

# Lifetime measurements in $^{105}\text{Sn}$ : the puzzle of $B(E2)$ strengths in Sn isotopes

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**Abstract.** One of the most studied case to explore the evolution of shell closures far from stability is the doubly-magic and self-conjugated  $^{100}\text{Sn}$  nucleus. Information on its doubly-magic nature can be extracted from the systematic study of the tin isotopic chain. In this context, the lifetimes of the neutron deficient  $^{105}\text{Sn}$  have been investigated with the coincidence Recoil Distance Doppler Shift (RDDS) technique through the reaction  $^{50}\text{Cr}(^{58}\text{Ni},2\text{pn})^{105}\text{Sn}$ . Preliminary results concerning the lifetimes of  $^{105}\text{In}$  excited states are in good agreement with the adopted lifetimes, demonstrating the feasibility to extract lifetimes with this experimental technique.

## 1 Introduction

The study of the nuclear structure of atomic nuclei with a number of protons and neutrons close to magic numbers is an effective mean to test different nucleon-nucleon interaction sets used as an input for the shell model codes. A prominent nucleus in this context is the doubly-magic and self-conjugated  $^{100}\text{Sn}$ . Decay-spectroscopy provided indirect indication that the  $Z=50$  shell closure is present for this system [1]. To test the robustness of the proton shell closure approaching  $N=50$  the spectroscopy of the Sn isotopic chain therefore becomes useful [2–4].

The generalized seniority scheme predicts a parabolic behaviour of the  $B(E2; 2^+ \rightarrow 0^+)$  values for Sn isotopes. Nevertheless, the experimental values for the  $B(E2; 2^+ \rightarrow 0^+)$  in neutron-deficient isotopes do not follow a parabola, at least up to  $^{114}\text{Sn}$ . The study of the reduced transition probabilities via fusion-evaporation reaction is hampered by the presence of low-lying isomers in even-even Sn isotopes. Therefore,  $B(E2; 2^+ \rightarrow 0^+)$  values have been extracted from measurements of Coulomb excitation, yet the results suffer from large uncertainties. Recently, a direct measurement of the lifetime of the  $2_1^+$  and the  $4_1^+$  excited states in  $^{106,108}\text{Sn}$  was performed via a multi-nucleon transfer reaction for the very first time [5].

Shell-model calculations with the CD-Bonn interaction in the full  $N=50$ – $N=82$  valence space show that the quadrupole strength of core-coupled states in odd-even nuclei closely follow the general trend of the corresponding even-even isotopes for the  $2^+$  states. In this regard, the neutron-deficient odd-even  $^{105}\text{Sn}$  isotope provides the opportunity for direct lifetime measurements of low-lying levels in odd Sn isotopes close to  $^{100}\text{Sn}$ .

Another indication of the decreasing of collectivity going towards  $^{100}\text{Sn}$  comes from the study of the M1 tran-

sition strength for the first excited states in odd-even tin isotopes. Shell model calculations predict a dominant M1 character for this transition, which is highly suppressed in case of a single-particle nature of this state, being an  $l$ -forbidden M1. This leads to a lifetime of several ns for this state, which is in a great disagreement with the  $^{105}\text{Sn}$  measured value of only several hundreds ps. Actually, this value has been measured only once and it was never published but only presented in a short annual report [11]. A precise re-measurement of the lifetime of the  $7/2^+$  first excited state in  $^{105}\text{Sn}$  is needed. Moreover, it will possibly shed light on the controversy regarding the spin-parity assignments of the ground state and first excited state,  $5/2^+$  and/or  $7/2^+$ , for odd Sn isotopes in this region [12], [13].

Since lifetimes of the order of ps are expected, the coincidence Recoil Distance Doppler Shift (RDDS) technique can be applied [6]. This method is based on the distinction, for a detected  $\gamma$ -ray transition, of a Doppler shifted component, emitted by nuclei in-flight, and a stopped component, emitted by nuclei at rest.

## 2 Experimental Details

The  $^{105}\text{Sn}$  nucleus was populated via a fusion evaporation reaction using a 180 MeV  $^{50}\text{Cr}$  beam and a  $^{58}\text{Ni}$  target of 1 mg/cm<sup>2</sup> thickness. Based on a previous spectroscopy investigation of this nucleus [7], such a reaction was chosen to optimize the production cross section of the channel of interest. The 16 mg/cm<sup>2</sup>  $^{197}\text{Au}$  stopper was mounted in the plunger device behind the target. Plunger was placed at the center of the reaction chamber.

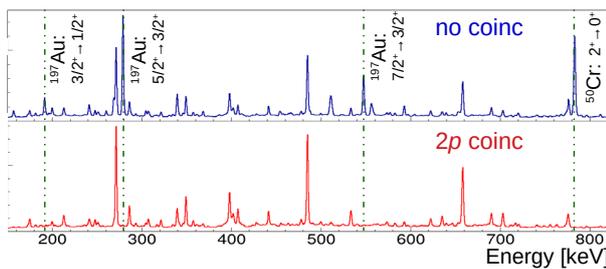
The experiment was performed at Legnaro National Laboratories using the GALIELO array [8] coupled to the EUCLIDES detector [9] and the GALILEO plunger device [10]. GALILEO is a  $\gamma$ -ray spectrometer composed of

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25 Compton-suppressed HPGe detectors. The position of the GALILEO detectors at different angles with respect to the beam direction ( $152^\circ$ ,  $129^\circ$ ,  $119^\circ$ ,  $61^\circ$  and  $51^\circ$ ), allows one to estimate excited-state lifetimes for each ring, as the energy shift of the  $\gamma$  ray emitted in-flight depends on the direction of emission. In this way, an average lifetime can be extracted, leading to a more precise measurement. The  $\Delta E$ -E silicon array EUCLIDES was used to detect evaporated light charged particles and select the reaction channel of interest. The array was placed only at forward angles in the plunger configuration. A total of 12 target-stopper distances in the range between  $10 \mu\text{m}$  and  $8000 \mu\text{m}$  were chosen to be able to measure the very short lifetimes of the high-spin magnetic band of  $^{105}\text{Sn}$  as well as its long-lived  $7/2^+$  first excited state.

### 3 Analysis and Preliminary Results

The selection of the channel of interest between all the possible fusion-evaporation and the Coulomb-excitation events is possible requesting  $\gamma$  coincidences with light charged particles. As an example, Figure 1 shows how the Coulomb-excitation events, due to the interaction between the beam and the stopper, can be significantly reduced in the spectrum requesting a 2-protons coincidence. A fur-



**Figure 1.** Comparison between the spectra in coincidence with two protons (bottom) and the total  $\gamma$  spectrum (top) detected at  $152^\circ$  with a target-stopper distance of  $10 \mu\text{m}$ . The suppression of the Coulomb excitation events between the  $^{50}\text{Cr}$  beam and the  $^{197}\text{Au}$  stopper are shown.

ther selection is possible by gating on a  $2p$ -coincidence  $\gamma$ - $\gamma$  matrix on the 200-keV,  $7/2^+ \rightarrow 5/2^+$ , ground state transition of  $^{105}\text{Sn}$ . The resulting spectrum is shown in Figure 2 and presents the identification of many  $^{105}\text{Sn}$  transitions among a few peaks owing to the main contaminants:  $^{105}\text{In}$  ( $3p$ ),  $^{104}\text{Cd}$  ( $4p$ ) and  $^{102}\text{Cd}$  ( $1\alpha 2p$ ).

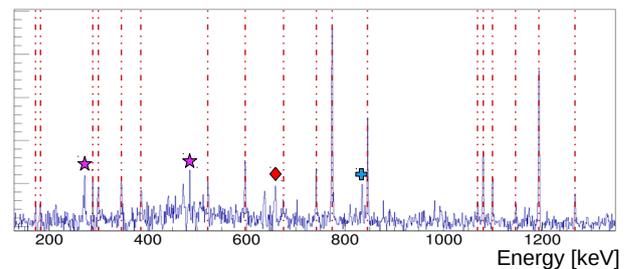
The lifetime of an excited state can be measured with the RDDS technique. The nucleus populated in the target from the reaction flies with a velocity  $v$  until the stopper. The energy of the  $\gamma$  ray emitted in-flight is Doppler shifted depending on the velocity of the nucleus and on the angle of the  $\gamma$ -ray emission. Depending on the distance between the target and the stopper, a different ratio between the intensities of the in-flight peak and the stopped peak is observed.

In this initial state of the analysis some of the excited states of  $^{105}\text{In}$ , which are known in the literature, are being

studied, to validate the adopted experimental technique. The analyzed spectra are obtained by gating on the in-flight component of the direct feeding transition, in a  $2p$ -coincidence  $\gamma$ - $\gamma$  matrix. The lifetime of the excited states of interest are estimated with the Differential Decay-Curve Method (DDCM) [6]. Preliminary results show a good agreement of our measurements with the adopted  $^{105}\text{In}$  lifetimes.

Data analysis is now oriented to the measurements of the lifetimes of  $^{105}\text{Sn}$  excited states. With the collected statistics it will be possible to precisely measure the lifetimes of the long-lived  $7/2^+$  and  $25/2^+$  excited states, the last corresponding to a possible core-breaking nature. A careful analysis is needed to extract the lifetimes of other excited states in  $^{105}\text{Sn}$ , which are characterized by shorter lifetimes.

Thanks to the GALILEO layout in 5 different rings it will be also possible to extract the mixing ratio of the  $7/2^+ \rightarrow g.s.$  transition in  $^{105}\text{Sn}$  by the ratios of angular distributions from oriented states.



**Figure 2.** From  $\gamma$ -ray detected at  $152^\circ$  with a target-stopper distance of  $10 \mu\text{m}$ , projection from a  $2p$ -coincidence  $\gamma$ - $\gamma$  matrix on the 200-keV energy ground state transition of  $^{105}\text{Sn}$ . The peaks corresponding to the main  $^{105}\text{Sn}$  transitions are marked with vertical dashed lines. The peaks corresponding to the main contaminants are also pointed out:  $\star$   $^{105}\text{In}$ ,  $\blacklozenge$   $^{102}\text{Cd}$ ,  $\oplus$   $^{104}\text{Cd}$ .

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