Quarkonium properties in hot equilibrium matter

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D meson mass from heavy quark potential

Schrodinger Eq. for quarkonium

$$\left[2m_c - \frac{1}{m_c}\nabla^2 + V(r,T)\right]\psi(r,T) = M\psi(r,T),$$

Redefining heavy-quark potential,

$$\left[-\frac{\nabla^2}{m_c} + \tilde{V}(r,T)\right]\psi(r,T) = -\varepsilon\psi(r,T),$$

$$\tilde{V}(r,T) \equiv V(r,T) - V(r=\infty,T),$$

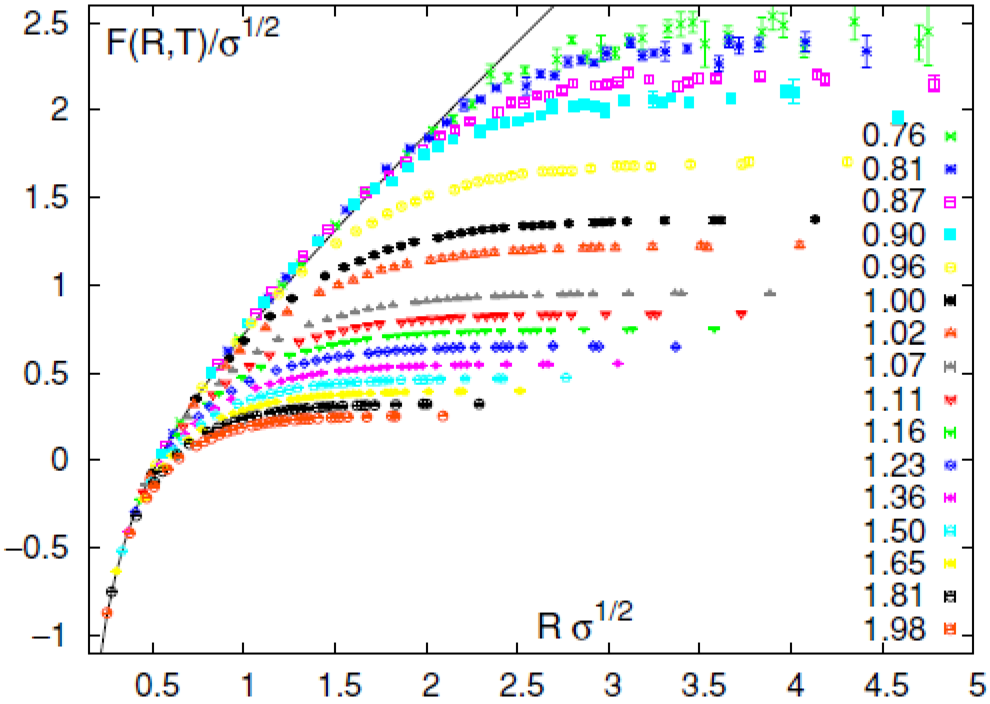
Binding energy

$$\varepsilon = 2m_c + V(r=\infty,T) - M.$$

D meson mass

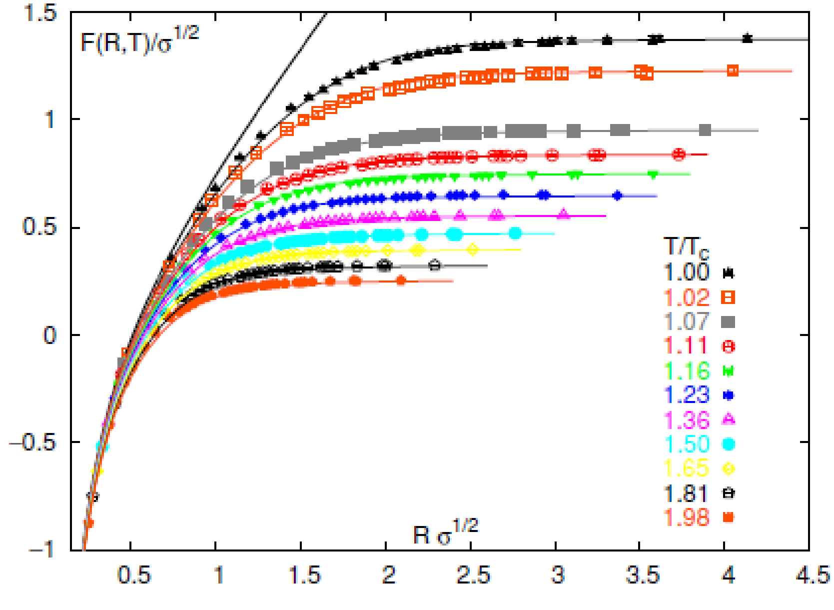
$$m_D(T) \equiv \frac{M}{2} = m_c + \frac{1}{2}V(r=\infty,T).$$

Free energy from lattice calculations

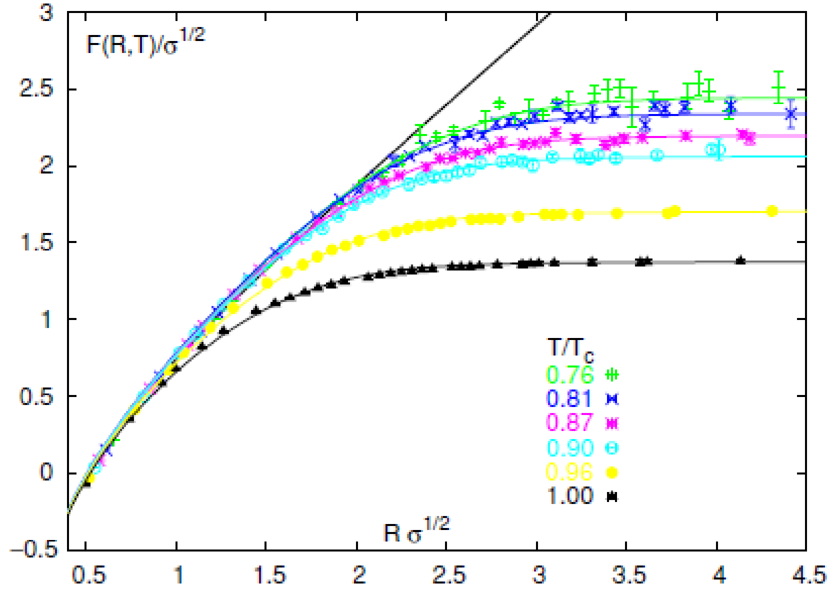


Parameterize free energy

H. Satz, J. Phys. G: Nucl. Part. Phys. 32 R25



(a)



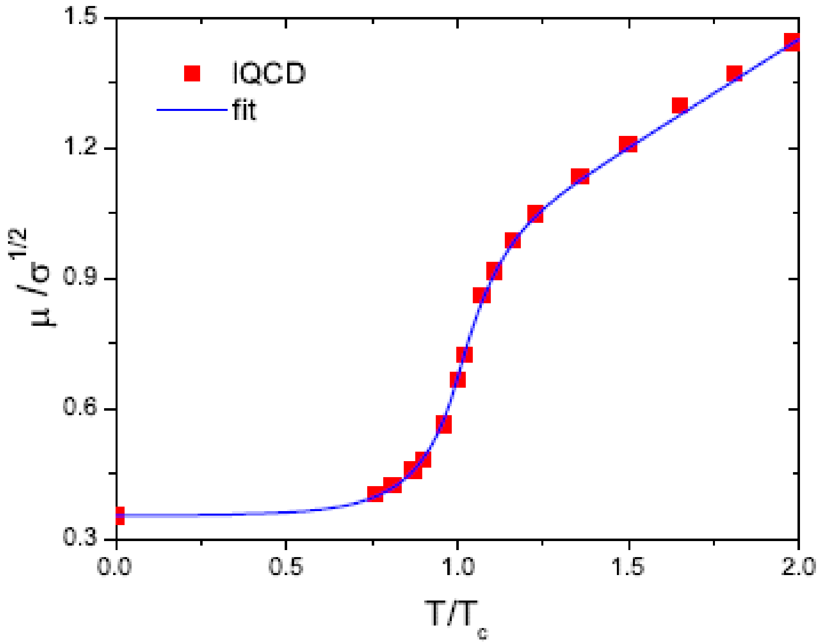
(b)

$$F(r,T) = F_s(r,T) + F_c(r,T)$$

$$F_c(r,T) = -\frac{\alpha}{r}[\mathrm{e}^{-\mu r} + \mu r]$$

$$F_s(r,T) = \frac{\sigma}{\mu}\left[\frac{\Gamma(1/4)}{2^{3/2}\Gamma(3/4)} - \frac{\sqrt{\mu r}}{2^{3/4}\Gamma(3/4)}K_{1/4}[(\mu r)^2]\right]$$

Screening mass



$$\frac{\mu}{\sqrt{\sigma}} = 0.35 + 0.0034\exp[(T/T_c)^2/0.22]$$
$$\text{for } T < T_c,$$
$$\frac{\mu}{\sqrt{\sigma}} = 0.45 + 0.5\left(\frac{T}{T_c}\right)\tanh\left[\frac{(T/T_c - 0.93)^2}{0.15}\right]$$
$$\text{for } T > T_c.$$

One can get explicit expressions of free energy and internal energy from the parametrizations and the thermodynamic relation

$$U(r,T) = F(r,T) + TS(r,T) = F(r,T) - T\frac{\partial F(r,T)}{\partial T}.$$

free energy vs. internal energy

- Free energy (F):

energy of QQbar system – 2*Q mass in heat bath

If V=F, quarkonium melts at a relatively low T

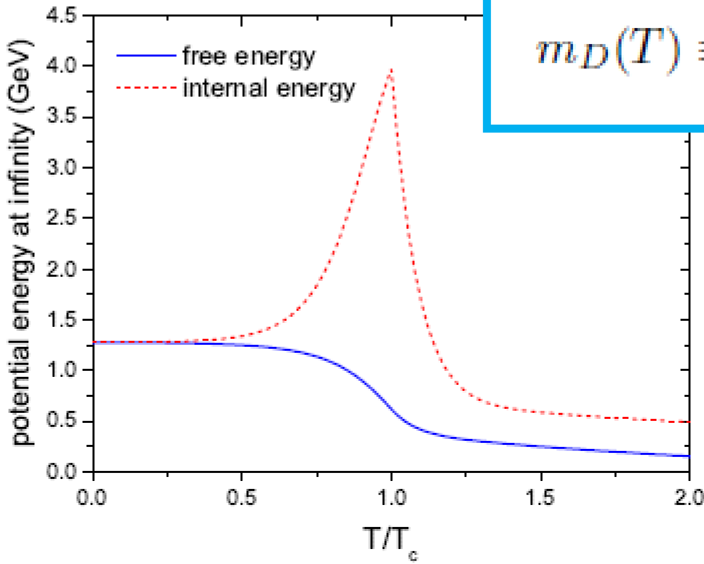
- Internal energy (U):

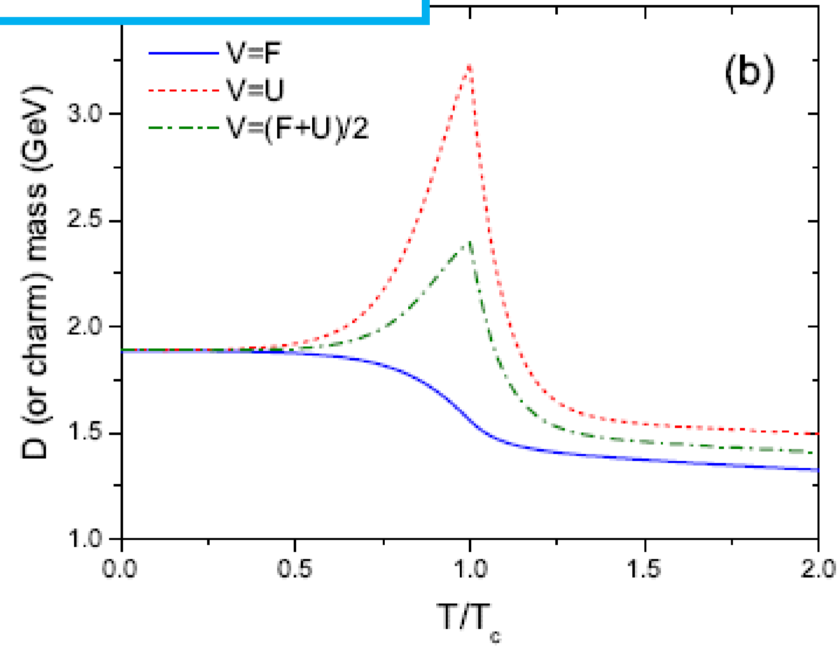
energy of QQbar system – 2*Q mass in isolated system

If V=U, quarkonium persists up to a high T

D meson (dressed charm quark) mass

$$m_D(T) \equiv \frac{M}{2} = m_c + \frac{1}{2}V(r=\infty, T).$$





$$\begin{aligned} U(r,T) &= F(r,T) + TS(r,T) \\ &= F(r,T) - T\frac{\partial F(r,T)}{\partial T}. \end{aligned}$$

QCD sum rule

Dispersion relation

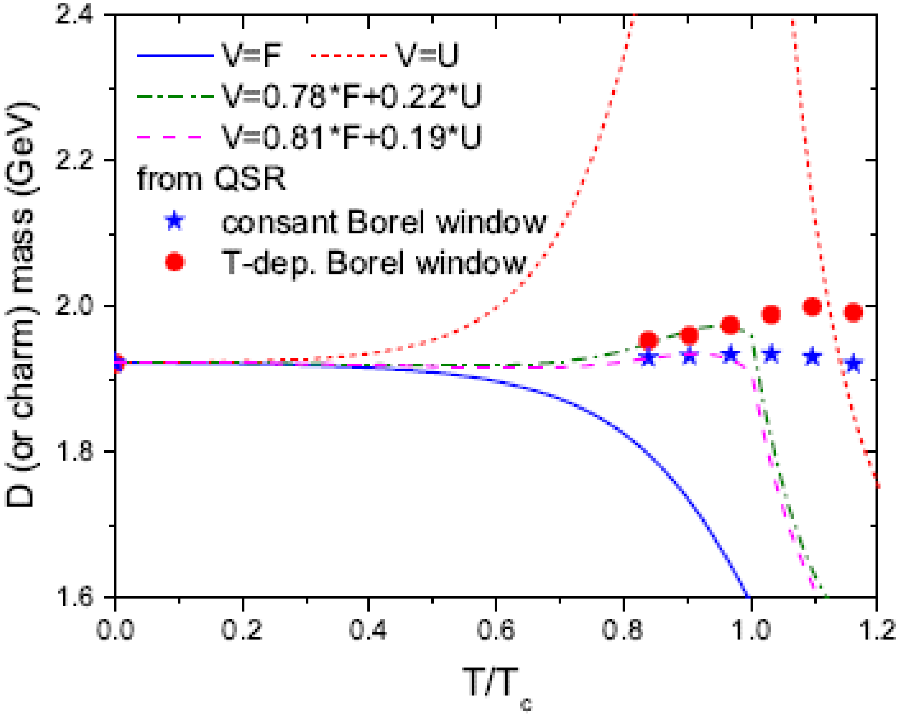
$$\frac{1}{\pi}\int \frac{\mathrm{Im}\Pi_1(s)}{s+Q^2}ds = \mathrm{Re}\Pi_1(q^2).$$

Spectral function:
pole (ground state) +
continuum

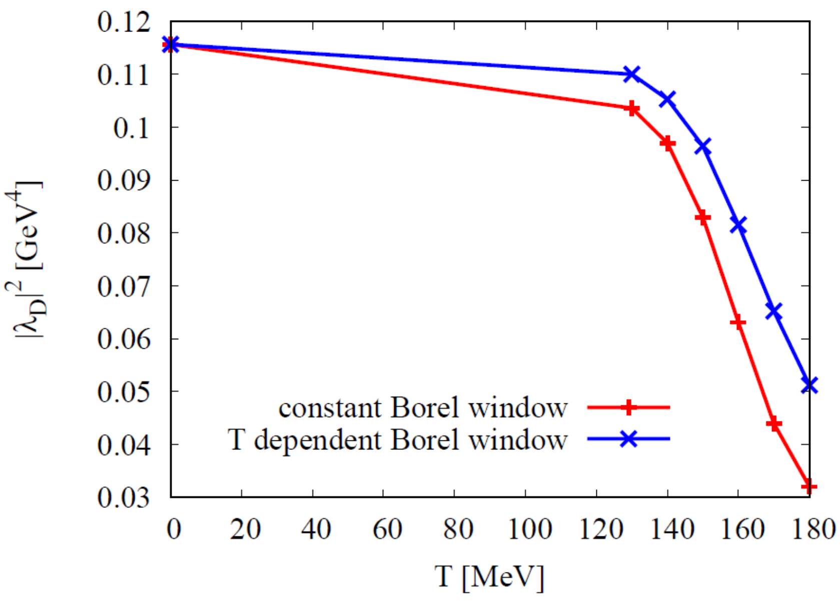
Operator Product
Expansion (OPE)
with non-vanishing
condensates (non-pQCD
effects)

Preliminary results on D meson from QCD sum rule (Philipp Gubler)

D meson mass



Residue ~ |ψ(0)|^2



- Heavy quark potential is crucial for quarkonium study in HIC.
- D meson (or dress charm quark) mass is closely related to (very) long-distance potential.
- The behavior of D meson mass as a function of temperature from QCD sum rule is reproduced with a combination of 80 % free energy and 20 % internal energy.