Nonlinear waves in the search for the QCD critical point

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Introduction

In Relativistic Heavy Ion Collision Experiments(RHIC-E), partons (quarks and gluons) are produced with a range of transverse momentum (p_T). Partons with relatively lower p_T, by subsequent scattering, produce a locally thermalized medium of quark gluon plasma (QGP), whereas the high p_T partons do not stay in the medium to form locally thermalised QGP, but pass through the medium as jets. The partons, especially the supersonic ones, produce perturbations in the medium leading to nonlinear waves. Apart from the disturbances generated by the jets, quantum fluctuations leading to inhomogeneity in the medium. The hydrodynamic response of the QGP to such perturbations, are reflected on the hadron spectra. Specifically, the appearance of two maxima at $\Delta\phi = \pi \pm 1.2$ radian in the quenched away side jet or the double-hump in the correlation function of the jet structure is explained as the effect of the Mach cone produced due to hydrodynamic response to the perturbation created by jets [1]. The momentum anisotropy, which is quantified as flow harmonics of the produced particle is a result of the hydrodynamic response of the QGP to the initial geometry. In general the hydrodynamic response can be treated as either linear or nonlinear depending on the magnitude of the perturbations. In QGP, both types of perturbations may be present. The linear perturbations are well studied and near the Critical-End-Point(CEP), they are highly damped and halted. Now the fate of the nonlinear perturbations are not well established near the CEP. In this work, we derive the equations for propagation of nonlinear perturbation(nonlinear waves) up to second order with all the relevant transport coefficients such as shear viscosity, bulk viscosity, and thermal conductivity(η, ζ, and κ), and study the fate of the nonlinear perturbations near the CEP.

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Results and discussion

To derive the required equations, we used relativistic second order viscous hydrodynamics(Israel-Stewart hydrodynamics). The equations are found to be KdV-like(Korteweg-De Vries), may resulting in maintaining the solitonic behaviour. The effect of CEP is taken through an Equation of State(EoS), containing the a critical point. The EoS is constructed from the Universality hypothesis, says that the critical point in QCD belongs to the same universality class[$\mathcal{O}(4)$] as that of the 3D Ising model. The construction of the EoS can be found in Refs. [2, 3].

Fig.1 shows the propagation of a nonlinear wave through the medium when the system is formed away from the CEP. It is found that the nonlinear wave is survived with reduced amplitude, though there are dissipative effects introduced via the non-zero values of transport coefficients. In contrast, the nonlinear wave is substantially dissipated near the CEP is shown in Fig. 2. It has been observed that the dissipative feature remains un-

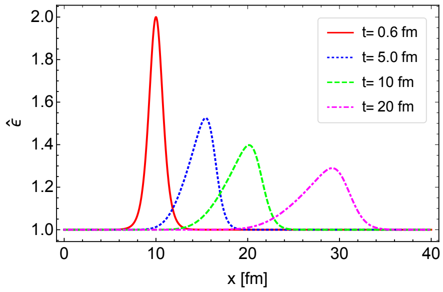

FIG. 1: (Color online) $\hat{\epsilon}$ as a function of x at different time, when the system is away from the CEP [4].

changed with the variation of the position of the CEP along the transition line in the QCD phase diagram. This clearly indicates that the nonlinear perturbations will provide detectable effects of the CEP.

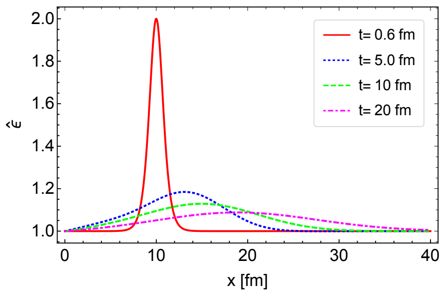

FIG. 2: (Color online) $\hat{\epsilon}$ as a function of x at different time when the system is very near to the CEP [4].

It has been predicted earlier [3, 7, 8] that the formation of Mach cone is prevented near the CEP for linear perturbation. In this work we find that even the nonlinear perturbations will not be able to retain the Mach cone effects if it hits the CEP. Therefore, the double hump present as the effect of Mach cone in two or three particle correlation will disappear if the system passes near the CEP.

The flow harmonics play important role in characterizing the medium formed in RHIC-E. It was shown in Refs. [5, 6] that some of the flow harmonics will collapse at the CEP. Based on linear analysis it has been argued in Refs. [3, 7, 8] that v_2 will be reduced near the CEP. The same conclusion can be drawn for the nonlinear waves too in presence of CEP. The present work suggests that v_2 and higher harmonics will be suppressed near the CEP due to the absorption of sound wave, even for highly off-central collisions. In Event-by-Event analysis different isentropic trajectories are created. Flow harmonics will survive when the trajectories are passing away from the CEP, but highly suppressed when passing near the CEP. Therefore, there will be a enhancement of fluctuation in flow harmonics in Event-by-Event analysis.

In conclusion, We argue that the disappearance of Mach cone effects and the enhancement of fluctuations in flow harmonics in the event-by-event analysisaccompanied by suppression of flow harmonics may be considered as signals of the critical-end-point.

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