# Conductivity of quark-gluon plasma from charged particles and photons

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## Introduction

Electrical conductivity is the transport parameter for electric charges in QGP. It is important for determining the lifetime of the electromagnetic (EM) fields produced in high-energy heavy-ion collisions and for phenomena like the chiral magnetic effect (CME), magnetic reconnection, etc...

We estimate the electrical conductivity by modeling the dynamic evolution of the QGP and EM fields using relativistic resistive magneto-hydrodynamics (RRMHD) [4] and compare it to experimental data [1]. We consider two different observables:

- Thermal photon elliptic flow (v2) [2]
- Charged particle directed flow (v1) [3]

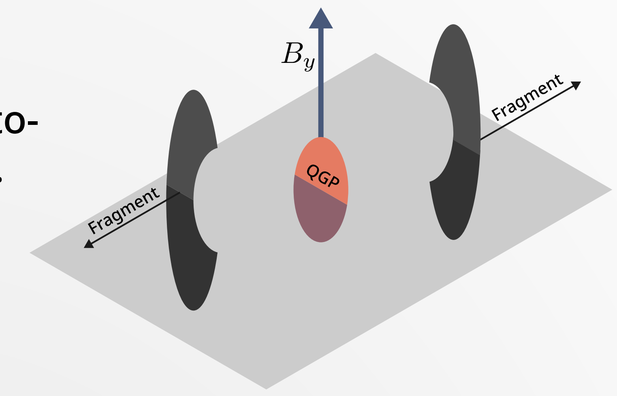


Figure 1. A diagram of a non-central collision illistrating how Quark-gluon plasma (QGP) and the strong electromagnetic fields have form in high-energy collisions at RHIC and LHC.

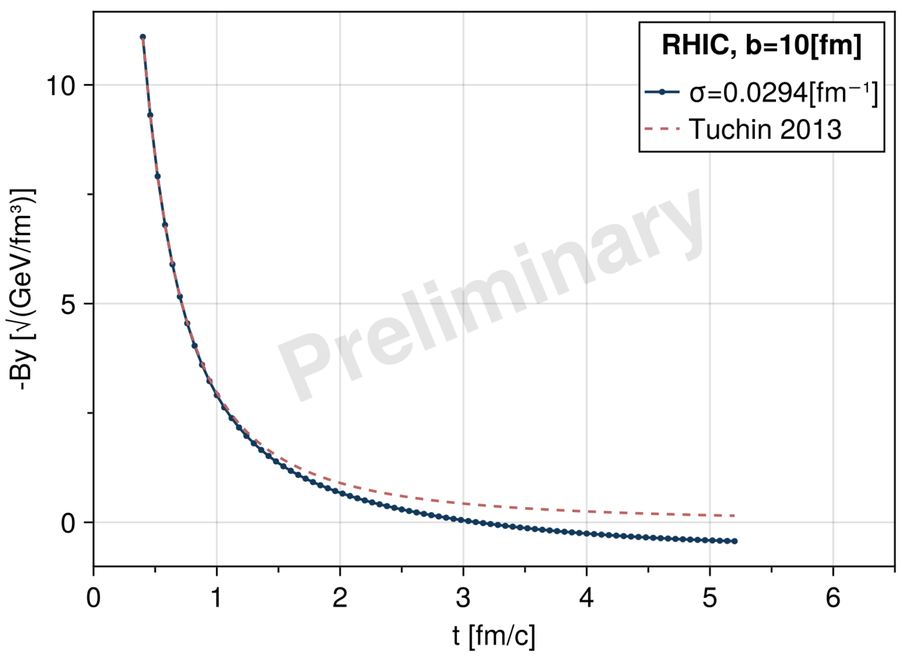


Figure 2. Time evolution of the By-field at the center of the collision region (x=0, y=0, z=0). Our RRMHD model does not include the collision fragments during the time evolution, so it is smaller than analytic estimations.

## Our RRMHD Model

We model the time evolution of QGP and the EM fields using relativistic resistive magneto-hydrodynamics (RRMHD) with the following workflow [4];

time (τ)

Smooth initial conditions
(optical Glauber model + Maxwell's equations in a medium)

Ideal Hydrodynamics

$$\nabla_\mu N^\mu = 0$$
$$\nabla_\mu T^{\mu\nu} = 0$$
$$\nabla_\mu S^\mu \geq 0$$

Maxwell's Equations

$$\nabla_\mu F^{\mu\nu} = -J^\nu$$
$$\nabla_\mu {}^*F^{\mu\nu} = 0$$

**Ohm's law: Sigma is the electric conductivity of QGP.**

$$\nabla_\mu J^\mu = 0$$
$$J^\mu = \sigma F^{\mu\nu} u_\nu + q u^\mu$$

Cooper-Frye with an electric chemical potential

## Results for electric conductivity of QGP

We find two key points:
1) The photon elliptic flow is enhanced by the EM fields similar to ref. [2] with a small dependence on the electric conductivity.
2) Charged particle directed flow is a cleaner observable for electric conductivity. Compared with the STAR [1] data our model estimates an O(1) conductivity to reproduce the results.

### Thermal photon elliptic flow

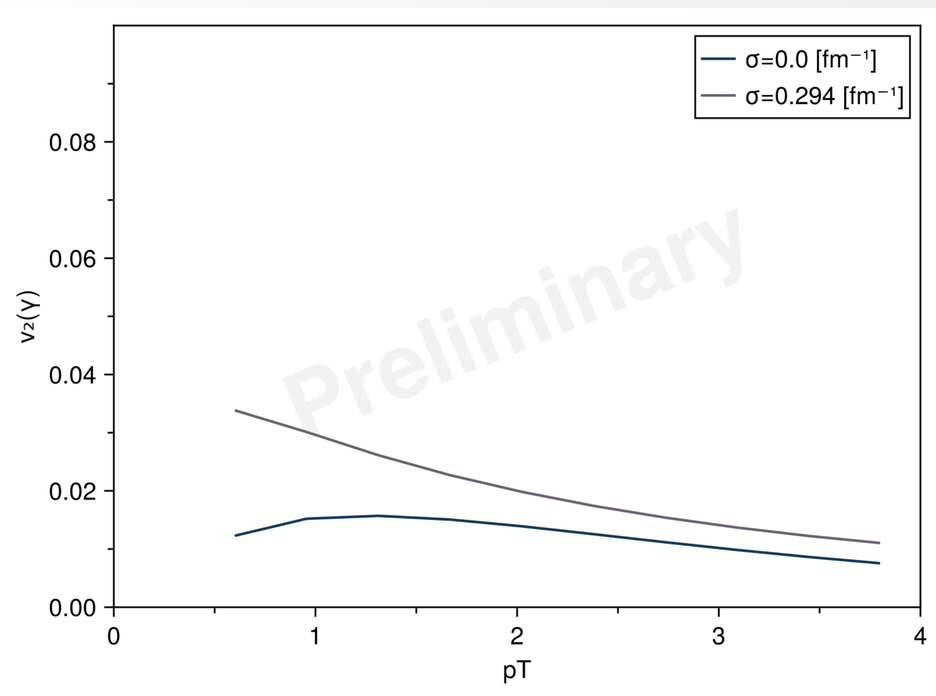


Figure 3. Photon elliptic flow from our RRMHD model + kinetic production. The kinetic production is for the small angle limit of 2 -> 2 processes in QGP based on ref. [2] with simplifications.

### Charged particle directed flow

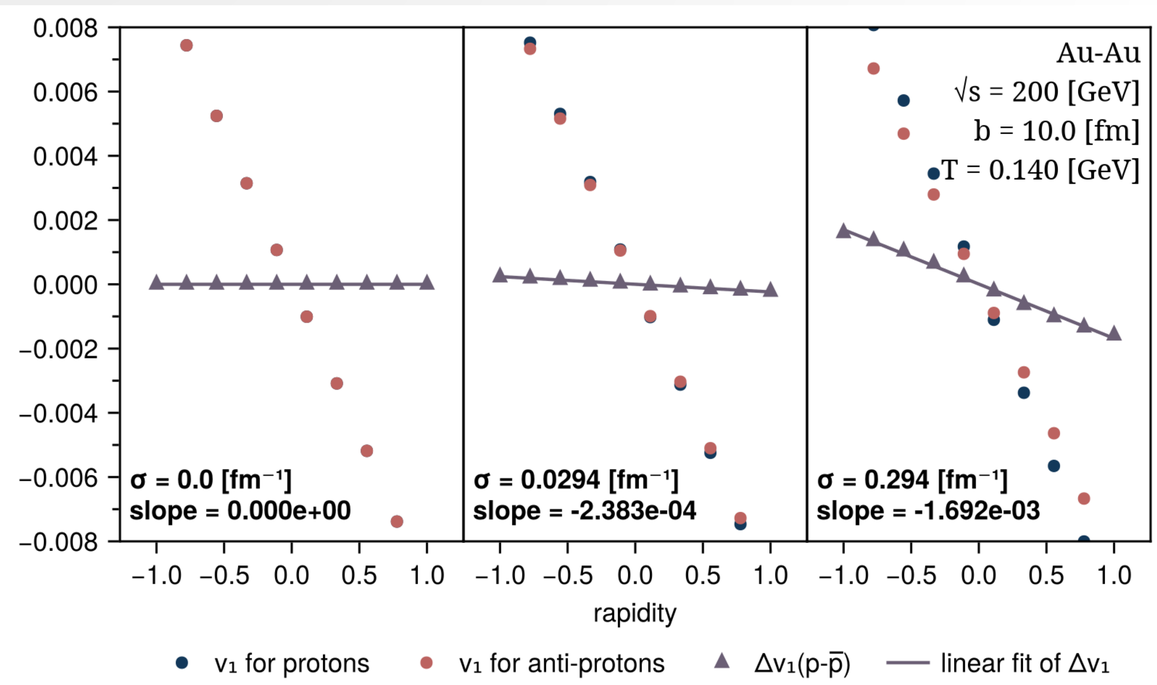


Figure 4. Charged directed flow of protons from our RRMHD model after Cooper-Frye. A negative slope is induced for finite conductivity.

References:

[1] STAR; *Phys. Rev. X 14, 011028 (2024)*, arXiv:2304.03430 [hep-ex]
[2] Sun and Yan, *Phys. Rev.C 109, 034917 (2024)*
[3] Gursoy, Kharzeev, and Rajagopal, *Phys. Rev.C 89, 054905 (2014)*
[4] K. Nakamura, T. Miyoshi, C. Nonaka, H. R. Takahashi; *Eur. Phys. J. C,* 83, 229 (2023), arXiv:2211.02310 [nucl-th]

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