Shear viscosity in a large-N_c NJL model from Kubo formalism

- Advertisement -

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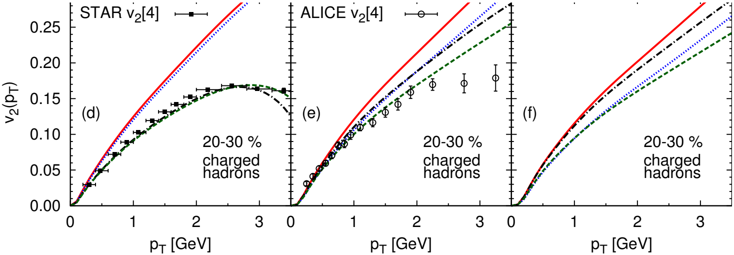
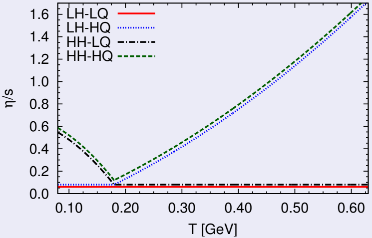
December 3, 2013

Temperature dependence of shear viscosity



[Niemi, Denicol, Molnár, Rischke: PRL 106 212302 (2011)]

T-dependent ratios η/s



Aim of my work:
Microscopic calculation of the (T, μ)-dependence of η/s within a large-N_c NJL model

NJL model: large-N_c analysis

QCD building blocks: A **four-gluon vertices**, B **three-gluon vertices**, and $C \geq N_f$ **quark-gluon vertices**

$\Rightarrow$ Any connected diagram obeys: $A + \frac{1}{2}(B + C) = N_f - 1 + L$

N_c scaling of a $2N$-vertex : $\frac{1}{N_c^{N-1+L}}$ e.g. $G \sim \frac{1}{N_c}$

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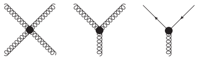

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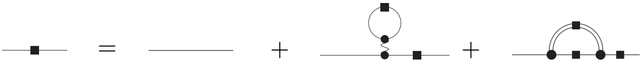
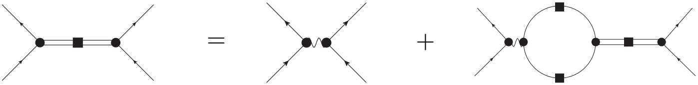
Application: rediscover standard approaches in many-body physics

DSE $\mathcal{O}(1)$:



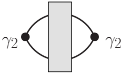
BSE $\mathcal{O}(N_c^{-1})$:



Shear viscosity from Kubo formula

Shear viscosity η relates to a four-point correlation function $\langle T_{\mu\nu}(t,\vec{x})T^{\mu\nu}(0)\rangle_{\mathrm{ret}}$:

$$\Pi(\omega_n) =$$



$$= \mathcal{O}(N_c^1) + \mathcal{O}(N_c^0) + \ldots$$

$$\eta[\Gamma(p)] = \frac{64 N_c N_f}{15\pi T}\int_{-\infty}^{\infty}\frac{\mathrm{d}\epsilon}{2\pi}\int_0^{\infty}\frac{\mathrm{d}p}{2\pi}\frac{p^6 m^2 \Gamma^2(p)\, n_F(\epsilon)[1-n_F(\epsilon)]}{\left[\left(\epsilon^2 - p^2 - m^2 + \Gamma^2(p)\right)^2 + 4m^2\Gamma^2(p)\right]^2}$$

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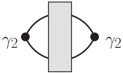
$\Pi(\omega_n) =$ 

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perturbative aspects: for "small" Γ we might perform a Laurent-series expansion of $\eta[\Gamma(p)]$:

$$\eta[\Gamma] = \frac{A_{-1}}{\Gamma} + A_0 + A_1\Gamma + A_2\Gamma^2 + \ldots$$

$$\Rightarrow\ \eta\cdot\Gamma = A_{-1} + A_0\Gamma + A_1\Gamma^2 + A_2\Gamma^3 + \ldots$$

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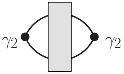

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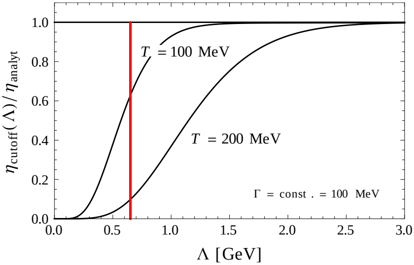
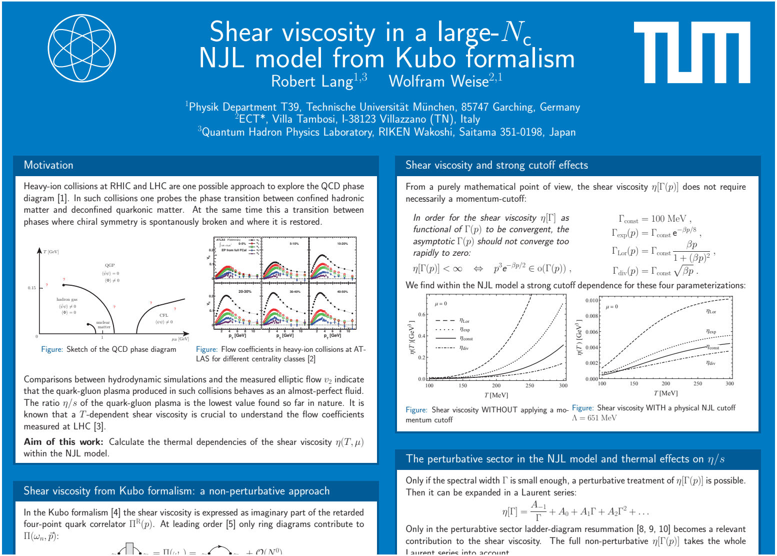


Hope to see and discuss with you at my poster...



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Motivation

Heavy-ion collisions at RHIC and LHC are one possible approach to explore the QCD phase diagram [1]. In such collisions one probes the phase transition between confined hadronic matter and deconfined quarkonic matter. At the same time this a transition between phases where chiral symmetry is spontanously broken and where it is restored.

Figure: Sketch of the QCD phase diagram

Figure: Flow coefficients in heavy-ion collisions at ATLAS for different centrality classes [2]

Comparisons between hydrodynamic simulations and the measured elliptic flow v_2 indicate that the quark-gluon plasma produced in such collisions behaves as an almost-perfect fluid. The ratio η/s of the quark-gluon plasma is the lowest value found so far in nature. It is known that a T-dependent shear viscosity is crucial to understand the flow coefficients measured at LHC [3].

Aim of this work: Calculate the thermal dependencies of the shear viscosity $\eta(T,\mu)$ within the NJL model.

Shear viscosity from Kubo formalism: a non-perturbative approach

In the Kubo formalism [4] the shear viscosity is expressed as imaginary part of the retarded four-point quark correlator $\Pi^{\mathrm{R}}(p)$. At leading order [5] only ring diagrams contribute to $\Pi(\omega_n,\vec{p})$:

Shear viscosity and strong cutoff effects

From a purely mathematical point of view, the shear viscosity $\eta[\Gamma(p)]$ does not require necessarily a momentum-cutoff:

In order for the shear viscosity $\eta[\Gamma]$ as functional of $\Gamma(p)$ to be convergent, the asymptotic $\Gamma(p)$ should not converge too rapidly to zero:

$$\eta[\Gamma(p)] < \infty \quad \Leftrightarrow \quad p^3 \mathrm{e}^{-\beta p/2} \in \mathrm{o}(\Gamma(p)) ,$$

$$\Gamma_{\mathrm{const}} = 100\ \mathrm{MeV} ,\quad \Gamma_{\exp}(p) = \Gamma_{\mathrm{const}}\,\mathrm{e}^{-\beta p/8} ,\quad \Gamma_{\mathrm{Lor}}(p) = \Gamma_{\mathrm{const}}\,\frac{\beta p}{1+(\beta p)^2} ,\quad \Gamma_{\mathrm{div}}(p) = \Gamma_{\mathrm{const}}\sqrt{\beta p} .$$

We find within the NJL model a strong cutoff dependence for these four parameterizations:

Figure: Shear viscosity WITHOUT applying a momentum cutoff

Figure: Shear viscosity WITH a physical NJL cutoff $\Lambda = 651$ MeV

The perturbative sector in the NJL model and thermal effects on η/s

Only if the spectral width Γ is small enough, a perturbative treatment of $\eta[\Gamma(p)]$ is possible. Then it can be expanded in a Laurent series:

$$\eta[\Gamma] = \frac{A_{-1}}{\Gamma} + A_0 + A_1\Gamma + A_2\Gamma^2 + \dots$$

Only in the perturbabtive sector ladder-diagram resummation [8, 9, 10] becomes a relevant contribution to the shear viscosity. The full non-perturbative $\eta[\Gamma(p)]$ takes the whole Laurent series into account