S parameter from a prototype composite-Higgs model

Yigal Shamir

Tel Aviv University

TACOS collaboration:

Maarten Golterman, Will Jay, Ethan Neil, Benjamin Svetitsky

Composite Higgs

- Hierarchy problem: [un]naturalness of the Higgs mass
- Composite Higgs: make the Higgs a [pseudo] Nambu-Goldstone boson
- "Hypercolor": new strong sector with scale $\Lambda_{HC} \gtrsim 1$ TeV
- *M6* model: SU(4) gauge theory with $N_f = 3$ fundamental Dirac fermions q and $N_{maj} = 5$ sextet (2-index antisymmetric) Majorana fermions Q
  Ferretti & Karateev, Ferretti
- Sextet spontaneous symmetry breaking SU(5) $\to$ SO(5)
  with SU(2)$_{EW}\times$U(1)$_Y$ $\subset$ SU(2)$\times$SU(2) $\sim$ SO(4) $\subset$ SO(5)
- Partially composite top quark: couples linearly to "chimera" baryon Qqq
- Here prototype (*2+2 model*):
  2 dynamical Dirac fermions of each rep.

Theory: L_{10} and S parameter at Next-to-Leading Order

$$\begin{aligned}
\langle J_{L\mu} J_{R\nu} \rangle &= (q^2\delta_{\mu\nu} - q_\mu q_\nu)\Pi^{(1)}(q^2) + q_\mu q_\nu \Pi^{(0)}(q^2) \\
\Pi^{(1)} &= \frac{F^2}{q^2} + \hat{\Pi}(q^2) \qquad \text{(kinematical singularity)} \\
\Pi^{(1-0)} &= \Pi^{(1)} - \Pi^{(0)} = \frac{F^2}{q^2 + M^2} + \hat{\Pi}(q^2) \\
\hat{\Pi}(q^2) &= \frac{N_{maj}+2}{96\pi^2}\left[\frac{1}{3} + \log\left(\frac{M^2}{\mu^2}\right) - H(s)\right] + \boxed{8L_{10}}
\end{aligned}$$

where $s = \sqrt{1 + 4M^2/q^2}$, and $H(s)$ has no free parameters

Then $S = \xi S_{\mathrm{NLO}}$ suppressed by vacuum misalignment parameter $\xi = 2v^2/F^2$,

with $F = F_6$ the sextet decay constant, and

$$S_{\mathrm{NLO}} = -2\pi \lim_{q^2\to 0} \hat{\Pi}(q^2) = -\frac{N_{maj}+2}{48\pi}\left[1 + \log\left(\frac{M^2}{\mu^2}\right)\right] - \boxed{16\pi L_{10}}$$

Lattice calculation

- Dynamical Wilson-clover fermions (both reps), nHYP smearing, dislocation-suppressing term
- Ensembles: twelve $16^3 \times 32$, three $24^3 \times 48$ $\qquad (M_\pi L > 4)$
- Chiral symmetry important $\Longrightarrow$ valence staggered fermions
  seven valence masses: $0.01 \le am_v \le 0.05$
- Scale setting using gradient flow scale t_0
- LO pole term: valence-valence pion, e.g. $\Pi^{(1-0)} = F_{vv}^2/(q^2 + M_{vv}^2) + \cdots$
- NLO one-loop term: mixed valence-sea pion ($\Delta_{\text{mix}} \ge 0$)

$$M_{vs}^2 = \frac{M_{ss}^2 + M_{vv}^2}{2} + \frac{a^2}{t_0^2}\,\Delta_{\text{mix}}$$

- NNLO analytic terms (test systematics):

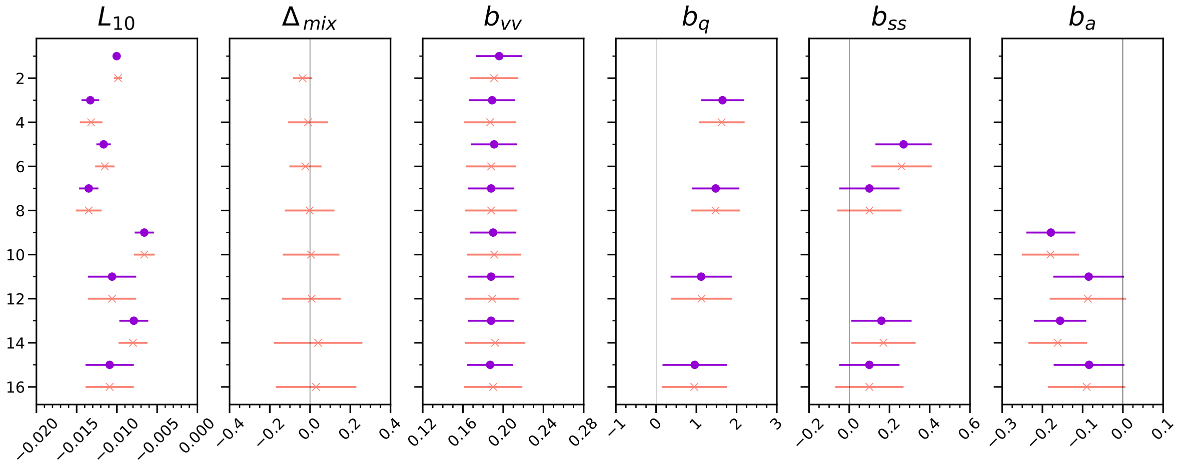
$$t_0\left(b_q\, q^2 + b_{ss}\, M_{ss}^2 + b_{vv}\, M_{vv}^2\right) + b_a\,\frac{a^2}{t_0}$$

Results

- Fit $\Pi^{(1-0)}$ to data from all seven valence masses
- Use only smallest (time like) q^2

$\Longrightarrow$ Limit sources of large NNLO corrections, besides valence mass

- Always keep L_{10} and b_{vv}, check all 16 combinations of other parameters



$$L_{10} = -0.0100(12)_{\rm stat}(35)_{\rm syst}$$

- Expt. bound on S parameter $\Longrightarrow$ misalignment parameter $\xi \leq 0.11(3)$ consistent with previous bounds

Problems with *2+2 model*

- top-quark – chimera mixing induced by 4-fermi operator: $G\,tQqq$
- Coupling G originates from yet much higher energy scale $\Lambda_{UV} \gg \Lambda_{HC} \sim F_6$
- Naively $GF_6^2 \;\sim\; (g_{UV}^2/\Lambda_{UV}^2)F_6^2 \;=\; g_{UV}^2\, F_6^2/\Lambda_{UV}^2 \;\ll\; 1$

$\Longrightarrow$ top Yukawa coupling $$y_t \sim \left(GF_6^2\right)^2 \left(\frac{Z}{F_6^3}\right)^2 \frac{F_6}{M_{Qqq}}$$

- Chimera mass: we find $M_{Qqq}/F_6 \simeq 6$
- Z analogue of the proton decay matrix element in GUTs, except $Z/F_6^3 \simeq 0.3$, which is 20 times smaller compared to QCD value!

$\Longrightarrow$ requires unrealistically small Λ_{UV}

Possible solution

- Add more fermions, make the theory near-conformal
- Can potentially generate large anomalous dimension $\gamma_{Qqq} \gtrsim 1$

$$\Rightarrow G \text{ enhanced by } \exp\left(\int_{F_6}^{\Lambda_{UV}} \frac{d\mu}{\mu}\,\gamma_{Qqq}\right)$$

- Conformal window (analytical est.)

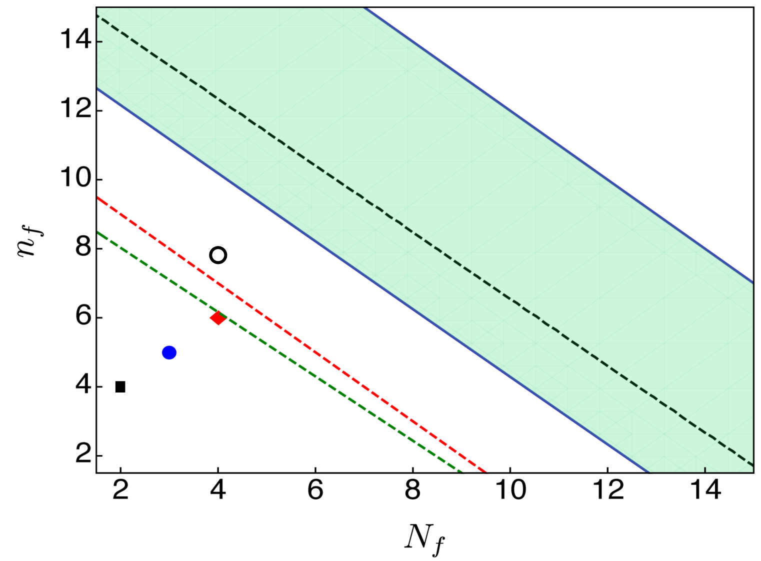
  Kim, Hong & Lee, PRD 101, 056008 (2020)

  blue circle: *M6 model*

  red diamond: *M11 model*

  black square: *2+2 model*

  open circle: *4+4 model*



- From *4+4 model* can reach *M6* or *M11* models by adding large masses
- Plan: study *4+4 model*. Stay tuned!