Bound-State β^--decay of Thallium-205

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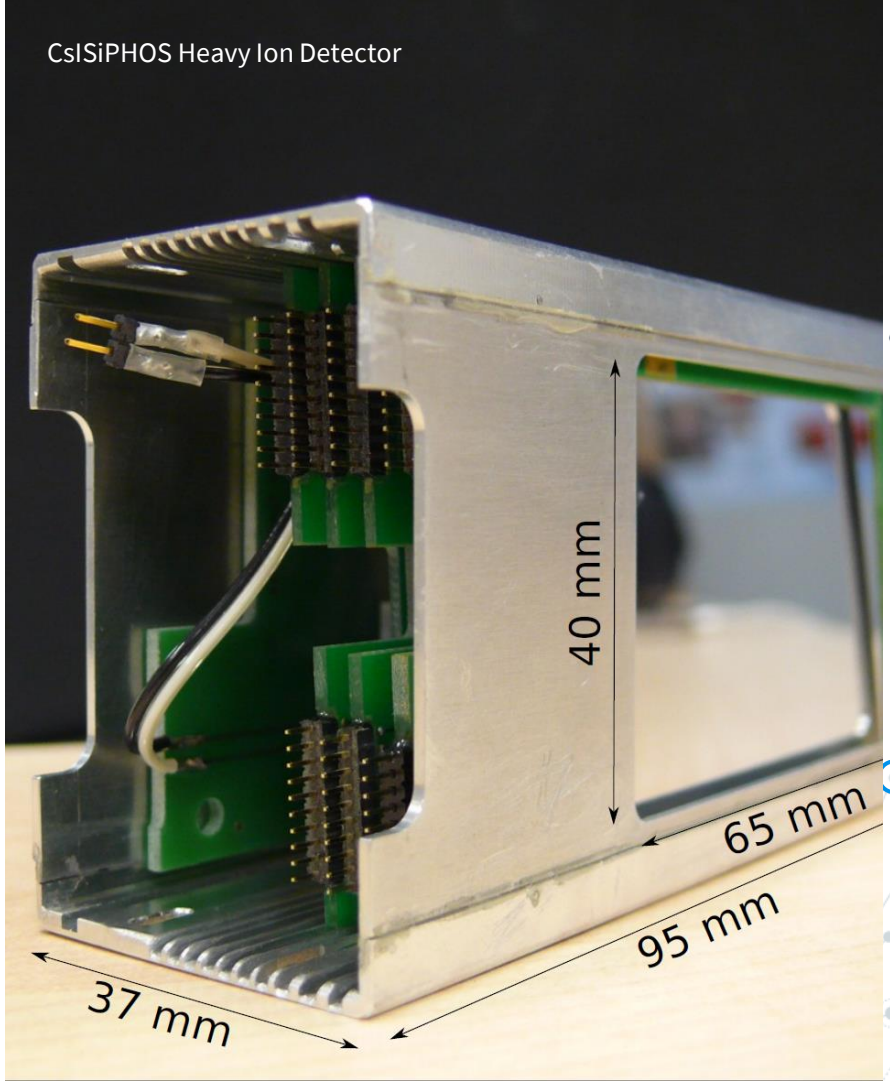

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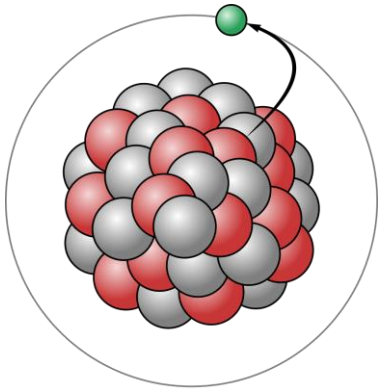
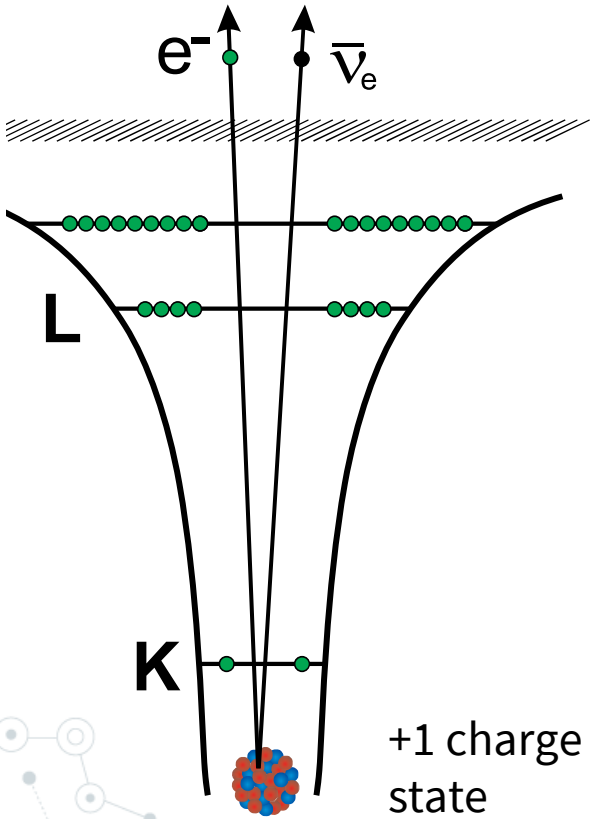
Outline

- What is bound-state β^--decay?
- Why Thallium-205? The Lorandite experiment!
- How to measure bound-state β^--decay?
  - Storage rings
  1. Electron stripping measurement
  2. Decay measurement

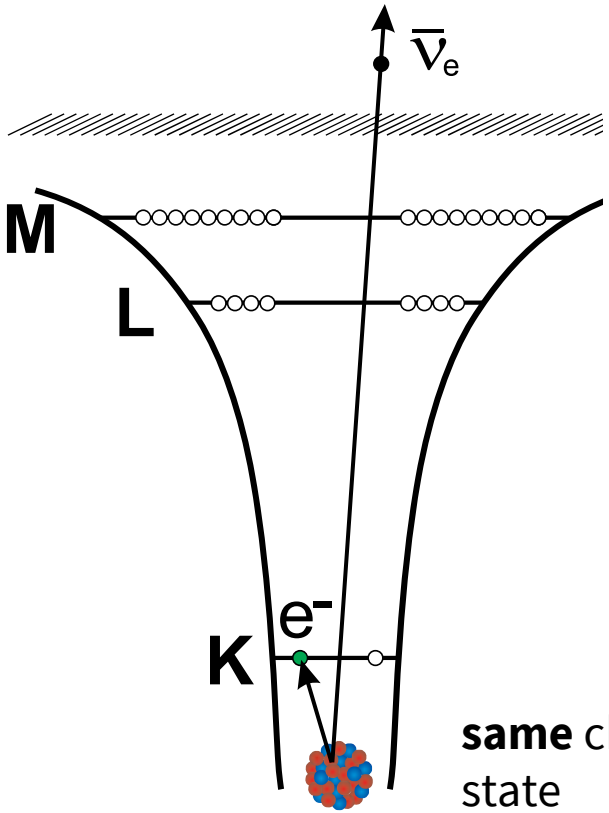


$^{206}\mathrm{Pb}^{81+}$

Bound-State Beta Decay

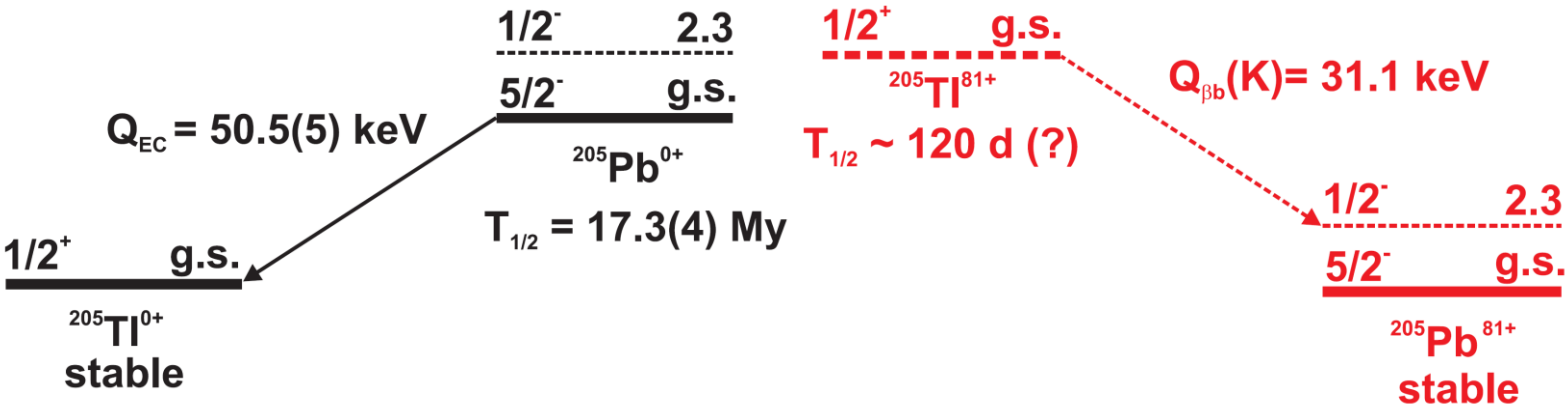


+1 charge state



same charge state

Thallium-205 Decay Scheme

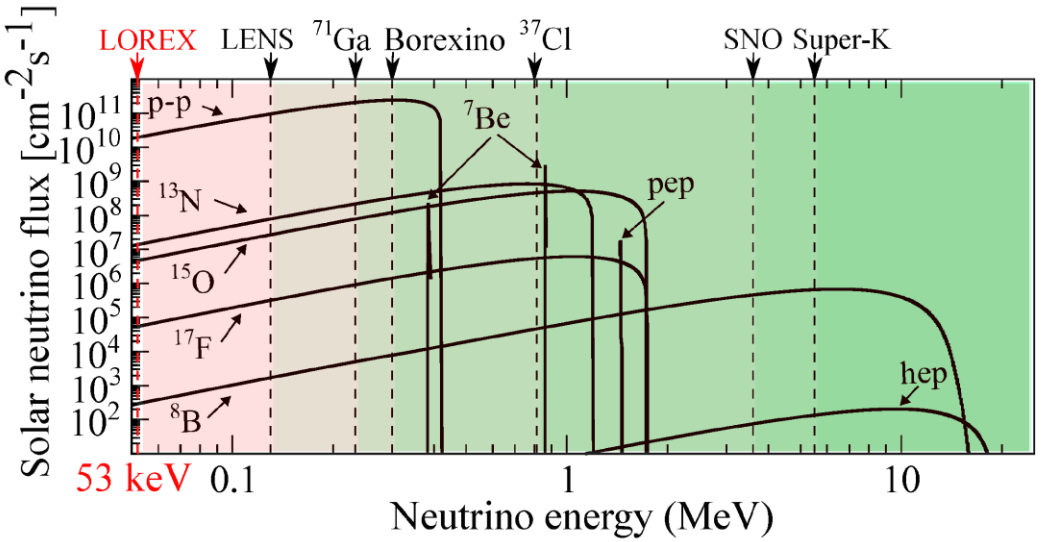


- Neutral $^{205}Tl^{0+}$ is stable
- Neutral $^{205}Pb^{0+}$ decays by EC
- Bare $^{205}Tl^{81+}$ ions are unstable

LOREX (LORandite EXperiment)

$$^{205}Tl^{0+} + \nu_e(E \geq 53\ keV) \rightarrow {}^{205}Pb^{0+,*}(2.3\ keV) + e^-$$

Lorandite ($TlAsS_2$)

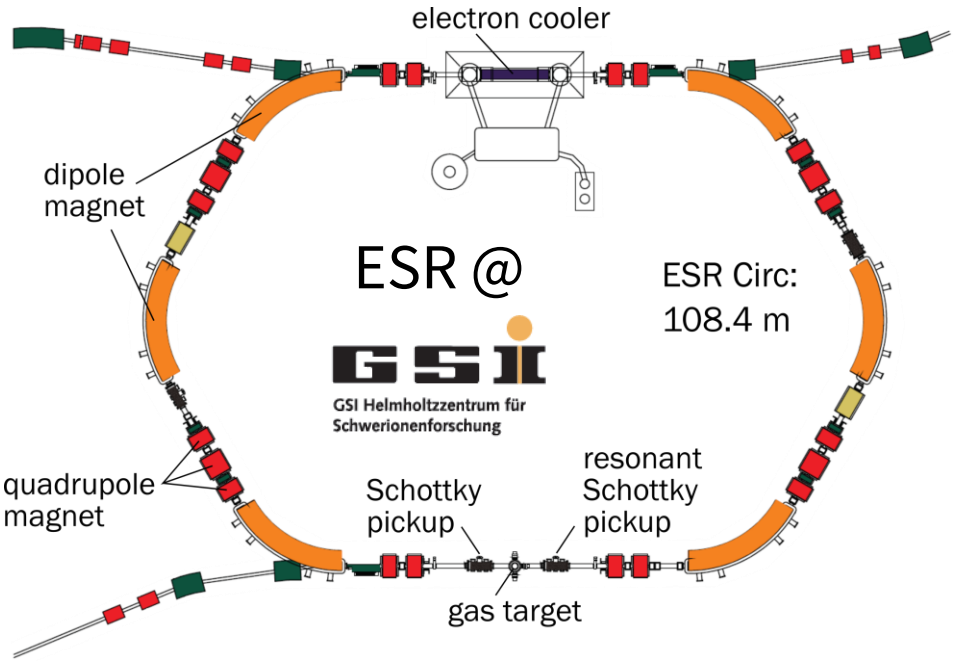


K.M. Subotic et al., AIP Conf. Proc. 455, 912 (1998)

M.K. Pavicevic, Nucl. Inst. Meth. A 895 (2018) 62

How to measure β_b^--decay

- Decay counting
- High charge state = highly reactive
- Storage rings hold ions for **several hours**



J Grumer, et. al. Phys. Rev. A 88, (2013) 022513

Original 1992 Proposal

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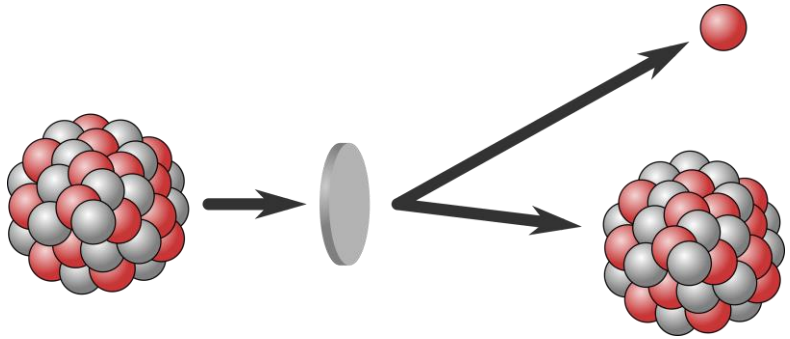
$^{205}Tl^{81+}$ directly from source.

Toxic



^{206}Pb
705 MeV/u

^{9}Be
target

$^{205}Tl^{81+}$
400 MeV/u

Measuring β_b^--decay

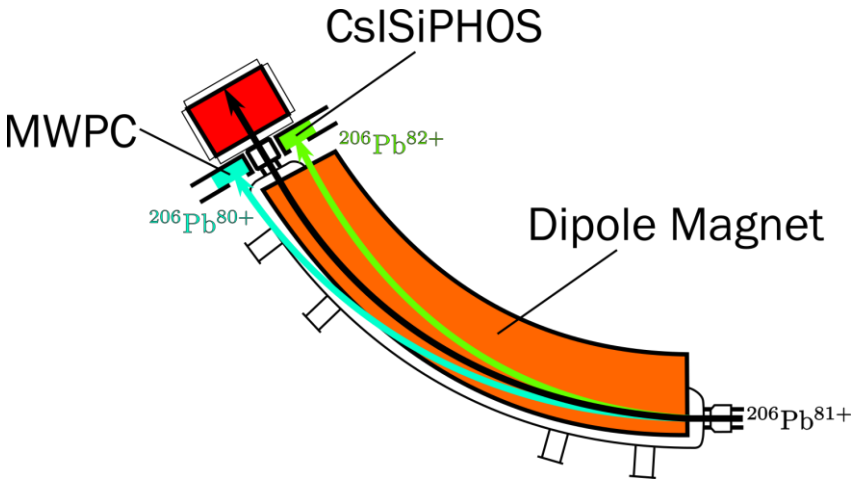
- $\frac{N_{Pb}(t_s)}{N_{Tl}(t_s)} = \frac{N_{Pb}^{+}(t_s)}{N_{Tl}(t_s)} \cdot \frac{\sigma_+ + \sigma_-}{\sigma_+} = \frac{\lambda_{\beta_b}}{\gamma} t_s \cdot \left[1 + \frac{1}{2}(\lambda_{Pb}^{cc} - \lambda_{Tl}^{cc}) t_s + \cdots\right]$

- Two parts to the measurement:
  - **Part 1:** charge-changing cross section ratio measurement with primary beam.
  - **Part 2:** measure ionised lead to thallium ratio for different storage times.

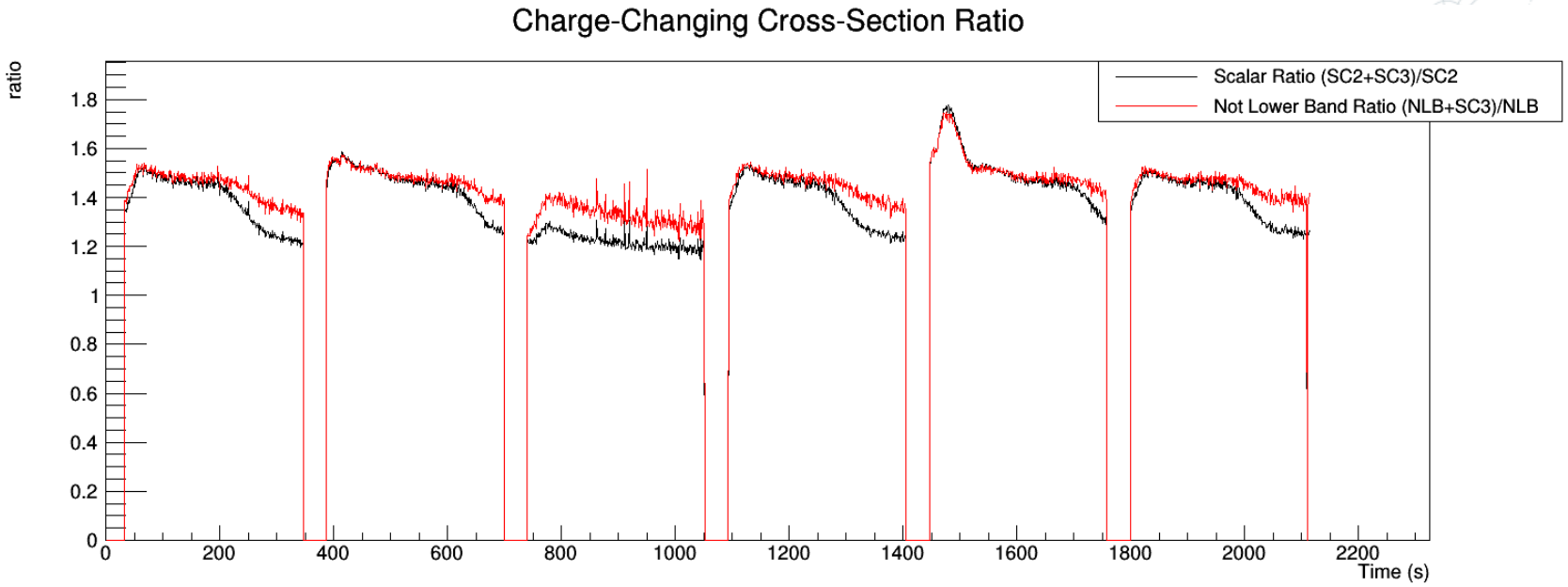
Part 1: Cross Sections

- **H-like** $^{206}Pb^{81+}$ primary beam in ESR.
- CsISiPHOS captures **bare** $^{206}Pb^{82+}$.
- MWPC captures **He-like** $^{206}Pb^{80+}$.
- Counting ions gives the ratio.

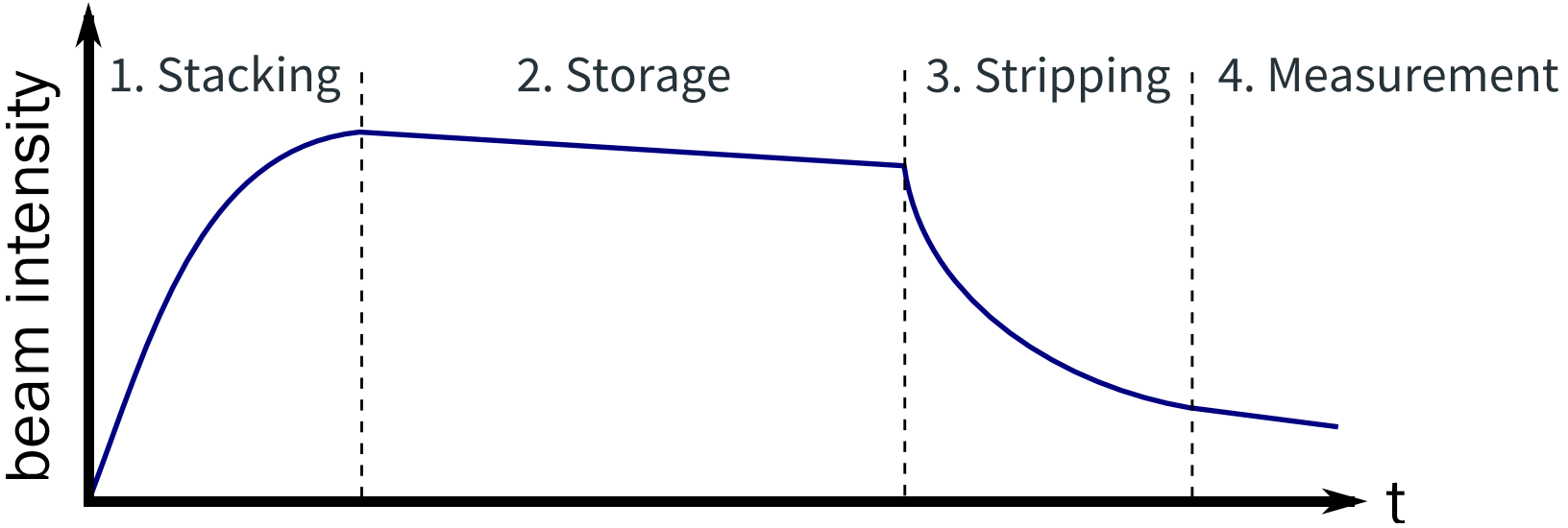
$$\frac{\sigma_+ + \sigma_-}{\sigma_+} = \frac{N(^{206}Pb^{82+}) + N(^{206}Pb^{80+})}{N(^{206}Pb^{82+})}$$

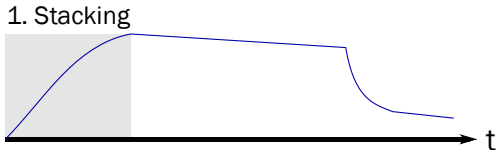


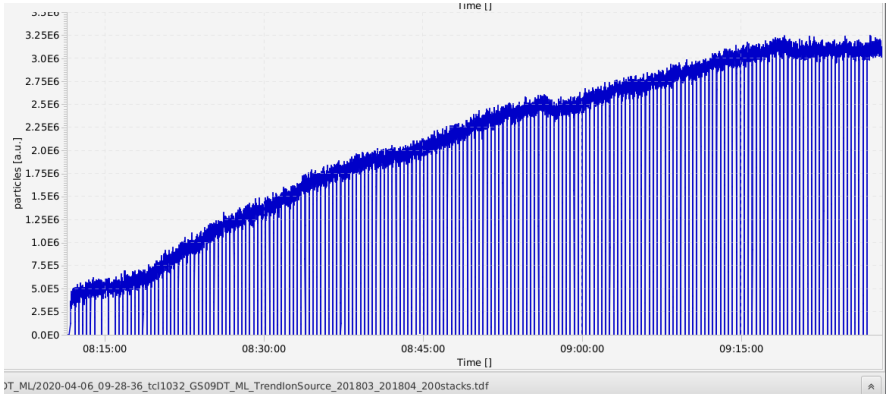
Cross Section Data



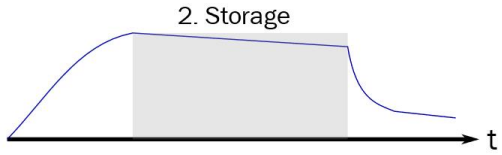
Part 2: Decay Storage



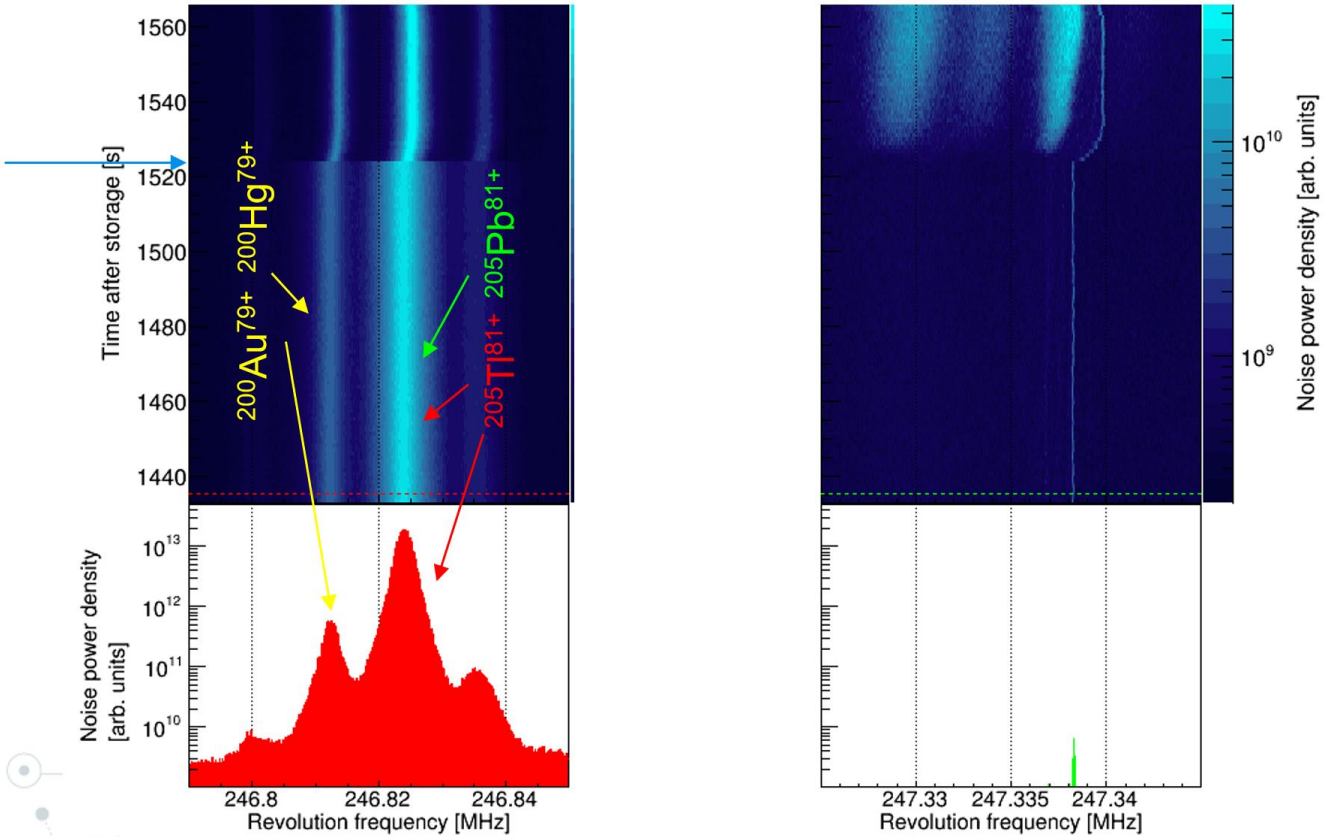




Step 1: Stacking $^{205}Tl^{81+}$ beam at the inside orbit of ESR.

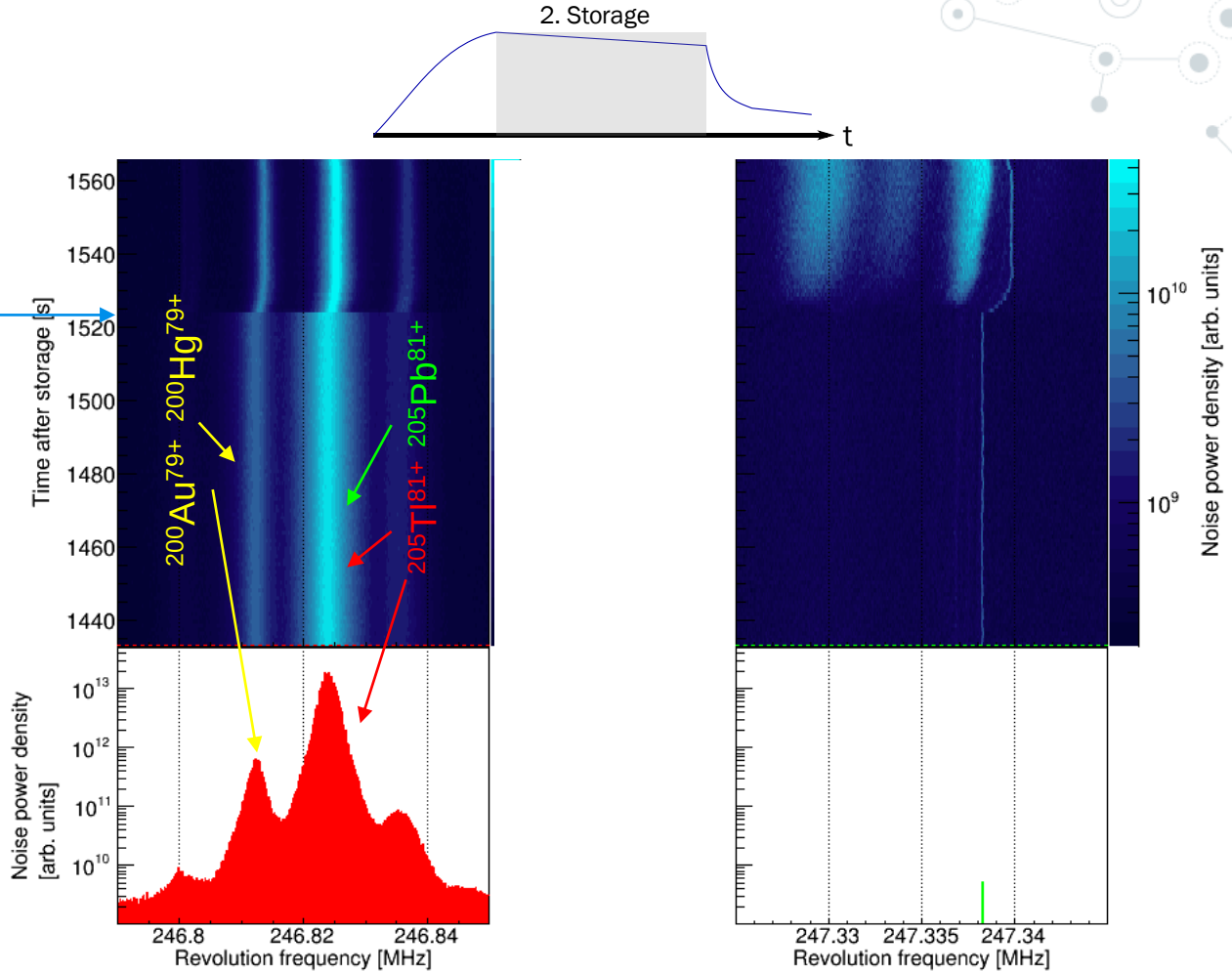


Gas target turned on.

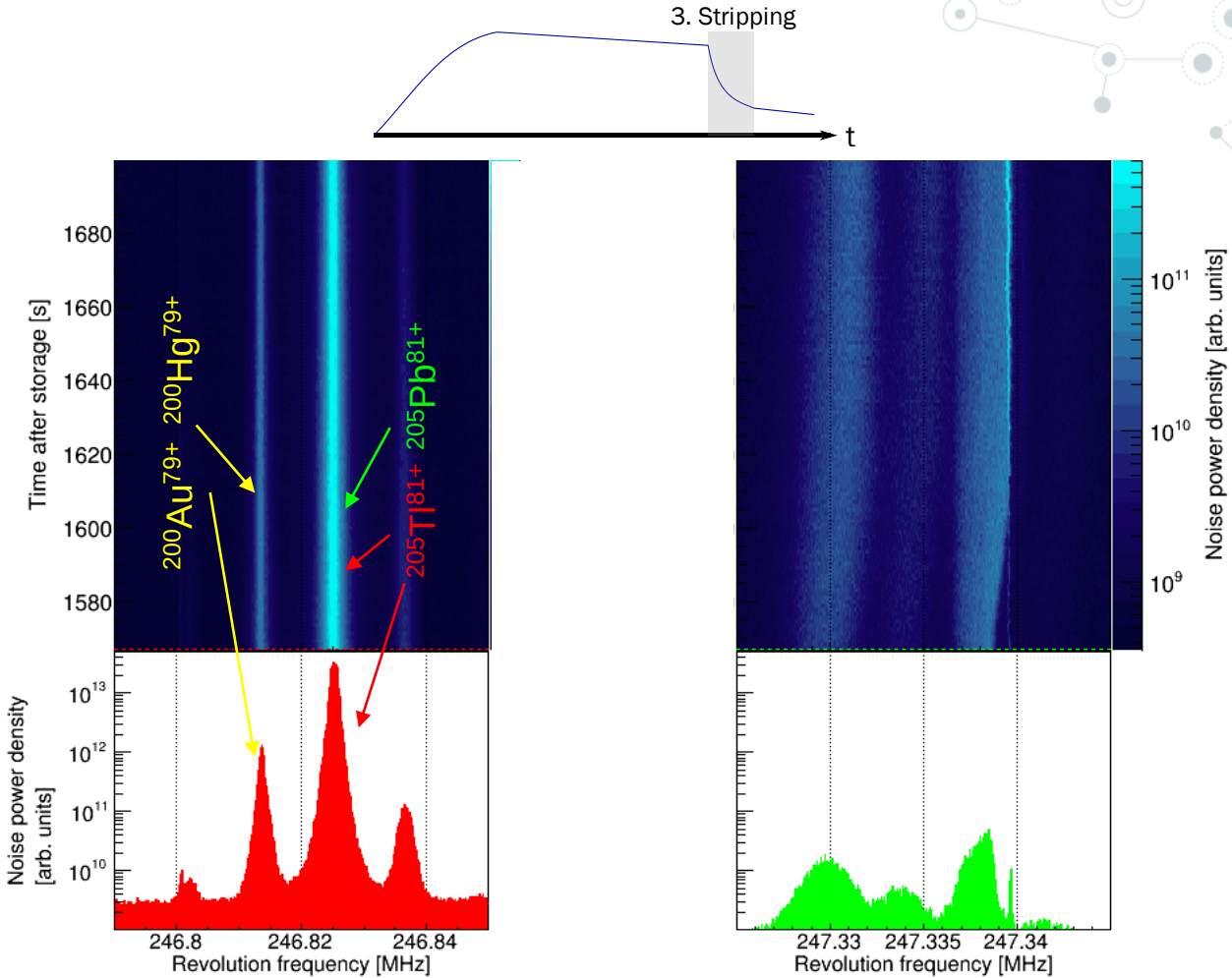


Animations courtesy of Rui Jiu Chen (https://www.researchgate.net/profile/Ruijiu_Chen).

Gas target turned on.



Animations courtesy of Rui Jiu Chen (https://www.researchgate.net/profile/Ruijiu_Chen).



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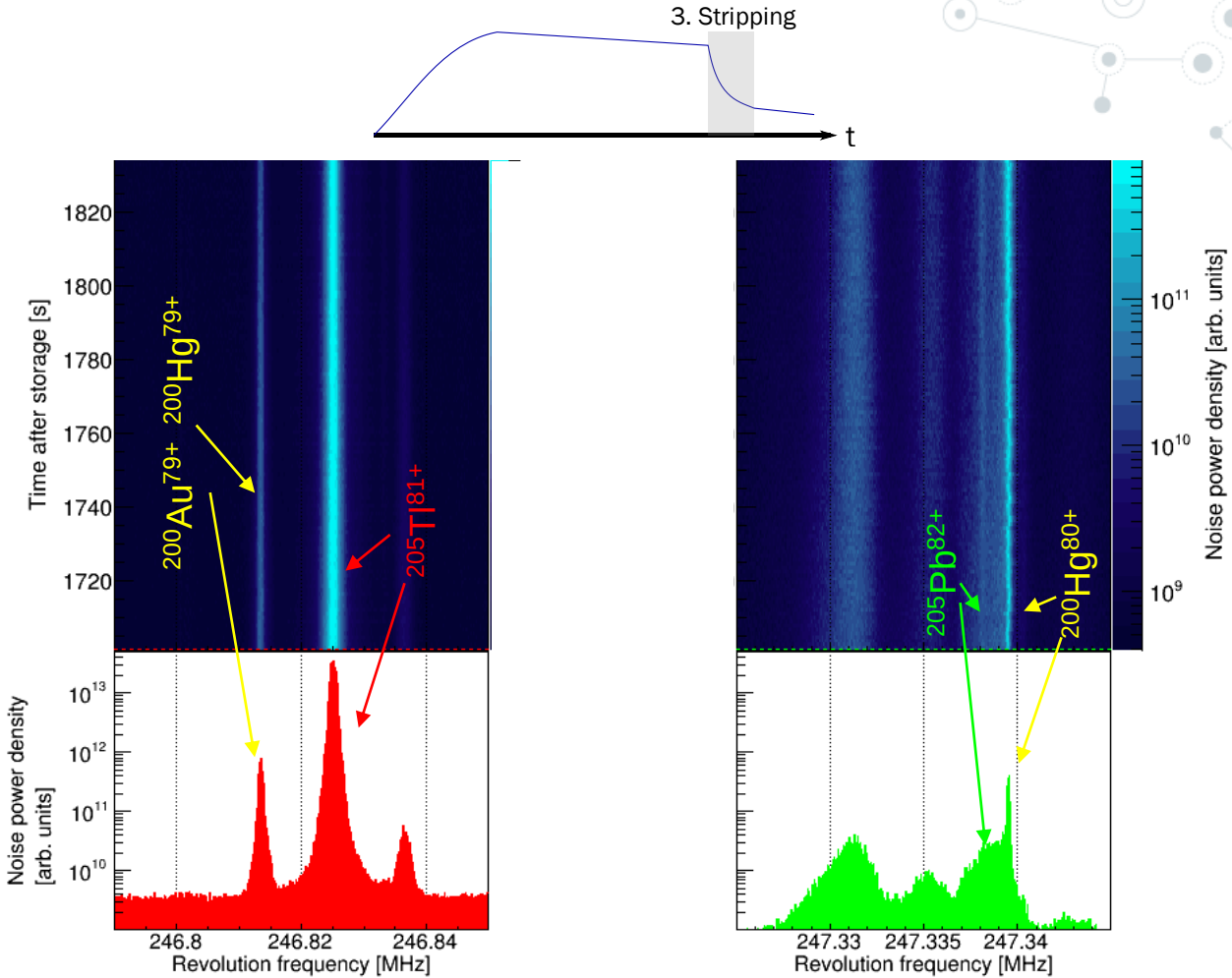
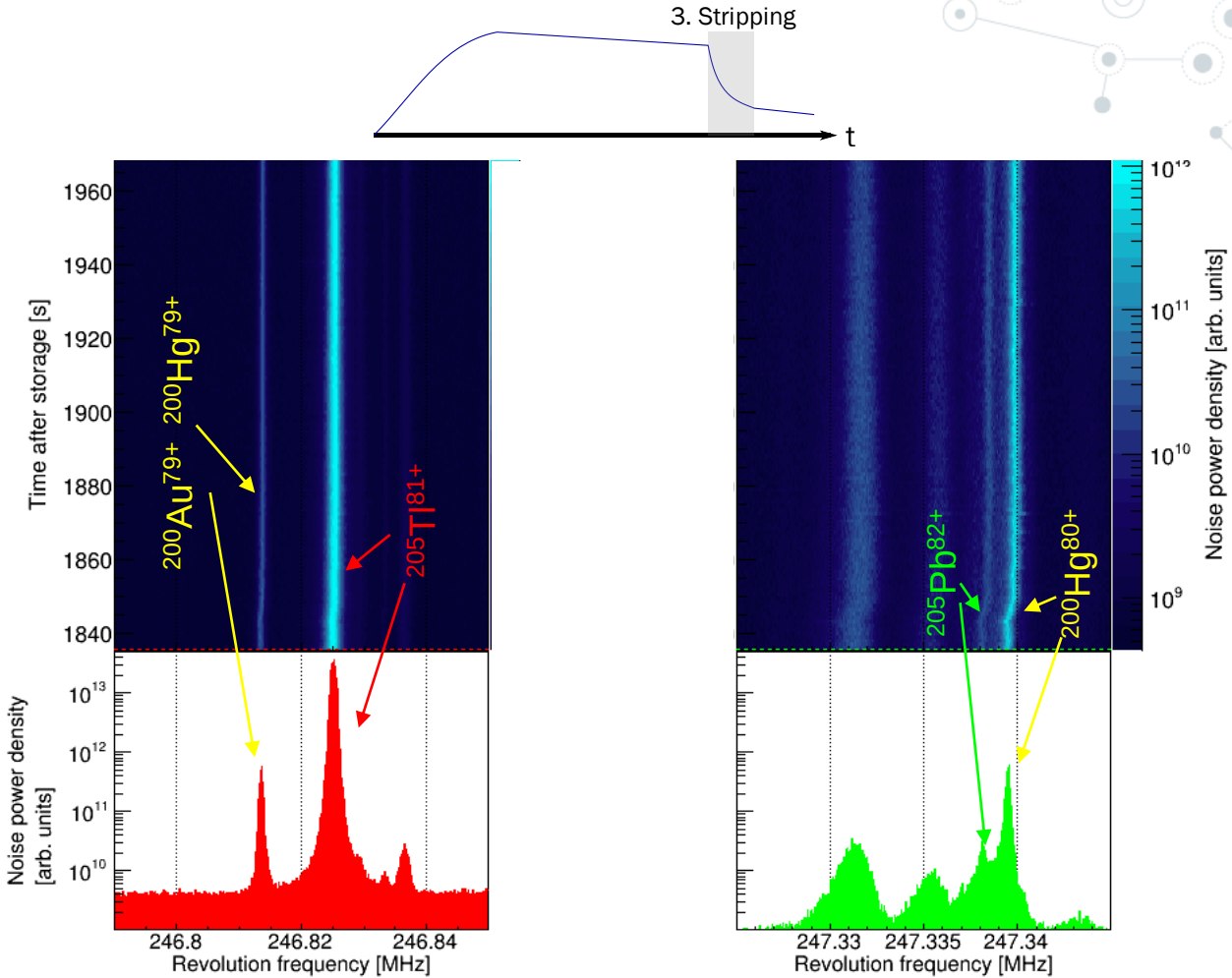
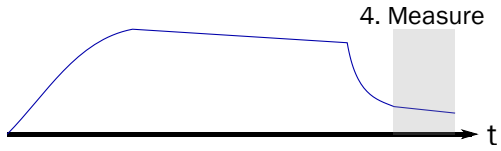


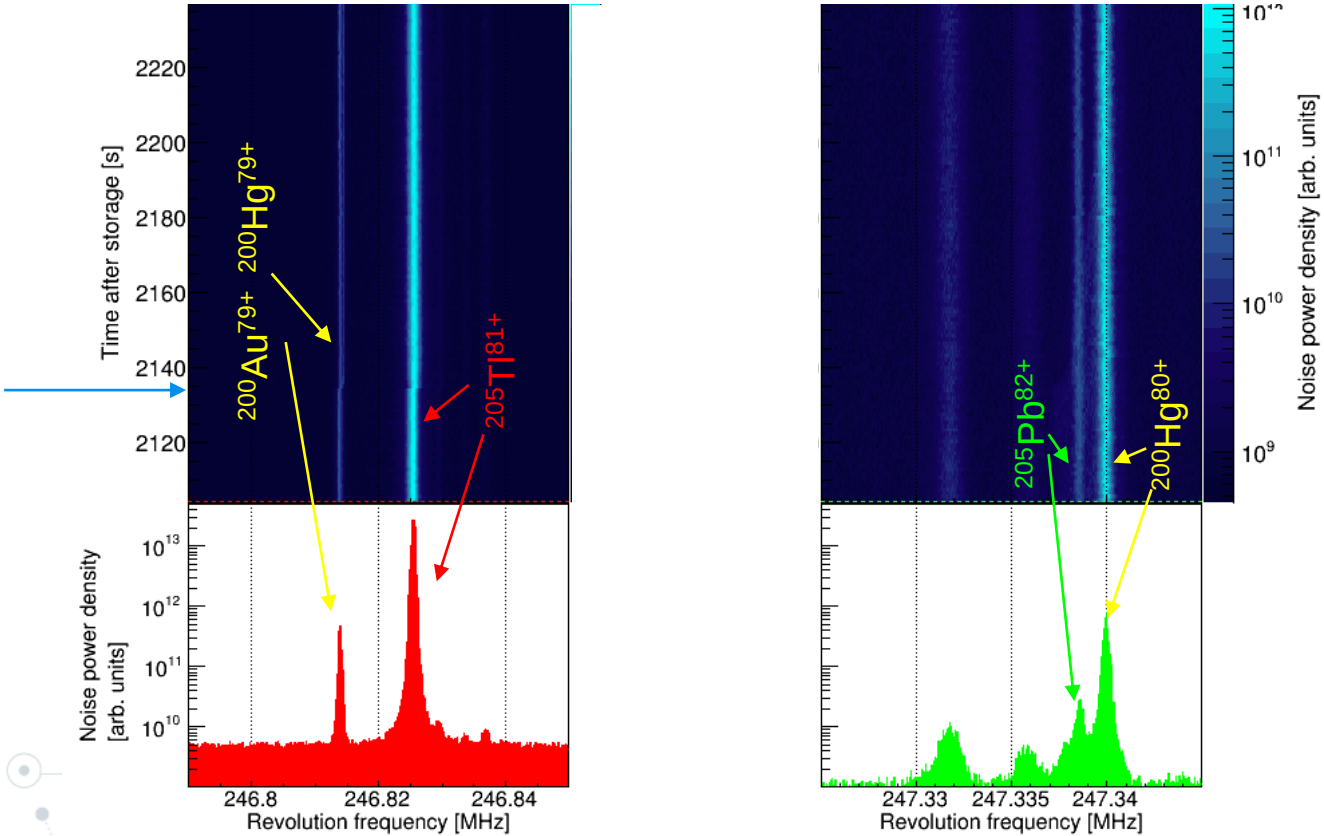
Animations courtesy of Rui Jiu Chen (https://www.researchgate.net/profile/Ruijiu_Chen).



Animations courtesy of Rui Jiu Chen (https://www.researchgate.net/profile/Ruijiu_Chen).



Gas target turned off.



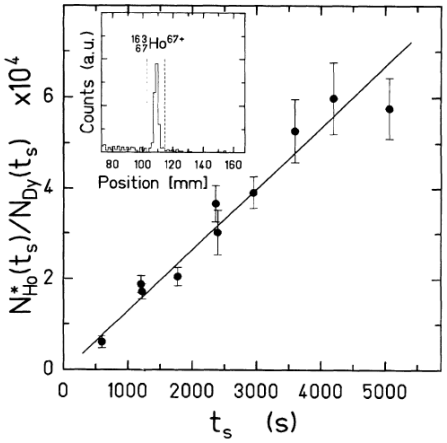
Animations courtesy of Rui Jiu Chen (https://www.researchgate.net/profile/Ruijiu_Chen).

Schottky Results

Results from $^{205}Tl^{81+}$

Results from $^{163}Dy^{66+}$

- $^{163}Dy^{0+}$ is stable.
- $t_{1/2}\left(^{163}Dy^{66+}\right) = 47^{+5}_{-4}\ d.$



M Jung, et. al. PRL. 69:15. (1992) 2164.

Recap:

- β_b^--decay is transformative.
- Need β_b^--decay rate for LOREX.
- Only storage rings hold bare ions long enough.

Thank you to my collaborators!

Analysis: Yu.A. Litvinov[1], R. Gernhaeuser[2], I. Dillmann[3], J. Glorius[1], R.S. Sidhu[1], R.J. Chen[1], C. Griffin[3].

1. Gesellschaft für Schwerionenforschung (GSI), 64291 Darmstadt, Germany
2. Technische Universität München, Germany
3. TRIUMF, Vancouver, Canada

Original Proposal: F. Bosch, C. Brandau, C. Dimopoulou, H. Geissel, O. Klepper, C. Kozhuharov, J. Kurcevicz, S.A. Litvinov, C. Nociforo, F. Nolden, C. Scheidenberger, U. Spillmann, M. Steck, T. Stöhlker, K. Takahashi, H. Weick, M.K. Pavicevic, G. Amthauer, I. Anicin, V. Pejovic, B.S. Meyer, Z. Djurcic, K. Blaum, D. Shubina, N. Winckler, T. Faestermann, P. Kienle, B. Boev

E121 Technical Specifics

- ^{206}Pb enriched source at 10^9 pps & 705 MeV/u in SIS.
- Spallation on Be target + FRS delivers 400 MeV/u $^{205}Tl^{81+}$ ions.
- ~100 stacks injected into ESR per storage.
- Non-destructive Schottky detectors monitor beam in ESR.

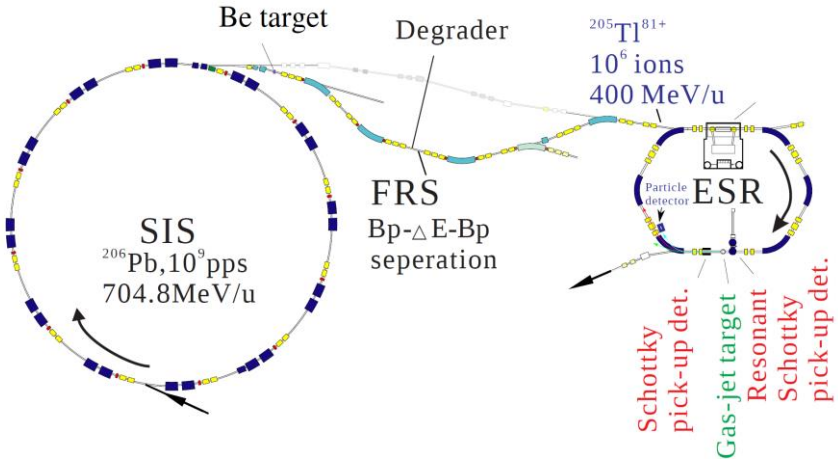


Image courtesy of Ragandeep Singh Sidhu (https://www.linkedin.com/in/ragandeep-singh-sidhu-2b2797b7).

LOREX Specifics

- t1/2(205Pb) = 17.3(7) Ma.
- Geological age of Lorandite ore is 4.31(2) Ma.
- Background 205Pb signal from muon induced reaction.
- Radioactive impurity level very low in crystals.

ESR Specifics

- Circumference: 108.3 m.
- Magnetic rigidity: 10 Tm.
- Ultra high vacuum: ~10^{-11} mbar.
  - Detectors deployed in pockets to maintain vacuum.
  - Whole ring can be baked at ~300°C.