

# Production rate of charm quarks in hot QCD

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# Motivation

☞ Charm quarks probe the properties of the QGP

Task: study the production rate of  $c\bar{c}$  in equilibrated QGP w.  $N_f = 2 + 1$

☞ Quasiparticle model

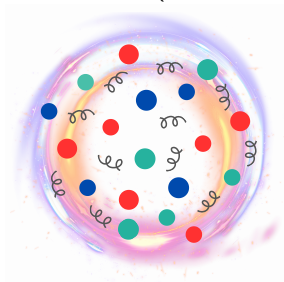
☞ Cross sections and differential rate equation

☞ Charm quark production rate in hot deconfined matter

# Quasiparticle Model - Effective Approach to QCD

☞ similar to massive quasidelectron moving freely in solid states

Real QGP:

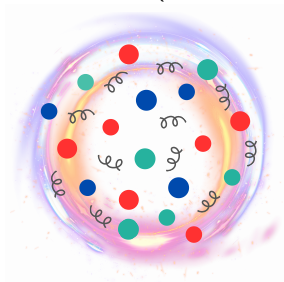


strongly-interacting particles,  
constant (bare) masses  $m_j$

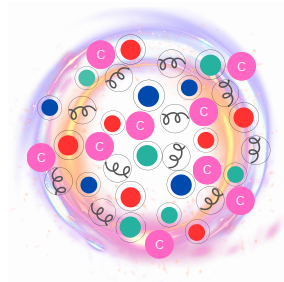
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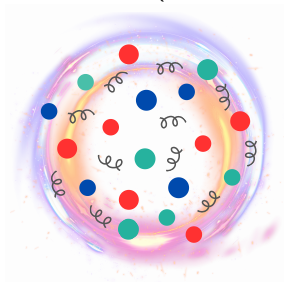
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weakly-interacting **quasi**particles,  
dynamical  $m_i^{eff} [T, G(T)]$

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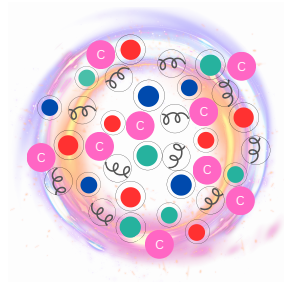
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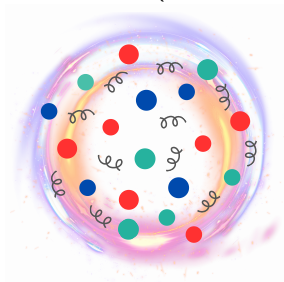
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$$m_i^{eff}[G(T), T] = \sqrt{m_i^2 + \Pi_i[G(T), T]}$$

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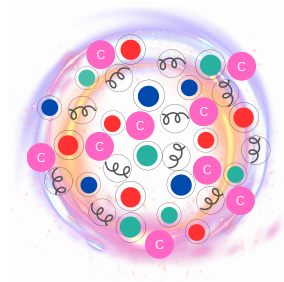
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$G(T)$  from lattice QCD EoS

# Quasiparticle Model

Quasiparticles are „dressed” with effective masses  $m_i[G(T), T]$ :

$$m_i[G(T), T] = \sqrt{(m_i^0)^2 + \Pi_i[G(T), T]} \quad (1)$$

self-energies  $\Pi_i$  from pQCD (Hard Thermal Loops):

$$\text{gluons: } \Pi_g[G(T), T] = \left(3 + \frac{N_f}{2}\right) \frac{G^2(T)}{6} T^2 \quad (2)$$

$$\text{quarks: } \Pi_{l,s}[G(T), T] = 2 \left[ m_{l,s}^0 \sqrt{\frac{G^2(T) T^2}{6}} + \frac{G^2(T) T^2}{6} \right] \quad (3)$$

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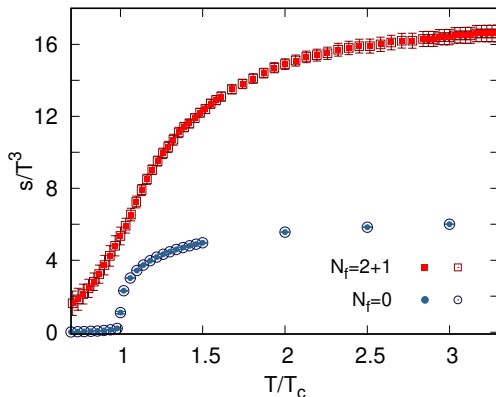
☞ effective coupling  $G(T)$  – reliable thermodynamics – lattice QCD



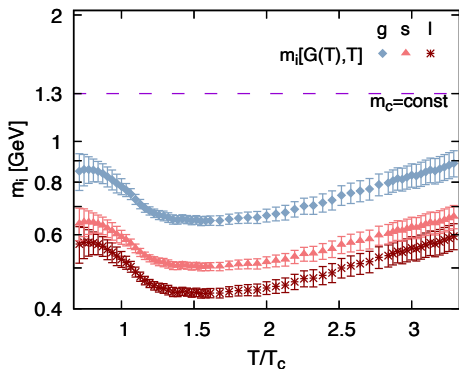
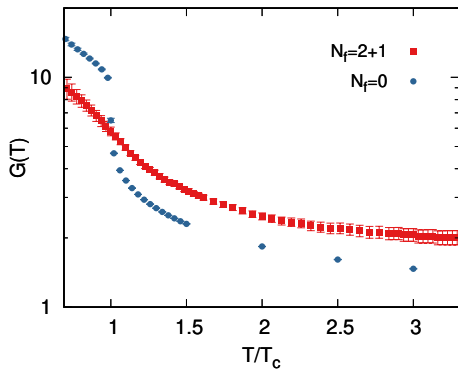
# Quasiparticle Model

$$s(T) \simeq \sum_{i=g,l,s,\dots} \int d^3p ([1 \pm f_i^0] \ln[1 \pm f_i^0] \mp f_i^0 \ln f_i^0) = \text{lattice data} \rightarrow G(T)$$

$$f_i^0(E_i) : E_i[G(T), T] = \sqrt{p^2 + m_i^2[G(T), T]} \quad (4)$$



# Effective Coupling and Masses



$$m_i[G(T), T] \gg m_l^0 = 5 \text{ MeV}, m_s^0 = 95 \text{ MeV}$$

# Charm Quark Evolution

Rate equation [Biro et al., PRC 48 '93; Zhang et al., PRC 77 '08]:

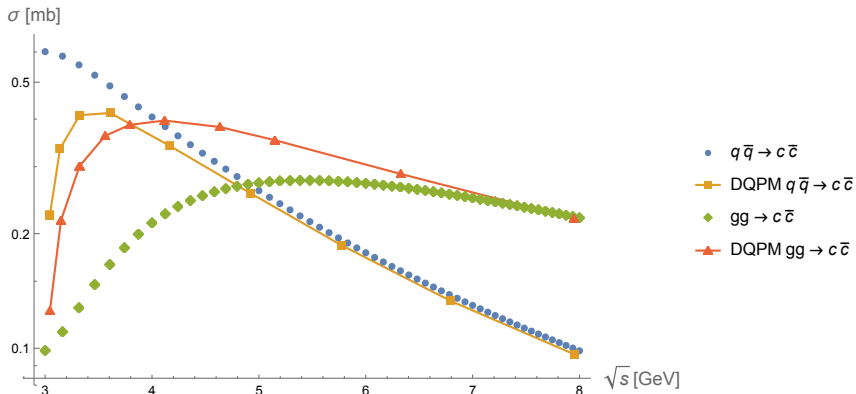
$$\partial_\mu (n_{c\bar{c}} u^\mu) \simeq R_{l\bar{l} \rightarrow c\bar{c}} + R_{s\bar{s} \rightarrow c\bar{c}} + R_{gg \rightarrow c\bar{c}} - R_{c\bar{c} \rightarrow l\bar{l}} - R_{c\bar{c} \rightarrow s\bar{s}} - R_{c\bar{c} \rightarrow gg} \quad (5)$$

$$\partial_\mu (n_c u^\mu) \simeq [\bar{\sigma}_{l\bar{l} \rightarrow c\bar{c}} (n_l)^2 + \bar{\sigma}_{s\bar{s} \rightarrow c\bar{c}} (n_s^0)^2 + \frac{1}{2} \bar{\sigma}_{gg \rightarrow c\bar{c}} (n_g^0)^2] \left(1 - \frac{n_c^2}{(n_c^0)^2}\right) \quad (6)$$

$$n_i^{(0)} = d_i \int d^3 p f_i^{(0)}(M_i) \quad (7)$$

\* LHS depends on the QGP expansion

# Total Cross Sections at $T_c = 0.155$ GeV



DQPM: T. Song, I. Grishmanovskii, O. Soloveva, E. Bratkovskaya, arXiv:2404.00425

# Thermal-Averaged Cross Sections

$$\sigma(\sqrt{s}) \rightarrow \bar{\sigma} = \langle \sigma v \rangle \quad (8)$$

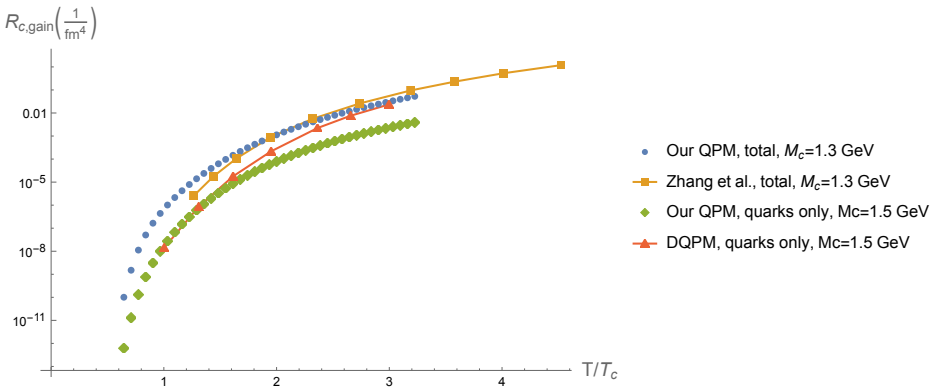
$$\bar{\sigma}_{ab \rightarrow cd} = \frac{\int d^3 p_a d^3 p_b f_a f_b \sigma_{ab \rightarrow cd} v_{ab}}{\int d^3 p_a d^3 p_b f_a f_b} = \quad (9)$$

$$\left[ 4 \frac{M_a^2}{T^2} \frac{M_b^2}{T^2} K_2\left(\frac{M_a}{T}\right) K_2\left(\frac{M_b}{T}\right) \right]^{-1} \times$$

$$\int_{\sqrt{s_0}}^{\infty} d(\sqrt{s}) K_1\left(\frac{\sqrt{s}}{T}\right) \sigma_{ab \rightarrow cd} \left[ \frac{s}{T^2} - \left( \frac{M_a^2}{T^2} + \frac{M_b^2}{T^2} \right)^2 \right] \left[ \frac{s}{T^2} - \left( \frac{M_a^2}{T^2} - \frac{M_b^2}{T^2} \right)^2 \right];$$

$$\sqrt{s_0} = \max[M_a + M_b, M_c + M_d]$$

# Charm Quark Production Rate



DQPM: T. Song, I. Grishmanovskii, O. Soloveva, E. Bratkovskaya, arXiv:2404.00425 (2024);  
Zhang et al., Phys. Rev. C 77 (2008)

# Summary

- ☞ **Charm quarks** – probe peculiar properties of the quark-gluon plasma.
- ☞ **Quasiparticle model** – well-established tool connecting non-perturbative and perturbative QCD regimes (strong vs weak coupling).
- ☞ **Possibilities** – finite  $\mu$ , quasisquarks out of chemical equilibrium,  
 $N_f = 2 + 1 + 1\dots$