

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

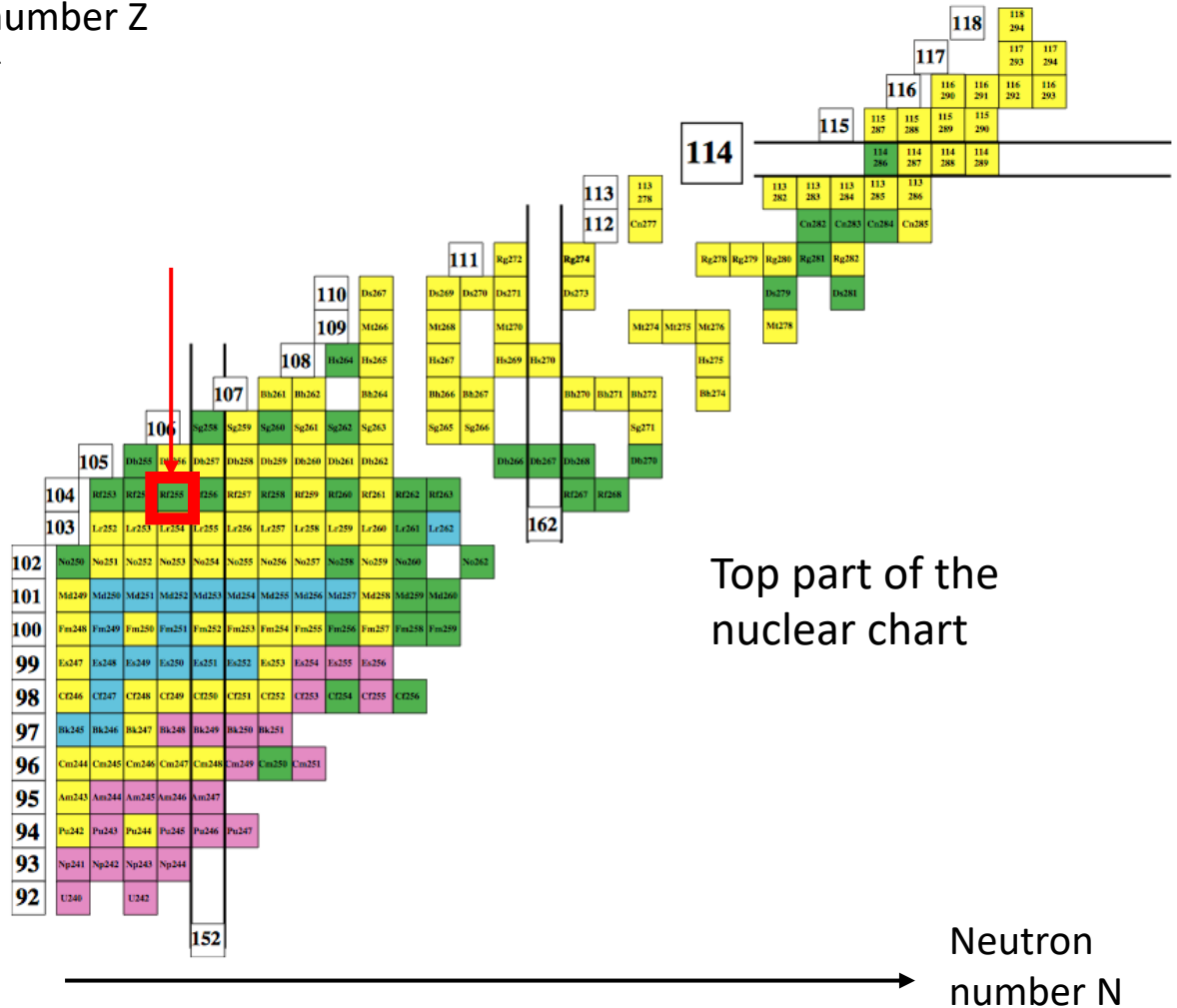
255Rf

PERIODIC TABLE OF ELEMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.008	2 He Helium 4.0026																
3 Li Lithium 6.94	4 Be Beryllium 9.0122																
11 Na Sodium 22.990	12 Mg Magnesium 24.305																
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29
55 Cs Caesium 132.91	56 Ba Barium 137.33	57-71 Lanthanoids (Lanthanides)	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89-103 Actinoids (Actinides)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flerovium (289)	115 Mc Moscovium (289)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

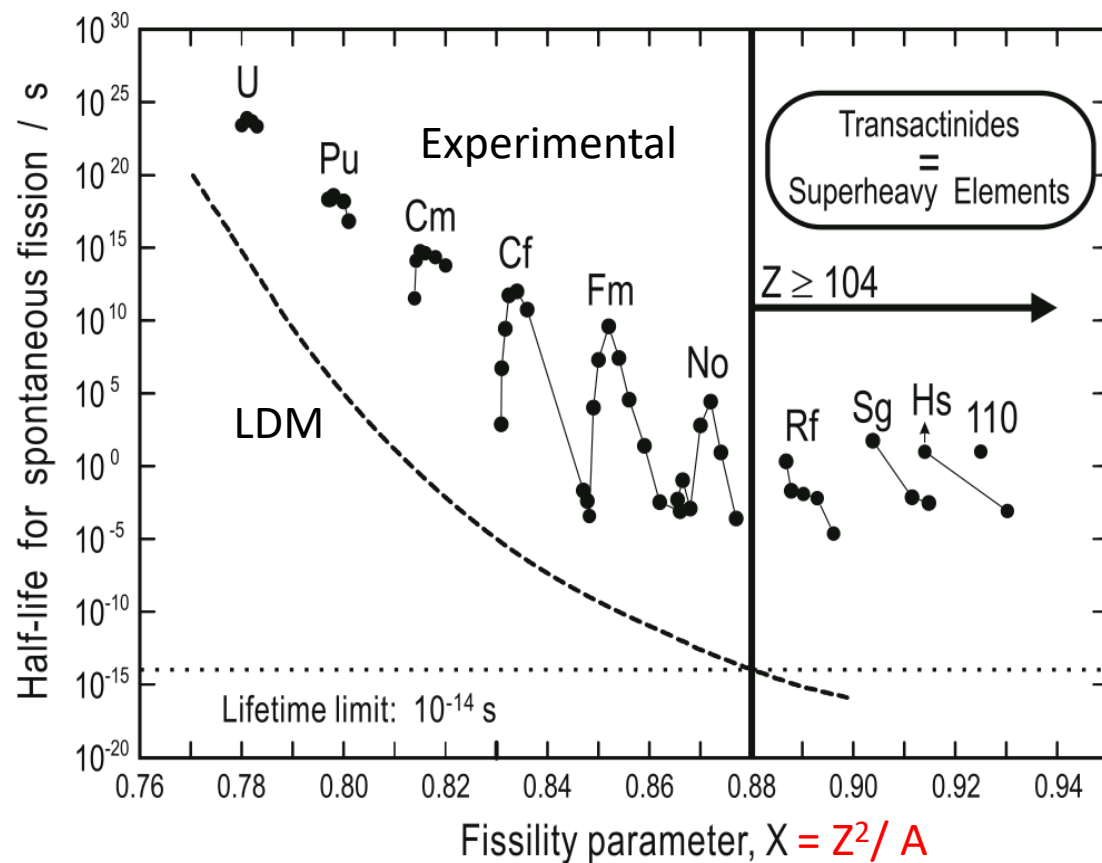
Proton number Z



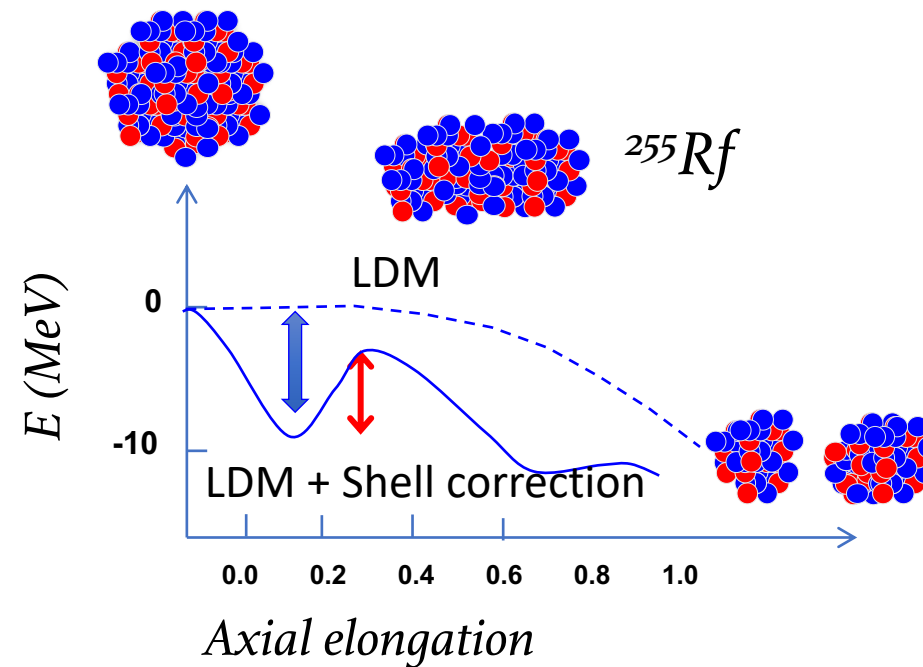
Rf is the first transactinide element

Rf is a superheavy nucleus

Superheavy: ^{255}Rf



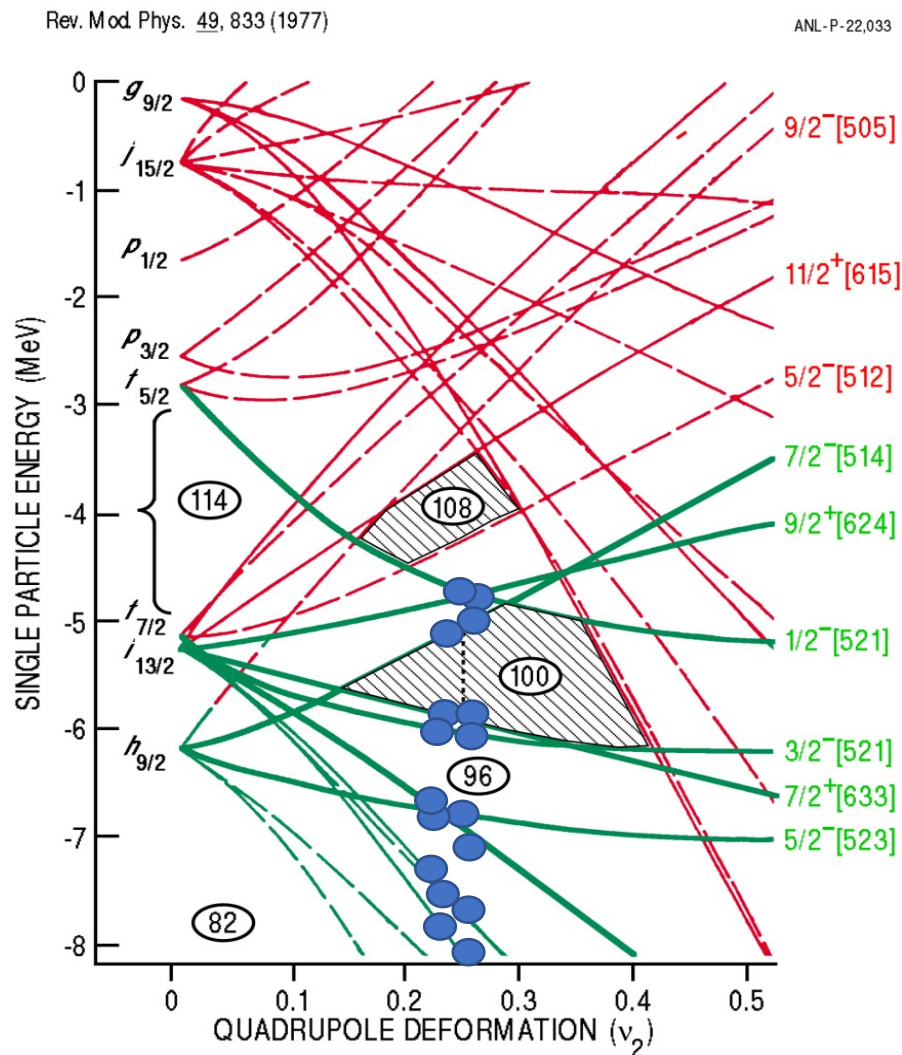
Minimum time required for hydrogen molecule to form



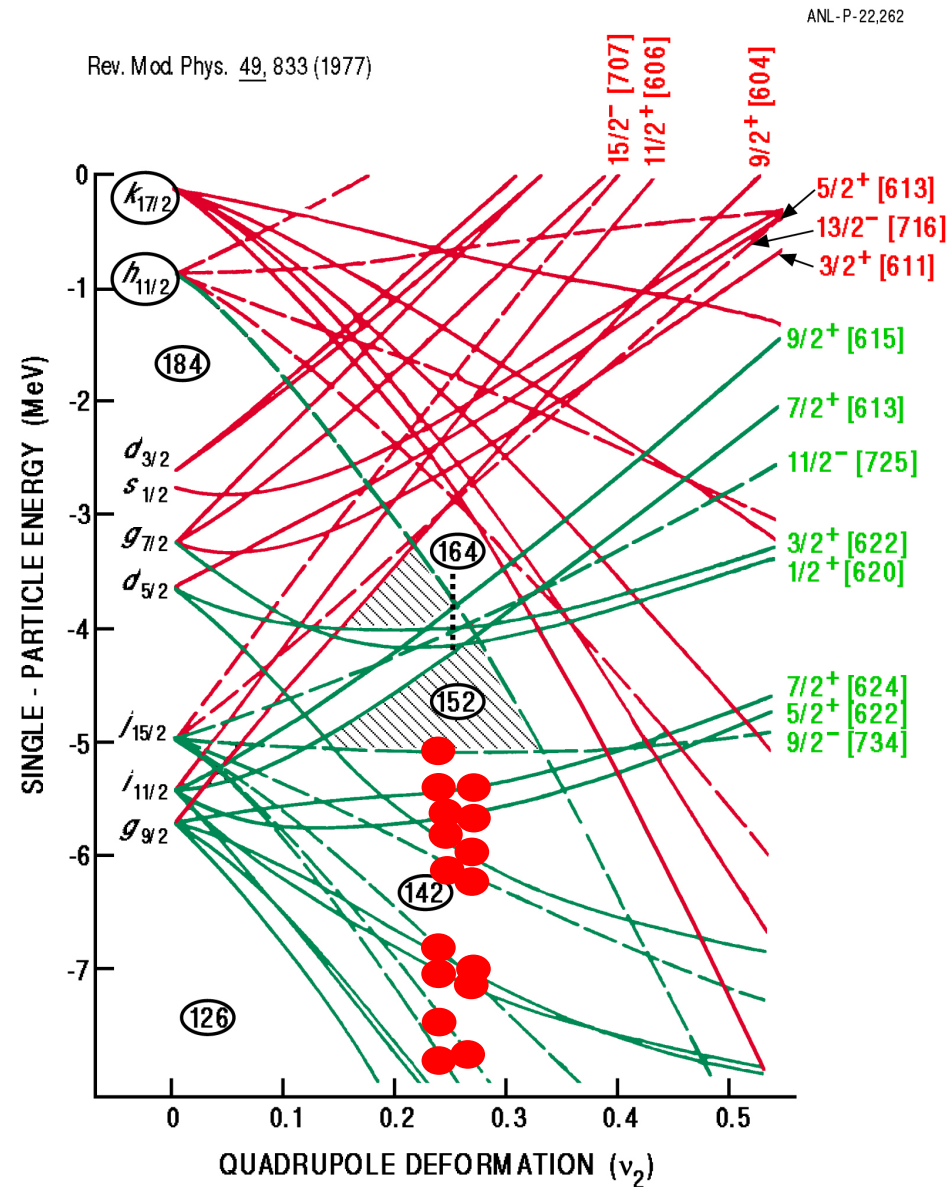
$$B_f = E_{\text{saddle}} - E_{\text{gs}}$$

Predicted shell structure around $N \sim 152$ and $Z \sim 100$

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



proton

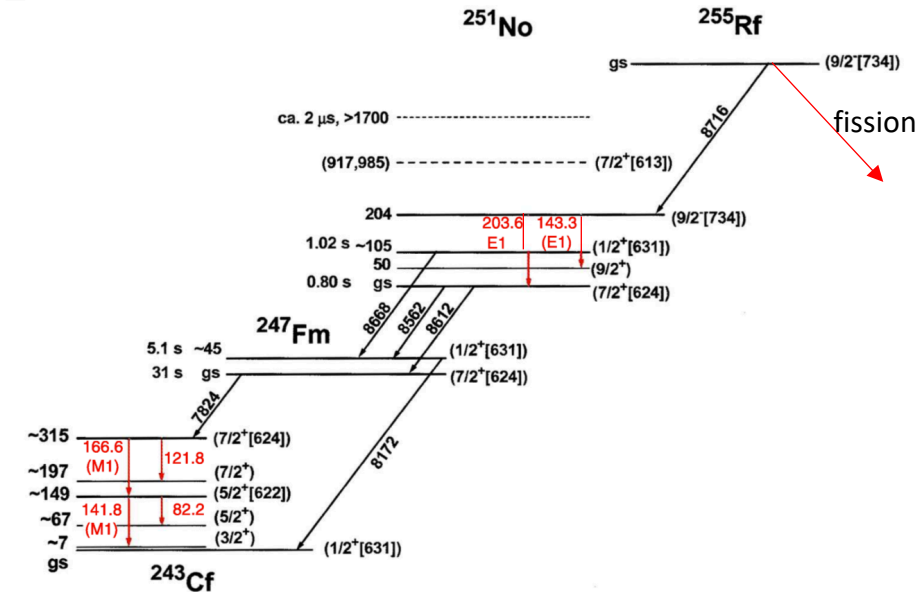
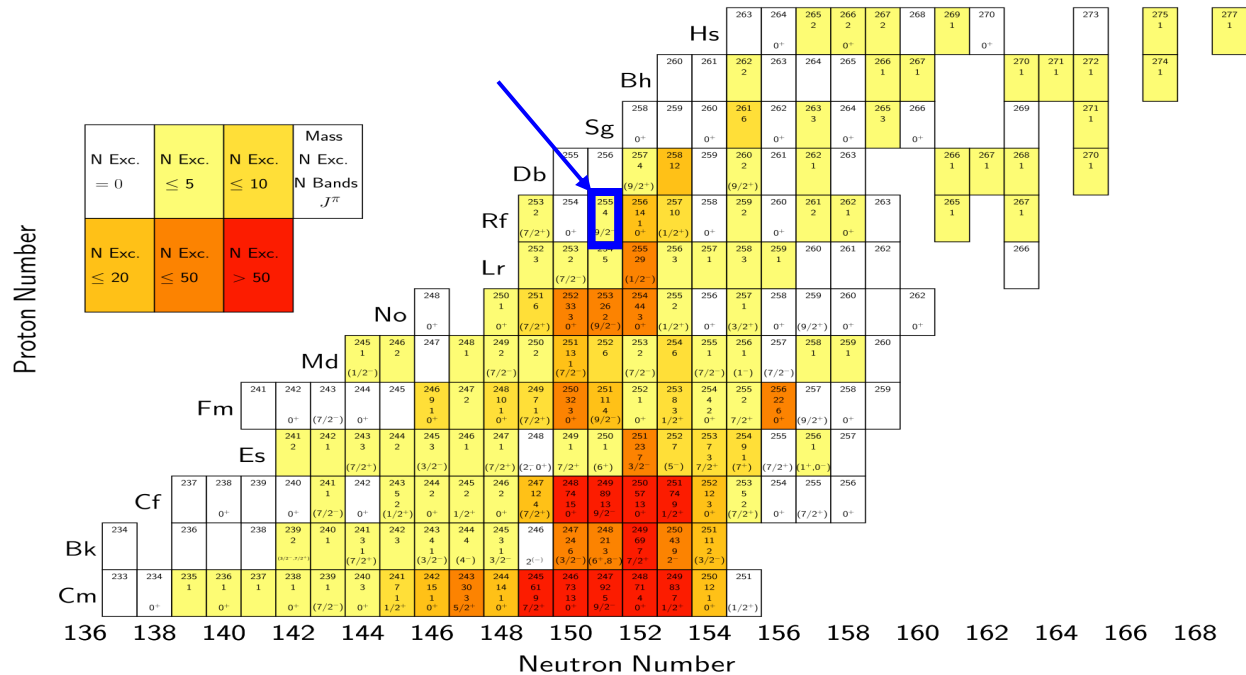


neutron

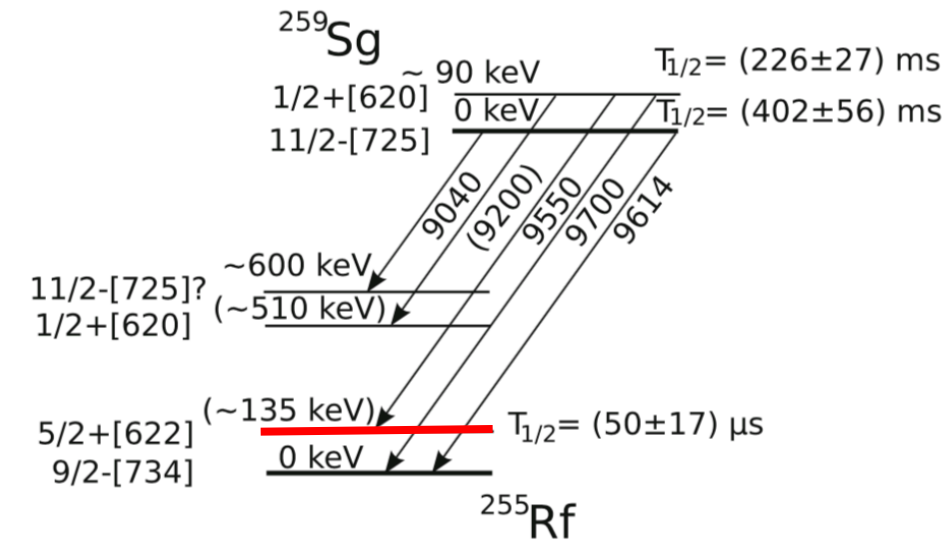
What is known about ^{255}Rf ?

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

Available spectroscopic data

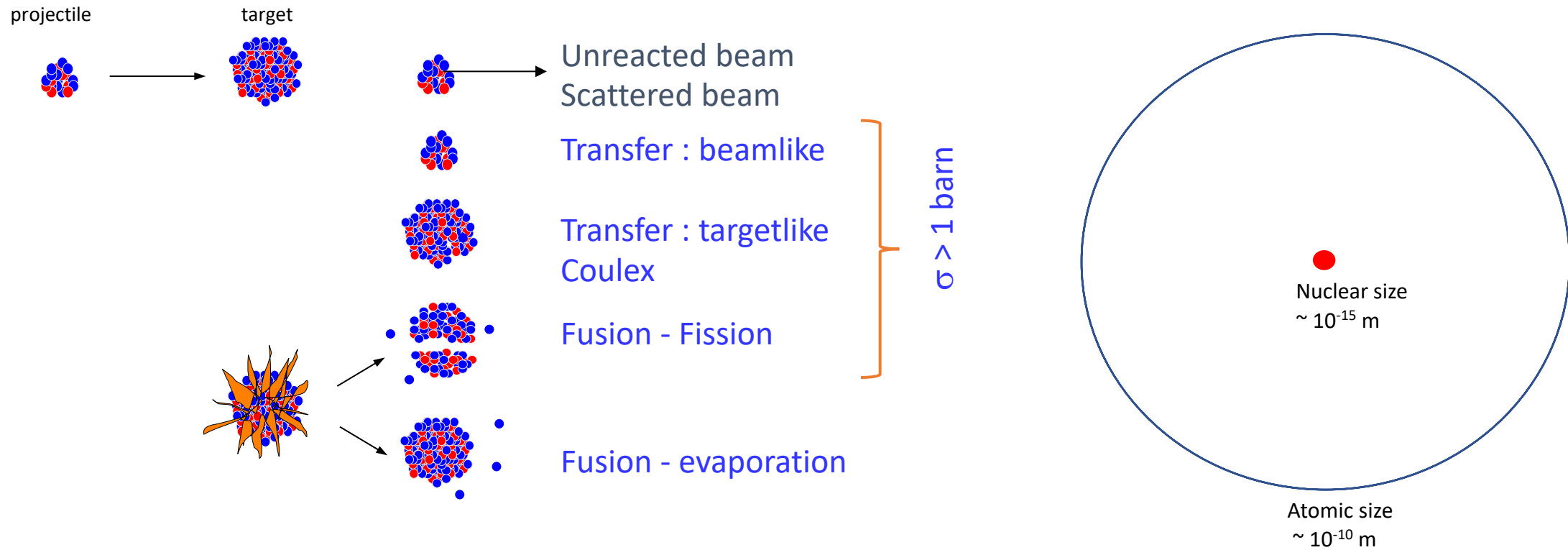


F.P. Heberger et al. Eur. Phys. J. A 30, 561-569 (2006)



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

Production : fusion-evaporation reaction



Survival of nucleus of interest : $\sigma \sim 10 \text{ nb}$



1 out of $\sim 10^{11}$ beam particles leads to a reaction of interest

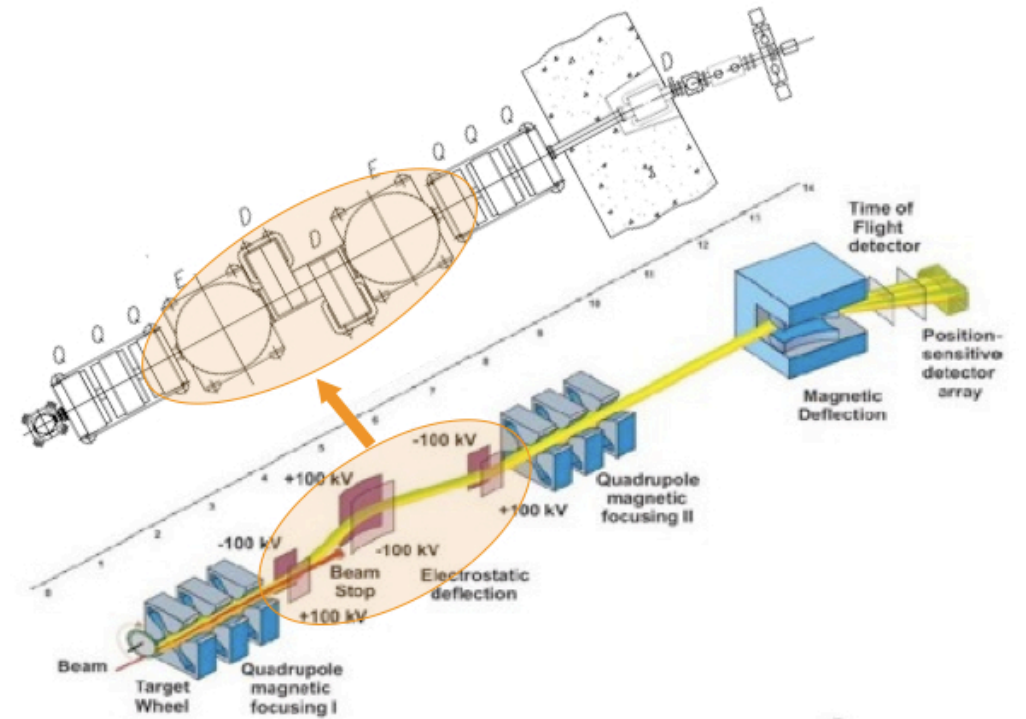
⇒ Need to select the needle in the hay stack !

VASSILISSA (Energy filter)

→ SHELS (velocity filter)

Gain in transmission, especially for asymmetric reactions

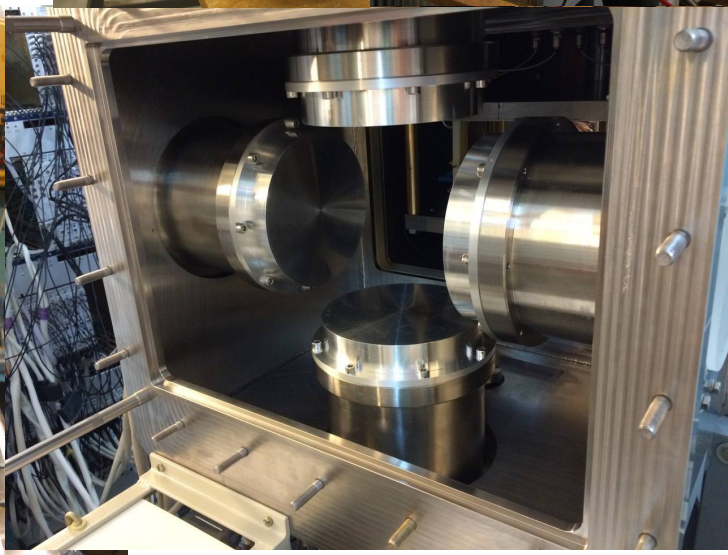
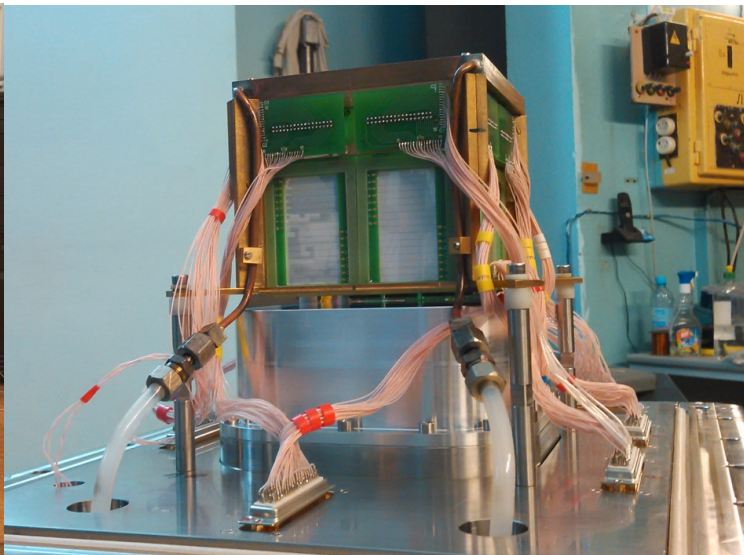
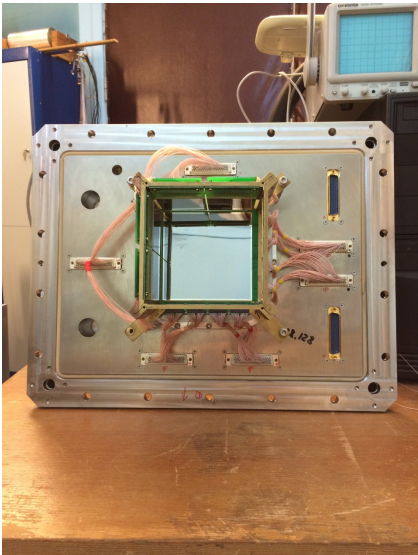
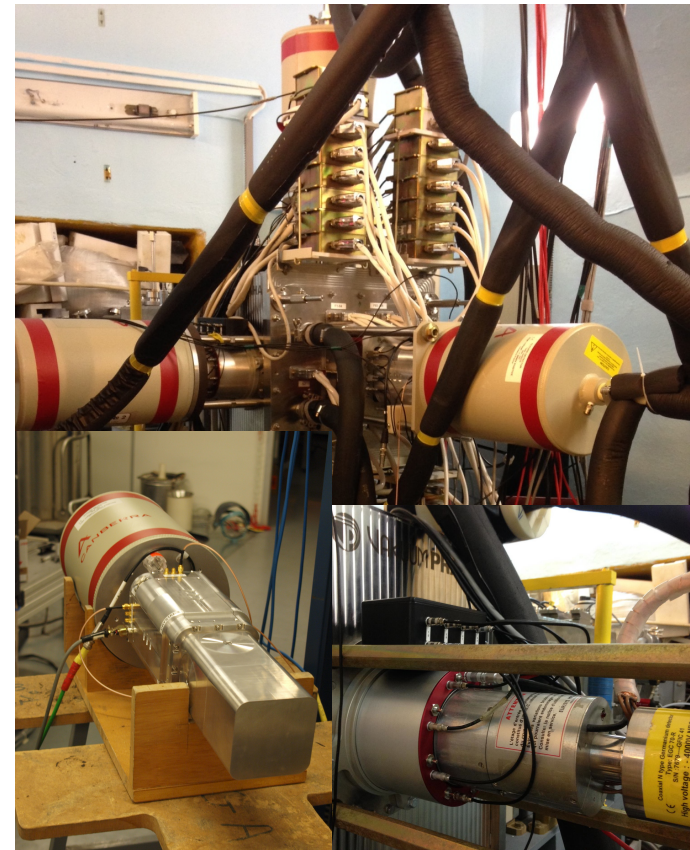
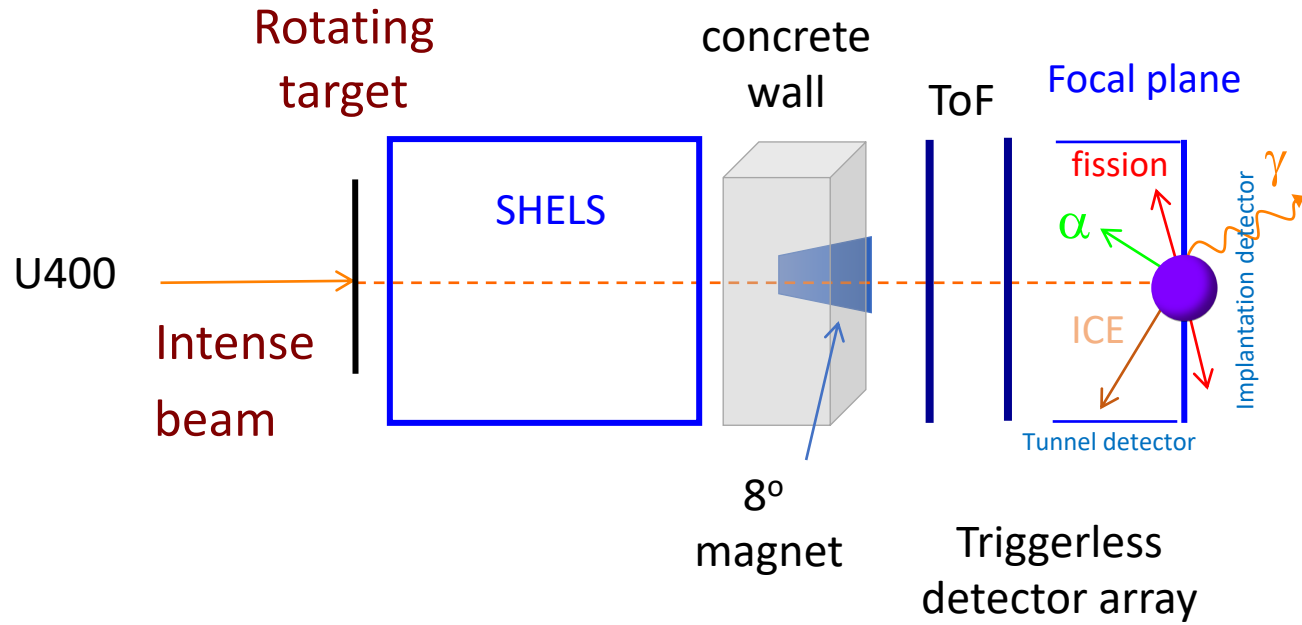
A. Popeko et al., Nucl. Instr. Meth. B 376 (2016) 140



ANR-SHELS (2006-2010) & Russian Foundation for Basic Research

GABRIELA@SHELS

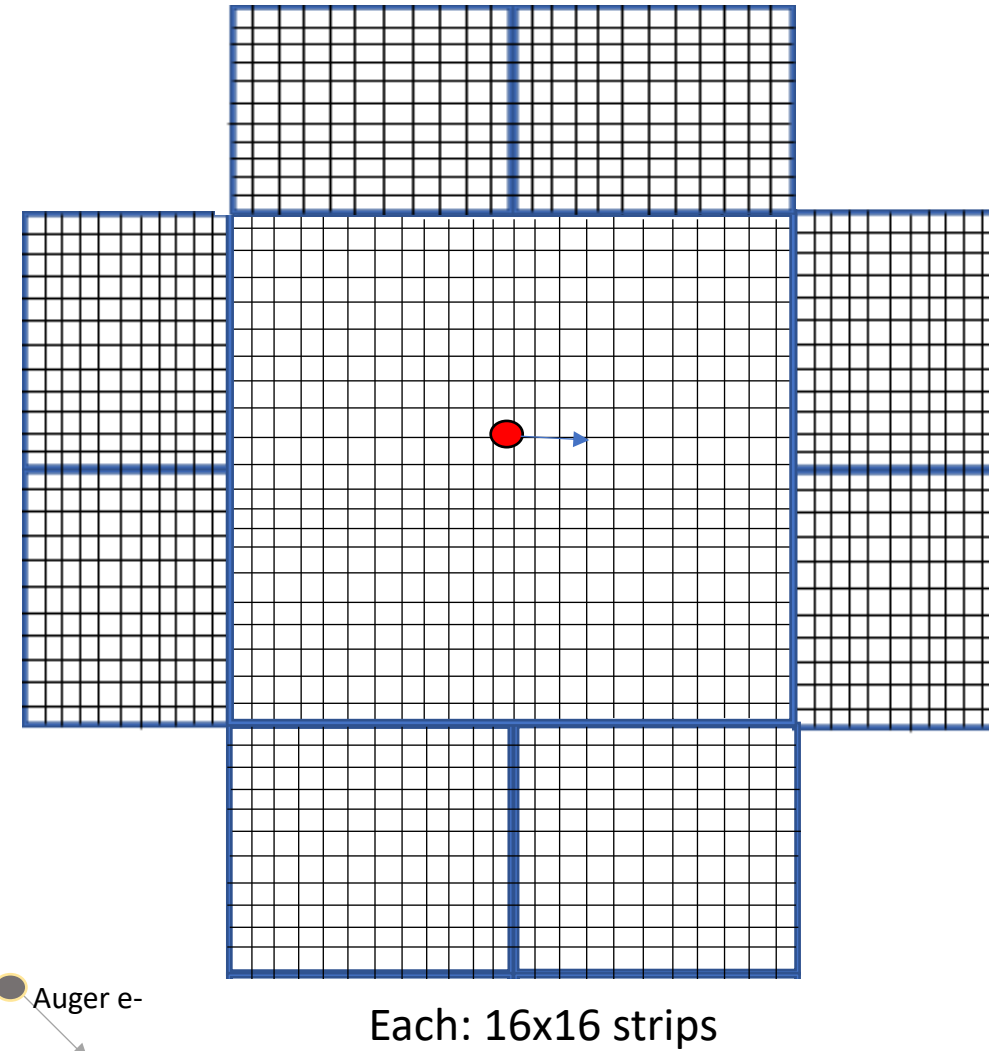
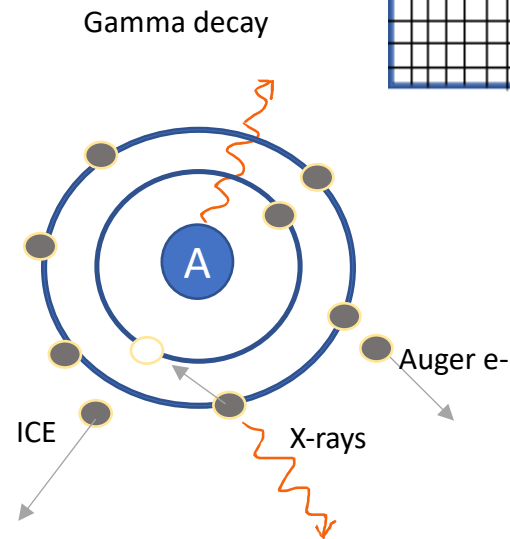
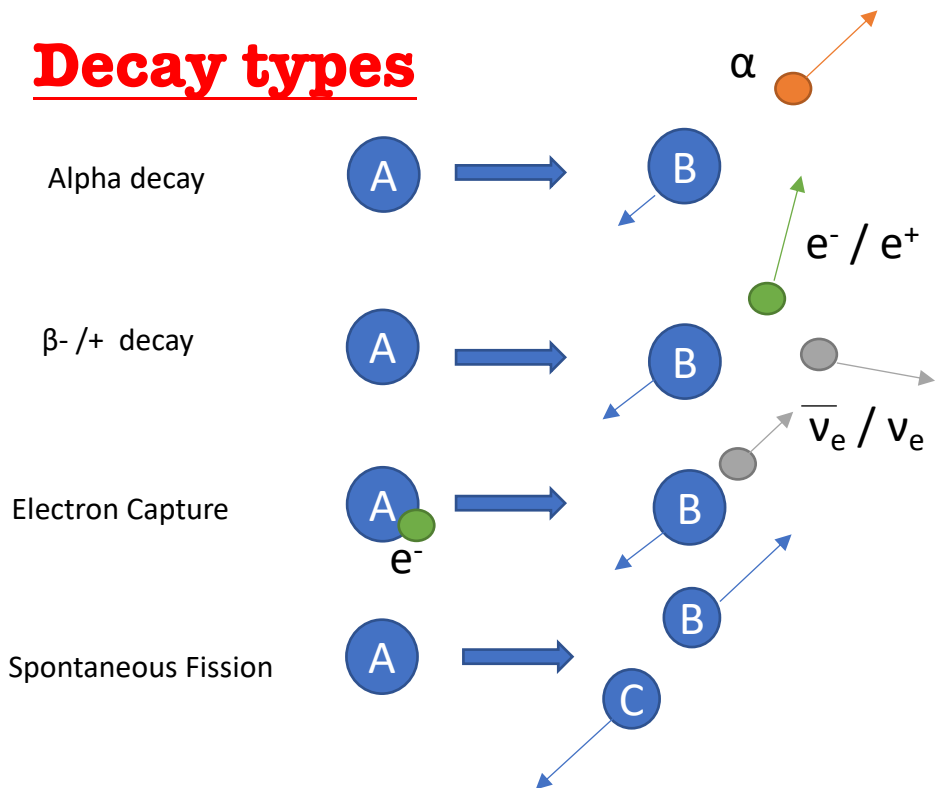
ANR-CLODETTE (2013-2017) & RFBR



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.

Decay types



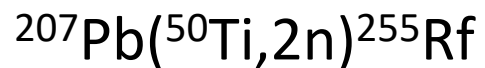
Experiment

Calibration: (Source and In beam)

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

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

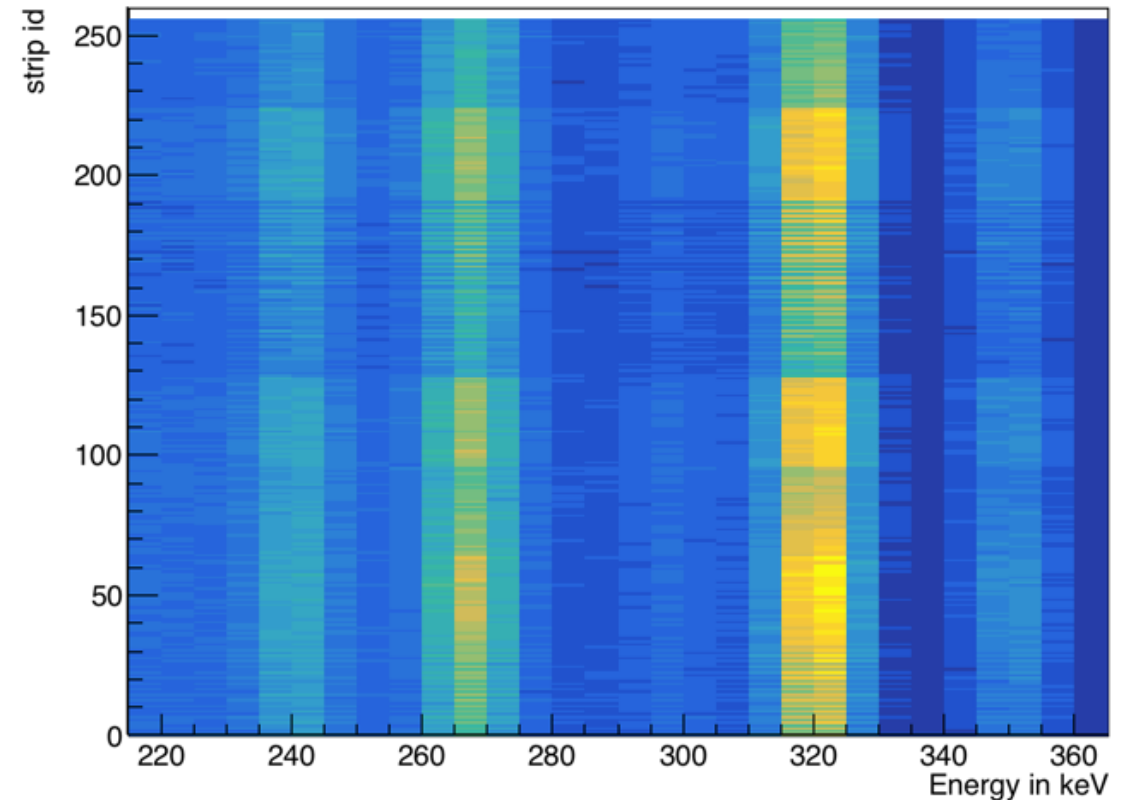
Main Reaction



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

Beam energy $\simeq 250$ MeV, intensity $\simeq 8.5$ e μ A == ~ 400 pA

DSSD electron calibration with ^{133}Ba Oct Run



Methodology: Position and time correlation



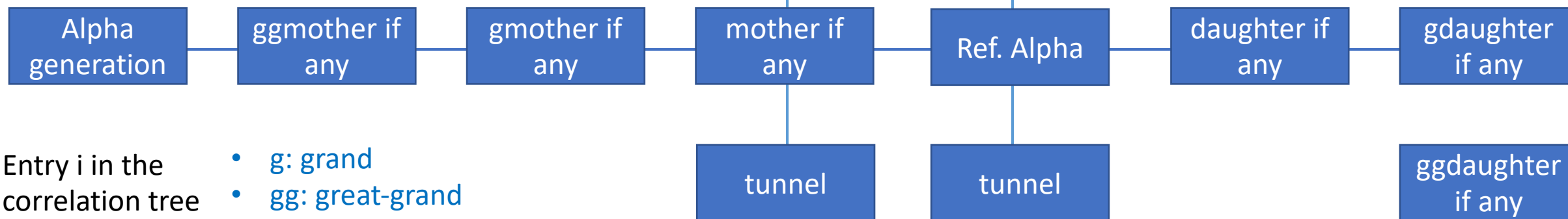
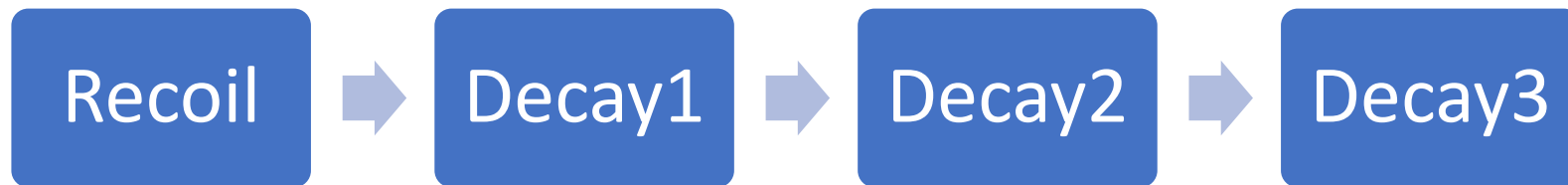
Genetic correlation in every pixel of the DSSD

Range in Silicon

alpha (8 MeV) $\sim 48 \mu\text{m}$

fission fragment (120 MeV) $\sim 18 \mu\text{m}$

Pixel size $760 \times 760 \mu\text{m}^2$

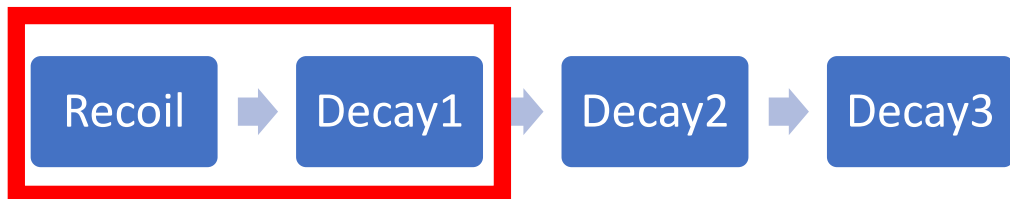


Entry i in the correlation tree

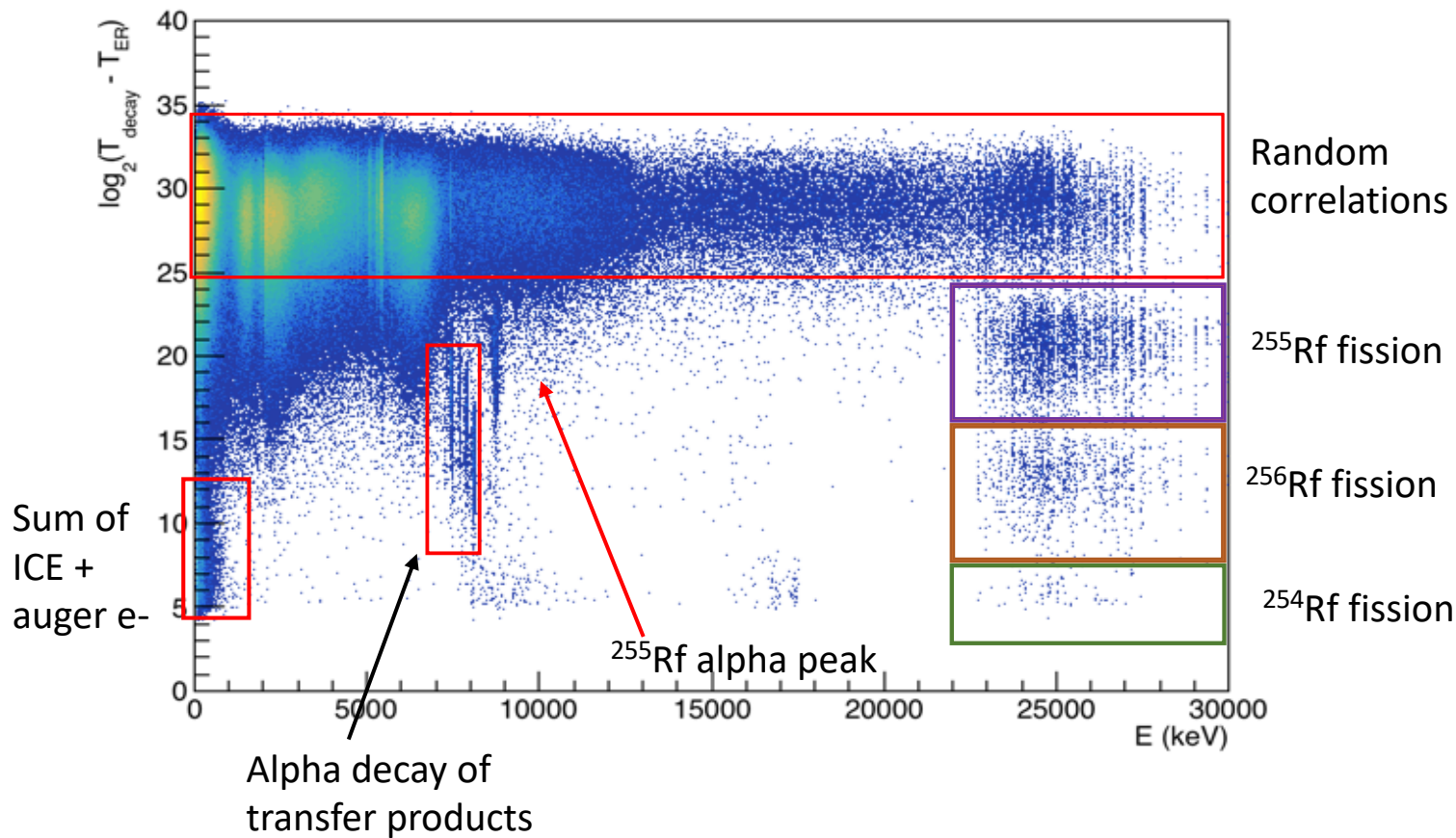
- g : grand
- gg : great-grand

Look forward and backward in time

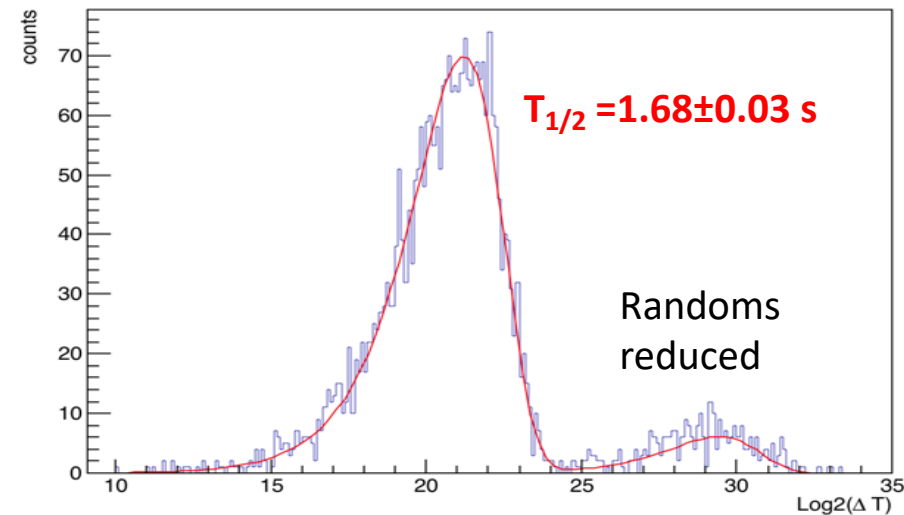
What do we see in the data



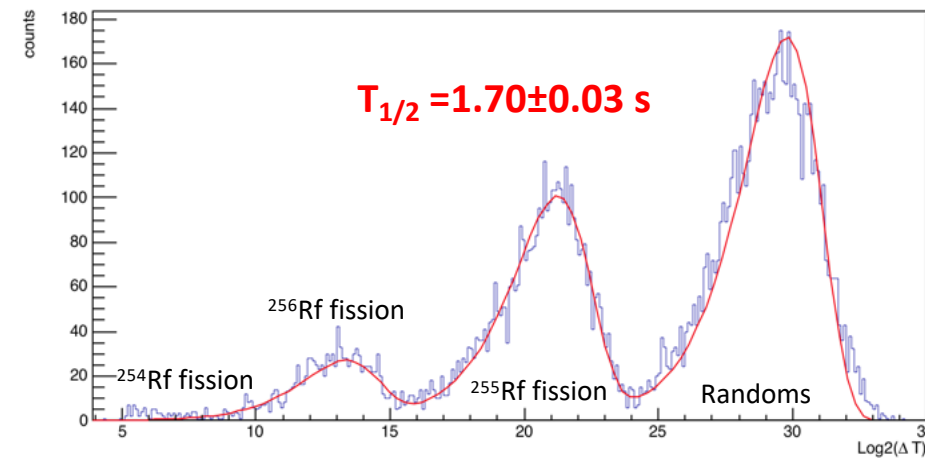
recoil decay correlation



Lifetime fit of alpha decay channel

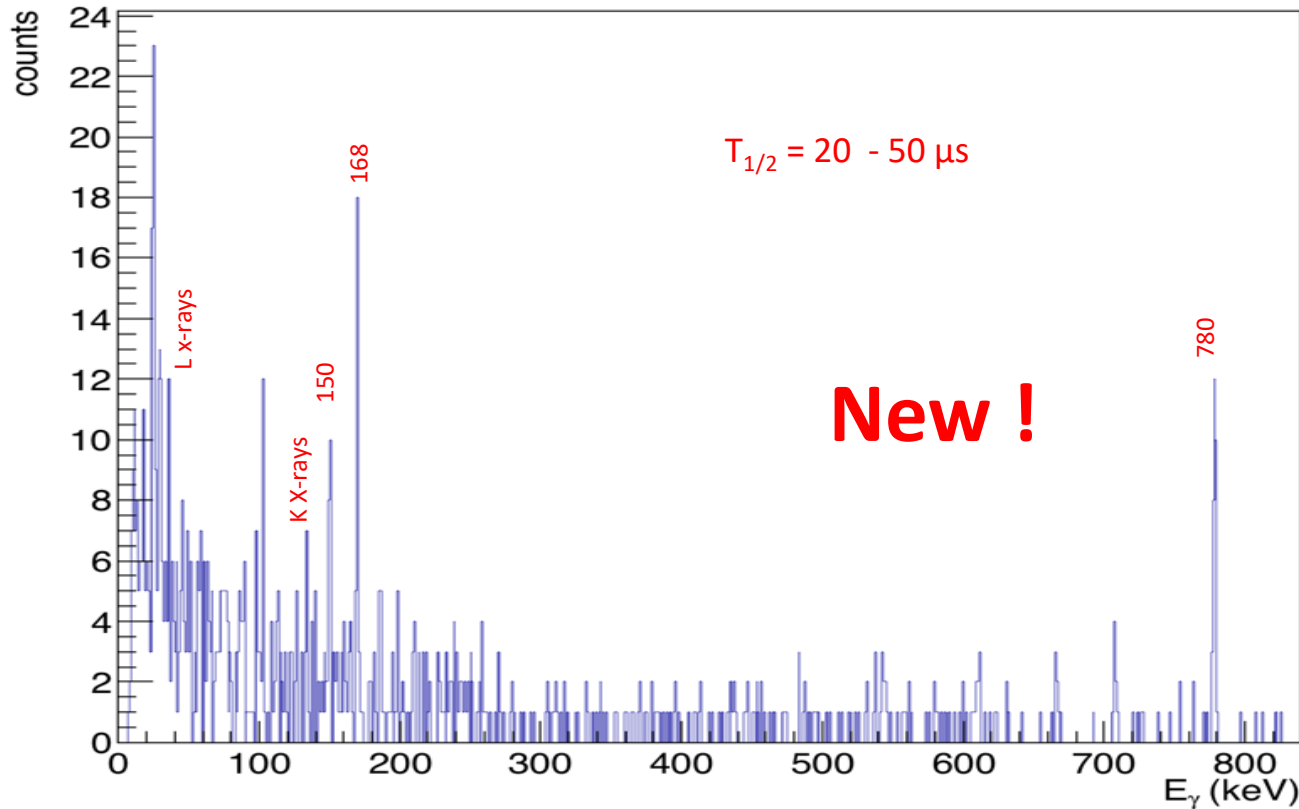


Lifetime fit of fission decay channel



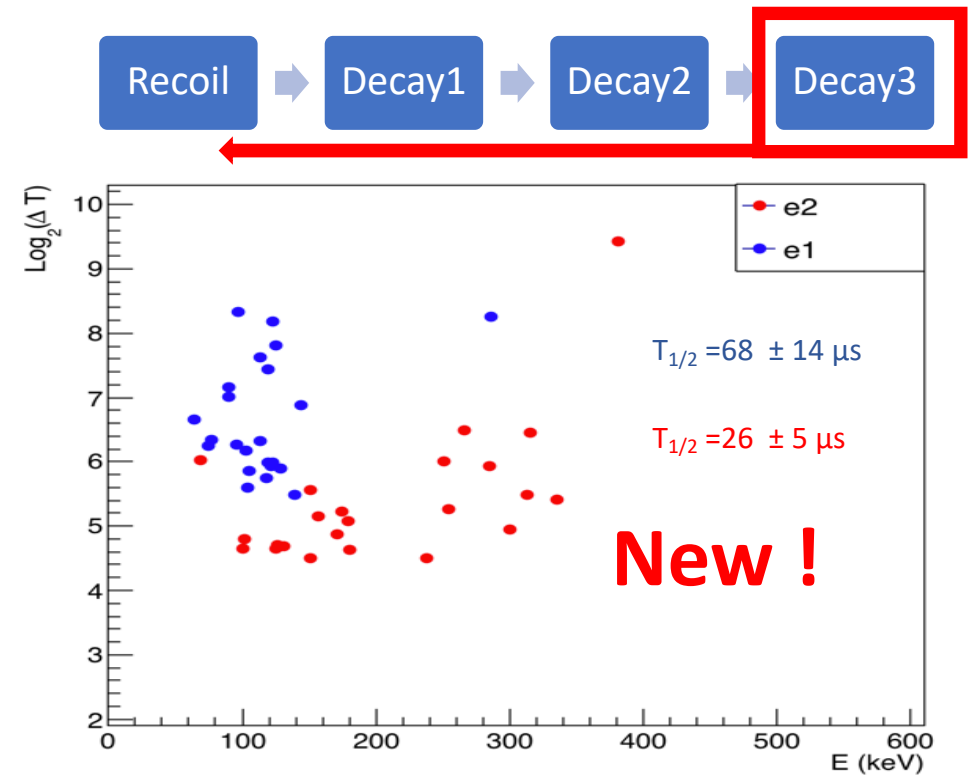
Total number of ^{255}Rf produced ≈ 7560 in 2 Runs

Results: ^{255}Rf

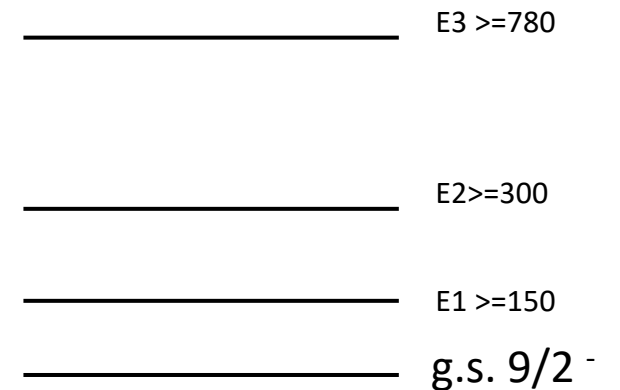


Ongoing work: (Trying to figure out the decay scheme)

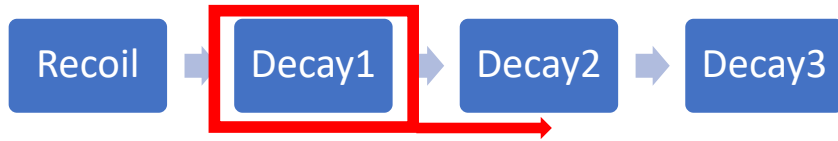
1. Gamma-gamma coincidences
2. Gamma-ICE correlations
3. electromagnetic nature of transitions from conversion electrons & intensity of K-X rays observed



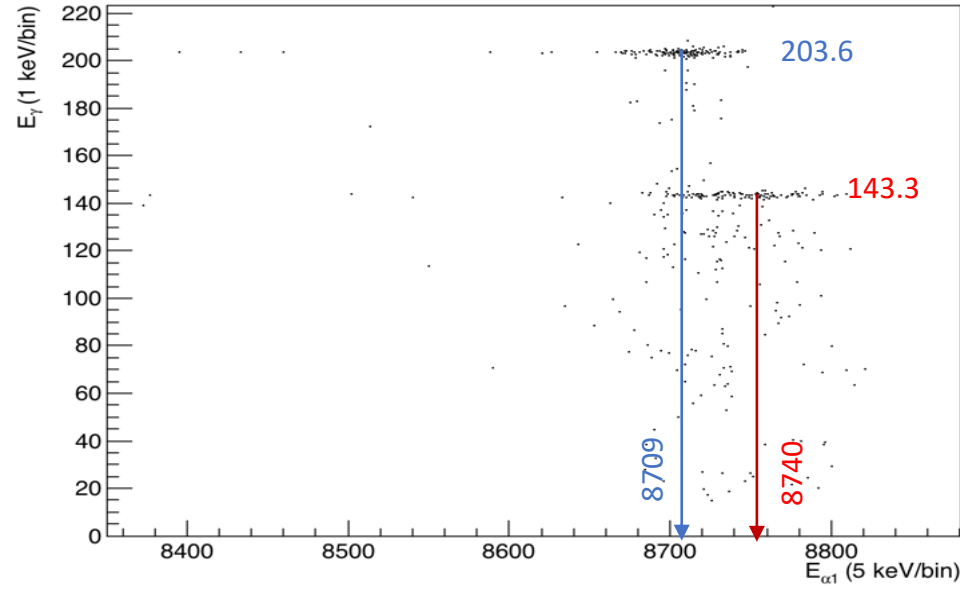
2 (and maybe 3?) isomers



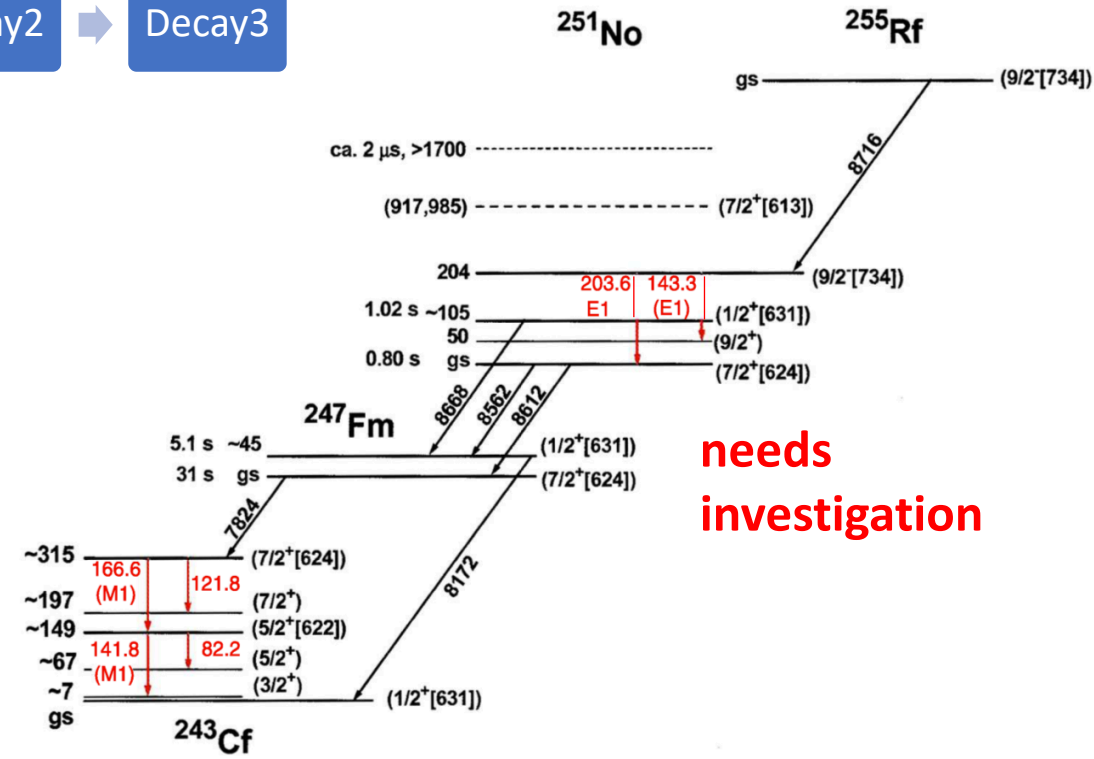
Results: ^{251}No



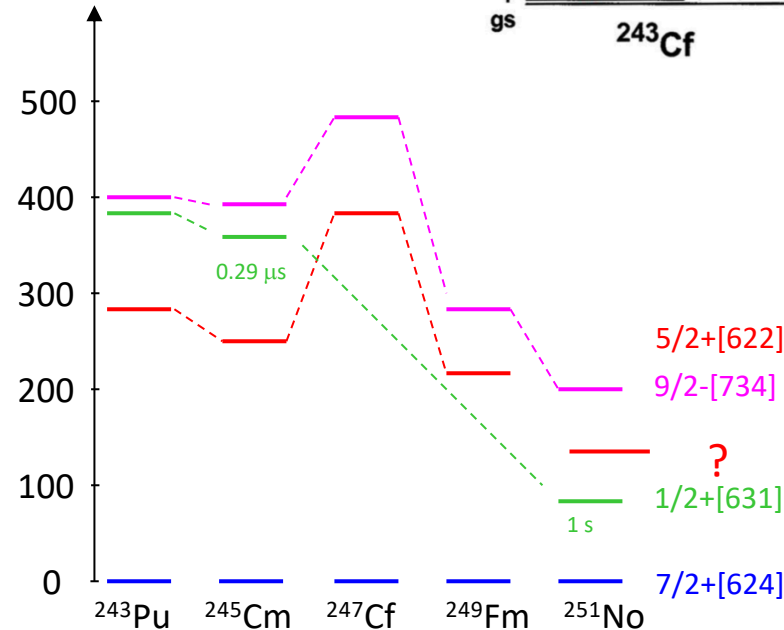
α - γ coincidence matrix



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



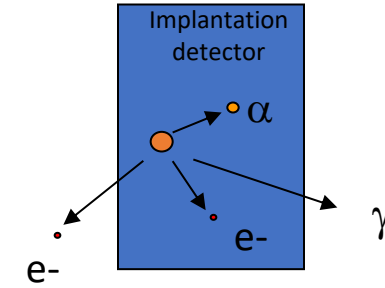
needs investigation



N=149

Geant4 Simulation: Why?

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



Current limitation of Geant4:
Auger electrons

No atomic deexcitation for element $Z > 100$ i.e. no ICE, no Fluorescence and no

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 ^{255}Rf (and in particular the isomers)

Remarks:

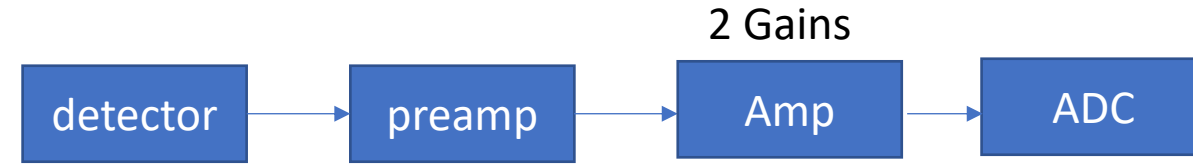
1. Could not participate in my thesis Experiment
2. **But**, participated in other similar experiments such as in the production of $^{256}, ^{257}\text{Rf}$,
 $^{250}, ^{252}, ^{254}, ^{256}\text{No}$
1. On the R&D side I participated once in preamplifier tests and will get more involved in the future

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

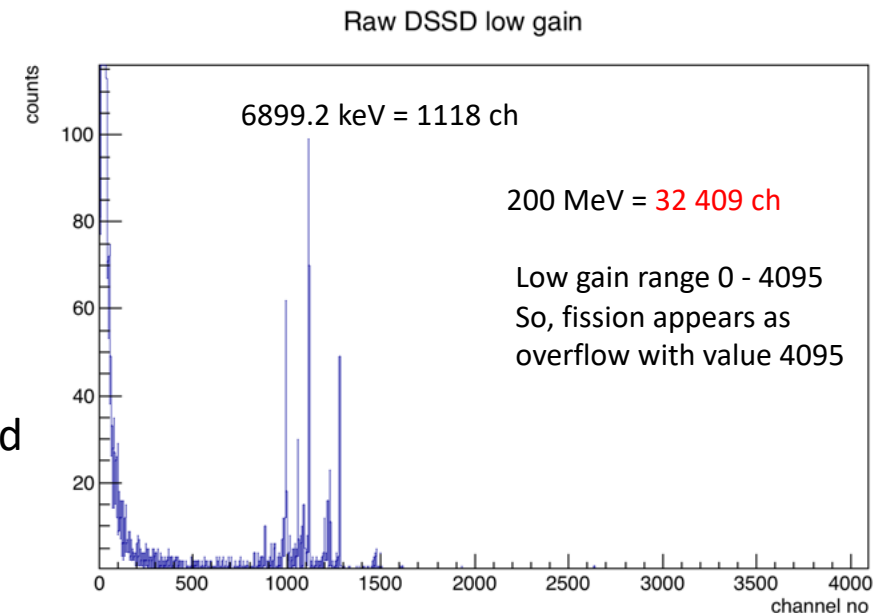
2. Alpha ~ 7 – 10 MeV

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

3. Fission ~ more than 200 MeV

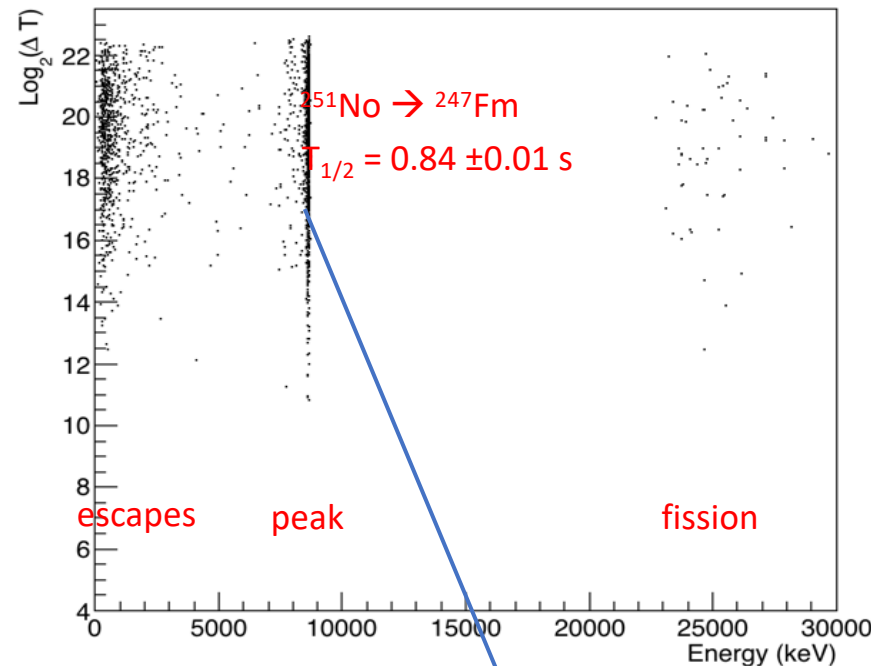
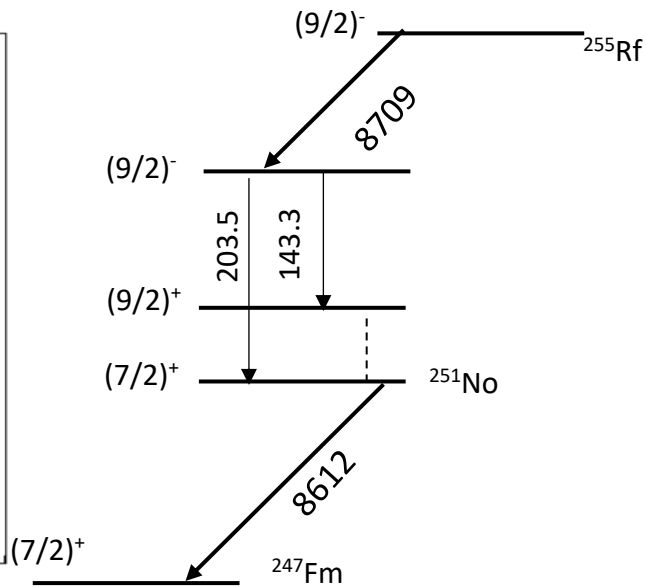
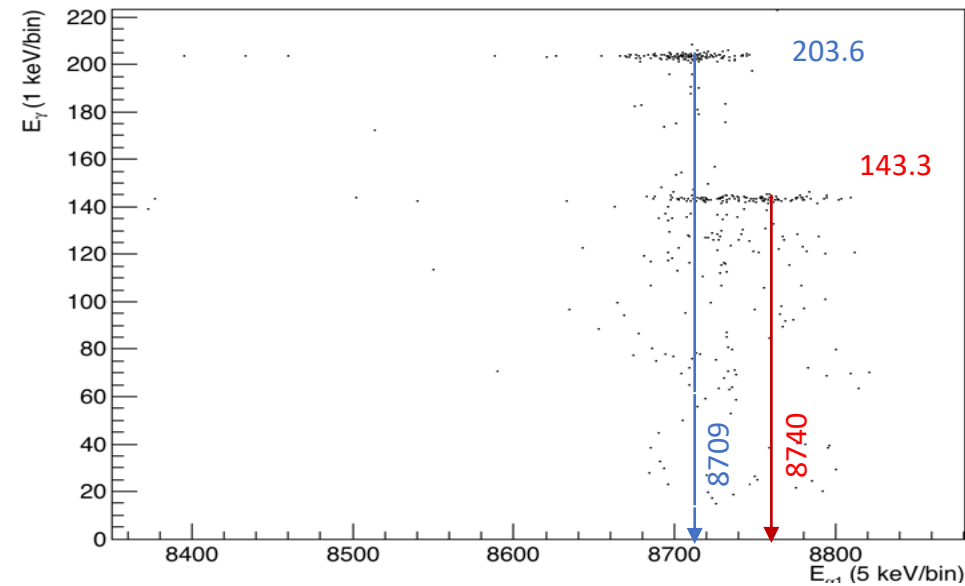
???

In electron High Gain and alpha Low Gain configuration

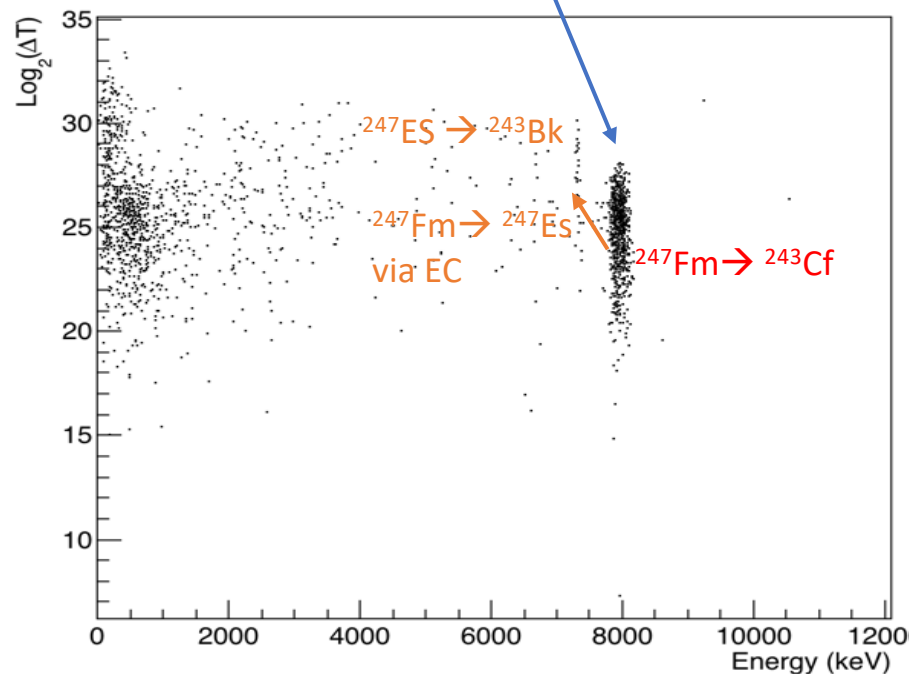
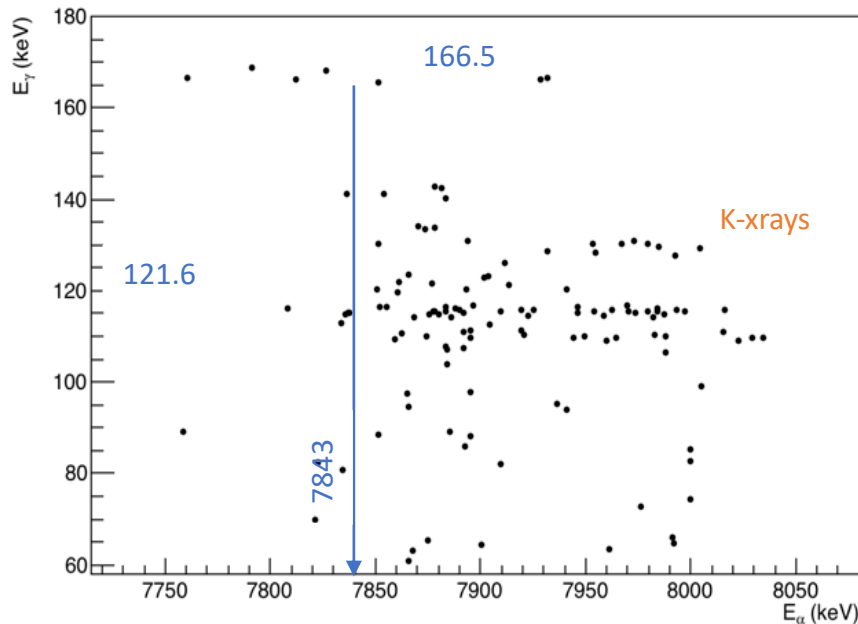


Results: ^{251}No

α - γ coincidence matrix



α - γ coincidence matrix of ^{247}Fm



**This Decay scheme is known
But needs revision**

