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Beta decay and isomer spectroscopy in the ^{132}Sn region: New results from EURICA

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Abstract. The first EURICA campaign with high intensity Uranium beams took place at RIKEN in November/December 2012. Within this campaign experiment NP1112-RIBF85 was performed dedicated to the study of the isomeric and beta decays of neutron-rich Cd, In, Sn and Sb isotopes towards and beyond the N=82 neutron shell closure. In this contribution we will first provide information about the status of the analysis of the extensive data set obtained in this experiment and close with a short outlook.

1. Introduction

The region around doubly-magic ^{132}Sn is of great importance for nuclear structure physics because it is the only region around a heavy doubly-closed shell nucleus far-off stability (8 neutrons relative to the last stable isotope ^{124}Sn) for which detailed spectroscopic information can be obtained using modern state-of-the-art techniques. It therefore plays an essential role in testing the shell model and serves as input for any reliable future microscopic nuclear structure calculations towards the neutron drip line. In addition, this region is also relevant for nuclear astrophysics, in particular nucleosynthesis calculations, due to the close relation between the N=82 shell closure and the A≈130 peak of the solar r-process abundance distribution.

The main goal of experiment NP1112-RIBF85 was to extend the current knowledge on excited states in very neutron-rich Cd, In, Sn and Sb isotopes. In particular we were aiming i) for first experimental information on excited states in ^{136,138}Sn via the search for 6^+ seniority isomers in these isotopes in anology to the one known in ^{134}Sn [1], ii) for the first observation of transitions within the $\pi g_{9/2}^{-1} \otimes \nu f_{7/2}$ multiplet in ^{132}In populated in the β-decay of ^{132}Cd and iii) to follow the evolution of the $\pi g_{7/2} \otimes \nu f_{7/2}$ multiplet in ^{136,138}Sb.

The results of this experiment should serve to test the predictions of shell-model calculations in a very neutron-rich, medium-heavy region of the chart of nuclides. Indeed, these nuclei, with just a few neutrons beyond ^{132}Sn, are very sensitive to deficiencies in current state-of-the-art shell-model interactions.

2. Experimental setup

The exotic nuclei of interest were produced by the in-flight fission of a 345 MeV/nucleon ^{238}U beam from the RIBF facility, impinging on a 3-mm thick Be target. The ions of interest were separated from other reaction products and identified on an ion-by-ion basis by the BigRIPS in-flight separator [2]. The particle identification was performed using the ΔE-TOF-$B\rho$ method in which the energy loss, (ΔE), the time of flight (TOF) and the magnetic rigidity ($B\rho$) are measured and used to determine the atomic number, Z, and the mass-to-charge ratio, A/q, of the fragments. Details about the identification procedure can be found in Ref. [3]. The identified ions are transported through the ZeroDegree spectrometer (ZDS) and finally implanted into the WAS3ABi (Wide-range Active Silicon Strip Stopper Array for β and Ion detection) Si array positioned at the focal plane of the ZDS (F11). The WAS3ABi detector [4] consists of eight DSSSD with an area of 60×40 mm^2, a thickness of 1 mm and a segmentation of 40 horizontal and 60 vertical strips each. A sketch of the experimental facility together with an identification plot of the isotopes implanted into WAS3ABI during experiment NP1112-RIBF85 is shown in Fig. 1. To detect γ radiation emitted in the decay of the implanted radioactive nuclei 12 large-volume Ge Cluster detectors [6] from the former EUROBALL spectrometer [7] were arranged in a close geometry around the WAS3ABi detector.

The combination of the unprecedented high intensity of the primary Uranium beam (on average 8-10 pnA) and the high efficiency of the setup for both the detection of γ rays (7% at 1 MeV) and particles allowed to perform detailed decay spectroscopy in a region of the chart of nuclides which has not been accessible for this type of studies before.

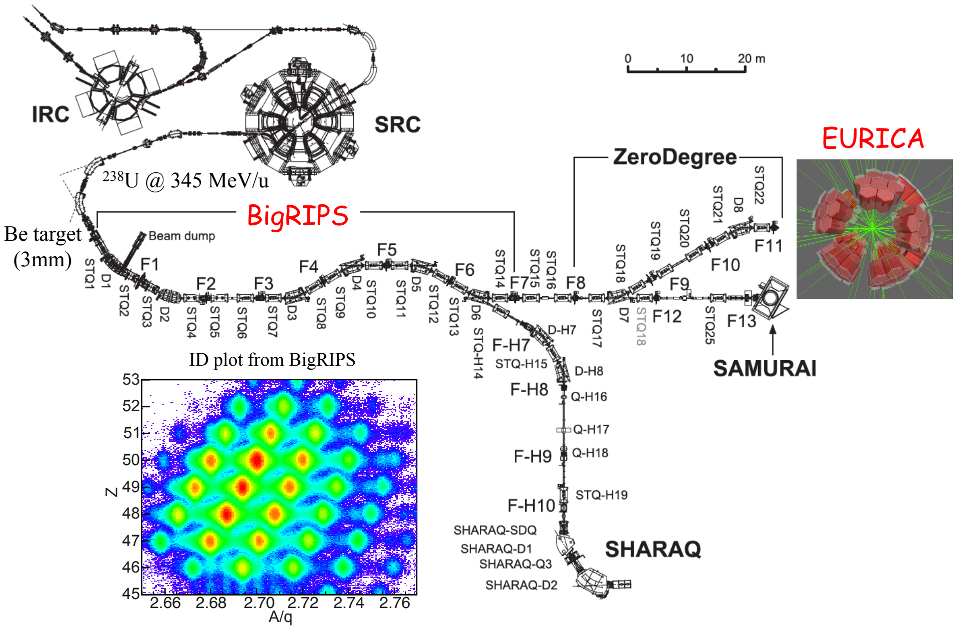

Figure 1. Sketch of the experimental facility (adopted from Ref. [5]) including the identification plot of the isotopes implanted into WAS3ABi during experiment NP1112-RIBF85.

3. First results

To study the γ radiation emitted in the β-decay of and after β-delayed neutron emission from the neutron-rich isotopes produced in this experiment, spectra were constructed including all the γ rays which were detected in prompt coincidence with decay events. Different conditions were applied on the correlations, both in space and time, between the implantation and the successive decay signals registered in the Si detectors of WAS3ABi. In the analysis process, we first concentrated on the decays of the Cd isotopes produced in our experiment (A=128-133). The high-statistics data obtained for the β-decay of ^{130}Cd, which had already previously been studied in detail [8], served as an excellent test case. In a next step, a β-decay scheme for ^{129}Cd was established for the first time. It comprises more than forty γ transitions connecting about twenty excited states. Only four of them, including a β-decaying $1/2^-$ isomer, were known previously. Finally, from the decay of the most exotic Cd isotopes, first information about excited states in nuclei in the quadrant south-east of ^{132}Sn was obtained.

In addition to the γ spectroscopy after β-decay, also information on isomeric decays is comprised in the data set. Several isomeric states with half-lifes in the μs and ms ranges are observed for the first time. One example are the neutron-rich Sn isotopes. Delayed γ rays are observed in coincidence with both ^{136}Sn and ^{138}Sn. They constitute the first observation of the decay of excited states in these very neutron-rich, semi-magic nuclei. Indeed, together with ^{128}Pd [9], they are the nuclei with the highest N/Z ratio in this region for which excited states are known and their semi-magic nature allows just the neutron-neutron part of the shell model interactions to be probed. Three delayed transitions have been observed for each nucleus and these have been assigned as E2 transitions from the 6^+, 4^+ and 2^+ states, by analogy with γ rays of similar energies observed from the decay of a 6^+ isomer in ^{134}Sn [1]. The small spacing between the 6^+ and 4^+ states, and their relatively pure $\nu(f_{7/2})^2$ configuration, are responsible for the isomerism.

We found that the energies of the 2^+, 4^+ and 6^+ levels remain fairly constant as the number of neutrons increases from N=84 to N=88. This agrees with the predictions of shell-model calculations performed using state-of-the-art interactions, e.g. the CD-Bonn bare nucleon-nucleon potential, renormalized using G-matrix [10] and V_{low-k} [11] prescriptions. In contrast calculations performed using empirical interactions (SMPN) deviate from the experimental data [12], despite the simple nature of these nuclei. These data serve as useful input for astrophysical r-process calculations as the path of this reaction includes these nuclei. A low excitation energy of the 2_1^+ state can change the effective half-lives of nuclei participating in this reaction at high temperatures.

4. Outlook

In the future, the energies of excited states will be established for the first time also in many other nuclei besides the cases discussed here. In particular, the data on the Sb and In isotopes will allow very sensitive tests of the shell-model predictions to be performed. Information on the excited states of these simple odd-Z nuclei is particularly important as the neutron-proton part of shell-model interactions is the most difficult part to reproduce. However, the data set obtained from the present experiment is not only of interest from the spectroscopic point of view. For many of the produced nuclei shown in Fig. 1 basic information such as β-decay half-lifes will become available for the first time, many of them being important ingredients for r-process calculations.

To conclude, a very rich data set has been obtained from experiment NP1112-RIBF85 which took place in December 2012 during the first EURICA campaign with high intensity Uranium beams at RIKEN. Exciting results with respect to the structure of neutron-rich Cd, In, Sn and Sb isotopes, some of them also relevant for nuclear astrophysics, will be presented in the near future.

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