

# Exploring the $gluoN_c$ plasma

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TIFR

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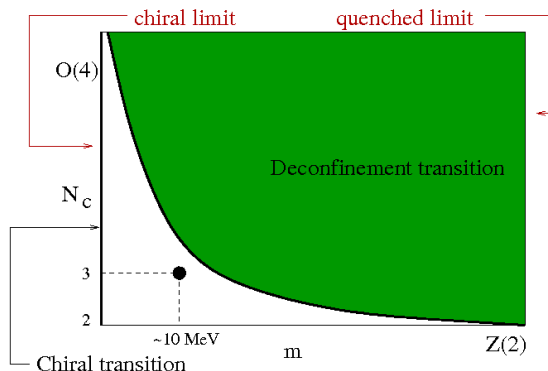
April 3, 2009

- 1 Introduction
- 2 The temperature scale
- 3 The equation of state
- 4 Conclusions

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## Deconfinement and chiral phase transition

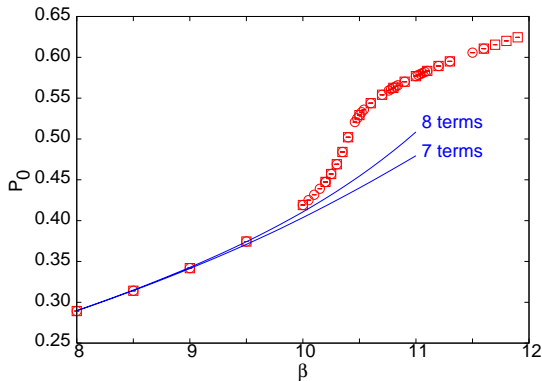


$$Z(T, m, N_c) = \int \mathcal{D}U \det M_f(T, m, N_c) \exp[-S_g(T, N_c)].$$

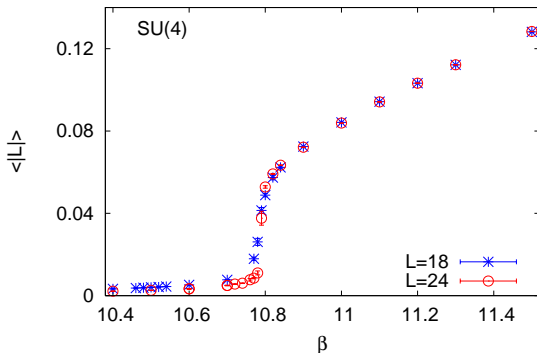
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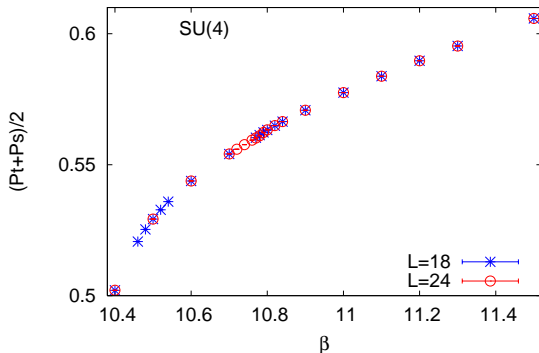
# SU(4): crossover to weak coupling



Strong coupling series fails: weak coupling should be understood in RG.  
 Coincidence: finite-T transition for  $N_t = 4$  interferes with this transition.  
 (Gocksch Okawa, Batrouni Svetitsky, Wingate Ohta, Gavai, Teper et al)  
 Our solution: go to larger  $N_t$ .

SU(4) with  $N_t = 6$ 

Thermal phase transition signalled by  $\langle |L| \rangle$ . No associated bulk transition seen in average plaquette. Similar for larger  $N_c$ .

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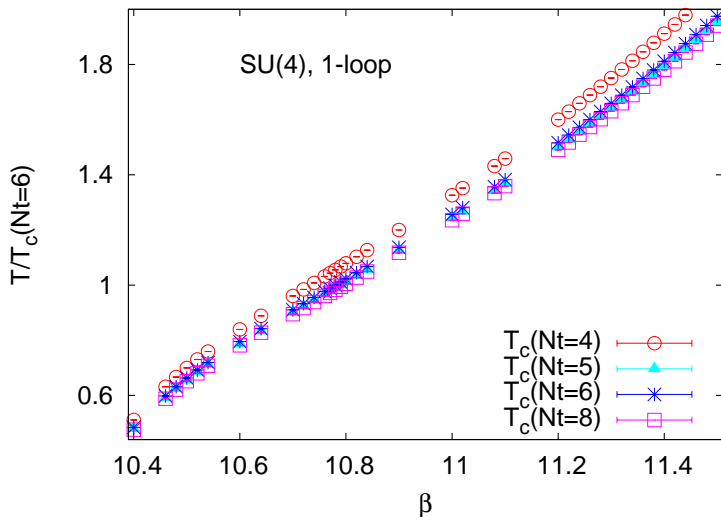
# Determining the temperature scale

- 1 Trade the bare coupling ( $\beta$ ) for the renormalized coupling ( $\alpha_S$ ). The zero-temperature plaquette ( $P$ ) is used to determine  $\alpha_S$  using the weak coupling expansion of carried out to second order: V-scheme.
- 2 Use the beta-function to find the lattice spacing for a given  $\alpha_S$ :

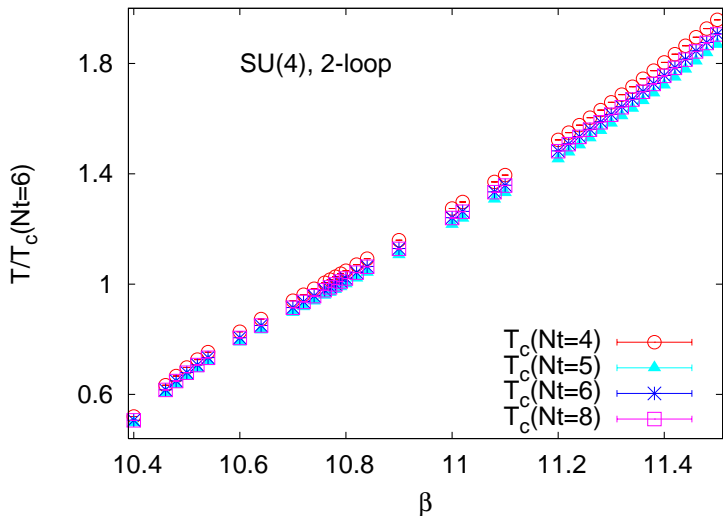
$$a\Lambda_{\overline{MS}} = kR(1/4\pi\beta_0\alpha_S) \quad R^2(x) = \exp(-x)x^{\beta_0/\beta_1}.$$

- 3 When  $\beta$  is tuned so that there is a finite temperature transition on an  $N_t \times N_s^3$  lattice ( $N_s \gg N_t$ ) then  $a = 1/(N_t T_c)$ . This allows us to determine  $T_c/\Lambda_{\overline{MS}}$ . Also, using the RGE, allows us to find  $T/T_c$  corresponding to any other  $\beta$ .
- 4 Consistency check on the approach to the continuum limit: the lattice spacings extracted from the RGE at fixed  $T$  with different  $N_t$  should be in the ratios of  $N_t$ .

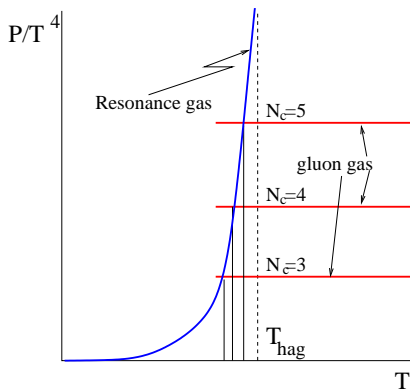
## SU(4) scaling with 1-loop RGE



## SU(4) scaling with 2-loop RGE

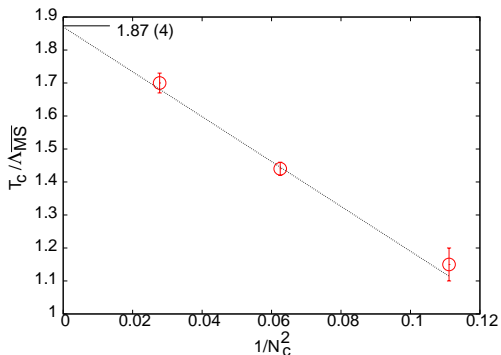


## A resonance gas?



A simple possibility at large  $N_c$ : pressure of a glueball resonance gas equals the pressure of a gluon gas at a first order deconfining transition. Correction should be regular in  $N_c$  and starts at order  $1/N_c^2$ .

# The Hagedorn temperature?



$N_c = 3$  from SG 2001. Fit gives the limiting temperature:  
 $T_c / \Lambda_{\overline{MS}} = 1.87(4)$ . Is this the Hagedorn temperature?

# Summary (1)

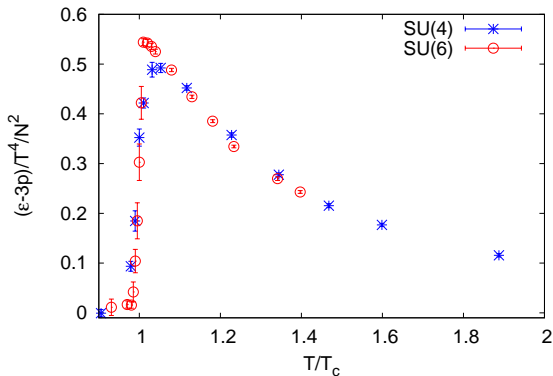
- Temperature scale determined for  $N_c = 4$  and 6 using lattice simulations at finite cutoff. Extrapolated to continuum limit using two-loop  $\beta$ -function of QCD. The result is  $T_c/\Lambda_{\overline{MS}}$  for each  $N_c$ .
- A model of the first order transitions seen is that on the low temperature side one has a resonance gas of glueballs, and on the plasma side one has a gas of gluons. If this picture becomes exact at  $N_c = \infty$ , then one should be able extrapolate smoothly to the limit.
- We find

$$\frac{T_c}{\Lambda_{\overline{MS}}} = 1.87 \pm 0.04. \text{ (stat only).}$$

Systematic errors involved in the choice of RG scheme remain to be evaluated.

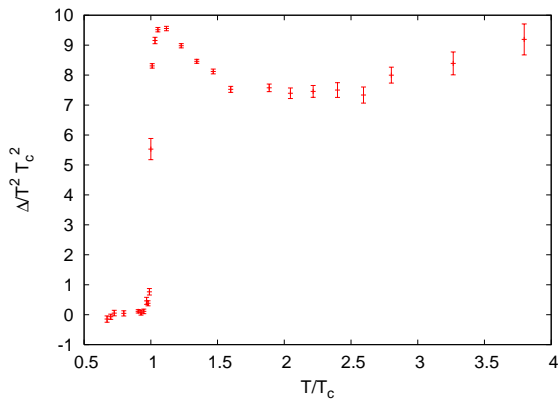
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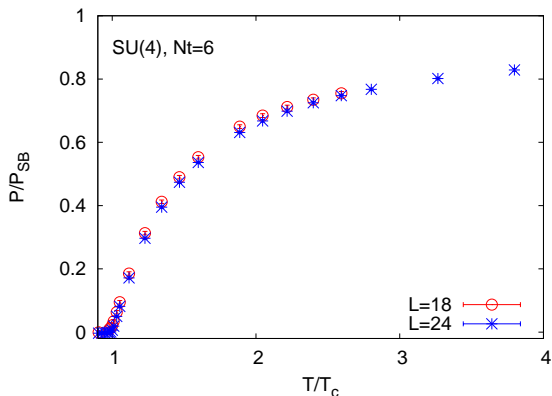
The conformal anomaly:  $\Delta = E - 3P$ 

Peak of  $\Delta/T^4$  shifted from  $T_c$ : evidence of change with  $N_c$ ? Perhaps peak shifts to  $T_H$  as  $N_c \rightarrow \infty$ ? (Pisarski)

## Pisarski plot

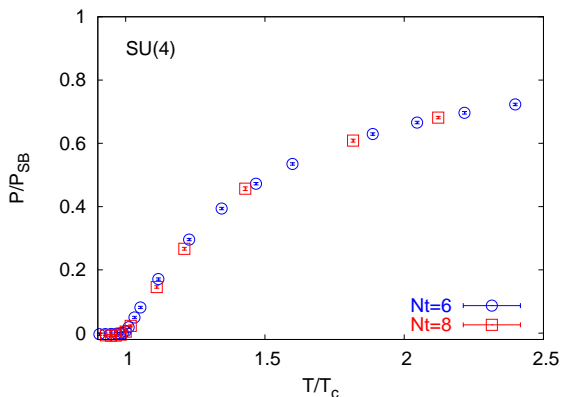


## Pressure in SU(4)



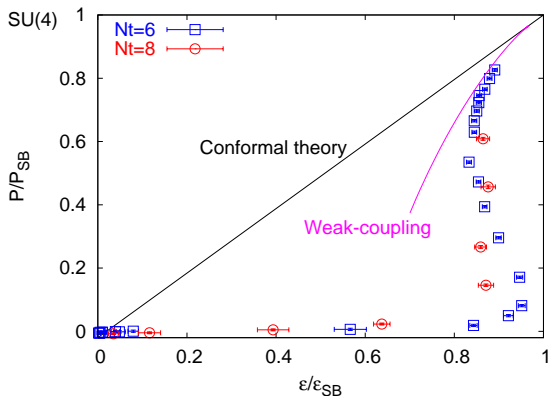
Evaluated using the integral method. Negligible volume dependence when  $N_s/N_t > T/T_C$ . Cutoff dependence within control: continuum limit within reach.

## Pressure in SU(4)



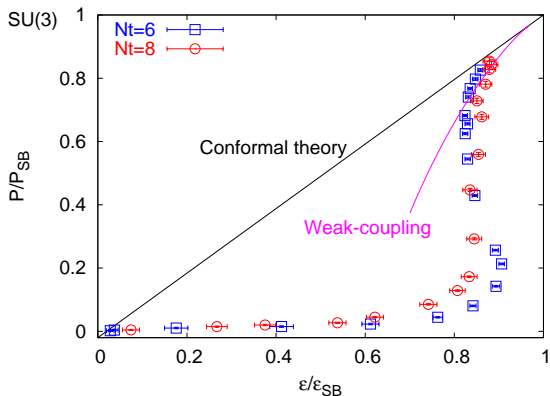
Evaluated using the integral method. Negligible volume dependence when  $N_s/N_t > T/T_C$ . Cutoff dependence within control: continuum limit within reach.

## Equation of state for SU(4)



Weak coupling theory treated in DR (Hietanen et al, hep-ph/0603048).  
 EOS closer to weak-coupling QCD than conformal theory.

## Equation of state for SU(3)



Weak coupling theory treated in DR (Hietanen et al, hep-ph/0603048).  
EOS closer to weak-coupling QCD than conformal theory.

## Summary (2)

- $P/T^4$  in SU(4) pure gauge theory scales for  $T \geq 3T_c/2$  already for  $N_t = 6$ . For  $T \simeq 1.1T_c$  there is scaling violation between  $N_t = 6$  and  $N_t = 8$ . The EOS curve becomes smoother with increasing  $N_t$ . Similar effects were also seen for SU(3).
- EOS comes close to the conformal symmetric limit only for  $T > 2T_c$ . Even at high temperature the results are closer to weak-coupling QCD (evaluated to order  $g^6 \ln g$ ) than to the conformal symmetric limit.
- The complete EQCD results in smaller  $\Delta/T^4$  than the weak-coupling results: this leaves out terms that could be important for the hard modes which dominate the EOS. However, the lattice results would still be closer to such a computation than to a conformal symmetric model.
- Qualitatively accurate intuition for the plasma may perhaps be obtained from conformally symmetric models only for temperatures higher than  $2T_c$ .

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# Summary

## Simple theory at large $N_c$

In the limit  $N_c \rightarrow \infty$  we find that  $T_c/\Lambda_{\overline{MS}} = 1.87(4)$  Consistent with a simple model of phase transition: resonance gas on one side, gluon gas on the other.

## Weak-coupling better than conformal field theory for EOS

There seems to be no window for non-trivial (almost) conformal scaling in the data for the equation of state. The EOS is either strongly non-conformal or compatible with a weak-coupling expansion.

## An advertisement

TIFR is planning to expand research directions: one of the new directions under consideration is **experimental and theoretical heavy-ion physics** and allied topics in extreme QCD.