Imaging the shape of atomic nuclei in high-energy collisions at STAR

Jiangyong Jia, Stony Brook University

Atomic nuclei across the nuclide chart exhibit a wide range of collective degrees of freedom, such as quadruple, triaxial, and octupole deformations. Nuclear deformations enhance the fluctuation of harmonic flow and radial flow, leading to an increase of v_2, v_3, and mean transverse momentum $[p_{\rm T}]$. As demonstrated in recent model studies, the shape parameters can be constrained precisely from ratios of observables between collisions of nuclei with similar mass numbers, such as between ^{96}Ru+^{96}Ru and ^{96}Zr+^{96}Zr or between ^{197}Au+^{197}Au and ^{238}U+^{238}U collisions.

We present measurements of v_n, $[p_{\rm T}]$ fluctuations as well as v_n-$p_{\rm T}$ correlations in these collision systems. Significant differences are observed for mean, variance, and skewness of $[p_{\rm T}]$ fluctuations between ^{197}Au+^{197}Au and ^{238}U+^{238}U collisions, which can be quantitatively explained by the large prolate deformation of ^{238}U, $\beta_{2,\rm U} \sim 0.28$. Striking differences are also observed in isobar collisions of ^{96}Ru and ^{96}Zr, where ratios of many observables show significant deviations from unity and exhibit rich patterns as a function of centrality. A comparison with hydrodynamic model simulations suggests a large quadruple deformation in Ru nucleus $\beta_{2,\rm Ru} \sim 0.16$ and a large octupole deformation in Zr nucleus $\beta_{3,\rm Zr} \sim 0.2$. The non-monotonic dependence of ratios of multiplicity distribution, v_2, and $p_{\rm T}$ fluctuations in the mid-central collisions also requires a difference in the surface diffuseness between Ru and Zr. By combining all these observables, we are able to constrain simultaneously the nuclear deformation and radial structure of isobar nuclei. Our results provide the first observation and quantitative extraction of the quadruple and octupole deformation in Ru and Zr nuclei using heavy-ion collisions.

PACS numbers: