Impact of quadrupole deformation on intermediate-energy heavy-ion collisions†

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An initial study on heavy-ion collisions between deformed nuclei was conducted in the year 2000.[1)] However, due to the absence of effective probes, it was generally assumed that the reacting nuclei were spherical. In recent years, a turning point has emerged as it has been recognized that at relativistic energies, a strong linear response relation exists between the higher-order mean square anisotropic flows and multipole deformations.[2)] This response relation is explained by the hot and dense quark-gluon plasma (QGP) formed in the overlap region, where the initial shape is correlated with the deformed shape of the nuclei. Driven by the large pressure gradient forces, the QGP expands hydrodynamically, converting the spatial anisotropies into azimuthal anisotropies of final-state particles in the momentum space.

We utilized transport models to simulate related research on intermediate-energy heavy-ion collisions where QGP cannot be formed. The collisions between stable, isospin-symmetric, prolate nuclei of ^{24}Mg were simulated at 500 MeV/nucleon via the isospin-dependent Boltzmann-Uehling-Uhlenbeck (IBUU) model. Our studies focused on various fixed-orientation reactions, highlighting the significant roles played by the eccentricity, ϵ, of the overlap and number of participants in influencing reaction observables including meson yields and final-state anisotropic flows.

In theoretical calculations of ultra-central non-polarized collisions (Fig. 1), the fluctuation ($\langle\langle v_2\rangle_N^2\rangle_{\beta=0}$, denoted as sph.-sph.) results in a significant correlation between the strength of the deformation effect, $I = f(\beta)/\langle\langle v_2\rangle_N^2\rangle_{\beta=0}$, and number of test particles N, while $f(\beta)$ is independent of N. Here, $f(\beta) = \langle\langle v_2\rangle_N^2\rangle - \langle\langle v_2\rangle_N^2\rangle_{\beta=0}$ is the deformation-changed mean square elliptic flow with $\langle v_2\rangle_N$ averaged over $\cos(2\phi)$ ($\phi = \arccos(p_x/p_t)$ is the transverse emission azimuth angle) of all emitted particles in the final state of N test particles with the same orientation, while the outer $\langle\ldots\rangle$ represents the average over all orientations. When comparing with experimental measurements, it is advisable to adjust N to align the fluctuations in both cases. Furthermore, by filtering out events with spectators from the projectiles (denoted as Avg. 2 in the upper panel), there is a noticeable increase in the mean squared elliptic flow.

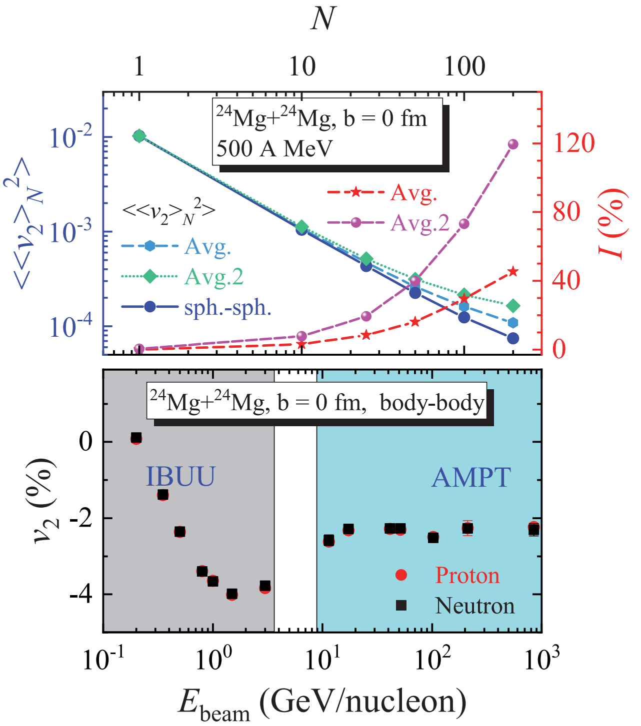

Fig. 1. Upper panel: Mean square elliptic flows resulting from the N test particles with the same orientation (curves in the blue-green color series) and strength of the deformation effect I (curves in the red color series). See text for details. Lower panel: The elliptic flows produced in the body-body collision as a function of beam energy.

Unlike in high-energy reactions, the observables at intermediate energies are also influenced by the spectators. The influence can potentially lead to the disruption of the linear response relation $f(\beta) \approx k^2\langle\epsilon^2(\beta)\rangle$, which aligns perfectly with that obtained via a multiphase transport model at $\sqrt{s_{NN}} = 200$ GeV. Through calculations of body-body reactions, the elliptic flow demonstrates a remarkable coincidence between $E_{beam} = 500$ MeV/nucleon and $\sqrt{s_{NN}} = 200$ GeV, resulting in a similar response ratio k ($= v_2/\epsilon$) (see the lower panel). However, in the results of the IBUU simulations averaging over all orientations (denoted as Avg.), $f(\beta)$ is less than that predicted by $k^2\langle\epsilon^2(\beta)\rangle$.

References

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