
EXTREME
QCD

Life after Deconfinement

Il Deserto Non-Perturbativo

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Extreme QCD

Overview

- KP and RBC/Bi, "Heavy Quark Thermodynamics", hep-lat/0701017, published **J. Phys. G**
- KP and RBC/Bi, "Thermodynamics of the static QQbar pair in full QCD", published in **PoS LAT06** , hep-lat/061004
- RBC/Bi, "Transition Temperature in QCD", published in **Phys. Rev. D 74**, 054507 (2006)
- ...with RIKEN-BNL-Columbia-Bielefeld Collaboration
- comparison with pure gauge and Nf=2 courtesy of Kaczmarek/Zantow 2002

L'Avventura

- Focus on strong interactions around and far above deconfinement
- Motivated by RHIC physics (STAR / PHENIX)
- Details of screening phenomena are important
- as dynamics of sQGP is not understood
- which is an understatement
- Potential models make lattice ...
- ... an important input to phenomenology
- Validity of perturbation theory ...
- in the land of strong strong coupling?

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- **Improved Hardware**
- Large Scale Simulation
- Multi-teraflop QCDOC (RIKEN/BNL) and APE (Bielefeld)
- **Improved Action: P4 + Fat3 fermion action**
- reduces cutoff effects
- reduces lattice-induced chiral symmetry violations
- **Improved Algorithm: Rational Hybrid Monte-Carlo**
- is exact [Kennedy/Clarke]
- factor of 10 speed-up compared to R-algorithm

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- Previous studies - P.Petreczky/KP, Asqtad, $N_t = 4, 6$, 3F [MILC]
- and Kaczmarek/Zantow, P4 (2F, $N_t = 4$)
- Full QCD, *two* light and *one* strange dynamical quarks
- Physical strange quark mass
- Almost physical quark masses [0.1 strange quark mass]
- Scale setting via zero temperature heavy quark potential (r_0)
- Heavy Quark physics
- EoS will be published soon

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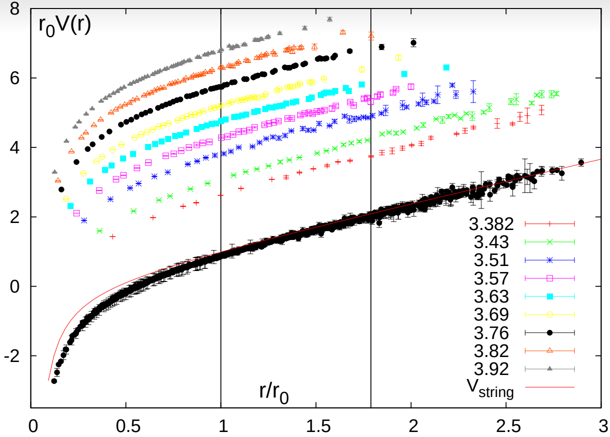
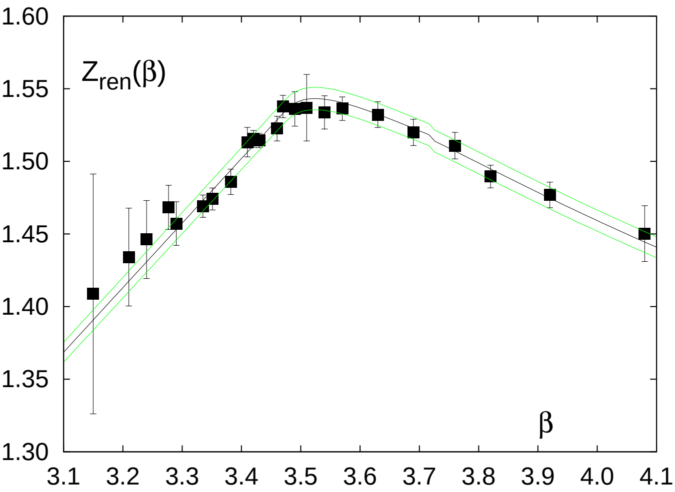


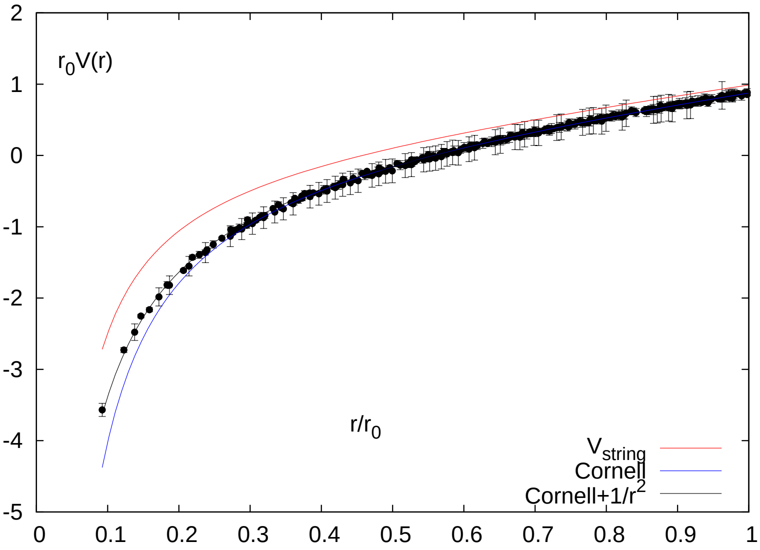
is well-described by string model prediction at large separations

$$V(r) = -\frac{\pi}{12r} + \sigma r$$

Renormalization: $V_{(T=0)} = -log(Z_{ren}(\beta)^2 \frac{W(r,\tau)}{W(r,\tau+1)})$

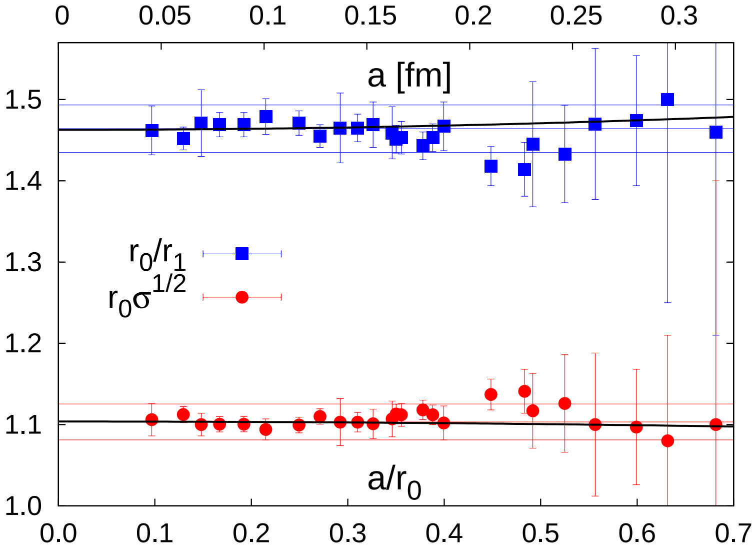

Z_ren(β)
β
1.60
1.55
1.50
1.45
1.40
1.35
1.30
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4.0
4.1

Blow Up



2
1
0
-1
-2
-3
-4
-5
$r_0 V(r)$
r/r_0
V_{string}
Cornell
Cornell+1/r^2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

L'Amici: R_1 et R_0



How do we study Heavy Quarks?

$$L(\vec{x}) = \frac{1}{3}\mathscr{P}\exp\int_0^{1/T} dx_0 A(x, x_0)$$

Determined from Polyakov Loop correlations

$$F_1(|x|, T)/T = -\ln\langle \mathrm{Tr} L(\vec{x}) L^{\dagger}(0)\rangle [McLerran]$$

- Straightforward physical interpretation in Coloumb Gauge [Philipsen]
- Gauge invariant at infinite separation of Q and Qbar
- Renormalization required

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Renormalization

- **Two schemes for renormalization**
- either short distance related
- assume that media is irrelevant at short distances
- force F_1 be zero temperature potential
- at shortest availible lattice distance
- **Or**
- renormalization factors obtained in T=0
- may be used at finite temperature
- with appropriate *Nt* power
- **Which one is better?**

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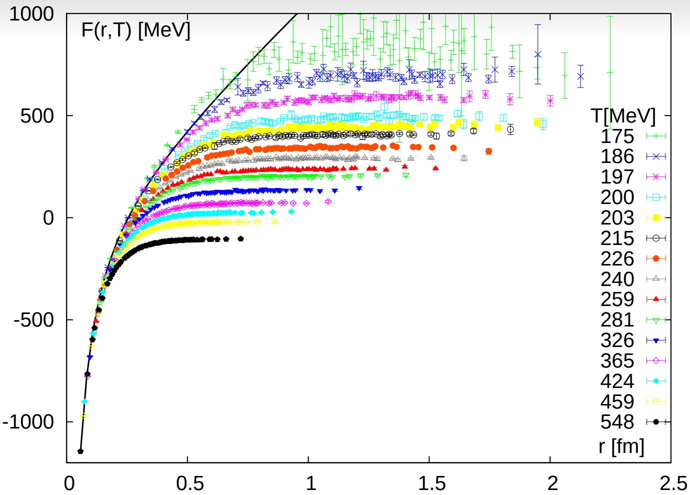
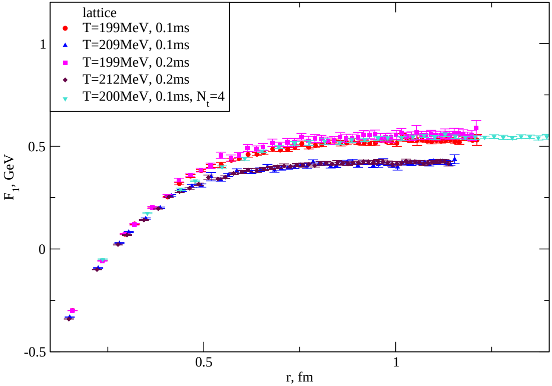


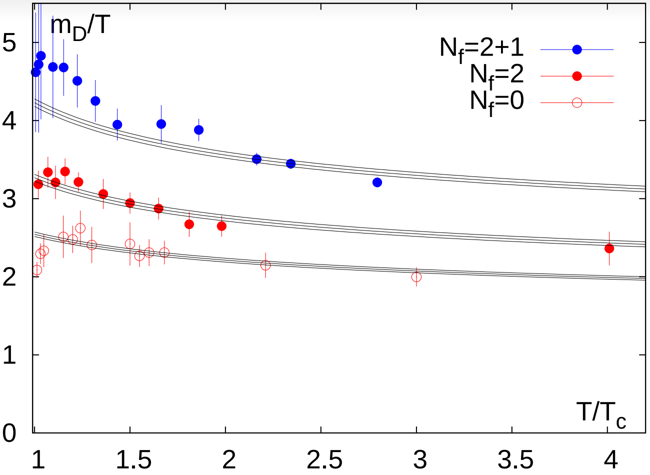
renormalization by factors $Z_r(g^2)$ obtained at T=0 is equivalent to matching with T=0 potential at short distances!

$$exp(-F_1(r,T)/T) = Z_r(g^2)^{2N_\tau} \langle Tr(L(x)L(x+r)^\dagger\rangle$$

Checks and Balances: Scaling with m_q and N_t



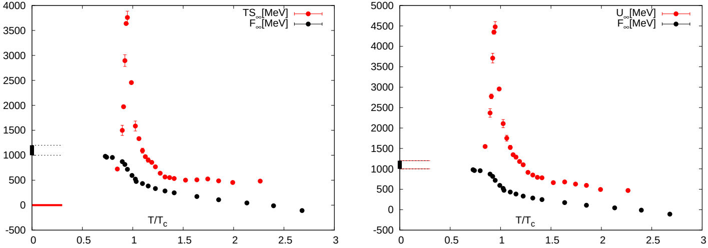
- Small cutoff effects
- Light quark mass scaling is also good



$$F_1(r,T) - F_1(r=\infty,T) = -\frac{4\alpha(T)}{3r} exp(-m_D(T)r)$$

$$\frac{m_D(T)}{T} = A(T)(1+\frac{N_f}{6})^{1/2} g(T)$$

Beyond the Gluonic Clouds



- big jump in critical region
- in potential models would mean 2-3x increase in effective mass
- Explanation? Correlation length higher in crossover area
- screening gluon clouds are bigger near transition
- enters perturbative regime at about 250MEV

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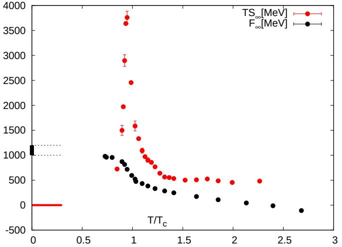

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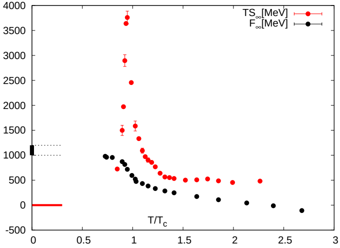

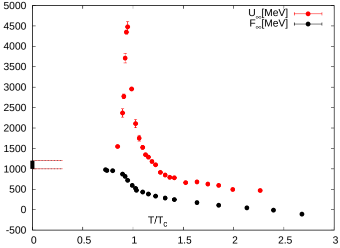

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Professione: Polyakov Loop

- Very nice oder parameter in pure glue
- Still interesting in full QCD
- Loved by model-builders
- needs renormalization [we all do]

$$L_{ren} = (Z_R(g^2))^{N_\tau} L_{lat}$$

- we define it through already renormalized F_1

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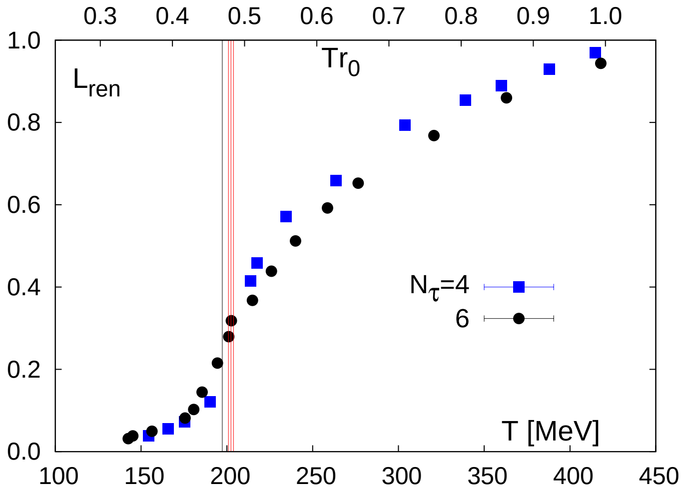
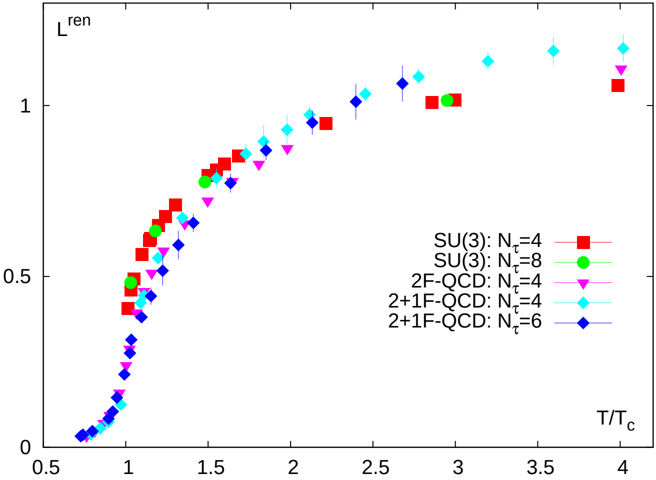
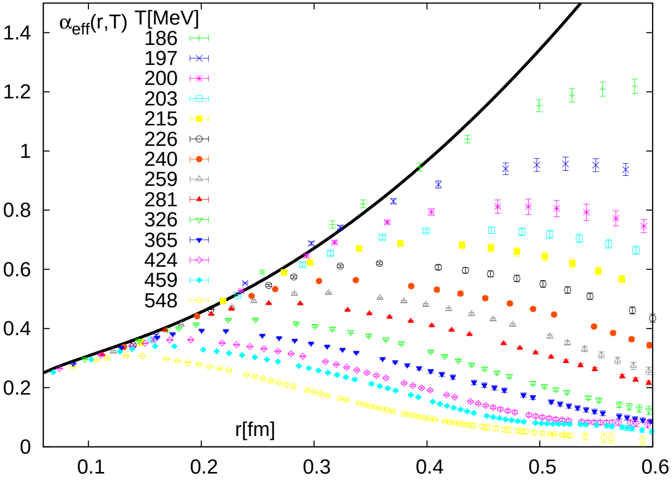
Renormalized Polyakov Loop in physical units

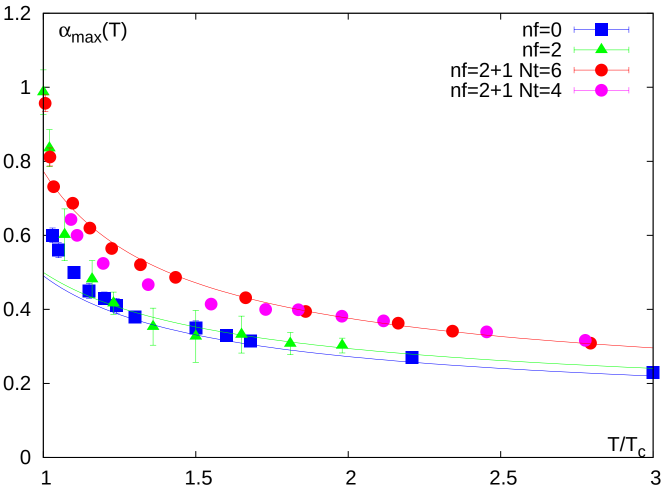


Flavour-dependence is largely due to T_c difference



Zabriskie Coupling




$\alpha_{max}(T)$
nf=0
nf=2
nf=2+1 Nt=6
nf=2+1 Nt=4
1.2
1
0.8
0.6
0.4
0.2
0
1
1.5
2
2.5
3
T/T_c

L'Eclisse

- Interaction in hot medium gets screened at increasingly short distances
- Scaling is good to very good
- Our two renormalization schemes match very well
- Screening masses will only slowly reach perturbative limit
- Entropy and Internal Energy have sharp peak
- Critical behaviour ends at 250MeV
- Can define and calculate Renormalized Polyakov Loop
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- *R.I.P. Michelangelo Antonioni*

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