LoI for AGATA prePAC

Investigation of the rotational band in ^{120}Sn

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Abstract

We propose to search for the intruder band that builds on the deformed excited 0^+ states in ^{120}Sn using fusion-evaporation. While our recent (n, γ) measurement showed that the low-lying excited $0^+_{2,3}$ states in ^{120}Sn are deformed, the expected rotational band which builds on the deformed 0^+ states have not yet been observed. The aim of this complementary fusion-evaporation experiment is to identify and place the high-spin members of the intruder band, exploiting the high sensitivity of the AGATA+SAURON setup. Observation of the band structure will unveil the underlying deformation and elucidate whether the intruder band is rotational, vibrational, or a mixture of both. Combined with the systematics of the other Sn isotopes, our results will contribute to improve the understanding of shell evolution in the semimagic chain.

1 Scientific motivations

The semi-magic $Z = 50$ Sn isotopes, which possess the largest number of stable isotopes of any element, constitute one of the best studied isotopic chains in the nuclear chart. The neutron mid-shell $^{114-122}$Sn nuclei have been of special interest because they exhibit shape coexistence, a phenomenon where individual states/bands in the same nucleus have different shapes. Once though to be an exotic and rare occurrence, shape coexistence now appears to be a global property across the nuclear chart. In these mid-shell Sn isotopes, shape coexistence arises where excited 0^+ states built on proton 2 particle-2 hole (2p-2h) configurations intrude into the "normal" states with two-neutron configurations [1], as shown in Fig. 1, due to the increased tensor interaction between the cross-shell promoted protons and the large number of valence neutrons. Further evidence for the deformation of the low-lying excited $0^+_{2,3}$ states were reported by Kantele *et al.* through an enhanced $E0$ transition between the 0^+_2 and 0^+_3 states in ^{116}Sn that lead to a $\Delta\beta_2 > 0.22$ [2].

Recently, the work by Wu *et al.* observed a large $E0$ transition strength from the excited 0^+_3 state in ^{120}Sn, which suggests that the 0^+_2 and 0^+_3 states in ^{120}Sn are strongly mixed and have different shapes, similar to ^{116,118}Sn [3]. While a large relative shape difference, $\Delta\beta_2 > 0.23$, between the 0^+_2 and 0^+_3 potential intruder band heads was deduced [3], the high spin members of the intruder band in ^{120}Sn have not yet been observed, as shown in Fig. 1, possibly due to the technical challenges of in-beam particle-γ-γ spectroscopy. With the highly-capable detector systems at LNL, we are well-equipped to identify the intruder band and fill in the missing parts of Fig. 1.

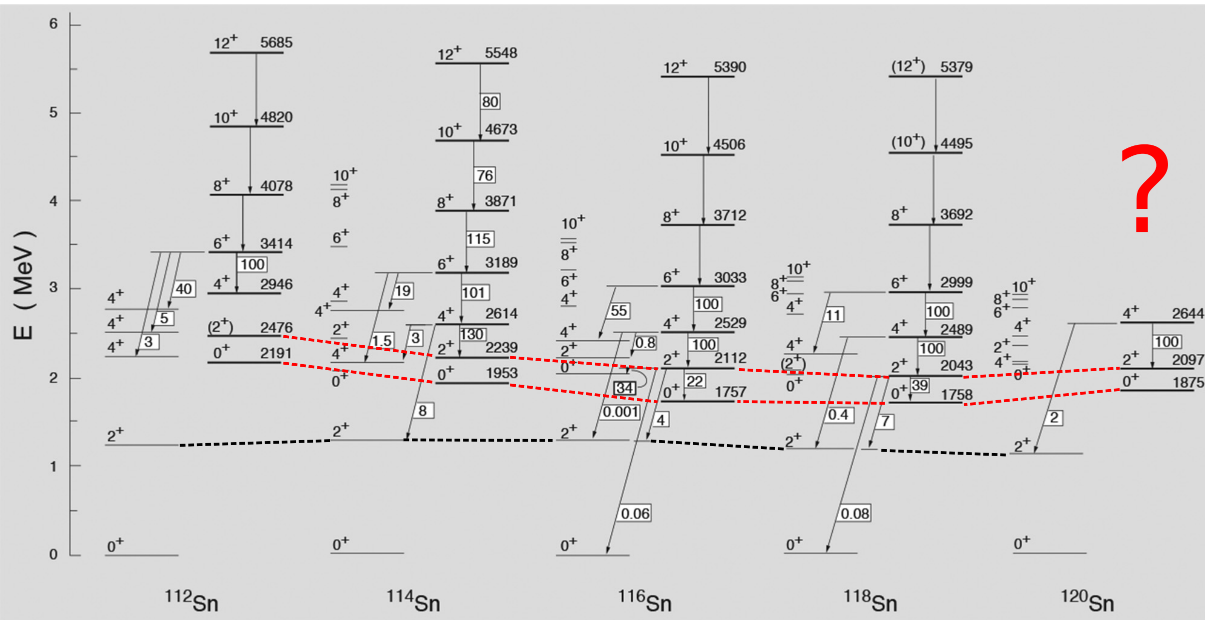

Figure 1: The systematics of the deformed bands built on the proton 2p-2h intruder configurations in the even Sn isotopes [4].

In addition to filling in the apparent gap in nuclear data, the observation of the intruder band in ^{120}Sn will provide direct physics insight to the structure of this very interesting nucleus. If the intruder band turns out to be purely rotational in nature, the energy difference between band members, $\Delta E_{J,J-2}$, can be directly used to deduce the moment of inertia, I, of the rotor and consequently the underlying deformation as $\beta_2^2 \propto I$. On the other hand, if the intruder band is not clearly rotational, even more physics can be extracted because we have to understand the underlying mechanism. For example, it could be evidence for band mixing between vibrational and rotational configurations of multiple shapes: such a theoretical analysis was recently performed using collective models, density functionals, and two-state mixing for ^{116}Sn in Ref. [5], which indicated the coexistence of prolate and oblate shapes in ^{116}Sn.

In order to discover the intruder band in ^{120}Sn, we propose a fusion-evaporation experiment to populate high-spin members of the band and measure the γ-ray cascade to identify and place them in the level scheme. Intensities and branching ratios will also be measured and, combined with future lifetimes measurements, will be used to calculate the $B(E2)$ values. Results of this experiment will shed light on the deformation in ^{120}Sn and, together with the systematics of $^{112-118}$Sn, fill in the bigger picture of shell evolution along the Sn isotope chain.

2 Proposed experiment

For the present experiment, we aim at populating the ^{120}Sn using a fusion-evaporation reaction with a beam of ^{7}Li at 30 MeV, provided by the TANDEM accelerator, impinging on a 1-mg/cm^2 thick ^{106}Cd target. Although fusion-evaporation reactions are unusual to study nuclei in the middle of the valley of stability, they are one of the main tools to study high-spin states. Furthermore, a similar reaction with the same beam-target combination was already employed in a previous experiment performed at LNL in 1987 [6]. Our channel of interest is expected in coincidence with the evaporation of 1p and 2n. The protons emitted in the reaction will be selected using the SAURON array. The γ-rays emitted in the reaction will be detected using the AGATA array. The other dominant channels populated in the reaction, namely ^{119,120}Sb, will emit neutrons only, and therefore these contaminant channels can be eliminated with a proton-γ coincidence gate. In order to further clean the γ-ray spectrum, the coincidence with the $2_1^+ \rightarrow 0_{g.s.}^+$ at 1171 keV can be placed offline to disentangle transitions with similar energies.

To place the observed transitions in the level scheme we will primary rely on the sequence of the transitions and the systematics with the neighbouring Sn isotopes. For transitions where statistics permits, we will also perform angular distribution and Compton polarization for firm J^π assignments.

The unique combination of AGATA and SAURON's position sensitivity for Doppler correction will allow us to detect the weak transitions in the intruder band with unprecedented sensitivities. Furthermore, the PSA PID capability of SAURON will allow for the proton-alpha discrimination and provide extra reaction-channel selectivity to remove unexpected contamination channels. Exploiting the p-γ-γ coincidences, we will be sensitive to identify and place weak transitions that were never observed before.

3 Beam time and rate estimates

The cross-section of the ^{116}Cd(^{7}Li,$p2n$)^{120}Sn at beam energy of 30 MeV is expected to be around 25 mb. Assuming each evaporated nucleon carries 8 MeV of excitation energy and $1-2\hbar$ of angular momentum from the compound nucleus, the residual ^{120}Sn is expected to have ≈ 20 MeV of excitation energy with $J \approx 12-18\hbar$, which is ideal for the investigation of the intruder band. According to β-decay study [7], the intensities of the γ rays belonging to the rotational band are expected to be around 1% of the $2_1^+ \rightarrow 0_{\mathrm{g.s.}}^+$ transition. Assuming an efficiency of AGATA of $10-15$%, depending on the energy of the transition, and an efficiency of 26% of two SAURON disks (forward-and-back at 2.5 cm) for protons, the expected rates for the rotational band are summarized in Table 1.

$J_i^\pi \rightarrow J_f^\pi$	E_γ [keV]	p-γ/day	p-γ-γ/day
$2_1^+ \rightarrow 0_{g.s.}^+$	1171	3.4×10^6	3.6×10^5
$2_{\mathrm{rot}}^+ \rightarrow 2_1^+$	926	7.9×10^4	1×10^4
$4_{\mathrm{rot}}^+ \rightarrow 2_{\mathrm{rot}}^+$	546	8.2×10^4	1.3×10^4

Table 1: Expected rates observed in AGATA-SAURON in particle-γ-γ coincidence

The rates for higher level transitions ($6_{\mathrm{rot}}^+ \rightarrow 4_{\mathrm{rot}}^+$, $8_{\mathrm{rot}}^+ \rightarrow 6_{\mathrm{rot}}^+$ etc...) are expected to be similar but slightly lower than the $4_{\mathrm{rot}}^+ \rightarrow 2_{\mathrm{rot}}^+$ rates. If the statistics are sufficient, higher-order intra-band coincidence will also be investigated, but the expected rate is two orders of magnitude lower. From the systematics of Fig. 1, each intra-band transition is expected to be between 500 to 900 keV, where the AGATA efficiency is $10-15$%.

In summary, we ask for

- Beam: ^{7}Li, 2 pnA, 30 MeV;
- Target: 1 mg/cm^2 of ^{116}Cd;
- Experimental Setup: AGATA + SAURON;
- Beam time: 5 days including 1-2 shifts for excitation function

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