Electromagnetic conductivity of quark-gluon plasma at non-zero baryon density

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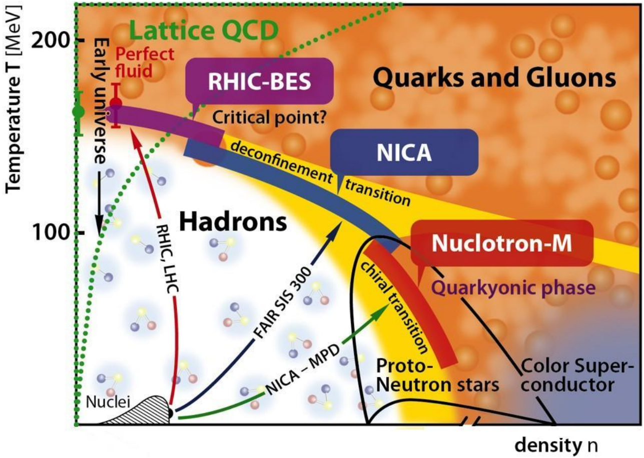
QCD phase diagram



Electromagnetic conductivity:

$$\mathbf{j} = \sigma \mathbf{E}$$

is one of the transport coefficients of QGP

How to measure conductivity?

- perturbative QCD and kinetic theory at weak couplings
- holography, effective models
- Lattice QCD

On the lattice, quenched and dynamical fermion results available for $\mu = 0$ (see, e.g. recent review [EPJA **57**, 118 (2021); 2008.12326])

$\mu \neq 0$ – sign problem

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- QCD-like theories

  SU(2) [PRD **102**, 094510 (2020); 2007.05639]

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- simulation at imaginary chemical potential $i\mu$

  this work

How to measure conductivity on the lattice?

Kubo relation:

$$\sigma = \frac{1}{6} \lim_{\omega \to 0} \frac{\rho^{ii}(\omega)}{\omega},$$

$\rho^{\mu\nu}(\omega) = \int d^4x\, e^{i\omega t} \langle [j^\mu(t, \mathbf{x}), j^\nu(0)] \rangle$ – current-current spectral function

$j^\mu(x) = \sum_f (eq_f)\, \bar{\psi}_f(x) \gamma^\mu \psi_f(x)$ – electromagnetic current

On the lattice we measure in Euclidean time

$$G_E(\tau) = \frac{1}{V} \sum_{\mathbf{x}} \langle j_i(\tau, \mathbf{x})\, j_i(0) \rangle$$

$$G_E(\tau) = \int_0^\infty \frac{d\omega}{2\pi}\, K(\omega, \tau)\, \rho(\omega), \qquad K(\omega, \tau) = \frac{\cosh[\omega(\tau - 1/2T)]}{\sinh(\omega/2T)}$$

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We use Backus-Gilbert method with Tikhonov regularisation

Lattice setup

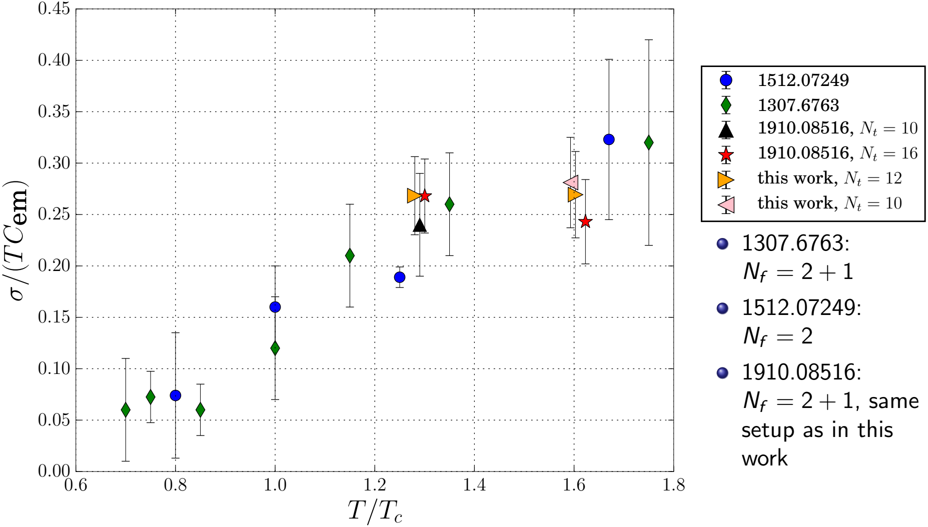
- $N_f = 2 + 1$ staggered fermions
- physical pion and strange masses
- $T \simeq 200, 250$ MeV
- imaginary chemical potential:

  $\mu_s = 0$

  $a\mu_u = a\mu_d = 0.140,\ 0.200,\ 0.245,\ 0.285$

N_s	N_t	a [fm]	T [MeV]
48	10	0.099	200
48	10	0.079	250
48	12	0.082	200
48	12	0.066	250

Electromagnetic conductivity: $\mu = 0$

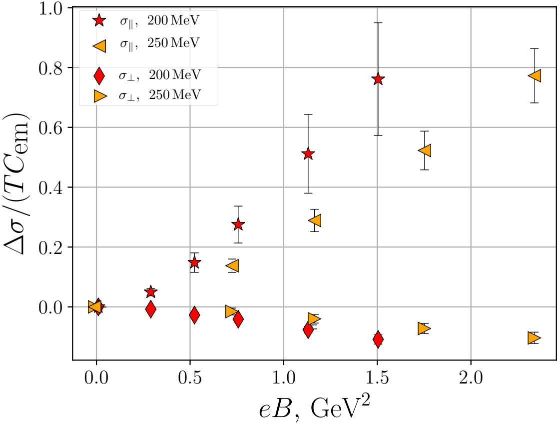


- 1307.6763: $N_f = 2 + 1$
- 1512.07249: $N_f = 2$
- 1910.08516: $N_f = 2 + 1$, same setup as in this work

Electromagnetic conductivity: $\mu = 0$

Conductivity at external magnetic field **B**:

$$\Delta\sigma(B) \equiv \sigma(B) - \sigma(B = 0)$$



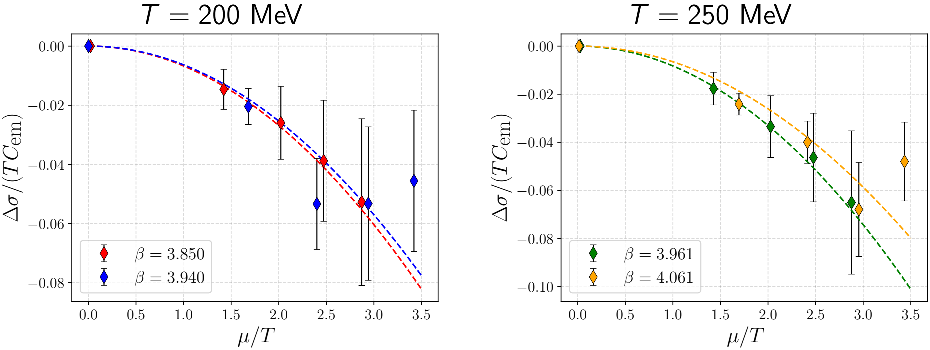
Conductivity rises in direction $\parallel$ **B** $\Longrightarrow$ chiral magnetic effect

[PRD **102**, 054516 (2020); 1910.08516]

Electromagnetic conductivity: imaginary μ

Preliminary:

$$\Delta\sigma \equiv \sigma(\mu) - \sigma(\mu = 0)$$



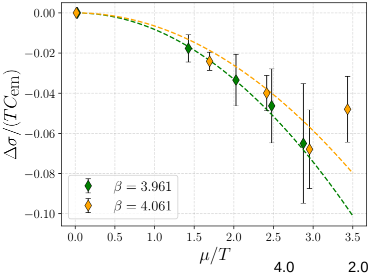
$$\frac{\sigma(\mu, T)}{\sigma(\mu = 0, T)} \simeq 1 + A_2(T)\left(\frac{\mu}{T}\right)^2$$

We are at imaginary μ:

$\mu \to i\mu_{\rm Re}$ $\implies$ Conductivity rises with baryon density

Electromagnetic conductivity: imaginary μ

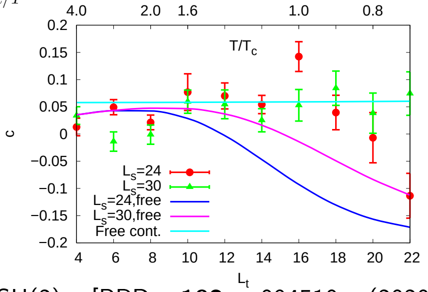
Preliminary:



$$\frac{\sigma(\mu, T)}{\sigma(\mu=0, T)} \simeq 1 + A_2(T)\left(\frac{\mu}{T}\right)^2$$

$$A_2 \simeq 0.02 - 0.08$$

- large uncertainty from reconstruction
- agreement with SU(2) within errors



SU(2) [PRD **102**, 094510 (2020); 2007.05639]

Summary

- The first calculation of the conductivity in QCD at physical pion mass and finite baryon density
- Conductivity increases with chemical potential
- Small $A_2 \Longrightarrow$ very weak dependence on chemical potential
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