Peak mass production: Role of colliding geometry

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Introduction

The incident beam energy and colliding geometry of a reaction are found to play an important role in deciding the fate of the reaction [1, 2]. An excited nuclear system formed in energetic nucleus-nucleus collisions, depending on the excitation energy deposited in the system, decays via emission of fragments of various sizes such as free-nucleons, light charged particles (LCPs), intermediate mass fragments (IMFs) etc. [1]. In last few decades, several attempts have been made to study the role of colliding geometry on multiframentation [1, 2]. But all these studies have been carried out for systems lying close to the line of stability. The neutron-content of a colliding pair is found to affect the fragment production [3]. Recently, Puri and co-workers [4] studied the effect of isospin degree of freedom on $\langle N_{IMF}\rangle^{max}$ and $E^{max}_{c.m.}$. This study was limited for semi-central collisions only. Here we will make an attempt to see the effect of colliding geometry on $\langle N_{IMF}\rangle^{max}$ and $E^{max}_{c.m.}$ for the whole impact parameter range [5].

The present study is carried out within the framework of the isospin-dependent quantum molecular dynamics (IQMD) model [6].

Results and Discussion

We simulated reactions of ^{34}Cl+^{34}Cl (N/Z = 1.0), ^{34}Al+^{34}Al (N/Z = 1.6), ^{34}Ne+^{34}Ne (N/Z = 2.4), ^{40}Ca+^{40}Ca (N/Z = 1.0) and ^{60}Ca+^{60}Ca (N/Z = 2.0) over whole impact parameter range (from b/b$_{max}$ = 0.0 to 0.8) at different incident beam energies between 30 and 150 MeV/nucleon. We, here, use a soft equation of state along with standard isospin- and energy-dependent cross section.

In Fig. 1, we display the impact parameter dependence of $\langle N_{\rm IMF}\rangle^{max}$ (upper panel) and $E^{max}_{c.m.}$ (lower panel) for reactions of ^{40}Ca+^{40}Ca and ^{60}Ca+^{60}Ca. $\langle N_{\rm IMF}\rangle^{max}$ and corresponding $E^{max}_{c.m.}$ are obtained by making quadratic fit to the model calculations for $\langle N_{\rm IMF}\rangle$ as a function of $E_{c.m.}$ [4]. From Fig. 1(a), we find that $\langle N_{\rm IMF}\rangle^{max}$ first increases with increase in the impact parameter, attains a maximum value and then decreases at peripheral geometries. In case of central geometries, excitation energy is very high. The nuclear matter breaks into much smaller pieces and intermediate mass fragments or heavy-mass fragments are formed rarely. In Ref. [7], it has been discussed that free-nucleons and LCPs are originated from the mid-rapidity whereas IMFs and heavy fragments are the remnants of spectator matter.

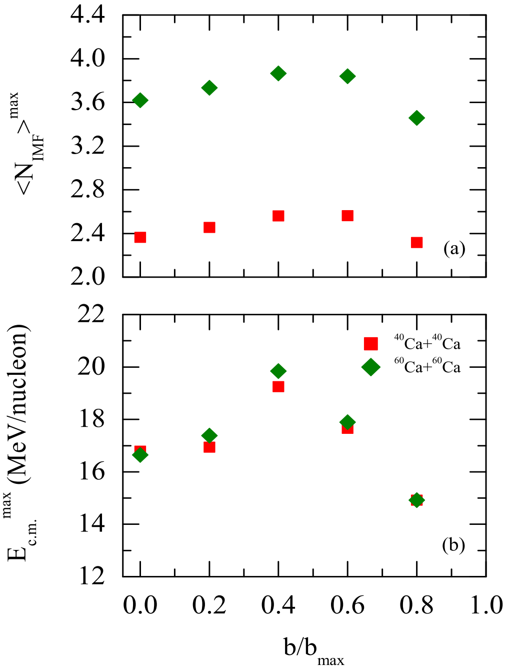

FIG. 1: $\langle N_{\rm IMF}\rangle^{max}$ (upper panel) and E$^{max}_{c.m.}$ (lower panel) as a function of impact parameter.

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With increase in the impact parameter, the degree of spectator matter increases, as a result number of IMFs increases. With further increase in the impact parameter i.e., for peripheral geometries, the formation of heavy fragments dominates, therefore the number of IMFs goes on decreasing. Thus, maximum number of IMFs are seen only between semi-central and semi-peripheral impact parameters. Also $\langle N_{\mathrm{IMF}} \rangle^{max}$ increases with the increase in system mass as we move from ^{40}Ca+^{40}Ca and ^{60}Ca+^{60}Ca.

From Fig. 1(b), we see that $E^{max}_{c.m.}$ is same for the reactions of ^{40}Ca+^{40}Ca and ^{60}Ca+^{60}Ca. In previous studies [4], it has been shown that $E^{max}_{c.m.}$ increases with increase in system mass but decreases with increase in isospin asymmetry. Here, both mass and neutron content increase. Both these variations cancel each other and no change is observed in $E^{max}_{c.m.}$. From Fig. 1(b), we find that $E^{max}_{c.m.}$ first increases with increase in the impact parameter, attains a maxima and then decreases at peripheral geometries. As impact parameter increases, the interaction volume decreases and a large amount of energy is needed to get a significant number of fragments. To explain this trend of $E^{max}_{c.m.}$, in Fig. 2, we plot the rapidity distribution of IMFs for reaction of ^{40}Ca+^{40}Ca for all colliding geometries at their respective $E^{max}_{c.m.}$. Solid, dashed, dotted, dash-dotted, dash double dotted lines represent rapidity distribution of IMFs at $\hat{b} = 0.0$, 0.2, 0.4, 0.6 and 0.8, respectively.

From Fig. 2, we find that in case of central geometries, there is a single Gaussian. It implies that IMFs are mainly coming from mid rapidity region. As we move towards peripheral collisions, the Gaussian gets broader and with further increase in the impact parameter, distribution splits into two Gaussians (at target and projectile rapidities), indicating correlated matter i.e., IMFs are originating from both participant as well as spectator matter. As the impact parameter increases, more and more energy is needed to break the colliding pair into large number of IMFs. At peripheral geometries, the formation of heavy fragments dominates and very few number of IMFs are emitted and that IMFs are coming from spectator zone and already cooled down.

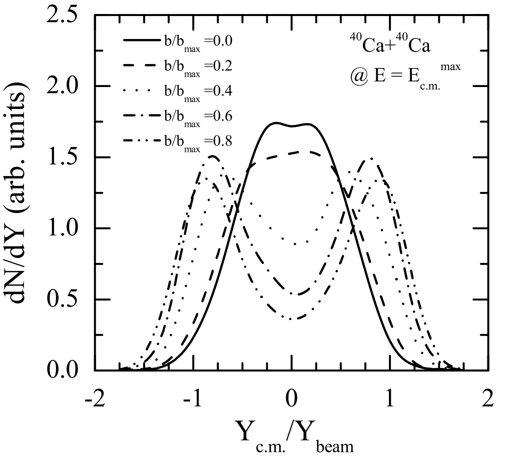

FIG. 2: The rapidity distribution, dN/dY, as a function of reduced rapidity, $Y_{c.m.}/Y_{beam}$ for the reaction of ^{40}Ca+^{40}Ca at all colliding geometries corresponding to their respective $E^{max}_{c.m.}$.

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