LITTLE CONFORMAL SYMMETRY

arXiv: 1603.00030

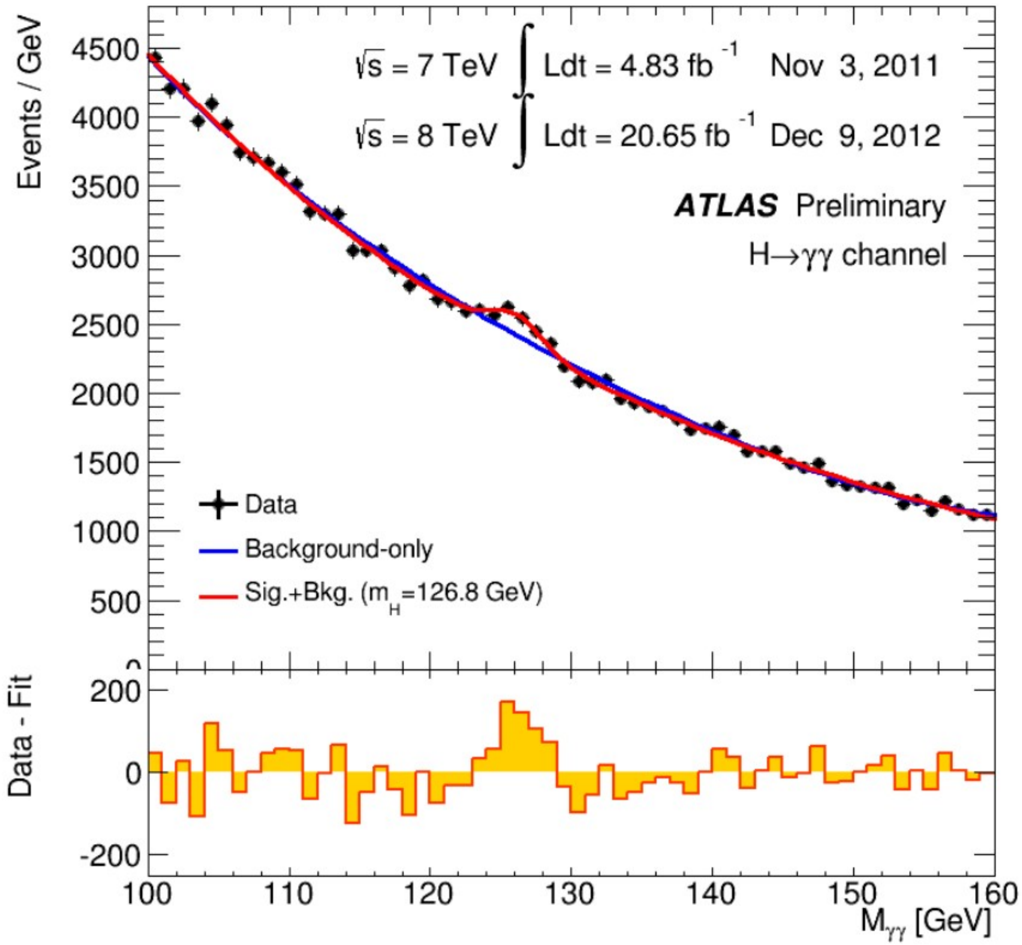
Rachel Houtz

Invisibles 2017 Workshop

Zurich, Switzerland

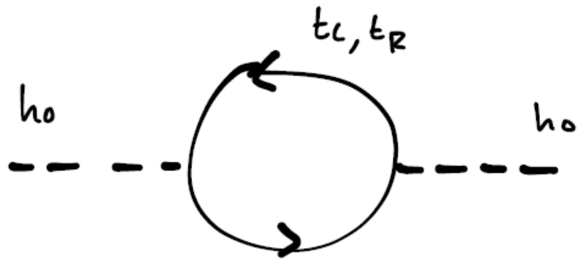
In Collaboration with John Terning (UC Davis),
Kitran Colwell (UC Davis)

125 GeV Higgs



Amazing!

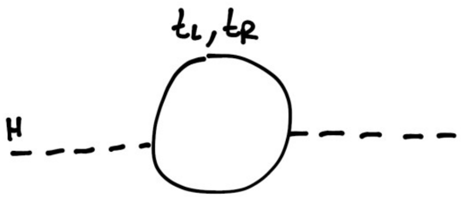
except...



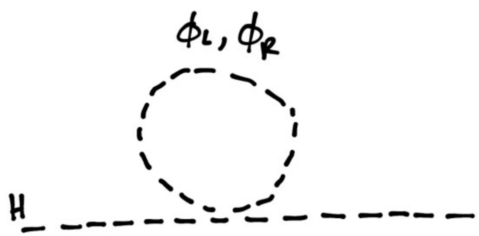
$$\delta m_h^2 = -\frac{N_C}{16\pi^2}|y_t|^2 \times \left[2\Lambda^2 - 6m_t^2 \ln\left(\frac{\Lambda^2 + m_t^2}{m_t^2}\right) + \cdots\right]$$

Cancelling the Divergence

SUSY's Claim to Fame



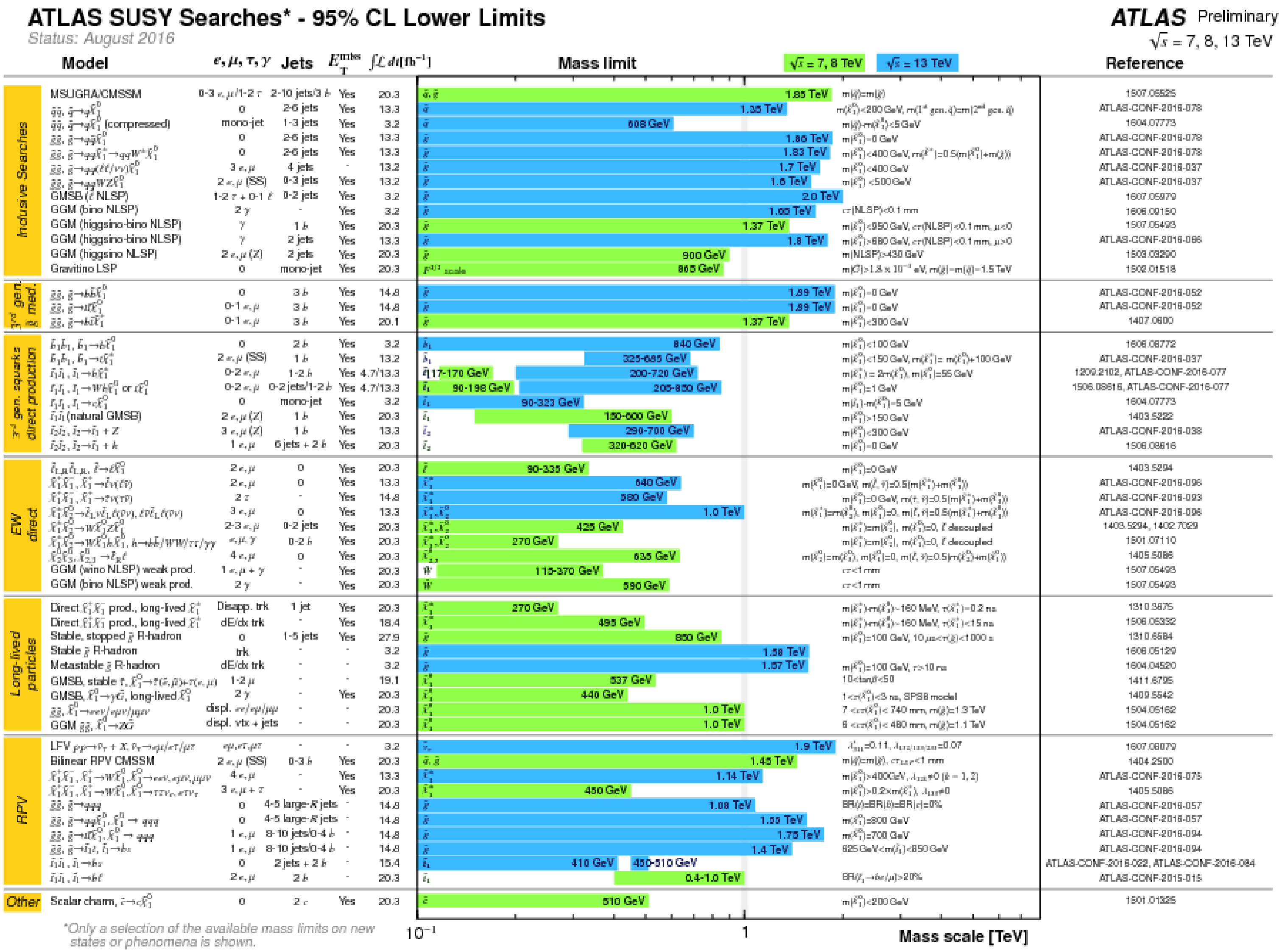
$$\delta m_h^2 = -\frac{N_C}{16\pi^2}|y_t|^2 \times \left[2\Lambda^2 - 6m_t^2 \ln\left(\frac{\Lambda^2 + m_t^2}{m_t^2}\right) + \cdots\right]$$



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

SUSY guarantees such a cancellation

Where are the superpartners?



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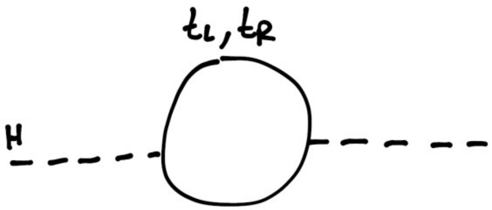
Alternative Theory:
Introduce a new Gauge Boson

$\delta m_h^2 \ni$



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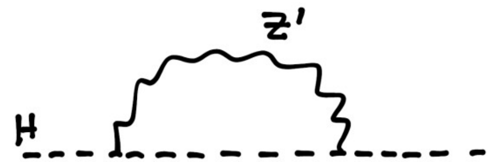


$$\delta m_h^2 \ni (-2N_C y_t^2 + 3C_2(S) g_N^2) \frac{\Lambda^2}{16\pi^2}$$

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

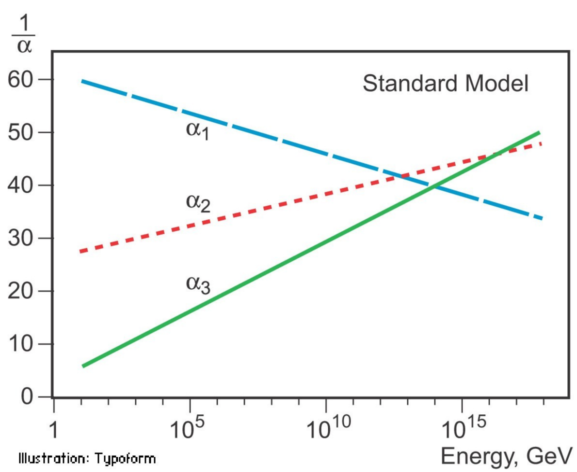
A cancellation is possible if y_t and g_N satisfy this relationship.

Some Problems….

- How is this not just different fine tuning?

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

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



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

Some Problems….

- Why would the cutoffs for both loops be the same?

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

$$\downarrow$$

$$\delta m_h^2 \ni -2N_C y_t^2 \Lambda_t^2 + 3C_2(S) g_N^2 \Lambda_N^2$$

➔ Depends on high energy theory

Solution:
Little Conformal Symmetry

What if this relation is the result of an IR 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.

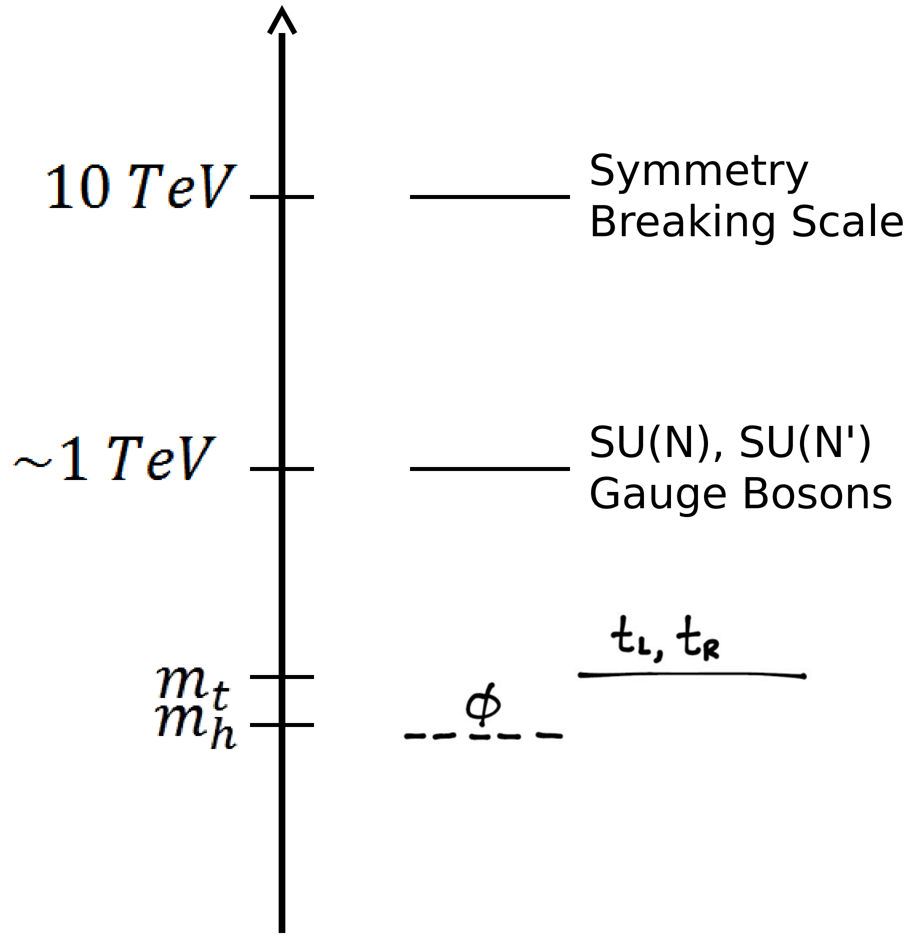
- Impose Conformal Symmetry to derive this relationship between couplings
- Allows for a naturally small Higgs mass with superpartners >10 TeV, similar to Little Higgs models

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

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

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



Conclusions

- Fixed points 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 complicated and realistic models can be explored
  - Add another gauge group: Embedding in QCD
  - Neutral Naturalness: Competing with QCD

Thank You!

Cancellation from an IR Fixed Point

- Quadratic Divergence Cancelled

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

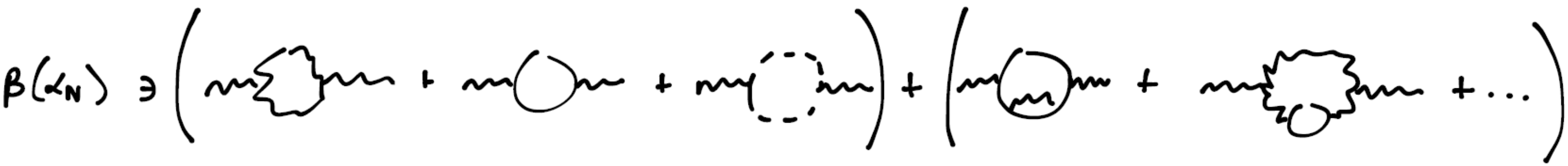
- Top Yukawa at fixed point

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

$$\alpha_t = \frac{B_N}{A}\,\alpha_N$$

- New Gauge coupling at 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

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

$$\beta(\alpha_t) = \frac{1}{2\pi}\left(A\alpha_t^2 - B_N \alpha_N \alpha_t - B_3 \alpha_3 \alpha_t - B_2 \alpha_2 \alpha_t - B_1 \alpha_1 \alpha_t\right)$$

$\delta m_h^2 = 0$

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

More Realistic Toy Model

	SU(N)	SU(N')
t_R	□	1
H	□	□
q_L	1	□

Constraints

$$\delta m_h^2 = 0$$

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

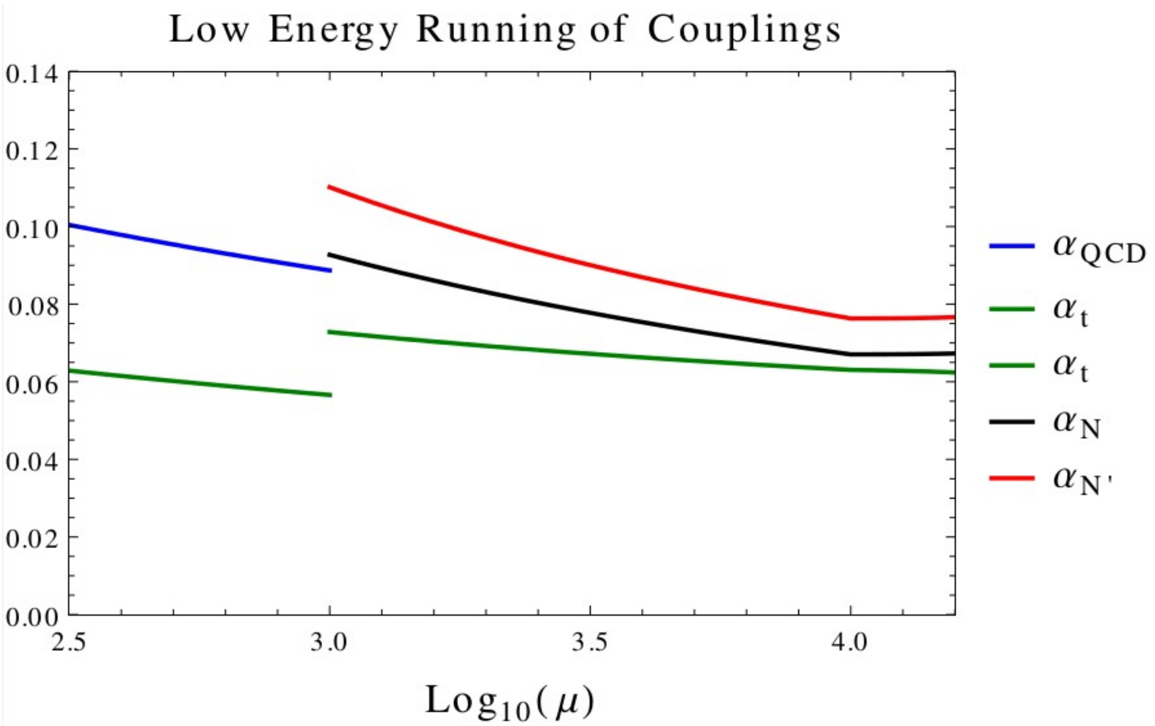
$$\dot{\alpha}_N = 0$$

$$\dot{\alpha}_{N'} = 0$$

new constraint & new variable

Theory with Realistic Symmetry Breaking

- ✔ Realistic symmetry breaking scenario: $\frac{1}{\alpha_3} \geq \frac{1}{\alpha_N} + \frac{1}{\alpha_{N'}}$
- ✘ Realistic top quark Yukawa coupling: $\alpha_t^{\overline{MS}}(m_t)$ within ±5.65 %



Theory with Realistic Yukawa Coupling

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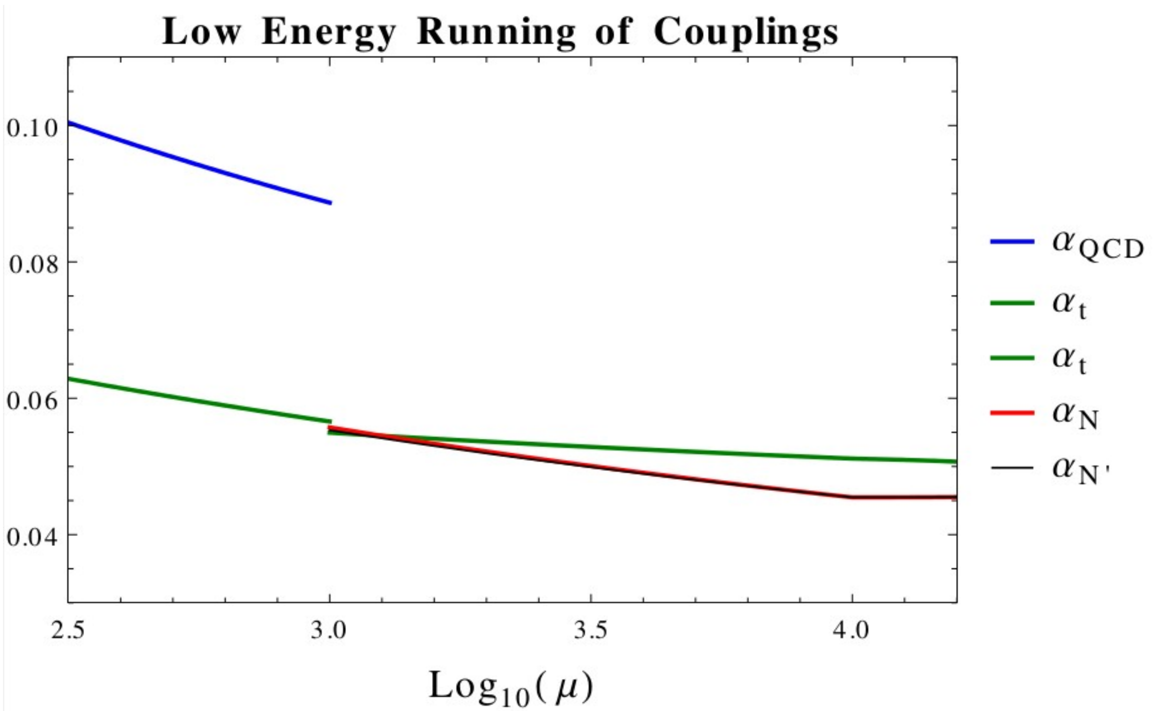
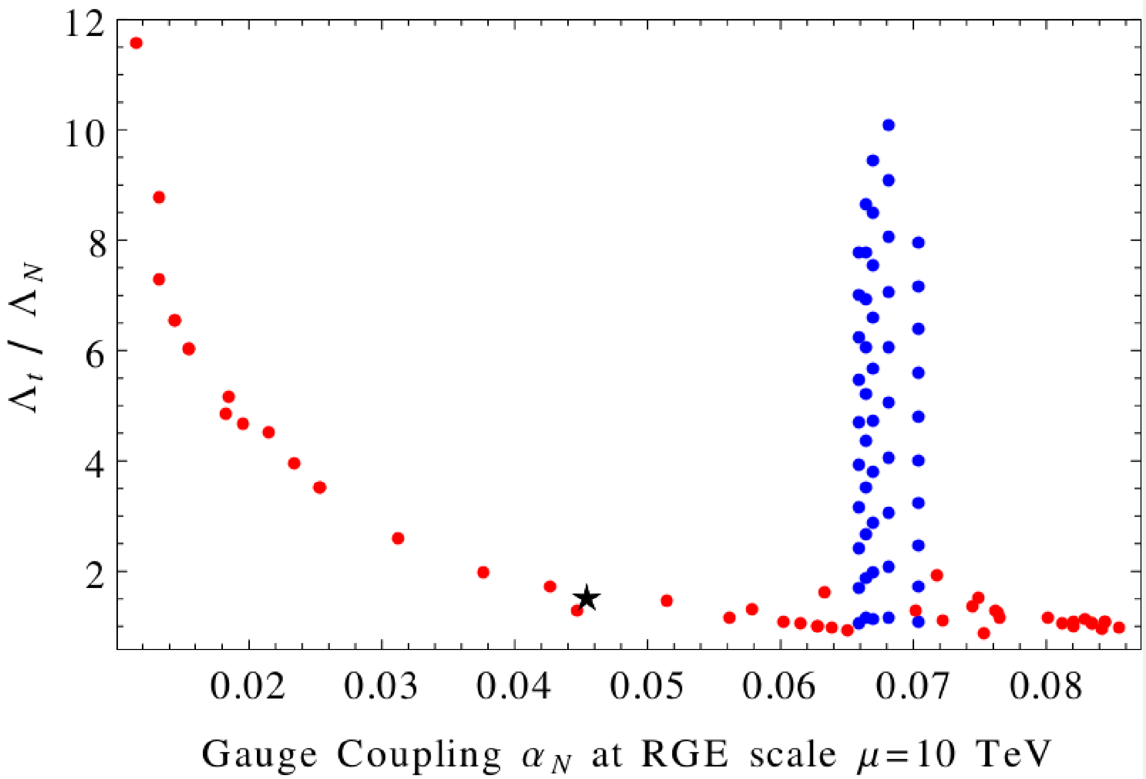


Little Conformal Symmetry UV Theories

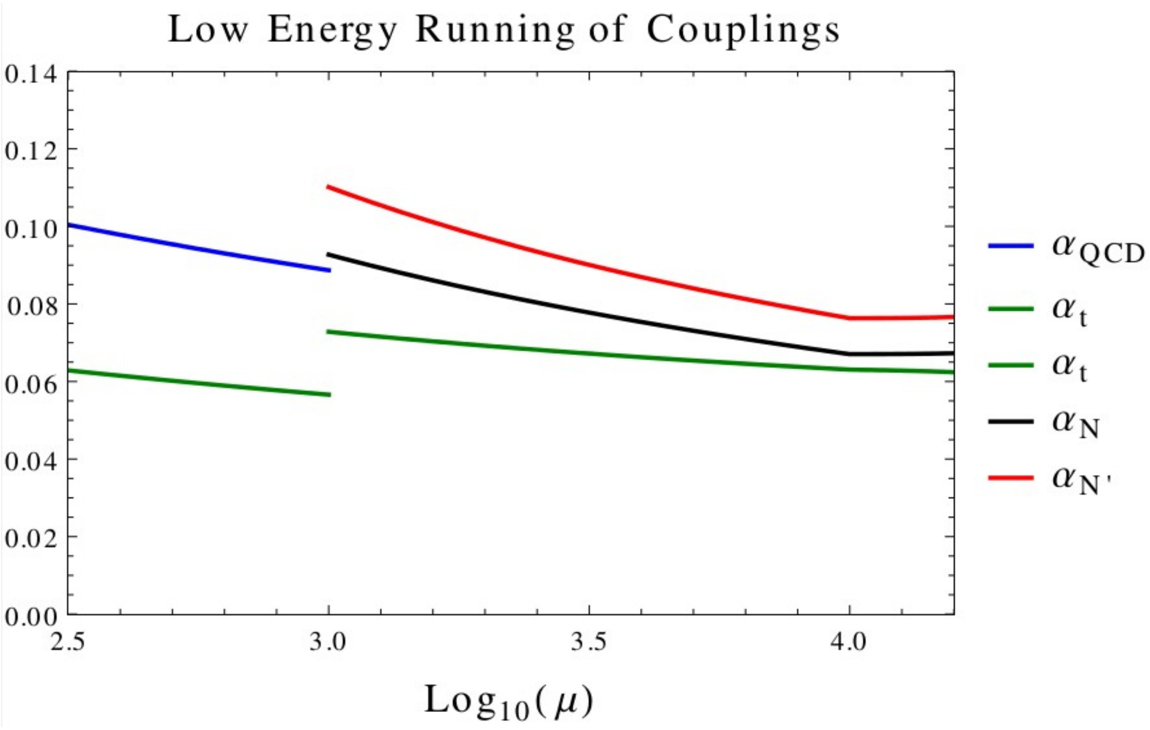
Realistic symmetry breaking scenario: $$\frac{1}{\alpha_3} \geq \frac{1}{\alpha_N} + \frac{1}{\alpha_{N'}}$$

Realistic top quark Yukawa coupling: $\alpha_t^{\overline{MS}}(m_t)$ within ±5.65 %



Top Yukawa and QCD

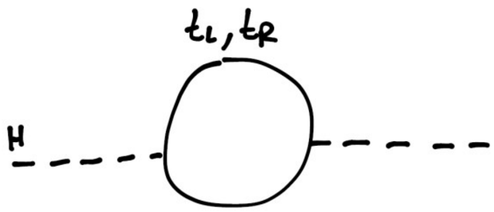
- The top Yukawa coupling is still being affected by QCD

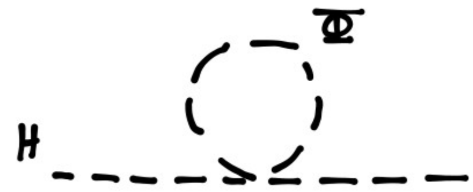


- Small improvements require more complicated matter content

- We need more control over $\beta(\alpha_t)$

Neutral Naturalness

$\delta m_h^2 \ni$ 

$+$ 

$$\delta m_h^2 \ni \left(-2 N_C \alpha_t + \lambda \right) \frac{\Lambda^2}{16\pi^2}$$

$$0 = -2 N_C \alpha_t \Lambda_t^2 + \lambda \Lambda_\Phi^2$$