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

Y.Kuramashi/A.Ukawa (U.Tsukuba)
for the PACS-CS collaboration

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Plan of talk

§**1.** Introduction

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

§**3.** PACS-CS specifications

§**4.** Preparatory study for production run

§**5.** Parameter choice and physics plan on PACS-CS

§**6.** Summary

§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

physicists:

S.Aoki, N.Ishii, N.Ishizuka, D.Kadoh, K.Kanaya, Y.Kuramashi, K.Sasaki, Y.Taniguchi, A.Ukawa, N.Ukita, T.Yoshié	Tsukuba
K-I.Ishikawa, M.Okawa	Hiroshima
T.Izubuchi	Kanazawa
N.Tsutsui	KEK
T.Ishikawa	BNL

computer scientists:

T.Boku, M.Sato, D.Takahashi, O.Tatebe	Tsukuba

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

simulation details

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

– three lattice spacings and continuum extrapolation in a^2

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

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

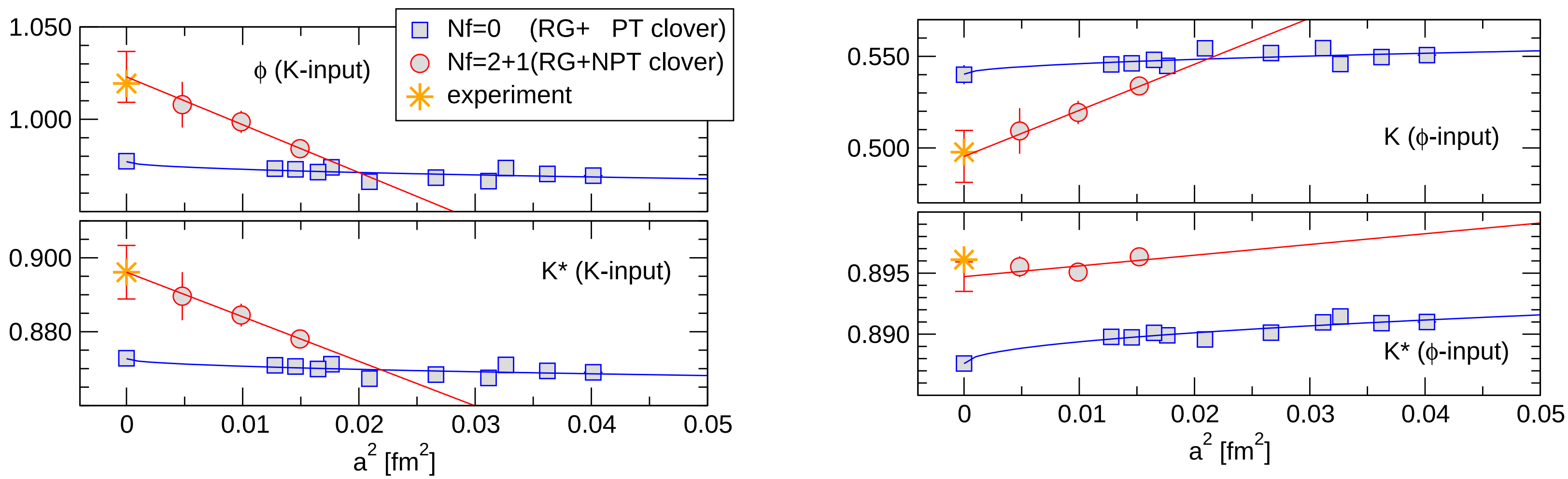
– conventional HMC for up-down quarks

– exact polynomial HMC for strange quark

encouraging results on meson spectrum and light quark masses

meson spectrum

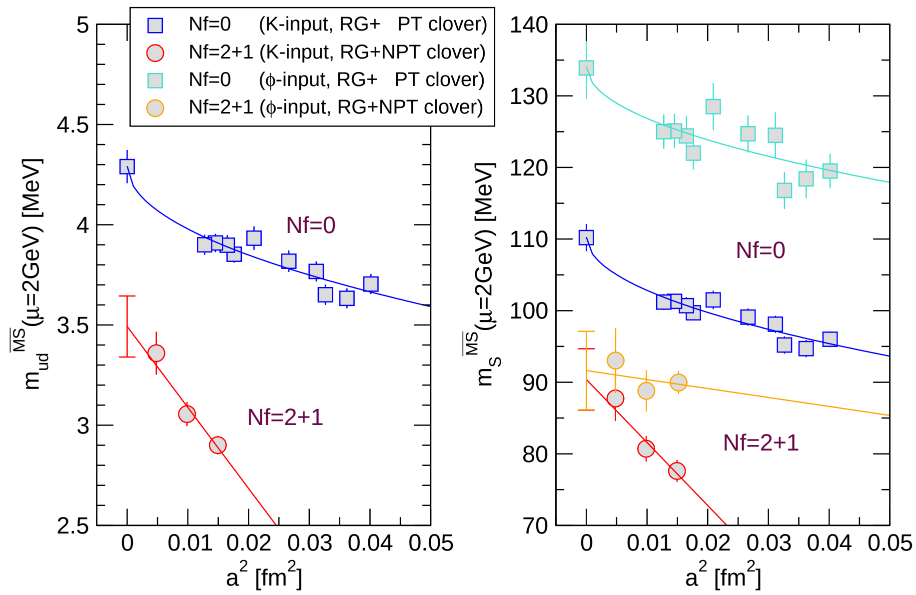
$$K\text{-input}(m_\pi, m_\rho, m_K) \quad \rightarrow \quad m_{K^*}, m_\phi$$
$$\phi\text{-input}(m_\pi, m_\rho, m_\phi) \quad \rightarrow \quad m_{K^*}, m_K$$



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

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

$\longrightarrow$ long chiral extrapolation to the physical point

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

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

§3. PACS-CS specifications

#nodes	2560($16 \times 16 \times 10$)
peak speed	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

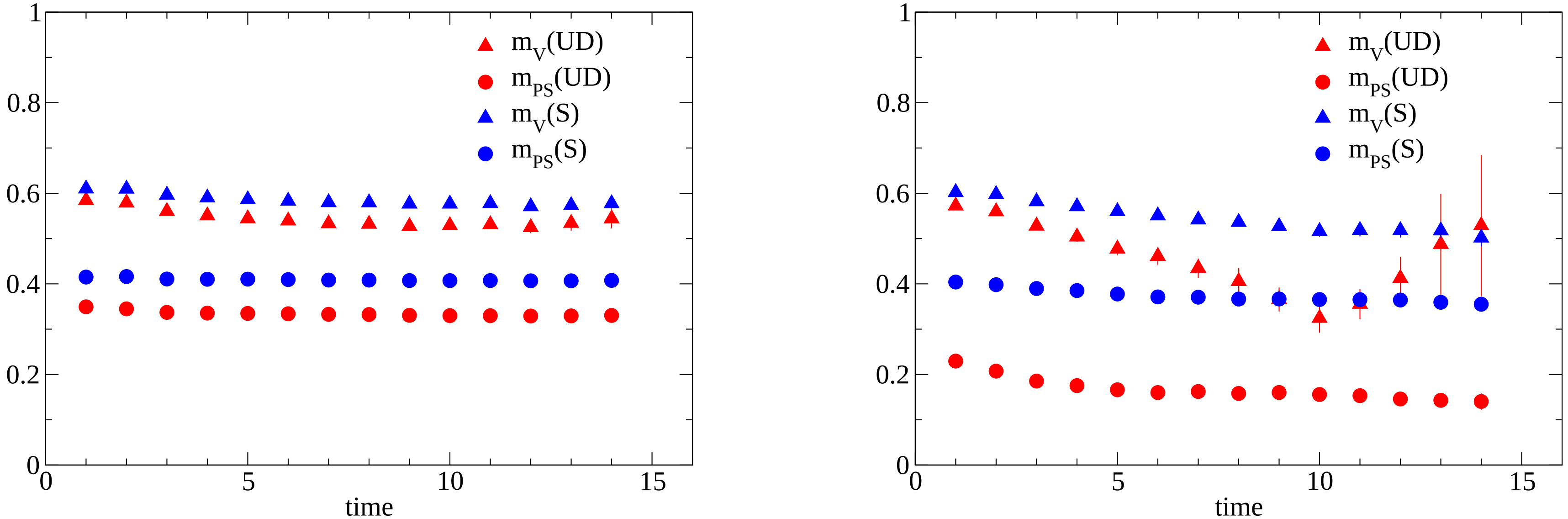
preparatory study at $\beta = 1.9$ on $16^3 \times 32$

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)

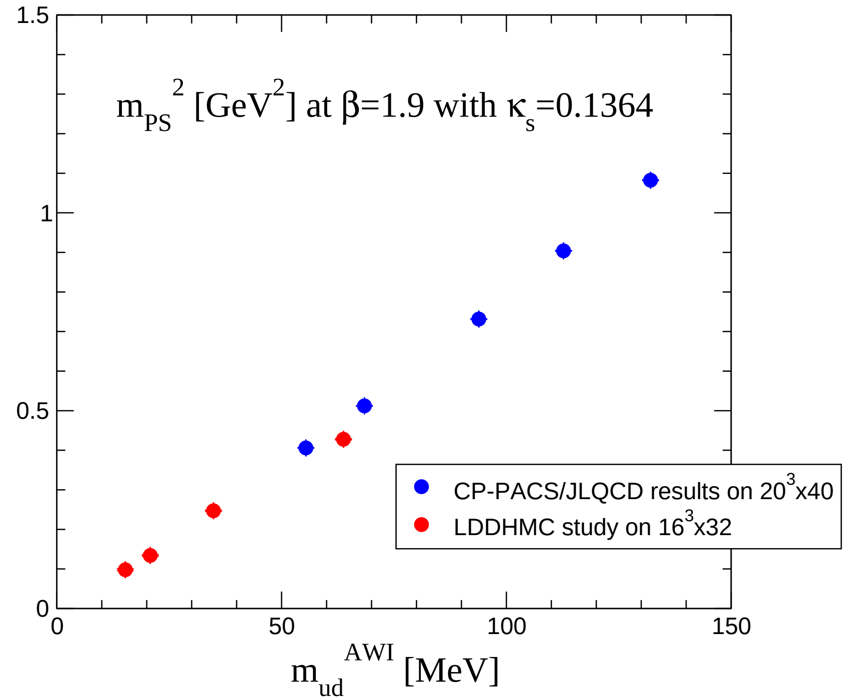


good plateau for m_{PS}(UD)

hard to extract m_V(UD) in the lightest case

PS meson mass and $m_{\rm ud}^{\rm AWI}$

$\kappa_{\rm ud}$	$m_{\rm PS}$[MeV]	$m_{\rm ud}^{\rm AWI}$[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)



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

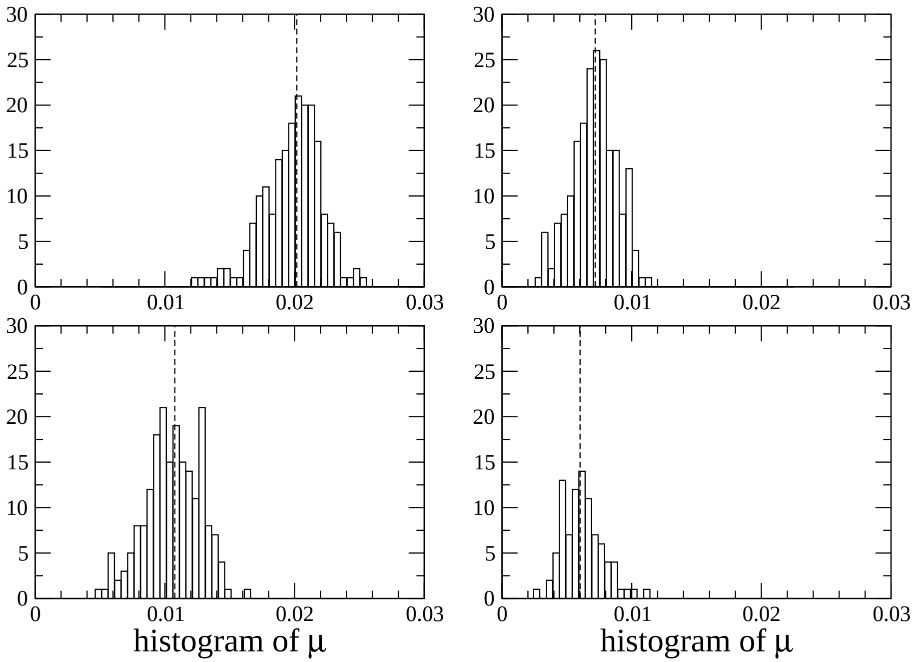
$\mu_{\text{median}} \propto m_q^{\text{AWI}}$

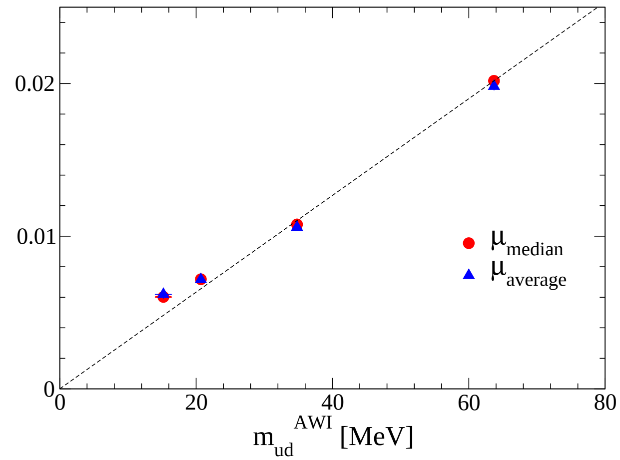
$\sigma_2 = c_2 a/\sqrt{V}$: $c_2 \approx 1$ independent of a, V, m_q^{AWI}

$\rightarrow$ 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
– $\beta = 1.83$(0.12fm), 1.90(0.10fm), 2.05(0.07fm)
– lattice spatial volume: (3.0fm)^3
$24^3 \times 48(\beta = 1.83)$, $32^3 \times 64(\beta = 1.9)$, $40^3 \times 80(\beta = 2.05)$
– $m_{\rm ud}^{\rm AWI}$=7, 15, 25, 35, 45MeV or less
15MeV on $16^3 \times 32$ → 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

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

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

target of PACS-CS project

– three β values, (3.0fm)^3, 10^4 trajs.

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

– current status of production runs:

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

physical results will be presented in next year