The investigation of the rotational band in ^{120}Sn using fusion-evaporation

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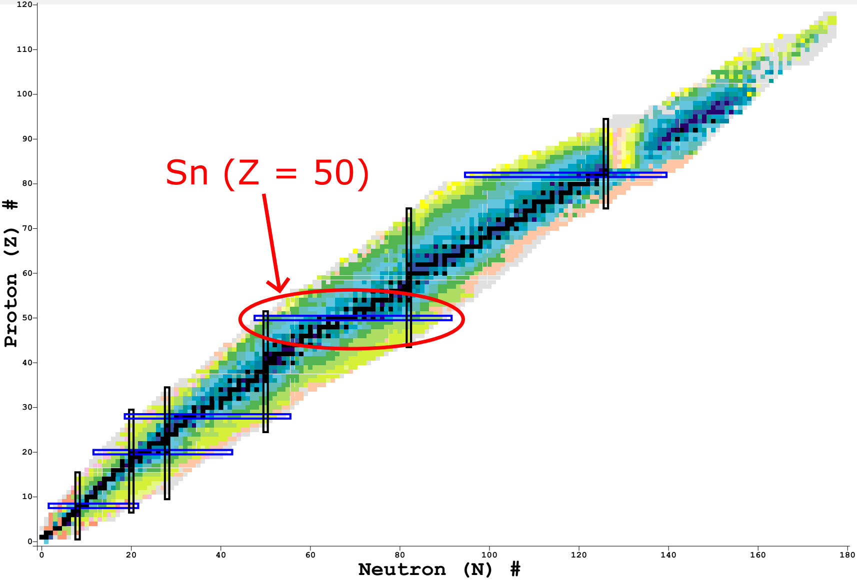
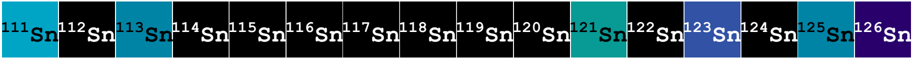
Sn on the chart of nuclides



NNDC

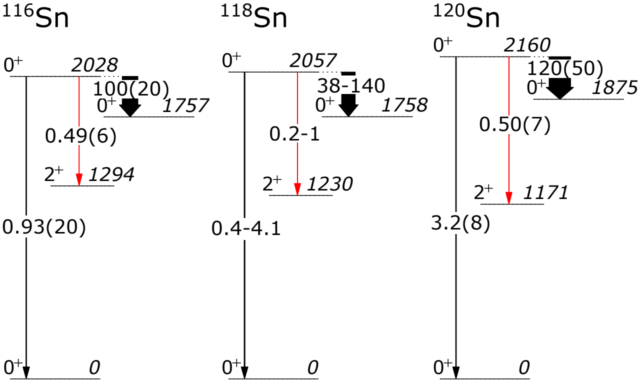
Sn offers an unique opportunity to study shell evolution



- Very long isotopic chain
  - Across the $N = 50$ and $N = 82$ shell closures.
  - Ten stable isotopes: rich spectroscopic data available in literature.
- Shape coexistence
  - Observed in mid-shell Sn nuclei.
  - $\pi\ 2p - 2h$: enhanced $\pi - \nu$ interaction in ν mid-shell.
  - Multiple shapes?

NNDC

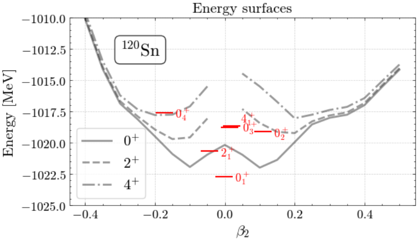
The excited $0^+_{2,3}$ states are deformed in ^{120}Sn

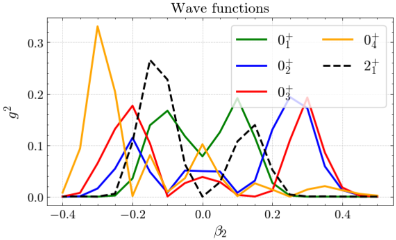


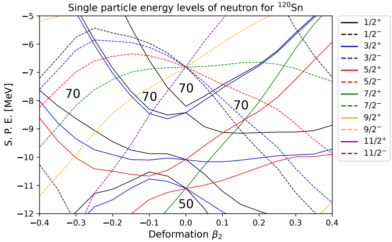
- We recently measured in ^{120}Sn $\rho^2(E0; 0^+_3 \to 0^+_2)$ 17× higher than the 2022 $E0$ review in PPNP.
- The large $\rho^2(E0)$ indicates strong mixing and large shape difference.
    - Minimum of $\Delta\beta_2 > 0.23$ between the 0^+_2 and 0^+_3.

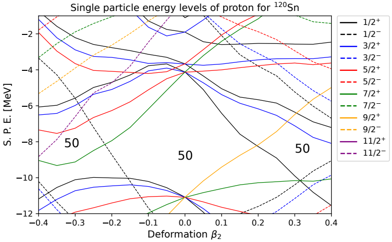
Wu et al. PRC 111 L051307 (2025)

CDFT calculations also shows deformation





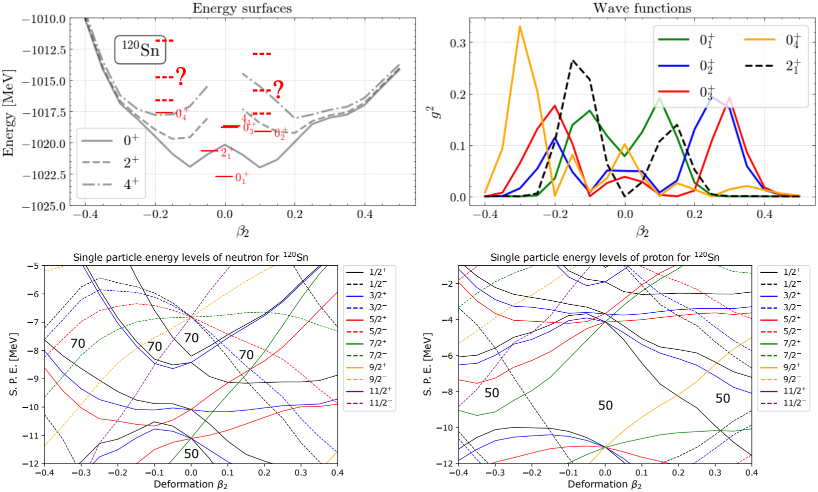




- Two group of states: seniority near-spherical-vibrational g.s. band and two $2p - 2h$ deformed excited 0^+ states.

CDFT-GCM calculations by C.R. Ding et al., based on Ding et al. PRC 108 054304 (2023), Yao et al. PRC 81 044311 (2010)

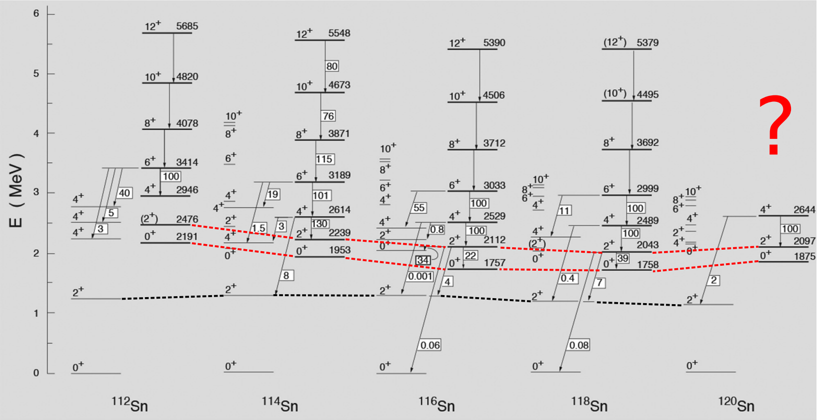
CDFT calculations also shows deformation



- Could there be collective excitations built on the two $2p-2h$ deformed excited 0^+ states? Intruder/rotational band(s)?

CDFT-GCM calculations by C.R. Ding et al., based on Ding et al. PRC 108 054304 (2023), Yao et al. PRC 81 044311 (2010)

Rotational band on the deformed 0^+ states?

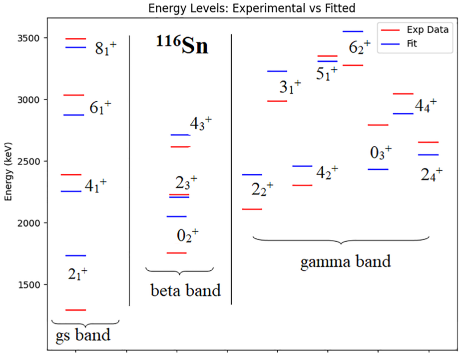


- Very little information on the intruder band(s) in ^{120}Sn.
  - 2644-keV 4_3^+ state as tentative band member vs. the 2466-keV 4_2^+?
  - Transitions from higher-spin members are critical for band assignment.

D.J. Rowe, J.L. Wood, Fundamentals of Nuclear Models: Foundational Models (2010)

Band mixing proposed in ^{116}Sn: also in ^{120}Sn?

- Recently, DFT and collective model calculations suggested multiple-shape coexistence and vibrational-rotational band mixing in ^{116}Sn.



- Calculation by Jalili et al. is underway for ^{120}Sn.
- Experimental level energies of the intruder (rotational) band is required for comparison with theory.

Jalili et al. PRC 111 064301 (2025)

Clear gap in nuclear data

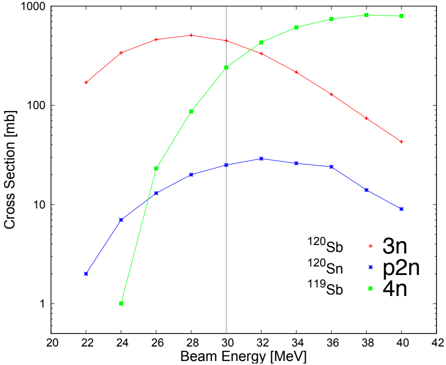
- The excited 0^+ states in ^{120}Sn are deformed.
- Rotational band observed in $^{112-118}$Sn.
- Intruder band is expected in ^{120}Sn, but not observed.
  - Energy spacing and linking transitions?
  - Excitation mode of the band?
  - Mixing between the intruder and g.s. bands?
  - Multiple bands like Pb?

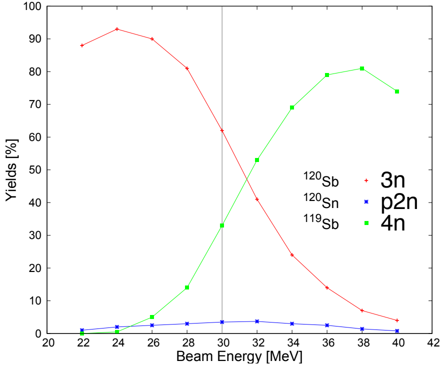
Goals of the experiment

- Identify and assign high-spin members of the intruder band(s) in ^{120}Sn.
- From the intra-band energy spacing:
  - $\Delta E = \dfrac{\hbar J(J+1)}{2I}$ if the band is purely rotational: $\beta_2^2 \propto I$.
  - Deviation would suggest involvement of other excitation modes.
- From the inter-band linking transitions:
  - Band mixing at different spins.
- Theory support is available to interpret the results.

The fusion evaporation experiment

- Reaction: ^{116}Cd(^{7}Li, p2n)^{120}Sn with $E_{\text{beam}} = 30$ MeV (Tandem).
- Compound formation ^{123}Sb: $E_{\text{exi}} = 44$ MeV at $18\hbar$.
- ^{120}Sn populated at $12 - 15\hbar$ and ≈ 20 MeV.





- PACE4: Clean reaction-channel selection with proton tagging.

Lunardi et al. Z. Phys. A 328 487 (1987) performed the same reaction at LNL: γ singles without charged-particle tagging.

^{120}Sn fusion-evaporation at LNL

Reaction: ^{116}Cd(^{7}Li,$p2n$)^{120}Sn:

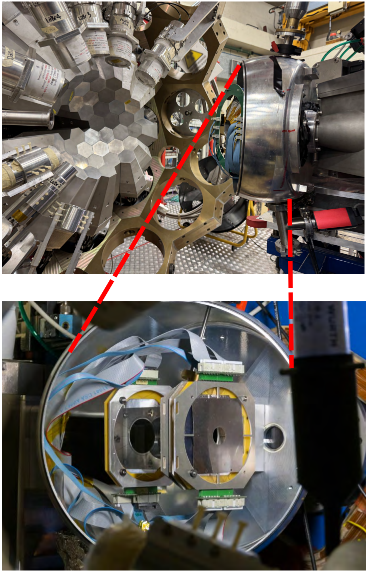
Gamma-ray detection: AGATA:

- $\epsilon_\gamma = 10 - 15\%$ at 500 - 900 keV.
- High position sensitivity.

Charged-particle identification: SAURON:

- 2 S1 detectors forward and backward.
- $\epsilon_{\boldsymbol{p}} = 25\%$ with PSA for PID.
- 150 μm Al absorber in forward angle.

The $p - \gamma - \gamma$ coincidences at high efficiencies will allow for the identification and placements of weak transitions like never before.



The fusion evaporation experiment

- Assuming $\epsilon_\gamma = 10 - 15\%$ at the expected E_γs and
- $\epsilon_p = 25\%$ for SAURON at 3 cm:

$J_i^\pi \to J_f^\pi$	E_γ [keV]	p-γ/day	p-γ-γ/day
$2_1^+ \to 0_{g.s.}^+$	1171	3.4×10^6	3.6×10^5
$2_{\rm rot}^+ \to 2_1^+$	926	7.9×10^4	1×10^4
$4_{\rm rot}^+ \to 2_{\rm rot}^+$	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 ($6_{\rm rot}^+ \to 4_{\rm rot}^+$, $8_{\rm rot}^+ \to 6_{\rm rot}^+$ etc...) are expected to be similar but slightly lower than the $4_{\rm rot}^+ \to 2_{\rm rot}^+$ rates.

Beam time request

- Considering the ambitious goals of the experiment, we ask for:
  - **Beam**: ^{7}Li, 2 pnA, 30 MeV (Tandem)
  - **Target**: ^{116}Cd, 1.0 mg/cm^2, self supporting
  - **Experimental setup**: AGATA + SAURON (+ $LaBr_3$)
  - **Beam time**: 5 days, including 1-2 shifts for excitation function.

Questions from the TAC

- *Which 4^+, 4_2^+ (2466) or 4_3^+ (2644), is a member of the intruder band?*
  - This is not clear. While the 4_3^+ is fed by the (6^+) at 3070-keV, which may suggest that the 4_3^+ is the intruder, no known transitions feeds into the 3070-keV level. More experimental information, such as decays from higher-spin members, is needed.
- *How was the cross section estimated? Are there neutron channels?*
  - The cross sections are calculated using PACE4. We expect two neutron channels (3n and 4n) with stronger cross sections than the p2n. The neutron channels can be cleaned out with proton-tagging in SAURON.
- *Elastic scattering of the beam in the target may cause possible issues.*
  - We propose to use a 40 mg/cm^2 (150 μm) Al absorber in front of the forward SAURON. This should fully stop the beam while only degrade proton energies by $\approx 2 - 3$ MeV.

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- Expanding list: Please let us know if you would like to collaborate!

Backup slide

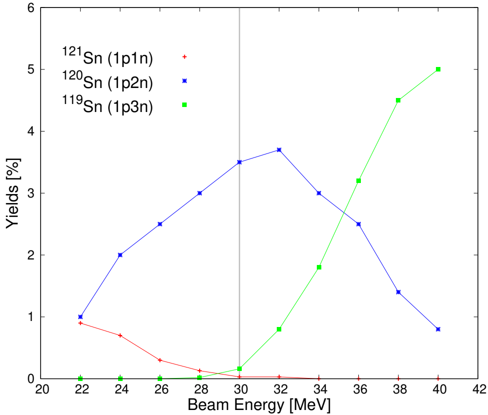

Figure: Yields of the Sn channels at different beam energies.