Gamma and fast-timing spectroscopy of the doubly magic ^{132}Sn and its one- and two-neutron particle/hole neighbours

Proposal to the ISOLDE and Neutron Time-of-Flight Committee
CERN-INTC-2015-049 Proposal P-449

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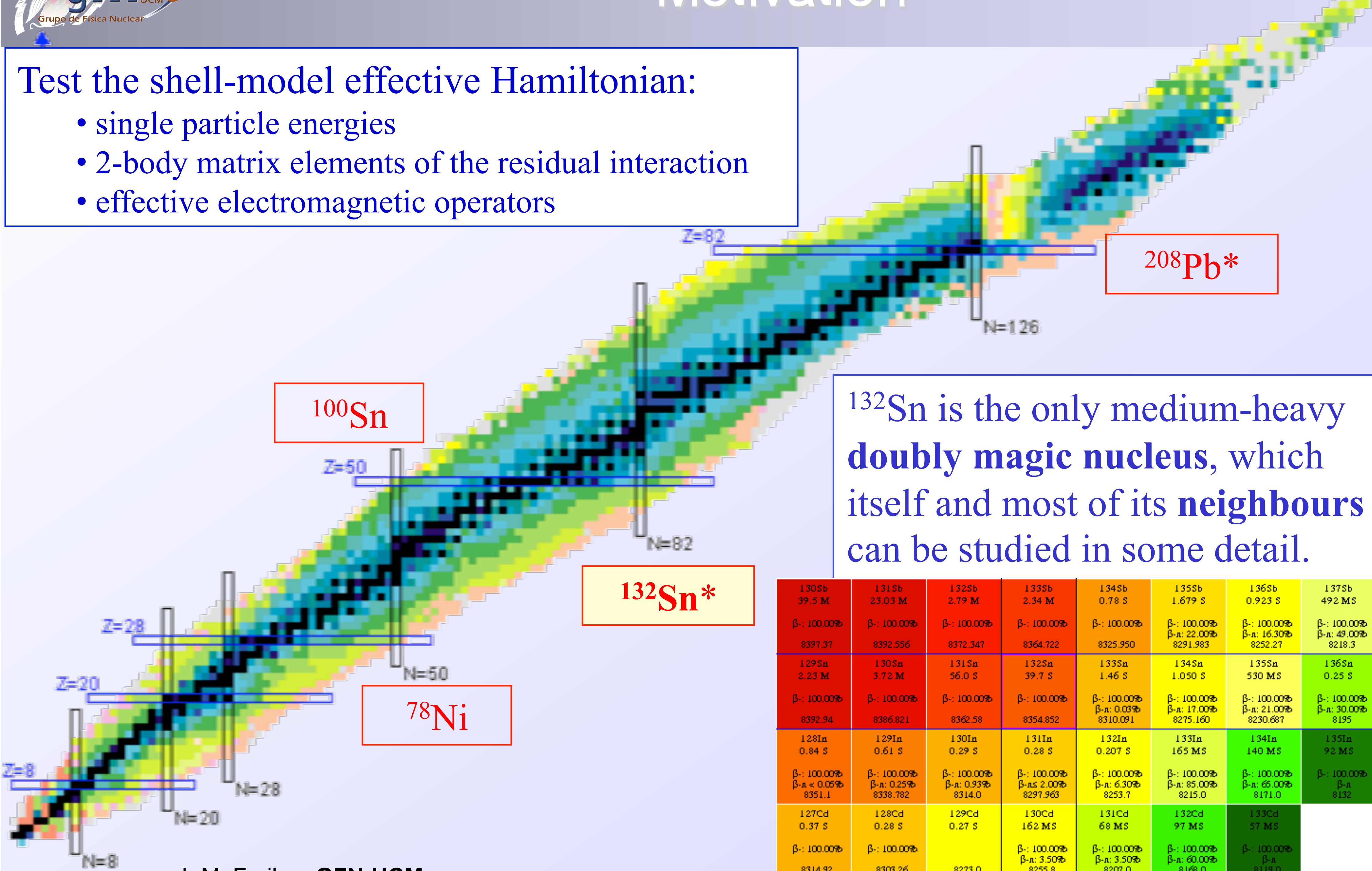
Motivation

Test the shell-model effective Hamiltonian:

- single particle energies
- 2-body matrix elements of the residual interaction
- effective electromagnetic operators



^{132}Sn is the only medium-heavy **doubly magic nucleus**, which itself and most of its **neighbours** can be studied in some detail.

130Sb 39.5 M β-: 100.00% 8397.37	131Sb 23.03 M β-: 100.00% 8392.556	132Sb 2.79 M β-: 100.00% 8372.347	133Sb 2.34 M β-: 100.00% 8364.722	134Sb 0.78 S β-: 100.00% 8325.950	135Sb 1.679 S β-: 100.00% β-n: 22.00% 8291.983	136Sb 0.923 S β-: 100.00% β-n: 16.30% 8252.27	137Sb 492 MS β-: 100.00% β-n: 49.00% 8218.3
129Sn 2.23 M β-: 100.00% 8392.94	130Sn 3.72 M β-: 100.00% 8386.821	131Sn 56.0 S β-: 100.00% 8362.58	132Sn 39.7 S β-: 100.00% 8354.852	133Sn 1.46 S β-: 100.00% β-n: 0.03% 8310.091	134Sn 1.050 S β-: 100.00% β-n: 17.00% 8275.160	135Sn 530 MS β-: 100.00% β-n: 21.00% 8230.687	136Sn 0.25 S β-: 100.00% β-n: 30.00% 8195
128In 0.84 S β-: 100.00% β-n < 0.05% 8351.1	129In 0.61 S β-: 100.00% β-n: 0.25% 8338.782	130In 0.29 S β-: 100.00% β-n: 0.93% 8314.0	131In 0.28 S β-: 100.00% β-n≤ 2.00% 8297.963	132In 0.207 S β-: 100.00% β-n: 6.30% 8253.7	133In 165 MS β-: 100.00% β-n: 85.00% 8215.0	134In 140 MS β-: 100.00% β-n: 65.00% 8171.0	135In 92 MS β-: 100.00% β-n 8132
127Cd 0.37 S β-: 100.00% 8314.92	128Cd 0.28 S β-: 100.00% 8303.26	129Cd 0.27 S 8273.0	130Cd 162 MS β-: 100.00% β-n: 3.50% 8255.8	131Cd 68 MS β-: 100.00% β-n: 3.50% 8207.0	132Cd 97 MS β-: 100.00% β-n: 60.00% 8168.0	133Cd 57 MS β-: 100.00% β-n 8119.0	
79	80	81	82	83	84	85	N

Motivation

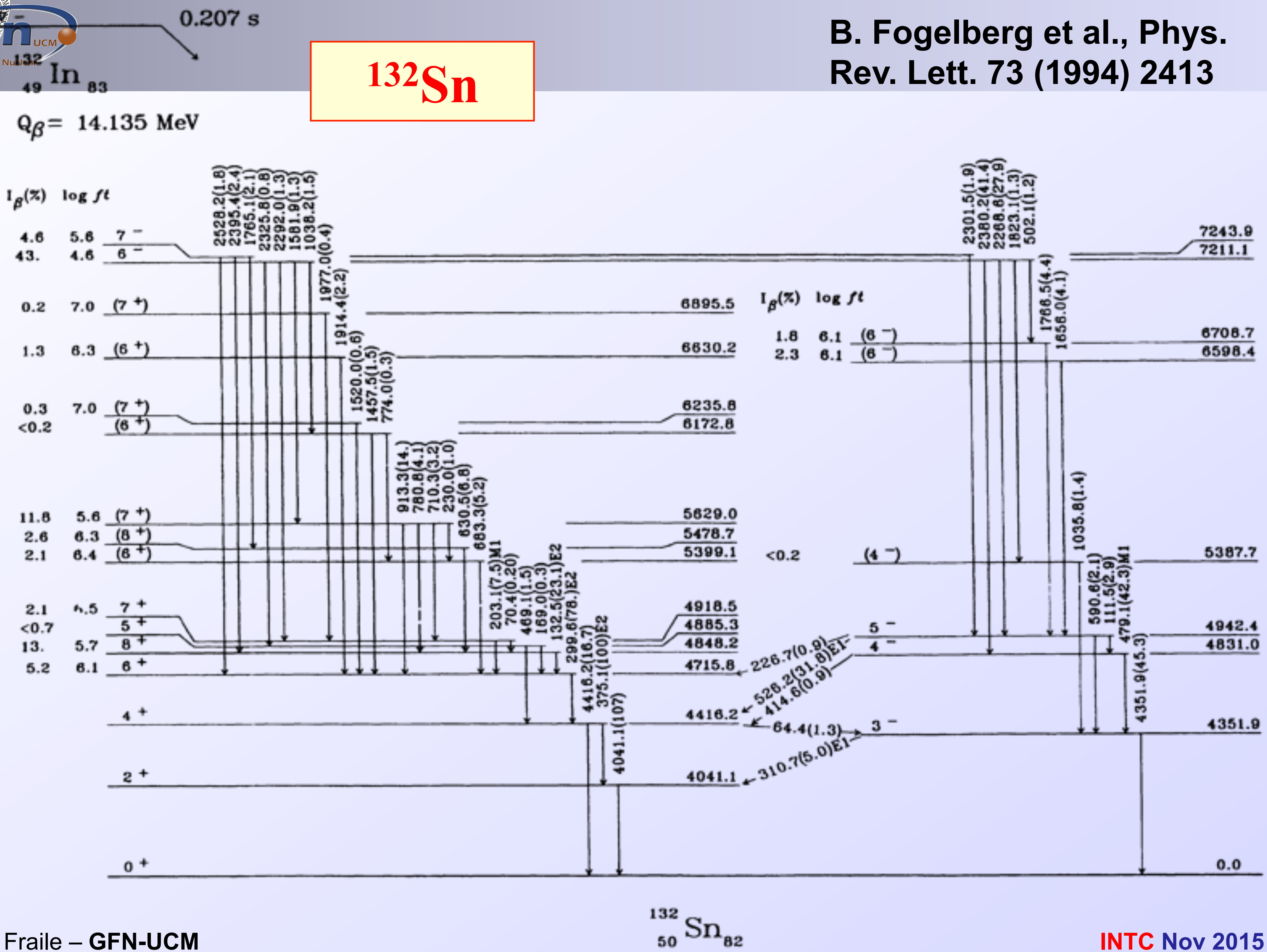
- ✓ Doubly-closed nuclei
- ✓ Test of nuclear models
  - → single particle energies, 2-body matrix elements, EM operators
- ✓ They are used in model calculations over an extended range of the nuclide chart.
- ✓ Gross properties of these nuclei are important to model the astrophysical r-process.

The present ISOLDE facility provides unique capabilities to study Sn nuclei populated in the β-decay of In isomers

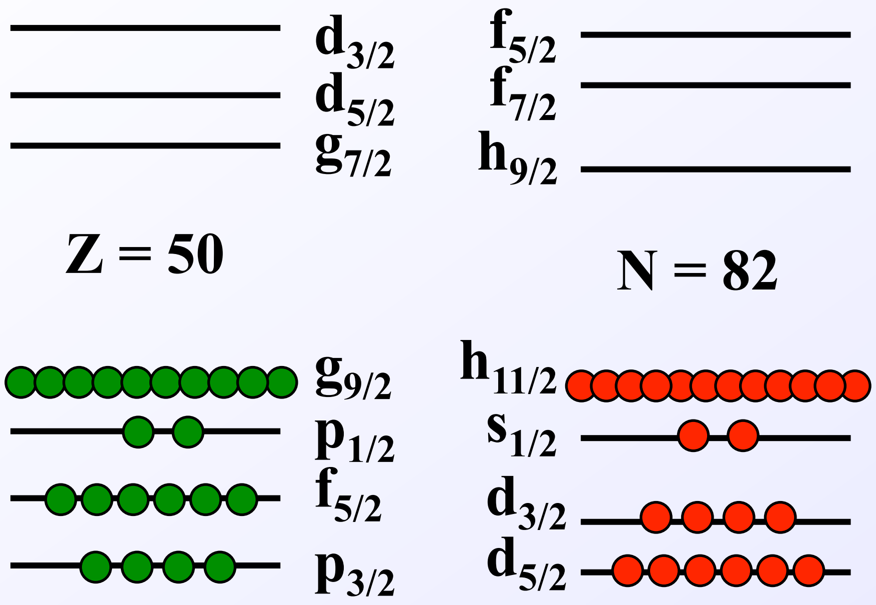
UC_x target + neutron converter + RILIS + isomer selectivity

^{132}Sn

B. Fogelberg et al., Phys. Rev. Lett. 73 (1994) 2413



Available information on ^{132}Sn



from Jan Blomqvist

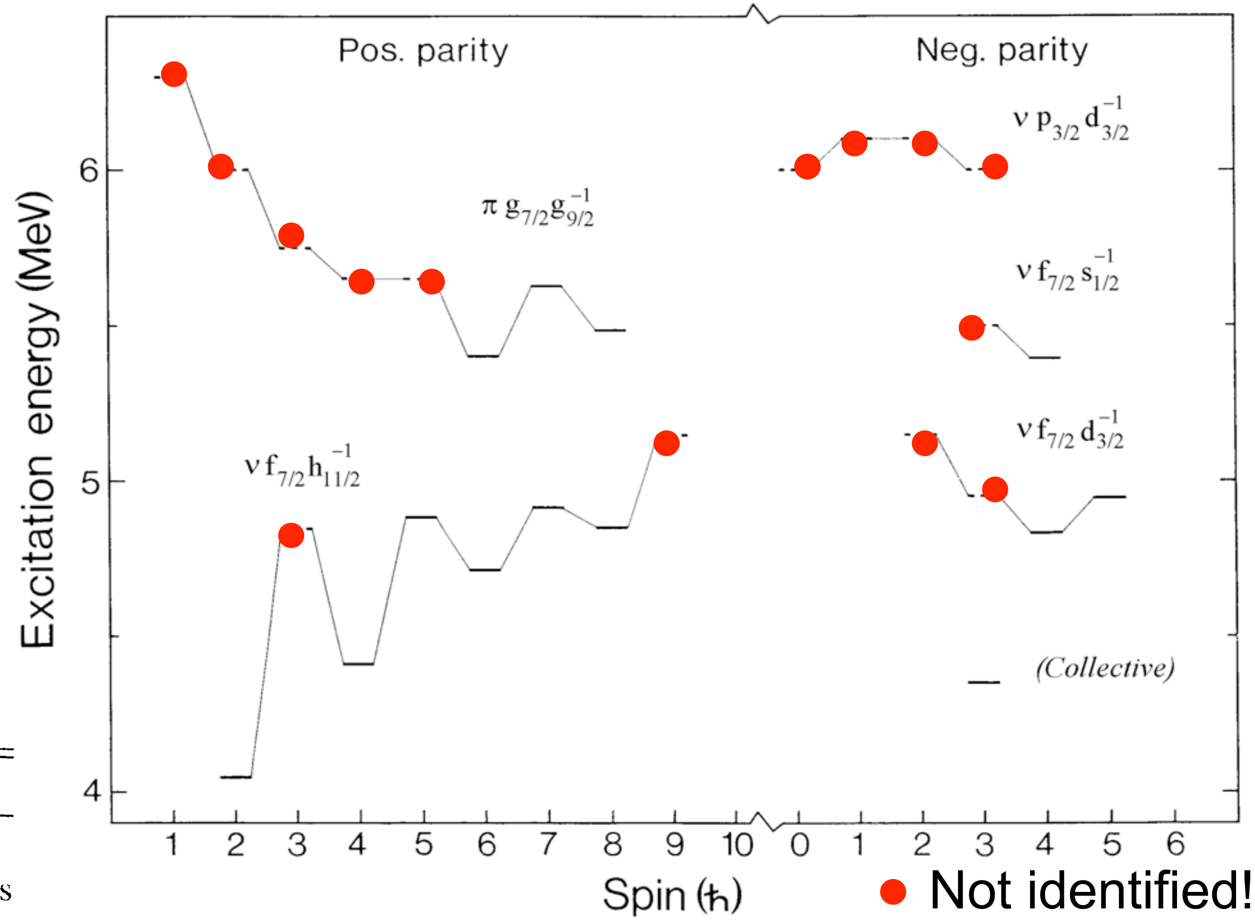


TABLE I. Half-lives of excited states in ^{132}Sn.

Level (keV)	J^{π}	Half-life[a,b]
4351.9	3^-	<5.0 ps
4416.2	4^+	3.95(13) ns
4715.8	6^+	20.1(5) ns
4831.0	4^-	26.0(5) ps
4848.2	8^+	2.03(4) μs
4885.3	5^+	<40.0 ps
4918.5	7^+	62.0(7) ps
4942.4	5^-	17.0(5) ps
5629.0	(7^+)	13.0(ps)

[a]All data from the present work.
[b]Uncertainties are given in units of the last digit.

H. Mach et al., Nuclear Physics A588 179c (1995)

Identification of ^{132}Sn multiplets

Multiplet $\nu f_{7/2} d_{3/2}^{-1}$ **from Henryk Mach after Jan Blomqvist**

$B(M1; 5^- - 4^-) = (9/140\pi) [\mu(f_{7/2}) - 7/3\ \mu(d_{3/2}^{-1})]^2$

$\mu(f_{7/2}) \sim -1.0\ \mu_N$ $\mu(d_{3/2}^{-1}) \sim +0.8\ \mu_N$

$B(M1; 5^- - 4^-)_{th} = 0.168\ \mu_N$

$B(M1; 5^- - 4^-)_{exp} = 0.127(36)\ \mu_N$ from experimental $T_{1/2} =$ **17(5) ps**

Multiplet $\nu f_{7/2} h_{11/2}^{-1}$

$B(M1; 7^+ - 8^+) = (27/98\pi) [\mu(f_{7/2}) - 7/11\ \mu(h_{11/2}^{-1})]^2$

$\mu(f_{7/2}) \sim -1.0\ \mu_N$ $\mu(h_{11/2}^{-1}) \sim -1.0\ \mu_N$

$B(M1; 7^+ - 8^+)_{th} = 0.012\ \mu_N$

$B(M1; 7^+ - 8^+)_{exp} = 0.042(6)\ \mu_N$ **from exp.** $T_{1/2} =$ **62(7) ps**

✓ Combination of **gamma** and **fast-timing** spectroscopy

Proposal for ^{132}Sn measurement

- ✓ The sensitivity of our study will be about 2 orders of magnitude higher than in the previous measurement (performed in 1994)
- ✓ Reach to several level lifetimes, including negative-parity states
  - → **transition rates**
- ✓ Beta decay of ^{132}In; single beta-decaying isomer
  - → spin/parity = 7^-
  - → $T_{1/2}$ = 207 ms, Q = 14.1 MeV
  - → S_n = 7.3 MeV, P_n = 6.3(9)%
  - → Daughter ^{132}Sn to ^{132}Sb ($T_{1/2}$ = 39.7 s)
- ✓ Beta decay of ^{133}In via β-n branch; two beta-decaying isomer
  - → spin/parity = $(1/2^-)$, $(9/2^+)$
  - → $T_{1/2}$ = 165 ms, Q = 12.9 MeV
  - → S_n = 2.37 MeV, **P_n = 85(10)%**

$^{132}Sn + 2n$ system

✓ Yrast states

→ $(\nu f_{7/2})^2$ multiplet

→ $\nu f_{7/2}h_{9/2}$ configuration

	^{134}Sn	^{136}Sn
0^+	80% $(f_{7/2})^2$	64% $(f_{7/2})^4$
2^+	85% $(f_{7/2})^2$	66% $(f_{7/2})^4$
4^+	94% $(f_{7/2})^2$	75% $(f_{7/2})^4$
6^+	98% $(f_{7/2})^2$	83% $(f_{7/2})^4$
2_2^+	80% $f_{7/2}p_{3/2}$	64% $(f_{7/2})^4$

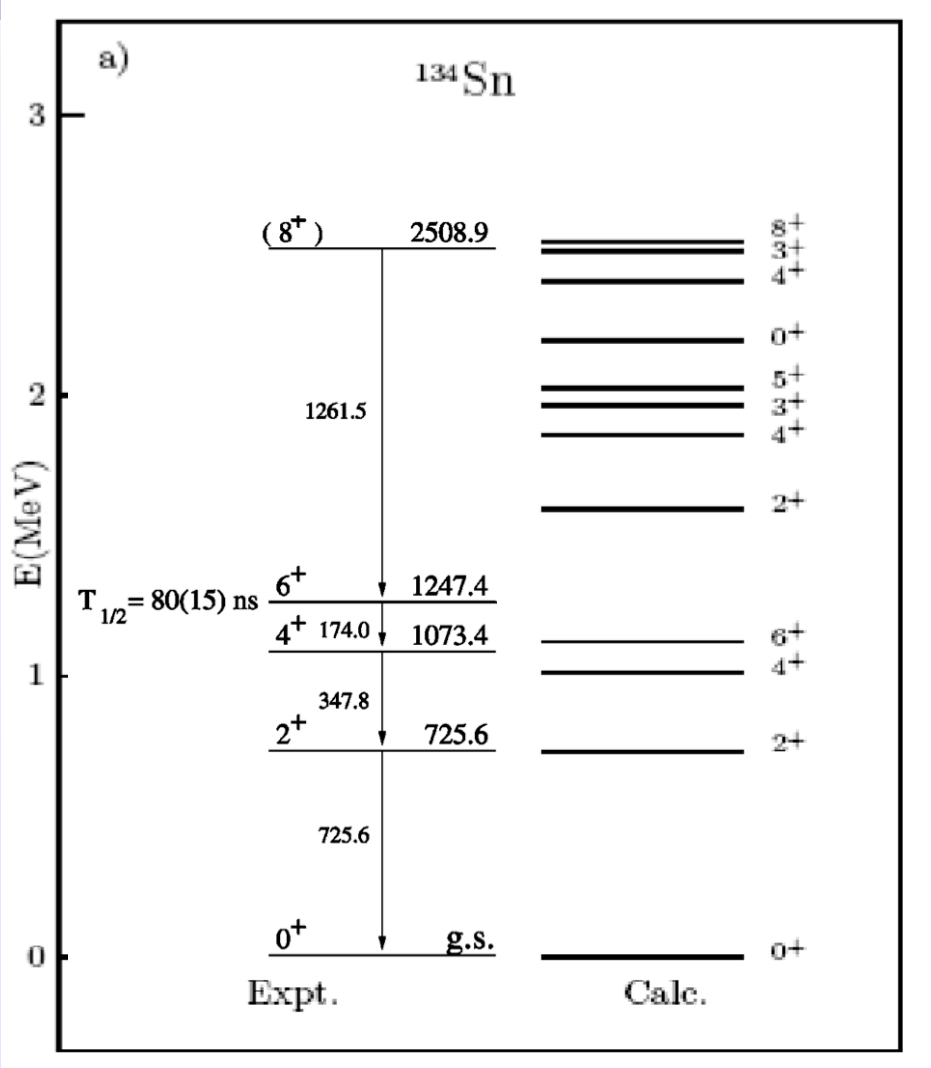
Angela Gargano *et al.*

	^{134}Sn		^{136}Sn
	Expt	Calc	Calc
$B(E2:2_1^+ \rightarrow 0^+)$ [in W.u.]	1.4(2)	1.6	2.8
$B(E2:4^+ \rightarrow 2^+)$		1.7	0.83
$B(E2:6^+ \rightarrow 4^+)$	0.89(17)	0.82	0.12
$B(E2:2_2^+ \rightarrow 0^+)$		0.35	0.06
$B(E2:2_2^+ \rightarrow 2_1^+)$		2.93	1.8
$B(E2:2_2^+ \rightarrow 4^+)$		0.23	1.0
$B(M1:2_2^+ \rightarrow 2_1^+)$		0.02	0.09×10^{-2}
$Q(2_1^+)$ [in eb]		-0.02	-0.13
$Q(2_2^+)$		-0.03	+0.06
$\mu(2_1^+)$ [in nm]		-0.57	+0.46
$\mu(2_2^+)$		-0.25	+0.54

~40 ps

~1.7 ns

~5 ps



A. Korgul et al., Eur. Phys. J. A 7, 167–176 (2000)

A. Covello et al., J. Phys. Conf. Ser. 267, 012019 (2011).

Proposal ^{134}Sn study

- ✓ No levels in ^{134}Sn identified from the beta decay of ^{134}In
  - → should be identified below 3 MeV
- ✓ Calculation prediction
  - → existence of members of the $\nu f_{7/2}p_{3/2}$ and $\nu f_{7/2}p_{1/2}$ multiplets
  - → 0^+ state of the $(\nu p_{3/2})^2$ configuration.

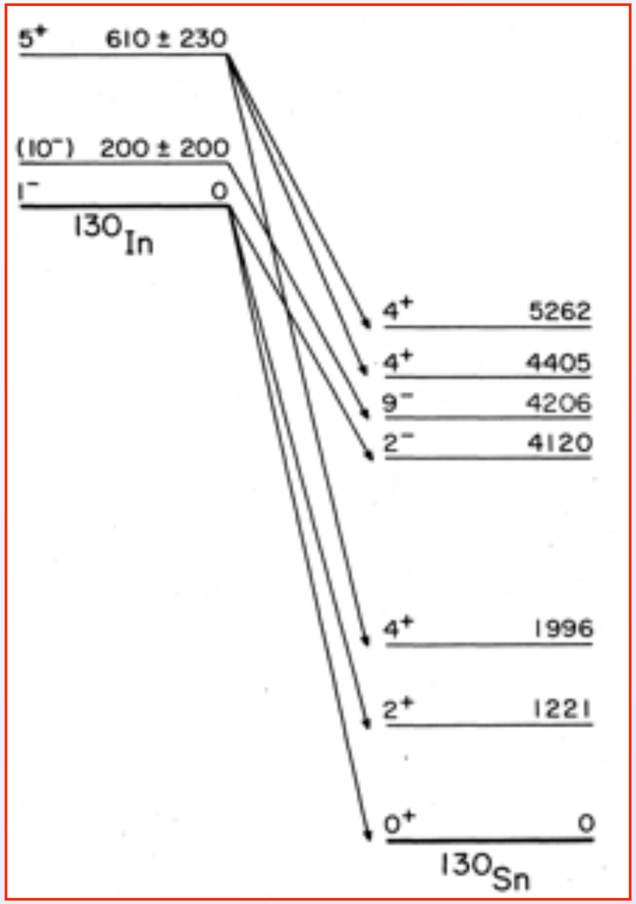
Shell model calculations Angela Gargano *et al.*

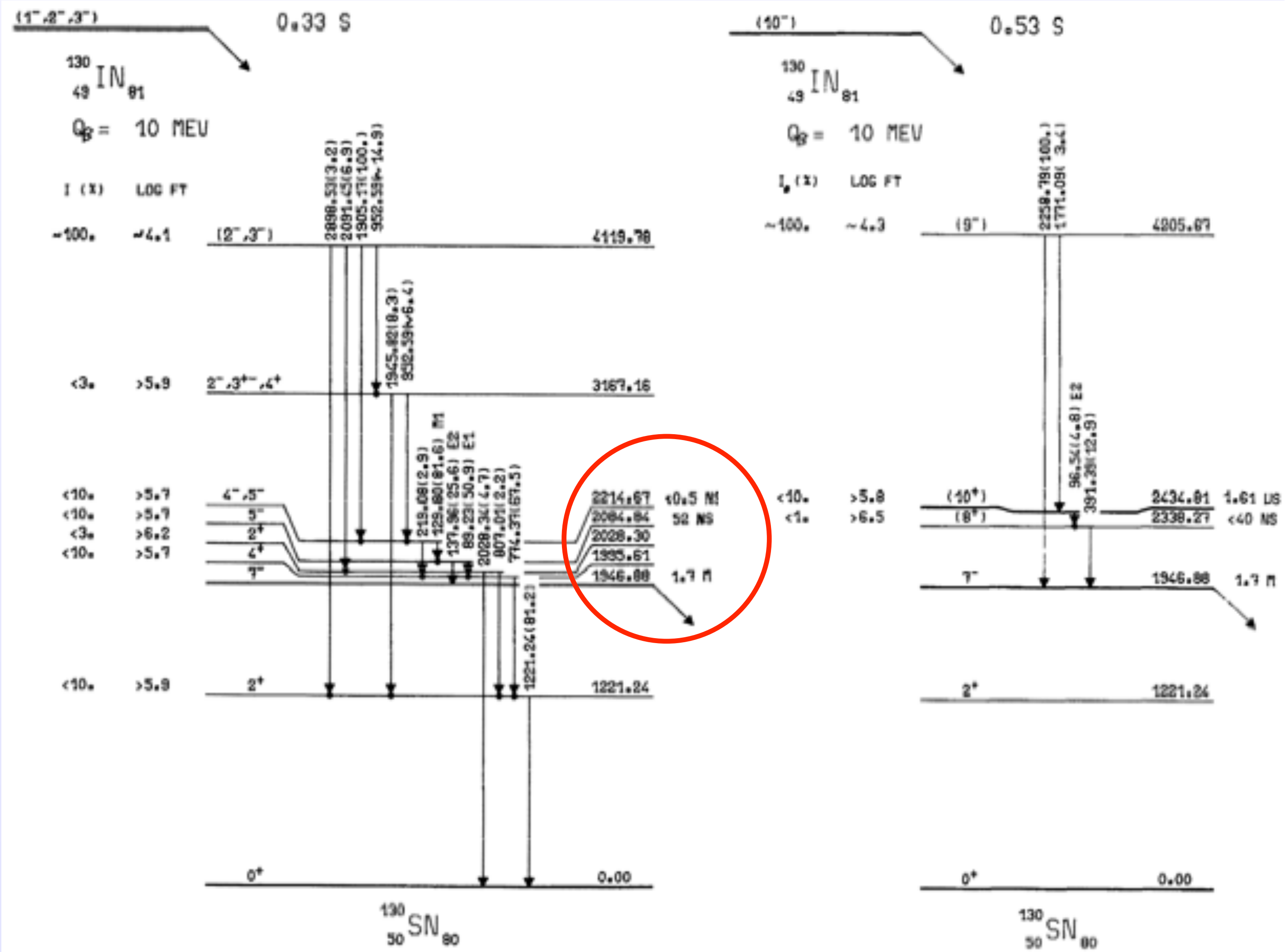
- ✓ Beta decay of ^{134}In; single beta-decaying isomer
  - → spin/parity = (4^- to 7^-)
  - → $T_{1/2}$ = 140 ms, Q = 14.8 MeV
  - → S_n = 3.9 MeV, P_n = 65%
- ✓ Strong branch from ^{135}In beta-delayed neutron emission

Proposed ^{130}Sn study

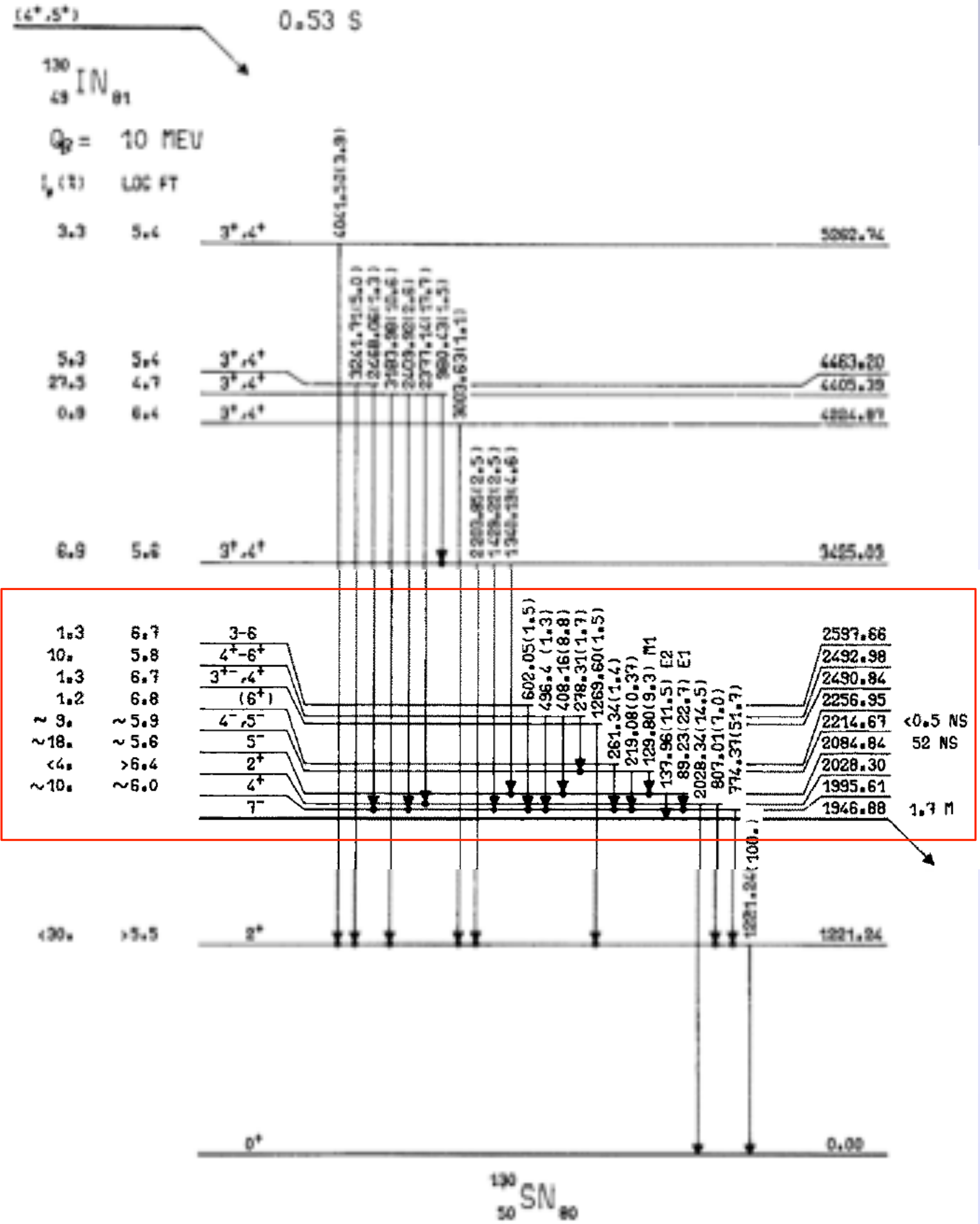
- ✓ Need modification of the In β-decay
- ✓ Measurable lifetimes
- ✓ Decay rates by shell-model?

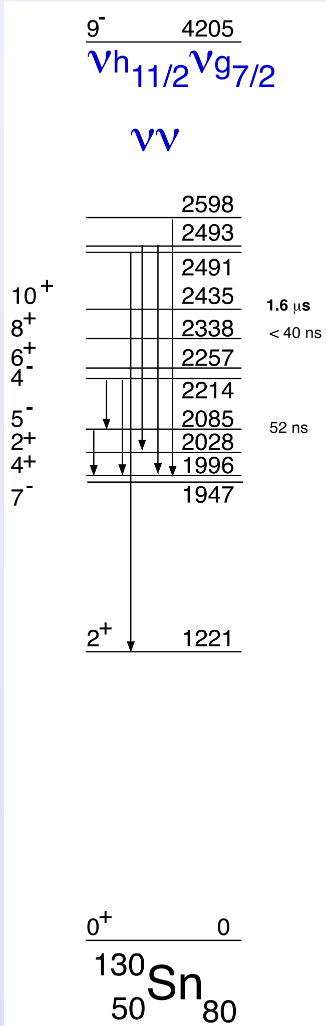
[B. Fogelberg et al., NPA 347 (1981)]





^{130}Sn study


0.53 S
Q$_\beta$ = 10 MEV
LOG FT
2597.66
2492.98
2490.84
2256.95
2214.67
2084.84
2028.30
1995.61
1946.88
1221.24
0.00
<0.5 NS
52 NS
1.7 M


9$^-$ 4205
$\nu h_{11/2} \nu g_{7/2}$
$\nu\nu$
2598
2493
2491
10$^+$ 2435 1.6 µs
8$^+$ 2338 < 40 ns
6$^+$ 2257
4$^-$ 2214
5$^-$ 2085 52 ns
2+ 2028
4+ 1996
7$^-$ 1947
2$^+$ 1221
0$^+$ 0
$^{130}_{50}$Sn$_{80}$

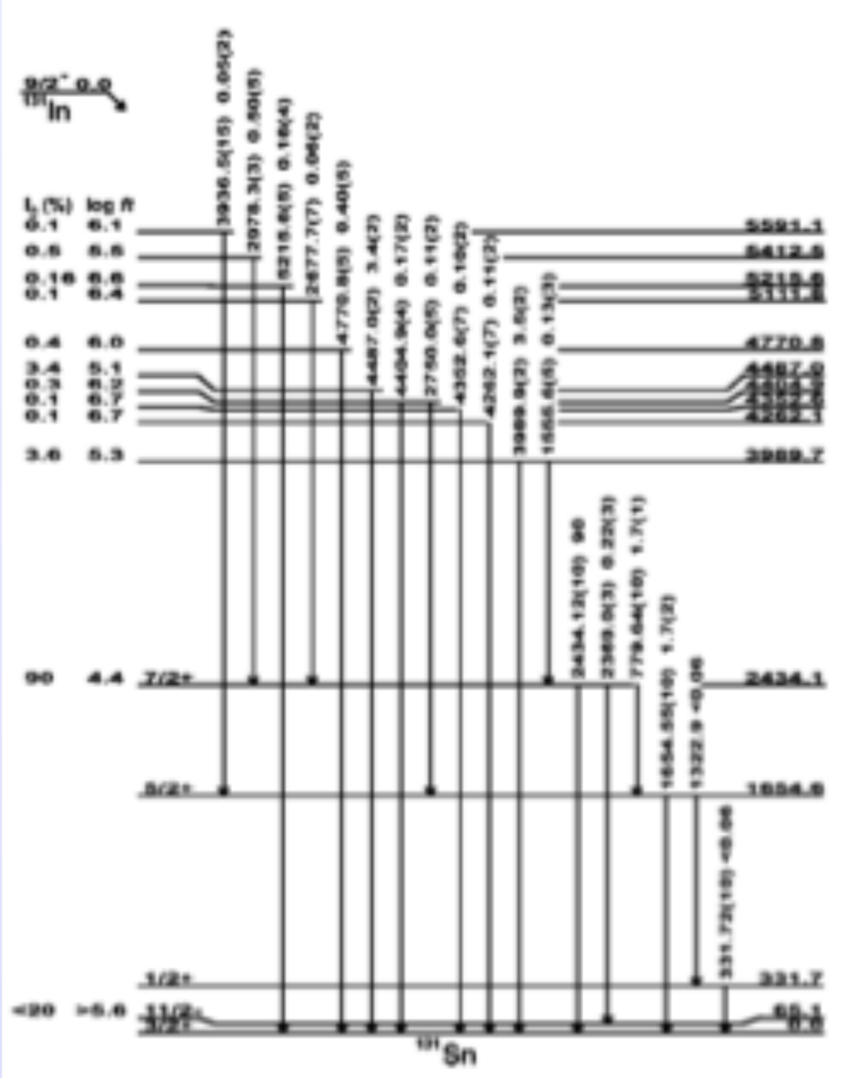
Odd mass Sn isotopes: ^{131}Sn

✓ (Indirect) information on single-particle states

→ the $\nu h_{11/2}$ (hole) at 69±14 keV

[B. Fogelberg PRC70 (2004)]

→ 65.1 keV measured without confirmation from coincidences…



✓ Three beta-decaying isomers

→ $1/2^-$, $T_{1/2} = 280(3)$ ms, $P_n = 2\%$ (?)

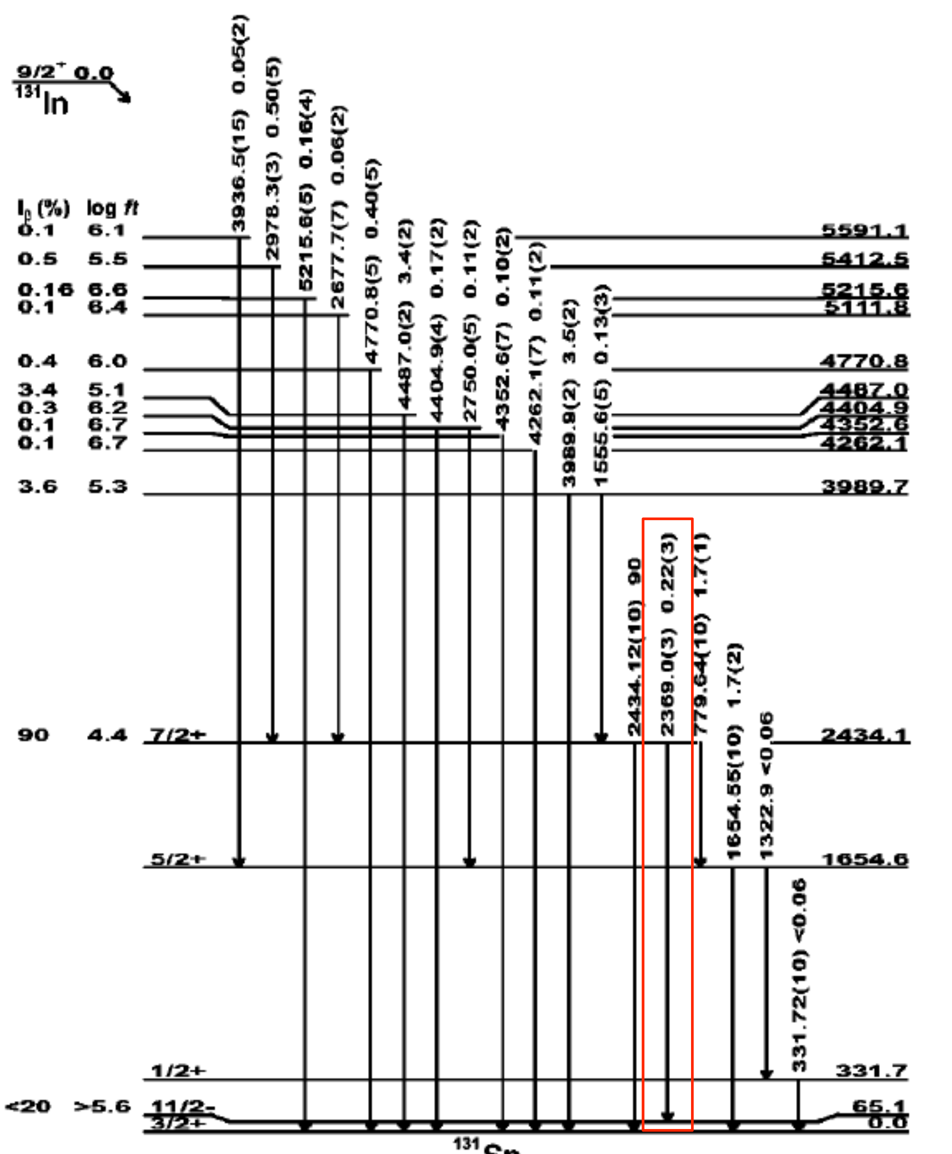
→ $9/2^+$, $T_{1/2} = 350(5)$ ms, $P_n = 2\%$ (?)

→ $21/2^+$, $T_{1/2} = 350(5)$ ms

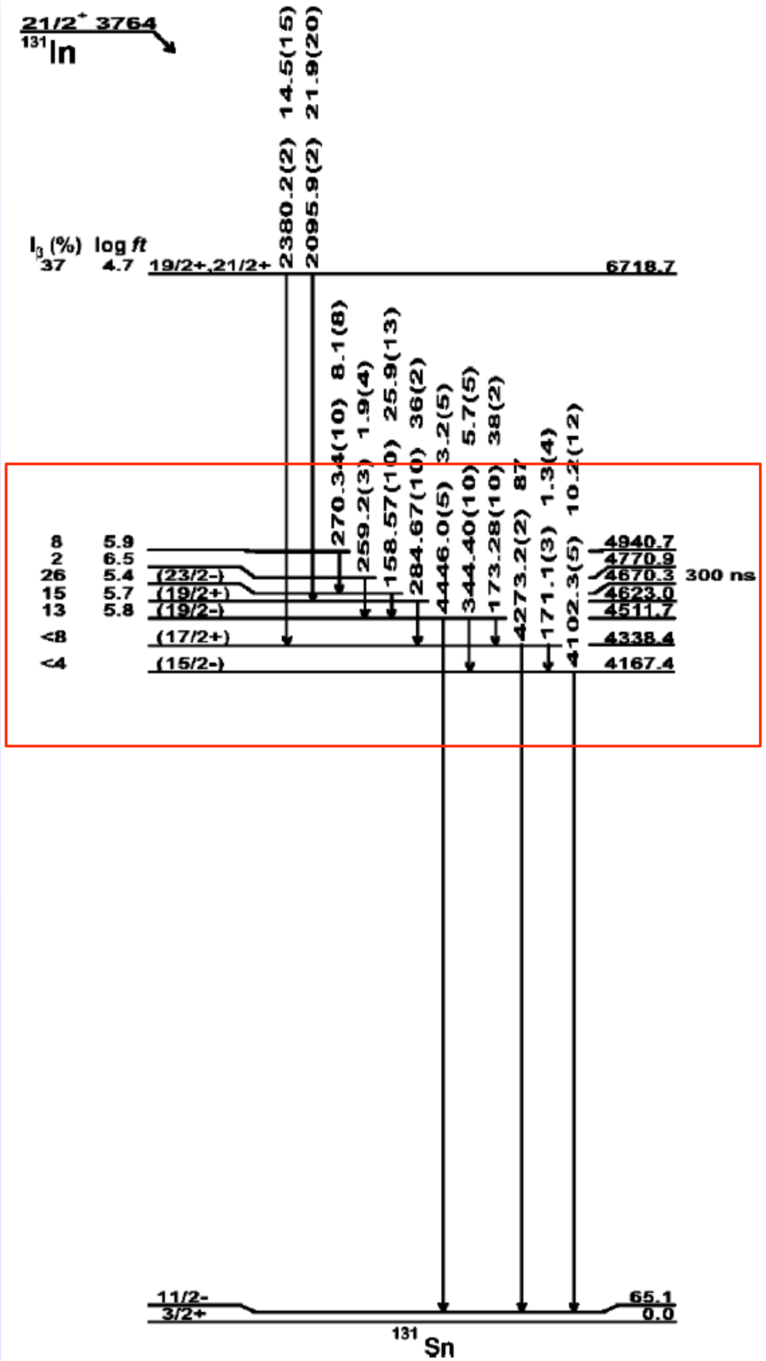
→ $Q_{g.s.} = 9177\ (18)$ keV

^{131}Sn measurement

- ✓ M2 branch may point to measurable $T_{1/2}$
  - → ~20 ps

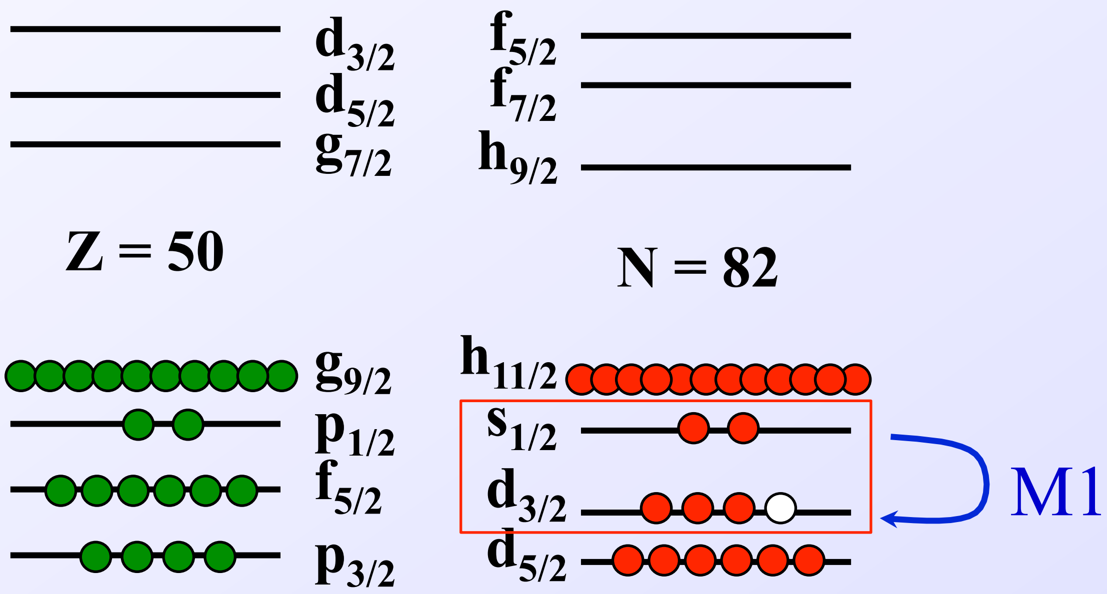


→ lifetimes

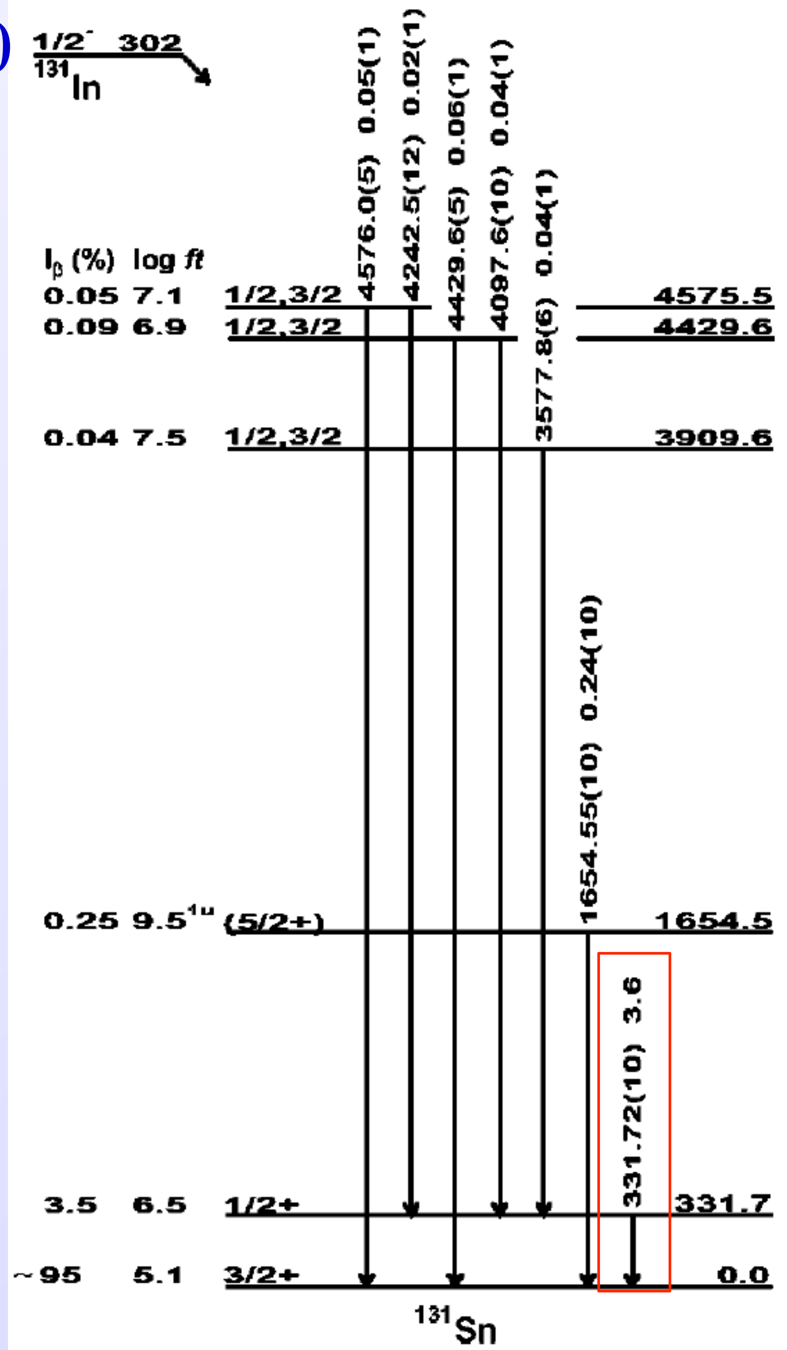


Proposal for ^{131}Sn measurement

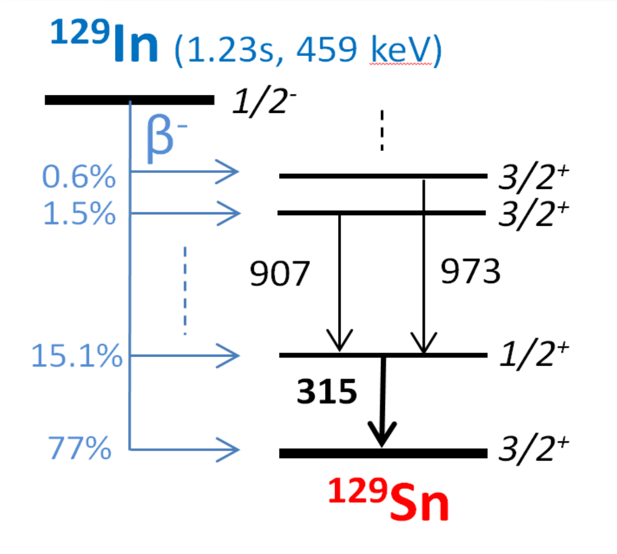
- ✓ Expected increased sensitivity by factor ~20
- ✓ Isomer selectivity in In
  - → disentangle decay schemes
- ✓ Lifetimes of high-lying levels
  - → from $21/2^+$ isomer, at ~4.5 MeV
- ✓ Lifetimes 331-keV $1/2^+$ level (& other)



- → forbiddenness of the transition, M1 operator
- → similar to ^{129}Sn measured at IDS



^{129}In decay at IDS



H. Gausemel et. al, PRC 69, 054307 (2004)

[R. Liča, H. Mach et al.]

Shell model calculations A. Gargano - ^{132}Sn core
Single hole energies taken from ^{131}Sn
Effective interaction: CD-Bonn

315-keV transition: Test for M1 effective operators

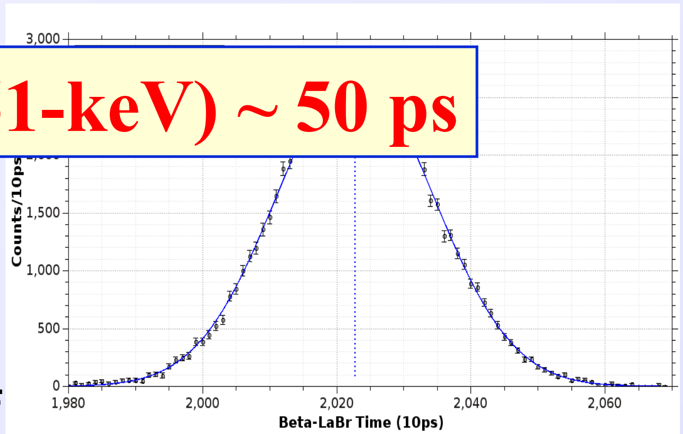
$3s_{1/2} \rightarrow 2d_{3/2}$ M1 l-forbidden

Predicting half-life using the effective charges and gyromagnetic factors from M. Danchev et. Al, PRC 84, 061306(R) (2011)

Unknown **M1 effective operator** for neutron holes:

$T_{1/2}^{theo}$ (<$d_{3/2}$|M1|$s_{1/2}$>) ~4 ns A. Gargano

$T_{1/2}^{exp}$ (351-keV) ~ 50 ps



A slightly different from zero **M1 effective operator** for neutron holes greatly improves the agreement without changing any other matrix elements

Study of ^{133}Sn and ^{135}Sn

✓ Information about the M1 operator above ^{132}Sn

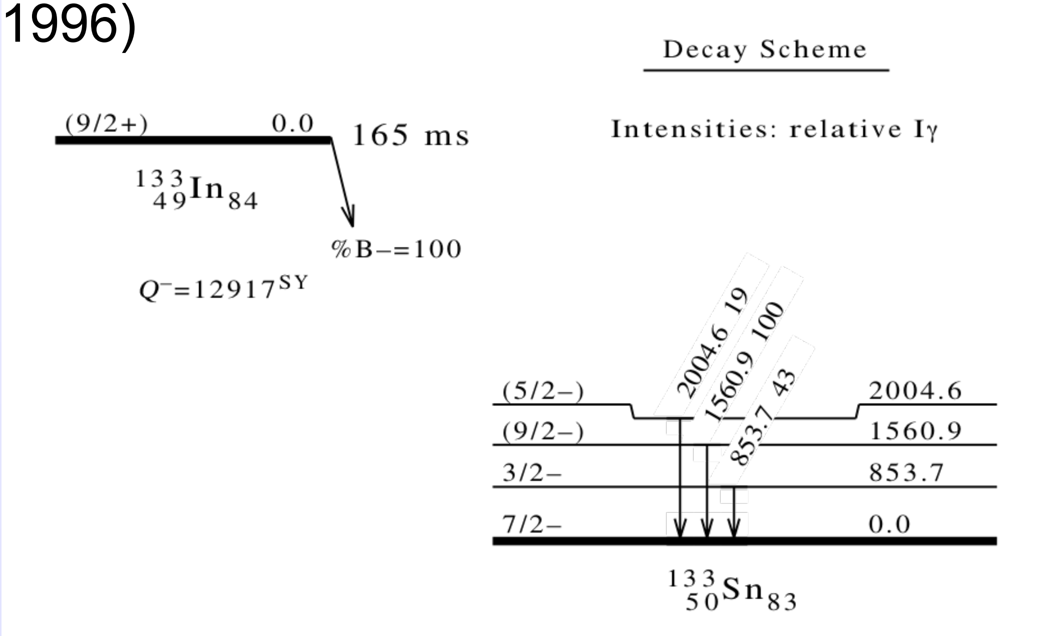
^{133}Sn

✓ $2p_{1/2}$ single-particle candidate from ^{132}Sn(d,p) was identified at 1.363 MeV

K.L. Jones et al., PRC84, 034601 (2011)

→ 300 keV lower than proposed value from β-decay

P. Hoff et al., Phys. Rev. Lett. 77, 1020 (1996)



✓ No $13/2^+$ observed to date

Isomer selective decay from ^{133}In isomers

→ $(9/2^+)$ ground state and $(1/2^-)$

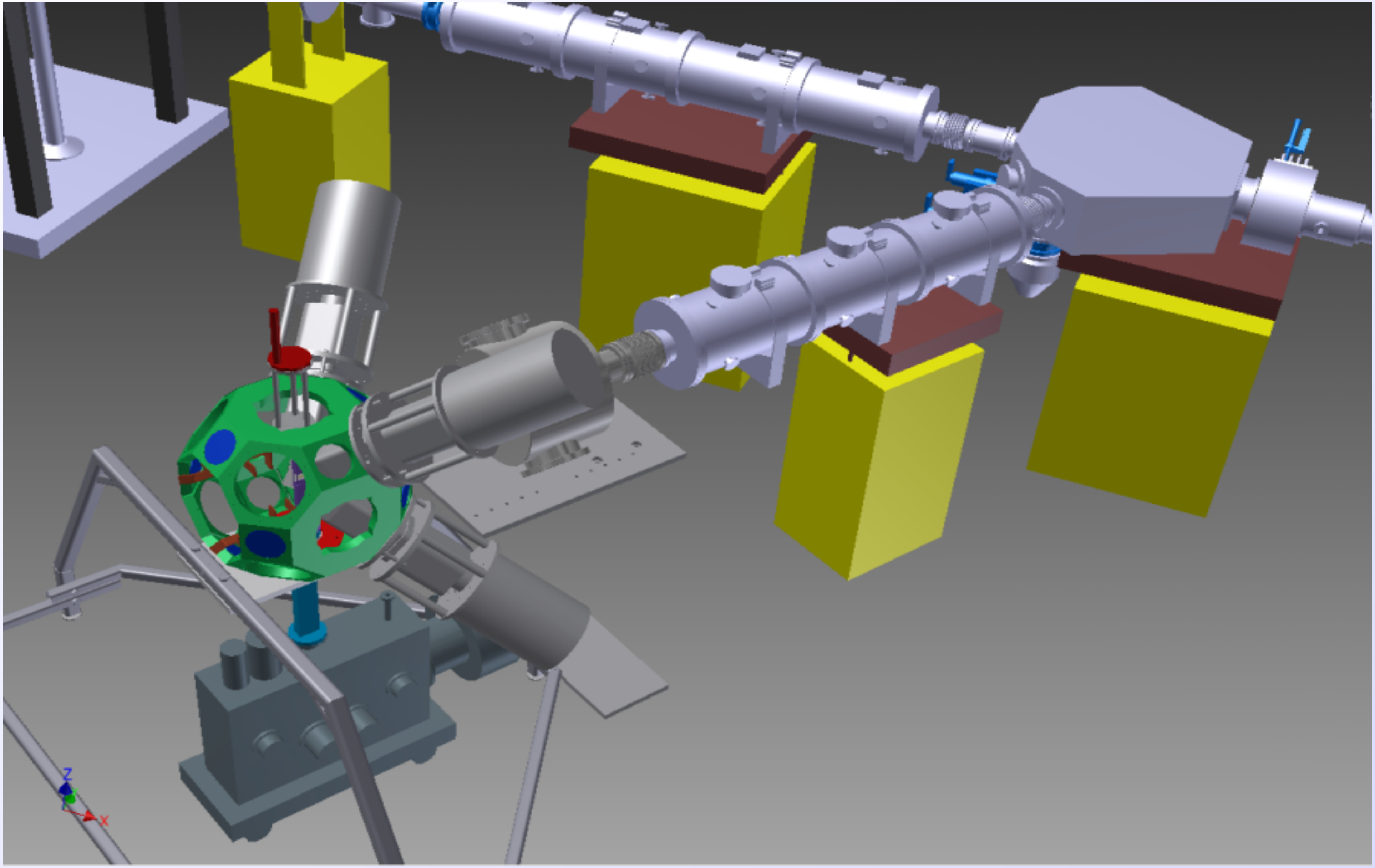
β-n branch from ^{134}In

Estimated sensitivity ~20 higher than 1996

^{135}Sn

✓ Level scheme maybe possible from ^{135}In decay

IDS setup



Sketch of the method

Coincidences, level scheme:

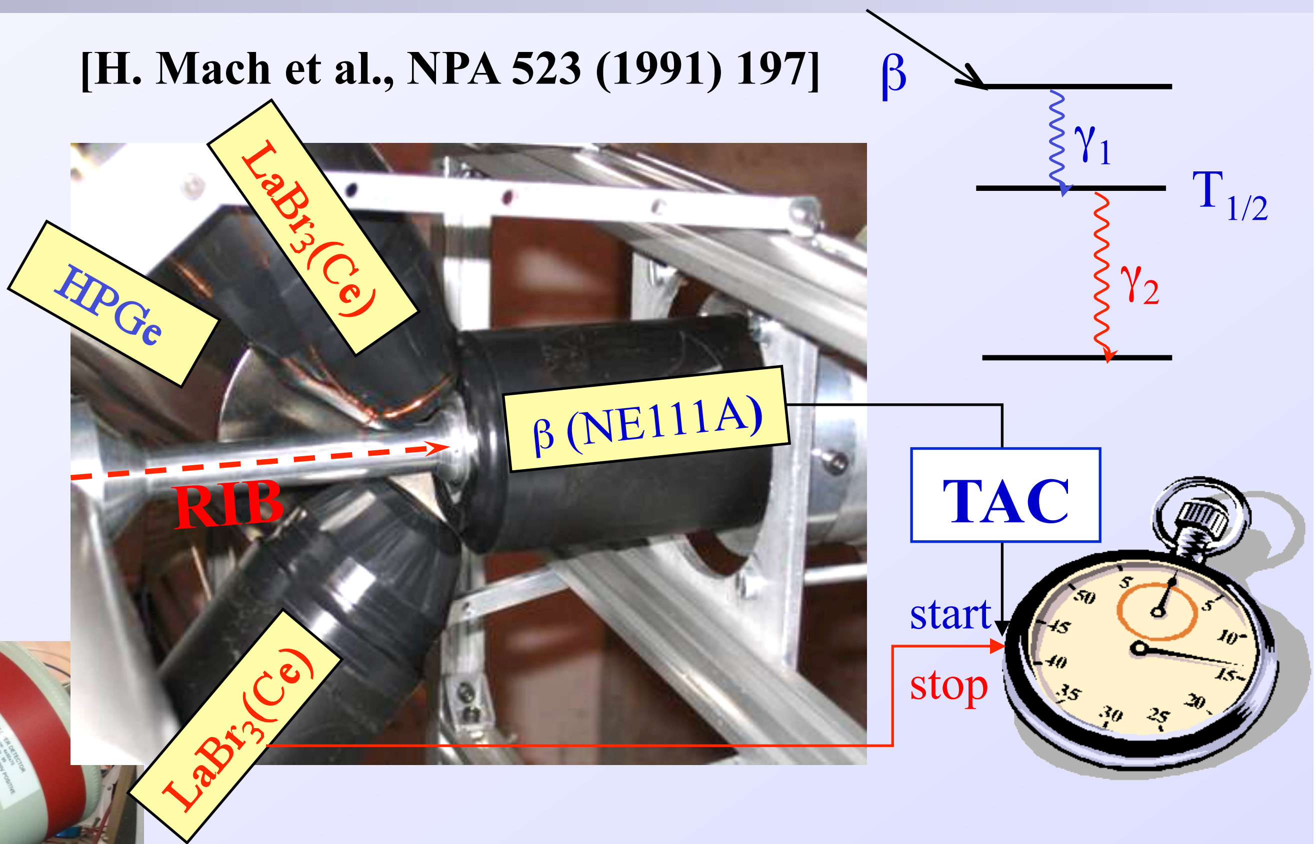
β–Ge–Ge

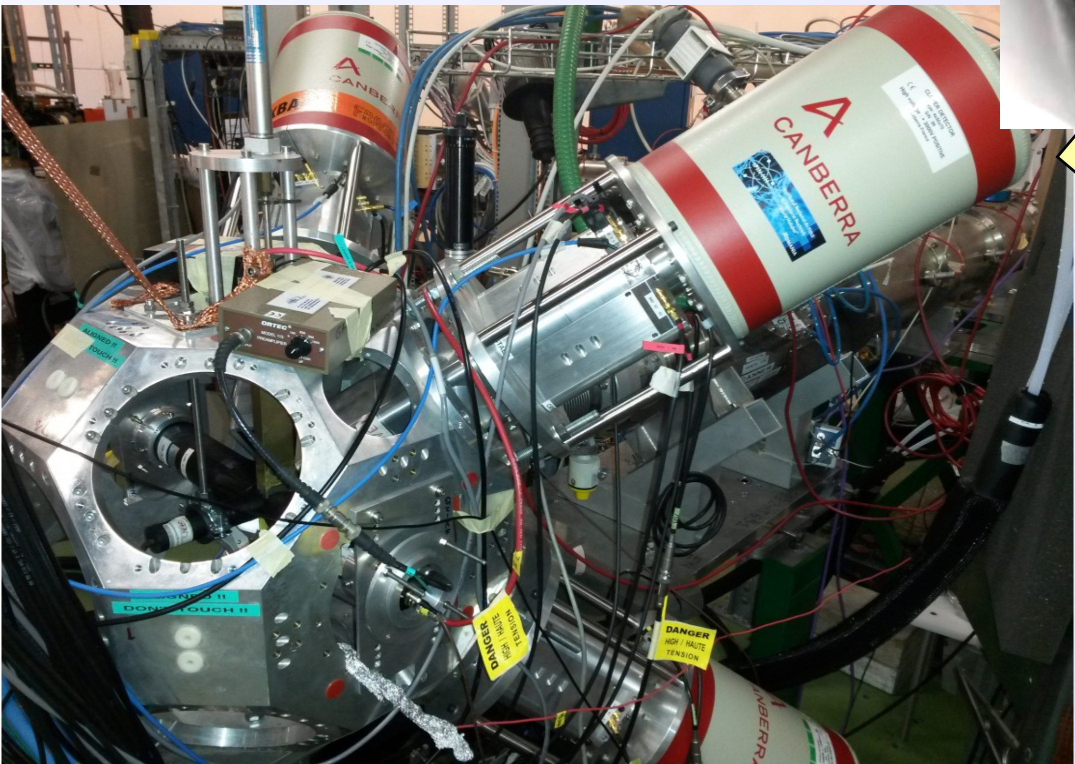
Lifetime measurements:

β-Ge-LaBr(t), β-LaBr(t), β-LaBr-LaBr(t), LaBr-LaBr(t)

CALIBRATIONS

[H. Mach et al., NPA 523 (1991) 197]





De-convolution of slope

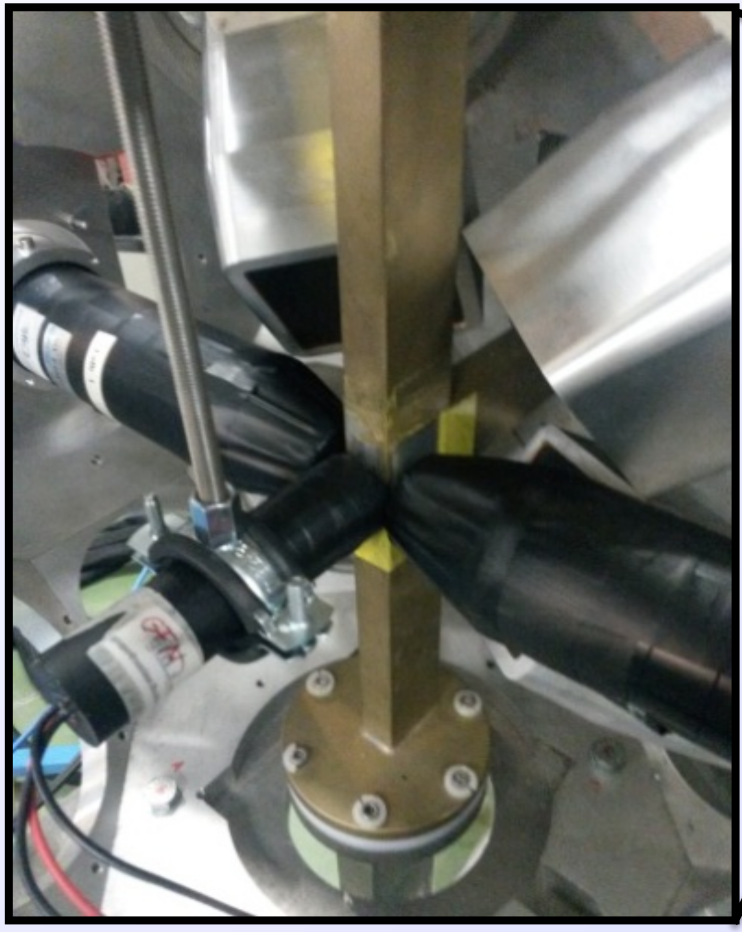
- Slope = $T_{1/2}$
- Range: 30 ps to 30 ns (or longer)

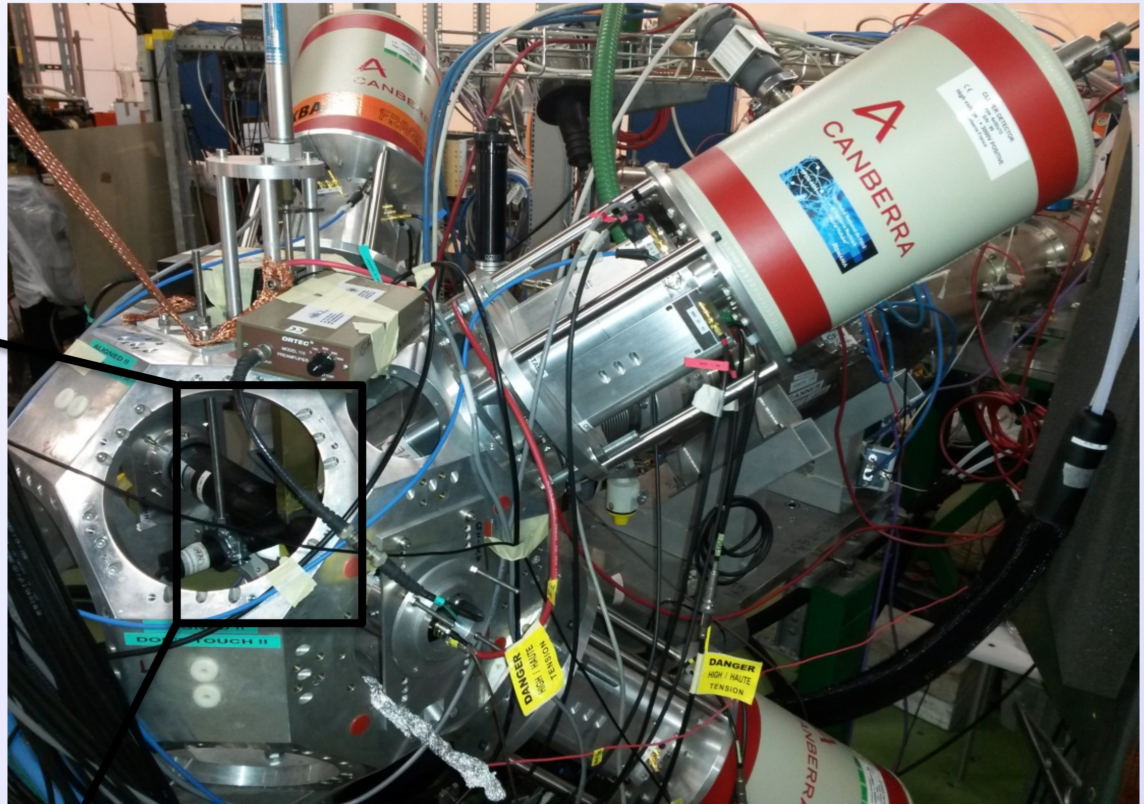
Centroid shift

- Shift in centroid position = τ
- Range: down to ~5-10 ps

Setup at the IDS

- 4 Clover HPGe ~ 3.7% **eff.** @600keV
- 2 $LaBr_3$(Ce) ~ 4% (2% each) @600keV
- 1 Plastic Scintillator ~ 20% eff.
- DAQ – Digital system
- Analog TACs





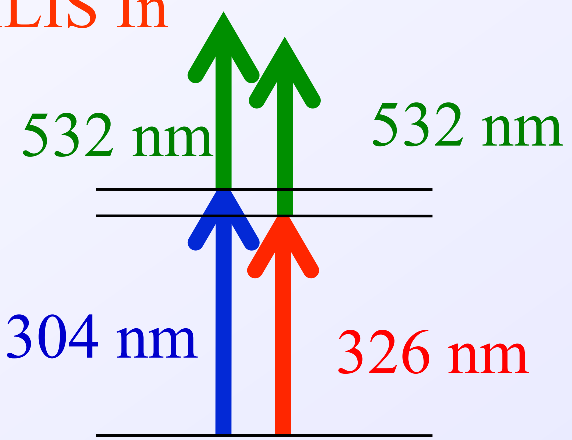
✓ Slight modification of T-section

→ increase of >50% in double coinc.

→ about a factor of 3 in triples

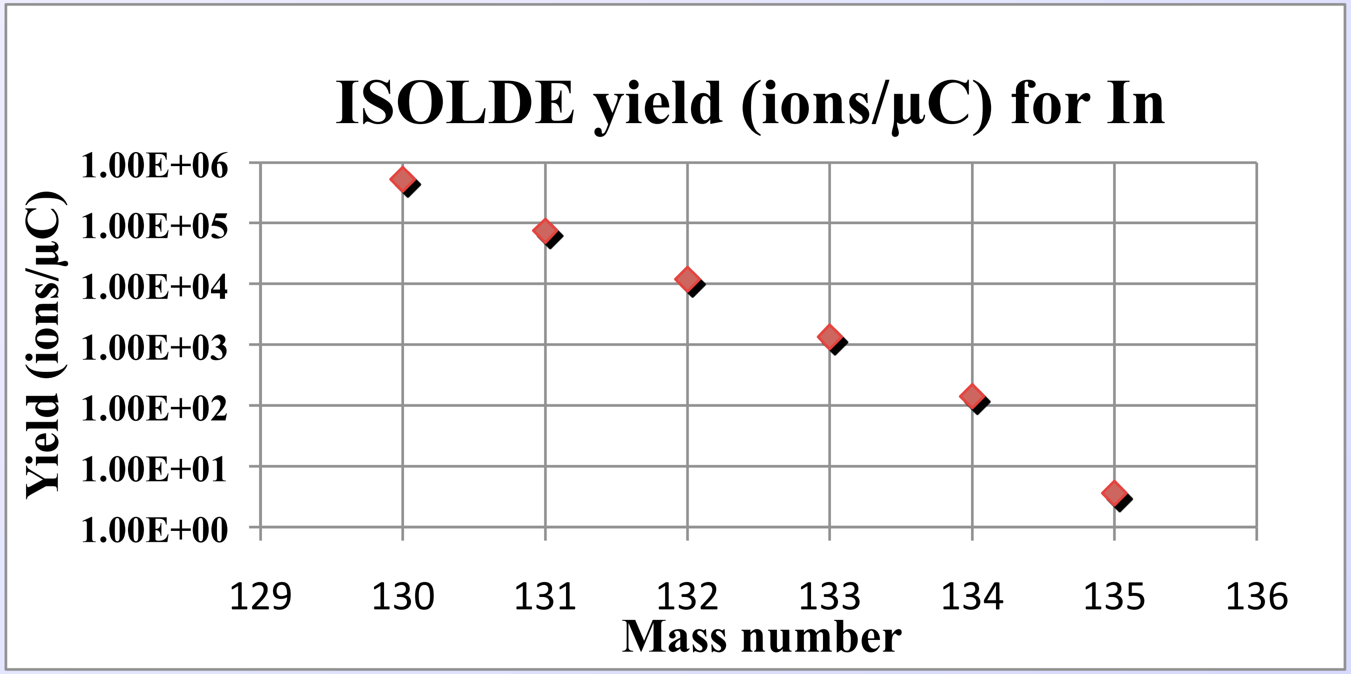
Yields and beam request

- ✓ UC_x target
  - → equipped with a new neutron converter
  - → no **p** on target prior to run
  - → RILIS In



- ✓ Assumptions: 1.9 uA proton beam and ~90% transmission to IDS
- ✓ Intensity in our setup is limited to ~30000 ions/s

^{130}In	>5.25E+05 /μC	>9.0E+05 s^{-1}	3 shifts
^{131}In	~7.50E+04 /μC	~1.3E+05 s^{-1}	3 shifts
^{132}In	1.20E+04 /μC	2.1E+04 s^{-1}	4 shifts
^{133}In	1.35E+03 /μC	2.3E+03 s^{-1}	5 shifts
^{134}In	~1.43E+02 /μC	~2.4E+02 s^{-1}	6 shifts
^{135}In	~3.60E+00 /μC	~6.2E+00 s^{-1}	3 shifts



Collaboration

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Thank you!