Evidence of Isomers in ^{255}No and ^{256}No

@ Dubna

Kieran Kessaci

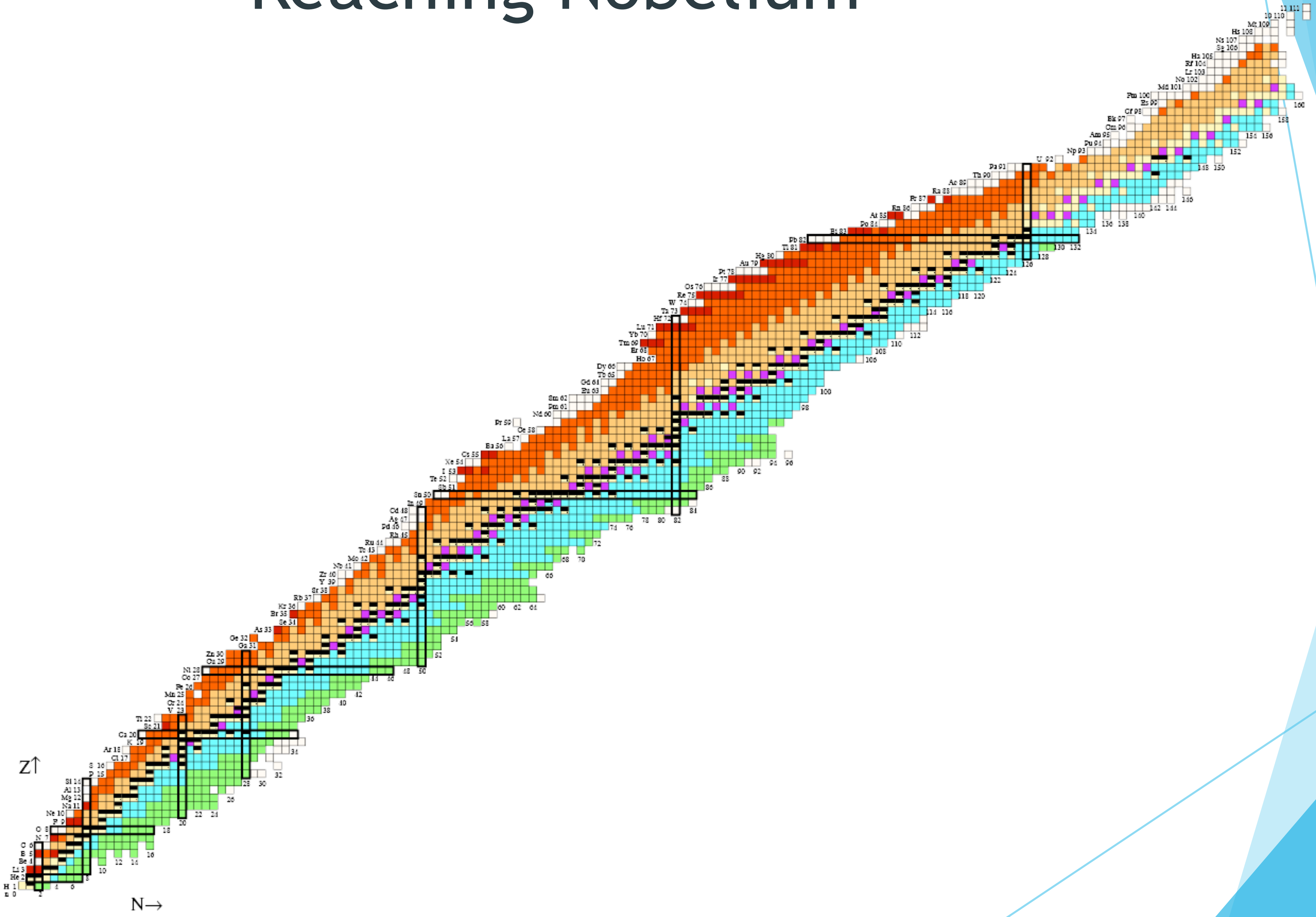
I. Scientific Context

II. Setup

III. Experiment : $^{22}Ne + ^{238}U \longrightarrow ^{260-x}No + xn$

IV. Preliminary Results

Reaching Nobelium



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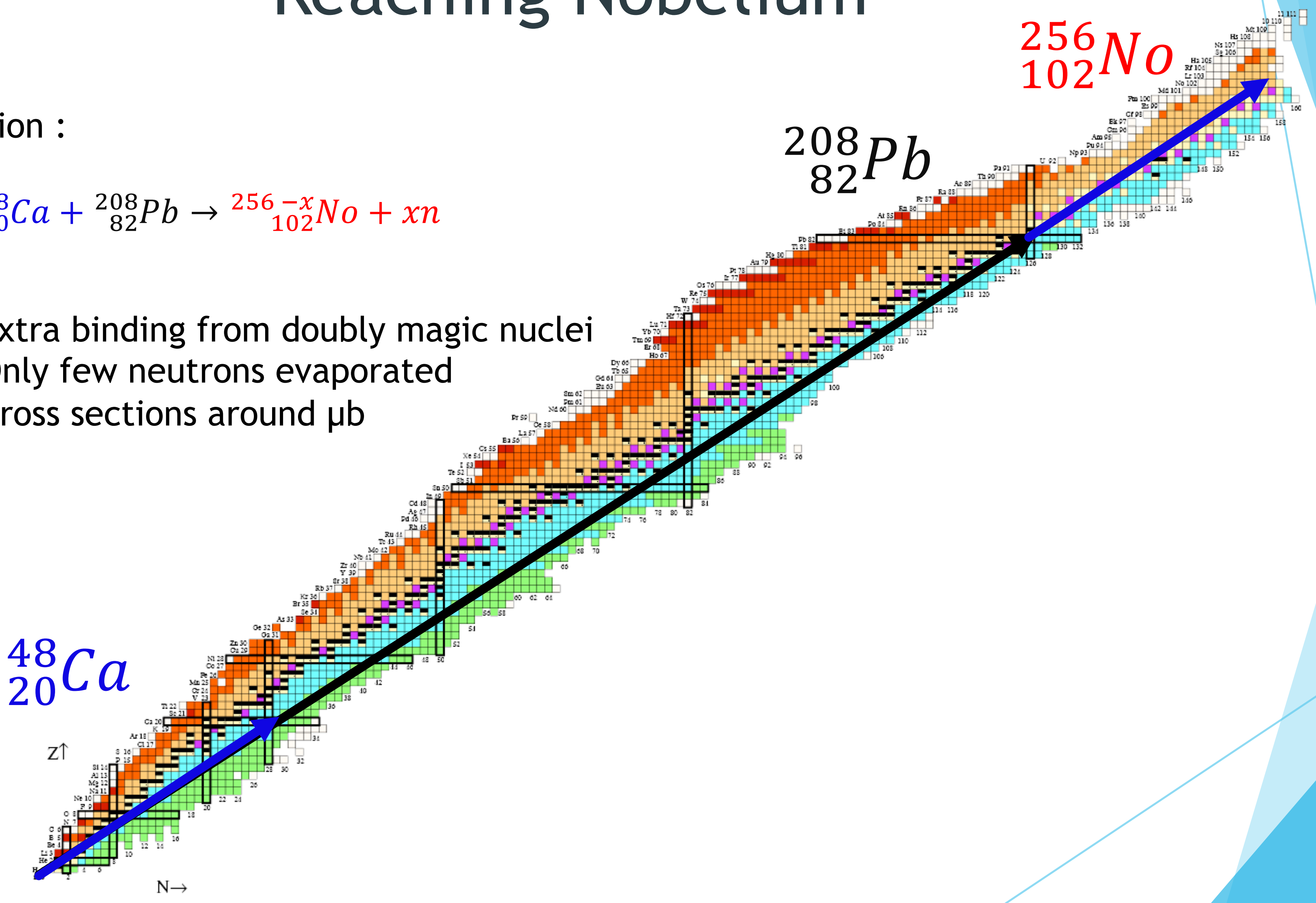
Reaching Nobelium

Cold Fusion :

- ${}^{48}_{20}Ca + {}^{208}_{82}Pb \rightarrow {}^{256-x}_{102}No + xn$

- Extra binding from doubly magic nuclei
- Only few neutrons evaporated
- Cross sections around µb



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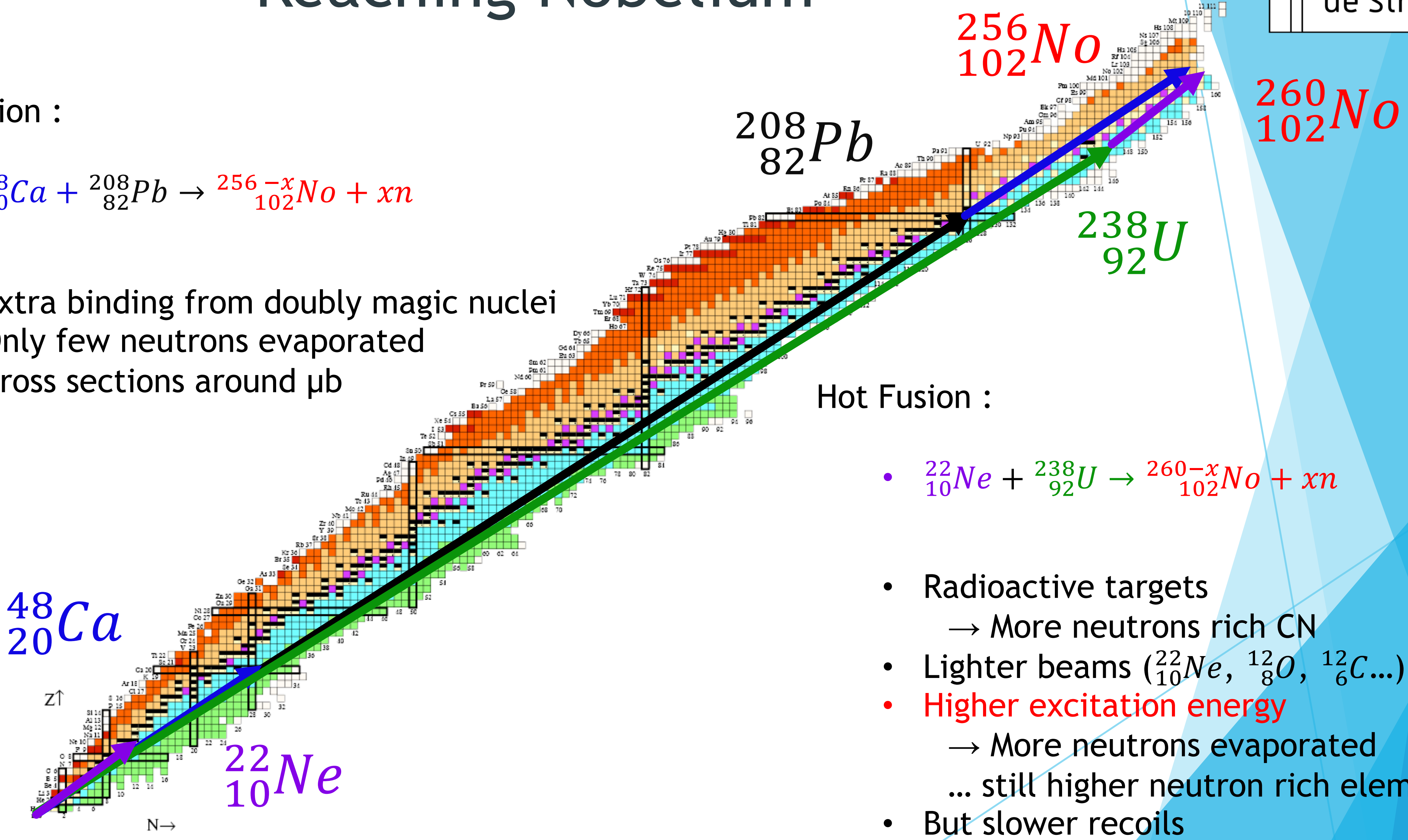


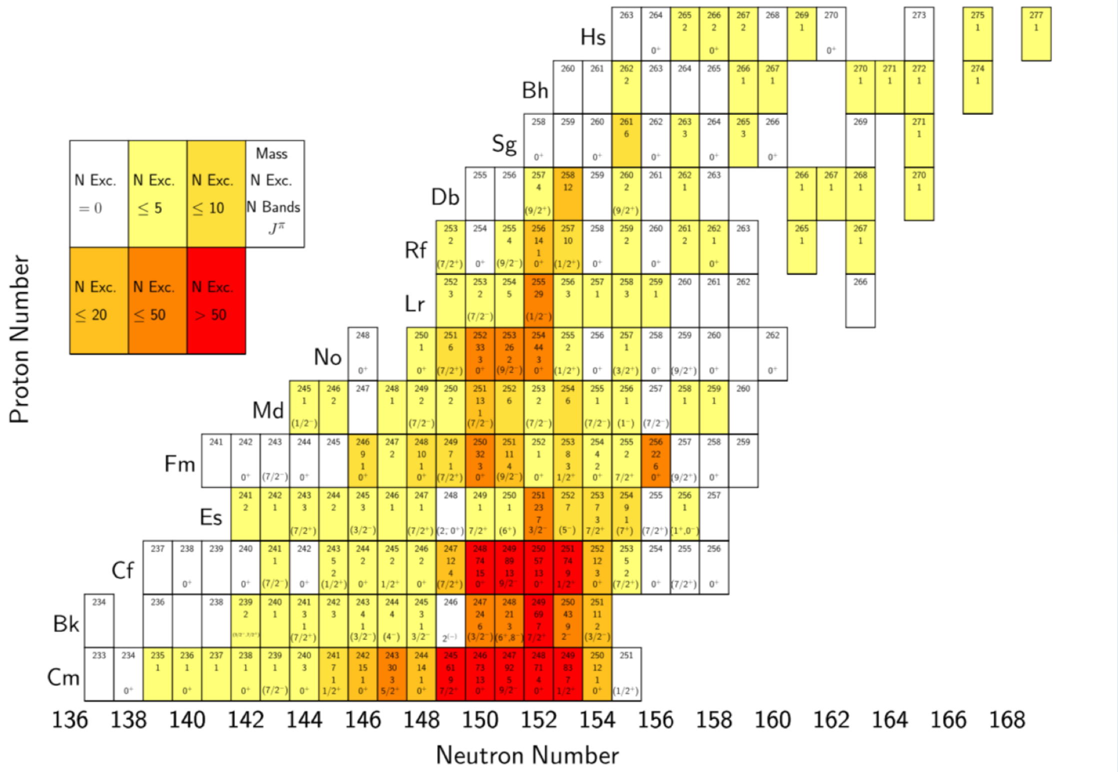
Hot Fusion :

- ${}^{22}_{10}Ne + {}^{238}_{92}U \rightarrow {}^{260-x}_{102}No + xn$

- Radioactive targets
  → More neutrons rich CN
- Lighter beams (${}^{22}_{10}Ne$, ${}^{12}_{8}O$, ${}^{12}_{6}C$…)
- Higher excitation energy
  → More neutrons evaporated
  … still higher neutron rich elements
- But slower recoils

Spectroscopy Around ^{254}No

- The region around $^{254}_{102}No$ was widely studied by cold fusion
  - $^{48}_{20}Ca + ^{208}_{82}Pb \rightarrow ^{254}_{102}No + 2n$
  - $^{50}_{22}Ti + ^{208}_{82}Pb \rightarrow ^{256}_{104}Rf + 2n$
  - $^{51}_{23}V + ^{208}_{82}Pb \rightarrow ^{258}_{102}Db + n$



Ch. Theisen et al. / Nuclear Physics A 944 (2015) 333–375

- Rotational structures and high-K isomers were observed
- $^{256}_{102}No$ can't be produced by cold fusion
- The first $^{22}_{10}Ne + ^{238}_{92}U \rightarrow ^{260-x}_{102}No + xn$ experiment was done by E. D. Donets et al. in 1966 [1]

  → Alpha spectroscopy only !

- $^{22}_{10}Ne + ^{238}_{92}U \rightarrow ^{260-x}_{102}No + xn$ was tried in Jyvaskyla in 2006 but the recoils were too slow to cross the gas filled separator

  → Slow Recoils (0 MeV to 6 MeV)

[1] E.D. Donets et al.– J. Nucl. Phys. (1966) 2, 1015-1023

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Ch. Theisen et al. / Nuclear Physics A 944 (2015) 333–375

No	248		250	251	252	253	254	255	256	257	258	259	260		262
			1	6	33	26	44	2		1					
					3	2	3								
	0^+		0^+	$(7/2^+)$	0^+	$(9/2^-)$	0^+	$(1/2^+)$	0^+	$(3/2^+)$	0^+	$(9/2^+)$	0^+		0^+

No excited states were already observed in ^{256}No

- Rotational structures and high-K isomers were observed
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I. Context

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IV. Preliminary Results

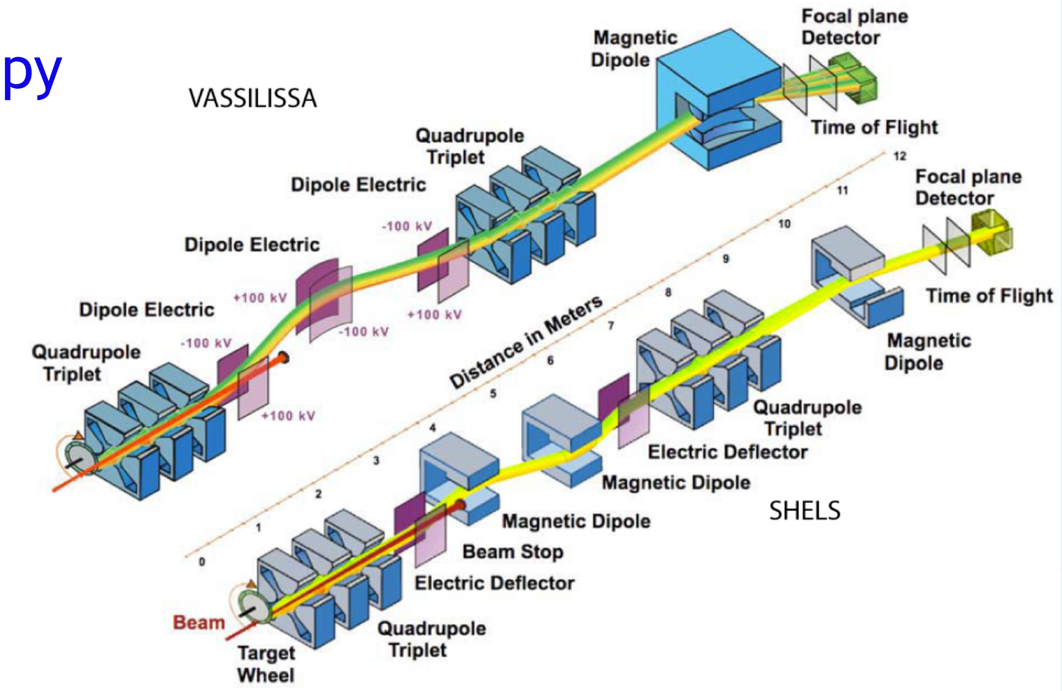
Setup

I. SHELS : Separator for Heavy Elements Spectroscopy

- Between 2006 and 2013, SHELS (JINR-IN2P3 collaboration) [4] was developed starting from the existing VASSILISSA separator

- SHELS was optimized for asymmetric reactions
  → Higher transmission
  → Light beams and heavy targets (Hot fusion)

- First Tests : 2013 [6] A.G. Popeko - Nuclear Instruments and Methods in Physics Research B 376 (2016) 140–143



Reaction	Beam energy	Target thickness (mg/cm^2)	ERs transmission		
			Old	New	
$^{22}Ne(^{198}Pt,5\text{-}7n)^{213-215}Ra$	115–125	0.30 (metal)	0.03	0.040 ± 0.015	x 1.3
$^{22}Ne(^{197}Au,4\text{-}6n)^{213-215}Ac$	120	0.35 (metal)	0.03	0.065 ± 0.030	x 2.2

- $^{22}_{10}Ne + ^{238}_{92}U \rightarrow ^{260-x}_{102}No + xn$
  → First asymmetric experiment with this setup

[4] A. Yeremin, O. Malyshev and al. - EPJ Web of Conferences 86, 00065 (2015)

Setup

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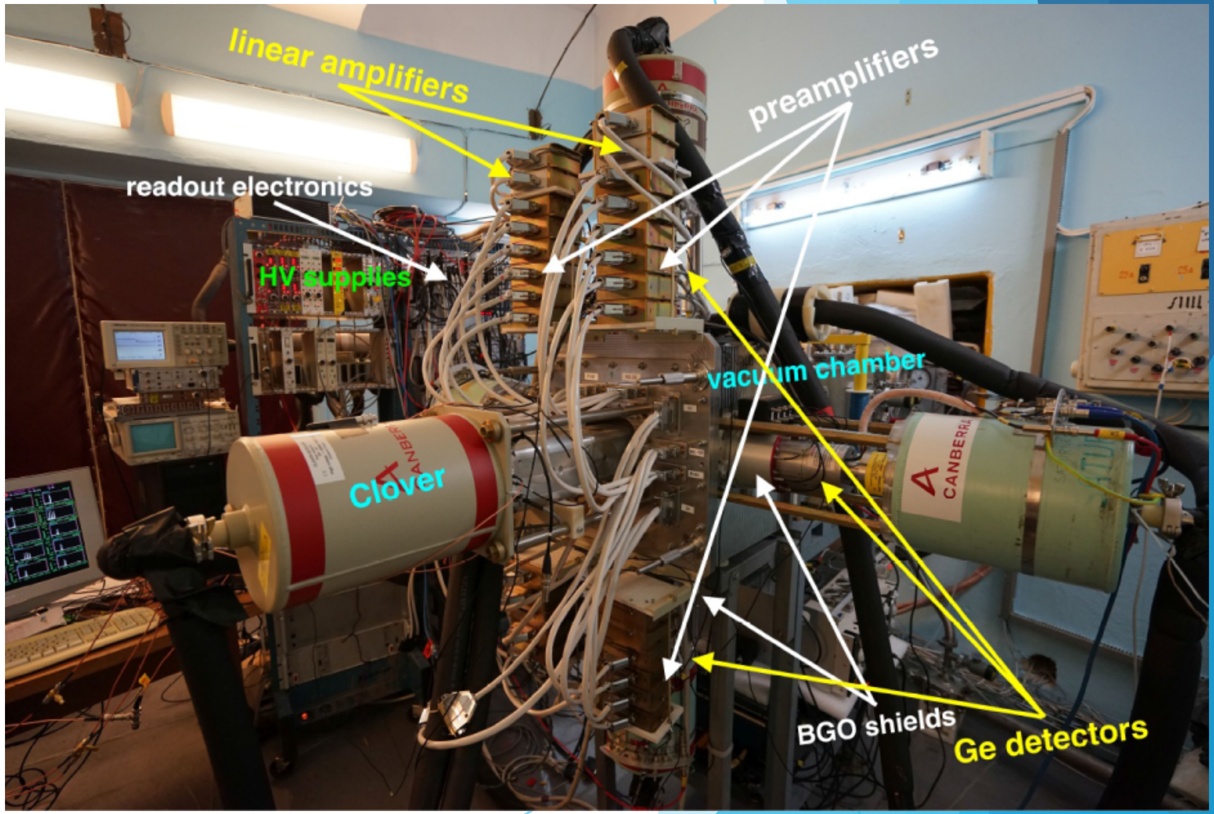
II. GABRIELA : Gamma Alpha Beta Recoil Investigations with the ELectromagnetic Analyzer

- Time of Flight detector (ToF) :
  - Usually two foils to give the time of flight between them
  - Each foil is made of one electron emissive foil and two MCP
  - **One of the ToF detector was unmounted because it could stopped the recoils before the focal plane (slow recoils)**
  - **Recoils range : 0 to 6 MeV**



- Implantation detector (DSSD 128x128)
- Tunnel detectors (8 DSSD)
- Germanium detectors (4 monocrystals + CLODETTE)

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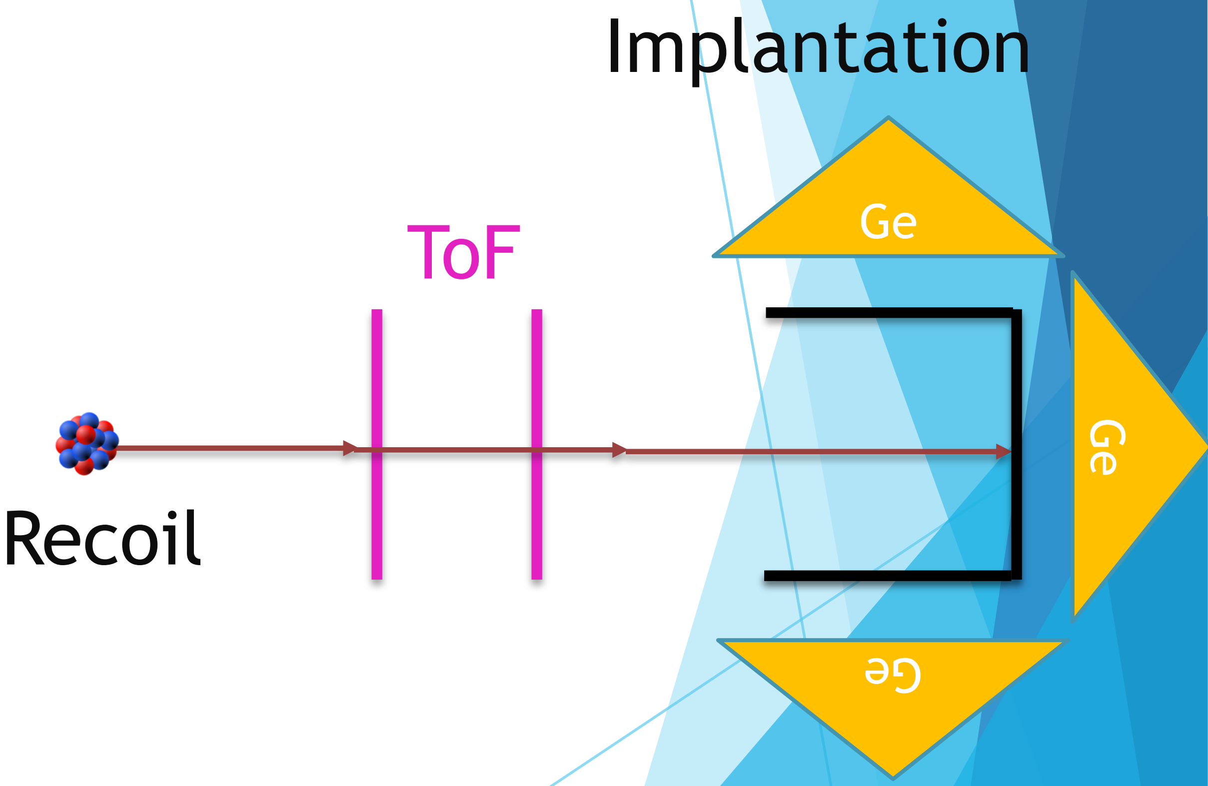

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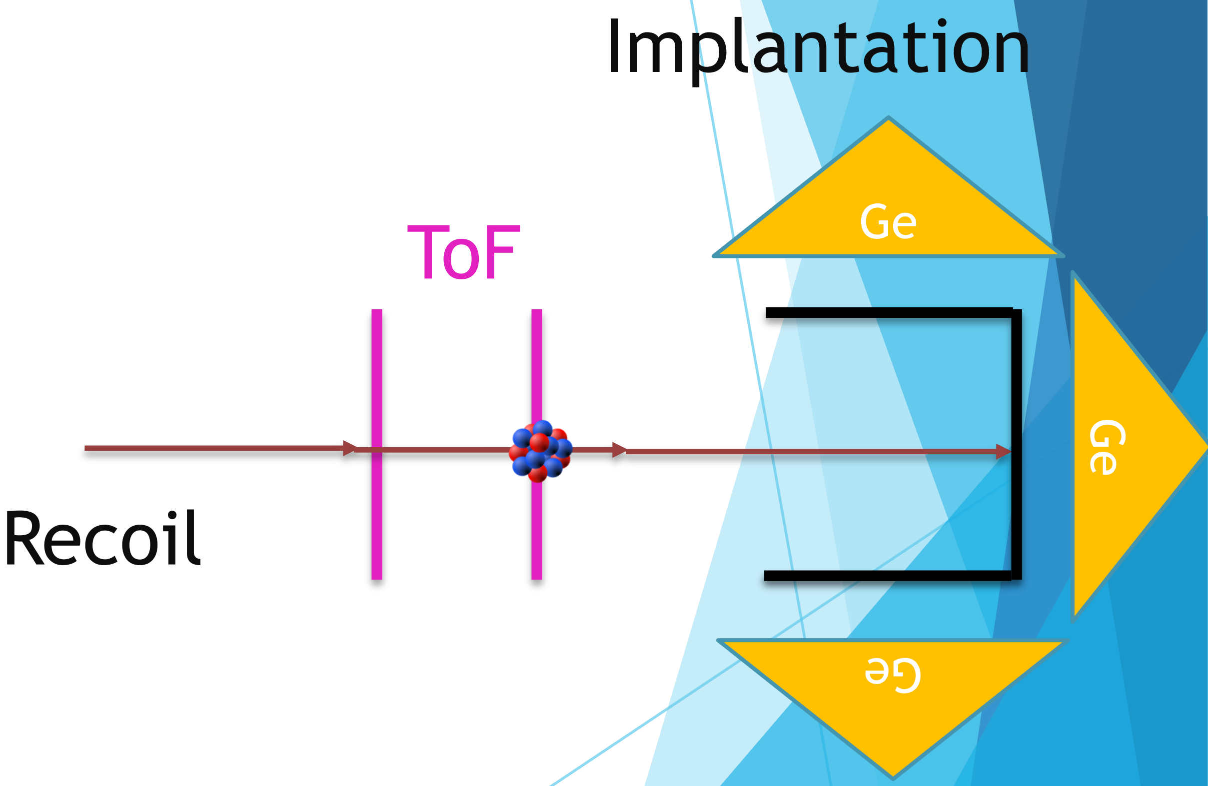

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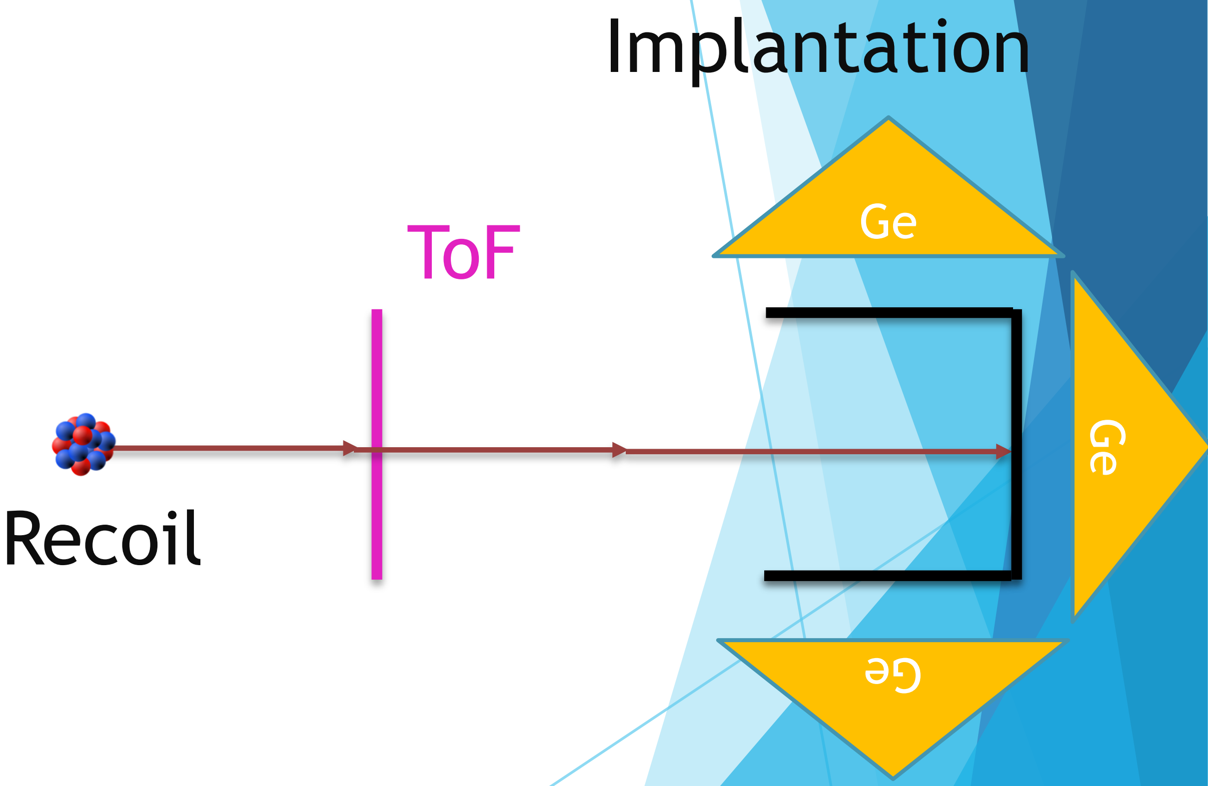

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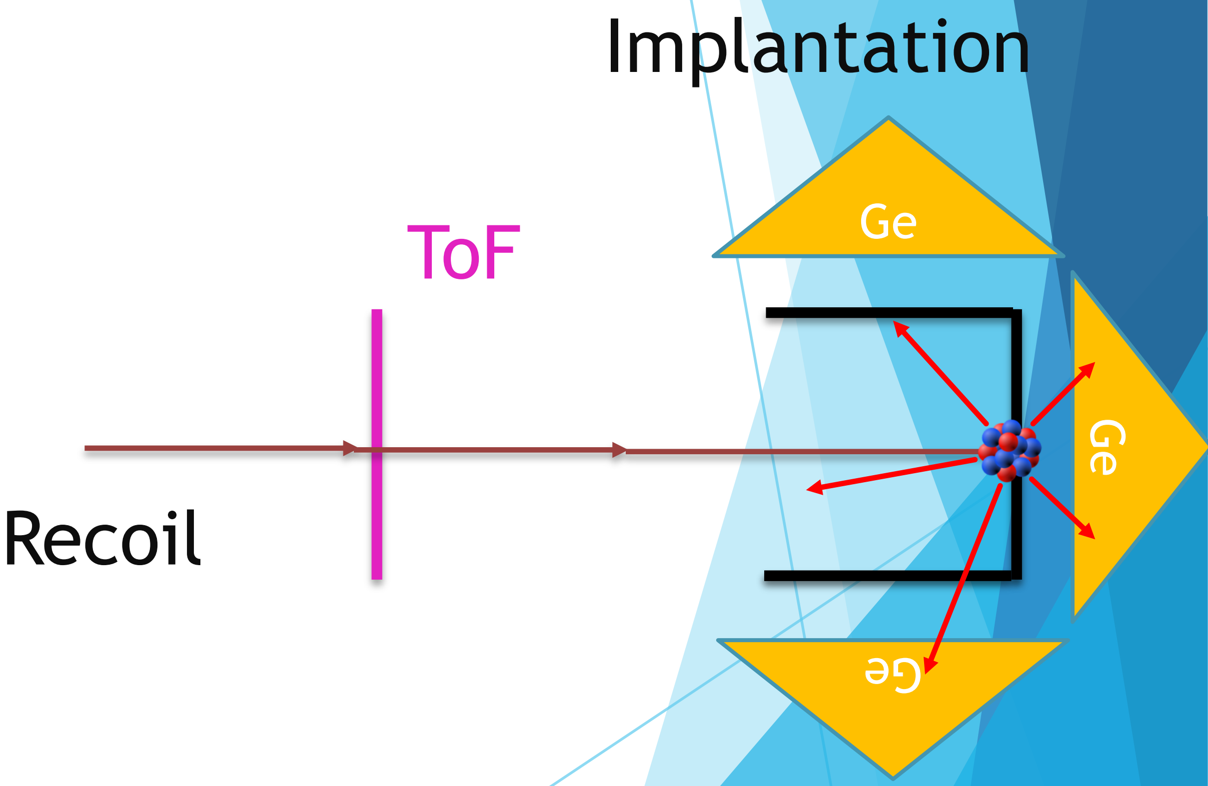


I. Context

II. Setup

III. Experiment : $^{22}Ne + ^{238}U \longrightarrow ^{260-x}No + xn$

IV. Preliminary Results

I. Experimental Conditions

$^{22}Ne + ^{238}U \rightarrow ^{260-x}No + xn$

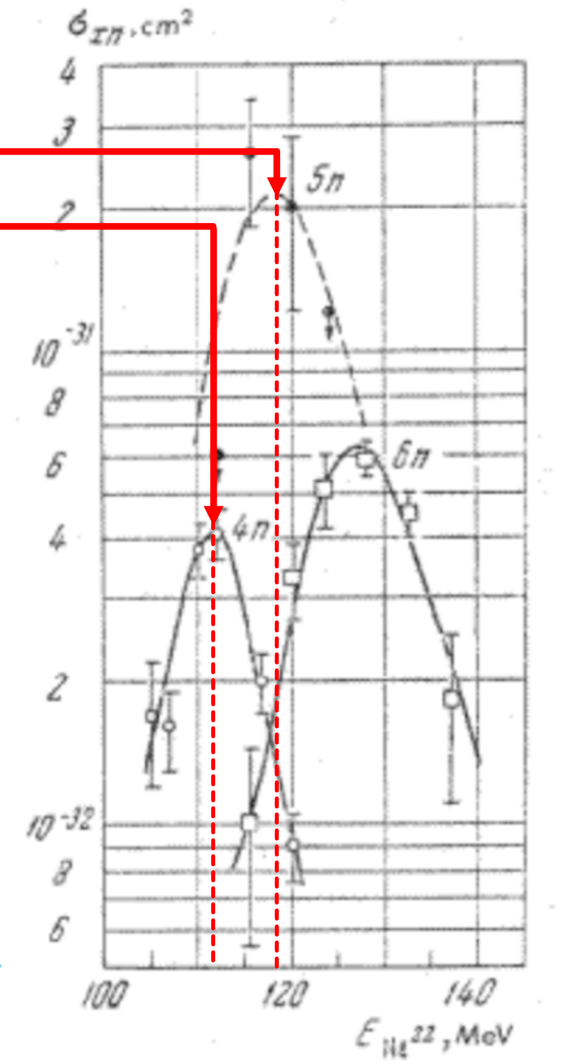
- April 2019 (4 months ago)
- 3 weeks of beamtime

- ^{238}U(M) Target (99,99% pure),
- 233µg/cm² 1.5 µm Titanium backing

- ^{22}Ne Beam
- Intensity between 0.6 and 1 pµA
- Integral 15 600 000 µC

- Beam Energy 107-112 MeV

Maxima of the excitation function are
$^{238}U(^{22}Ne,5n)^{255}No$ 118 MeV
$^{238}U(^{22}Ne,4n)^{256}No$ 112 MeV



[1] E.D. Donets - J. Nucl. Phys. 66

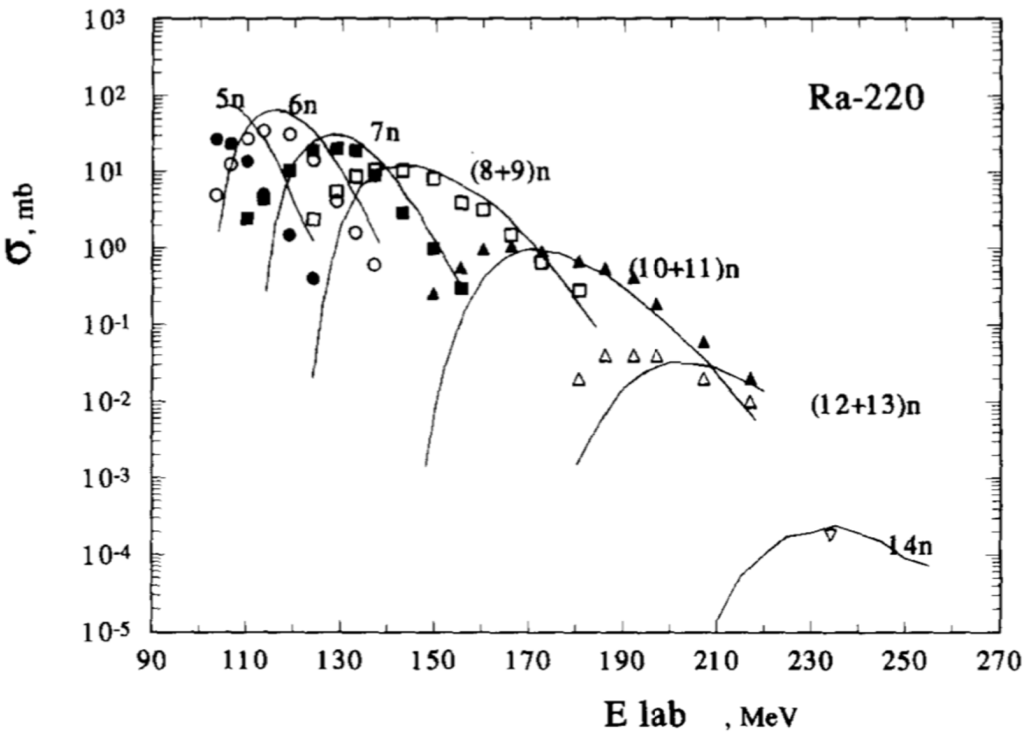
Experiment

II. Calibration : ${}^{22}_{10}Ne + {}^{198}_{78}Pt \rightarrow {}^{220-x}_{88}Ra + xn$

- ${}^{22}_{10}Ne + {}^{198}_{78}Pt \rightarrow {}^{220-x}_{88}Ra + xn$
- Beam Energy : 112.5 MeV
  - → 5n channel : 8 mb
  - → 6n channel : 33.5 mb
  - → 7n channel : 2.5 mb
- Integral 12 280 μC
- Alpha : ${}^{214}Ra$, ${}^{215}Ra$, ${}^{210}Rn$
- Beta : ${}^{214}Ra$ with the sequence of transitions :

  46-182-257-1382 keV
- Gamma : ${}^{152}Eu$ and ${}^{133}Ba$ sources

A.N. Andreyev et al./Nuclear Physics A 620 (1997) 229–248



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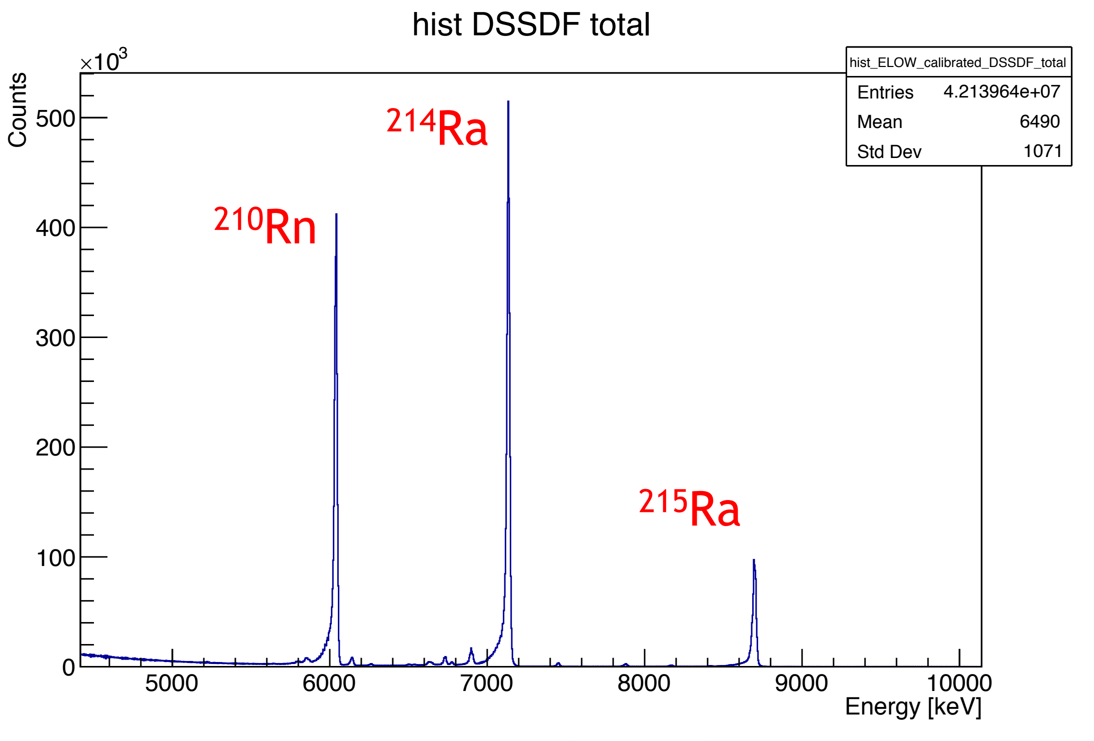

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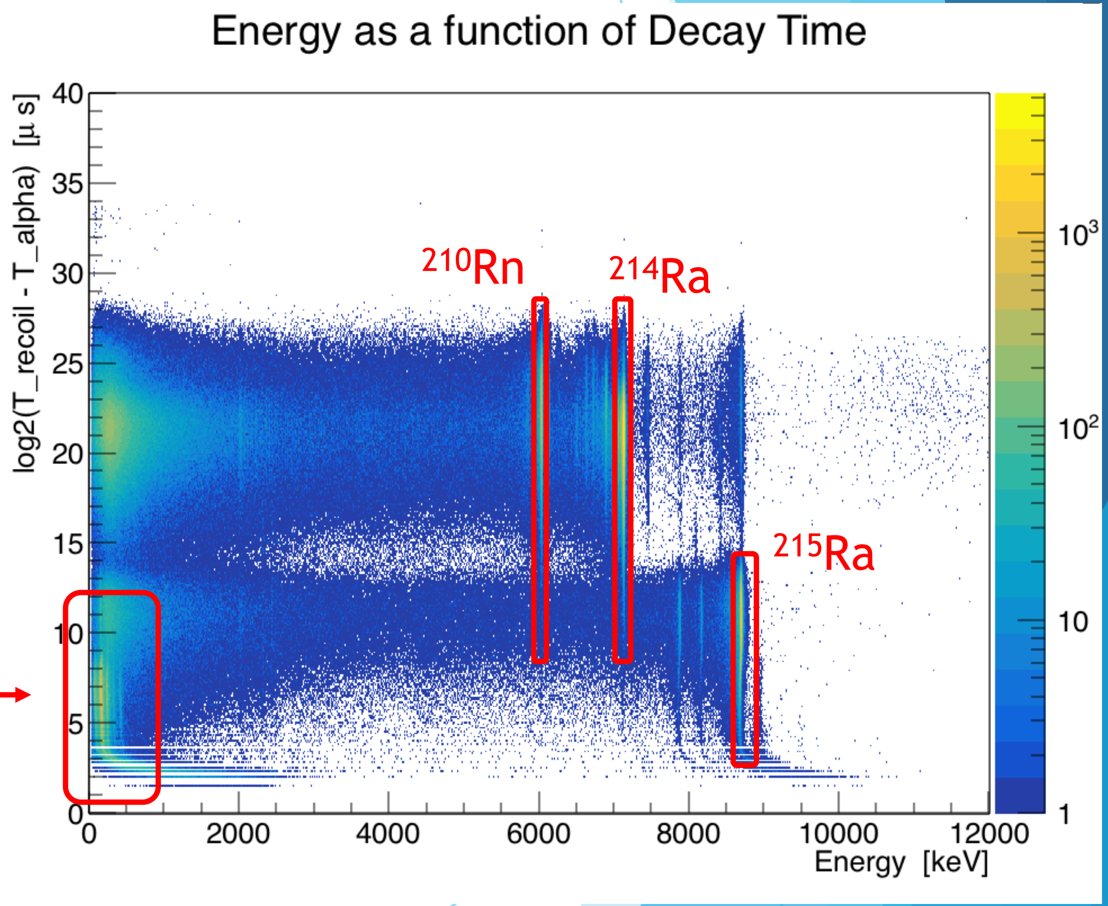

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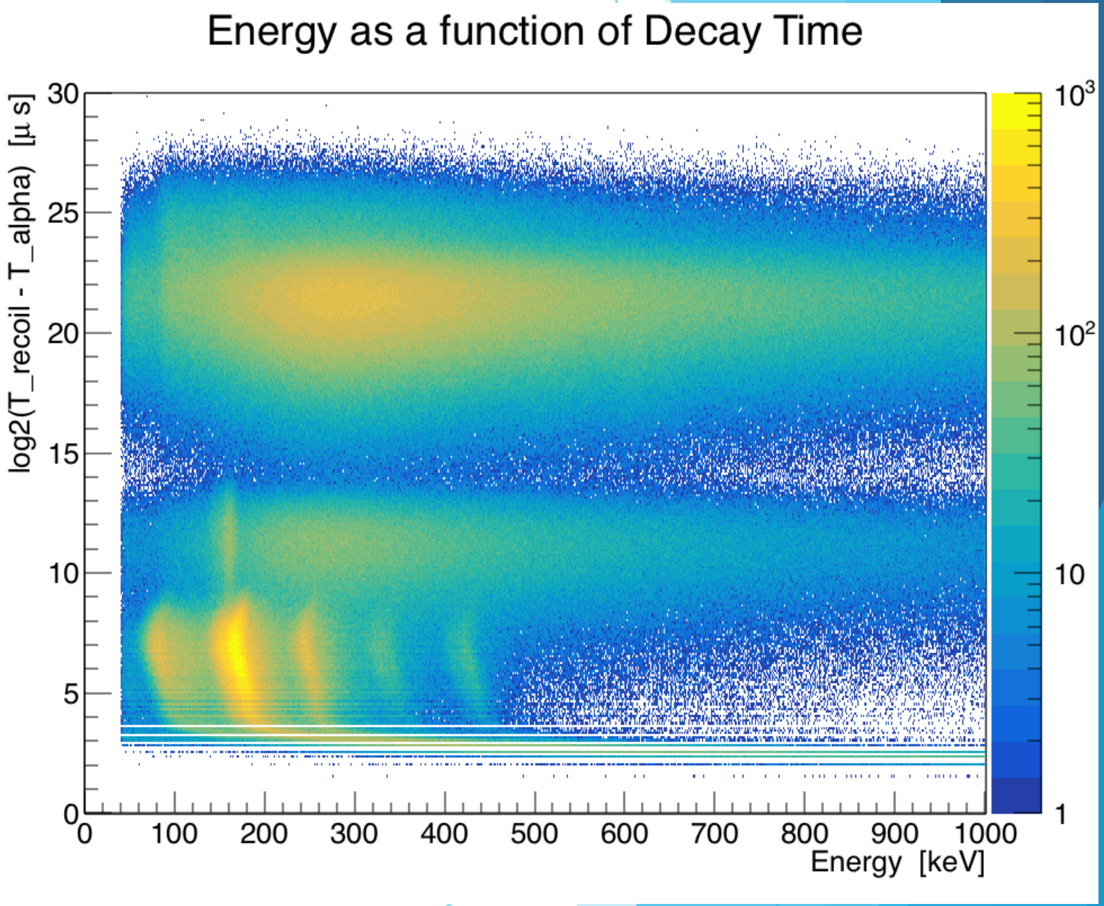

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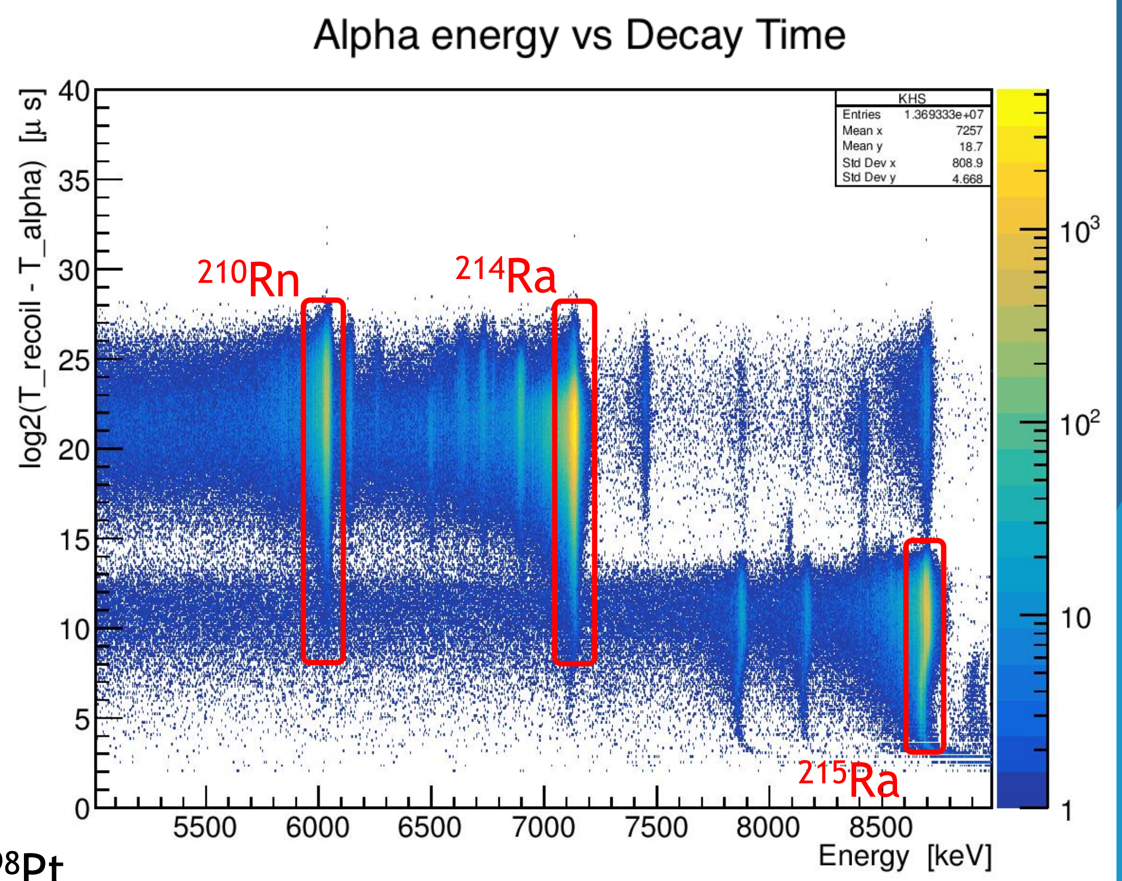
IV. Preliminary Results

Results : SHELS Transmission

Calibration reaction $^{22}Ne + ^{198}Pt \rightarrow ^{220-x}Ra + xn$ [8]

	^{215}Ra seen	^{214}Ra seen
Run 1	4.602e5	2.070e6
Run 2	6.921e5	2.852e6
Total	1.161e6	4.922e6
σ (mb)	8.0	35
Integral (µC)	12 280	
Transmission (%)	4.5% (5)	



Lower limit for the transmission of SHELS is 4.5% in $^{22}Ne + ^{198}Pt$

- Charge collection issues due to high counting rate
- Recoil detection

[8] A.N. Andreyev and al. – Nucl.r Phys. A 620 (1997) 229-248

Results : Lifetime and Energy

$^{22}Ne + ^{238}U \rightarrow ^{260-x}No + xn$

- ^{256}No : 8431 ± 1 keV
- ^{255}No : 7748 ± 2 keV
  7843 ± 4 keV
  7909 ± 2 keV
  8101 ± 1 keV
  8232 ± 8 keV

- Lifetime scale in log(delta_T)/log(2)

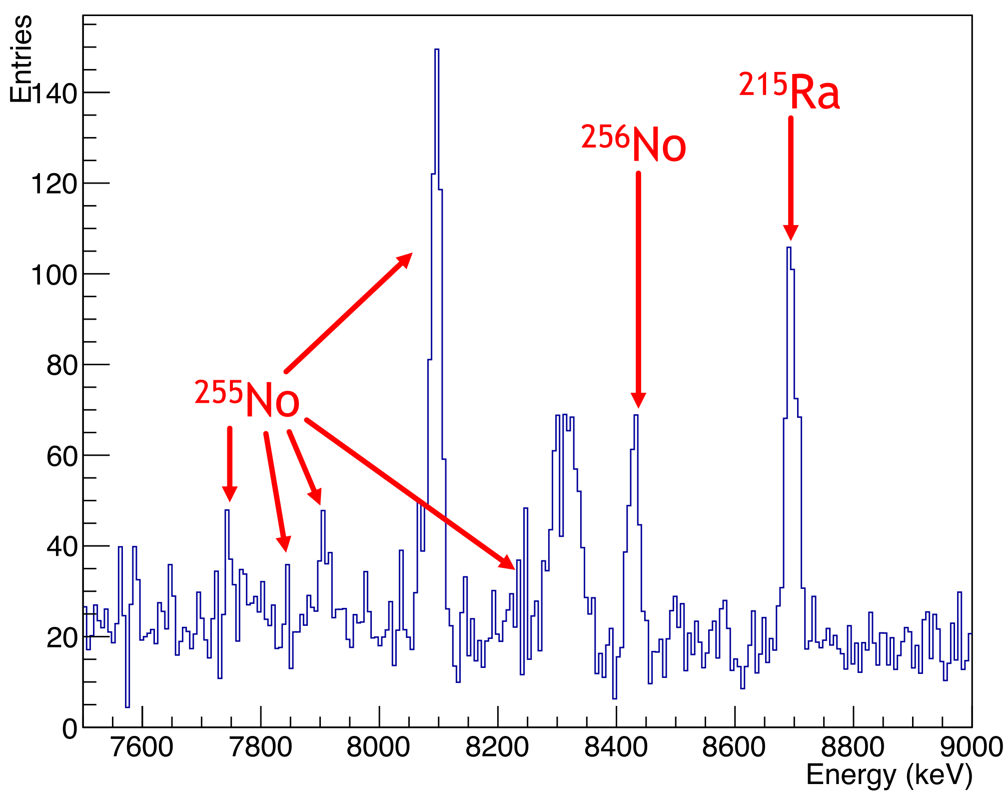
- Lifetime fitted. By a two components function with fixed background's parameters (random correlations)

- Random correlations: $T_{1/2} = \frac{\ln(2)}{\lambda} = 28{,}1 \pm 0{,}6\ s$

- Half-life of ^{256}No: $T_{1/2} = \frac{\ln(2)}{\lambda} = 2{,}79 \pm 0{,}18\ s$
  Literature half-life : 2,8 ± 0,3 s [9]

- Half-life of ^{255}No is in the random correlations
  Literature half-life : 3,52 ± 0,21 min [10]

Alpha Energy Spectrum



[9] Sikkeland, Torbjorn and al. - Berkeley National Laboratory (1967)
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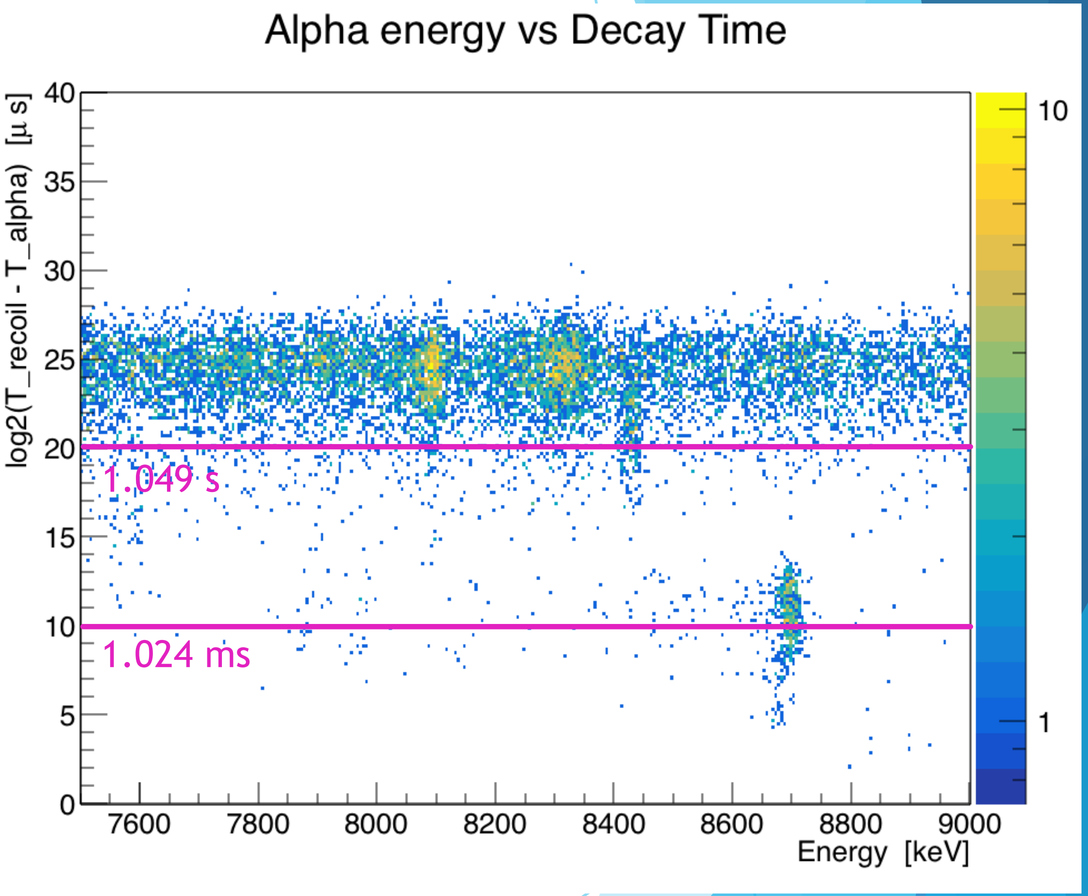

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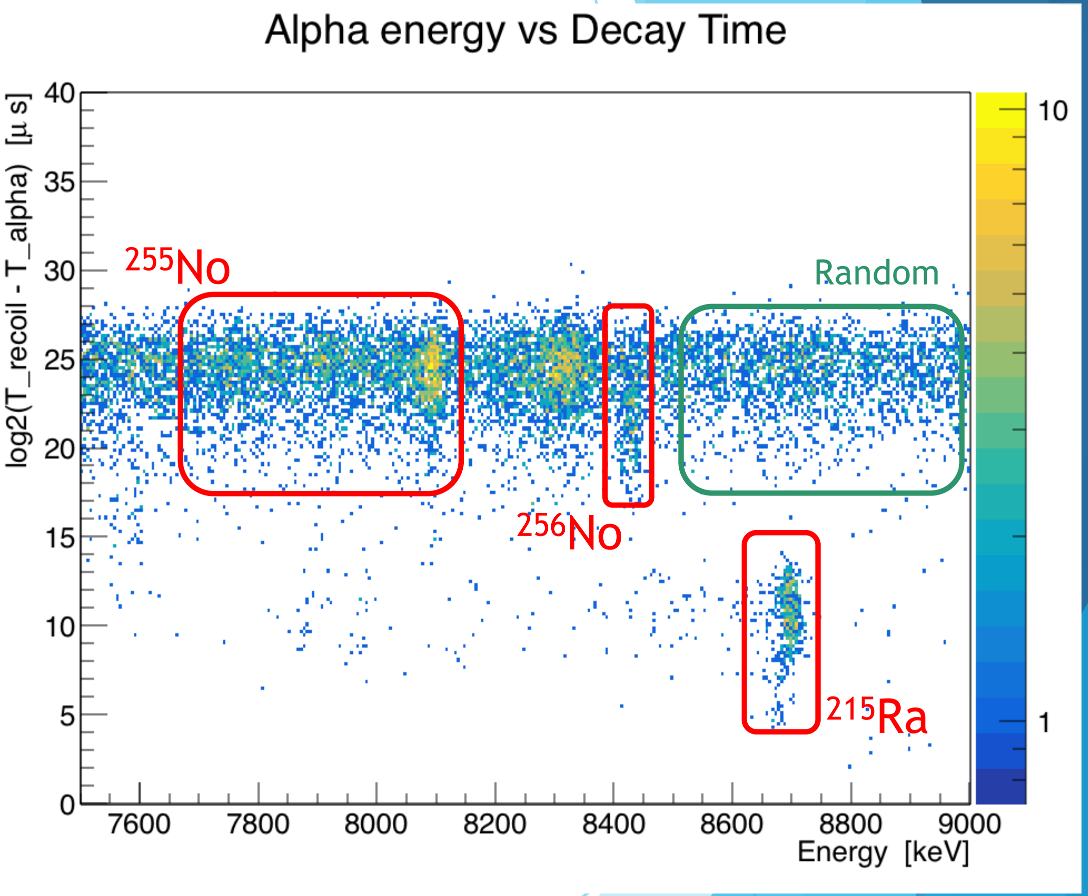

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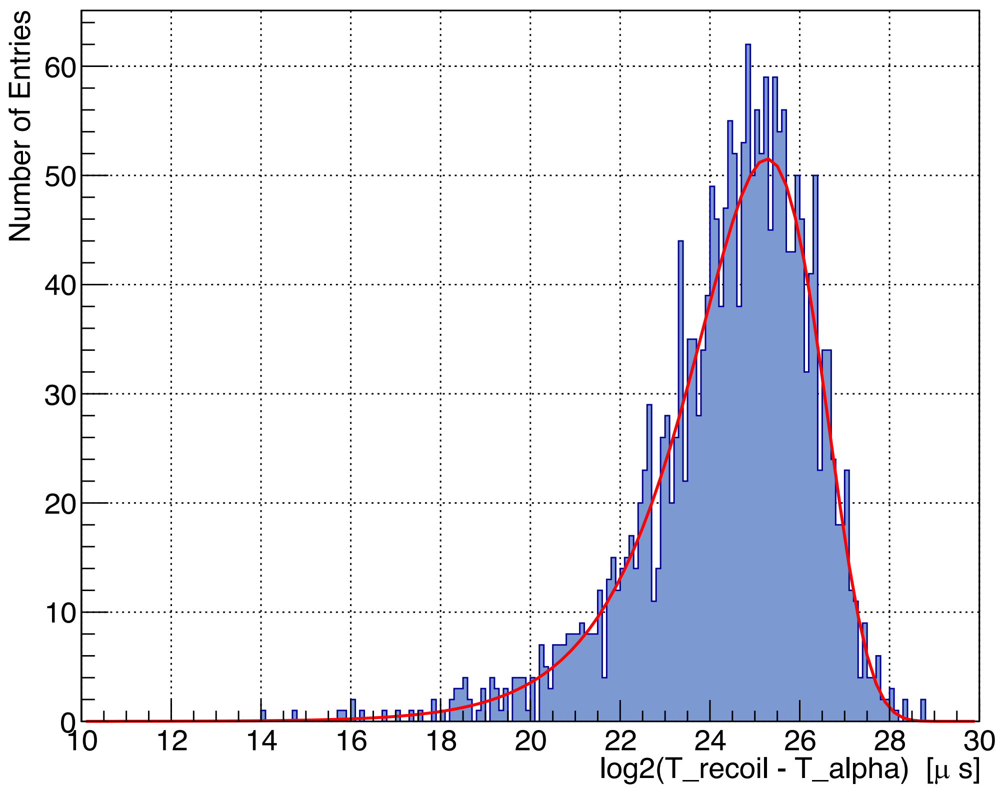

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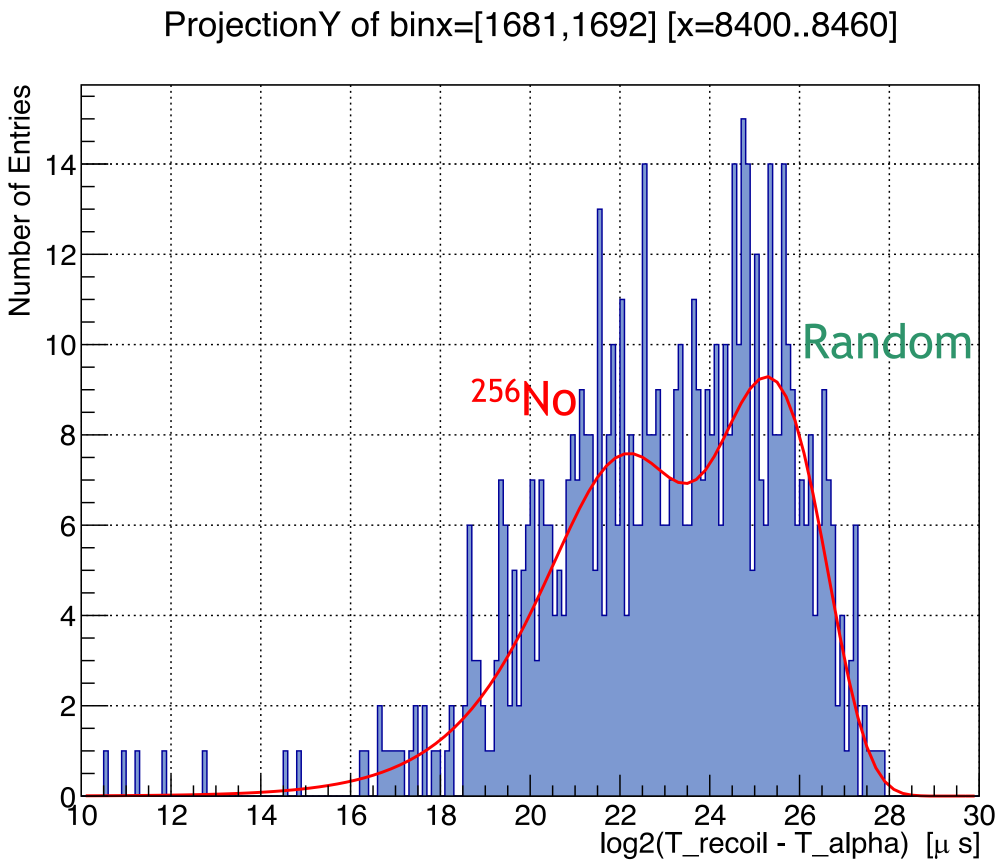

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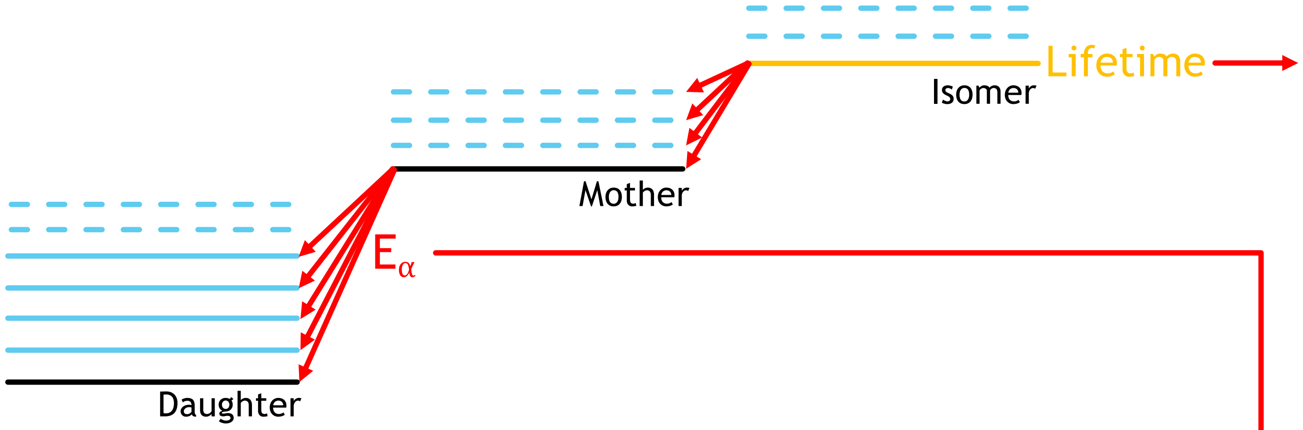
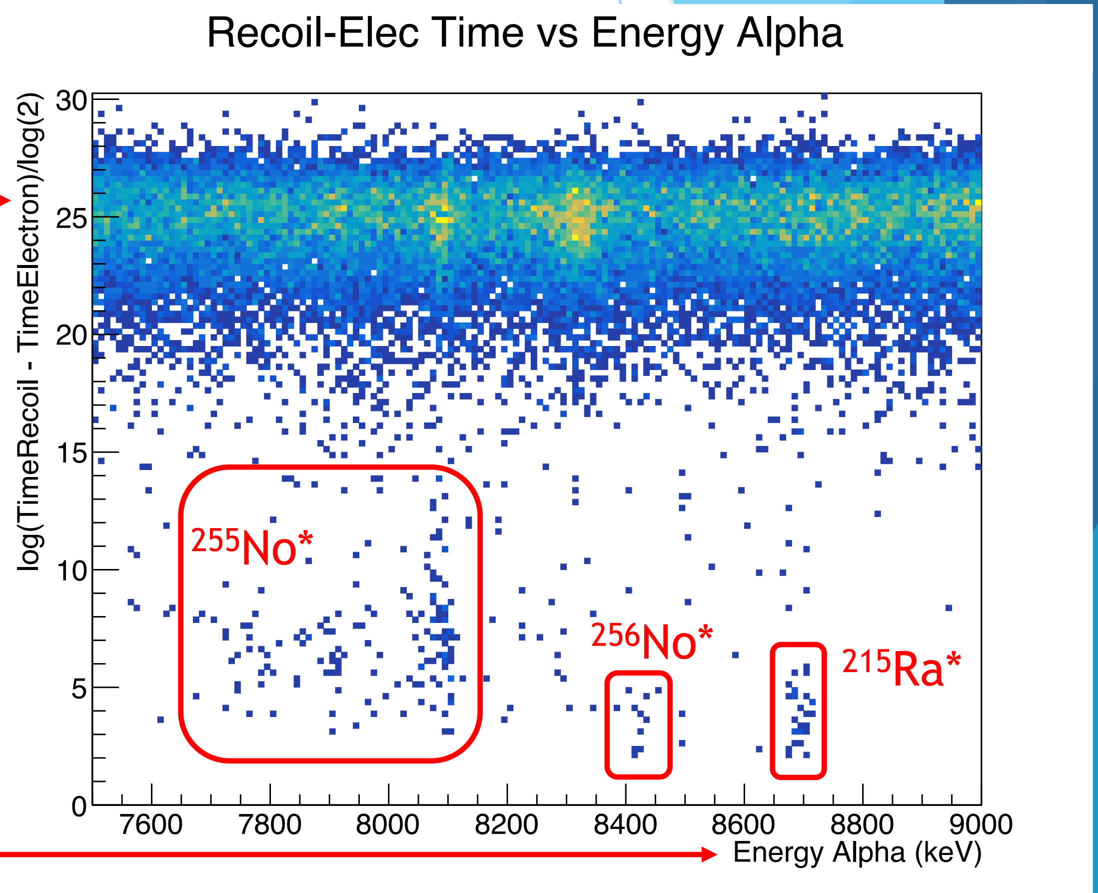
Results : Isomers

- This plot shows the lifetime of the isomers as a function of the following alpha decay energy





- We can see the known isomer in ^{215}Ra at 8699 keV from the ^{198}Pt Calibration
- At 8430 keV we can see the 11 events of a new isomer in ^{256}No
- Between 7700 and 8150 keV we can see many events of an isomer in ^{255}No

Results : Isomer in ^{256}No

- With only 11 events of an isomeric state in ^{256}No, we need to use the K. H. Schmidt method [11] to extract its lifetime and the confidence interval

- 2 σ → Confidence level 95.45%

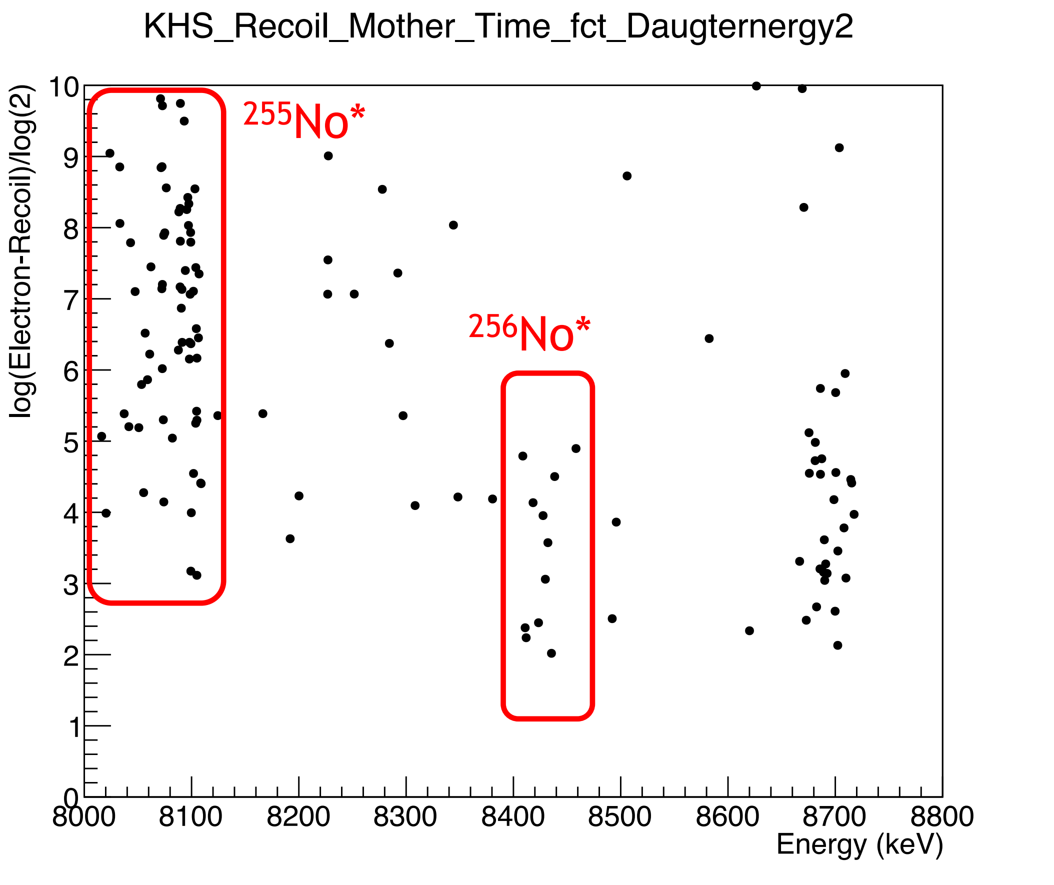
  $T_{1/2} = 9{,}7\ ^{+14}_{-3{,}6}\ \mu s$

- 1 σ → Confidence level 68.27%

  $T_{1/2} = 9{,}7\ ^{+4{,}2}_{-2{,}2}\ \mu s$

- For small numbers, this method is much more accurate than the generally used symmetric errors

- We can see events of a K_α X-Ray in coincidence with the decay of the isomer



[11] K. H. Schmidt - Zei. Fur Phy. A, Atomes and Nuclei 316, 19-26 (1984)

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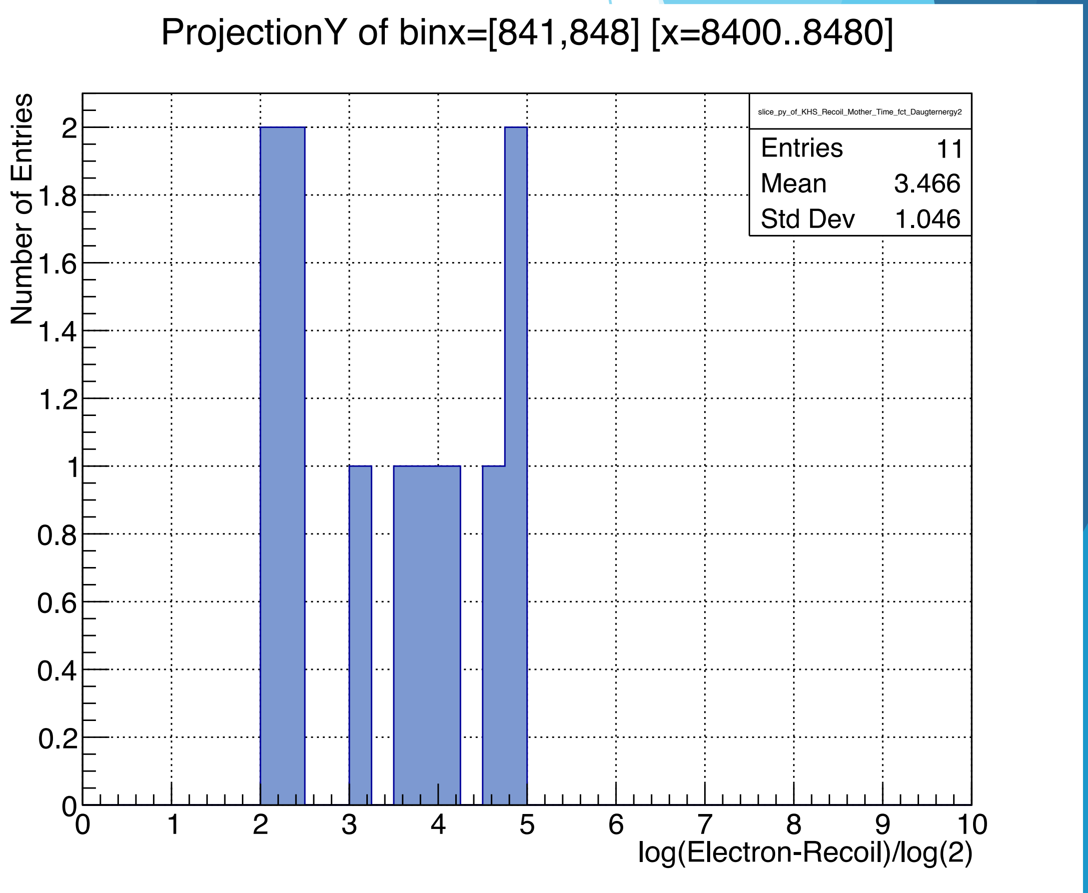
- 1 σ → Confidence level 68.27%
  $T_{1/2} = 9{,}7\ ^{+4{,}2}_{-2{,}2}$ μs
- For small numbers, this method is much more accurate than the generally used symmetric errors
- We can see events of a K_{α} X-Ray in coincidence with the decay of the isomer



[11] K. H. Schmidt - Zei. Fur Phy. A, Atomes and Nuclei 316, 19-26 (1984)

Results : Isomer in ^{255}No

- The alpha decay of ^{255}No is distributed in 10 different alpha rays
- ^{255}No was already studied to extract a level scheme for the daughter of this nucleus, the ^{251}Fm [ref]
- Energy range 7700-8300 keV
- With this statistic, we can fit the lifetime distribution

$T_{1/2} = 136{,}9 \pm 3{,}2\ \mu s$

Energy (keV)	Relative intensity[a]	Excited-state energy (keV) From α energies	Excited-state energy (keV) From γ energies
7702(5)	9.0(20)	604(4)	
7726(6)	9.1(29)	579(5)	
7748(3)	62(5)	557.3(18)	558.7(2)
7842(4)	14.4(22)	461(3)	
7909(3)	56(4)	393.8(18)	395.4(2)
8001(4)	22.8(26)	301(3)	
8057(4)	34.7(31)	243(3)	
8100(3)	100(5)	200.09[b]	200.09(11)
8233(4)	23.1(26)	64.6(28)	63.9(8)
8296(6)	4.0(12)	0.7(52)	0

[a]For I_α per 100 α decays, multiply by 0.297.
[b]Normalized at this level.

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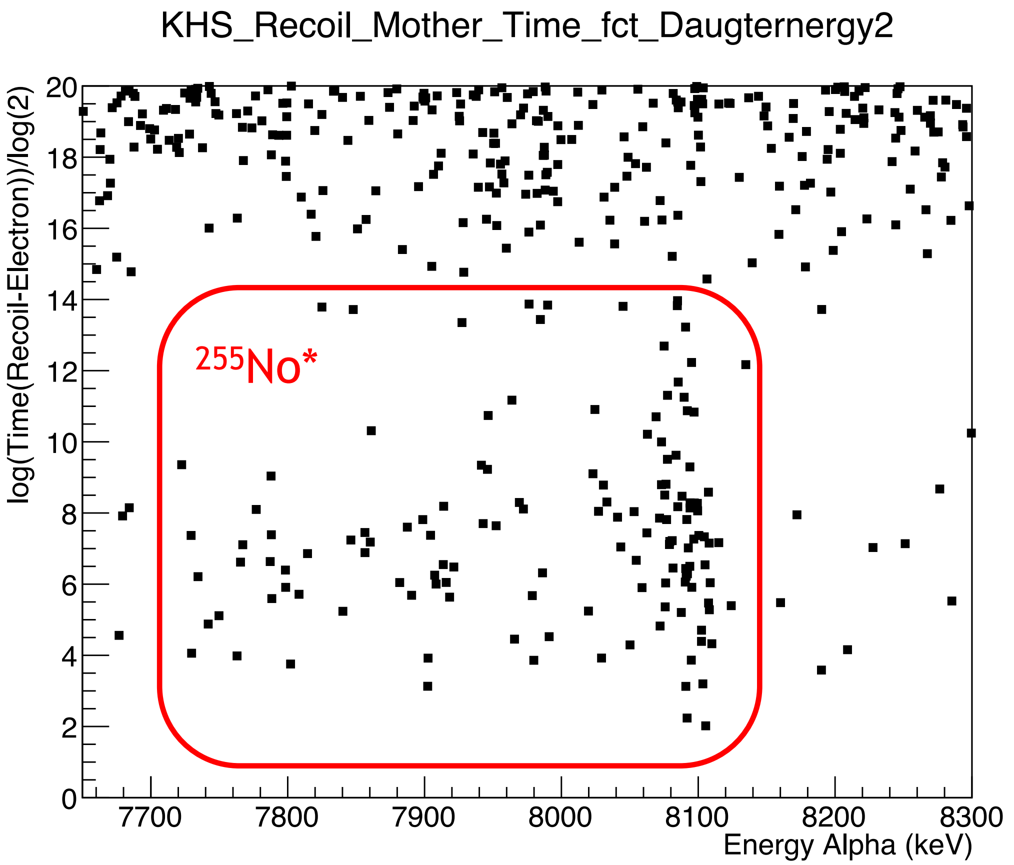
$T_{1/2}$ = 136,9 ± 3,2 µs



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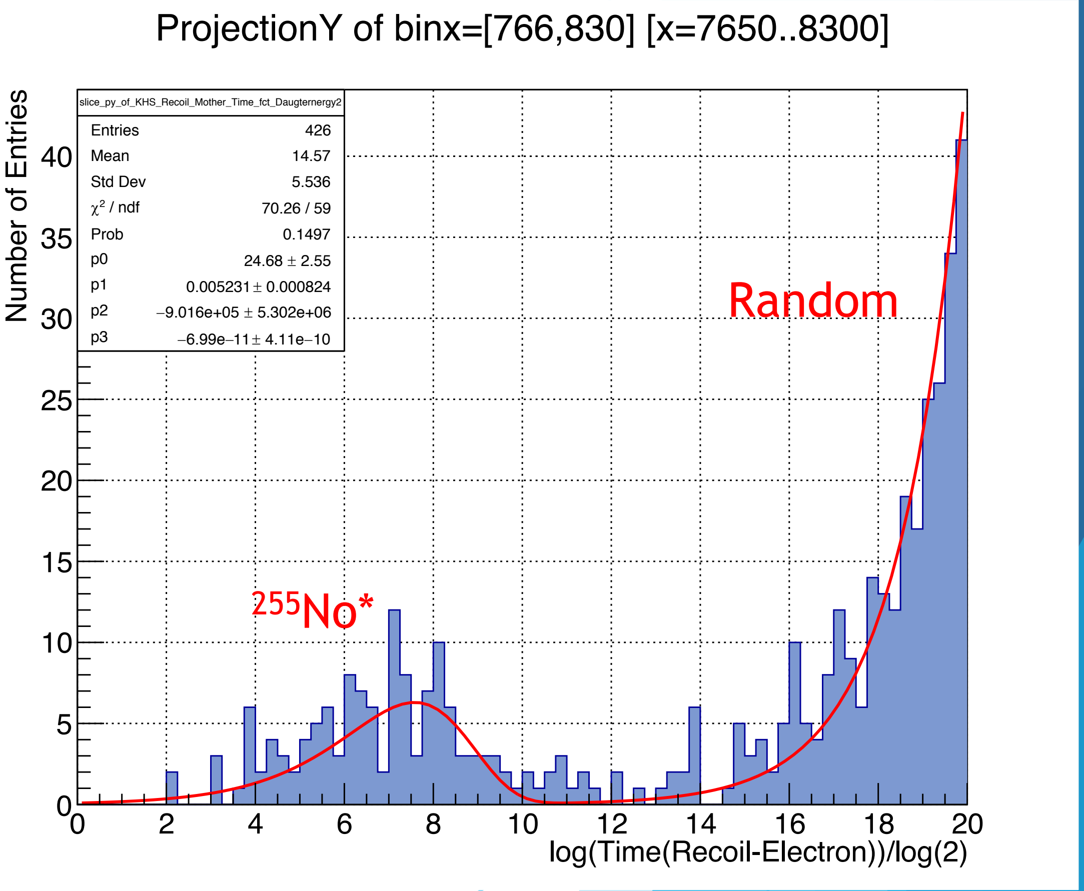

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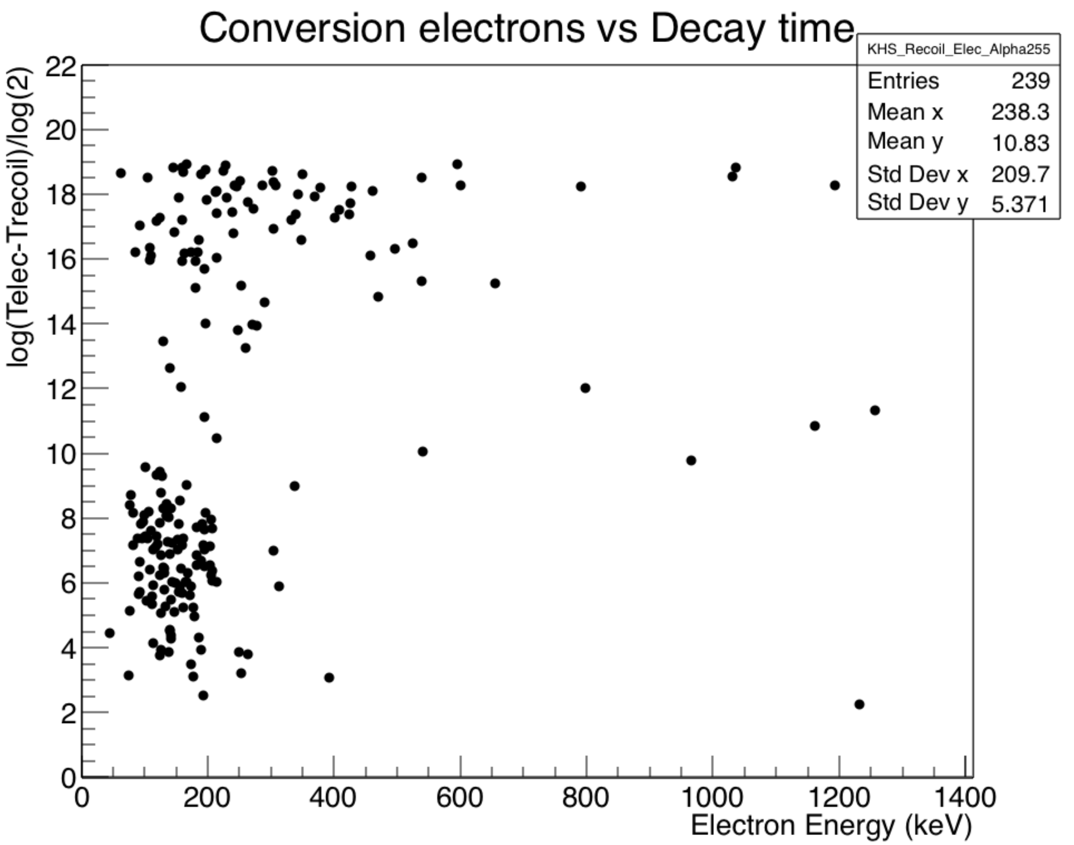

Eur. Phys. J. A 32, 245-250 (2007) – A. Lopez-Martens and al.

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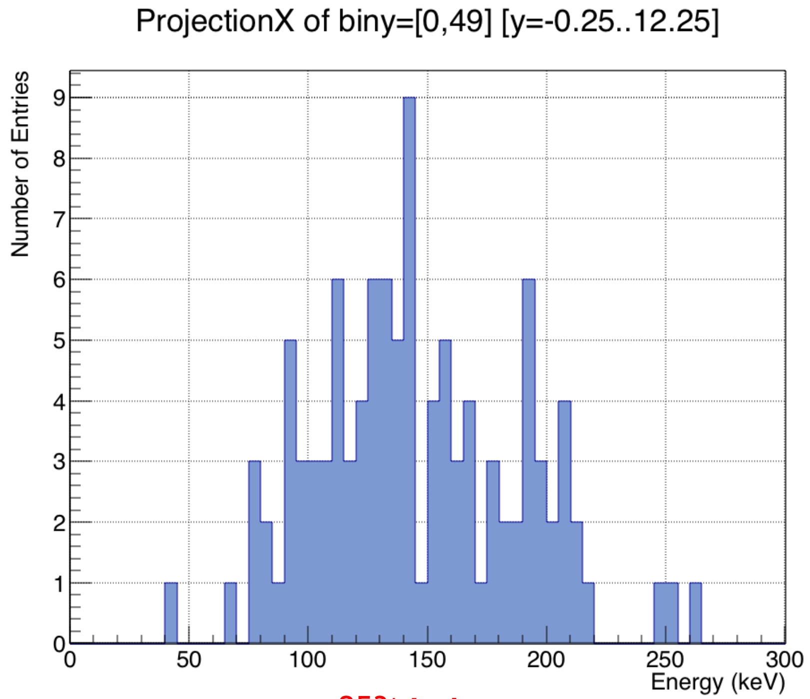
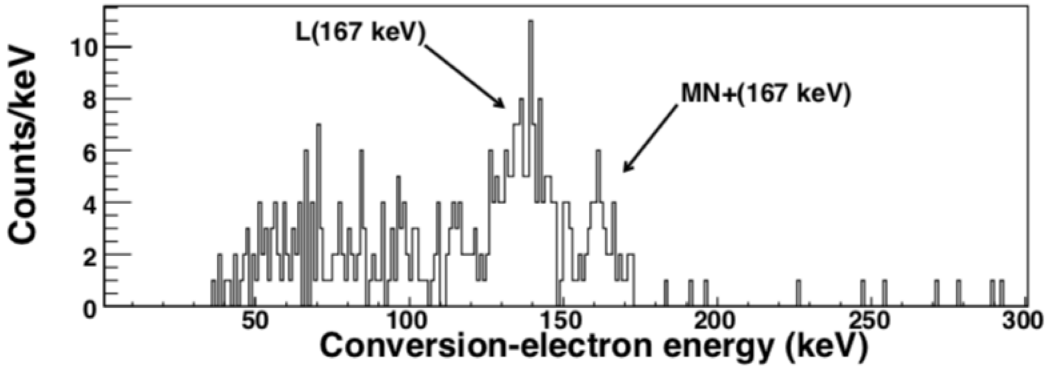


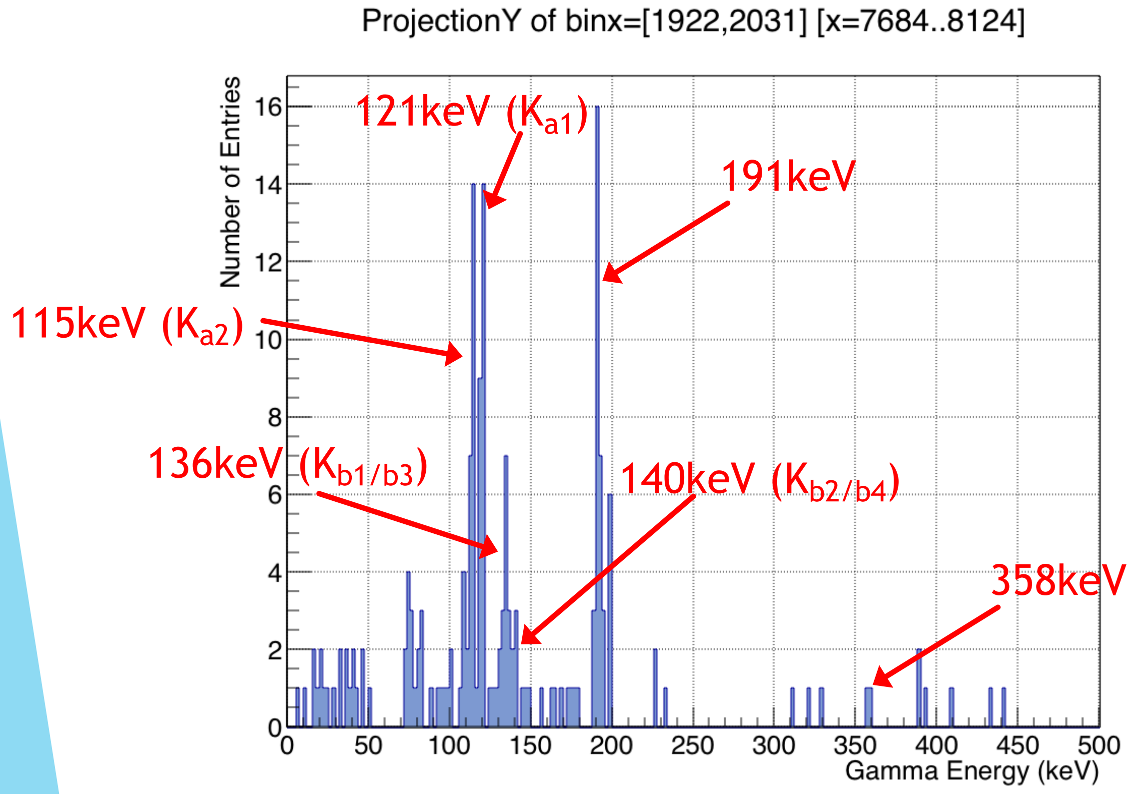
$^{253}No^{*}$

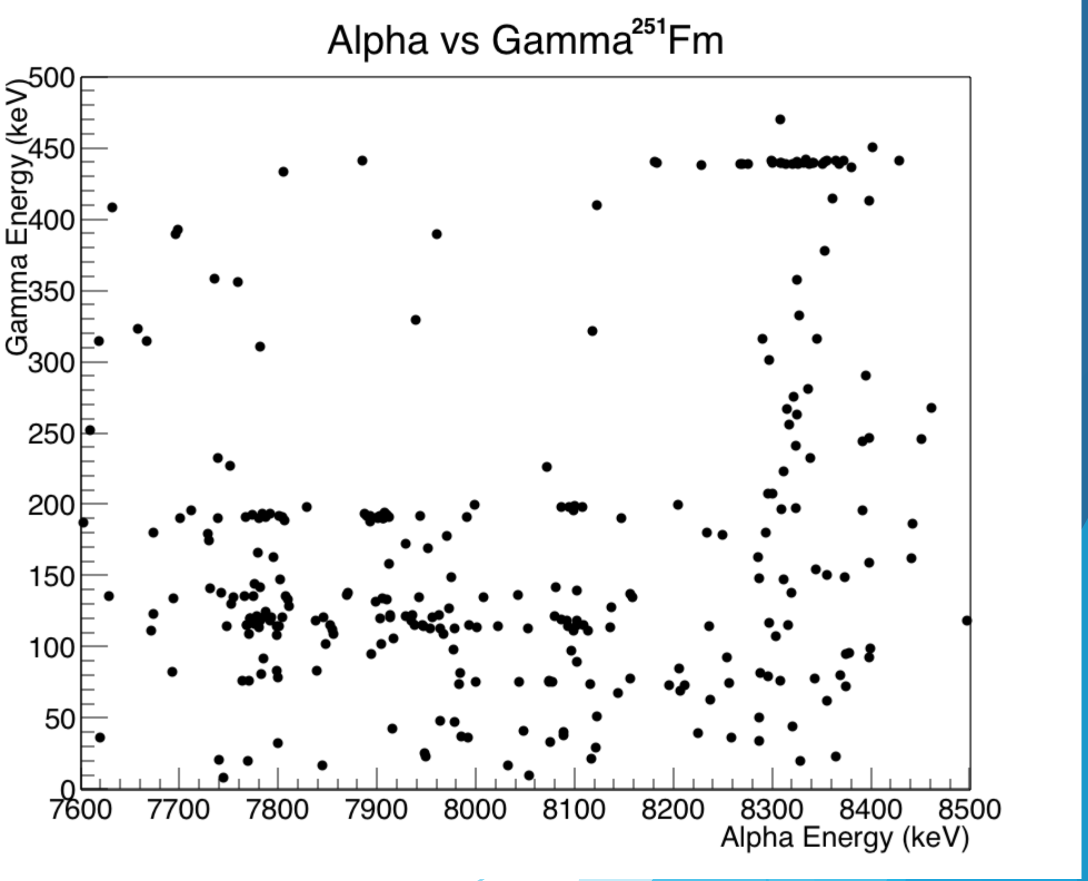


Eur. Phys. J. A 32, 245-250 (2007) – A. Lopez-Martens and al.

Results : ^{251}Fm X-rays

- Through the decay of ^{255}No we can see the X-rays of ^{251}Fm
- These results are in perfect agreement with the study from M. Asai (2011) [9] or K. Rezynkina (2018) [12]





[9] M. Asai, K. Tsukada, H. Haba and al. - PHYSICAL REVIEW C 83, 014315 (2011)
[12] K. Rezynkina, A. Lopez-Martens, K. Hauschild and al. - PRC 97, 054332 (2018)

Conclusion

- We found a new isomeric state in ^{255}No with a half-life of :

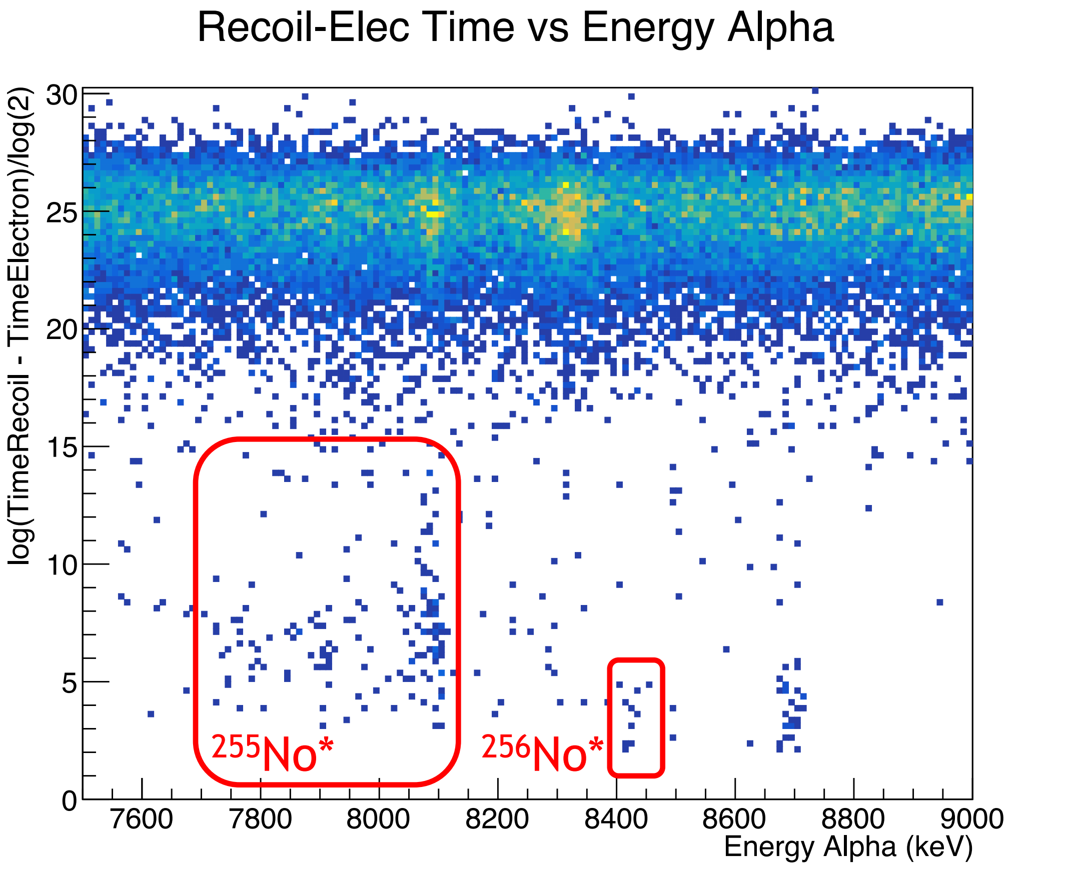
$$T_{1/2} = 136{,}9 \pm 3{,}2\ \mu s$$

- We also found a new isomeric state in ^{256}No with a half-life of :

$$T_{1/2} = 9{,}7\ ^{+4{,}2}_{-2{,}2}\ \mu s$$

- The analysis on these data is still ongoing and I hope to extract the energies of excited states in the decay of ^{255}No*

- We need more statistics for the ^{256}No*, so this experiment will be repeated at the beginning of 2020, with the same team in Dubna



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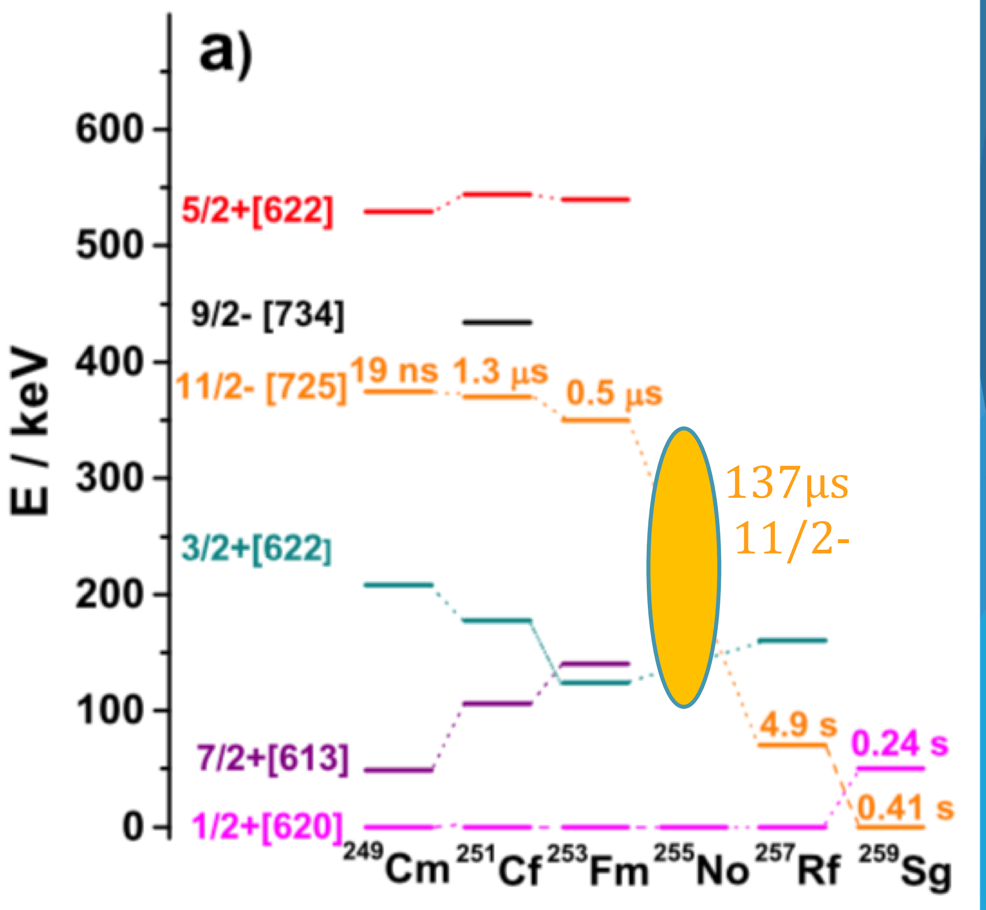
Single particle levels in N = 153 isotones.



M. Asai et al. / Nuclear Physics A 944 (2015) 308–332

Collaborators :

- IN2P3/GANIL Collaboration : B. J. P. Gall, O. Dorvaux, A. Lopez-Martens, K. Hauschild, J. Piot, R. Chakma, Z. Asfari
- FLNR : A. V. Yeremin, M. L. Chelnokov, V. I. Chepigin, A. V. Isaev, O. N. Malyshev, A. G. Popeko, Y. A. Popov, A. A. Kuznetsova, A. I. Svirikhin, E. A. Sokol, M. S. Tezekbayeva
- Chinese Academy of Science : B. Ding, Z.Liu, F. Zhang

Thank you

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- [10] M. Asai, K. Tsukada, H. Haba and al. - Neutron one-quasiparticle states in ^{251}Fm populated via the α decay of 255No - PHYSICAL REVIEW C 83, 014315 (2011)
- [11] K. H. Schmidt - Some Remarks on the Error Analysis in the Case of Poor Statistics – Zei. Fur Phy. A, Atomes and Nuclei 316, 19-26 (1984)
- [12] K. Rezynkina, A. Lopez-Martens, K. Hauschild and al. - Influence of octupole vibration on the low-lying structure of 251Fm and other heavy *N*=151 isotones - PHYSICAL REVIEW C 97, 054332 (2018)

Level Scheme of ^{251}Fm

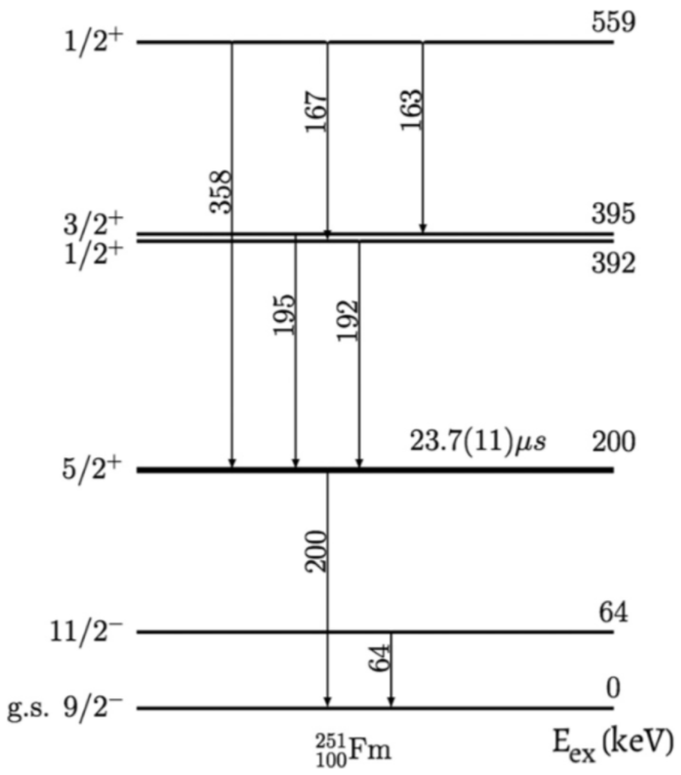


FIG. 2. A simplified level scheme depicting the observed transitions in ^{251}Fm populated in α decay of ^{255}No.

M. ASAI *et al*. PHYSICAL REVIEW C **83**, 014315 (2011)

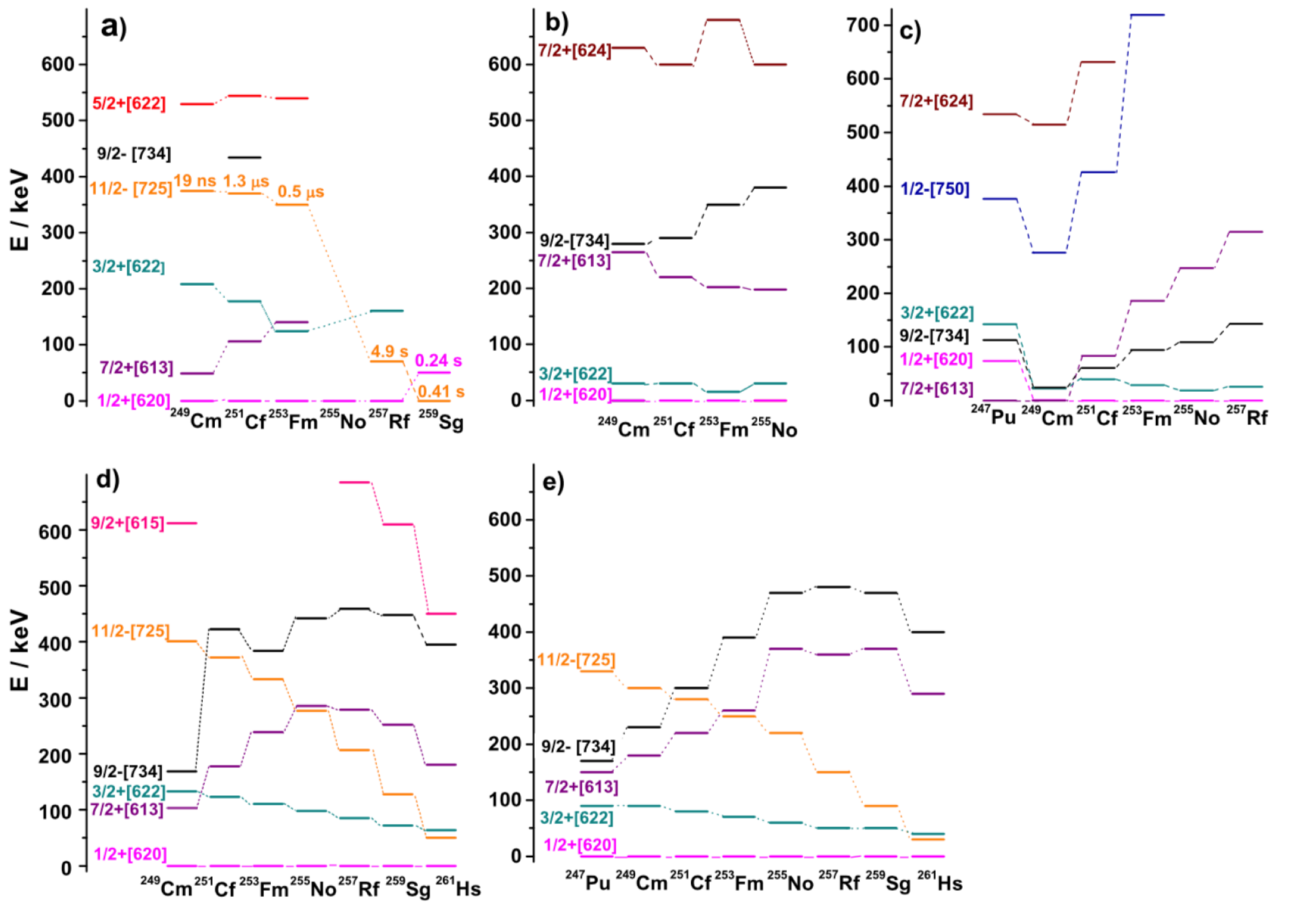


Fig. 9. Experimental (a) and calculated ((b) [78], (c) [79,80], (d) [81], (e) [82]) low lying single particle levels in $N = 153$ isotones.

Hot/Cold fusion targets

- *Cibles Stables*
- *Cibles Radioactives*

Z	142		144		146		148		150		152		154		156		158		160	
105						Ha Hahnium							Ha 259 209Bi + 50Ti							
104						Rf Rutherfordium (263.1125)		Rf 253	Rf 254 206Pb+48Ti	Rf 255 207Pb+48Ti	Rf 256 208Pb+48Ti 206Pb + 50Ti	Rf 257 233U+24Mg 207Pb + 50Ti	Rf 258 208Pb + 50Ti 226Ra+32S 230Th+28Si 234U+24Mg	Rf 259 235U+24Mg	Rf 260 236U+24Mg 230Th+30Si 232Th+28Si	Rf 261	Rf 262 238U+24Mg 226Ra + 36S 232Th+30Si	Rf 263 247Cm+16O	238U+26Mg 248Cm+16O	Rf 265 ? 247Cm+18O
103						Lr Lawrencium (262.1097)		Lr 252	Lr 253 203Tl+50Ti 205Tl+48Ti	Lr 254	Lr 255 205Tl+50Ti	Lr 256 236Np+20Ne	Lr 257 237Np+20Ne 209Bi+48Ca 230Th+27Al	Lr 258 237Np+21Ne	Lr 259 237Np+22Ne 232Th+27Al	Lr 260	Lr 261 247Cm+14N	Lr 262 247Cm+15N 248Cm+14N	248Cm+15N 244Pu+19F	
102					No Nobelium (259.1010)		No 250	No 251	No 252	No 253 233U+Ne20	No 254 234U+Ne20 206Pb+48Ca 230Th+24Mg 226Ra+28Si	No 255 235U+Ne20 207Pb+48Ca 236Np+19F	No 256 236U+Ne20 208Pb+48Ca 232Th+24Mg 226Ra+30Si	No 257 236U+21Ne	No 258 236U+Ne22 238U+Ne20	No 259 238U+21Ne 247Cm+12C	No 260 248Cm+12C 244Pu+16O		No 262	
101	Md Mendelevium (258.0984)		Md 245	Md 246	Md 247 197Au+50Ti	Md 248	Md 249 209Bi+40Ar	Md 250	Md 251 203Tl+48Ca	Md 252 233U+19F 236Np+16O	Md 253 234U+19F 205Tl+48Ca 237Np+16O 226Ra+27Al	Md 254 235U+19F 236Np+18O	Md 255 236U+19F 237Np+18O	Md 256	Md 257 238U+19F	Md 258 244Pu+14N 247Cm+11B	Md 259 244Pu+15N 248Cm+11B	Md 260		
100	Fm 242	Fm 243	Fm 244 209Bi+35Cl	Fm 245	Fm 246 209Bi+37Cl 206Pb+40Ar	Fm 247 207Pb+40Ar	Fm 248 208Pb+40Ar	Fm 249 233U+16O 200Hg+48Ca	Fm 250 234U+16O 226Ra+24Mg 230Th+20Ne 201Hg+48Ca	Fm 251 235U+16O 236Np+15N 237Np+14N 202Hg+48Ca	Fm 252 236U+16O 232Th+20Ne 237Np+15N 204Hg+48Ca	Fm 253 232Th+21Ne	Fm 254 238U+16O	Fm 255	Fm 256 244Pu+12C	Fm 257	Fm 258	Fm 259	Fm 260	
99	Es 241 209Bi+32S	Es 242	Es 243 208Pb+35Cl	Es 244 207Pb+37Cl	Es 245 208Pb+37Cl 197Au+48Ca	Es 246	Es 247 233U+14N	Es 248 233U+15N 236Np+12C	Es 249 234U+15N 230Th+19F 237Np+12C	Es 250 235U+15N	Es 251 236U+15N 232Th+19F	Es 252	Es 253 238U+15N	Es 254	Es 255 244Pu+11B	Es 256	Es 257			
98	Cf 240 208Pb+32S	Cf 241	Cf 242 194Pt+48Ca	Cf 243	Cf 244 196Pt+48Ca	Cf 245 233U+12C	Cf 246 233U+12C 226Ra+20Ne 230Th+16O 198Pt+48Ca	Cf 247 234U+12C 236Np+11B	Cf 248 235U+12C 232Th+16O 230Th+18O 237Np+11B	Cf 249 236U+12C	Cf 250 232Th+18O	Cf 251 238U+12C	Cf 252	Cf 253	Cf 254	Cf 255	Cf 256			

F.Khalfallah, PhD@IReS

NRV Excitation Function Calculations

Deformed Proton single particle energies

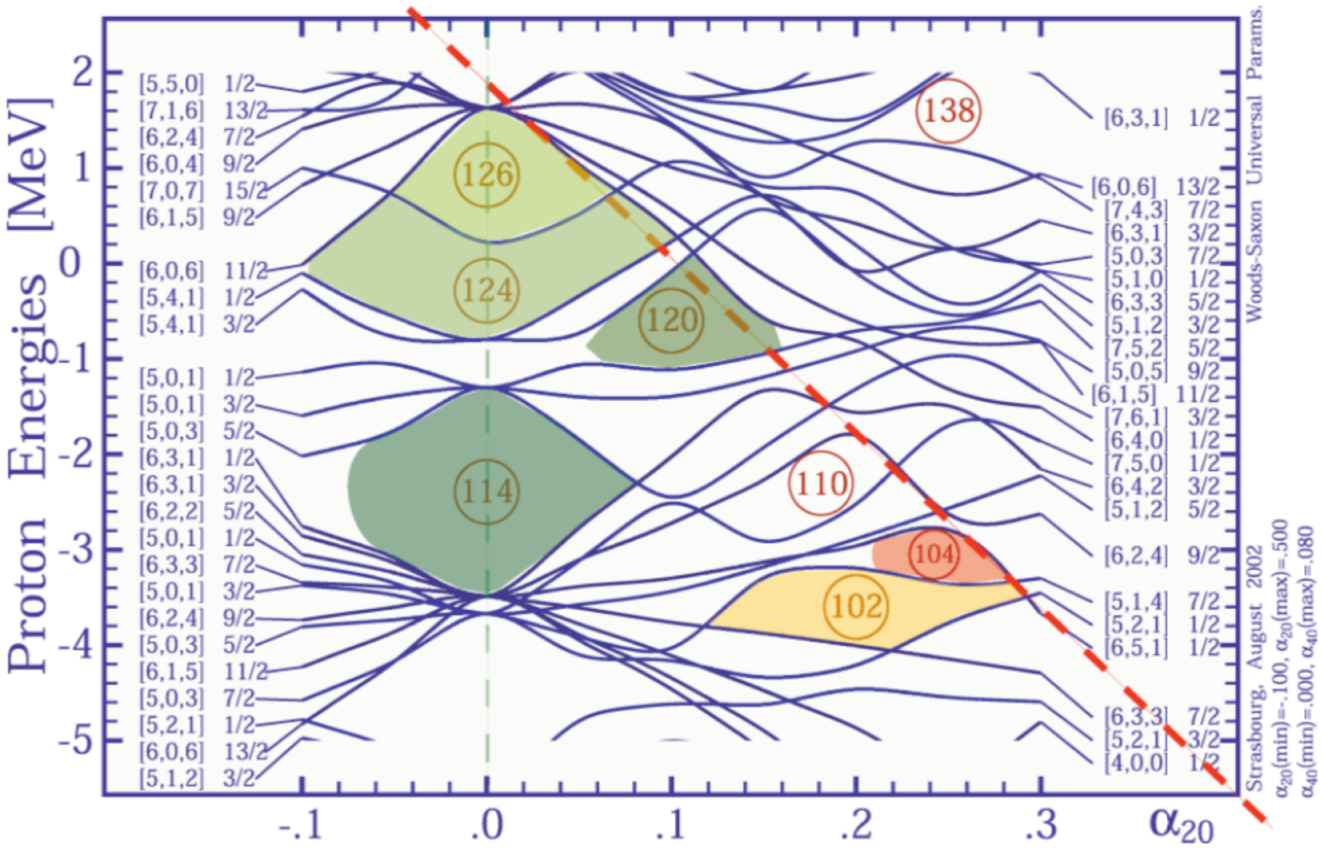


Fig. 1.: Proton single particle energies for VHE [Du02]

J. Dudek et al., private communication.

Deformed Neutron single particle energies

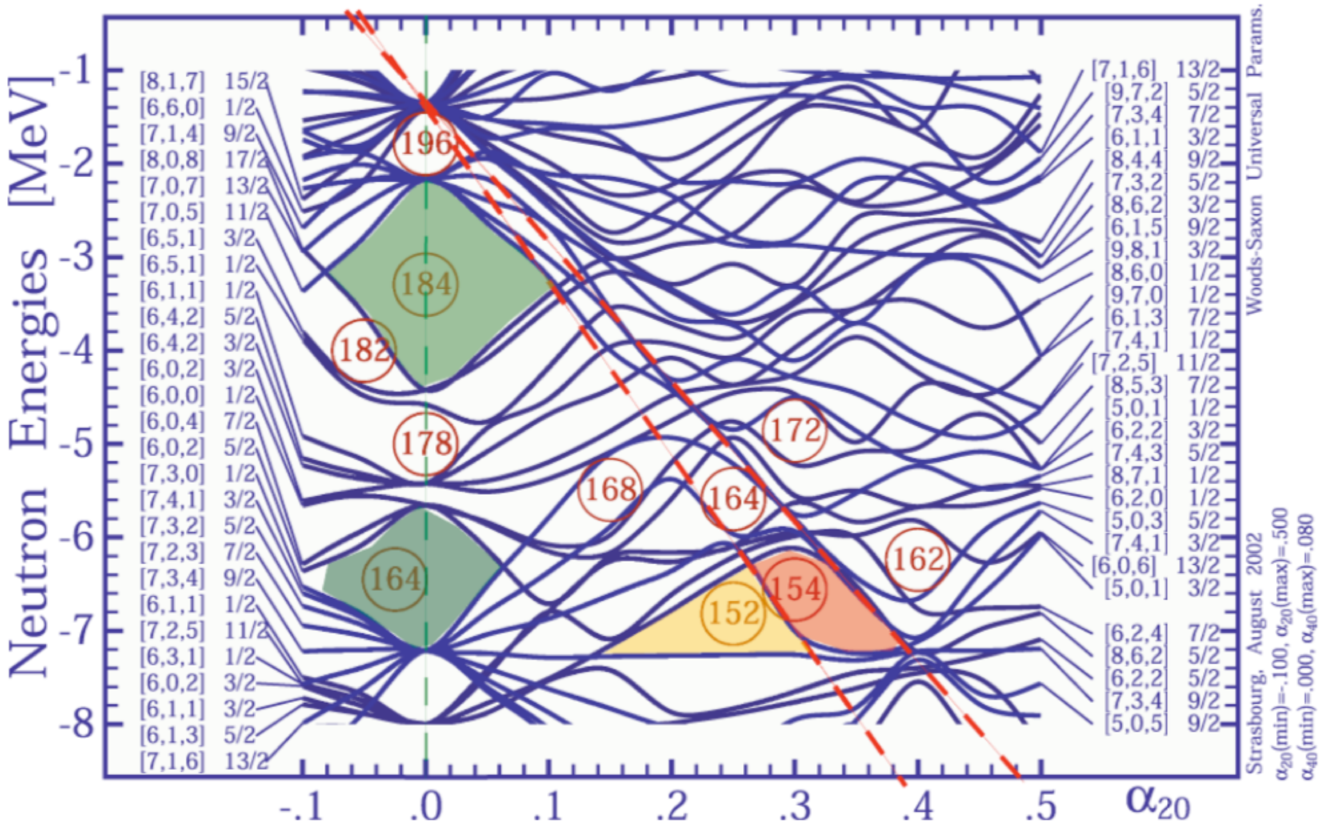
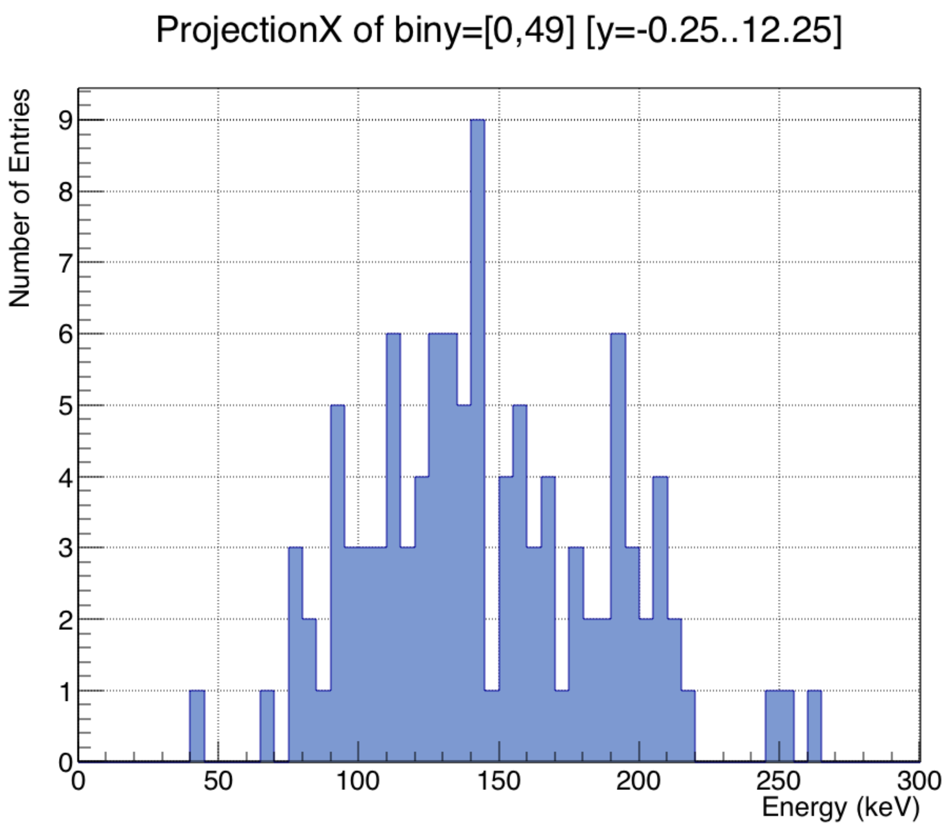
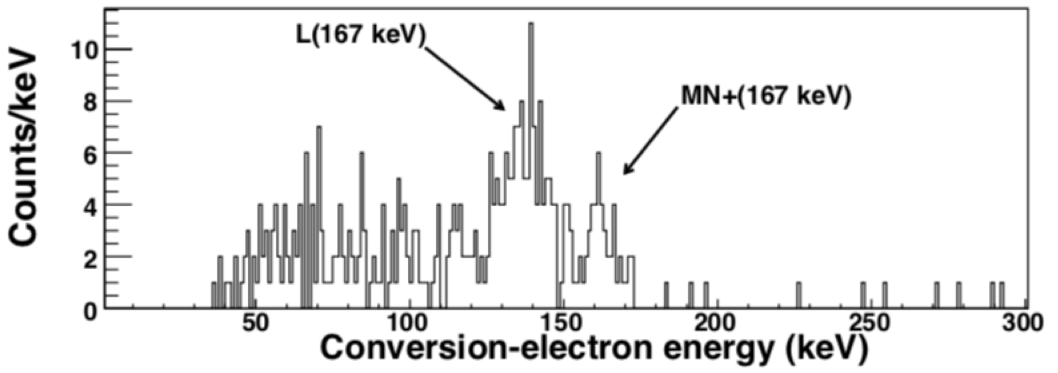


Fig. 2.: Neutron single particle energies for VHE [Du02]

J. Dudek et al., private communication.

Energy Conversion Electrons $^{255}No^{*}$





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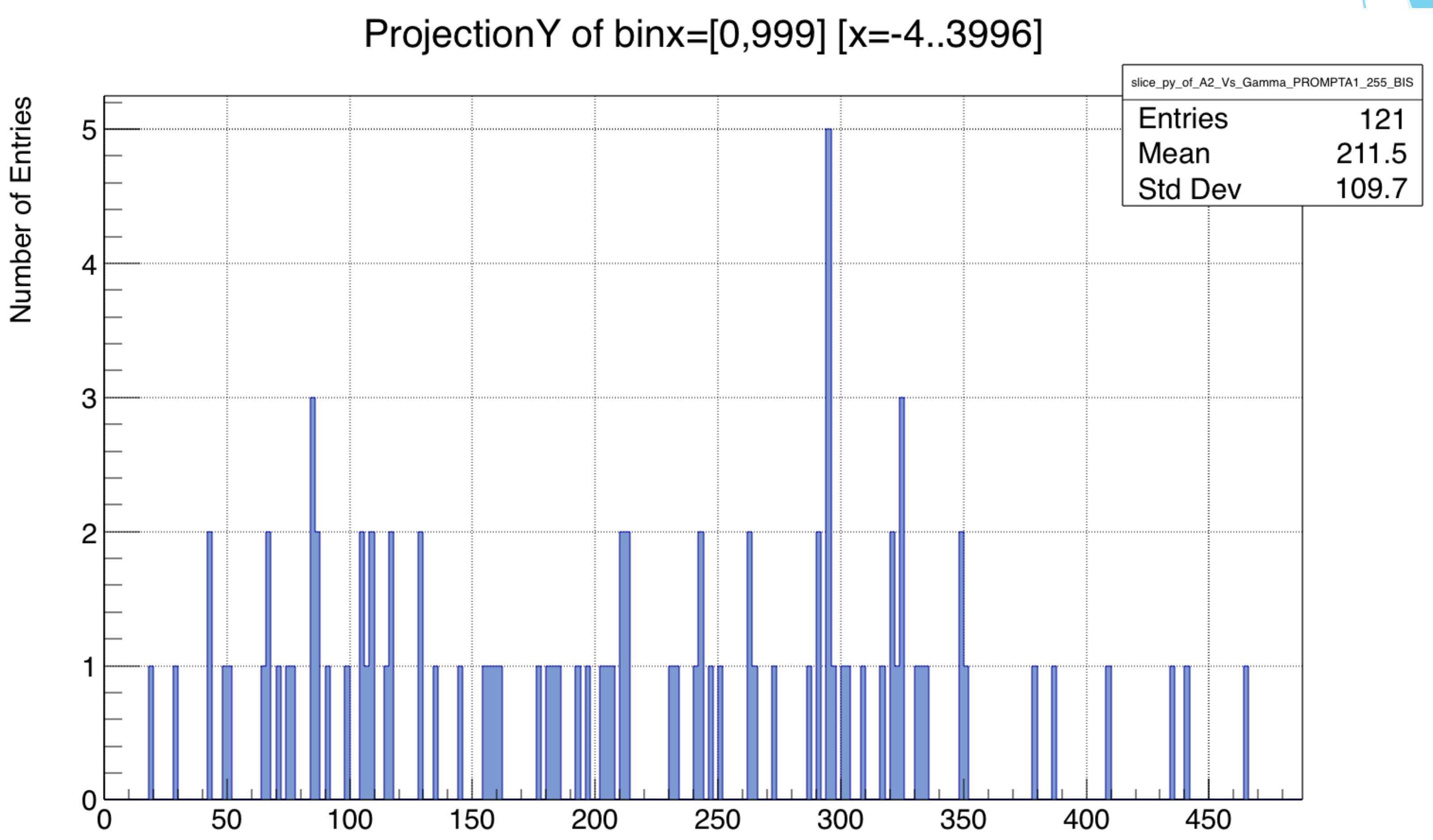
Gamma Prompt with Conversion Electron Energy

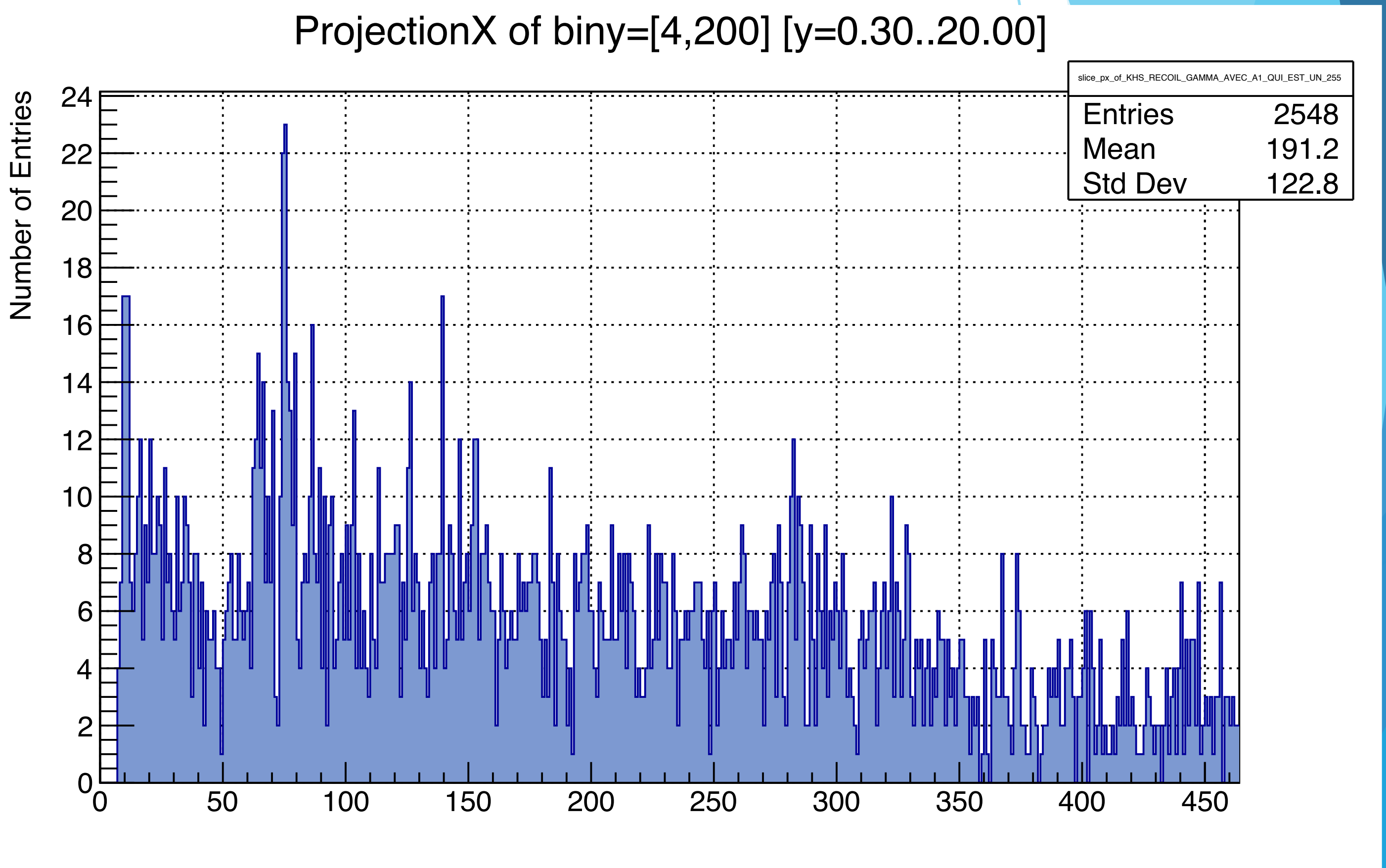


Conversion electrons spectrum

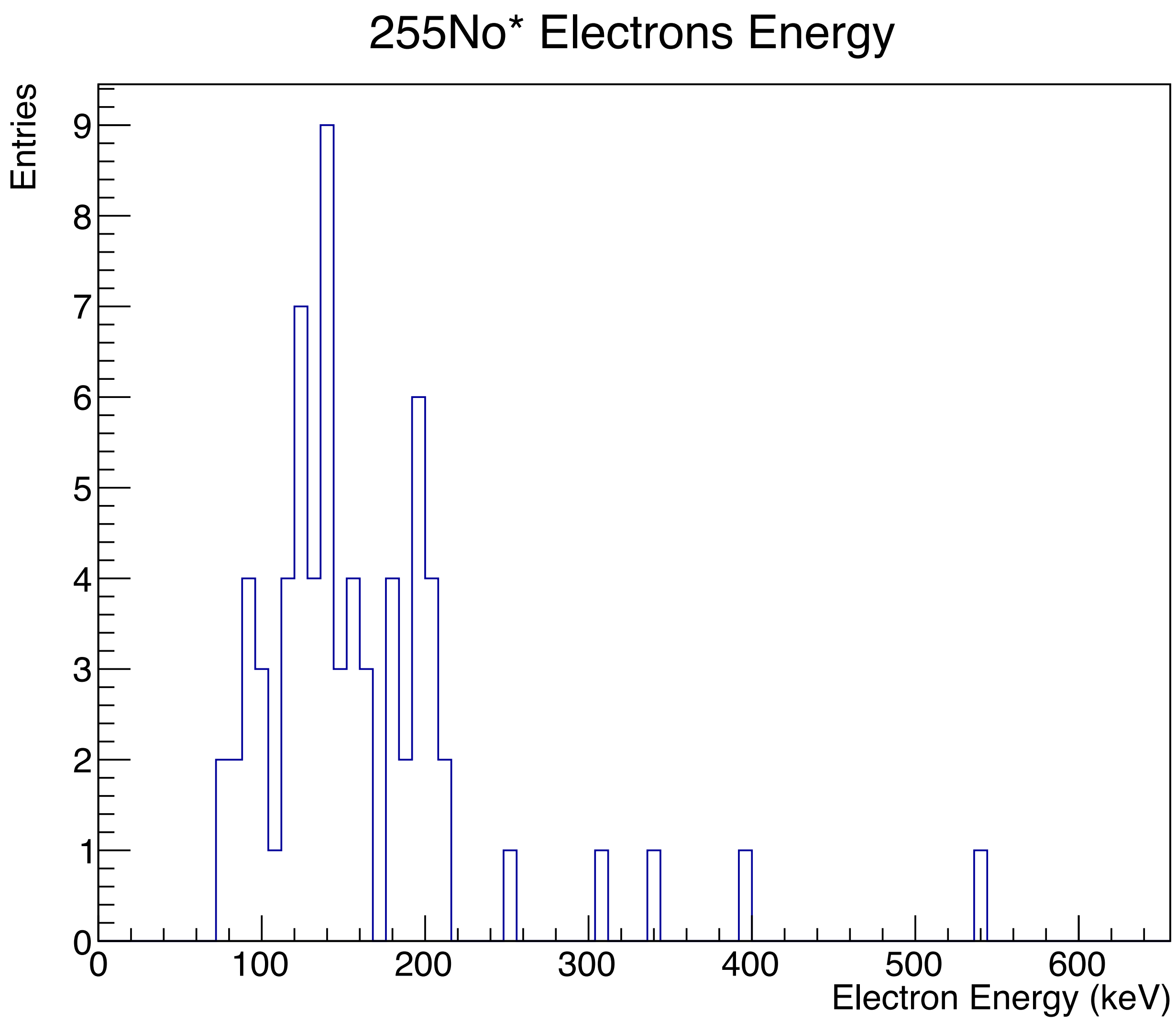
^{255}No*

- Projection of a recoil-gamma lifetime vs energy graph

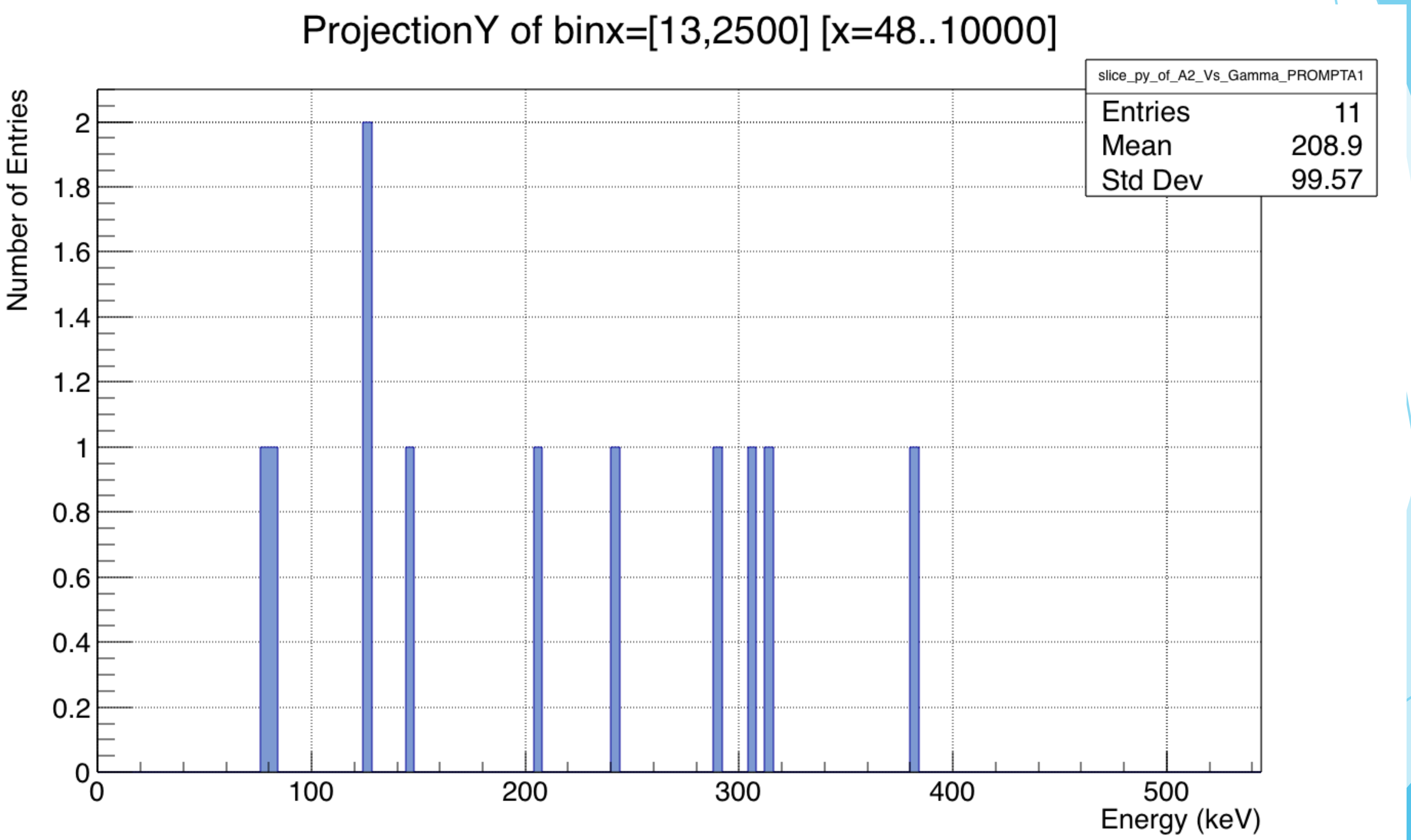
- With a 255No decay following in the same pixel to clean the spectrum



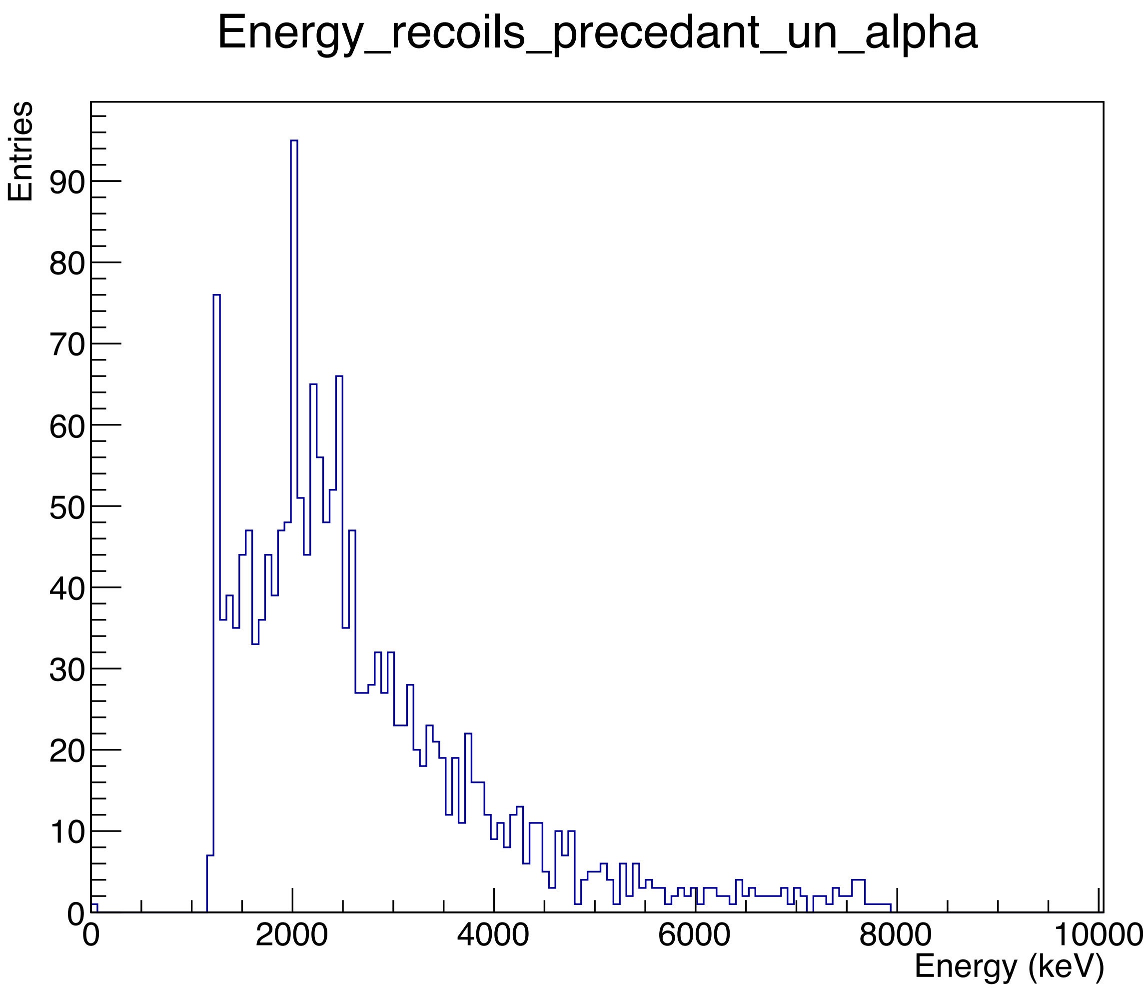
Conversion Electron Energy



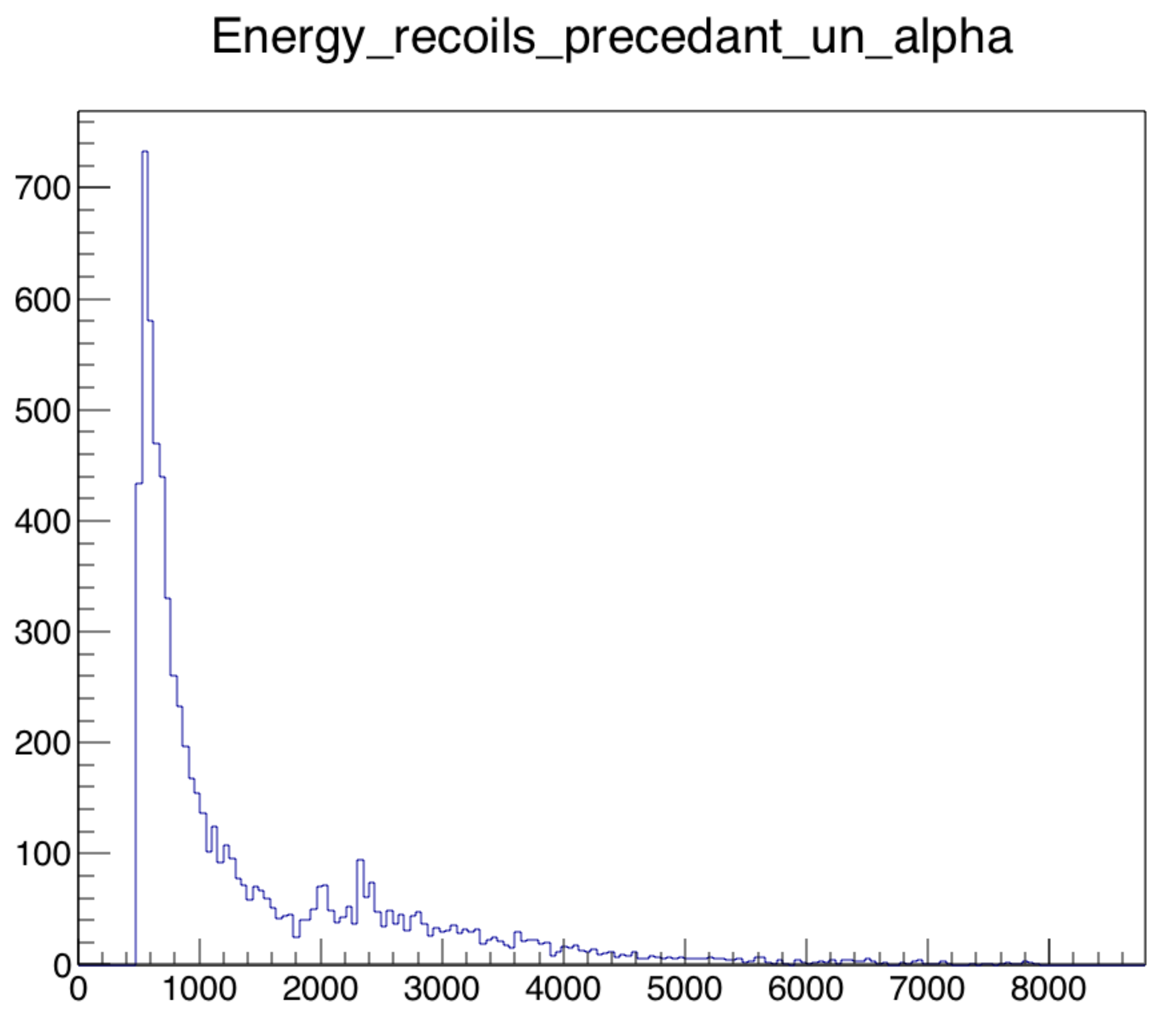
Conversion Electron Energy ^{256}No*



Recoil Distribution $^{22}Ne + ^{238}U$



Recoil Distribution $^{22}Ne+^{238}U$



Pic 8300 keV on decay runs