Taking the ratio between shear viscosity and electric conductivity of the QGP

A.Puglisi, S. Plumari and V. Greco
Department of Physics and Astronomy, University of Catania, Via S. Sofia 64, I-95125 Catania, Italy
Laboratorio Nazionale del Sud, INFN-LNS, Via S. Sofia 63, I-95125 Catania, Italy

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Abstract

The transport coefficients of strongly interacting matter are currently subject of intense studies due to their relevance for the characterization of the Quark-Gluon Plasma produced in ultra-relativistic heavy-ion collisions.
We discuss the connection between shear viscosity and electric conductivity and explain why the ratio $(\eta/s)/(\sigma_{el}/T)$ supplies a measure of the quark to gluon scattering rates whose knowledge would allow to significantly advance in the understanding of the QGP phase. We also predict that the ratio should increase near the critical temperature contrary to the flat behavior predicted by a conformal theory. We show that $(\eta/s)/(\sigma_{el}/T)$, independently on the running coupling $\alpha_s(T)$, should increase up to about ≈20 for $T \to T_c$, while it goes down to a nearly flat behavior around ≈4 for $T \geq 4T_c$. Therefore we in general predict a stronger T dependence of σ_{el}/T with respect to η/s as $T \to T_c$.

Motivations

Shear Viscosity

- ✓ collective behavior -> v_2
- ✓ perfect fluid -> $\eta/s=1/4\pi$
- ✓ Lattice QCD calculations

$$\boxed{\frac{\eta}{s} = \frac{1}{15Ts} \underbrace{\left\langle \frac{p^4}{E^2} \right\rangle}_{\text{fixed by lQCD}} (\tau_q \rho_q^{tot} + \tau_g \rho_g)}$$

Electric Conductivity

- ✓ mass-asymmetric collisions -> v_1 [3]
- ✓ emission rate soft photons σ_{el}
- ✓ Lattice QCD results

$$\boxed{\sigma_{el} = \frac{e_\star^2}{3T} \underbrace{\left\langle \frac{p^2}{E^2} \right\rangle}_{\text{fixed by lQCD}} \tau_q \rho_q}$$

Thermodynamical averages

$$\langle p^4/E^2 \rangle \simeq \epsilon T/\rho \qquad \langle p^2/E^2 \rangle \simeq T/m(T) \quad \Rightarrow \quad \eta/s \simeq \tau\rho/T^2$$

Extra Temperature dependence for σ_{el}

$$\boxed{\sigma_{el}/T \simeq T/m(T)\, \eta/s}$$

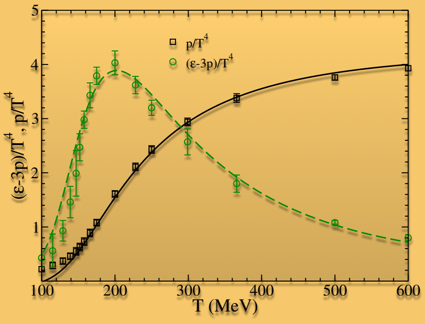
Fixing the Thermodynamics

Strongly interacting system ⇨ weakly interacting particles whose masses arise from the non-perturbative effects [1].

$$P_{QP}(T) = \sum_{i=u,d,s,g} d_i \int \frac{d^3p}{(2\pi)^3} \frac{\vec{p}^2}{3E_i(p)} f_i(p) - B(T)$$

$$m_q^2(T) = \frac{1}{3} g^2 T^2, \qquad m_g^2(T) = \frac{3}{4} g^2 T^2$$

$$g_{QP}^2(T) = \frac{48\pi^2}{(11N_c - 2N_f) \log \left[\lambda \left(\frac{T}{T_c} - \frac{T_s}{T_c} \right) \right]^2}$$



Transport relaxation times

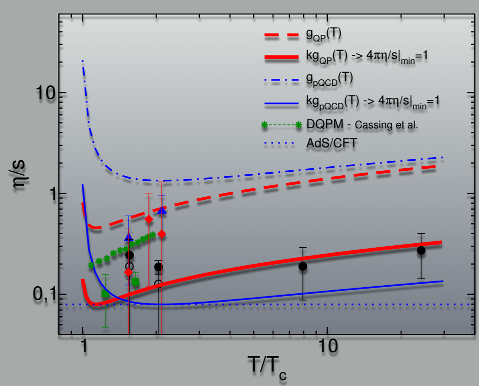
$$\tau_q^{-1} = \langle \sigma(s) v_{rel} \rangle \left(\sum_{i=u,\bar{d},\bar{s}}^{\bar{u},\bar{d},\bar{s}} \beta^{qi} + \rho_g \beta^{qg} \right)$$

$$\tau_g^{-1} = \langle \sigma(s) v_{rel} \rangle \left(\rho_q^{tot} \beta^{gq} + \rho_g \beta^{gg} \right)$$

Transport cross-section

$$\sigma_{tr}^{ij}(s) = \beta^{ij} \sigma(s) = \beta^{ij} \frac{\pi \alpha_s^2}{m_D^2} \frac{s}{s + m_D^2}$$

$$\beta^{qq} = 16/9, \beta^{qq'} = 8/9, \beta^{qg} = 2, \beta^{gg} = 9$$

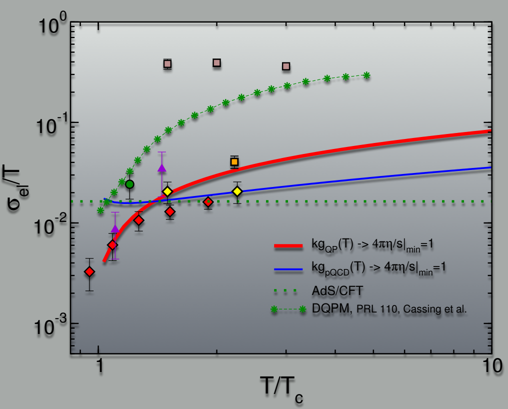


Results η/s

- ✦ η/s predicted ≈5/4π (red dashed line)
- ✦ symbols: Lattice QCD data [2]
- ✦ upscaling the coupling by k-factor in order to reproduce η/s≈1/4π
- ✦ What does happen to σ_{el} using the same relaxation times?

Results σ_{el}

- ✤ σ_{el}/T consistent with the minimum $\eta/s=1/4\pi$
- ✤ extra T-dependence: $\sigma_{el}/T \simeq T/m(T)\, \eta/s$
- ✤ ϵ-3P>0 as the origin of extra T-dependence
- ✤ conformal theory: $\sigma_{el}/T \simeq \eta/s$

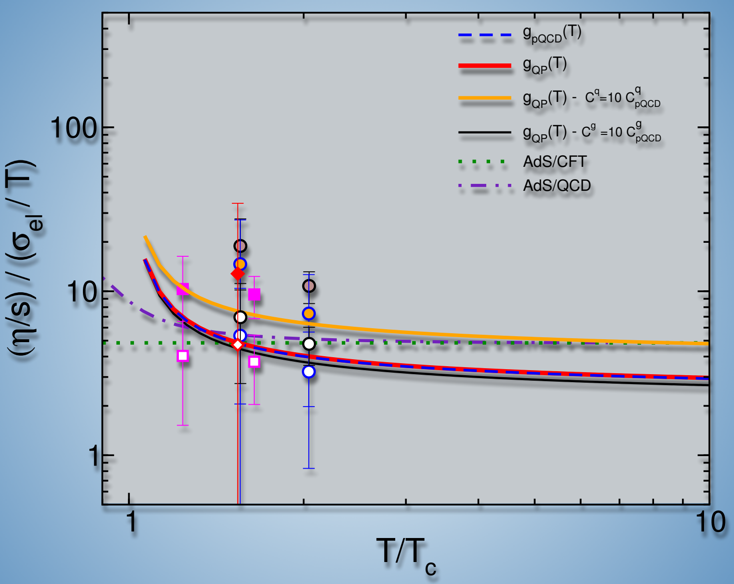


Taking the ratio

A. Puglisi, S. Plumari and V. Greco, arXiv:1407.2559 (2014)

$$\frac{\eta/s}{\sigma_{el}/T} = \frac{6}{5} \frac{T \langle p^2/E^2 \rangle^{-1}}{s e_\star^2} \left\langle \frac{p^4}{E^2} \right\rangle \left(1 + \frac{\tau_g}{\tau_q} \frac{\rho_g}{\rho_q^{tot}} \right)$$

$$\frac{\tau_g}{\tau_q} = \underbrace{\frac{C^q + \frac{\rho_g}{\rho_q}}{6 + \frac{\rho_g}{\rho_q} C^g}}_{\text{quark to gluon scattering rates}}$$



- gluon-gluon/quark-gluon scatterings $\quad C^g = \beta^{gg}/\beta^{qg}$
- quark-quark/quark-gluon scatterings $\quad C^q = (\beta^{qq} + \beta^{q\bar{q}} + 2\beta^{qq'} + 2\beta^{q\bar{q}'})/\beta^{qg}$

Results $(\eta/s)/(\sigma_{el}/T)$

- ★ Independent of k-factor and $\alpha_s(T)$
- ★ Sensitive only on C^q
- ★ Increases near T_c
- ★ Constant value for $T \gg T_c$
- ★ Conformal Theory prediction: flat behavior
- ★ σ_{el}/T extra T-dependence
- ★ Understanding the relative role of quarks and gluons in the QGP
- ★ Lattice results interpretation

Referencens

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