Initial state fluctuations study in heavy ion collisions at FAIR energy using Principal Component Analysis

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In high energy heavy ion collisions, the overlap region between two colliding nuclei in an event has an asymmetric shape in non-central collision. The imprint of this initial asymmetry is reflected in the final state in terms of anisotropy in the azimuthal distribution of produced particles known as the asymmetric flow (v_2, v_3) . It is also known that the nucleon positions in the overlap region also fluctuate from event to event. Because of this event by event fluctuation, local domains may form that has group of nucleons with relatively small inter-nucleonic separation. These local domains are also called hot spots [1], where the energy density is higher than the average value. If the produced medium expand hydrodynamically, such hot spots in the initial state might manifest itself as large fluctuations in the final state observables. Thus, it is important to understand how these hot spots in the initial state get reflected in the final state observables like anisotropic flow and flow fluctuations which is required to constrain both the initial state model and transport properties of the bulk medium. In this work we have explored the sensitivity to these event wise initial state fluctuations by using the Principal Component Analysis (PCA) technique [2]. This technique reduces the dimensionality of the problem by determining an orthogonal basis set, called eigenvectors, in such a way that the most of the information are contained within first few components and the variance along those components are called eigenvalues. To implement a hot spot like initial condition, we perform a spatial rearrangement of the nucleons positions on top of the Woods-Saxon potential. Subsequently, we extract the PCA eigenvalues from the final state pions for various initial conditions as inputs and also studied its sensitivity to the size of the hot spot. We have done this work using UrQMD hadronic transport model at $\sqrt{s}_{NN}$ = 6.27 GeV which is likely to be accessible in the upcoming FAIR facility at GSI and previous studies suggest that the UrQMD model is well suited to describe the phenomenology of particle production in this energy range.

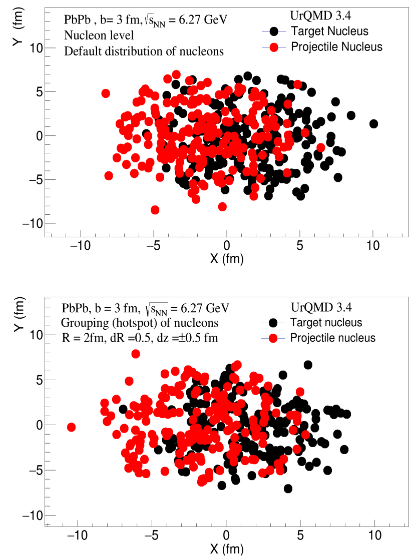

FIG. 1: The XY distributions of the nucleons in projectile and target nucleus in the transverse plane before (top) and after hotspot creation (bottom)

In the present study, the nucleon positions in the projectile (Pb) and target (Pb) nuclei are rearranged such that hot spot like initial structures may form after the collision. For this, we select a nucleon as a seed at random and the seed is taken as the center. Subse-

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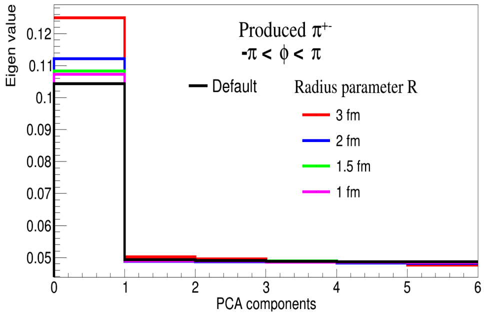

FIG. 2: PC eigenvalues with radius parameter R for ϕ distributions

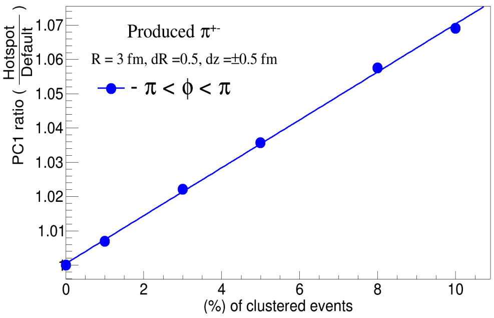

FIG. 3: Variation of PC1 ratio with event fraction for ϕ distributions

quently, nucleons whose inter-nucleonic separation with respect to the seed nucleon on the transverse plane (with a small longitudinal width (dZ) of $\pm$ 0.5 fm) lying within a certain radial distance (parameter R), are brought closer to the seed nucleon by minimizing the radial distance between them by a certain factor (parameter dR). When the formation of one such localized group or say hot spot is completed, same process is repeated till all nucleons are exhausted.

Figure 1 shows the nucleon position distributions in the X-Y plane before (top) and after (bottom) the rearrangement for R = 2 fm and dR= 0.5. It clearly shows local domains are formed with slightly increased nucleon density after rearrangement. The effect of this spatial rearrangement is studied with

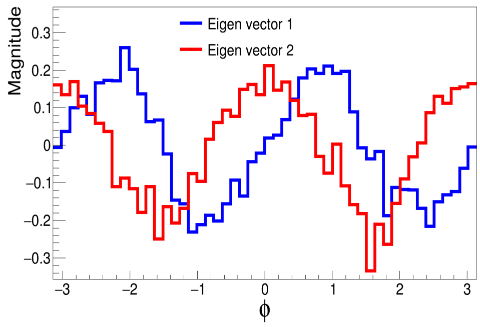

FIG. 4: First and second eigenvector in PC decomposition in ϕ

PCA analysis by obtaining PCA eigenvalues for the ϕ distributions of the produced particles under different initial conditions characterized by the R-parameter. Fig.2 shows first few PC component for the ϕ distribution and it is found to be sensitive to the change in the initial conditions and sensitivity is highest for the 1^{st} PC component and thereafter it reduces drastically. We varied fraction of events with hot spots in the initial condition upto 10% and a linear increase in the ratio of PC1 w.r.to default upto 7% is observed as shown in Fig.3. Finally we plot first two eigenvectors in Fig.4, which can be identified with the sin2ϕ and cos2ϕ component in the Fourier decomposition of the ϕ distribution. This can be further extended to analyse anisotropic flow coefficients, v_2, v_3, etc for these events. This study suggests that PCA technique can be employed to analyze the effect of initial state fluctuations on final state observables with improved sensitivity.

References

[1] R. Snyder, M. Byres, S. H. Lim, and J. L. Nagle, Phys. Rev. C 103, 024906 (2021).

[2] Ziming Liu, Wenbin Zhao and Huichao Song,The European Physical Journal C 79 (2019) 870.