LITTLE CONFORMAL SYMMETRY

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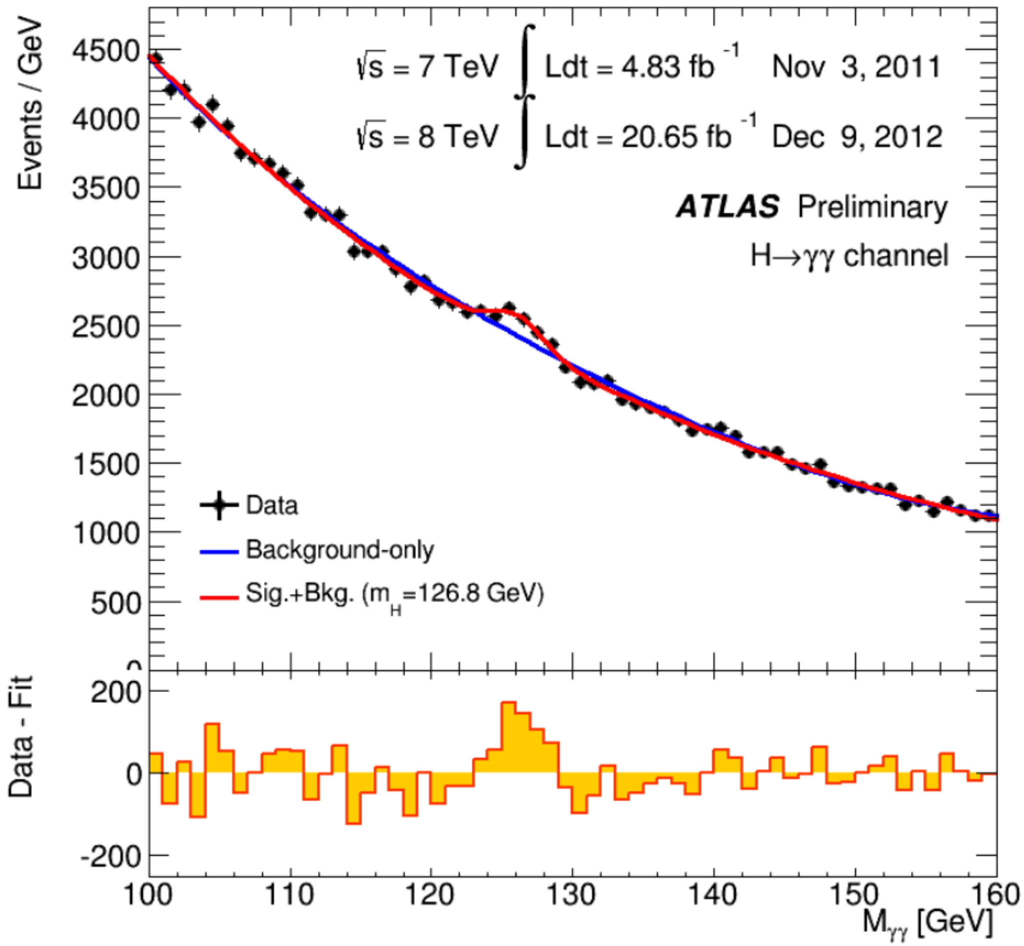
SUSY 2015

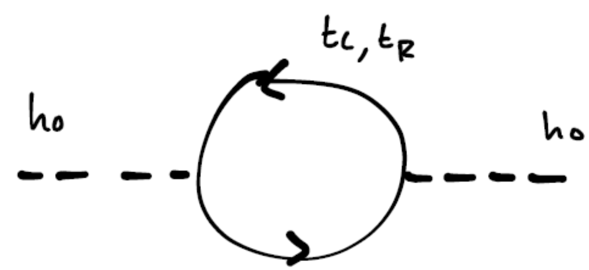
In Collaboration with John Terning (UC Davis),
Kit Colwell (UC Davis)

125 GeV Higgs



Amazing!

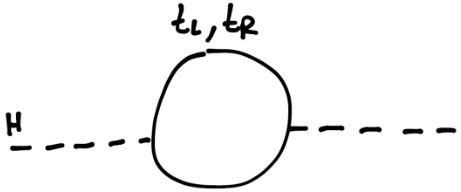
except…



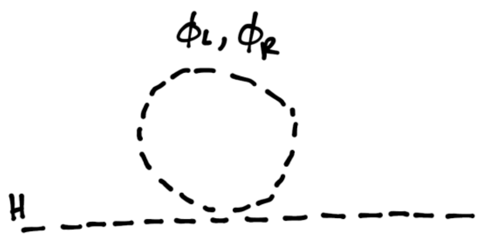
$$\delta m_h^2 = -\frac{N_C}{16\pi^2}|y_t|^2 \times \left[2\Lambda^2 - 6m_t^2 \ln\left(\frac{\Lambda^2 + m_t^2}{m_t^2}\right) + \cdots\right]$$

Cancelling the Divergence

SUSY's Claim to Fame



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

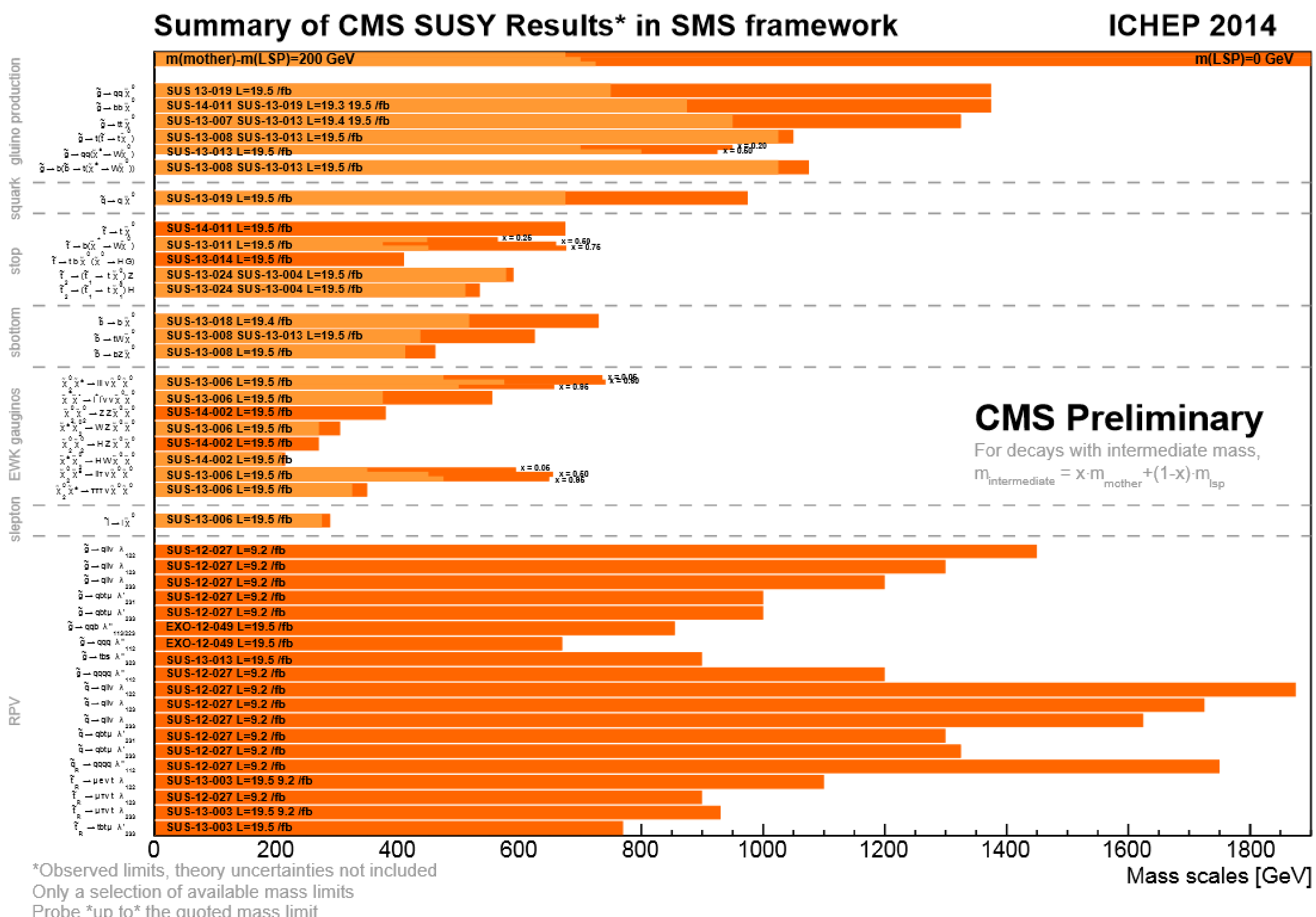


$$\delta m_h^2 = \frac{\lambda N}{16\pi^2}\left[2\Lambda^2 - m_L^2 \ln\left(\frac{\Lambda^2 + m_L^2}{m_L^2}\right) - m_R^2 \ln\left(\frac{\Lambda^2 + m_R^2}{m_R^2}\right) + \cdots\right]$$

SUSY guarantees such a cancellation

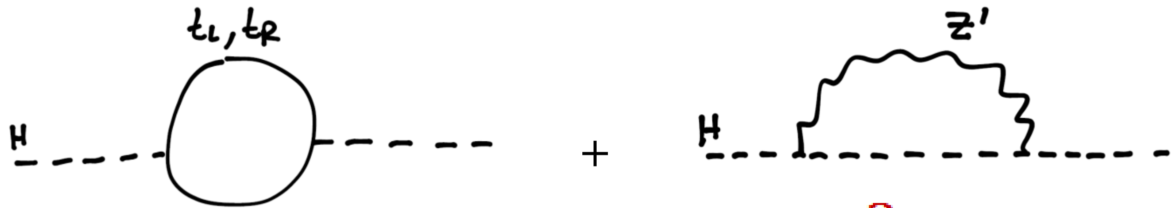
Terning. *Modern Supersymmetry: Dynamics and Duality.* Oxford University Press USA, 2006.

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.

Little Conformal Symmetry

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

What if this is a result of an underlying Symmetry?

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

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

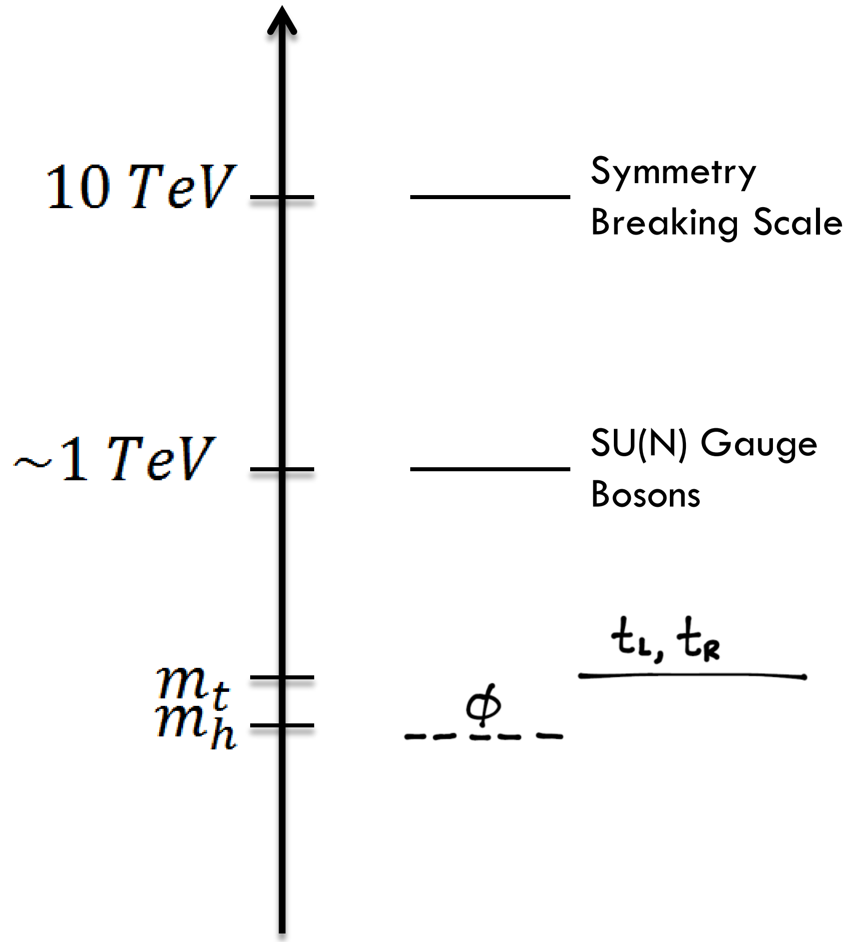
N. Arkani-Hamed, A. G. Cohen, T. Gregoire, and J. G. Wacker, *Phenomenology of electroweak symmetry breaking from theory space, hep-ph/0202089*

Little Conformal Symmetry: A Simple Toy Model

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

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

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



Top Yukawa Fixed Point

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

$$0 = a\Gamma_t - b_N \alpha_N$$

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

Quadratic Divergence Cancellation

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

$$0 = -2N_C \Gamma_t + 3C_2(S)\alpha_N$$

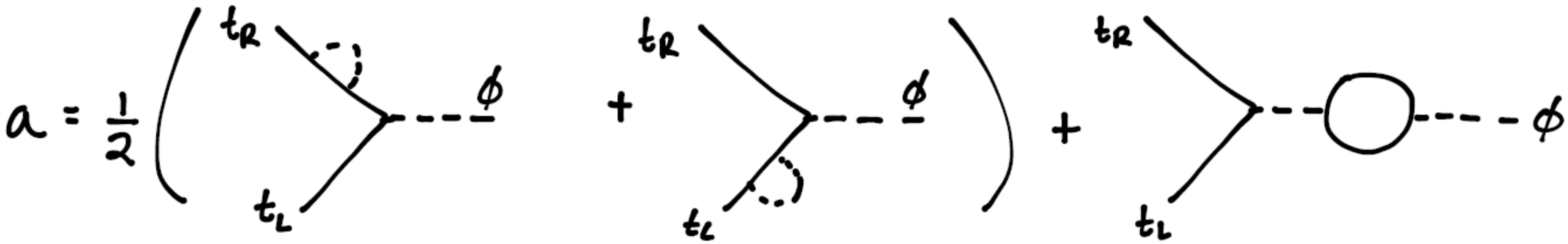
$$\Gamma_t = \frac{3C_2(S)}{2N_C}\alpha_N$$

Symmetry Condition

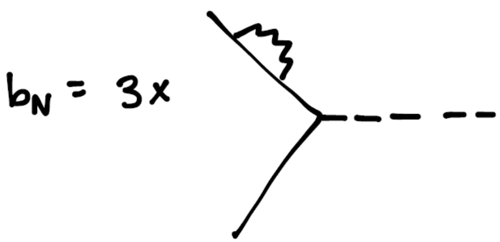
$$\frac{b_N}{a} = \frac{3C_2(S)}{2N_C}$$

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

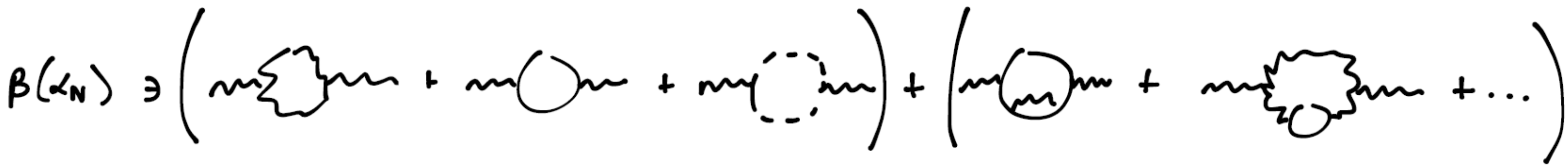
$$\frac{b_N}{a} = \frac{3C_2(S)}{2N_C} \Longrightarrow \boxed{N = 4}$$

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

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

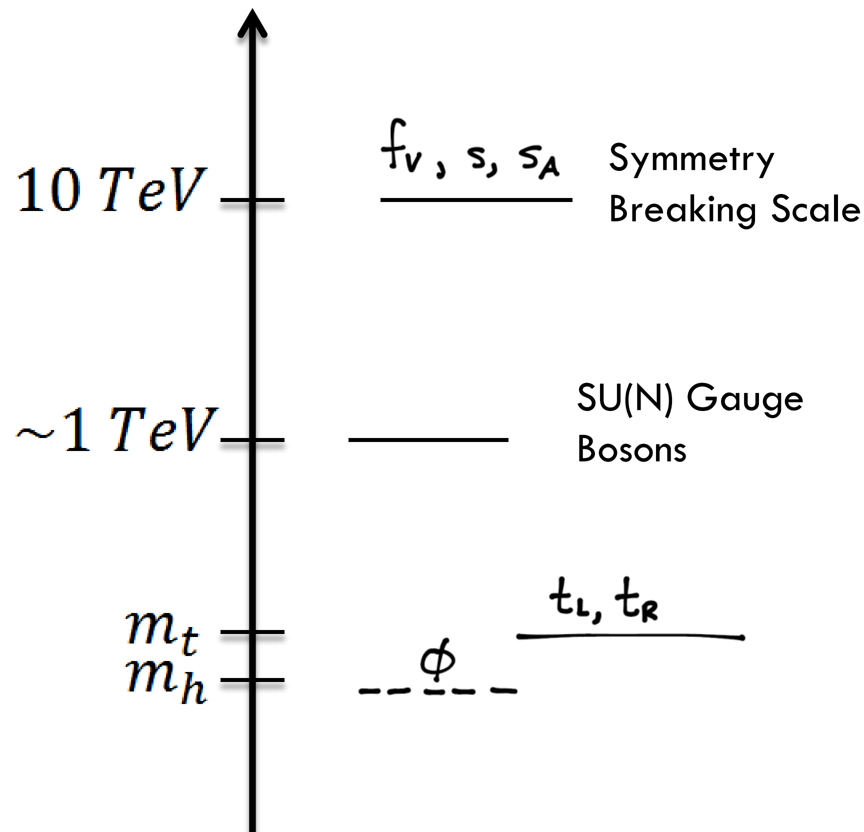
Gauge Coupling Banks-Zaks Fixed Point

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

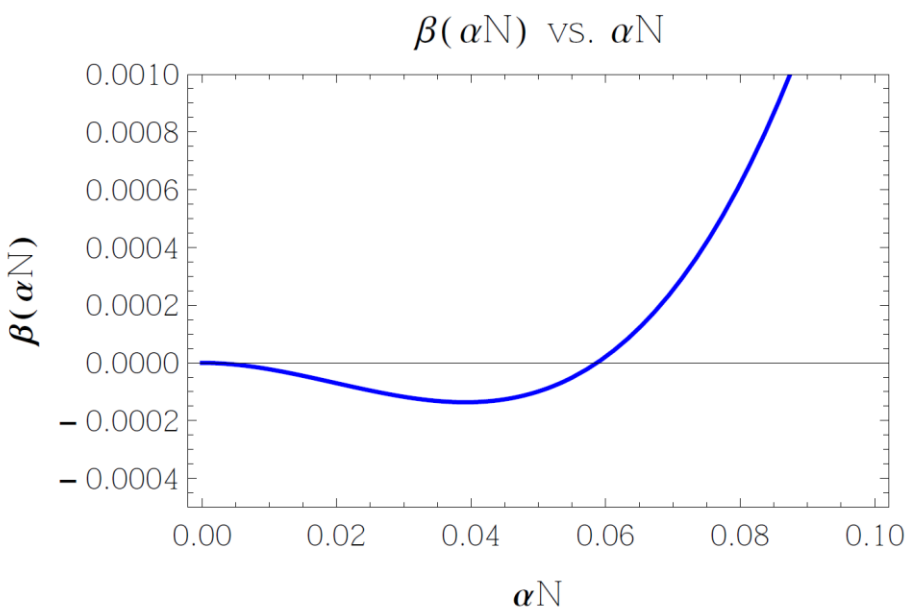
	copies	SU(N)
t_L	$2N_c$	1
t_R	N_c	□
ϕ	2	□
f_V	7	□
s	4	□
s_A	10	Ad

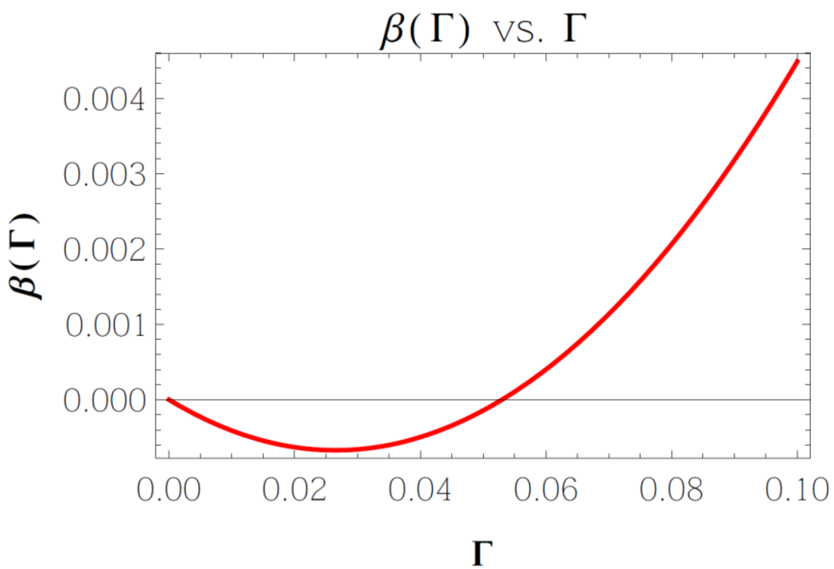


Gauge Coupling Banks-Zaks Fixed Point

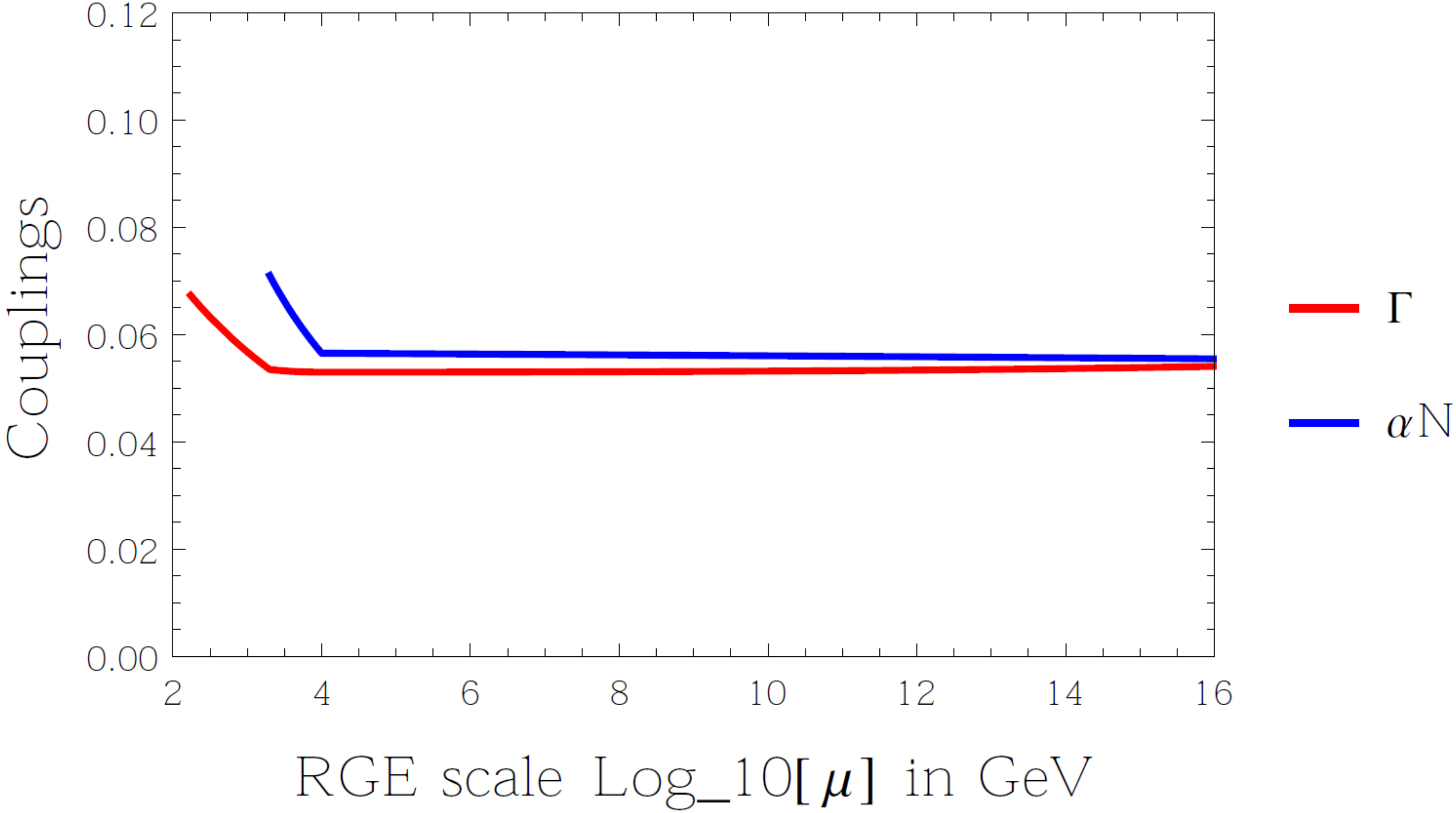
- Remember, the values of α is already set from our Γ/α relation.

- In order to make this value of α coincide with its fixed point, we added new matter to the UV theory





Running of αN and Γ



Little Conformal Symmetry: Including the Standard Model

Problem:

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

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

We still want these to cancel

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

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

More Specifically …

- Allow t_R to be charged under $SU(3)_A$ and the other quarks to be charged under $SU(3)_B$
- $SU(3)_A$ mixes with $SU(3)_B$ to form $SU(3)_C$
- $SU(3)_A$ is a subgroup of the larger gauge group $SU(N)$

Little Conformal Symmetry: Matter Content

Low Energy Theory

	$SU(2)_L$	$SU(3)_c$
t_L	$\square$	$\square$
t_R	$\mathbf{1}$	$\square$
ϕ	$\square$	$\mathbf{1}$

UV Theory

	$SU(2)_L$	$SU(N)$	$SU(M)$
t_L	$\square$	$\mathbf{1}$	$\square$
t_R	$\mathbf{1}$	$\square$	$\square$
ϕ	$\square$	$\square$	$\mathbf{1}$

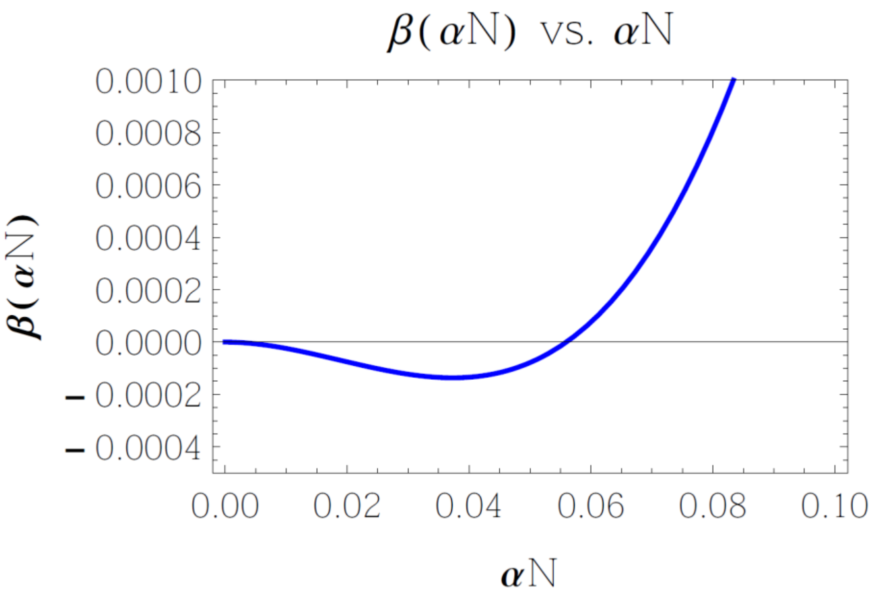
Impose symmetry relation to set the top Yukawa coupling at its fixed point: $\Longrightarrow$ $\boxed{N = 4}$ & $\boxed{M = 3}$ yield quadratic divergence cancelation.

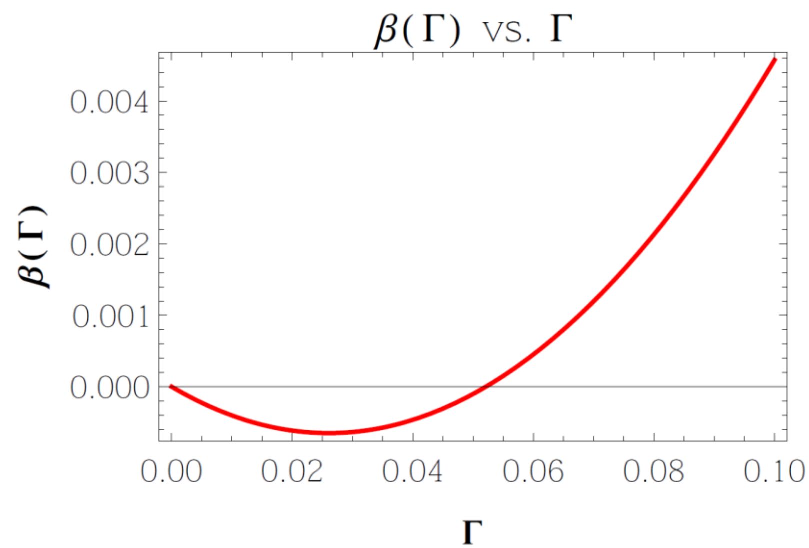
$$\Gamma_t = \frac{15}{16}\alpha_N$$

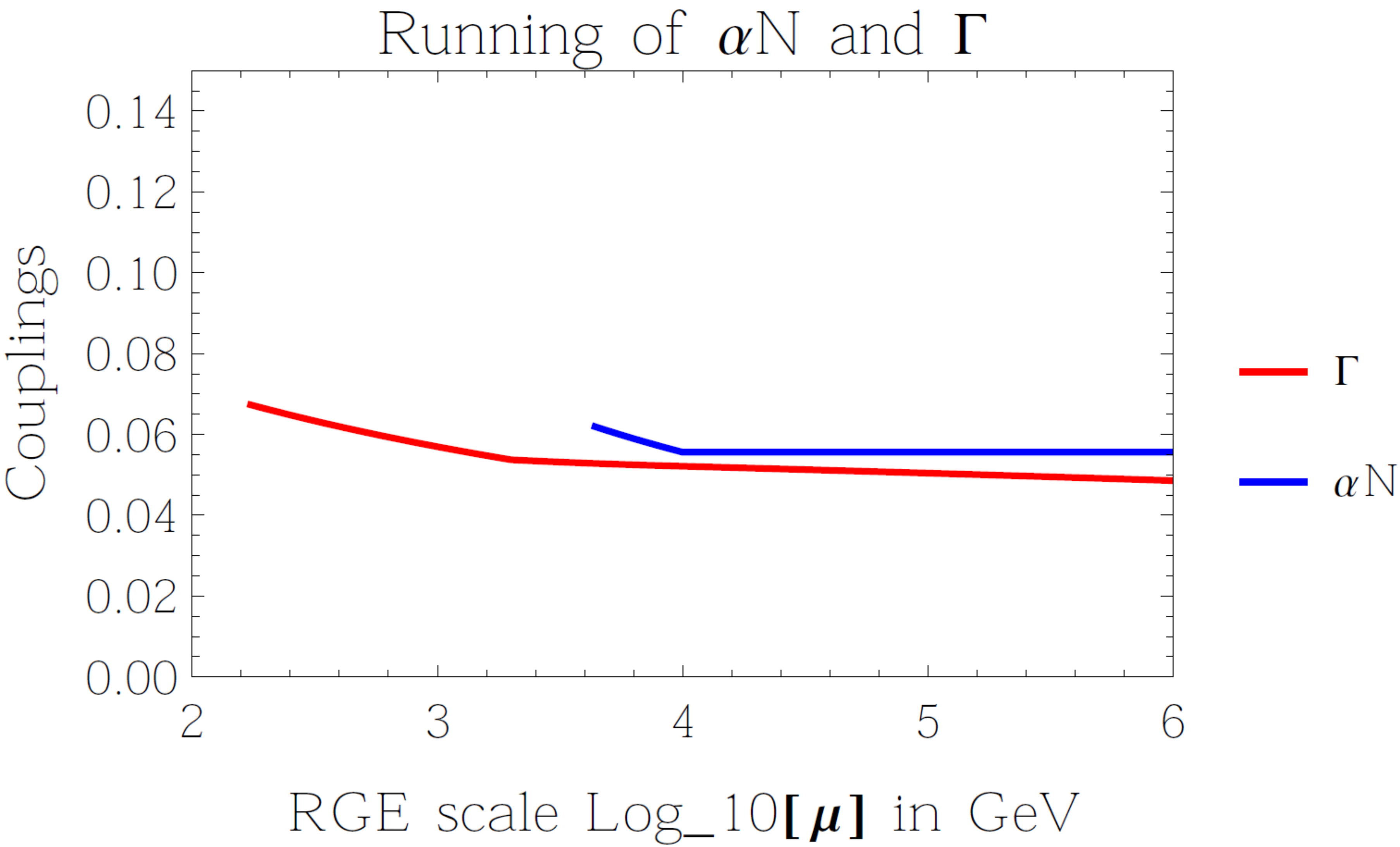
Yukawa and Gauge Coupling Fixed Points

Add in new fields to set α_N at its fixed point value:

	$SU(2)_L$	$SU(N)$	$SU(M)$	copies
t_L	□	1	□	
t_R	1	□	□	
ϕ	□	□	1	
f_V	1	□	1	4
s	1	□	1	2
s_A	1	Ad	1	13







Running of αN and Γ
Couplings
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
2
3
4
5
6
RGE scale Log_10[μ] in GeV
Γ
αN

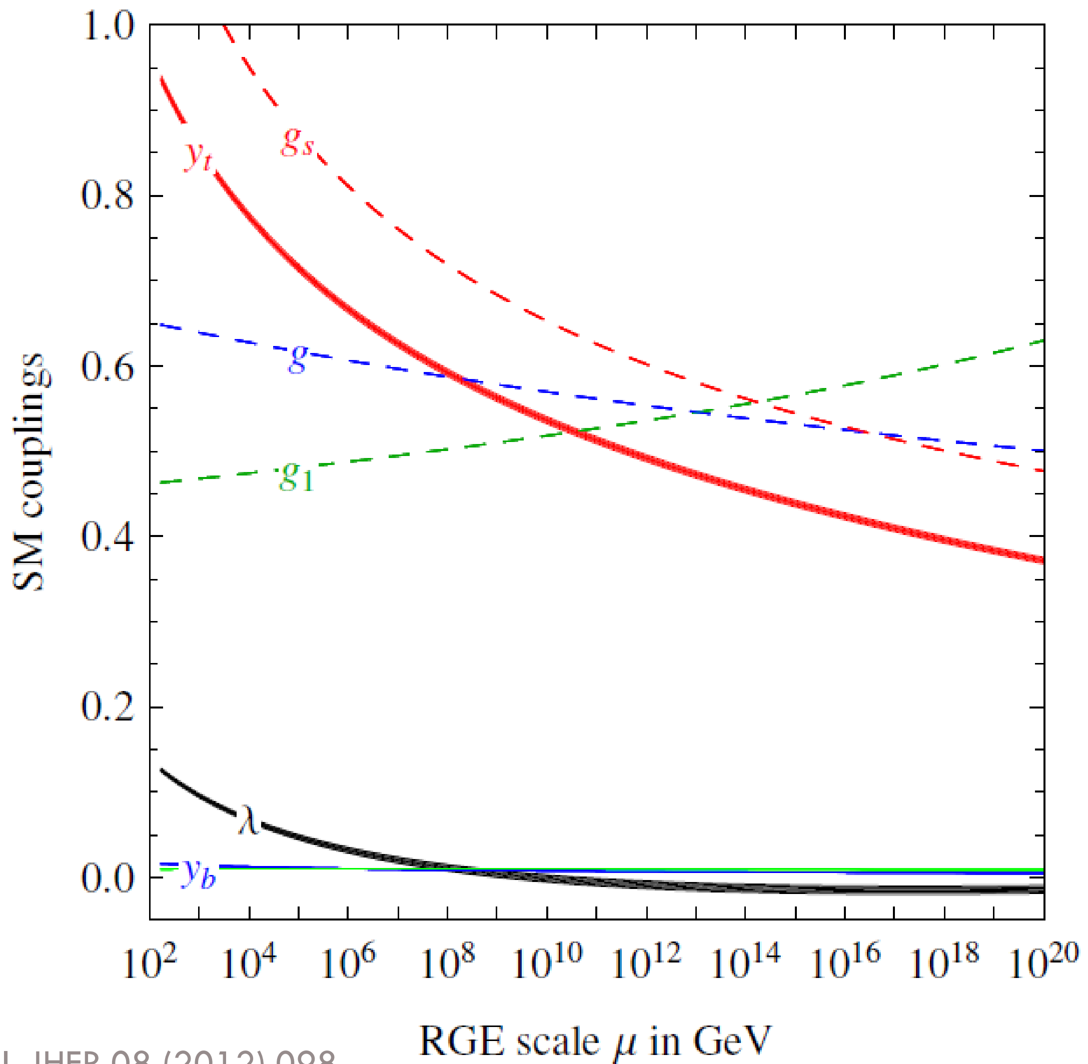
Conclusions

- 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 the10 TeV scale

- To do this with a theory that includes the SM, we must get creative with the new SU(N).
  - Set up $b_N \alpha_N \gg b_3 \alpha_3$ or Embed SU(3) in SU(N)

Back-up Slides



Degrassi, et al. JHEP 08 (2012) 098