Quarkonium in the QGP from N_f=2+1 lattice QCD

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Introduction

The quarkonium is considered as a thermometer of the QGP in heavy ion collisions. The spectral functions $\rho_H(\omega)$ contains information about the in-medium hadron properties and related to Euclidean time correlator as

$$\sum_{\mathbf{x}} \langle \bar\psi \Gamma_H \psi(\tau,\mathbf{x}) (\bar\psi \Gamma_H \psi(0,\mathbf{0}))^\dagger \rangle \equiv G_H(\tau) = \int_0^\infty \frac{\omega}{\pi} \rho_H(\omega) \frac{\cosh(\omega(\tau - \frac{1}{2T}))}{\sinh(\frac{\omega}{2T})} \quad (1)$$

We compute $G_H(\tau)$ on the lattice, extract spectral function from Eq. (1) and estimate in-medium hadronic properties. In addition transport coefficients, like heavy quark diffusion coefficients, are encoded in the vector meson spectral function.

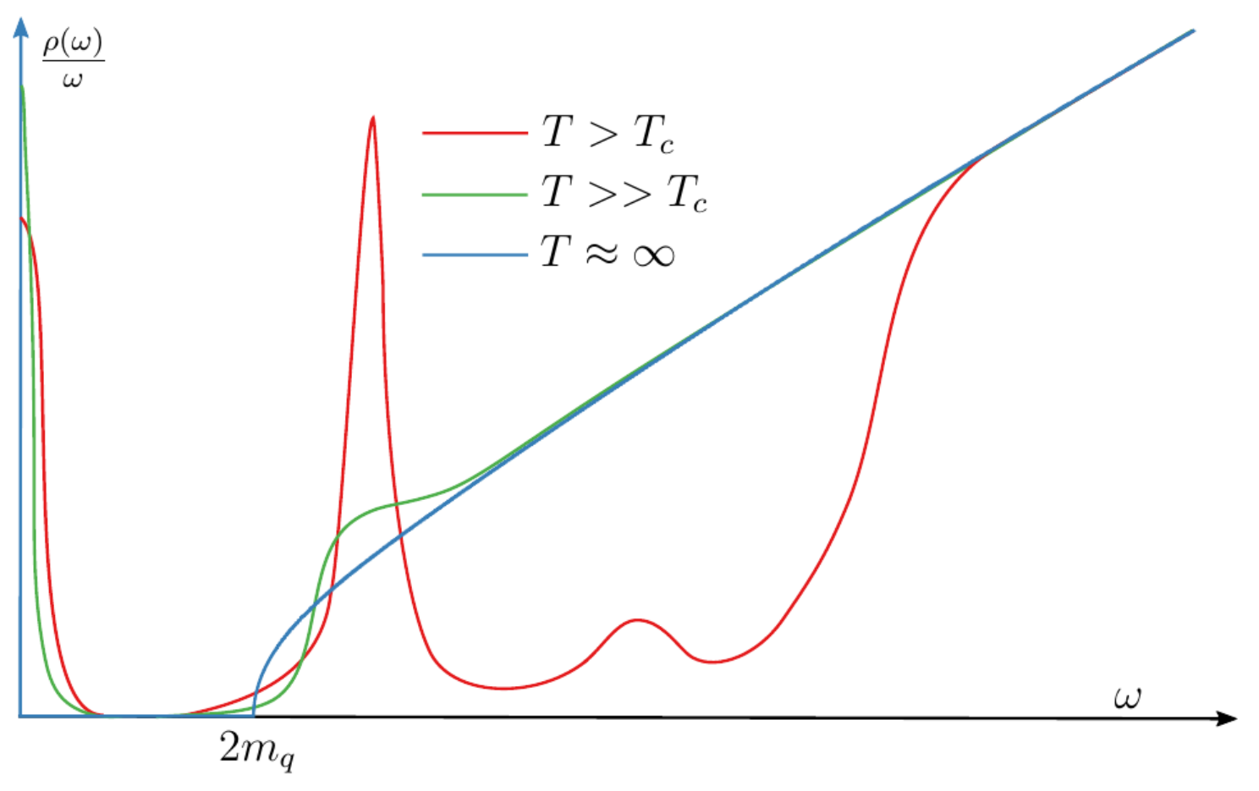


Fig. 1: Sketch of a heavy quark current-current spectral function for the vector channel at different temperatures. The high temperature limit corresponds to the free spectral function from equation for the vector channel (1). [1]

We discuss charmonium and bottomonium spectral functions at different temperatures above the transition temperature. As the temperature decreases, the continuum threshold shifts upwards and the peak structure corresponding to certain bound states is restored. However, the problem of dealing with unknown parameters and the ill-posed inversion problem still remains. To address this issue, several statistical methods have been suggested. In this study of quarkonium in 2+1-flavor QCD, we employ χ^2-fitting.

Perturbative Model Spectral Functions

We extend the methodology developed in the quenched approximation [5] to 2+1-flavor QCD. Initially, we focus on the thermal contributions near the threshold, specifically for $\omega \approx 2M$. When the energy is significantly above the threshold, thermal effects become less significant and are suppressed. As a result, by identifying the point on the spectra where the slope of both the thermal and vacuum components is at a minimum, typically between $\omega = 2M$ and $\omega = 3M$, the vacuum spectral function can effectively replace the thermal spectral function [4]. The resulting perturbative spectral functions for charmonium and bottomonium are illustrated in Figure 2.

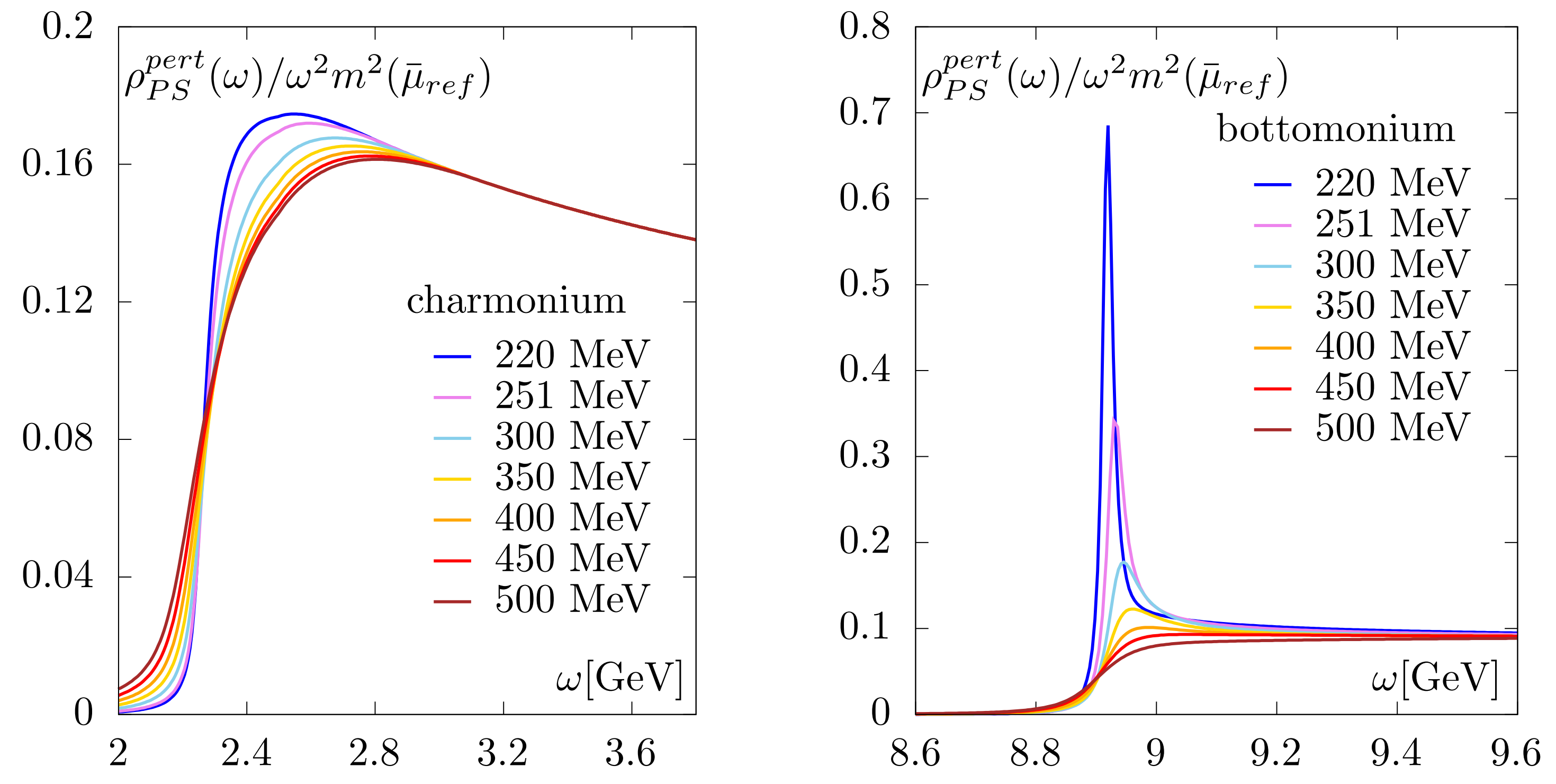


Fig. 2: Perturbative spectral functions, normalized by $\omega^2 m^2(\bar\mu_{ref})$ for charmonium and bottomonium at various temperatures.

Lattice Correlators

The mixed action approach was employed to obtain numerical data utilizing clover-improved Wilson fermions on large N_f=2+1 HISQ gauge field configurations, where m_π=315 MeV (see Fig. 3).

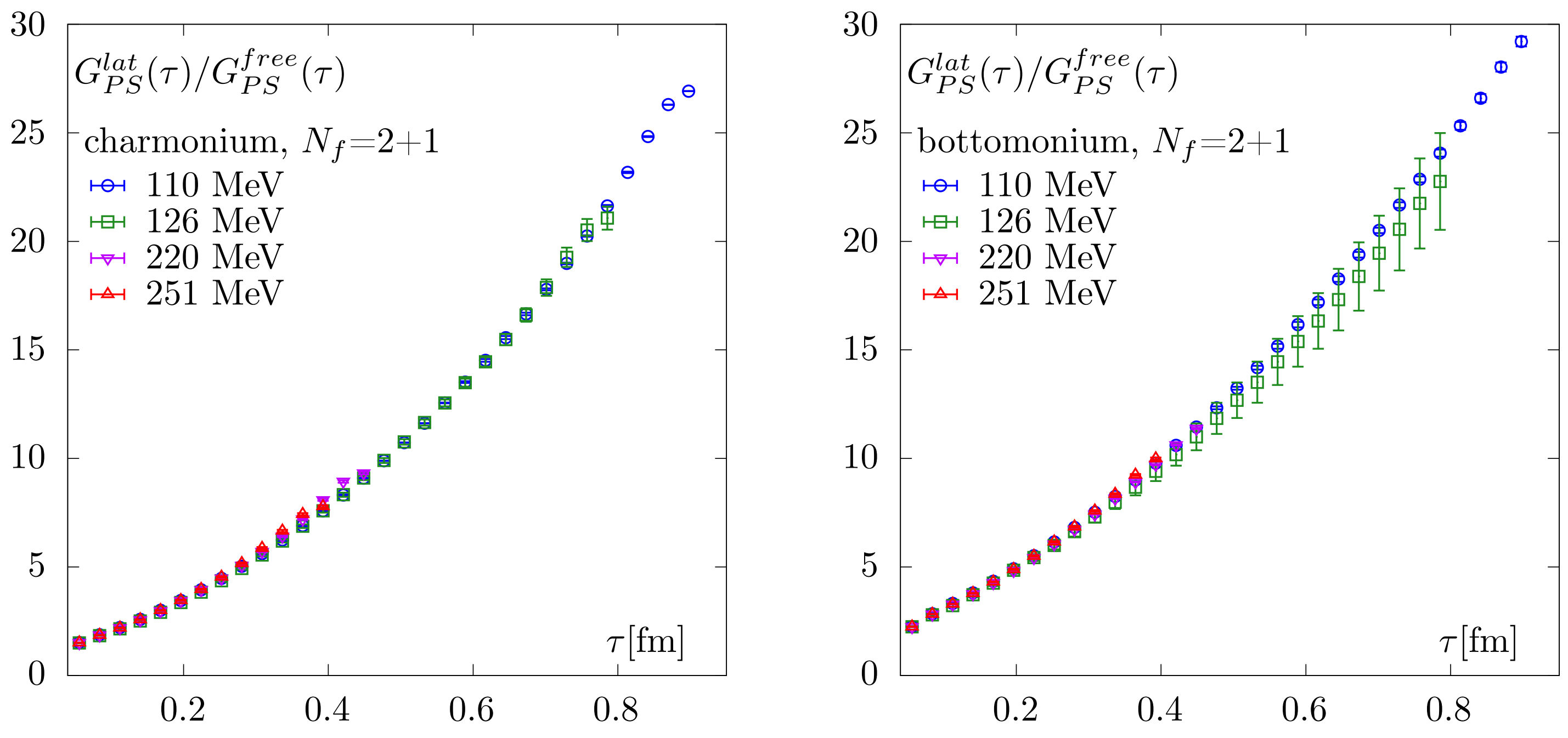
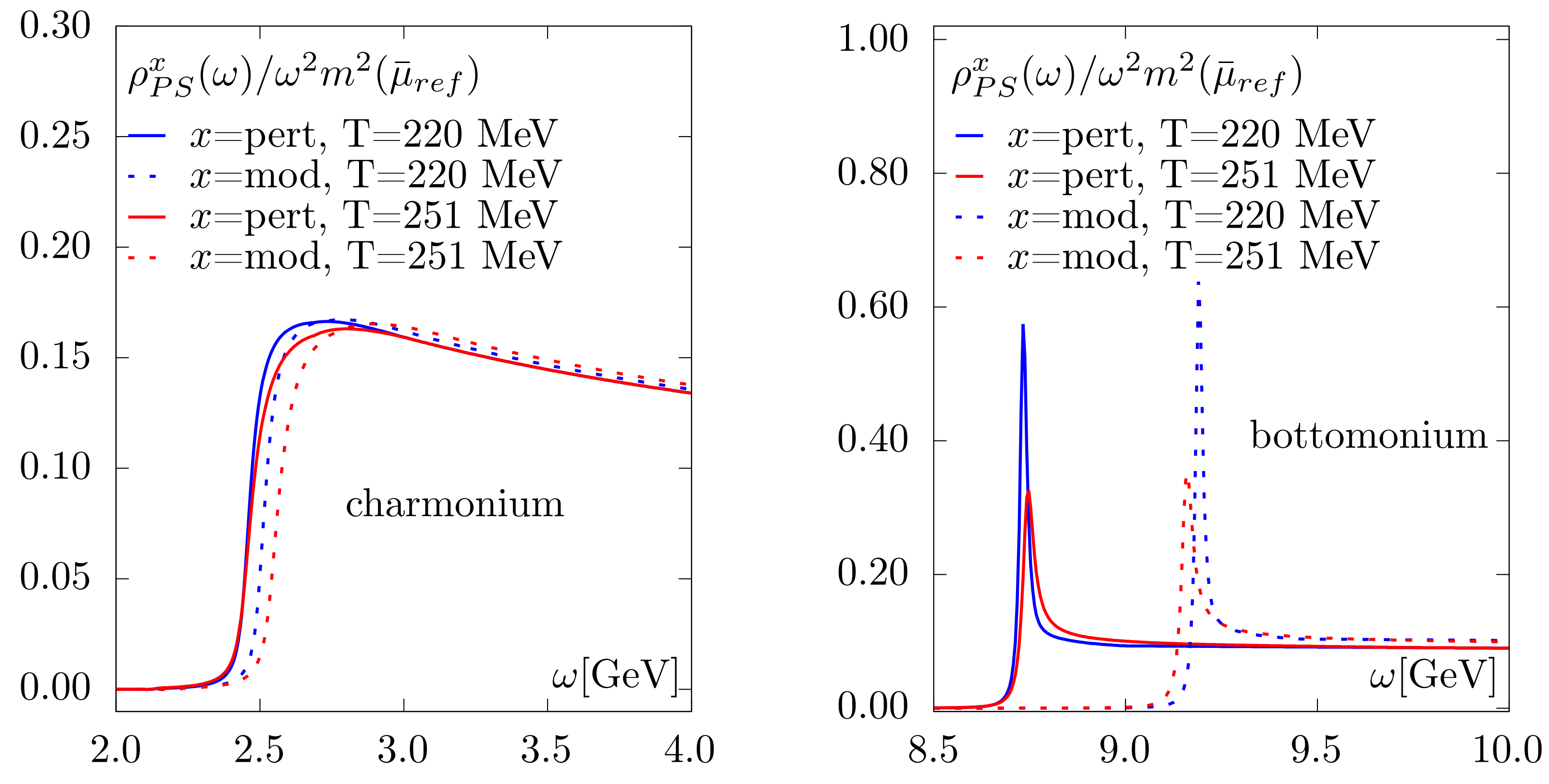


Fig. 3: Average values of correlator ratios at different temperatures for pseudoscalar quarkonium correlators. Our lattice sizes are 64^3x64, 96^3x56, 96^3x32 and 64^3x28 from the lowest temperature to the highest.

Spectral Reconstruction

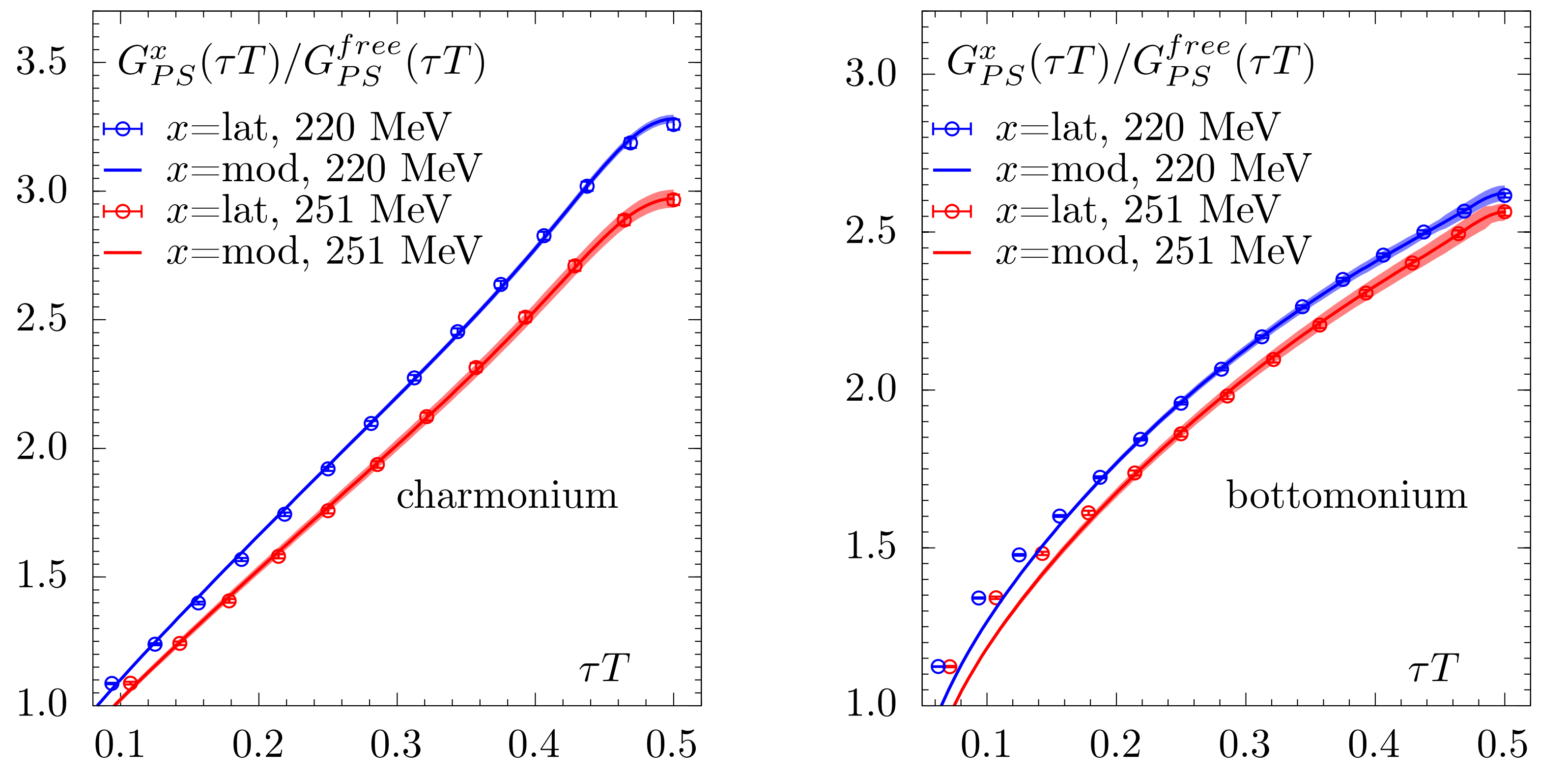
The model spectral function $\rho^{\mathrm{mod}}_{\mathrm{PS}}$ is derived from the perturbative spectral function, and incorporates two parameters, A and B to accommodate the normalization of the correlator data and a possible thermal mass shift, which will be determined using the χ^2 fitting procedure.

$$\rho^{\mathrm{mod}}_{\mathrm{PS}}(\omega) = A\rho^{\mathrm{pert}}_{\mathrm{PS}}(\omega - B)\ . \quad (2)$$



The next figure shows lattice correlators (points) and the correlators obtained from the model spectral function fits (lines) for charmonium and bottomonium. Both are normalized by the massive free correlation function,

$$\frac{G^{free}_{PS}(\tau)}{m^2(\bar\mu_{ref})} \equiv \int_{2M_q}^{\infty} \frac{\mathrm{d}\omega}{\pi} \left\{ \frac{N_c \omega^2}{8\pi} \tanh\left(\frac{\omega}{4T}\right) \sqrt{1 - \frac{4M_q^2}{\omega^2}} \right\} \frac{\cosh\left(\left(\frac{1}{2T} - \tau\right)\omega\right)}{\sinh\left(\frac{\omega}{2T}\right)} \quad (3)$$



It is observed that at small distances, the lattice correlator and the model correlator do not align with each other, indicating possible cut-off effects, while at large distances the lattice data is well described by the model fits.

Conclusion and Outlook

In this poster, we presented initial findings of correlation functions for pseudoscalar charmonium and bottomonium. These results were derived from 2+1-flavor HISQ gauge field configurations with physical strange quark masses and light quark masses set to $m_l = m_s/5$. The resulting m_π value was 315 MeV, and the measurements were taken at temperatures of 220 and 251 MeV, using clover-improved Wilson valence quarks. To obtain the perturbative spectral function in the pseudoscalar channel, we performed a seamless matching of the thermal and vacuum components.

Similar as in the quenched approximation [2,5] also for our recent 2+1-flavor study the lattice data can be well described by the perturbative model. Charmonium correlators can be well reproduced by perturbative spectral functions, showing a threshold enhancement but no bound states above T_c. Thermally broadend resonance peaks still persist for bottomonium in the analyzed temperature region.

Next we will investigate cut-off effects by incorporating additional lattice spacings, and ultimately carrying out a continuum extrapolation. This ongoing effort will expand upon our previous research conducted within the quenched approximation towards full QCD [5]. To further our understanding of the in-medium modifications of quarkonium states, we also intend to incorporate more temperatures. Furthermore, we aim to estimate the heavy quark diffusion coefficient by modeling the transport peak in the vector channel of quarkonium.

References

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