Quarkonia Correlators after Deconfinement

from Isotropic Lattice QCD

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Quarkonia in Hot Medium

Extracting properties of Quarkonia from Lattice calculations
Look at correlators of suitable operators
Matsubara correlator
$G_H(\tau, \vec{p}, T) = \sum_{\vec{r}} e^{i\vec{p}.\vec{r}} \langle J_H(\tau, \vec{r}) J_H(0, \vec{0}) \rangle$

$$J_H = \begin{array}{lll} \bar{c}c & {}^3P_0 & \chi_{c_0} \\ \bar{c}\gamma_5 c & {}^1S_0 & \eta_c \\ \bar{c}\gamma_i c & {}^3S_1 & J/\psi \\ \bar{c}\gamma_i\gamma_5 c & {}^3P_1 & \chi_{c_1} \end{array}$$

$$G_H(\tau, T) = \int_0^\infty d\omega \, \sigma_H(\omega, T) \, \frac{\cosh(\omega(\tau - 1/(2T))}{\sinh(\omega/(2T))}$$

Difficulty: Correlator only at short distance $\tau \leq \frac{1}{2T}$

Spectral function from correlator

Inverting the integral equation using **Maximum Entropy Method**
Information about high energy structure of $\sigma_H(\omega, T)$ as prior information.

M. Jarrel & J. Gubernatis, Phys. Rept. 269, 133 (1996)
M Asakawa *et al.*, Prog. Part. Nucl. Phys. 46, 459 (2001)

Has been used by many groups to study in-media quarkonia
Datta, Karsch,Petreczky,Wetzorke Isotropic lattice (PRD 69,094507('04))
Asakawa and Hatsuda, Anisotropic lattice (PRL92,012001 ('04))
Matsufuru et al., Anisotropic, smeared operator (Eur.P.J.C39S1,9('05))
Jakovác et al., Anisotropic lattice, improved action (PRD75,014506('07))
Aarts et al., Anisotropic lattice, 2-flavor QCD (PRD76, 094513('07))

Our Analysis

At high temperatures, low ω part sensitive to the prior information about high ω part

- Supply high ω information from low temperature studies
- Compare high temperature correlators with correlators "reconstructed" from spectral function at low temperature

Reconstructed correlator

$$G_{\mathrm{recon,T^*}}(\tau, T) = \int d\omega\, \sigma(\omega, T^*)\, K(\omega, \tau, T)$$

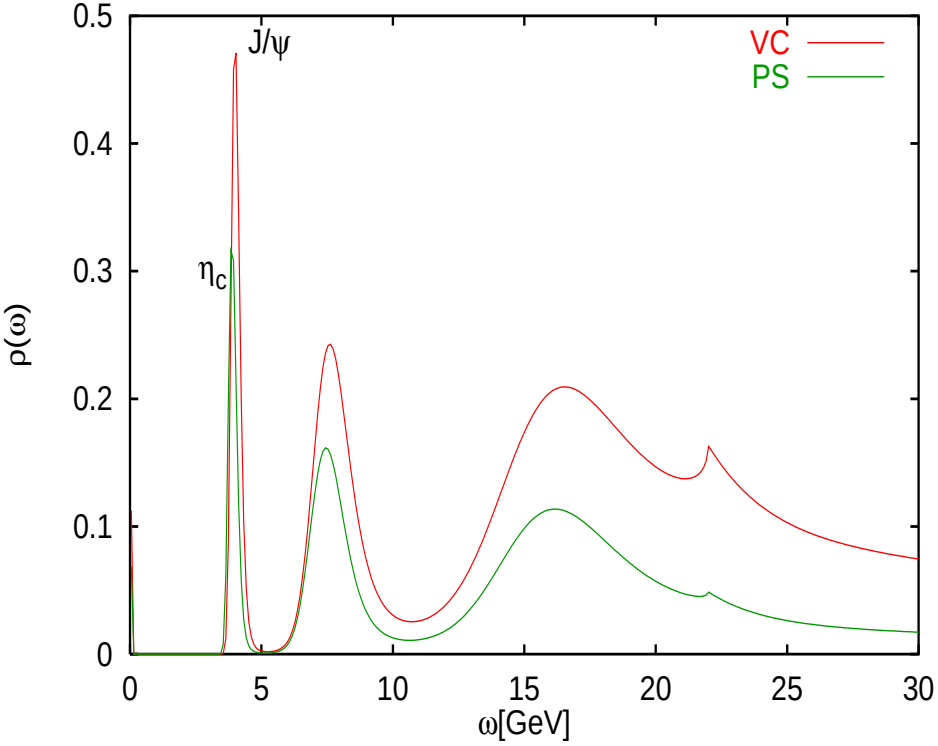
Deviation of $G(\tau, T)$ from $G_{\mathrm{recon}}(\tau, T)$ indicate medium modification

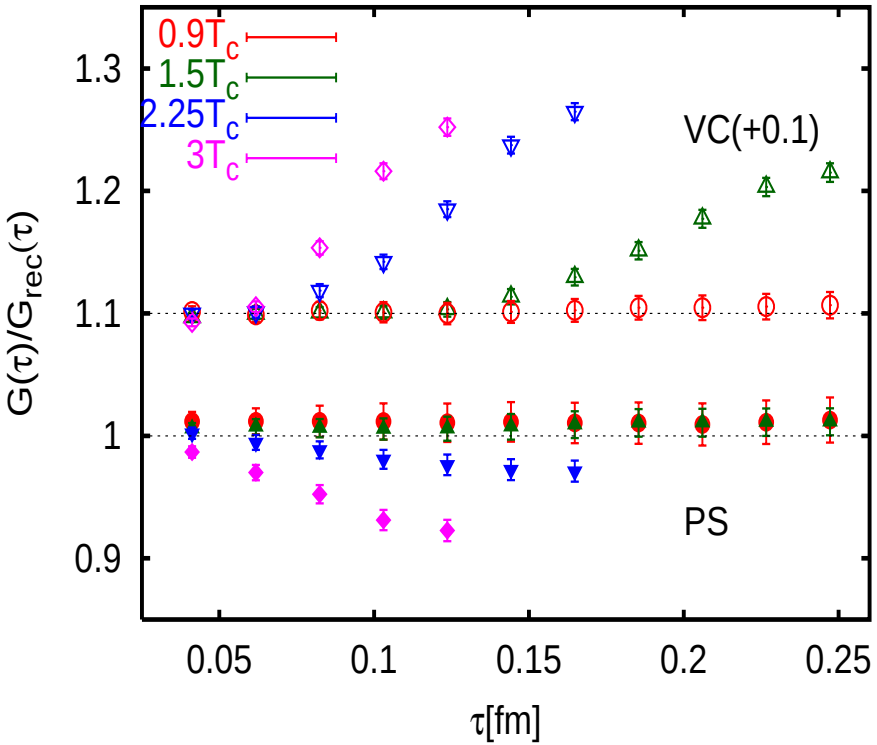
Lattices

- Quenched lattices with $a = 0.02$-0.05 fm
- Nonperturbatively improved clover action

a[fm]	$m_{J/\psi}$[GeV]	T/T_c
0.05	2.7	
	3.1	0.6, 0.9, 1.2, 1.5
	4.0	
0.04	3.1	0.75, 1.1, 1.5
0.02	3.5	0.56, 0.9, 1.5, 2.2, 3.0
	9.7	

Results for J/ψ and η_c

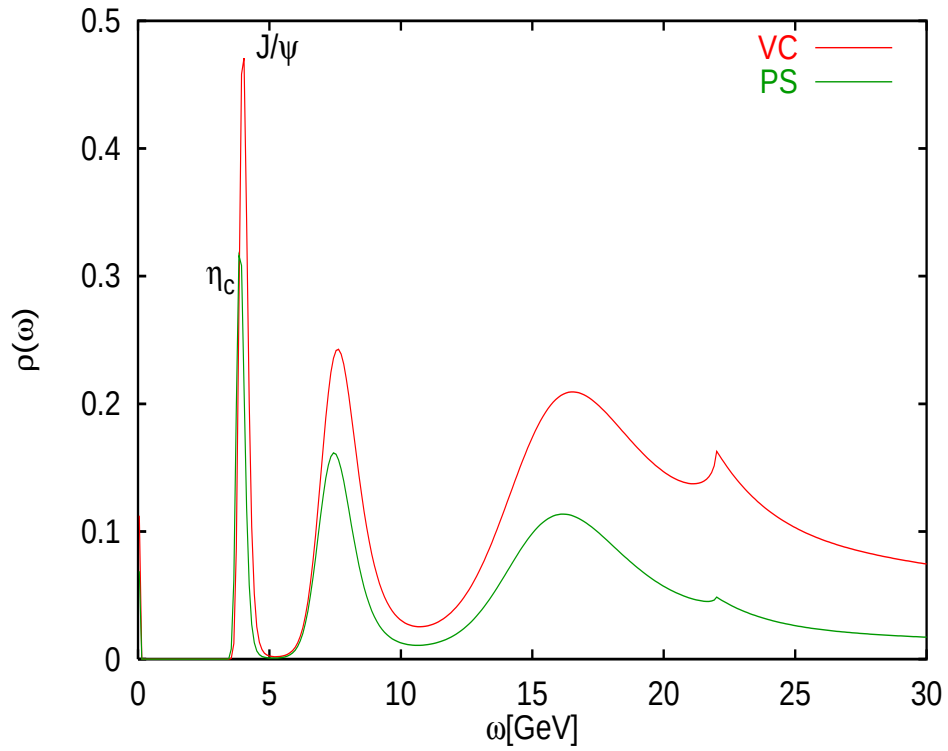


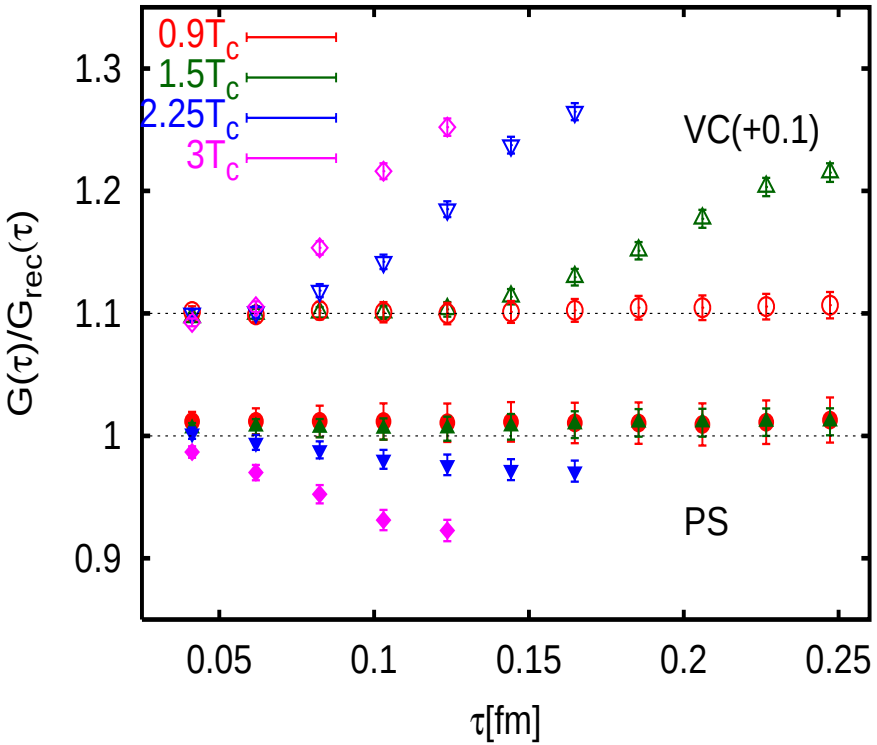


1S charmonia survive till high temperatures

Datta et al., PRD 2004

Results for J/ψ and η_c





1S charmonia survive till high temperatures

Datta et al., PRD 2004

Small modification in correlators does not necessarily imply small changes in the states. Mocsy and Petreczky, PRD 2008

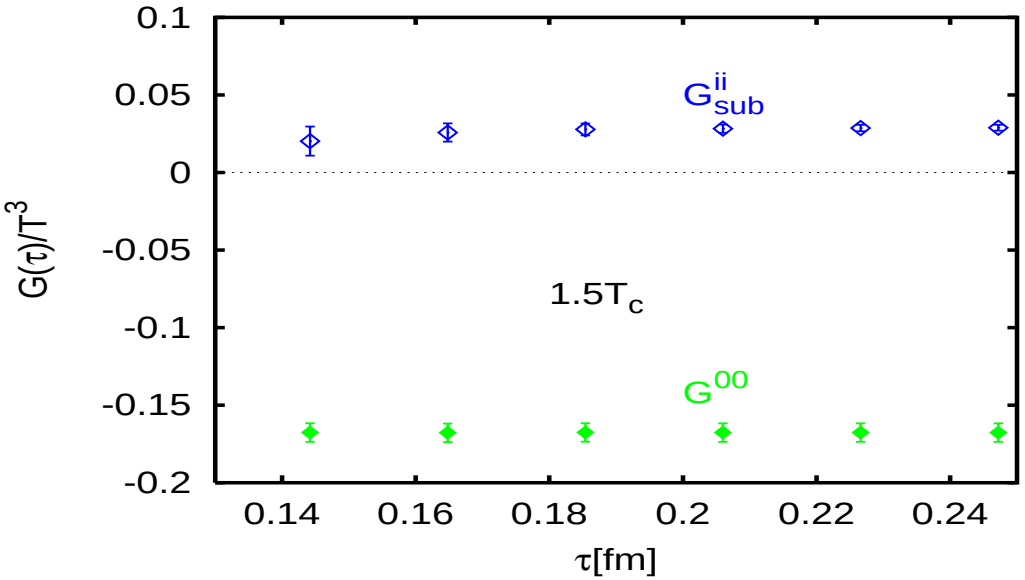
Zero Modes and Susceptibility

Temperature modification of vector correlator:related to transport?

Petreczky & Teany, PRD 73, 014508('06)

$$\rho^V_{00}(low\omega) = \frac{-2\beta}{\pi}\omega\delta(\omega)\int dp p^2 e^{\beta p_0} n_F(p_0)^2$$

$$\rho^V_{ii}(low\omega) = \frac{2\beta}{\pi}\omega\delta(\omega)\int dp p^2 e^{\beta p_0} n_F(p_0)^2$$



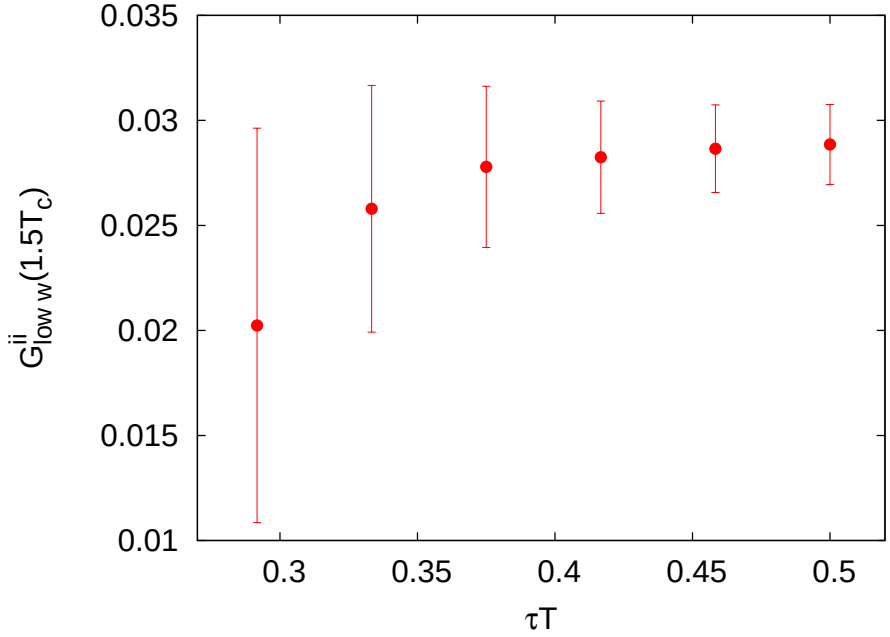
Datta,Jakovác, Karsch,Petreczky, PANIC 2005

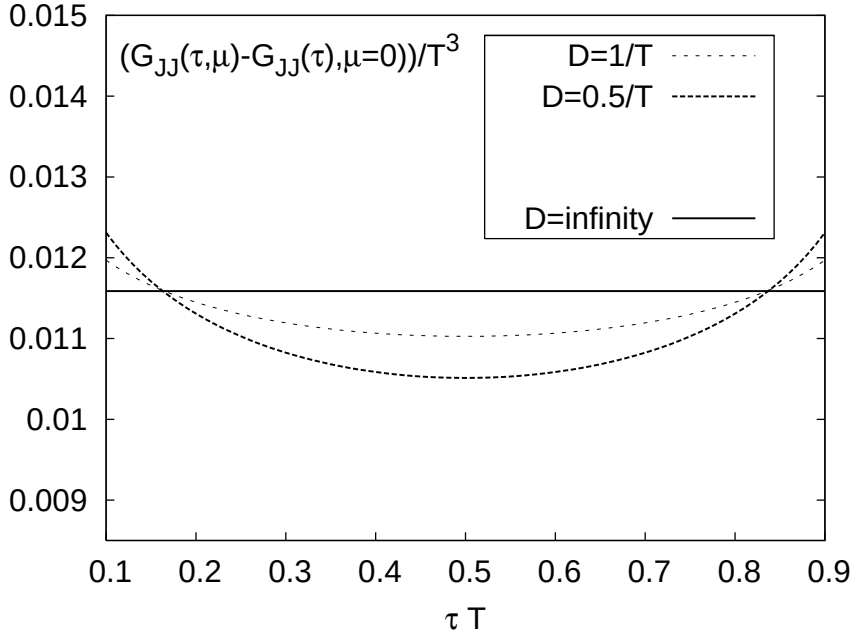
Zero Mode and transport

In the interacting theory, the zero mode gets smeared into a Lorentzian

$$\sigma^{ii}_{\rm sub}(\omega, T) \sim \chi_s(T)\omega \frac{T}{\pi M} \frac{\eta}{\omega^2 + \eta^2}$$

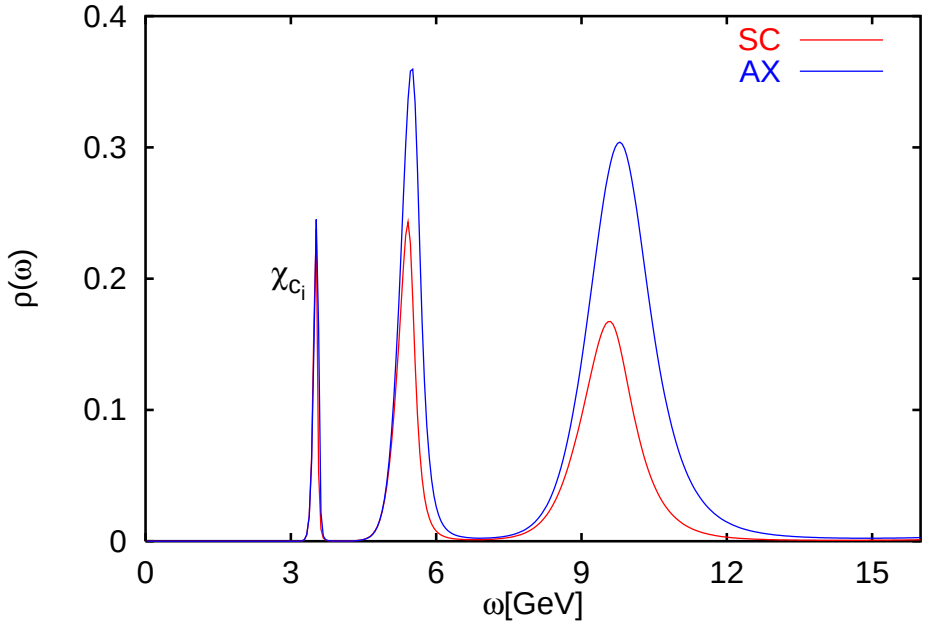
The current data not accurate enough to distinguish free streaming from diffusion Petreczky and Teaney, PRD 2005

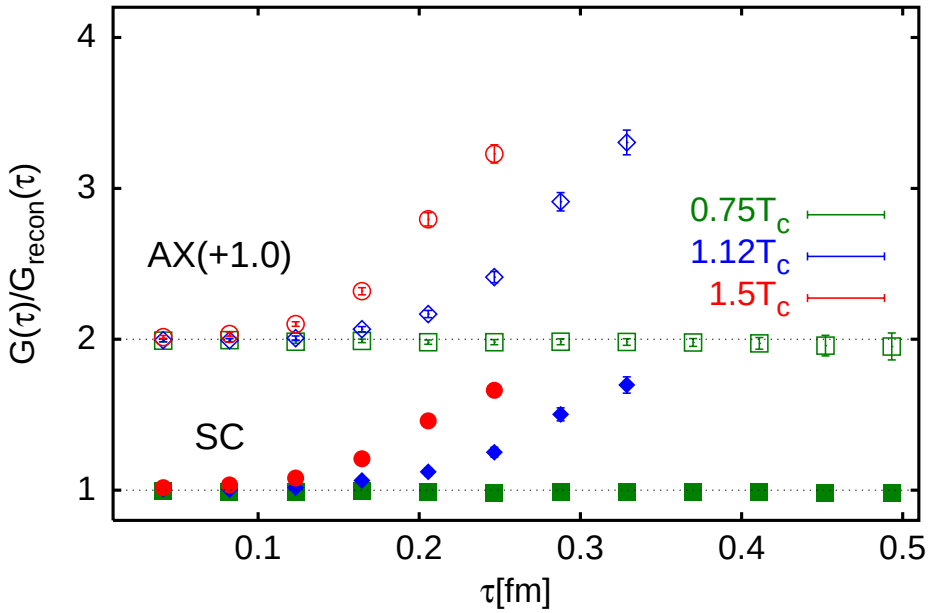




1P states

Much larger changes are seen in the scalar and axial vector correlators, suggesting large system modifications in χ_{c_0} and χ_{c_1}





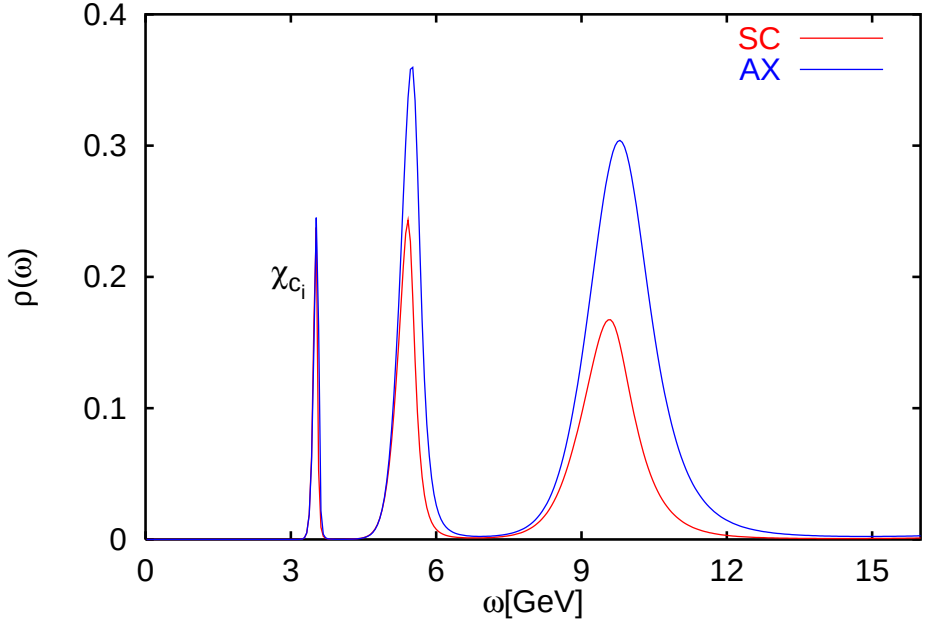
However, zero mode contributions in these channels can explain the large modifications

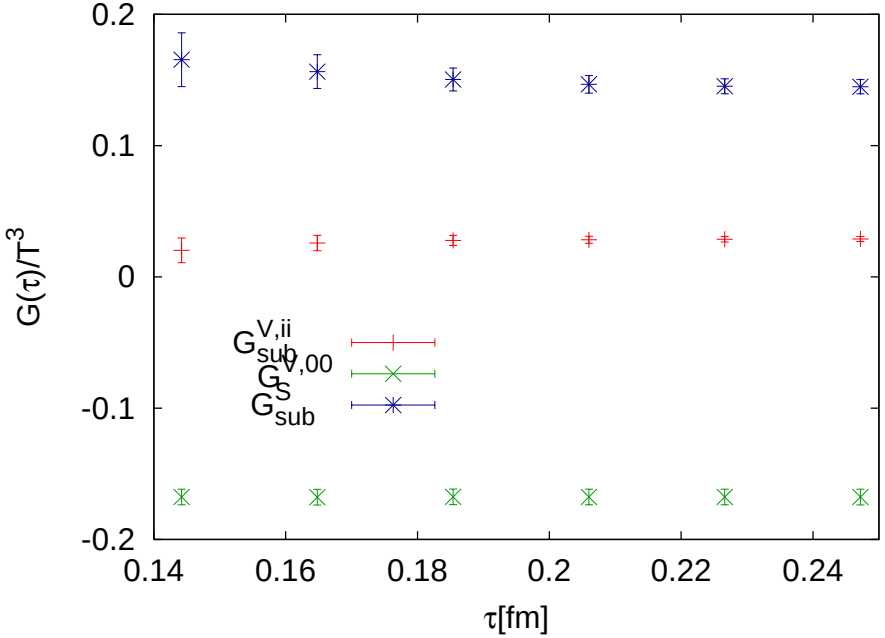
Umeda, PRD 75, 094502 ('07)

Zero Modes in 1P states

$$\rho^S(\omega=0) = \frac{2\beta}{\pi}\omega\delta(\omega)\int dp p^2 \frac{m^2}{p_0^2} e^{-\beta p_0} n_F(p_0)^2$$

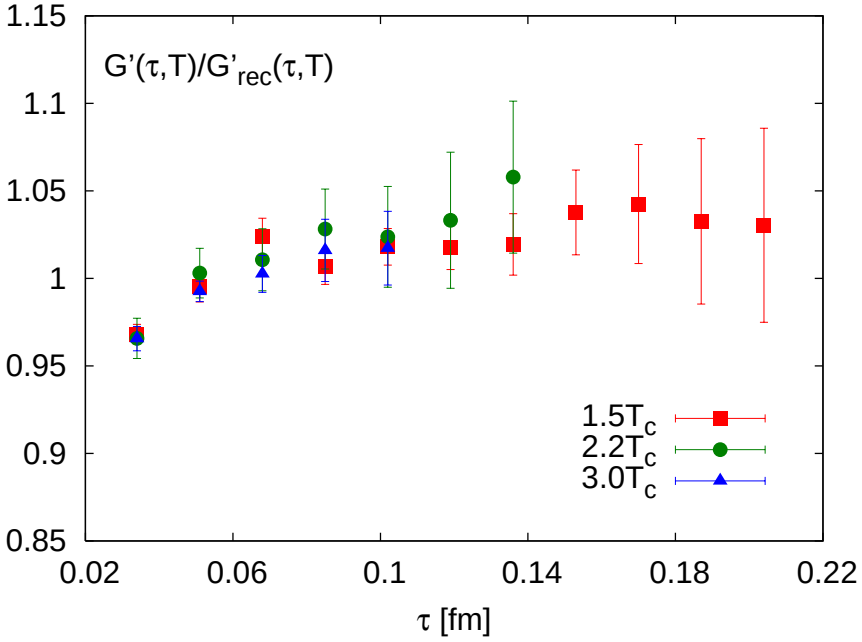
$$\rho^{AX}(\omega=0) = \frac{2\beta}{\pi}\omega\delta(\omega)\int dp p^2 \frac{1+2m^2}{p_0^2} e^{-\beta p_0} n_F(p_0)^2$$

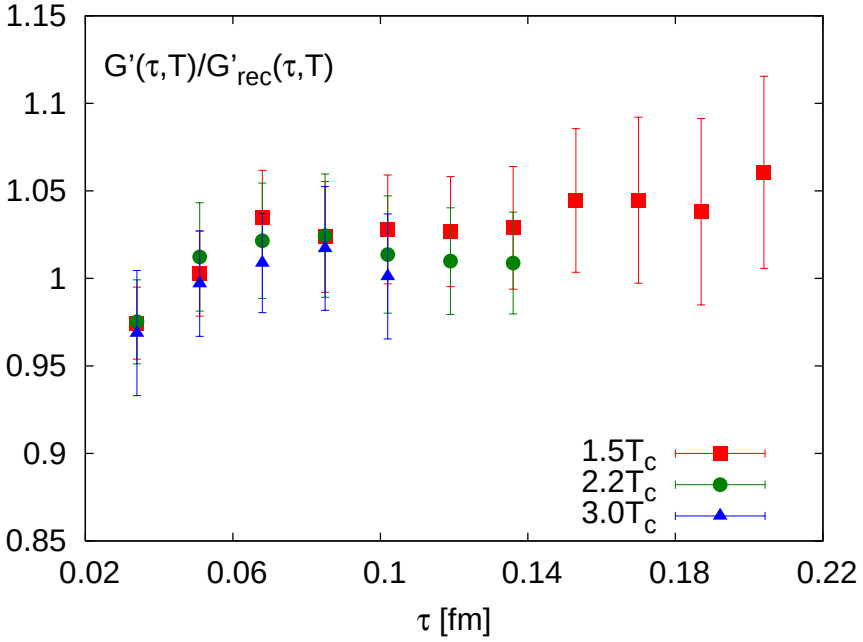




1P states (Contd.)

Similar conclusions can be drawn by looking at time derivatives of correlators



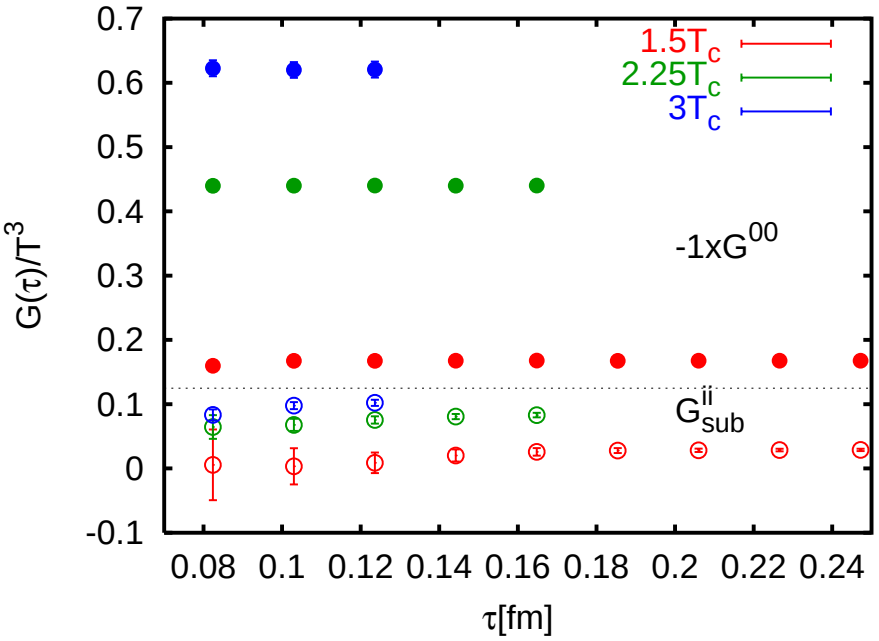


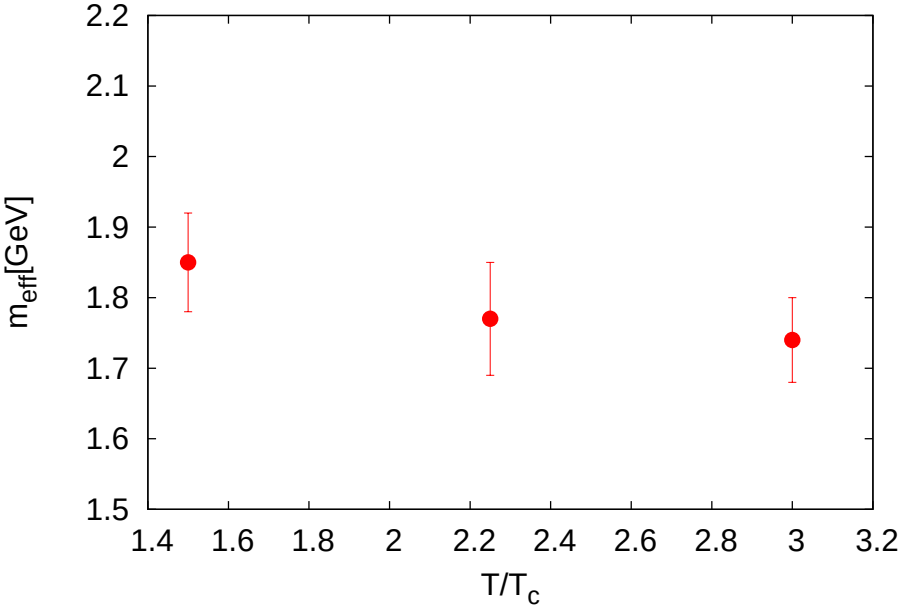
P.Petreczky, Quark Matter 2008

v_{00} Correlator and Quasiparticle mass

A quasiparticle description can describe the "zero mode" contributions reasonably well.

Petreczky, Quark Matter 2008





Quasiparticle model:

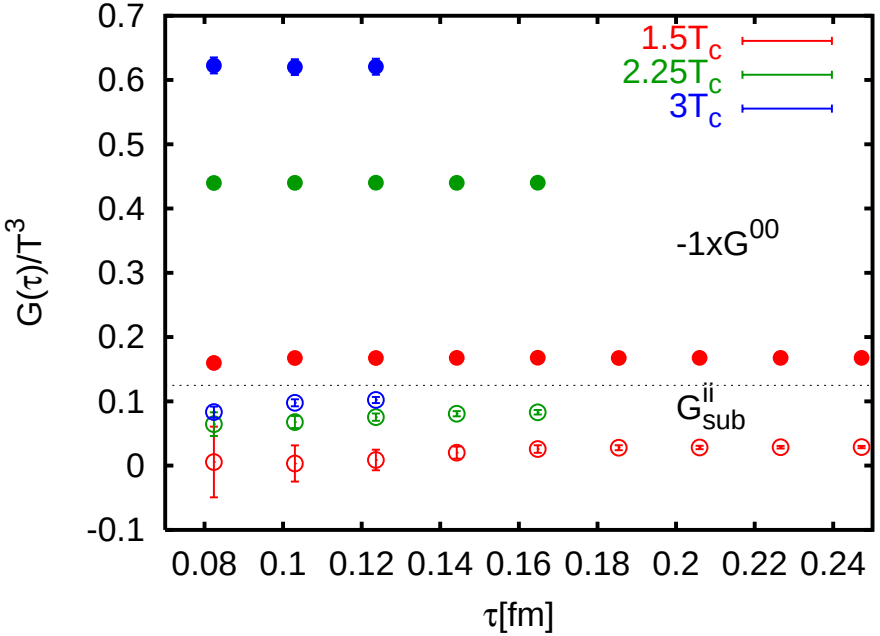
$$\frac{\chi_{00}}{T^3} = 12\left(\frac{M}{T}\right)^{3/2} e^{-M/T}$$

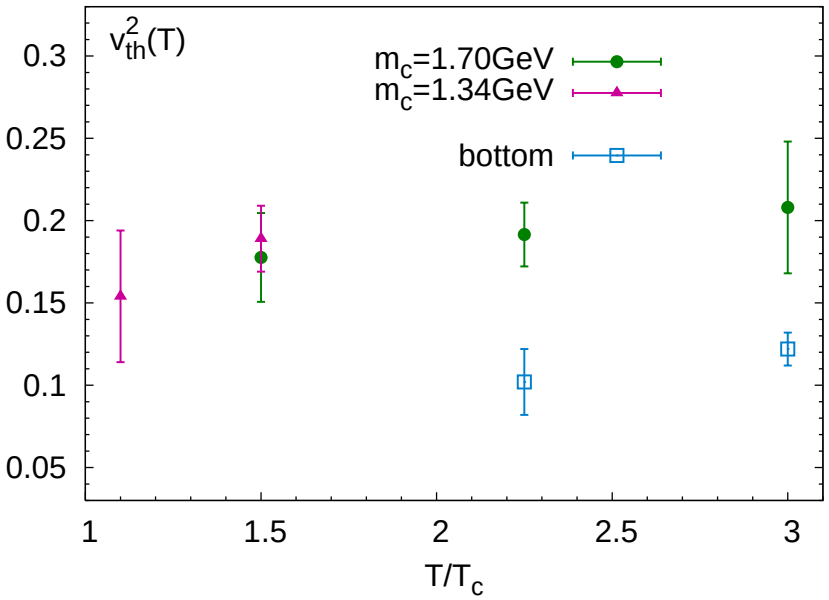
V_{ii} Correlator and Quasiparticle Velocity

Assuming free quasiparticle form for $G^V_{ii,low}$ a rough estimate of thermal velocity of quasiparticles

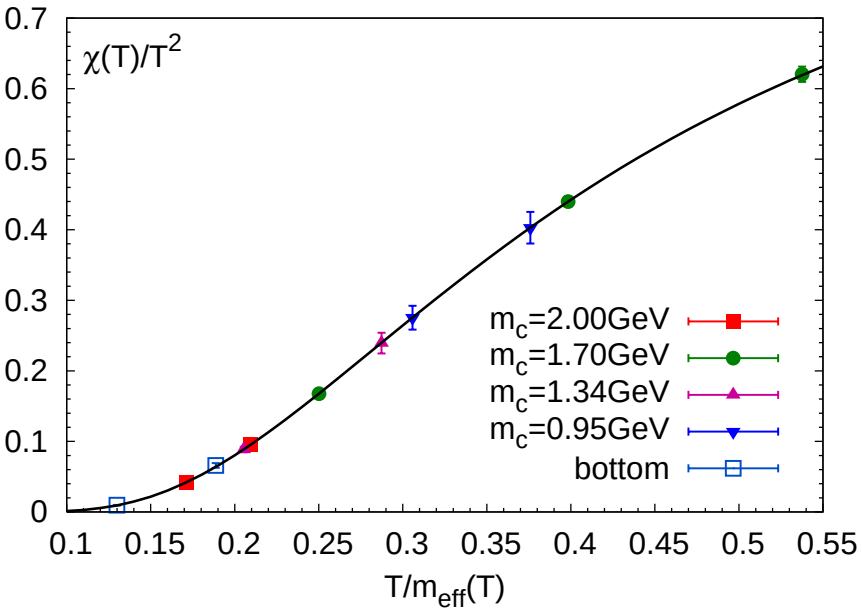
Petreczky, Quark Matter 2008

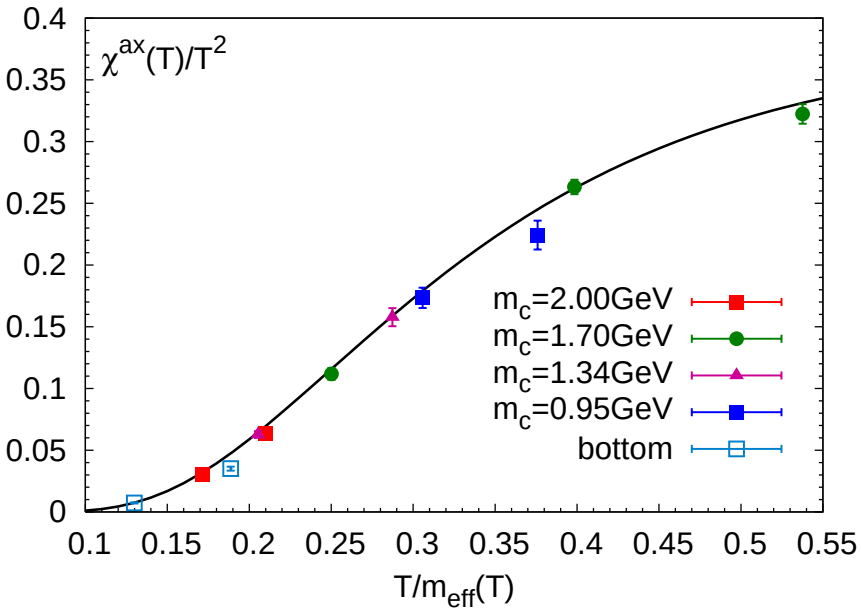
$$\frac{G^V_{ii,low}}{G^V_{00}} \sim \frac{\int d^3p \, \frac{p^2}{p_0^2} e^{-p_0/T}}{\int d^3p \, e^{-p_0/T}} \sim v^2_{th}(T)$$





Scalar and Axial Vector Zero Modes





Quasiparticle description seems to work reasonably well for describing the zero mode contributions.

Conclusions

- The zero mode contribution plays a dominant role in understanding the temperature dependence of the quarkonia correlators.
- The zero mode contribution is connected to heavy quark diffusion. A quantitative estimate of diffusion constant from lattice needs more prcise data than is currently available.
- A quasiparticle description seems to work reasonably well in describing the zero mode contributions.