Quark-gluon plasma and the charm quark production in the quasiparticle approach

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Work supported by the OPUS 16 and PRELUDIUM 20 grants
by Polish National Science Center

V. M., C. Sasaki, Phys.Rev.D 103 (2021) [arXiv:2007.06846]
V. M., M. Bluhm, C. Sasaki, K. Redlich, Phys.Rev.D 100 (2019) [arXiv:1906.01697]

Motivation: Charm quark behavior in the QGP

- Quarkonium suppression, QGP existence (Matsui, Satz 1986)
- Heavy quarks (e.g. charm) survive through the QGP lifetime
- Production/Reduction of C quarks in the QGP?
- Better understanding of the in-medium heavy quark interaction

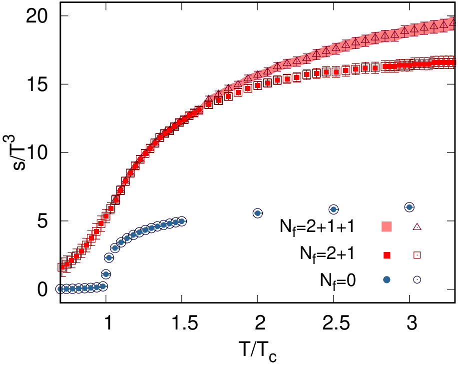
Task:

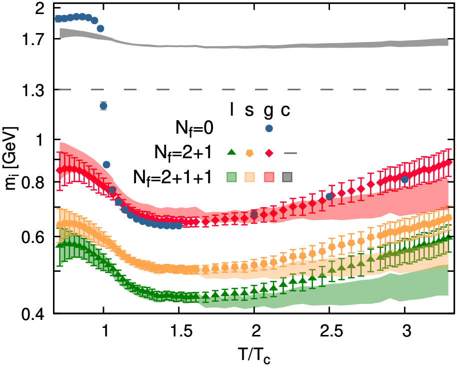
Evolution of C quarks in QGP with $N_f = 2 + 1$. Light, strange quarks and gluons are quasiparticles in equilibrium, charm quarks are „obstacles" with $M_c = 1.3$ GeV.

Quasiparticle Model Setup

QGP = weakly-interacting system of massive, dressed quarks and gluons

$$s = \sum_{i=g,(l,\bar{l},s,\bar{s},c,\bar{c})} \frac{d_i}{\pi^2} \int dp\; 2p^2\, \frac{\frac{4}{3}p^2 + m_i^2[G(T),T]}{E_i(T)\,T}\, f_i^0 \Longrightarrow G(T) \Longrightarrow m_i[G(T),T]$$



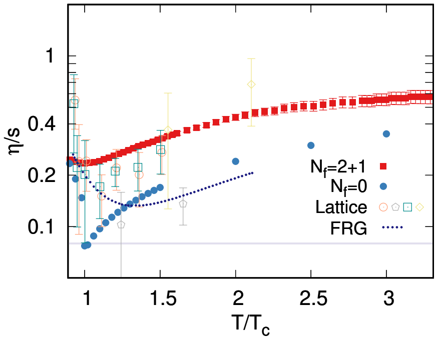


Interactions are encoded in dynamically generated masses m_i through effective coupling $G(T)$ deduced from lQCD EoS (s/T^3).

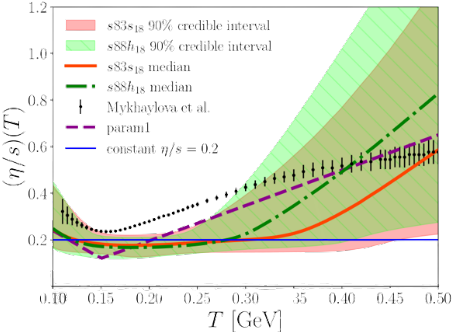
[V.M, M. Bluhm, C. Sasaki, K. Redlich, PRD 100 (2019) and preliminary; lQCD: Wuppertal-Budapest]

Specific Shear Viscosity

Computed in kinetic theory under the relaxation time approximation



[V.M, M. Bluhm, C. Sasaki, K. Redlich, PRD 100 (2019)]



[J. Auvinen et al., Phys.Rev.C 102 (2020)]

Red curve on LHS = black on RHS.

$$\eta = \frac{1}{15\,T}\sum_{i=l,\bar{l},s,\bar{s},g}\int \frac{d^3p}{(2\pi)^3}\frac{p^4}{E_i^2}\,d_i\tau_i f_i^0(1\pm f_i^0)\,.$$

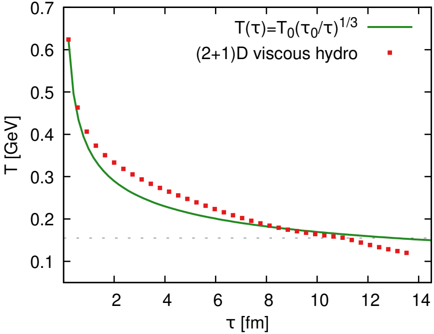
Time evolution of the QGP

For boost-invariant medium we juxtapose:

I_{id}: Bjorken scaling (1D expansion): [J. D. Bjorken, PRD 27 '83]

$$T(\tau) = T_0 \left(\frac{\tau_0}{\tau} \right)^{1/3}$$

II_{vis}: (2+1)D 2^{nd} order viscous hydro with η/s from QPM [J. Auvinen et al., PRC 102 '22]



⋆ Same initial conditions for both: $\tau_0 = 0.2$ fm, $T_0 = 0.624$ GeV

Rate Equation for charm quarks

$$\partial_\mu (n_c[\lambda_c(\tau)]\, u^\mu) = \overbrace{\left(R_{l\bar{l}\to c\bar{c}} + R_{s\bar{s}\to c\bar{c}} + R_{gg\to c\bar{c}}\right)}^{R_{c\ gain}} \left(1 - \frac{(n_c[\lambda_c(\tau)])^2}{(n_{c\ eq})^2}\right) \quad (1)$$

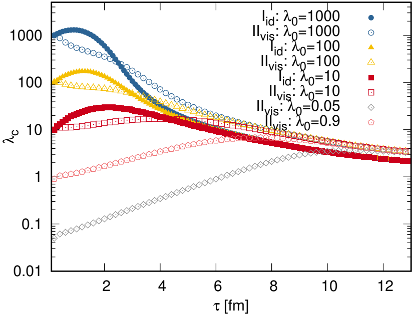
$$R_{c\ gain} = \bar{\sigma}_{l\bar{l}\to c\bar{c}}\, n^2_{q\ eq} + \bar{\sigma}_{s\bar{s}\to c\bar{c}}\, n^2_{s\ eq} + \frac{1}{2}\,\bar{\sigma}_{gg\to c\bar{c}}\, n^2_{g\ eq} \quad (2)$$

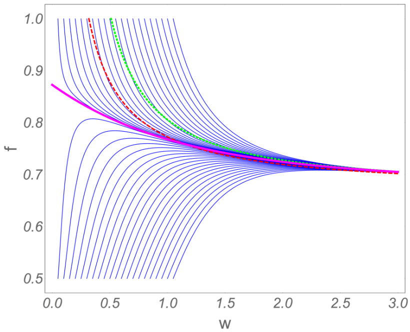
$$n_c[\lambda_c(\tau)] = d_c \int \frac{d^3p}{(2\pi)^3}\, \underbrace{\lambda_c(\tau)\left(e^{\sqrt{p^2+M_c^2}/T(\tau)} + \lambda_c(\tau)\right)^{-1}}_{=f_c,\ \text{Jüttner distribution}} \quad (3)$$

$$\longrightarrow \lambda_c(\tau) = ? \quad (4)$$

[Biro et al., PRC 48 '93]

Charm quark fugacity - Attractor



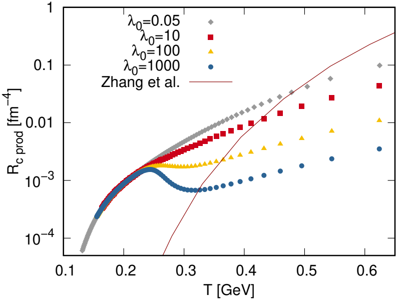


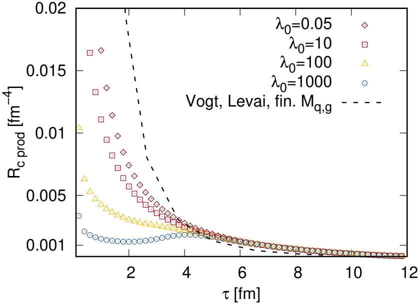
Preliminary
Fugacity of C quarks in perfect 1D
vs viscous (2+1)D QGP

[RHS: Heller, Spalinski, PRL 115 '15]

$$w = T\tau, \; f(w) = \frac{1}{w}\frac{\partial w}{\partial \tau}$$

Production Rate of Charm Quarks





In perfect QGP

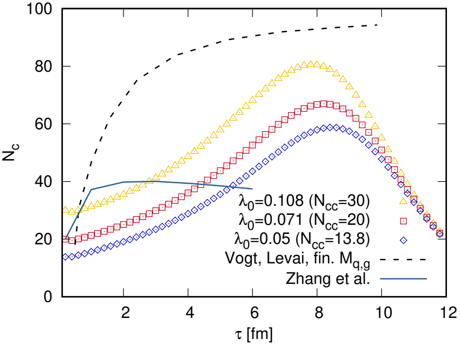
In viscous QGP

[Preliminary; Zhang et al., PRC 77 ’08; Vogt, Levai, PRC 56 ’97]

Number of Charm Quarks

$$N_c = n_c[\lambda_c(\tau)]\, V[\tau], \tag{5}$$

$$V[\tau] = \pi R^2(\tau)\tau = \pi[R_0 + 0.1(\tau - \tau_0)^2]^2\tau, \quad R_0 = 7\ \mathrm{fm} \tag{6}$$



[Preliminary; Zhang et al., PRC 77 '08; Vogt, Levai, PRC 56 '97]

Summary

- Charm quarks are the important probes of the QGP properties
- The hydrodynamic attractor observed for λ_c
- Production rates agree with other models in certain regions of temperature and time
- Distinct evolution of $N_c(\tau)$ - influence of dynamical masses and coupling in the cross-sections