Thermodynamic Study For Conformal Phase in Large N_f QCD

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Talk in QFT and Condensed Matter
at LNF-INFN, September 9

QCD Phase Diagram VS Graphene Phase Diagram

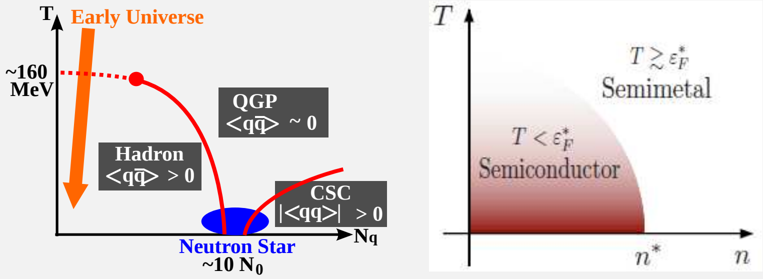


Figure: Left: QCD Phase Diagram. Right: Durt('09), Graphene Phase Diagram

Graphene Phase Diagram in $N_f - \beta$ Plane, $\beta = \epsilon_0 v_{\rm F}/e^2$

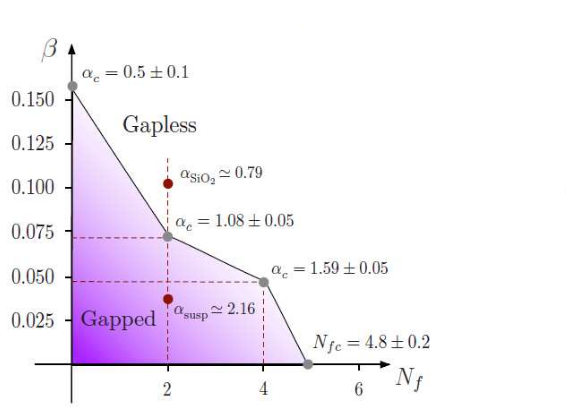
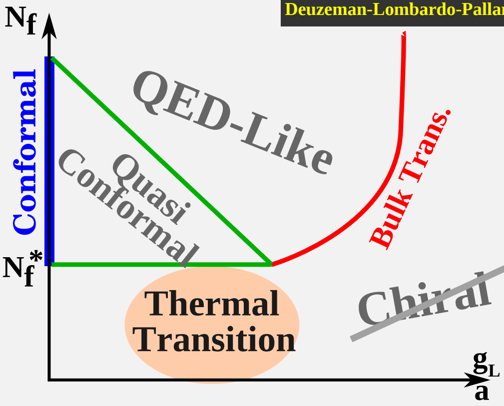


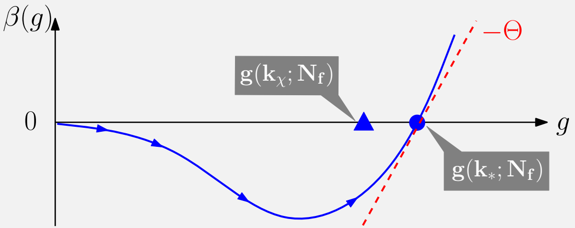
Figure: Right: Durt('09), Graphene Phase Diagram II

Miransky-Yamawaki Phase Diagram: Naive Speculation

Banks-Zaks ('82)
Miransky-Yamawaki ('97)
Deuzeman-Lombardo-Pallante ('10)



Beyond Miransky Scaling



$$\frac{k_\chi}{\Lambda_{\rm UV}} \sim \exp\left[-\frac{\pi}{2C\sqrt{|N_f^* - N_f|}}\right] \quad \text{(Miransky-Yamawaki('97) Scaling)}\ , \quad (1)$$

$$\frac{T_\chi}{k_*} \sim \left|N_f - N_f^*\right|^{-1/\Theta} \quad \text{(Braun-Gies('06))}\ , \quad (2)$$

$$N_f^* \ : \ \text{Lower Bound of CW.} \quad g^2(k_\chi; N_f^*) = g^2(k_*; N_f^*)\ . \quad (3)$$

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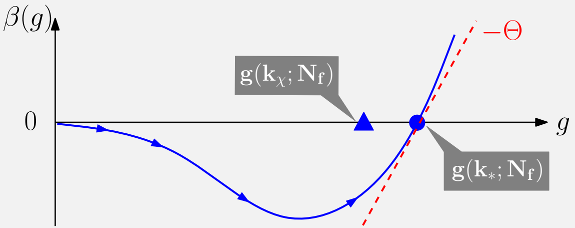

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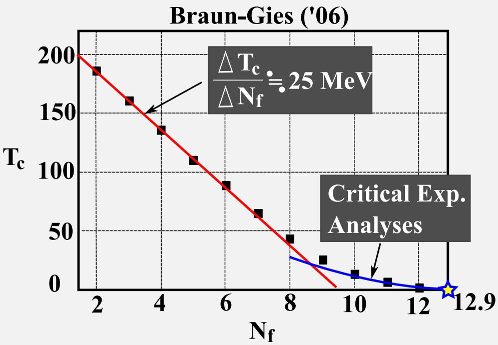
$T - N_f$ Phase Diagram: Functional Renormalization Group



∃Critical Exponent

- Beyond Miransky Scaling??
- Indicated in Large N_f QCD (FRG, Braun-Gies ('06)) and Graphene (Lattice, Durt-Lahde ('09))!!

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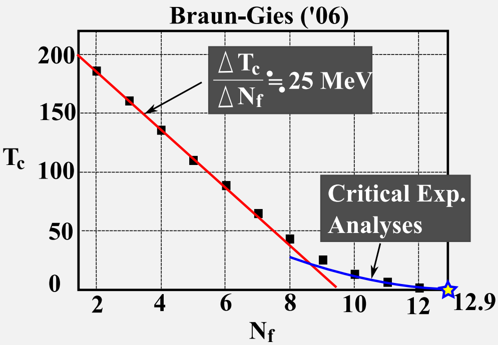

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Large N_f Gauge Theory at Finite T

Status

- **Conformality:** Interesting Phase in Strongly Interacting Gauge Theory.
- **Beyond Standard Model:** AdS/CFT, Electroweak Symmetry Breaking, Walking Technicolor.
- **Critical Phenomena:** Quantum PT and Beyond Miransky Scaling, From QGP To Conformal Window.
- **Good Conversations:** Lattice, FRG, and Graphene!!

$$\frac{\langle\bar{\Psi}\Psi\rangle|_{\rm ETC}}{\langle\bar{\Psi}\Psi\rangle|_{\rm TC}} = \exp\left[\int_{\Lambda_{\rm TC}}^{\Lambda_{\rm ETC}} d(\log\mu)\ \gamma\left[g^2(\mu)\right]\right] \xrightarrow{\text{Conformal}} \left(\frac{\Lambda_{\rm ETC}}{\Lambda_{\rm TC}}\right)^{\gamma[g_*^2]} . \quad (4)$$

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Setups

Observations

- Use Staggered Fermions with 0, 4, 6, 8, and 12 Flavors in Fundamental Representation.
- Measure Chiral condensates (PBP) and Polyakov loop (PLOOP).
- Observe Chiral and/or Deconfinement Trans. at Finite T ($N_s \gg N_t$).
- Obtain $\beta_c(N_t, N_f) \longrightarrow$ Miransky-Yamawaki Diagram.
- Investigate $T_c/\Lambda_{\rm L}(N_f)$ etc.
- Determine $a(\beta_c(N_f), N_f)$ and $T_c(N_f)$ by using a common UV scale as ruler. $\longrightarrow$ Beyond Miransky Scaling??

Code and Computers

- MILC-Code: http://www.physics.utah.edu/˜detar/milc/milc_qcd.html
- Rational Hybrid Molecular-Dynamics with Omelyan-Integrator
- IBM-sp6 in CINECA, SP16000 in YITP, and Italian-Grid-Infrastructures

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Scaling Behavior in QCD-Like (with Confinement) Theory on Lattice

$$B(g) = M\frac{dg}{dM}\ , \qquad \int_{g_L}^{\infty}\frac{dg}{B(g)} = \int_{1/a}^{\Lambda_L}\frac{dM}{M}\ , \tag{5}$$

$$\Lambda_L a(\beta) = \left(\frac{\beta}{2N_c b_0}\right)^{(b1/(2b_0^2))} \exp\left[-\frac{\beta}{4N_c b_0}\right]\ , \quad \text{(2-Loop)} \tag{6}$$

$$T \equiv \frac{1}{a(\beta)\cdot N_\tau}\ . \tag{7}$$

LARGER $\beta \equiv 2N_c/g_L^2$

1. Close to Continuum.
2. LAGER TEMPERATURE T with $N_s \gg N_\tau$.

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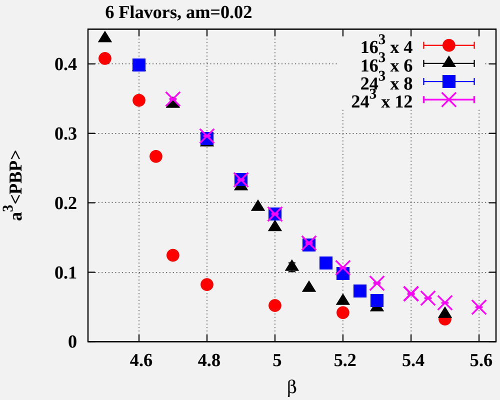
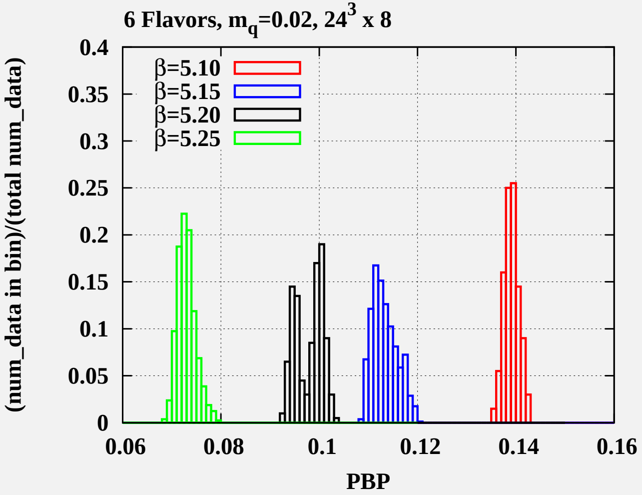
Thermal Scaling of Chiral Phase Transition



$$\frac{N_\tau^{-1}}{N_\tau'^{\,-1}} = \left(\frac{\beta_c}{\beta_c'}\right)^{b_1/(2b_0^2)} \exp\left[-\frac{\beta_c - \beta_c'}{4N_c b_0}\right] \quad (8)$$

The Histogram of Chiral Condensate



Collection of β_c, $N_f = 6$

Table: The summary table of β_c at $N_f = 6$.

$N_f \backslash N_t$	4	6	8	12
6	4.675 ± 0.025	5.025 ± 0.025	5.225 ± 0.025	5.45 ± 0.05

$$\Lambda_L a(\beta_c) = \left(\frac{\beta}{2N_c b_0}\right)^{(b1/(2b_0^2))} \exp\left[-\frac{\beta_c}{4N_c b_0}\right], \quad \text{(2-Loop)} . \tag{9}$$

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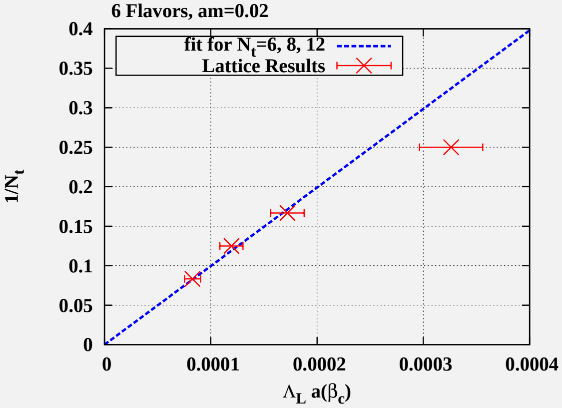
$1/N_\tau = (T_c/\Lambda_{\rm L}) \times \Lambda_{\rm L} a(\beta_c)$



$$\frac{1}{N_\tau} = \frac{T_c}{\Lambda_{\rm L}} \cdot \Lambda_{\rm L} a(\beta_c) \ . \tag{10}$$

Collection of β_c, for several N_f

Table: The summary table of β_c. The values are obtained by using the same action except the number of flavors.

$N_f \backslash N_t$	4	6	8	12
0	-	7.88 ± 0.05	-	-
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

$$\frac{1}{N_\tau} = \frac{T_c}{\Lambda_{\rm L}}(N_f) \cdot \Lambda_{\rm L} a(\beta_c(N_f)) \ . \tag{11}$$

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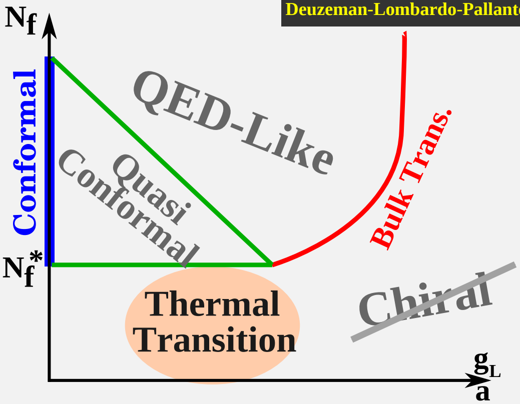
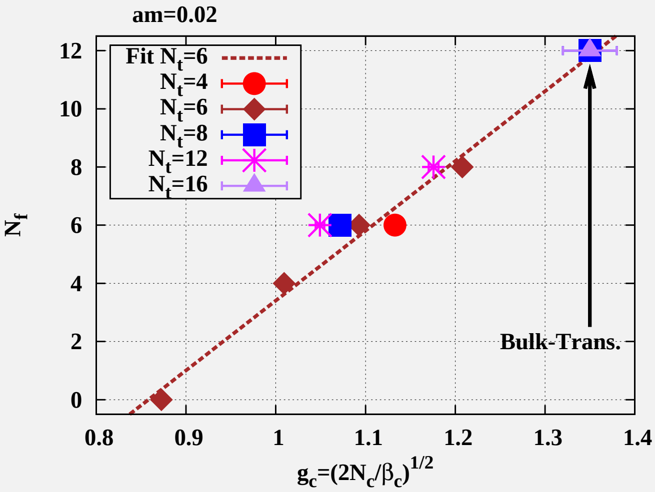
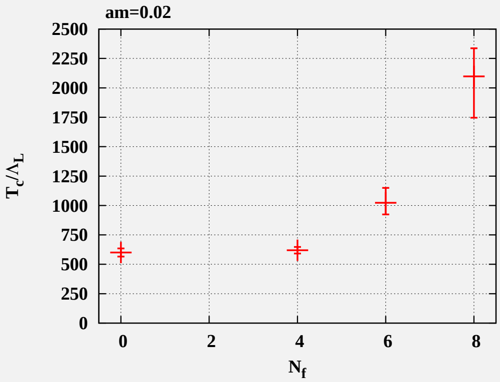


Thermal Transition Lines in Miransky-Yamwaki Phase Diagram



Comparison of Slope $T_c/\Lambda_{\rm L}$



Enhancement of $T_c/\Lambda_{\rm L}$

- Around $N_f \simeq 6$, the role of has started being different from that in $N_f \leq 4$.
- Onset of Walking? c.f. S.Guputa('01) and Appelquist('10).

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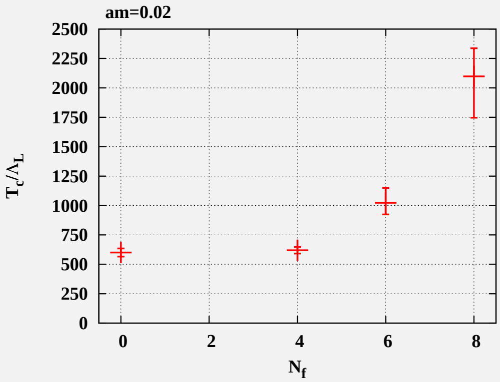

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Reference-Scale $\Lambda_{\rm ref}$

Integrating 2-loop beta function from $\Lambda_{\rm ref}(\beta_{\rm ref})$ to $a^{-1}(\beta_c)$, We obtain

$$\Lambda_{\rm ref}(\beta_{\rm ref}) \times a(\beta_c) = \left(\frac{b_0^2}{b_1} \, \frac{\beta_c + 2N_c b_1/b_0}{\beta_{\rm ref} + 2N_c b_1/b_0} \right)^{b1/(2b_0^2)} \exp\left[-\frac{\beta_c - \beta_{\rm ref}}{4N_c b_0} \right] .$$

Scheme Settings

- $\Lambda_{\rm ref}(\beta_{\rm ref}) \to \Lambda_{\rm L}(1 + \mathcal{O}(1/\beta_c))$ $\quad \beta_{\rm ref} \to 0$
- Using larger $\beta_{\rm ref}$ gives more UV $\Lambda_{\rm ref}$.

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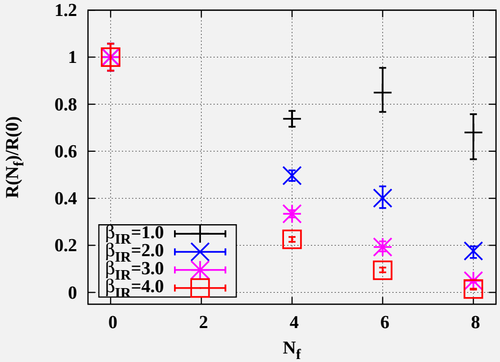
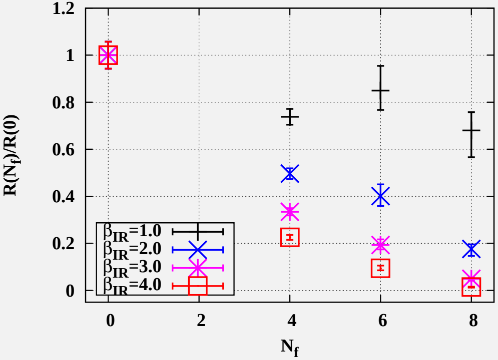
Comparison of Slope $R(N_f) \equiv T_c/\Lambda_{\rm ref}(N_f)$



Using Larger $\beta_{\rm ref}$

- The ruler $\Lambda_{\rm ref}$ becomes a UV quantity.
- Decreasing $T_c/\Lambda_{\rm ref}(N_f) \to$ Consistent with FRG.

Comparison of Slope $R(N_f) \equiv T_c/\Lambda_{\mathrm{ref}}(N_f)$



Using Larger β_{ref}

- The ruler Λ_{ref} becomes a UV quantity.
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Future Works

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THANKS!!

THANK YOU FOR YOUR ATTENTION!!