Quark susceptibilities in a generalized quasiparticle model

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Abstract

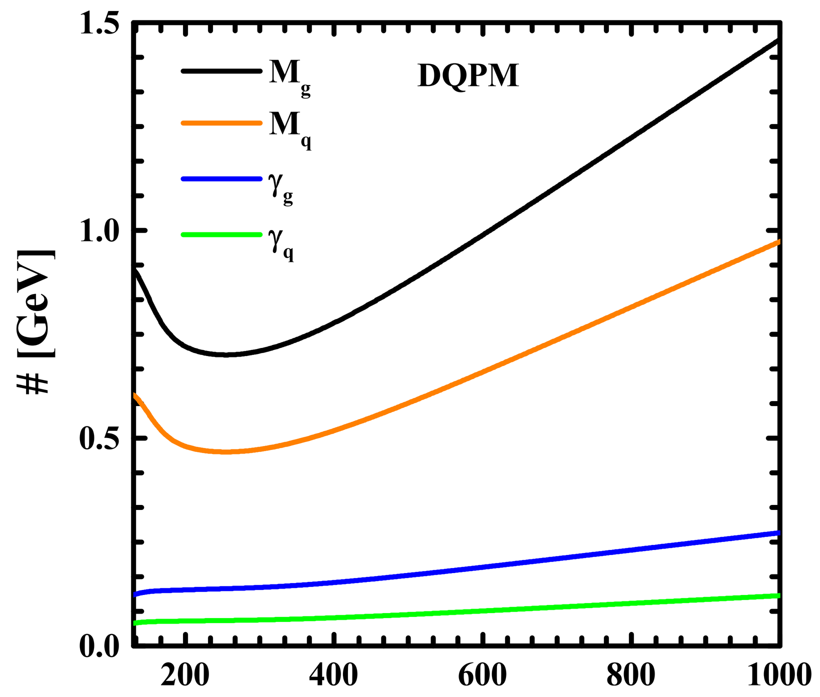
The QCD equation of state as predicted by lattice QCD calculations (lQCD) is well reproduced in terms of effective quasiparticle models. These models so far fail to describe the susceptibilties and underestimate the pressure at finite densities. We present a generalised quasiparticle model where the partonic propagators explicitly depend on the three-momentum with respect to the medium. Within this extended model we reproduce simultaneously the equation of state and the susceptibilties as provided by lQCD. We calculate the shear and bulk viscosity as well as the electric conductivity and compare them to default quasiparticle models. We find a good agreement between our model and available lattice data for all transport coefficients. This work is published in Refs. [1, 2]

Dynamical QuasiParticle Model

The Dynamical QuasiParticle Model (DQPM) assumes relativistic Breit-Wigner spectral functions as a phenomenological ansatz for quarks and gluons:

$$A(\omega, \mathbf{p}) = \frac{2\gamma\omega}{(\omega^2 - \mathbf{p}^2 - M^2)^2 + 4\gamma^2\omega^2}.$$

The spectral function is defined by an effective mass $M \sim gT$ and an effective width $\gamma \sim g^2 T$. The parameter g^2 is the effective coupling that carries the nonperturbative information of the system [3, 4].



Momentum dependence

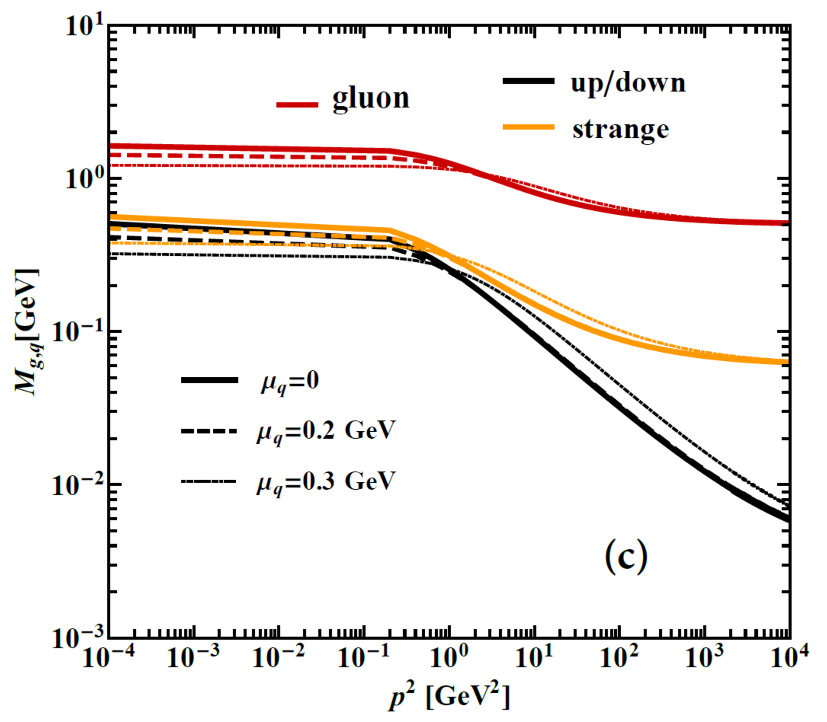
High energetic partons should propagate like massless particles. This is not the case in default quasiparticle models. We introduce a three-momentum dependent correction factor $h(\Lambda, \mathbf{p})$ to account for the right perturbative limit:

$$M_g(T, \mu_q, \mathbf{p}) = M_{g,\text{DQPM}} \cdot h(\Lambda_g, \mathbf{p}) + m_{g0} \qquad \gamma_g(T, \mu_q, \mathbf{p}) = \gamma_{g,\text{DQPM}} \cdot h(\Lambda_g, \mathbf{p})$$
$$M_{q\bar{q}}(T, \mu_q, \mathbf{p}) = M_{q\bar{q},\text{DQPM}} \cdot h(\Lambda_q, \mathbf{p}) + m_{q0} \qquad \gamma_{q\bar{q}}(T, \mu_q, \mathbf{p}) = \gamma_{q\bar{q},\text{DQPM}} \cdot h(\Lambda_{q\bar{q}}, \mathbf{p})$$

The correction factor is motivated by the momentum-dependent mass function in Dyson-Schwinger calculations:

$$h(\Lambda, \mathbf{p}) = \frac{1}{\sqrt{1 + \Lambda \cdot \mathbf{p}^2 \cdot (T_c/T)^2}}.$$

It ensures the limit $M(\mathbf{p} \to \infty) = m_0$ and $\gamma(\mathbf{p} \to \infty) = 0$. We call this generalized quasiparticle model DQPM*.

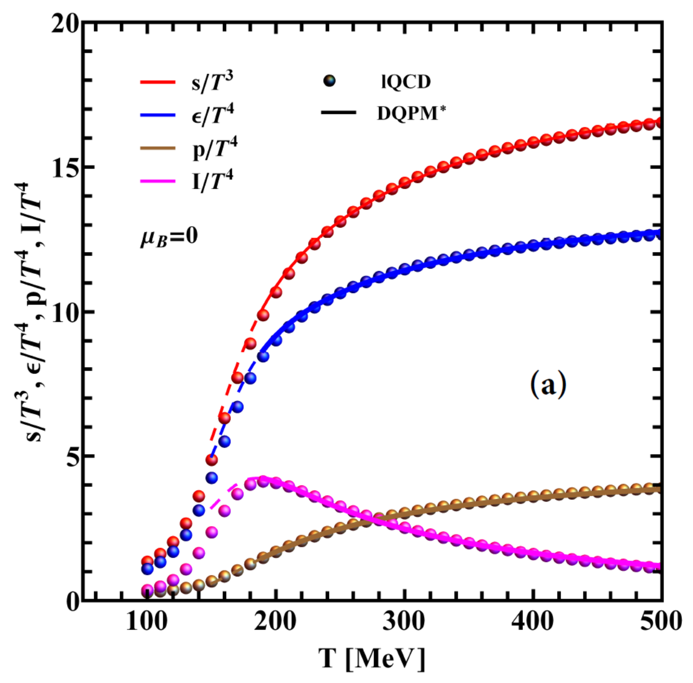


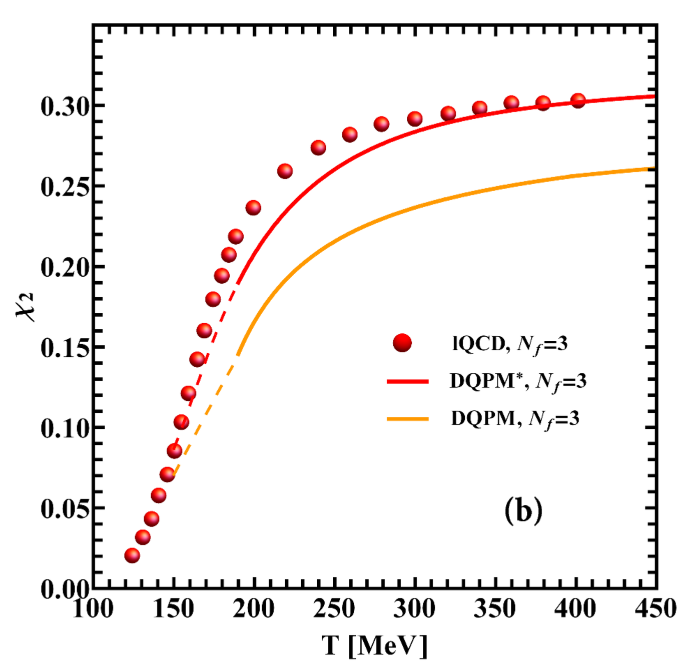
Equation of state

The thermodynamics of the model follow from the quasiparticle entropy and particle density [5]:

$$s^{dqp} = -d \int \frac{d^3p}{(2\pi)^3} \frac{d\omega}{2\pi} \frac{\partial n_{B/F}}{\partial T} \left(\text{Im}(\ln D^{-1}) - \text{Re}(D)\text{Im}(\Pi) \right),$$
$$n^{dqp} = -d \int \frac{d^3p}{(2\pi)^3} \frac{d\omega}{2\pi} \frac{\partial n_{B/F}}{\partial \mu} \left(\text{Im}(\ln D^{-1}) - \text{Re}(D)\text{Im}(\Pi) \right),$$

for the propagator $D^{-1} = D_0^{-1} + \Pi = -\omega^2 + \mathbf{p}^2 + M^2(\mathbf{p}) - 2i\omega\gamma(\mathbf{p})$ and thermodynamic consistency $P = \partial s/\partial T$. Only momentum-dependent selfenergies allow for a simultaneous description of the lQCD EoS [6] and susceptibility $\chi_2 = (\partial^2 P/\partial \mu_B^2)/T^2$ [7].





Relaxation time

The calculation of transport coefficients in the relaxation time approximation (RTA) requires the knowledge of the relaxation times τ_i [8]. One can determine them from scattering events for known cross sections. In the DQPM and DQPM* this is not necessary. The relaxation time is the inverse of the the momentum averaged thermal width,

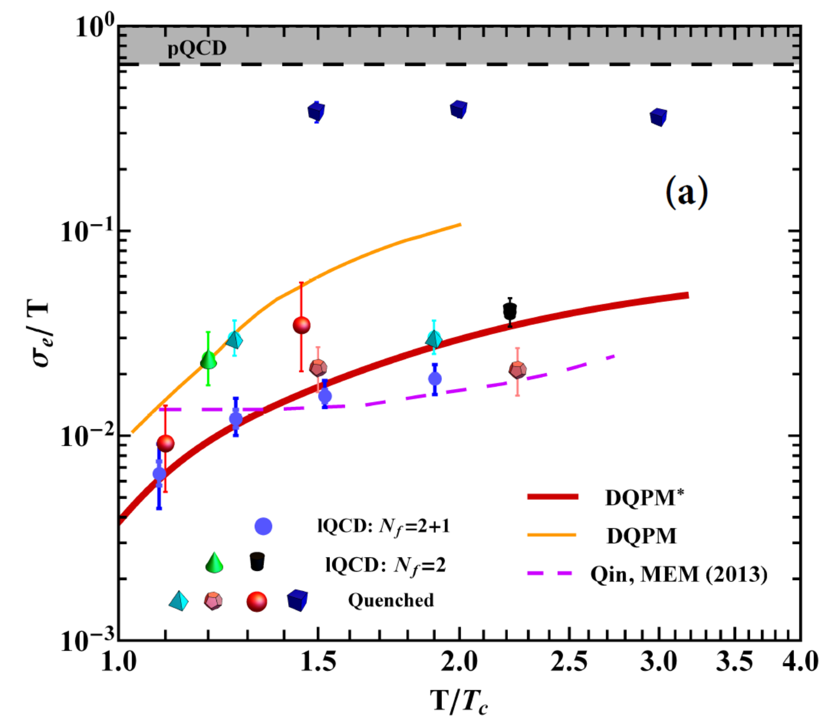
$$\tau_i = \frac{1}{\langle \gamma_i \rangle_{\mathbf{p}}}.$$

Electric conductivity

The electric conductivity is independent from the gluons and determined by the quarks alone. In RTA the conductivity reads

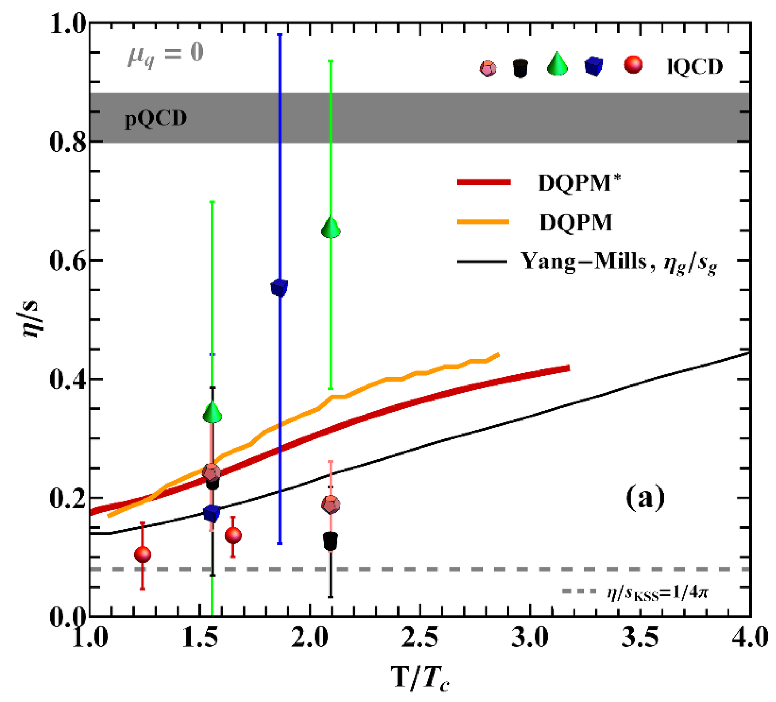
$$\frac{\sigma}{T} = \frac{2}{9} \frac{n_{q+\bar{q}}}{\langle M_{q\bar{q}} \rangle_{\mathbf{p}} \cdot \langle \gamma_{q\bar{q}} \rangle_{\mathbf{p}} \cdot T}.$$

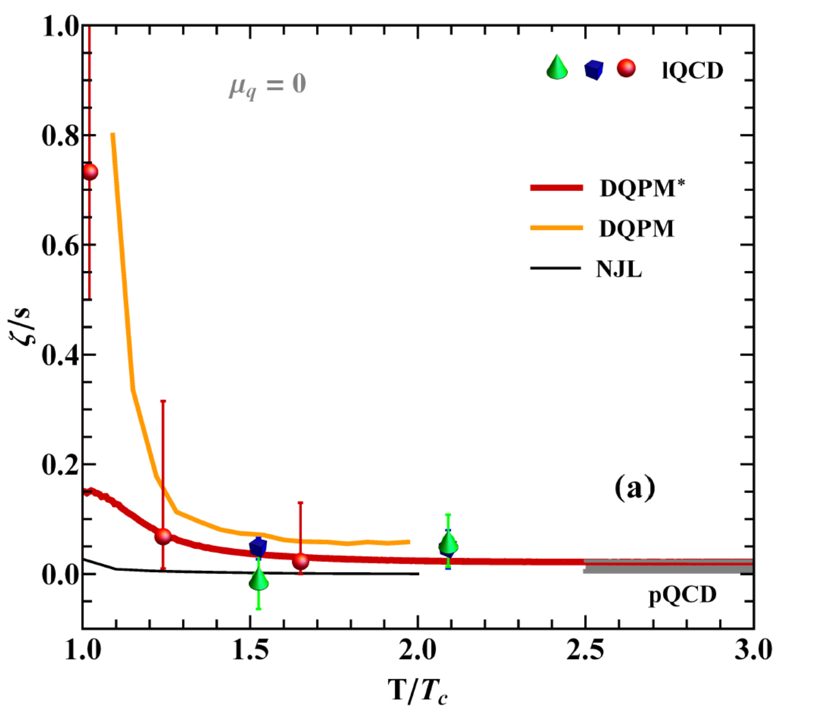
The combination of χ_2 and σ/T probes the quasiparticle properties of the whole quark sector.



Shear and bulk viscosity

The shear and bulk viscosity probe the whole system including the gluons. The good agreement between the DQPM* and lQCD justifies the choosen quasiparticle picture.





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