Lattice NRQCD study of quarkonium at non-zero temperature

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Outline

1. Motivation
2. Result
3. Summary

previously

- quarkonium, a "thermometer" for QGP
- M_b is quite larger than "binding energy"
- use lattice NRQCD to separate M_b scale physics from bound state scale
- lattice NRQCD bottomonium correlator + reconstruction of spectral function on non-zero temperature

previously

- expect no new UV complication at non-zero T

- temperature, $T = \frac{1}{N_\tau a_\tau}$

- for consistent lattice NRQCD,

$$Ma_\tau \sim 1 \rightarrow N_\tau \sim \frac{M}{T}$$

- for $M = M_b(\sim 4.5\mathrm{GeV})$ and $T \sim 2T_c(\sim 2 \times 150\mathrm{MeV})$

$$N_\tau = O(10)$$

- at $T > 0$, spectral function is more complicated while available lattice data points is smaller ($\rightarrow$ reliability of the method is important)

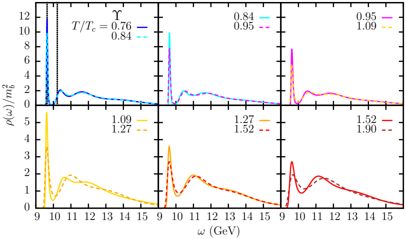
previously

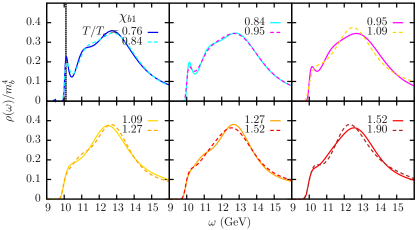
FASTSUM collaboration

- bottomonium NRQCD correlator analysis (PRL106 (2011) 061602)
- S-wave bottomonium spectral function at rest (JHEP1111(2011) 103)
- S-wave bottomonium spectral function moving (JHEP1303(2013) 084)
- P-wave bottomonium spectral function at rest (JHEP1312(2013) 064)

previously

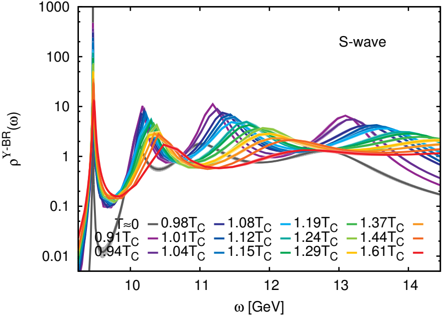
- Bottomonium, FASTSUM with $N_f = 2+1$ (JHEP1407 (2014) 097)

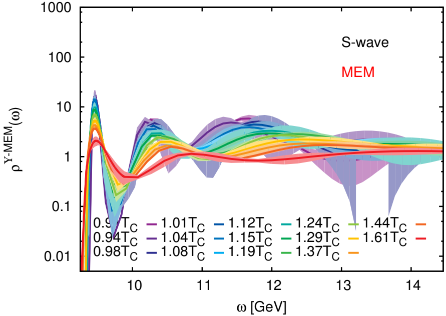




previously

- Bottomonium, KPR with $N_f = 2+1$ (PRD91 (2015) 054511)





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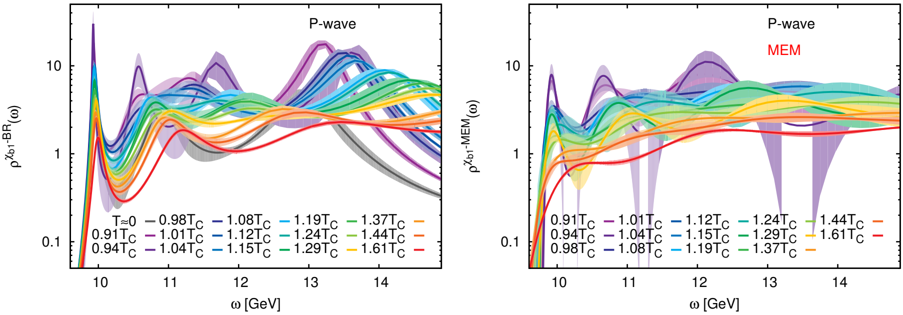


Charmonium at $T \neq 0$

- can we see more pronounced temperature effect in charmonium?
- melting at lower temperature?

Charmonium at $T \neq 0$

- $\mathcal{O}(v^2)$: ~ 0.3 for J/ψ and ~ 0.1 for Υ
- $\mathcal{O}(a^2 p^2)$ and $\mathcal{O}(aK)$
- radiative corrections in the coefficients of NRQCD lagrangian

lattices ($N_f = 2+1$ HotQCD configurations with HiSQ)

$M_b a$	$M_c a$	β	T(MeV)	T/T_c	a_τ^{-1} (fm)	No. of Conf.(analyz
2.759	0.7566	6.664	140.40	0.911	0.1169	400
2.667	0.7314	6.700	145.32	0.944	0.1130	400
2.566	0.7035	6.740	150.97	0.980	0.1087	400
2.495	0.6841	6.770	155.33	1.008	0.1057	400
2.424	0.6657	6.800	159.33	1.038	0.1027	400
2.335	0.6403	6.840	165.95	1.078	0.09893	400
2.249	0.6167	6.880	172.30	1.119	0.09528	400
2.187	0.5996	6.910	177.21	1.151	0.09264	400
2.107	0.5776	6.950	183.94	1.194	0.08925	400
2.030	0.5566	6.990	190.89	1.240	0.08600	400
1.956	0.5364	7.030	198.08	1.286	0.08288	400
1.835	0.5030	7.100	211.23	1.371	0.07772	400
1.753	0.4806	7.150	221.08	1.436	0.07426	400
1.559	0.4274	7.280	248.63	1.614	0.06603	400

Table: summary for the $T \neq 0, 48^3 \times 12$ lattice data set

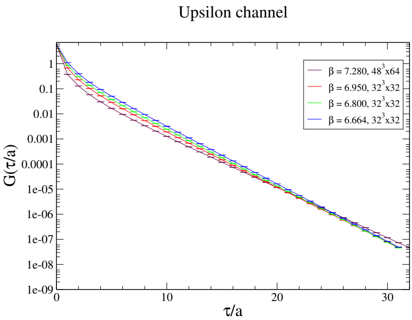
lattices ($N_f = 2+1$ HotQCD configurations with HiSQ)

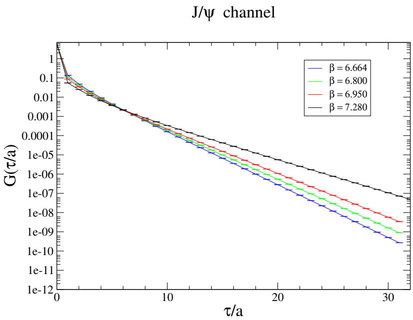
N_s	N_t	β	T(MeV)	T/T_c	a_τ^{-1} (fm)	No. of Conf.(analyzed)
32	32	6.664	140.40	0.911	0.1169	1600
48	48	6.740	150.97	0.980	0.1087	400
32	32	6.800	159.33	1.038	0.1027	400
48	48	6.880	172.30	1.119	0.09528	400
32	32	6.950	183.94	1.194	0.08925	400
48	48	7.030	198.08	1.286	0.08288	400
48	64	7.150	221.08	1.436	0.07426	400
48	64	7.280	248.63	1.614	0.06603	400

Table: summary for the $T = 0$ lattice data set

$T = 0$ comparison (preliminary)

- $G(\tau)$ for 3S1 bottomonium (left) and charmonium (right)





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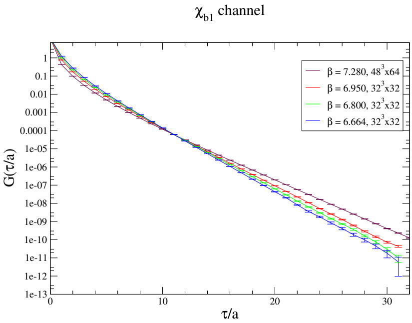
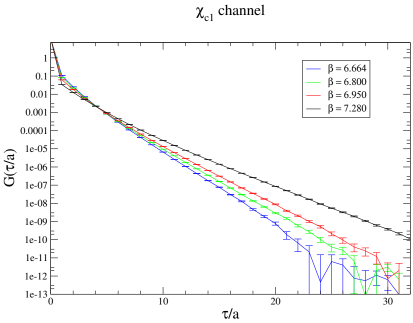
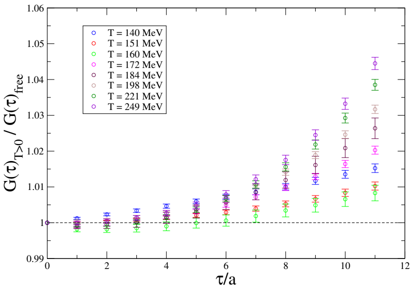




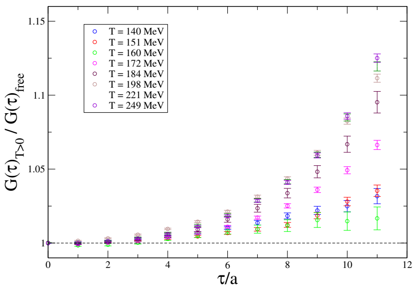
$T \neq 0$ correlator analysis (preliminary)

- $\frac{G_{T>0}(\tau)}{G_{T\simeq 0}(\tau)}$ for several β

J/ψ channel

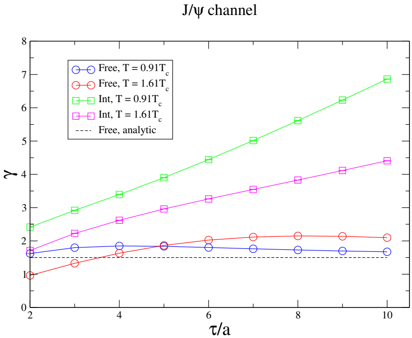


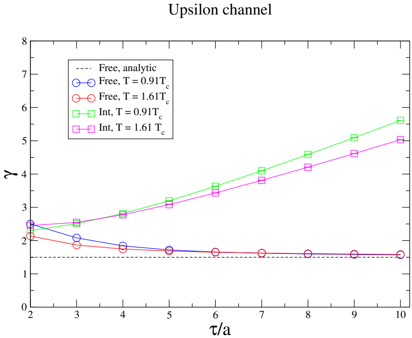
χ_{c1} channel



$T \neq 0$ correlator analysis (preliminary)

- $\gamma = \frac{\frac{\tau dG(\tau)}{d\tau}}{G(\tau)}$ (if free, $G(\tau) \sim A\tau^{\gamma}$ and $\frac{\tau dG(\tau)}{d\tau} / G(\tau) \sim \gamma$)
(cf. PRL106 (2011) 061602)





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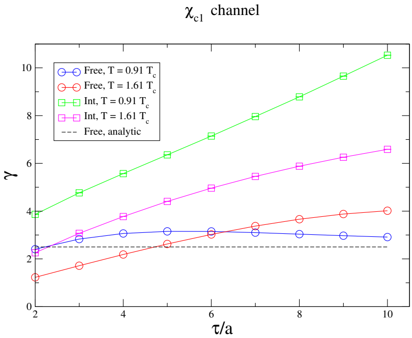
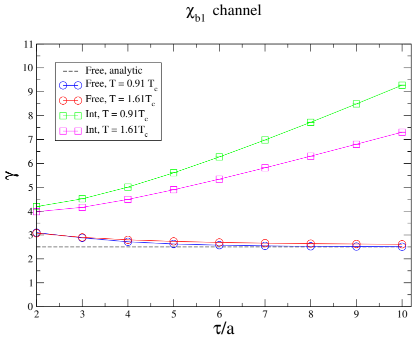
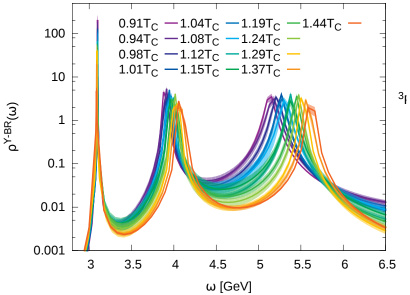
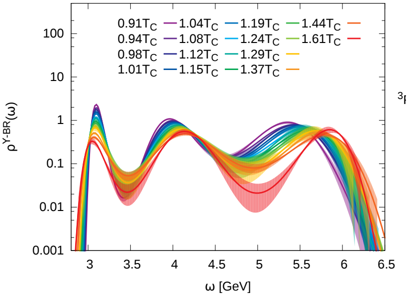




$T \neq 0$ spectral functions (preliminary)

- 3S1 charmonium spectral function from BR (left) and MEM (right)





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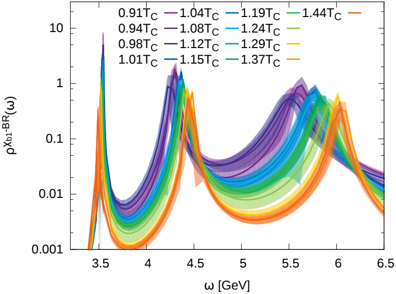

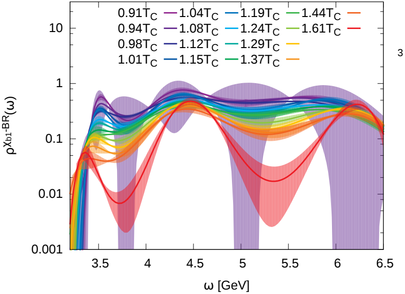

Summary

- Despite the large relativistic effect, a tentative investigation on charmonium at non-zero temperature is under way.

- Larger temperature effect is seen for charmonium system than bottomonium system

- S-wave $T \neq 0$ charmonium correlators show binding behavior upto $T = 1.61\,T_c (= 249)$ MeV

- P-wave $T \neq 0$ charmonium correlators show free behavior at $T = 1.61\,T_c (= 249)$ MeV

- Further work on Bayesian reconstruction of spectral function will follow