Structure of Heavy Nuclei and associated R&D

Decay spectroscopy of ^{255}Rf

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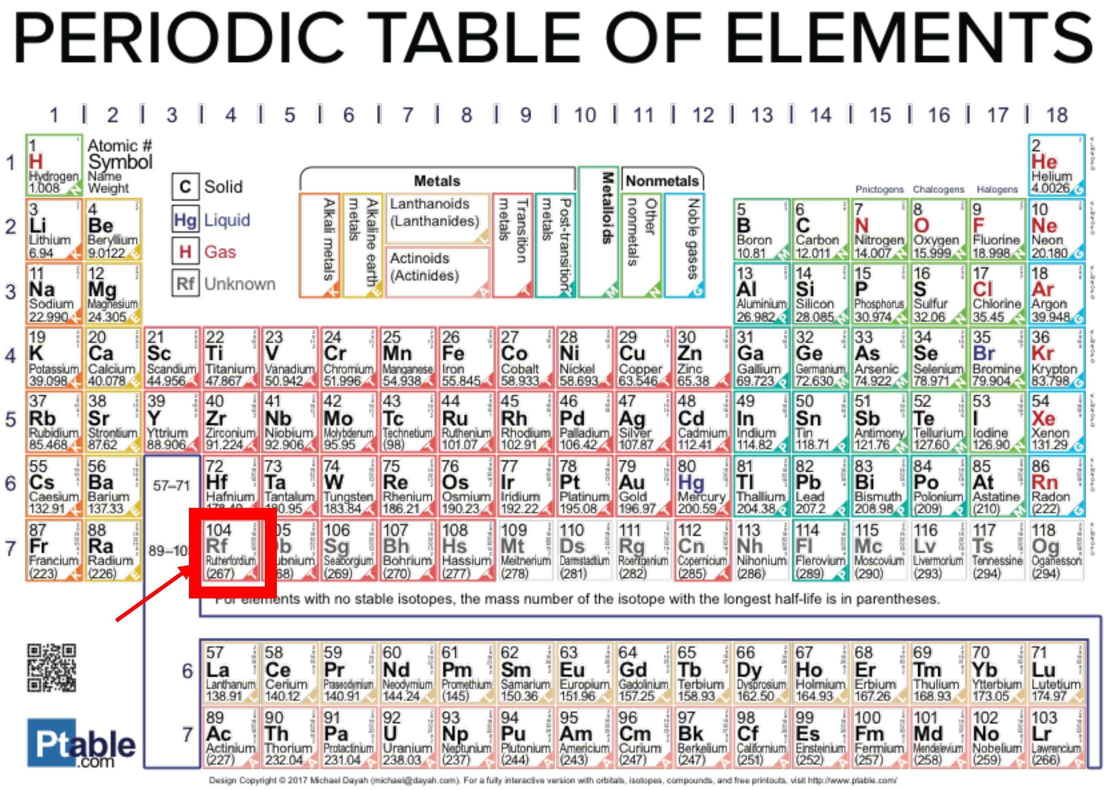
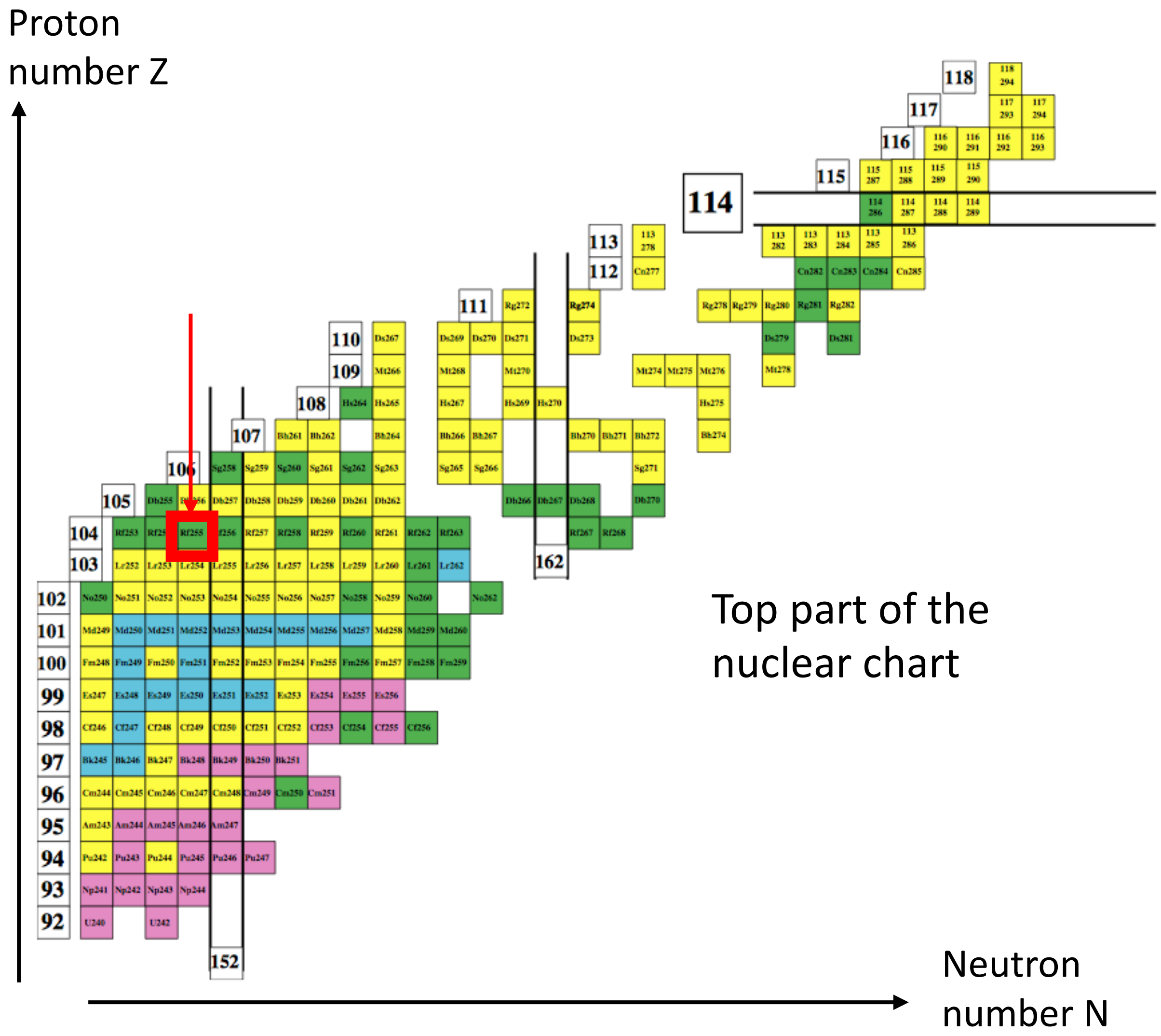
Outline

1. Introduction and Motivation
2. Production
3. Experimental Setup
4. Calibration and the Experiment
5. Analysis Method
6. Preliminary results
7. Geant4 Simulation
8. Conclusion

^{255}Rf

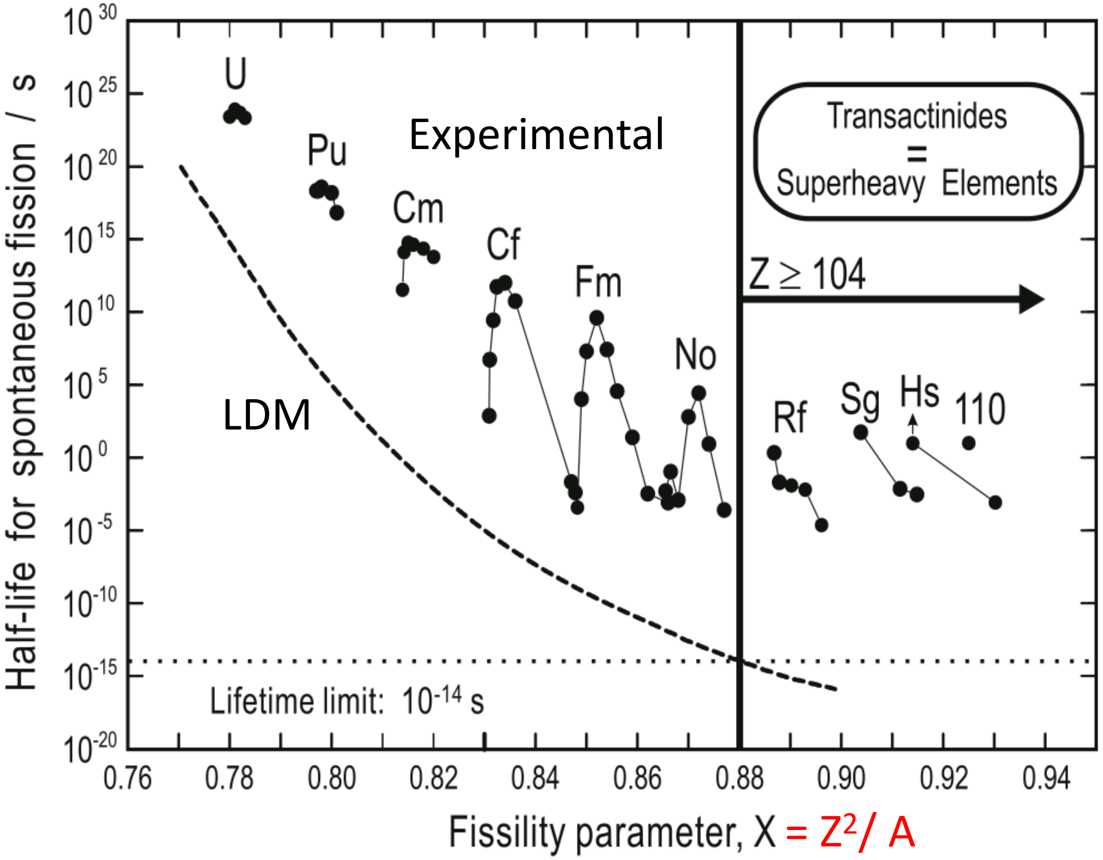




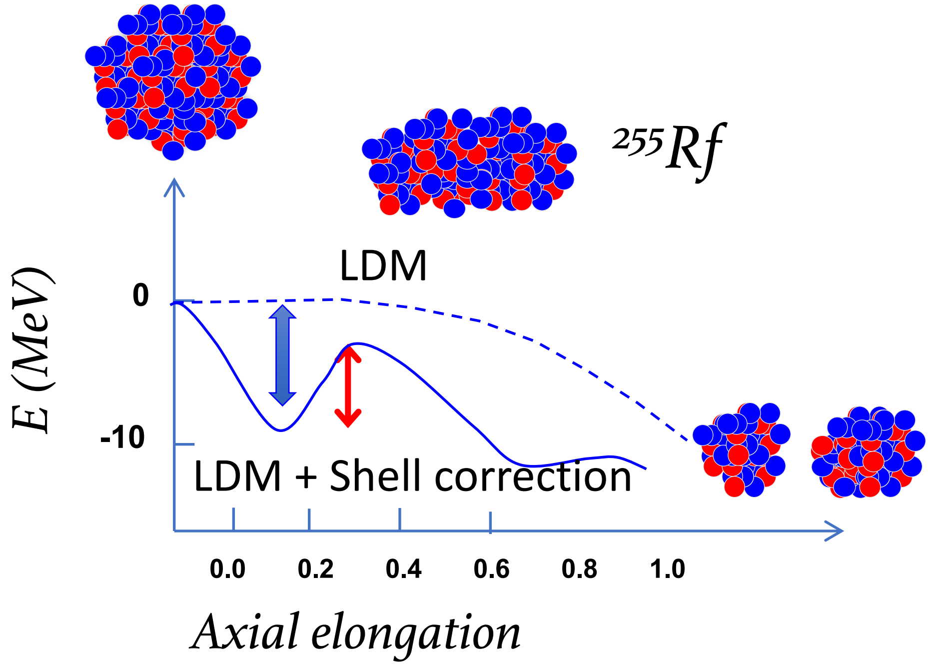
Rf is the first transactinide element

Rf is a superheavy nucleus

Superheavy: ^{255}Rf



Minimum time required for hydrogen molecule to form

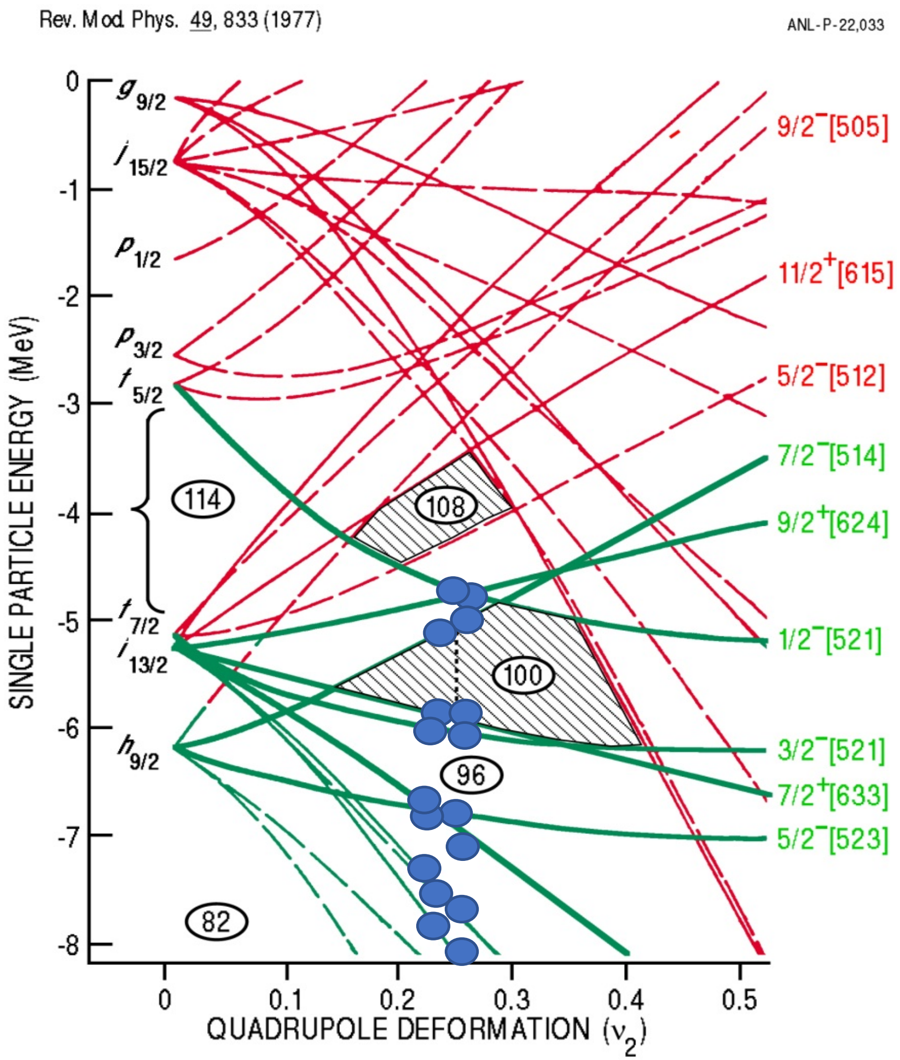


$$B_f = E_{saddle} - E_{gs}$$

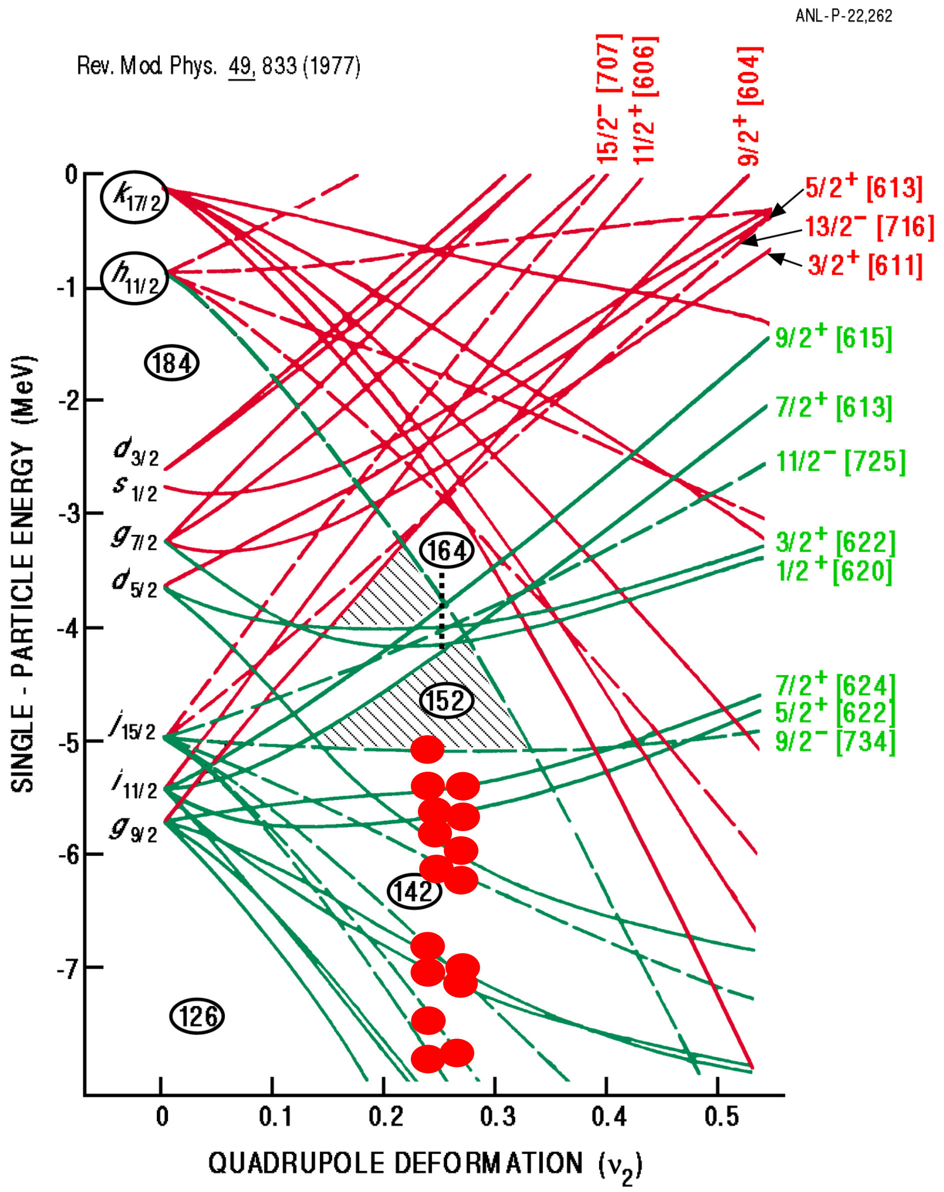
R. D. Herzberg, The chemistry of superheavy elements 2nd Edition, P. 89

Predicted shell structure around N ~152 and Z~100

R. Chasman et al., Rev. Mod. Phys. 49, 833 (1977)



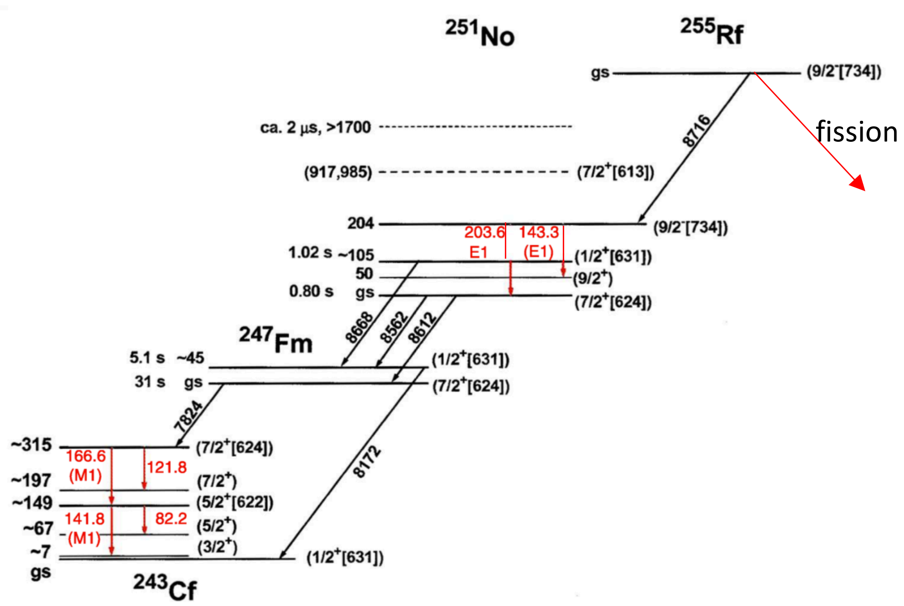
proton



neutron

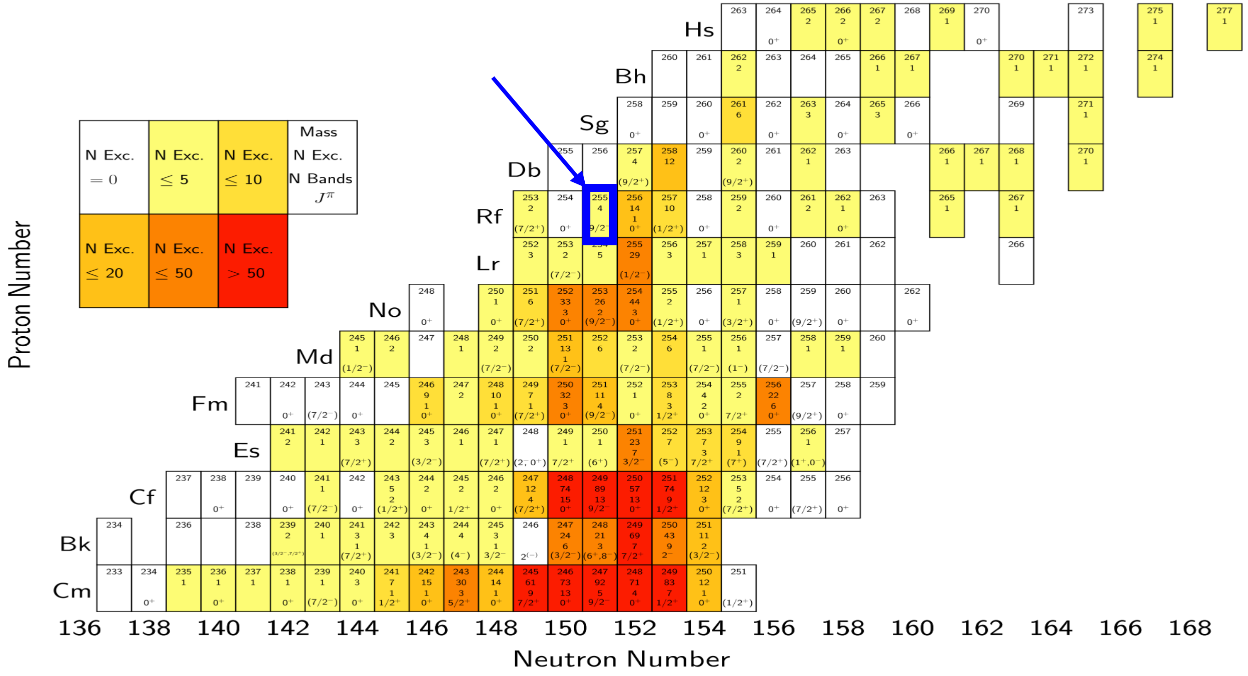
What is known about ^{255}Rf ?

- In 1975, Ogennessian's group in Dubna measured $T_{1/2}$ > 1 s
- In 2006, GSI group studied its decay and found $T_{1/2}$ =1.68± 0.09 s
- In 2015, GSI group populated an isomeric state from the alpha decay of ^{259}Sg

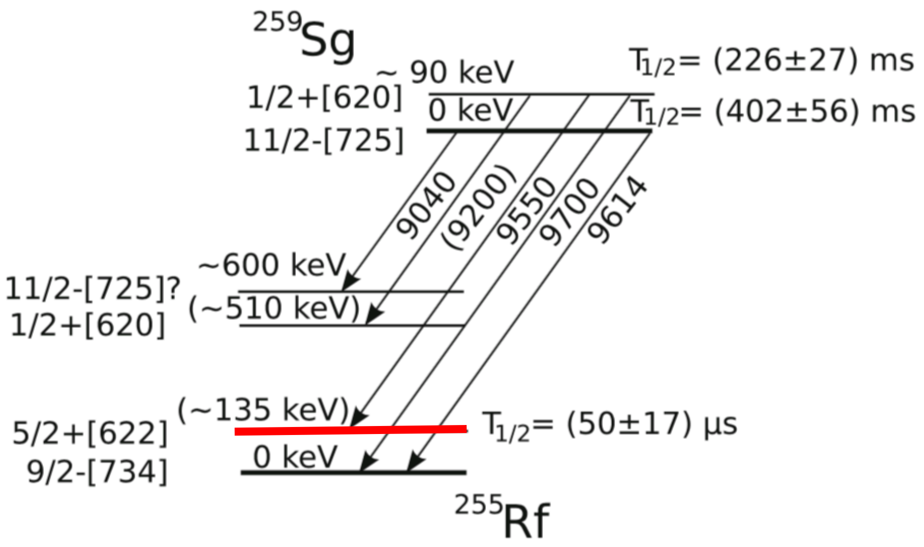


F.P. Hebberger et al. Eur. Phys. J. A 30, 561-569 (2006)

Available spectroscopic data

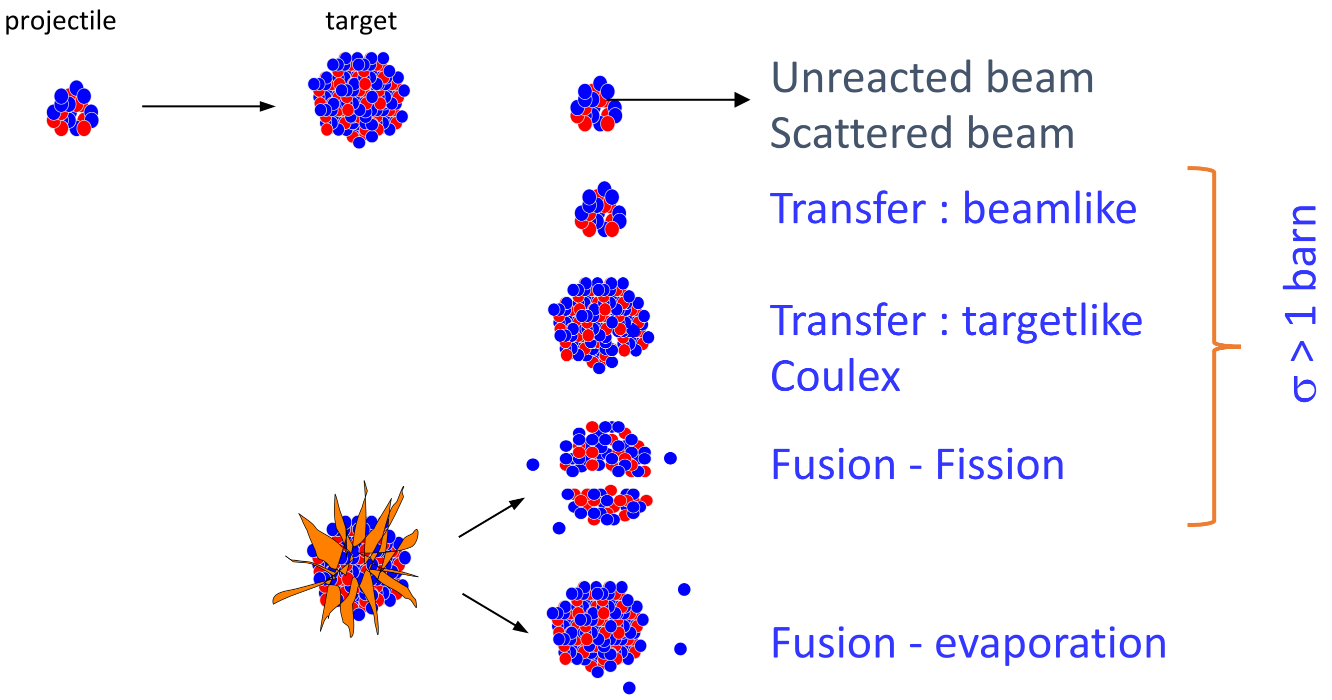


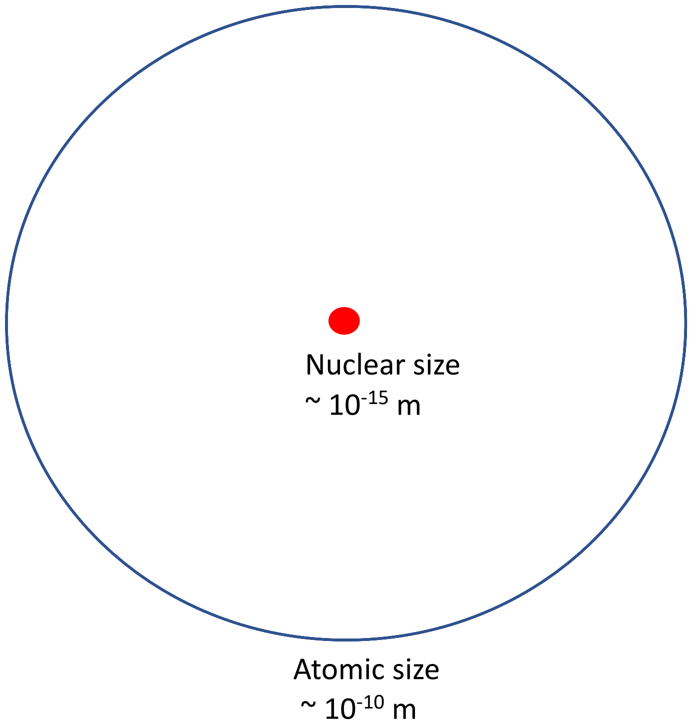
Ch. Theisen et al., Nucl. Phys. A 944 (2015) 333



S. Antalic et al. Eur. Phys. J. A (2015) 51: 41

Production : fusion-evaporation reaction





Survival of nucleus of interest : σ ~ 10 nb

1 out of ~10^{11} beam particles leads to a reaction of interest

⇨ Need to select the needle in the hay stack !

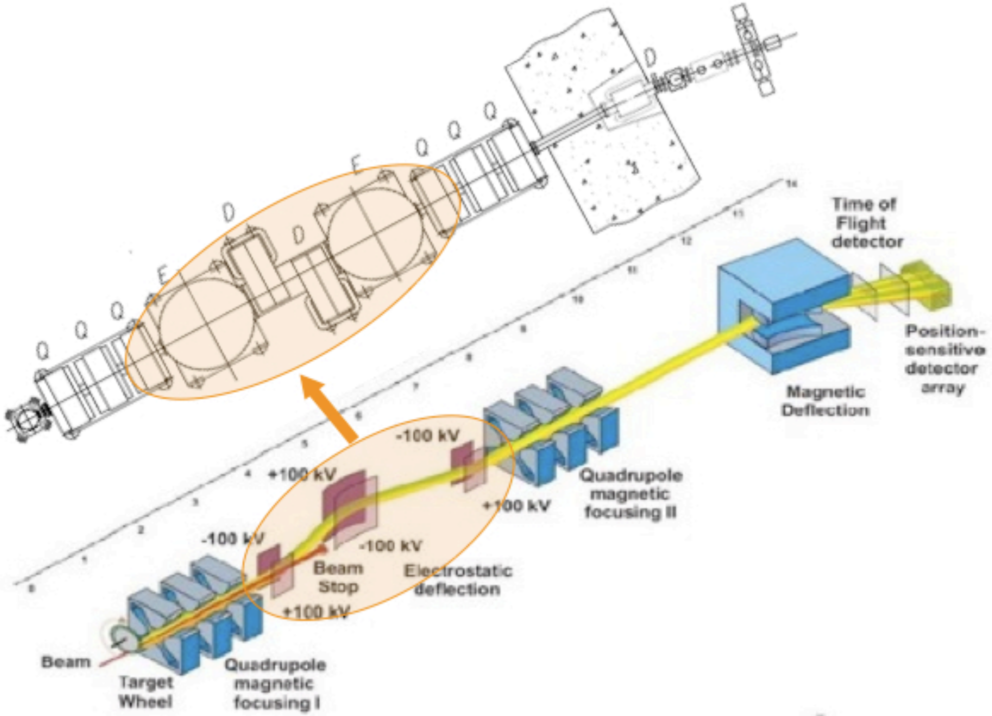
SHELS@Dubna

VASSILISSA (Energy filter)

➔SHELS (velocity filter)

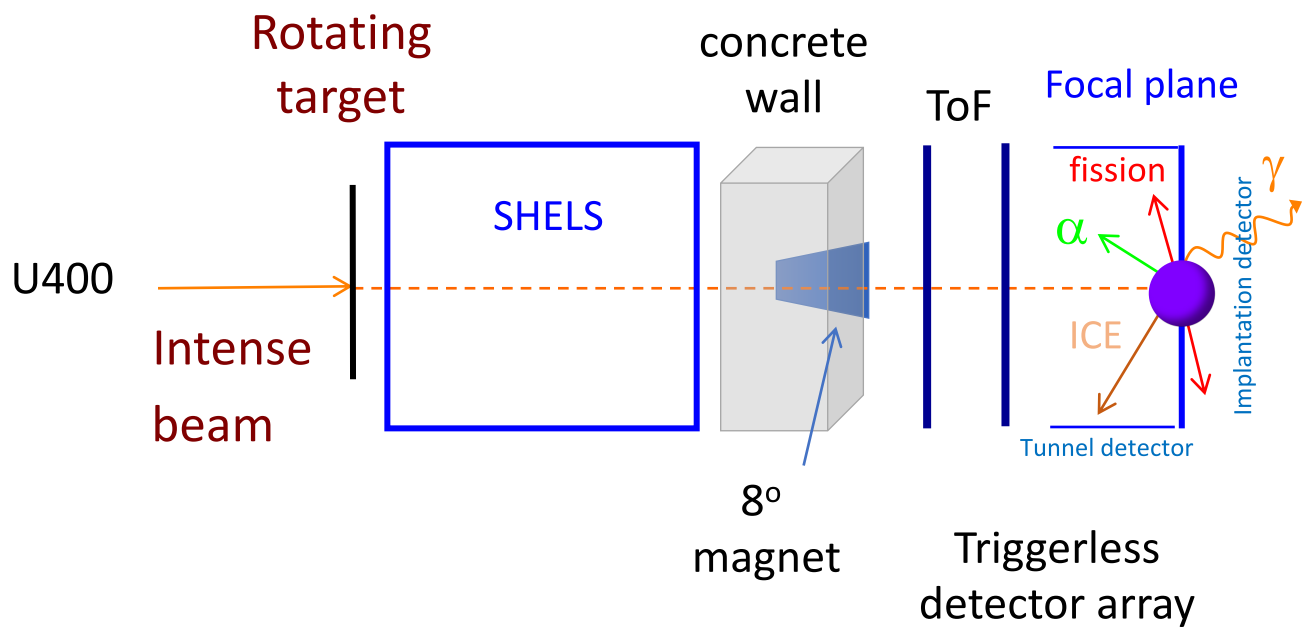
Gain in transmission, especially for asymmetric reactions

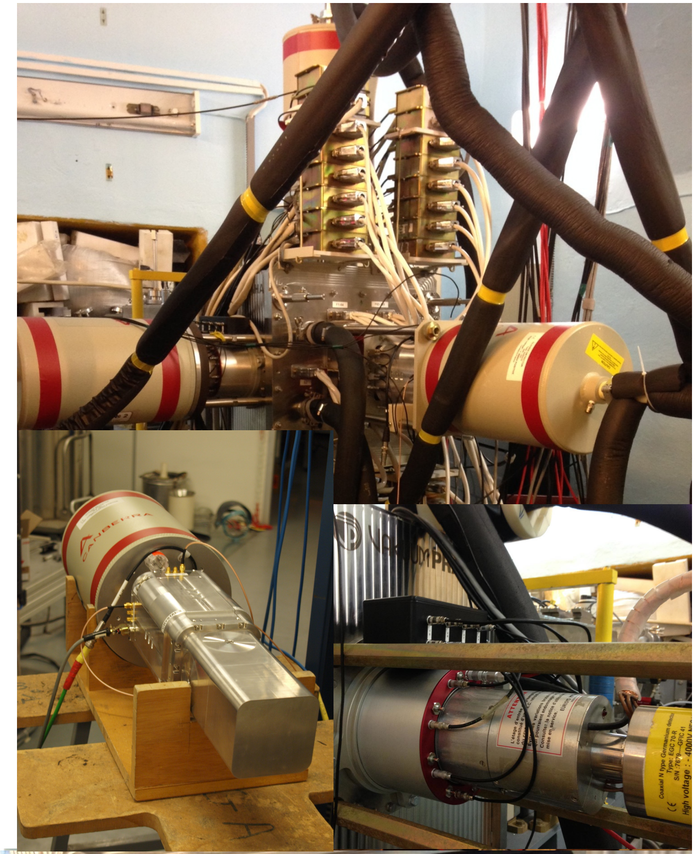
A. Popeko et al., Nucl. Instr. Meth. B 376 (2016) 140

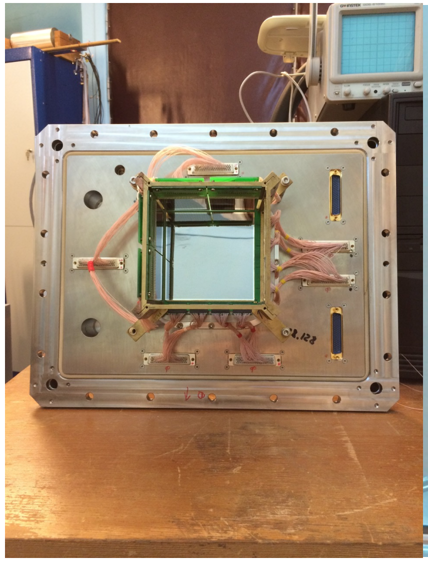


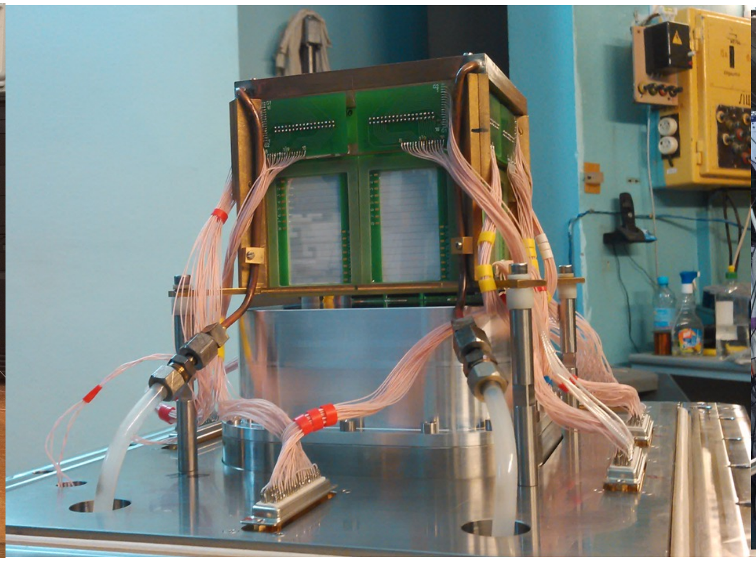
GABRIELA@SHELS

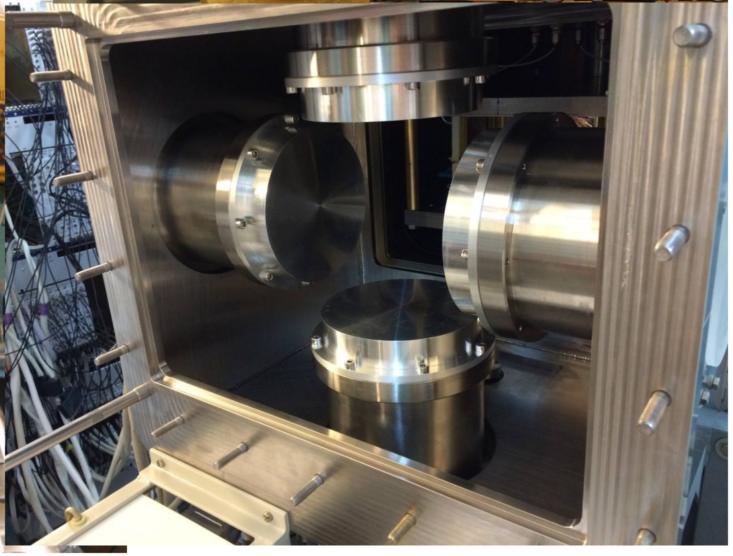
ANR-CLODETTE (2013-2017) & RFBR





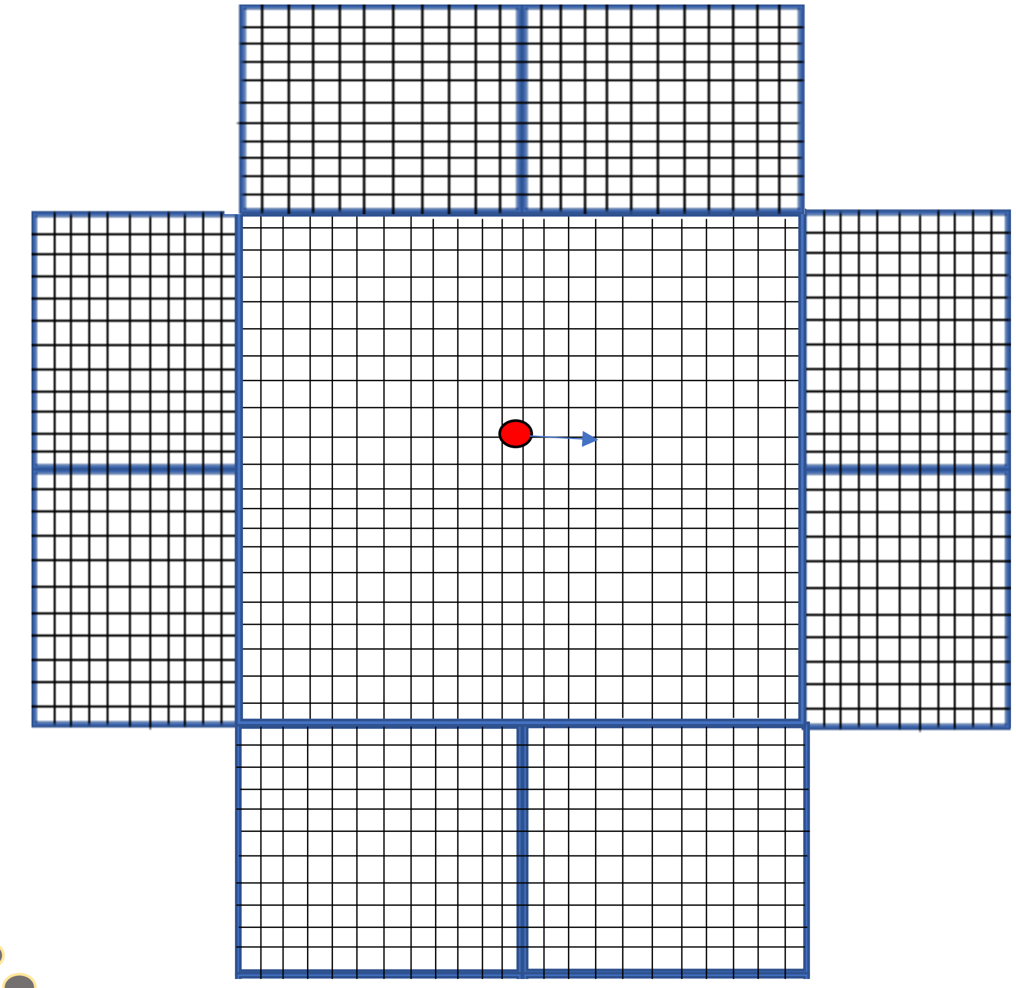






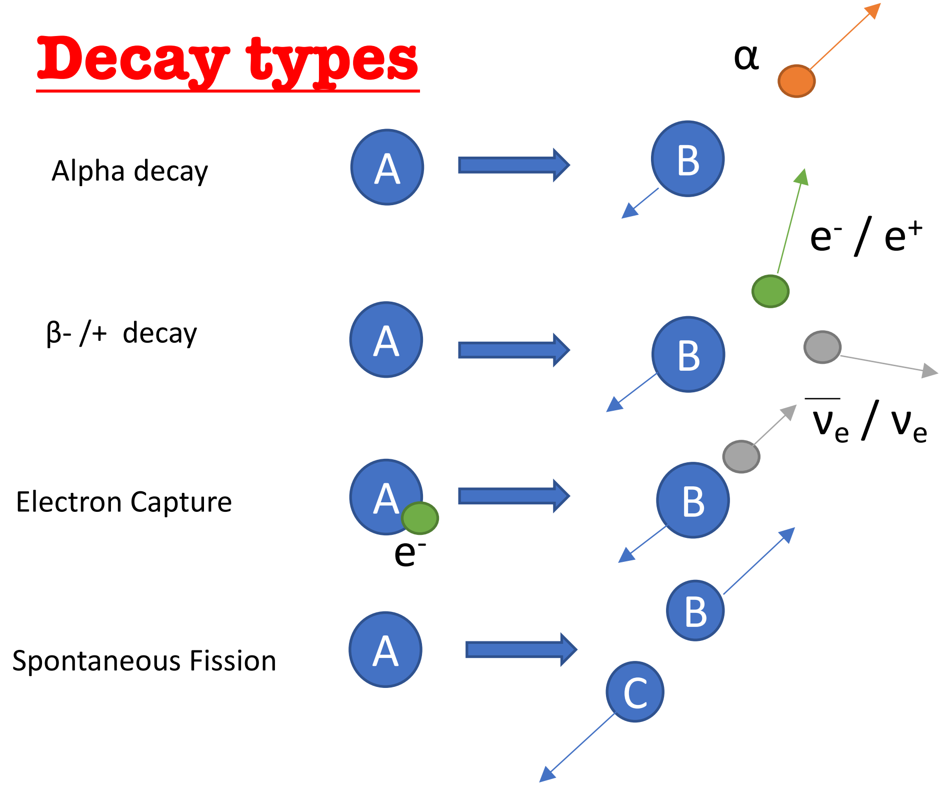
Detectors

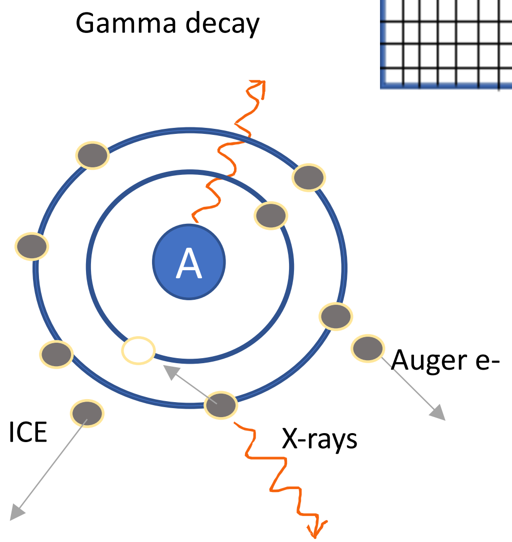
- Implantation detector 128 x 128 strips = 16384 pixels
- 4 sides x 2 tunnel detectors = 8 x (16 + 16) =256 strips
- 4 High purity Ge side detectors and 1 clover with 4 crystals
- 5 BGO shields surrounding the Ge detectors
- Since it is a triggerless system all the signals are recorded.
- Each signal has a time stamp, channel number and other markers.



Each: 16x16 strips

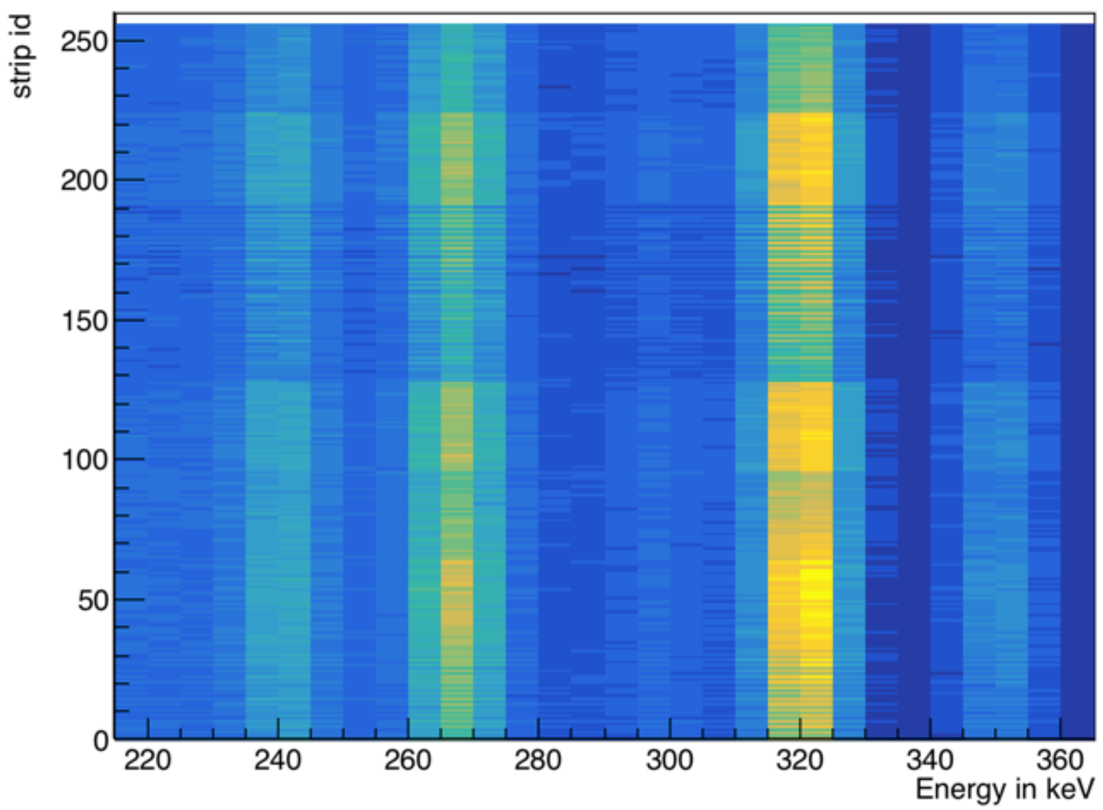
Decay types





Experiment

DSSD electron calibration with ^{133}Ba Oct Run



Calibration: (Source and In beam)

- Alpha: ^{170}Er(^{50}Ti,4n)^{216}Th
- Electron: ^{133}Ba Source
- Gamma: ^{164}Dy(^{50}Ti,2n)^{212}Ra

2 Experiments (2 Gains x 256 DSSD + 256 Tunnel + 8 Gamma) = 1552 channels

Main Reaction

^{207}Pb(^{50}Ti,2n)^{255}Rf

2 Runs: May and Oct 2017 (veto removed), each lasted about 3 weeks

Beam energy ≃ 250 MeV, intensity ≃8.5 eμA == ~400 pnA

Methodology: Position and time correlation

ROOT
Data Analysis Framework

Genetic correlation in every pixel of the DSSD

Recoil → Decay1 → Decay2 → Decay3

Range in Silicon
alpha (8 MeV) ~ 48 µm
fission fragment (120 MeV) ~ 18 µm
Pixel size 760 x 760 µm^2

gamma
gamma

Alpha generation — ggmother if any — gmother if any — mother if any — Ref. Alpha — daughter if any — gdaughter if any

tunnel
tunnel
ggdaughter if any

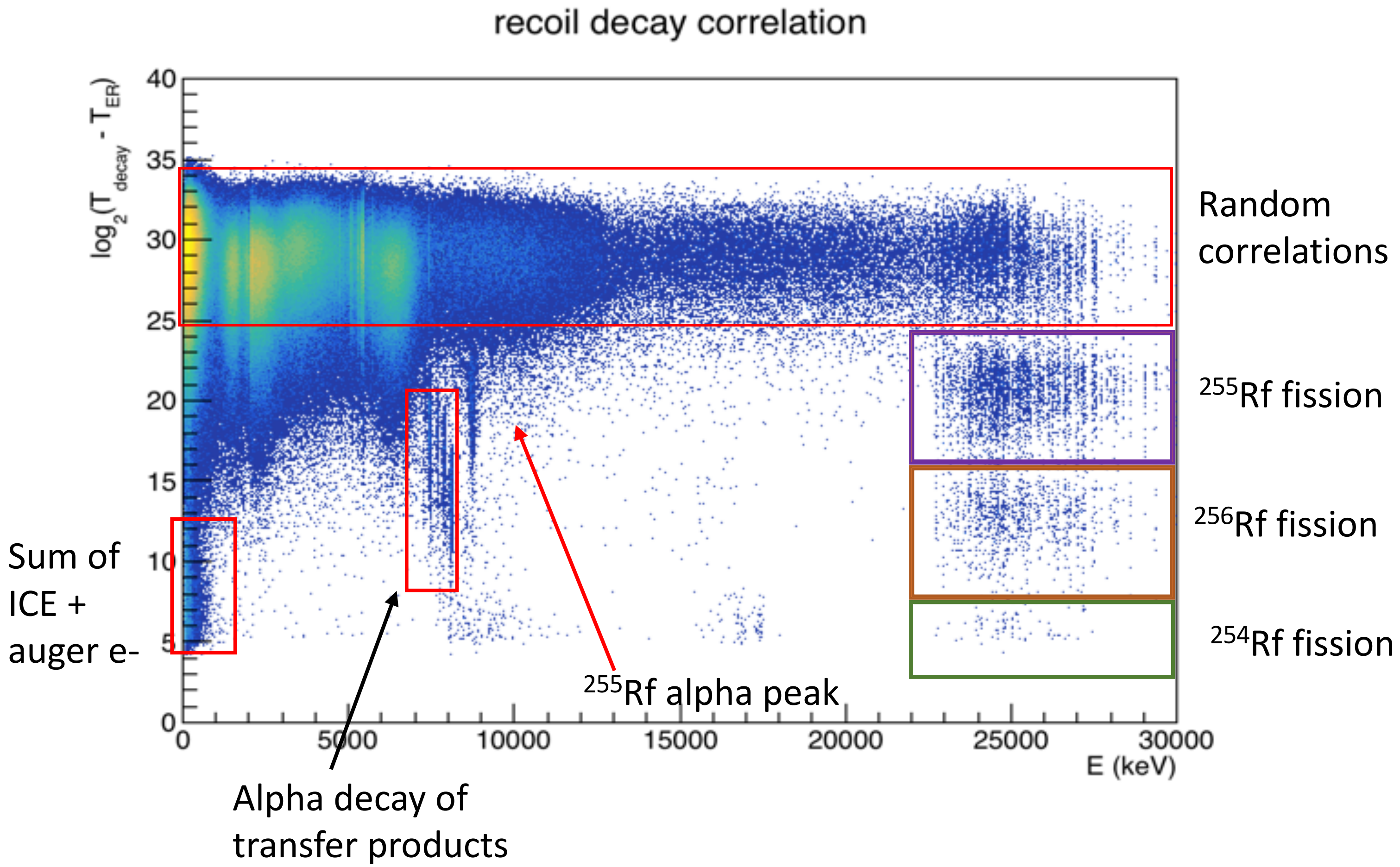
Entry i in the correlation tree

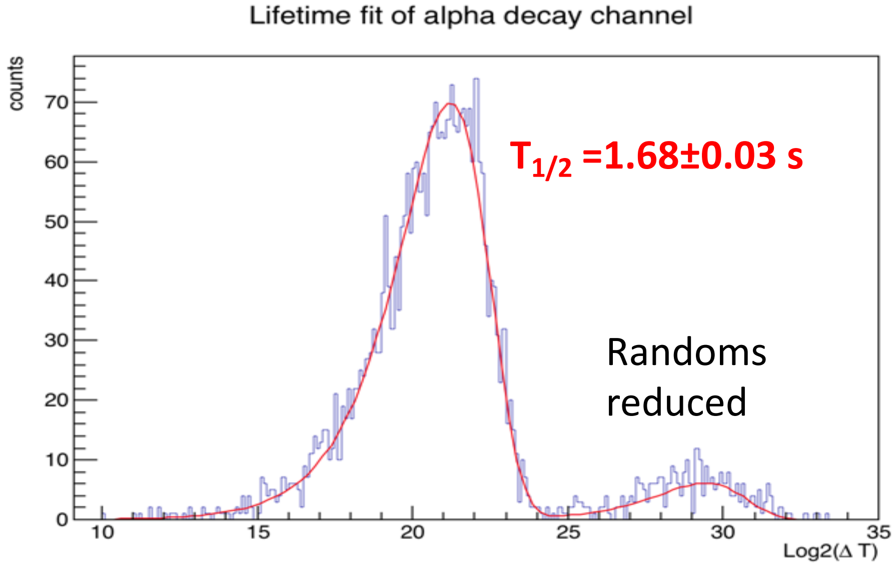
- g: grand
- gg: great-grand

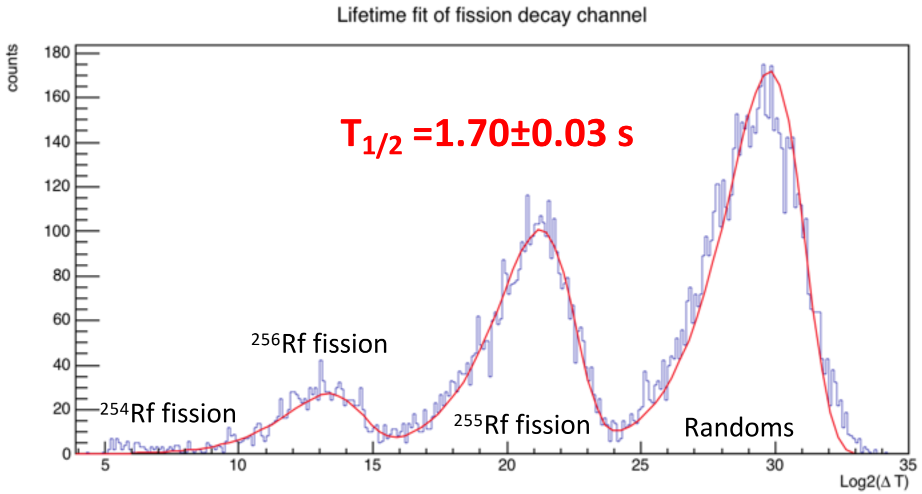
Look forward and backward in time

What do we see in the data

Recoil → Decay1 → Decay2 → Decay3

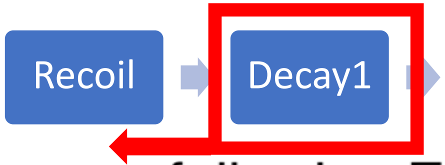


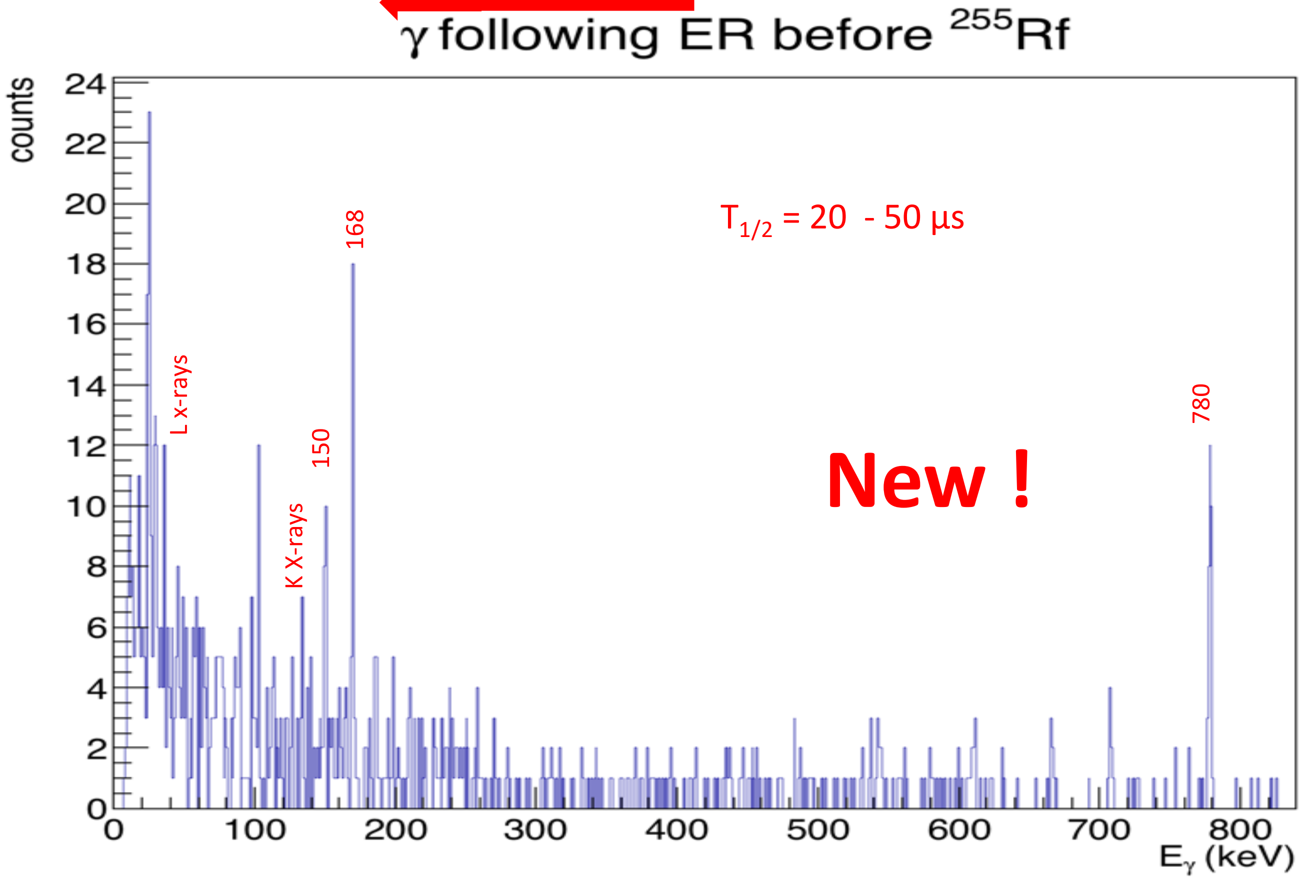


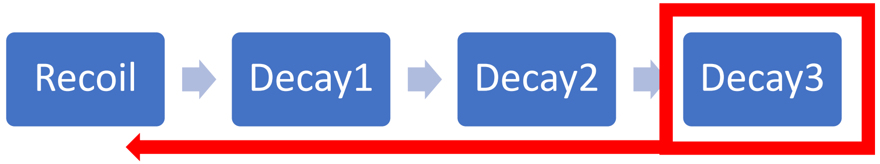


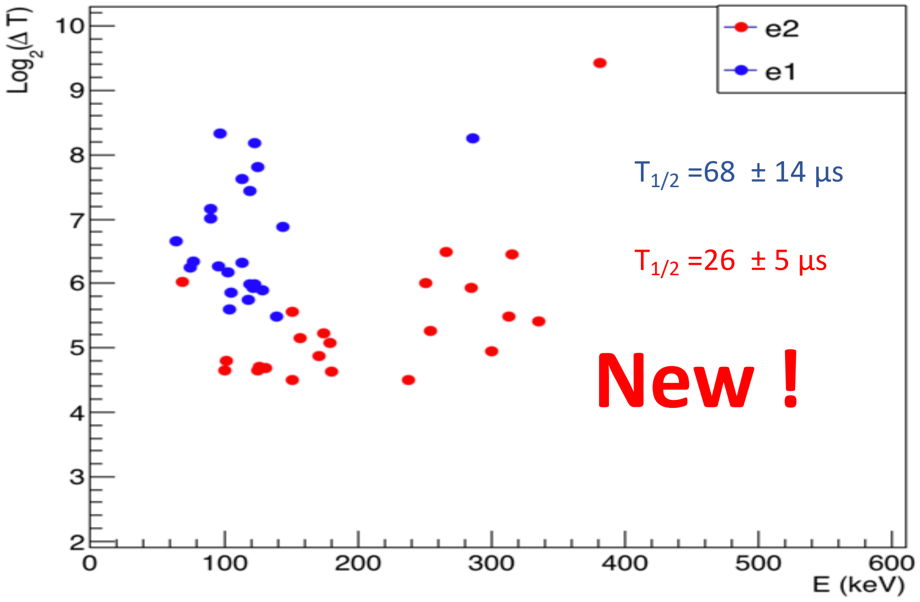
Total number of ^{255}Rf produced ≈ 7560 in 2 Runs

Results: ^{255}Rf

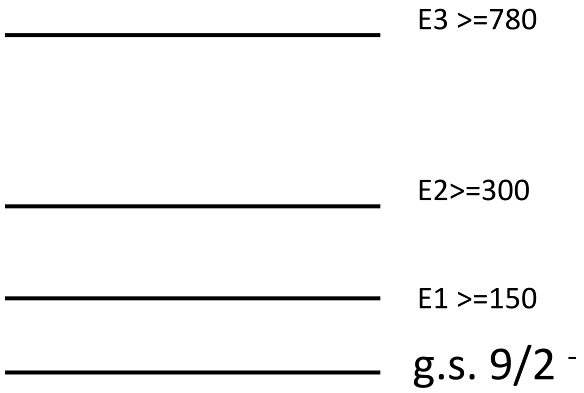








2 (and maybe 3?) isomers

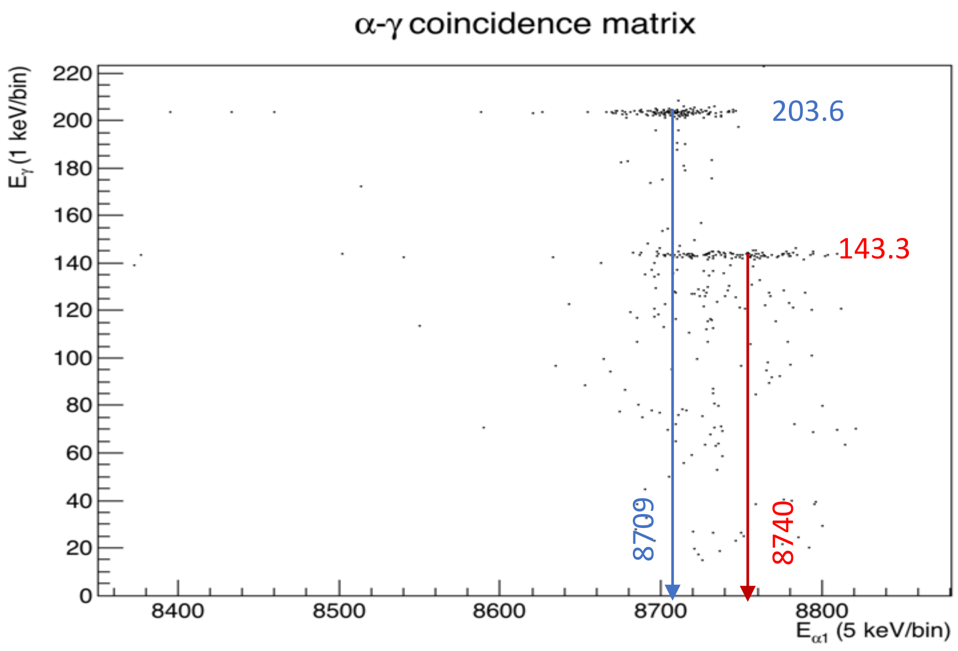


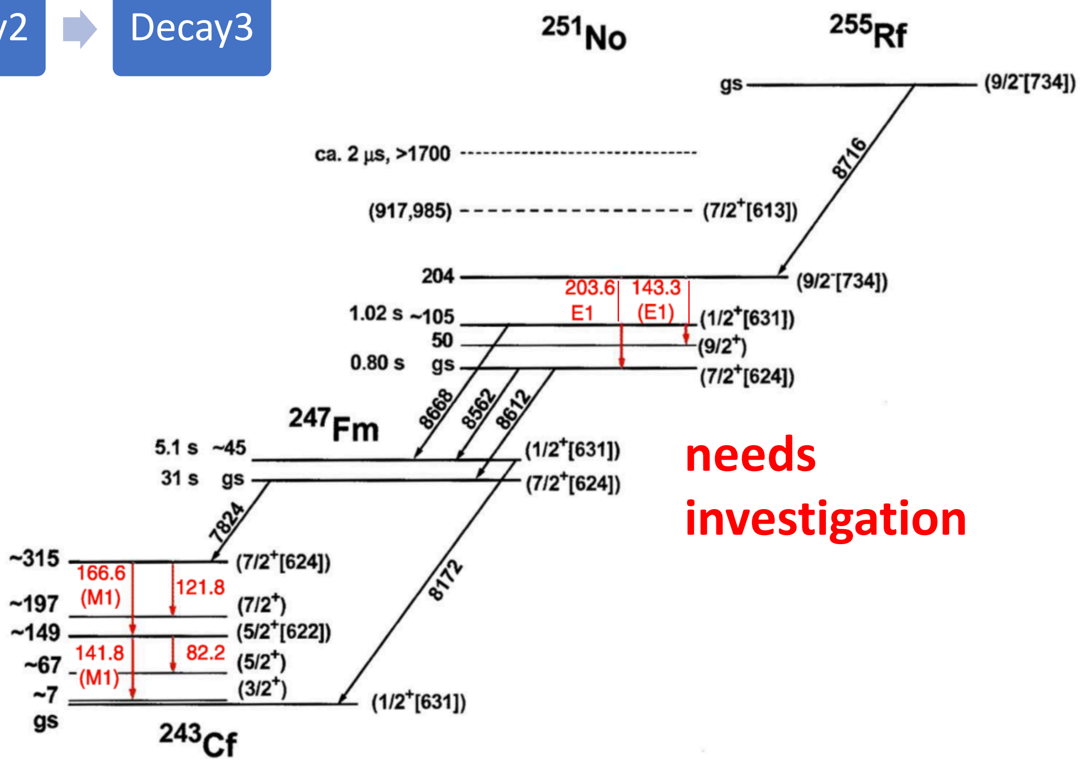
Ongoing work: (Trying to figure out the decay scheme)

1. Gamma-gamma coincidences
2. Gamma-ICE correlations
3. electromagnetic nature of transitions from conversion electrons & intensity of K-X rays observed

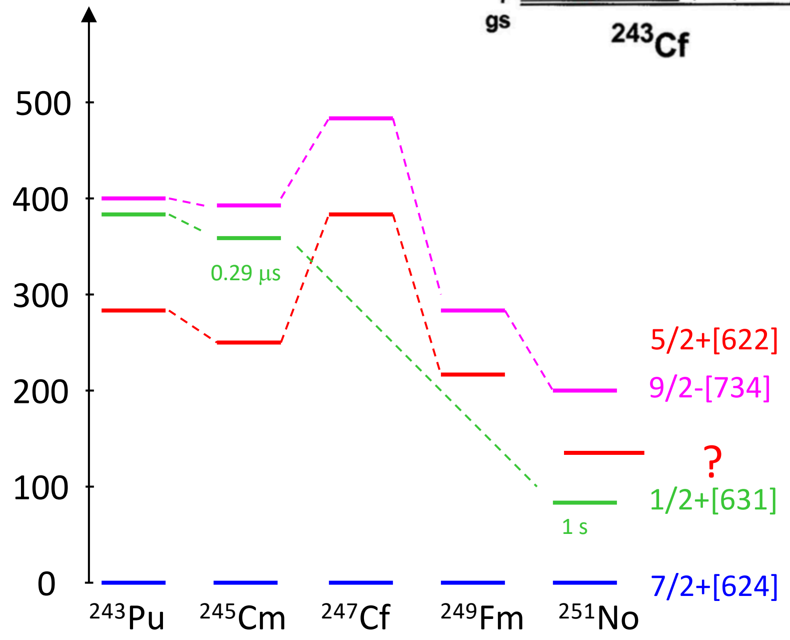
Results: ^{251}No

Recoil → **Decay1** → Decay2 → Decay3





needs investigation

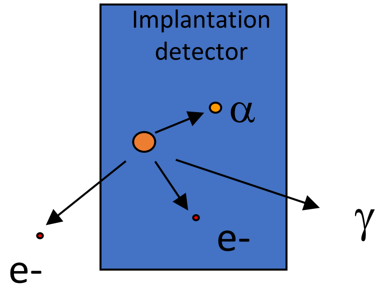


N=149

Is there evidence of 5/2+ state in our data ?

Geant4 Simulation: Why?

1. Test level scheme and interpret the experimental results
2. summing problem



Current limitation of Geant4: No atomic deexcitation for element Z > 100 i.e. no ICE, no Fluorescence and no Auger electrons

What did I do?

- Modified some low energy electromagnetic classes in Geant4 source code
- Added Binding Energy and Electronic Shell Data up to Rf
- Added Fluorescence Data and Auger Data up to Rf
- References: 1. Table of isotopes 2. Handbook of chemistry and physics

Does it work now?

Test with ^{251}No : successful, Enough for my need.

Conclusion and Perspectives

- We see two (or maybe 3) isomers in ^{255}Rf.
- Need further investigation to figure out the decay scheme of these states and establish (E^*, I, π)
- ^{251}No level scheme by GSI group: complete???
- Geant4 simulation to reproduce the experimental spectra (test of level schemes)
- Possibly meet a theoretician for some calculation

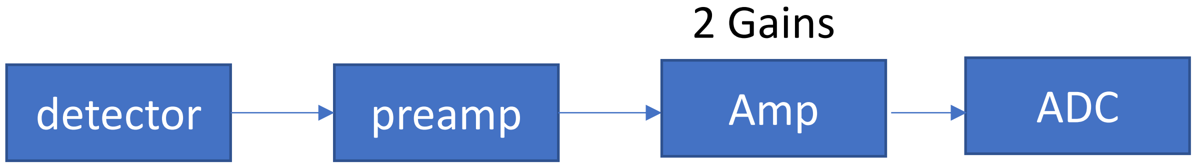
Goal: Determine the microscopic nature of the states in 255Rf (and in particular the isomers)

Remarks:

1. Could not participate in my thesis Experiment
2. **But,** participated in other similar experiments such as in the production of **$^{256, 257}$Rf, $^{250, 252, 254, 256}$No**
1. On the R&D side I participated once in preamplifier tests and will get more involved in the future

Backup

How do these events appear in our Electronics



2 Resolutions in our ADC

1. 13 bits : $2^{13} = 8192$
2. 12 bits : $2^{12} = 4096$

Resolution determines how small an input can be resolved

We want to detect

1. Internal conversion electrons ~ few hundreds keV

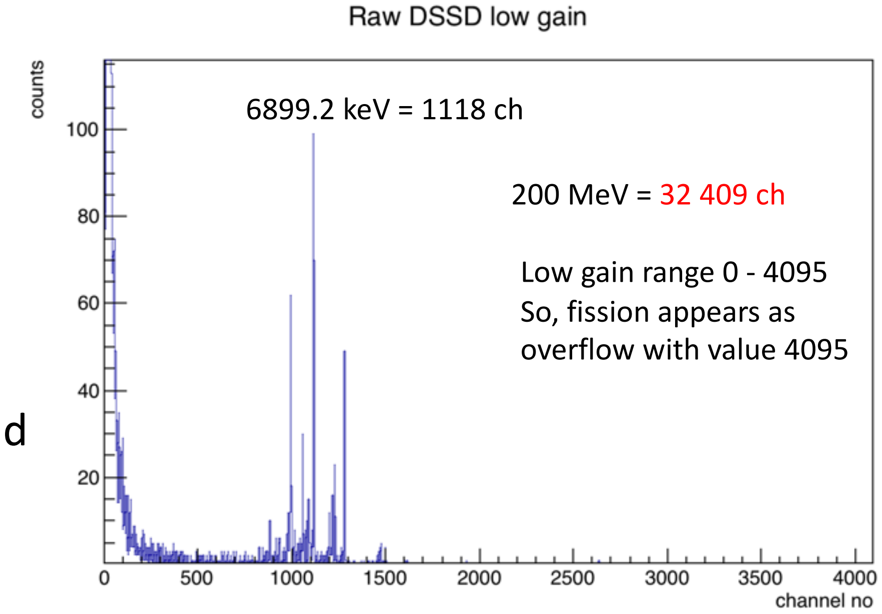
Small signal need more amplification (High Gain) and use 13bits resolution of ADC

2. Alpha ~ 7 – 10 MeV

Need less amplification (Low Gain) and use the remaining 12bits resolution

3. Fission ~ more than 200 MeV

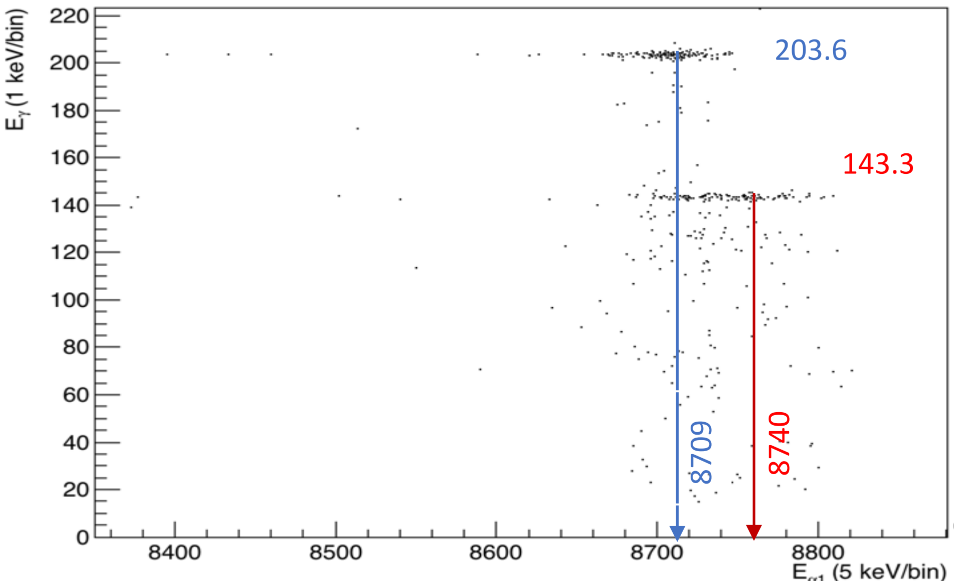
???

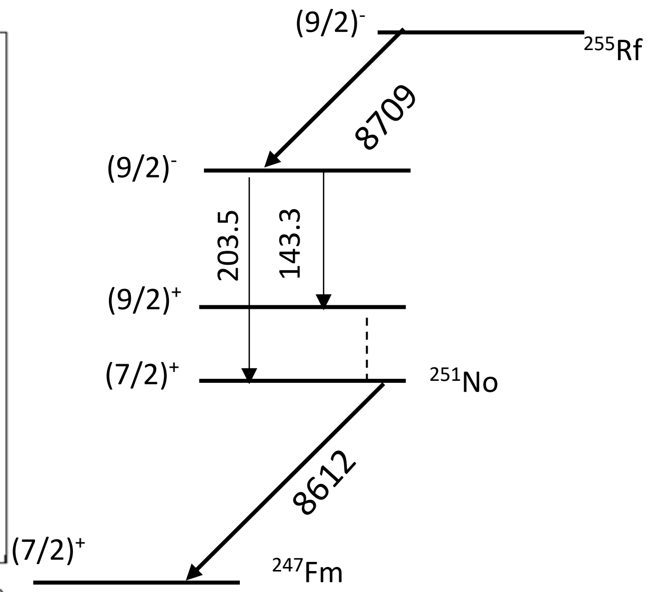


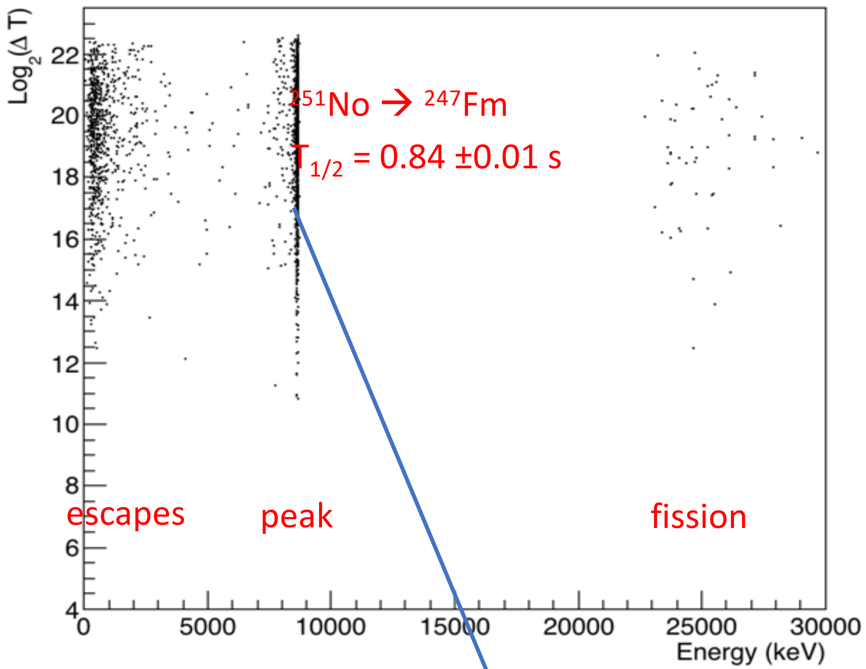
In electron High Gain and alpha Low Gain configuration

Results: ^{251}No

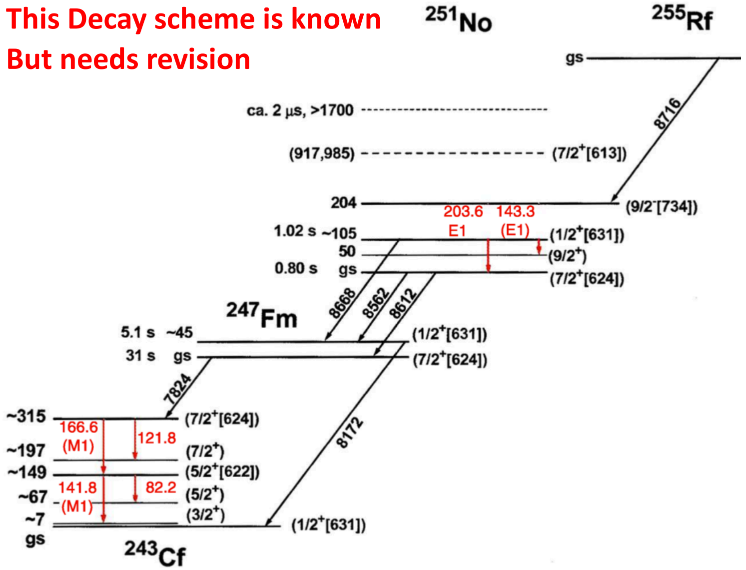
α-γ coincidence matrix







This Decay scheme is known
But needs revision



F.P. Hebberger et al. Eur. Phys. J. A 30, 561-569 (2006)

α-γ coincidence matrix of 247Fm