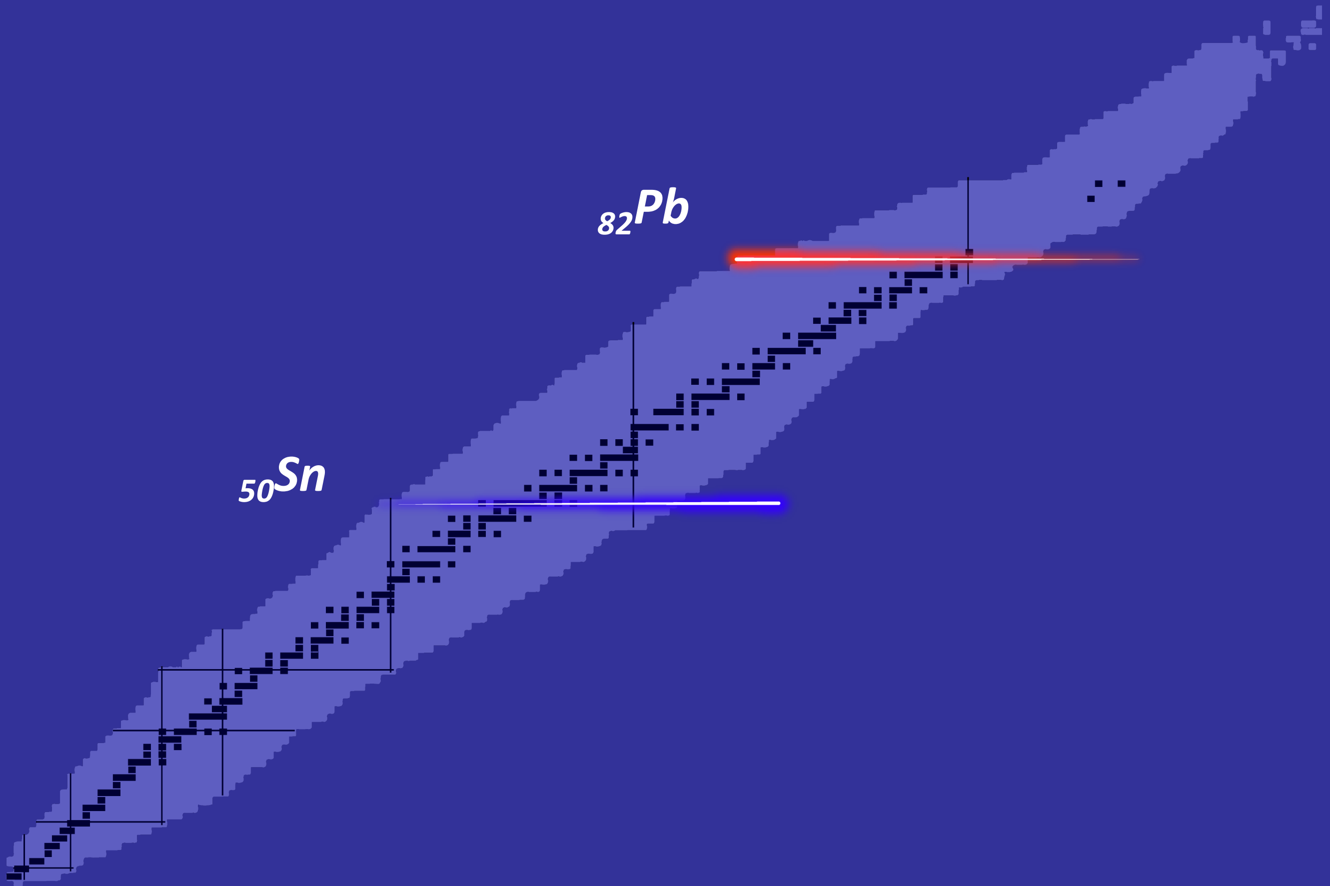
Recent highlights from laser spectroscopy at COLLAPS-CERN



Liss Vázquez Rodríguez[1,2] on behalf of the COLLAPS collaboration

[1]Experimental Physics Department, CERN, Geneva, Switzerland
[2]Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Outline

Introduction- Physics motivation

Laser spectroscopy and hyperfine structure

Experimental set-up, COLLAPS at ISOLDE/CERN

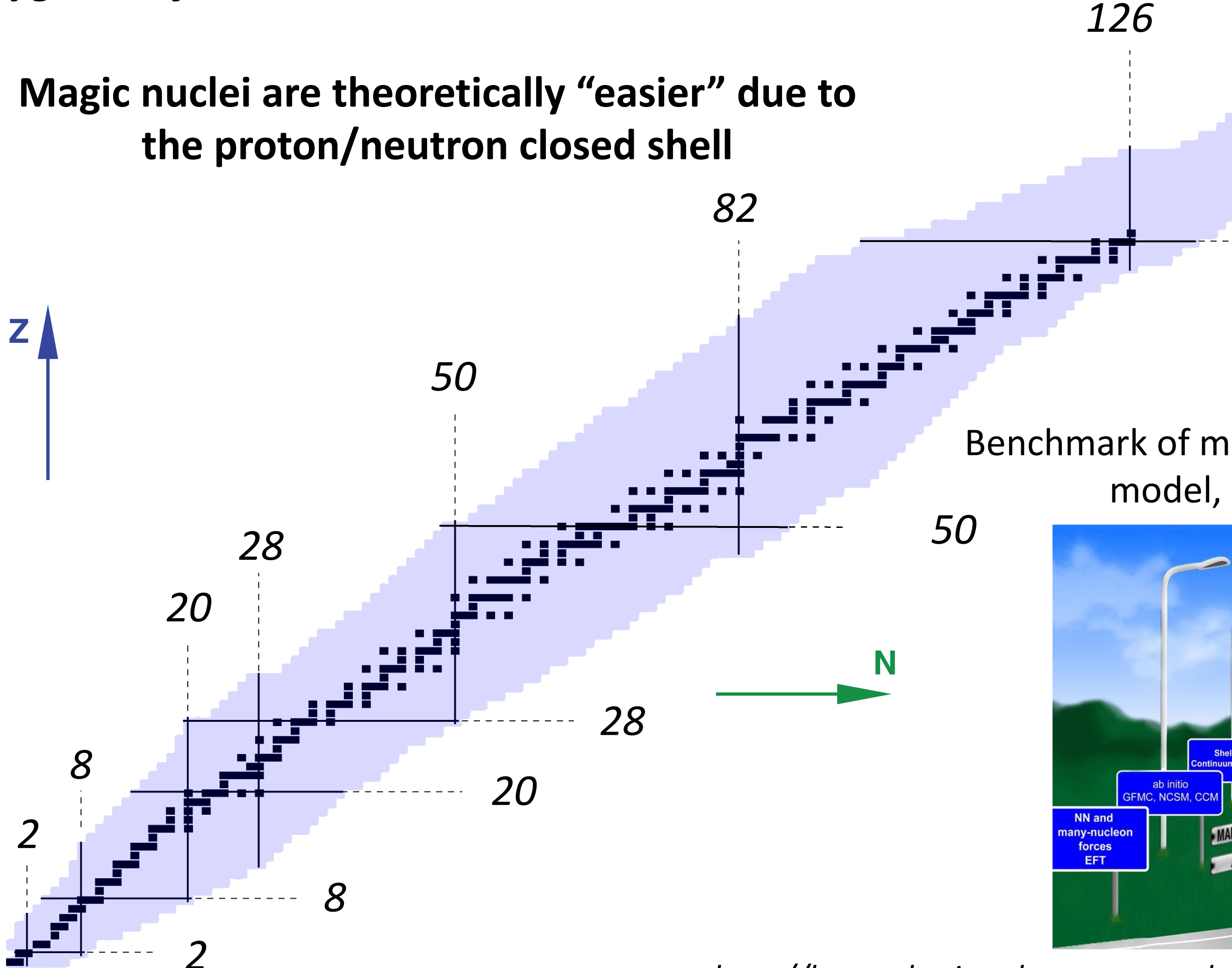
Results, Sn and Pb

Perspectives

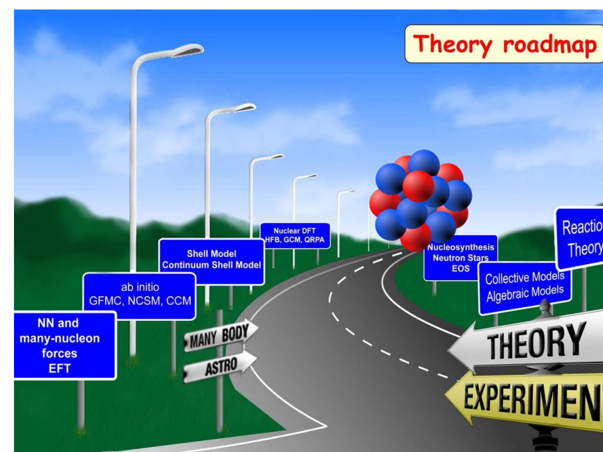
The Segrè chart

Playground for measurements to discriminate nuclear models

Magic nuclei are theoretically "easier" due to the proton/neutron closed shell



Benchmark of many-body methods (Shell model, DFT, Ab-intio, …)



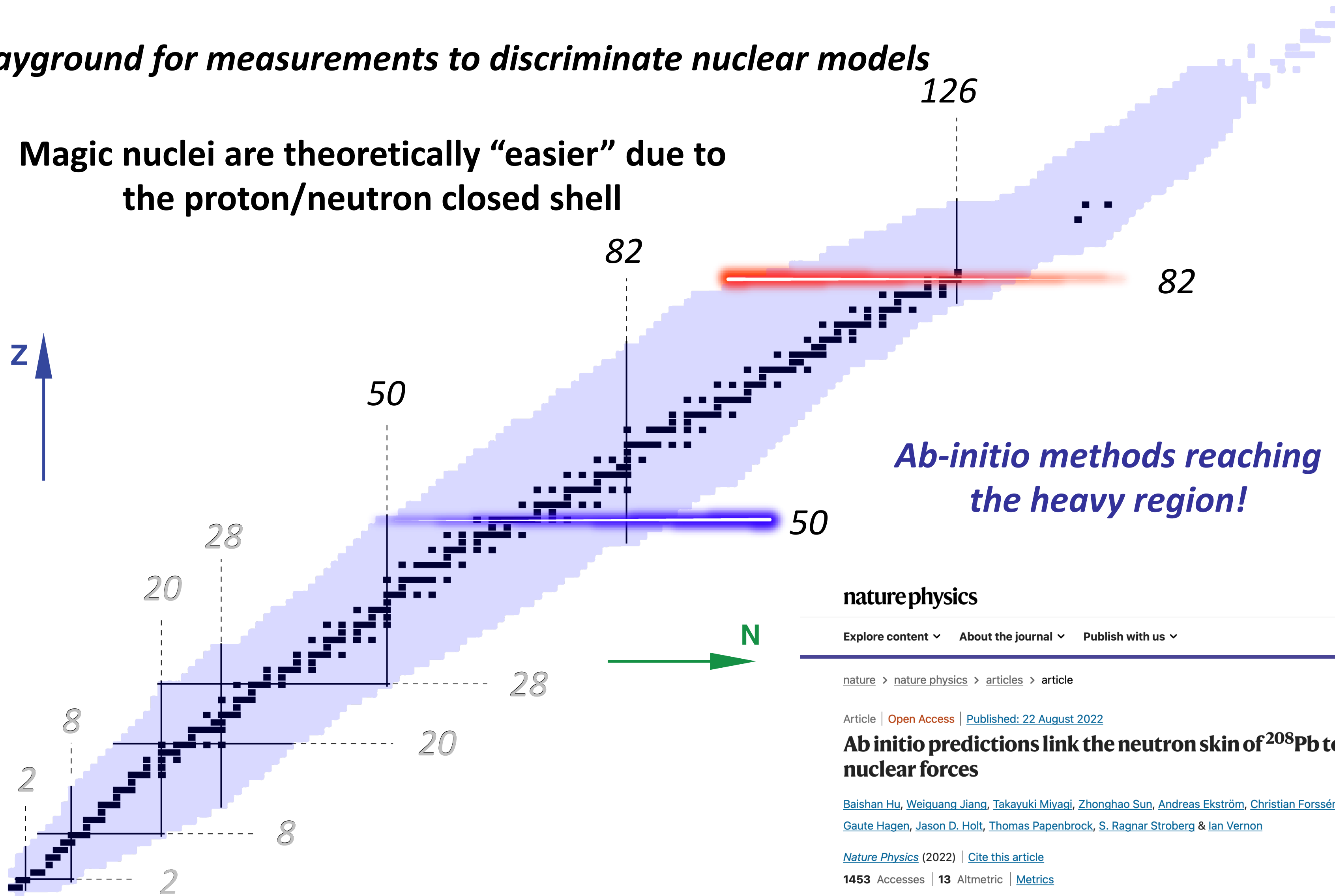
http://hyperphysics.phy-astr.gsu.edu/hbase/Nuclear/shell2.html

Introduction

The Segrè chart

Playground for measurements to discriminate nuclear models

Magic nuclei are theoretically “easier” due to the proton/neutron closed shell



Ab-initio methods reaching the heavy region!

nature physics

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Article | Open Access | Published: 22 August 2022

Ab initio predictions link the neutron skin of ^{208}Pb to nuclear forces

Baishan Hu, Weiguang Jiang, Takayuki Miyagi, Zhonghao Sun, Andreas Ekström, Christian Forssén, Gaute Hagen, Jason D. Holt, Thomas Papenbrock, S. Ragnar Stroberg & Ian Vernon

Nature Physics (2022) | Cite this article

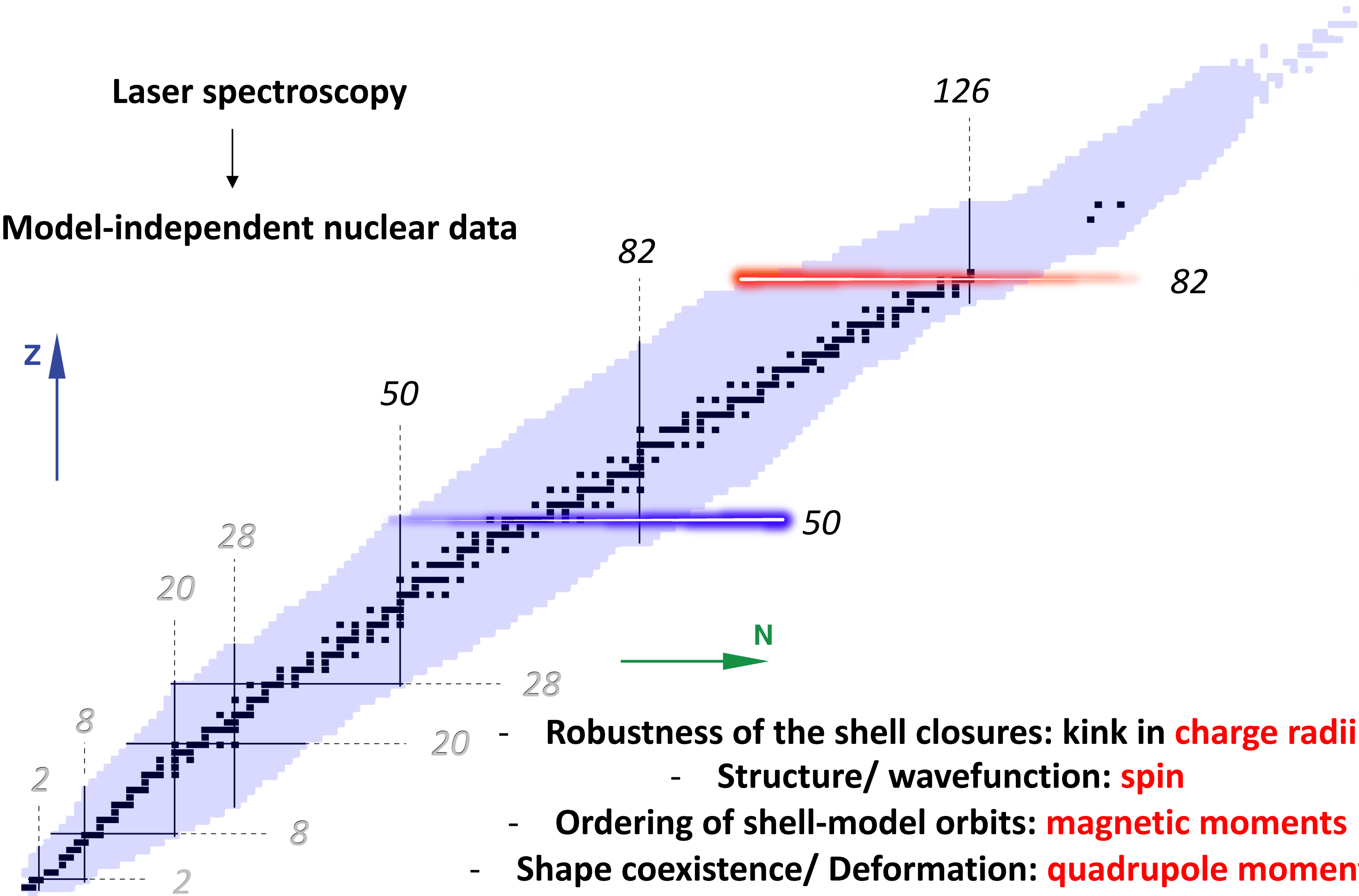
1453 Accesses | **13** Altmetric | Metrics

What can we learn from laser spectroscopy?

Laser spectroscopy

↓

Model-independent nuclear data



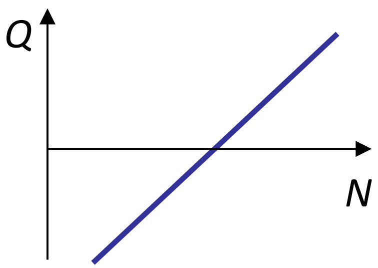
- **Robustness of the shell closures: kink in charge radii**
- **Structure/ wavefunction: spin**
- **Ordering of shell-model orbits: magnetic moments**
- **Shape coexistence/ Deformation: quadrupole moments**

Physics motivation

Very rich isomerism!

Seniority scheme

Electric quadrupole moment



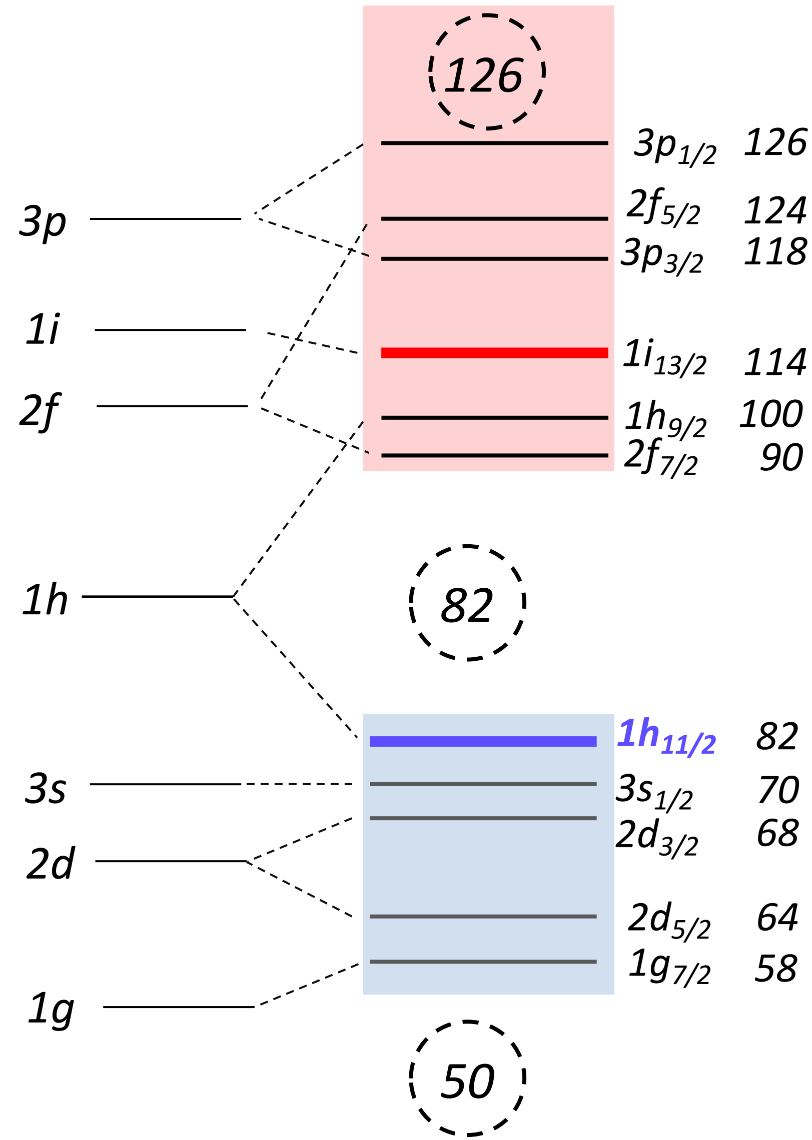
$$Q = \frac{2j+1-2n}{2j-1} Q_{sp}$$

$h_{11/2}$ and $i_{13/2}$: unique-parity orbitals

odd particle confined due to parity constrain

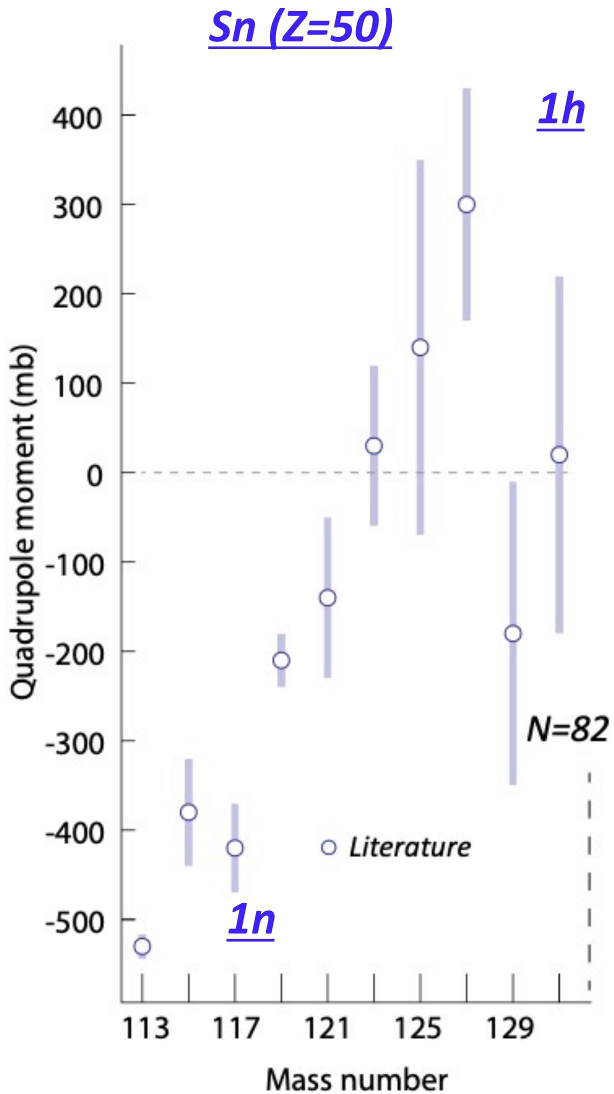
Spherical shell model

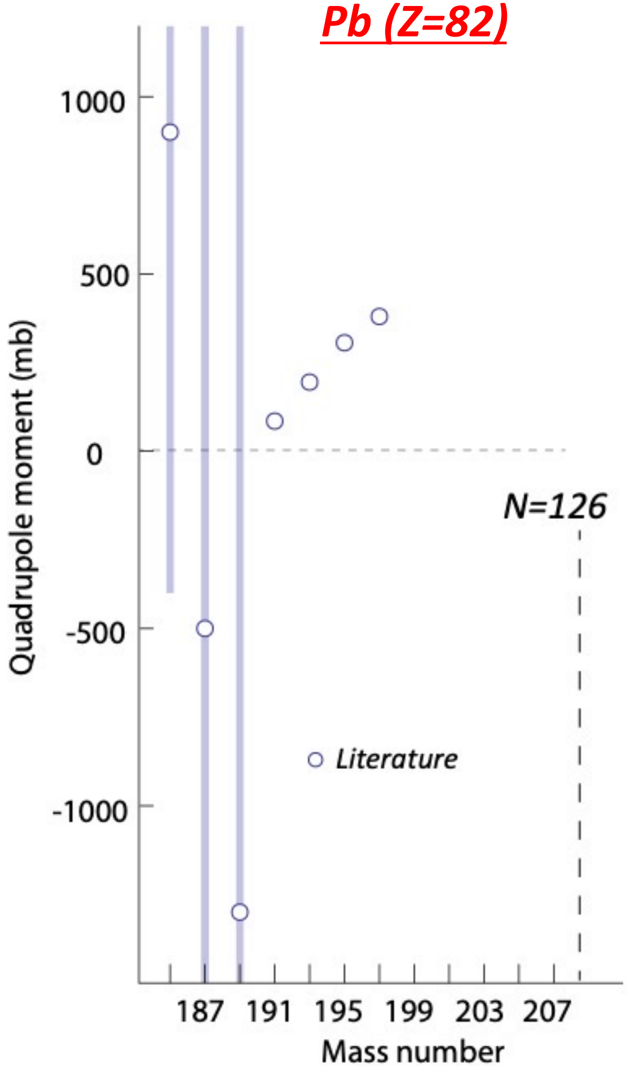
Neutron orbitals (blue: Sn, red: Pb)



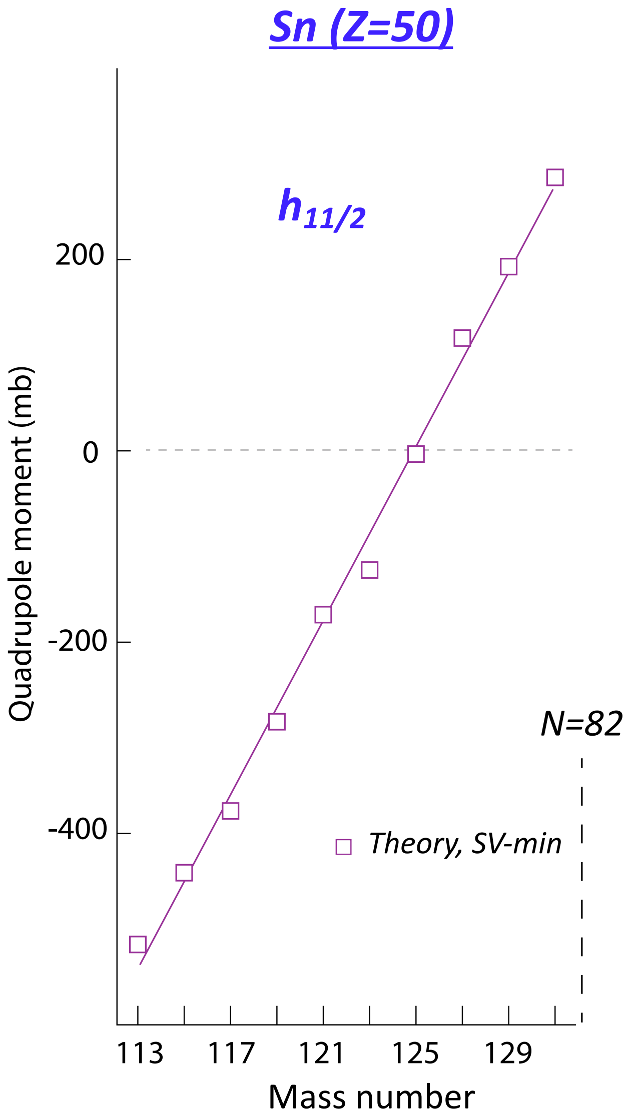
Physics motivation

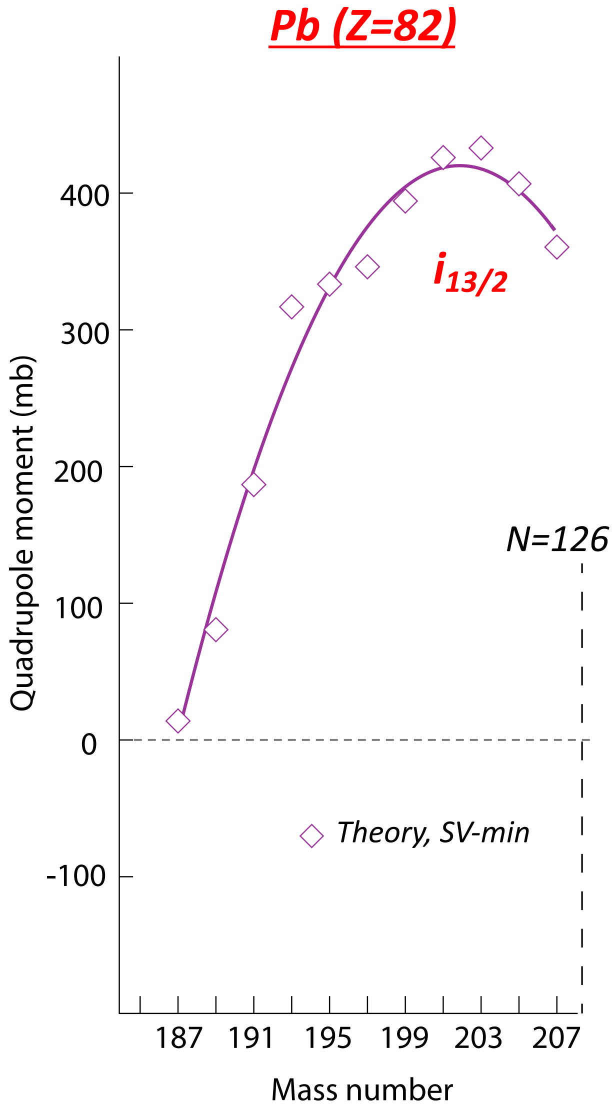
Data prior our measurements





Theory predictions





Physics motivation

Linear trends in Q observed in Cd (Sn-2p)

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

D. T. Yordanov,[1,2,*] D. L. Balabanski,[3] J. Bieroń,[4] M. L. Bissell,[5] K. Blaum,[1] I. Budinčević,[5] S. Fritzsche,[6] N. Frömmgen,[7] G. Georgiev,[8] Ch. Geppert,[6,7] M. Hammen,[7] M. Kowalska,[2] K. Kreim,[1] A. Krieger,[7] R. Neugart,[7] W. Nörtershäuser,[6,7] J. Papuga,[5] and S. Schmidt[6]

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[2]CERN European Organization for Nuclear Research, Physics Department, CH-1211 Geneva 23, Switzerland
[3]INRNE, Bulgarian Academy of Science, BG-1784 Sofia, Bulgaria
[4]Instytut Fizyki imienia Mariana Smoluchowskiego, Uniwersytet Jagielloński, Reymonta 4, 30-059 Kraków, Poland
[5]Instituut voor Kern-en Stralingsfysica, KU Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium
[6]GSI Helmholtzzentrum für Schwerionenforschung GmbH, D-64291 Darmstadt, Germany
[7]Institut für Kernchemie, Johannes Gutenberg-Universität Mainz, D-55128 Mainz, Germany
[8]CSNSM-IN2P3-CNRS, Université de Paris Sud, F-91405 Orsay, France
(Received 28 January 2013; published 6 May 2013)

Produced by the neutrons (seniority)

or

by the two p-holes

or

a combination of both?

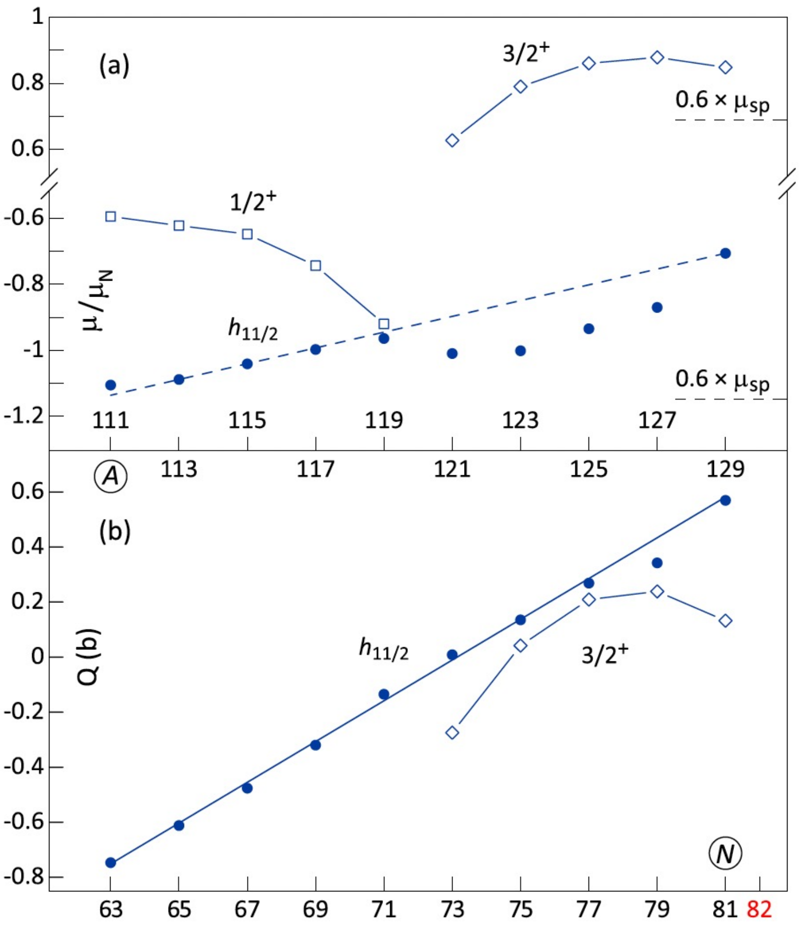

FIG. 2 (color online). Magnetic (a) and quadrupole (b) moments of $^{111-129}$Cd from this work. The experimental error bars are smaller than the markers. A straight line is fitted through the $h_{11/2}$ quadrupole moments, consistent with Eq. (2). The dashed line indicates the effect of core polarization.

Physics motivation

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

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

D. T. Yordanov,[1,2,3,*] D. L. Balabanski,[4] M. L. Bissell,[5] K. Blaum,[2] I. Budinčević,[5] B. Cheal,[6] K. Flanagan,[7] N. Frömmgen,[8] G. Georgiev,[9] Ch. Geppert,[8,10] M. Hammen,[8] M. Kowalska,[3] K. Kreim,[2] A. Krieger,[8] J. Meng,[11] R. Neugart,[2,8] G. Neyens,[5] W. Nörtershäuser,[8,12] M. M. Rajabali,[5] J. Papuga,[5] S. Schmidt,[10] and P. W. Zhao[13]

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(Received 13 October 2015; published 22 January 2016)

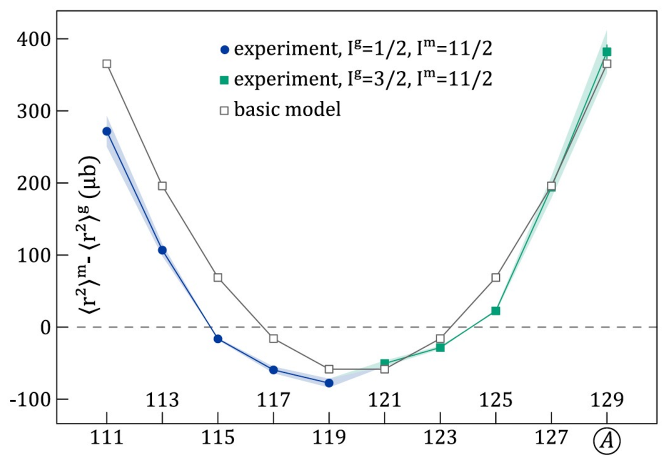


FIG. 2. Mean square charge-radii differences between isomers (m) and ground states (g) in $^{111-129}$Cd compared with calculations discussed in the text. The data correspond to the ionic transition except for ^{117}Cd whose value is taken from the atomic one. In all but one case, the statistical errors are smaller than the dots. The shaded bands represent the systematic uncertainty.

First observation of such mass dependency!

$$Q = \frac{3}{\sqrt{5\pi}} \frac{I(2I-1)}{(I+1)(2I+3)} \langle {r_0}^2 \rangle Z\beta$$

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

<u>*if Q linear --- isomer shift quadratic*</u>

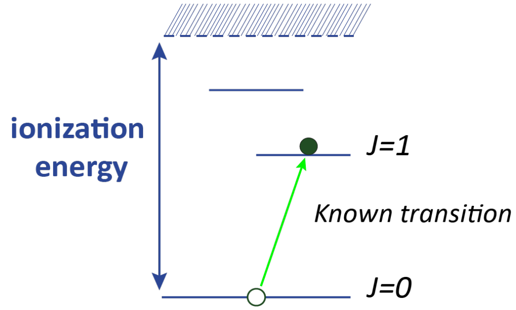
Laser spectroscopy and hyperfine structure

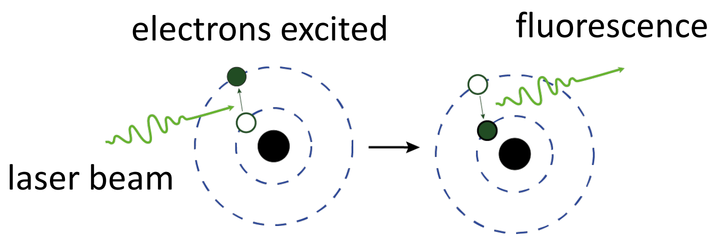
Laser spectroscopy

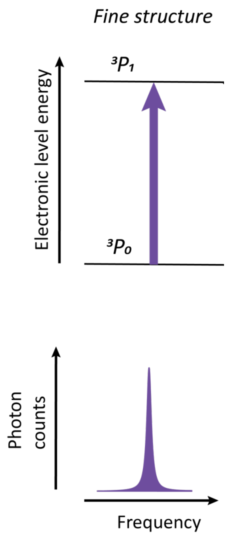
Nuclear properties (spin, μ, Q, charge radius)

Model (nuclear) independent

Atomic laser spectroscopy: a fruitful marriage of atomic and nuclear physics



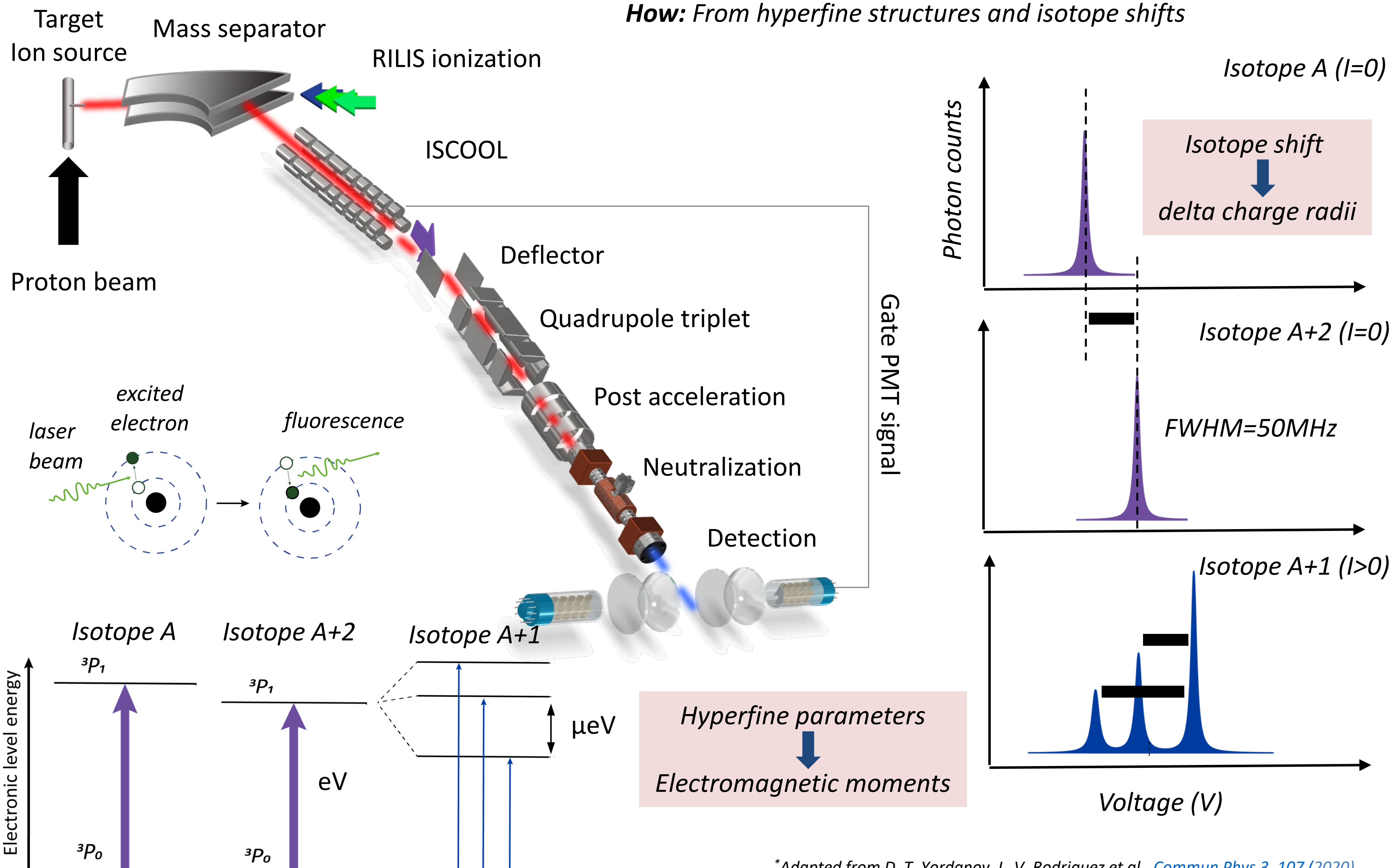




Experimental set-up, COLLAPS @ ISOLDE

What we measure: *Spin, magnetic and quadrupole moments, charge radii*

How: *From hyperfine structures and isotope shifts*



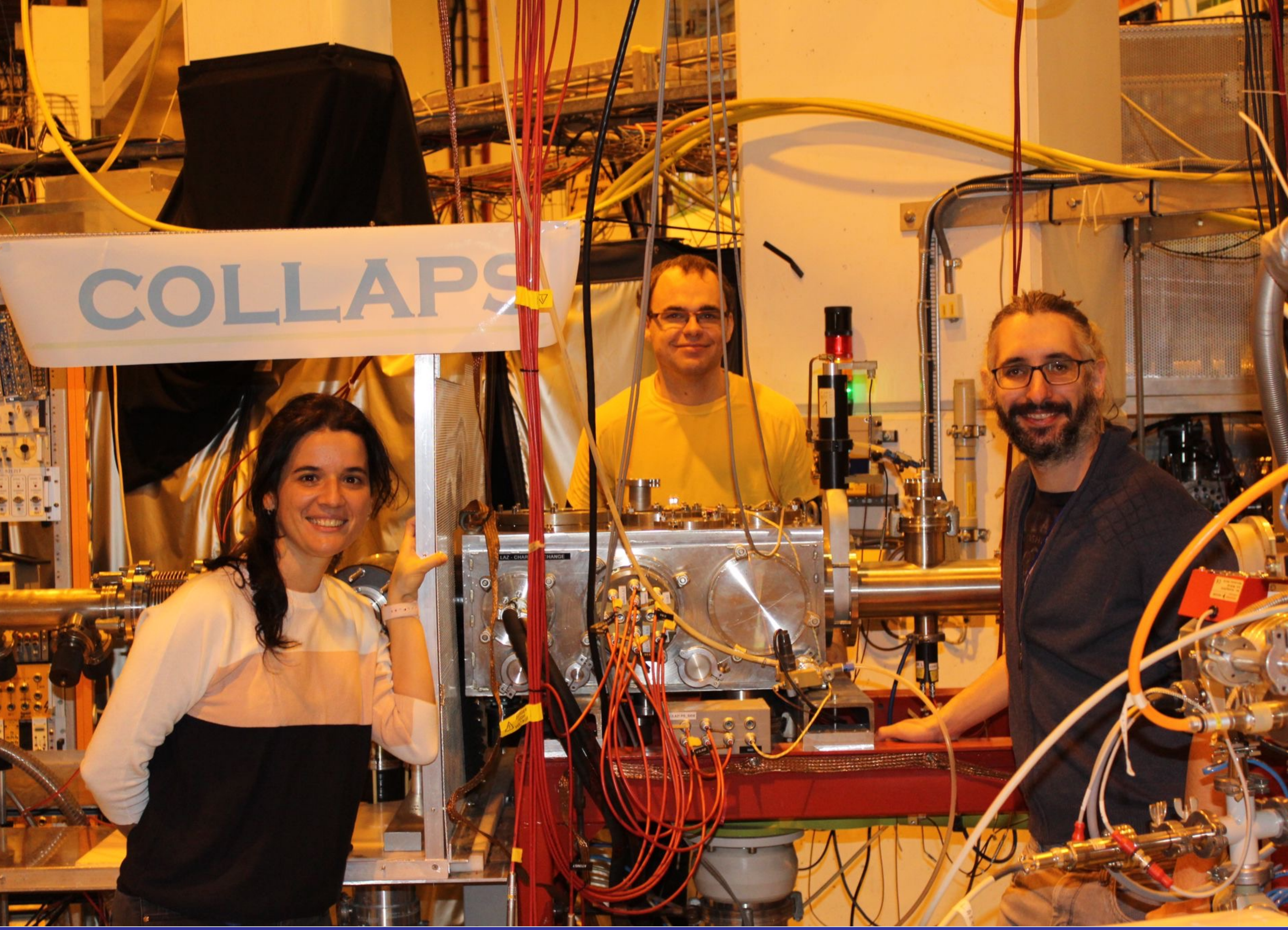
*Adapted from D. T. Yordanov, L. V. Rodriguez et al., Commun Phys 3, 107 (2020)

Nuclear properties from laser spectroscopy at COLLAPS

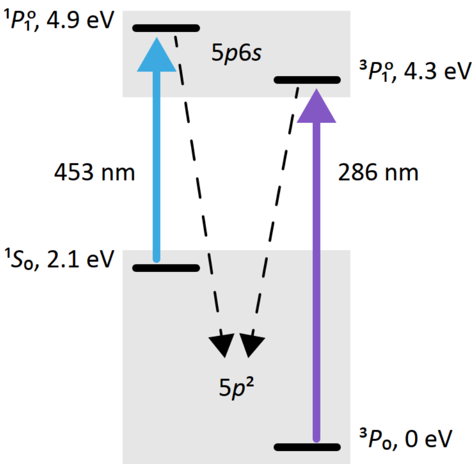
$$A \frac{I}{\boldsymbol{\mu}} = \text{const}$$

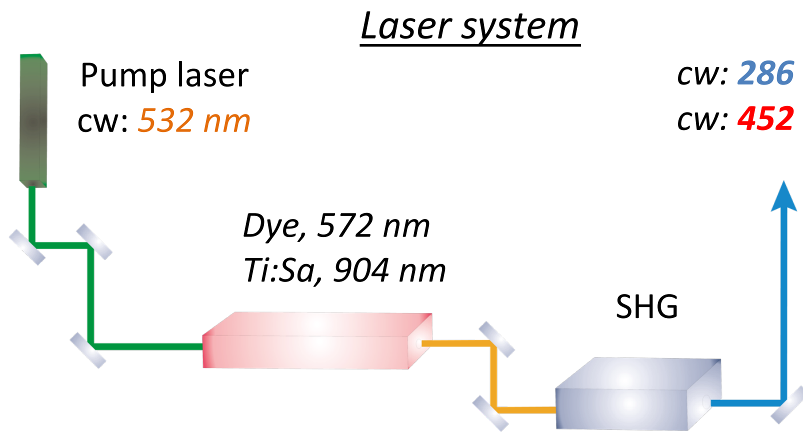
$$\frac{B}{\boldsymbol{Q}} = \text{const} = eV_{jj}$$

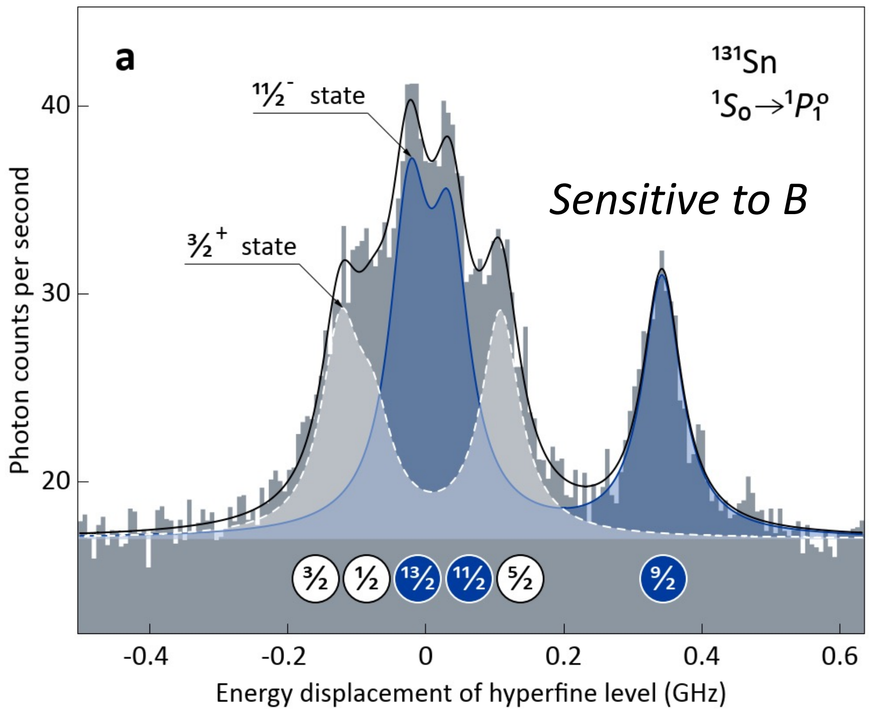
Isotope shift ∝ ***ms charge radii***

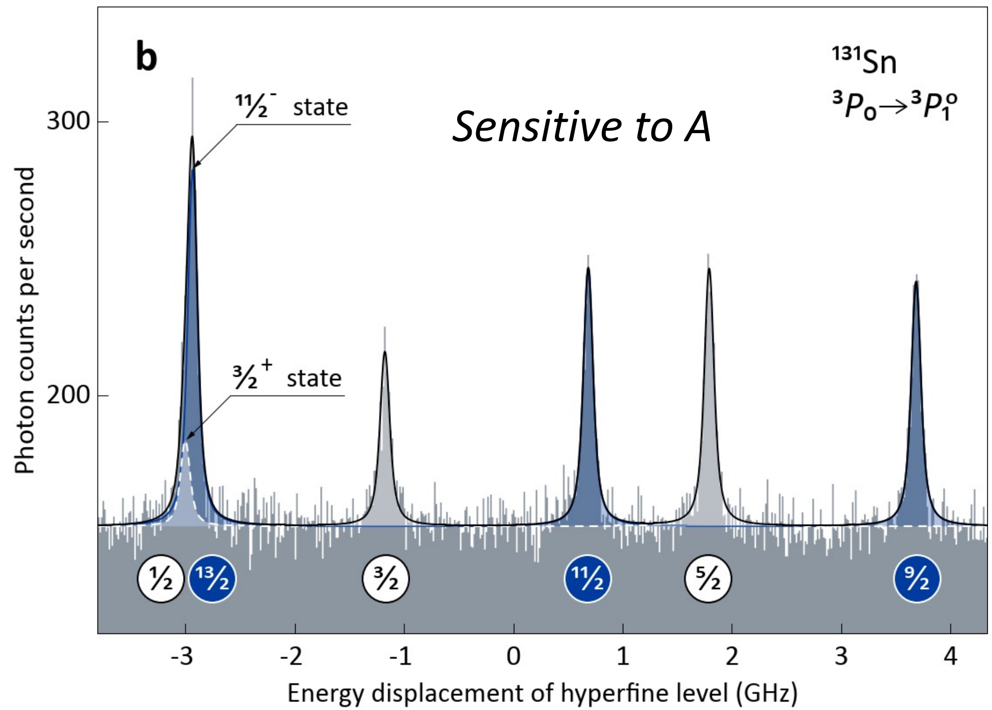

COLLAPS

Electronic transitions used for the Sn experiment



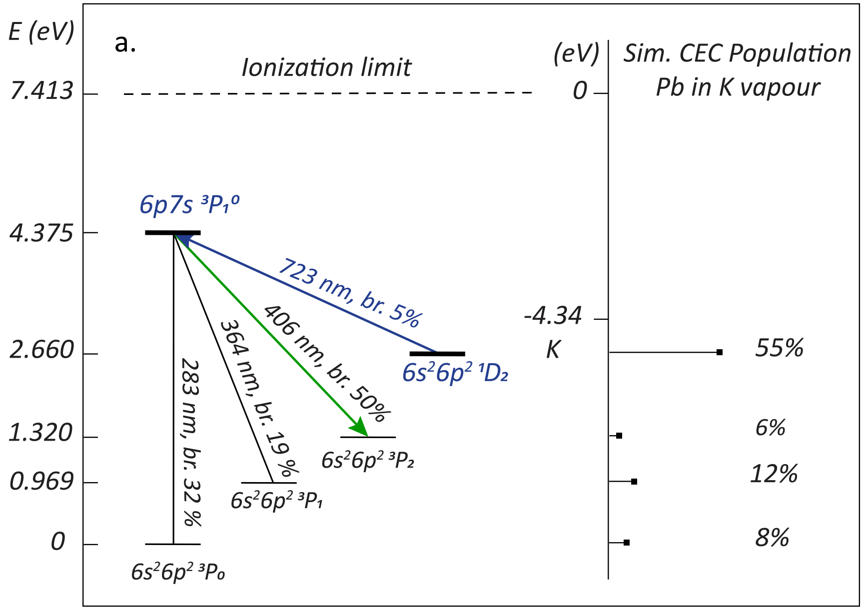




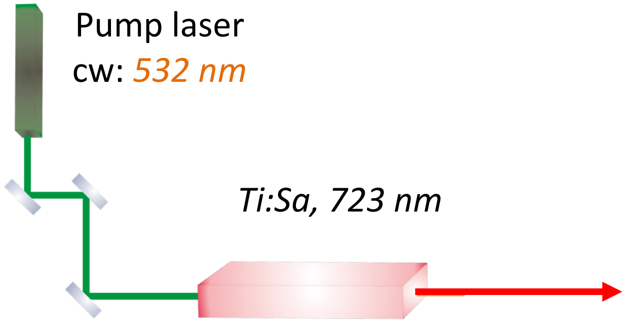


D. T. Yordanov, L. V. Rodríguez, et al. Commun. Phys. ***3****, 107 2020*

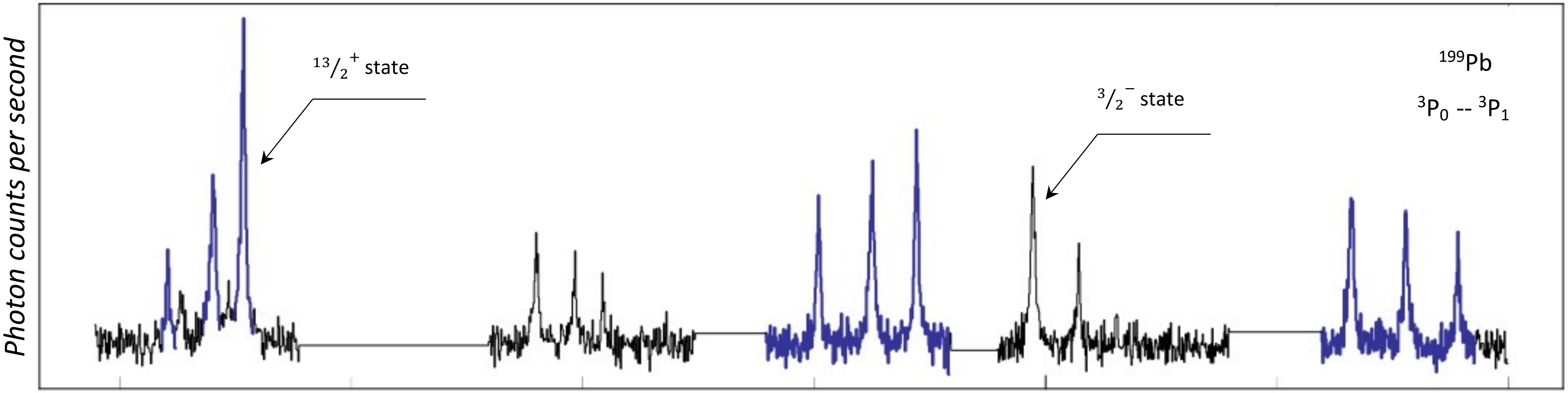
Electronic transition used for the Pb experiment



Laser system



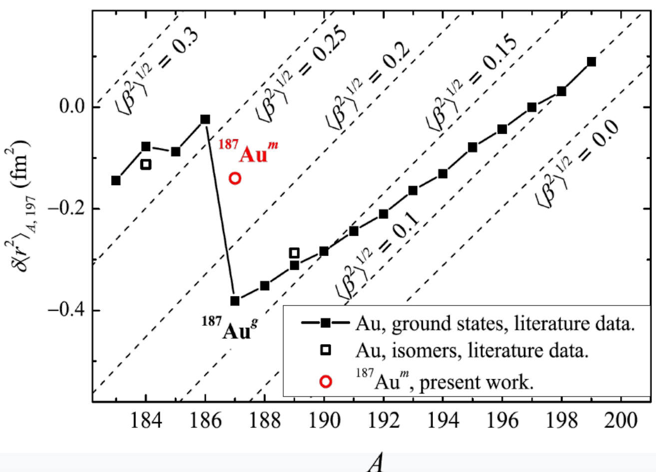
Example HFS spectra of ^{201}Pb in the 723nm transition

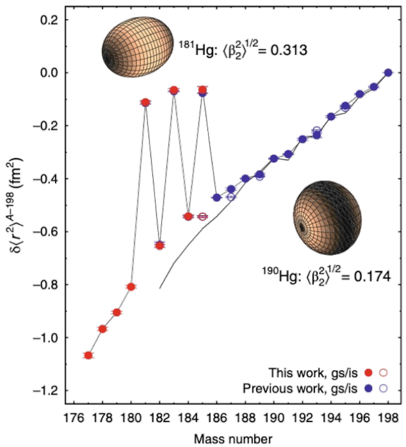


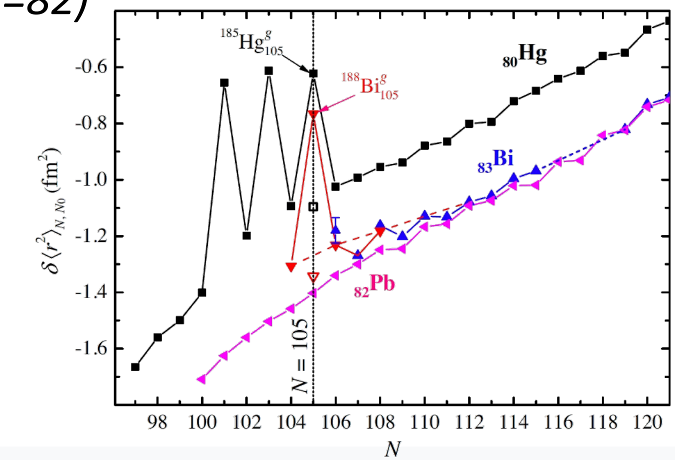
L. V. Rodríguez, et al. INTC-CERN, 2021

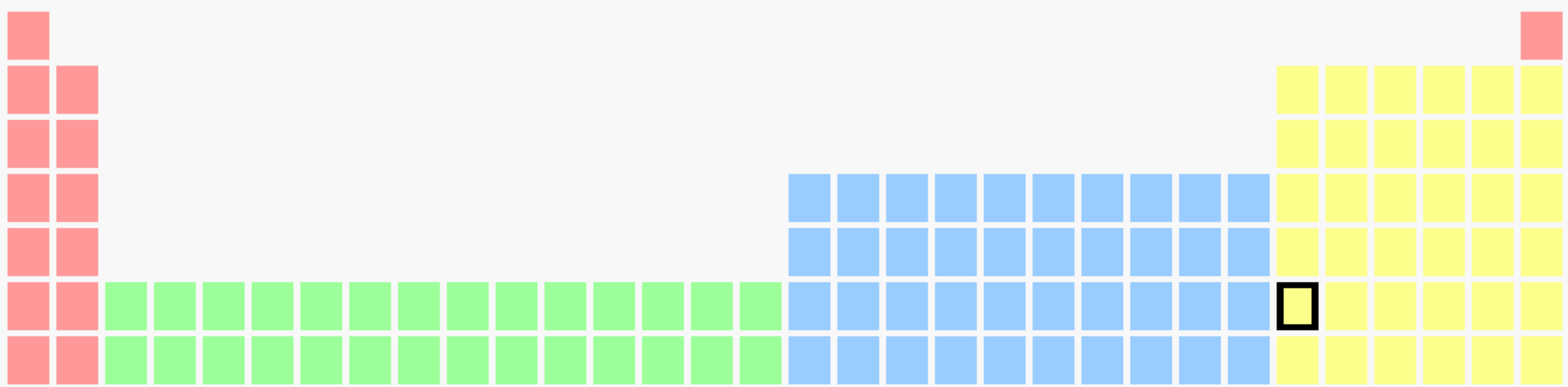
High-resolution laser spectroscopy of thallium (Z=81) isotopes

Au (Z=79) *Hg (Z=80)* *Tl (Z=81)* *Pb (Z=82)* *Bi (Z=83)*









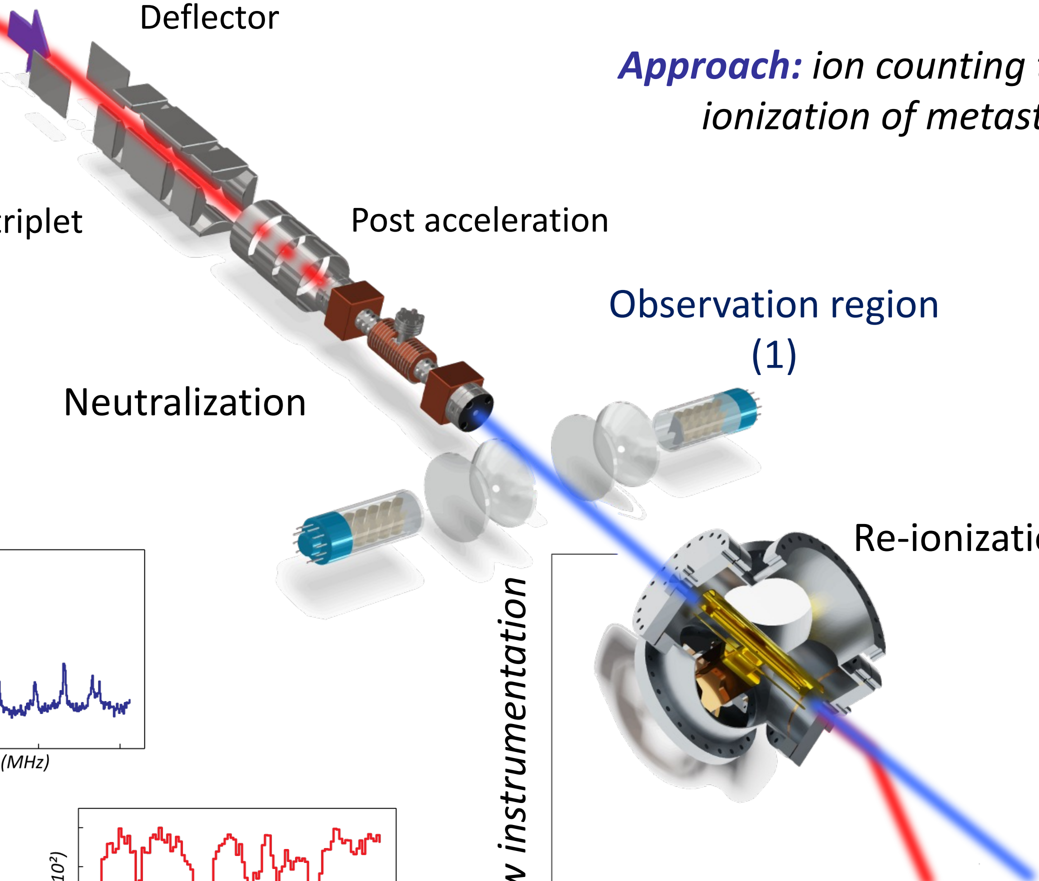
In
↑
Tl
↓
Nh

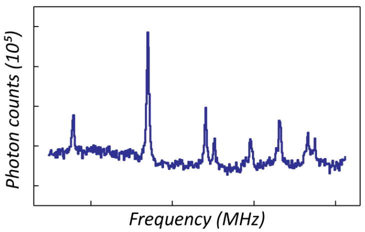
mercury ← thallium → lead

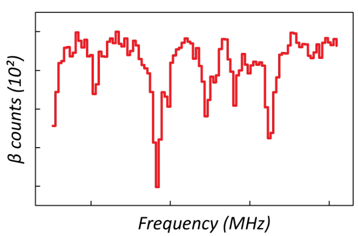
Perspectives

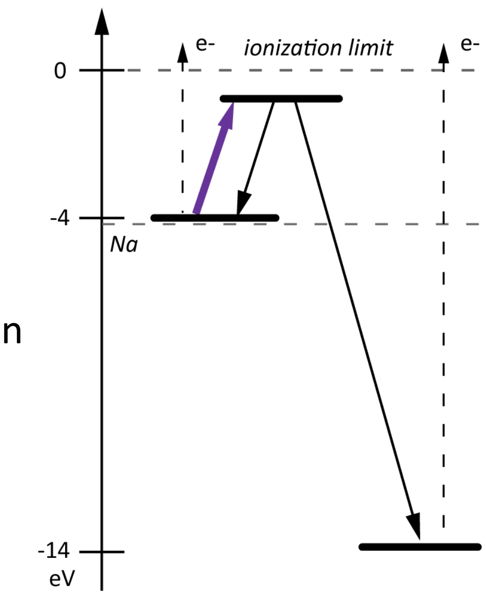
***Motivation:* Towards the most exotic Tl nuclei at ISOLDE**

Approach: *ion counting technique based on selective ionization of metastable atoms in a gas cell*









Expected improvements:
Increase in detection efficiency
Background reduction

Conclusions

High-resolution laser spectroscopy is been performed in a long sequence of Sn and Pb magic nuclei

The quadrupole moments and charge radii in Sn and Pb evolve in a simple way, along a line or a parabola

New measurements will be performed in the Tl isotopic chain, with optical and particle detection.

Thank you for your attention!