Actinide quest at IGISOL

A. Raggio[1], I. Moore[1], I. Pohjalainen[1] and the IGISOL group

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FIN-40014 Jyväskylä, Finland

LISA
LASER IONISATION AND SPECTROSCOPY OF ACTINIDES

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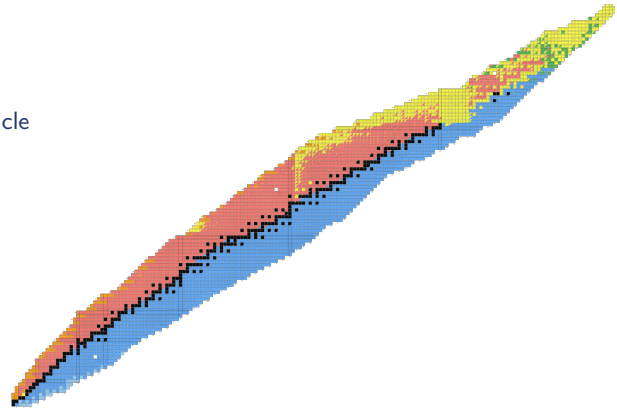
Content

Physics Case

- Optical spectroscopy for nuclear physics
- A test bench for collective vs single particle behaviour



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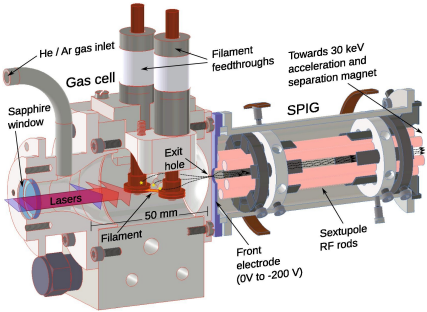
Offline studies

- Resonance ionization of Plutonium samples
- The ^{235m}U isomeric state



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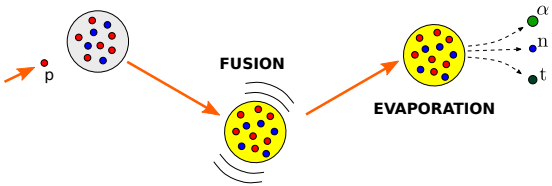
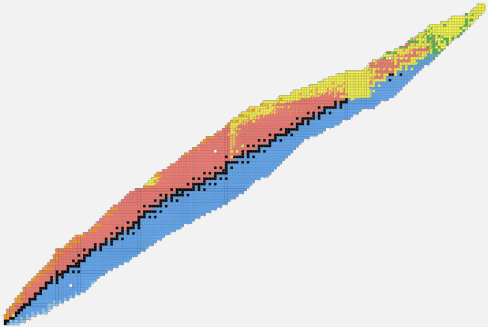
Online studies

- Fusion evaporation reaction on Th metallic target

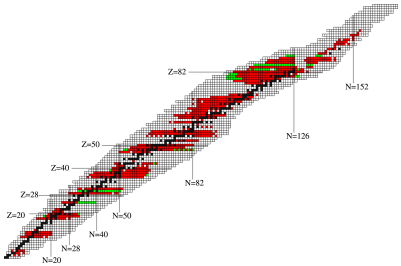


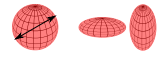
PHYSICS CASES



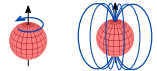
Optical Spectroscopy on Actinides

A useful tool to extract fundamental nuclear ground state properties





Sizes Shapes



Spins Magnetic properties

Nuclear model-independent measurement

[1] Updated from P. Campbell et al., PPNP 86 (2016) 127–180

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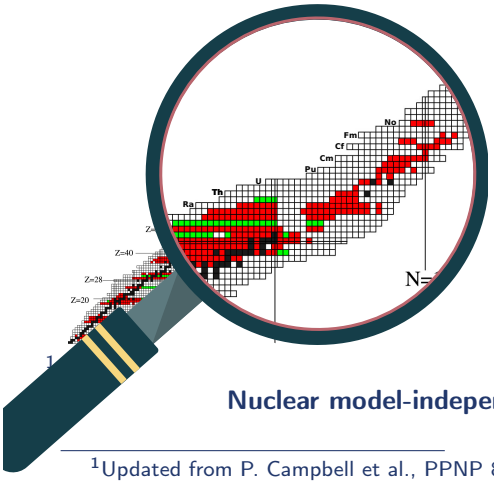
Optical Spectroscopy on Actinides



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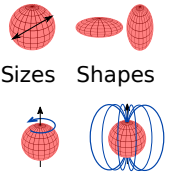
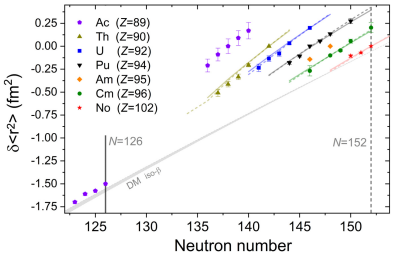


General lack of optical data

- Lack of Stable isotopes
- Challenging Production

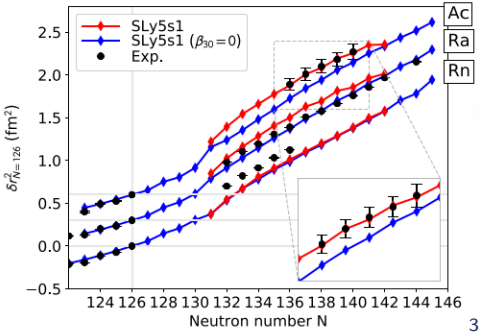


Nuclear model-independent measurement

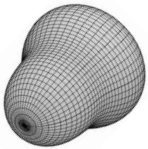
[1]Updated from P. Campbell et al., PPNP 86 (2016) 127–180
[2]M. Block et al., PPNP, 116 (2021), 103834

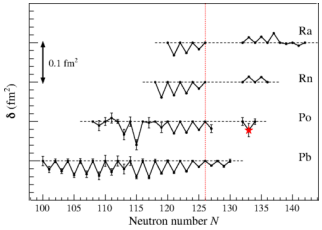
Octupole Deformation and Charge Radii

$$\langle r^2 \rangle = \langle r^2 \rangle_{sph} \left(1 + \frac{5}{4\pi} \left(\langle \beta_2^2 \rangle + \langle \beta_3^2 \rangle + ... \right) \right)$$



[3]

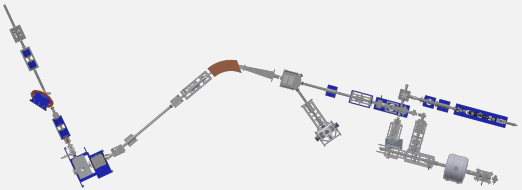




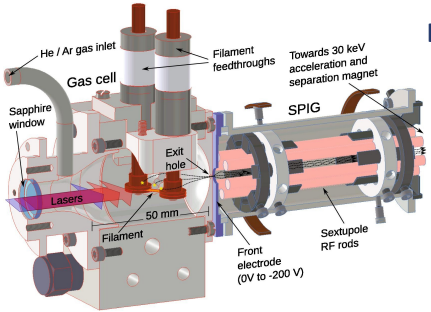
- Comparison with EDF predictions. [4]
- Need to extend to heavier actinide experimental data
- Correlation between odd-even staggering reversal and octupole deformation?
- Collective behavior ↔ enhancement of symmetry-violating nuclear properties

[3] M. Bender, private communication
[4] D. Fink et al., PRX 5 (2015) 011018

OFFLINE STUDIES

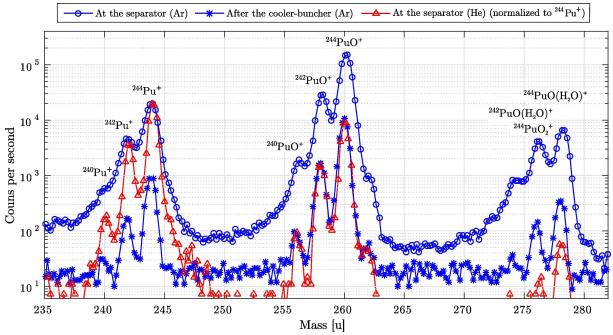


Filament based sources



Resonance Ionization Spectroscopy of Pu samples

- Development of gas-cell for offline actinide studies
- $^{238-242,244}$Pu on Ta substrate, T=1100°C
- Molecular formation in He and Ar buffer Gas[5]



[5] I. Pohjalainen, NIM B 376 (2016) 233

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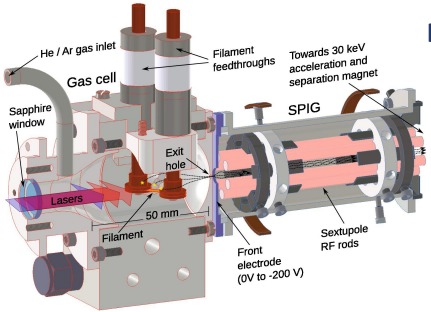

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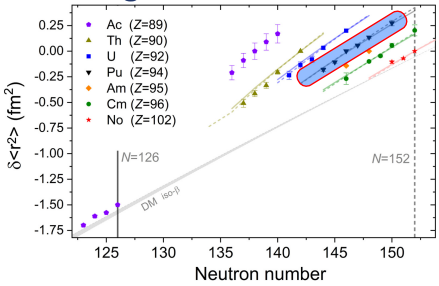
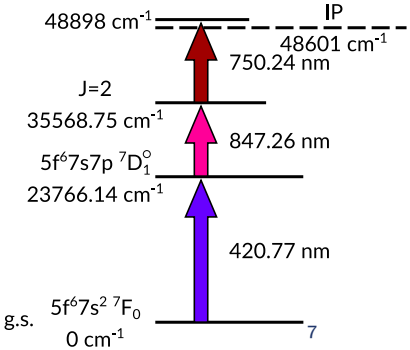
Source used for high resolution CLS of Pu isotopes[6]



[5] I. Pohjalainen, NIM B 376 (2016) 233
[6] A. Voss, PRA 95 (2017) 032506

Collisional de-excitation phenomena



The gas-cell environments has been observed to greatly reduce the sensitivity of the ionization scheme

[7] S.Raeder et al. ABC 404 (2012) 2163 (2012)

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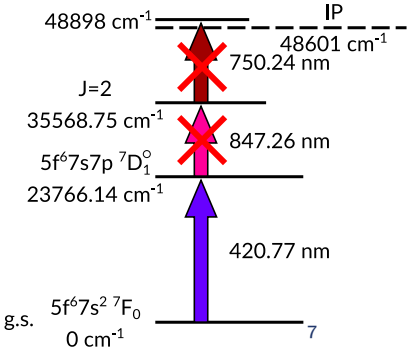

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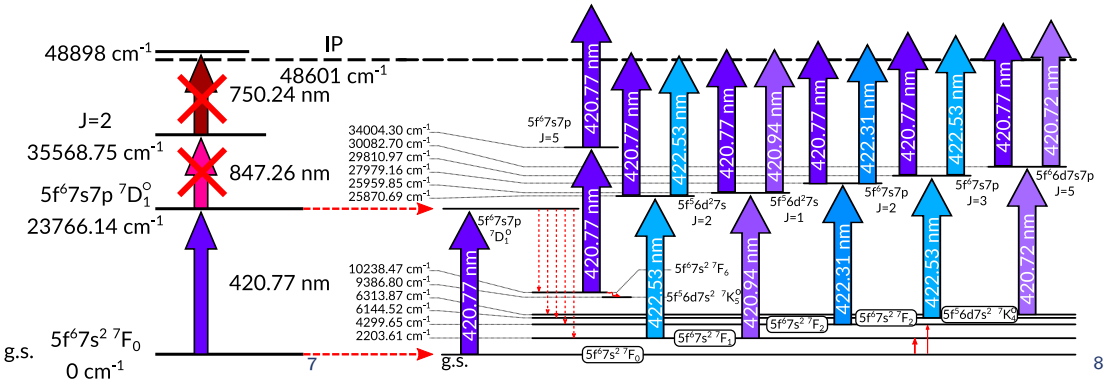
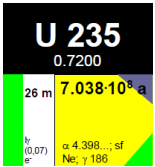


The gas-cell environments has been observed to greatly reduce the sensitivity of the ionization scheme → Competition between resonant laser excitation and collisional de-excitation

[7] S.Raeder et al. ABC 404 (2012) 2163 (2012)
[8] A.Raggio et al. Atoms 10 (2022)40

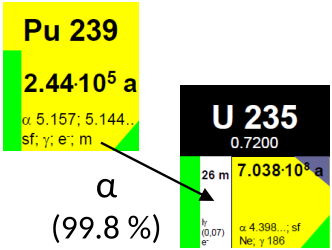
^{235m}U isomeric state



Second lowest isomeric state in the nuclide landscape

- 76 eV
- ∼26 minutes half life

^{235m}U isomeric state



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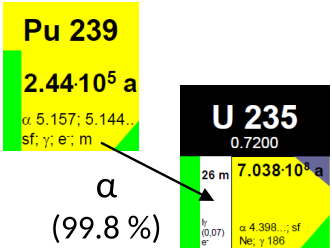

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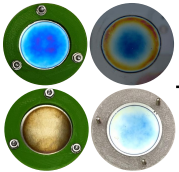
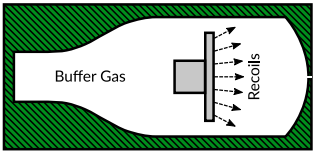
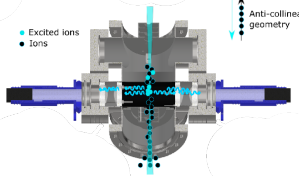


Extraction



Measurement



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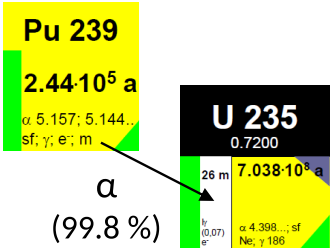

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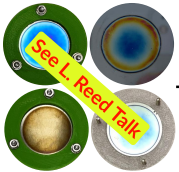

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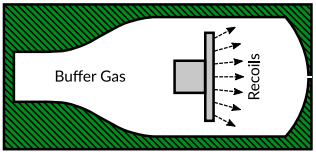

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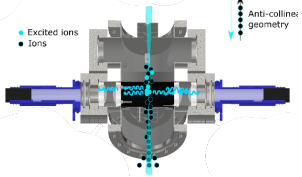
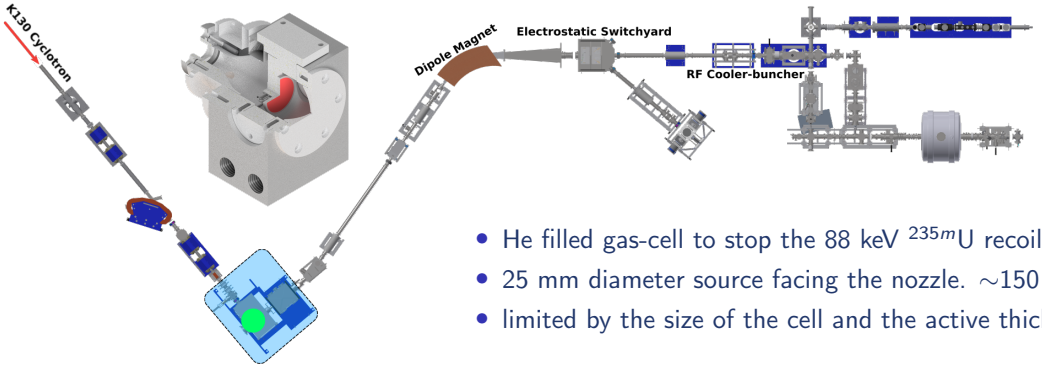
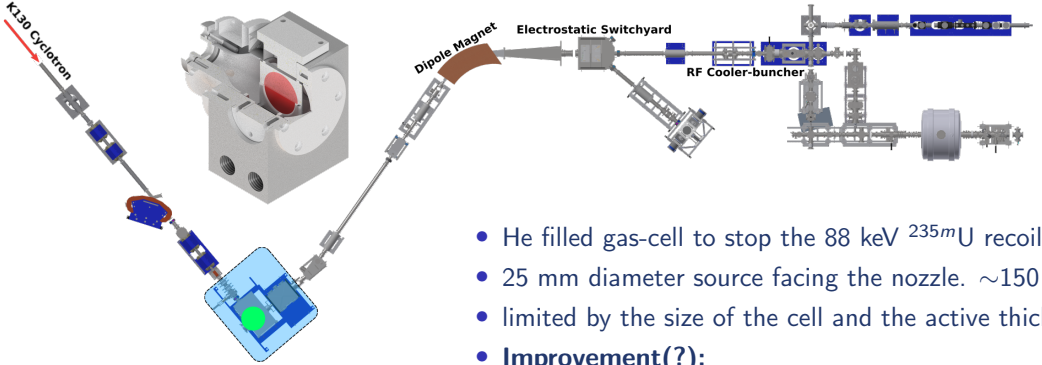


Actinide gas-cell



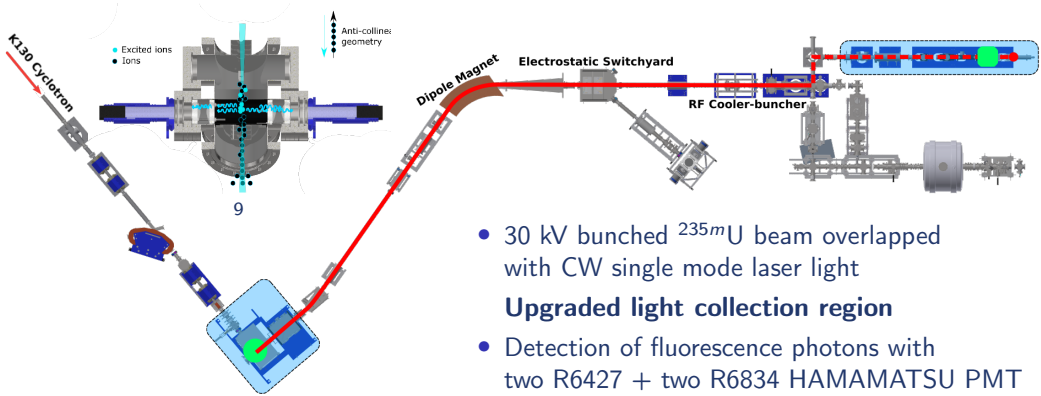
- He filled gas-cell to stop the 88 keV ^{235m}U recoils
- 25 mm diameter source facing the nozzle. $\sim$150 kBq
- limited by the size of the cell and the active thickness

Actinide gas-cell



- He filled gas-cell to stop the 88 keV ^{235m}U recoils
- 25 mm diameter source facing the nozzle. $\sim$150 kBq
- limited by the size of the cell and the active thickness
- **Improvement(?):**
  Two sources back to back longitudinally mounted
  Testing of the sources and configurations in August

Collinear Laser Spectroscopy



9

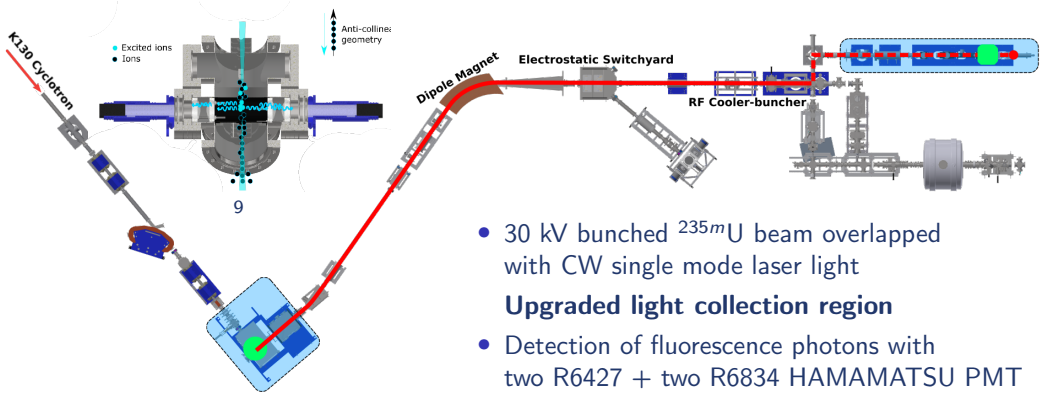
- 30 kV bunched ^{235m}U beam overlapped with CW single mode laser light

  Upgraded light collection region

- Detection of fluorescence photons with two R6427 + two R6834 HAMAMATSU PMT

[9] A. Koszorus et al. submitted to Spectrochimica Acta Part B: Atomic Spectroscopy.

Collinear Laser Spectroscopy



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- 30 kV bunched ^{235m}U beam overlapped with CW single mode laser light

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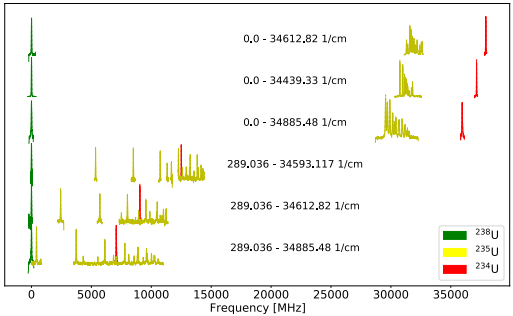
→ **Find optimal atomic transition**

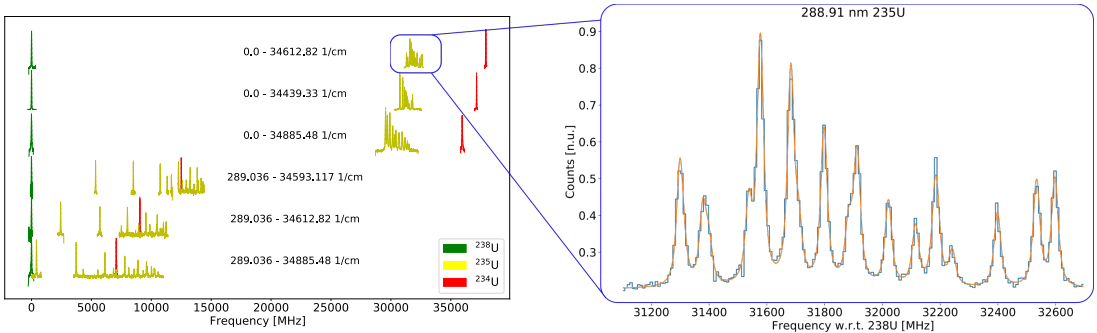
[9] A. Koszorus et al. submitted to Spectrochimica Acta Part B: Atomic Spectroscopy.

Groundwork: CLS of ^{nat}U



- ^{234}U 0.0054%, ^{235}U 0.7204%,^{238}U 99.2742%
- Offline study of 12 ionic transition in the UV range 288-314 nm
- Optimum transition had a spectroscopy efficiency of $\sim$ 1/3000 photons/ion

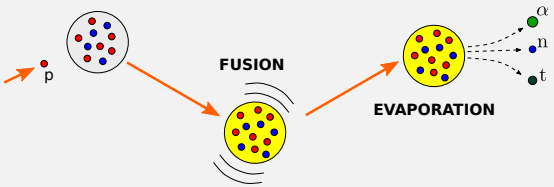
Groundwork: CLS of ^{nat}U



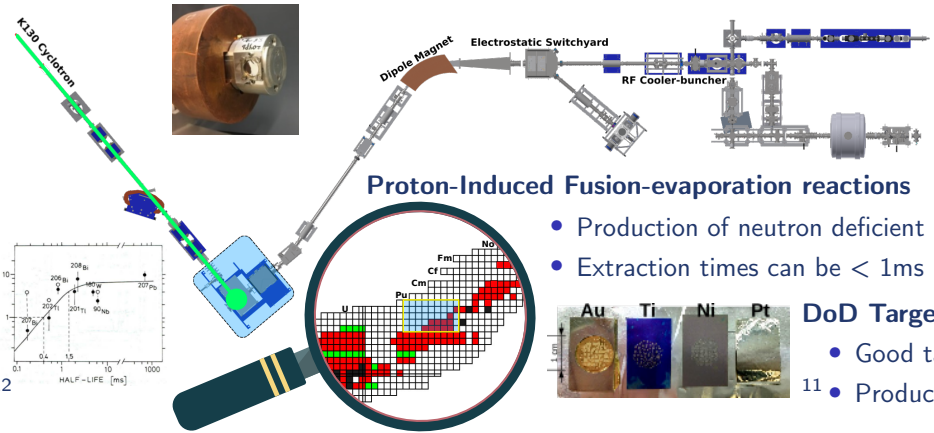
HFS and Isotope shifts determined [10]

[10] A. Raggio et al. to be submitted

ONLINE STUDIES



Online Production



Proton-Induced Fusion-evaporation reactions

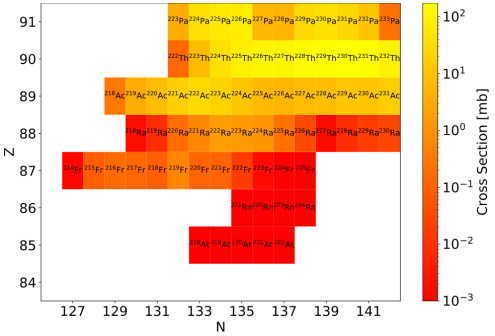
- Production of neutron deficient actinides
- Extraction times can be $<$ 1ms

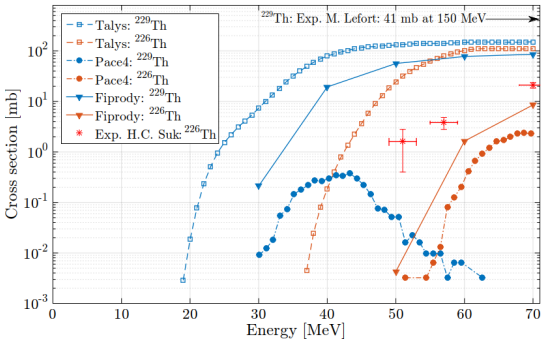
DoD Target

- Good target durability
- Production yield stability

[11] R. Haas et al., NIMA 874 (2017) 43
[12] J. Ärje, J. Äystö et al., Phys. Rev. Lett. 54 (1985) 99

Production yields



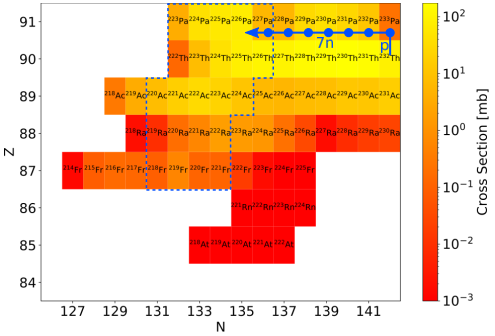


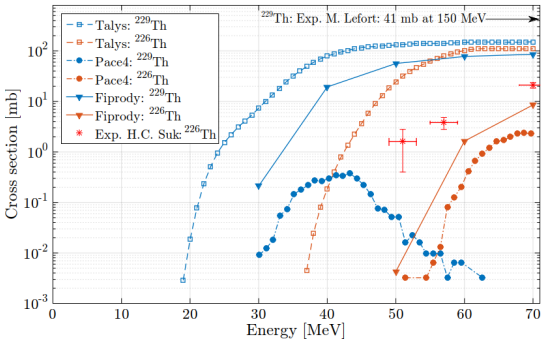
- Decay Spectroscopy experiment to evaluate yields?

- Lack of experimental data
- Simulation routines gives different results

  ^{232}Th(p,pxn)Y

Production yields



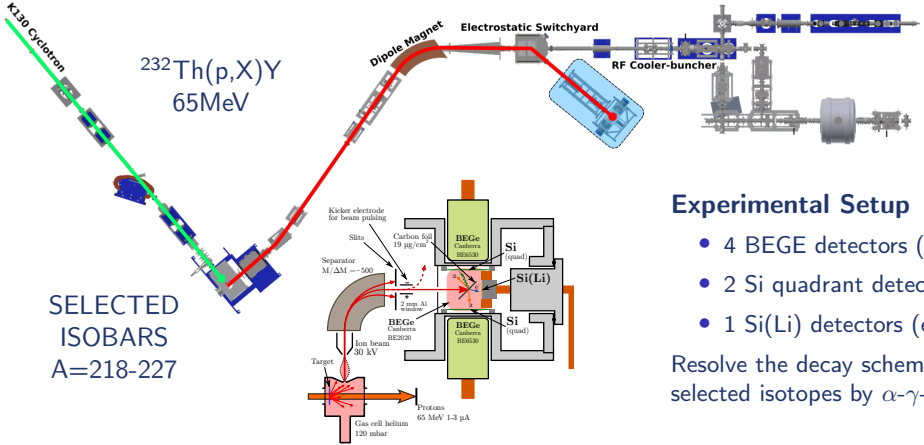


- Decay Spectroscopy experiment to evaluate yields?
- Detecting isotope with $\sim$1 ms$<\tau<\sim$3 h.
- 65 MeV selected as optimal energy (8 nucleons evaporated)

- Lack of experimental data
- Simulation routines gives different results

^{232}Th(p,pxn)Y

Decay Spectroscopy

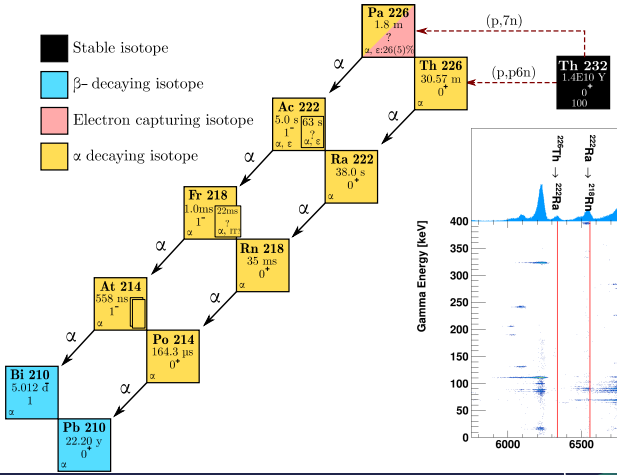


Experimental Setup

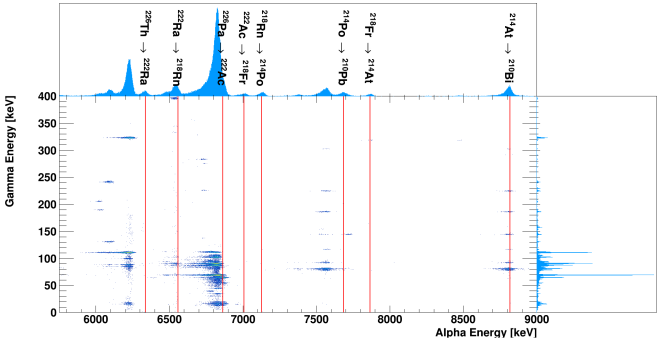
- 4 BEGE detectors (γ)
- 2 Si quadrant detectors (α)
- 1 Si(Li) detectors (e)

Resolve the decay scheme and lifetime of selected isotopes by α-γ-e^- coincidences

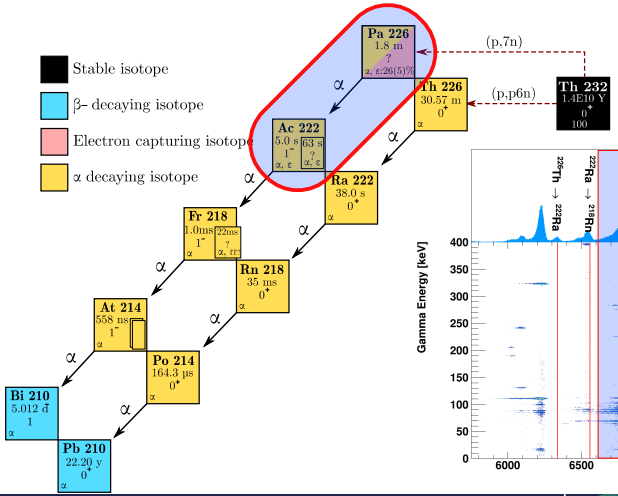
226 Isobar chains



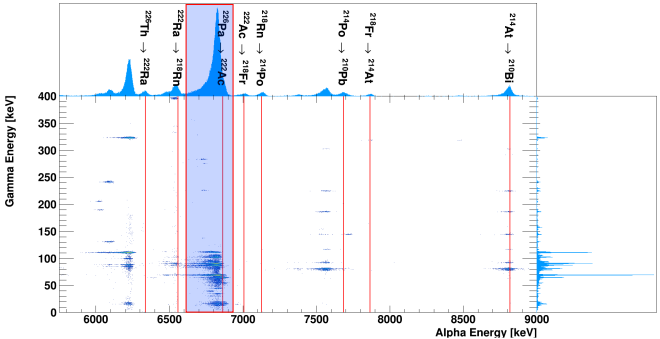
α-γ coincidence matrix
2 μs time window



226 Isobar chains



α-γ coincidence matrix
2 μs time window



SUMMARY AND OUTLOOK

Summary

Interest in Actinide region

- Optical spectroscopy data
- Basic nuclear decay and structure information

Studies

- Gas induced effects in optical spectroscopy
- ^{235m}U isomeric state investigation
- Online production for neutron deficient actinides

Outlook

Collisional de-excitation

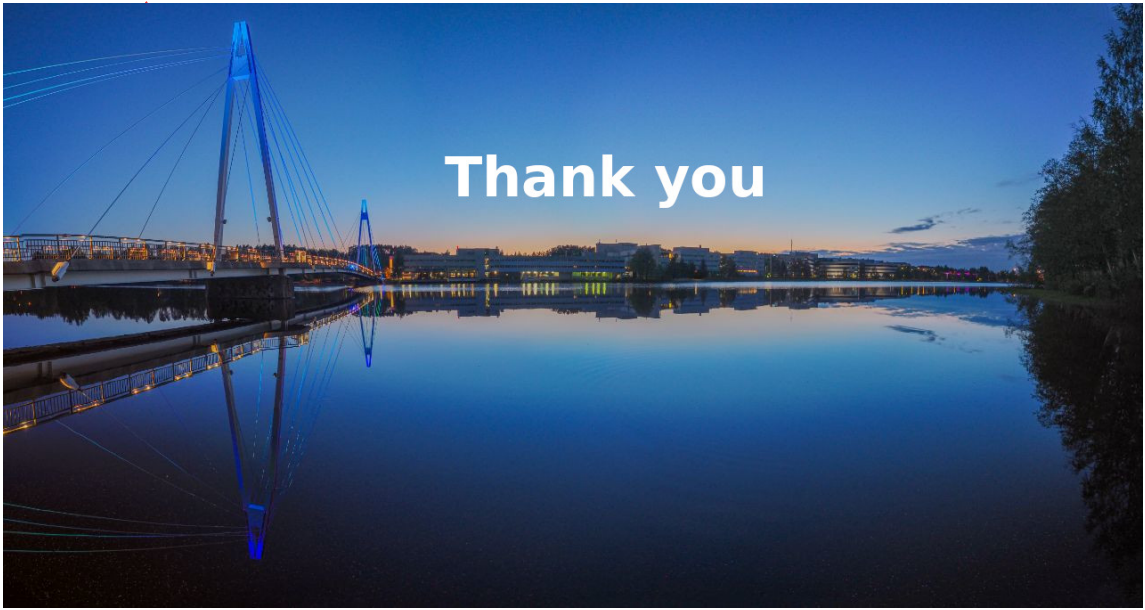
- Planned RIS measurement of U

^{235m}U isomer

- Testing of the sources
- CLS measurement

Online production

- Planned experiment with ^{233}U target (November)


Thank you