An in-medium heavy-quark potential from the $Q\bar{Q}$ free energy

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The large suppression and elliptic flow of heavy-flavor spectra in heavy-ion collisions at RHIC and the LHC indicate that heavy quarks couple strongly to the quark gluon plasma (QGP), see Ref. [1] for a recent review. This finding calls for a tractable non-perturbative microscopic model that can bridge first-principles computations in thermal lattice QCD with experimental data. Toward this end we have been developing a many-body T-matrix approach, to evaluate the interactions of heavy quarks in the QGP and connect them to observables [2]. A key input to this approach is the in-medium two-body interaction potential (driving kernel) which must be determined with good accuracy to ensure reliable results. In the present work [3] we investigate the problem of extracting a static potential between a heavy quark and its antiquark in the QGP from lattice-QCD computations of the singlet free energy, $F_{Q\bar{Q}}$.

The original definition of the free energy $F_{Q\bar{Q}}$ [4] implies that it is related to the static $Q\bar{Q}$ 4-point Green function, which can be calculated within the many-body T-matrix formalism. We find that the free energy can be expressed from an underlying potential ansatz resummed in ladder approximation as,

$$F_{Q\bar{Q}}(r) = -T\,ln\left(\int_{-\infty}^{\infty} dE\,\frac{1}{\pi}\frac{(V+\Sigma)_I(E)}{(E-(V+\Sigma)_R(E))^2+(V+\Sigma)_I^2(E)}e^{-\beta E}\right).$$

In the weakly coupled limit, the imaginary part, $(V+\Sigma)_I$, is parametrically small and turns the Lorentzian function in the integrand into a Dirac δ-function, which implies that the real part of "potential", $(V+\Sigma)_R$, equals the free energy, $F_{Q\bar{Q}}(r)$. For a strongly coupled system, however, large imaginary parts of both $Q\bar{Q}$ potential-type and single-quark self-energies are expected from previous results of the T-matrix approach [3]. We find that such large imaginary parts, and in particular their energy dependence which figures in the integrand of the above expression, induce marked deviations of the potential from the resulting free energy. Indeed, when fitting lattice-QCD results [5] of the latter, we obtain a potential as shown in Fig. 1, which is characterized by significant long-range contributions from remnants of the confining force, in stark contrast to the free energy especially at low temperatures close to

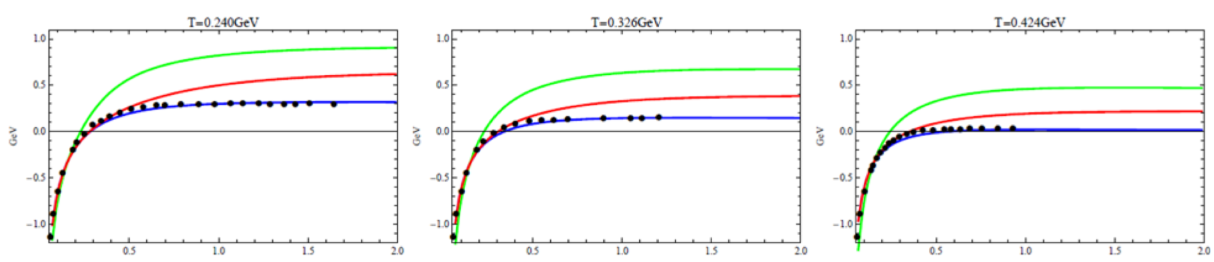

FIG. 1. Our fit (blue/lower lines) to the color-singlet $\mathbf{Q\bar{Q}}$ free energy computed in lattice QCD (black dots) [5] at 3 different temperatures, T = 240, 326 and 424 MeV, in the left, middle and right panel, respectively. The red/middle lines are the real parts of the underlying potential, while the green/upper lines represent the corresponding internal energies.

T_c. Such a long-range force range will allow heavy quarks to interact with a large number of surrounding medium partons, with important consequences for the properties of heavy quarks and quarkonia in the QGP. For example, preliminary estimates of the pertinent heavy-quark transport coefficient indicate a very small spatial diffusion coefficient and short thermalization time, characteristic for a strongly coupled system.

[1] F. Prino and R. Rapp, arXiv:1603.00529.
[2] F. Riek and R. Rapp. Phys. Rev. C **82**, 035201 (2010); New J. Phys. **13**, 045007 (2011).
[3] S.Y.F Liu and R. Rapp. Nucl. Phys. **A941**, 179 (2015).
[4] L.D. McLerran and B. Svetitsky, Phys. Rev. D **24**, 450 (1981).
[5] O. Kaczmarek, PoS **CPOD07**, 043 (2007).