Hydrodynamic Fluctuations and Two Point Correlations

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Motivation

We are interested in the impact of *local* fluctuations on two particle correlation data from RHIC and LHC. In contrast to typical initial state fluctuations, here the fluctuations are localized in both transverse *and* longitudinal extent. Related recent work includes [1], which demonstrated that initial state hotspots placed at a particular position in the transverse plane could reproduce many of the features of the two-particle azimuthal correlations.

Point-like fluctuations occur naturally due to thermal noise in hydrodynamics. In [2] it was shown that local hydrodynamic fluctuations occurring throughout the evolution of the system could induce long range rapidity correlations.

Here, we extend these investigations by examining the energy-energy correlations (induced by a local perturbation propagating according to hydrodynamics) as a function of both azimuthal angular difference $\Delta\phi$, and rapidity difference, $\Delta\xi$.

Background Flow

We add perturbations on top of the Gubser flow, a generalization of Bjorken flow which includes expansion in the transverse plane [3,4]. The fluid is at rest in the following coordinate system

$$ds^2 = \tau(\rho,\theta)^2\left[-d\rho^2 + \cosh^2\rho\left(d\theta^2 + \sin^2\theta\, d\phi^2\right) + d\xi^2\right]$$

Conformal coordinates ρ and θ are related to proper time τ and the radial distance r by the transformations. We denote the space-time rapidity as ξ.

$$\sinh\rho = -\frac{1-(q\tau)^2+(qr)^2}{2q\tau} \qquad \tan\theta = \frac{2qr}{1+(q\tau)^2-(qr)^2}$$

Important properties of the Gubser flow:

- Exact, boost invariant solution of the hydro equations which includes radial flow.
- Free parameter: q, which is related to the finite size of the system. Bjorken flow is recovered by taking $q \to 0$.
- Radial velocity of the fluid is

$$v_r = \frac{2q^2 r\tau}{1+(q\tau)^2+(qr)^2}.$$

- Requires azimuthal symmetry; applicable to central collisions only.
- Requires *conformal* symmetry; equation of state is fixed at $\varepsilon = 3P$.

[1] P. Staig and E. Shuryak *Phys. Rev.* **C84** (2011) 044912 [1105.0676]
[2] J. I. Kapusta, B. Müller and M. Stephanov, *Phys Rev.* **C85** (2012) 054906 [1112.6405]
[3] S.S. Gubser, *Phys Rev.* **D82** (2010) 085027 [1006.0006]
[4] S. S. Gubser and A. Yarom *Nucl. Phys.* **B846** (2011) 469-511 [1012.1314]

Perturbing The Flow

- Introduce small perturbations of energy density and fluid velocity

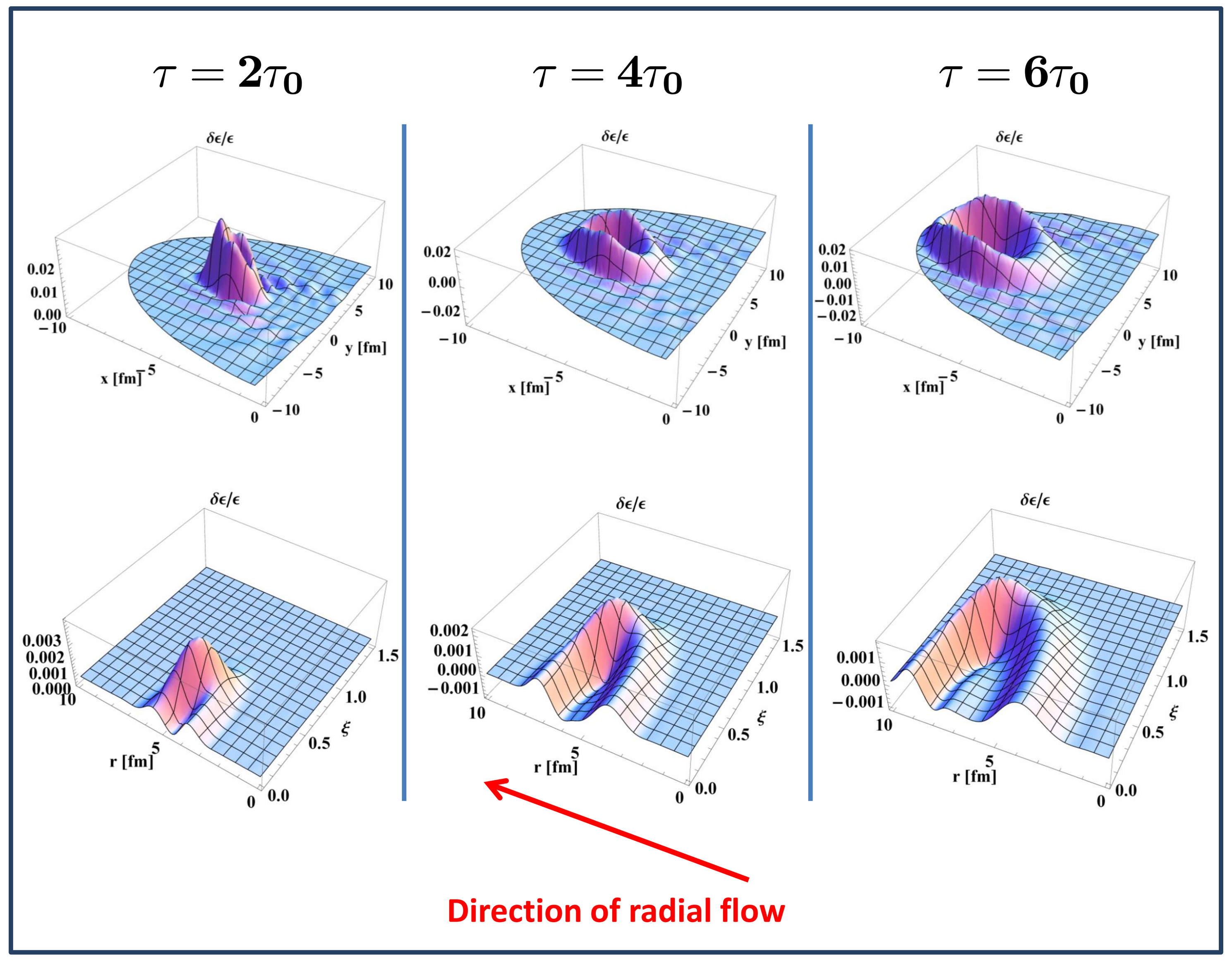
$$\begin{aligned}\varepsilon(\rho,\theta,\phi,\xi) &= \frac{\hat{\varepsilon}_0(\rho)}{\tau^4}\left[1+\lambda\delta(\rho,\theta,\phi,\xi)\right] + \mathcal{O}(\lambda^2),\\ u^\mu(\rho,\theta,\phi,\xi) &= \frac{1}{\tau}\left(1,\lambda u^i(\rho,\theta,\phi,\xi)\right) + \mathcal{O}(\lambda^2).\end{aligned}$$

- Linearize the resulting hydrodynamic equations to first order in the small parameter λ.
- Fourier transform in ξ, and employ a spherical harmonic expansion in the angular (θ,ϕ) directions.
- Initial condition is a Gaussian hotspot in energy density with vanishing fluid velocity:

$$\delta(\rho_0,\theta,\phi,\xi) = A\exp\left\{-\frac{\theta^2+\theta_0^2-2\theta\theta_0\cos(\phi-\phi_0)+\xi^2}{2\Sigma^2}\right\}.$$

- Solve the linearized equations numerically to evolve the perturbation in ρ.
- Transform the coordinates from ρ,θ to τ, r.

Time Evolution



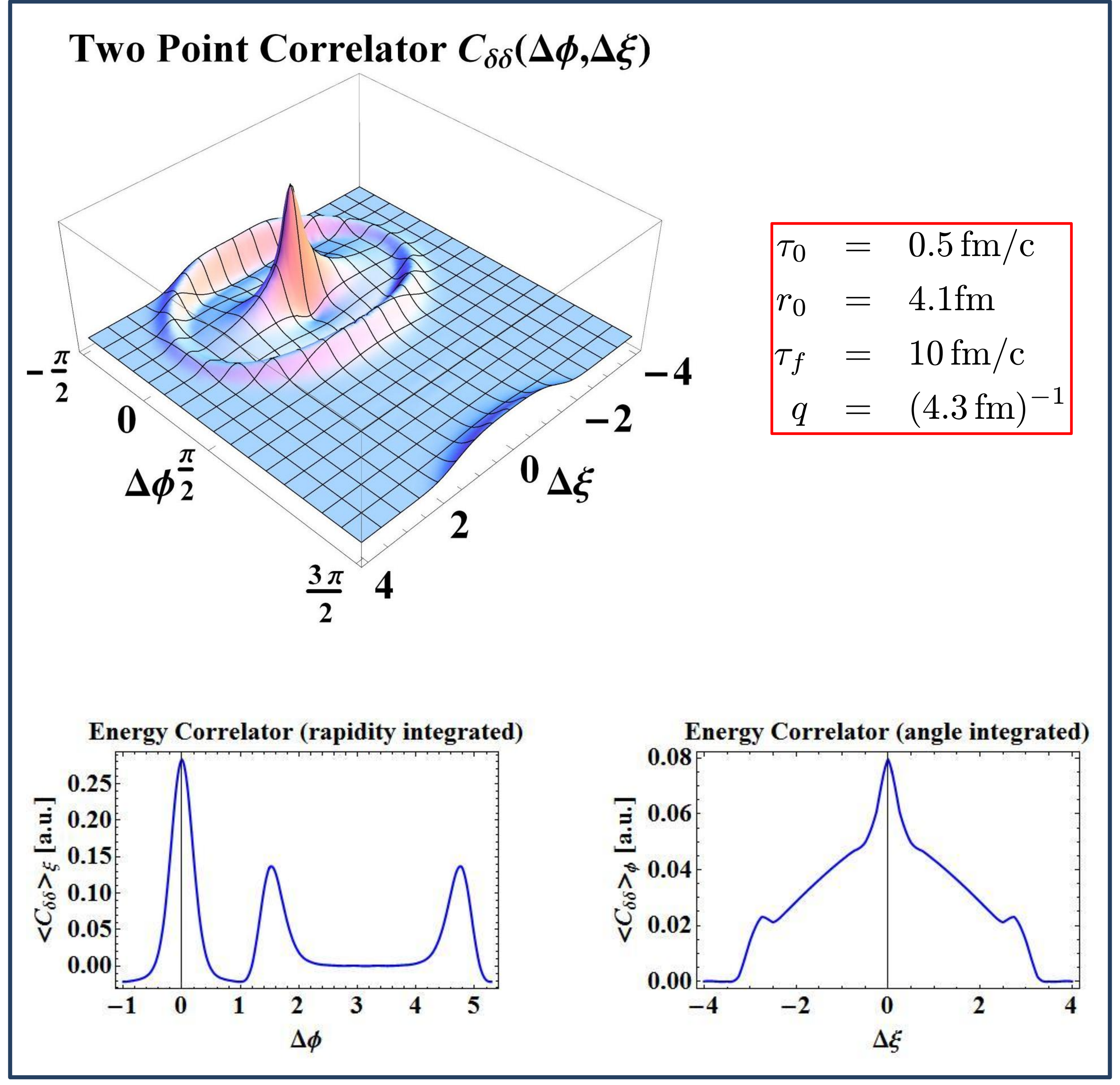
Correlations

- Integrate over the transverse plane,

$$\bar{\delta}(\tau,\phi,\xi) \equiv \frac{1}{r_{\max}}\int_0^{r_{\max}} r dr\, \delta(\tau,r,\phi,\xi).$$

- Compute correlation function by averaging over the initial aziumuthal angle and rapidity,

$$C_{\delta\delta}(\tau,\Delta\phi,\Delta\xi) \equiv \int d\chi d\eta\, \bar{\delta}(\tau,\phi_1-\chi,\xi_1-\eta)\bar{\delta}(\tau,\phi_2-\chi,\xi_2-\eta).$$



Discussion

- Perturbations lead to propagating sound waves. Sound front peaks are visible in both azimuth and rapidity.
- Central peak is broadened in rapidity direction due to expansion.
- In progress: replacing the hotspots presented here with stochastic hydrodynamic fluctuations. What impact do these fluctuations have on the two-particle correlation data, or equivalently the flow coefficients v_n?

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