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

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(arXiv:1605.04659)

3 Aug. 2016

XQCD 2016 in Plymouth

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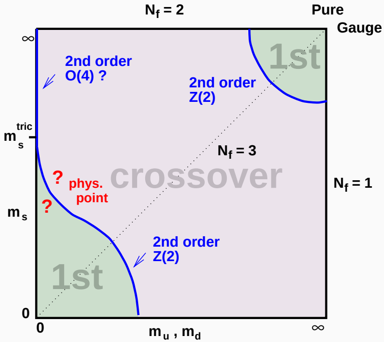
Motivation

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



[Laermann, Philipsen, '03]

Taylor expansion of kurtosis at critical endpoint around m^{sym} $(= m_{\mathrm{l}} = m_{\mathrm{s}})$

$$K_E + c(\delta m_{\mathrm{u}} + \delta m_{\mathrm{d}} + \delta m_{\mathrm{s}}) + O(\delta m^2)$$

when changing quark mass as $\delta m_{\mathrm{s}} = -2\delta m_{\mathrm{l}}$, K_E remains unchanged up to $O(\delta m^2)$

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

- we determine the critical endline around m^{sym} with clover fermions

Slope -2 for the critical endline at sym. point

- Taylor expansion of flavor symmetric operator at symmetric point $m_u = m_d = m_s = \bar{m}$

$$\mathcal{O}(\delta m_u, \delta m_d, \delta m_s) = \mathcal{O}(\bar{m}, \bar{m}, \bar{m}) + c(\delta m_u + \delta m_d + \delta m_s) + O(\delta m_q^2)$$

where $\delta m_i = m_i - \bar{m}$ and

$$c = \frac{\partial \mathcal{O}(\bar{m}, \bar{m}, \bar{m})}{\partial m_u} = \frac{\partial \mathcal{O}(\bar{m}, \bar{m}, \bar{m})}{\partial m_d} = \frac{\partial \mathcal{O}(\bar{m}, \bar{m}, \bar{m})}{\partial m_s}$$

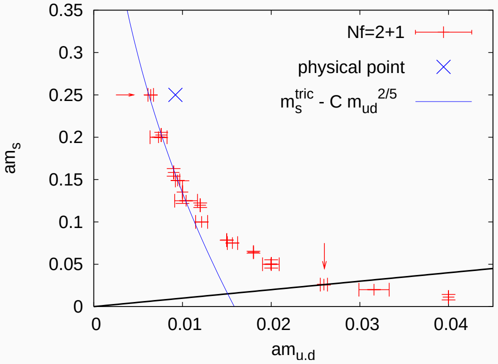
- changing $\delta m_u + \delta m_d + \delta m_s = 0$ ($\delta m_s = -2\delta m_l$)

$$\mathcal{O}(\delta m_u, \delta m_d, \delta m_s) = \mathcal{O}(\bar{m}, \bar{m}, \bar{m}) + O(\delta m_q^2)$$

- χ, S, K with $\delta m_s = -2\delta m_l$

$$\chi(\bar{m}, \bar{m}, \bar{m}) = \chi(\delta m_u, \delta m_d, \delta m_s) + O(\delta m_q^2)$$
$$S(\bar{m}, \bar{m}, \bar{m}) = S(\delta m_u, \delta m_d, \delta m_s) + O(\delta m_q^2)$$
$$K(\bar{m}, \bar{m}, \bar{m}) = K(\delta m_u, \delta m_d, \delta m_s) + O(\delta m_q^2)$$

Previous study with staggered fermions



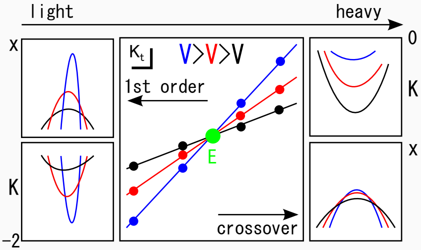
[de Forcrand, Philipsen, ’06]

- $N_T = 4$, $a \approx 0.3$ 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})

Simulations

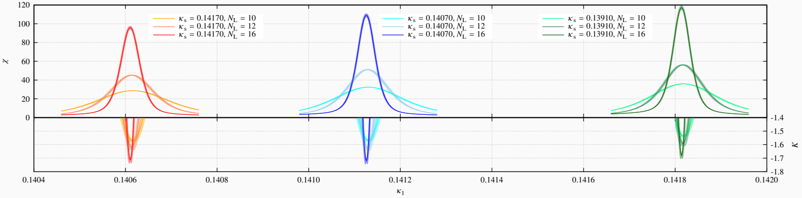
- Iwasaki gauge + NP O(a) improved Wilson fermions
- chiral condensate (10 - 20 noises for $\mathrm{Tr}D^{-1,-2.-3,-4}$)
- kurtosis intersection method to determine the critical endpoint
- reweighting method to obtain more critical endpoints
- $N_t = 6$ ($a \approx 0.19$fm)
- $N_l = 10, 16, 20, 24$

β	κ
1.715	0.140900 – 0.141100
1.73	0.140420 – 0.140450
1.75	0.139620 – 0.139700

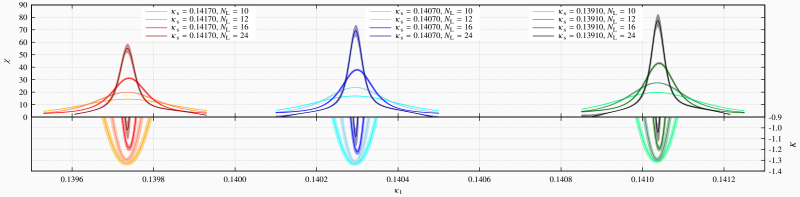


Susceptibility and kurtosis

$\beta = 1.715$



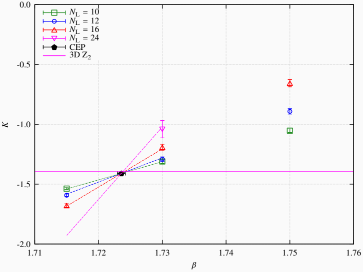
$\beta = 1.73$



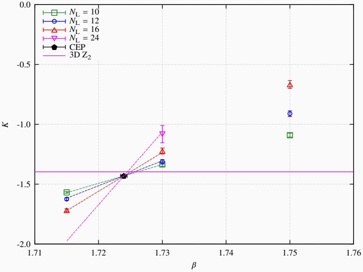
↑ $\kappa_s = 0.1417$ ↑ $\kappa_s = 0.1407$ ↑ $\kappa_s = 0.1391$

Kurtosis intersection plot

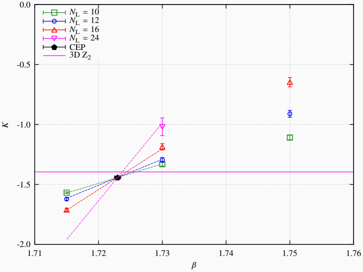
$\kappa_s = 0.1391$



$\kappa_s = 0.1407$

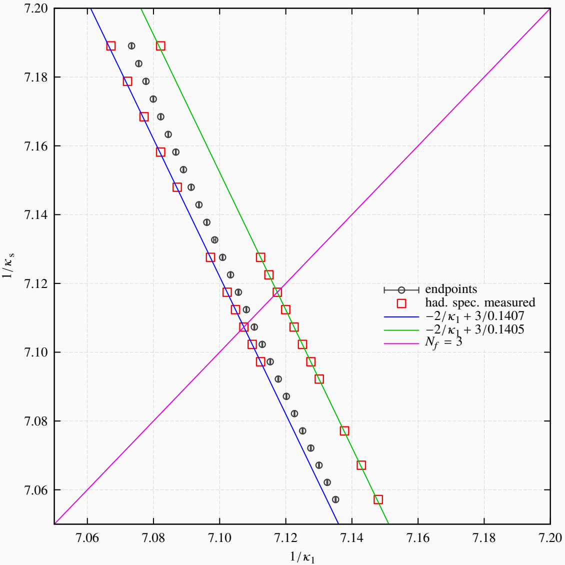


$\kappa_s = 0.1417$

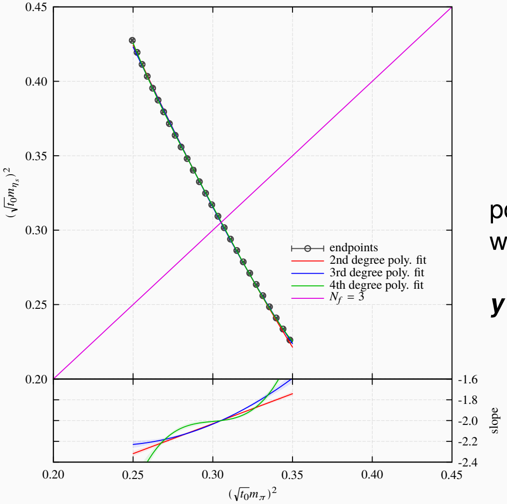


fit : $K_{\mathrm{E}} + aN_l^{1/\nu}(\beta - \beta_{\mathrm{E}})$

Critical endpoints in bare parameter plane



Critical endline



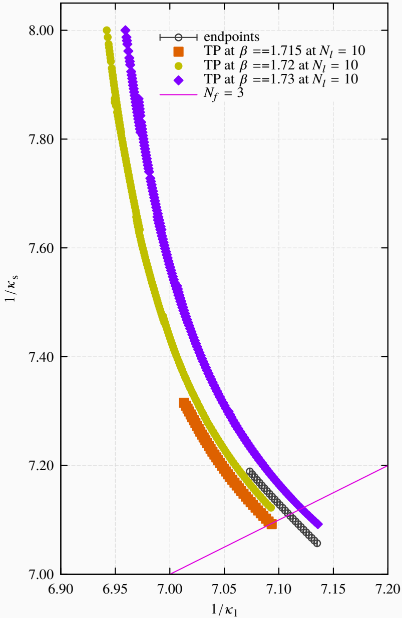
polynomial fits
with slope -2 at m^{sym}

$$y = c - 2(x-c) + a_1(x-c)^2$$

- χ^2/d.o.f. $\sim$ **1**
- positive 2nd derivative

(cf. $\mathbf{1/\sqrt{t_0} = 1.347(30)}$ GeV [Borsanyi et al. '12])

Critical endpoints away from m^{sym}(preliminary)



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

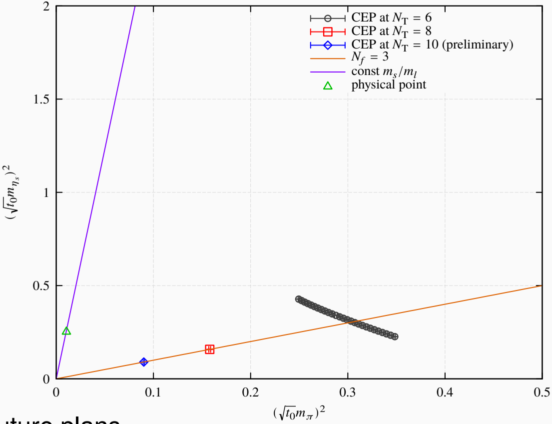
We are doing same analysis by using $N_f = 2 + 1$ configurations, so far only transition points at $N_t = 10$ are determined

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

[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



- confirmed slope -2
- found positive 2nd derivative

Future plans

- critical endpoints away from symmetric point
- larger N_t for the continuum limit