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Longitudinal hydrodynamic response and pseudo-rapidity dependent harmonic flow in relativistic heavy-ion collisions

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In heavy-ion collisions, it is well-established that geometrical shapes of the initial density distribution in transverse plane are responsible for the observed harmonic flow, through the hydrodynamic response of a set of modes. In particular, elliptic flow V_2 is linearly proportional to initial eccentricity $\mathcal{E}_2$.

In this work, we generalize the framework to study hydrodynamic response along the longitudinal direction. We propose a differential hydrodynamic response relation, $V_2(\eta) = \int d\xi G(\eta - \xi)\mathcal{E}_2(\xi)$, to describe the formation of a pseudo-rapidity dependent elliptic flow, in response to a 3D initial density profile. By analyzing the medium expansion using event-by-event simulations of 3+1D MUSIC, with initial conditions generated via the AMPT model for the Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, the differential response relation is verified and expansion coefficients to very high orders are identified in the response function $G(\eta - \xi)$.

Our investigations of the hydrodynamic response function have yielded two important insights: 1. The two-point auto-correlation of elliptic flow in pseudo-rapidity (an observable in heavy-ion experiments), can be separated as medium response and two-point correlation of initial $\mathcal{E}_2$. Especially, shear viscosity of the medium reduces the correlation length systematically. 2. Higher order expansion coefficients increase exponentially, which implies a finite radius of convergence of the gradient expansion in the dispersion relation of hydrodynamics. The radius of convergence in the response function results in a minimal length scale that can be used to estimate the applicability of hydrodynamic modeling of heavy-ion collisions, which provides a possible solution to the question of fluidity in small systems.

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