BARC–TIFR Pelletron Linac Facility Beam Time Request @2024

Title of the Experiment: Investigation of the E(5) critical point symmetry in 74Se

Principle Investigator: ***Dr. Sajad Ali***

Local Collaborator / Spokesperson: *Prof. R. Palit*
Note: Local collaborator is mandatory for non BARC (NPD) / TIFR (DNAP) user

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11. Mr. Vishal Malik, TIFR, Mumbai
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13. Dr. Ananya Kundu, TIFR, Mumbai
14. Mr. A. Sindhu, TIFR, Mumbai
15. Mr. Shouvik Pal, TIFR, Mumbai

Motivation of the experiment:

Beam details: Beam spices, Beam energy in (MeV), Beam current in (pnA), Beam Port.:
7Li, 35MeV, 2-3pnA, Beam Hall 2, 15D

Buncher requirement: ~~Yes~~/ No

Number of shifts (1 shifts=8 hr.) required:

Experimentdetails:

Objective of Experiment:

Phase transitions in the different state of matter have become one of the most spectacular subjects that have been investigated over years in any branch of Physics. Like other physical systems, atomic nuclei are also expected to exhibit the phase transitions. The phase transition in nuclear system has been well described using quantum mechanics within the IBM calculations. Two distinct critical phase transitional points have been identified in the pathway of the spherical to deformed one. One critical point is situated in between the spherical and the gamma vibrational limit that has been termed as E(5) symmetry breaking. Other one fall in the path of gamma vibration to deformed system and that has been described as X(5) critical point [1-3]. Recently, several experimental and theoretical investigations have been performed to reveal the X(5) and E(5) critical point nuclei all over the nuclear chart. Indeed, the experimental evidences in ^{152}Sm, ^{150}Nd and ^{154}Gd nuclei strongly support their X(5) behaviour [4 – 7] whereas E(5) critical point has been identified in ^{134}Ba and ^{128}Xe only, until today [8 – 11]. Therefore, more investigations are required to reveal the complete intrinsic characteristic of such a critical point nuclear system. Recently we have also established a Experimental evidence of exact E(5) symmetry in ^{82}Kr [14]. Using our experimental data, theoretically by the Vibron model **Yu Zhang *et. al.*** has shown that the low-lying structure of ^{82}Kr can serve as an excellent empirical realization of the E(5) Dynamical Symmetry, which provides a specific example of the Euclidean DS in experiments [15]. This prompts our motivation of examining the critical point nuclei throughout the nuclear chart to get complete picture of the phase transitional behavior.

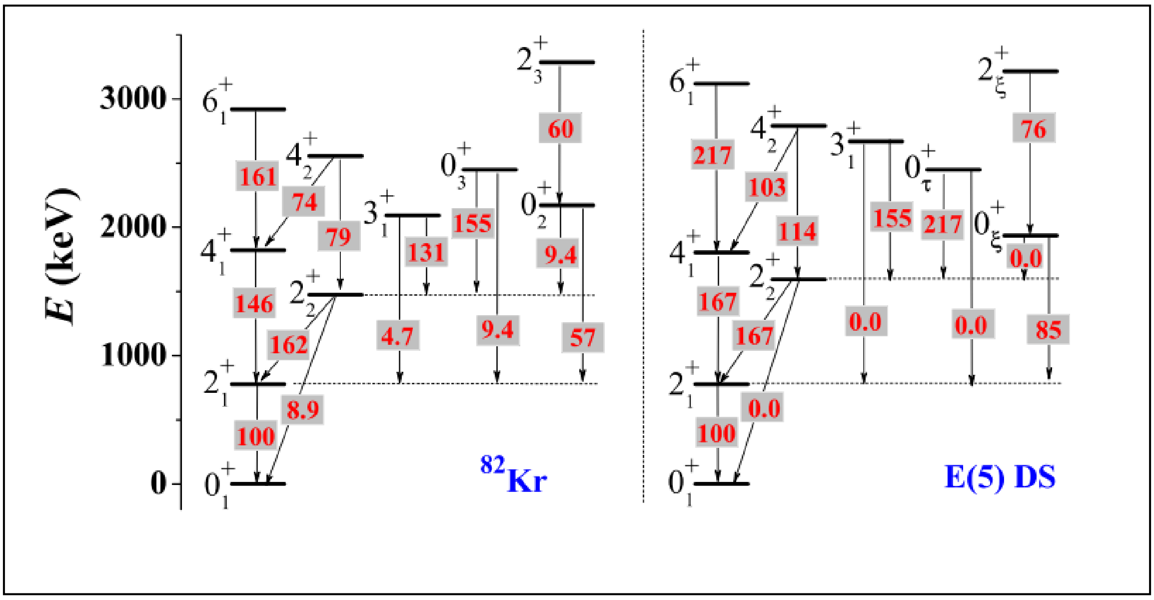
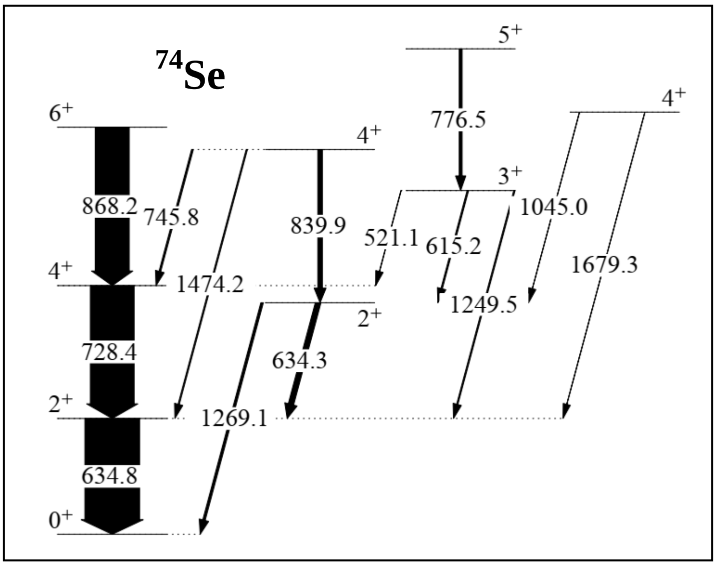


Fig 1. The low-lying structure of ^{82}Kr. The experimentally obtained states [13] compare with the results solved from the E(5) Hamiltonian [14].

The present experimental proposal focuses to investigated the E(5) critical point symmetry in ^{74}Se nucleus [16]. The experimental $R_{4/2}$ = 2.15 for ^{74}Se which are close to the predicted value of 2.20 [11]. The previous measurement on this nucleus extracted the B(E2) transition rates of the ground state band up to the 6^+ state and within the error bars transition strength are in well agreement with the E(5) prediction [11]. The low lying structure of these nucleus has very similar to the established E(5) nucleus ^{82}Kr. These signatures predicted that ^{74}Se would be the next candidates of the island of E(5) limit, more specially, exploring a new mass region in the periodic table.

Fig 2. The low-lying structure of ^{74}Se. representing the E(5) symmetry braking phenomena. The data were taken from the reference [16].



References:

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[4] R. Krcken *et al.*, Phys. Rev. Lett. 88 232501 (2002).
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[13] L. Funke *et al.*, Nucl. Phys. A 455 206 (1986).
[14] S. Rajbanshi *et. al.*, Phys. Rev. C 104, L031302 (2021).
[15] Yu Zhang *et. al.*, Symmetry 14, 2219 (2022).
[16] R. B. Piercey, *et. al.*, Phys. Rev Lett 37, 9 (1976).

Description of Experiment:

The ^{74}Se nucleus will be populated through the fusion evaporation reaction of ^{7}Li at energy 35 MeV with the ^{70}Ge as target. The PACE4 calculation shows that this stable target and projectile combination produces the ^{74}Se with large cross-section ~ 600 mb, demanding almost 45% of the total fusion cross-section (Fig. 3). Such a large cross section will be useful to determine the non-yrast states which are utmost important to establish the E(5) behavior. The residual nuclei populated in this reaction have velocity almost 1% of c. This ensures the applicability of the Doppler shift attenuation method to determine the sub picosecond level lifetimes for the structure of interest. To extract the level lifetime from DSAM we have to use a backed target.

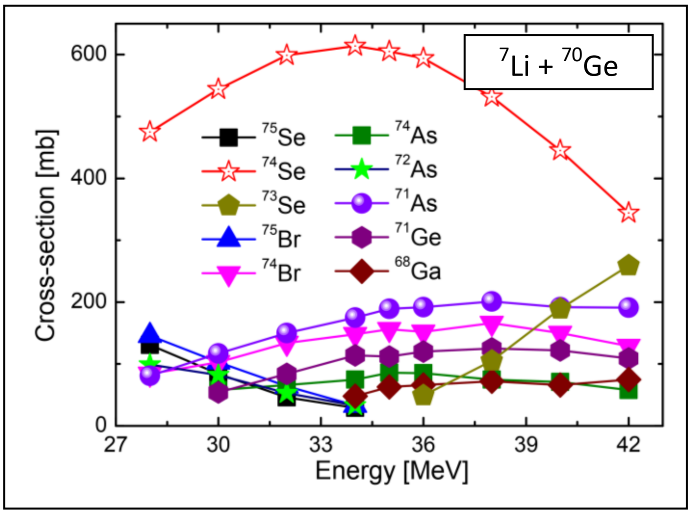

Fig. 3. The PACE4 predicted cross-section of the nuclei produce in the fusion reaction of ^{7}Li beam on ^{70}Ge energies.

The planning of experimental needs is given in Table:

Characteristic	**Desired quantities/Description**
Nucleus of Interest	**^{74}Se**
Projectile	^{7}Li
Energy range	33-36 MeV
Beam Current	1-2 pnA
Target	^{70}Ge of Tantalum Backing
Target Thickness	0.5 mg/cm^{2}
Backing Material	Natural Tantalum
Backing Thickness	7.5 mg/cm^{2}
Coulomb Barrier of the ^{7}Li and with targets	13.6 MeV
Energy loss of ^{7}Li (@ 35 MeV) inside target and projected range	400 keV/(mg/cm^{2}) & 103.7 µm
Velocity of the compound nucleus (^{77}Br)	~ 1% of c
Compound nucleus recoil energy (MeV)	3.2 MeV

Energy loss of compound nucleus inside target	4.5 MeV/(mg/cm^2)@ 3.2 MeV
Energy loss of compound nucleus inside backing	2.2 MeV/(mg/cm^2)@ 3.2 MeV
Cross section of the ^{74}Se nucleus	600 mb (45%) of total 1336 mb [@ 35 MeV]
Beam time Required	15 Shift

Calculation for number of Shift:

M = Number of photons emitted per event ~ 20

($\Omega/4\pi$) = Solid angle coverage by a Clover = $0.12/4\pi$ (Clover rad = 46mm, detector dis. = 25cm)

ε_{int} = Intrinsic γ detection efficiency of a Clover = $\varepsilon_{abs}(4\pi/\Omega)$ ~ 1.2x 10^{-3} x 1.3 x 4π / 0.12 ~ 0.16

(Assuming Clover Addback efficiency ~ 130%)

N_r = Number of residual nuclei produced per Sec. = $\sigma N_B N_T$

Where: N_B = No. of Beam incident per sec. = 2 pnA/e x 10^9 = 1.25 x 10^{10}

N_T = No. density of target nuclei per volume x thickness of the target = N x t

Where N = N_A x ρ/M = 6.023 x 10^{23} x 5.327/70 per cm^3 = 4.58 x 10^{28} /m^3, (ρ = 5.327 gm/cm^3)

$$t = \frac{0.5\ in\ mg/cm^2}{5.327\ in\ g/cm^3} = \frac{0.5\times10^{-3}}{5.327}\ in\ cm = 9.39\ \times 10^{-7}\ \ in\ m$$

N_T = N x t = 4.58 x 10^{28} x 9.39 $\times 10^{-7}$ *per* m^2 = 4.3 x 10^{22} *per* m^2

N_r = 600 x 10^{-31} x 1.25 x 10^{10} x 4.3 x 10^{22} = 3.23 x 10^4 /sec

2- fold coincidence rate for 2 Clover: $N_{12} = M(M-1)\, N_r\, (\Omega/4\pi)^2\, \varepsilon_{int}^2$

= 20 x 19 x 3.23 x 10^4 x (0.12/4π)^2 x (0.16)^2

~ 29 /sec

For 16 Clover array = 8 x 29 /sec = 232 /sec

So in 15 shift (5 days) 2 fold events acquired = 232 x 3600 x 15 x 8 = 1.0 x 10^8 events.

Details of paper published based on experiments at PLF since 2021:

1. S. Rajbanshi et al., Physical Review C (Letter) 104, L031302 (2021).

2. S. Rajbanshi et al., Physical Review C 104, 064316 (2021).

3. Rajkumar Santra et al., Physical Review C 107, 064611 (2023); DOI: 10.1103/PhysRevC.107.064611