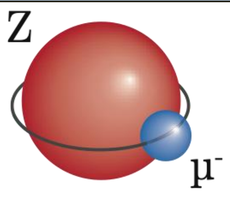
Muonic X-ray Spectroscopy on Implanted Targets

Michael Heines[1], Luke Antwis[2], Bart Caerts[1], Thomas E. Cocolios[1], Lino Da Costa Pereira[1], Stefan Eisenwinder[3], Julian Fletcher[2], Tom Kieck[4], Andreas Knecht[5], André Vantomme[1], Stergiani M. Vogiatzi[5,6], Katharina von Schoeler[5,6], Frederik Wauters[7], Roger Webb[2], Qiang Zhao[1], and the muX collaboration

[1] KU Leuven, [2] Surrey Ion Beam Centre, [3] HZDR, [4] GSI, [5] PSI, [6] ETH Zürich, [7] JGU Mainz

michael.heines@kuleuven.be

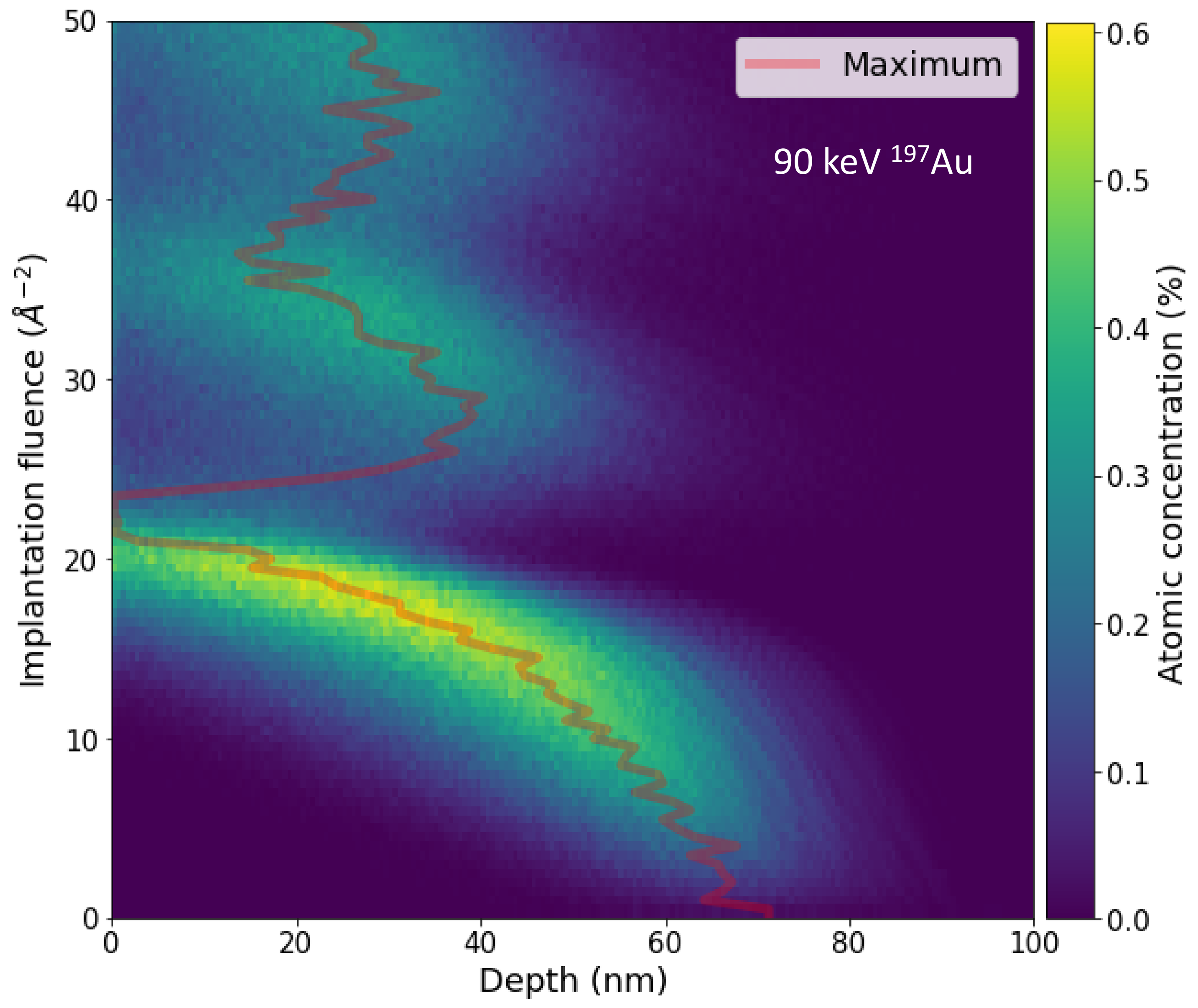
Background



Muonic X-ray spectroscopy:

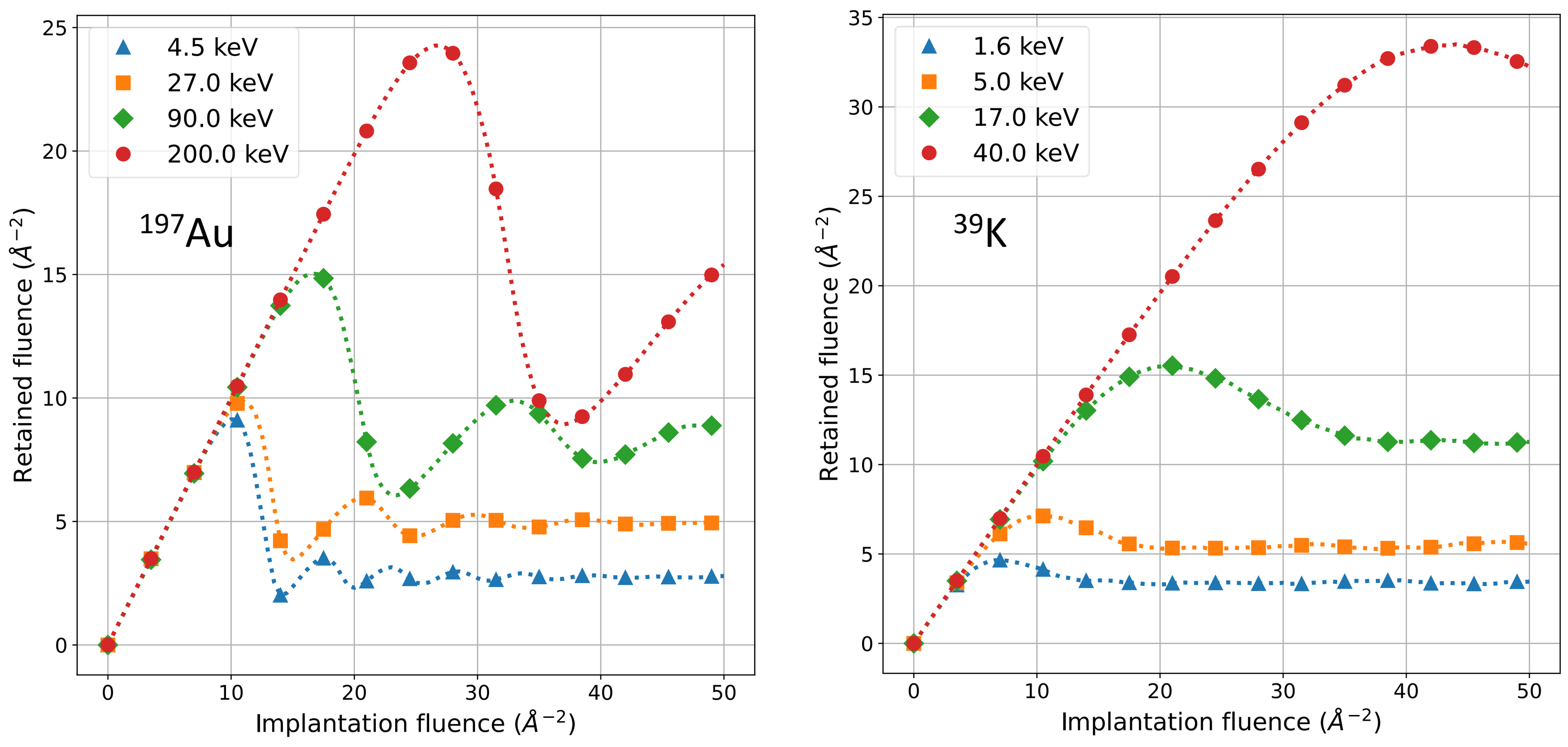
- Measure X-ray cascade in a muonic atom to investigate properties of the nucleus
- Muon mass much larger than electron mass ($m_\mu \approx 207\ m_e$) → Increased sensitivity to nuclear effects (10^7 times more to the charge radius)
- High-energy X-rays (up to 10 MeV)
- Using transfer reactions in high-pressure hydrogen cell → Measure target quantities down to a few micrograms [1]
- Measure radioactive isotopes if sufficiently long-lived (> 20 years) and isotopically pure (> 99 %)

Aim of this work: Show the feasibility of muX on implanted targets with the purpose of benchmarking the isotope measurements of laser spectroscopy.



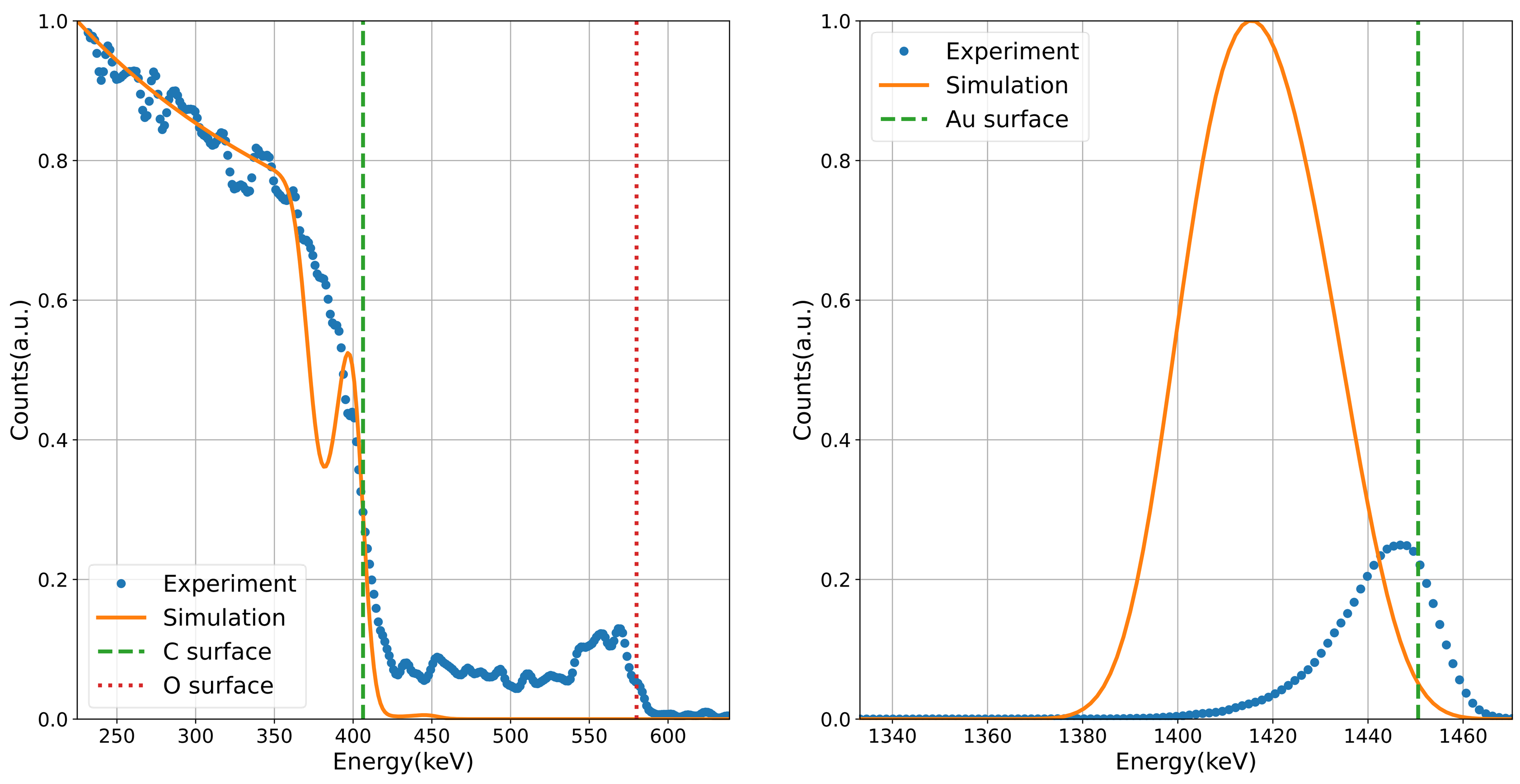
Changing depth profile as a function of fluence calculated with TRIDYN for Au-197 at 90.0 keV. The maximum of the distribution at each fluence is marked in red.

Sample preparation



TRIDYN simulations on the retained fluence as a function of implantation fluence for gold (left) and potassium (right).

- TRIDYN [2] simulations of high-fluence self-sputter limits in glassy carbon
- Exotic oscillatory behavior predicted near the self-sputter limits, similar to that observed experimentally in [3]
- Implantation through RADIATE at HZDR Dresden and Surrey Ion Beam Centre
- Performed RBS → Underestimation of the amount of sputtering, most likely due to the porous nature of glassy carbon

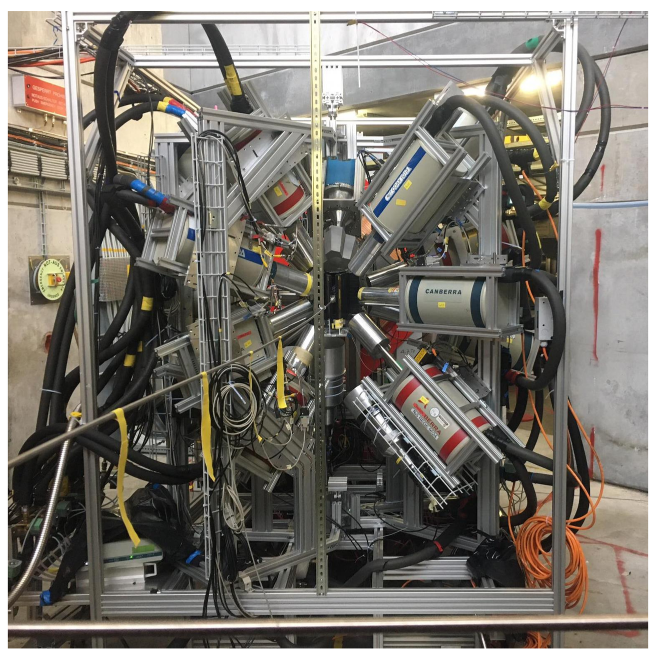


Comparison of the experimental RBS spectrum and the RBS spectrum obtained from the simulated depth profile for ^{197}Au fluence of 10 $\AA^{-2}$ of at 90.0 keV

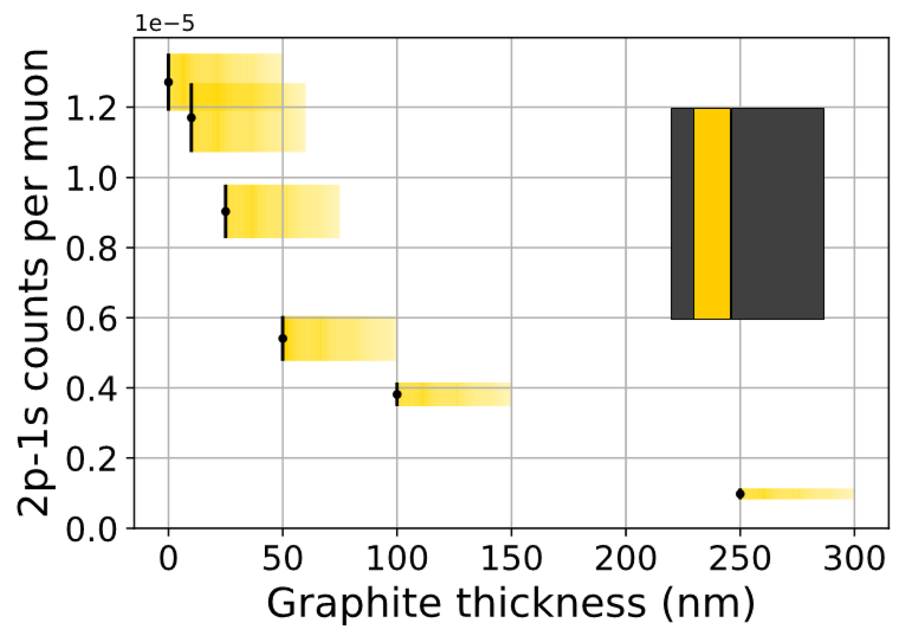
Experimental campaign at PSI (preliminary results)

Investigate conditions required for implanted targets

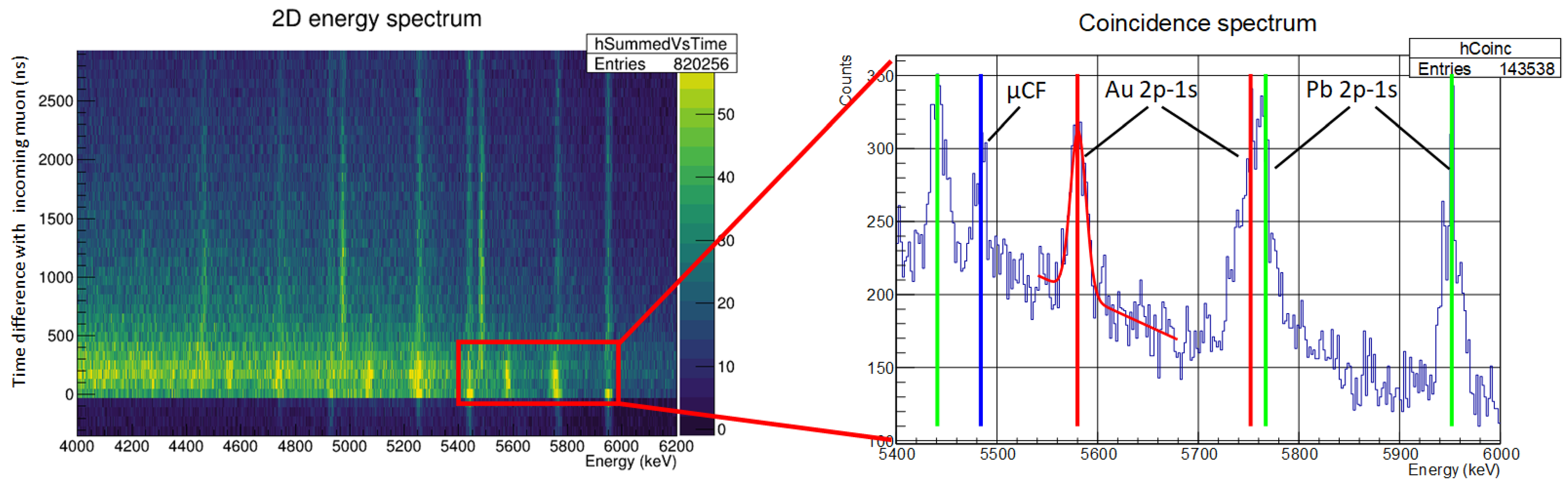
- Glassy carbon samples + 50 nm gold + different layer thicknesses of graphite → Successful
- Implanted ^{197}Au (~ 5 μg) → Successful
- Implanted ^{39}K (~ 3.5 μg) → Successful



Germanium detector array used for the experimental campaign



Count rate of the K_α of gold with a thin layer of graphite on top



Germanium energy spectrum time gated with incoming muons (left) and its projection between −50 ns and 500 ns with respect to the muon hit

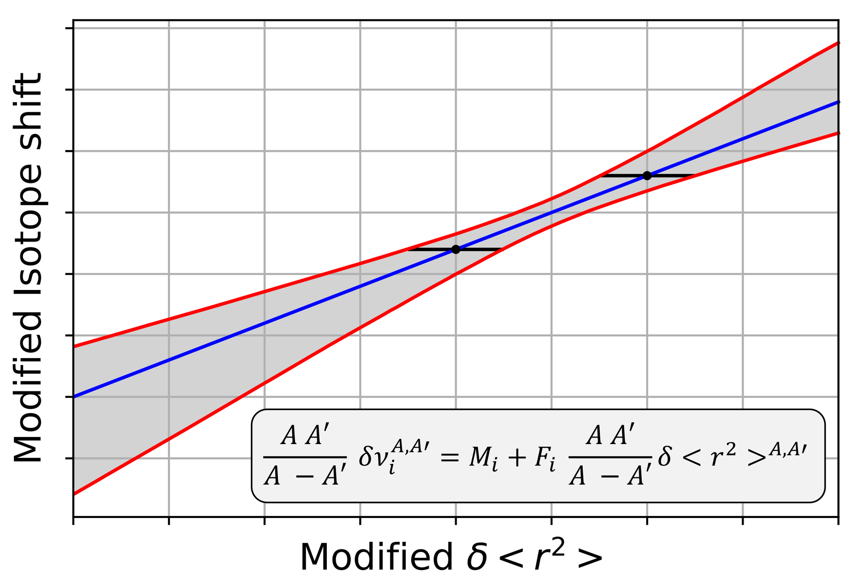
Benchmarking laser spectroscopy (future campaign)

Measure charge radius of 3 isotopes of an element

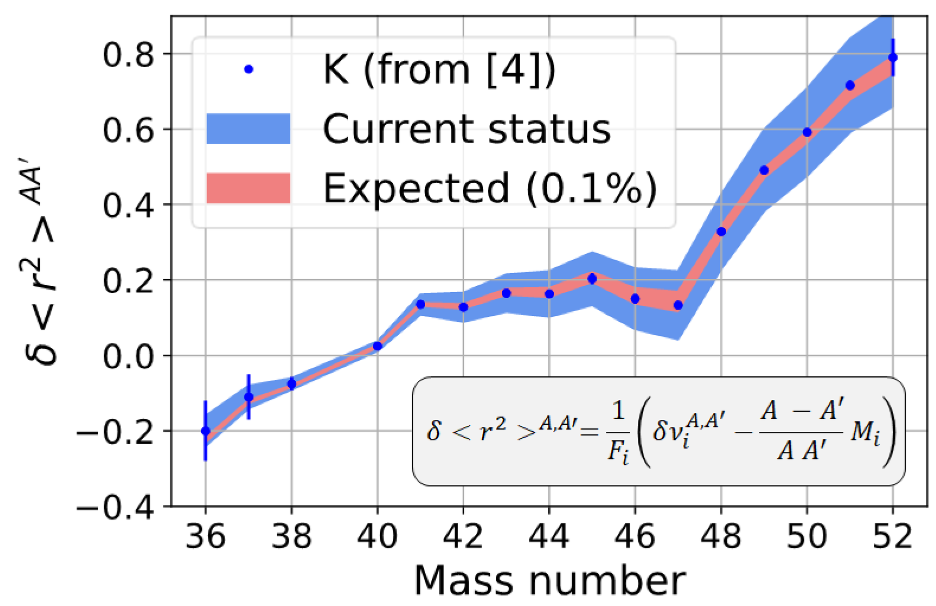
→ 2 points for change in mean square radius

→ King plot analysis to determine M_i and F_i

→ Reduced systematics in laser spectroscopy results



General King plot for determination of M_i and F_i



Least expected improvement on the systematic effect of the potassium isotopic chain

Conclusion

- Muonic X-ray spectroscopy was successfully performed on microgram implanted samples of stable gold and potassium.
- Sputtering of glassy carbon is underestimated in TRIDYN simulations
- Systematic study of the retained fluence is required for future investigations

References

[1] Knecht, Andreas, Alexander Skawran, and Stergiani Marina Vogiatzi. "Study of nuclear properties with muonic atoms." *The European Physical Journal Plus* 135.10 (2020): 1-18.
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[3] Roth, J., et al. "Formation and Erosion of WC under W+ Irradiation of Graphite." *MRS Online Proceedings Library* 658.1 (2000): 5311-5316.
[4] 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.