KSC (A)

12/7/2017

"STRONG EWSB"

Introduction: - Per Tony's TALK - Dynamical Assumption
- LARGE γ, operator with nontrivial scaling dimension

Sezkotten

Review:

- Λ_{UV} ← All flavor here

Flavor Information from high energies must feed down

$$\mathcal{L} = \lambda_L \psi_L \mathcal{O}_R + \lambda_R \psi_R \mathcal{O}_L.$$

- $\Lambda \sim$ "g_ρ" f

dim $\mathcal{O}_{L,R} > 5/2$ → Light ferm

dim $\mathcal{O}_{L,R} \sim 5/2$ Top

↪ ⇒ $\psi_{L,R}\mathcal{O}_{L,R}$ Marginal.

- f
- v
- h

$$\text{dim}(\psi\psi\psi) = \frac{9}{2} - \gamma$$

⇒ $\gamma = 2$ for top

? ≤ $\gamma < 2$ for light ferms.

"ETC"/TC

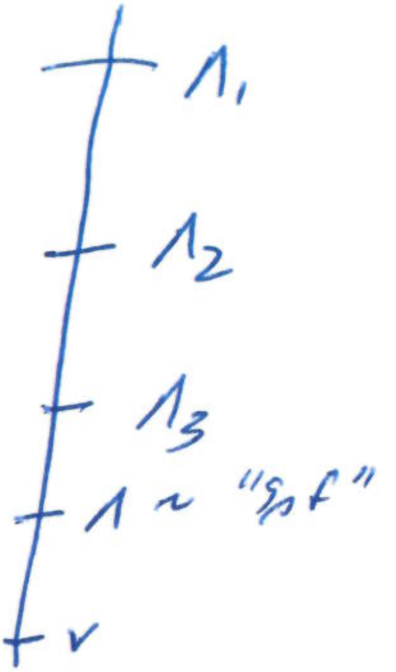
- $\Lambda_1 \sim$ light flav, 1st Gen
- $\Lambda_2 \sim$ 2nd Gen
- $\Lambda_3 \sim$ 3rd Gen ← top?
- $\Lambda = g_\rho v \sim$ 1 TeV
- v ← h? ← Dog-ki

TC

What γ_m is required for flavor?

Composite Higgs/ETC

RSC
12/7/2017 (B)



$\underline{f > v}$

What γ is required to keep $\underline{f \sim 1\,\text{TeV}}$?

$\Rightarrow \underline{\Lambda = \text{"}g_* f\text{"} \lesssim 10\,\text{TeV}}$

{ EHS → Technicolor/ETC
RSC → Composite Higgs/ETC
Also: Partial Compositeness + g_A
Deog-Ki → Light higgs/dilaton }

EHS

→ RSC (follows) (g_A)

→ Deog-Ki

Schemes:
* LADDER Approx S-D equations
* CJT effective potential
* SUSY/Seiberg duality
* Holographic construction, large-N
input vs. output?

Walking TC and FCNC

new $SU(N_{TC})$ gauge force felt by techniquarks

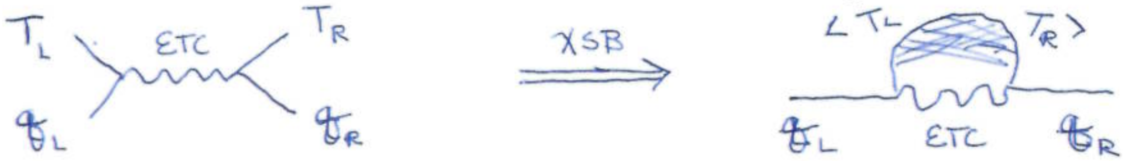
e.g. $T_L^a \equiv \begin{pmatrix} U^a \\ D^a \end{pmatrix}_L$ and U^a_R, D^a_R

so Lagrangian has $SU(2)_L \times SU(2)_R$ chiral symmetry

when running gauge coupling becomes strong at $\Lambda_{TC} \sim 1$ TeV, χSB occurs

$\langle T_L T_R \rangle \neq 0$, Π_{TC} become W_L, Z_L

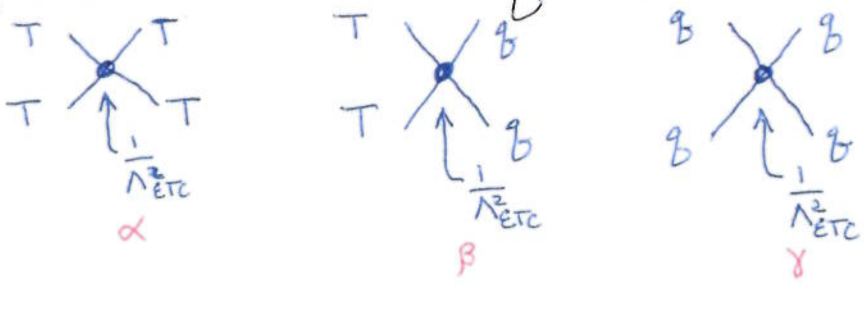
to generate m_f, extend TC group to include ETC bosons that couple ordinary and techni quarks



$m_q \sim \left(\frac{g_{ETC}}{M_{ETC}}\right)^2 \langle T_L T_R \rangle \cdot$ flavor

↑ $1/\Lambda^2_{ETC}$

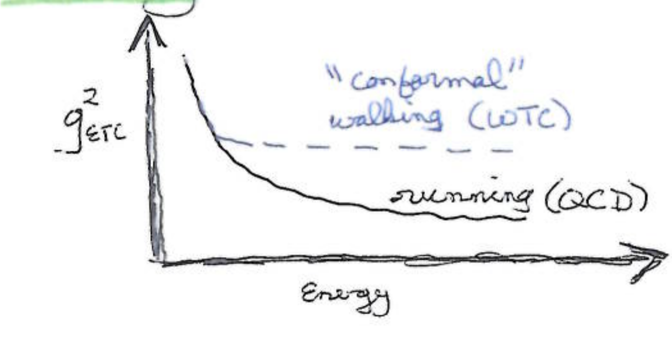
but heavy ETC bosons will yield all possible 4-fermion contact interactions among quarks and techniquarks



Since the β terms treat q of same gauge charges differently to yield varied m_q ... γ terms will do likewise $\Rightarrow$ FCNC

$\Rightarrow$ make Λ_{ETC} too large to produce m_q!

Walking TC intervenes:



$m_q \approx \frac{g^2_{ETC}}{m^2_{ETC}} \langle \bar{T}T \rangle = \frac{1}{\Lambda^2_{ETC}} \langle \bar{T}T \rangle$

is now larger for a given $\langle \bar{T}T \rangle$

[flavor symmetry breaking pushed to higher scale]

Condensate → m_q

ETC operator $\frac{1}{\Lambda^2_{ETC}} \left(\bar{Q}_L^a \gamma^\mu q_L^i\right)\left(\bar{q}_R^i \gamma_\mu U_R^a\right)$

yields mass term value: $\langle \bar{U}_L U_R \rangle_{\Lambda_{ETC}} \cdot \Lambda^{-2}_{ETC}$

<u>But</u> what we know in TC is $\langle \bar{U}_L U_R \rangle_{\Lambda_{TC}}$!

$$\langle \bar{U}_L U_R \rangle_{\Lambda_{ETC}} = \exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} \gamma_m \left(\alpha_{TC}(\mu)\right) \frac{d\mu}{\mu} \right) \langle \bar{U}_L U_R \rangle_{\Lambda_{TC}}$$

↑ anomalous dimension of TF mass operator

in <u>extreme</u> walking $\gamma_m =$ constant

$$\langle \bar{U}_L U_R \rangle_{\Lambda_{ETC}} = \left(\frac{\Lambda_{ETC}}{\Lambda_{TC}}\right)^{\gamma_m} \langle \bar{U}_L U_R \rangle_{\Lambda_{TC}}$$

$$m_q = \frac{1}{\Lambda^2_{ETC}} \left(\frac{\Lambda_{ETC}}{\Lambda_{TC}}\right)^{\gamma_m} \langle \bar{U}_L U_R \rangle_{\Lambda_{TC}}$$

2 common estimates of size of $\langle \bar{U}_L U_R \rangle_{\Lambda_{TC}}$

<u>NDA</u>: $\Lambda_{TC} \equiv \Lambda_{\chi SB} = 4\pi v_{ew}$

$$\langle \bar{U}_L U_R \rangle_{\Lambda_{TC}} = \left(\frac{\Lambda^3_{\chi SB}}{(4\pi)^2}\right)$$

$$\Rightarrow m_q^{NDA} = \left(\frac{\Lambda_{\chi SB}}{(4\pi)^2}\right)\left(\frac{\Lambda_{\chi SB}}{\Lambda_{ETC}}\right)^{2-\gamma_m}$$

<u>DA</u>: $\Lambda_{TC} = 1$ TeV

$$\langle \bar{U}_L U_R \rangle_{\Lambda_{TC}} = \Lambda^3_{TC}$$

$$\Rightarrow m_q^{DA} = \Lambda_{TC} \left(\frac{\Lambda_{TC}}{\Lambda_{ETC}}\right)^{2-\gamma_m}$$

UTFit Collaboration Limits

<u>Notation</u>: $C^{1}_{meson} \cdot (\bar{q}_L \gamma^{\mu} q'_L)(\bar{q}_L \gamma_{\mu} q'_L)$

$C^{1}_{meson} = \dfrac{F_{qq'} \, L_{qq'}}{\Lambda^2}$

$F_{qq'}$: 1 w/o GIM

$L_{qq'}$: 1 for tree-level FCNC

$\Lambda^2 \equiv \Lambda^2_{ETC}$ in this context

Reported Limits

CP conserving (ETC not involved in CPV)

$Re(C^1_K)$ (2016), $|C^1_D|$ (2010), $|C^1_{B_d}|$ (2016) $\rightarrow \Lambda_{ETC} \gtrsim 1{,}000$ TeV

$|C^1_{B_s}|$ (2016) $\rightarrow \Lambda_{ETC} \gtrsim 200$ TeV

CP violating

$Im(C^1_K)$ (2016) $\rightarrow \Lambda_{ETC} \gtrsim 20{,}000$ TeV

$Im(C^1_D)$ (2016) $\rightarrow \Lambda_{ETC} \gtrsim 7{,}000$ TeV

Required γ_m ?

In CP-conserving scenario, UTFIT data on K, D, B_d all set similar $\Lambda_{ETC} \gtrsim 1000$ TeV

But γ_m required for walking ETC to generate associated quark mass is quite different

	m_s	m_c	m_b
NDA	0.75	1.5	1.75
DA	0.4	1.0	1.25

In CPV scenario, UTFIT finds K data sets highest limit $\Lambda_{ETC} > 20,000$ TeV

$\Rightarrow$ γ_m^{NDA} needed for m_s is 1.25

γ_m^{DA} " " " " 0.9

Yet, CPV limit from D data saying $\Lambda_{ETC} > 7,000$ GeV requires higher γ_m to generate the heavier charm mass

$\Rightarrow$ γ_m^{NDA} needed for m_c is 1.625

γ_m^{DA} " " " " 1.25

Conclusions

Even with looser DA estimate, using walking ETC to produce m_q requires $\gamma_m \gtrsim 1$

- we've neglected details like N_{TC} effects, # weak doublets in TC sector, and possibility of less extreme walking ... all of which would <u>lower</u> produced m_q

- need lattice to determine feasible γ_m in specific WTC theories & if $\gamma_m < 1$ one would need to incorporate flavor symmetries into theory
- also interesting to know more @ composite scalars that can be part of WTC with high γ_m (how light? how broad?)

Note - γ_m scheme-independent strictly only at conformal point & but WTC is nearly conformal so one could extrapolate

RSC (C)

"Composite Higgs/ETC", RSC, Dobrescu, Eichten 12/7/2017
hep-ph/9702416, PLB 401, 74 (1997)

$\Lambda_{flavor} \sim M$ $\qquad \frac{g^2}{M^2}\left[(\bar\psi u)(\bar T T) \text{ or } (\bar\psi d)\bar T T\right]$

Scaling ↓ $\qquad \frac{g^2}{M^2}\left(\frac{M}{\Lambda}\right)^\gamma (\bar\psi u)(\bar T T), (\bar\psi d)(\bar T T)$

$\Lambda \sim g_p f$

$\bar T T \to f\Lambda \cdot \phi$.

f $\qquad \leftarrow \left(\frac{g^2}{M^2}\right)\left(\frac{M}{\Lambda}\right)^\gamma f\Lambda \; (\bar\psi u \phi, \bar\psi d \phi)$

v

$$\text{Yukawa} \sim \frac{g^2}{M^2}\left(\frac{M}{\Lambda}\right)^\gamma f\Lambda \cong \frac{\sqrt{2}\, m_q}{v}.$$

($\gamma = 0$!) "TC-like" Composite Higgs ← vs. $g_p v^3$ ← TC

$$m_q \sim \frac{g^2}{M^2} f\Lambda v = g_p f^2 v$$

⇒ Enhanced by $\left(\frac{f^2}{v^2}\right)$ wrt Technicolor w/ Mixing Angles

Take Λ fixed ~ 10 TeV, $f \sim 1$ TeV, $\frac{M}{g} \gtrsim 100$ TeV

$$m_q \sim \frac{g^2}{(100\text{ TeV})^2}\, 10 \cdot (\text{TeV})^2 \frac{250\text{ GeV}}{\sqrt{2}}$$

$$\sim g^2 10^{-3} \cdot 250 \text{ GeV} \cong 200\text{ MeV} \cdot g^2$$

Need $\gamma \neq 0$ for heavy quarks

m_s ok! not charm or strange

$\gamma = 1$ $\quad$ $M = 100$ TeV, $f = 1$ TeV, $\Lambda = 10$ TeV $\quad$ (P)

$$m_q \simeq \frac{v}{\sqrt{2}} \frac{g^2}{M^2} \left(\frac{M}{\Lambda}\right) f \Lambda$$

$$\simeq \frac{v}{\sqrt{2}} \frac{g^2}{M} f \simeq \frac{250 \text{ GeV}}{\sqrt{2}} \frac{(1)}{(100 \text{ TeV})} (\text{TeV})$$

$$\simeq 2.5 \text{ GeV} \leftarrow \text{charm, bottom?}$$

$\gamma = 2$ $\quad$ NJL limit ⇒ Fundamental scalar

M integrated

$$\text{Yukawa} \sim \frac{g^2}{M^2} \left(\frac{M}{\Lambda}\right)^2 f \Lambda \sim g^2 \frac{f}{\Lambda}$$

$$\sim \frac{1}{10} - 1 \Leftarrow \text{bottom tops} \Rightarrow \text{[illegible]}$$

Despite the enhancement by $\left(\frac{f}{v}\right)^2$, still need $\gamma \sim 1-2$ to explain quark masses in $_\wedge$ Composite Higgs Theories

ETC-like