Update on potential models

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Motivation

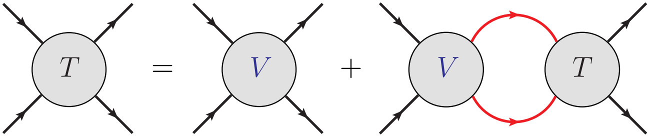
- Heavy Quarks are probes for the QGP

  Bound states: Changes in spectral functions
  Transport observables: Relaxation rate
  } Establish link!

- Open and hidden charm / bottom in common approach
- Non-perturbative information essential
  $\rightarrow$ Potential form lQCD
- Relativistic corrections
- Map out systematic uncertainties

T-Matrix formalism

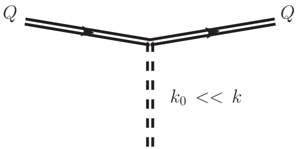
Start with the Bethe-Salpeter equation



Reduction: $4d \to 3d$ (Different schemes: BbS, Th, ...)

$$T(E,\vec{q},\vec{k}) = V(\vec{q},\vec{k}) + \int \frac{d^3\vec{p}}{(2\pi)^3} V(\vec{q},\vec{p}) G(E,\vec{p}) T(E,\vec{p},\vec{k})$$

- Heavy quarks: $k_0 \ll k$
  $\to$ Potential
- One heavy quark determines kinematics
- Non-perturbative interactions
  $\to$ constrains from lQCD



Field theoretical Ansatz for the Potential

Megías, Arriola and Salcedo [05]

In perturbation theory:

$$e^{-F_1(r,T)/T} = e^{(g^2/(2N_c T^2))\,\langle A_{0,a}(x)A_{0,a}(y) - A_{0,a}^2(x)\rangle} + \cdots$$

Ansatz for propagator:

$$D_{00}(\vec{k}\,) = \frac{1}{k^2 + m_D^2} + \frac{m_G^2}{(k^2 + \tilde{m}_D^2)^2}$$

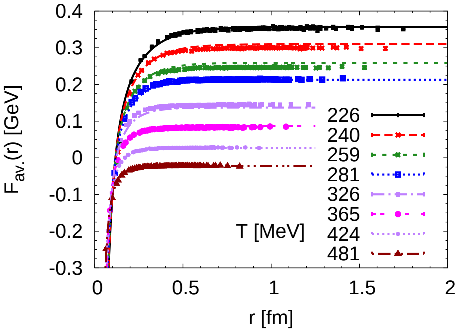
We arrive at:

$$\begin{aligned} F_a(r,T) &= F_a^C(r,T) + F^S(r,T) + F^\infty(T) \\ &= -\frac{4}{3}\alpha\left(\frac{C_a}{r}e^{-m_D r} + \frac{m_G^2}{2\tilde{m}_D}e^{-\tilde{m}_D r}\right) + \frac{4}{3}\alpha\left(\frac{m_G^2}{2\tilde{m}_D} - m_D\right) \end{aligned}$$

Casimir scaling only for the Coulomb term

Allows different relativistic factors for Coulomb and String

Determination of the parameters



Kaczmarek et. al. [07]
($n_f = 2 + 1$)

- Parameters: α_s, m_D, $\tilde{m}_D$, m_G
- Fit color averaged free Energy $\rightarrow$ gauge invariant ($\rightarrow$ requires again model)
- Fit in the region from 0.8 T_c to 2 T_c
- Non-perturbative effects (string term) important at finite T

Potential

- What to use: F or U?
- U has direct connection to $\langle H \rangle$: static limit: $U_1 = \langle H_{int.} \rangle$
- Studies in effective field theories seem to suggest F
- Bracket uncertainty by using F and U
- Quark self energy:

Heavy Quarks:

$$\begin{aligned} m_{eff} &= m_0 + \Sigma_Q(T) \\ &= m_0 + \frac{1}{2} X(\infty) \\ X &\in \{U_1, F_1\} \end{aligned}$$

Light Quarks:

$$m_{th} = \frac{1}{\sqrt{3}} gT$$

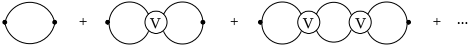
$$m_q = \sqrt{(m_q^0)^2 + (m_{th})^2}$$

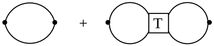
$$m_u^0 = m_d^0 = 0 \quad m_s^0 = 0.11\text{GeV}$$

Additionally supply imaginary part: $\Gamma_{q,c} \sim 0.1$ GeV
(connection to "imaginary potential" (e.g. Laine [07]))

Spectral functions and euclidian correlators

- Quarkonium spectral function:





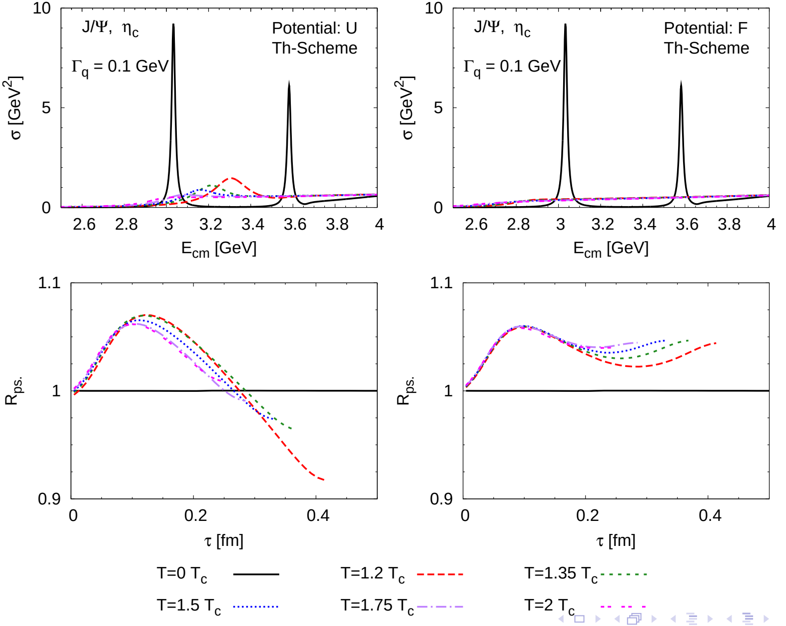
$$\sigma(\omega) = \frac{1}{\pi} \Im(\Gamma\, G\, \Gamma + \Gamma\, G\, T\, G\, \Gamma)$$

- In vacuum $\rightarrow$ check spectrum
- In medium $\rightarrow$ use Correlator ratios

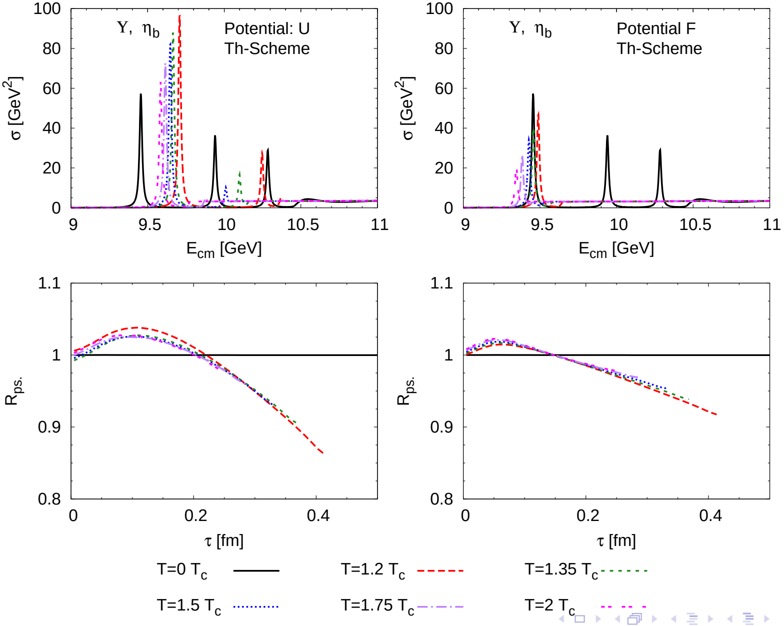
$$R_G(\tau, T) = \frac{\int \sigma(\omega, T)\, K(\omega, \tau, T)\, d\omega}{\int \sigma(\omega, T_{rec.})\, K(\omega, \tau, T)\, d\omega}$$

- Use vacuum spectral function for reconstruction
- Concentrate on pseudo-scalar channel
- Lattice suggests ratio $\sim$ 0.9 - 1.0 (Jakovac [07], Aarts [07])

Results for $c\bar{c}$



Results for $b\bar{b}$



Charm quark transport

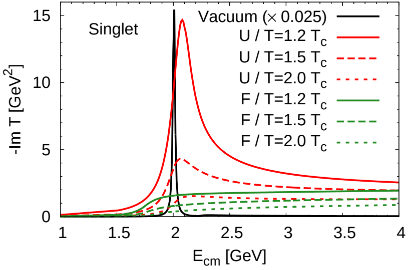
Heavy Quarks $\rightarrow$ Consider Fokker-Planck equation:

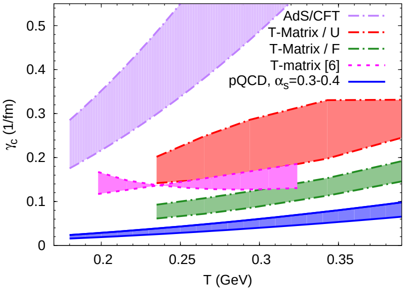
$$\frac{\partial f_Q}{\partial t} = \frac{\partial}{\partial p_i}(p_i A f_Q) + \frac{\partial^2}{\partial p_i \partial p_j}(B_{ij} f_Q)$$

$$A(\vec{p}\,) = \frac{1}{2\,E_p} \int \frac{d^3\vec{q}}{(2\pi)^3 2\,E_q} \int \frac{d^3\vec{q}\,'}{(2\pi)^3 2\,E_{q'}} \int \frac{d^3\vec{p}\,'}{(2\pi)^3 2\,E_{p'}}$$
$$\times \frac{1}{\gamma_c}\, f_{kin.} \sum |\,T_{HL}|^2\,(2\pi)^4\,\delta(q + p - q' - p')f_B(\vec{q}\,)$$

- Calculate heavy-light T-Matrix
- Sum over color channels and s- and p-waves.
- Include pQCD contribution from gluon interaction. ($\alpha_s = 0.4$)

Charm quark transport





- Feshbach resonance if U is used (melting at $\sim 1.5\,T_c$)
- No resonance structures when using F
- $\gamma_c = A(0)$
- Non perturbative interactions
  $\Rightarrow$ rate significantly larger than pQCD

Conclusions / Outlook

- Conclusions
  - T-matrix is a consistent thermodynamic approach for scattering and bound states
  - T-Matrix includes broad range of medium effects (quark self-energies, in-medium potential (lQCD), absorption, ...)
  - Open and hidden charm / bottom described in one approach (check with lQCD)
  - Link to transport properties (and constraints of them!)

  - arXiv:1005:0769 [hep-ph]

- Outlook
  - Calculation of correlator ratios also in other channels
  - Realistic quark spectral functions (zero modes)
  - What is the potential?
  - ...