Influence of Coriolis Force on the Electrical Conductivity of a Hadron Gas System in Heavy Ion Collisions

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1. Introduction

The Relativistic Heavy Ion Collider (RHIC) aims to explore the properties of strongly interacting matter at extreme temperatures and densities, replicating conditions similar to those just after the Big Bang. Transport properties are crucial for understanding the dynamical evolution of systems created in such ultra-relativistic heavy ion collisions. Hydrodynamical models, often employed to describe the particle spectra of hadrons produced in these collisions, reveal the medium's dissipative effects through transport coefficients.

In peripheral heavy ion collision (HIC) experiments, a significant orbital angular momentum (OAM) can be generated, depending on the impact parameter and collision energy. A portion of this initial angular momentum is transferred to the resulting plasma phase, leading to various novel effects, including the chiral vortical effect and spin polarizations.

The impact of OAM on the shear viscosity and electrical conductivity of the medium has been previously studied under the simplifying assumption of a globally rotating non-relativistic quark-gluon plasma (QGP), leading to the determination of anisotropic transport coefficients. In this work, we extend this analysis by developing a relativistic framework, relaxing the earlier non-relativistic assumptions. This relativistic framework is then employed to study the anisotropic electrical conductivity of rotating hadronic matter produced in HICs.

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2. Result and Discussion

The dissipative current density which is the link between microscopic to macroscopic deffinition is given by,

$$J^i = \sum_r J^i_r = \sum_r g_r q_r \int \frac{d^3\vec{p_r}}{(2\pi)^3} \frac{p^i_r}{E_r} \delta f_r, (p_{r0} \equiv E_r) \tag{1}$$

Where g_r represents the degeneracy of each hadron and δf_r is the change in the distribution function which can be seen When the system is slightly out of equilibrium.
We have used the covariant form of the Boltzmann equation for the calculation of δf_r is given by,

$$p^\mu_r \frac{\partial f_r}{\partial x^\mu} - \Gamma^\alpha_{\mu\lambda} p^\mu_r p^\lambda_r \frac{\partial f_r}{\partial p^\alpha_r} + m_r F^\alpha_r \frac{\partial f_r}{\partial p^\alpha_r} = C[f_r], \tag{2}$$

Introducing the Coriolis forcce and Electric field in Eq. 2 and referring to the details calculation in [1], in the relaxation time approximation, then the BTE becomes

$$\frac{\partial f^0}{\partial E}\frac{\vec{p}}{p_0}\cdot(q\vec{\tilde{E}}) + 2m\gamma_v(\vec{v}\times\vec{\Omega})\cdot\frac{\partial \delta f}{\partial \vec{p}} = -\frac{\delta f}{\tau_c}. \tag{3}$$

We have taken the IHRG model for the calculation of the electrical conductivity of rotating hadronic matter. Like the Lorentz force in a magnetic field, here we observe the Coriolis force due to rotation, the isotropic electrical conductivity becomes anisotropic and form three components parallel, perpendicular and hall. The parallel component is same as isotropic electrical conductivity, so we have focused on perpendicular and hall comonents.

The parallel, perpendicular and hall components of electrical conductivity are given below

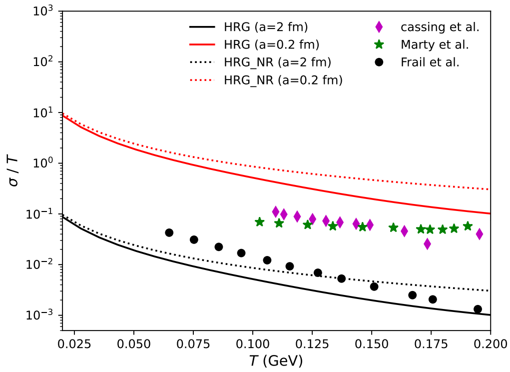

FIG. 1: σ/T vs T at a = 0.2 and 2 fm and its comparison with the models

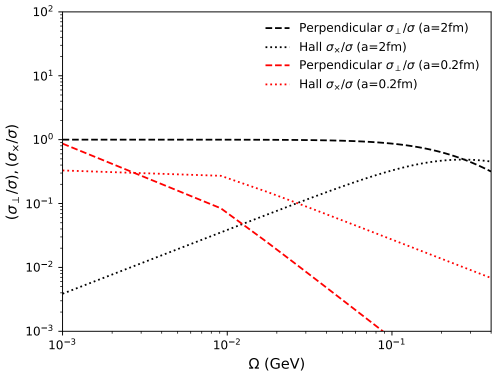

FIG. 2: $(\sigma_\perp/\sigma, \sigma_\times/\sigma)$ vs Ω at T=0.150 GeV.

$$\sigma^{||}_{\rm HRG} \equiv \sigma_{\rm HRG} = \sum_B \frac{g_B q_B^2}{3T}\int \frac{d^3p}{(2\pi)^3}\tau_c \frac{p^2}{E^2} f^0(1-f^0) + \sum_M \frac{g_M q_M^2}{3T}\int \frac{d^3p}{(2\pi)^3}\tau_c \frac{p^2}{E^2} f^0(1+f^0)$$

$$\sigma^{\perp}_{HRG} = \sum_B \frac{g_B q_B^2}{3T}\int \frac{d^3p}{(2\pi)^3}\frac{\tau_c}{1+\left(\frac{\tau_c}{\tau_\Omega}\right)^2} \frac{p^2}{E^2} f^0(1-f^0) + \sum_M \frac{g_M q_M^2}{3T}\int \frac{d^3p}{(2\pi)^3}\frac{\tau_c}{1+\left(\frac{\tau_c}{\tau_\Omega}\right)^2} \frac{p^2}{E^2} f^0(1+f^0)$$

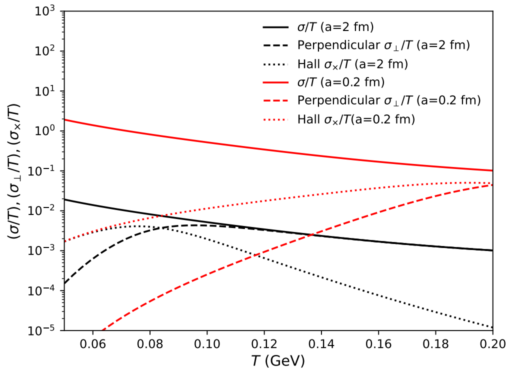

FIG. 3: $(\sigma/T,\, \sigma_\perp/T,\, \sigma_\times/T)$ as functions of temperature (T) with $\tau_c(T)$ and $\tau_\Omega = 6$ fm.

$$\sigma^{\times}_{HRG} = \sum_B \frac{g_B q_B^2}{3T}\int \frac{d^3p}{(2\pi)^3}\frac{\tau_c\left(\frac{\tau_c}{\tau_\Omega}\right)}{1+\left(\frac{\tau_c}{\tau_\Omega}\right)^2} \frac{p^2}{E^2} f^0(1-f^0) + \sum_M \frac{g_M q_M^2}{3T}\int \frac{d^3p}{(2\pi)^3}\frac{\tau_c\left(\frac{\tau_c}{\tau_\Omega}\right)}{1+\left(\frac{\tau_c}{\tau_\Omega}\right)^2} \frac{p^2}{E^2} f^0(1+f^0)$$

In summary, we compared the non-relativistic and relativistic normalized electrical conductivities, demonstrating a decreasing trend consistent with previous estimates [2]. We observe that the inclusion of relativistic effects results in a noticeable compression of conductivity values, particularly when the hard-sphere scattering radius is varied from 0.2 to 2 fm. Additionally, we analyze the behavior of conductivity components introducing the Coriolis force under rotation, Ω, finding that the perpendicular component decreases while the Hall component first increases and then decreases with Ω. Furthermore, our investigation of the temperature dependence of these components reveals that a strongly rotating hadron resonance gas (HRG) is evident at a scattering radius of $a = 0.2$ fm, underscoring the intricate relationship between rotation, temperature, and transport properties in such systems.

References

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