Disentangling Quasi-fission and fusion-fission

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One of our major interests in the recent era is to synthesize super-heavy elements (SHE) and to understand the natural laws behind its existence. The cross-sections for formation of SHE using heavy ion induced reactions is very low as the compound nucleus tends to decay via nuclear fission immediately after its formation. Additionally, the formation of compound nucleus is severely hindered by quasi-fission where the di-nuclear system formed by the capture of the projectile by the target gets re-separated without forming an equilibrated compound nucleus.

Though the presence of quasi-fission is manifested through different observables like FF mass-angle correlations, width of FF mass-distributions, it is difficult to disentangle the contributions of quasi-fission and compound nuclear fission from the measured FF mass distribution. With the advancement of theoretical models it is now possible to calculate the FF mass distributions for compound nuclear fission with much accuracy. Thus one can attempt to disentangle the two fission processes discussed above.

In the present work, FF mass-distributions have been measured in ^{19}F + ^{238}U reaction and compared with the theoretical model calculations. From the difference between the measurement and the calculation, the mass distributions and the contributions due to quasi-fission process have been obtained for the present reaction system.

The experiment on ^{19}F + ^{238}U reaction was carried out at 14-UD BARC-TIFR Pelletron-Linac facility, Mumbai using pulsed beam with energies ranging from 99.7 MeV to 142.1 MeV using two multiwire proportional counters developed inhouse[1]. From the measured velocities of the fragments in the centre of mass frame the mass distribution spectrum is obtained for all the measured energies as shown in Fig. 1(d-g) by black circles. The previously measured data[2] on the same reaction system was also shown in the same Fig. 1(a-c) by green circles. Now to understand the data, FF mass distributions are calculated using the semi-empirical model code GEF[3] for compound nuclear fission processes. It can be observed that the measured distributions are wider than the calculations (red solid line in Fig. 1), specially at lower excitation energies. The calculated peak heights overshoot the measured peak height for all the cases, more prominently for the beam energies up to 107.2 MeV. Simultaneously the tail part of the calculated distributions undershoots the measured data. Further, the calculated distributions have been broadened by taking into account the mass resolution (σ=6-8u)as shown by blue dashed lines in Fig. 1. One can notice that even after broadening the calculated

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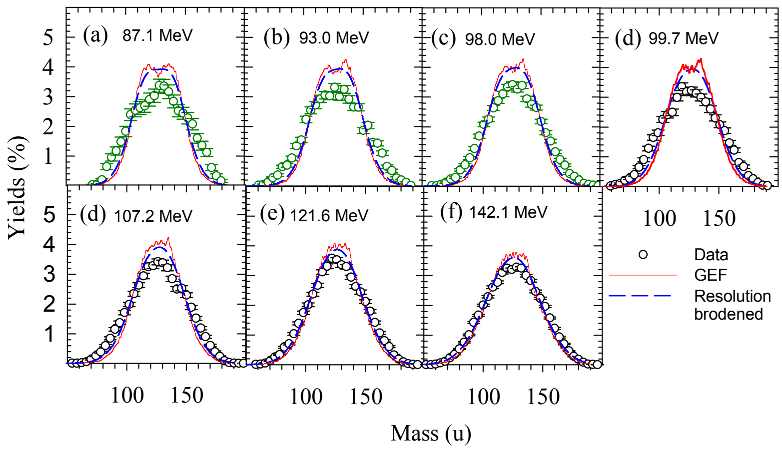

FIG. 1: (Color online) Mass distribution obtained in $^{19}F + ^{238}U$ reaction at different projectile energies.

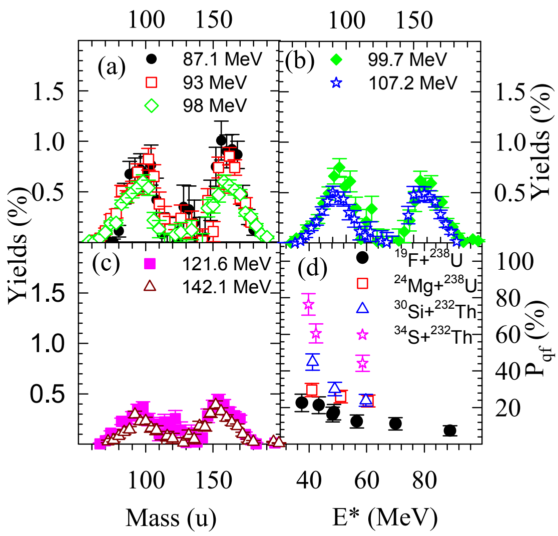

FIG. 2: (Color online) (a-c) FF mass-distributions and (d) probability corresponding to quasi-fission process.

distributions fail to explain the much wider measured data. Thus the above analysis indicates the possibility of having admixture of quasi fission along with the compound nuclear fission.

The mass-distribution for quasi-fission component could be obtained after matching the peak of calculated distributions (blue line in Fig. 1) with the measured data after multiplying (by a factor < 1) and then subtracting it from the measured data. The mass-distributions thus obtained only for quasi-fission process are shown in Fig. 2(a-c) for all the beam energies, where two peaks are observed at mass ratio ∼0.4 and 0.6 irrespective of beam energies, consistent with the literature data. From the area of the above yields, the probabilities of quasi-fission process (P_{qf})have been obtained as a function increasing excitation energy as shown in Fig. 2(d), where P_{qf} is observed to decrease with increasing excitation energy as expected.

Similar analysis have been done for reaction systems whose mass distributions are available in literature [4]. The quasi-fission probabilities for all the above systems show similar trend as shown in Fig. 2(d). Most interestingly, the systematics shows that quasi-fission probability is non-zero even at very high excitation energy (∼ 80MeV).

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