Experiences at Nf=3

Shoji Hashimoto (KEK)
for the JLQCD collaboration

at an ILFT informal workshop on “Twisted mass QCD and phase structure of QCD with Wilson-type quarks,”
Izu-Shuzenji, September 24, 2004

This talk

- A brief summary of our recent paper "*Bulk first-order phase transition in three-flavor lattice QCD with O(a)-improved Wilson fermion at zero temparature*," hep-lat/0409016.

- No introduction; jumps to results…

Actions

- Nf=3 lattice QCD with the O(a)-improved Wilson fermion. The unimproved Wilson fermion will also be discussed.
- c_{sw} is from tadpole improved one-loop PT (boosted by $1/P^{3/4}$).
- Plaquette and improved (LW or Iwasaki) gauge action

Algorithm

- HMC for Nf=2, Polynomial HMC for Nf=+1; The correction factor for the polynomial approx. is included in Monte Carlo using a stochastic estimator.

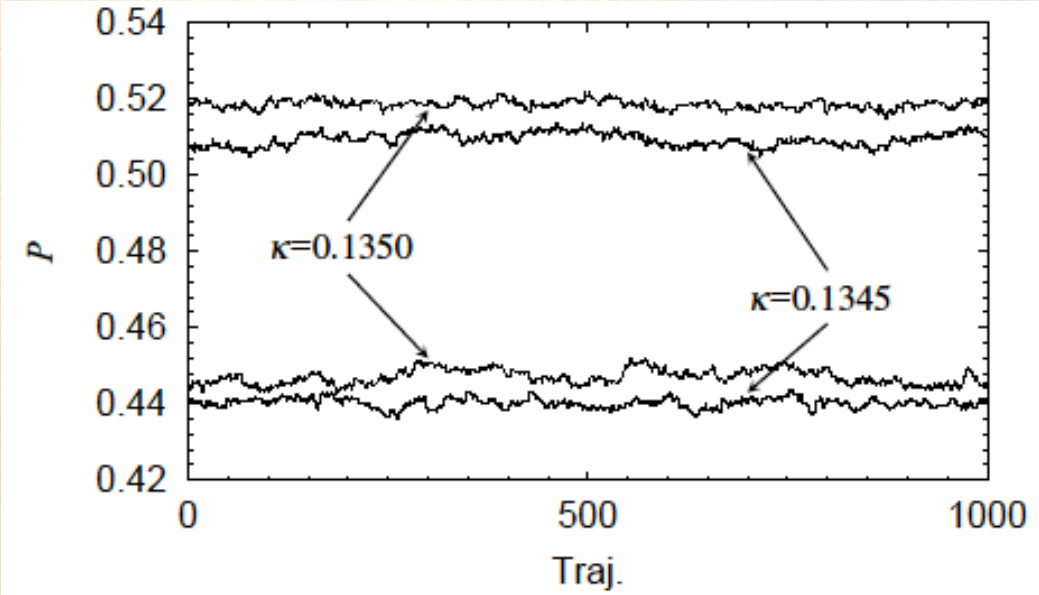
  To be short, an exact algorithm.

Lattice

- Zero temparature simulation on 4^3x8, 8^3x16 and 12^3x32.
- Systematically scan the parameter space (β , κ) to find a target simulation point a = 0.1~0.15 fm and m_q = 50~100 MeV.

What was found

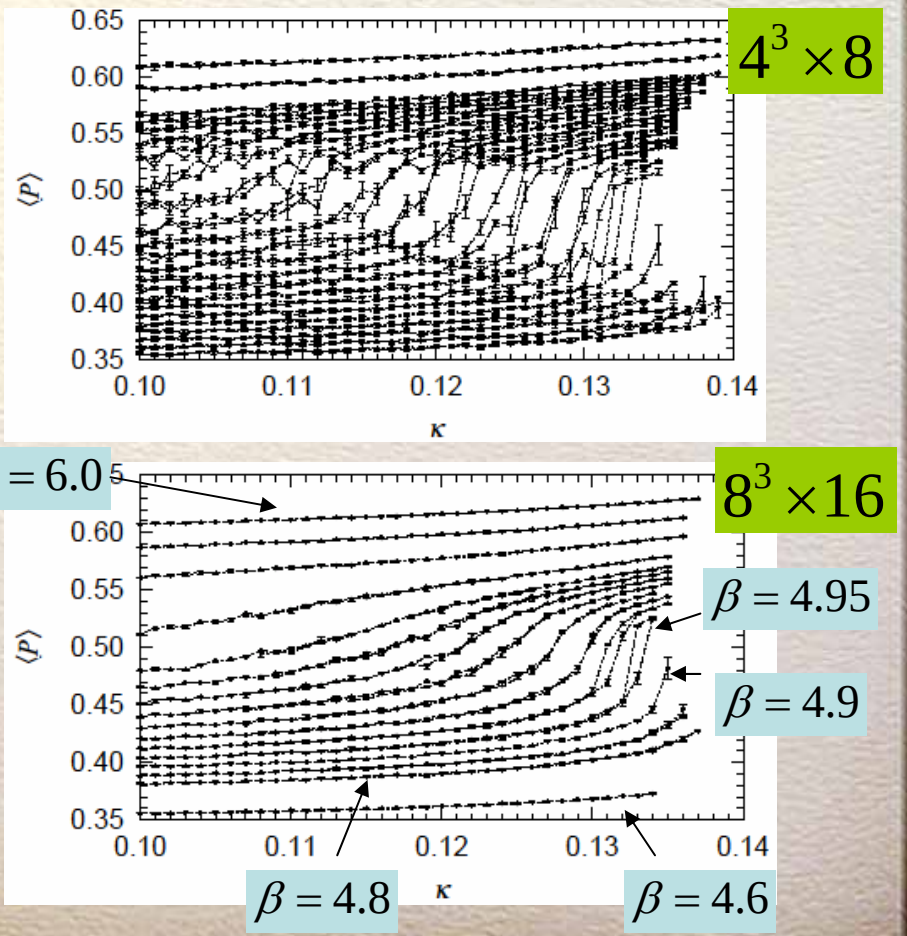
Plaquette history at β=4.88, c_{sw}=2.15 on 12^3x32



Very clear two-state signal!

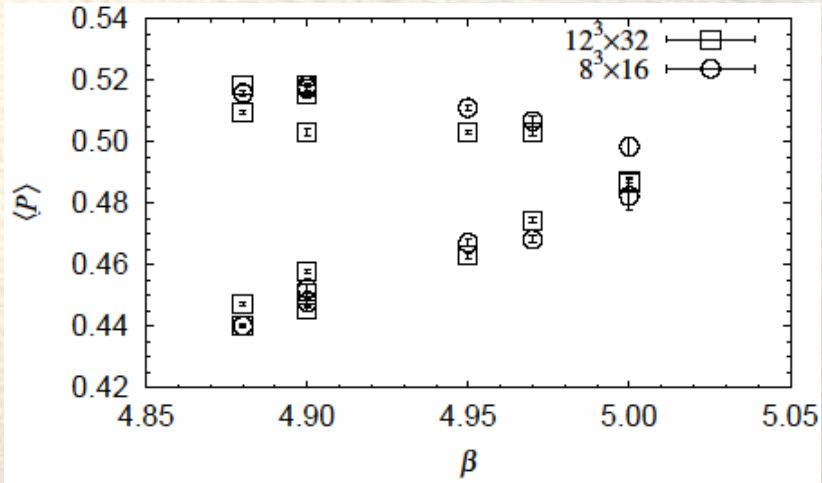
Thermal cycles

- Global scan on the parameter space.
- Without the Metropolis tests (inexact simulations)
- 100 (therm) + 100 (meas) at each point
- Start from low **κ** and increase; comes back when **Δ**H>100 is encountered with a fixed *dt* and N_{poly}



The gap

- Large gap in the plaquette expectation value at β=4.88-5.0
- Vanishes around β=5.0
- Stable against the lattice volume, indicating that the phase transition is of the bulk nature.



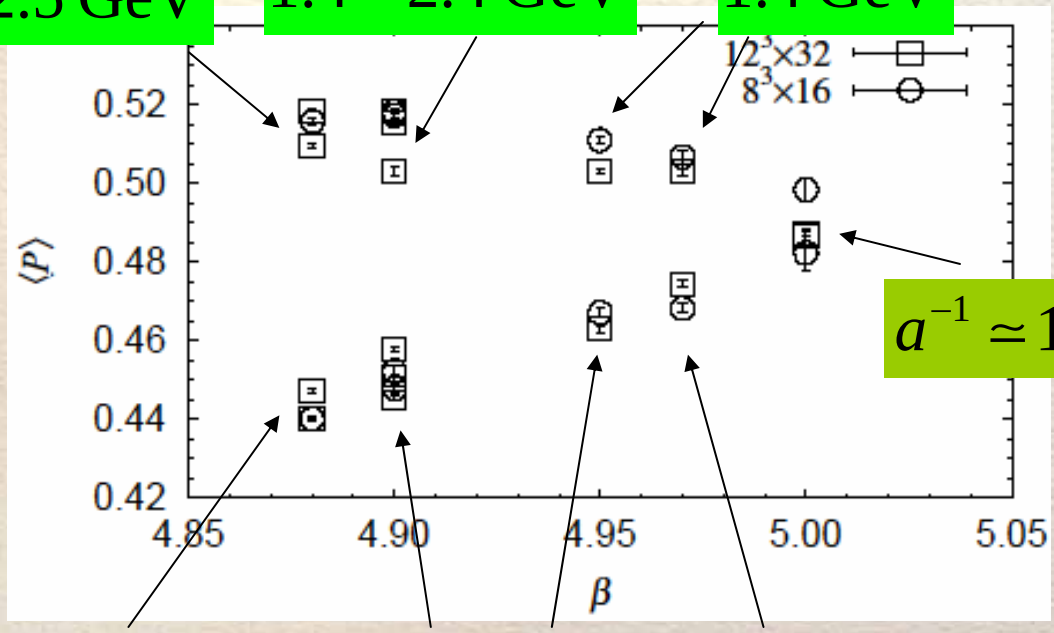
Lattice spacing

Lattice spacing measured through r_0

$a^{-1} \simeq 2.5\,\mathrm{GeV}$

$1.4 - 2.4\,\mathrm{GeV}$

$1.4\,\mathrm{GeV}$



$a^{-1} \simeq 1.5 - 2.6\,\mathrm{GeV}$

$a^{-1} \simeq 0.8\,\mathrm{GeV}$

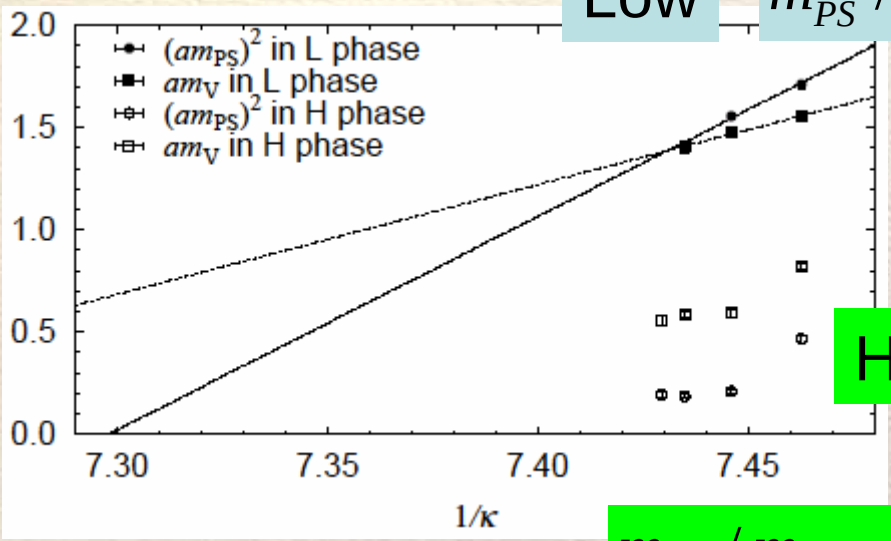
$\simeq 0.83\,\mathrm{GeV}$

$\simeq 0.85\,\mathrm{GeV}$

Quark mass

At β=4.9 meson masses are measured for both phases

Low $m_{PS} / m_V \simeq 0.84$



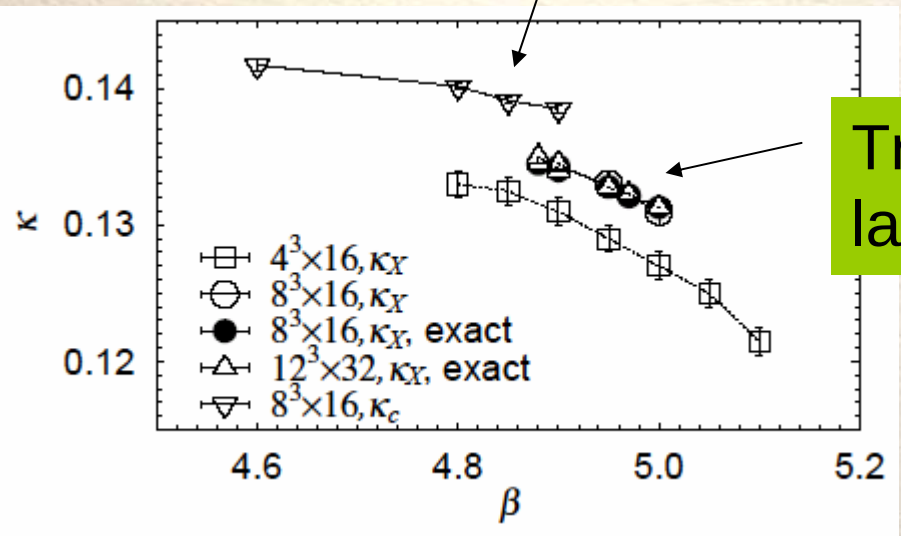
High

$m_{PS} / m_V \simeq 0.83 - 0.74$

The transition point is far from the chiral limit.

Phase structure

Would-be κ_{crit} extrapolated from the LOW phase



Transition line for larger volumes

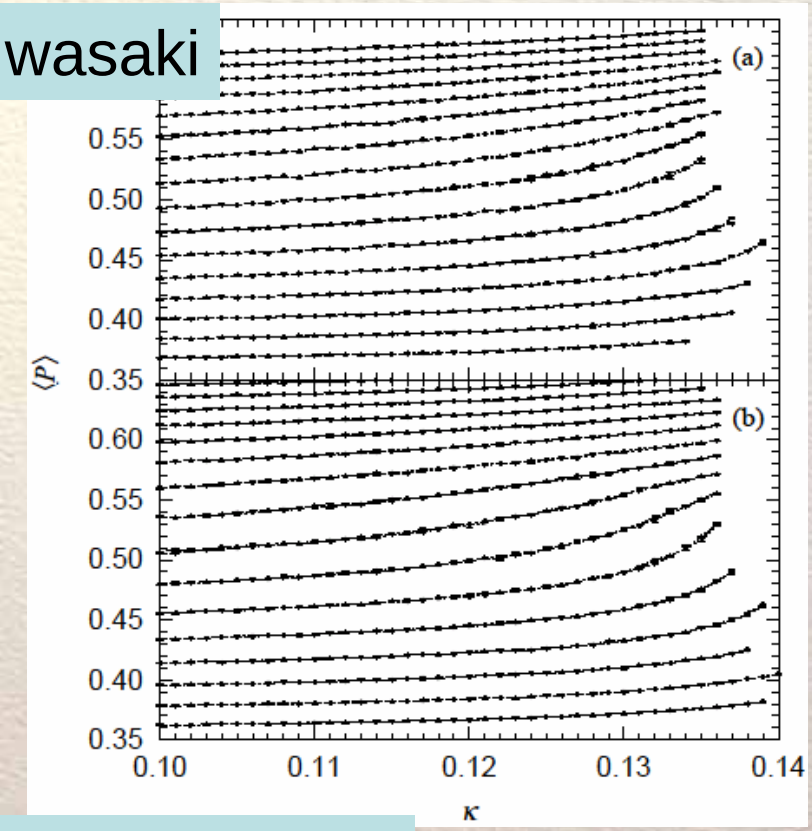
Transition line disappears around β=5 on the weak coupling side.

- What happens on the strong coupling side: an open issue. Does the “High” phase exist?

Improvements

- Improvement of the gauge action changes the situation drastically.
  - Iwasaki
  - Luscher-Weisz
- No phase transition is found in the thermal cycle.

Iwasaki



Luscher-Weisz

8^3x16

Facts and speculations

Related phenomena

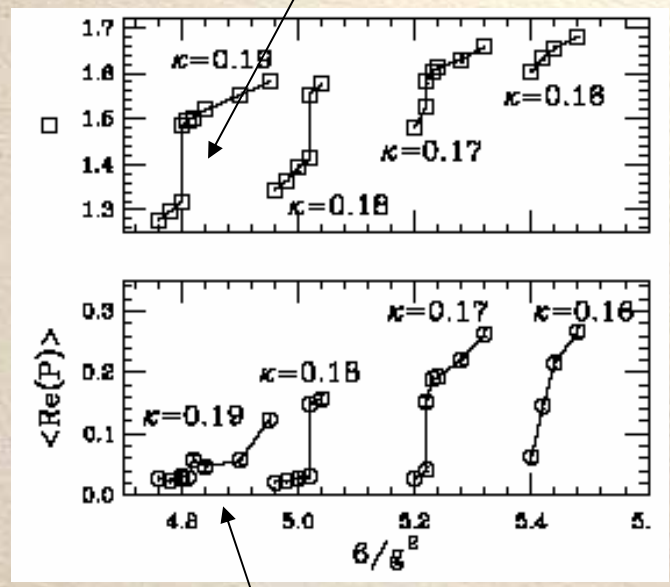
- Thermodynamics with two flavors of Wilson fermion
- Pure gauge with fundamental-adjoint couplings
- Three-flavor unimproved Wilson fermion

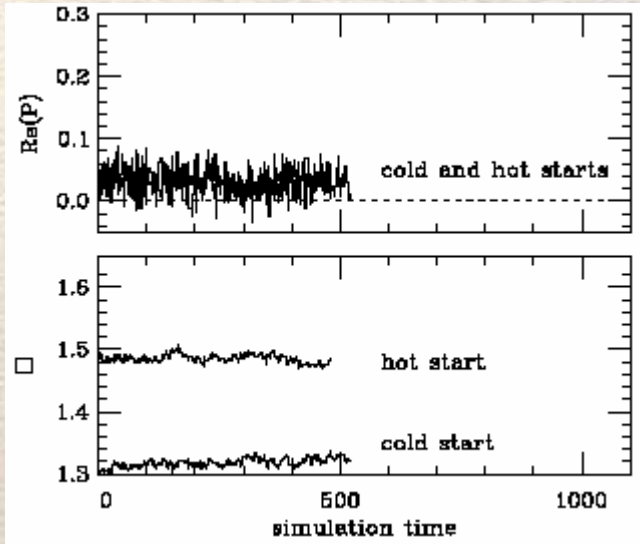
Nf=2 Wilson fermion

Blum et al. (MILC), PRD50 (1994) 3377.

$12^3 \times 6$

Strong metastability in plaquette





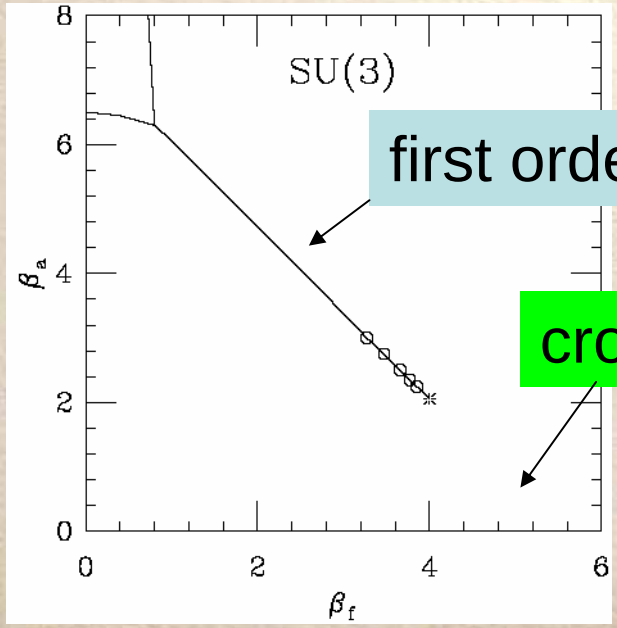
No jump in Polyakov line

"Bulk transition"

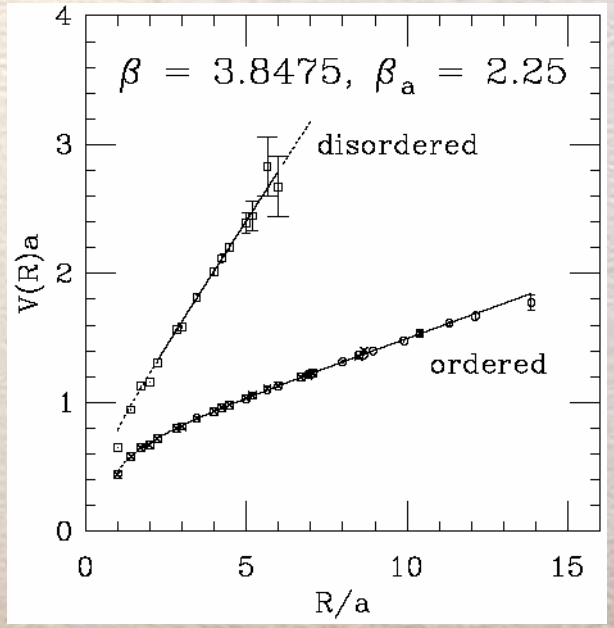
Pure gauge with fundamental-adjoint gauge couplings

$$S = \beta_f \sum_P \left[1 - \frac{1}{N} \mathrm{Re}\,\mathrm{Tr} U_P \right] + \beta_a \sum_P \left[1 - \frac{1}{N^2} \mathrm{Tr} U_P \mathrm{Tr} U_P^\dagger \right]$$

Blum et al., NPB442 (1995) 301.



Heller, PLB362 (1995) 123.

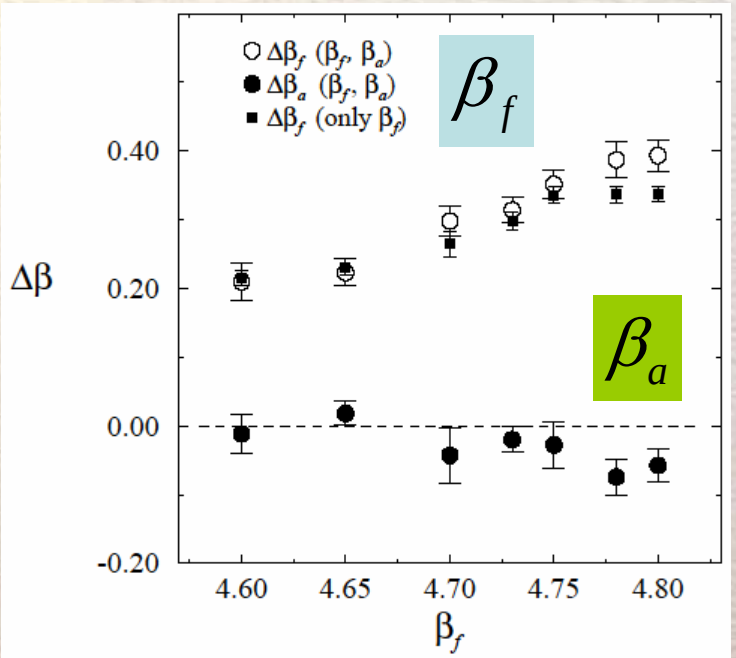


Are they related?

If the dynamical Wilson fermion induces the adjoint gauge coupling, they are naturally explained…

Blum et al., NPB442 (1995) 301.

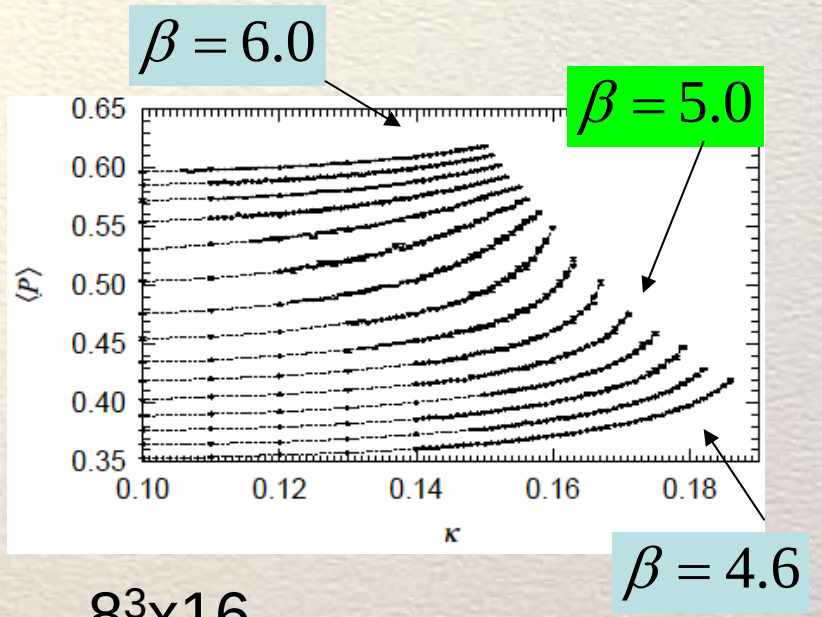
Calculated the induced couplings, both β_f and β_a



Not really.

Nf=3 Wilson fermion

- Is the phase transition due to the clover term? It may induce the adjoint coupling in a different way.
- Thermal cycles for the unimproved Wilson fermion.



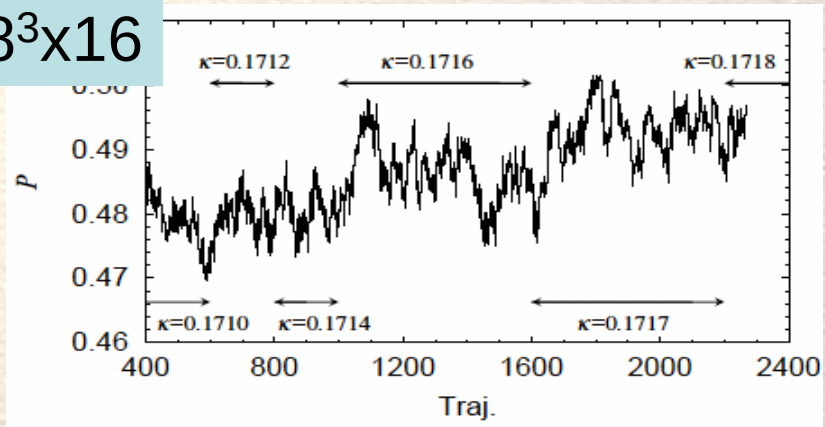
8^3x16

No visible jump is observed.

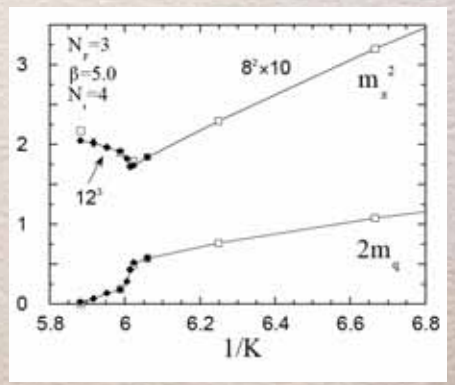
Beyond the end point

- The thermal cycle ended when a large ΔH is encontered.
- Sea quarks are not necessarily light enough.

$8^3 \times 16$



1st order-like history; finally PHMC stacked at κ=0.1718 (need extremely high order for the polynomial ~ 400). Note that this point is far from the chiral limit.



Iwasaki et al. PRD54 (1996) 7010.

No conclusion