α-particle multiplicity spectra in ^{28}Si + ^{209}Bi fission reaction

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Introduction

Despite the substantial advances in the field of nuclear physics, nuclear fission continues to reveal surprising results. Mass distributions, angular distribution, mass-angle correlation, and kinetic energy distributions of fission fragments (FFs), often deviate from the expected decay of an equilibrated compound nucleus in heavy-ion fusion reactions [1]. These deviations exhibit signature of "Non-Equilibrium (NEQ) fission. Over the years, "quasifission", "pre-equilibrium fission" [2] and "slow quasifission" [3] have been associated with NEQ fission. The reaction dynamics for NEQ fission are more complex than those leading to equilibrated compound nuclear fission, and the precise mechanisms for NEQ fission are not fully understood yet. Therefore, it is crucially important to investigate the NEQ fission using different probes.

During heavy-ion induced fission, particle emissions (mainly neutron, proton and α-partilces) occur at various stages: from the fissioning nucleus (pre-scission) and from the accelerated fission fragments (post-scission) [5, 6]. Particle emission during fission provides a decent estimate of fission timescale [2, 4]. In addition to pre- and post- scission emissions, particle emission also takes place near to the scission stage, these are referred as "Near-Scission Emission" (NSE). Theroretical predication shows that among all the particles, neutron emission dominates in near scission stage [7]. However, it has not been possible to disentangle NSE neutrons from emission of other stages. On the other hand, for protons not only the perpendicular ("equatorial emission") but the parallel component ("polar emission") is also well decomposed from integral spectra [6]. However, in the case of α particles parallel component has not been observed yet in any of the heavy-ion induced reaction. A systematic study of near-scission emissions can provide valuable insights about the neck rupture process.

In addition to the near-scission emissions, there is a renewed interest in pre-scission emission. A new signature of non-equilibrium fission has been observed from pre-scission α-particle multiplicity data [5]. The observations reveal that α_{pre} undergoes a transitions from high to a low value as it traverses the Businaro-Gallone point in mass asymmetry in the entrance channels during heavy-ion induced fission of ^{232}Th. A similar discontinuity was previously observed in fission fragment angular anisotropy data [2]. While the measured anisotropies in ^{11}B and ^{12}C induced fission were consistent with the theoretical prediction, the observed anisotropies for ^{16}O and ^{19}F induced fission were significantly larger than expected. The observed similarities between the discontinuities in α_{pre} and angular anisotropies for same set of reactions with comparable energetics point toward a common underlying mechanism leading to non-equilibrium fission.

It is of furthermore interest to investigate aforesaid transition around the BG point in different mass regions. With this motivation, we have chosen ^{209}Bi as the target and measuring charged particle multiplicity spectra with different projectiles. Here we report results on

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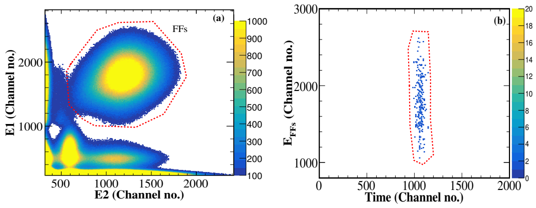

FIG. 1: (a) A two dimensional plot of fission fragments energies from MWPC1 versus MWPC2. (b) The time correlations between fission events and α particles.

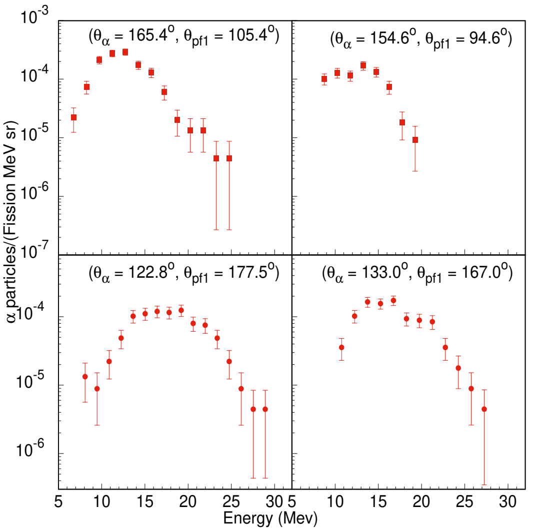

FIG. 2: α-particle multiplicity spectra in ^{28}Si + ^{209}Bi reaction at different laboratory angles.

α particles multiplicity spectra in ^{28}Si+^{209}Bi reaction at a lab energy of 163.7 MeV.

I. EXPERIMENTAL DETAILS AND RESULTS

163.7 MeV ^{28}Si beam was obtained from 14-MV BARC-TIFR Pelletron Linac booster facility, Mumbai. A self-supporting metallic foil of ^{209}Bi ($\sim$ 1.8 mg/cm^2) was used as the target. The compound nucleus, ^{237}Bk was populated to an excitation energy of 51.4 MeV. The FFs from reaction were detected using two large area Multi-Wire Proportional Counters (MWPCs), arranged in folding angle configuration. MWPCs were placed at $\theta_f = 60°$ ($\phi = 0°$) and $\theta_f = 88°$ ($\phi = 180°$) with angular opening of 26.5° and 42.2°, respectively. The charged particles emitted in the reaction were detected with five collimated CsI(Tl)-Si(PIN) detectors. Calibration of all CsI(Tl) detectors was periodically performed throughout the experiment using a ^{229}Th α-source. Zero Crossover Time (ZCT) as well as Ballistic Deficit (BD) technique were employed for the particle identification in CsI(Tl) detectors. Among these five CsI detectors, two were having same angle with respect to the beam direction and scission axis, therfore an average of their energy spectra was obtained. Fission events were clearly separated from other reaction products by plotting cathode pulse height from one MWPC against the other as shown in fig. 1(a). The time correlations between both the MWPCs were recorded by using a time-to-amplitude converter(TAC). A coincidence between the two MWPCs defined the fission-single event. A total of 9×10^6 fission single events were recorded. Time correlations between the charged particle detectors and the fission detectors were obtained using an another time-to-amplitude converter as shwon in fig. 1(b).

The normalized α particles multiplicity spectra were obtained by dividing the coincidence energy spectra with total number of fission single events and solid angle of the CsI(Tl) detectors. Typical multiplicity spectra for α particles are shown in the Fig. 2. The preliminary analysis indicatess contribution from pre-scission as well as post-scission components. Details about the moving source fit to disentangle the contributions in α-particle multiplicity from different stages of the fusion-fission process will be presented.

References

[1] A. N. Andreyev, *et al.*, Rep. Prog. Phys. **81** (2018) 016301.

[2] V. S. Ramamurthy, *et al.*, Phys. Rev. Lett. **65** (1990) 25.

[3] T. Banerjee, *et al.*, Phys. Rev. C **102** (2020) 024603.

[4] D. J. Hinde, *et al.*, Phys. Rev. C **39**, 2268(1989).

[5] Y. K. Gupta, *et al.*, Phys. Lett. B .**Vol. 834** (2022).

[6] Pawan Singh, *et al.*, Phys. Lett. B **858** (2024) 139014.

[7] N. Carjan, *et al.*, Phys. Lett. B, **747** 2015