Toward $N_f = 2 + 1$ Lattice QCD Simulation at the Physical Point on PACS-CS

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Plan of talk

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§**2.** Review of previous CP-PACS/JLQCD results

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§1. Introduction

PACS-CS
(Parallel Array Computer System for Computational Sciences)
2560 nodes, 14.3 Tflops peak, 5.12TB memory
installed at U.Tsukuba on 1 July 2006
specifications will be explained later

collaboration members

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§2. Review of previous CP-PACS/JLQCD results

simulation details

– RG improved gauge + clover quarks with $c_{\rm SW}^{\rm NP}$

– three lattice spacings and continuum extrapolation in a^2

$\beta = 1.83(0.12\text{fm}),\ 1.90(0.10\text{fm}),\ 2.05(0.07\text{fm})$

– fixed physical volume $\sim (2\text{fm})^3$

– conventional HMC for up-down quarks

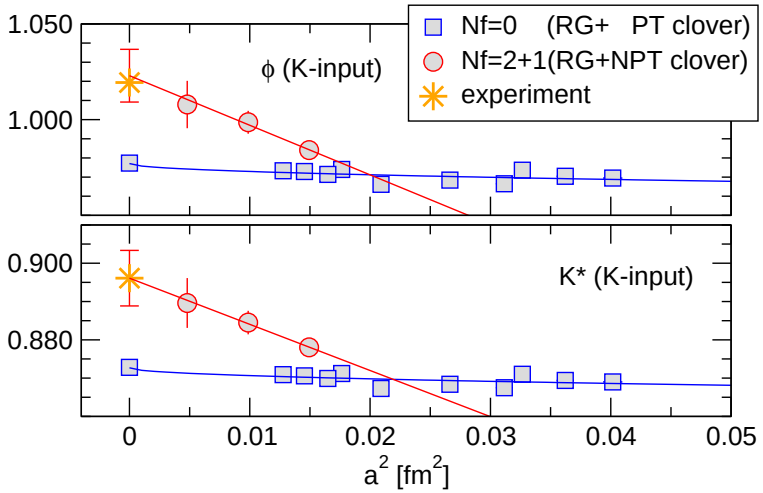
– exact polynomial HMC for strange quark

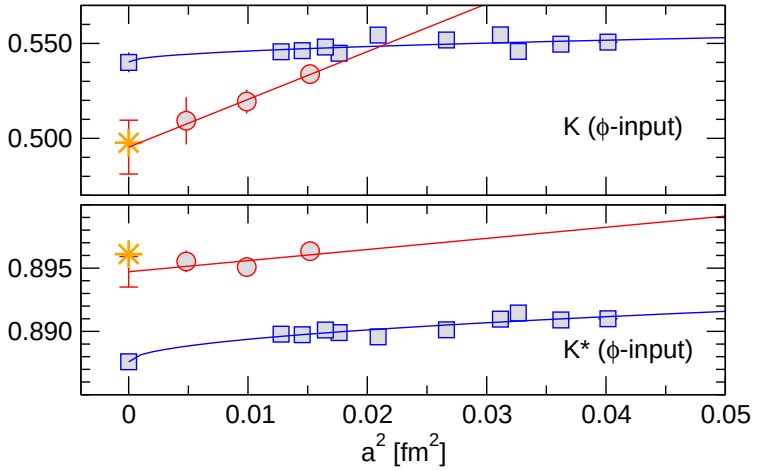
encouraging results on meson spectrum and light quark masses

meson spectrum

K-input(m_π, m_ρ, m_K) $\longrightarrow$ m_{K^*}, m_ϕ

ϕ-input(m_π, m_ρ, m_ϕ) $\longrightarrow$ m_{K^*}, m_K

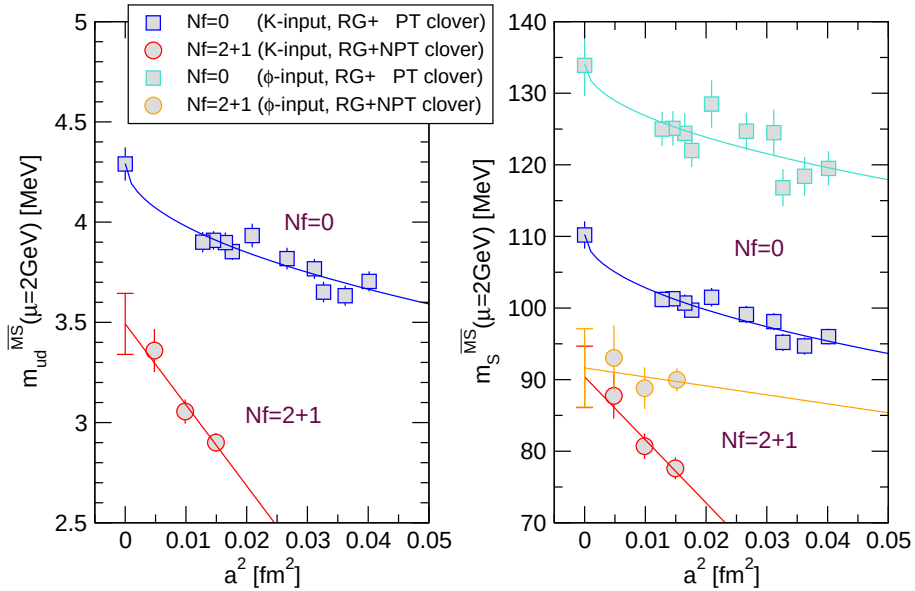




clear deviation from quenched results

consistent with experimental values in the continuum

m_q^{AWI} with perturbative Z



smaller than quenced results

$m_s(\phi$-input) and $m_s(K$-input) are consistent in the continuum limit

however, light quark masses only down to

$$m_{\mathrm{PS}}/m_{\mathrm{V}} \sim 0.6 \ (m_{\mathrm{ud}}^{\mathrm{AWI}} \approx 64\mathrm{MeV})$$

$\longrightarrow$ long chiral extrapolation to the physical point

wish to go down to lighter quark masses, e.g.

$$m_{\mathrm{PS}}/m_{\mathrm{V}} \sim 0.2 - 0.3 \text{ or less } (m_{\mathrm{ud}}^{\mathrm{AWI}} < 10\mathrm{MeV})$$

§3. PACS-CS specifications

#nodes	2560($16 \times 16 \times 10$)
peak performance	14.3Tflops
node	single CPU + memory + HDD + 8GBEthernet ports
CPU	Intel LV Xeon EM64T, 2.8GHz, 1MB L2 cache
memory	2GB/node (5.12TB/system)
network	3 dimensional hyper-crossbar uses dual GBEthernet/link
network performance	250MB/s/direction 750MB/s/node (3 dim. simultaneous send/receive)
local HDD	160GB×2 (RAID-1) (410TB×2/system)
#racks	59 racks
footprint	$100m^2$
power	545kW
OS	Linux, Score
programming	Fortran, C, C++, MPI for communication

§4. Preparatory study for production run

basic strategy

– Lüscher's domain-decomposed HMC(LDDHMC) for up-down quarks

– exact polynomial HMC for strange quark

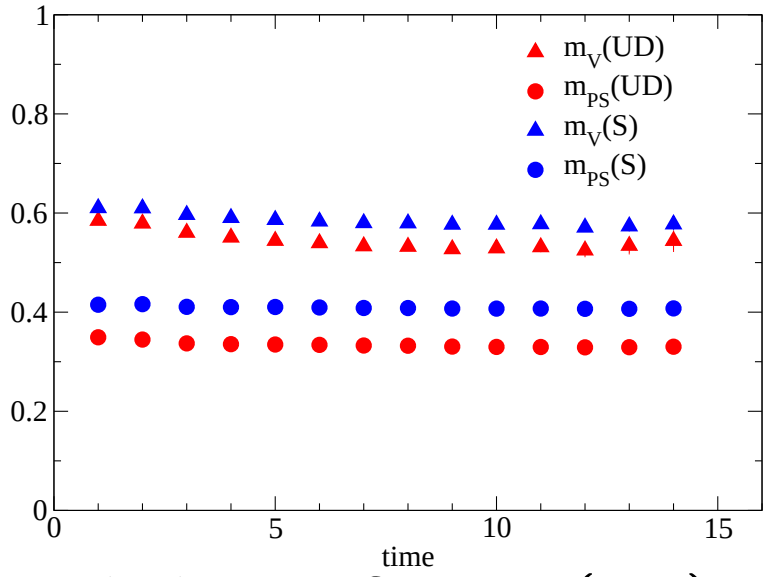
preparatory study at $\beta = 1.9$ on $16^3 \times 32$

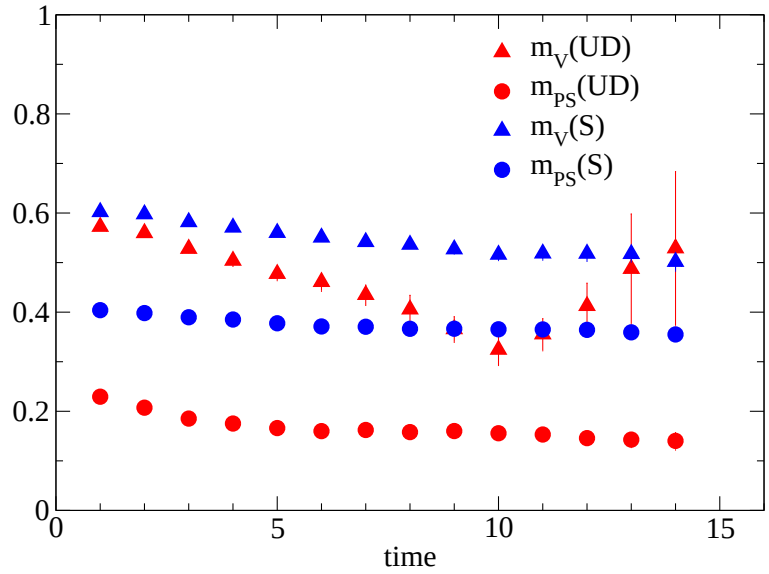
1. how light quark masses we can reach with LDDHMC
2. stability study using eigenvalues of the Dirac operator

κ_{ud}	0.13700	0.13741	0.13759	0.13770
N_0, N_1, N_2	4,5,6	4,5,8	4,5,12	4,5,14
N_{poly}	130	140	140	140
#traj.	2000	2000	2000	900

hadron effective masses

heaviest ud quark mass(left) and lightest(right)



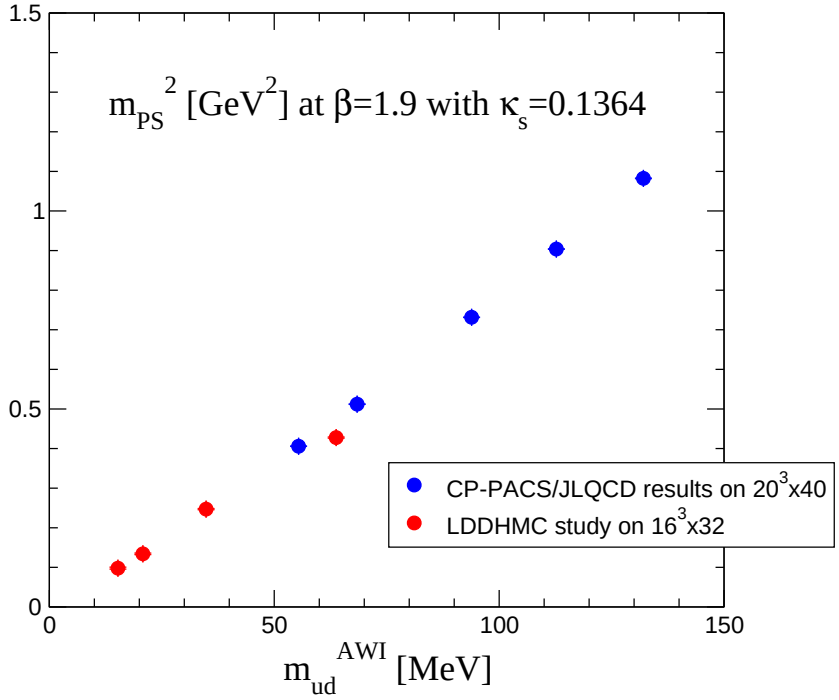


good plateau for $m_{\mathrm{PS}}(\mathrm{UD})$

hard to extract $m_V(\mathrm{UD})$ in the lightest case

PS meson mass and m_{ud}^{AWI}

κ_{ud}	m_{PS}[MeV]	m_{ud}^{AWI}[MeV]
0.13700	655(4)	63.7(4)
0.13741	498(6)	34.8(5)
0.13759	367(9)	20.7(5)
0.13770	313(16)	15.4(12)



$m_{ud}^{AWI} \approx 15$MeV ($m_{PS} \approx 300$MeV) is reached

stability study

Wilson fermions break chiral symmetry

$\rightarrow$ no protection from small eigenvalues

exceptionally small eigenvalues are source of instabilities

spectral gap distribution

$\mu = \min\{|\lambda| \mid \lambda \text{ is an eigenvalue of } \gamma_5(D_W + m_0)\}$

investigate probability distribution of μ

μ_{median}, μ_{average}, width σ

2 flavor results — Del Debbio et al. 06

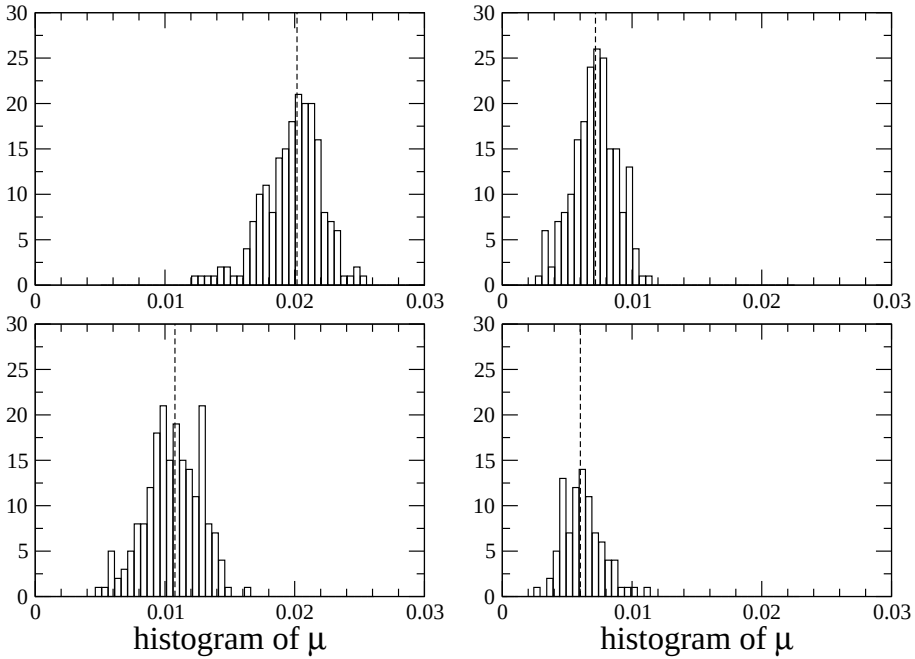
$\mu_{\text{median}} \propto m_q^{\text{AWI}}$

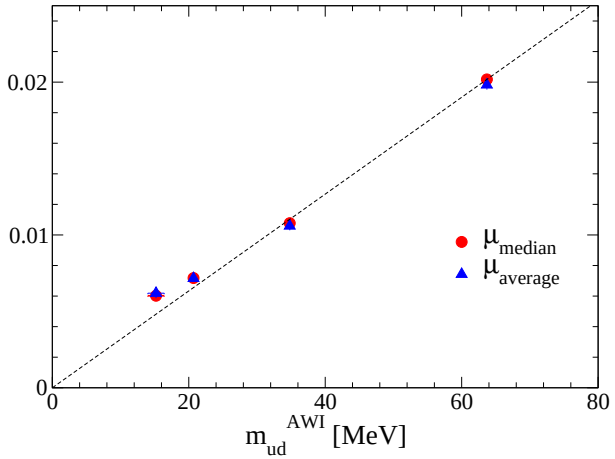
$\sigma_2 = c_2 a/\sqrt{V}$: $c_2 \approx 1$ independent of a, V, m_q^{AWI}

$\rightarrow$ how about 2+1 flavor case?

strange quark may change the situation?

histogram of μ





roughly symmetric distribution about μ_{median}

μ_{median} and μ_{average} are roughly proportional to $m_{\text{ud}}^{\text{AWI}}$

width of the distribution

– smaller width than 2 flavor case: $c_{2+1} < c_2 \approx 1$
– width decreases as m_q^{AWI} becomes smaller

κ_{ud}	0.13700	0.13741	0.13759	0.13770
$m_{\mathrm{ud}}^{\mathrm{AWI}}$[MeV]	63.7(4)	34.8(5)	20.7(5)	15.4(12)
$c_{2+1} = \sigma_{2+1}\sqrt{V}/a$	0.755(60)	0.735(53)	0.601(54)	0.501(76)

$\longrightarrow$ strange quark contributions may stabilize the simulation

§5. Parameter choice for production run on PACS-CS

algorithm → K.Ishikawa's talk
– LDDHMC with replay trick for ud quarks
  SAP+GCR solver for IR part
– UV-filtered PHMC for s quark

parameters
– $\beta = 1.83(0.12\text{fm}),\ 1.90(0.10\text{fm}),\ 2.05(0.07\text{fm})$
– lattice spatial volume: $(3.0\text{fm})^3$
  $24^3 \times 48(\beta = 1.83),\ 32^3 \times 64(\beta = 1.9),\ 40^3 \times 80(\beta = 2.05)$
– $m_{\text{ud}}^{\text{AWI}}$=7, 15, 25, 35, 45MeV or less
  15MeV on $16^3 \times 32 \rightarrow$ 4MeV on $32^3 \times 64$ from $\sigma \propto a/\sqrt{V}$
– two strange quark masses
– 10^4 trajs. for 100 indep. cfgs.

physics plan on PACS-CS

- **light hadron spectrum including baryon**
- **heavy quark physics with the relativistic heavy quark action**
- α_s **and quark masses with nonperturbative renormalization**
  Schrödinger functional method(under way)
- **physics associated with topology**
  η' meson mass, NEDM
- **hadron matrix elements**
- **hadron-hadron interactions**
  $I = 0, 2$ π-π scattering, ρ resonance

§6. Summary

preliminary study with LDDHMC

– $m_{\mathrm{ud}}^{\mathrm{AWI}} \approx 15$MeV reached

– $\sigma\sqrt{V}/a$ (2+1 flavor) $< \sigma\sqrt{V}/a$ (2 flavor)

target of PACS-CS project

– three β values, $(3.0\mathrm{fm})^3$, 10^4 trajs.

– go down to $m_{\mathrm{ud}}^{\mathrm{AWI}}$=7MeV or less

– current status of production runs:

$m_{\mathrm{ud}}^{\mathrm{AWI}}$=7, 15, 25MeV at $\beta = 1.9$ on $32^3 \times 64$

physical results will be presented in next year