MAX-PLANCK INSTITUTE FÜR KERNPHYSIK

“Shining light on the unknown, high-resolution laser spectroscopy of exotic nuclei”

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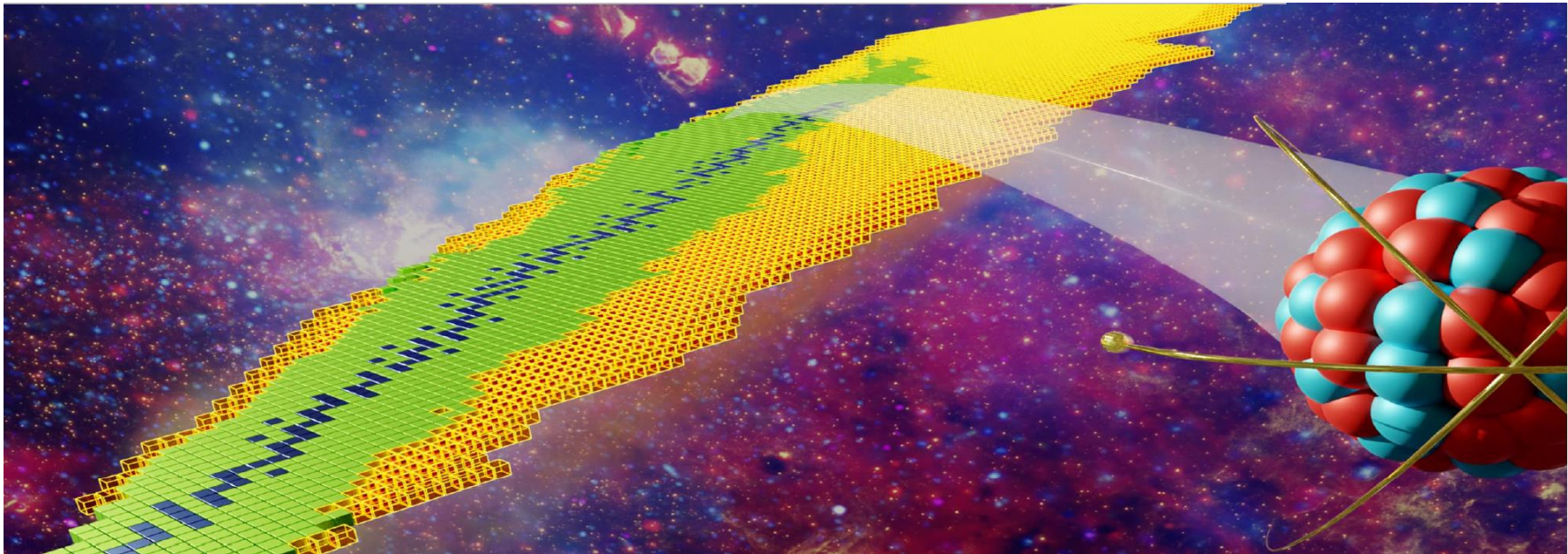


Outline

- **Motivation**
  - **Emergence/disappearance of magic numbers**
  - **Probing shell closures with laser spectroscopy**

- **Experiment**
  - **Laser spectroscopy and the atomic nucleus**
  - **The ROC technique**

- **Results**
  - **Nuclear properties of ^{53,54}Ca and the *N=32* shell closure**

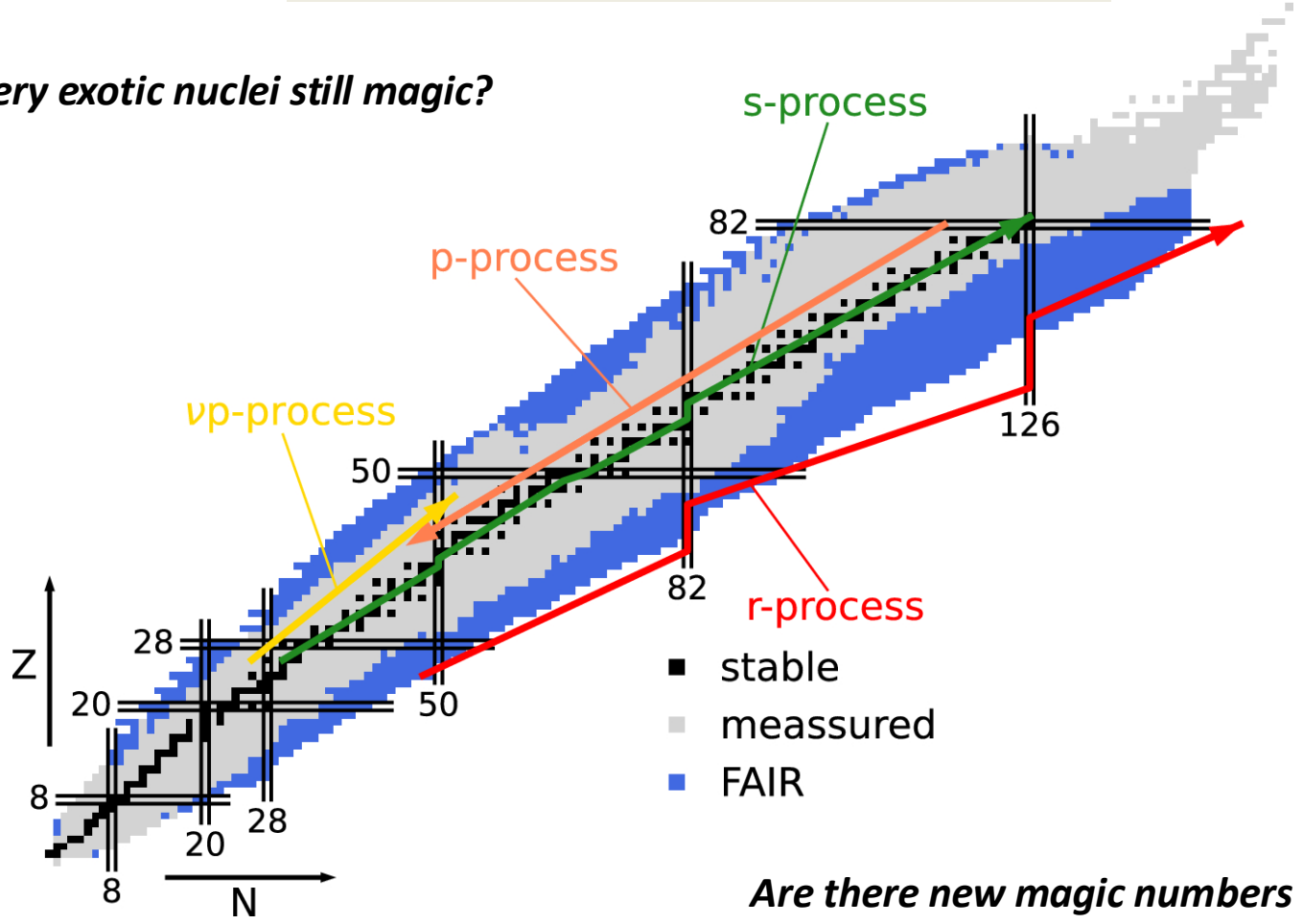
- **Accessing unexplored regions of the nuclear chart**

  Recent developments towards the study of proton-halo nuclei

Motivation: Emergence/disappearance of magic numbers

Open questions in Nuclear Physics Research

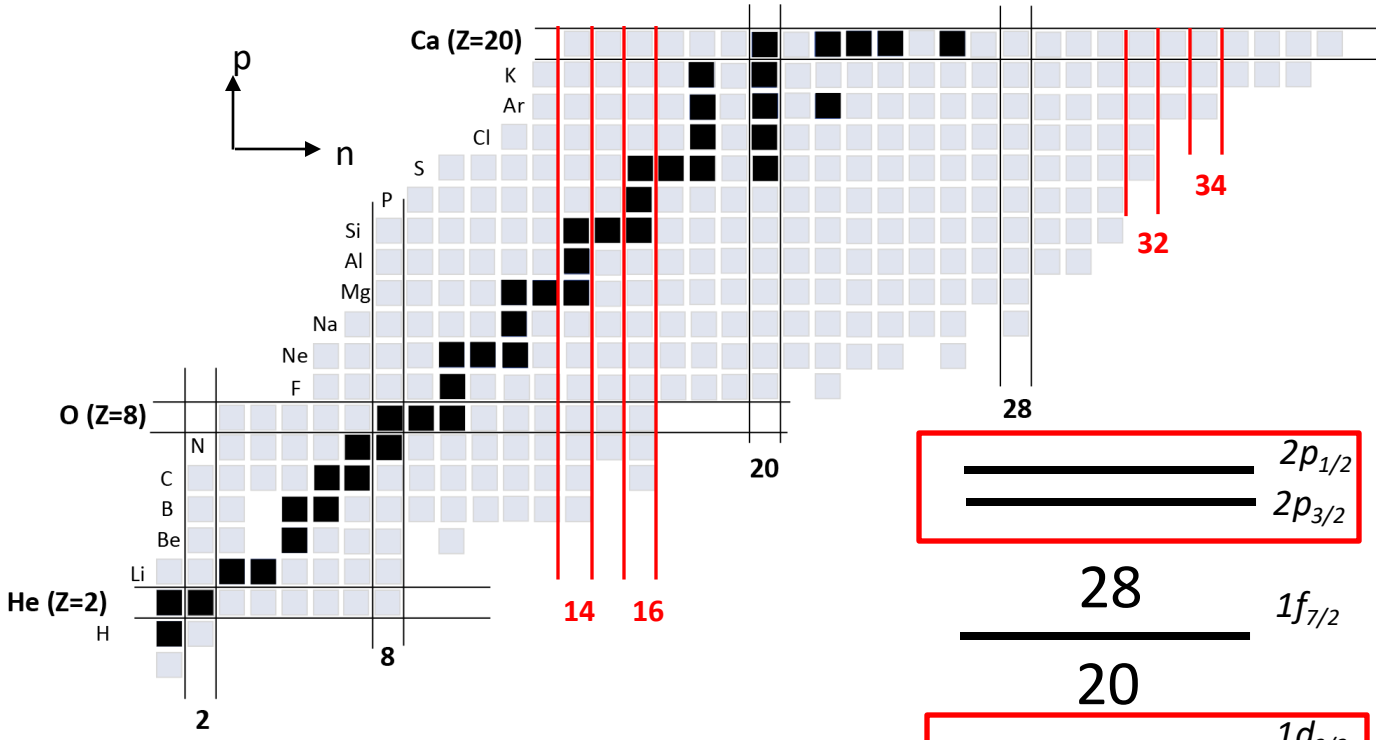
Are very exotic nuclei still magic?

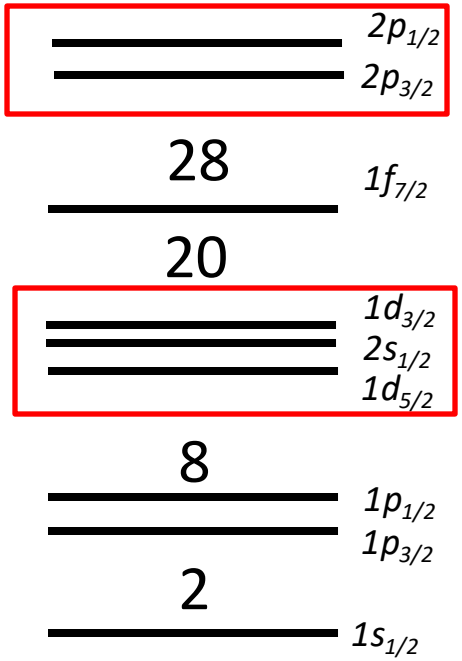


Are there new magic numbers away from stability?

Motivation: Emergence/disappearance of magic numbers

Exotic beam





Shell model of nuclei

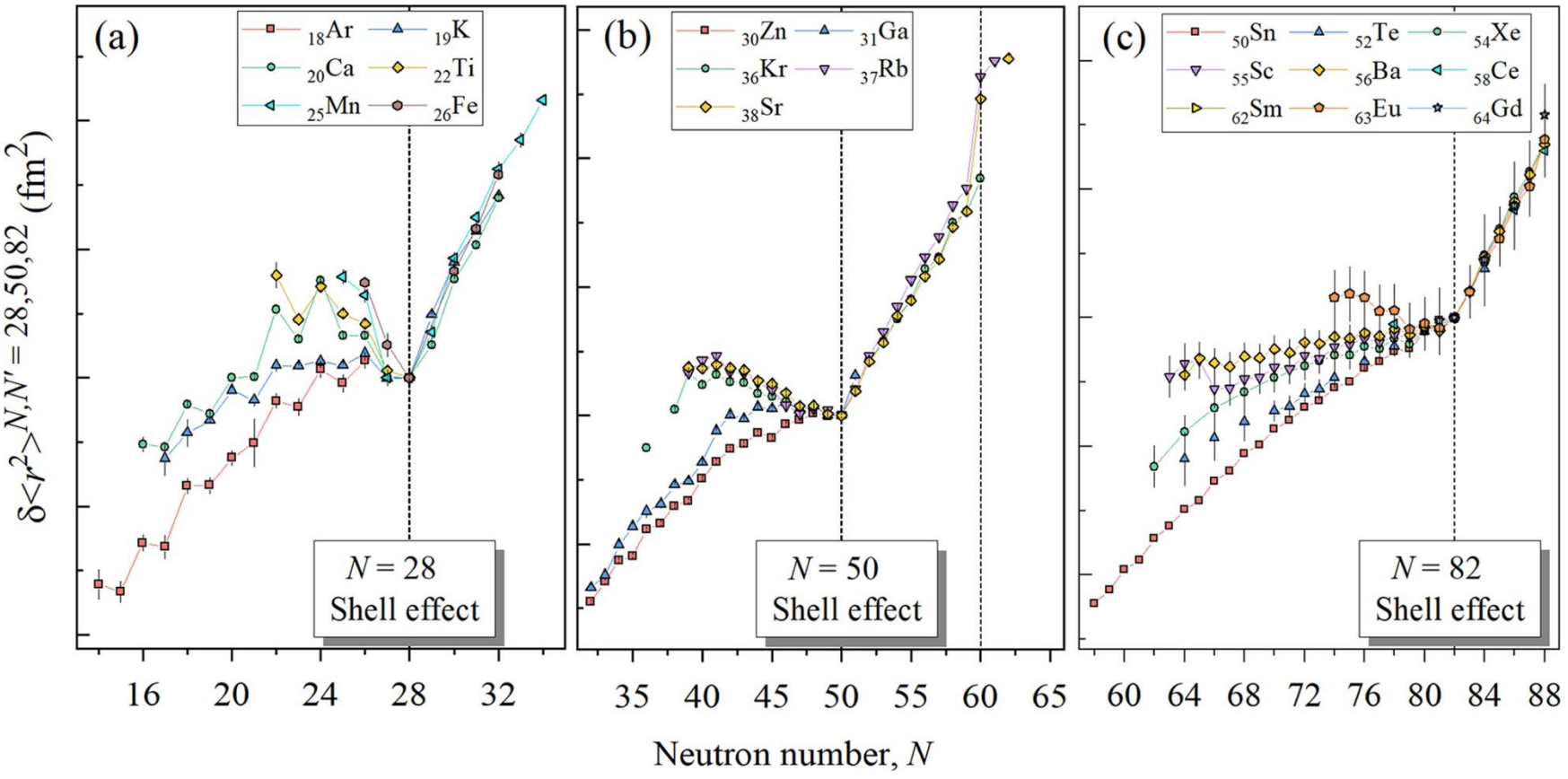
Established shell closures: 2, 8, 20, 28, 50, 126

➡ **Emergence/disappearance of magic numbers?**

N = 14, 16, 32 and 34

Probing shell closures with laser spectroscopy

Charge radii measurements at shell closures



Kink = indicative of a shell effect

X.F. Yang, et al., Prog. Part. Nucl. Phys., 129, 104005, 2023

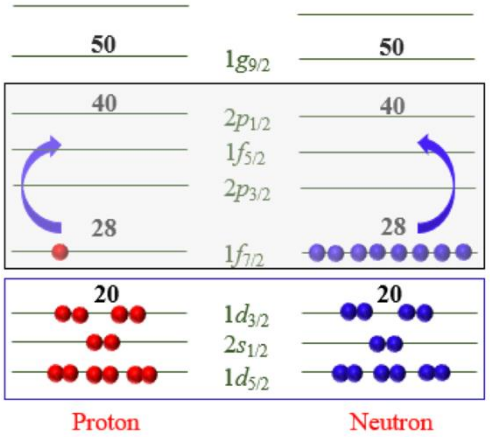
Probing shell closures with laser spectroscopy

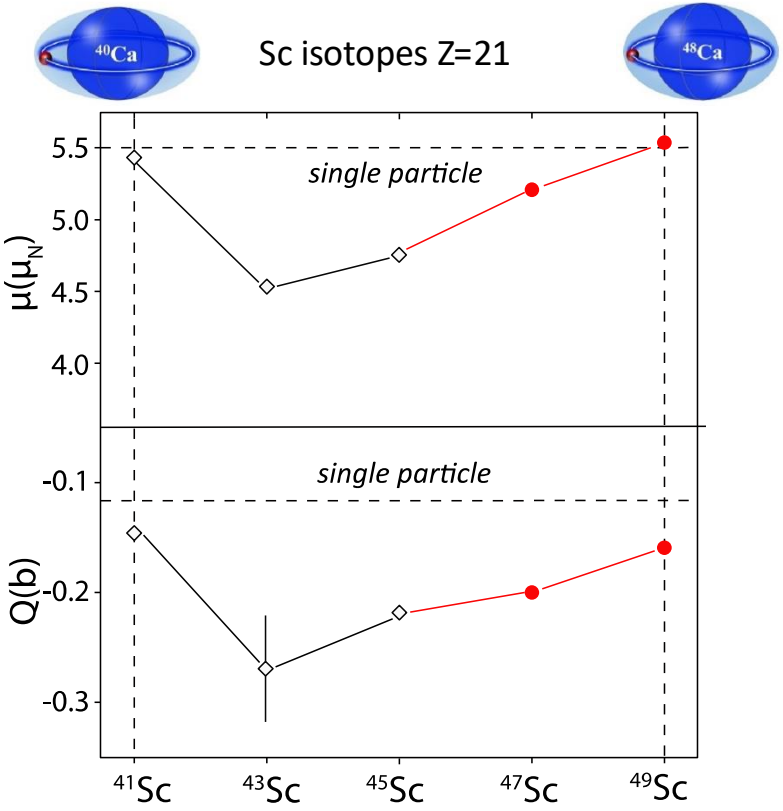
Magnetic moments (and Q) of doubly magic ± 1 nucleus

Shell model : particles are paired one-to-one

Single particle like system: The magnetic moment is determined by *a single particle* on top of a core of protons and neutrons (Schmidt limit)

Spherical shell model





Single particle like system
=
Evidence of shell closure

S.W.Bai et al. Phys. Lett. B 829 (2022) 137064

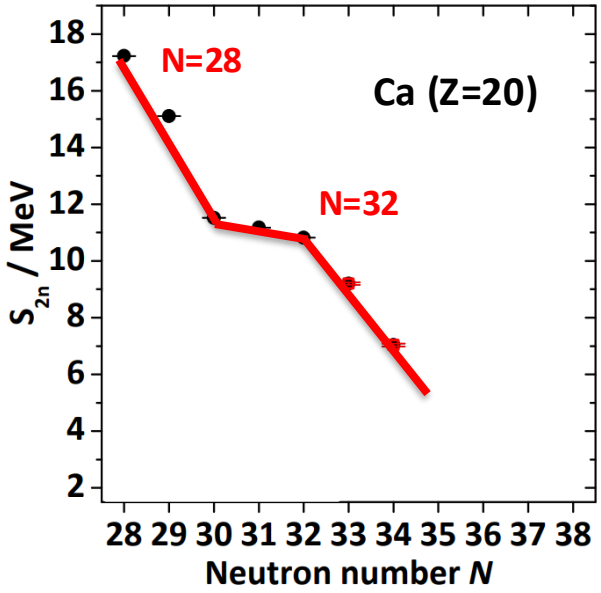
Motivation: Probing shell closures with laser spectroscopy

The emergence of a shell closure at *N* = 32: an unresolved puzzle

^{34}Ca ^{35}Ca ^{36}Ca ^{37}Ca ^{38}Ca ^{39}Ca ^{40}Ca ^{41}Ca ^{42}Ca ^{43}Ca ^{44}Ca ^{45}Ca ^{46}Ca ^{47}Ca ^{48}Ca ^{49}Ca ^{50}Ca ^{51}Ca ^{52}Ca ^{53}Ca ^{54}Ca ^{55}Ca ^{56}Ca ^{57}Ca

***N* =20** **N =28** **N =32**

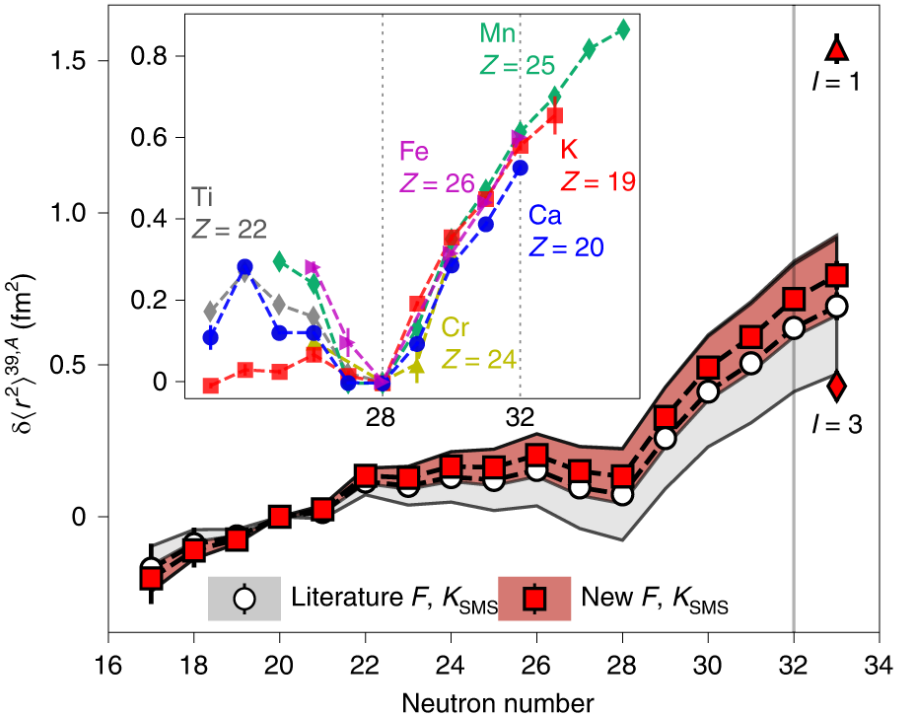
Two-neutron separation energy S2n of the neutron-rich calcium isotopes as a function of neutron number N



Kink observed at 32 neutrons in Ca!

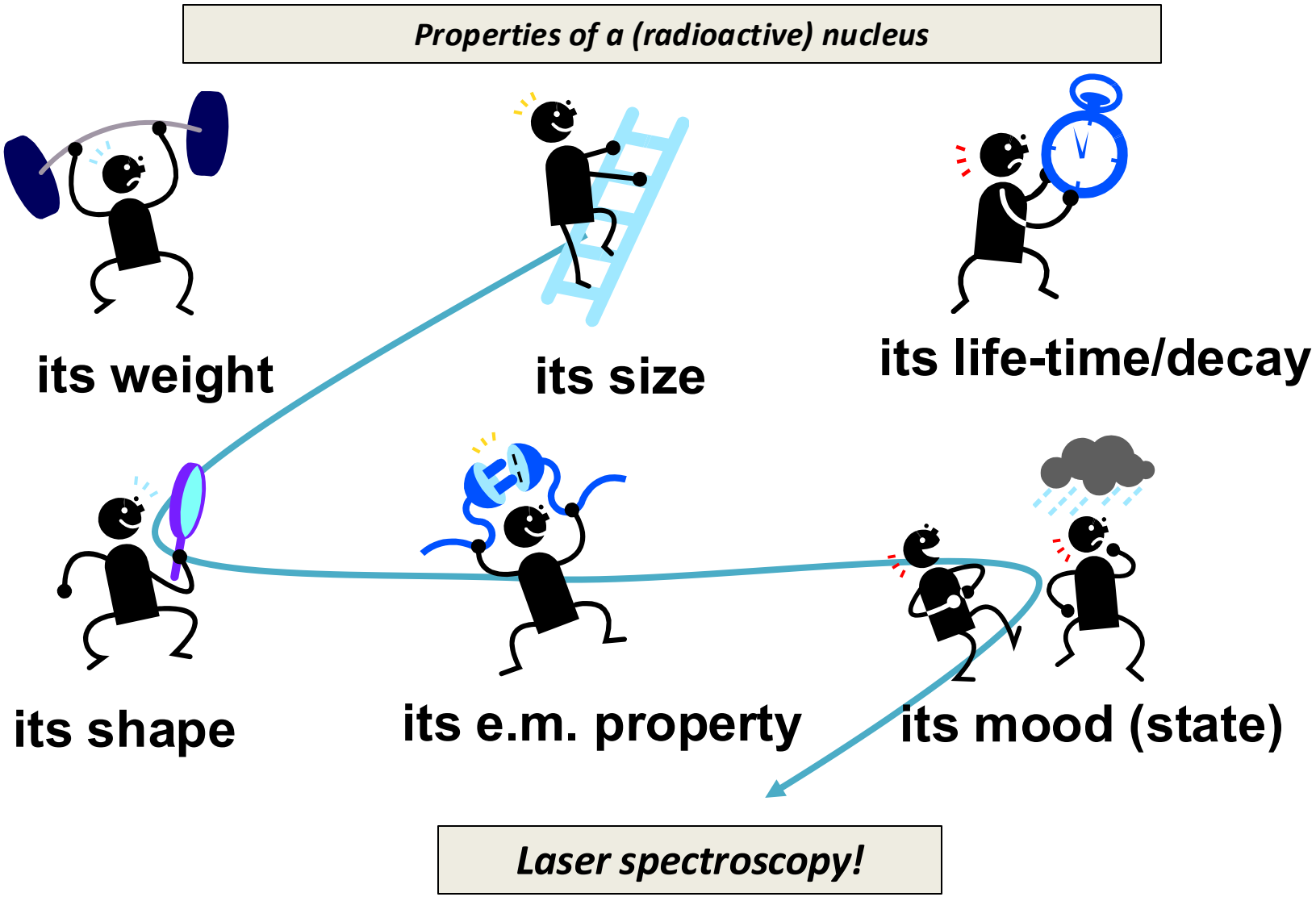
VS

Nuclear charge radius of K

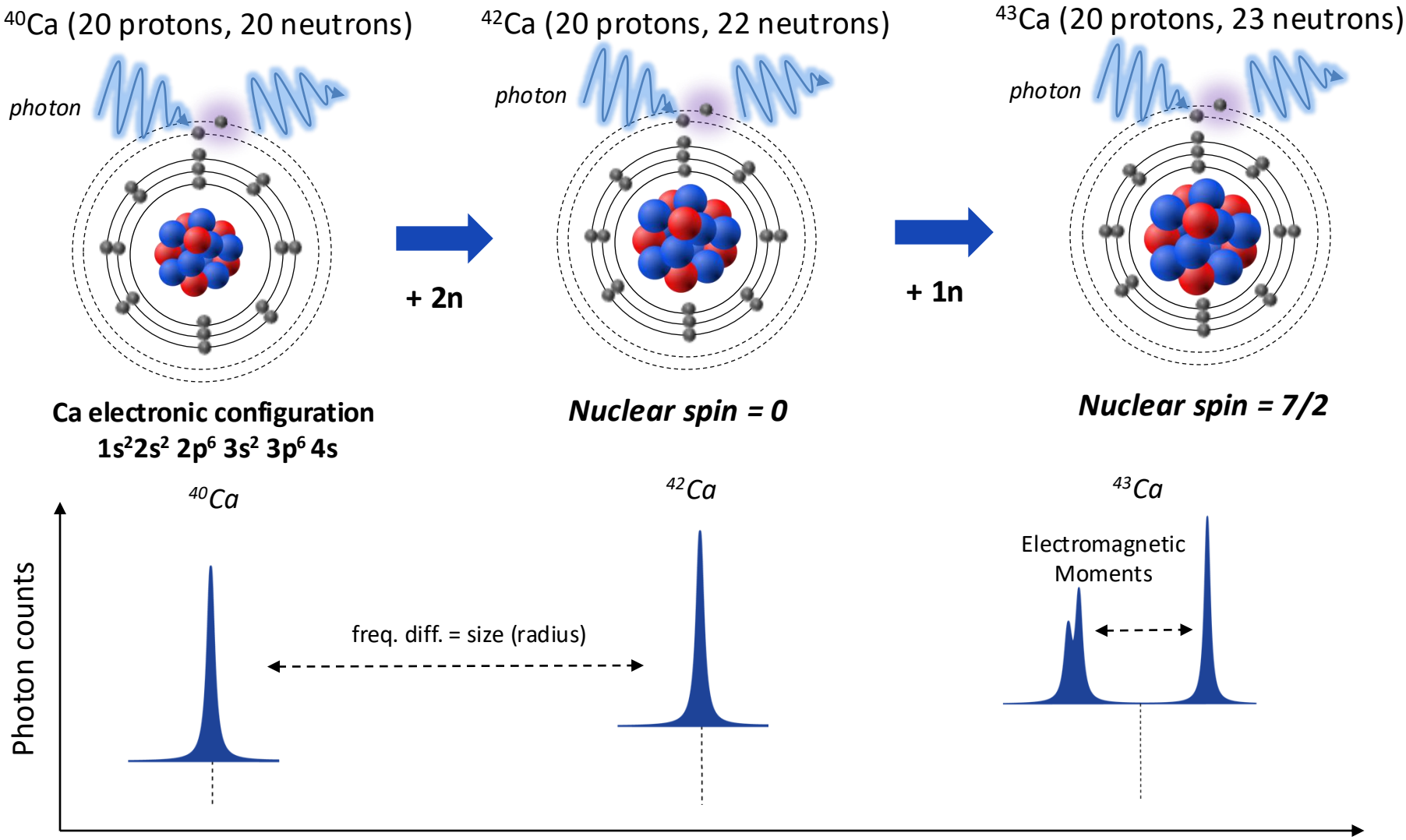


NO sign of a kink observed at 32 neutrons in K!

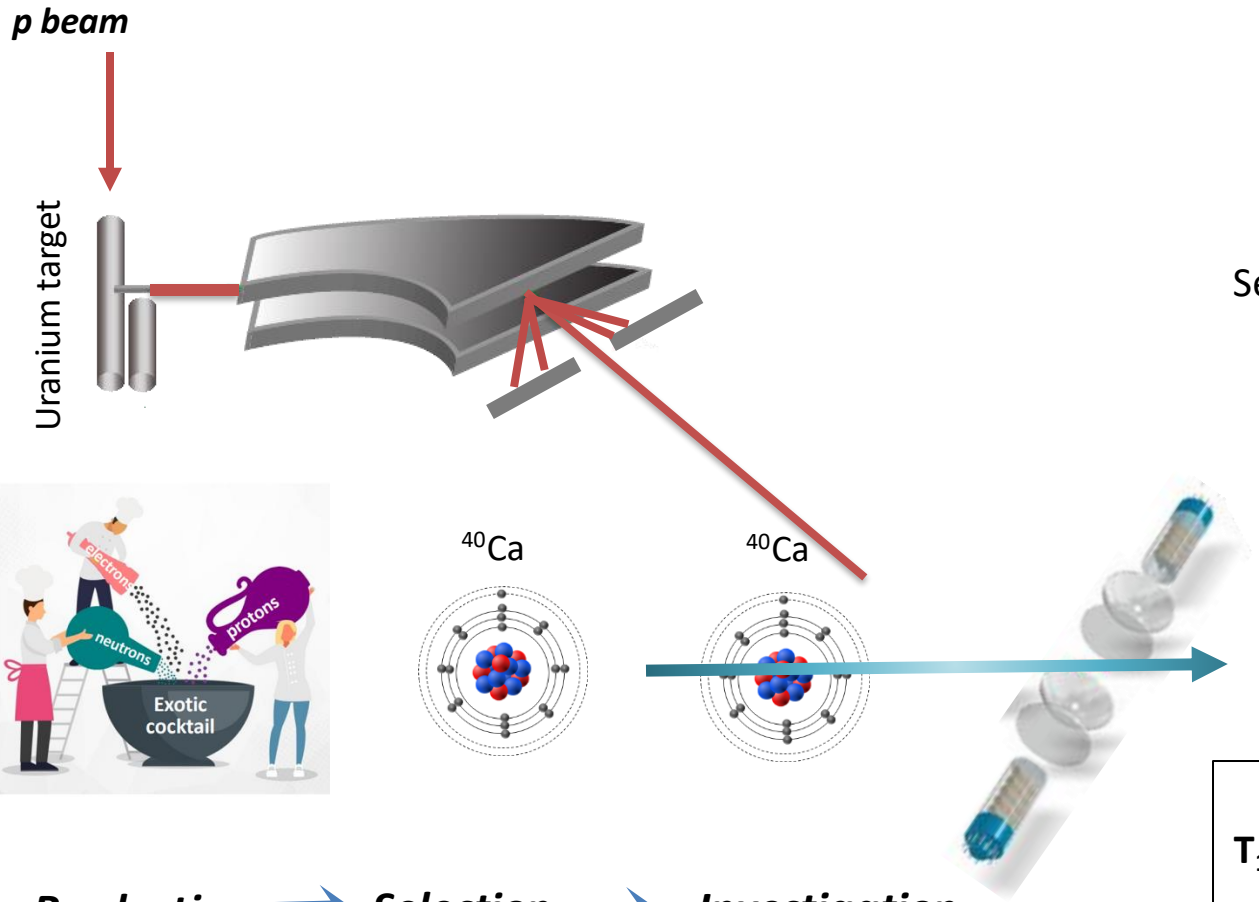
Laser spectroscopy and the atomic nucleus



Laser spectroscopy and the atomic nucleus



Experimental technique: The ROC technique



Conventional methods

Sensitivity limit of 1000 ions/s

Production → ***Selection*** → ***Investigation***

^{53}Ca	^{54}Ca
$T_{1/2}$: 461 ms	$T_{1/2}$: 90 ms
6 ions/s	1 ion/s

Need of a more sensitive technique: The **ROC** technique

Experimental technique: The ROC technique

CLS techniques to reach high-resolution and sensitivity

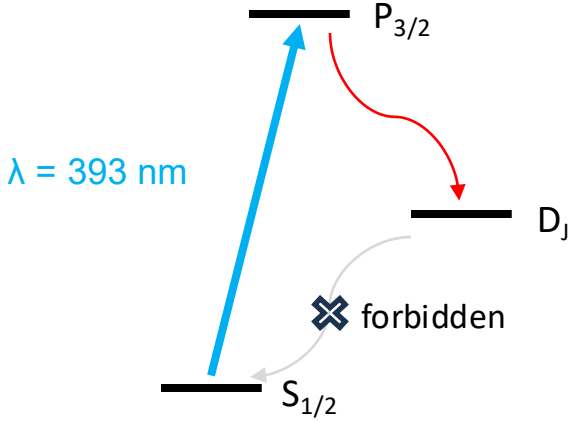
Radiation detection after **O**ptical pumping and state-selective **C**harge exchange **(ROC)**

Idea: Exploit electronic structure of Ca II

(1) Optical pumping

- Use laser to excite S - P transition

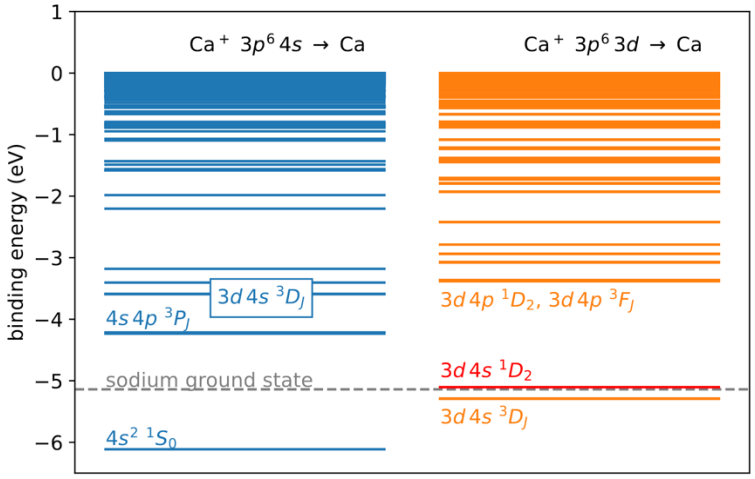
Relevant Ca^+ level scheme



If laser on resonance, electron will be permanently "pumped" to D-states

(2) State-Selective Charge Exchange

- Detect electronic state change to find out if laser was on resonance



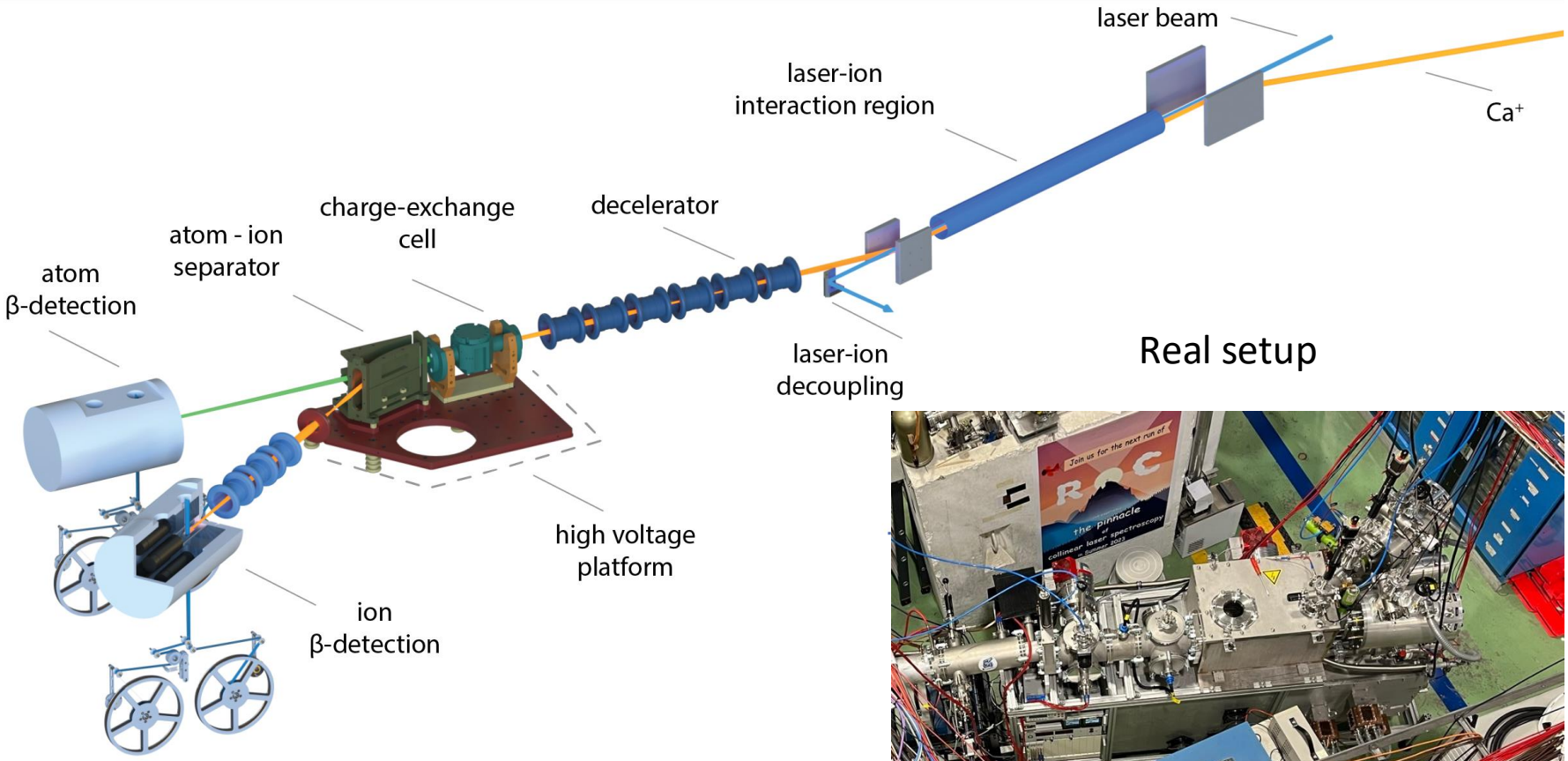
Charge exchange from Ca^+ *d*-state is "quasi-resonant" with the sodium ground state ($\Delta E \approx 0$)

(3) Radiation detection

Experimental technique: The ROC technique

CLS techniques to reach high-resolution and sensitivity

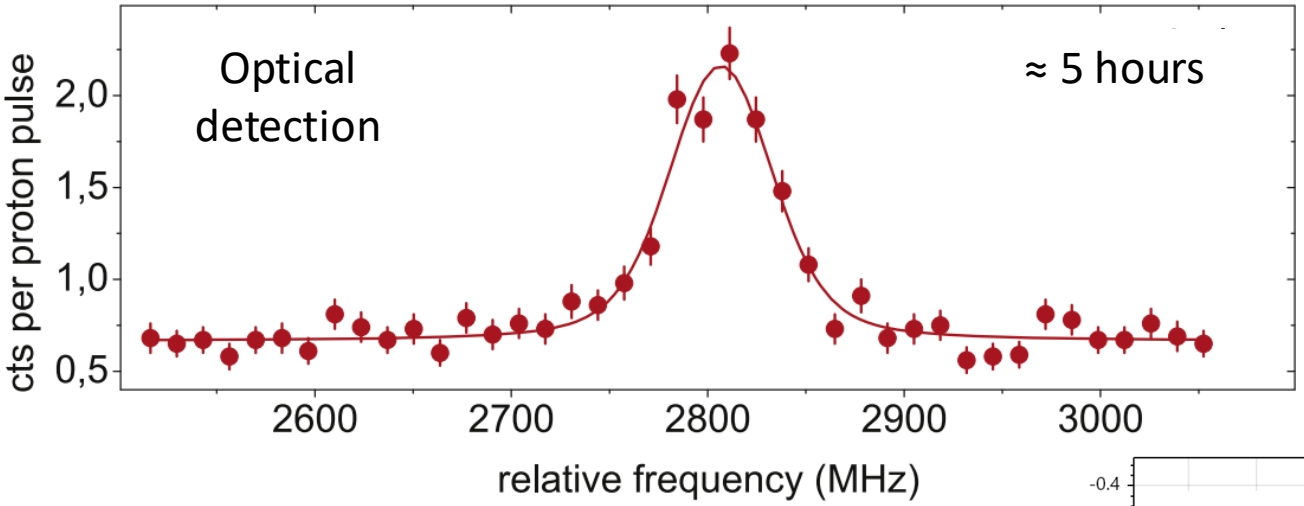
Radiation detection after **O**ptical pumping and state-selective **C**harge exchange **(ROC)**



Real setup

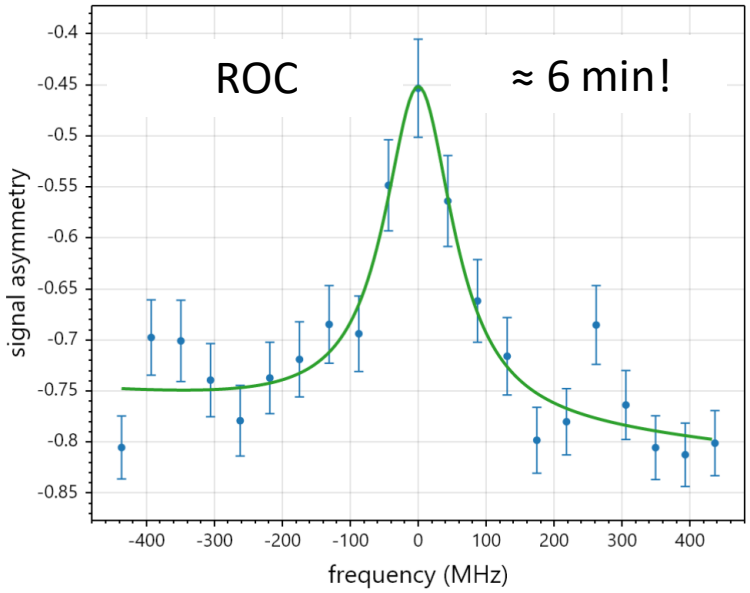
Results: Laser spectroscopy of exotic calcium isotopes

Sensitivity test – ^{52}Ca, produced at 200 ions/s



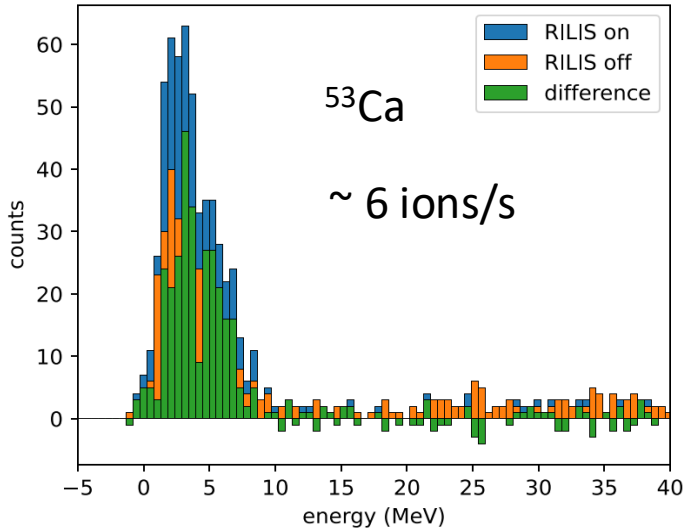
Very challenge for optical detection

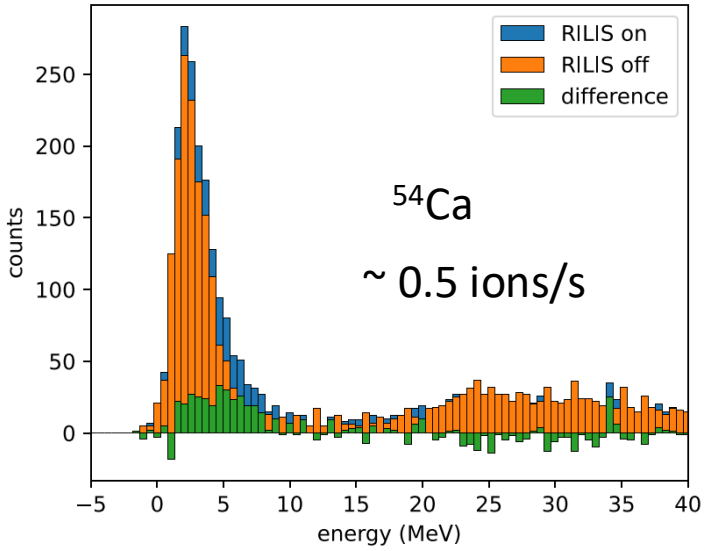
Done in minutes with ROC!

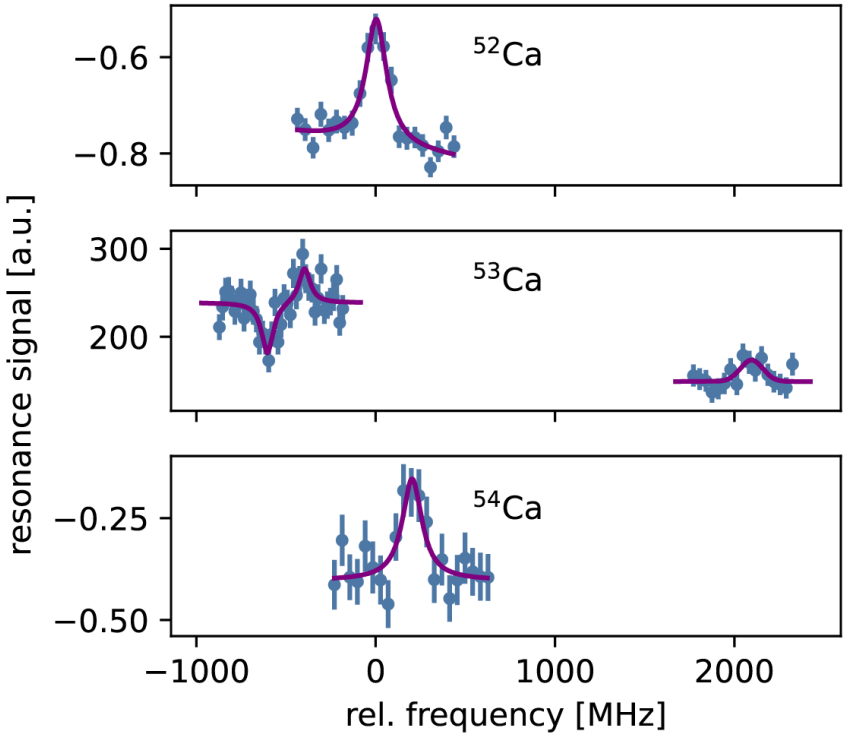


Results: Laser spectroscopy of exotic calcium isotopes

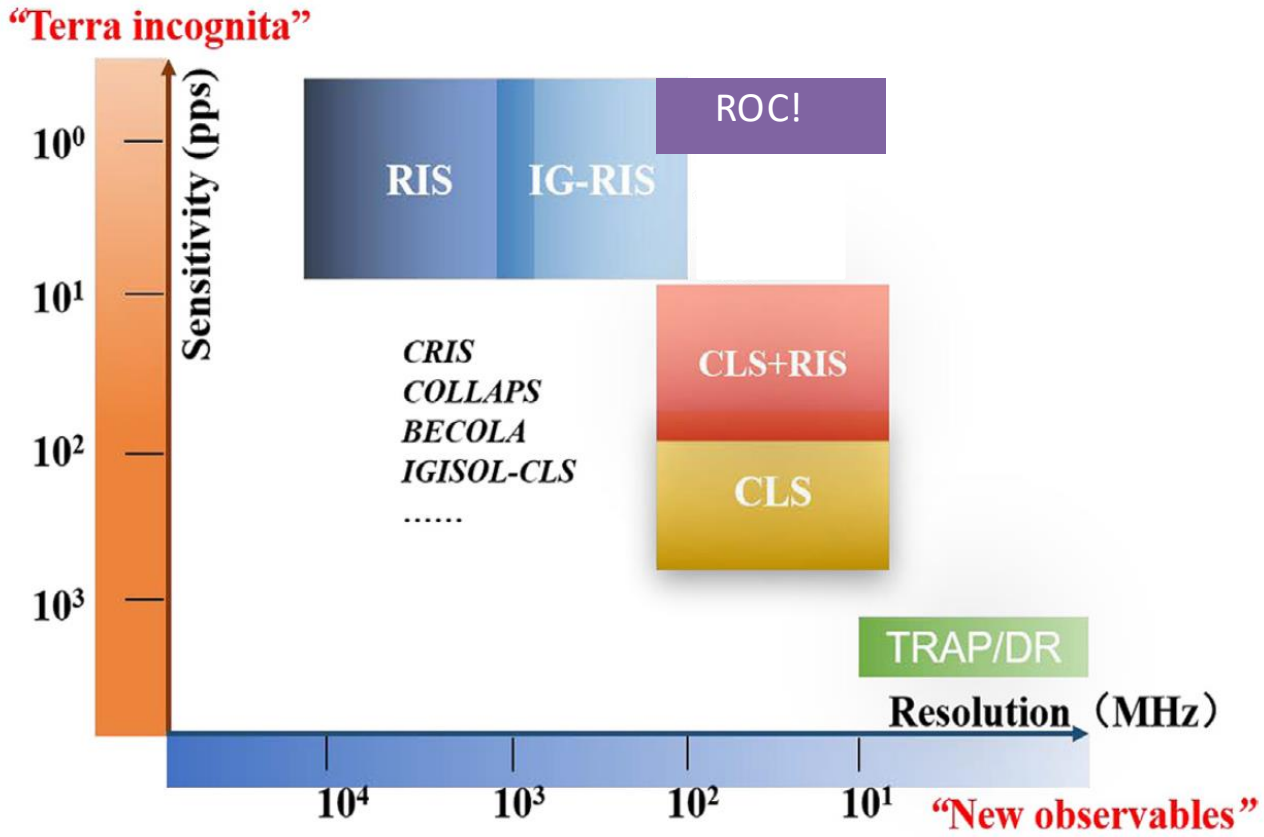
Example spectra of ^{53}Ca and ^{54}Ca with ROC





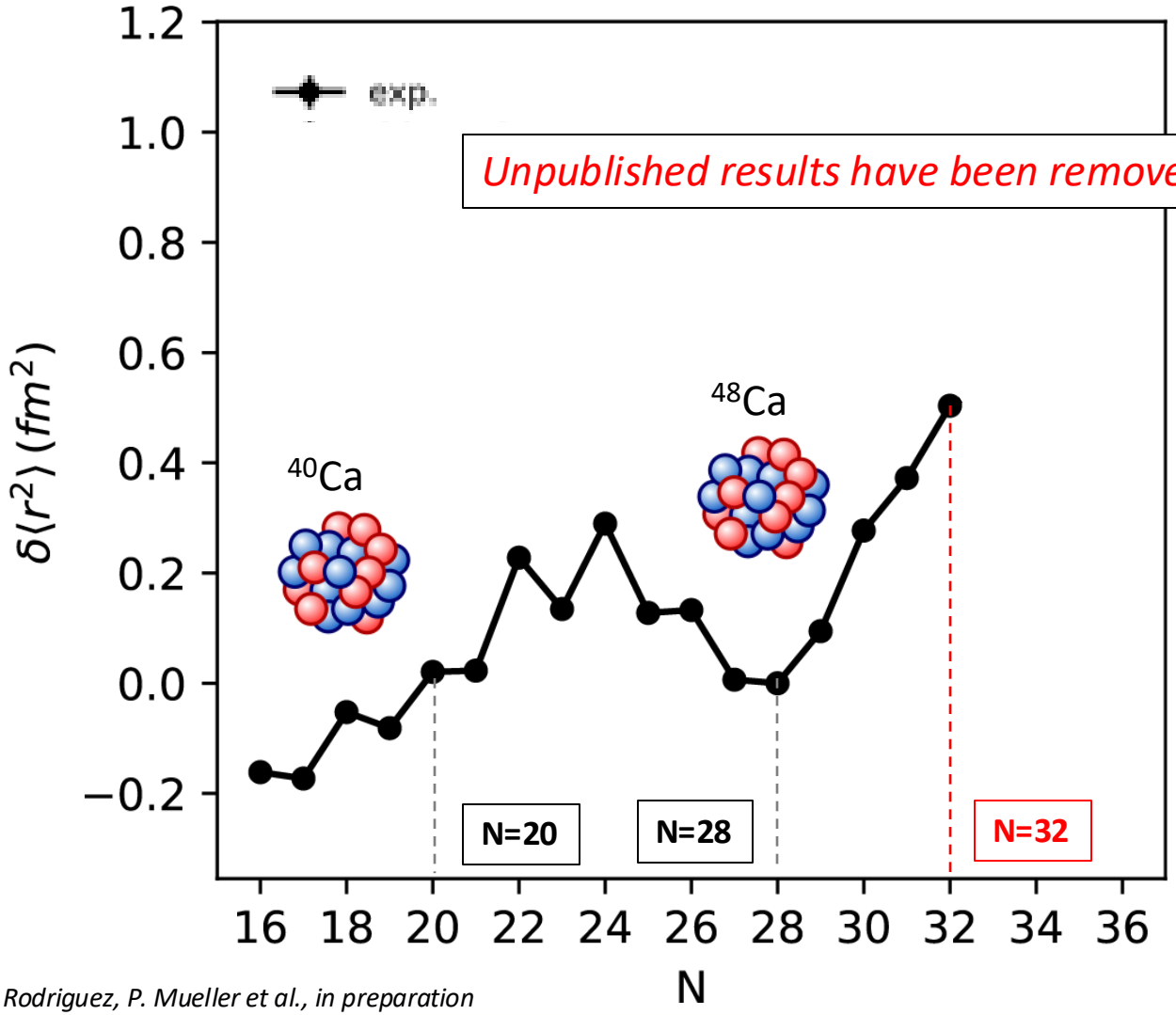


Record in sensitivity achieved for CLS experiments



Laser spectroscopy of exotic calcium isotopes: the *N=32* shell closure

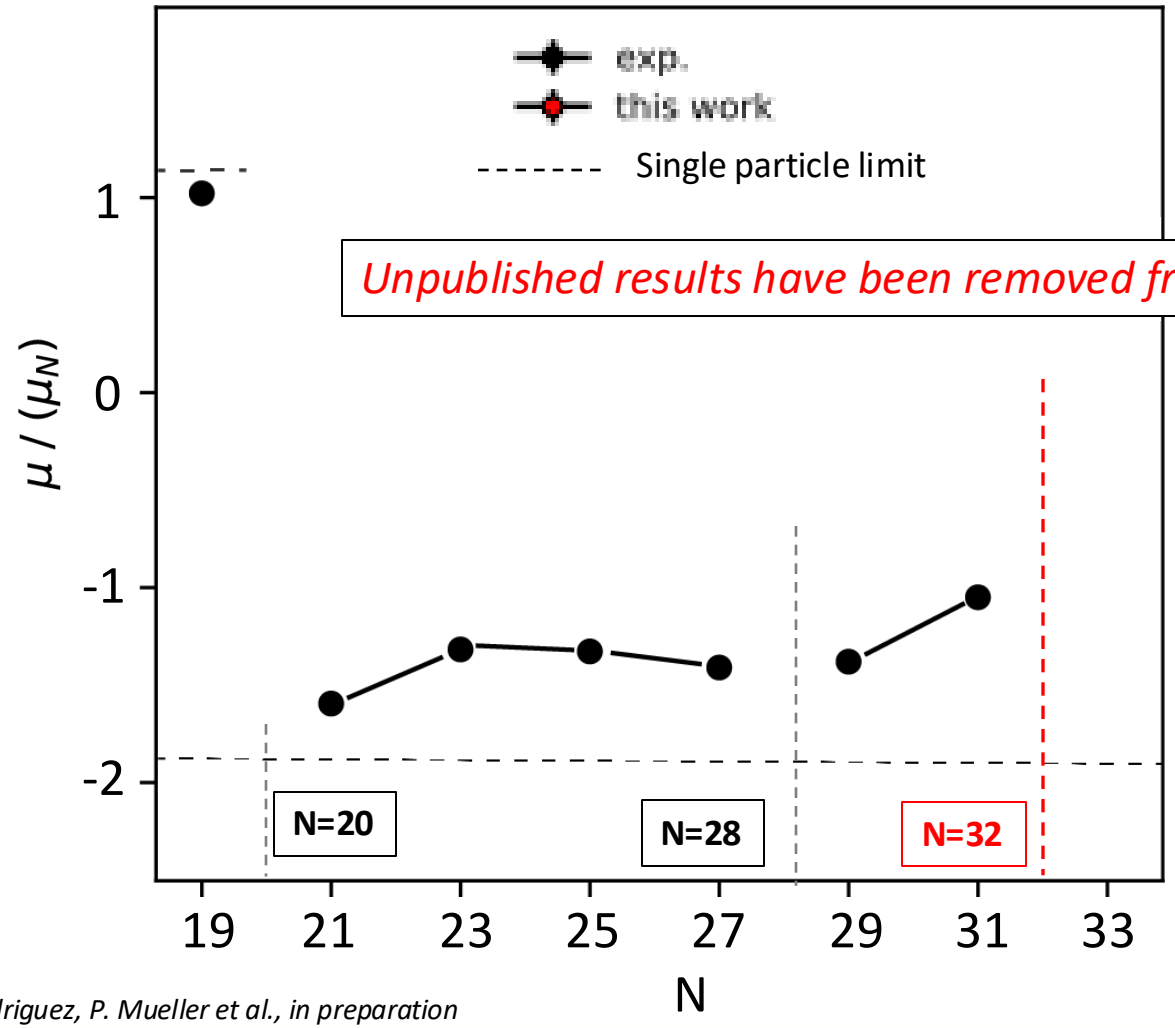
Charge radii of calcium isotopes



T. E. Lellinger, L. V. Rodriguez, P. Mueller et al., in preparation

Laser spectroscopy of exotic calcium isotopes: the *N=32* shell closure

Magnetic moments of calcium isotopes



Unpublished results have been removed from the plots

Single particle like system!

T. E. Lellinger, L. V. Rodriguez, P. Mueller et al., in preparation

Laser spectroscopy of exotic calcium isotopes: the *N=32* shell closure

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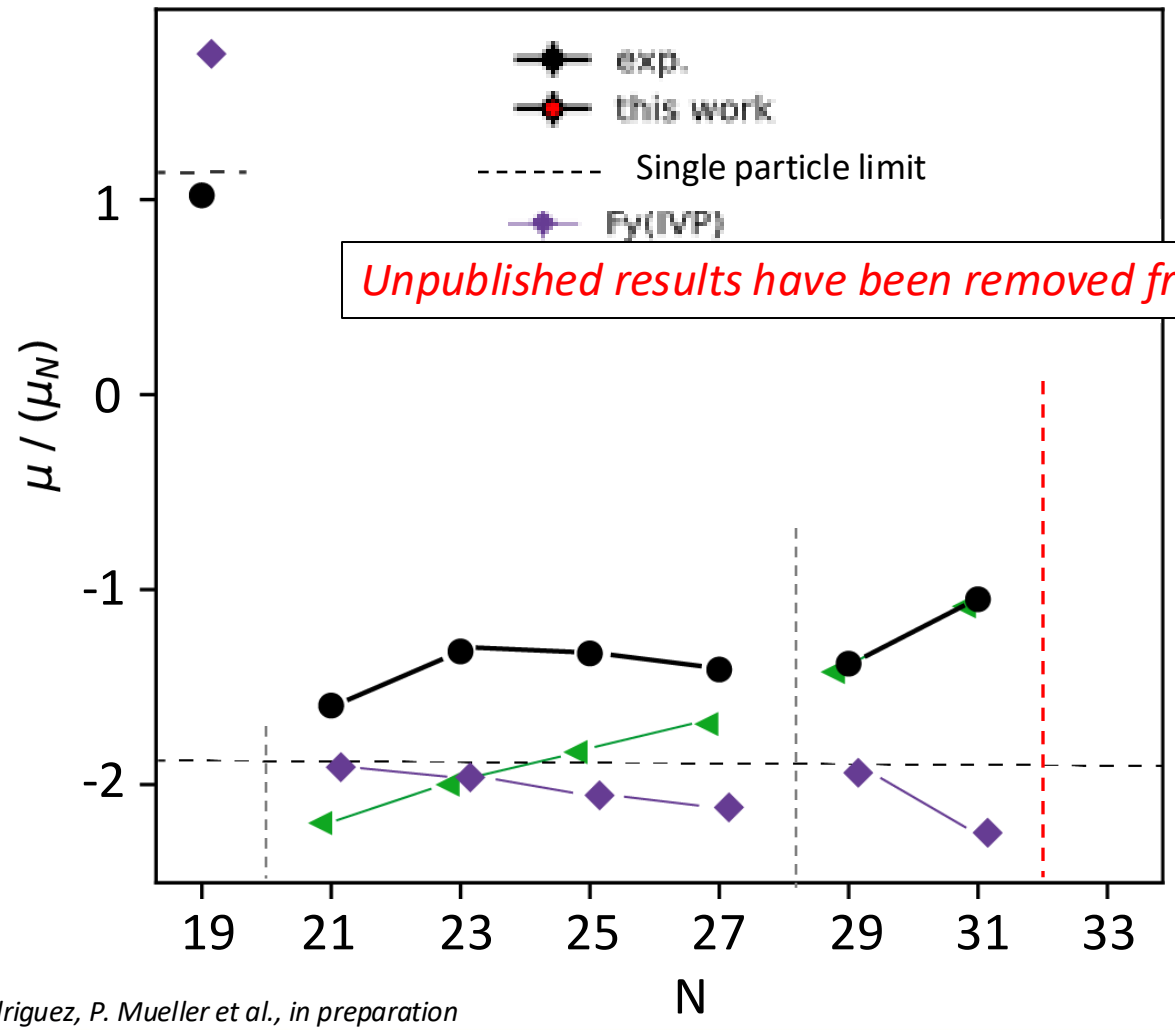

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Single particle like system!

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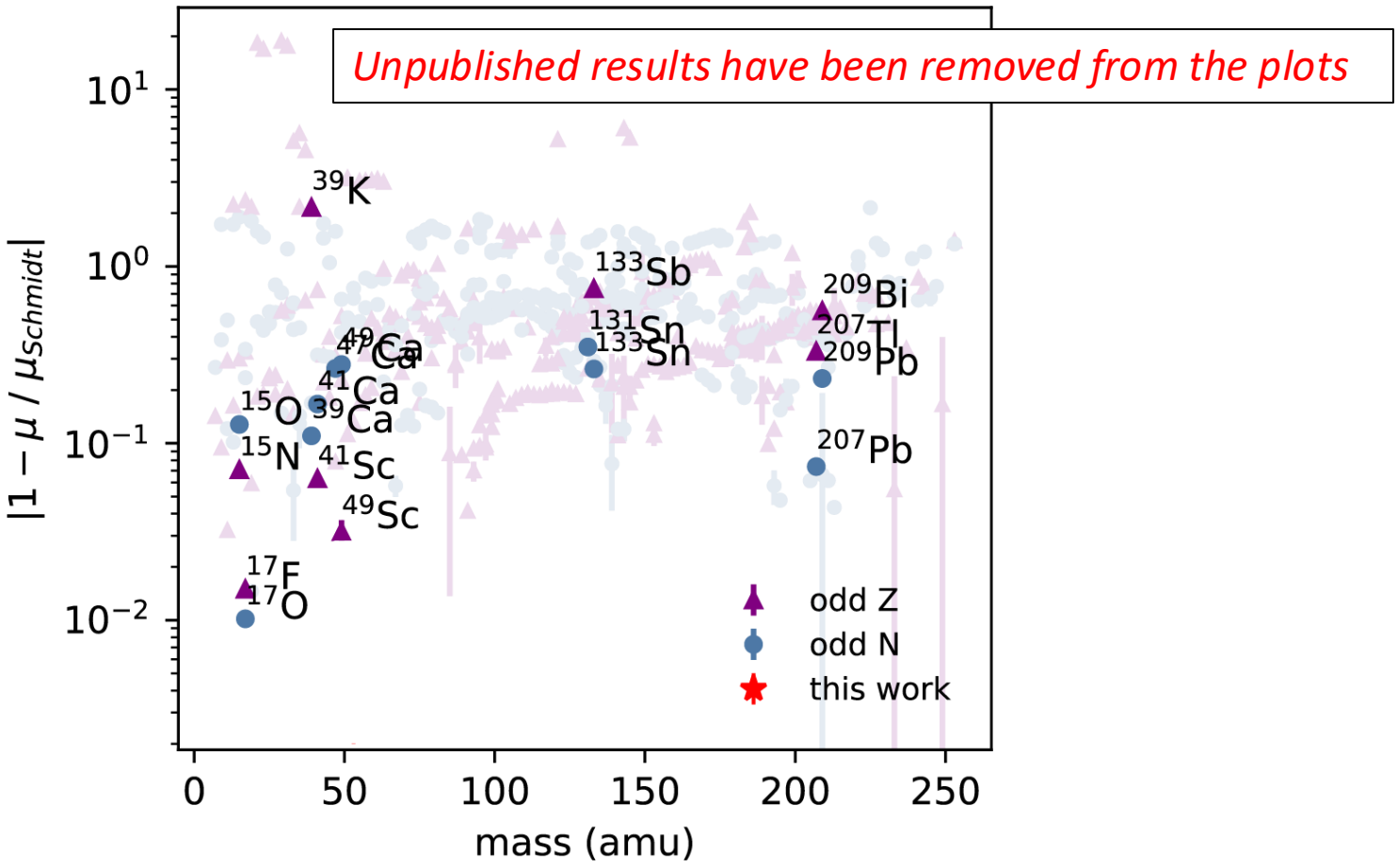
Magnetic moments of even-odd and odd-even isotopes compared to their single particle moments



^{53}Ca is as single particle like as ^{17}O!

T. E. Lellinger, L. V. Rodriguez, P. Mueller et al., in preparation

Accessing unexplored regions of the nuclear chart

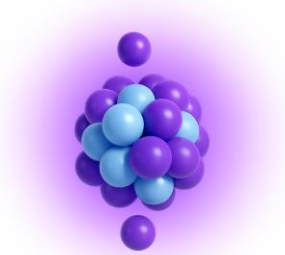
Exotic beam

- Proton and neutron halo nuclei

➡ view into the complex interactions of nuclear forces

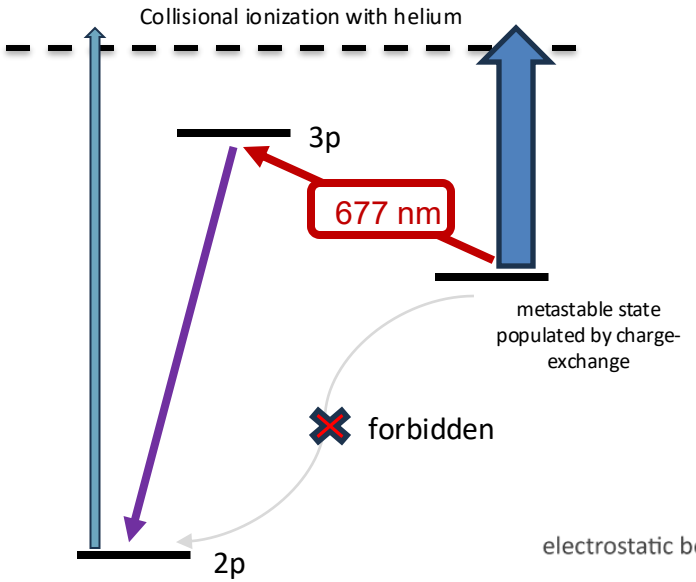
p halo nucleus

n halo nucleus



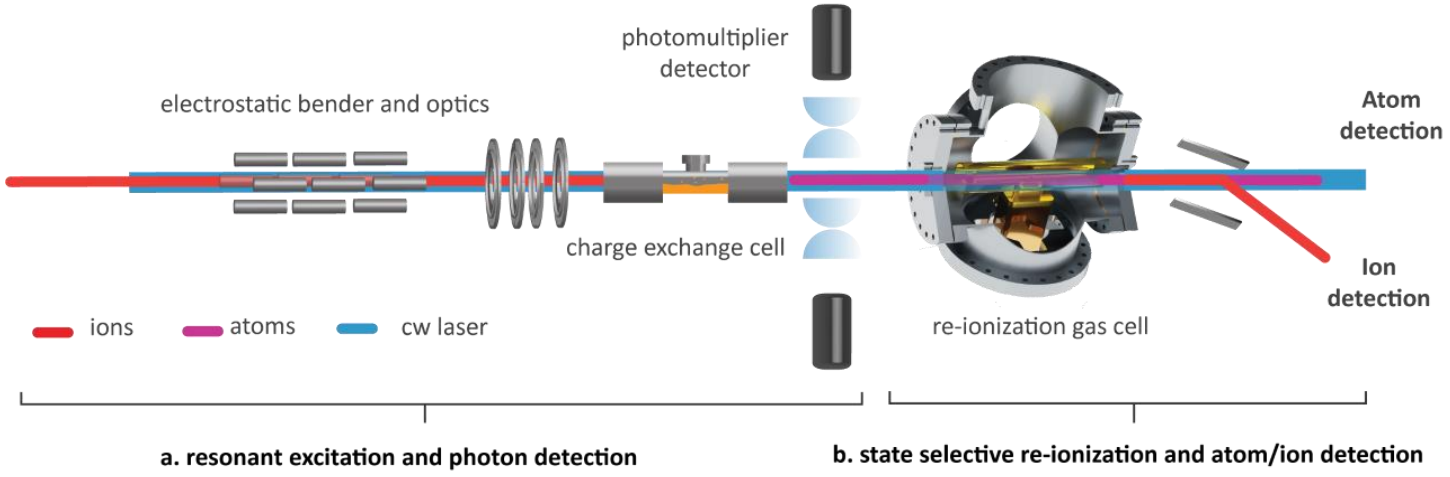
Implementation of ion counting/ radiation technique based on selective ionization continuous ionization (SSCI)

SSCI detection scheme



Challenge:

- Low bunching efficiency for light masses
- Fluorine forms molecules with everything



Recent developments towards the study of proton-halo nucleus ^{17}F

Real setup

Thank you for your attention

CERN

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Technische Universität Darmstadt

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Massachusetts Institute of Technology

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UNIVERSITY OF LIVERPOOL