Laser spectroscopy of neutron-rich  isotopes

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INTC- P- 561, June 2020

Outline

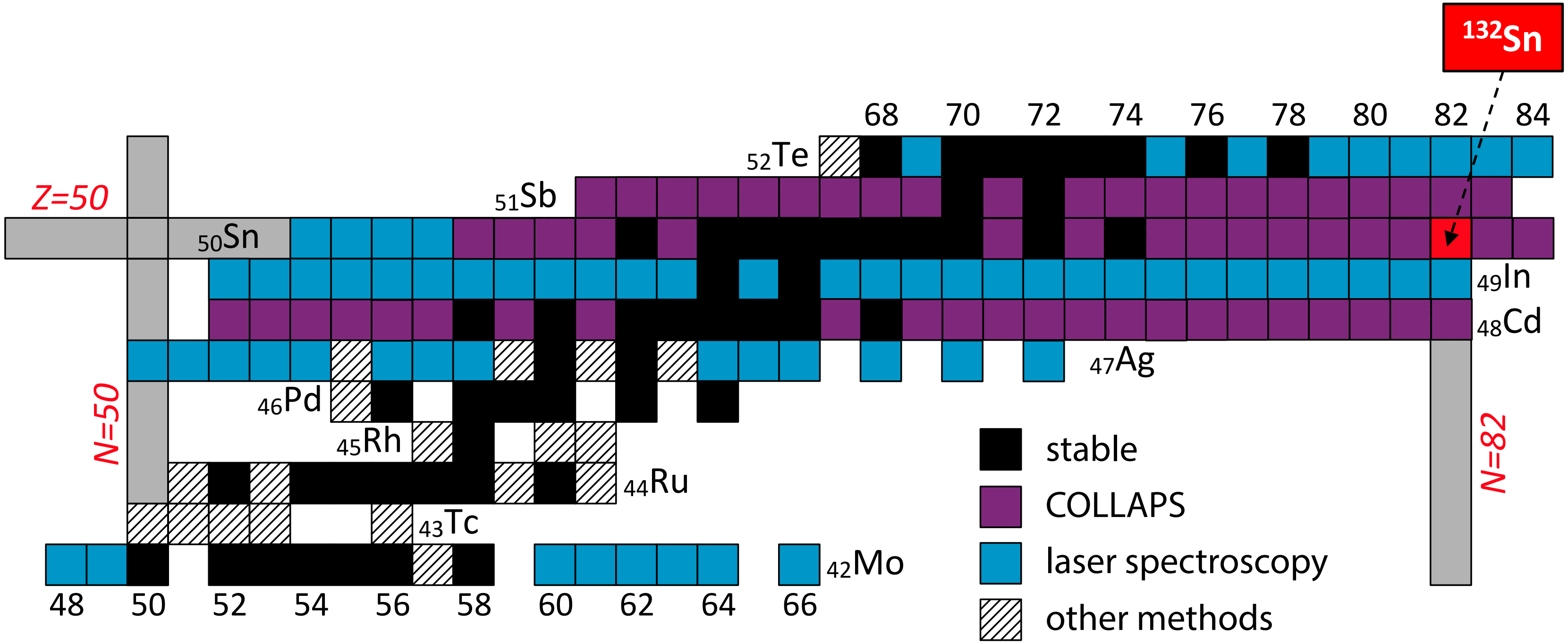
Physics case

Experimental setup

Beamtime request

Physics case

Survey of COLLAPS studies in the tin region

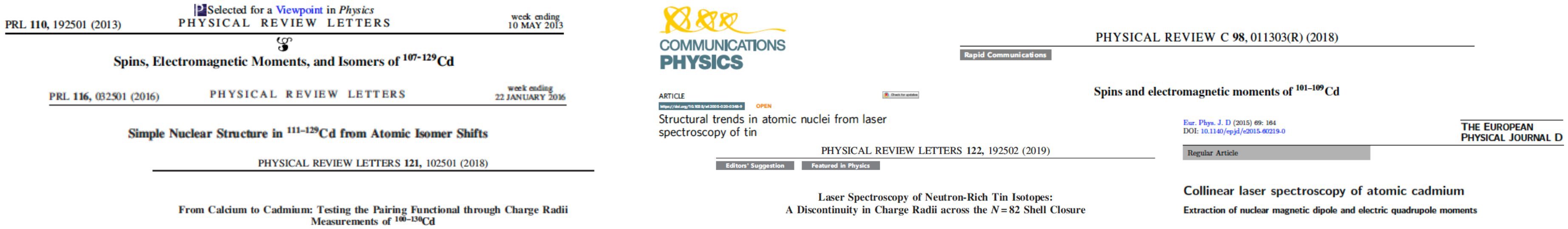


$^{100-130}$Cd

$^{108-134}$Sn

$^{112-134}$Sb

2010-2013 2016-2017 2018 *timeline*



Selected for a Viewpoint in *Physics*

PRL **110,** 192501 (2013) PHYSICAL REVIEW LETTERS week ending 10 MAY 2013

Spins, Electromagnetic Moments, and Isomers of $^{107-129}$Cd

PRL **116,** 032501 (2016) PHYSICAL REVIEW LETTERS week ending 22 JANUARY 2016

Simple Nuclear Structure in $^{111-129}$Cd from Atomic Isomer Shifts

PHYSICAL REVIEW LETTERS **121,** 102501 (2018)

From Calcium to Cadmium: Testing the Pairing Functional through Charge Radii Measurements of $^{100-130}$Cd

COMMUNICATIONS PHYSICS

ARTICLE

OPEN

Structural trends in atomic nuclei from laser spectroscopy of tin

PHYSICAL REVIEW LETTERS **122,** 192502 (2019)

Editors' Suggestion Featured in Physics

Laser Spectroscopy of Neutron-Rich Tin Isotopes: A Discontinuity in Charge Radii across the $N = 82$ Shell Closure

PHYSICAL REVIEW C **98,** 011303(R) (2018)

Rapid Communications

Spins and electromagnetic moments of $^{101-109}$Cd

Eur. Phys. J. D (2015) 69: 164
DOI: 10.1140/epjd/e2015-60219-0

THE EUROPEAN PHYSICAL JOURNAL D

Regular Article

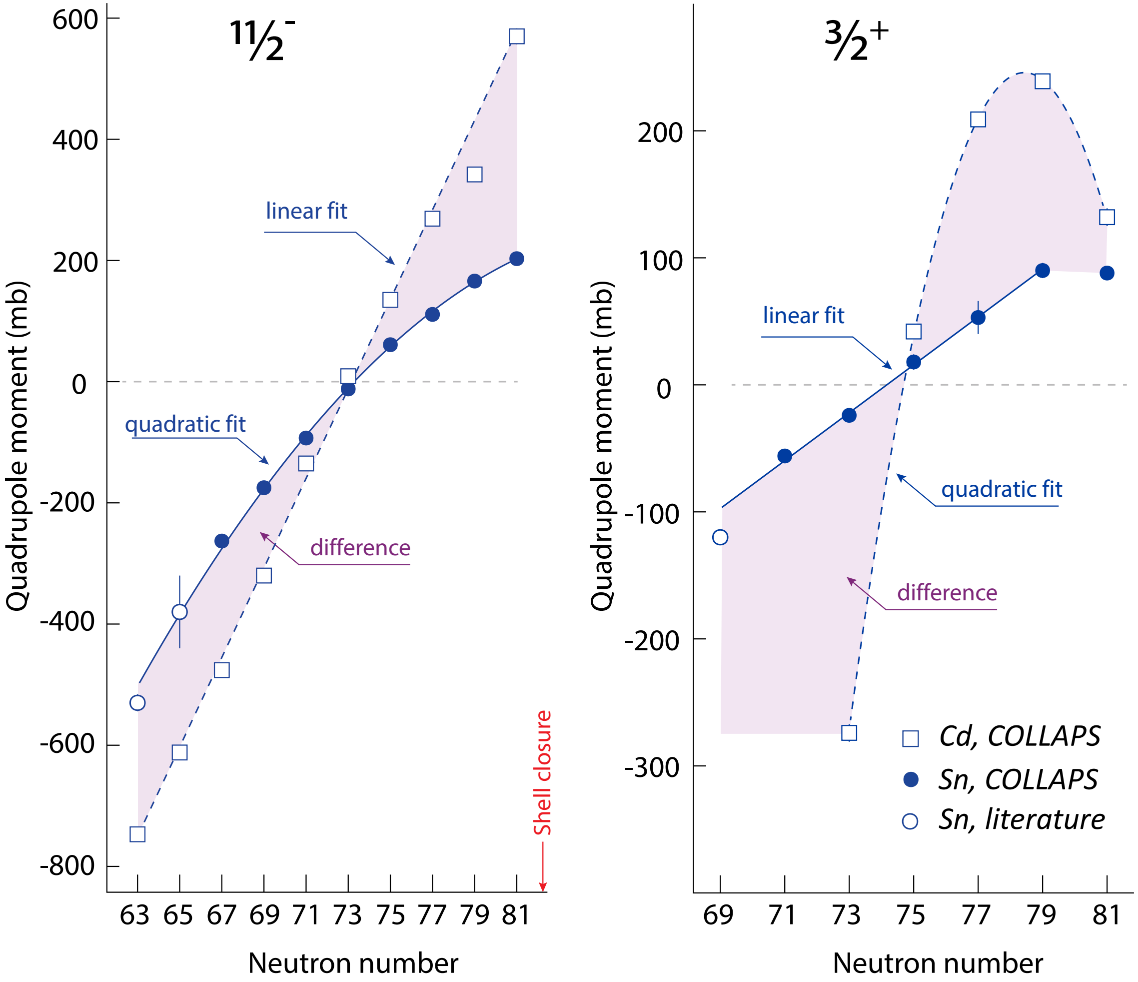
Collinear laser spectroscopy of atomic cadmium

Extraction of nuclear magnetic dipole and electric quadrupole moments

Physics case

Simple patterns in complex nuclei: Cd (Sn-2p) – Sn (Z=50)

Quadrupole moments



D. T. Yordanov, L. V. Rodríguez, et al. Commun. Phys. ***3****, 107 2020*

Physics case

Simple patterns in complex nuclei: Cd (Sn-2p) – Sn (Z=50)

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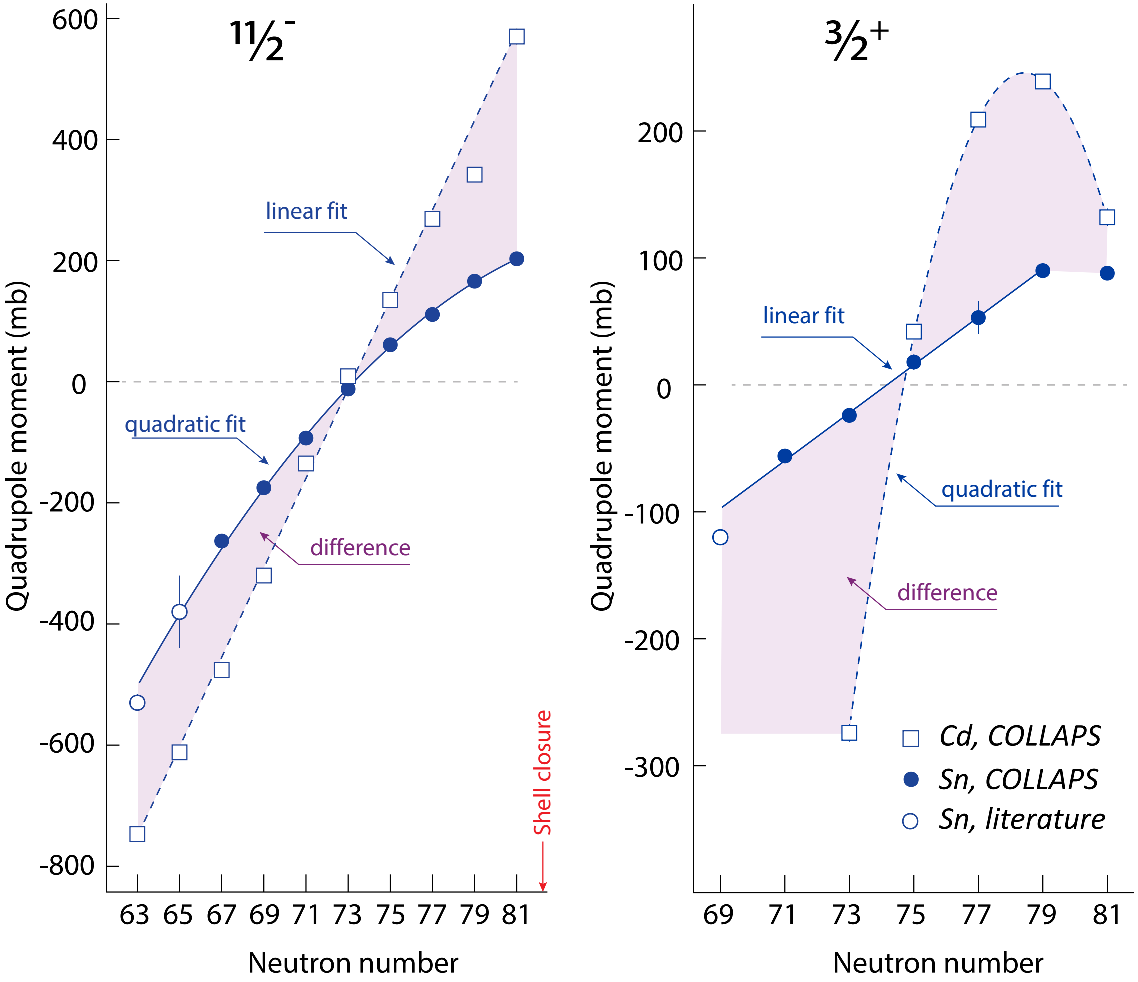
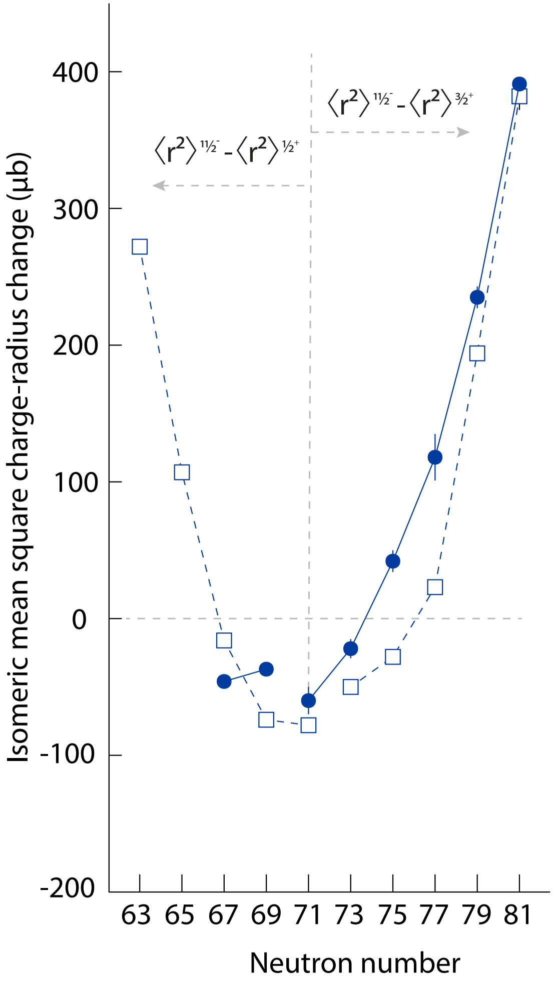


Isomer shifts



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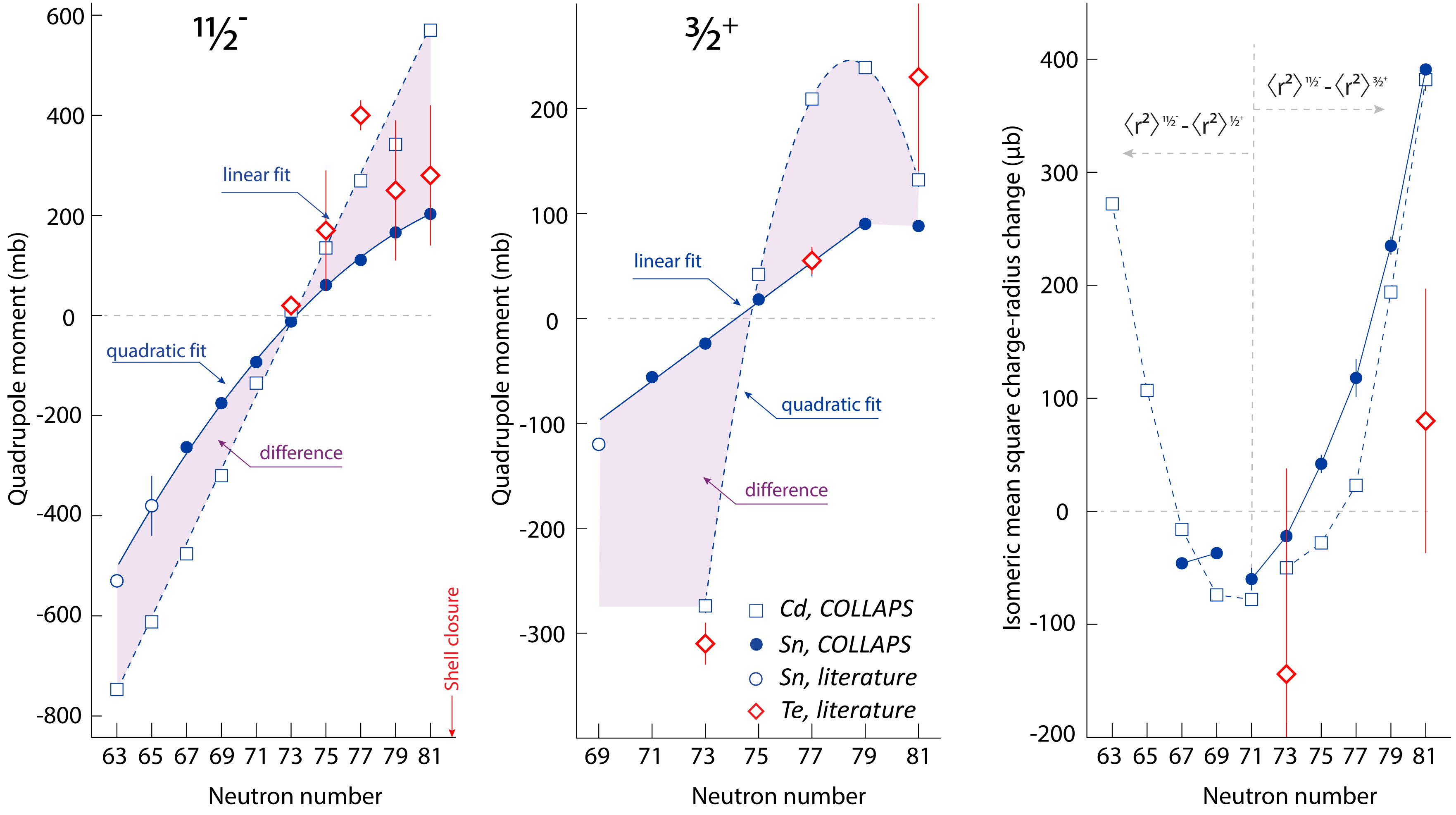
Physics case

Simple patterns in complex nuclei: Cd (Sn-2p) – Sn (Z=50) – Te (Sn+2p)

Quadrupole moments

Isomer shifts



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Physics case

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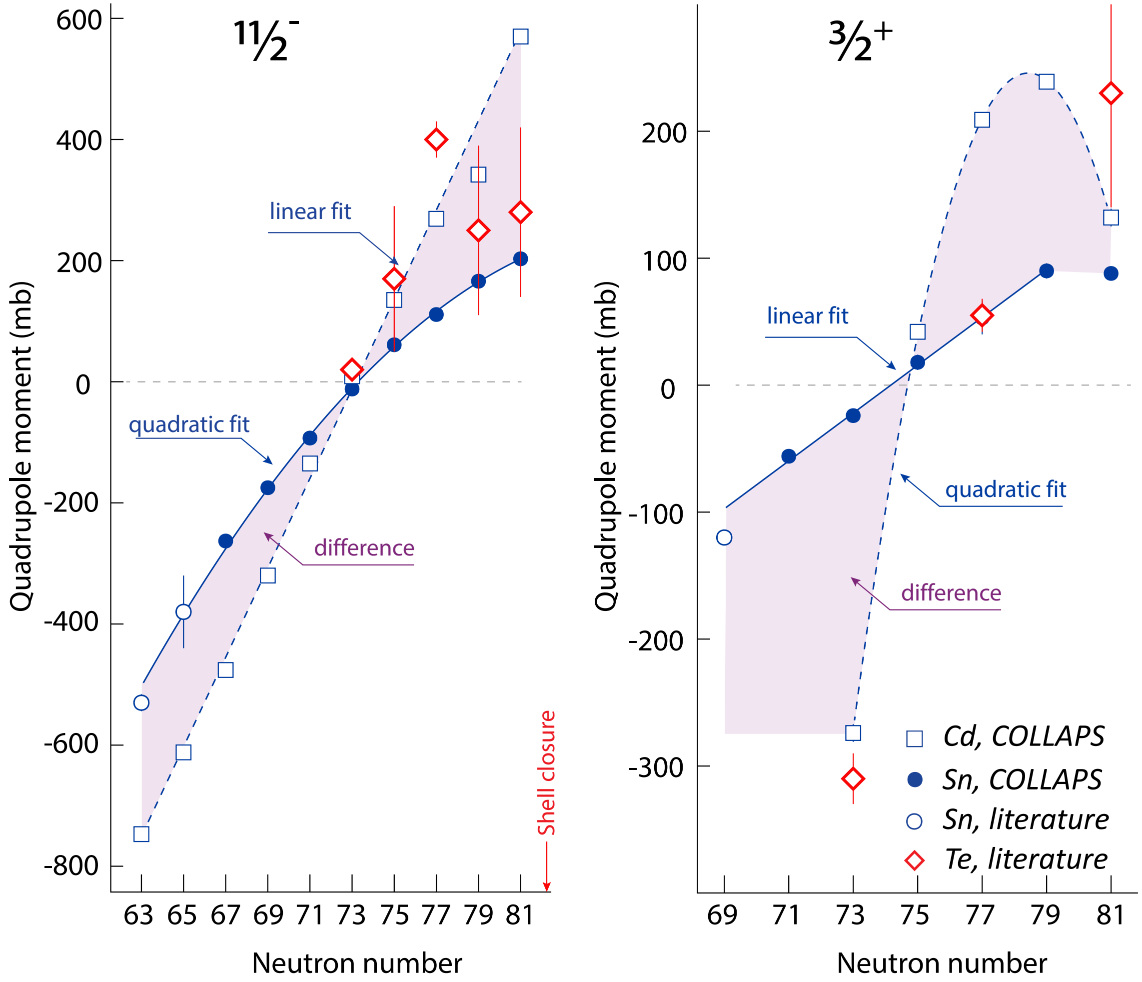
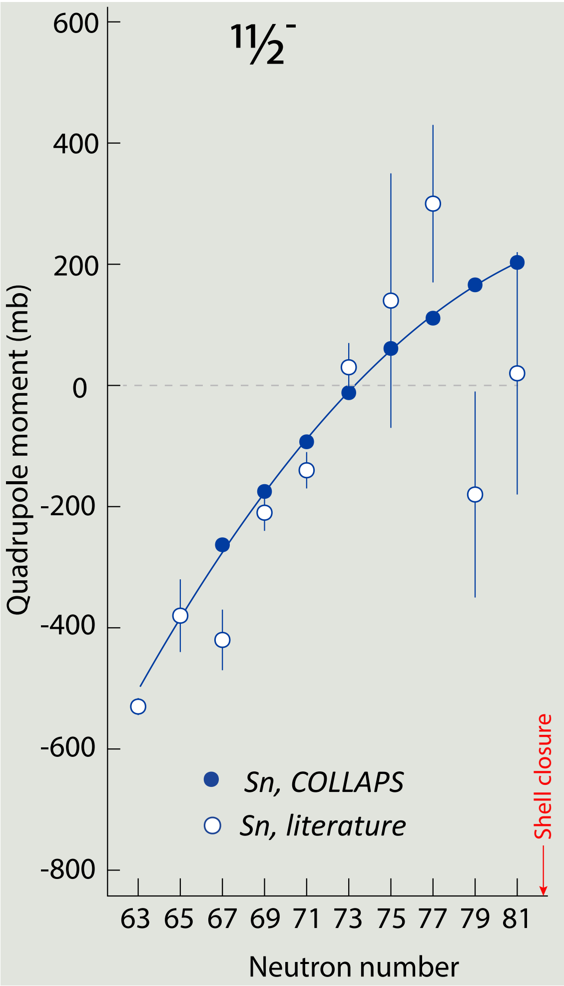


Sn

COLLAPS vs lit.



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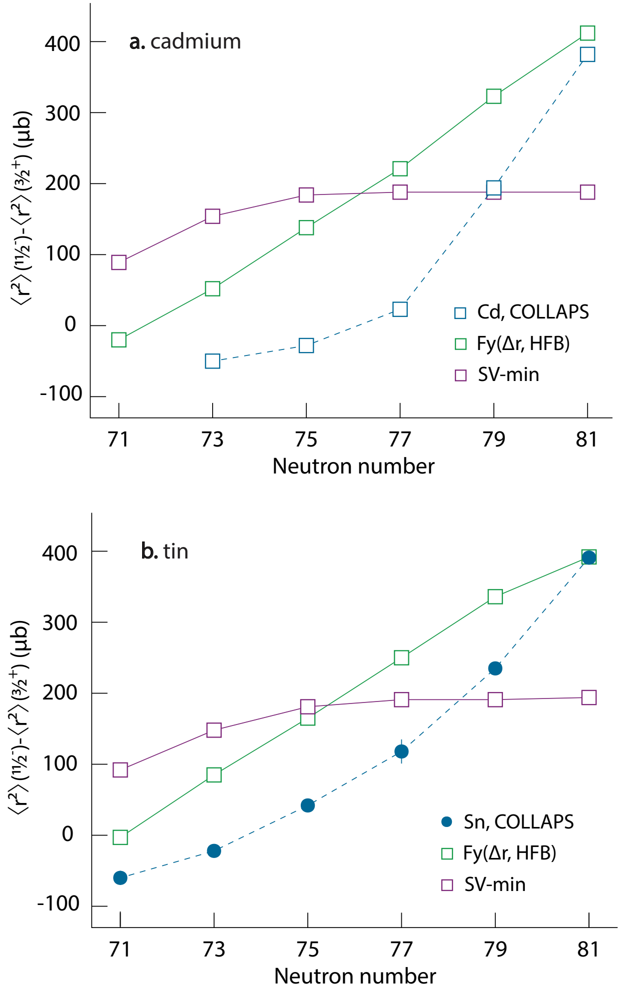
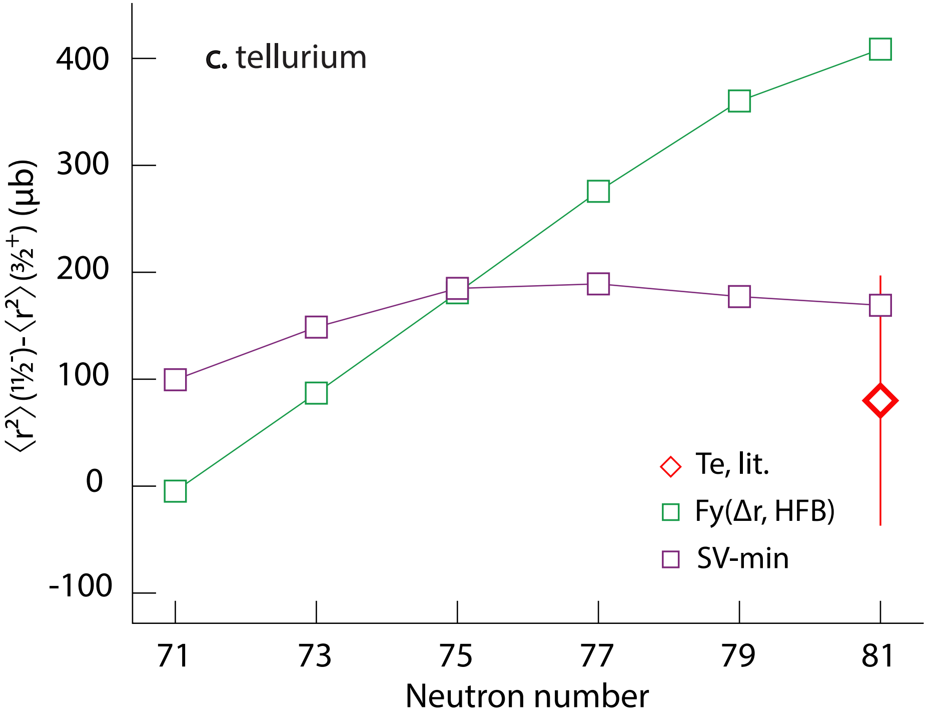
Benchmarking of calculations using the Fy and SV-min functionals

Isomer shifts

Theory vs exp.





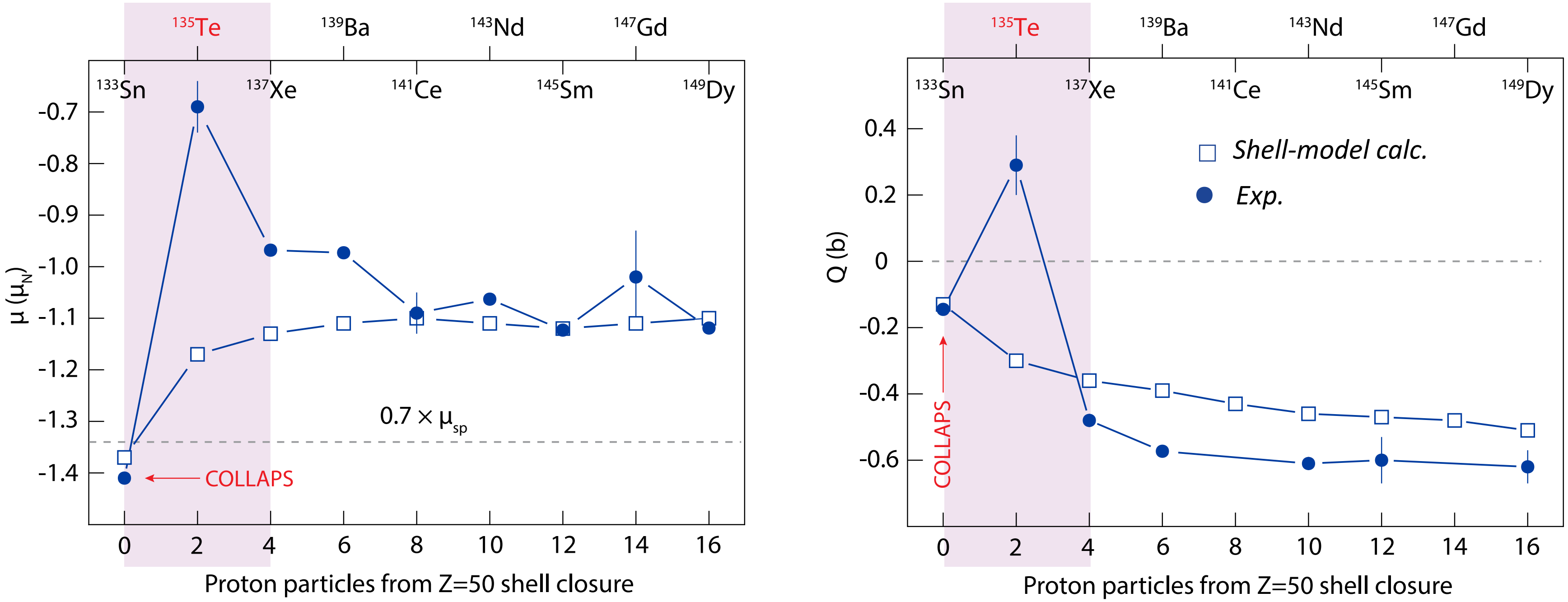
Courtesy of Paul-Gerhard Reinhard and Witold Nazarewicz

Physics case

Electromagnetic moments of N=83 isotones ($I=7/2^-$)

Magnetic moments

Quadrupole moments



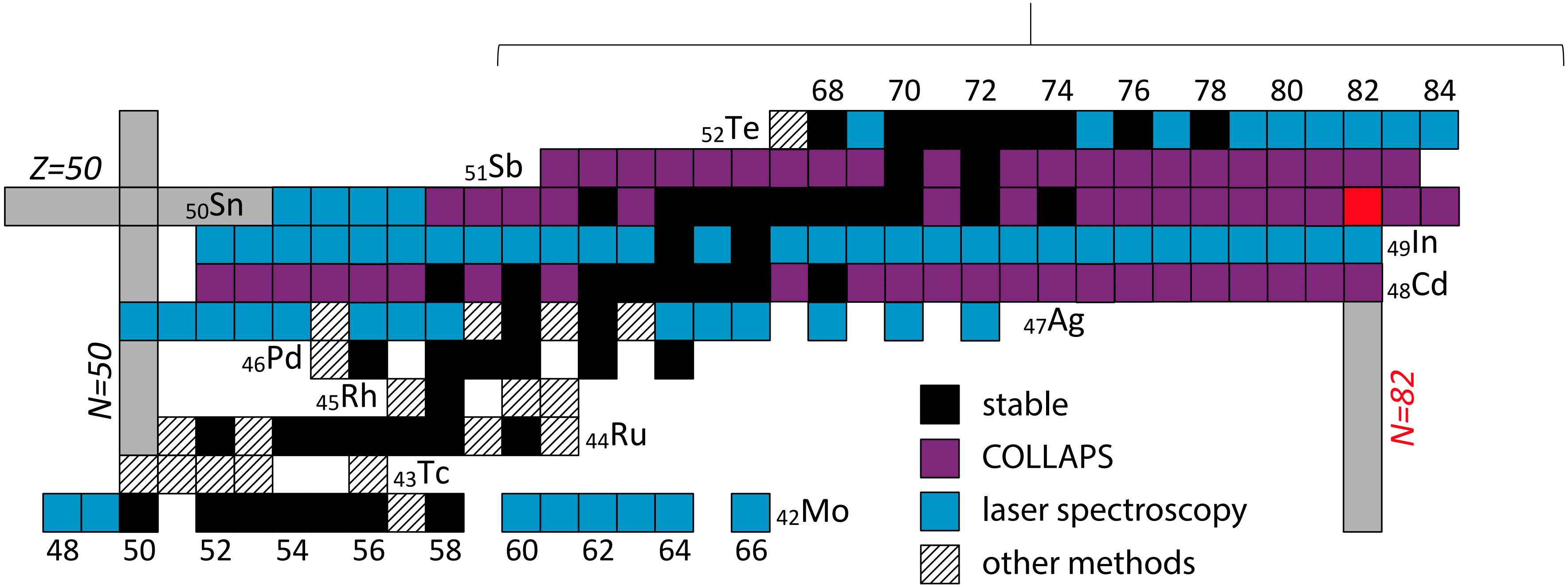
Unravelling of the nuclear structure of ^{135}Te

Benchmarking of state-of-the-art shell model calculations

L. V. Rodríguez et al. in preparation, 2020

Physics case

Proposed range for studies: $^{112\text{-}137}$***Te, Z=52***



Aim: Determination of spins, electromagnetic moments and charge radii of ground- and isomeric-states using collinear laser spectroscopy

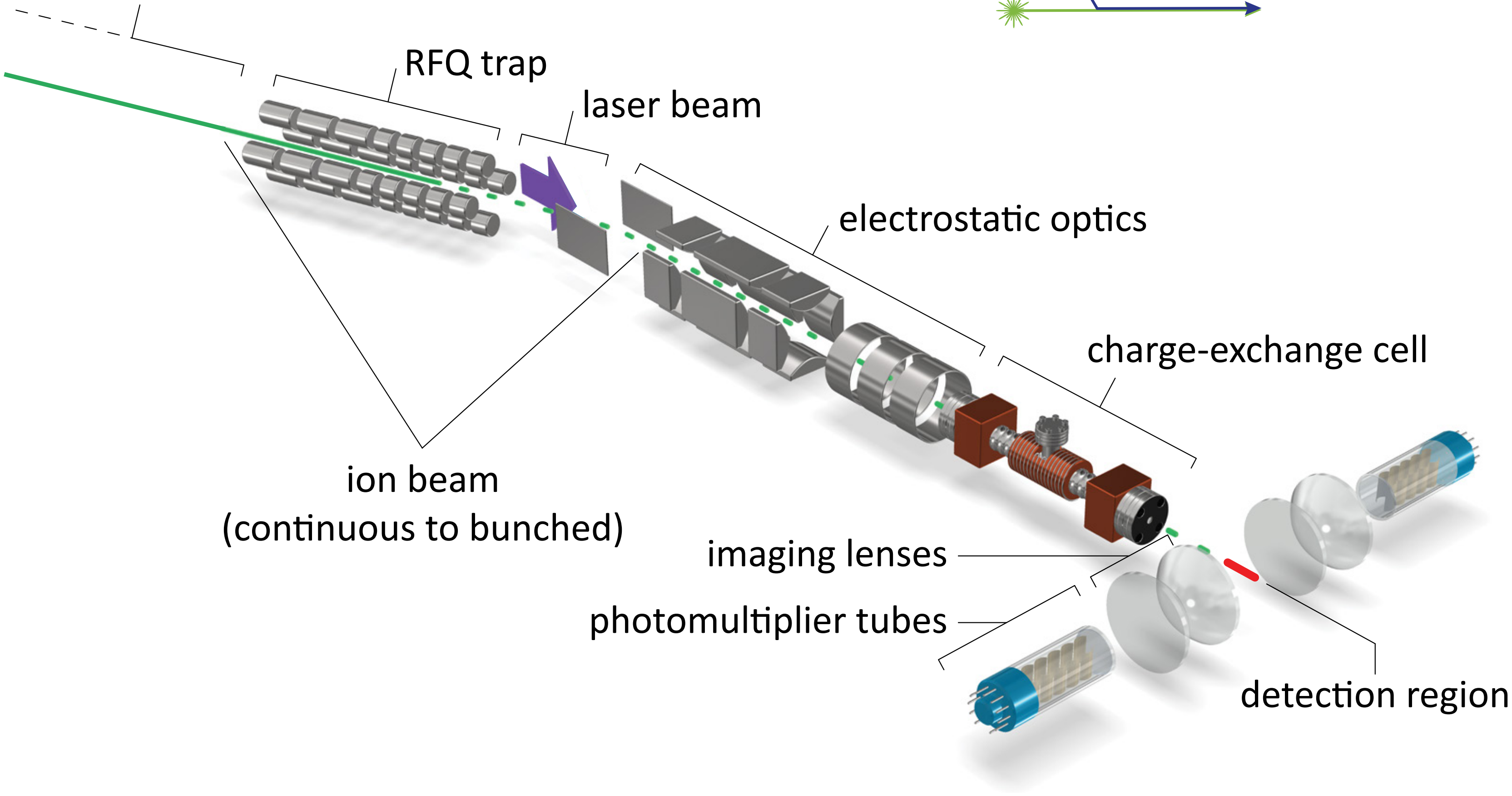
Experiment

1.) PSB
2.) Uranium carbide + n-converter
3.) RILIS
4.) HRS

Experimental method

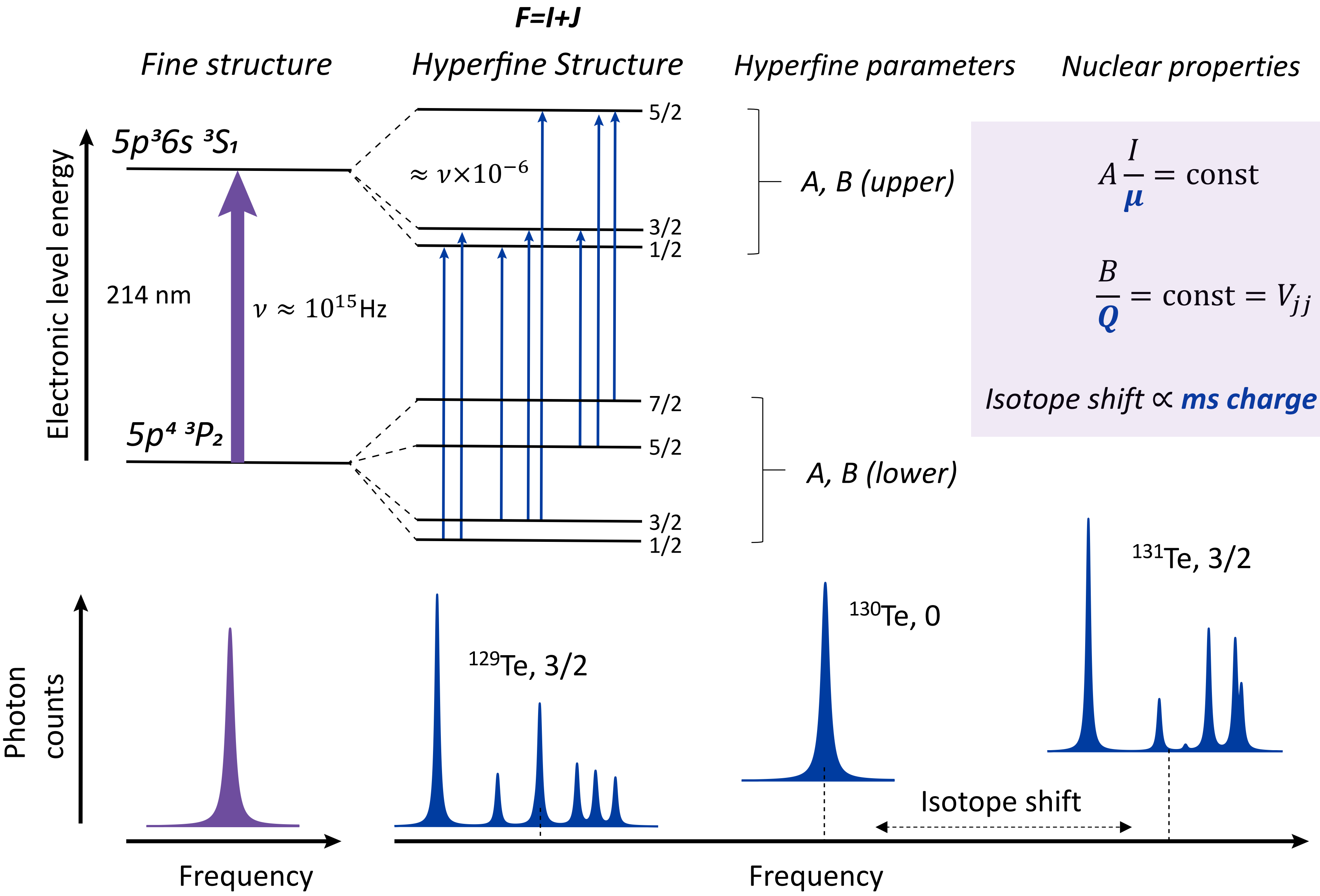
Laser spectroscopy: the art of shining light on atoms

COLLAPS



Taken from D. T. Yordanov, L. V. Rodriguez, et al. Commun. Phys. ***3****, 107 2020*

Experiment

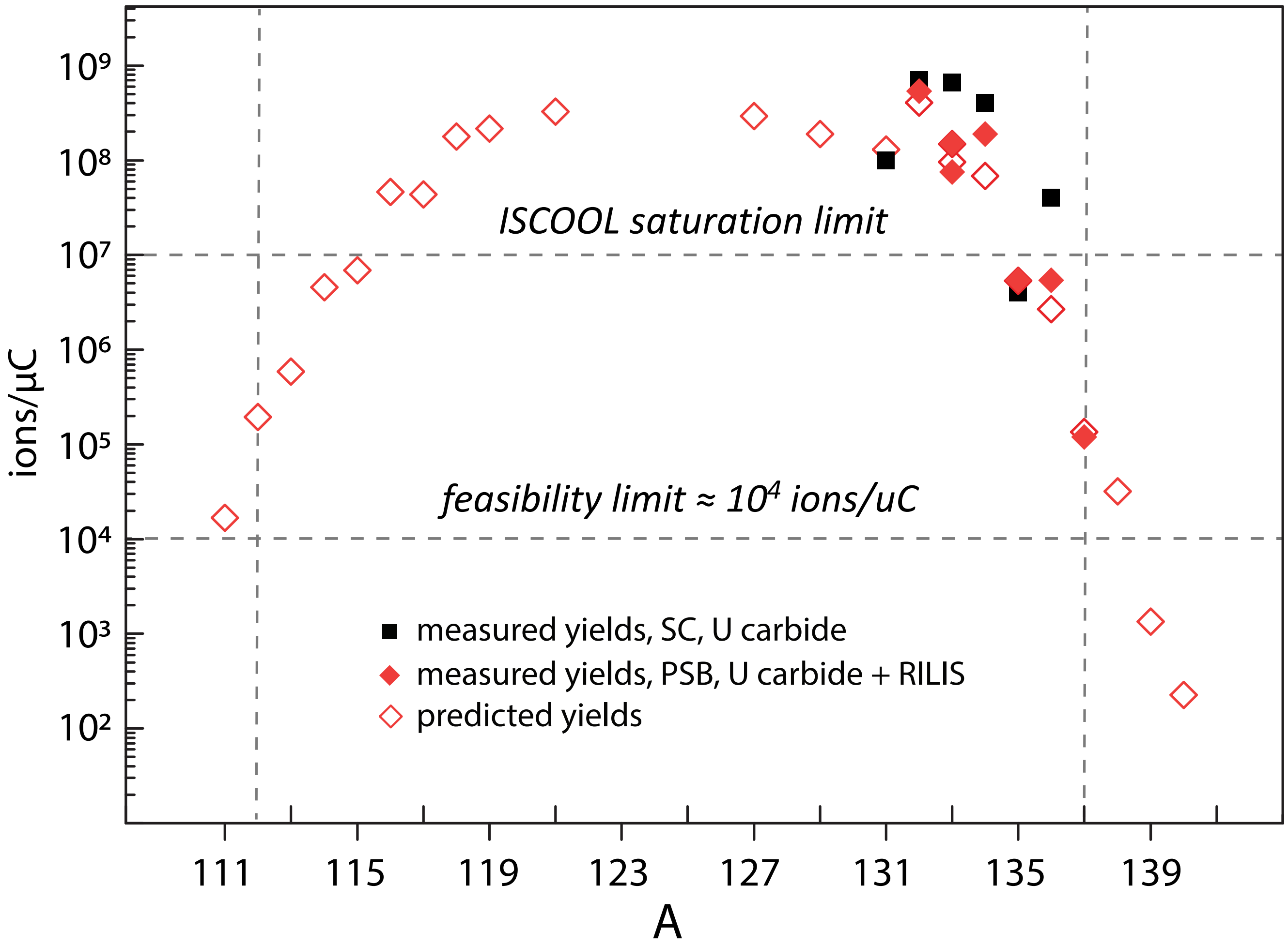


$$A\frac{I}{\boldsymbol{\mu}} = \text{const}$$

$$\frac{B}{\boldsymbol{Q}} = \text{const} = V_{jj}$$

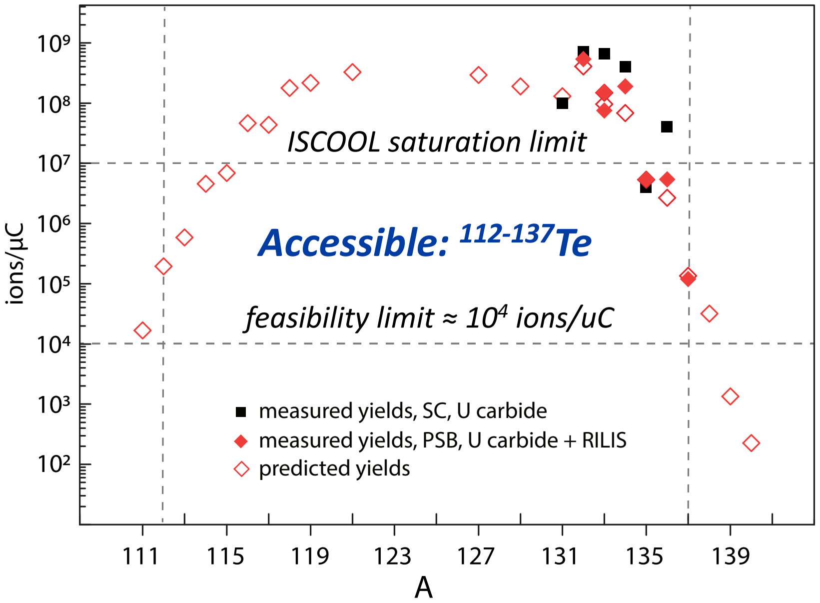
Isotope shift ∝ ***ms charge radii***

Yields



Expected contamination : $^{133\text{-}137}$Cs ≈ 10^8 ions/uC

TAC: The level of contaminants which can be accepted by the experiment needs to be addressed for neutron-rich Te (beyond ^{131}Te)

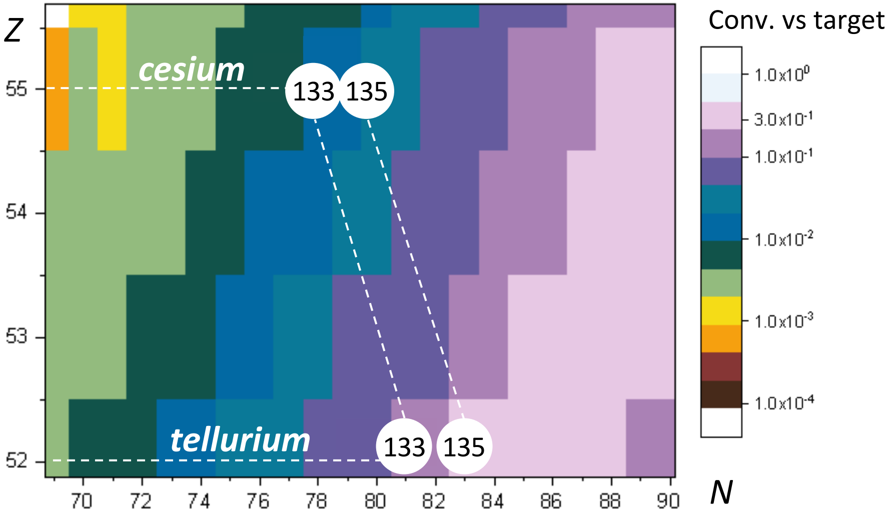


	UC$_x$ + RILIS + n-conv.		
A	ions / uC	ions/ uC	ions / uC
133	1.5E+07	5.2E+06*	1.5E+06
134	**1.9E+07**	**4.1E+06**	**2.0E+05**
135	5.4E+05	1.8E+07	
136	**5.4E+05**	**5.3E+07**	
137	1.2E+04	8.3E+07*	
	tellurium	*cesium*	*tin*

A=134 → yield (Sn)/yield (Cs)=0.05

yield (Te)/yield (Cs)=5

A=136 → Yield(Te)/Yield (Cs)=0.01



Courtesy of S. Rothe

Factors that favor the Te measurements compared to our previous measurements in Sn

- *The transition to be used for Te is 6 times stronger than the one we used for the Sn measurements*
- *The cross section for beam neutralization in Te is 10 times higher than in Sn*

Beam-time request

BEAM-TIME REQUEST

16 shifts of radioactive beam : UC + n-conv. + RILIS + HRS + ISCOOL
1 shift of stable beam
1 shift for RILIS setup

TOTAL: 18 shifts (preferred in one run)

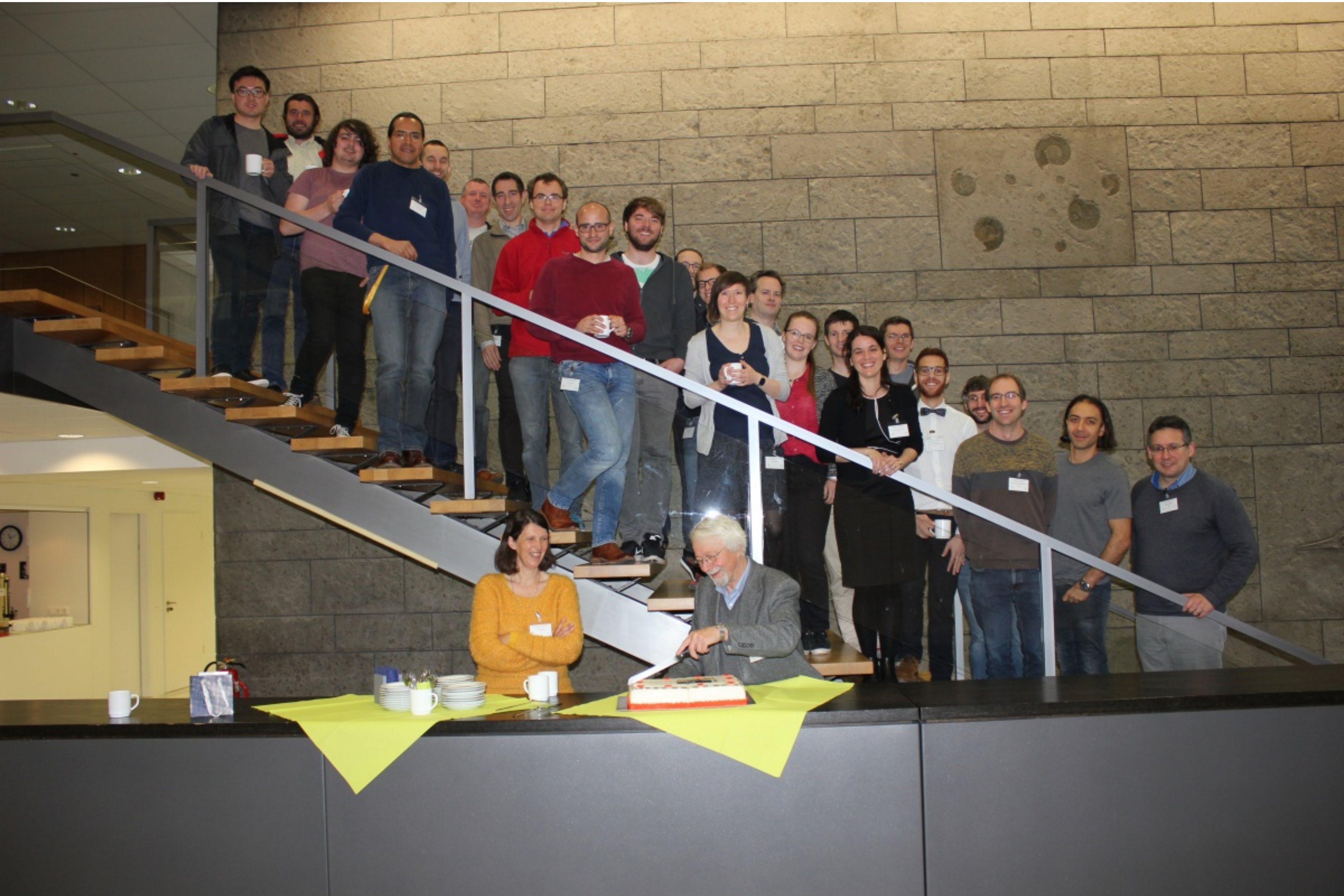
for measuring spins, electromagnetic moments and charge radii of 26 isotopes and 10 isomers along the tellurium chain.

The estimate above (based on previous experience at COLLAPS) includes:

1.) the time for scanning the hyperfine structure and searching for isomeric states
2.) at least three independent HFS measurements for each isotope and one measurement on a reference isotope for isotope shifts extraction

A	Yield / uC	*Requested shifts*
112	1.96E+05	0.5
113	5.84E+05	1
114	4.56E+06	0.5
115	6.90E+06	0.5
116	4.66E+07	0.5
117	4.34E+07	0.5
118	1.78E+08	0.5
119	2.16E+08	0.5
120		
121	3.27E+08	0.5
122		
123		0.5
124		
125		0.5
126		
127	2.93E+08	0.5
128		0.5
129	1.90E+08	0.5
130		0.5
131	1.30E+08	0.5
132	5.40E+07	0.5
133	7.50E+06	1
134	1.90E+07	1
135	5.40E+05	1.5
136	5.40E+05	1.5
137	1.20E+04	2.5

Thank you!



TAC

Laser spectroscopy of neutron-rich tellurium isotopes					
CDS#	**Proposal #**	**IS #**	**Setup**	**Shifts**	**Isotopes**
CERN-INTC-2020-036	INTC-P-561		COLLAPS	18	112-137Te
Beam intensity/purity, targets-ion sources	The levels of contaminants on the requested Te beams could be highly variable. The estimated Te yields seem realistic but the ability to handle contaminants needs to be addressed. Contaminants such as Cs will be present. The neutron convertor will not suppress all isobars. The region from neutron deficient and up to 131-132Te seem feasible with the neutron convertor arrangement. Beyond this the presence of contaminants will become an issue. What level of contamination can be handled? Is there a risk of the ISCOOL being unable to handle Cs levels of 10^8? Alternative methods of suppressing contaminants such as VADLIS and LIST will be available, although with a corresponding drop in Te yield (LIST). Tests for checking the Cs isobar suppression with VADLIS are planned for 2020.				
General implantation and setup	The RP assessment based on the yields provided by the experiment revealed several isotopes for which the intensity shall be reduced and/or shielding put in place: Te-114, Te-115, Te-116, Te-117, Te-119, Te-129, Te-131, Te-132, Te-133, Te-134, Te-135 and Te-136.				
General Comments					
Safety	Safety clearance of COLLAPS set- up can be found at 1806800 – No additional hazards. New ISIEC file at EDMS 2369257.				
TAC recommendation	**The TAC consider that a sizeable part of the proposed isotopic chain should be measurable but note that neutron-rich – beyond 131Te – will be affected by contaminants. The level of contaminants which can be accepted by the experiment needs to be addressed for neutron-rich Te. LIST and VADLIS are alternative ion source combinations which may assist in this region but the suppression needs to be demonstrated. Several Te isotopes will require a reduced intensity and/or adding shielding to the set-up.**				

Literature values for the electromagnetic moments of Te isotopes

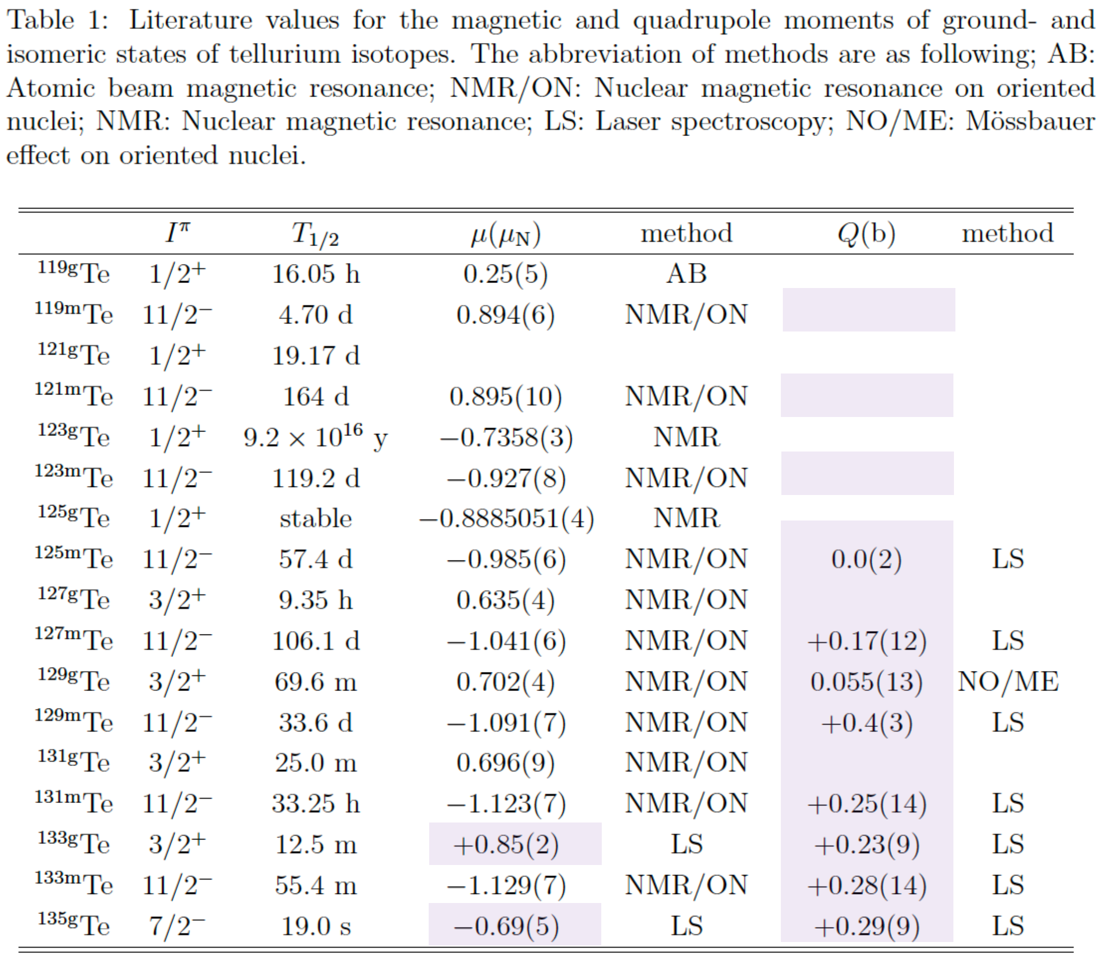


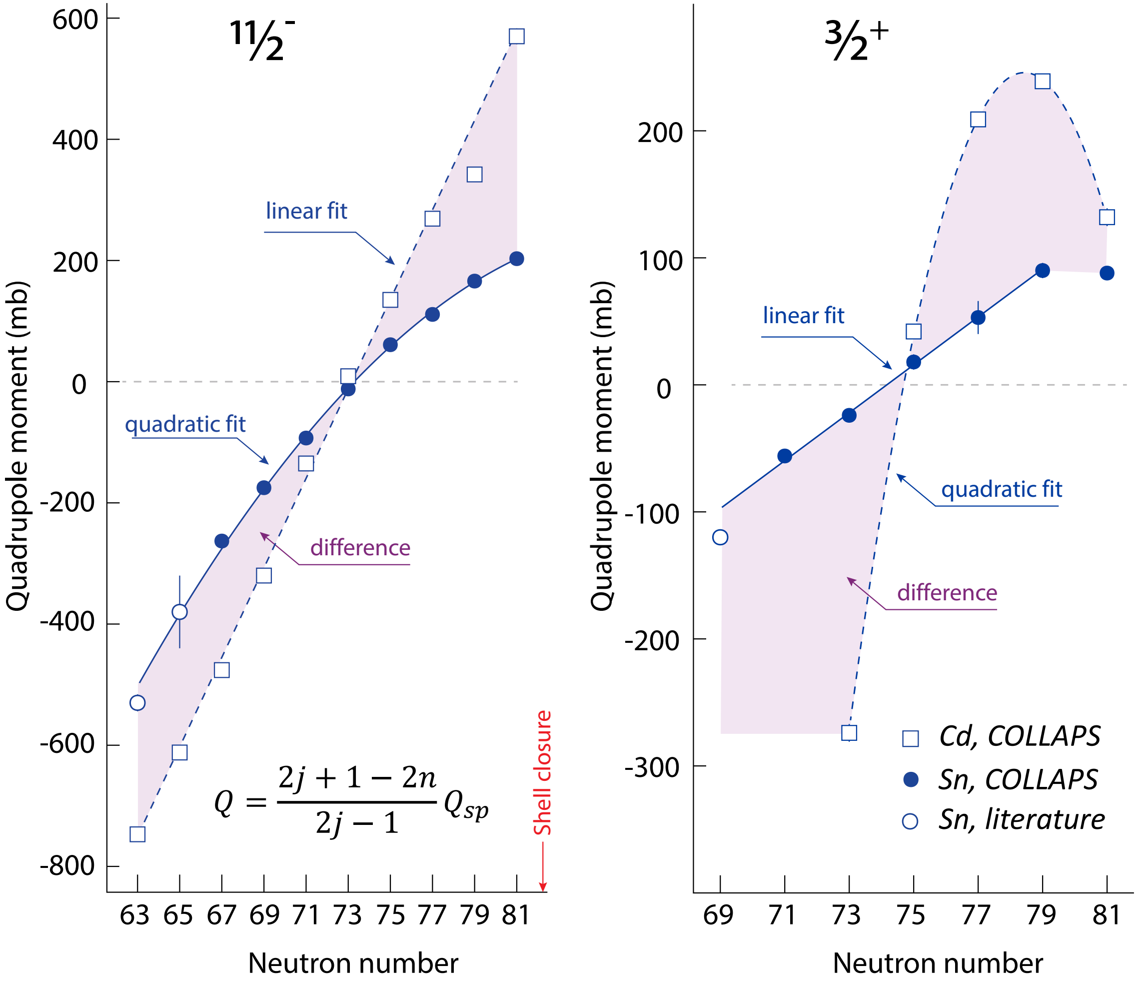
Table 1: Literature values for the magnetic and quadrupole moments of ground- and isomeric states of tellurium isotopes. The abbreviation of methods are as following; AB: Atomic beam magnetic resonance; NMR/ON: Nuclear magnetic resonance on oriented nuclei; NMR: Nuclear magnetic resonance; LS: Laser spectroscopy; NO/ME: Mössbauer effect on oriented nuclei.

	I^π	$T_{1/2}$	$\mu(\mu_N)$	method	Q(b)	method
^{119g}Te	$1/2^+$	16.05 h	0.25(5)	AB		
^{119m}Te	$11/2^-$	4.70 d	0.894(6)	NMR/ON		
^{121g}Te	$1/2^+$	19.17 d				
^{121m}Te	$11/2^-$	164 d	0.895(10)	NMR/ON		
^{123g}Te	$1/2^+$	9.2×10^{16} y	−0.7358(3)	NMR		
^{123m}Te	$11/2^-$	119.2 d	−0.927(8)	NMR/ON		
^{125g}Te	$1/2^+$	stable	−0.8885051(4)	NMR		
^{125m}Te	$11/2^-$	57.4 d	−0.985(6)	NMR/ON	0.0(2)	LS
^{127g}Te	$3/2^+$	9.35 h	0.635(4)	NMR/ON		
^{127m}Te	$11/2^-$	106.1 d	−1.041(6)	NMR/ON	+0.17(12)	LS
^{129g}Te	$3/2^+$	69.6 m	0.702(4)	NMR/ON	0.055(13)	NO/ME
^{129m}Te	$11/2^-$	33.6 d	−1.091(7)	NMR/ON	+0.4(3)	LS
^{131g}Te	$3/2^+$	25.0 m	0.696(9)	NMR/ON		
^{131m}Te	$11/2^-$	33.25 h	−1.123(7)	NMR/ON	+0.25(14)	LS
^{133g}Te	$3/2^+$	12.5 m	+0.85(2)	LS	+0.23(9)	LS
^{133m}Te	$11/2^-$	55.4 m	−1.129(7)	NMR/ON	+0.28(14)	LS
^{135g}Te	$7/2^-$	19.0 s	−0.69(5)	LS	+0.29(9)	LS

Physics case

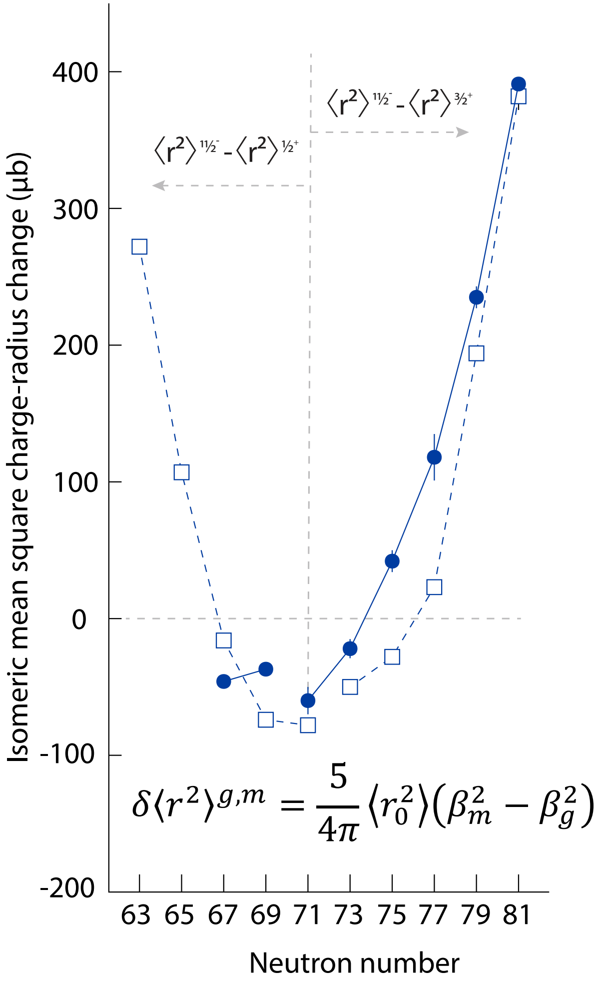
Simple patterns in complex nuclei: Cd (Sn-2p) – Sn (Z=50)

Quadrupole moments



$$Q = \frac{2j+1-2n}{2j-1} Q_{sp}$$

Isomer shifts



$$\delta\langle r^2\rangle^{g,m} = \frac{5}{4\pi}\langle r_0^2\rangle\left(\beta_m^2 - \beta_g^2\right)$$

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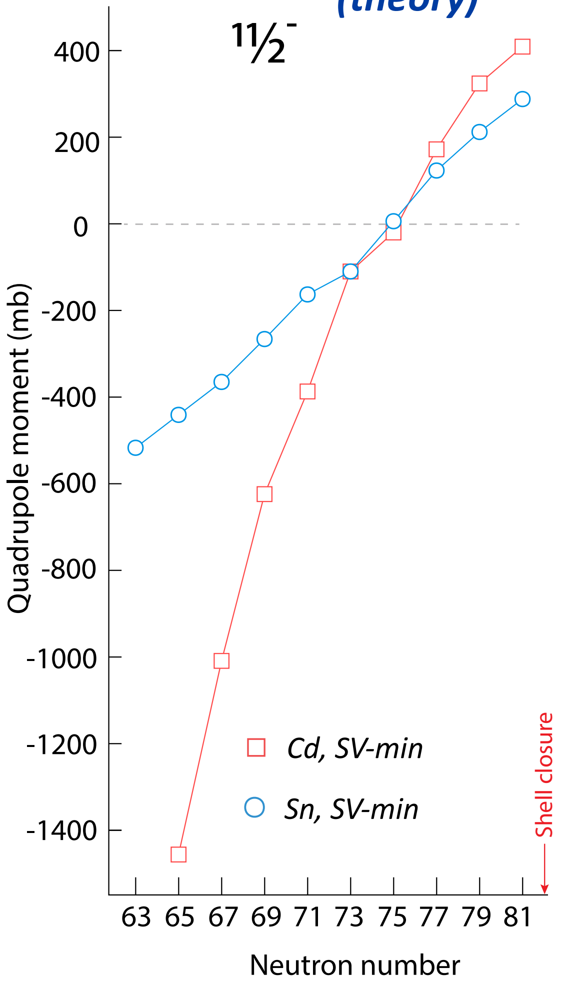
Physics case

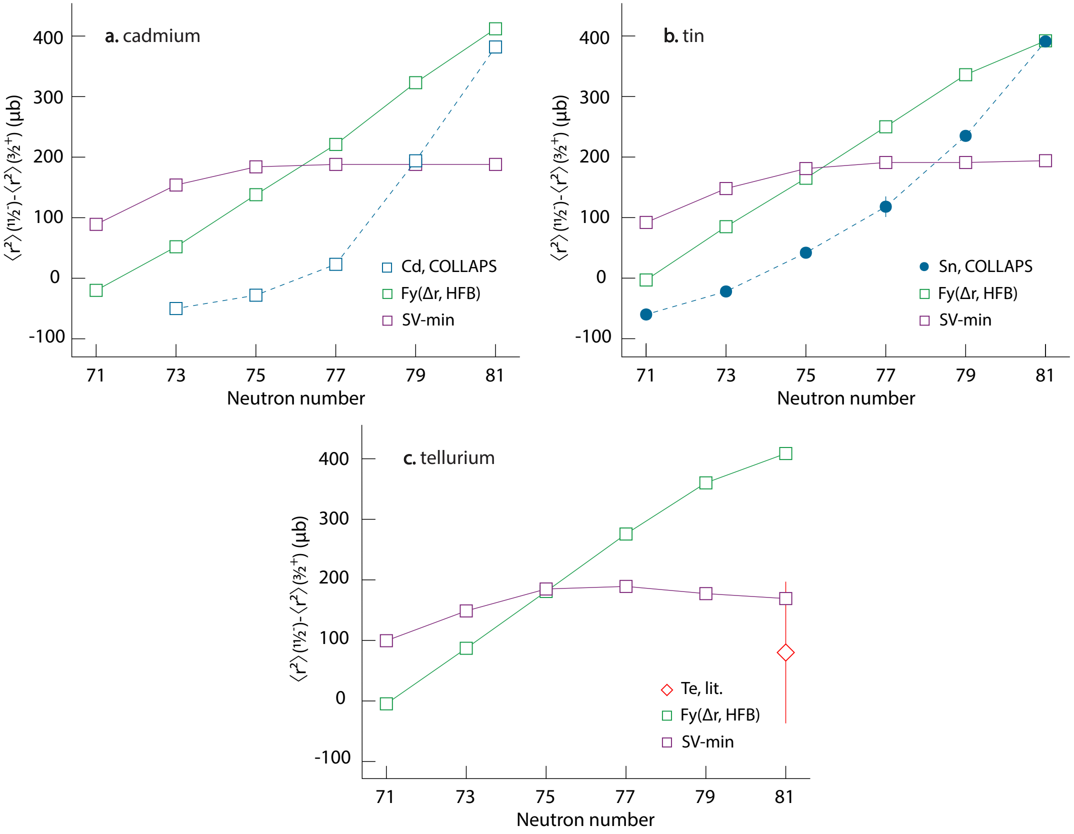
Benchmarking of calculations using the Fy and SV-min functionals

Quadrupole moments (theory)



Isomer shifts

Theory vs exp.



Courtesy of Paul-Gerhard Reinhard and Witold Nazarewicz

Physics case

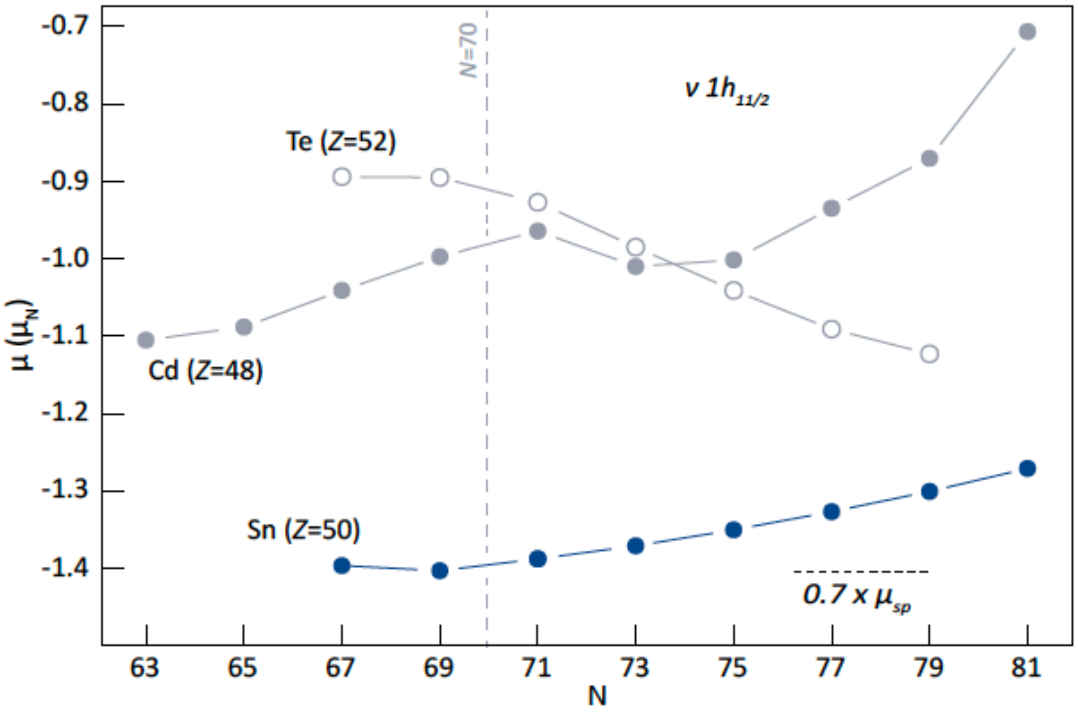


Figure 4.8: Magnetic moments of the $h_{11/2}$ neutron states in cadmium, tin and tellurium. The dashed black line represents the single particle magnetic moment calculated with the Schmidt value for the $h_{11/2}$ orbit. The experimental error bars are smaller than the markers.

Charge radii-Theory