Continuum extrapolation of critical point for finite temperature QCD with N_f=3

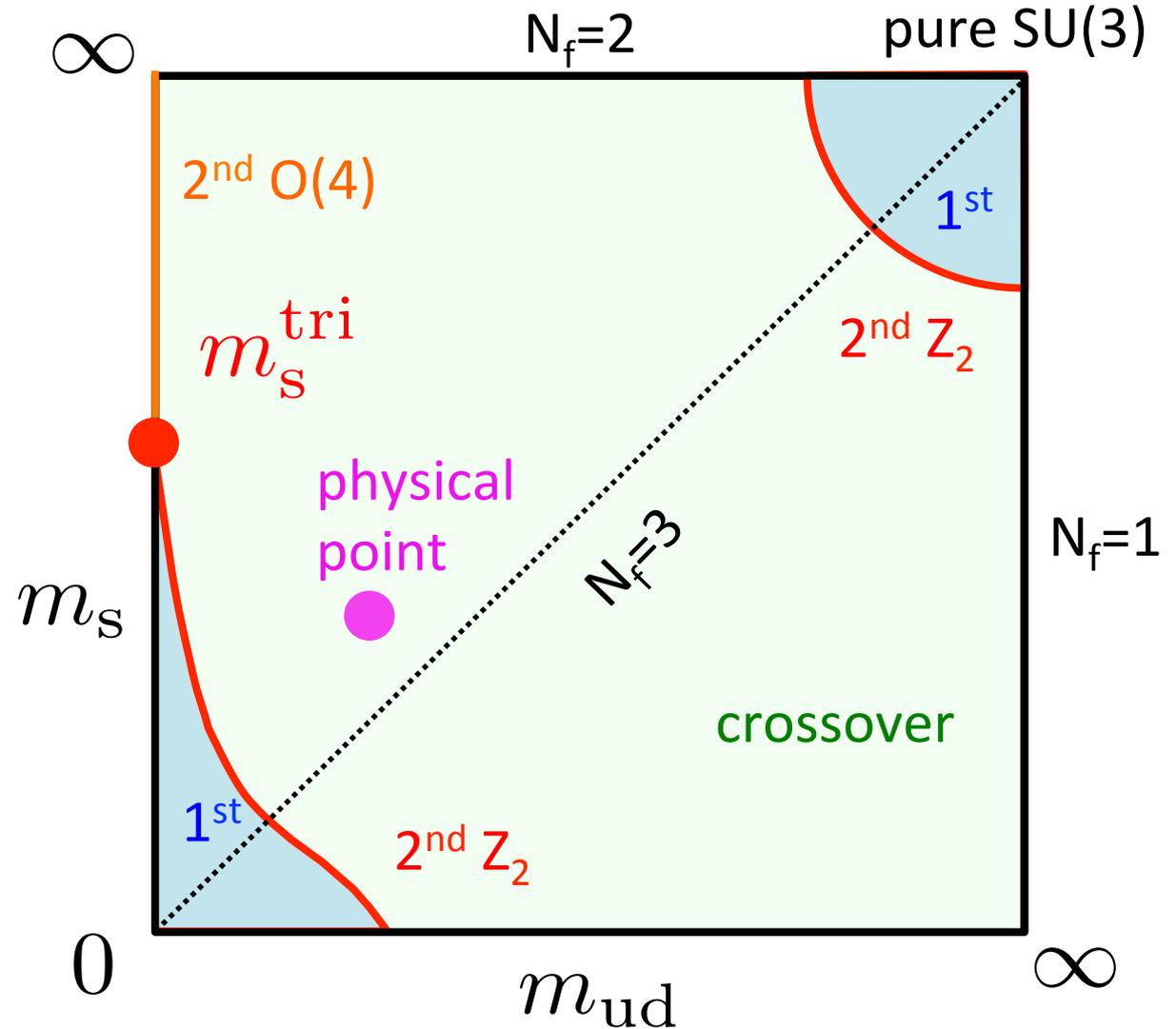arXiv:1706.01178

Shinji Takeda

(Kanazawa University)

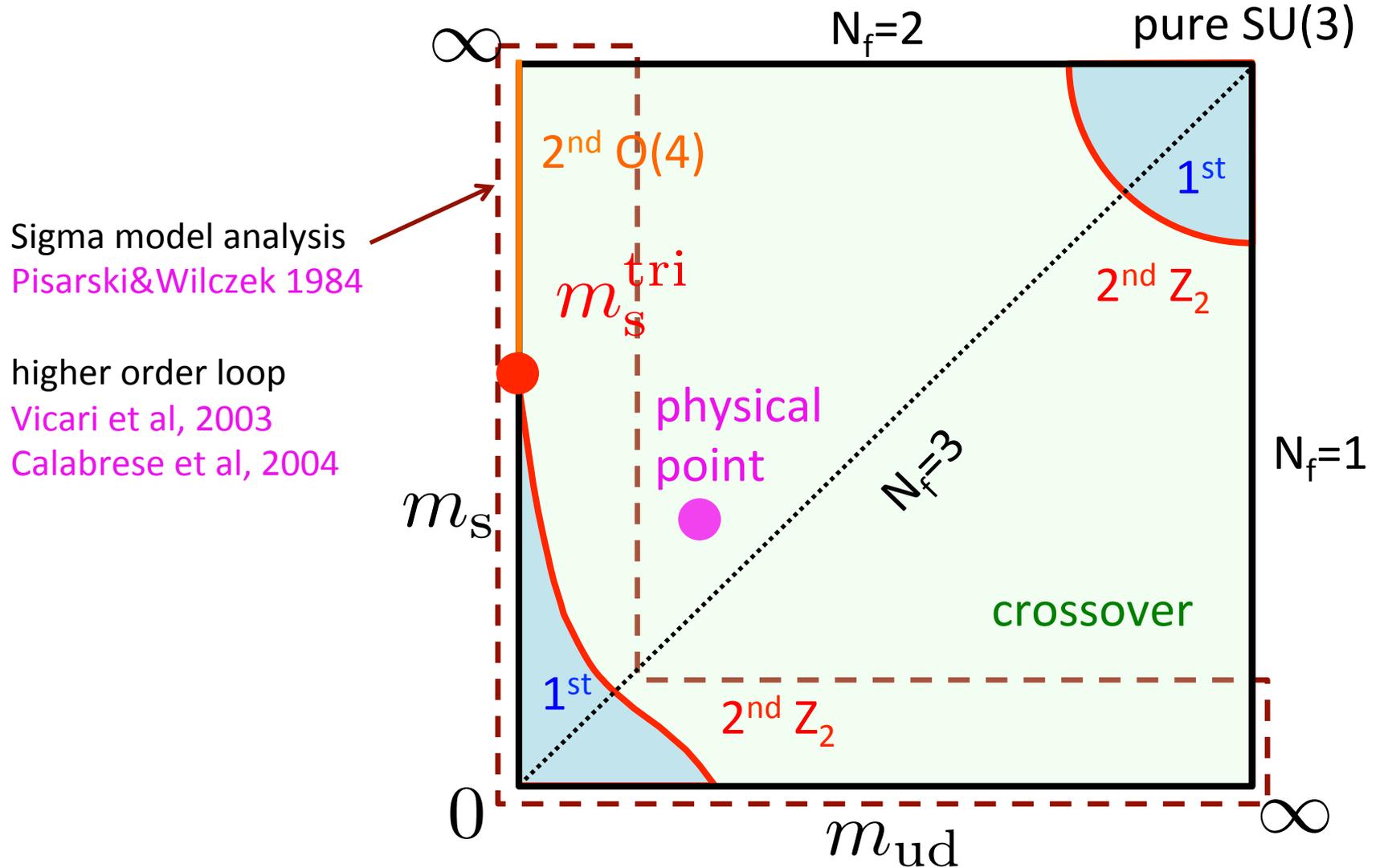in collaboration with

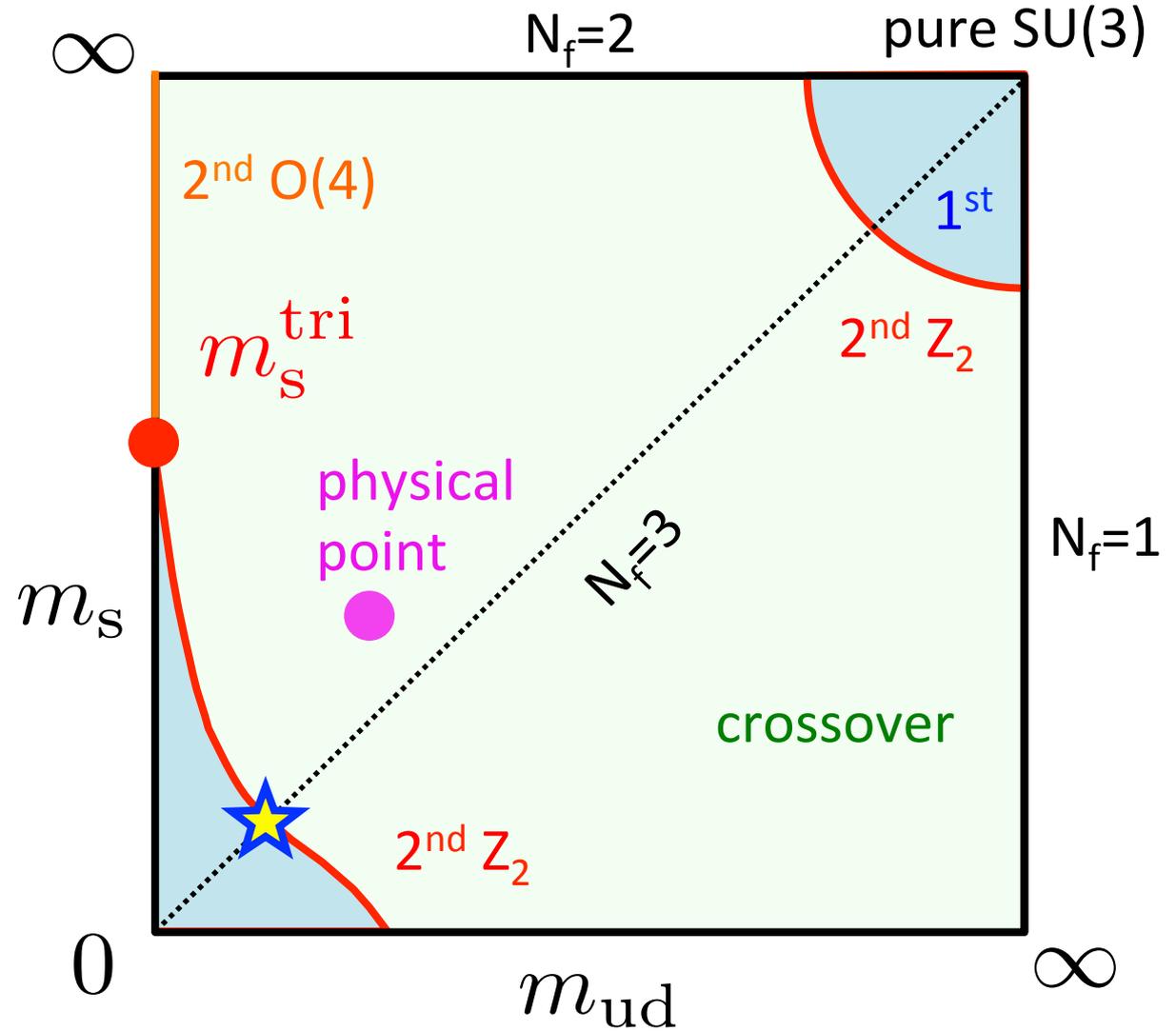X-Y. Jin, Y. Kuramashi, Y. Nakamura & A. Ukawa

Lattice 2017 in Granada

Columbia plot

Columbia plot


Sigma model analysis
Pisarski&Wilczek 1984

higher order loop
Vicari et al, 2003
Calabrese et al, 2004

$N_f=2$ pure SU(3)

2nd O(4)

1st

m_s^{tri}

2nd Z$_2$

physical
point

$N_f=3$

$N_f=1$

m_s

crossover

1st

2nd Z$_2$

0 m_{ud} ∞

∞

Columbia plot

History for N_f=3 QCD critical point

Action	N_t	$m_{\pi,critical}$	Ref.
KS, standard	4	290MeV	Karsch et al '01, Liao '01
KS, p4	4	67MeV	Karsch et al '04
KS, standard	6	150MeV	de Forcrand et al '07
KS, HISQ	6	$\lesssim$ 50MeV	Ding et al '17
KS, stout	4-6	could be 0	Varnhorst '14

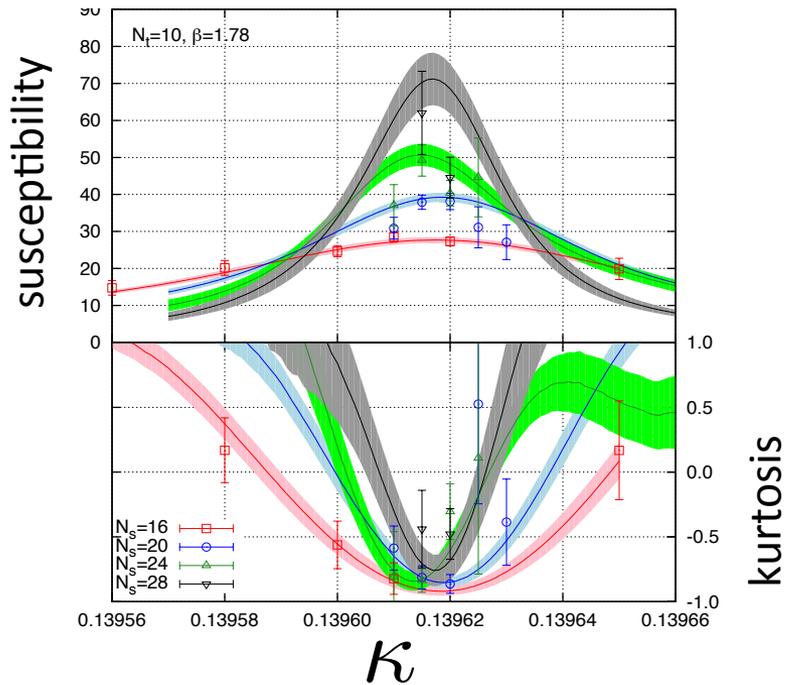| Wilson, standard	4	$\lesssim$ 670MeV	Iwasaki et al, '96
Wilson, O(a) impr.	6-8	300MeV	Nakamura et al, '14
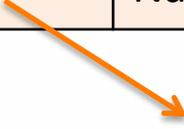
We will update it!

de Forcrand et al '16, Varnhost '14, Szabo '13

Our simulation details
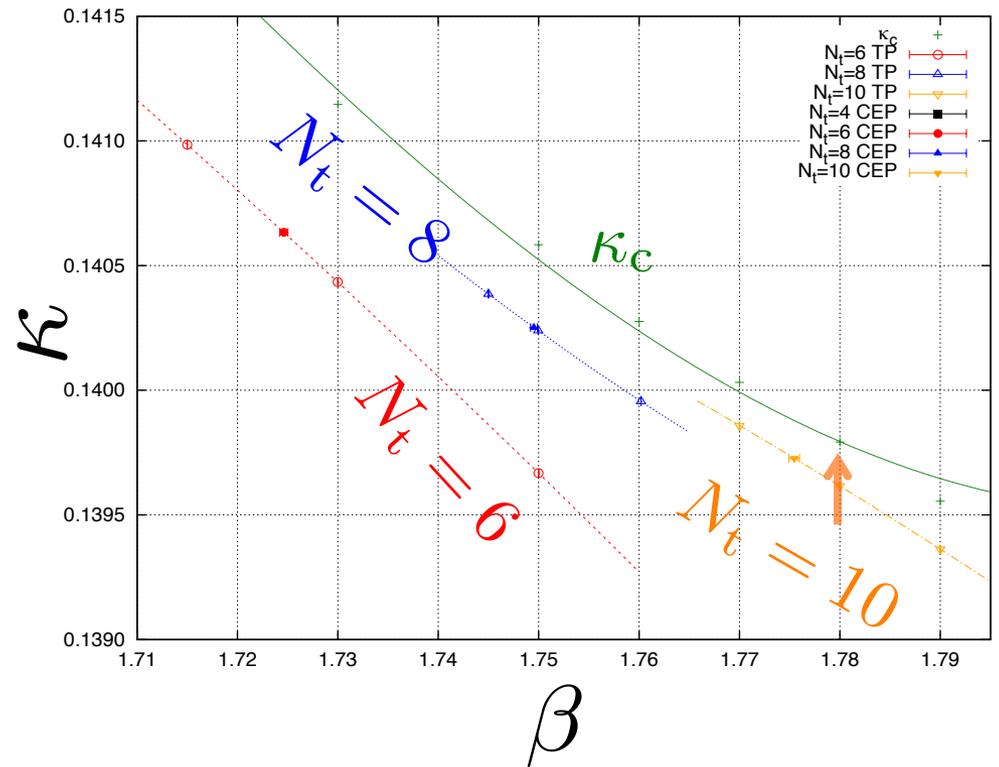
- Iwasaki gauge + NP O(a) improved Wilson

- N_t=4, 6, 8 and 10

- Kurtosis intersection to determine critical point

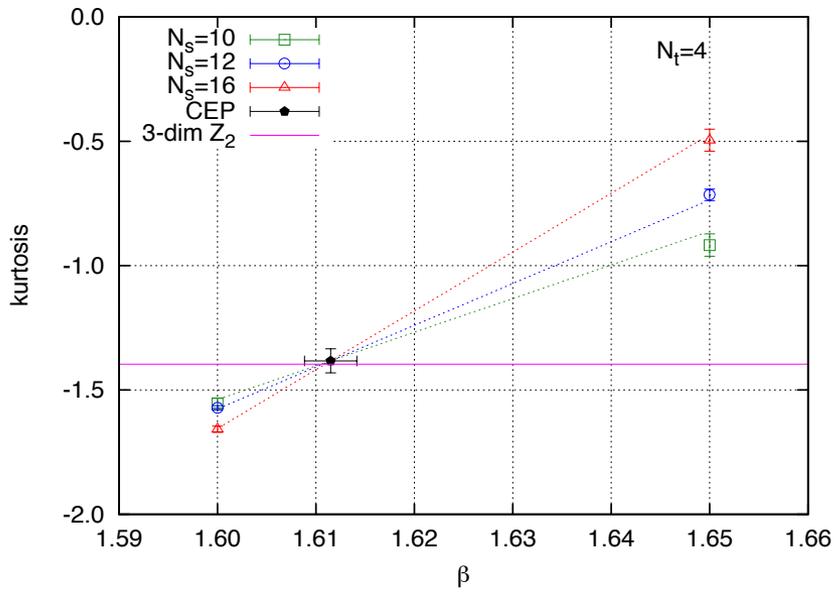- Chiral condensate as "order parameter"

Moments for chiral condensate
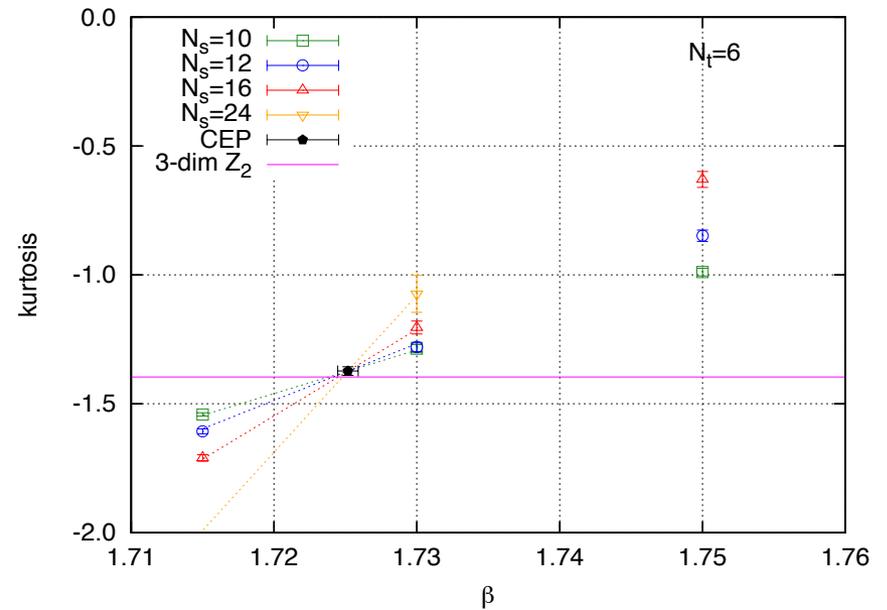

$N_{\mathrm{t}} = 10, \beta = 1.78$

$N_{\mathrm{s}} = 16 - 28$

Kurtosis intersection

$N_{\mathrm{t}} = 4$

$N_{\mathrm{t}} = 6$

$$K = K_{\mathrm{E}} + A N_{\mathrm{s}}^{1/\nu}(\beta - \beta_{\mathrm{E}})$$

Kurtosis intersection

$N_\mathrm{t} = 8$
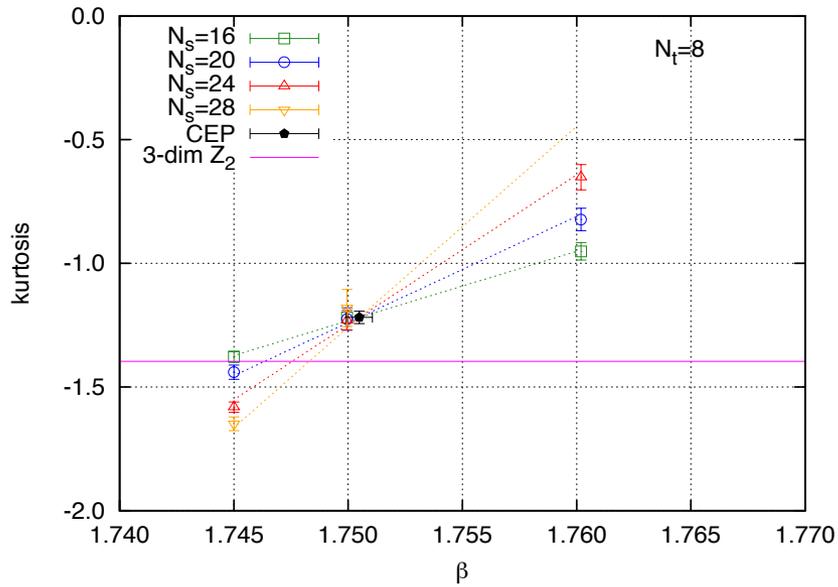
$N_\mathrm{t} = 10$
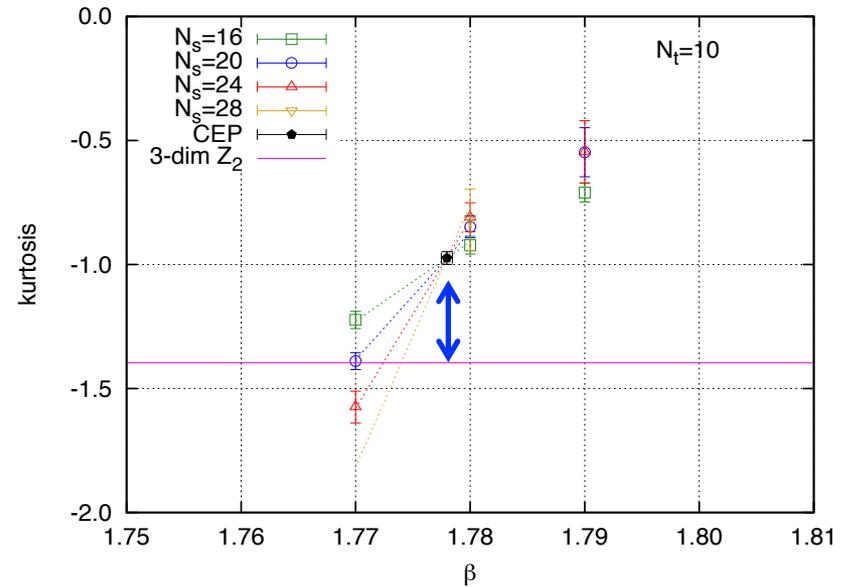
Due to finite size effect?

Fitting for kurtosis intersection

$$K = \left[K_{\mathrm{E}} + A N_{\mathrm{s}}^{1/\nu}(\beta - \beta_{\mathrm{E}}) \right] (1 + B N_{\mathrm{s}}^{-c})$$

Correction term of finite size effect

N_{t}	Fit	β_{E}	κ_{E}	K_{E}	ν	A	B	$y_{\mathrm{t}} - y_{\mathrm{h}}$	$\chi^2/\mathrm{d.o.f.}$
4	1	1.6115(26)	0.1429337(13)	−1.383(48)	0.84(13)	0.88(42)	×	×	1.75
	2	1.61065(61)	0.1429713(13)	−1.396	0.63	0.313(12)	×	×	3.05
	3	1.6099(17)	0.1430048(13)	−1.396	0.63	0.311(14)	0.10(21)	−0.894	3.77
6	1	1.72518(71)	0.1406129(14)	−1.373(17)	0.683(54)	0.58(17)	×	×	0.68
	2	1.72431(24)	0.1406451(14)	−1.396	0.63	0.418(11)	×	×	0.70
	3	1.72462(40)	0.1406334(14)	−1.396	0.63	0.422(12)	−0.052(52)	−0.894	0.70
8	1	1.75049(57)	0.1402234(11)	−1.219(25)	0.527(55)	0.146(88)	×	×	0.73
	2	1.74721(42)	0.14031921(76)	−1.396	0.63	0.404(36)	×	×	5.99
	3	1.74953(33)	0.1402512(10)	−1.396	0.63	0.414(13)	−1.33(15)	−0.894	0.73
10	1	1.77796(48)	0.1396661(17)	−0.974(25)	0.466(45)	0.084(52)	×	×	0.22
	2	1.7694(16)	0.1398724(22)	−1.396	0.63	0.421(95)	×	×	10.03
	3	1.77545(53)	0.1397274(17)	−1.396	0.63	0.559(29)	−2.97(25)	−0.894	0.43

Hadronic quantity at critical point

$N_{\mathrm{t}} = 10$
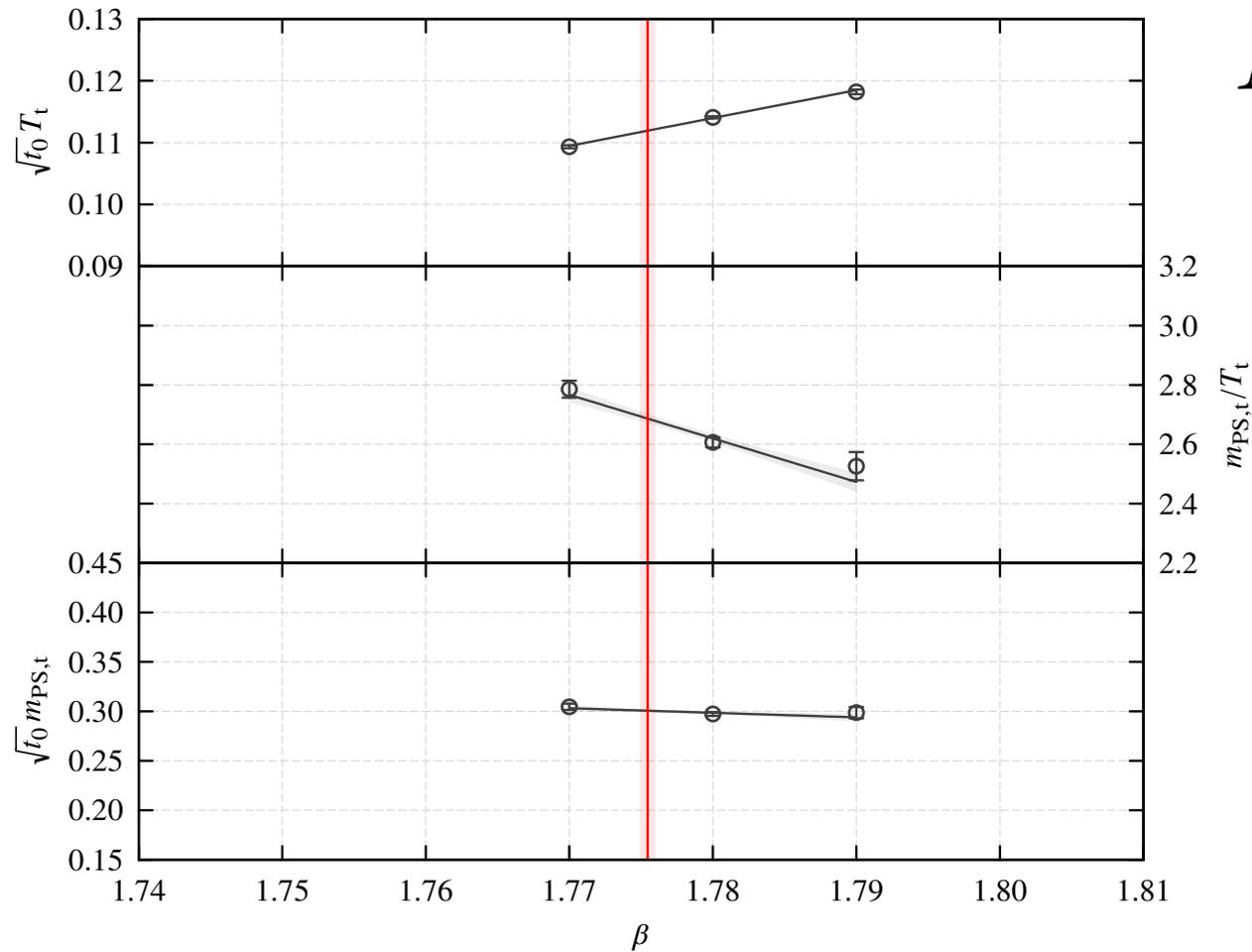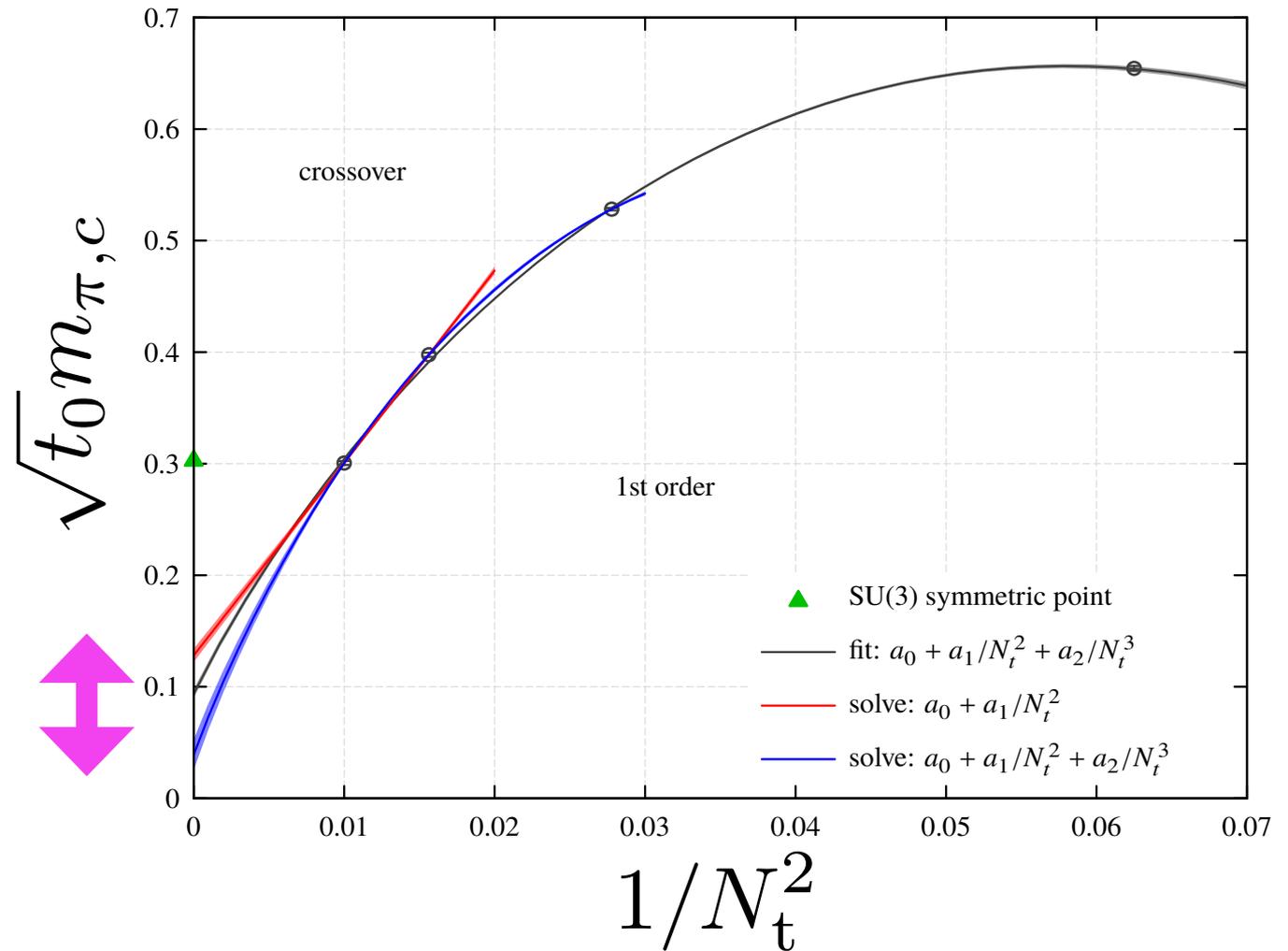
Continuum extrapolation
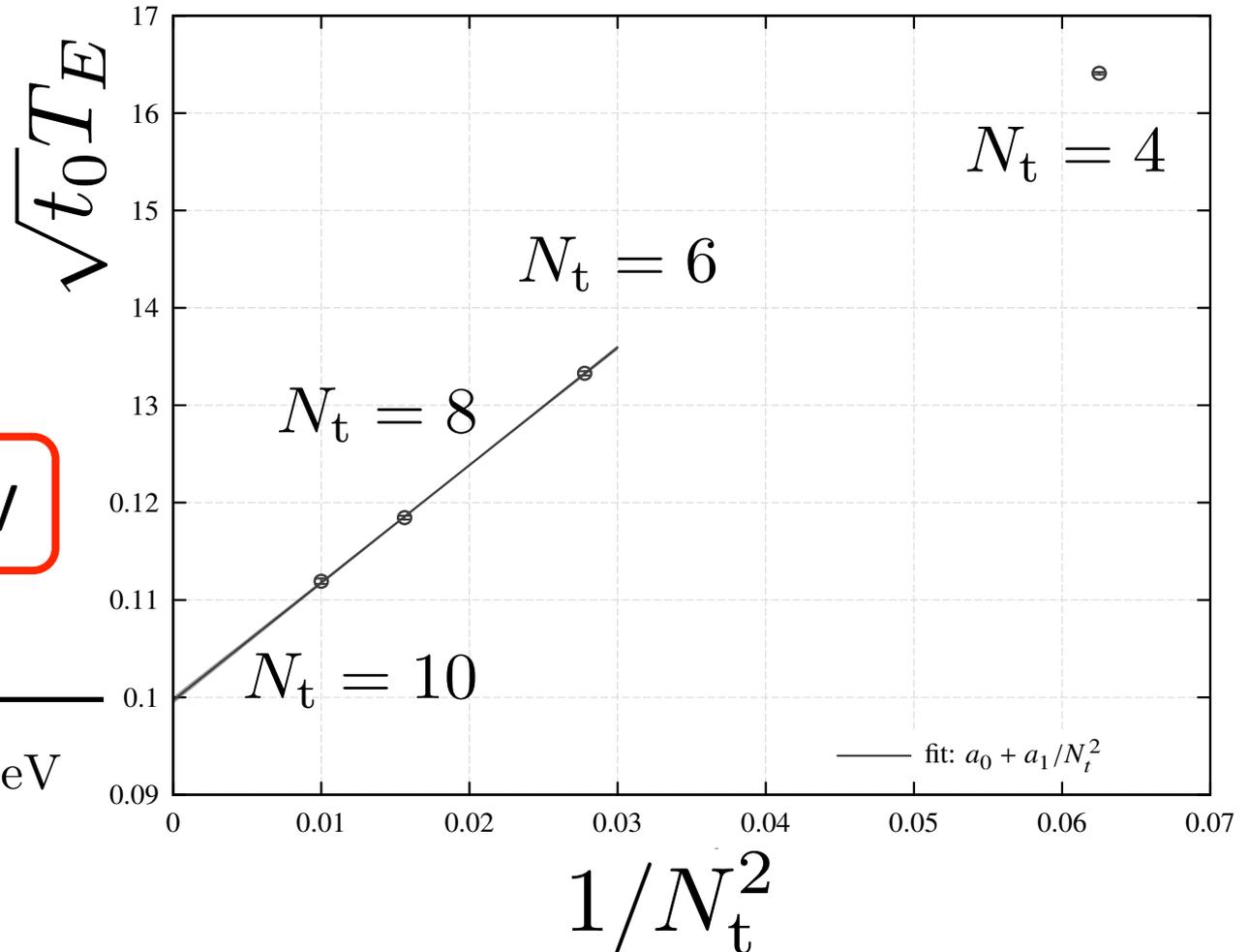
$T_E = 134(3)\text{MeV}$

$1/\sqrt{t_0} = 1347(30)\text{MeV}$

Borsanyi et al, 2012

Continuum extrapolation
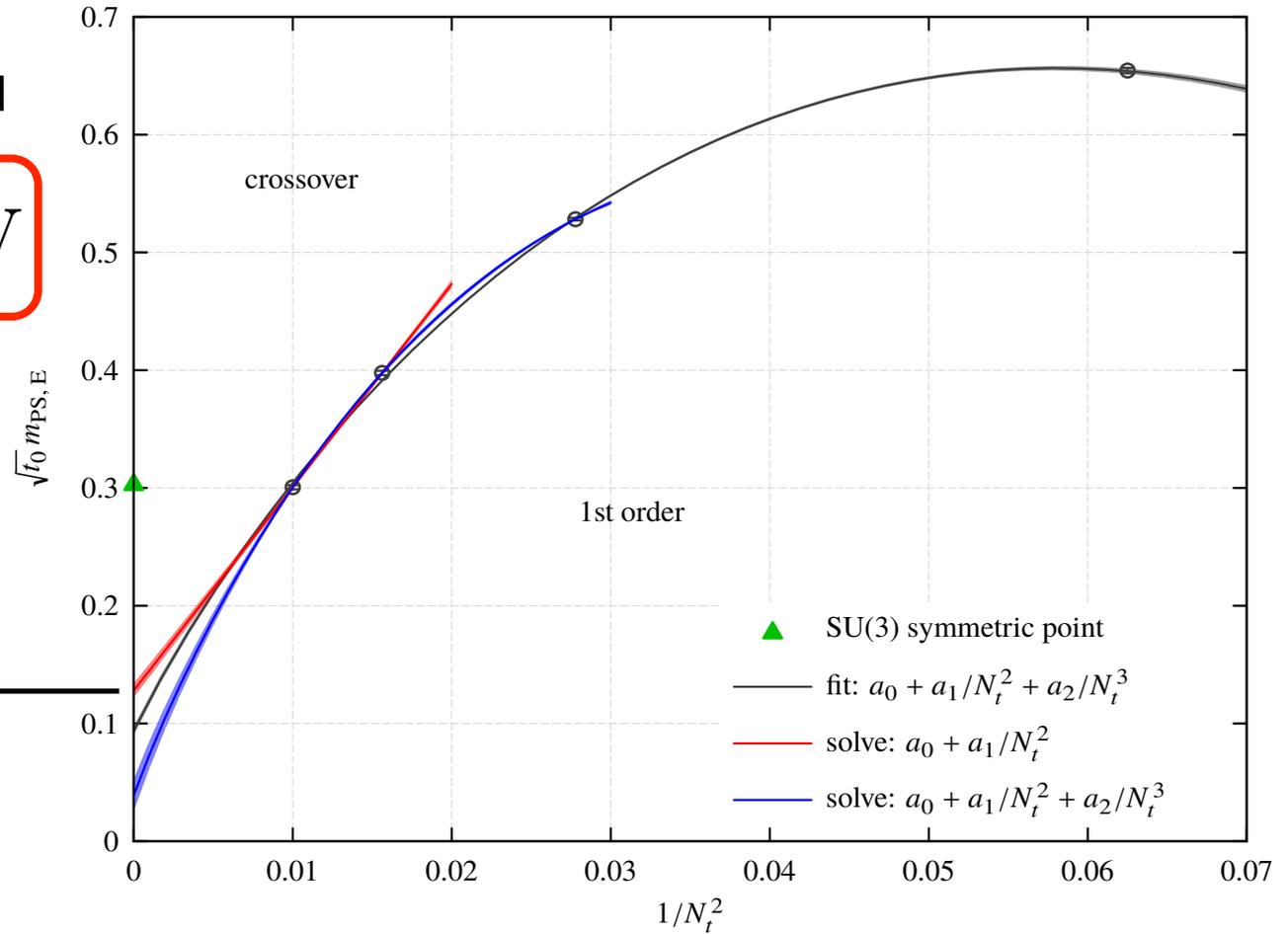
Continuum extrapolation

$$m_\pi^2 \propto m_{\mathrm{q}}$$

negative!
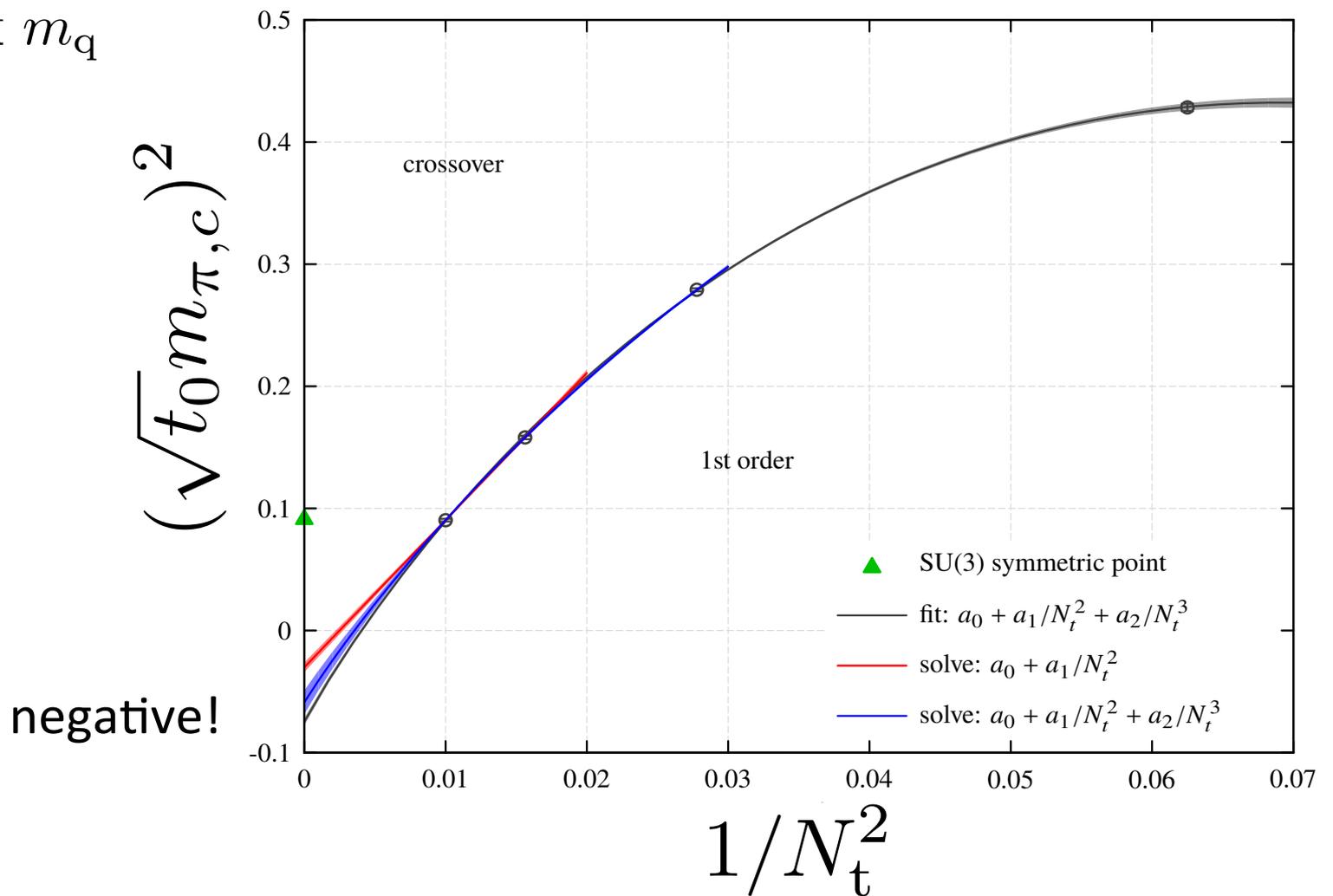
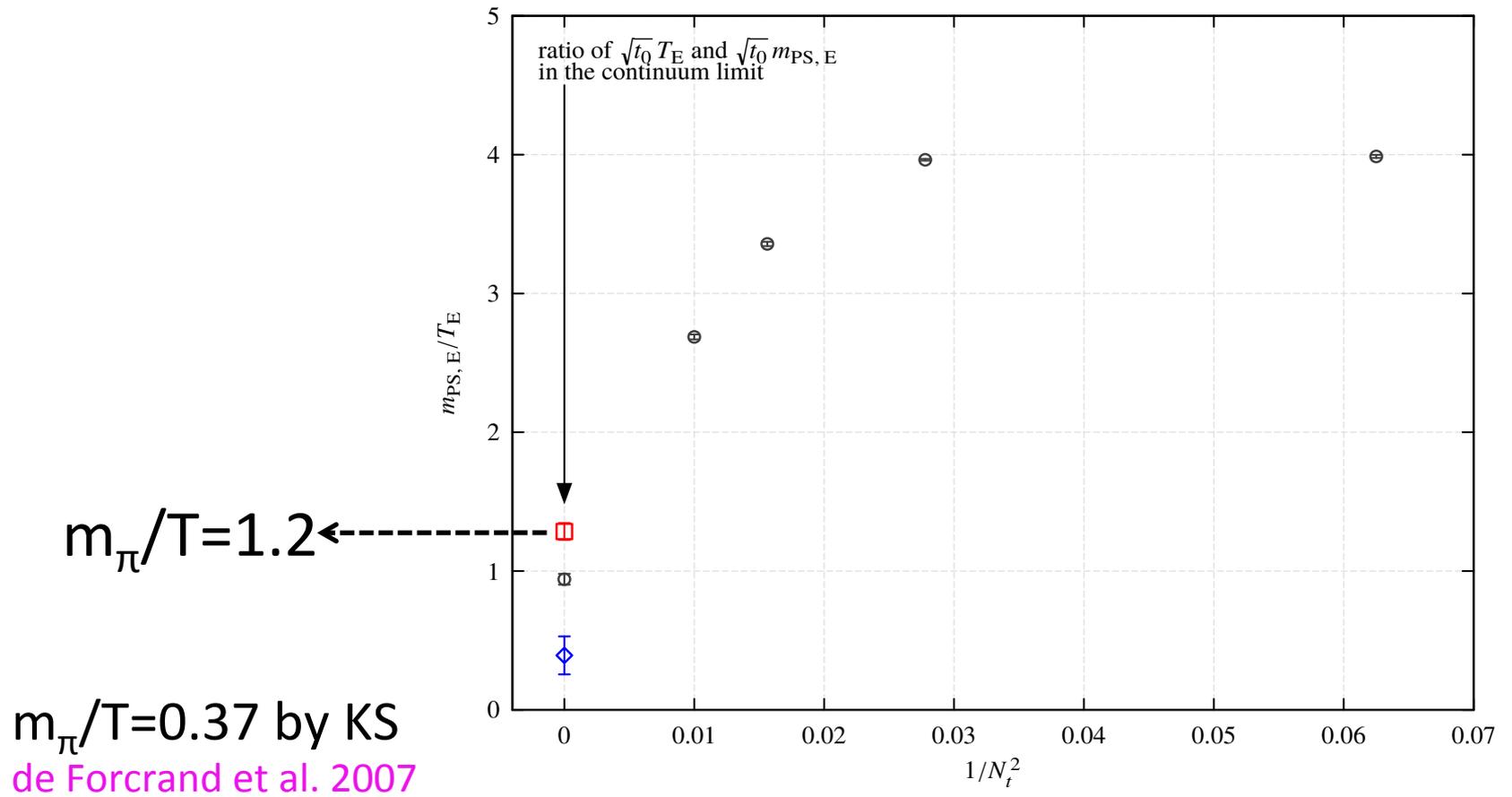# Continuum extrapolation

upper bound

$$m_{\pi,c} \lesssim 170\text{MeV}$$

Summary and outlook
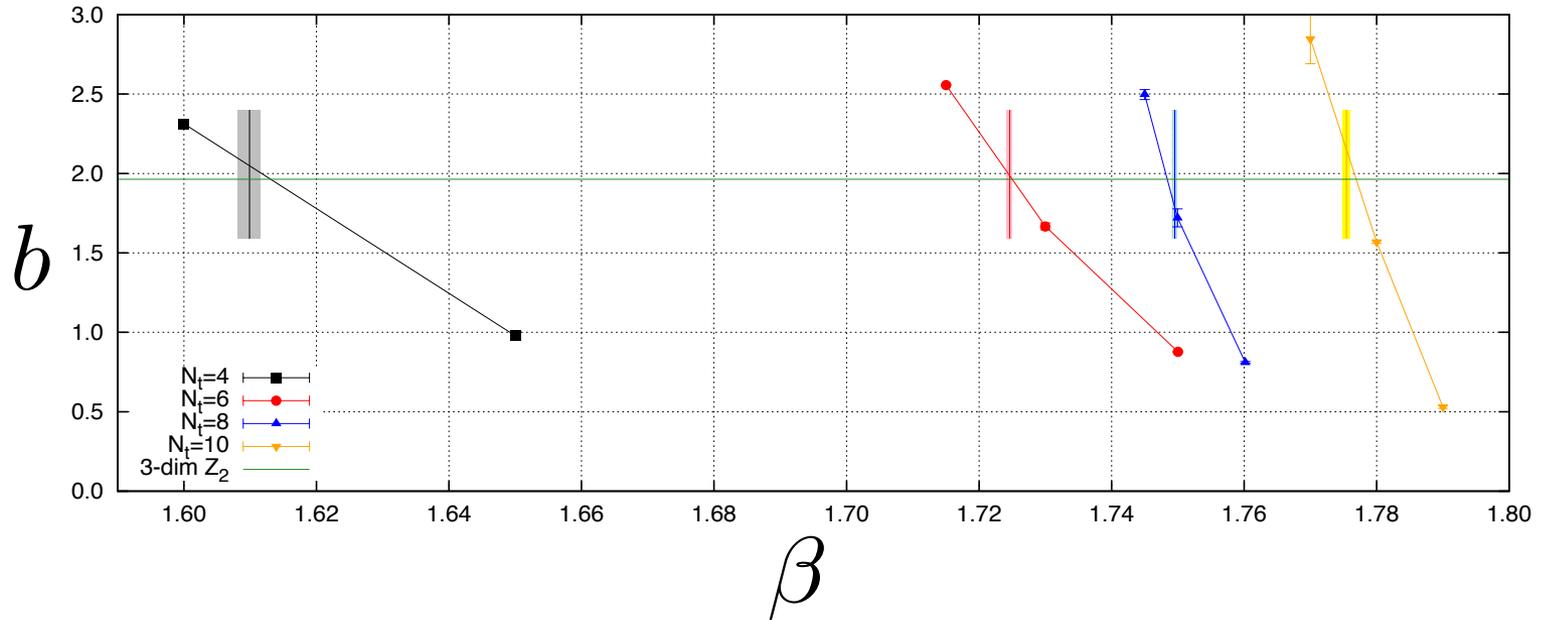
- Upper bound $m_\pi \lesssim 170$ MeV ($m_\pi \lesssim 50$ MeV by KS HISQ)

- Our estimate of the upper bound is derived from the existence of critical point as an edge of 1st order phase transition

- Further large N_t or some improvement are needed in future

- For critical line on Columbia plot, see the next talk by Nakamura

- Checking universality for N_f=4 QCD where no rooting issue, see Ohno's talk on 6/21

BACKUP SLIDES

Continuum extrapolation

ratio of $\sqrt{t_0}\,T_{\rm E}$ and $\sqrt{t_0}\,m_{\rm PS,\,E}$ in the continuum limit

$m_\pi/T = 1.2$

$m_\pi/T = 0.37$ by KS
de Forcrand et al. 2007

$$\chi_{\max} \propto N_{\mathrm{s}}^{b}$$

Exponent b along the transition line projected on β