Search for double alpha decay

Louis Heitz
Double alpha @CERN collaboration

ISOL-France Worskshop 2024

28.05.2024

Outline

Double alpha

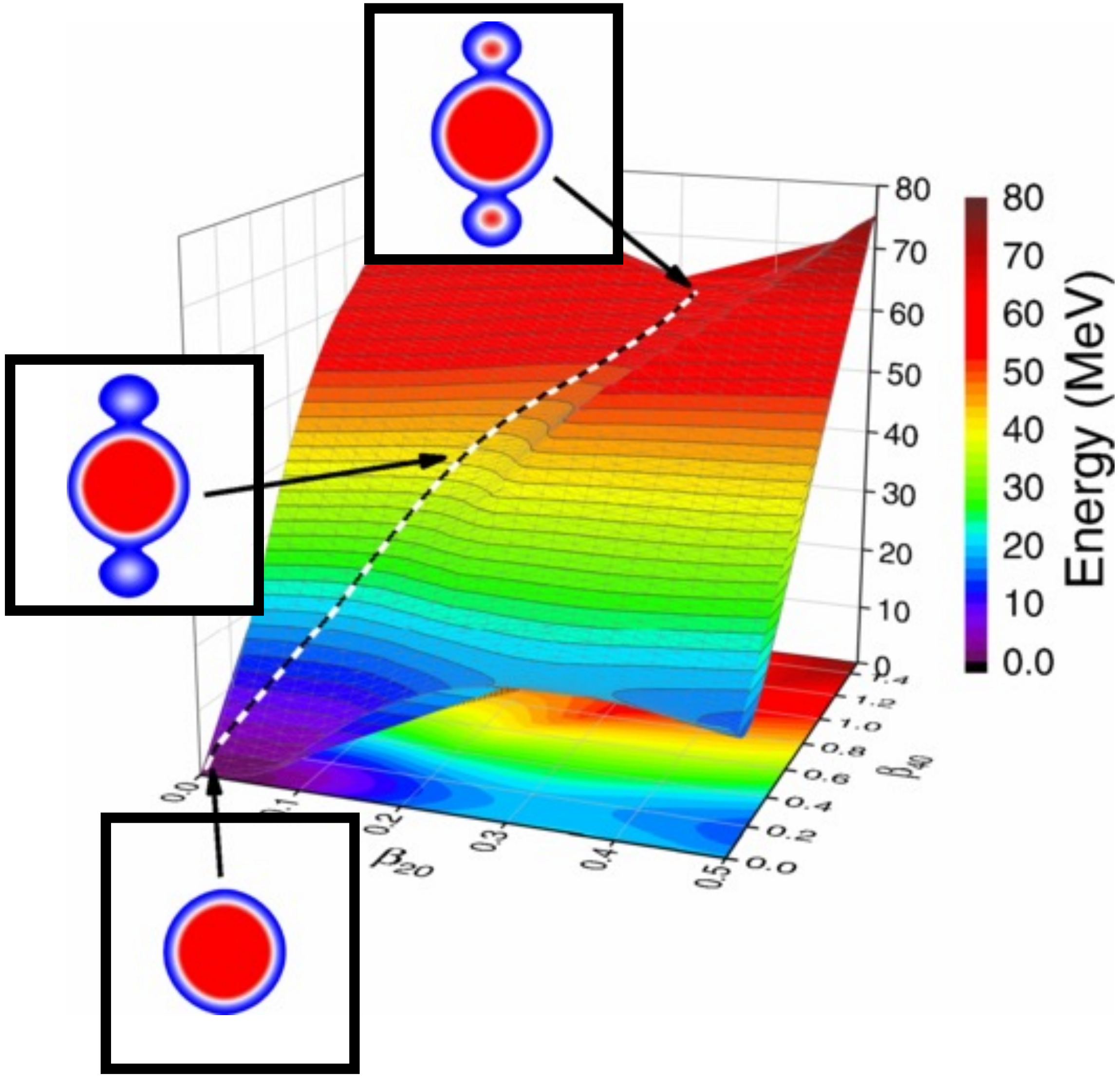
université PARIS-SACLAY

cea

IJCLab Irène Joliot-Curie

Motivations

Theoretical Trigger
2021
Microscopic description of alpha radioactivty



F. Mercier, J. Zhao, J.-P. Ebran, E. Khan, T. Nikšić, and D. Vretenar
Phys. Rev. Lett. **127**, 01250

Motivations

Zur Quantentheorie des Atomkernes.

Von G. Gamow, z. Zt. in Göttingen.

Mit 5 Abbildungen. (Eingegangen am 2. August 1928.)

Two alpha, three alpha and multiple heavy-ion radioactivities

D. N. Poenaru and M. Ivaşcu

Institute for Physics and Nuclear Engineering, P.O. Box MG-6, R-76900, Bucharest, Romania

(Reçu le 25 mars 1985, accepté sous forme définitive le 30 avril 1985)

First α decay model

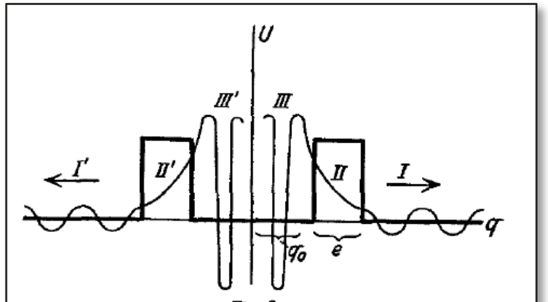
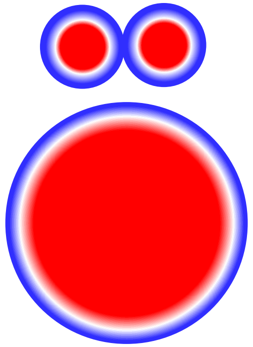


Fig. 3.

Quantum tunneling explains empirical **Geiger-Nutall law:**

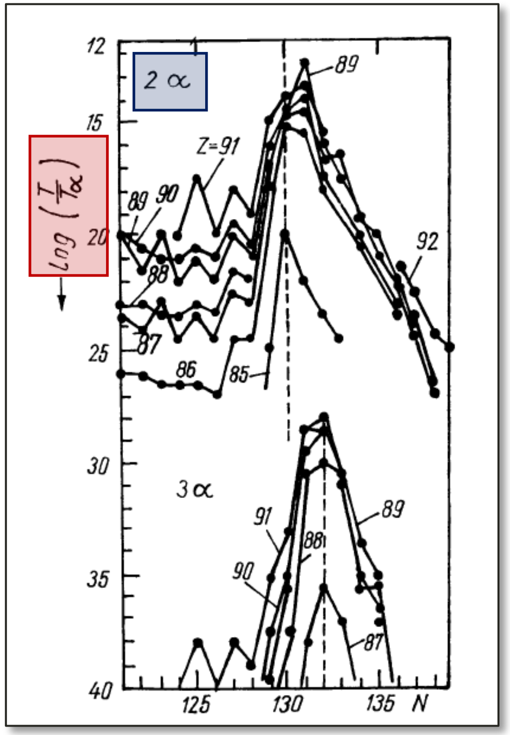
$$\log T_{1/2} \sim \frac{1}{\sqrt{Q_\alpha}}$$

$\alpha + \alpha = {}^{8}\text{Be}$



Schematic view

+ pheno parameters explains **cluster radioactivity**



First prediction of 2α (as ^{8}Be) decay…

…but Very long half-life

Motivations

Zur Quantentheorie des Atomkernes.
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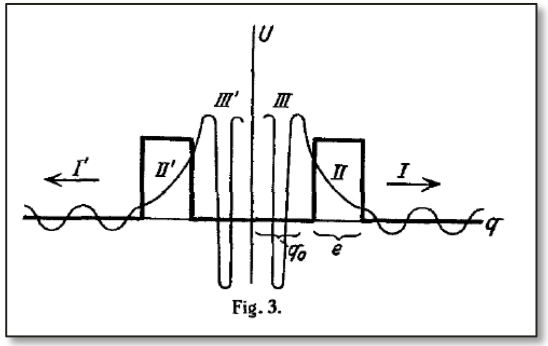
First α decay model



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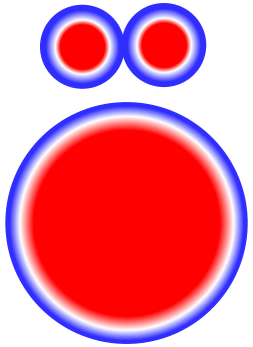

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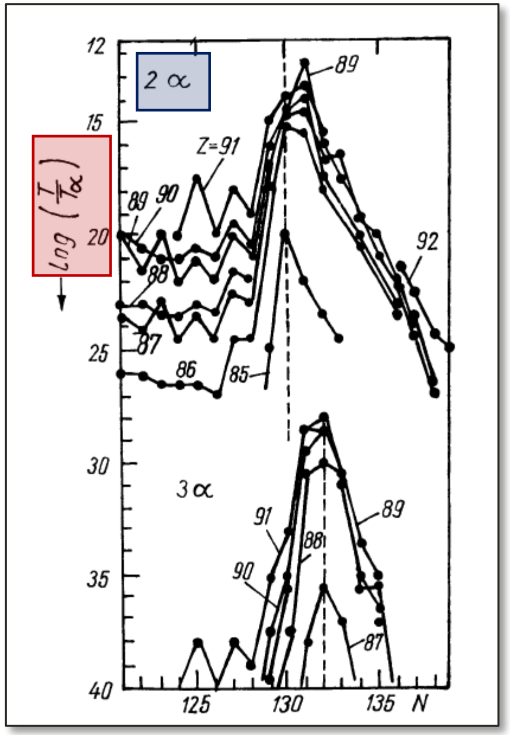
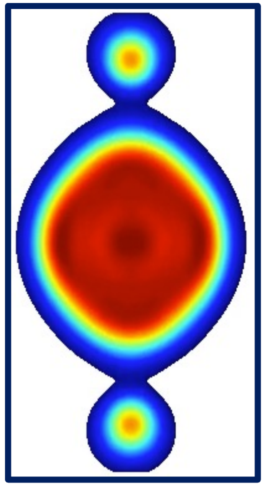


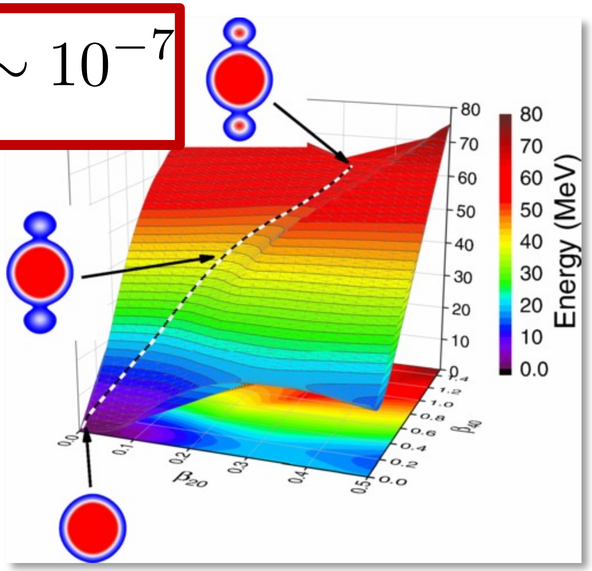
Microscopic Description of 2α Decay in ^{212}Po and ^{224}Ra Isotopes
F. Mercier,[1] J. Zhao,[2] J.-P. Ebran,[3,4] E. Khan,[1] T. Nikšić,[5] and D. Vretenar[5]
[1]IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405 Orsay Cedex, France
[2]Center for Circuits and Systems, Peng Cheng Laboratory, Shenzhen 518055, China
[3]CEA, DAM, DIF, F-91297 Arpajon, France
[4]Université Paris-Saclay, CEA, Laboratoire Matière en Conditions Extrêmes, 91680 Bruyères-le-Châtel, France
[5]Physics Department, Faculty of Science, University of Zagreb, 10000 Zagreb, Croatia
(Received 2 April 2021; revised 11 May 2021; accepted 8 June 2021; published 2 July 2021)

First microscopic (EDF) model of α **decay (+cluster)**

$$\mathrm{BR} \sim \frac{\tau_{2\alpha}}{\tau_\alpha} \sim 10^{-7}$$



calculations

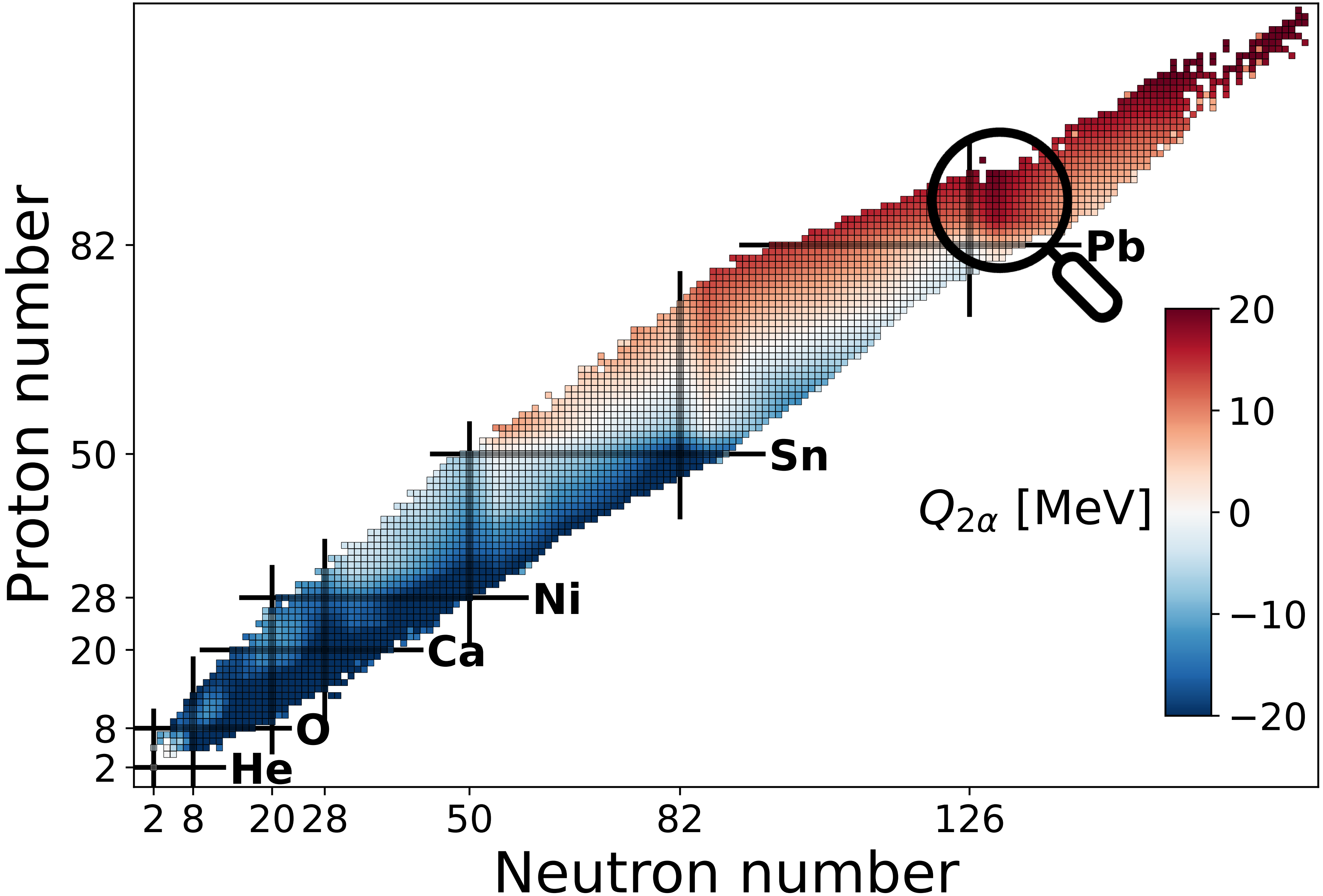


\+ back-to-back 2α prediction

\+ Experimentally Interesting half-life

F. Mercier, J. Zhao, J.-P. Ebran, E. Khan, T. Nikšić, and D. Vretenar Phys. Rev. Lett. 127, 012501
J. Zhao, J.-P. Ebran, L.H., E. Khan, F. Mercier, T. Nikšić, and D.Vretenar Phys. Rev. C 107, 034311

Best candidates for 2α decay ?



Expected :

$$Q_{2\alpha} \nearrow \Longleftrightarrow T_{2\alpha} \searrow$$

~Geiger-Nutall :
more energy available = more likely

« Natural » candidate

^{208}Pb$+2\alpha=$ **^{216}Rn**

Other candidates

$^{218\text{-}220}$Rn, $^{220\text{-}224}$Ra

Experimental campaigns

2021

Theoretical trigger

2022

GSI – FRS Ion Catcher

^{224}Ra – ^{220}Rn

Source

~3 months

2023

CERN - ISOLDE

$^{220,222}Ra$ - $^{216,218}Rn$

Beam

~1 week

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

ELSEVIER

Full Length Article

Novel device to study double-alpha decay at the FRS Ion Catcher

L. Varga [a,b,*], H. Wilsenach [c,f], O. Hall [a], T. Dickel [b,c], M.P. Reiter [a], D. Amanbayev [c,l], T. Davinson [a], D.J. Morrissey [d], I. Pohjalainen [b], N. Tortorelli [b,e], J. Yu [b], J. Zhao [b], S. Ayet [h,b,a], S. Beck [b], J. Bergmann [c], Z. Ge [b], H. Geissel [b,c], L. Heitz [i,m], C. Hornung [b], N. Kalantar-Nayestanaki [j], E. Khan [m], G. Kripko-Koncz [c,l], I. Mardor [f,g], M. Narang [j,b], W. Plass [b,c], C. Scheidenberger [b,c,l], M. Simonov [c,l], S.K. Singh [b], A. State [k], C. Theisen [i,†], M. Vandebrouck [i], P.J. Woods [a], FRS Ion Catcher Collaboration

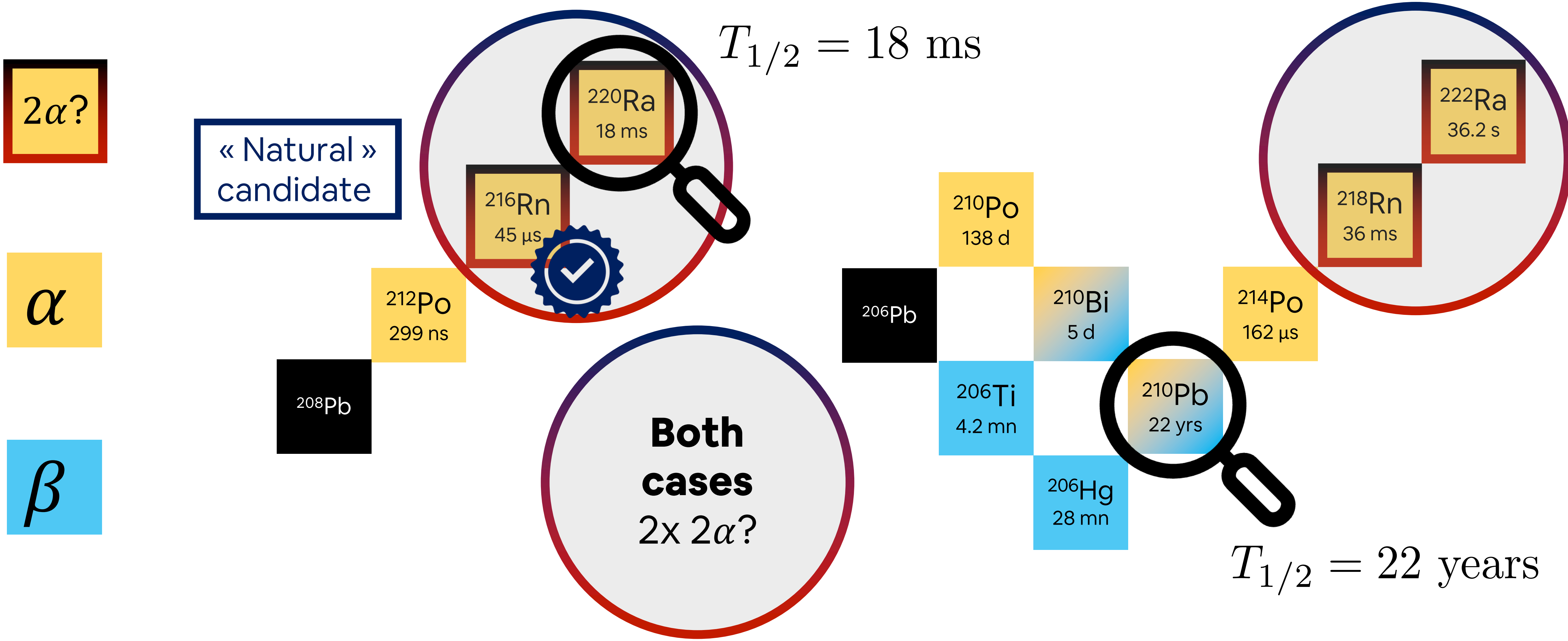
Status :

Technical paper published

Data being analysed

Right now !

Decay chains & contaminants



✅ Clean decay chain
❗ Short half-life (see later)

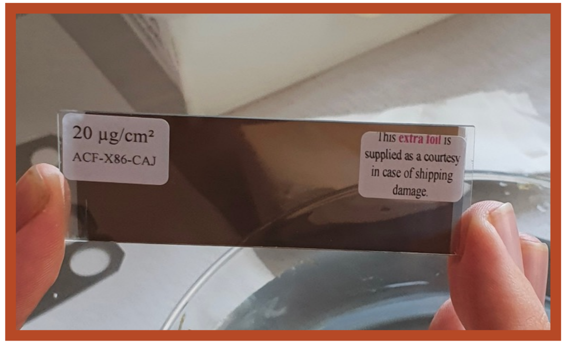
❗ Beta contaminants
✅ Blocked by (longed-lived) ^{210}Pb

Experimental setup

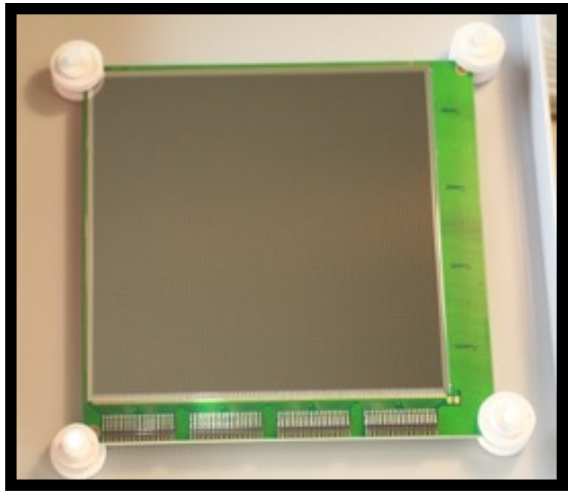
Incoming beam
^{220}Ra / ^{222}Ra
30 keV

ISOLDE

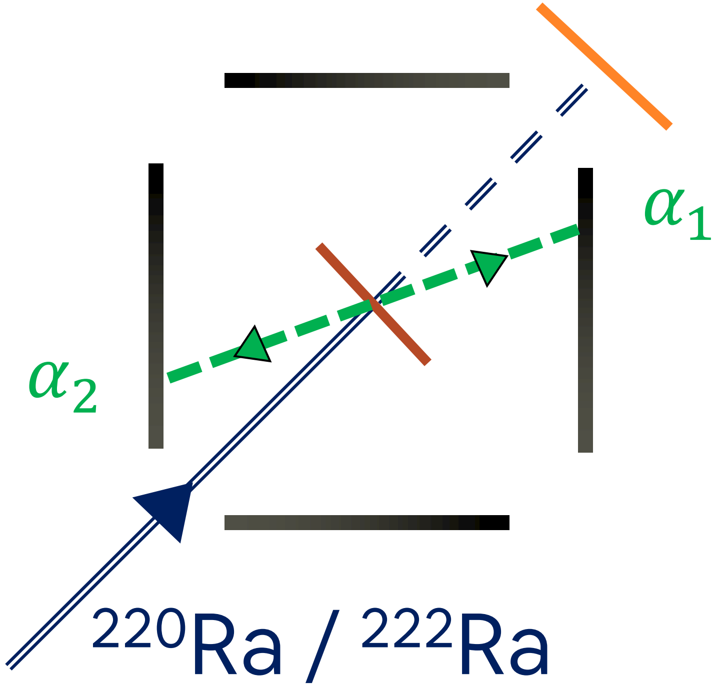
Implantation in carbon foil
20µg/cm²

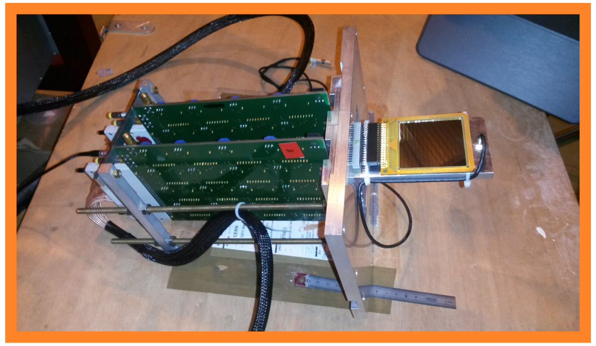


4 DSSD
MUSETT
10x10 cm, 128x128 strips

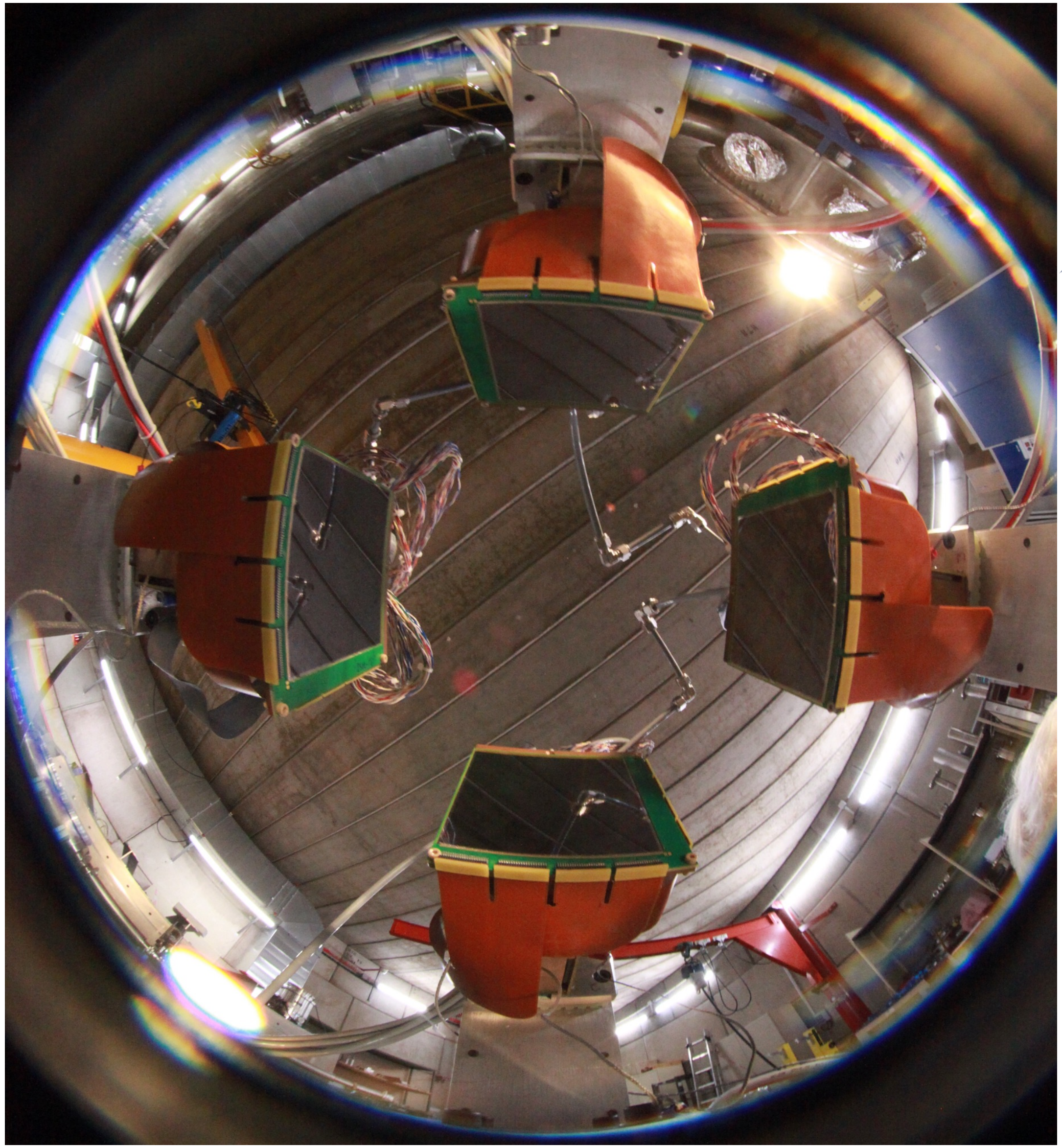


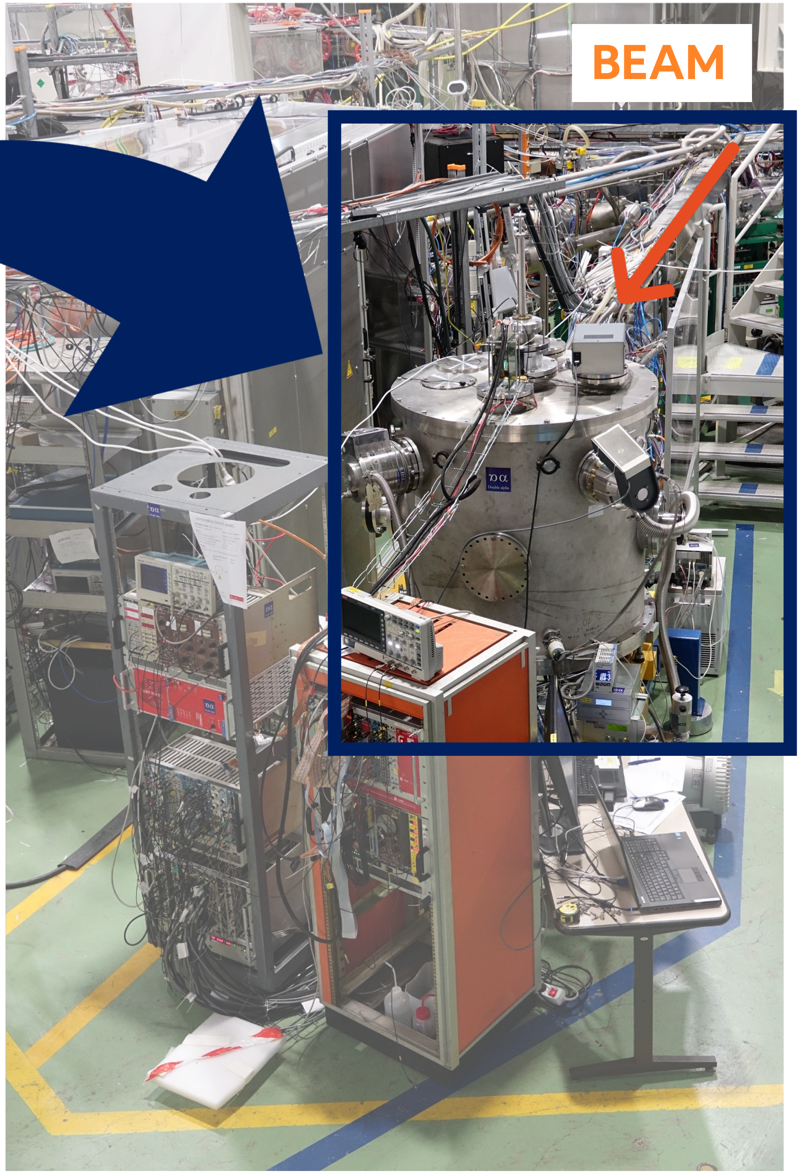
Beam Inspection DSSD



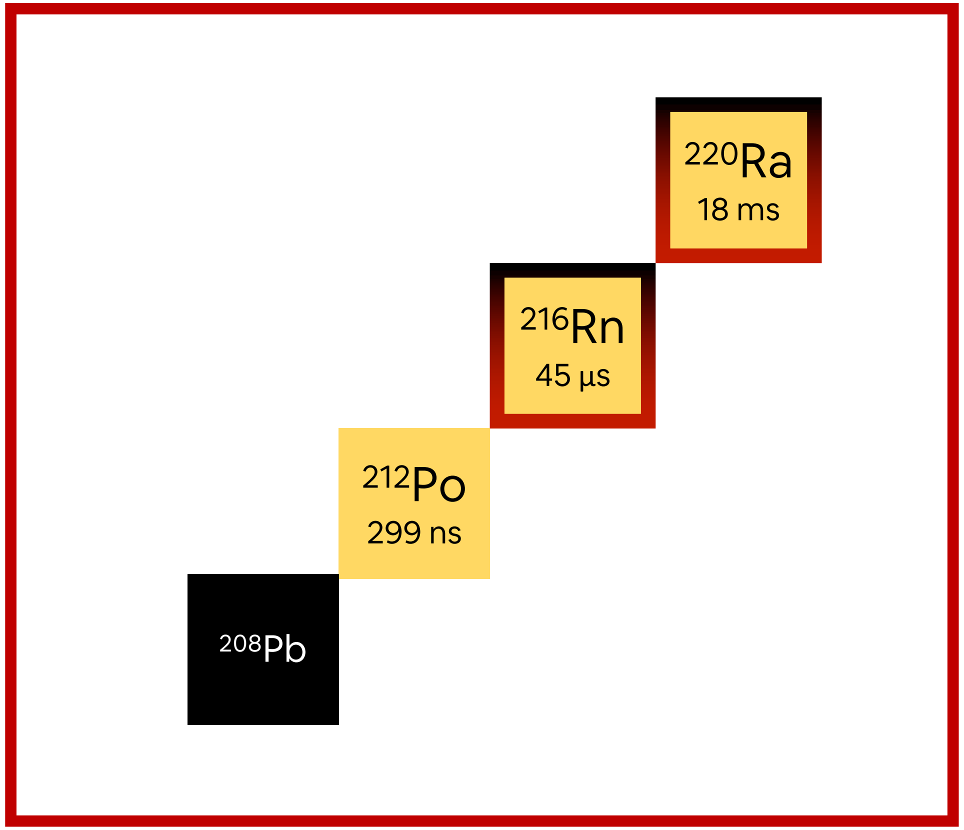


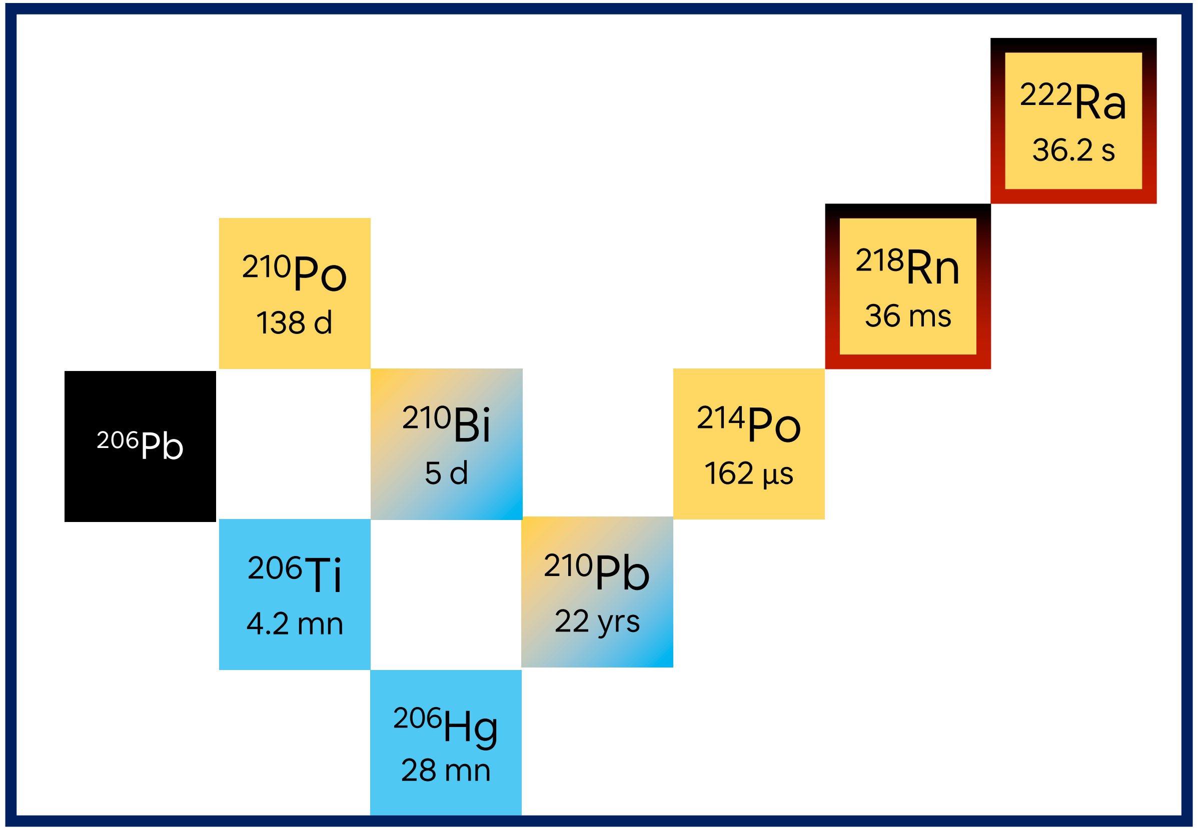
Experimental setup... in real life





A few numbers





~ 2.5 days
$\sim 10^3$ pps
$\sim 10^8$ implantations

10^{-2} due to short half-life

~ 4.5 days
$\sim 10^5$ pps
$\sim 10^{10}$ implantations

How to identify double α decay ?

2 α particles +…

Energy condition

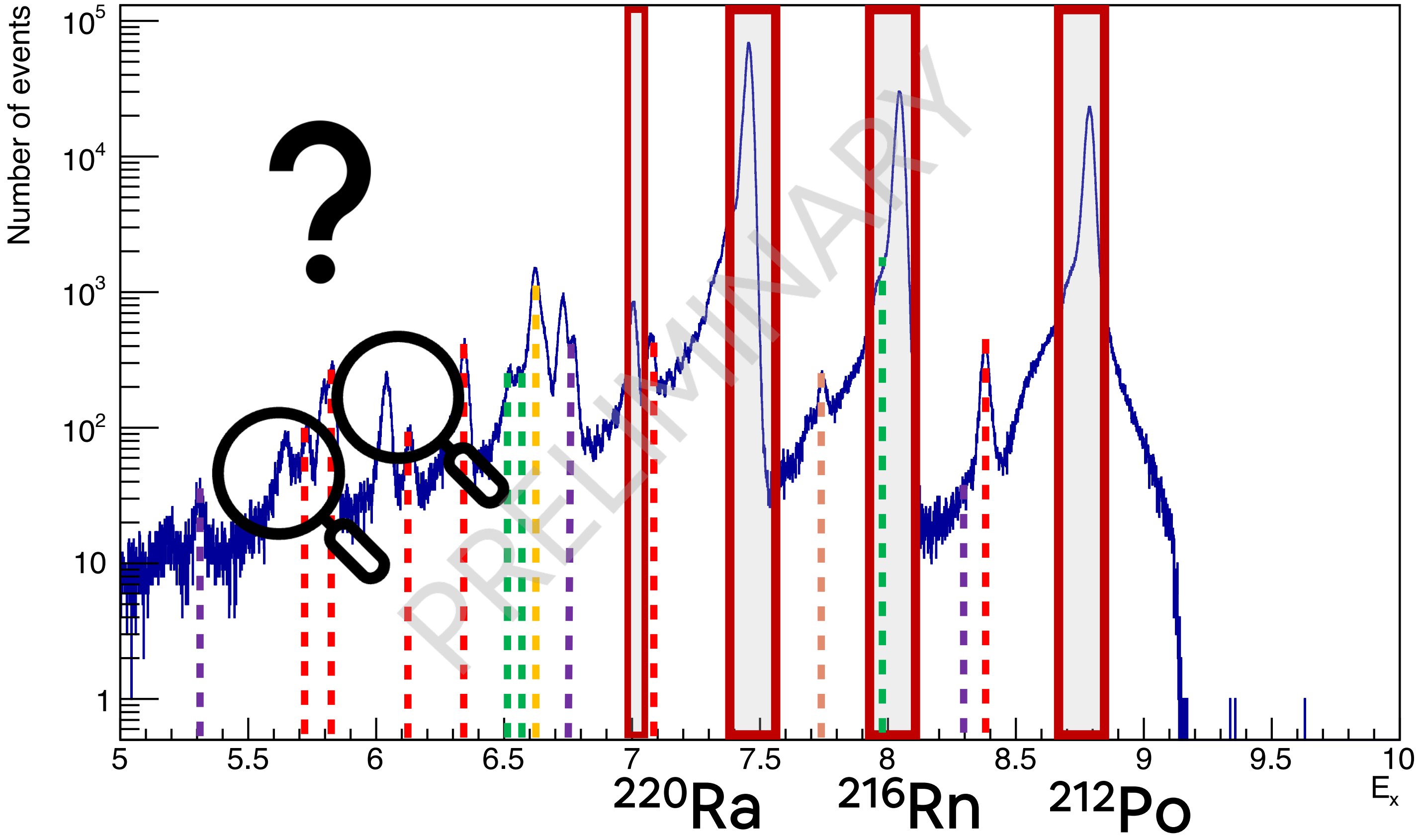
$$E_1 + E_2 \sim Q_{2\alpha}$$

A glance at energy spectra

Expected energy resolution
(~30 keV FWHM)

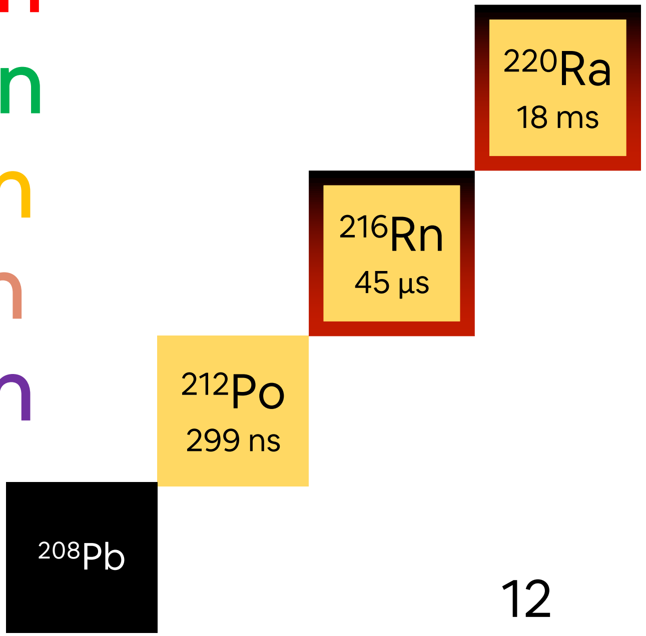
Expected :
3 peaks
(+1 satellite)

In experiment :
A lot of contaminants
... to be identified



$^{220}Ra \rightarrow {}^{216}Rn \rightarrow {}^{212}Po \rightarrow {}^{208}Pb$

^{225}Ac chain
^{223}Ac chain
^{223}Ra chain
^{221}Ra chain
^{222}Ra chain



How to identify double α decay ?

2 α particles +...

Energy condition
$E_1 + E_2 \sim Q_{2\alpha}$

Contaminants
To be identifed

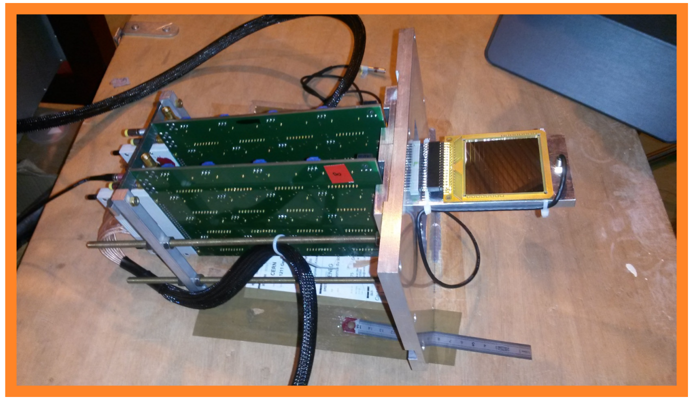
Time condition
$T_1 \sim T_2$

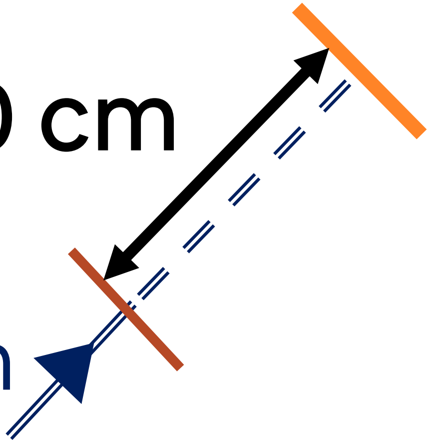
not shown here

Spatial condition
$\theta \sim 180°$

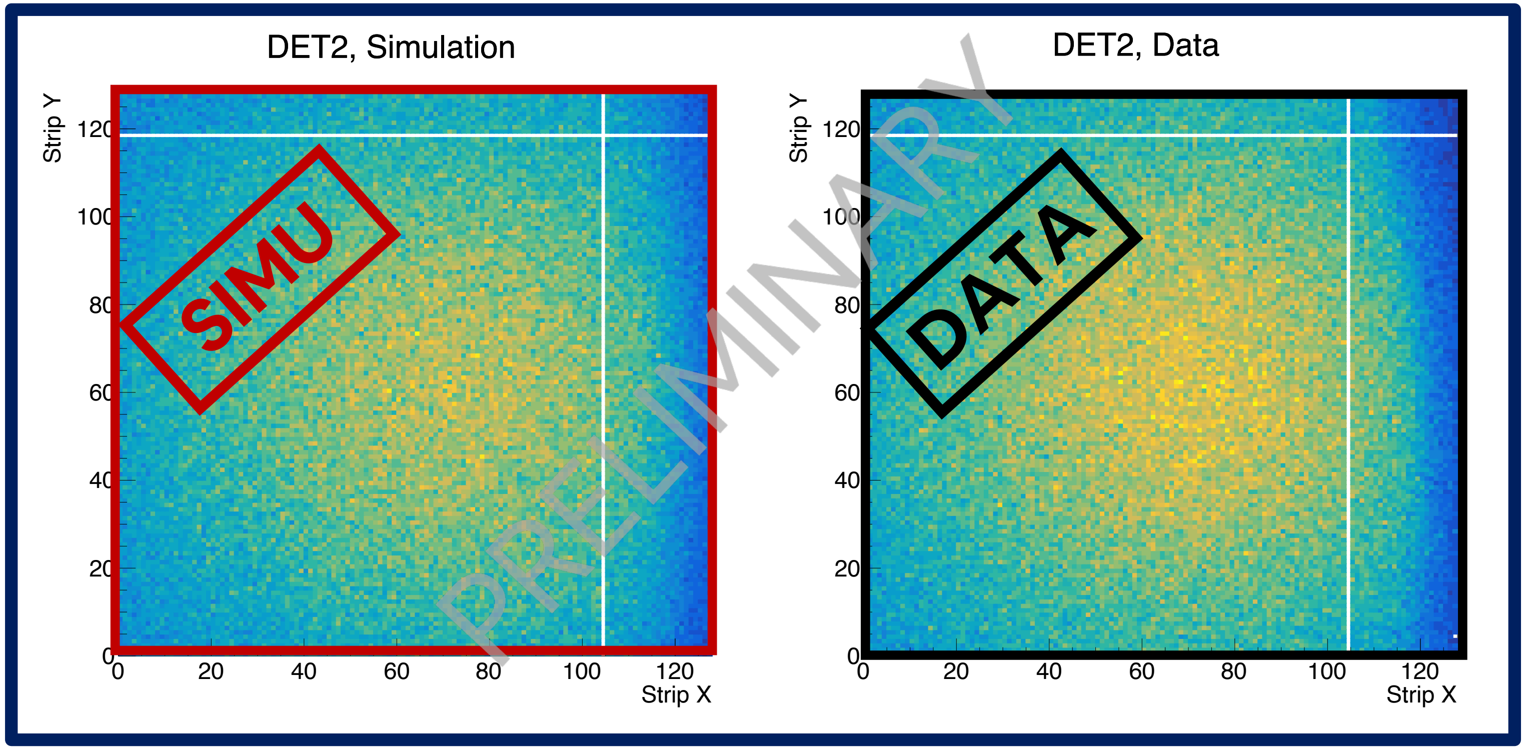
Beam spot reconstruction

Beam Inspection DSSD :
Too far from target to monitor beam spot





Beam spot determined with **simulation**



How to identify double α decay ?

2 α particles +...

Energy condition
$E_1 + E_2 \sim Q_{2\alpha}$

Contaminants to be identifed

Time condition
$T_1 \sim T_2$

not shown here

Spatial condition
$\theta \sim 180°$

Qualitatively OK

How to identify double α decay ?

Energy condition
$E_1 + E_2 \sim Q_{2\alpha}$

Time condition
$T_1 \sim T_2$

Spatial condition
$\theta \sim 180°$

DATA

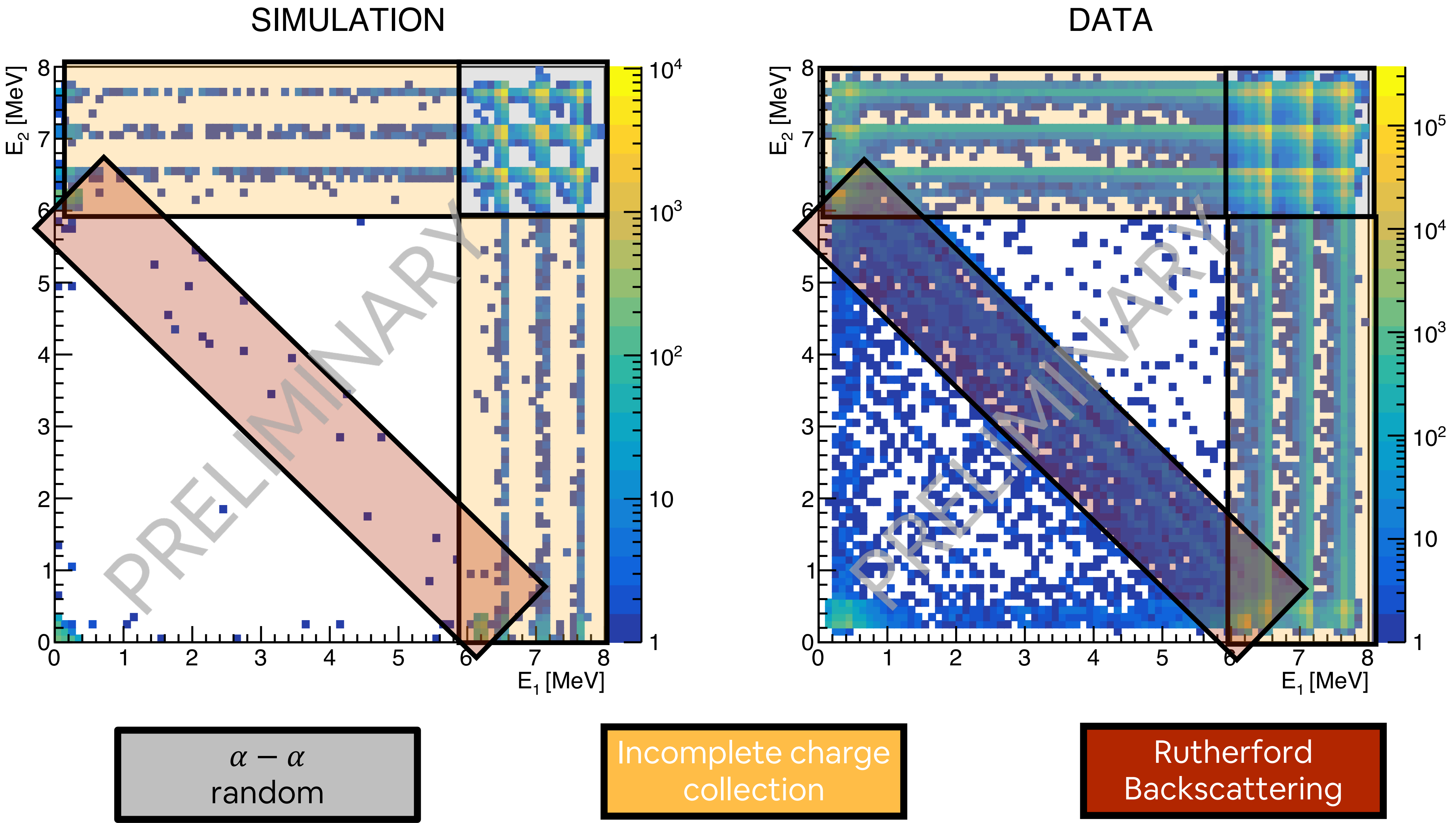
+

SIMULATION

Signal/Noise
Bckgd, efficiency

Cuts choice
ΔE, ΔT, $\Delta\theta$

Simulation status



Conclusion

DATA

Energy

Time

Space

Statistics

SIMULATION

Qualitatively OK

Towards quantitative

Thank you for your attention !

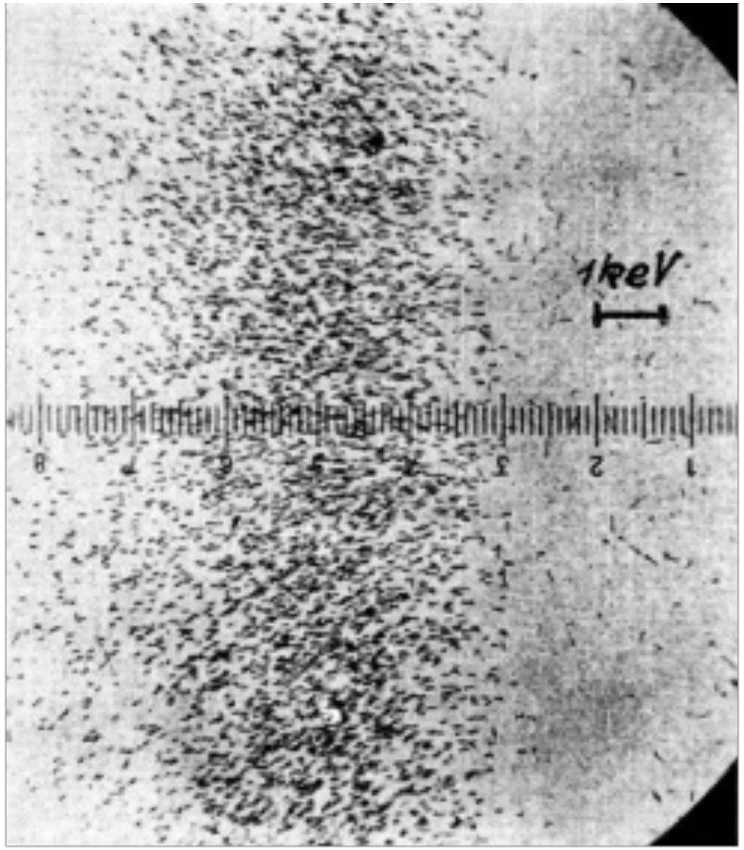
L. Heitz[1,2], E. Khan[2], Ch. Theisen[1,†], T. Chaminade[1], V. Alcindor[2], M.Assié[2], B. Blank[3], D. Beaumel[2], J. Bequet[1], Y. Blumenfeld[2], D. Cotte[1,(4)], T.Davinson[5], D. Desforges[1], T. Dickel[6], J.-P. Ebran[7], J.Giovinazzo[3], C.Houarner[8], K. Johnston[4], M. Kowalska[4], U. Köster[9], I. Moore[10], V.Morel[8], L. Nies[6], A. Ortega-Moral[3], I. Pohjalainen[10],P.M. Reiter[5], T. Roger[8], F.Saillant[8], M. Simonov[6], B. Sulignano[1], D. Thisse[1], L. Thulliez[1], G. Toccabens[1], M. Vandebrouck[1], H. Wilsenach[6]

[1]Irfu, [2]IJCLAB, [3]Bordeaux, [4]CERN, [5]Edinburgh, [6]GSI, [7]CEA DAM, [8]Ganil, [9]ILL, [10]Jyväskylä,

This project has received funding from the European Union's Horizon Europe Research and Innovation programme under Grant Agreement N°101057511

Back-up

Energy spectra : literature



The example of ^{210}Po measured by Rytz using a photographic plate.

Literature rather old :

^{220}Ra weighted average of 7449 (10) from Hessberger 2000, 7455 (10) from Valli **1970** and 7460 (20) from Andreev

^{214}Po : measurement with a magnetics spectrograph. Rytz. Helv.Phys.Acta 34, 240 (**1961**), again adjusted by Rytz in 1991.

In our background data, peaks not (yet) identified

Room to improve **alpha-decay data** in actinide region

2 alpha predictions

	Approach	Comments	Best B.R.
Poenaru - 1985	Super Asymetric Fission	Large BR. Close to ^{8}Be	~10^{-13}
Tretyak - 2021	^{8}Be cluster	Very Large BR ($T_{2alpha}>10^{33}$ yr)	…
Santhosh - 2021	Modified Liquid Drop Model	Large BR. Close to ^{8}Be, weird ^{209}Bi	Close to Poenaru
Mercier Zhao - 2021,2023	Time Dependant evolution, EDF	uncertainties hard to estimate	~$10^{-6.5}$
Denisov - 2022	Modification of Unified Model for Alpha Decay	Very small B.R.	~10^{-2}

Half-life computation

- **Generic (phenomenological) formula for radioactive decays**

$$\tau^{-1} = \nu \times S \times P_s$$

Half-life

Assault frequency
$(\sim 10^{20}\ s^{-1})$

Preformation factor
Hard to estimate

Barrier Penetration Probability
WKB-like expressions

$$\log P_s \propto -2\int dr \sqrt{2B(r)(E(r) - E_0)}$$

B ~ reduced mass
E ~energy of the system

- **Different models : different** S**,** P_s $(E\ and\ B)$

Half-life computation

$$\tau^{-1} = \nu \frac{1}{1 + \exp 2S}$$

Assault frequency

Minimised integral action

$$\delta S = 0$$

$$S = \int_{s_{in}}^{s_{out}} ds \sqrt{\mathcal{M}_{eff}(s)(V_{eff}(s) - E_0)}$$

$$\mathcal{M}_{\text{eff}}(s) = \sum_{ij} \mathcal{M}_{ij} \frac{\mathrm{d}q_i}{\mathrm{d}s} \frac{\mathrm{d}q_j}{\mathrm{d}s}$$

$$\mathcal{M} = M_{(1)}^{-1} M_{(3)} M_{(1)}^{-1}$$

$$\left[M_{(k)}\right]_{ij} = \sum_{\mu\nu} \frac{\langle 0|\hat{q}_i|\mu\nu\rangle \langle \mu\nu|\hat{q}_j|0\rangle}{(E_\mu + E_\nu)^k}$$

Inertial effective mass

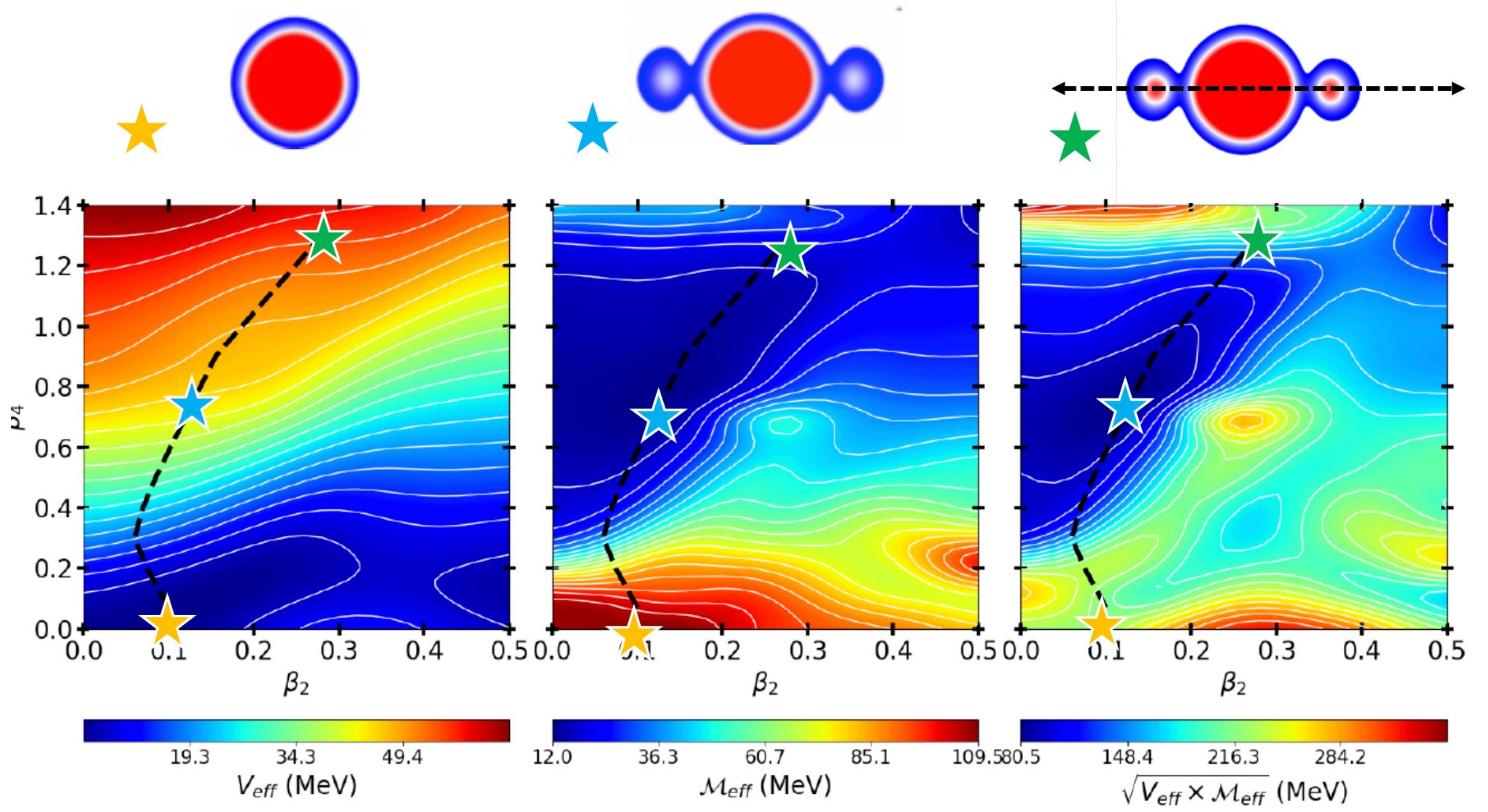
Information about energy needed to deform nucleus

(Computed w/ ATDHB & perturbed cranked approx)

PES

Information about energy cost of a path

(Computed w/ RHB)



H. Wilsenach courtesy

$$S(L) = \int_{s_{\text{in}}}^{s_{\text{out}}} \frac{1}{\hbar} \sqrt{2\mathcal{M}_{\text{eff}}(s)[V_{\text{eff}}(s) - E_0]}\, ds \qquad P = \frac{1}{1 + \exp[2S(L)]} \qquad T_{1/2} = \frac{\ln(2)}{nP}$$