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Shape evolution and collectivity beyond ^{78}Ni: Low-lying states in neutron-rich ^{82}Zn

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Abstract. An in-beam γ-spectroscopy study on neutron-rich ^{82}Zn was conducted at RIKEN Nishina Center during the HiCARI-2020 campaign. The secondary beam, ^{83}Ga produced by the abrasion-fission reaction, impinged on a 6-mm Be reaction target at the F8 focal plane. The one proton knock-out channel was selected by ZeroDegree in combination with the BigRIPS Spectrometer. The deexcited γ rays from the low-lying states in ^{82}Zn were measured for the first time with high resolution high-purity germanium detectors array. The lifetime and precise energy measurements were performed on the first 2^+ and 4^+ states.

1 Introduction

The atomic nucleus is a quantum many-body system, consisting of many protons and neutrons. The interplay between the single-particle and the many-body system can lead to the emergence of collective motion. It has turned out that the multipole particle-hole excitation across the closed shell can give rise to the low-lying collective structure. Recently, the doubly magic nature in ^{78}Ni has been evidenced by the large excitation energy of the first 2^+ state [1]. The second 2^+ state was predicted to be prolate by the large-scale shell mode (LSSM) and Monte Carlo shell model (MCSM), where the multipole particle-hole excitation across the closed shell plays an important role. In the neighbouring ^{79}Zn, a low-lying isomer was discovered using the ^{78}Zn$(d,p)^{79}$Zn transfer reaction at REX-ISOLDE, CERN [2] which is assigned to be $1/2^+$ based on the proton angular distribution [2] and magnetic moment [3] and originates from the $1p$-$2h$ excitation.

In a recent lifetime measurement study, a shape transition from soft triaxial (Z = 34) to prolate (Z = 32) deformation was suggested in the N = 52 isotones [4]. The systematics of the reduced transition rate $B(E2)$ are shown in Fig. 1. The $B(E2;2_1^+\longrightarrow 0_{gs}^+)$ values increase monotonically from the N = 40 neutron sub-shell closure to N = 32, shedding light on the predicted "fifth island of inversion" for much lighter (Z < 28) systems [5]. However, several theoretical models predicted a maximum of $B(E2;2_1^+\longrightarrow 0_{gs}^+)$ around Z = 32 and a sudden drop when moving towards Z = 28 [4], which was understood as due to the pseudospin symmetry. A similar trend could also be found from the systematics of $B(E2;4_1^+\longrightarrow 2_1^+)$, as shown in Fig 1(b), with smaller values by comparing with the corresponding $B(E2;2_1^+\longrightarrow 0_{gs}^+)$. The smaller $B(E2;4_1^+\longrightarrow 2_1^+)$ in ^{90}Sr$_{52}$ was explained by the effect of the $d_{5/2}$ neutron subshell closure at N = 56 [6]. A comprehensive understanding of the overall smaller $B(E2)$ value is essential. The experimental $B(E2)$ values below Z = 32 are still unknown.

The N = 50 magicity was confirmed in the neutron-rich Zn isotopes with the help of the energy systematics of the first 2^+ and 4^+ states and the $R_{4/2}$ ratio [7]. When moving toward the heavier Zn isotopes, an onset of deformation was suggested by the newly observed 2_1^+ and 4_1^+ levels in ^{84}Zn [7] consistent with the Ni78-II and

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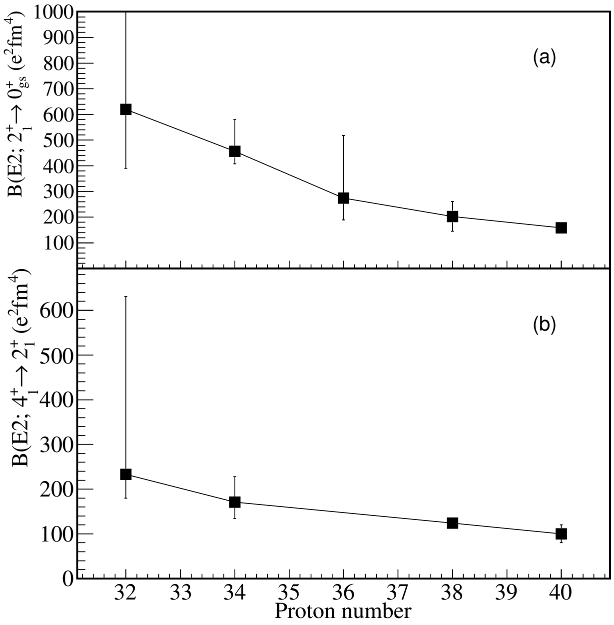

Figure 1: Systematics of the reduced transition rate, $B(E2;2_1^+ \longrightarrow 0_{gs}^+)$(a) and $B(E2;4_1^+ \longrightarrow 2_1^+)$(b) for the $N = 52$ isotone chain. Data are taken from [4, 8].

PFSDG-U shell model calculations by involving the upper *sdg* orbitals. The evolution of the collectivity could also be examined by the systematics of $B(E2)$ values. The $B(E2;2_1^+ \longrightarrow 0_{gs}^+)$ and $B(E2;4_1^+ \longrightarrow 2_1^+)$ in even-even Zn isotopes up to ^{80}Zn have been measured using different methods, such as the direct lifetime measurements and Coulomb excitation [8–10]. Overall agreement was obtained between the $B(E2;2_1^+ \longrightarrow 0_{gs}^+)$ values measured by using different methods while a visible discrepancy could be found between the $B(E2;4_1^+ \longrightarrow 2_1^+)$ values in the same nuclide. A steep increase of $B(E2;2_1^+ \longrightarrow 0_{gs}^+)$ was observed around N = 42 [9, 10]. When moving towards the neutron magic number, the $B(E2)$ decreases corresponding to the existence of N = 50 magicity. The lifetime of 2_1^+ and 4_1^+ states is still unknown for heavier Zn isotopes. So the lifetime measurement of those states is essential to further understand the evolution of collectivity beyond N = 50. Triaxial deformation is also found in neutron-rich Zn isotopes around N = 42. In a recent Coulex measurement, ^{72}Zn was reported to have triaxial deformation by considering the R_{22} value and measured quadrupole moment [10], which is in good agreement with the shell model and beyond mean-field calculations. Similar structures were also observed in ^{74}Zn [11]. No evidence of triaxial deformation is reported now beyond N = 50.

The experimental information of ^{82}Zn, with two neutrons beyond N = 50, is still very scarce. The first gamma-ray spectroscopy study was performed at RIKEN with DALI2 [12]. Because of the low statistic, only one peak was identified which was assigned to be the transition de-exciting the 2_1^+ state. A follow-up $(p, 2p)$ experiment was also performed at RIKEN with MINOS and DALI2 [7]. Much higher statistic was obtained and two new levels were identified associated with 2_1^+ and 4_1^+. Because of the poor energy resolution of the NaI detector, two peaks around 600 keV which could not be separated well, were identified with the help of GEANT4 Monte Carlo simulation. Precise energy measurement of those two levels is essential for the discussion of collectivity evolution beyond N = 50.

2 Experimental setup

To further investigate the collectivity in ^{82}Zn, a new experiment was performed at the Radioactive Isotope Beam Factory (RIBF), operated jointly by the RIKEN Nishina Center and the Center for Nuclear Study of the University of Tokyo, within the HiCARI-2020 campaign. A 345 MeV/u ^{238}U primary beam with an intensity of 60 pnA impinged on a 5 mm Be primary target at the entrance of the BigRIPS separator [13]. The ions of interest were later separated and identified by BigRIPS using the ΔE-$B\rho$-TOF technique [14] and transported to the F8 focal plane. Here the secondary beams were incident on a 6-mm thick Be secondary target surrounded by a new segmented HPGe detector array HiCARI, consisting of 6 segmented MINIBALL triple clusters, 4 Clover four-crystal detectors and two GRETINA-type tracking detectors [15]. HiCARI was mounted at the forward angle relative to the outgoing beam direction with MINIBALL detectors covering from 20° to 50° and the other detectors covering 60° to 90°. Because of the highly segmented feature and excellent intrinsic energy resolution, the total energy resolution of HiCARI is much better than the scintillation detectors based DALI2, which allows us to perform precise energy measurements. Following the F8 focal plane, reaction products were identified within the ZeroDegree spectrometer [13]. The Doppler correction of measured γ rays was done by HiCARI together with the reconstructed reaction vertex information obtained from the downstream Parallel Plate Avalanche Counters (PPAC) at F8 behind the secondary target. Since a passive target was used in this experiment, the velocity at the reaction point was deduced by using the velocity before and after the target measured by downstream plastic detectors at F8 and F9 with empty and physical target, respectively. The mid-target velocity with v/c $\sim$ 0.60 was determined on an event-by-event basis and used for the Doppler correction. The lifetime will be determined by fitting the least χ^2 between the experimental and simulated γ-ray lineshape using the GEANT4 toolkit.

3 Preliminary Result

Some preliminary results are shown in Fig 2. In the current analysis, only data from the MINIBALL and Clover detectors are included. The doppler-corrected γ spectrum for ^{82}Zn was deduced by selecting one proton knock-out channel from ^{83}Ga secondary beam. Much higher statistic was obtained than in the previous DALI2 experiment. The two peaks around 600 keV, associated with γ-ray transition from 2_1^+ to g.s. and 4_1^+ from to 2_1^+ states, respectively, are well separated and identified without any doubt, which

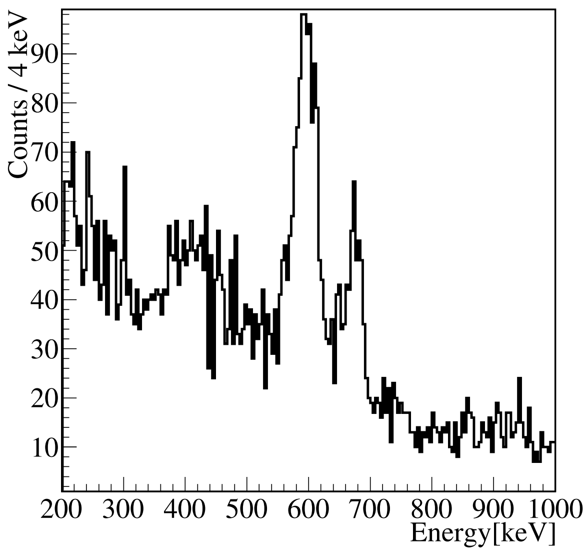

Figure 2: Doppler-shift-corrected γ-ray energy spectra for ^{82}Zn.

supports the previous assignment and simulation. An unexpected "bump" comes up at around 400 keV on the energy spectrum measured in this work, which can be associated with Compton scattering from the intense γ-ray transition. Similar structures could also be found in (^{85}Ge,^{84}Ge) and (^{84}Ge,^{82}Ge) reaction channels as ^{85}Ge and ^{84}Ge are the most intense secondary beam in this experiment. But a possible feeding from the higher excitation could not be ruled out. Further analysis of the origin of the "bump" is still ongoing.

4 Summary

Much attention has been attracted to the collectivity and shape evolution in the ^{78}Ni region. A new experiment ^{9}Be(^{83}Ga,^{82}Zn) to study the collectivity of ^{82}Zn was performed at RIKEN within the HiCARI campaign. The 2_1^+ and 4_1^+ states are well separated, for the first time, by using highly segmented HPGe detectors. The lifetime of the 2_1^+ and 4_1^+ states will be deduced in a more advanced analysis based on the current results.

References

[1] R. Taniuchi et al., Nature(London) **569**, 53(2019).
[2] R. Orlandi et al., Phys. Lett. B **740**, 298(2015).
[3] X. F. Yang et al., Phys. Rev. Lett. **116**, 219901(2016).
[4] C. Delafosse et al., Phys. Rev. Lett. **121**, 192502(2018).
[5] F. Nowacki et al., Phys. Rev. Lett. **117**, 272501(2016).
[6] H. Mach et al., Nucl Phys A. **523**, 197(1991).
[7] C. M. Shand et al., Phys. Lett. B **773**, 492(2017).
[8] http://www.nndc.bnl.gov/.
[9] A. Illana et al., Phys. Rev. C **108**, 044305 (2023).
[10] S. Hellgartner et al., Phys. Lett. B **841**, 137933(2023).
[11] M. Rocchini et al., Phys. Rev. Lett. **130**, 122502(2023).
[12] Y. Shiga et al., Phys. Rev. C **93**, 024320(2016).
[13] T. Kubo et al., Prog. Theor. Exp. Phys. **2012**(2012).
[14] N. Fukuda et al., Nucl. Instrum. Methods Phys. Res., Sect. B **317**, 323(2013).
[15] K. Wimmer et al., RIKEN Accelerator Progress Report **54**, 27(2021).