Beta-delayed gamma spectroscopy of ^{122}Ag: excited-state structure of ^{122}Cd

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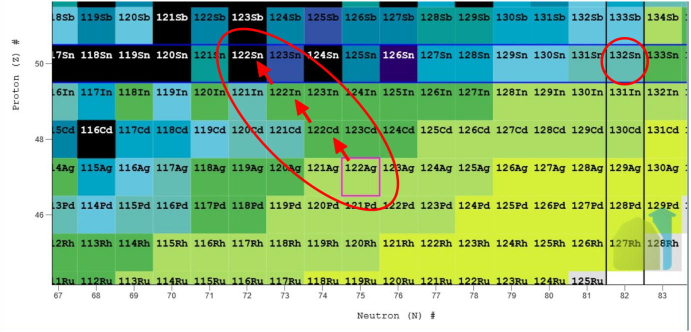
Motivation: Structural evolution near $^{132}\mathrm{Sn}$

- **Key Region:**
  Proximity to doubly-magic $^{132}\mathrm{Sn}$ ($Z = 50$, $N = 82$).
- **Cadmium Nuclei ($Z = 48$):**
  Two proton holes relative to $Z = 50$ shell closure.
- **$^{122}\mathrm{Cd}$ ($N = 74$):**
  Interplay between collectivity, single-particle states and seniority.

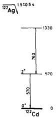


Source: nndc.bnl.gov/nudat3/

Core Questions

1. How does the β^- decay of $^{122}\mathrm{Ag}$ populate levels in $^{122}\mathrm{Cd}$?
2. How many long-lived isomeric states of $^{122}\mathrm{Ag}$ exist?

Previous studies of $^{122}\mathrm{Ag} \to {}^{122}\mathrm{Cd}$ decay



Fogelberg et al.

1971

OSIRIS (Studsvik)

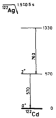
Ge(Li) γ-spec.

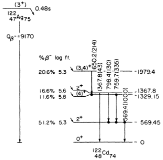
$^{122}\mathrm{Ag} \to {}^{122}\mathrm{Cd}$

decay observed

for the first time

Previous studies of $^{122}\mathrm{Ag} \to {}^{122}\mathrm{Cd}$ decay





Fogelberg et al. | **Shih et al.**

1971 — **1978**

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Ge(Li) / ISOL

First $^{122}\mathrm{Cd}$ level scheme

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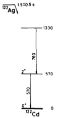

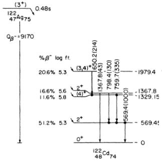

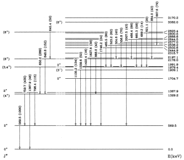

Fogelberg et al. | **Shih et al.** | **Zamfir et al.**

1971 — **1978** — **1995**

1971: OSIRIS (Studsvik)

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$^{122}\mathrm{Ag} \to {}^{122}\mathrm{Cd}$ decay observed for the first time

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Ge(Li) / ISOL

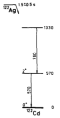
First $^{122}\mathrm{Cd}$ level scheme

1995: TRISTAN (BNL)

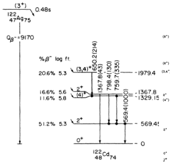
HPGe + BaF_2 (FEST)

Low-spin & 0^+ structure of $^{122}\mathrm{Cd}$

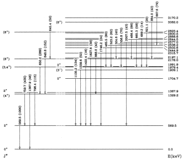
Previous studies of $^{122}\mathrm{Ag} \to {}^{122}\mathrm{Cd}$ decay



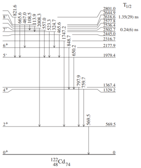
Fogelberg et al.



Shih et al.



Zamfir et al.



Smith et al.

1971 — **1978** — **1995** — **2008** →

1971 — OSIRIS (Studsvik)

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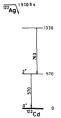
2008 — IGISOL (Jyväskylä)

HPGe + $LaBr_3$(Ce)

Lifetimes of 7^- and 8^- states in $^{122}\mathrm{Cd}$

Previous studies of $^{122}\mathrm{Ag} \rightarrow {}^{122}\mathrm{Cd}$ decay



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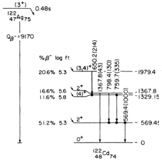

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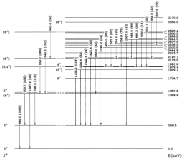

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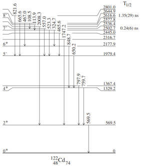

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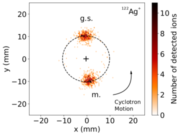


Jaries et al.

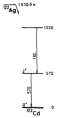
2024

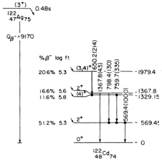
IGISOL JYFLTRAP (Jyväskylä)

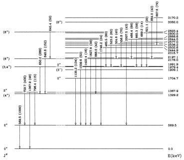
Penning trap (PI-ICR)

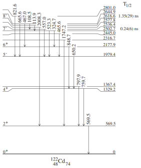
Long-lived $^{122}\mathrm{Ag}$ isomers

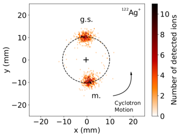
Previous studies of $^{122}\mathrm{Ag} \to {}^{122}\mathrm{Cd}$ decay





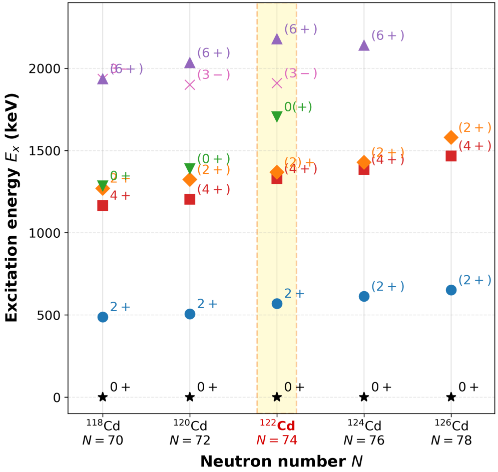




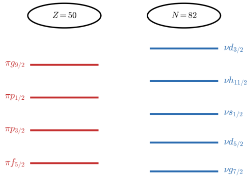


Fogelberg et al.	Shih et al.	Zamfir et al.	Smith et al.	Jaries et al.	Present work
1971	1978	1995	2008	2024	2026
OSIRIS (Studsvik)	TRISTAN (Ames)	TRISTAN (BNL)	IGISOL (Jyväskylä)	IGISOL JYFLTRAP (Jyväskylä)	IGISOL JYFLTRAP (Jyväskylä)
Ge(Li) γ-spec.	**Ge(Li) / ISOL**	**HPGe + BaF_2 (FEST)**	**HPGe + $LaBr_3$(Ce)**	**Penning trap (PI-ICR)**	**HPGe decay spec.**
$^{122}\mathrm{Ag} \to {}^{122}\mathrm{Cd}$ decay observed for the first time	First $^{122}\mathrm{Cd}$ level scheme	Low-spin & 0^+ structure of $^{122}\mathrm{Cd}$	Lifetimes of 7^- and 8^- states in $^{122}\mathrm{Cd}$	Long-lived $^{122}\mathrm{Ag}$ isomers	High-precision decay study

Cadmium systematics: Daughter level structure ($Z = 48$)

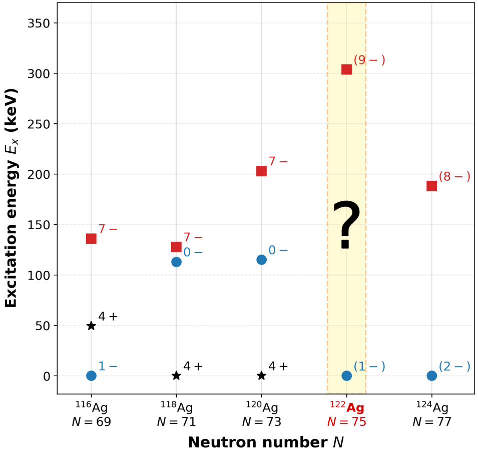


Data source: ENSDF / NNDC Adopted Levels (A = 118–126).



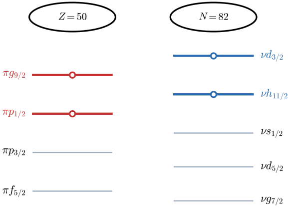
- **Proton-hole structure:** Two proton holes below $Z = 50$ lead to a smooth $(2^+, 4^+, 6^+)$ sequence.
- **Core question:** Which of these established levels are directly populated in the β decay of $^{122}\mathrm{Ag}$?
- **Spectroscopy goal:** Identify new levels and weak γ transitions to ensure accurate β-feeding values.

Silver systematics: Parent states in $^{122}\mathrm{Ag}$ $(Z = 47)$



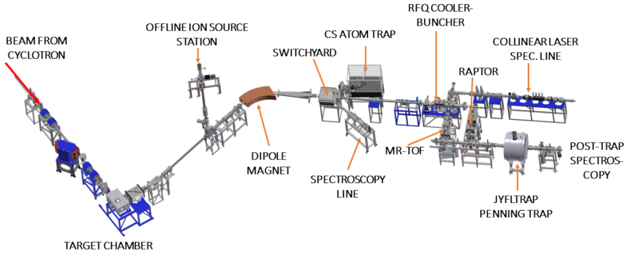
Data sources: ENSDF / NNDC Adopted Levels ($A = 116$–124),
A. Jaries et al. Phys. Rev. C 110 (2024),
B. van den Borne et al. Phys. Rev. C 111 (2025).

- Low-Spin State (g.s.)
  $J^\pi = (1^-)$, $T_{1/2} = 0.55(5)$ s
  $\pi(p_{1/2})^{-1} \otimes \nu(d_{3/2})^{-1}$
- High-Spin Isomer (~ 300 keV)
  $J^\pi = (9^-)$, $T_{1/2} = 0.20(5)$ s
  $\pi(g_{9/2})^{-1} \otimes \nu(h_{11/2})^{-1}$ multiplet (1^- to 10^-)



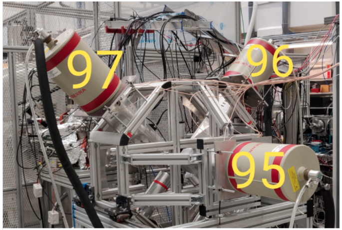
- Is 9^- physically consistent or could it be another state from the multiplet?
- Where is the expected positive-parity multiplet? $(\pi g_{9/2}^{-1} \otimes \nu d_{3/2}^{-1})$?

Experimental setup: IGISOL & JYFLTRAP



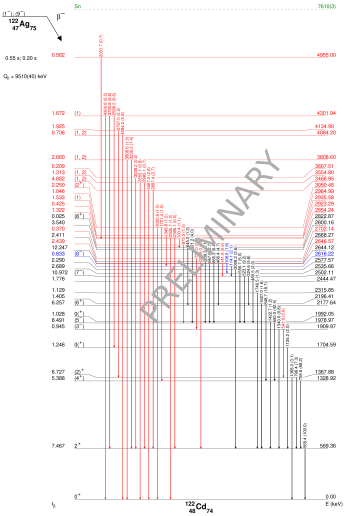
University of Jyväskylä, IGISOL facility layout.

- Proton beam energy: **30 MeV**
- Target: **uranium-molybdenum alloy** (15 mg/cm^2)
- Beam purification: **JYFLTRAP** (no isomeric separation)



- **3 HPGe** Clover detectors (8 MeV energy range)
- **2 single-crystal Canberra coaxial HPGe** detectors
- **Plastic** β scintillator
- **Saturation mode** – no tape movement (decay products build up to equilibrium)

Extended ^{122}Ag $\rightarrow$ ^{122}Cd decay scheme



Color Legend

Known (evaluated) — Known (unevaluated) — New (present work)

Scheme Topology

- Low-spin path populated via 1^- decay
- High-spin path populated via 9^- decay
- Major extension of the decay scheme:
  - 15 new levels identified
  - 24 new placed transitions
  - 3 previously reported levels and transitions modified or removed
- Unplaced weak transitions:
  - Low statistics or ambiguous coincidence gates
  - Represent minor fraction of total γ intensity

Unexpected Apparent β Feedings ($^{122}\mathrm{Ag} \rightarrow {}^{122}\mathrm{Cd}$)

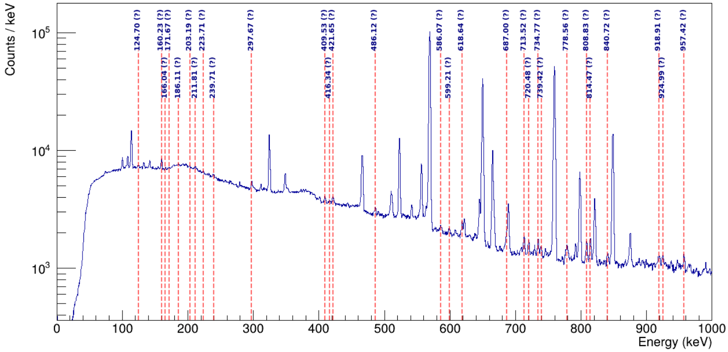
Parent J^π	Daughter J^π	E_x (keV)	I_β	log *ft* (non-unique)
1^-	4^+	1329.2	$\sim 5\%$	~ 6
1^- or 9^-	5^-	1979.0	$\sim 8.5\%$	< 6
9^-	6^+	2177.9	$\sim 6\%$	~ 6
9^-	7^-	2502.7	$\sim 11\%$	< 6

Transition types

- Based on spin difference $\rightarrow$ **2nd, 3rd or 4th forbidden** transitions
- Based on log *ft* values $\rightarrow$ **allowed or 1st forbidden** transitions

Direct 2nd, 3rd and 4th forbidden feeding of this strength is **extremely unlikely!**

Explanation 1: Pandemonium effect & Unplaced γ transitions



Unidentified peaks in the 0 — 1000 keV $\beta\gamma$ spectrum fragment.

The Pandemonium Scenario

- High Q_β window populates high-density states.
- Numerous weak γ transitions visible in $\beta\gamma$ spectrum.
- Low statistics in $\beta\gamma\gamma$ spectra prevents firm coincidence placement.
- Unobserved γ feeding from above artificially inflates apparent β-feedings.

Explanation 2: Spin Misassignments & Tentative Levels

Parent J^π candidate	Configuration candidate	Daughter J^π	E_x (keV)	I_β	log ft
6^-	$\pi(g_{9/2})^{-1} \otimes \nu(h_{11/2})^{-1}$	4^+	1329.2	$\sim 5\%$	~ 8
6^-	$\pi(g_{9/2})^{-1} \otimes \nu(h_{11/2})^{-1}$	5^-	1979.0	$\sim 8.5\%$	< 6
6^-, 7^- or 8^-	$\pi(g_{9/2})^{-1} \otimes \nu(h_{11/2})^{-1}$	6^+	2177.9	$\sim 6\%$	~ 6 / ~ 8
6^-, 7^- or 8^-	$\pi(g_{9/2})^{-1} \otimes \nu(h_{11/2})^{-1}$	7^-	2502.7	$\sim 11\%$	< 6

Uncertainty in Parent Isomer Spin ($^{122}\mathrm{Ag}$)

- High-spin isomer in $^{122}\mathrm{Ag}$ is tentatively assigned (9^-) based on the $\pi(g_{9/2})^{-1} \otimes \nu(h_{11/2})^{-1}$ multiplet.
- Lower spin couplings cannot be ruled out; a 8^-, 7^- or 6^- parent permits allowed and 1st forbidden (non-unique and unique) transitions to known daughter states in $^{122}\mathrm{Cd}$.

Explanation 3: Evidence for a 3rd isomer in $^{122}\mathrm{Ag}$?

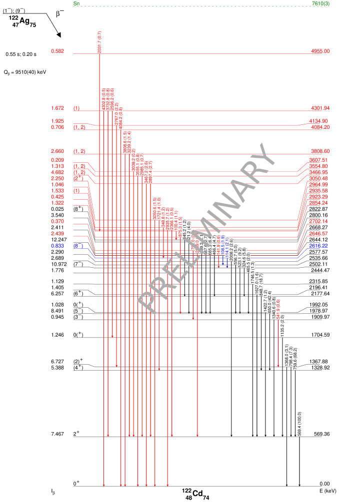
Parent J^π candidate	Configuration candidate	Daughter J^π	E_x (keV)	I_β	log *ft* (non-unique)
5^+	$\pi(g_{9/2})^{-1} \otimes \nu(d_{3/2})^{-1}$	4^+	1329.2	$\sim 5\%$	~ 6
?	$\pi(g_{9/2})^{-1} \otimes \nu(d_{3/2})^{-1}$	5^-	1979.0	$\sim 8.5\%$	< 6
5^+	$\pi(g_{9/2})^{-1} \otimes \nu(d_{3/2})^{-1}$	6^+	2177.9	$\sim 6\%$	~ 6
?	$\pi(g_{9/2})^{-1} \otimes \nu(d_{3/2})^{-1}$	7^-	2502.7	$\sim 11\%$	< 6

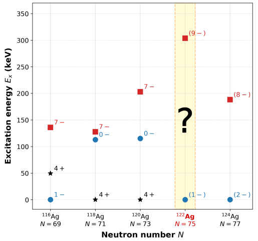
- An intermediate-spin isomer ($J^\pi = 5^+$) in $^{122}\mathrm{Ag}$ could directly feed 4^+ and 6^+ states via allowed GT decay.
- However, it does not explain feedings to 5^- and 7^- states.

What supports the existence of 3rd isomer?

- **Jaries et al. (2024):** PI-ICR non-observation $\implies \Delta E < 25$ keV.
- **Lalkovski et al. (2013):** Proposed an isomer at $\mathbf{E_x \approx 22}$ **keV**, based on the level systematics in the neighbouring indium isotopes. Fits remarkably inside PI-ICR blind spot!

- **Decay Scheme Extension:** High-statistics $\beta\gamma$ spectroscopy at IGISOL yielded an expanded level scheme for $^{122}\mathrm{Ag} \rightarrow {}^{122}\mathrm{Cd}$.
- **Resolution of Feeding Puzzle:** Apparent forbidden β-feeding to 4^{+}, 6^{+}, 5^{-} and 7^{-} states evaluated via three scenarios:
    1. *Pandemonium effect* – unplaced γ cascades.
    2. High spin misassignment in $^{122}\mathrm{Ag}$ isomer.
    3. Existence of a **3rd β-decaying isomer** (5^{+}, $\Delta E < 25$ keV), consistent with Lalkovski (22 keV) & JYFLTRAP bounds.
- $^{122}\mathrm{Ag}$ and $^{122}\mathrm{Cd}$ will return...





ENSDF / NNDC Adopted Levels (A = 116–124)
A. Jaries et al. Phys. Rev. C 110 (2024)
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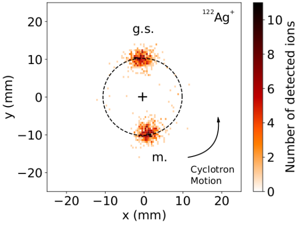

A. Jaries et al. Phys. Rev. C 110 (2024)

Acknowledgements & Collaboration

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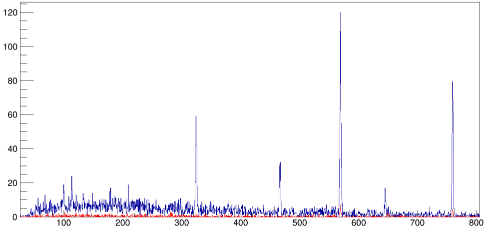
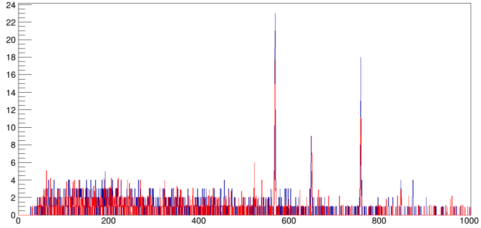
S. Ujeniuc (IFIN-HH Bucharest)
V. Virtanen (Univ. of Jyväskylä)
A. Weaver (Univ. of Brighton)

Thank you for your attention!

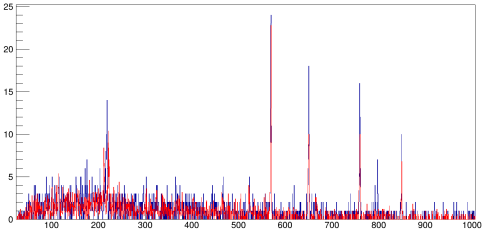
Backup: $\gamma\gamma$ coincidence spectra



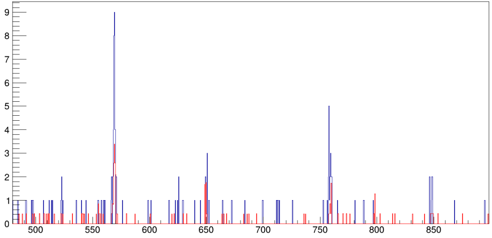
Gate on 849 keV



Gate on 778 keV

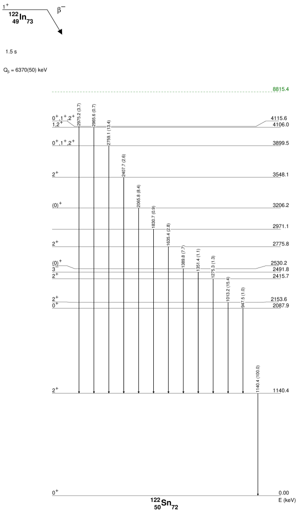


Gate on 541 keV



Gate on 1667 keV

Backup: $^{122}\mathrm{In} \rightarrow {}^{122}\mathrm{Sn}$ decay scheme



- No new levels nor transitions found in $^{122}\mathrm{Sn}$
- Known levels and gammas were confirmed
- No transitions in $^{122}\mathrm{In}$ were observed because $^{122}\mathrm{Cd}$ g.s. 0^+ decays directly into 1^+ $^{122}\mathrm{In}$ g.s. (allowed transition)

Backup: References

1. B. Fogelberg *et al.*, Phys. Scr. **3** (1971) 237.
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