Critical endline of the finite temperature phase transition for 2+1 flavor QCD around the SU(3)-flavor symmetric point

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Motivation

- the critical endline at zero chemical potential for small quark mass region has not determined

Taylor expansion of kurtosis at critical endpoint around \( m^{\text{sym}} (=m_1=m_s) \)

\[ K_E + c(\delta m_u + \delta m_d + \delta m_s) + O(\delta m^2) \]

when changing quark mass as \( \delta m_s = -2\delta m_1 \), \( K_E \) remains unchanged up to \( O(\delta m^2) \)

So, slope for the critical endline at \( m^{\text{sym}} \) should be - 2

- we determine the critical endline around \( m^{\text{sym}} \) with clover fermions

[Laermann, Philipsen, '03]
Previous study with staggered fermions

$N_T = 4$, $a \approx 0.3$ fm

- data exhibits that slope at $m_{sym}$ is not -2

- $am_{s}^{crit} \approx 0.7$ (roughly 5 times larger than $m_{s}^{phy}$)

[de Forcrand, Philipsen, '06]
Simulations

- Iwasaki gauge + NP O(a) improved Wilson fermions
- chiral condensate (10 - 20 noises for $\text{Tr}D^{-1,-2,-3,-4}$)
- kurtosis intersection method to determine the critical endpoint
- reweighting method to obtain more critical endpoints
- $N_t = 6 \ (a \approx 0.19\text{fm})$
- $N_l = 10, 16, 20, 24$

<table>
<thead>
<tr>
<th>$\beta$</th>
<th>$\kappa$</th>
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</thead>
<tbody>
<tr>
<td>1.715</td>
<td>0.140900 – 0.141100</td>
</tr>
<tr>
<td>1.73</td>
<td>0.140420 – 0.140450</td>
</tr>
<tr>
<td>1.75</td>
<td>0.139620 – 0.139700</td>
</tr>
</tbody>
</table>
Susceptibility and kurtosis

\[ \beta = 1.715 \]

\[ \kappa_s = 0.14170, N_L = 10 \]
\[ \kappa_s = 0.14170, N_L = 16 \]

\[ \beta = 1.73 \]

\[ \kappa_s = 0.14070, N_L = 10 \]
\[ \kappa_s = 0.14070, N_L = 24 \]

\[ \kappa_s \uparrow \]
\[ \kappa_s = 0.1417 \]
\[ \kappa_s = 0.1407 \]
\[ \kappa_s = 0.1391 \]
Kurtosis intersection plot

$K_S = 0.1391$

$K_S = 0.1407$

$K_S = 0.1417$

fit : $K_E + aN_{l}^{1/\nu} (\beta - \beta_E)$
Critical endpoints in bare parameter plane

\[ \frac{1}{\kappa} \]

\[ s \]

\[ \frac{1}{\kappa} l \]

Endpoints had. spec. measured

\[ -\frac{2}{\kappa_1} + \frac{3}{0.1407} \]

\[ -\frac{2}{\kappa_1} + \frac{3}{0.1405} \]

\[ N_f = 3 \]
Critical endline

polynomial fits with slope -2 at \( m_{\text{sym}} \)

- \( \chi^2/\text{d.o.f.} \approx 1 \)
- positive 2nd derivative

(cf. \( 1/\sqrt{t_0} = 1.347(30) \) GeV [Borsanyi et al. '12])
Critical endpoints away from $m^{\text{sym}}$(preliminary)

We have determined the critical endpoints (black points) by using $N_f = 3$ configurations.

We are doing same analysis by using $N_f = 2 + 1$ configurations, so far only transition points at $N_f = 10$ are determined.

Question: $m_s - m_s^{\text{tric}} \sim m_1^{2/5}$? 

[Rajagopal '95]
Summary

We have determined the critical endline around the SU(3)-flavor symmetric point at $N_t = 6$ with NP O(a) improved Wilson fermions

- we have confirmed slope -2 of the critical endline at symmetric point
- we have found positive 2nd derivative of the critical endline at symmetric point

Future plans

- critical endpoints away from symmetric point
- larger $N_t$ for the continuum limit
Backup slides
CEP at $N_T = 6$
CEP at $N_T = 8$
CEP at $N_T = 10$ (preliminary)
$N_f = 3$
const $m_s/m_l$
physical point