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

Manoj Meher,[1] P.C Rout,[1,*] and S. Santra et.al.[1]
[1] *Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA*
(Dated: March 26, 2024)

In this BTR, we propose to carry out an experiment to measure the angular momentum gated proton spectra from ^{73}As*(^{18}O+ ^{55}Mn system). The main objective of this experiment is to study the pairing re-entrance phenomenon in ^{72}Ge. In earlier investigations on pairing reentrance phenomena, angular momentum dependent nuclear level density obtained from the measured proton evaporation spectra in ^{12}C+ ^{93}Nb →105Ag* → 104Pd* + p reaction at the incident energy of 40–50 MeV shows an unusual bump in level density in the nucleus ^{104}Pd at low excitation energy (temperature) and high angular momentum. This observation was described as pairing re-entrance phenomenon and explained within the framework of the finite temperature BCS(FTBCS) theory. The Shell Model Monte Carlo (SMMC) calculations for ^{72}Ge has also predicted similar features at low temperature (T) and high angular momentum (J). A seven days of beam time is requested to complete the measurement with a meaningful statistics.

1. Introduction

The re-entrance phenomenon is a unique behavior observed in various physical systems, including nuclear physics, superconductors, and soft matter. It is characterized by the reappearance of a phase or property that was previously suppressed or absent. In the context of nuclear physics, the re-entrance phenomenon is associated with pairing correlations in heated rotating nuclei, where the pairing correlations are predicted to reappear at high rotational frequencies. The re-entrance effect is characterized by anomalous behavior in specific heat and level density [1] as shown in Fig. 1. The figure shows a local dip in the heat capacity at a rotational frequency of 0.5 MeV and temperature T ≈ 0.45MeV , and a local maximum on the temperature dependence of the logarithm of level density is observed at the same rotational frequency and temperature . These irregularities in the heat capacity and level density are associated with the signatures of the pairing re-entrance.

Pairing re-entrance in nuclear physics is significant, as it influences various aspects of nuclear behavior. This phenomenon modifies proton single-particle energies around the Fermi level, affecting occupation numbers and level density [2]. In odd nuclei, pairing re-entrance is observed, particularly in nuclei with an odd number of protons and/or neutrons, potentially due to specific structural characteristics [3]. Additionally, the occurrence of pairing re-entrance introduces changes in proton entropy excess, providing a distinctive signature of this phenomenon in finite nuclei [4].

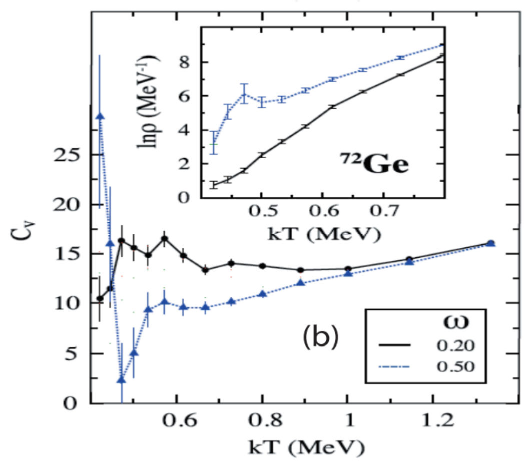

FIG. 1: SMMC for ^{72}Ge at different angular momentum.The inset shows the calculated logarithm of total level density. Taken from [1].

2. Earlier investigations on pairing re-entrance in A∼70 region

An experiments was carried out for the reaction ^{9}Be + ^{64}Ni →^{73}Ge*→ ^{72}Ge* + n at the incident energy of 28 MeV. The neutrons were measured in coincidence with the BGO multiplicity array. A 38 elements BGO multiplicity detector array arranged in two close-packed groups of 19, were used to measure the angular momentum populated in the compound nucleus while an array of 15 Liquid Scintillation(LS) detectors were used to measure neutron by time of flight techniques. The neutron evaporation spectrum deduced from the measured TOF spectrum at different folds is shown in Fig. 2. It has been found that no structure in the high energy part of fold gated neutron spectrum was observed in ^{72}Ge. The temperature of the excited ^{72}Ge populated at the temperature T≈2.2 MeV and angular momentum $J \approx 15\hbar$. At this temperature, the pairing correlation is washed out, and thus no effect has been observed in the fold-gated neutron spectrum. The results of preliminary analysis of the ^{9}Be + ^{64}Ni system were reported in DAE SNP-2023 [5]. To study such a phenomenon, we would like to populate the ^{72}Ge at low temperature where such effects are pronounced.

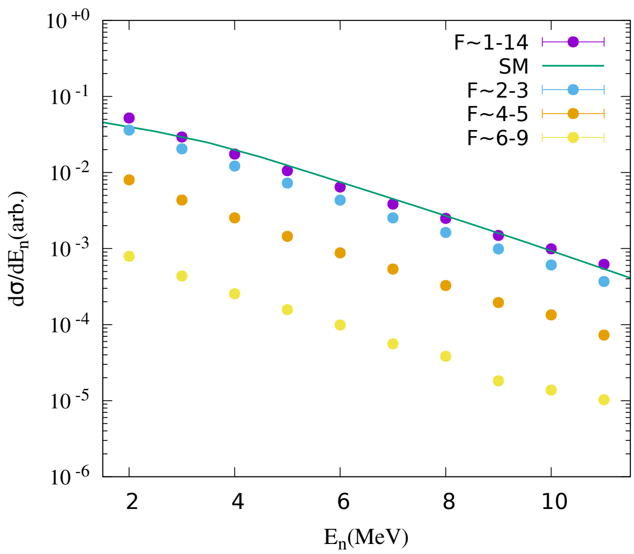

FIG. 2: Measured neutron spectra for different folds for ^{9}Be+^{64}Ni system populating the residual ^{72}Ge. The line shows the statistical model(SM) calculation and comparison with for inclusive spectra (summed over all folds)

3. Experimental Details

It is proposed to use ^{18}O beam of 35 to 45 MeV on the ^{55}Mn targets to populate the residual nucleus ^{72}Ge nuclei after proton evaporation. The self supported ^{55}Mn targets of typical thickness of 0.5 mg/cm^2 will be used for this experiment. The protons will be measured in coincidence with the BGO multiplicity array. The details of the detector set-up are describe as follows:

CsI(Tl) Detector Array: An array of eight CsI(Tl) scintillators(the active area of the CsI(Tl) is 25×25 mm^2 and the thickness is 10 mm), each coupled to a Si(PIN) photodiode will be used for the measurement of protons from 1.0 MeV to 20 MeV. These detectors will be grouped into two arrays, each consisting of four detectors, and the energy of protons will be measured by pulse height analysis and identified by pulse shape discrimination. Alternatively, two hybrid telescopes with Si-Strip as ΔE and an array of four CsI(Tl) as E will be used for particle identification by Bethe's energy loss technique.

BGO Multiplicity Array: A 14 elements BGO multiplicity detector array arranged in two close-packed groups of 7, will be used to measure the angular momentum populated in the compound nucleus. Each detector is 6.3 cm thick and had a regular hexagonal cross section with a distance of 5.6 cm between two opposite edges. The two groups are placed at a distance of ∼7cm on either side of the target.

4. Count rate and beam time requirement

The count rate of proton produced in the ^{18}O+^{55}Mn system at 43 MeV beam, assuming the 1 pnA beam current, is 0.5 counts/min. The expected proton count rate would be 38000 counts for 6 days assuming the efficiency of 8% for the CsI(Tl) detector array and 60% efficiency of the BGO multiplicity array and cross section at 19 MeV proton is about 50ub. The meaningful counts at fold gated proton at 19.5 MeV is 2700 per fold and higher fold the counts are still less. Thus about 6 days of data taking is required for a meaningful statistics and 1 day for electronic setup with beam required. Therefore, we request 7 days of beam time for the study of pairing reentrance in ^{72}Ge.

---

* Electronic address: prout@barc.gov.in

[1] Dean, D.J., Langanke, K., Nam, H., and Nazarewicz, W. 2010 Phys. Rev. Lett. 105 212504
[2] Mohamed Belabbas et. al. PHYSICAL REVIEW C 96, 024304 (2017)
[3] T. Vu Dong et al. PHYSICAL REVIEW C 107, 064319 (2023)
[4] Balaram Dey et al. Physics Letters B 819 (2021) 136445
[5] Manoj Meher et al., DAE Symp.Nucl.Phys. 67 (2024) 57