Lifetime measurements of excited states in (super)-heavy nuclei

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Outline

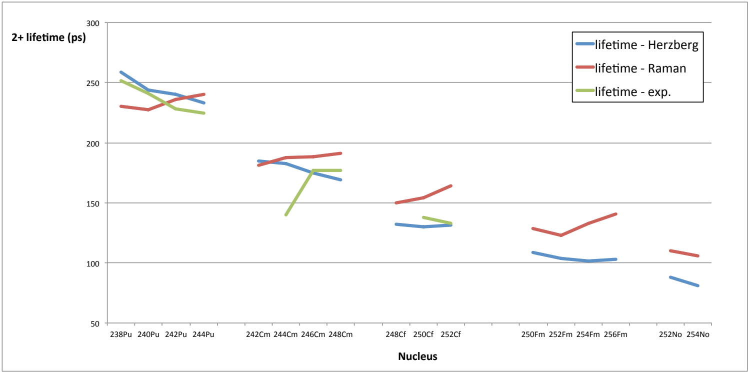
Why measure lifetimes?

- Model-independent information
- Transition Energy+Lifetime $\rightarrow$ Acces to wavefunction (although no longer model independent)

Imagine we've measured some lifetimes in gsb of ^{254}No

1. They behave like a rotor - we get an anchor point for theory
2. They dont behave like a rotor - ???

What is known (courtesy of A. Lopez-Martens)



How to measure the lifetime of a non-isomeric exicted state?

Three "big" techniques for γ-ray spectroscopy

1. Doppler Shift Attenuation Method $\leftarrow$1ps
2. Recoil-Distance Doppler Shift 1ps$\rightarrow$
3. "Fast timing" 20ps$\rightarrow$

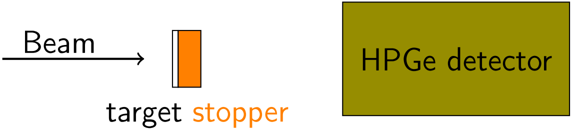
And if we forget about γ-rays?

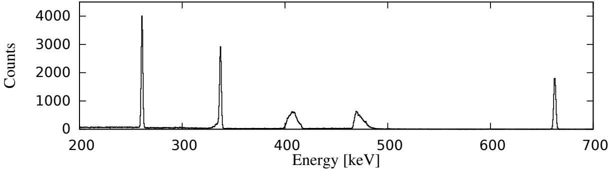
- See end of talk

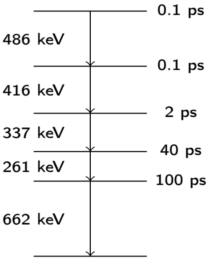
How to measure the lifetime of a non-isomeric exicted state?

Doppler Shift Attenuation Method ←1ps

- Lineshape effects from the slowing down of recoil
- Slowing down of nuclei modeled







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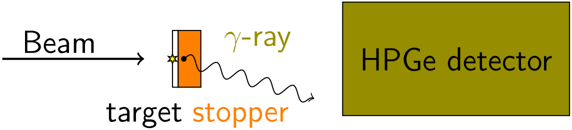

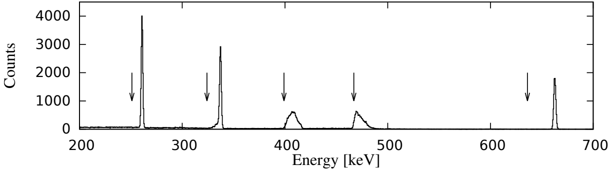

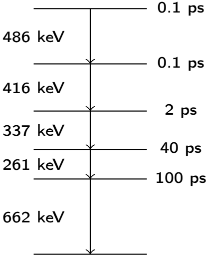

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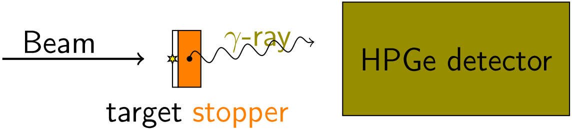

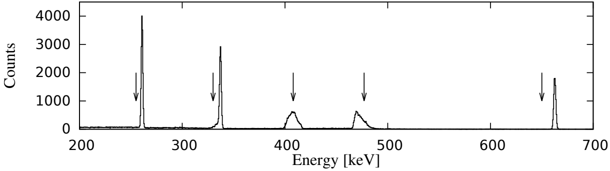

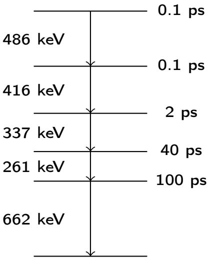

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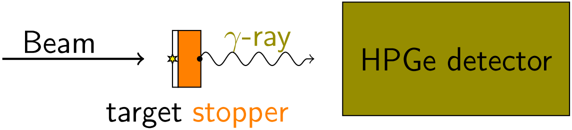
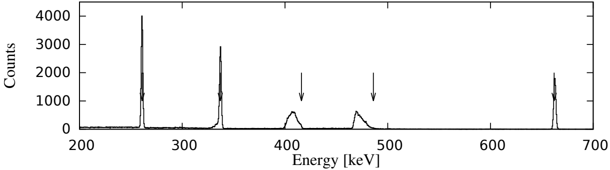
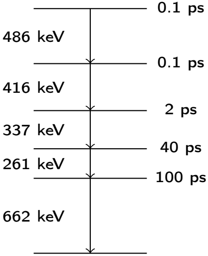


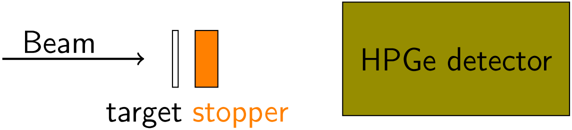


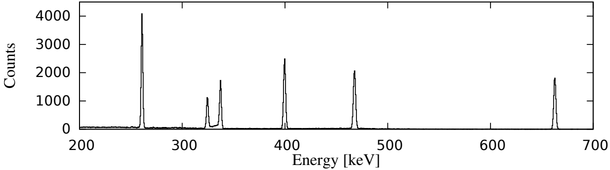


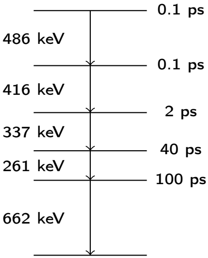
How to measure the lifetime of a non-isomeric exicted state?

Recoil-Distance Doppler Shift

- Tracing the solution of Batemans equations
- Velocity and distance used to get time of flight







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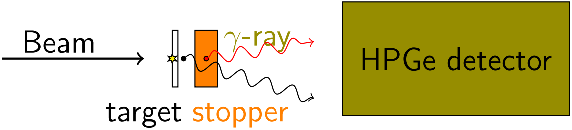

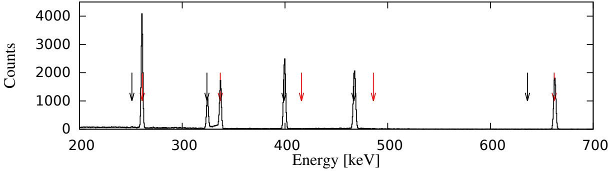

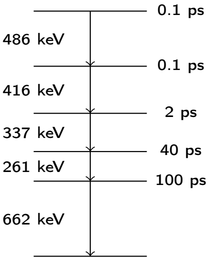

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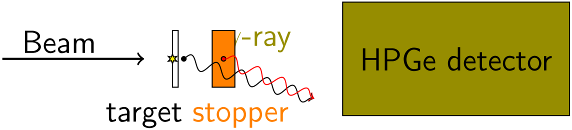

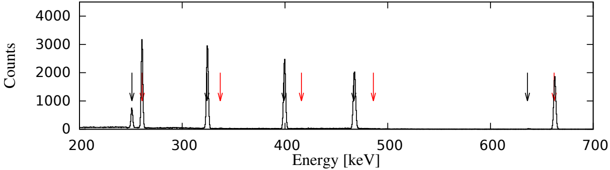

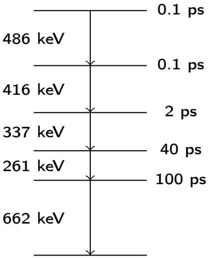

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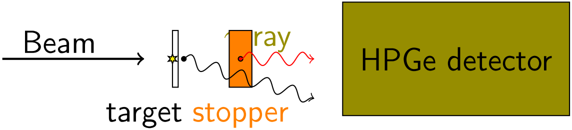
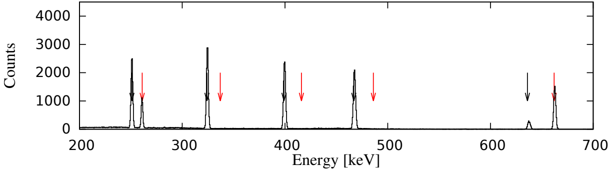
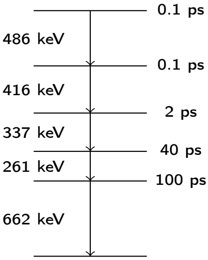


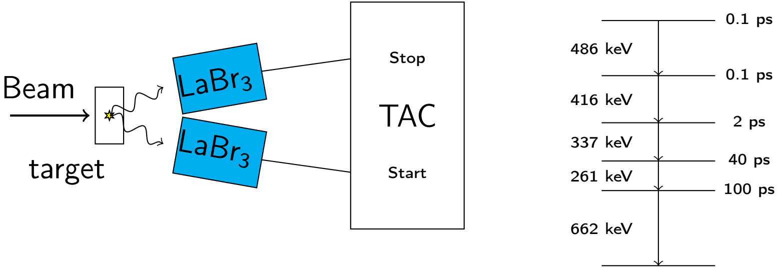




How to measure the lifetime of a non-isomeric exicted state?

Fast timing

- "Stop watch" $2\tau = \Delta T(261X662) - \Delta T(662X261)$
- Possible with decay-spectroscopy
- Devil is in the details. Complicated measurements



For the heavies - What to choose?

What lifetimes are we trying to measure?

Example: ^{254}No

J	E [keV]	γ-ray [keV] (J$\rightarrow$J-2)	τ [ps] (estimated)	α
2	44.2	44.2	79	1511
4	145.3	101.2	43	29.9
6	304.2	158.9	25	4.01
8	518.3	214.1	12	1.21
10	785.5	267.2	6	0.536
12	1103.7	318.2	3	0.3
14	1470.2	366.5	1	0.195
16	1884.2	414.0	1	0.139
18	2340.2	456.0	1	0.107

For the heavies - What to choose?

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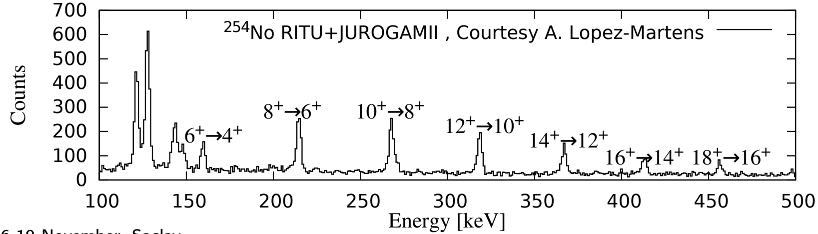


For the heavies - What to choose?

Conclusion - In the domain of RDDS, i.e. "Plunger measurements"

Challenges we are facing

Which are our contraints?

1. Δv to see two peaks
2. Energy resolution of γ rays, again for peak separation
3. Recoil (Decay) Tagging, needs a separator
4. Compound nulei and its exciatation energy

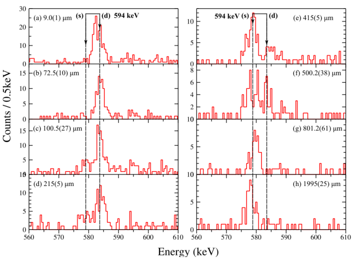
State of the art

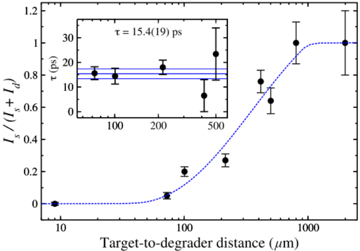
What has been done that reminds us of what we want to do?

^{109}I - M.G. Procter at al. PLB 704

- 40 μb (0.01% of HIF xs)
- 2.5 pnA beam
- 1 mg/cm^2 target
- Recoil Decay Tagging (RITU+PRE-JUROGAMII)
- v/c=3.5% degraded to 2.7% before separator

M.G. Procter et al. / Physics Letters B 704 (2011) 118–122





Challenges we are facing

4. Compound nulei and its exciatation energy

Staying with ^{254}No, $2\mu b$ if ^{48}Ca and ^{208}Pb with CM energy of 178 MeV

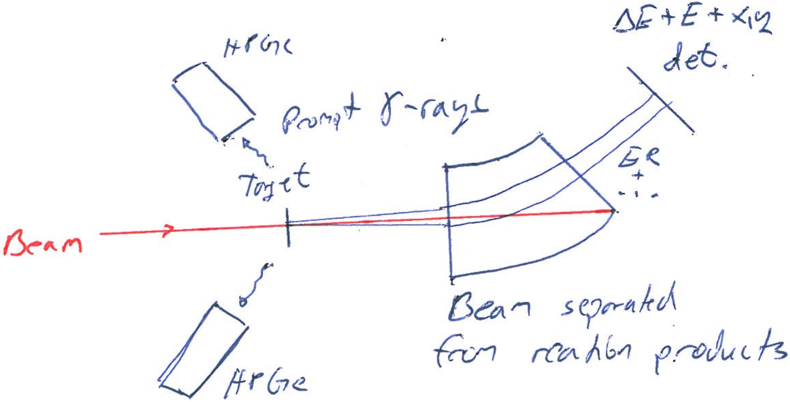
- ^{48}Ca@220 MeV $\rightarrow$ Recoil velocity 1.9%
- ^{208}Pb@950 MeV $\rightarrow$ Recoil velocity 8.1%

Take note of:

1. ^{48}Ca target very complicated
2. ^{208}Pb much closer to ^{254}No than what ^{48}Ca is

Challenges we are facing

3. Recoil (Decay) Tagging, needs a separator



Challenges we are facing

3. Recoil (Decay) Tagging, needs a separator

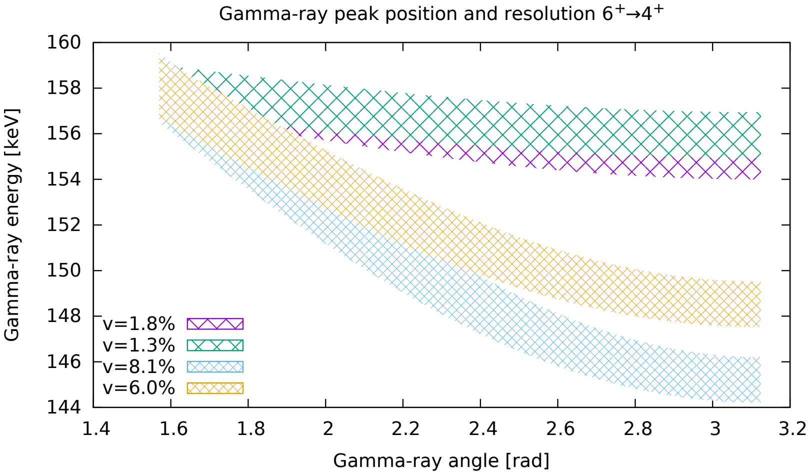
1. We need to get rid of fisson and beam
2. We need recoil decay tagging → 10s of MeV recoil energy

- Vacuum separator, FMA, VAMOS, MARA. Typically good rejection, low transmission, mass resolution
- Gas filled seprator, RITU, VAMOS GF. Good rejection and transmission, no mass resolution

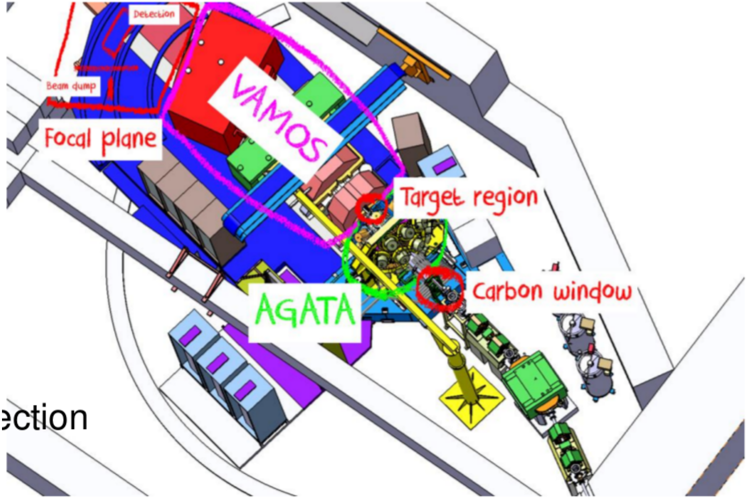
Best choice a gas-filled separator

Challenges we are facing

2. Gamma-ray spectrometer resolution, 1. Velocity difference before/after degrader



^{254}No experiment - direct or inverse kinematics



(picture stolen from C. Thiesen)

^{254}No experiment - direct or inverse kinematics

Direct

- Target not so complicated
- Separtion of beam from ERs "simple"

but

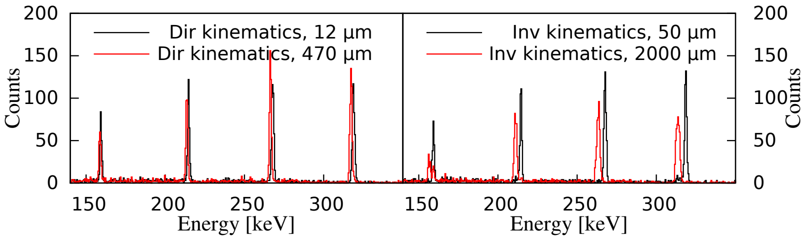
- No peak separation, use "lineshapes"

Inverse

- Peak separtion

but

- Target very comlicated
- Beam separation from ERs very questionable



Or just forgetting about γ rays

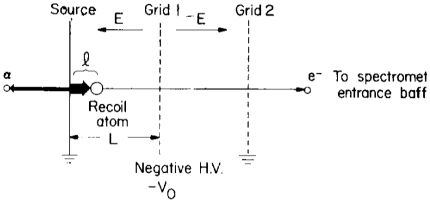
NUCLEAR INSTRUMENTS AND METHODS 26 (1964) 189–200; © NORTH-HOLLAND PUBLISHING CO

AN ELECTROSTATIC METHOD FOR THE RECOIL MEASUREMENT OF SUB-NANOSECOND NUCLEAR LIFETIMES†

T. NOVAKOV*, J. M. HOLLANDER and R. L. GRAHAM§

Lawrence Radiation Laboratory, University of California, Berkeley, California

Received 23 August 1963



$$E_f = E_i + \frac{l}{L} V_0 \text{ (electron volts)}.$$

If we denote $E_f - E_i = \varepsilon$, then

$$l = \frac{\varepsilon}{(V_0/L)}. \qquad (2)$$

The time t is therefore

$$t = \frac{\varepsilon}{(V_0/L)\cdot v_r}. \qquad (3)$$

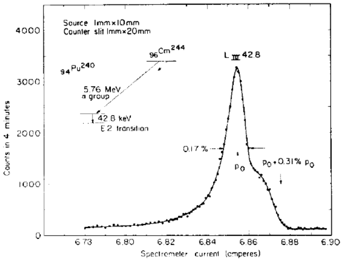


Fig. 1. Shape of the L_{III} 42.8 conversion line in Pu^{240} as observed from an uncovered source of Cm^{244} in an iron free doublefocusing spectrometer adjusted for an instrumental resolution of ~ 0.07% in momentum. The high momentum shoulder is due to electrons emitted from Pu^{240} atoms recoiling from the source surface after alpha emission. If the source were infinitely thin the shoulder would be rectangular and extend to the "half height" position indicated by the arrow labelled p_0 + 0.31 % p_0 which is the maximum Doppler recoil effect.

Or just forgetting about γ rays

Estimate needed electric field

- Our classic - ^{208}Pb(^{48}Ca,2n)^{254}No $\rightarrow$ 1.8% v/c recoil
- Lifetimes not much longer than 10 ps
- In beam experiment with RDT suggest a Si detector based electron spectrometer, i.e. resolution about 10 keV

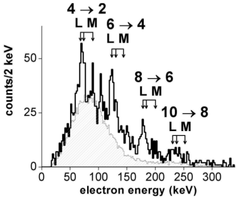


Fig. 23. A conversion-electron spectrum tagged by ^{254}No recoils. The hashed area shows a simulated spectrum of electrons from M1 transitions of high K bands in ^{254}No [67]

Plugging in the numbers in equation 3 on previous slide gives E=20MV/m! Or we need a electron energy resolution < 1 keV!

Summarizing

1. A lifetime measurement for the (super)-heavies not a simple thing
2. Although imaginable we have to do a factor of at least 20! better than has been done.
3. Conflicting optimisation between different experimental aspects.
4. Problem not new, old ideas could be recycled as new ones (an ERC for the CRAC someone?-)
5. If we feel this should be done we have to dedicate a facility and setup to "run until done"!