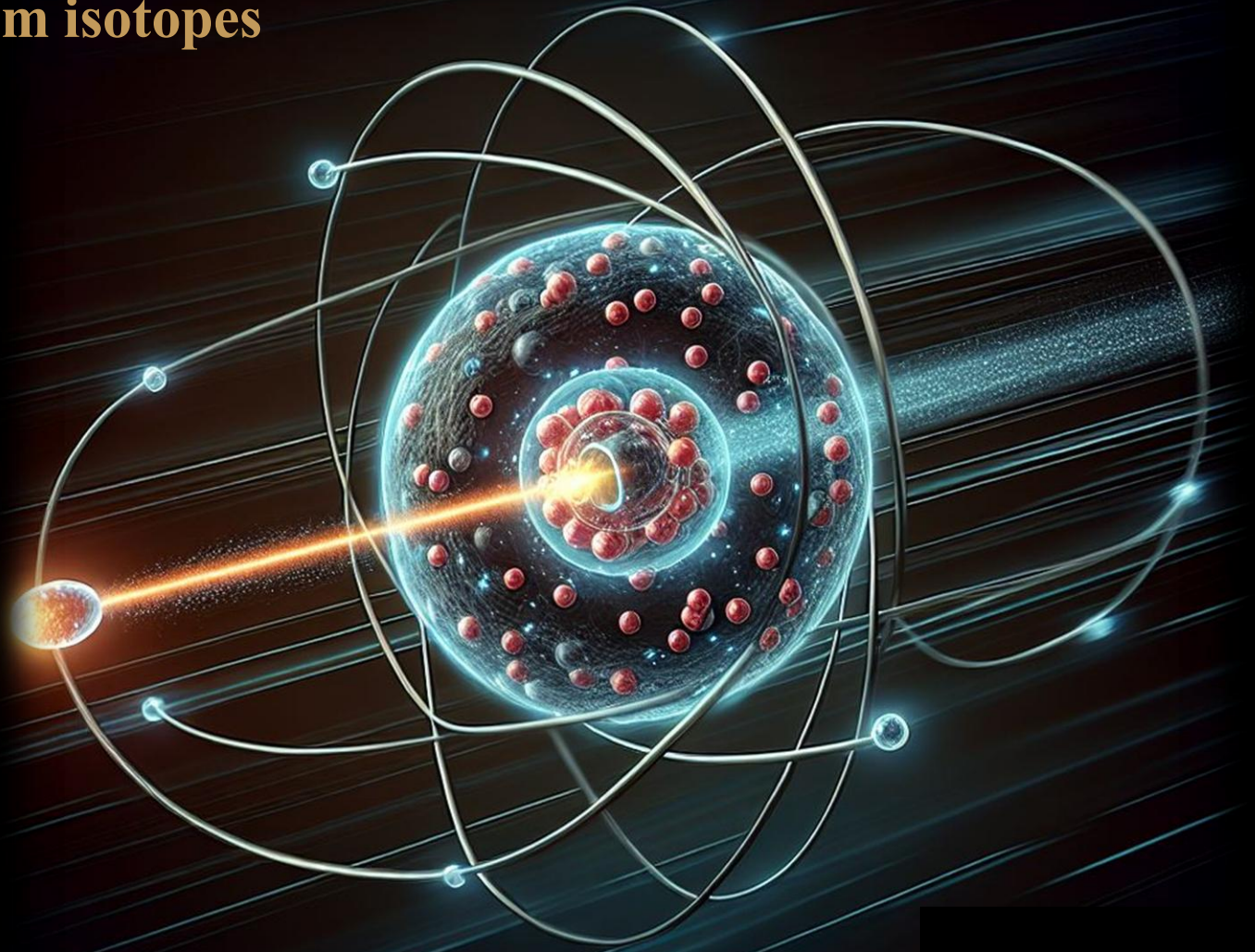
Probing the structure of neutron-deficient Actinium isotopes



Kalle Auranen

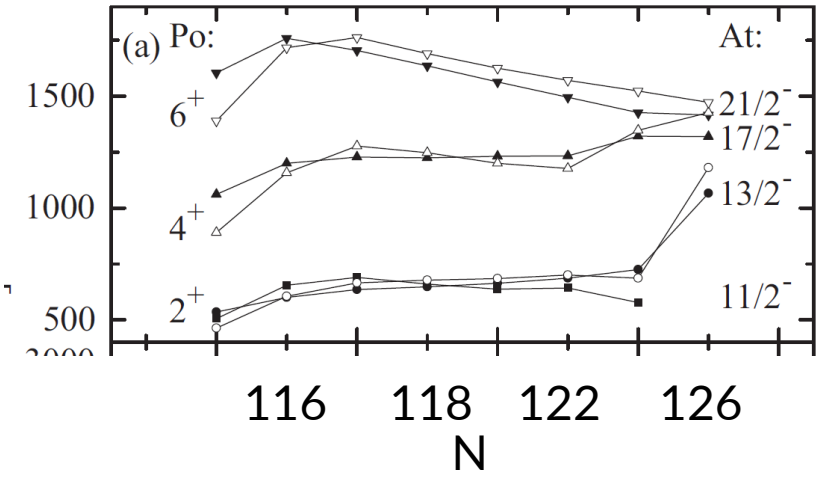
Nordic Meeting 2026

5.5.2026

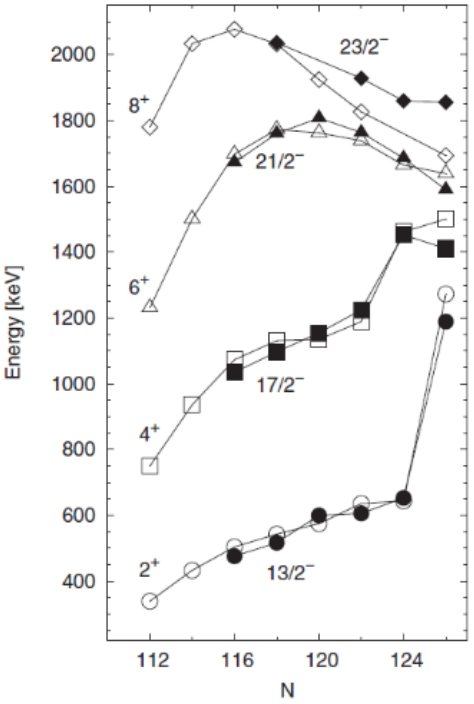
Motivation

- In odd-A Astatine, and Francium isotopes the lowest negative parity states follow the energy of 2^+, 4^+, or 6+ state of the even-even isotone core
  - Odd $h_{9/2}$ proton is a “spectator”

Astatines



Franciums



Auranen et al PRC 91, 024324 (2015)
Jakobsson et al PRC 87, 054320 (2013)

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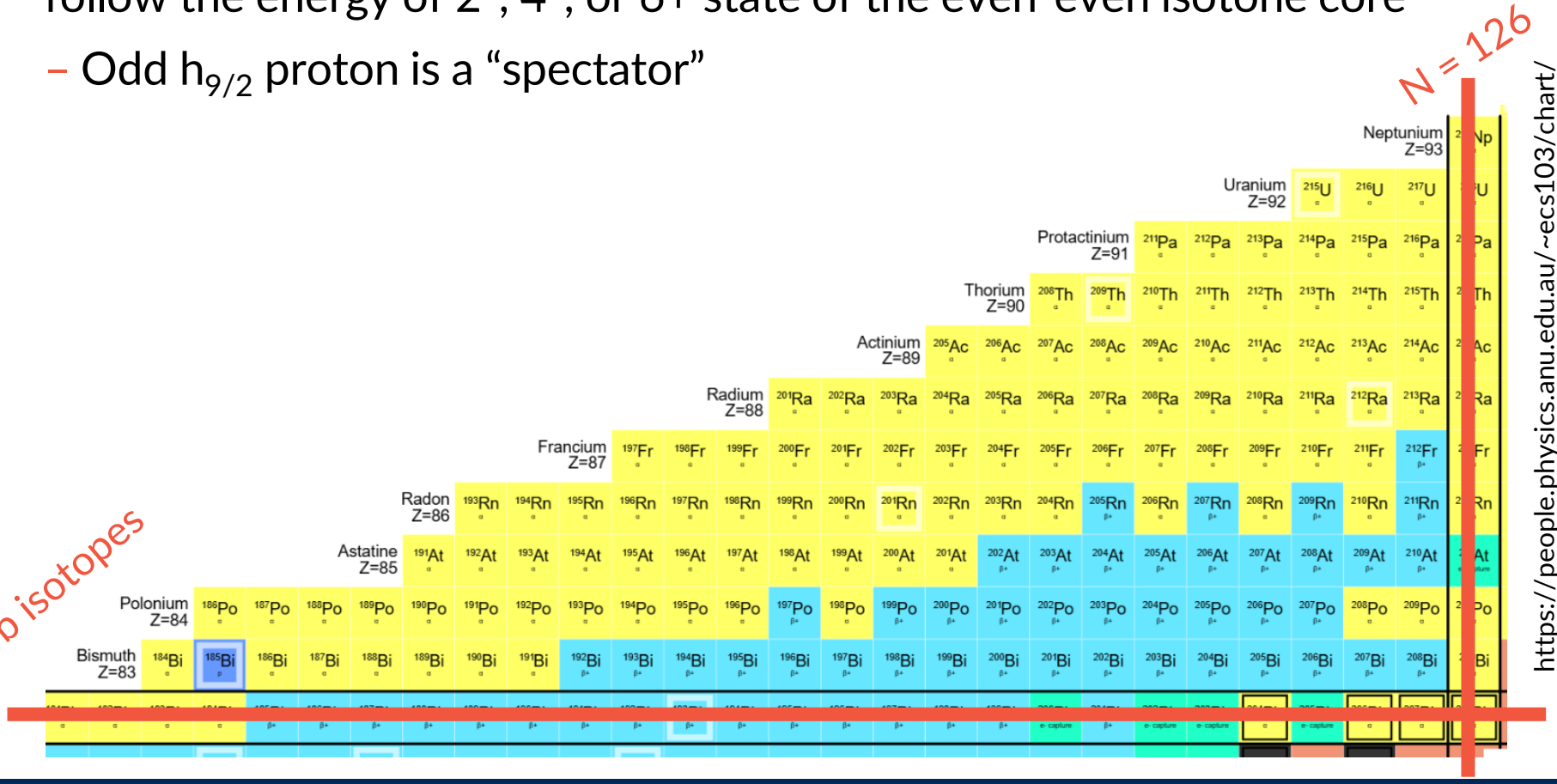

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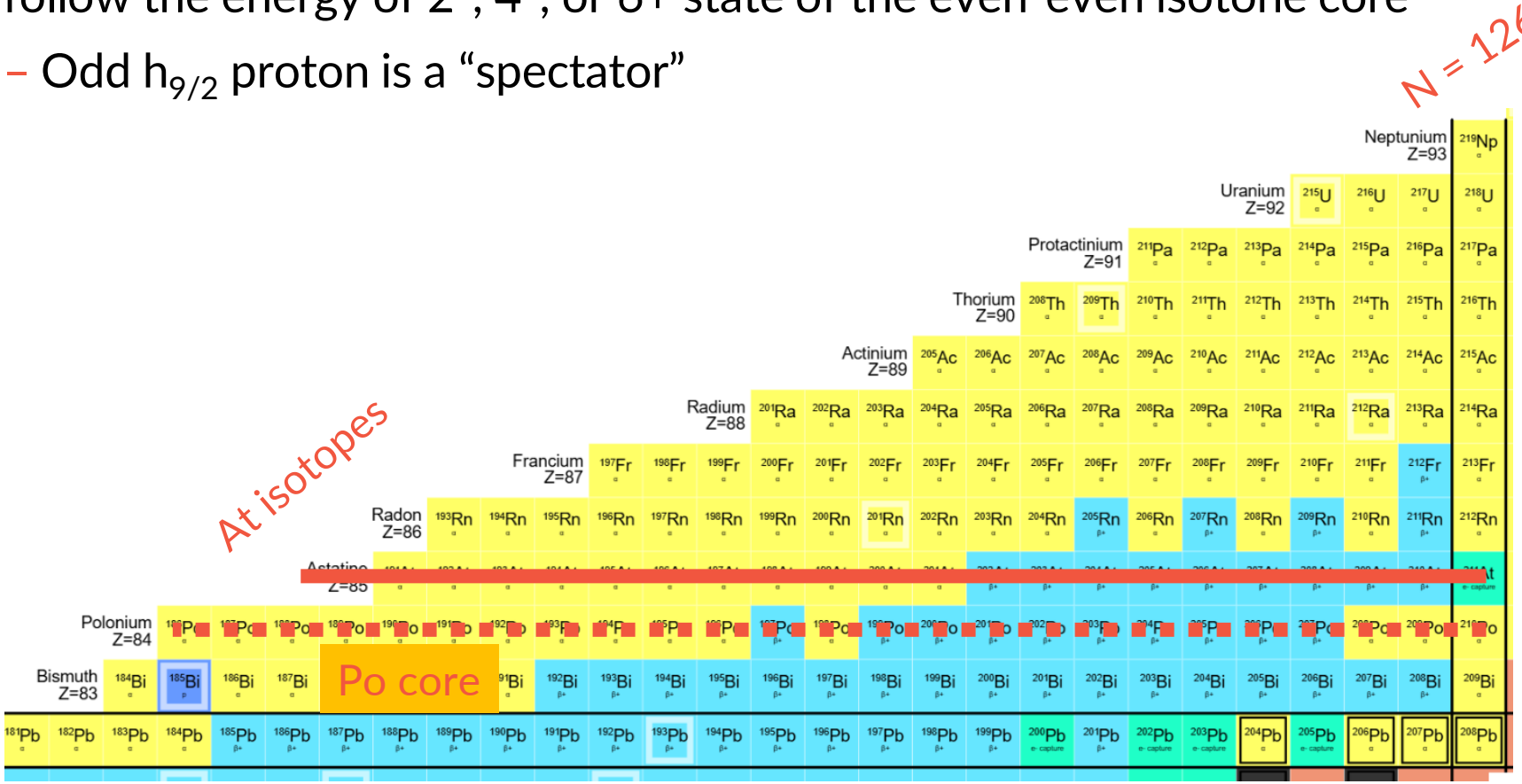

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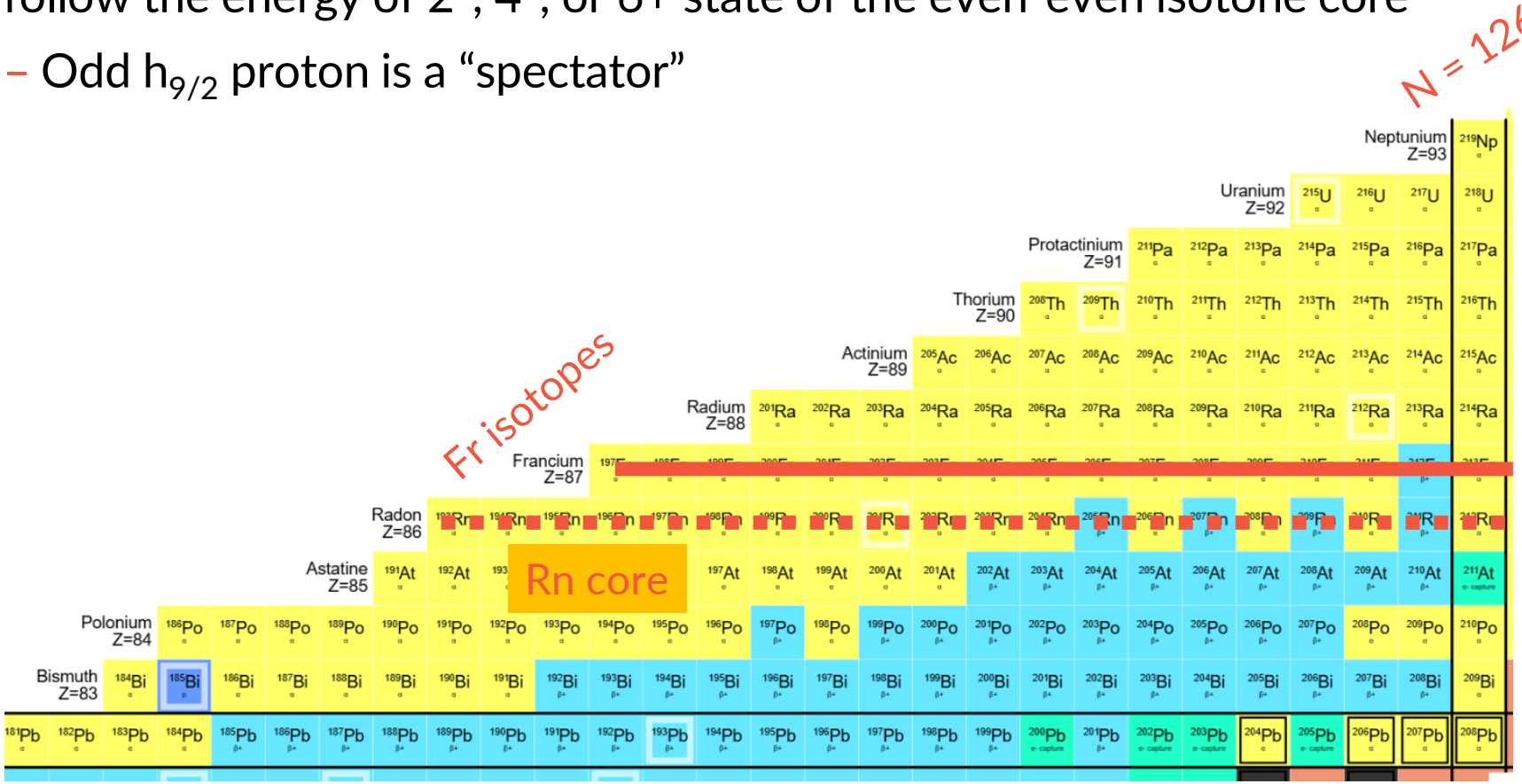

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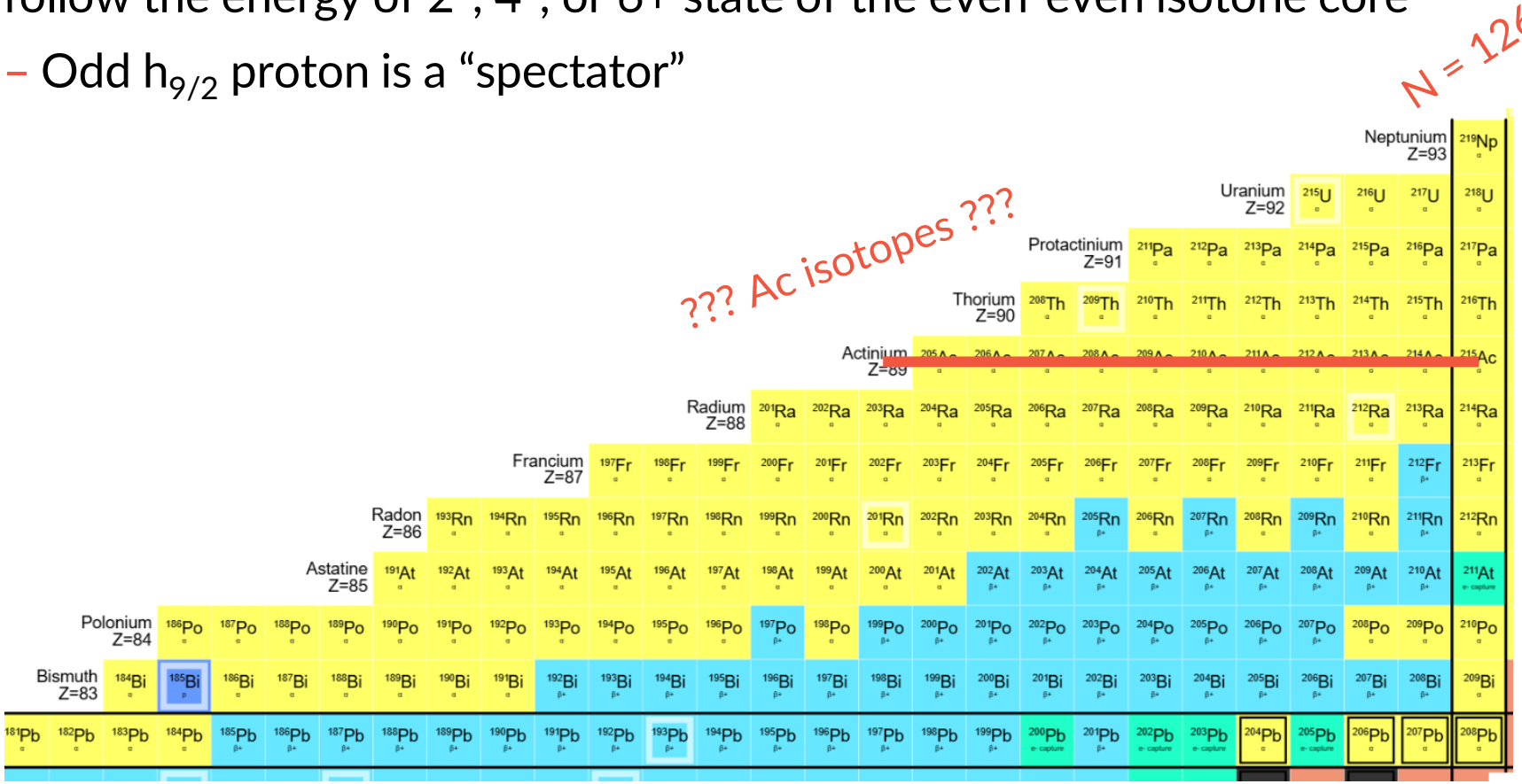

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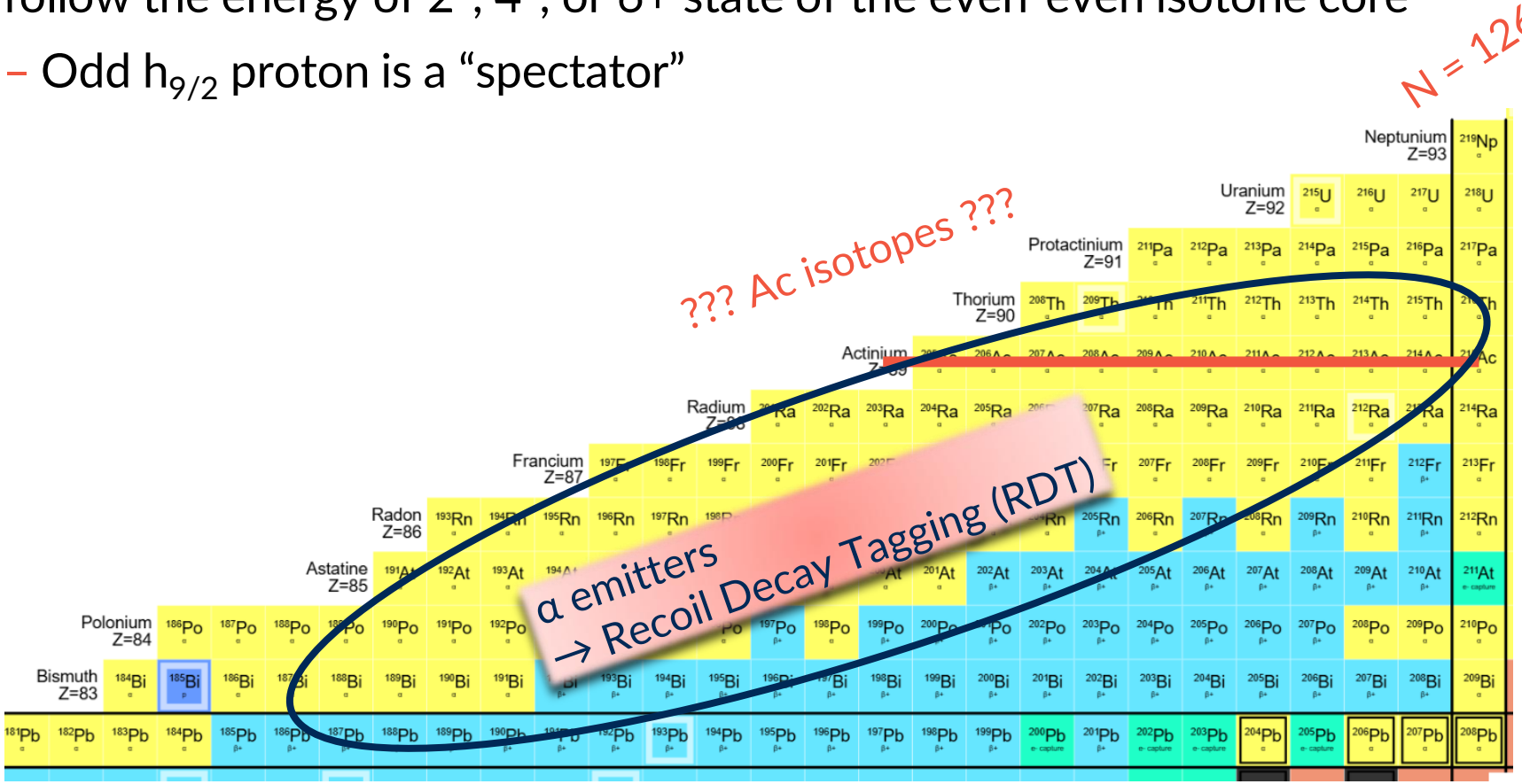
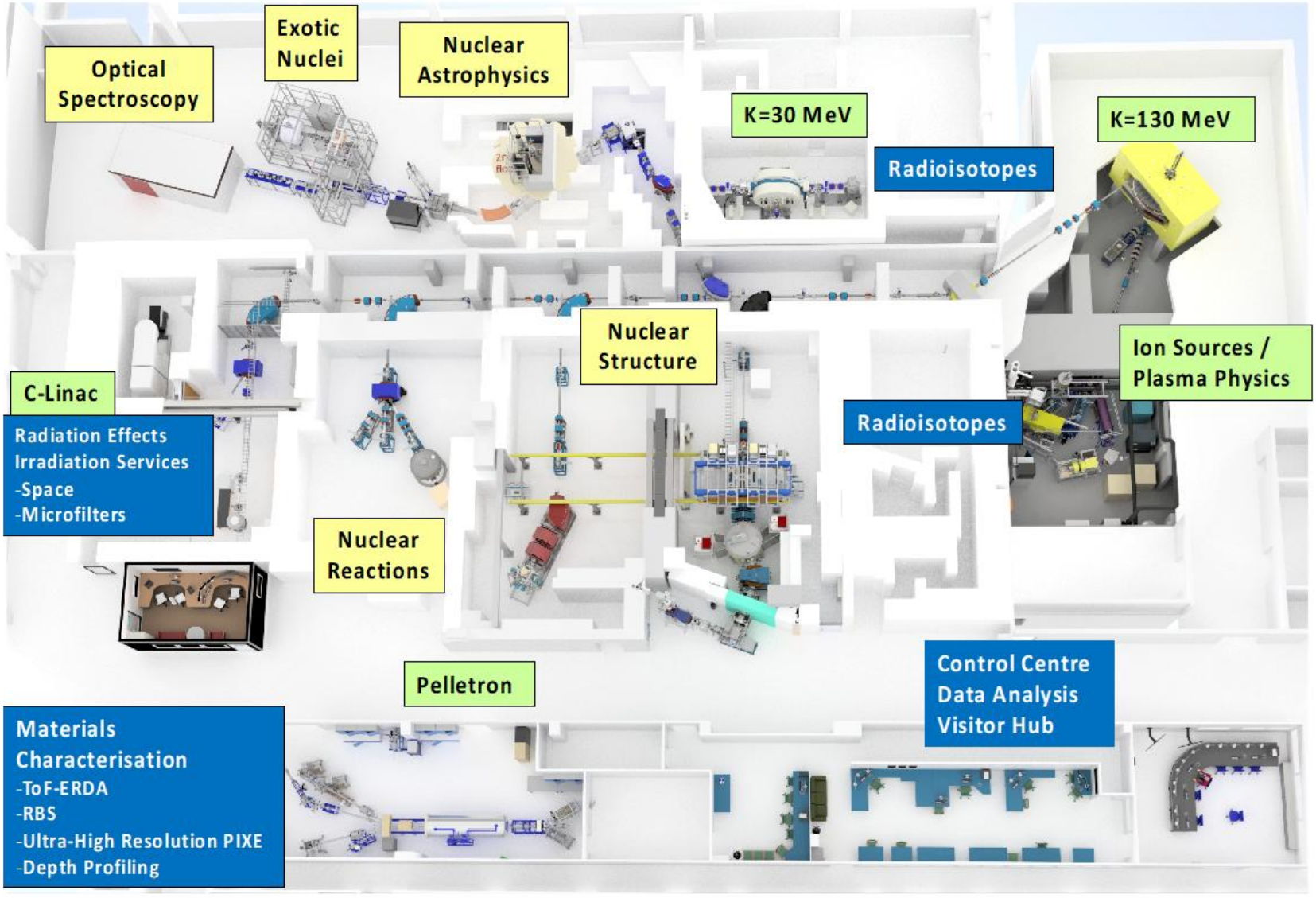


JYFL-ACCLAB


Optical Spectroscopy
Exotic Nuclei
Nuclear Astrophysics
K=30 MeV
K=130 MeV
Radioisotopes
Nuclear Structure
Ion Sources / Plasma Physics
C-Linac
Radiation Effects
Irradiation Services
-Space
-Microfilters
Radioisotopes
Nuclear Reactions
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Control Centre
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Visitor Hub
Materials Characterisation
-ToF-ERDA
-RBS
-Ultra-High Resolution PIXE
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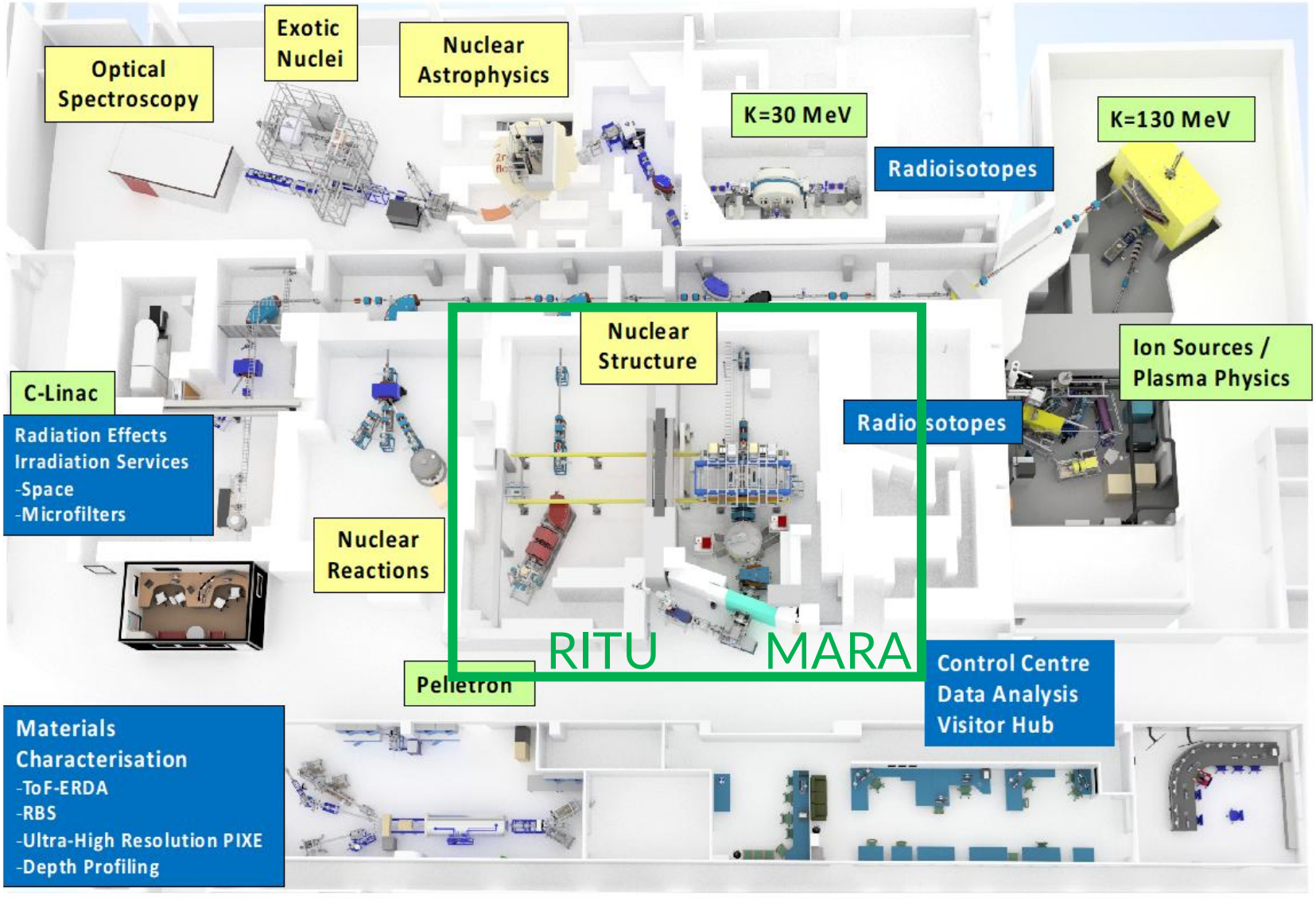
JYFL-ACCLAB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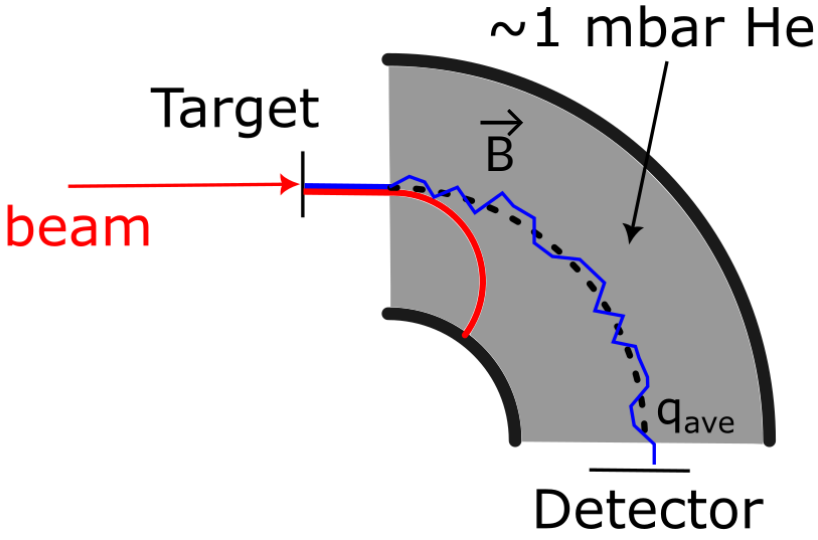
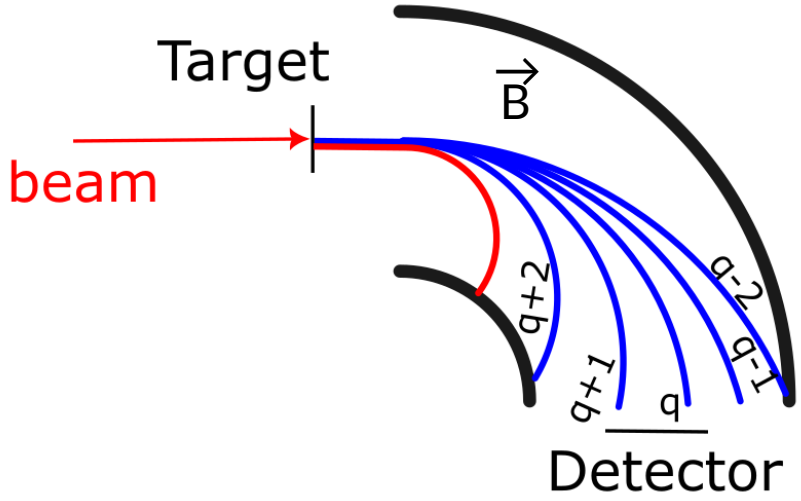
-Depth Profiling

Two complementary recoil separators
(to collect fusion-evaporation residues)

- Recoil Ion Transport Unit (RITU)*
  - Gas filled
  - No mass information
  - \+ Collects all charge states

- Mass Analyzing Recoil Apparatus (MARA)*
  - Vacuum mode
  - \+ A/q information
  - \- A few (~ 2 - 4) charge states collected at once



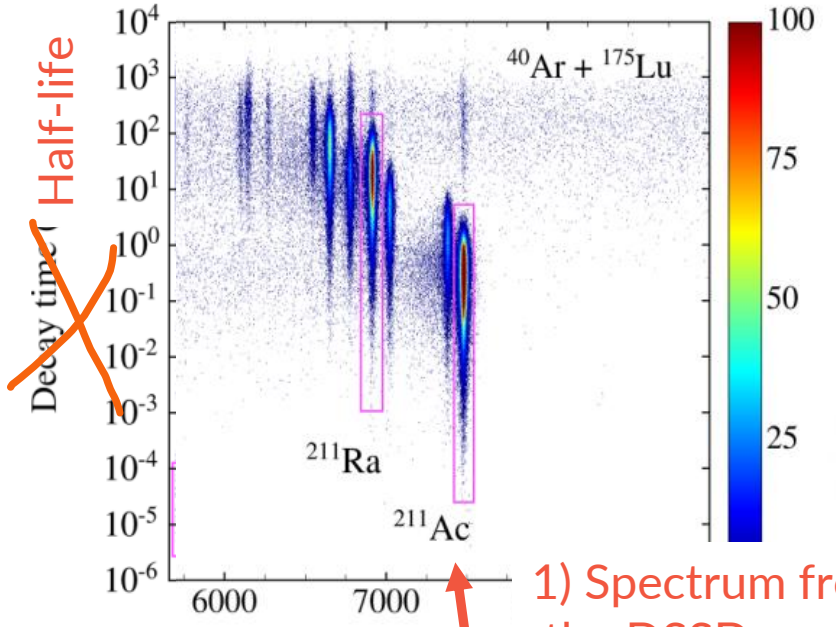


*Over simplified sketches

Experiments

	^{207}Ac	^{209}Ac	^{211}Ac	^{213}Ac
Reaction	^{175}Lu(^{36}Ar, *4n*)^{207}Ac	^{180}Hf(^{35}Cl, *6n*)^{213}Ac	^{175}Lu(^{40}Ar, *4n*)^{211}Ac	^{180}Hf(^{37}Cl, *4n*)^{213}Ac
Cross section	3 nb	420 nb	50 µb	50 µb
I_{beam} (Hours)	200 pnA (64 h)	28 pnA (150 h)	17 pnA (101 h)	10 pnA (140 h)
Setup	RITU FP Spectrometer	RITU JUROGAM3 FP Spectrometer	MARA JUROGAM3 FP Spectrometer	MARA JUROGAM3 FP Spectrometer

Recoil-Decay Tagging method (RDT)



1) Spectrum from the DSSD

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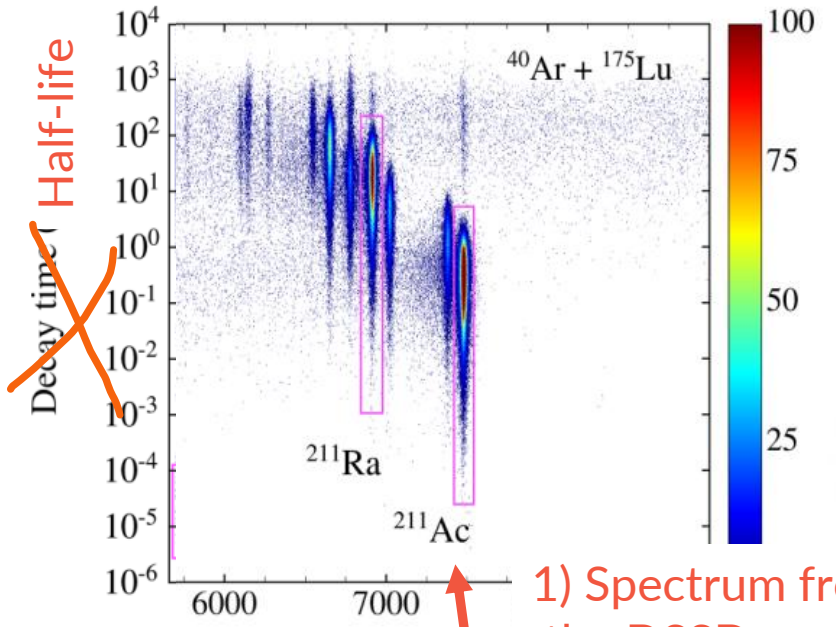

1) Spectrum from the DSSD

2) Navigate back in time by the time-of-flight

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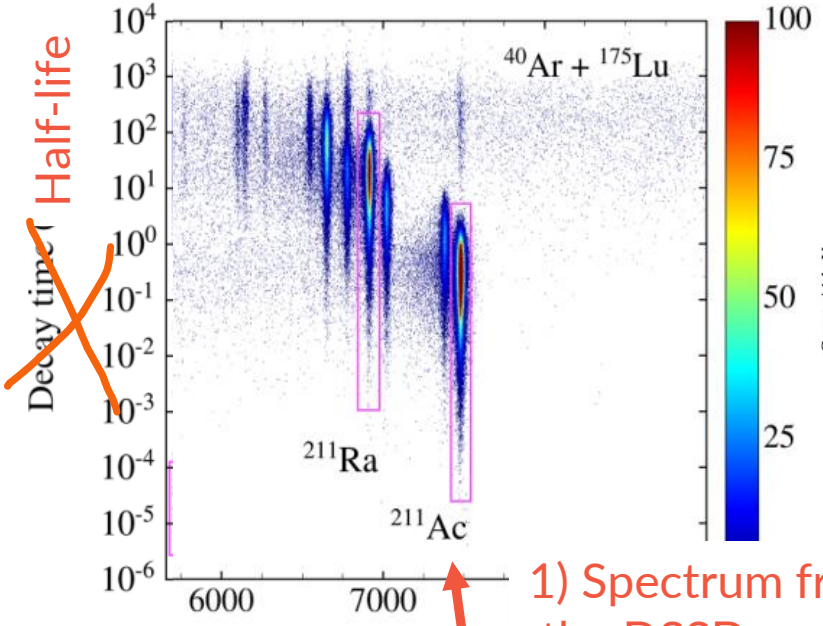
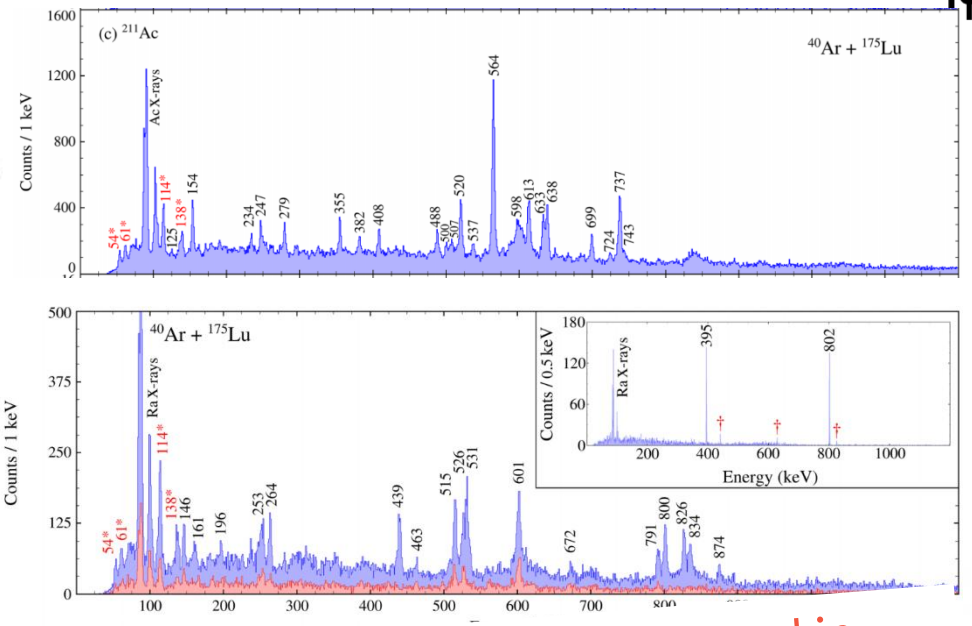


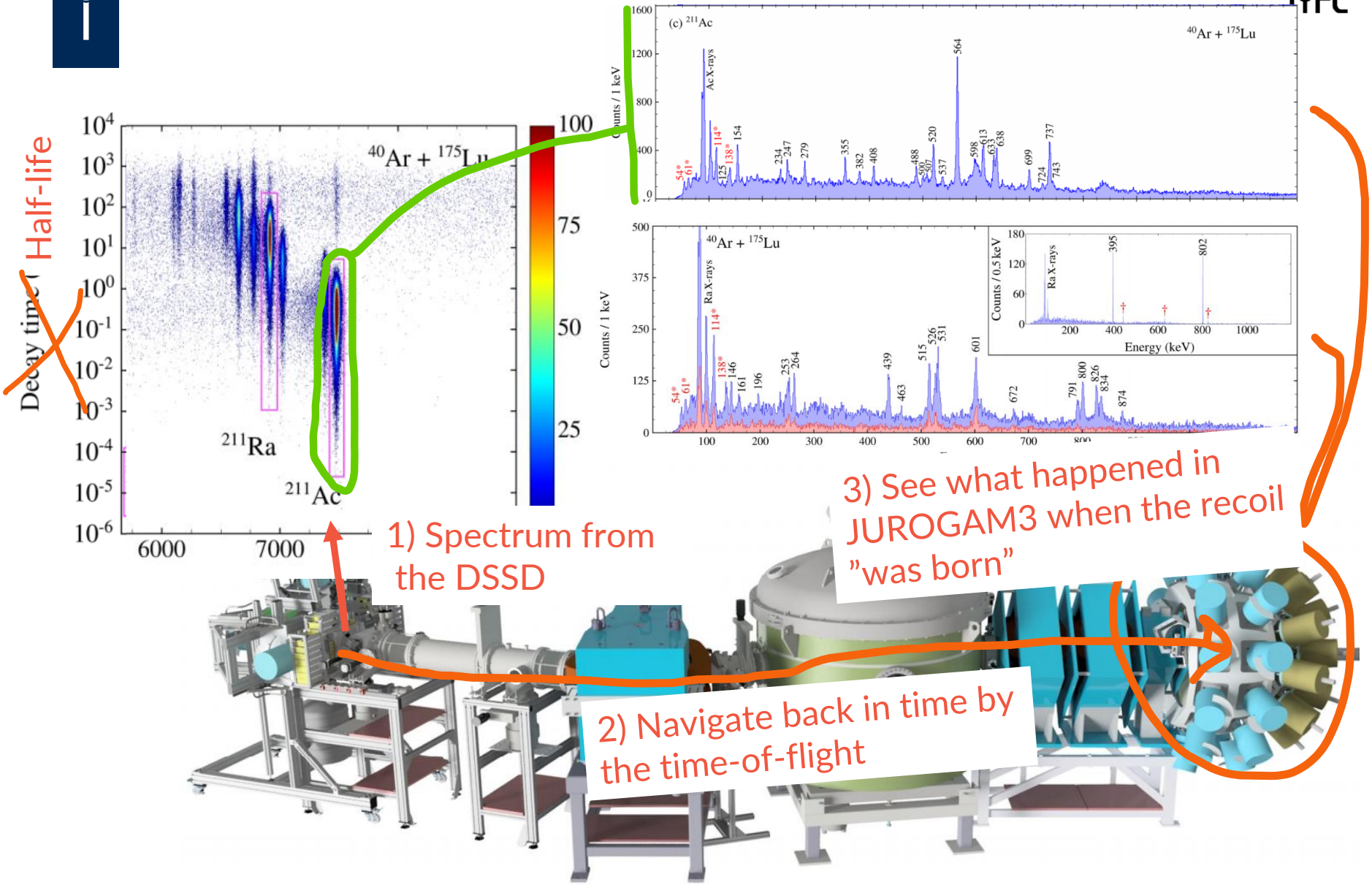


1) Spectrum from the DSSD

2) Navigate back in time by the time-of-flight

3) See what happened in JUROGAM3 when the recoil "was born"

Recoil-Decay Tagging method (RDT)



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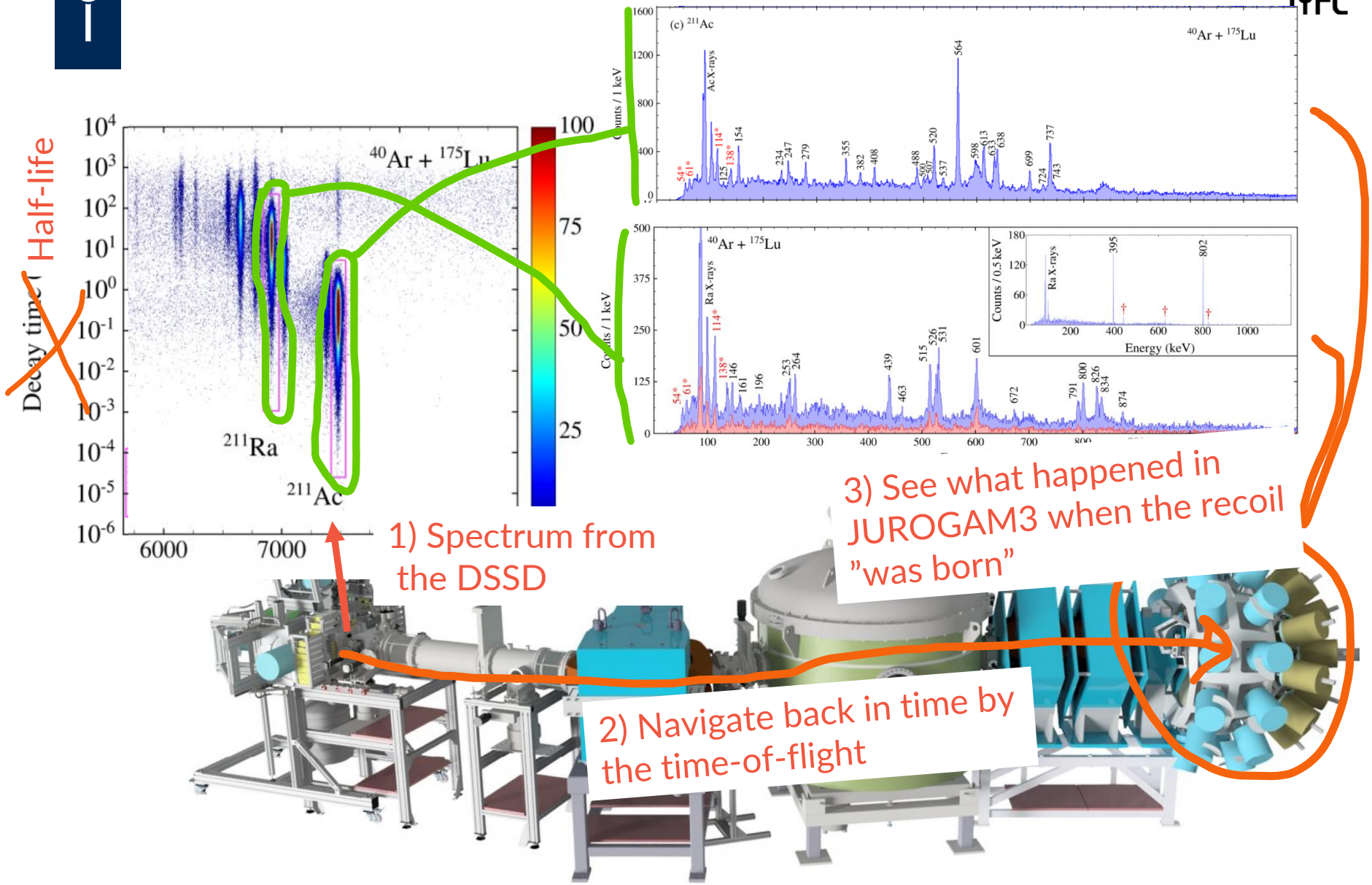
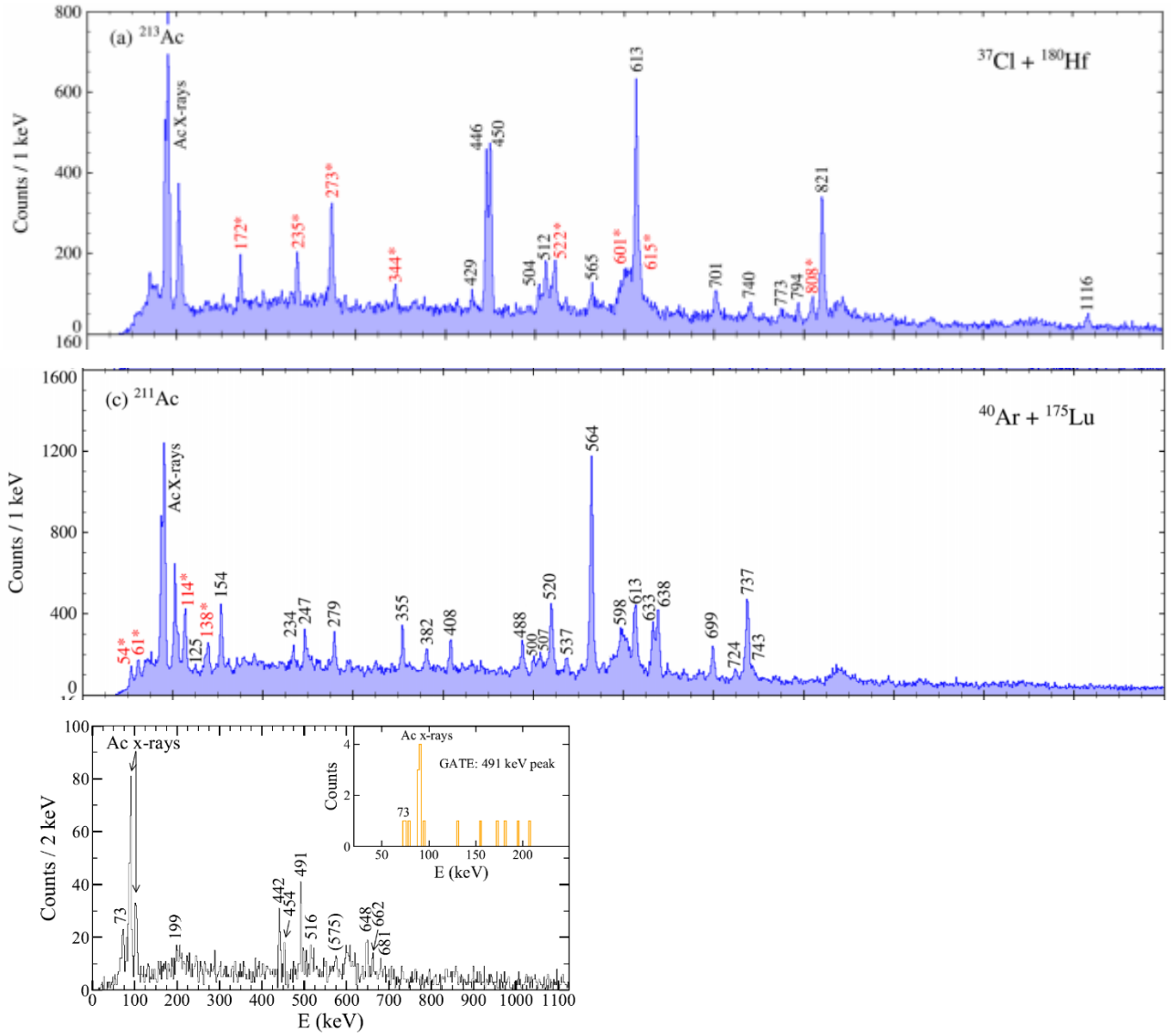


Results (singles)

^{213}Ac

^{211}Ac

^{209}Ac

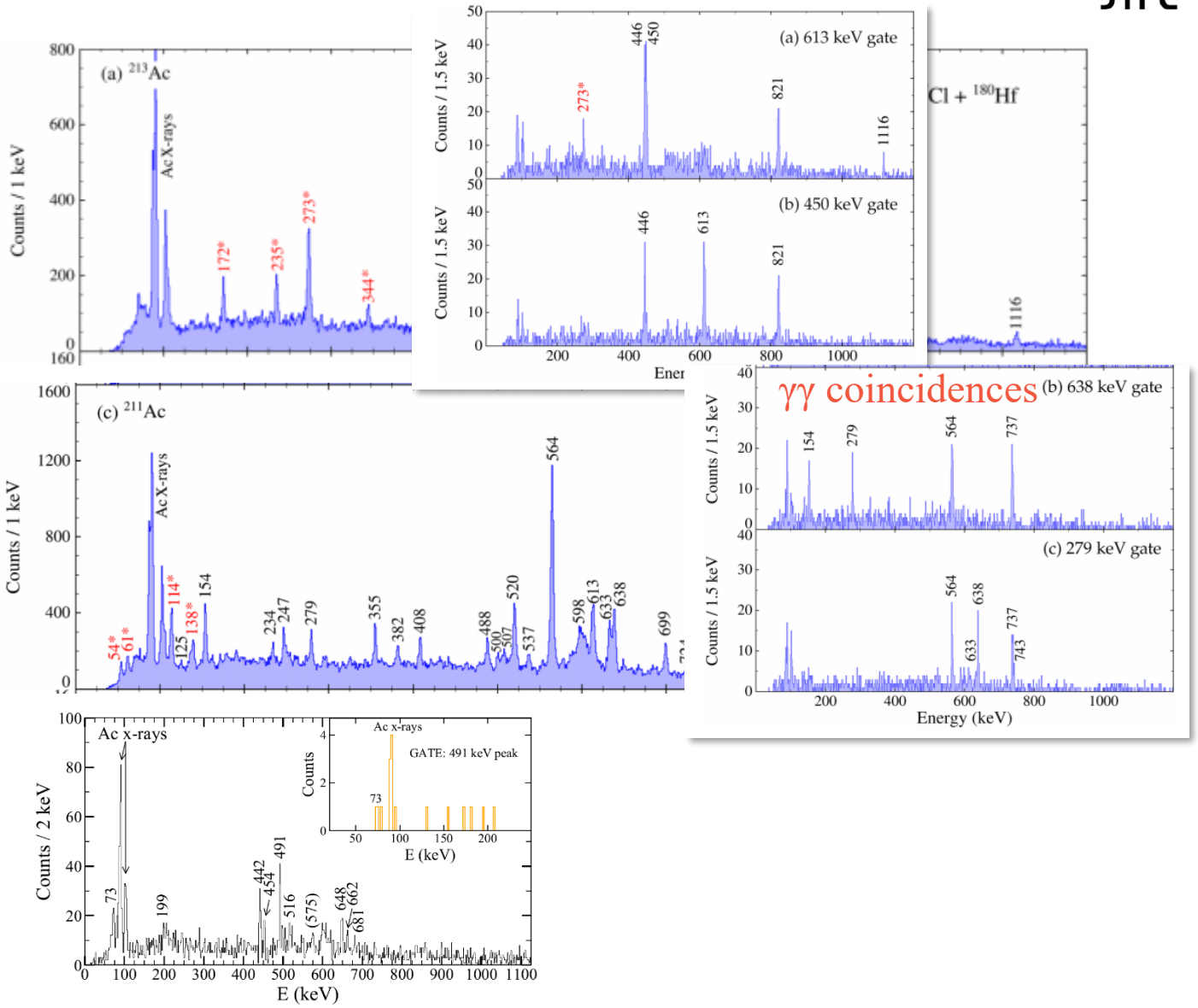


Results

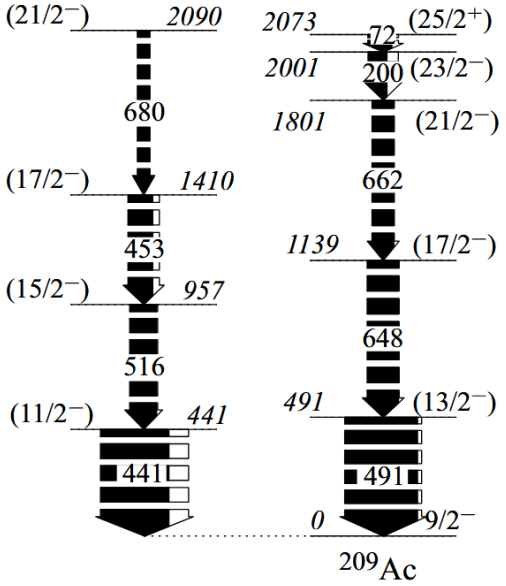
^{213}Ac

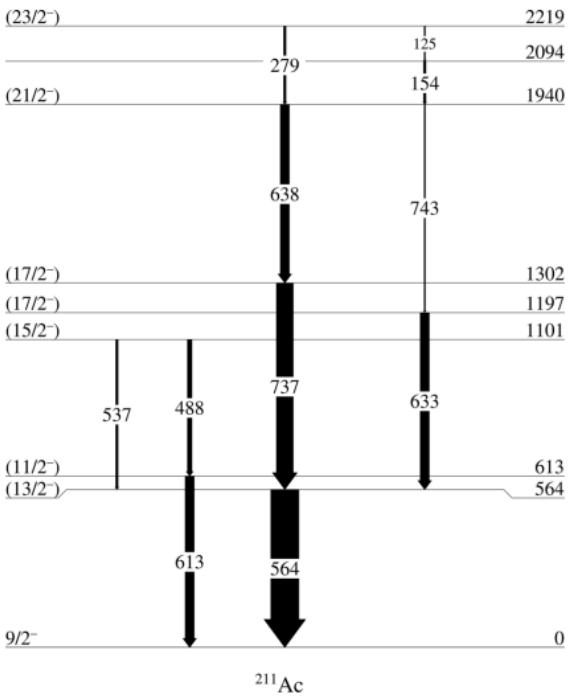
^{211}Ac

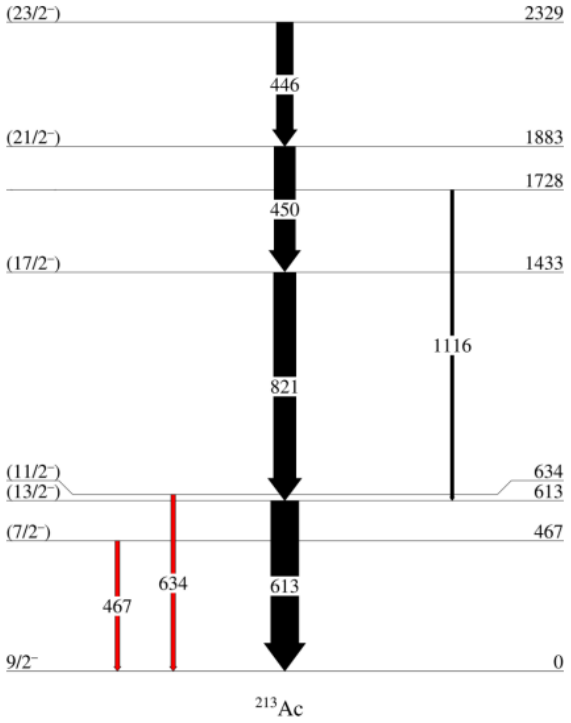
^{209}Ac



Results (level schemes)

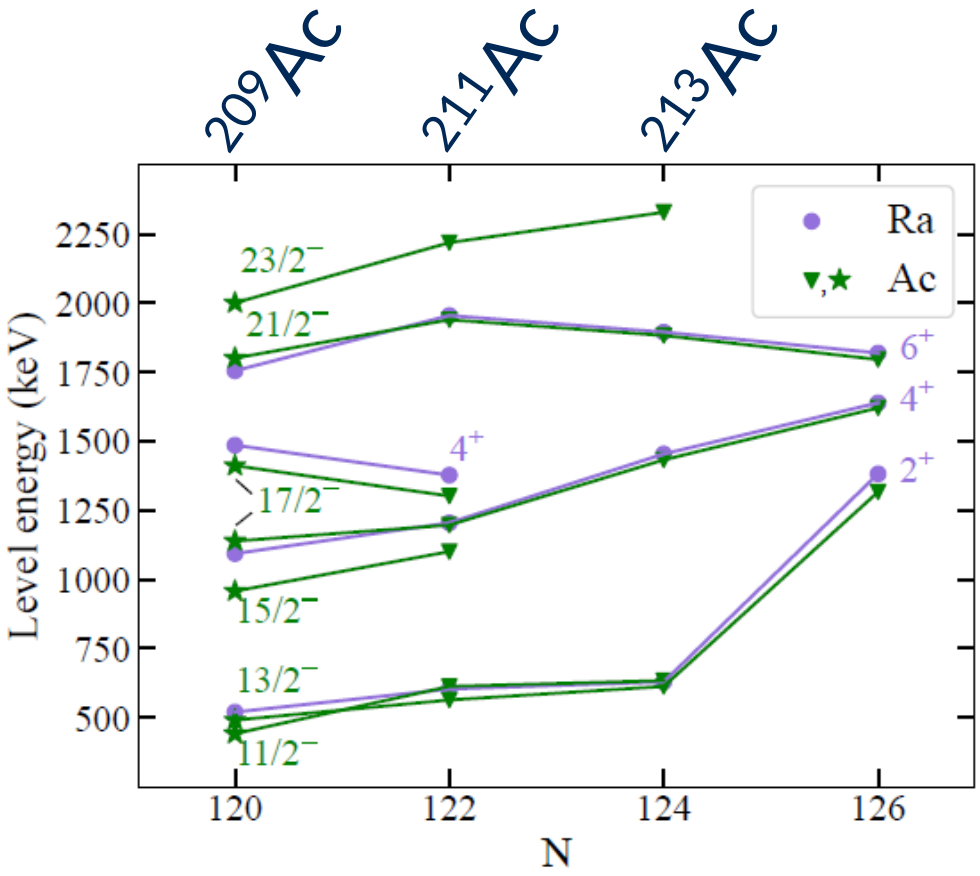






^{209}Ac ^{211}Ac ^{213}Ac

Results (systematics)



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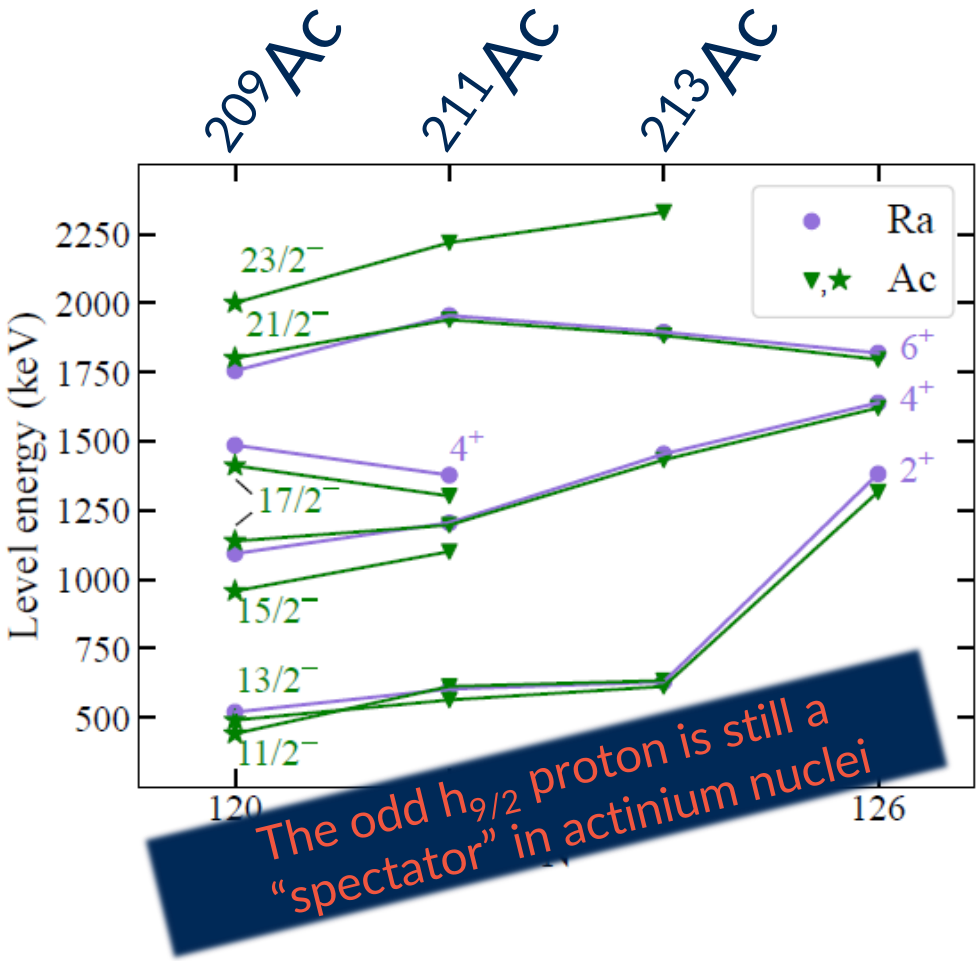
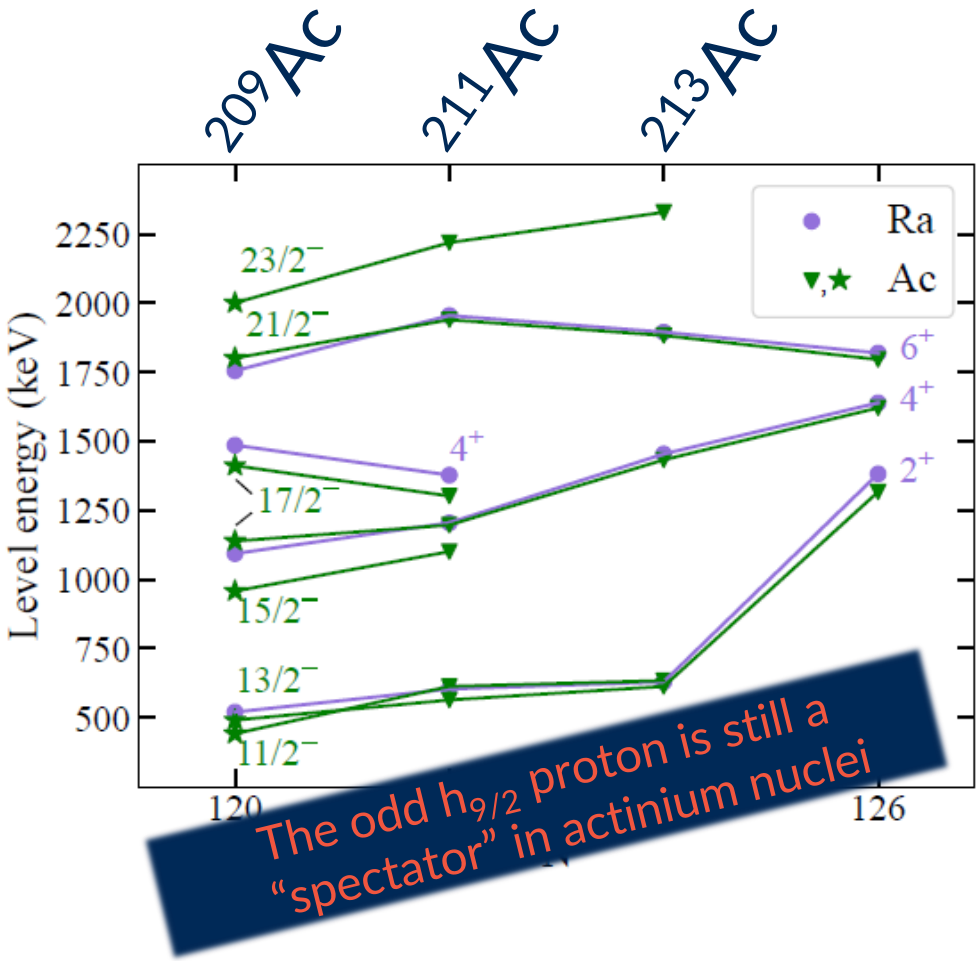


The odd $h_{9/2}$ proton is still a "spectator" in actinium nuclei

Results (systematics)

Alternative way to plot systematics:

-States come down in energy as the nucleus gets deformed



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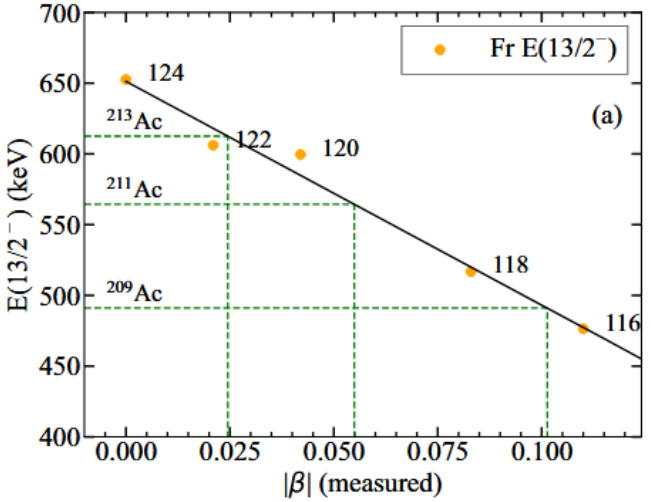
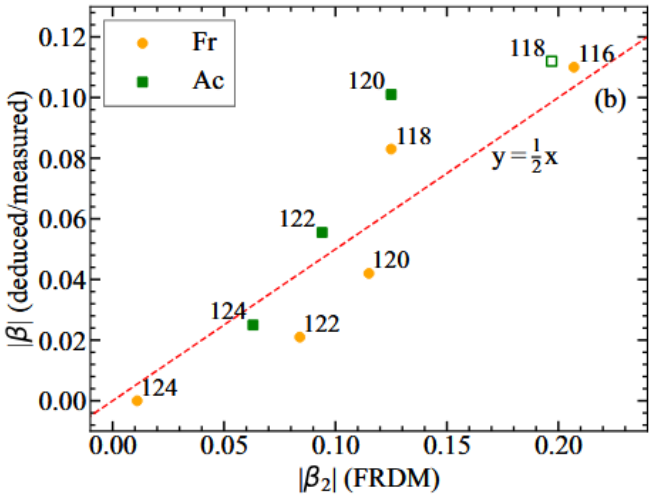
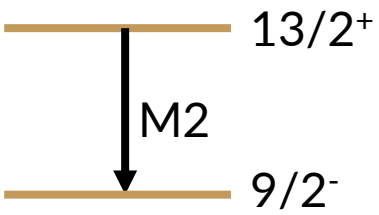
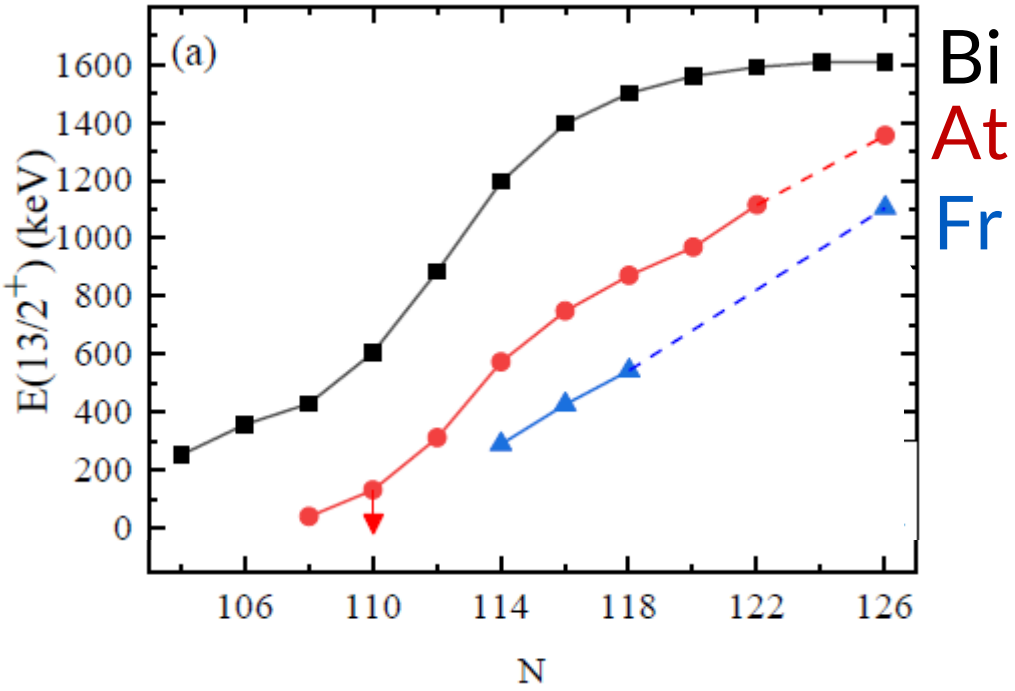




Bonus result: $13/2^+$ ($\pi i_{13/2}$) isomer in ^{207}Ac





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- No sign in 209-213 actiniums

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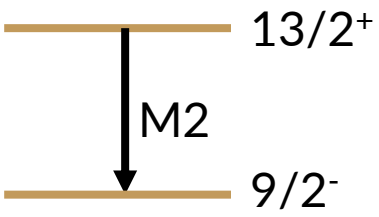

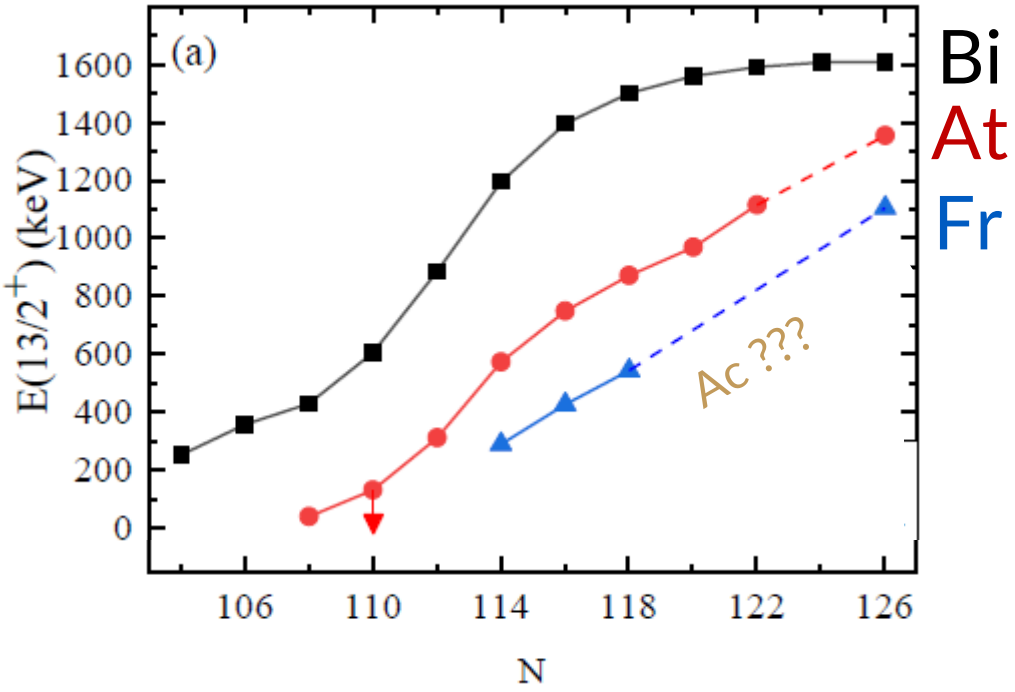

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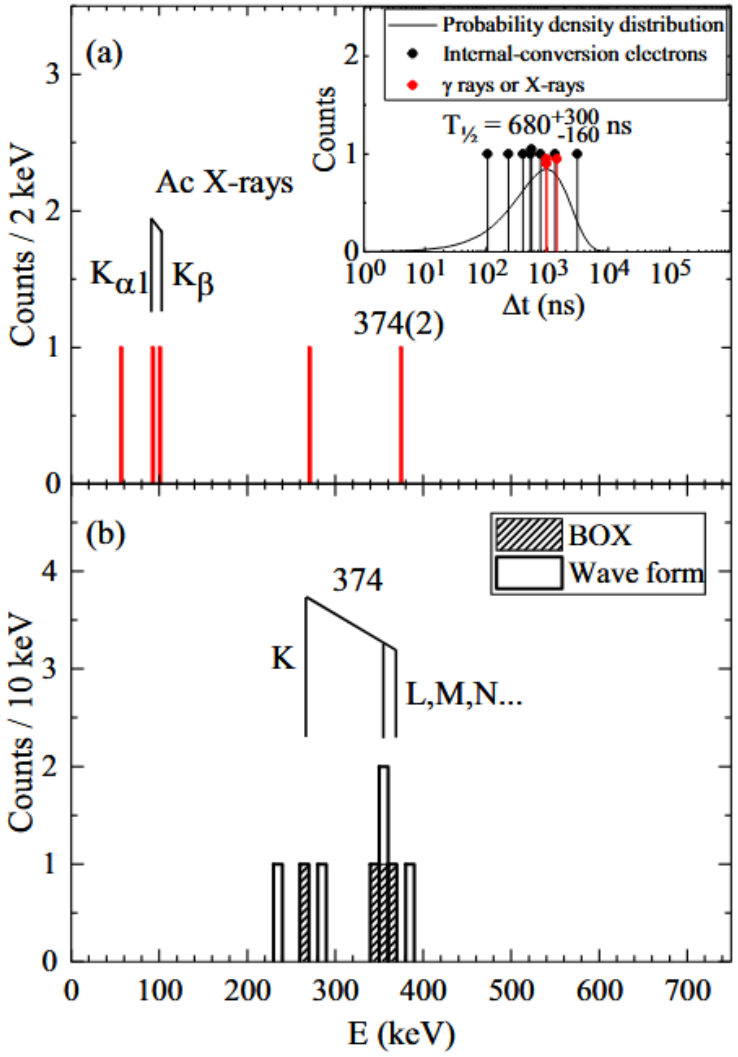

γ-rays at RITU FP array, correlated with ^{207}Ac α decay

Internal conversion electrons, correlated with ^{207}Ac α decay

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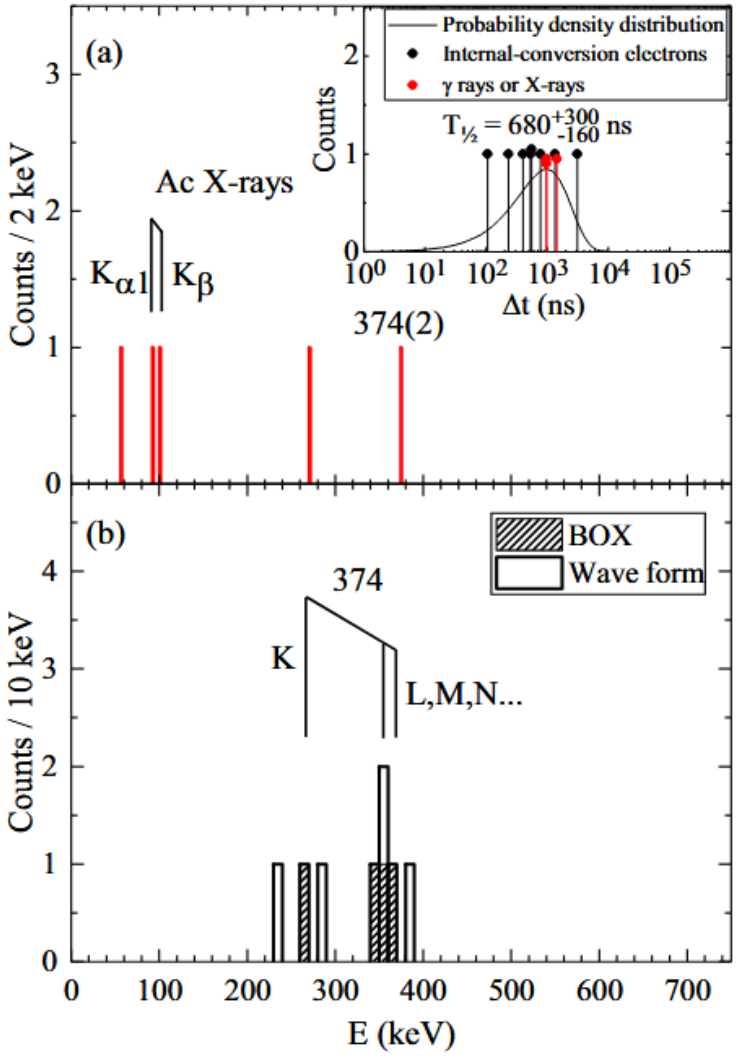
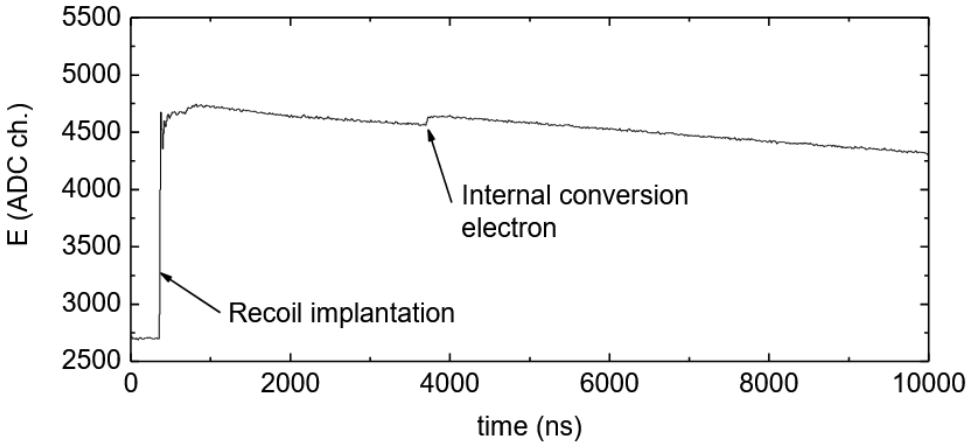


γ-rays at RITU FP array, correlated with ^{207}Ac α decay

Example waveform (”trace”) with IC event



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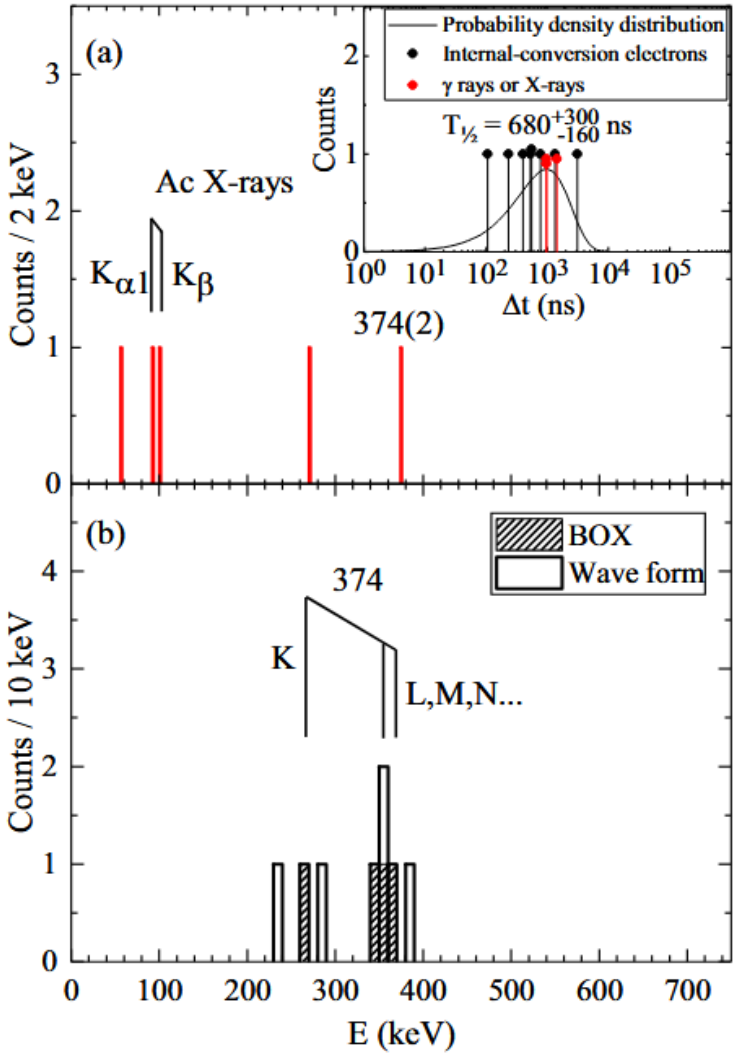

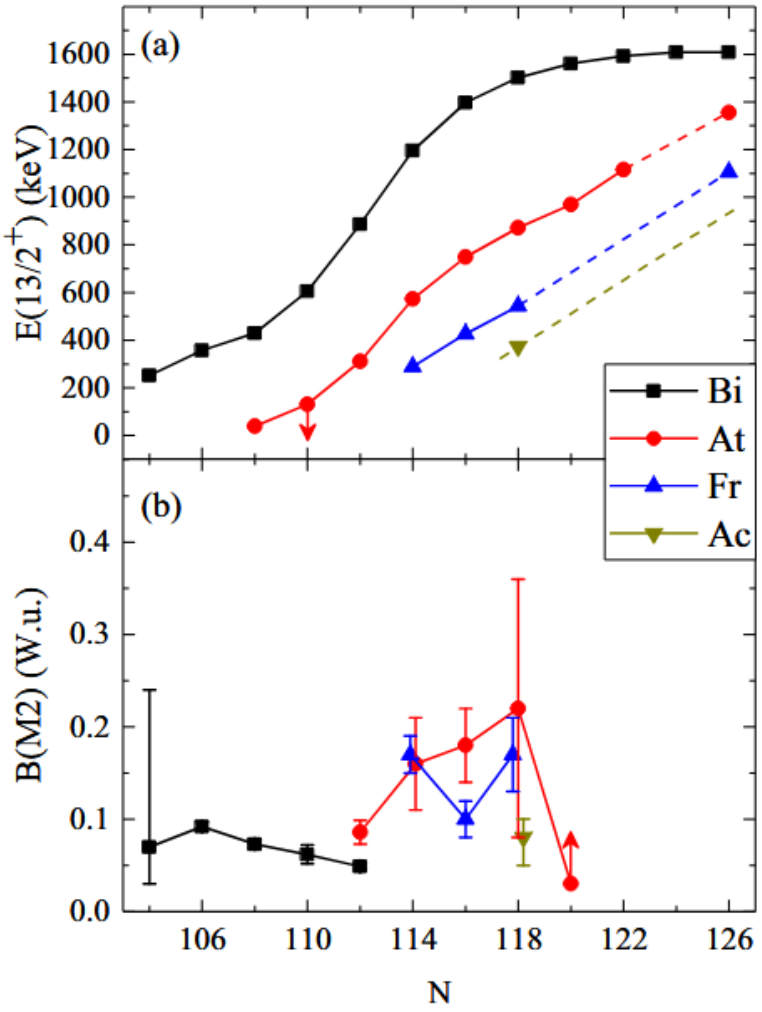

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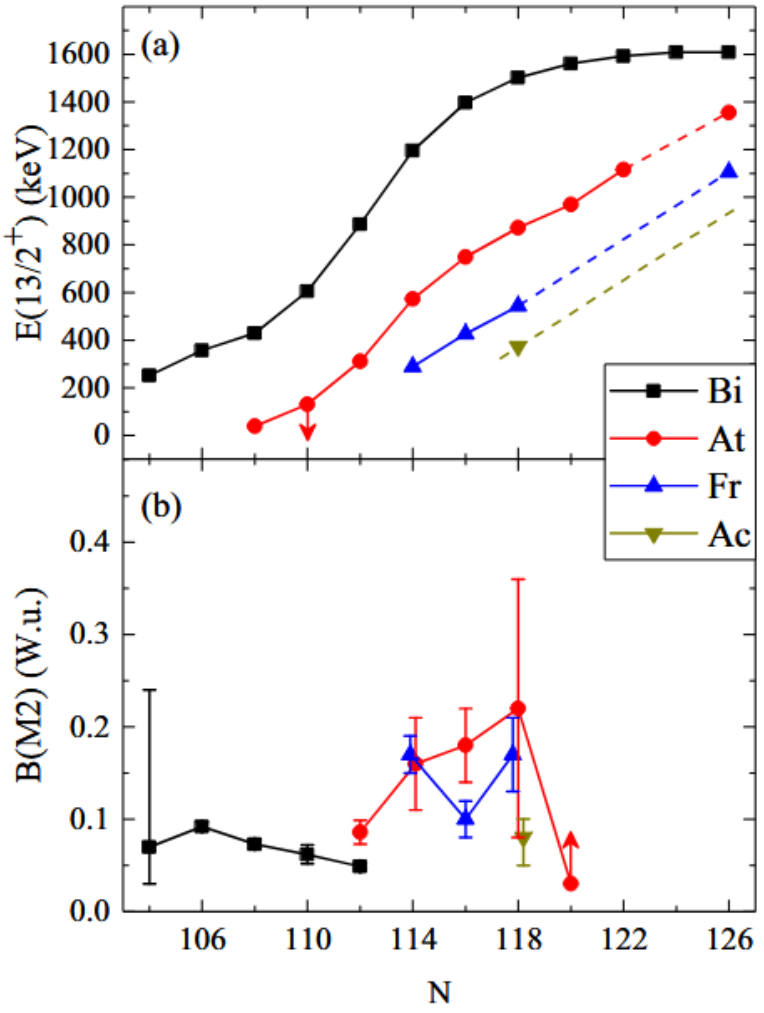
Why can't we see the state in ^{209,211,213}Ac???

- Slope from At and Fr
  - Offset from ^{207}Ac
  - Extrapolate level energies…

- Assume B(M2) = 0.1 W.u.
  → Calculate half-life

^{A}Ac	E($13/2^+$) [keV]	$T_{½}$ [ns]
^{213}Ac	790	25
^{211}Ac	650	60
^{209}Ac	520	160



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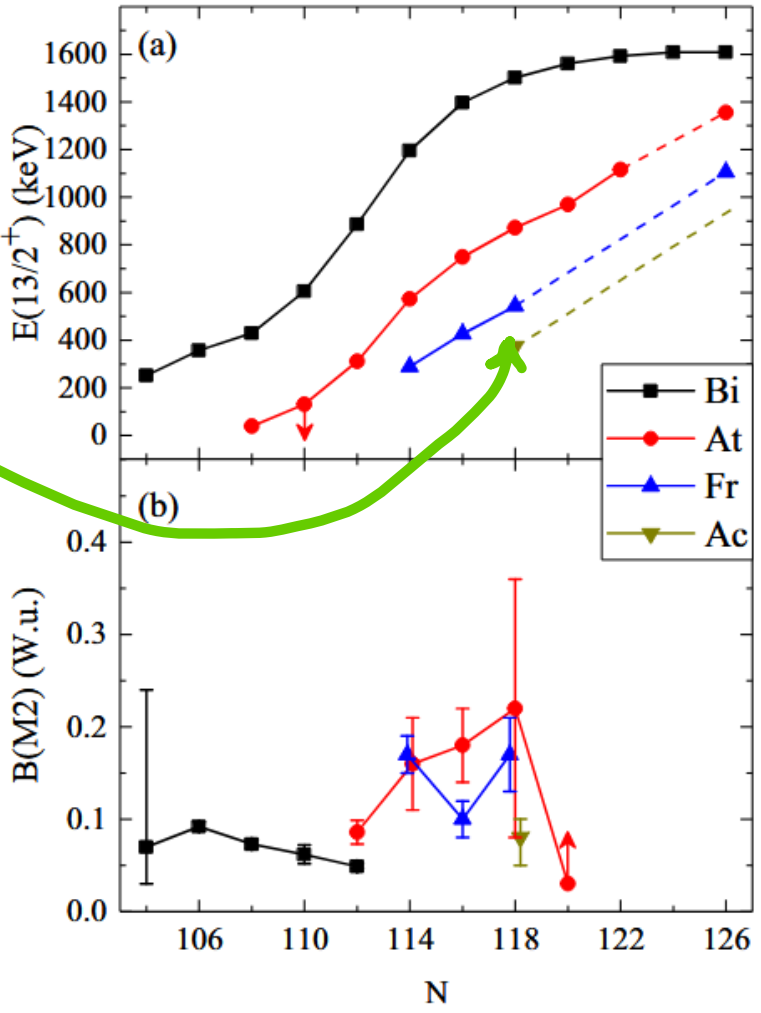

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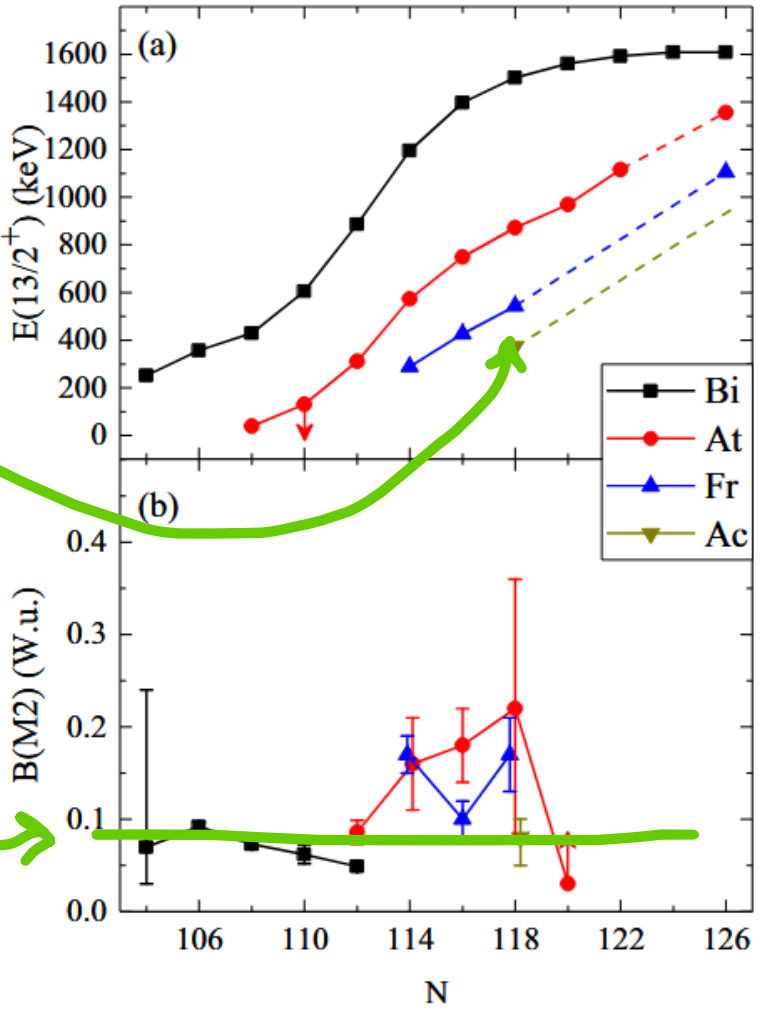

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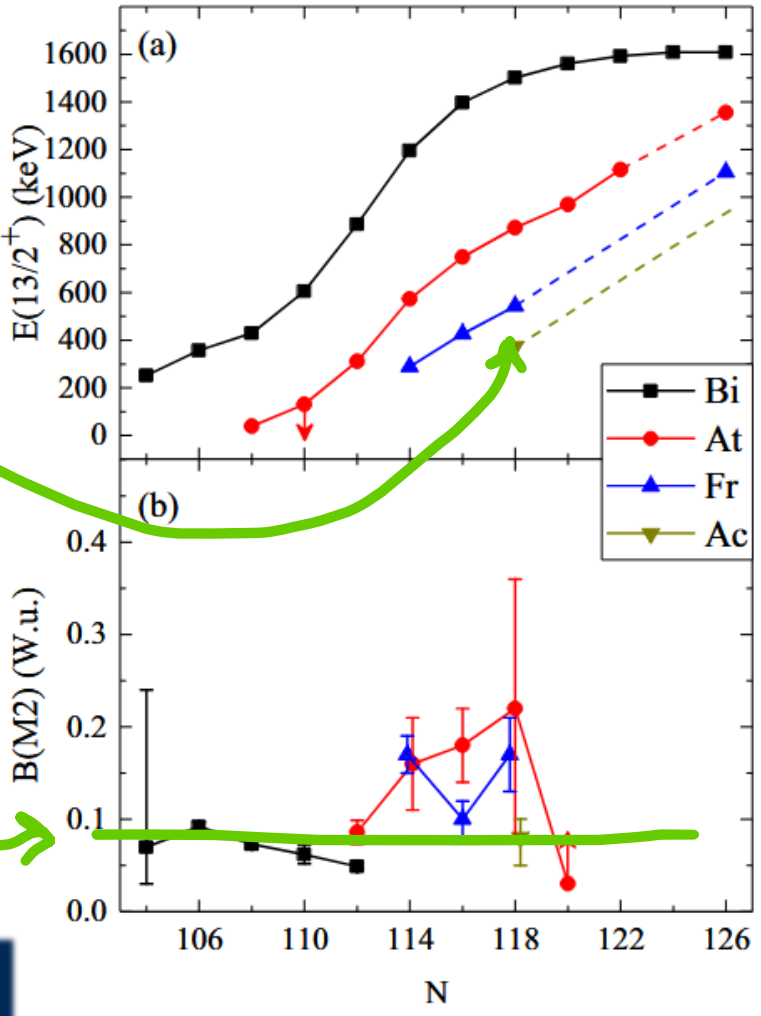

- TOF through separator ~ 0.5 – 1 µs
→ In-flight decay

Final remarks

- Prompt and delayed spectroscopy for odd-mass $^{207\text{-}213}$Ac isotopes was performed at JYFL-ACCLAB
  - The odd $h_{9/2}$ proton is still a “spectator” in ^{209,211,213}Ac nuclei
  - First observation of isomeric states in N<126 Ac nuclei
    - $13/2^+$ ($\pi i_{13/2}$)

- ^{211,213}Ac results published
  - J. Louko *et al.* PRC 110, 034311 (2024)

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  - The odd $h_{9/2}$ proton is still a “spectator” in ^{209,211,213}Ac nuclei
  - First observation of isomeric states in N<126 Ac nuclei
    - $13/2^+$ ($\pi i_{13/2}$)

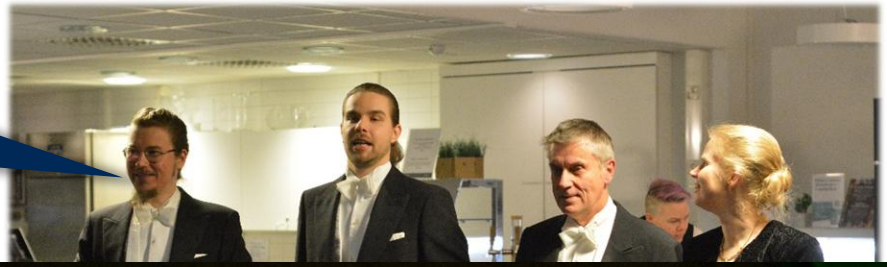
- ^{211,213}Ac results published
  - J. Louko *et al.* PRC 110, 034311 (2024)

- ^{209,207}Ac manuscript just published
  - H. Kokkonen *et al.* PRC 113, 034309 (2026)

See my talk / Nature paper

Final remarks

See you in PROCON2027



- [illegible]
  mas[illegible]
  JYFL-ACCEL[illegible]
  - The odd h[illegible] proton is still a "spectator" in