Composite Higgs model from the lattice: Infrared fixed point and anomalous dimensions

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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
- Ferretti & Karateev list of HC models:

  a) asymptotically free
  b) vector-like
  c) two fermion reps: Q, q
  d) SM symmetries embedded in unbroken $\mathcal{H}$ of global $\mathcal{G}$.

  e) Partially composite top quark
  top is the only quark with mass $m_t \sim m_{\text{higgs}}$

Partial compositeness

- t couples linearly to "chimera" HC baryon $B = Qqq$
- Requires 4-fermion interactions $G(\bar{t}B + \bar{B}t)$ where $G \sim \Lambda_{EHC}^{-2}$

$$t \xrightarrow{G} B \xrightarrow{G} t$$

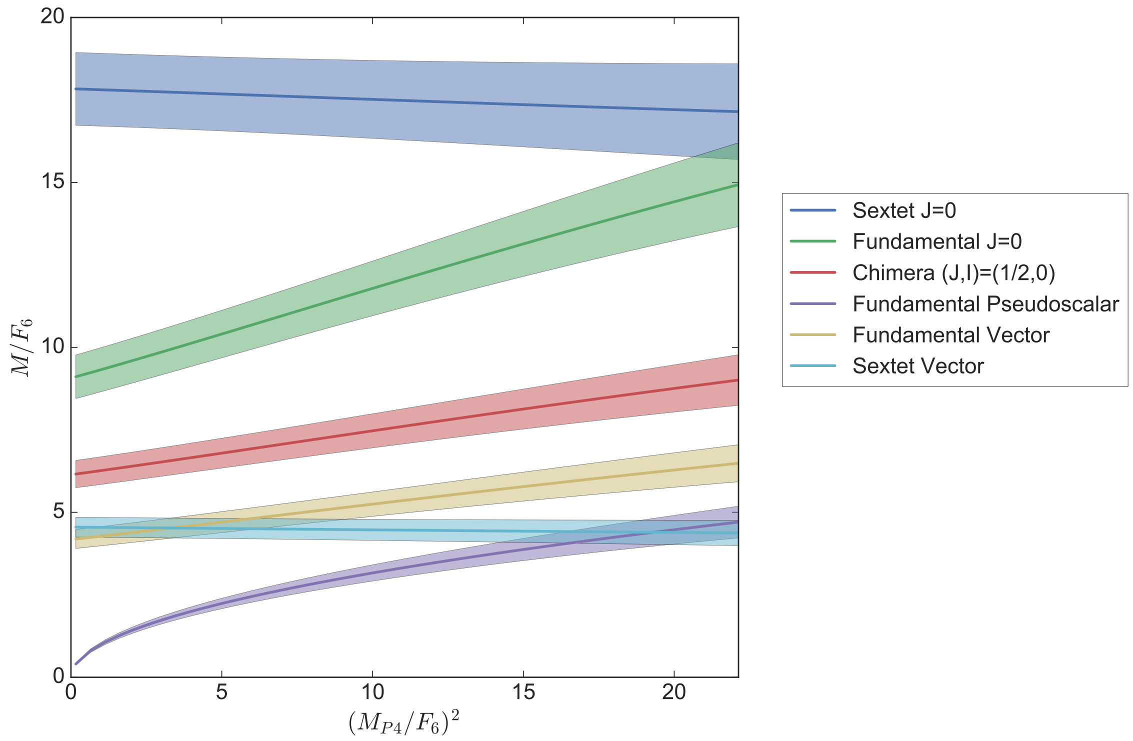
- Must be induced by *extended hypercolor* with some yet higher scale Λ_{EHC}
- Problem (same as Technicolor): flavor violations coming from similar 4-fermion interactions among SM fermions $\Rightarrow \Lambda_{EHC} \gg \Lambda_{HC}$
- Problem (cont.): To generate realistic top mass, need to overcome naive suppression factor $\sim (\Lambda_{HC}/\Lambda_{EHC})^4$
- Solution: a) *Near-conformal* HC theory

  b) *Large anomalous dimension* for B such that suppression factor reduces to $(\Lambda_{HC}/\Lambda_{EHC})^{2(2-\gamma_B)}$

  $\Rightarrow$ Ideally $\gamma_B \sim 2$ all the way from EHC to HC scale!

Prototype: 2 + 2 model

- Ferretti & Karateev "M6": SU(4) gauge theory with $3 \times$ fund. $+ 5 \times$ sextet
- 2+2 model: $2 \times$ fund. $+ 4 \times$ sextet (Note: $4 \times$ Majorana $= 2 \times$ Dirac)



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But:

2+2 model is QCD like

matrix element $\langle 0 | B_i | B \rangle$ of partial compositeness is very small

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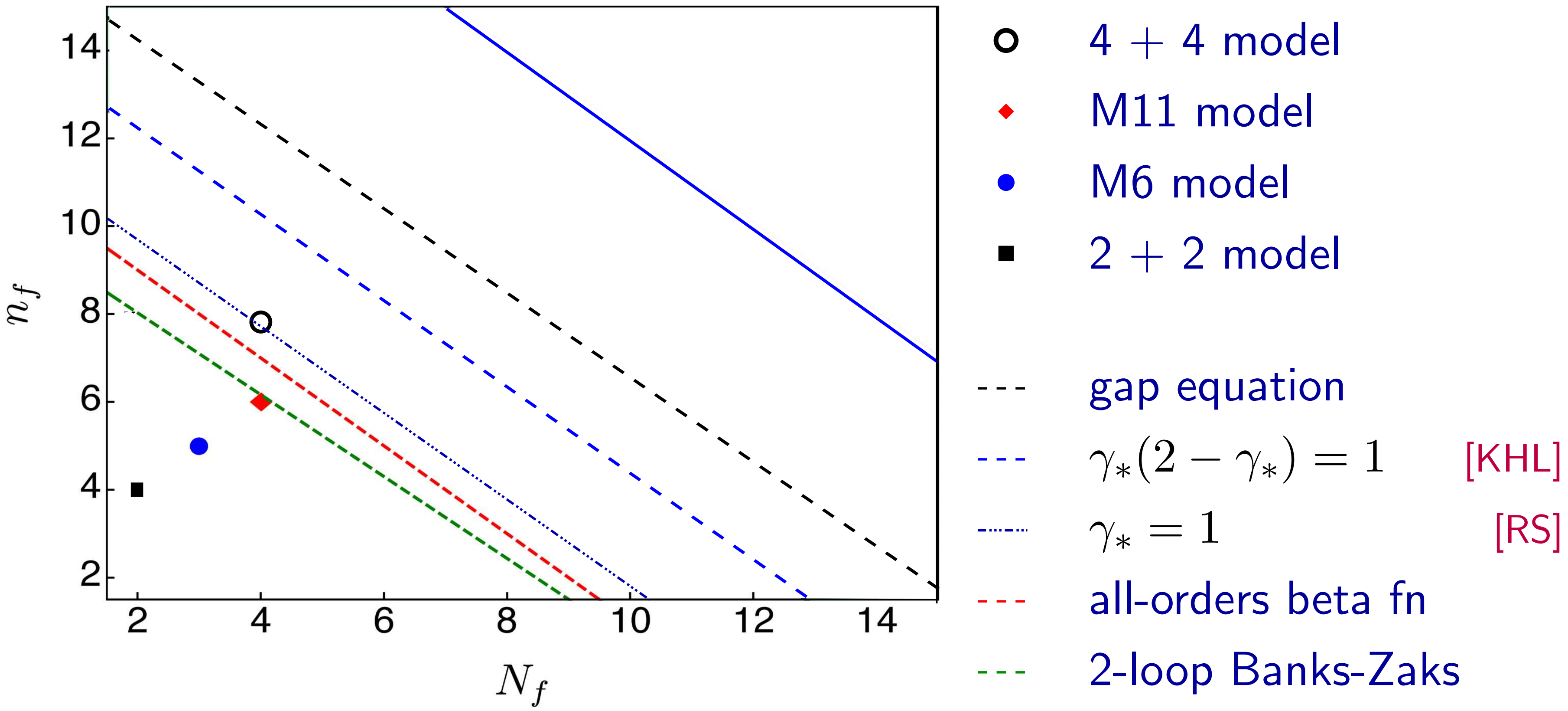
Looking for (near) conformality: 4 + 4 model

- Analytic estimates for the conformal window (dashed lines)
  SU(4) with $N_f \times$ Dirac fund. $+ n_f \times$ Maj. sextets



Improvement!

Plaquette action and Wilson fermions with:

- Clover term
- nHYP smeared links
- nHYP dislocation suppressing gauge term
- PV bosons PRD 104 (2021) 7, 074509

  decouple in continuum limit, while generating

  well behaved effective gauge action

$\Rightarrow$ Payoff: ever stronger renormalized coupling with each improvement

Continuous RG

- Gradient flow

$$\frac{\partial B_\mu}{\partial t} = -\frac{\partial S_g}{\partial B_\mu}\,, \qquad B_\mu\Big|_{t=0} = A_\mu$$

$$g^2(t) = Ct^2\,\langle E(t)\rangle\;, \qquad E(t) = G^a_{\mu\nu}G^a_{\mu\nu}(t)$$

- Flow as RG: $g^2(t)$ is the running coupling at scale $\mu^2 = 1/t$, and

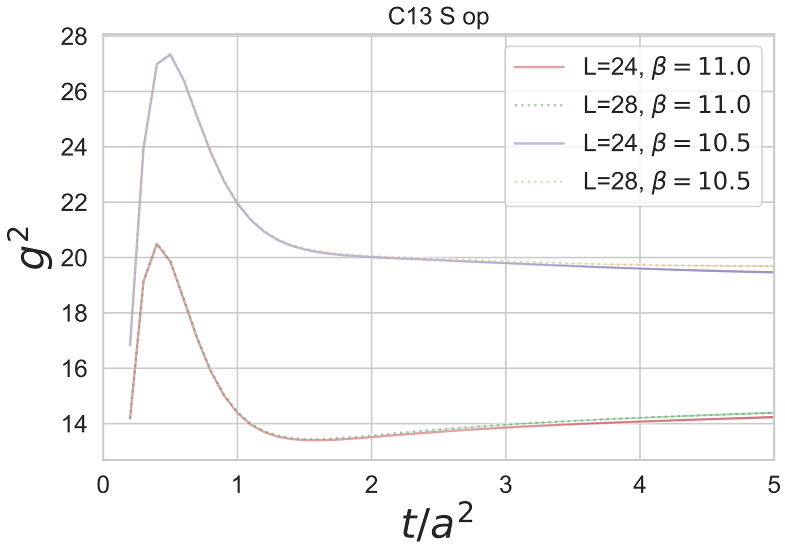
$$\beta(g^2) = -t\frac{\partial g^2}{\partial t}$$

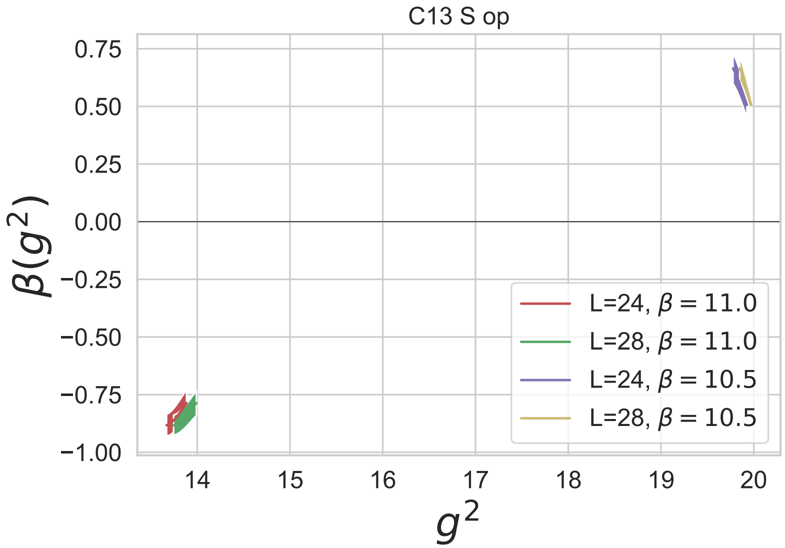
- Discretizations: $S_g^{\rm latt} = c_p S_{\rm plaq} + c_r S_{\rm rec}$ with $c_p + 8c_r = 1.$

  Symanzik flow: $c_p = 5/3$
  C43 flow: $c_p = 4/3$
  Wilson flow: $c_p = 1$
  C23 flow: $c_p = 2/3$
  C13 flow: $c_p = 1/3$

- $E(t)$ operators: Symanzik, Wilson, Clover

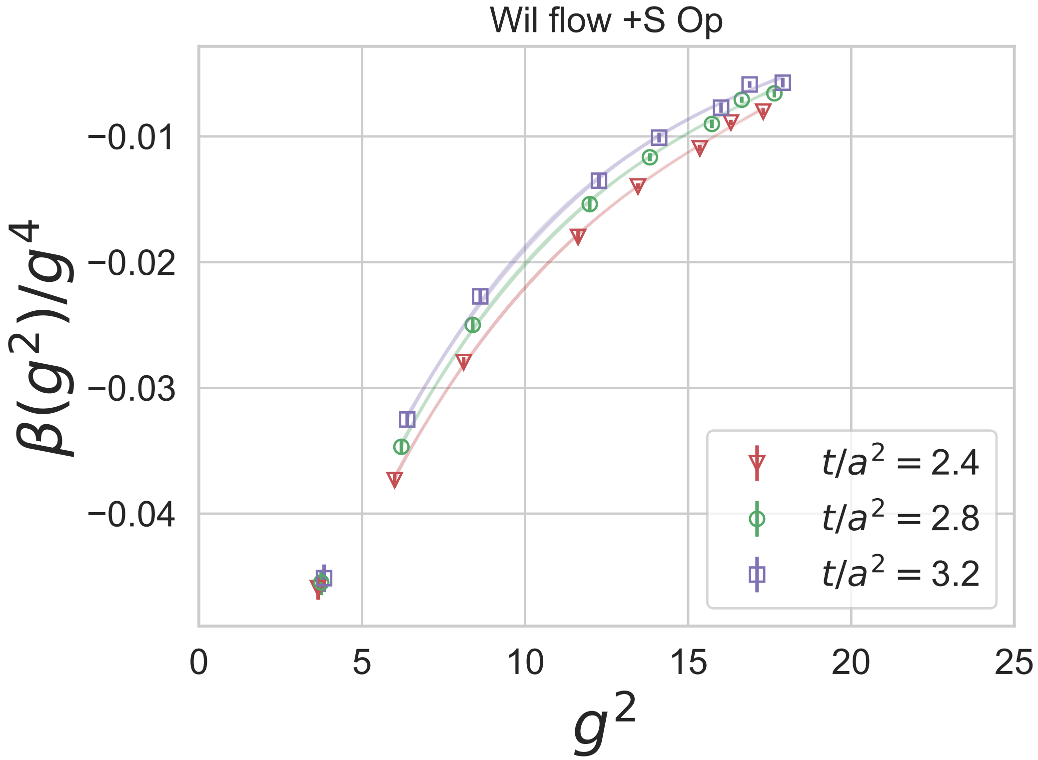
Raw flow, finite volume





- We use $2.4 \leq t/a^2 \leq 3.2$
- We only estimated FV effects
- Infinite volume limit $\Rightarrow$ small shift of g^2

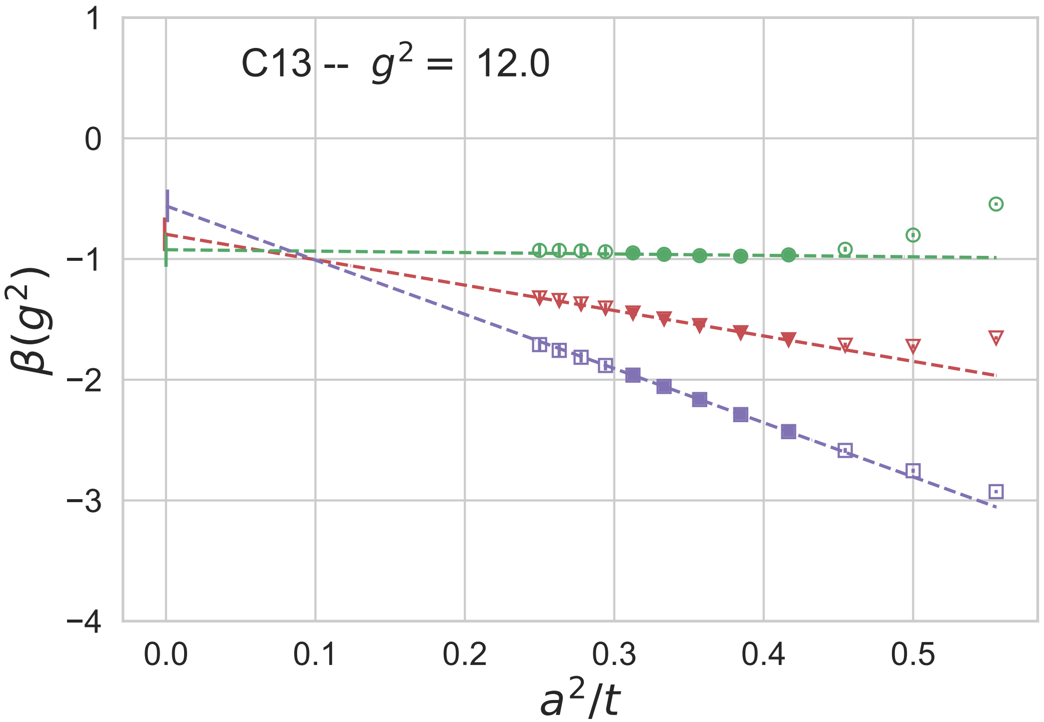
Interpolation



$g^2(g_0, t)$, $\beta(g_0, t)$

Interpolate $\Rightarrow$ $\beta(g^2, t)$

Continuum limit: $a^2/t \to 0$ at fixed g^2



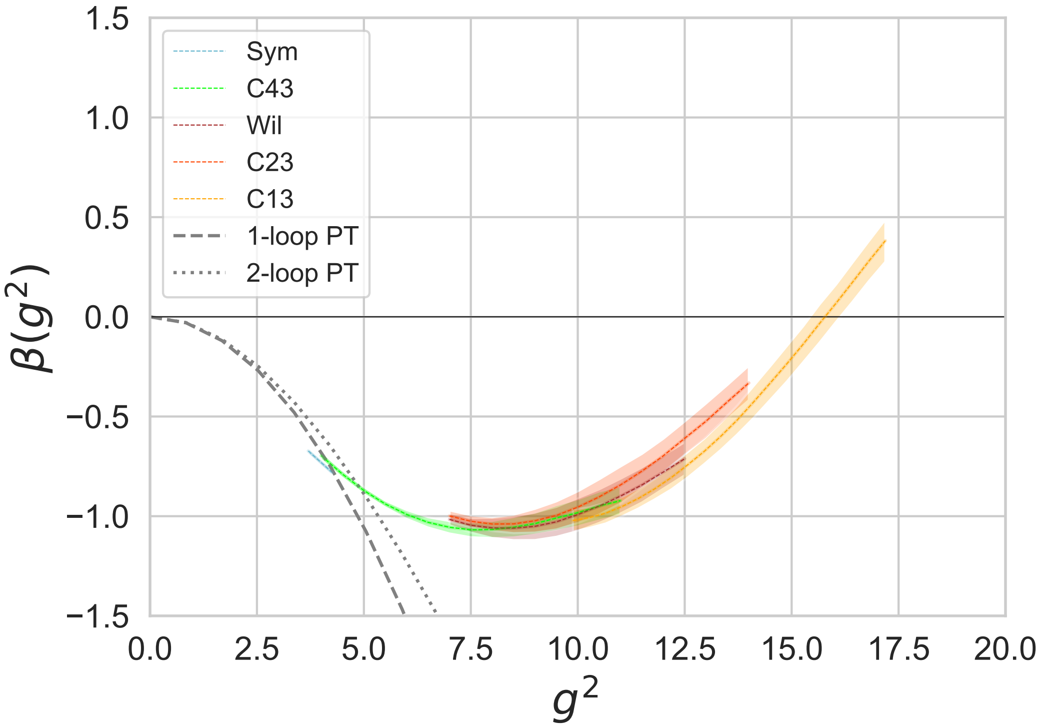
Precise condition:

Require consistency of

S and W:

$$\langle \beta_S - \beta_W \rangle \leq \sqrt{2}\,\sigma_S$$

Beta function



Use 5 different flows

Cover $4 \lesssim g^2 \lesssim 17$

Infrared fixed point

$g_*^2 \sim 15.5$

Anomalous dimensions

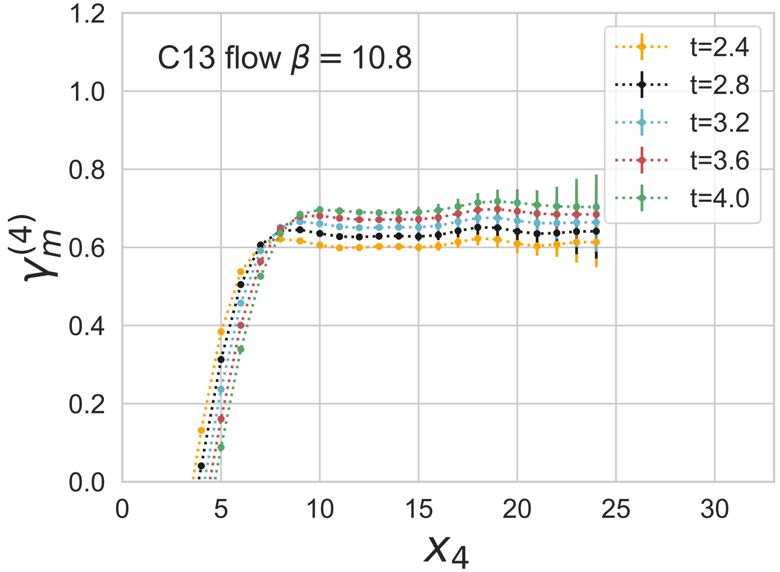
- Fermion flow
$$\frac{\partial \chi}{\partial t} = \Delta\chi, \qquad \chi\big|_{t=0} = \psi$$

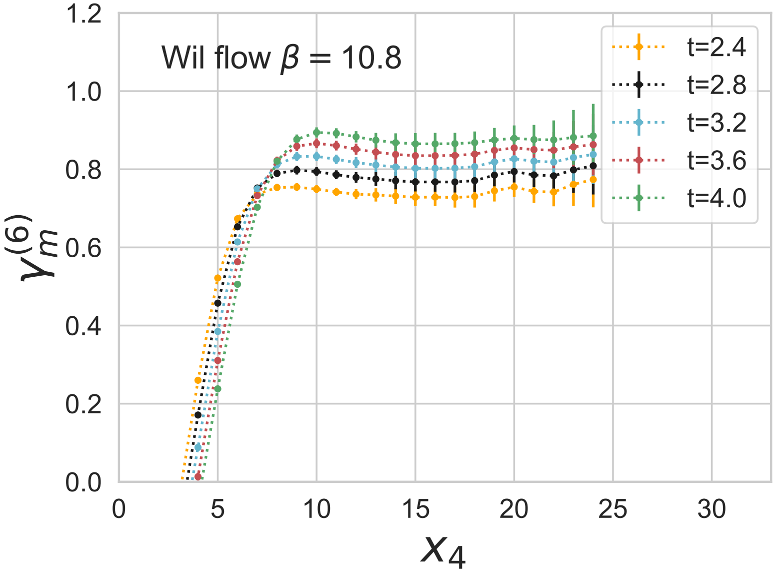
- Flowed meson correlators $\langle X(0)\, X'(x_4,t)\rangle$
  source $X = \bar\psi\Gamma\psi$ (not flowed; Gaussian point-split)
  sink $X' = \bar\chi\Gamma\chi$ (flowed; point operator, $\vec p = 0$)

- Correct for anomalous dim. of ψ field:
  divide by converved current $\Longrightarrow$ anomalous dim. of X composite

$$\gamma_X = -2\frac{t}{R}\frac{\partial R}{\partial t} \qquad R = \frac{\langle X(0)\, X'(x_4,t)\rangle}{\langle V(0)\, V'(x_4,t)\rangle}$$

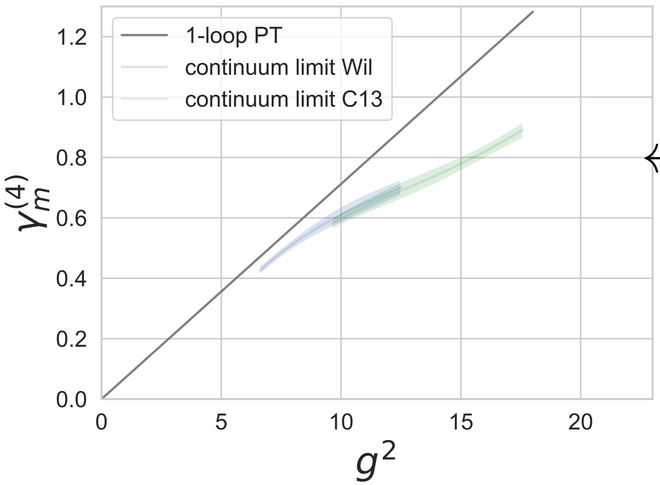
x_4 plateau



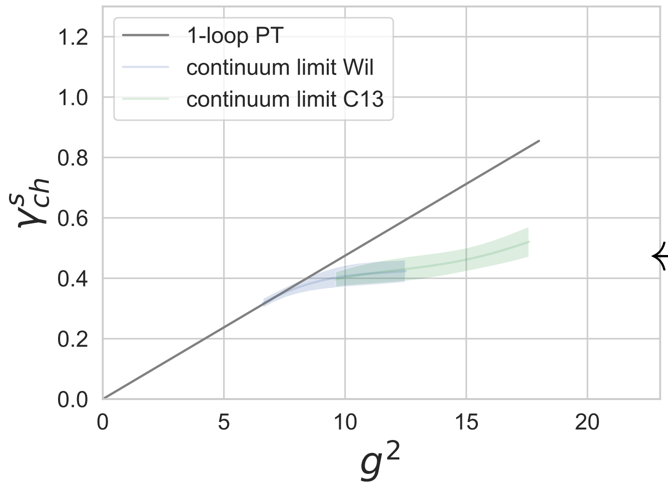


- x_4-dependence: look for plateau $x_4 \gg \sqrt{8t}$ where separation $\gg$ smearing by flow
- For the rest, same as for beta function
- Generalizes to chimera operators

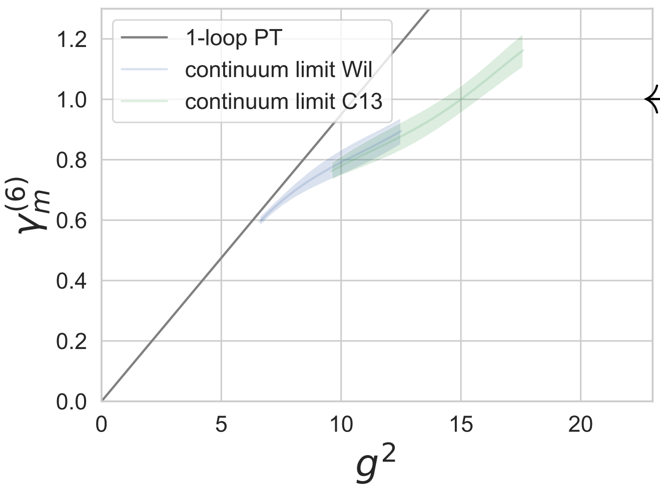
Anomalous dimensions



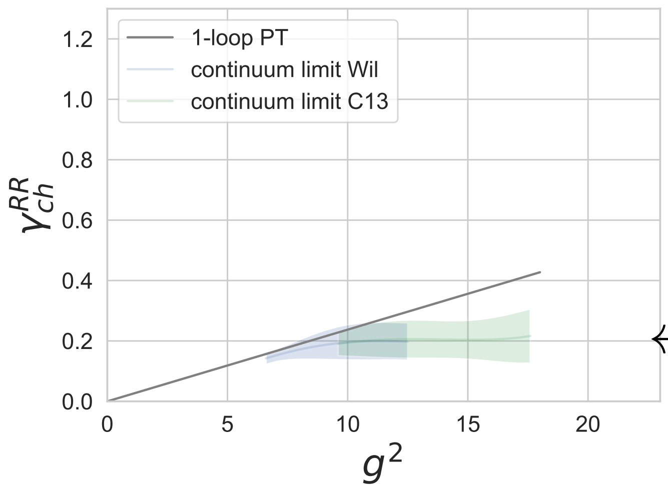
$\leftarrow 0.8$



$\leftarrow 0.5$



$\leftarrow 1.0$



$\leftarrow 0.2$

mass anomalous dim.

chimera anom. dim. (wanted $\gamma \sim 2$!!)

In summary

- $4 + 4$ model is IR conformal: $g_*^2 \sim 15.5$

- By giving some fermions a (large) mass
  can obtain M6 or M11 models of the Ferretti-Karateev list

- Large mass anomalous dimensions at the IRFP; but:

- If we hoped for large $\gamma_{\rm chimera} \sim 2$
  what we actually find is small $\gamma_{\rm chimera} \lesssim 0.5$