

EXTREME

QCD





Life after Deconfinement

II Deserto Non-Perturbativo

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Niels Bohr Institute, KU and SDU

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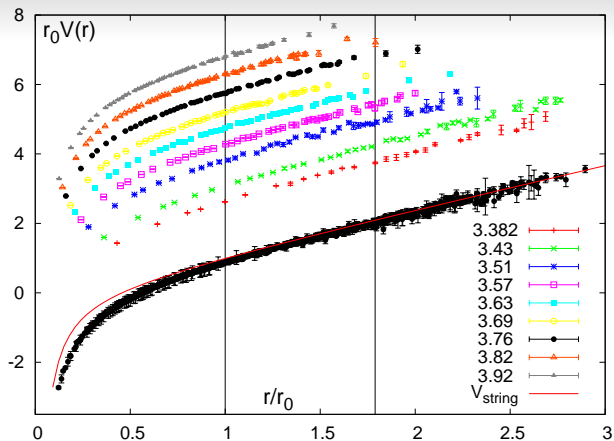
- Previous studies - P.Petreczky/KP, Asqtad, $N_t = 4, 6, 3F$ [MILC]
- and Kaczmarek/Zantow, P4 (2F, $N_t = 4$)
- Full QCD, *two* light and *one* strange dynamical quarks
- Physical strange quark mass
- Almost physical quark masses [0.1 strange quark mass]
- Scale setting via zero temperature heavy quark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



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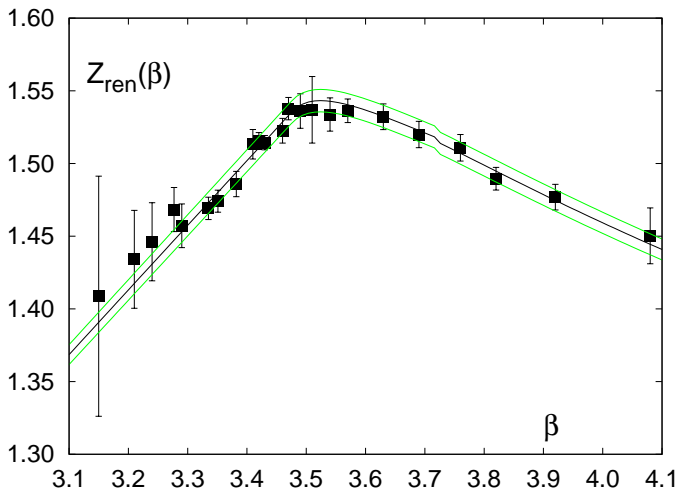
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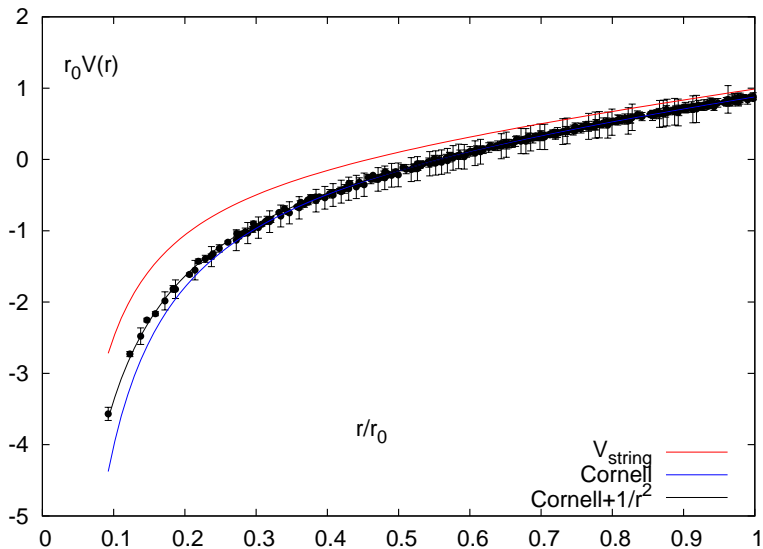
is well-described by string model prediction at large separations

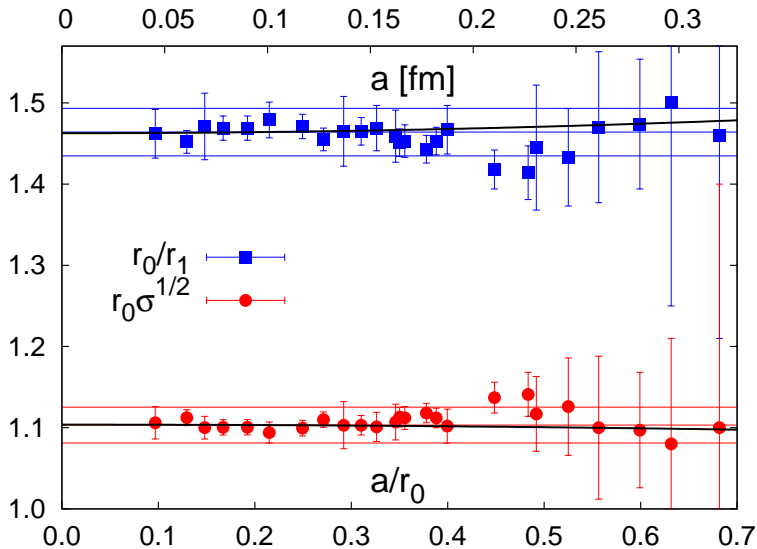
$$V(r) = -\frac{\pi}{12r} + \sigma r$$

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



Blow Up



L'Amici: R_1 et R_0 

How do we study Heavy Quarks?

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

Determined from Polyakov Loop correlations

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

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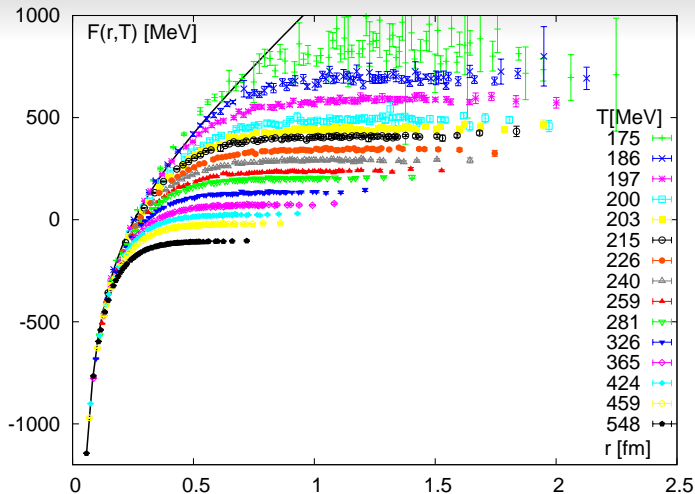
Renormalization

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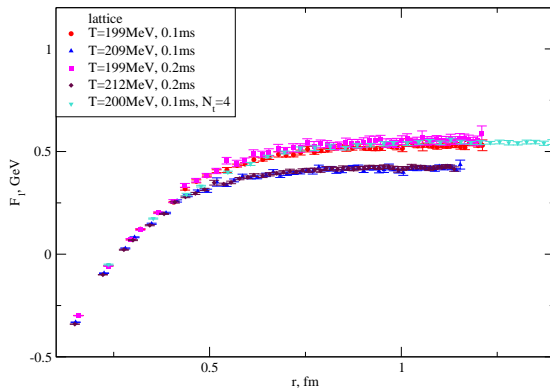
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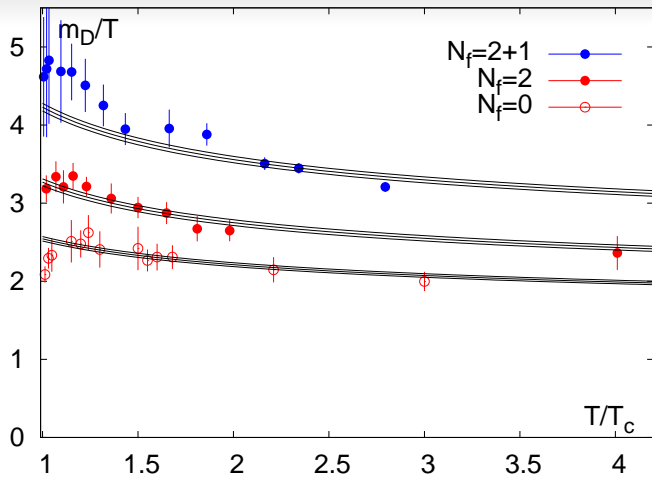
renormalization by factors $Z_r(g^2)$ obtained at $T=0$ is equivalent to matching with $T=0$ potential at short distances!

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

Checks and Balances: Scaling with m_q and N_t



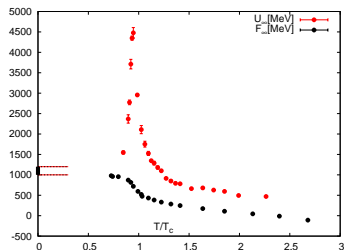
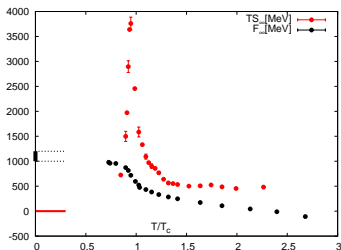
- Small cutoff effects
- Light quark mass scaling is also good



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

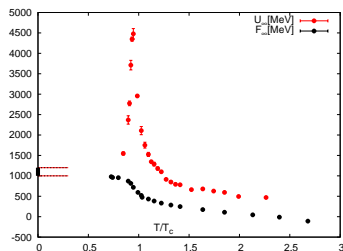
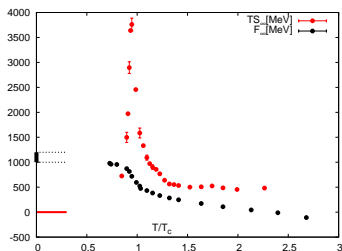
$$\frac{m_D(T)}{T} = A(T) \left(1 + \frac{N_f}{6}\right)^{1/2} g(T)$$

Beyond the Gluonic Clouds



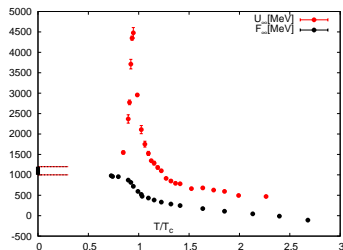
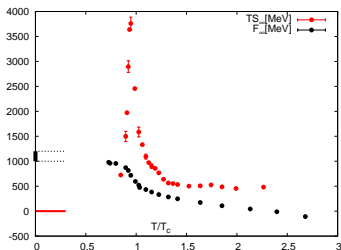
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- Explanation? Correlation length higher in crossover area
- screening gluon clouds are bigger near transition
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Professione: Polyakov Loop

- Very nice order 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

$$L_{ren} = \exp(-F_{r=\infty}/2T)$$

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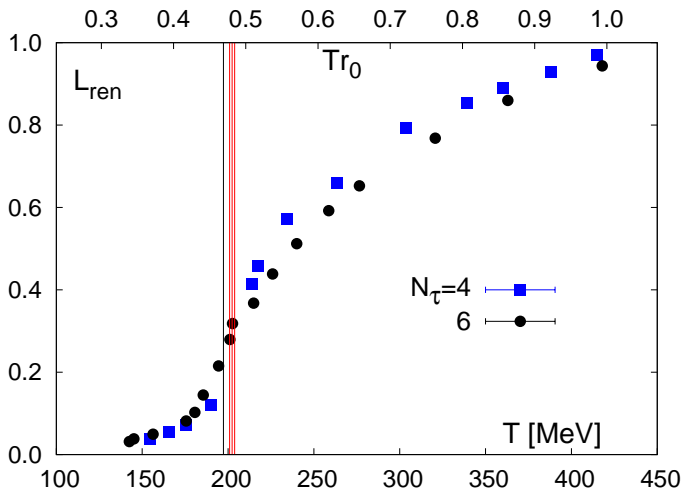
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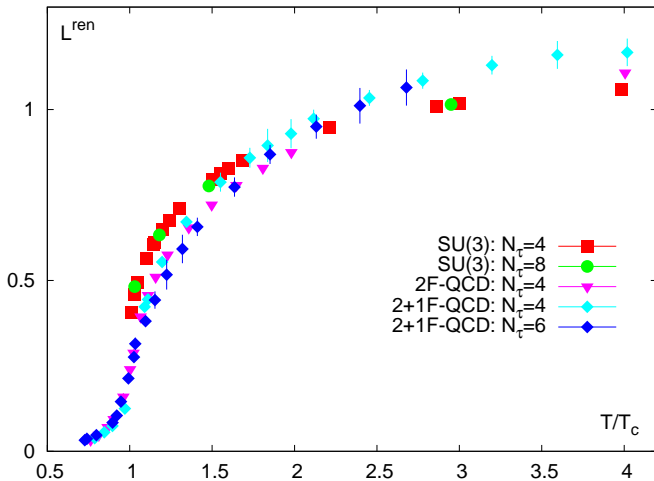
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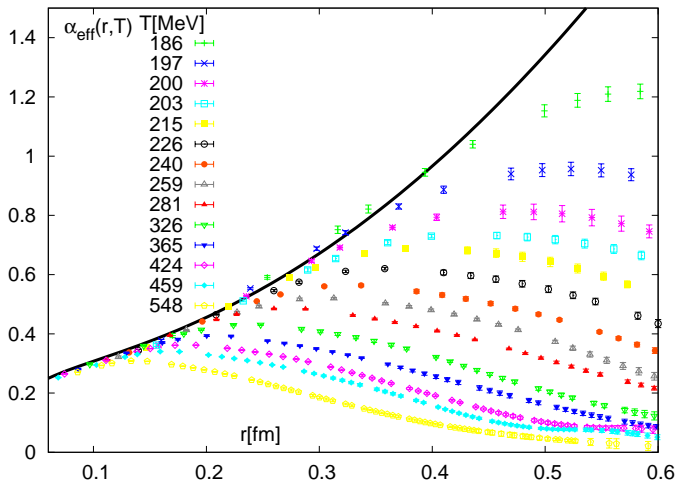
Renormalized Polyakov Loop in physical units

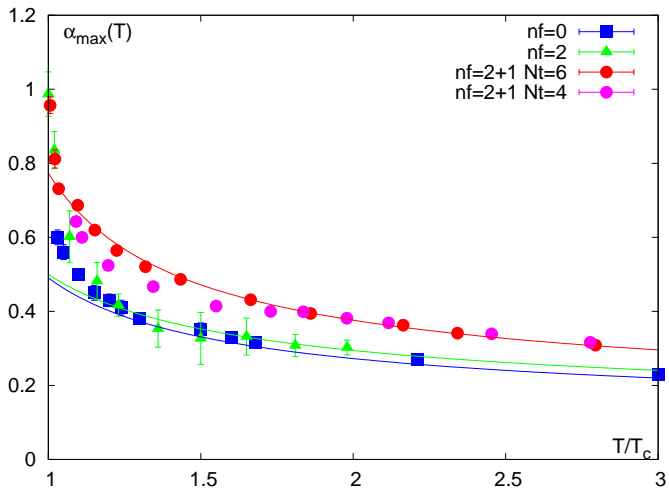


Flavour-dependence is largely due to T_c difference



Zabriskie Coupling





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- 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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 - running coupling α_s starts at around 1 and decreases slowly
 - stronger than in 2-flavour case
 - *R.I.P. Michelangelo Antonioni*



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