Thermodynamic Lattice Study for Preconformal Dynamics in Strongly Flavored QCD-Like Theory

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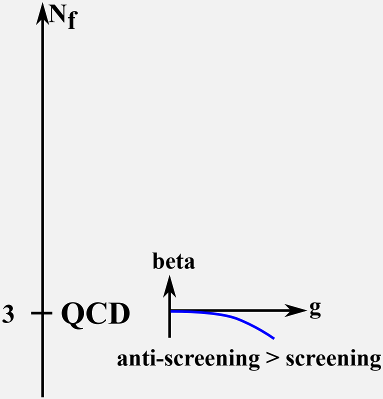
Talk at KMI-SCGT, Nagoya Univ. Dec. 04, 2012

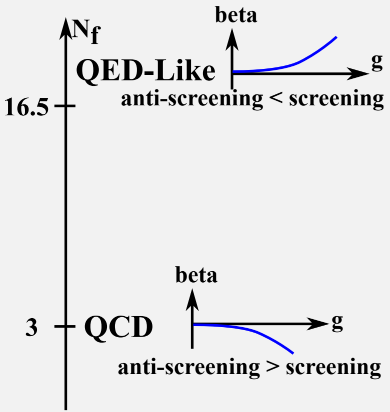
Reference

- K. Miura, M. P. Lombardo and E. Pallante, Phys. Lett. B **710** (2012) 676.
- K. Miura, M. P. Lombardo and E. Pallante, PoS Lattice 2011, arXiv:1111.1098 [hep-lat].

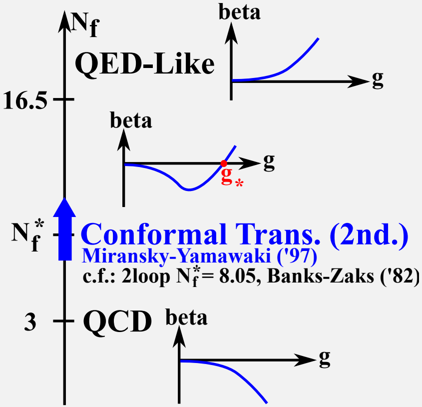
QCD: Negative Beta-Func.



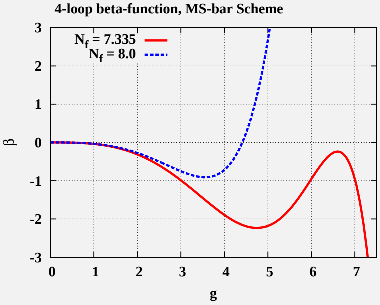
Loss of Asymptotic Freedom at Large N_f

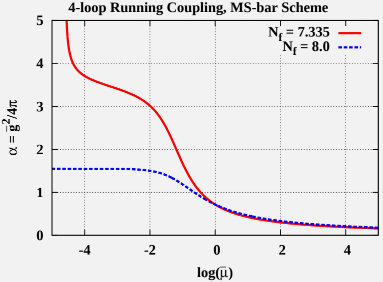


Emergence of Conformality in Perturbation



Four-Loop Example





IRFP Conformality

- The emergence of IRFP Conformality due to the Non-Perturbative Gauge Interaction leads to a new class of a gauge theory different from both QCD and QED. (Lattice Reviews: Pallante, PoS LAT2009; Del Debbio, PoS LAT2010; Neil, PoS Lat2011).
- The IRFP (pre-)conformal dynamics plays an essential role in a technicolor model to implement a mass of standard model particles with avoiding too much FCNC (Review: Yamawaki ('96), Sannino ('06), Chivukula ('12)).
- The FRG method (Braun-Gies '06-11) and the Gauge/Gravity model (Kiritsis et.al.('08 - '12), Kajantie et.al. ('09 - '12), *c.f.* Panero ('09)) indicates that a cold conformal phase and a hot QGP phase is continuously connected at large N_f. In other words, the vanishing of the thermal chiral transition with increasing N_f indicates the onset of the conformal phase.
- Partly motivated by recent works of Shuryak ('12), the vanishing of the chiral dynamics is also elucidated by introducing the notion of a thermal critical coupling, whose approach to the IRFP coupling indicates the emergence of the conformal phase.

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   - N_f^* from Thermal Critical Coupling ${g_{\mathrm{T}}}^{\mathrm{c}}$
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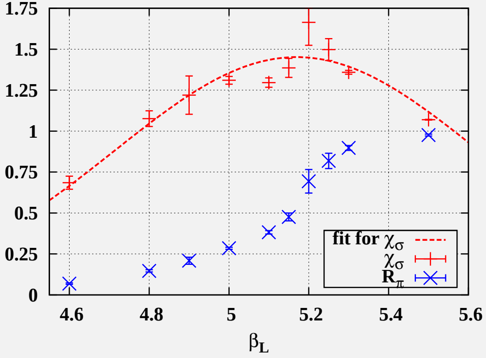
Lattice Critical Coupling $\beta_L{}^c$



In this example ($N_f = 6$, $ma = 0.02$, $24^3 \times 8$), we estimate the pseudo critical coupling to be $\beta_L{}^c = 5.20 \pm 0.05$ from the peak of chiral susceptibility χ_σ and the drastic increase of the susceptibility ratio $R_\pi \equiv \chi_\sigma / \chi_\pi$.

Lattice Critical Coupling $\beta_L{}^c$

Table: Summary of $\beta_L{}^c = 10/(g_L{}^c)^2$. The entries with $*$ are the update for our previous results (KM,Lombardo,Pallante 2011). The entries with $\dagger$ have been quoted from the previous studies on $N_f = 8$ (Deuzeman,Lombardo,Pallante, 2008). We have used $ma = 0.02$ for all finite N_f.

$N_f \backslash N_t$	4	6	8	12
0	7.35 ± 0.05	$7.97^* \pm 0.07$	8.26 ± 0.06	—
4	5.65 ± 0.05	$6.00^* \pm 0.05$	6.15 ± 0.15	—
6	$4.675^* \pm 0.05$	$5.025^* \pm 0.05$	$5.20^* \pm 0.05$	$5.55^* \pm 0.1$
8	—	$4.1125^\dagger \pm 0.0125$	4.275 ± 0.05	$4.34^\dagger \pm 0.04$

Thermal Step Scaling

The chiral transition temperature should be unique at fixed N_f:

$$T_c = \left[N_t\ a(g_L{}^c)\right]^{-1} = \left[N_t'\ a(g_L{}^{c\prime})\right]^{-1}, \tag{1}$$

The set $\{g_L{}^c\}$ satisfying this equation gives a non-perturbative running coupling constructed by using the lattice measurements. Then, the vanishing (smaller) step-scaling

$$\Delta g_L{}^c = g_L{}^c - g_L{}^{c\prime}, \tag{2}$$

at large N_f indicates a vanishing (slow) running coupling, or equivalently, (pre-)conformal dynamics.

Thermal step scalings in MY Diagram

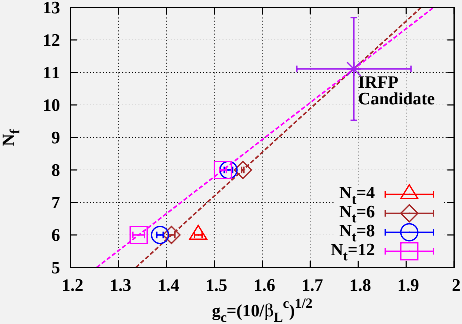


Figure: $T_c = [N_t\ a(g_L{}^c)]^{-1} = [N_t'\ a(g_L{}^{c\prime})]^{-1}$ should holds at each N_f.

- By using $N_f = 6, 8$ data, $N_t = 6$ and 12 lines get into the intersection at $N_f^* \sim 11.1 \pm 1.6$.
- We also observe the stronger fermion screenings at larger N_f (*c.f.* Kogut et al. ('85)).

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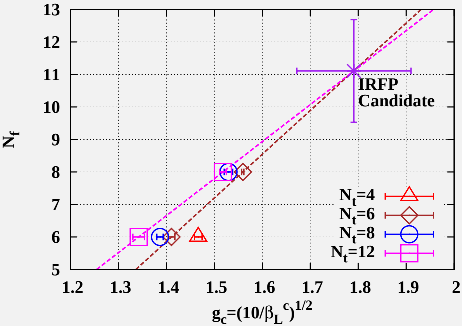

Figure: $T_c = [N_t\ a(g_{\mathrm{L}}{}^c)]^{-1} = [N_t'\ a(g_{\mathrm{L}}{}^{c\prime})]^{-1}$ should holds at each N_f.

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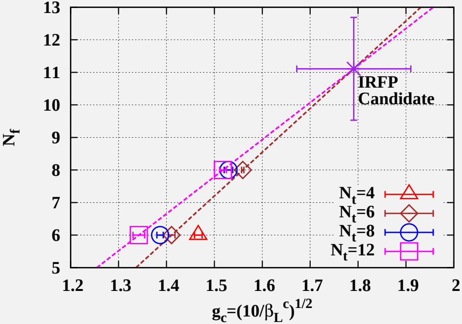

Figure: $T_c = [N_t \; a({g_L}^c)]^{-1} = [N_t' \; a({g_L}^{c\prime})]^{-1}$ should holds at each N_f.

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Thermal Critical Coupling ${g_{\rm T}}^{\rm c}$

- We consider the renormalization flow from T_c to $a^{-1}({g_{\rm L}}^{\rm c} = \sqrt{10/{\beta_{\rm L}}^{\rm c}})$ with the two-loop approximation:

$$log\left[\frac{T_c}{a^{-1}(g_c)}\right] = \int_{{g_{\rm L}}^{\rm c}}^{{g_{\rm T}}^{\rm c}} \frac{dg}{B_{2L}(g)}\ , \quad T_c = \left[N_t\ a({g_{\rm L}}^{\rm c})\right]^{-1}\ . \qquad (3)$$

- The coupling ${g_{\rm T}}^{\rm c}$ gives a typical interaction strength at the scale $\mu = T_c$.

Thermal Critical Coupling $g_T{}^c$

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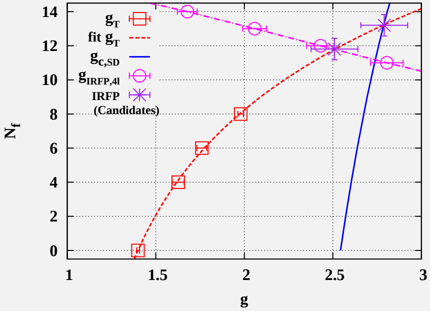
- The coupling $g_T{}^c$ gives a typical interaction strength at the scale $\mu = T_c$.

$g_T{}^c$ VS $g_{c,\mathrm{SD}}$ and $g_{\mathrm{IRFP,4l}}$



- Thermal critical coupling $g_T{}^c$ meets the zero temperature critical couplings estimated by the two-loop Schwinger Dyson equation (Appelquist et al, ('99)) or the IRFP coupling in the four-loop beta-function (Ryttov-Shrock ('12)) around $N_f^* \sim 12.5 \pm 0.7$.
- Larger N_f gives more strongly interacting QGP! (c.f. Shuryak et al. ('12)).

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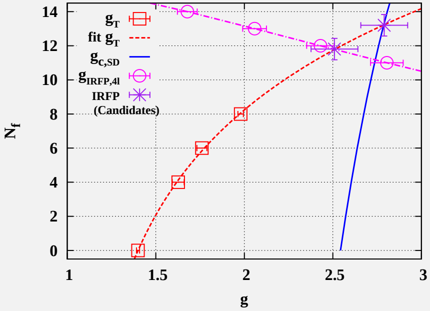

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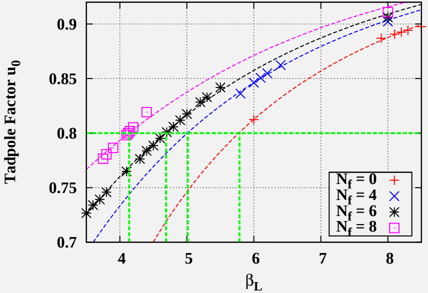
UV Reference Scale M



- Consider the two-loop renormalization flow which connects the scale T_c and some other scale M

$$\log\left[\frac{T_c}{M({g_L}^{\mathrm{ref}})}\right] = \int_{\exists {g_L}^{\mathrm{ref}}}^{{g_T}^c} \frac{dg}{B_{2L}(g)} \ . \tag{4}$$

- We extract the reference coupling ${g_L}^{\mathrm{ref}}$ from $u_0 \sim 0.8$ line with N_f independently, which results in $a^{-1}({g_L}^c) \gtrsim M({g_L}^{\mathrm{ref}}) \gg T_c$ for all N_f.

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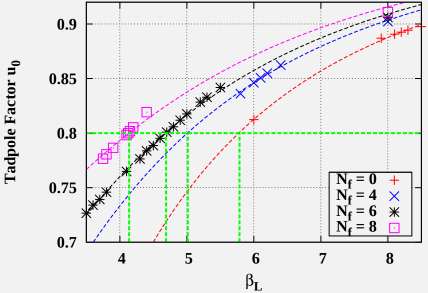

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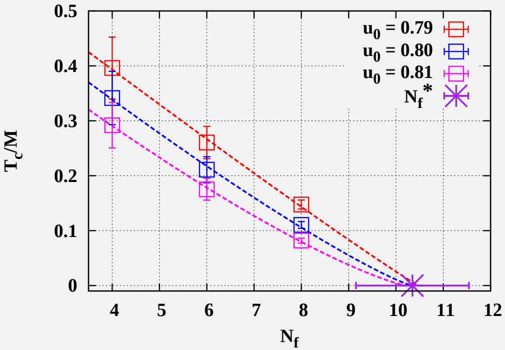
T_c/M, with a UV scale M: Preliminary (c.f. Miura et.al. ('12))



$$\frac{T_c}{M(g_L{}^{\rm ref})} = \exp\left[\int_{g_L{}^{\rm ref}}^{g_T{}^{c}} \frac{dg}{B_{2L}(g)}\right] \sim K(N_f^* - N_f)^{-(2b_0^2/b_1)(N_f^*)} . (\text{c.f. Braun-Gies,'11}) \quad (5)$$

$N_f^* = 10.4 \pm 1.2$ for $u_0 = 0.79 - 0.81$.

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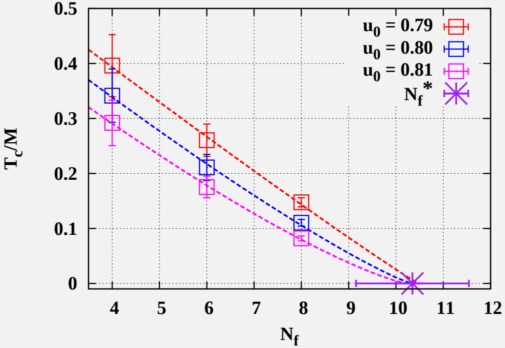

$$\frac{T_c}{M(g_{\rm L}{}^{\rm ref})} = \exp\left[\int_{g_{\rm L}{}^{\rm ref}}^{g_{\rm T}{}^{\rm c}} \frac{dg}{B_{2L}(g)}\right] \sim K(N_f^* - N_f)^{-(2b_0^2/b_1)(N_f^*)} .(\text{c.f. Braun-Gies,'11}) \quad (5)$$

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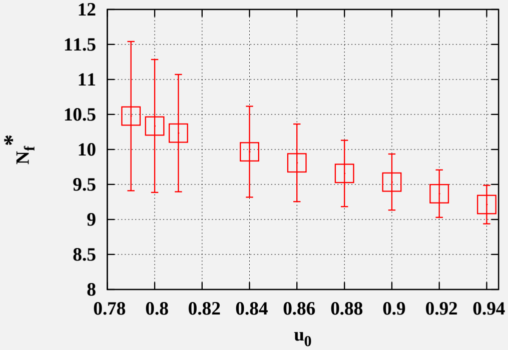
u_0 dependences of N_f^* Preliminary (c.f. Miura et.al. ('12))



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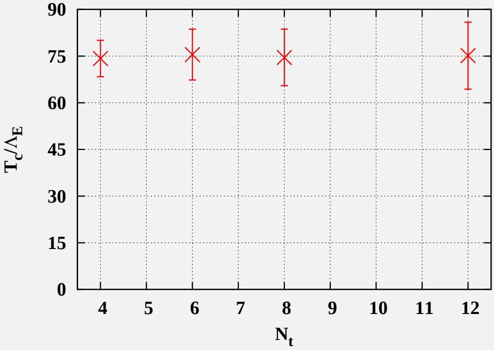
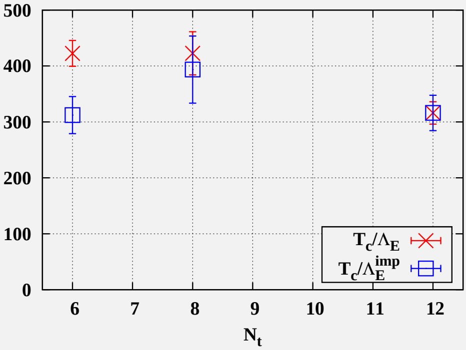
Two-Loop Asymptotic Scaling at $N_f = 6$



T_c/Λ_{E} is almost N_t independent!! (*c.f.* Gupta ('06)).

Two-Loop Asymptotic Scaling at $N_f = 8$



- It is difficult to make three data being consistent.
- $ma = 0.02$ effects? Far from continuum limit? Or something interesting?

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Summary

Thermodynamic Lattice Study for QCD-like Theory with IRFP Conformality ($ma = 0.02$)

$$N_f^* \sim \begin{cases} 11.1 \pm 1.6 & \text{(the vanishing thermal scaling of } \beta_{\mathrm{L}}{}^{\mathrm{c}}\text{)} \ , \\ 12.5 \pm 0.7 & \text{(the approach of } g_{\mathrm{T}}{}^{\mathrm{c}} \text{ to } g_{c,\mathrm{SD}} \text{ and } g_{\mathrm{IRFP},4\mathrm{l}}\text{)} \ , \\ 10.4 \pm 1.2 & \text{(the vanishing of } T_c/M \text{ for } u_0 = 0.79 - 0.81\text{)} \ . \end{cases} \quad (6)$$

Future Works

- Thermodynamic and chiral limits, in particular at $N_f = 8$.
- 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.
- Gauge/Gravity Duality as a theoretical guide.

Thank you for your attention!