

**ZAKOPANE
CONFERENCE**
on Nuclear Physics **2026**
Extremes of the Nuclear Landscape

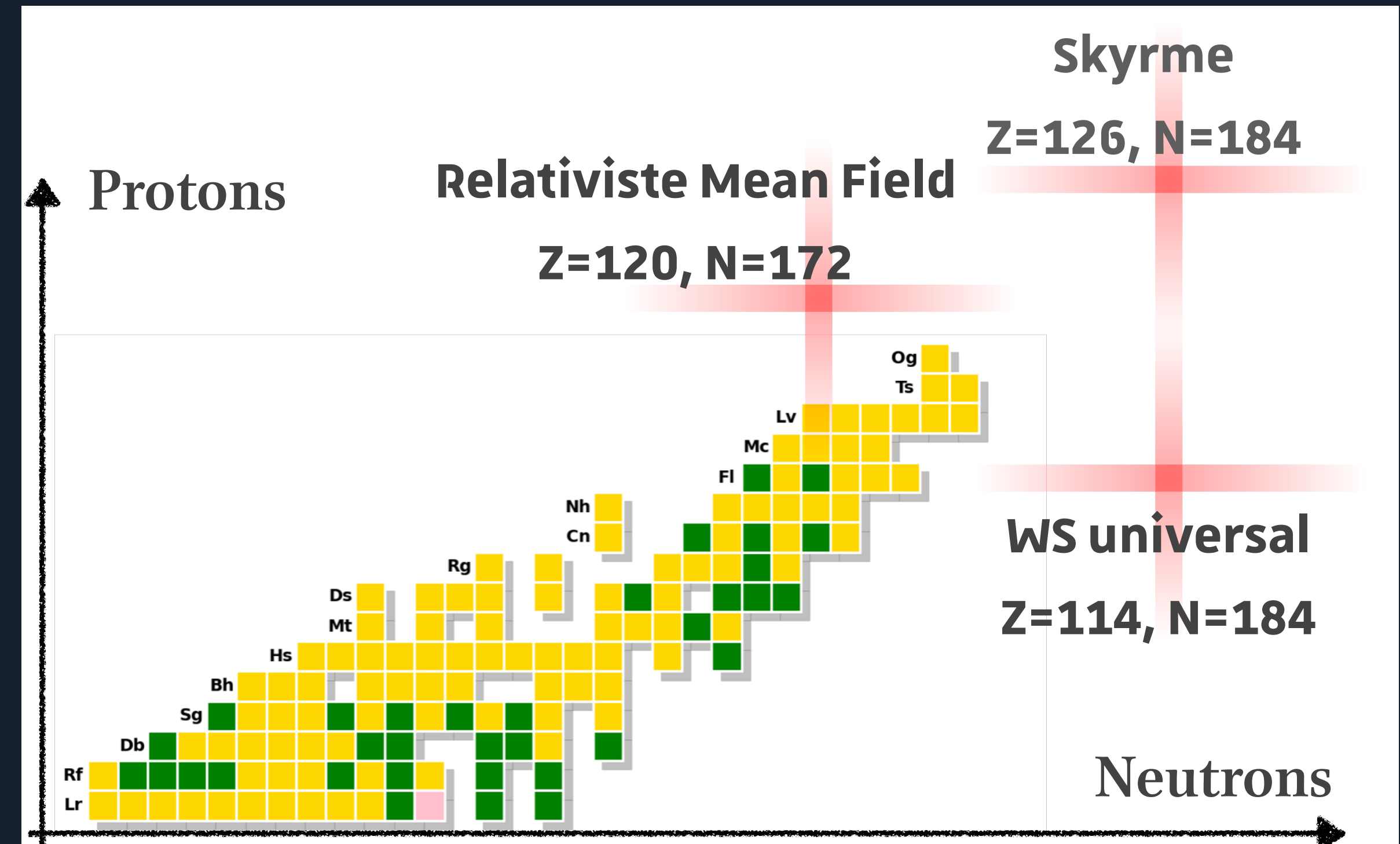


Beyond the spectroscopy of ^{254}No : Experimental evidence for spin splitting and a second 0^+ state



Physics motivations

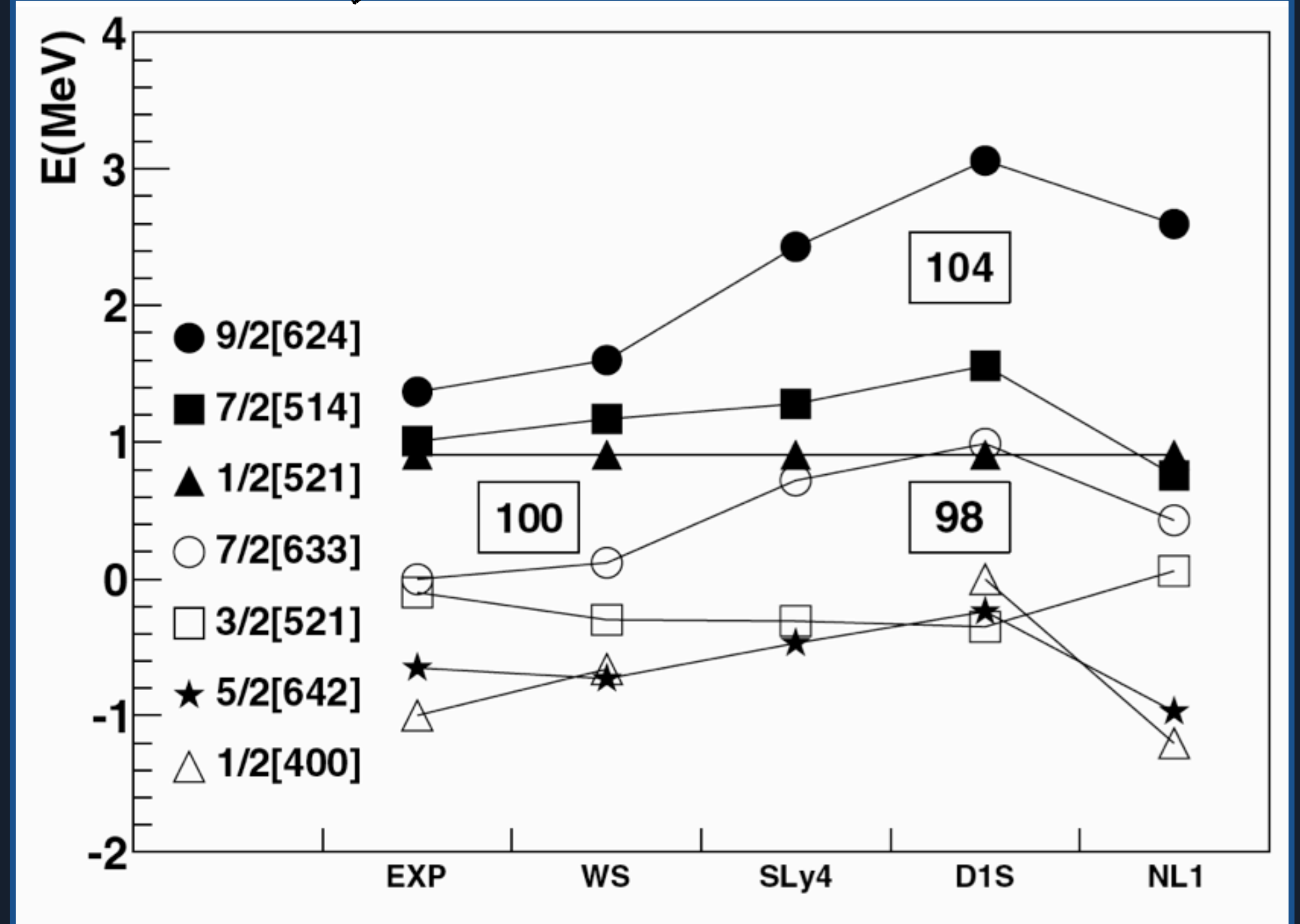
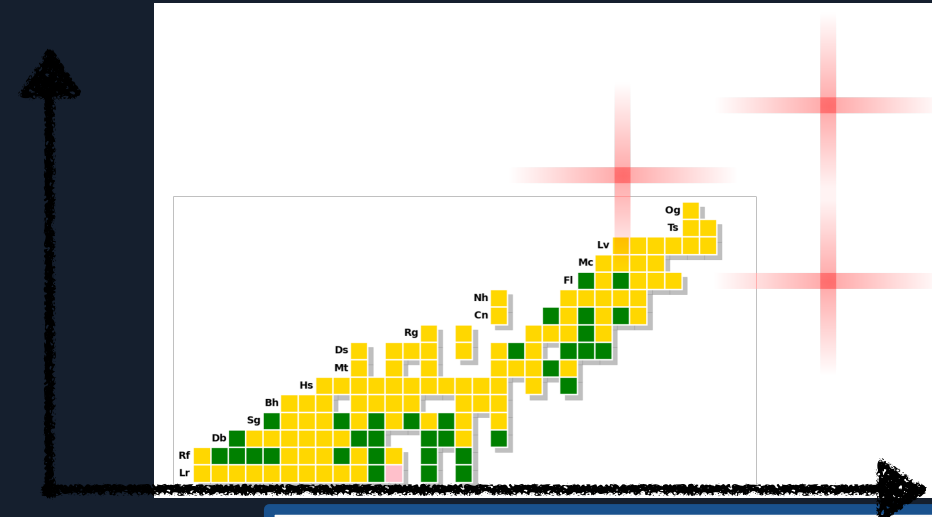
Next island of stability



Physics motivations

Next island of stability

Constraints on effective interactions

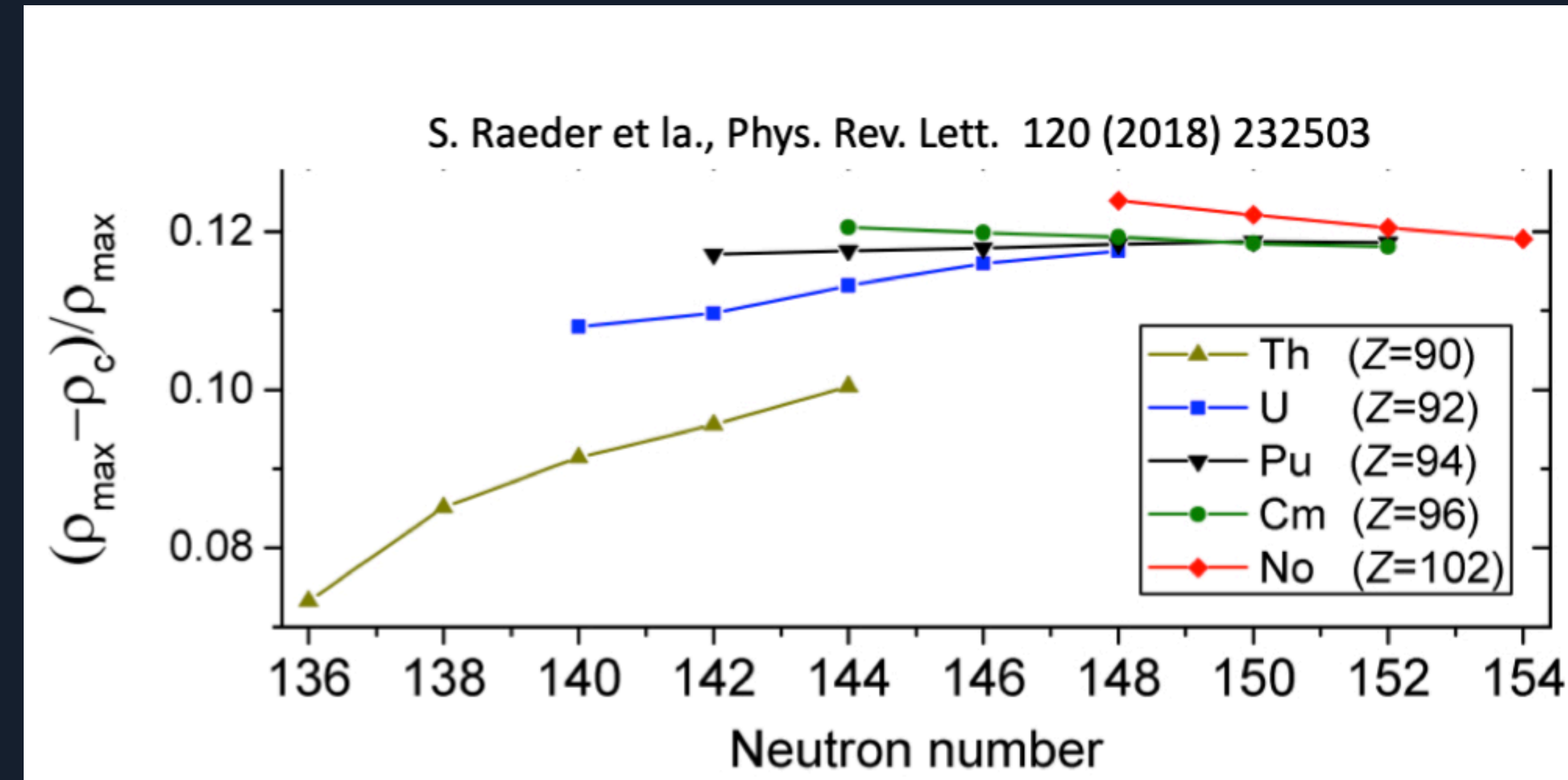
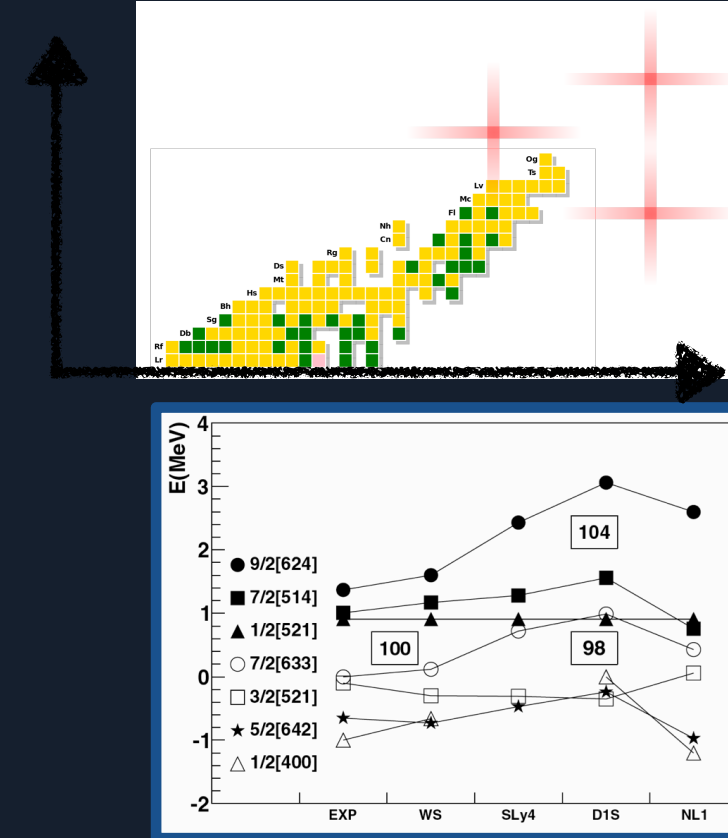


Physics motivations

Next island of stability

Constraints on effective interactions

Challenging theories with very large states density



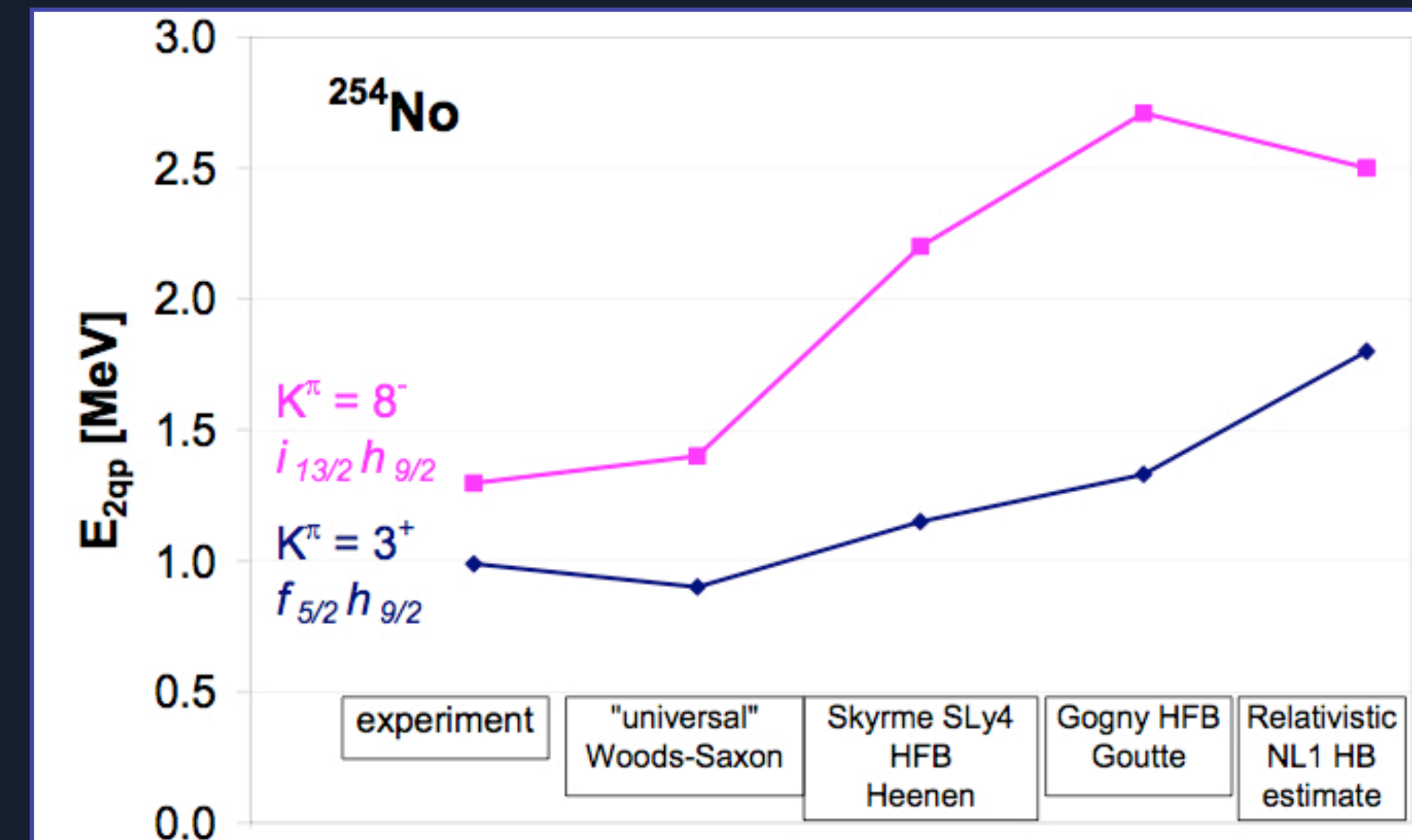
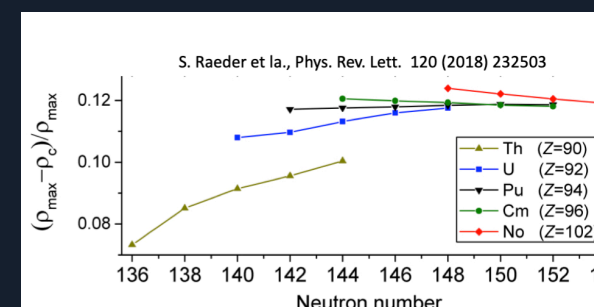
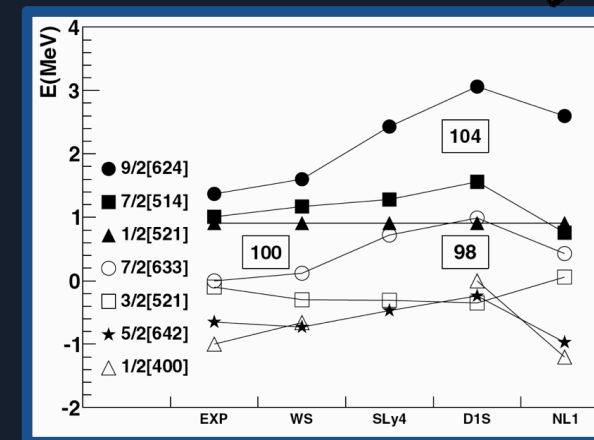
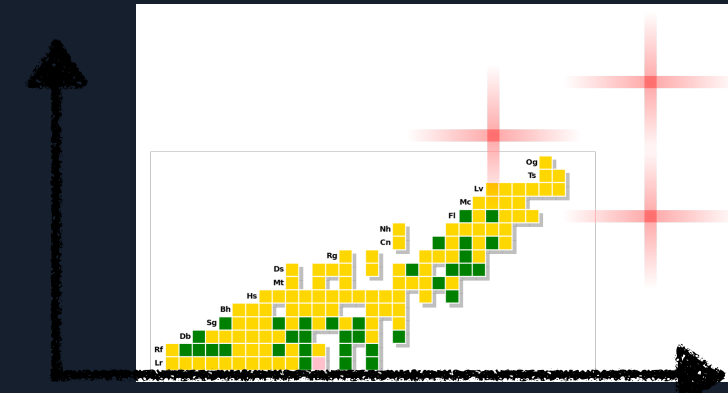
Physics motivations

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Constraints on effective interactions

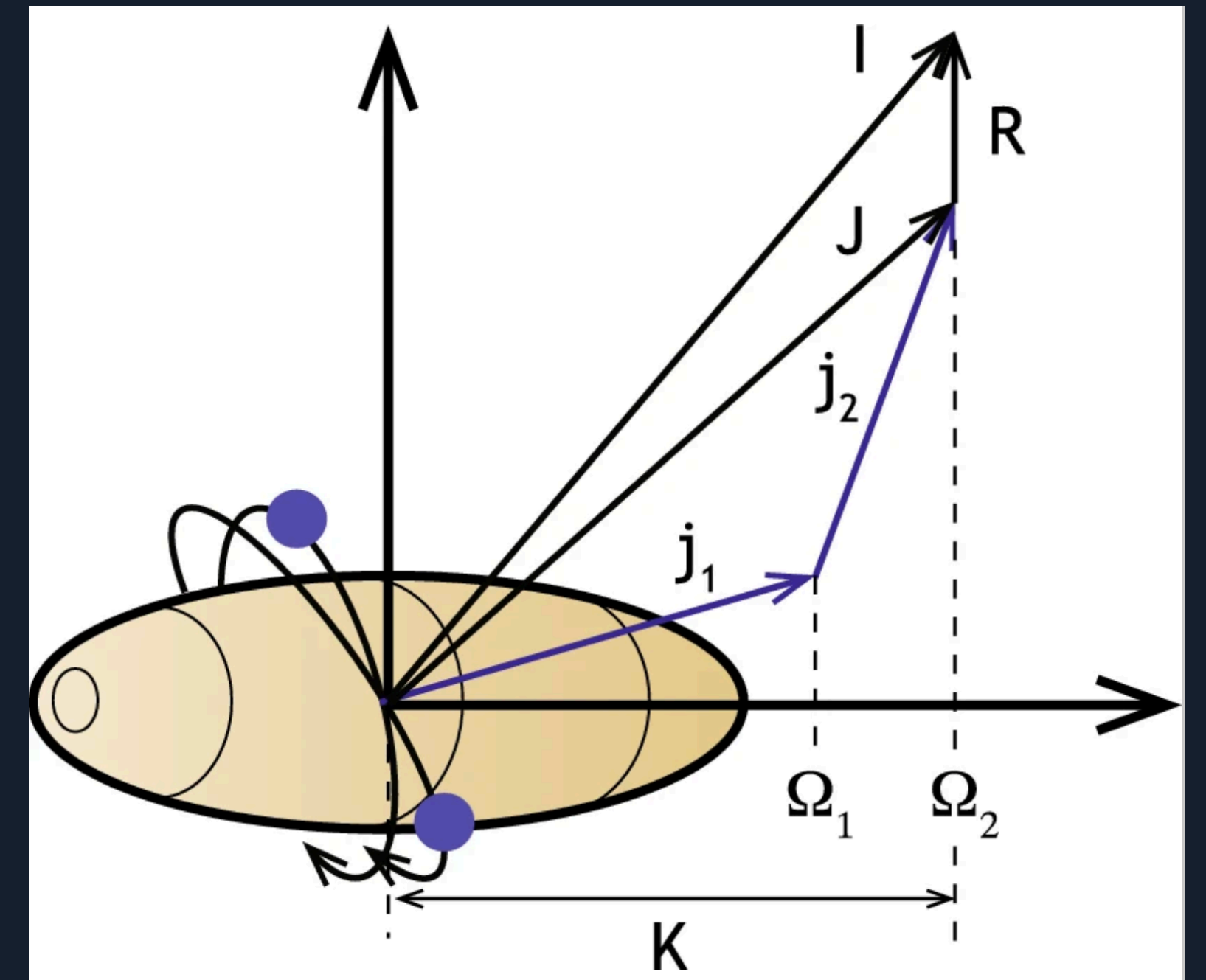
Challenging theories with very large states density

Predictions for GS / band head of **K-isomers**



K-isomers

K-quantum number for a deformed nucleus



K-isomers

K-quantum number for a deformed nucleus

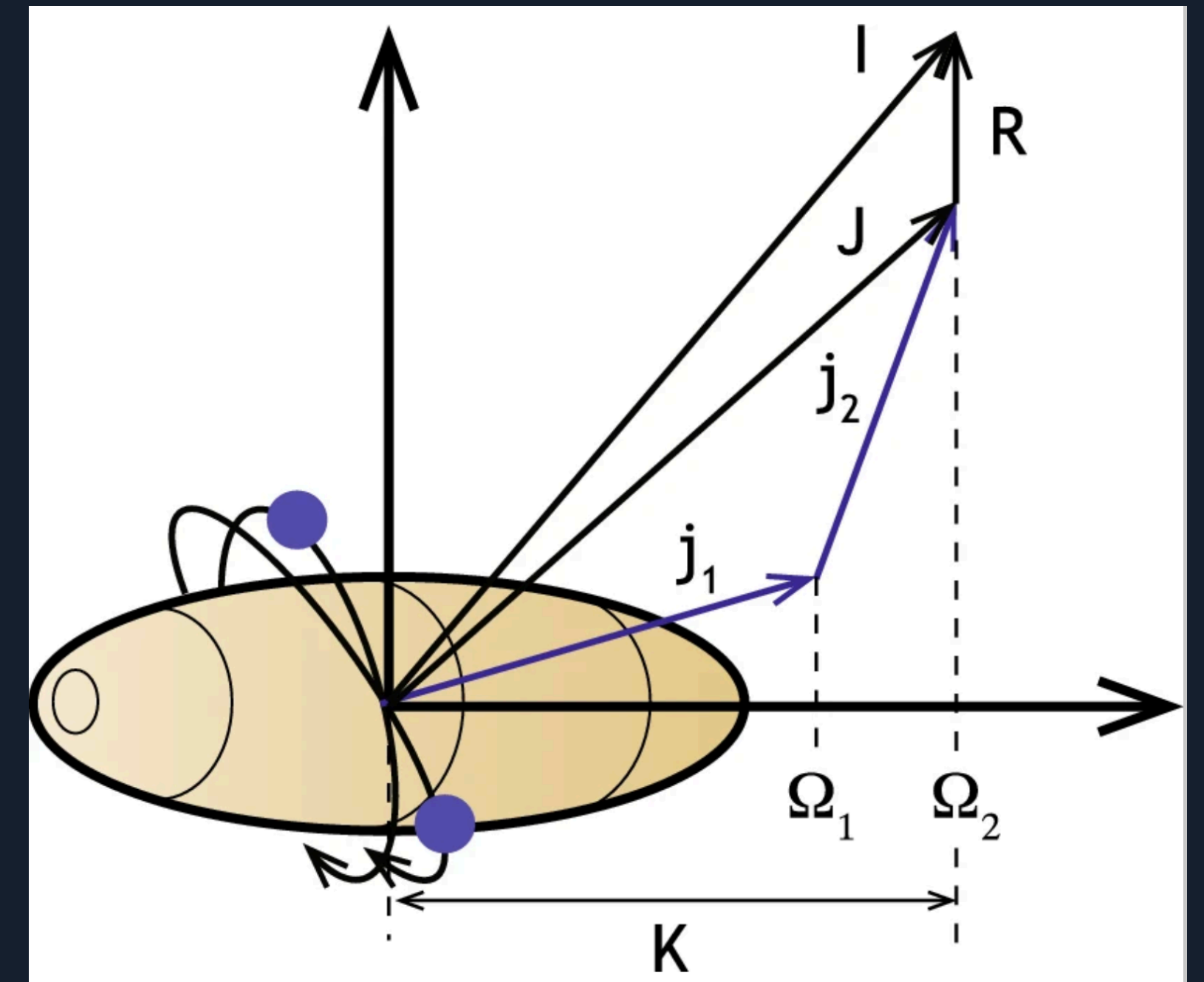
K-isomerism

K_i, L_i, π_i

Initial state

K_f, L_f, π_f

Final state



K-isomers

K-quantum number for a deformed nucleus

K-isomerism

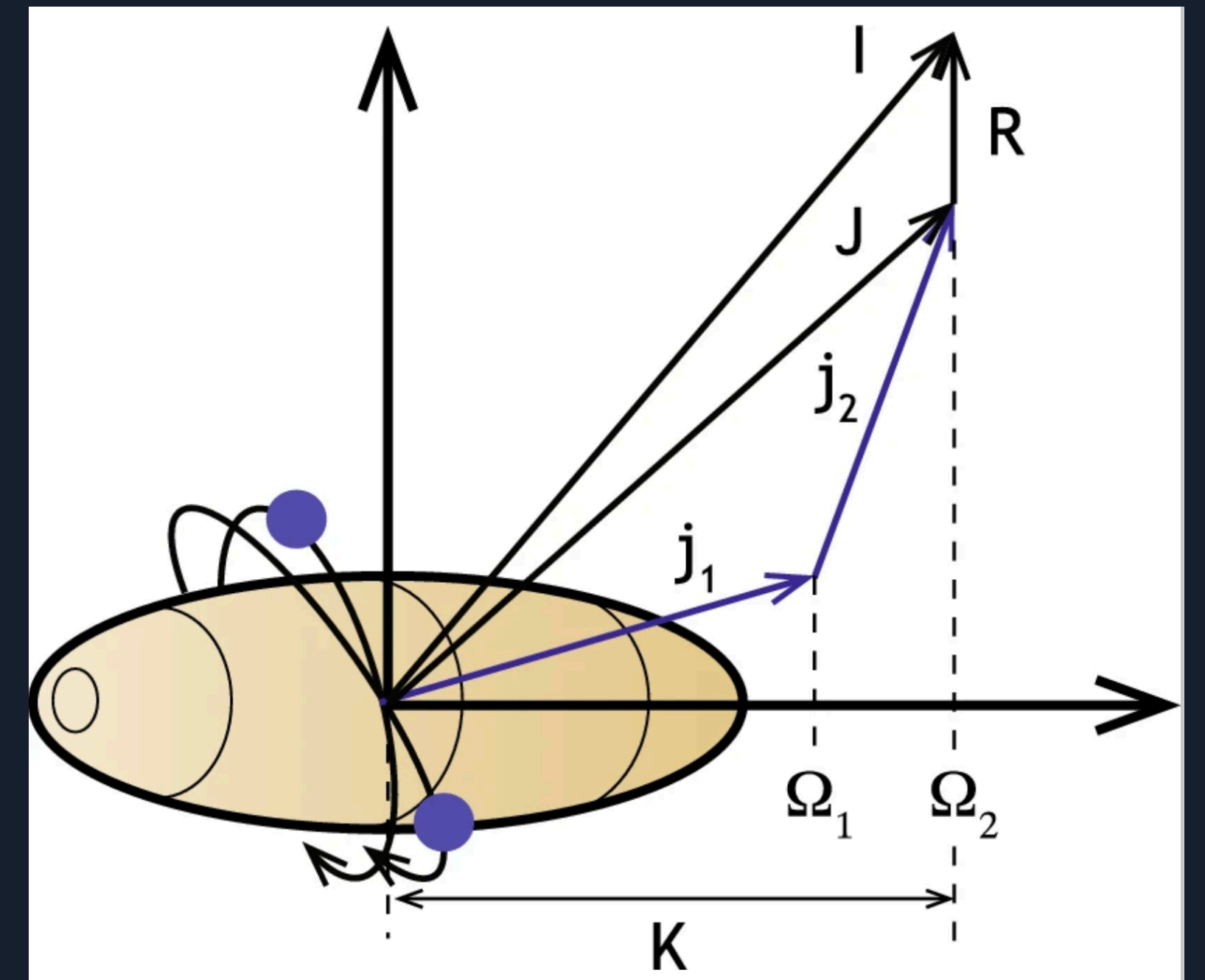
K_i, L_i, π_i

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Final state

$$|\Delta K| > \lambda \quad (\text{Multipolarity of the transition})$$



K-isomers

K-quantum number for a deformed nucleus

K-isomerism

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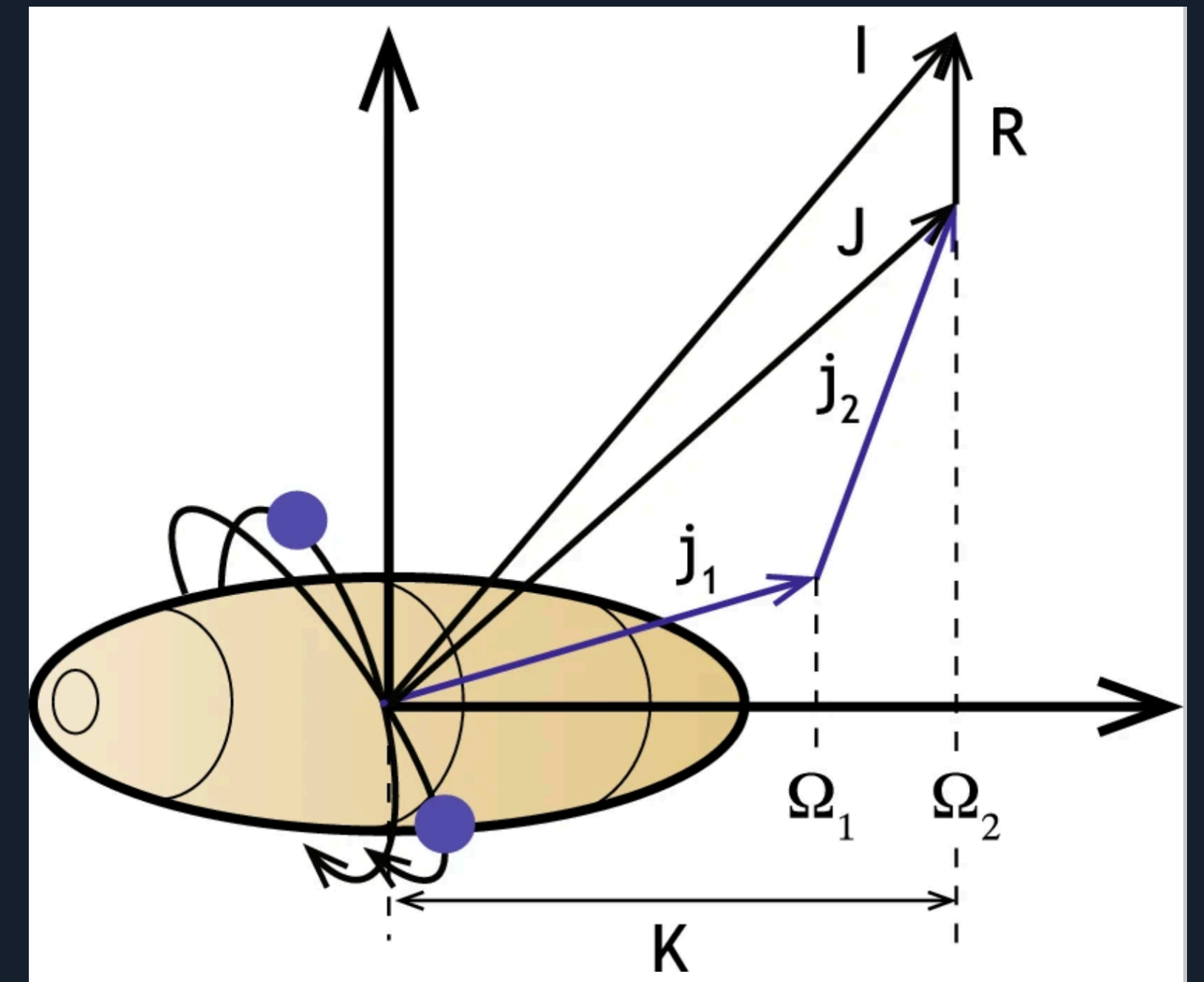
Initial state

K_f, L_f, π_f

Final state

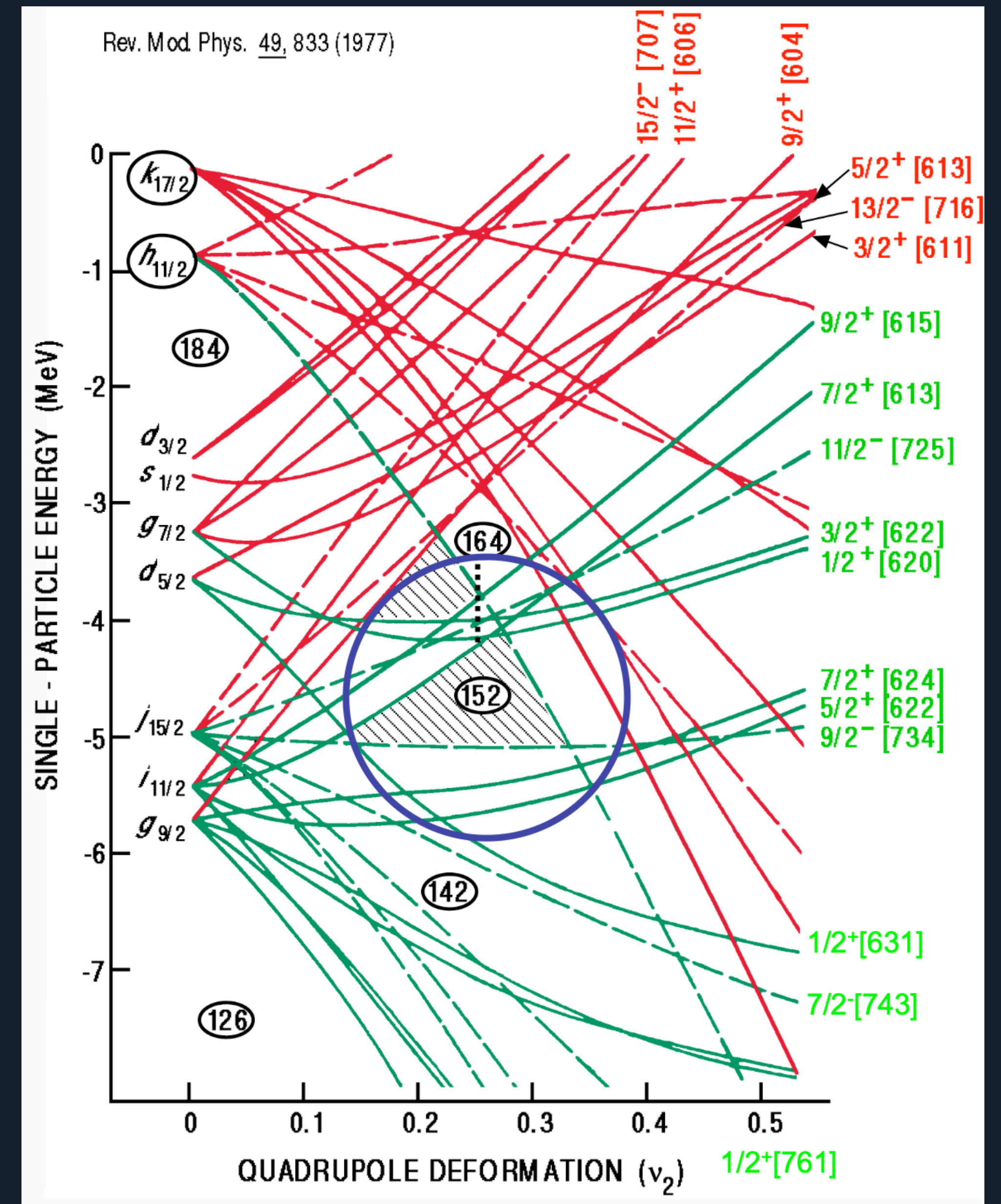
$$|\Delta K| > \lambda \quad (\text{Multipolarity of the transition})$$

The transition is strongly hindered -> transition probability reduced -> long lifetime for the isomeric state



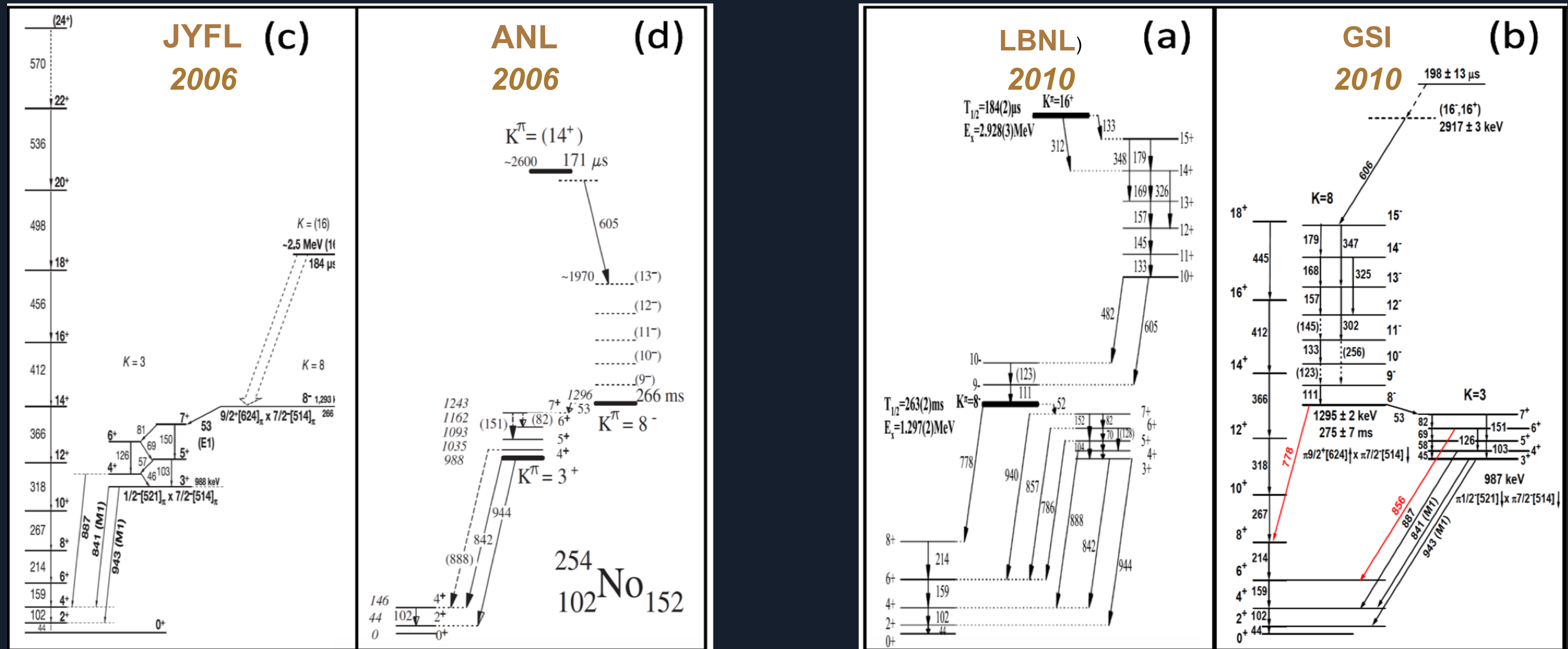
$^{254}\text{No}_{152}$: ideal case

N=152 corresponds to a deformed shell gap



$^{254}\text{No}_{152}$: ideal case

2 isomeric states have been studied by 4 experiments



$^{254}\text{No}_{152}$: ideal case

2 isomeric states have been studied by 4 experiments

4 experiments with controversial results

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 $\{\pi^2(8^-), \nu^2(8^-)\}16^+$?
 $\{\pi^2(8^-), \nu^2(6^-)\}14^+$?

2. A Long-lived isomer :

- a. Configuration assignment at 8-
- b. Nature of the state as $\pi 7/2^- [514] \otimes \pi 9/2^+ [624] ?$
 $\nu 7/2^+ [613] \otimes \nu 9/2^- [734] ?$

Experimental setup : a modernised separator

High separator transmission

SHELS separator @ FLNR Dubna

Table 2
Test reactions studied at the SHELS velocity filter.

Reaction	Beam energy	Target thickness (mg/cm ²)	ERs transmission		Ref.
			Old	New	
²² Ne(²³⁸ U,4-5n) ^{255,256} No	115	0.35 (U ₃ O ₈)	0.01	–	
²² Ne(²⁰⁸ Pb,4n) ²²⁶ U	117	0.36 (PbS)	0.02	–	
²² Ne(²⁰⁶ Pb,4n) ²²⁴ U	117	0.23 (metal)	0.02	–	[10]
²² Ne(¹⁹⁸ Pt,5-7n) ²¹³⁻²¹⁵ Ra	115–125	0.30 (metal)	0.03	0.040 ± 0.015	[11]
²² Ne(¹⁹⁷ Au,4-6n) ²¹³⁻²¹⁵ Ac	120	0.35 (metal)	0.03	0.065 ± 0.030	[11]
⁵⁰ Ti(¹⁶⁴ Dy,3-5n) ²⁰⁹⁻²¹¹ Ra	240	0.3 (Dy ₂ O ₃)	0.3	0.4	[12,13]
⁴⁰ Ar(²⁰⁸ Pb,2-3n) ^{245,246} Fm	237	0.36 (PbS)	0.20	0.4	[13]
⁵⁰ Ti(²⁰⁸ Pb,2n) ²⁵⁶ Rf	237	0.36 (PbS)	0.20	0.3 ± 0.1	[14]

A.G. Popeko et al./Nuclear Instruments and Methods in Physics Research B 376 (2016) 140–143

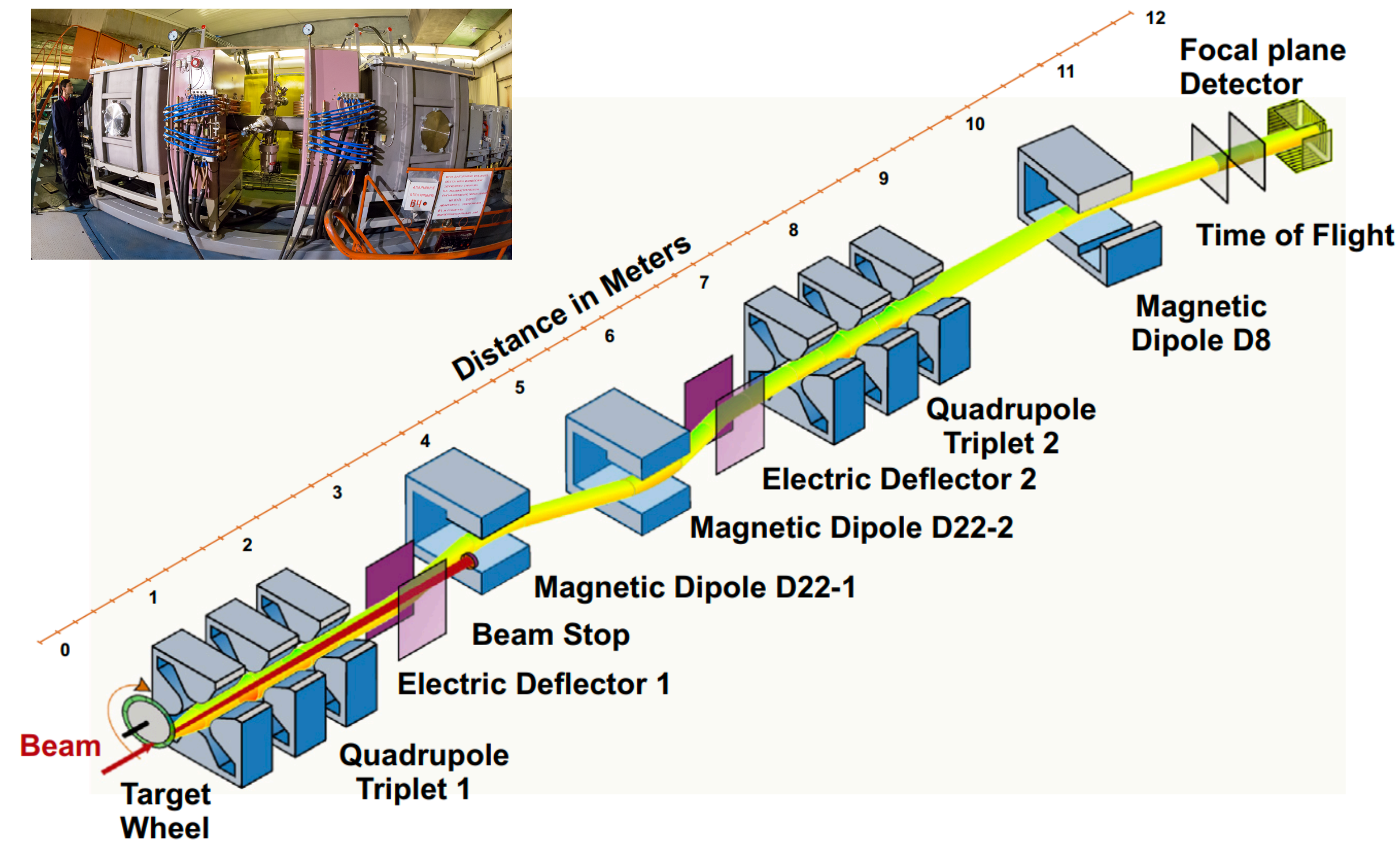


Fig. 1. Ion optical scheme of the SHELS velocity filter.

Experimental setup : a modernised setup

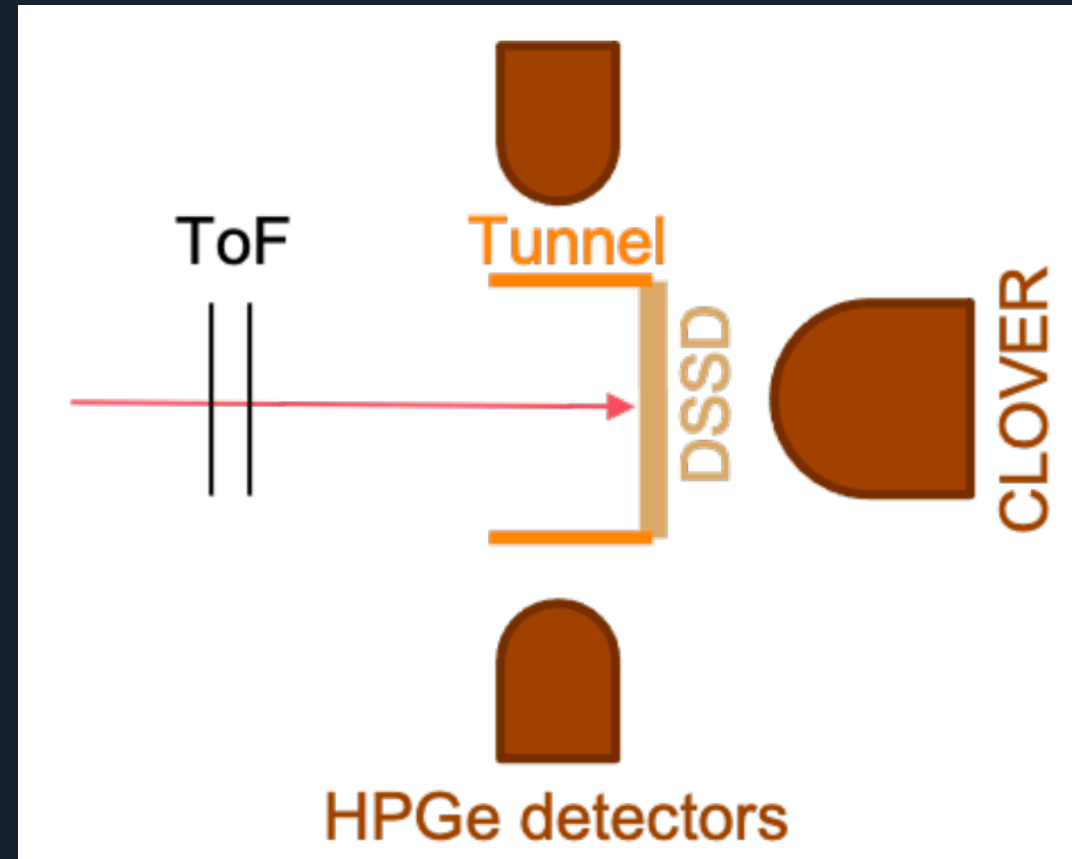
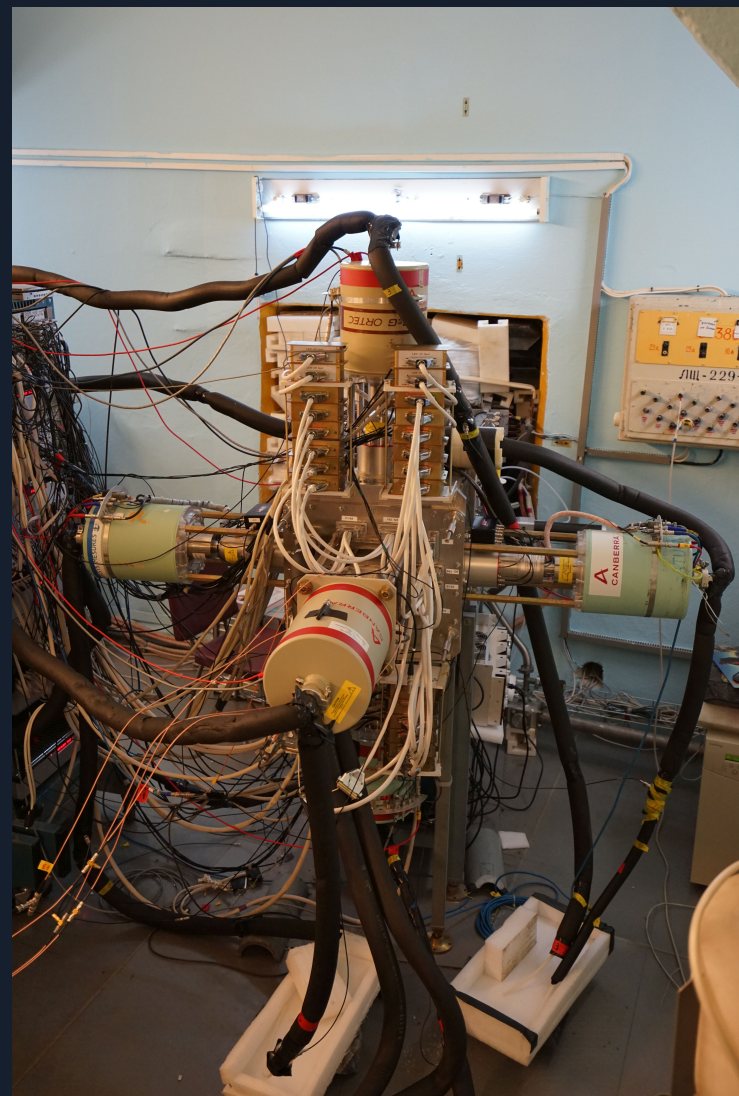
Optimized focal plane for alpha, gamma and **conversion electron** for spectroscopy

and its GABRIELA focal plane

Experimental setup : a modernised setup

Optimized focal plane for alpha, gamma and **conversion electron** for spectroscopy

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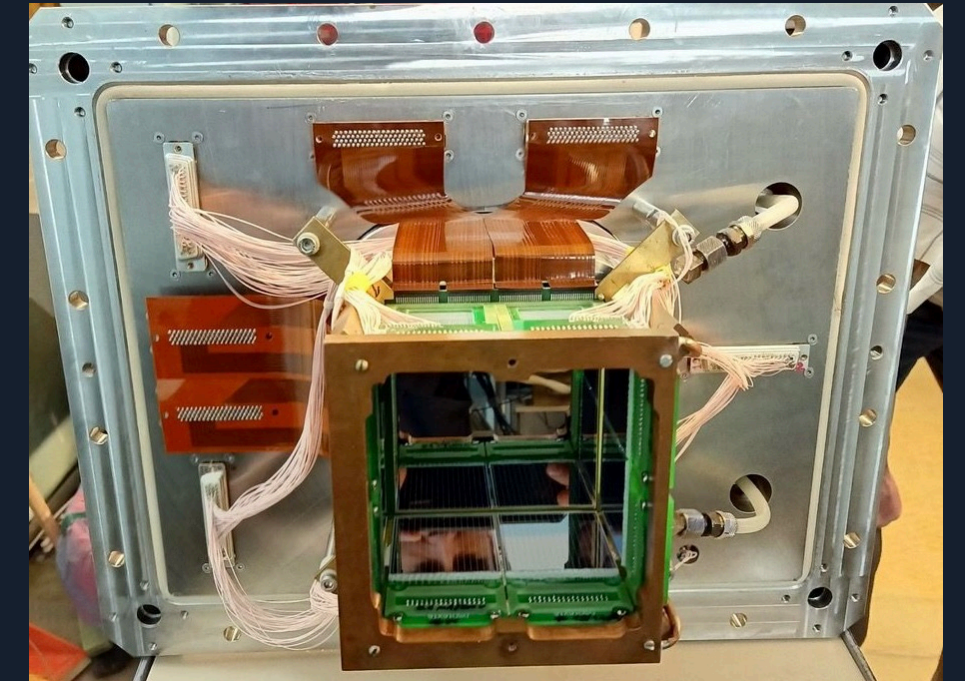
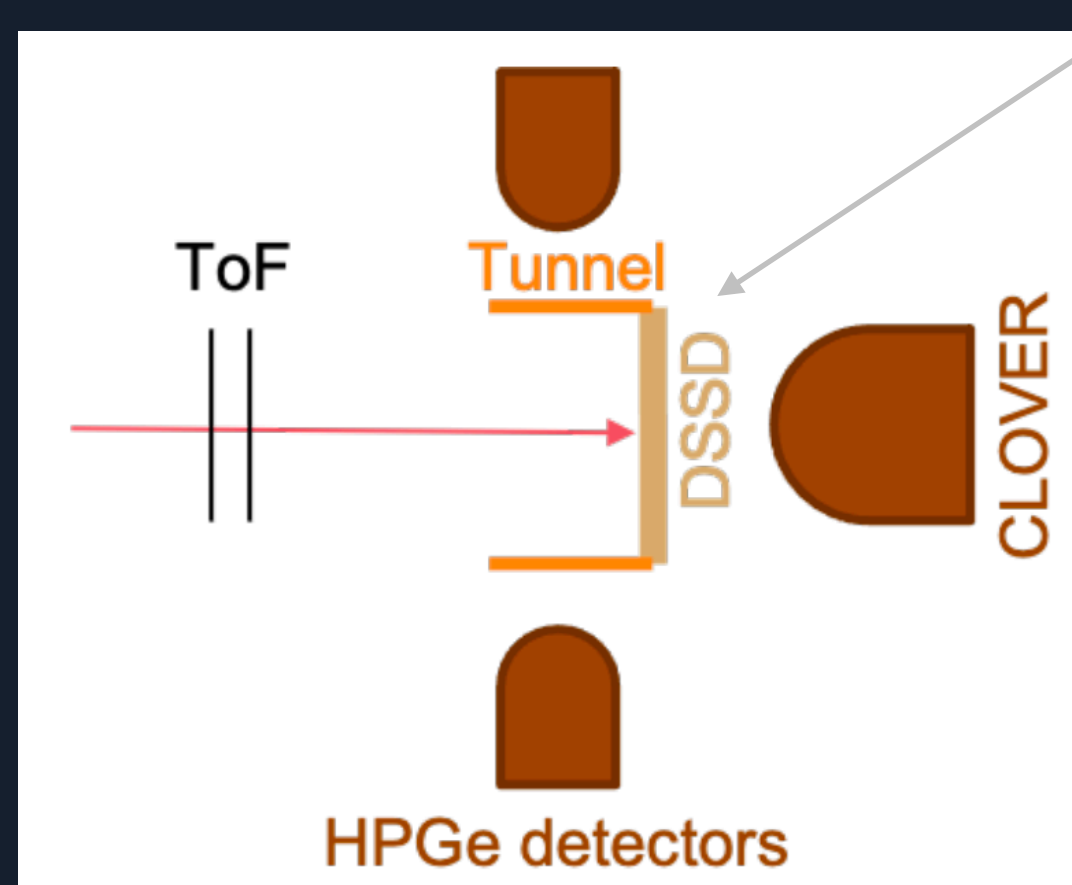
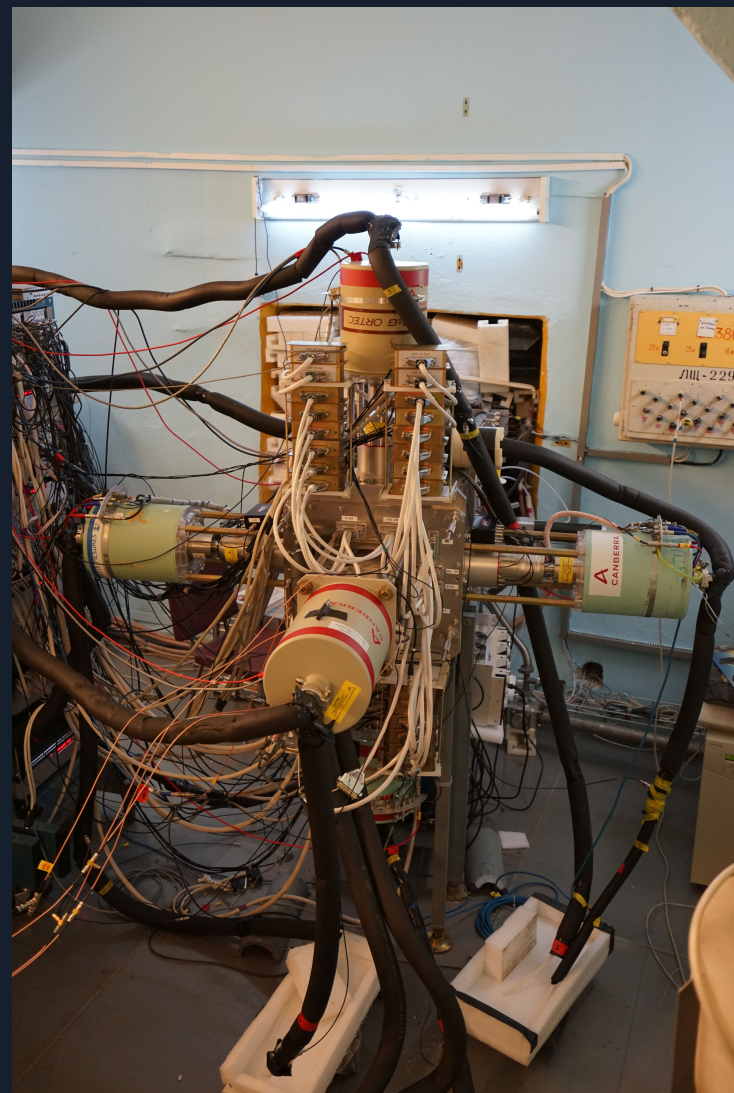


Experimental setup : a modernised setup

Optimized focal plane for alpha, gamma and **conversion electron** for spectroscopy

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1 DSSD 128x128, 100.4 x 100.4 mm²
4x2 DSSD 72x72, 50 x 60 mm², 0.7 mm thick

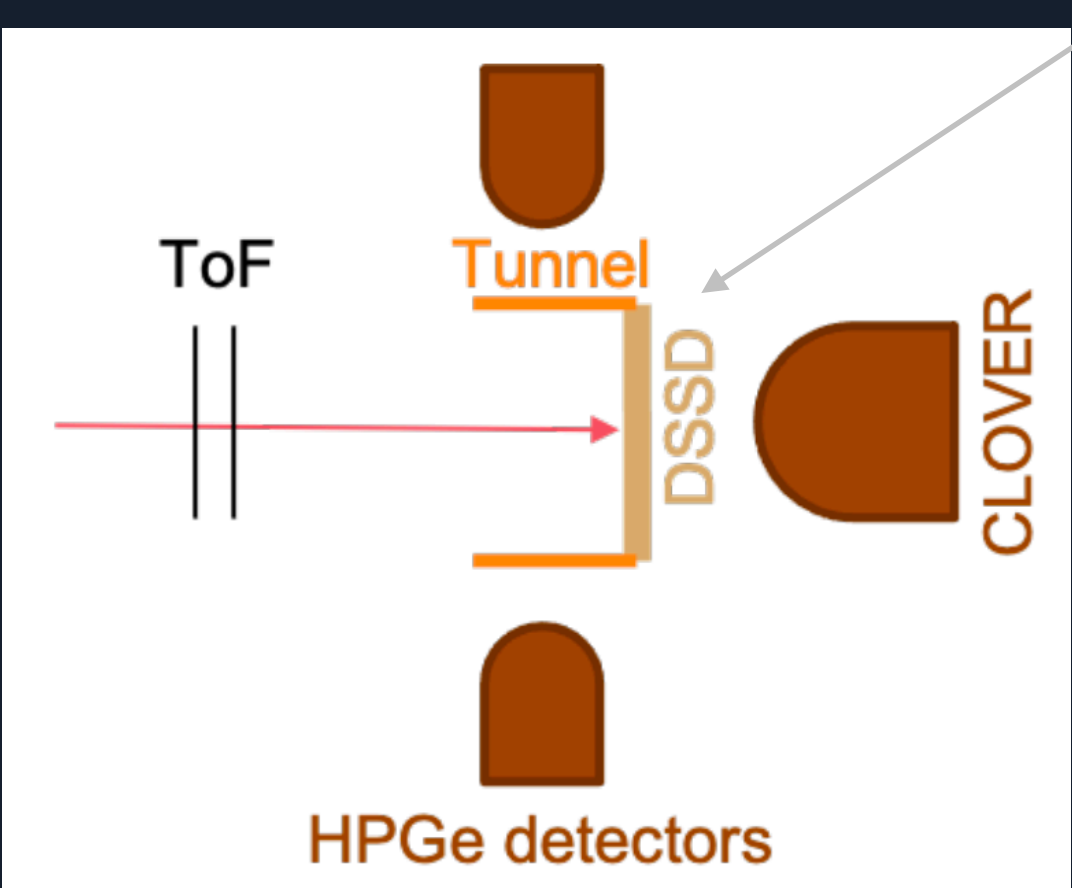
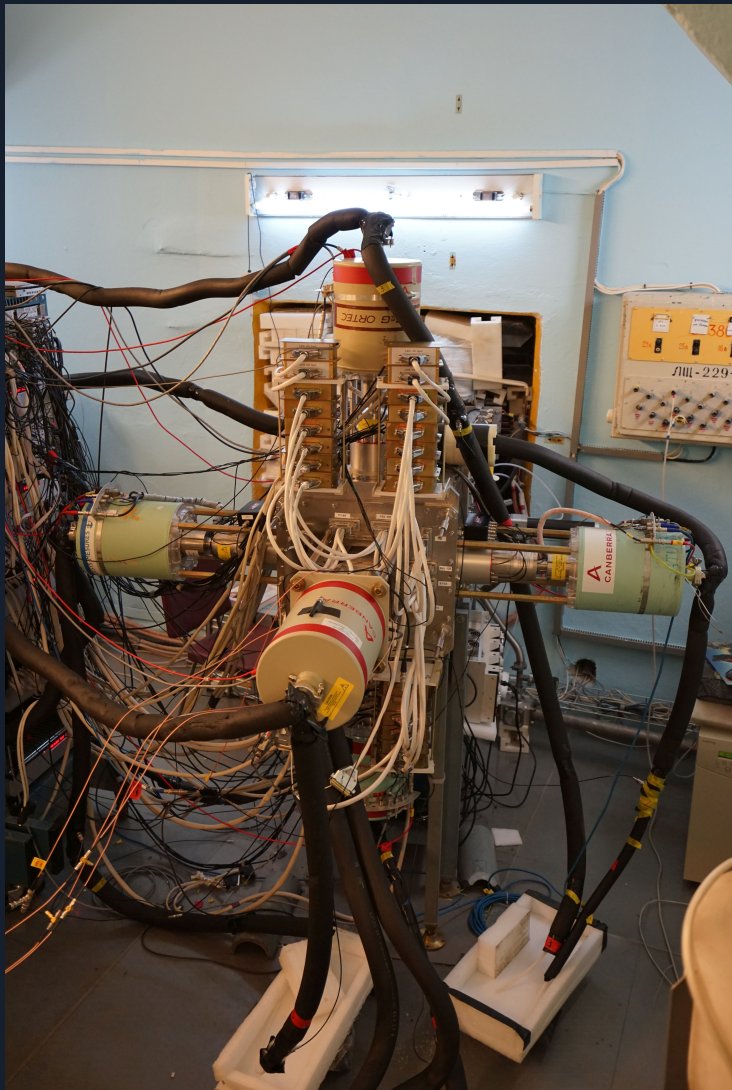
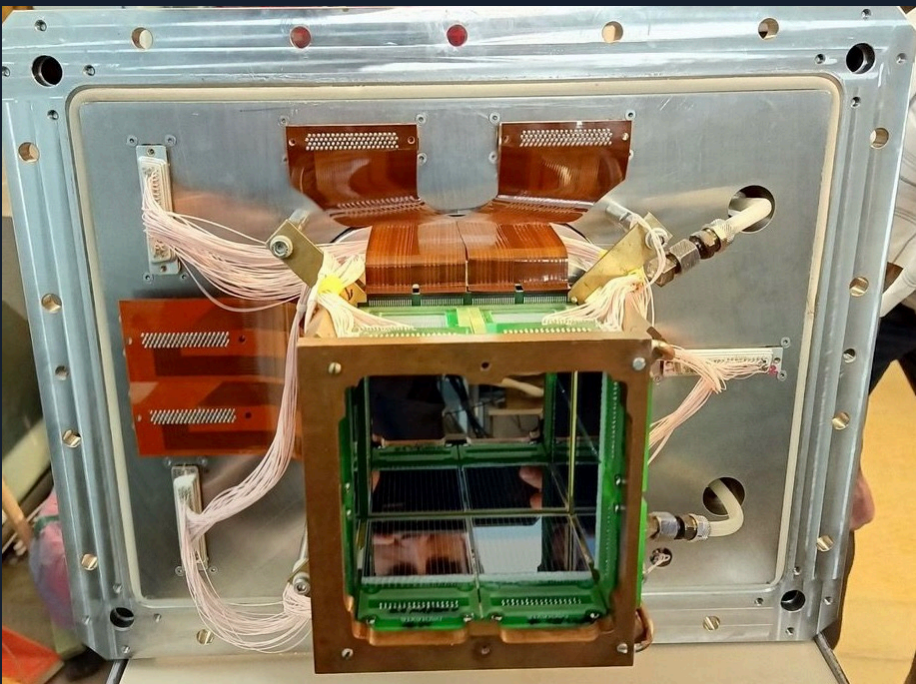


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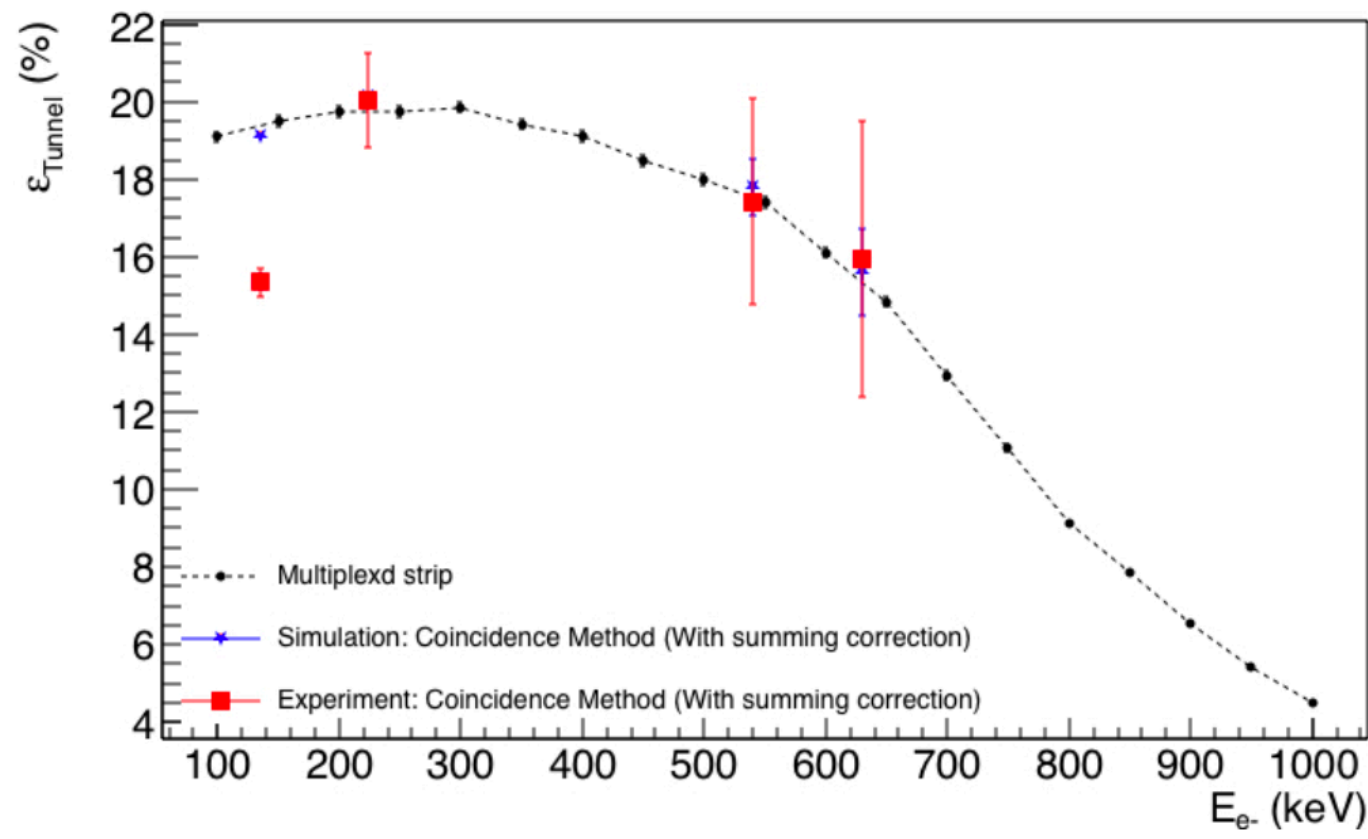
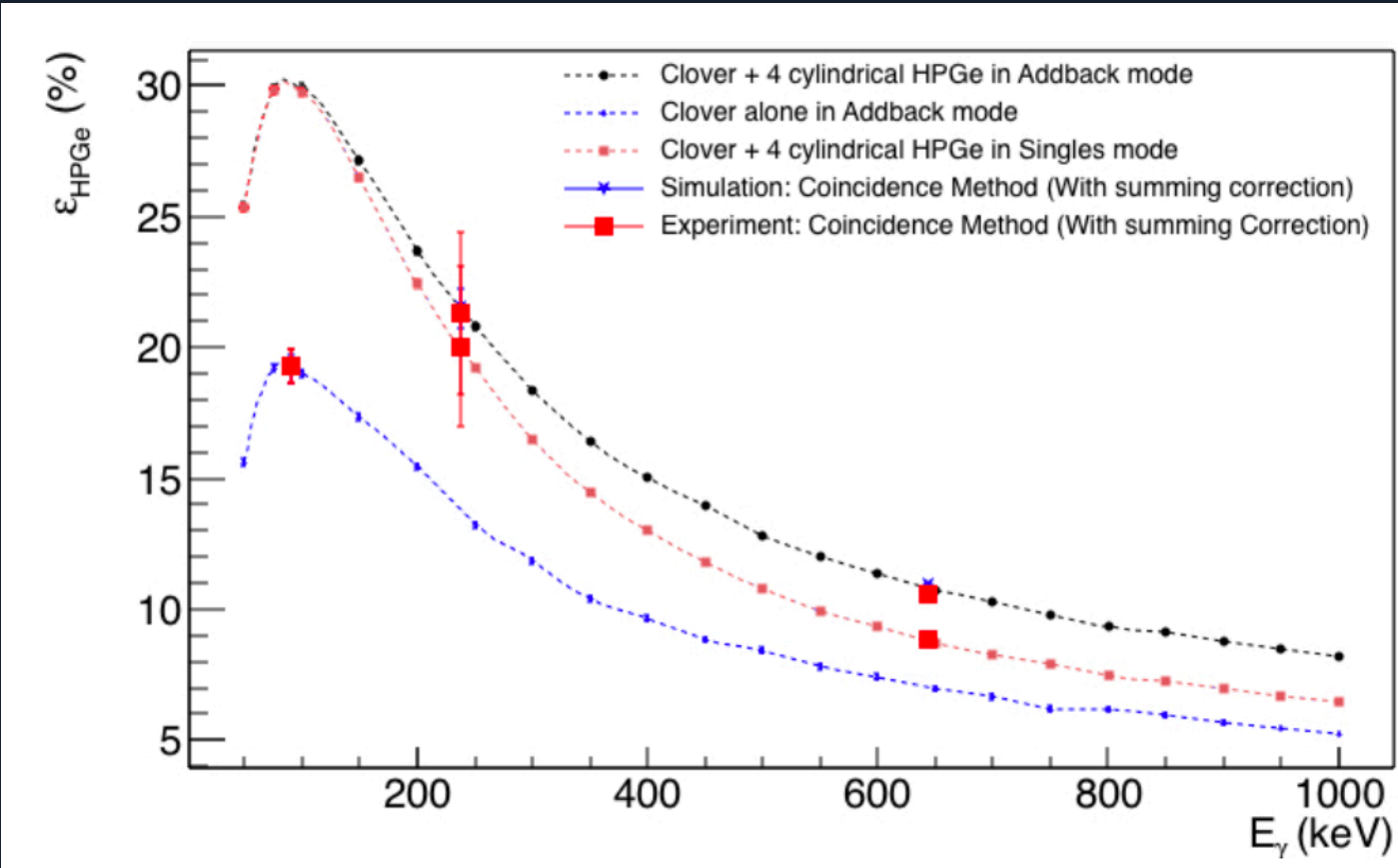
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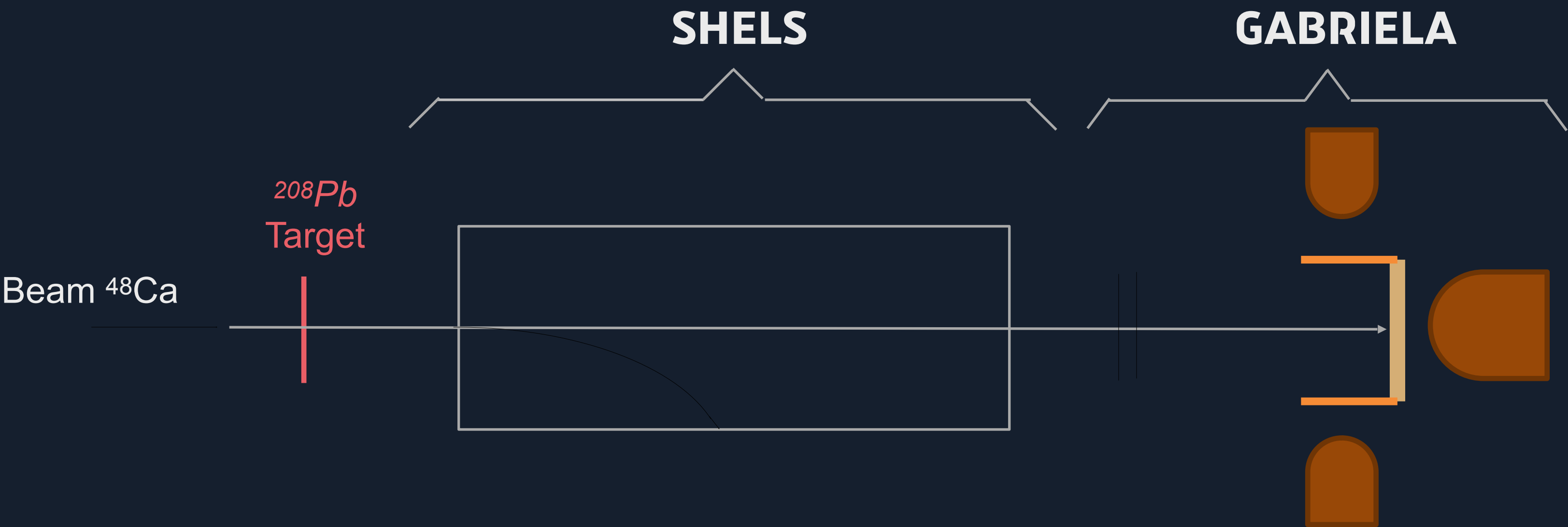


High γ and ICE efficiency



R. Chakma et al., Gamma and conversion electron spectroscopy using GABRIELA. EPJA 2020. **56**(10) 245

The genetic correlation



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



Courtesy of M. Forge

The genetic correlation



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



Courtesy of M. Forge

The genetic correlation



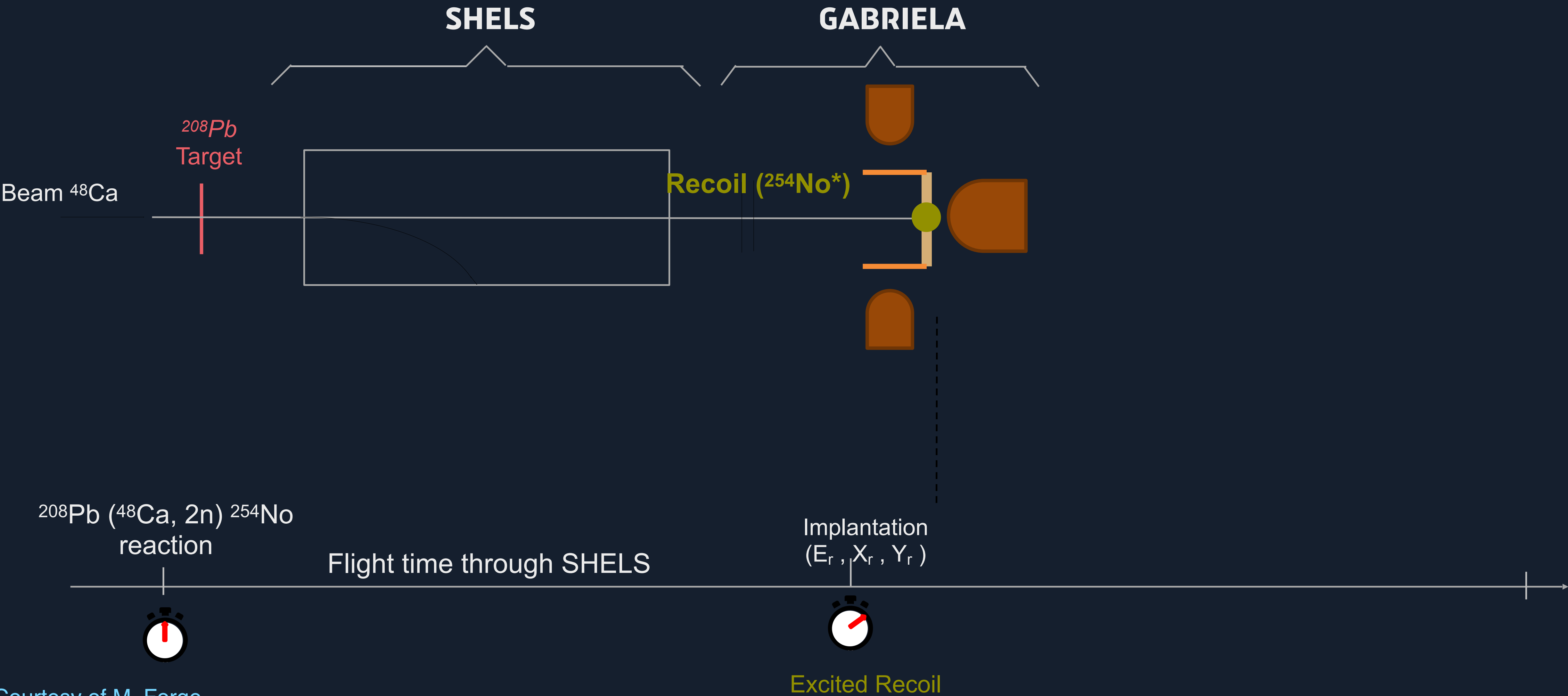
$^{208}\text{Pb} (^{48}\text{Ca}, 2n) ^{254}\text{No}$
reaction

Flight time through SHELS



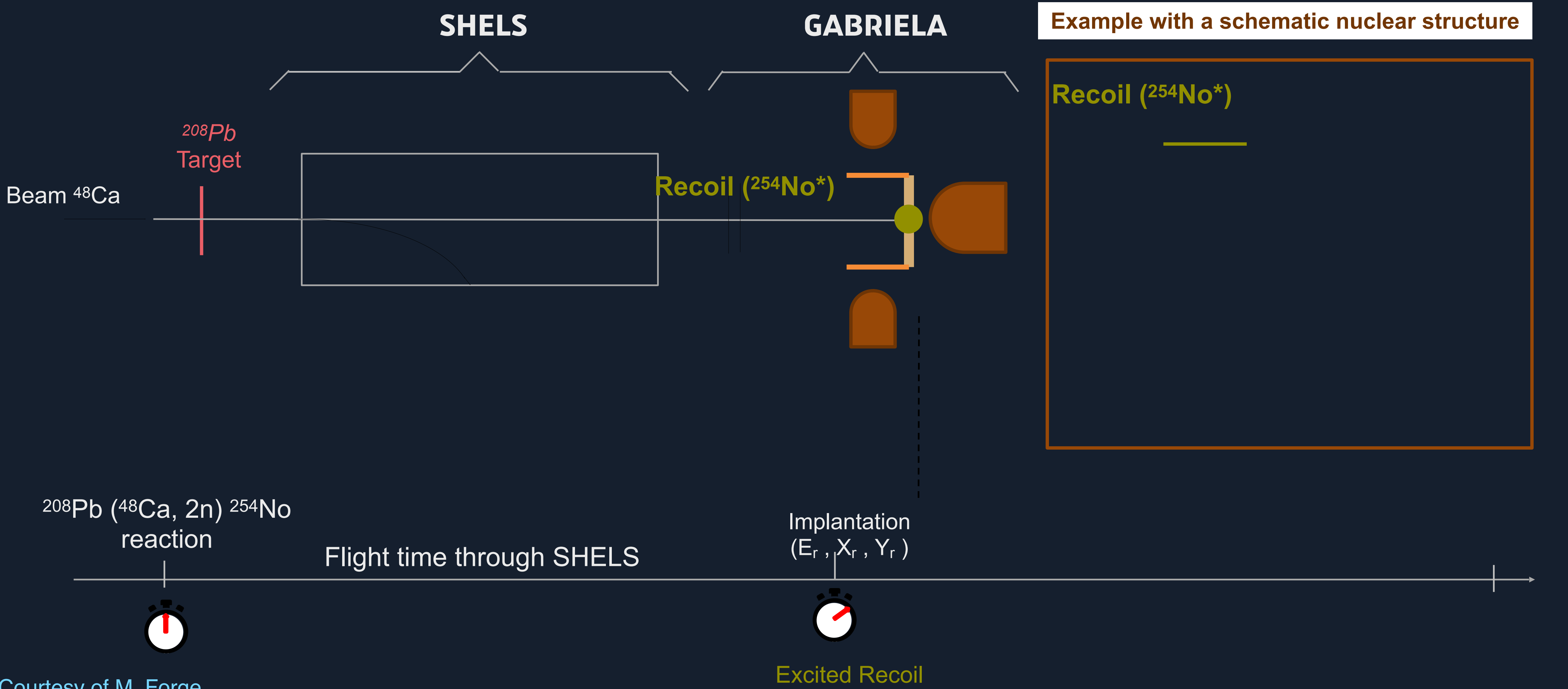
Courtesy of M. Forge

The genetic correlation



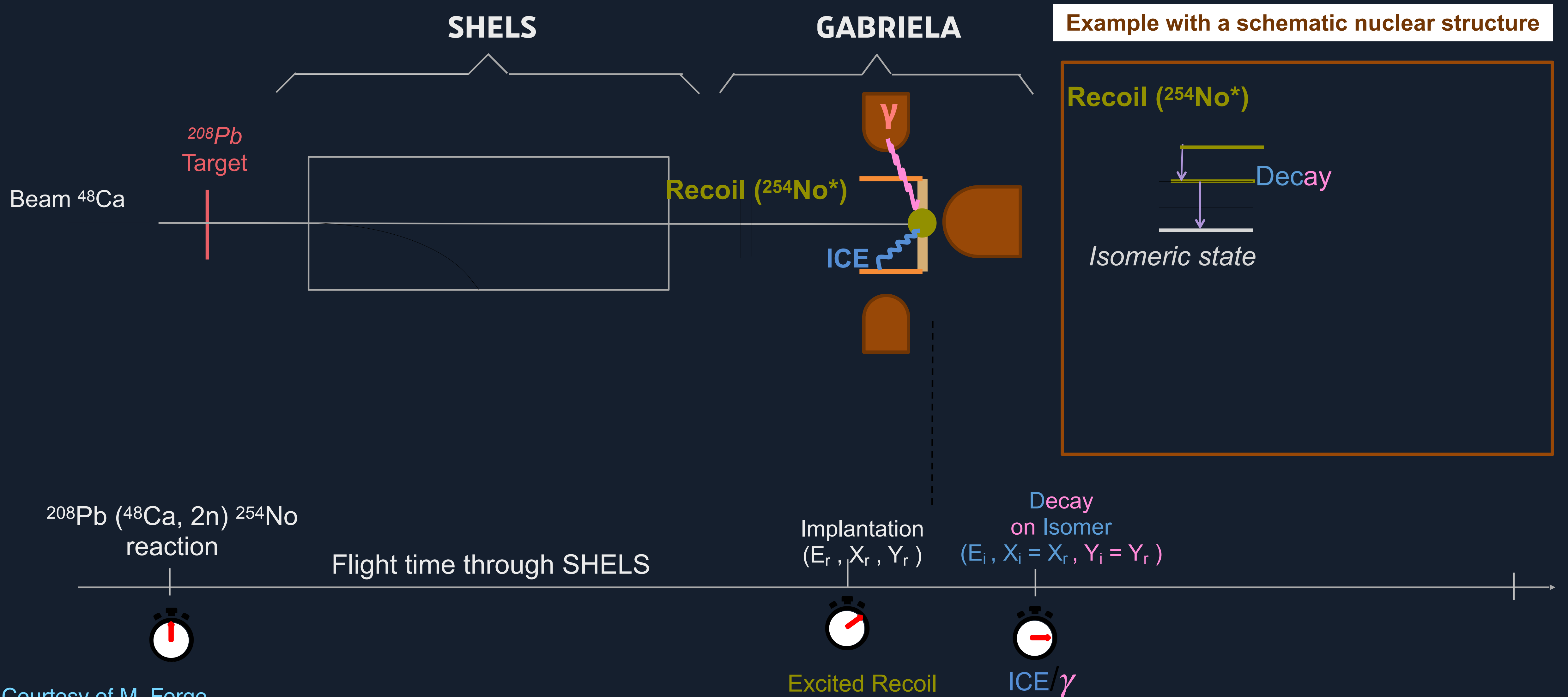
Courtesy of M. Forge

The genetic correlation



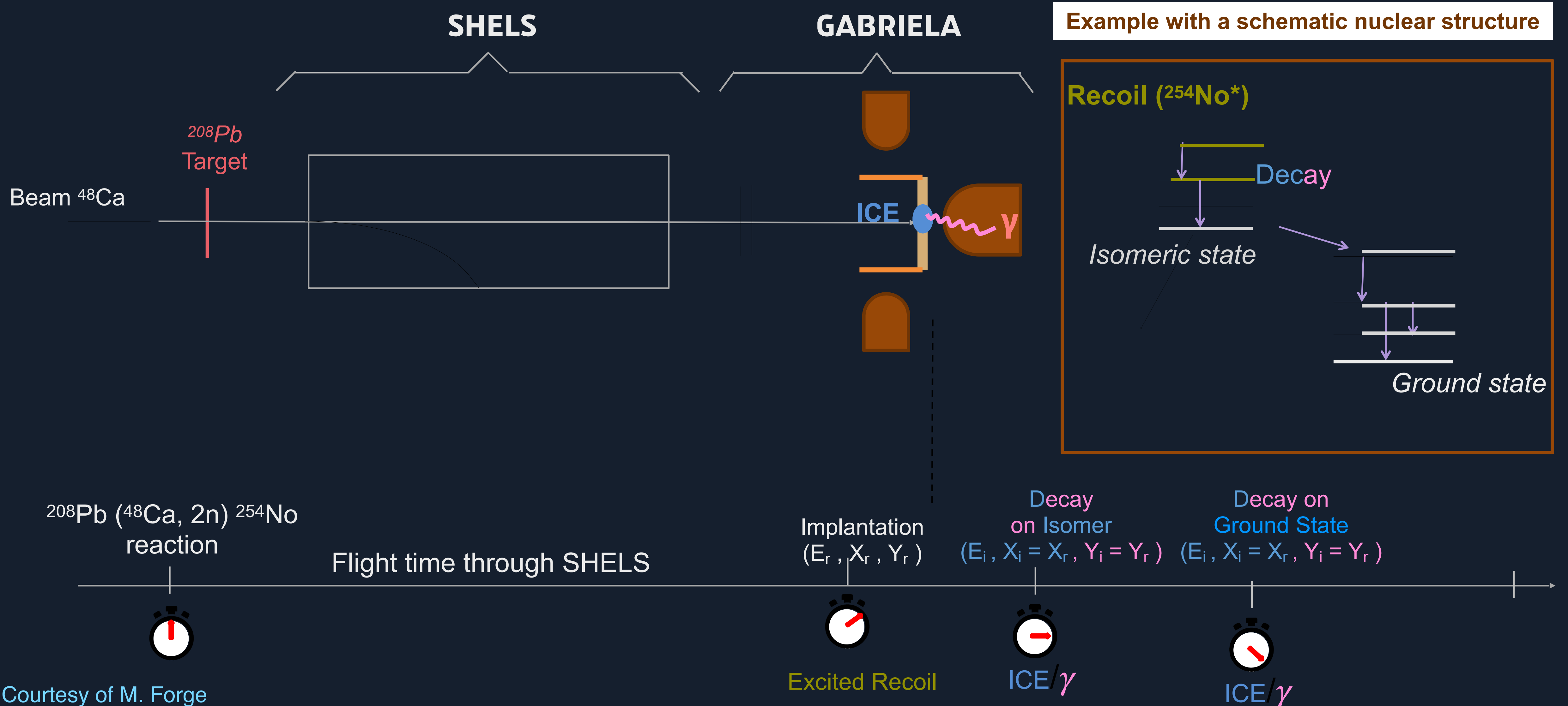
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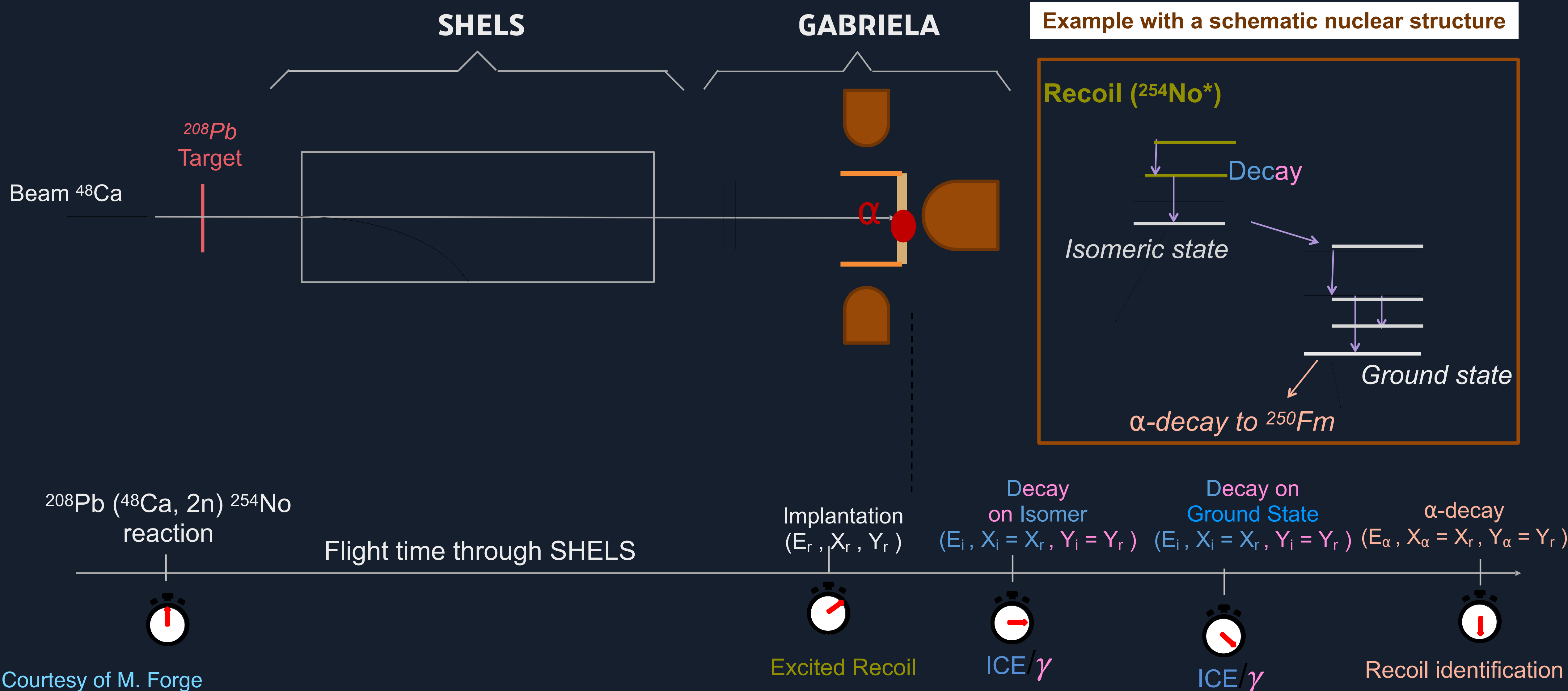
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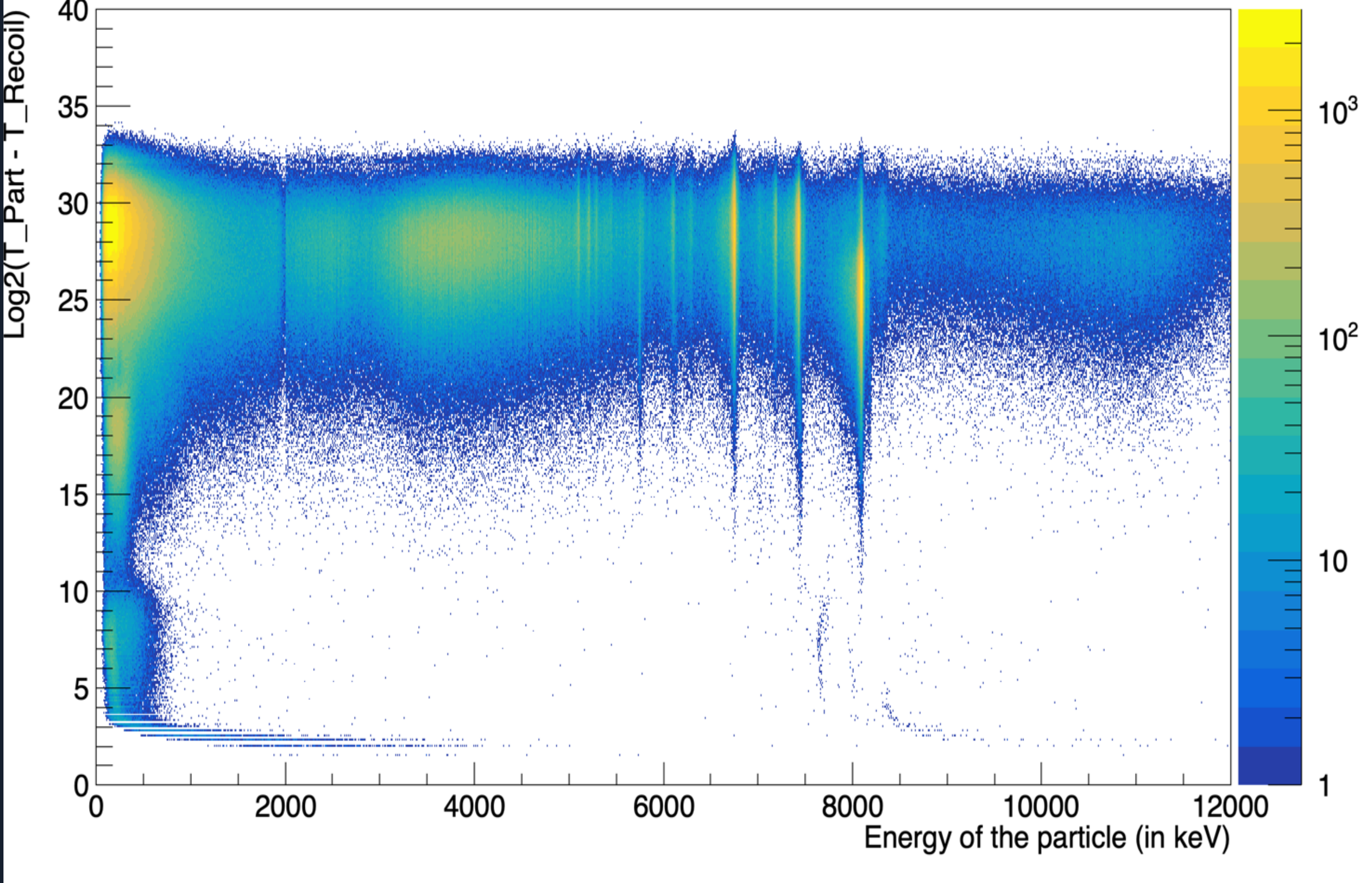
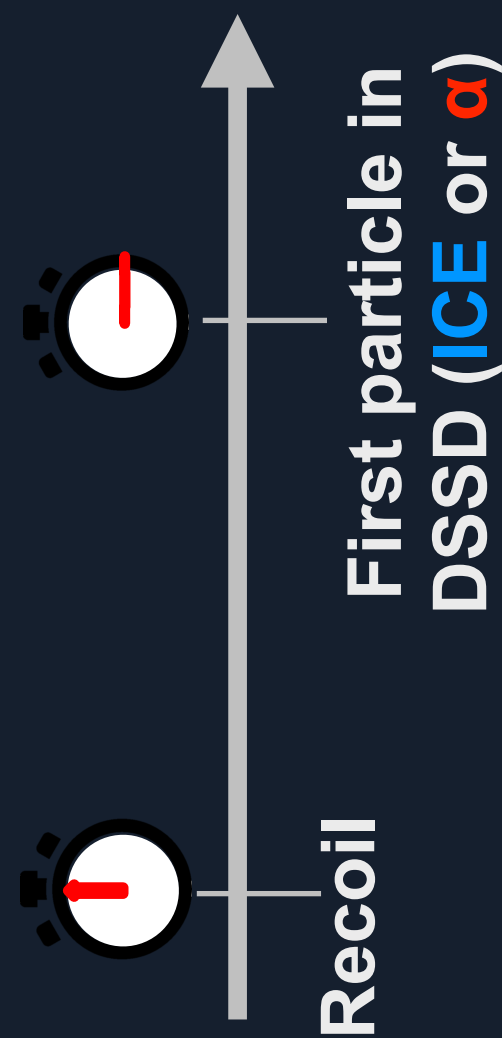
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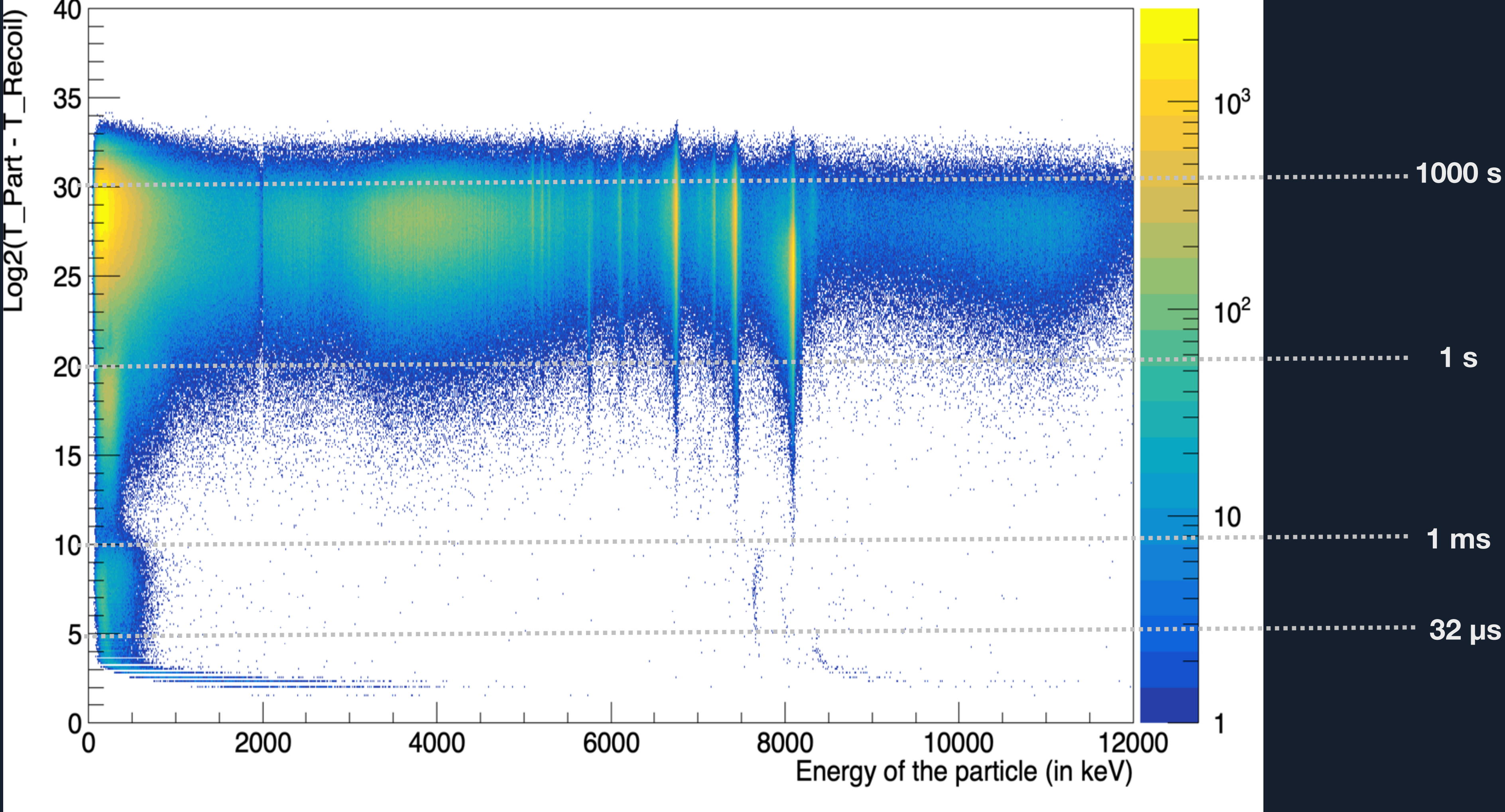
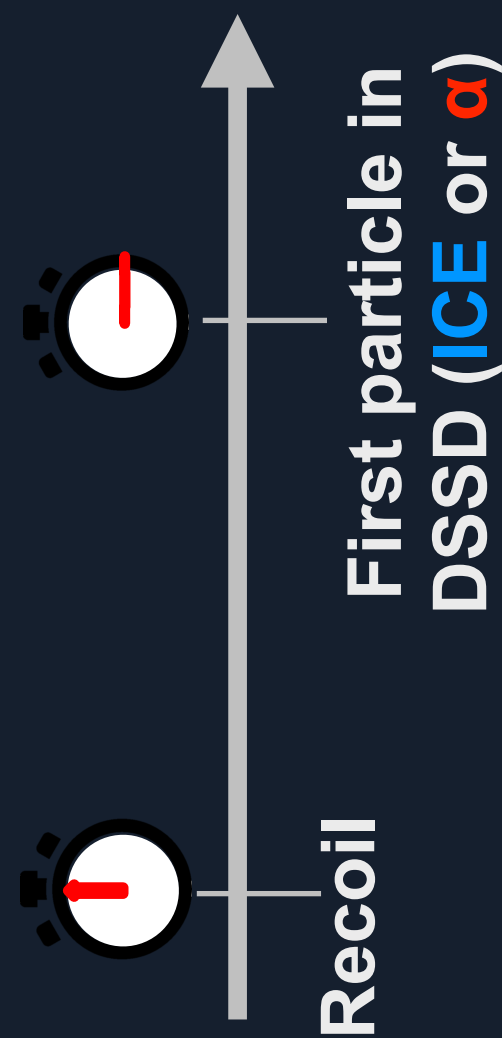
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Genetic correlation : Decay energy vs lifetime graph



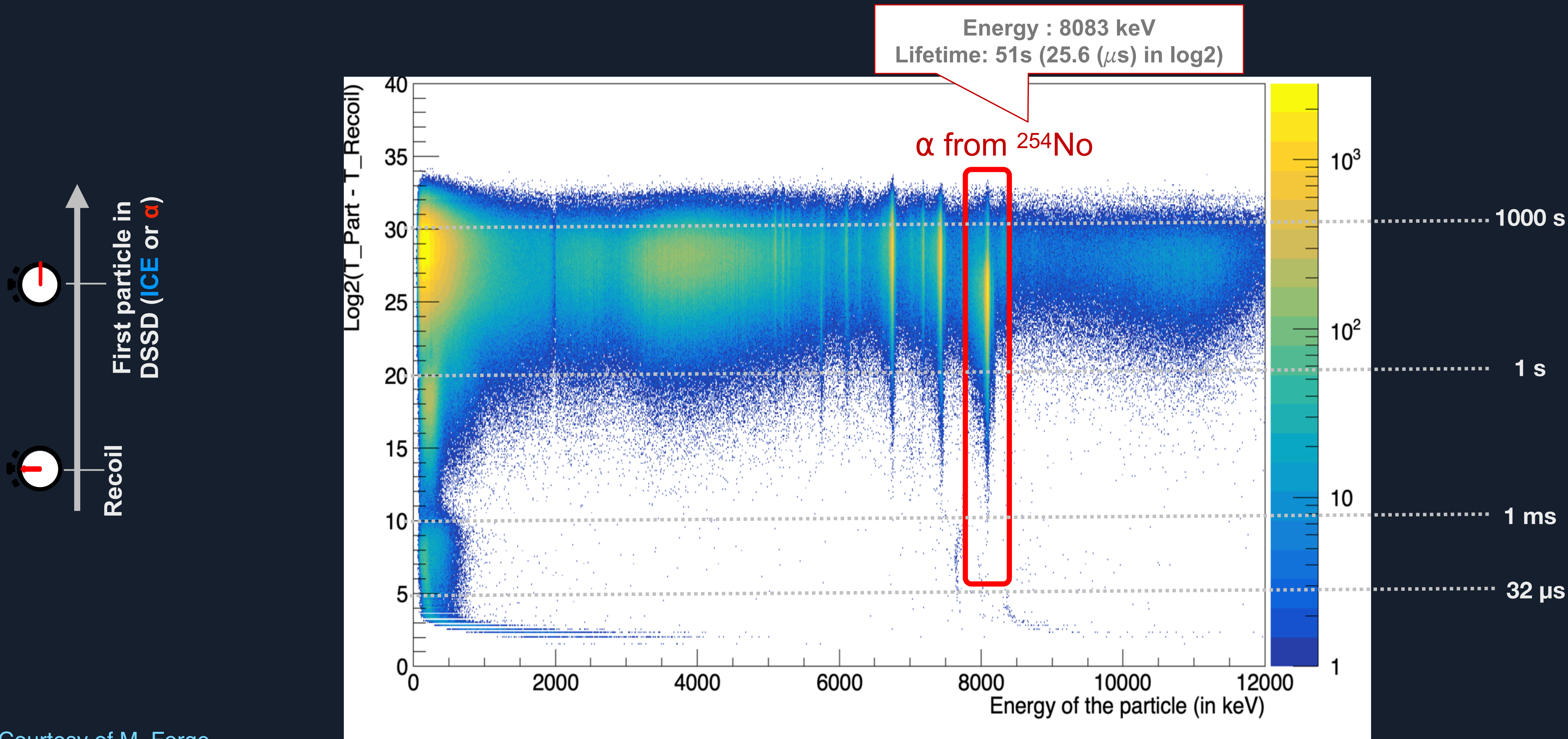
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Genetic correlation : Decay energy vs lifetime graph



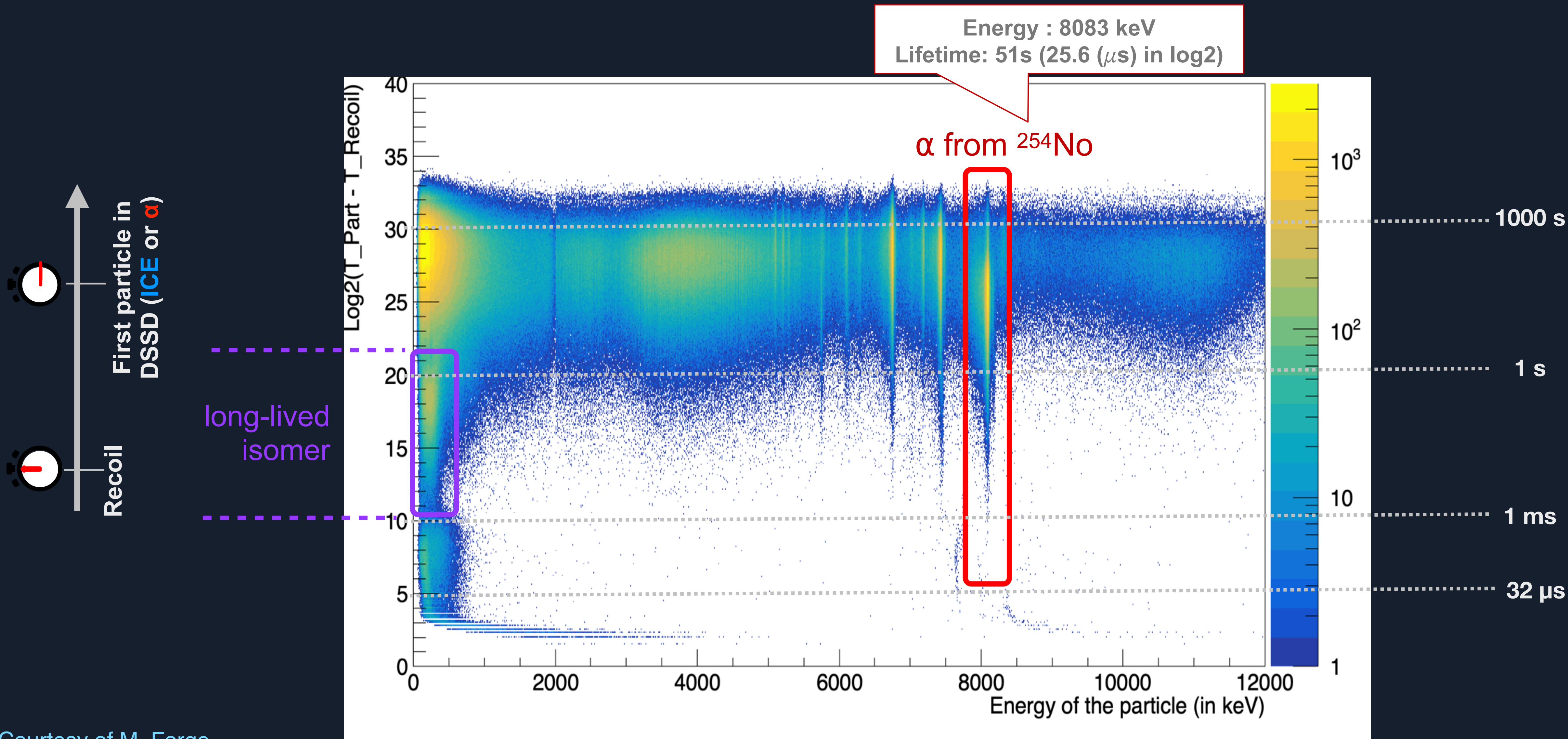
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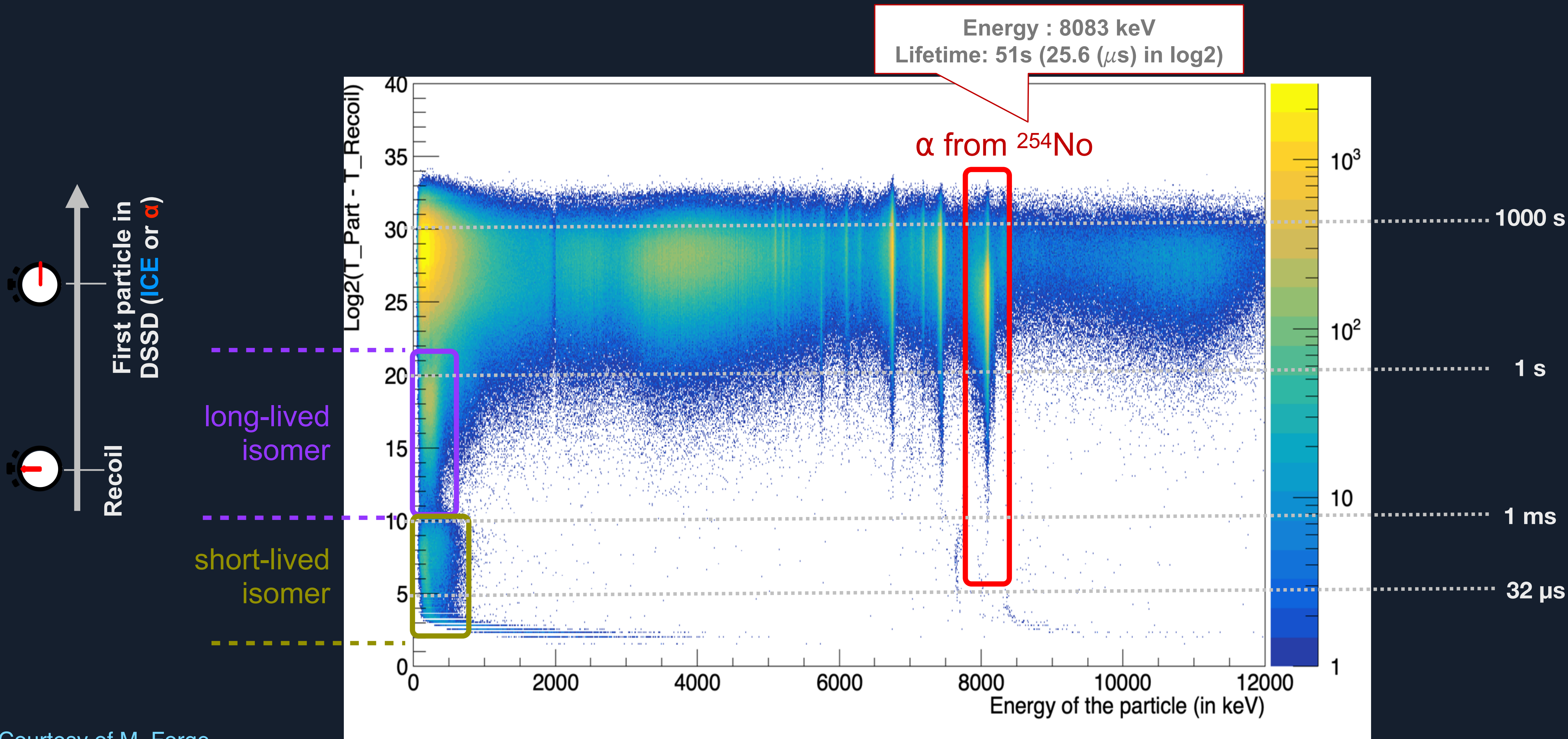
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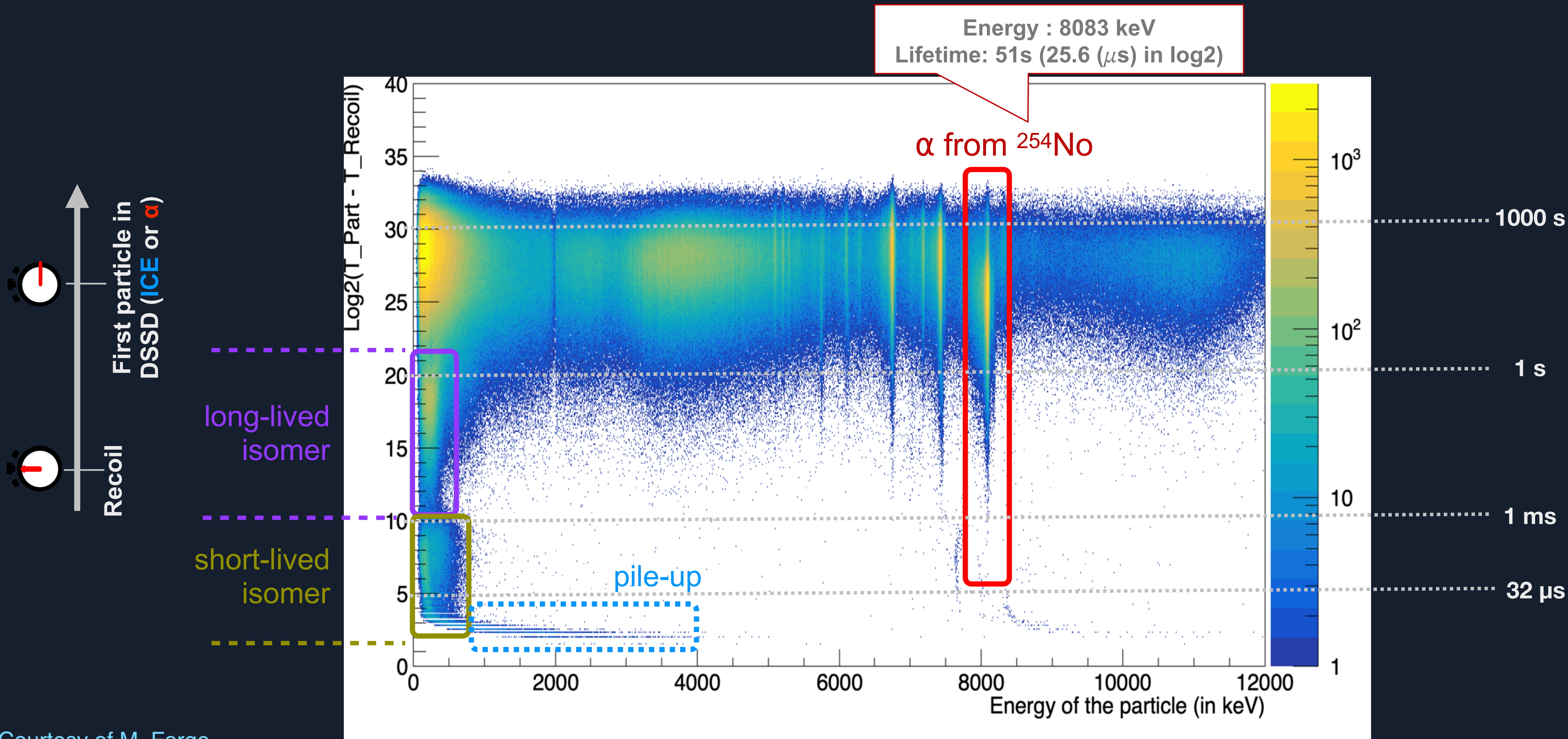
Courtesy of M. Forge

Genetic correlation : Decay energy vs lifetime graph



Courtesy of M. Forge

Genetic correlation : Decay energy vs lifetime graph



Courtesy of M. Forge



3 weeks beam time

^{208}Pb target (99,98% purity)

233 $\mu\text{g}/\text{cm}^2$ - 1.5 μm titanium backing

^{40}Ca beam

~400 pA - Energy : 225-228 MeV



3 weeks beam time

^{208}Pb target (99,98% purity)
233 $\mu\text{g}/\text{cm}^2$ - 1.5 μm titanium backing

^{40}Ca beam
~400 pA - Energy : 225-228 MeV

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

1.2×10^4 electrons from
short-lived isomer

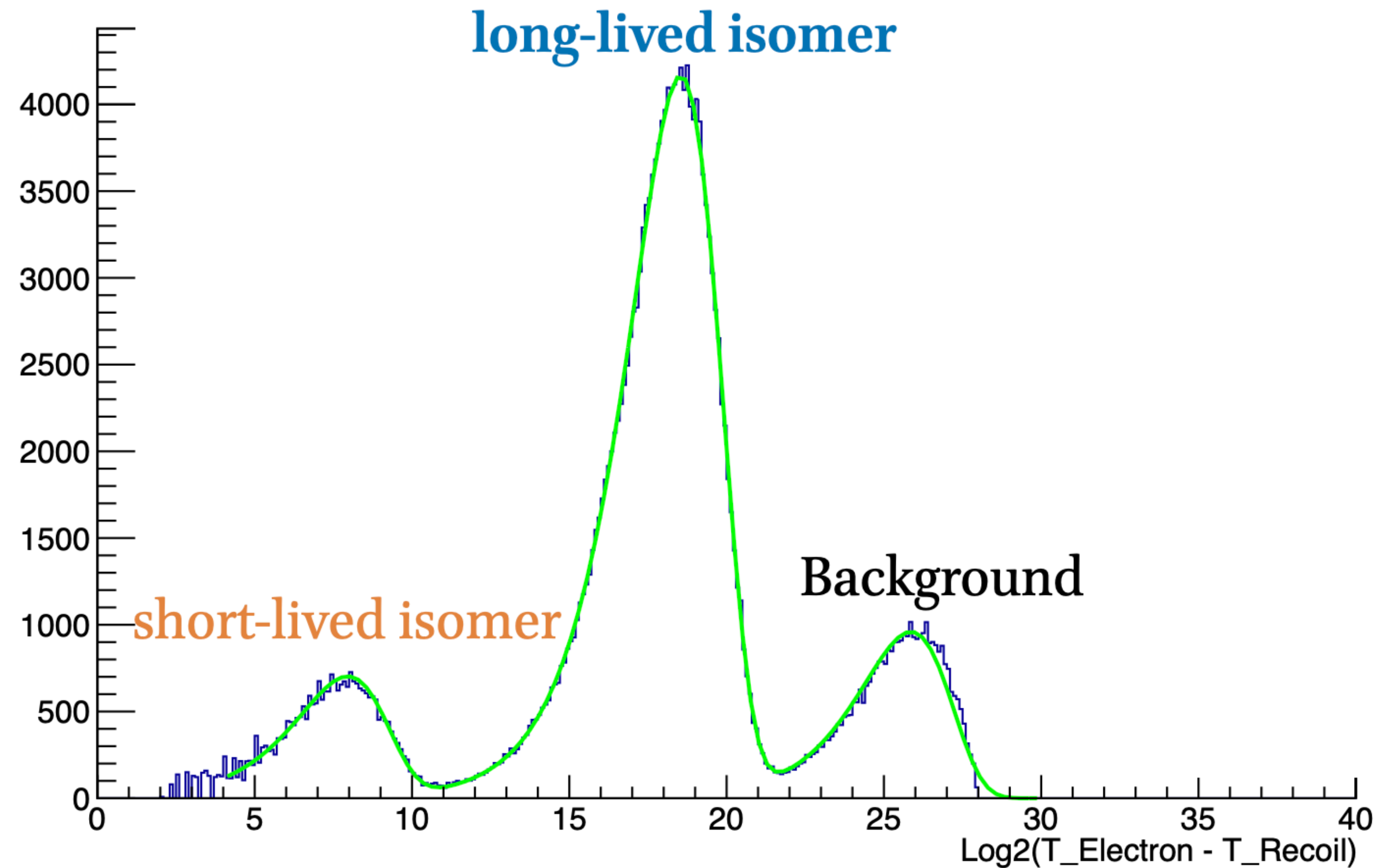
6.6×10^5 electrons from
long-lived isomer

HIGH STATISTICS AND QUALITY DATA !

Results

Confirmation of 2 isomeric states

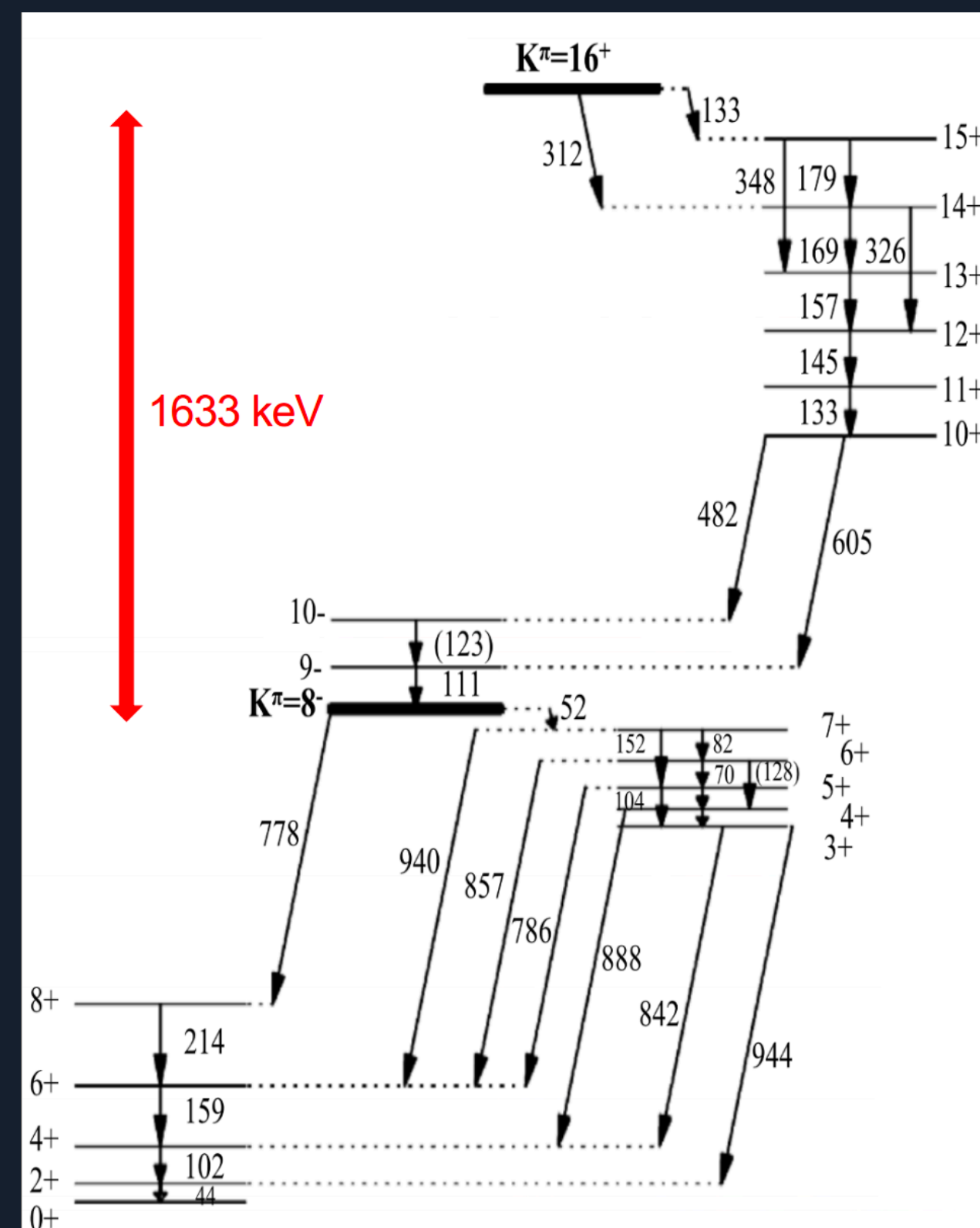
- a **long-lived isomer** state : $T_{1/2} = 263,5 \pm 0,7 \text{ ms}$
- a **short-lived isomer** state : $T_{1/2} = 170,5 \pm 1,2 \mu\text{s}$



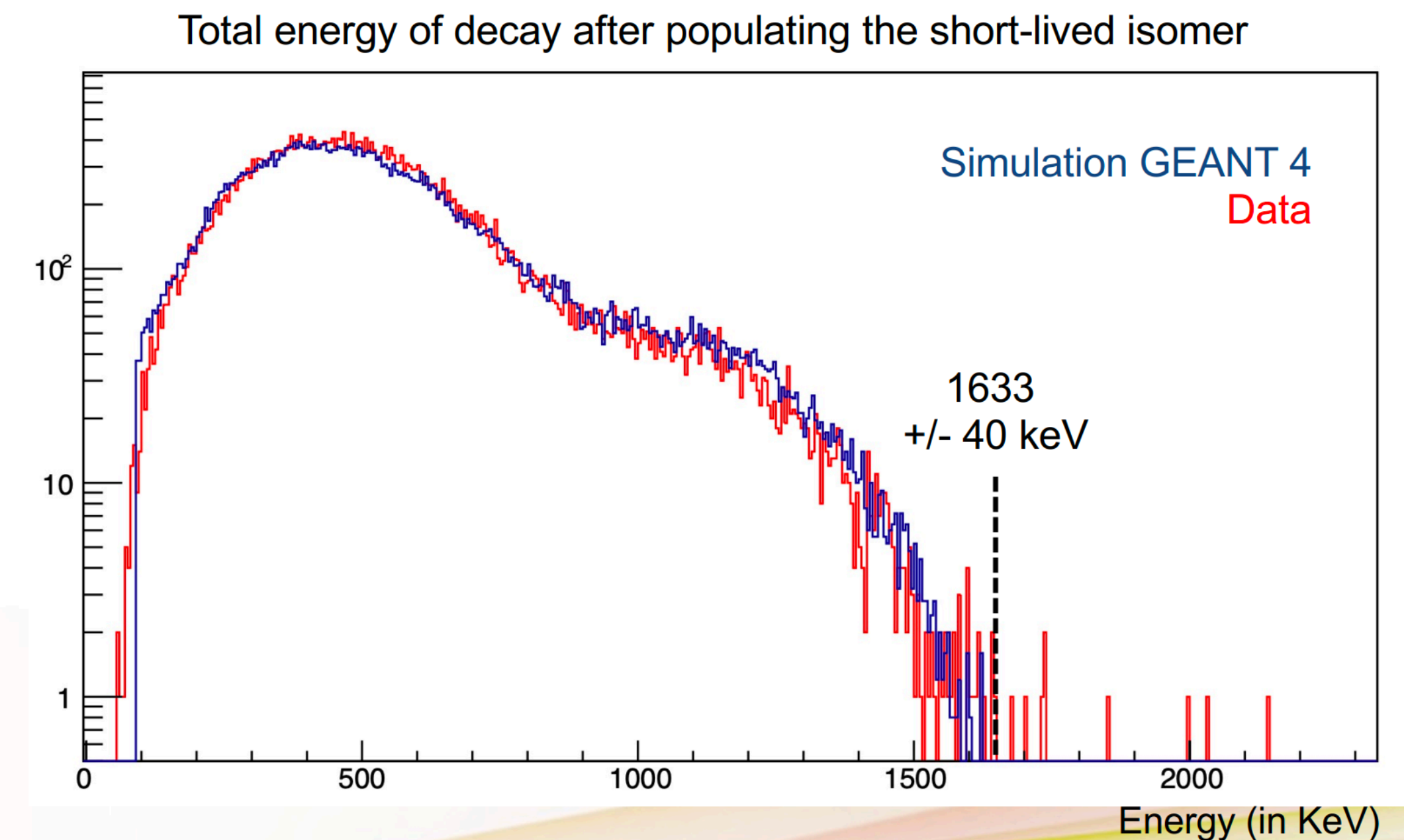
Results on short-lived isomer

K=16 at 1633 keV from long-lived isomeric state

The parity has to be investigated

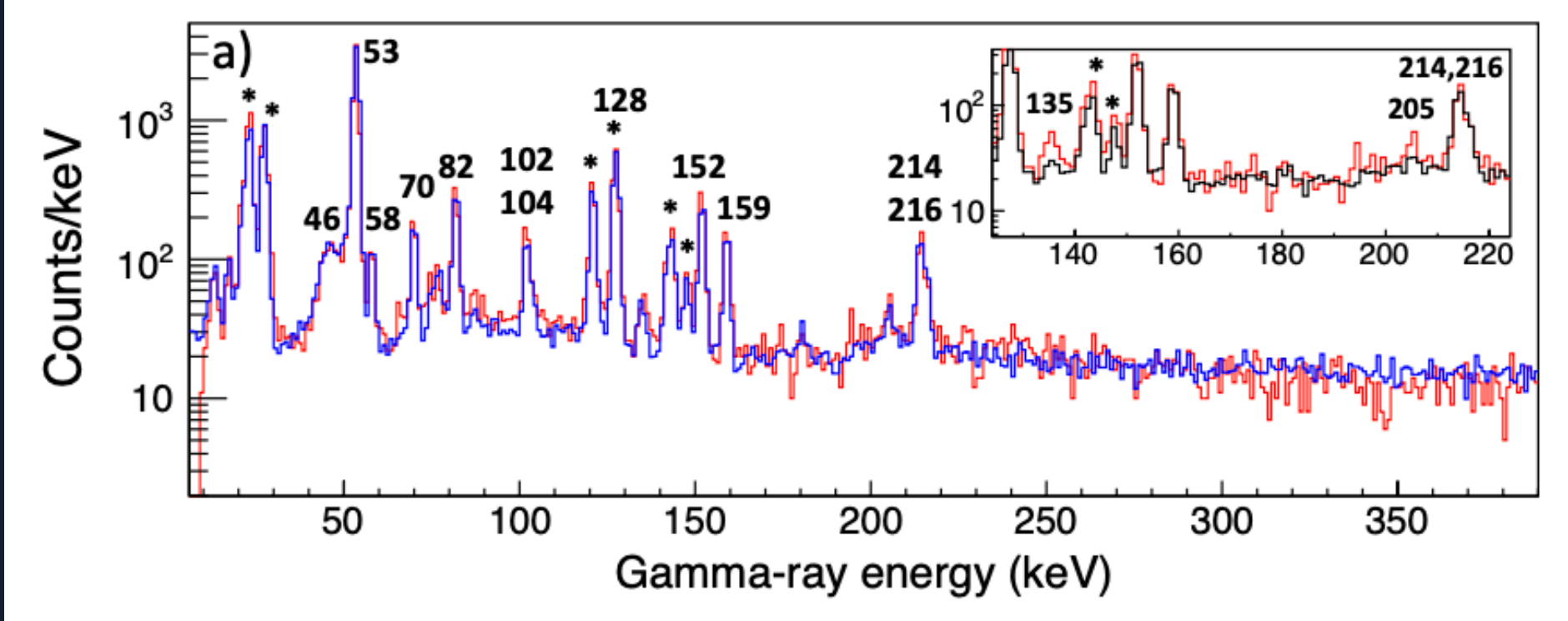


Thanks to A. Lopez-Martens, for the G4 simulations

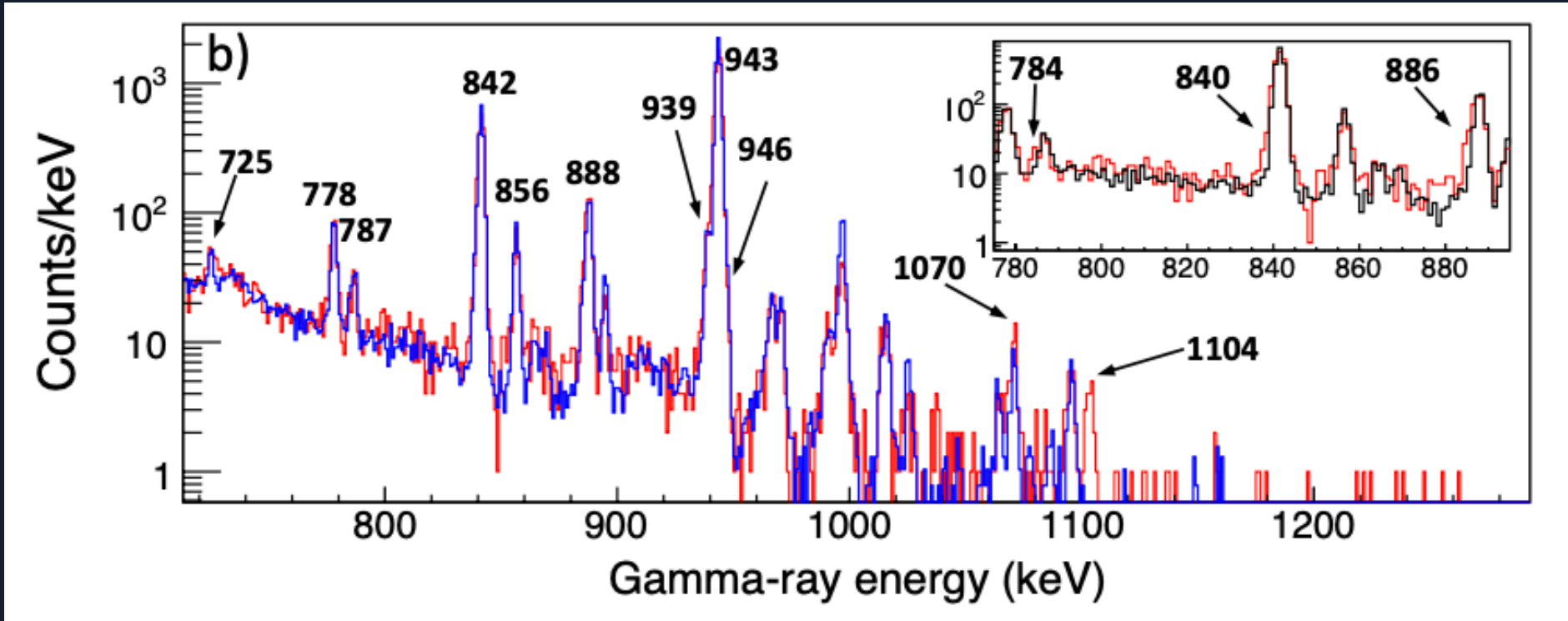


Results on long-lived isomer

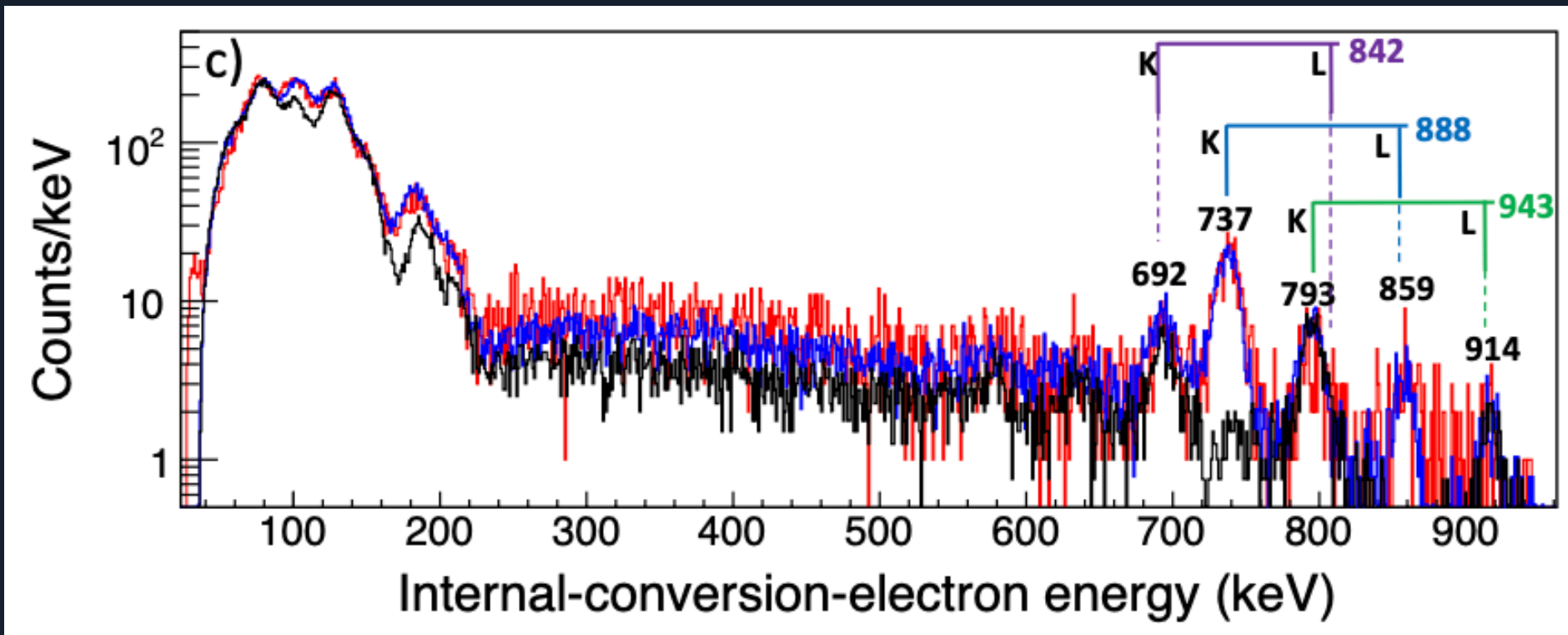
Low energy γ -rays



High energy γ -rays

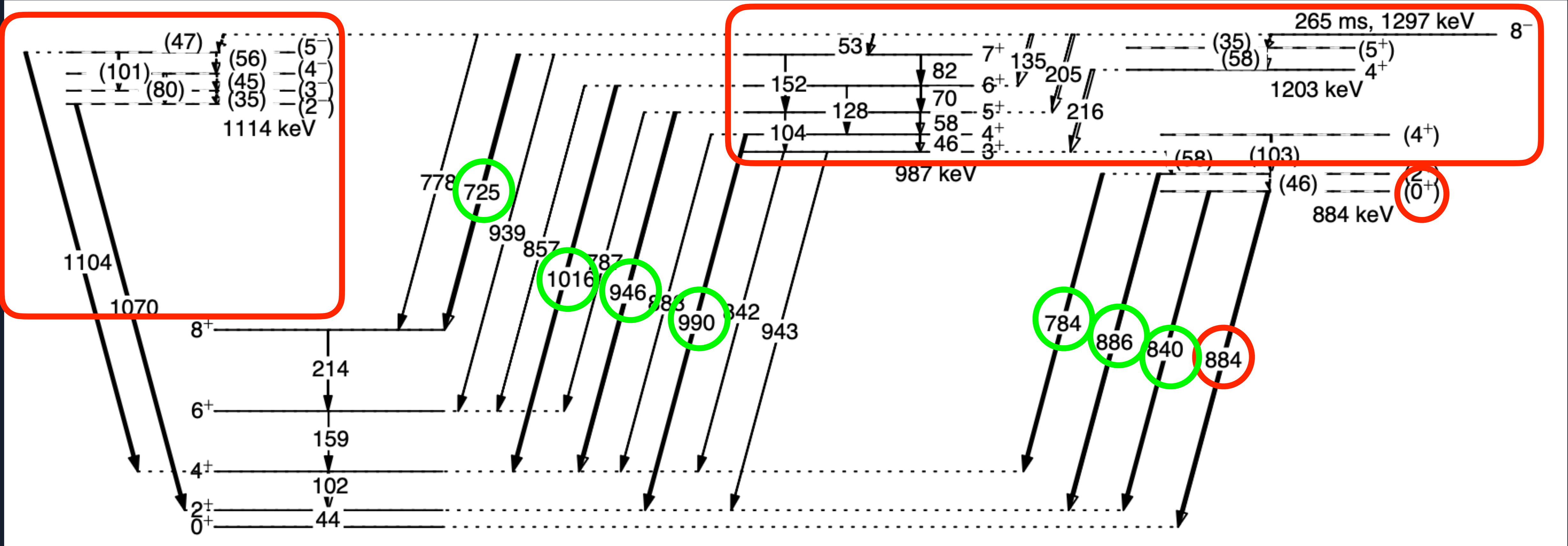


Conversion electron energy



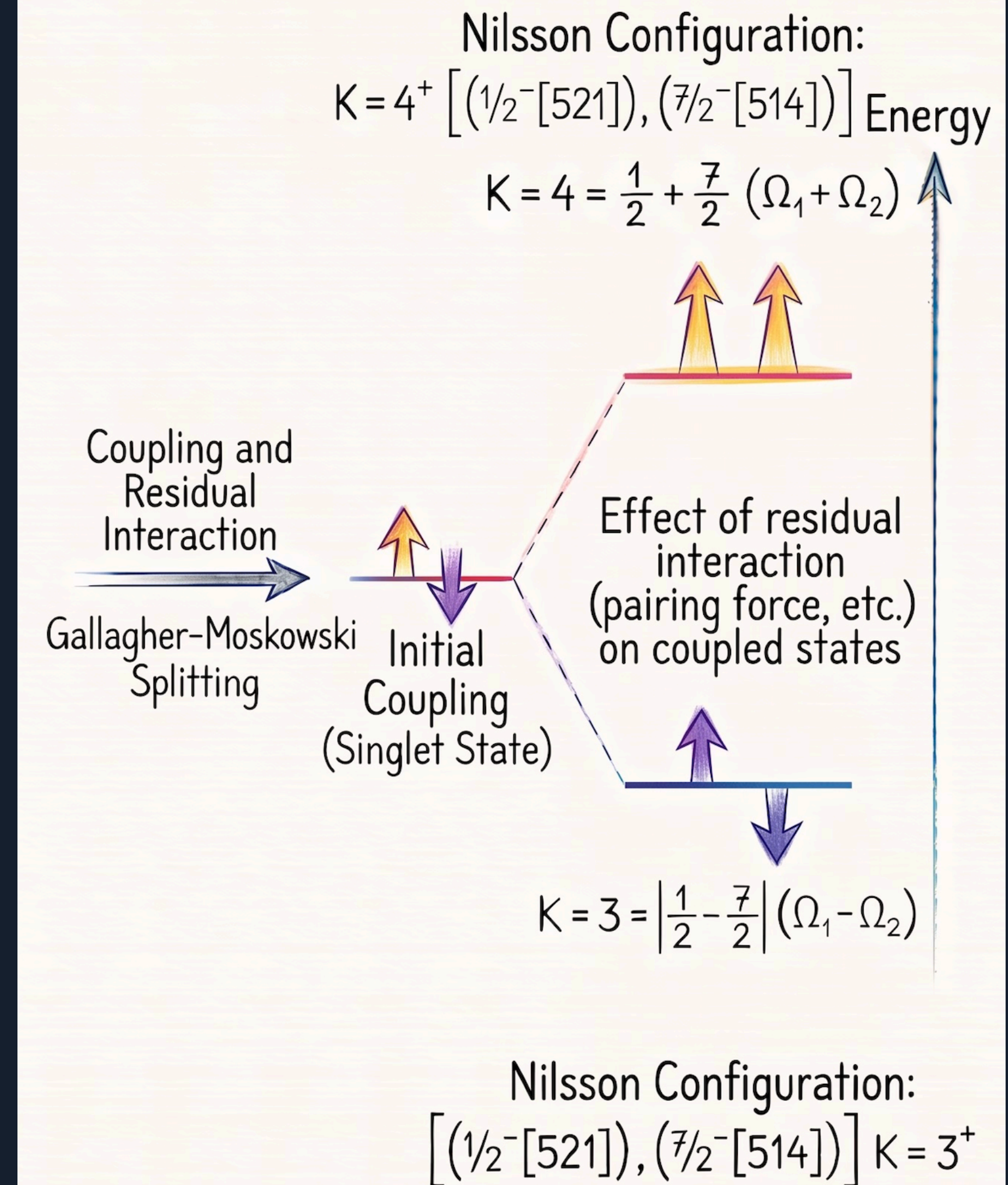
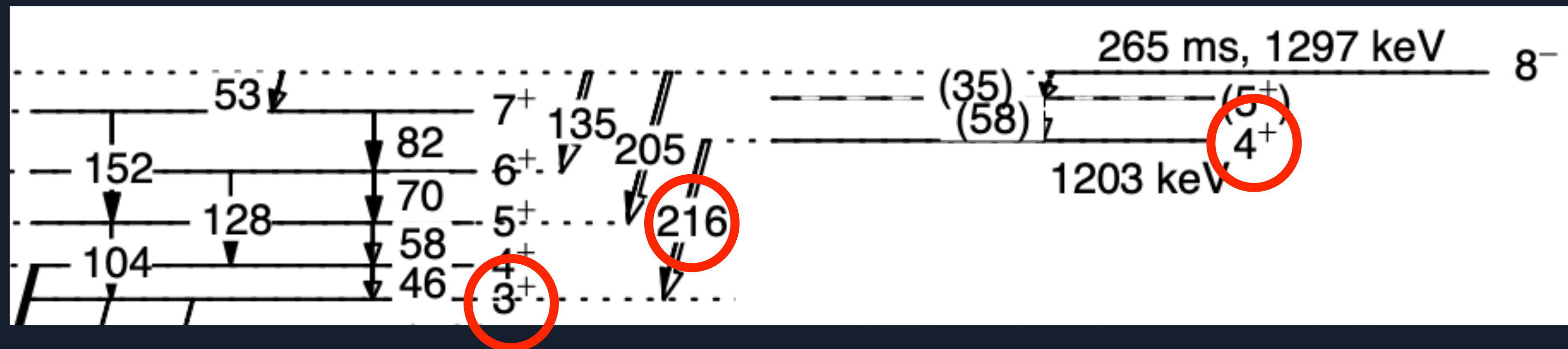
Proposed new level scheme

M. Forge et al. Phys. Rev. C 114 (2026) 024324_



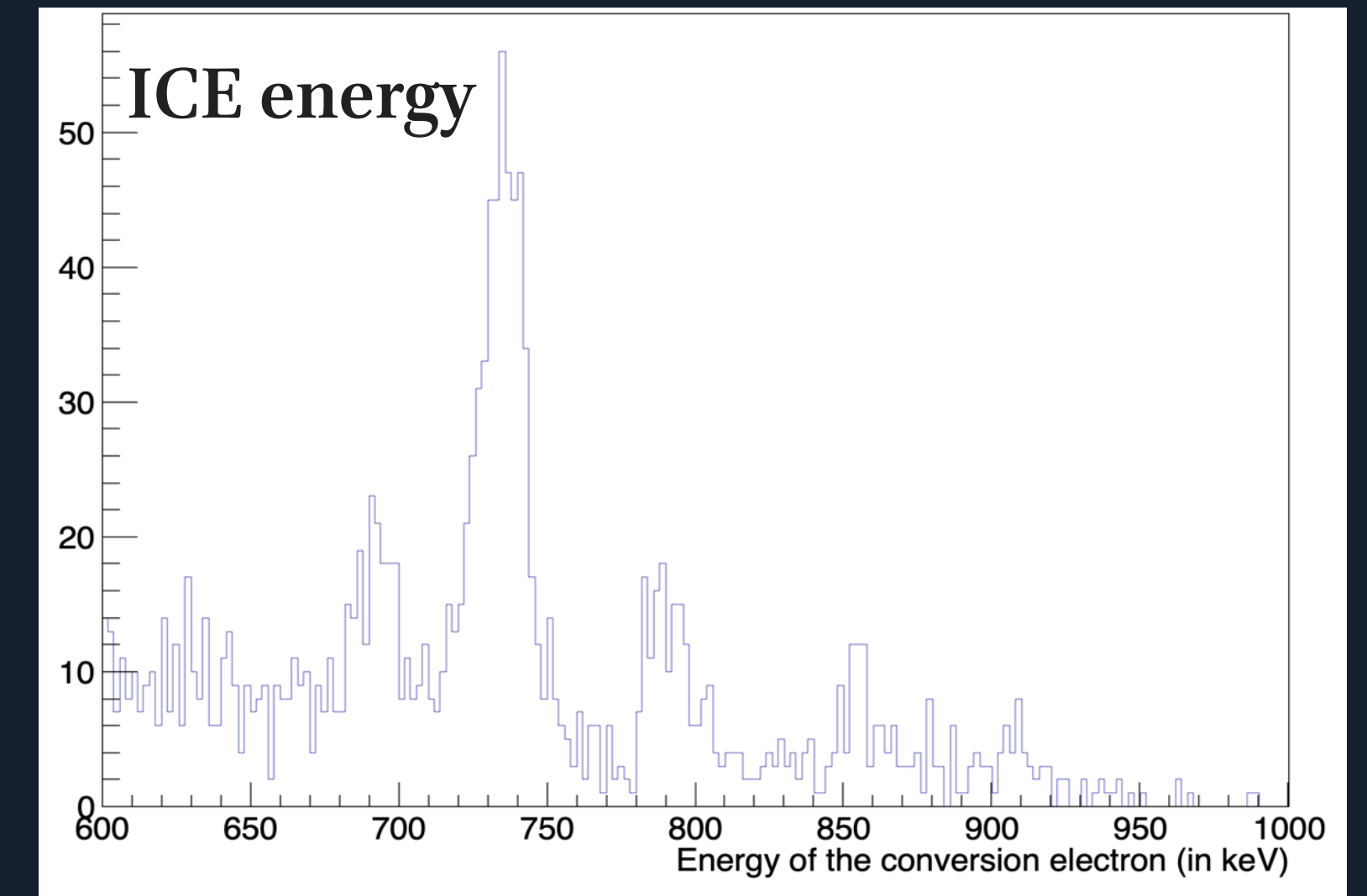
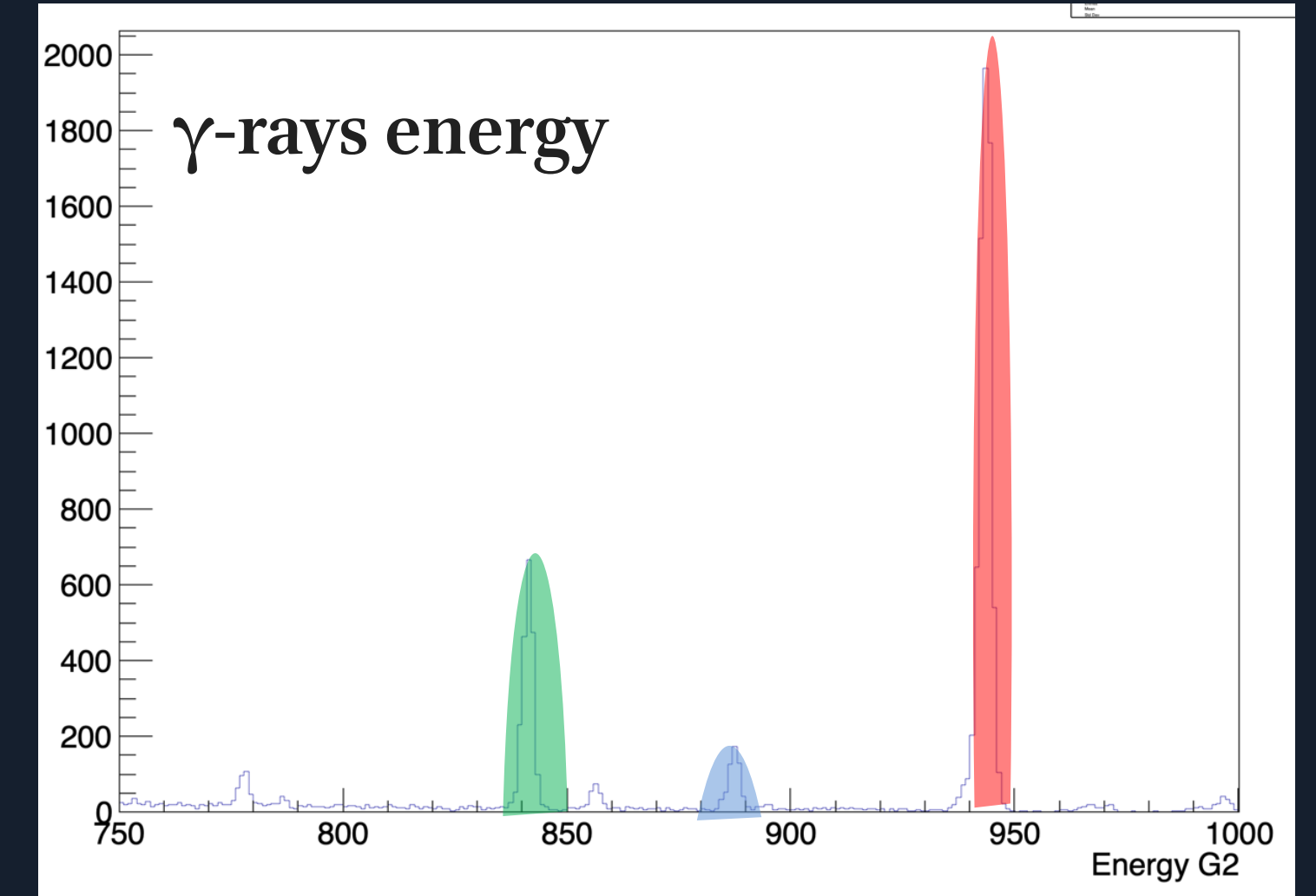
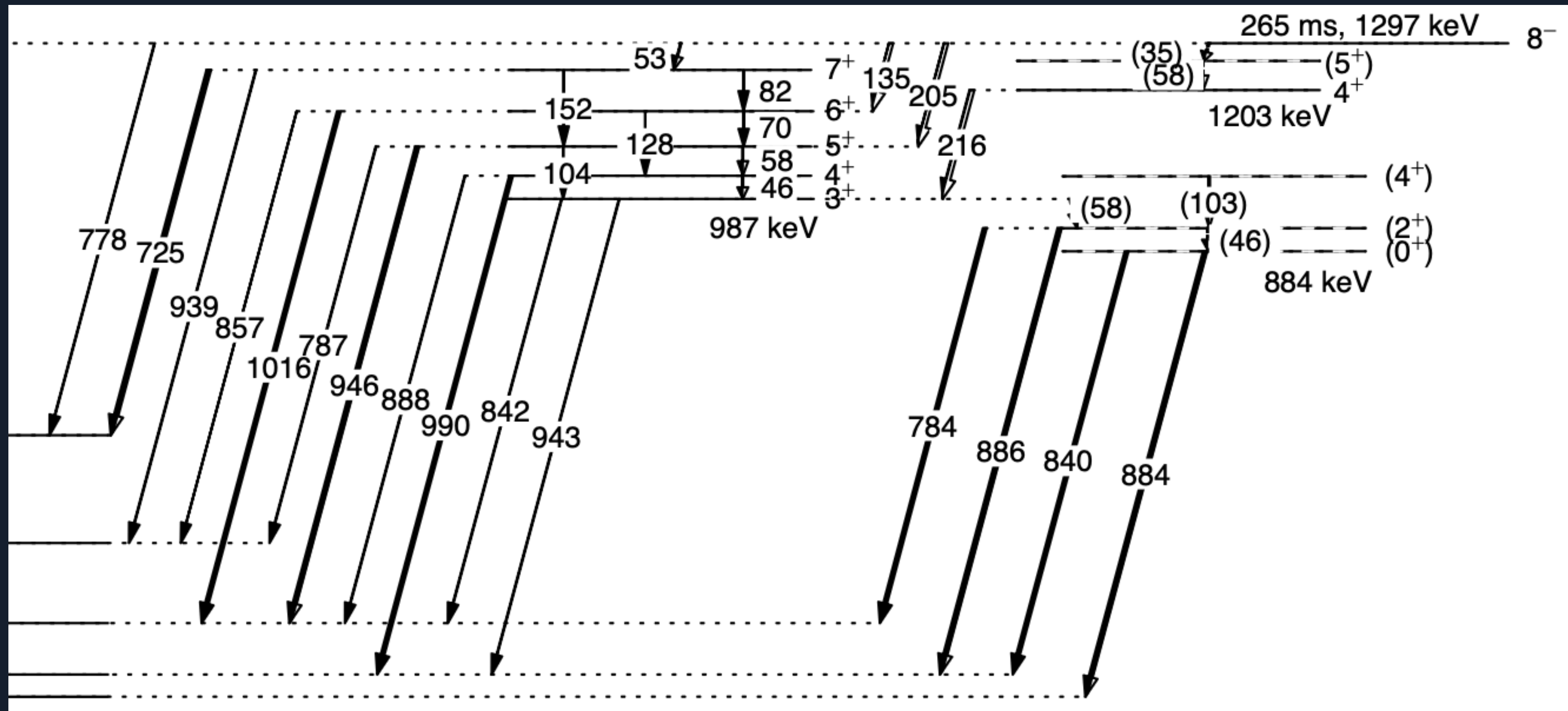
Interpretation of this new level scheme

First measurement of the Gallagher-Moszkowski splitting in such heavy nuclei of **216 keV**



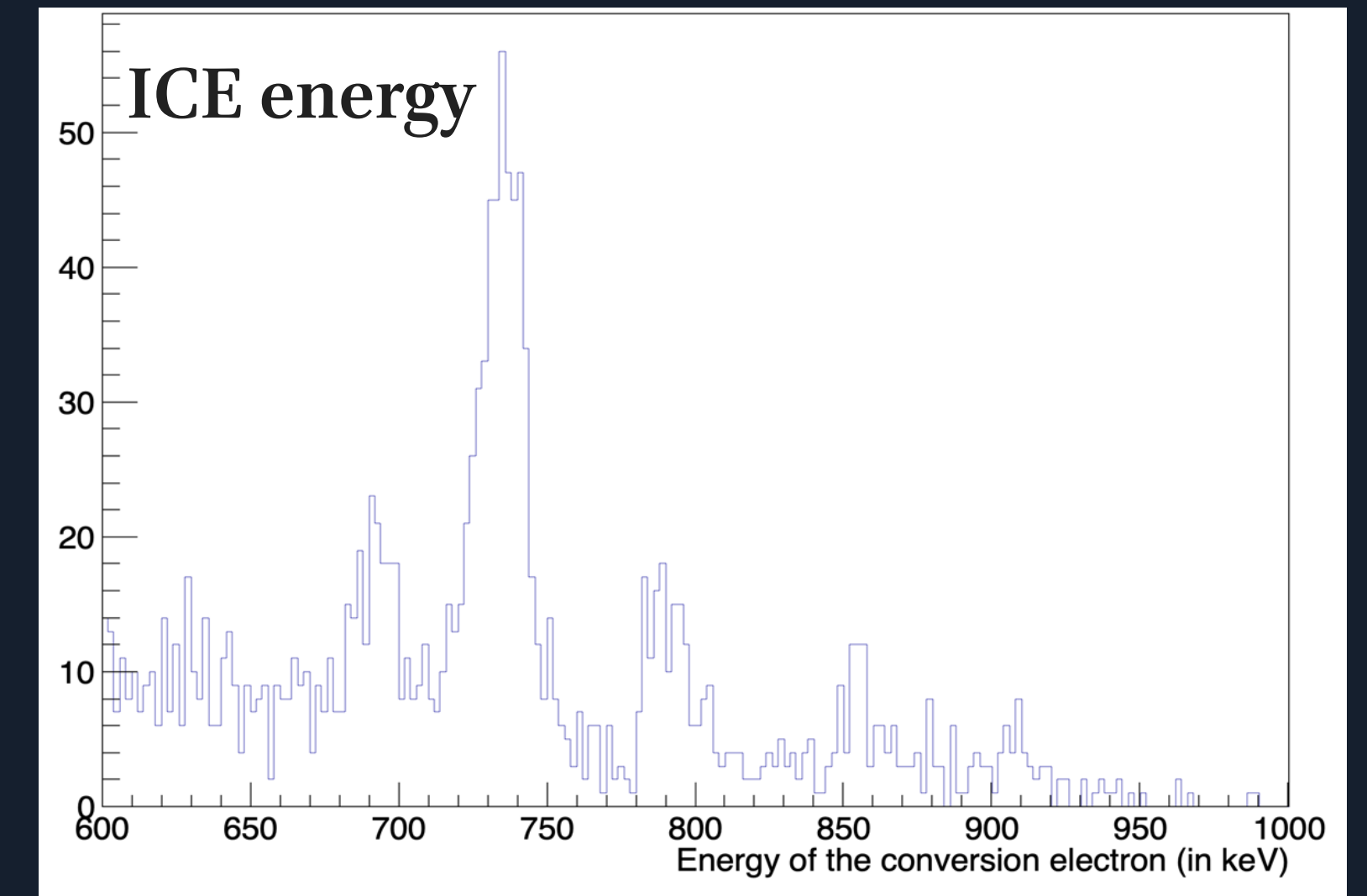
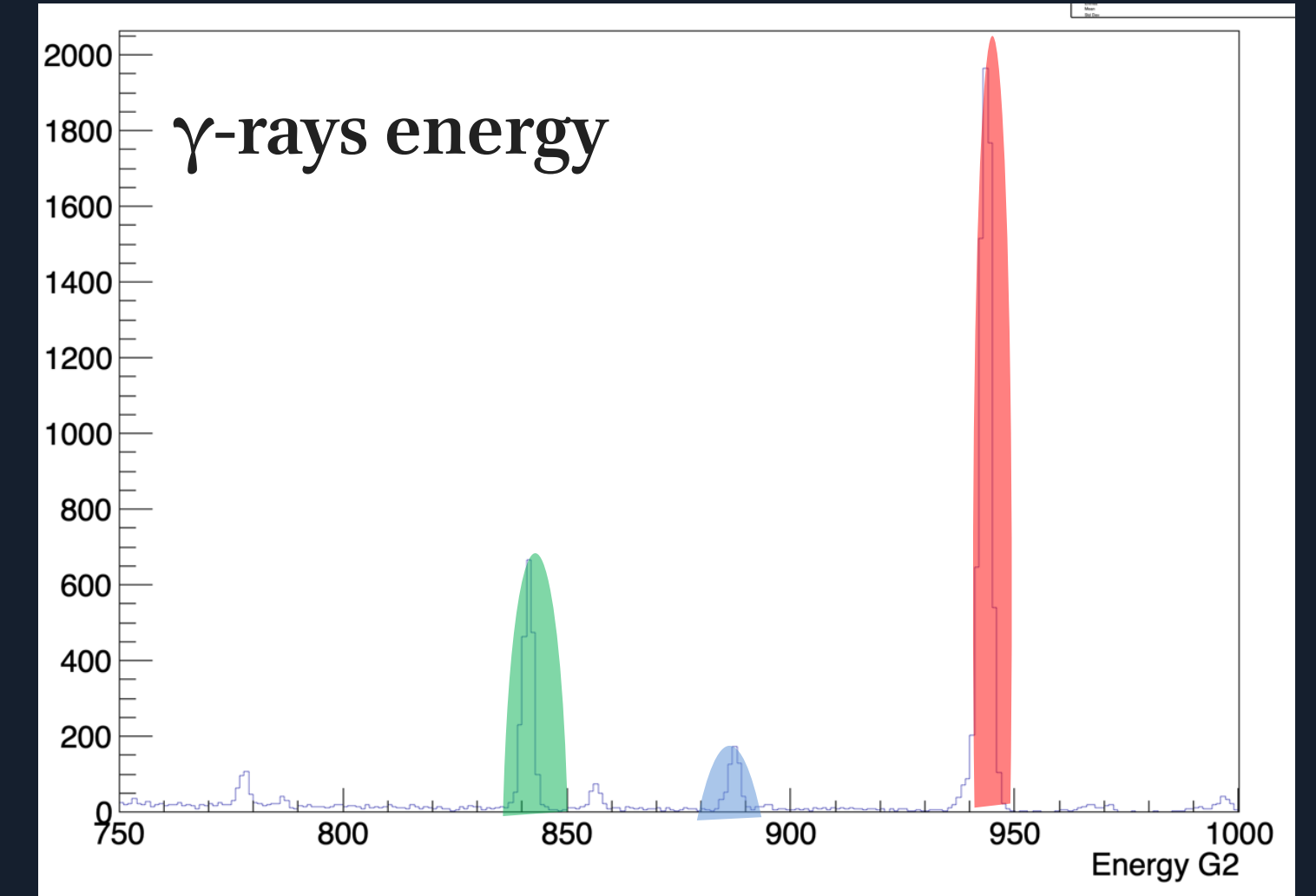
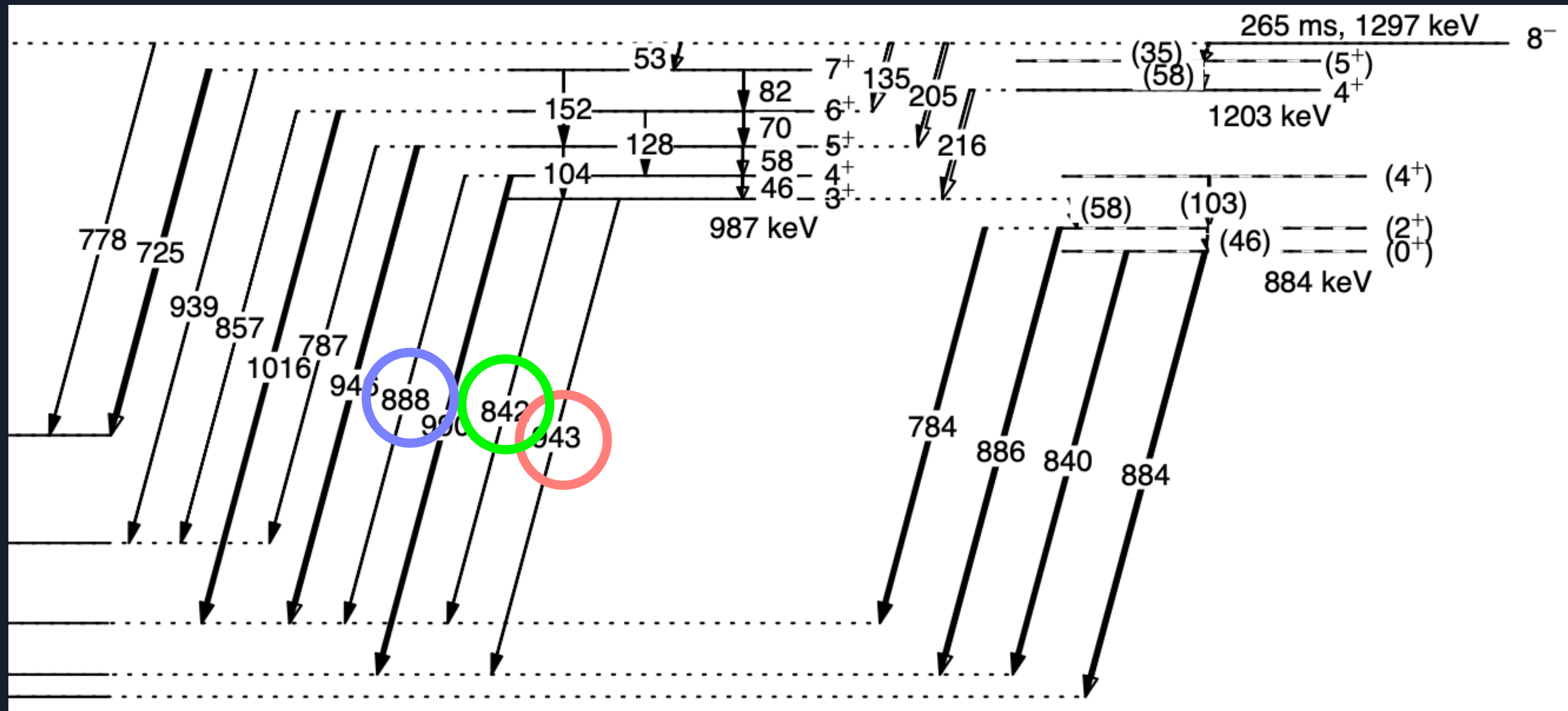
Interpretation of this new level scheme

First evidence of a new E0 transition



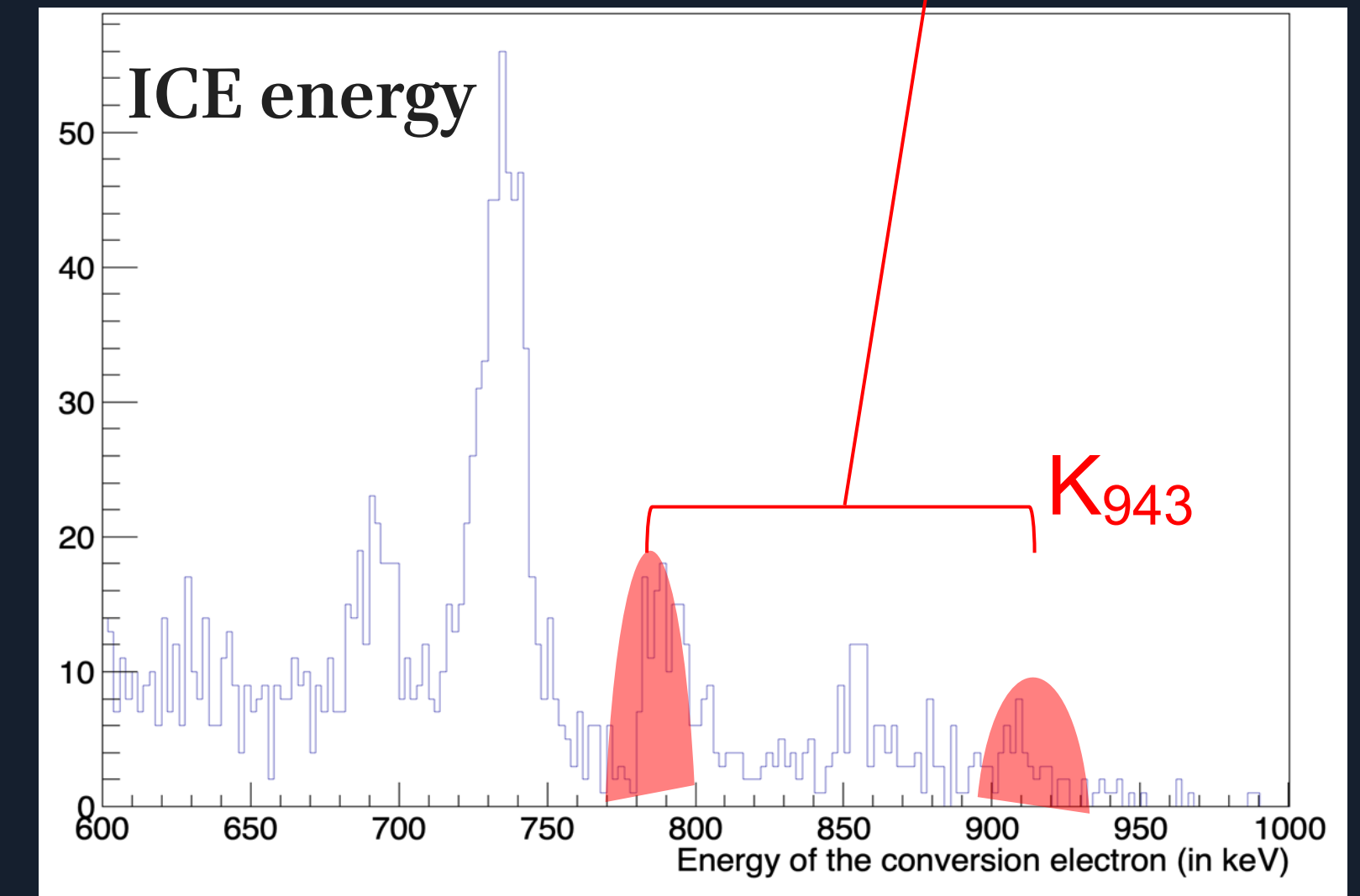
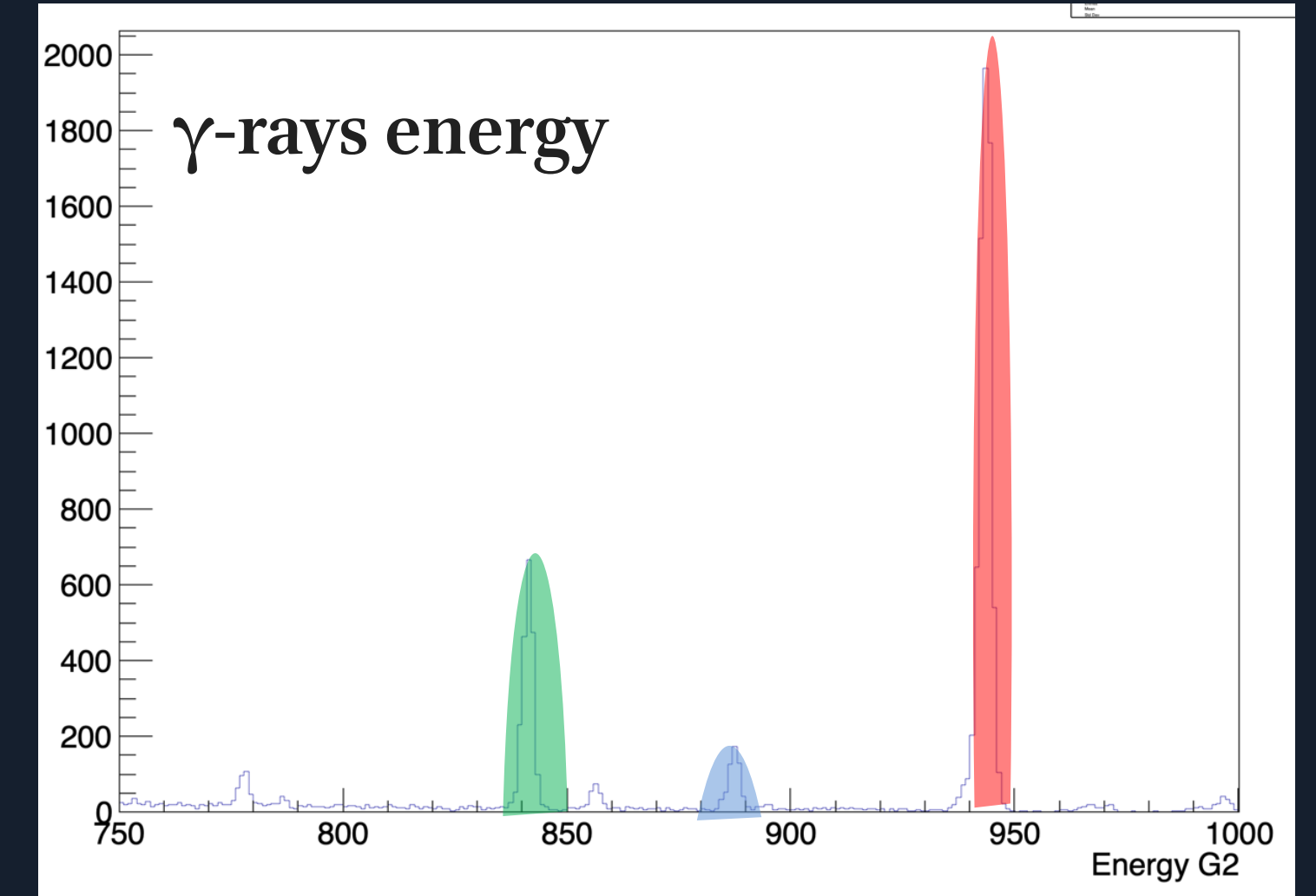
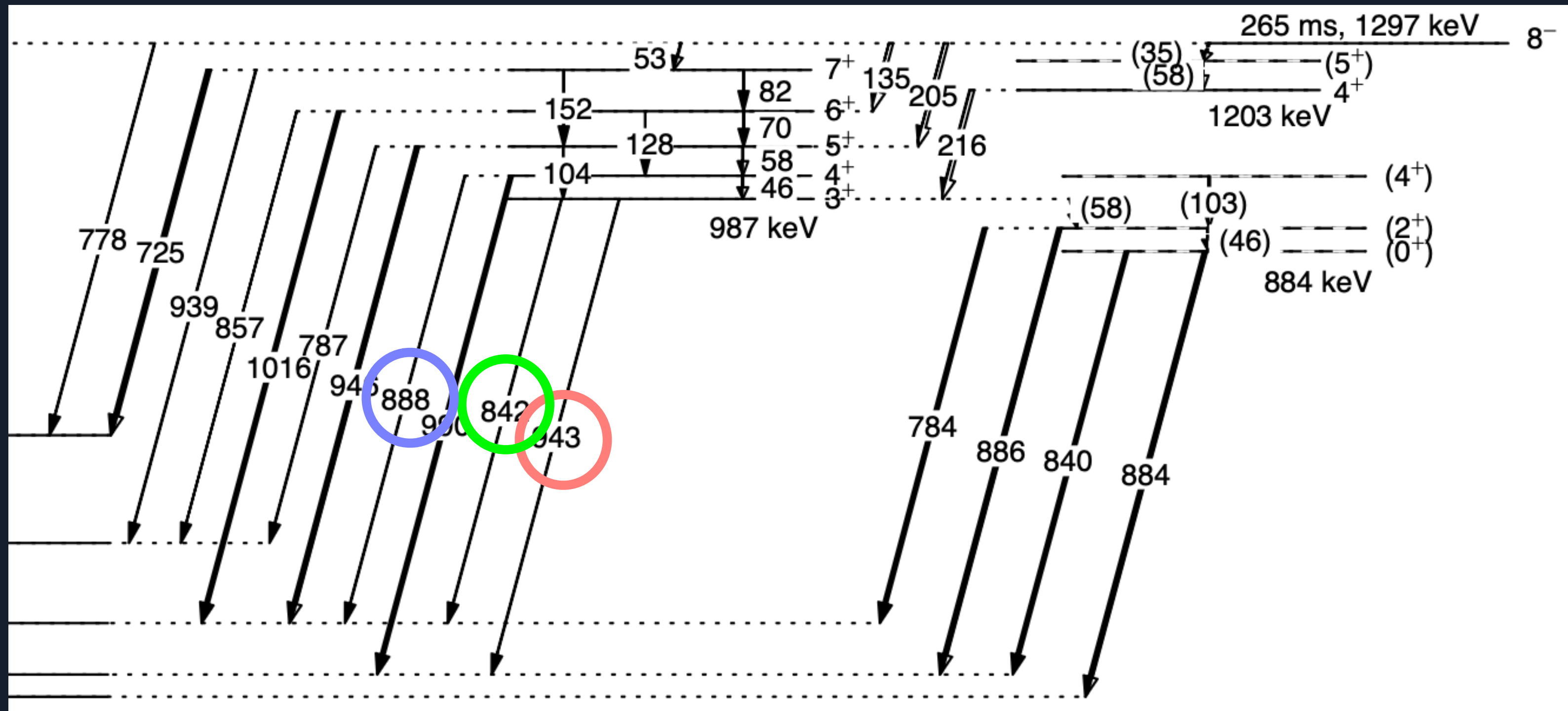
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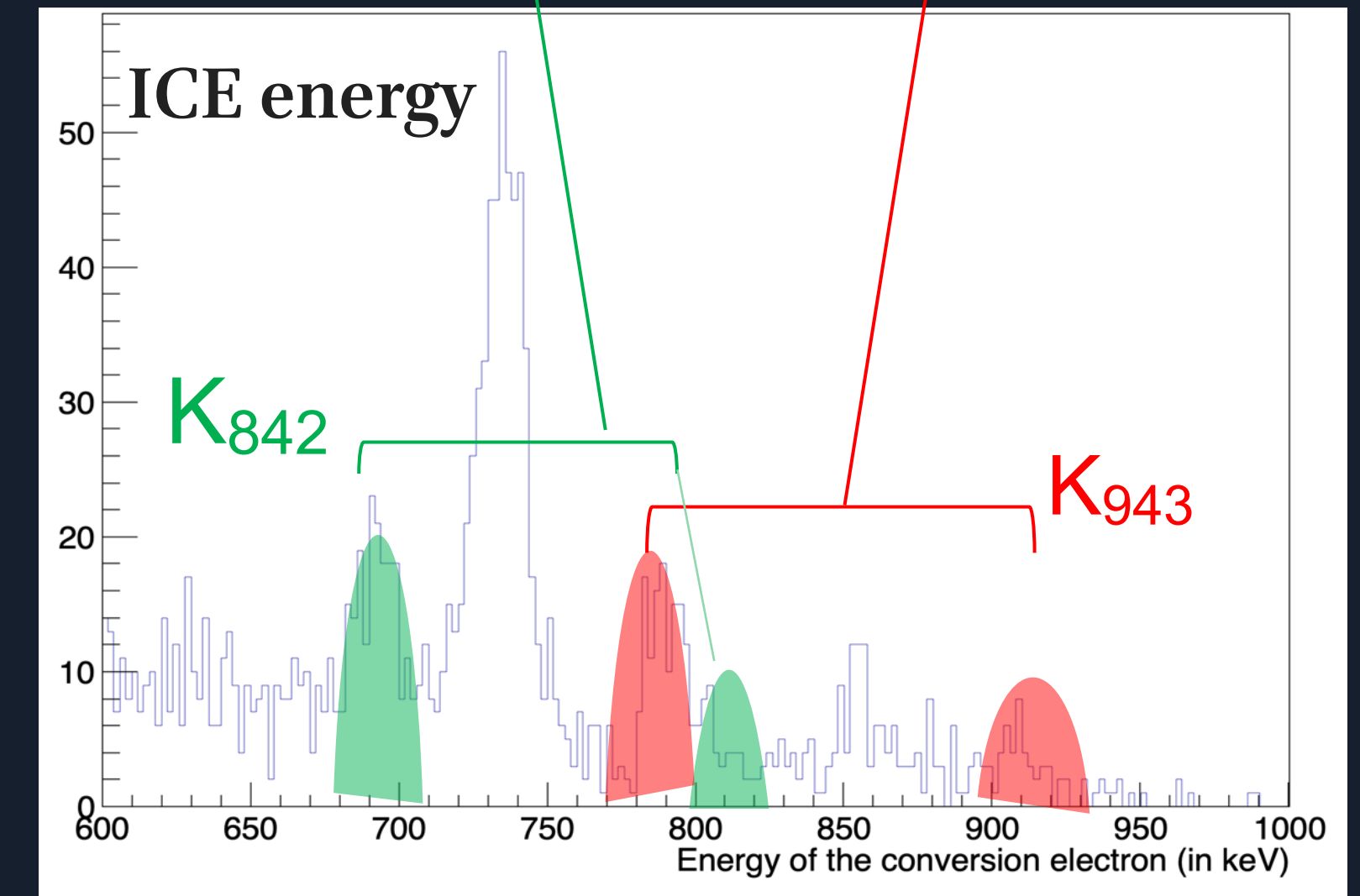
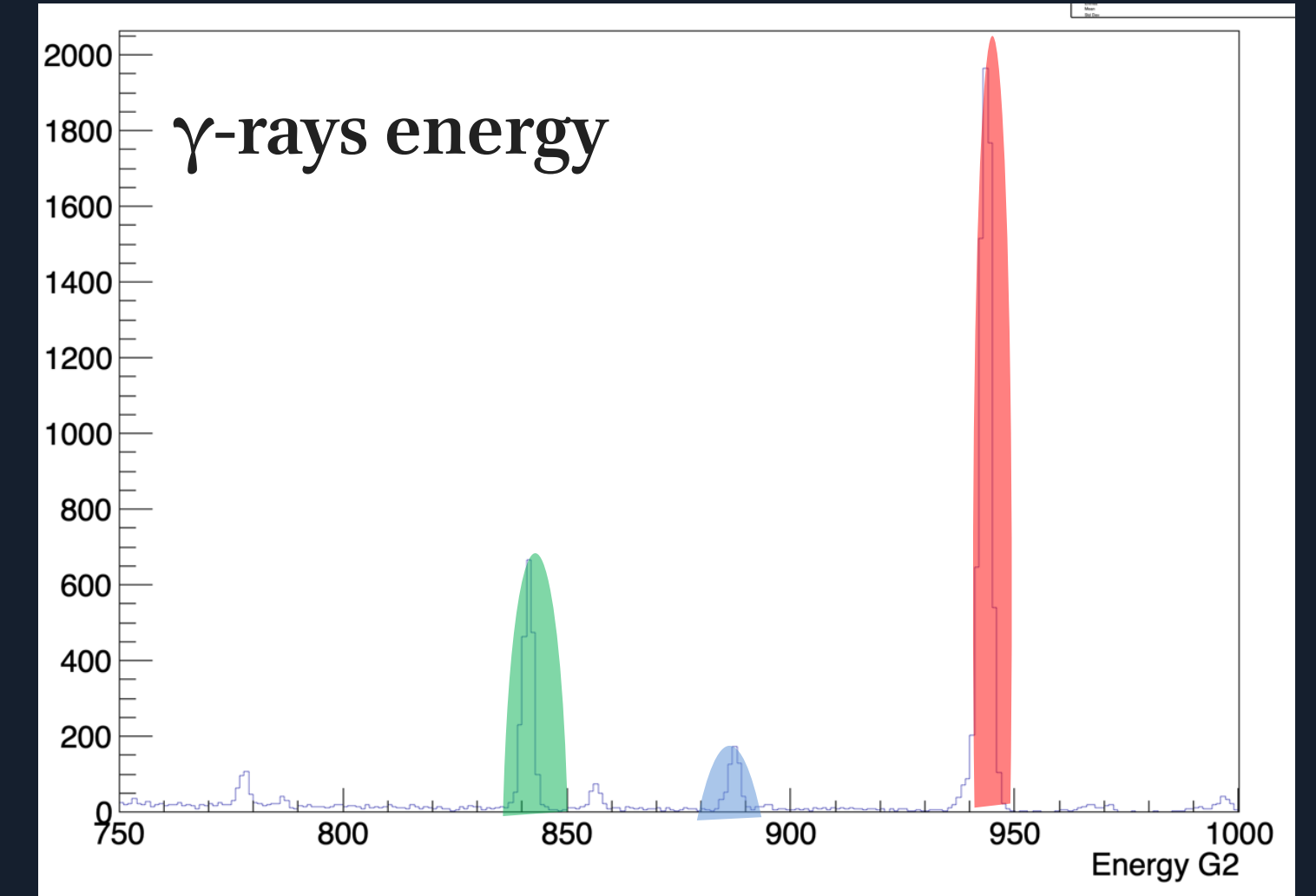
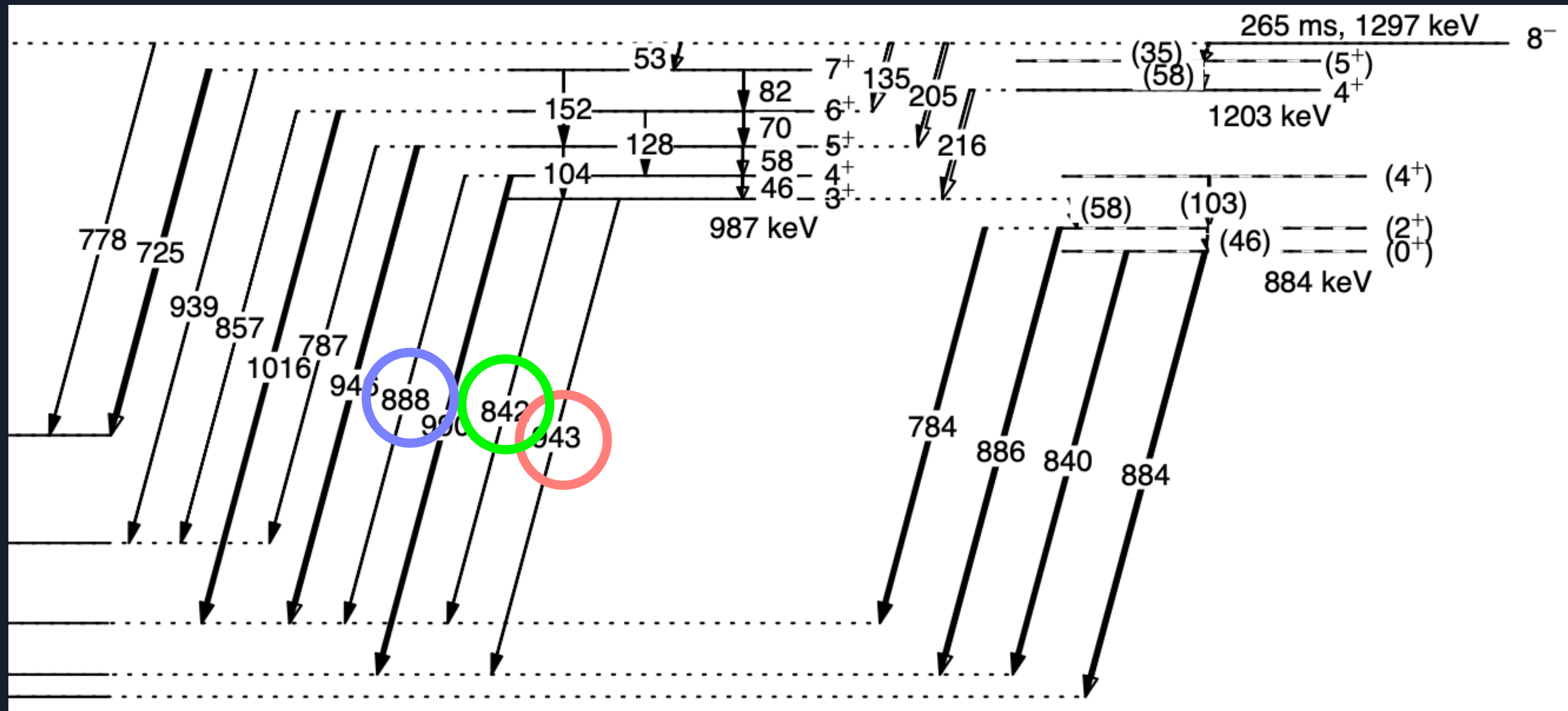
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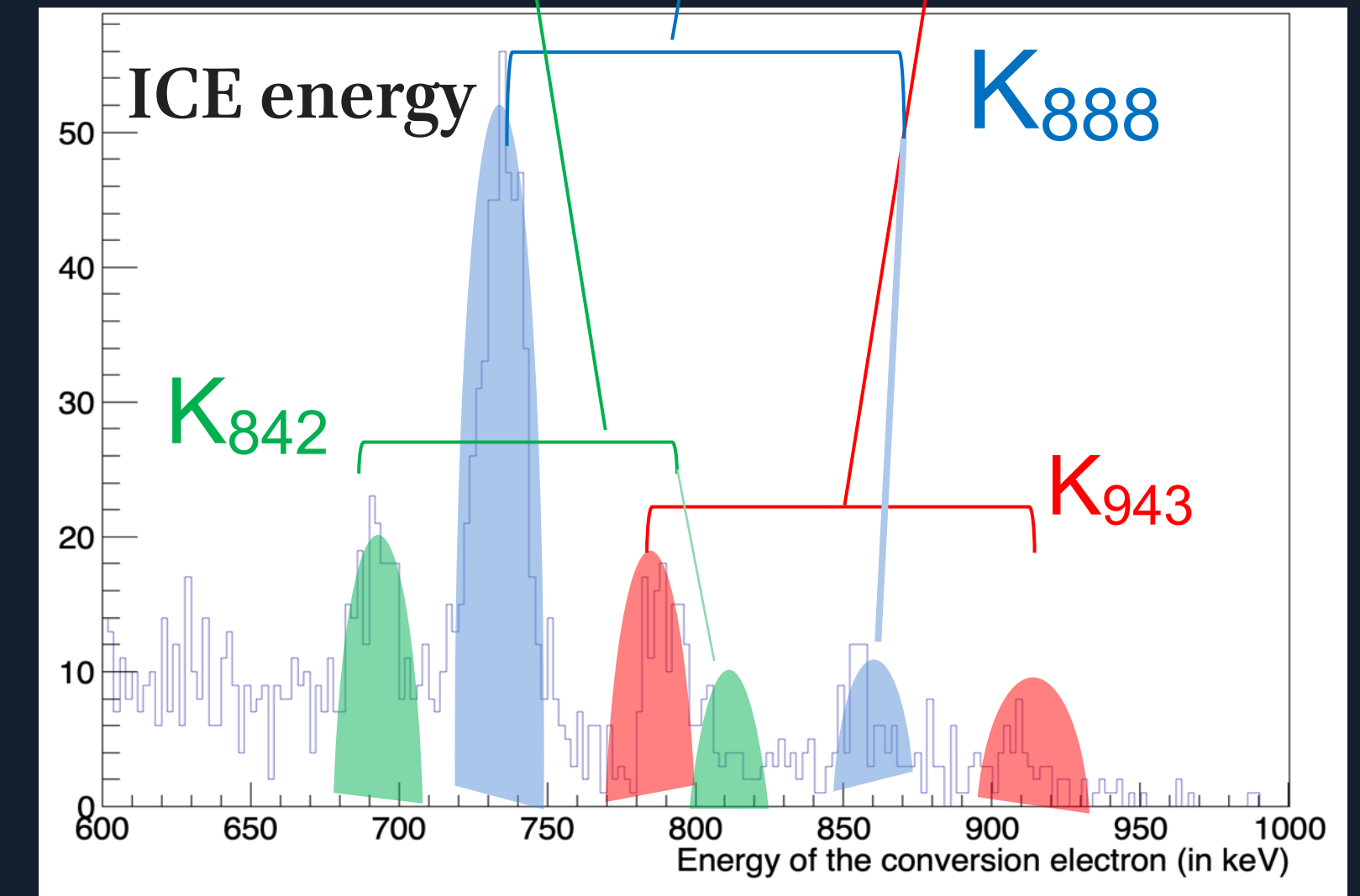
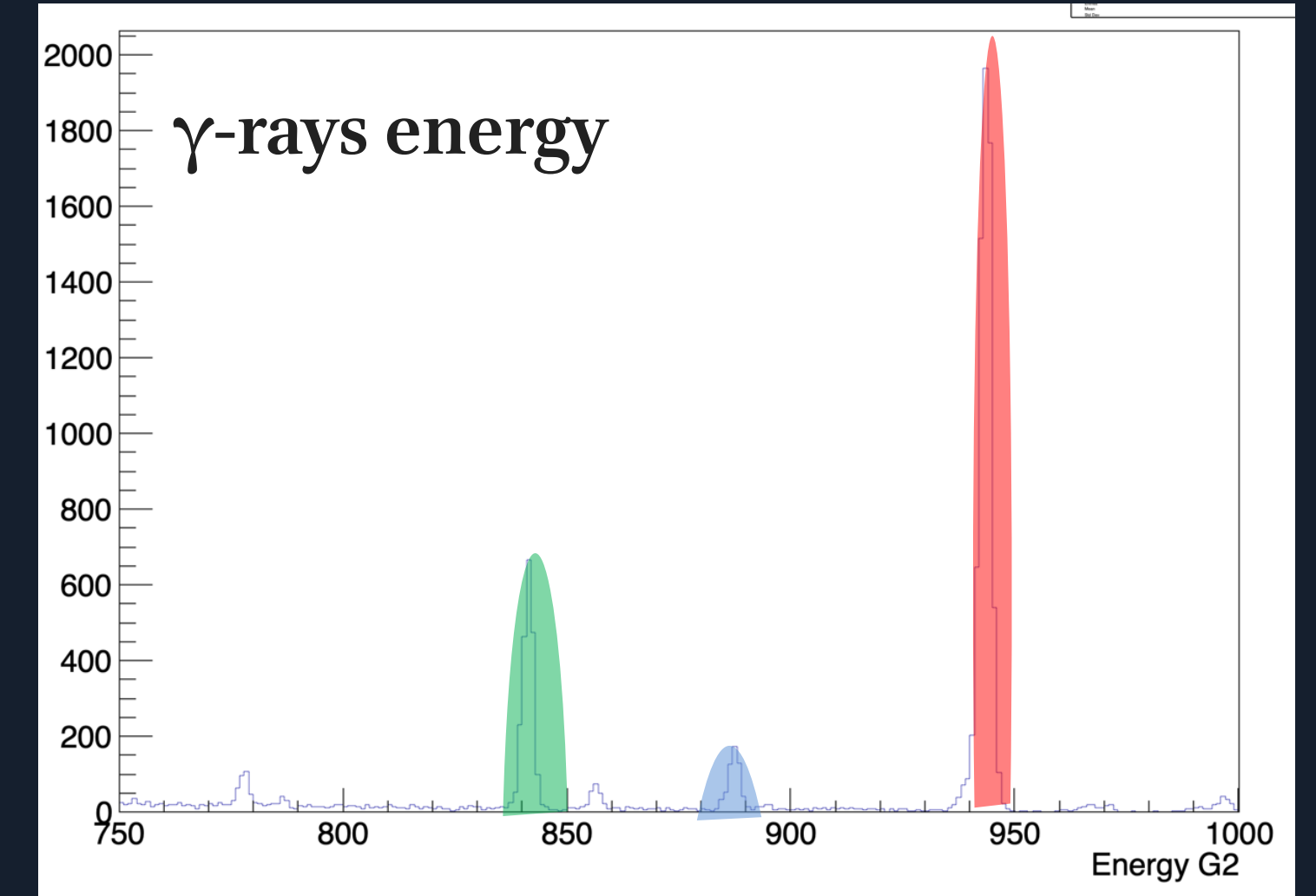
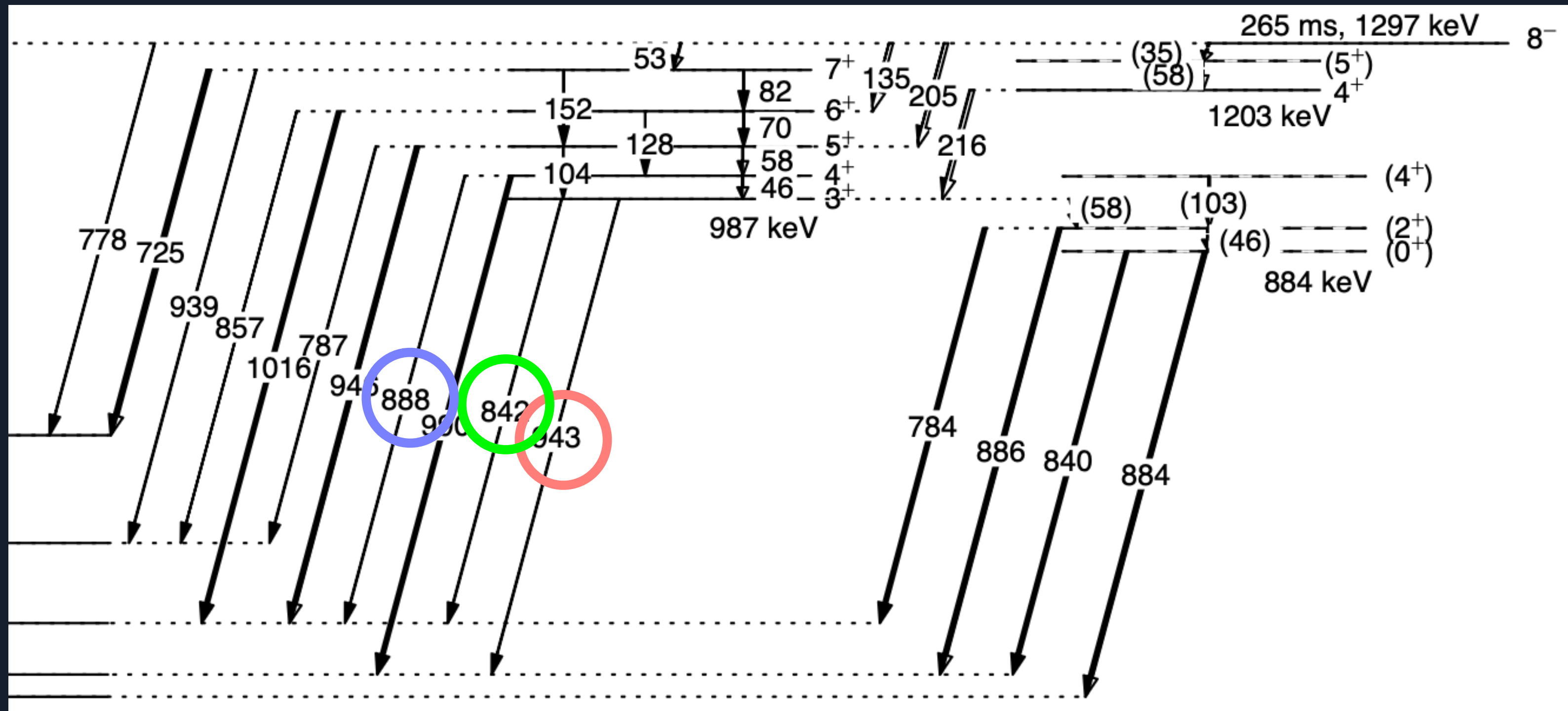
Interpretation of this new level scheme

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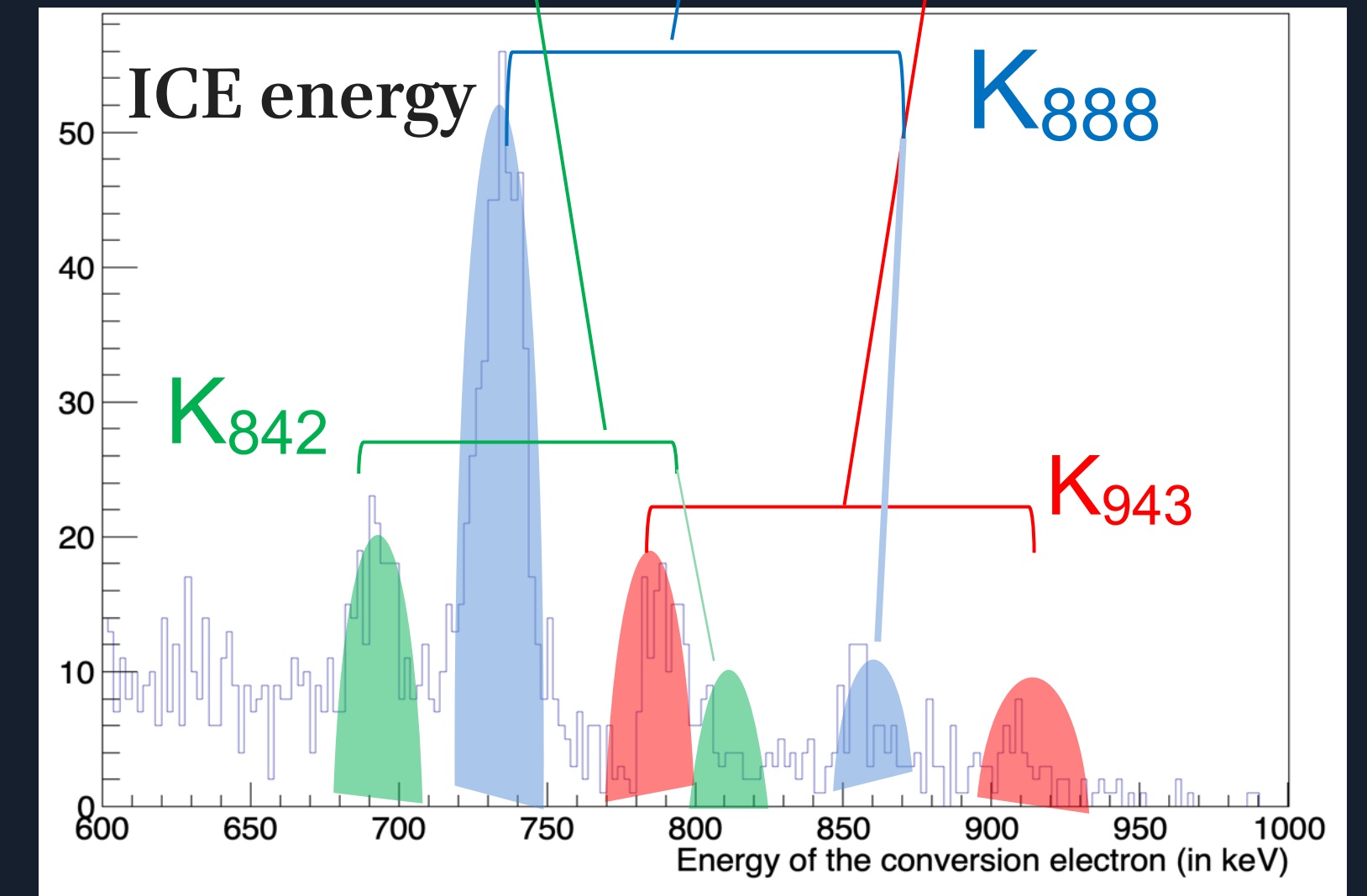
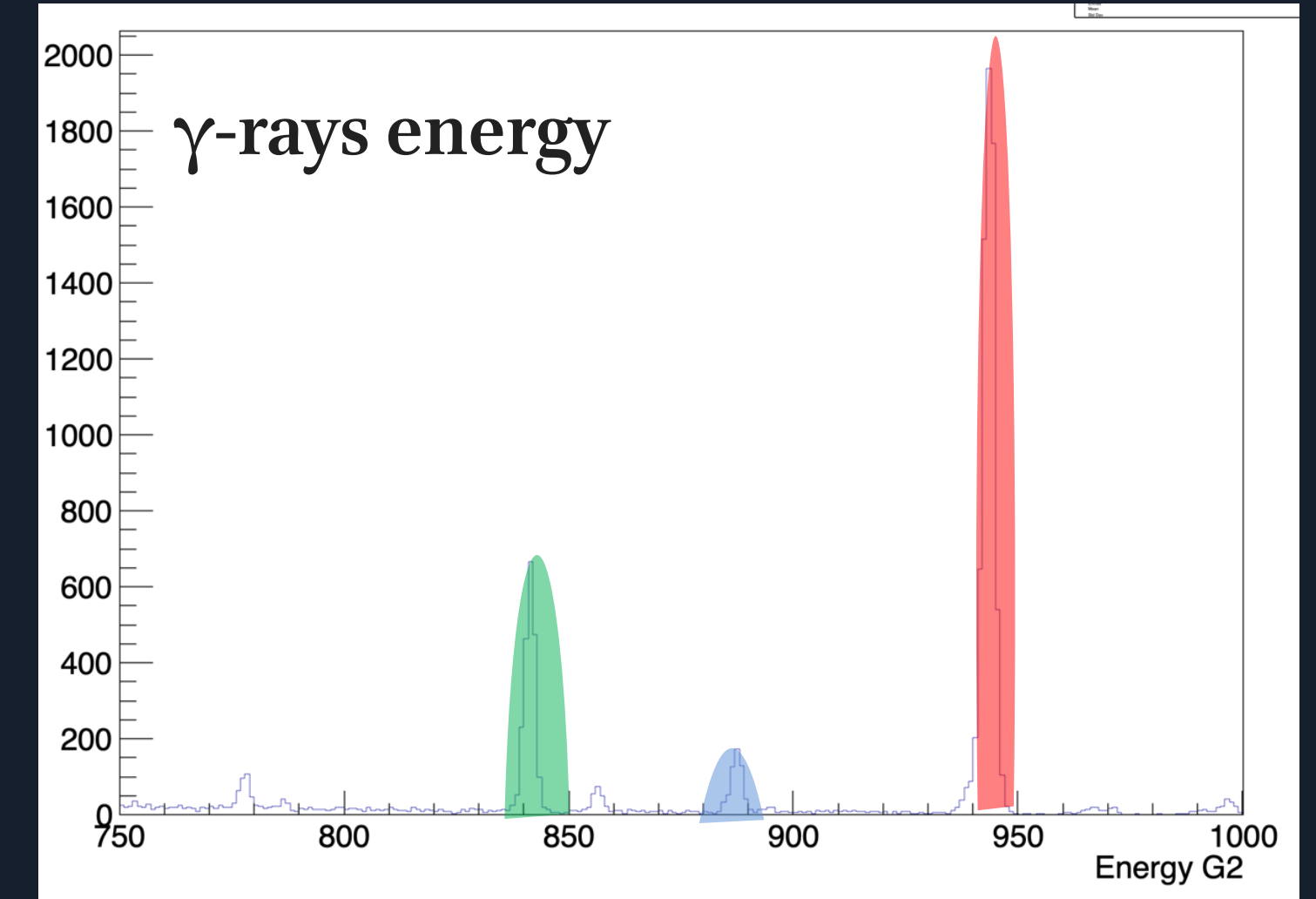
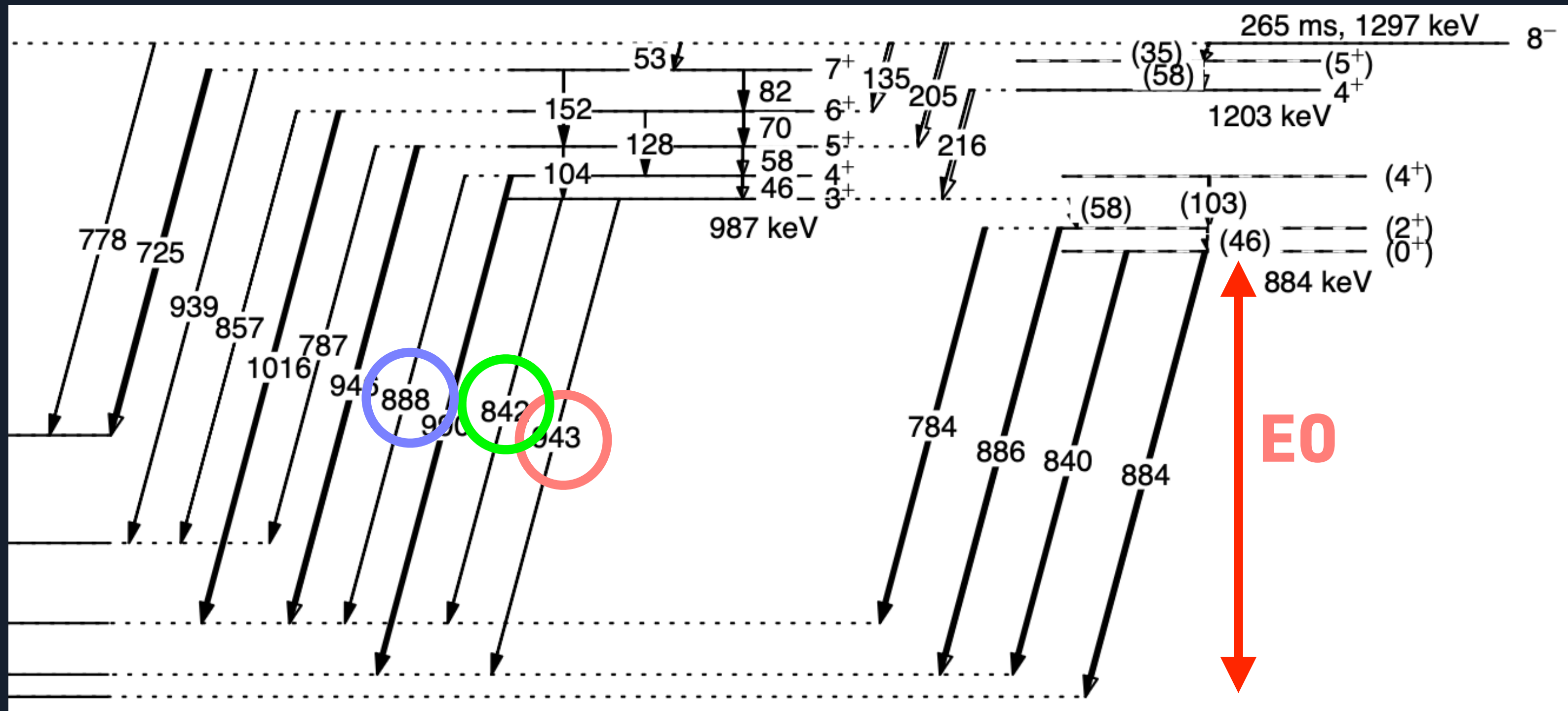
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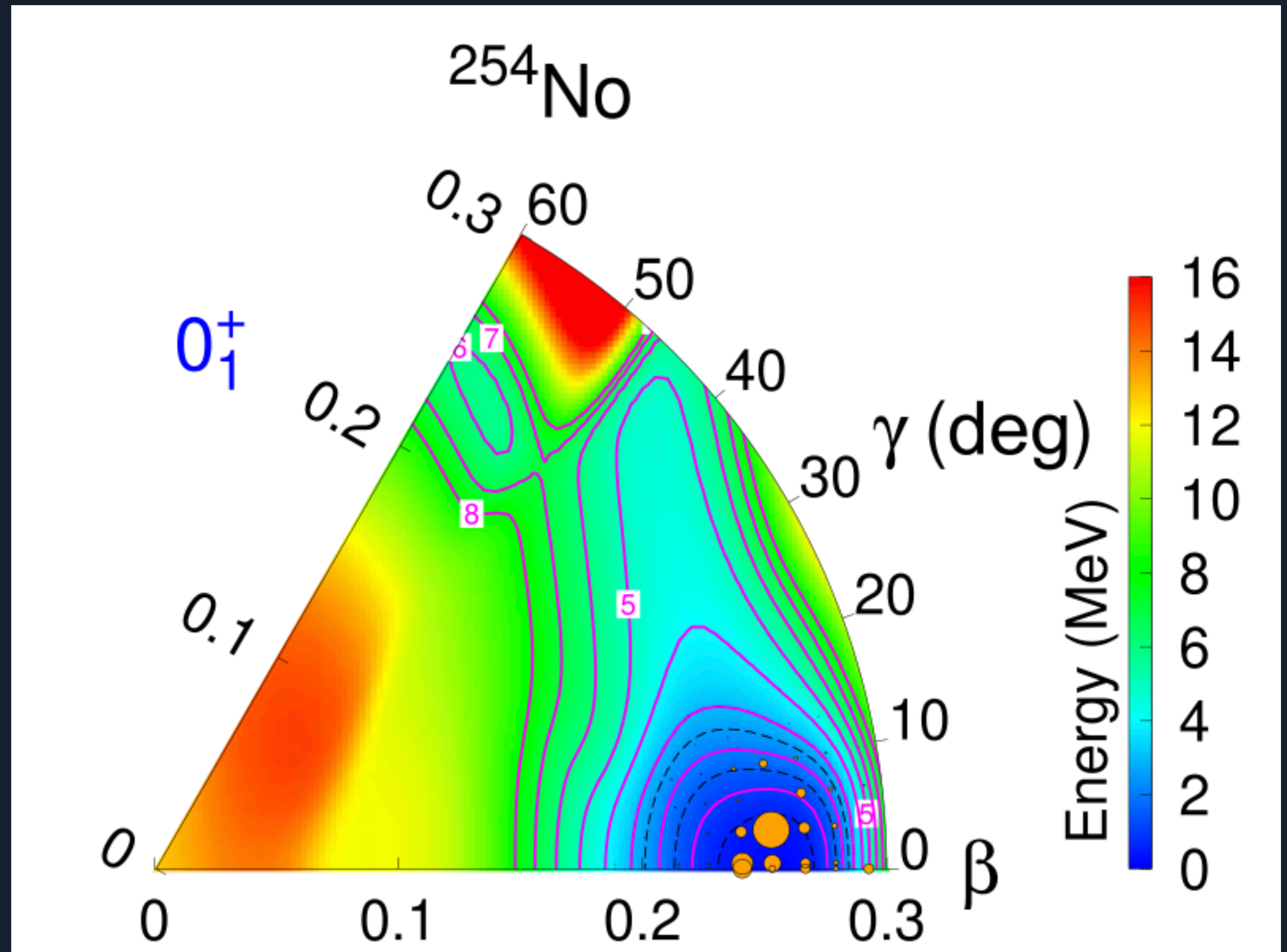


Interpretation of this new level scheme

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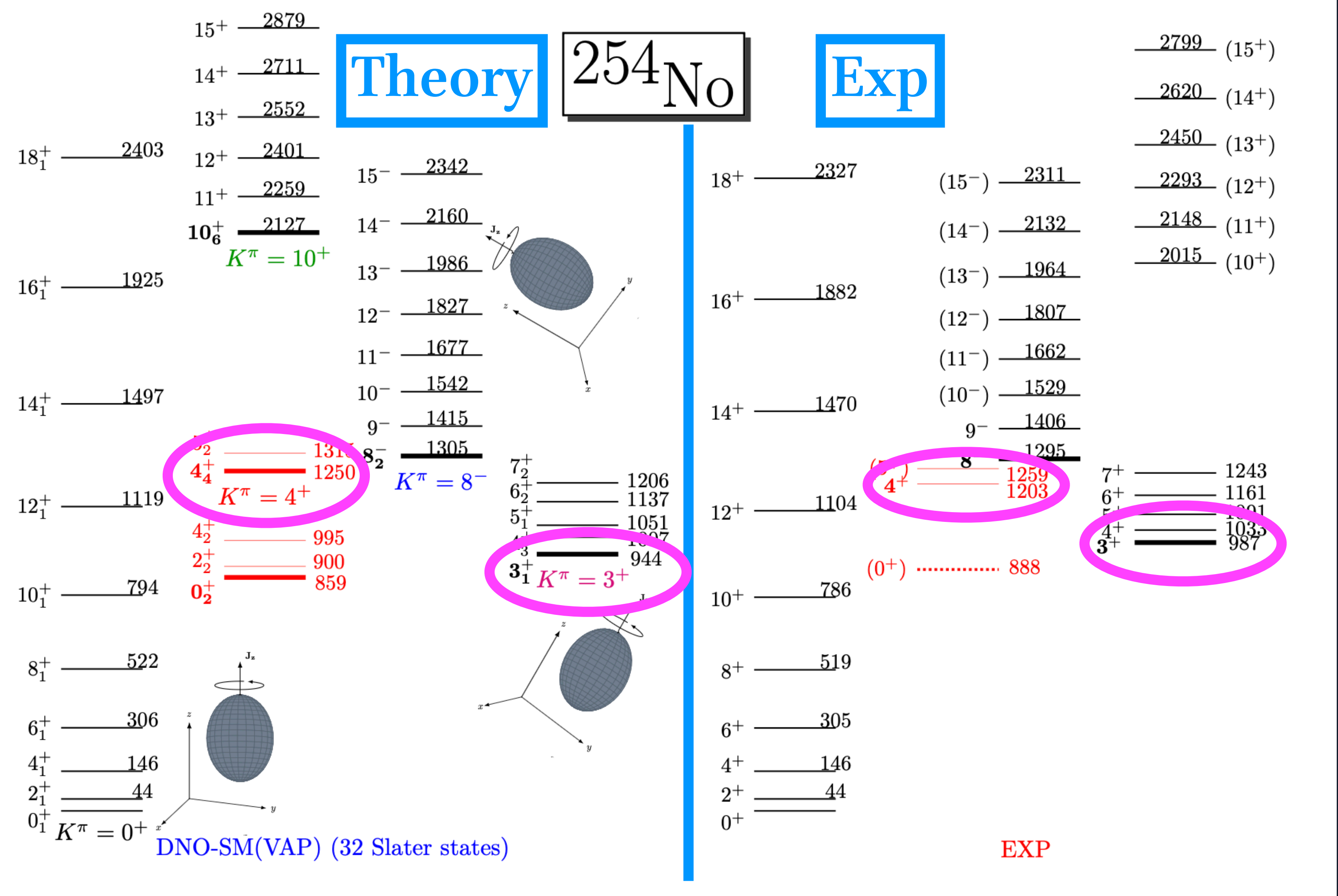


Potentiel energy surface



Comparison experiment - Discrete Non-Orthogonal Shell Model (DNO-SM) (D. Dao & F. Nowacki)

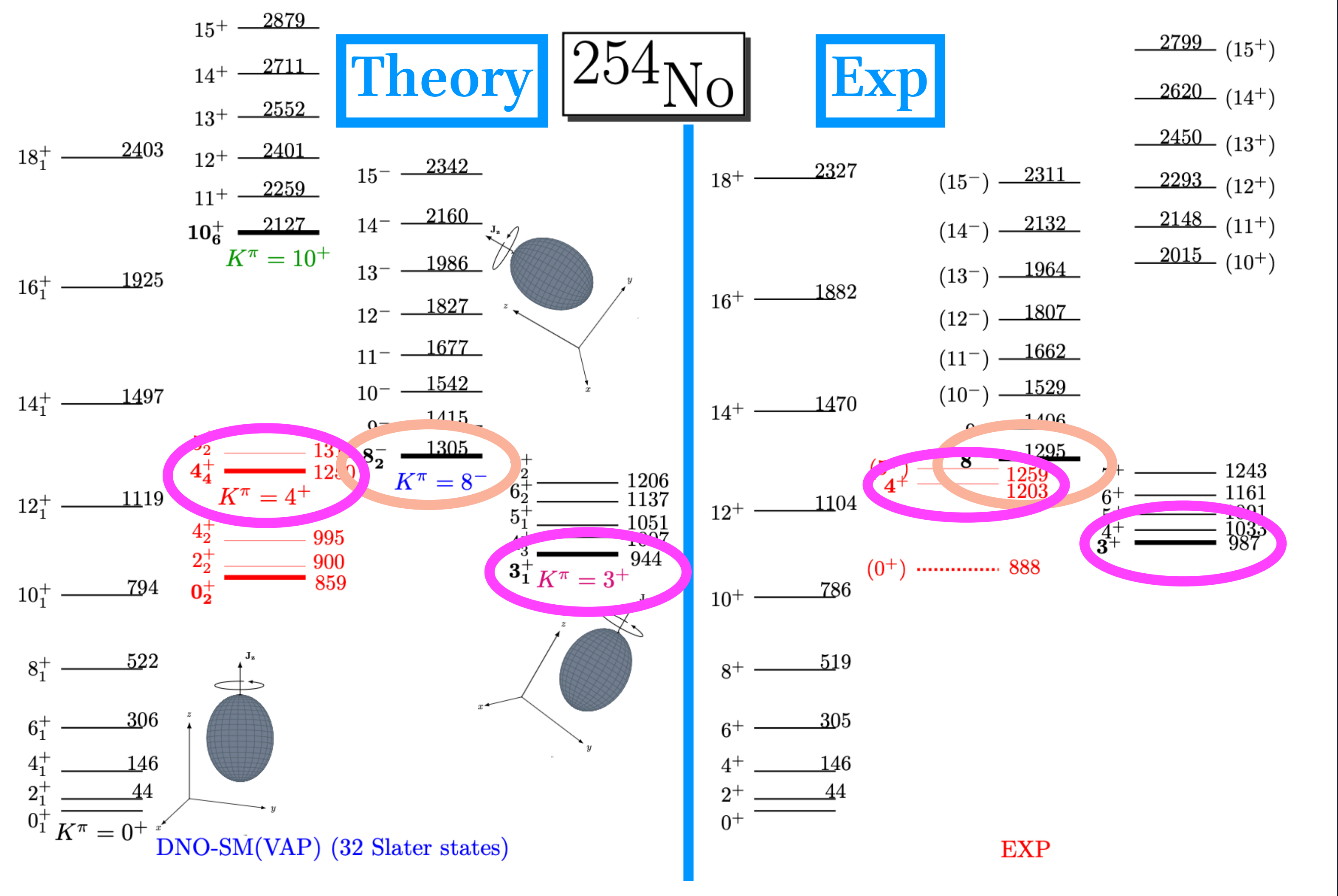
3+ and 4+ states interpreting as a GM splitting = proton excitation involving the 7/2-[514] and 1/2-[521] orbitals



Comparison experiment - Discrete Non-Orthogonal Shell Model (DNO-SM) (D. Dao & F. Nowacki)

3+ and 4+ states interpreting as a GM splitting = proton excitation involving the 7/2-[514] and 1/2-[521] orbitals

8- long-lived isomer interpreted as a neutron-neutron coupling [vg9/2 ⊗ vj15/2]



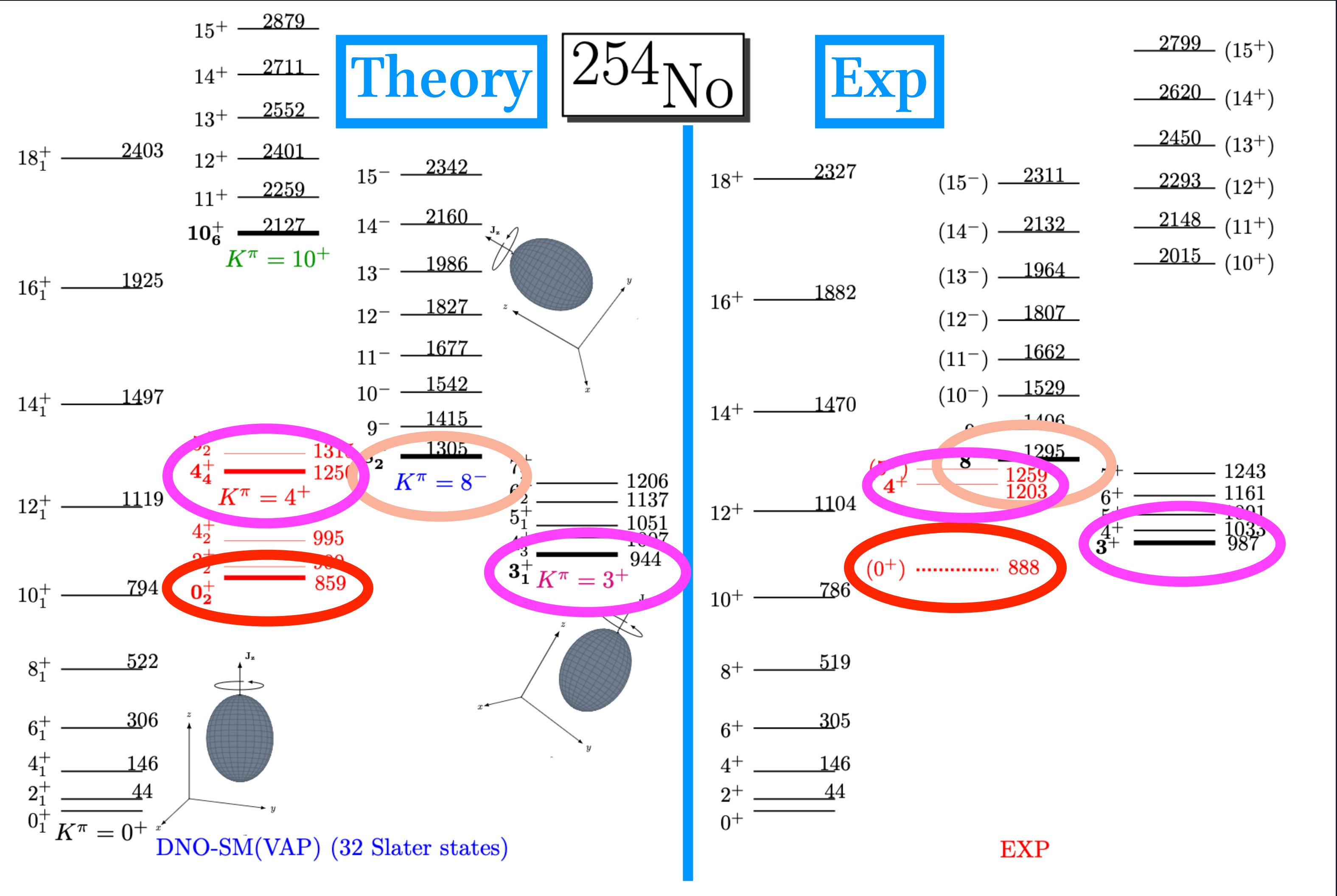
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3+ and 4+ states interpreting as a GM splitting = proton excitation involving the 7/2-[514] and 1/2-[521] orbitals

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Existence of a second 0^+_2 state

Excellent agreement



254No152 : 2 recent publications

PHYSICAL REVIEW C 114, 024324 (2026)

First experimental measurement of spin splitting and evidence for a second 0+ state in 254No152

M. Forge¹, O. Dorvaux¹, A. Lopez-Martens², K. Kessaci¹, B. J. P. Gall¹, K. Hauschild², D. D. Dao¹, F. Nowacki¹, S. Péru³, Z. Asfari¹, R. Chakma^{2,*}, A. V. Yeremin^{4,5}, M. L. Chelnokov⁴, V. I. Chepigin⁴, A. V. Isaev^{4,5}, I. N. Izosimov⁴, D. Katrsev⁴, A. A. Kuznetsova⁴, O. N. Malyshev^{4,5}, R. Mukhin⁴, A. G. Popeko^{4,5}, Yu. A. Popov⁴, B. Saylaubekov⁴, A. I. Svirikhin^{4,5}, E. A. Sokol⁴, M. S. Tezekbayeva⁴, N. I. Zamyatin⁶ and J. Piot⁷

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Letter

First complete shell-model description of low-lying spectroscopy in 254No

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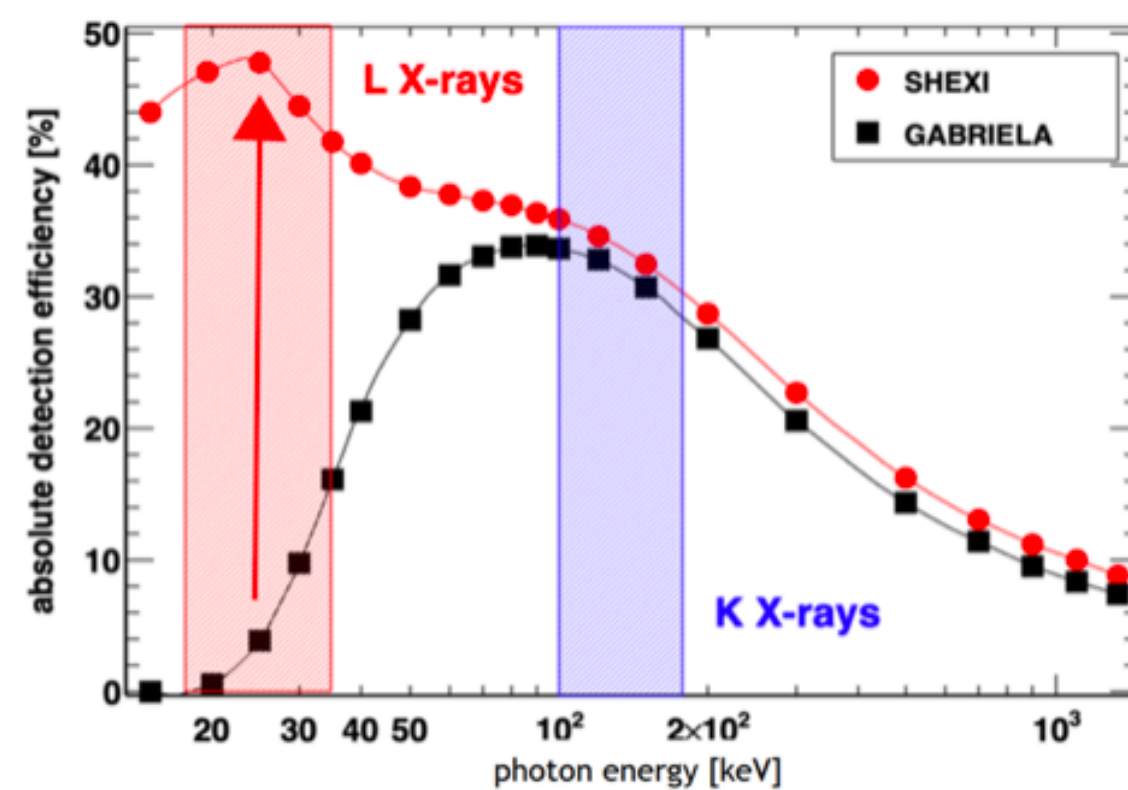
This paper reports on the first complete shell-model description of low-lying structures of ²⁵⁴No. Employing the Kuo-Herling effective interaction, the calculations are performed using the discrete nonorthogonal shell model recently implemented within the angular-momentum variation after projection applied on nonaxial wave functions. Our calculations show a striking agreement with the experimentally known spectroscopy: the yrast band, the 8⁻ (*K* = 8), 3⁺ (*K* = 3), and 10⁺ (*K* = 10) isomers together with associated *K* bands. We reproduce the recently measured Gallagher-Moszkowski splitting between the 3⁺ (*K* = 3) and 4⁺ (*K* = 4) bandheads. We predict the appearance of a second 0⁺ state in excellent agreement with recent observations. In addition, we systematically examine the ground state spectra and the dipole and spectroscopic quadrupole moments of even-even, odd-even, odd-odd nuclei from *A* = 251 to *A* = 256, which are favorably reproduced. The present description of ²⁵⁴No shows the ability of the shell model framework to describe the low-lying properties for such an exotic nucleus at the frontier of modern experimental nuclear physics research.

DOI: 10.1103/5jh8-tdc6

Perspectives

See K. Hauschild's talk for SHEXI

- **SHEXI** project :
- **S**uper **H**heavy **E**lements **X**-Ray **I**dentification for an unambiguous Identification



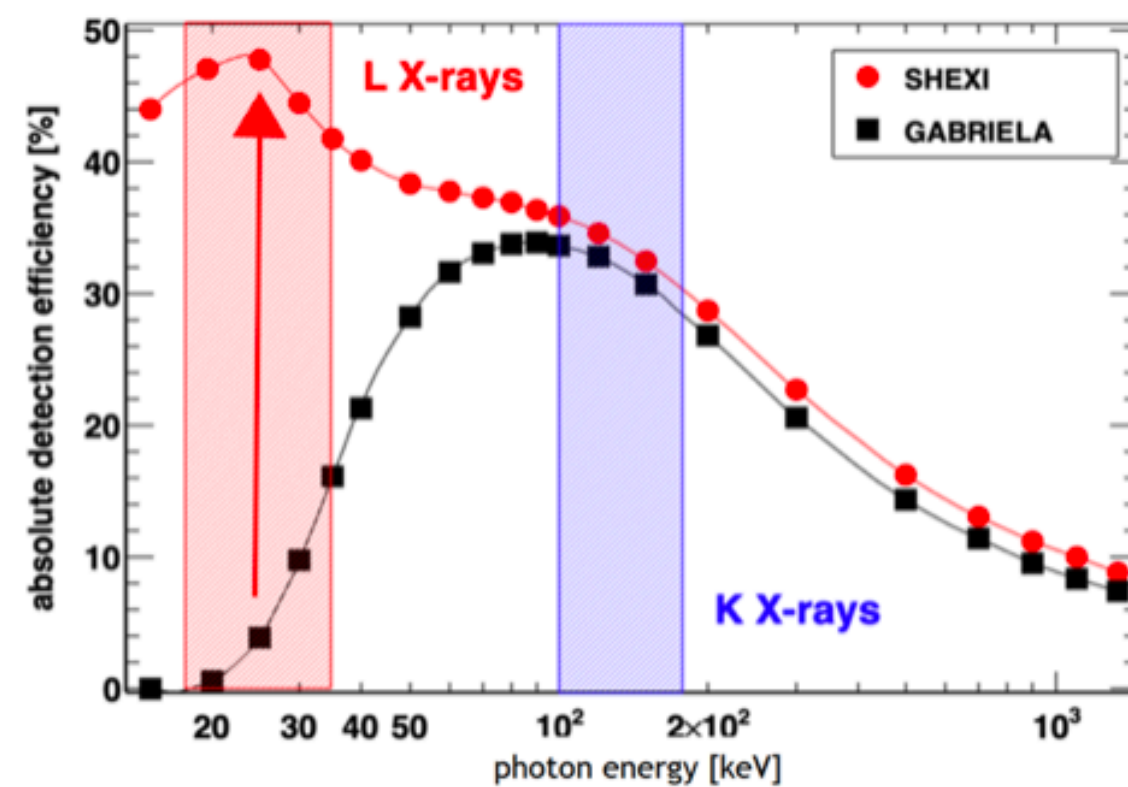
Karl HAUSCHILD

- Beam and target developments (^{48}Ca , ^{51}V , ^{54}Cr ...)
- B. Gall - MIVOC and/or induction oven

Perspectives

See K. Hauschild's talk for SHEXI

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Karl HAUSCHILD

- Beam and target developments (48Ca, 51V, 54Cr...)
- B. Gall - MIVOC and/or induction oven

Possible experiments campaign with
SIRIUS @ JYFL

Start of S₃ @ GANIL/SPIRAL₂.

Coupled with SIRIUS focal plane :
Commissioning planned in 2028

Thank you for your attention

And thanks to all collaborators



**O. Dorvaux, M. Forge, K. Kessaci, D. Dao, A. Lopez-Martens,
B. J. P. Gall, K. Hauschild, Z. Asfari, R. Chakma, F. Nowacki**

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

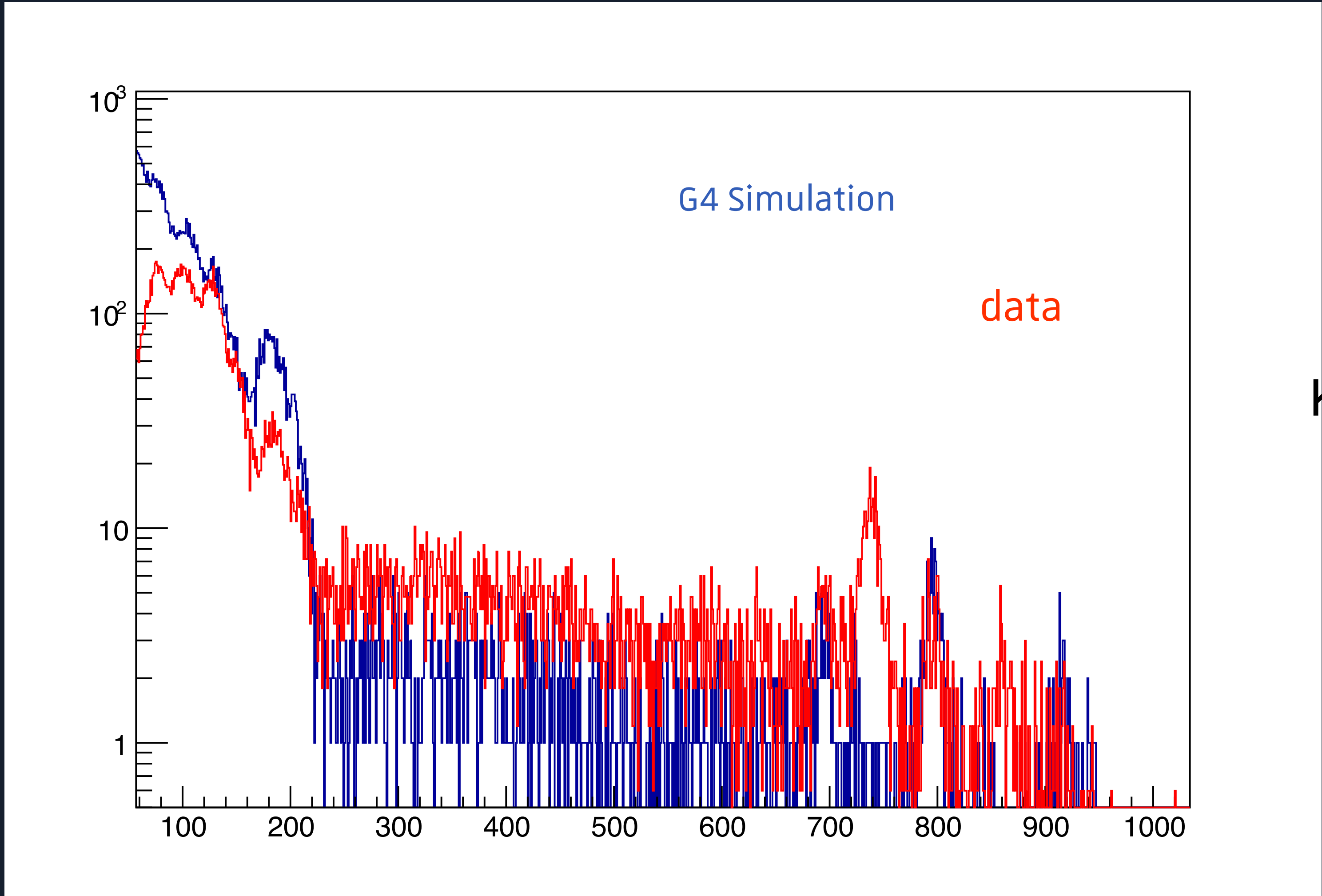
D. Ackermann, J. Piot



Backup slides

Geant 4 simulations of ICE spectra

Geant 4 simulations of ICE spectra



K₈₈₇

Orbitals occupation from DNO-SM calculations

Proton orbits	$0h_{9/2}$	$0i_{13/2}$	$1f_{7/2}$	$1f_{5/2}$	$2p_{3/2}$	$2p_{1/2}$	
0_1^+	6.03	7.75	3.43	1.49	0.77	0.52	
0_2^+	7.08	7.91	3.23	0.89	0.69	0.21	
$3_1^+(K=3)$	6.47	7.98	3.34	1.15	0.72	0.34	
$4_4^+(K=4)$	6.50	7.83	3.41	1.18	0.72	0.36	
$8_2^-(K=8)$	6.48	7.90	3.36	1.19	0.70	0.37	
$10_6^+(K=10)$	6.55	7.03	3.48	1.56	0.79	0.58	
Neutron orbits	$0i_{11/2}$	$0j_{15/2}$	$1g_{9/2}$	$1g_{7/2}$	$2d_{5/2}$	$2d_{3/2}$	$3s_{1/2}$
0_1^+	7.30	9.91	5.43	1.00	1.09	0.84	0.43
0_2^+	7.36	9.95	5.45	0.96	1.05	0.80	0.42
$3_1^+(K=3)$	7.32	9.94	5.46	0.97	1.07	0.81	0.42
$4_4^+(K=4)$	7.34	9.79	5.48	1.03	1.11	0.81	0.44
$8_2^-(K=8)$	7.42	9.00	6.30	0.98	1.06	0.81	0.43
$10_6^+(K=10)$	7.23	8.89	5.72	1.40	1.34	0.97	0.45

Table III: Spherical occupancies of the ground state 0_1^+ , the second 0_2^+ , the long and short-lived isomers 8_2^- , 3_1^+ , and the 4_4^+ , 10_6^+ obtained from the DNO-SM(VAP) calculations shown in Fig. 4.