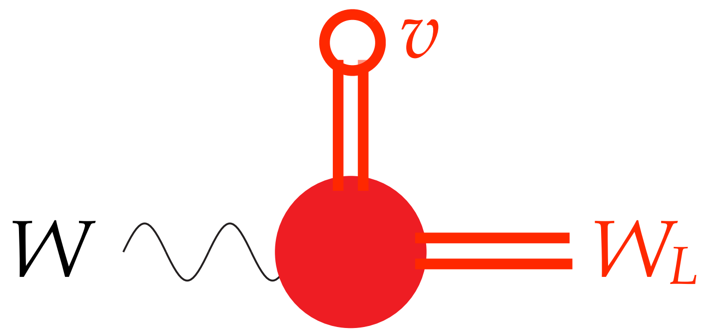
Composite top, models
and implications at hadron colliders

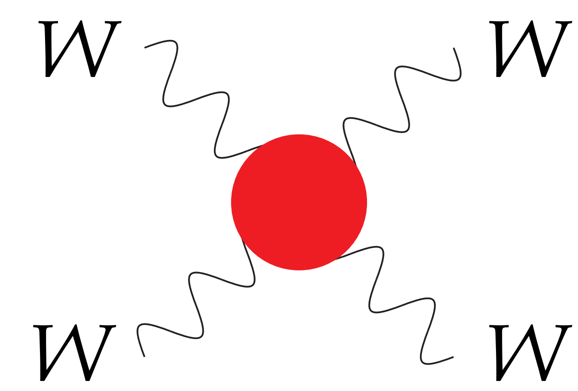
Javi Serra
(Univ. Autònoma Barcelona & CERN)

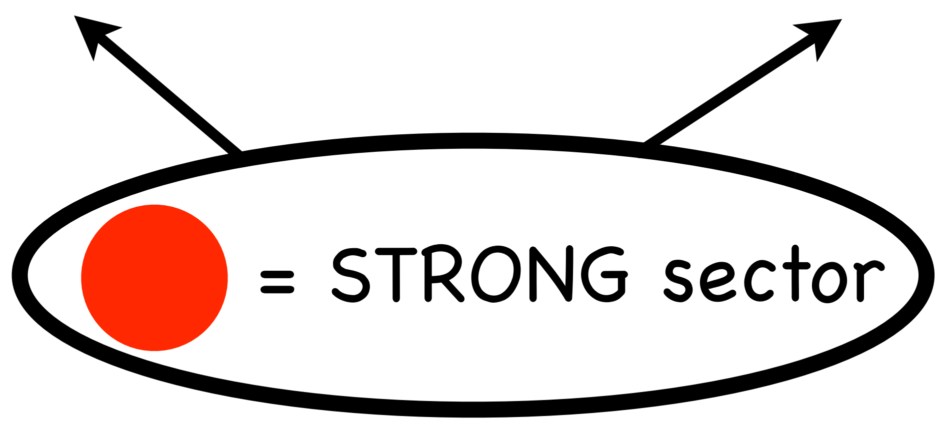
WHY THE TOP? **Experimental “evidence”**

W mass:



WW scattering:





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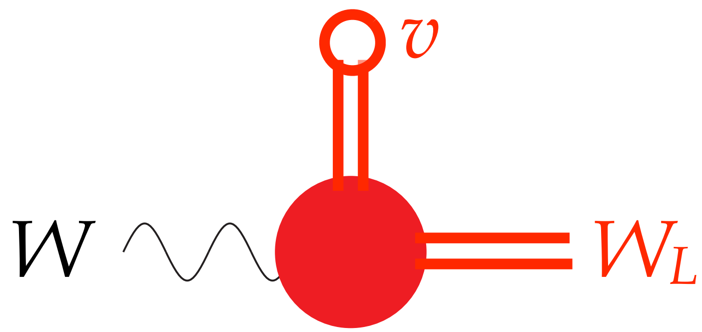

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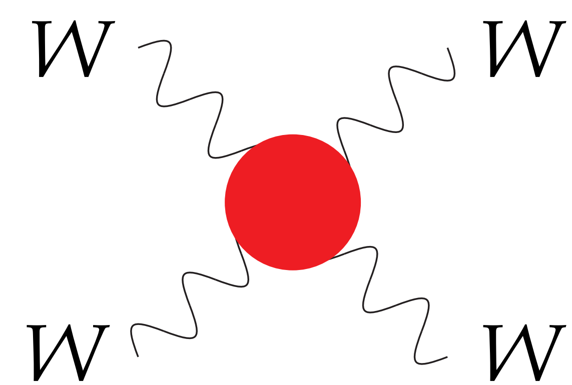
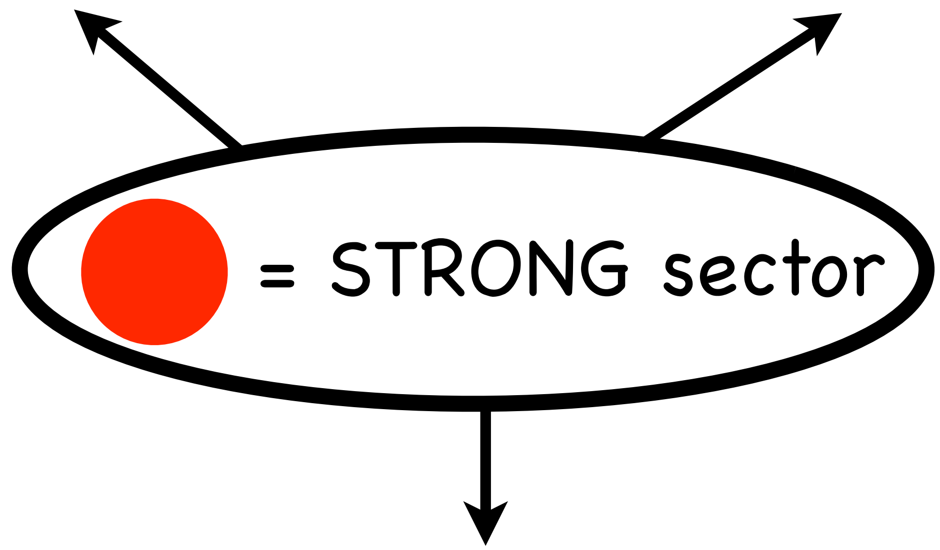


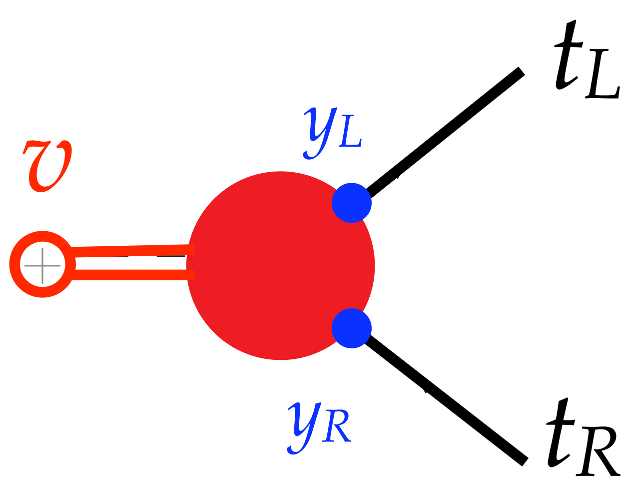


partial compositeness

Kaplan, '91

Agashe, Contino, Pomarol, '05

Top mass:



$$y_t = \frac{y_L y_R}{4\pi} \sim 1$$

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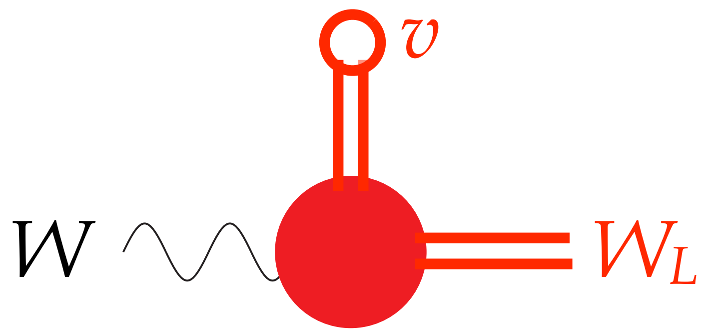

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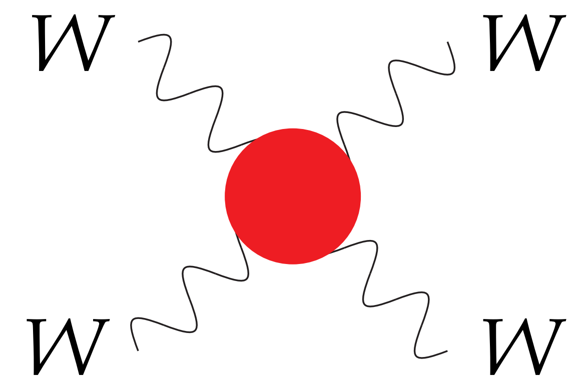

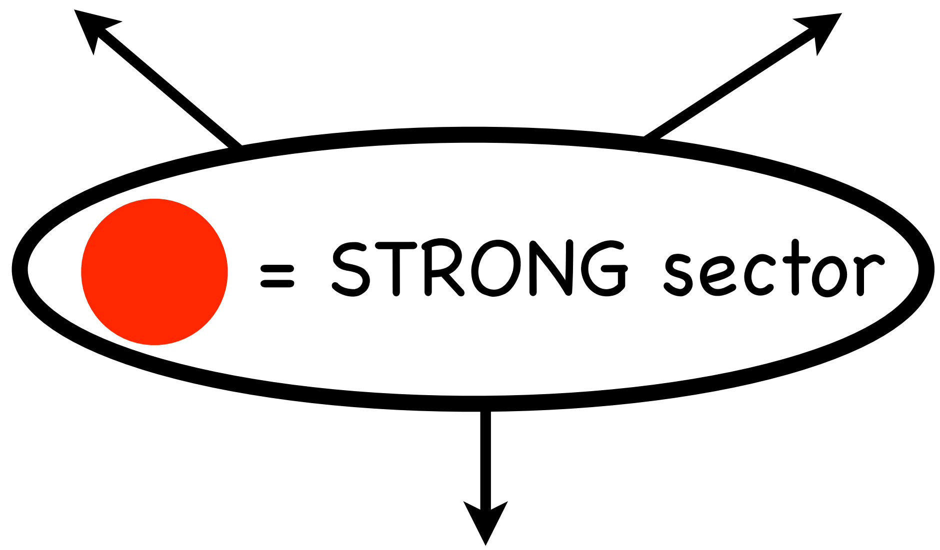

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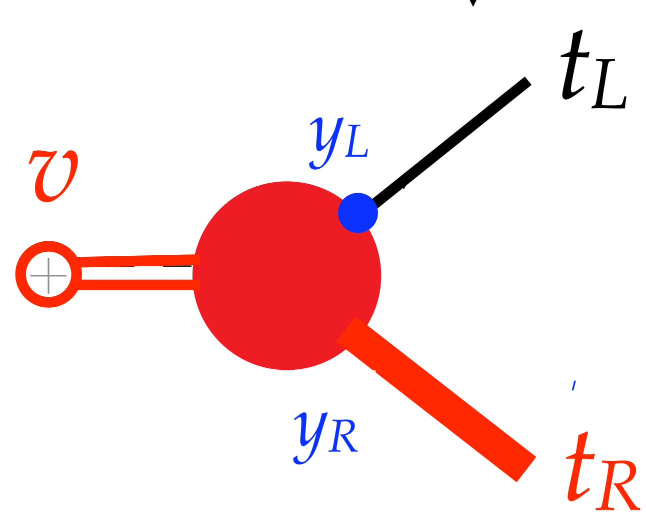
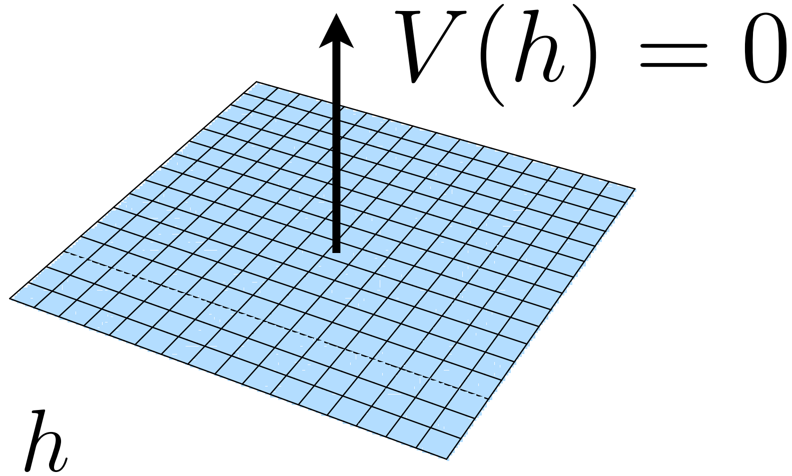


$$y_t = \frac{y_L y_R}{4\pi} \sim 1$$

Composite Top: $y_{R,L} = 4\pi$

WHY THE TOP? Theoretical motivations, **1**:

composite-NGB Higgs and EWSB



$$\frac{h}{f} \to \frac{h}{f} + \alpha$$

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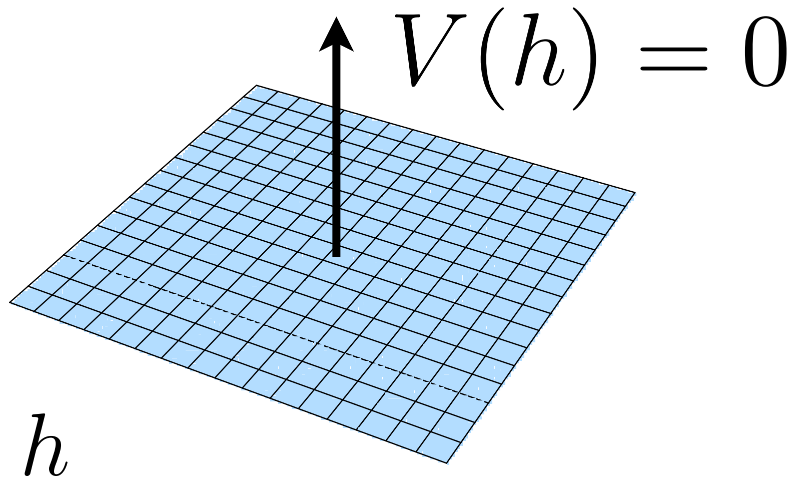

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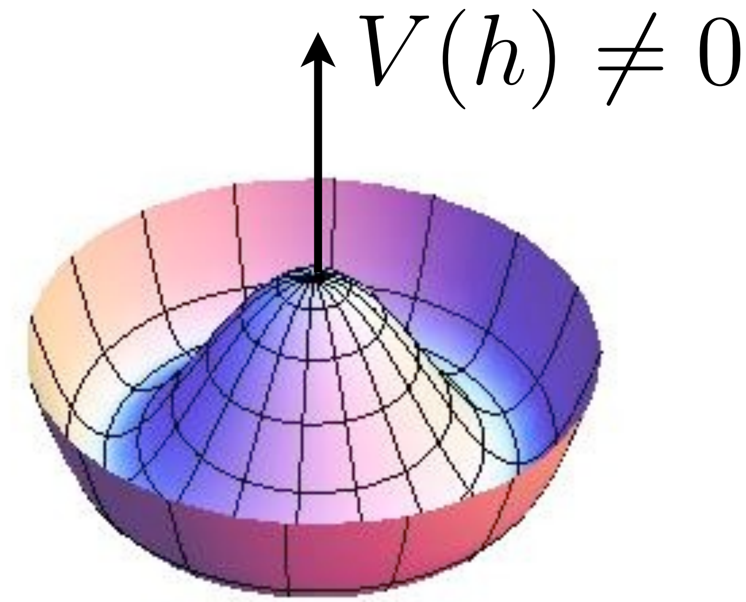

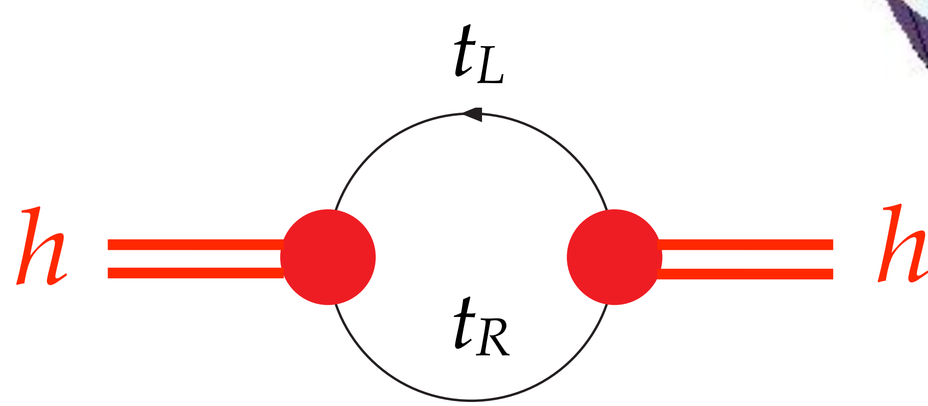

radiatively generated potential

Kaplan, Georgi, ‘84

Top responsible for EWSB

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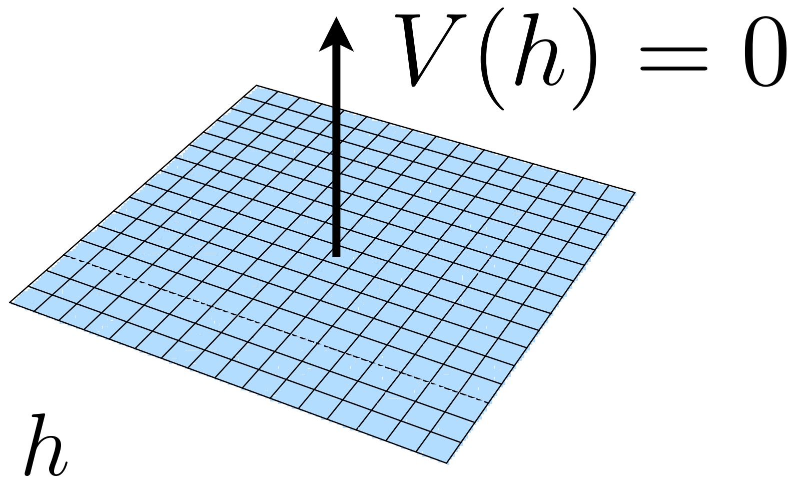

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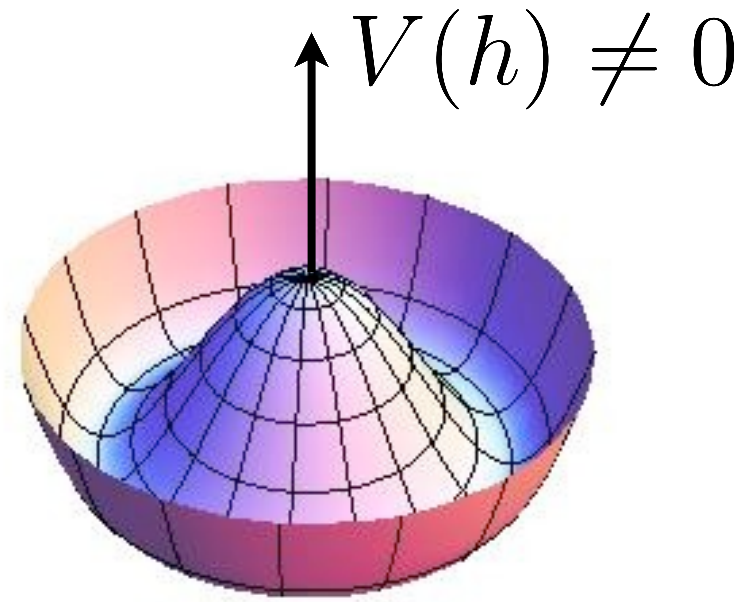
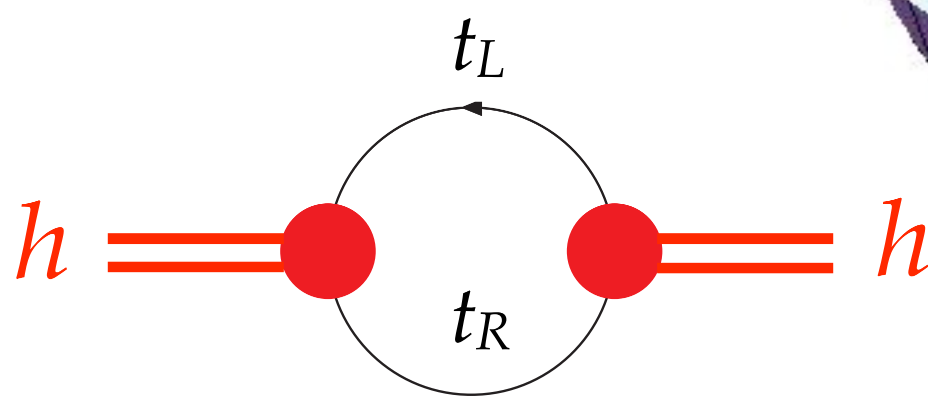




radiatively generated potential

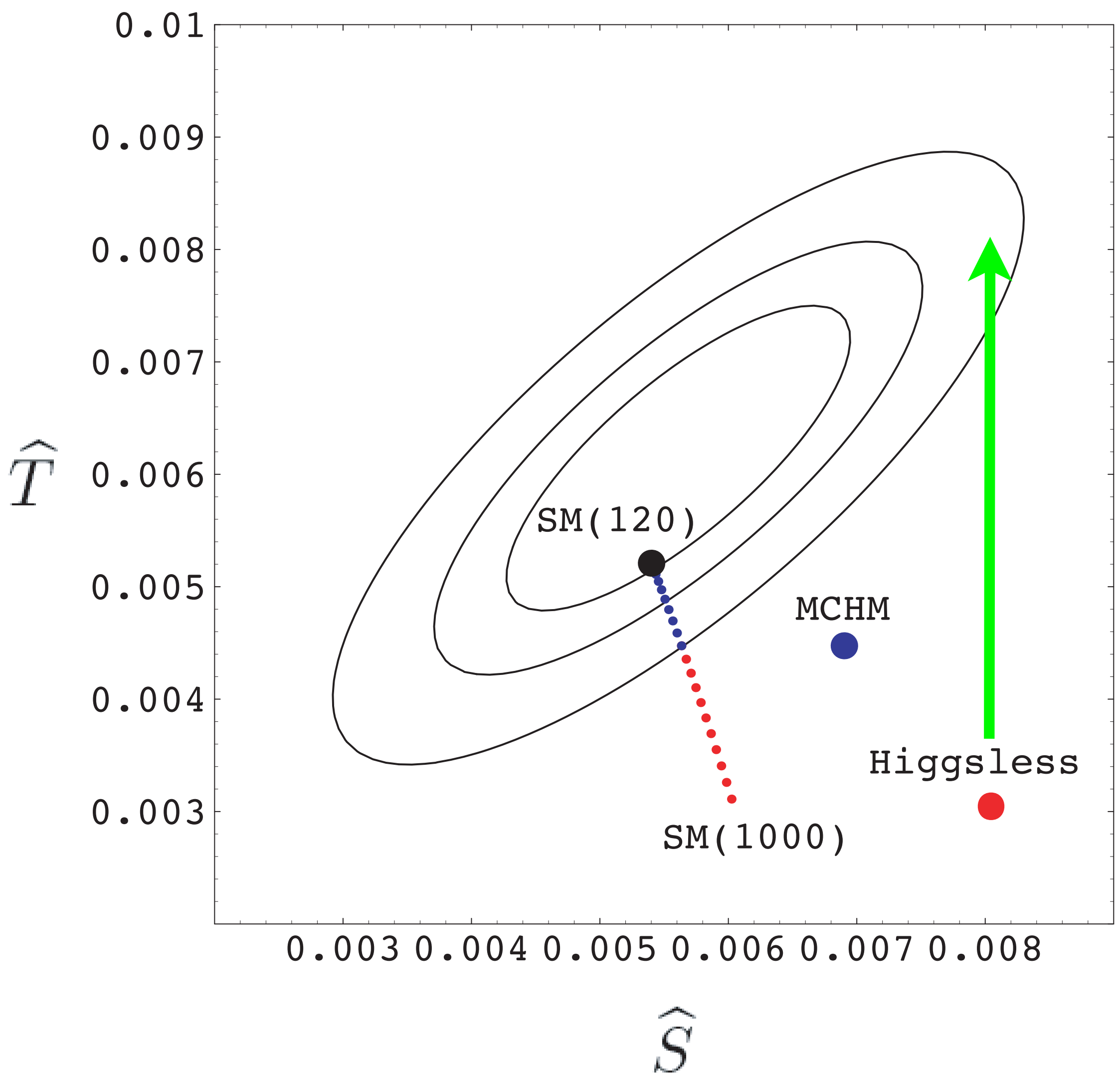
Kaplan, Georgi, '84

Top responsible for EWSB

$$m_h \sim \sqrt{N_c}\, y_t v$$

WHY THE TOP? Theoretical motivations, 2:

strong dynamics and EWPT's



$$= \quad SU(2)_L \times SU(2)_R \times P_{LR}$$

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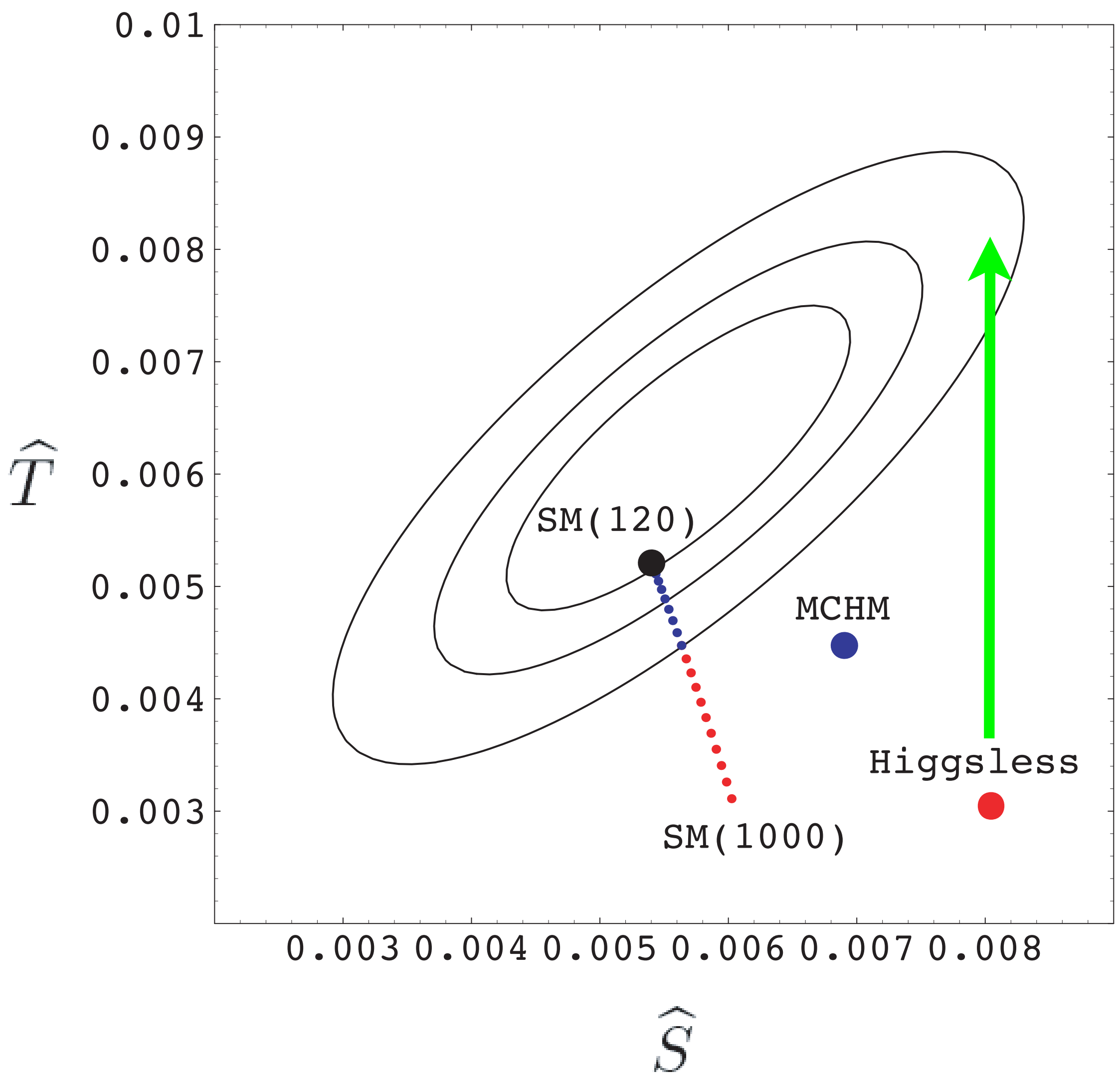

● = $SU(2)_L \times SU(2)_R \times P_{LR}$

	Q	T
Case (a)	$(\mathbf{2},\mathbf{2})_{\mathbf{2/3}}$	$(\mathbf{1},\mathbf{1})_{\mathbf{2/3}}$
Case (b)	$(\mathbf{2},\mathbf{2})_{\mathbf{2/3}}$	$(\mathbf{1},\mathbf{3})_{\mathbf{2/3}} + (\mathbf{3},\mathbf{1})_{\mathbf{2/3}}$

$t_L \in Q = (q_L, q_L^*)$ $\qquad$ $t_R \in T$

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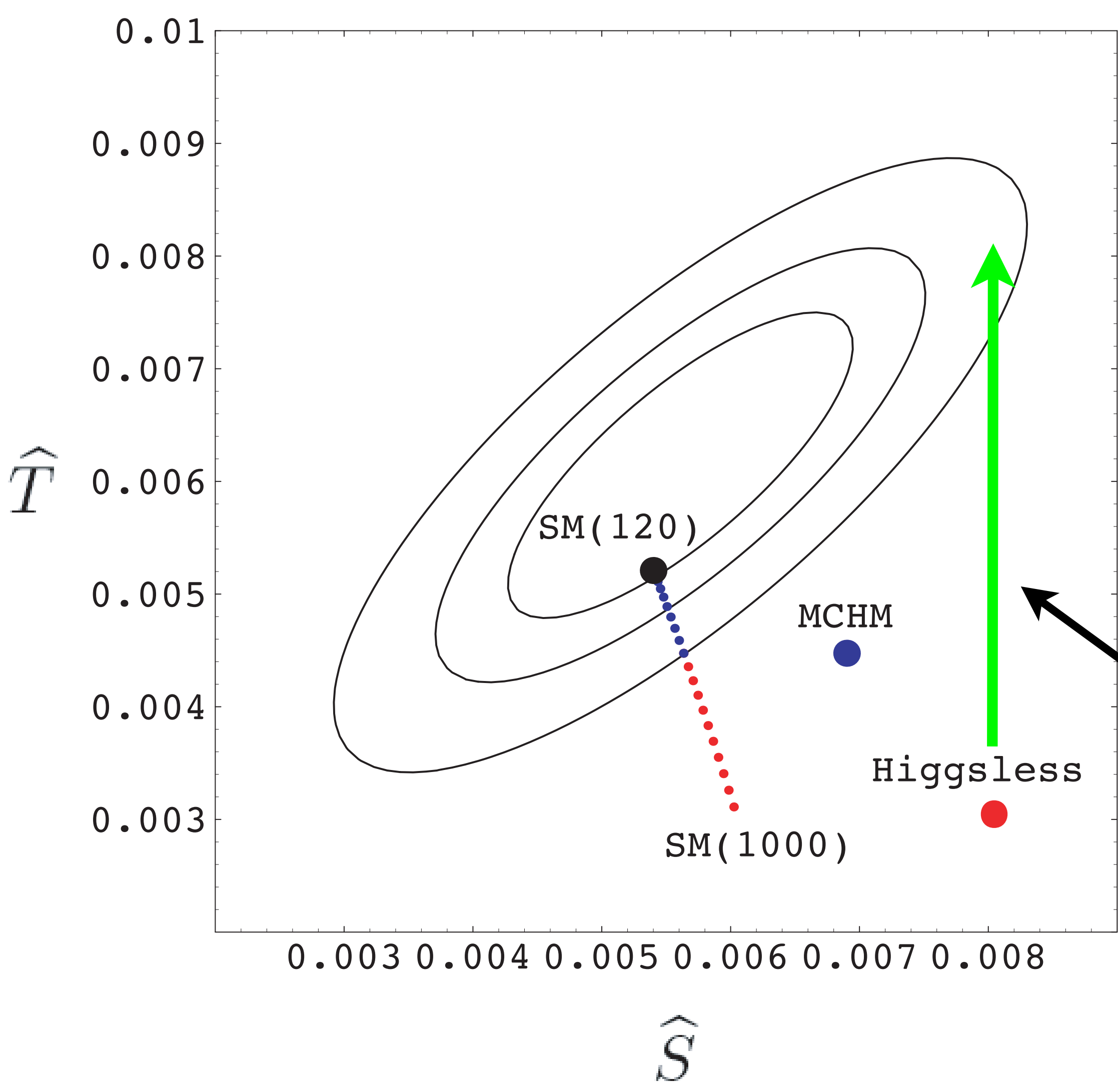

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$t_L \in Q = (q_L, q_L^*)$ $\qquad$ $t_R \in T$

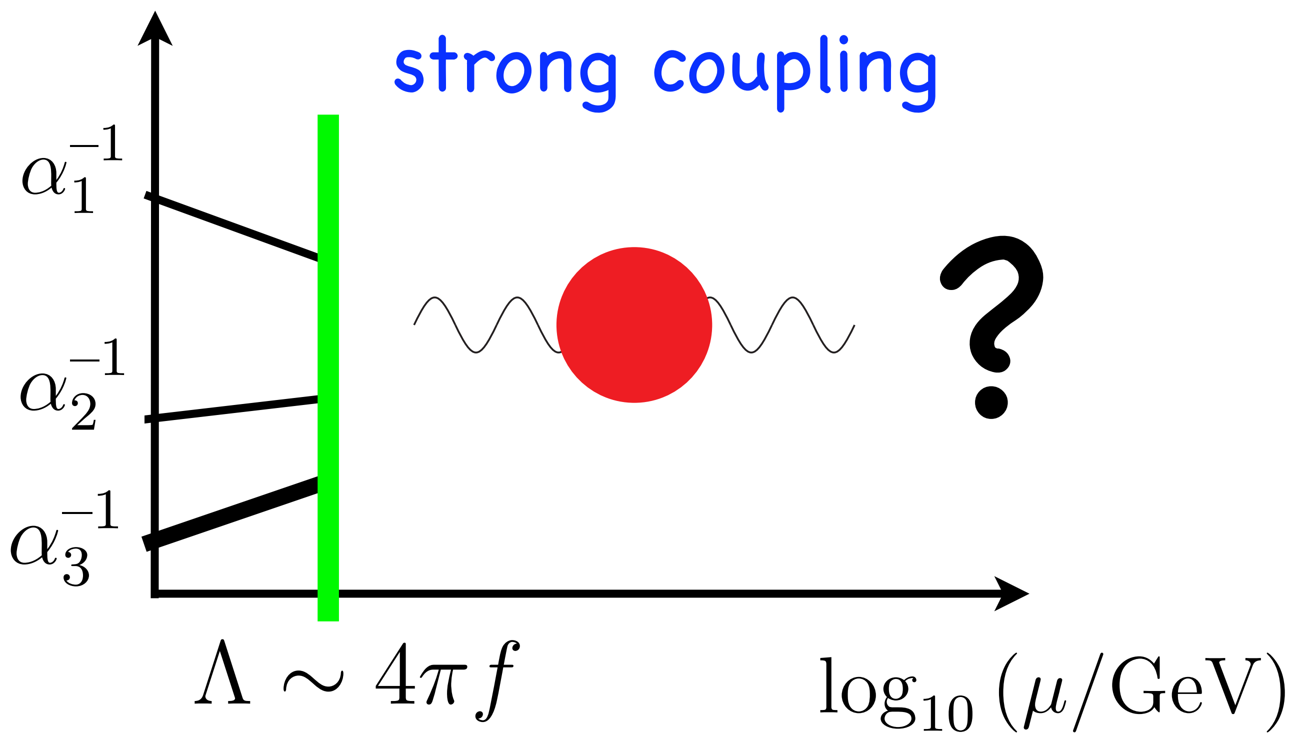
$$\widehat{T} \simeq \frac{N_c}{16\pi^2}\frac{v^2}{f^2}\frac{m_{t^*}^2}{f^2}$$

Top and partners come to help

Pomarol, JS, '08

WHY THE TOP? Theoretical motivations, 3:

composite unification



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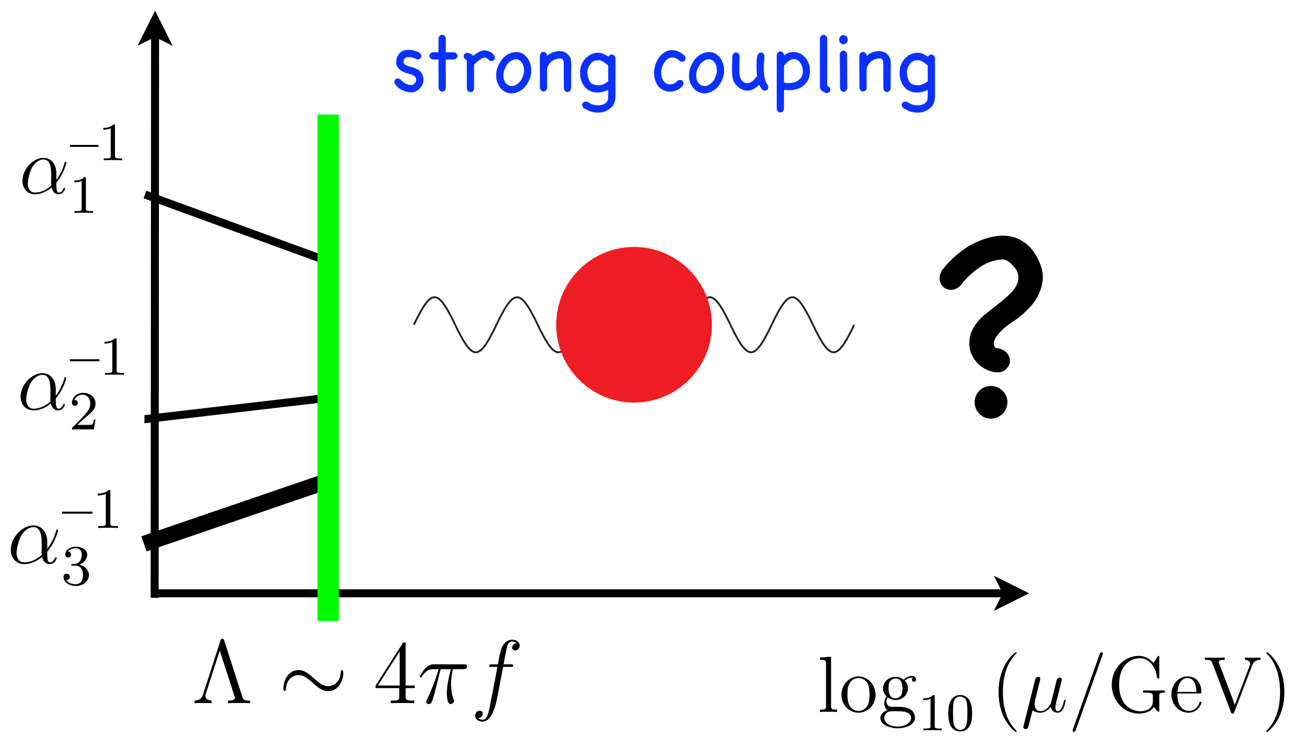

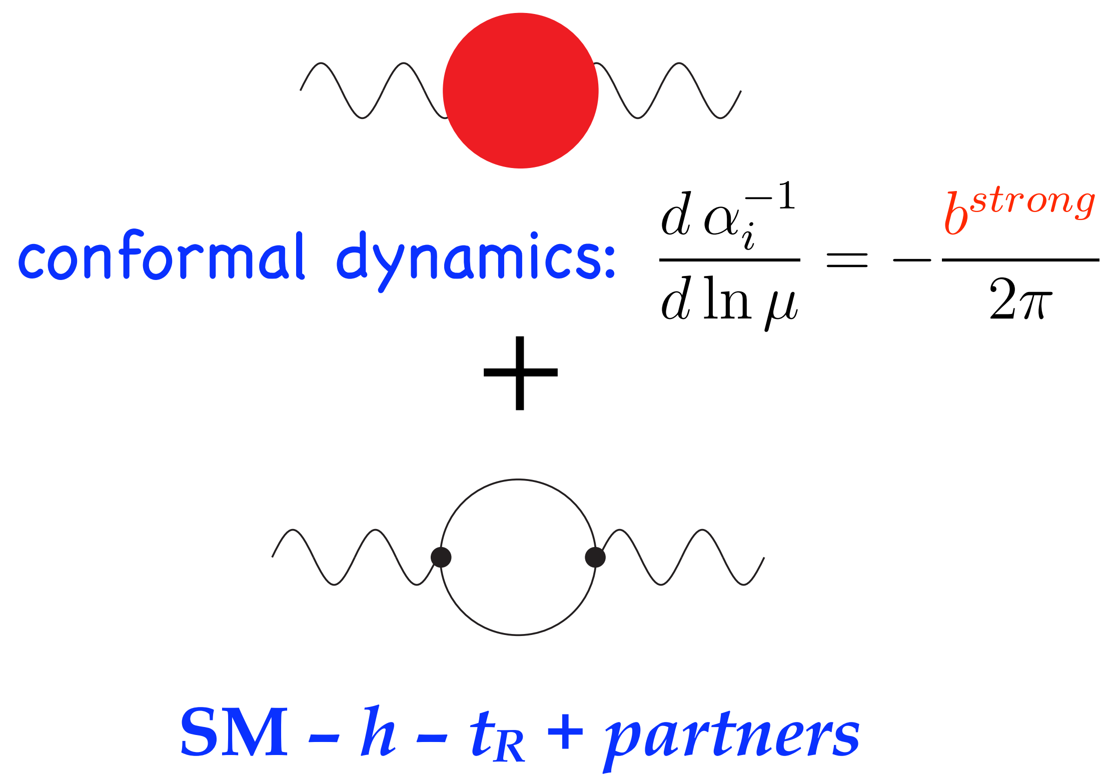

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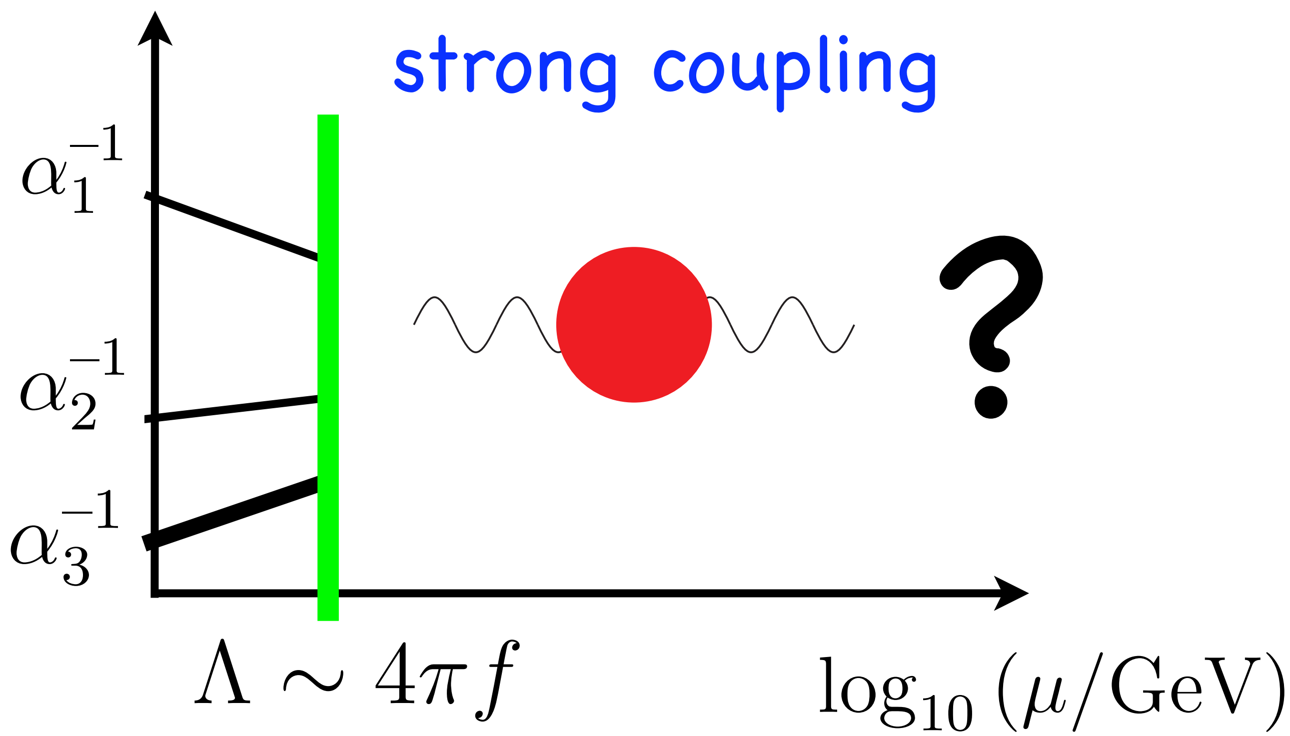
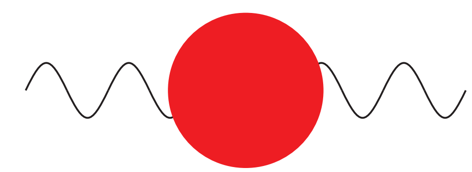
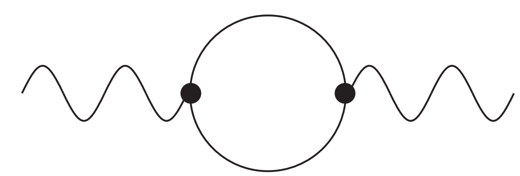


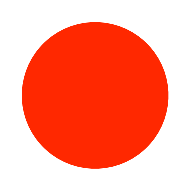


conformal dynamics: $\dfrac{d\,\alpha_i^{-1}}{d\ln\mu} = -\dfrac{b^{strong}}{2\pi}$

+



SM - *h* - *t*$_R$ + *partners*

$R = R(partners) \simeq \mathbf{1.45}$ if  = $SO(10)$

$R_{exp} = 1.395 \pm 0.015$

Agashe, Contino, Sundrum, ‘08
Frigerio, JS, Varagnolo, ‘11

top compositeness allows precise unification

WHAT IF THE TOP IS COMPOSITE ?

an effective Lagrangian approach

compo t_R :

$$i c_R \frac{(4\pi)^2}{\Lambda^2} (H^\dagger D_\mu H)(\bar{t}_R \gamma^\mu t_R) + c_{4t} \frac{(4\pi)^2}{\Lambda^2} (\bar{t}_R \gamma_\mu t_R)(\bar{t}_R \gamma^\mu t_R)$$

compo $q_L = (t_L, b_L)$:

$$i c_L^{(1)} \frac{(4\pi)^2}{\Lambda^2} (H^\dagger D_\mu H)(\bar{q}_L \gamma^\mu q_L) + i c_L^{(3)} \frac{(4\pi)^2}{2\Lambda^2} (H^\dagger \sigma^i D_\mu H)(\bar{q}_L \sigma^i \gamma^\mu q_L) + c_{4q} \frac{(4\pi)^2}{\Lambda^2} (\bar{q}_L \gamma_\mu q_L)(\bar{q}_L \gamma^\mu q_L)$$

due to P_{LR}: $c_L^{(3)} \simeq -c_L^{(1)}$

$$c_i = \mathcal{O}(1)$$

$$\Lambda \sim 4\pi f$$

subleading: $c_M \frac{y_t}{16\pi^2} \frac{(4\pi)^2}{\Lambda^2} \bar{q}_L G_{\mu\nu} \tilde{H} \sigma_{\mu\nu} t_R + \ldots$

model independent implications

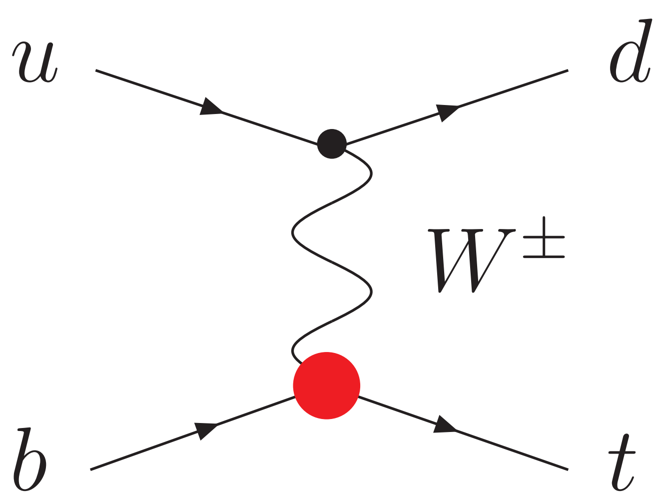
WHAT IF THE TOP IS COMPOSITE ?

Modification of top - gauge bosons couplings

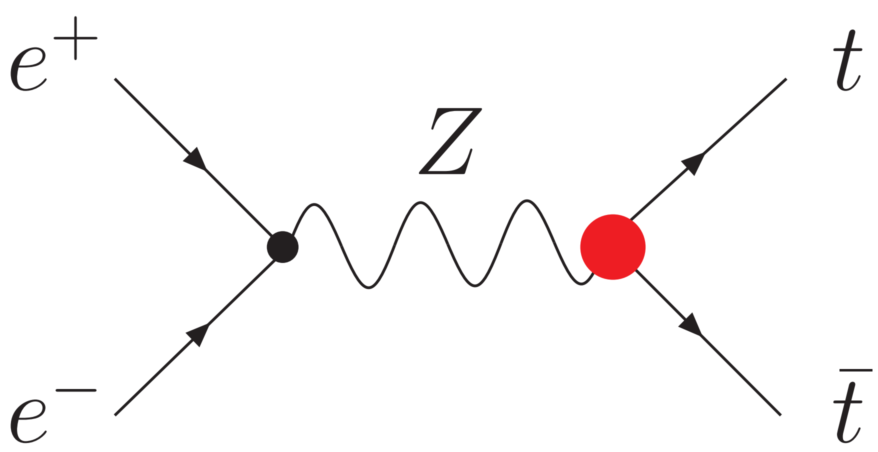
$$\frac{\delta g_{W t_L b_L}}{g_{W t_L b_L}} = c_L \frac{v^2}{f^2} \qquad \frac{\delta g_{Z t_L t_L}}{g_{Z t_L t_L}} \simeq 2 c_L \frac{v^2}{f^2} \qquad \frac{\delta g_{Z t_R t_R}}{g_{Z t_R t_R}} = \frac{3 c_R}{4 \sin^2 \theta_W} \frac{v^2}{f^2}$$

$f = 500\ \mathrm{GeV}$ no strong present (direct) contraints

LHC, 7%



LC, 1%

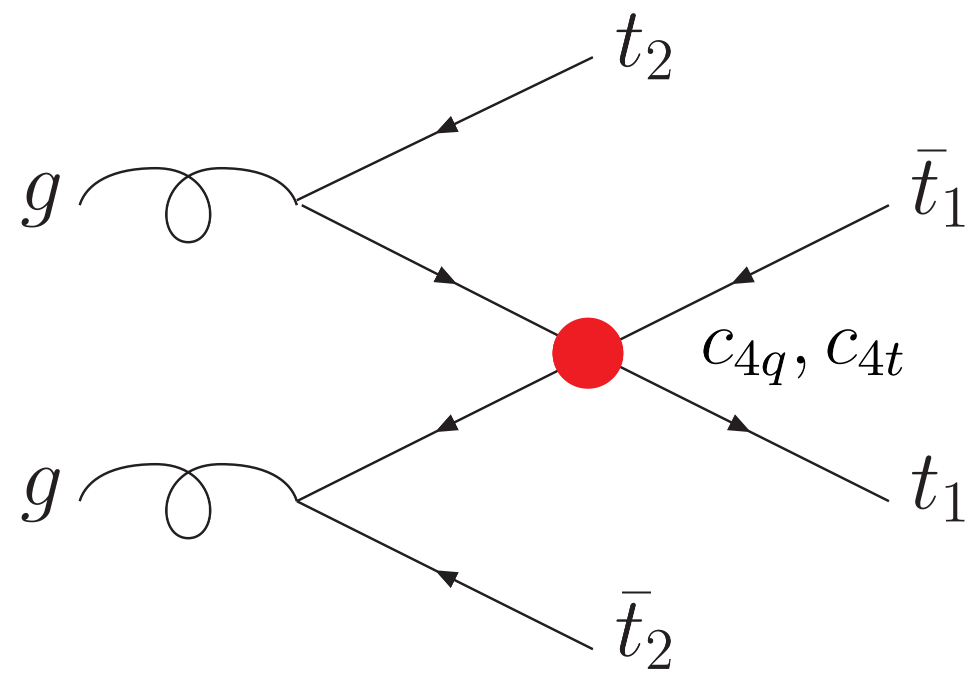


WHAT IF THE TOP IS COMPOSITE ?

strong 4-top production

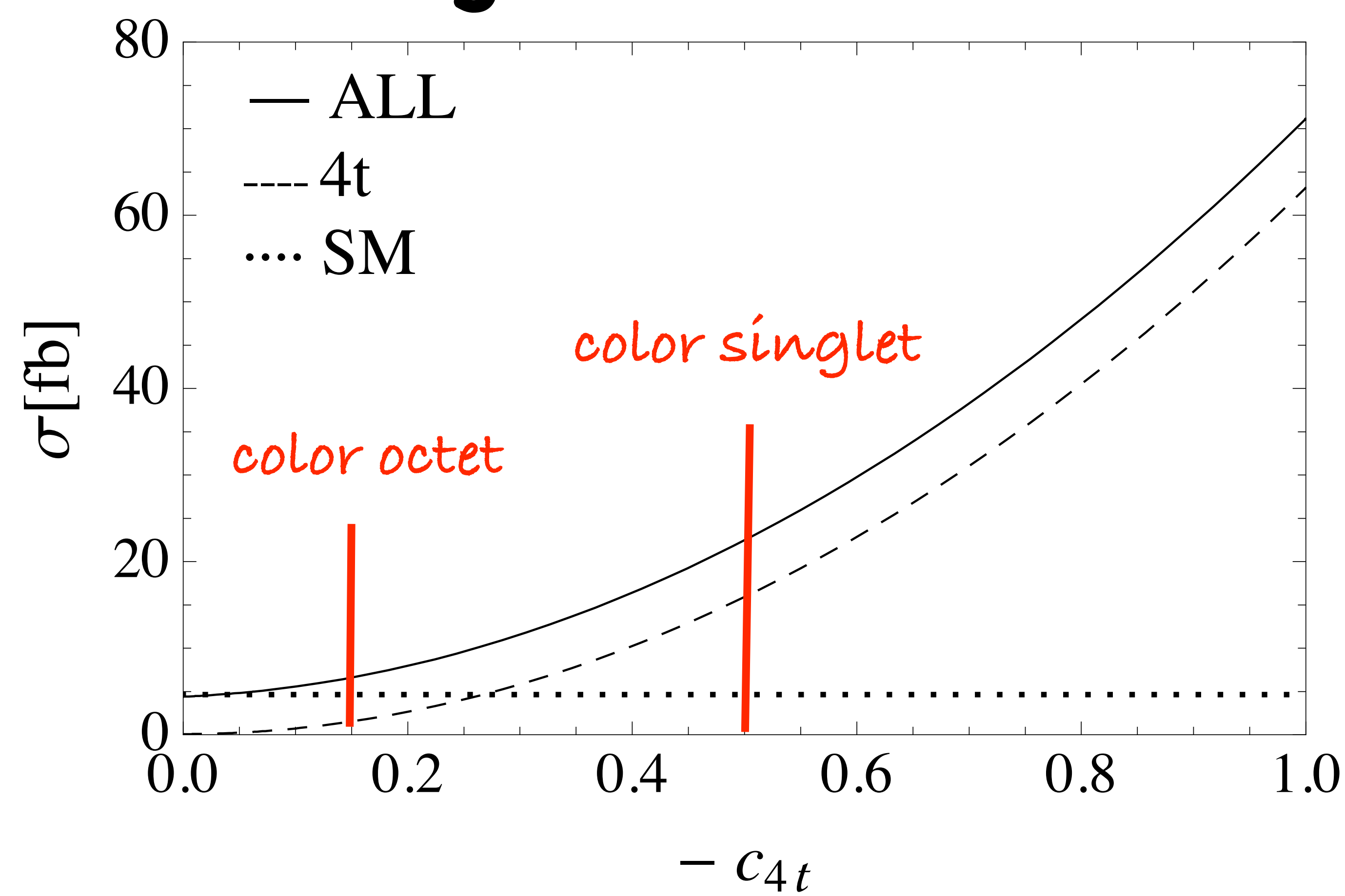
$pp \to t\bar{t}t\bar{t}$

$pp \to t\bar{t}b\bar{b}$



$$|\mathcal{A}[t\bar{t} \to t\bar{t}(b\bar{b})]|^2 \propto \frac{c_4^2}{f^4} u^2$$

genuine effect



$$\sigma_{SM} \simeq 4.6 \text{ fb}$$

$$\sigma_{octet} \simeq 1.8 \text{ fb}$$

$$\sigma_{singlet} \simeq 16 \text{ fb}$$

WHAT IF THE TOP IS COMPOSITE ?

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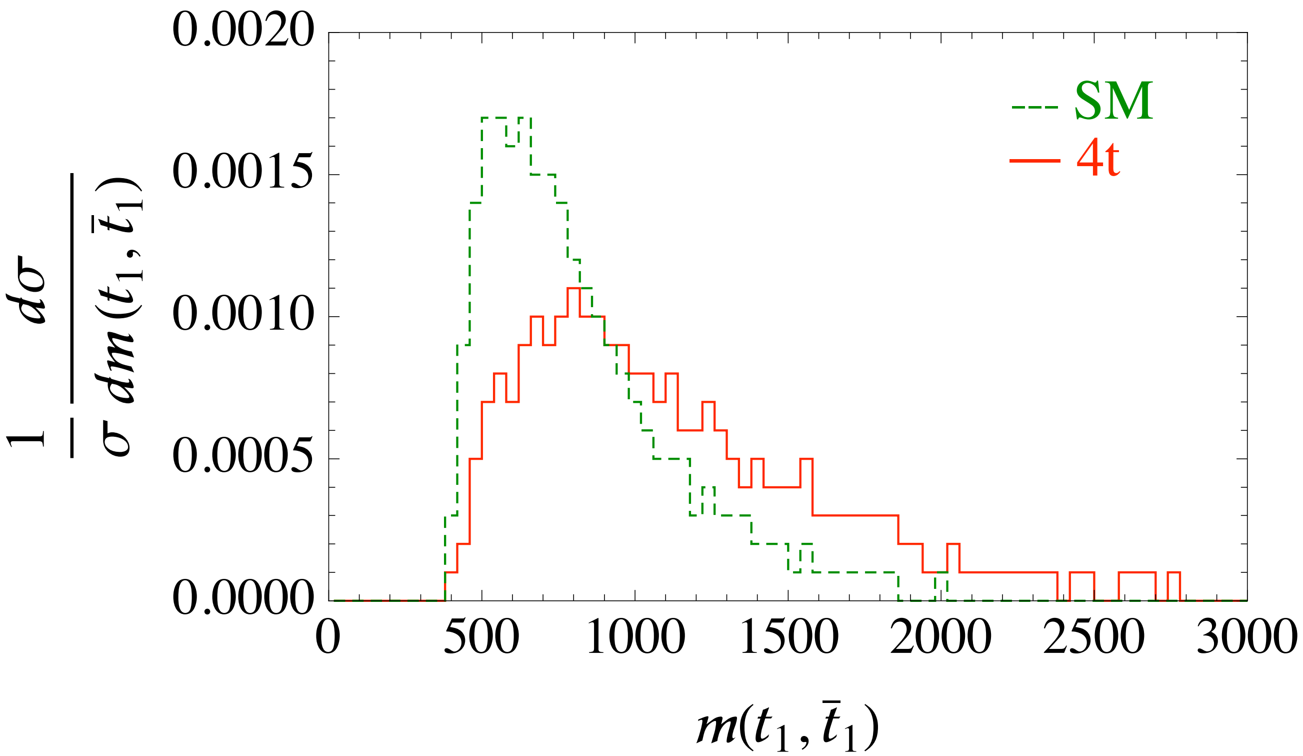
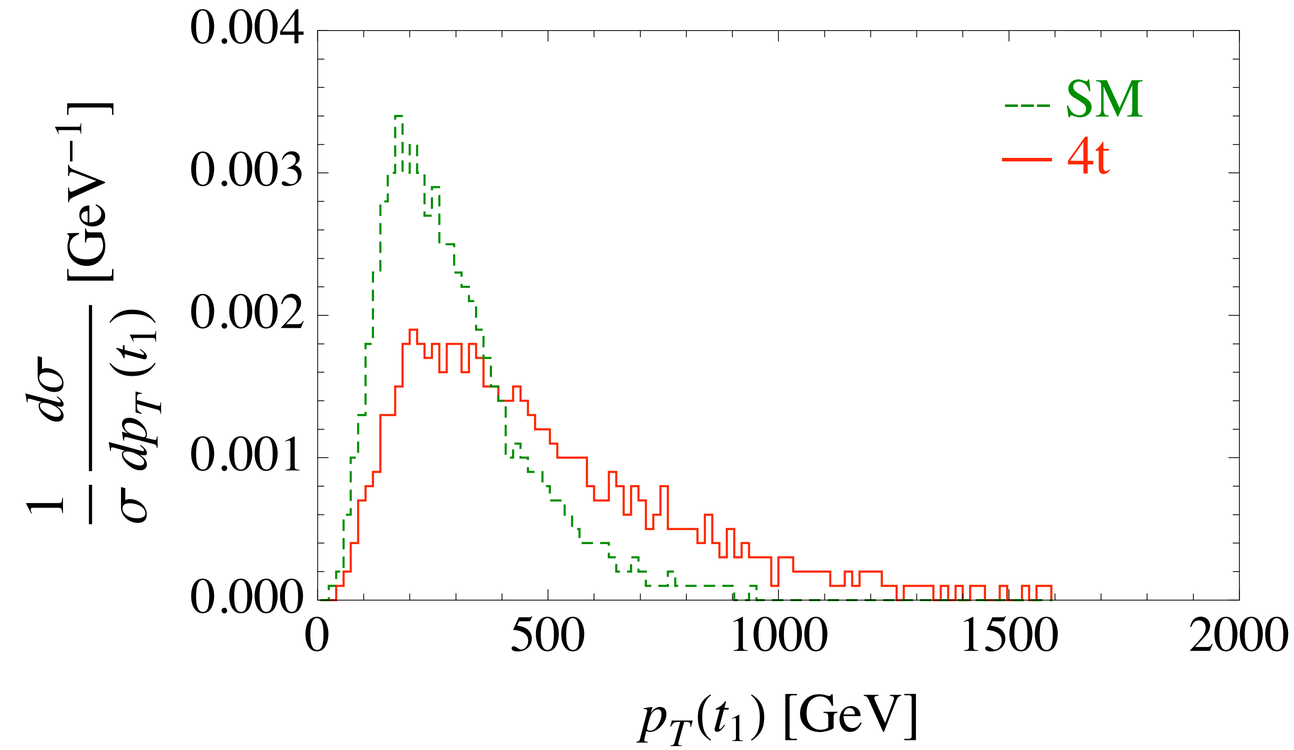




2 tops (t_1) very energetic ($p_T(t_1) > p_T(t_2)$)

strong cuts are needed to reduce backgrounds

several "detector level" analyses: $l^\pm l^\pm jj$ Kumar, Tait, Vega-Morales, '09

$l^\pm jj E_T^{miss}$ Jung, Wells, '10

What if the top is composite ?

Top-partners direct detection

model-dependent

EXAMPLE: $T_{5/3} \quad (Q = 5/3)$

golden channel

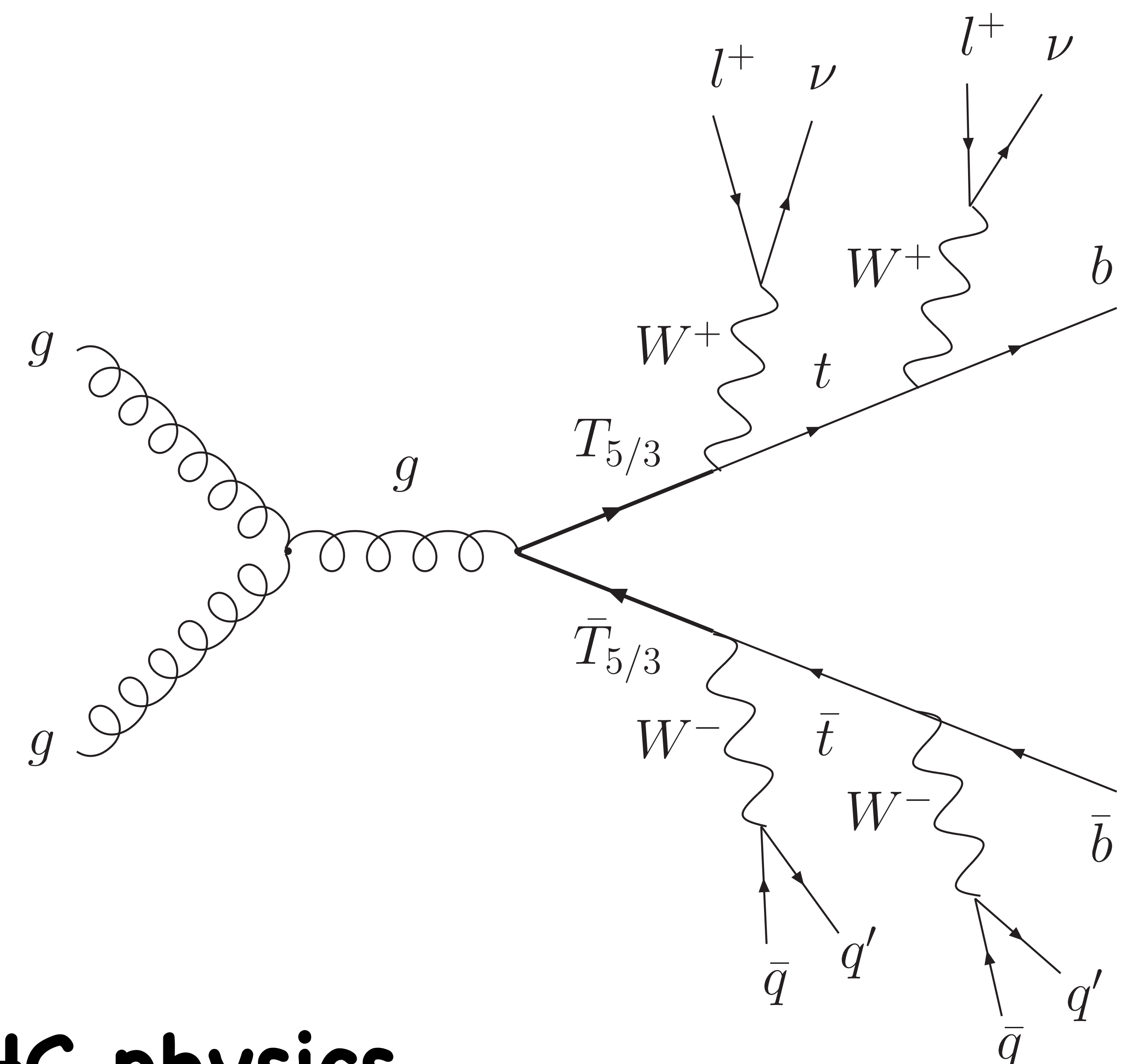
$l^{\pm}l^{\pm} + n\, jets + E_T^{miss}$

both single and double production

Contino, Servant, '08

Mrazek, Wulzer, '09

Dissertori, Furlan, Moortgat, Nef, '09



early LHC physics

PRELIMINARY

What if the top is composite ?

Top forward-backward asymmetry

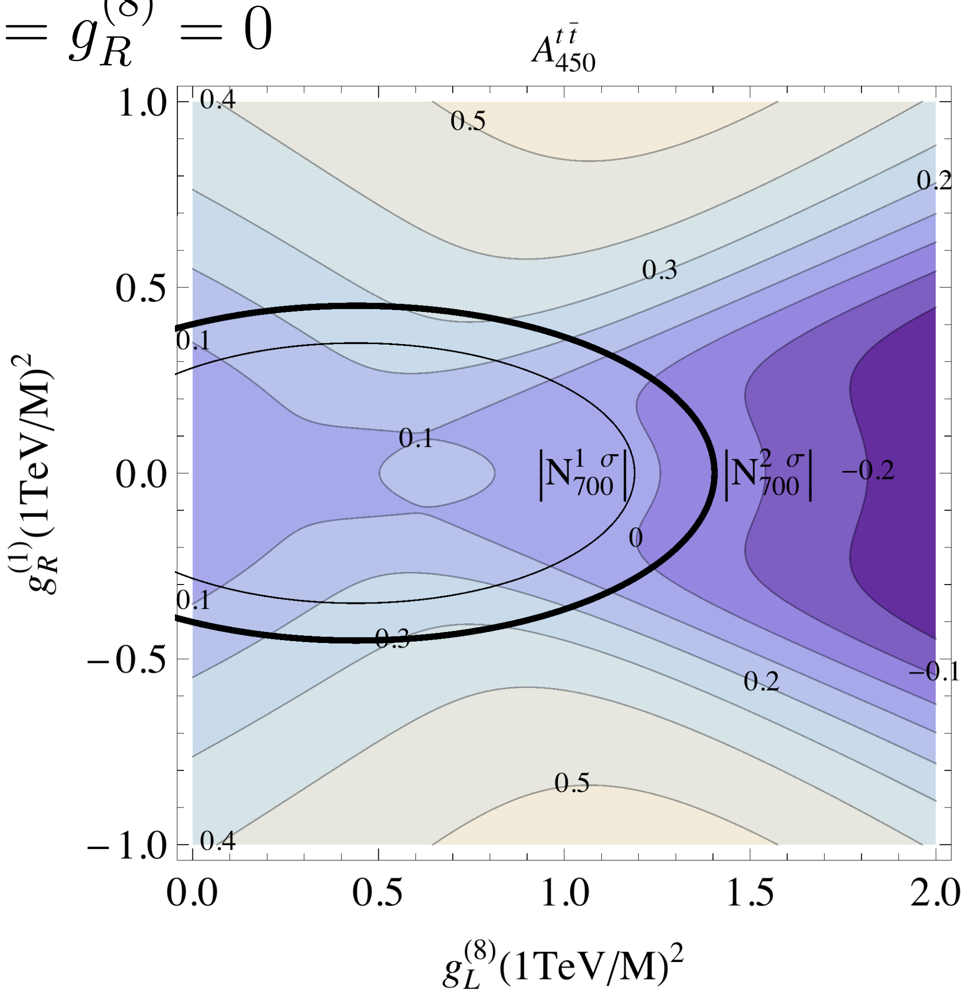
Right-handed composite top + partial compositeness of light quarks

Effective Lagrangian approach:

$$c_{RL}^{(8)}\frac{4\pi g_L^{(8)}}{\Lambda^2}(\bar{t}_R\gamma_\mu T^a t_R)(\bar{q}_L\gamma^\mu T^a q_L) + c_{RR}^{(8)}\frac{4\pi g_R^{(8)}}{\Lambda^2}(\bar{t}_R\gamma_\mu T^a t_R)(\bar{u}_R\gamma^\mu T^a u_R)$$

$$c_{RL}^{(1)}\frac{4\pi g_L^{(1)}}{\Lambda^2}(\bar{t}_R\gamma_\mu t_R)(\bar{q}_L\gamma^\mu q_L) + c_{RR}^{(1)}\frac{4\pi g_R^{(1)}}{\Lambda^2}(\bar{t}_R\gamma_\mu t_R)(\bar{u}_R\gamma^\mu u_R)$$

$g_L^{(1)} = g_R^{(8)} = 0$



$$|N_{700}| = |\sigma_{700}^{NP}/\sigma_{700}^{SM}|$$

$$A_{450}^{t\bar{t}} = +0.40 \pm 0.11$$

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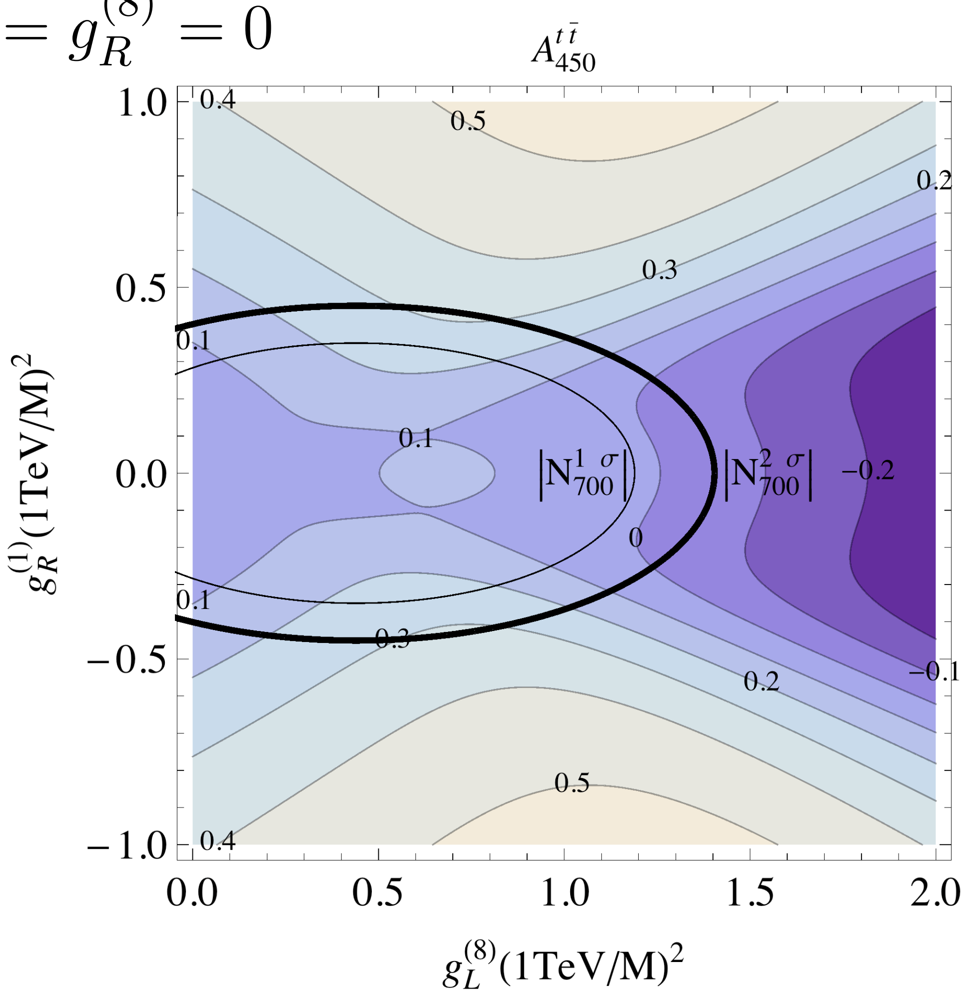
small

due to LHC dijets

$g_L^{(1)}=g_R^{(8)}=0$



$$|N_{700}|=|\sigma^{NP}_{700}/\sigma^{SM}_{700}|$$

$$A_{450}^{t\bar t}=+0.40\pm0.11$$

CONCLUSIONS

The top quark is the most sensitive fermion to the strong sector responsible for EWSB and SM masses.

Top quark compositeness has a lot to offer

↓

Look for it at the LHC !

- ★ Anomalous couplings
- ★ Strong 4-top production
- ★ Top partners
- ★ Top asymmetries