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High-Statistics Sub-Barrier Coulomb Excitation of ^{106,108,110}Sn

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A Coulomb excitation campaign on ^{106,108,110}Sn at 4.4-4.5 MeV/u was launched at the HIE-ISOLDE facility at CERN. Larger excitation cross sections and γ-ray statistics were achieved compared to previous experiments at ~2.8 MeV/u. More precise $B(E2; 0^+_1 \to 2^+_1)$ values, lifetimes of states via the Doppler shift attenuation method, and new $B(E2; 0^+_1 \to 2^+_x)$, $B(E2; 2^+_1 \to 4^+_1)$ and $Q(2^+_1)$ values from the new Miniball data will be obtained and applied to test modern nuclear structure theories.

KEYWORDS: shell model, nuclear collectivity, Coulomb excitation

1. Introduction

In nuclear structure, the doubly magic nucleus ^{100}Sn is a key test case of the robustness of the traditional shells far away from stability. The single-particle description of ^{100}Sn and nuclei with similar N and Z may be weakened by collective behavior, driven by proton-neutron interactions and exhibited through core excitations and nuclear deformation. Many experiments to determine nuclear collectivity in even-mass Sn isotopes through measurements of reduced electromagnetic transition probabilities, $B(E2)$, have been performed [1–6]. In order to achieve a higher experimental precision on the $B(E2)$ values to better evaluate different modern theories addressing this phenomenon, as discussed in Ref. [7] for instance, a series of safe Coulomb excitation (CE) experiments was carried out in a new campaign at CERN-ISOLDE.

2. Experiment method

Three unstable Sn isotopes ^{106,108,110}Sn were produced in separate experiments, where a 1.4-GeV proton beam from the CERN PS Booster induced spallation reactions on a lanthanum carbide target. Sn isotopes were selectively ionized with the Resonance Ionization Laser Ion Source (RILIS). and were post-accelerated at the HIE-ISOLDE [8] facility to 4.4-4.5 MeV/u before impinging on a ^{206}Pb target with a thickness of ~4 mg/cm^2. At these beam energies, contributions to the excitation cross section from nuclear reactions which are subject to large systematic uncertainties, are eliminated.

The γ rays emitted from the excited states of Sn isotopes were detected with Miniball [9], an array of segmented high-purity germanium detectors. Doppler correction of γ rays emitted in flight from beam nuclei was performed by measuring the particles' scattering angles with a CD-shaped double-sided silicon strip detector that is segmented in sectors and rings. Forward scattering angles of nuclei in the range of 20°-60° in the lab frame were covered by the CD detector, as shown in Fig. 1.

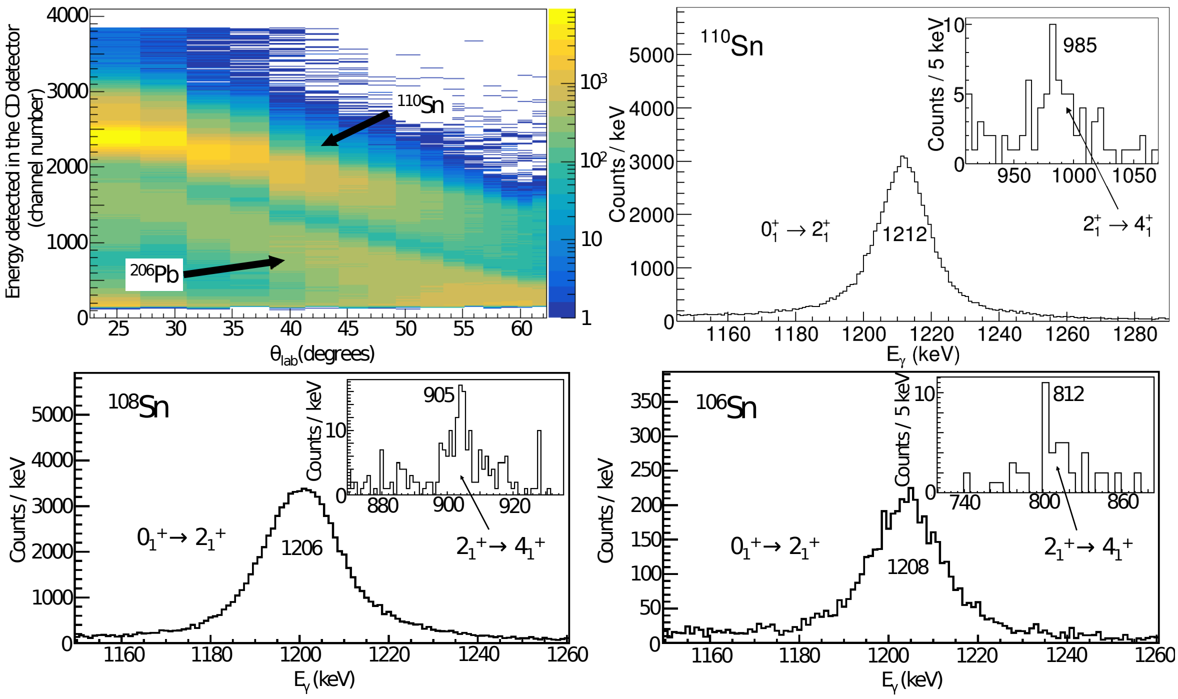

Fig. 1. Top left: energies detected in the CD detector as a function of the lab scattering angle θ, for a beam nucleus ^{110}Sn and the knocked-out target nucleus ^{206}Pb. Top right, bottom left and bottom right: Doppler-corrected γ-ray energy spectra for the $0_1^+ \rightarrow 2_1^+$ excitations of ^{110}Sn, ^{108}Sn and ^{106}Sn, respectively. The $\gamma\gamma$ coincidence projection spectra, gated on the $2_1^+ \rightarrow 0_1^+$ transitions, are shown in the insets. In all three Sn isotopes, the $4_1^+ \rightarrow 2_1^+$ γ rays were observed for the first time in Coulomb excitation. Approximately 50% of the γ-ray data is shown for ^{110}Sn, where the rest is pending a refined data sorting.

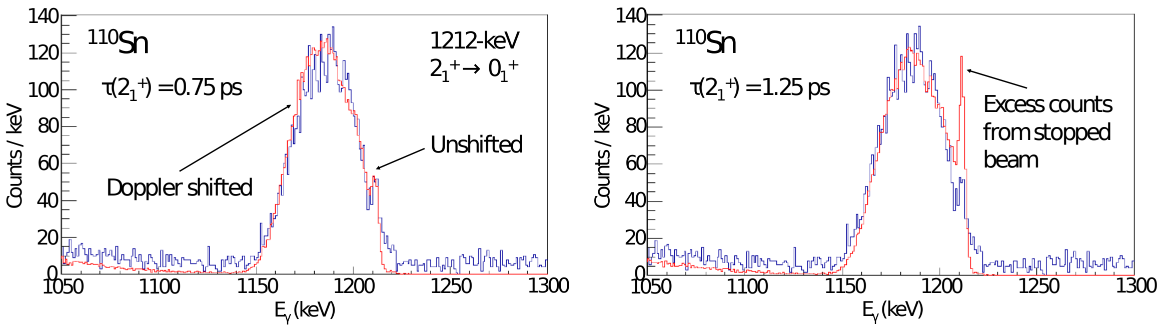

Fig. 2. Left: comparison of experimental (blue) and simulation (red) forward-emitted γ-ray energy spectra from the ^{110}Sn beam, where the target nucleus ^{206}Pb was detected in the same quadrant of the CD detector as Miniball. This spectrum was well reproduced in the simulation when assuming a 0.75-ps lifetime of the 2_1^+ state. Right: the same spectra, but with a simulated lifetime of 1.25 ps.

3. Preliminary results and outlook

By using a higher-Z target with higher beam energies, the CE cross sections were significantly enhanced compared to past CE experiments at REX-ISOLDE involving the same tin isotopes on a ^{58}Ni target [10, 11]. The γ-ray spectra from this experimental campaign at HIE-ISOLDE are shown in Fig. 1, along with a CD detector energy matrix for beam/target particle identification and Doppler correction. The gain in statistics is expected to improve the precision on $B(E2; 0_1^+ \to 2_1^+)$ values significantly. Furthermore, the CE to the 4_1^+ states in all three Sn isotopes was observed for the first time based on $\gamma\gamma$ coincidence projection spectra. This enables an opportunity to determine $B(E2; 2_1^+ \to 4_1^+)$ for the first time in ^{106,108,110}Sn. Evidence of γ rays from non-yrast states was also found, so that additional $B(E2; 0_1^+ \to 2_x^+)$ values may be extracted from the data.

In addition, a lifetime estimate of the 2_1^+ state in ^{110}Sn was performed via the Doppler shift attenuation method (DSAM). Using Geant4, the experimental setup, reaction kinematics and γ-ray emission/detection were simulated. By varying the hypothetical lifetime of the 2_1^+ state in ^{110}Sn, simulated γ-ray spectra from both the partially and fully stopped nuclei were then compared with the experimental spectrum. As shown in Fig. 2, a good agreement was found for $\tau = 0.75$ ps. Efforts to determine the final lifetime and proper uncertainties will be taken. Lifetime measurements of other CE γ rays will be attempted using the same DSAM, and compared to the values reported in Ref. [12].

By combining the CE results with previous experiments using the ^{58}Ni target, $Q(2_1^+)$ will be investigated for ^{108,110}Sn and plotted against their $B(E2)$ values for comparisons with shell model theories. Further analysis of the data and simulations are underway.

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