Transverse and longitudinal spectral functions of charmonia at finite temperature with maximum entropy method

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I. Background

- Strongly coupled Quark Gluon Plasma
  Ultra Relativistic Heavy Ion Collision (RHIC, LHC)
- Heavy meson in QGP(J/ψ, ηc, etc)
  → Dynamical properties in QGP (dissociation, dispersion)
- Lattice QCD
  Charmonium at rest frame were considered.
  →Charmonium at moving frame

Purpose

1. Dispersion relations of charmonium at finite temperature
2. Dissociation
3. Decomposition into transverse and longitudinal components with vector channel

II. Maximum entropy method

Analytic continuation

Euclidean correlator (Lattice QCD)

$$\boxed{D(\tau,\vec{p})} = \int d^3x e^{i\vec{p}\cdot\vec{x}} \left\langle J_i(\tau,\vec{x}) J_i^\dagger(0,\vec{0})\right\rangle$$

$$= \int_0^\infty K(\tau,\omega)\boxed{A(\omega,\vec{p})}d\omega \qquad K(\tau,\omega) = \frac{e^{-\tau\omega}+e^{-(\beta-\tau)\omega}}{1-e^{-\beta\omega}}$$

Spectral function (real time information)

MEM

$$A_{\mathrm{out}} = \int d\alpha \int [dA]\, A(\omega) P(A,\alpha)$$

$$P(A,\alpha) = [\text{Likelihood function}](A) \times [\text{Prior probability}](A,\alpha)/Z$$

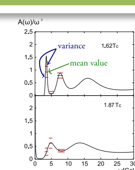
Likelihood function Lattice QCD info	*Prior probabilty* Supply a pQCD info
$\exp(-\chi^2)$ $= \exp\left[-\frac{1}{2}\sum_{i,j}(D(\tau_i)-D_A(\tau_i))C_{ij}^{-1}(D(\tau_j)-D_A(\tau_j))\right]$	$\exp\left(\alpha\int_0^\infty \left[A(\omega)-m(\omega)-A(\omega)\log\left(\frac{A(\omega)}{m(\omega)}\right)\right]d\omega\right)$ $m(\omega)=m_0\omega^2$

Error estimation in MEM

$$\langle(\delta A_{\mathrm{out}})^2\rangle_I = \int d\alpha \int [dA] \int_{I\times I} d\omega d\omega' \delta A(\omega)\delta A(\omega') P(A,\alpha)$$

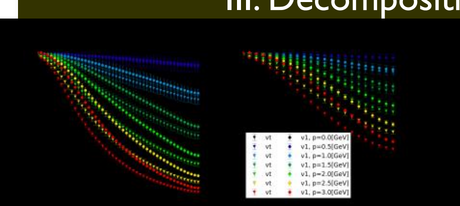
$$/ \int_{I\times I} d\omega d\omega'$$

$$\delta A(\omega) = A(\omega) - A_\alpha(\omega)$$



M.Asakawa and T.Hatsuda, PRL. 92, (2004).

III. Decomposition



...tor channel correlators decompose with zero momentum

Decomposition of Spectral function

$$A^{\mu\nu}(\omega,\vec{k}) = P_L^{\mu\nu}A_L(\omega,\vec{k}) + P_T^{\mu\nu}A_T(\omega,\vec{k})$$

When $k=(\omega,p,0,0)$,

$$A_T(\omega,p) = \frac{A_2(\omega,p)+A_3(\omega,p)}{2}$$

$$A_L(\omega,p) = \frac{\omega^2-p^2}{\omega^2}A_1(\omega,p)$$

Same quantity at zero temperature

IV. Results

Lattice setup

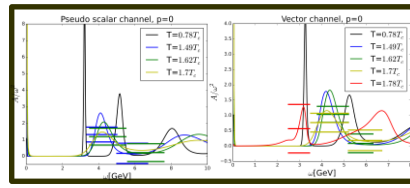
- SU(3) pure gauge theory
- Wilson gauge and standard Wilson quark action

N_τ	T/T_c	N_σ	L_σ[fm]	a_σ[fm]	a_σ/a_τ	β	Nconf
42	1.86	64	2.5	0.00975	4	7	500
46	1.62	64	2.5	0.00975	4	7	500
50	1.49	64	2.5	0.00975	4	7	500
96	0.78	64	2.5	0.00975	4	7	500

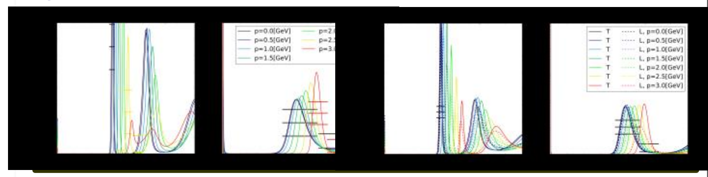
Calculated on Blue Gene @ KEK, FermiQCD & iroiro++

Dissociation

- Charmonium survive up to 1.62Tc
  →consistent with a prior research
- We analyzed the dispersion and the residue under 1.62Tc



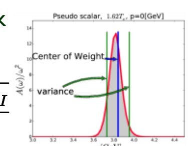
Spectral function with momentum



Despersion relation

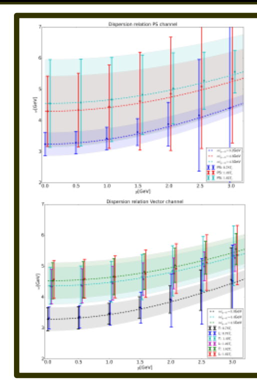
- Error estimation with the center of weight of a peak

$$(\text{variance}) = \frac{\sqrt{\langle(\omega\delta A(\omega)/\omega^2)^2\rangle_I}}{\langle A(\omega)/\omega^2\rangle_I}$$



- Consistent with the Lorentz invariant dispersion relation form

$$\omega = \sqrt{{m_0}^2+p^2}$$



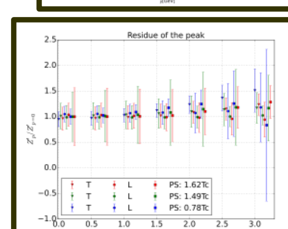
Residue of the peak

- In vacuum, from Lorentz invariance

$$A(\omega,p) = Z\delta(\omega^2-p^2-m^2)$$
$$= \frac{Z}{2\omega}\delta\left(\omega-\sqrt{p^2-m^2}\right)$$

$\Rightarrow Z' \sim \langle\omega A(\omega)\rangle_I$ is const.

- At finite temperature, the residue of the peak with high momentum doesn't decrease.
  (Tc〜300MeV)



V. Summary

- We reconstruct the spectral functions which corresponds to J/ψ and η_c from lattice Euclidean correlators with Maximum Entropy Method.
  ⇒The bound states survive up to 1.62Tc.
- The form of dispersion relations at finite temperature is same with vacuum and the residue of the peak with finite momentum doesn't decrease.
  ⇒ The medium effect on the momentum dependence is not observed in the present statistics.