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Fakultät für Physik

Lattice correlator

Spectral reconstruction (Full G

Outlook



Study of quarkonium in QGP from unquenched lattice QCD

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Baryons 2022, 08.11.2022





Correlators and SPFs

The spectral function

Lattice correlators

Spectral reconstruction (Full QCD)

Outlook



Correlators and SPFs The spectral function Lattice correlators Spectral reconstruction (Full QCD)

- Heavy $q\bar{q}$: a thermometer of QGP in heavy ion collisions
- The spectral functions ρ_H(ω) contains information about the in-medium hadron properties

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



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Strategy:

- $G_H(\tau)$ on the lattice
- Extract spectral function
- Estimate in-medium hadronic properties
- In addition transport coefficients, like heavy quark diffusion coefficients, are encoded in the vector meson spectral function



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The spectral function



Ref. [H. Sandmeyer's thesis]

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The spectral function



• At infinite temperature there cannot be bound states

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Ref. [H. Sandmeyer's thesis]

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The spectral function



- At infinite temperature there cannot be bound states
- Melting of states visualizes in shrinking and broadening of bound peaks

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Ref. [H. Sandmeyer's thesis]

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The spectral function



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Ref. [H. Sandmeyer's thesis]

The spectral function



- At infinite temperature there cannot be bound states
- Melting of states visualizes in shrinking and broadening of bound peaks
- Heavy quark diffusion constant can be read off in vector channel

$$D = \frac{\pi}{3\chi_q} \lim_{\omega \to 0} \sum_{i=1}^3 \frac{\rho_V(\omega, T)}{\omega}$$

Extraction of spectral function is ill-posed problem \rightarrow large lattices needed. Ref. [H. Sandmeyer's thesis]



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SPF's contribution to correlators



Figure: Visualization of which parts of the spectral function contribute to the correlator at different τT . Ref. [H. Sandmeyer's thesis]



Lattice correlation

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Outlook

Spectral reconstruction (Quenched)

$$\rho_{PS}^{pert}(\omega) = \rho_{PS}^{VAC}(\omega) + A^{match}\rho_{PS}^{THERM}(\omega)$$
$$\rho_{PS}^{mod}(\omega) = A\rho_{PS}^{pert}(\omega - B)$$



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Spectral reconstruction (Full QC

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Spectral reconstruction (Quenched)

$$\begin{aligned} \rho_{PS}^{pert}(\omega) &= \rho_{PS}^{VAC}(\omega) + A^{match} \rho_{PS}^{THERM}(\omega) \\ \rho_{PS}^{mod}(\omega) &= A \rho_{PS}^{pert}(\omega - B) \end{aligned}$$



Ref. [JHEP 11 (2017) 206, A. Lorenz's thesis]

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Spectral reconstruction (Quenched)



Ref. [JHEP 11 (2017) 206, A. Lorenz's thesis]

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Mass tuning on mixed action (Full QCD)



- Mixed action approach (Wilson Clover fermions on HISQ configurations)
- Tadpole improved tree-level, $c_{SW} = \frac{1}{u_0^3}, \ u_0 = (tr[U_{\mu\nu}])^{\frac{1}{4}}$
- Quark mass tuning
- Tune spectrum to experimental values

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Mass tuning on mixed action (Full QCD)



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- Tune spectrum to experimental values
- HISQ lattices from HotQCD (arXiv:2110.11659) ($m_l = m_s/5$); 64³x64, 96³x32, new temperatures at 96³x56 and 96³x28
- Gradient flow (renormalizes the operators, removes cut-off and mixed action effects and improves signal-to-noise ratio)

Outlook

Correlators: Quenched VS Unquenched



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Outlook

Perturbative SPF (Full QCD)

$$\frac{\rho_{PS}^{VAC}(\omega)}{\omega^2 m^2(\bar{\mu})} \equiv \frac{N_c}{8\pi} \tilde{R}_c^p(\omega,\bar{\mu})$$



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Perturbative SPF (Full QCD)

$$\frac{\rho_{PS}^{VAC}(\omega)}{\omega^2 m^2(\bar{\mu})} \equiv \frac{N_c}{8\pi} \tilde{R}_c^p(\omega,\bar{\mu})$$

$$\rho_V^{NRQCD}(\omega) = \frac{1}{2} \left(1 - e^{-\frac{\omega}{T}} \right) \int_{-\infty}^{\infty} \mathrm{d}t \, e^{i\omega t} \, C_{>}$$

$$\rho_{PS}^{THERM} = \frac{M^2}{3} \rho_V^{NRQCD} , \quad \omega \approx 2M$$

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Spectral reconstruction (Full QCD)

Perturbative SPF (Full QCD)

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 $\rho_{PS}^{pert}(\omega) = \rho_{PS}^{VAC}(\omega) + A^{match} \rho_{PS}^{THERM}(\omega)$ Ref. [JHEP 11 (2017) 206] ◆□ ▶ ◆● ▶ ◆ ■ ▶ ◆ ■ ・ ● ● の へ ● 10/13



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Perturbative SPF (Full QCD)



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Spectral reconstruction (Full QCD)

$$\rho_{PS}^{mod}(\omega) = \mathbf{A} \rho_{PS}^{pert}(\omega - \mathbf{B})$$



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Spectral reconstruction (Full QCD)

$$\rho_{PS}^{mod}(\omega) = A \rho_{PS}^{pert}(\omega - B)$$



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Outlook

- Extend the studies on spectral and transport properties from quenched to dynamical QCD
- Study light quark mass effects by comparing $m_l = m_s/5$ and $m_l = m_s/27$
- Study cut-off effects and perform continuum extrapolation
- Improve on perturbative and non-perturbative spectral function models
- Spectral reconstruction based on spectral function model fits and other reconstruction methods
- Estimate in-medium hadronic and transport properties (Kubo relation)

Thank you for your attension !