The finite temperature QCD transition (is there still any T_c mystery)

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new results of the Wuppertal-Budapest group arXiv:1005.3508
(N_t=16, about scaling and lattice artefacts)

Lattice 2010 Conference

Outline

Literature: discrepancies between T_c

Bielefeld-Brookhaven-Riken-Columbia Coll. (+MILC='hotQCD'):

M. Cheng et.al, Phys. Rev. D74 (2006) 054507

T_c from $\chi_{\bar{\psi}\psi}$ and Polyakov loop, from both quantities:

T_c=192(7)(4) MeV

Wuppertal-Budapest group (WB):

Y. Aoki, Z. Fodor, S.D. Katz, K.K. Szabo, Phys. Lett. B. 643 (2006) 46

chiral susceptibility: T_c=151(3)(3) MeV

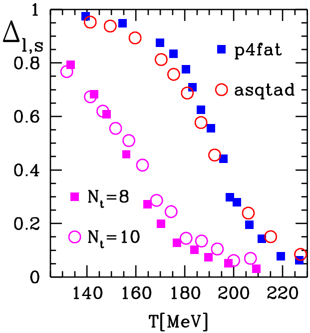
Polyakov and strange susceptibility: T_c=175(2)(4) MeV

'chiral T_c': ≈40 MeV; 'confinement T_c': ≈15 MeV difference

both groups give continuum extrapolated results with physical m_π

Literature: discrepancies between T dependencies

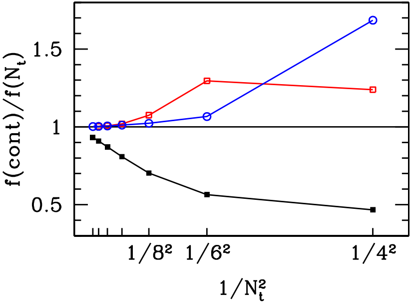
Reason: shoulders, inflection points are difficult to define?
Answer: no, the whole temperature dependence is shifted



for chiral quantities ≈35 MeV; for confinement ≈15 MeV
this discrepancy would appear in all quantities (eos, fluctuations)

Examples for improvements, consequences

how fast can we reach the continuum pressure at T=∞?



p4 action is essentially designed for this quantity T$\gg T_c$

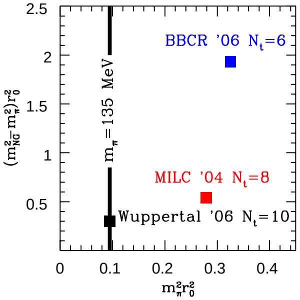
asqtad designed mostly for T=0 physics (but good at high T, too)

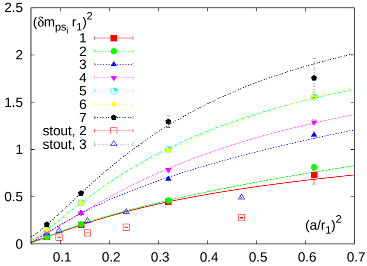
stout-smeared one-link converges slower but in the a^2 scaling regime (e.g. extrapolation from N_t=8,10 provides a result within about 1%)

Chiral symmetry breaking and pions

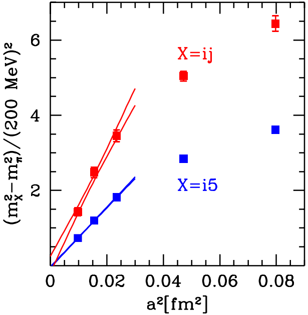
transition temperature for remnant of the chiral transition:
balance between the chirally broken and chirally symmetric sectors
chiral symmetry breaking: 3 pions are the pseudo-Goldstone bosons

staggered QCD: 1 ($\frac{3}{16}$) pseudo-Goldstone instead of 3 (taste violation)
staggered lattice artefact $\Rightarrow$ disappears in the continuum limit
WB: stout-smeared improvement is designed to reduce this artefact





Scaling for the pion splitting



scaling regime is reached if a^2 scaling is observed

asymptotic scaling starts only for $N_t \gtrsim 8$ ($a \lesssim 0.15$ fm): two messages

a. N_t=8,10 extrapolation gives 'p' on the $\approx$1% level: good balance

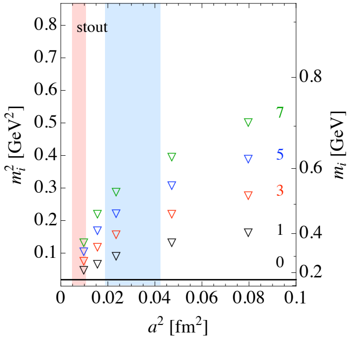
b. stout-smeared improvement is designed to reduce this artefact

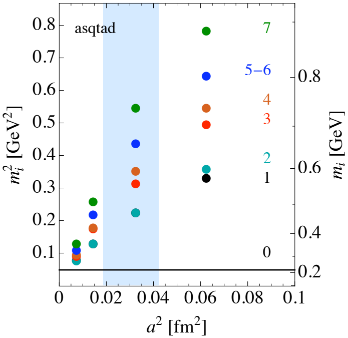
most other actions need even smaller 'a' to reach scaling

Wuppertal-Budapest 2010 results arXiv:1005.3508

both T=0 and T>0 with physical quark masses: $m_s/m_{ud} \approx 28$
2006 with N_t=6,8,10 $\Longrightarrow$ 2008/09 with N_t=12 $\Longrightarrow$ 2010 with N_t=16

illustration: progress in pion splitting



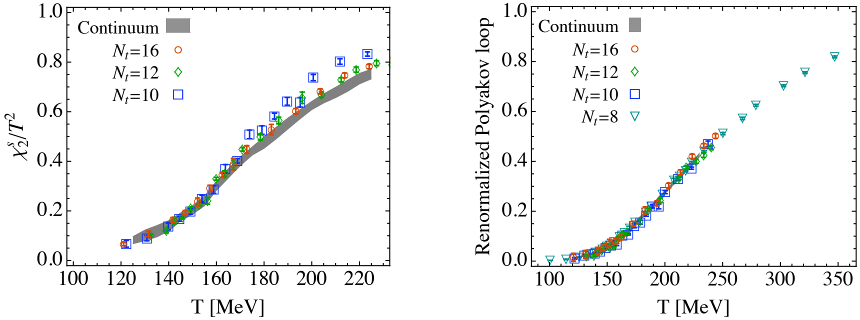


strange quark number susceptibility and Polyakov-loop

strange susceptibility: $\chi_2^s = (T/V) \cdot \partial^2 \ln Z/\partial \mu_s^2$

Polyakov-loop renormalization procedure: Aoki, Fodor, Katz, Szabo: PLB643 46 (2006)

continuum behaviour can be given for both observables



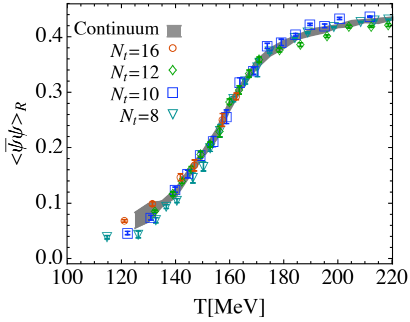
renormalized chiral condensate

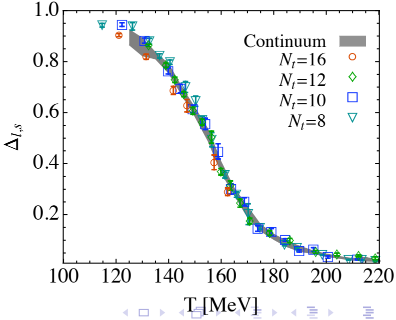
$$\langle\bar\psi\psi\rangle_R = -\left[\langle\bar\psi\psi\rangle_{l,T} - \langle\bar\psi\psi\rangle_{l,0}\right]\frac{m_l}{X^4}$$

$$\Delta_{l,s} = \frac{\langle\bar\psi\psi\rangle_{l,T} - \frac{m_l}{m_s}\langle\bar\psi\psi\rangle_{s,T}}{\langle\bar\psi\psi\rangle_{l,0} - \frac{m_l}{m_s}\langle\bar\psi\psi\rangle_{s,0}}$$

X can be chosen as m_π

$\Delta_{l,s}$ (strange subtraction)





T_c summary of the Wuppertal-Budapest group

list of pseudocritical temperatures (various observables)

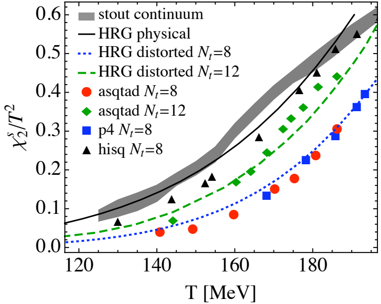
	$\chi_{\bar\psi\psi}/T^4$	$\Delta_{l,s}$	$\langle\bar\psi\psi\rangle_R$	χ_2^s/T^2	ϵ/T^4	$(\epsilon\text{-}3p)/T^4$
WB'10	147(2)(3)	157(3)(3)	155(3)(3)	165(5)(3)	157(4)(3)	154(4)(3)
WB'09	146(2)(3)	155(2)(3)	-	169(3)(3)	-	-
WB'06	151(3)(3)	-	-	175(2)(4)	-	-

all numbers (in a given coloumn) are in complete agreement
different variables give different pseudocritical T_c-s: 147–165 MeV
reason: the transition is a broad one with 30-40 MeV broadness

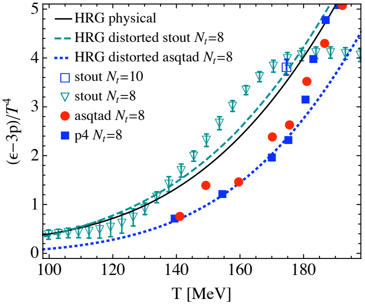
3% shift to lower values between 2006 and 2009
reason: 3% experimental change in f_K (no change in lattice results)

compare with the hadron resonance gas model: HRG

strange quark number susceptibility



trace anomaly



Wuppertal-Budapest: test of HRG (agrees with the continuum result)

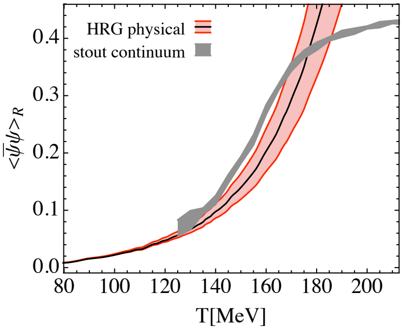
P. Huovinen, P. Petreczky, arXiv:1005.0324 use heavier than physical hadrons in HRG

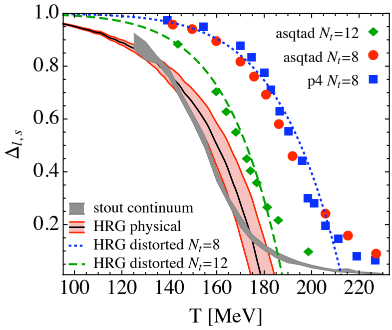
hotQCD: agreement only with the distorted spectrum

(our splittings and hadron spectrum gives minimal change: EoS)

though their results are gradually getting closer to ours

temperature dependence of the chiral condensate





Wuppertal-Budapest: good agreement with the physical HRG

Borsanyi, Fodor, Hoelbling, Katz, Krieg, Ratti, Szabo, arXiv:1005.3508

hotQCD: agreement only with the distorted spectrum
though their results are gradually getting closer to ours

progress in T dependence of the chiral condensate

Wuppertal-Budapest: physical quark masses (m_s/m_{ud} ≈28)
gauge configs: N_t=8,10 in 2006 ⇒ N_t=12 in 2009 ⇒ N_t=16 in 2010

hotQCD 2009: realistic quark masses (m_s/m_{ud} =10)
hotQCD 2010 preliminary: physical quark masses (m_s/m_{ud} =20)

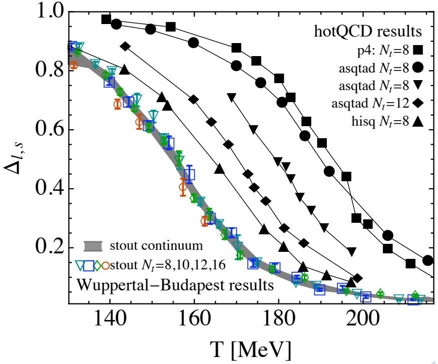
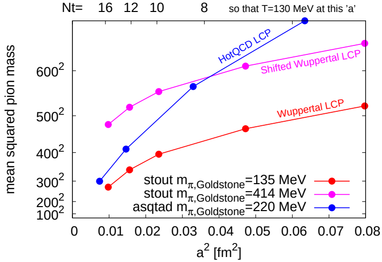
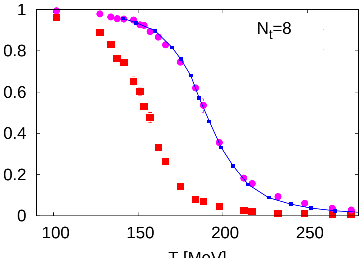


Illustration: lattice artefacts due to pion splitting

we have seen: our action (WB) has less unphysical pion splitting than the asqtad (MILC) and far less than the p4 (Bielefeld) action

in the continuum limit: no problem; at $a \neq 0$ it mimics larger M_π
"reproduce" the result of hotQCD with larger M_π (asqtad is better)





$m_\pi \approx$220 MeV (hotQCD) "corresponds" to $M_\pi \approx$410 MeV (WB)
asqtad (MILC) needs finer p4 (Bielefeld) needs much finer lattices in order to handle physical quark masses

Summary

- the T>0 QCD transition is an analytic cross-over
- new (2010) results for the transition and its scale
- three improvements since 2006 (in 2009 and 2010)
  a. at T=0 all simulations are done with physical quark masses
  b. to verify that the results are independent of the scale setting
  we use 5 experimentally well-known quantites: f_K,f_π,m_{K^*},m_Ω,m_Φ
  c. smaller and smaller lattice spacings: N_t=16
- all our findings are in complete agreement with our 2006 results
- Particle Data Group reduced the experimental value of f_K: 3%
- discrepancy between Wuppertal-Budapest & 'hotQCD' results
  'hotQCD' results are approaching our findings