Electric conductivity in hot pion matter

Joseph Atchison and Ralf Rapp

Transport parameters are pivotal to the understanding of strong-interaction matter and its investigations through high-energy heavy-ion collisions. Prime examples of high current interest are the ratio of viscosity over entropy density, η/s, which is a key input to hydrodynamic simulations [1], and the heavy-flavor diffusion coefficient (relative to the thermal wavelength), $\mathcal{D}_s$ (2πT), which can be probed through charm and bottom-hadron observables [2].

In this work we focus on the electric conductivity, which is more difficult to extract from experiment and has received less attention thus far. On the theoretical, there are significant discrepancies between various calculations for its value in hot hadronic matter [1]. In the present work we calculate the electric conductivity from the zero-energy limit of the in-medium electromagnetic spectral function at vanishing 3-momentum,

$$\sigma_{el} = e^2/2\ \rho_{EM}(q_0 \to 0, q=0)/q_0 \quad .$$

This is particularly promising as the EM spectral function has been directly probed in heavy-ion collisions through photon and dilepton spectra [4], albeit the very low-mass and momentum region has not been accessible yet. Along the lines of our previous work [5] we employ hadronic many-body theory in connection with the Vector Dominance Model (VDM) to compute the photon coupling to the hadronic EM current via the in-medium ρ-meson spectral function, ρ_{EM} ~Im D_ρ, and focus on the simplified system of hot pion matter. We compute the ρ-meson selfenergy through a dressing of its pion cloud with thermal π-ρ(770) and π-σ(500) loops; this, in particular, mandates the inclusion of in-medium corrections to the 3- and 4-point vertices of the ρ-π couplings, to maintain gauge invariance of the current correlator. A further challenge is that all in-medium propagators have to be dressed (i.e., acquire a finite width) to avoid

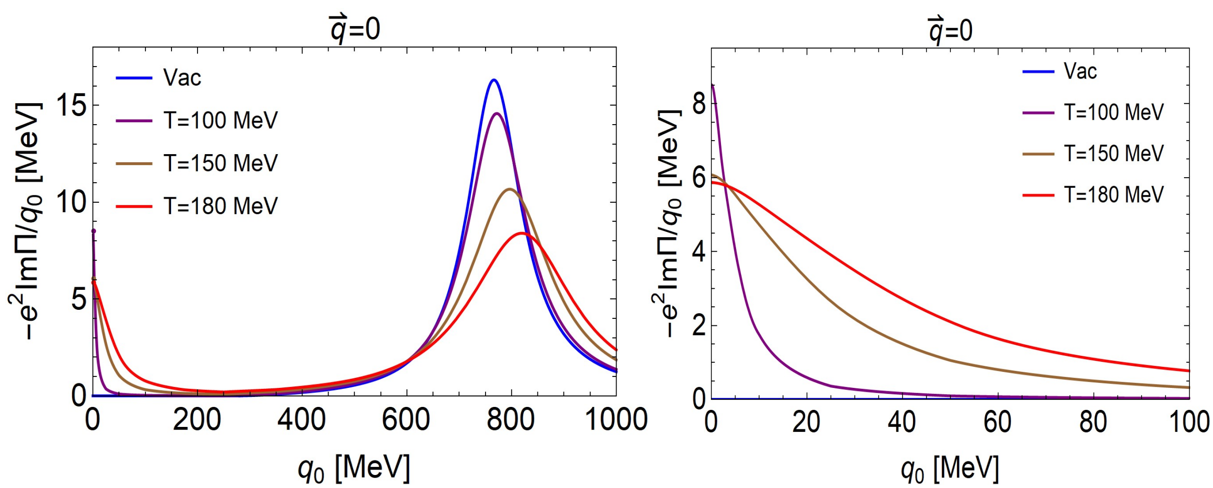

Fig. 1. EM spectral function in the isospin-1 r-meson channel in pion matter for three temperatures. Left: mass range covering the r resonance; right: low-energy region exhibiting the conductivity peak.

singularities in the zero-energy limit. Our results for the in-medium EM spectral function are shown in Fig.1. The ρ-meson peak broadens moderately with temperature (much less pronounced than what was found for baryon-induced medium effects [5]), cf. left panel, while a conductivity peak develops in the low energy limit which also broadens with temperature, see right panel.

The different contributions to the conductivity are displayed in Fig. 2 left. At low temperatures the σ(500) resonance is most effective in reducing σ_{el} via ππ scattering, while for T>100 MeV the scattering through a ρ(770) resonance is more important. Vertex corrections tend to increase the conductivity, as they provide additional channels for charge propagation. In comparison to other model calculations for hot pion matter, we find good agreement with the thermal-field theory calculations by Ghosh *et al.* [6].

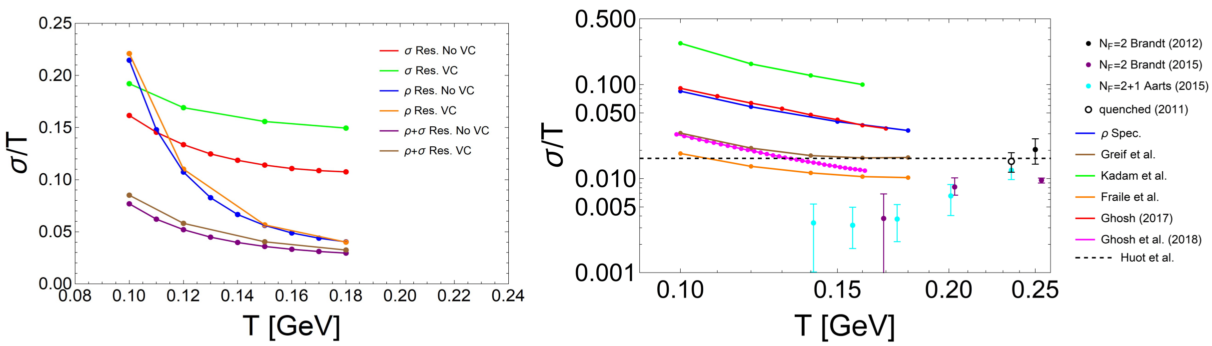

Fig. 2. Electric conductivity, scaled dimensionless by temperature, in hot pion matter as a function of temperature. Left: our results using hadronic many-body theory upon inclusion of only s(500) or only r(770) resonance scattering, and the total (lower lines), with and without vertex corrections (VC). Right: comparison of our result (blue) to results from the literature including lattice QCD (which include more than pions) and other model calculations (see Ref. [3] for more details).

In summary, we have conducted new calculations of the electric conductivity in hot pion matter through the EM spectral function in pion matter, utilizing hadronic many-body theory that has previously been applied to dilepton spectra in heavy-ion collisions. This provides a direct link between dilepton phenomenology and a fundamental transport parameter of QCD matter. Extensions to include the important effects of baryons are in progress, and experimental efforts are underway to measure dileptons at very low mass and momentum in Au-Au(1.23GeV) collisions at SIS with HADES and the future Pb-Pb(5TeV) run-5 at the LHC with the ALICE-3 detector.

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