Chiral Aspects of Improved Staggered Fermions with $2+1$-Flavors from the hotQCD Collaboration

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Lattice 2010, Sardinia, Italy

The *hotQCD Collaboration*

Members of the *hotQCD Collaboration*

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P. Vranas		

Motivation

Motivation

Different results of the two groups: hotQCD $\leftrightarrow$ Wuppertal-Budapest

$\Rightarrow$ calculations closer to the continuum are necessary, i.e.

go to larger N_τ and/or improve action

NEW RESULTS

- asqtad action for $N_\tau = 12$ (larger N_τ)
- HISQ action for $N_\tau = 8$ (more improved action)
- in addition: asqtad action for $N_\tau = 8$ for $m_l = 0.05m_s$

Outline

Topics covered by this talk:

- Chiral properties of QCD thermodynamics
  - (Subtracted) chiral condensate
  - Connected and disconnected chiral susceptibility
- Renormalized Polyakov loop, strange quark number susceptibility
- T_c: continuum extrapolation
- QCD Equation of State

See also talk by A. Bazavov for the hotQCD collaboration

Taste symmetry and QCD thermodynamics with improved staggered fermions

Numerical Details

Data Overview

- p4fat3: $N_\tau = 4, 6, 8 \quad \frac{m_l}{m_s} = \ldots, 0.2, 0.1, 0.05$
- asqtad: $N_\tau = 4, 6, 8, 12 \quad \frac{m_l}{m_s} = \ldots, 0.2, 0.1, 0.05$
- hisq: $N_\tau = 6, 8 \quad \frac{m_l}{m_s} = 0.2, 0.05$

Scale Setting and LCP

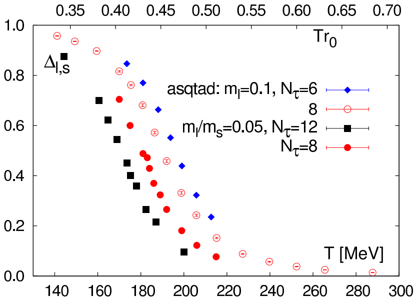
- Scale is set by $r_1 = 0.318\mathrm{fm}$ $(0.3117\mathrm{fm})$, $r_0 = 0.469\mathrm{fm}$
- Line of constant physics (LCP): set strange quark mass m_s to physical value, keep $\frac{m_l}{m_s}$ fixed

Thanks to

supercomputing centers at Brookhaven (BNL), Jülich, Livermoore (LLNL)

(Subtracted) Chiral Condensate

Preliminary



Definition: $\Delta_{l,s} = \dfrac{\langle\bar\psi\psi\rangle_{l,\tau} - \frac{\hat m_l}{\hat m_s}\langle\bar\psi\psi\rangle_{s,\tau}}{\langle\bar\psi\psi\rangle_{l,0} - \frac{\hat m_l}{\hat m_s}\langle\bar\psi\psi\rangle_{s,0}}$

- combination: cancel add. renormalization
- normalization by $T = 0$: cancel mult. renormalization factors

Details

- sharp drop in $\Delta_{l,s}$ for $m_l = 0.1 m_s$ and $m_l = 0.05 m_s$
- $N_\tau = 12 \rightarrow$ shift towards lower temperature

(Subtracted) Chiral Condensate

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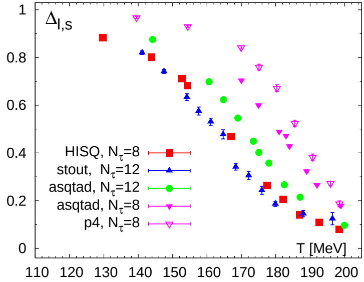

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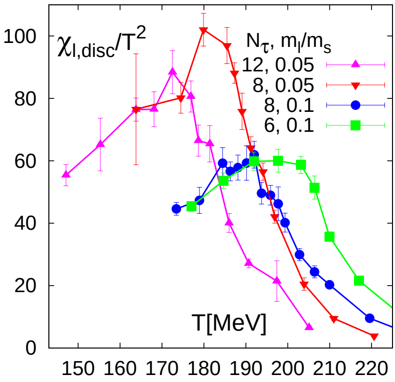
Disconnected Chiral Susceptibility

Preliminary



Asqtad action

(Full) chiral susceptibility

$$\chi_{m,l} \equiv \chi_{l,disc} + 2\chi_{l,con}$$

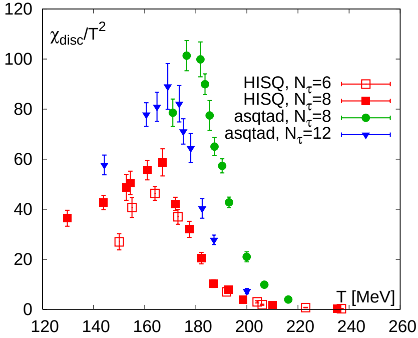
- peak location related to singular part of partition function: $\chi_{m,l} \equiv \frac{T}{V}\frac{\partial^2}{\partial m_l^2} \ln Z$
- pseudo-critical temperature $T_{m,l}$ chiral limit $\rightarrow \chi_{m,l}(T_{m,l}) \sim m_l^{\frac{1}{\delta}-1}$

Disconn. chiral susceptibility $\chi_{l,disc}$

- dominated by singular part in partition function (in chiral limit)
- T_c determination

Disconnected Chiral Susceptibility

Preliminary



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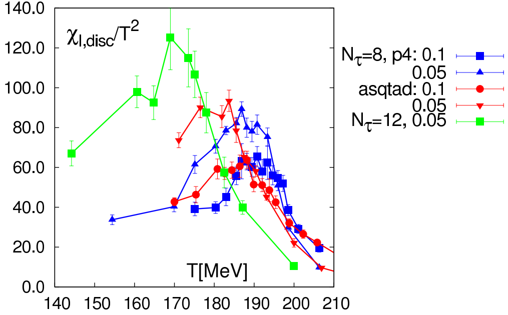
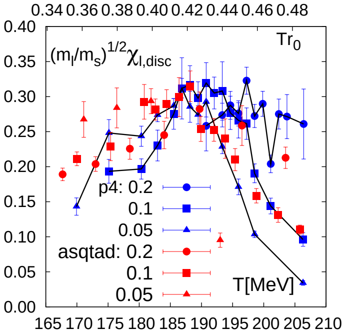




Expected behavior $\sim \frac{1}{\sqrt{m}}$ ($\rightarrow$ due to Goldstone modes)

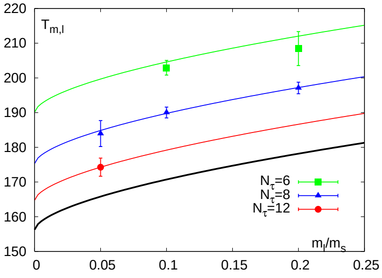
T_c: continuum extrapolation I

Procedure

- find peak position in disconnected chiral susceptibility
- data set: Asqtad action
  $N_\tau = 6$ $(\frac{m_l}{m_s} = 0.2, 0.1)$
  $N_\tau = 8$ $(\frac{m_l}{m_s} = 0.2, 0.1, 0.05)$
  $N_\tau = 12$ $(\frac{m_l}{m_s} = 0.05)$
- different ansätze for fitting function of peak position, e.g.
  $\chi_{l,disc} = c_0 + c_2(T - T_p)^2 + c_3(T - T_p)^3$
  $\chi_{l,disc} = c_0 + c_2(T - T_p) + c_3\sqrt{(T - T_p)^2 + c_4^2}$
  $\rightarrow$ asymmetric peak shape
  $\rightarrow$ systematic error

T_c: continuum extrapolation II

Preliminary



Details

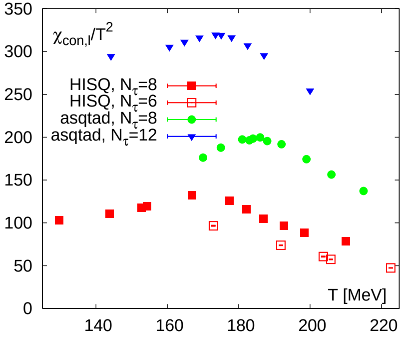
- Ansatz for mass and N_τ dependence: $T_c = a + b(\frac{m_l}{m_s})^d + c\frac{1}{N_\tau^2}$ $\rightarrow$ using critical exponent $d \approx 1.08$ from $\mathrm{O}(N)$ model
- stable fit (when omitting $N_\tau = 4$ data)

$\Rightarrow$ continuum extrapolated T_c at physical mass parameter $\frac{m_l}{m_s} = \frac{1}{27}$:

(preliminary) $T_c = 164 \pm 6\ \mathrm{MeV}$ (stat. and syst.)

Connected Chiral Susceptibility

Preliminary



Details: $\chi_{l,con}$

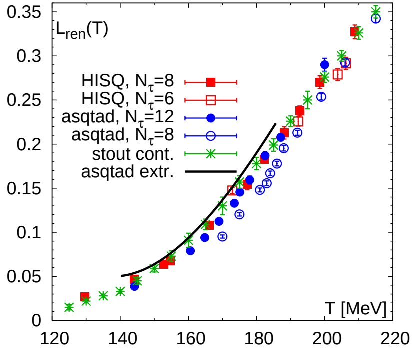
- related to scalar, non-singlet screening mass
  $\rightarrow$ thermal properties of medium
- Note: $\mathrm{U}_A(1)$ becomes effectively restored at $T > T_c(chiral)$

$\chi_{l,con}$ peak position at $T > T_c(chiral)$

$$\chi_{l,con} \equiv \frac{1}{4} \sum_x \left\langle D_l^{-1}(x,0) D_l^{-1}(0,x) \right\rangle$$

Renormalized Polyakov Loop

Preliminary



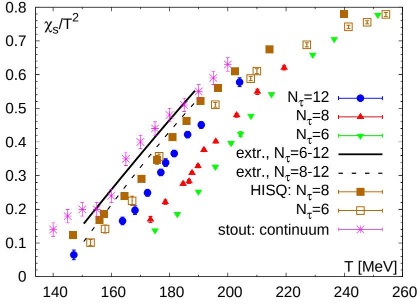
Details: Polyakov loop

- indicator of the deconfinement transition
- rapid rise in the transition region
  $\longrightarrow$ screening of color charges
- good agreement of different actions with different N_τ

$$L_{ren}(\vec{x}) = Z_r \, \frac{1}{3} \mathrm{Tr} \prod_{x_0=1}^{N_\tau} U_0(x_0, \vec{x})$$

Strange Quark Number Susceptibility

Preliminary



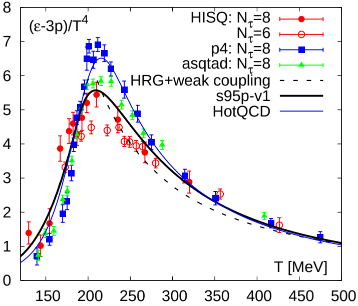
$$\frac{\chi_s}{T^2} \equiv \frac{1}{VT^3} \frac{\partial^2 \ln Z}{\partial(\mu_s/T)^2}$$

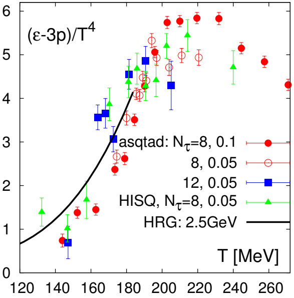
Details: χ_s(T)

- indicator of the deconfinement transition
- rapid rise in the transition region $\rightarrow$ liberation of degrees of freedom
- dependence on the action and N_τ visible
- chiral symmetry restoration and deconfinement appear at about the same temperature

Equation of State

Preliminary





QCD Lattice EoS

- left panel: data for $\frac{m_l}{m_s} = 0.1 \Rightarrow$ smooth parameterization available
- right panel: EoS at low T
  $\Rightarrow$ qualitative agreement, still more work needs to be done!

Summary

New Data

- asqtad action for $N_\tau = 12$ (larger N_τ)
- HISQ action for $N_\tau = 8$ (more improved action)
- in addition: asqtad action for $N_\tau = 8$ for $m_l = 0.05 m_s$

Chiral Aspects

- T_c continuum extrapolation from disconnected chiral susceptibility
  $\rightarrow$ at physical point (preliminary) $T_c = 164 \pm 6\ \mathrm{MeV}$ (stat. and syst.)
- Goldstone modes: $\sim 1/\sqrt{m}$ in disconnected chiral susceptibility
- connected chiral susceptibility: peak position at $T > T_c(chiral)$
- chiral symmetry restoration and deconfinement appear at about the same temperature

Equation of State: Updated with new data

- good qualitative agreement, but more work needs to be done!