KU LEUVEN

Muonic X-ray spectroscopy on implanted targets

Michael Heines

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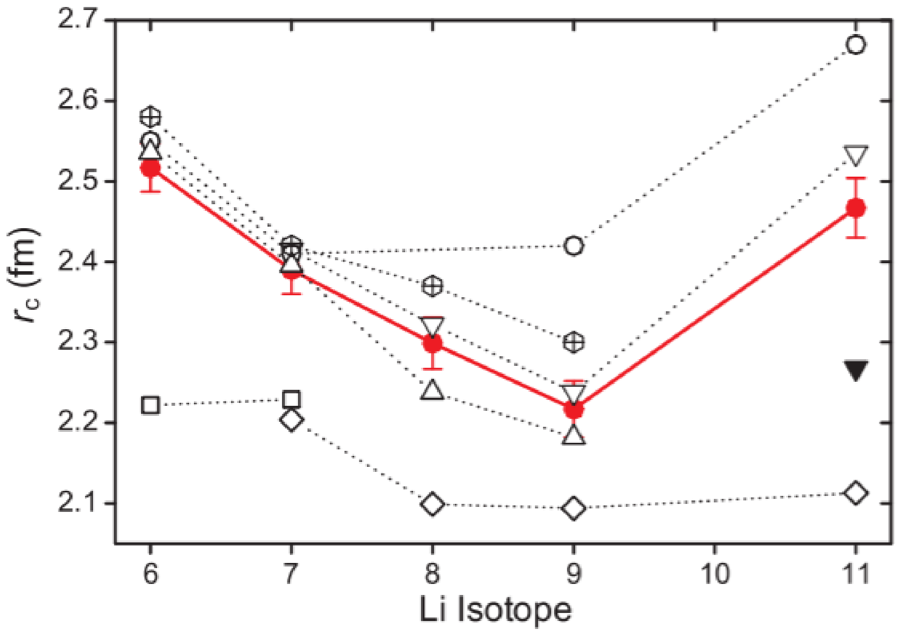
General framework

Charge radii for low-Z nuclei

- All low-Z elements from Z = 6 have been measured
- Changing number of neutrons affects charge radius
- Extreme cases
  - Halo nuclei
  - Shape staggering
- Laser spectroscopy



Sanchez, Rodolfo, et al. "Nuclear charge radii of Li 9, 11: The influence of halo neutrons." *Physical review letters* 96.3 (2006): 033002.

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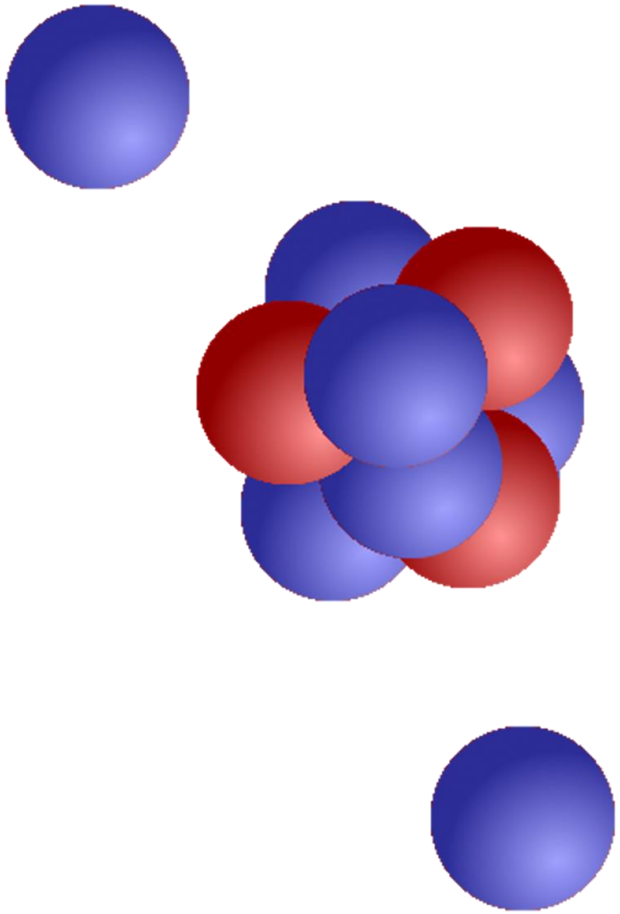

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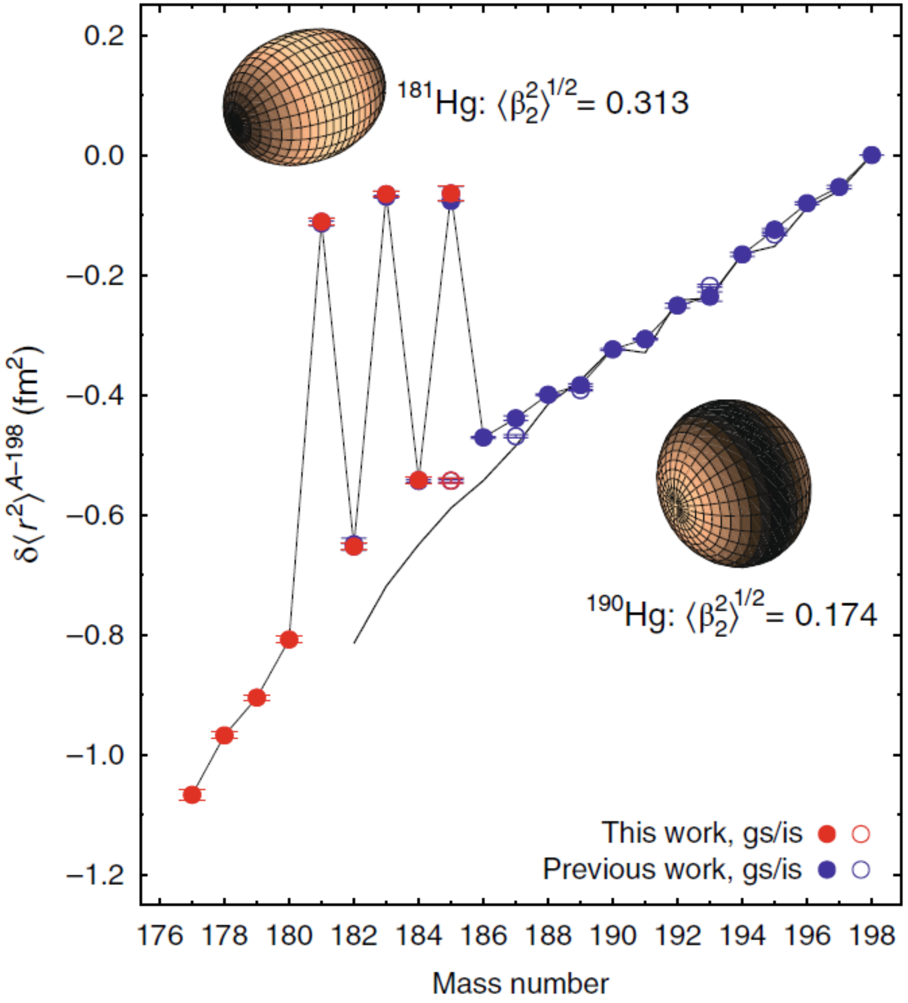

Marsh, B. A., et al. "Characterization of the shape-staggering effect in mercury nuclei." *Nature Physics* 14.12 (2018): 1163-1167.

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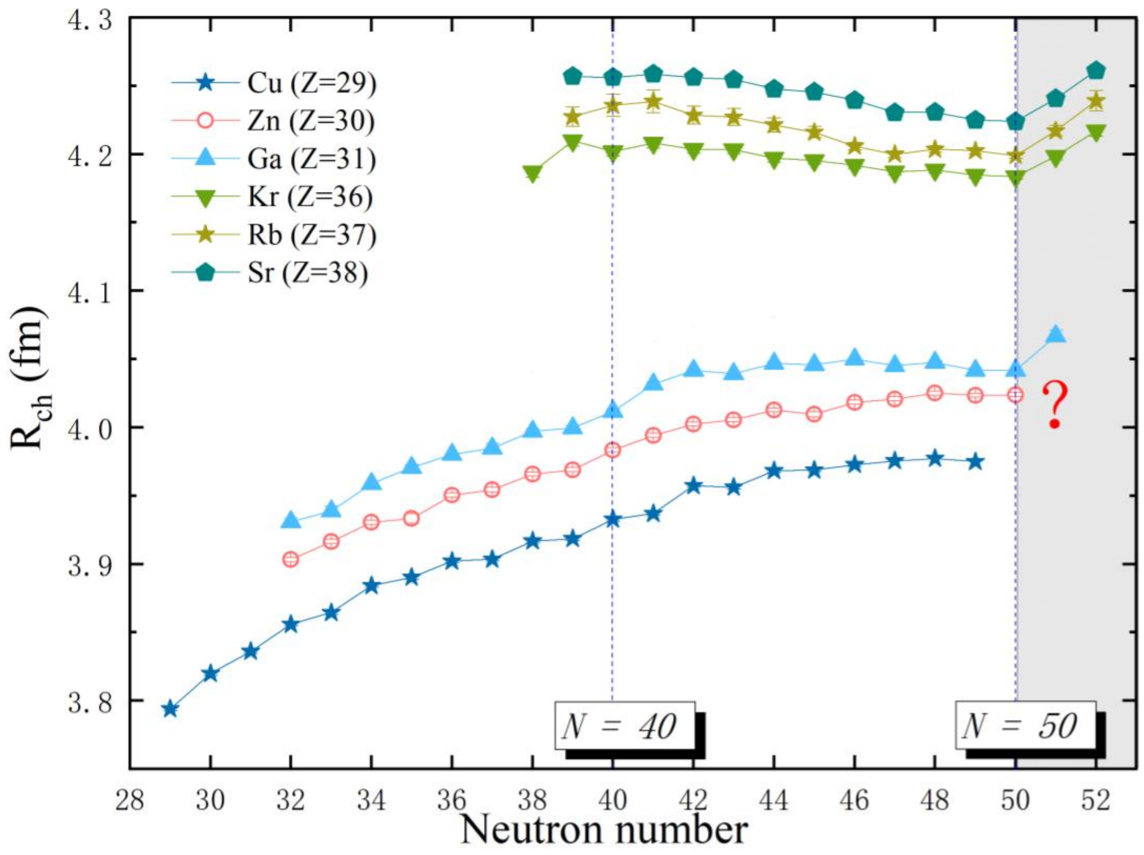
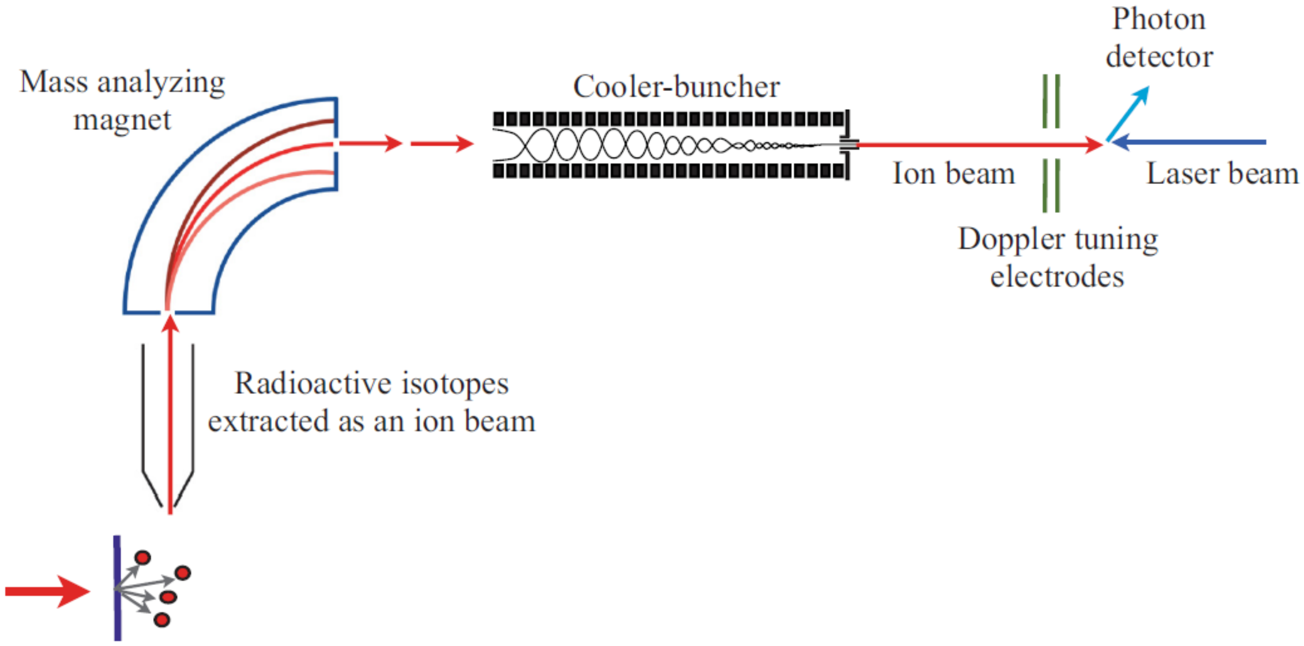


Yang, Xiaofei, Thomas Cocolios, and Sarina Geldhof. *Probing the magicity and shell evolution in the vicinity of N= 50 with high-resolution laser spectroscopy of ^{81,82}Zn isotopes*. No. CERN-INTC-2020-064. 2020.

Laser Spectroscopy

- Isotopic shift
  - Mass shift → effective mass
  - Field shift → charge distribution

- Collinear resonance ionization spectroscopy (CRIS)
  - Produce isotopes
  - Mass separate
  - Trap
  - Doppler tune



Cheal, B., Thomas Elias Cocolios, and S. Fritzsche. "Laser spectroscopy of radioactive isotopes: Role and limitations of accurate isotope-shift calculations." *Physical Review A* 86.4 (2012): 042501.

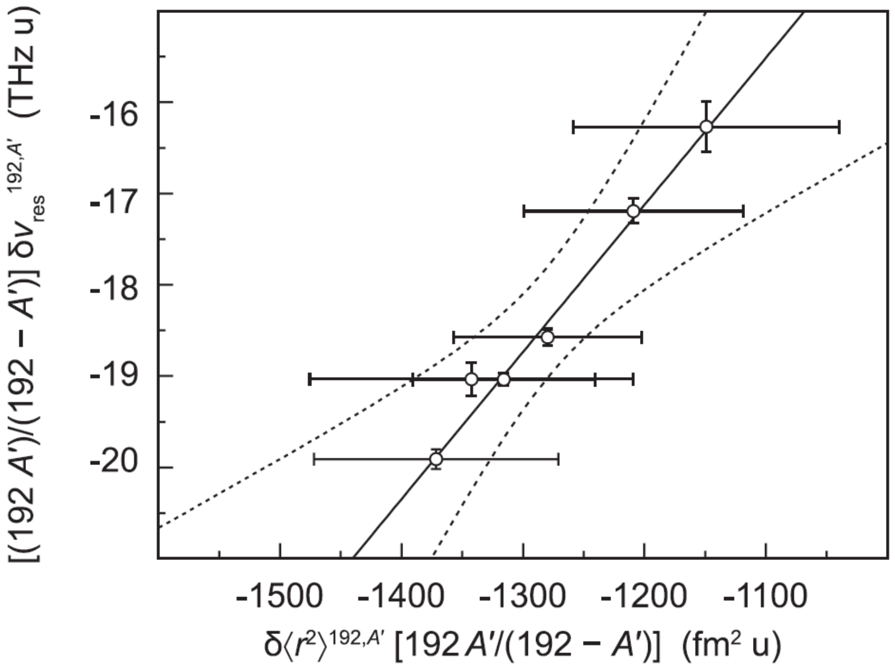
King plot method

$$\delta\nu_i^{A,A'} = M_i \frac{A' - A}{A\,A'} + F_i\,\delta\langle r^2\rangle^{A,A'}$$

$$\Rightarrow \left(\frac{AA'}{A' - A}\,\delta\nu_i^{A,A'}\right) = M_i + F_i\left(\frac{AA'}{A' - A}\delta\langle r^2\rangle^{A,A'}\right)$$

$$\Rightarrow \left(\frac{AA'}{A' - A}\,\delta\nu_j^{A,A'}\right) = \frac{F_j}{F_i}\left(\frac{AA'}{A' - A}\,\delta\nu_i^{A,A'}\right) + M_j - \frac{F_j}{F_i}M_i$$

- Slope and intercept provide information on atomic parameters



Kellerbauer, Alban, et al. "Isotope shift of the electric-dipole transition in Os−." *Physical Review A* 84.6 (2011): 062510.

King plot method

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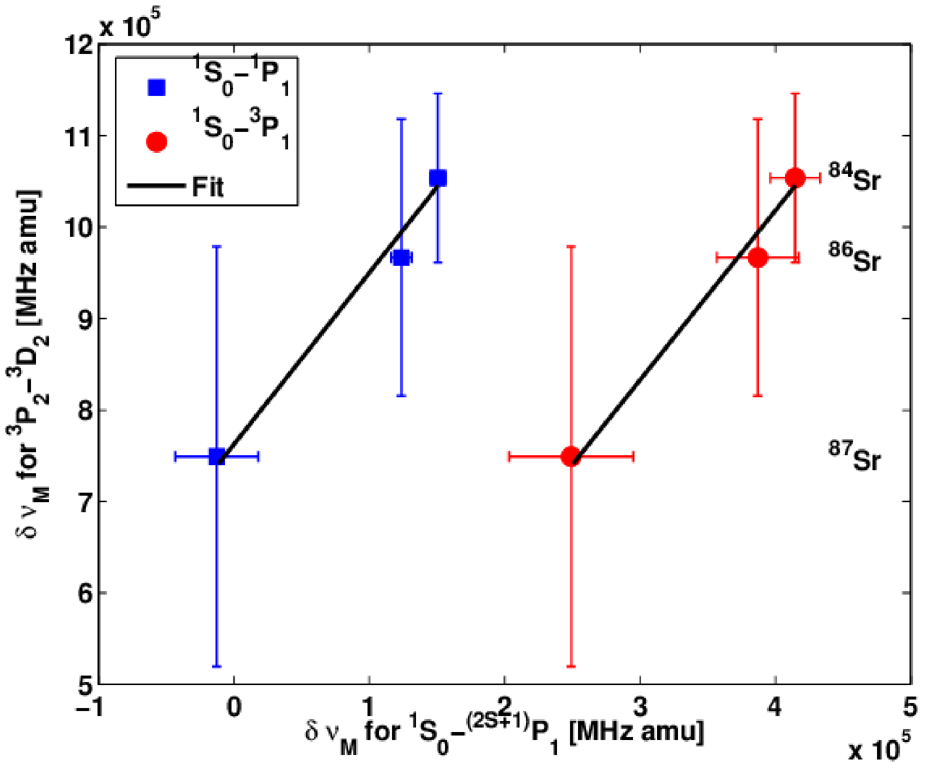
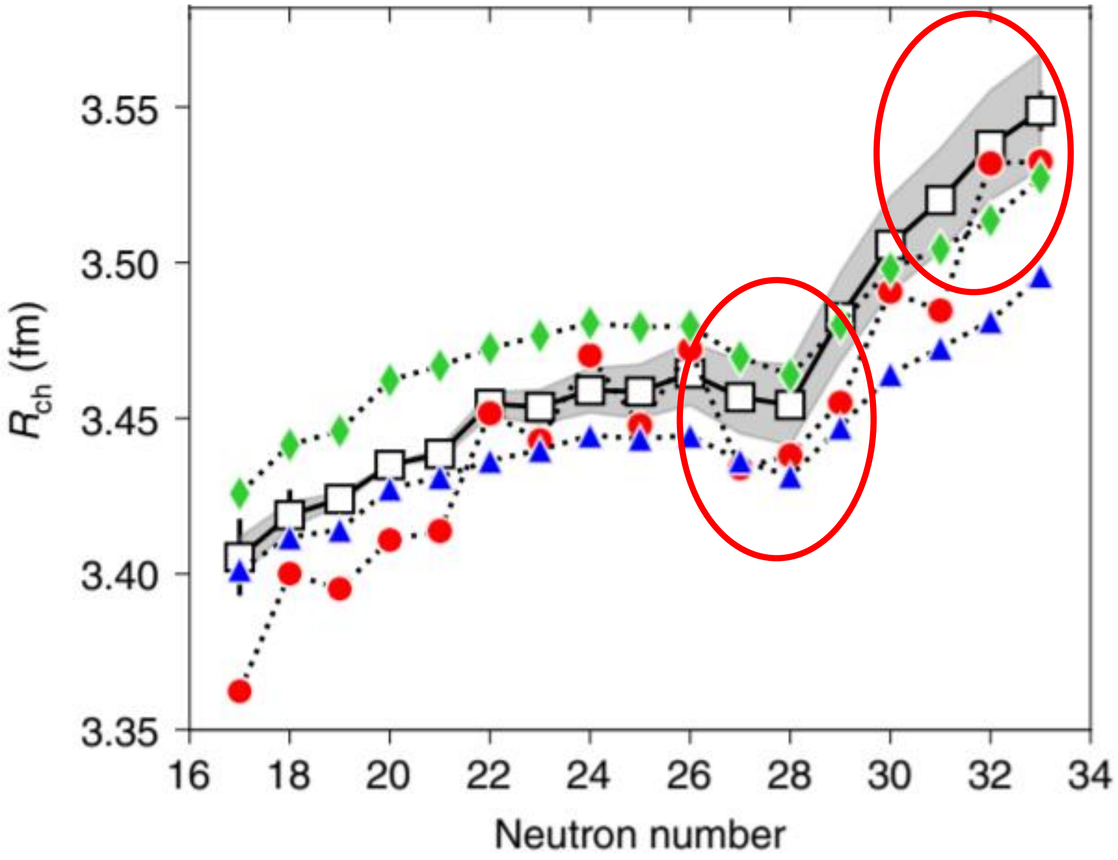


Mickelson, P. G., et al. "Repumping and spectroscopy of laser-cooled Sr atoms using the (5s5p) 3P2–(5s4d) 3D2 transition." *Journal of Physics B: Atomic, Molecular and Optical Physics* 42.23 (2009): 235001.

The problem with odd-Z nuclei

- Three stable isotopes
- Not for odd-Z nuclei
- Systematic effect dominates the statistical uncertainty
- Half-lives down to 20 years

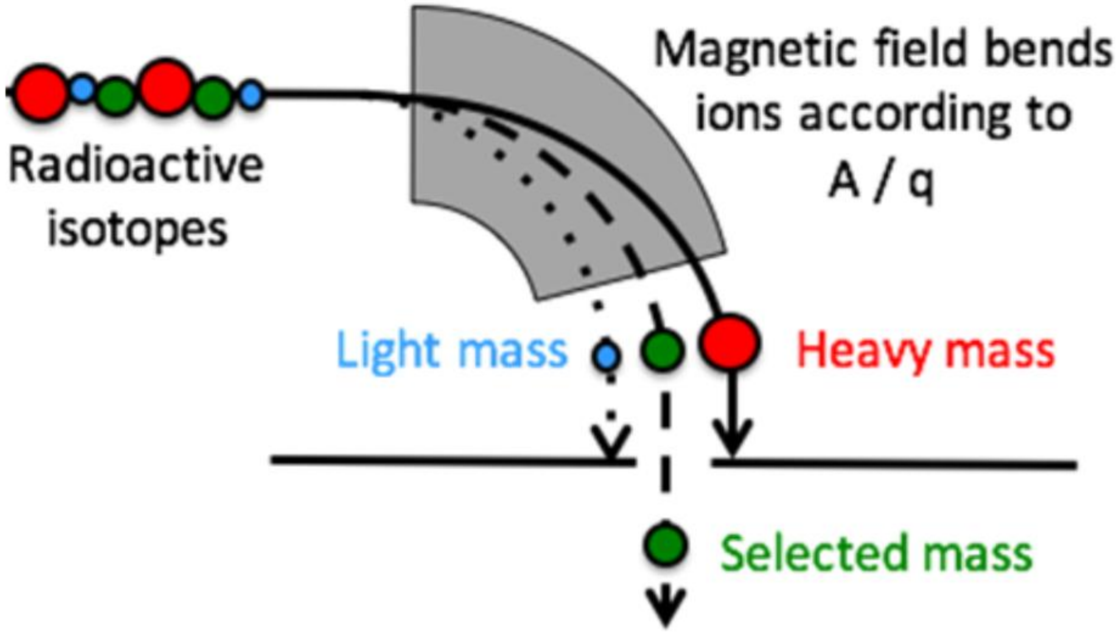


Koszorús, Á., et al. "Charge radii of exotic potassium isotopes challenge nuclear theory and the magic character of N= 32." *Nature Physics* 17.4 (2021): 439-443.

MuX on implanted targets

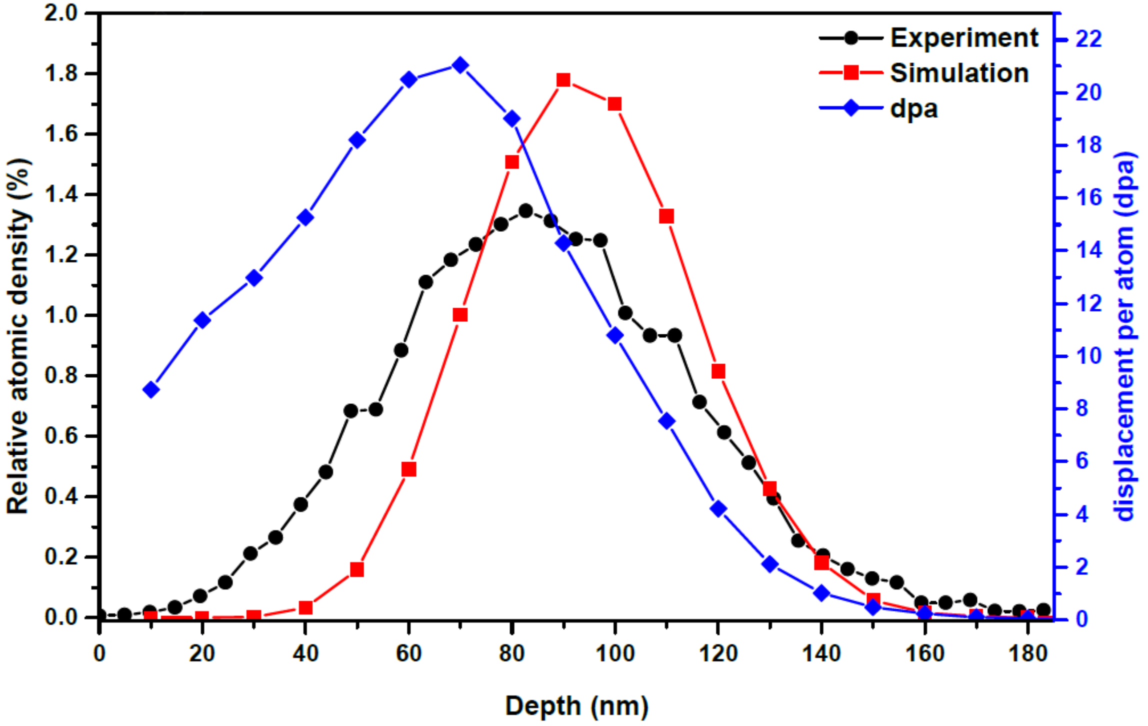
Why do we need implanted targets?

- Mass separation
  - Elemental purity
  - Isotopic purity
- Protecting the sample
  - Physical
  - Chemical
  - Thermodynamic
  - Sputtering
- Glassy carbon



Depth profile with SRIM

- Simulate depth profile using SRIM software
- No guarantee for accuracy
- Experiments vs Simulation
  - Sigradur G → Straggling underesitmated
  - Sigradur K → Better?

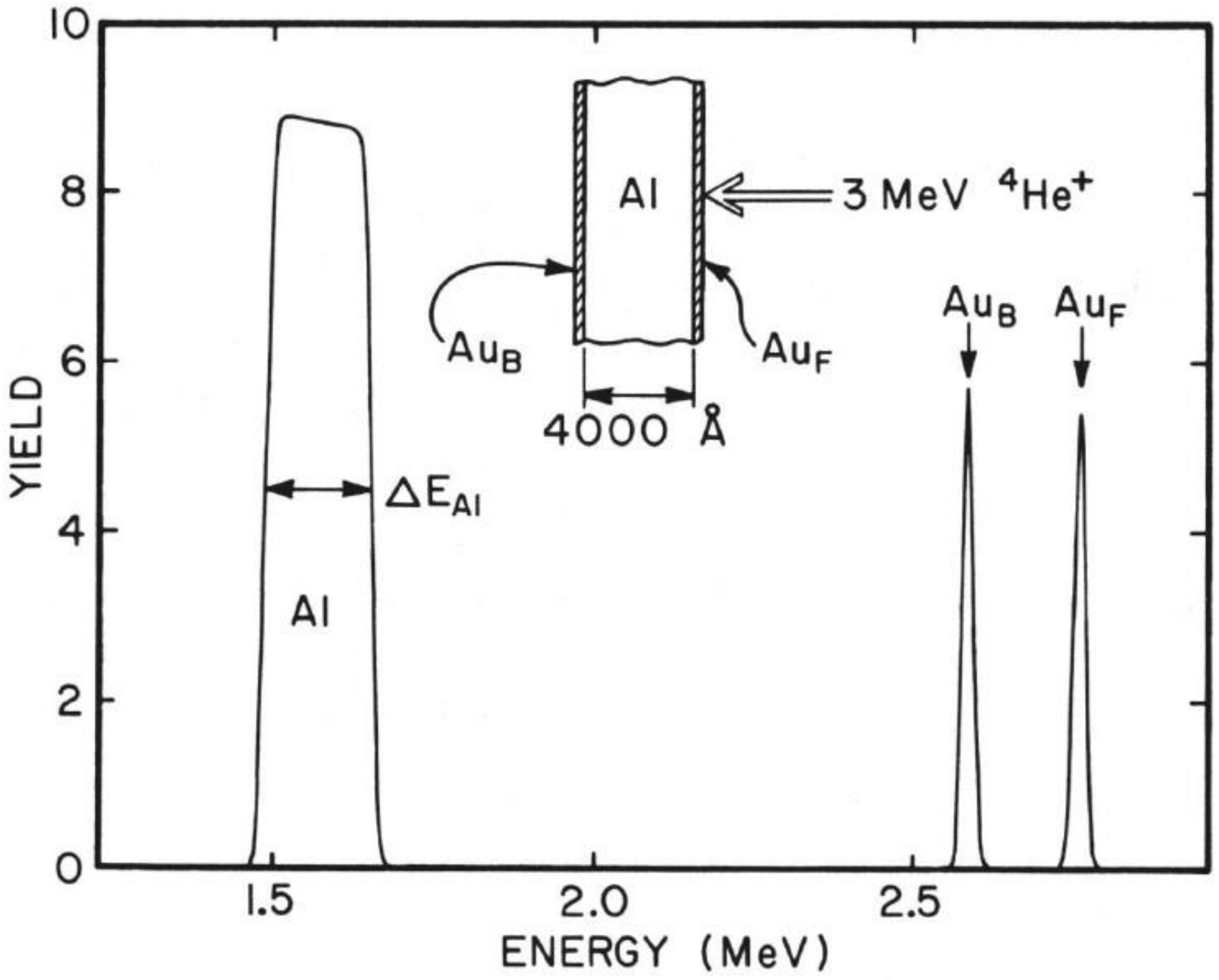


Adeojo, S. A., et al. "Effect of sequential isochronal annealing on the structure and migration behaviour of selenium-ion implanted in glassy carbon." *Vacuum* 182 (2020): 109689.

Depth profile with RBS

- Rutherford backscattering spectrometry (RBS)
  - Composition
  - Density

- Using software → Complete depth profile



Planned measurements

Gold targets

- Different depths of ^{197}Au
- Earlier tests: 30% of muons passes through 100 nm graphite layer
- Implantation
  - IMBL KU Leuven
  - RADIATE
- Aim for 50-100 µg implanted
- Self sputtering

Desired depth (nm)	Approximate energy (keV)	Approximate straggling (nm)
5	0.9	0.9
10	4.5	1.8
25	27	3.9
50	90	6.9
100	250	12.1

Potassium targets

- Different depths of ^{39}K
- Less sputtering expected
- More reactive than ^{197}Au
- If possible
  - ^{40}K → Unlikely in 2022
  - ^{41}K

Desired depth (nm)	Approximate energy (keV)	Approximate straggling (nm)
5	1.6	1.7
10	5	3.1
25	17	6.8
50	40	12.3
100	80	20.5

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Questions