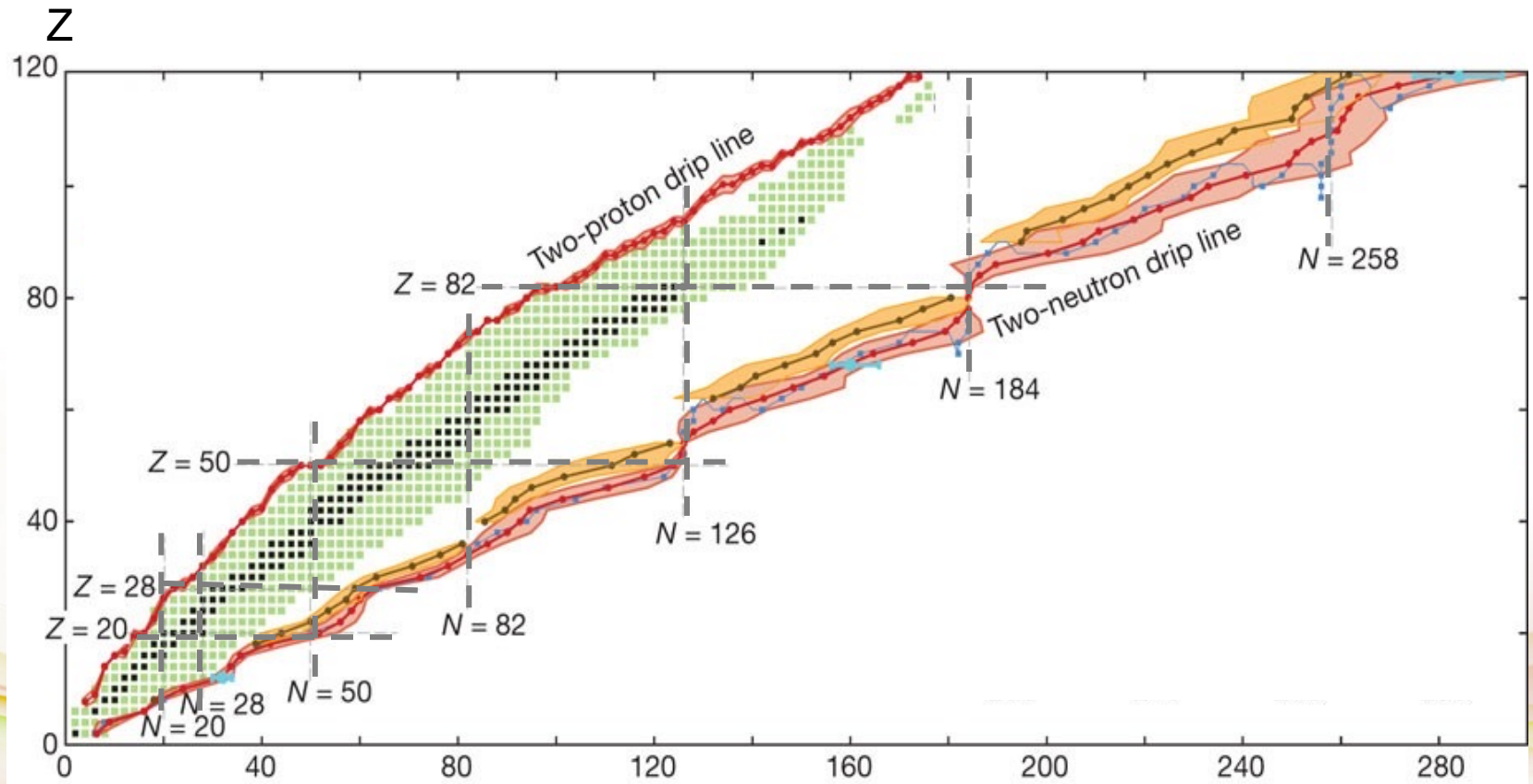
New results
on the decay spectroscopy of ^{254}No with GABRIELA @ SHELS

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

Table of Contents

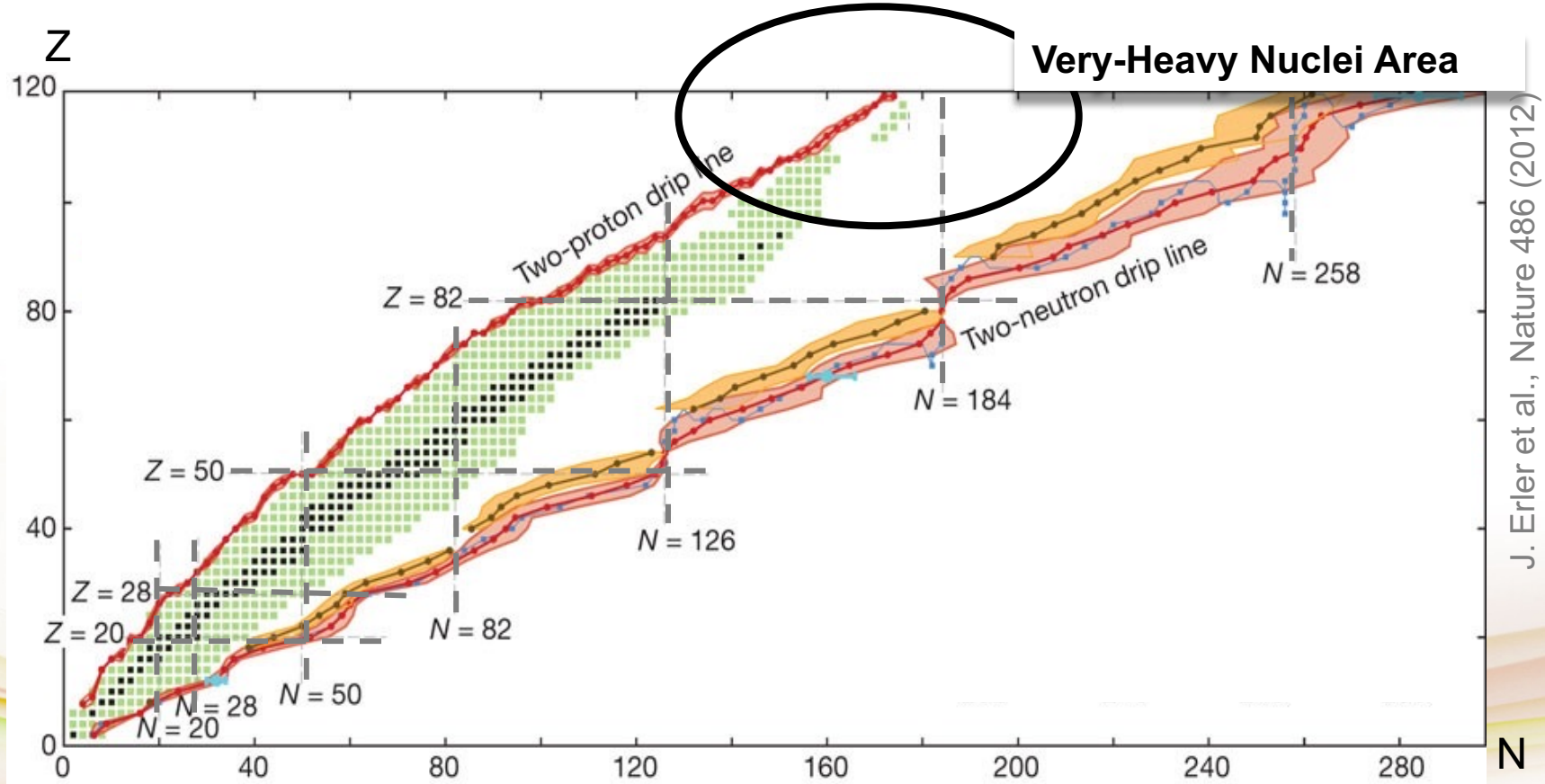
1. **Scientific context**
2. Experimental Set up
3. Results from $^{208}Pb + ^{48}Ca \rightarrow ^{254}No + 2n$ reaction
4. Super-Deformation in ^{254}No?
5. Conclusion

Motivation

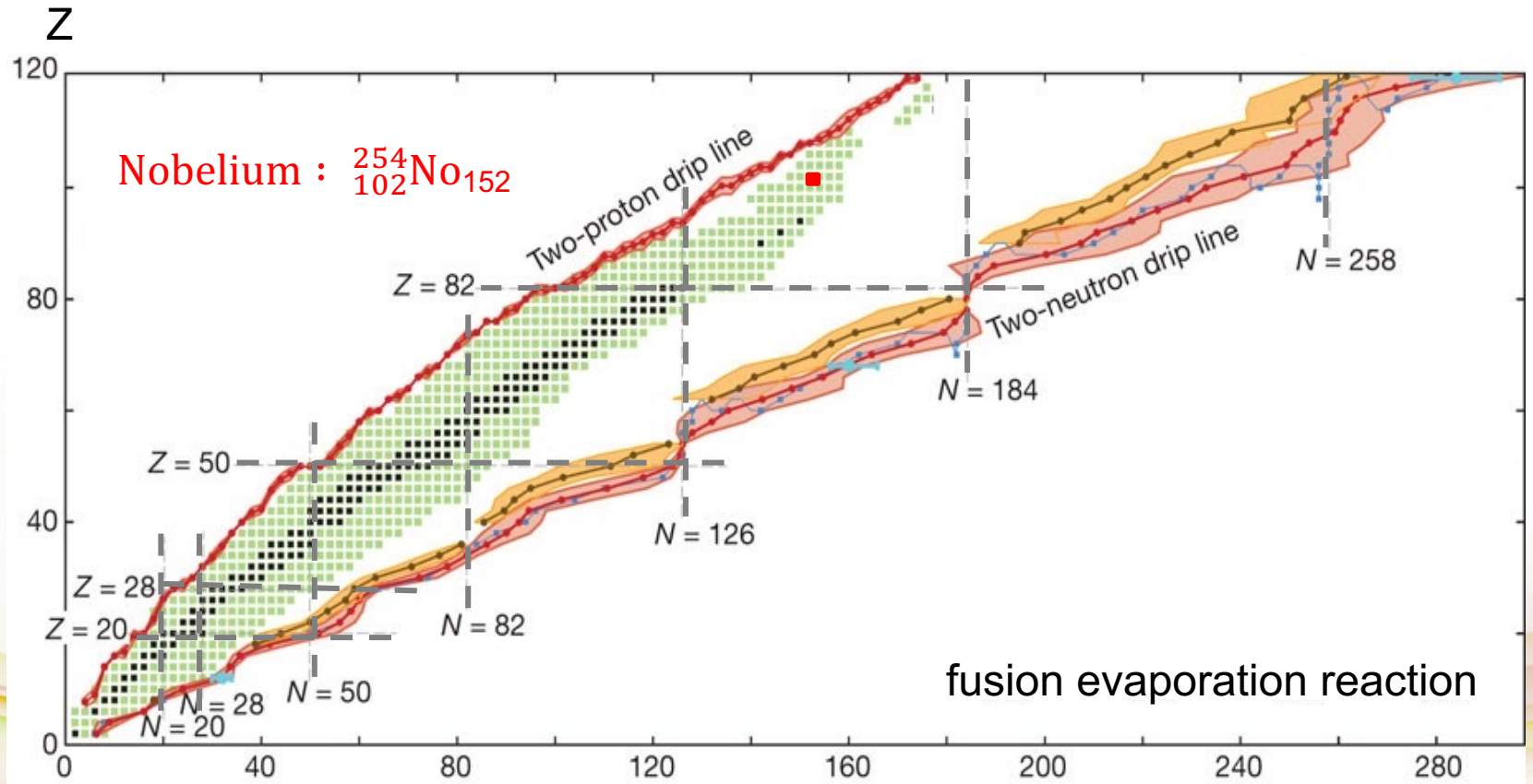


J. Erler et al., Nature 486 (2012)

Motivation

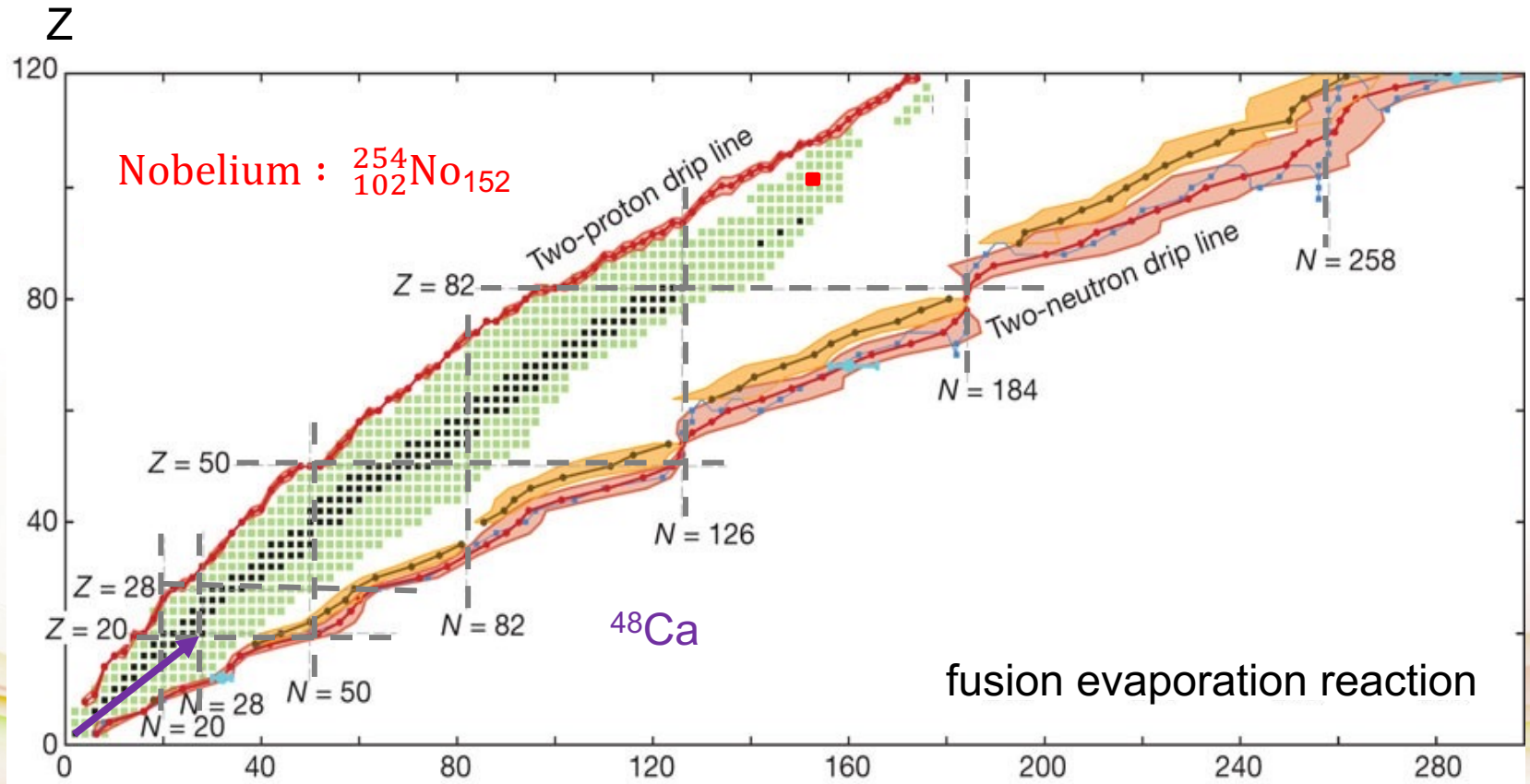

Very-Heavy Nuclei Area
Z
N
Two-proton drip line
Two-neutron drip line
Z = 82
Z = 50
Z = 28
Z = 20
N = 258
N = 184
N = 126
N = 82
N = 50
N = 28
N = 20
0
40
80
120
160
200
240
280
J. Erler et al., Nature 486 (2012)

Reaching ^{254}No



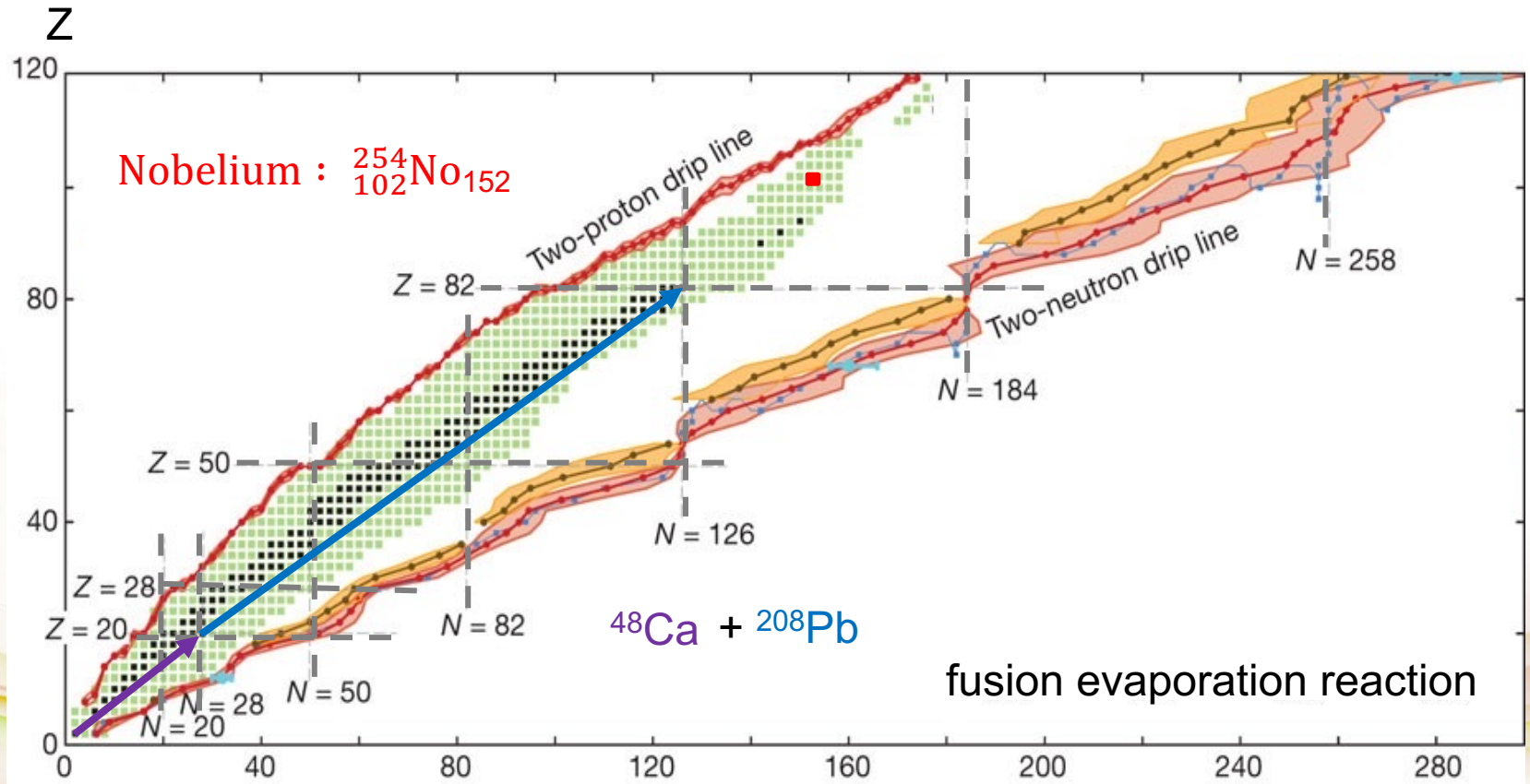
J. Erler et al., Nature 486 (2012)

Reaching ^{254}No



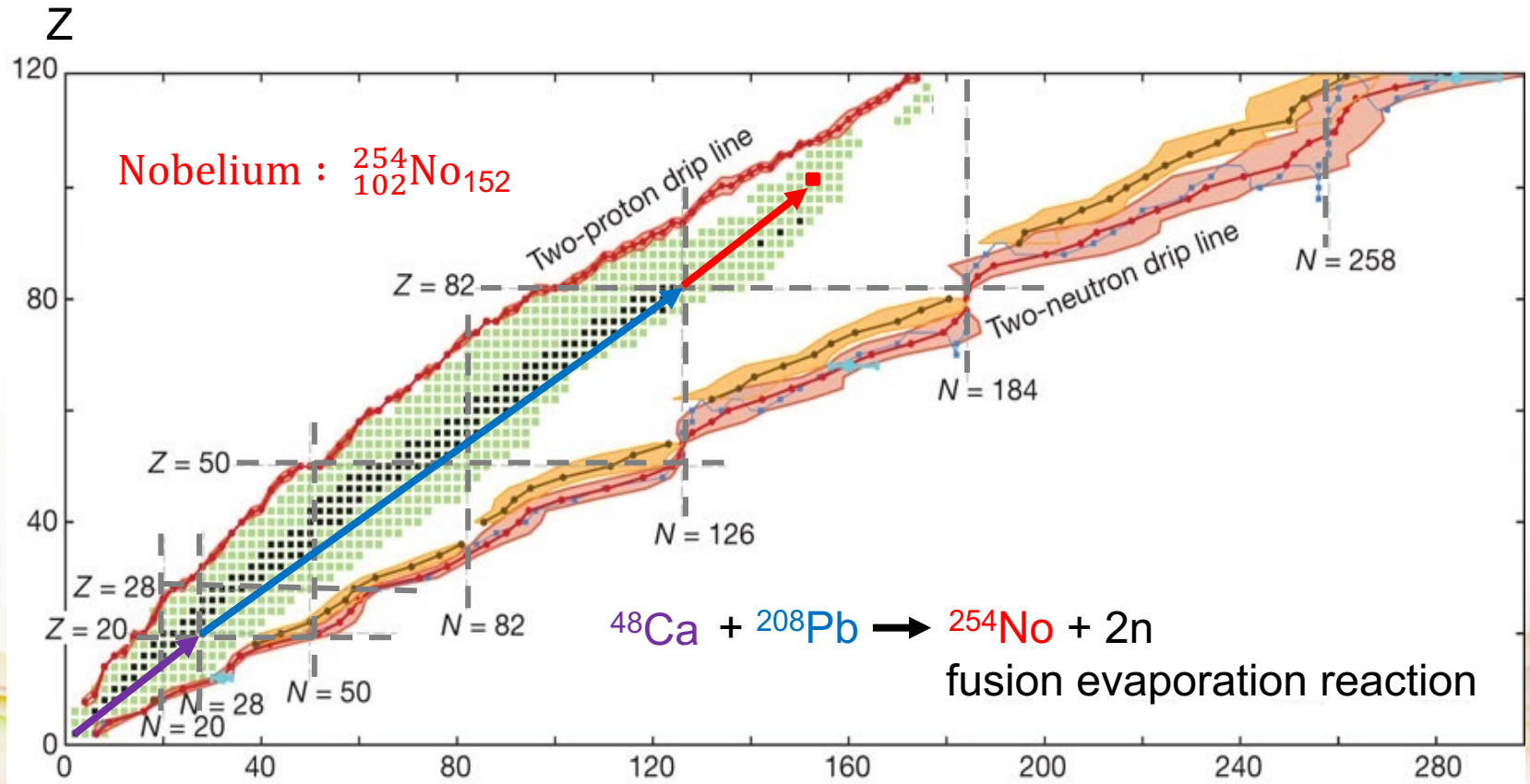
J. Erler et al., Nature 486 (2012)

Reaching ^{254}No



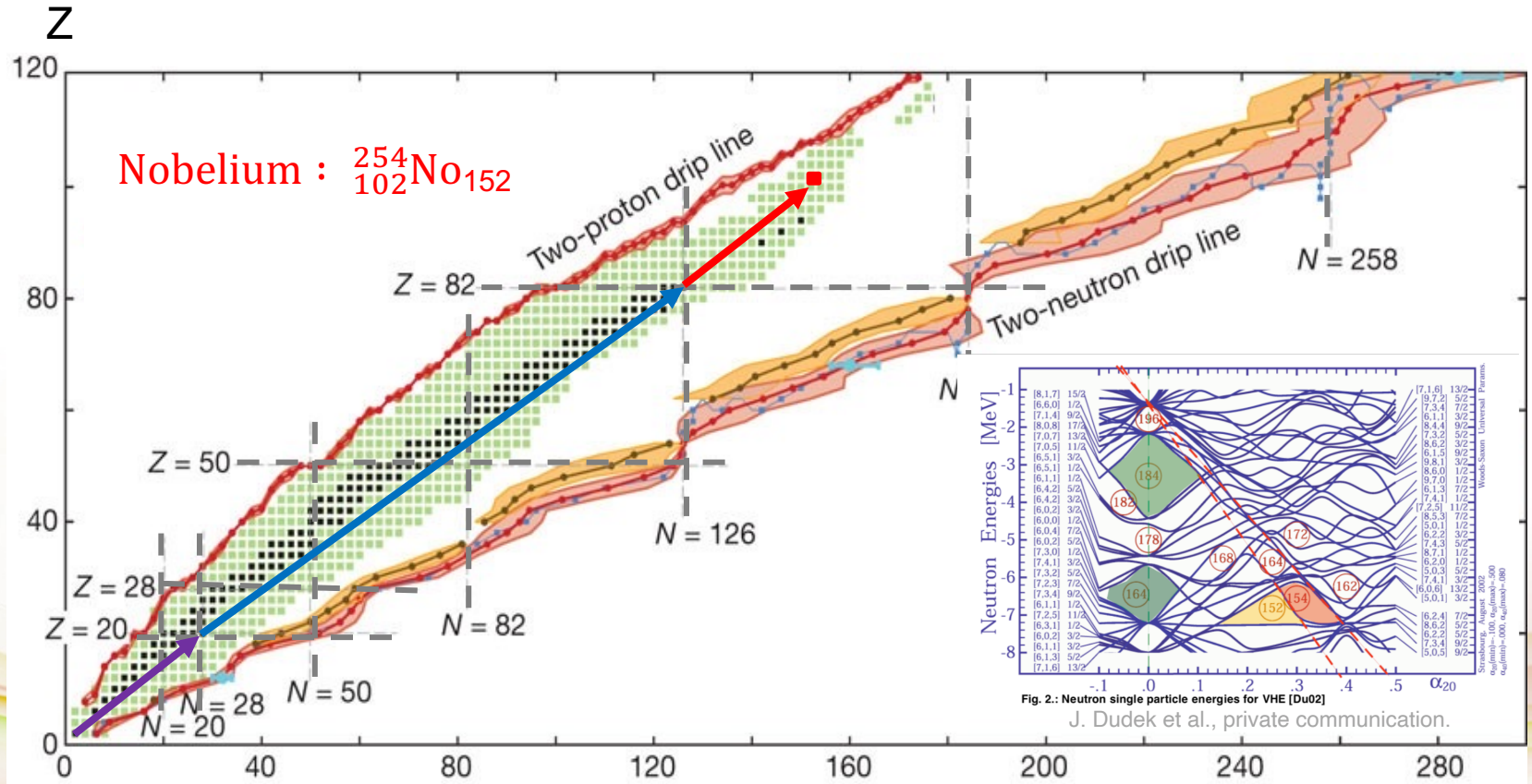
J. Erler et al., Nature 486 (2012)

Reaching ^{254}No



J. Erler et al., Nature 486 (2012)

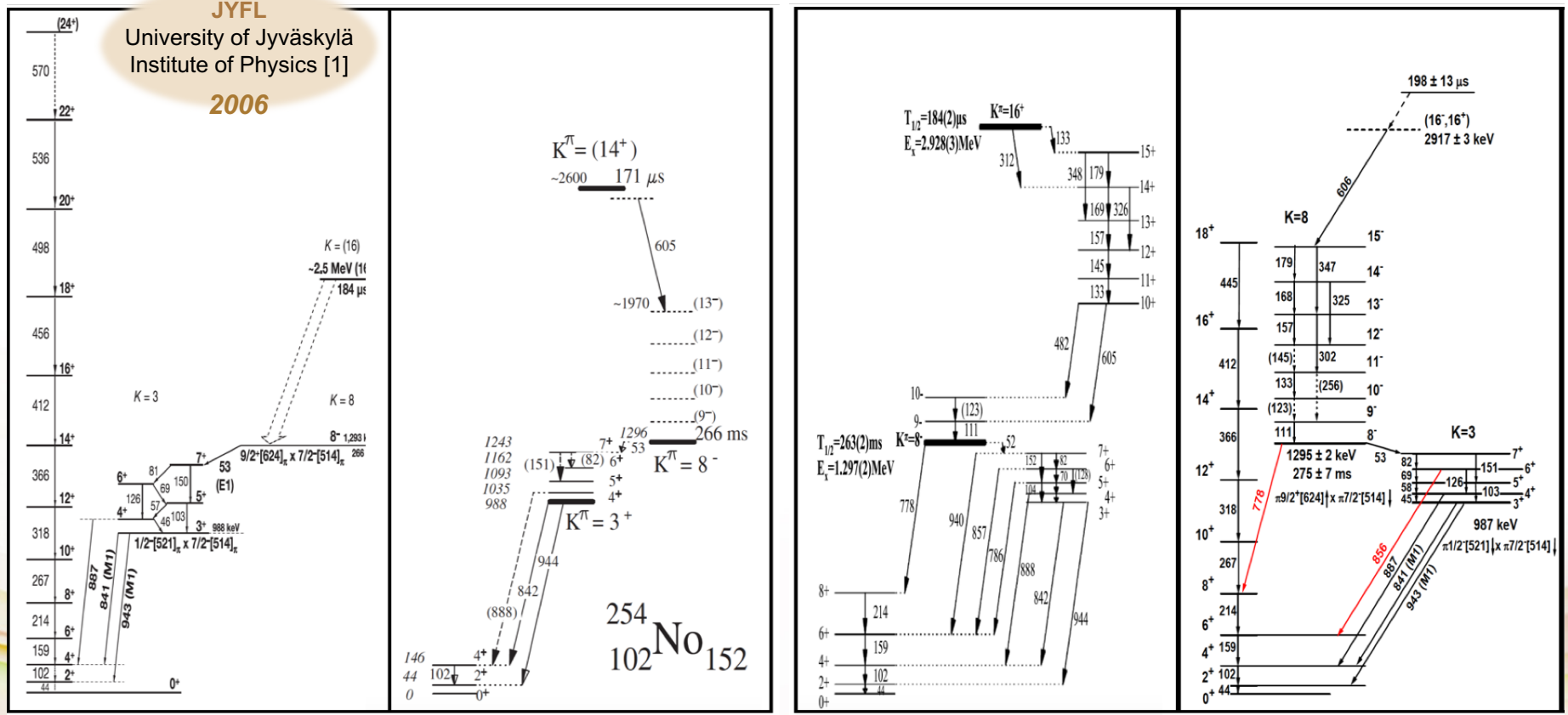
Reaching ^{254}No



J. Erler et al., Nature 486 (2012)

Past experiments & disagreements

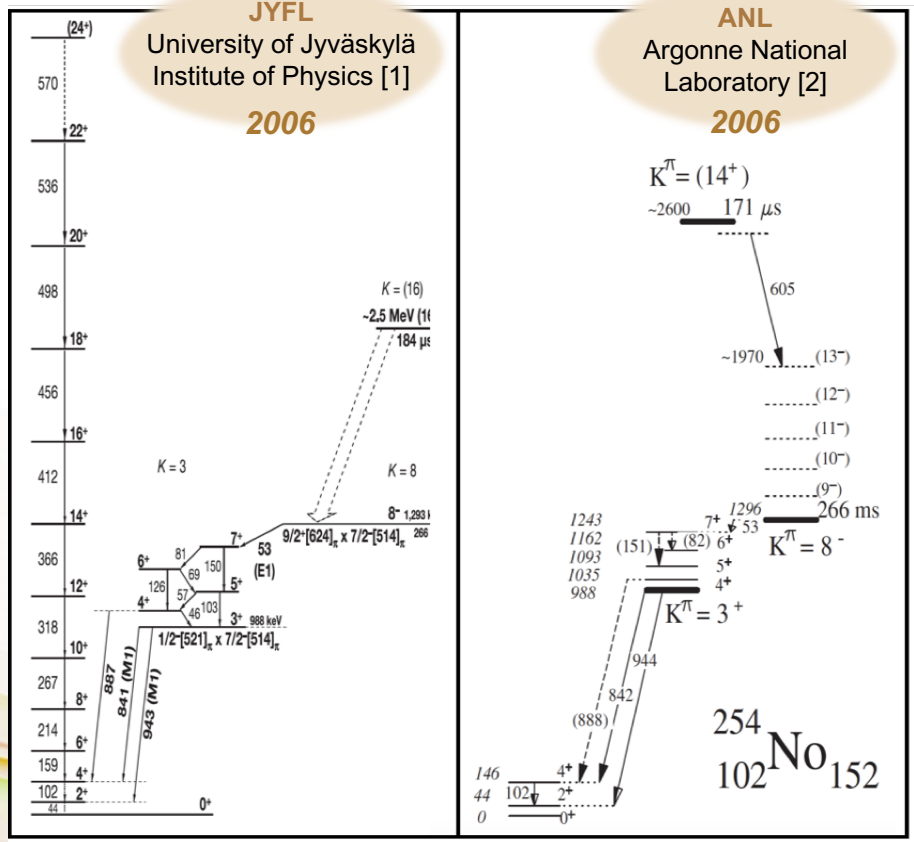
JYFL
University of Jyväskylä
Institute of Physics [1]
2006

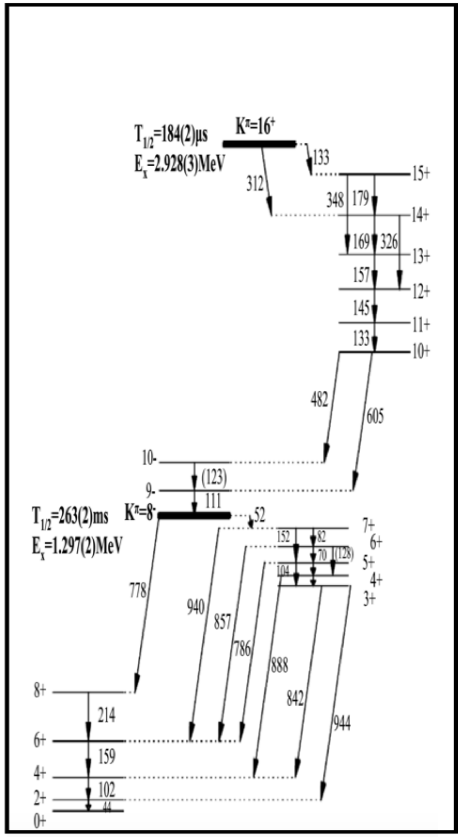


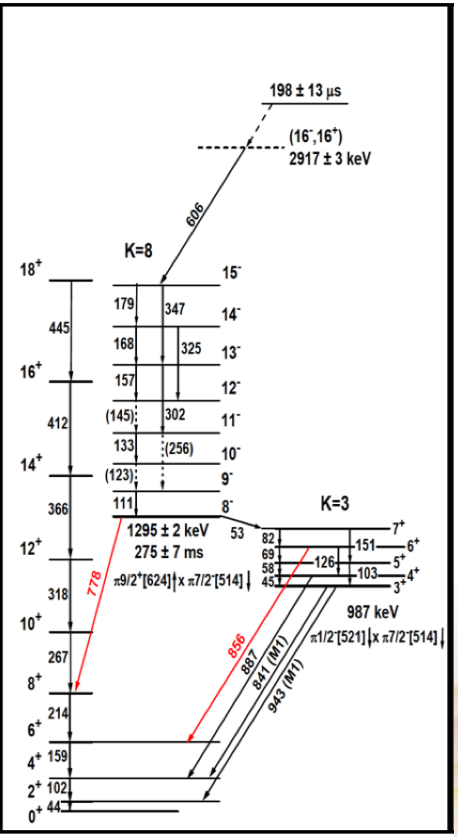
Past experiments & disagreements

JYFL
University of Jyväskylä
Institute of Physics [1]
2006

ANL
Argonne National
Laboratory [2]
2006

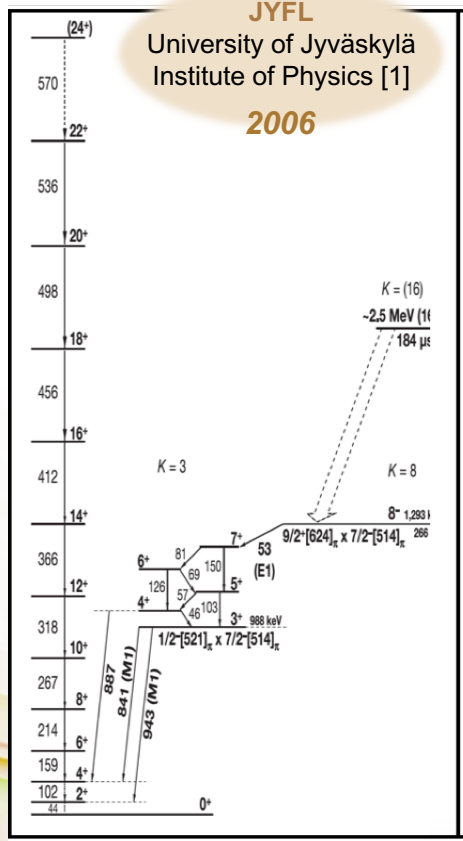




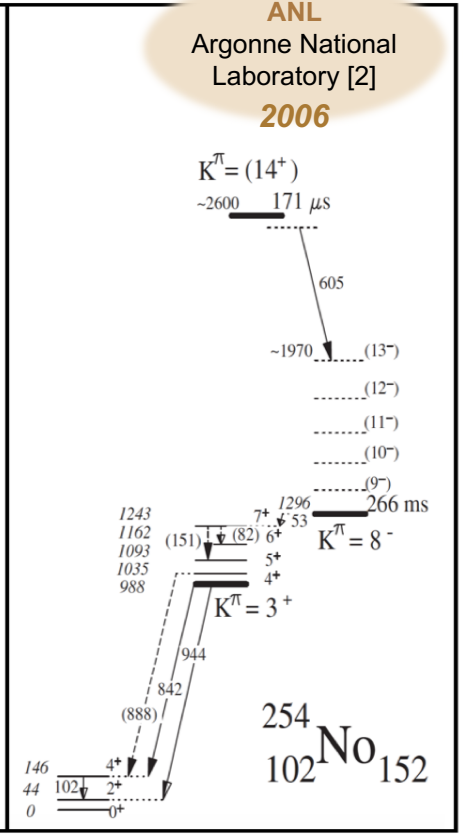


Past experiments & disagreements

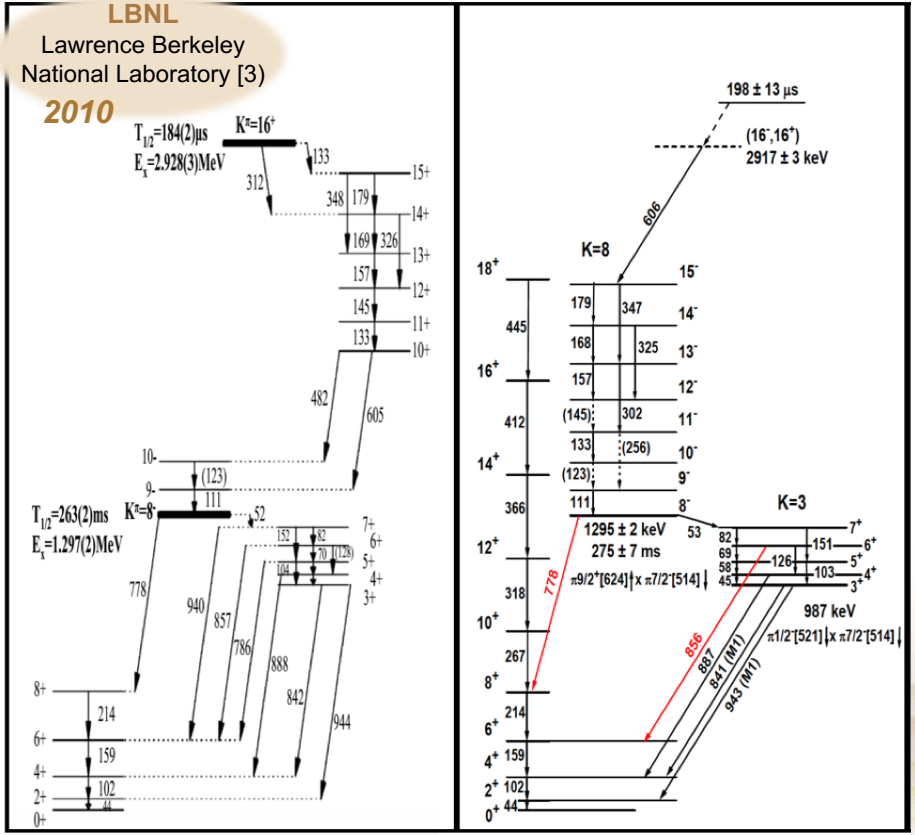
JYFL
University of Jyväskylä Institute of Physics [1]
2006



ANL
Argonne National Laboratory [2]
2006

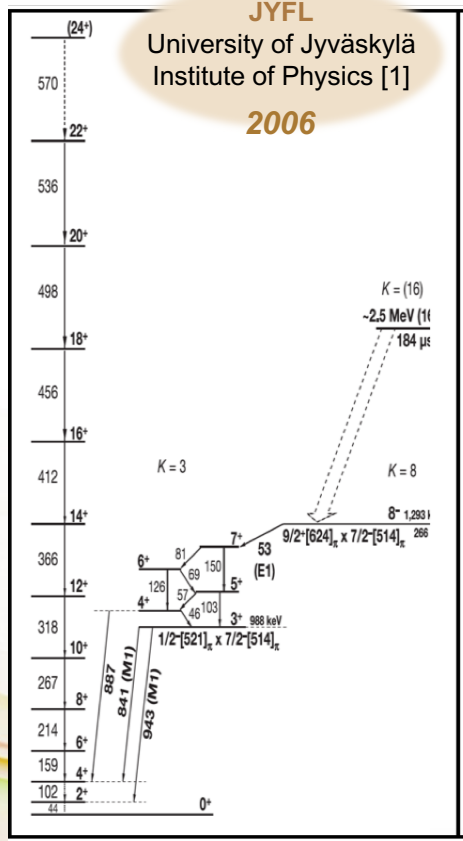


LBNL
Lawrence Berkeley National Laboratory [3]
2010

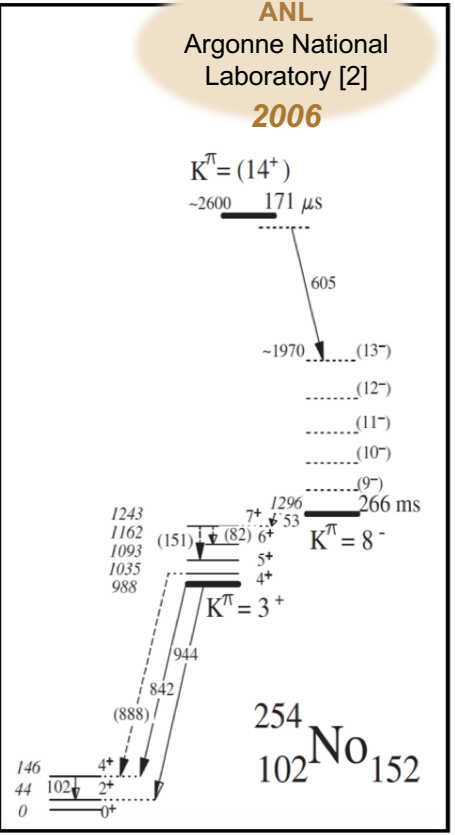


Past experiments & disagreements

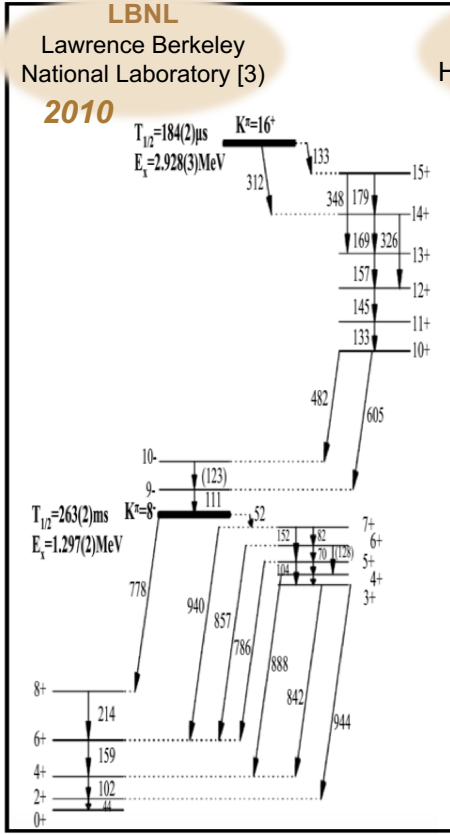
JYFL
University of Jyväskylä Institute of Physics [1]
2006



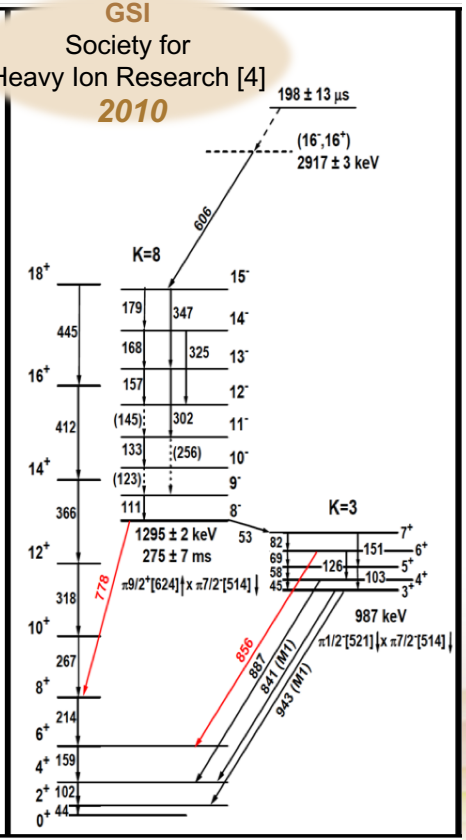
ANL
Argonne National Laboratory [2]
2006



LBNL
Lawrence Berkeley National Laboratory [3]
2010

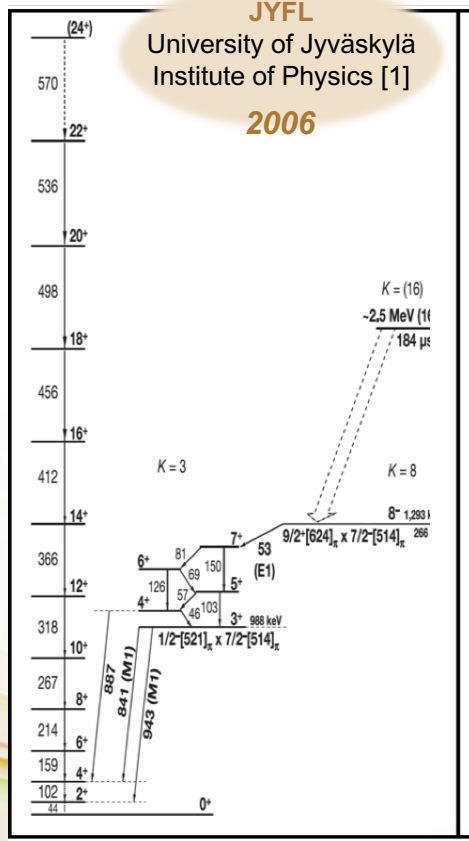


GSI
Society for Heavy Ion Research [4]
2010

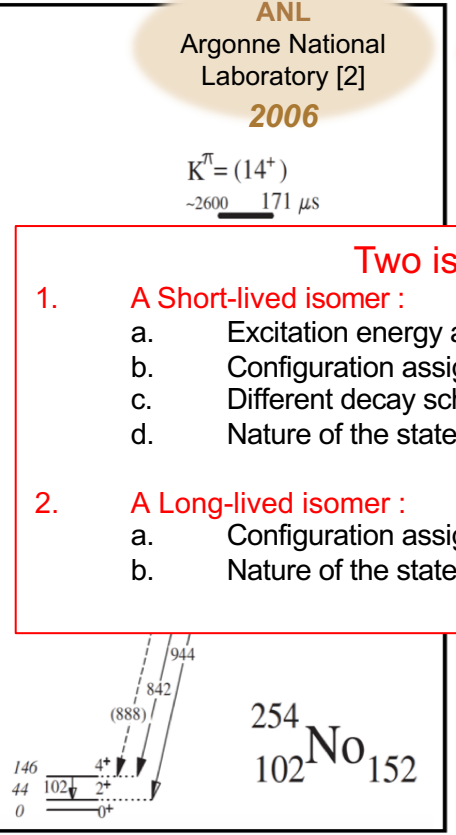


Past experiments & disagreements

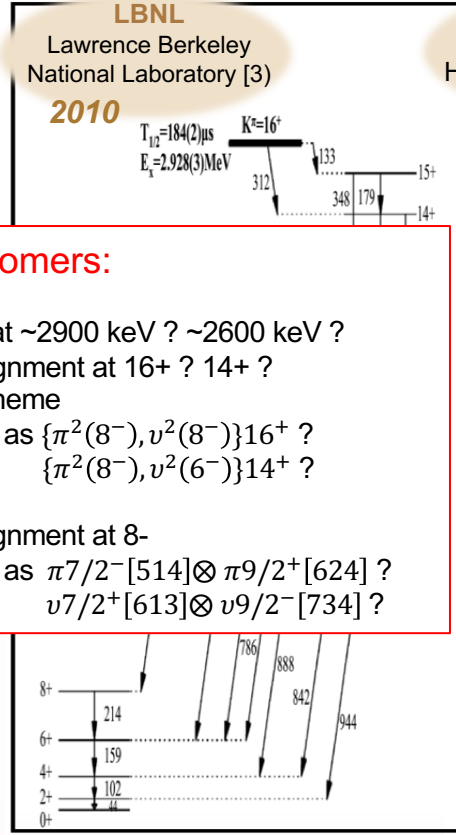
JYFL
University of Jyväskylä Institute of Physics [1]
2006



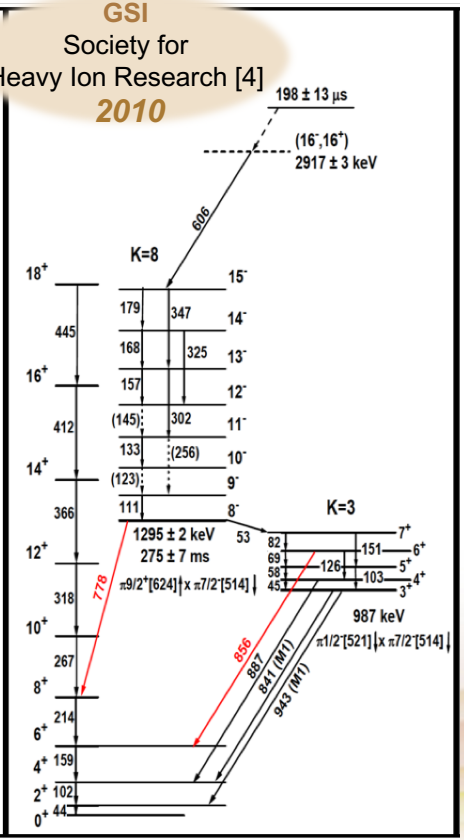
ANL
Argonne National Laboratory [2]
2006



LBNL
Lawrence Berkeley National Laboratory [3]
2010



GSI
Society for Heavy Ion Research [4]
2010



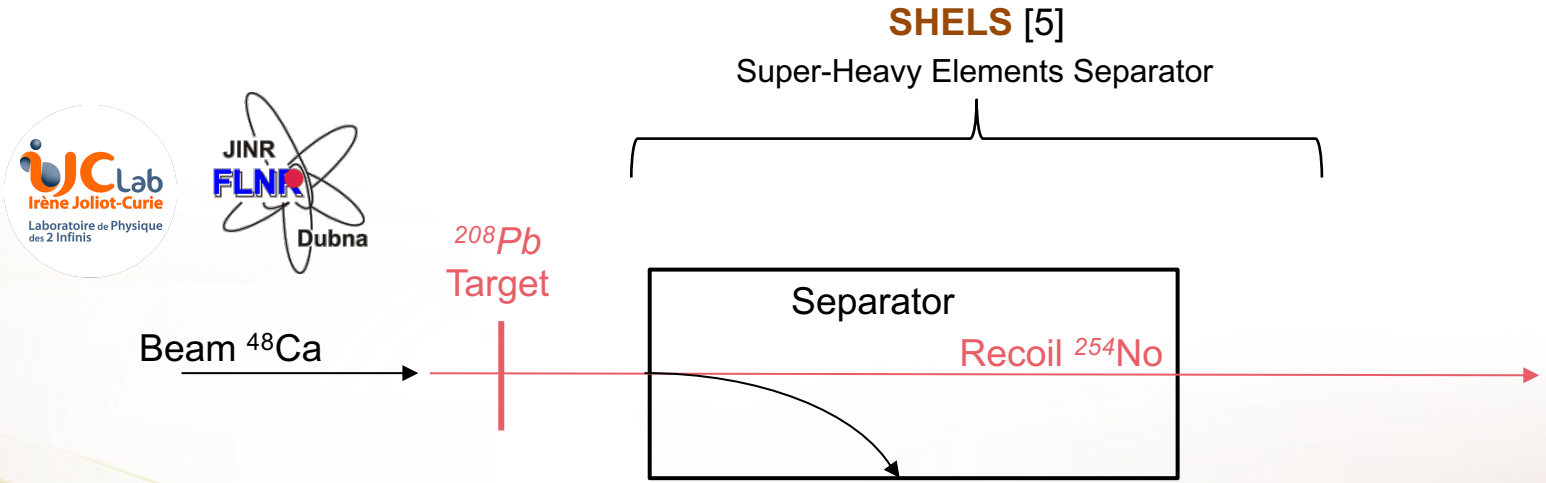
Two isomers:

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 $\pi 7/2^-[514] \otimes \pi 9/2^+[624]$?
      $\upsilon 7/2^+[613] \otimes \upsilon 9/2^-[734]$?

1. Scientific context
2. **Experimental Set up**
3. Results from $^{208}Pb + ^{48}Ca \rightarrow ^{254}No + 2n$ reaction
4. Super-Deformation in ^{254}No?
5. Conclusion

GABRIELA @ SHELS

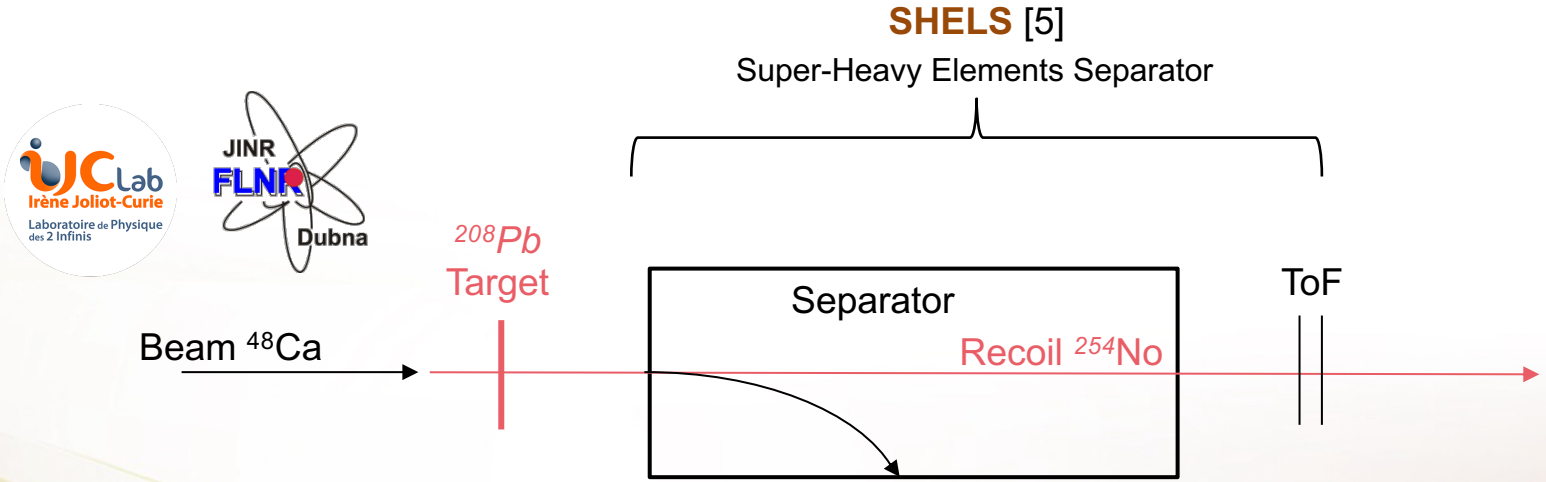
- Separator SHELS (JINR-IN2P3 collaboration) from existing VASSILISSA separator



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

GABRIELA @ SHELS

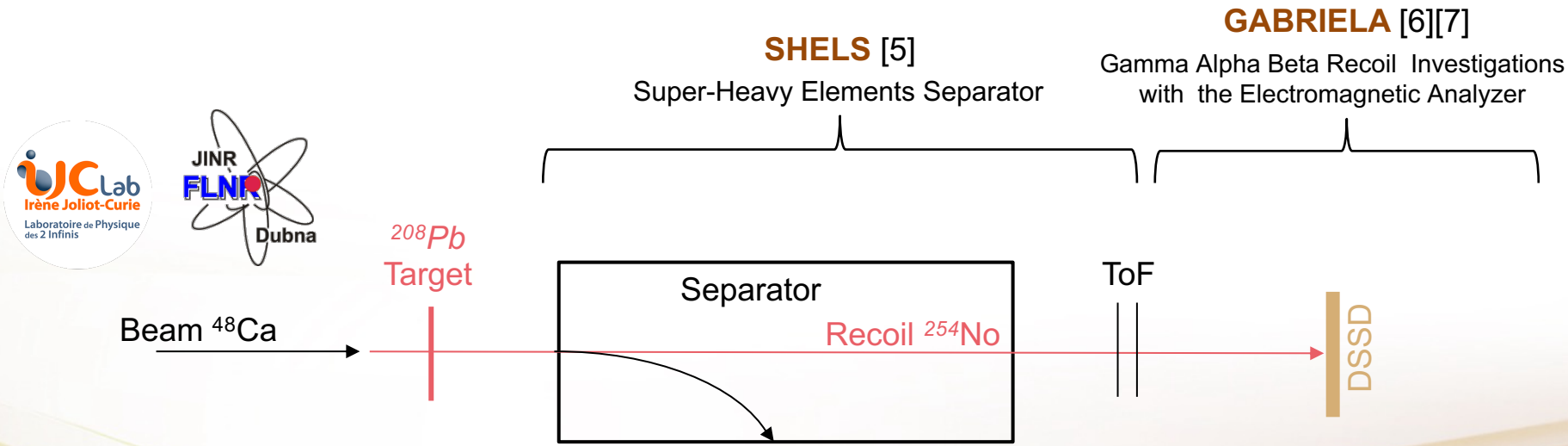
- Separator SHELS (JINR-IN2P3 collaboration) from existing VASSILISSA separator
- Time of Flight (2 MCP)



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

GABRIELA @ SHELS

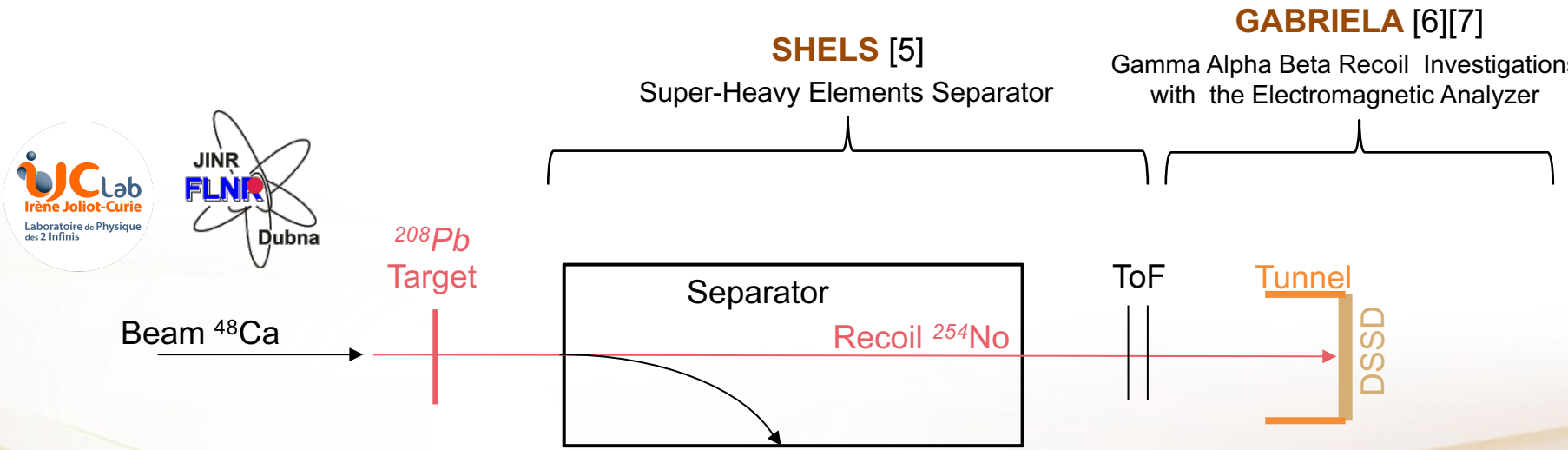
- Separator SHELS (JINR-IN2P3 collaboration) from existing VASSILISSA separator
- Time of Flight (2 MCP)
- **Implantation detector (1 DSSD 128x128, 100.4 x 100.4 mm^2)**



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

GABRIELA @ SHELS

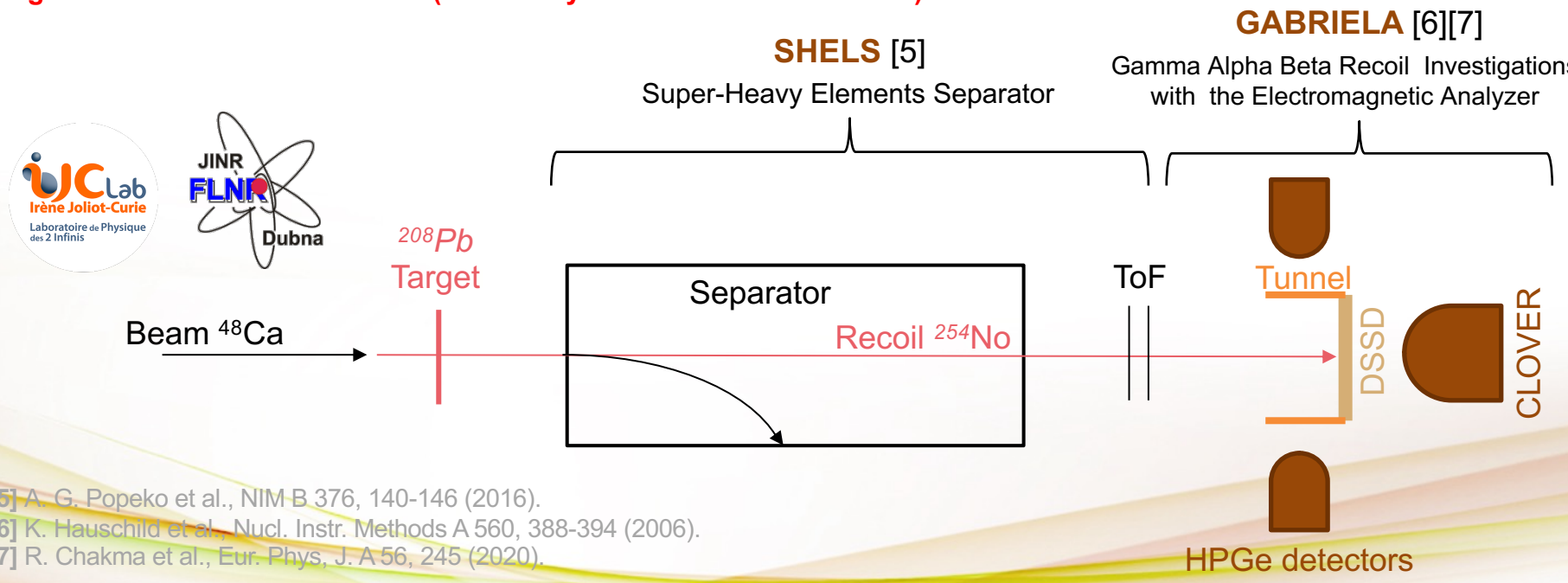
- Separator SHELS (JINR-IN2P3 collaboration) from existing VASSILISSA separator
- Time of Flight (2 MCP)
- **Implantation detector (1 DSSD 128x128, 100.4 x 100.4 mm^2)**
- **Tunnel detectors (4x2 DSSD 72x72, 50 x 60 mm^2, 0.7 mm thick)**



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

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 mm^2)**
- **Tunnel detectors (4x2 DSSD 72x72, 50 x 60 mm^2, 0.7 mm thick)**
- **High Pure Germanium detectors (4 monocrystals + CLODETTE clover)**

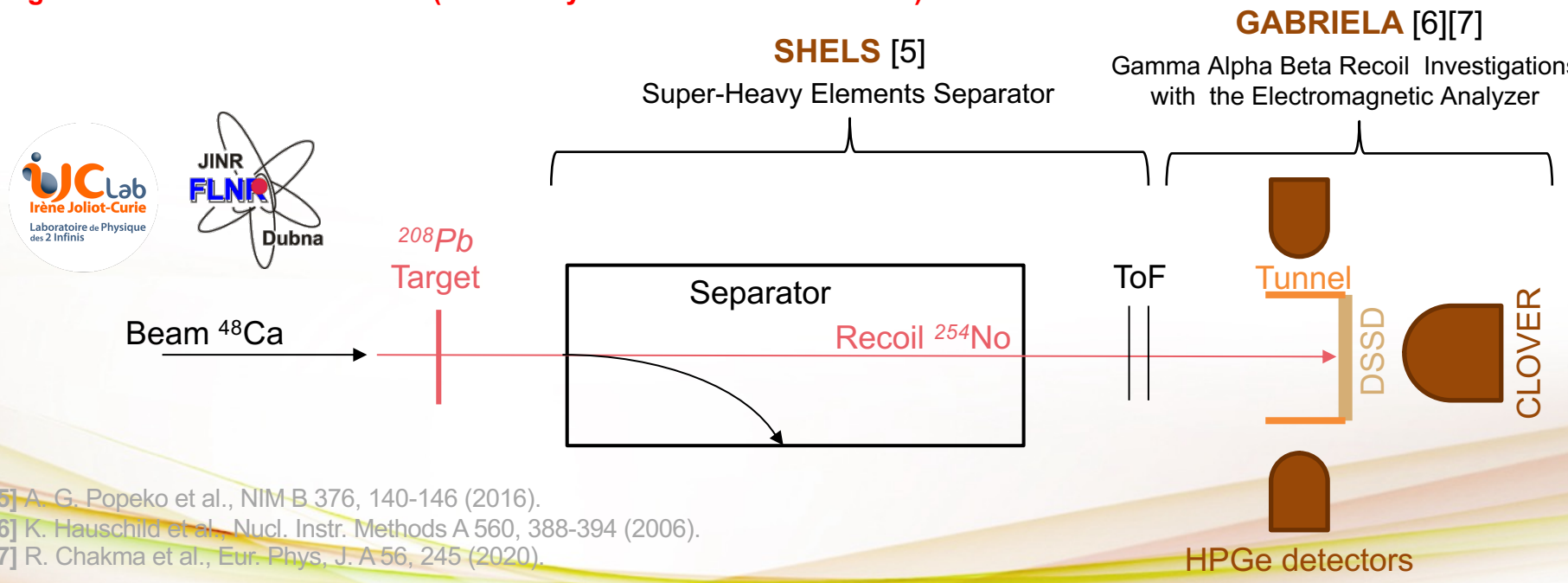


[5] A. G. Popeko et al., NIM B 376, 140-146 (2016).
[6] K. Hauschild et al., Nucl. Instr. Methods A 560, 388-394 (2006).
[7] R. Chakma et al., Eur. Phys. J. A 56, 245 (2020).

GABRIELA @ SHELS

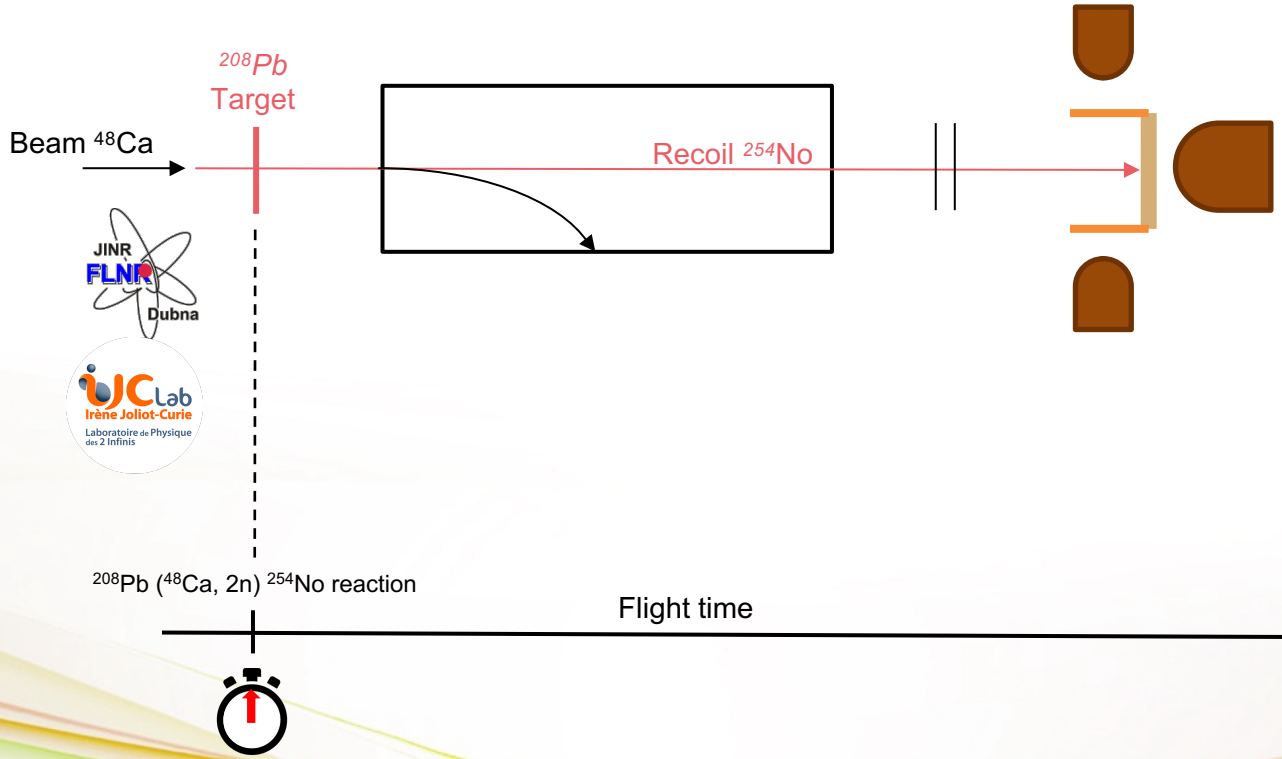
- Separator SHELS (JINR-IN2P3 collaboration) from existing VASSILISSA separator
- Time of Flight (2 MCP)
- **Implantation detector (1 DSSD 128x128, 100.4 x 100.4 mm^2)**
- **Tunnel detectors (4x2 DSSD 72x72, 50 x 60 mm^2, 0.7 mm thick)**
- **High Pure Germanium detectors (4 monocrystals + CLODETTE clover)**

Efficiency largely improved

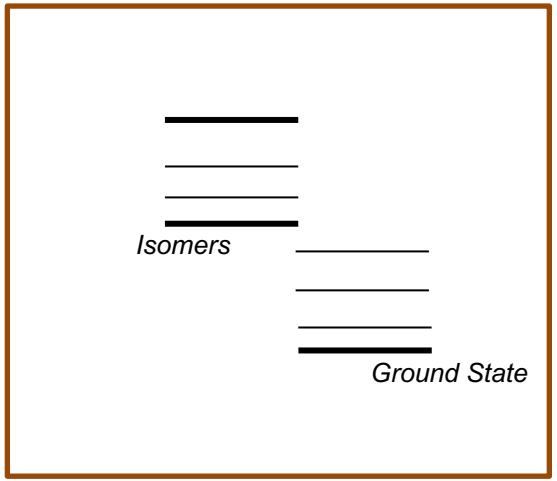


[5] A. G. Popeko et al., NIM B 376, 140-146 (2016).
[6] K. Hauschild et al., Nucl. Instr. Methods A 560, 388-394 (2006).
[7] R. Chakma et al., Eur. Phys. J. A 56, 245 (2020).

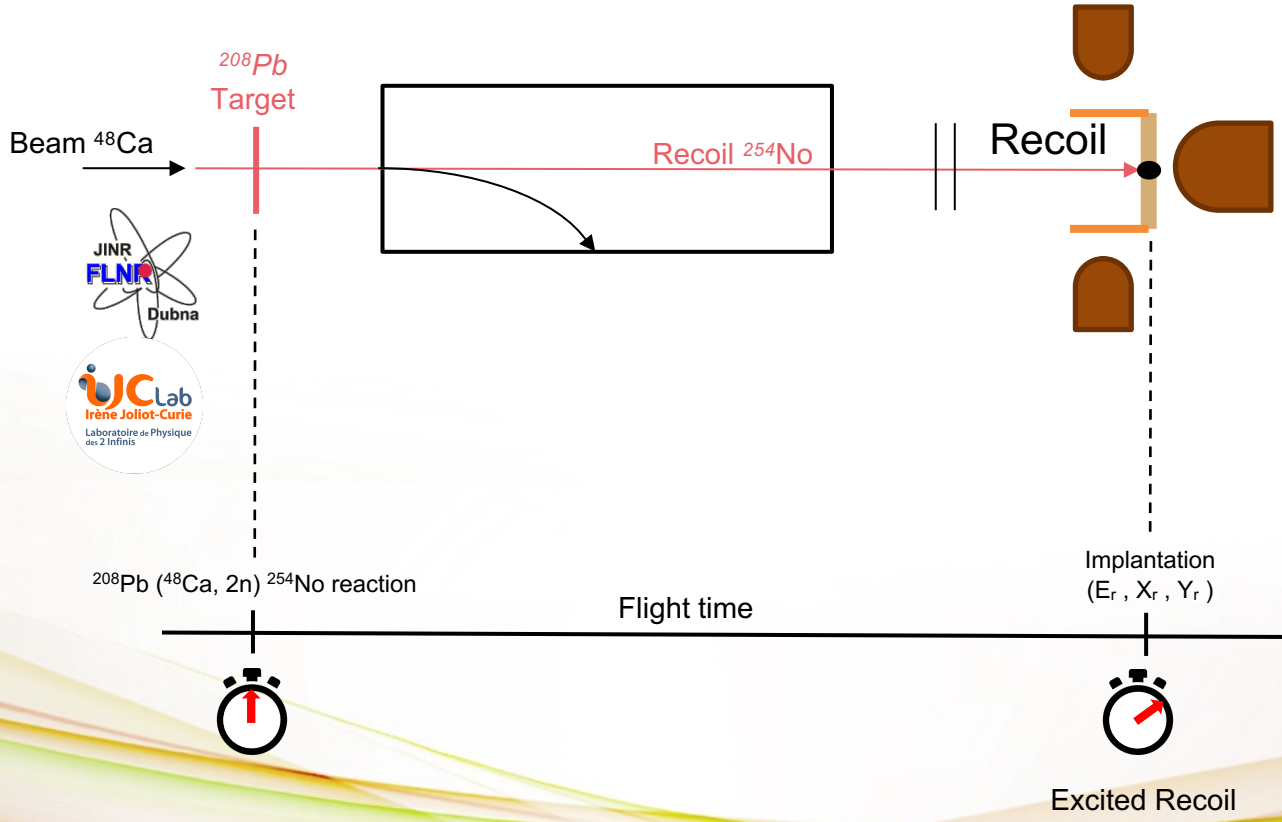
Genetic Correlations (Time + Space)



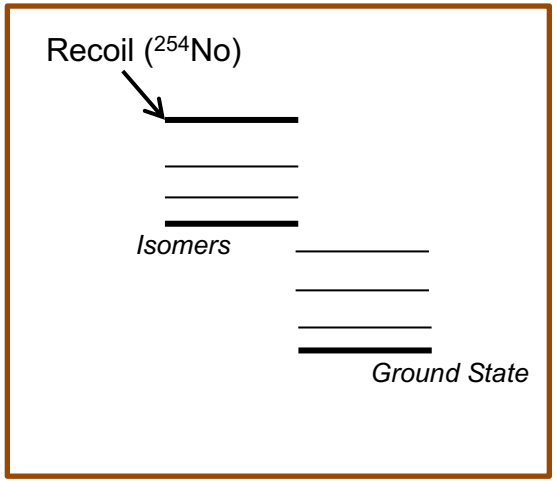
Example with a schematic nuclear structure



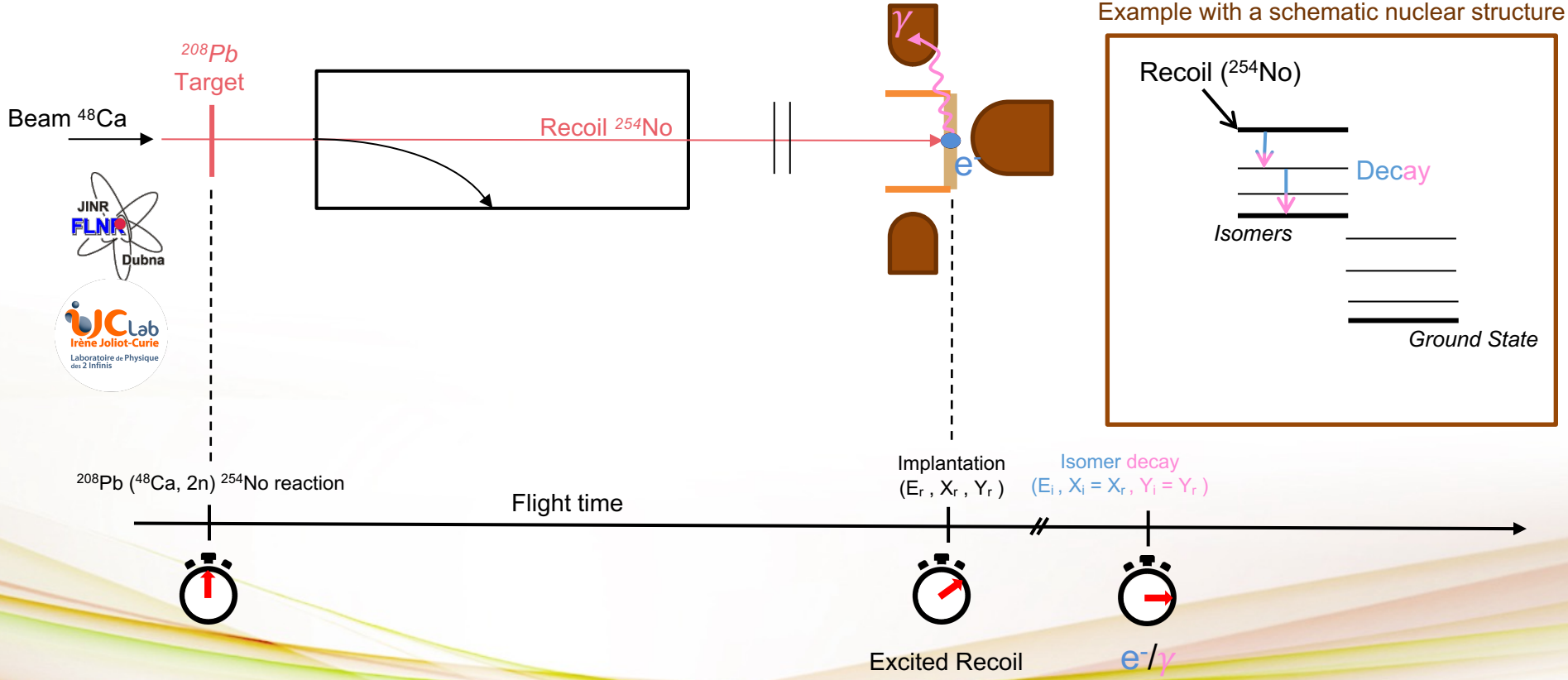
Genetic Correlations (Time + Space)



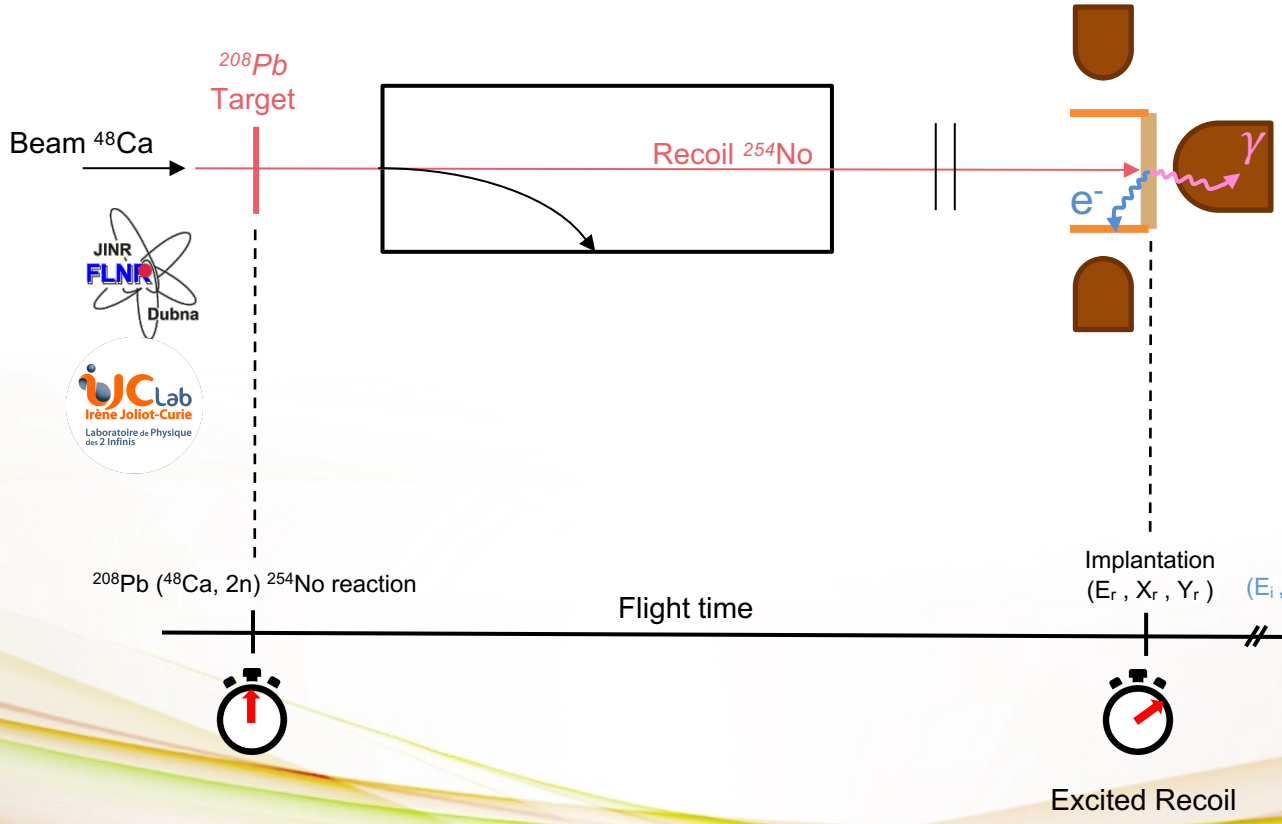
Example with a schematic nuclear structure



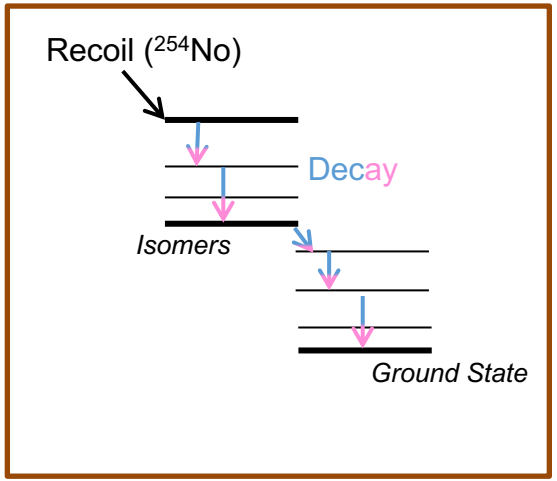
Genetic Correlations (Time + Space)



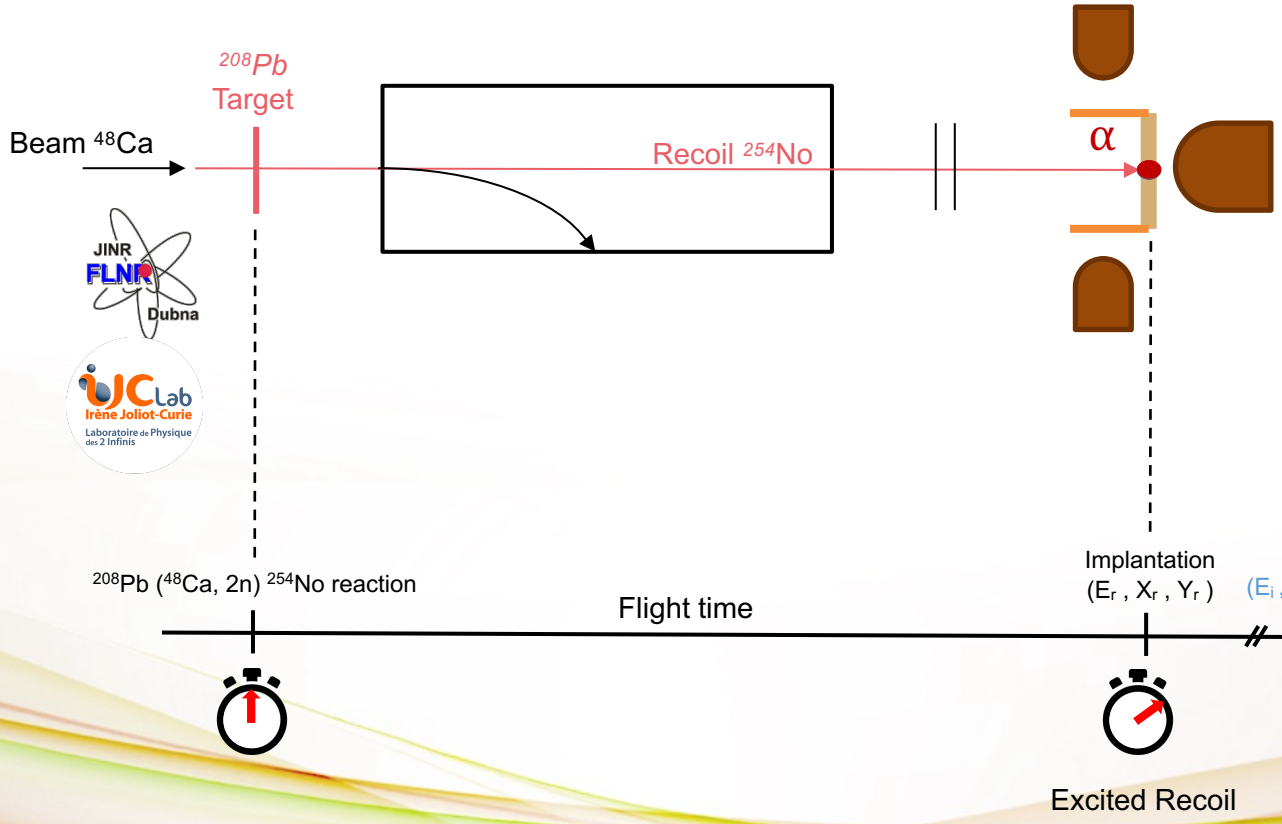
Genetic Correlations (Time + Space)



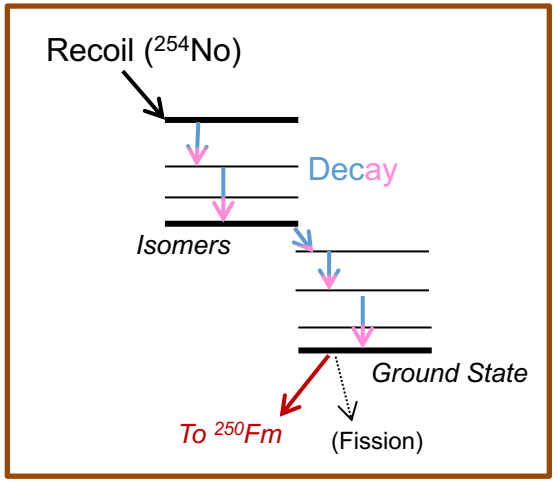
Example with a schematic nuclear structure



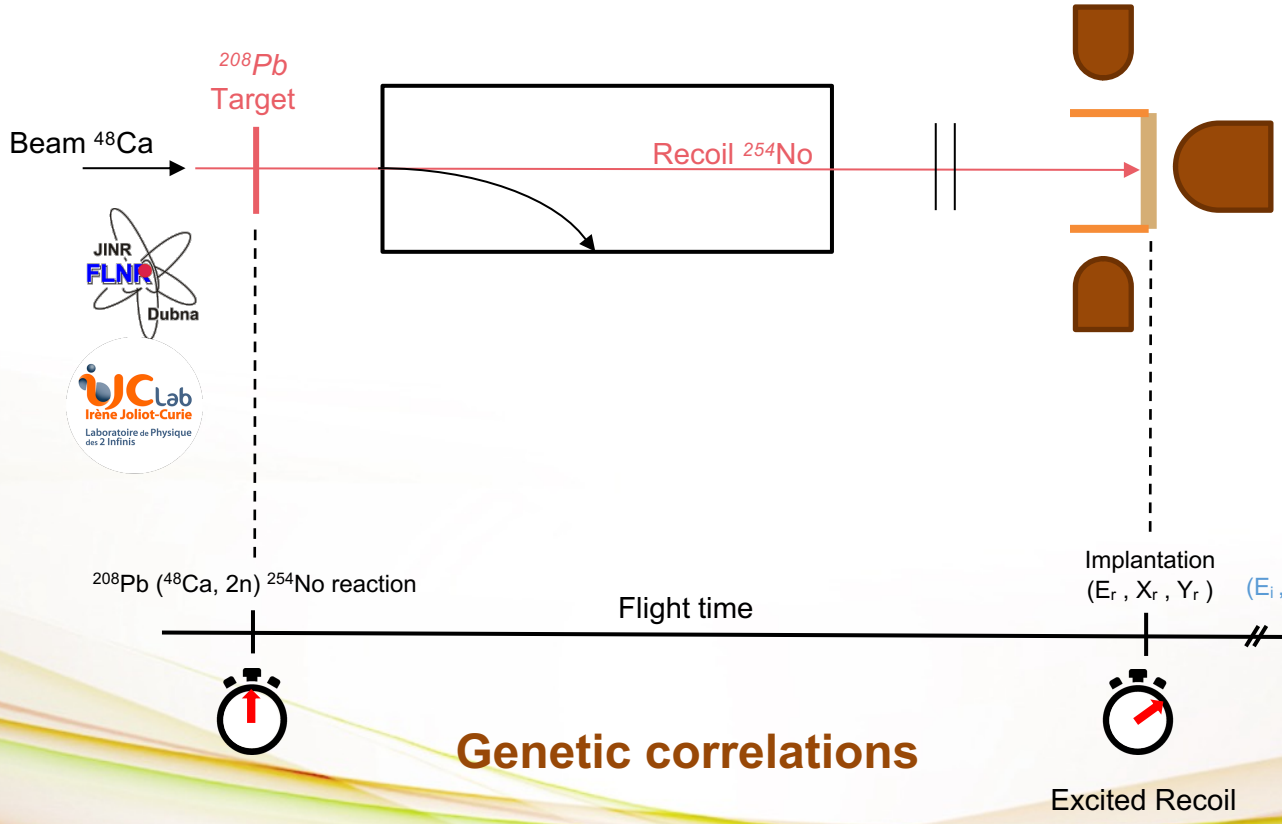
Genetic Correlations (Time + Space)



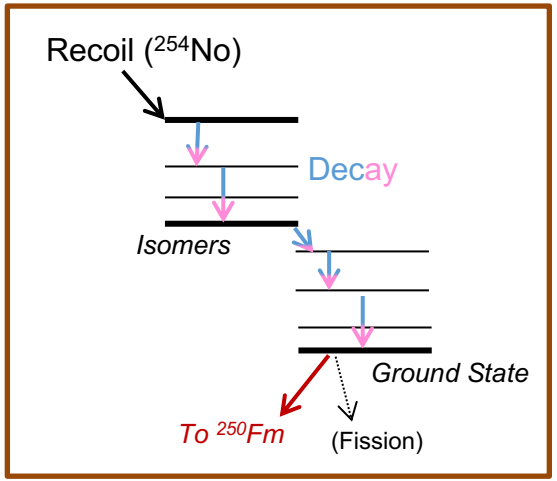
Example with a schematic nuclear structure



Genetic Correlations (Time + Space)



Example with a schematic nuclear structure



1. Scientific context

2. Experimental Set up

3. **Results from $^{208}Pb + ^{48}Ca \rightarrow ^{254}No + 2n$ reaction**

4. Super-Deformation in ^{254}No?

5. Conclusion

Experiment's parameters

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

- October 2019 (2 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
- 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

- Initial purpose of the experiment :
  Fission branch of ground state and isomers

Experiment's parameters

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

- October 2019 (2 years ago)
- 3 weeks of beamtime

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

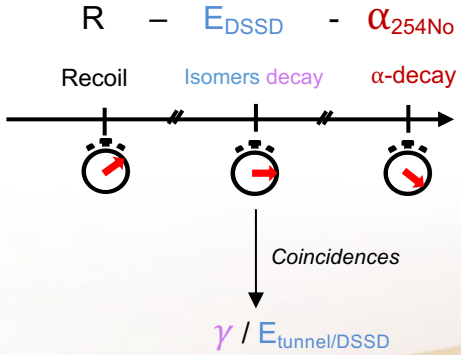
- ^{48}Ca beam
- Intensity = 300 – 400pnA
- Beam Energy = 225 – 228 MeV

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

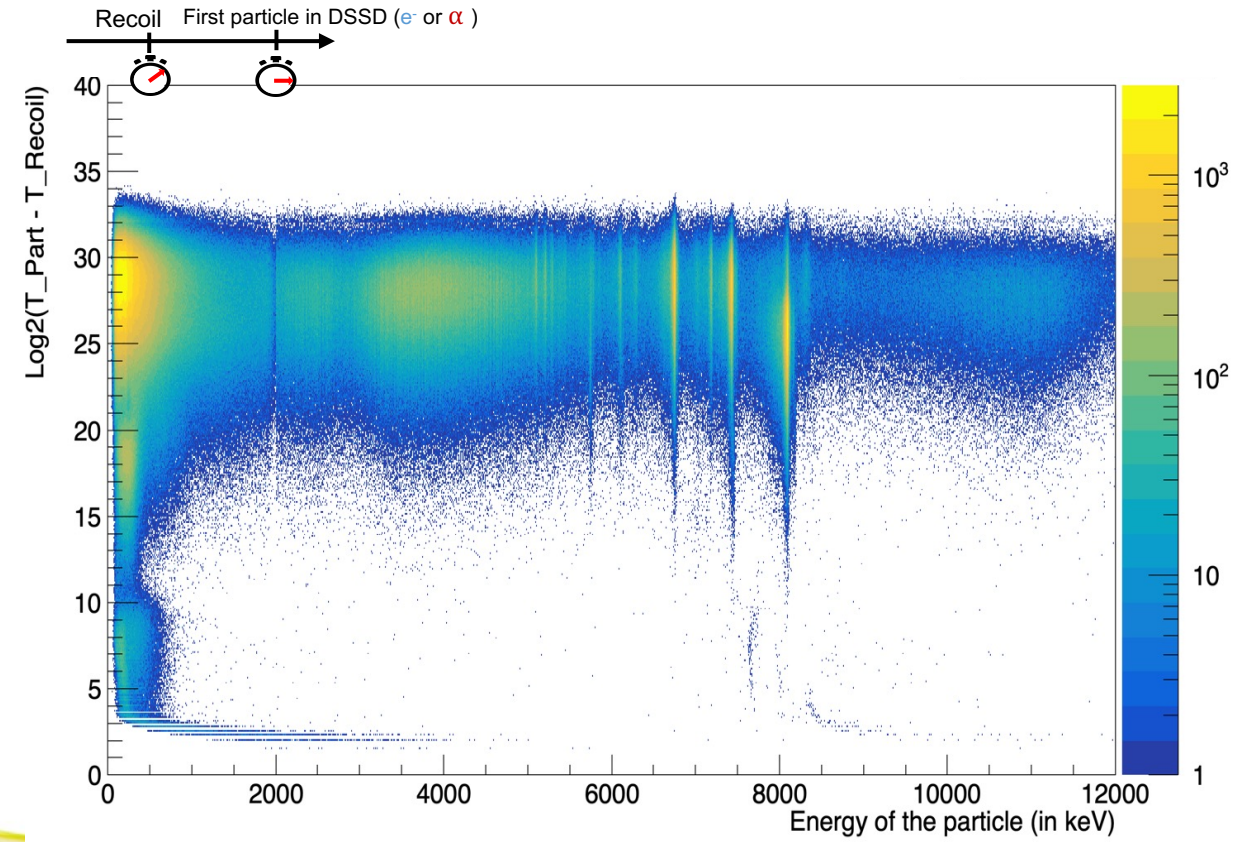
- Initial purpose of the experiment :
  Fission branch of ground state and isomers

Parameters used for data analyze :

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

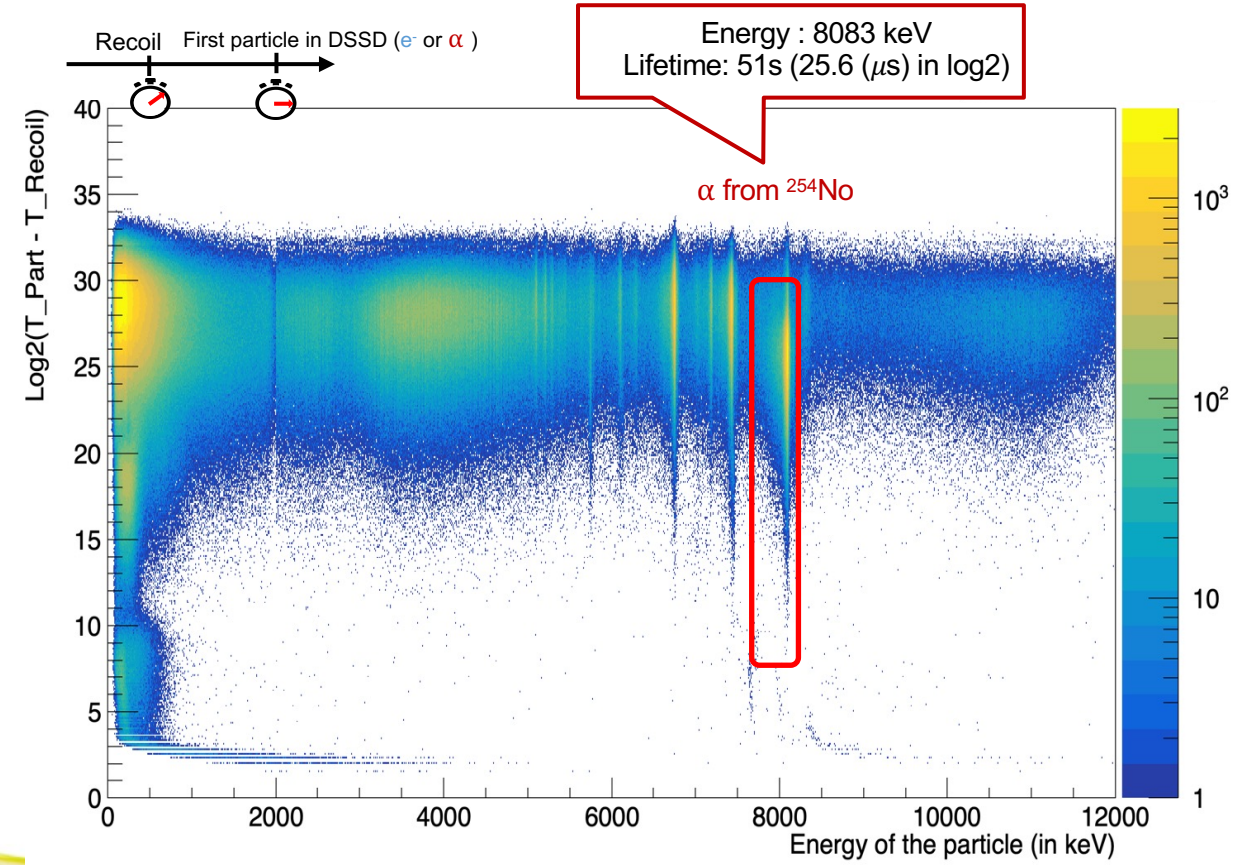


Energy – Lifetime correlation graph



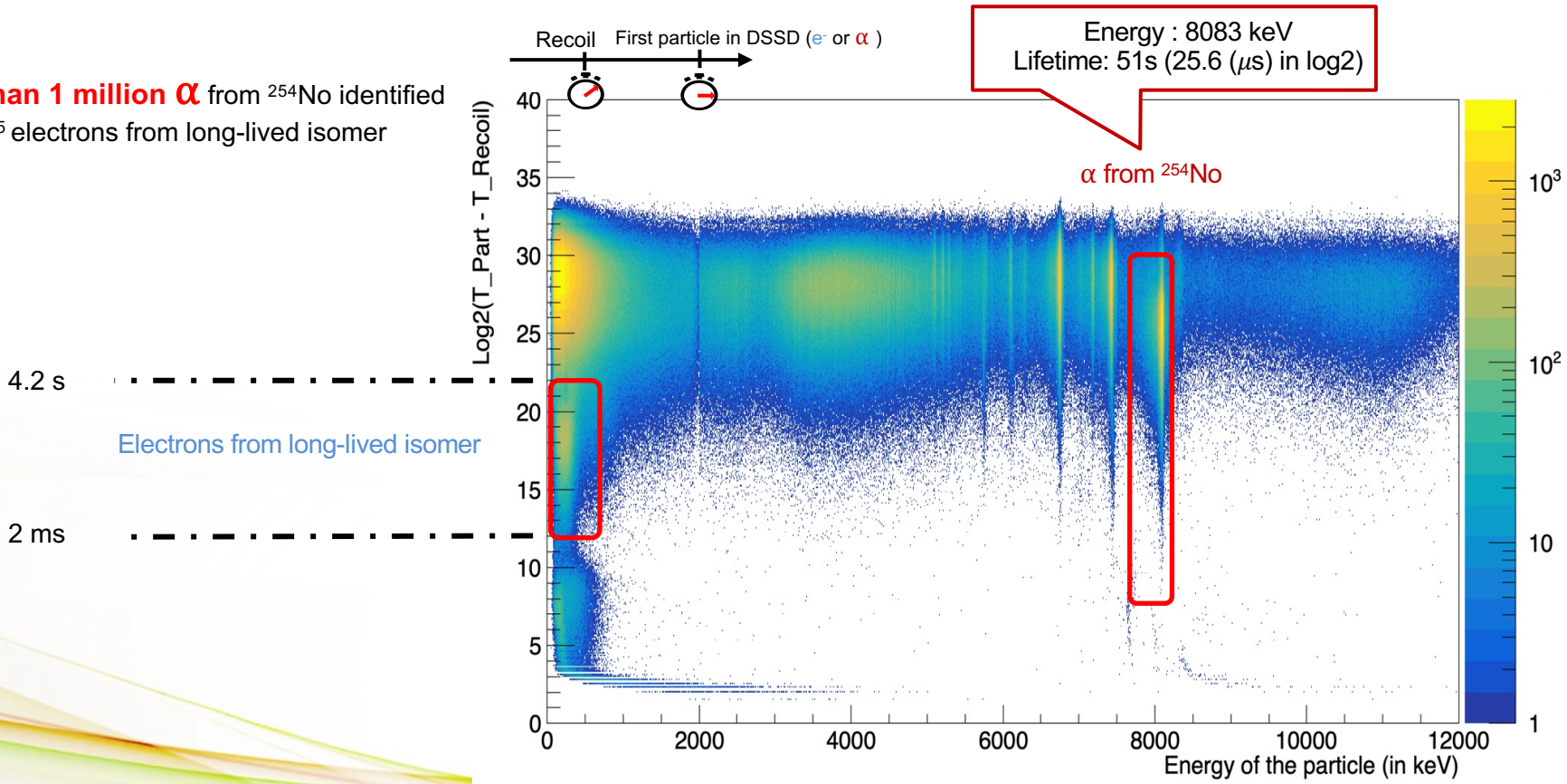
Energy – Lifetime correlation graph

- **More than 1 million α** from ^{254}No identified



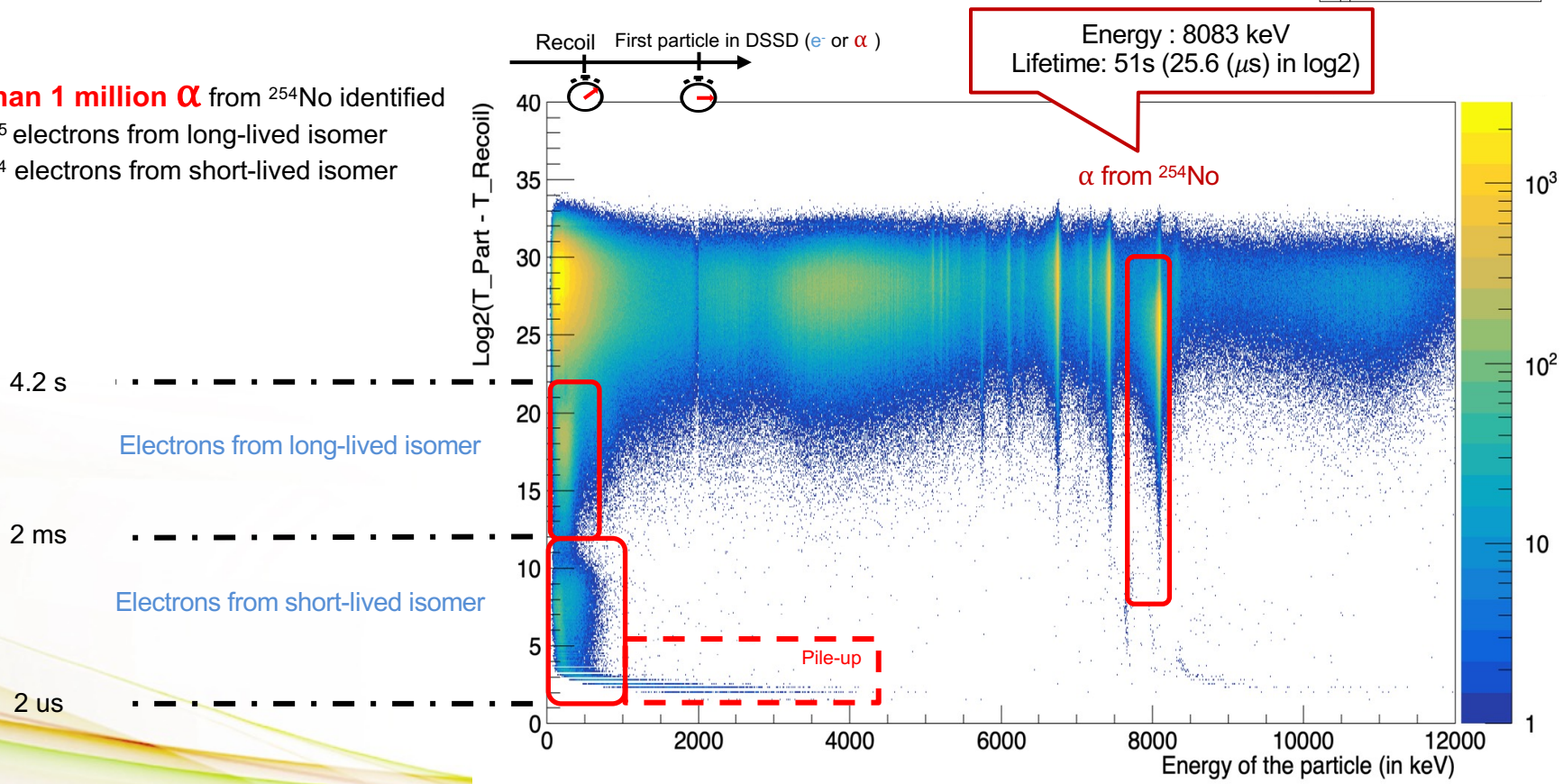
Energy – Lifetime correlation graph

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



Energy – Lifetime correlation graph

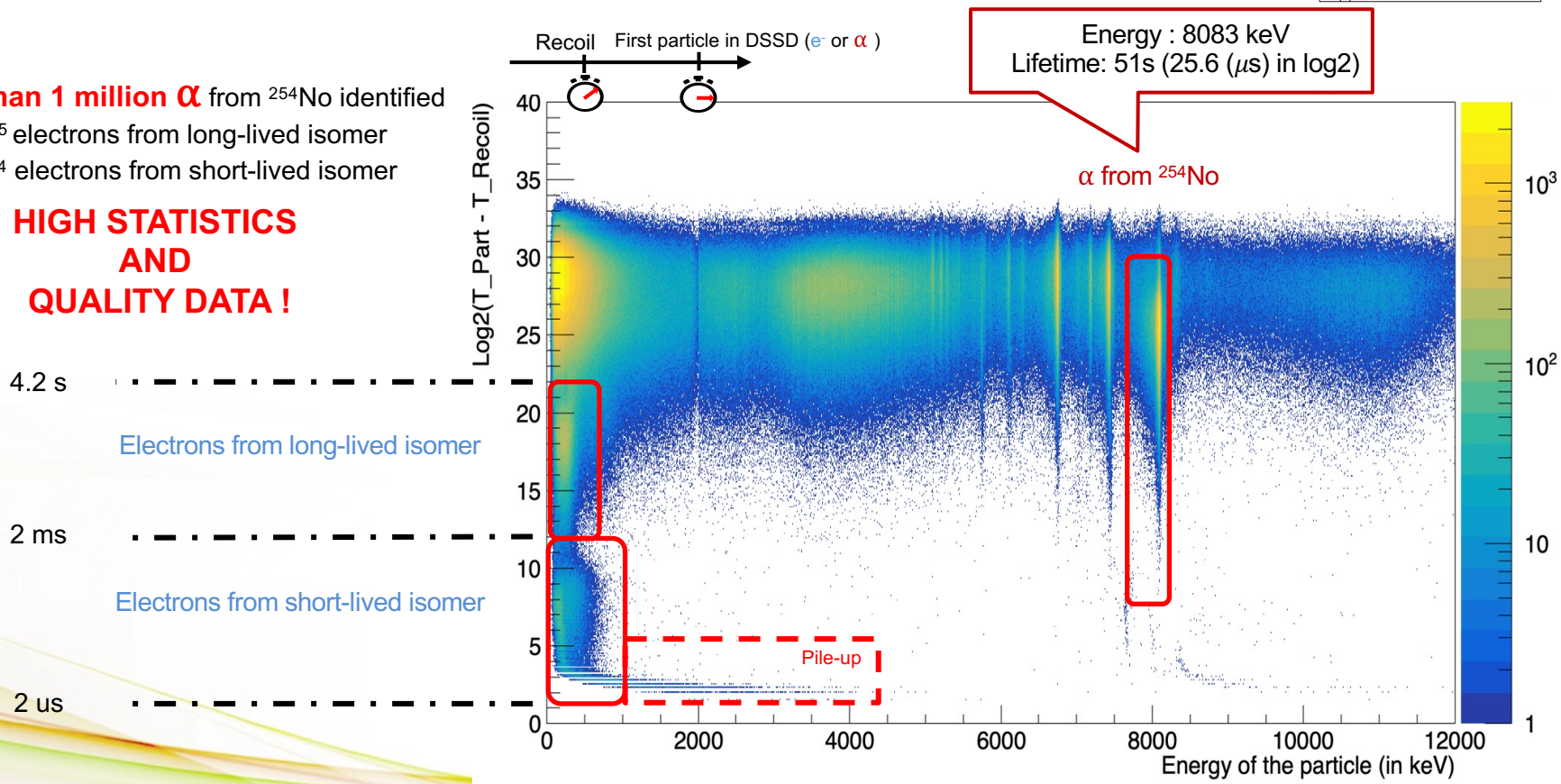
- **More than 1 million α** from ^{254}No identified
- 6.6 x 10^5 electrons from long-lived isomer
- 1.2 x 10^4 electrons from short-lived isomer



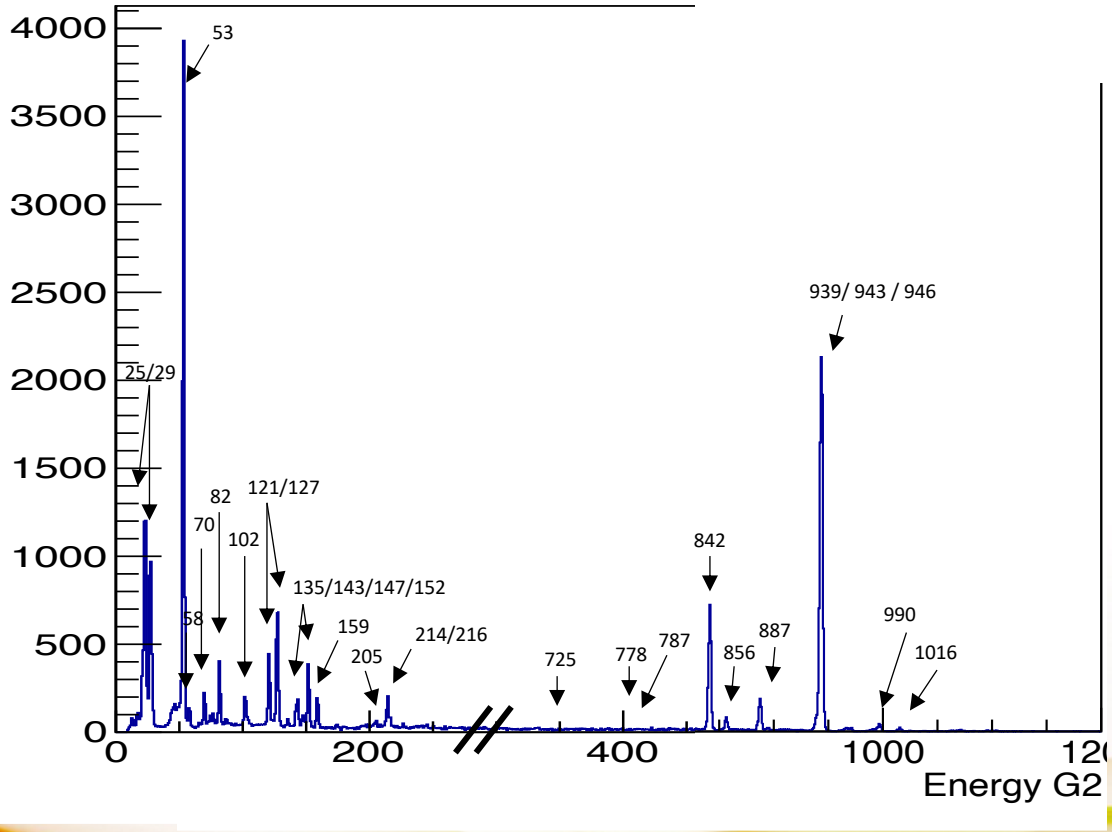
Energy – Lifetime correlation graph

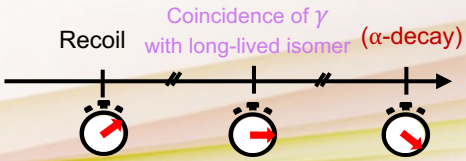
- **More than 1 million α** from ^{254}No identified
- 6.6 x 10^5 electrons from long-lived isomer
- 1.2 x 10^4 electrons from short-lived isomer

HIGH STATISTICS AND QUALITY DATA !

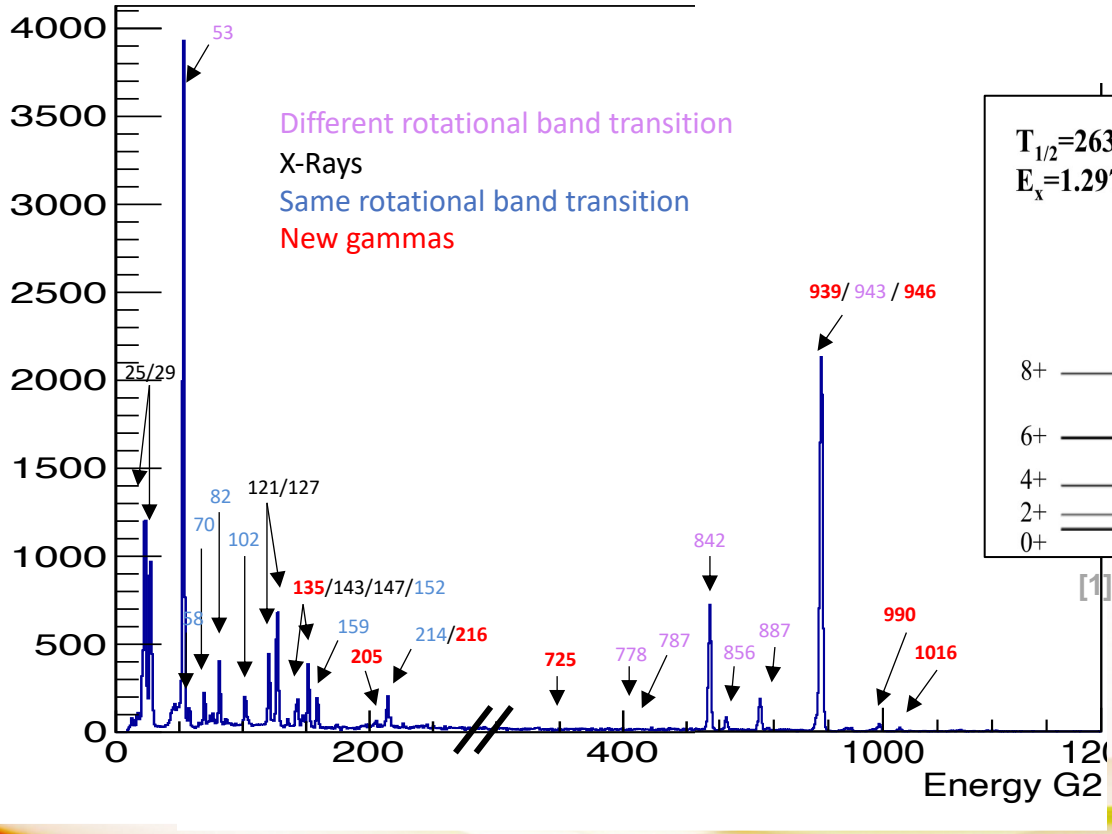


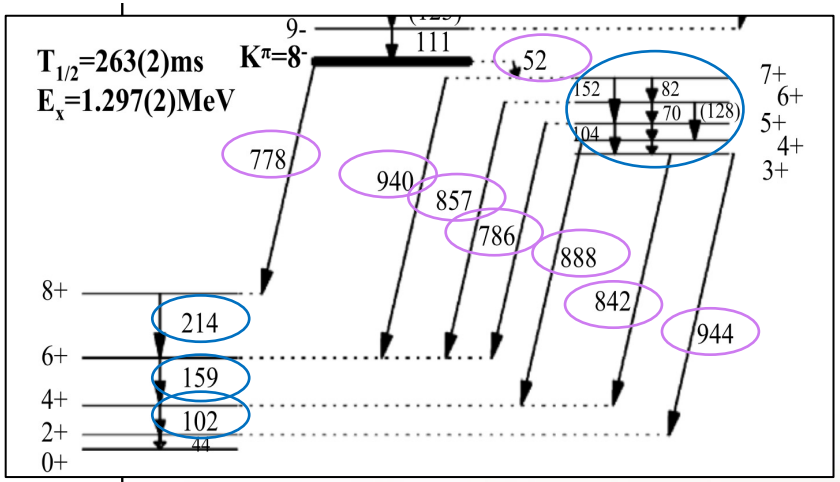
Coincidence Gammas (long-lived isomer)



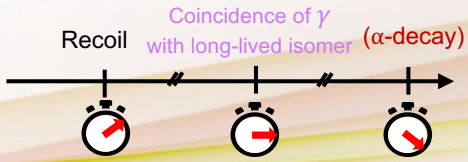


Coincidence Gammas (long-lived isomer)

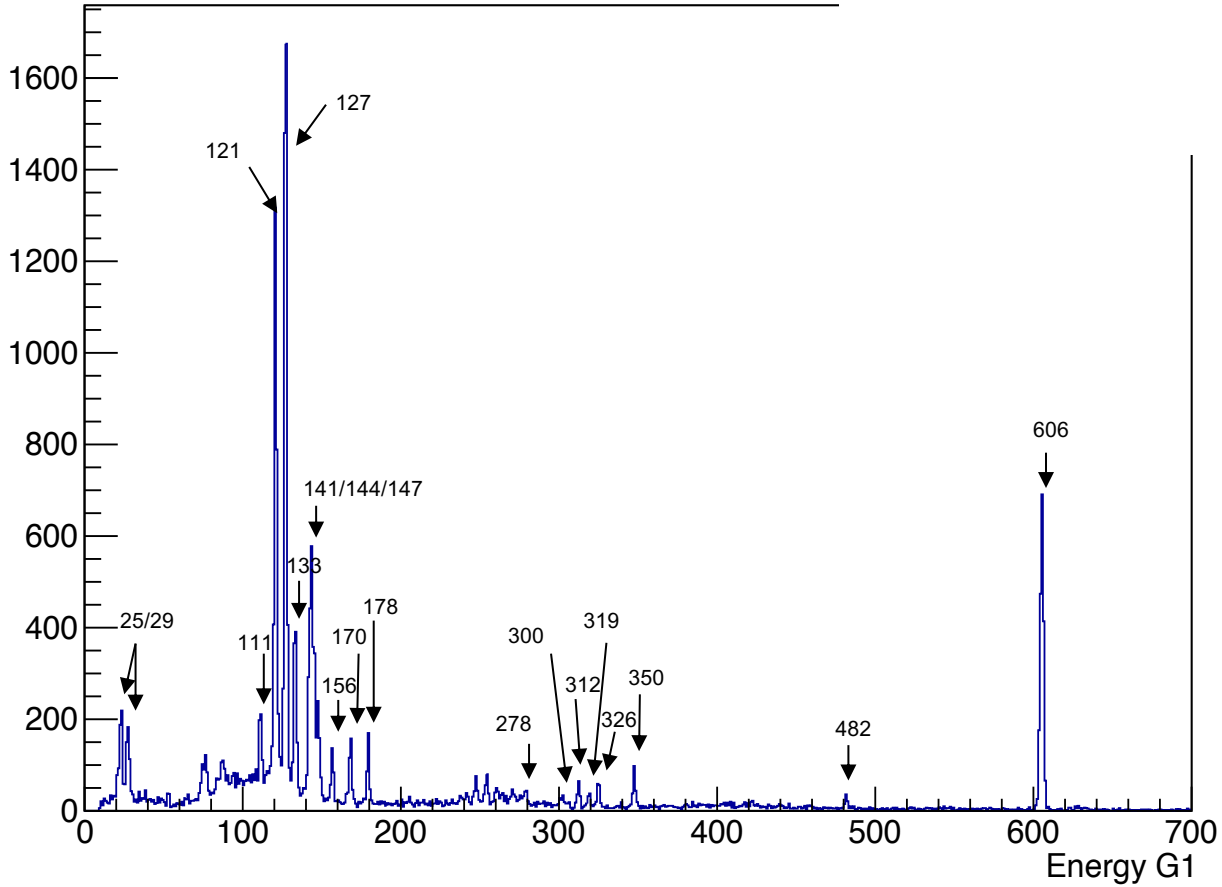


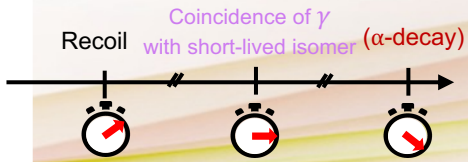


[1] R. M. Clark et al., Phys. Lett. B B 690 (2010) 19.

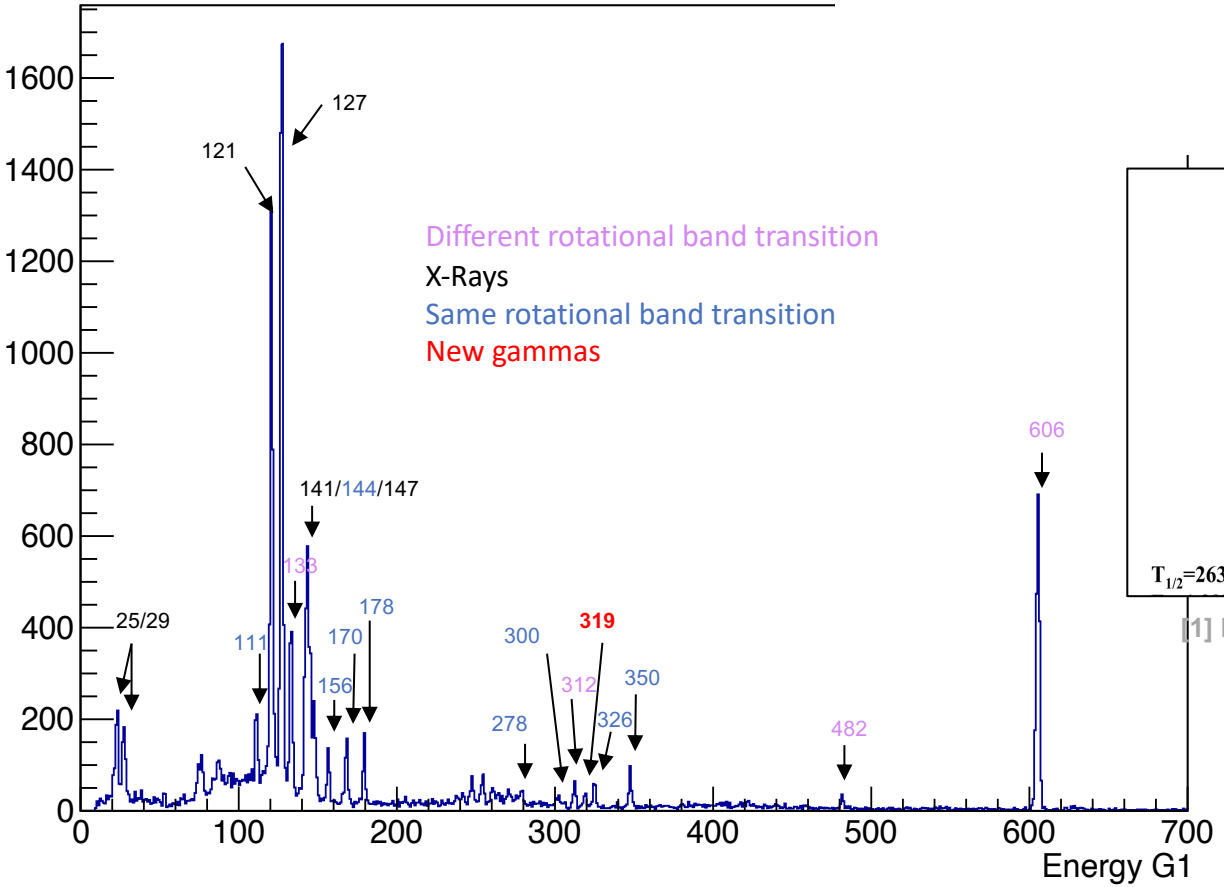


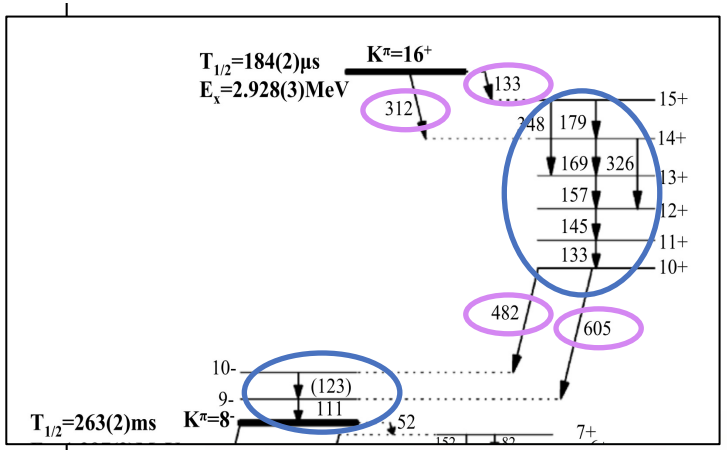
Coincidence Gammas (short-lived isomer)



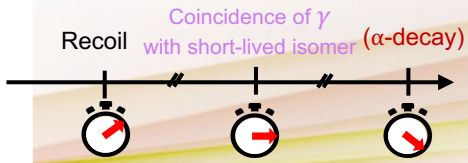


Coincidence Gammas (short-lived isomer)



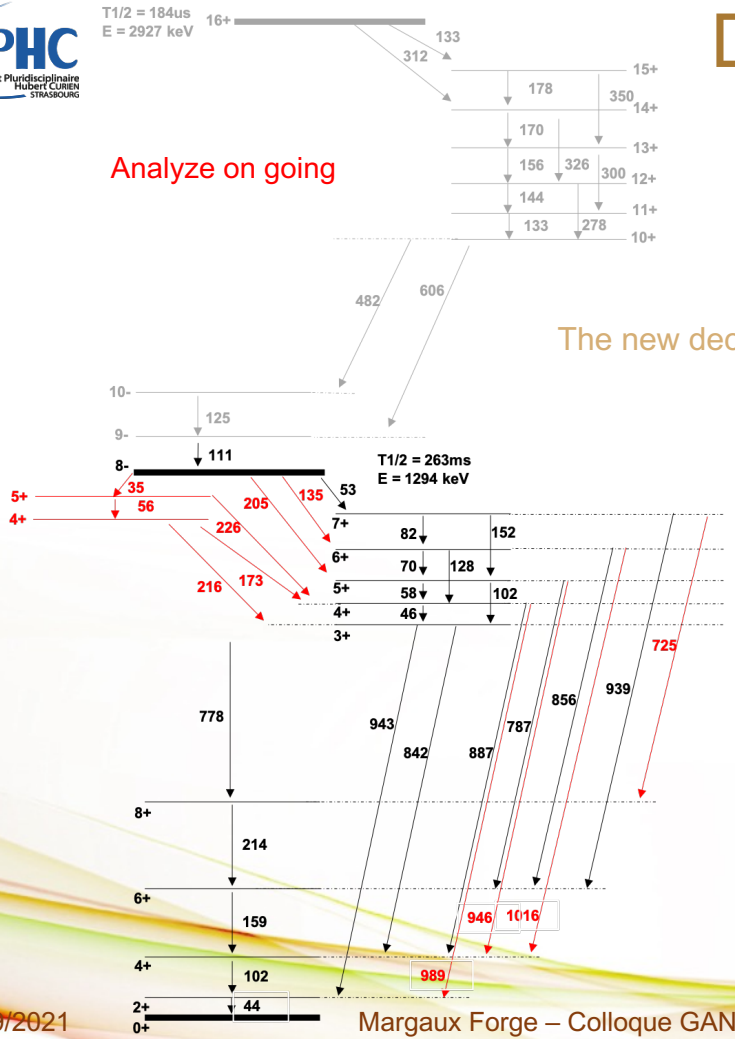


[1] R. M. Clark et al., Phys. Lett. B B 690 (2010) 19.



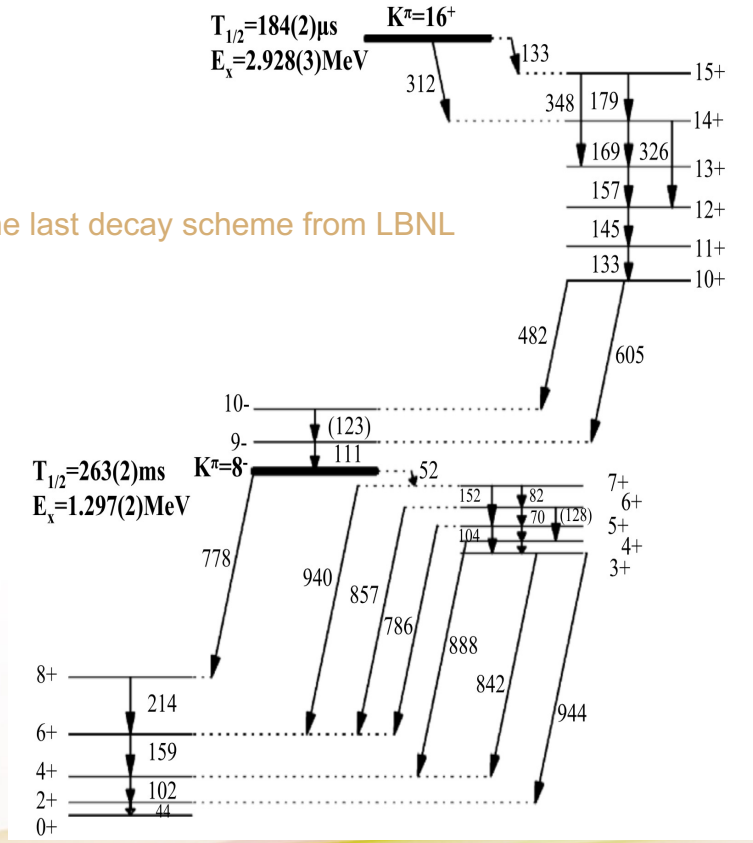
Decay scheme

Analyze on going



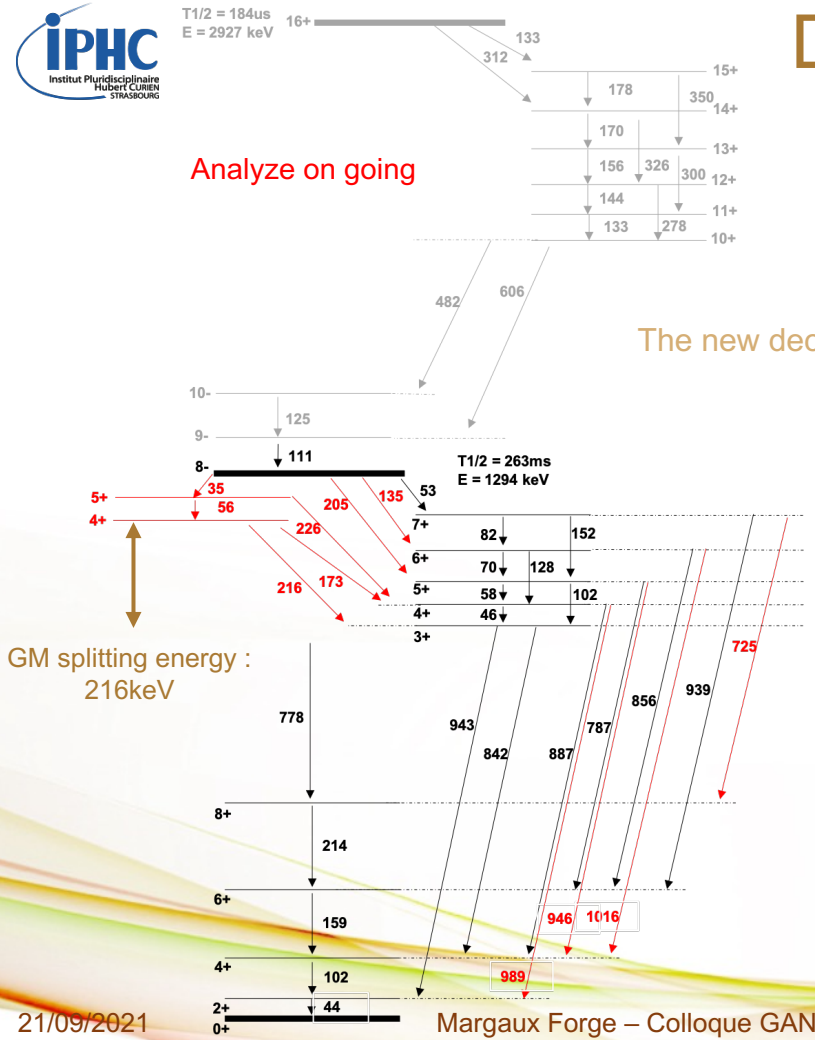
The new decay scheme

The last decay scheme from LBNL



Decay scheme

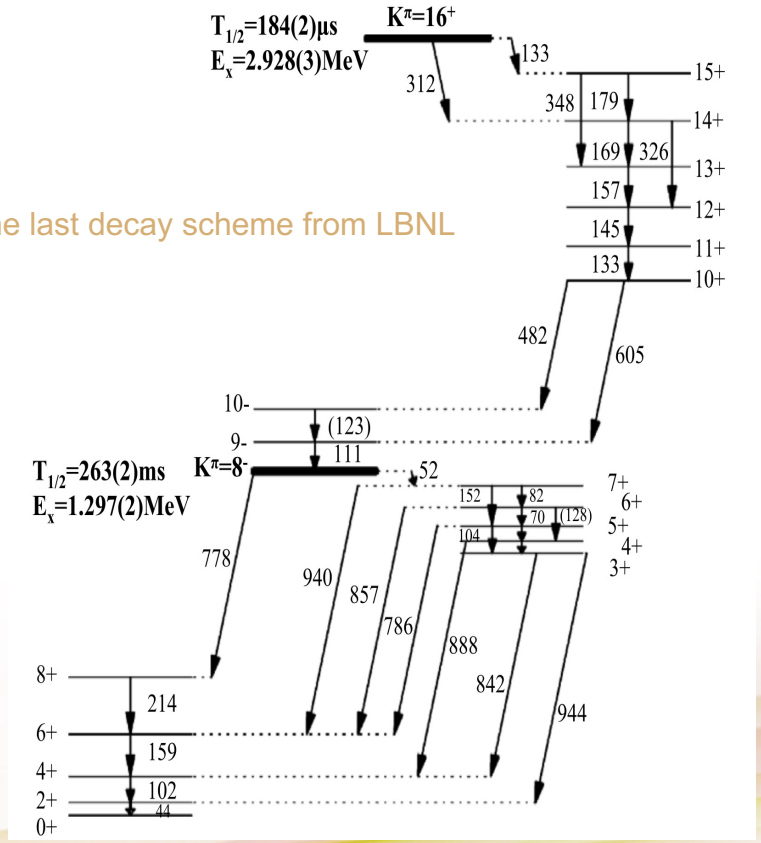
Analyze on going



GM splitting energy : 216keV

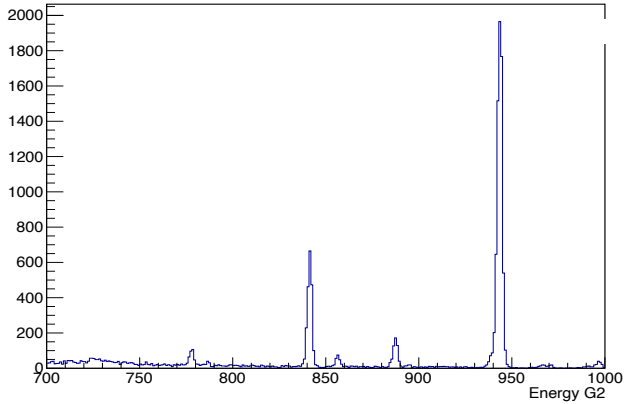
The new decay scheme

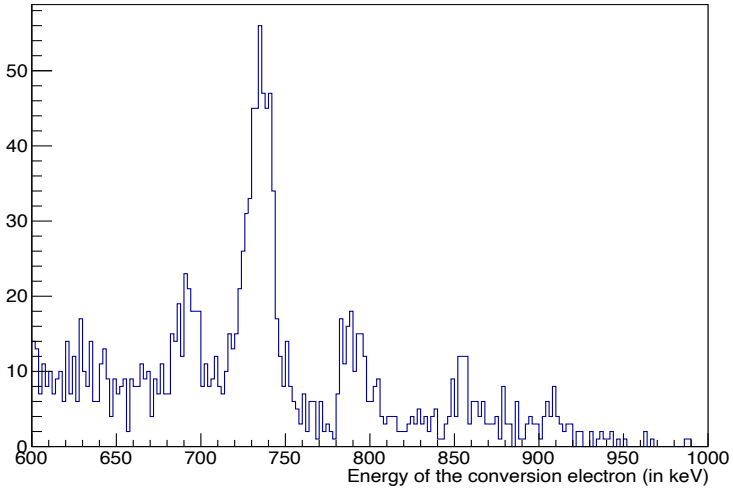
The last decay scheme from LBNL



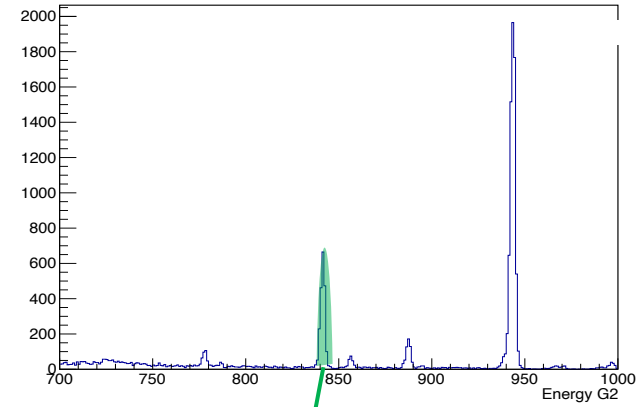
1. Scientific context
2. Experimental Set up
3. Results from $^{208}Pb + ^{48}Ca \rightarrow ^{254}No + 2n$ reaction
4. **Super-Deformation in ^{254}No?**
5. Conclusion

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

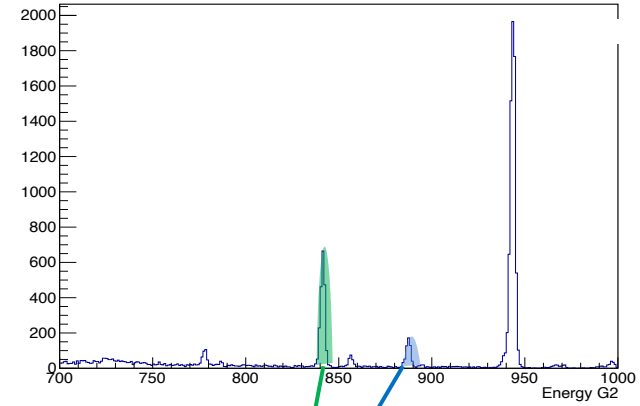




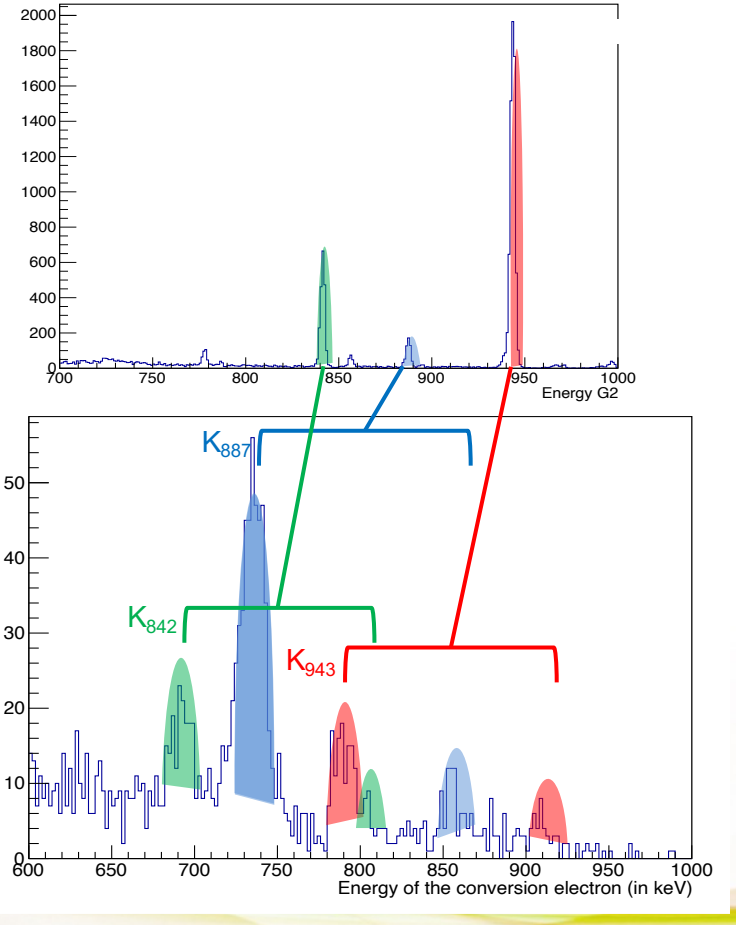
Coincidence of e^-_{Tunnel} / e^-_{DSSD} – Long-lived isomer



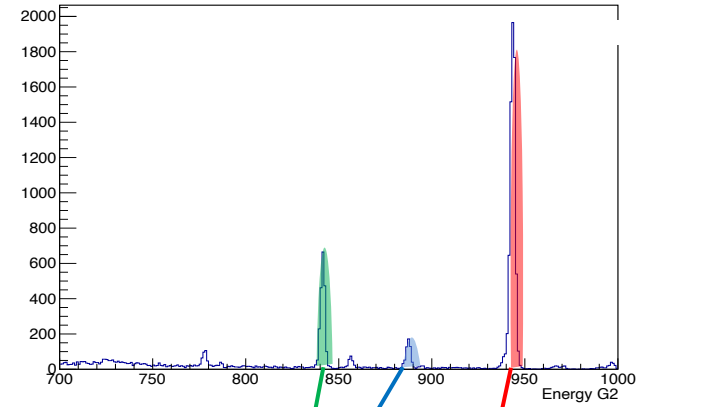
Coincidence of e^-_{Tunnel} / e^-_{DSSD} – Long-lived isomer



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



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



2 solutions to this super conversion :

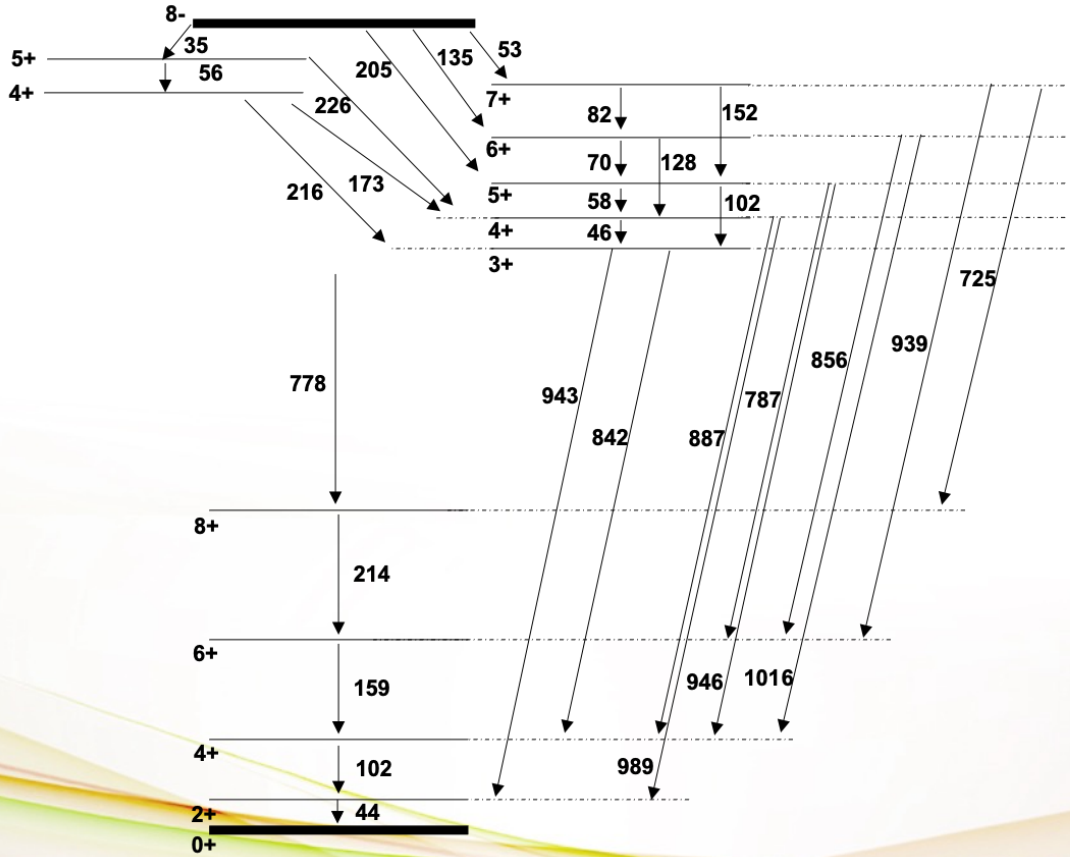
- The existing 887keV is a very highly converted transition (M4 or more)…

  …But its lifetime doesn't fit…

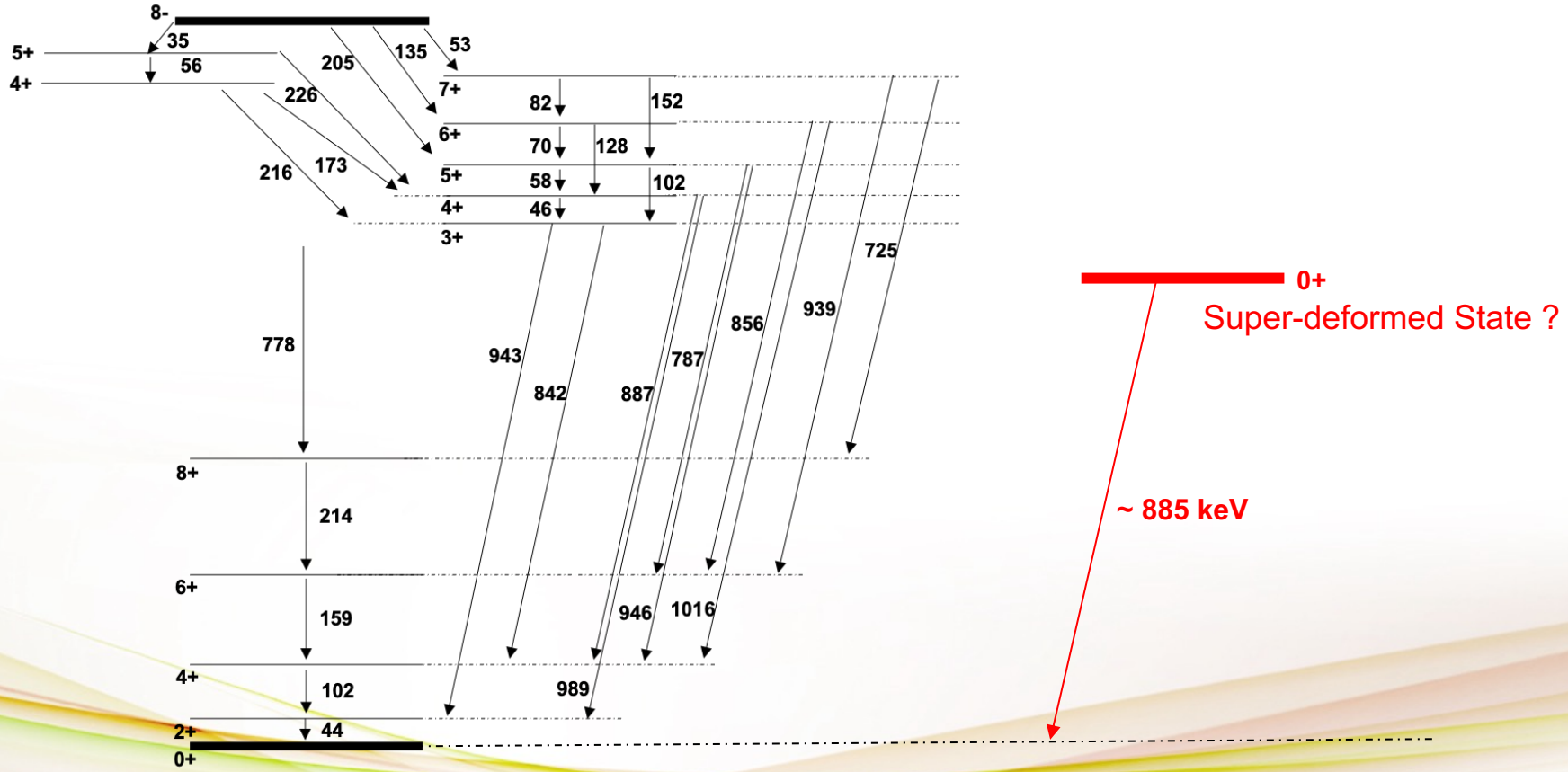
- Contribution from an E0 transition…

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

New potential decay scheme



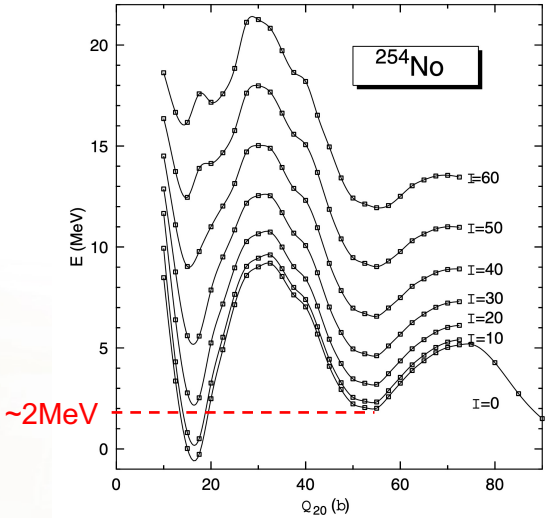
New potential decay scheme



Comparison with theory

From 2000

Fission barriers for different spin values



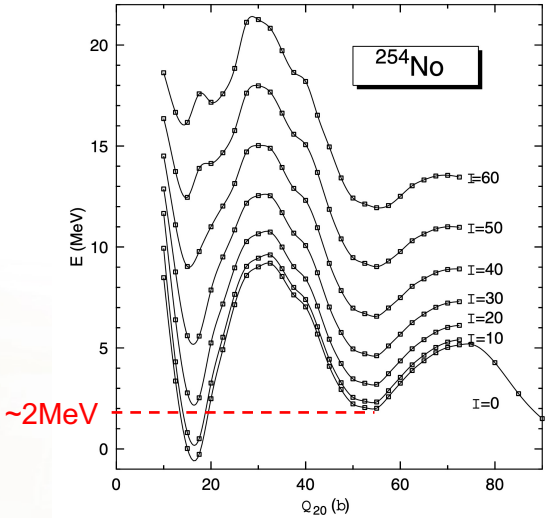
Egido & Robledo predicted a SD well at around 2MeV.

[8] J.L. Egido and L.M Robledo, Phys. Rev. Let. V85, 6 (2006)

Comparison with theory

From 2000

Fission barriers for different spin values

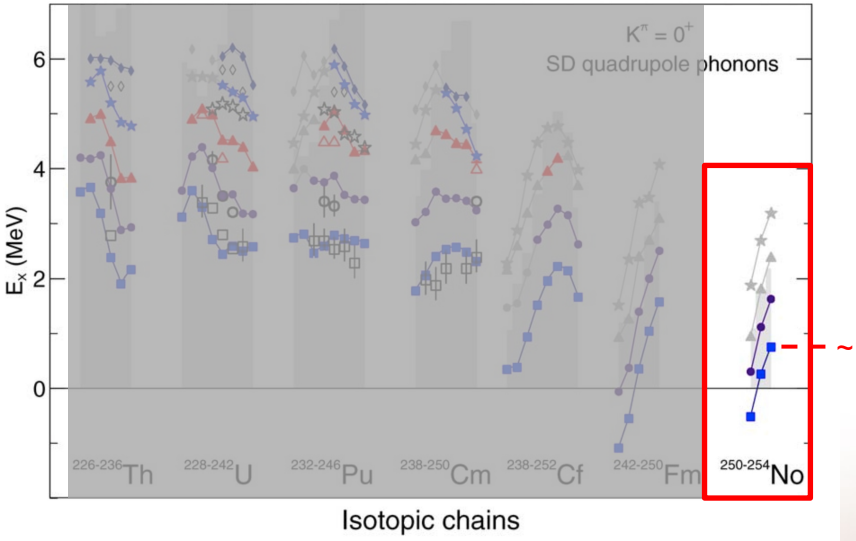


Egido & Robledo predicted a SD well at around 2MeV.

[8] J.L. Egido and L.M Robledo, Phys. Rev. Let. V85, 6 (2006)

From 2006

Excitation energy from SD state in different nuclei



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

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

Comparison with theory in IPHC

From 2021

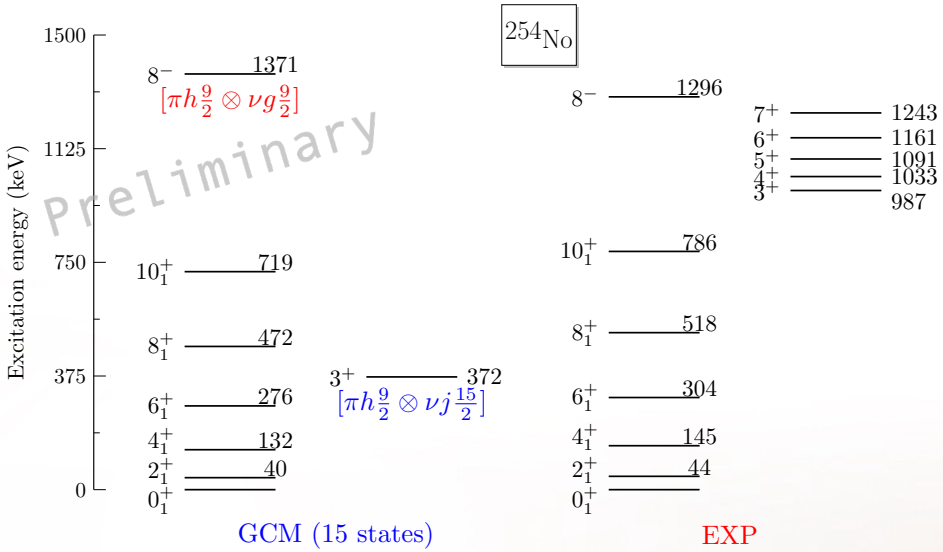
Shell models calculations
+
mean field theory

Preliminary !

D. Dao & F. Nowacki shell model calculations reproduce
8- long-lived isomer / 3+ state (interpretation in discussion)

&

J. Dudek calculations on going



Talk on *"Generator Coordinate Method with effective nuclear Shell Model interaction s and Applications"* on Wednesday 29th October in Colloque GANIL at 11:45am

Conclusion

- The study of the **long-lived isomer decay** has revealed new states in ^{254}No
- In particular, a super-deformed state (calculation ongoing…)
- We need theoretical calculations (expected soon) which can explain **why** we are able to populate the **SD state**
- Analysis ongoing concerning the **short-lived isomer**…

Collaborators

IN2P3: O. Dorvaux, A. Lopez-Martens, K. Kessaci, K. Hauschild, B. J. P. Gall, Z. Asfari, R. Chakma

FLNR : A. V. Yeremin, M. L. Chelnokov, V. I. Chepigin, A. V. Isaev, I.N. Izosimov, D. Katrasev, A.A. Kuznetsova, O. N. Malyshev, R. Mukhin, A. G. Popeko, Y. A. Popov, A. I. Svirikhin, E. A. Sokol, M. S. Tezekbayeva

GANIL: J. Piot

Thank you for your attention !

Bibliography

J. Erler et al., Nature 486 (2012)

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

F.P. Heßberger et al., Eur. Phys. J A 43 (2010) 55.

R. -D. Herzberg et al., Nature 442 (2006) 896.)

S.K. Tandel et al., Phys. Rev. Lett. 97 (2006) 082502.

K. Hauschild et al., Nucl. Instr. Methods A 560, 388-394 (2006).

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

A. G. Popeko et al., NIM B 376, 140-146 (2016).

J.L. Egido and L.M Robledo, Phys. Rev. Let. V85, 6 (2006)

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

J. Erler et al., Nature 486 (2012)

Duc Dao presentation for Colloque GANIL 2021