

# LITTLE CONFORMAL SYMMETRY

arXiv: 1603.00030



Rachel Houtz

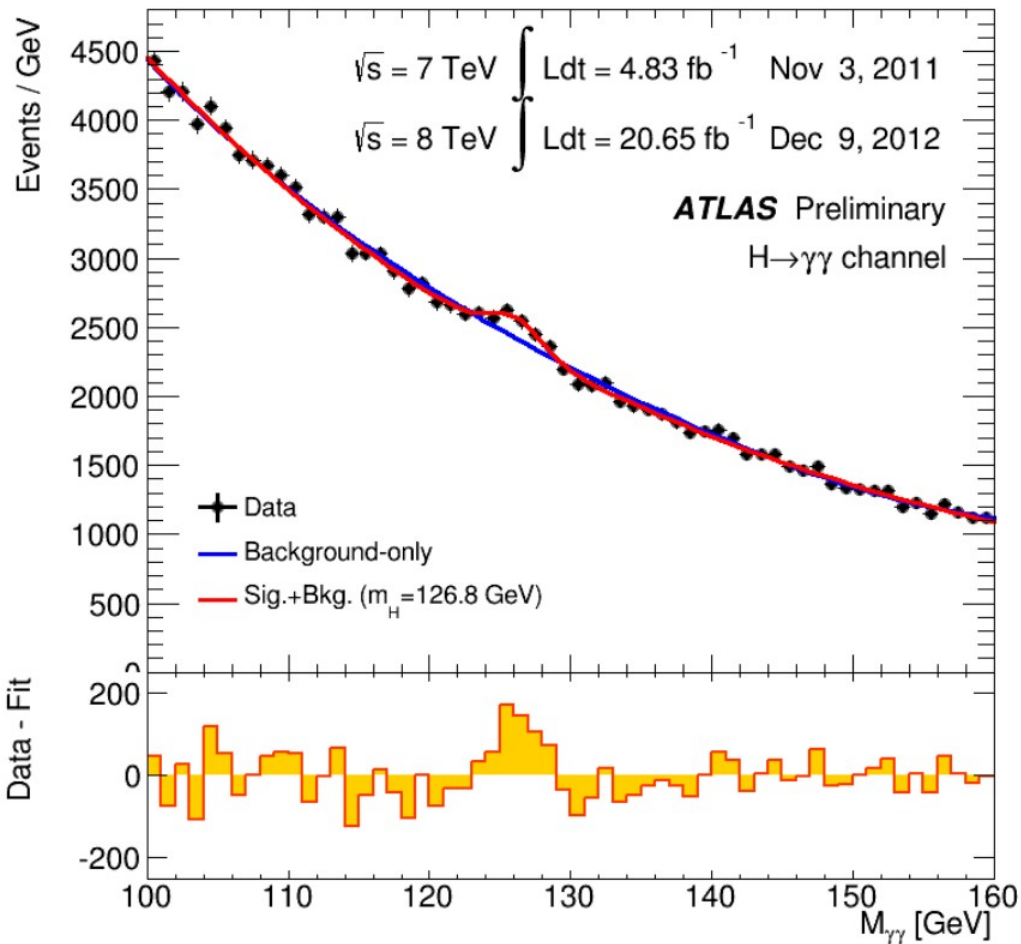
Invisibles 2017 Workshop

Zurich, Switzerland

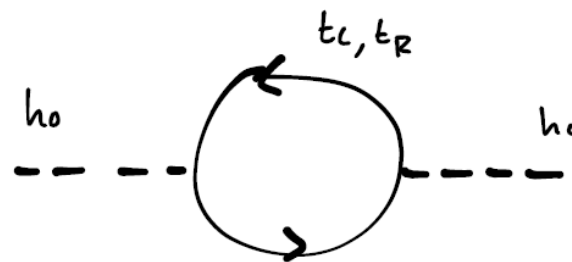
In Collaboration with John Terning (UC Davis),  
Kitran Colwell (UC Davis)

# 125 GeV Higgs

Amazing!



*except...*

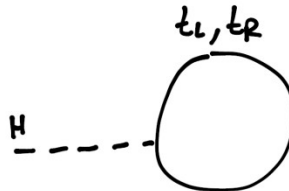


$$\delta m_h^2 = -\frac{N_C}{16\pi^2} |y_t|^2$$

$$\times \left[ 2\Lambda^2 - 6m_t^2 \ln \left( \frac{\Lambda^2 + m_t^2}{m_t^2} \right) + \dots \right]$$

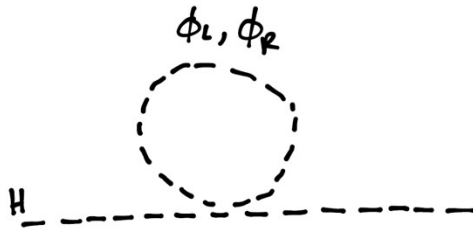
# Cancelling the Divergence

## *SUSY's Claim to Fame*



A Feynman diagram showing a dashed line labeled 'H' entering from the left and exiting to the right. A solid loop is attached to this line, with two vertices labeled  $t_L, t_R$  above it.

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



A Feynman diagram showing a dashed line labeled 'H' entering from the left and exiting to the right. A dashed loop is attached to this line, with two vertices labeled  $\phi_L, \phi_R$  above it.

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

**SUSY guarantees such a cancellation**

# Where are the superpartners?

ATLAS SUSY Searches\* - 95% CL Lower Limits

Status: August 2016

ATLAS Preliminary

$\sqrt{s} = 7, 8, 13$  TeV

	Model	$\epsilon, \mu, \tau, \gamma$	Jets	$E_T^{miss}$	$\int \mathcal{L} d\Omega [fb^{-1}]$	Mass limit		Reference	
						$\sqrt{s} = 7, 8$ TeV	$\sqrt{s} = 13$ TeV		
Inclusive Searches	MSUGRA/CMSSM	0-3 $e, \mu$ / 1-2 $\tau$	2-10 jets/3 $b$	Yes	20.3	4 $\tilde{g}$	1.85 TeV	$m(\tilde{g}) \geq m(\tilde{g})$	1507.05525
	$\tilde{g}\tilde{g} \rightarrow \tilde{g}\tilde{g}$	0	2-6 jets	Yes	13.3	4 $\tilde{g}$	1.35 TeV	$m(\tilde{g}_1) < 200$ GeV, $m(\tilde{g}_2) < m(\tilde{g}_1) + 2m(\tilde{g}_1)$	ATLAS-CONF-2016-078
	$\tilde{g}\tilde{g} \rightarrow \tilde{g}\tilde{g}$ (compressed)	mono-jet	1-3 jets	Yes	3.2	4 $\tilde{g}$	608 GeV	$m(\tilde{g}) + m(\tilde{g}_1) < 5$ GeV	1604.07773
	$\tilde{g}\tilde{g} \rightarrow \tilde{g}\tilde{g}$	0	2-6 jets	Yes	13.3	4 $\tilde{g}$	1.80 TeV	$m(\tilde{g}_1) = 0$ GeV	ATLAS-CONF-2016-078
	$\tilde{g}\tilde{g} \rightarrow \tilde{g}\tilde{g}$	0	2-6 jets	Yes	13.3	4 $\tilde{g}$	1.83 TeV	$m(\tilde{g}_1) < 400$ GeV, $m(\tilde{g}_2) \leq 0.5(m(\tilde{g}_1) + m(\tilde{g}_2))$	ATLAS-CONF-2016-078
	$\tilde{g}\tilde{g} \rightarrow \tilde{g}\tilde{g}$	3 $e, \mu$	4 jets	-	13.2	4 $\tilde{g}$	1.7 TeV	$m(\tilde{g}_1) < 400$ GeV	ATLAS-CONF-2016-037
	$\tilde{g}\tilde{g} \rightarrow \tilde{g}\tilde{g}$	2 $e, \mu$ (SS)	0-3 jets	Yes	13.2	4 $\tilde{g}$	1.6 TeV	$m(\tilde{g}_1) < 500$ GeV	ATLAS-CONF-2016-037
	GMSB ( $\tilde{t}$ NLSP)	1-2 $\tau$ + 0-1 $\ell$	0-2 jets	Yes	3.2	4 $\tilde{g}$	2.0 TeV	$m(\tilde{g}_1) < 0.1$ mm	1607.05079
	GGM (bino NLSP)	2 $\gamma$	-	Yes	3.2	4 $\tilde{g}$	1.05 TeV	$m(\tilde{g}_1) < 500$ GeV, $c\tau(\text{NLSP}) < 0.1$ mm, $\mu < 0$	1606.09150
	GGM (higgsino-bino NLSP)	$\gamma$	1 $b$	Yes	20.3	4 $\tilde{g}$	1.37 TeV	$m(\tilde{g}_1) > 580$ GeV, $c\tau(\text{NLSP}) < 0.1$ mm, $\mu < 0$	1507.05493
	GGM (higgsino-bino NLSP)	$\gamma$	2 jets	Yes	13.3	4 $\tilde{g}$	1.8 TeV	$m(\tilde{g}_1) > 580$ GeV, $c\tau(\text{NLSP}) < 0.1$ mm, $\mu < 0$	ATLAS-CONF-2016-095
	GGM (higgsino NLSP)	2 $e, \mu$ (Z)	2 jets	Yes	20.3	4 $\tilde{g}$	900 GeV	$m(\text{NLSP}) > 430$ GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$\tilde{g}$	805 GeV	$m(\tilde{g}) > 1.5 \times 10^{-3}$ eV, $m(\tilde{g}) + m(\tilde{g}) = 1.5$ TeV	1502.01518
	$\tilde{g}$ gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g} \rightarrow \tilde{g}\tilde{g}$	0	3 $b$	Yes	14.8	4 $\tilde{g}$	1.89 TeV	$m(\tilde{g}_1) < 0$ GeV
$\tilde{g}\tilde{g} \rightarrow \tilde{g}\tilde{g}$		0-1 $e, \mu$	3 $b$	Yes	14.8	4 $\tilde{g}$	1.89 TeV	$m(\tilde{g}_1) < 0$ GeV	ATLAS-CONF-2016-052
$\tilde{g}\tilde{g} \rightarrow \tilde{g}\tilde{g}$		0-1 $e, \mu$	3 $b$	Yes	20.1	4 $\tilde{g}$	1.37 TeV	$m(\tilde{g}_1) < 300$ GeV	1407.0600
$\tilde{g}$ gen. squarks direct prod.	$\tilde{t}_1\tilde{t}_1 \rightarrow \tilde{t}_1\tilde{t}_1$	0	2 $b$	Yes	3.2	$\tilde{t}_1$	840 GeV	$m(\tilde{t}_1) < 100$ GeV	1606.08772
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1\tilde{t}_1$	2 $e, \mu$ (SS)	1 $b$	Yes	13.2	$\tilde{t}_1$	325-685 GeV	$m(\tilde{t}_1) < 150$ GeV, $m(\tilde{t}_2) \leq m(\tilde{t}_1) + 100$ GeV	ATLAS-CONF-2016-037
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1\tilde{t}_1$	0-2 $e, \mu$	1-2 $b$	Yes	4.7/13.3	$\tilde{t}_1$	117-170 GeV	$m(\tilde{t}_1) = 2m(\tilde{t}_2), m(\tilde{t}_2) \leq 55$ GeV	1209.2102, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow W\tilde{t}_1^0$ or $\tilde{t}_1^0$	0-2 $e, \mu$	0-2 jets/1-2 $b$	Yes	4.7/13.3	$\tilde{t}_1$	90-198 GeV	$m(\tilde{t}_1) = 1$ GeV	1506.03618, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	0	mono-jet	Yes	3.2	$\tilde{t}_1$	90-323 GeV	$m(\tilde{t}_1) + m(\tilde{t}_2) = 5$ GeV	1604.07773
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 $e, \mu$ (Z)	1 $b$	Yes	20.3	$\tilde{t}_1$	150-500 GeV	$m(\tilde{t}_1) > 150$ GeV	1403.5222
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 + Z$	3 $e, \mu$ (Z)	1 $b$	Yes	13.3	$\tilde{t}_1$	290-700 GeV	$m(\tilde{t}_1) < 300$ GeV	ATLAS-CONF-2016-038
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 + b$	1 $e, \mu$	6 jets + 2 $b$	Yes	20.3	$\tilde{t}_1$	320-620 GeV	$m(\tilde{t}_1) = 0$ GeV	1506.03618
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 + \tilde{g}$	2 $e, \mu$	0	Yes	20.3	$\tilde{t}_1$	90-335 GeV	$m(\tilde{t}_1) = 0$ GeV	1403.5294
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 + \tilde{g}$	2 $e, \mu$	0	Yes	13.3	$\tilde{t}_1$	640 GeV	$m(\tilde{t}_1) = 0$ GeV, $m(\tilde{t}_2) = 0.5(m(\tilde{t}_1) + m(\tilde{t}_2))$	ATLAS-CONF-2016-095
EW direct	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 + \tilde{g}$	2 $\tau$	-	Yes	14.8	$\tilde{t}_1$	580 GeV	$m(\tilde{t}_1) = 0$ GeV, $m(\tilde{t}_2) = 0.5(m(\tilde{t}_1) + m(\tilde{t}_2))$	ATLAS-CONF-2016-029
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 + \tilde{g}$	3 $e, \mu$	0	Yes	13.3	$\tilde{t}_1$	1.0 TeV	$m(\tilde{t}_1) = m(\tilde{t}_2), m(\tilde{t}_2) = 0, m(\tilde{t}_2) = 0.5(m(\tilde{t}_1) + m(\tilde{t}_2))$	ATLAS-CONF-2016-095
	$\tilde{t}_1\tilde{t}_1 \rightarrow W\tilde{t}_1^0, \tilde{t}_1 \rightarrow \tilde{t}_1 + \tilde{g}$	2-3 $e, \mu$	0-2 jets	Yes	20.3	$\tilde{t}_1$	425 GeV	$m(\tilde{t}_1) = m(\tilde{t}_2), m(\tilde{t}_2) = 0, \text{decoupled}$	1403.5294, 1402.7029
	$\tilde{t}_1\tilde{t}_1 \rightarrow W\tilde{t}_1^0, \tilde{t}_1 \rightarrow \tilde{t}_1 + \tilde{g}$	$e, \mu, \gamma$	0-2 $b$	Yes	20.3	$\tilde{t}_1$	270 GeV	$m(\tilde{t}_1) = m(\tilde{t}_2), m(\tilde{t}_2) = 0, \text{decoupled}$	1501.07110
	$\tilde{t}_1\tilde{t}_1 \rightarrow W\tilde{t}_1^0, \tilde{t}_1 \rightarrow \tilde{t}_1 + \tilde{g}$	4 $e, \mu$	0	Yes	20.3	$\tilde{t}_1$	635 GeV	$m(\tilde{t}_1) = m(\tilde{t}_2), m(\tilde{t}_2) = 0, m(\tilde{t}_2) = 0.5(m(\tilde{t}_1) + m(\tilde{t}_2))$	1405.5096
	GGM (wino NLSP) weak prod.	1 $e, \mu$ + $\gamma$	-	Yes	20.3	$\tilde{W}$	115-370 GeV	$c\tau < 1$ mm	1507.05493
	GGM (bino NLSP) weak prod.	2 $\gamma$	-	Yes	20.3	$\tilde{W}$	590 GeV	$c\tau < 1$ mm	1507.05493
	Direct $\tilde{t}_1\tilde{t}_1$ prod., long-lived $\tilde{t}_1$	Disapp. trk	1 jet	Yes	20.3	$\tilde{t}_1$	270 GeV	$m(\tilde{t}_1) + m(\tilde{t}_2) = 160$ MeV, $\tau(\tilde{t}_1) = 0.2$ ns	1310.3675
	Direct $\tilde{t}_1\tilde{t}_1$ prod., long-lived $\tilde{t}_1$	dE/dx trk	-	Yes	18.4	$\tilde{t}_1$	495 GeV	$m(\tilde{t}_1) + m(\tilde{t}_2) = 160$ MeV, $\tau(\tilde{t}_1) < 15$ ns	1506.05332
	Stable, stopped $\tilde{t}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{t}$	800 GeV	$m(\tilde{t}_1) = 100$ GeV, $\mu, \tau < c(\tilde{g}) < 1000$ s	1310.6584
Stable $\tilde{t}$ R-hadron	trk	-	-	3.2	$\tilde{t}$	1.58 TeV	-	1606.05129	
Metastable $\tilde{t}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{t}$	1.57 TeV	-	1604.04520	
GMSB, stable $\tilde{t}, \tilde{t}_1 \rightarrow \tilde{t} + \tilde{g}$	1-2 $\mu$	-	-	19.1	$\tilde{t}_1$	537 GeV	$10 < \text{Lan}(\tilde{t}_1) < 50$	1411.6795	
GMSB, $\tilde{t}_1 \rightarrow \tilde{t} + \tilde{g}$ , long-lived $\tilde{t}_1$	2 $\gamma$	-	Yes	20.3	$\tilde{t}_1$	440 GeV	$1 < \tau(\tilde{t}_1) < 3$ ns, SPSB model	1409.5542	
$\tilde{g}\tilde{g}, \tilde{t}_1 \rightarrow \tilde{t} + \tilde{g}$	displ. $e, \mu, \tau, \gamma$	-	-	20.3	$\tilde{t}_1$	1.0 TeV	$7 < \tau(\tilde{t}_1) < 740$ mm, $m(\tilde{t}_1) = 1.3$ TeV	1504.05162	
GGM $\tilde{g}\tilde{g}, \tilde{t}_1 \rightarrow \tilde{t} + \tilde{g}$	displ. vtx + jets	-	-	20.3	$\tilde{t}_1$	1.0 TeV	$8 < \tau(\tilde{t}_1) < 480$ mm, $m(\tilde{t}_1) = 1.1$ TeV	1504.05162	
RPV	LFV $\mu\mu \rightarrow \nu_\tau + X, \nu_\tau \rightarrow \mu\mu\tau/\mu\tau$	$e\mu, \nu\tau, \mu\tau$	-	-	3.2	$\tilde{g}$	1.9 TeV	$A_{111} = 0.11, A_{132}/A_{133}/A_{233} = 0.07$	1607.08079
	Bilinear RPV CMSSM	2 $e, \mu$ (SS)	0-3 $b$	Yes	20.3	4 $\tilde{g}$	1.45 TeV	$m(\tilde{g}) \geq m(\tilde{g})$ , $c\tau_{\tilde{g}} < 1$ mm	1404.2500
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow W\tilde{t}_1^0, \tilde{t}_1 \rightarrow \nu\tau, e\mu, \mu\mu$	4 $e, \mu$	-	Yes	13.3	$\tilde{t}_1$	1.14 TeV	$m(\tilde{t}_1) > 400$ GeV, $A_{133} \neq 0$ ( $k = 1, 2$ )	ATLAS-CONF-2016-075
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow W\tilde{t}_1^0, \tilde{t}_1 \rightarrow \nu\tau, e\mu, \mu\mu$	3 $e, \mu$ + $\tau$	-	Yes	20.3	$\tilde{t}_1$	450 GeV	$m(\tilde{t}_1) > 0.2 \times m(\tilde{t}_2), A_{133} \neq 0$	1405.5096
	$\tilde{g}\tilde{g} \rightarrow \tilde{g}\tilde{g}$	0	4-5 large-R jets	-	14.8	$\tilde{g}$	1.08 TeV	$BR(\tilde{g} \rightarrow BR) = BR(\tilde{g} \rightarrow BR) = 0\%$	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g} \rightarrow \tilde{g}\tilde{g}$	0	4-5 large-R jets	-	14.8	$\tilde{g}$	1.35 TeV	$m(\tilde{g}_1) = 800$ GeV	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g} \rightarrow \tilde{g}\tilde{g}$	1 $e, \mu$	8-10 jets/0-4 $b$	-	14.8	$\tilde{g}$	1.75 TeV	$m(\tilde{g}_1) = 700$ GeV	ATLAS-CONF-2016-094
	$\tilde{g}\tilde{g} \rightarrow \tilde{g}\tilde{g}$	1 $e, \mu$	8-10 jets/0-4 $b$	-	14.8	$\tilde{g}$	1.4 TeV	$825$ GeV $< m(\tilde{g}_1) < 850$ GeV	ATLAS-CONF-2016-094
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\tilde{t}$	0	2 jets + 2 $b$	-	15.4	$\tilde{t}_1$	410 GeV	$BR(\tilde{t}_1 \rightarrow b\tilde{t}) > 20\%$	ATLAS-CONF-2016-022, ATLAS-CONF-2016-084
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\tilde{t}$	2 $e, \mu$	2 $b$	-	20.3	$\tilde{t}_1$	450-510 GeV	-	ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c} \rightarrow \tilde{c}\tilde{g}$	0	2 $c$	Yes	20.3	$\tilde{c}$	510 GeV	$m(\tilde{c}) < 200$ GeV	1501.01325

\*Only a selection of the available mass limits on new states or phenomena is shown.

10<sup>-1</sup> 1 Mass scale [TeV]



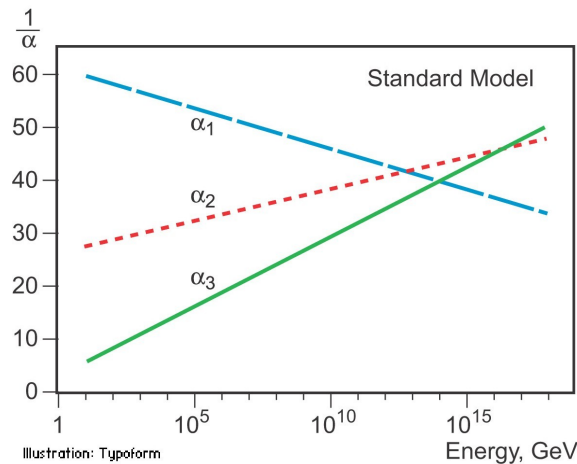
# Some Problems....

- 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/](http://www.nobelprize.org/nobel_prizes/physics/laureates/2004/)

# Some Problems....

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

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



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

 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

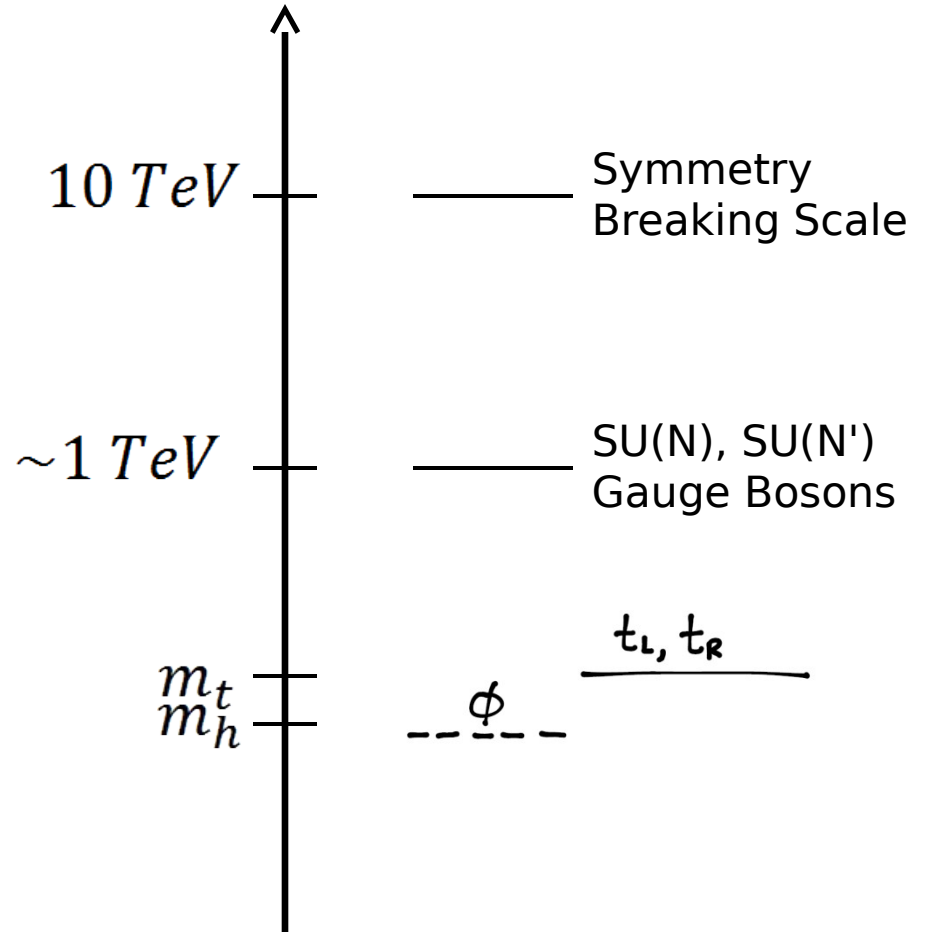
N. Arkani-Hamed, A. G. Cohen, T. Gregoire, and J. G. Wacker,  
*Phenomenology of electroweak symmetry breaking from theory space*,  
*hep-ph/0202089*



# Little Conformal Symmetry: A Simple Toy Model

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

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

$$\beta(\alpha_N) \ni \left( \text{triangle} + \text{circle} + \text{dashed circle} \right) + \left( \text{circle} + \text{triangle} + \dots \right)$$

- $\beta$  –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:

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

$SU(2)_L$        $U(1)_Y$   
 $\downarrow$                        $\downarrow$   
 $\overline{\alpha_t}$                        $0$

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:  $\alpha_N$  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

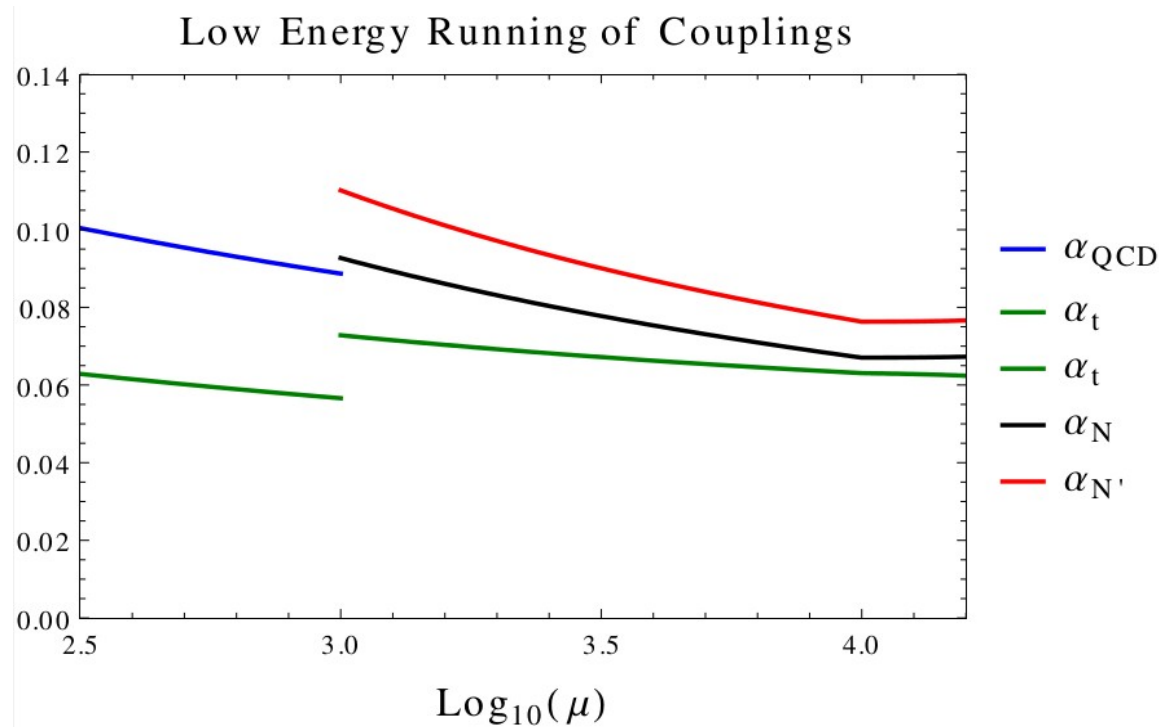
# Theory with Realistic Symmetry Breaking

✓ Realistic symmetry breaking scenario:

$$\frac{1}{\alpha_3} \geq \frac{1}{\alpha_N} + \frac{1}{\alpha_{N'}}$$

✗ Realistic top quark Yukawa coupling:

$$\alpha_t^{\overline{MS}}(m_t) \text{ within } \pm 5.65 \%$$



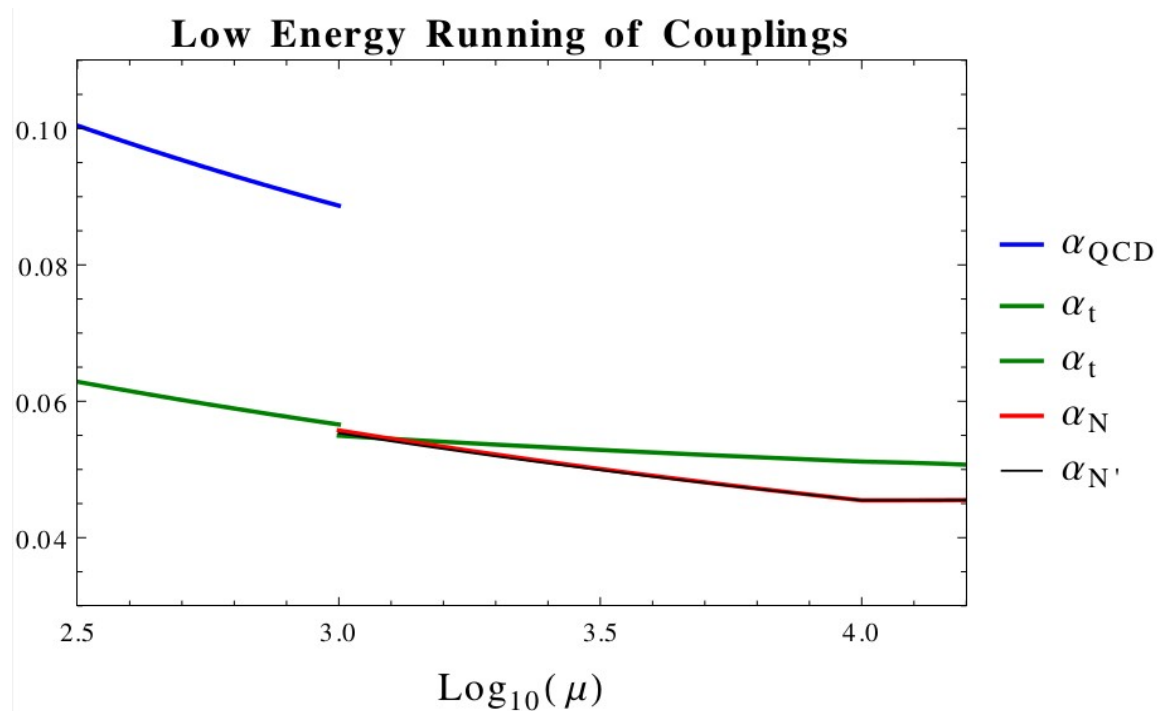
# Theory with Realistic Yukawa Coupling

✗ Realistic symmetry breaking scenario:

$$\frac{1}{\alpha_3} \geq \frac{1}{\alpha_N} + \frac{1}{\alpha_{N'}}$$

✓ Realistic top quark Yukawa coupling:

$$\alpha_t^{\overline{MS}}(m_t) \text{ within } \pm 5.65 \%$$





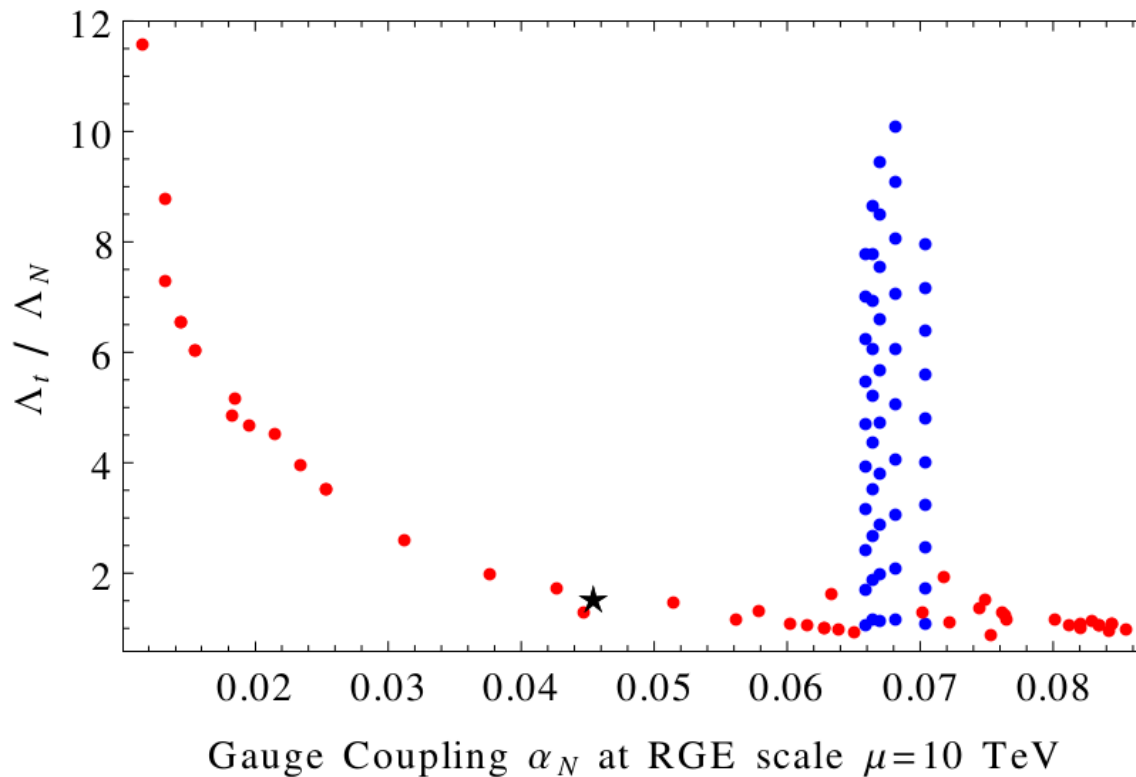
# Little Conformal Symmetry UV Theories

Realistic symmetry  
breaking scenario:

$$\frac{1}{\alpha_3} \geq \frac{1}{\alpha_N} + \frac{1}{\alpha_{N'}}$$

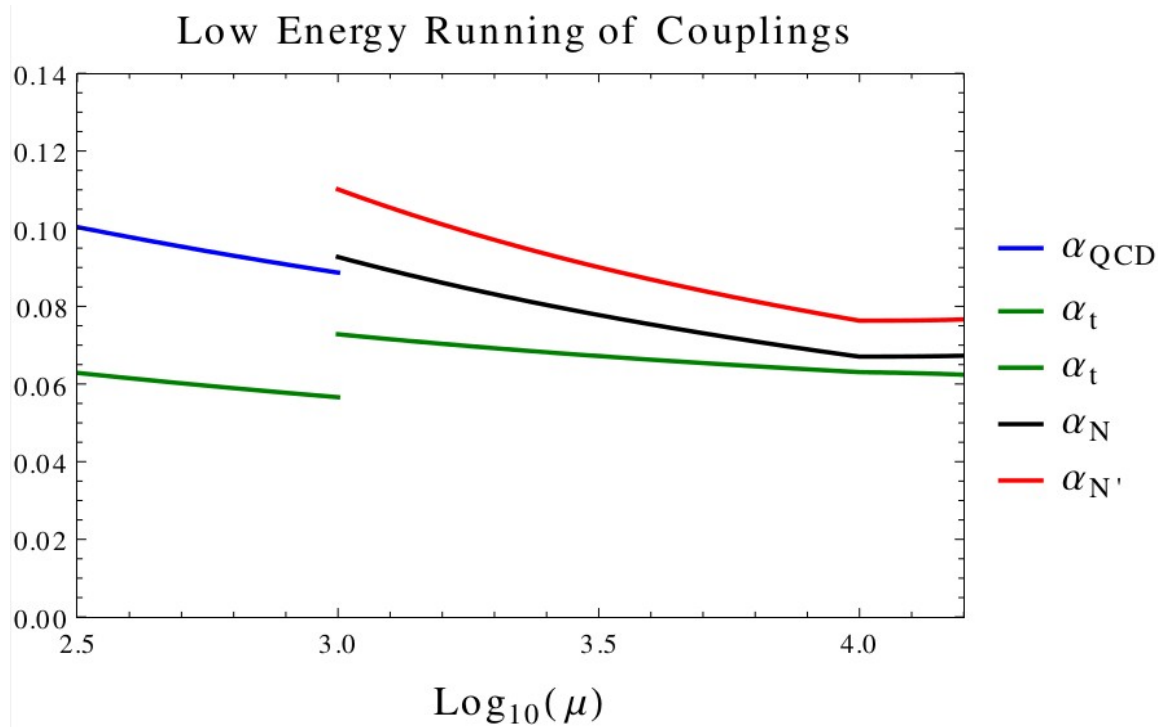
Realistic top quark  
Yukawa coupling:

$$\alpha_t^{\overline{MS}}(m_t) \text{ within } \pm 5.65 \%$$



# 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  $\beta(\alpha_t)$

