Quarkonium correlators and spectral functions at zero and finite temperature

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- Introduction : meson spectral functions and correlators
- Lattice set-up and analysis methods
- Numerical results for charmonium
- Numerical results for bottomonium

Introduction: spectral functions and mesons

In medium properties of meson can be studied in terms of spectral function

$$\frac{dW}{d\omega d^3p} = \frac{5\alpha^2}{27\pi^2}\frac{1}{\omega^2(e^{\omega/T}-1)}\sigma_V(\omega,\vec{p},T)$$

$$\sigma(\omega) = \frac{1}{\pi}\mathrm{Im}D_R(\omega)$$

Dilepton rate

Quarkonium melting above deconfinement ⟺ signal of QGP

lattice claculations of quarkonium spectral functions

Sequential melting: the smaller the system at higher temperatures it melts

$$T_M(\Upsilon) > T_M(\chi_b) \simeq T_M(J/\psi) > T_M(\chi_c)$$

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

⟸

$$G(\tau,T) = D^>(-i\tau)$$

Motivations for present study :

Ground state (1S) charmonia survive in the deconfined phase

Asakawa, Hatsuda, PRL 93 (2004) 132001

Datta, Karsch, Petreczky, Wetzorke, PRD 69 (2004) 094507

Umeda, Nomura, Matsufuru, hep-lat/0211003

But what happens to the excited states (2S, 1P) ?

1P state dissolves in the plasma (Datta et al.) but no independent study yet

2S ???

What determines the dissolution temperature, system size or quantum numbers

What happens to bottomonium states in the plasma ?

Control of the lattice artifacts in the limit $am_q > 1$

⇨ Fermilab action

Lattice setup

Fermilab action on anisotropic $a_t/a_s = \xi \neq 1$ lattice

reduce lattice artifacts due large quark mass using non-relativistic interpretation of the Wilson term $\bar{q}D^2 q$ in the quark action

El-Khadra, Kronfeld, Mackenzie, PRD 55 (97) 3933

Charmonia:

$\xi = 2,\ \beta = 5.6,\ 5.7,\ 5.9,\ 6.1 \leftrightarrow a_t^{-1} = 1.56,\ 1.91,\ 2.91,\ 4.11\mathrm{GeV}$

$T = 0$: $8^3 \times 32,\ 16^3 \times 64$; $T > 0$: $8^3 \times 6,\ 16^3 \times 12$ $\quad T \sim 1.2T_c$

Bottomonia:

$\xi = 4,\ \beta = 6.1,\ 6.3 \leftrightarrow a_t^{-1} = 8.18,\ 12.12\mathrm{GeV}$

$T = 0$: $16^3 \times 96,\ 16^3 \times 128$;

$T > 0$: $16^3 \times N_t,\ N_t = 12,\ 16,\ 20,\ 24,\ 32,\ 36,\ 40$

$T = (1.1 - 2.7)T_c$

Typical statistics : 500-1000 configs. using RBRC QCDOC prototypes

$\mathrm{Pseudo-scalar(PS)} \rightarrow \eta_{c,b}\ (^1S_0)$ $\quad$ $\mathrm{Scalar(SC)} \rightarrow \chi_{c0,b0}\ (^3P_0)$

$\mathrm{Vector(VC)} \rightarrow J/\psi, \Upsilon\ (^3S_1)$ $\quad$ $\mathrm{Axial-Vector(AX)} \rightarrow \chi_{c1,b1}\ (^3P_1)$

Meson correlators and spectral functions

$$G(\tau,\vec{p},T)=\int d^3x\, e^{i\vec{p}\cdot\vec{x}}\left\langle J_H(\tau,\vec{x})\, J_H^{\,+}(0,0)\right\rangle,\quad J_H(\tau,\vec{x})=\bar{q}(\tau,\vec{x})\Gamma_H q(\tau,\vec{x})$$

$$\Gamma_H = 1,\ \gamma_5,\ \gamma_\mu,\ \gamma_5\cdot\gamma_\mu$$

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

$\mathcal{O}(10)$ data and $\mathcal{O}(100)$ degrees of freedom

⇓

Bayesian techniques: maximize $P[\sigma|DH] = \exp(-\frac{1}{2}\chi^2+\alpha S)$

↙ ↘

Constrained curve fitting

$$\sigma(\omega)=\sum_{i=1}^{n} A_i\delta(\omega-m_i)$$

$$\alpha S = -\sum_{i=1}^{n}\left[\frac{(A_i-\bar{A}_i)^2}{\sigma_{A_i}^2}+\frac{(m_i-\bar{m}_i)^2}{\sigma_{m_i}^2}\right]$$

G.P. Lepage et al., hep-lat/0110175

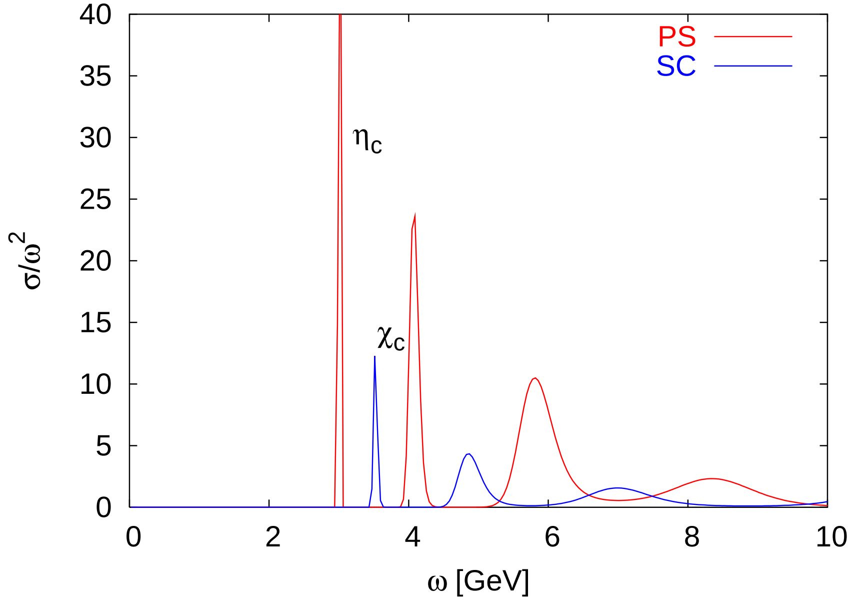
Maximum Entropy Method:

$$S=\int_0^\infty d\omega\left[\sigma(\omega)-m(\omega)-m(\omega)\ln\frac{\sigma(\omega)}{m(\omega)}\right]$$

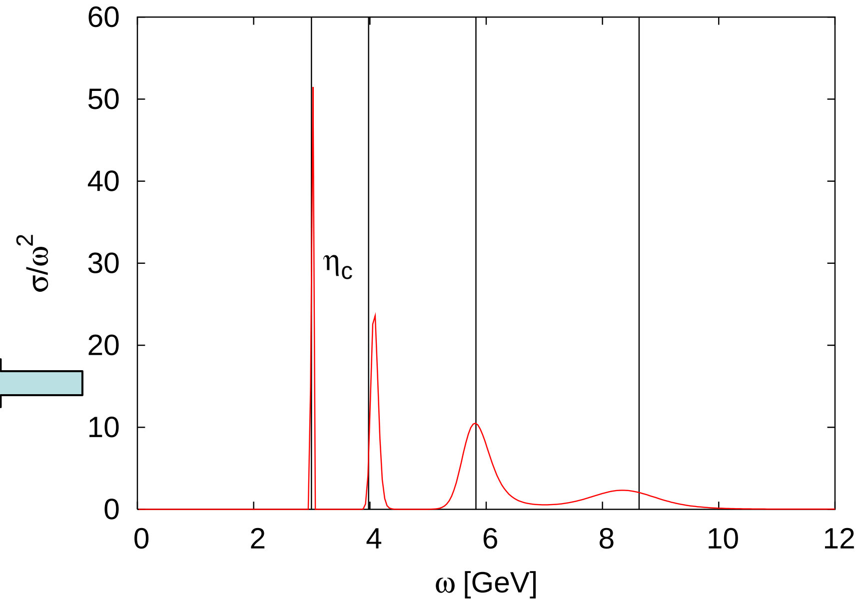
Asakawa, Hatsuda, Nakahara,
PRD 60 (99) 091503,
Prog. Part. Nucl. Phys. 46 (01) 459

Charmonia spectral functions at T=0

$$\beta = 6.1,\ a_t^{-1} = 4.11\text{GeV}$$

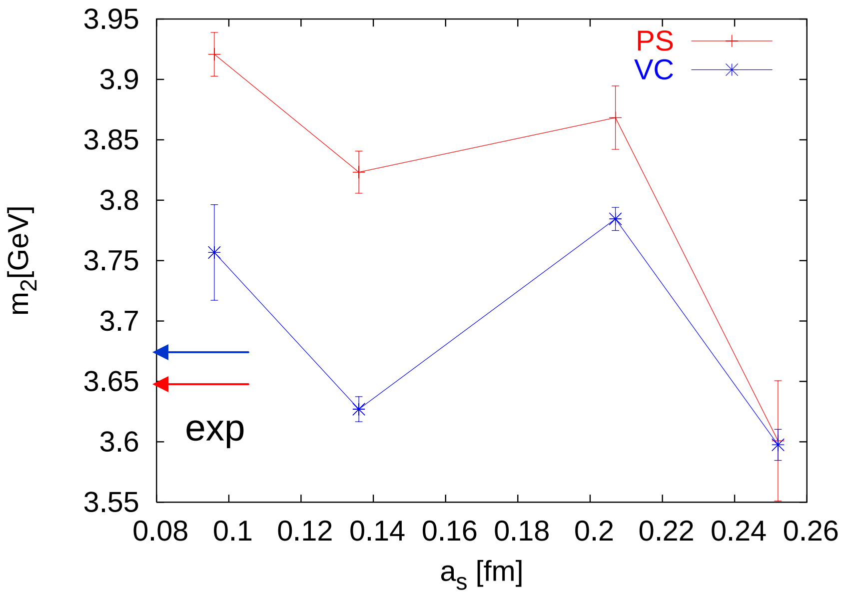


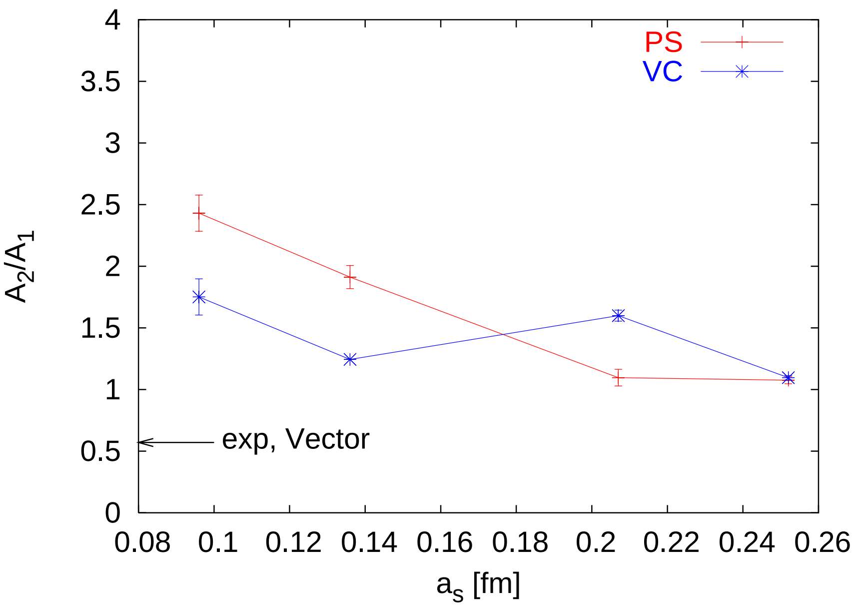
What is the physics in the 2nd and 3rd peaks



Consistency between MEM and constrained curve fitting

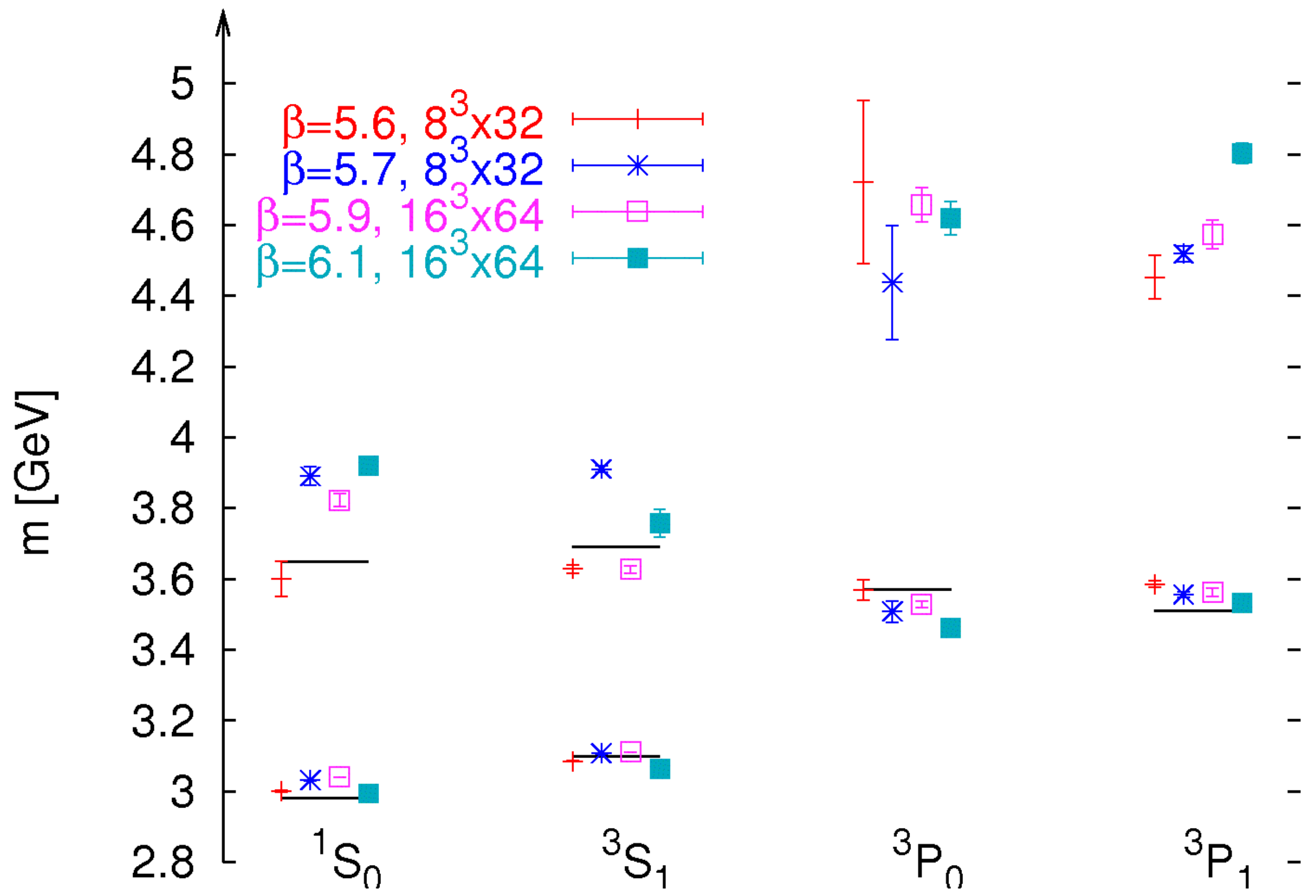
The mass and the amplitude of the 2nd peak (1st radially excited state)





If the 2nd peak is an lattice artifact m_2 and A_2 / A_1 should increase with decreasing a_s

T=0 charmonium spectroscopy from point correlators

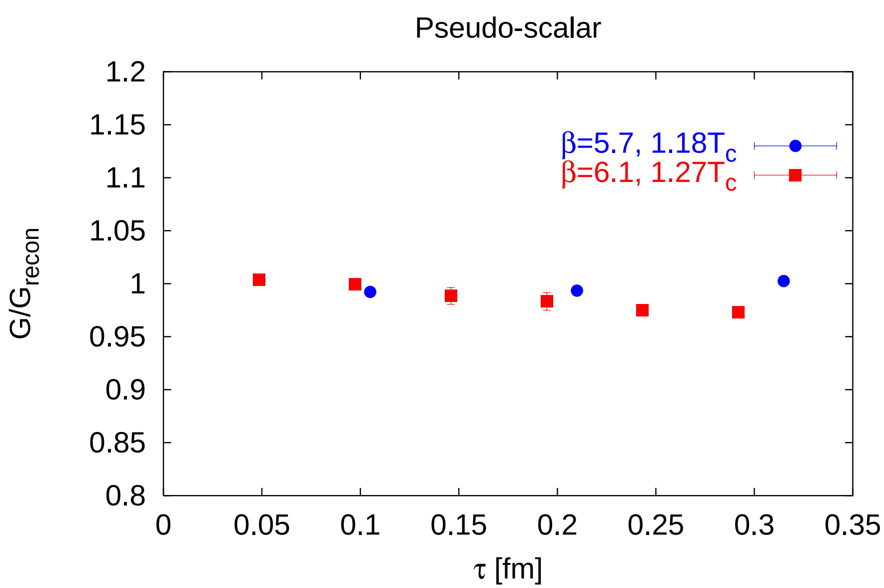


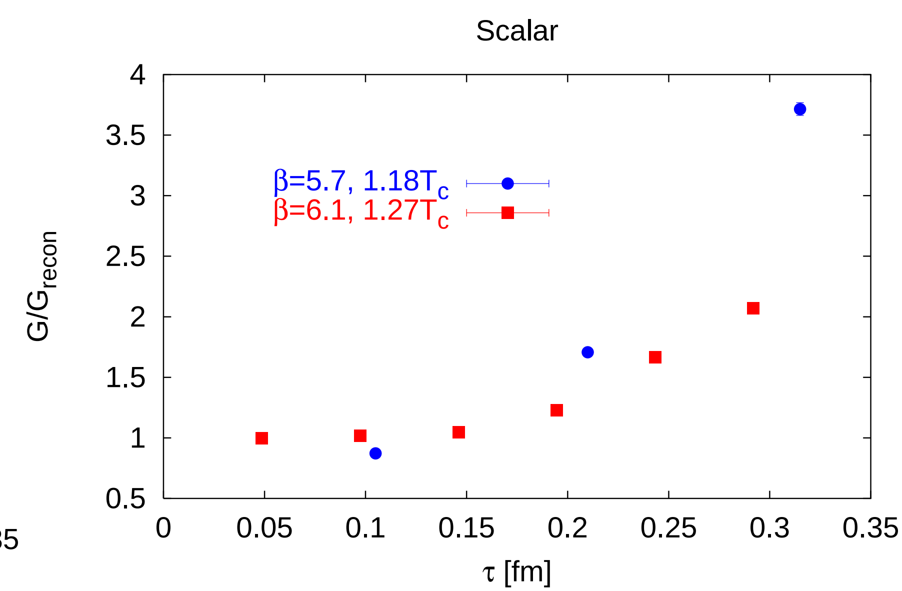
Temperature dependence of charmonia correlators

The temperature dependence of the correlators

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

If there is no T-dependence in the spectral function, $G(\tau,T)/G_{recon}(\tau,T) = 1$

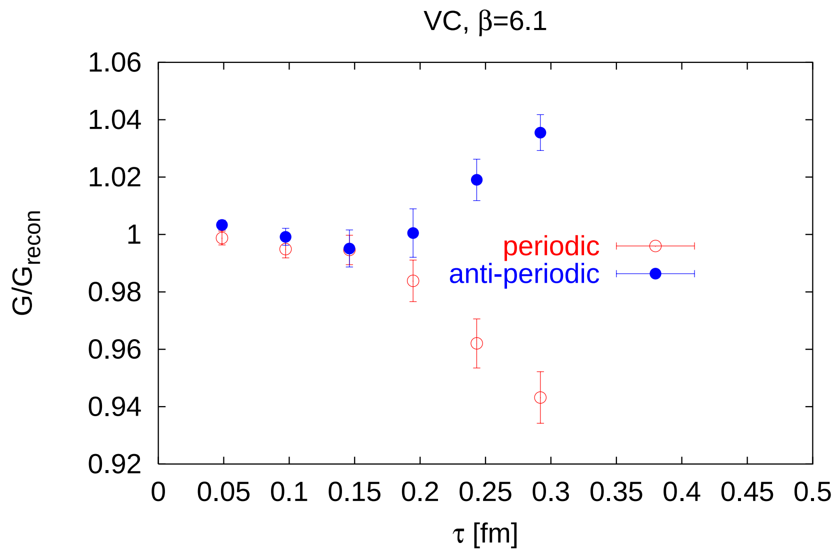


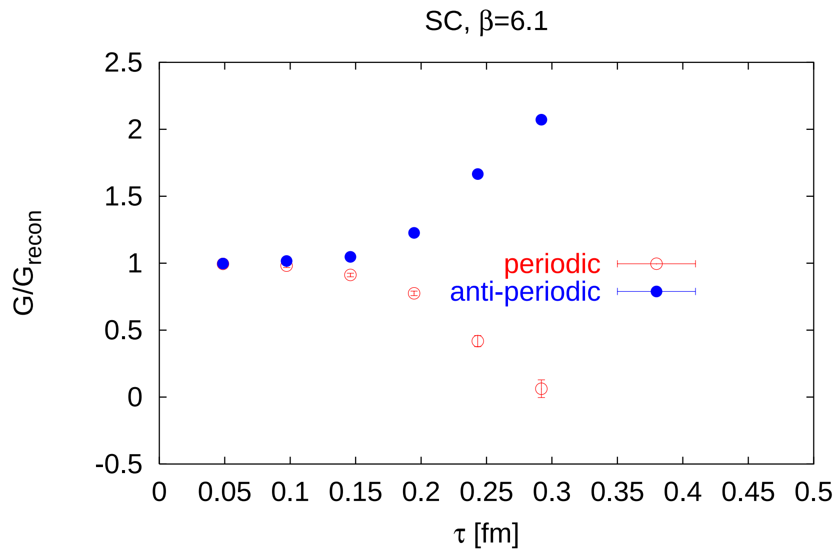


Sensitivity to boundary condition of the charmonium correlators at finite temperature :

No medium modification of the spectral function ➡ no dependence on b.c.

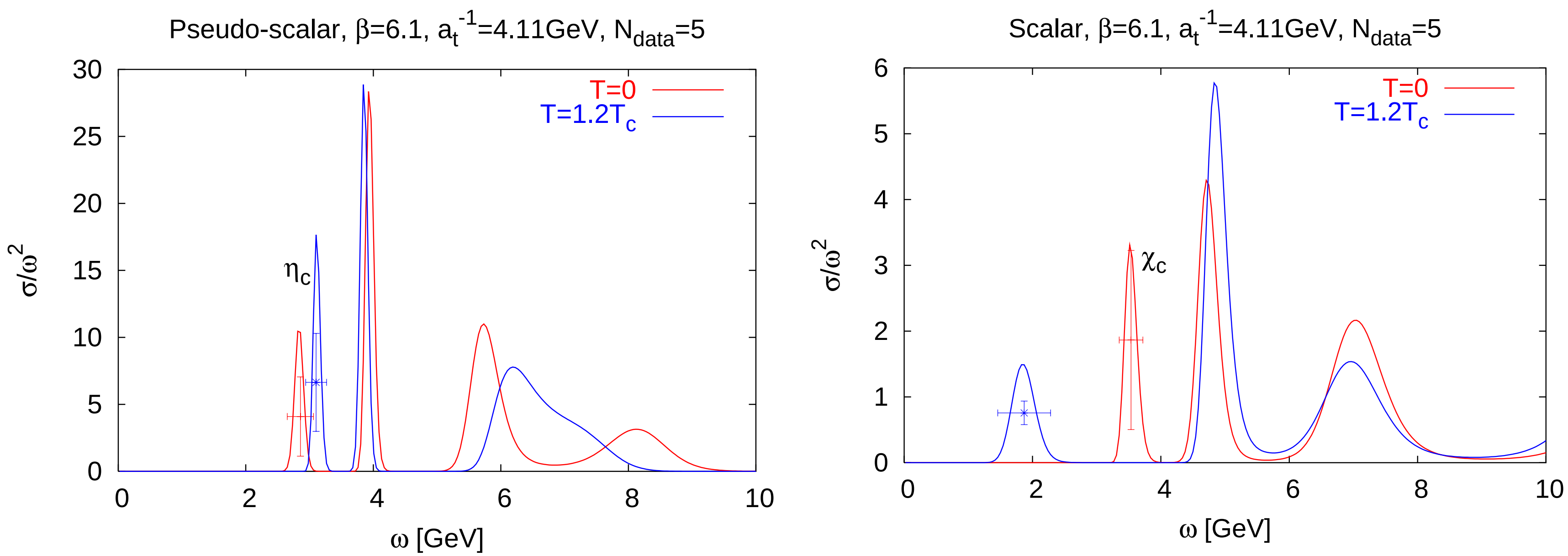
$$T \simeq 1.27 T_c$$





Below deconfinement no dependence of the correlators on boundary conditions was observed with present statistical accuarcy

Charmonia spectral functions above deconfinement

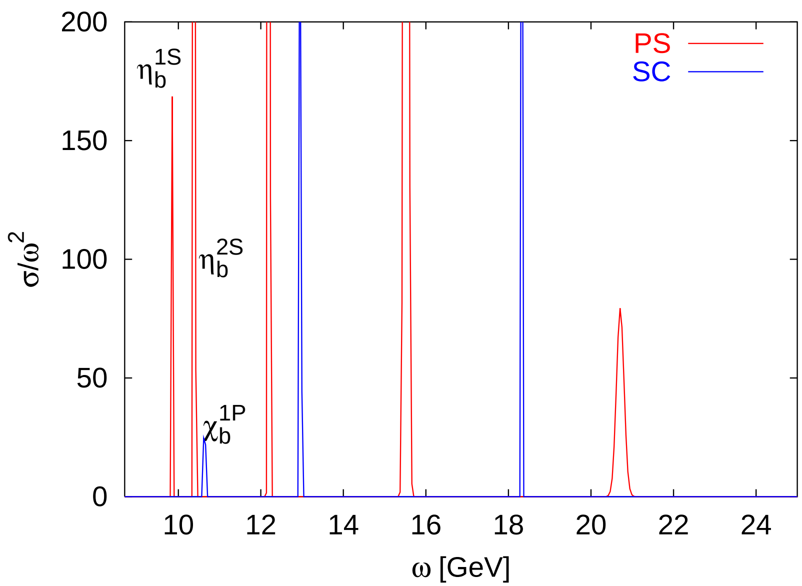


$\eta_c(1S)$ survives in the deconfined phase, $\chi_c(1P)$ is dissolved at $1.2T_c$

Agreement with previous findings from isotropic lattices

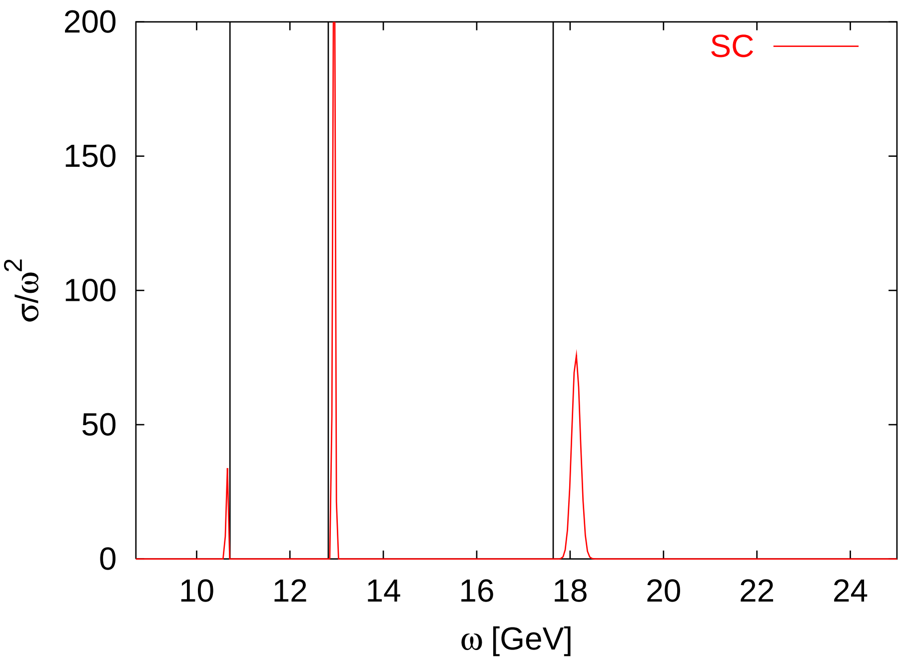
Datta, Karsch, Petreczky, Wetzorke, PRD 69 (2004) 094507

Bottomonia spectral functions at T=0



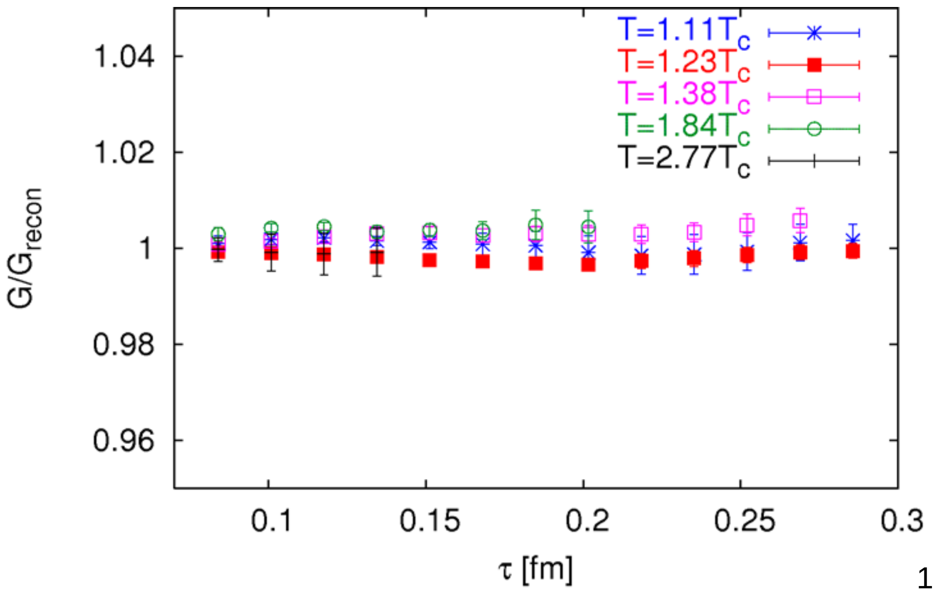
Excited 1P and 2S bottominia states are identified.

Peaks at $\omega > 12\mathrm{GeV}$ are presumably lattice artifacts.



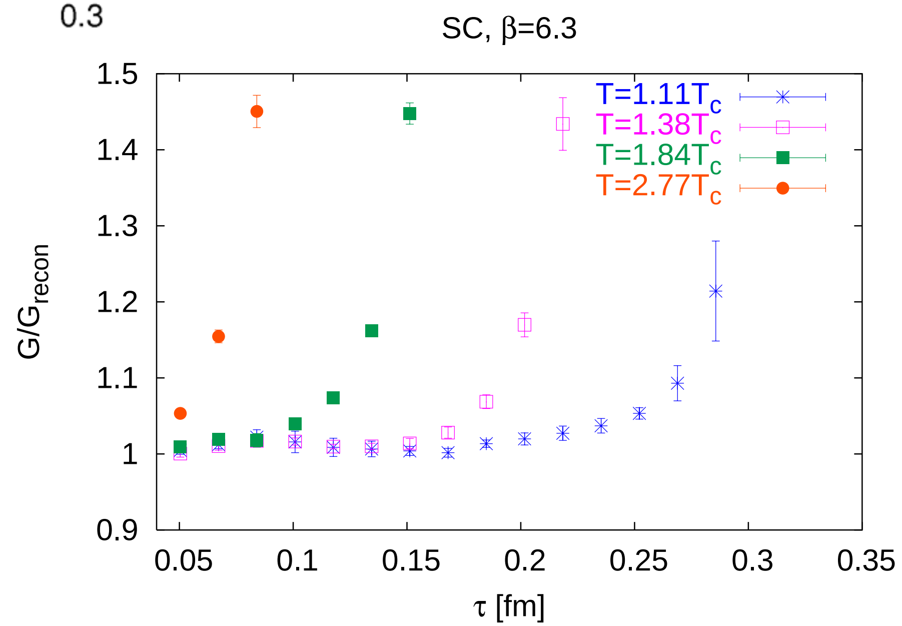
Consistency between constrained curve fitting and MEM

T-dependence of bottomonia correlators

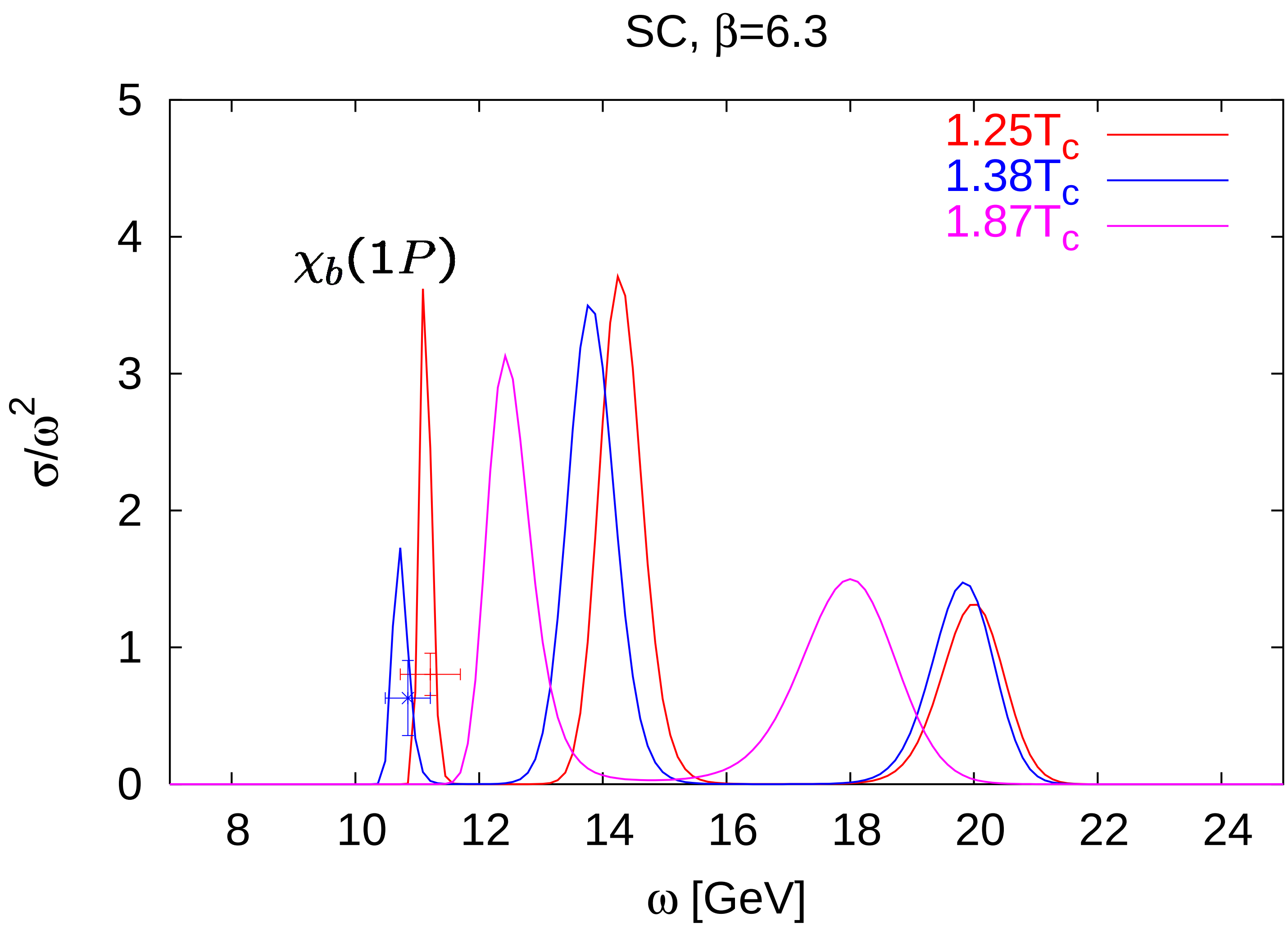


1S bottomonia behave according to expectations, no change till $2.7T_c$.

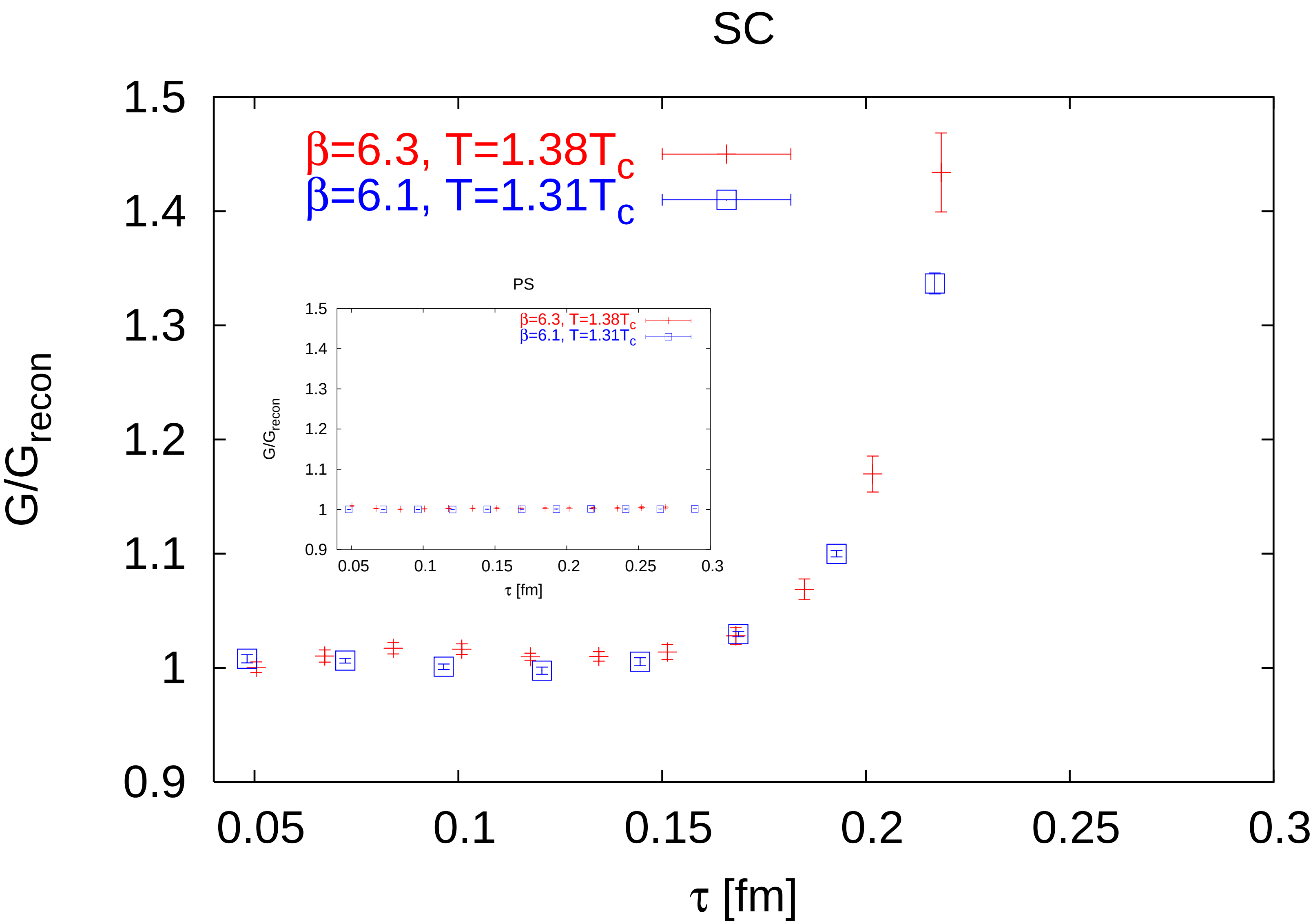
Suprise suprise: visible changes in the scalar (χ_{b0}) correlator already at $1.11T_c$



Does 1P bottomonium state exist in the plasma ?



Despite of large lattice artifacts temperature effects in the correlators are indpenedent of the lattice spacing



Conclusions

- Anisotropic Fermilab action allows a simultaneous study of charmonium and bottomonium spectral functions.

- Study of charmonium correlators and spectral functions shows that 1P state dissolves at $1.2T_c$ while the 1S state survive at this temperature confirming earlier studies

- Bottomonium correlators and spectral functions are studied at T>0 for the first time, no change in the S-state till $2.8T_c$, 1P state were shown to exist till $1.38T_c$ but no 1P signal was observed at $1.87T_c$

- Future directions: extension to larger anisotropies (especially for charmonium) and full QCD !