Binary fragmentation study of near super-heavy nucleus ^{256}Rf using mass-angle distribution probe

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Introduction

Over the years, several efforts have been made to investigate the formation of super-heavy elements (SHE) [1]. Such experiments are extremely challenging as the formation of SHE is strongly inhibited by a dynamical non-equilibrium fission process called quasi-fission [2]. The evolution of several degrees of freedom in dynamics of fusion and decay of the super-heavy composite system can be understood by studying the properties of fusion-fission and quasi-fission products. Understanding the competition between quasi-fission and fusion-fission could lead to more reliable predictions to choose the best combinations of projectile and target to form new isotopes of SHE. The identification of quasi-fission events is not trivial, since after the fusion forming a CN, the most probable decay mode is fission. The mass distribution of quasi-fission and fusion-fission generally show a considerable overlap which makes it difficult to unambiguously disentangle these processes. A key quantity characterizing quasi-fission is its timescale (sticking time between capture and breakup). Earlier measurements of mass-angle distribution (MAD) [2, 3] showed that the timescale corresponding to the quasi-fission process is significantly shorter than the typical timescale of the fusion-fission process. Thus, the measurements of MAD offers a key insight into the quasi-fission process. The already existing fusion probability and evaporation residue cross-sections for the near super-heavy nucleus ^{256}Rf encourage us to investigate its reaction dynamics. With this motivation, we have performed the MAD measurements for ^{256}Rf nuclei populated through the reaction ^{48}Ti + ^{208}Pb. The results from MAD have been used to check the presence of quasi-fission processes in such a heavy system and are reported in this paper.

Experimental Setup

The experiment was carried out using a pulsed beam of ^{48}Ti obtained from the 15UD Pelletron + LINAC accelerator facility at Inter University Accelerator Centre (IUAC), New Delhi. ^{48}Ti beam (current = 0.7 pnA and repetition rate = 250 ns) with the laboratory energy of 275 MeV was bombarded on ^{208}Pb target of thickness 251 μg/cm^2 with carbon backing of thickness 20 μg/cm^2. The target ladder was tilted to an angle of 40° with respect to the beam axis in order to minimize the shadowing to position-sensitive multiwire proportional counter (MWPC). For the fission fragment detection, two large area ($5'' \times 3''$) MWPCs were used. MWPCs were kept at a distance of 25 cm from the target on movable arms on either sides of the beam axis at angle of 73° and 54° respectively. The fission fragment detected in any of the MWPCs in

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coincidence with RF is used as a trigger for list mode data collection with LAMPS as the acquisition software.

Data Analysis and Results

Data analysis was performed using the two-body kinematics [4, 5]. For the pulsed beams, the measured positions and times-of-flight information of the fragments allowed direct reconstruction of the fragment velocities [5]. The recoil velocity components of the composite system parallel $V_{\|}$ and perpendicular $V_{\perp}$ to the beam, were determined from the measured folding angle and fragment velocities. Binary fragmentation events originating from full momentum transfer are characterized by $V_{\|} - V_{CN} = 0$ and $V_{\perp} = 0$. Fig. 1 shows the two-dimensional plot of $V_{\|} - V_{CN}$ and $V_{\perp}$ for the ^{48}Ti + ^{208}Pb reaction at an excitation energy of 56.4 MeV.

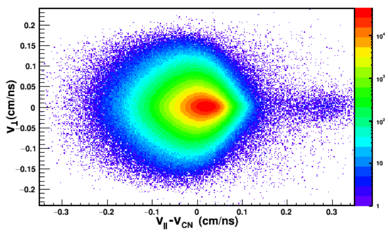

FIG. 1: The scatter plot of $V_{\|} - V_{CN}$ vs. $V_{\perp}$ for the ^{48}Ti + ^{208}Pb reaction at an excitation energy of 56.4 MeV.

Following the iterative correction for energy loss in the target, the mass ratio of all binary events and the centre-of-mass (c.m.) scattering angle $\theta_{c.m.}$ were deduced. The mass ratio is defined as:

$$M_R = \frac{m_1}{m_1 + m_2} = \frac{V_2}{V_1 + V_2},$$

where m_1, m_2 are the two fragment masses and V_1, V_2 are the center-of-mass velocities of the fragments. Since both fragments are detected, MAD is populated twice [4], at (M_R, $\theta_{c.m.}$) and (1 - M_R, π - $\theta_{c.m.}$). The measured MAD for the reaction is shown in the upper panels of Fig. 2. Here, the fission-like events clearly show a correlation of fragment mass with the emission angle, resulting from the short reaction times ($\leq 10^{-20}$s). The shape

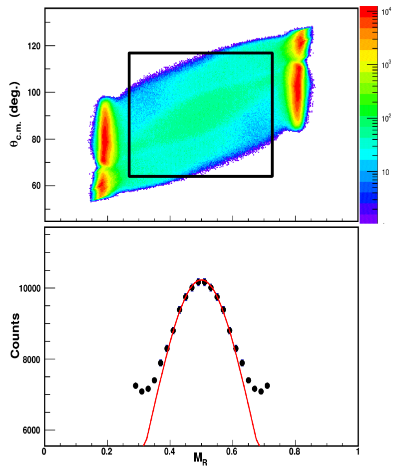

FIG. 2: Measured MAD scatter plot for ^{48}Ti+^{208}Pb reaction (upper panel). Lower panel shows the projected M_R spectrum corresponding to the rectangular gated region where red line represents Gaussian fit to the region around M_R=0.5.

and results of MAD for the present case are consistent with that of the reactions using the ^{48}Ti beam in literature [6]. The lower panel of Fig. 2 indicates the projection of the gated region of MAD (in rectangular gate shown in the upper panel) onto M_R axis. The side shoulders in M_R distribution are attributed to the contribution from asymmetric fission components. The fragment M_R distribution is fitted with the Gaussian function and the extracted width (σ_{M_R}) is 0.15, larger than that for ^{48}Ca+^{208}Pb [6]. This difference in σ_{M_R} may be ascribed due to the influence of entrance channel magicity and charge product effects.

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