Alpha decay and identification of nuclides produced

November 2023

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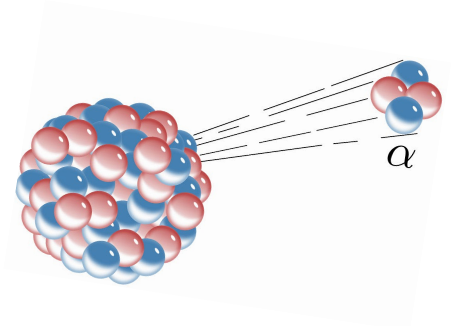
Outline

- Key Points of Alpha Decay
- Isotope Identification Examples

About Alpha Collapse



α Decay is a process by which an unstable nucleus gains stability by emitting an α particle, that is a nucleus of helium made of 2 protons and 2 neutrons

$$ {}^{A}Z \longrightarrow {}^{(A-4)}(Z-2) + {}^{4}He $$

Mother nucleus

Daughter nucleus

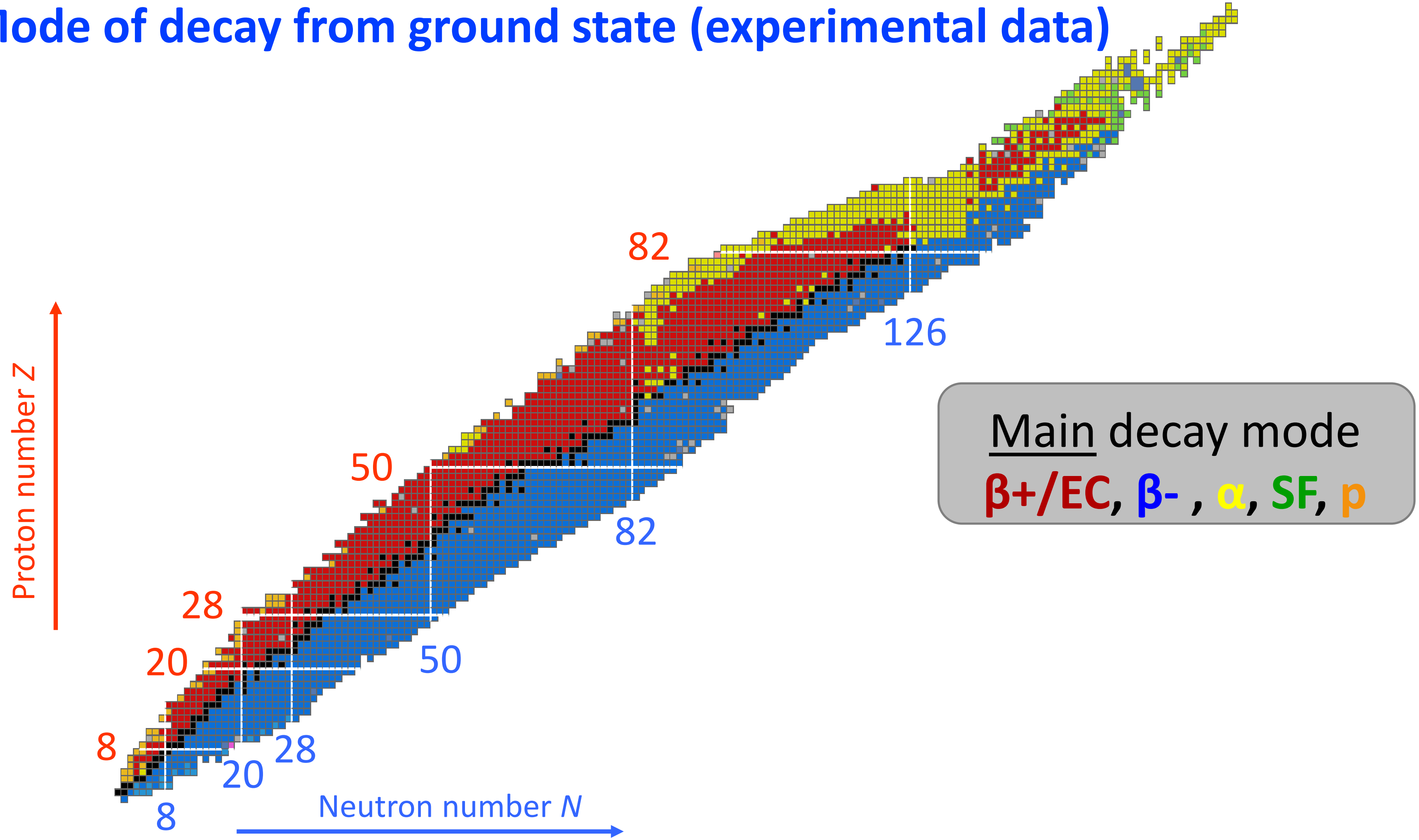
Alpha decay occurs spontaneously if the Q-value for the reaction is positive, i.e. $Q_\alpha > 0$.
The Q-value is the difference of the mass of the mother (m_M) and the combined mass of the daughter (m_D) and α particle (m_α), multiplied by c^2, i.e. :

$$ Q_\alpha = m_M c^2 - (mDc^2 + m_\alpha c^2) $$

In terms of the binding energies of the mother (B_M), daughter (B_D) and alpha (B_α)

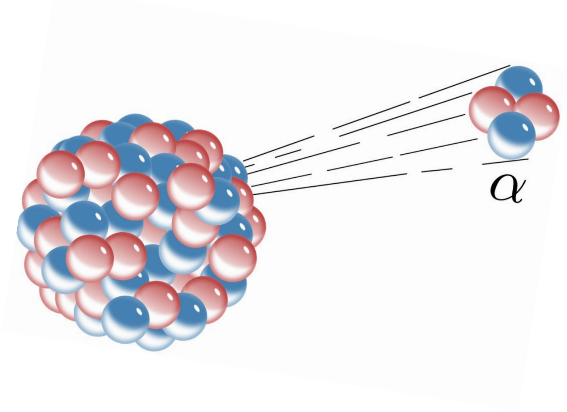
$$ Q_\alpha = (BD + B_\alpha) - BM $$

Mode of decay from ground state (experimental data)



Alpha decay (yellow) in proton-rich, heavy nuclei

About Alpha Collapse



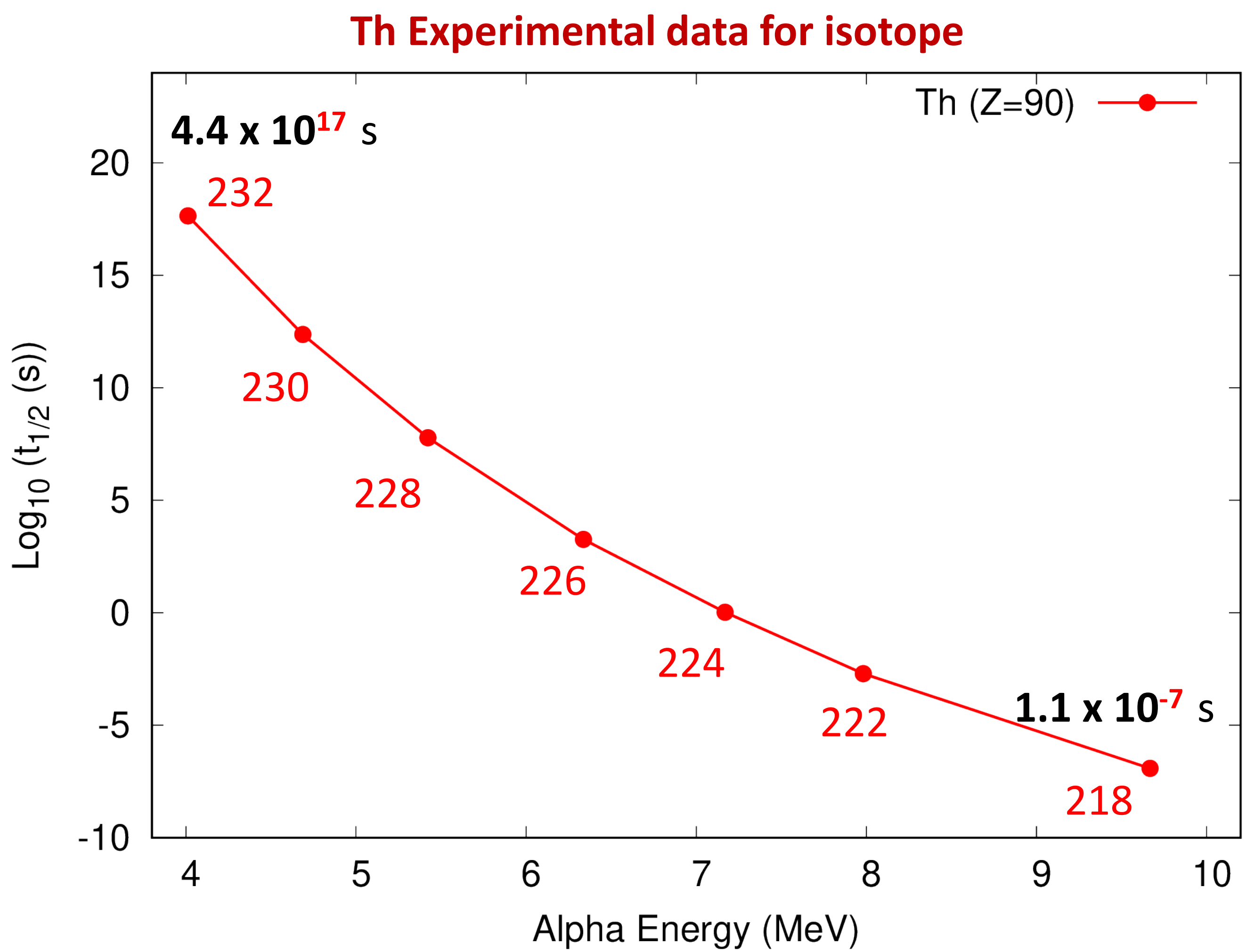
Experimental observables: E_α and $T_{1/2}$

Alpha energy can be derived from the law of conservation of momentum:

$$E_\alpha = \frac{m_D}{m_D + m_\alpha} Q_\alpha \approx \frac{A_D}{A_D + 4} Q_\alpha$$

Example A=238, $E_\alpha \approx 238/242\ Q_\alpha = 0.983\ Q_\alpha$

About Alpha Collapse： Very large variation in half-life



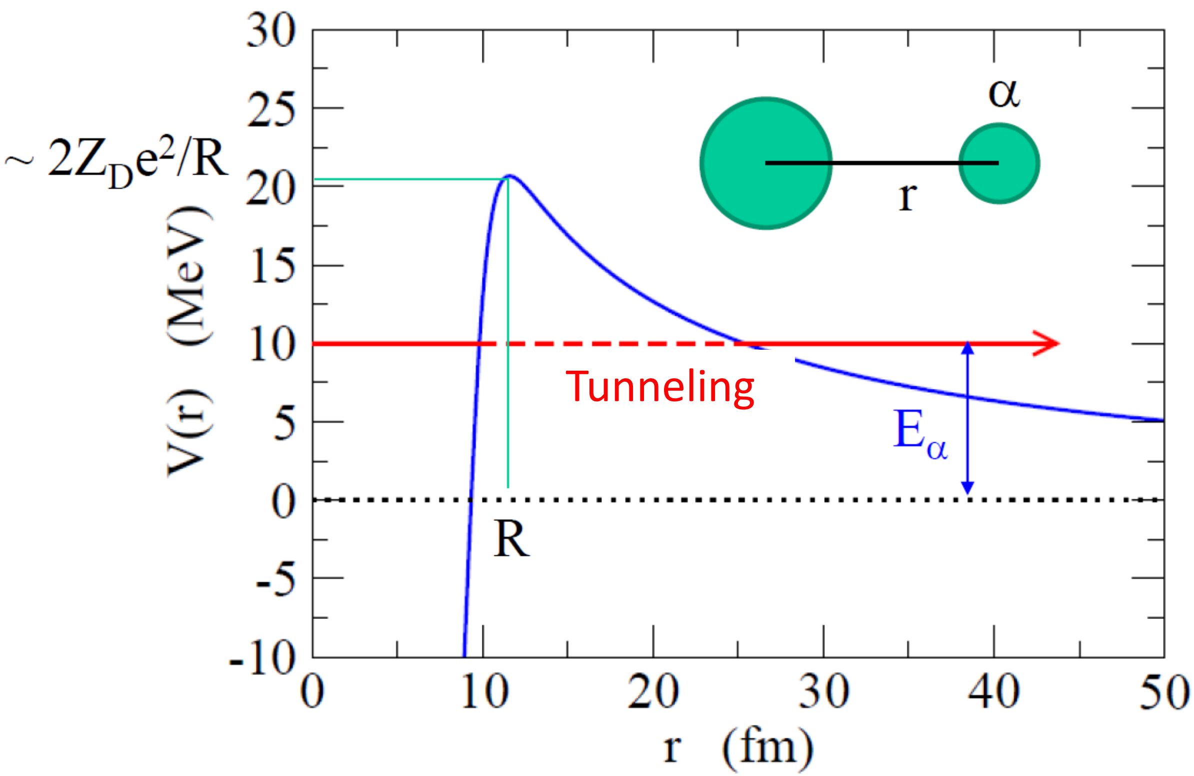
Even a slight change in E_α changes $T_{1/2}$ by many orders of magnitude.

Example) ^{232}Th : E_α = 4.01 MeV, $T_{1/2}$ = 1.4 x 10^{10} years = **4.4 x 10^{17}** seconds

^{218}Th : E_α = 9.68 MeV, $T_{1/2}$ = 0.11 μs = **1.1 x 10^{-7}** seconds

Gamow's explanation of alpha decay

$E_\alpha < V_b \rightarrow$ Collapse due to tunnel eff



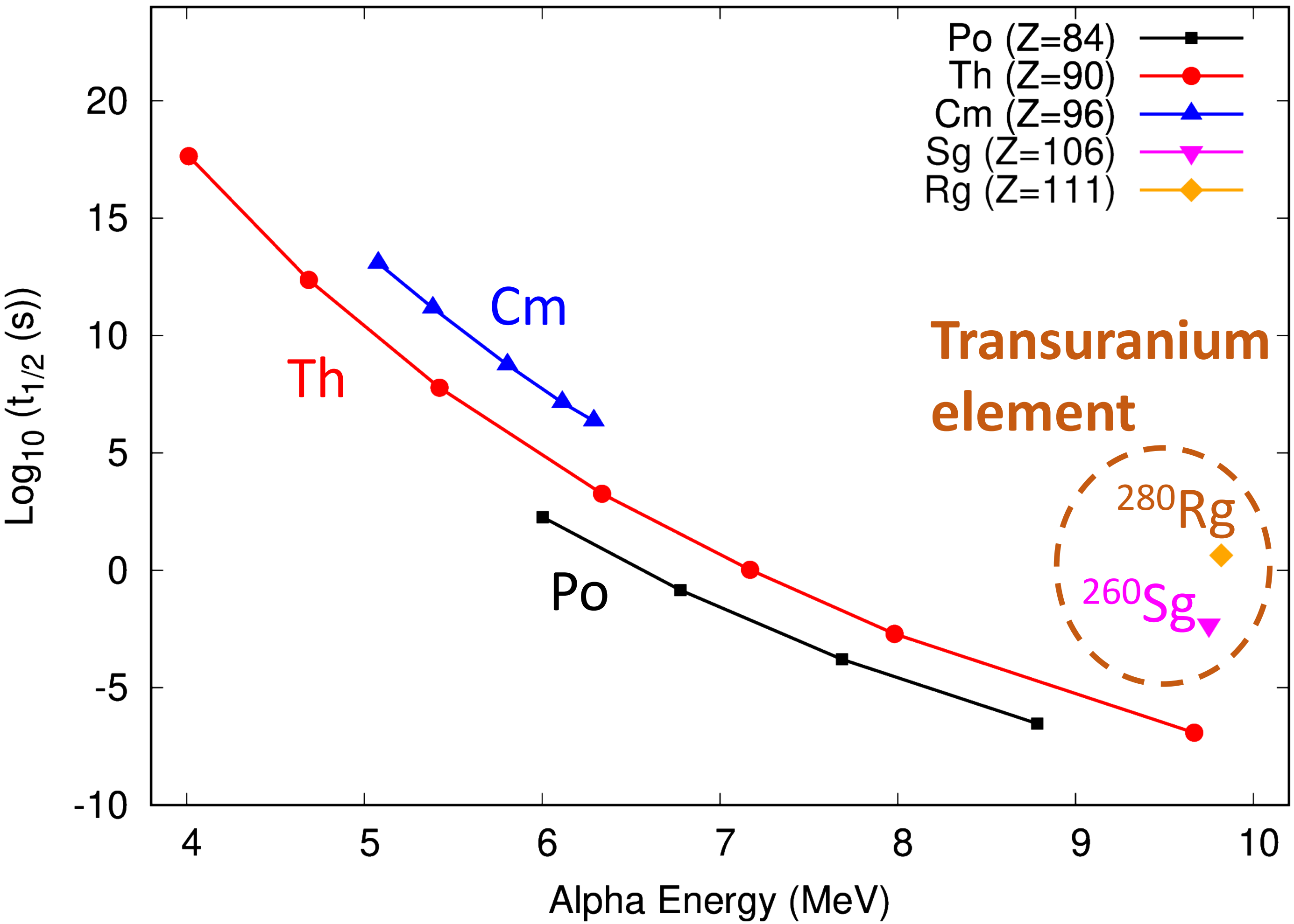
Example) Th Against isotopes

$$R \sim 1.2 \text{ x } (230^{1/3} + 4^{1/3}) = 9.26 \text{ fm}$$

$$V_b = \frac{q_1 q_2}{4\pi\varepsilon_0 r} \cong 1.44\frac{q_1 q_2}{r} = 1.44 \times \frac{88 \times 2}{9.26} = 27.3 \text{ MeV}$$

E_α(Th): 4~10 MeV !

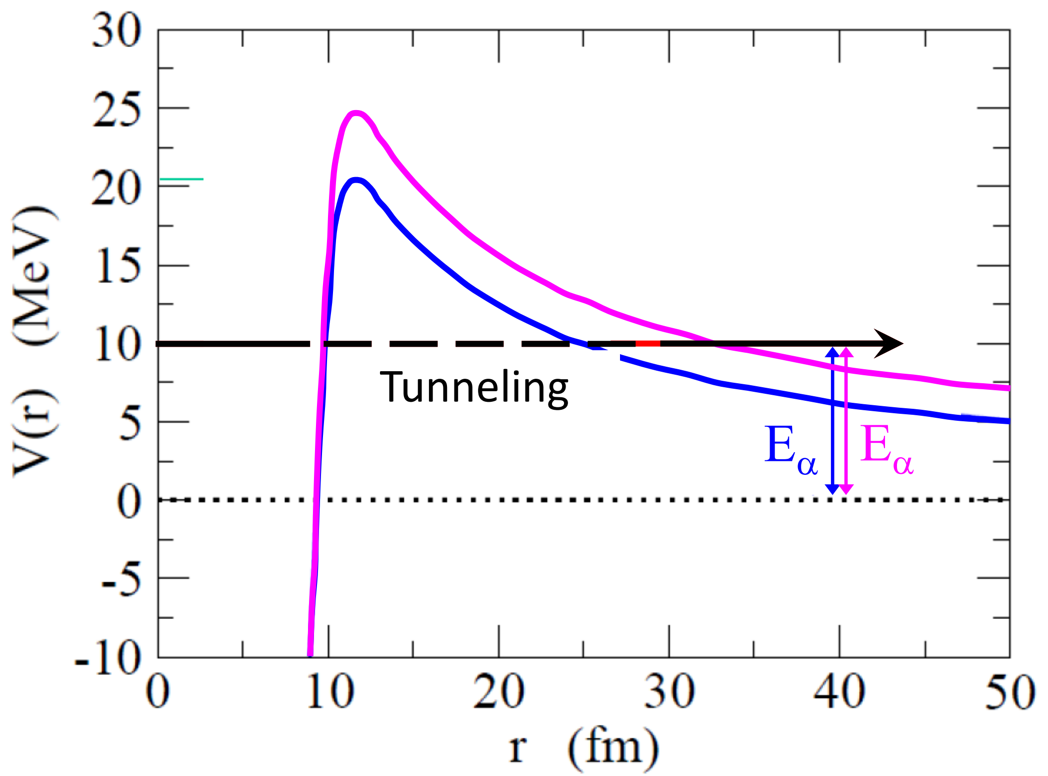
Relationship between half-life and element number



For the same energy, the alpha decay half-life increases with proton number
(Longer half-lives are one evidence of the formation of superheavy elements)

Gamow's explanation of alpha decay

$E_\alpha < V_b \rightarrow$ Collapse due to tunnel effect



The larger the atomic number, the larger the potential barrier.

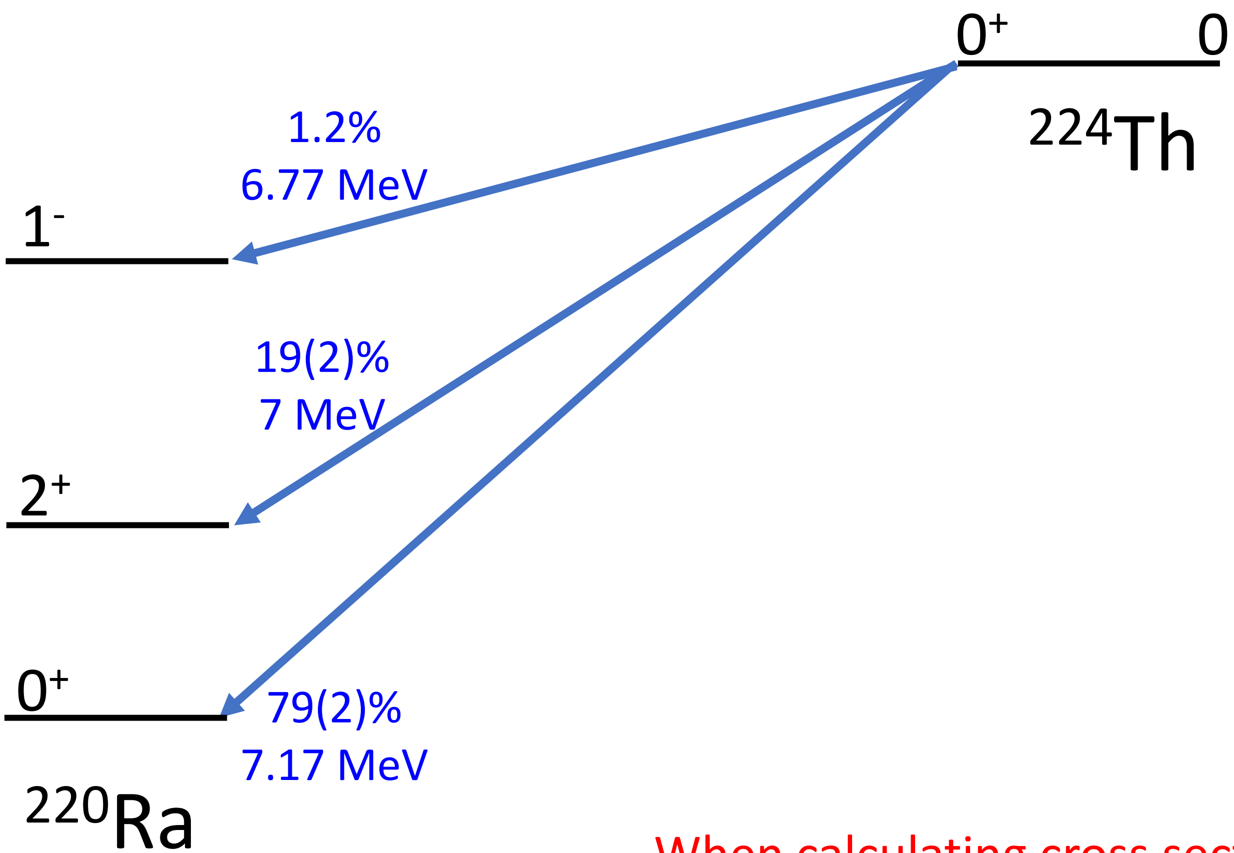
The same Q_α may also be due to the tunneling effect,

A slight increase in barrier height significantly increases the half-life

Blanching of alpha decay

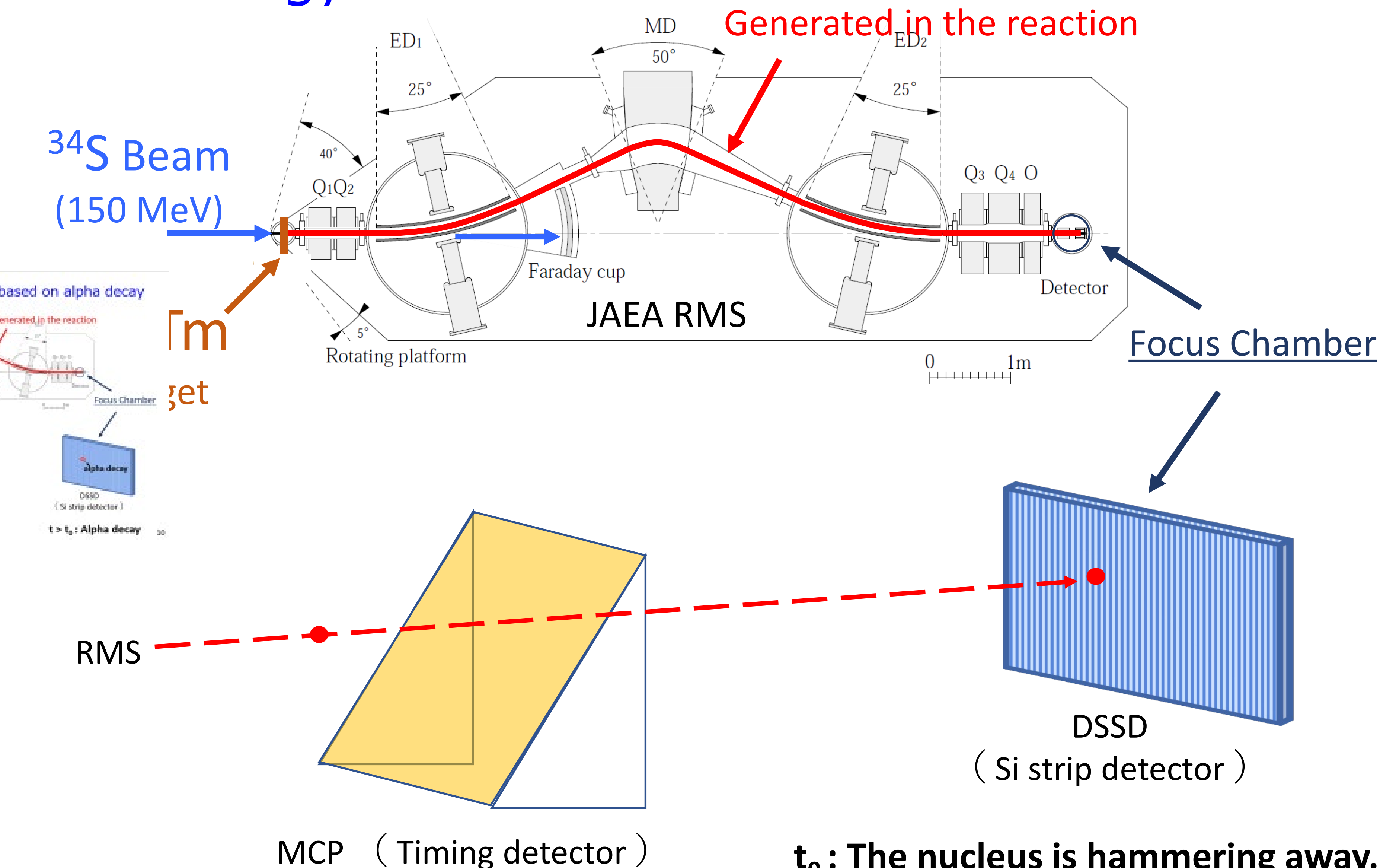
Some radionuclides undergo multiple forms of decay, called branched decay

例



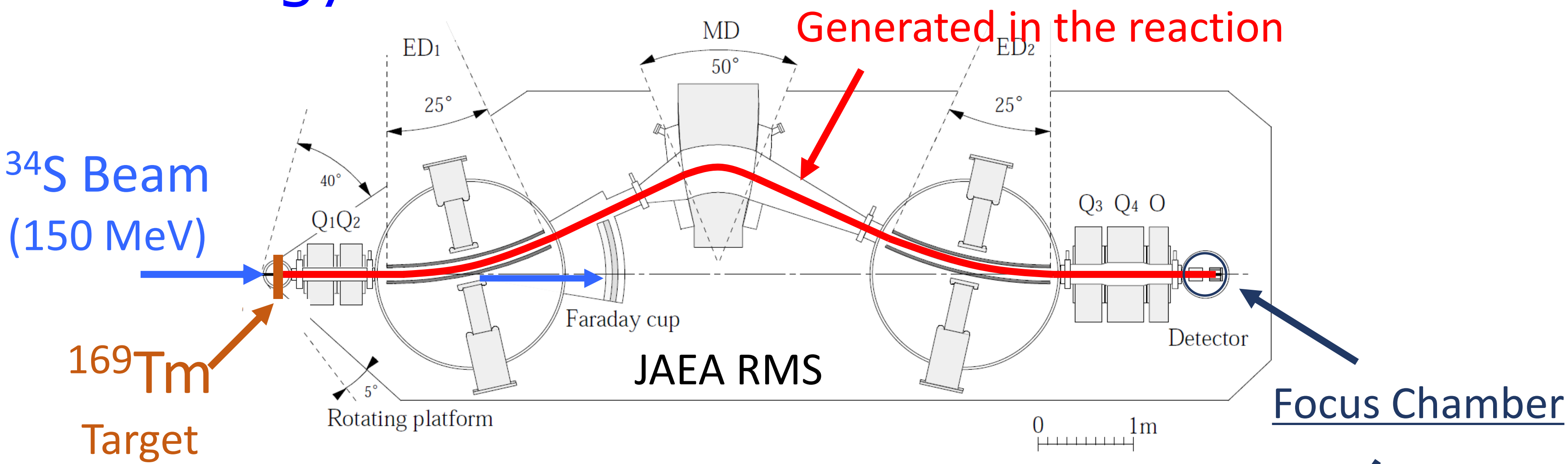
When calculating cross sections,
Branching must be taken into account

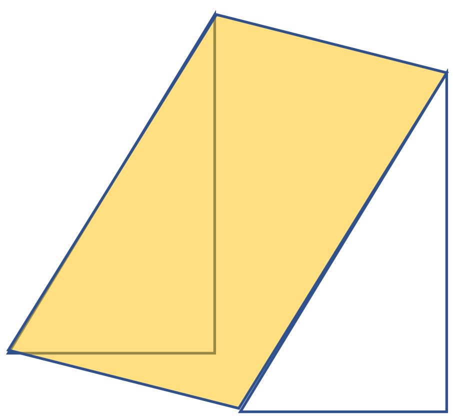
Nuclide identification based on alpha decay energy and half-life



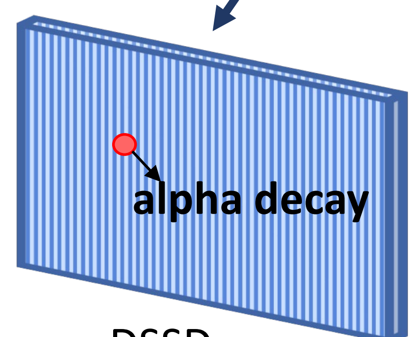
t_0 : The nucleus is hammering away.

Nuclide identification based on alpha decay energy and half-life





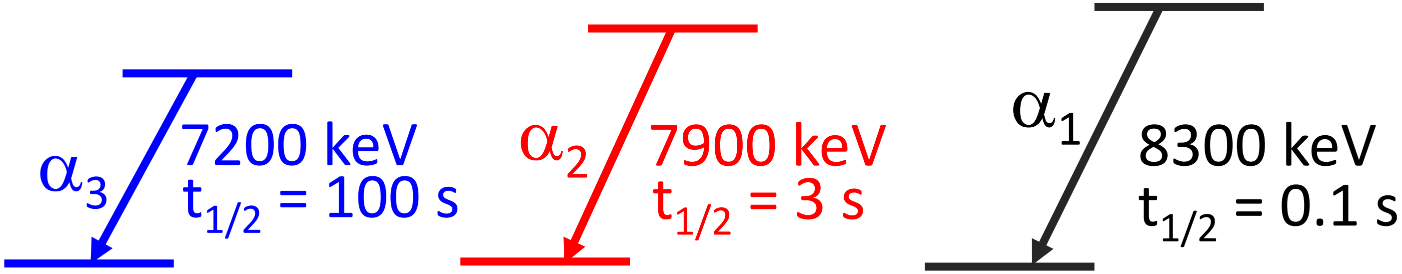
MCP （Timing detector）



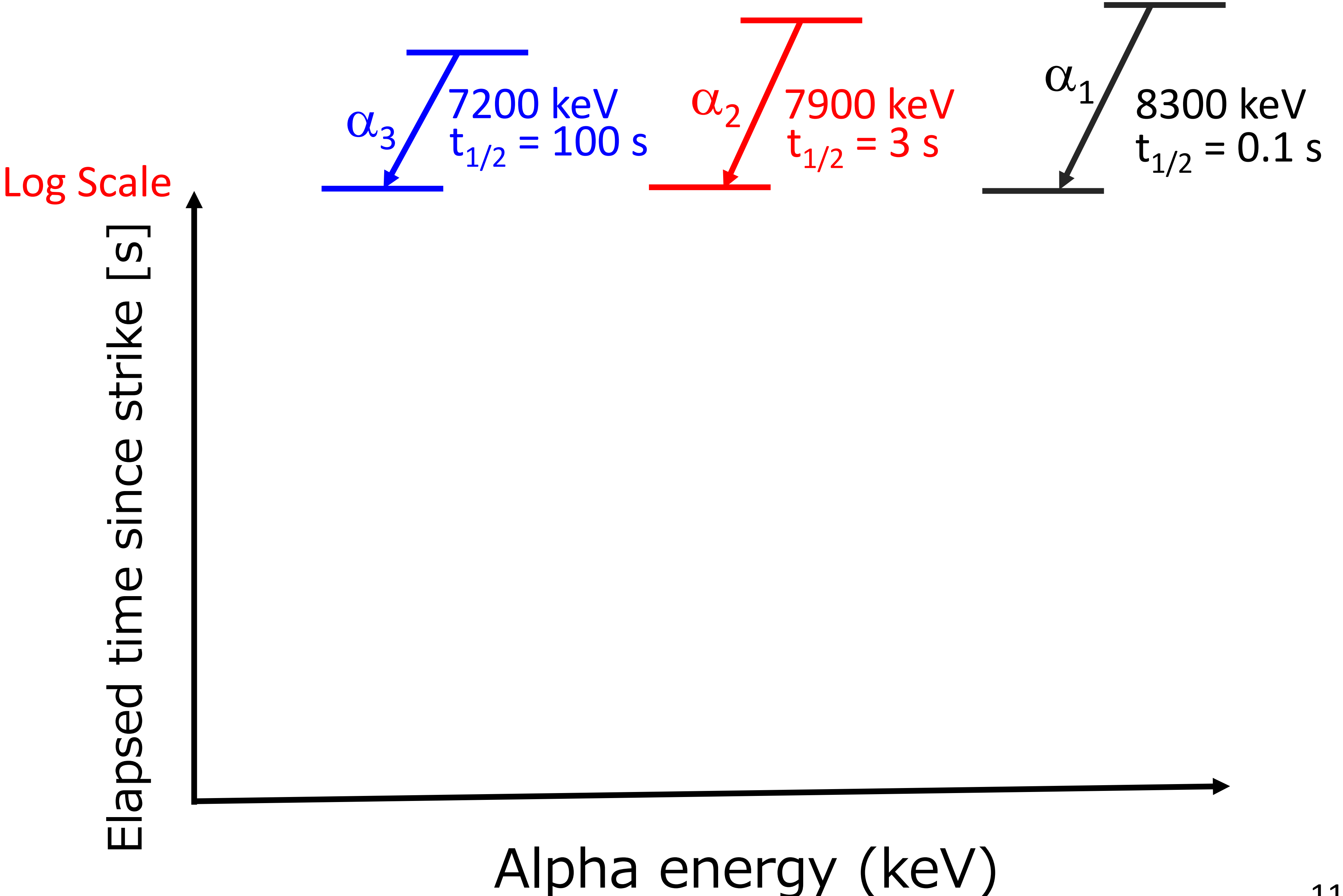
DSSD
（Si strip detector）

$t > t_0$: Alpha decay

Example

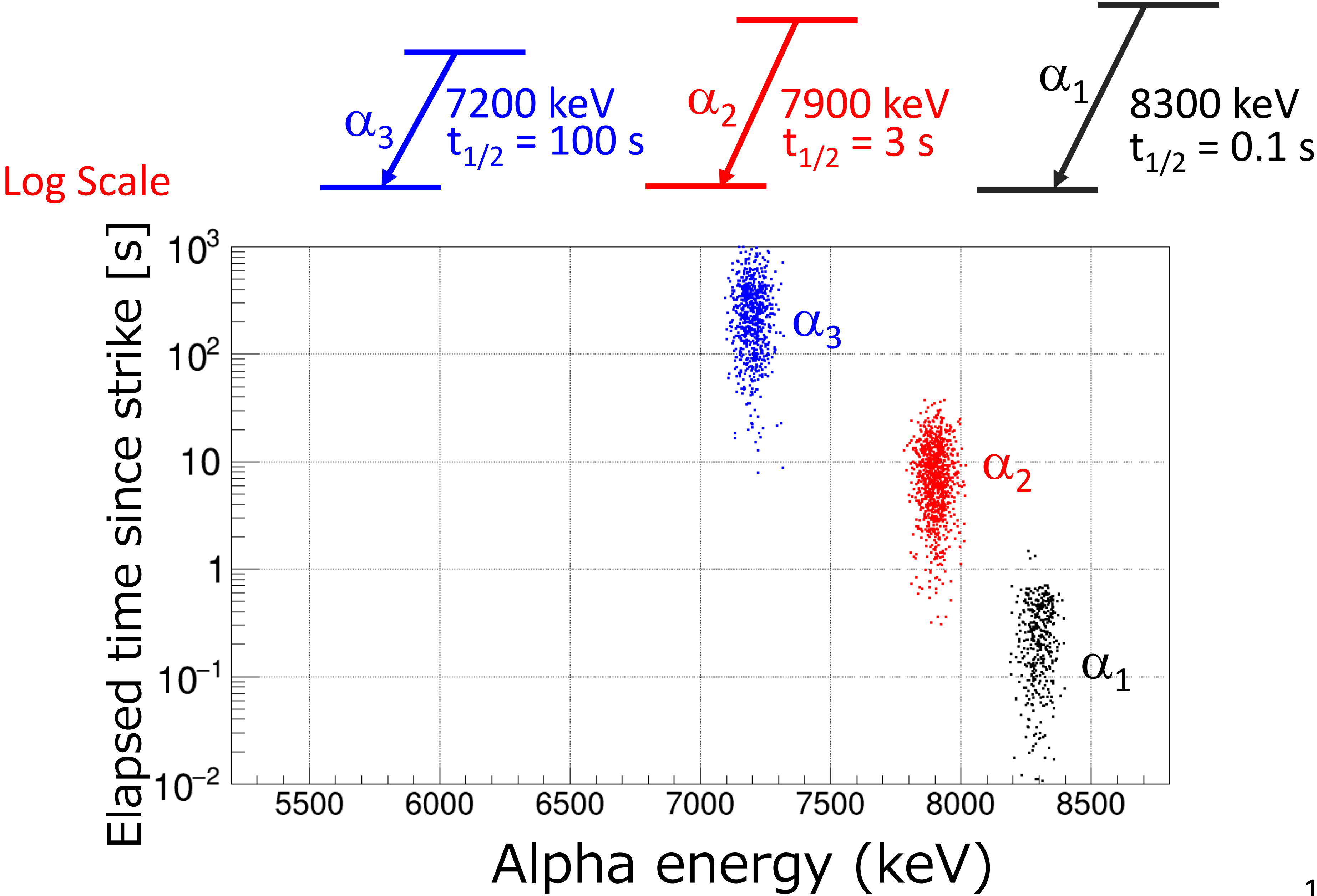


Example

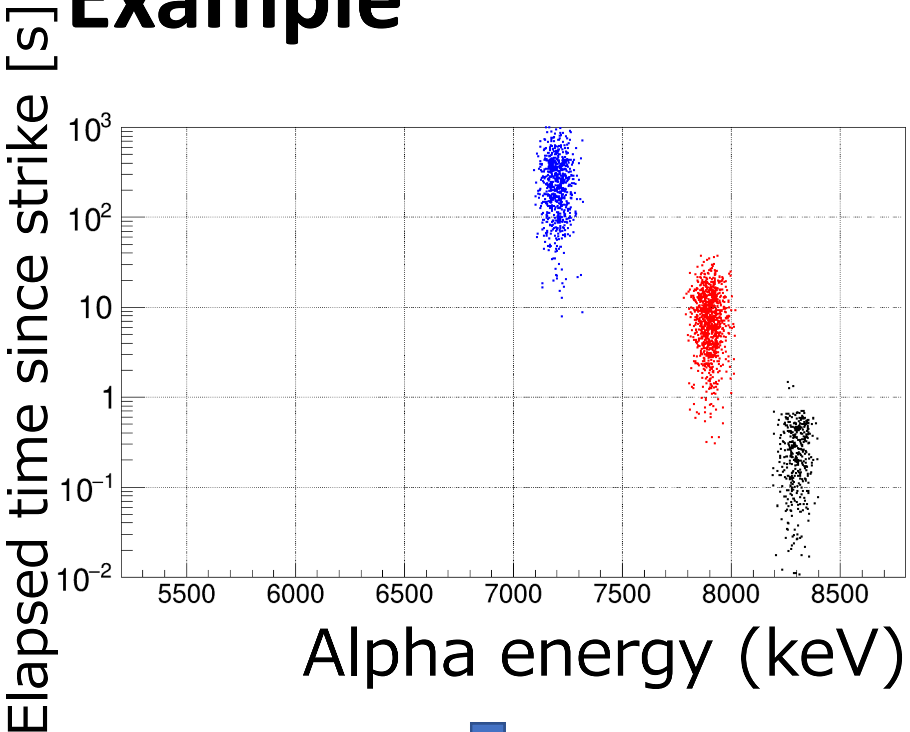


α3
7200 keV
t1/2 = 100 s
α2
7900 keV
t1/2 = 3 s
α1
8300 keV
t1/2 = 0.1 s
Log Scale
Elapsed time since strike [s]
Alpha energy (keV)

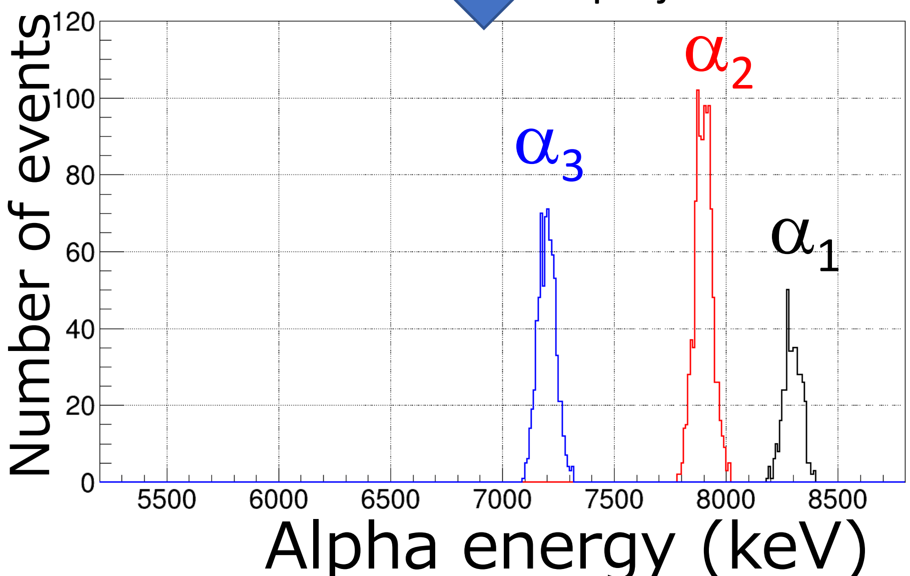
Example


α3
7200 keV
t1/2 = 100 s
α2
7900 keV
t1/2 = 3 s
α1
8300 keV
t1/2 = 0.1 s
Log Scale
Elapsed time since strike [s]
10^3
10^2
10
1
10^−1
10^−2
5500
6000
6500
7000
7500
8000
8500
Alpha energy (keV)
α3
α2
α1

Example



X projection



Alpha energy confirmed with database

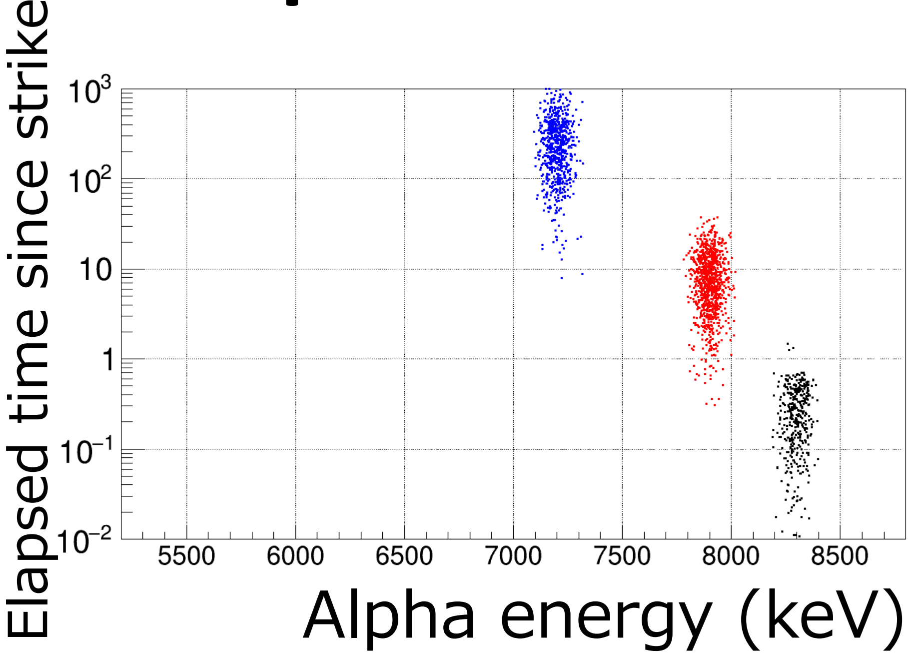
For example

National Nuclear Data Center （NNDC）

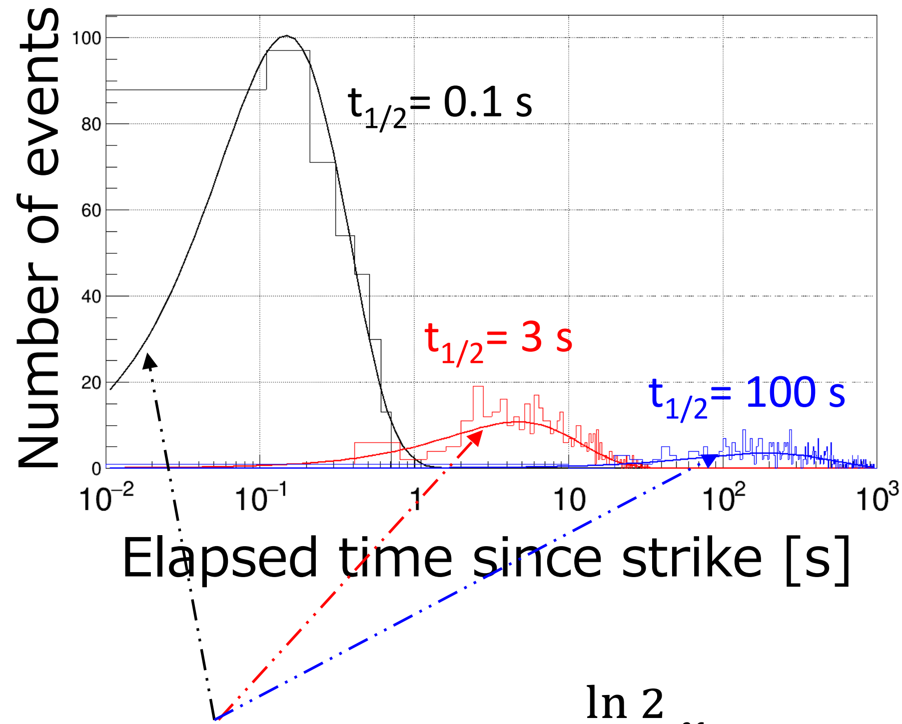
Radiation Search

https://www.nndc.bnl.gov/nudat3/indx_dec.jsp

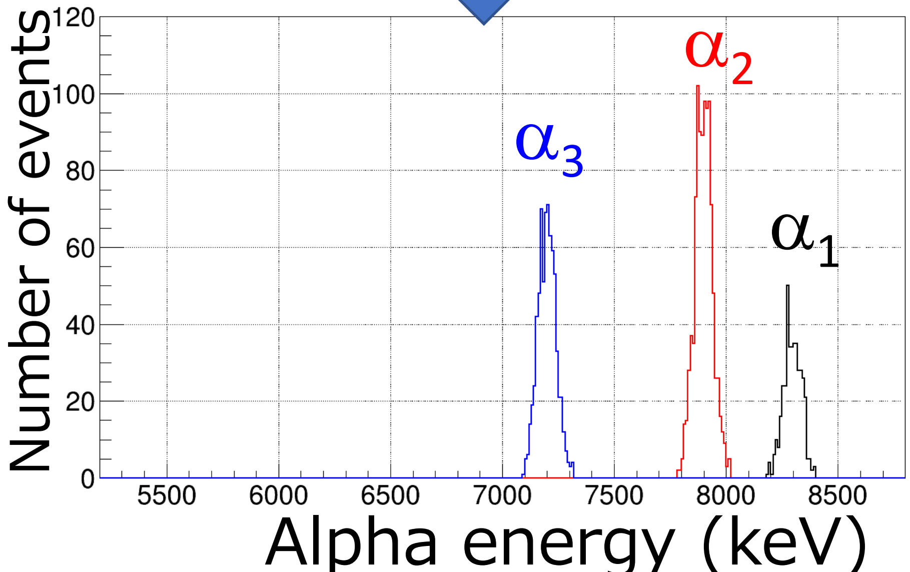
Example



Y proj



X projection



$$f = c * x * e^{-\frac{\ln 2}{b} x}$$

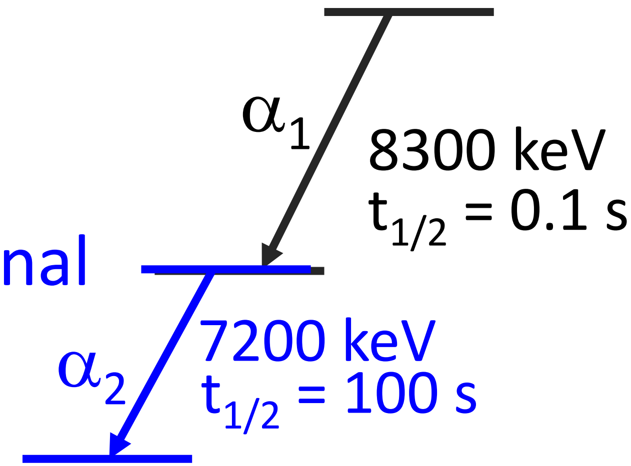
Parameter b is $t_{1/2}$

x is Time

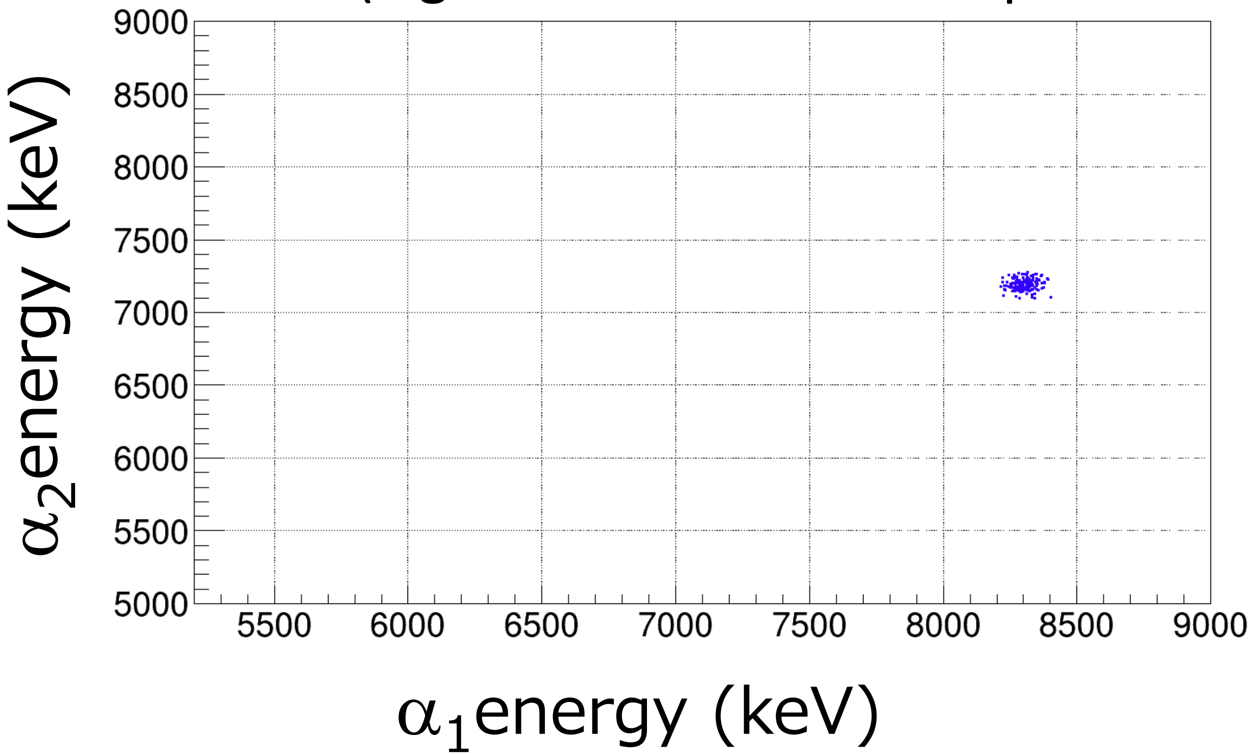
K.-H. Schmidt et.al.,
Z. Phys. A 316, 19-26(1984)

Example

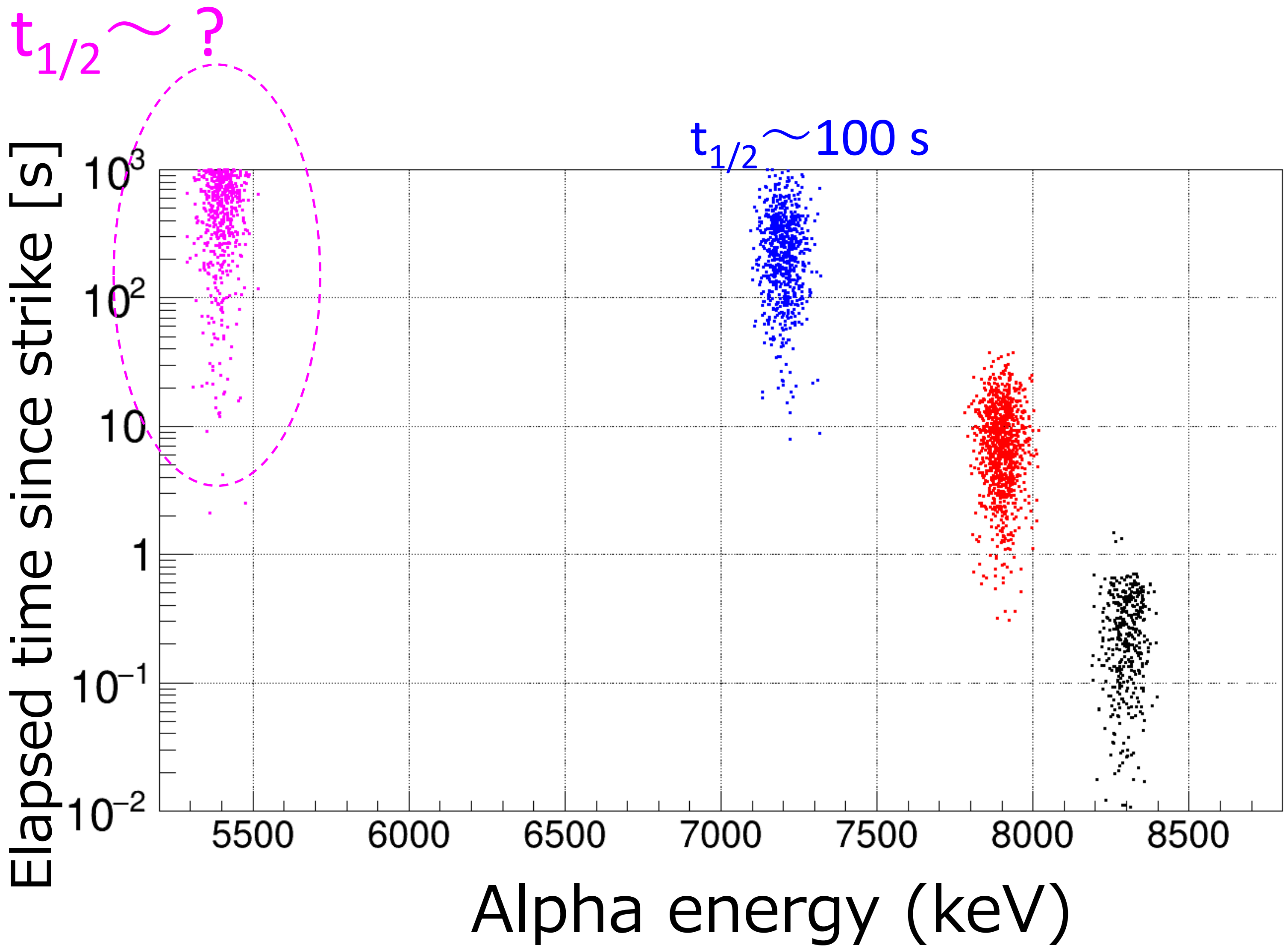
For decay chains,
Correlated measurement of alpha signal



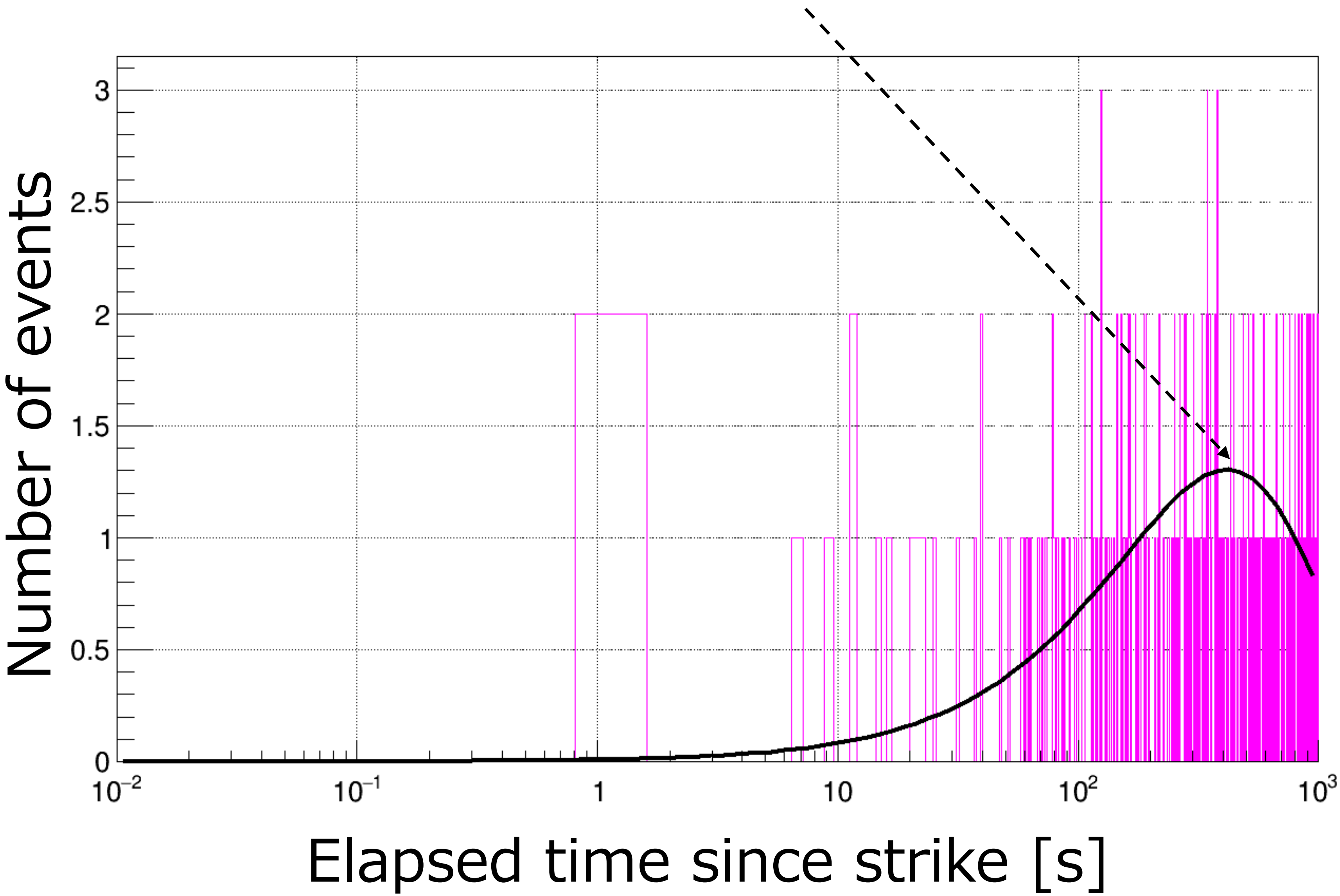
$\Delta t = t(\alpha_2) - t(\alpha_1) < \sim 300$ sec
(Figured on the same strip)



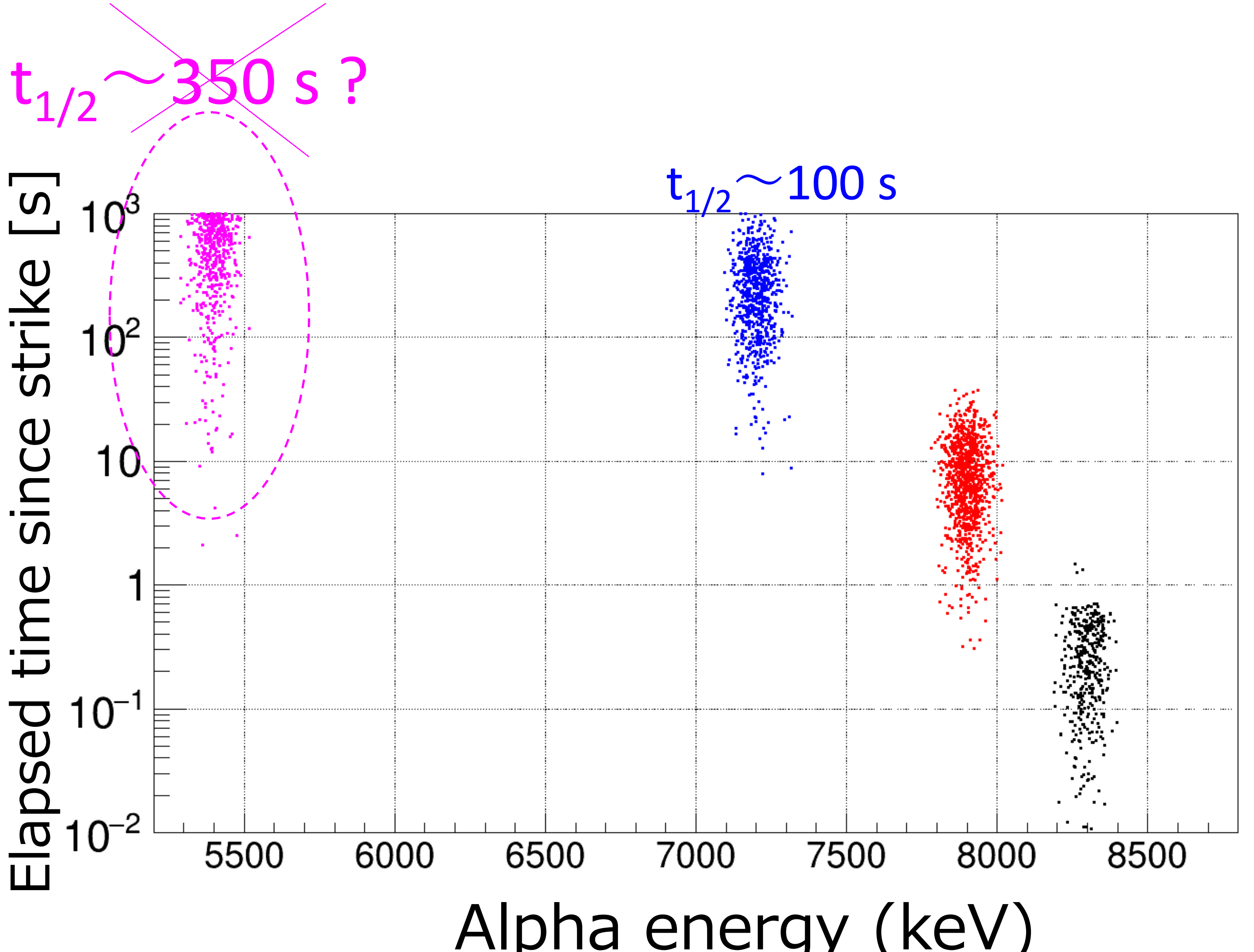
Example Important point



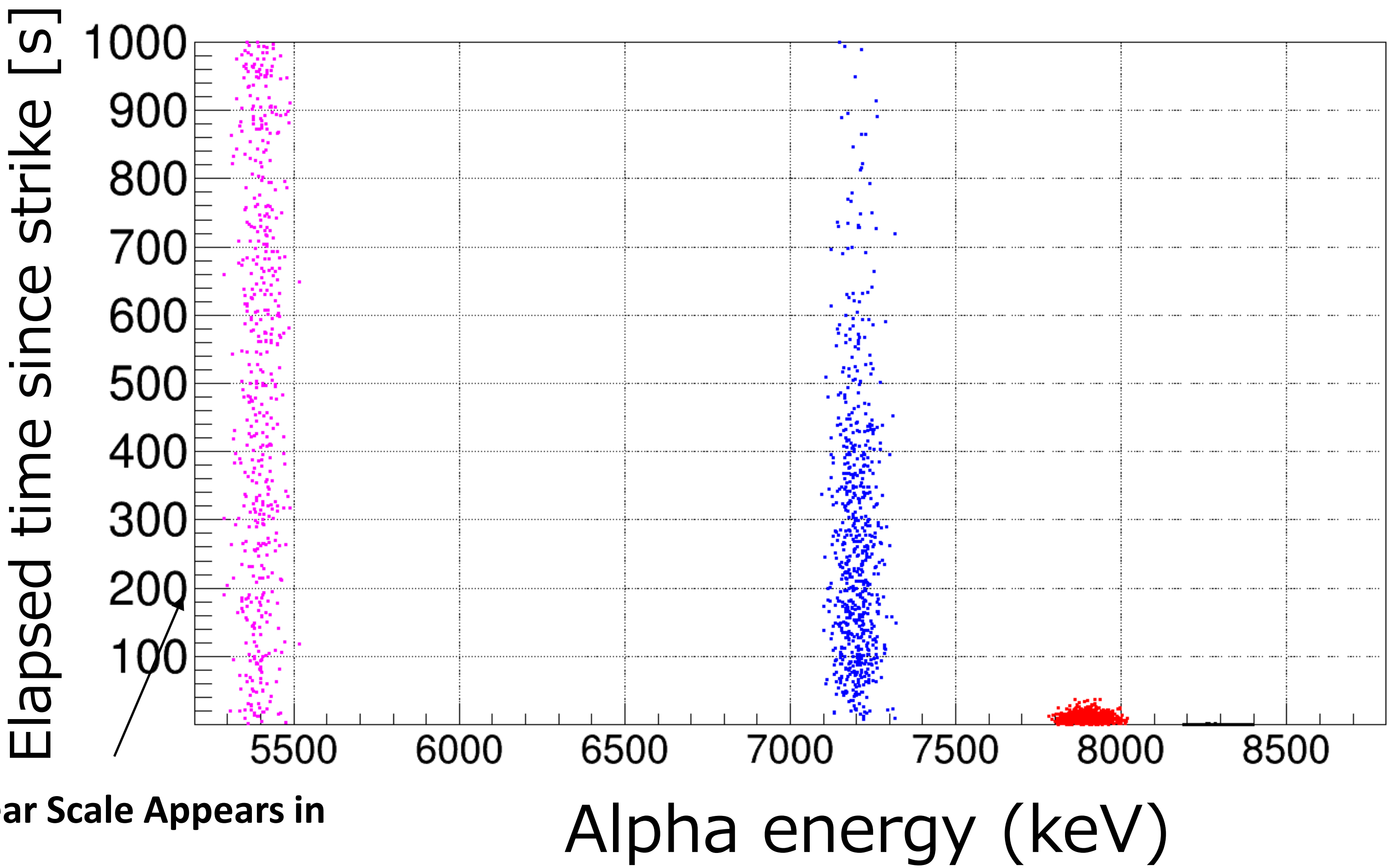
The $t_{1/2}$ appears to be ~350 sec, which is wrong, but ...



Example　<u>Important point</u>



Actually constant **background**
(from nuclei with very long half-lives)



Linear Scale Appears in