String Tension vs Critical Temperature in Walking Regime

Kohtaroh Miura (KMI, Nagoya Univ.)

Lattice 2013, Mainz, July 30, 2013

Collaboration

Albert Deuzeman	University of Bern, Switzerland
Maria Paola Lombardo	Laboratori Nazionali di Frascati, Rome, Italy
Kohtaroh Miura	KMI, Nagoya University, Japan
Elisabetta Pallante	University of Groningen, Netherlands
Tiago Nunes Da Silva	University of Groningen, Netherlands

References

- K. Miura, M. P. Lombardo and E. Pallante, Phys. Lett. B **710** (2012) 676; K. Miura and M. P. Lombardo, Nucl. Phys. **B871** (2013) 52-81.
- A. Deuzeman, M. P. Lombardo and E. Pallante, Phys. Lett. B **670** (2008) 41; Phys. Rev. D **82** (2010) 074503; T. N. da Silva and E. Pallante, arXiv:1211.3656 [hep-lat]; A. Deuzeman, M. P. Lombardo, T. N. da Silva and E. Pallante, arXiv:1209.5720 [hep-lat].

Motivation

QCD with MANY FLAVORs!

- **Theoretically Interesting:** Many flavor QCD can be a new class of gauge theory having a novel (Quasi-)Conformal Dynamics associated with Infra-Red Fixed Point (IRFP).
- **Phenomenologically Interesting:** The quasi-conformal (walking) dynamics plays an essential role in the Walking Technicolor Model, a modern technicolor model admitting a composite Higgs with a mass ~ 126 (GeV).

Motivation

QCD with MANY FLAVORs!

- **Theoretically Interesting:** Many flavor QCD can be a new class of gauge theory having a novel (Quasi-)Conformal Dynamics associated with Infra-Red Fixed Point (IRFP).
- **Phenomenologically Interesting:** The quasi-conformal (walking) dynamics plays an essential role in the Walking Technicolor Model, a modern technicolor model admitting a composite Higgs with a mass ~ 126 (GeV).

Motivation

QCD with MANY FLAVORs!

- **Theoretically Interesting:** Many flavor QCD can be a new class of gauge theory having a novel (Quasi-)Conformal Dynamics associated with Infra-Red Fixed Point (IRFP).
- **Phenomenologically Interesting:** The quasi-conformal (walking) dynamics plays an essential role in the Walking Technicolor Model, a modern technicolor model admitting a composite Higgs with a mass ~ 126 (GeV).

Our Motivation and Goal

- We investigate the quasi-conformal region ($N_f = 6$ and 8) by using the lattice Monte-Carlo simulations.
- We study the N_f dependence of $T_c/\sqrt{\sigma}$. This may be the first work investigating $T_c/\sqrt{\sigma}$ in the walking regime ($N_f = 12, 16$: T. Silva, Wed. 31, Room F).
- We also discuss the order of the chiral phase transition for $N_f = 6$ and 8, which is a potential interst in the scenario of the electroweak baryogenesis.

Our Motivation and Goal

- We investigate the quasi-conformal region ($N_f = 6$ and 8) by using the lattice Monte-Carlo simulations.
- We study the N_f dependence of $T_c/\sqrt{\sigma}$. This may be the first work investigating $T_c/\sqrt{\sigma}$ in the walking regime ($N_f = 12, 16$: T. Silva, Wed. 31, Room F).
- We also discuss the order of the chiral phase transition for $N_f = 6$ and 8, which is a potential interst in the scenario of the electroweak baryogenesis.

Our Motivation and Goal

- We investigate the quasi-conformal region ($N_f = 6$ and 8) by using the lattice Monte-Carlo simulations.
- We study the N_f dependence of $T_c/\sqrt{\sigma}$. This may be the first work investigating $T_c/\sqrt{\sigma}$ in the walking regime ($N_f = 12, 16$: T. Silva, Wed. 31, Room F).
- We also discuss the order of the chiral phase transition for $N_f = 6$ and 8, which is a potential interst in the scenario of the electroweak baryogenesis.

Table of Contents

Table of Contents

Measurements

1. We measure the chiral condensates $a^3\langle\bar{\psi}\psi\rangle$, the Polyakov loops L_p and their susceptibilities in various temperature (lattice couplings, $N_s \gg N_t$) for $N_f = 6$ and 8.
2. In each N_f, We evaluate the critical coupling $\beta_{\mathrm{L}}{}^{\mathrm{c}}(N_f)$ which is associated with the chiral phase transition.
3. We perform zero temperature simulations by using the obtained $\beta_{\mathrm{L}}{}^{\mathrm{c}}(N_f)$ as inputs, and evaluate the Wilson-loop and the string tension.

We will obtain $(T_c/\sqrt{\sigma})(N_f)$.

Measurements

1. We measure the chiral condensates $a^3\langle\bar{\psi}\psi\rangle$, the Polyakov loops L_p and their susceptibilities in various temperature (lattice couplings, $N_s \gg N_t$) for $N_f = 6$ and 8.
2. In each N_f, We evaluate the critical coupling $\beta_L{}^c(N_f)$ which is associated with the chiral phase transition.
3. We perform zero temperature simulations by using the obtained $\beta_L{}^c(N_f)$ as inputs, and evaluate the Wilson-loop and the string tension.

We will obtain $(T_c/\sqrt{\sigma})(N_f)$.

Measurements

1. We measure the chiral condensates $a^3\langle\bar{\psi}\psi\rangle$, the Polyakov loops L_p and their susceptibilities in various temperature (lattice couplings, $N_s \gg N_t$) for $N_f = 6$ and 8.
2. In each N_f, We evaluate the critical coupling $\beta_{\mathrm{L}}{}^{\mathrm{c}}(N_f)$ which is associated with the chiral phase transition.
3. We perform zero temperature simulations by using the obtained $\beta_{\mathrm{L}}{}^{\mathrm{c}}(N_f)$ as inputs, and evaluate the Wilson-loop and the string tension.

We will obtain $(T_c/\sqrt{\sigma})(N_f)$.

Measurements

1. We measure the chiral condensates $a^3\langle\bar{\psi}\psi\rangle$, the Polyakov loops L_p and their susceptibilities in various temperature (lattice couplings, $N_s \gg N_t$) for $N_f = 6$ and 8.
2. In each N_f, We evaluate the critical coupling ${\beta_{\rm L}}^{\rm c}(N_f)$ which is associated with the chiral phase transition.
3. We perform zero temperature simulations by using the obtained ${\beta_{\rm L}}^{\rm c}(N_f)$ as inputs, and evaluate the Wilson-loop and the string tension.

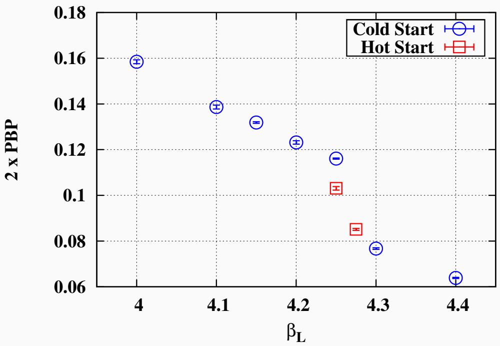
We will obtain $(T_c/\sqrt{\sigma})(N_f)$.

Supercomputer and Codes

- **Finite T Simulations:** MILC-Code, BGP on Fermi in CINECA (Italy) and SR-16000 in YITP (Japan).
- **Zero T Simulations:** MILC-Code, BGQ on Fermi in CINECA (Italy).
- **Wilson-Loop Measurements:** Code developed by Dr. Marc Wagner, HPC φ in KMI (Japan).

Chiral Condensate as a Function of T, $N_f = 8$, $ma = 0.02$, $24^3 \times 8$

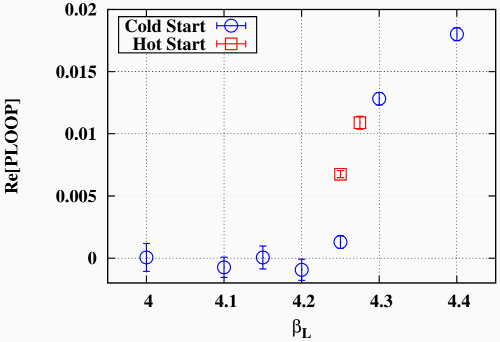
Update for Miura-Lombardo Nucl. Phys. B ('13). *c.f.* Deuzeman et.al. Phys. Lett. B ('08).



$$\beta_L{}^c = 4.275 \pm 0.05$$

Polyakov Loop as a Function of T. $N_f = 8$, $ma = 0.02$, $24^3 \times 8$

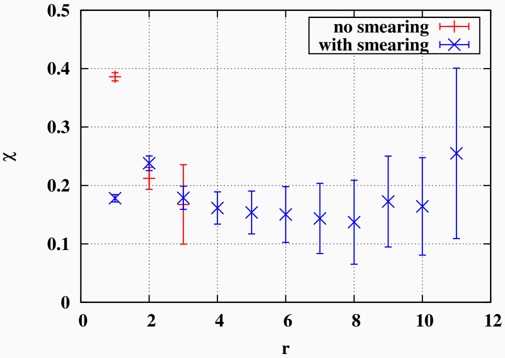
Update for Miura-Lombardo Nucl. Phys. B ('13). *c.f.* Deuzeman et.al. Phys. Lett. B ('08).



$$\beta_L{}^c = 4.275 \pm 0.05$$

Creutz Ratio for $N_f = 8$

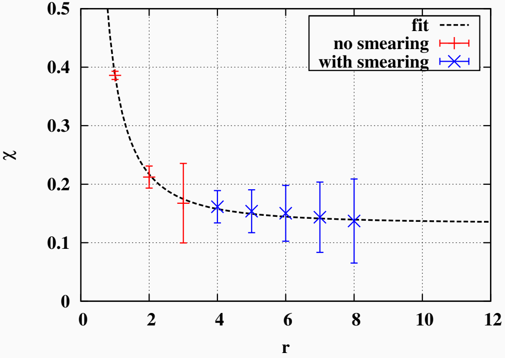
Preliminary, $\beta = \beta_{\mathrm{L}}{}^{\mathrm{c}} = 4.275$, $ma = 0.02$, $32^3 \times 64, t = 3$



$$\chi_{r,t} = -\log\left[\frac{W_{r,t}W_{r+1,t+1}}{W_{r,t+1}W_{r+1,t}}\right] = \frac{\alpha}{\hat{r}(\hat{r}+1)} + \hat{\sigma}\ . \tag{1}$$

Creutz Ratio, $N_f = 8$, *Fit*

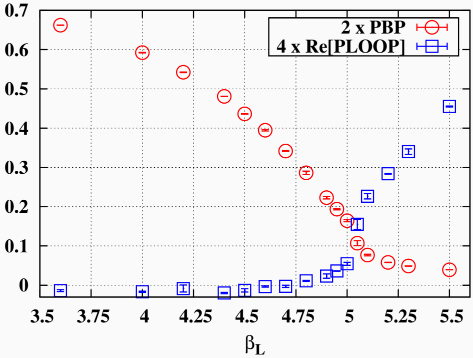
Preliminary



$$\alpha = 0.506821 \pm 0.005149 \quad (1.016\% \quad \text{error}) \, ,$$
$$\hat{\sigma} = 0.132381 \pm 0.002283 \quad (1.724\% \quad \text{error}) \, ,$$
$$X^2/\text{d.o.f.} = 0.0203838 \, . \tag{2}$$

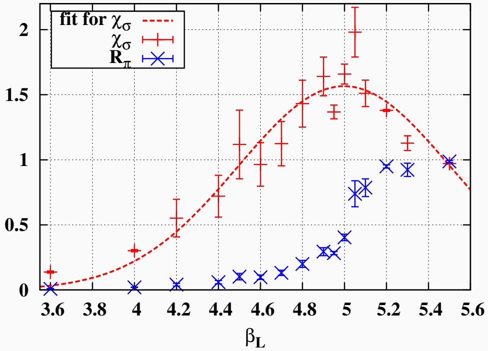
Chiral phase transition for $N_f = 6$, $ma = 0.02$, $16^3 \times 6$

Miura-Lombardo Nucl. Phys. B ('13).



Chiral Susceptibility for $N_f = 6$, $ma = 0.02$, $16^3 \times 6$

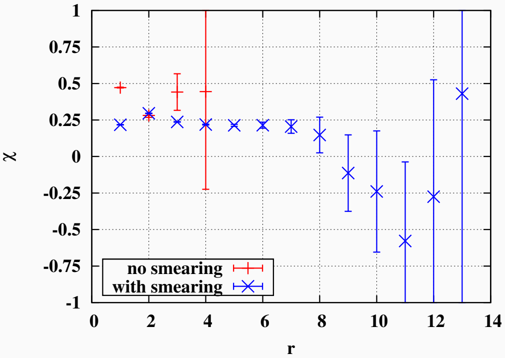
Miura-Lombardo Nucl. Phys. B ('13). $R_\pi = \chi_\sigma / \chi_\pi$.



$\beta_L{}^c = 5.025 \pm 0.025$

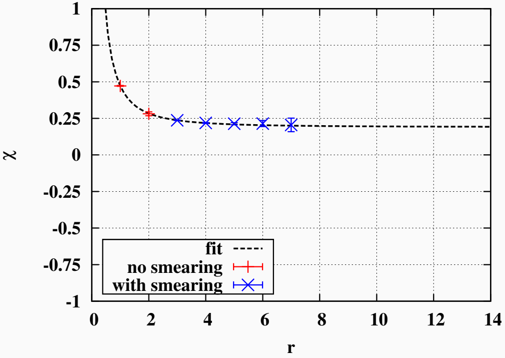
Creutz Ratio for $N_f = 6$

Preliminary, $\beta = \beta_{\mathrm{L}}{}^{\mathrm{c}} = 5.025$, $ma = 0.02$, $32^3 \times 64$, $t = 3$



Creutz Ratio, $N_f = 6$, *Fit*

Preliminary

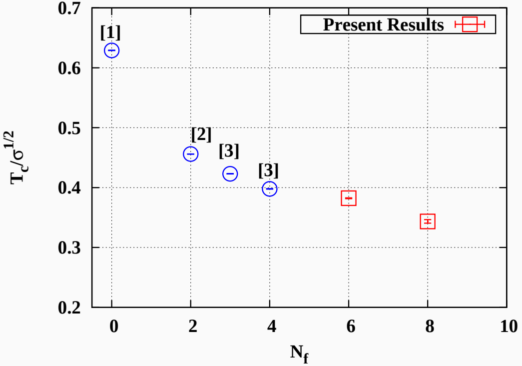


$$\alpha = 0.563763 \pm 0.002853 \quad (0.506\% \quad \text{error}) ,$$
$$\hat{\sigma} = 0.190117 \pm 0.0006817 \quad (0.3586\% \quad \text{error}) ,$$
$$X^2/\text{d.o.f.} = 0.184966 . \tag{3}$$

Table of Contents

$T_c/\sqrt{\sigma}(N_f)$: Conformal or Broken?

Preliminary



[1] E.Laermann, Nucl.Phys.B, '96, [2] F.Karsch and E.Laermann, Nucl.Phys.B, '01, [3] Engels, Nucl.Phys.B, '97.

$T_c/\sqrt{\sigma}$ gives an input for the model building based on the Gauge/Gravity Duality at finite T: Gursoy et.al. arXiv:1006.5461.

Deviation from Quasi-Conformal Scaling

- **Miransky Scaling ('85):**

$$T_c,\ \sigma \sim A^{(\mathrm{reg})}_{T,\sigma}(N_f)\exp\left[-\frac{B_{\mathrm{reg}}(N_f)}{\sqrt{|N_f^* - N_f|}}\right]. \qquad (4)$$

- **Braun-Gies Scaling ('06):**

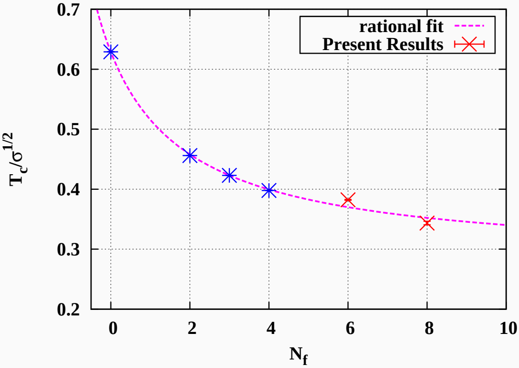
$$T_c,\ \sigma \sim a^{(\mathrm{reg})}_{T,\sigma}(N_f)|N_f^* - N_f|^{b_{\mathrm{reg}}(N_f)}. \qquad (5)$$

- **Assumption:**

$$\frac{T_c}{\sqrt{\sigma}}(N_f) = C \times \frac{1 + D_1 N_f + \cdots}{1 + E_1 N_f + \cdots}. \qquad (6)$$

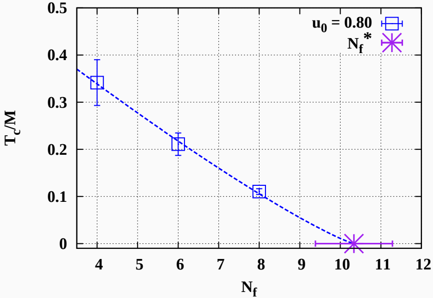
$T_c/\sqrt{\sigma}(N_f)$: Rational Fit

Preliminary



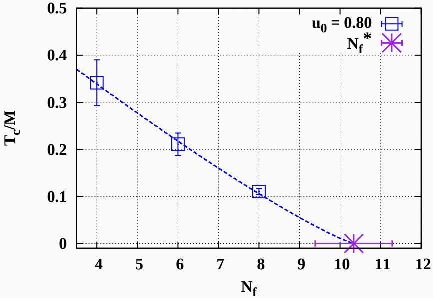
$$\frac{T_c}{\sqrt{\sigma}}(N_f) = C \cdot \frac{1 + D \cdot N_f}{1 + E \cdot N_f} \ . \qquad (7)$$

$T_c/M_{\rm UV}$: Miura-Lombardo Nucl. Phys. B ('13).



- The onset of the conformal phase N_f^* was determined from $(T_c/M)(N_f^*) = 0 \to N_f^* \sim 10.4 \pm 1.2$.
- However, the UV Scale M was determined at the plaquette scale with the help of the two-loop beta-function.
- Question: How we can define the UV scale from the lattice measurement without the help of the perturbation?

$T_c/M_{\rm UV}$: Miura-Lombardo Nucl. Phys. B ('13).



- The onset of the conformal phase N_f^* was determined from $(T_c/M)(N_f^*) = 0 \to N_f^* \sim 10.4 \pm 1.2$.
- However, the UV Scale M was determined at the plaquette scale with the help of the two-loop beta-function.
- Question: How we can define the UV scale from the lattice measurement without the help of the perturbation?

Table of Contents

Summary

- We have investigated the chiral phase transition in $N_f = 6$ and 8 QCD by using Monte-Carlo simulations.
- The QCD with $N_f = 8$ shows the first-order chiral transition, which is important information for the electroweak baryogenesis.
- We have argued that the lattice result for $T_c/\sqrt{\sigma}$ is the important input for the bottom-up gauge/gravity duality models.
- Future work:
  - Meson Mass Spectram and its comparison with T_c in many flavor QCD.
  - Estimate of N_f^* from the vanishing of T_c.

Summary

- We have investigated the chiral phase transition in $N_f = 6$ and 8 QCD by using Monte-Carlo simulations.
- The QCD with $N_f = 8$ shows the first-order chiral transition, which is important information for the electroweak baryogenesis.
- We have argued that the lattice result for $T_c/\sqrt{\sigma}$ is the important input for the bottom-up gauge/gravity duality models.
- Future work:
  - Meson Mass Spectram and its comparison with T_c in many flavor QCD.
  - Estimate of N_f^* from the vanishing of T_c.