Hydrodynamic Fluctuations and Two Point Correlators

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What sort of correlations are generated by

- A local hotspot,
- Propagating according to hydrodynamics,
- In a background with radial flow?
Gubser Flow (background)

Advantages:

- **Exact** solution to the hydro equations
- Radial flow

\[
u_r(\tau, r) = \frac{2q^2 r \tau}{1 + q^2 (r^2 + \tau^2)}
\]

- Bjorken is a special case \( q \to 0 \)

Limitations (reasons for the simplicity):

- Azimuthal symmetry (**central** collisions)
- **Conformal** symmetry

\[
\begin{align*}
\varepsilon &= 3P \\
\zeta &= 0
\end{align*}
\]

Gubser [1006.0006], Gubser and Yarov [1012.1314]
Gubser Flow (Perturbations)

- Introduce perturbations

\[
\varepsilon(\rho, \theta, \phi, \xi) = \frac{\hat{\varepsilon}_0(\rho)}{\tau^4} [1 + \lambda \delta(\rho, \theta, \phi, \xi)] + \mathcal{O}(\lambda^2)
\]

\[
u^\mu = \frac{1}{\tau} (1, \lambda \nu^i(\rho, \theta, \phi, \xi)) + \mathcal{O}(\lambda^2)
\]

- Linearize hydro equations in conformal coordinates

\[
\nabla_\mu T^{\mu\nu} = 0
\]

\[
T^{\mu\nu} = \frac{4\varepsilon}{3} u^\mu u^\nu + \frac{\varepsilon}{3} g^{\mu\nu} + T_{\text{viscous}}^{\mu\nu}
\]

- Spherical harmonics and Fourier transform reduces this to a set of coupled ODEs
Gubser Flow (Perturbations)

- Neglecting rapidity dependence, (and viscosity) the equations can be solved analytically.
- A strategically placed hotspot gives a reasonable result for the azimuthal dependence.

Shuryak and Staig [1105.0676]

What happens if we extend these results in longitudinal direction?
Proper time evolution

\[ \tau = 2\tau_0 \quad \tau = 4\tau_0 \quad \tau = 6\tau_0 \]
Methodology

Compute two point functions (energy-energy correlator)

- In lieu of proper freeze-out, average over radius

\[
\tilde{\delta}(\tau, \phi, \xi) \equiv \frac{1}{r_{\text{max}}} \int_{0}^{r_{\text{max}}} rdr \, \delta(\tau, r, \phi, \xi)
\]

- Average over initial azimuthal angle and rapidity

\[
C_{\delta\delta}(\tau, \Delta\phi, \Delta\xi) \equiv \int d\chi d\eta \, \tilde{\delta}(\tau, \phi_1 - \chi, \xi_1 - \eta)\tilde{\delta}(\tau, \phi_2 - \chi, \xi_2 - \eta)
\]
Results

Two Point Correlator $C_{\delta\delta}(\Delta \phi, \Delta \xi)$

\[ \tau_0 = 0.5 \text{ fm/c} \]
\[ r_0 = 4.1 \text{ fm} \]
\[ \tau_f = 10 \text{ fm/c} \]
\[ q = (4.3 \text{ fm})^{-1} \]

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Discussion

- The peak at zero angular separation has some contribution from a structure which is elongated in rapidity.
- Rapidity correlations can be long, but limited by the finite sound propagation speed.
- Narrow peak in $\Delta \phi$ should persist after freeze-out due to radial flow.
- These results are for a single (initial state) hotspot.
- Extension to include stochastic noise is in progress.