Mid-term defense :

Study of isomeric states in so-called superheavy nuclei

Speaker: **Margaux Forge**, 2nd year PhD Student
Director: **Olivier Dorvaux**, professor in University of Strasbourg
Group: **Du noyau aux étoiles**, IPHC / University of Strasbourg

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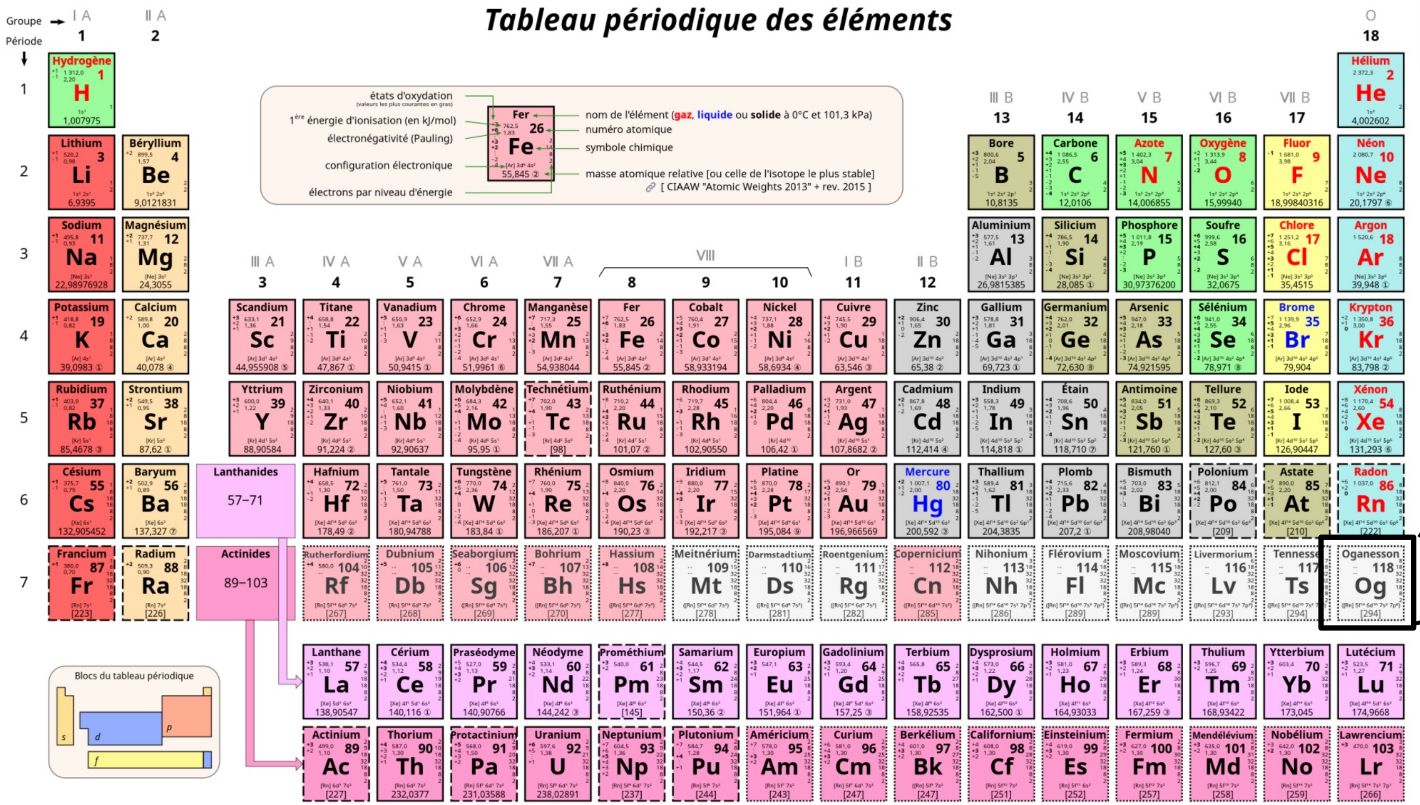
Aux limites du monde atomique…



JINR FLNR Dubna

$$^{48}_{20}Ca + ^{249}_{98}Cf \rightarrow ^{294}_{118}Og + 3n$$

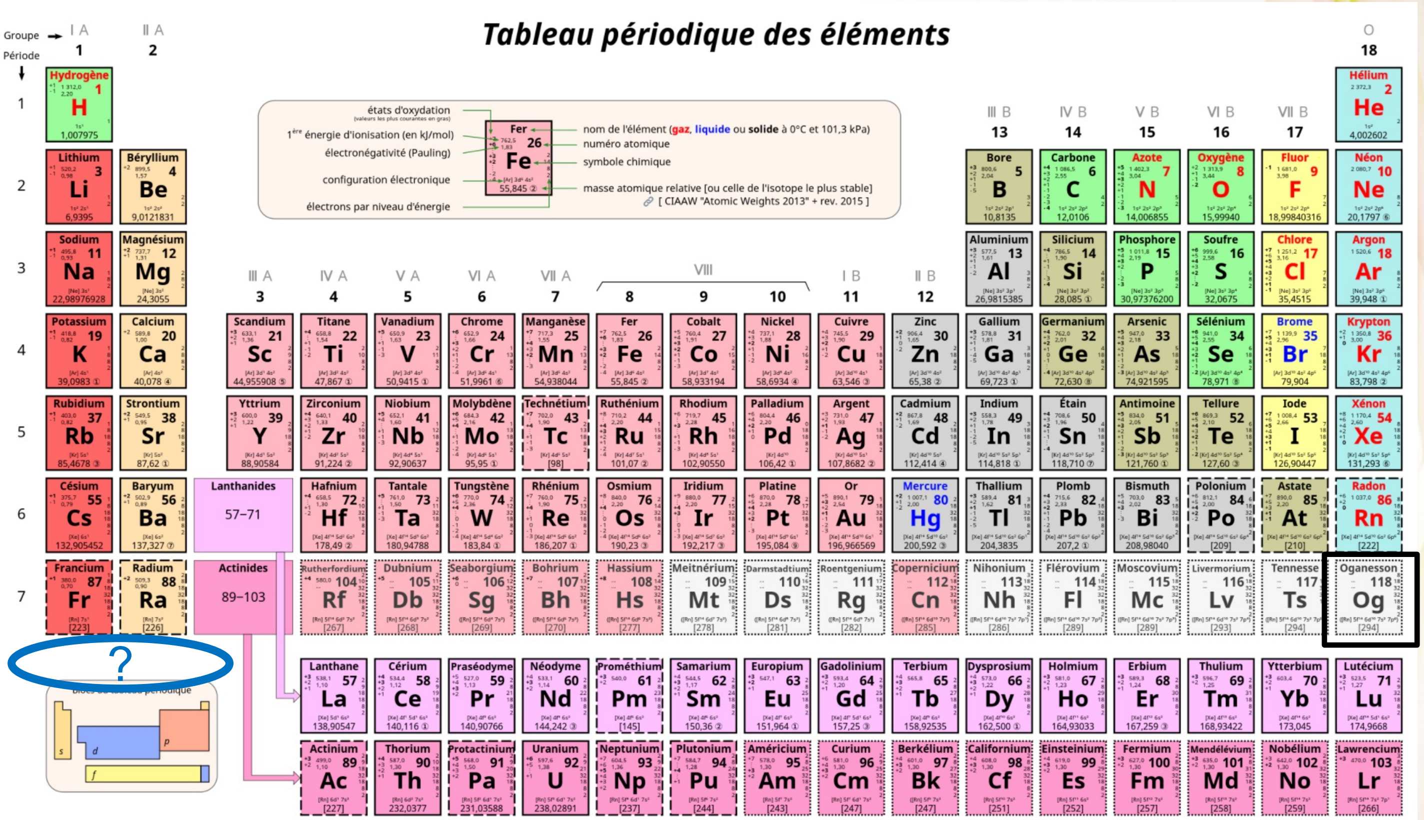
Yuri Oganessian

Z=118 element

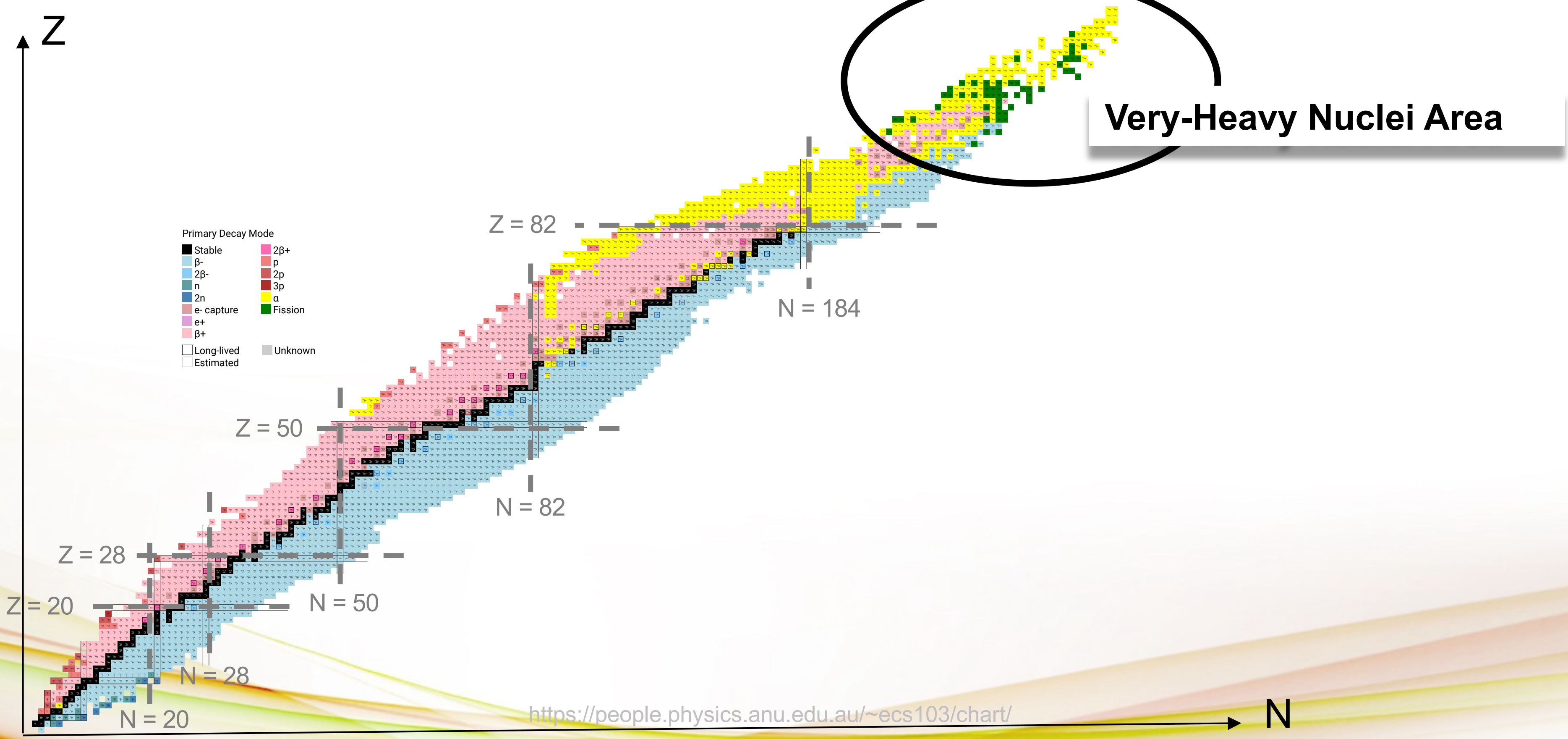
Aux limites du monde atomique…

Next element :
Z = 119

Add another period?



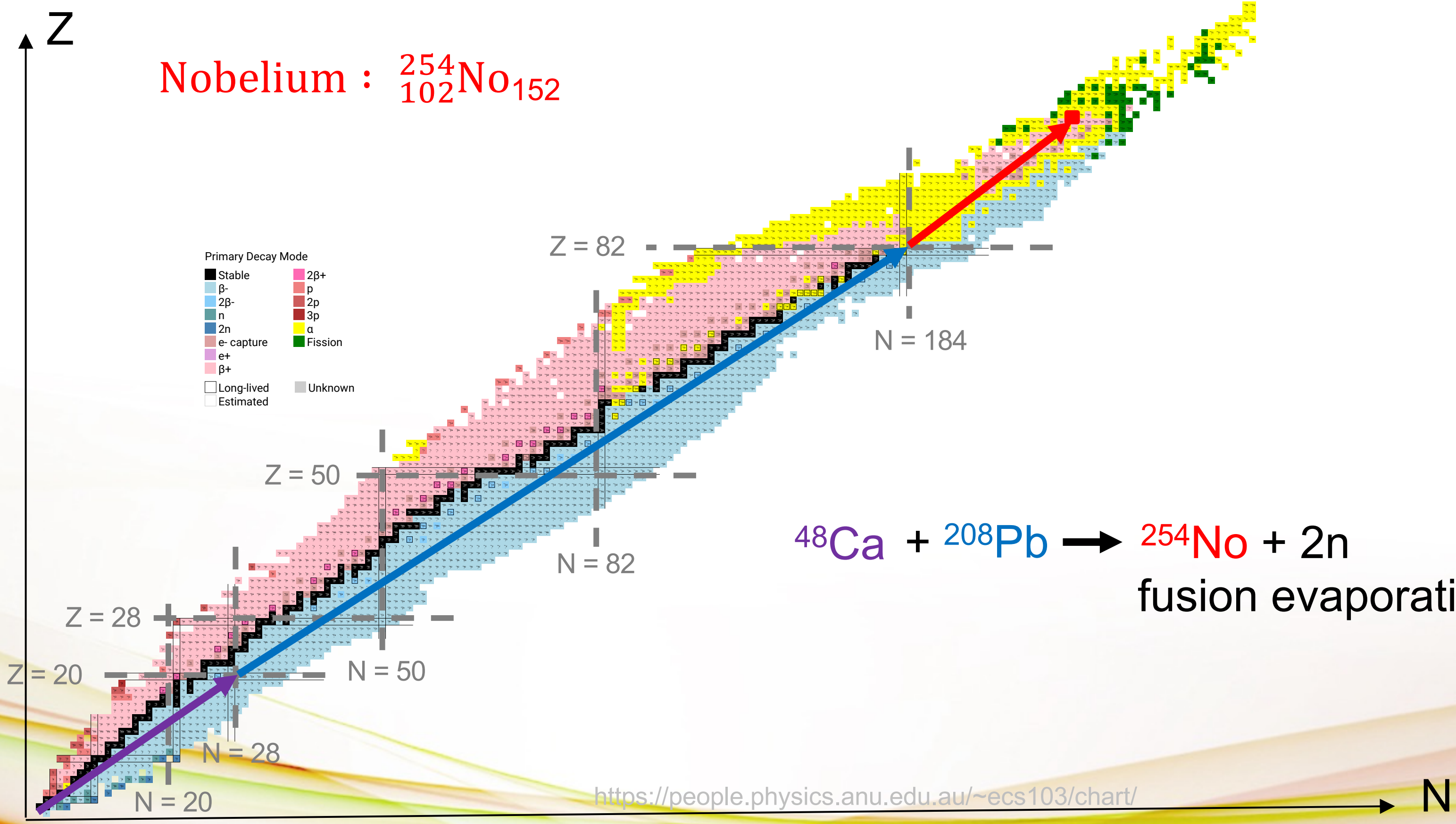
Motivation



Z
N
Very-Heavy Nuclei Area
Z = 82
Z = 50
Z = 28
Z = 20
N = 184
N = 82
N = 50
N = 28
N = 20
Primary Decay Mode
Stable
β-
2β-
n
2n
e- capture
e+
β+
2β+
p
2p
3p
α
Fission
Long-lived
Estimated
Unknown
https://people.physics.anu.edu.au/~ecs103/chart/

Motivation

Nobelium : $^{254}_{102}No_{152}$



$^{48}Ca + ^{208}Pb \longrightarrow ^{254}No + 2n$

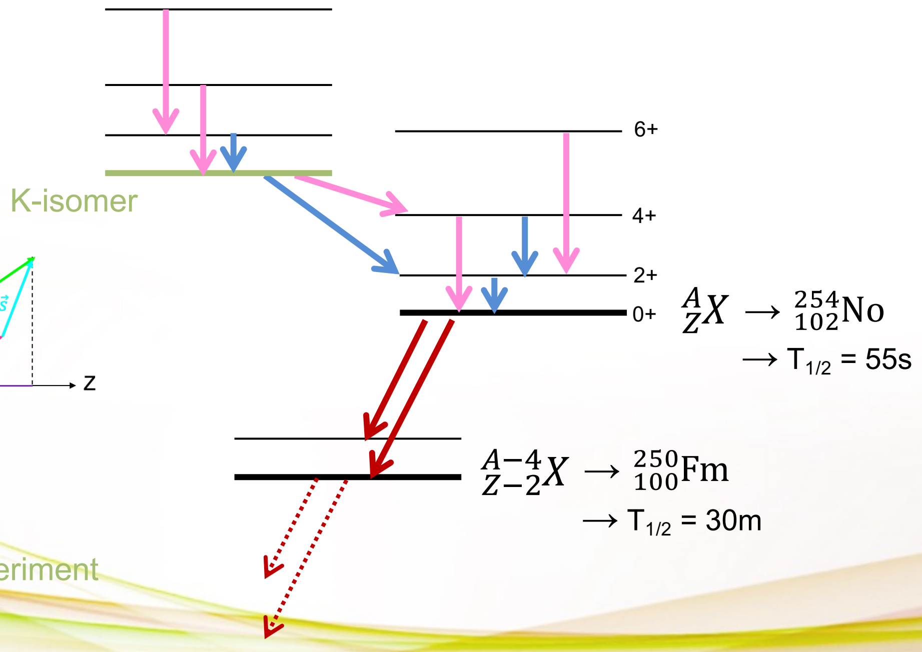
fusion evaporation reaction

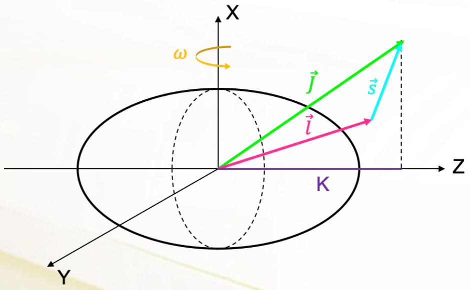
Isomers in decay spectroscopy

Decay spectroscopy studies:

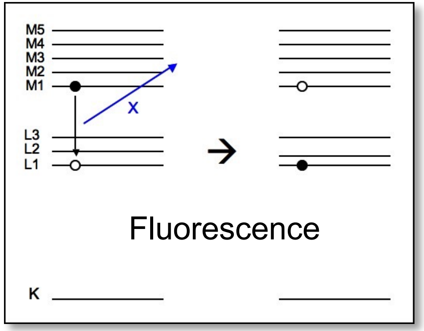
We detect all the possible emissions from the nuclei such as :

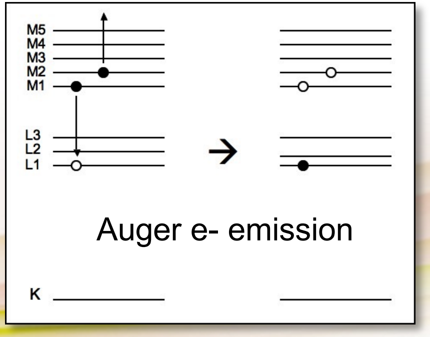
γ emission | α decay | Internal conversion electrons (ICE) | + Atomic relaxation after ICE





= Long lifetime (>μs)
= Detectable by the experiment





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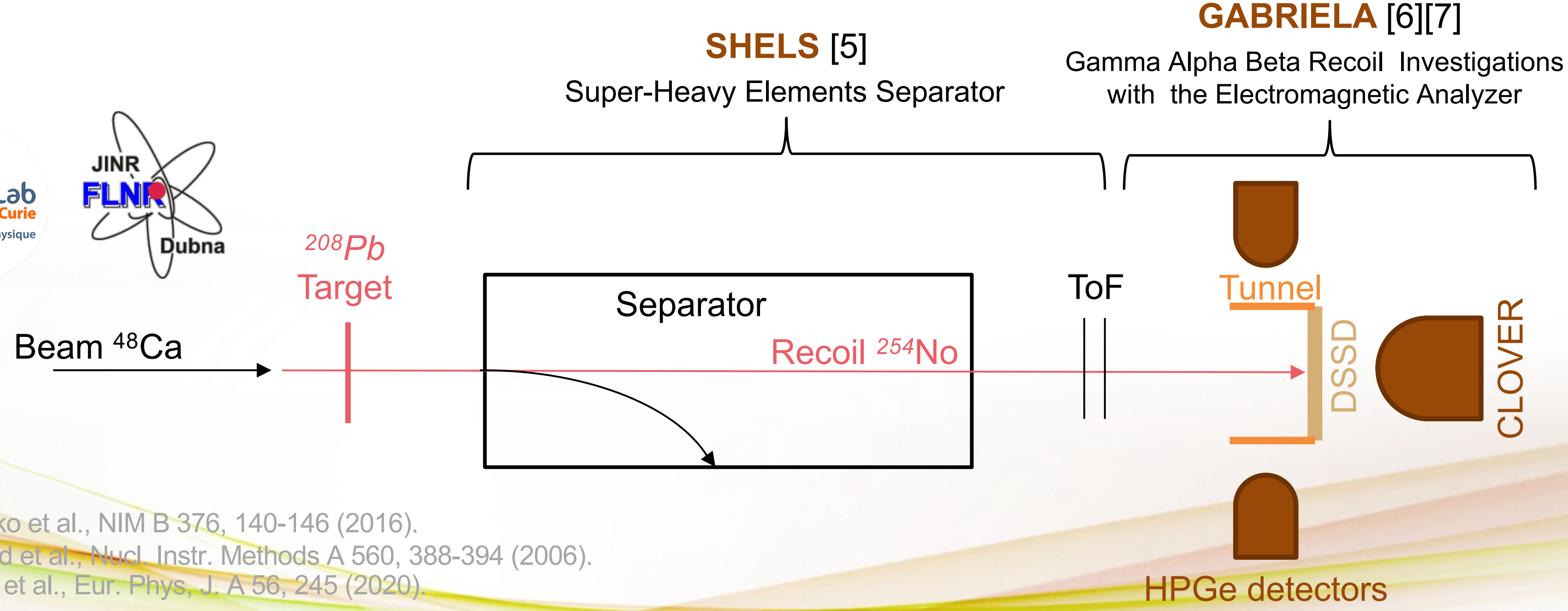
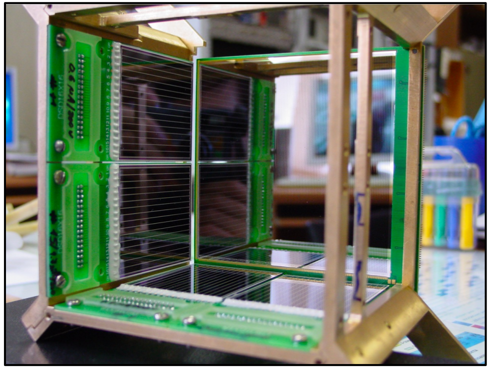
GABRIELA @ SHELS

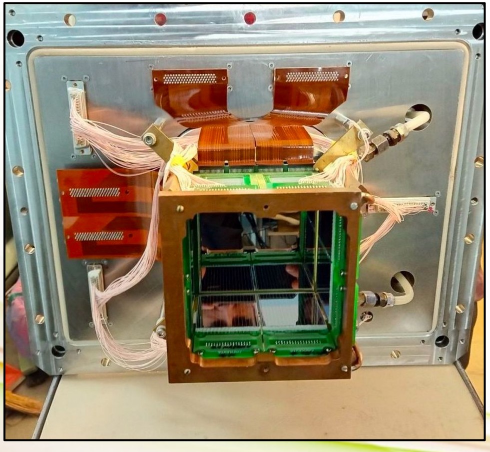
- Separator SHELS (JINR-IN2P3 collaboration) from existing VASSILISSA separator
- Time of Flight *(2 MCP)*
- Implantation detector *(1 DSSD 128x128, 100.4 x 100.4 mm²)*
- Tunnel detectors *(4x2 DSSD 72x72, 50 x 60 mm², 0.7 mm thick)*
- High Pure Germanium detectors *(4 monocrystals + CLODETTE clover)*

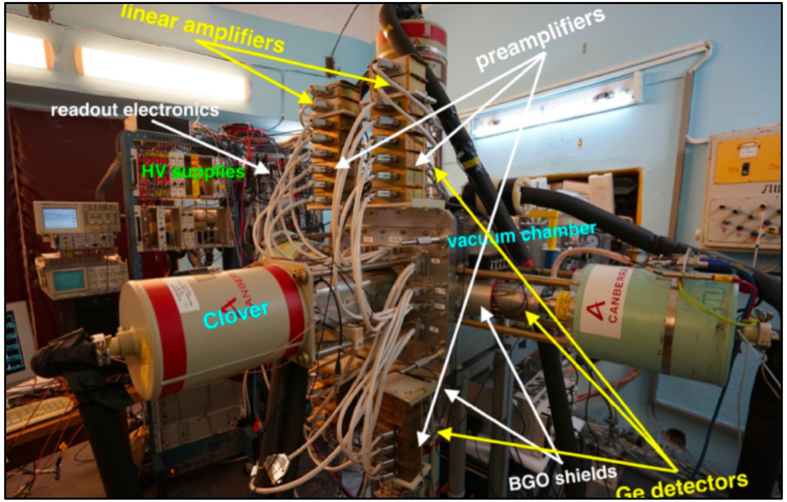


A. G. Popeko et al., NIM B 376, 140-146 (2016).
K. Hauschild et al., Nucl. Instr. Methods A 560, 388-394 (2006).
R. Chakma et al., Eur. Phys. J. A 56, 245 (2020).

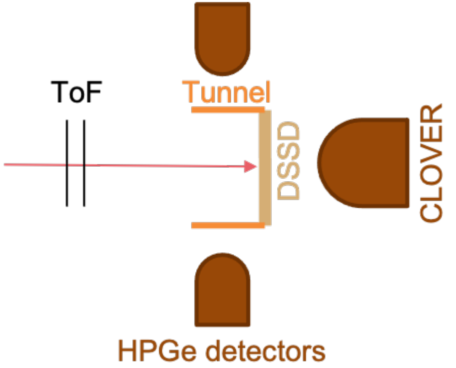
GABRIELA @ SHELS



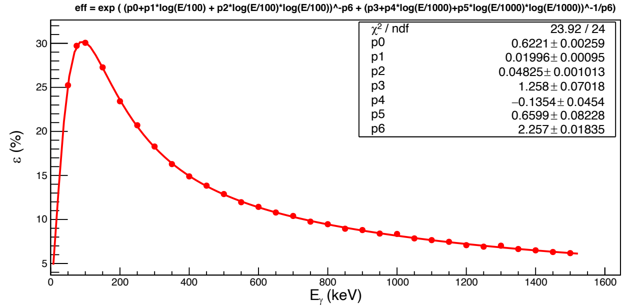




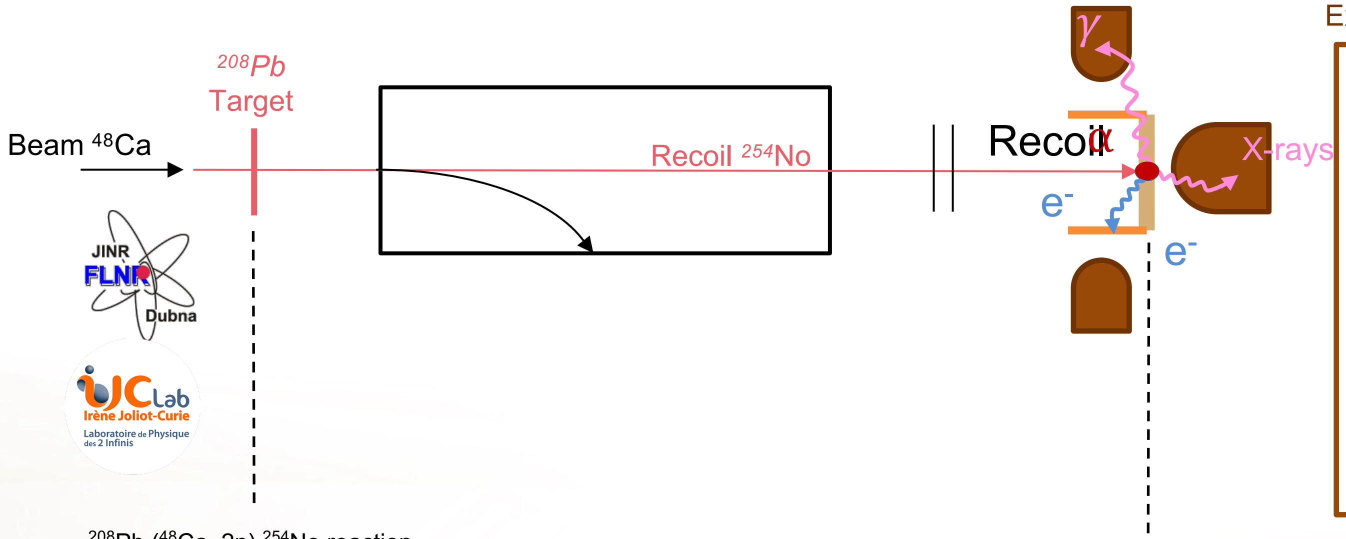
Photos taken from thèse de Kseniia Rezynkina (2016)



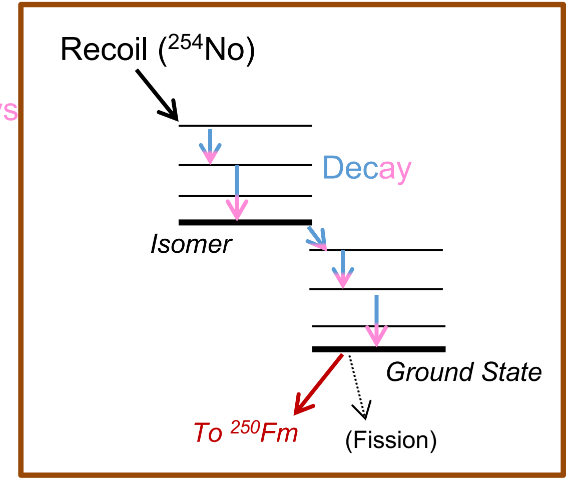
Efficiency largely improved



Genetic Correlations (Time + Space)

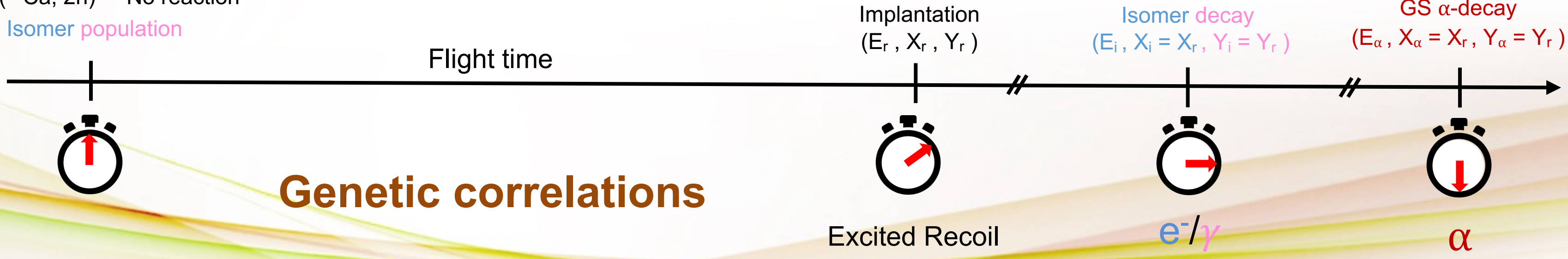


Example with a schematic nuclear structure



^{208}Pb (^{48}Ca, 2n) ^{254}No reaction

Isomer population



Genetic correlations

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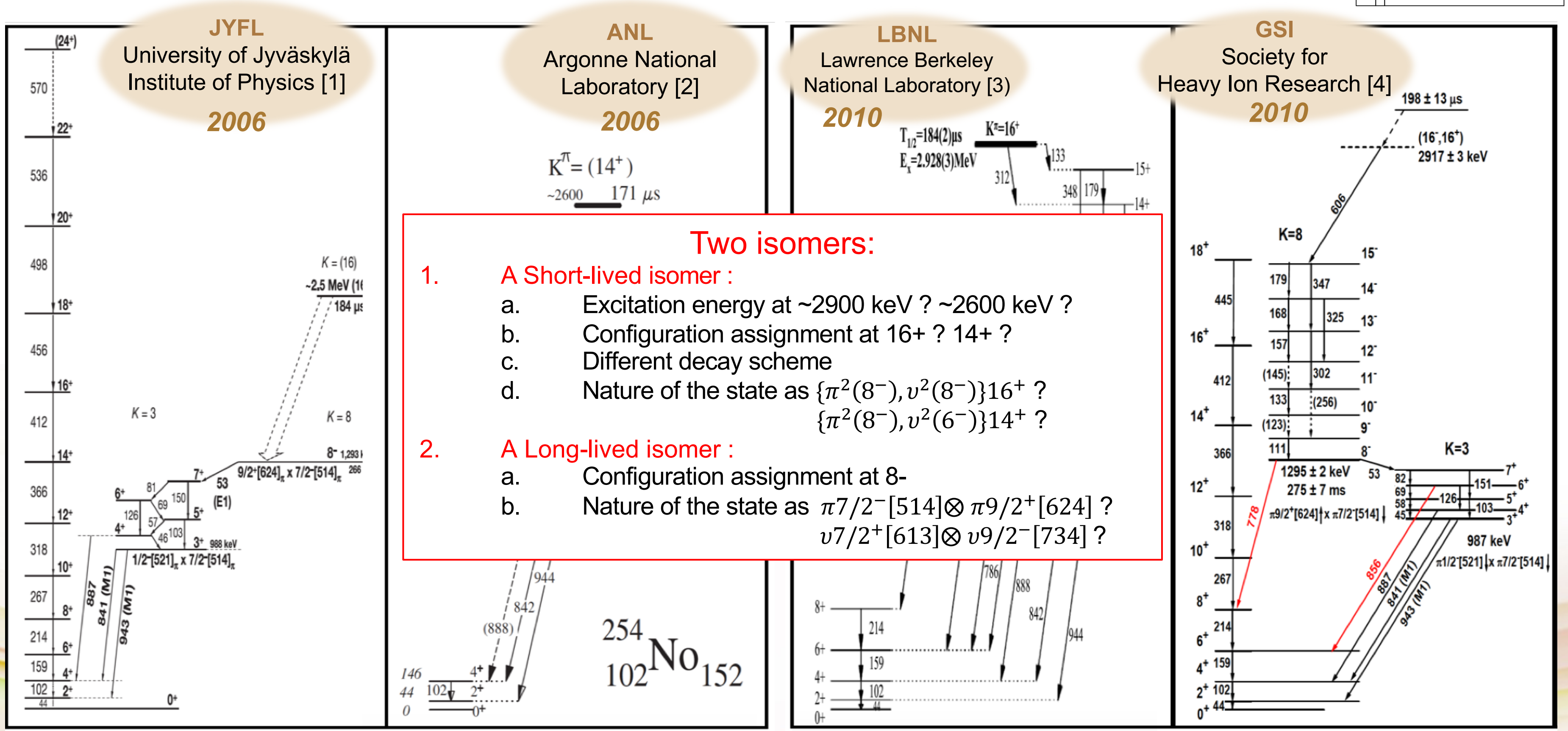
Past experiments & disagreements



Two isomers:

1. A Short-lived isomer :
   a. Excitation energy at ~2900 keV ? ~2600 keV ?
   b. Configuration assignment at 16+ ? 14+ ?
   c. Different decay scheme
   d. Nature of the state as $\{\pi^2(8^-), \upsilon^2(8^-)\}16^+$?
      $\{\pi^2(8^-), \upsilon^2(6^-)\}14^+$?
2. A Long-lived isomer :
   a. Configuration assignment at 8-
   b. Nature of the state as $\pi 7/2^-[514] \otimes \pi 9/2^+[624]$?
      $\upsilon 7/2^+[613] \otimes \upsilon 9/2^-[734]$?

Experiment's parameters

^{208}Pb (^{48}Ca, 2n) ^{254}No reaction

- October 2019 (3 years ago)
- 3 weeks of beamtime

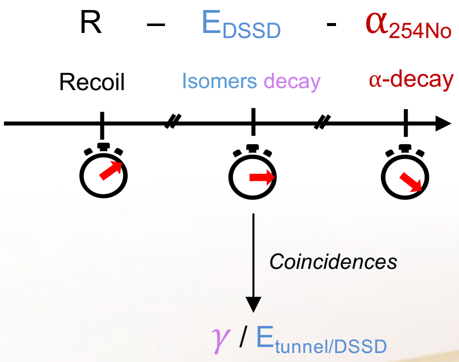
- 208Pb Target (99,99% pure)
- 233µg/cm^2 1.5 µm Titanium backing

- ^{48}Ca beam
- Intensity = 300 – 400pnA = 1,8E12– 2,5E12 pps
- Beam Energy = 225 – 228 MeV

- Calibration in α and e^-: ^{164}Dy(^{48}Ca,xn)$^{212-xn}$Rn reaction
  γ : ^{133}Ba and ^{152}Eu sources

Parameters used for data analyze :

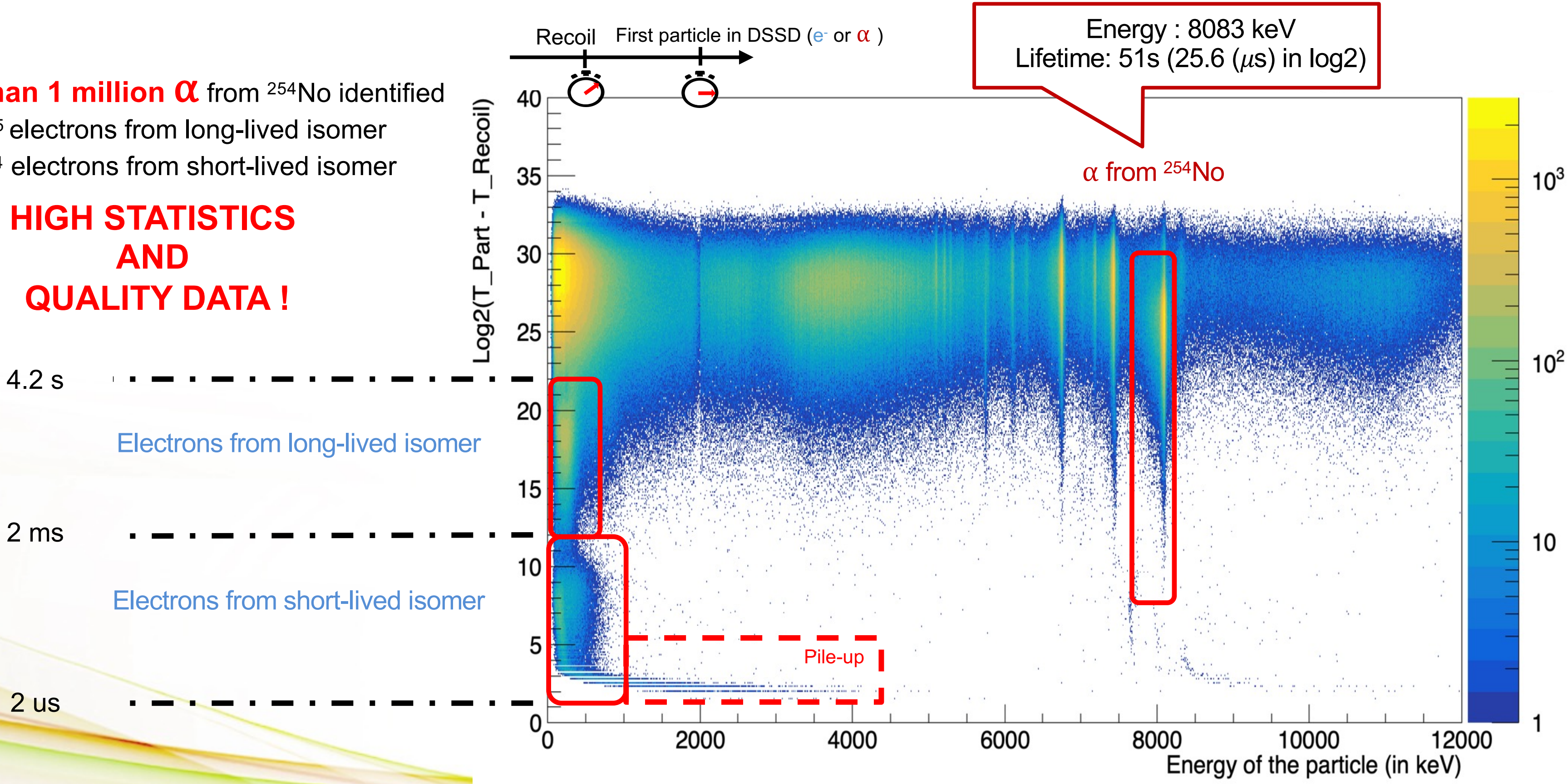
1. With BGO Veto (Anti-Compton detector)
2. With / Without Add Back for the CLOVER detector
3. Correlations :



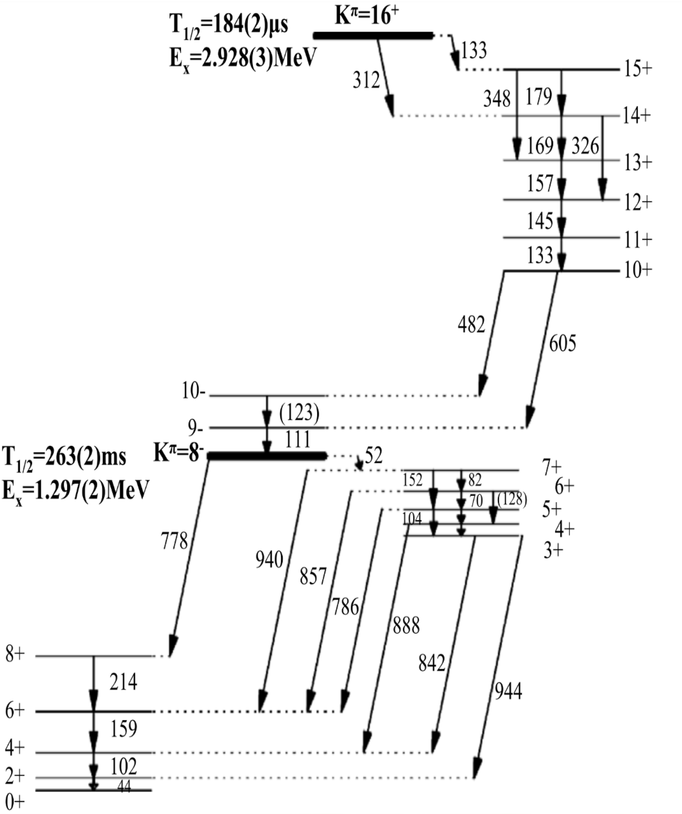
Energy – Lifetime correlation graph

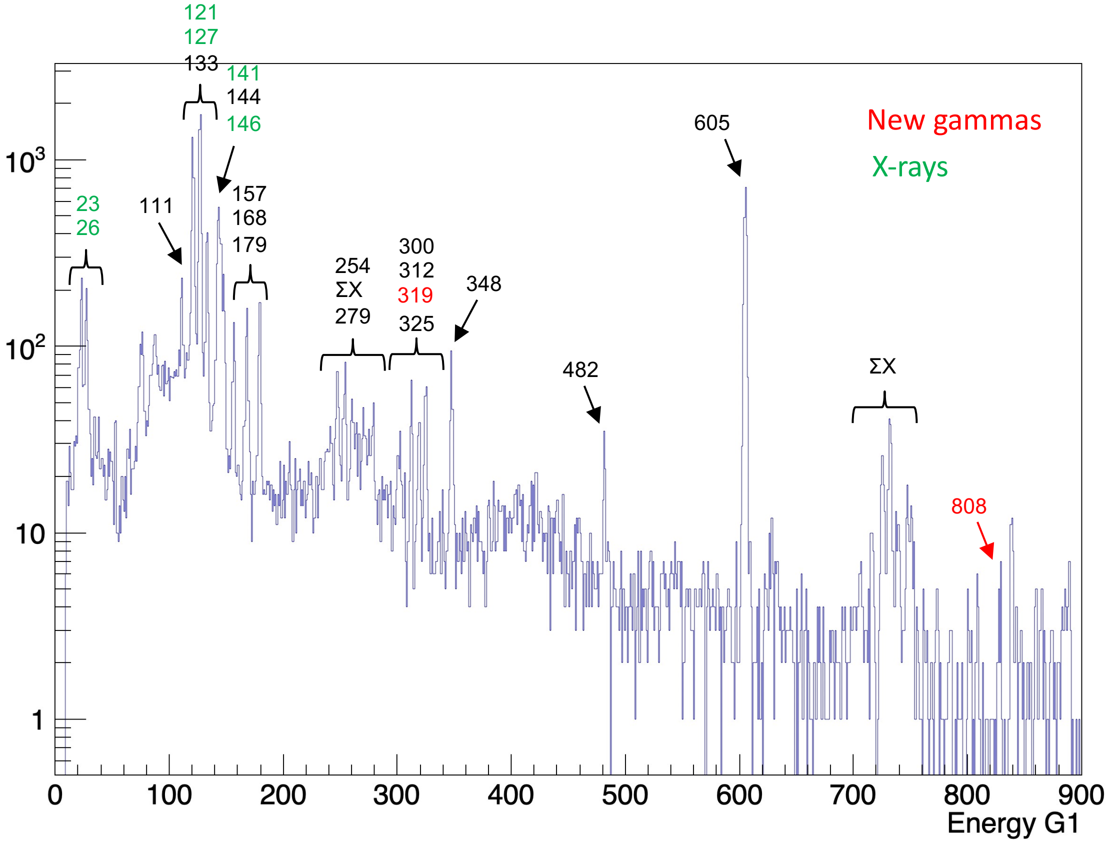
- **More than 1 million α** from ^{254}No identified
- 6.6 x 10^5 electrons from long-lived isomer
- 1.2 x 10^4 electrons from short-lived isomer

HIGH STATISTICS AND QUALITY DATA !



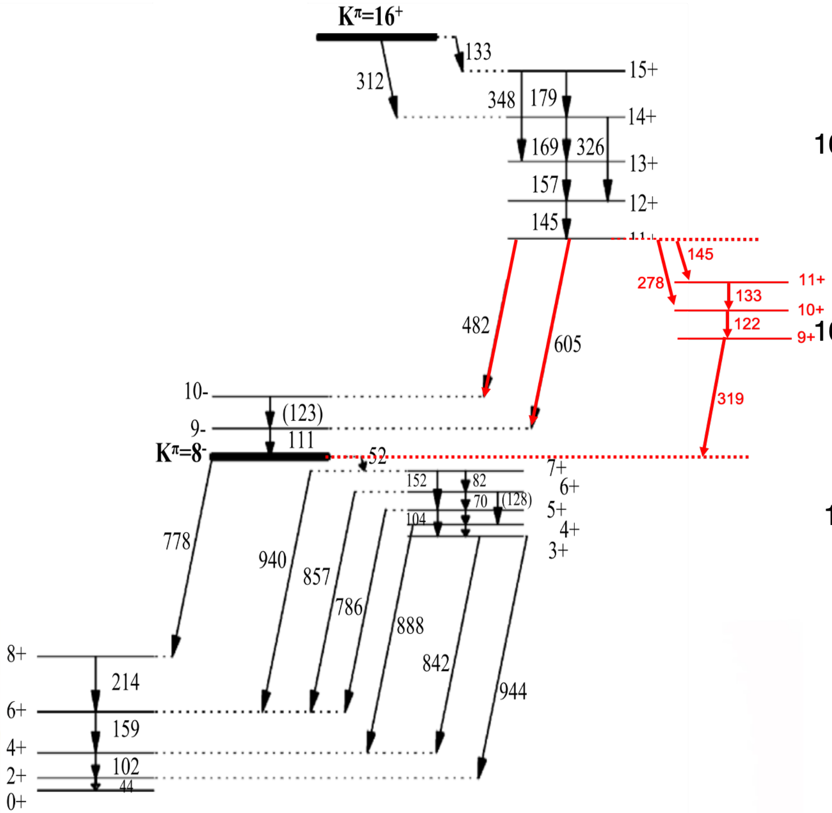
Coincidence with short-lived isomer

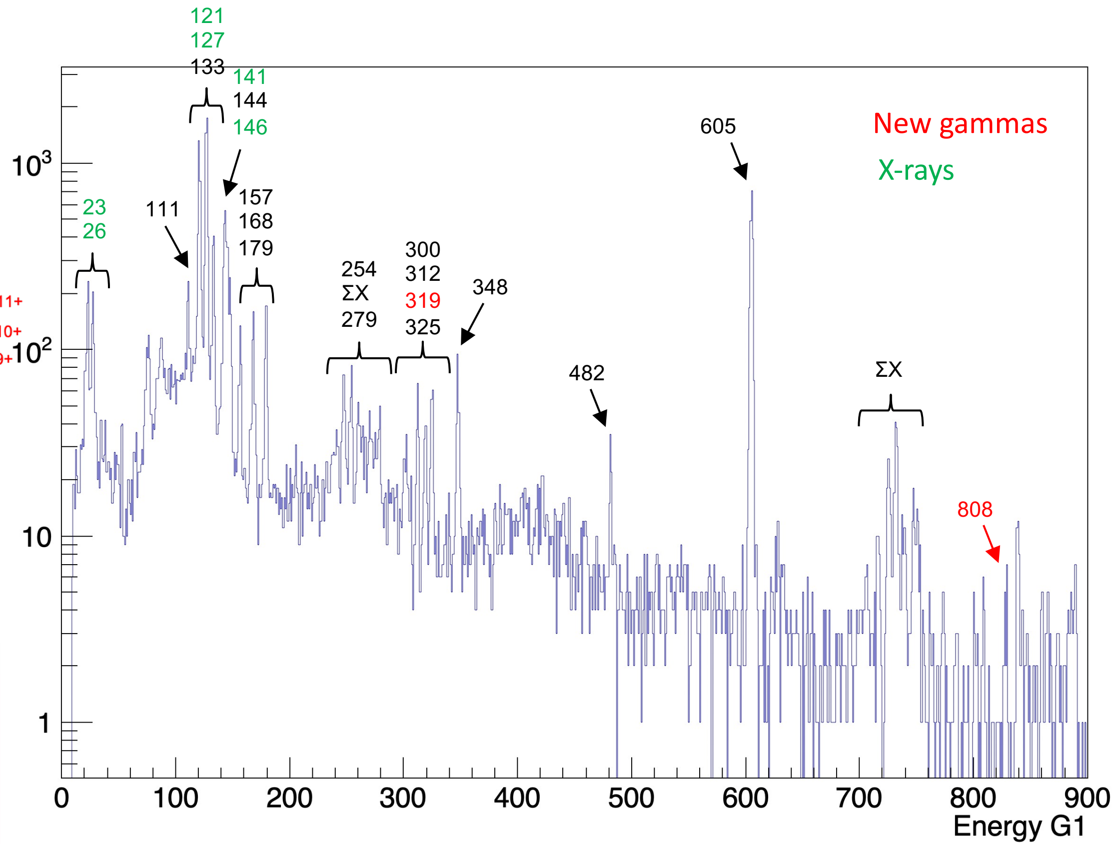




R. M. Clark et al., Phys. Lett. B B 690 (2010) 19.

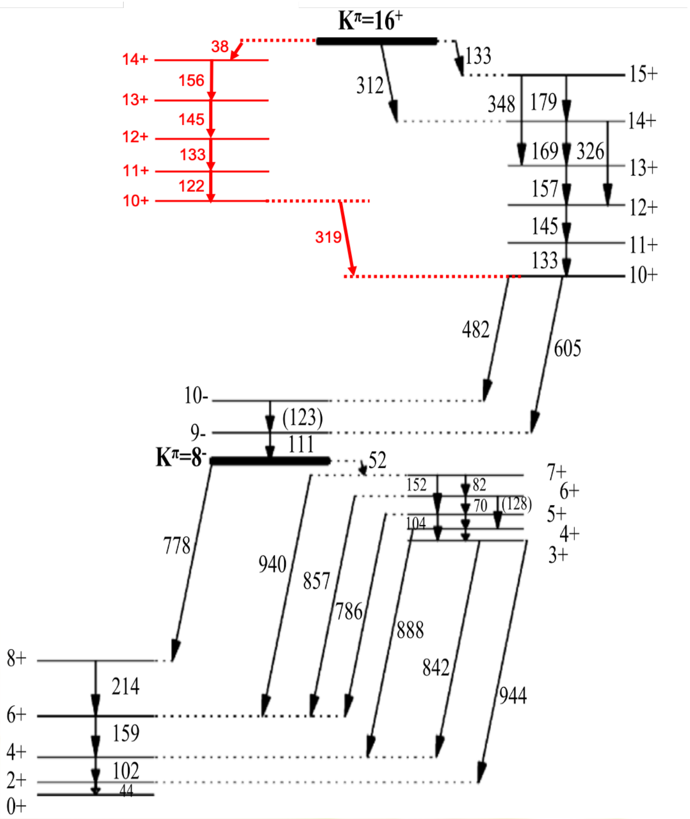
Coincidence with short-lived isomer



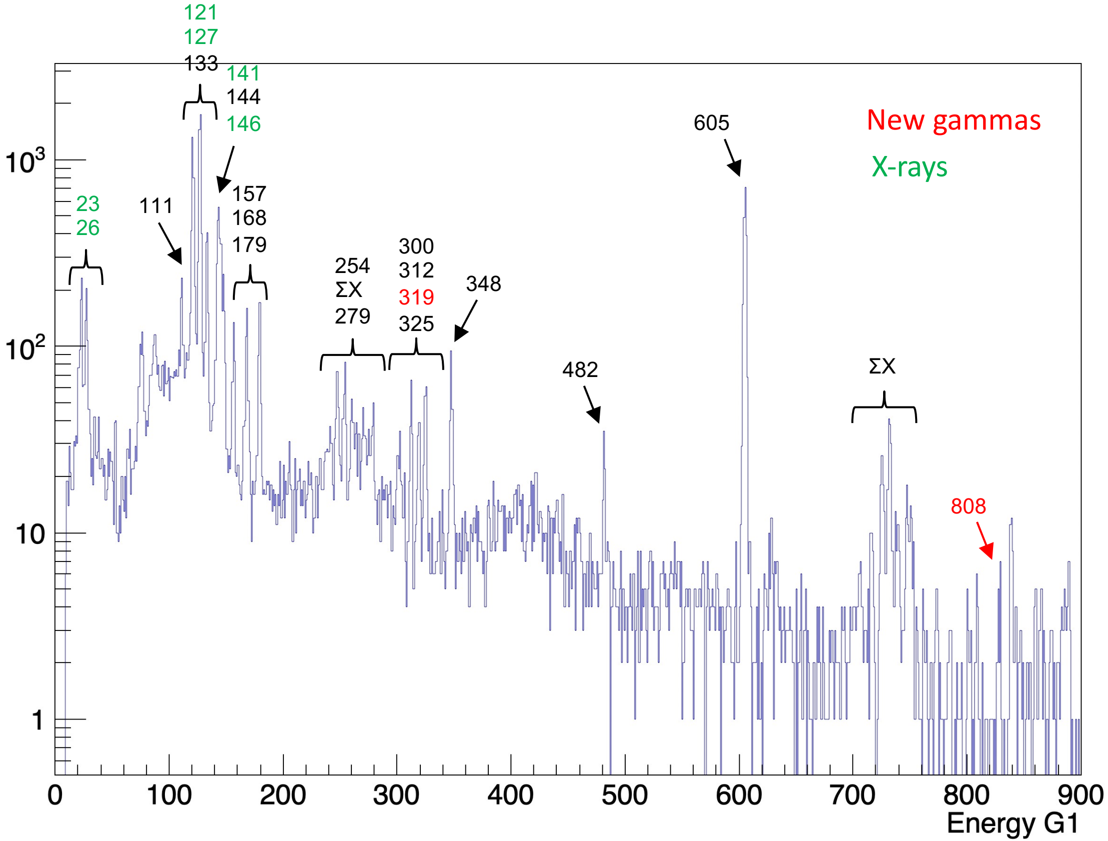


R. M. Clark et al., Phys. Lett. B B 690 (2010) 19.

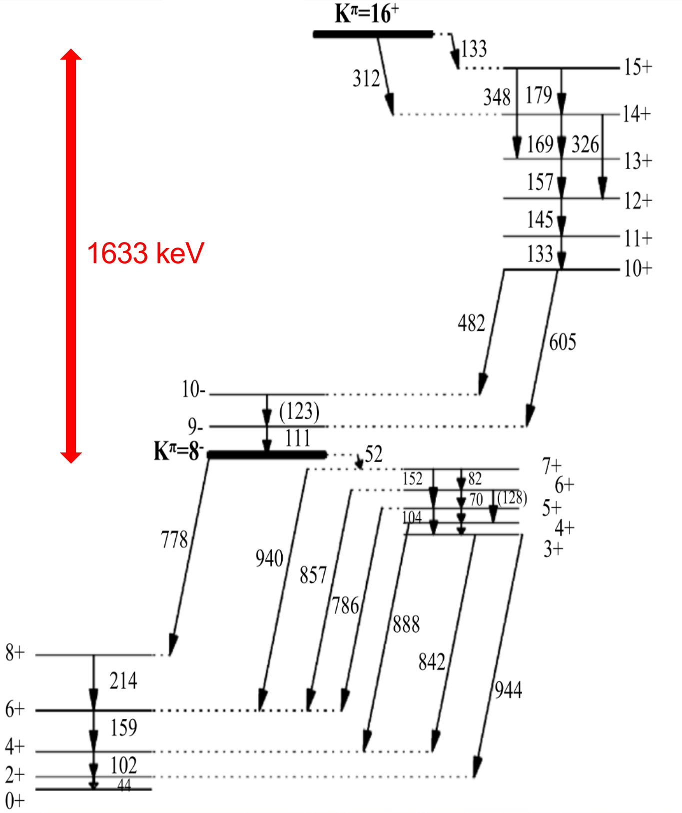
Coincidence with short-lived isomer



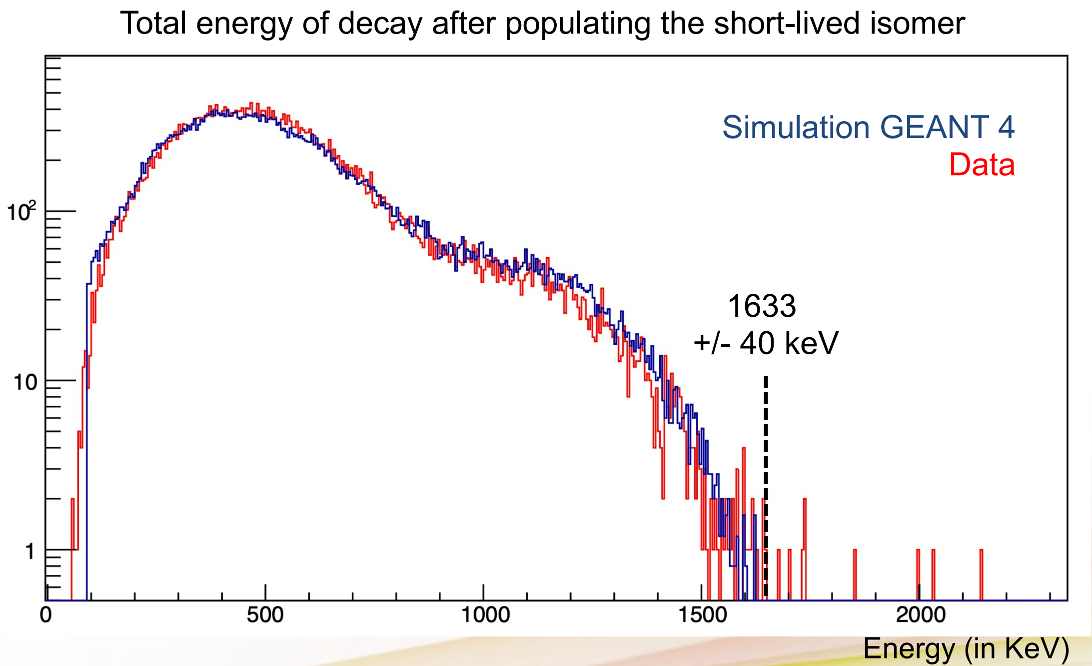
R. M. Clark et al., Phys. Lett. B B 690 (2010) 19.



Coincidence with short-lived isomer

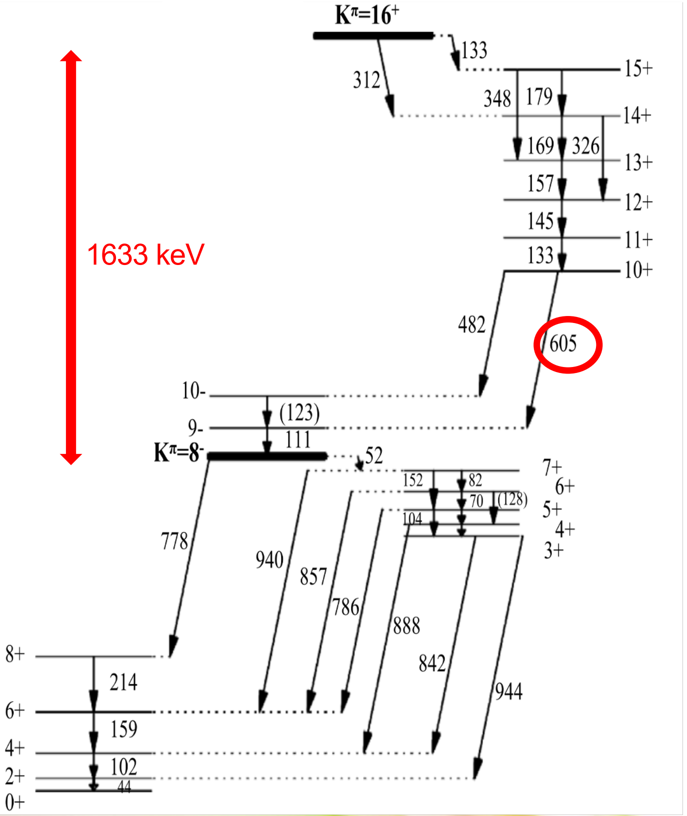


R. M. Clark et al., Phys. Lett. B B 690 (2010) 19.



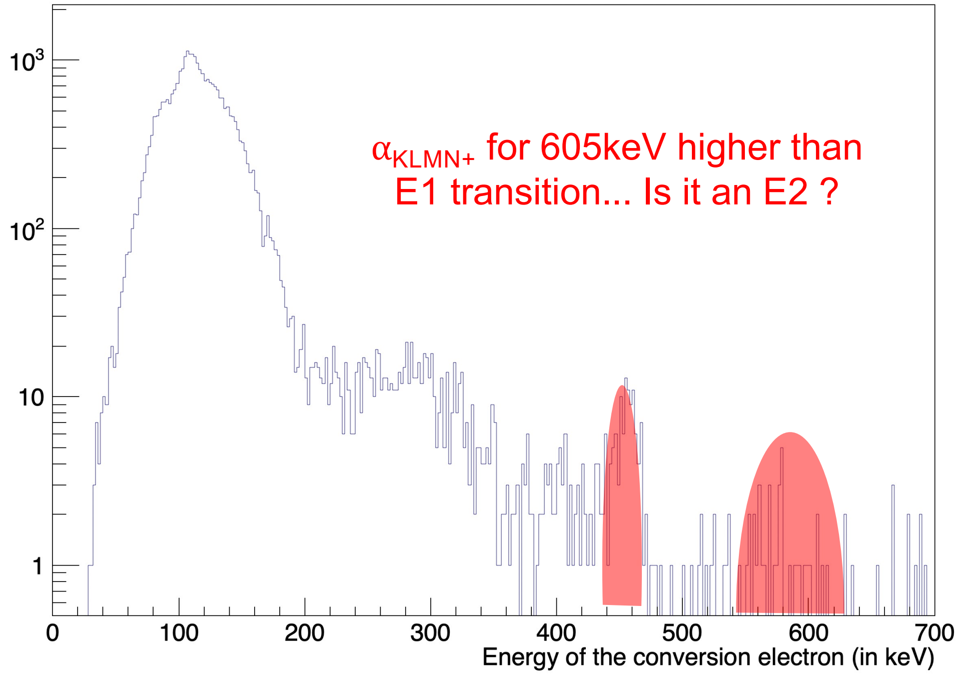
Graph of GEANT 4 simulation built by A. Lopez Martenz

Coincidence with short-lived isomer

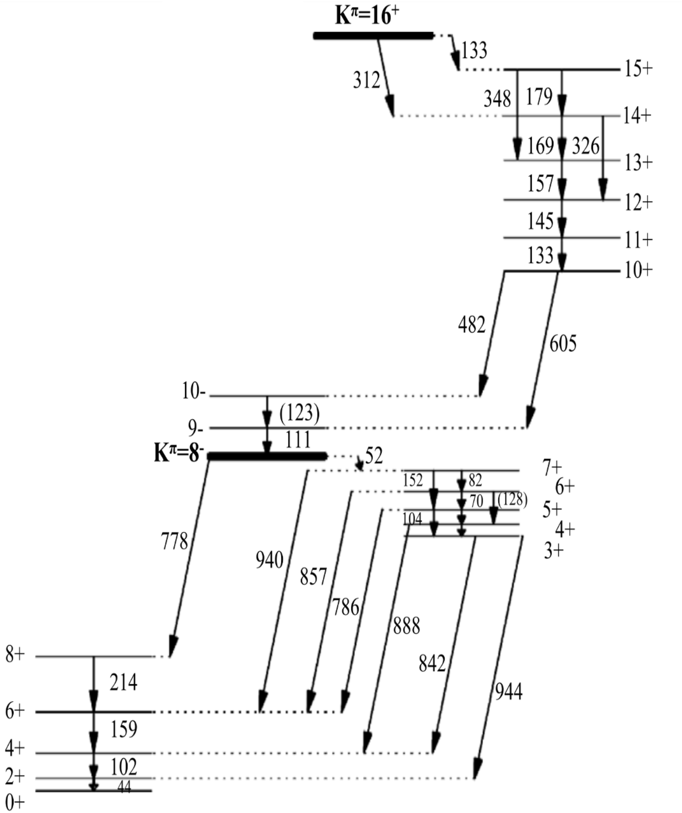


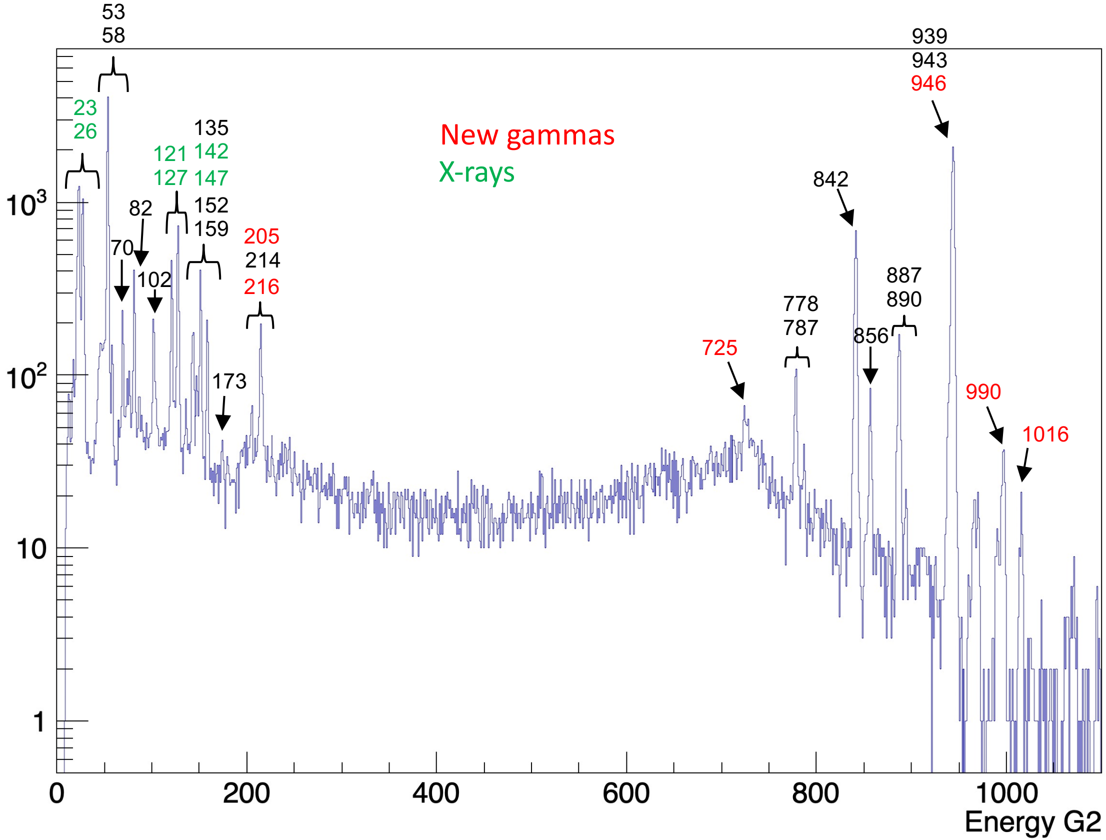
R. M. Clark et al., Phys. Lett. B B 690 (2010) 19.

Energy of the conversion electrons (in tunnel) in coincidence with short-lived isomer



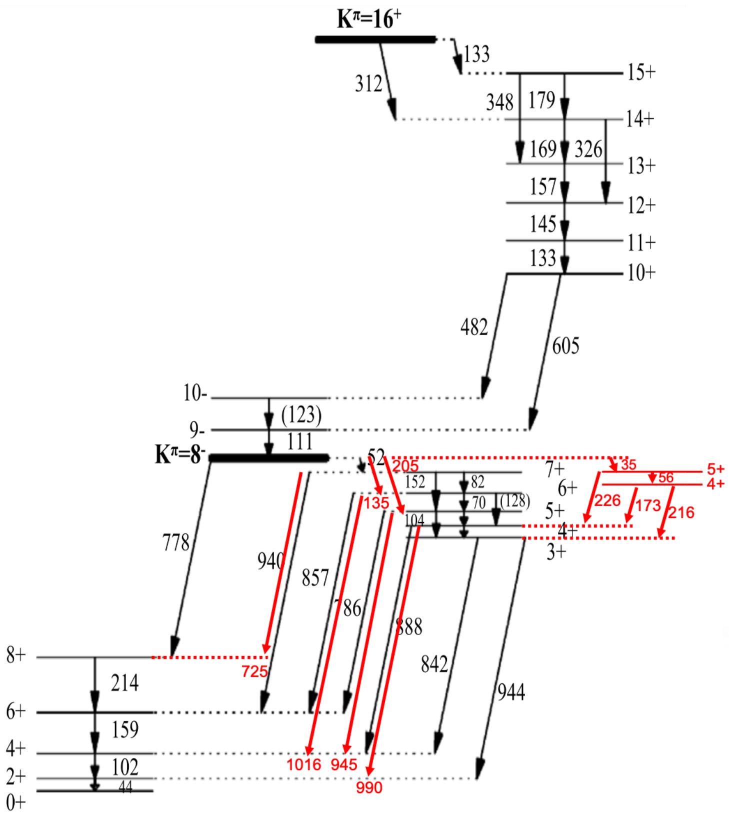
Coincidence with long-lived isomer

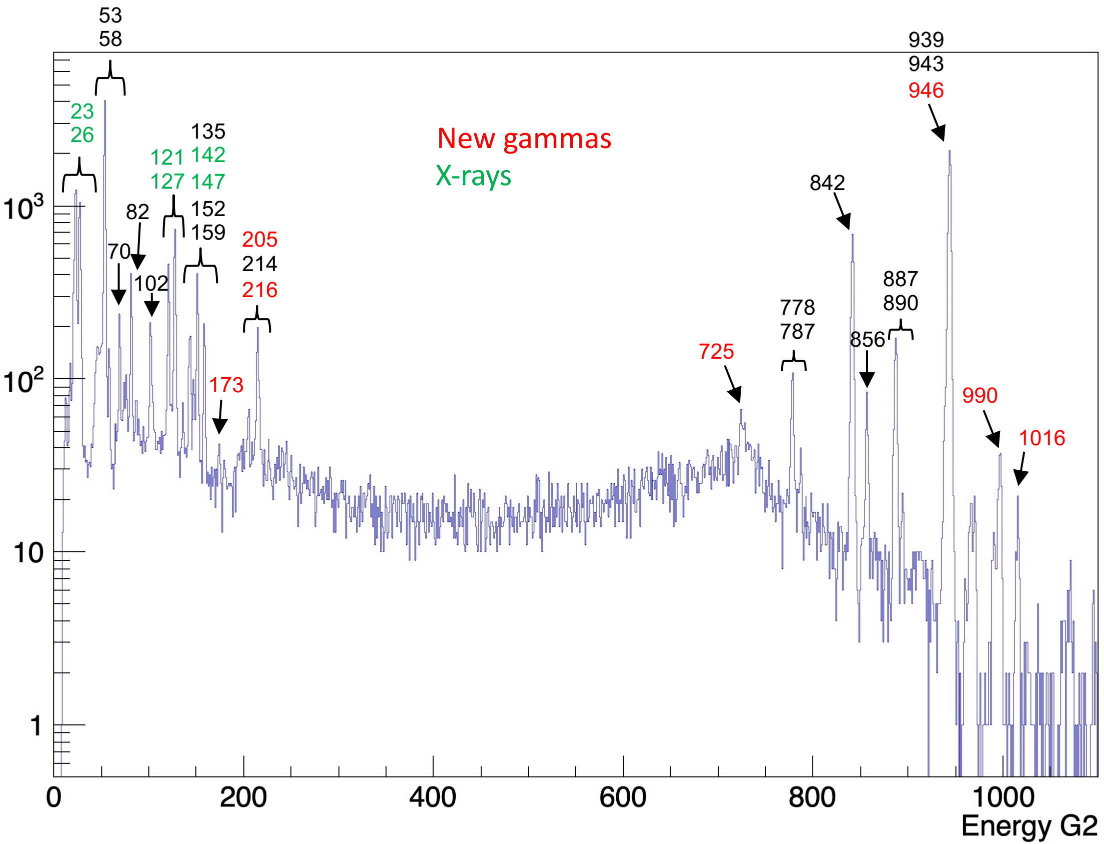




R. M. Clark et al., Phys. Lett. B B 690 (2010) 19.

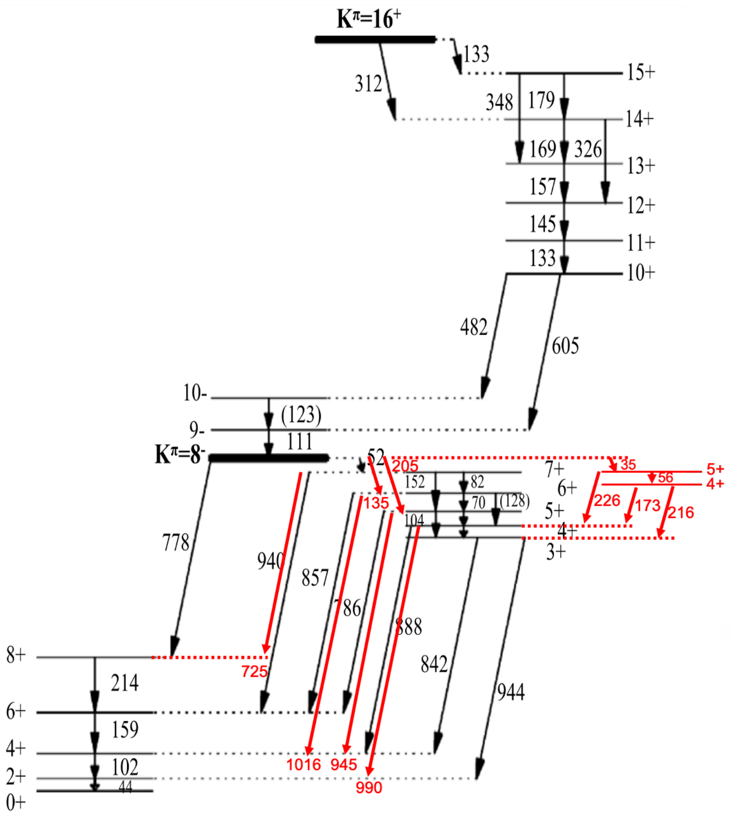
Coincidence with long-lived isomer



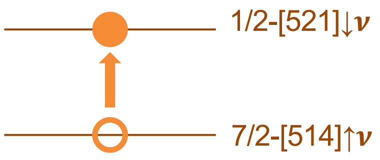


R. M. Clark et al., Phys. Lett. B B 690 (2010) 19.

Coincidence with long-lived isomer



R. M. Clark et al., Phys. Lett. B B 690 (2010) 19.



Favoured coupling : **3+** (7/2 - 1/2)
Unfavoured coupling : **4+** (7/2 + 1/2)

Gallagher-Moszkowski energy splitting :
216keV

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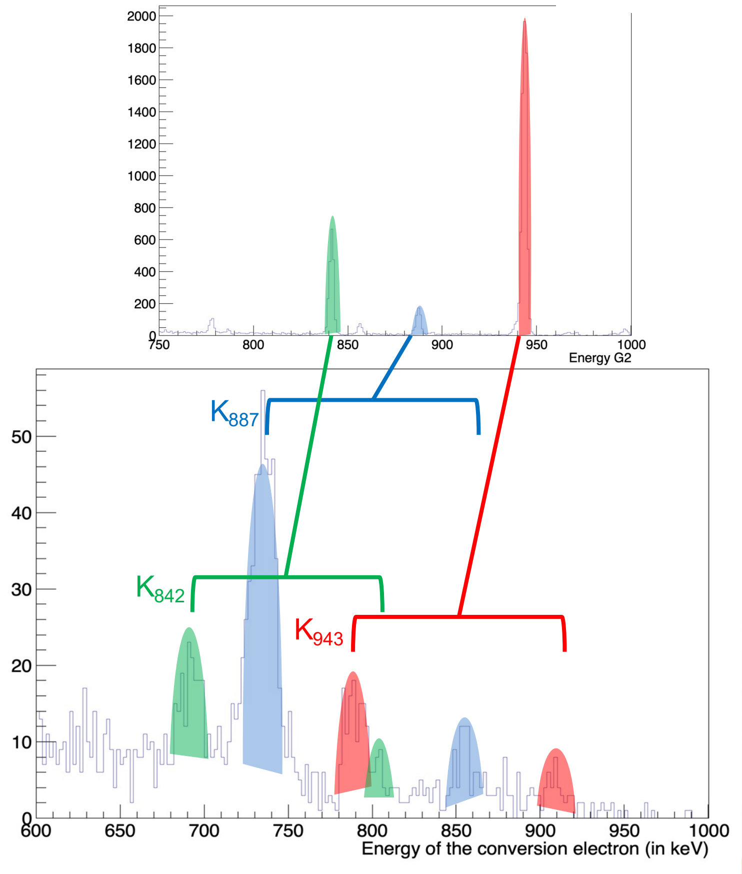
Coincidence of e^-_{Tunnel} / e^-_{DSSD} – Long-lived isomer



2 solutions to this super conversion :

- The existing 887keV is a very highly converted transition (M4 or more)…

  …But its lifetime doesn't fit…

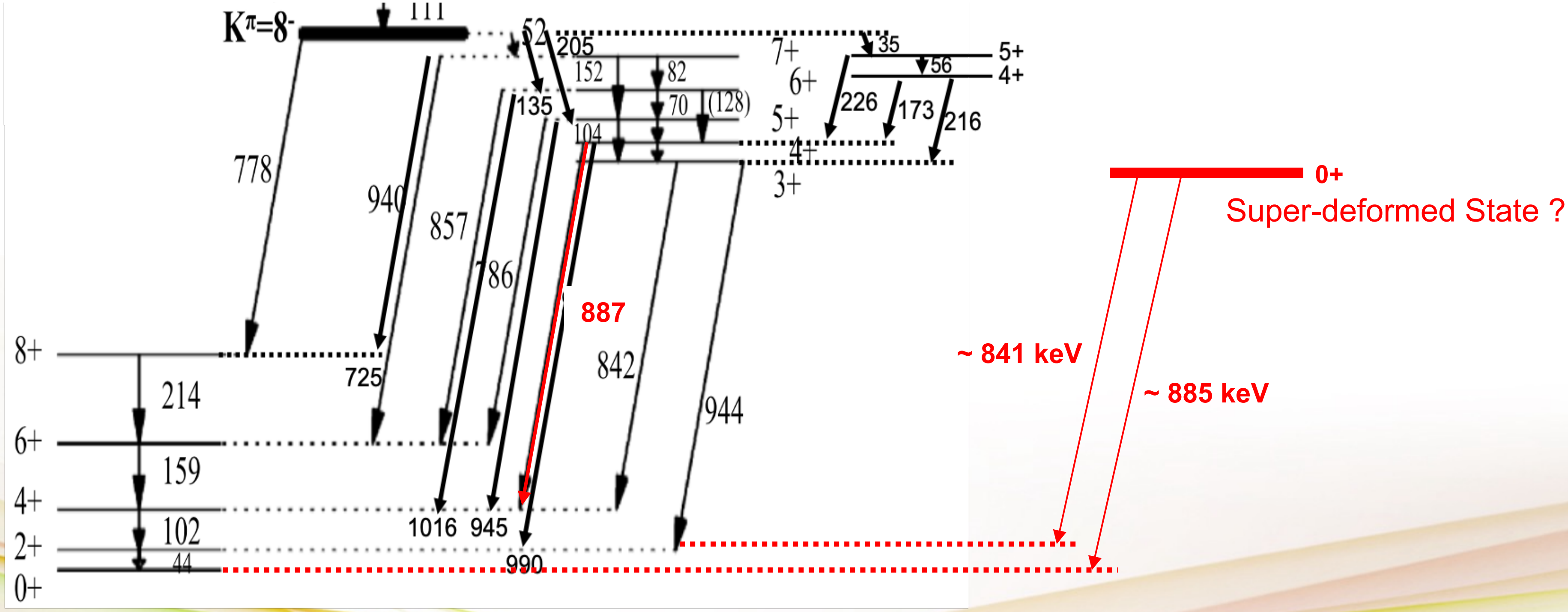
- Contribution from an E0 transition…

  … Accidental mixing with E0 contribution in 887keV from 4+ to 4+

  OR

  …Interpreted as a pure and new E0 transition from 0+ state to Ground State !

New potential decay scheme

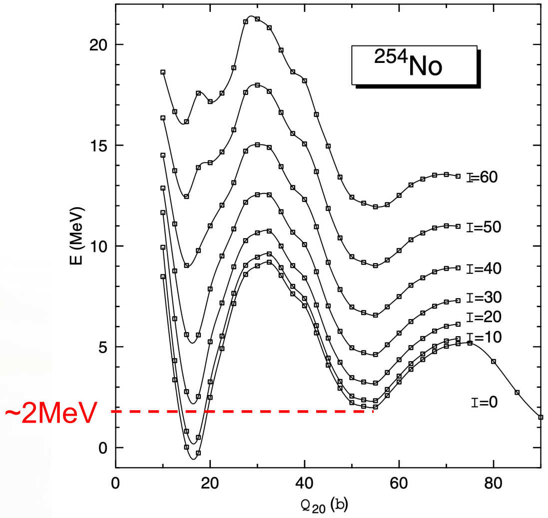


Comparison with theory

Université de Strasbourg

From 2000

Fission barriers for different spin values

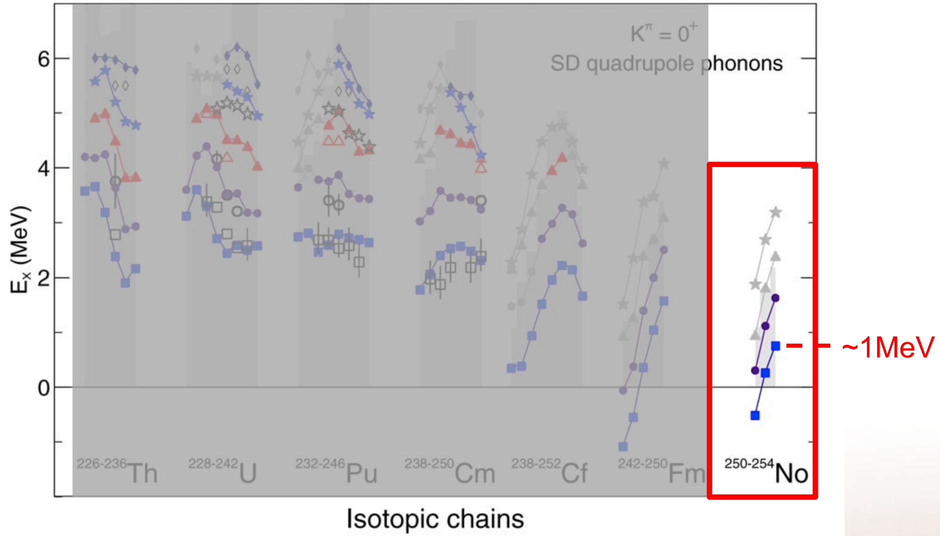


Egido & Robledo predicted a SD well at around 2MeV.

J.L. Egido and L.M Robledo, Phys. Rev. Let. V85, 6 (2000)

From 2006

Excitation energy from SD state in different nuclei



Delaroche results : prediction of a SD state at around 1MeV.

J. -P. Delaroche et al., Nucl. Phys. A 771, 103-168 (2006).

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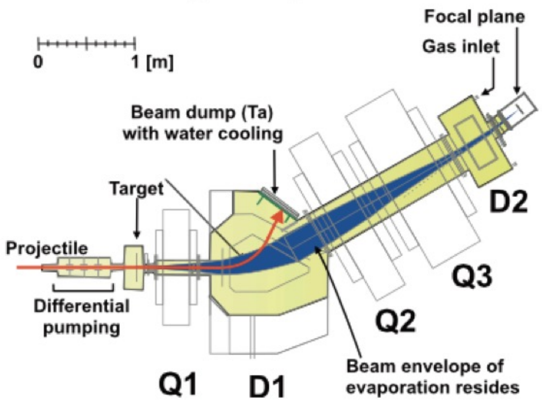
GARIS III

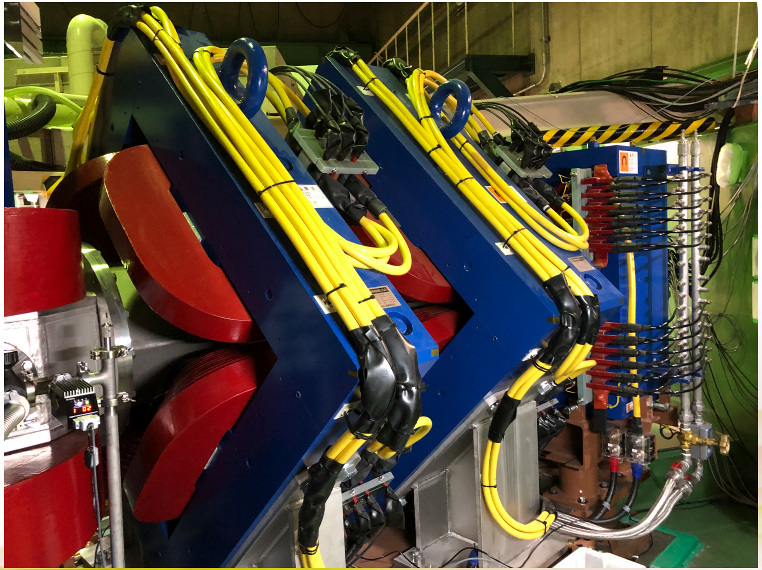
GARIS III → asymmetric reaction (hot fusion)

$^{51}V + ^{248}Cm \rightarrow ^{299-x}119 + xn$

- Gas filled
- High transmission (40-70%) → Optimized for synthesis of new elements (Z>118) experiments

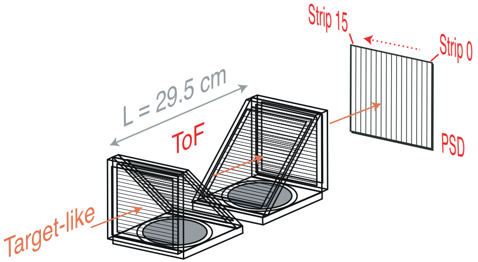


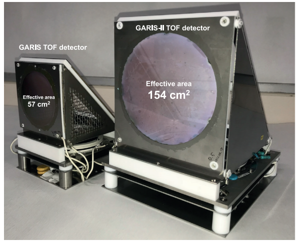
K. Morimoto, Detector, Workshop GARIS (2008).

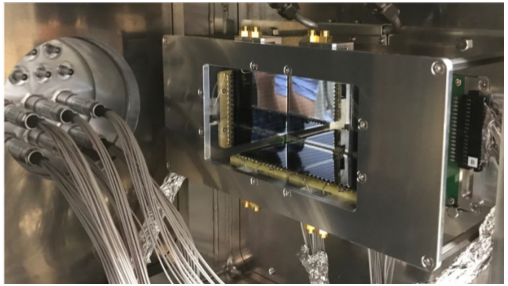


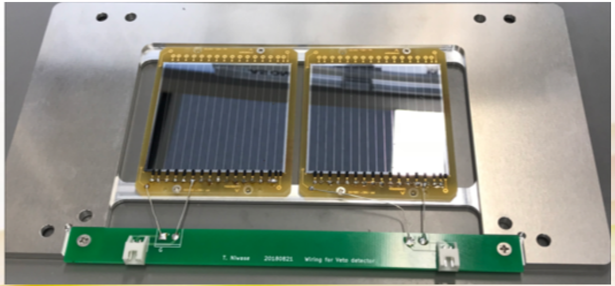
GARIS focal plane setup

- Time of Flight detector
  - Recoil event selection
  - Very high efficiency (99%)
  - Time correlation with the DSSD
- VETO detector
  - 2 silicon pads behind the DSSD
  - Detect passing through particles
  - Timing correlations with DSSD
- Silicon Box : high alpha detection efficiency (~88 %)
  - 2 implantation DSSD side by side
  - Tunnel Si detectors
  - Escape alpha
  - Energy summations









Algorithm Strategy

- My work : Analyse the experiment to find a 119 decay chain
  Very low cross section = around 10 fb

- Theoretical predictions for 119 :
  - Lifetime around the ms
  - Alpha decay Energy around 12 MeV

- But Ts (Z=117) isotopes are not known

- My algorithm :
  - Genetic correlations to isolate decay chains
  - No time selection on 119
  - Large selection gates
  - Low filtering

- Calibration :
  → *La* target : ^{139}La (^{51}V, *xn*) $^{190-x}$Hg reaction
  → *Tb* target : ^{159}Tb (^{51}V, *xn)* $^{210-xn}$Ra reaction

- Code validated by tests on calibration reactions and ^{257}Db synthesis

We can't miss an event !!!

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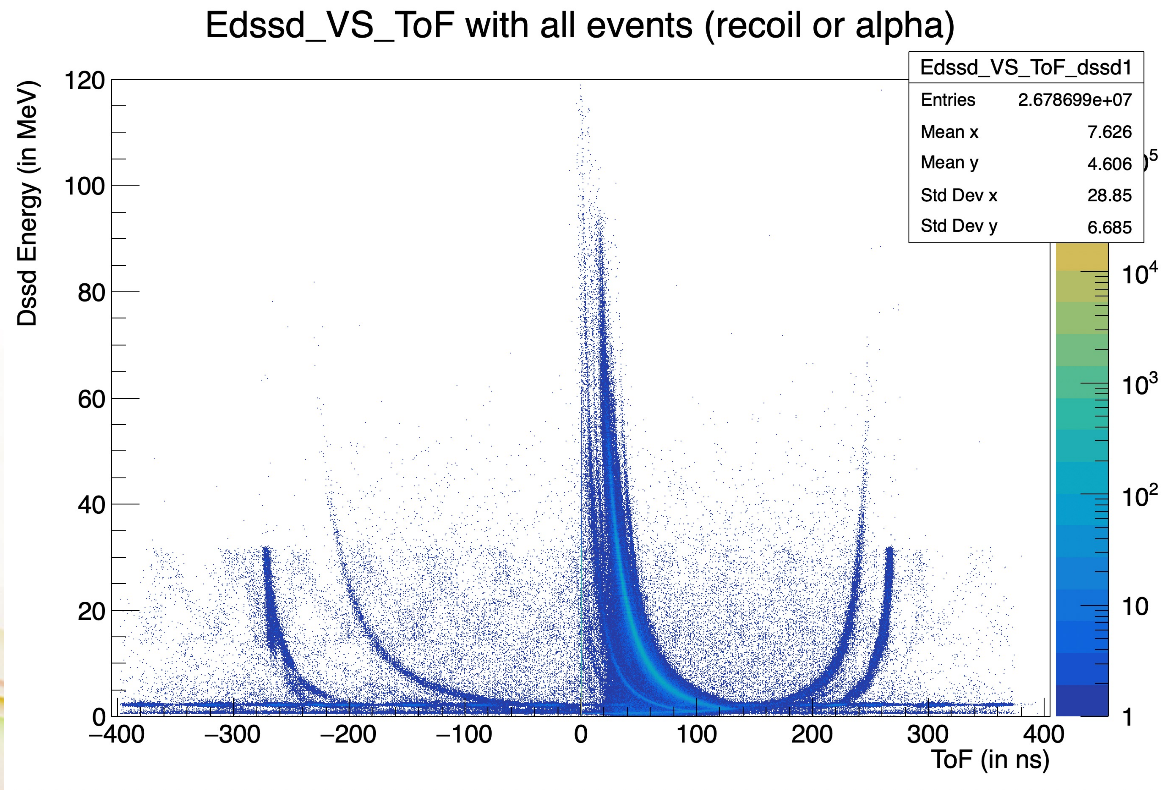
Data filtering



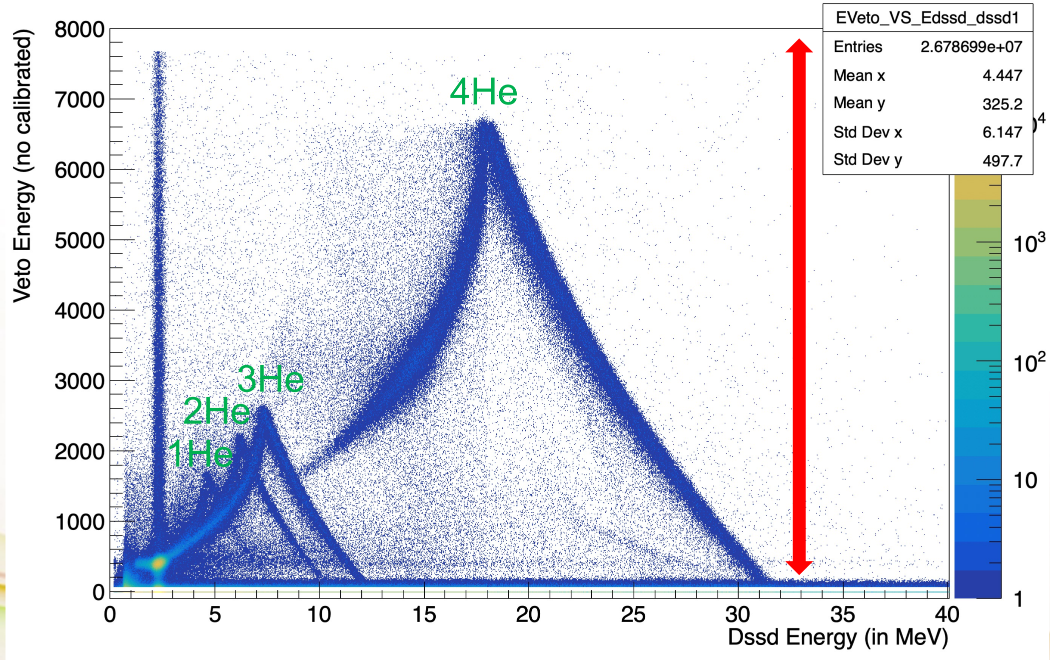
Filtering methods :

1. VETO silicon pads
2. QDC Measurements
3. Tunnel Si detectors

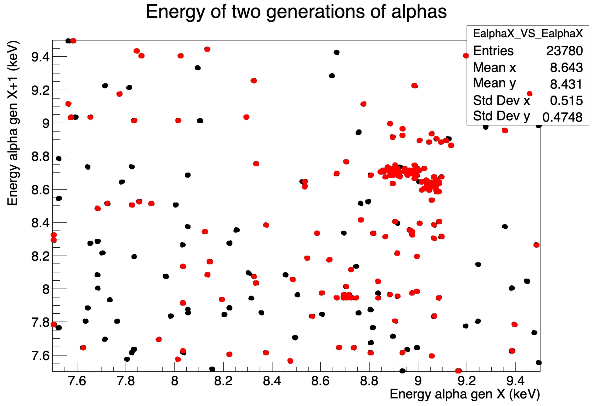
Data filtering - Veto

Anti-coincidence with veto signal → Removal of light particles
or
→ Removal of particle with veto energy above 200keV

EVeto_VS_Edssd with all events (recoil or alpha)



In black : raw data
In red : data with current filter

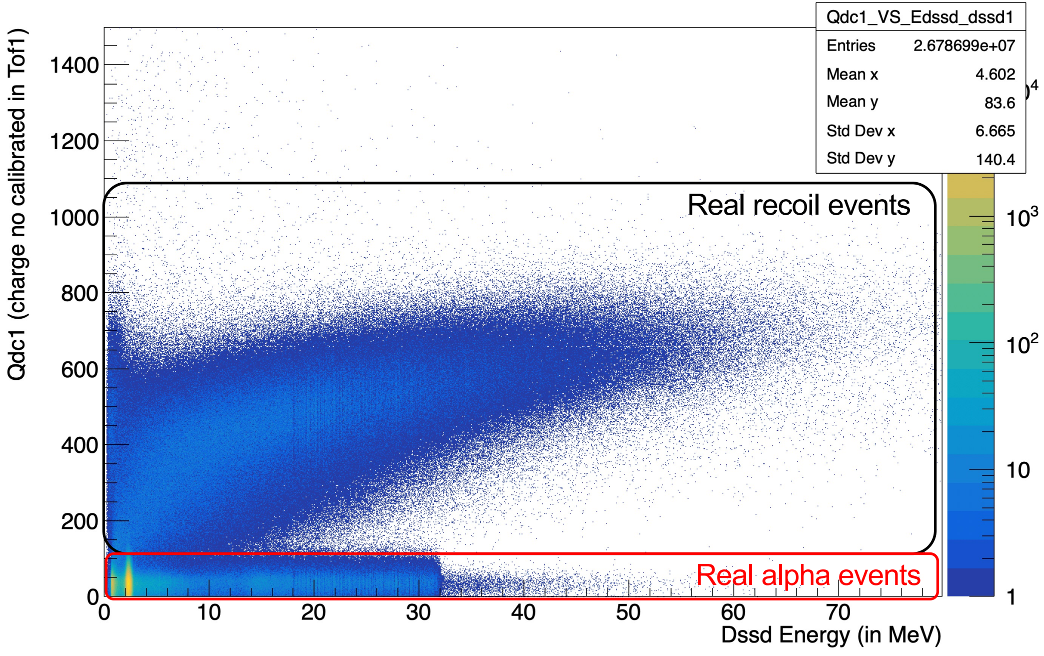


Data filtering – QDC

Filtering of the noise created by QDC → If QDC below a threshold, the event has not triggered the ToF

Threshold =
- 170 for QDC1
- 430 for QDC2

Qdc1_VS_Edssd with all events (recoil or alpha)



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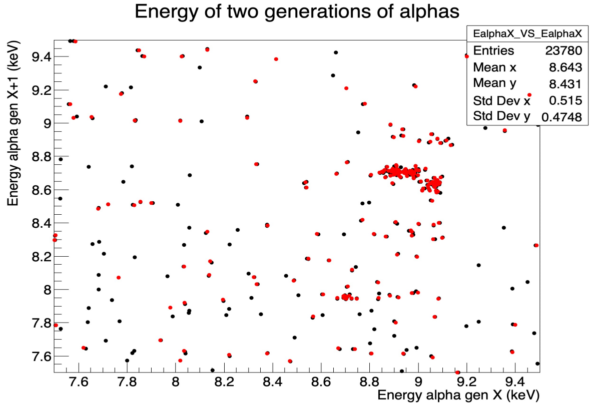
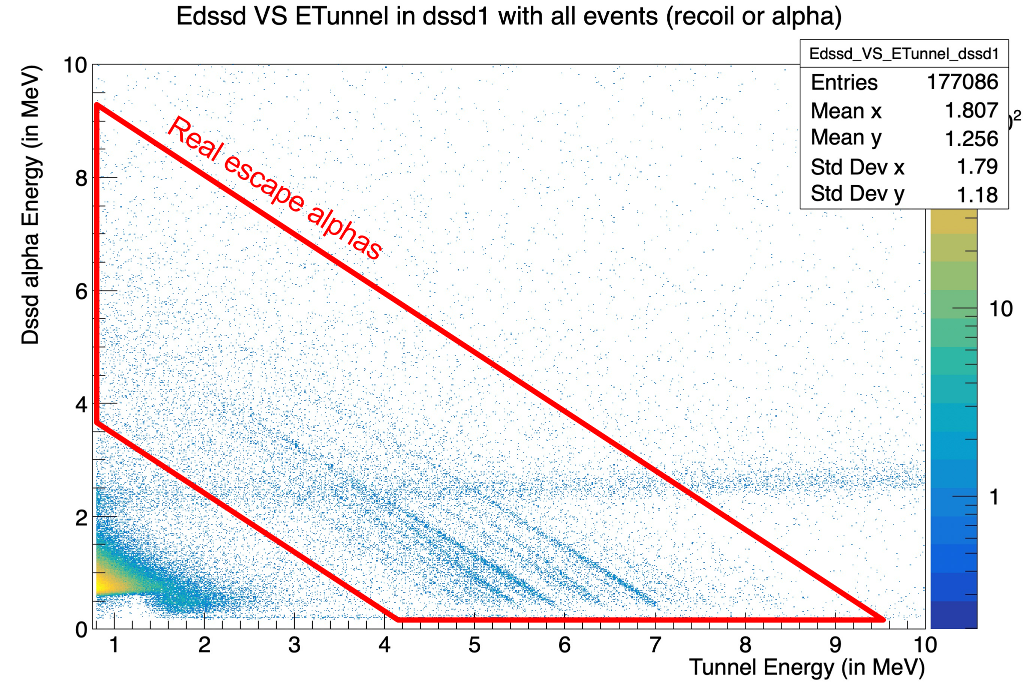


Data filtering – Tunnel

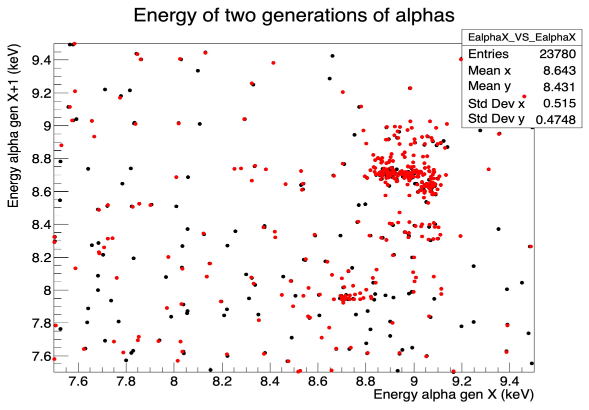
Summation of energy with tunnel & DSSD → Gives the real energy of the event

$E_{real} = E_{DSSD} + E_{Tunnel}$



In black : raw data

In red : data with current filter

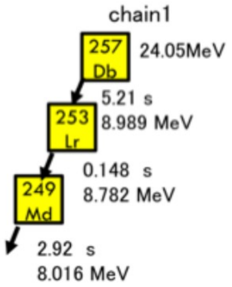


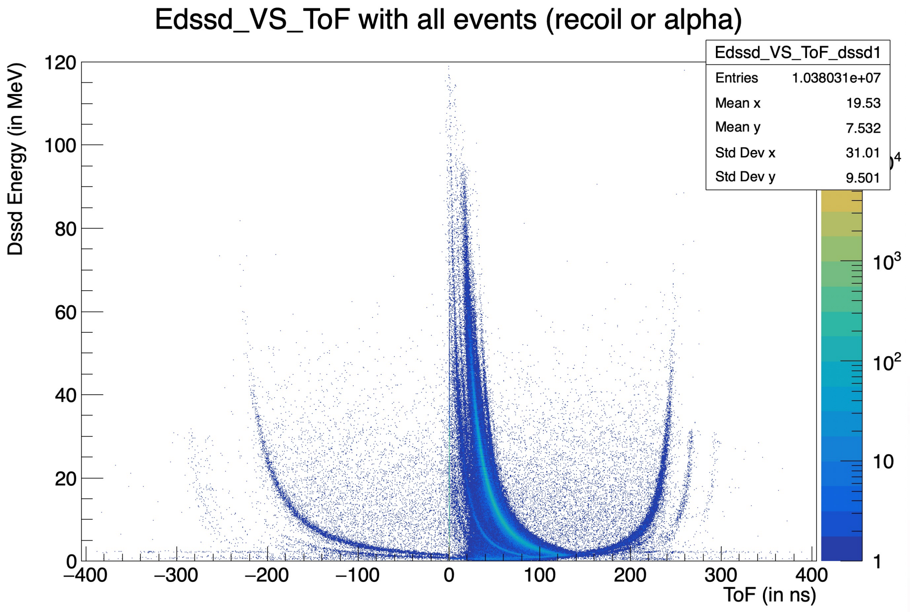
Results with Dubnium

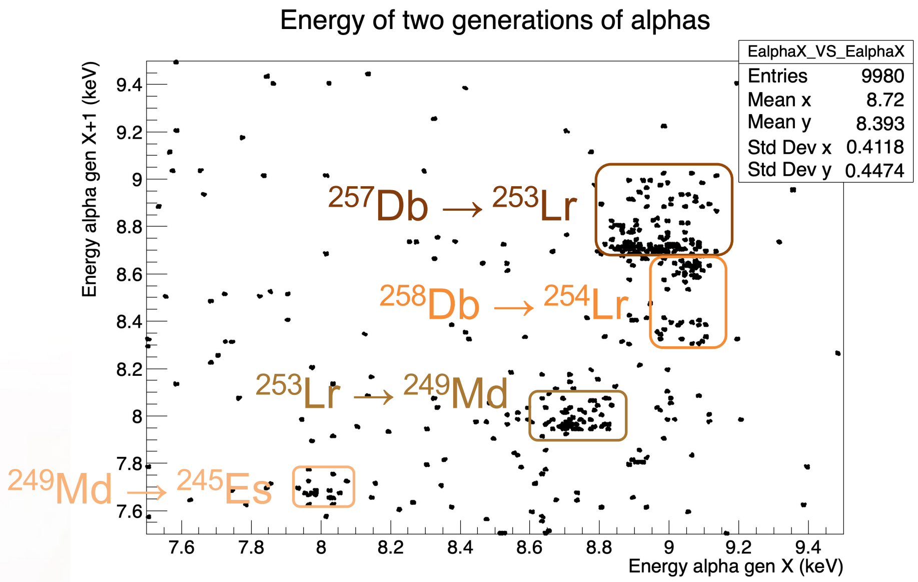
I found **163 correlations R - ^{257}Db - ^{253}Lr**

In agreement with 3 others analysis codes (P. Brionnet, Go-San and K. Kessaci)

Same cut but different energies and lifetimes







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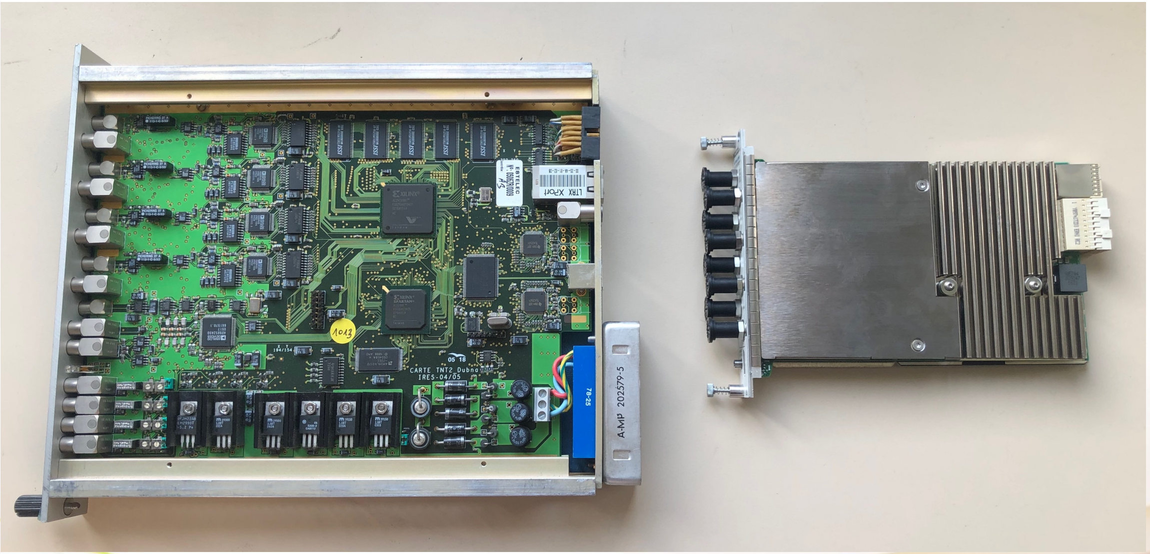
Université de Strasbourg

TNT2 & NI electronic cards

Purpose : get NI cards performances

Steps followed :
1) Apply Jordanov algorithm (C++) with TNT2 cards
2) Comparison of spectrum (LabView & C++) with NI cards
3) Test & characterization of NI cards on MICRON Si detectors

TNT2
Fe = 100MHz (Te = 10ns)
12 bits
FPGA virtex 3 or 4



NI PXI 5170R
Fe = 250MHz (Te = 4ns)
14 bits
FPGA virtex 6

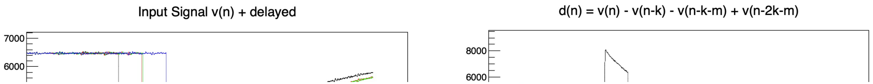
Jordanov Algorithm

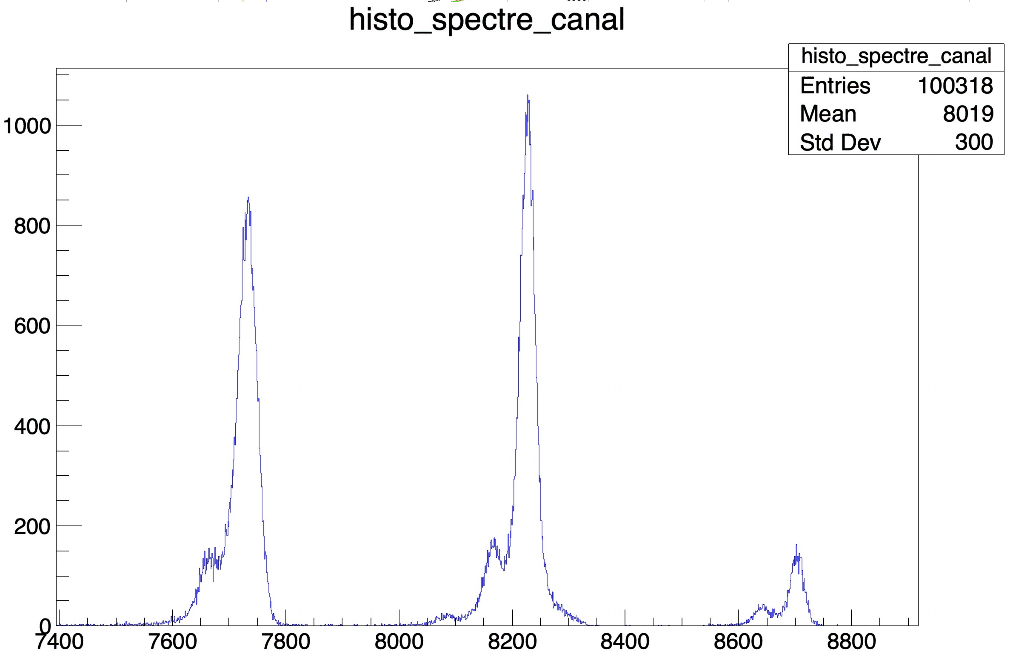
Test on TNT2 electronics cards :

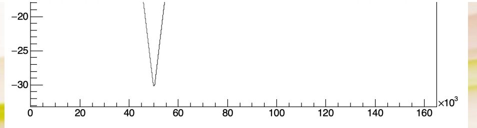
- Tri-alpha source
- τ_{decay_time} = 50us
- Te = 10ns

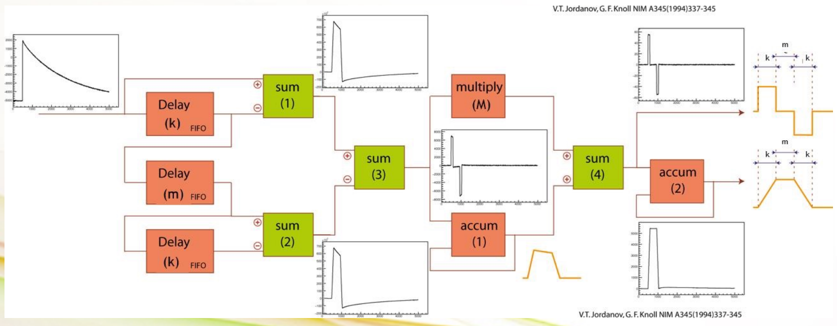
Parameters used for Jordanov algorithm :

- k = 10000 ns
- m = 500 ns
- M = $\frac{1}{e^{-Te/\tau}-1}$ =







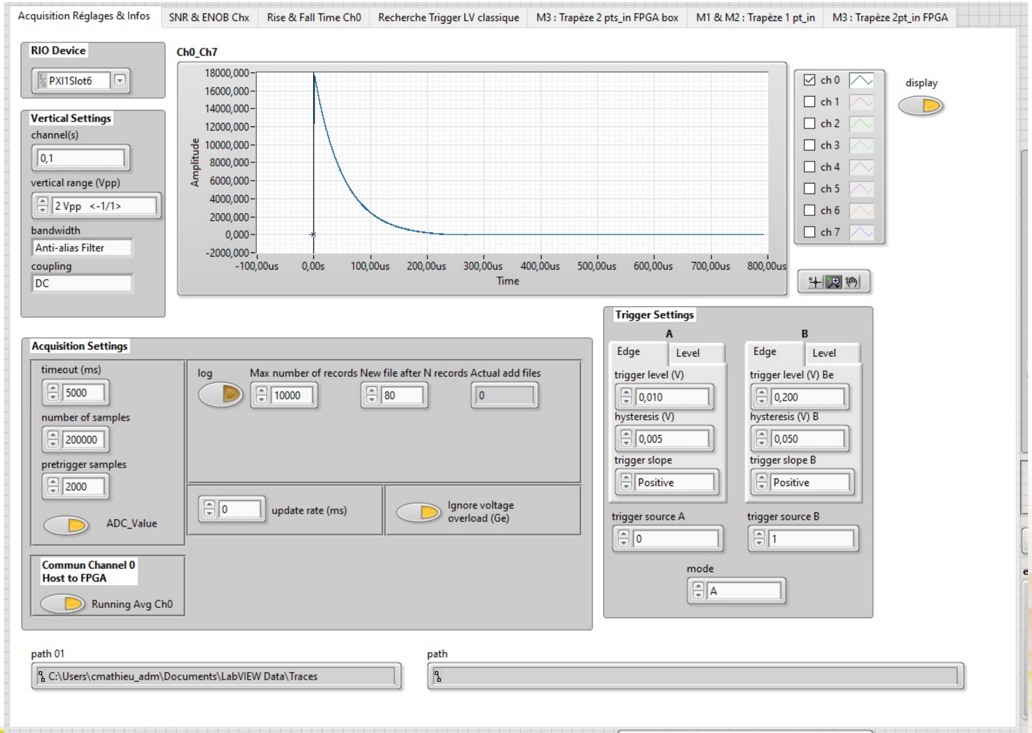


Pierre Brionnet, Thesis, Université de Strasbourg n°3844, 2017

NI performances

Offline test with LabView codes / C++ codes

Thank you to Cedric Mathieu !



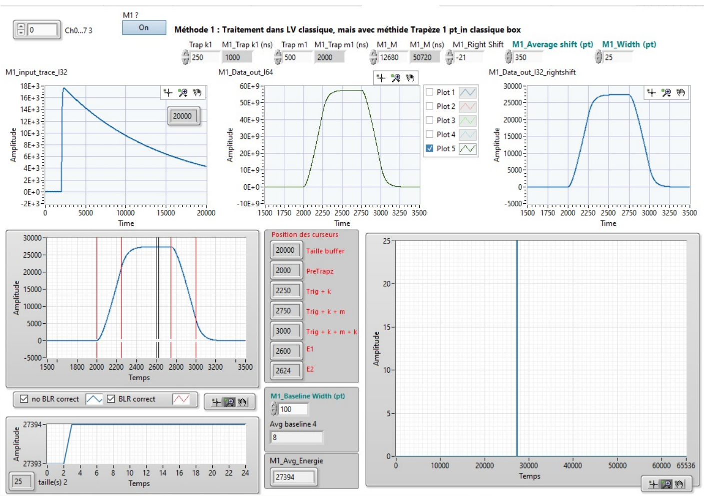
Test on NI electronics cards :

- Signal generator
- τ_{decay_time} = 50us
- Te = 4ns

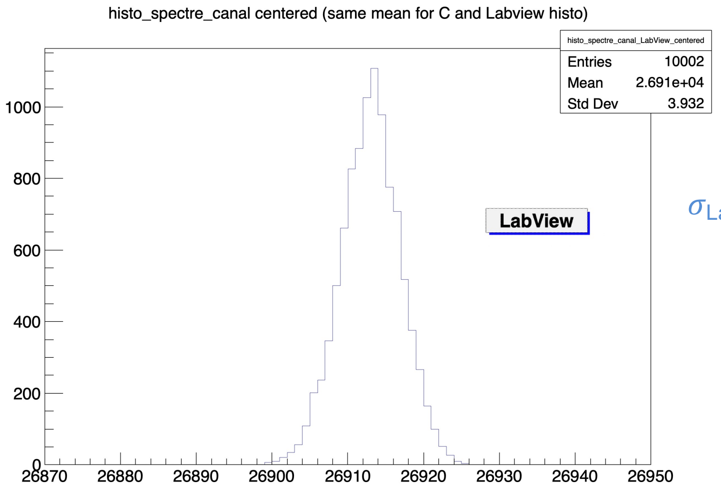
Parameters used for Jordanov algorithm :

- k = 1000 ns
- m = 2000 ns
- $M = \frac{1}{e^{-Te/\tau} - 1} =$

NI performances

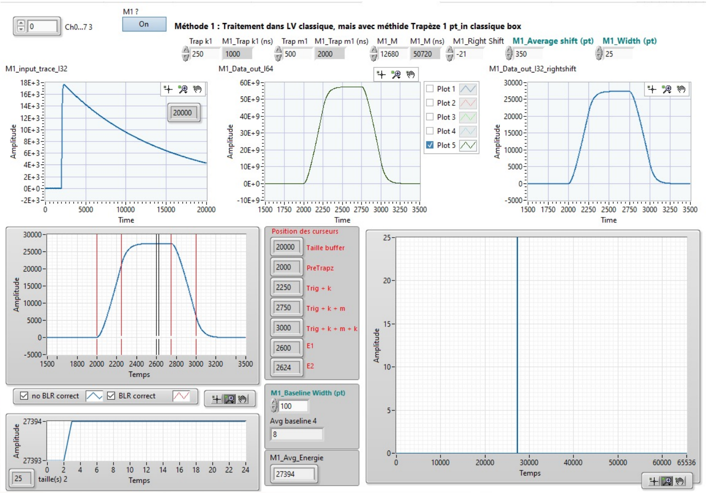


Direct results from LabView

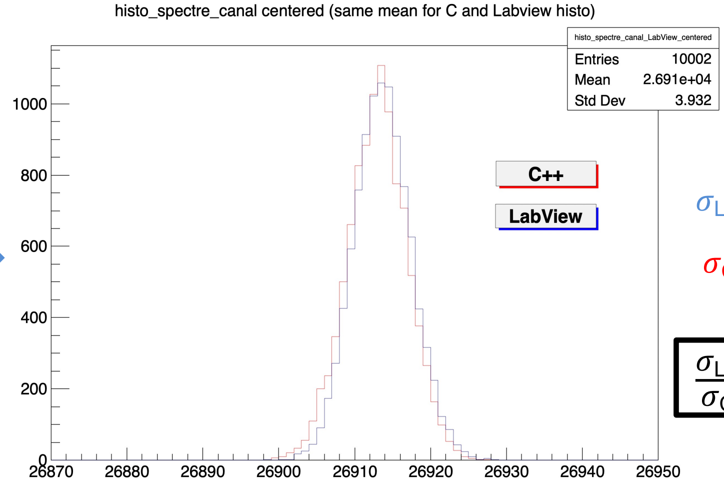


σ_{LabV} = 3.9136

NI performances



Direct results from LabView

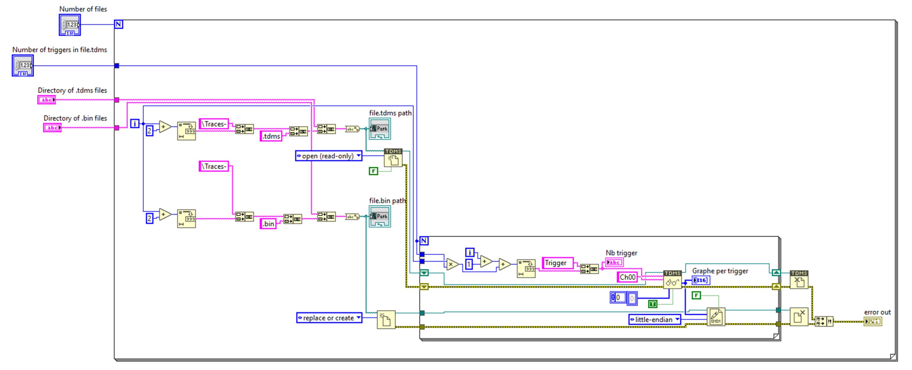


$\sigma_{LabV} = 3.9136$

$\sigma_{C++} = 3.7618$

$$\frac{\sigma_{LabV}}{\sigma_{C++}} = 0.9612$$

Conversion from tdms file to binary file



Application of Jordanov code (in C++) on traces converted in binary file

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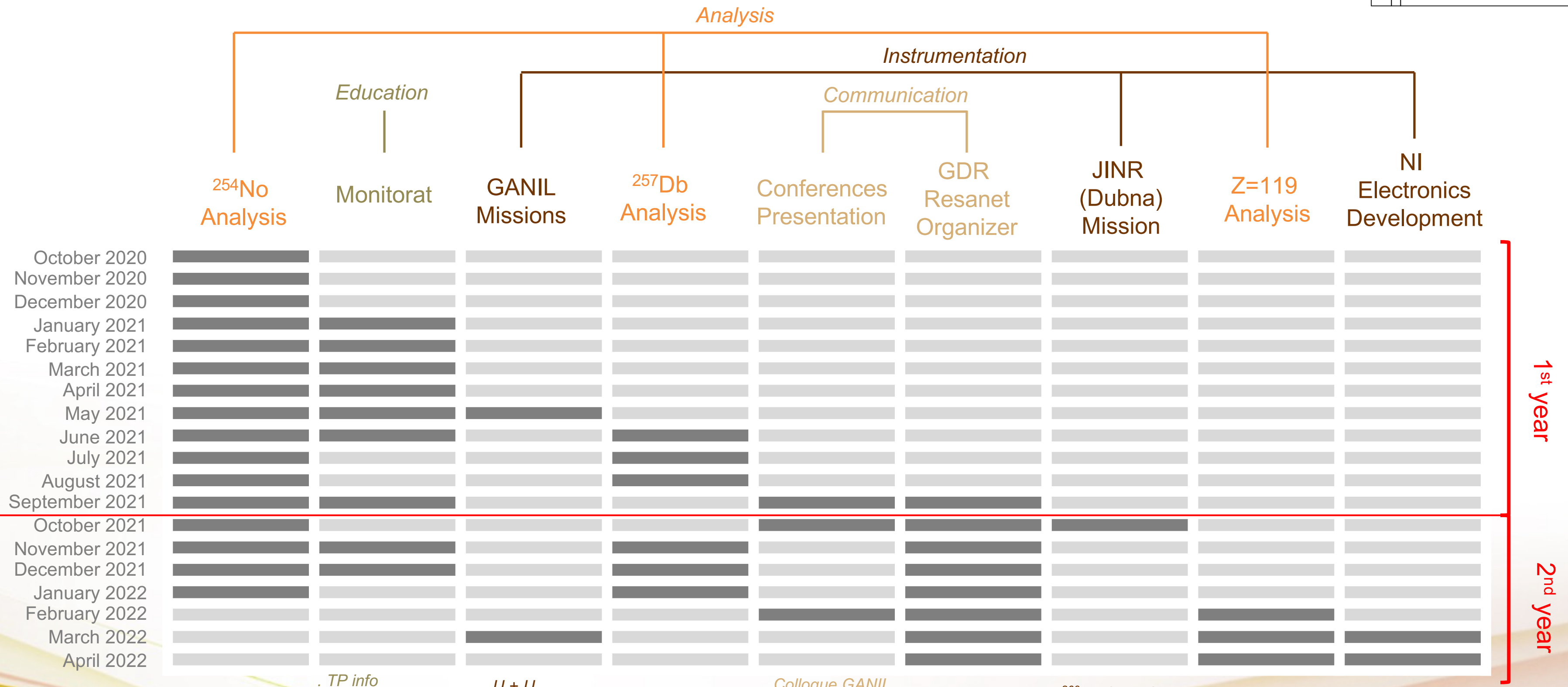
Assessments - PhD



. TP info
. TD Analyse Num
. TP Bio

. U + U
. Fission

. Colloque GANIL
. Poland
. GDR Resanet
. Poster at EJC School

^{260}Rh SHELS transmission

Assessments – ED182

Scientific formations		Transversal formations	
EJC 2021	18h	Assemblée générale des doctorants 2020	2h
Bloc séminaires Mathématiques	7h30	Cours de Japonais	20h
Bloc séminaires Chimie	26h	Journée de sensibilisation à la prévention des risques	4h
Bloc séminaires Entreprise	3h	MOOC	10h
Bloc séminaires Physique	2h	Integrity charter in Scientific profession	3h
		Congrès des doctorants	5h
		Initiation à la lecture rapide	12h

=56h30 =56h

International conference :

- Colloque GANIL 2021 – talk of 15m – 27/09/2021 *"New results on the decay spectroscopy of 254No with GABRIELA @ SHELS"*
- GDR Resanet Webinars – talk of 30m – 14/02/2022

Scientific papers (as co-author):

1) K. Kessaci et al.,
Evidence of high-K isomerism in $^{256}No_{154}$,
PRC 104, 044609 (2021)

2) A. Lopez-Martens et al.,
Fission properties of Rf253 and the stability of neutron-deficient Rf isotopes,
PRC 105, L021306 (2022)

3) M. S. Tezekbayeva et al.,
Study of the production and decay properties of neutron-deficient nobelium isotopes,
Eur. Phys. J. A (2022)

Perspectives

1. Analysis :

Keep going **analysis on Z=119**
2nd nuclei to be analysed in Dubna ? (if political situation is better)

2. Instrumentation :

JSPS fellowship of 2 months in RIKEN to work on Z = 119 experiment (from May to July 2022)
Development and characterization of NI electronic cards
SHEXI = ANR asked on X-rays detection (purchase + installation of NI cards on it)

3. Simulation :

GEANT 4 formation & simulation

4. Communication :

Redaction & **Publication of the scientific paper about ^{254}No (PRL)**
Talk in international conferences (Zakopane 2022 conference on nuclear physics – 28/08/22 to 04/09/2022)
Redaction of my PhD manuscript

Thank you for your attention !

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R. Chakma et al., Eur. Phys, J. A 56, 245 (2020).

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J. -P. Delaroche et al., Nucl. Phys. A 771, 103-168 (2006).

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