EPJ Web of Conferences **93**, 01024 (2015)
DOI: 10.1051/epjconf/20159301024

Study of ground and excited state decays in $N \approx Z$ Ag nuclei

K. Moschner[1,a], A. Blazhev[1], N. Warr[1], P. Boutachkov[2], P. Davies[3], R. Wadsworth[3], F. Ameil[2], H. Baba[4], T. Bäck[5], M. Dewald[1], P. Doornenbal[4], T. Faestermann[6], A. Gengelbach[7], J. Gerl[2], R. Gernhäuser[6], S. Go[8], M. Górska[2], H. Grawe[2], E. Gregor[9], H. Hotaka[10], T. Isobe[4], D. G. Jenkins[3], J. Jolie[1], H. S. Jung[11], I. Kojouharov[2], N. Kurz[2], M. Lewitowicz[12], G. Lorusso[4], E. Merchan[9], F. Naqvi[13], H. Nishibata[14], D. Nishimura[10], S. Nishimura[4], N. Pietralla[9], H. Schaffner[2], P.-A. Söderström[4], K. Steiger[6], T. Sumikama[15], J. Taprogge[16,17], P. Thöle[1], H. Watanabe[18], V. Werner[9,13], Z. Y. Xu[8], A. Yagi[14], K. Yoshinaga[10], and Y. Zhu[10]

[1] *University of Cologne, Germany*
[2] *GSI, Darmstadt, Germany*
[3] *University of York, UK*
[4] *RIKEN, Japan*
[5] *KTH, Stockholm, Sweden*
[6] *Technische Universität München, Germany*
[7] *Uppsala University, Sweden*
[8] *University of Tokyo, Japan*
[9] *Technische Universität Darmstadt, Germany*
[10] *Tokyo University of Science, Japan*
[11] *Chung-Ang University, Republic of Korea*
[12] *GANIL, France*
[13] *Yale University, USA*
[14] *Osaka University, Japan*
[15] *Tohoku University, Japan*
[16] *IEM, CSIC, Madrid, Spain*
[17] *Universidad Autónoma de Madrid, Spain*
[18] *Beihang University, China*

Abstract. A decay spectroscopy experiment was performed within the EURICA campaign at RIKEN in 2012. It aimed at the isomer and particle spectroscopy of excited states and ground states in the mass region below the doubly magic ^{100}Sn. The $N = Z$ nuclei ^{98}In, ^{96}Cd and ^{94}Ag were of particular interest for the present study. Preliminary results on the neutron deficient nuclei ^{93}Ag and ^{94}Ag are presented. In ^{94}Ag a more precise value for the half-life of the ground state's superallowed Fermi transition was deduced. In addition the energy spectra of the mentioned decay could be reproduced through precise Geant4 simulations of the used active stopper SIMBA. This will enable us to extract Q_β values from the measured data. The decay of ^{93}Ag is discussed based on the observed implantation-decay correlation events.

1 Introduction

The $N \approx Z$ nuclei in the vicinity of the doubly magic nucleus ^{100}Sn exhibit a large abundance of isomeric nuclear states and are of particular importance for astrophysical element synthesis. The systematic study of these nuclei and their decay modes gives important insights for the understanding of the astrophysical rp-process and provides a sensitive probe of the residual proton-neutron interaction and the role of excitations of the ^{100}Sn core [1]. Earlier experiments performed within the RISING stopped beam campaign showed excellent agreement with shell model predictions made for the ^{100}Sn region. The aim of the experiment RIBF83 performed within the EURICA [2] project at the Radioactive Isotope Beam Facility (RIBF) at RIKEN, Japan was to further extend the knowledge on decays of $N \approx Z$ nuclei below ^{100}Sn to provide more detailed tests of large scale shell model calculations.

2 Experimental Setup

Projectile fragmentation of a 345 MeV/u ^{124}Xe beam on a ^{9}Be target was used to create the nuclei of interest. The fragments were then separated and identified on an event-by-event basis in the BigRIPS spectrometer and transported to the EURICA array to perform decay spectroscopy after implantation in the active stopper SIMBA (Silicon IMplantation Beta Absorber) [3], which was previously used in the RISING campaign at GSI. Figure 1

---

[a] e-mail: kmoschner@ikp.uni-koeln.de

shows the identification plot for all nuclei delivered to the EURICA setup. The total number of identified and implanted ^{98}In, ^{96}Cd and ^{94}Ag nuclei were 3200, 13500 and 32000, respectively.

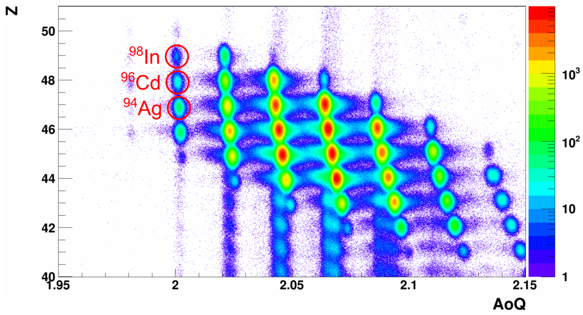

Figure 1. Identification plot for all nuclei identified by BigRIPS and sucessfully implanted in SIMBA during the experiment RIBF83. The nuclei of primary interest are circled in red.

The EURICA setup utilises the γ-ray efficiency of 12 EUROBALL HPGe cluster detectors in the RISING Stopped Beam configuration. For the purpose of particle decay studies, the active stopper SIMBA, composed of a highly segmented silicon-array, was installed in the center of the germanium array. In order to meet the requirements for an operation at RIBF and in order to enable β-calorimetry for Q_β values up to more than 10 MeV in the desired mass region, SIMBA had to be modified with respect to its old geometry. For the present study it consisted of three highly segmented DSSSD serving as the implantation area and a stack of 20 SSD situated downstream serving as a calorimeter for positrons emitted in β^+ decays.

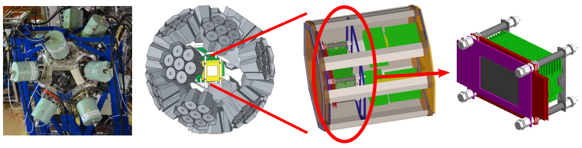

Figure 2. The EURICA array consisting of 12 EUROBALL germanium clusters and the active stopper SIMBA in its center.

3 Lifetime Measurement for ^{94}Ag

The decay modes of the (7^+) and (21^+) isomer in ^{94}Ag were the object of a large number of studies in the past years and precise knowledge on the half-life of these states is given in the literature. However, for the superallowed Fermi decay of the (0^+) ground state only one lifetime measurement is available at the present time, stating a half-life of 26^{+26}_{-9} ms [4].

The spectrum given in figure 3 shows the correlation time between implantations of ^{94}Ag and succeeding decay events. Two main components associated with the decay of the (0^+) ground state and of the (7^+) isomer in ^{94}Ag were observed. The decay of the (21^+) high-spin isomer was not observed due to the low population in the fragmentation reaction.

From a Maximum Likelihood analysis – including all observed decay branches as well as the decays of the daughters – a preliminary value of 29(6) ms for the half-life of the the ground state, consistent with the previous measurement, was determined [5].

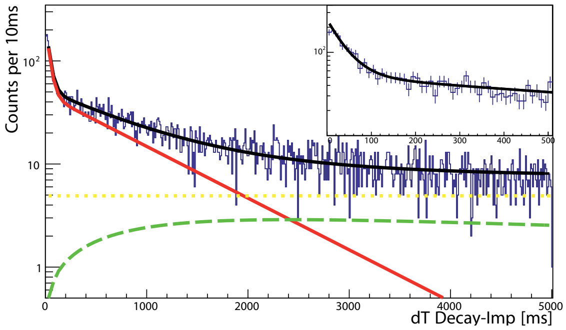

Figure 3. Comparison between the experimental lifetime data (blue histogram) for ^{94}Ag together with the result of the MLH analysis (solid black curve). The resulting time distribution for the decay of ^{94}Ag is given as a solid red curve, while the time distribution for the grow-in and decay of the daughter nucleus ^{94}Pd and a constant background are given as a dashed green and dotted yellow curve, respectively.

4 Determination of Q_β values for ^{94}Ag

Up to the present date no direct mass or ground state Q-value measurement for ^{94}Ag is available. The only values available stem from systematics [7], calculations based on the lifetime [6] or from mass measurements of the β^+ daughter nucleus ^{94}Pd together with extrapolations of the Coulomb displacement energy [8].

The goal of the present study was therefore to determine Q_β-values by means of positron calorimetry. In order to be able to extract the needed β endpoint energies from the experimental data, detailed Monte Carlo simulations of the response of SIMBA became necessary. These were realised on the basis of Geant4 along the lines of the work presented in Ref. [9] and showed good results in a number of test cases [10].

For the case of ^{94}Ag, separate β-energy spectra for the decay of the ground state and the (7^+) isomer were generated by applying appropriate time gates in the implantation-decay correlation matrices. These spectra are shown in figure 4 together with the simulations based on input spectra for the Q-values and β^+-branchings given in [8, 11] and reveal the reliability of the used method.

From minimising the deviation between the simulations and the experimental data the endpoints of the energy distribution can be extracted with approximately 500 keV accuracy in the case of ^{94}Ag. This will enable us to determine Q_β-values and β-strength for the decay of the ground state and the (7^+) isomer. These are important for rp-process calculations and have impact on the ongoing

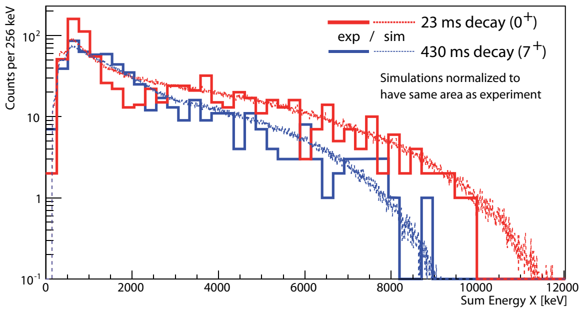

Figure 4. Comparison between the experimental β-energy spectra for the decay of the (0^+) ground state and the (7^+) isomer in ^{94}Ag and simulation with the new Geant4 code. The experimental spectra are gated on the decay times for both transitions. For the simulations input function derived from literature values [8, 11] were used.

discussion of the claimed two-proton decay of the (21^+) spin gap isomer in ^{94}Ag [8, 12].

5 The Decay of the Drip Line Nucleus ^{93}Ag

Up to the present day it remains unclear if the very neutron deficient nucleus ^{93}Ag is proton bound or unbound [13, 14]. While ^{93}Ag has been already observed in previous experiments [15], there is no further experimental data available apart from lower limits for the nuclear half life based on the observational limit.

In the present experiment 75 ^{93}Ag nuclei were identified and implanted in the active stopped. The analysis of the observed time spectrum of the succeeding decay events is compatible with two different scenarios. First, a fast (proton) decay of ^{93}Ag in the order of μs would not be detected due to the systems dead time after an implantation event. Therefore the resulting time spectrum would show only events from the (proton) decay daughter. Second, the observed time spectrum is also compatible with a slow decay of ^{93}Ag in the order of a few hundred ms and the successive feeding and decay of either the proton decay daughter ^{92}Pd or the beta decay daughter ^{93}Pd.

Due to the lack of statistics in the coincident γ-ray spectra, none of both scenarios can be further validated at this time.

6 Summary and Outlook

In conclusion, we performed a decay spectroscopy experiment aimed at a deeper understanding of particle and isomeric decays in $N \approx Z$ nuclei below ^{100}Sn. We presented a more precise lifetime measurement for the very exotic nucleus ^{94}Ag. With the help of detailed Geant4 simulations of the used active stopper SIMBA, we will be able to extract Q_β values for the (0^+) ground state's superallowed Fermi and the Gamow-Teller decay of the (7^+) isomer of ^{94}Ag. The obtained data for ^{93}Ag is still under analysis.

Acknowledgements

This work was carried out at the RIBF operated by RIKEN Nishina Center, RIKEN and CNS, University of Tokyo. We acknowledge the EUROBALL Owners Committee for the loan of germanium detectors and the PreSpec Collaboration for the readout electronics of the cluster detectors. This work was supported by the German BMBF under Contract No. 05P12PKFNE and by the U.S. Department of Energy under grant No. DE-FG02-91ER-40609.

References

[1] T. Faestermann et al., Prog. Part. Nucl. Phys. **69**, 85 (2013)

[2] P.-A. Söderström et al., NIM B **317**, 649 (2013)

[3] C. B. Hinke, PhD thesis, Technischen Universität München (2010)

[4] A. Stolz et al., AIP Conf. Proc. **610**, 728 (2002)

[5] K. Moschner et al. to be published

[6] T. Faestermann et al., Eur. Phys. J. A **15**, 185 (2002)

[7] M. Wang et al., Chinese Phys. C **36**, 1603 (2012)

[8] A. Kankainen et al., Phys. Rev. Lett. **101**, 142503 (2008)

[9] K. Steiger, Diploma thesis, Technische Universität München (2009)

[10] N. Warr et al., contribution to these proceedings

[11] M. La Commara et al., Nucl. Phys. A **708**, 167 (2002)

[12] I. Mukha et al., Nature **439**, 298 (2006)

[13] S. Patra et al., Phys. Rev. C **63**, 024311 (2001)

[14] G. Lalazissis et al., Nucl. Phys. A **679**, 481 (2001)

[15] R. Krücken et al., AIP Conf. Proc. **1072**, 52 (2008)