固定格子間隔で行う有限温度格子QCD計算

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研究会「有限温度密度系の物理と格子ＱＣＤシミュレーション」
筑波大学　計算科学研究センター　2015年9月5日

金谷さんとの繋がり（梅田の経歴）

Education

March 1996 Bachelor of Science, Hiroshima University

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Positions held

April 2001 -- March 2003 :
COE Research Fellow at Center for Computational Physics, Tsukuba University

April 2003 -- May 2005 :
JSPS Research Fellow at YITP, Kyoto University

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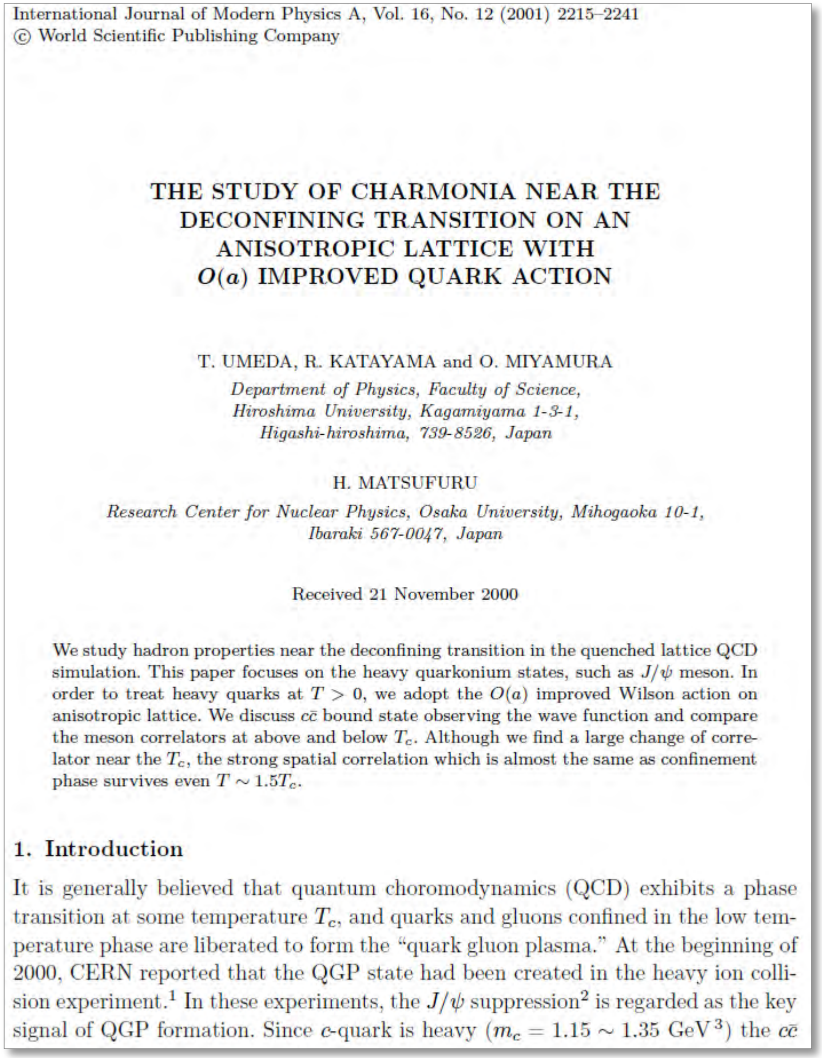
相転移近傍でのチャーモニウムの性質



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THE STUDY OF CHARMONIA NEAR THE DECONFINING TRANSITION ON AN ANISOTROPIC LATTICE WITH $O(a)$ IMPROVED QUARK ACTION

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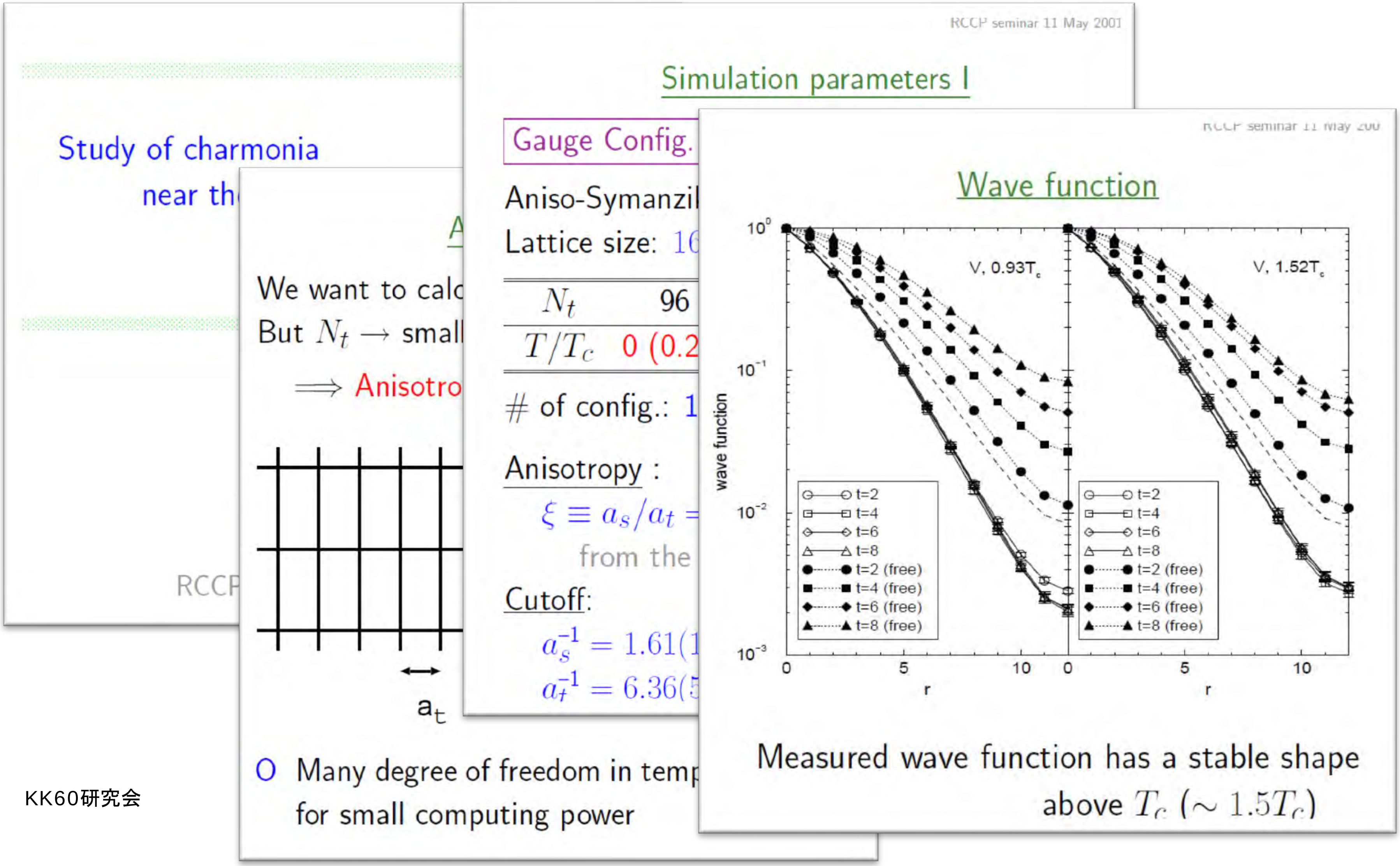
Received 21 November 2000

We study hadron properties near the deconfining transition in the quenched lattice QCD simulation. This paper focuses on the heavy quarkonium states, such as J/ψ meson. In order to treat heavy quarks at $T > 0$, we adopt the $O(a)$ improved Wilson action on anisotropic lattice. We discuss $c\bar{c}$ bound state observing the wave function and compare the meson correlators at above and below T_c. Although we find a large change of correlator near the T_c, the strong spatial correlation which is almost the same as confinement phase survives even $T \sim 1.5T_c$.

1. Introduction

It is generally believed that quantum choromodynamics (QCD) exhibits a phase transition at some temperature T_c, and quarks and gluons confined in the low temperature phase are liberated to form the "quark gluon plasma." At the beginning of 2000, CERN reported that the QGP state had been created in the heavy ion collision experiment.[1] In these experiments, the J/ψ suppression[2] is regarded as the key signal of QGP formation. Since c-quark is heavy ($m_c = 1.15 \sim 1.35$ GeV[3]) the $c\bar{c}$

相転移近傍でのチャーモニウムの性質



Study of charmonia

near th

RCCP

A

We want to calc

But $N_t \to$ small

$\Longrightarrow$ Anisotro

a_t

O Many degree of freedom in temp

for small computing power

RCCP seminar 11 May 2001

Simulation parameters I

Gauge Config.

Aniso-Symanzil

Lattice size: 16

N_t	96
T/T_c	0 (0.2

# of config.: 1

Anisotropy :

$\xi \equiv a_s/a_t =$

from the

Cutoff:

$a_s^{-1} = 1.61(1$

$a_t^{-1} = 6.36(5$

RCCP seminar 11 May 200

Wave function

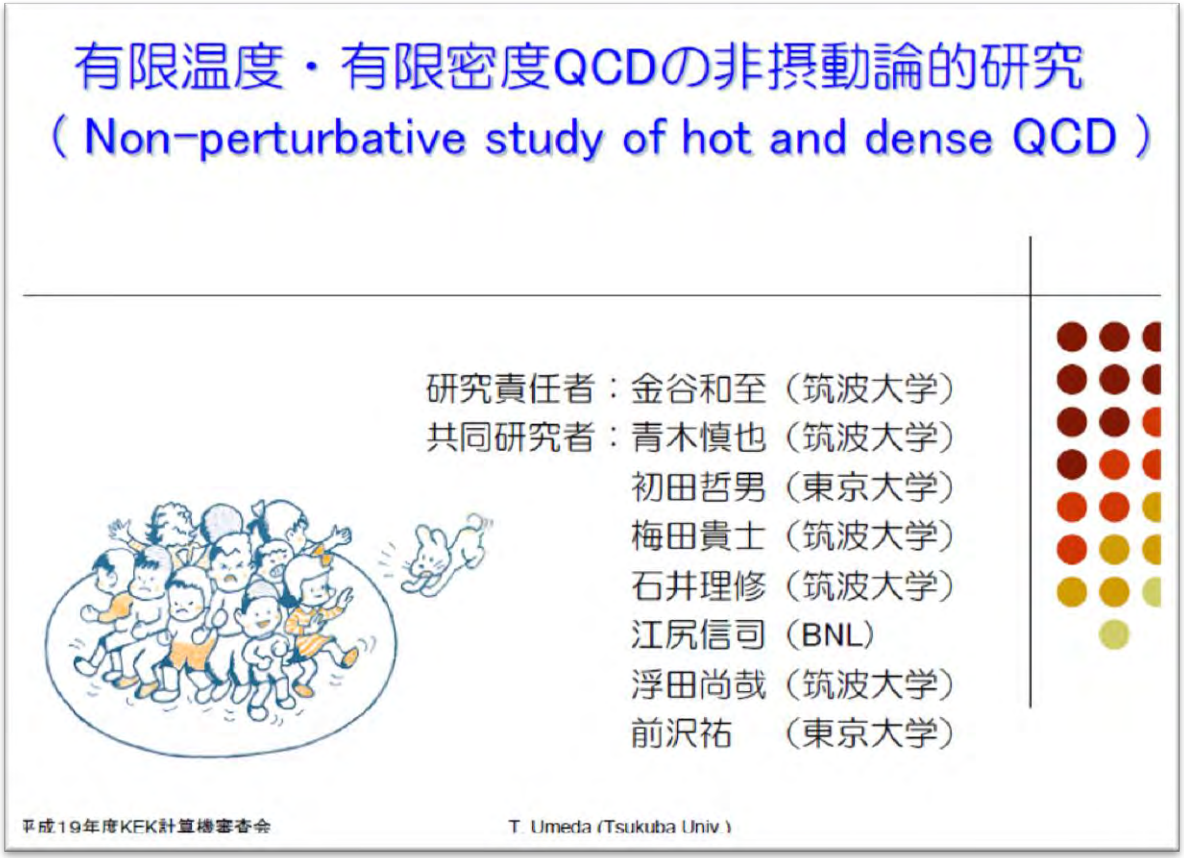
Measured wave function has a stable shape above T_c ($\sim 1.5 T_c$)

固定格子間隔のメリット

- 純粋に温度依存性が分かる
  - 体積、格子間隔、クォーク質量などが一定

- ゼロ温度での性質が共通
  - “素性”の分かっているパラメータを使える
  - ゼロ温度の解析が十分にできる
    - ハドロンスペクトル、クォークポテンシャルなど
    - 非等方格子など

2007~2008年 WHOT-QCD Collab.



有限温度・有限密度QCDの非摂動論的研究

(Non−perturbative study of hot and dense QCD)

研究責任者：金谷和至（筑波大学）
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梅田貴士（筑波大学）
石井理修（筑波大学）
江尻信司（BNL）
浮田尚哉（筑波大学）
前沢祐　（東京大学）

平成19年度KEK計算機審査会

T. Umeda (Tsukuba Univ.)

W(ilson quark を用いた)Hot(&Dense)-QCD (研究の為の) Collaboration

Wilson quark で有限温度QCDの研究

状態方程式などの有限温度計算を行う準備として

(ゼロ温度計算での)大規模なパラメータサーチが必要

- Line of Constant Physics
- T=0 subtraction
- Beta-function

→ Wilson quark では計算コストが大変

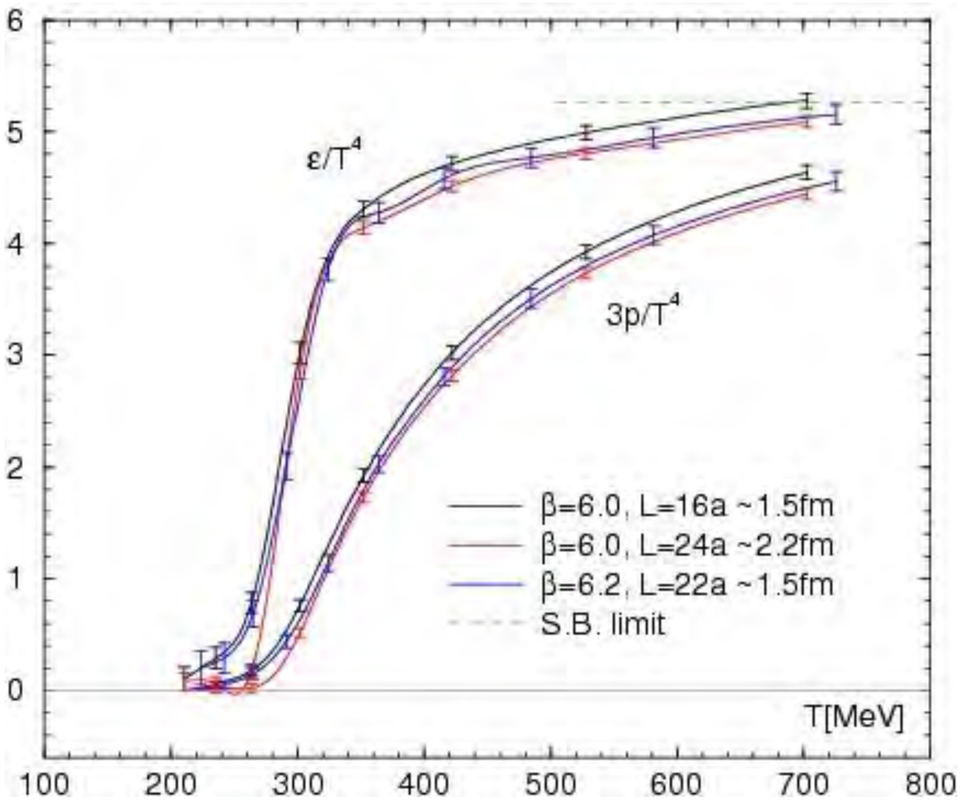
固定格子間隔のアプローチは使えないだろうか？

(状態方程式を計算する手法である積分法は使えない)

$$\frac{\epsilon - 3p}{T^4} = T\frac{\partial(p/T^4)}{\partial T} \Longrightarrow \frac{p}{T^4} = \int_0^T dT' \, \frac{\epsilon - 3p}{T'^5}$$

(温度積分法)

Equation of State in quenched QCD @ Lattice2008



- Integration $\left(\frac{p}{T^4} = \int_0^T dT' \frac{\epsilon - 3p}{T'^5}\right)$

  is performed with the cubic spline of $(e-3p)/T^4$

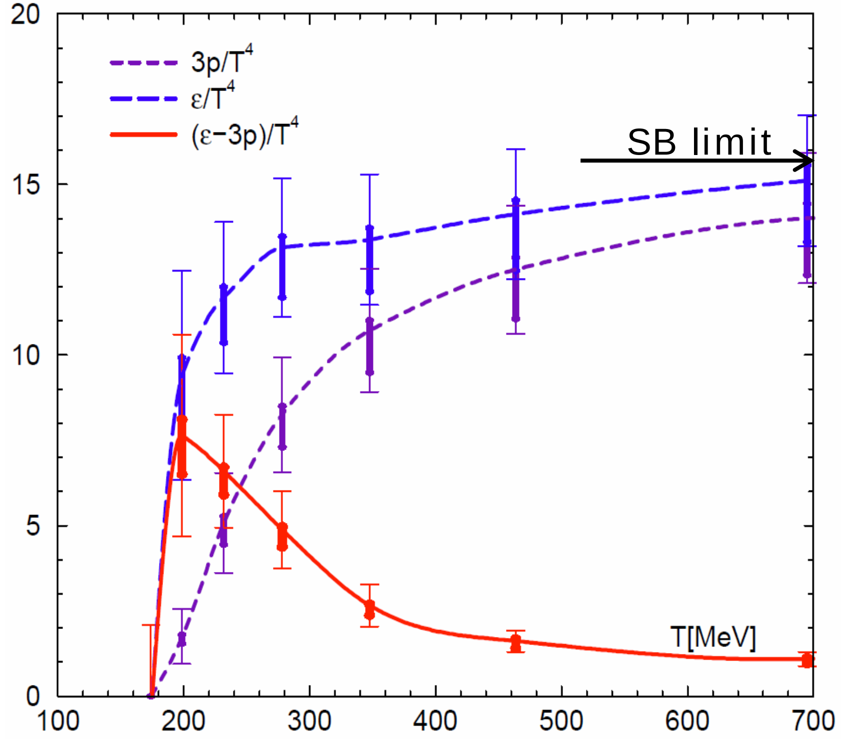
- Our results are roughly consistent with previous results.
  - -- mild scale violation
  - -- Large volume is important

- Unlike the fixed N_T approach, scale/temp. is not constant.

→ Lattice artifacts increase as temperature increases.

T. Umeda et al. (WHOT-QCD) Phys.Rev.D79 (2009) 051501.

Equation of State in N_f=2+1 QCD @ Lattice2012



T. Umeda et al. (WHOT-QCD)
Phys. Rev. D85 (2012) 094508

EOS is obtained by

temperature integration

in the Fixed scale approach

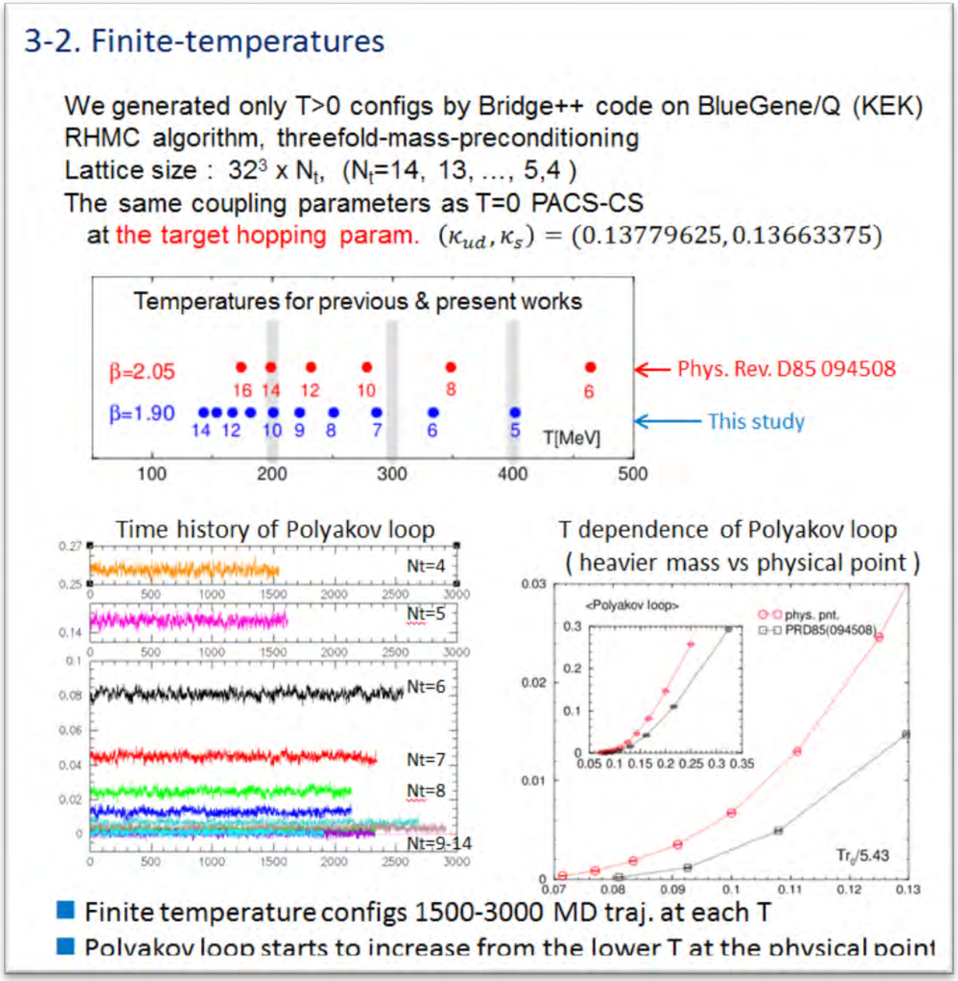
$$\frac{p}{T^4} = \int_0^T dt \frac{\epsilon - 3p}{t^5}$$

Some groups adopted the approach

- tmfT, arXiv:1311.1631
- Wuppertal, JHEP08(2012)126.

However possible temperatures are restricted by integer N_t

Toward the physical point @ Lattice2015



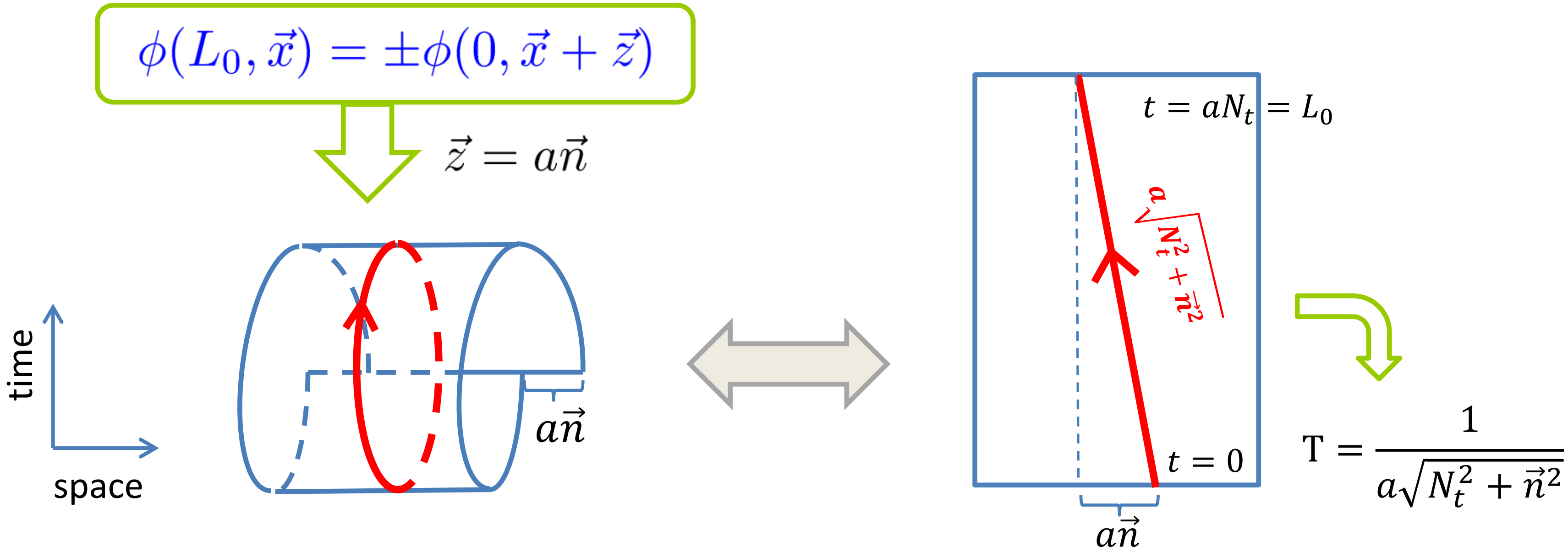
3-2. Finite-temperatures

We generated only T>0 configs by Bridge++ code on BlueGene/Q (KEK)
RHMC algorithm, threefold-mass-preconditioning
Lattice size : 32^3 x N_t, (N_t=14, 13, …, 5,4)
The same coupling parameters as T=0 PACS-CS
at the target hopping param. $(\kappa_{ud}, \kappa_s) = (0.13779625, 0.13663375)$

- Finite temperature configs 1500-3000 MD traj. at each T
- Polyakov loop starts to increase from the lower T at the physical point

Shifted boundary conditions at the fixed scale

L. Giusti and H. B. Meyer, Phys. Rev. Lett. 106 (2011) 131601.



$$\boxed{\phi(L_0, \vec{x}) = \pm\phi(0, \vec{x} + \vec{z})}$$

$\vec{z} = a\vec{n}$

$$\mathrm{T} = \frac{1}{a\sqrt{N_t^2 + \vec{n}^2}}$$

By using the shifted boundary
various T's are realized with the same lattice spacing

T resolution is largely improved
while keeping advantages of the fixed scale approach

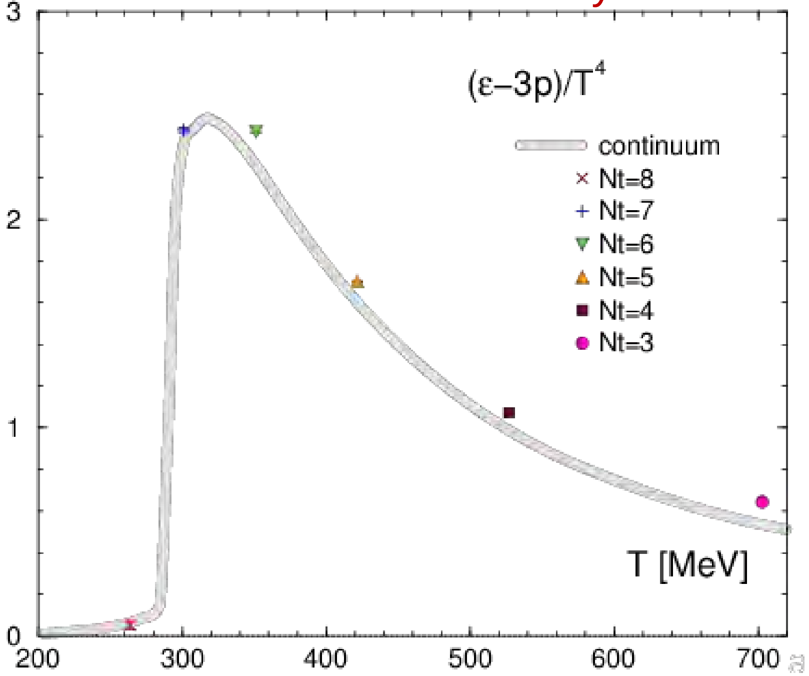
Trace anomaly (e-3p)/T^4

$$\frac{\epsilon - 3p}{T^4} = \left(\frac{1}{VT^3}\right) a \frac{d\beta}{da} \left\langle \frac{dS}{d\beta} \right\rangle_{sub}$$

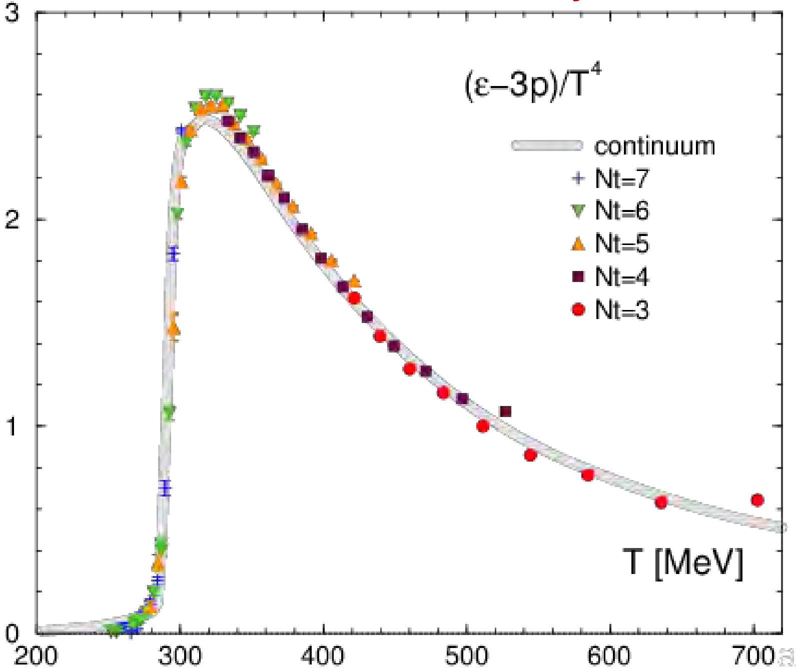
$$T = \frac{1}{a\sqrt{N_t^2 + \vec{n}^2}}$$

$$V = \prod_{i=1}^{3} \frac{aN_s}{\sqrt{1 + (\frac{n_i}{N_t})^2}}$$

w/o shifted boundary



w/ shifted boundary

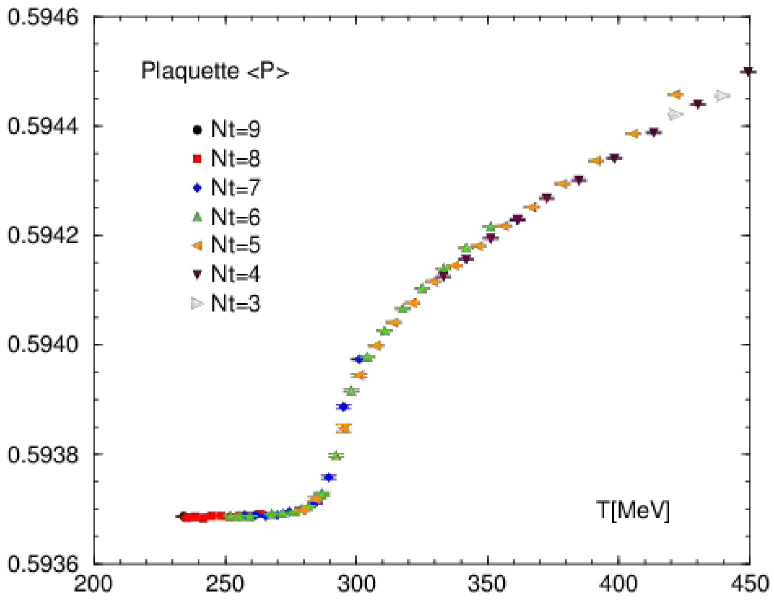


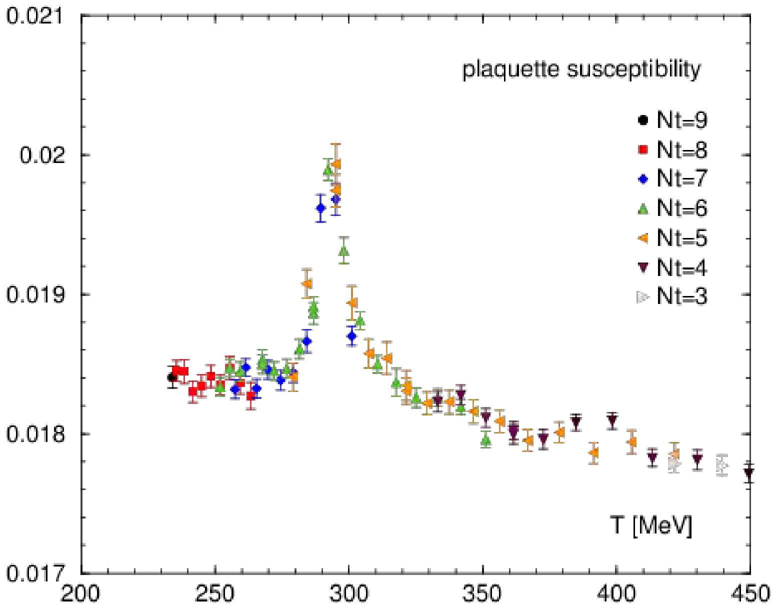
T. Umeda, Phys. Rev. D90 (2014) 5, 054511

Critical temperature Tc

Plaquette value $\langle P \rangle = \frac{1}{6N_s^3 N_t} \sum_P \langle 1 - \frac{1}{3} ReTrU_P \rangle$

Plaquette susceptibility $\chi_P = 6N_s^3 N_t \left(\langle P^2 \rangle - \langle P \rangle^2 \right)$





T. Umeda, Phys. Rev. D90 (2014) 5, 054511

Plaq. suscep. has a peak
around T = 294 MeV

Gradient flow を用いた熱力学量の計算

RAPID COMMUNICATIONS

PHYSICAL REVIEW D **90,** 011501(R) (2014)

Thermodynamics of $SU(3)$ gauge theory from gradient flow on the lattice

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(Received 5 January 2014; published 9 July 2014)

A novel method to study the bulk thermodynamics in lattice gauge theory is proposed on the basis of the Yang-Mills gradient flow with a fictitious time t. The energy density ε and the pressure P of $SU(3)$ gauge theory at fixed temperature are calculated directly on $32^3 \times (6, 8, 10)$ lattices from the thermal average of the well-defined energy-momentum tensor $T^R_{\mu\nu}(x)$ obtained by the gradient flow. It is demonstrated that the continuum limit can be taken in a controlled manner from the t dependence of the flowed data.

DOI: 10.1103/PhysRevD.90.011501 PACS numbers: 11.15.Ha, 05.70.Ce, 11.10.Wx

The symmetric energy-momentum tensor (EMT), $T_{\mu\nu}$, which is the generator of the Poincaré transformations, is a fundamental operator in quantum field theory [1]. Since T_{00}, T_{i0}, and T_{ij} correspond to the energy density, the momentum density, and the momentum-flux density, respectively, the EMT and its correlation functions provide useful information on the bulk and transport properties at finite temperature (T). For example, the energy density ε and the pressure P are given by $\langle T_{00}\rangle$ and $\langle T_{11,22,33}\rangle$,

[9–11]. (See, also, related works, Refs. [12–16].) In this paper, we demonstrate, for the first time, that the thermal $SU(3)$ gauge theory can be studied by the direct lattice measurement of the proper EMT by considering ε and P as examples. The key idea is to represent the EMT in the continuum limit by UV-finite and local operators obtained from the gradient flow. Then, by taking the limit of small flow time and small lattice spacing in an appropriate way, as discussed later, accurate thermodynamic observables are

まとめ

- 固定格子間隔による有限温度QCDの研究
  - 従来のアプローチとは異なる強み
  - Physical point の計算を目指して
- 固定格子間隔のデメリットの克服
  - Shifted boundary condition
  - Gradient flow

- 金谷さんとの共同研究
  - 要所要所で金谷さんのエッセンスを吸収しつつ研究をしてきた
  - これからも有限温度QCDの研究を発展させていきたい

金谷さん還暦おめでとうございます

Lattice2002@MIT のエクスカージョン(?)にて