QCD thermodynamics with N_f=3,2+1 near the continuum limit at realistic quark mass

~ status report ~

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Motivation

- The critical parameters of the QCD transition and EoS from first principle calculation (Lattice QCD)

  T_c, ε_c, phase diagram, small μ_B, etc...

- These are very important for Heavy Ion Phenomenology

  many phenomenological models based on the parameters from lattice QCD results

More accurate determination of these params. is required !

from recent studies
these results strongly depend on quark mass & N_f

Our aim is thermodynamics at almost realistic quark mass & N_f

(2+1)-flavor with, pion mass ~ 200MeV, kaon mass ~ 500MeV

Our Strategy

For "the almost realistic quark mass at N_f=2+1"
- pion mass ~ 200MeV, kaon mass ~ 500MeV

- Choice of quark action
  → Staggered type quark action
- huge computational resource is required
  → QCDOC machine, APE-Next machine
- continuum limit
  - Nt=4,6(,8) → a=0.2,0.16(,0.1)fm
  → improved action for reliable continuum limit with not so fine lattices

Our Computers

US/RBRC QCDOC

20.000.000.000.000 ops/sec

- critical temperature
- equation of state
- hadron properites in matter

BI – apeNEXT

5.000.000.000.000 ops/sec

today: 1.6 TFlops

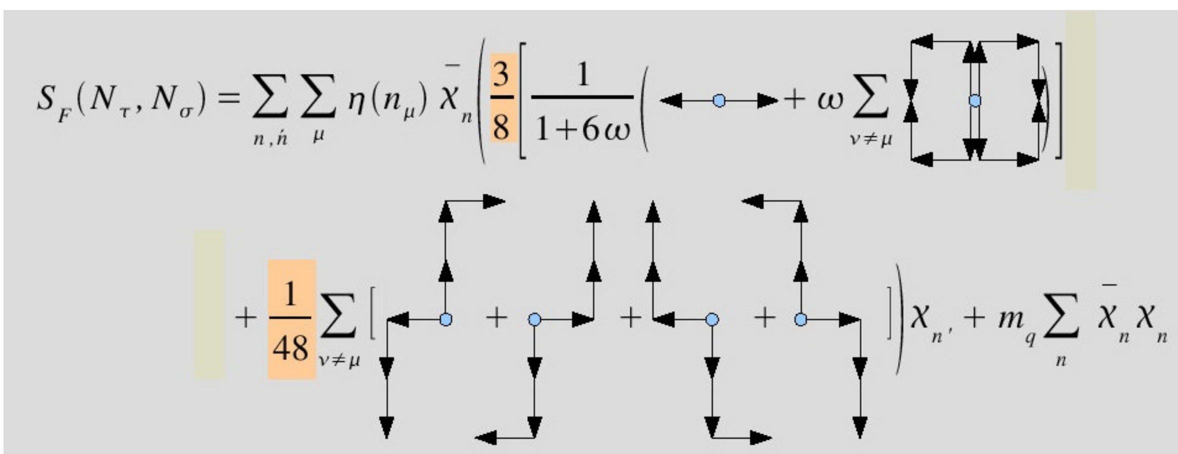
http://www.quark.phy.bnl/~hotqcd

Lattice Action

improved Staggered action : p4-action

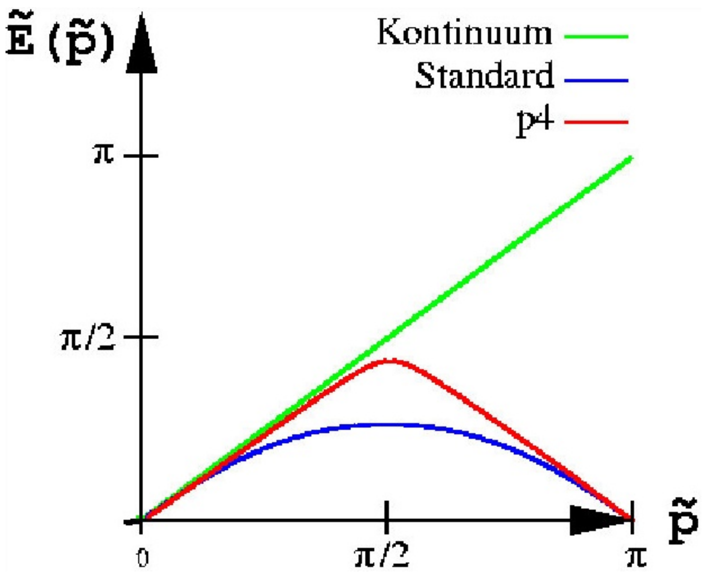
Karsch, Heller, Sturm (1999)

- gluonic part : Symanzik improvement scheme
  - remove cut-off effects of $O(a^2)$
  - tree level improvement $O(g^0)$
- fermion part : improved staggered fermion
  - remove cut-off effects & improve rotational sym.
  - improve flavor symmetry by smeared 1-link term

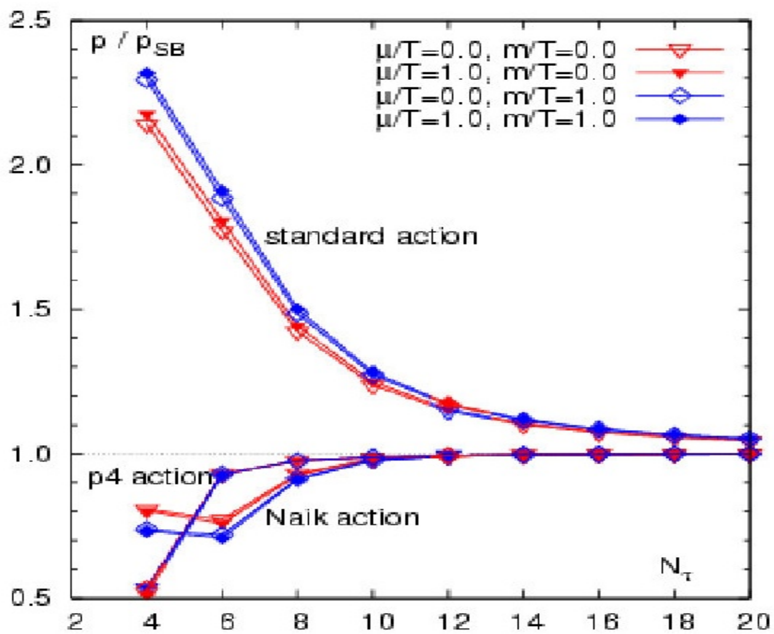


Properties of the p4-action

Dispersion relation



pressure in high T limit



The free quark propagator is rotational invariant up to $O(p^4)$

Bulk thermodynamic quantities show drastically reduced cut-off effects

flavor sym. is also improved by fat link

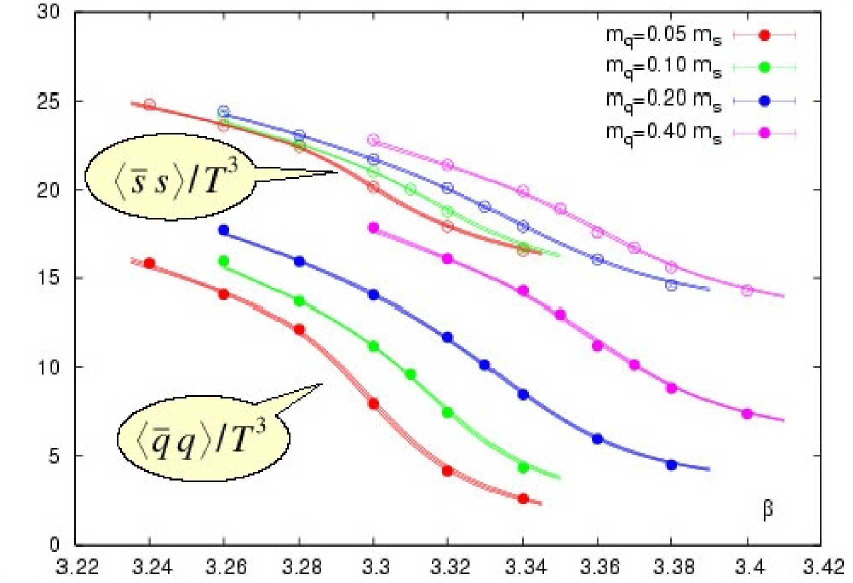
Numerical results

Calculation for Critical temperature

Order parameters

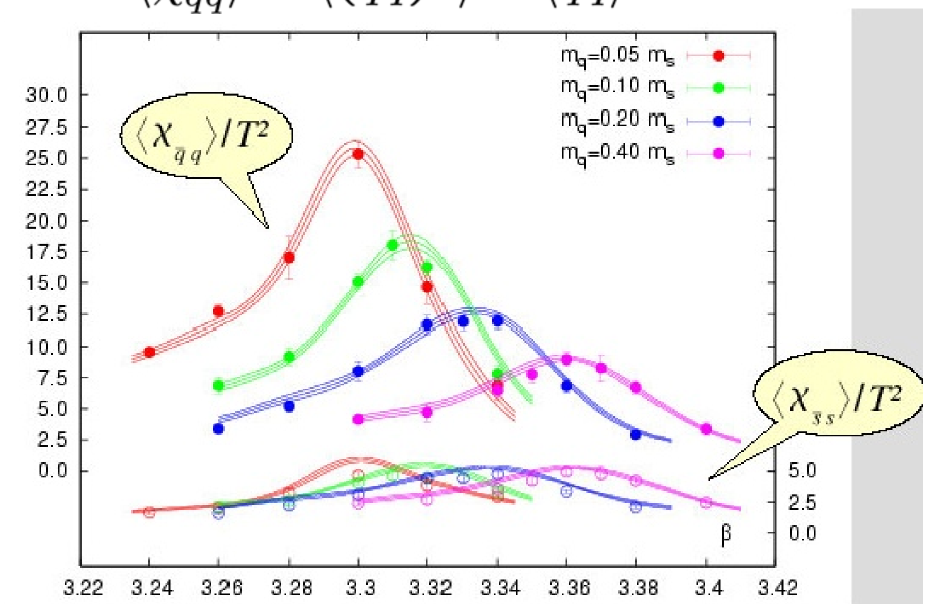
(2+1)-flavor, 8^3x4 lattice

strange- & light quark-
chiral condensate:



strange- & light quark-
chiral susceptibility:

$$\langle \chi_{\bar{q}q} \rangle \equiv \langle (\bar{q}q)^2 \rangle - \langle \bar{q}q \rangle^2$$



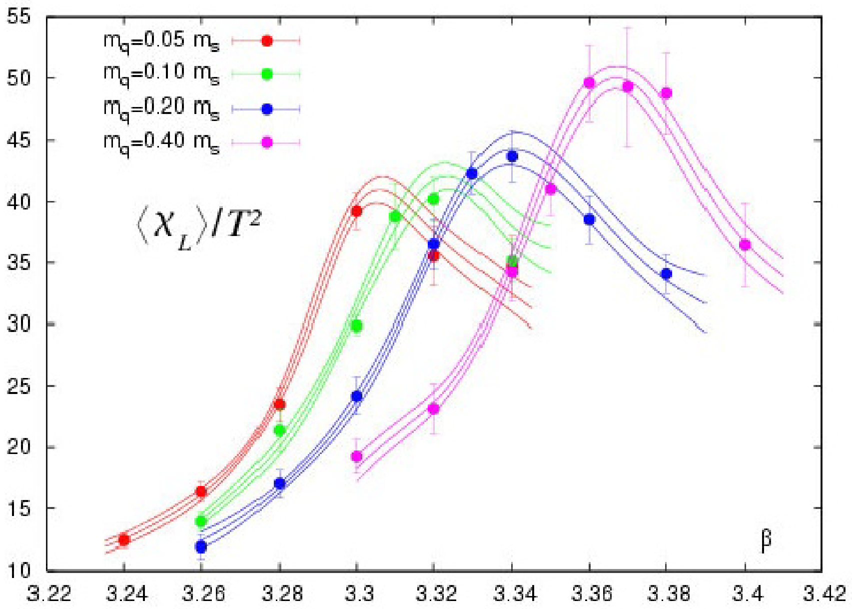
- multi-histogram method (Ferrenberg-Swendson) is used
- Transition becomes stronger for smaller light quark masses
- β_c are determined by peak positions of the susceptibilities

Order parameters

(2+1)-flavor, 8^3x4 lattice

Polyakov loop susceptibility:

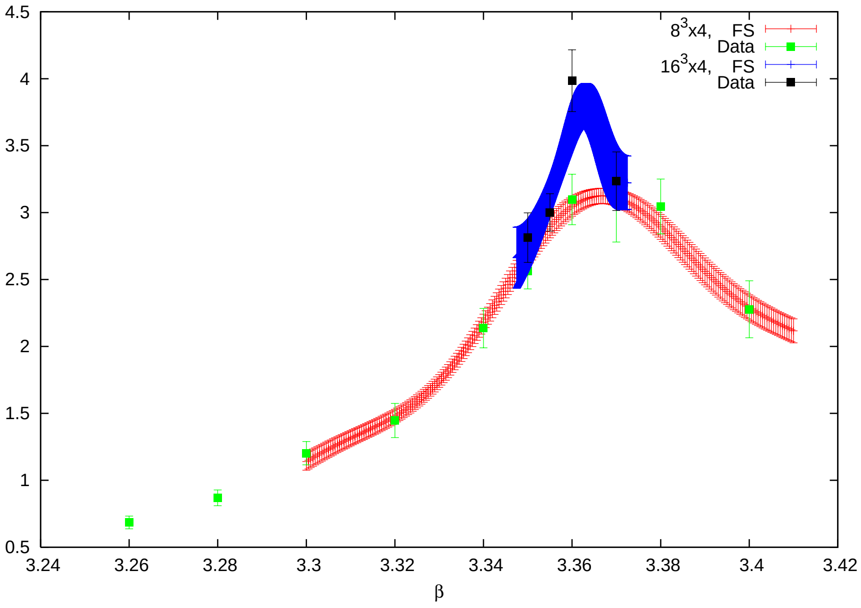
$$\langle \chi_L \rangle \equiv \langle L^2 \rangle - \langle L \rangle^2$$



16^3x4 & 8^3x4 lattices

Polyakov loop susceptibility:

$$\langle \chi_L \rangle \equiv \langle L^2 \rangle - \langle L \rangle^2$$

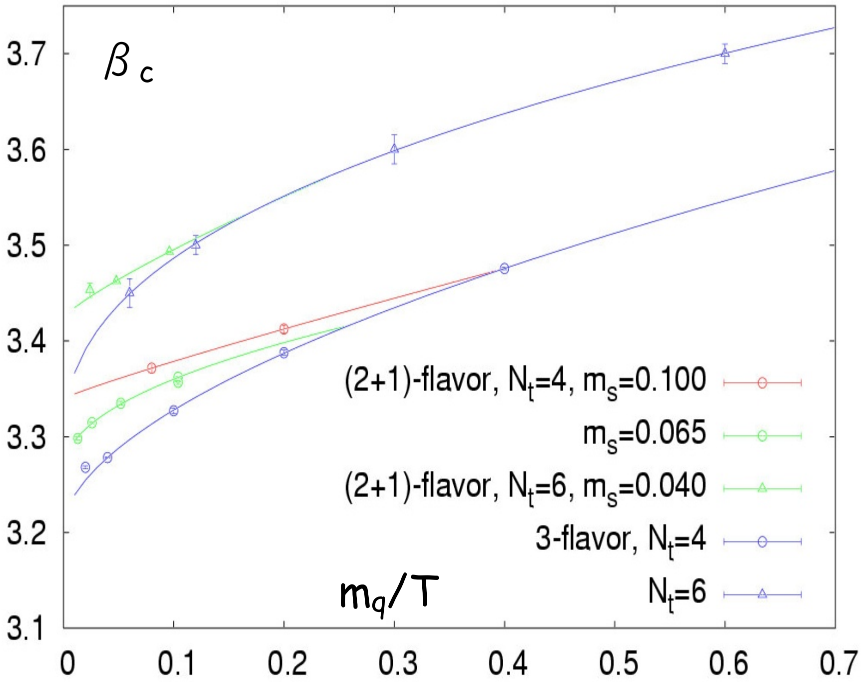


- β_c are determined by peak positions of the susceptibilities
  → consistent with β_c from chiral susceptibility
- Transition becomes stronger for larger volume

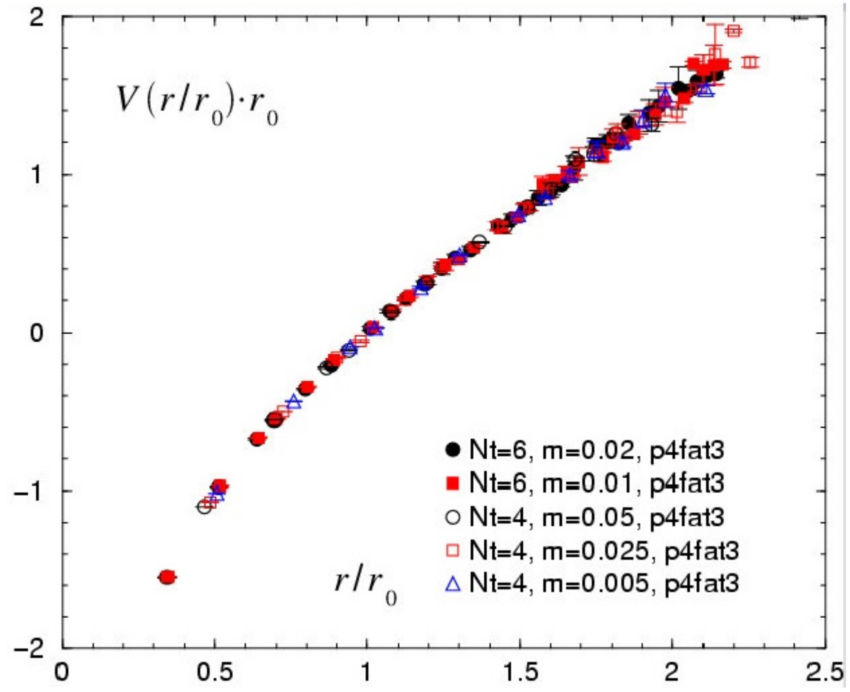
Critical temperature

(1) critical beta search
- from the chiral susceptibilities
- fits with power lows

Critical couplings:



(2) scale determination
from static quark potential
Sommer scale & string tention

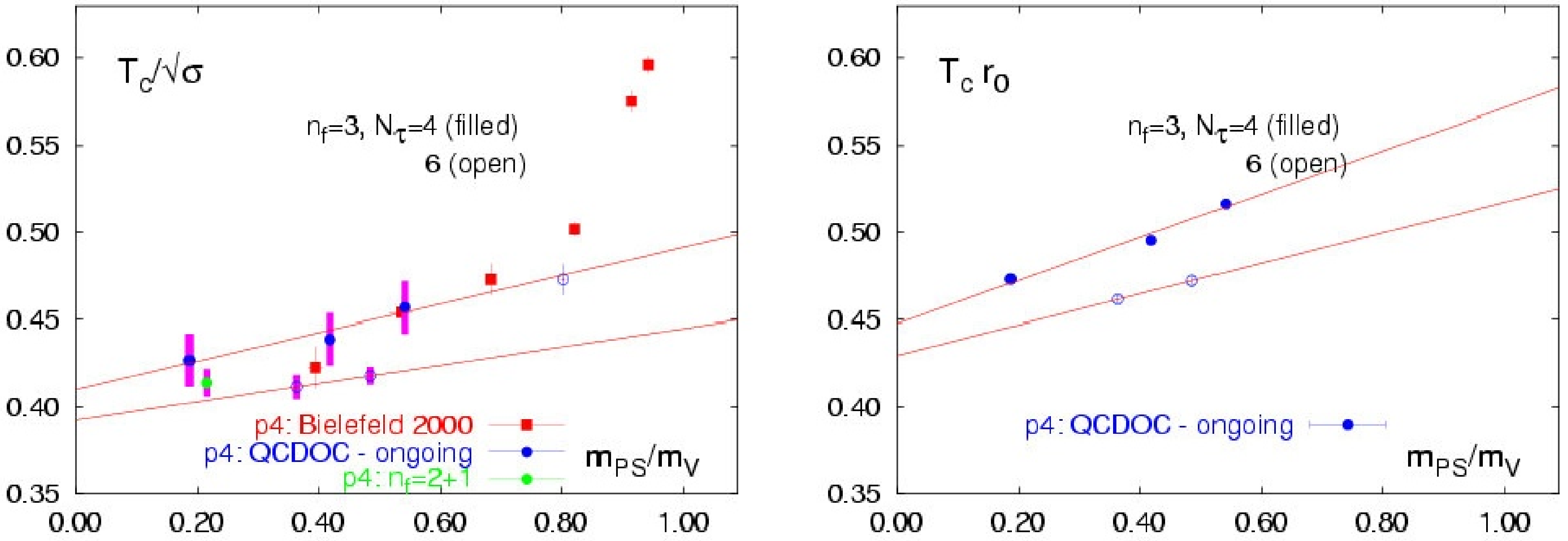


Almost no mass & cutoff dep. in potential scaled by r_0

Critical temperature

3-flavor results

from string tension: from Sommer scale:



- The cut-off effect in T_c is about 5% in m_q=0 limit of 3-flavor QCD
- Results is consistent with previous Bielefeld result

Summary

Critical coupling, temperature

- 3-flavor QCD
  - $m_{pi}/m_{rho} \geq 0.2$, $N_\sigma=8,16,32$, $N_\tau=4,6$
- (2+1)-flavor QCD
  - $m_q/m_s \geq 0.05$, $N_\sigma=8,16$, $N_\tau=4$

Outlook

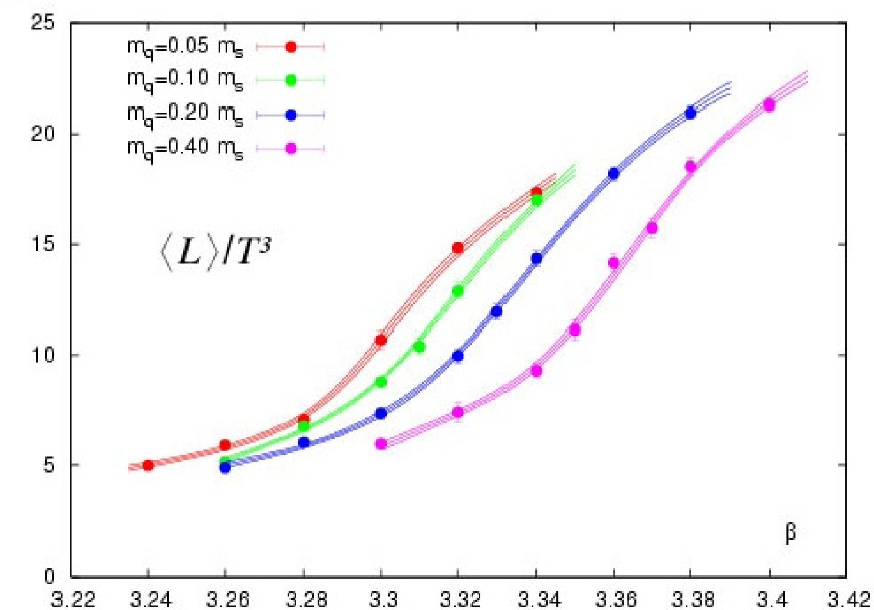
(2+1)-flavor $N_\tau=4,6$

- determination of Tc
- Calculation of EoS
- etc...

Order parameters

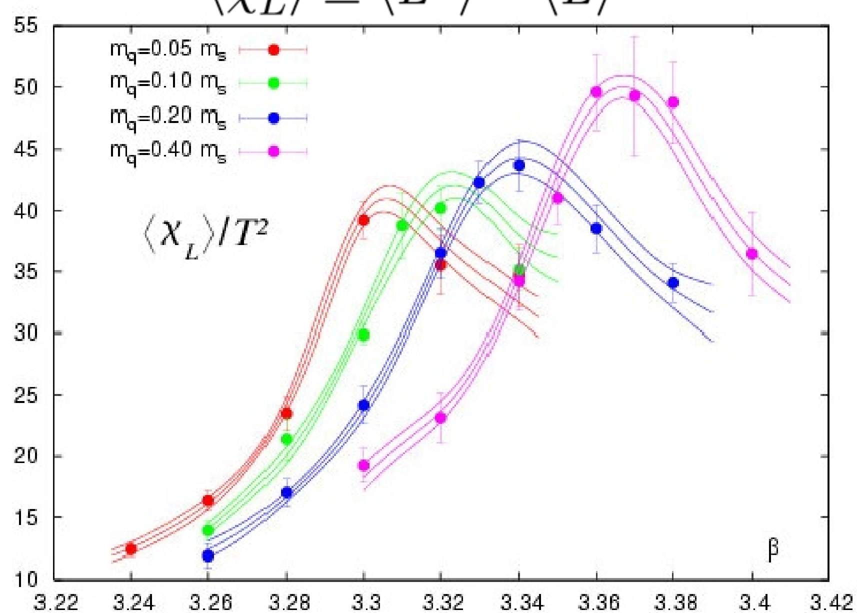
(2+1)-flavor, 8^3x4 lattice

Polyakov loop:



Polyakov loop susceptibility:

$$\langle \chi_L \rangle \equiv \langle L^2 \rangle - \langle L \rangle^2$$



- β_c are determined by peak positions of the susceptibilities
  → consistent with β_c from chiral susceptibility

(2)finite V fig.
(4)Order param. + finite V = 2pages

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