

# LITTLE CONFORMAL SYMMETRY

arXiv: 1603.00030

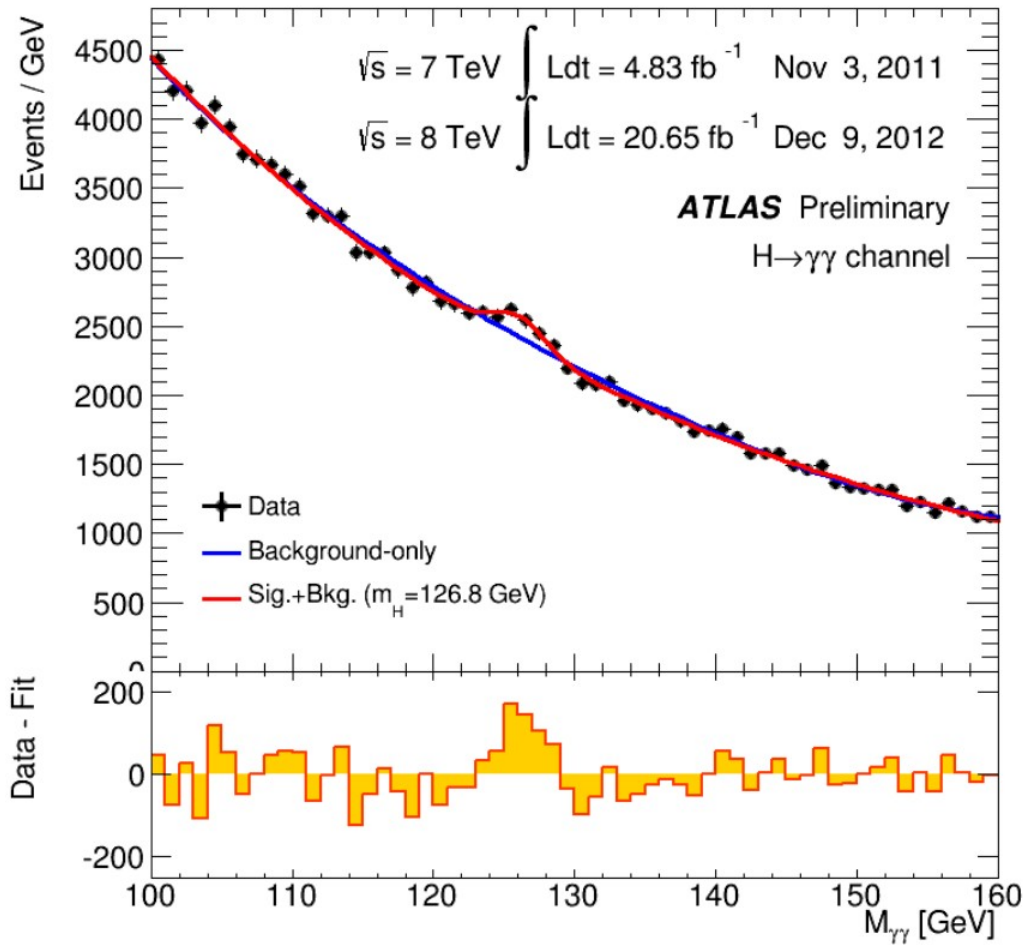


Rachel Houtz  
ICHEP 2016  
Chicago

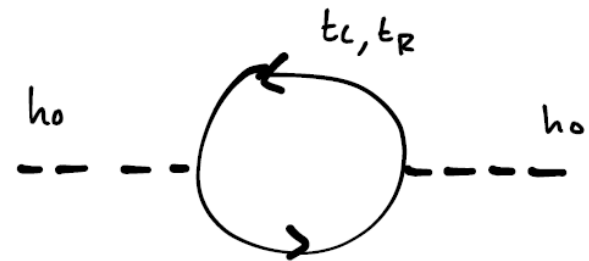
In Collaboration with John Terning (UC Davis),  
Kitran Colwell (UC Davis)

# 125 GeV Higgs

Amazing!



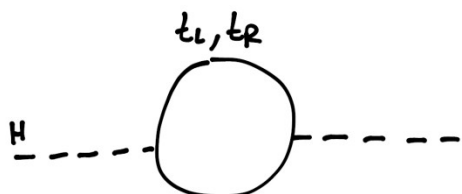
*except...*



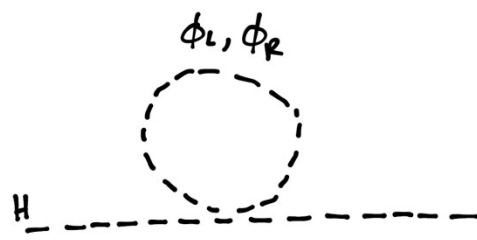
$$\delta m_h^2 = -\frac{N_c}{16\pi^2} |y_t|^2 \times \left[ 2\Lambda^2 - 6m_t^2 \ln \left( \frac{\Lambda^2 + m_t^2}{m_t^2} \right) + \dots \right]$$

# Cancelling the Divergence

## *SUSY's Claim to Fame*



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



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

**SUSY guarantees such a cancellation**

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

# Where are the superpartners?

## ATLAS SUSY Searches\* - 95% CL Lower Limits

Status: July 2016

ATLAS Preliminary

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

Model	$e, \mu, \tau, \gamma$	Jets	$E_{\text{T}}^{\text{miss}}$	$\int \mathcal{L} d\tau [\text{fb}^{-1}]$	Mass limit	$\sqrt{s} = 7, 8 \text{ TeV}$	$\sqrt{s} = 13 \text{ TeV}$	Reference		
Inclusive Searches	MSUGRA/CMSSM	0-3 $e, \mu/1\text{-}2 \tau$	2-10 jets/3 $b$	Yes	20.3	$\tilde{q}, \tilde{g}$	1.85 TeV	$m(\tilde{q})=m(\tilde{g})$	1507.05525	
	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	3.2	$\tilde{q}$	1.03 TeV	$m(\tilde{\chi}_1^0) < 250 \text{ GeV}, m(1^{\text{st}} \text{ gen. } \tilde{q})=m(2^{\text{nd}} \text{ gen. } \tilde{q})$	1605.03814	
	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	3.2	$\tilde{q}$	608 GeV	$m(\tilde{q})-m(\tilde{\chi}_1^0) < 5 \text{ GeV}$	1604.07773	
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	3.2	$\tilde{g}$	1.51 TeV	$m(\tilde{\chi}_1^0) < 250 \text{ GeV}$	1605.03814	
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0 \rightarrow q\tilde{q}W^\pm\tilde{\chi}_1^0$	1 $e, \mu$	2-6 jets	Yes	3.3	$\tilde{g}$	1.6 TeV	$m(\tilde{\chi}_1^0) < 350 \text{ GeV}, m(\tilde{\chi}^\pm) = 0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	1605.04285	
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}(\ell\ell/\ell\gamma/\nu\nu)\tilde{\chi}_1^0$	2 $e, \mu$	0-3 jets	-	20	$\tilde{g}$	1.38 TeV	$m(\tilde{\chi}_1^0) = 0 \text{ GeV}$	1501.03555	
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}WZ\tilde{\chi}_1^0$	0	7-10 jets	Yes	3.2	$\tilde{g}$	1.4 TeV	$m(\tilde{\chi}_1^0) = 100 \text{ GeV}$	1602.06194	
	GMSB ( $\tilde{\ell}$ NLSP)	1-2 $\tau + 0\text{-}1 \ell$	0-2 jets	Yes	3.2	$\tilde{g}$	2.0 TeV	$\tau\tau(\text{NLSP}) < 0.1 \text{ mm}$	To appear	
	GGM (bino NLSP)	2 $\gamma$	-	Yes	3.2	$\tilde{g}$	1.65 TeV	$m(\tilde{\chi}_1^0) < 950 \text{ GeV}, \tau\tau(\text{NLSP}) < 0.1 \text{ mm}, \mu < 0$	1606.09150	
	GGM (higgsino-bino NLSP)	$\gamma$	1 $b$	Yes	20.3	$\tilde{g}$	1.37 TeV	$m(\tilde{\chi}_1^0) < 850 \text{ GeV}, \tau\tau(\text{NLSP}) < 0.1 \text{ mm}, \mu < 0$	1507.05493	
	GGM (higgsino-bino NLSP)	$\gamma$	2 jets	Yes	20.3	$\tilde{g}$	1.3 TeV	$m(\text{NLSP}) > 430 \text{ GeV}$	1507.05493	
	GGM (higgsino NLSP)	2 $e, \mu$ (Z)	2 jets	Yes	20.3	$\tilde{g}$	900 GeV	$m(\text{NLSP}) > 430 \text{ GeV}$	1503.03290	
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale	865 GeV	$m(\tilde{G}) > 1.8 \times 10^{-4} \text{ eV}, m(\tilde{g})=m(\tilde{q})=1.5 \text{ TeV}$	1502.01518	
3 <sup>rd</sup> gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow b\tilde{b}\tilde{\chi}_1^0$	0	3 $b$	Yes	3.3	$\tilde{g}$	1.78 TeV	$m(\tilde{\chi}_1^0) < 800 \text{ GeV}$	1605.09318	
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	0-1 $e, \mu$	3 $b$	Yes	3.3	$\tilde{g}$	1.8 TeV	$m(\tilde{\chi}_1^0) = 0 \text{ GeV}$	1605.09318	
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow b\tilde{t}\tilde{\chi}_1^0$	0-1 $e, \mu$	3 $b$	Yes	20.1	$\tilde{g}$	1.37 TeV	$m(\tilde{\chi}_1^0) < 300 \text{ GeV}$	1407.06000	
3 <sup>rd</sup> gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$	0	2 $b$	Yes	3.2	$\tilde{b}_1$	840 GeV	$m(\tilde{\chi}_1^0) < 100 \text{ GeV}$	1606.08772	
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{\chi}_1^\pm$	2 $e, \mu$ (SS)	0-3 $b$	Yes	3.2	$\tilde{b}_1$	325-540 GeV	$m(\tilde{\chi}_1^\pm) = 50 \text{ GeV}, m(\tilde{\chi}_1^\pm) = m(\tilde{\chi}_1^0) + 100 \text{ GeV}$	1602.09058	
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$	1-2 $e, \mu$	1-2 $b$	Yes	4.7/20.3	$\tilde{t}_1$	117-170 GeV	$m(\tilde{\chi}_1^\pm) = 2m(\tilde{\chi}_1^0), m(\tilde{\chi}_1^\pm) = 55 \text{ GeV}$	1209.2102, 1407.0583	
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$ or $\tilde{\chi}_1^0$	0-2 $e, \mu$	0-2 jets/1-2 $b$	Yes	20.3	$\tilde{t}_1$	90-198 GeV	$m(\tilde{\chi}_1^0) = 1 \text{ GeV}$	1506.08616, 1606.03903	
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$	0	mono-jet/ $c$ -tag	Yes	20.3	$\tilde{t}_1$	90-245 GeV	$m(\tilde{\chi}_1^0) = 1 \text{ GeV}$	1407.0608	
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 $e, \mu$ (Z)	1 $b$	Yes	20.3	$\tilde{t}_1$	150-600 GeV	$m(\tilde{\chi}_1^0) < 85 \text{ GeV}$	1403.5222	
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3 $e, \mu$ (Z)	1 $b$	Yes	20.3	$\tilde{t}_2$	290-610 GeV	$m(\tilde{\chi}_1^0) < 200 \text{ GeV}$	1403.5222	
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + h$	1 $e, \mu$	6 jets + 2 $b$	Yes	20.3	$\tilde{t}_2$	320-620 GeV	$m(\tilde{\chi}_1^0) = 0 \text{ GeV}$	1506.08616	
	EW direct	$\tilde{\ell}_L\tilde{\ell}_L, \tilde{\ell} \rightarrow \tilde{\ell}\tilde{\chi}_1^0$	2 $e, \mu$	0	Yes	20.3	$\tilde{\ell}$	90-335 GeV	$m(\tilde{\chi}_1^0) = 0 \text{ GeV}$	1403.5294
		$\tilde{\chi}_1^0\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow \tilde{\ell}\nu(\tilde{\nu})$	2 $e, \mu$	0	Yes	20.3	$\tilde{\chi}_1^0$	140-475 GeV	$m(\tilde{\chi}_1^\pm) = 0 \text{ GeV}, m(\tilde{\ell}, \tilde{\nu}) = 0.5(m(\tilde{\chi}_1^0)+m(\tilde{\chi}_1^\pm))$	1403.5294
$\tilde{\chi}_1^0\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow \tilde{\ell}\nu(\tilde{\nu})$		2 $\tau$	-	Yes	20.3	$\tilde{\chi}_1^0$	355 GeV	$m(\tilde{\chi}_1^\pm) = 0 \text{ GeV}, m(\tilde{\ell}, \tilde{\nu}) = 0.5(m(\tilde{\chi}_1^0)+m(\tilde{\chi}_1^\pm))$	1407.0350	
$\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \tilde{\ell}_L\nu\tilde{\ell}_L(\tilde{\nu}\nu), \tilde{\ell}\tilde{\nu}(\tilde{\ell}\tilde{\nu})$		3 $e, \mu$	0	Yes	20.3	$\tilde{\chi}_1^0, \tilde{\chi}_1^0$	715 GeV	$m(\tilde{\chi}_1^\pm) = m(\tilde{\chi}_1^0), m(\tilde{\chi}_1^\pm) = 0, m(\tilde{\ell}, \tilde{\nu}) = 0.5(m(\tilde{\chi}_1^0)+m(\tilde{\chi}_1^\pm))$	1402.7029	
$\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$		2-3 $e, \mu$	0-2 jets	Yes	20.3	$\tilde{\chi}_1^0, \tilde{\chi}_1^0$	425 GeV	$m(\tilde{\chi}_1^\pm) = m(\tilde{\chi}_1^0), m(\tilde{\chi}_1^\pm) = 0, \text{ sleptons decoupled}$	1403.5294, 1402.7029	
$\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow W\tilde{\chi}_1^0 \tilde{\chi}_1^\pm, h \rightarrow b\tilde{b}/WW/\tau\tau/\gamma\gamma$		$e, \mu, \gamma$	0-2 $b$	Yes	20.3	$\tilde{\chi}_1^0, \tilde{\chi}_1^0$	270 GeV	$m(\tilde{\chi}_1^\pm) = m(\tilde{\chi}_1^0), m(\tilde{\chi}_1^\pm) = 0, \text{ sleptons decoupled}$	1501.07110	
$\tilde{\chi}_1^0\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow \tilde{\ell}_L\tilde{\ell}_L$		4 $e, \mu$	0	Yes	20.3	$\tilde{\chi}_1^0, \tilde{\chi}_1^0$	635 GeV	$m(\tilde{\chi}_1^0) = m(\tilde{\chi}_1^\pm), m(\tilde{\chi}_1^0) = 0, m(\tilde{\ell}, \tilde{\nu}) = 0.5(m(\tilde{\chi}_1^0)+m(\tilde{\chi}_1^\pm))$	1405.5086	
GGM (wino NLSP) weak prod.		1 $e, \mu + \gamma$	-	Yes	20.3	$\tilde{W}$	115-370 GeV	$\tau\tau < 1 \text{ mm}$	1507.05493	
GGM (bino NLSP) weak prod.		2 $\gamma$	-	Yes	20.3	$\tilde{W}$	590 GeV	$\tau\tau < 1 \text{ mm}$	1507.05493	
Long-lived particles		Direct $\tilde{\chi}_1^0\tilde{\chi}_1^0$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$	270 GeV	$m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0) \sim 160 \text{ MeV}, \tau(\tilde{\chi}_1^\pm) = 0.2 \text{ ns}$	1310.3675
	Direct $\tilde{\chi}_1^0\tilde{\chi}_1^0$ prod., long-lived $\tilde{\chi}_1^0$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^0$	495 GeV	$m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0) \sim 160 \text{ MeV}, \tau(\tilde{\chi}_1^0) < 15 \text{ ns}$	1506.05332	
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$	850 GeV	$m(\tilde{\chi}_1^0) = 100 \text{ GeV}, 10 \mu\text{s} < \tau(\tilde{g}) < 1000 \text{ s}$	1310.6584	
	Stable $\tilde{g}$ R-hadron	trk	-	-	3.2	$\tilde{g}$	1.58 TeV		1606.05129	
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{g}$	1.57 TeV		1604.04520	
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0 \rightarrow \tilde{\tau}(\tilde{e}, \tilde{\mu}) + \tau(e, \mu)$	1-2 $\mu$	-	-	19.1	$\tilde{\chi}_1^0$	537 GeV	$10 < \tan\beta < 50$	1411.6795	
	GMSB, $\tilde{\chi}_1^0 \rightarrow \gamma G$ , long-lived $\tilde{\chi}_1^0$	2 $\gamma$	-	Yes	20.3	$\tilde{\chi}_1^0$	440 GeV	$1 < \tau(\tilde{\chi}_1^0) < 3 \text{ ns}$ , SPS8 model	1409.5542	
	$\tilde{g}\tilde{g}, \tilde{\chi}_1^0 \rightarrow e\tilde{e}\nu/\mu\tilde{\nu}/\mu\mu\nu$	displ. $e\tilde{e}/\mu\tilde{\nu}/\mu\mu\nu$	-	-	20.3	$\tilde{\chi}_1^0$	1.0 TeV	$7 < \tau(\tilde{\chi}_1^0) < 740 \text{ mm}, m(\tilde{g}) = 1.3 \text{ TeV}$	1504.05162	
	GGM $\tilde{g}\tilde{g}, \tilde{\chi}_1^0 \rightarrow ZG$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$	1.0 TeV	$6 < \tau(\tilde{\chi}_1^0) < 480 \text{ mm}, m(\tilde{g}) = 1.1 \text{ TeV}$	1504.05162	
	RPV	LFV $pp \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e\mu/\tau\mu/\mu\tau$	$e\mu, e\tau, \mu\tau$	-	-	20.3	$\tilde{\nu}_\tau$	1.7 TeV	$\lambda'_{311} = 0.11, \lambda_{132/133/233} = 0.07$	1503.04430
Bi-linear RPV CMSSM		2 $e, \mu$ (SS)	0-3 $b$	Yes	20.3	$\tilde{q}, \tilde{g}$	1.45 TeV	$m(\tilde{q})=m(\tilde{g}), \tau\tau_{\text{LSP}} < 1 \text{ mm}$	1404.2500	
$\tilde{\chi}_1^0\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow W\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow e\tilde{e}\nu_\mu, e\mu\nu_\tau$		4 $e, \mu$	-	Yes	20.3	$\tilde{\chi}_1^0$	760 GeV	$m(\tilde{\chi}_1^0) > 0.2 \times m(\tilde{\chi}_1^\pm), \lambda_{121} \neq 0$	1405.5086	
$\tilde{\chi}_1^0\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow W\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \tau\tilde{\tau}\nu_\mu, e\tau\nu_\tau$		3 $e, \mu + \tau$	-	Yes	20.3	$\tilde{\chi}_1^0$	450 GeV	$m(\tilde{\chi}_1^0) > 0.2 \times m(\tilde{\chi}_1^\pm), \lambda_{133} \neq 0$	1405.5086	
$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0$		0	6-7 jets	-	20.3	$\tilde{g}$	917 GeV	$\text{BR}(\eta)=\text{BR}(h)=\text{BR}(c)=0\%$	1502.05686	
$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0 \rightarrow q\tilde{q}\tilde{\chi}_1^0$		0	6-7 jets	-	20.3	$\tilde{g}$	980 GeV		1502.05686	
$\tilde{g}\tilde{g}, \tilde{g} \rightarrow h\tilde{t}, \tilde{t}_1 \rightarrow b\tilde{s}$		2 $e, \mu$ (SS)	0-3 $b$	Yes	20.3	$\tilde{g}$	880 GeV		1404.2500	
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\tilde{s}$		0	2 jets + 2 $b$	-	3.2	$\tilde{t}_1$	345 GeV		ATLAS-CONF-2016-022	
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\tilde{\ell}$		2 $e, \mu$	2 $b$	-	20.3	$\tilde{t}_1$	0.4-1.0 TeV	$\text{BR}(\tilde{t}_1 \rightarrow b\tilde{e}/\mu) > 20\%$	ATLAS-CONF-2015-015	
Other		Scalar charm, $\tilde{c} \rightarrow c\tilde{\chi}_1^0$	0	2 $c$	Yes	20.3	$\tilde{c}$	510 GeV	$m(\tilde{\chi}_1^0) < 200 \text{ GeV}$	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]

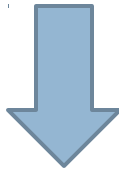
\*Only a selection of the available mass limits on new states or phenomena is shown.

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

# Alternative Theory: Introduce a new Gauge Boson

$$\delta m_h \ni \text{H} \text{---} \text{---} \text{---} \text{---} \text{---} + \text{H} \text{---} \text{---} \text{---} \text{---} \text{---}$$

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



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

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



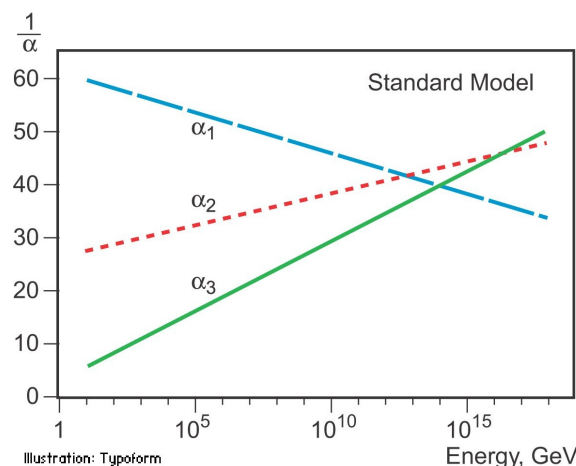
# Some Problems....

1) How is this not just different fine tuning?

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



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/)

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

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

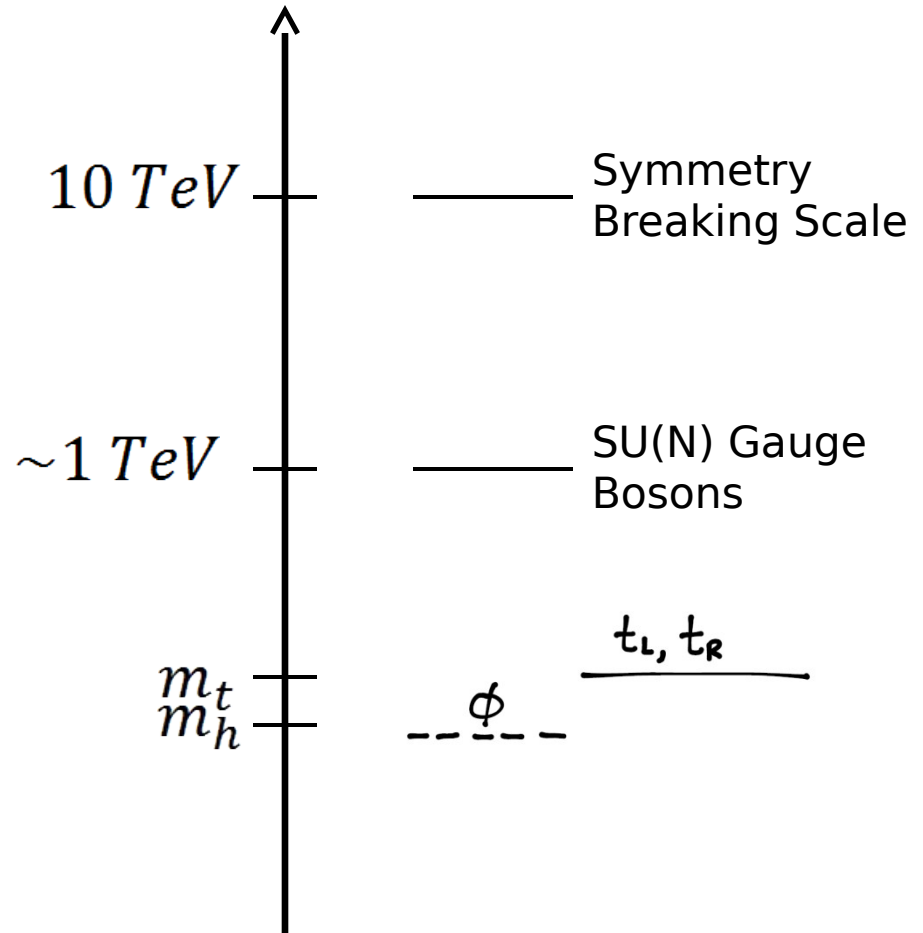
N. Arkani-Hamed, A. G. Cohen, T. Gregoire, and J. G. Wacker,  
*Phenomenology of electroweak symmetry breaking from theory space*,  
*hep-ph/0202089*

# Little Conformal Symmetry: A Simple Toy Model

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

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

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





## Top Yukawa Fixed Point

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

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

## Quadratic Divergence Cancellation

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

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

### 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

$$a = \frac{1}{2} \left( \text{triangle with } t_R, t_L \text{ and } \phi \text{ external lines} + \text{triangle with } t_R, t_L \text{ and } \phi \text{ external lines} \right) + \text{triangle with } t_R, t_L \text{ and } \phi \text{ external lines}$$

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

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

Symmetry Condition

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

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

✓ Quadratic Divergence Cancelled

✓ Top Yukawa at a fixed point

- New Gauge coupling at a fixed point.

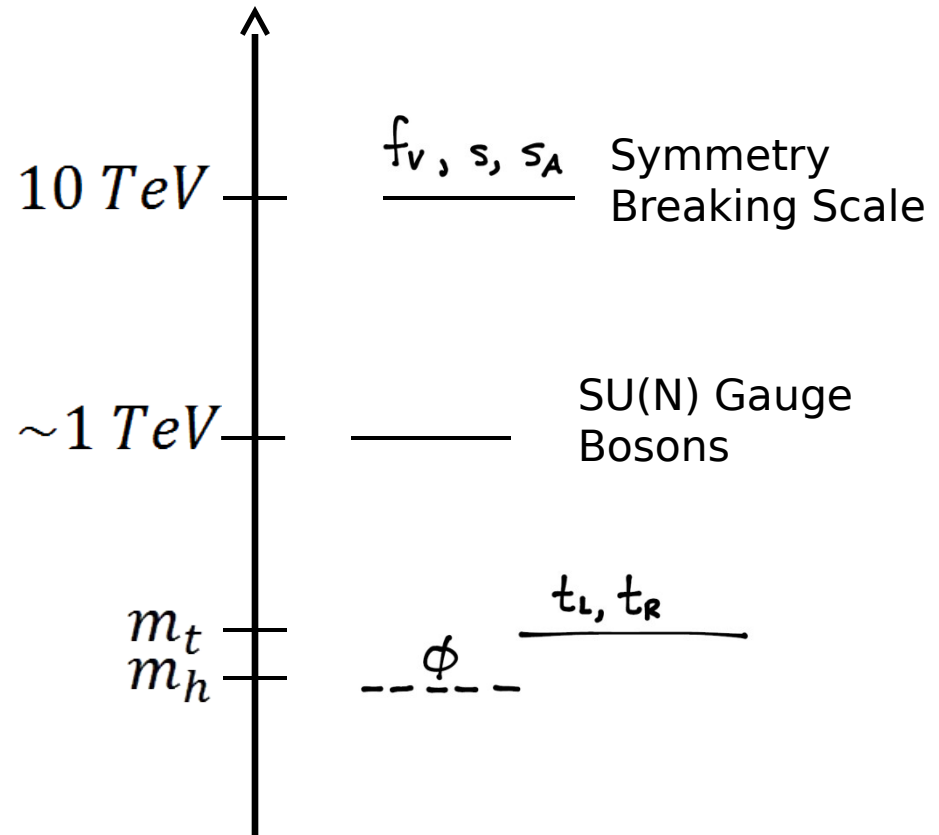
# Gauge Coupling Banks-Zaks Fixed Point

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

$$\beta(g_N) \ni \left( \text{triangle} + \text{bubble} + \text{ghost} \right) + \left( \text{self-energy} + \text{tadpole} + \dots \right)$$

$\beta$  -function coefficients depend on the matter content of the UV theory

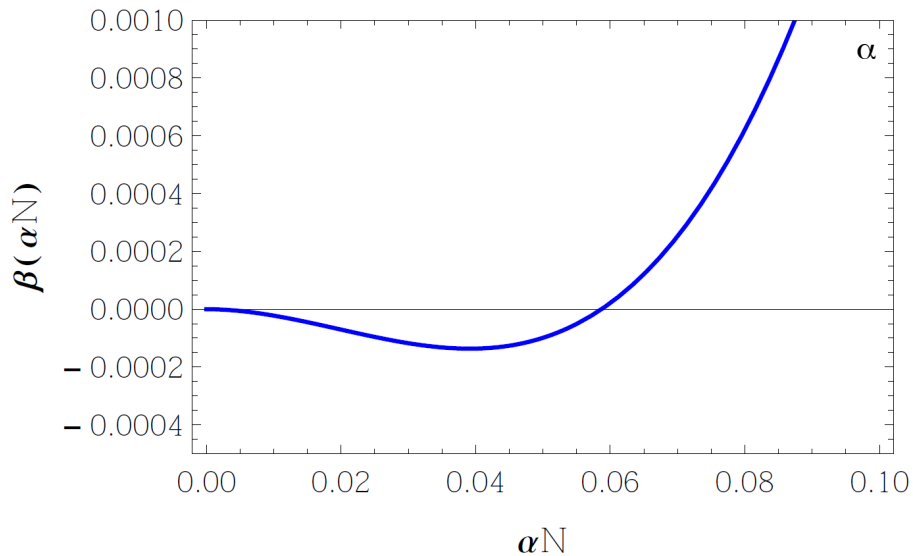
	copies	SU(N)
$t_L$	$2N_c$	1
$t_R$	$N_c$	$\square$
$\phi$	2	$\square$
$f_V$	7	$\square$
$s$	4	$\square$
$s_A$	10	Ad



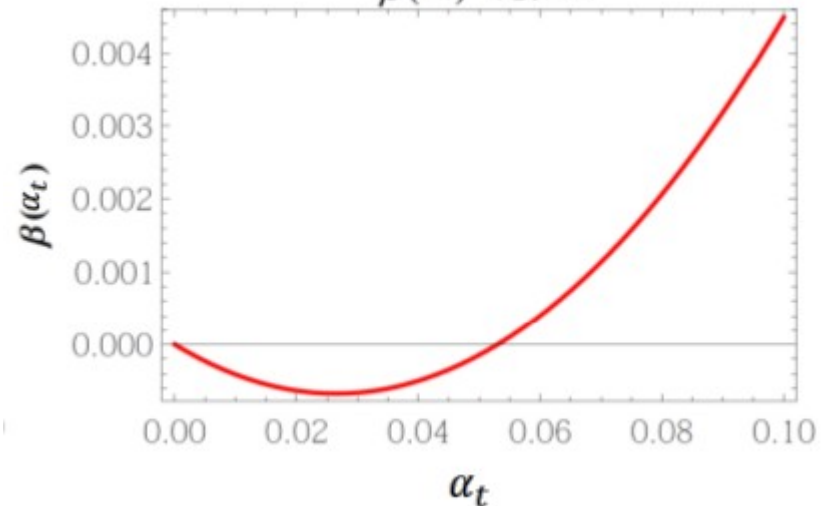
# Gauge Coupling Banks-Zaks Fixed Point

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

$\beta(\alpha_N)$  vs.  $\alpha_N$



$\beta(\alpha_t)$  vs.  $\alpha_t$



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:

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

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

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

# Little Conformal Symmetry: Matter Content

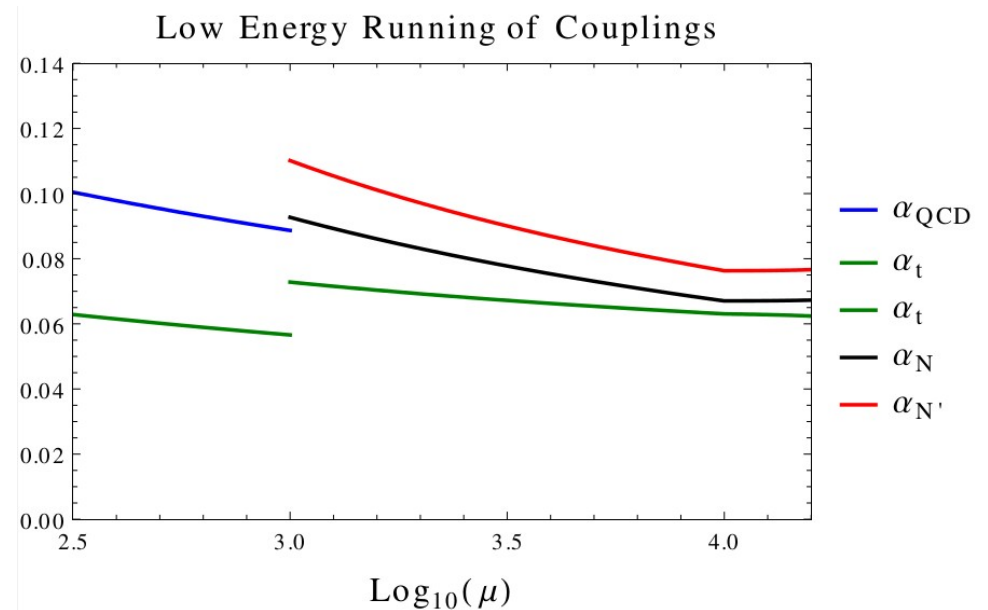
	$SU(N)$	$SU(N')$
$q_L$	$\square$	$\mathbf{1}$
$H$	$\square$	$\square$
$t_R$	$\mathbf{1}$	$\square$

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

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

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

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



# Take another look at the cutoffs...

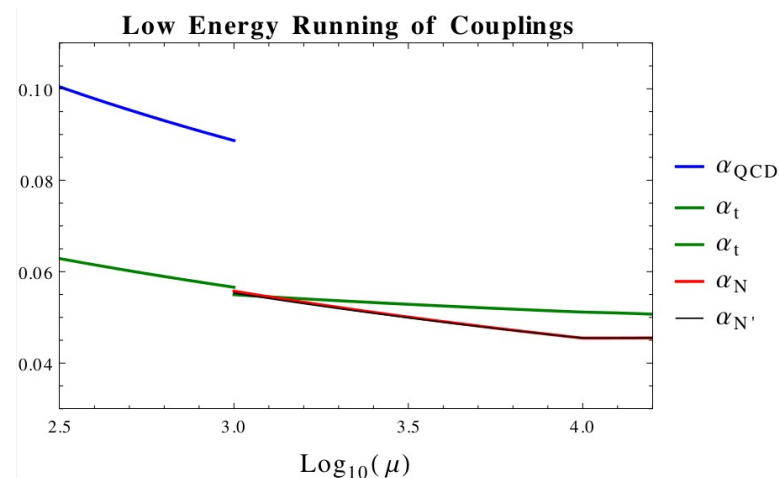
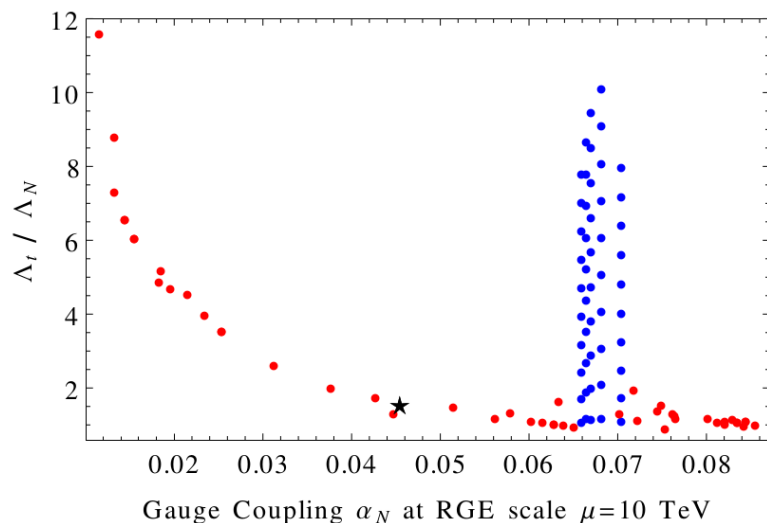
$$\delta m_h^2 \ni -2N_C \alpha_t \Lambda_t^2 + 3C_2(S) \alpha_N \Lambda_N^2 + 3C_2(S) \alpha_{N'} \Lambda_{N'}^2$$

➤ For a relationship among  $\Lambda_N$ ,  $\Lambda_{N'}$ , and  $\Lambda_t$ , 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. Rattazzi, 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

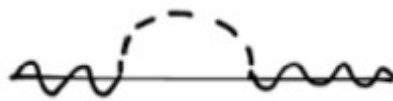




# Back-up Slides

# Gauge-Mediated SUSY

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



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

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



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

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

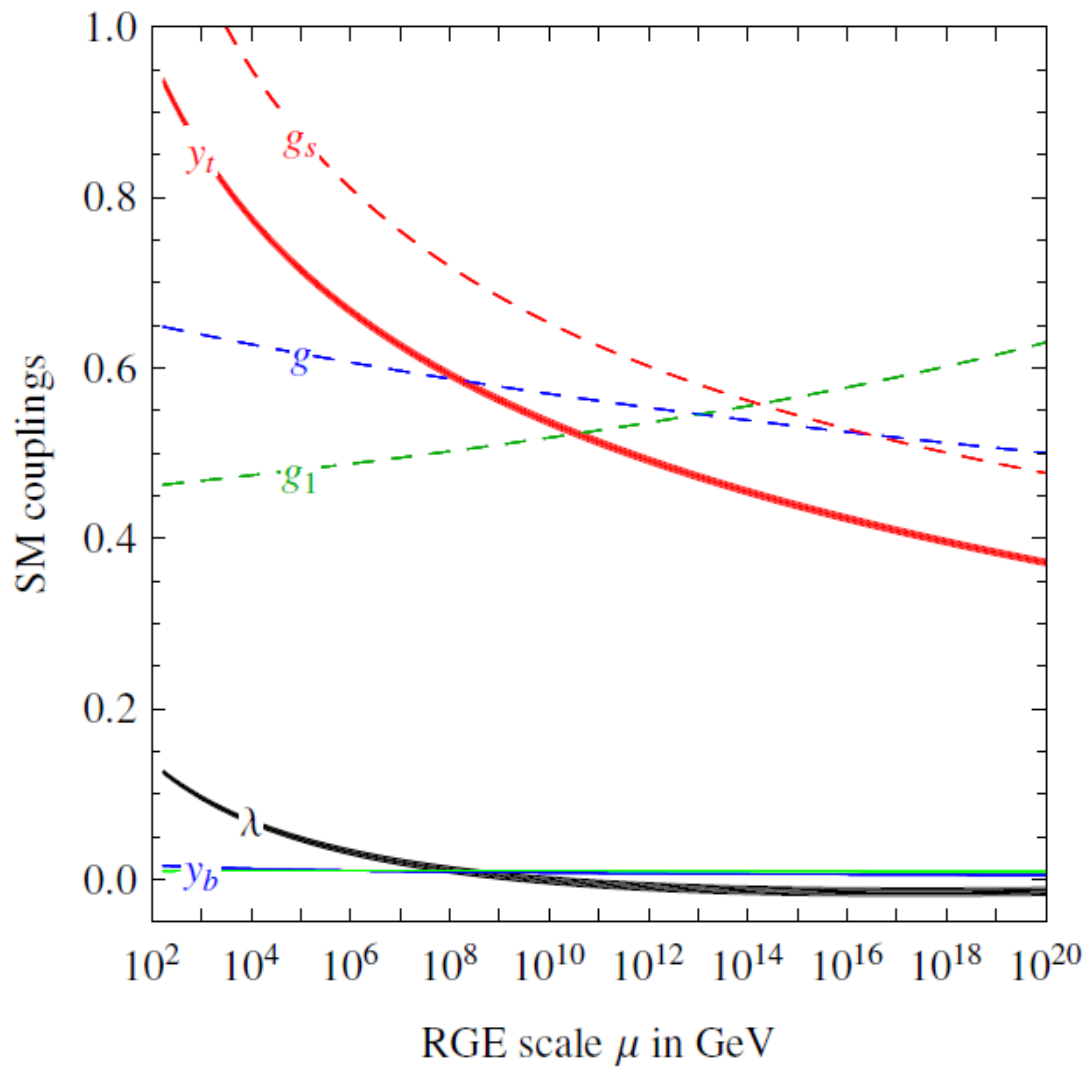
$$\frac{m_{\tilde{t}_R}^2}{m_N^2} = \frac{2C_2^N(\blacksquare)}{S_2^N(m)}$$

$$\frac{m_{\tilde{t}_L}^2}{m_M^2} = \frac{2C_2^M(\blacksquare)}{S_2^M(m)}$$

$$\frac{m_N^2}{m_M^2} = \frac{S_2^N(m)}{S_2^M(m)} \left(\frac{\alpha_N}{\alpha_M}\right)^2$$

For  $N_m$  messengers in the fundamental representation:

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



Degrassi, et al. JHEP 08 (2012) 098