Electric conductivity of a hadron gas

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Introduction

In order to understand the dynamical behavior of heavy-ion collisions, it is important to study transport coefficients, which characterize the behavior of the system out of equilibrium. After the quark-gluon plasma is formed in a heavy ion collision it rapidly cools down and undergoes a phase transition to the hadronic phase. This gas is still hot and the particles interact with each other. There are several applications of the electric conductivity. It is possible to relate the soft photon rates for low to it. Furthermore for hydrodynamical calculations one needs transport coefficients as an input parameter. Knowing the electric conductivity for both hadronic and QGP matter gives a better understanding of their nature.

Model: SMASH

Simulating Many Accelerating Strongly-interacting Hadrons [1]

Hadronic transport approach which effectively solves Boltzmann equation

\[ p^a \delta f_a(x, p) + m_a F^a \partial_p f_a(x, p) = C_{\text{coll}}. \]

It uses a geometric collision criterion for particle collision

\[ \sigma_{\text{col}} < \frac{\sqrt{s}}{\tau}, \]

in order to calculate the electric conductivity we use a box with periodic boundary conditions. When initialising the box, the momentum of the particles are sampled with a Boltzmann distribution.

Method

In order to extract the transport coefficient we apply the well established Green-Kubo formalism which is based on linear response theory. The electric conductivity can be calculated in the following way

\[ \sigma_{\text{el}}(0) = \frac{\langle j_0(0) j(t) \rangle}{T \tau C(0)}, \]

where \( V \) is the volume of the system, \( T \) the temperature of the box in equilibrium and \( \langle j(0) j(t) \rangle \) is the so-called auto-correlation function of the electric current. The auto-correlation function can be calculated in the following way

\[ \langle j(0) j(t) \rangle = \frac{1}{K} \sum_{k=1}^{K} \lambda_k \tau \langle \lambda_k(t+\tau) \rangle \tau = \{ t_1, t_2, ..., t_N \} \quad s_{\text{max}} = K - t, \]

where \( K \) denotes the total number of time steps. It is possible to make a simple ansatz to this function, which has an exponential shape as seen in Figure 2

\[ \langle j(0) j(t) \rangle = C(0) e^{-\frac{t}{\tau}}. \]

That implies that the electric conductivity can be computed the following way:

\[ \sigma_{\text{el}}(0) = \frac{V C(0)}{T \tau}. \]

Where \( C(0) \) is the correlation function at the origin and \( \tau \) the inverse slope parameter of the correlation function.

Results

In this work the electric conductivity of a hot hadron gas has been calculated using the Green-Kubo formalism. In comparison with the results in [3], we have excellent agreement with analytic calculation for systems interacting with constant isotropic cross sections. This comparison is a good cross-check to the numerical results from SMASH.

Conclusion and Outlook

In future work would include going to non-zero baryochemical potential and investigation more on the differences between the results from this work and the analytical calculation from [3].

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References