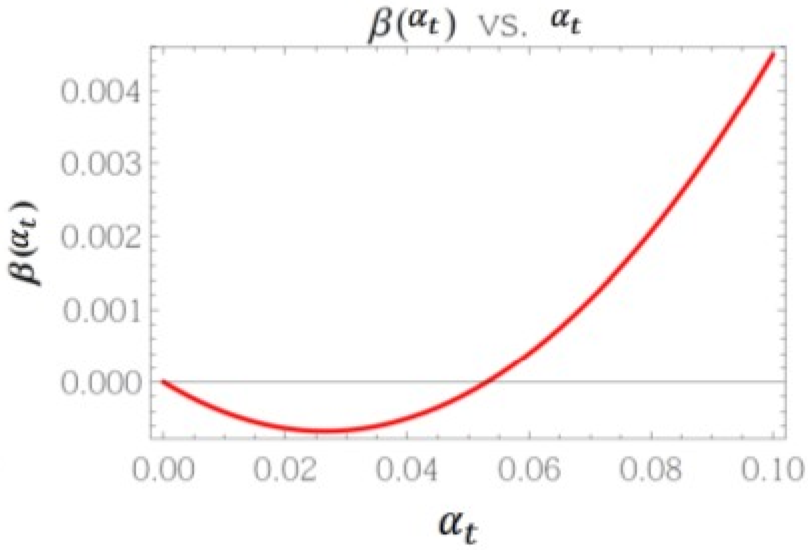
	copies	SU(N)
t_L	$2N_c$	1
t_R	N_c	□
ϕ	2	□
f_V	7	□
S	4	□
S_A	10	Ad



Gauge Coupling Banks-Zaks Fixed Point

- Remember, the values of α_N is already set from our $\frac{\alpha_t}{\alpha_N}$ relation.
- In order to make this value of α_N to coincide with its fixed point, we added new matter to the UV theory





T. Banks and A. Zaks, "On the Phase Structure of Vector-Like Gauge Theories with Massless Fermion," *Nucl. Phys. B* 196 (1982) 189.

Little Conformal Symmetry: More Realistic Toy Model

Problem:

QCD $\quad SU(2)_L \quad U(1)_Y$

$$\beta(\alpha_t) = \frac{1}{2\pi}\left(a\alpha_t^2 - b_N\alpha_N\alpha_t - b_3\alpha_3\alpha_t - b_2\alpha_2\alpha_t - b_1\alpha_1\alpha_t\right)$$

We still want these to cancel

Too big! Drags $\beta(\alpha_t)$ negative quickly

Idea: Embed $SU(3) \subset SU(N)$

More Specifically …

$$SU(3) \subset SU(3)_L \times SU(3)_R \subset SU(N) \times SU(N')$$

- We have two new gauge couplings instead of one: α_N and $\alpha_{N'}$
- Add another constraint to ensure both gauge groups are at a fixed point

Little Conformal Symmetry: Matter Content

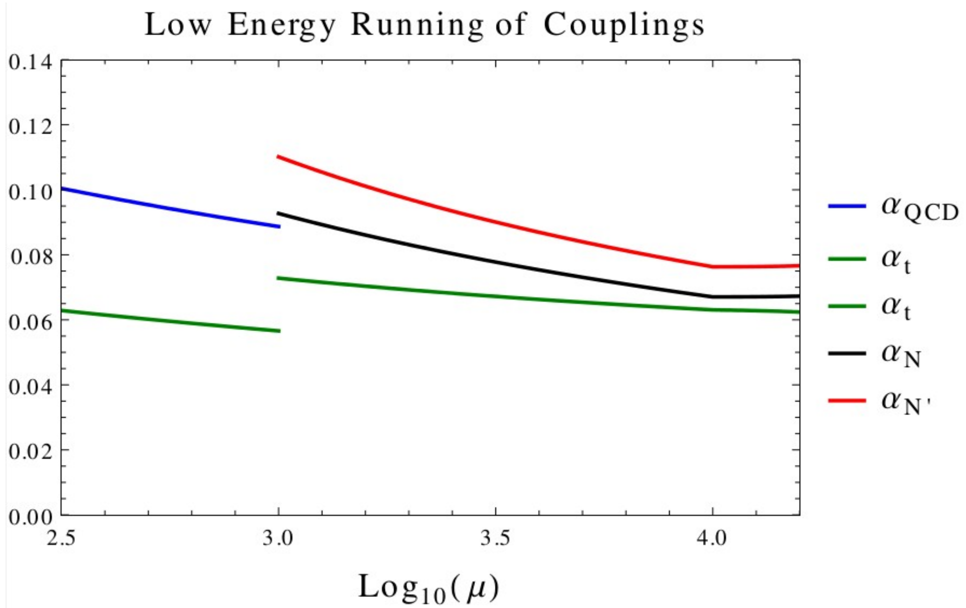
	SU(N)	SU(N')
q_L	$\square$	1
H	$\square$	$\square$
t_R	1	$\square$

$$\dot{\alpha}_N = 0 \qquad \dot{\alpha}_t = 0$$

$$\dot{\alpha}_{N'} = 0 \qquad \delta m_h^2 = 0$$

Realistic symmetry breaking scenario: $\frac{1}{\alpha_3} \geq \frac{1}{\alpha_N} + \frac{1}{\alpha_{N'}}$

Realistic top quark Yukawa coupling: $\alpha_t^{\bar{M}S}(m_t)$ within ± 5.65 %

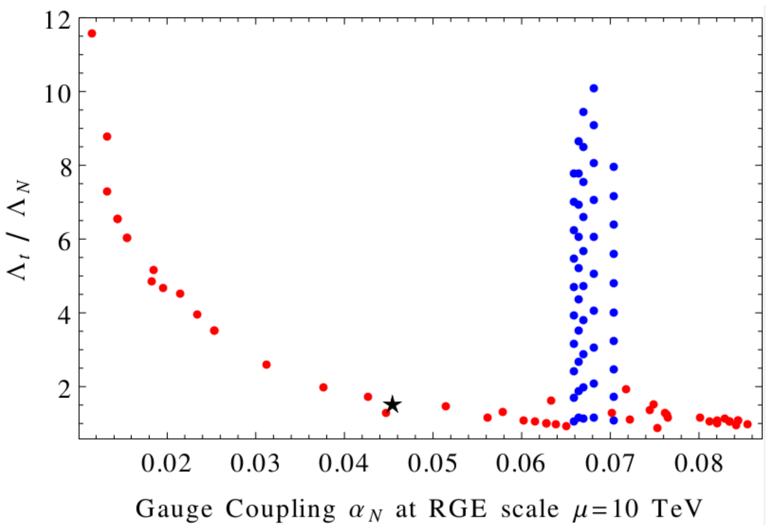


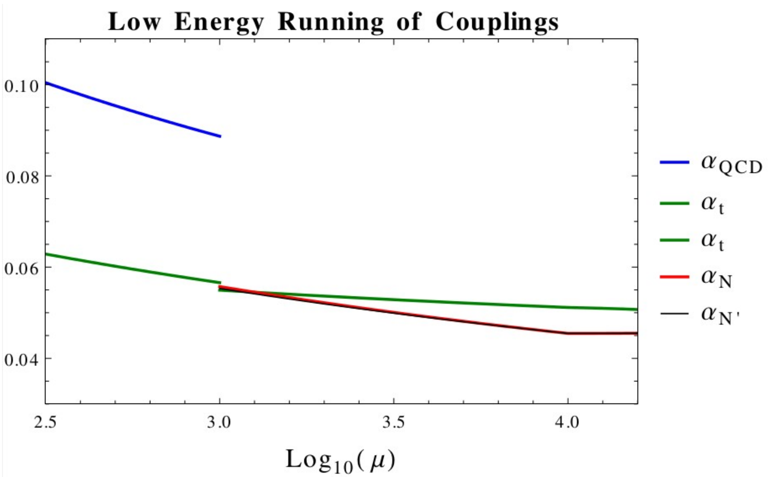
Take another look at the cutoffs…

$$\delta m_h^2 \ni -2N_C\alpha_t\Lambda_t^2 + 3C_2(S)\alpha_N\Lambda_N^2 + 3C_2(S)\alpha_{N'}\Lambda_{N'}^2$$

- For a relationship among Λ_N , $\Lambda_{N'}$ and Λ_t , a UV theory must be chosen.
- Choice: SUSY with the cutoffs being masses of superpartners
- Let $\frac{\Lambda_N}{\alpha_N} = \frac{\Lambda_{N'}}{\alpha_{N'}}$ as in Gauge-Mediated SUSY Breaking

G. F. Giudice and R. Ratazzi, Phys. Rept. 322 (1999) 419, hep-ph/9801271





Conclusions

- Conformal symmetry can produce a cancellation of the Higgs mass quadratic divergence with a new SU(N) gauge boson

- This cancellation prevents the Higgs mass from being sensitive to new physics up to the 10 TeV scale

- More parameter space to explore by requiring fixed points only of ratios of couplings

Back-up Slides

Gauge-Mediated SUSY

$$M_N = \frac{\alpha_N}{4\pi} S_2^N(m) \frac{\mathcal{F}}{M}$$

$$\langle X \rangle = M + \theta^2 \mathcal{F}$$

$$M_M = \frac{\alpha_M}{4\pi} S_2^M(m) \frac{\mathcal{F}}{M}$$

$$m_{\tilde{t}_R}^2 = 2C_2^N(t_R) \frac{\alpha_N^2}{16\pi^2} S_2^N(m) \left(\frac{\mathcal{F}}{M}\right)^2$$

$$m_{\tilde{t}_L}^2 = 2C_2^M(t_L) \frac{\alpha_M^2}{16\pi^2} S_2^M(m) \left(\frac{\mathcal{F}}{M}\right)^2$$

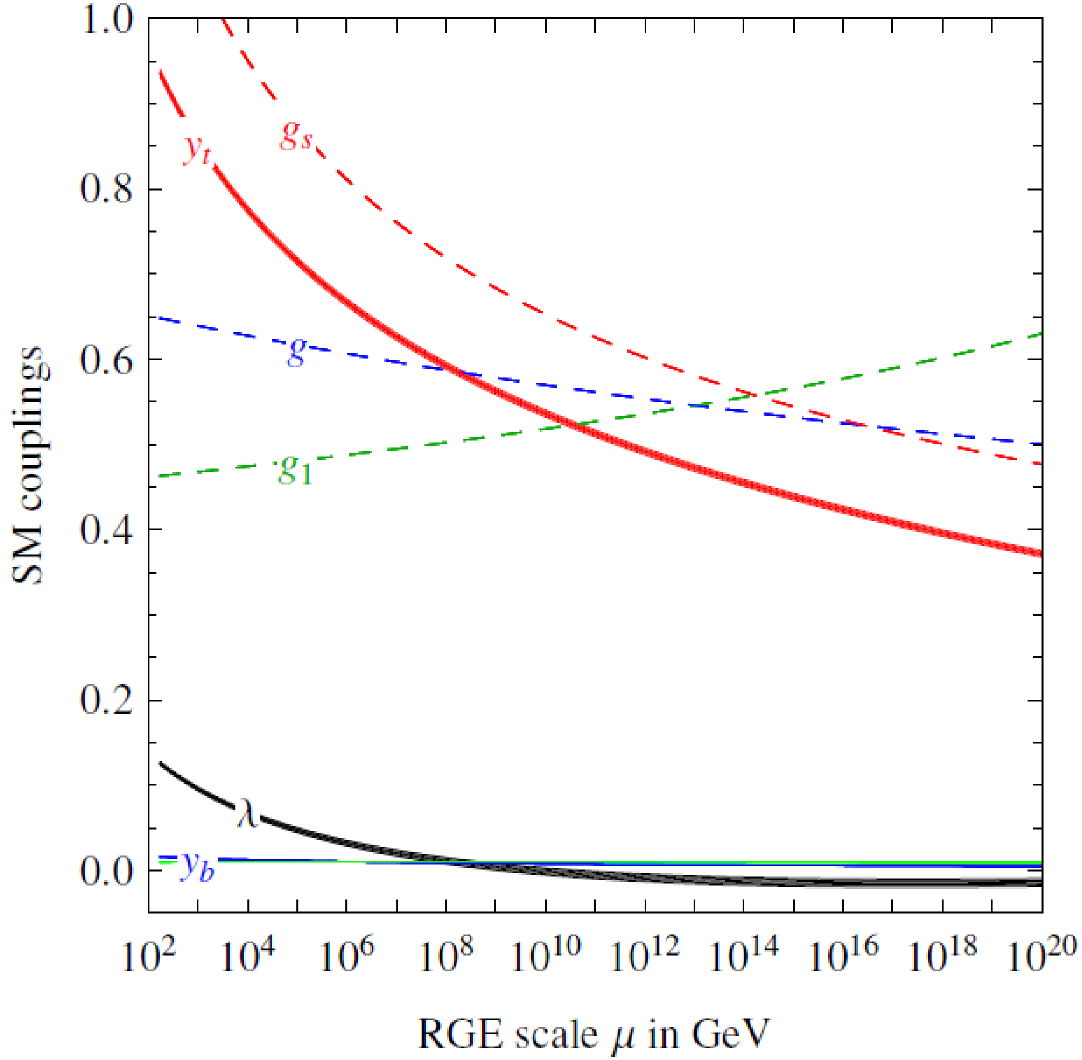
$$\frac{m_{\tilde{t}_R}^2}{m_N^2} = \frac{2C_2^N(\blacksquare)}{S_2^N(m)}$$

For N_m messengers in the fundamental representation:

$$\frac{m_{\tilde{t}_L}^2}{m_M^2} = \frac{2C_2^M(\blacksquare)}{S_2^M(m)} \qquad \frac{m_N^2}{m_M^2} = \frac{S_2^N(m)}{S_2^M(m)} \left(\frac{\alpha_N}{\alpha_M}\right)^2$$

$$S_2^N(m) = 2N_m \left(\frac{1}{2}\right)$$

G. F. Giudice and R. Ratazzi, Phys. Rept. 322 (1999) 419, hep-ph/9801271



Degrassi, et al. JHEP 08 (2012) 098