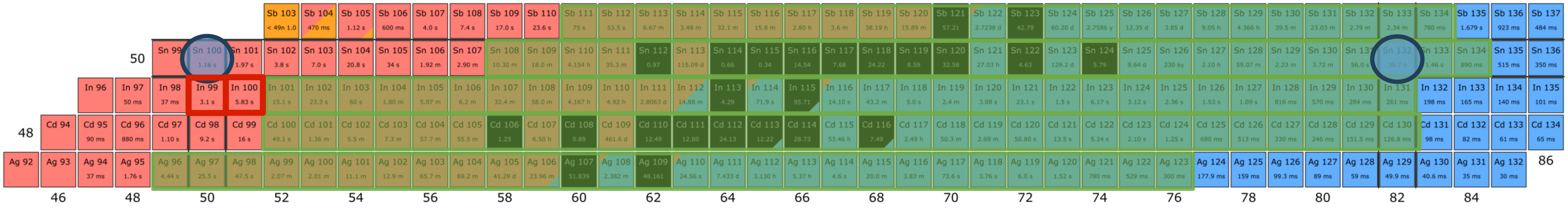
Collinear resonance ionization of neutron-deficient indium: closing up on $N = 50$

Jessica Warbinek

CRIS collaboration meeting 2025, Leuven

Introduction



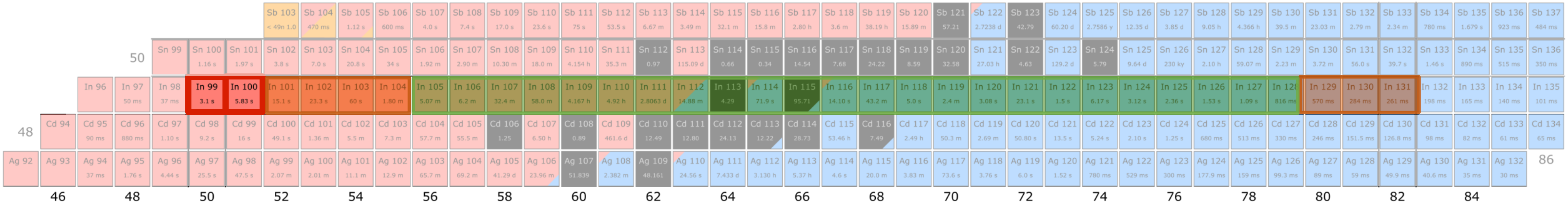
This proposal

(Un-)published laser spectroscopy

Studying the shell structure around doubly magic ^{100}Sn

- Testing the shell model under extreme conditions
- Robustness of N=50 near Z=50, towards dripline
- Proton-neutron interactions near shell closure
- Role of electro-weak currents

Previous indium runs at CRIS



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Recent CRIS results

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- Proton-neutron interactions near shell closure
- Role of electro-weak currents

Studying In isotopes at CRIS, with one p-hole to ^{100}Sn

- Studying nuclear structure evolution approaching N=50 and N=82
- Correlations of single proton hole with n / n-holes

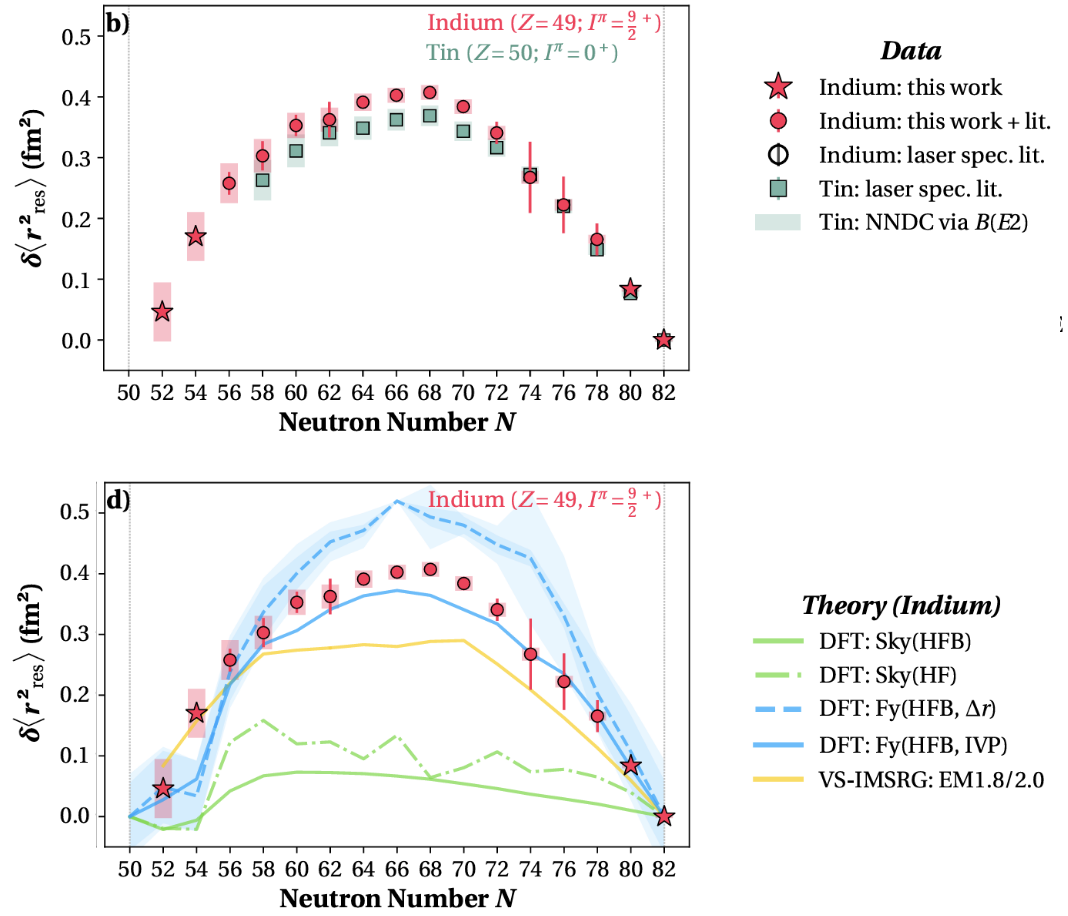
^{99,100}In: pin-point the evolution of nuclear structure, sensitive to the presence of mixed configurations, benchmarking nuclear theory, investigating magicity of N=50

Charge radii of neutron-deficient In

Changes in mean square charge radii:
A sensitive probe to study the evolution of nuclear size and deformation

- Kink in charge radii: probe for shell closure
- Odd-even staggering: many body correlations & local effects

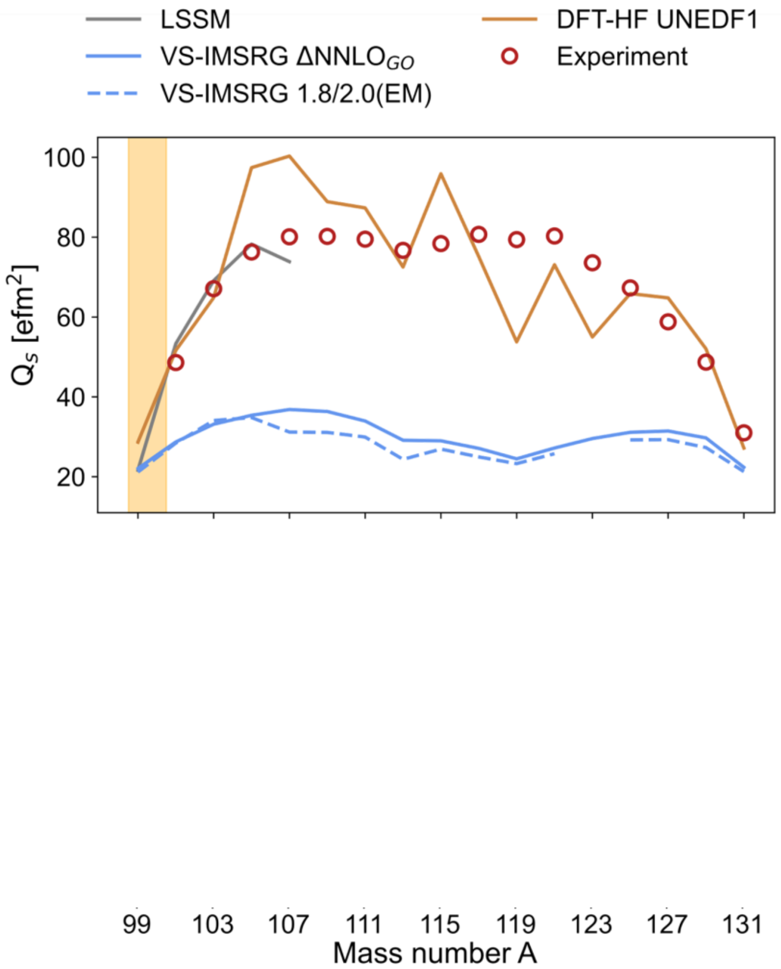
- Benchmarking nuclear theory models: Predictions for indium by DFT and ab-initio frameworks available, discrepancies observed towards N=50



M. Reponen et al., Nat. Commun. 12, 4596 (2021).
J. Karthein et al., Nat. Phys. (2024).
J. Karthein et al., arXiv preprint 2310.15093 (2023).

Nuclear moments and spins of In nuclei

Electric quadrupole moments:
Reflects the evolution of collectivity towards mid-shell
Probe arising collectivity beyond shell closure
Reflects arising deformation



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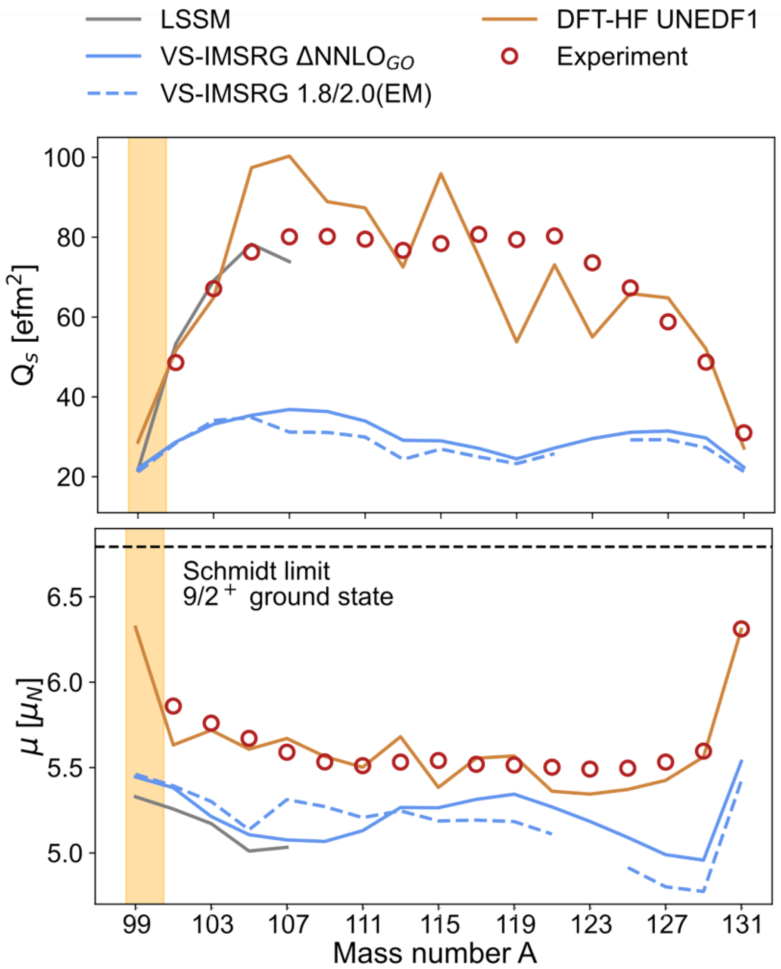
Magnetic dipole moments:
A sensitive probe to study the interplay between the single particle structure and many-body correlations.
Reflect the strength of a shell closure
Ordering of shell model levels and leading configuration for odd-odd nuclei



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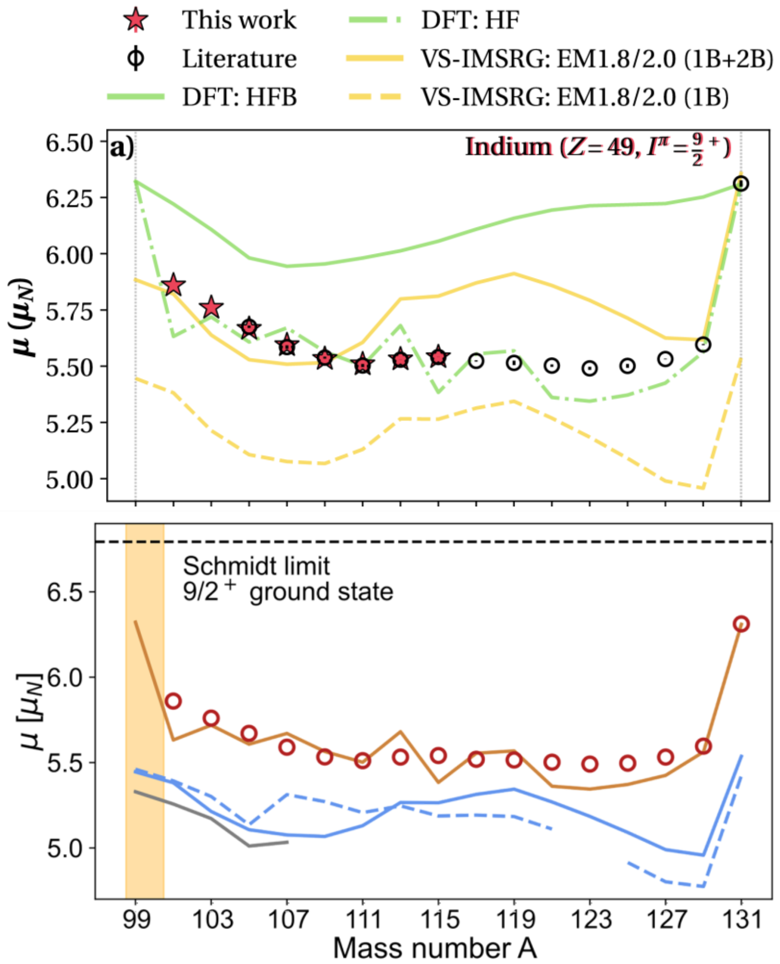

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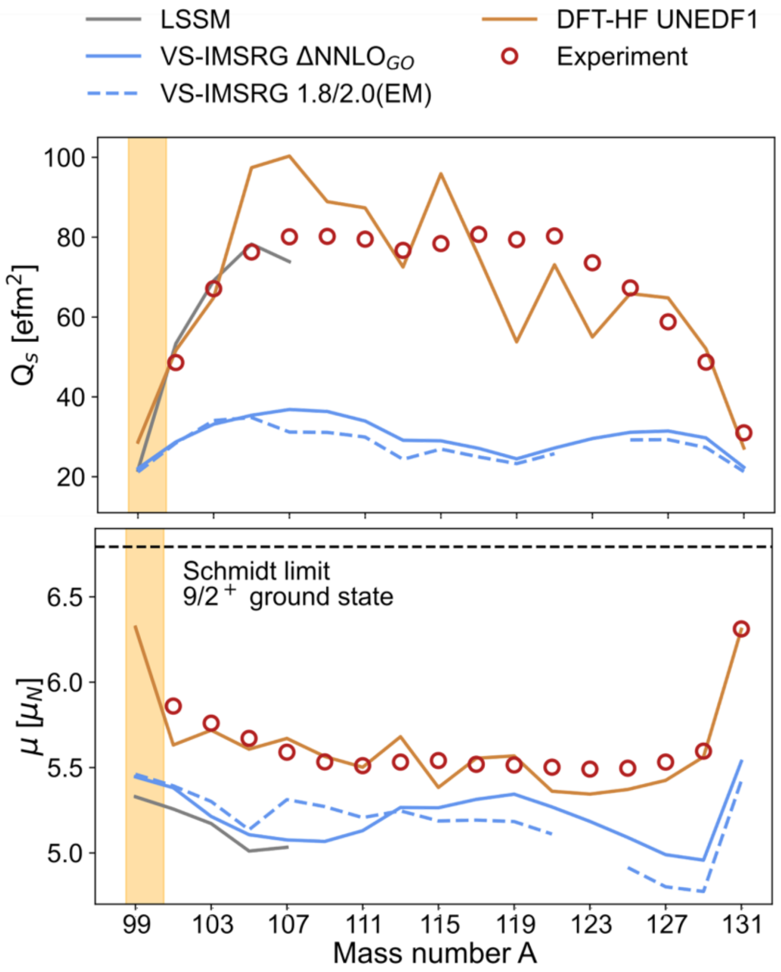
			?	(6⁺)	9/2⁺	(6⁺)	9/2⁺	6⁺	9/2⁺	7⁺	9/2⁺	7⁺	9/2⁺	7⁺	9/2
In 96	In 97	In 98	In 99	In 100	In 101	In 102	In 103	In 104	In 105	In 106	In 107	In 108	In 109	In 110	In 111
	50 ms	37 ms	3.1 s	5.83 s	15.1 s	23.3 s	60 s	1.80 m	5.07 m	6.2 m	32.4 m	58.0 m	4.167 h	4.92 h	2.8063
	48		50		52		54		56		58		60		62



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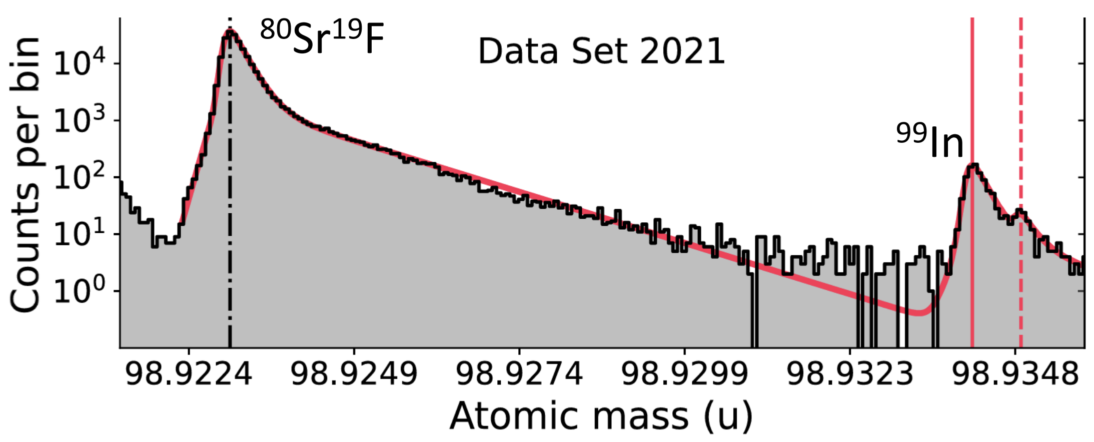
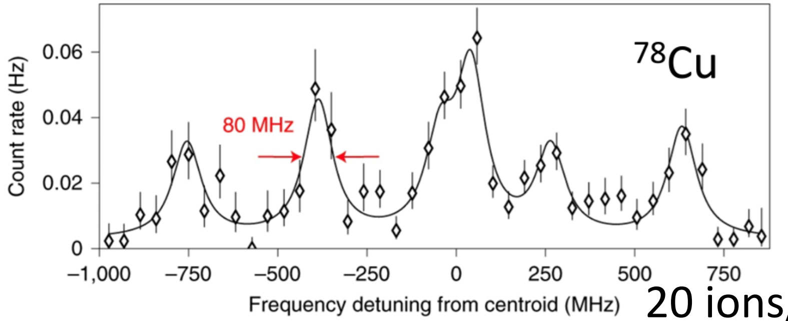
Challenge: low yields and large contamination



L. Nies et al., Phys. Rev. Lett. 131, 022502 (2023).

- In 2 days of measurements: no decrease in yield for ^{99}In
- Main contamination $^{81,80}SrF$ yields known from ISOLTRAP

→ CRIS technique selective, previously handled 3 orders of magnitude and more higher contamination

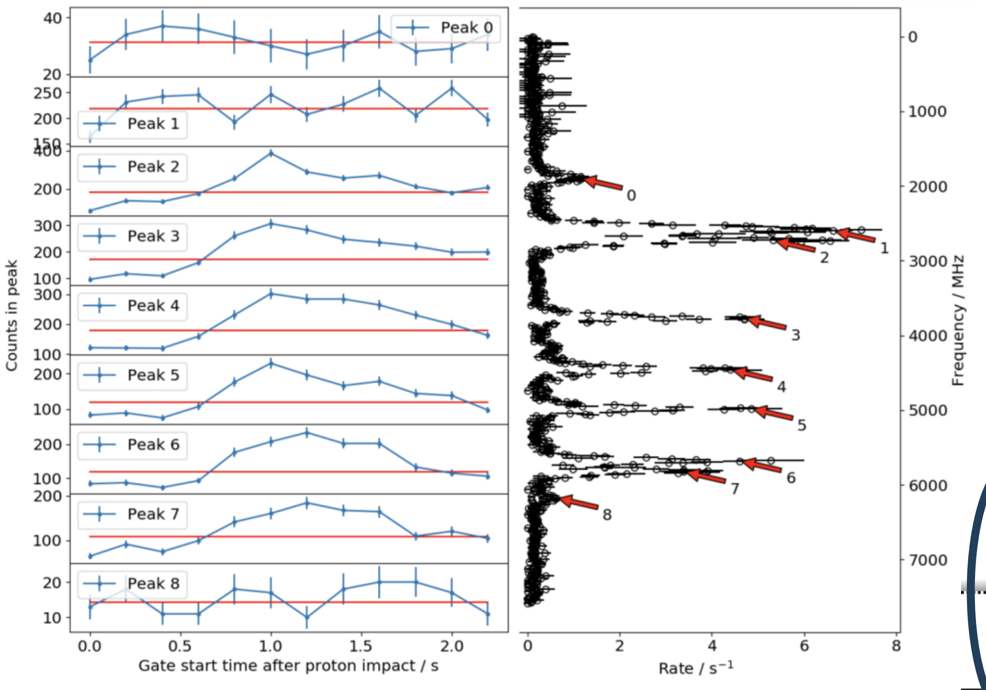


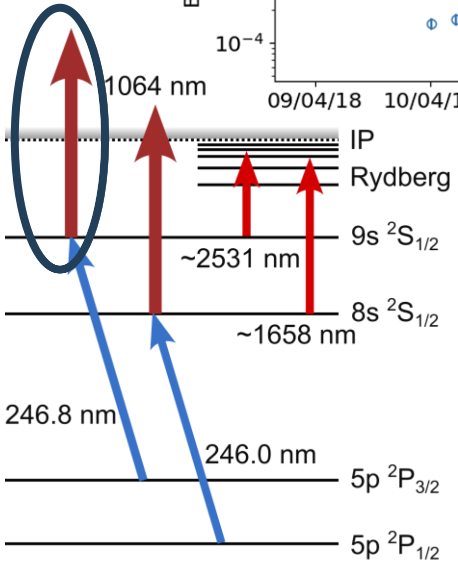
20 ions/s

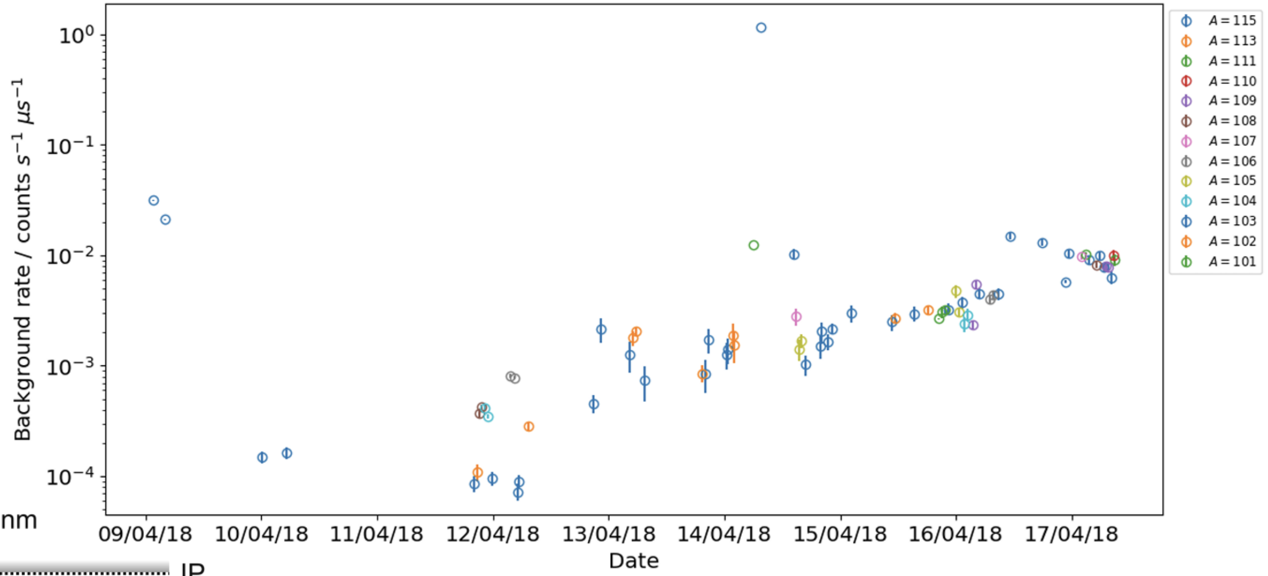
	Half live	Yields (/2μC)	Shifts	New results
$^{112-122}In$	> 1s	$> 10^4$	3	Reference
^{100}In	5.65(6) s	3×10^2	3	$I, \mu, Q_s, \delta\langle r^2\rangle$
^{99}In	3.1(2) s	5×10^0	15	$I, \mu, Q_s, \delta\langle r^2\rangle$
Stable		CRIS setup	3 (no protons)	

- Measurement done in 1 shift, single ion counting
- Similar CE cross section and transition strength
- Similar complex HFS

Limitations in previous runs







Resonant background observed
Suspected to come from 1064nm step
→ FIU required for suppression

Molybdenum contamination from target

Increasing background from long-lived contaminants decay on magnetof

→ FIU + Tape station for suppression

^{99}In	^{80}Sr
3.11 s	106.3 m

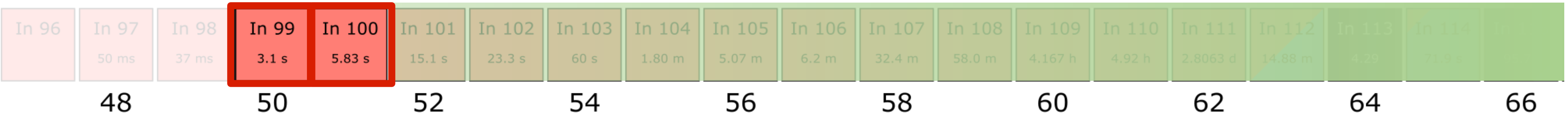
C. Ricketts, PhD thesis (2021).

Conclusion laser spectrosocpy

We propose to study neutron deficient indium isotopes closing up on the *N*=50 shell closure to investigate the structural evolution in the direct vicinity of in ^{100}Sn

- Assess the charge radii towards the shell gap for the onset of collectivity
- Determine spins which are only tentatively assigned
- Investigate g-factor and nuclear moments to investigate impact of the N=50 shell closure in In

This proposal



21+3 shifts using LaC_x target + RILIS ion source

Perform collinear resonance ionization laser spectroscopy using CRIS

Acknowledgments

The University of Manchester

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Massachusetts Institute of Technology

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CERN

sck cen

iPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

J. Warbinek[1], O. Ahmad[2], J. Berbalk[2,3], A. Belley[4], T.E. Cocolios[2], R.P. de Groote[2], C.M. Fajardo-Zambrano[2], K.T. Flanagan[5], R.F. Garcia Ruiz[4], J. Karthein[6], A. Koszorus[2,7], L. Lalanne[8], P. Lassegues[2], Y. Liu[9], K.M. Lynch[5], D. McElroy[5], A.C. McGlone[5], J. Munoz[4], G. Neyens[2], L. Nies[1], F. Pastrana[4], A. Raggio[10], J.R. Reilly[3], B. van den Borne[2], R. Van Duyse[2], J. Wessolek[3,5], S.G. Wilkins[4], X.F. Yang[9].

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[6]Department of Physics & Astronomy, Cyclotron Institute, Texas A&M University, TX 77840, USA
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[8]IPHC, Universite de Strasbourg, Strasbourg F-67037, France
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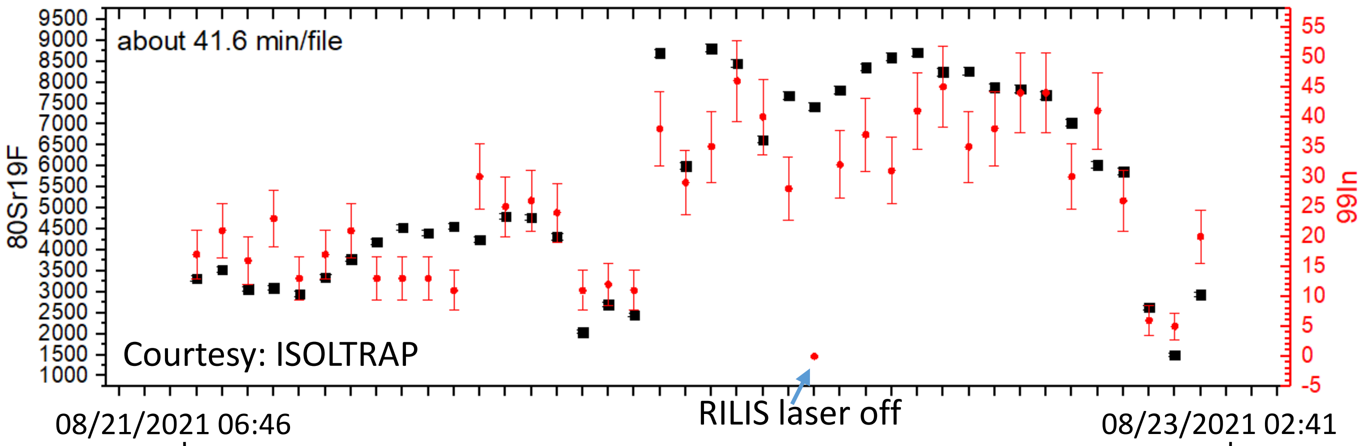
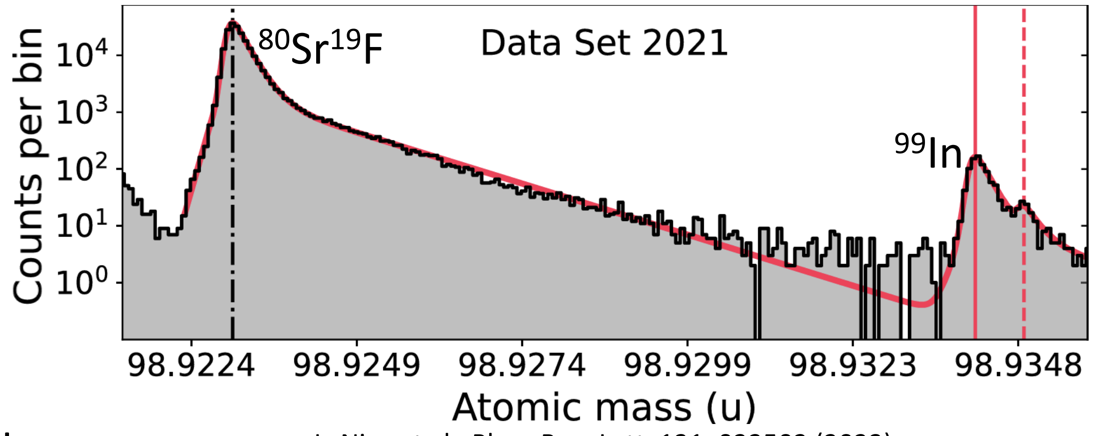
Challenge: low yields and large contamination



ISOLTRAP efficiency 0.3% to CA0 rate:

Corresponds to average of 4 cps in CA0
No drop observed in SrF or In

In 2 days of measurements: no decrease in yield observed
Conservative target heating ensured longevity

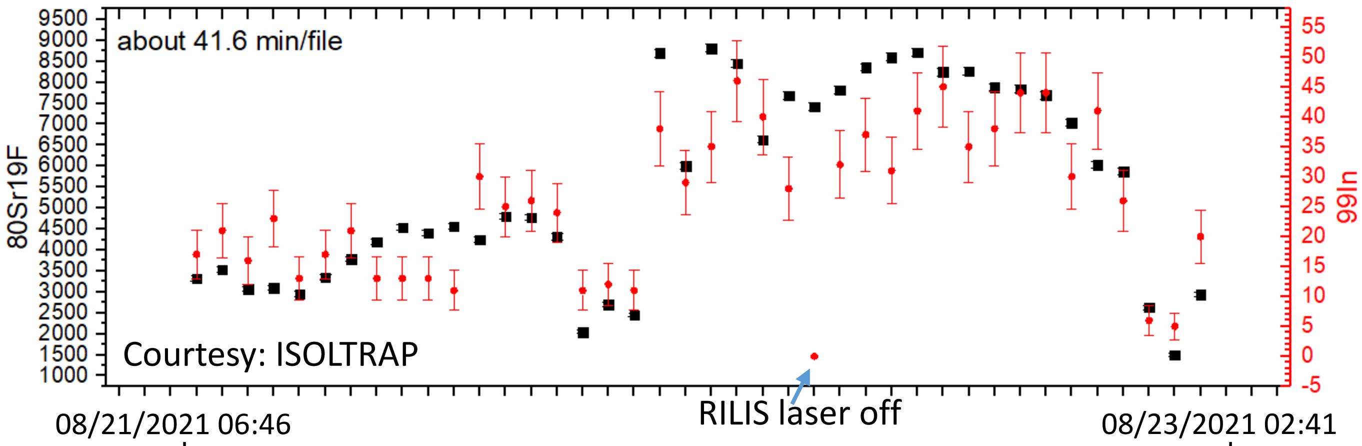


L. Nies et al., Phys. Rev. Lett. 131, 022502 (2023).

Accidental Mo contamination in target container: increased background on mass 100 hindered ^{100}In in 2018

(Resonant) background for ^{100}In from laser scheme on SrF observed

Challenge: low yields and large contamination



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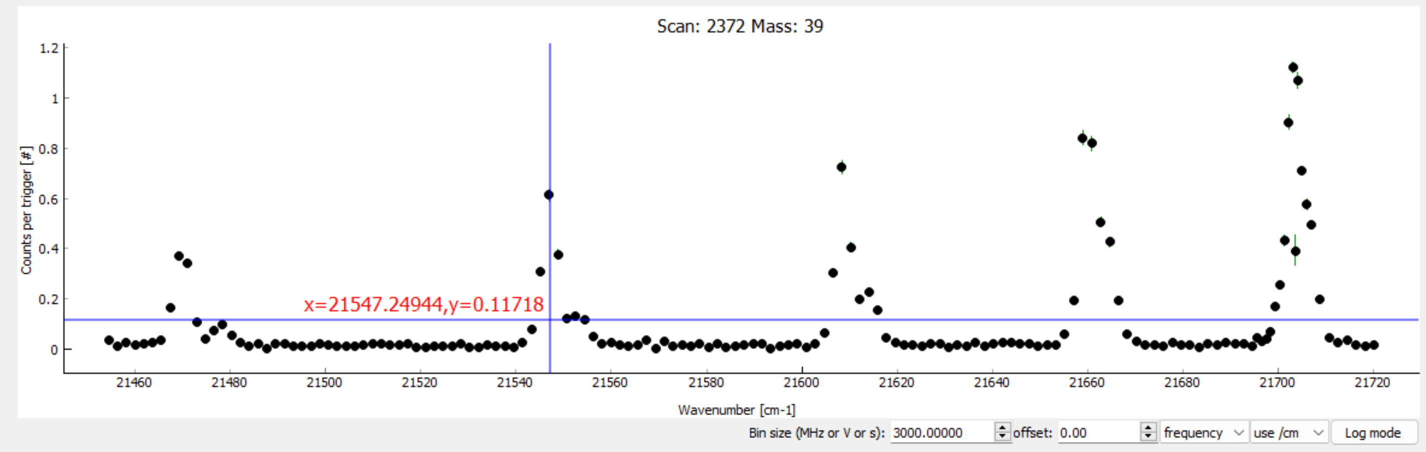
TAC comments:

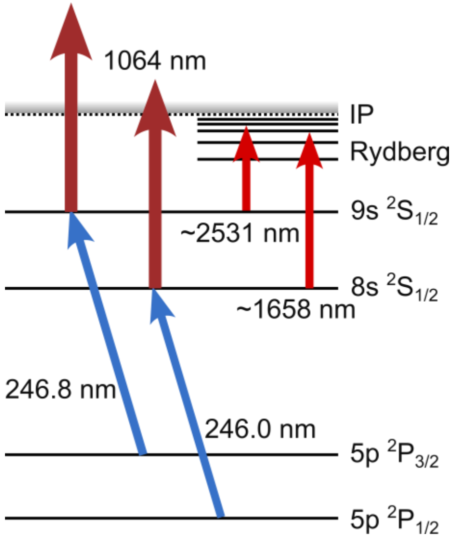
- Contamination mainly from SrF (as in case of IS661) -> should be removed by tape station on experiment side -> Recommend proton trigger to handle SrF – In is likely faster ✔ setup prepared on CRIS side
- For such exotic cases RILIS would certainly be operated with both 1st steps from gs and first thermal ✔ increase yield by ~20%

Field ionization unit + Decay station



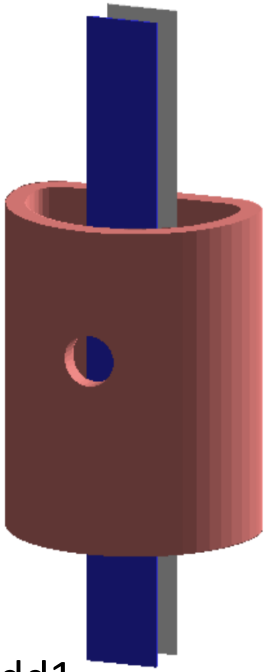
Field ionization unit successfully implemented in CRIS

Principle shown with stable K beam from ISOLDE



Laser background from 1064 observed from molecular species during ^{101}In experiment

FIU via Rydberg state makes high power laser obsolete



Upgraded CRIS decay station available with new plastic scintillators: enhanced sensitivity

T.E. Cocolios, IS682 – Add1

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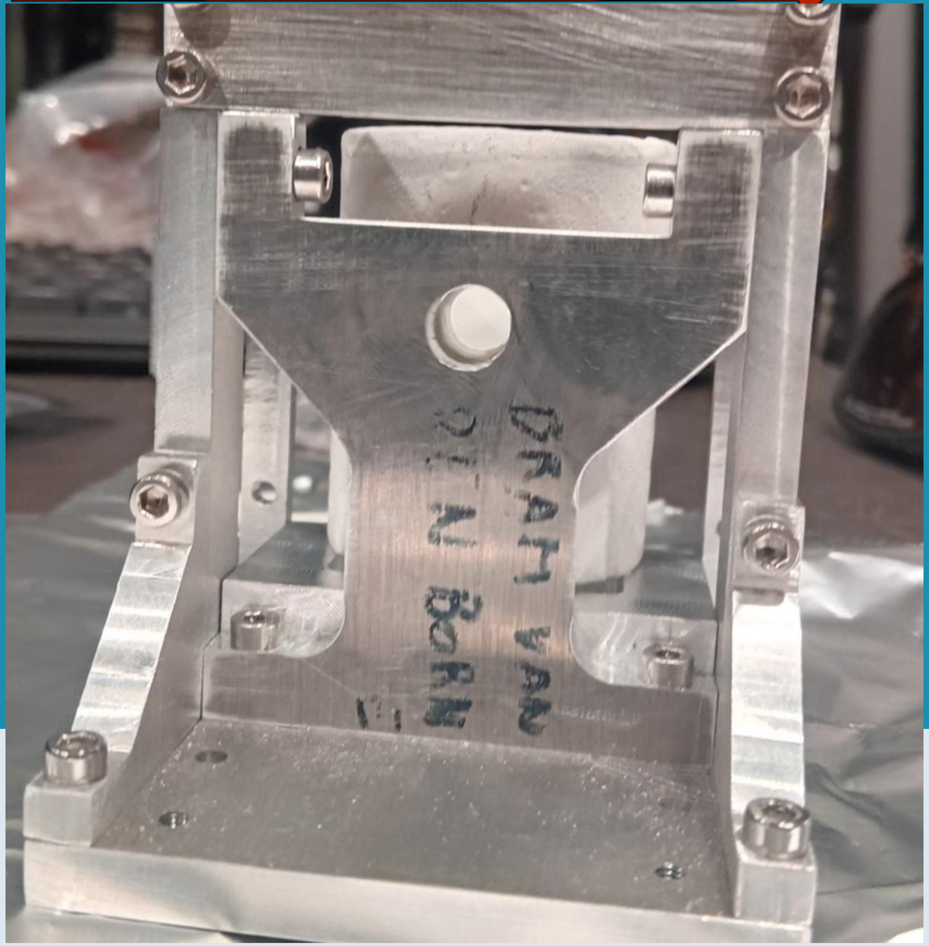
Indium decay options with CRIS DSS



Simone Casci

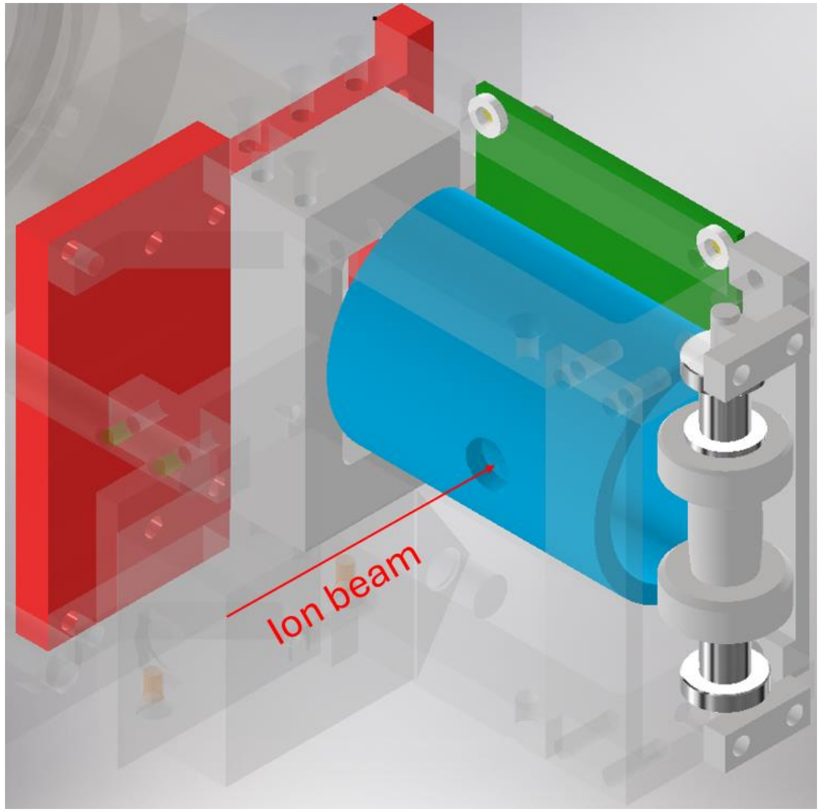
Supervisor: Prof. Thomas Elias Cocolios

Co-Supervisor: Prof. Gerda Neyens, Prof. Xiaofei Yang

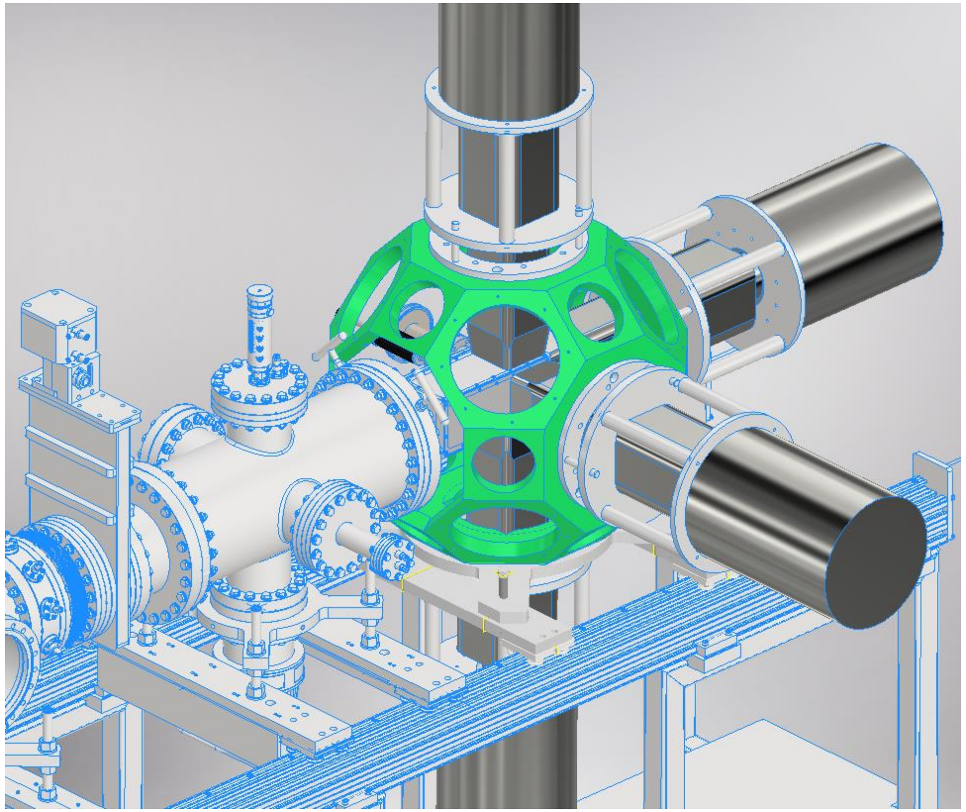
CRIS Decay Spectroscopy Station (DSS)

→ Talk on DSS commissioning tomorrow

Beta detection (simulated ε > 60%)



Gamma detection (average ε ~ 5% from IDS)



Measurement opportunities with CRIS DSS

1. β tagging of ions (Decay-Assisted Laser Spectroscopy):
   - Background suppression from stable[1] and long-lived (tape station) contaminants in hyperfine spectra

2. Decay measurements on ion beam from CRIS (Laser-Assisted Decay Spectroscopy[2]):
   - Selectivity in laser ionization of isomers using narrow-band lasers
   - Access to atomic transitions populated in the Charge Exchange Cell (CEC)

[1] A. Koszorus et al., *Nature Physics 17(4):439–443,* 2021
[2] K. M. Lynch et al., *Physical Review X 4, 011055,* 2014

Previous studies on Indium decay (Z = 49)

Neutron-deficient side (β^+/EC)

- Decay measurements at GSI and LISOL in early 2000s

^{100}In	^{101}In	^{102}In	^{103}In	^{104}In	^{105}In	^{106}In	^{107}In

GSI 2002[3]

GSI 2003

Evaluated decay schemes

Neutron-rich side (β^-)

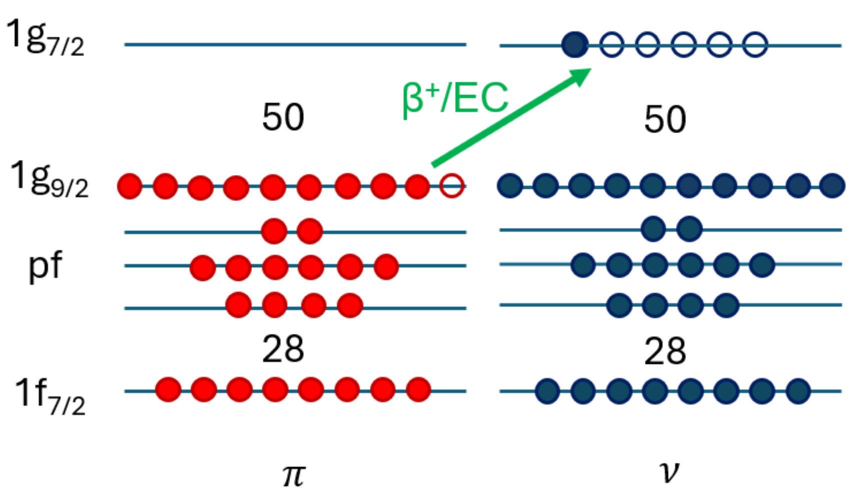
- Recent measurements at the ISOLDE Decay Station (IDS)

^{131}In	^{132}In	^{133}In	^{134}In	^{135}In
OSIRIS mass separator	GRIFFIN	IDS	IDS	IDS
2004	2020	2019	2021[4]	

[3] C. Plettner et al., *Phys. Rev. C 66, 044319, 2002*
[4] M. Piersal, A. Korgul et al., *Phys. Rev. C 104, 044328*, 2021

Decay near ^{100}Sn (Z = 50, N = 50)

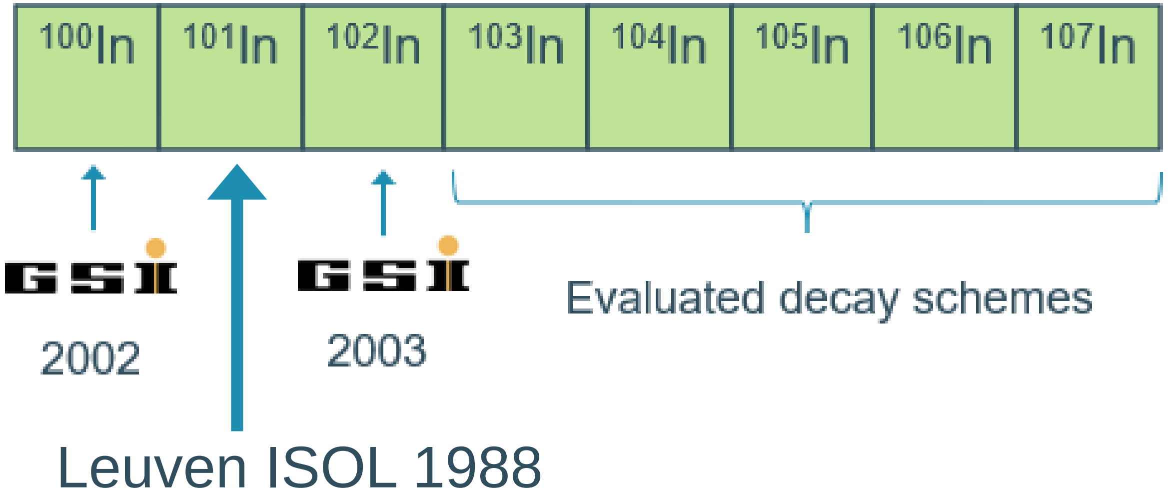
- Mirror nuclei (N ~ Z)
- Gamow-Teller resonance of beta-decays south-east of ^{100}Sn (e.g. ^{100}In)[5]

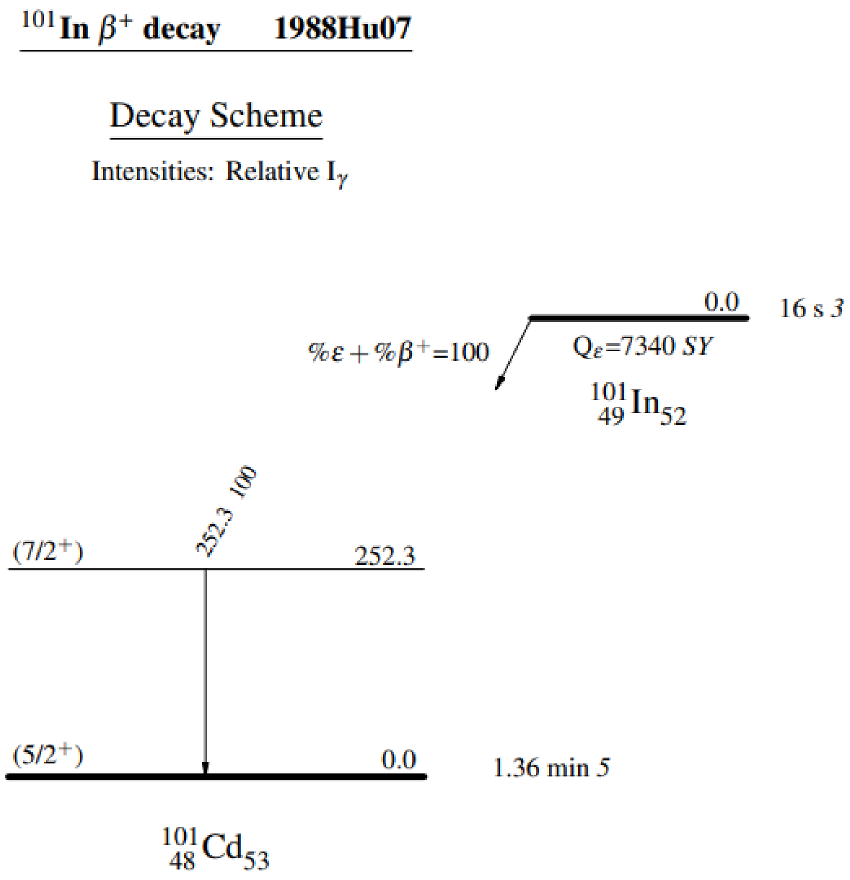


→ Decay measurements at GSI on odd-odd In with Total Absorption Spectroscopy before 2004

[5] Roeckl, E.,*The Euroschool Lectures on Physics with Exotic Beams, Vol. I. Lecture Notes in Physics, vol 651*(1988)

Beta decay of ^{101}In





Z. Phys. A – Atomic Nuclei 330, 121–122 (1988)

Zeitschrift für Physik A
Atomic Nuclei
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Short Note

Decay Study of Neutron-Deficient ^{101}In

M. Huyse[1], P. del Marmol[2], E. Coenen[1], K. Deneffe[1], P. Van Duppen[1], and J. Vanhorenbeeck[3]

[1] LISOL, Instituut voor Kern-en Stralingsfysica, Celestijnenlaan 200D, B-3030 Leuven, Belgium
[2] CEN/SCK, B-2400 Mol, Belgium
[3] Maitre de Recherche FNRS, Université Libre de Bruxelles, CP 165, Av. F.D. Roosevelt 50, B-1050 Bruxelles, Belgium

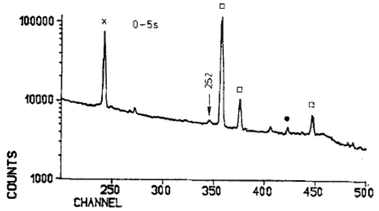
Received March 14, 1988

PACS: 23–40.-s; 27.60.+j; 28.60.+s

ABSTRACT.

The very neutron-deficient nucleus ^{101}In has been identified for the first time by studying the β-delayed γ rays of on-line mass-separated samples. The deduced half life is 16(3)s. This study assigns a hitherto unplaced γ-ray cascade of a recently published in-beam study to ^{101}Cd.

The experimental approach to ^{100}Sn is as well undertaken by in-beam as by decay studies. In both cases the selection of the nucleus under investigation out of the rest of the reaction



I = 9/2 ground state
I = 1/2 isomer

[6] M. Huyse et al., *Z. Phys. A - Atomic Nuclei 330, 121-122* (1988)

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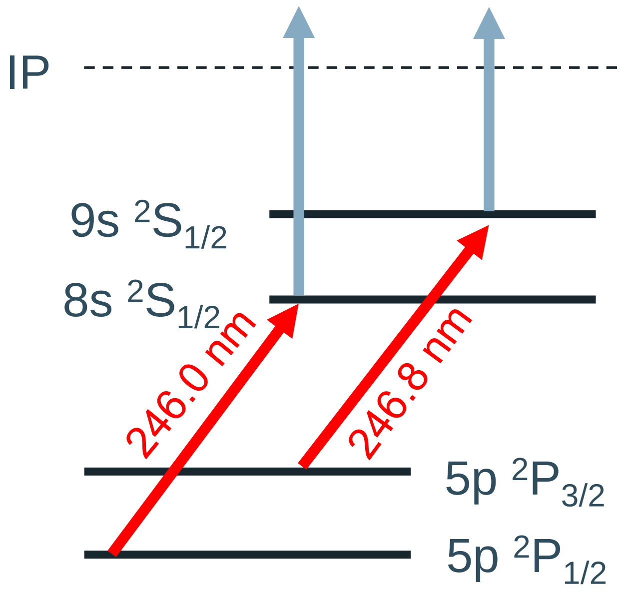
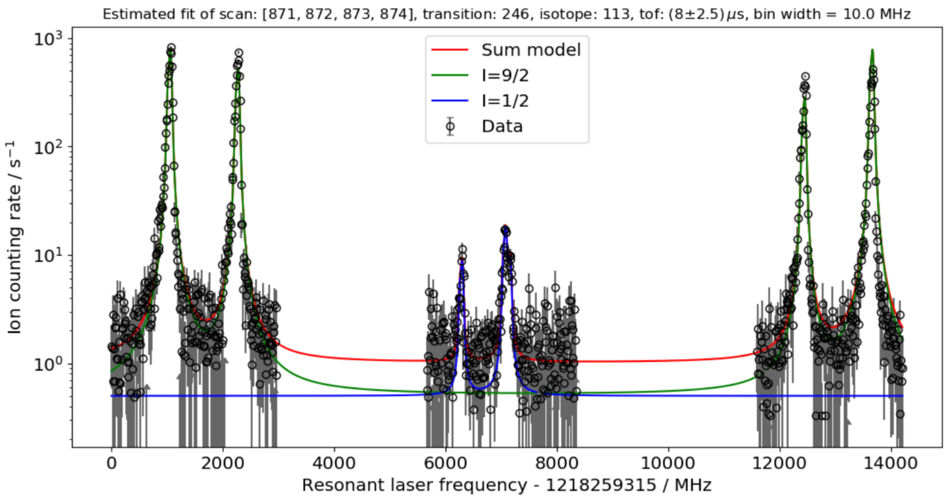
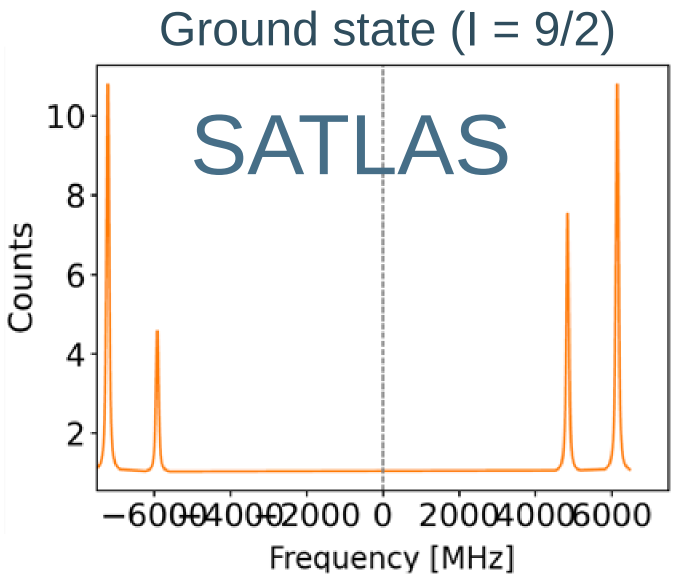
Selectivity on ^{101m}In

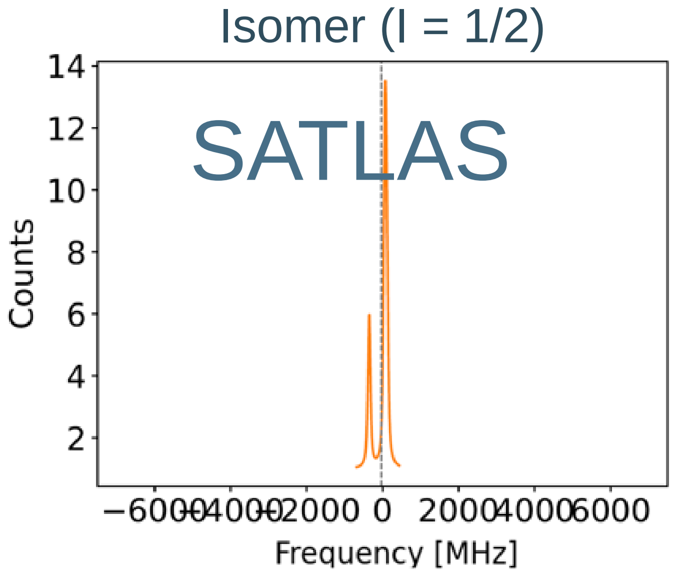
- The 246.0nm atomic transition (μ-sensitive) is selective on the low-spin isomer

→ Half-life measurements with LADS









[7] C. M. Ricketts, PhD thesis, The University of Manchester (2021)
[8] J Karthein, C. M. Ricketts et al., *Nature Physics*, 2024.

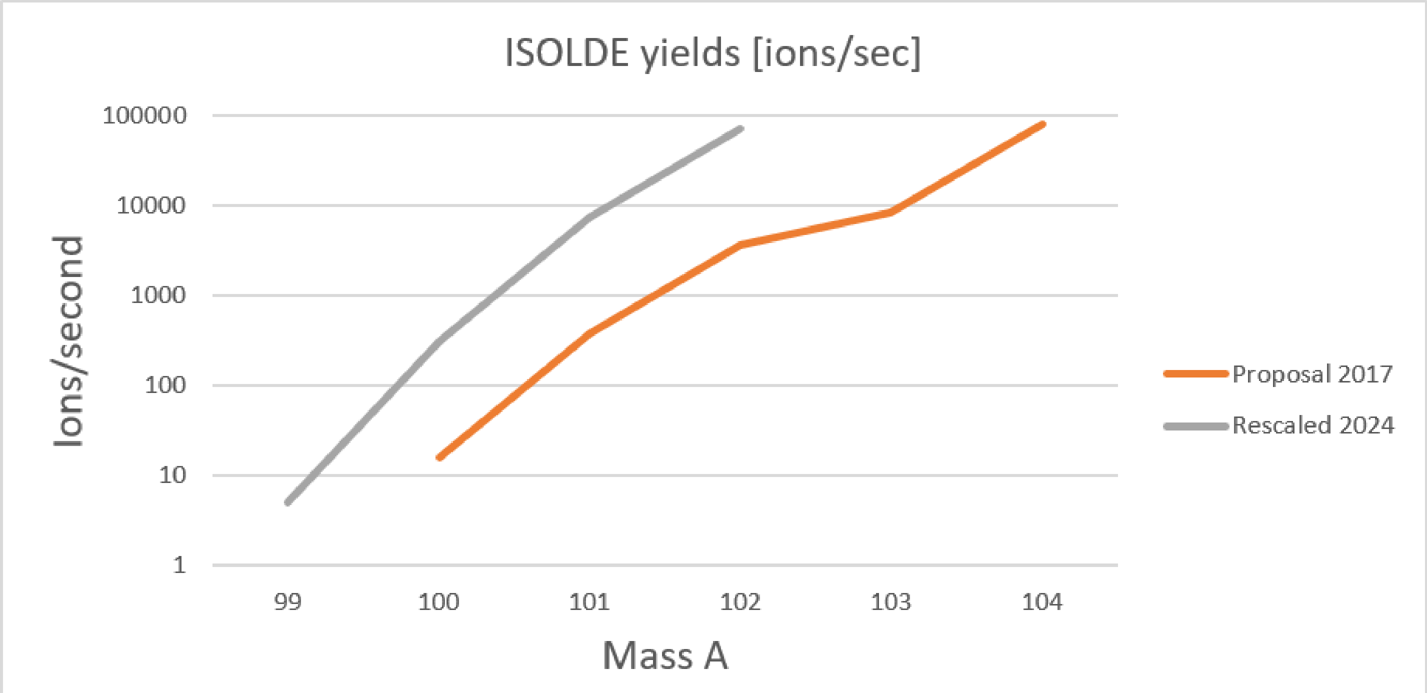
Decay measurement opportunities

	Decay spectroscopy of ^{101}In (mixed g.s. + isomer)	Laser-Assisted Decay spectroscopy of ^{101g}In	Laser-Assisted Decay spectroscopy of ^{101m}In
Possible outcomes	Decay scheme of mixed ^{101}In	Beta feeding of pure ground state ^{101g}In	Half-life of pure isomer ^{101m}In
Methodology	DSS on ions from ISOLDE	DSS with CRIS tuned on I = 9/2	DSS with CRIS tuned on I = 1/2
Relative risk	**Low**	**Medium**	**High**
Estimated shifts required	1	1	~ 1-2
Estimated β-counts per shift	10^8	10^6	10^4

Back-up slides

Yields of ^{101}In

Jessica 2024		Ronald 2017		Expected now	beta_counts/sec	beta_counts per shift
A	Ions/sec	A	Ions/sec	Ions/sec		
99	5	99		5		
100	320	100	16	320		
101		101	380	7600	4560	1,31E+08
102		102	3600	72000		
103		103	8600			
104		104	80000			



- $\epsilon_{transport} = 30\%$
- $\epsilon_{CEC} = 37 - 57\%$
- $\epsilon_{ionisation} = 10\%$
- $\epsilon_{total} \sim 1 - 2\%$

~ 10^6 beta counts per shift on LADS of ^{101}In ground state

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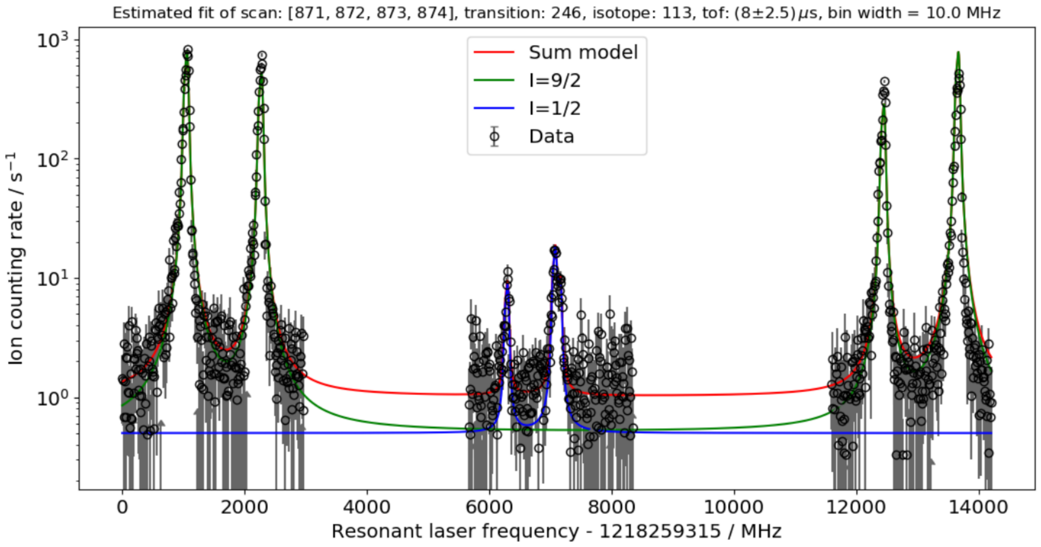
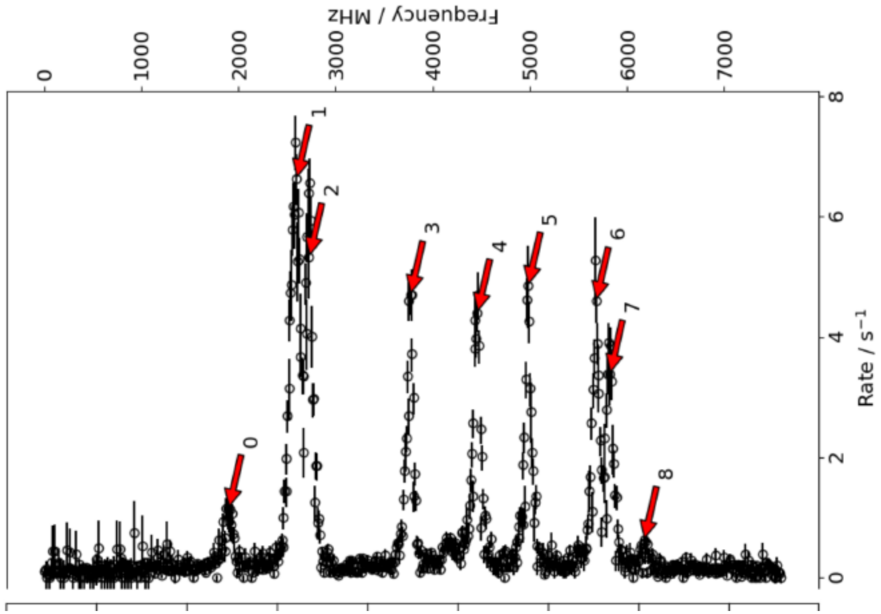
Previous experiment on ^{101}In

- Peaks 0, 1 and 8 are contaminants





[7] C. M. Ricketts, PhD thesis, The University of Manchester (2021)

Quadrupole moments of isomers

A	N	I^{π}	A_{hf} (MHz)				$\mu(\mu_N)$		B_{hf} (MHz)	Q_s (efm^2)	
			5p $^2P_{3/2}$	9s $^2S_{1/2}$	5p $^2P_{1/2}$	8s $^2S_{1/2}$	This work	Literature	5p $^2P_{3/2}$	5p $^2P_{3/2}$	5p $^2P_{3/2}$ (lit.)
101	52	9/2$^+$	255(4)	137(3)	2,413(4)	260(2)	5.861(10)	NA	280(10)	48.6(16)[3]	NA
		1/2$^-$	−52(27)	−28(24)	−418(19)	−45(4)	−0.113(5)	NA			
103	54	9/2$^+$	252(2)	136(2)	2,372(1)	253(2)	5.760(3)	NA	387(10)	67.1(17)[4]	NA
		1/2$^-$	−55(5)	−29(13)	−458(17)	−49(2)	−0.125(4)	NA			
105	56	9/2$^+$	248(1)	134(2)	2,334(1)	250(1)	5.667(2)	5.675(5)	437(8)	76.0(13)[5]	79.9(49)[6]
		1/2$^-$	−63(9)	−34(15)	−534(6)	−57(1)	−0.144(1)	NA			
107	58	9/2$^+$	244(5)	133(4)	2,304(1)	247(2)	5.594(2)	5.585(8)	455(12)	79.0(20)[5]	77.8(50)[5]
		1/2$^-$	-66(13)	−35(24)	−569(42)	−61(1)	−0.154(3)	NA			
109	60	9/2$^+$	242(4)	132(2)	2,279(1)	244(1)	5.533(2)	5.538(4)	479(8)	83.2(14)[5]	81.1(26)[6]
		1/2$^-$	−60(4)	−33(12)	−634(3)	−68(1)	−0.171(1)	NA			
111	62	9/2$^+$	240(5)	129(3)	2,269(1)	243(1)	5.508(3)	5.503(7)	443(19)	76.9(33)[5]	77.4(21)[5]
		1/2$^-$	−61(18)	−33(22)	−686(4)	−73(1)	−0.185(1)	NA			
113	64	9/2$^+$	241(1)	131(1)	2,278(1)	243(1)	5.530(4)	5.5289(2)	446(11)	77.5(18)[5]	77.0(1)[5]
		1/2$^-$	−82(6)	−44(4)	−784(5)	−84(1)	−0.211(1)	−0.21074(2)			
115	66	9/2$^+$	241.9(3)	130.5(4)	2,282(1)	244(1)	5.541(2)	5.5408(2)	452.4(2.9)	78.5(5)[5]	78.0(1)[5]
		1/2$^-$	−79(9)	−43(17)			−0.20(2)[a]	−0.24398(5)			

[8] J Karthein, C. M. Ricketts et al., *Nature Physics*, 2024.

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