Holographic Analysis of Quasinormal modes at large density in QCD

Holographic Perspectives on Chiral Transport
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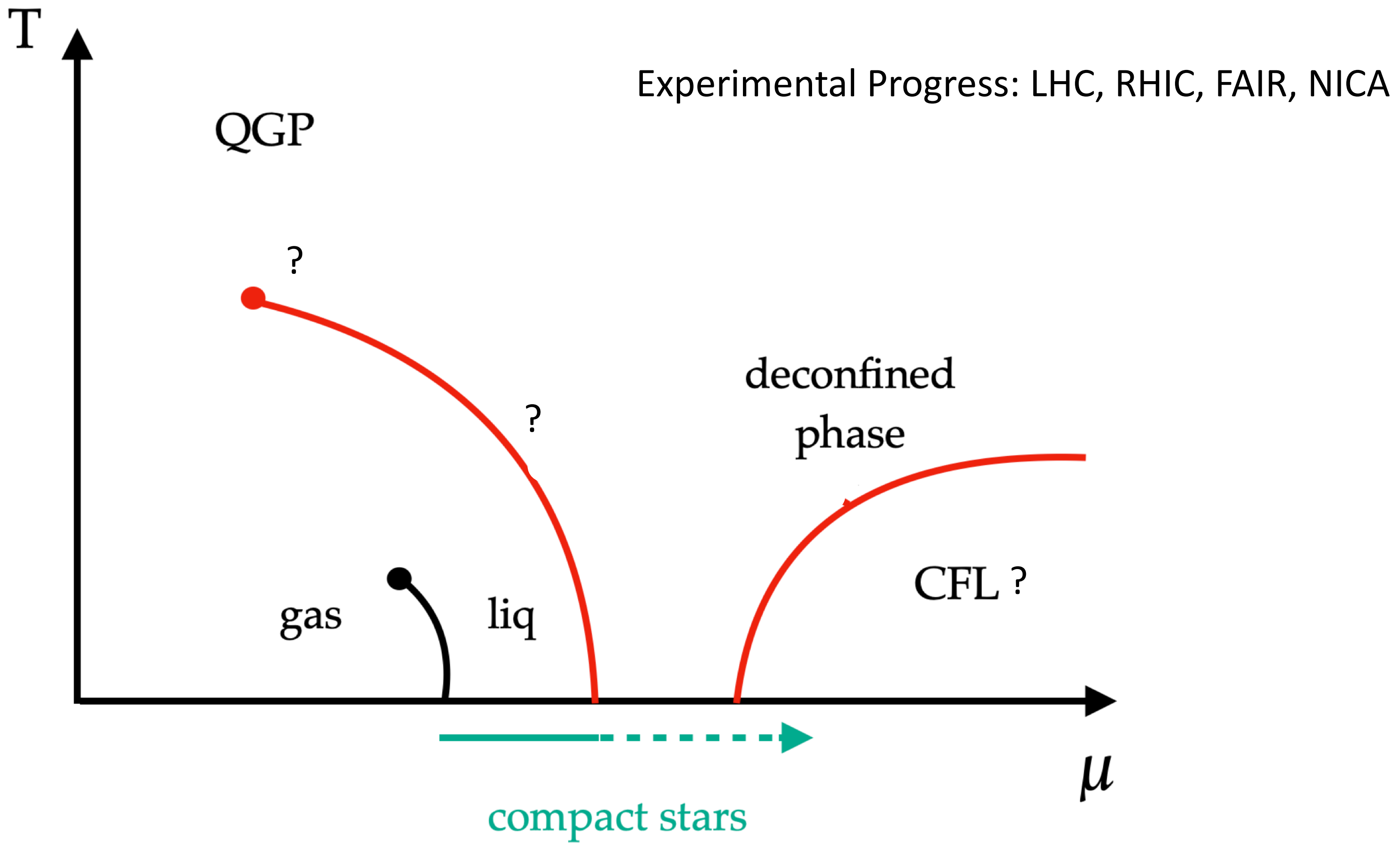
Work in collaboration with T. Demircik and M. Järvinen

Description of the phase diagram

We are interested in studying the strongly coupled regime of QCD at low temperature and high densities at the deconfined phase.



Stabilities at large densities and small T

In the V-QCD phase diagram of QCD there is a new quantum critical regime at T = 0, with exotic properties which realize the symmetries of the associated geometry $AdS_2 \times \mathbb{R}^3$

Alho, Järvinen , Kajantie, Kiritsis, Rosen, Tuominen

Such AdS_2 solutions, studied in the context of Condense Matter are highly unstable as it has a rather restrictive Breitenlohner-Freedman bound

It also has been showed that holographic QCD models predict that the presence of a CS coupling between vector and axial mesons at finite density, produces an instability at sufficiently large density.

Domokos, Harvey

There are studies in the literature regarding instabilities coming from Imaginary modes at finite momentum related with striped faces.

e. g. Bergman, Jokela, Lifschytz, Lippert; Faedo, Matteos, Pantelidou, Tarrío

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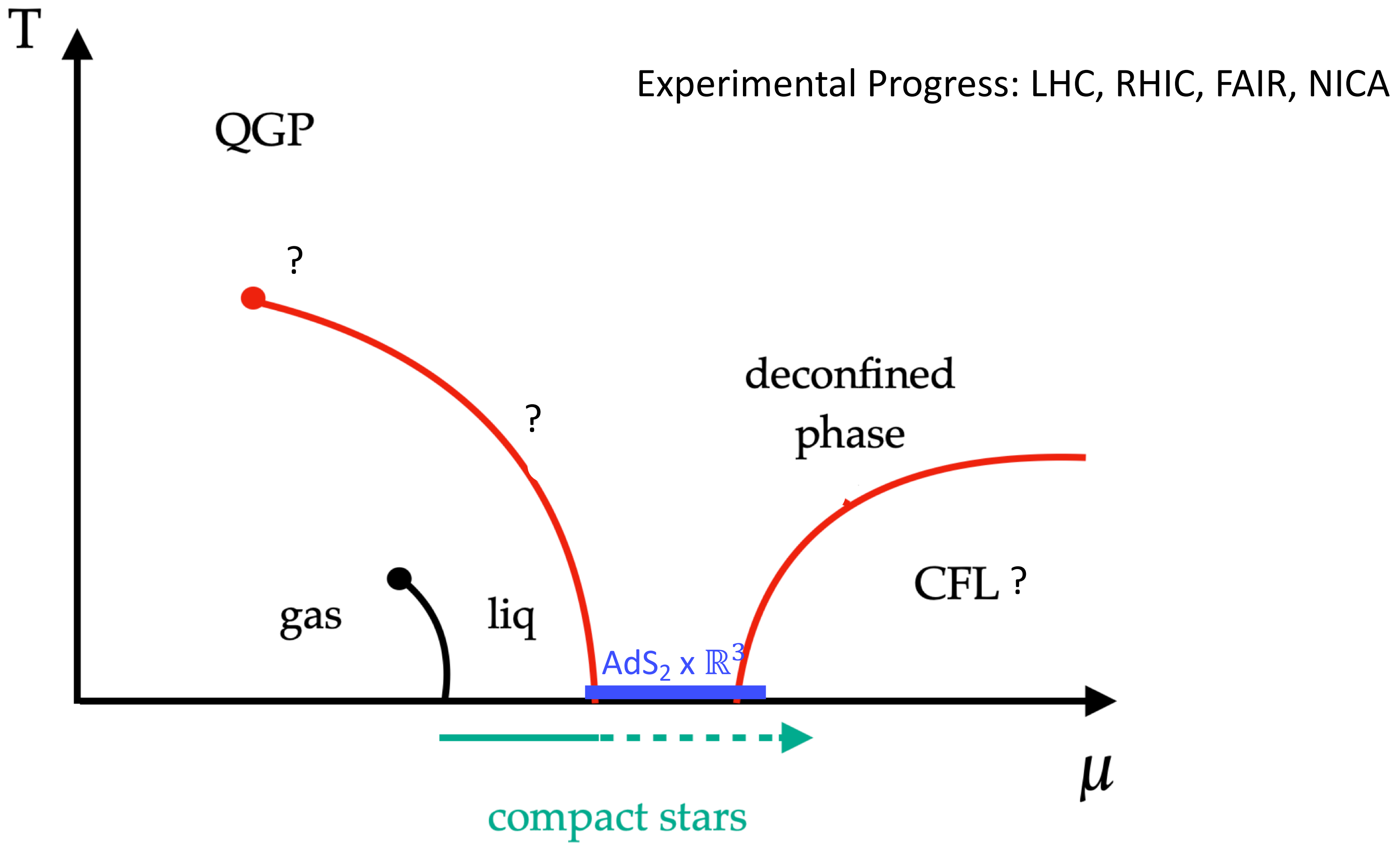

The V-QCD framework

A bottom-up holographic model for QCD, but trying to follow principles from string theory closely. Full backreaction from flavor sector.

Järvinen, Kiritsis

The model has 2 main building blocks:

- IHQCD inspired in 5D String Theory, this describe the glue sector.

Gürsoy, Kiritsis, Nitti; Gubser, Nellore

- A Flavour action with a Chiral symmetry breaking mechanism inspired in D-branes.

Klebanov, Maldacena; Bigazzi, Casero et. al

The V-QCD framework

The V-QCD action is built by parting from what it is known from String Theory and deforming the theory with phenomenological parameters

- It implements back-reaction of the flavour sector onto the color sector keeping $\frac{N_f}{N_c}$ fixed at large N_f , N_c
- The structure is therefore richer than those of most other bottom-up models in the literature .
- Two bulk scalars $\phi \leftrightarrow \mathrm{Tr}F^2, \quad \tau \leftrightarrow \bar{q}q$

Comparison to data

V-QCD is constrained by fixing potentials and parameters requiring qualitative agreement with QCD.

- Fit to lattice data (EoS and baryon number susceptibility) near $\mu=0$.

Gürsoy, Kiritsis, Mazzanti, Nitti; Järvinen, Jokela Remes

- The UV expansions of potentials match pQCD.

Gürsoy, Kiritsis ; Järvinen, Kiritsis

- The extrapolated V-QCD equation of state for cold quark matter agrees with the new constraints.

Järvinen, Jokela Remes

Our Set-up

The action of the model is: $S = S_g + S_f + S_{\rm CS}$ with:

$$S_g = \frac{1}{16\pi G_5}\int d^5x\sqrt{-g}\left[R - \frac{4}{3}g^{MN}\partial_M\phi\partial_N\phi + V_g(\phi)\right]$$

$$S_f = -\frac{1}{32\pi G_5 N_c}\mathrm{Tr}\int d^4x\,dr\,\left(V_f(\lambda, T^\dagger T)\sqrt{-\det \mathbf{A}_L} + V_f(\lambda, TT^\dagger)\sqrt{-\det \mathbf{A}_R}\right)$$

$$\mathbf{A}_{L\,MN} = g_{MN} + w(\lambda, T)F^{(L)}_{MN} + \frac{\kappa(\lambda, T)}{2}\left[(D_M T)^\dagger(D_N T) + (D_N T)^\dagger(D_M T)\right]$$

$$D_M T = \partial_M T + iTA^L_M - iA^R_M T$$

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Our Set-up

We are interested in the chirally symmetric phase ⟶ tachyon fluctuations will decouple.

As the only non zero component in the background is $V_t(r) = \Phi(r)$ where $V=A_L+A_R/2$, the CS term can be written as:

$$S_{\rm CS} = \frac{N_c}{2\pi^2}\int \Phi dt \wedge {\rm Tr}\left[d\tilde{A}\wedge d\tilde{V}\right]$$

Since we only need the action to be at second order in the fluctuations, it is enough the terms which are of the third order in the gauge fields.

Fluctuation Equations

To find the QNM spectrum, we solve the coupled system of eqs. describing a linearized perturbation on top of a black hole.

We classify the fluctuations according to their helicity.

$$g1_{\mu\nu} = e^{-i(\omega t - qz)}\delta g_{\mu\nu}(r) \qquad \phi 1 = e^{-i(\omega t - qz)}\delta\phi(r)$$

$$A1_{\mu} = e^{-i(\omega t - qz)}\delta A_{\mu}(r) \qquad T1 = e^{-i(\omega t - qz)}\delta T(r)$$

$$\text{helicity } \pm 2 \rightarrow \quad \delta g_{xy}$$

$$\text{helicity } \pm 1 \rightarrow \quad \delta A_x, \delta g_{tx}, \delta g_{rx}, \delta g_{zx}$$

$$\text{helicity } 0 \rightarrow \quad \delta\phi, \delta A_t, \delta A_r, \delta A_z, \delta g_{tt}, \delta g_{tr}, \delta g_{tz}, \delta g_{rr}, \delta g_{rz}, \delta g_{zz}, \delta g_{xx}$$

Fluctuation Equations

To male life easy use gauge invariant combinations, e.g. for Helicity 0:

$$Z_2 = e^{2A(r)} \left[-q^2 f(r)\delta g_{tt} + 2\omega q \delta g_{tz} + \delta g_{xx}(q^2 f(r) - \omega^2 + \frac{q^2 f'(r)}{2A'(r)}) + \omega^2 \delta g_{zz} \right]$$

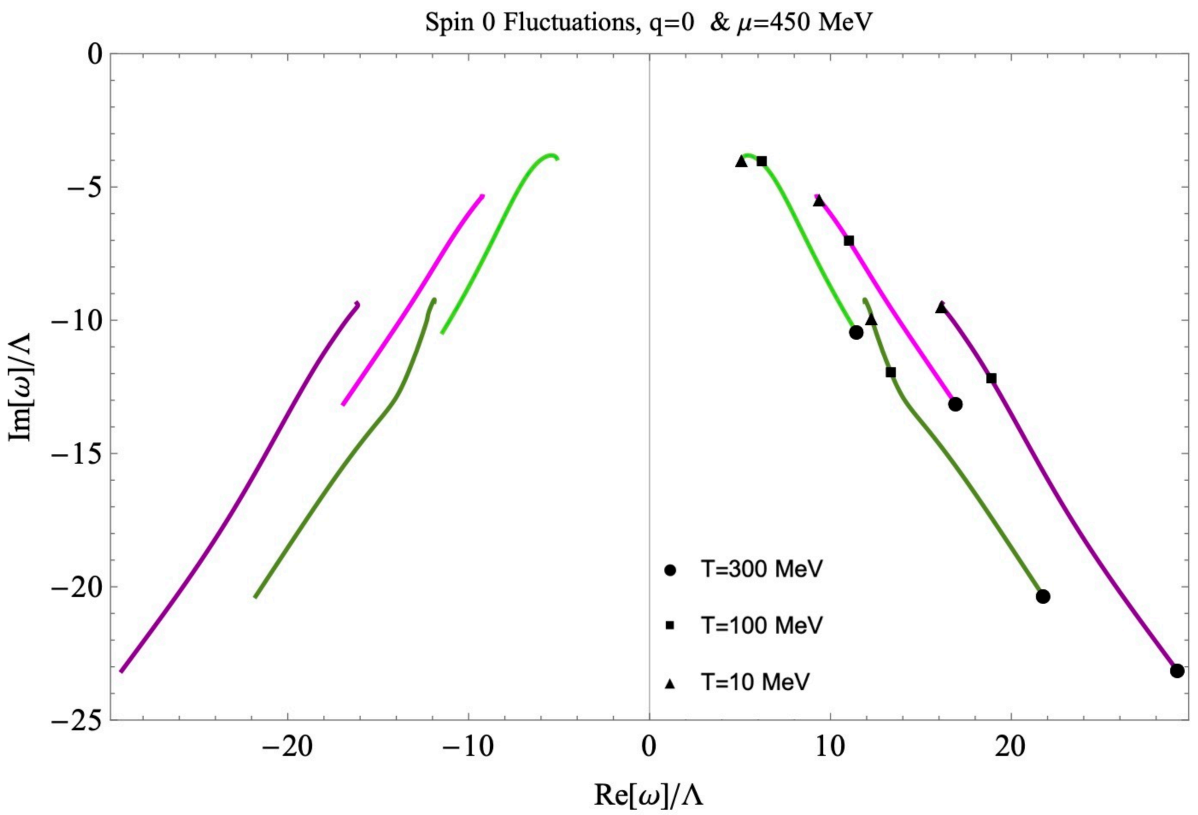
$$E_z = q\delta A_t + \omega \delta A_z - \frac{\delta g_{xx} q \dot{\Phi}}{2A'(r)}$$

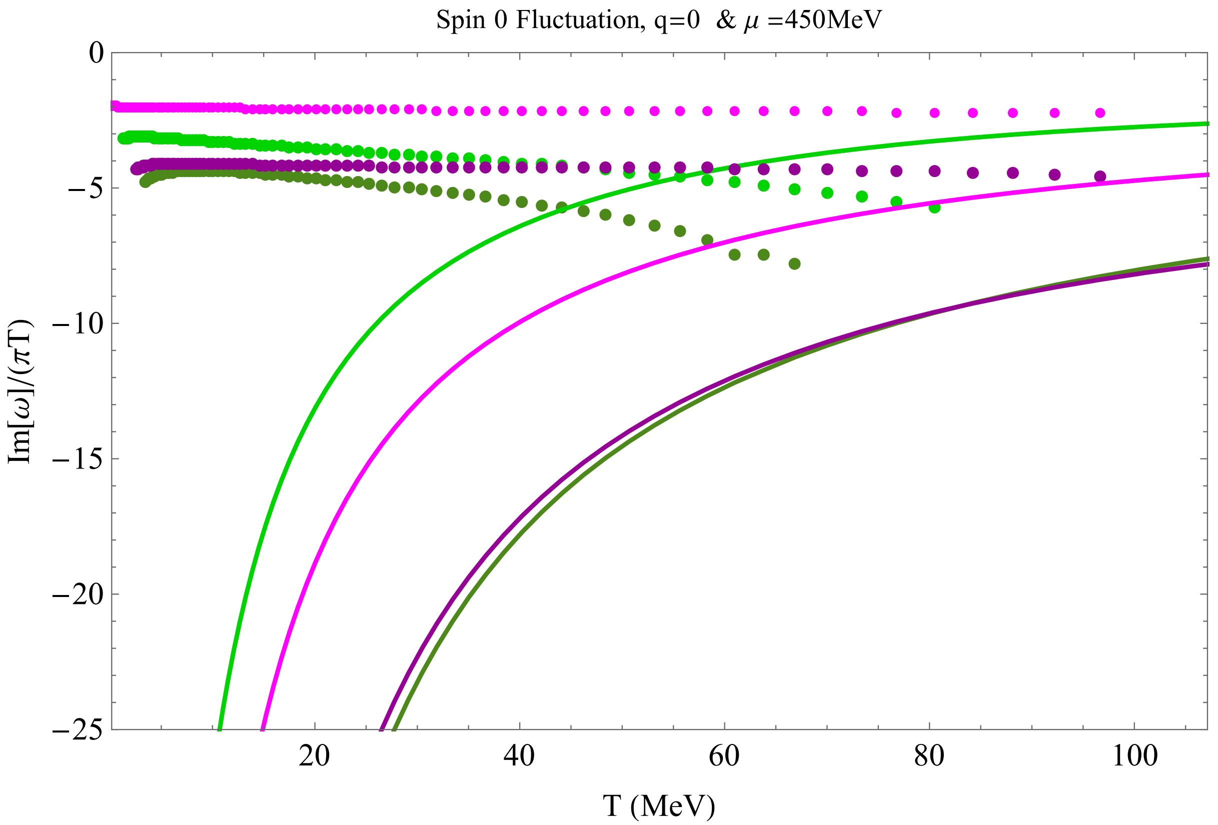
$$Z_\phi = \delta\phi - \frac{\phi' \delta g_{xx}}{2A'(r)}$$

We solve Einstein's equations to obtain the background fields solutions. Then turn on the fluctuations considered in each sector and obtain the linearized equations of motion. We then put these in terms of gauge invariant combinations and transform to EF coordinates.

Results: modes at q=0

The Imaginary modes are closer to the real axis at small T.

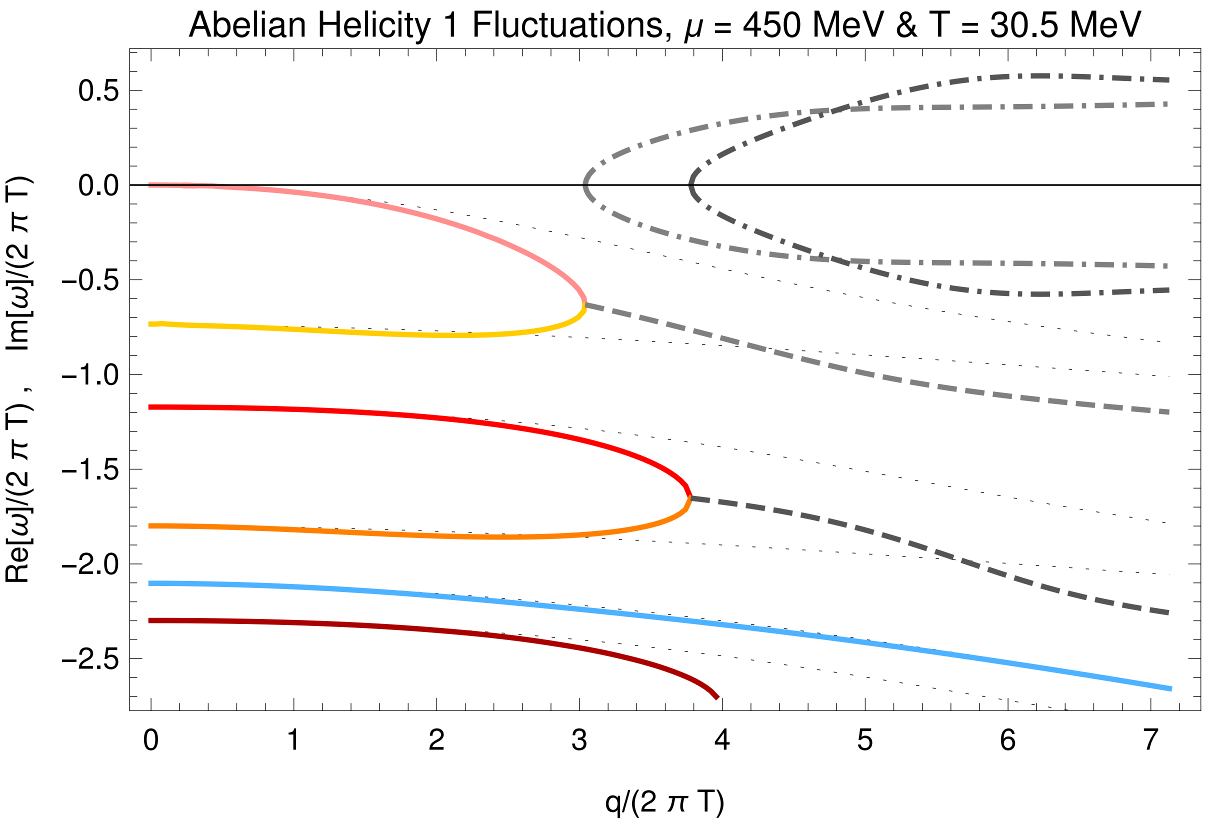


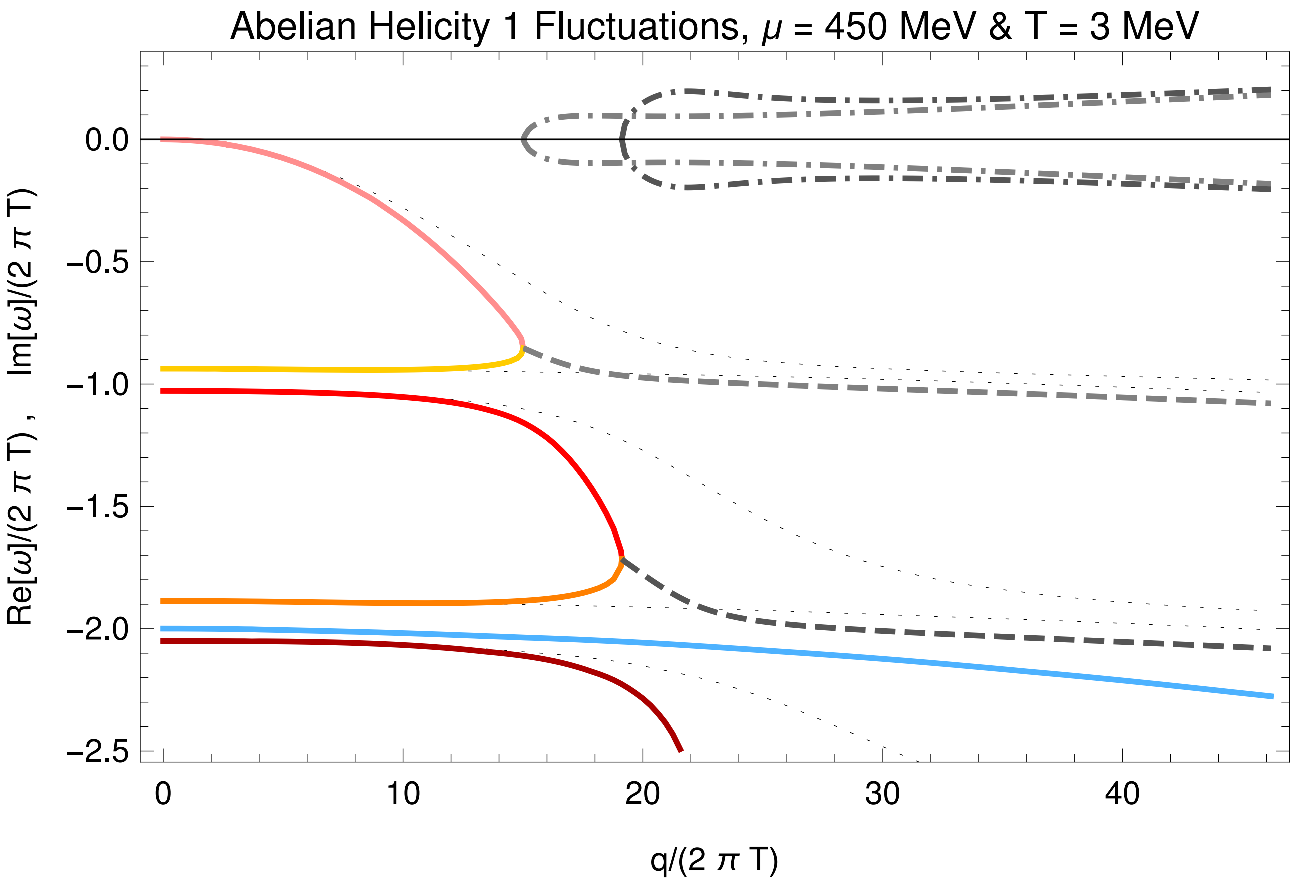


Results: modes at finite q (work in progress)

Behaviour of imaginary modes resemble results from AdS_4 RN

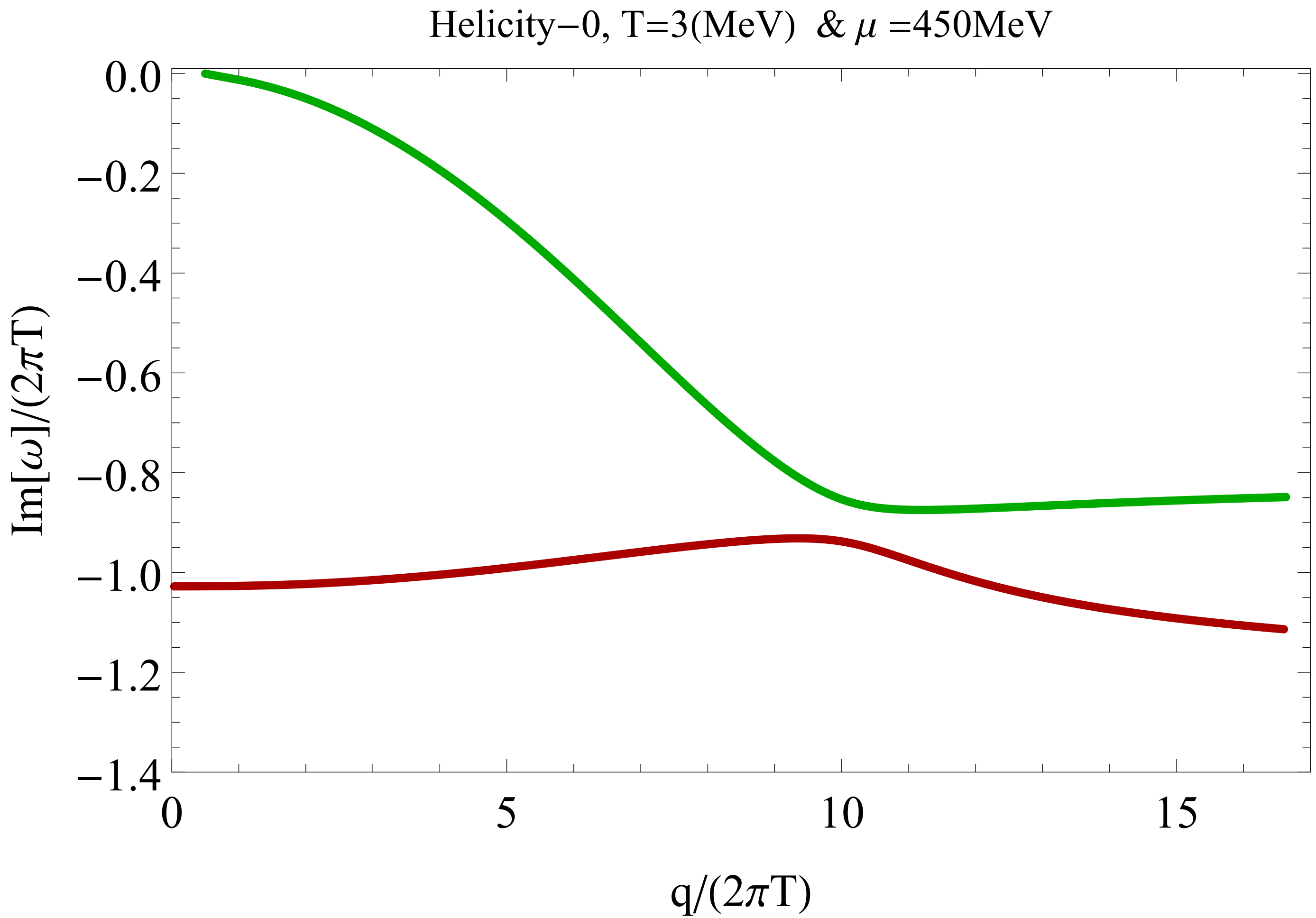
Areán, Davison, Goutéraux, Susuki





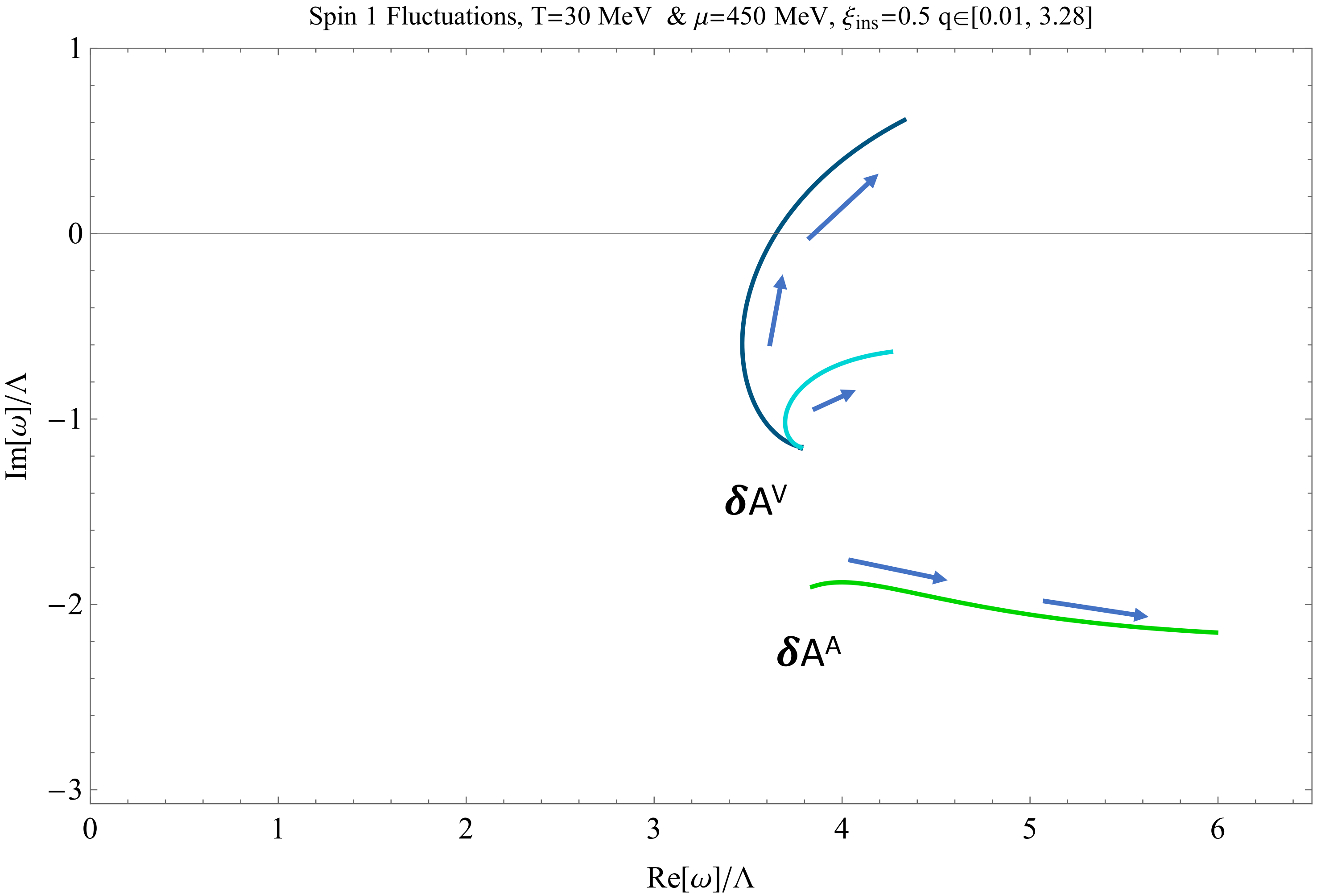
Results: modes at finite q (work in progress)

We find the expected interaction between the hydro diffusion mode and AdS_2 modes



Results: modes at finite q (work in progress)

There is a complex mode with an imaginary part that becomes positive at large momentum if we enhance the CS term.



Summary

- We have analyzed the QNM for all sectors as a function of momentum, temperature and for different fixed values of chemical potential and found the behavior at finite momentum of the modes.

- The Imaginary modes show a complex behavior in which they collide with other modes becoming complex modes. In particular at small T the behavior of the hydro mode and the first imaginary mode is consistent with the results from 2011.1230 in an AdS_4 RN

- We have found that at small temperatures there is no instabilities, however if we enhance the Chern-Simons term an instability appears at small temperatures and finite momentum in a complex mode.

Outlook

- Analyze the hydro-modes and the structure of collisions at smaller T
- Study directly the fluctuations at the T=0 limit with a AdS_2 Metric
- Now that we see that the low temperature regime is stable, we want to explore the possibility of adding extra ingredients to propose a mechanism for CSC

Thank you !