A Dangerous Irrelevant UV Completion of the CH

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LIO (11/2015)

A few preliminary points

1. A realistic UV picture of the Composite Higgs is **needed** (here, no scalars)

2. Partial Compositeness proposed to address the **flavor problem**

3. PC is a significant advantage **ONLY IF**
   - the theory has a strongly-coupled IR fixed point
   - 3-fermion operators have <u>very large anomalous dimensions</u>
   - All fermions get a mass from PC

1. Why UV completion?

- **Plausibility of the Composite Higgs framework:**
  - Do 4D realizations without fund. scalars exist? Do we need SUSY?

- **Phenomenological question:**
  - UV is constrained: What cosets? What spectrum? What EFT?

2. Partial Compositeness and flavor

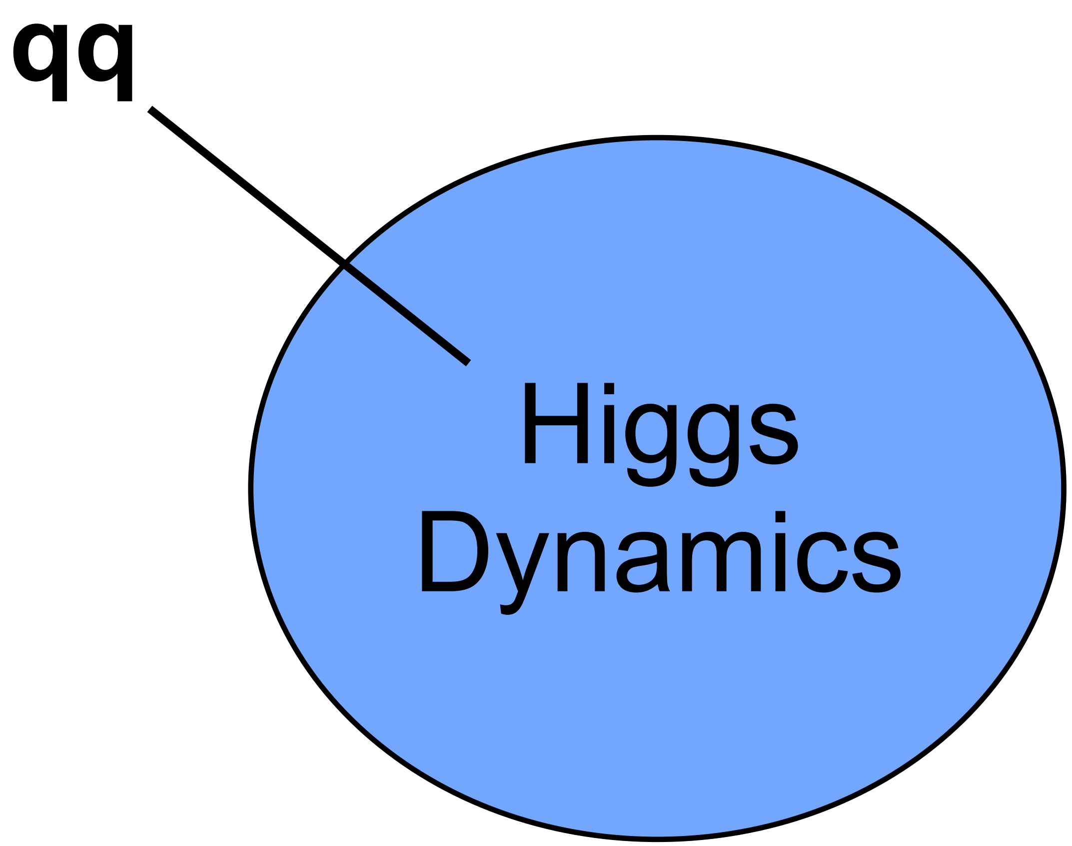
The real problem of the Composite Higgs

$$\mathcal{L} = -\frac{1}{4}F^2 + qiDq + |DH|^2 - V$$

$+yqqH$ **Getting the Yukawa couplings???**

$+\mathcal{O}\left(\frac{1}{\Lambda^2_{\text{cutoff}}}\right)$ **Deviations from the SM ✔**
EWPT, rare processes, etc.


qqO
qO

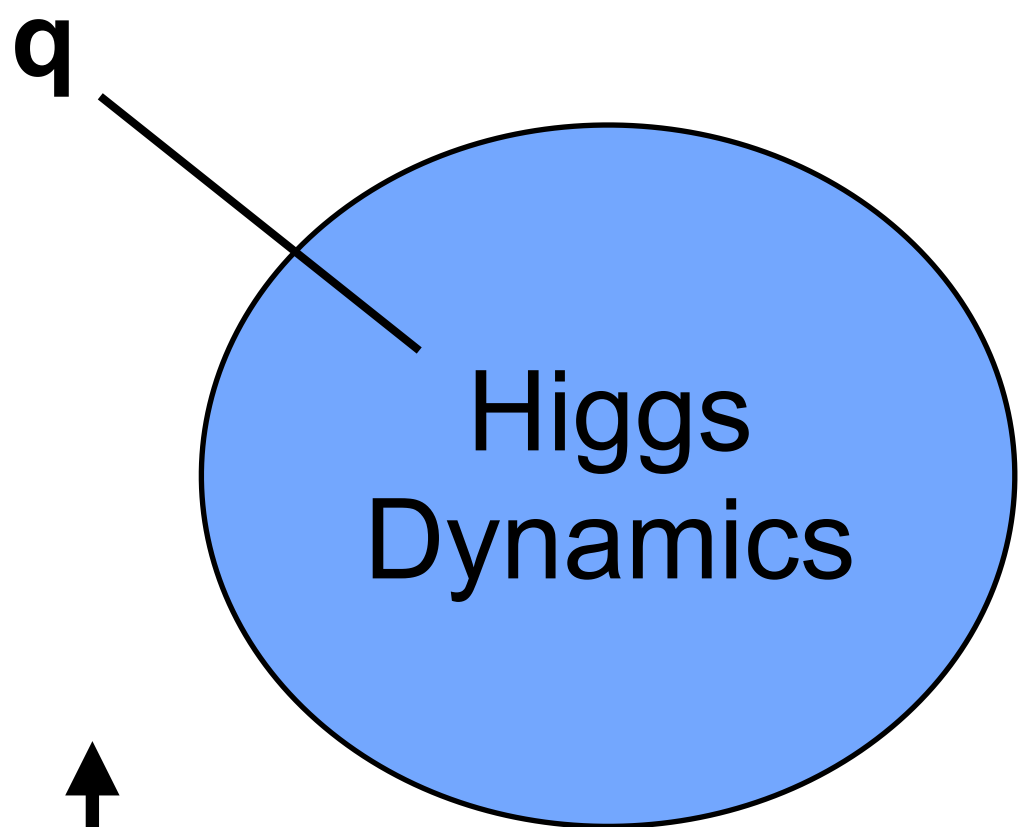


$$\Rightarrow \quad y_t \lesssim 4\pi \left(\frac{\Lambda}{\Lambda_F}\right)^{d-4}$$

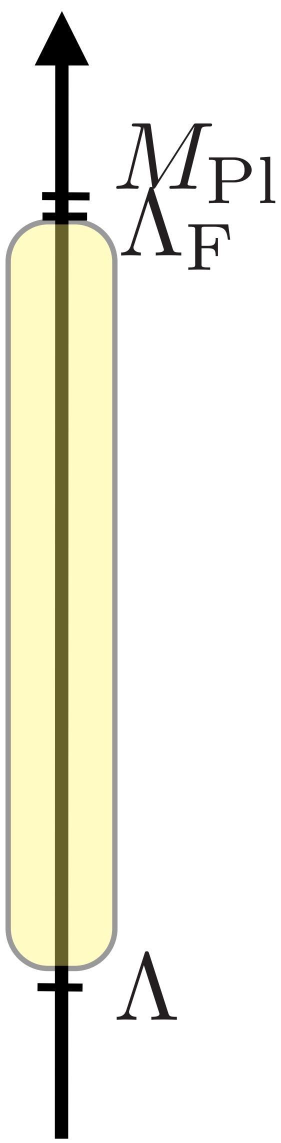
IRRELEVANT (d>4)

the flavor scale is close to the TeV:
must explain fermion masses, mixings.

very very very hard....



$$y_t \propto \left(\frac{\Lambda}{\Lambda_F}\right)^{d_L+d_R-5}$$



RELEVANT **ONLY for d<2.5**

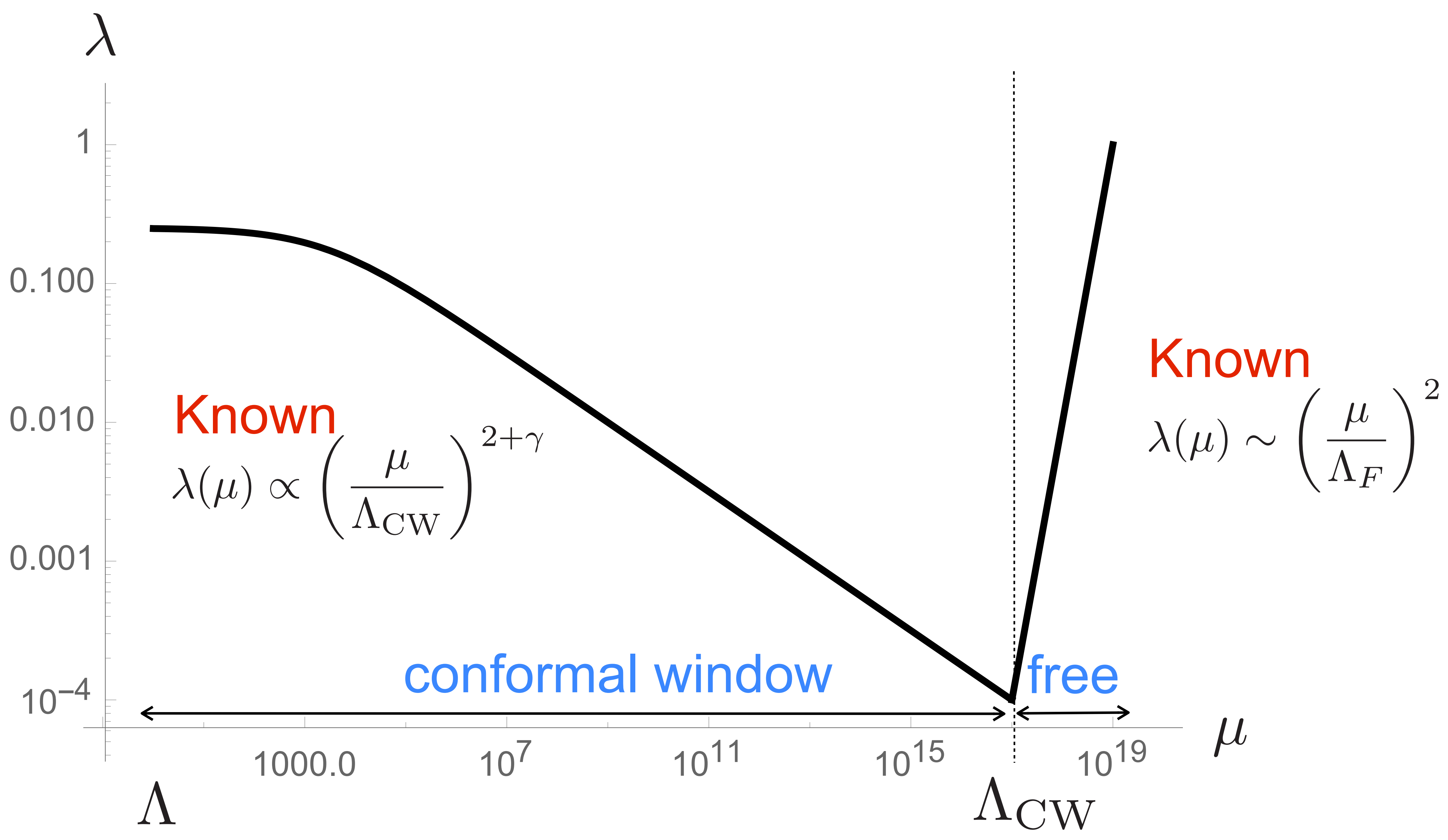
the Yukawa is not suppressed:
origin of fermion masses, mixings may decouple.

3. Key ingredients to decouple flavor scale

(no scalars)

- Strongly-coupled IR fixed point
- 3-fermion operators with <u>very large anomalous dimensions</u>
- A very large energy window $\Longrightarrow$ all fermions get a mass from PC

Take for instance **qO=** $\frac{q\Psi\Psi\Psi}{M_{\mathrm{Pl}}^2}$



Note:

qO= $\frac{q\sigma^{\mu\nu}Q^a F^a_{\mu\nu}}{\Lambda_F}$ is not sufficient nor necessary

$$\mu\frac{dg}{d\mu} = -\frac{g^3 C_2}{16\pi^2}\left(\frac{11}{3} - \frac{2}{3}N_F\right) + \cdots$$

A candidate and its Pheno

Wish-list

- ❑ A strong IR fixed point (conformal window)
- ❑ Realistic phenomenology (ex: Higgs potential)
- ❑ Partners O for all SM quarks (to decouple the flavor scale)
- ❑ No Landau poles at low energy
- ❑ $d<2.5$ within the conformal window?

Ferretti-Karateev (2013)

Wish-list

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An QCD-like SU(3) candidate with Nf Dirac flavors

	$SU(3)$	$SU(3)_c$	$SU(2)_w$	$U(1)_Y$
T	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{1}$	a
D	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{2}$	$\frac{1}{3} - \frac{1}{2}a$
S	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$	$-\frac{1}{6} - \frac{1}{2}a$
S'	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$	$\frac{5}{6} - \frac{1}{2}a$

Plus the right handed components

$$\psi_1\psi_2\psi_3 \equiv \Gamma\psi_1 \left(\overline{\psi_2^c}\Gamma'\psi_3\right)$$

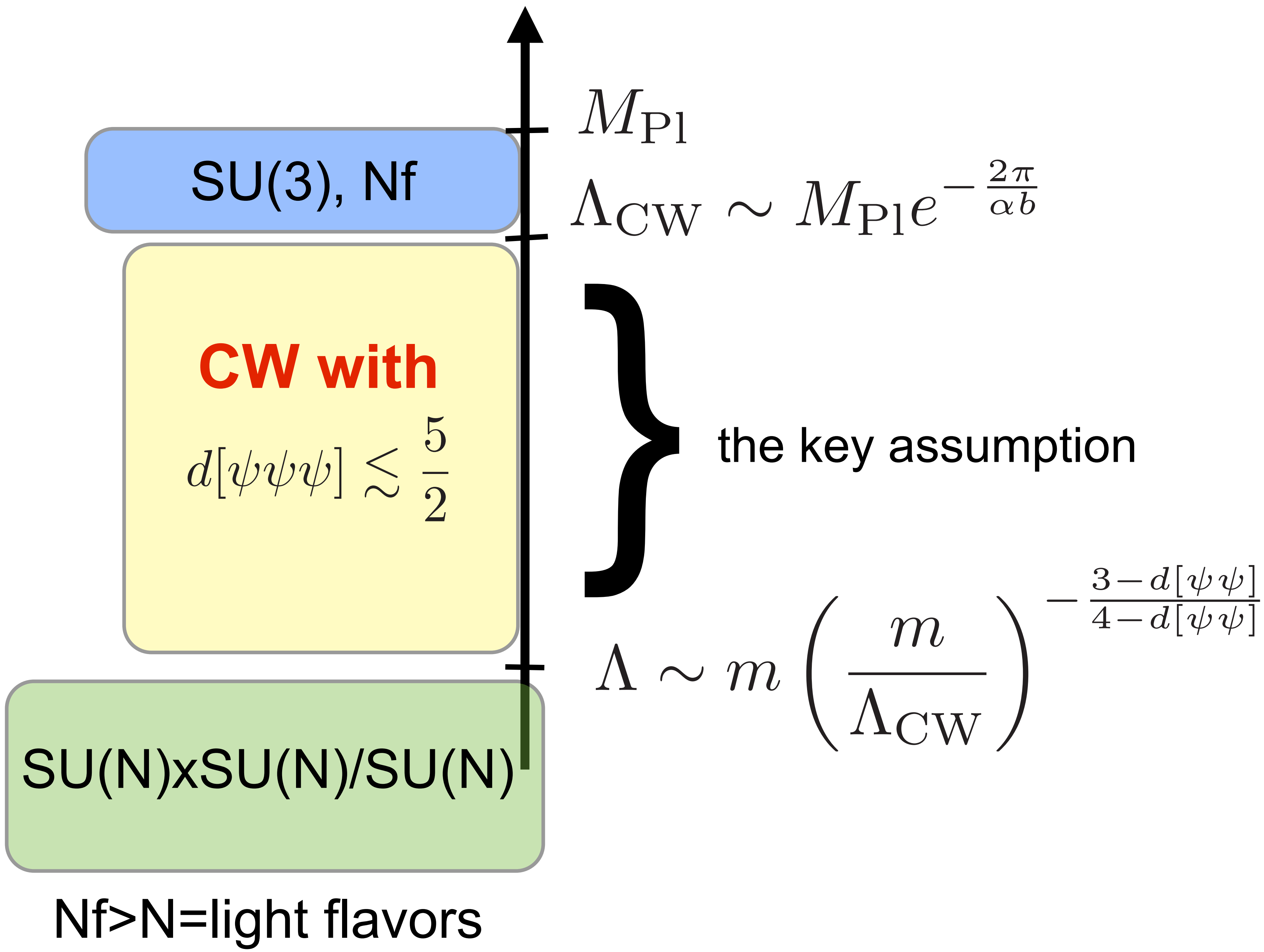
$$\mathcal{L}_{\rm PC} = q\overline{TDS} + uTDD + uTSS' + dTSS + \text{hc.}$$

$$\mathcal{L}_{\rm ETC} = quD\overline{S} + qu\overline{D}S' + qd\overline{D}S + qdD\overline{S'}$$
$$+\ell e\overline{D}S + \ell eD\overline{S'} + Q^\dagger\overline{\sigma}^\mu Q\psi^\dagger\overline{\sigma}_\mu\psi + \text{hc}$$

Exit CFT:

$$\mathcal{L}_{\rm mass} = -m_T T\overline{T} - m_D D\overline{D} - m_S S\overline{S} - m_{S'} S'\overline{S'} + \text{hc.}$$

...



$M_{\rm Pl}$
SU(3), Nf
$\Lambda_{\rm CW} \sim M_{\rm Pl} e^{-\frac{2\pi}{\alpha b}}$
CW with
$d[\psi\psi\psi] \lesssim \frac{5}{2}$
the key assumption
$\Lambda \sim m \left(\frac{m}{\Lambda_{\rm CW}}\right)^{-\frac{3-d[\psi\psi]}{4-d[\psi\psi]}}$
SU(N)xSU(N)/SU(N)
Nf>N=light flavors

Phenomenology

- non-minimal SU(N)xSU(N)/SU(N) ⇒ Collider (exotic NGBs)
- color not factorized ⇒ Collider (direct production of colored NGBs)
- accidental symmetries ⇒ Collider (new collider signatures)

Vacuum Alignment in SU(4)xSU(4)/SU(4) $SU(2)_w \times SU(2)_{\rm cust} \subset SU(4)_V$

- 15 Goldstones:

$$\mathrm{NGB} = (2,2) + (2,2) + (3,1) + (1,3) + (1,1)$$

- Fermions in (reducible) 2-index representations:

$$O \sim T\Psi_i \Psi_j$$

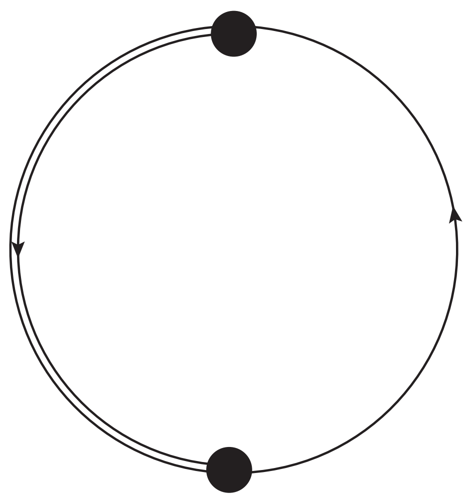
- Generically, couplings to fermions break custodial: problem with rho parameter

Gripaios et al. (2009)
Mrazek et al. (2011)

$$\delta\mathcal{L} = m_{1,2}^2 \; iH_1^\dagger H_2 + \mathrm{hc}$$

<u>Robust solution</u>: $\lambda_R \overline{t_R} O$

choose O in the $\mathbf{6} \in SU(4)_V$ of $(\mathbf{4}, \mathbf{4}) \in SU(4)_L \times SU(4)_R$



$$\delta V = C_u \ \mathrm{tr}\left[(\lambda_R U)(\lambda_R U)^*\right]$$

$$C_u = 4 \int \frac{d^4 p_E}{(2\pi)^4} \int ds \frac{\rho(s)}{p_E^2 + s} > 0.$$

$\Longrightarrow$ **no tadpole for H_2** (respects custodial)

& positive masses for the "dangerous" NGBs (rho is OK!)

technically natural:

$$\mathrm{NGB} = (2,2) + \cancel{(2,2)} + \cancel{(3,1)} + \cancel{(1,3)} + (1,1)$$

effectively SU(4)/Sp(4)!

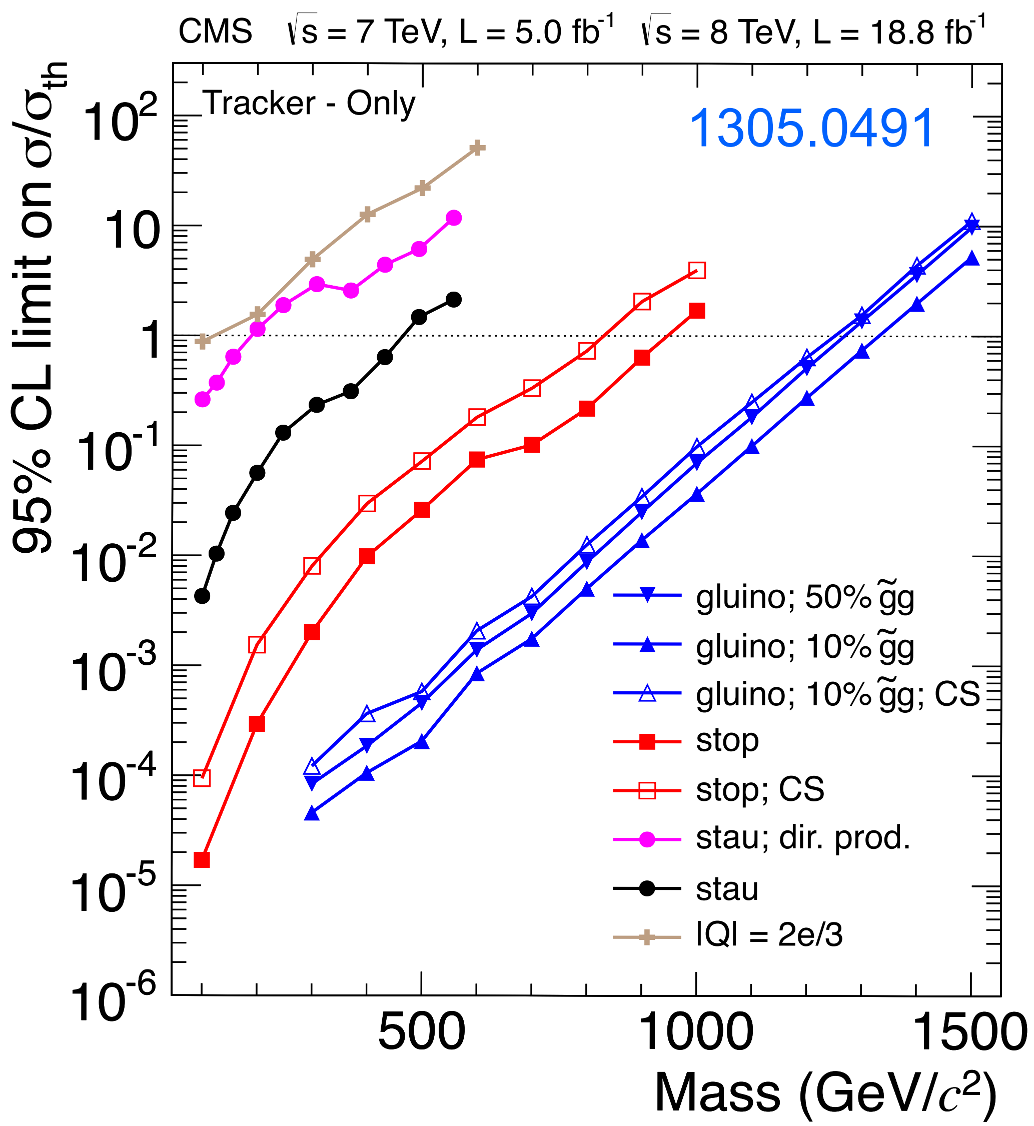
⁕ realistic Higgs potential

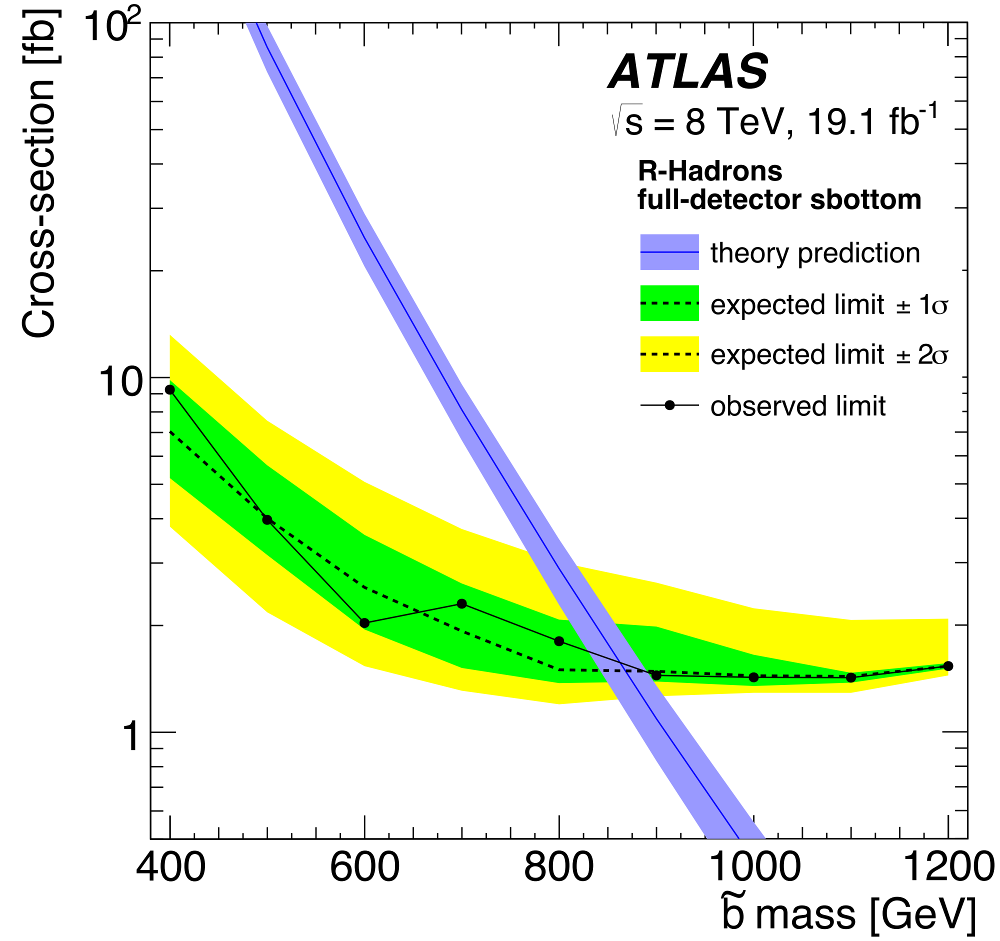
$$V_{\text{NDA}} = \frac{(g_* f)^4}{16\pi^2}\left[a\left(\frac{y_t^2}{g_*^2}s_h^2\right) + b\left(\frac{y_t^2}{g_*^2}s_h^2\right)^2 + \cdots\right]$$

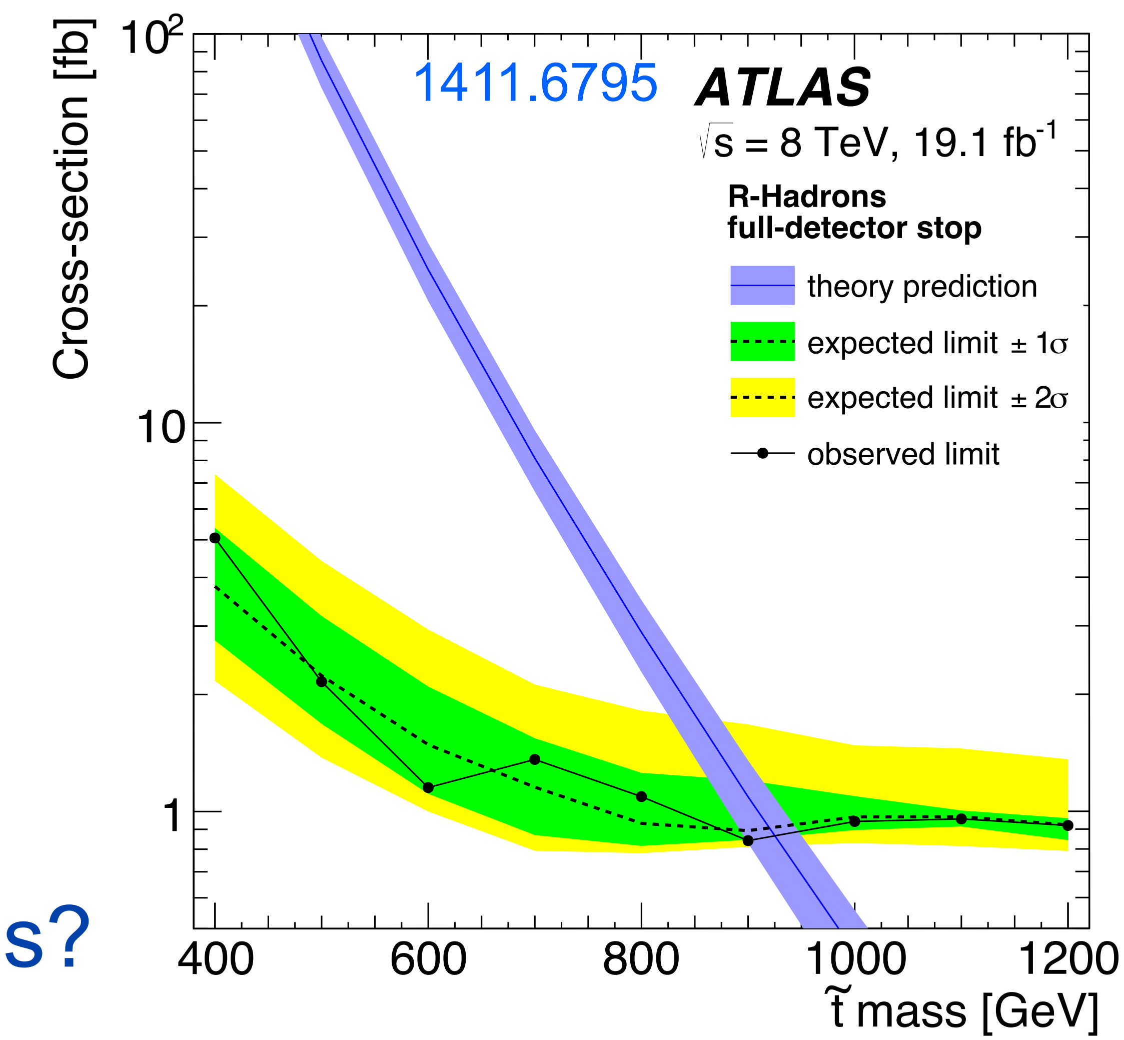
- To achieve v<<f ONE tuning (a<<b~1) of order $\sim (g_* f/m_t)^2$ "double-tuning" in Panico et al. (2013)
- The 126 GeV Higgs quartic is reproduced for b~4=O(1) and $g_* = 4\pi$

✻ Color-Triplet PNGBs with EW charges

▶ accidental baryon & lepton & U(1)_T family ⇒ **T-hadrons**







Fractional charge? Displaced vertices?

Conclusions

* Honest (pheno) question: **models without fund. scalars?**

* “Obvious” candidate: **SU(3) gauge with light flavors**
  - satisfies all basic requirements theoretically under control
  - has realistic vacuum alignment ($v<f$) and Higgs mass
  - familiar to lattice community (baryon scaling dimension**?)**

* **UV models $\Longrightarrow$ phenomenological work to do:**
  - extend studies to non-minimal cosets (SU(4)^2/SU(4), etc.)
  - collider pheno of colored scalars (generic from PC)
  - novel signatures (T-hadrons, etc.)