Study of Pairing Re-entrance Phenomenon in ^{72}Ge

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Introduction

Pairing correlations play a critical role in understanding nuclear structure and reaction dynamics at low energy. These correlations are significantly influenced by both the temperature (T) and angular momentum (J). As the T of a nucleus increases, thermal excitations provide sufficient energy to break nucleon pairs near the Fermi surface, which are responsible for the pairing interaction. These unpaired nucleons then scatter into nearby single-particle states, effectively blocking those levels as a result of the Pauli exclusion principle. At critical temperature (T_c), the pairing correlations vanish. Similarly, when the rotation of the warm nucleus increases, the pairing correlations gradually decreases and vanish at the critical angular momentum (J_c), due to the Coriolis force resisting the nuclear rotation.

Interestingly, when the effects of both T and J are combined in a warm or hot rotating nucleus, an anomalous pairing or thermally assisted pairing correlation has been observed. This is also known as the *pairing reentrance phenomenon* . This anomalous behavior in finite atomic nuclei could be understood through the extension of the Bardeen-Cooper-Schrieffer theory to finite temperature and angular momentum (FTBCS) [1, 2] and Shell Model Monte Carlo (SMMC) Calculations. The reentrance of pairing correlations manifests itself through the anomalous behavior of specific heat and level density [3]. The

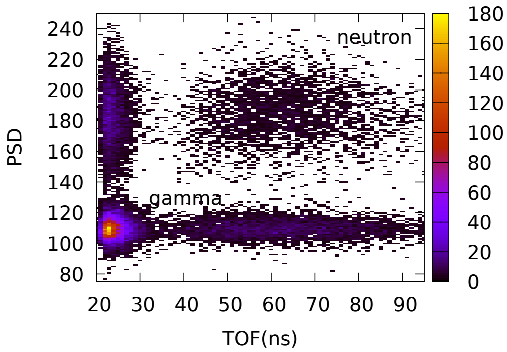

FIG. 1: Two-dimensional plot of PSD vs. TOF, showing the separation of gamma and neutron events for single beam bunch.

pairing re-entrance phenomenon has been predicted in several nuclei for N=40 isotones such as ^{72}Ge, ^{68}Ni,^{70}Zn,^{80}Zr [4] . In the nucleus ^{72}Ge [3], calculations using the shell-model Monte Carlo method revealed a distinct signature of pairing re-entrance, marked by irregularities in the heat capacity and level density at specific temperatures and rotational frequencies. In the measured angular momentum and excitation energy dependent nuclear level density obtained from the proton evaporation spectrum from ^{104}Pd [5] shows anomalous behaviour. This observation was qualitatively explained using FTBCS formalism, which is the first experimental evidence of pairing re-entrance, showing enhanced level density at low excitation energies and high angular momenta. The motivation of the present work is to study the excitation energy (temperature) and angular momentum dependence of nuclear level density in Ge isotopes to investigate pairing re-entrance phenomenon.

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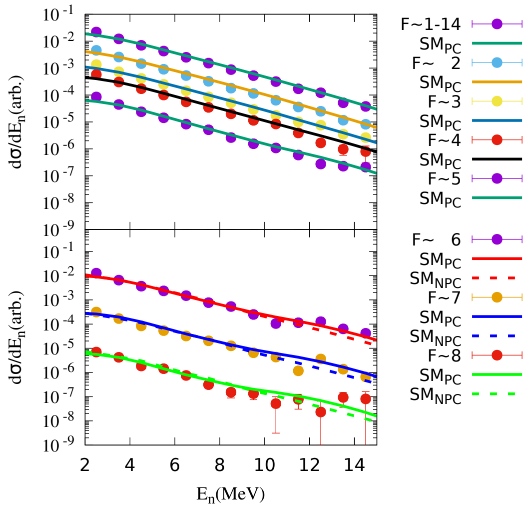

FIG. 2: Measured various fold (related to J) gated neutron spectra with a statistical model calculation using the level density parameter $a = A/8.5$ MeV^{-1}. The solid line shows the calculation with pairing correlation ($\mathrm{SM_{PC}}$), and the dashed line shows the calculation without pairing correlation ($\mathrm{SM_{NPC}}$).

Experimental Details

An experiment was carried out at the BARC-TIFR Pelletron Linac Facility to investigate the pairing re-entrance phenomenon by using a ^{9}Be pulsed beam with an energy of 28 MeV, bombarding self-supported ^{64}Ni targets (2 mg/cm^2) to populate ^{73}Ge compound nuclei. The experimental setup included a 38-element BGO detector array for measuring gamma-ray multiplicity (fold distribution) and 15 liquid scintillation detectors for neutron measurement using the time-of-flight (TOF) technique. The details of the experimental set-up with preliminary analysis can be found in [6].The pulse shape discrimination (PSD) as a function of time of flight (TOF) in the ^{9}Be+^{64}Ni reaction is shown in Fig 1 in which neutrons are clearly separated from the prompt γ rays.

Result and Discussion

The TOF spectra obtained from the LS detectors were transformed into neutron energy spectra using appropriate Jacobian transformations and energy & threshold dependent neutron detection efficiency. The upper panel of Fig. 2 presents the measured fold gated neutron evaporation spectrum with a statistical model calculation using the level density parameter $a = A/8.5$ MeV^{-1} for the folds 1-14, 2,3,4 while the lower panel displays that of the folds 6,7,8. The solid line shows the calculation with pairing correlation ($\mathrm{SM_{PC}}$), and the dashed line shows the calculation without pairing correlation ($\mathrm{SM_{NPC}}$).

The experimental data reveal no significant deviation in the inclusive spectra. However, a small deviations is observed starting from a neutron energy of 10.5 MeV when compared to predictions from the conventional statistical model calculations in the fold-gated (related with J) neutron evaporation spectra for folds 6, 7, and 8. This deviation occurs at a temperature $T \sim 1.55 \pm 0.05\ MeV$(for $E_n \sim 10.5 - 14$ MeV) and high angular momenta $J \sim 14 \pm 2\ \hbar$ estimated from the excitation energy and fold distribution respectively. These deviations reasonably explained invoking the combined effect of J and T dependent nuclear level density and enhancement due to pairing correlation as reported in [5]. These results indicated a weak signature of pairing re-entrance phenomenon in ^{72}Ge at such high T which corroborates with theoretical predictions from the FTBCS with quasi-particle fluctuations. This understanding throws light on the intricate interplay of temperature and angular momentum on pairing correlations for many body finite quantum systems.

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