Developing techniques for lifetime measurements in the heaviest elements

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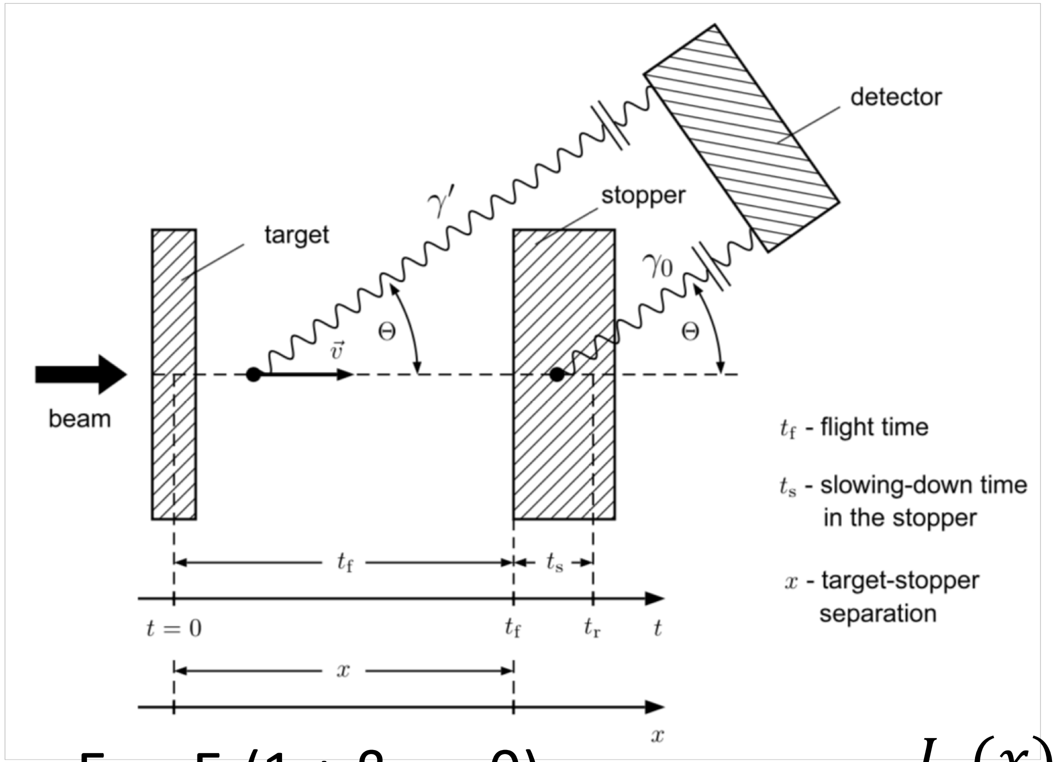
Background

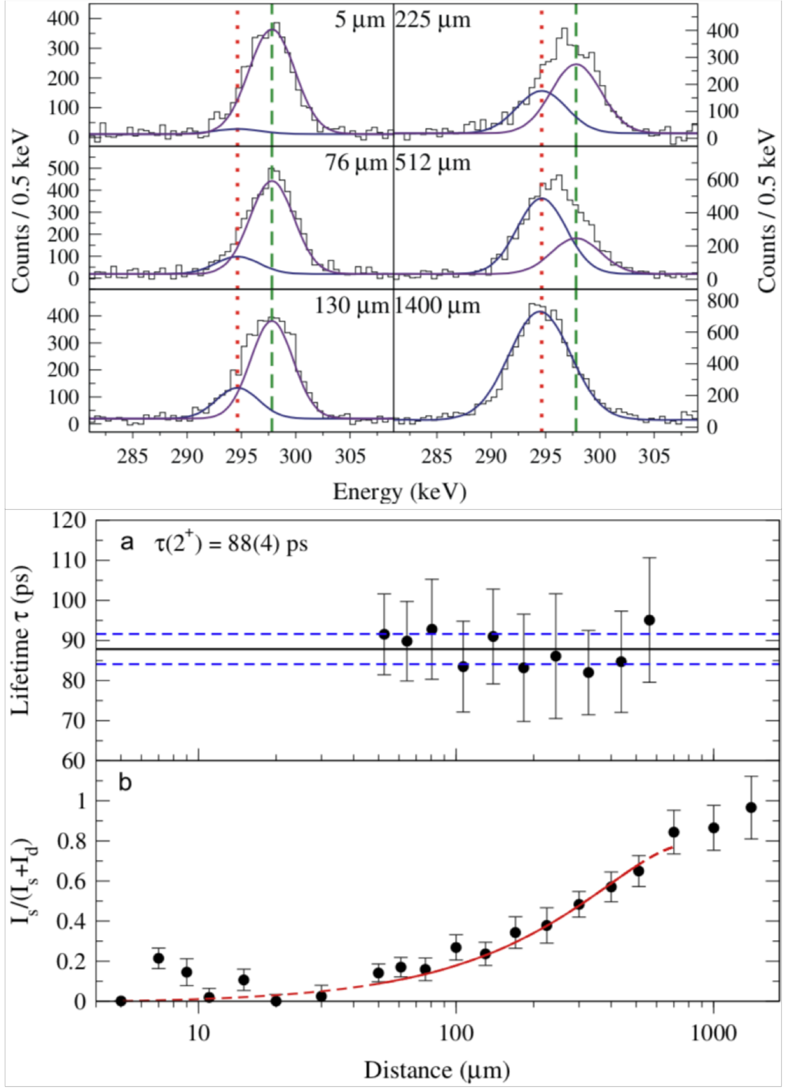
Usual way of measuring nuclear lifetimes: Plunger method



$E_{\gamma'} = E_\gamma(1 + \beta \cos\theta)$

$\beta = v/c$

$$\tau = \frac{I_u(x)}{\frac{d}{dx} I_s(x)} \cdot \frac{1}{v}$$



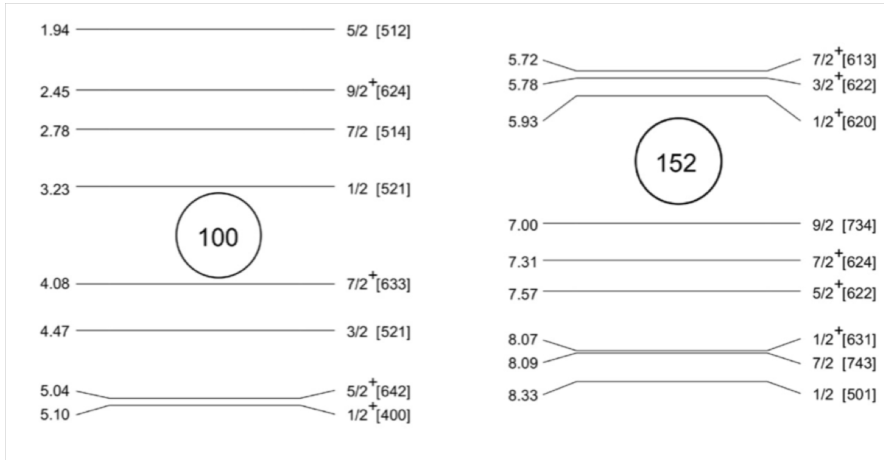
2^+ state in ^{134}Nd

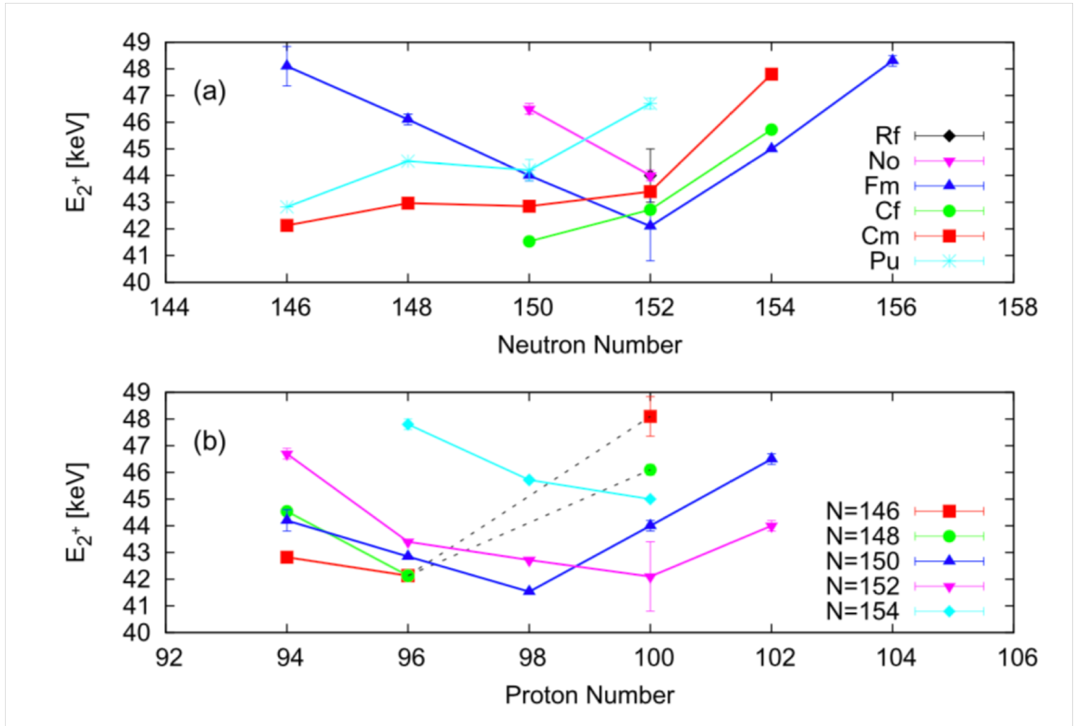
A. Dewald et al., Prog. Part. Nuc. Phys. **67** (2012) 786 – 839

M.J. Taylor et al., Nuc. Instr. & Meth. In Phys Res. A **707** (2013) 143 - 148

Background

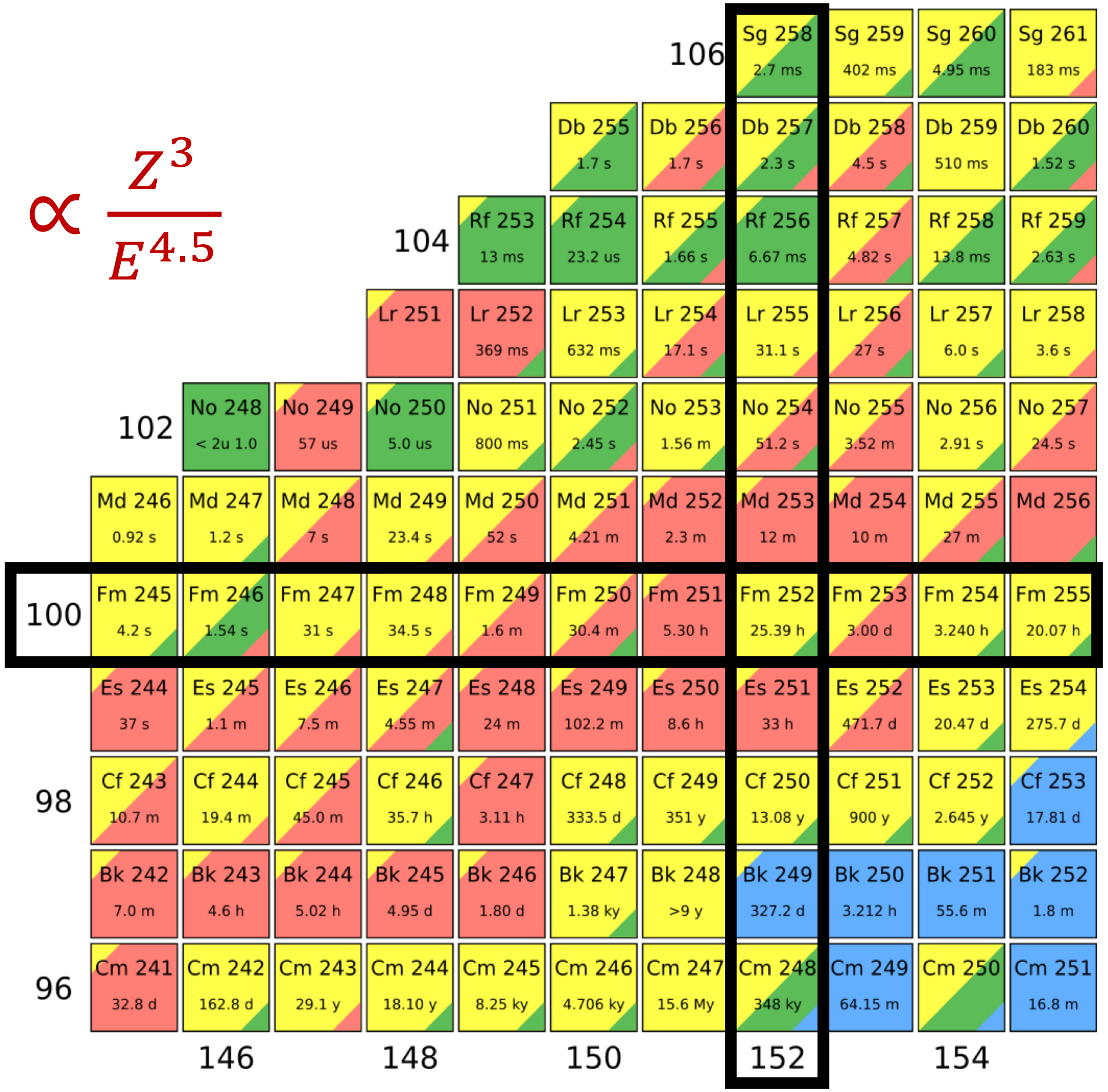
Wood-Saxon





[C. Theisen Nuc. Phys. A **944** (2015) 333-375]

$$\alpha(E2) \propto \frac{Z^3}{E^{4.5}}$$



[M. Leino Eur. Phys. J. A. **6**, 63-69 (1999)]

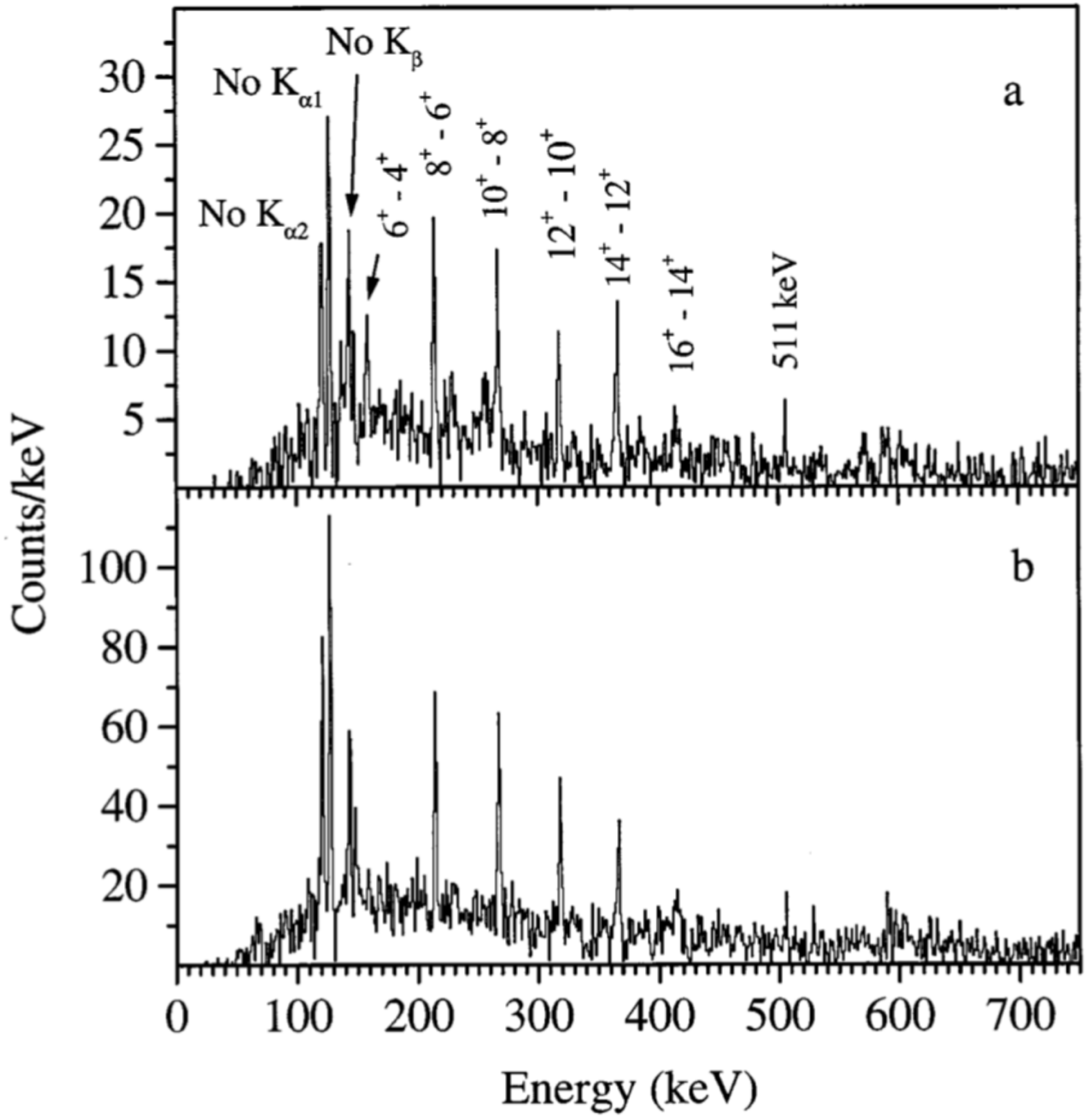
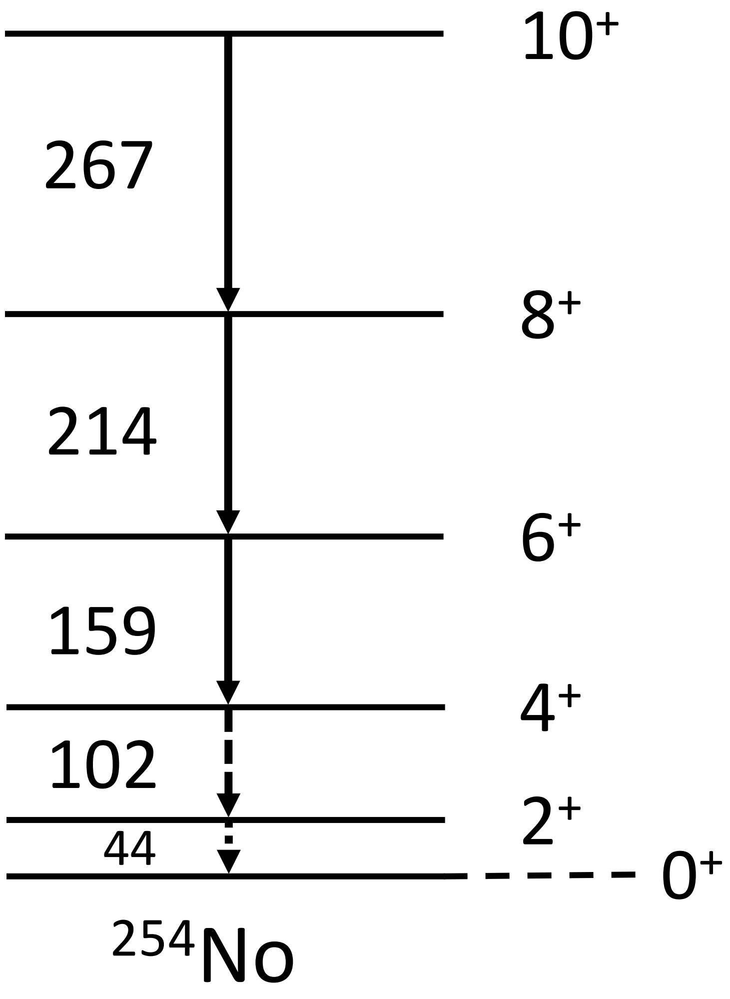


Fig. 3. (a) Spectrum of γ rays in coincidence with ^{254}No evaporation residues. (b) Spectrum of recoil-gated γ rays. The intensity of the 159 keV $6^+ \to 4^+$ transition in (b) is reduced due to a peak of similar energy in the subtracted background spectrum



Grodzins formula:

$$\tau_{\gamma} \propto E^{-4} Z^{-2} A$$

E in keV

τ_{γ} in ps

[L. Grodzins, Phys. Lett. 2, **88** (1962)]

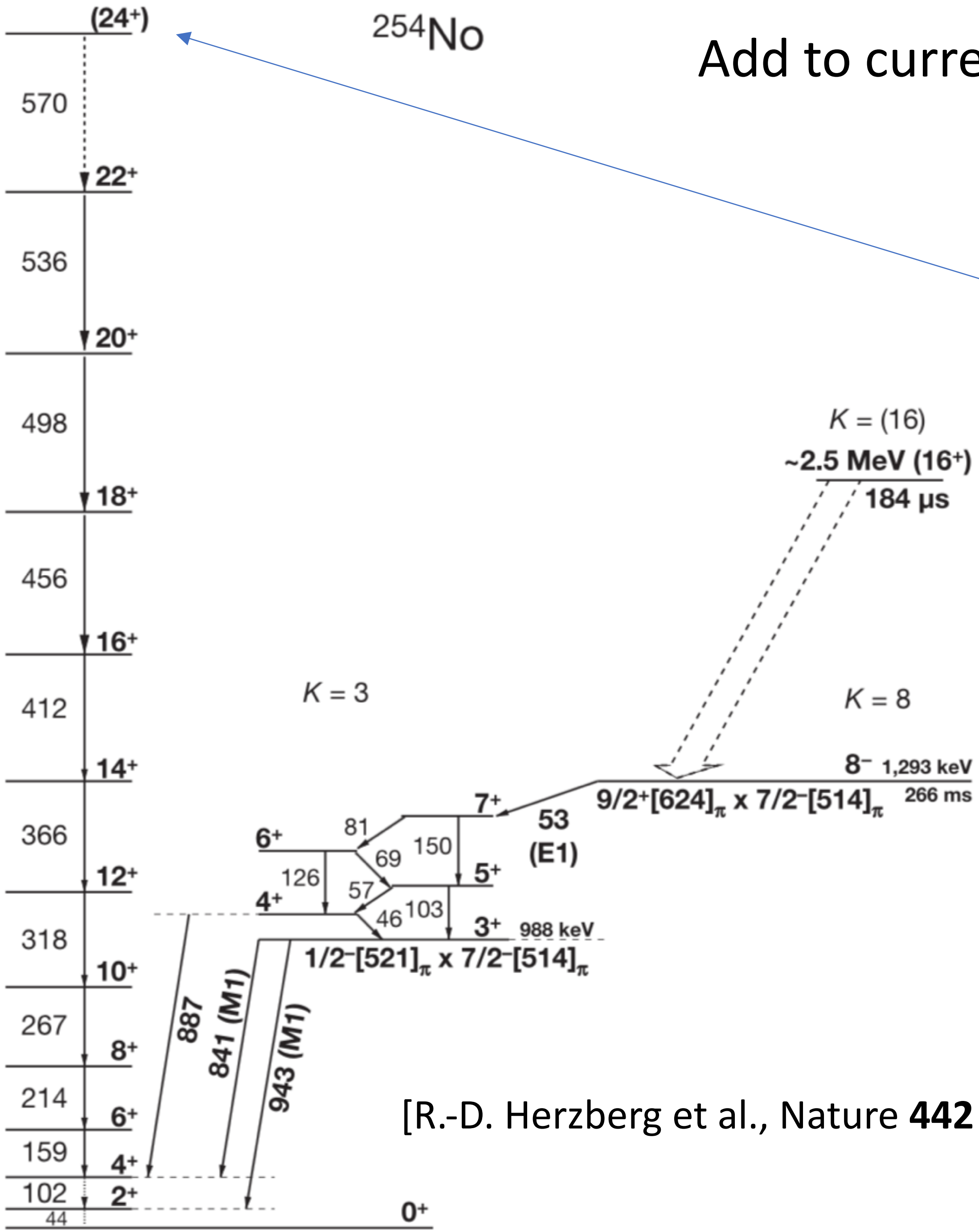
[R.-D. Herzberg et al. Phys. Rev. C **65** 1 (2001)]

$\tau_{2^+} = \;$ 79(22) ps → β_2=0.29(2)

Aim: Directly measure lifetime of $2^+ \rightarrow 0^+$ transition using a charge plunger method

Why do this?

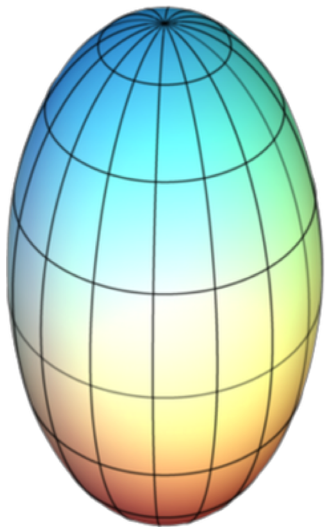
Add to current knowledge of structure in Z = 100, N=152 region



High spin ground states

K-Isomerism - assignment of Nilsson configurations

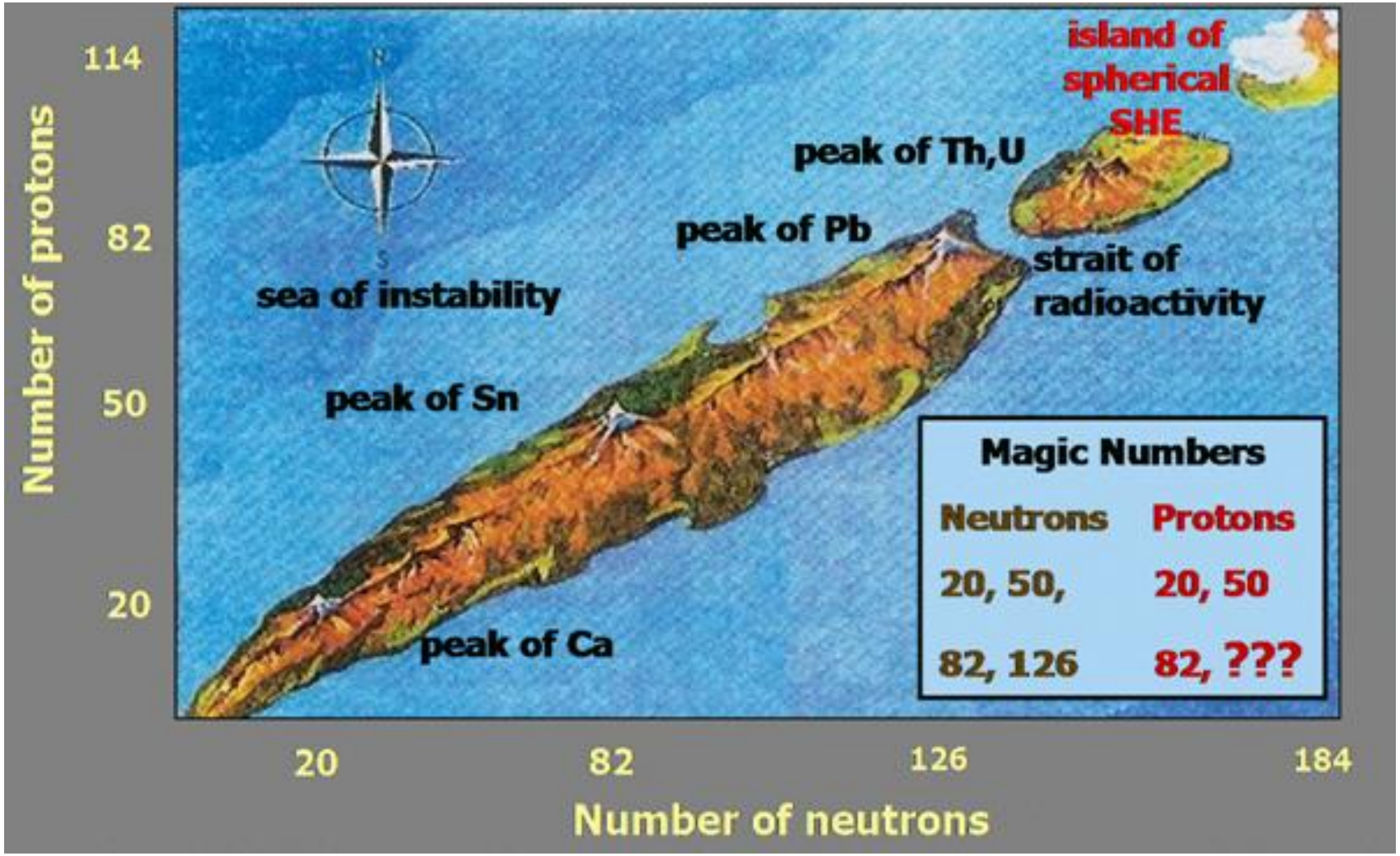
[R.-D. Herzberg et al., Nature **442** 896-899 (2006)]



Characterise shape of ground state bands

Q_0 = ?

Improve theoretical models at boundary of superheavy region of chart



Predict which models will work best for superheavy region of chart.

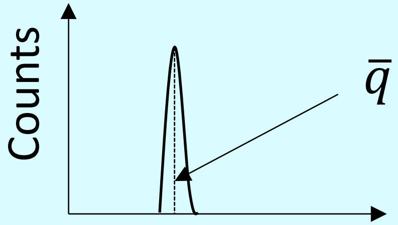
Key Concepts

Ion passing through carbon foil

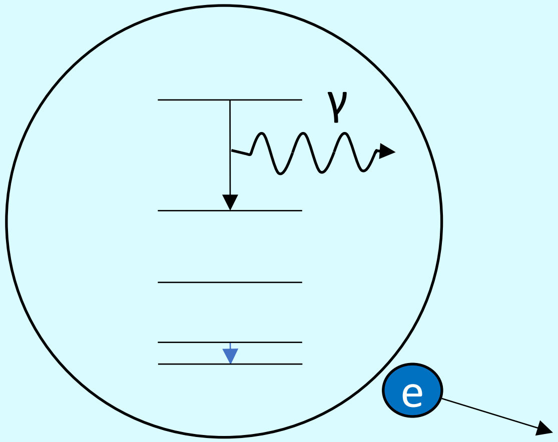
Nikolaev and Dimitriev,

$$\bar{q} = Z[1 + (\frac{v}{Z^{\alpha} v'})^{-1/k}]^{-k}$$

- Z = proton number of the ion
- v = speed of the ion
- k = 0.6
- α = 0.45
- $v' = 3.6 \cdot 10^6$ m/s

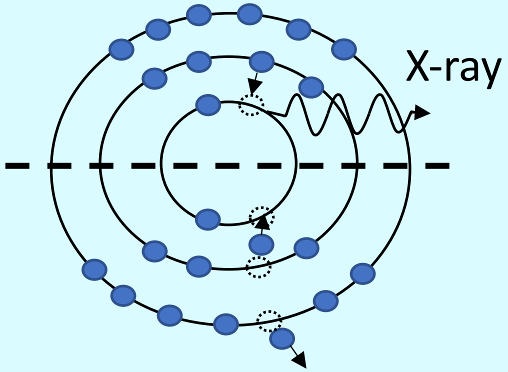


Internal Conversion (IC)

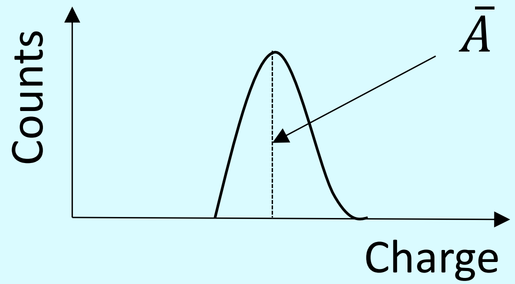


- IC coefficient, **α** = I_e/I_γ
  - I_γ = gamma intensity rays
  - I_e = electron intensity
- **α** is larger for smaller energies and higher Z

Auger Cascade



- Several Auger emissions in one cascade



Charge Plunger Method

NUCLEAR INSTRUMENTS AND METHODS 148 (1978) 369-379 ; © NORTH-HOLLAND PUBLISHING CO.

LIFETIME MEASUREMENTS OF NUCLEAR LEVELS WITH THE CHARGE PLUNGER TECHNIQUE

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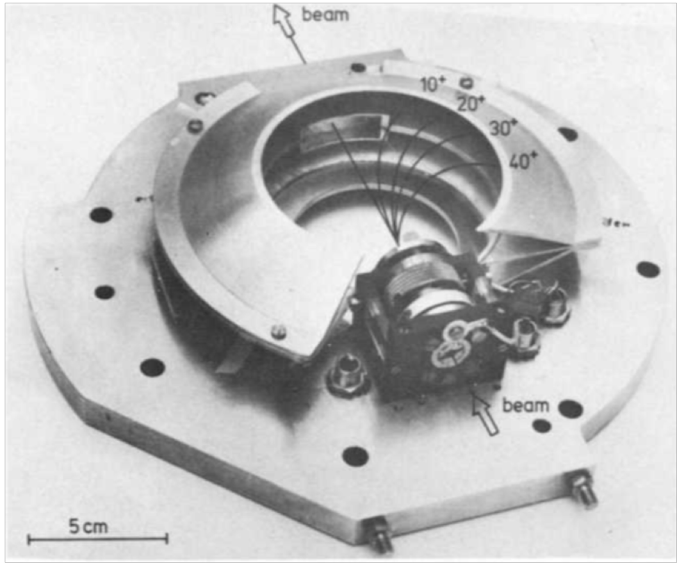
Physikalisches Institut der Universität Heidelberg and Max-Planck-Institut für Kernphysik, Heidelberg, W. Germany

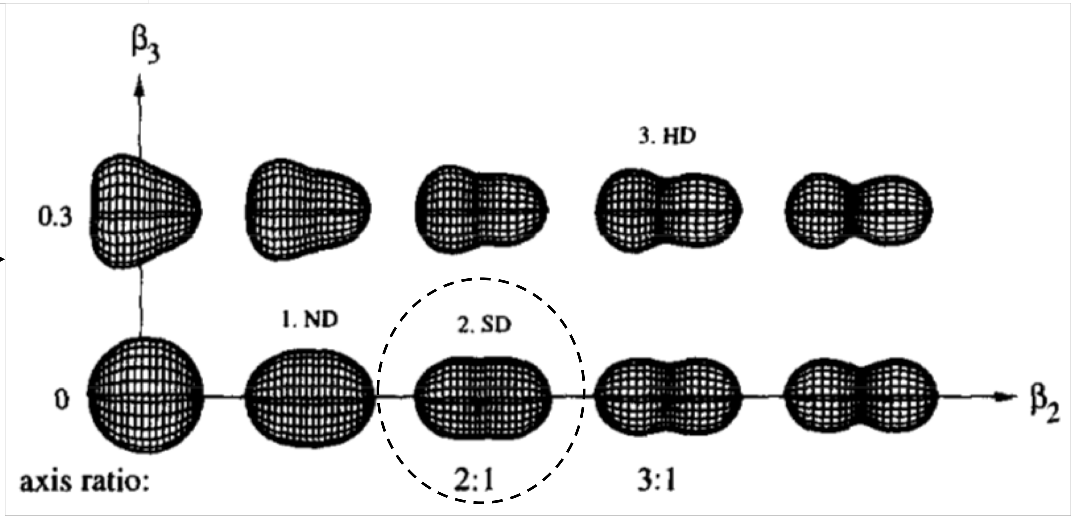
Received 29 June 1977

A new type of recoil distance method has been developed for in-beam measurements of nuclear lifetimes. States decaying by converted transitions lead to highly charged recoil ions as a result of fast Auger cascades in the atomic shells. The high charges are reset to the equilibrium value by traversing a thin carbon foil. The lifetimes are determined by measuring the intensity ratio of high and low charge recoil ions as a function of the target–carbon foil distance. An interesting application of this new technique is the lifetime measurement of rotational states in the second minimum of actinide nuclei.



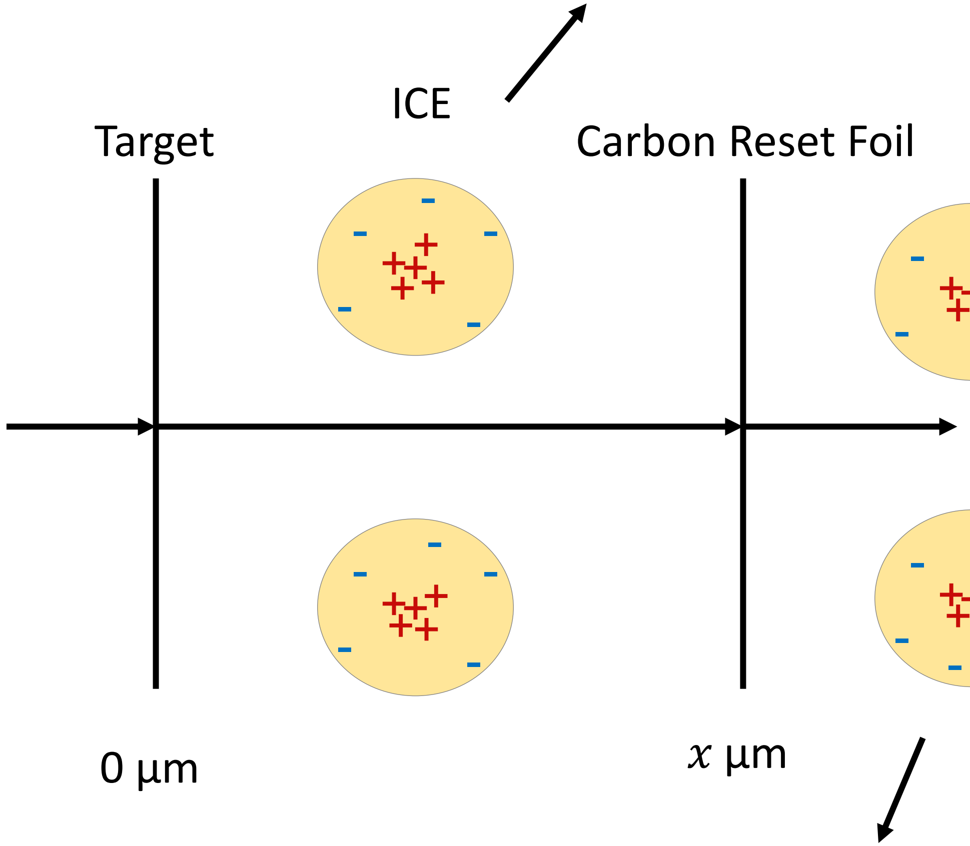
- ^{238}U: Q_0 = (29 ± 3) b for the 200-ns isomer
- ^{239}Pu: Q_0 = (36 ± 4) b for the 8-µs isomer

[P.G. Thirolf and D. Habs, Prog. Part. Nuc. Phys. **49** (2002) 325 – 402]



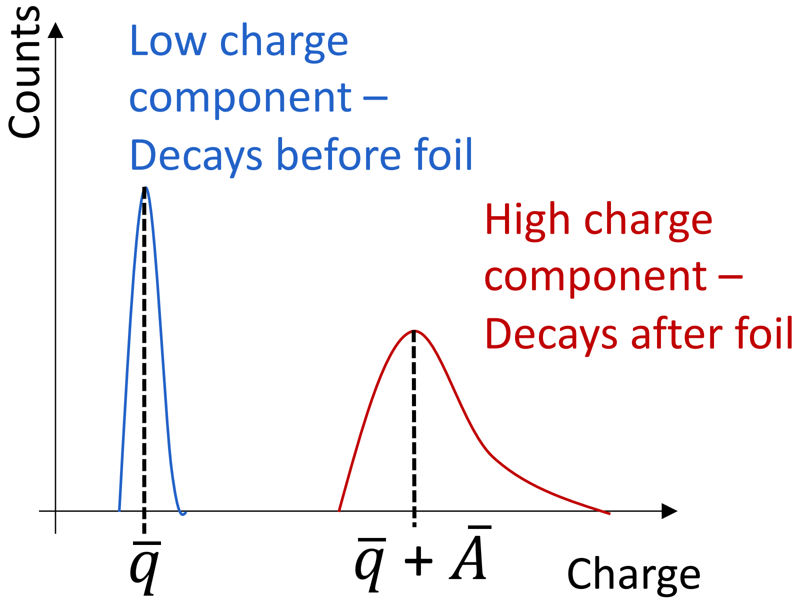
Charge Plunger Method

- Basic Concept:

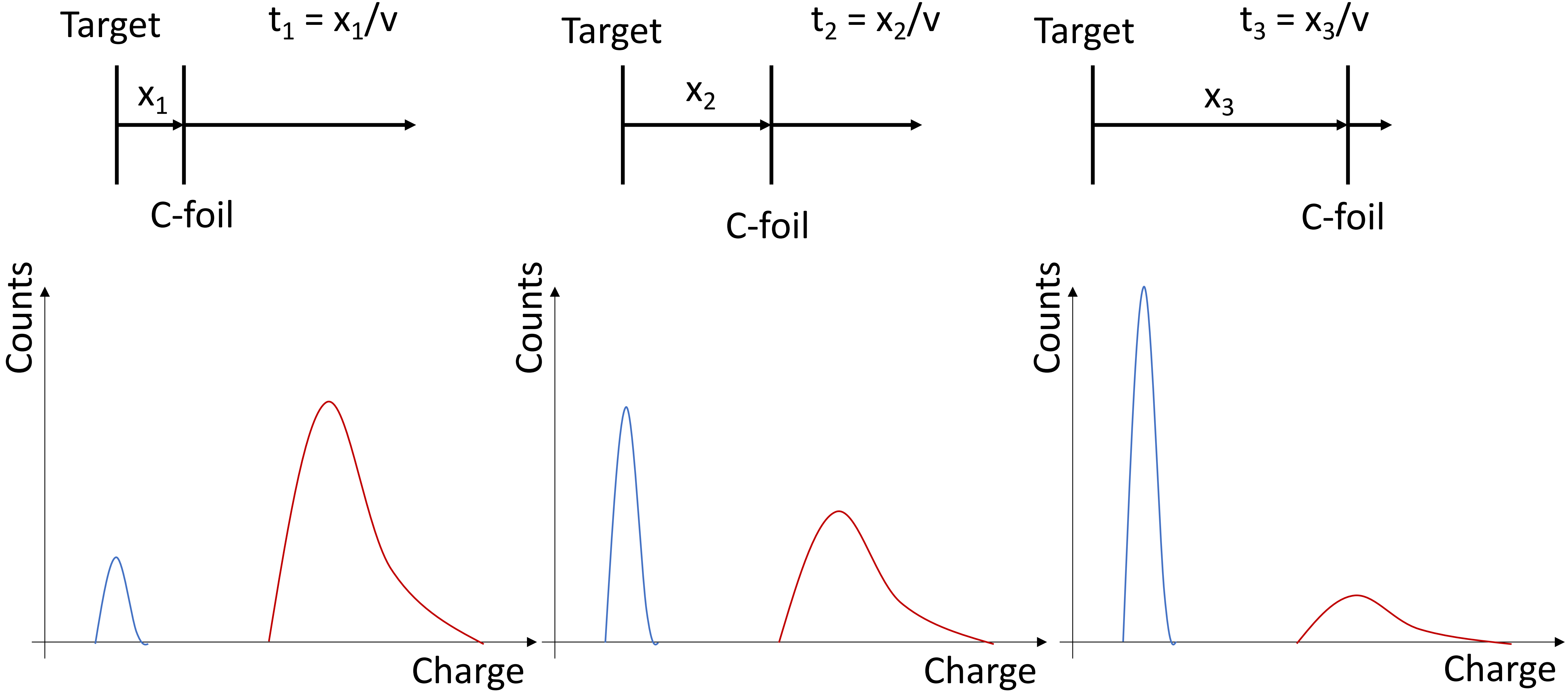


Decay before foil:
Charge state = $\bar{q}$

Decay after foil:
Charge state = $\bar{q}$ + $\bar{A}$



Charge Plunger Method

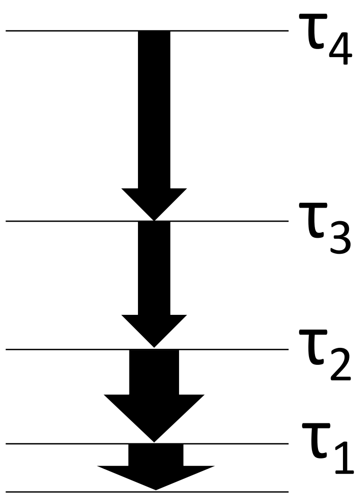


Charge Plunger Method

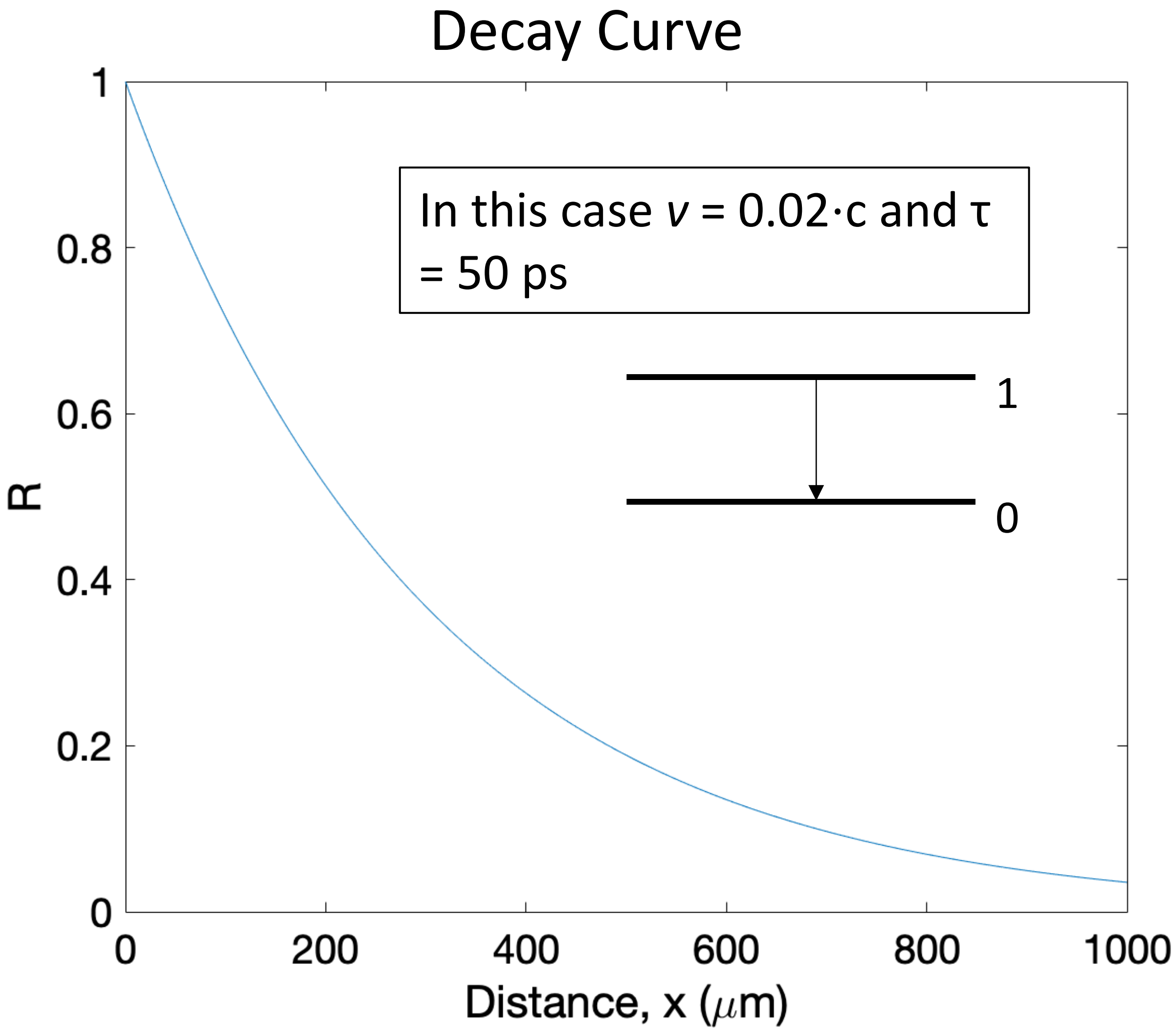
$$\mathbf{R} = \frac{I_H}{I_L+I_H} = \exp\left(-\frac{t}{\tau}\right) = \exp\left(-\frac{x}{v\cdot\tau}\right)$$

I_H = High charge component intensity
I_L = Low charge component intensity

More realistic case: Rotational band

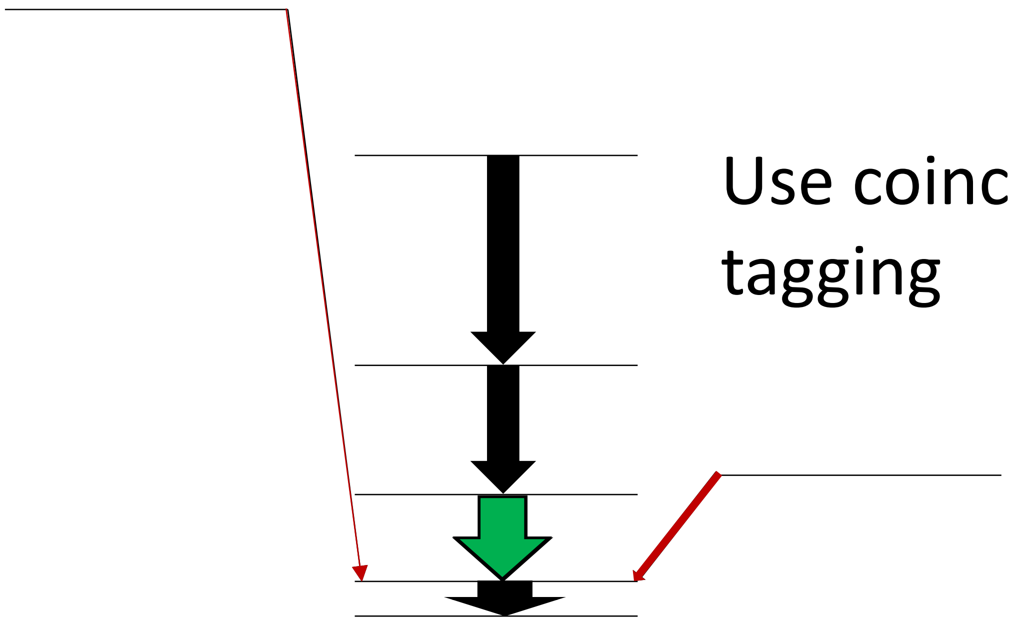


Solve appropriate Bateman equations
- More free parameters

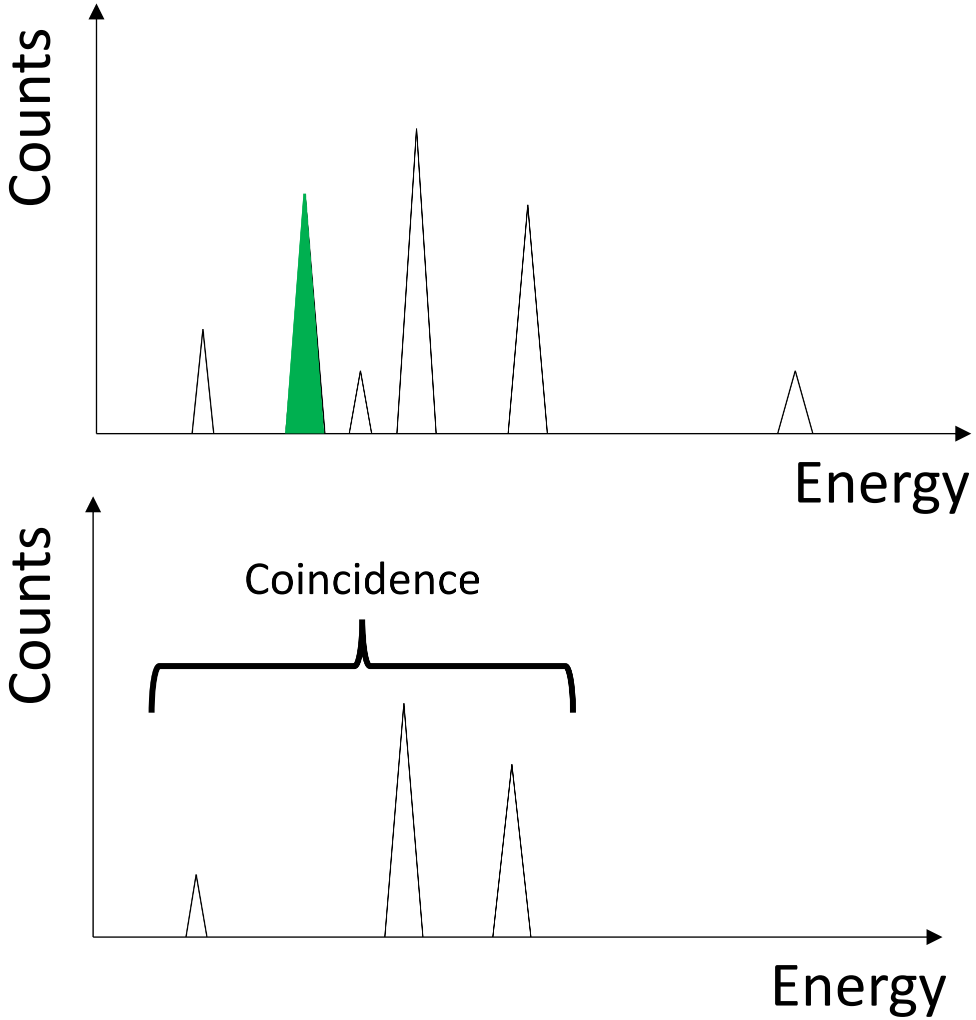


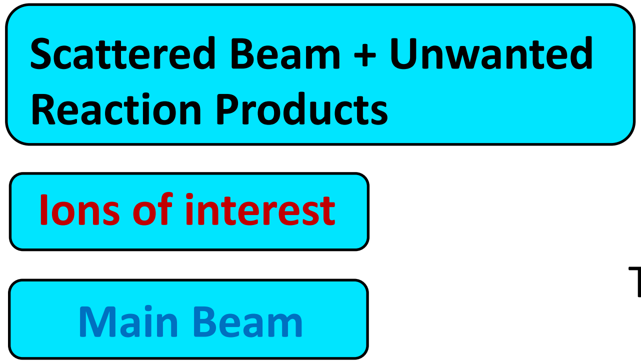
Side Feeding

- Common problem in all plunger experiments

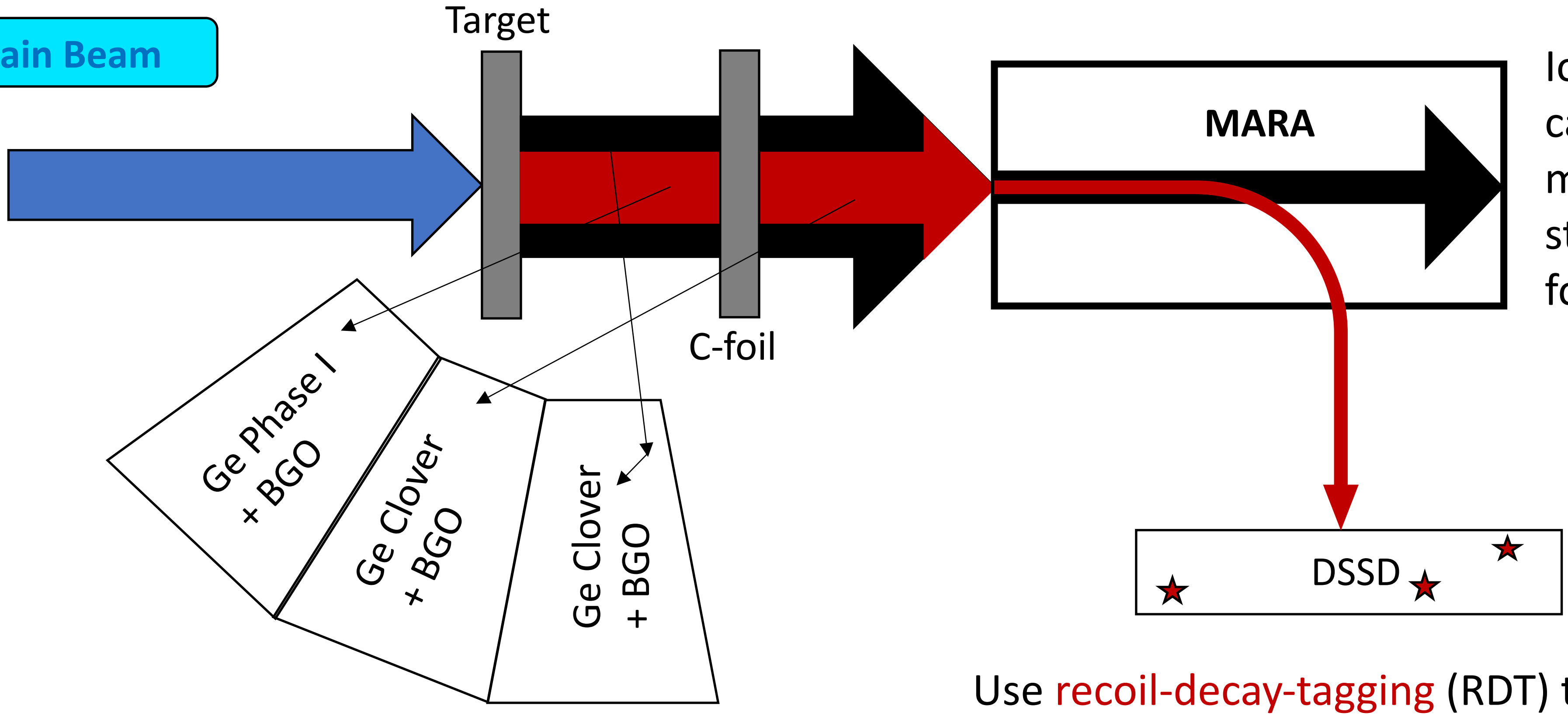


Use coincidence tagging





Charge Plunger Method



Ions separated by m/q. We can scan across a range of m/q values to obtain charge state distribution (CSD) at focal plane.

Prompt gamma rays detected at target using Jurogam

Use recoil-decay-tagging (RDT) technique

Only expect 2-3 charge states at focal plane

Need to be careful about normalization

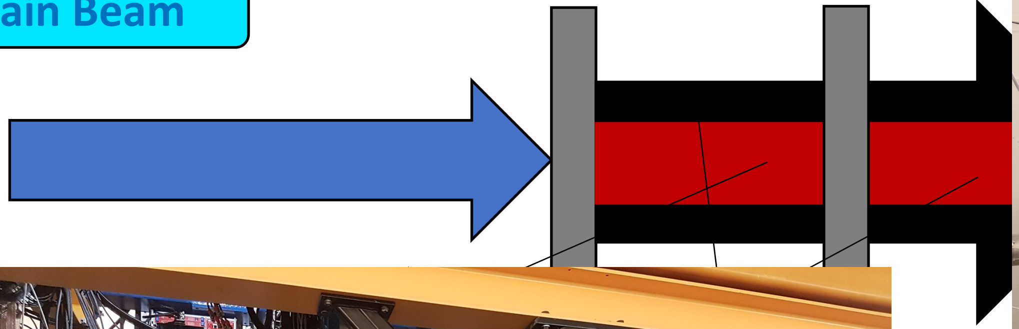
Charge Plunger Method

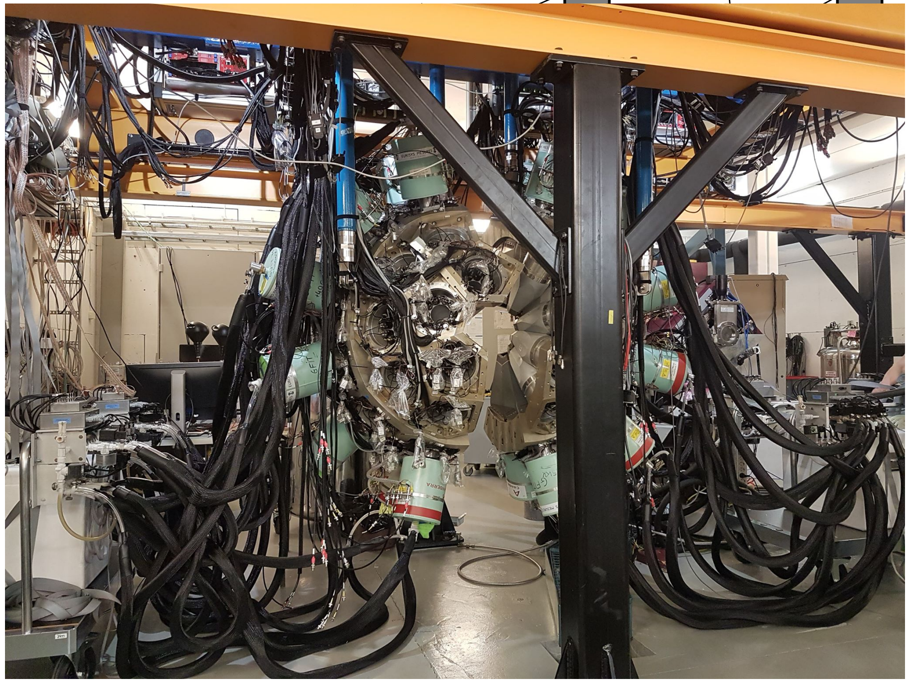
Scattered Beam + Unwanted Reaction Products

Ions of interest

Main Beam

Target





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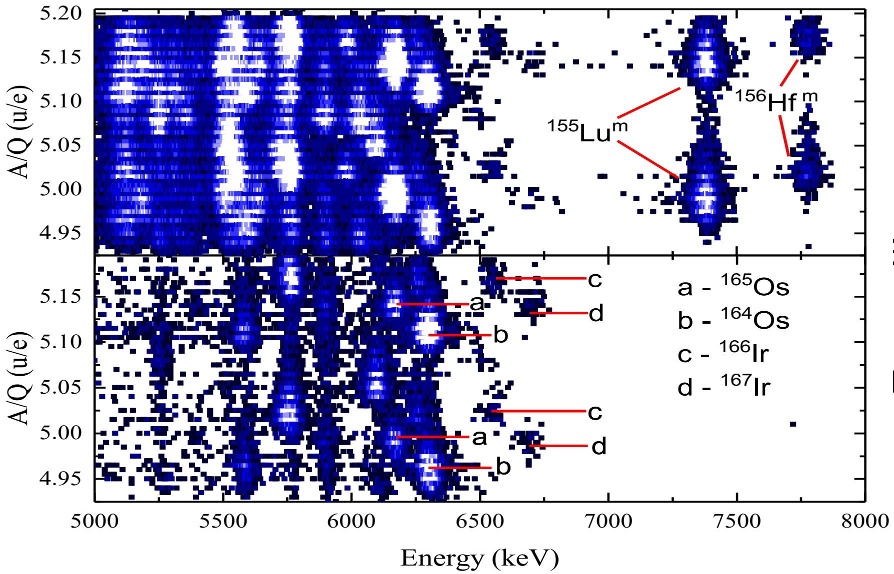

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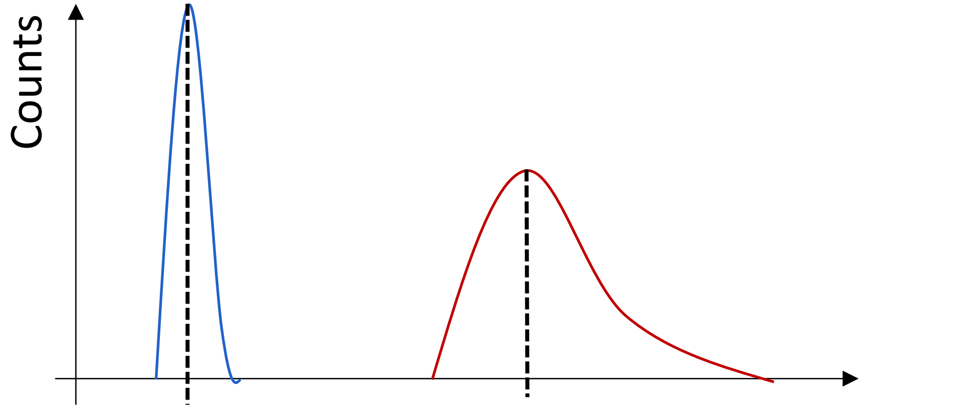
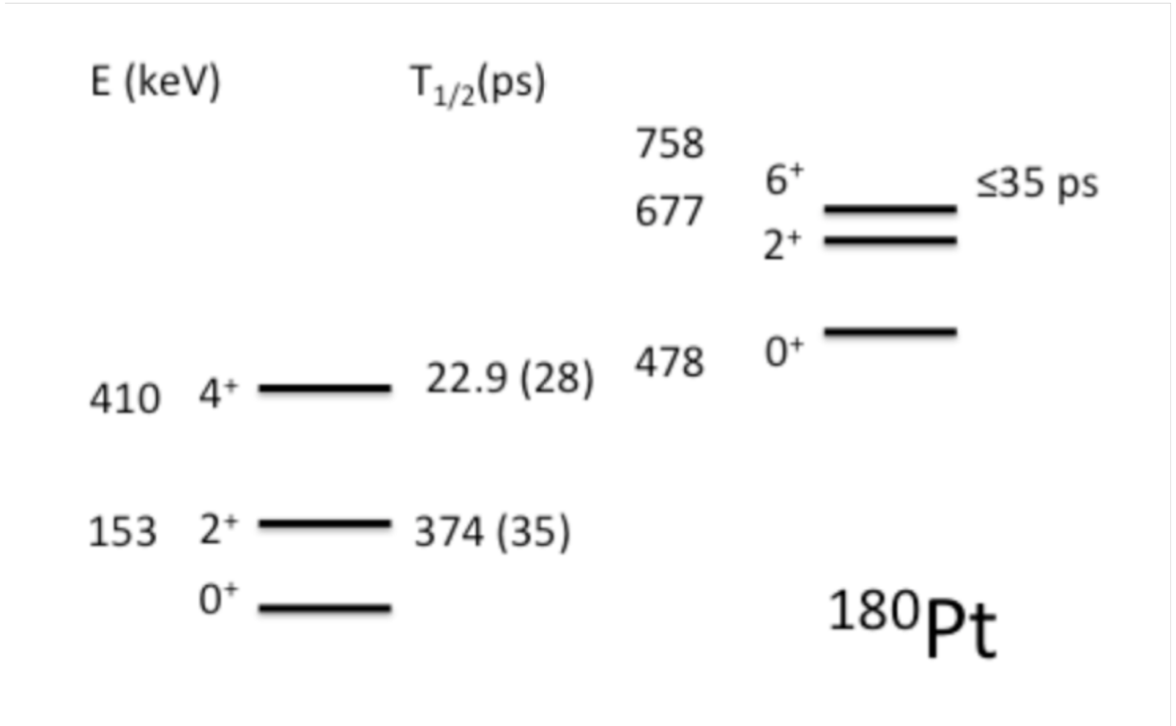
Planned Experiment

- Planned experiment at JYFL using MARA this year
- Proof of concept experiment
- $^{152}Sm(^{32}S,4n)^{180}Pt$ reaction @ 165 MeV



$\bar{q} \approx 13+$ $\bar{q} + \bar{A} \approx 24+$

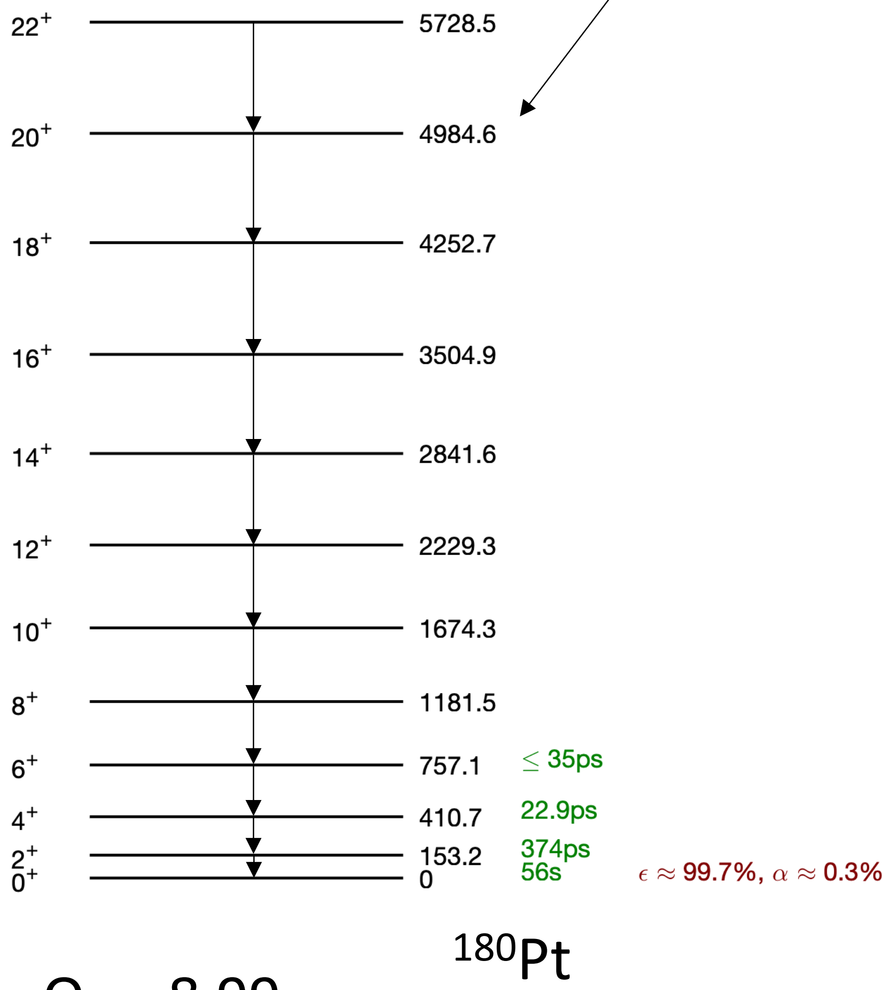


The 153 keV transition: α = 0.929

Simulation

- A Monte Carlo `MATLAB` code to estimate CSD
- Input parameters:
  - IC coefficients
  - Lifetimes
  - Speed of nuclei
  - Charge distributions due to Auger cascade [Carlsson et al., Phys. Rev. **151** 1 (1966)]
  - Target-foil distance
- Experimental values for parameters used where possible.

Input Level Scheme

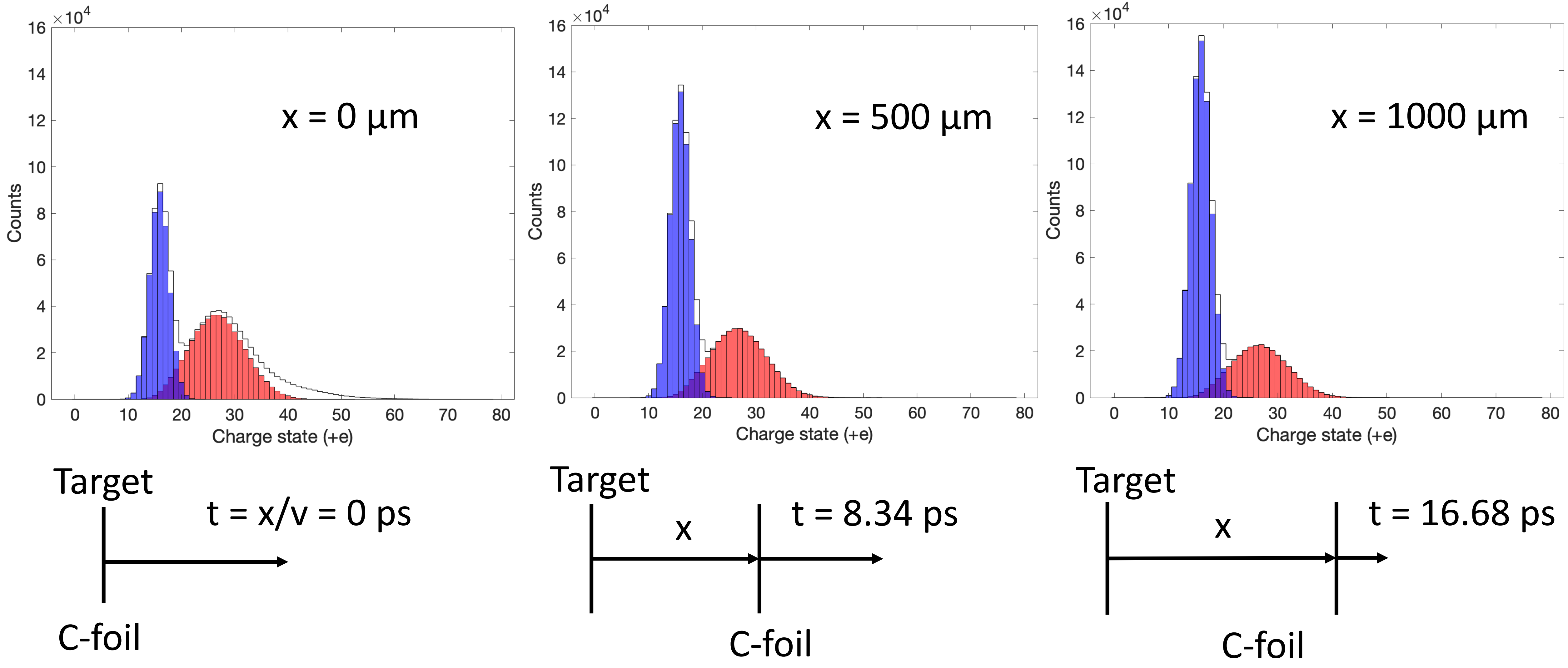


$Q_0 \approx 8.99$

[M.J.A. De Voigt et al. Nuc. Phys. **A507** (1990) 472]

Number of nuclei in simulation = 10^6, speed of nuclei v = 0.02c

$$R = \frac{I_H}{I_L + I_H}$$



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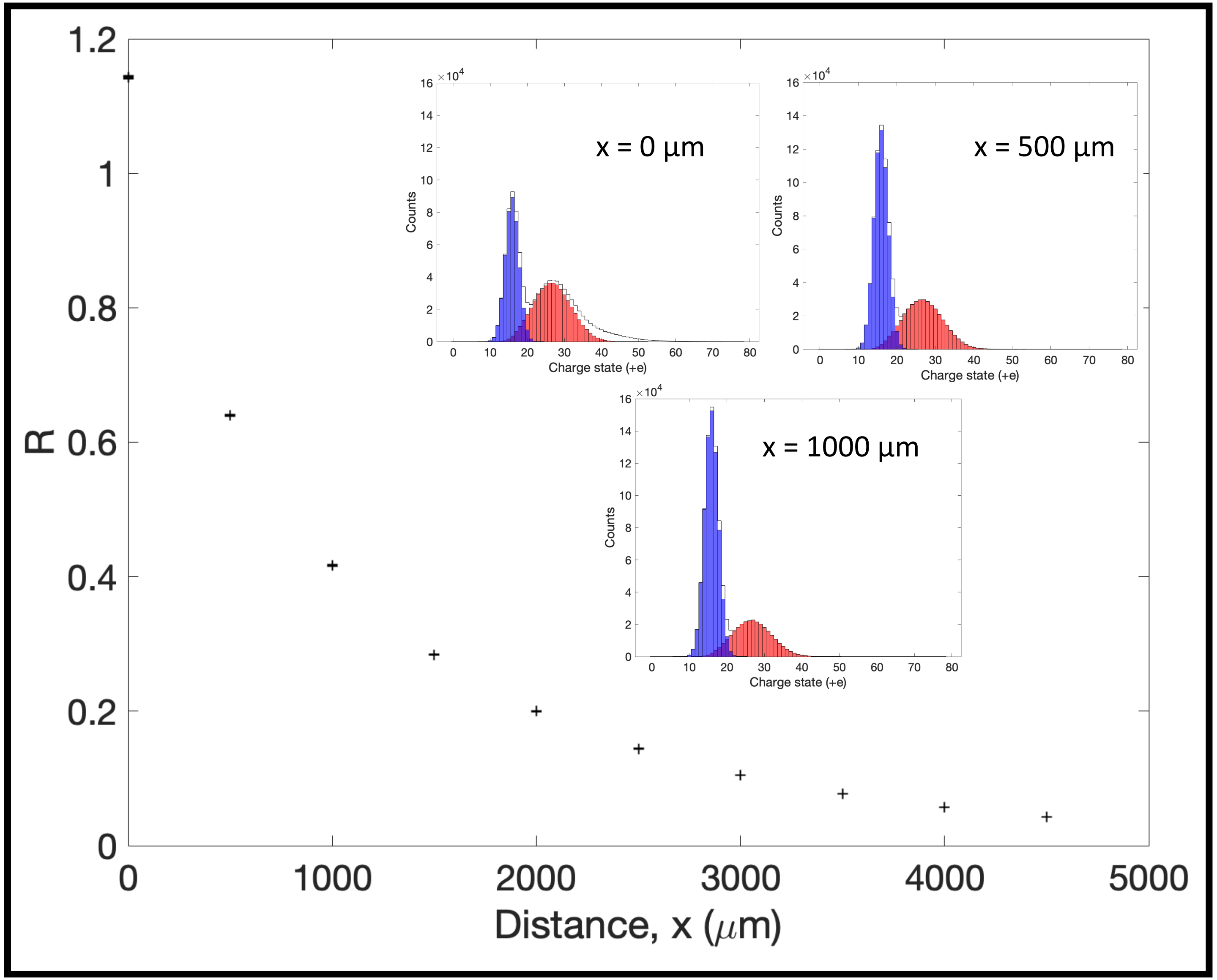
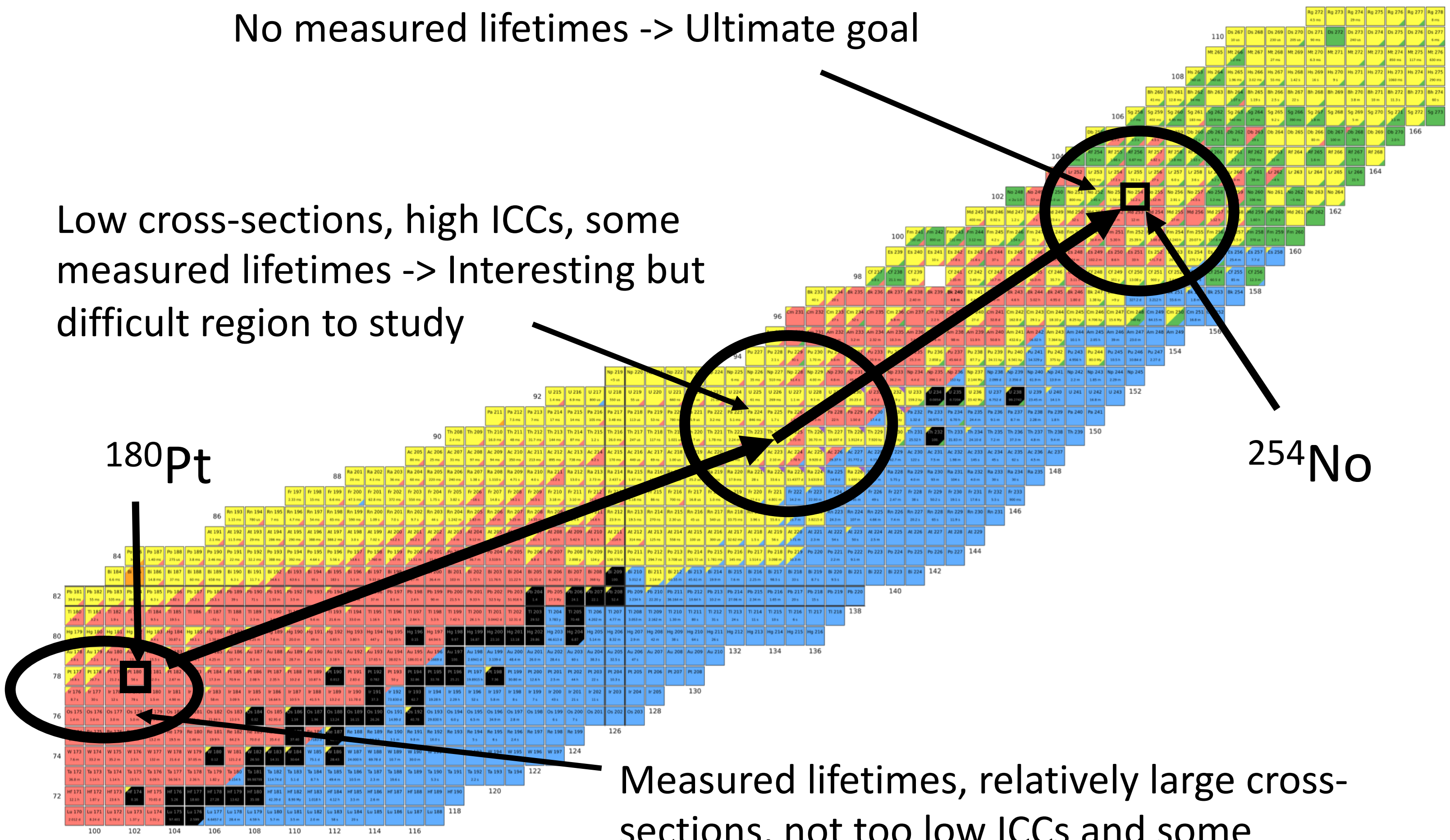


Future Experiments

Very low cross-sections, very high ICCs,
No measured lifetimes -> Ultimate goal

Low cross-sections, high ICCs, some measured lifetimes -> Interesting but difficult region to study



Measured lifetimes, relatively large cross-sections, not too low ICCs and some probability of alpha decay -> good for proof-of-concept experiments

- Aim is to push towards an experiment looking at the lifetime of yrast 2^+ state in ^{254}No.
- Low production cross section ➞ more experiments testing the method needed first.
- ^{176}Pt/^{178}Pt?
- ^{224}Th/^{226}U region?

Summary

- First direct lifetime measurement of yrast 2^+ state in ^{254}No. Currently lifetime assigned through empirical relationship.
- Test nuclear models at the boundary of superheavy region.
- Experiment upcoming this year to test charge plunger method on ^{180}Pt. Will give us an idea of how effective the method is and what pitfalls to look out for.
- More experiments will be needed before we can reach goal of studying ^{254}No.

Thank you for listening

any questions?