# Applications of AdS/CFT in Quark Gluon Plasma

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# SUMMARY

QGP is one of the phases in QCD where quarks are deconfined and form a fluid with gluons. It could exist in an environment with strong or weak coupling. However, there are many indications that the QGPs created at RHIC are strongly coupled. Hence, we need a tool that goes beyond perturbation theory. AdS/CFT(or in general gauge/gravity) correspondence is one of the tools which we discussed briefly in chapter 1. In this thesis, we used AdS/CFT correspondence to compute some of observables of QGP such as photon and dilepton production rates, mean-free path time of the plasma constituents, and anisotropic drag force effect to the elliptic flow.

There is still no a complete description of gauge/gravity correspondence where the dual theory is QCD. Nevertheless, there are models constructed to mimic some of phenomenological properties of QCD such as linear confinement, lowest mesons spectrum, and etc. One of these models is softwall AdS/QCD which is an interesting model particularly because the critical temperature is found to be relatively close to the current lattice computation. This model has non-trivial dilaton background in addition to the gravity background. We used this model to compute photon and dilepton production rates in chapter 2.

The observable that we computed in photon and dilepton production rates is the spectral density function $\chi(K)$ given as the imaginary part of the retarded electromagnetic current-current correlation function. For this purpose, we only considered the quadratic terms of the $U(1)$ gauge field in softwall AdS/QCD action. Using Minkowski prescription by Son and Starinet, we computed the results analytically at low and high frequency and then confirmed them with numerical result.

At low frequency, the result depended on the IR-cutoff parameter $c$, with $c \geq 0$. Unfortunately, for some higher values of $c$ we found no peaks in the spectrum which meant no signal of confinement. This may due to the fact that softwall AdS/QCD does not take into account the backreaction from dilaton field to the geometry. Softwall AdS/QCD is some how much cruder description of QCD in the unstable regime $c > 0.419035$. We showed this by comparing with the computation from $\mathcal{N} = 2$ SQCD theory, where the peaks appear in the spectrum. Although softwall AdS/QCD does not capture the confinement in

the unstable regime, it still describes the IR-consequences of a mass gap from the confinement phase remarkably well in the stable regime $0 \leq c \leq 0.419035$. We also computed the electrical conductivity $\sigma$ and found that the IR-cutoff parameter $c$ gives a damping effect.

The mean-free path time of the plasma can be computed by studying the Brownian motion of an external quark in the plasma. The Brownian motion is described by the generalized Langevin equation which basically consists of two terms: friction and random force terms. We showed in chapter 3 that for a simple model, the mean-free path time can be extracted from two- and four-point functions of random force $R$ at low frequency limit $\omega \to 0$.

In the bulk, this Brownian motion is represented by the motion of a fundamental string $X$ at the boundary where the action is given by Nambu-Goto action under some black hole backgrounds. We computed the two- and four-point functions using holographic prescription to the small fluctuation around static strings configuration. Holographically, the boundary value of the string $x = X(r \to \infty)$ couples to the total force $F$ on an external quark. In the large mass limit, $m \to \infty$, the total force is equal to random force. We also used Minskowski prescription by Skenderis and van Rees to compute the real-time propagators and holographic renormalization to remove the UV divergence that appear at the boundary. However, there was also an IR divergence near the horizon. We argued that this IR divergence can be removed by introducing an IR cut-off to the geometry.

An explicit computation of the mean-free path time was done for the case of non-rotating BTZ black hole, which corresponds to a neutral plasma. We generalized the computation for various black hole backgrounds and obtained a general formula of the mean-free path time. This generalized formula was used to compute the mean-free path time of STU black holes, which corresponds to charged plasma. The results showed that the mean-free path time is proportional to the inverse of $\log \eta$, with $\eta$ is a function of Hawking temperature $T_H$ and charge $\kappa$. When $\kappa$ increases, the plot 3.4 showed that $\eta$ decreases for 1- and 2-charge cases and increases for 3-charge case. These results are in accordance with our intuition as for the black holes with a fixed mass the mean free path-time increases when $\kappa$ increases in all of the charge cases. We also computed friction coefficient of STU black holes and found that the result at low frequency limit, $\omega \to 0$, is similar to the drag force computation at non-relativistic limit.

The non-central collisions at the RHIC experiments show an anisotropic particle distribution of QGP. The signal of this anisotropic distribution can be seen in some of observables e.g. jet-quenching or drag force. In gauge/gravity correspondence's language, the anisotropic distribution can be related to the anisotropic of black hole backgrounds. One way to realize this is by considering the rotating black holes. This is the main focus of chapter 4.

At first, we considered the non-rotating 4D AdS-Schwarzschild black hole. The drag force in gravity side is interpreted as a world sheet conjugate momentum in radial direction of the Nambu-Goto action evaluated at the boundary. With a linear ansatz, we obtained that the total drag force of arbitrary great circle is proportional to the angular velocity of the string $\omega$ and the square of critical radius $r_{Sch}$, which is similar to the flat case [35, 39]. Unfortunately, we found that the friction coefficient is not a linear function of the plasma temperature $T$.

We then continued the study of the drag force to the 4D Kerr-AdS black hole. A simple computation was done for equatorial case. Unlike the case of 4D Ads-Schwarzschild black hole, the drag force does not vanish if we take the angular velocity of the string to be zero, $\omega = 0$, but instead it is proportional to the angular momentum of the black hole $a$. For more general case, we considered a particular “static” solution in Boyer-Lindquist coordinates. This solution contributes to the leading order of drag forces at small angular momentum $a$ with vanishing velocities $\omega = 0$. We plotted the drag forces for different values of angular momentum $a$ and parameter $M_T$. We found that the drag force in $\theta$-direction tends to drive the quark back to the equatorial plane and the amount of force is proportional to the static thermal rest mass of the quark $m_{rest}$ and temperature of the plasma $T$.