Flavour-singlet meson and multi-hadron spectroscopy using a new hadron correlator algorithm

Justin Foley, University of Utah

Collaborators: J.Bulava, K.J. Juge, D. Lenkner, C. Morningstar, M. Peardon, C.H. Wong.

- Part of the Hadron Spectrum Collaboration program
- A technique for estimating all elements of a smeared quark propagator
- Based on a redefinition of the quark smearing operator - LapH smearing, Peardon et al. Phys. Rev. D80:054506 (2009)
- Combined with a dilute stochastic estimate
- First results from $N_f = 2 + 1$ simulations

Equation of state and magnetic monopoles in SU(2) gluon plasma

Katsuya Ishiguro

（Kochi Univ. ＆ RIKEN）

Lattice QCD confronts experiments

– Japanese-German Seminar 2010 –

4-6 Nov. 2010, Mishima, Japan

- Motivated by the paper

"*Manifestation of magnetic vortices in the equation of state of a Yang-Mills plasma*"

[M.N.Chernodub, A.Nakamura, V.I.Zakharov, Phys. Rev. D78, 074021 (2008)],

we study the effect of magnetic monopoles to the equation of state of SU(2) gauge theory.

Outline

- Thermodynamics of Yang-Mills theory
- Models of color confinement at $T < Tc$

  \- Abelian monopoles
- In deconfinement (gluon plasma at $T > Tc$)

  \- Are they (still) alive as real object?
- Contribution to (trace of) energy-momentum tensor from Abelian monopoles

Conclusion and future works

- Conclusion
  - Found: strong contributions from the plaquettes around Abelian monopoles to the trace anomaly, and, consequently, to the pressure and to the energy density of the gluon plasma.
  - Gluonic configurations around the Abelian monopoles are similar to the worldsheets of the center vortex.
- Future works
  - Check of scaling for trace anomaly (wrapped monopole (T>0) and the largest monopole cluster (T=0))
  - What is the correct regularization scheme?

JG2010
10/11/5

QCD thermodynamics with Wilson-type quarks

– Summary of the results from the WHOT-QCD Collaboration*

K. Kanaya

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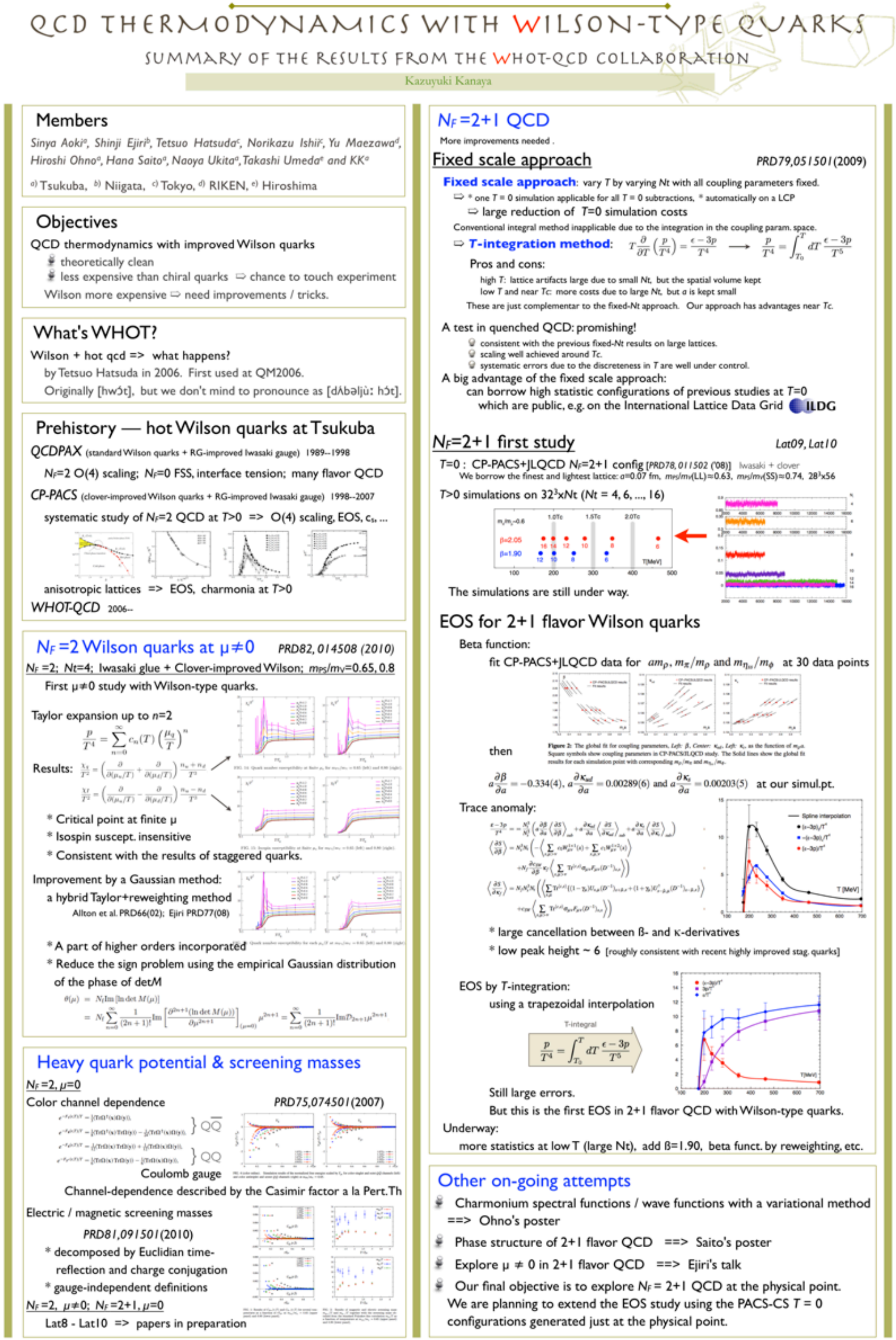
*) *S. Aoki, S. Ejiri, T. Hatsuda, N. Ishii, Y. Maezawa, H. Ohno, H. Saito, N. Ukita, T. Umeda and KK*
(Tsukuba, Tokyo, Niigata, Hiroshima, RIKEN)



after

- some historical notes
  including
  how to pronounce WHOT
  etc.
- our previous studies
  - μ≠0 with 2-flavor clover quarks
  - color-channel dep. of heavy quark potential

EOS in 2+1flavor QCD
with clover qurks
+ Iwasaki glue

EOS is expensive

=> we adopt **fixed-scale approach**

developing "***T*-integration method**" PR D79 (2009)

A good point:

we can take advantage of *T*=0 config's on ILDG

We borrow *Nf*=2 clover+Iwasaki at

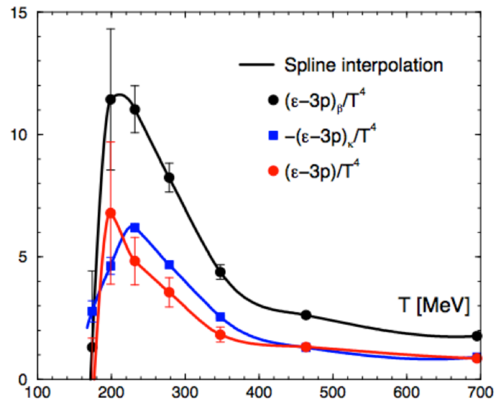
$$a = 0.07\mathrm{fm},\ m_\pi/m_\rho = 0.63$$ by CP-PACS+JLQCD

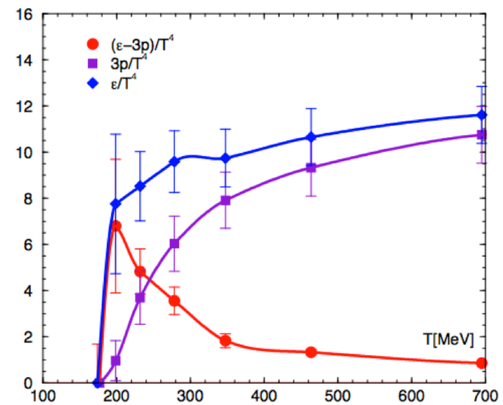
and perform *T*>0 simulations (*T*≈170–700 MeV) on

$$32^3 \times N_t, \quad N_t = 4,\ 6, \cdots,\ 16$$

to get EOS.

(preliminary)





Still far from
confronting experiments,
but we could make the first step.

Lattice QCD study of the heavy quark potential

... when the quark mass is finite

Yoshiaki Koma and Miho Koma

Numazu College of Technology

Japanese-German Seminar 2010
4-6 Nov 2010, Mishima

1. Introduction

- **Heavy quarkonia:**

  bound states of heavy quark and heavy antiquark

  $\Rightarrow \eta_c$, J/Ψ , χ_{cJ} **etc. for** $c\bar{c}$

  $\Rightarrow \eta_b$, Υ , χ_{bJ} **etc. for** $b\bar{b}$

- **Phenomenological approach**

  $\Rightarrow$ **assume "Coulomb + linear (confining) potential"**
  between heavy quarks and solve the Schrödinger equation
  (with relativistic corrections, such as spin-dependent ones)
  [e.g. Godfrey&Isgur('85), there are many works along this line]

  $\Rightarrow$ **compute mass spectra, wave functions, decay widths,**
  transition amplitudes, etc.

1. Introduction

- **Can QCD support phenomenological approaches ?**
  - ⇒ use "static potential" from lattice QCD ?

    Coulomb + linear

- **Problems are ...**
  - ⇒ QCD does not tell how to use the potential
    (remember that QCD is not quantum mechanics)
  - ⇒ masses of heavy quarks are not infinitely heavy
    (flavor dependence ? fine & hyper-fine splitting ?)
  - ⇒ multiscale hierarchy $m_q \gg m_q v \gg m_q v^2$ and $m_q \gg \Lambda_{\rm QCD}$

1. Introduction

- **A promising approach:**
  use an effective field theory "potential NRQCD"
  - ⇒ **related to QCD**
  - ⇒ **potential picture of heavy quarkonium**
  - ⇒ **but need nonperturbative inputs from QCD**
    (contain "unknown" functions corresponding to static potential and corrections classified in powers $1/m_q$)

Determine "unknown" functions from lattice QCD !

(presented also by Miho Koma, tomorrow)

Confinement/Deconfinement Mechanism and Quantum Field

X-QCD Japan
(K.Nagata, Y.Nakagawa, A. Nakamura and T.Saito)
and
M.Chernodub and V.I.Zakharov

Lattice QCD confronts experiments

— Japanese-German Seminar 2010 —

4- 6 November 2010, Mishima, Japan.

X QCD-J

Lattice QCD confronts Experiments

- Experiments
  - Heavy Ion Collisions at RHIC and LHC
    - Viscosity
- Lattice QCD
  - SU(2), Quench (still R/D phase)
  - Tool to study Features of Quantum Field Theory
    - Confinement
    - Magnetic Degrees of Freedom
    - Vortex

Finite temperature QCD with SLiNC fermions

Yoshifumi Nakamura

Center for Computational Sciences, University of Tsukuba, Japan
with M. Koma (Numazu) and Y. Koma (Numazu)

Japanese-German Seminar 2010 in Mishima, Nov. 4 - 6, 2010

1 Introduction

Recent results for the critical temperature T_c for N_f=3

T_c [MeV]	Fermion	observable	–
196(3)	KS	$\bar{\psi}\psi$	RBC/Bielefeld [1]
170(7)	KS	L	Wuppertal [2]
146(5)	KS	$\bar{\psi}\psi$	Wuppertal [2]
155-185	DWF	L	M. Cheng *et al.* [3]
171(10)(17)	DWF	$\bar{\psi}\psi$	M. Cheng *et al.* [3]

Motivation:

- determination T_c with dynamical u-, d-, s-quarks of Wilson type fermions
- to find cheap way to get T_c at the physical point
- to test fixed $m_u + m_d + m_s$ simulations at $T > 0$

2 Simulation

Tree level Symanzik glue + 3 flavors of SLiNC fermions [4]

$$S_G = \frac{6}{g^2}\left[c_0 \sum_{\text{plaq}} \frac{1}{3}\,\mathrm{Re\,Tr}\,(1 - U_{\text{plaquette}}) + c_1 \sum_{\text{rect}} \frac{1}{3}\,\mathrm{Re\,Tr}\,(1 - U_{\text{rectangle}})\right],$$

$$\frac{c_1}{c_0} = -\frac{1}{20}, \quad c_0 + 8c_1 = 1\,.$$

$$S_F = \sum_x \Big\{\bar\psi(x)\psi(x) - \kappa\,\bar\psi(x)U_\mu{}^\dagger(x-\hat\mu)[1+\gamma_\mu]\psi(x-\hat\mu) - \kappa\,\bar\psi(x)U_\mu(x)[1-\gamma_\mu]\psi(x+\hat\mu) + \frac{i}{2}\kappa\, c_{\text{SW}}\,\bar\psi(x)\sigma_{\mu\nu}F_{\mu\nu}(x)\psi(x)\Big\},$$

U_μ is replaced by stout link $e^{iQ_\mu(x)}U_\mu(x)$.

$$Q_\mu(x) = \frac{\alpha}{2i}\left[V_\mu(x)U_\mu^\dagger(x) - U_\mu(x)V_\mu^\dagger(x) - \frac{1}{3}\mathrm{Tr}\,\left(V_\mu(x)U_\mu^\dagger(x) - U_\mu(x)V_\mu^\dagger(x)\right)\right],$$

with smearing parameter $\alpha = 0.1, n = 1$. Simulations have performed by BQCD [5].

2.1 Results

$L_s^3 \times L_t = 32^3 \times 12$, $\beta = 5.50$, $\kappa = 0.1200, 0.1203, 0.1205, 0.1207, 0.1209$ (degenerate), $O(5000)$ trajectories. The critical point is around κ=0.1207 (cf. m_{PS} ~600 MeV, a ~0.09 fm, T ~ 180 MeV). More statistics is needed.

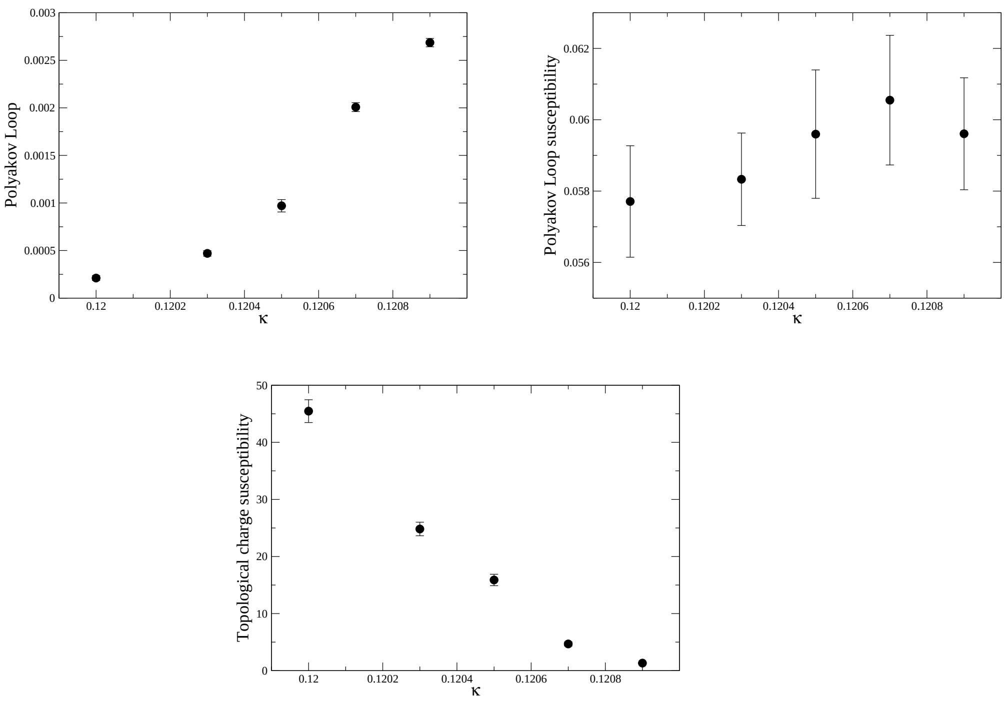


Figure 1: Polyakov loop (top left) and its susceptibility (top right) Topological charge susceptibility (bottom) as a function of κ at $L_t = 12$, β=5.50.

3 To the physical point

Traditionally, m_{ud} is decreased with fixing m_s as the physical value. It is difficult to tune parameters. Simulations are expensive around m_{ud}^{phy}.

3.1 New approach

Chiral perturbation theory, flavor singlet, e.g.

$$2m_K^2 + m_\pi^2 = 2(2B_0 m_s^R + 2B_0 m_l^R) + 2B_0 m_l^R + 2B_0 m_l^R + O((m_{q\in u,d,s}^R)^2) = 12B_0 m_q^R + O((m_{q\in u,d,s}^R)^2)$$

where $m_q^R = (2m_l^R + m_s^R)/3$.

Considering the Taylor expansion at $m_l^R = m_s^R = m_q^R$ with $\delta m_u^R + \delta m_d^R + \delta m_s^R = 0$ (for Wilson type fermion $1/\kappa_u + 1/\kappa_d + 1/\kappa_s = \text{const}$)

- $O(\delta m_{q\in u,d,s}^R)$ vanishes
- $O((\delta m_{q\in u,d,s}^R)^2)$ does not vanish
- a/r_0 does not depend on δm_q^R

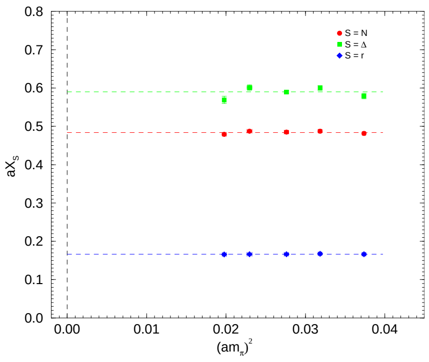


Figure 2: Some flavor singlet v.s. $(am_\pi)^2$ with $m_u + m_d + m_s$ = const. $X_r = 1/r_0$, $X_N = \frac{1}{3}(m_N + m_\Sigma + m_\Xi)$, $X_\Delta = \frac{1}{3}(2m_\Delta + m_\Omega)$ [6].

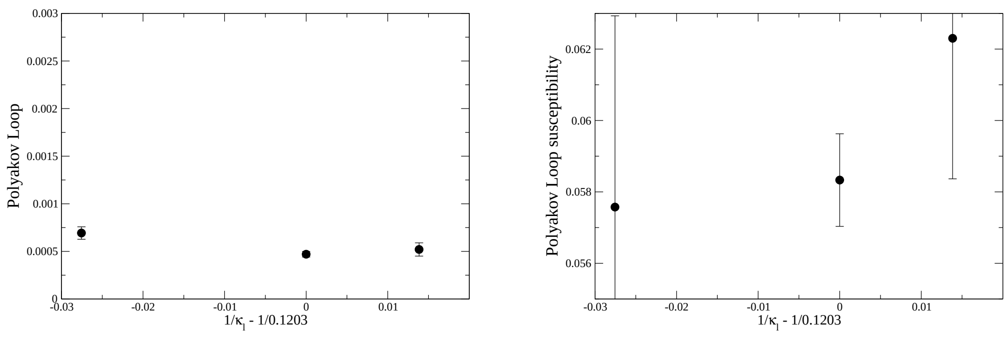


Figure 3: Polyakov loop and its susceptibility v.s. $(1/\kappa_l - 1/0.1203)$ (non-degenerate). O(500) trajectories except for one at $(1/\kappa_l - 1/0.1203)$=0.

If flavor blind quantities, flavor singlet such as Polyakov loop and chiral condensate do not depend on δm_q when $m_u + m_d + m_s$ = const,

$$T_c(m_u^{phy}, m_d^{phy}, m_s^{phy}) = T_c(m_q^{sym}) \quad \text{or} \quad T_c(m_\pi^{phy}, m_K^{phy}) = T_c(m_{PS}^{sym}),$$

wherer $m_{PS}^{sym} = \sqrt{(2(m_K^{phy})^2 + (m_\pi^{phy})^2)/3} \sim 413$ MeV).

4 Conclusion

We have performed finite temperature QCD simulations with 3 flavors of SLiNC fermions and presented preliminary results. New approach to the physical point for the critical temperature is described.

- more statistics to check $T_c(m_\pi, m_K) = T_c(m_{PS}^{sym}, m_{PS}^{sym})$
- more statistics and data point to determine T_c at β=5.50, L_t=12
- planing simulation for $a \to 0$, $m_{PS} \to 413$ MeV

5 Acknowledgements

We would like to thank the computer centers at KEK and RIKEN.

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Charm quark system on the physical point
in 2+1 flavor lattice QCD

Yusuke Namekawa(Univ. of Tsukuba)
for the PACS-CS collaboration

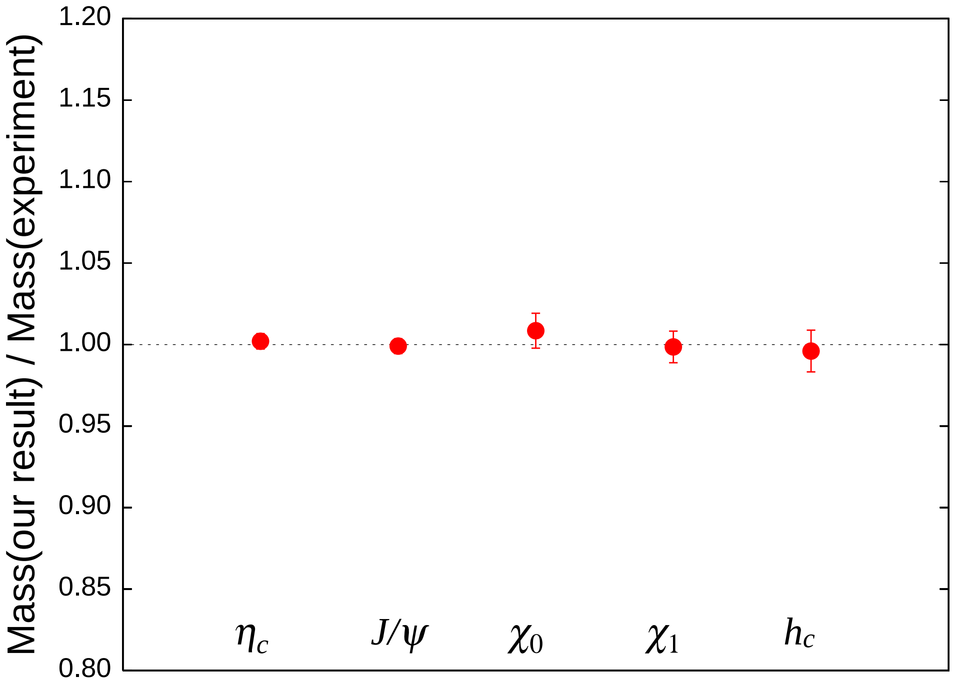
1 Simulation setup

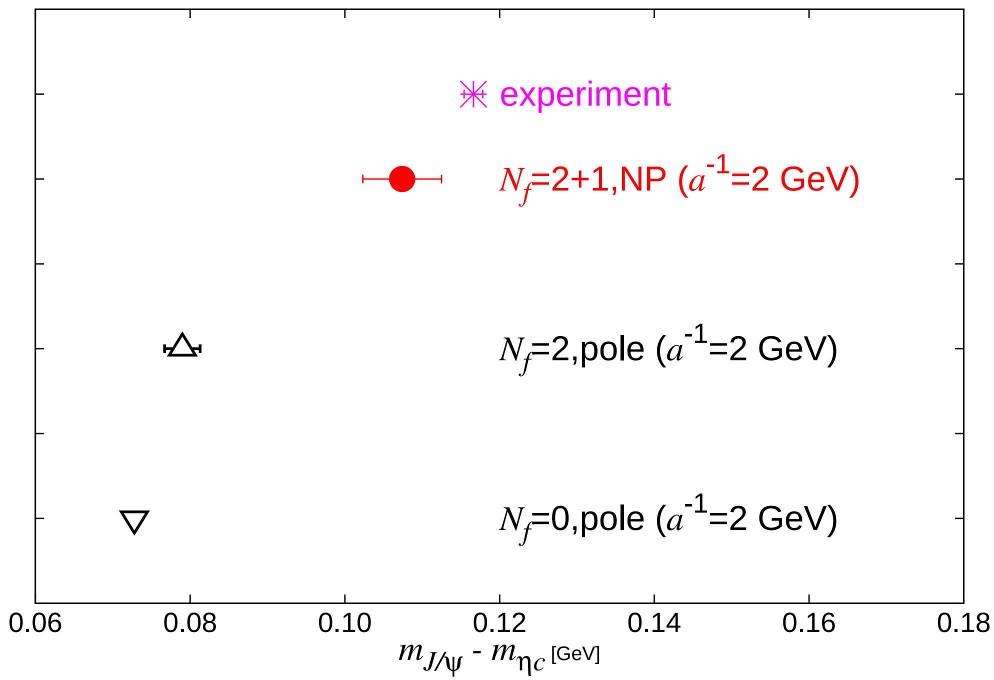
We use $N_f = 2 + 1$ configurations on the physical point. PACS-CS, 2009

- Quark masses : on the physical point(i.e. $m_\pi = 135$ MeV)
  $m_{ud}^{\overline{\rm MS}}(\mu = 2\ {\rm GeV}) = 3.0(3)$ MeV, $m_s^{\overline{\rm MS}}(\mu = 2\ {\rm GeV}) = 93(1)$ MeV
  - ◇ Inputs for m_{ud},m_s,a :
    $m_\pi = 135$ MeV, $m_K = 498$ MeV, $m_\Omega = 1673$ MeV
  - ◇ Input for m_{charm} :
    $\overline{m}(1S) := \frac{1}{4}(m_{\eta_c} + 3m_{J/\psi}) = 3068$ MeV

2 Heavy-heavy and heavy-light spectrum

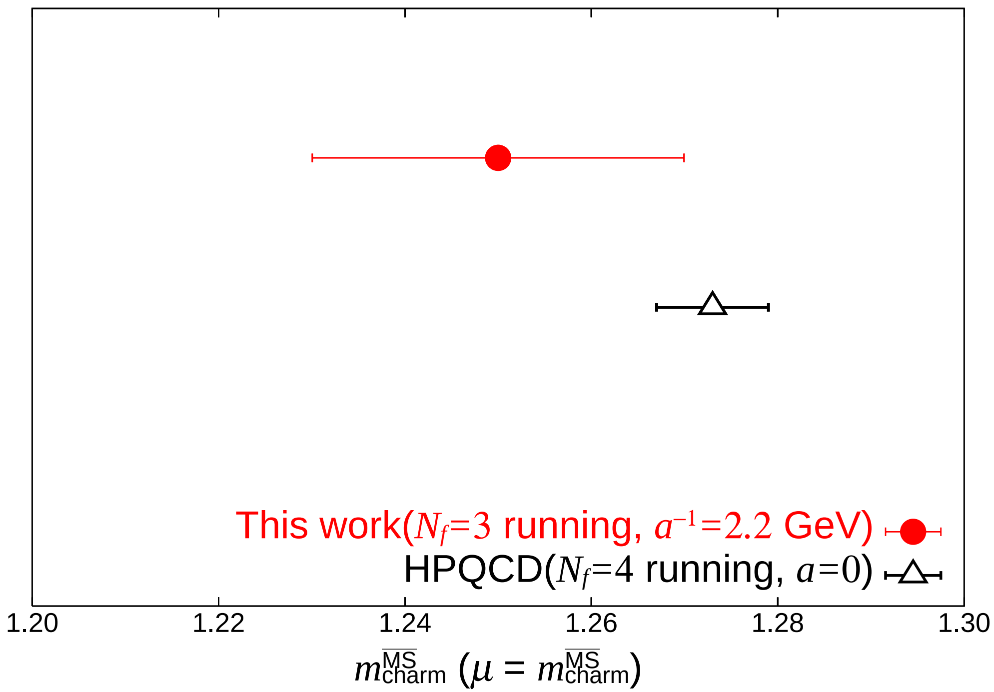
- Heavy-heavy and heavy-light spectrums agree with experiment.
- Hyperfine splitting of charmonium agrees with experiment in 2 σ. (But, more calculation is needed.) cf. C.DeTar's talk
  - ◇ Disconnected diagram has not been included, yet.
  - ◇ Continuum extrapolation has not been performed, yet.





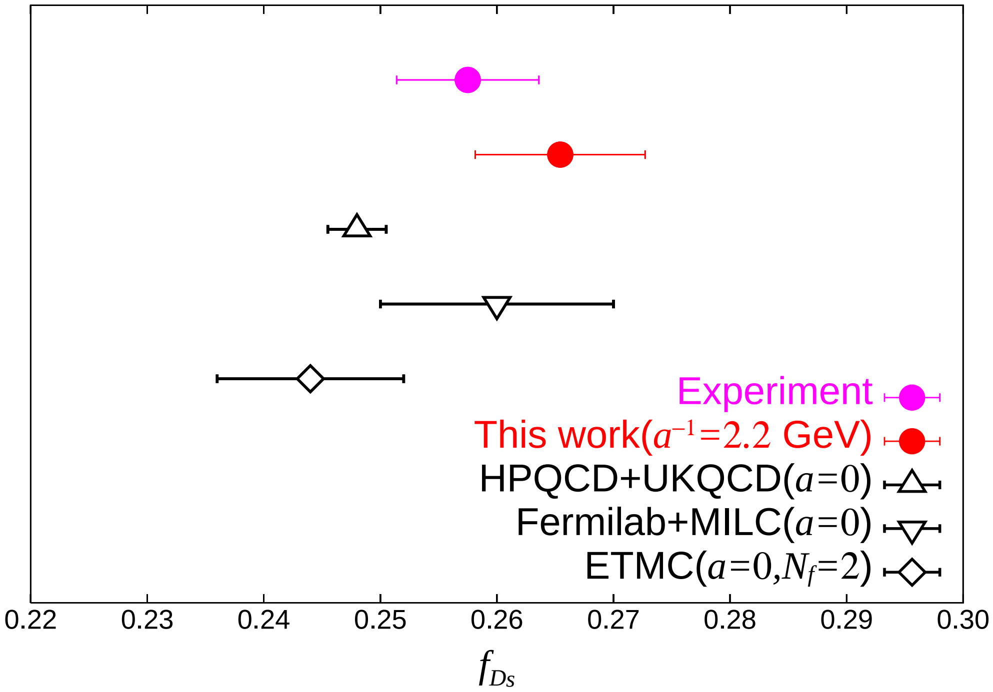
3 Charm quark mass

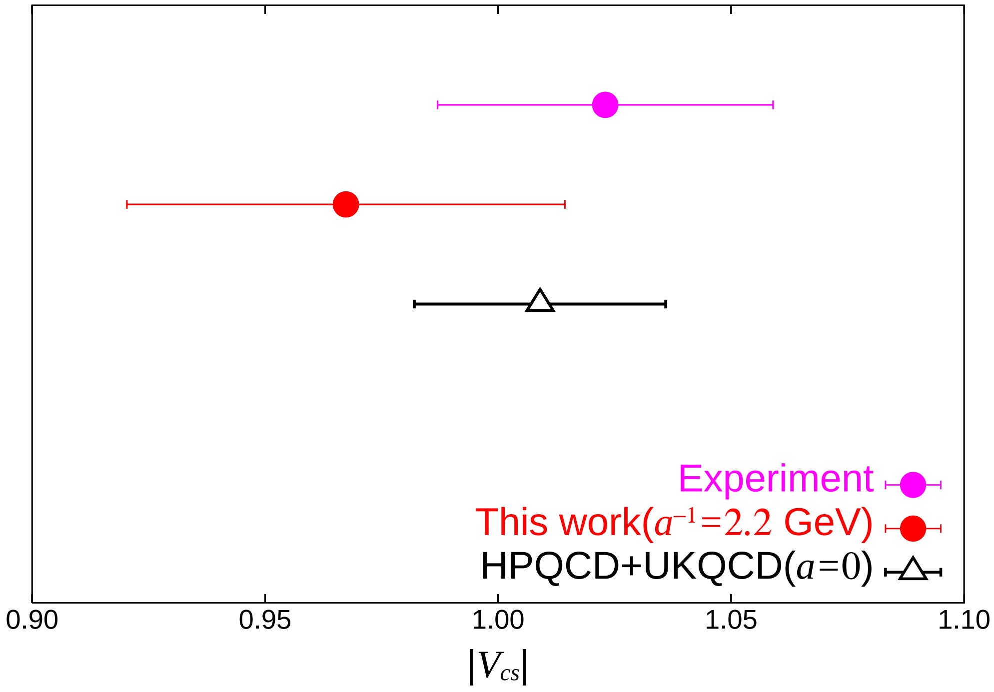
- Our result for the charm quark mass is consistent with HPQCD value.
  - ◇ Continuum extrapolation has not been performed, yet.
  - ◇ Our error is mainly from the scale determination and the non-perturbative renormalization factor.



4 Decay constants and CKM matrix elements

- Our decay constants agree with experiment in 2 σ.
- CKM matrix values are consistent. The errors are mainly from $\Gamma^{exp}(D_s \to l\nu)$.





Light meson physics with dynamical overlap simulations

Jun Noaki for the JLQCD and TWQCD collaborations

We summarize the project of the light meson spectrum with $N_f = 2+1$ overlap fermions by the JLQCD and TWQCD collaborations. We study the finite size effect by comparing the analytical correction with the data on a larger volume lattice. With the degenerate quark masses $m_{ud} = m_s$, we study the convergence property of ChPT. We also update the results of the chiral extrapolation to obtain physical quantities

Introduction

Dynamical overlap fermions [1] conserve chiral symmetry on the lattice and enable us to study the continuum ChPT for any N_f. In particular, the convergence property of ChPT at $m_s \sim$ 500 MeV is phenomenologically important. As an extension of our previous study for the $N_f = 2$ case [2], we generate $N_f = 2+1$ gauge configurations [3]. In this study, chiral extrapolation with NNLO ChPT formulae is necessary. We also update the chiral extrapolation with the increased number of data points.

Data points

- Our gauge configurations are summarized as

volume	m_{ud}	m_s	Q	trajs	
16^3x48	0.015 – 0.080 (5pts)	0.080	0	5,000	
	0.015 – 0.100 (5pts)	0.100	0	5,000	
	0.025	0.025	0	1,200	additional degenerate mass
	0.035	0.035	0	1,250	for the convergence study
	0.015	0.080	1	900	non-trivial topology
24^3x48	0.015	0.080	0	2,500	large volume to check finite size
	0.025	0.080	0	2,500	corrections

- We determine the lattice scale a^{-1} = 1.759(8)(5) GeV from the Ω-baryon mass as in Figure 1.
- Our pion mass covers 290 MeV < m_π < 780 MeV.
- Low-lying modes are computed & stored in disk. Used to improve the correlator (Low-Mode-Averaging).
- Quark mass is renormalized non-perturbatively through RI/MOM scheme [4].

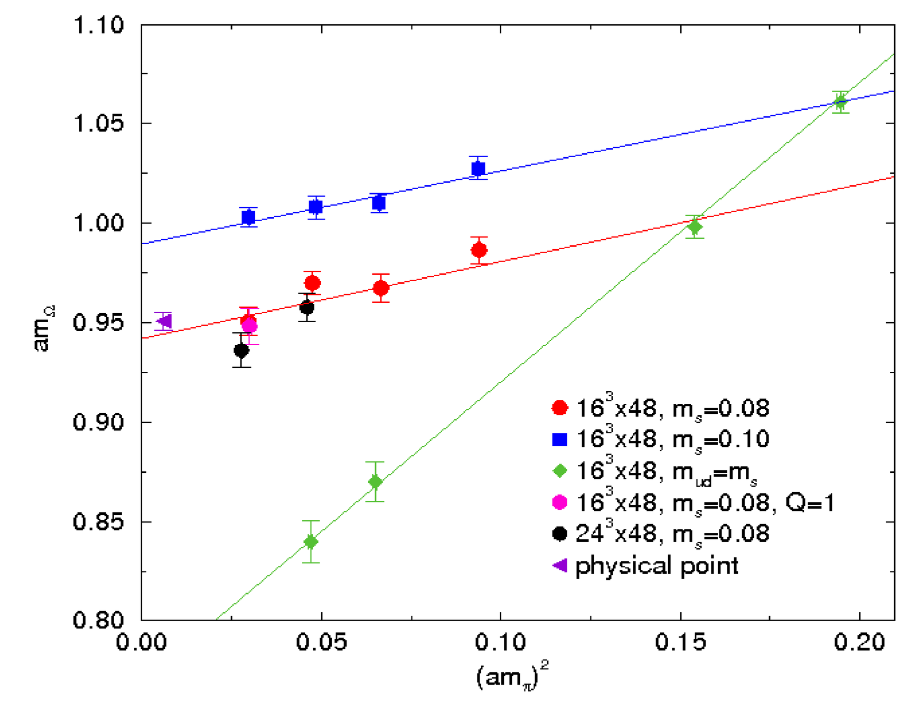


Figure 1: Ω-baryon mass as a function of pion mass in the lattice unit

Finite size effect (FSE)

We correct the data by a combination of the formulae for the two sources of FSE.

Conventional FSE: Caused by the pion wrapping around the spatial directions [5].

Fixed topology effect: Deviation from the θ-vacuum [6,7]. Topological susceptibility χ_t needed for the correction is calculated in [8].

Figure 2 shows how much FSE corrections the original data receive on the different volumes ($m_\pi L$ = 2.75 and 4.01). The smaller volume receive significant correction.

The remaining difference between the fully corrected values might be explained by higher order effects of the fixed-topology FSE. In this case, the correlators may have non-exponential functional [7]. We take this difference into account in the systematic error of the final result.

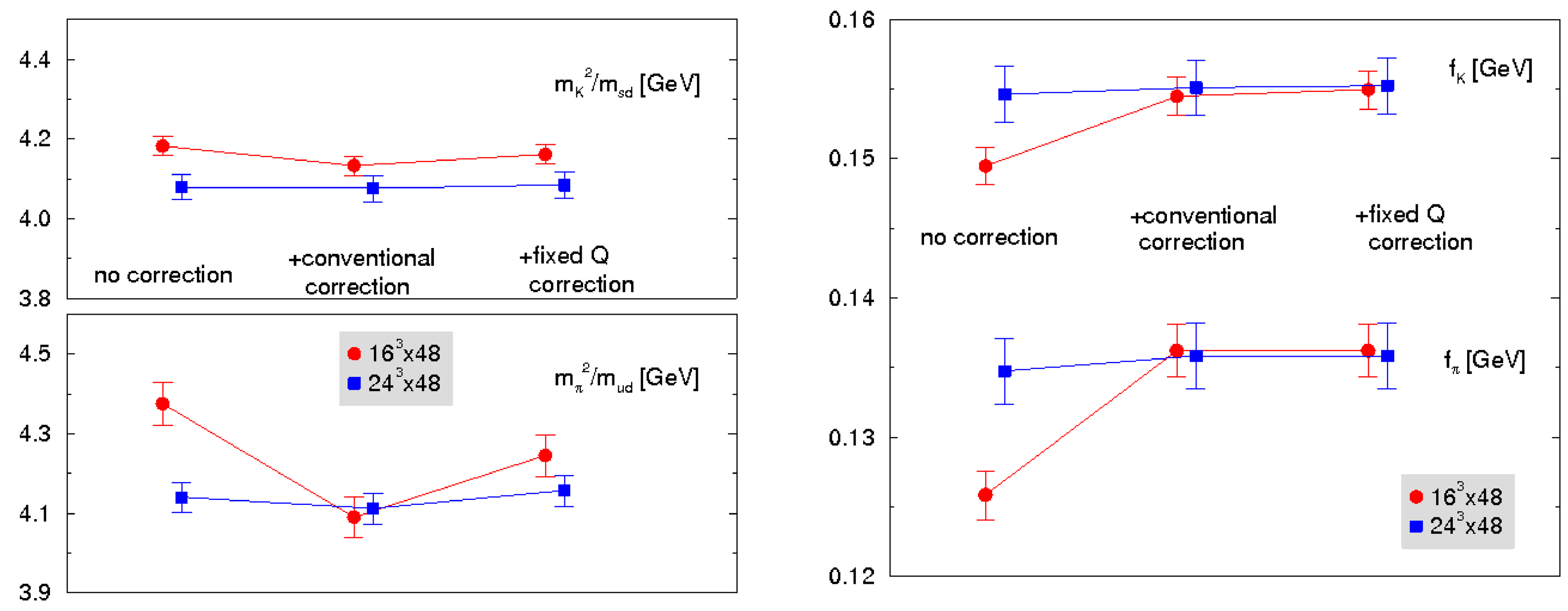


Figure 2: Transition of the data (the lightest quark mass) by FSEs

Convergence of SU(3) ChPT

The discussion on the convergence can be made simpler by considering ChPT in the SU(3) limit with the degenerate quark masses. Using eight such data points, we carry out the chiral extrapolation. The deviations from the tree level values are plotted in Figure 3. The convergence ratio around 500 MeV is summarized as follows.

	m_π^2/m_{ud} (NLO)	m_π^2/m_{ud} (NNLO)	f_π (NLO)	f_π (NNLO)
$N_f = 2+1$	–56(71)%	+95(268)%	+41(29)%	+23.7(5.6)%
$N_f = 2$	–4.5(2.1)%	+1.91(63)%	+29.6(5.7)%	+16.0(1.0)%

Also, results from $N_f = 2$ case is listed in the table for comparison. While the large error does not allow solid conclusion for m_π^2/m_{ud}, we see, for f_π, decreasing ratio and similar magnitude of convergence to the $N_f = 2$ case.

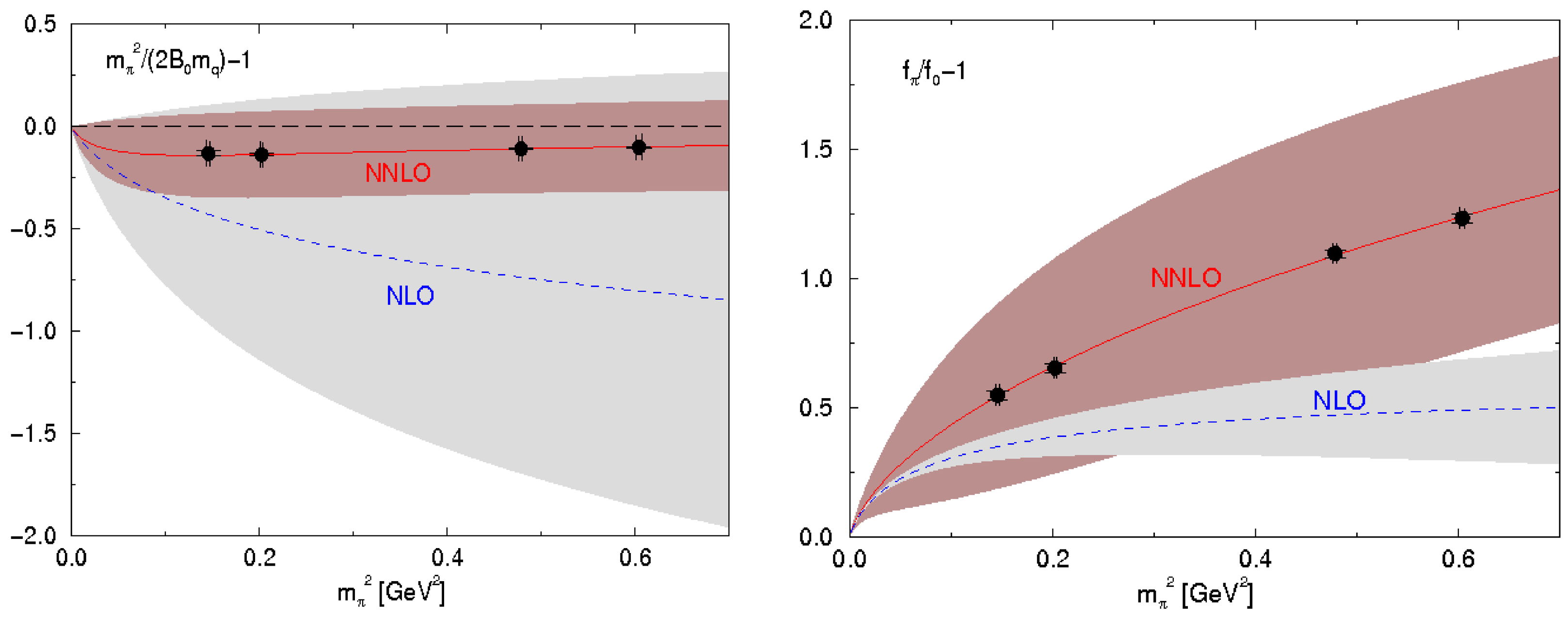


Figure 3: Results of the simultaneous fit to the NNLO ChPT at the SU(3) limit. Dashed curves indicate the truncation to NLO.

Chiral extrapolation at NNLO

With increased data points explained above, we update the chiral extrapolation of the light meson observables using the NNLO ChPT formulae. We use expansion parameters $\xi_\pi = 2m_\pi^2/(4\pi f_\pi)^2$, $\xi_K = 2m_K^2/(4\pi f_K)^2$ for a stable fit. See [9] for more detail about the chiral fit. Figure 4 shows the fit curves obtained from the correlated simultaneous fit with χ^2/dof = 2.6.

Because of the degenerate mass point, we obtain more stable fit results for SU(3) LECs than before. The pre-final results are

$$f_0 = 74.0(6.6)\ \text{MeV},\quad \Sigma_0^{1/3} = 177(12)\ \text{MeV},$$

$$L_4^r(m_\rho) = 8.2(3.4)\times 10^{-4},\ L_5^r(m_\rho) = -8.0(6.7)\times 10^{-4},$$

$$L_6^r(m_\rho) = 3.5(2.5)\times 10^{-4},\ L_8^r(m_\rho) = -3.2(3.0)\times 10^{-4}.$$

Result of f_0 is substantially smaller than the phenomenological estimate f_0 = 124 MeV. However, as seen in Figure 5, the N_f dependence of our data can be described by ChPT. Therefore, it is inevitable $f_0 < f$=110 MeV (the $N_f = 2$ value we obtain). Also, there is a large difference between $\Sigma_0^{1/3}$ the SU(2) chiral condensate $\Sigma^{1/3}$ = 230 MeV.

Results of the physical quantities are

$$f_\pi = 118.5(3.6)\ \text{MeV},\quad f_K = 145.8(2.7)\ \text{MeV},\quad f_K/f_\pi = 1.230(19),$$

$$m_{ud} = 4.028(57)\ \text{MeV},\quad m_s = 113.4(1.2)\ \text{MeV},\quad m_s/m_{ud} = 28.15(23).$$

There are also systematic errors to be considered.

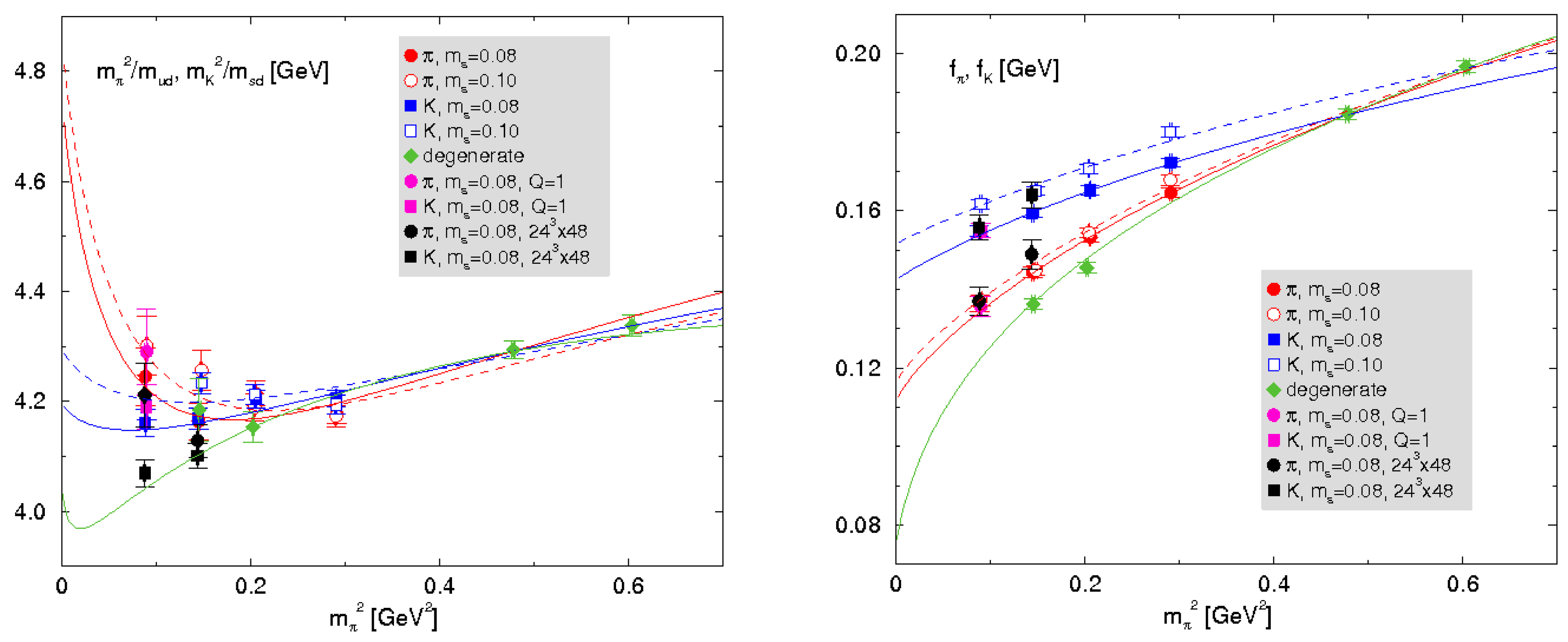


Figure 4: Chiral extrapolation with the NNLO ChPT using all available data points.

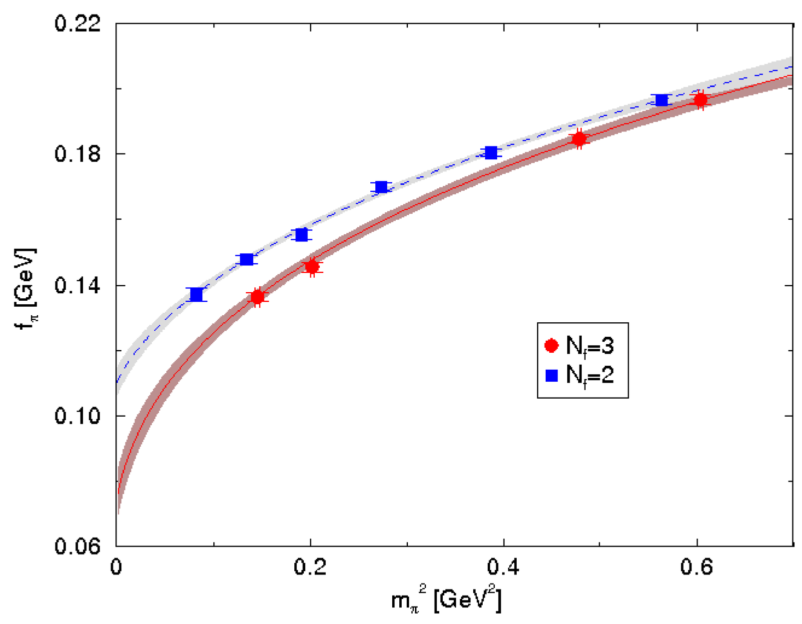


Figure 5: f_π for $N_f = 2$ and 3.

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A method to calculate meson spectral functions with a variational method in lattice QCD

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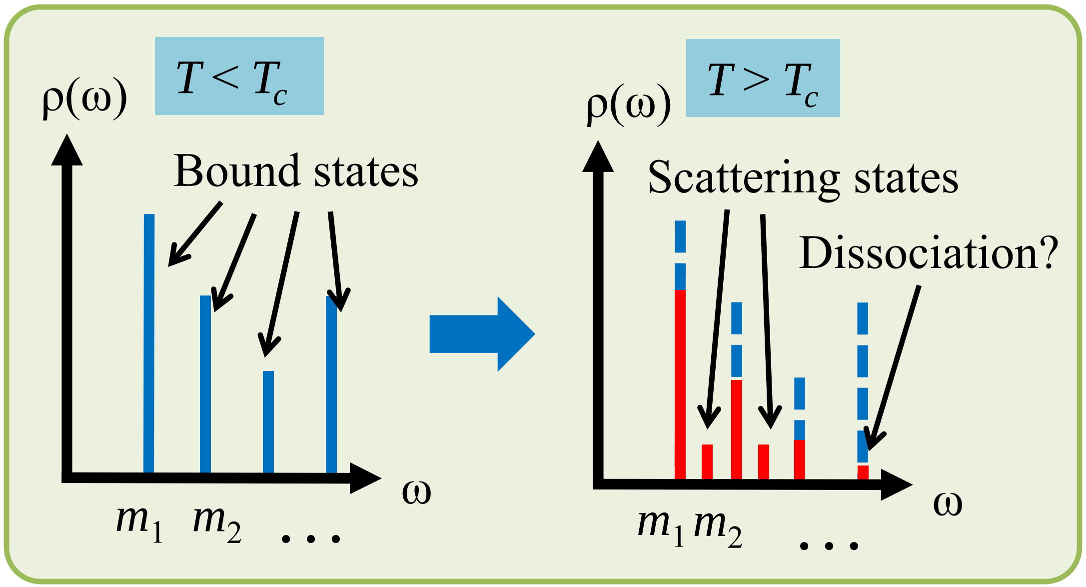
(WHOT-QCD Collaboration)
筑波大学 University of Tsukuba

Japanese German Seminar 2010, Mishima, Japan, November 2, 2010



- **Meson spectral functions** at finite temperature

  → important to investigate the behavior of mesons in medium

- On a finite volume lattice,

  → **discrete spectra only**

- A suitable way to extract such discrete signals is needed

variational method

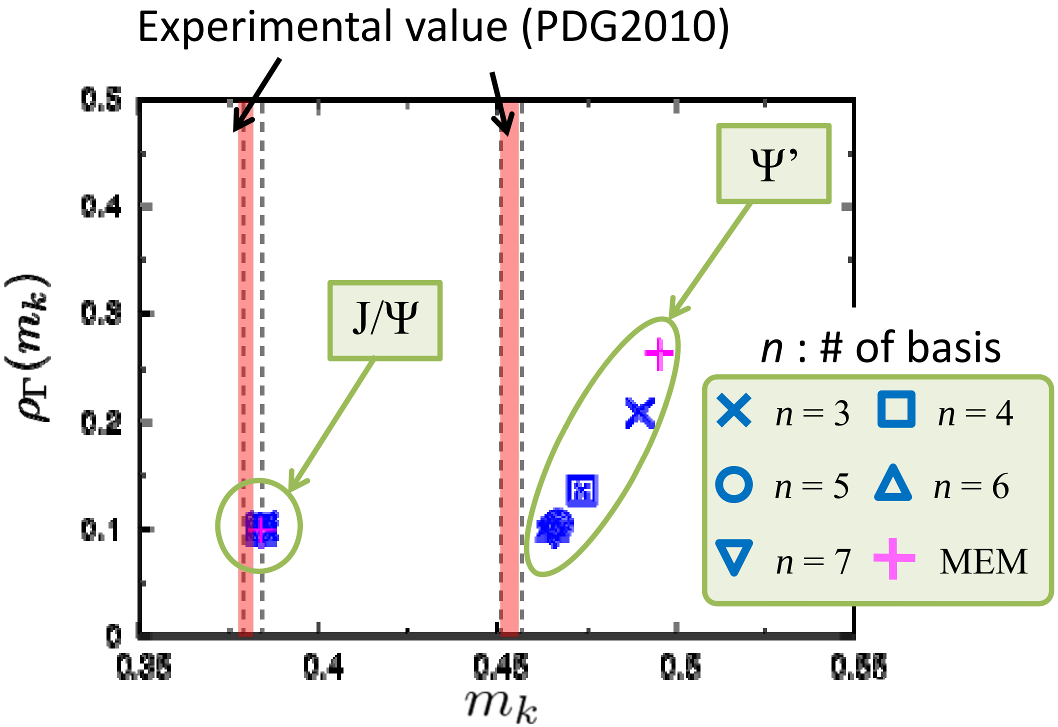
$$\mathcal{O}_\Gamma(\vec{x},t) \equiv \bar{q}(\vec{x},t)\Gamma q(\vec{x},t)$$

$$C_\Gamma(t) \equiv \sum_{\vec{x}} \langle \mathcal{O}_\Gamma(\vec{x},t)\mathcal{O}_\Gamma^\dagger(\vec{0},0)\rangle$$

$$= \sum_k \rho_\Gamma(m_k)\frac{\cosh[m_k(t-N_t/2)]}{\sinh[m_k N_t/2]}$$

m_k : effective mass

$\rho_\Gamma(m_k)$: SPF



Charmonium SPF at T=0

- Ps, Ve, Sc and Av channels
- The ground and 1st excited states
- The ground state

→ **consistent with MEM results**

- The 1st excited state

→ **converge to the exp. value as *n* increases for S-wave**

→ **the signals are reliably extracted**

Charmonium SPF at T>0

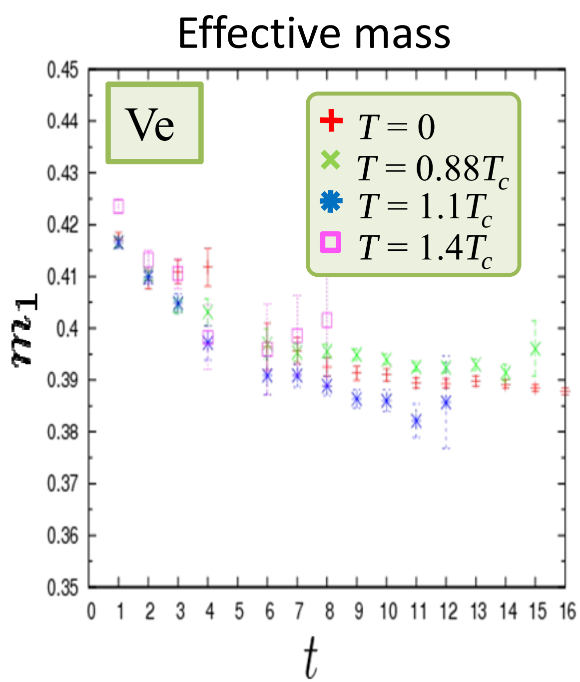
- Ps and Ve channels
- The ground state
- Up to $1.4T_c$
- Effective masses

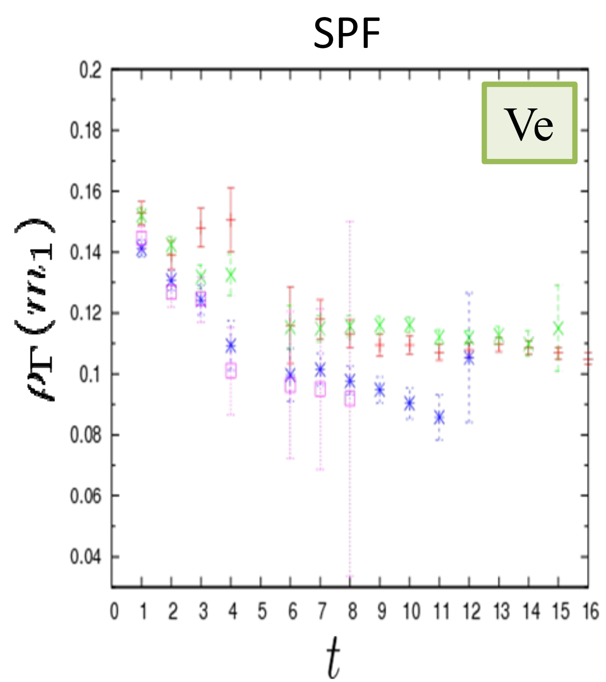
→ **no clear temp. dep.**

- SPFs

→ **modification is quite small**

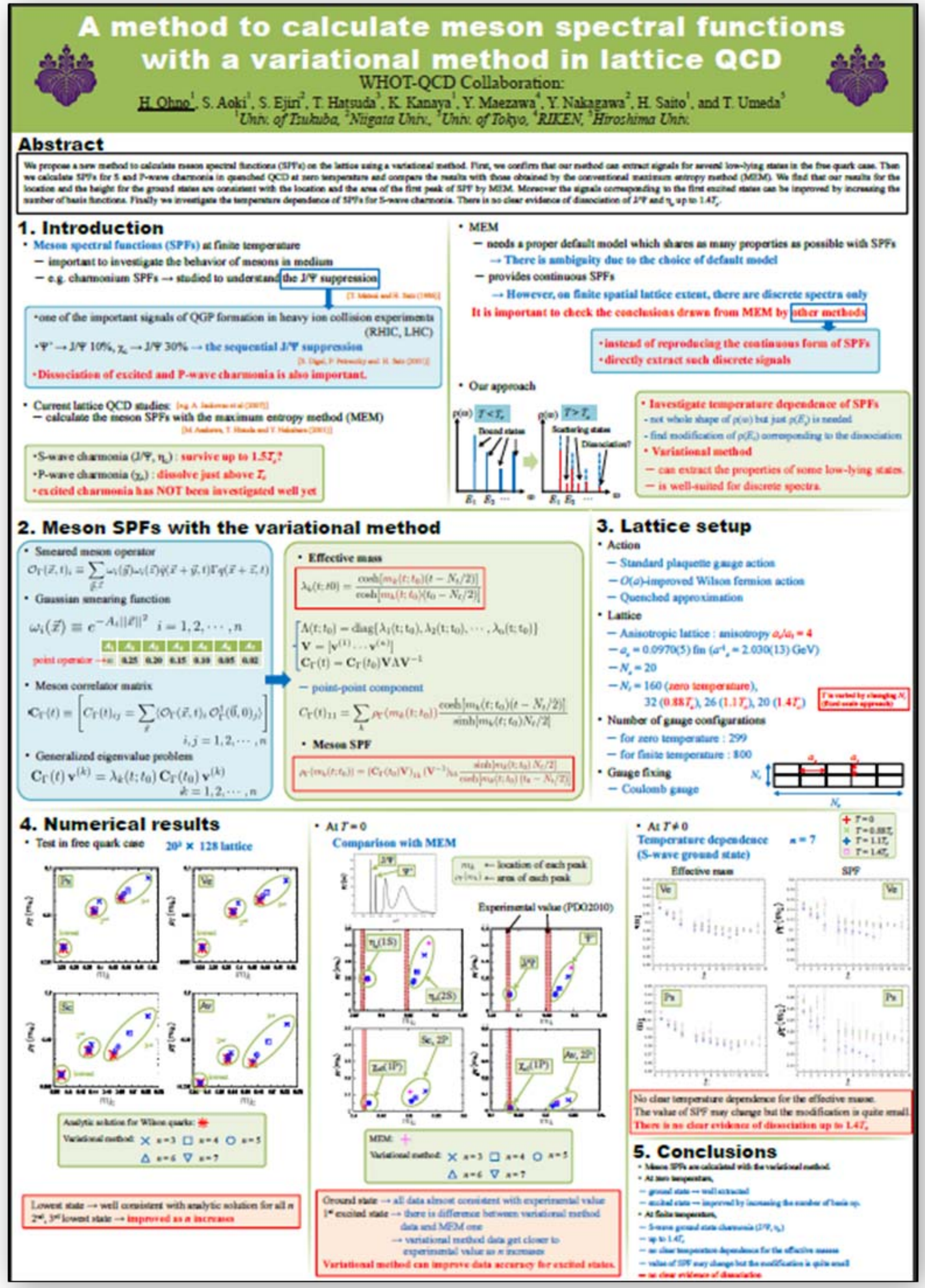
- **No clear evidence of dissociation**





The details are here! →

Please see my poster,
if you have some interest.



The order of the deconfinement phase transition in a heavy quark region - Dependence on N_f -

H. Saito for WHOT-QCD Collaboration

University of Tsukuba

Lattice QCD confronts experiments, Mishima, 2010 11/4-6

WHOT-QCD Collaboration:
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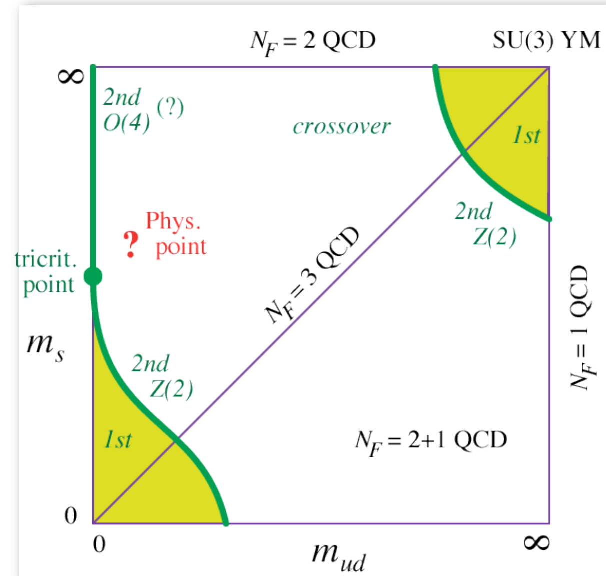
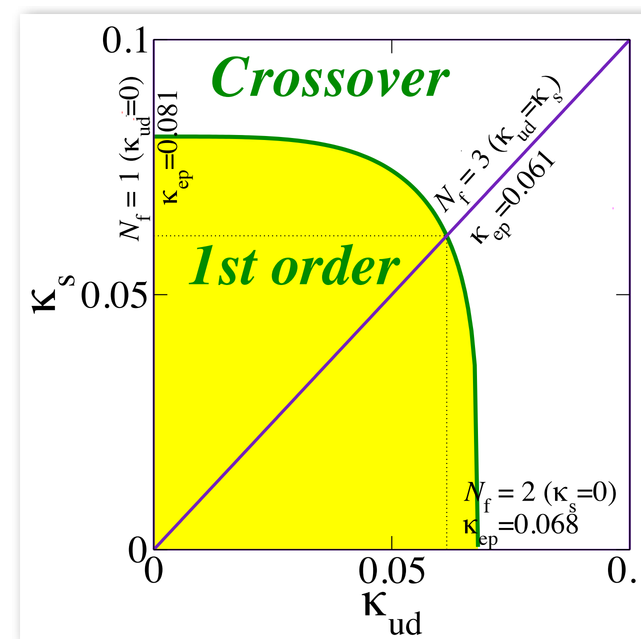
The order of the deconfinement phase transition

- **What is the order of the deconfinement phase transition?**
  - quark mass dependence
  - the end point of the 1st order transition



- **In this study**
  - the end point for $N_f = 2+1$ case in heavy quark mass region
  - test a method:
    { probability distribution function
    { reweighting



Method - Probability distribution function -

- probability distribution function

$$w(P') = \int \mathcal{D}U\mathcal{D}\psi\mathcal{D}\bar{\psi}\,\delta(P(U) - P')e^{-S}$$

plaquette: $P = -S_g/6N_{\rm site}\beta$

an effective potential

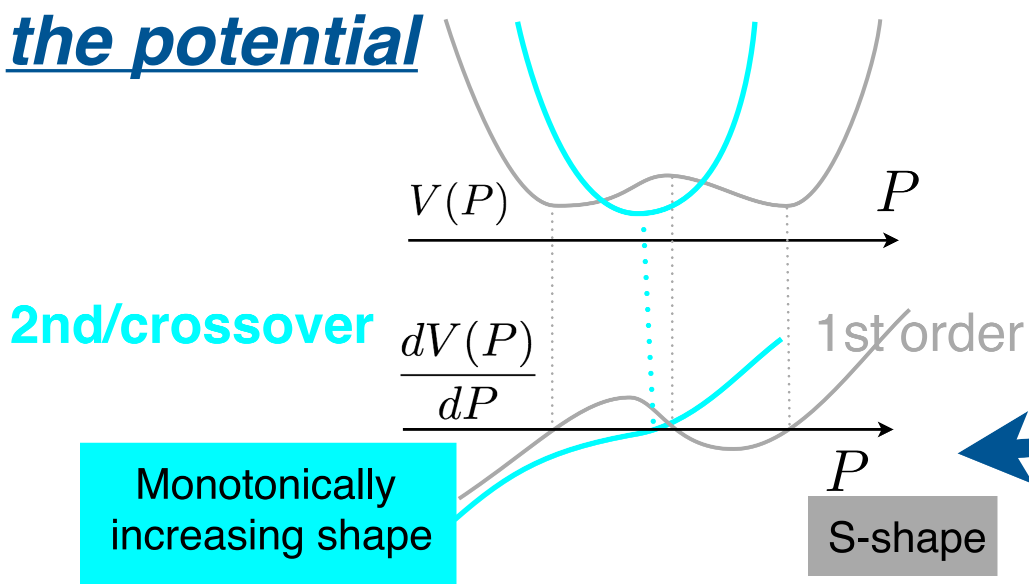
$$V(P) = -\ln w(P)$$

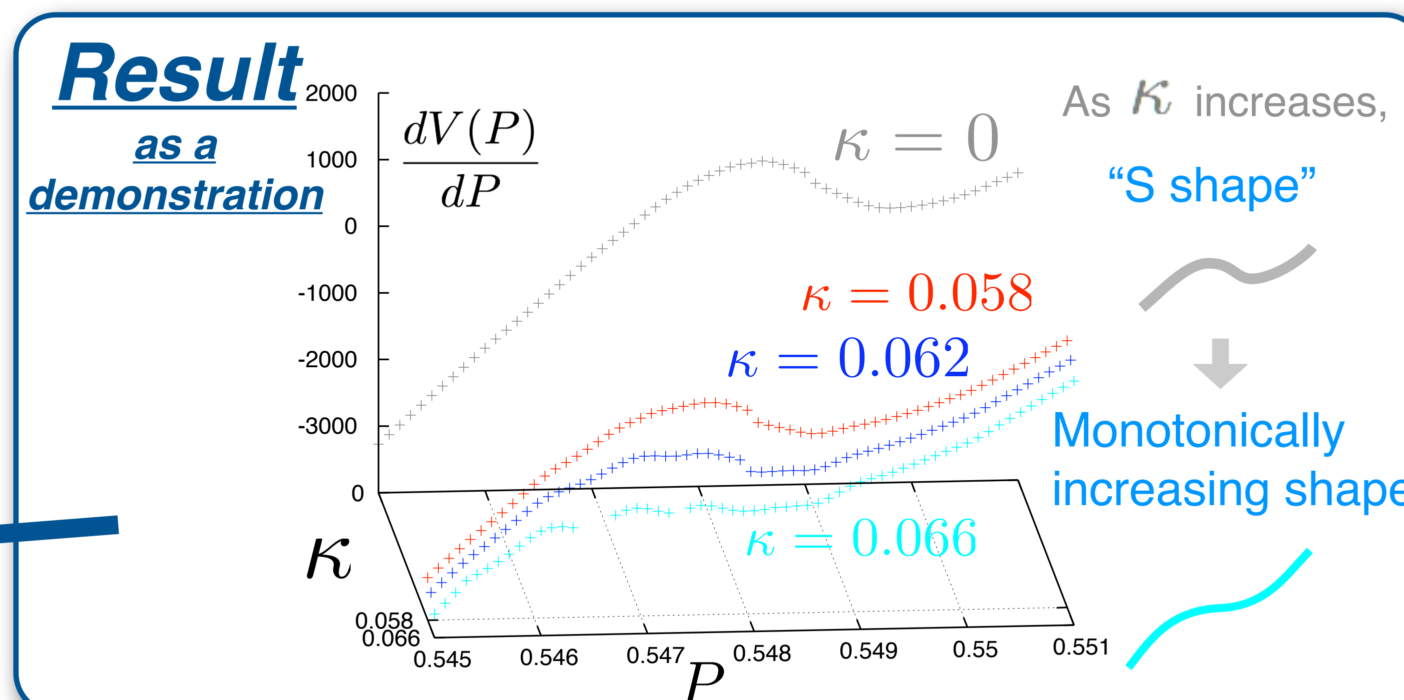
- reweighting of κ

$$V(P,\kappa) = -\ln R(\kappa) - \ln w(P,0) \quad \text{where} \quad R(\kappa) = \frac{w(P,\kappa)}{w(P,0)}$$

- The derivative of the effective potential

Nature of the potential





Phase structure of SU(2) gauge theory with adjoint Wilson fermions

H. Matsufuru in collab. with Y. Kikukawa, K.-I. Nagai, and N. Yamada

- Motivation: dynamical overlap simulations with SU(2) gauge
  - Fundamental and adjoint repr., Nf dependence, ε-regime
  - Search for conformal window
- Status: investigating phase structure of Wilson operator
  - Locality of overlap operator ⇔ Wilson kernel out of Aoki phase
  - Still "quenched" (Wilson fermions for topology fixing)
  - PS and V meson masses, quark mass, static potential
  - In progress: spectrum of overlap/Wilson operator, dynamical overlap simulations