ER-gated spin distribution measurement for ^{19}F+^{197}Au

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Study of heavy ion fusion reactions provides valuable insights into the dynamics of a fused compound nucleus (CN). Detection of an evaporation residue (ER) serves as a direct evidence of CN formation and the spin distribution reveals information about the angular momenta that survive both compound and non-compound nuclear fission [1]. Notably, the partial wave distribution is more sensitive to the finer details of theoretical models than the cross section, making the spin distribution a crucial tool for testing and refining fusion theories. Despite its importance, detailed studies on ER spin distribution for heavy CN are quite limited.

Berriman *et al.* [2] measured ER cross sections and fission fragment (FF) mass distributions for three reactions, *viz.*, ^{12}C+^{204}Pb, ^{19}F+^{197}Au and ^{30}Si+^{186}W, all forming the same compound nucleus ^{216}Ra*. The authors of this work observed signatures of quasifission in the two reactions induced by heavier projectiles. However, a study of FF angular distribution by Tripathi *et al.* [3] found no evidence of quasifission in ^{19}F+^{197}Au, revealing a striking discrepancy between the two investigations. To probe this inconsistency further, we carried out ER-gated spin distribution measurements for ^{19}F+^{197}Au.

The experiment was performed using the HYbrid Recoil mass Analyzer (HYRA) [4] at IUAC, New Delhi. The HYRA, coupled with the TIFR 4π spin spectrometer [5], was operated in gas-filled mode. A pulsed ^{19}F beam, with a pulse separation of 2 μs, was obtained from the 15UD Pelletron and bombarded on a ^{197}Au (250 μg/cm^2) target. Measurements were carried out at beam energies ($E_{\rm lab}$) ranging from 90 to 115 MeV. ERs produced in the reaction were separated from the background by the HYRA and detected by a multiwire proportional counter (MWPC) placed at the HYRA focal plane. Fig. 1 shows a two-dimensional spectrum of well-separated ERs.

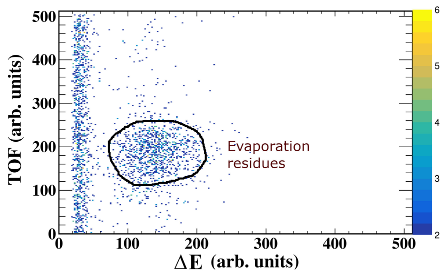

FIG. 1: ERs, produced in the reaction ^{19}F+^{197}Au at $E_{\rm lab} = 110$ MeV, identified by energy loss (ΔE) in the MWPC and the time-of-flight (TOF).

The TIFR 4π spin spectrometer, consisting of 32 NaI(Tl) scintillation detectors arranged in a soccer-ball configuration around the HYRA target chamber, was employed to measure the fold distribution of low-energy non-statistical γ-rays emitted from the decay cascade of the ERs, allowing the determination of angular momentum distribution. Raw γ-fold distributions were recorded at each $E_{\rm lab}$. To extract the true ER γ-fold distribution, the raw spectra were gated with the

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ERs detected at the focal plane. Raw and ER-gated γ-fold distributions at $E_{\rm lab} = 110$ MeV are shown in Fig. 2.

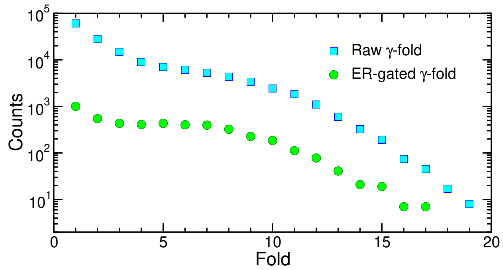

FIG. 2: Measured γ-fold distributions (ungated and ER-gated) for ^{19}F+^{197}Au at $E_{\rm lab} = 110$ MeV.

The γ-multiplicity distribution was derived from the ER-gated γ-fold distribution using the following equation

$$P(F) = \sum_{M=0}^{M_{\rm max}} S(F,M)P(M), \qquad (1)$$

where $P(F)$ represents the γ-fold distribution, $S(F,M)$ is the response matrix of the detector array and $P(M)$ is the γ-multiplicity distribution. The response matrix of the spin spectrometer was obtained using a recursive algorithm [6].

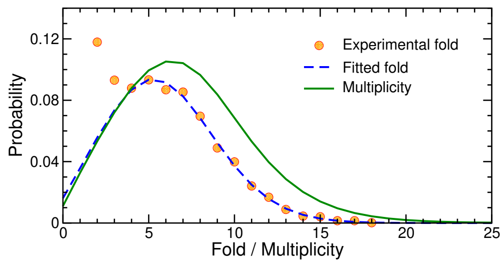

FIG. 3: Experimental γ-fold and γ-multiplicity distributions for ^{19}F+^{197}Au at $E_{\rm lab} = 110$ MeV.

For constructing the multiplicity distribution, we assumed a function $P(M)$ of the form

$$P(M) = \frac{2M+1}{1+\exp(\frac{M-M_0}{\Delta M})}, \qquad (2)$$

with two free parameters M_0 and ΔM. Using Eq. 2, $P(F)$ was calculated based on Eq. 1 and the experimental γ-fold distribution was compared with the calculated values. The parameters M_0 and ΔM were varied to achieve the best fit of the experimental γ-fold distribution. Fig. 3 shows both the experimental and best-fitted γ-fold distributions, as well as the derived γ-multiplicity distribution at $E_{\rm lab} = 110$ MeV.

To obtain the spin distribution, one can construct a more generalized relation between the mean γ-multiplicity $\langle M_\gamma \rangle$ and the mean angular momentum $\langle \ell_{\rm CN} \rangle$ [7], based on the decay pattern of the CN, of the form

$$\langle \ell_{\rm CN} \rangle = \Delta I_{\rm ns} \left(\langle M_\gamma \rangle - M_{\gamma s} \right) + \sum_i \Delta I_i M_i + I_0, \qquad (3)$$

with i = γs, n, p, α. Here, $\Delta I_{\rm ns}$ is the average spin carried away by the non-statistical γ-rays, ΔI_i are the spins carried away by statistical γ-rays (γs), neutrons (n), protons (p) and α-particles (α) and M_i are the corresponding multiplicities. I_0 denotes the ground-state spin of the CN.

Dynamical model calculations will complement the experimental efforts to understand the intricate reaction dynamics. Further analysis and theoretical study are underway.

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