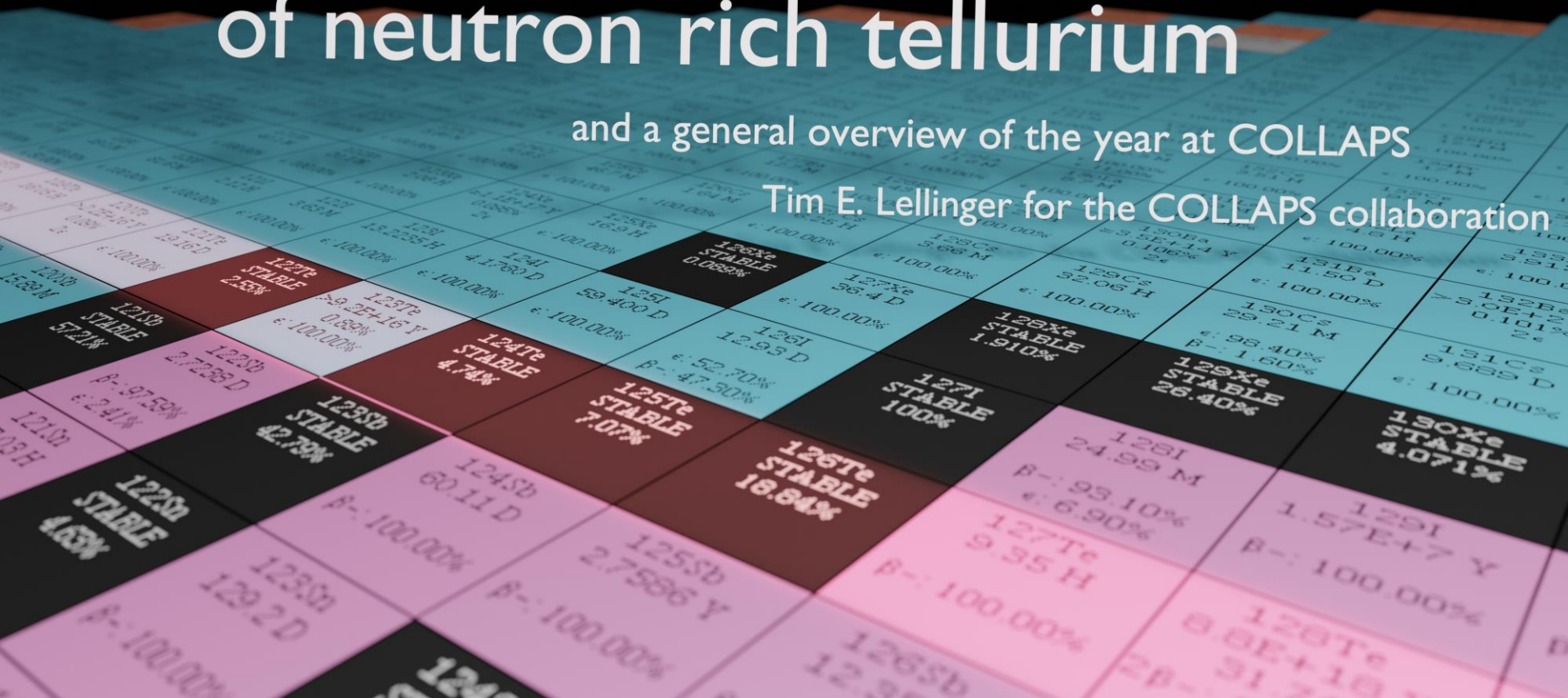


High resolution laser spectroscopy of neutron rich tellurium

and a general overview of the year at COLLAPS

Tim E. Lellinger for the COLLAPS collaboration



Tellurium physics case

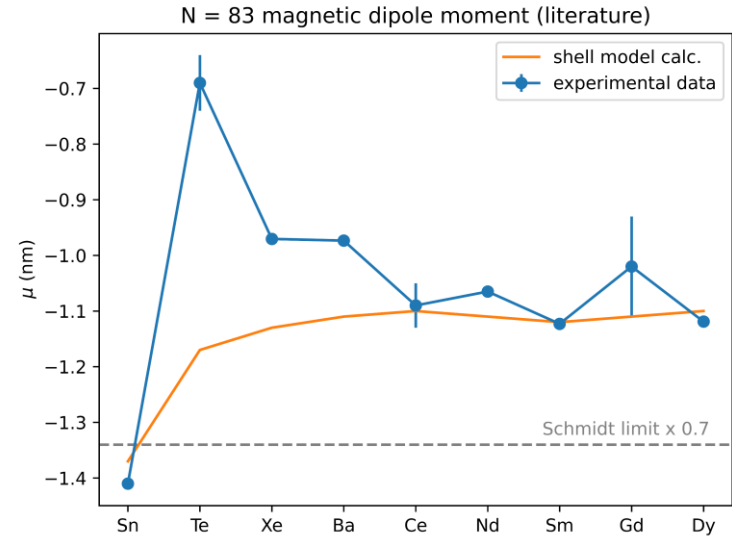
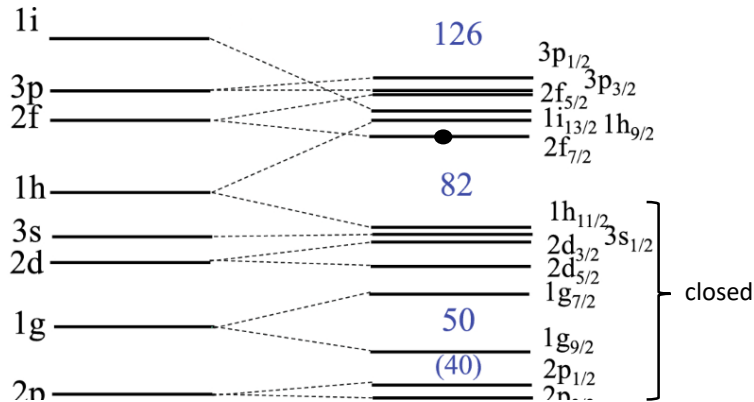
$Z = 52 \rightarrow 50 (\text{Sn}) + 2p$

37 isotopes, 25 accessible with COLLAPS (^{112}Te - ^{137}Te)

			14 S	>0.5 S	>0.8 S	1.2 S	3.3 S	3.14 S	4.2 S	2.84 S	3.2 S	4.0 S	1.51 M	1.6 M	6.5 M	17 M	24 M	13.1 M	1.28 H	1.45 M	4.41 H	3.39 M	STABLE 100%	19.12 H	13.57 D	17.28 M	5.984 H	
			P	.	.	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	140C STABLE 98.450%	141C STABLE 32.508 D	142C >2.6E+17 Y	143C 33.039 H	144C 284.91 D	
			119Ca	120Ca	121Ca	122Ca	123Ca	124Ca	125Ca	126Ca	127Ca	128Ca	129Ca	130Ca	131Ca	132Ca	133Ca	134Ca	135Ca	136Ca	137Ca	138Ca	139Ca	140Ca	141Ca	142Ca	143Ca	144Ca
			117La	118La	119La	120La	121La	122La	123La	124La	125La	126La	127La	128La	129La	130La	131La	132La	133La	134La	135La	136La	137La	138La	139La	140La	141La	142La
			P-39.90% < 6.10%	.	.	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%
114Ba	115Ba	116Ba	117Ba	118Ba	119Ba	120Ba	121Ba	122Ba	123Ba	124Ba	125Ba	126Ba	127Ba	128Ba	129Ba	130Ba	131Ba	132Ba	133Ba	134Ba	135Ba	136Ba	137Ba	138Ba	139Ba	140Ba	141Ba	142Ba
< 99.10%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%
115Ce	116Ce	117Ce	118Ce	119Ce	120Ce	121Ce	122Ce	123Ce	124Ce	125Ce	126Ce	127Ce	128Ce	129Ce	130Ce	131Ce	132Ce	133Ce	134Ce	135Ce	136Ce	137Ce	138Ce	139Ce	140Ce	141Ce	142Ce	
167.00 μs	0.5 s	1.1 s	1.5 s	2.1 s	2.8 s	3.5 s	4.2 s	5.0 s	5.8 s	6.5 s	7.2 s	8.0 s	8.8 s	9.5 s	10.2 s	11.0 s	11.8 s	12.5 s	13.2 s	14.0 s	14.8 s	15.5 s	16.2 s	17.0 s	17.8 s	18.5 s		
P-100.00%	< 99.99%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	
112Xe	113Xe	114Xe	115Xe	116Xe	117Xe	118Xe	119Xe	120Xe	121Xe	122Xe	123Xe	124Xe	125Xe	126Xe	127Xe	128Xe	129Xe	130Xe	131Xe	132Xe	133Xe	134Xe	135Xe	136Xe	137Xe	138Xe	139Xe	
< 99.16%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	
111I	112I	113I	114I	115I	116I	117I	118I	119I	120I	121I	122I	123I	124I	125I	126I	127I	128I	129I	130I	131I	132I	133I	134I	135I	136I	137I		
2.5 S	3.42 S	6.6 S	2.1 S	1.3 M	2.91 S	2.22 M	13.7 M	19.1 M	81.6 M	2.12 H	3.63 M	12.3 H	124I	126I	128I	127I STABLE 100%	128I	129I	130I	131I	132I	133I	134I	135I	136I	137I		
< 99.90%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%		
110Te	111Te	112Te	113Te	114Te	115Te	116Te	117Te	118Te	119Te	120Te	121Te	122Te	123Te	124Te	125Te	126Te	127Te	128Te	129Te	130Te	131Te	132Te	133Te	134Te	135Te	136Te		
18.6 S	19.3 S	2.0 M	1.7 M	11.47e	5.57e	2.49 H	11.77e	11.67e	16.05 H	12.07e	12.17e	12.27e	12.37e	12.47e	12.57e	12.67e	12.77e	12.87e	12.97e	13.07e	13.17e	13.27e	13.37e	13.47e	13.57e			
< 100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%			
109Bi	110Bi	111Bi	112Bi	113Bi	114Bi	115Bi	116Bi	117Bi	118Bi	119Bi	120Bi	121Bi	122Bi	123Bi	124Bi	125Bi	126Bi	127Bi	128Bi	129Bi	130Bi	131Bi	132Bi	133Bi	134Bi	135Bi		
23.0 S	7.5 S	11.35e	51.4 S	11.93e	3.49 M	32.1 M	11.93e	15.8 M	2.9 H	3.6 M	38.19 M	15.89 M	57.21 M	12.28e	2.7238 D	15.89e	10.11 D	12.35e	12.35e	12.35e	12.35e	12.35e	12.35e	12.35e	12.35e			
<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%			
108Po	109Po	110Po	111Po	112Po	113Po	114Po	115Po	116Po	117Po	118Po	119Po	120Po	121Po	122Po	123Po	124Po	125Po	126Po	127Po	128Po	129Po	130Po	131Po	132Po	133Po	134Po		
10.30 M	18.0 M	4.11 H	35.3 M	STABLE 0.97%	11.93e D	0.68%	STABLE 0.34%	STABLE 1.454%	STABLE 7.68%	STABLE 2.422%	STABLE 8.59%	STABLE 32.58%	121Sn	122Sn	123Sn	124Sn	125Sn	126Sn	127Sn	128Sn	129Sn	130Sn	131Sn	132Sn	133Sn			
<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%			
107Th	108Th	109Th	110Th	111Th	112Th	113Th	114Th	115Th	116Th	117Th	118Th	119Th	120Th	121Th	122Th	123Th	124Th	125Th	126Th	127Th	128Th	129Th	130Th	131Th	132Th			
32.4 M	58.0 M	4.167 H	4.9 H	2.8047 D	14.97 M	11.3h	STABLE 4.29%	11.41h	11.5h	11.6h	11.7h	11.8h	11.9h	12.0h	12.1h	12.2h	12.3h	12.4h	12.5h	12.6h	12.7h	12.8h	12.9h	13.0h				
<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%			
106Df	107Df	108Df	109Df	110Df	111Df	112Df	113Df	114Df	115Df	116Df	117Df	118Df	119Df	120Df	121Df	122Df	123Df	124Df	125Df	126Df	127Df	128Df	129Df	130Df	131Df			
>2.6E+17 Y	6.50 H	>1.0E+18 Y	4.614 D	STABLE 12.49%	STABLE 12.80%	STABLE 24.13%	11.93e D	7.7E+15 Y	>6.4E+18 Y	53.46 H	3.1E+19 Y	1.77e D	50.3 M	11.93e	11.93e	11.93e	11.93e	11.93e	11.93e	11.93e	11.93e	11.93e	11.93e	11.93e				
<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%				
105Ae	106Ae	107Ae	108Ae	109Ae	110Ae	111Ae	112Ae	113Ae	114Ae	115Ae	116Ae	117Ae	118Ae	119Ae	120Ae	121Ae	122Ae	123Ae	124Ae	125Ae	126Ae	127Ae	128Ae	129Ae	130Ae			
41.29 D	23.96 M	STABLE 51.859%	STABLE 48.161%	11.04e	7.41e	11.24e	3.130 H	5.37 H	14.44e	20.2 M	2.69 M	11.74e	11.84e	11.94e	12.04e	12.14e	12.24e	12.34e	12.44e	12.54e	12.64e	12.74e	12.84e	12.94e				
<100.00%	< 99.55%	< 1.00%	< 97.15%	< 2.85%	< 99.70%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%	< 100.00%				
104Pr	105Pr	106Pr	107Pr	108Pr	109Pr	110Pr	111Pr	112Pr	113Pr	114Pr	115Pr	116Pr	117Pr	118Pr	119Pr	120Pr	121Pr	122Pr	123Pr	124Pr	125Pr	126Pr	127Pr	128Pr				
STABLE 11.14%	STABLE 22.33%	STABLE 27.33%	STABLE 6.5E+6 Y	STABLE 26.46%	STABLE 13.7012 H	STABLE 11.72%	11.11p	11.09p	11.07p	11.05p	11.03p	11.01p	10.99p	10.97p	10.95p	10.93p	10.91p	10.89p	10.87p	10.85p	10.83p	10.81p	10.79p	10.77p				
<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%	<100.00%				
103Pb	104Pb	105Pb	106Pb	107Pb	108Pb	109Pb	110Pb	111Pb	112Pb	113Pb	114Pb	115Pb	116Pb	117Pb	118Pb	119Pb	120Pb	121Pb	122Pb	123Pb	124Pb	125Pb	126Pb	127Pb				
STABLE 100%	42.3 S	35.36 H	29.80 S	21.7 M	16.9 S	8.0 S	3.2 S	11.1 S	3.45 S	2.80 S	1.85 S	0.99 S	0.68 S	0.44 S	0.26 M	>150 MS	136 MS	151 MS	>226e	>300 MS	>100 MS	>100 MS	>100 MS					

The physics case of ^{135}Te

Hagino, K., Maeno, Y. A nuclear periodic table. *Found Chem* **22**, 267–273 (2020)



add. data from <https://doi.org/10.1103/PhysRevC.102.051301>

- (simple shell model picture): single neutron over closed 82 core
- Single particle like for tin: doubly magic + 1n
- Otherwise: Contribution from valence protons

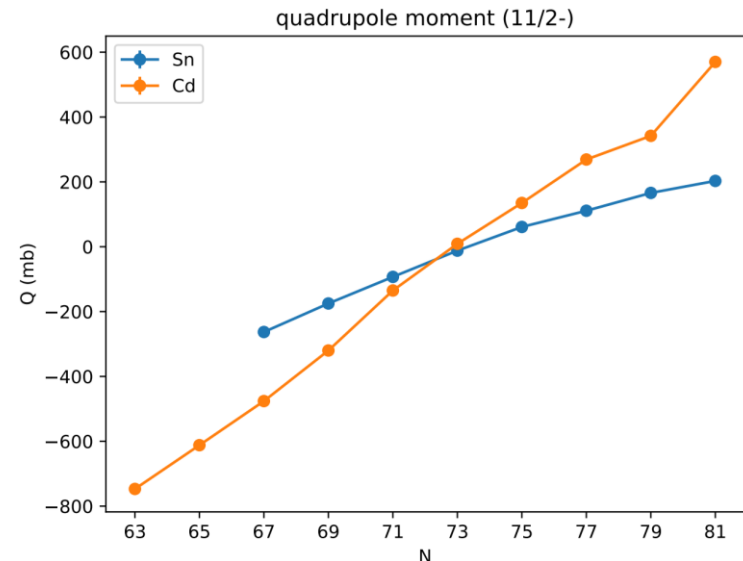
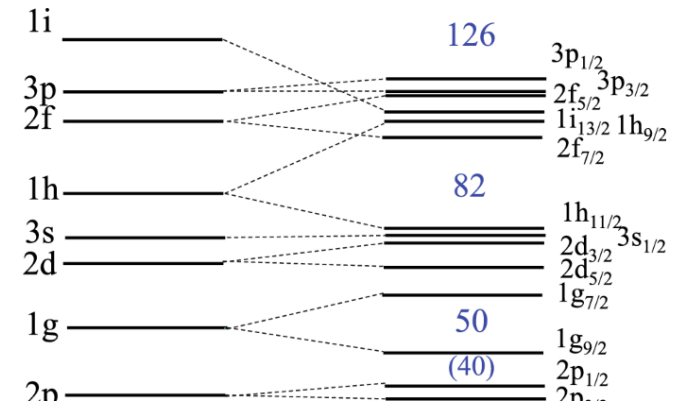
→ Should be decently described by theory

But: Large deviation for tellurium

11/2 isomeric chains

- Long chains of 11/2 isomeric states in Cd, Sn, Te
- Single unpaired neutron in h11/2 shell
- Parity defining orbital \rightarrow pure wave function
- Cd, Sn completely different!

Goal: Compare effect of two valence protons of tellurium to two holes of cadmium



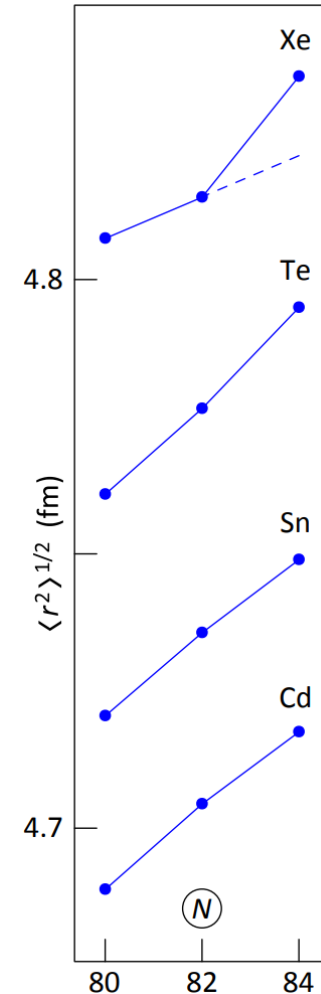
Charge radii at the shell closure

$N = 82$ shell closure

→ “kink” in charge radius

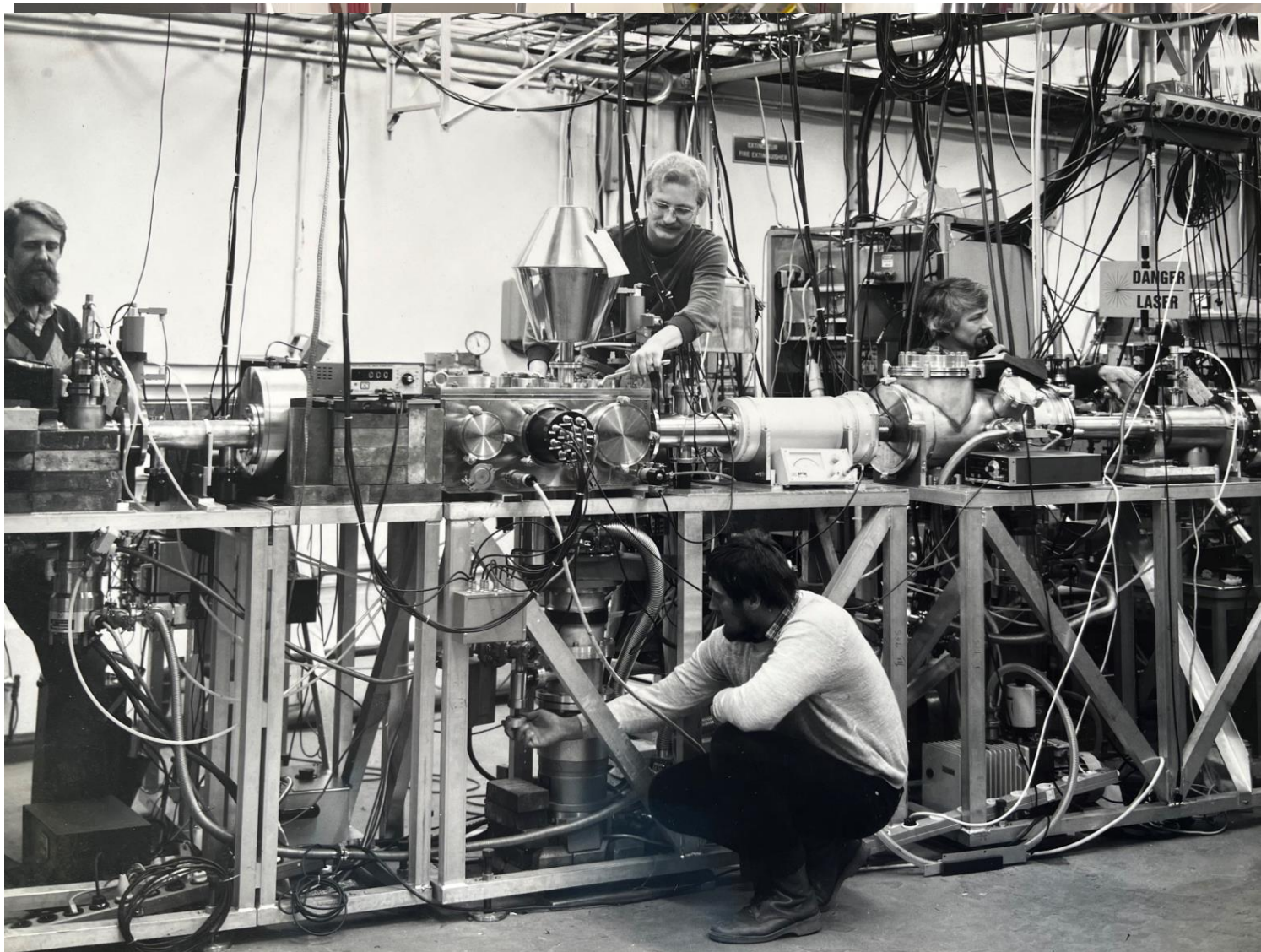
Any “quenching”?

Goal: Compare “kink” in charge radius to Sn, Xe, Cd...



<https://cds.cern.ch/record/1601818/files/INTC-CLL-011.pdf>

COLLAPS beamline

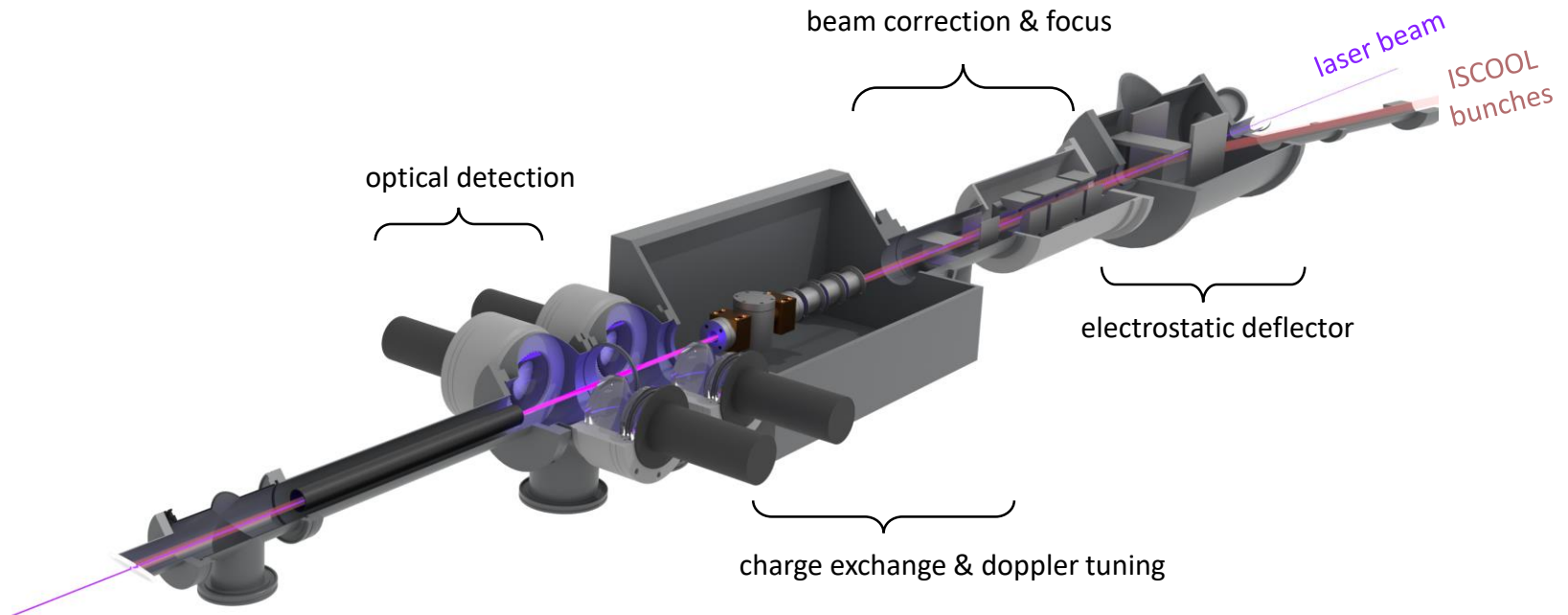


Photographic service CERN, 237-04-80

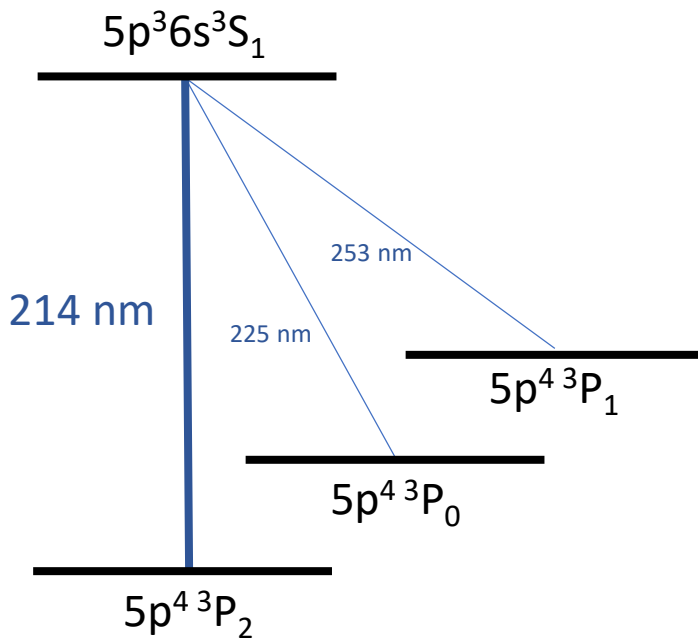
COLLAPS beamline

Measurement principle:

- 1) Overlap laser beam and ion bunches
- 2) Focused beam into optical detection
- 3) Sensitive to ion bunch via change and scan beam energy
- 4) Measure fluorescence in optical detection



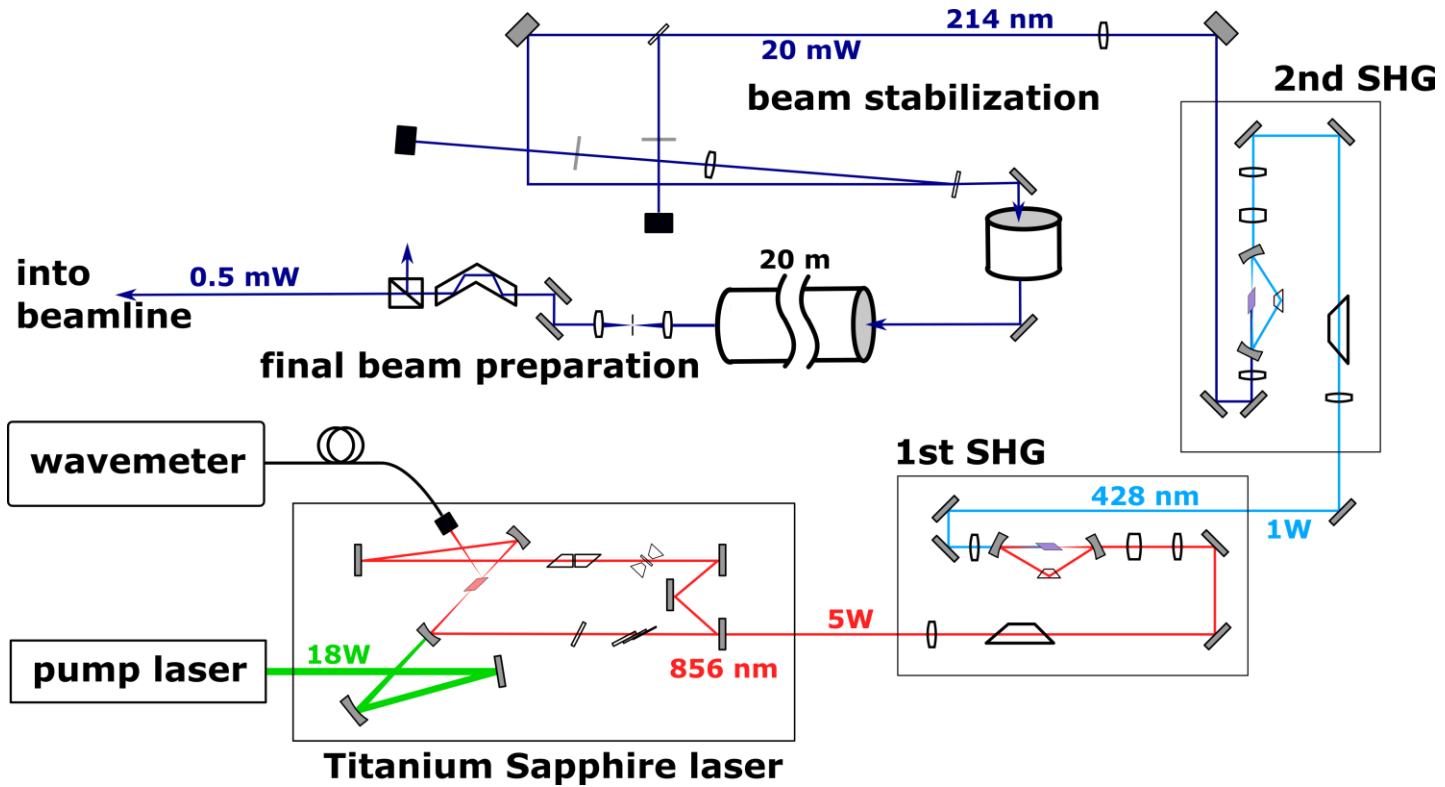
Tellurium atomic level scheme



Why choose the 214 nm transition?

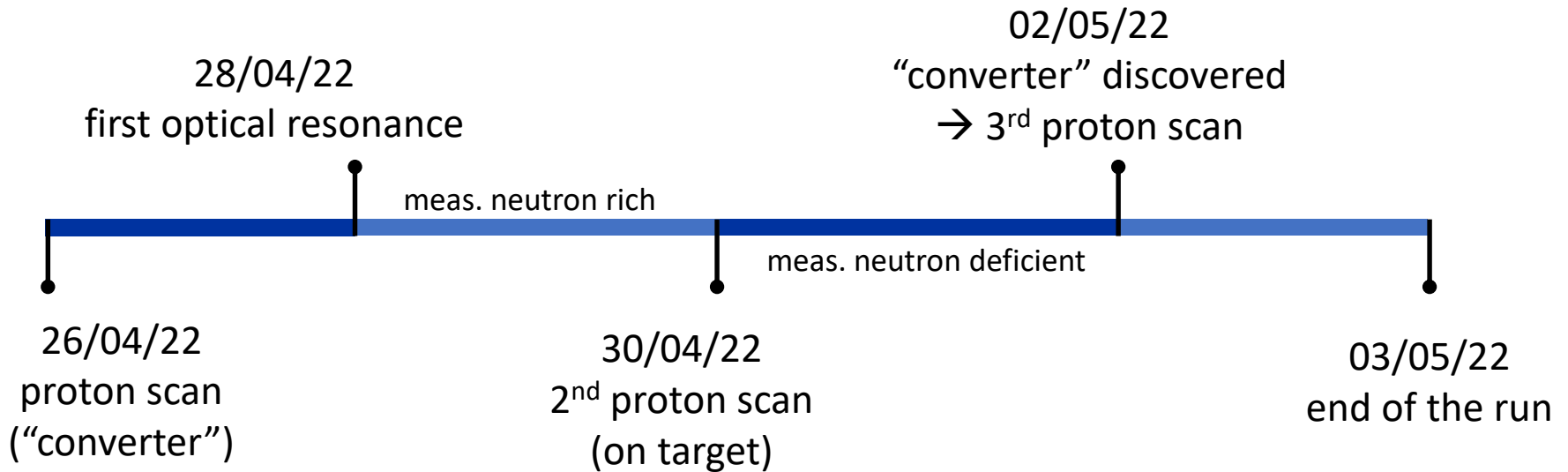
- (Simulated) $5p^4 3P_2$ ground state most populated in charge exchange process (>50%)
- Highly sensitive to “nuclear signature”
 - Ground state sensitive to quadrupole moment
 - Upper state sensitive to dipole moment
 - $S \rightarrow P$ transition sensitive to charge radii
- Challenge: Laser system to produce 214 nm light

Laser setup for 214 nm



→ Stable operation during the entire run

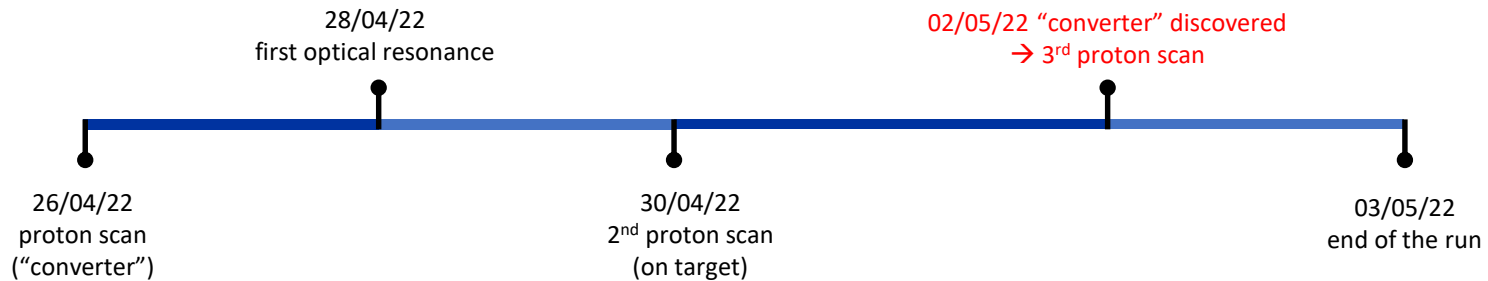
Overview of the run



→ Measured ^{112}Te - ^{136}Te with 10 isomers

→ 328 (!) usable spectra in total

Curiosity: Copper neutron converter



- Shoot on converter → steer p-beam "down"
- Confusion over which way is up/down
- ➔ Ended up hitting the copper blocks instead of the real converter

A "makeshift spallation neutron source" for neutron-rich Te isotopes at ISOLDE

- ➔ Ulli Köster, Jochen Ballof¹, Cyril Bernerd², Katerina Chrysalidis³, Reinhard Heinke³, Bruce Marsh³, João Pedro Ramos⁴, Edgar Reis³, Sebastian Rothe³, Simon Stegemann³, Liss Vazquez Rodriguez³, COLLAPS collaboration

¹ CERN, present address MSU

² KU Leuven - CERN

³ CERN

⁴ CERN, present address: SCK CEN



<https://cds.cern.ch/record/2759094>

Spins

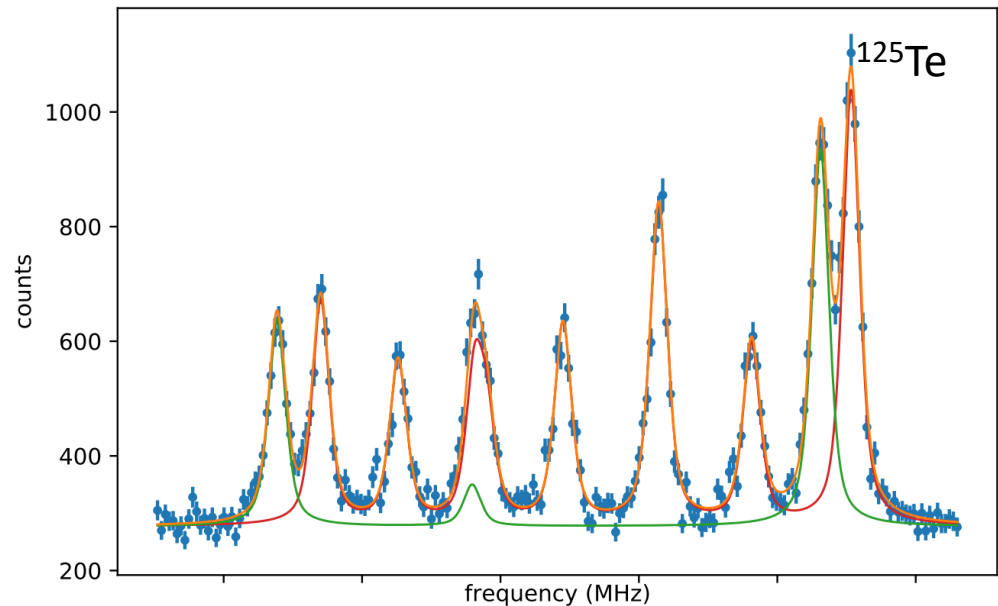
¹¹² Te z: 52 n: 60 J π : 0+ T _{1/2} : 2.0 m 0.2 decay ec β^+ 100%	¹¹³ Te z: 52 n: 61 J π : (7/2+) T _{1/2} : 1.7 m 0.2 decay ec β^+ 100%	¹¹⁴ Te z: 52 n: 62 J π : 0+ T _{1/2} : 15.2 m 0.7 decay ec β^+ 100%	¹¹⁵ Te z: 52 n: 63 J π : 7/2+ T _{1/2} : 5.8 m 0.2 decay ec β^+ 100%	¹¹⁶ Te z: 52 n: 64 J π : 0+ T _{1/2} : 2.49 h 0.04 decay ec β^+ 100%	¹¹⁷ Te z: 52 n: 65 J π : 1/2+ T _{1/2} : 62 m 2 decay ec β^+ 100%	¹¹⁸ Te z: 52 n: 66 J π : 0+ T _{1/2} : 6.00 d 0.02 decay ec 100%	¹¹⁹ Te z: 52 n: 67 J π : 1/2+ T _{1/2} : 16.05 h 0.05 decay ec β^+ 100%	¹²⁰ Te z: 52 n: 68 J π : 0+ T _{1/2} : stable	¹²¹ Te z: 52 n: 69 J π : 1/2+ T _{1/2} : 19.17 d 0.04 decay ec β^+ 100%	¹²² Te z: 52 n: 70 J π : 0+ T _{1/2} : stable	¹²³ Te z: 52 n: 71 J π : 1/2+ T _{1/2} : 9.2 10 ¹⁶ y decay ec 100%	¹²⁴ Te z: 52 n: 72 J π : 0+ T _{1/2} : stable
¹²⁵ Te z: 52 n: 73 J π : 1/2+ T _{1/2} : stable	¹²⁶ Te z: 52 n: 74 J π : 0+ T _{1/2} : stable	¹²⁷ Te z: 52 n: 75 J π : 3/2+ T _{1/2} : 9.35 h 0.07 decay β^- 100%	¹²⁸ Te z: 52 n: 76 J π : 0+ T _{1/2} : 7.7 10 ²⁴ y 0.4 10 ²⁴ decay 2 β^- 100%	¹²⁹ Te z: 52 n: 77 J π : 3/2+ T _{1/2} : 69.6 m 0.3 decay β^- 100%	¹³⁰ Te z: 52 n: 78 J π : 0+ T _{1/2} : 0.79 10 ²¹ y decay 2 β^- 100%	¹³¹ Te z: 52 n: 79 J π : 3/2+ T _{1/2} : 25.0 m 0.1 decay β^- 100%	¹³² Te z: 52 n: 80 J π : 0+ T _{1/2} : 3.204 d 0.013 decay β^- 100%	¹³³ Te z: 52 n: 81 J π : (3/2+) T _{1/2} : 12.5 m 0.3 decay β^- 100%	¹³⁴ Te z: 52 n: 82 J π : 0+ T _{1/2} : 41.8 m 0.8 decay β^- 100%	¹³⁵ Te z: 52 n: 83 J π : (7/2-) T _{1/2} : 19.0 s 0.2 decay β^- 100%	¹³⁶ Te z: 52 n: 84 J π : 0+ T _{1/2} : 17.63 s 0.09 decay β^- 100% β^- n 1.31%	¹³⁷ Te z: 52 n: 85 J π : (7/2-) T _{1/2} : 2.49 s 0.05 decay β^- 100% β^- n 2.99%

from IAEA – Nuclear Data Section (on 16/11/2022)

Ideal case → Just count peaks

More complex cases:

- Peaks overlapping
- Isomers present
- Limited statistics
- Peak count not unambiguous for high spin states



Spins

^{113}Te , ~~$11/2^-$~~

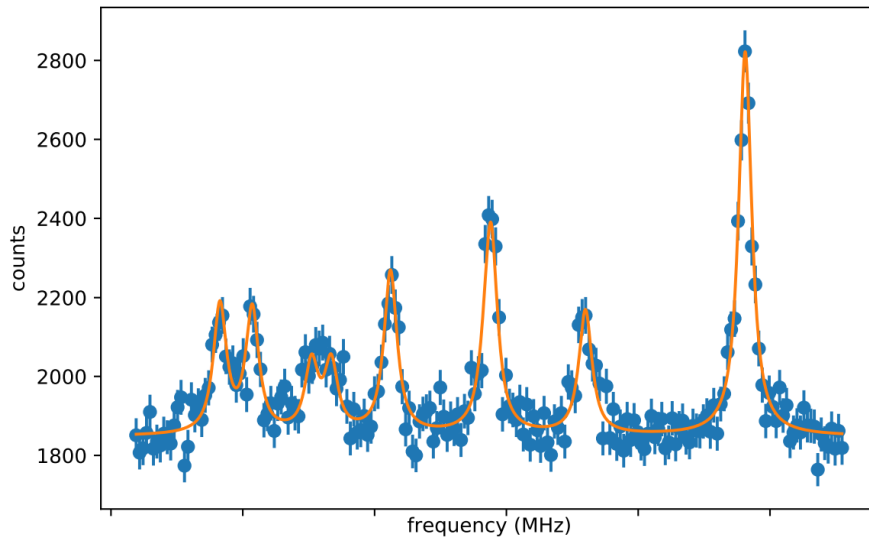
This graph contained unpublished data and was therefore removed to comply with the open access policy of the COLLAPS collaboration

→ Spin $7/2$ doesn't fit at all (with reasonable parameters)

→ Maybe Spin $11/2$?

Further analysis required...

Nuclear moments



Get hyperfine parameters A,B
from fit

→ Related to nuclear moments

$$\Delta\nu = \frac{A}{2}C + B \frac{\frac{3}{4}C(C+1) - I(I+1)J(J+1)}{2I(2I-1)J(2J-1)}$$

$$A = \frac{\mu_I B_e(0)}{hIJ} \quad B = \frac{eQ_s}{h} \frac{\partial^2 V}{\partial z^2}$$

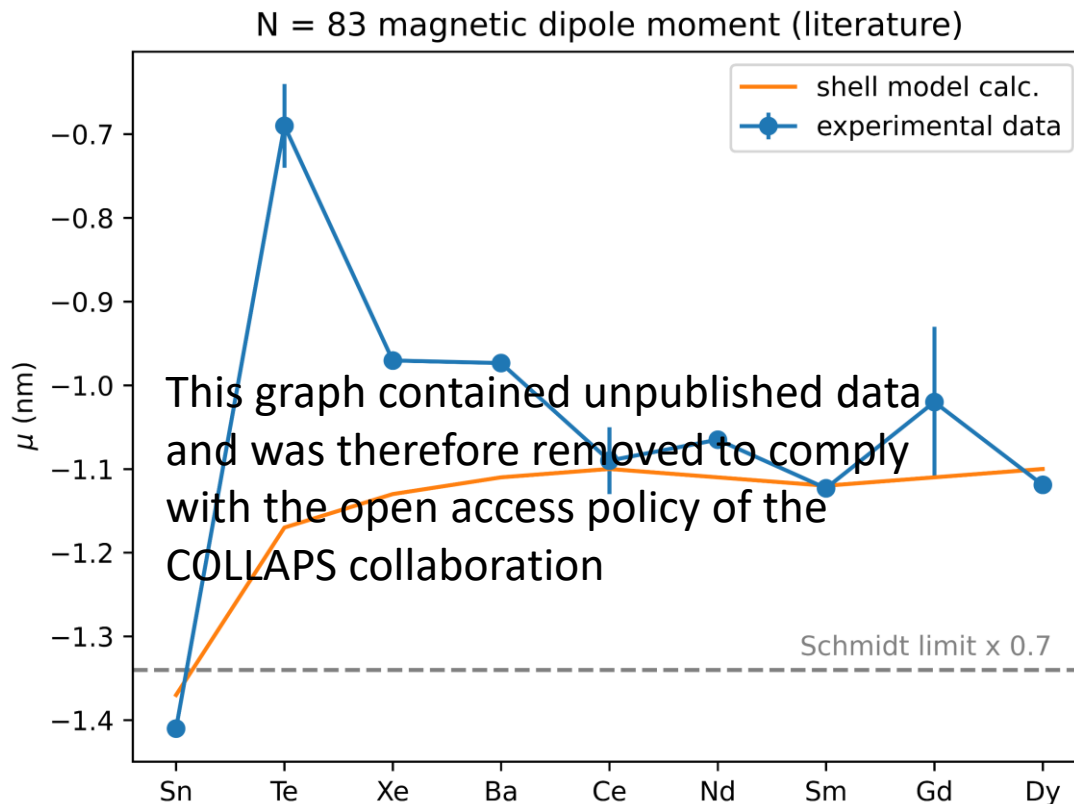
- $B_e(0)$ from NMR reference

<https://doi.org/10.1103/PhysRev.89.923>

- Field gradient from theory = $5.83 \times 10^{22} \text{ V/m}^2$

DOI 10.1007/s10751-006-9505-0

Dipole moment of N = 83



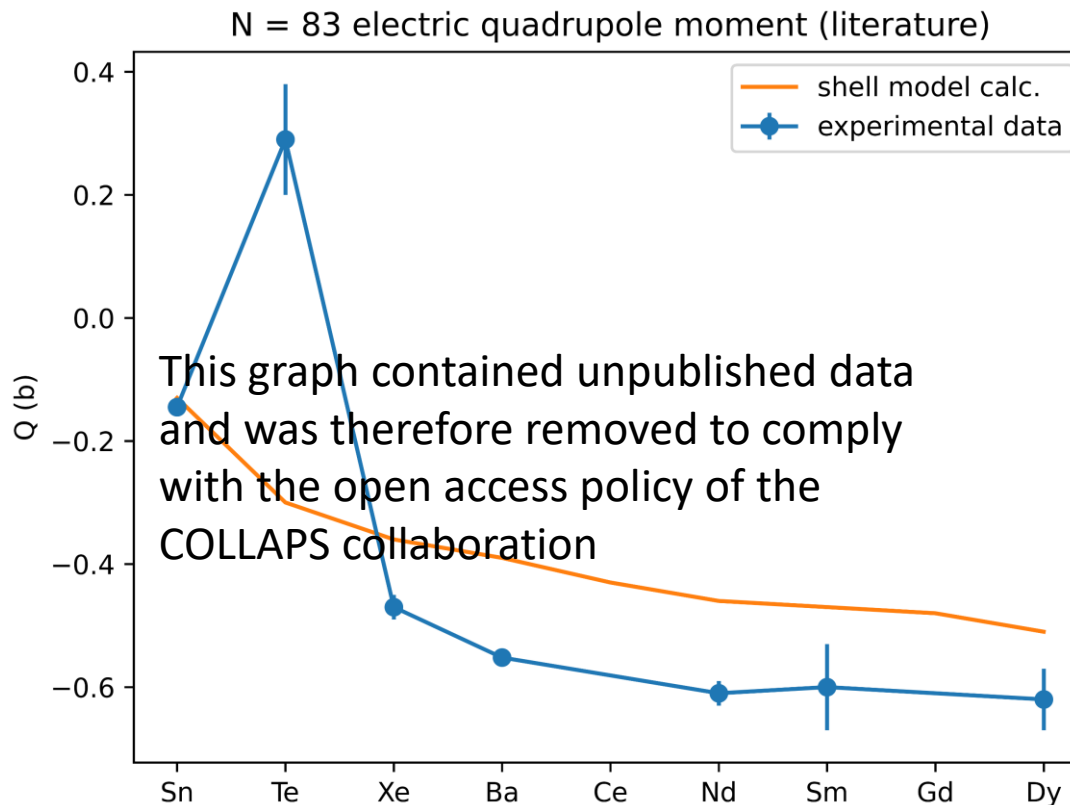
$N = 82 + 1$

“true” single particle state for Sn

Higher $Z \rightarrow$ positive contribution from valence protons

add. data and theory from <https://doi.org/10.1103/PhysRevC.102.051301>

Quadrupole moment of $N = 83$

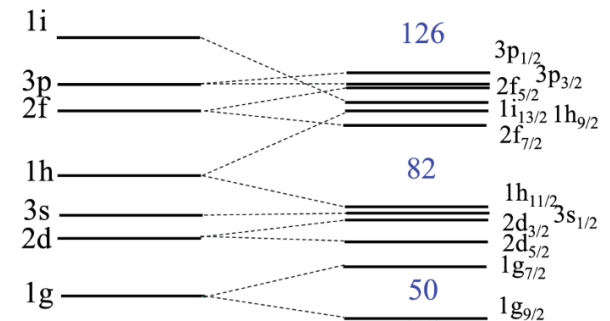


→ N = 83 “mystery”: Everything is well described in the end...

add. data and theory from <https://doi.org/10.1103/PhysRevC.102.051301>

11/2⁻ dipole moment

This graph contained unpublished data and was therefore removed to comply with the open access policy of the COLLAPS collaboration



Hagino, K., Maeno, Y. A nuclear periodic table. *Found Chem* 22, 267–273 (2020)

- Single unpaired neutron in 1h_{11/2} orbital
- “pure” state because only orbital with negative parity

Expected qualitatively similar trend to Cadmium

→ This did not turn out to be true

11/2- quadrupole moment

This graph contained unpublished data and was therefore removed to comply with the open access policy of the COLLAPS collaboration

- Expected similar trend as Cd

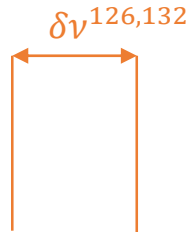
→ Kind of correct

Linear trend as predicted by simple seniority scheme

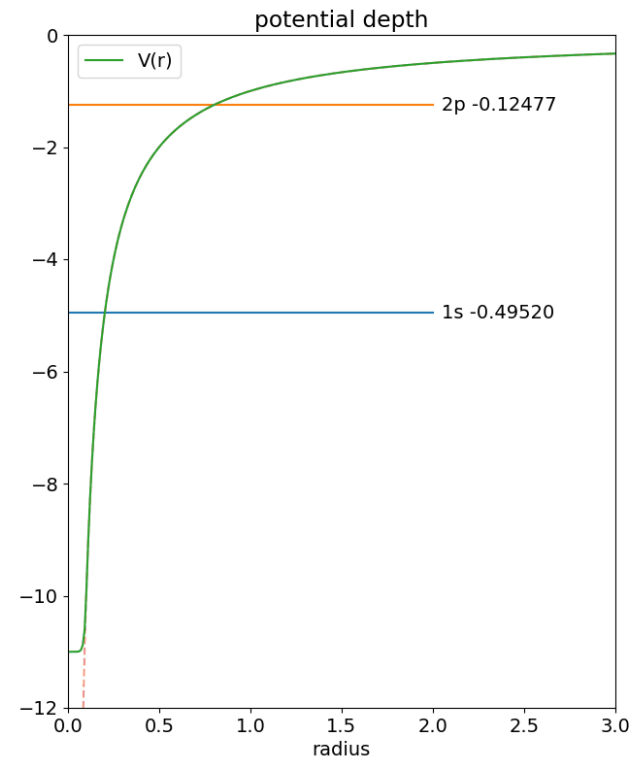
$$\langle Q \rangle = \langle Q_{sp} \rangle \left[1 - 2 \frac{n-1}{2j-1} \right]$$

Important difference: Te flattens out at high N

Isotope shift & charge radii



This graph contained unpublished data and was therefore removed to comply with the open access policy of the COLLAPS collaboration



$$\delta\nu^{AA'} = K_{MS} \cdot \frac{M_{A'} - M_A}{M_A M_{A'}} + F \delta \langle r_c^2 \rangle^{AA'}$$

Charge radii

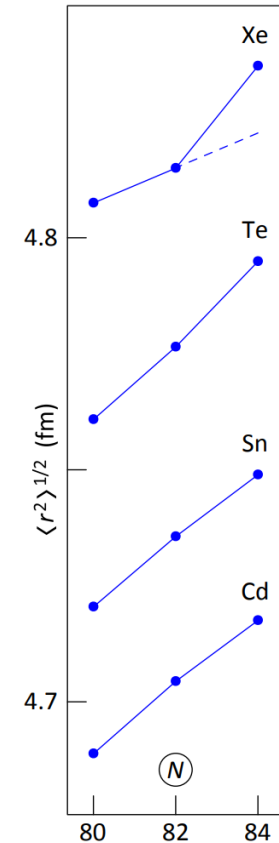
This graph contained unpublished data and was therefore removed to comply with the open access policy of the COLLAPS collaboration

Charge radii

Experiment

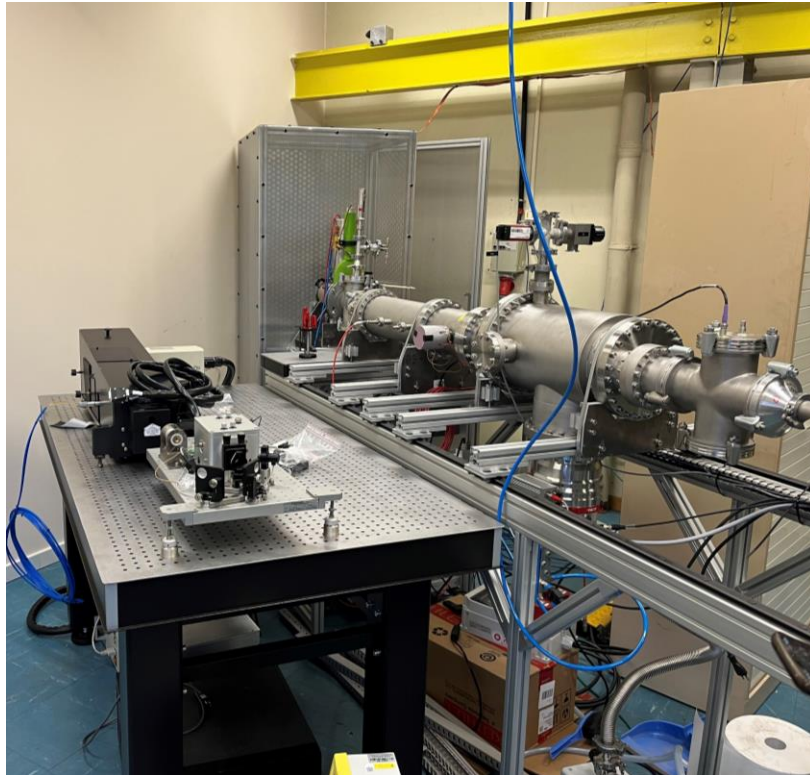
This graph contained unpublished data and was therefore removed to comply with the open access policy of the COLLAPS collaboration

Quenching prediction



→ No “quenching”

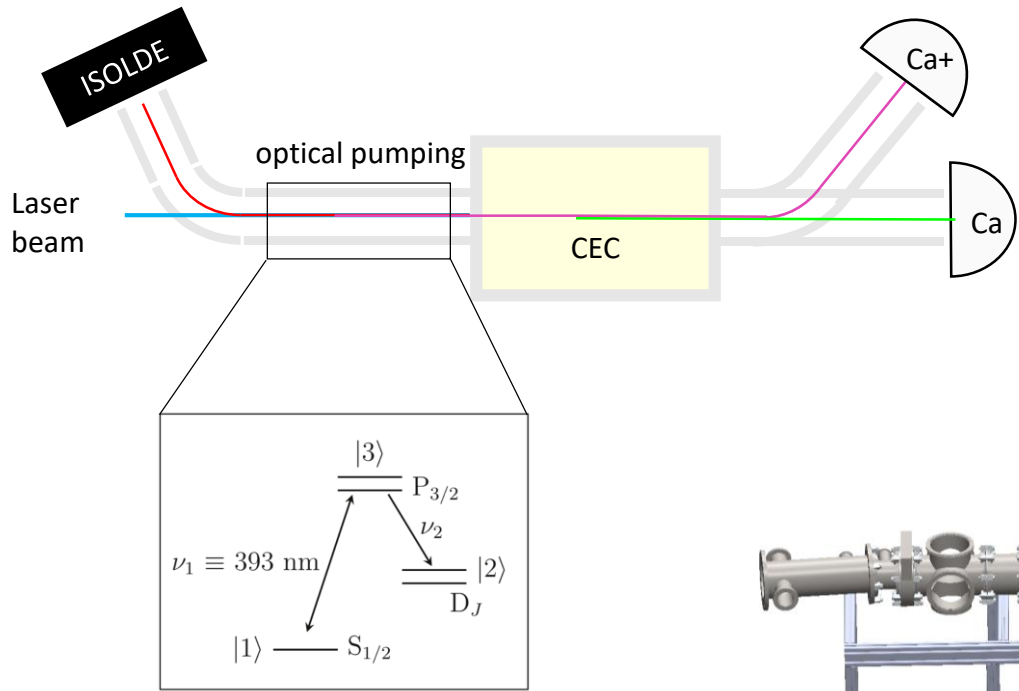
Other projects at COLLAPS in 2022



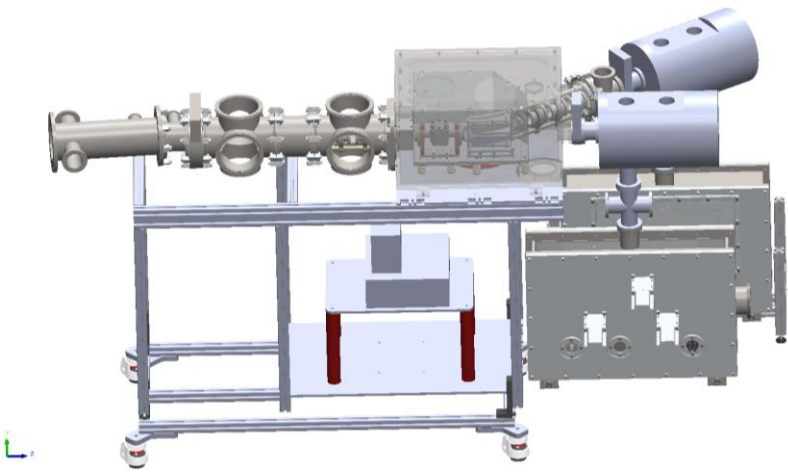
- Offline setup in Bd. 275
- Basically, a copy of COLLAPS + ion source/mass separator
- First ion beam trough in October
- Waiting for laser

→ Test platform for new techniques
First case: ROC

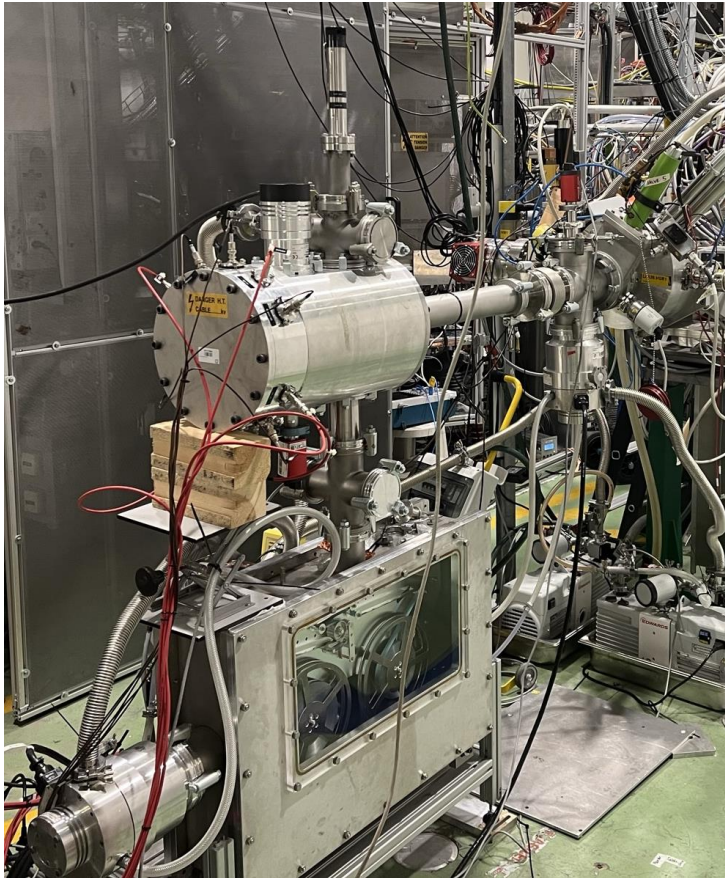
ROC (Radioactive detection after optical pumping and state selective charge exchange)



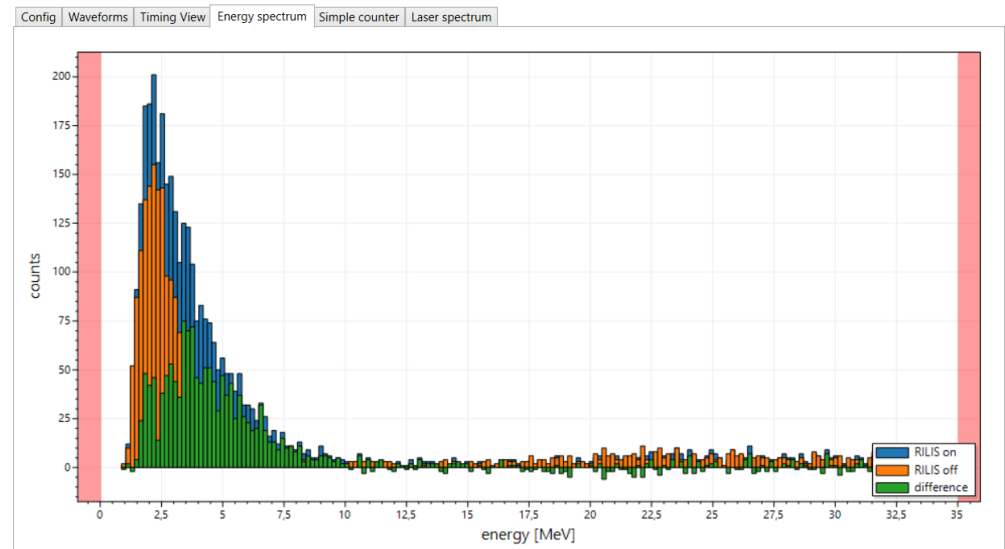
- Particle detection technique
- Use CEC to detect if laser in resonance
- Goal: charge radii of ^{54,53}Ca



ROC detector test



- Test production and detector efficiency for $^{54,53}\text{Ca}$
 - Single tape station on LA1
 - Part of TISD 1.7 GeV test
- 4 counts per proton pulse for ^{54}Ca



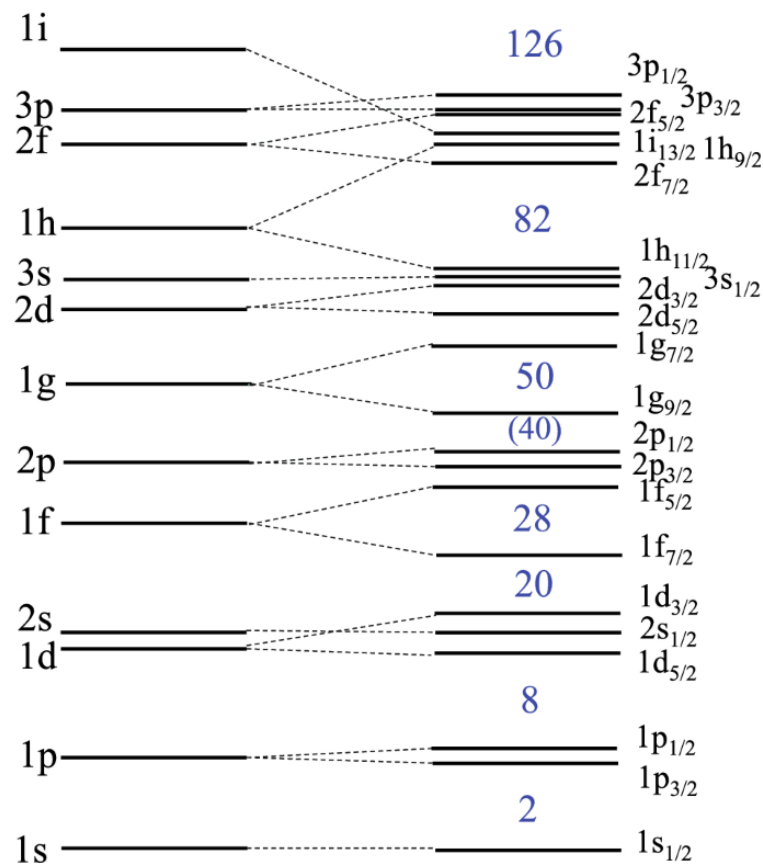
Thank you



Not included slides following – proceed at own risk!

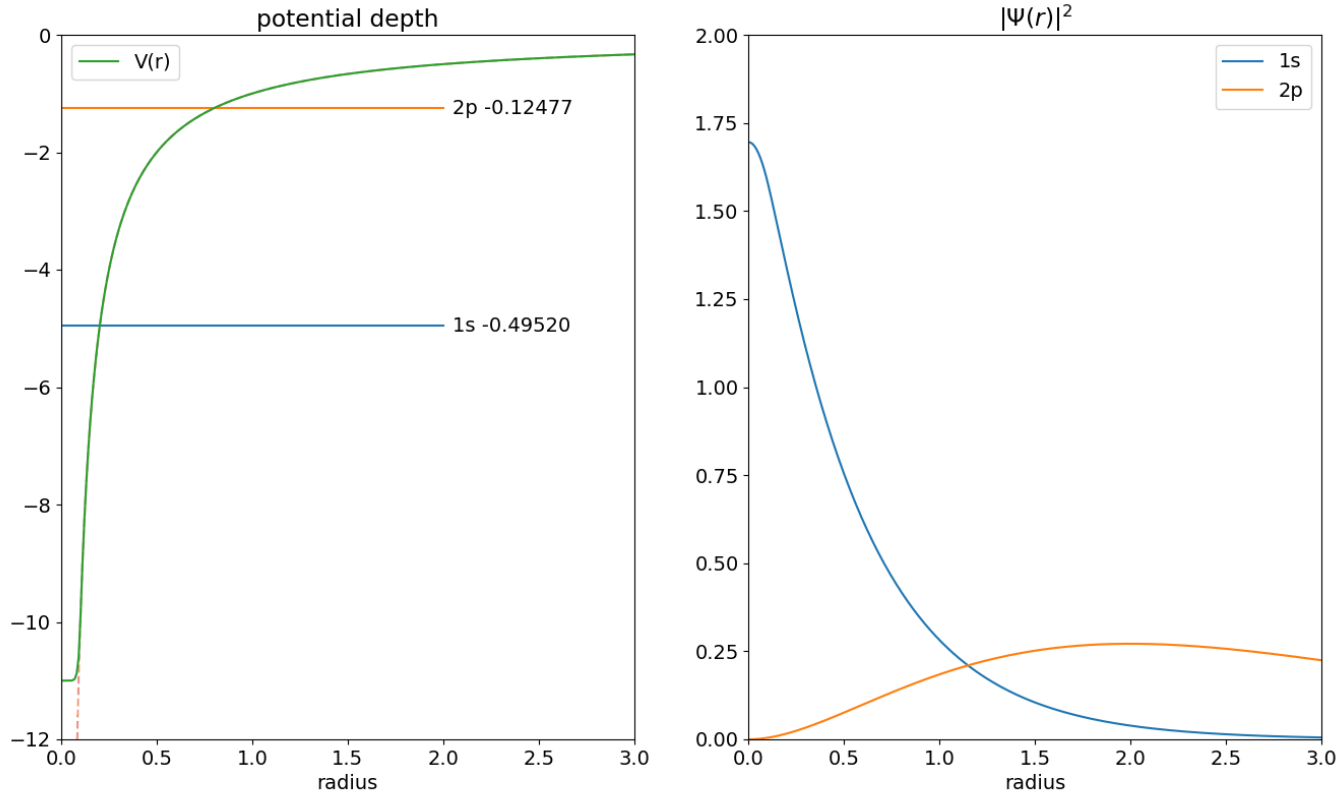
Single particle like states

- 1) $N = 83 \rightarrow N = 82$ (magic) +1n
- 2) $11/2^-$ isomer chain
 - Single unpaired neutron in $1h_{11/2}$ orbital
 - “pure” state because only orbital with negative parity



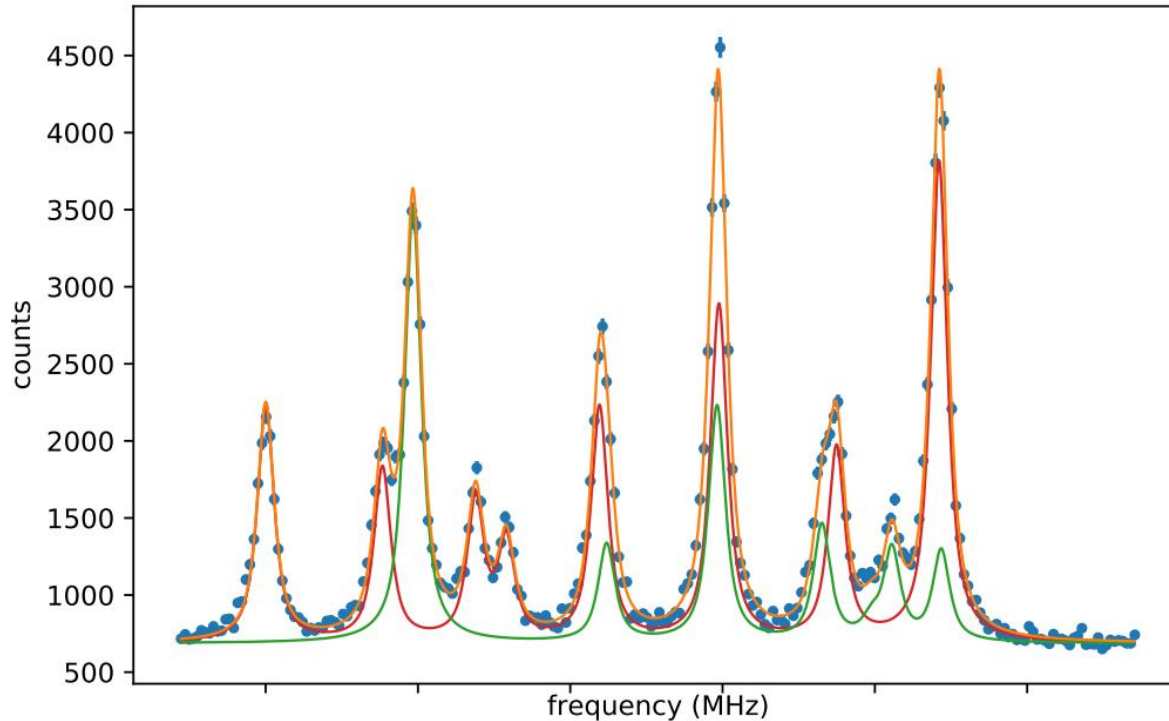
Hagino, K., Maeno, Y. A nuclear periodic table. *Found Chem* **22**, 267–273 (2020)

Charge radii



$$\delta\nu^{AA'} = K_{MS} \cdot \frac{M_{A'} - M_A}{M_A M_{A'}} + F\delta \langle r_c^2 \rangle^{AA'}$$

^{133}Te – the special one



- Ground state Racah fixed
- Isomer only two peaks fixed to each other
- B ratio fixed to value from 115,135
- Tried various starting parameters (swapping peaks etc)
- Either converged to same value or not at all

ISOLDE setup

- UCn target on HRS target station
- Te mass marker for stable isotopes*
- RILIS (also on 214 nm transition)
- Bunching and cooling with ISCOOL

* Ended up being Thallium due to ambiguous handwriting

Overview of an atomic spectrum

