Charged particle elliptic flow splitting at non-zero rapidity in heavy ion collisions

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Introduction

Recently it has been proposed that the global vorticity in non central heavy ion collisions entails a new effect named as the splitting of elliptic flow [1]. In a subsequent work, using the transport model simulation it has been shown that the split in elliptic flow (v_2) is a consequence of non-zero directed flow at finite rapidities [2]. However the transport models are not able to explain the experimental data of rapidity dependent directed flow (v_1) of charged particles. In this work, we have considered a tilted matter profile which after hydrodynamic evolution explains the experimental data of $v_1(\eta)$ at $\sqrt{s_{NN}} = 200$ GeV in Au+Au collisions. We have observed that the split in v_2 can be attributed to the presence of rapidity odd harmonics in final momentum distribution of the produced particles. Especially the first and third components are found to be dominant contributors [3]. The proposed splitting in v_2 may be used to constrain initial conditions which has been demonstrated with two different models.

Initial profile and hydrodynamic evolution

We have considered two different models widely used to construct the initial rapidity profile of energy density in heavy ion collisions, the shifted initial condition (SIC) [4] and tilted initial condition(TIC) [5]. In the SIC model, the energy density deposited along the space-time rapidity at each transverse coordinate is shifted by a value identified as the rapidity of the center of mass at that transverse position. The TIC assumes asymmetric matter deposition of a participating nucleon in forward and backward rapidity region which creates a tilted profile in the reaction plane.

The hydrodynamic evolutions of the input energy density profiles have been performed by the publicly available MUSIC code. The code provides the final momentum space probability distribution of the produced particles after doing the Cooper-Frye freezeout and resonance decays from which various observables have been calculated. Used parameters in the initial conditions and during hydrodynamic evolution have been mentioned in [3].

Splitting of the elliptic flow

The Fourier expansion of the azimuthal distribution of produced hadrons is

$$\frac{dN}{d\phi} = \frac{1}{2\pi}\left(1 + 2\sum_n \left(v_n \cos(n(\phi - \psi_{\rm RP})) + s_n \sin(n(\phi - \psi_{\rm RP}))\right)\right) \quad (1)$$

It is important to note here that all the Fourier coefficients(v_n and s_n) have been defined with respect to reaction plane angle ($\psi_{\rm RP}$) which is different from the usual definition where they are defined with respect to the respective event planes. The split in v_2 is defined as

$$\Delta v_2 = {v_2}^{\rm R} - {v_2}^{\rm L} \quad (2)$$

where ${v_2}^{\rm R} = \langle \cos(2(\phi^{\rm R} - \psi_{\rm RP}))\rangle$ with $\phi^{\rm R} \in ((\psi_{\rm RP} - \pi/2), (\psi_{\rm RP} + \pi/2))$ and ${v_2}^{\rm L} = \langle \cos(2(\phi^{\rm L} - \psi_{\rm RP}))\rangle$ with $\phi^{\rm L} \in ((\psi_{\rm RP} + \pi/2), (\psi_{\rm RP} + 3\pi/2))$. Using Eq. 1 in Eq. 2 one can get the following relation.

$$\Delta v_2 \approx \frac{8v_1}{3\pi} + \frac{24v_3}{5\pi} - \frac{40v_5}{21\pi} \quad (3)$$

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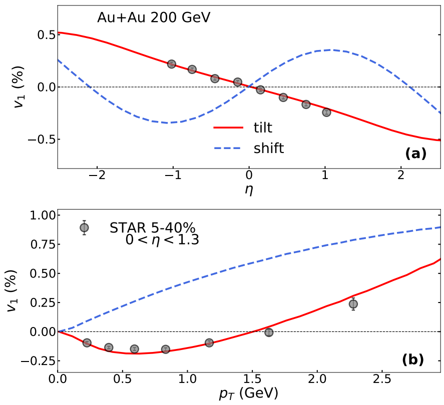

FIG. 1: (Color online) Rapidity and p_T differential directed flow (v_1) is computed both for TIC (red solid line) and SIC (blue dashed line) for 5-40 % centrality Au+Au collisions at $\sqrt{NN} = 200$ GeV. The model expectations are compared to measurements from the STAR collaboration.

Results

As seen in Eq. 3, the leading contributions to Δv_2 arise from the odd harmonics. We first compare the model results calculated using both SIC and TIC with $v_1 - \eta$ and $v_1 - p_T$ data measured by STAR collaboration in Fig. 1. We have observed that the TIC is able to explain the experimental data. Hence it is expected to get correct prediction of Δv_2 within the used framework.

We have presented the Δv_2 prediction from both TIC and SIC together in Fig. 2 for comparison although the SIC fails to describe the existing experimental data. We have noted that Δv_2 results out of tension between v_1 and v_3 in the TIC however in the SIC we have found that it is mostly controlled by v_1 as v_3 turns out to be small in this case. It is worth noting here that an earlier study of Δv_2 within the transport framework of the AMPT model had similar conclusions as the results here with SIC [2]. Thus, the characteristics of Δv_2 can serve as a sensitive probe of rapidity dependent initial condition of the fireball.

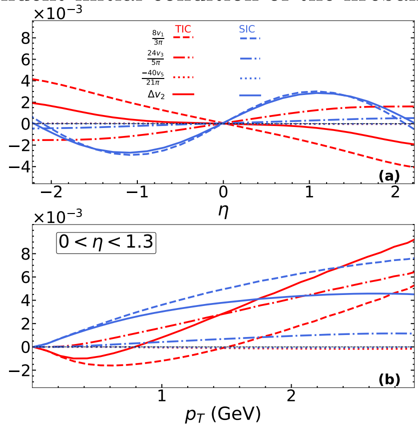

FIG. 2: (Color online) The predictions for phase space dependence of Δv_2 has been compared between TIC and SIC.

Summary

We have calculated the Δv_2 within a 3+1 D relativistic hydrodynamic framework with tilted and shifted initial condition. Unlike earlier studies, the tilted initial condition which describes the experimental data of v_1 gives sizeable rapidity odd v_3 which contributes significantly to Δv_2 alongwith v_1. The sensitivity of initial conditions on Δv_2 has been demonstrated by comparing the results from tilted initial condition with shifted initial condition.

References

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