Thermodynamic Lattice Study for Walking Dynamics in Strongly Flavored Gauge Theory

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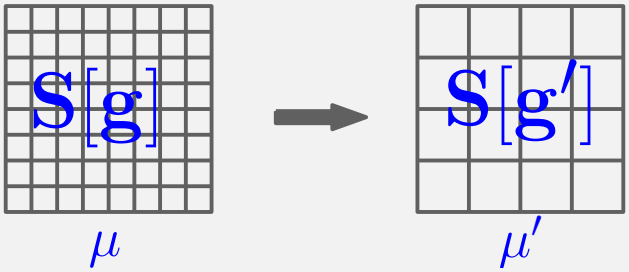
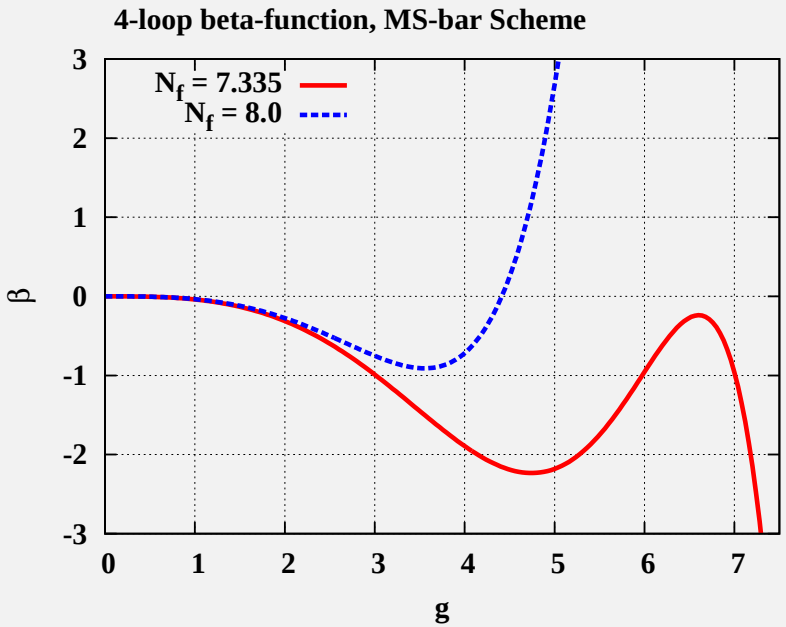
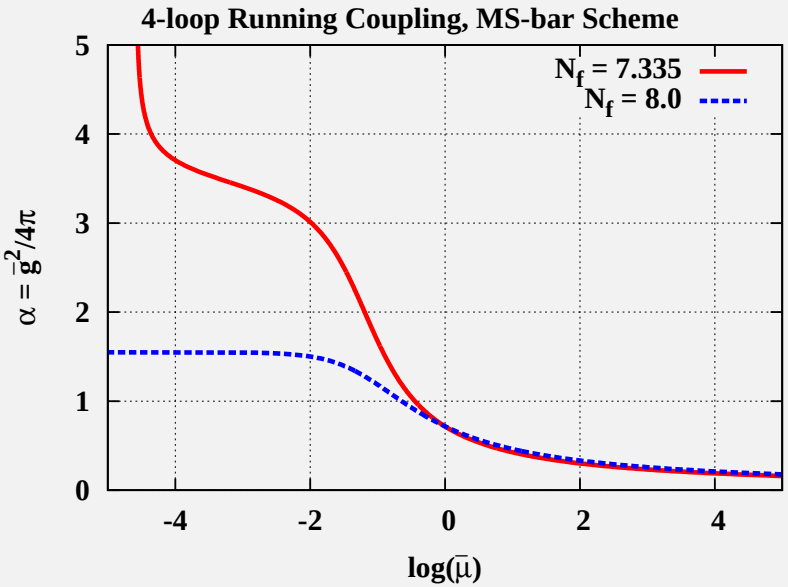
(Pre-) Conformal Gauge Theory



$$\beta(g, N_c, N_f) = \mu \frac{dg}{d\mu} = -g^3 \sum_{n=0}^{\infty} b_n(N_c, N_f) g^{2n} \ . \qquad (1)$$





Motivation and Goal

$$\frac{\langle\bar{\Psi}\Psi\rangle|_{\rm ETC}}{\langle\bar{\Psi}\Psi\rangle|_{\rm TC}} = \exp\left[\int_{\Lambda_{\rm TC}}^{\Lambda_{\rm ETC}} d(\log\mu)\ \gamma\left[g^2(\mu)\right]\right] \xrightarrow{\textit{Conformal}} \left(\frac{\Lambda_{\rm ETC}}{\Lambda_{\rm TC}}\right)^{\gamma[g_*^2]} . \quad (2)$$

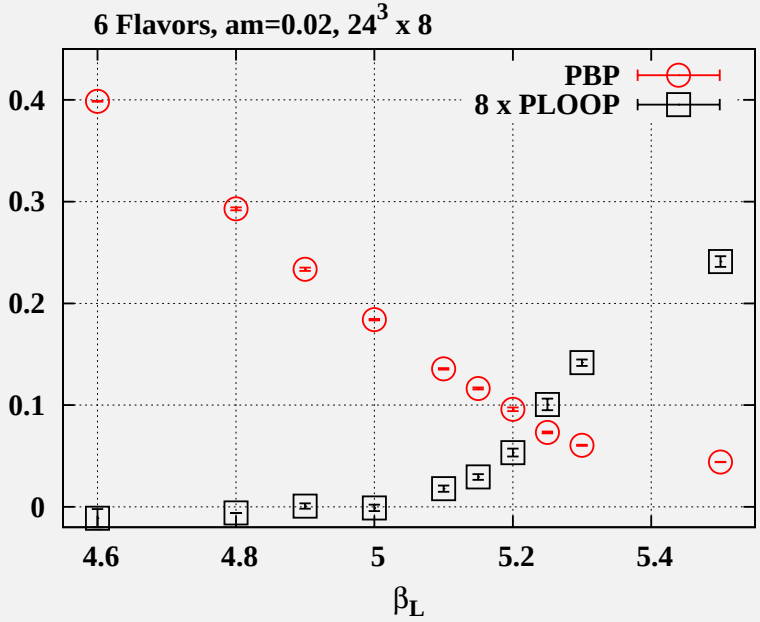
Motivations

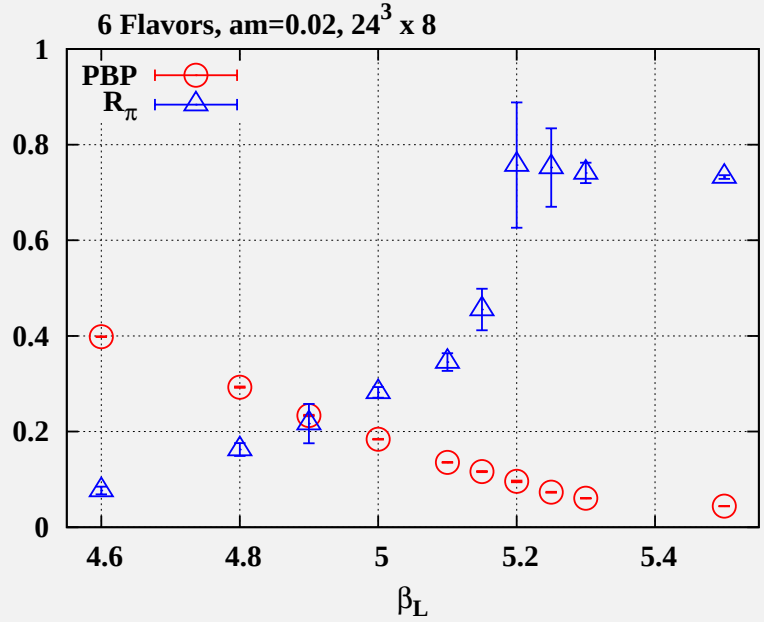
- Application to the Walking Technicolor Model.
- Fundamental Question: Is there Conformal and/or Walking?
- Connection to the AdS/CFT Conjecture.

Goal of Our Project

- To study the (pre-) conformal dynamics in lattice gauge theory at finite T.
- To elucidate the Braun-Gies ($T_c - N_f$) phase diagram.
- To reveal the Miransky-Yamawaki ($N_f - g_c$) phase diagram.

Finite T Chiral Phase Transition





- Larger $\beta_{\mathrm{L}} \longrightarrow$ Larger $T = \left[a(\beta_{\mathrm{L}})N_t\right]^{-1}$, with $N_s \gg N_t$.
- In the chiral limit ($ma \longrightarrow 0$),

$$R_\pi \equiv \frac{\chi_\sigma}{\chi_\pi} = \begin{cases} 0 & \text{(Chiral Broken)} \\ 1 & \text{(Chiral Restored)} \end{cases} . \tag{3}$$

From $\beta_{\mathrm{L}}{}^{\mathrm{c}}$ to $T_c(N_f)$

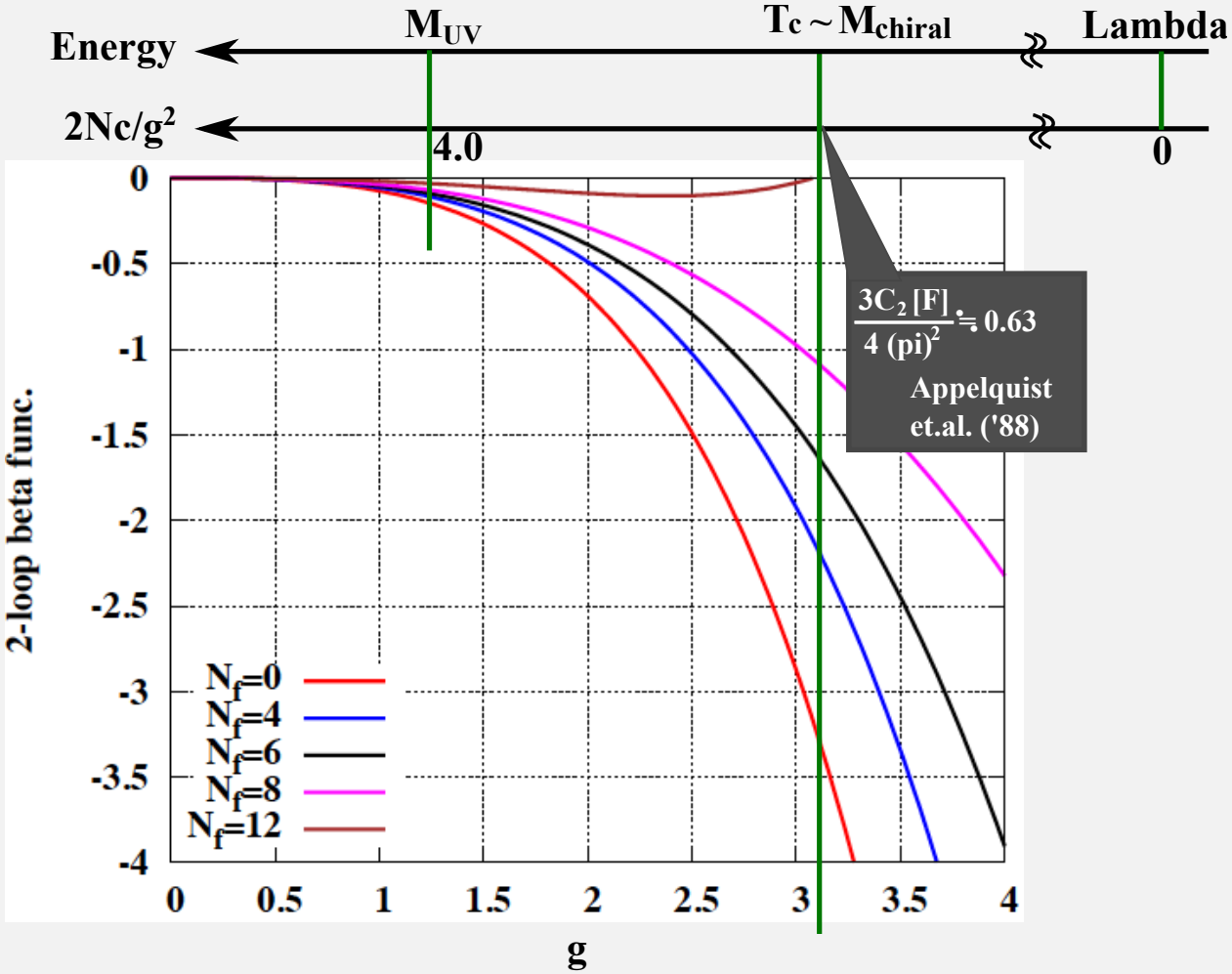
Table: The summary table of $\beta_{\mathrm{L}}{}^{\mathrm{c}}$. which has been obtained by using the same action except a choice of N_f. Blue: Deuzeman-Lombardo-Pallante ('08).

$N_f \backslash N_t$	4	6	8	12
0	-	7.88 ± 0.05	8.20 ± 0.10	-
4	-	5.89 ± 0.03	-	
6	4.675 ± 0.025	5.025 ± 0.025	5.225 ± 0.025	5.45 ± 0.05
8	-	4.1125 ± 0.0125	-	4.34 ± 0.04

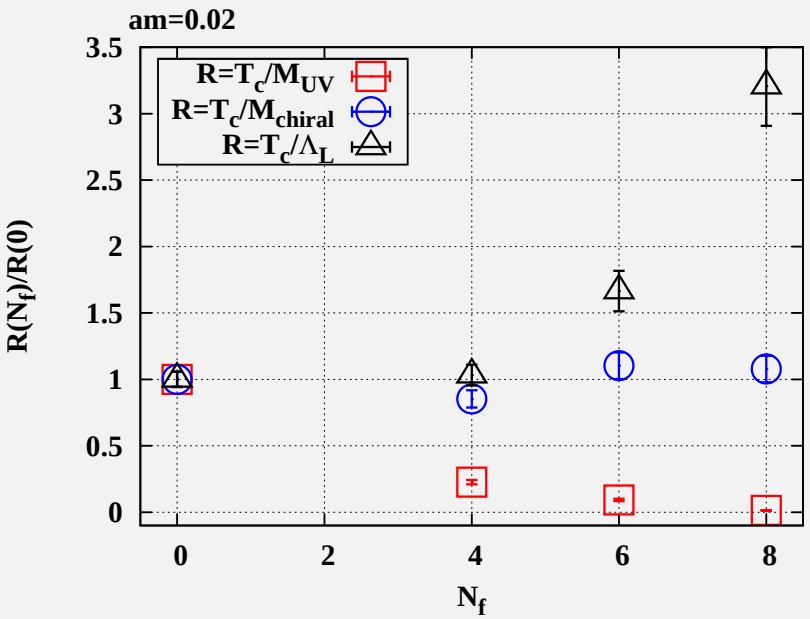
$$M(\beta_{\mathrm{L}}{}^{\mathrm{ref}}) \times a(\beta_{\mathrm{L}}{}^{\mathrm{c}}) = \left(\frac{b_0^2}{b_1} \frac{\beta_c + 2N_c b_1/b_0}{\beta_{\mathrm{L}}{}^{\mathrm{ref}} + 2N_c b_1/b_0} \right)^{b1/(2b_0^2)} \exp\left[-\frac{\beta_{\mathrm{L}}{}^{\mathrm{c}} - \beta_{\mathrm{L}}{}^{\mathrm{ref}}}{4N_c b_0} \right] . \quad (4)$$

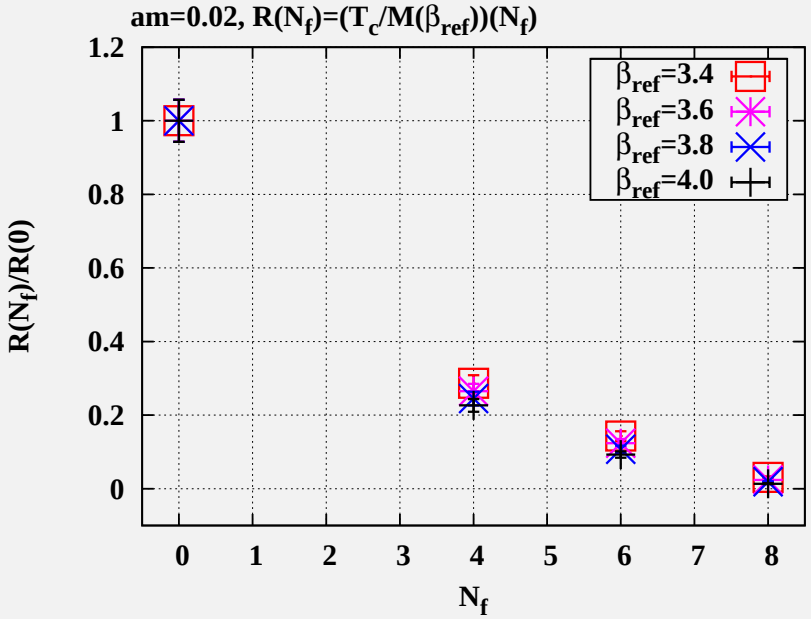
$$\frac{1}{N_\tau} = \frac{T_c}{M(\beta_{\mathrm{L}}{}^{\mathrm{ref}})}(N_f) \times M(\beta_{\mathrm{L}}{}^{\mathrm{ref}})\ a(\beta_{\mathrm{L}}{}^{\mathrm{c}}(N_f, N_t)) . \quad (5)$$

Reference-Scale M

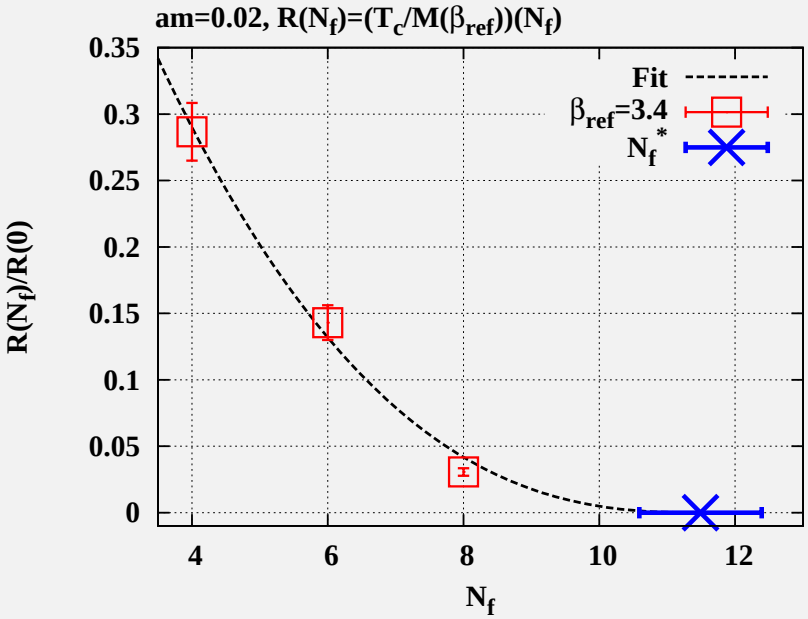


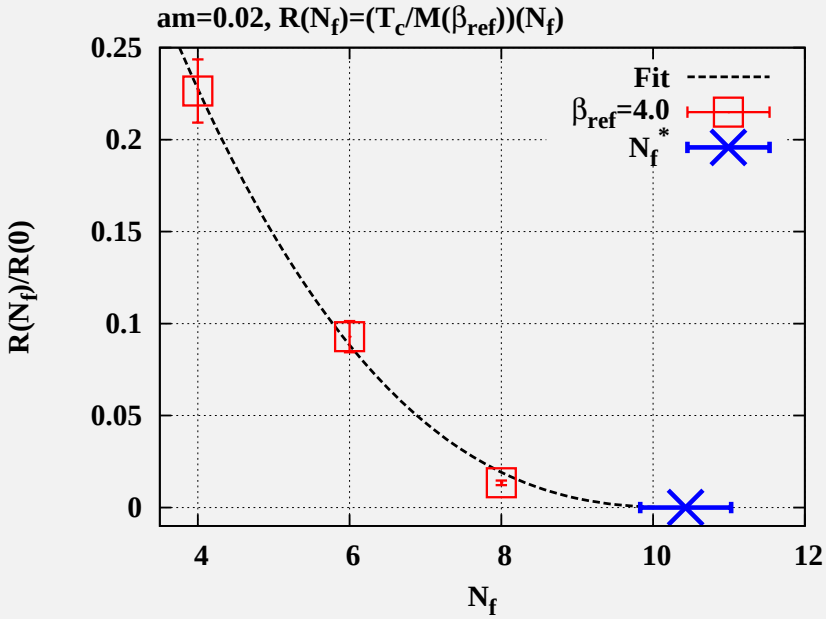
T_c/M as a function of N_f





Critical Flavor Number N_f^*

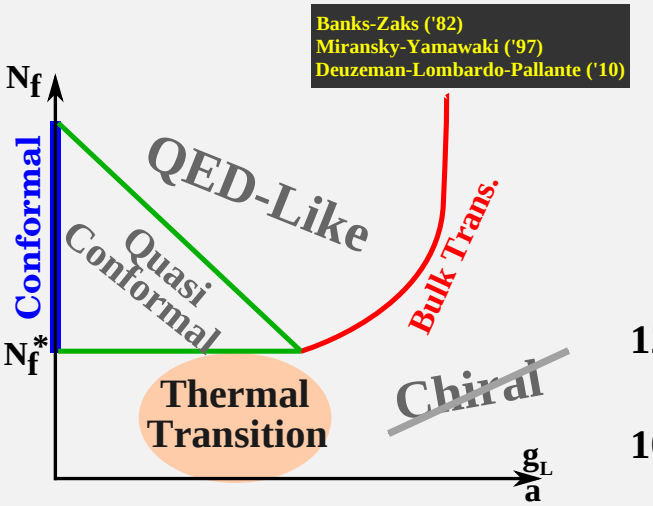


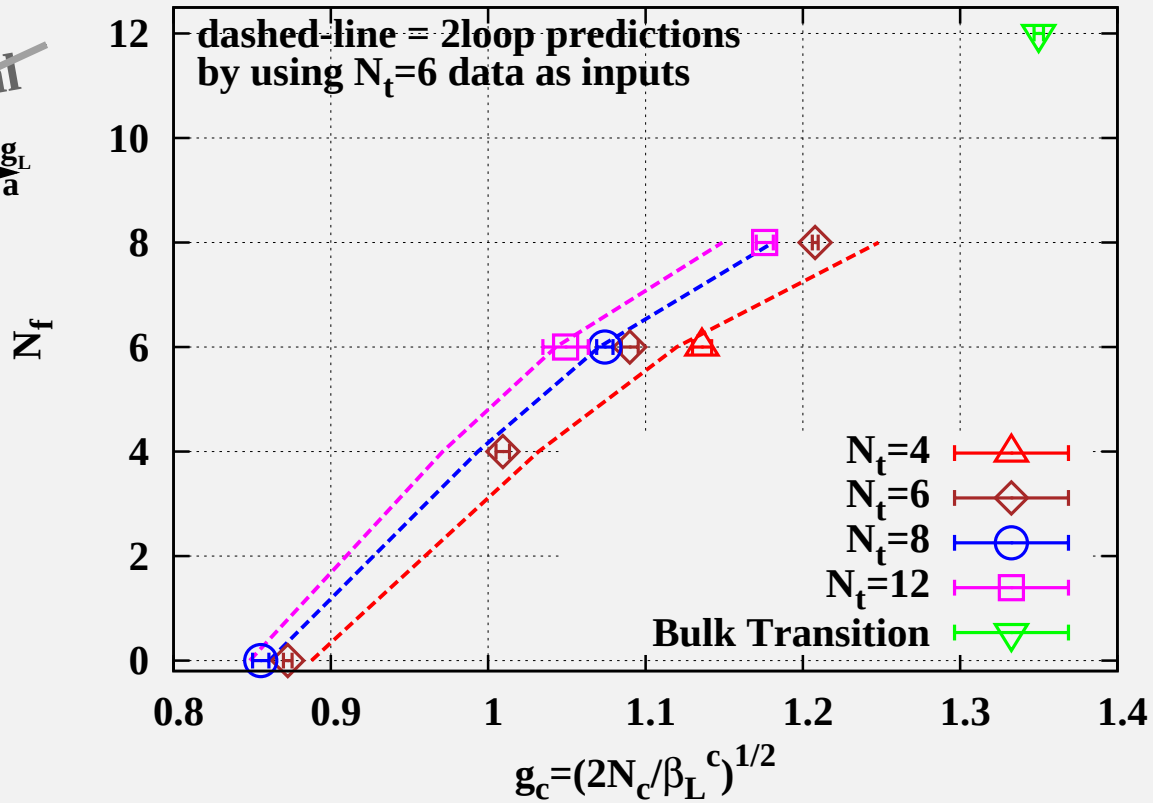


$$T_c(N_f) = K|N_f - N_f^*|^{-(2b_0^2/b_1)(N_f^*)}, \quad \text{(c.f. Braun-Geis ('11))} \tag{6}$$

$$N_f^* = \begin{cases} 11.49 \pm 0.9 & (\beta_{\rm ref} = 3.4)\ , \\ 10.43 \pm 0.6 & (\beta_{\rm ref} = 4.0)\ . \end{cases} \tag{7}$$

Miransky-Yamawaki Phase Diagram





AdS/CFT: As a Guide (Kiritsis et.al. ('08))

- **5D Einstein-Dilaton Action:**

$$\mathcal{S} = \frac{1}{16\pi G_5}\int d^5x\sqrt{-g}\left[R - \frac{4}{3}(\partial_\mu\phi)^2 + V(\phi)\right] . \tag{8}$$

- **Black-Hole Metric Ansatz:**

$$ds^2 = b^2(z)\left[-f(z)dt^2 + d\mathbf{x}^2 + \frac{dz^2}{f(z)}\right] . \tag{9}$$

  Outputs from Einstein Eqs. are $f(z)$, $b(z)$, and $\lambda(z) = e^{\phi(z)} \sim N_c g^2(z)$.

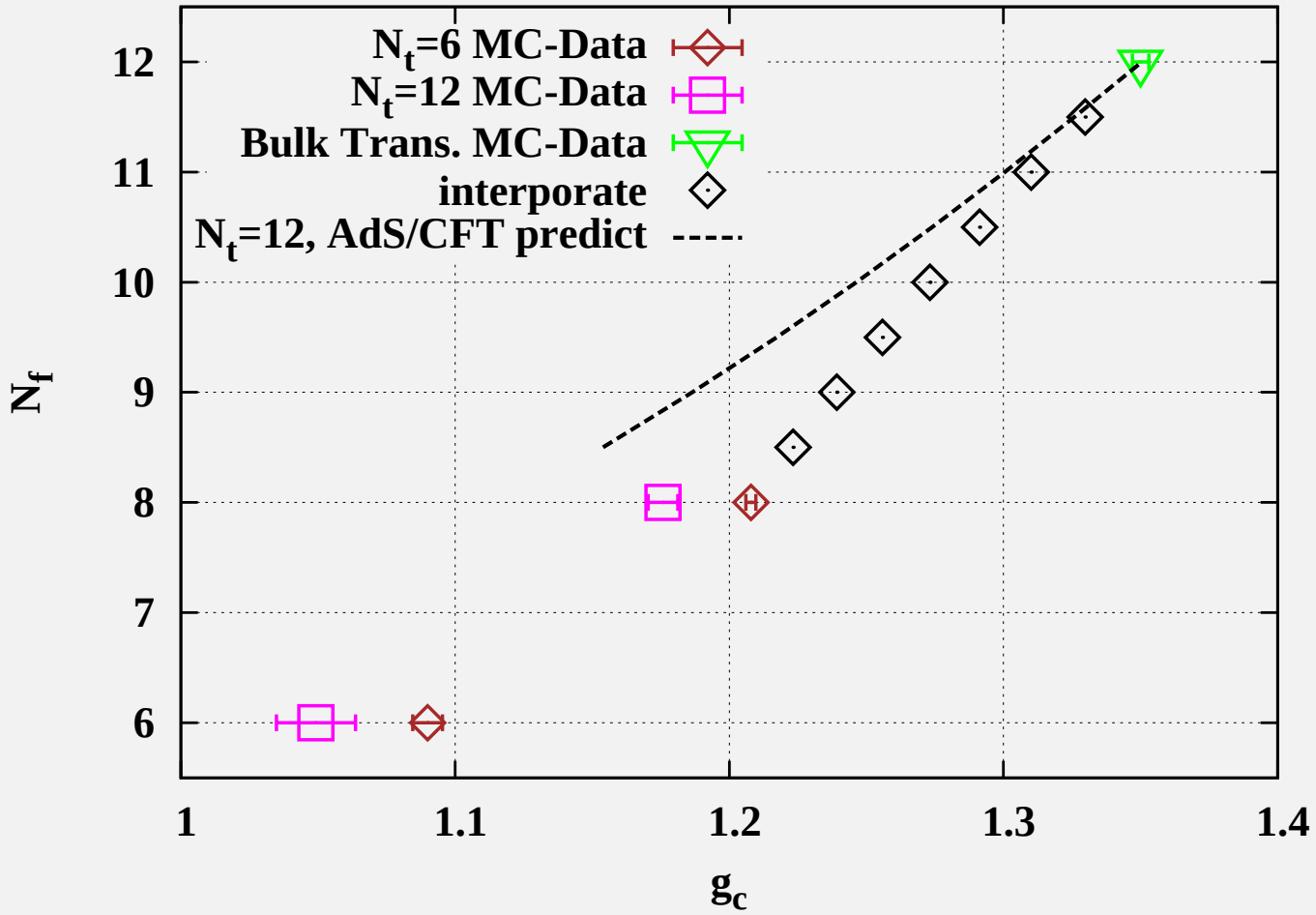
- **beta-function Ansatz, (Alanen et.al. ('10)):**

$$\beta(\lambda) = b(z)\frac{d\lambda(z)}{db(z)} = -c\lambda^2\frac{(1-\lambda)^2 + e}{1 + 2c\lambda^3/3} . \tag{10}$$

- **Thermodynamics:**

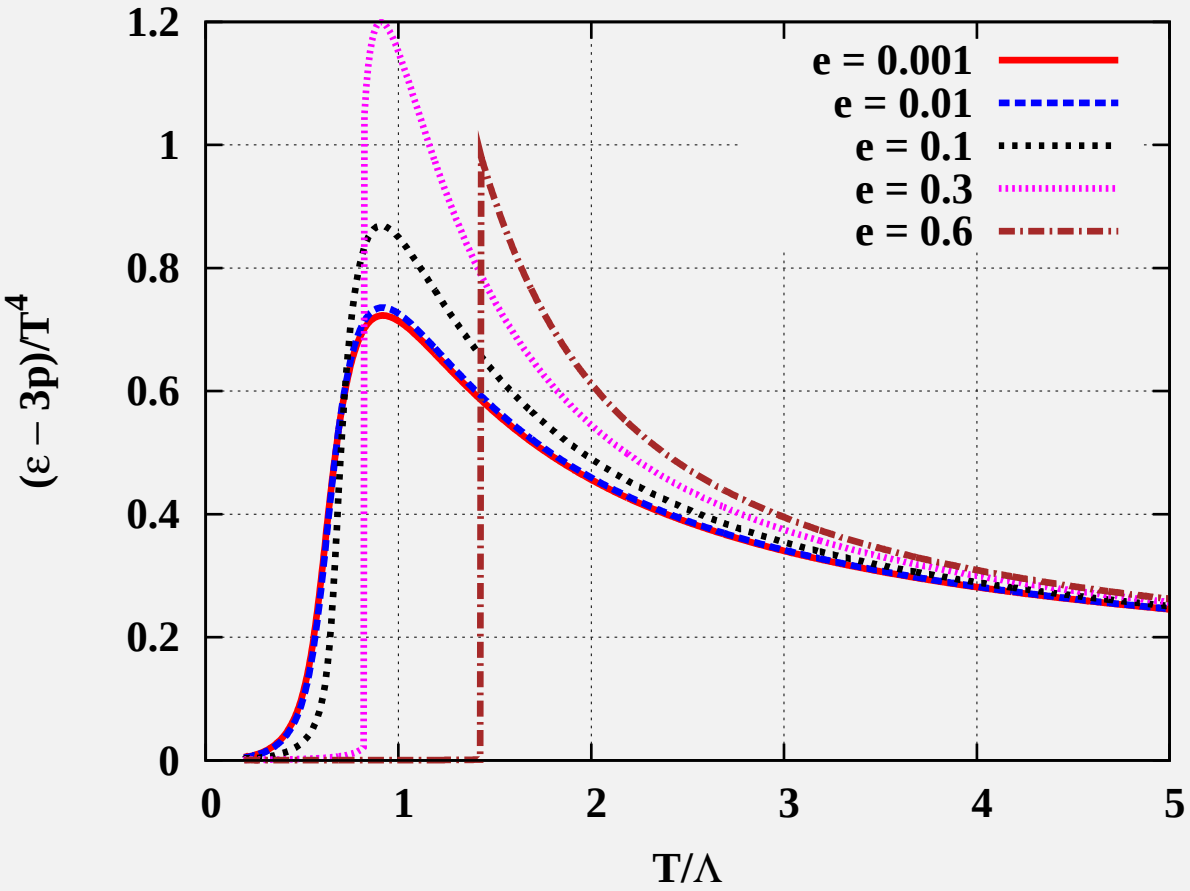
$$4\pi T_h = -df(z_h)/dz\ , \quad f(z_h) = 0\ , \quad s(T_h) = \frac{b^3(\lambda(z_h))}{4G_5} . \tag{11}$$

Walking Signal in MY Phase Diagram, From AdS/CFT



Trace Anormaly, From AdS/CFT

Based on the model proposed Alanen et.al. ('08), we investigate the trace anormaly with variations of conformal breaking effects e:



Summary

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- We have investigated the chiral phase transition (crossover) at finite T in the strongly flavored QCD-Like theory by using the lattice gauge theory.
- We have discussed the lower edge of conformal window N_f^* by using our lattice data with the generalized 2-loop asymptotic scaling. We have obtained $N_f^* \sim 9.8 - 12.4$
- We have discussed the signal of the walking dynamics in the Miransky Yamawaki Diagram and the Trace Anormaly with a help of AdS/CFT.

Future Works

- To set a scale a^{-1} and complete $T - N_f$ Phase Diagram:
  The potential measurement is on progress.
- Critical behavior near the IR-Fixed Pt.
- The color SU($N_c = 2$) with 8 flavors at finite T.

References

References

- K. Miura, M. P. Lombardo and E. Pallante, "Chiral phase transition at finite temperature and conformal dynamics in large N_f QCD," Phys. Lett. B **710** (2012) 676.
- K. Miura, M. P. Lombardo and E. Pallante, "Thermodynamic Study for Conformal Phase in Large Nf Gauge Theory," PoS Lattice 2011, arXiv:1111.1098 [hep-lat].

Computers and Code

- **MILC Code:** http://www.physics.utah.edu/~detar/milc/milc_qcd.html
- **Argolithm:** Rational Hybrid Molecular-Dynamics with Omelyan-Integrator
- **Computers:** SP6 and BG/P in CINECA, SP16000 in YITP, and Italian-Grid-Infrastructures