Investigation of shell structure and shape evolution in ^{102,104}Sn with IDATEN

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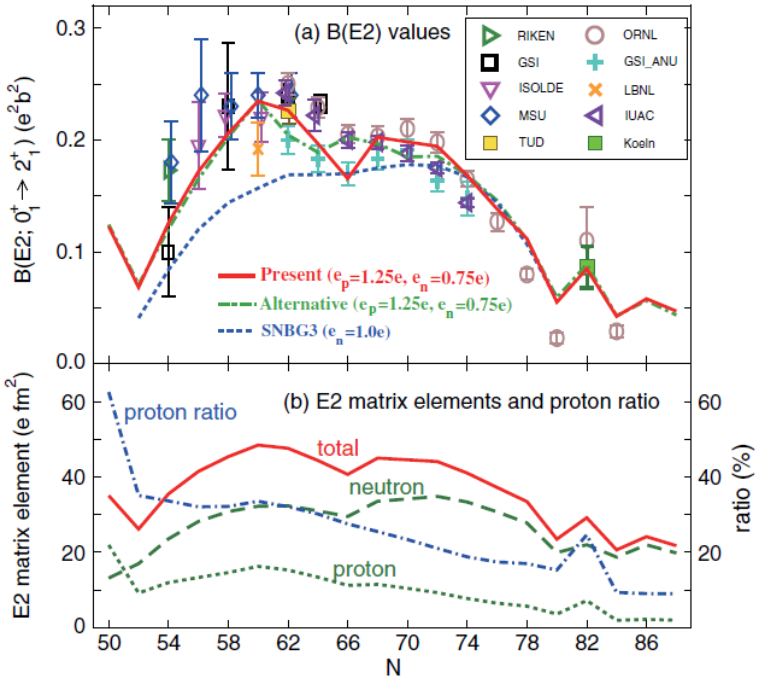
IDATEN workshop

July 6, 2022

Physics motivation

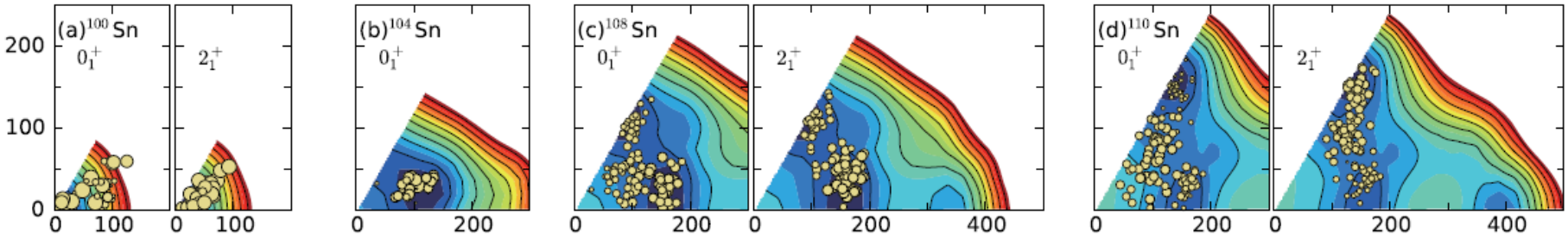


B(E2) systematics of even-even Sn isotopes still under major investigation

Lower precision (statistics) on neutron-deficient isotopes, production method challenging for reliable Coulex experiments

[in-flight → high energy → unsafe Coulex]

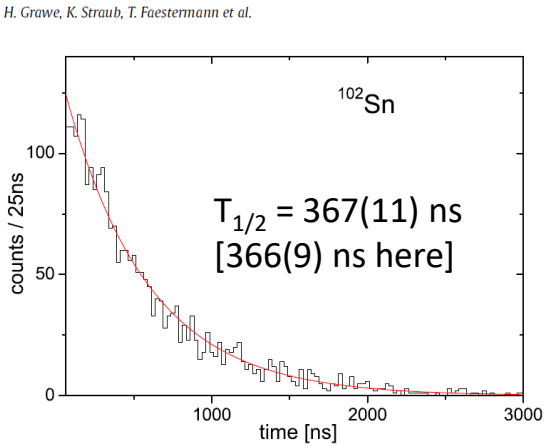
Wavefunction components away from origin → deformation in Sn isotopes!

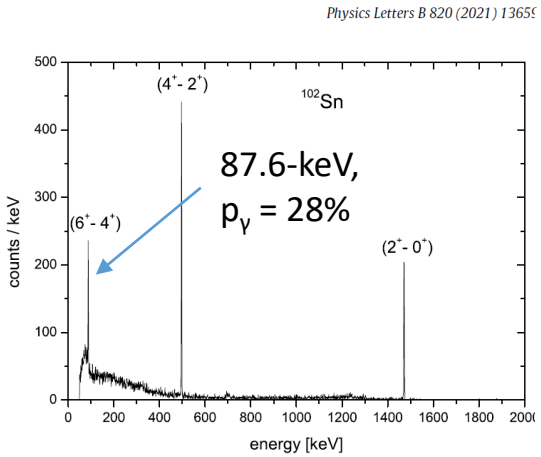


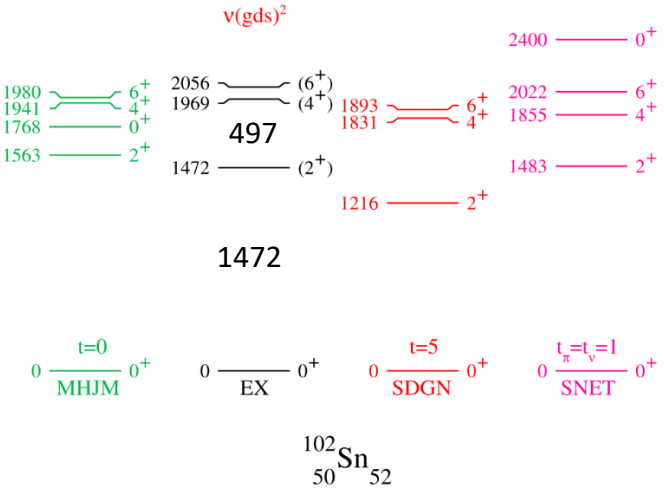
T. Togashi et al., PRL 121, 062501 (2018)

Physics case of ^{102}Sn

^{102}Sn: effects of 2n on core polarization of ^{100}Sn

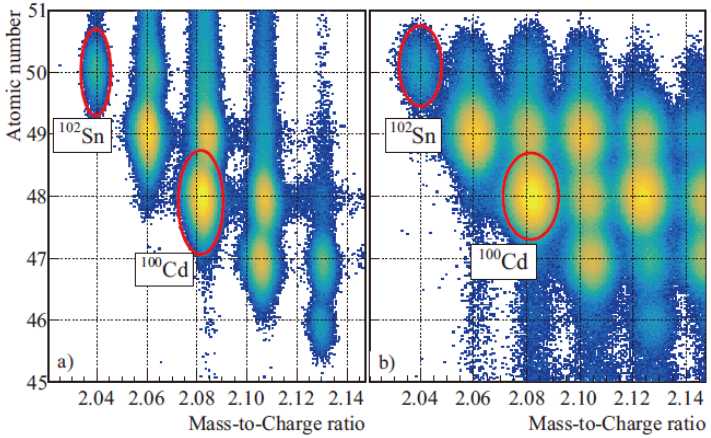






Half-life of the 6^+ state known with good precision

Intermediate-energy Coulex experiment performed at RIBF for B(E2) of the 2^+



M. L. Cortés et al., RIKEN APR 53, 36 (2020)

Goal: measure $T_{1/2}$ of the intermediate 4^+ state precisely for B(E2) systematics

Physics case of ^{104}Sn

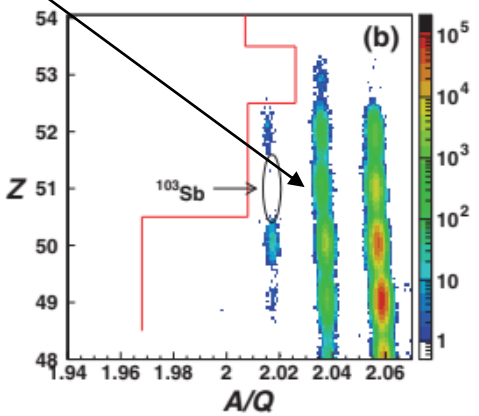
Level scheme of ^{104}Sn not known through β decay spectroscopy of ^{104}Sb

Only $T_{1/2}$ measured at GSI, **J^{π} unknown**

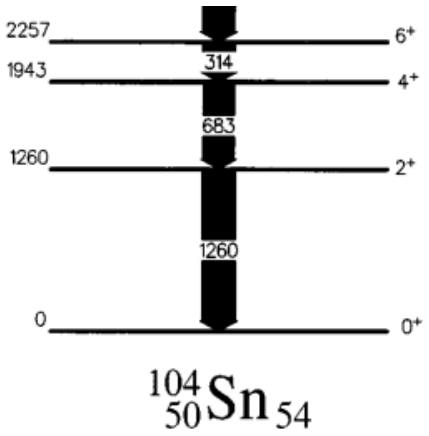
Isotope	*half life [s]*	*decay energy [MeV]*	*branching ratio*
^{100}Sn	$T_{1/2} = 0.94^{+0.54}_{-0.27}$	$E_{\beta} = 3.4^{+0.7}_{-0.3}$ $E_{\gamma} = 2.76 \pm 0.43$	$\frac{\beta p}{\beta \gamma} < 20\%$
^{104}Sb	$T_{1/2} = 0.44^{+0.15}_{-0.11}$		$\frac{p}{\beta \gamma} < 7\%$, $\frac{\beta p}{\beta \gamma} < 7\%$
^{105}Sb	$T_{1/2} = 1.12 \pm 0.16$	$(E_p = 0.550 \pm 0.030)$	$(\frac{p}{\beta \gamma} \approx 1\%)$
^{102}Sn	$T_{1/2} = 4.6 \pm 1.4$	$E_{\gamma mean} = 1.86 \pm 0.250$	
^{100}In	$T_{1/2} = 6.3^{+1.0}_{-0.9}$		

T. Faestermann et al., GSI Sci. Rep. 96-1, 21 (1996)

^{104}Sb production at RIBF



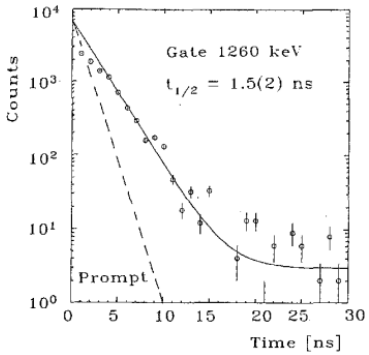
H. Suzuki et al., PRC 96, 034604 (2017)



$^{104}_{50}Sn_{54}$

M. Górska et al.,
PRC 58, 108 (1998)

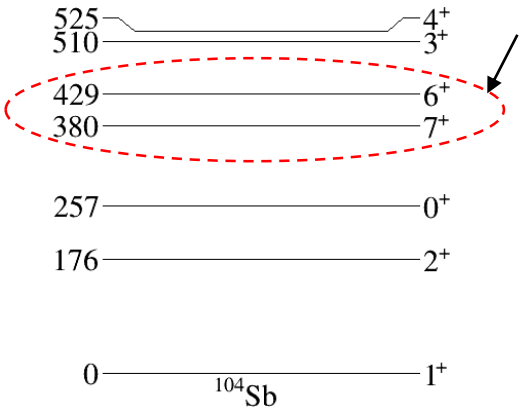
τ(6⁺) = 2.2(3) ns
[$T_{1/2}$ = 1.53(21) ps]



R, Schubart et al.,
Z. Phys. A 352, 373 (1995)

- $T_{1/2}(4^+)$ through 314(start)-683(stop)
- Structure expansion of ^{104}Sb and ^{104}Sn

<u>High spin of ^{104}Sb needed to populate 6^+ isomer</u>

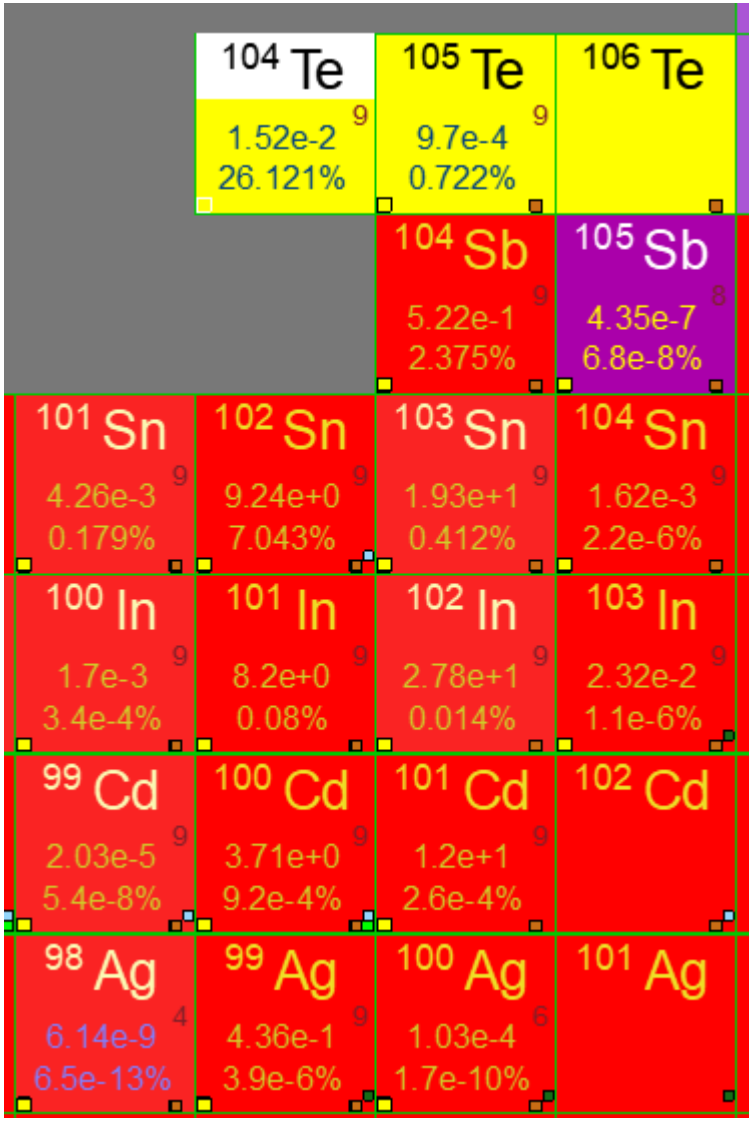


Feeding to $6^+/7^+$ isomer possible

NuShellX calculation with ^{100}Sn core

B. A. Brown et al.,
PRC 71, 044317 (2005)

LISE++ RIB production setting



Primary beam:
^{124}Xe beam, 140 pnA

Dipole magnet settings: ^{103}Sb
[interpolation of ^{104}Te and ^{102}Sn]

F1 slit adjustment: -25 mm
F5 slit adjustment: 30 mm

Nuclei of interest and rates:

- ^{102}Sn: 9.24 pps
- ^{104}Sb: 0.522 pps
- ^{104}Te → ^{100}Sn alpha decay, 1.52e-2 pps

[comparable to ^{100}Sn setting, $T_{1/2}$ ~ 20 ns]

Overall rate on WAS3ABi: 81.2 pps

Feasibility calculations – ^{102}Sn

	102Sn		
Beam time (days)	5		
Production rate	9.24E+00		
implantation counts	3.99E+06		
isomeric ratio	0.25		
Half-life (ns)	366		
flight time (ns)	630		
surviving isomers after F11	302642		
	6 to 4, 88 keV	4 to 2, 497 keV	2 to 0, 1472 keV
IDATEN efficiency	0.2	0.088	0.032
internal conversion coefficient	2.51	0.00751	0.000645
gammas (singles)	17245	26434	9678
gammas (coincidence)		**1518**	**552**

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 Ei      Ji   ni      T_(1/2)       width      M1 moment    Q moment
(MeV)                  (psec)        (eV)       (u_N)    (e^2 fm^2)

1.580     2+   1      2.421713   0.1883E-03      0.048       -3.80 ----------------------

      Ef     Jf   nf    BR      Eg       del    B(1)       B(2)         A_p      A_n
      0.000  0+   1 100.0000  1.580   999.00  0.0000E+00  0.2372E+02      0.000   21.782

2.098     4+   1   0.6377E+03  0.7152E-06      0.149       -6.74 ----------------------

      Ef     Jf   nf    BR      Eg       del    B(1)       B(2)         A_p      A_n
      1.580  2+   1 100.0000  0.518   999.00  0.0000E+00  0.2378E+02      0.000  -29.258

2.203     6+   1    0.3615E+07   0.1262E-09      0.077       -17.38 ----------------------

      Ef     Jf   nf    BR      Eg       del    B(1)       B(2)         A_p      A_n
      2.098  4+   1 100.0000  0.105   999.00  0.0000E+00  0.1227E+02      0.000  -25.266
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NuShellX sn-snt interaction

Statistics for precise measurement, $T_{1/2}$ ~ 0.1-1 ns

Feasibility calculations – ^{104}Sn

	104Sn		
Beam time (days)	5		
Production rate	5.22E-01		
implantation counts	2.26E+05		
Beta decay correlation	0.5		
isomeric ratio	0.1	Rough estimate	
	6 to 4, 314 keV	4 to 2, 683 keV	2 to 0, 1260 keV
IDATEN efficiency	0.14	0.068	0.038
internal conversion	0.0306	0.00318	0.000645
gammas (singles)	**1532**	764	428
gammas (coincidence)		**104**	**58**

Statistics slightly challenging for $T_{1/2}(4+)$, largely dependent on the isomeric ratio

Experimental isomeric ratios of odd-odd nuclei

Nucleus	J^{π}_{m}	Decay mode(s)	R_{exp} (%)
^{88}Zr	(8^+)	γ, IC	69(5)
^{90}Nb	(11^-)	γ, IC	16(3)
^{90}Mo	(8^+)	γ, IC	61(3)
^{90}Rh	(7^+)	β, βp	86(3)
^{91}Nb	$(17/2^-)$	γ, IC	47(12)
^{92}Mo	(8^+)	γ, IC	48(10)
^{92}Tc	(4^+)	γ, IC	10(1)
^{92}Ru	(8^+)	γ, IC	32(33)
^{92}Rh	(4^+)	γ, IC	6.8(32)
^{93}Tc	$(17/2^-)$	γ, IC	54(5)
^{93}Ru	$(21/2^+)$	γ, IC	53(2)
^{94}Ru	8^+	γ, IC	68(6)
^{94}Pd	(19^-)	γ, IC	6.8(29)
	(14^+)	γ, IC	30(1)
^{94}Ag	(7^+)	β, βp	77(3)
	(21^+)	β, βp, p	<3
^{95}Pd	$(21/2^+)$	β	77(11)
^{95}Ag	$(37/2^+)$	γ, IC	7.7(7)
	$(23/2^+)$	γ, IC	41(7)
	$(1/2^-)$	γ, IC	2.9(8)
^{96}Pd	(8^+)	γ, IC	76(1)
^{96}Ag	(19^+)	γ, IC	1.4(8)
	(15^+)	γ, IC	18.7(4)
	(13^-)	γ, IC	12.4(13)
	(2^+)	β, βp	22(3)
^{96}Cd	(16^+)	β, βp	22(3)
^{97}Cd	$(25/2^+)$	β, βp	37(3)
^{98}Ag	(4^+)	γ, IC	4.2(10)
^{98}Cd	(12^+)	γ, IC	10(1)
	(8^+)	γ, IC	97(36)
^{98}In	(9^+)	β, βp	59(2)
		$\sigma(J^+_m > 4$ only)	

JP et al., PRC 96, 044311 (2017)

Summary of aims

^{102}Sn

- $T_{1/2}$ and B(E2) of 4^+ state below the 6^+ isomer

^{104}Sb

- Detailed beta-decay spectroscopy: $T_{1/2}$, J^π of the ground state/isomer, first beta-delayed γ-ray spectroscopy
- Population and $T_{1/2}$ measurement of the 4^+ state in ^{104}Sn for B(E2) systematics of higher excited states in Sn isotopes