Meson screening masses at finite temperature with Highly Improved Staggered Quarks

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Contents

Introduction

Meson propagators in HISQ and spectrum at $T=0$
  Strangeness, open-charm and charmonium

Screening mass at finite $T$
  At $T < T_c$, consistency with pole mass at $T = 0$
  At $T \sim T_c$, modification of meson bound state in QGP
  At high $T$, comparison with thermal perturbation theory

Summary
Introduction

In-medium properties of hadronic excitations in hot QCD matter

Heavy-Ion Collision Experiments at RHIC and LHC

Charmonium

purely created after collision: direct probe in HIC experiments
e.g. dissociation of $J/\psi$ at high temperature
direct signal that Quark-Gluon plasma is created Matsui and Satz (1986)

Survival probability of $J/\psi$
in PHENIX experiment at RHIC…

Suppression of survival probability of $J/\psi$
Understanding suppression of hadronic excitation in QGP
Theoretical understanding
of meson thermal properties: indispensable

Gunji et al. 2007

PHENIX Au+Au (0<y<0.35)

$S_n$, $S_{1/2}$, $0.7S_n + 0.3S_{1/2}$

$N_{part}$
**Introduction**

**Lattice QCD at finite temperature**

Direct investigation of hadronic excitation: Difficult

Meson correlation function to spatial direction: Screening mass

\[
G(z, T) = \int dx dy \int_0^{1/T} d\tau \langle \bar{q}\Gamma q(x, y, z, \tau)\bar{q}\Gamma q(0, 0, 0, 0)\rangle \xrightarrow{z \to \infty} A e^{-M_T z}
\]

\[
G(z, T) = \int_0^\infty \frac{2d\omega}{\omega} \int_{-\infty}^{\infty} dp ze^{ipz} \sigma(\omega, p_z, T)
\]

Spectral function

in thermal medium...

at \( T \sim 0 \), hadron structure: pole mass at \( T = 0 \): \( M(T) \sim m_0 \)

at \( T \sim T_c \), sensitive to quark structure: bound states broaden

at \( T \to \infty \), free meson with two quark propagators

which have the lowest Matsubara mode: \( M_{\text{free}} = 2\sqrt{(\pi T)^2 + m_q^2} \)
Meson screening mass at finite $T$

Boundary Condition to temporal direction:
Investigation of hadronic modification due to thermal effect

- Anti-periodic BC: $q(\vec{x}, 1/T) = -q(\vec{x}, 0)$
- Periodic BC: $q(\vec{x}, 1/T) = q(\vec{x}, 0)$

at low $T$: bosonic bound state $\Rightarrow$ no discrepancy
at high $T$: difference due to Matsubara mode

$M(T) \rightarrow \begin{cases} 
2\sqrt{(\pi T)^2 + m_q^2} & \text{for APB} \\
2m_q & \text{for PB} 
\end{cases}$

probe of temporal broadening $\Rightarrow$ width of the spectral function

Screening mass in lattice QCD simulations
in p4 action for light and charm sector (2011)
in this study: in HISQ action for charmonium,
open-charm and strangeness sectors
Highly Improved Staggered Quarks

**HISQ action** Bazavov et al. (2011)

- Reduction of the taste violation
- Control of the cutoff effects

Bulk thermal properties: investigated
Hot-QCD Coll. (2011)

- Abundant statistics with widely $T$ range: utilizable

**Lattice setup**

- 2+1 flavor QCD (charm quenched)
- $m_l/m_s = 0.05$ ($m_\pi \sim 160$ MeV, $m_K \sim 504$ MeV)
- $48^3 \times 48$ or 64 at $T = 0$
- $48^3 \times 12$, $\beta = 6.664 - 7.280$ ($T = 138 - 245$ MeV, 15 points)
- $N_\tau = 10, 8, 6, 4$ at $\beta = 7.280$, $N_s/N_\tau = 4$ ($T = 297 - 743$ MeV)

- Scale: $f_K$ input
- Meson propagators: point and wall sources (5000—10000 traj.)
$T = 0$

- Meson propagators in HISQ
- Meson spectrum in strange and charm
Meson correlators in staggered action

Staggered propagator: mixture of parities

\[ C(\tau) = A_{NO} e^{-m_- \tau} \]

\[ - (-)^{\tau} A_O e^{-m_+ \tau} \]

Meson propagator: S and PS

\[ C(C) = 48^3 \times 64 \]

\[ \beta = 7.280 \]

Effective masses

Taste different meson

Artifacts due to the taste violation:

well suppressed at large distance in HISQ action
Meson spectrum at $T = 0$

Ground states with negative parity

\[ M_{PS}^-, M_V^- \]

Determination of quark mass at $T = 0$

Strange-quark mass:

\[
m_{\eta_{s\bar{s}}} = \sqrt{2m_K^2 - m_\pi^2}\]

Charm-quark mass:

\[
\frac{1}{4}m_{\eta_c} + \frac{3}{4}m_{J/\psi}
\]

No significant $\beta$ dependence:

well improvement of the cutoff effect in HISQ action
Finite temperature

- Screening mass: Anti-periodic BC and periodic BC
  - Charmonium
  - Open-charm and strangeness
- At high temperature
  - comparison with thermal perturbation theory
Charmonium screening mass at $T \sim T_c$

Screening mass divided by pole mass at $T = 0$

- At low $T$: $M(T)/m_0 = 1$
- At $T \sim 200—220$ MeV:
  - APB: increases
  - PB: decreases
- At high $T$:
  - $M^{APB} \sim 2\sqrt{(\pi T)^2 + m_c^2}$
  - $M^{PB} \sim 2m_c$
- $\eta_c$, $J/\psi$ survive at $T < 1.3T_c$
- and modified at $T > 1.3—1.4T_c$
Open-charm and strangeness: $T \sim T_c$

at $T \sim 160$ MeV:
- discrepancy btw APB and PB

$D_s, D_s^*$ modified at $T > T_c$

$\eta_{s\bar{s}}, \phi$ significant modification at $T < 0.8T_c$

even at $T < 140$ MeV:
- discrepancy btw APB and PB
Screening mass at high $T$ vs. thermal perturbation

with $T$ increasing...

$c\bar{c}$, $s\bar{c}$

$M/T$ decreases and converges to $2\pi$

$S\bar{S}$

Significant $T$ dependent slightly above $T_c$

Convergence to $2\pi$

PS: from below

V: from above

Thermal perturbation

- all channel converges
- described by

$$M_{\text{weak}} = 2\pi T(1 + g^2 \times \begin{cases} 0.022(N_f = 0) \\ 0.033(N_f = 3) \end{cases})$$

on lattice: no convergence

similar results in p4 (2011)

precise investigations at high $T$: future
Summary

Meson screening masses in Highly Improved Staggered Quarks
for charmonium, open-charm and strangeness

at low $T$: corresponding to pole mass at $T = 0$

at high $T$: convergence to $2\sqrt{\left(\pi T\right)^2 + m_q^2}$ with Anti-periodic BC

$2m_q$ with periodic BC

Modification due to thermal medium

$\eta_c$, $J/\psi$ survive at $T \sim 1.3 T_c$

$D_s$, $D_s^*$ modified at $T \sim T_c$

$(\eta s\bar{s})$, $\phi$ significant modification even at $T < 0.8 T_c$

Comparison with thermal perturbation: $S\bar{S}$ V— is similar, but PS— is not

no convergence: precise investigation at higher $T$