Production rate of charm quarks in hot QCD

Valeriya Mykhaylova

In collaboration with Chihiro Sasaki and Krzysztof Redlich

Institute of Theoretical Physics

University of Wrocław

Uniwersytet Wrocławski

National Science Centre Poland

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

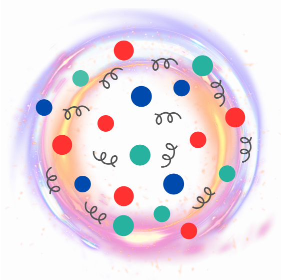
☞ Cross sections and differential rate equation

☞ Charm quark production rate in hot deconfined matter

Quasiparticle Model - Effective Approach to QCD

☞ similar to massive quasielectron moving freely in solid states

Real QGP:



strongly-interacting particles,
constant (bare) masses m_i

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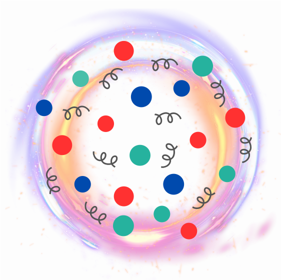

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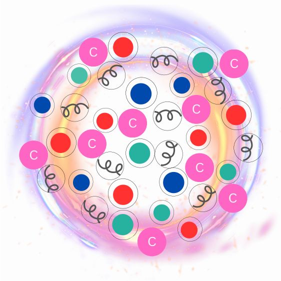
$\longrightarrow$

Effective approach:



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

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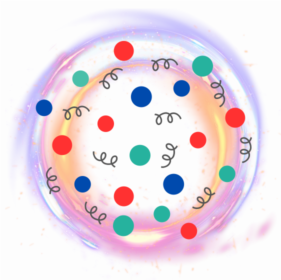

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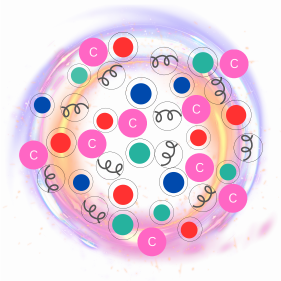

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$$m_i^{eff}[G(T), T] = \sqrt{m_i^2 + \Pi_i[G(T), T]}$$

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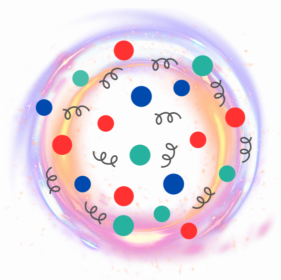
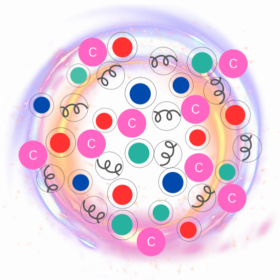


$\longrightarrow$

Effective approach:



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$G(T)$ from lattice QCD EoS

Quasiparticle Model

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

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

self-energies Π_i from pQCD (Hard Thermal Loops):

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

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

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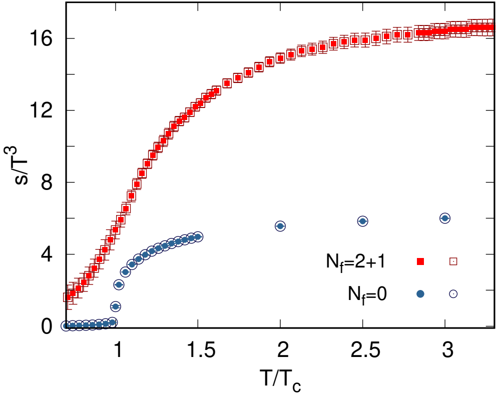
☞ effective coupling $G(T)$ – reliable thermodynamics – lattice QCD

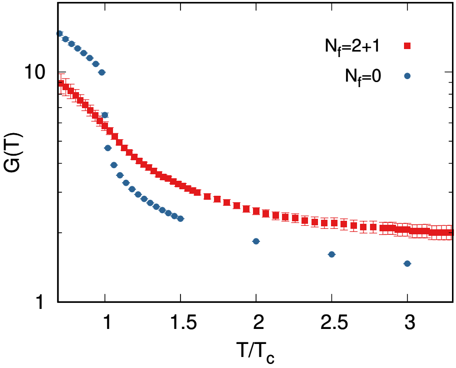
Quasiparticle Model

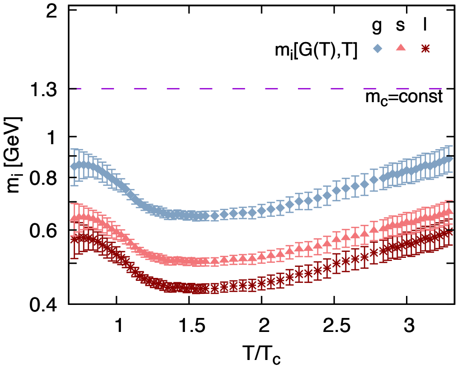
$$s(T) \simeq \sum_{i=g,l,s,..} \int d^3p\,([1 \pm f_i^0]\ln[1 \pm f_i^0] \mp f_i^0 \ln f_i^0) = \text{lattice data} \to G(T)$$

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



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]:

$$\partial_\mu \left(n_{c\bar{c}} u^\mu\right) \simeq R_{l\bar{l}\to c\bar{c}} + R_{s\bar{s}\to c\bar{c}} + R_{gg\to c\bar{c}} - R_{c\bar{c}\to l\bar{l}} - R_{c\bar{c}\to s\bar{s}} - R_{c\bar{c}\to gg} \tag{5}$$

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

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

* LHS depends on the QGP expansion

Thermal-Averaged Cross Sections

$$\sigma(\sqrt{s}) \to \bar{\sigma} = \langle \sigma\, v \rangle \tag{8}$$

$$\bar{\sigma}_{ab\to cd} = \frac{\int d^3p_a\, d^3p_b\, f_a\, f_b\, \sigma_{ab\to cd}\, v_{ab}}{\int d^3p_a d^3p_b\, f_a\, f_b} = \tag{9}$$

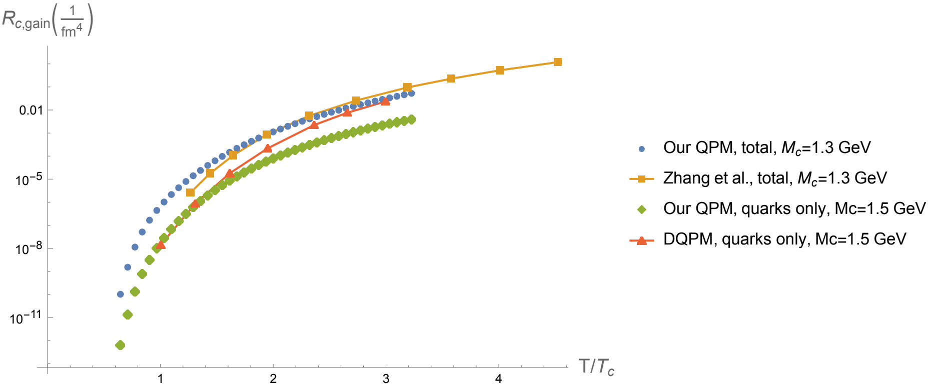
$$\left[4\frac{M_a^2}{T^2}\frac{M_b^2}{T^2}K_2\left(\frac{M_a}{T}\right)K_2\left(\frac{M_b}{T}\right)\right]^{-1} \times$$

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

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

P. Braun-Munzinger, K. Redlich, Eur.Phys.J.C 16 (2000), 519-525

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 μ, quasiquarks out of chemical equilibrium, $N_f = 2 + 1 + 1$...