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In-source laser spectroscopy of mercury isotopes (P-424)

Liam Gaffney
Tom Day Goodacre
Andrei Andreyev
Maxim Seliverstov

RILIS, Windmill, and ISOLTRAP collaborations

The beginnings

Letter of Intent to the ISOLDE and Neutron Time-of-Flight Committee

In-source laser spectroscopy of mercury isotopes

30th September 2013

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“Having a better source of light mercury isotopes will undoubtedly be important for improved nuclear-structure studies in this region, which presents numerous fascinating properties.

*Thus, the committee **endorsed** the Letter of Intent.”*

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Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Today!

In-source laser spectroscopy of mercury isotopes

October 10, 2014

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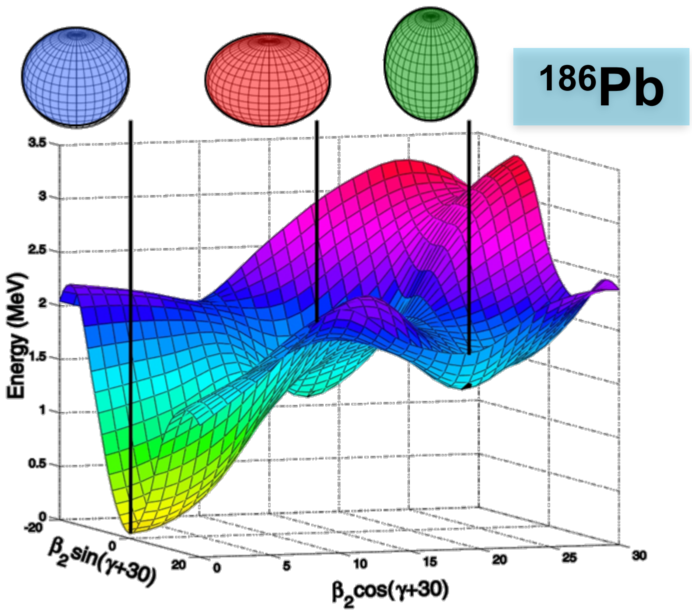
Shape coexistence

- Different types of deformation at low excitation energy
- Interplay between two opposing tendencies
  - Stabilizing effect of closed shells
  - Residual proton-neutron interaction

Heyde and Wood, Review of Modern Physics (2011)



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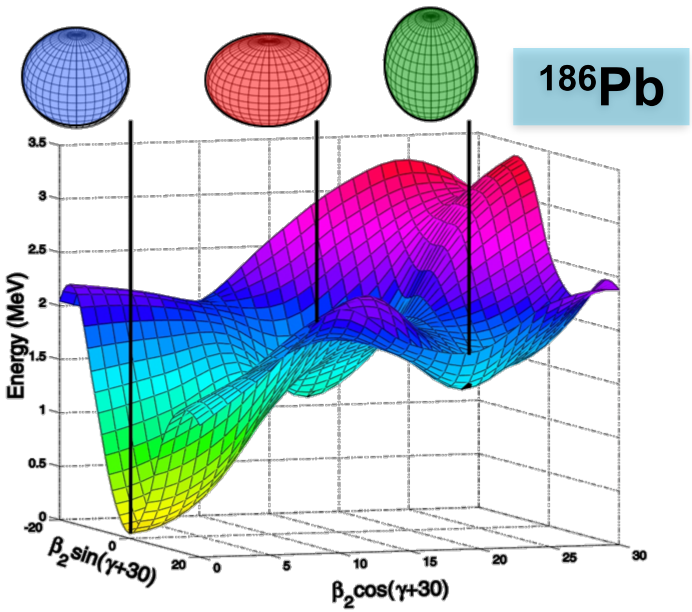

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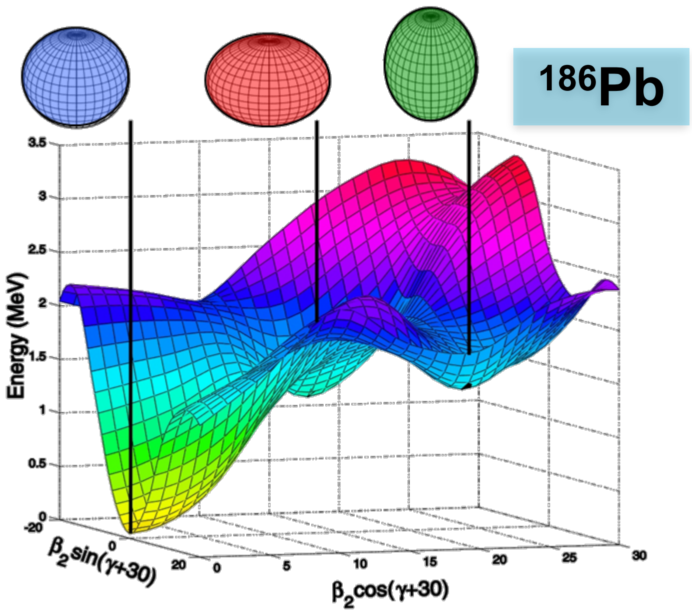

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- Evidence across the light-lead region
- Lack of experimental information
  - Nature of deformation
  - Degree of mixing
- Complementary experimental approach required.

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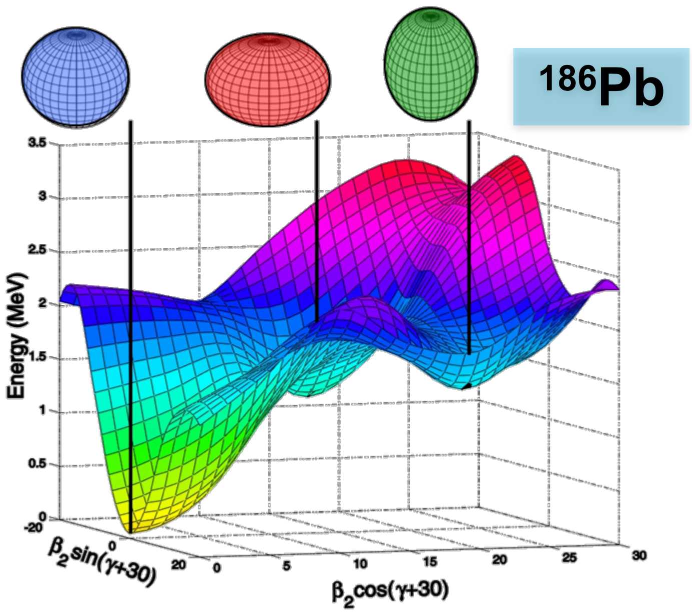

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- Lack of experimental information
  - Nature of deformation
  - Degree of mixing
- Complementary experimental approach required.

- Case and point - ^{182,184,186,188}Hg Coulex (IS152)…

  In-beam; laser spec.; decay spec.; lifetimes…
  then Coulex

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A complementary experimental picture: Shape coexistence around Z=82

- **Energy-level** systematics show intruder structure, usually parabolic.
  - ➢ In-beam and decay spectroscopy

L. P. Gaffney et al, PRC **89**, 024307 (2014)
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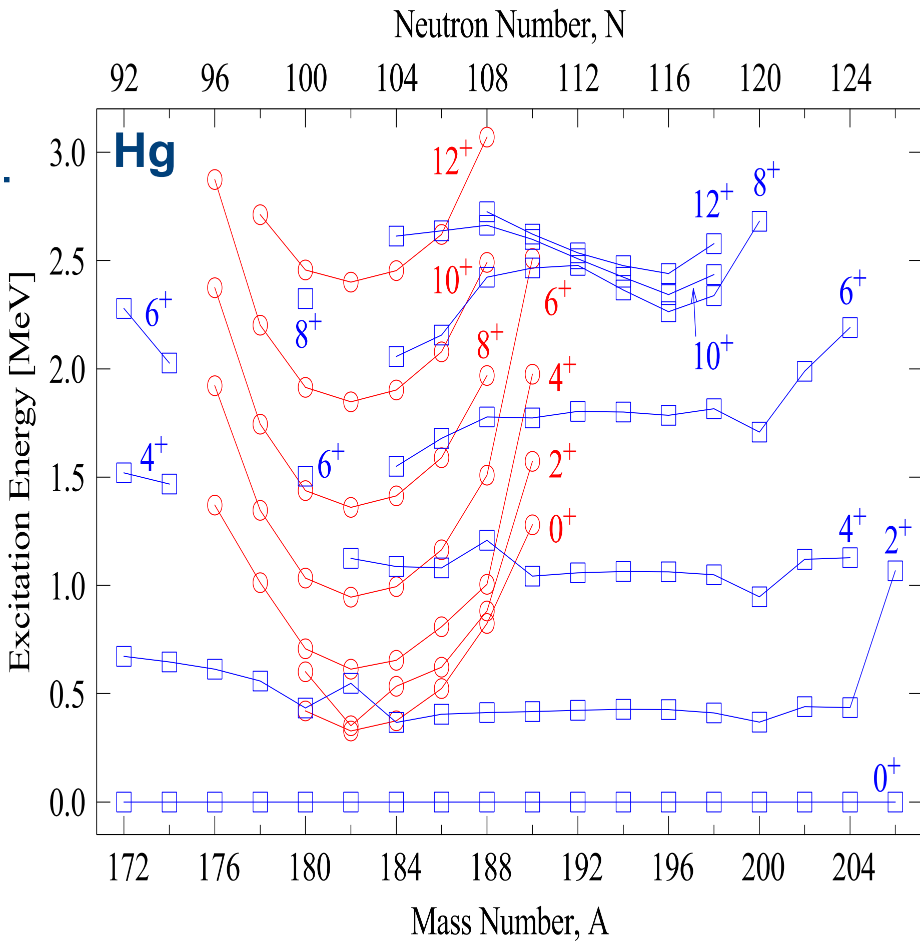

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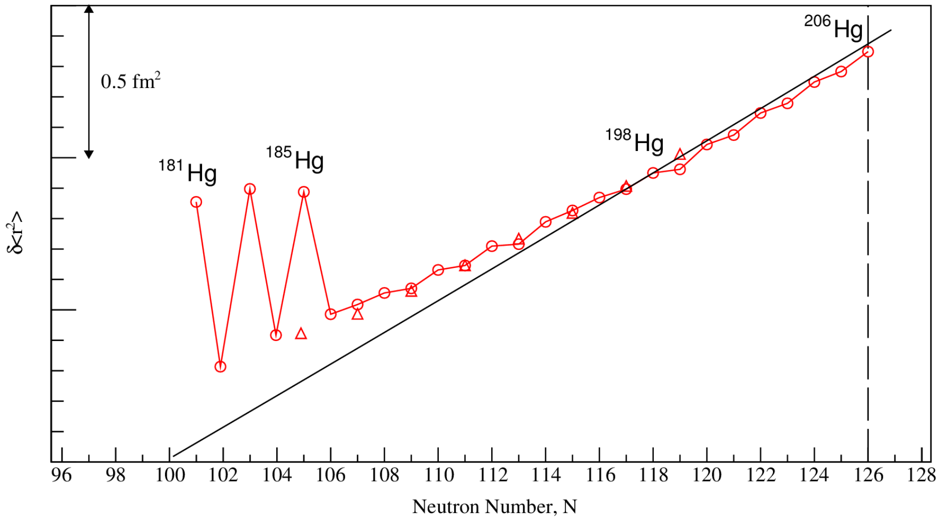

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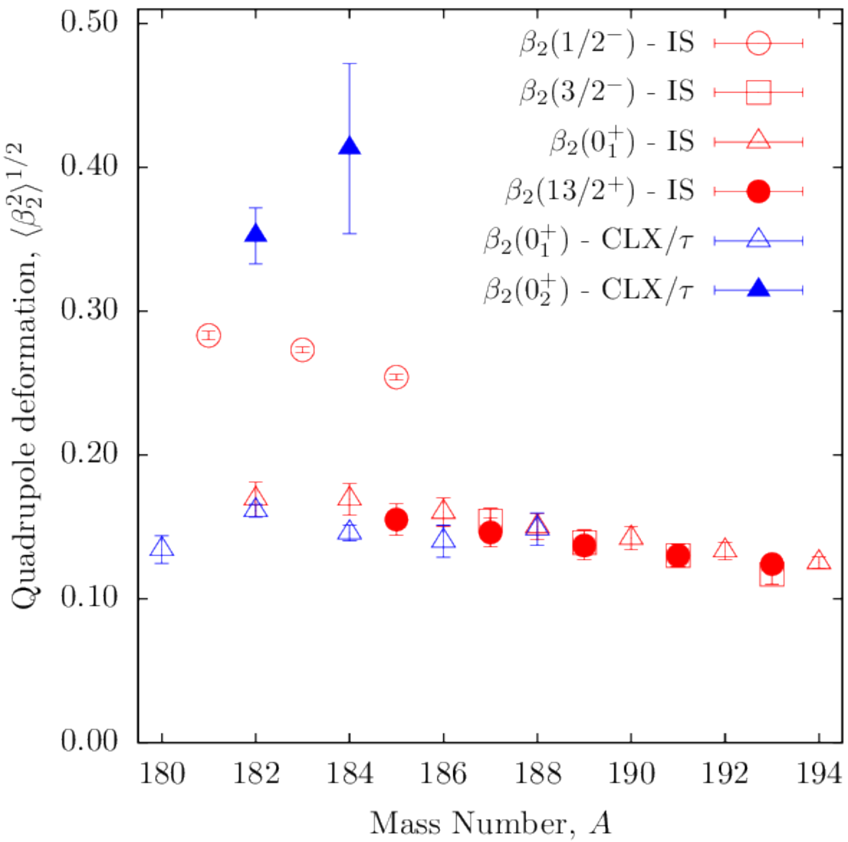
- **Energy-level** systematics show intruder structure, usually parabolic.
  - ➢ In-beam and decay spectroscopy
- **Charge radii** reveal the onset of deformation.
  - ➢ Optical and Laser spectroscopy (!)
- **B(E2)'s** and **quadrupole moments** complete picture of shape.
  - ➢ Lifetimes, Coulomb excitation, laser spec.



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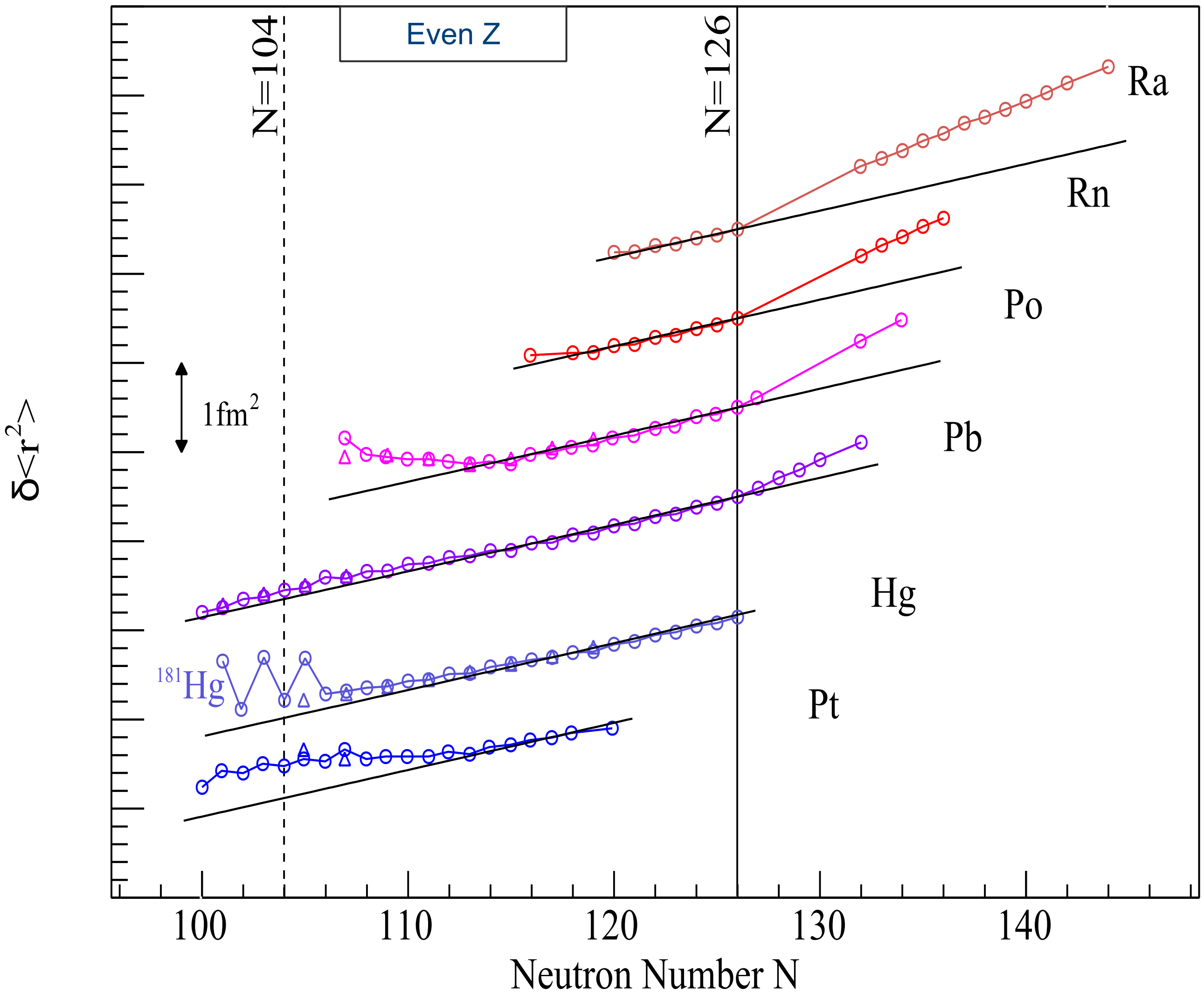
Mean-square charge radii around Z=82



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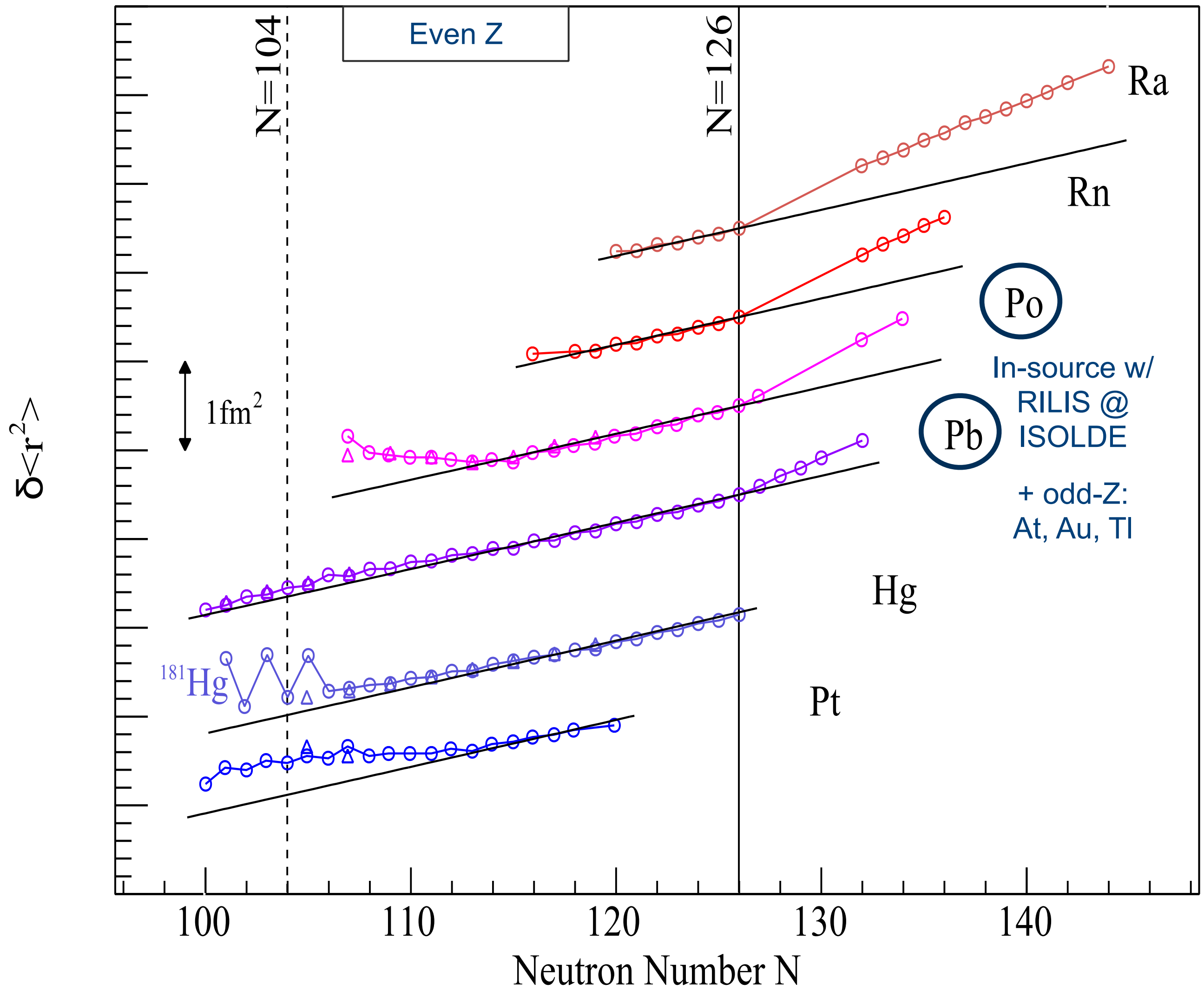

In-source w/ RILIS @ ISOLDE

+ odd-Z: At, Au, Tl

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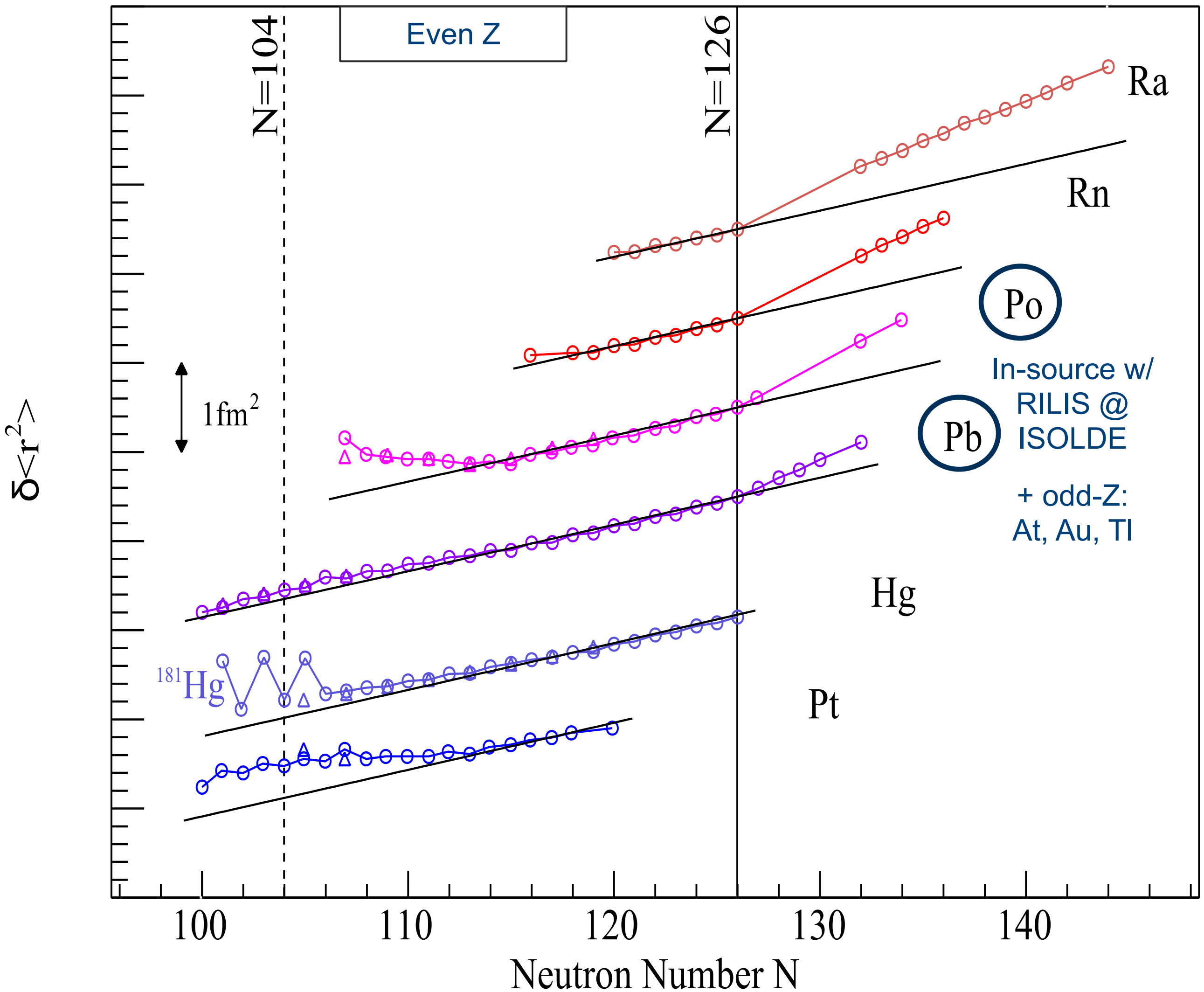
Mean-square charge radii around Z=82

- Odd-even staggering of charge radii in Hg

  Shape coexistence

  ν-orbitals below N=104



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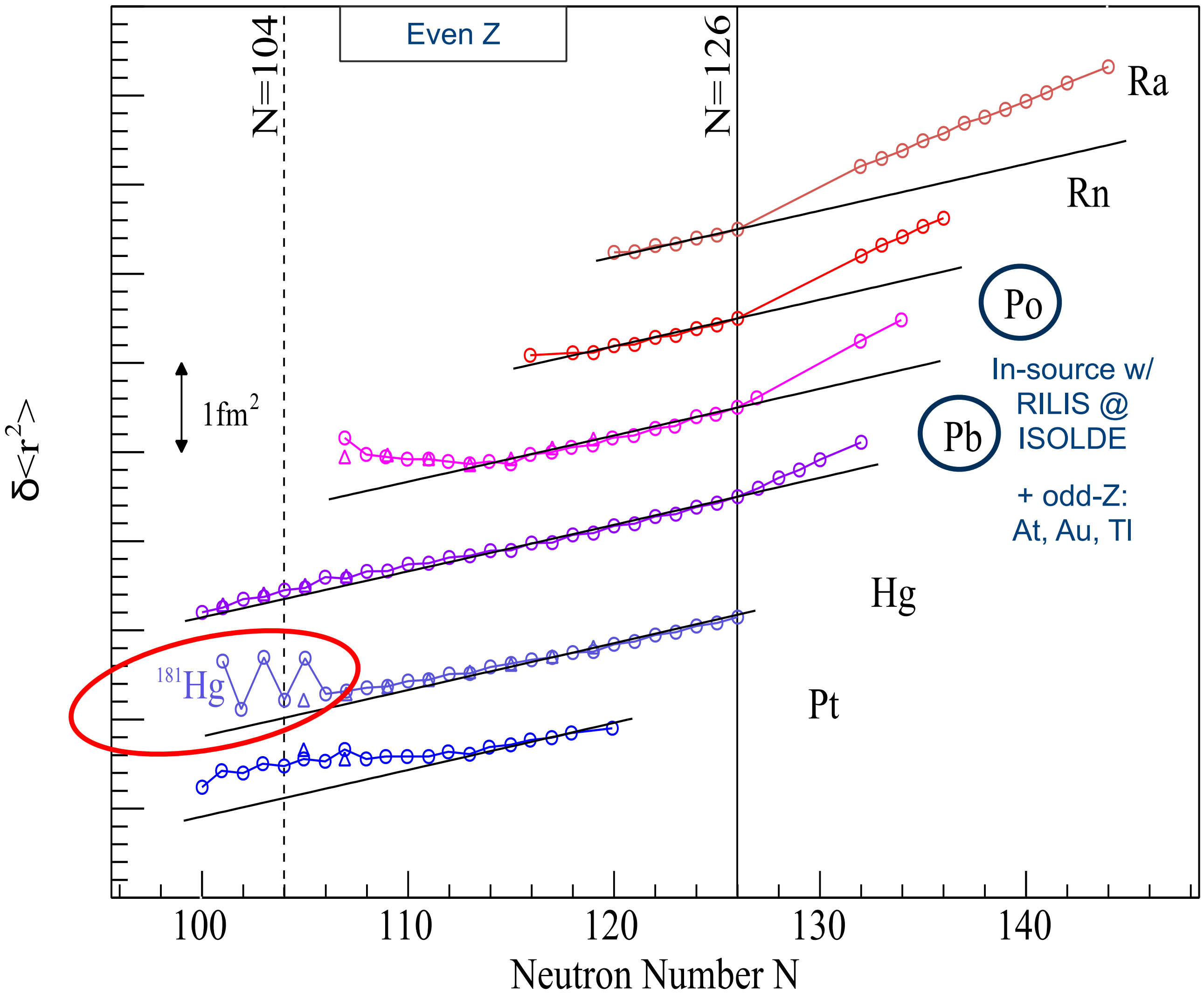

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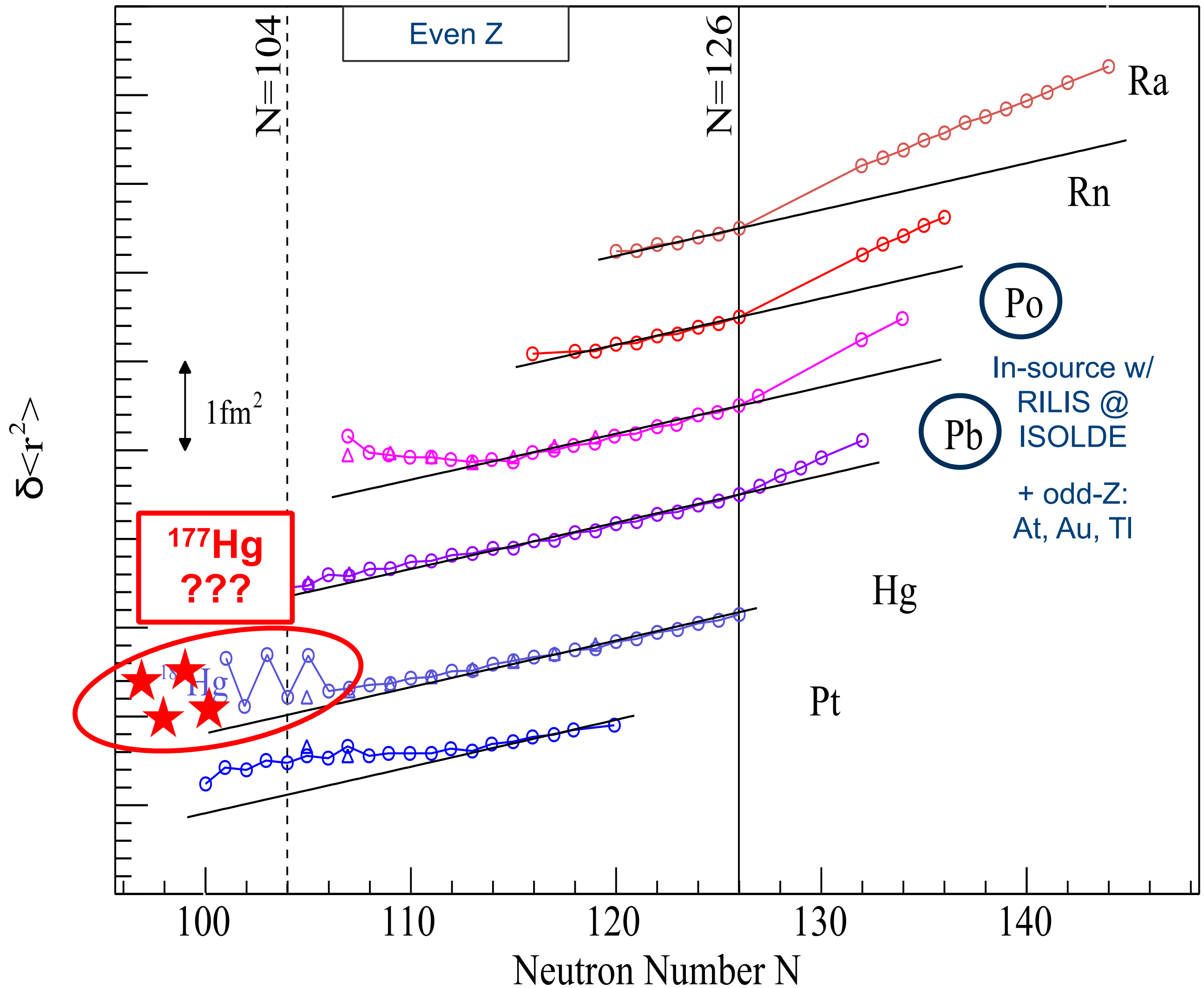

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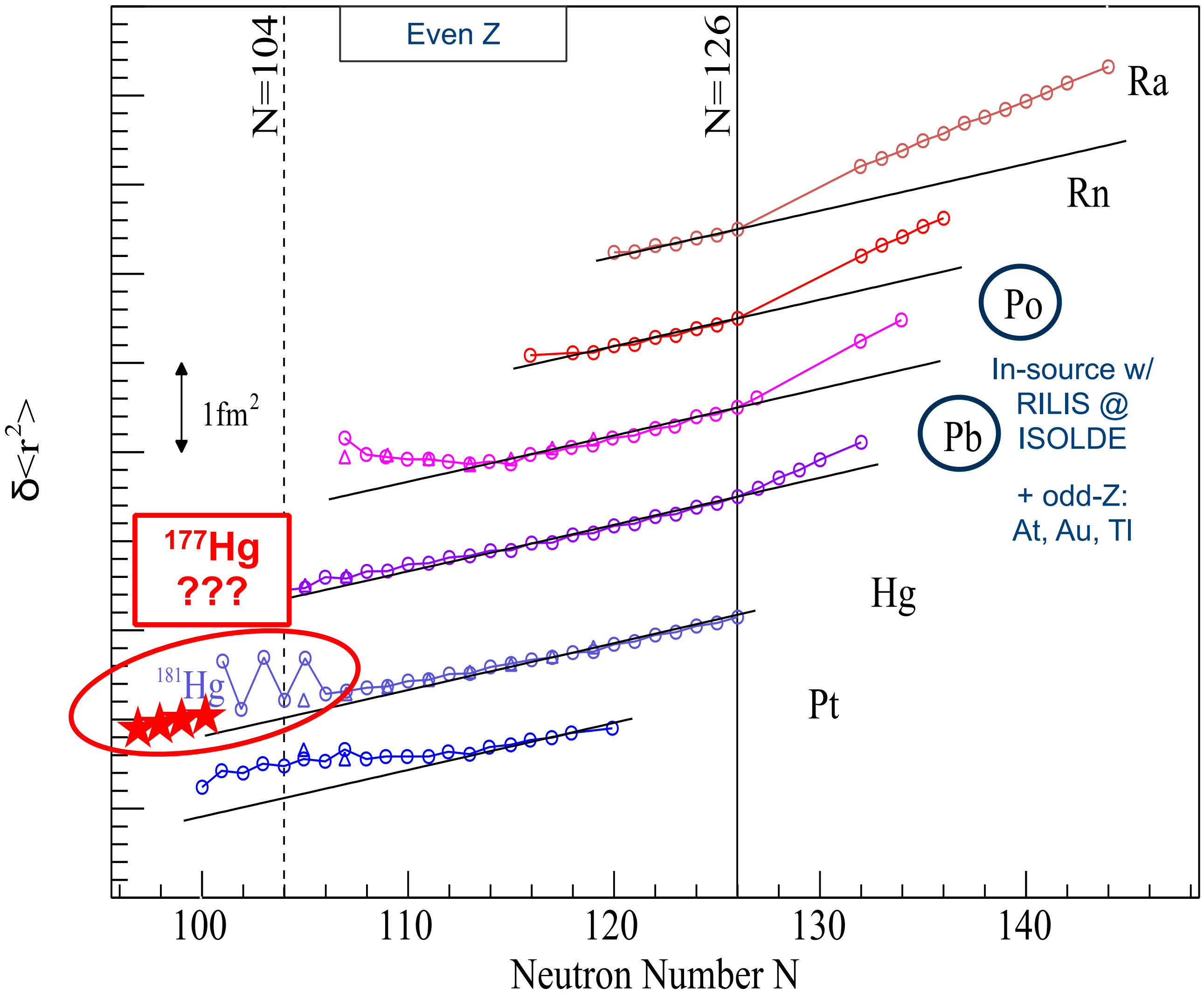

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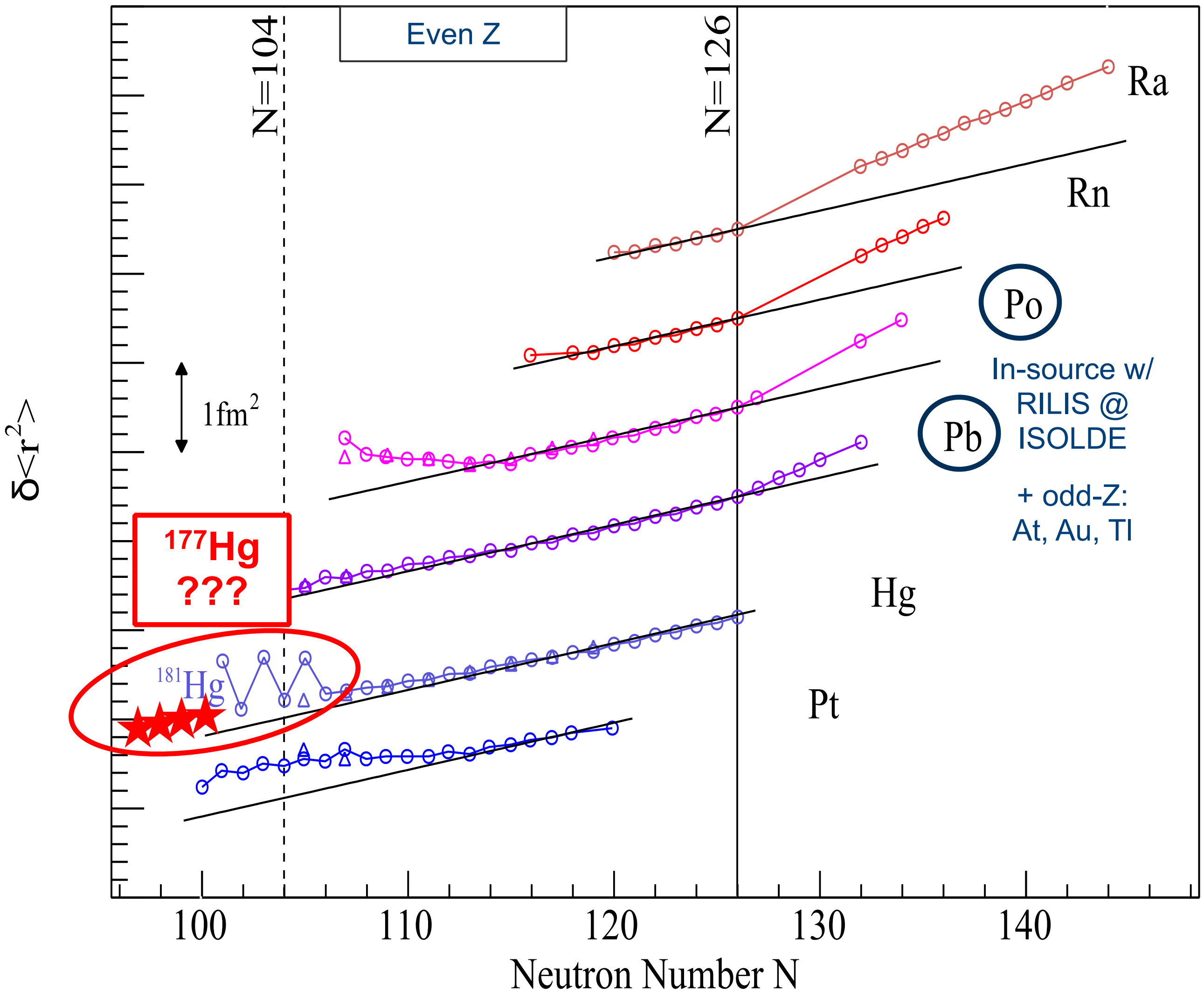

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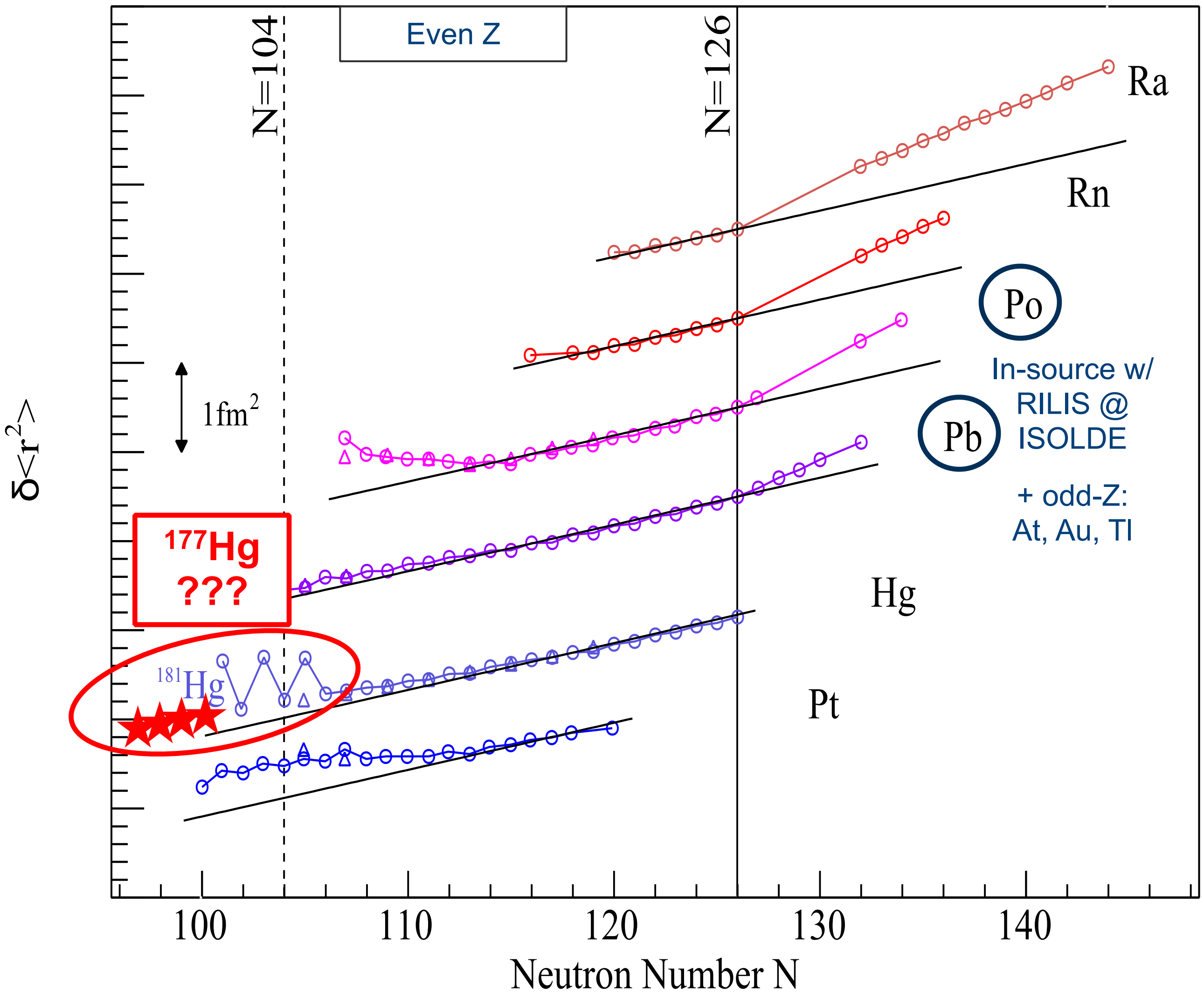
  - ^{177,178,179,180}Hg



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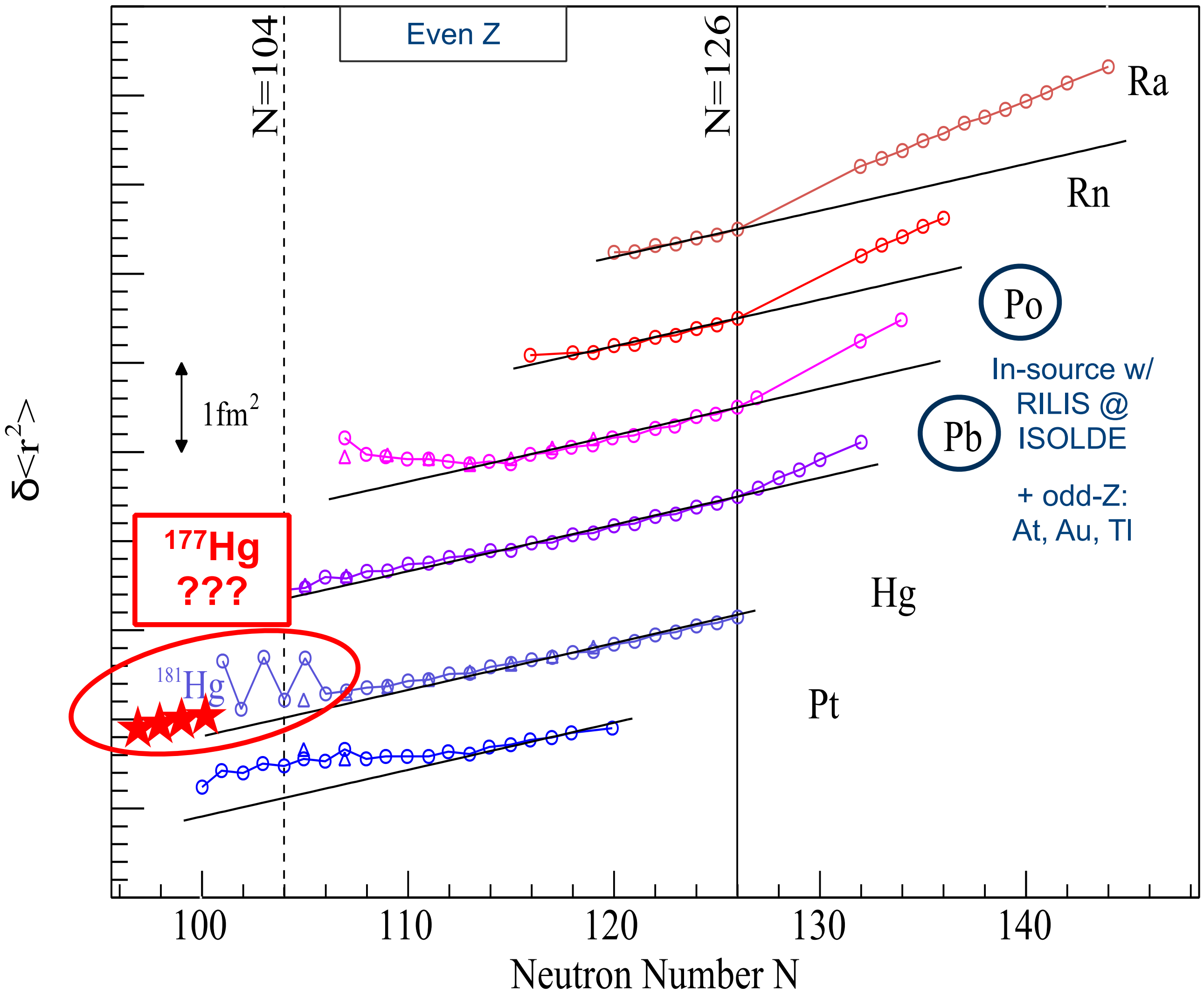
- "Kink" in charge radii above N=126 for Z≥82



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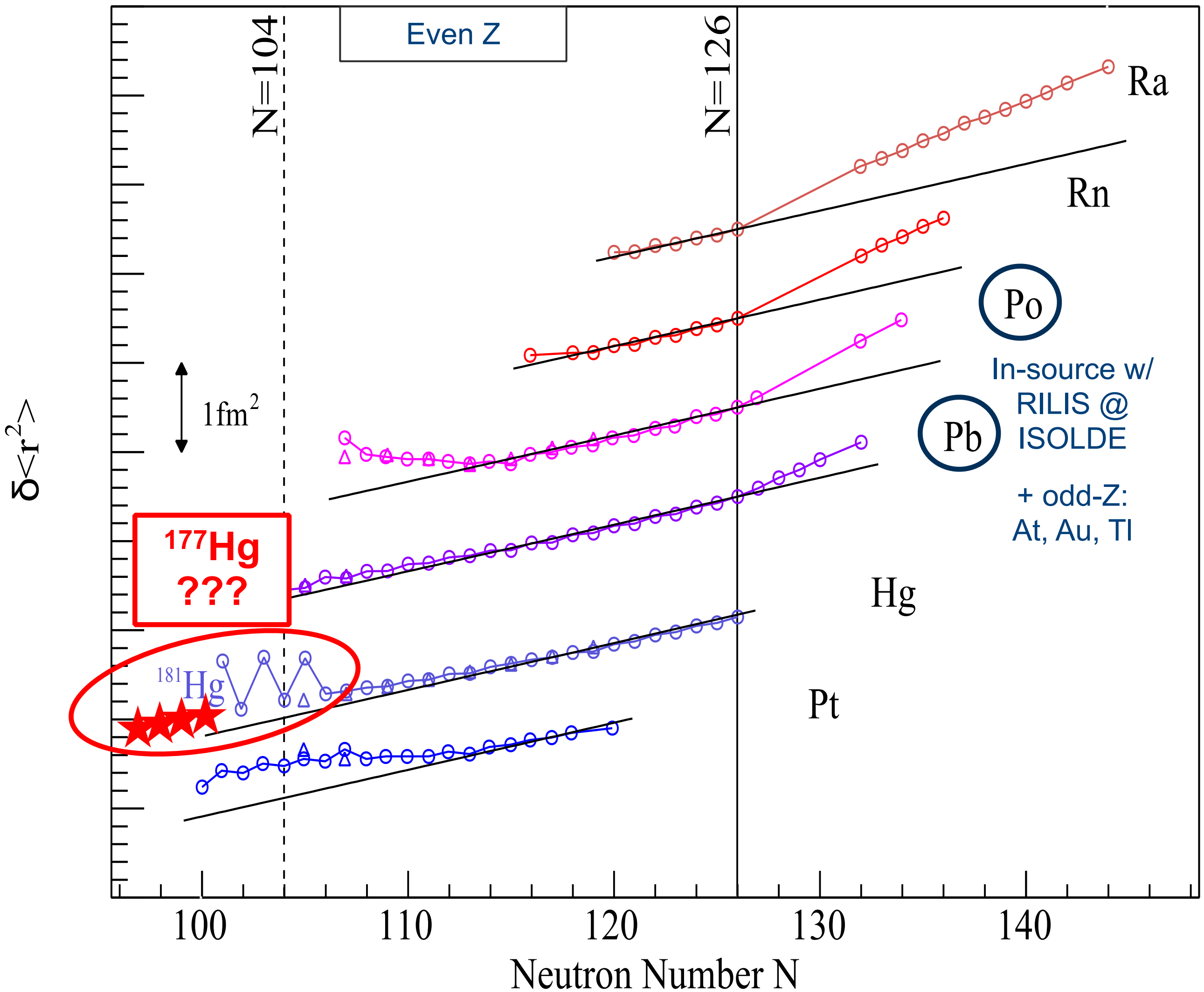
  Population of $\nu(i_{11/2})$?



In-source w/ RILIS @ ISOLDE

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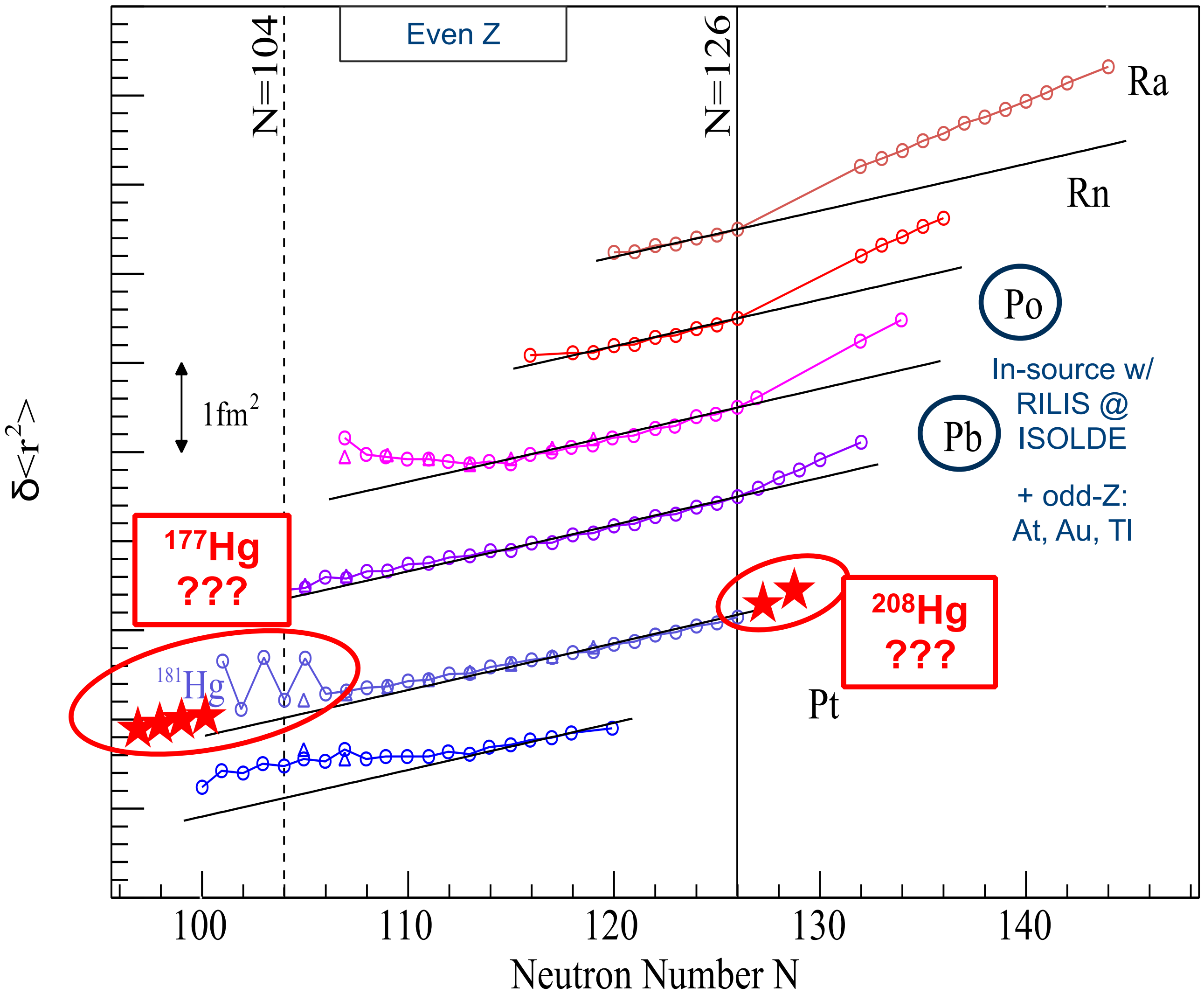
  - ^{177,178,179,180}Hg

- "Kink" in charge radii above N=126 for Z≥82
  Population of $\nu(i_{11/2})$?

  - ^{207,208}Hg would represent first measurement in Z<82



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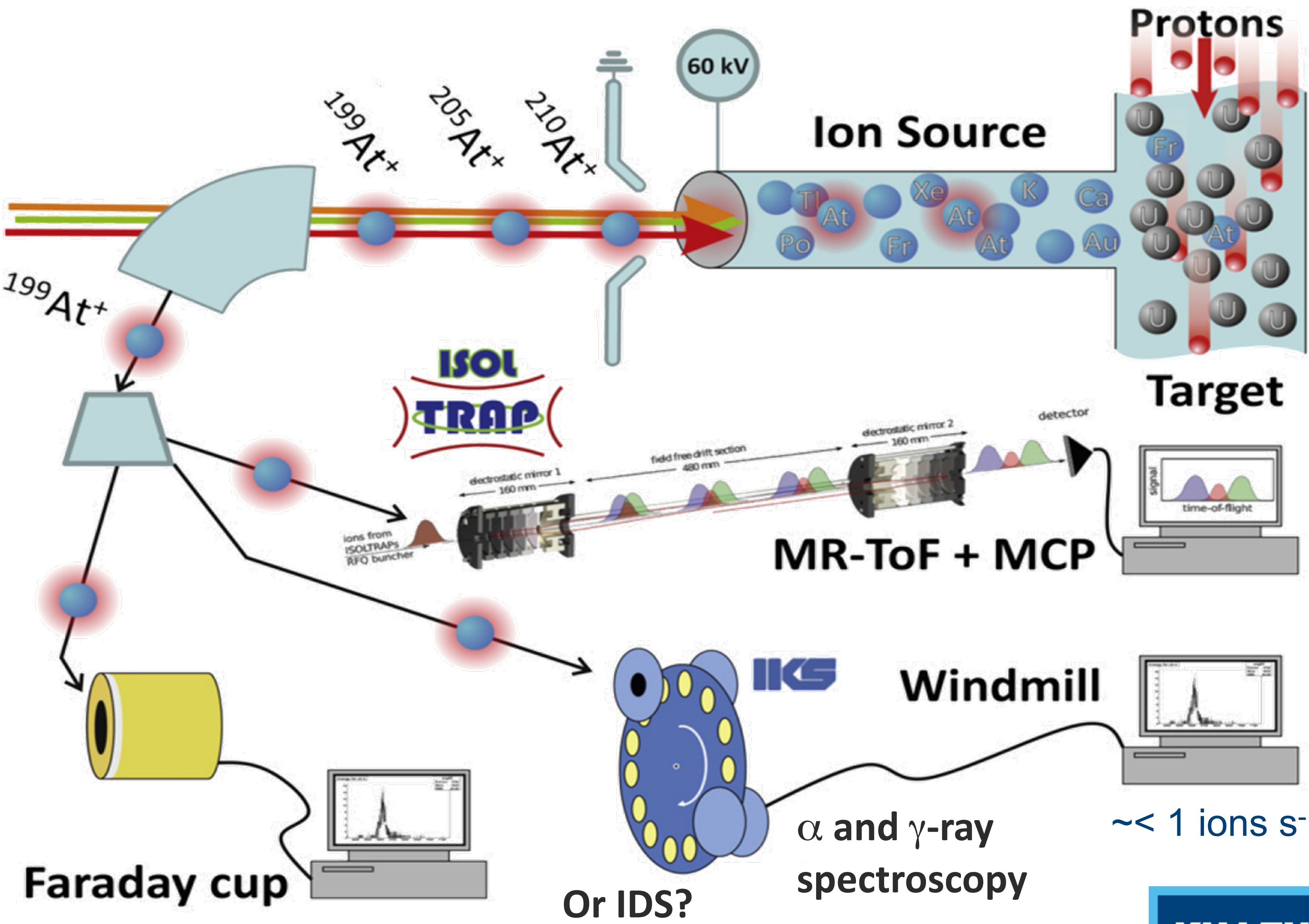
Measurement Tools: WM, FC, MR-TOF MS



RILIS: B. A. Marsh et al., 2013 EMIS conference, NIM B317, p.550 (2013)
WM: A.Andreyev et al, Phys. Rev. Lett 105, 252502 (2010)
MR-ToF MS: R. N. Wolf et al, NIM, A686, 82 (2012)

LOI-153 Tests (21st Aug. – 1st Sept. 2014)

Improve ionisation efficiency by >10 from current 0.1%

Part 1

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LOI-153 Tests (21^{st} Aug. – 1^{st} Sept. 2014)

Improve ionisation efficiency by >10 from current 0.1%

Part 1

Coupling of molten Pb target to RILIS

Part 2

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LOI-153 Tests (21st Aug. – 1st Sept. 2014)

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Coupling of molten Pb target to RILIS

Part 3

Yields of n-deficient Hg from Pb+VD5 and UC_x +RILIS targets

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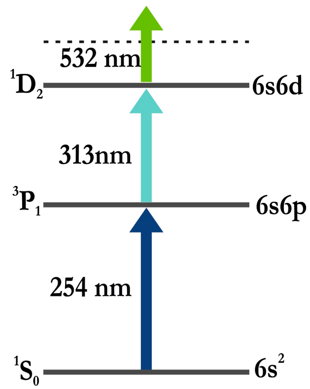
LOI-153 Tests (21st Aug. – 1st Sept. 2014)

Improve ionisation efficiency by >10 from current 0.1%

Part 1

➔ 6%

RILIS: Tom Day Goodacre



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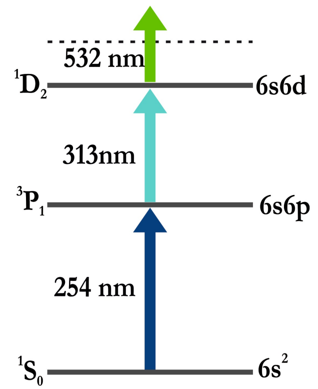

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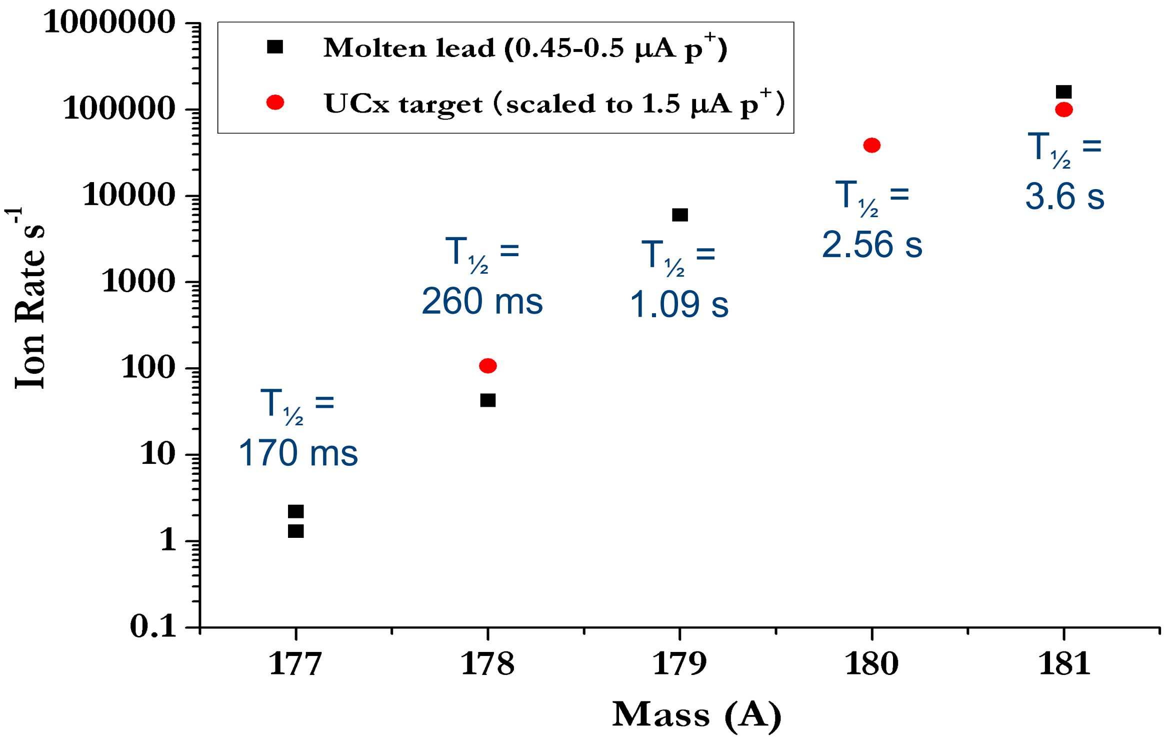

Yields of n-deficient Hg from Pb+VD5 and UC_x +RILIS targets

Part 3

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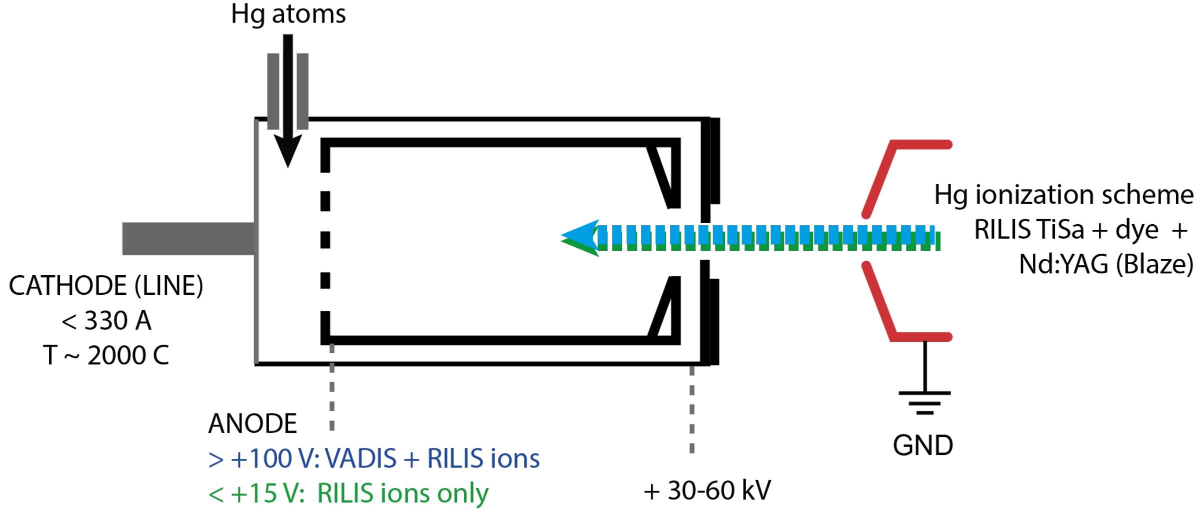
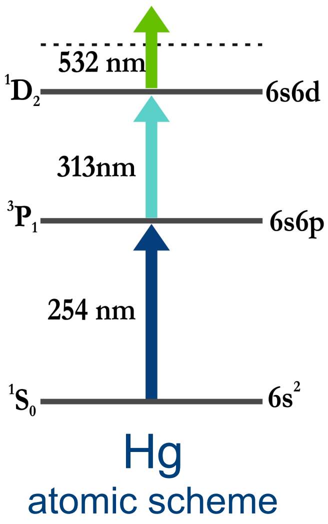
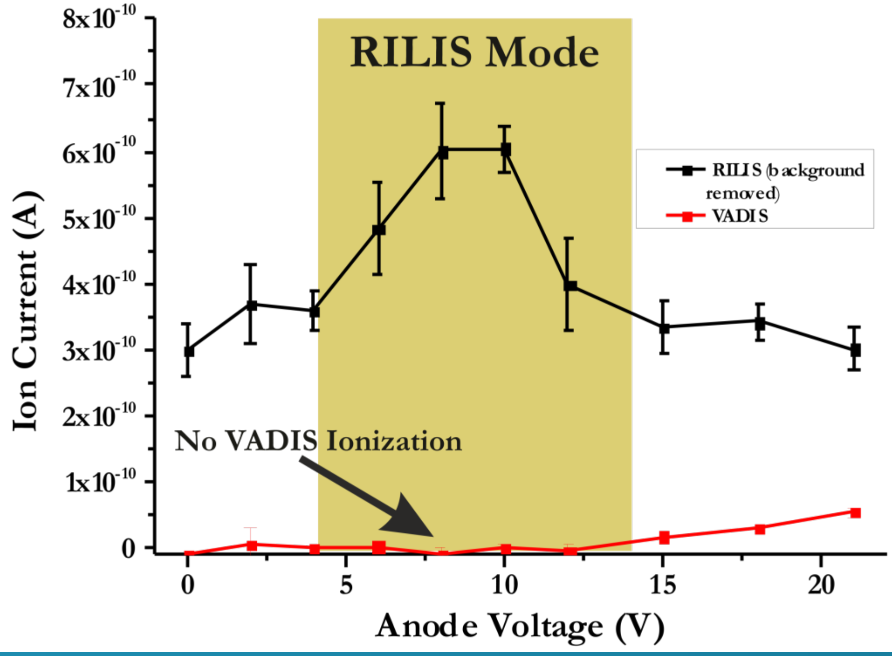
VADIS in RILIS mode with Pb target







- Anode voltage optimised to have good extraction of RILIS ions, using ^{197}Hg.
- Minimal or no VADIS ionisation <+15 V.
- +10 V used for on-line tests with ^{178}Hg.

Selective + efficient

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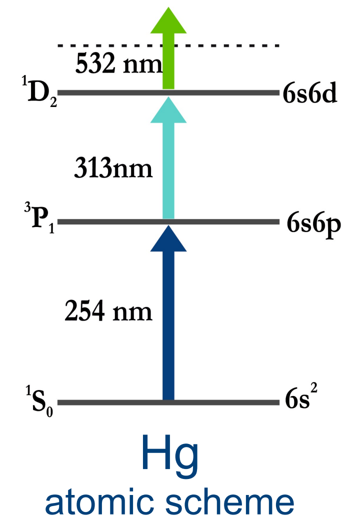
Proof of principle: ^{178}Hg

- RILIS mode (+10 V)
- 5 supercycles



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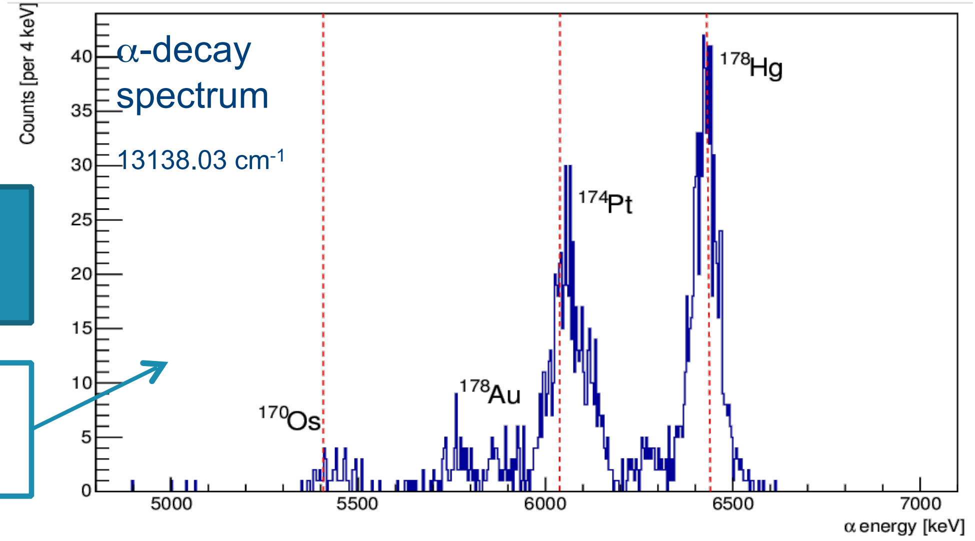
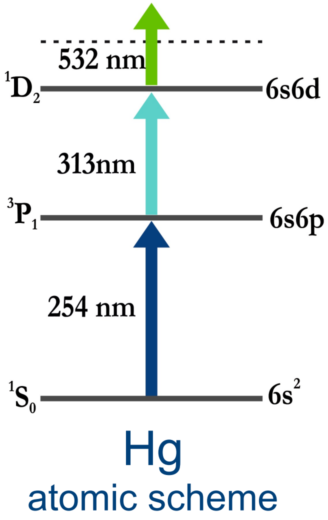
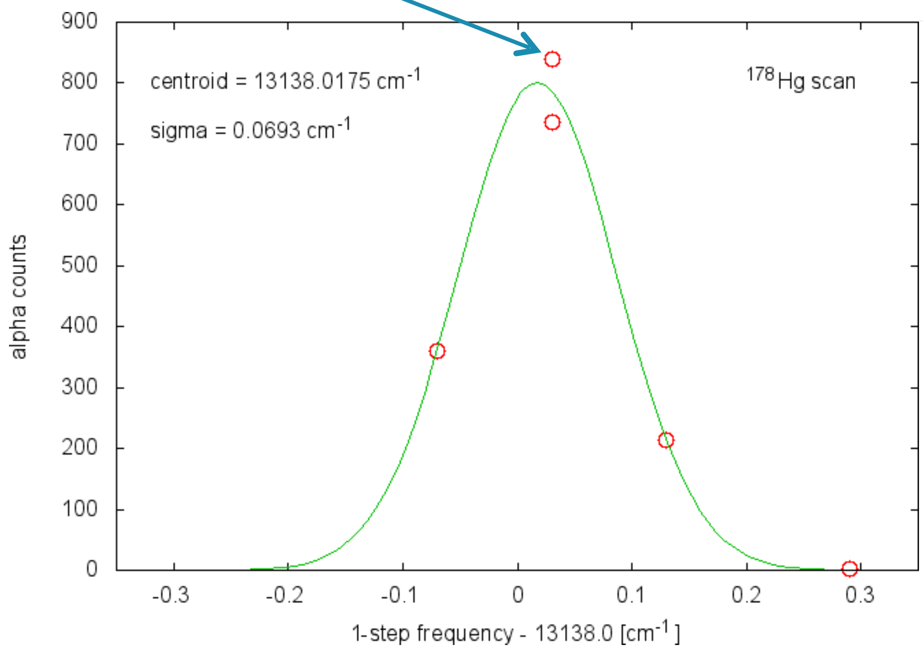
Proof of principle: ^{178}Hg

- **RILIS mode (+10 V)**
- **5 supercycles**

Found resonance in broadband mode







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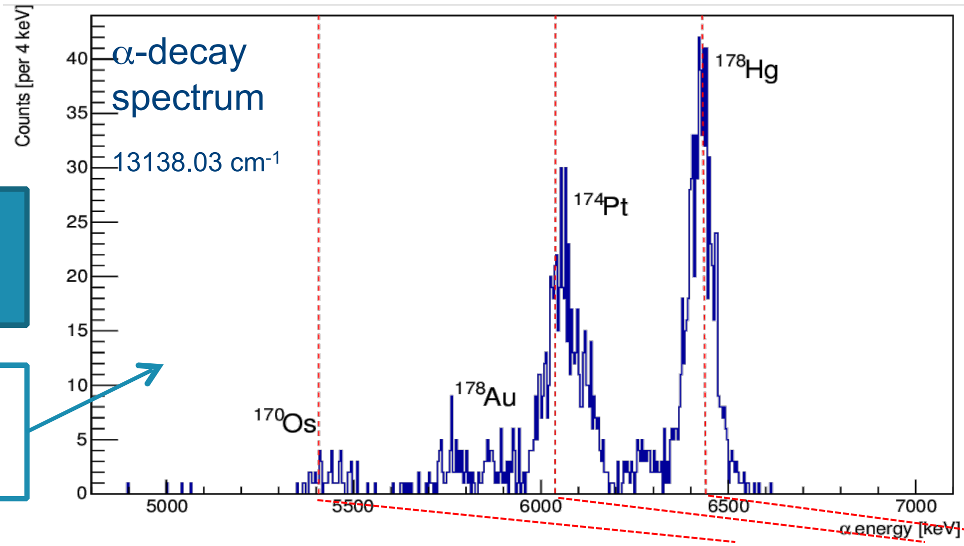

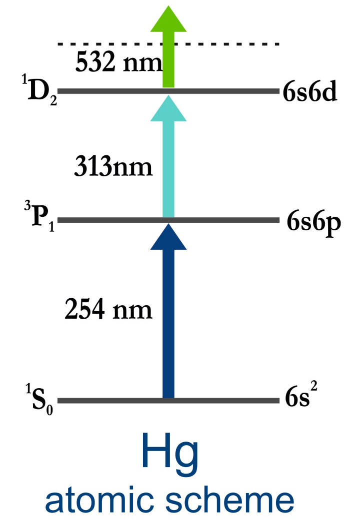

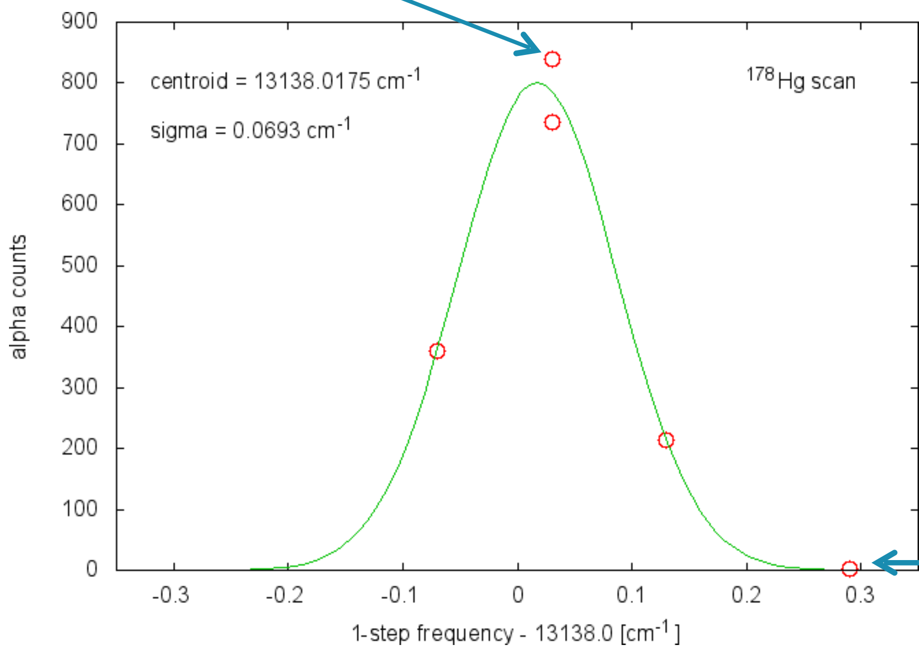

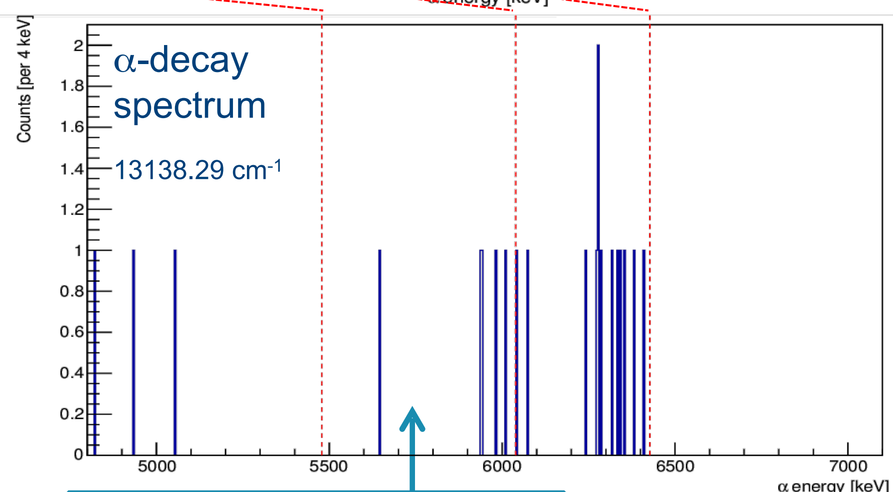

Found background level… Almost zero!

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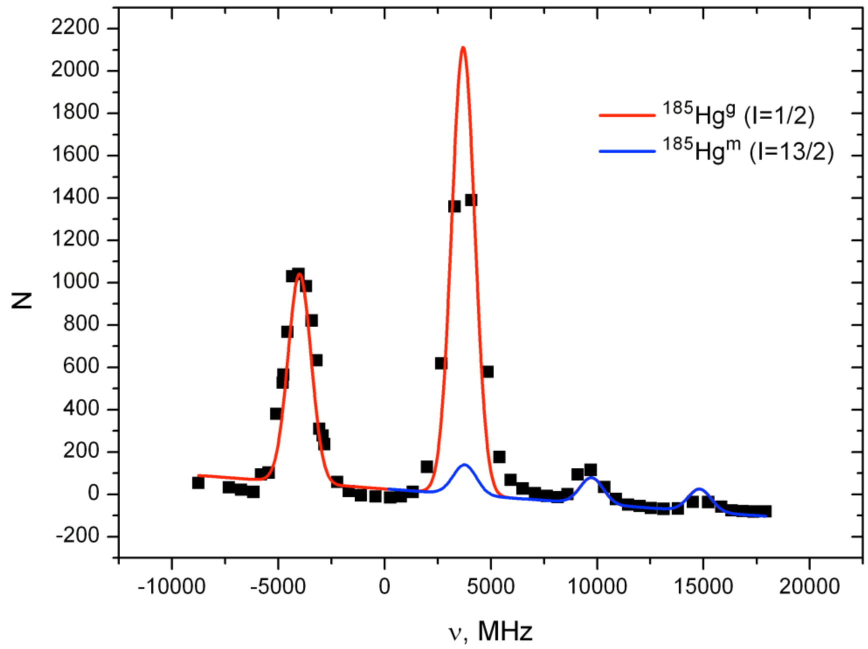
Proof of principle: ^{185}Hg

- HFS of ^{185}Hg was measured on FC
  - Separation of isomer and ground state possible
  - Relative production observed



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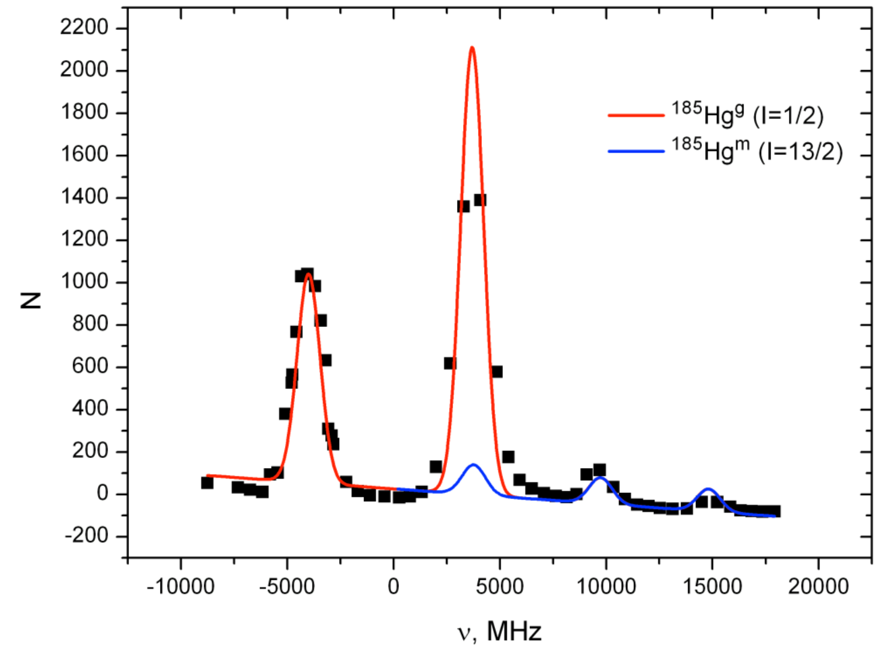

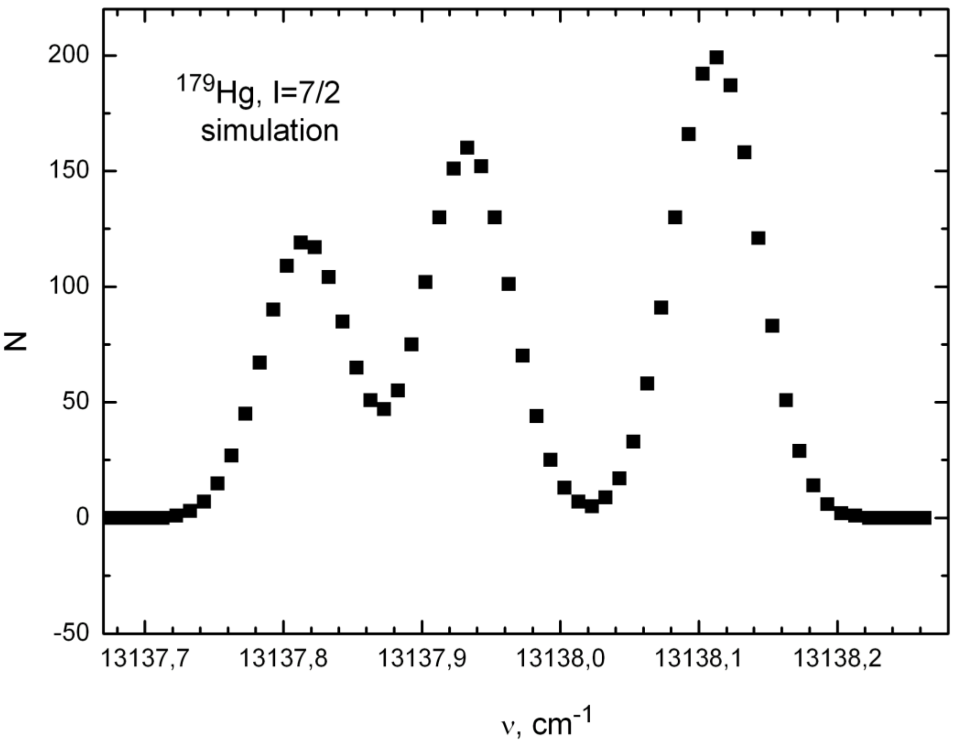

- Simulation of ^{179}Hg ground-state splitting with measured resolution
  - Both IS and HFS measurements are feasible

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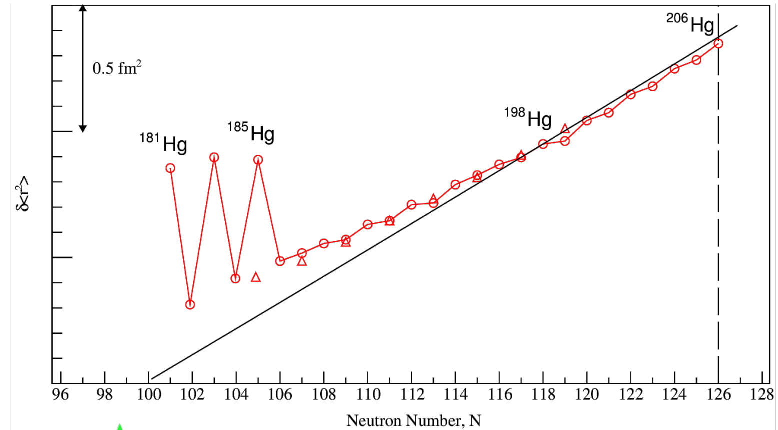
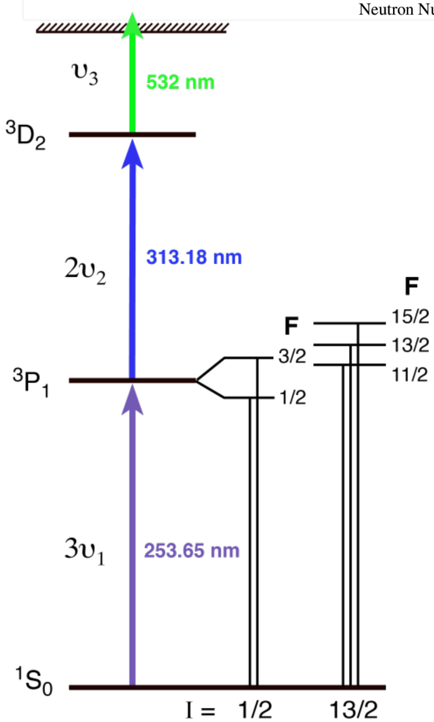
Beam-time request

Target: Molten Pb + VADIS(<15 V) + RILIS
Supercycle: 0.45 μA and ~40 pulses long

A	δν (253.7 nm)	notes	Yield (Pb)
177	?	***≥4 scans; HFS+IS***	***0.9 ions/s***
179	***?***	***≥4 scans; HFS+IS***	***3 x 10***
181	✔	***2 scans; look for 13/2+ isomer***	***1.5 x 10***
178	***?***	***≥3 scans; IS***	***77 ions/s***
180	***?***	***≥3 scans; IS***	***9 x 10***
182	***?***	***2 scans; current IS for 546.1 nm***	***4 x 10***
183-197	✔	***Not requested***	***--***
198	Reference	***2 scans per shift***	***--***
199-206	✔	***Not requested***	***--***
207	***?***	***≥4 scans; HFS+IS***	***>10***
208	***?***	***≥3 scans; HFS+IS***	***~20 ions/s***



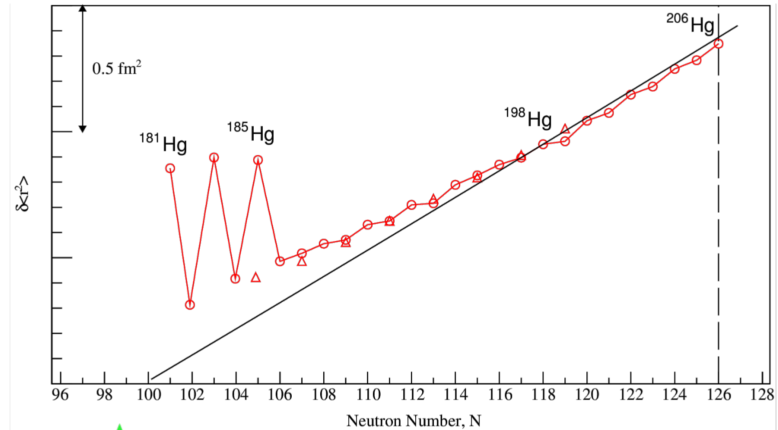


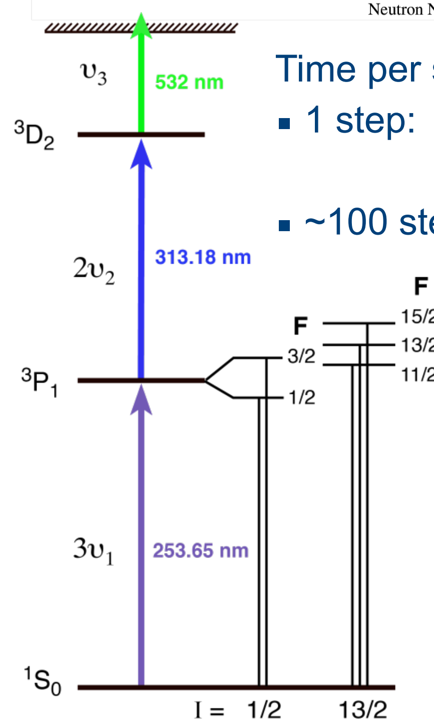
* Extrapolated
† Measured in IS588 (Aug 2014)

Beam-time request

Target: Molten Pb + VADIS(<15 V) + RILIS
Supercycle: 0.45 μA and ~40 pulses long

A	min # scans	hours	shifts
177	4	***34***	***6 (Windmill)***
179	***4***	***10***	
181	2	***4***	
178	***3***	***10***	***3 (Windmill)***
180	***3***	***7***	
182	***3***	***7***	
183-197	--	***--***	
198	Reference	***2 per shift***	***2 (Faraday Cup)***
199-206	--	***--***	
207	***4***	***8***	***3 (MR-ToF MS)***
208	***3***	***16***	





Time per scan ~1.5 – 3 hours

- 1 step: normal = 1 SS
  ^{177,208}Hg = 2/3 SS
- ~100 steps, HFS dependent

I	Peaks
0	***1***
½	***2***
>½	***3***

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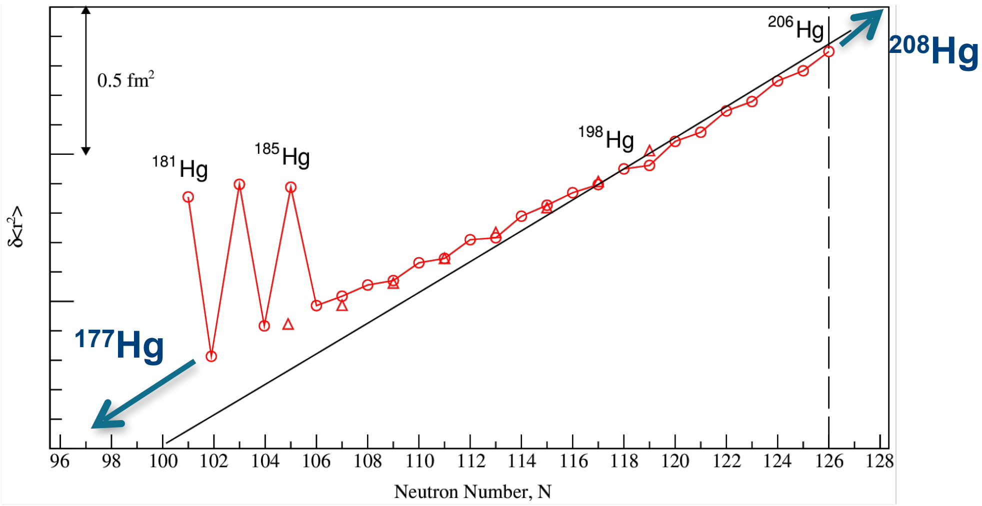
* Extrapolated
† Measured in IS588 (Aug 2014)

Summary

IS and HFS measurements: 12 shifts +
Reference measurements: 2 shifts +
Setup and optimisation: 2 shifts =
16 shifts

- Investigate odd-even staggering of charge radii in ***n*-deficient** Hg isotopes
- Investigate charge-radii kink **above N=126** shell closure in Hg
- Tested and proved with **Pb + VADIS (<15V) + RILIS (^{178}Hg)**
- Measured HFS and isomer separation in 185Hg
- UC_x yields feasible for *n*-deficient, but **Fr contamination** at A=207,208



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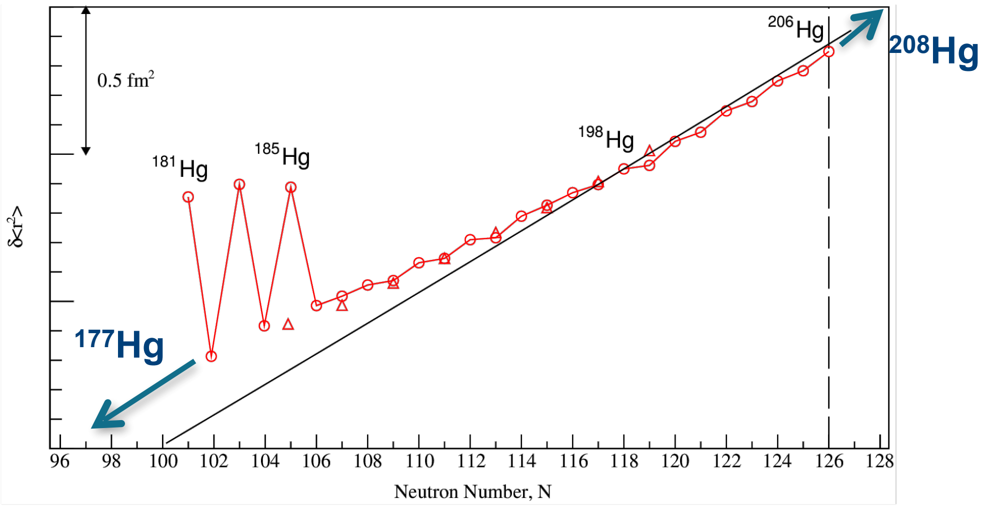
Summary

IS and HFS measurements: 12 shifts +
Reference measurements: 2 shifts +
Setup and optimisation: 2 shifts =
16 shifts

- Investigate odd-even staggering of charge radii in ***n*-deficient** Hg isotopes
- Investigate charge-radii kink **above N=126** shell closure in Hg
- Tested and proved with **Pb + VADIS (<15V) + RILIS (^{178}Hg)**
- Measured HFS and isomer separation in 185Hg
- UC_x yields feasible for *n*-deficient, but **Fr contamination** at A=207,208



Thank you!

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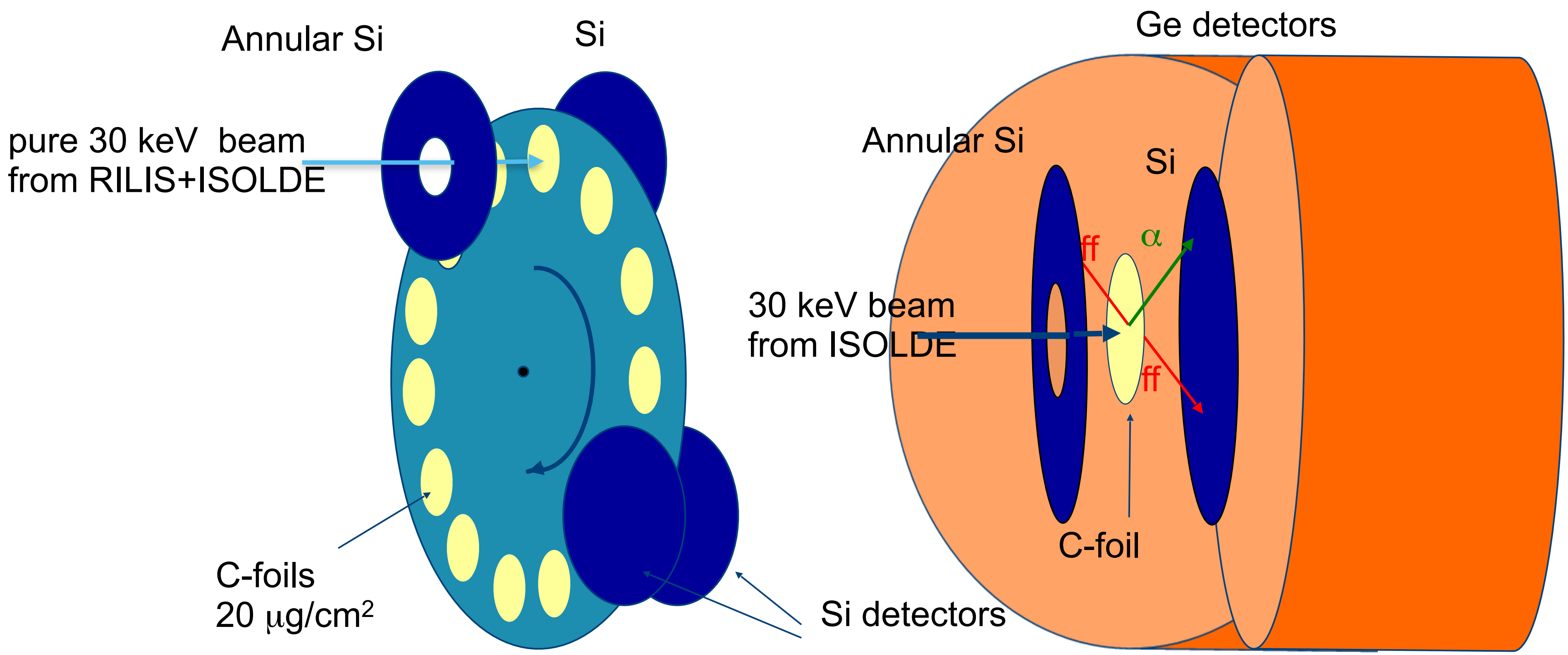
Bonus slides

Windmill System at ISOLDE

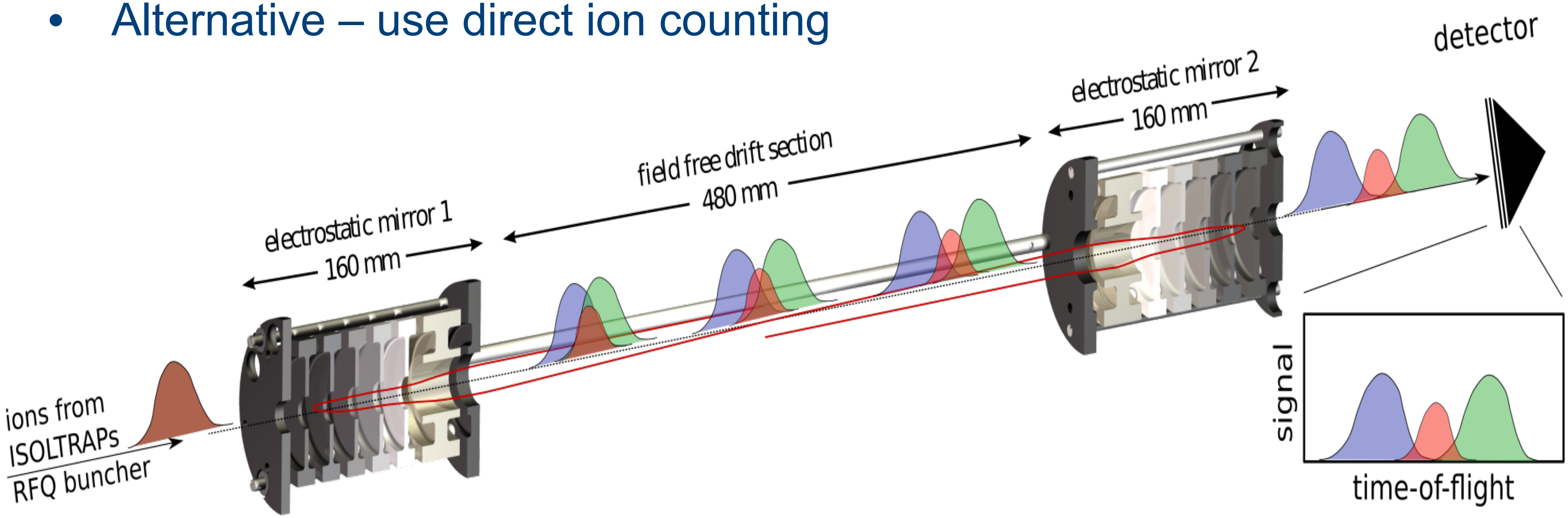


Setup: Si detectors from both sides of the C-foil

- Large geometrical efficiency (up to 80%)
- α-gamma coincidences
- Simple setup & DAQ: 4 PIPS (1 of them – annular)

Multi-Reflection Time-of-Flight Mass Spectrometer (MR-ToF)

- The WM technique requires detection of α-decay to count.
- Not practical for long-lived or stable isotopes (or for β-decaying) i.e. 207,208Hg!!
- Alternative – use direct ion counting



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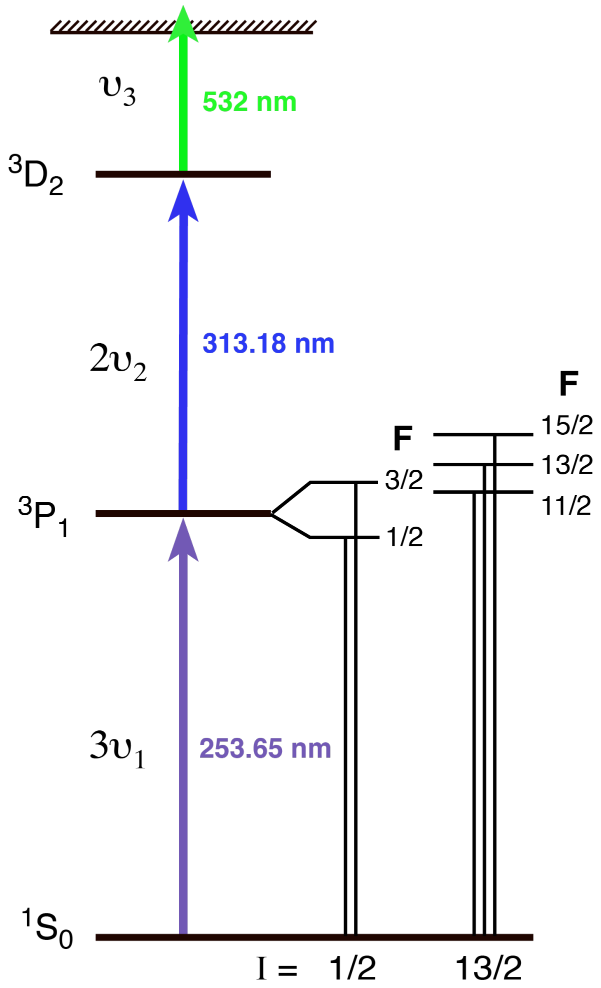
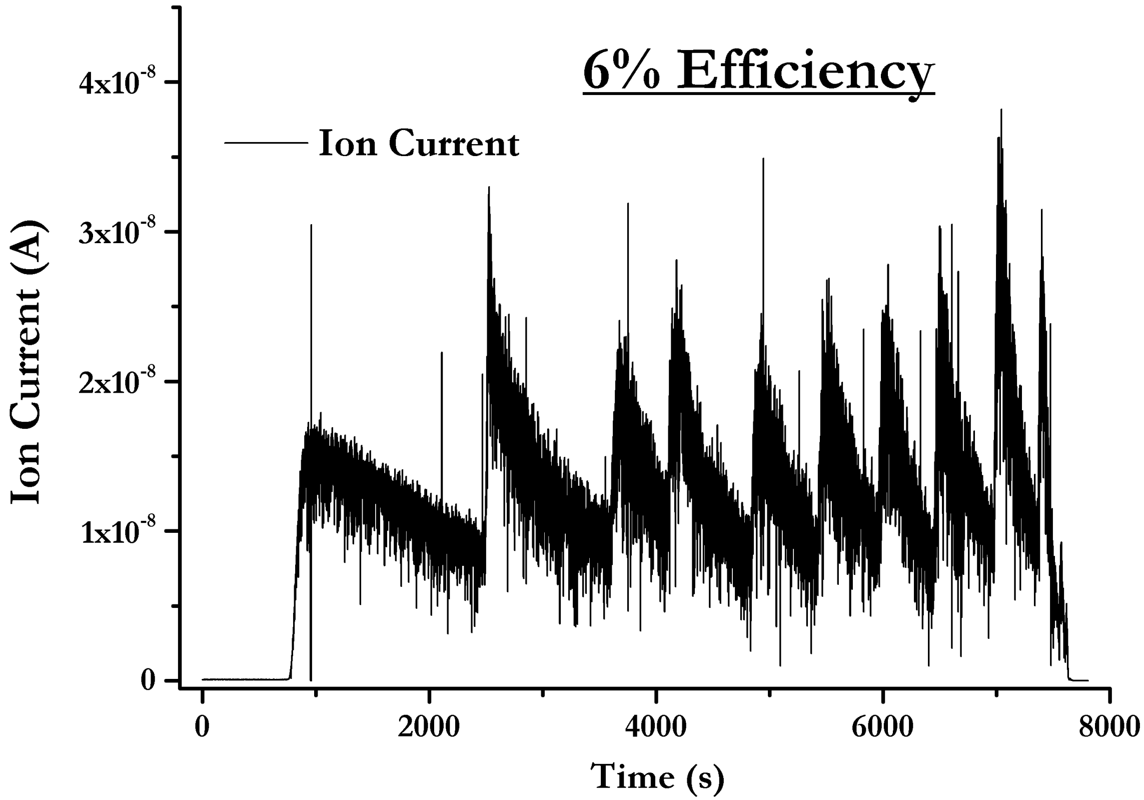
R. N. Wolf et al, NIM, A686, 82 (2012)

New ionisation scheme - Hg





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^{207,208}Hg yields

- TISD group yield checks* (~100% pure from gamma ID) -
  - ^{207}Hg: **6 x 10^4 ions/μC** @ 0.09 μA with 54% transmission

- IS588† at IDS with betas -
  - A = 208: ~100 ions/s @ 0.45 μA …
- Confirmed with gamma ID -
  - ^{208}Hg = ~20% of total beta activity = **~20 ions/s**
  - Also present: ^{208}Pb, ^{208}Po and ^{192}Au^{16}O
    - Laser selectivity in VADIS(+5 V) mode can reduce contamination

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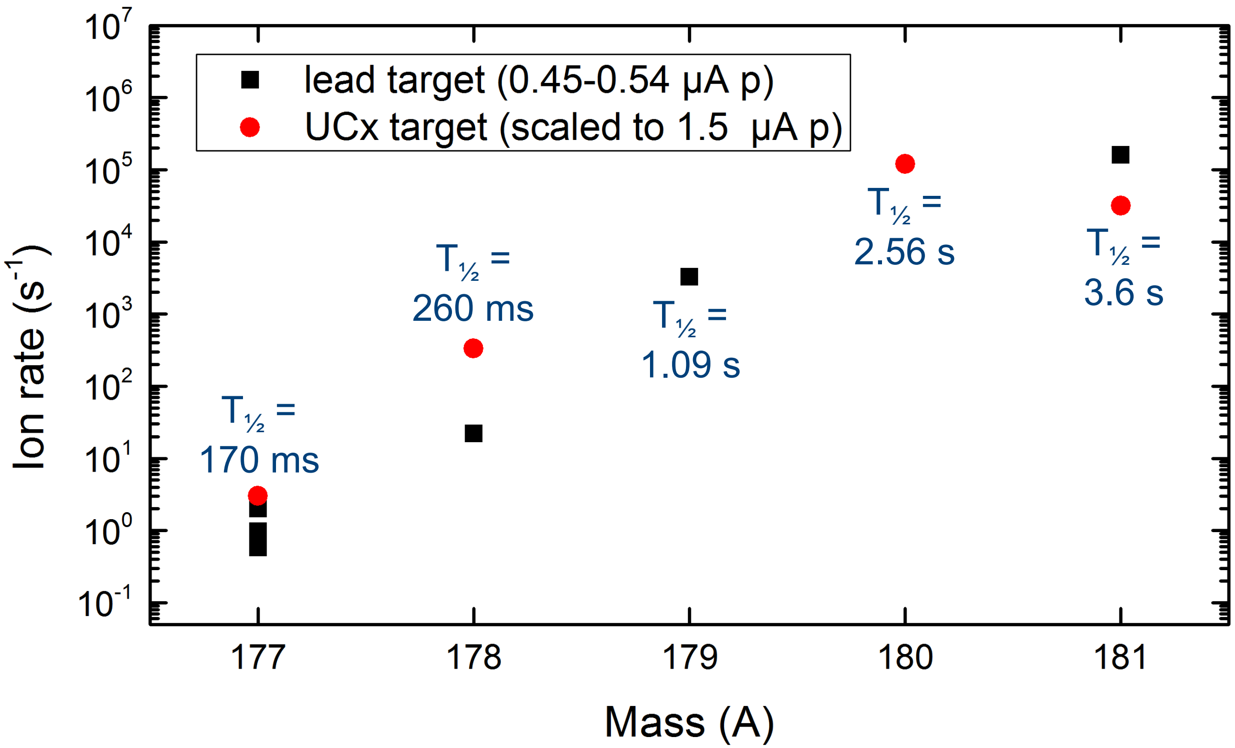
* GPS eLog – 22/08/14 18:19
† August 2014 – Zsolt Podolyak, Surrey, UK

LOI-153 Tests (21st Aug. – 1st Sept. 2014)

- Coupling of molten Pb target to RILIS
- Investigate slow release of Pb target
- Yields of n-deficient Hg from Pb+VD5

Phase 1



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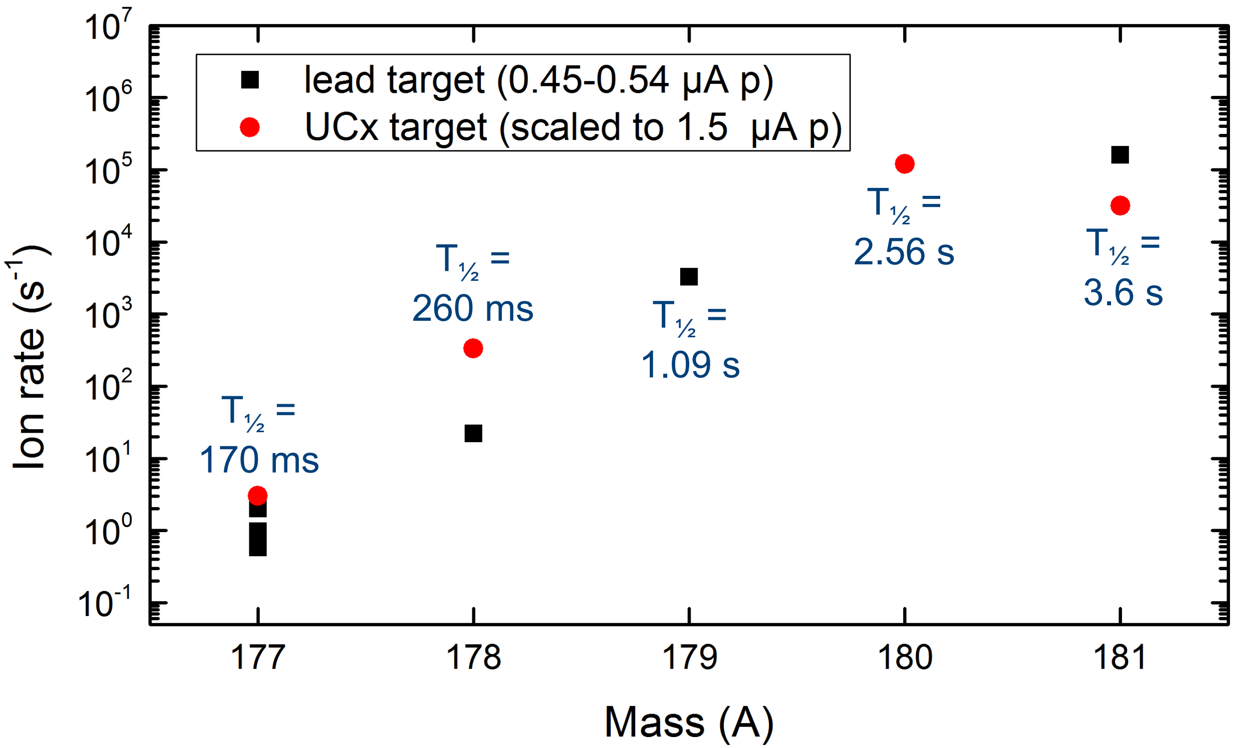
LOI-153 Tests (21st Aug. – 1st Sept. 2014)

- Coupling of molten Pb target to RILIS
- Investigate slow release of Pb target
- Yields of n-deficient Hg from Pb+VD5

Phase 1

Yields of n-deficient Hg from UC_x+RILIS

Phase 2



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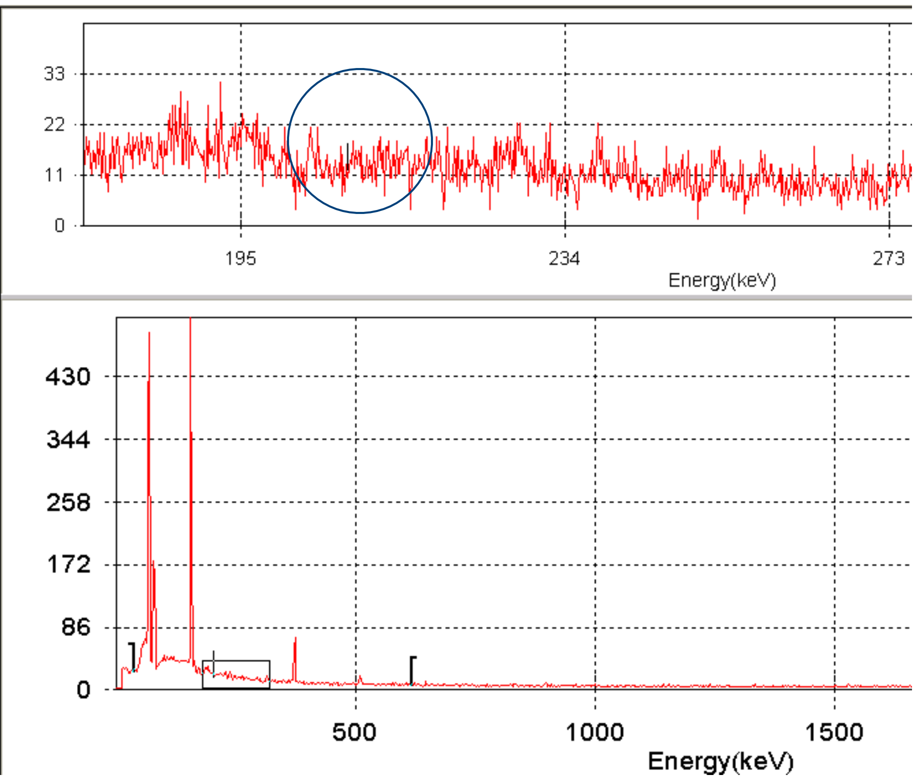
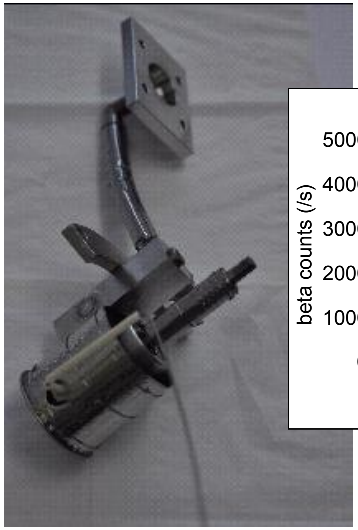
Hg beams from Pb-VD5

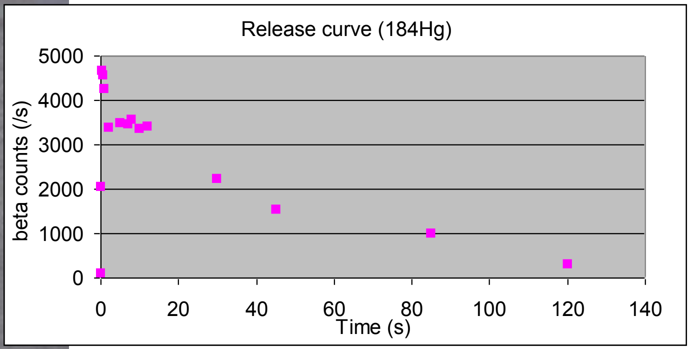
(T. Stora ISOLDE Workshop 2010)

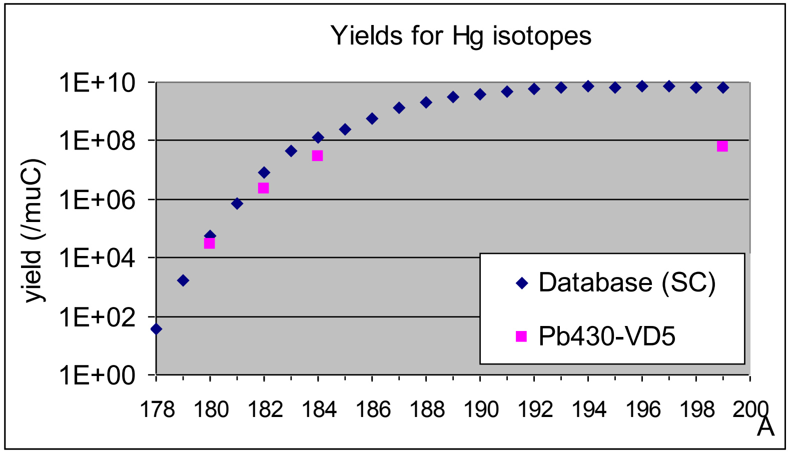
Pb430-VD5

199mHg









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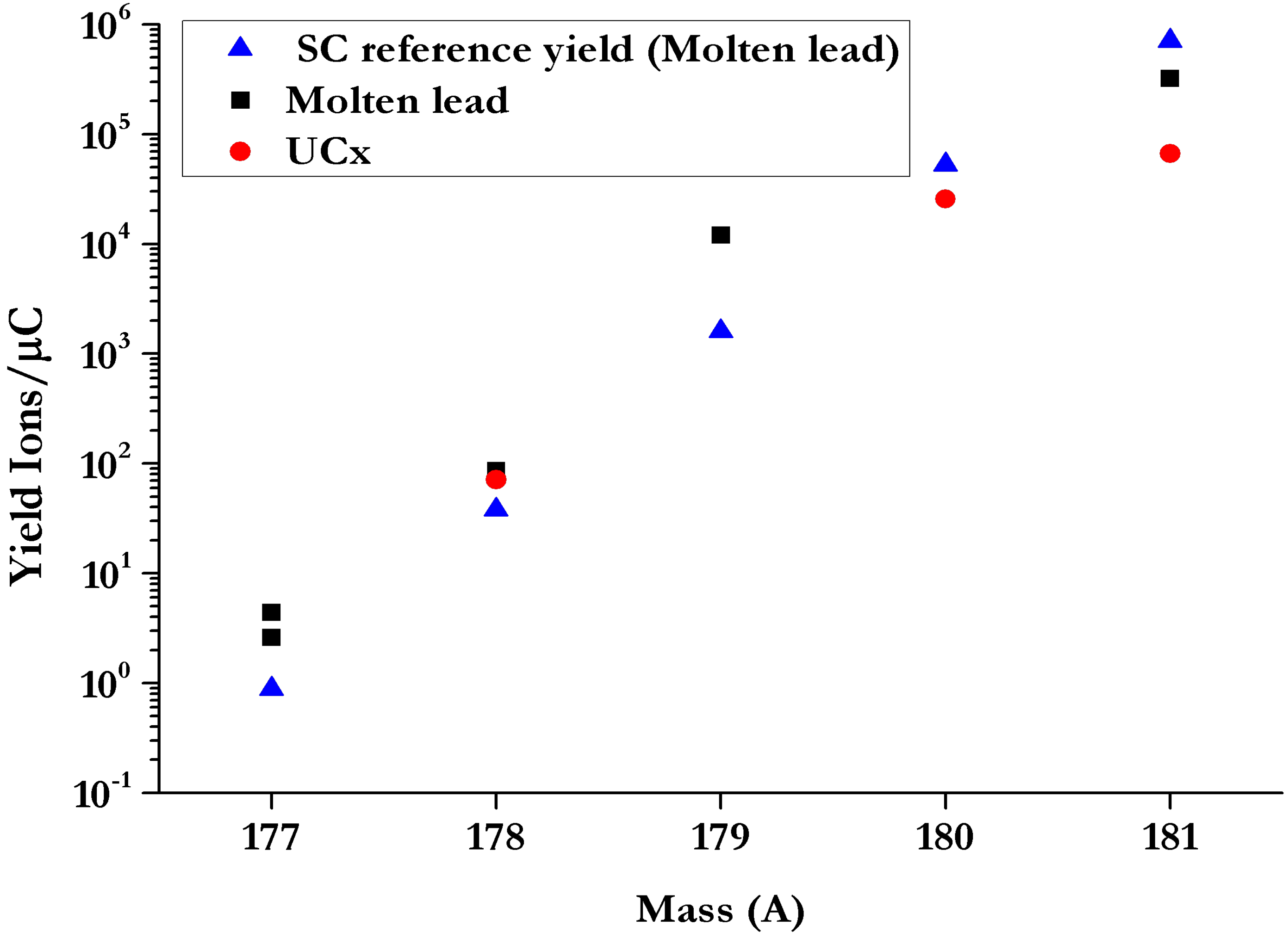
Hg yields comparison



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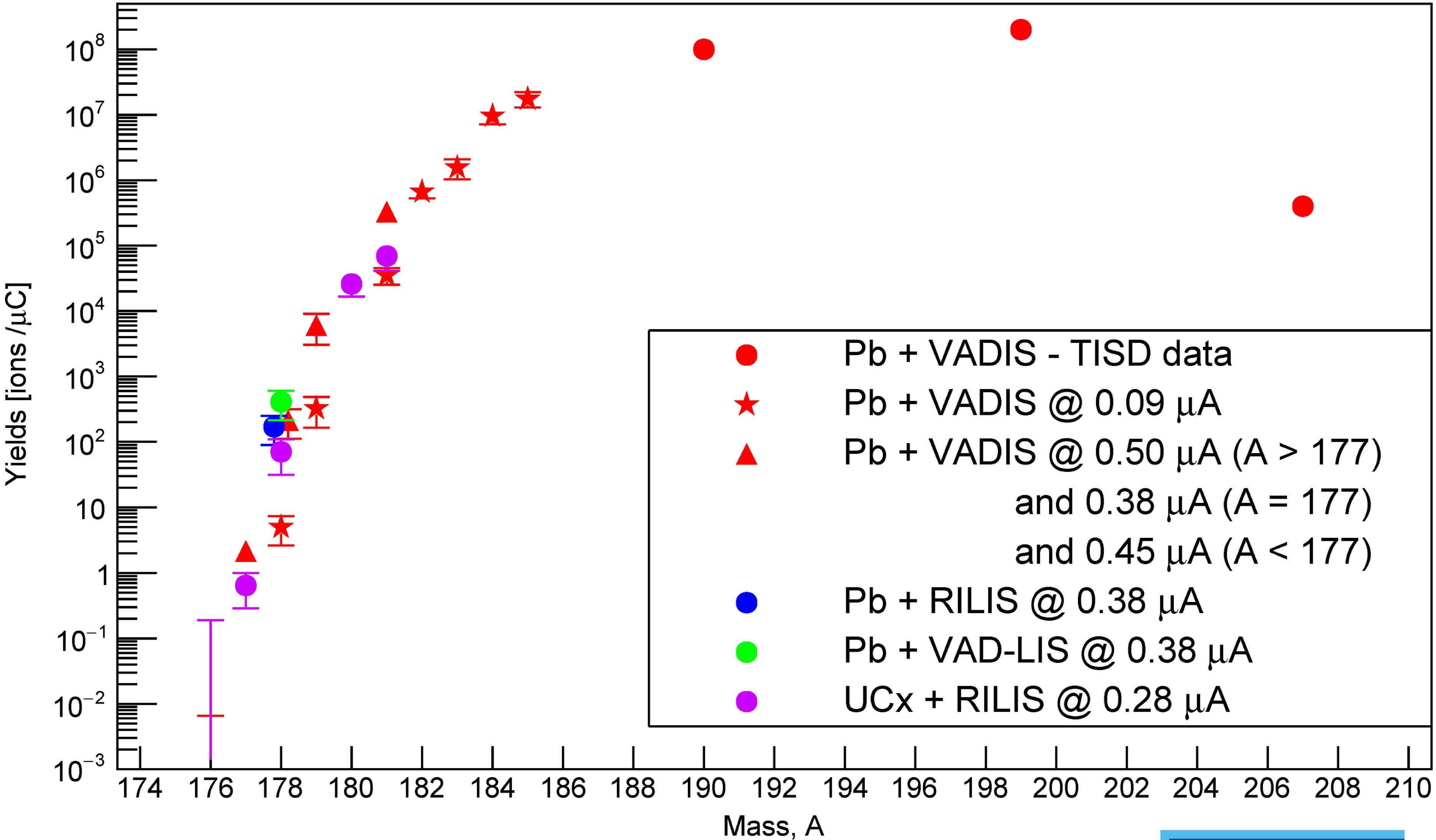
Hg Yields – August tests



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