Open charm correlators and spectral functions at high temperature

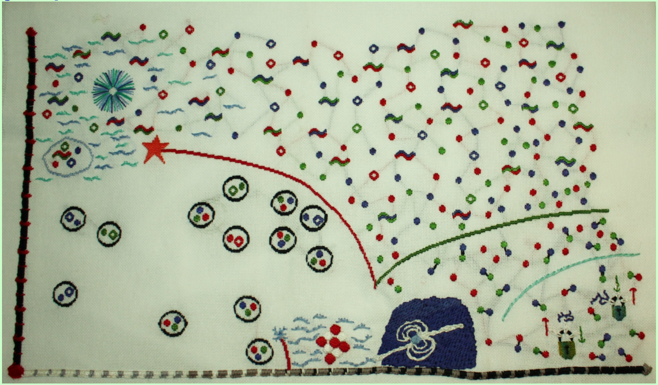
Jon-Ivar Skullerud, Aoife Kelly

National University of Ireland Maynooth
FASTSUM collaboration

Lattice 2016, Southampton, 28 Jul 2016

Outline

Why open charm?



- Heavy quarks are important probes of medium
- Long history of $c\bar{c}$ studies: experiment, pheno, lattice
- Open charm still in its infancy

Why D mesons?

Open and hidden charm

Cannot study $c\bar{c}$ in isolation from open charm

- Recombination at freeze-out
- Increased yield of D mesons relative to J/ψ?
- Double ratio better measure than R_{AA}?
- Thermal modifications of D mesons may be important
- Charm quark diffusion $\leftrightarrow$ D meson flow

Open charm — issues

Open charm

- Increased experimental interest in open charm
- Suggestions of D meson survival in QGP?
- Modifications of yields of open charm states?
- Increased D_s/D ratio (strangeness enhancement)?

Open charm from the lattice

Very few studies so far:

- Cumulants [Bazavov et al, Mukherjee et al (2015)]
- Screening correlators [Bazavov et al (2014)]

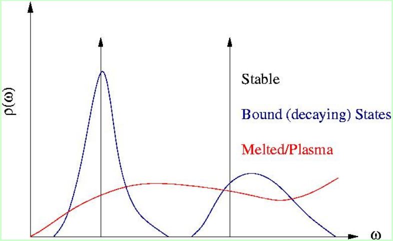
May contribute up to $1.2T_c$?

Spectral functions

- contain information about the fate of hadrons in the medium
  - stable states $\rho(\omega) \sim \delta(\omega - m)$
  - resonances or thermal width $\rho(\omega) \sim$ lorentzian
  - continuum above threshold

Spectral functions

- contain information about the fate of hadrons in the medium
  - stable states $\rho(\omega) \sim \delta(\omega - m)$
  - resonances or thermal width $\rho(\omega) \sim$ lorentzian
  - continuum above threshold



Spectral functions

- contain information about the fate of hadrons in the medium
  - stable states $\rho(\omega) \sim \delta(\omega - m)$
  - resonances or thermal width $\rho(\omega) \sim$ lorentzian
  - continuum above threshold
- $\rho_\Gamma(\omega, \vec{p})$ related to euclidean correlator $G_\Gamma(\tau, \vec{p})$ according to

$$G_\Gamma(\tau, \vec{p}) = \int \rho_\Gamma(\omega, \vec{p}) K(\tau, \omega) d\omega\,, \quad K(\tau, \omega) = \frac{\cosh[\omega(\tau - 1/2T)]}{\sinh(\omega/2T)}$$

- an ill-posed problem — requires a large number of time slices
  - Fit to physically motivated Ansatz
  - Use Maximum Entropy Method or other Bayesian methods
  - Other inversion methods, eg Cuniberti, Tikhonov–Morozov

Reconstructed correlators

The systematic uncertainty of the MEM can be avoided by studying the reconstructed correlator, defined as

$$G_r(\tau; T, T_r) = \int_0^\infty \rho(\omega; T_r) K(\tau, \omega, T) d\omega$$

where K is the kernel

$$K(\tau, \omega, T) = \frac{\cosh[\omega(\tau - 1/2T)]}{\sinh(\omega/2T)}$$

If $\rho(\omega; T) = \rho(\omega; T_r)$ then $G_r(\tau; T, T_r) = G(\tau; T)$

Small changes in correlators is compatible with large changes in spectral function [Mocsy&Petreczky (2007)]

Direct correlator reconstruction

[Ding et al (2012)]

With

$$T = \frac{1}{a_\tau N}, \;\; T_r = \frac{1}{a_\tau N_r}, \quad \frac{N_r}{N} = m \in \mathbb{N}$$

and using

$$\frac{\cosh\left[\omega(\tau - N/2)\right]}{\sinh(\omega N/2)} = \sum_{n=0}^{m-1} \frac{\cosh\left[\omega(\tau + nN + mN/2)\right]}{\sinh(\omega m N/2)}$$

we have

$$G_r(\tau; T, T_r) = \sum_{n=0}^{m-1} G(\tau + nN, T_r)$$

Simulation parameters

FASTSUM Gen2 ensemble: $N_f = 2 + 1$ anisotropic clover
[HadSpec, PRD **79** 034502 (2009); FASTSUM, JHEP **1502** 186 (2015)]

ξ	3.5
a_s (fm)	0.123
a_τ^{-1} (GeV)	5.63
m_π (MeV)	380
m_π/m_ρ	0.45
N_s	24
L_s (fm)	2.94

N_τ	T (MeV)	T/T_c	N_{cfg}
128	44	0.24	500
40	141	0.76	500
36	156	0.84	500
32	176	0.95	1000
28	201	1.09	1000
24	235	1.27	1000
20	281	1.52	576
16	352	1.90	1000

Charm action params from Hadspec: JHEP **1207** 126 (2012)

Spectral function reconstruction

Spectral function $\rho(\omega)$ is expressed in terms of default model $m(\omega)$

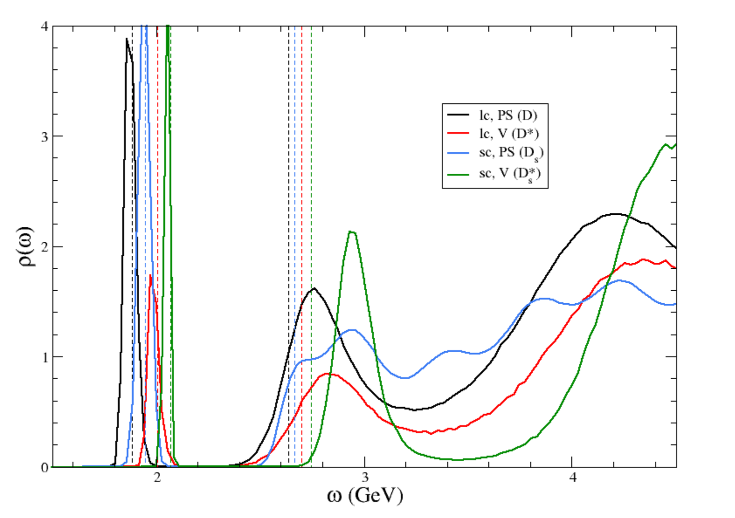
$$\rho(\omega) = m(\omega)\exp[\sum_{k=1}^{N_b} b_k u_k(\omega)]$$

Singular value decomposition:

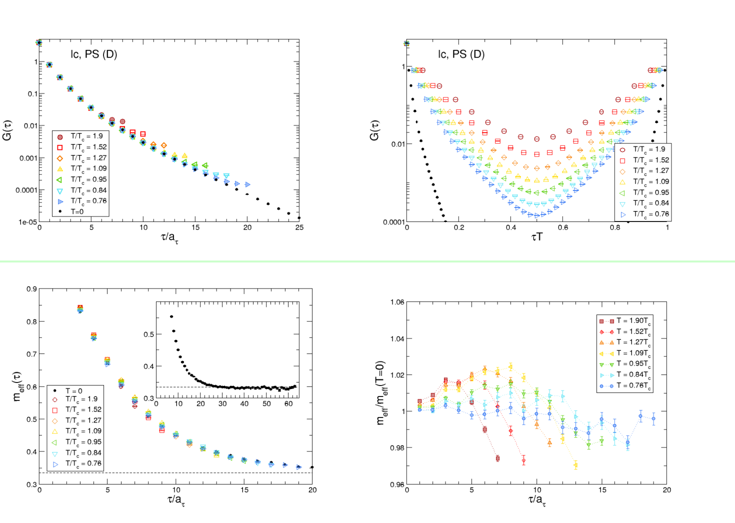
$$K(\omega,\tau) \to K(\omega_i,\tau_j) = K_{ij} = U\Xi V^T$$

Standard MEM (SVD basis): u_k are column vectors of U:
$N_b = N_s \leq N_{\text{data}}$
Extended basis: use N_{ext} additional column vectors of U
Fourier basis: use N_b Fourier modes as u_k
Using MEM analysis code from Alexander Rothkopf

Zero temperature spectral functions

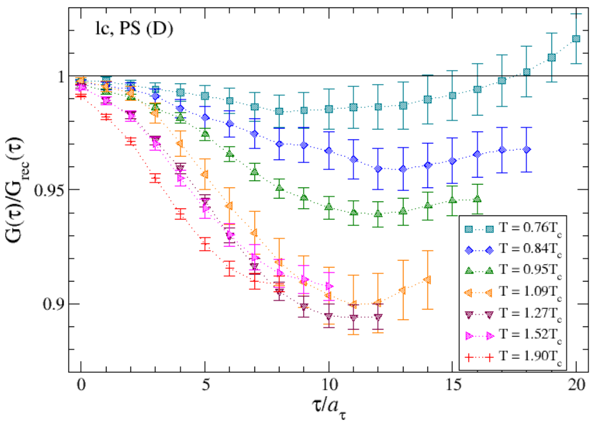


D meson correlators



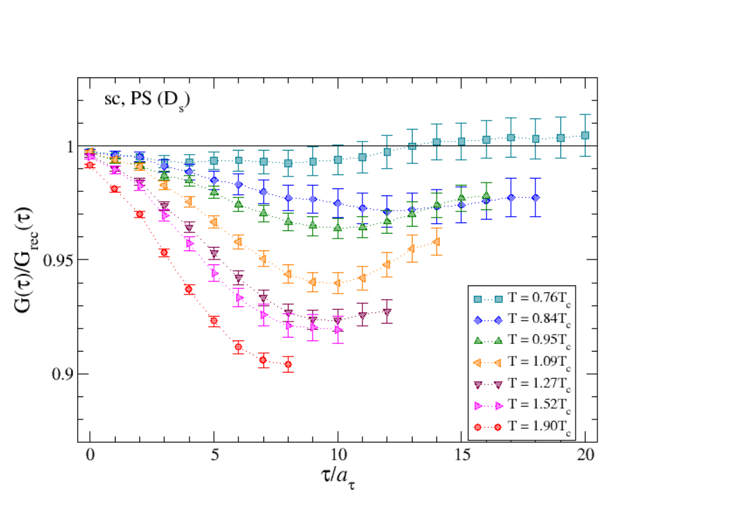
Reconstructed correlators

D channel (lc, PS)



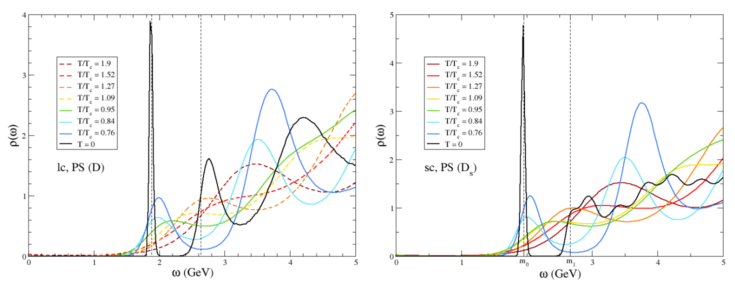
Reconstructed correlators

D_s channel (sc, PS)



Open charm: spectral functions

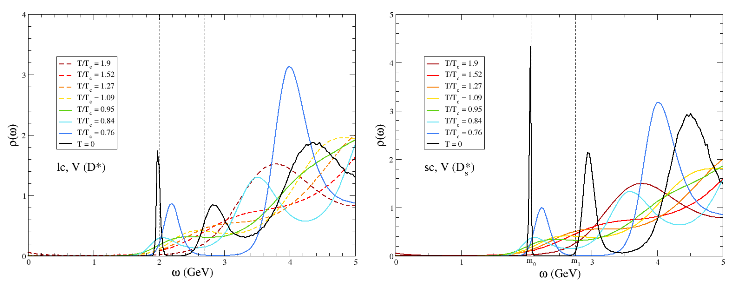
Pseudoscalar channel



- Both D and D_s mesons dissociate close to T_c
- Thermal mass shift below T_c?

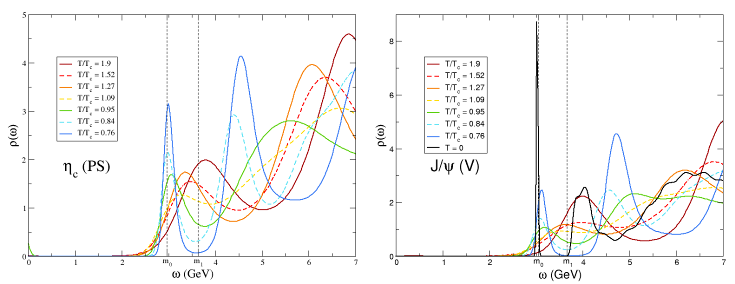
Open charm: spectral functions

Vector channel



- Thermal mass shift stronger in vector channel?

Charmonium


T/T_c = 1.9
T/T_c = 1.52
T/T_c = 1.27
T/T_c = 1.09
T/T_c = 0.95
T/T_c = 0.84
T/T_c = 0.76
η_c (PS)
ρ(ω)
ω (GeV)
m_0
m_1
T/T_c = 1.9
T/T_c = 1.52
T/T_c = 1.27
T/T_c = 1.09
T/T_c = 0.95
T/T_c = 0.84
T/T_c = 0.76
T = 0
J/ψ (V)
ρ(ω)
ω (GeV)
m_0
m_1

Summary and outlook

Summary

- First lattice study of open charm temporal correlators and spectral functions
- Clear thermal modifications already below T_c
- Possible thermal mass shift observed?
- No sign of surviving bound states above T_c

Summary and outlook

Summary

- First lattice study of open charm temporal correlators and spectral functions
- Clear thermal modifications already below T_c
- Possible thermal mass shift observed?
- No sign of surviving bound states above T_c

Outlook

- Complete study of MEM systematics
- Improved statistics (using multiple sources)
- Open beauty?