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β-decay measurements of very neutron-rich isotopes around mass A=130 within the BRIKEN project at RIBF

Vi H. Phong[1,2], Shunji Nishimura[2], Alfredo Estrade[3], Fernando Montes[4], Giuseppe Lorusso[2,5,6], Thomas Davinson[7], Oscar Hall[7], Jiajian Liu[8] for the BRIKEN collaboration

[1] *Faculty of Physics, VNU University of Science, 334 Nguyen Trai, Thanh Xuan, 120062 Hanoi, Vietnam*
[2] *RIKEN Nishina Center, RIKEN, 2-1 Hirosawa, Wako-shi, Saitama 351-0198, Japan*
[3] *Department of Physics and Science of Advanced Materials Program, Central Michigan University, Mount Pleasant, Michigan 48859, USA*
[4] *National Superconducting Cyclotron Laboratory, East Lansing, Michigan 48824, USA*
[5] *Chemical Medical and Environmental Science Division, National Physical Laboratory, Teddington TW110LW, United Kingdom*
[6] *Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom*
[7] *School of Physics and Astronomy, University of Edinburgh, EH9 3FD Edinburgh, United Kingdom*
[8] *Department of Physics, the University of Hong Kong, Pokfulam Road, Hong Kong*

E-mail: hophongmc@gmail.com

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β-decays of very neutron-rich isotopes around mass A=130 in the region " south-east " of doubly magic nucleus ^{132}Sn, with particular focus on measurement of β-delayed neutron emission probability (P_n values), were studied in the Radioactive Isotope Beam Factory [1] at RIKEN by means of β-neutron-γ spectroscopy. In this nuclear region, the gross beta decay properties such as β-decay half-life ($T_{1/2}$) and β-delayed neutron emission probability are important inputs for modeling the astrophysical r-process and provide first access to the nuclear structure information. The isotopes were produced by fragmentation of high intensity ^{238}U beam on a beryllium target, being separated and identified by the BigRIPS fragment separator [2] and terminated by the implantation of ions into the state-of-art AIDA implantation detector [3], which serves as a highly granular beta-counting system. Subsequent delayed neutrons were detected by the BRIKEN neutron detector array [4] consisted of 140 gas-filled ^{3}He counter, a world largest beta delayed neutron detector ever built, together with two large volume HPGe clover detectors. The experimental setup allows measurement of $T_{1/2}$ and P_n values as well as spectroscopic information from measured delayed γ-rays of nuclei of interest. In this paper, the experimental details, the analysis procedure and preliminary results will be provided.

KEYWORDS: r-process, β-decay, β-delayed neutrons

1. Introduction

A majority of elements heavier than iron in stars is synthesized by neutron capture processes such as r- and s-process [5]. While the s-process is relatively well-studied, the mechanism and environment of the r-process remain open questions [6], which are partly due to the involvement of very neutron-rich isotopes, as the competition between the β-decay and the successive neutron capture reaction drives the nuclear matter far from stability line. Therefore, for a reliable modeling of the r-process, nuclear physics data specifically for such very neutron-rich isotopes are desired. β-decay properties such as β decay half-lives and β-delayed neutron emission probability of involved nuclei are among important nuclear physics data for the r-process. In addition to the nuclear astrophysics interest, measurements of β decay half-life and β-delayed neutron emission probability are often the first means to access the nuclear structure information from the experimental point of view [7, 8].

In particular, β-decay properties of nuclei around neutron magic numbers N=50,82 and 126 are expected to have a direct impact on the r-process abundance peaks, which are sensitive to the yet-unknown astrophysical scenario. Studying nuclear properties around these nuclear regions also offers testing ground for nuclear theories, thereby help improving their predictive power to experimentally unknown regions.

In this paper, we report on β-decay measurements of very neutron-rich isotopes around mass A=130. We focus particularly on P_n measurements of neutron-rich nuclei in the region "south-east" of doubly-magic nucleus ^{132}Sn ($Z \leq 50$ and $N \geq 82$), where large impact on final r-processes abundance are expected according to the recent sensitivity study on P_n value assuming various astrophysical scenarios [9]. Details of the experimental setup, data analysis and preliminary results on P_n values are presented.

2. Experimental setup

The nuclei of interested were produced at the Radioactive Isotope Beam Factory of the RIKEN Nishina Center by in-flight fission of ^{235}U primary beam striking on a 4 mm beryllium target. The fragments were separated and identified by the BigRIPS spectrometer, where a two-stages separation scheme using $\Delta E - B\rho - \Delta E$ method was implemented, allowing for separation of various ion species according to their mass-to-charge ratio and charge state. The energy loss, magnetic rigidity and time-of-flight of the fragments were measured event-by-event by dedicated detectors along the BigRIPS beam-line, providing Z and mass-to-charge information for each fragment. Using such information, a particle identification matrix, shown in Fig. 1, was constructed for further analysis.

The identified fragments were transmitted through the Zero-Degree spectrometer and reached the BRIKEN setup at the final focal plane F11. In the present experiment, the BRIKEN setup consists of a polyethylene-moderated ^{3}He-based neutron counters and 2 HpGE clover-shape detectors placed around the AIDA Double-sided Silicon Detector. Details of the BRIKEN setup can be found in Ref. [10].

3. Analysis procedure and preliminary results

β-decay half-lives are obtained simultaneously with the β-delayed neutron emission probability using the so-called decay curves, which are histograms of the time difference between heavy-ion implantation events and correlated β-decay and β-delayed neutron events. The later is constructed by gating on the neutron signals detected within neutron thermalization time in the BRIKEN detector. The measured time and position information in AIDA were used to construct such decay curves. At the first step of data analysis, the raw data from ion implantation and β-decay events detected in AIDA DSSDs were analyzed using a designated sorting program [11]. The implantation of identified ions in BigRIPS spectrometer was associated with subsequent β-decay by applying the spatial correlation method reported in Ref. [12], which greatly reduce the amount of uncorrelated background due to the decay of other isotopes in the resulting decay curves. The β-decay events were correlated in time with delayed-neutron events to construct the neutron-gated decay curves. Finally, the constructed decay curves without neutron gate d_β, with one neutron gate $d_{\beta-1n}$ and with two neutrons gate $d_{\beta-2n}$ were fitted to appropriate functions to extract the simultaneously the β-decay half-life and the β-delayed neutron emission probabilities. Details of this fitting method can be found in Ref. [13].

Applying the analysis procedure outlined above, we have obtained preliminary results of the $T_{1/2}$ and P_n for 17 isotopes "south-east" of ^{132}Sn, with several candidates for new two β-delayed neutron emitters. An example of the fit to the decay curve for ^{135}In are shown in Fig. 2 for an exhibition. This fit yields a half-life of 104(4) ms in good agreement with previous results in Refs. [14, 15].

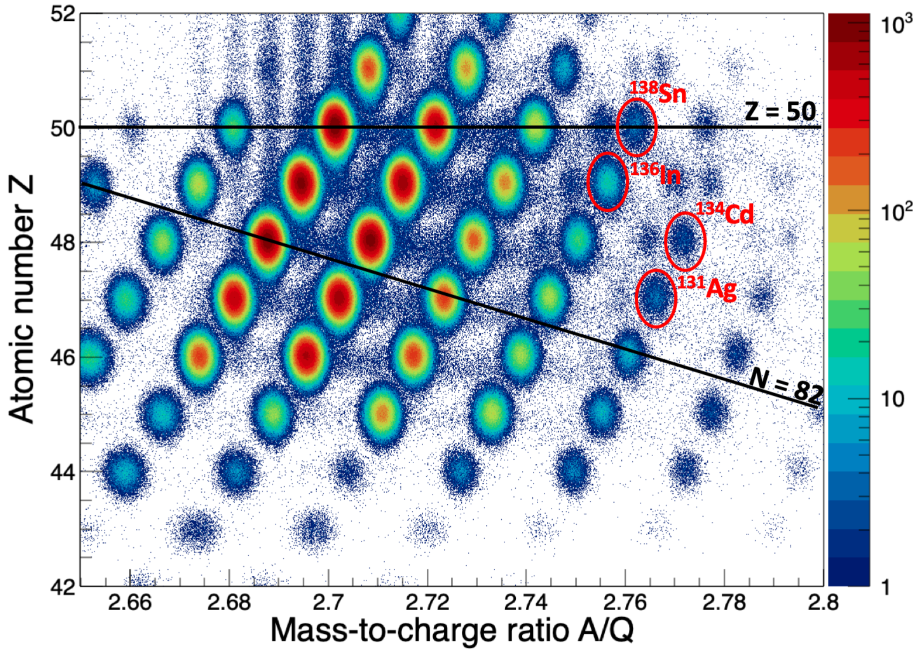

Fig. 1. Z versus A/Q particle-identification plot on ions implanted in AIDA detector. The corresponding nuclei with Z=50 and N=82 are located a along the black solid lines.

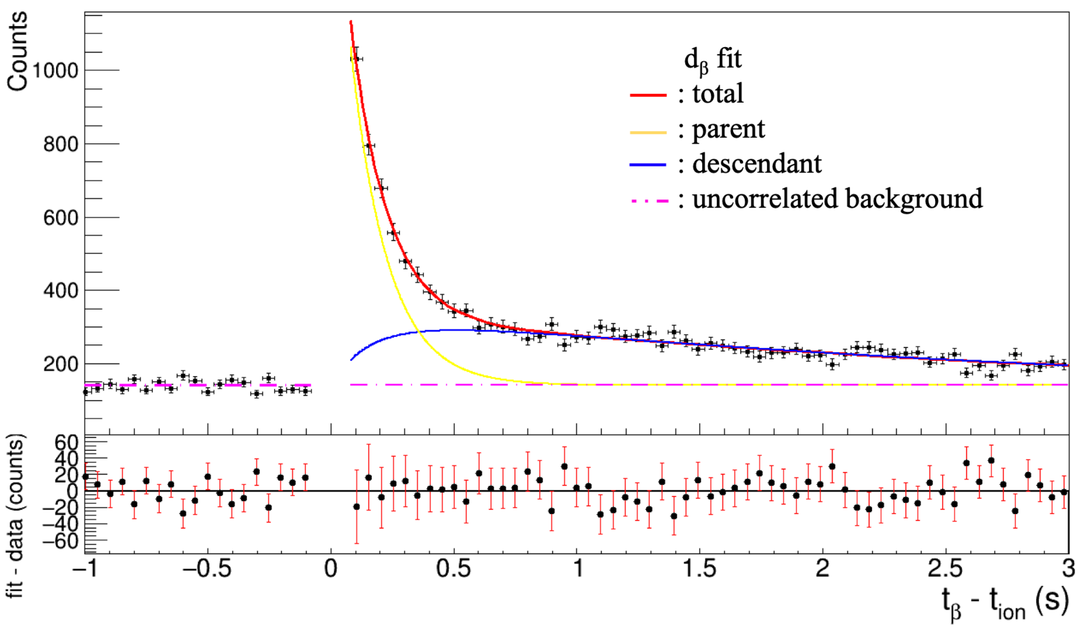

Fig. 2. Decay curve d_β data for ^{135}In. The total fit function is shown together with decomposition of parent, descendants decay and constant background components. The corresponding residual plot is shown below the fitted decay curve.

4. Summary

The measurements of β-decay half-lives and β-delayed neutron emission probabilities around A=130 have been performed at RIBF. By fitting the decay curves gated on delayed-neutron events, preliminary results on $T_{1/2}$ and P_n values of 17 isotopes ”south-east” of ^{132}Sn were obtained, which will serve as important experimental data for better understanding the mysterious r-process.

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