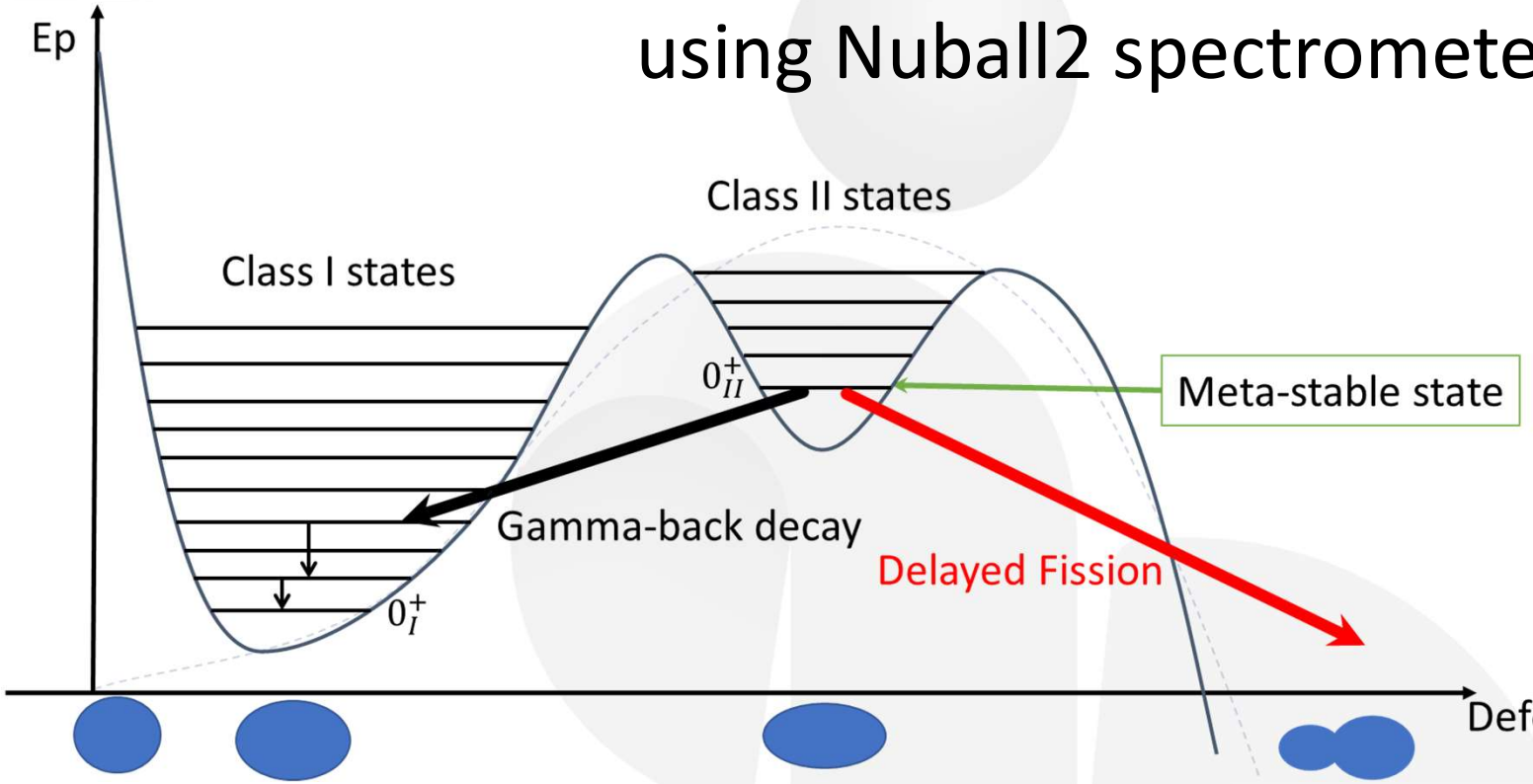
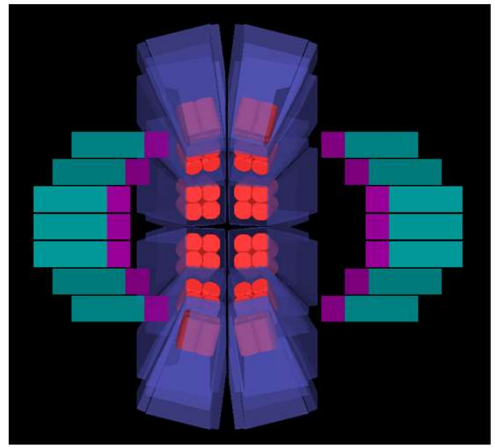
Study of shape isomer back-decay in actinides using Nuball2 spectrometer





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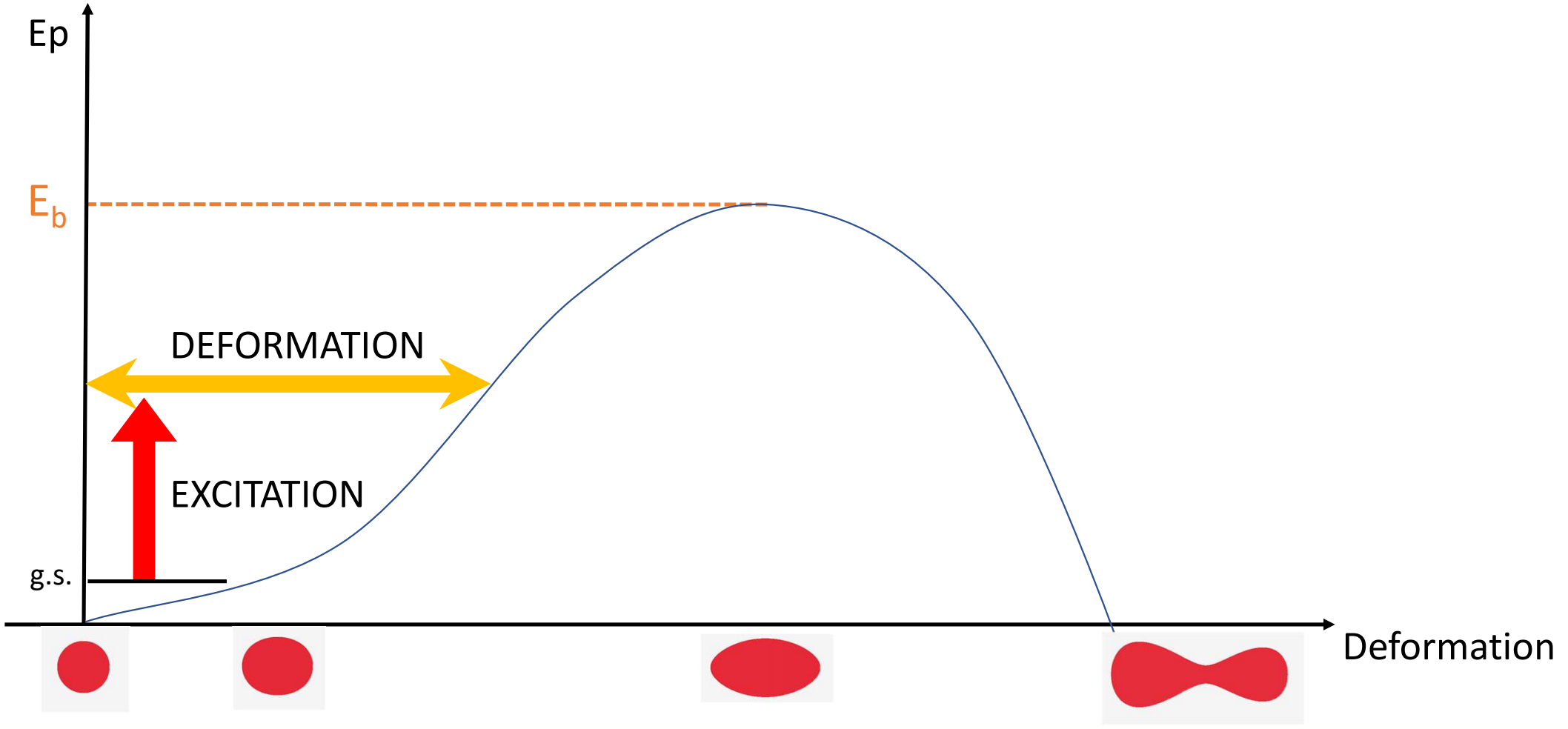

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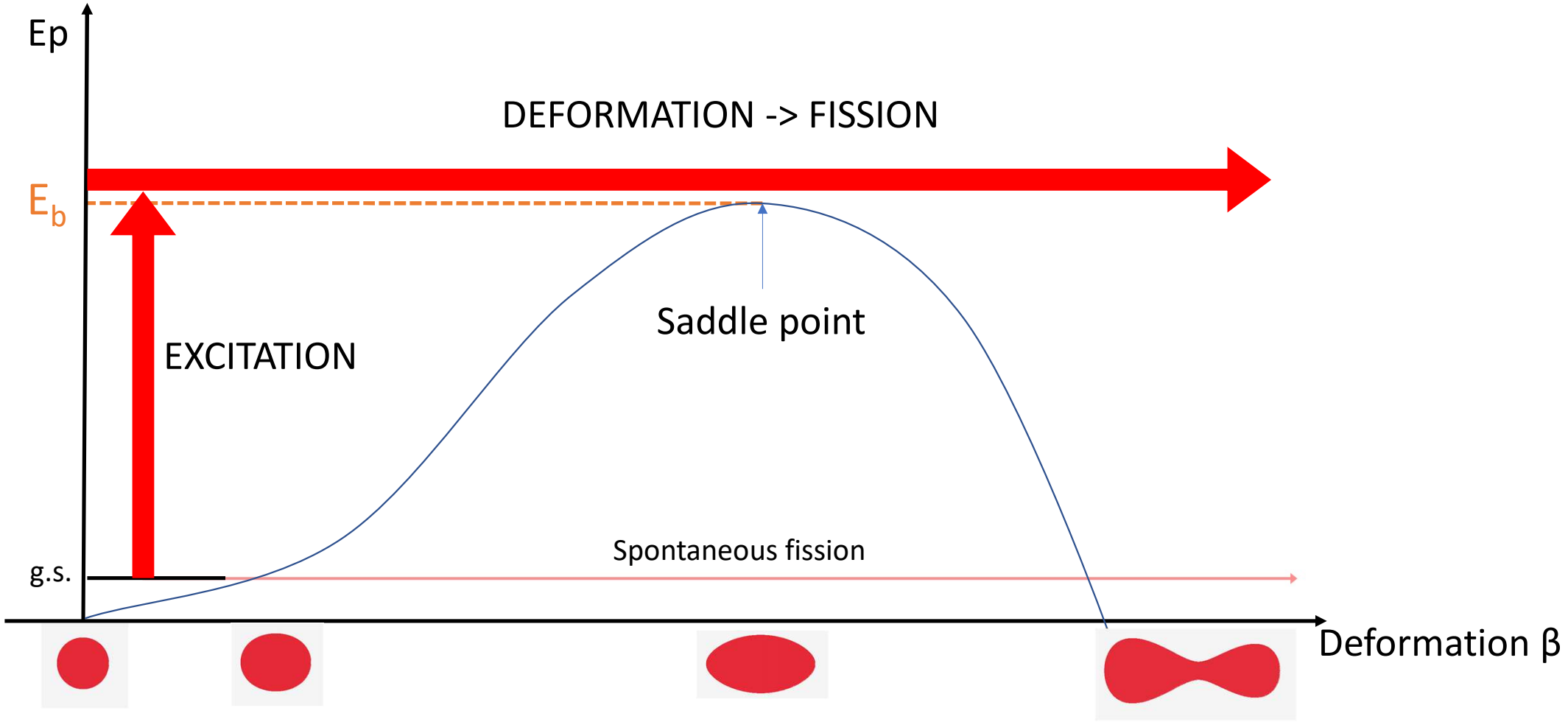

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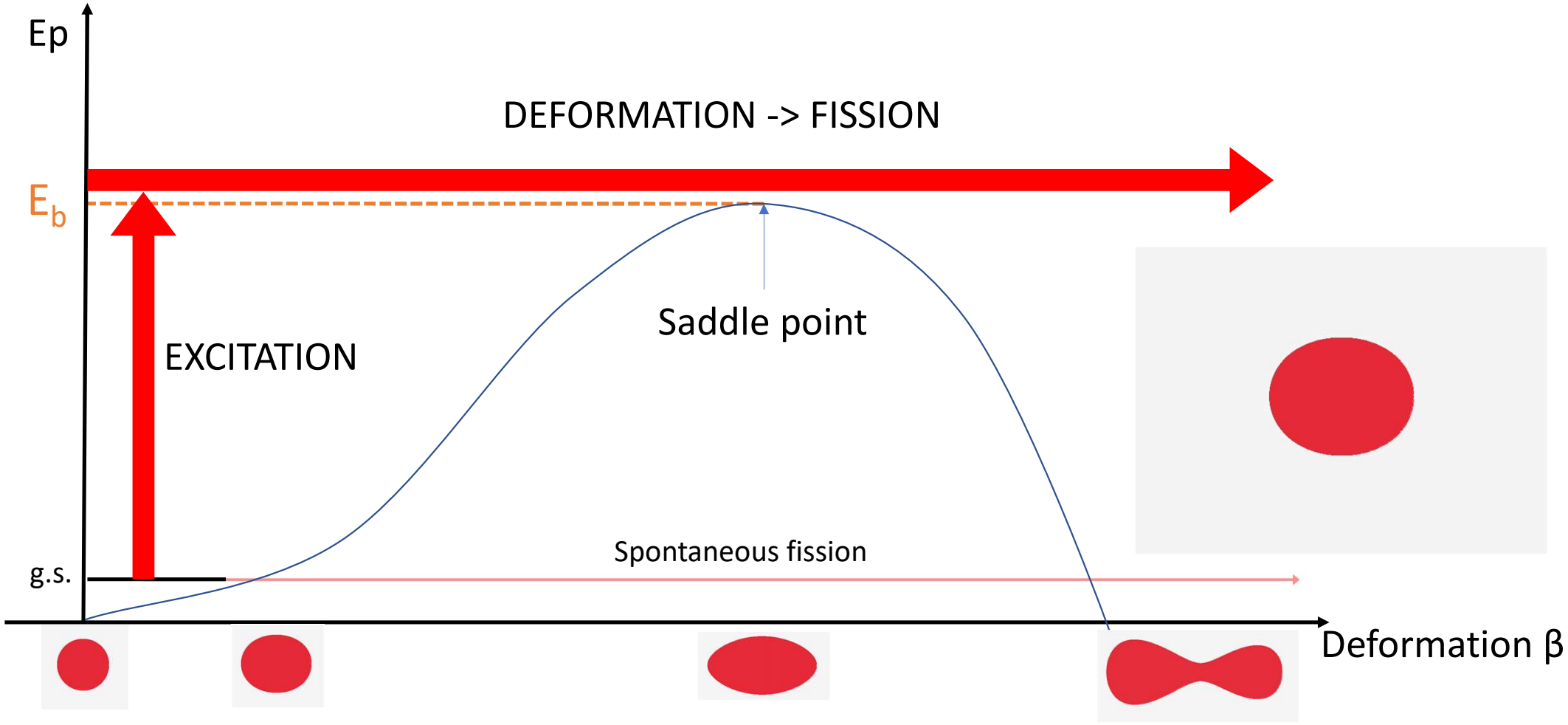
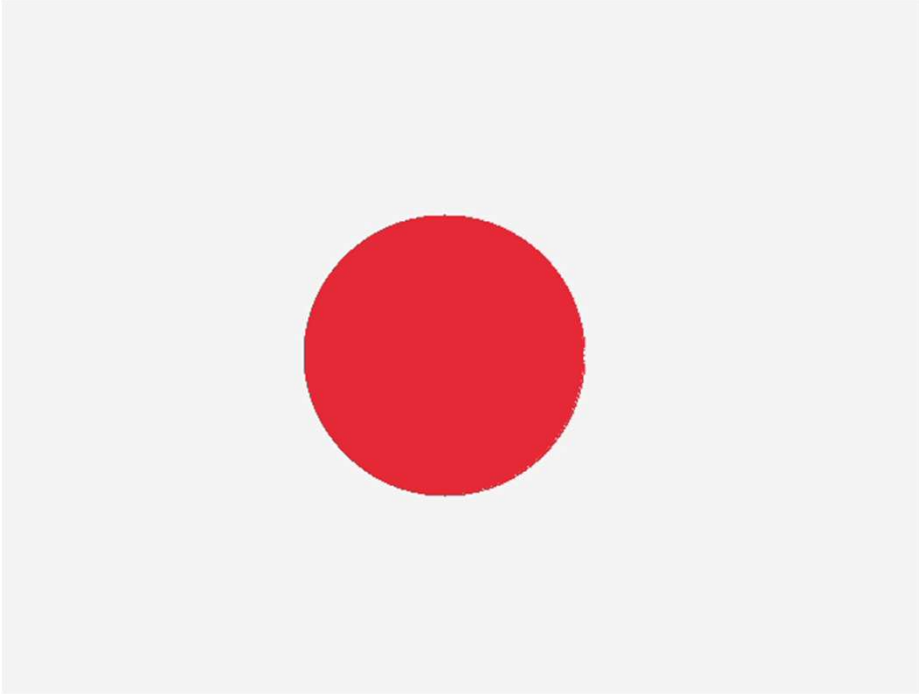


1. Introduction : Fission

- Rare phenomenon : fission isomerism



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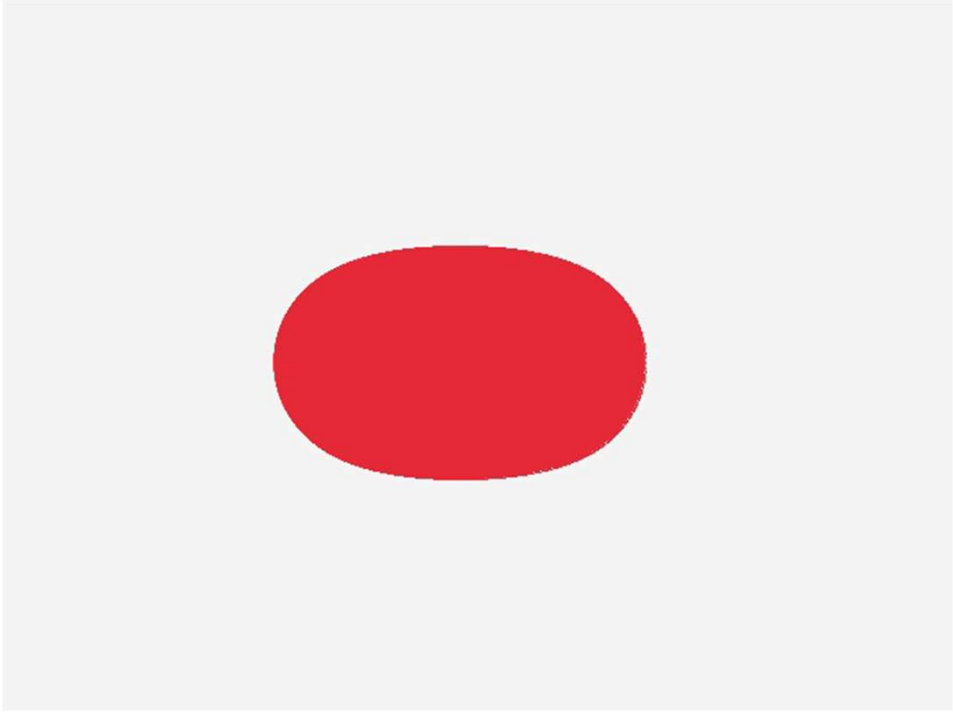
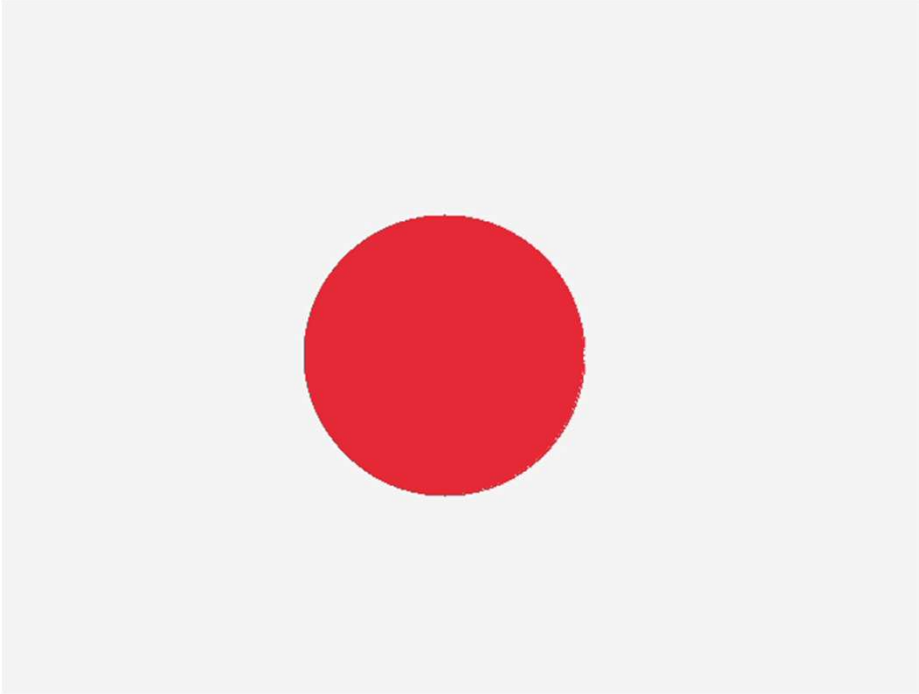


1. Introduction : Fission

- Extremely rare phenomenon : gamma back-decay



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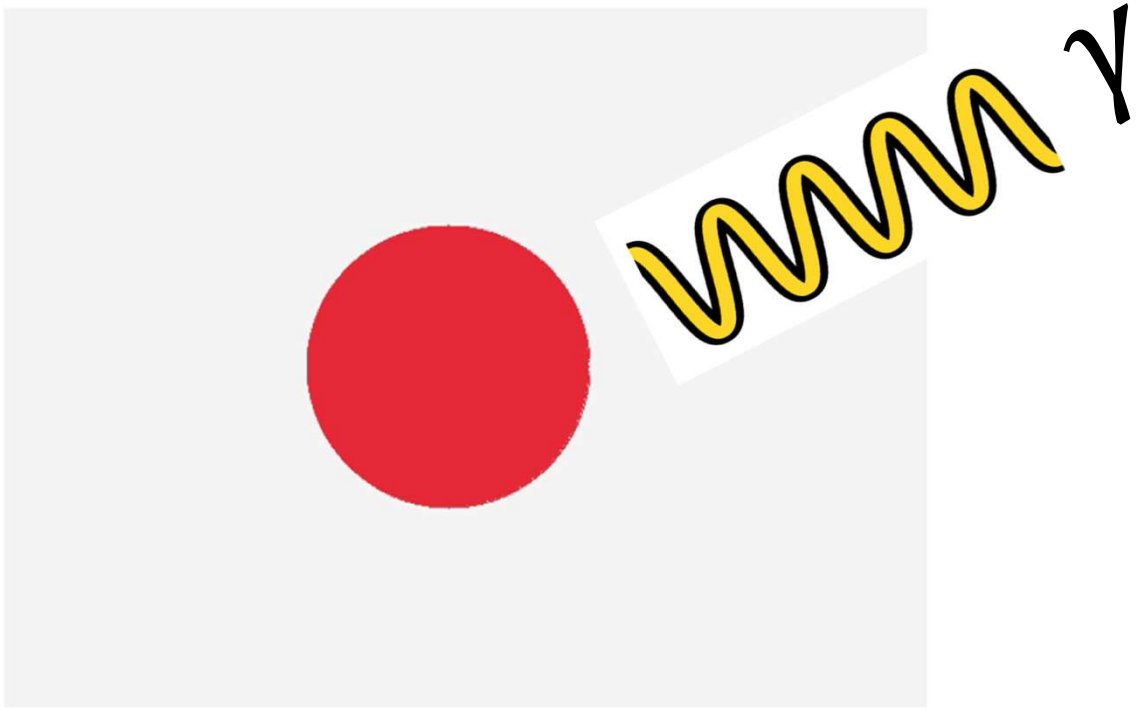
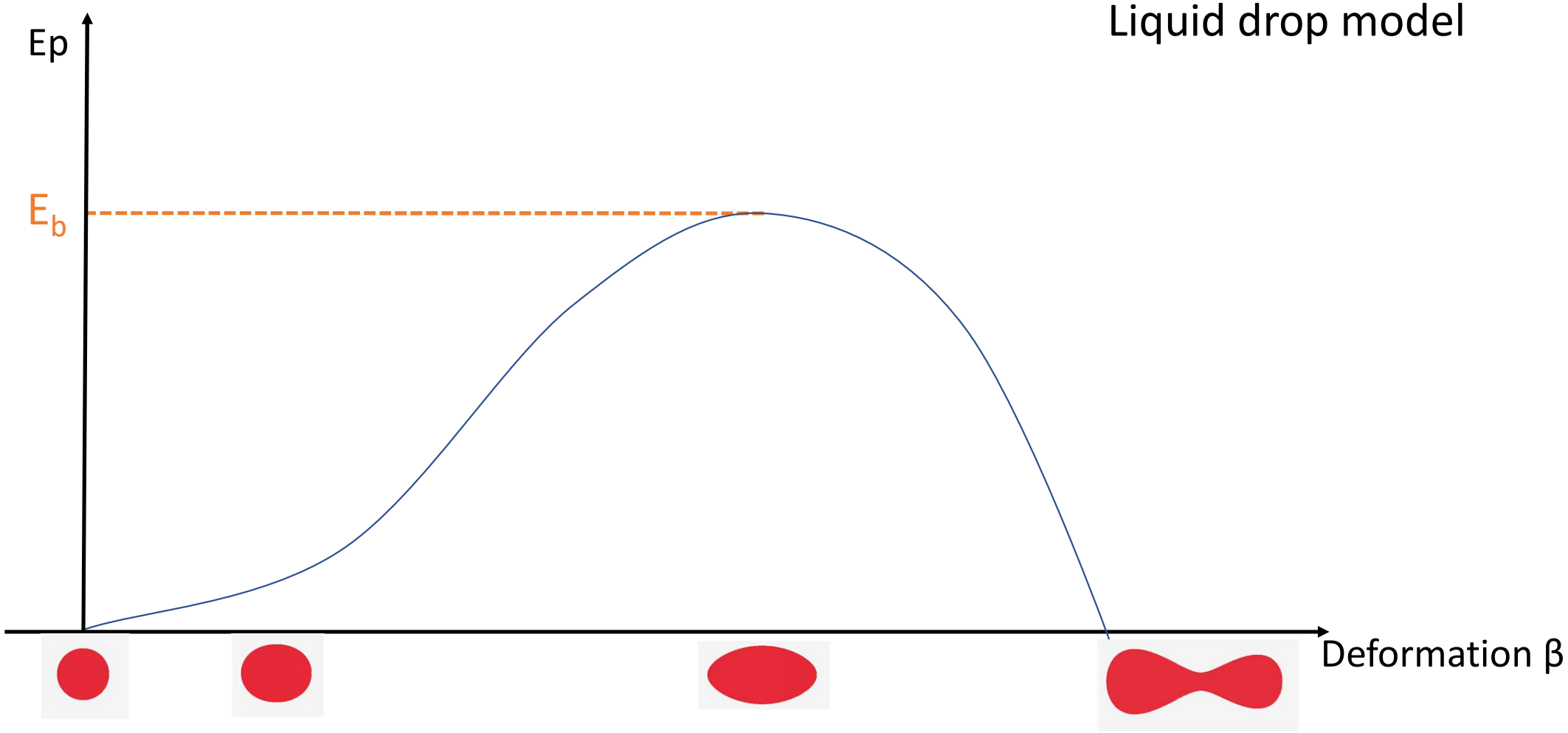


Liquid drop model



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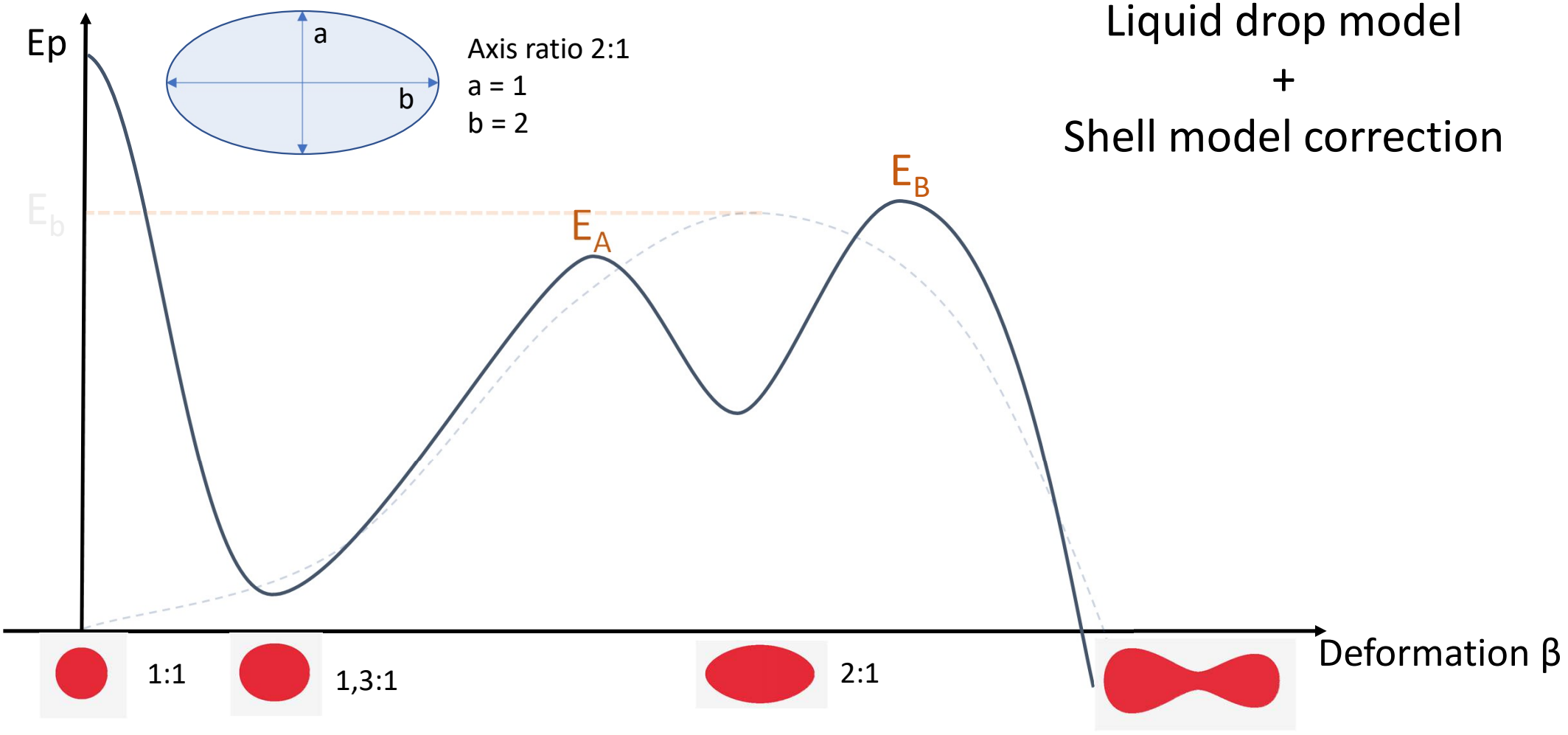

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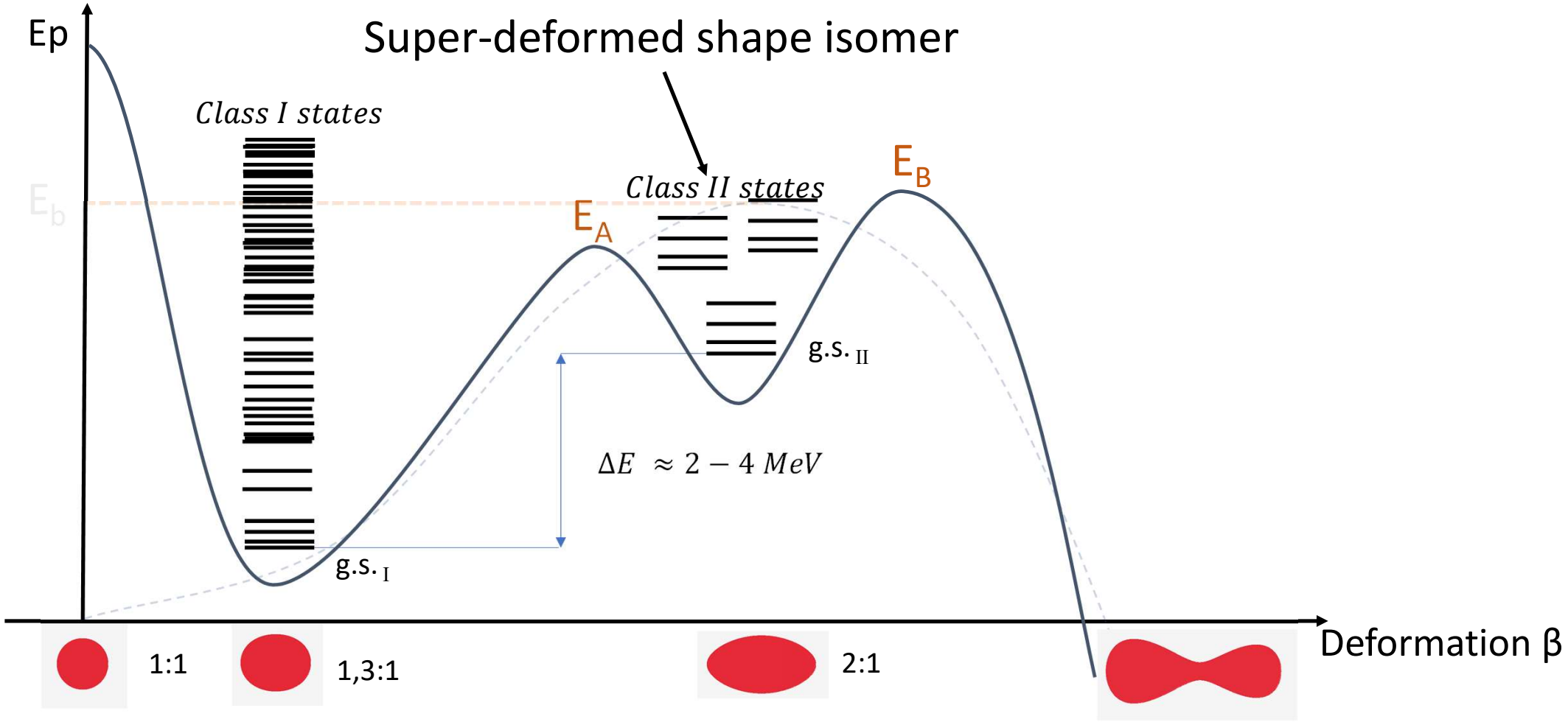
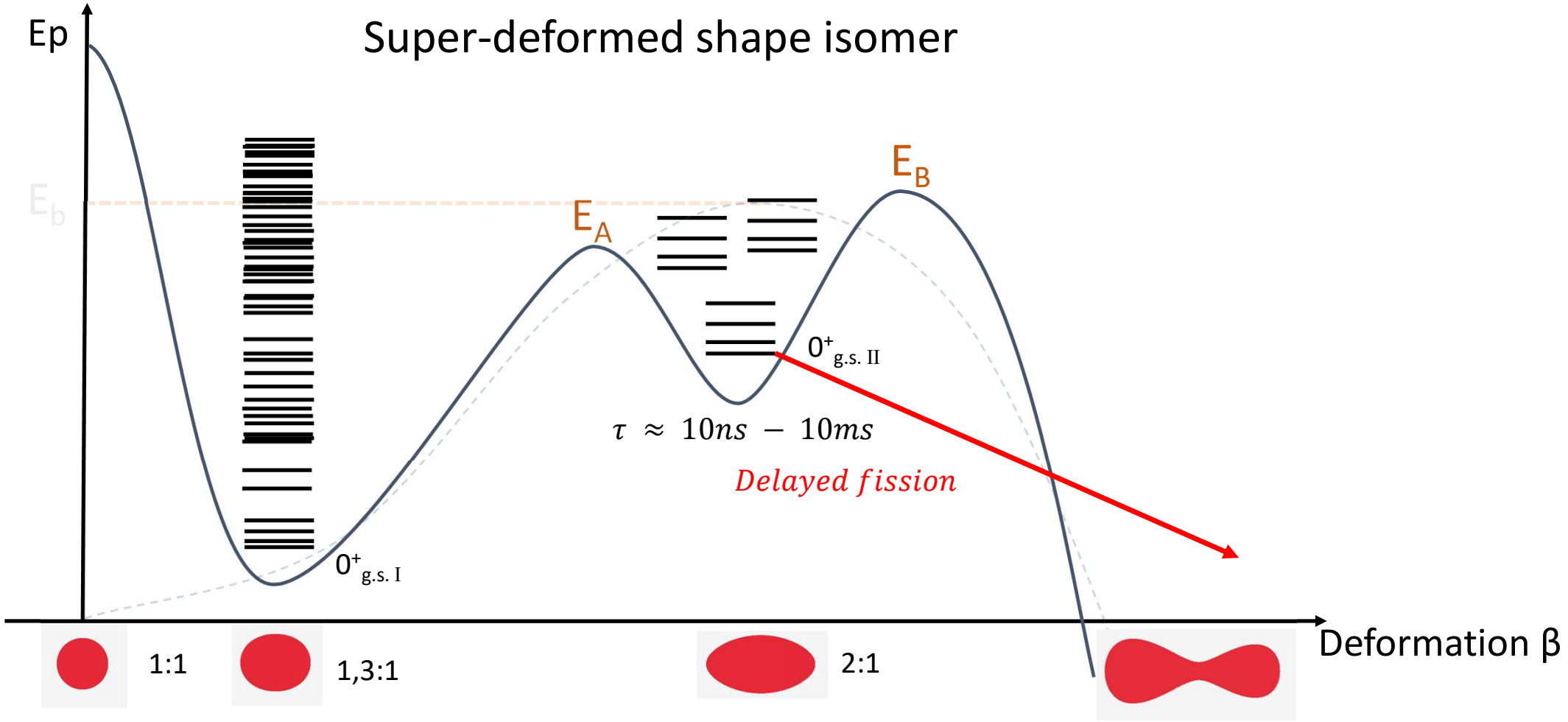
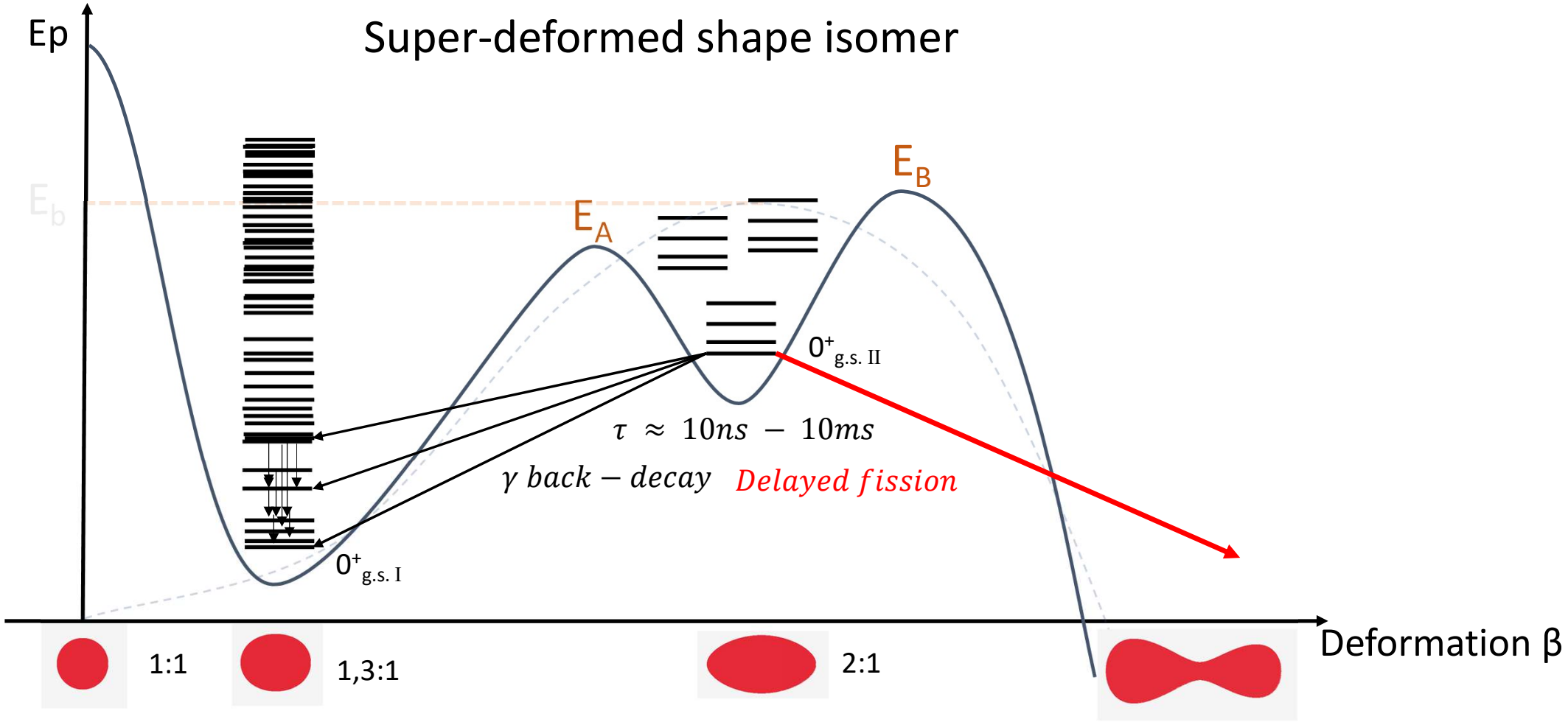
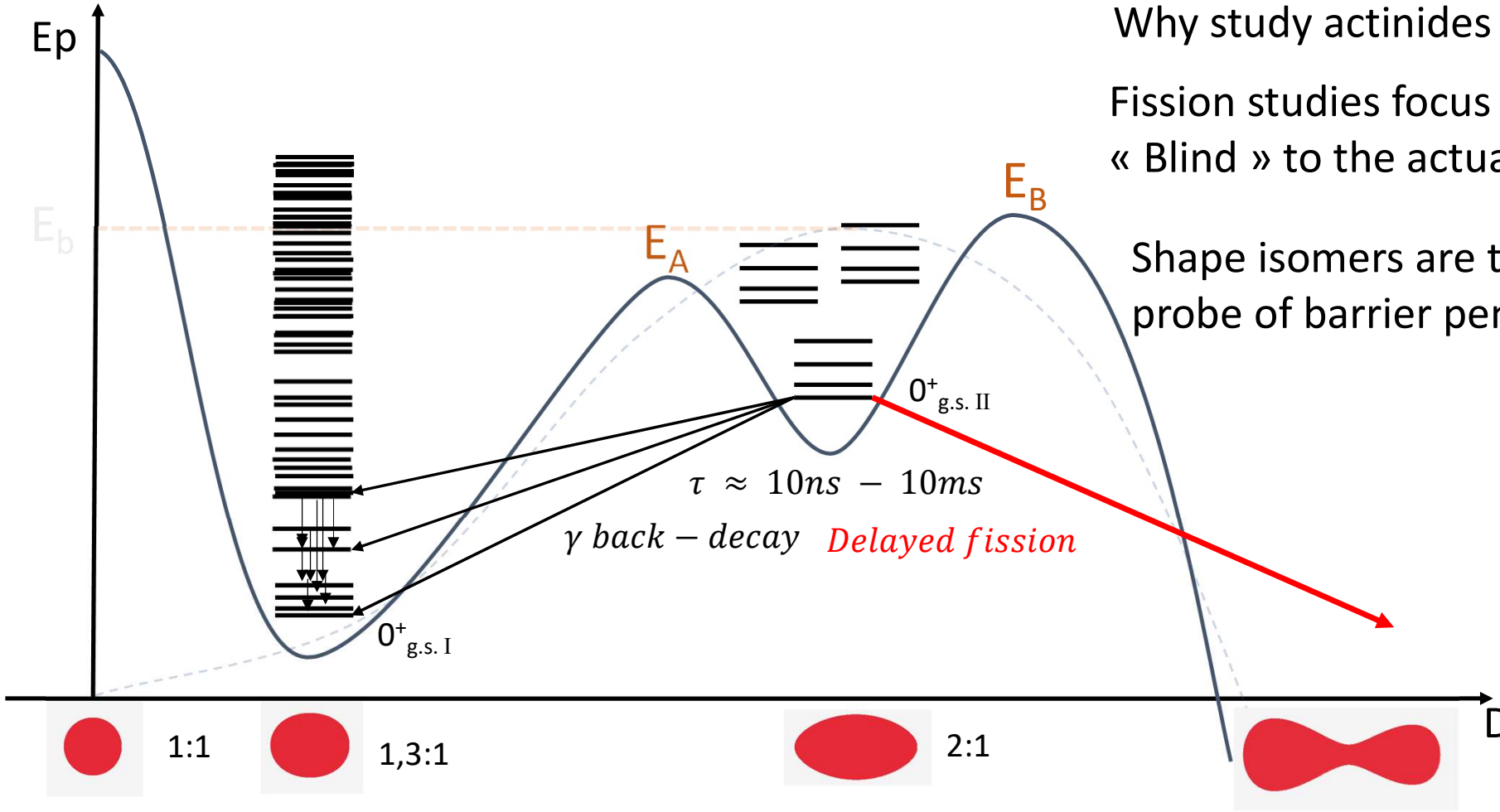



Ep
Super-deformed shape isomer
E_b
E_A
E_B
$0^+_{g.s.\ I}$
$0^+_{g.s.\ II}$
$\tau \approx 10ns - 10ms$
Delayed fission
1:1
1,3:1
2:1
Deformation β


Super-deformed shape isomer
Ep
Eb
EA
EB
0+ g.s. II
0+ g.s. I
τ ≈ 10ns − 10ms
γ back − decay
Delayed fission
1:1
1,3:1
2:1
Deformation β

1. Introduction

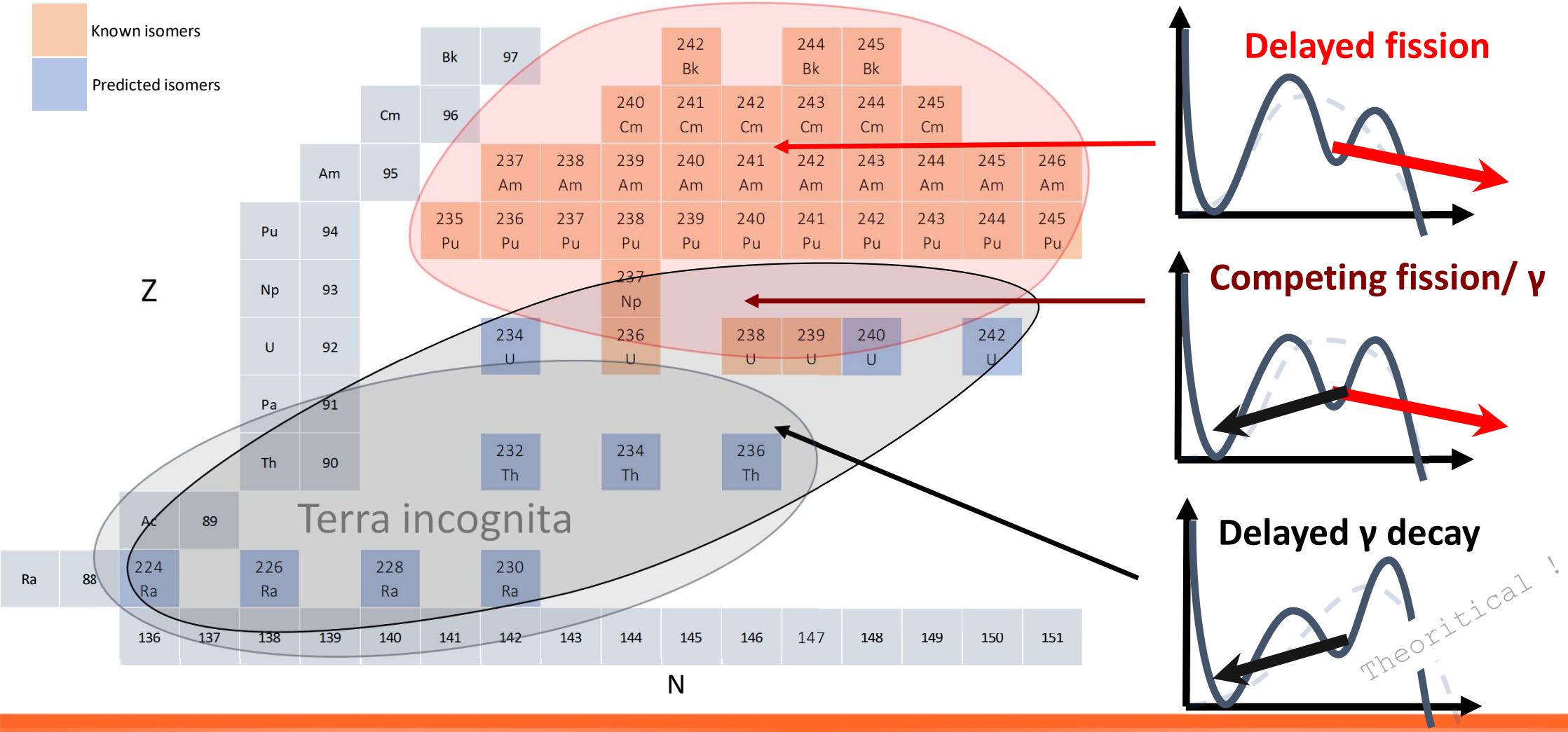


Why study actinides shape isomers ?

Fission studies focus on post-scission
« Blind » to the actual path

Shape isomers are the only direct probe of barrier penetrability

1. Introduction



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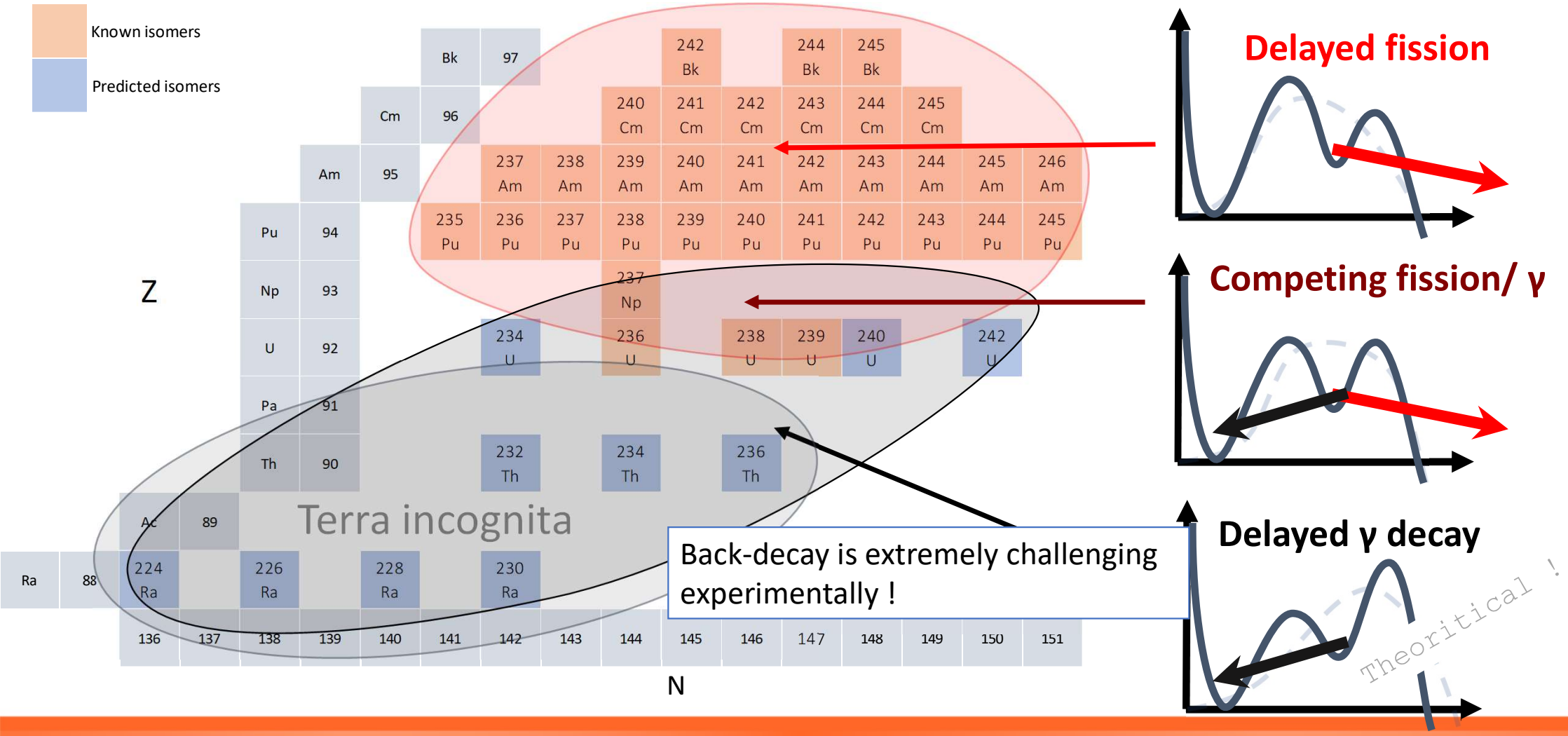

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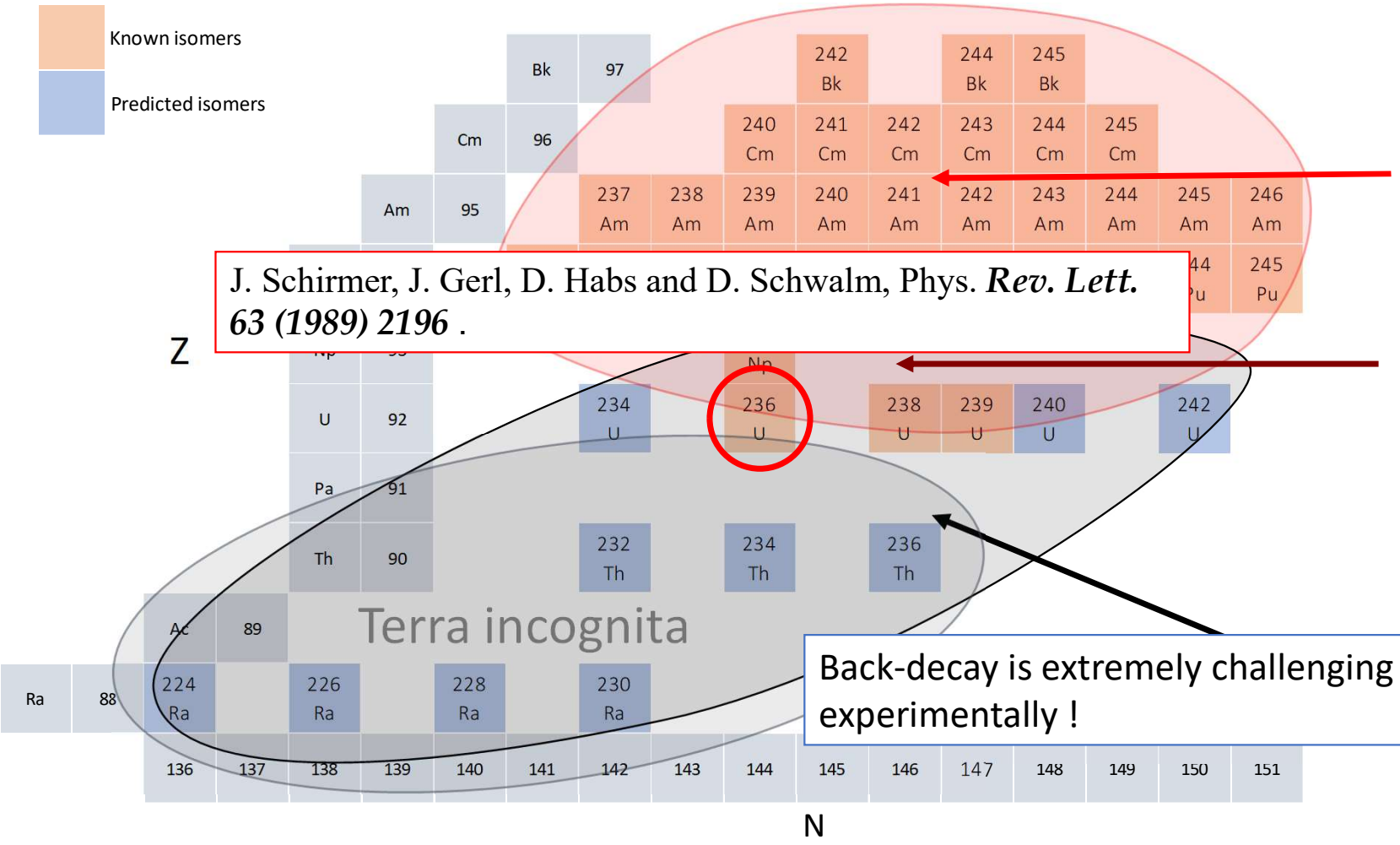
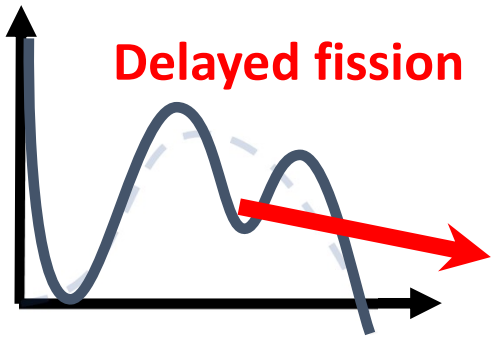
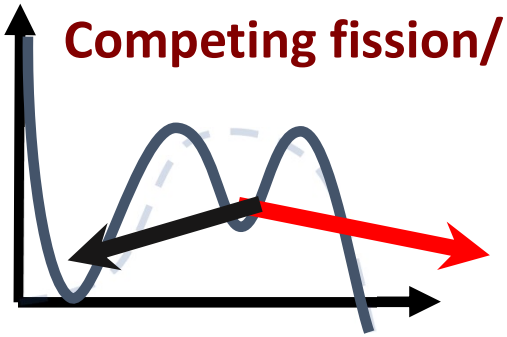
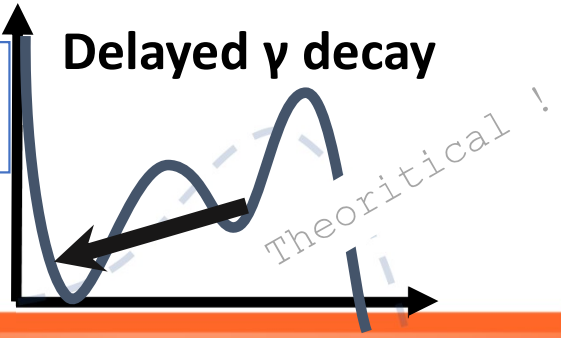








1. Introduction

Motivations :

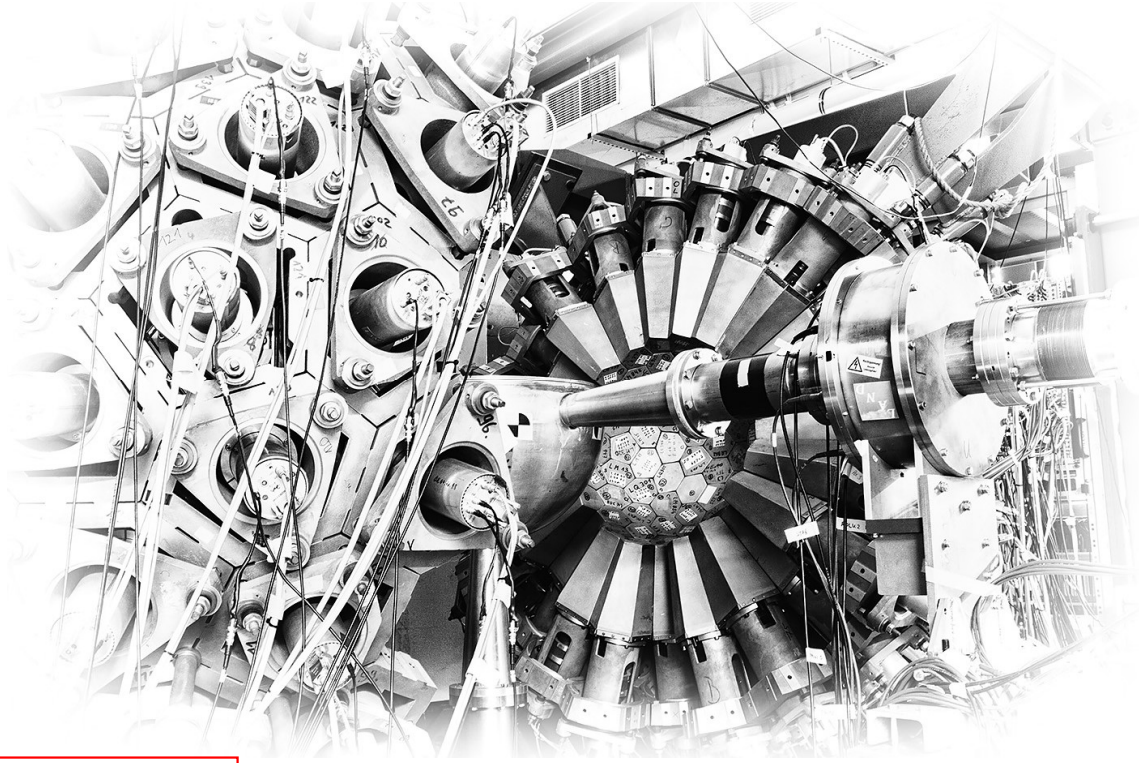
- Explore in greater details the gamma back-decay of ^{236}U
- Perform spectroscopy in the second minimum with prompt-delayed coincidences
- First steps of high resolution spectroscopy of back-decay in this « Terra incognita »

2. Crystal ball experiment : The unambiguous detection

$$^{235}_{92}U(d,p)^{236f}_{90}U$$

↓

Missing energy
VS
delayed energy



J. Schirmer, J. Gerl, D. Habs and D. Schwalm, Phys. ***Rev. Lett. 63 (1989) 2196*** .

Darmstadt 4π NaI crystal ball :
60% total energy efficiency calorimeter

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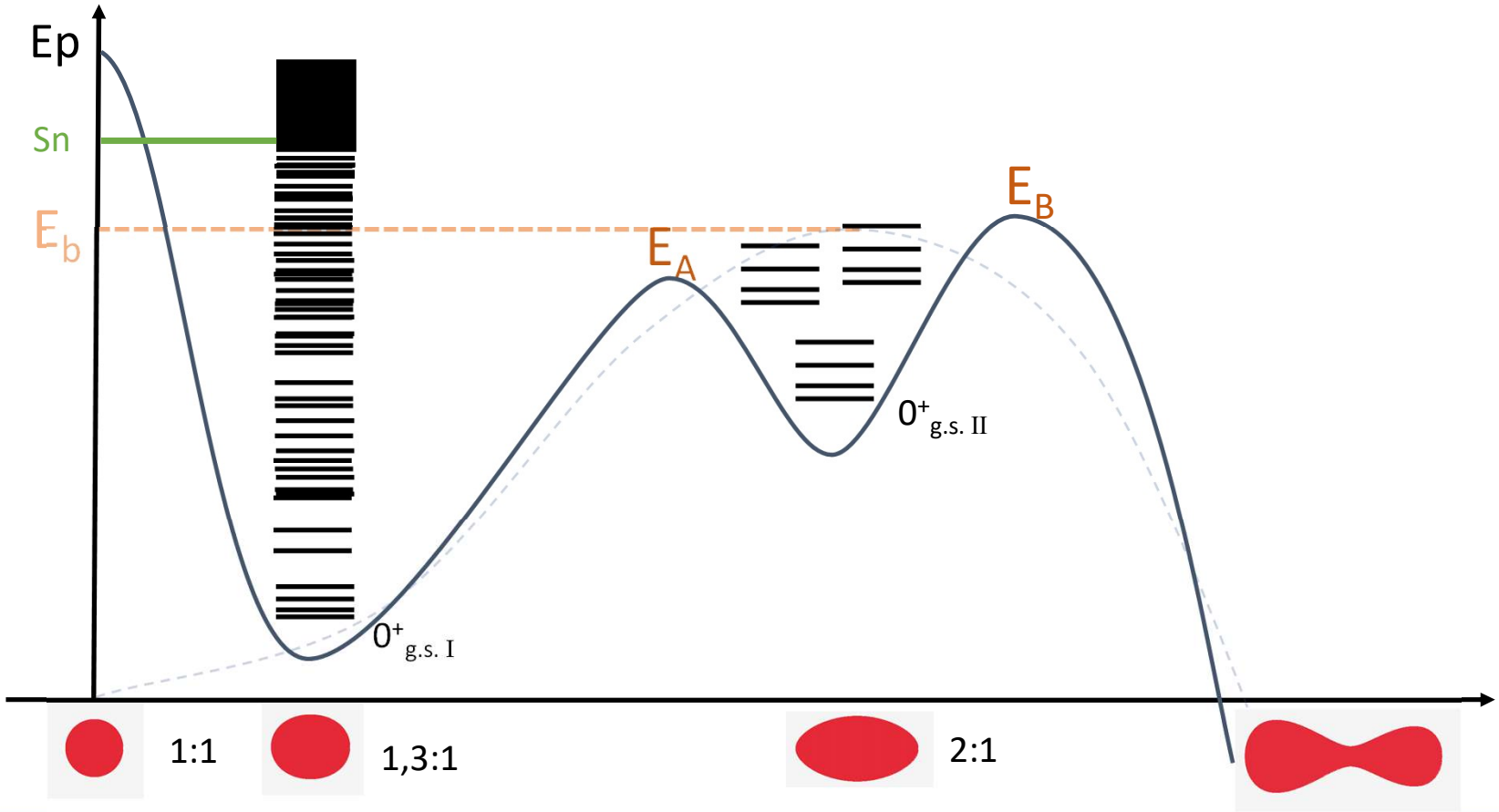
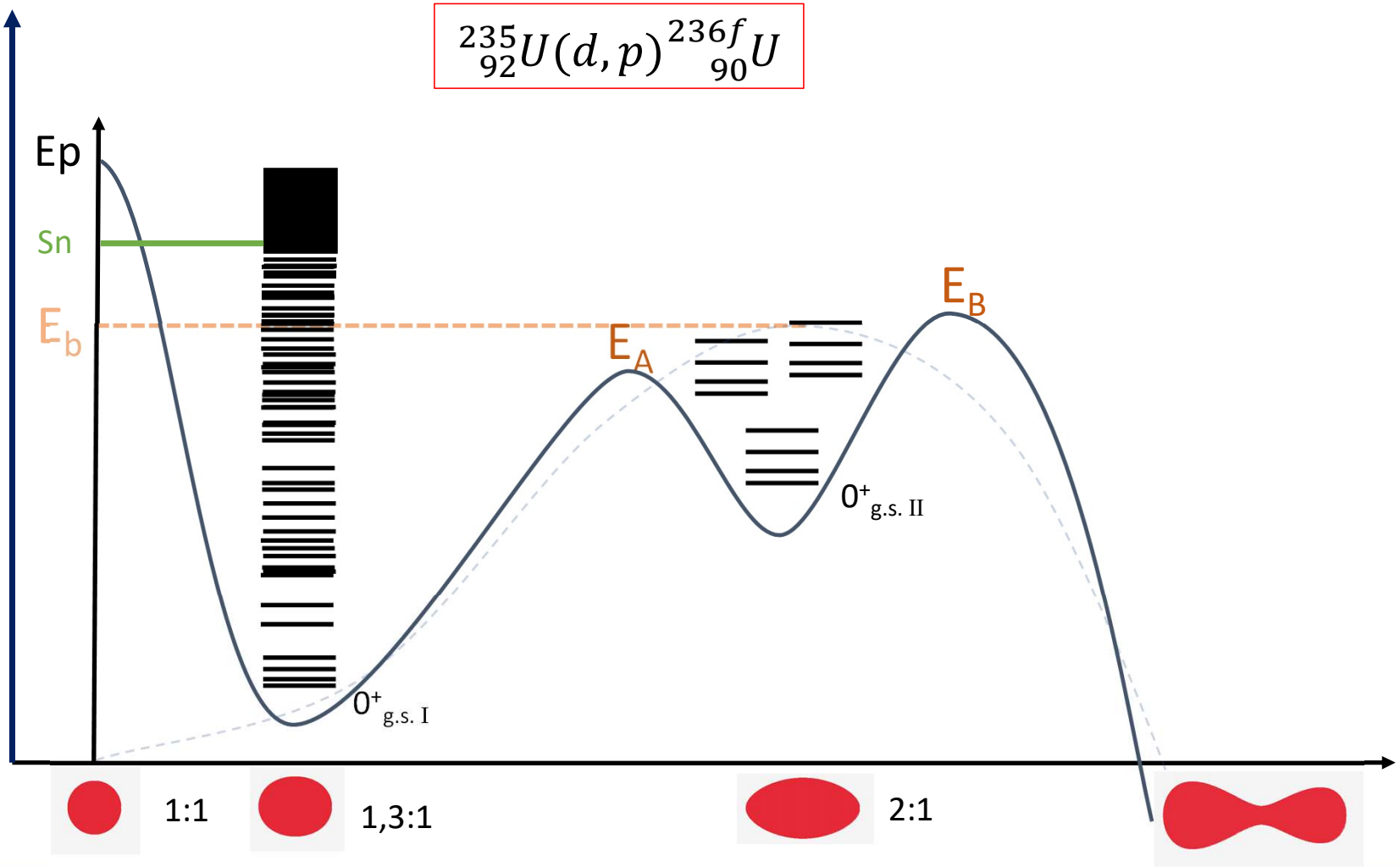


2. Crystal ball experiment : The unambiguous detection

Input energy :
$E_{beam}+Q_{(d,p)}$

$$^{235}_{92}U(d,p)^{236f}_{90}U$$



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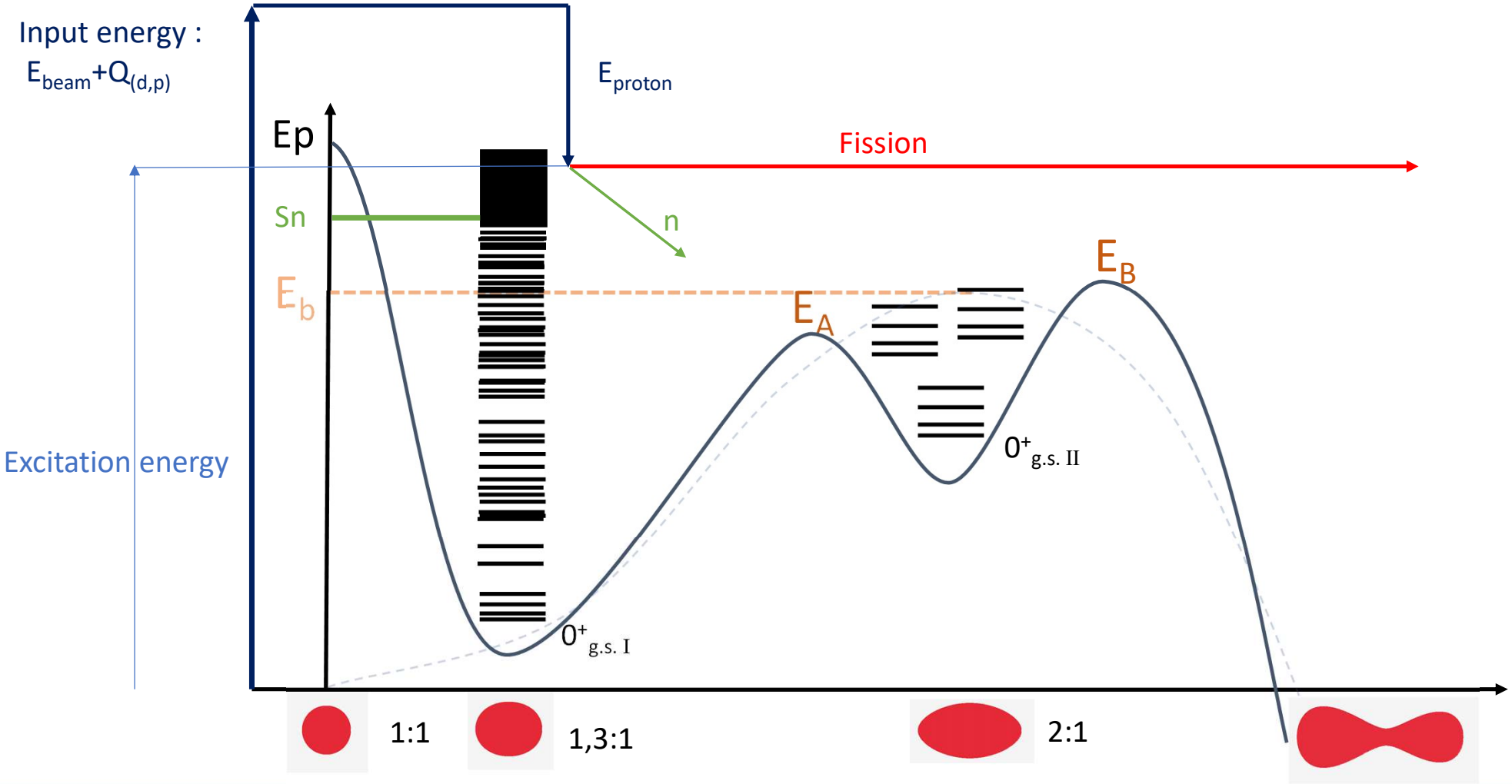

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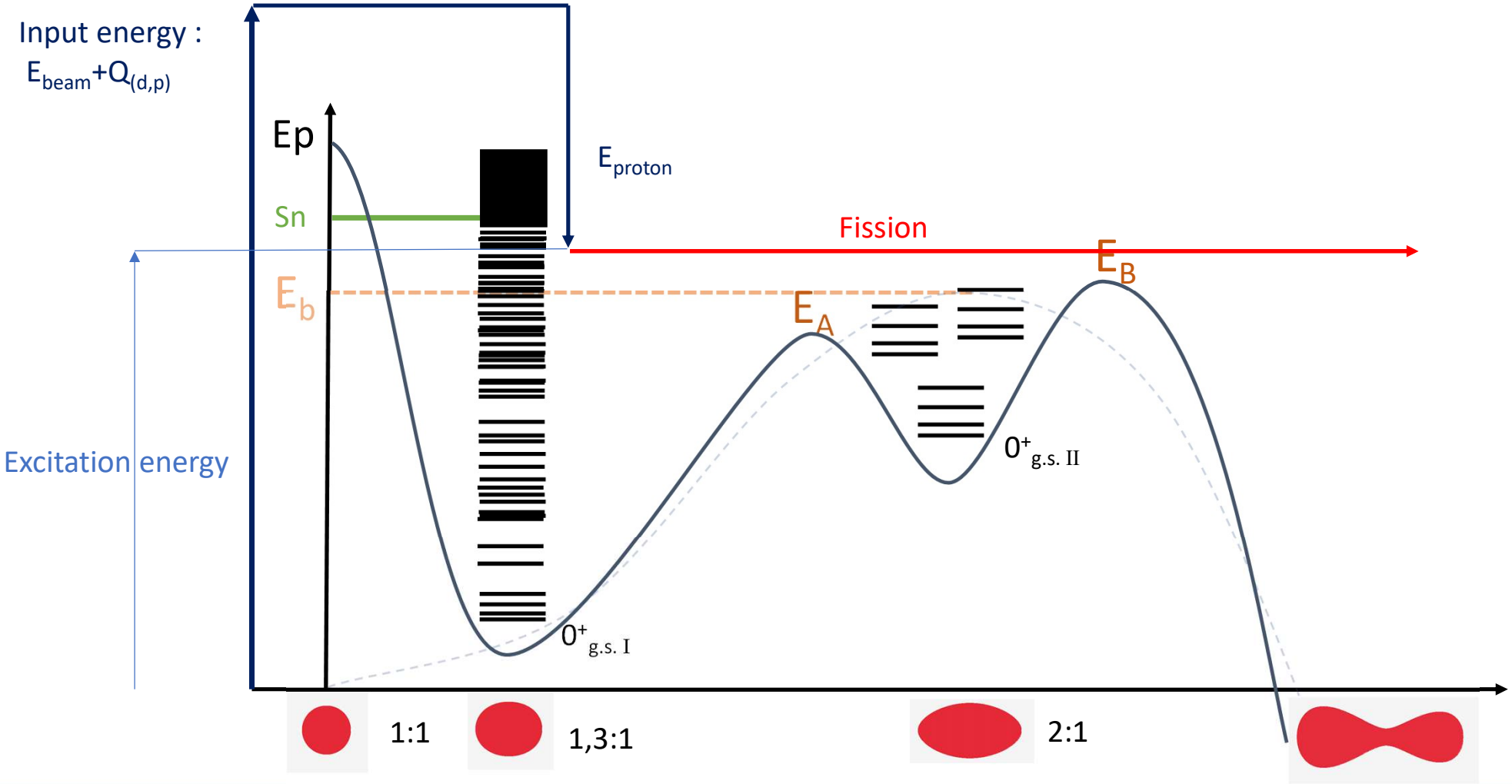

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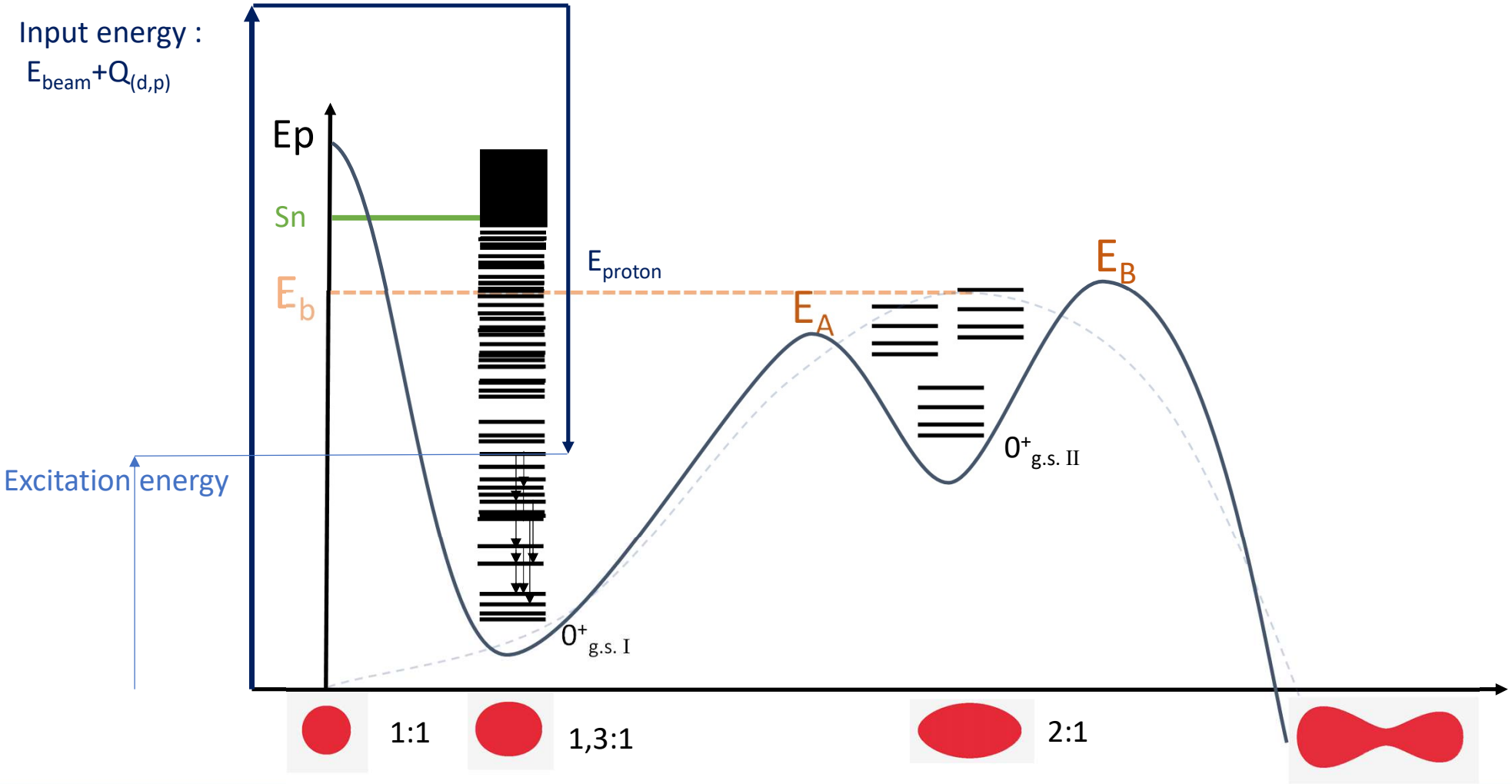

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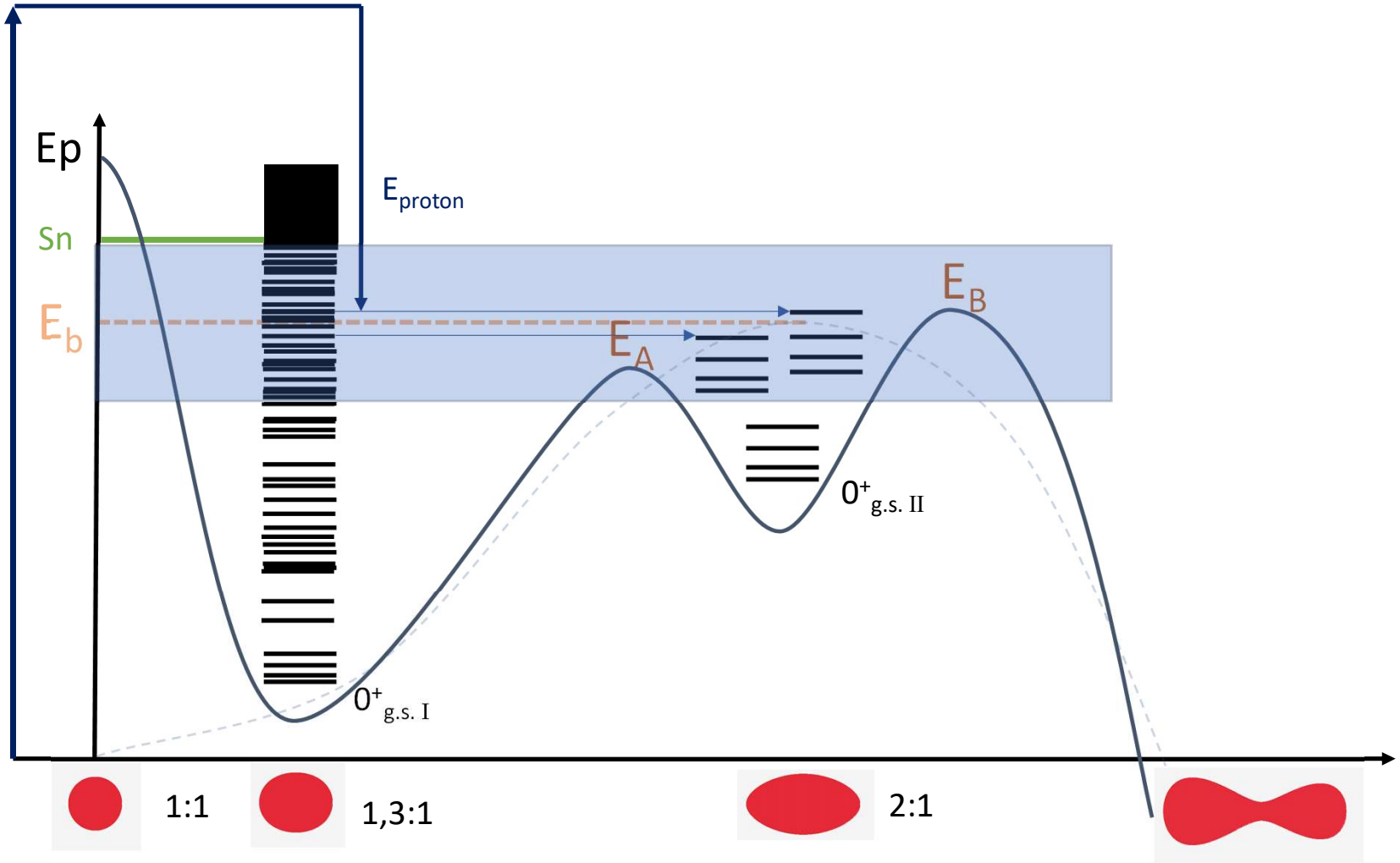
Excitation range
for fission isomer



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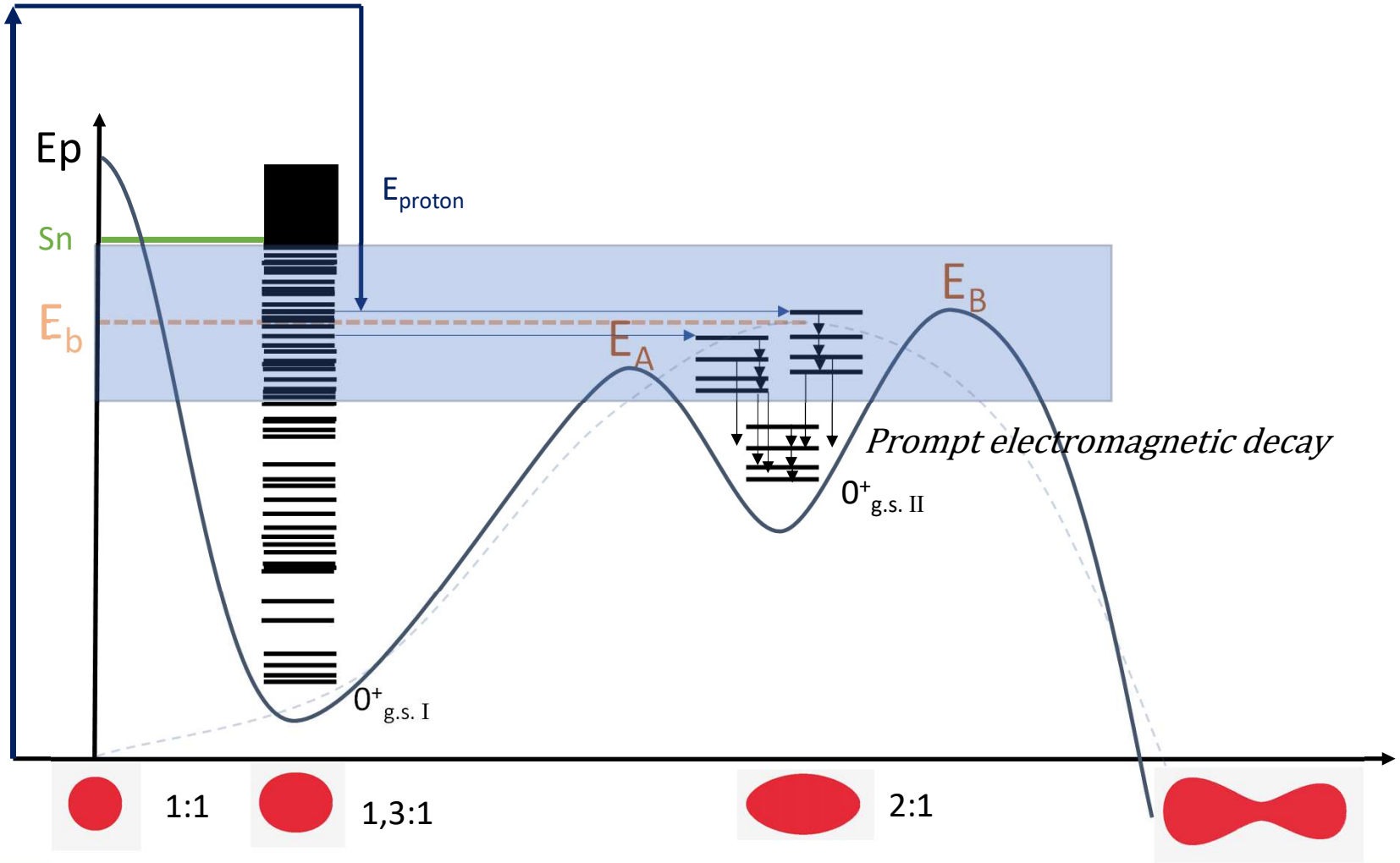

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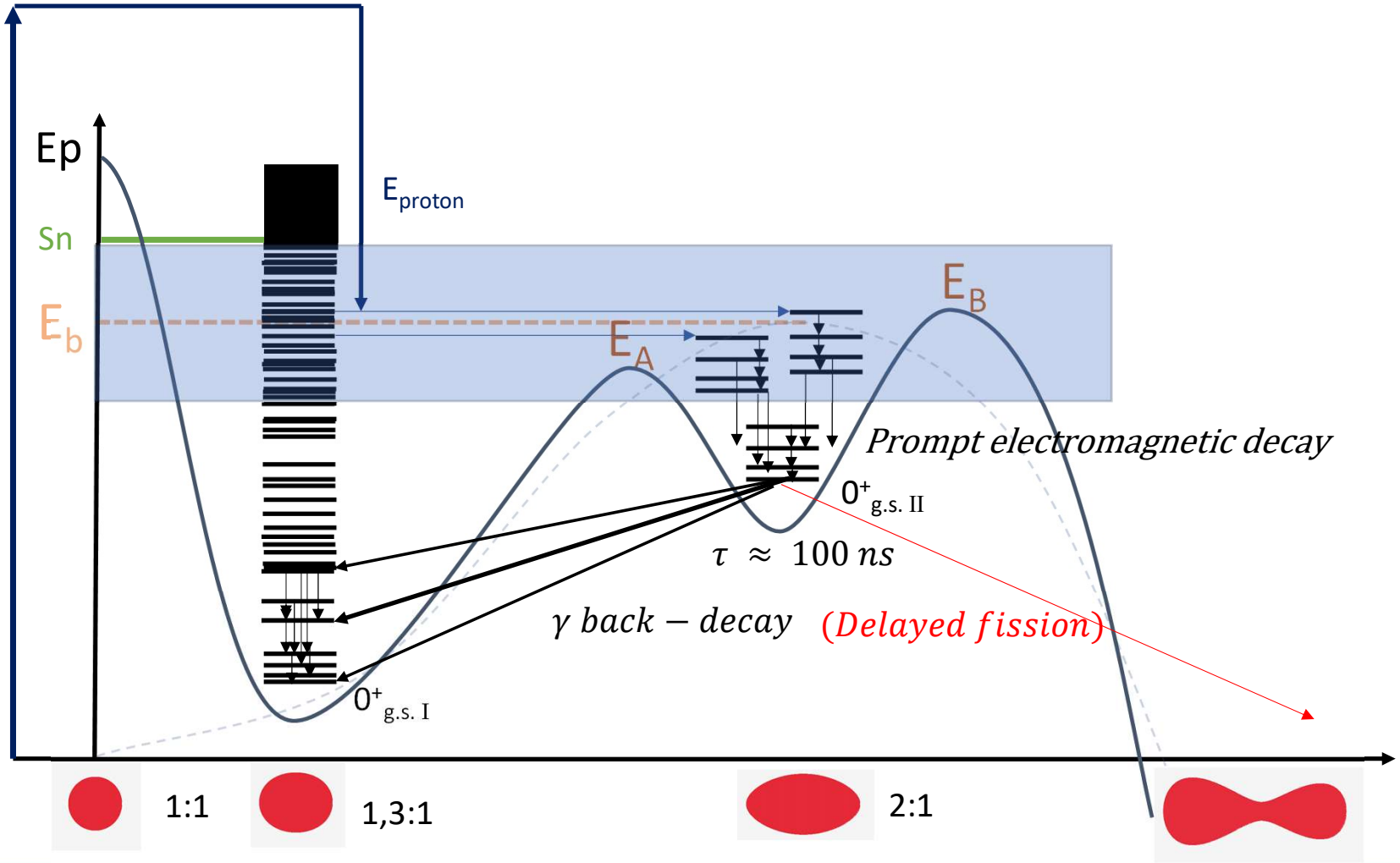

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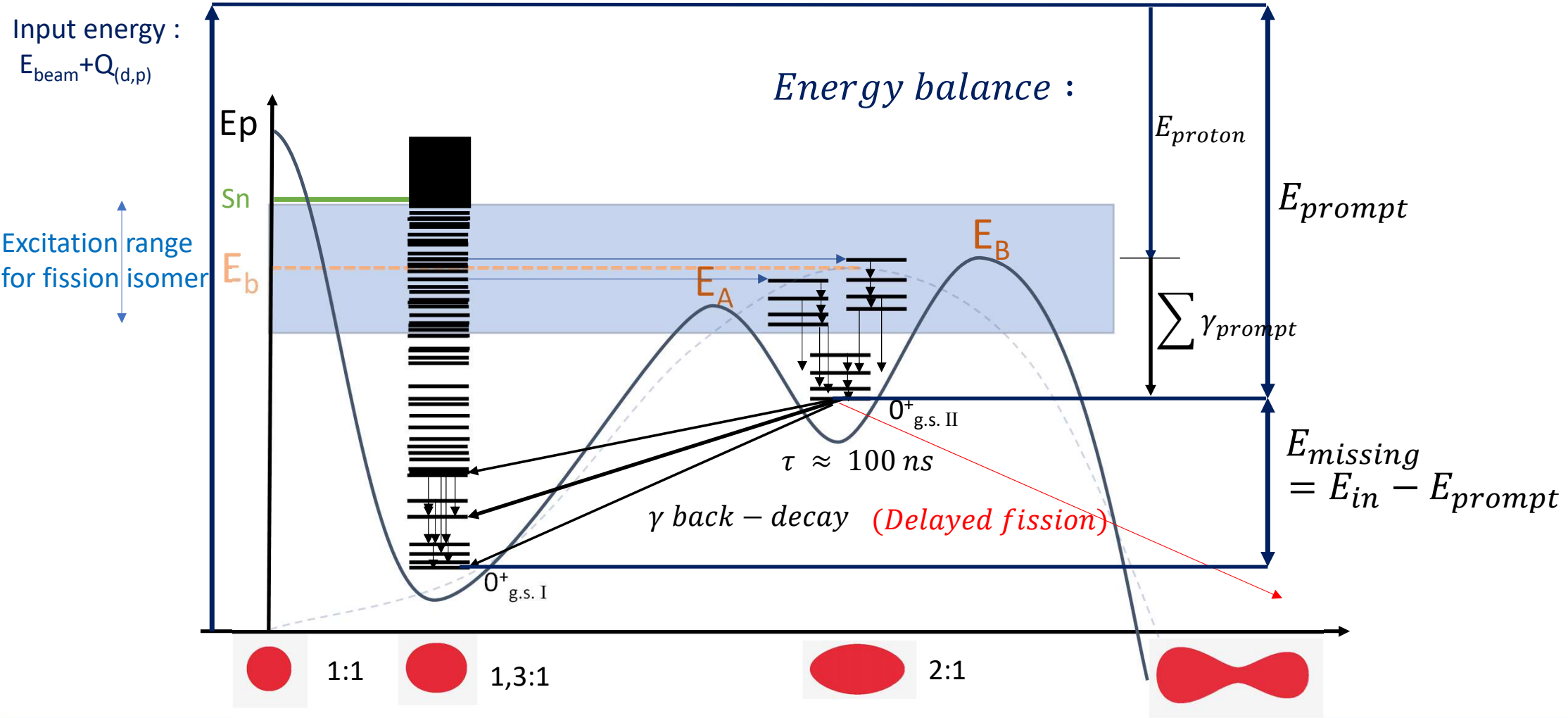

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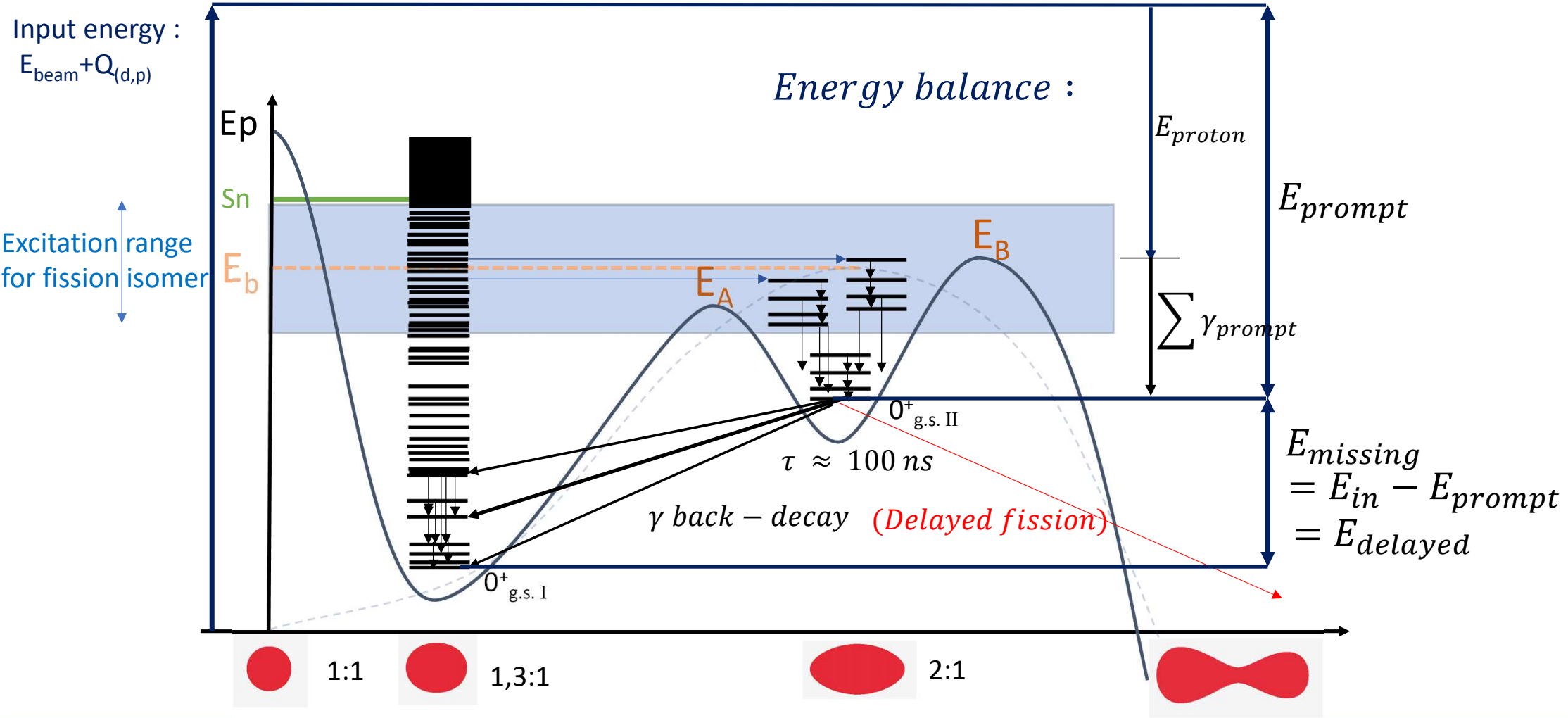
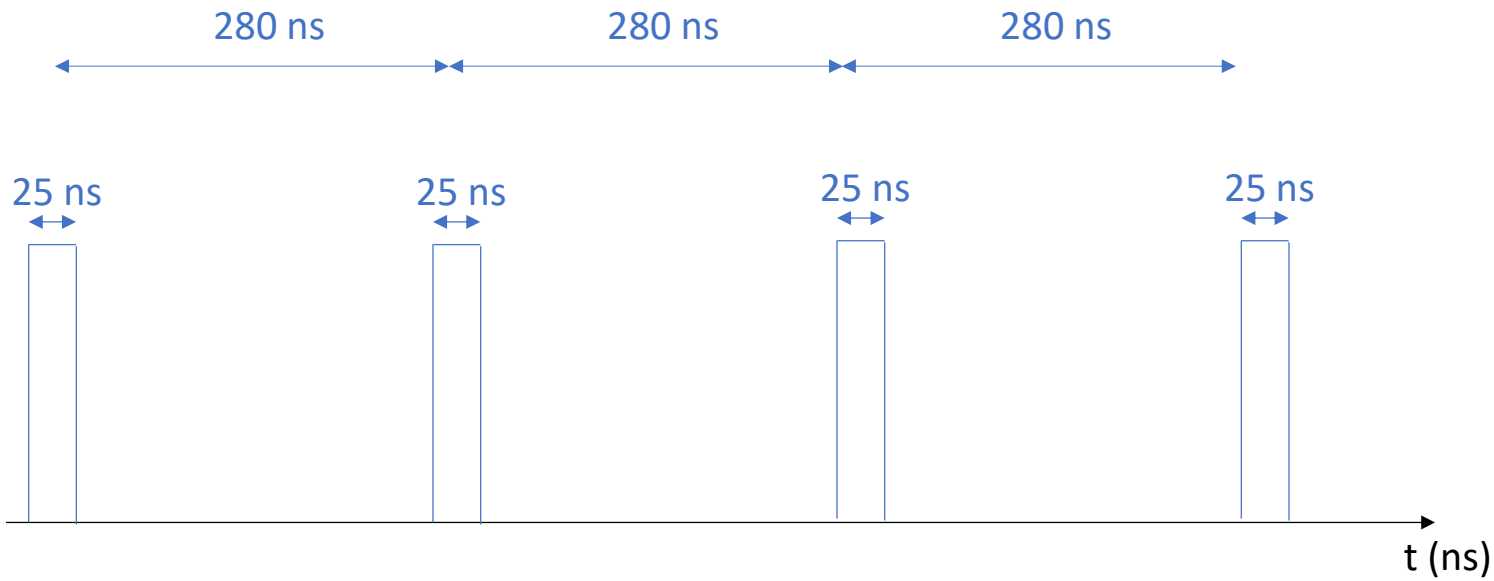


2. Crystal ball experiment : The unambiguous detection

Pulsation system : 25ns wide beam pulse, 280 ns between pulses



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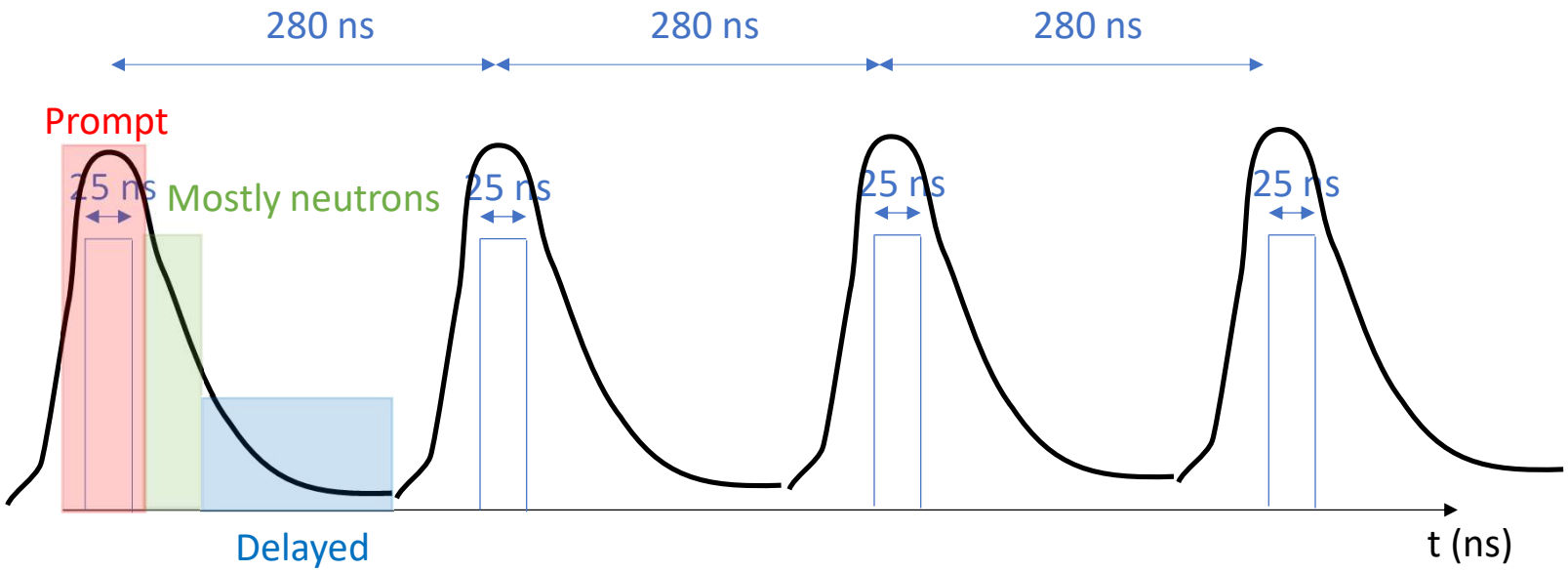

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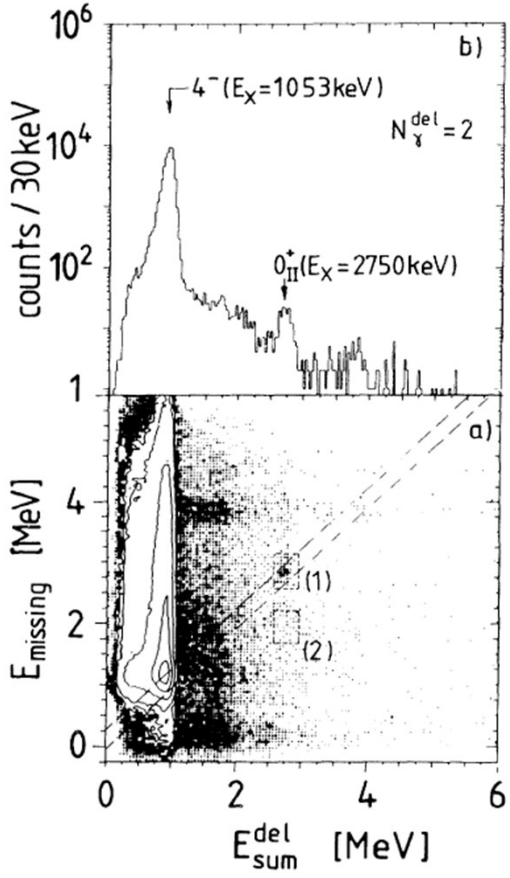
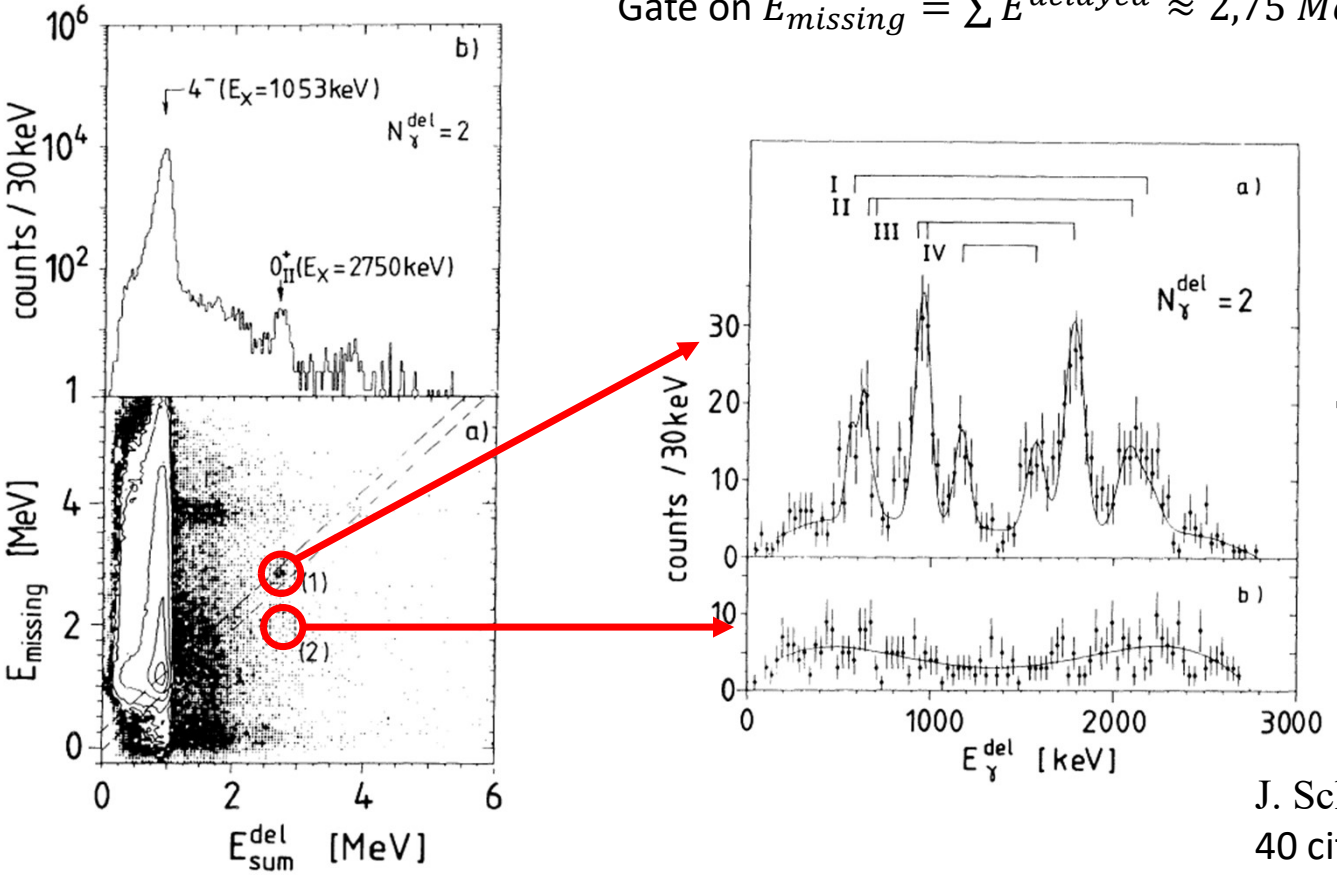
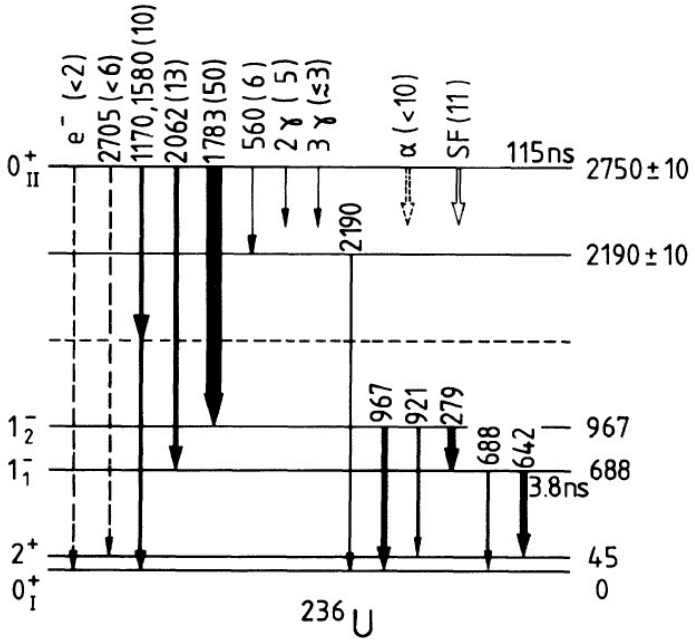


J. Schirmer, J. Gerl, D. Habs, and D. Schwalm (1898)
40 citations

2. Crystal ball experiment : The unambiguous detection

Gate on $E_{missing} = \sum E^{delayed} \approx 2{,}75\ MeV$





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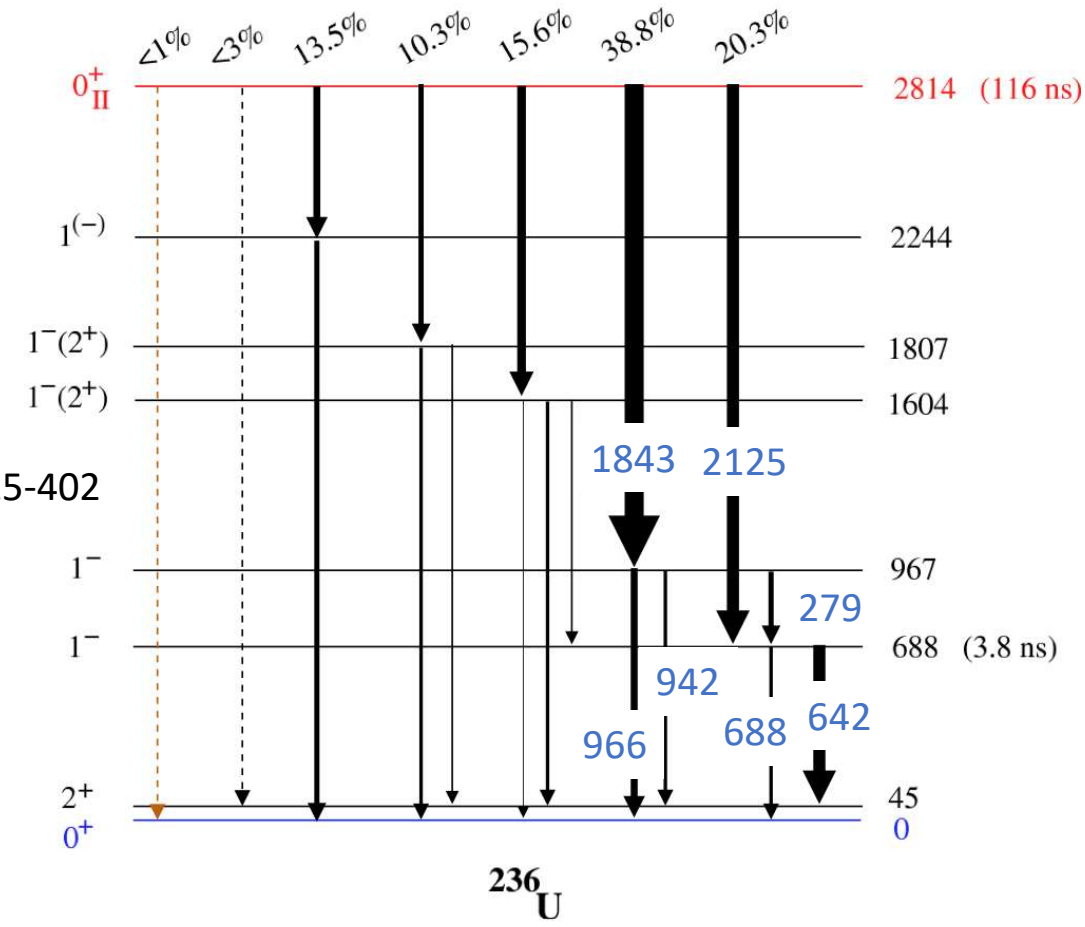
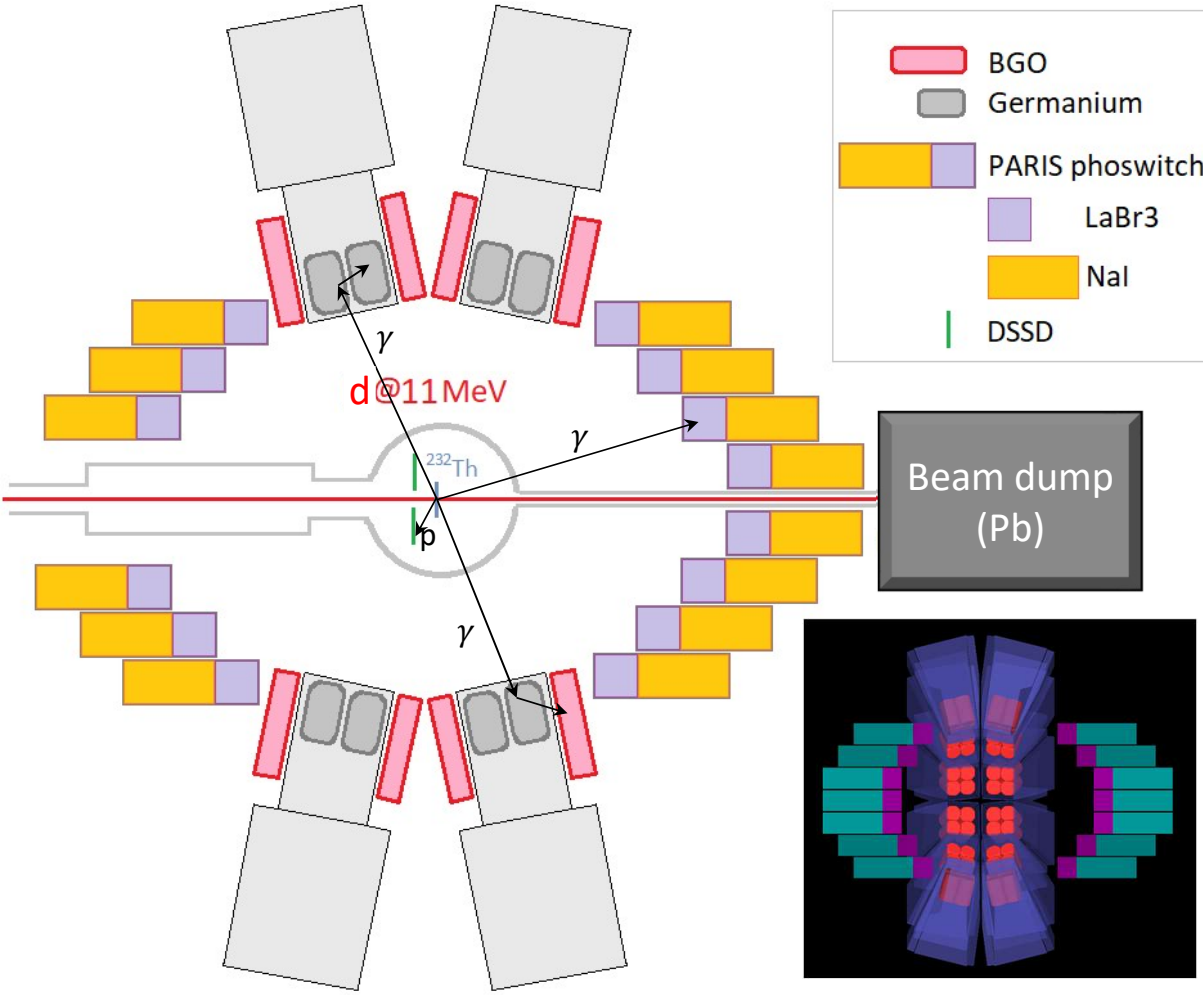
2. Crystal ball experiment : The unambiguous detection

Later remeasurement by P. Reiter, Published in
TPG. Thirolj D. Habs / Prog. Part. Nucl. Phys. 49 (2002) 325-402
125 citations



3. 2023, Orsay : High precision spectroscopy with Nuball2



Setup :
24 Ge clovers + BGO, 64 PARIS phoswhich + DSSD
> 300 independent digital channels (FASTER system)

Advantages :

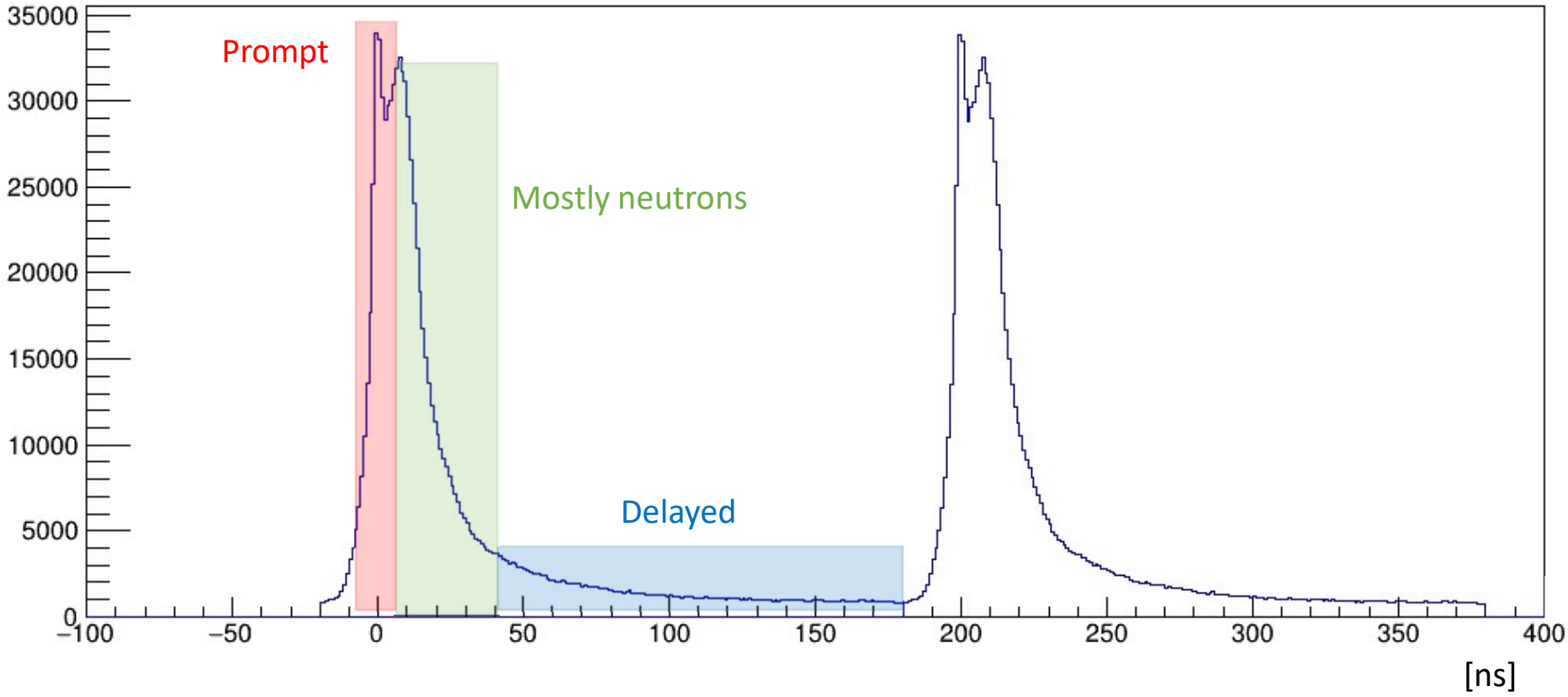
- Much better energy resolution (HPGe)
- Better beam pulsation (2ns wide pulse vs 25 ns)
- Segmented Si DSSD (16 rings, 32 sectors)
  -> 10 kHz particle detection rate vs 800 Hz
- Triggerless DAQ -> Great flexibility in data analysis

Disadvantages :

- Calorimetry full energy efficiency 30% vs 60%
- Proton punch through in DSSD

3. 2023, Orsay : High precision spectroscopy with Nuball2

200 ns pulsed beam



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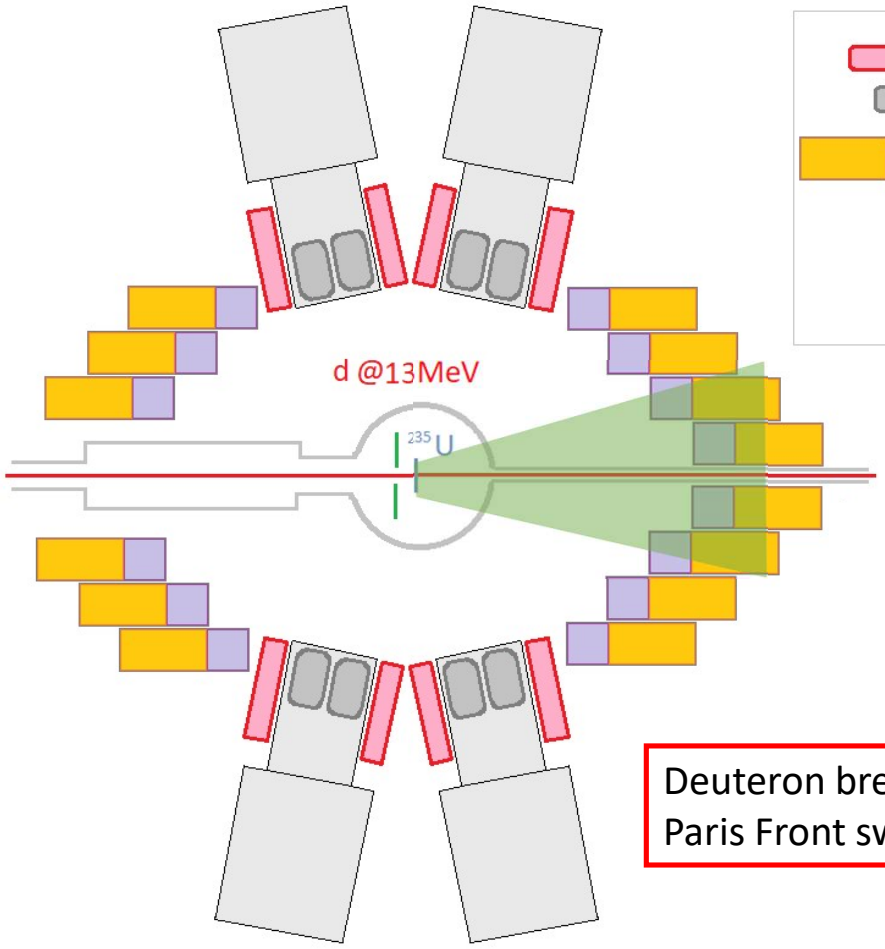
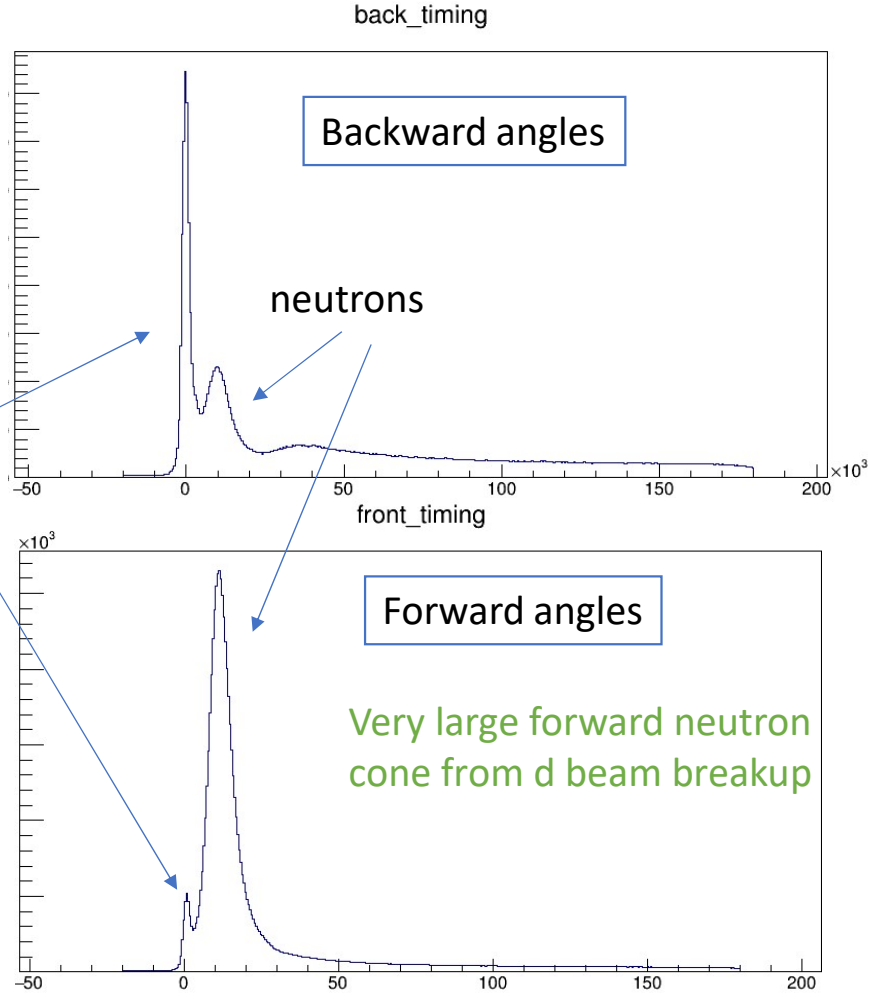


BGO
Germanium
PARIS phoswitch :
LaBr3
NaI
DSSD

Deuteron breakup
Paris Front swarmed by neutrons

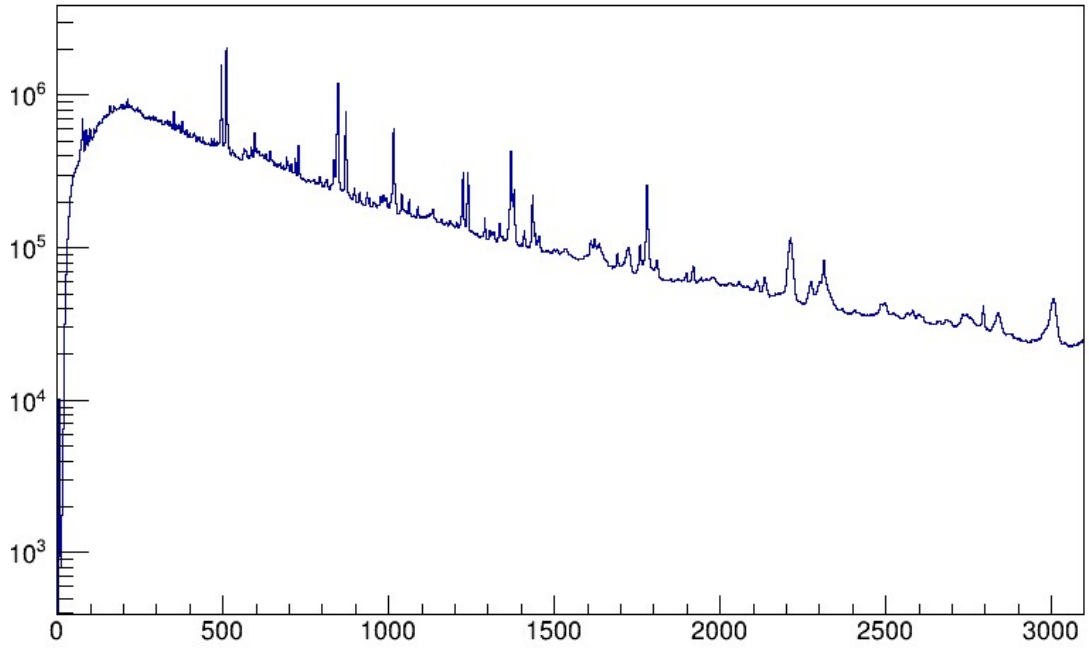
Gamma prompts



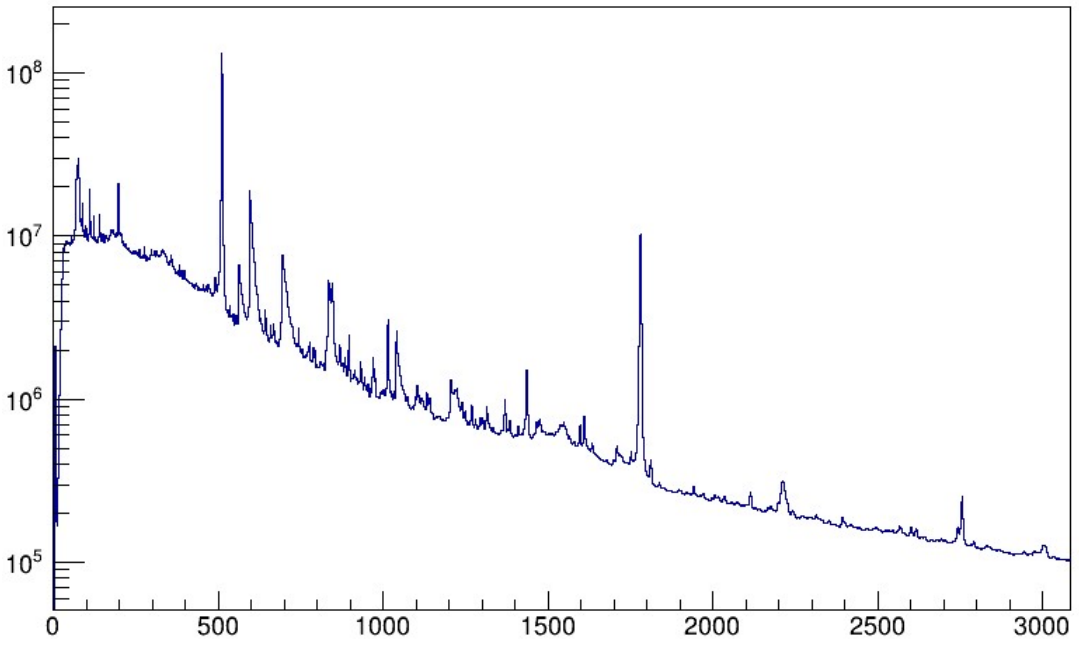
3. 2023, Orsay : High precision spectroscopy with Nuball2

- Other open channels (e.g. 235U(d,n))
- Transfer induced *prompt fission*
- Beta decay of fission products
- Target impurities (e.g. oxygen, aluminium)
- Inelastic neutron scattering, capture (break-up of d beam)

prompt



delayed



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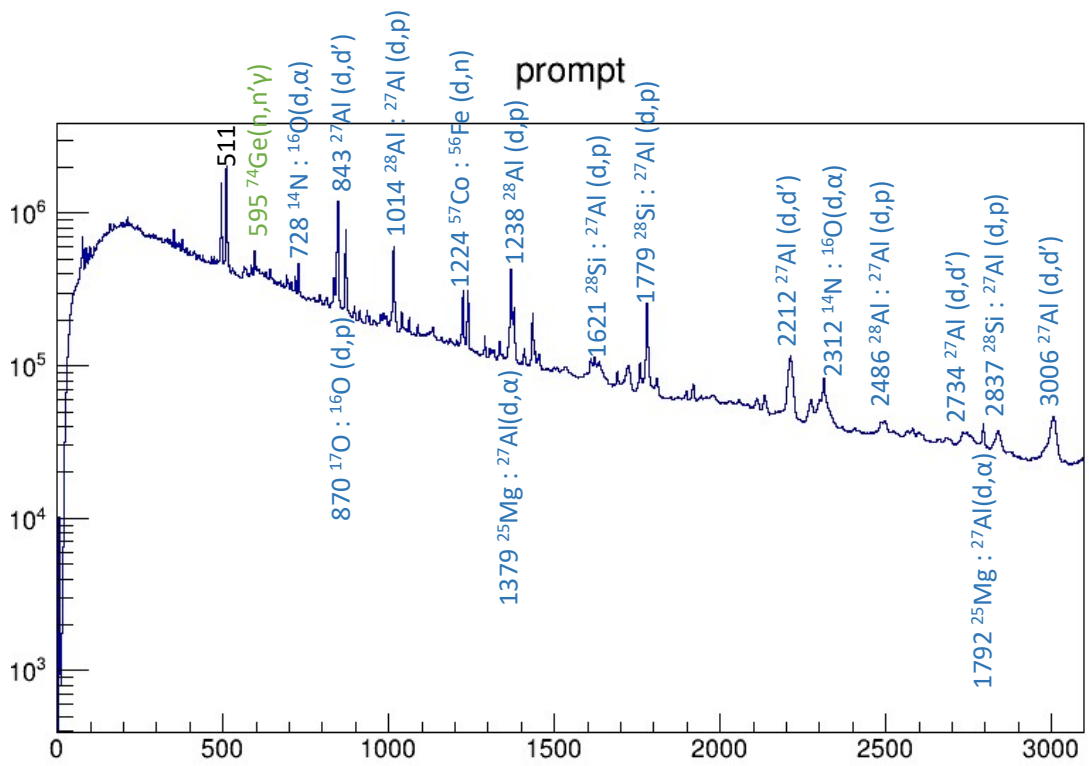
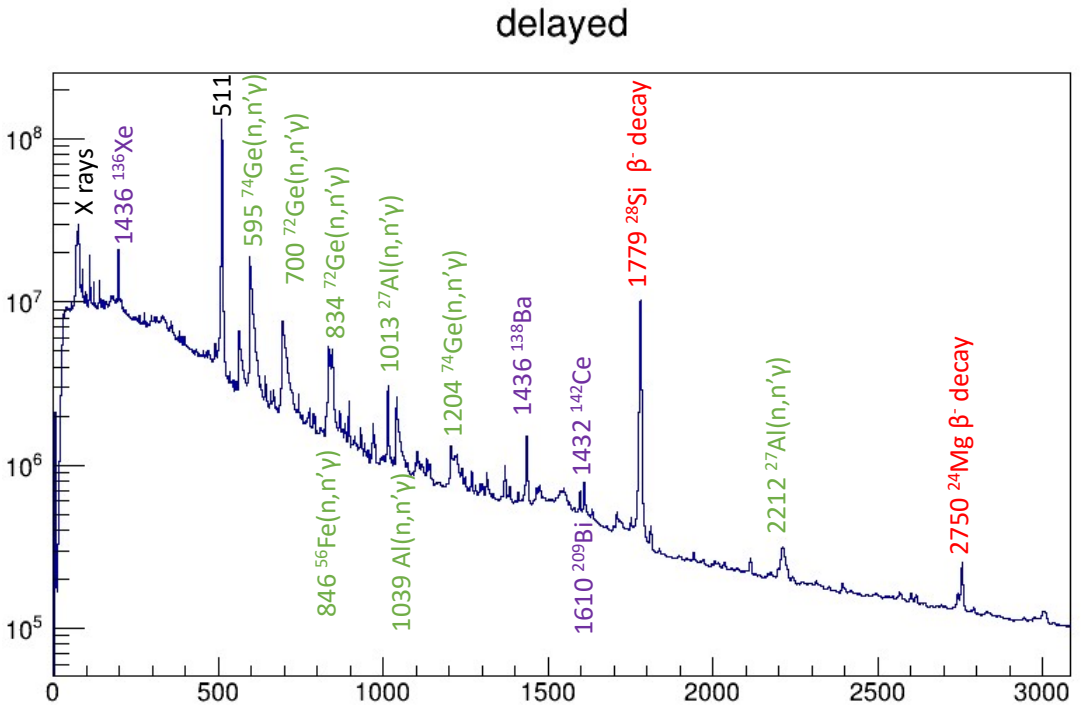


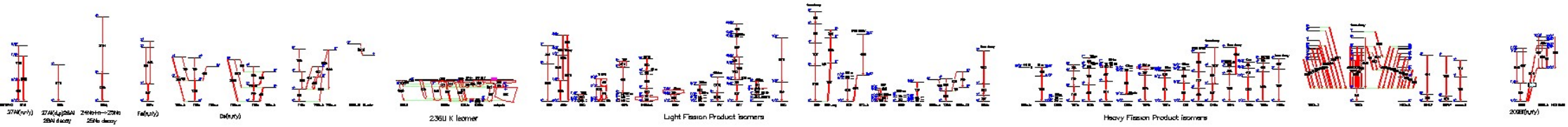


3. 2023, Orsay : High precision spectroscopy with Nuball2

Very complex spectra :
many reaction channels open
not pure target (Oxyde, aluminum backing)
neutron scattering on structure

Identified prompt cascades :

Identified delayed cascades :



And those are only the prominant lines !

3. 2023, Orsay : High precision spectroscopy with Nuball2

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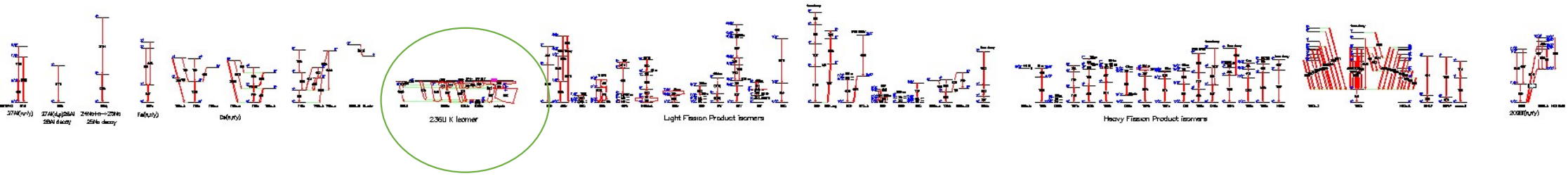
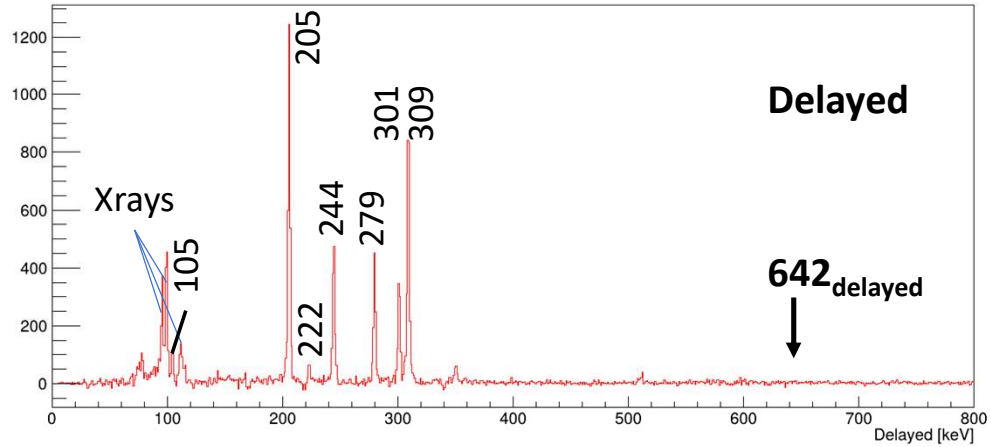
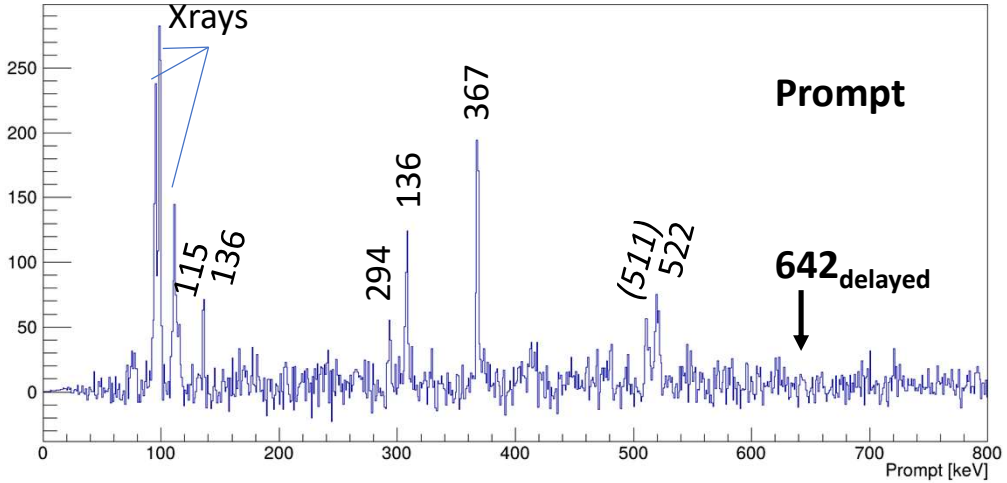


And those are only the prominant lines !

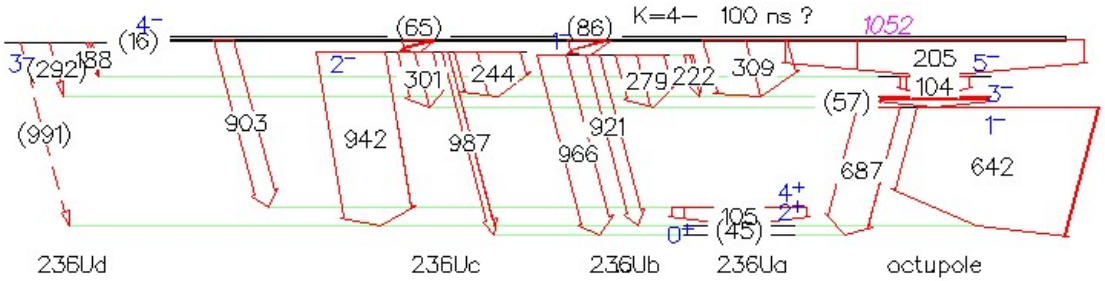
3. 2023, Orsay : High precision spectroscopy with Nuball2

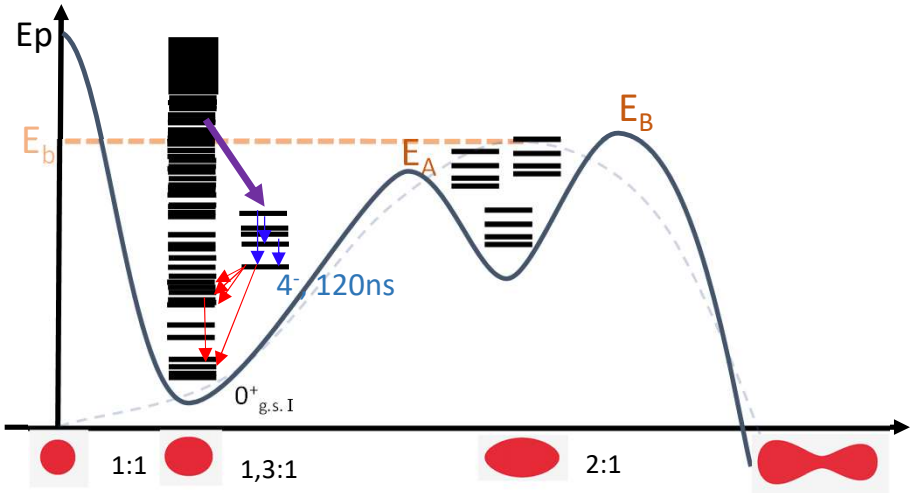
Gate on the 642 keV transition in the delayed spectra :



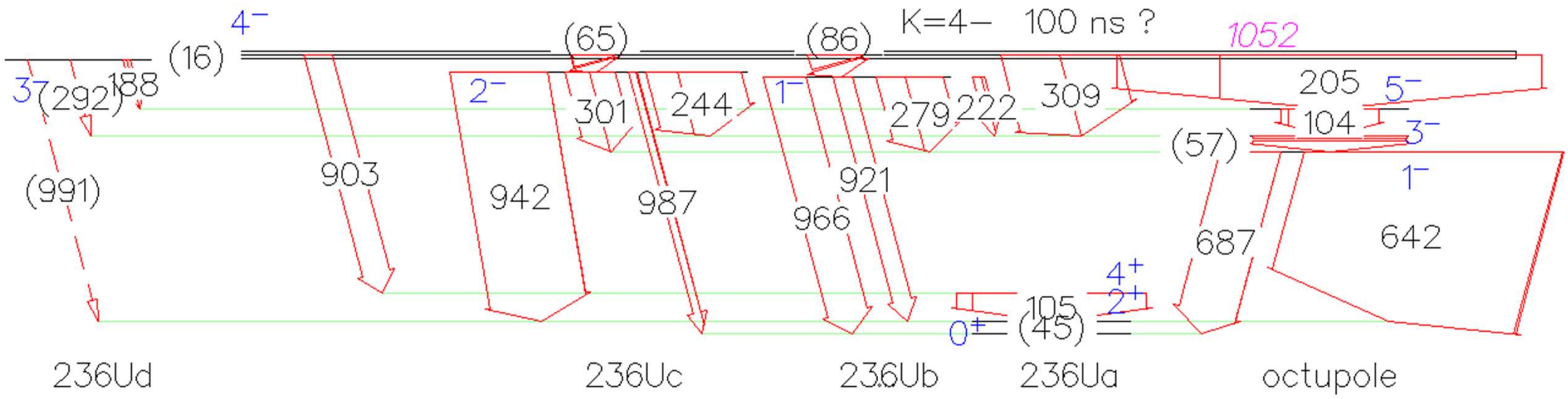


K = 4- isomer, τ=120 ns





3. 2023, Orsay : High precision spectroscopy with Nuball2



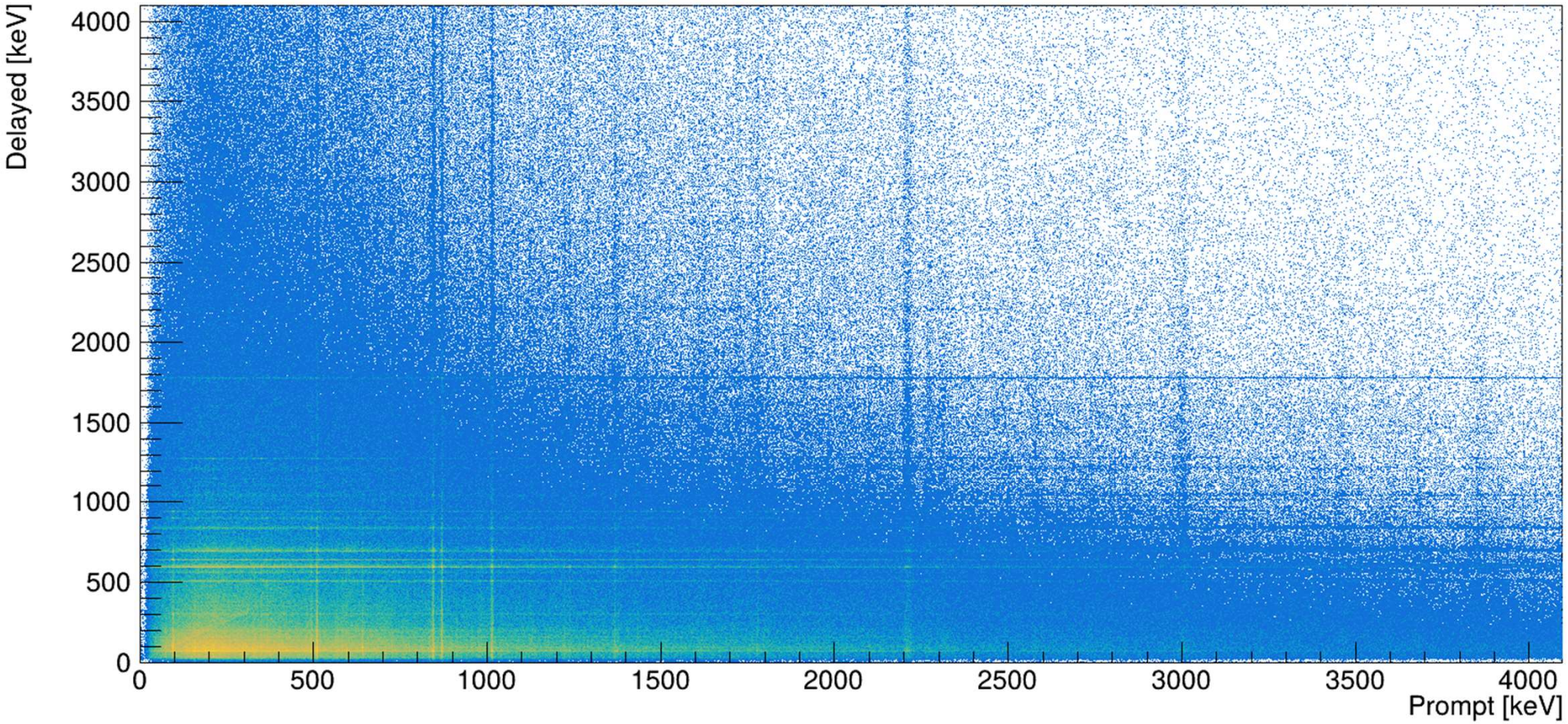
Half life measurement :

Energy [keV]	Calculated half-life [ns]
642	96
688	125
903	60
942	105
966	142

Two remarks :

- Very preliminary measurements (errors to be determined ?)
- Seems to indicate different half lives -> more than one isomer ?

3. 2023, Orsay : High precision spectroscopy with Nuball2



3. 2023, Orsay : High precision spectroscopy with Nuball2

AN ISOMERIC TWO-PARTICLE STATE IN ^{236}U

H.F. BRINCKMANN*, D.D. CLARK**, N.J.S. HANSEN and J. PEDERSEN
The Niels Bohr Institute, University of Copenhagen, Denmark

Received 24 January 1973

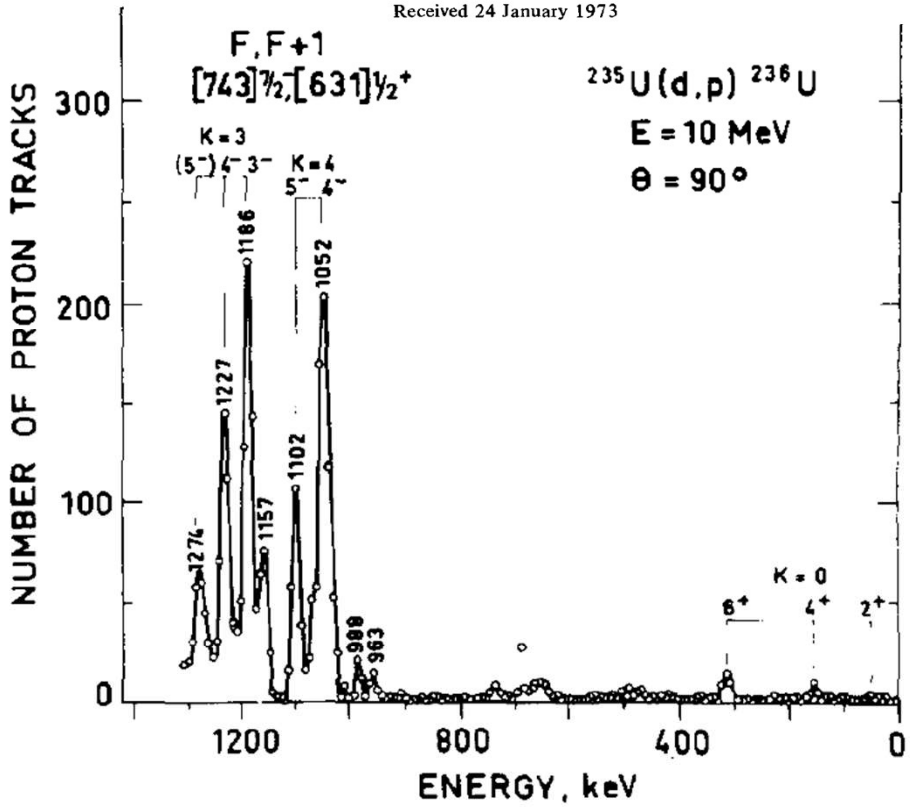
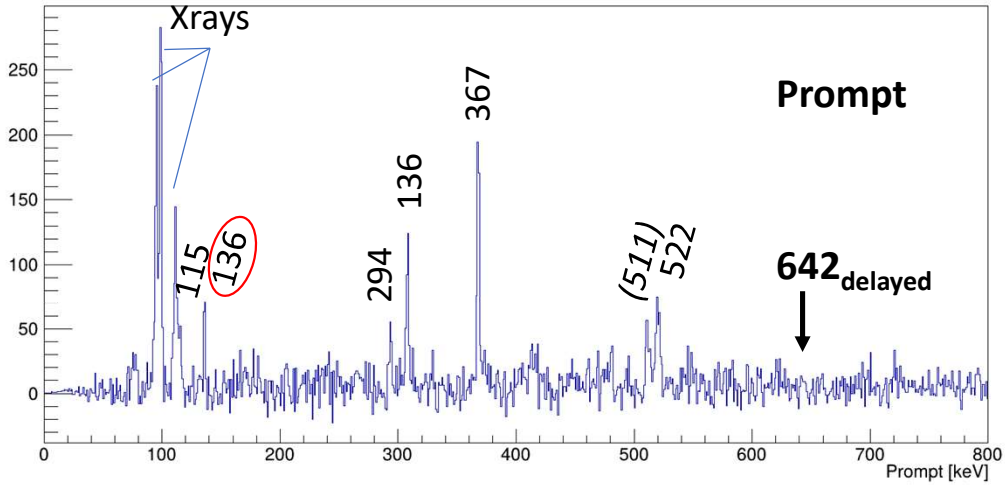


Fig. 1. Proton spectrum of the reaction ^{235}U(d, p)^{236}U.

- Lowest prompt gamma E_γ = 136 keV could be $(K, J^\pi = 3, 3^-)$ 1186 → $(K, J^\pi = 4, 4^-)$ 1052
- States not in nndc !!



3. 2023, Orsay : High precision spectroscopy with Nuball2

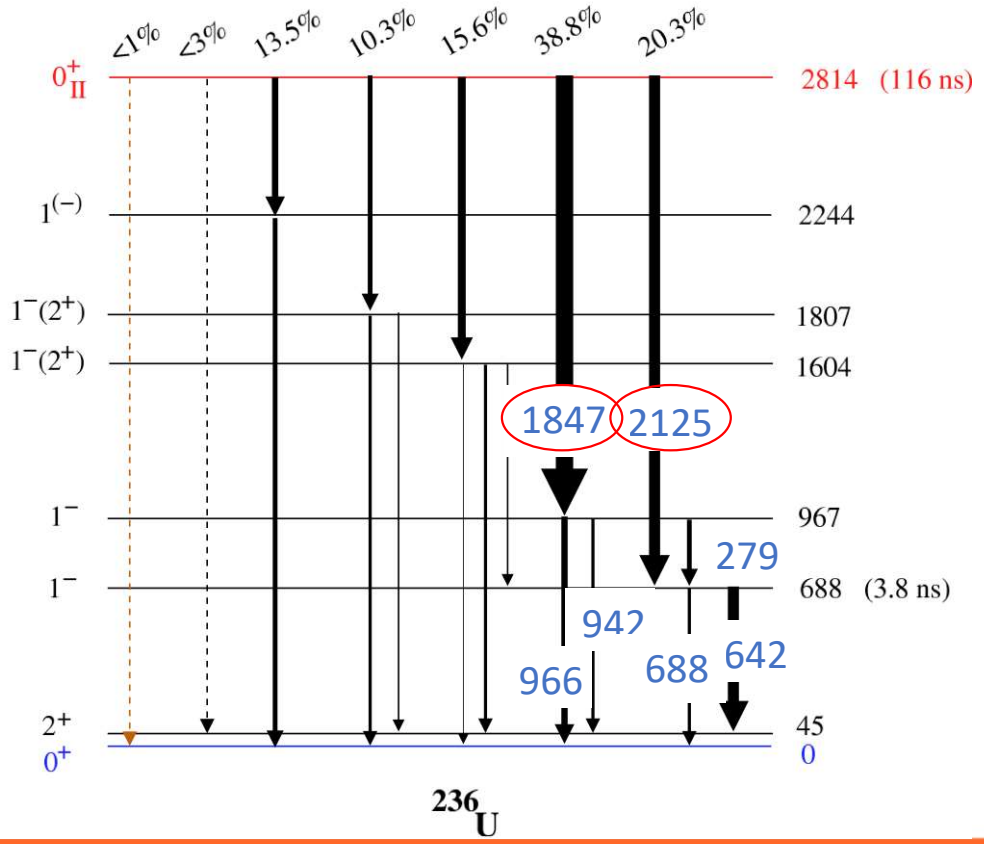
A few numbers :

- 10^9 ^{236}U produced
- From Habs&al measurement, $\frac{I(^{236IIU})}{I(^{236IU})} = 3.10^{-4}$
- Deduced 3.10^5 Shape Isomers produced

Methodology : stronger and stronger event-by-event conditions to tend to theirs :

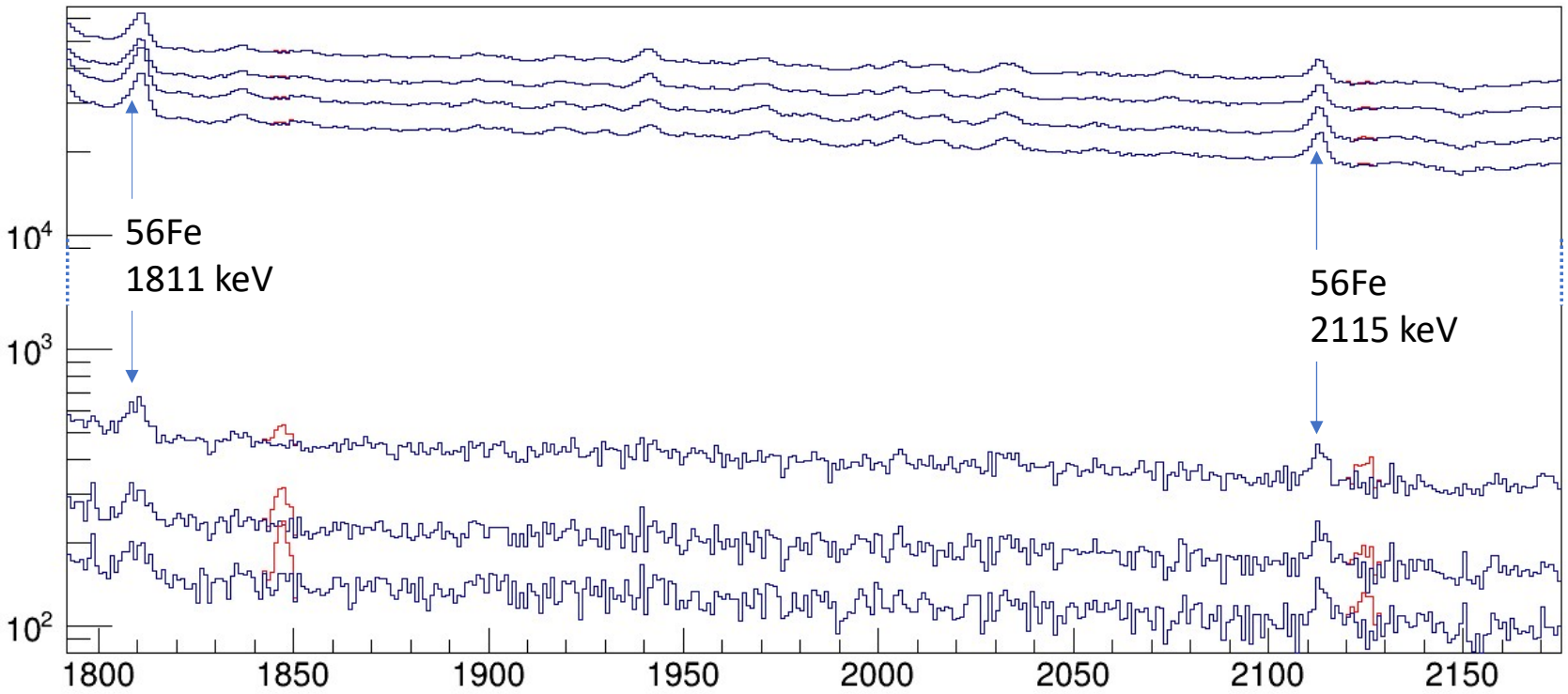
- Prompt gamma ray
- Prompt and delayed calorimetry condition
- Excitation energy conditions

Deduce the expected intensity of and 2125 lines :
1847 keV : 3492 counts
2125 keV : 1671 counts



3. 2023, Orsay : High precision spectroscopy with Nuball2

From top to bottom spectra :
1 : Prompt gamma
2 : 1 , ΣE_{prompt}<3,7 MeV
3 : 1 , $\Sigma E_{delayed}$<3,0 MeV
4 : 2 , 3
5 : 4 , particule
6 : 5 , $E_{excitation}$ < 6,5 MeV
7 : 5 , $E_{excitation}$ > 4,5 MeV



3. 2023, Orsay : High precision spectroscopy with Nuball2

From top to bottom spectra :

1 : Prompt gamma

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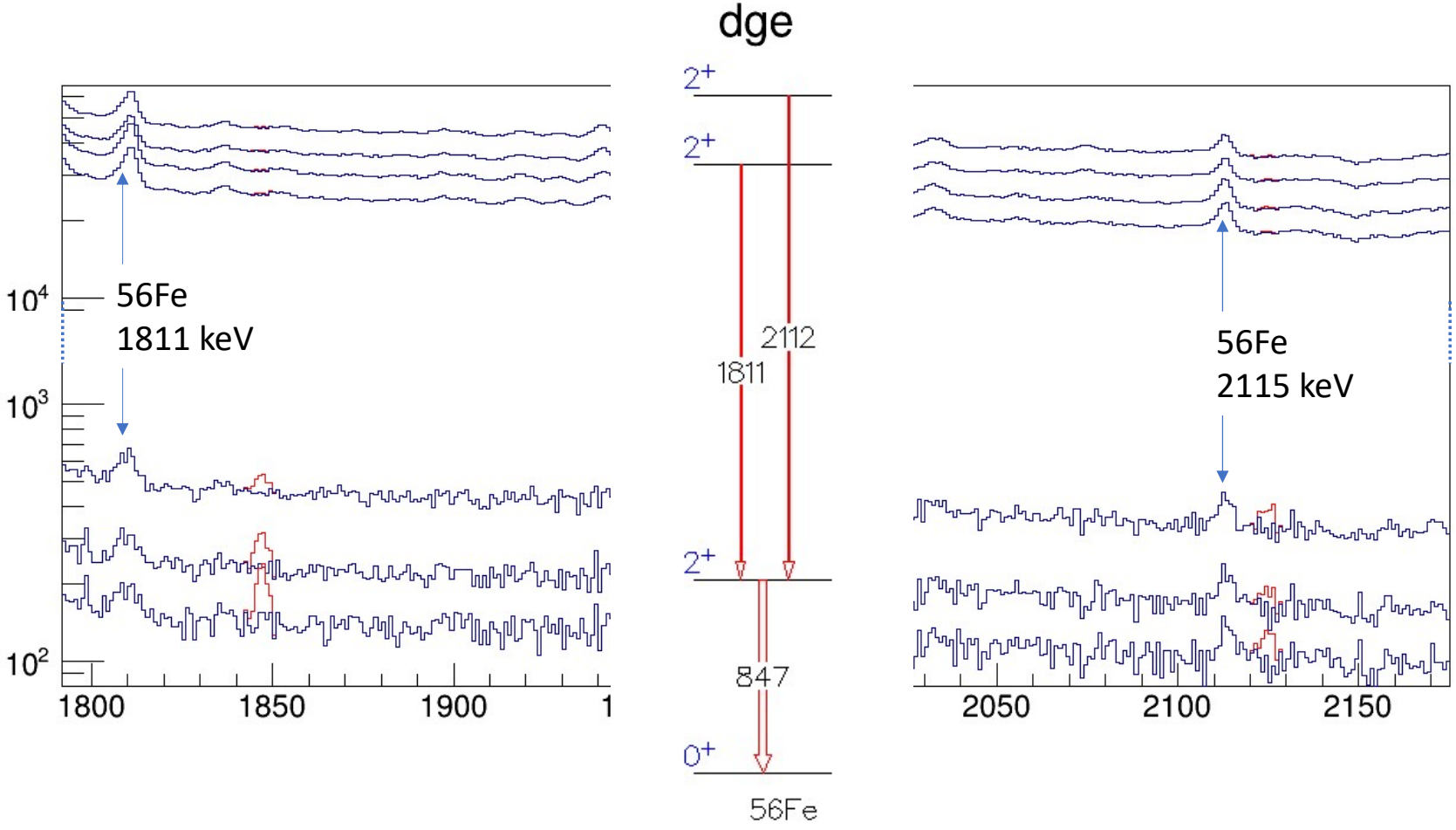
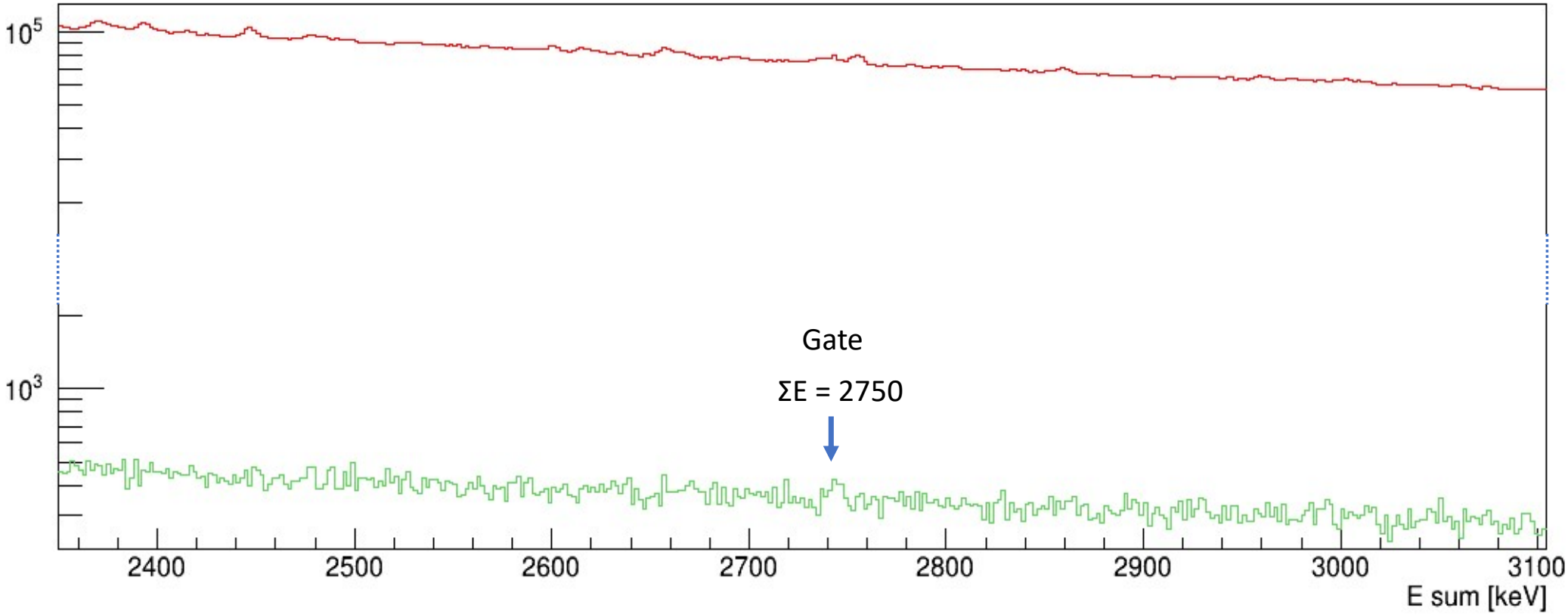
7 : 5 , $E_{excitation}$ > 4,5 MeV

^{56}Fe(n,n') in the structure

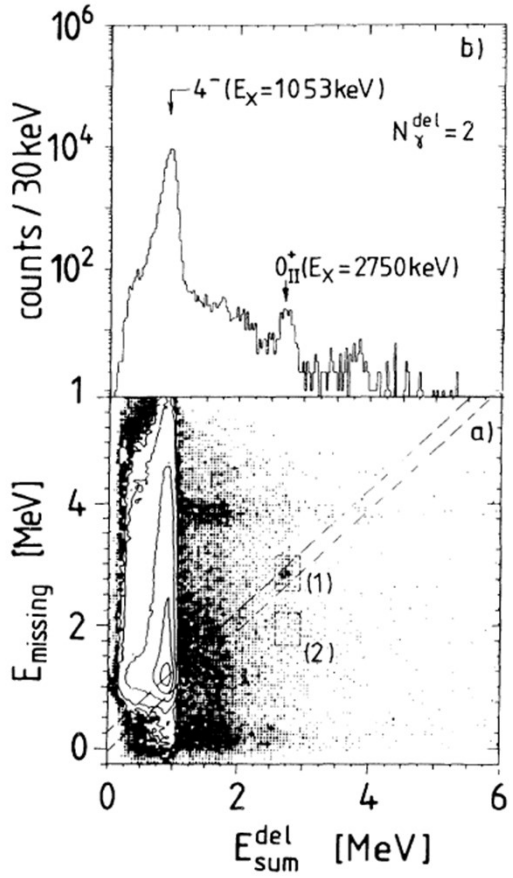


3. 2023, Orsay : High precision spectroscopy with Nuball2

Energy sum of events with two gamma rays :

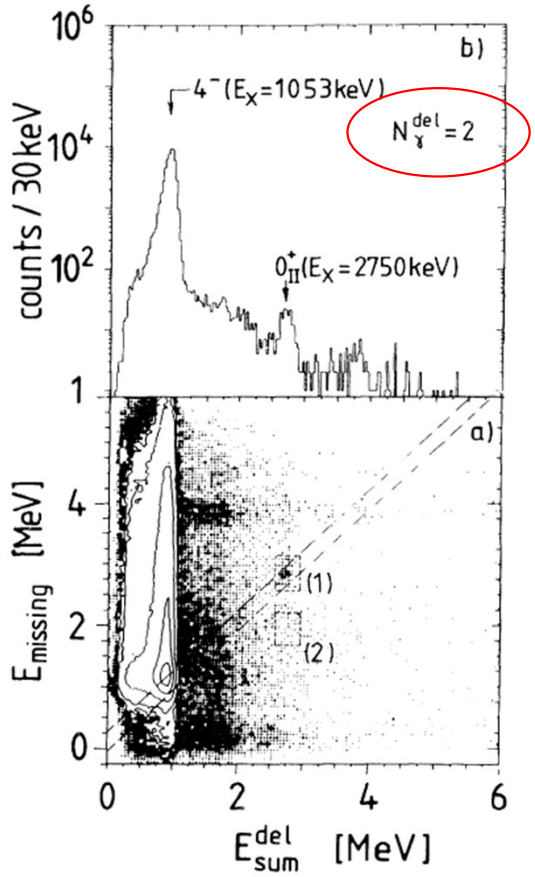


2. Crystal ball experiment : The unambiguous detection



$$E_{missing} = \sum E^{delayed} \approx 2{,}75\ MeV$$

2. Crystal ball experiment : The unambiguous detection



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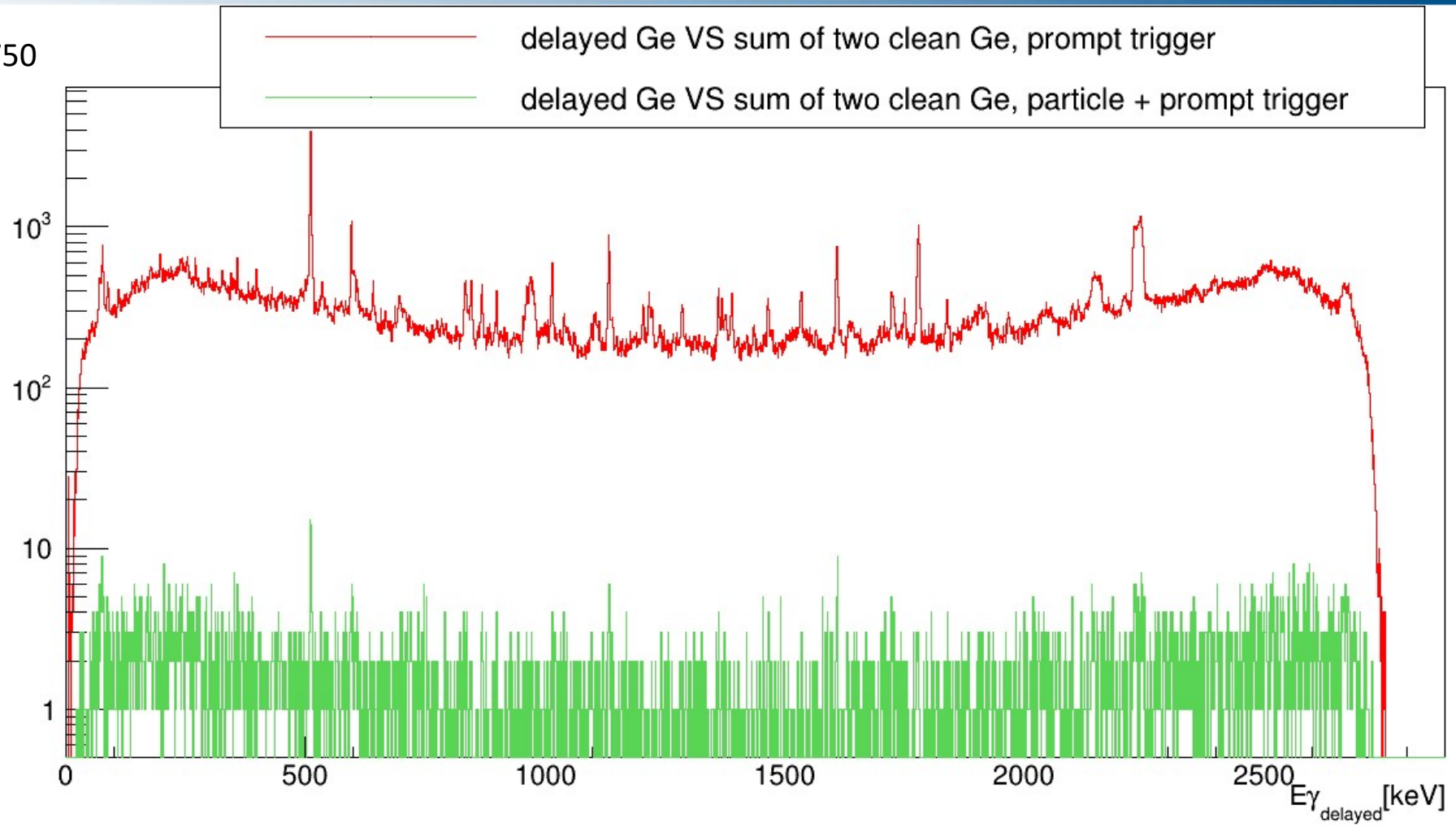
3. 2023, Orsay : High precision spectroscopy with Nuball2

Gate ΣE = 2750



3. 2023, Orsay : High precision spectroscopy with Nuball2

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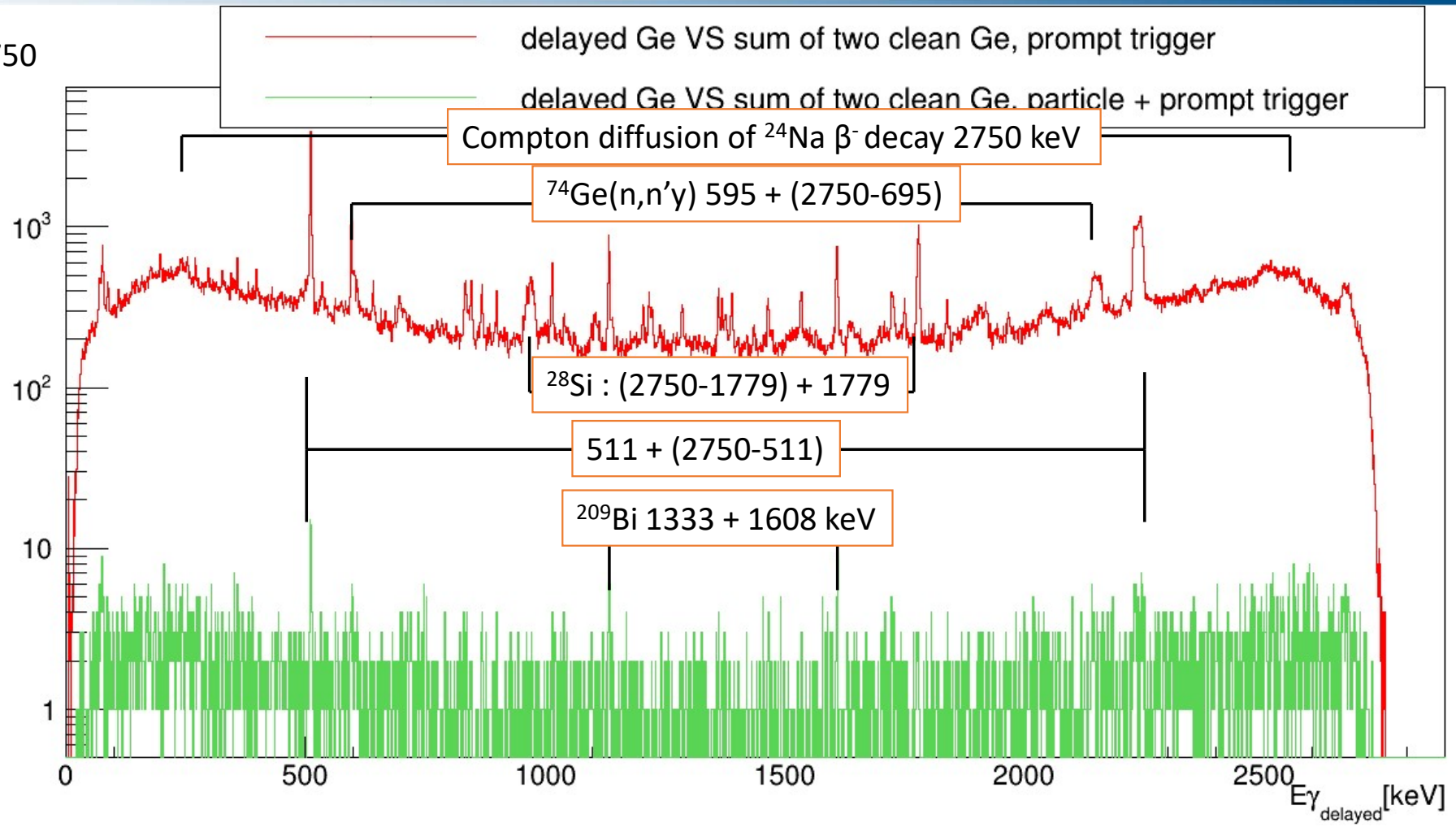
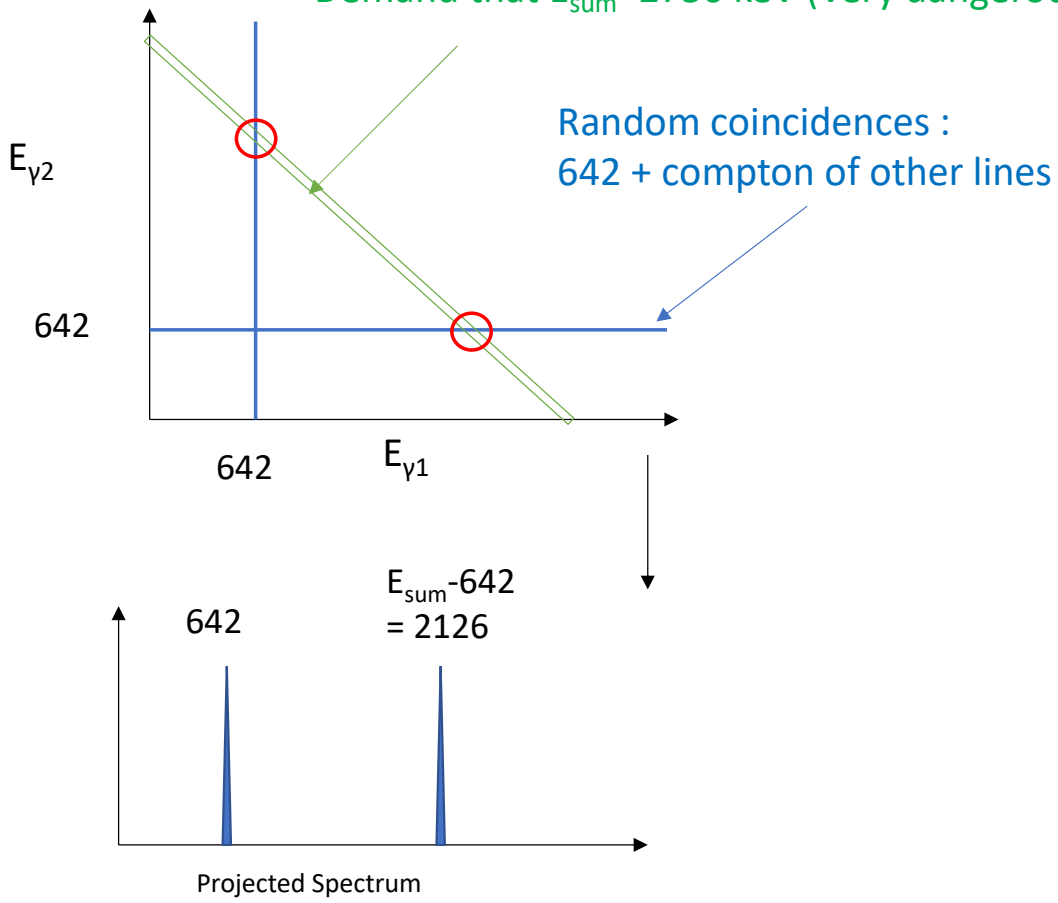
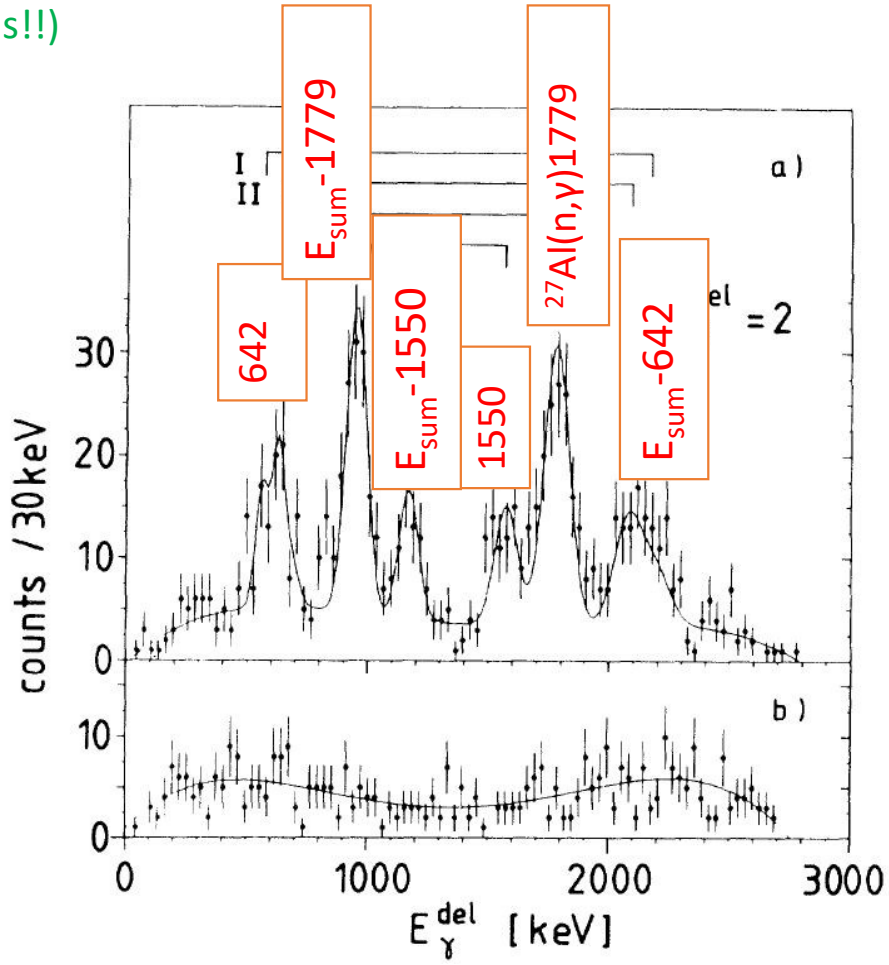


3. 2023, Orsay : High precision spectroscopy with Nuball2

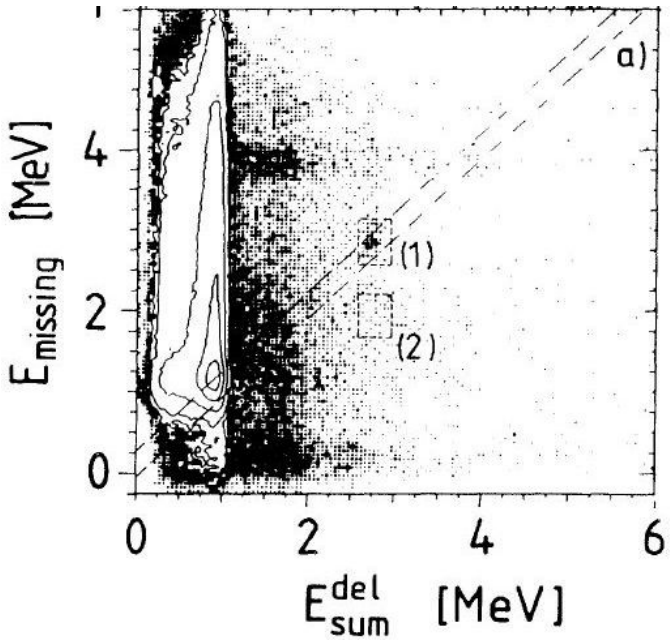
Demand that E_{sum}=2750 keV (Very dangerous!!)

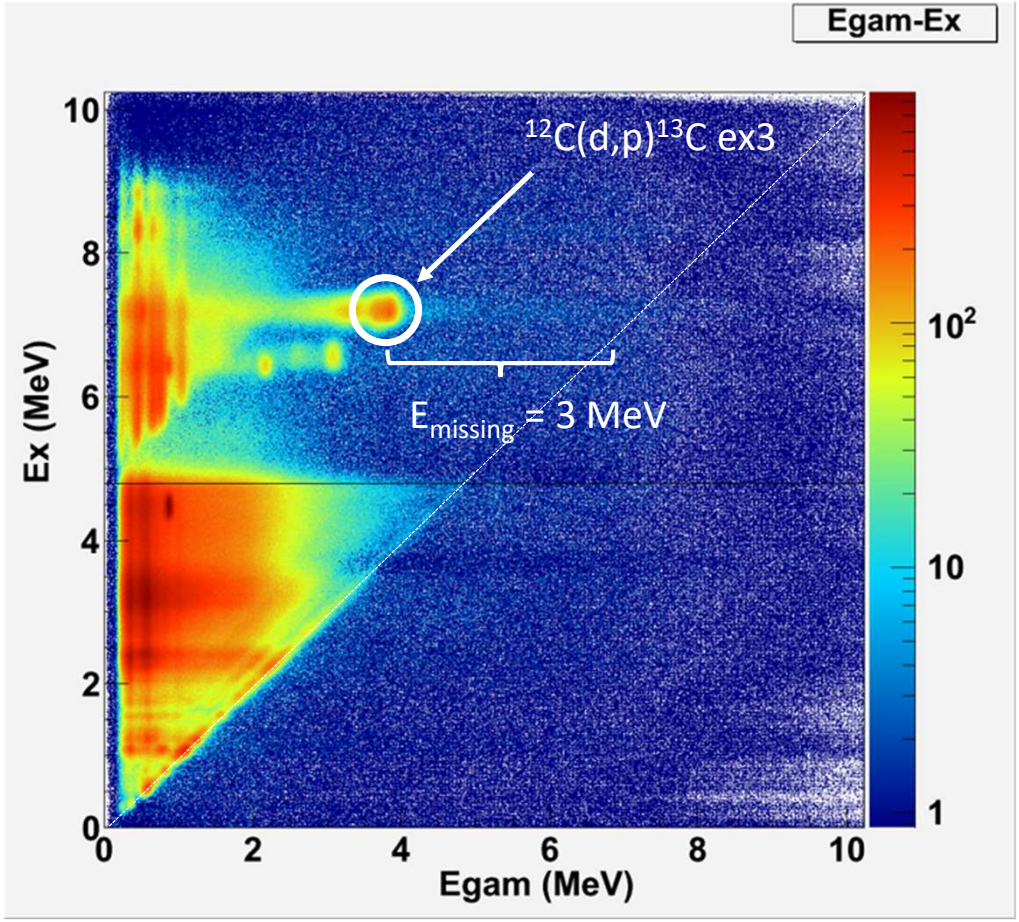




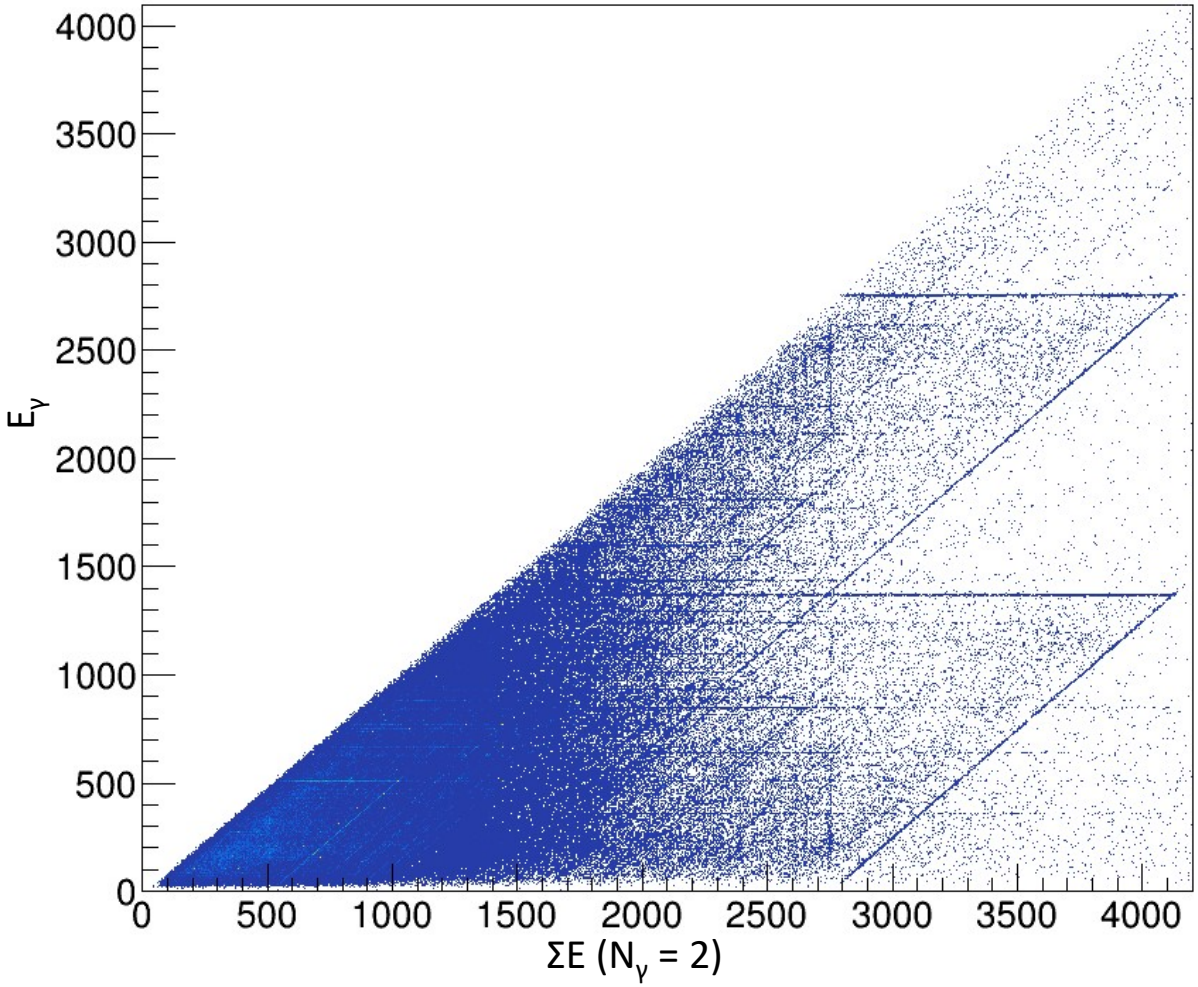
3. 2023, Orsay : High precision spectroscopy with Nuball2

Discrete peaks in $E_{missing}$ can be caused by light target contaminants (e.g. 16O, 12C)

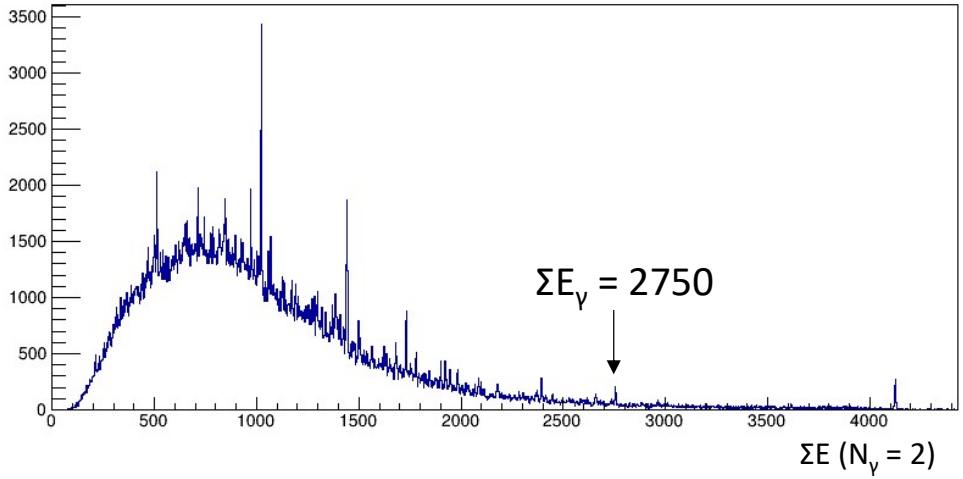


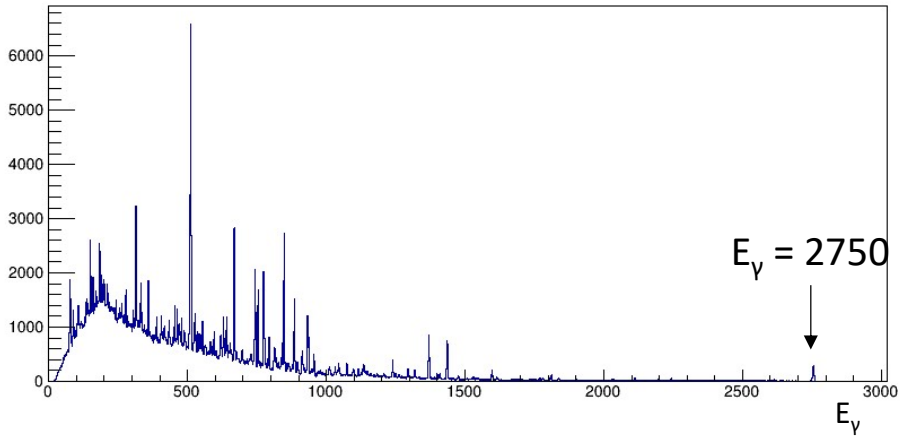


3. 2023, Orsay : High precision spectroscopy with Nuball2



Beam off after the experiment :

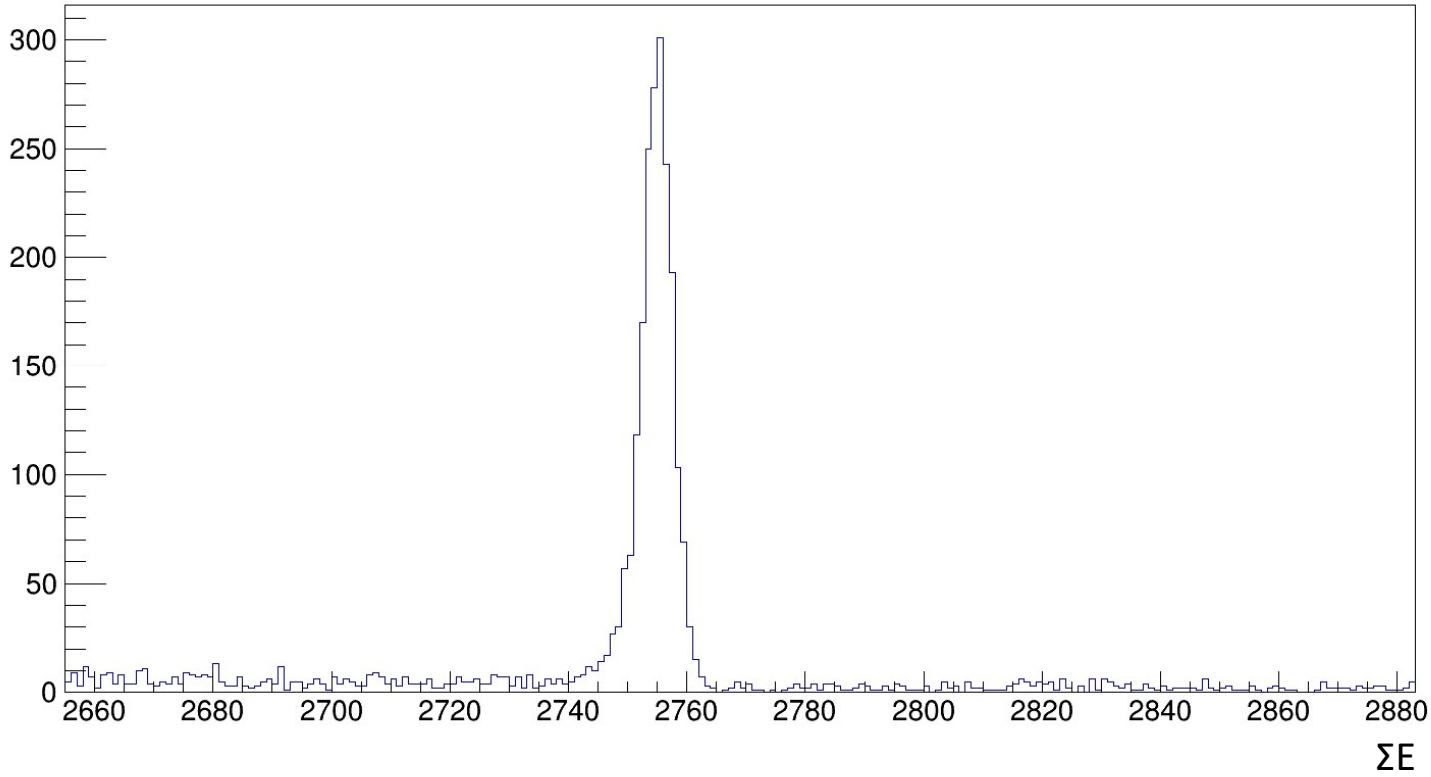




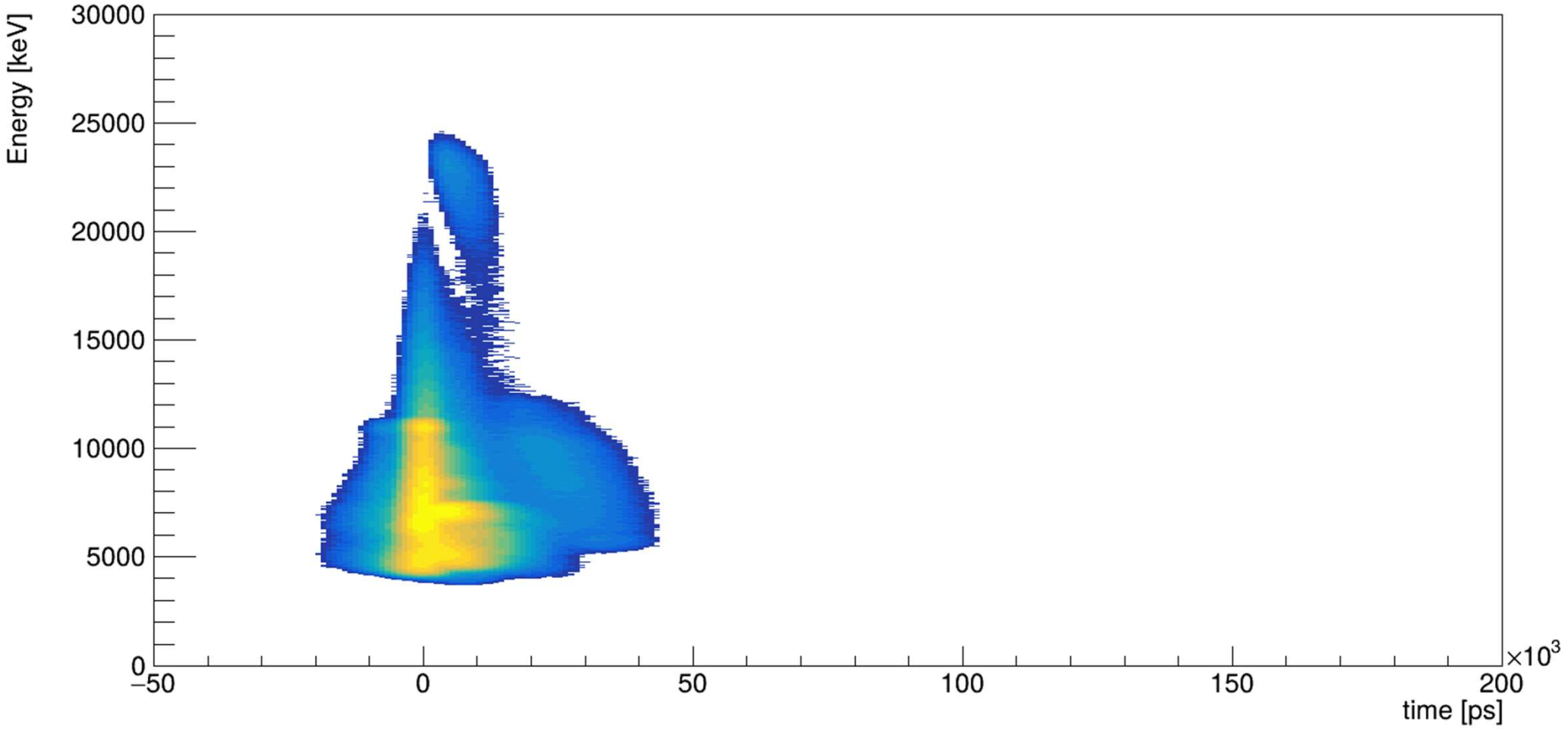
3. 2023, Orsay : High precision spectroscopy with Nuball2

Beam off spectra

^{23}Na neutron capture -> ^{24}Na
β^- decay : ^{24}Na -> ^{24}Mg + 2750 keV



4. A word on the DSSD



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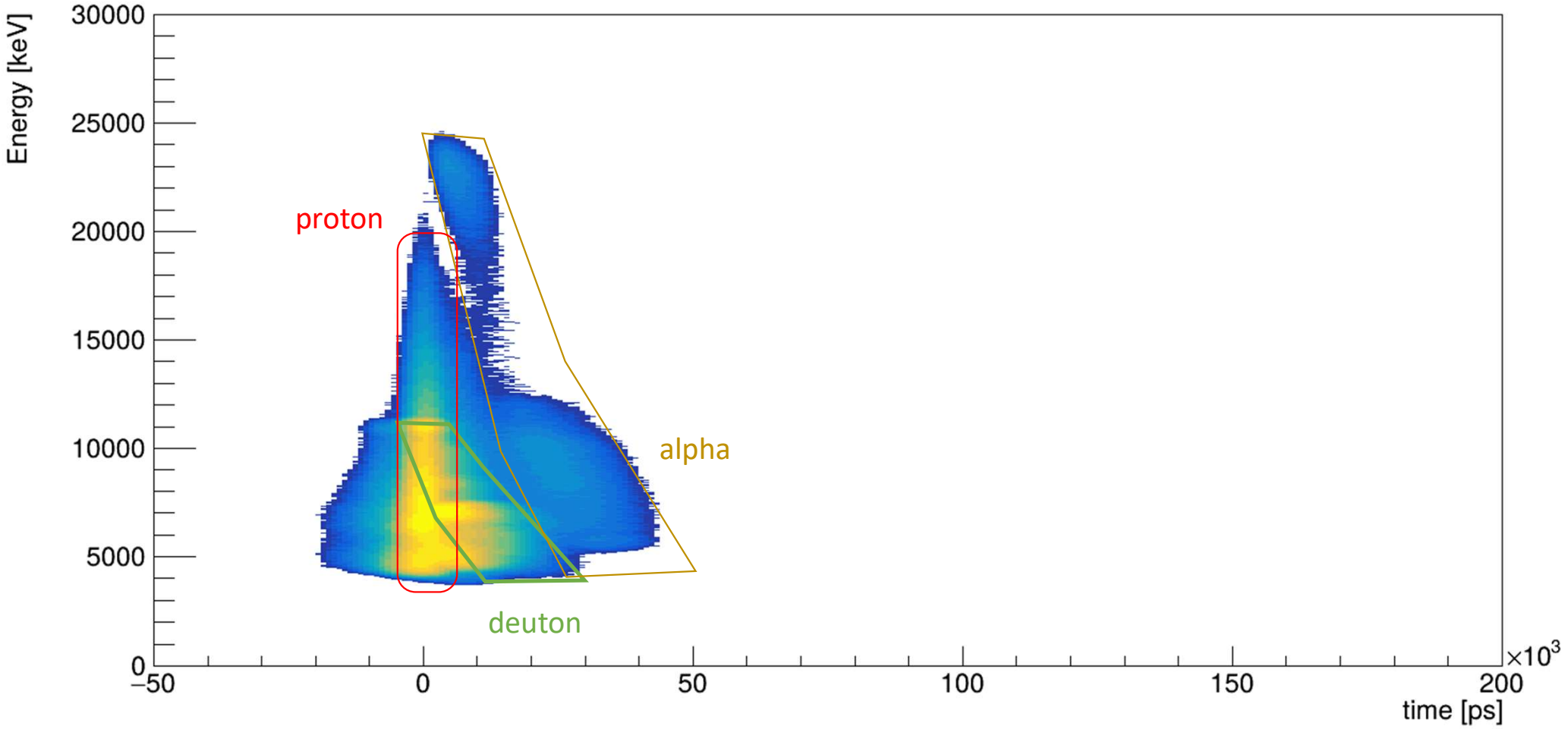
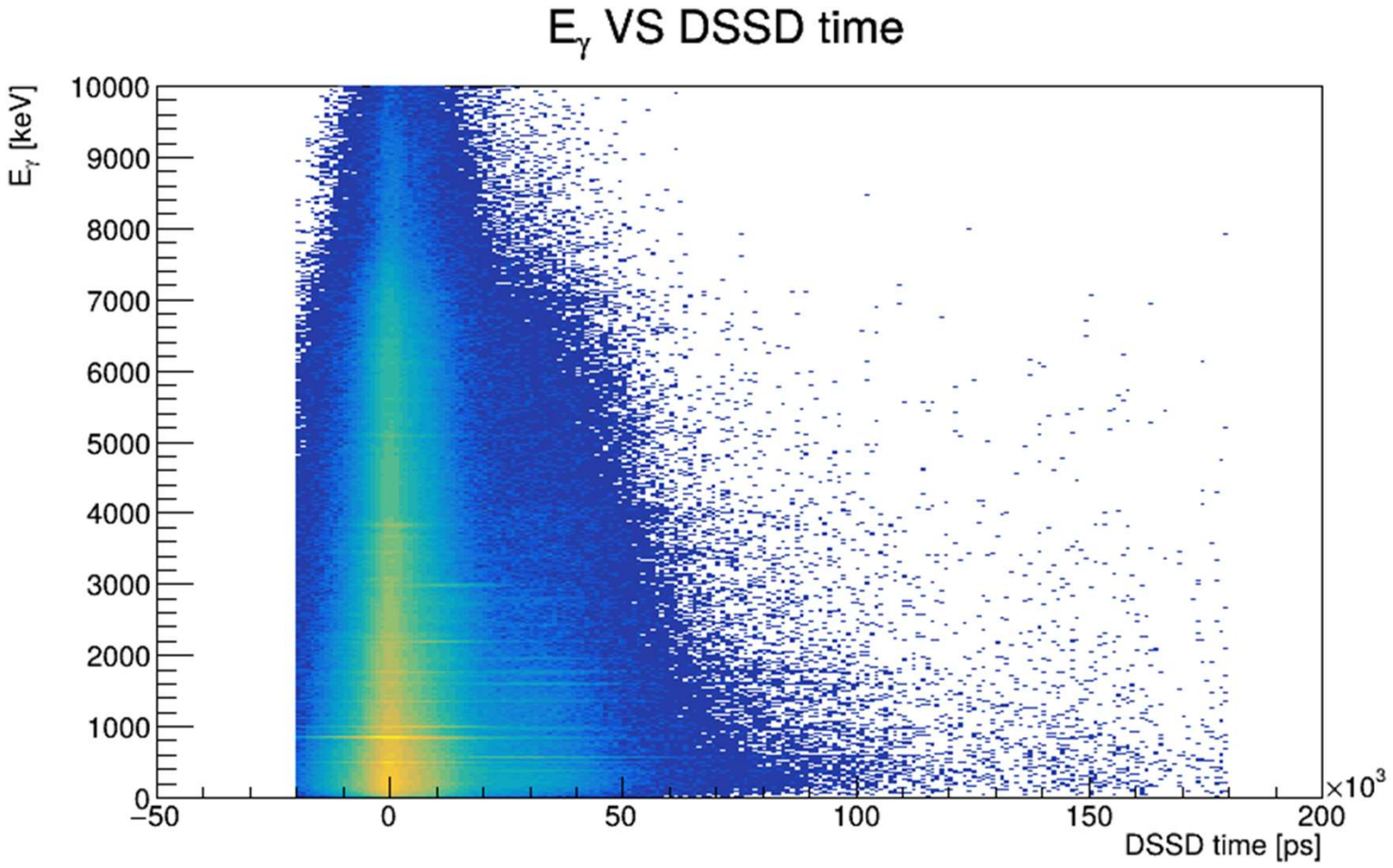


4. A word on the DSSD



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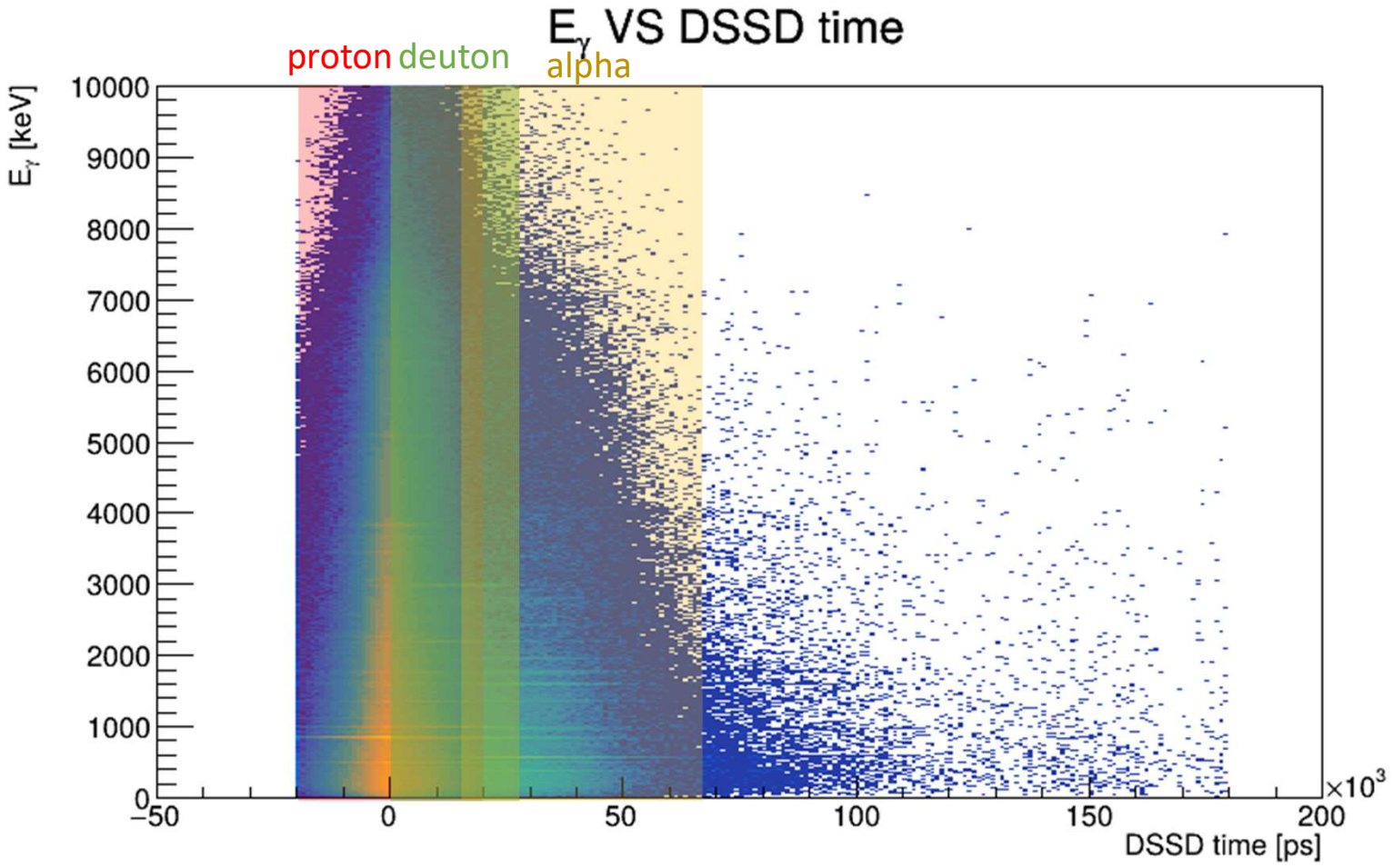

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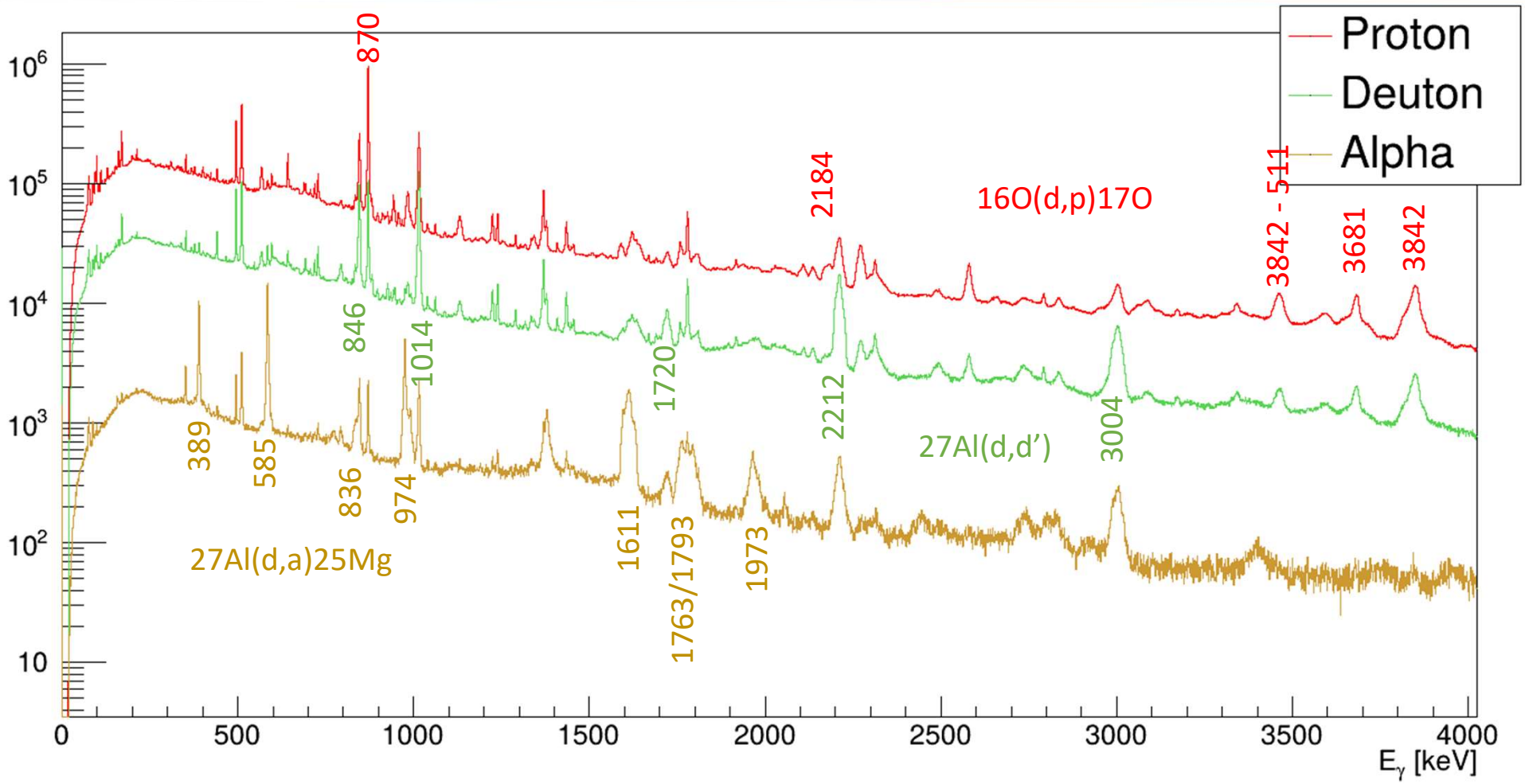

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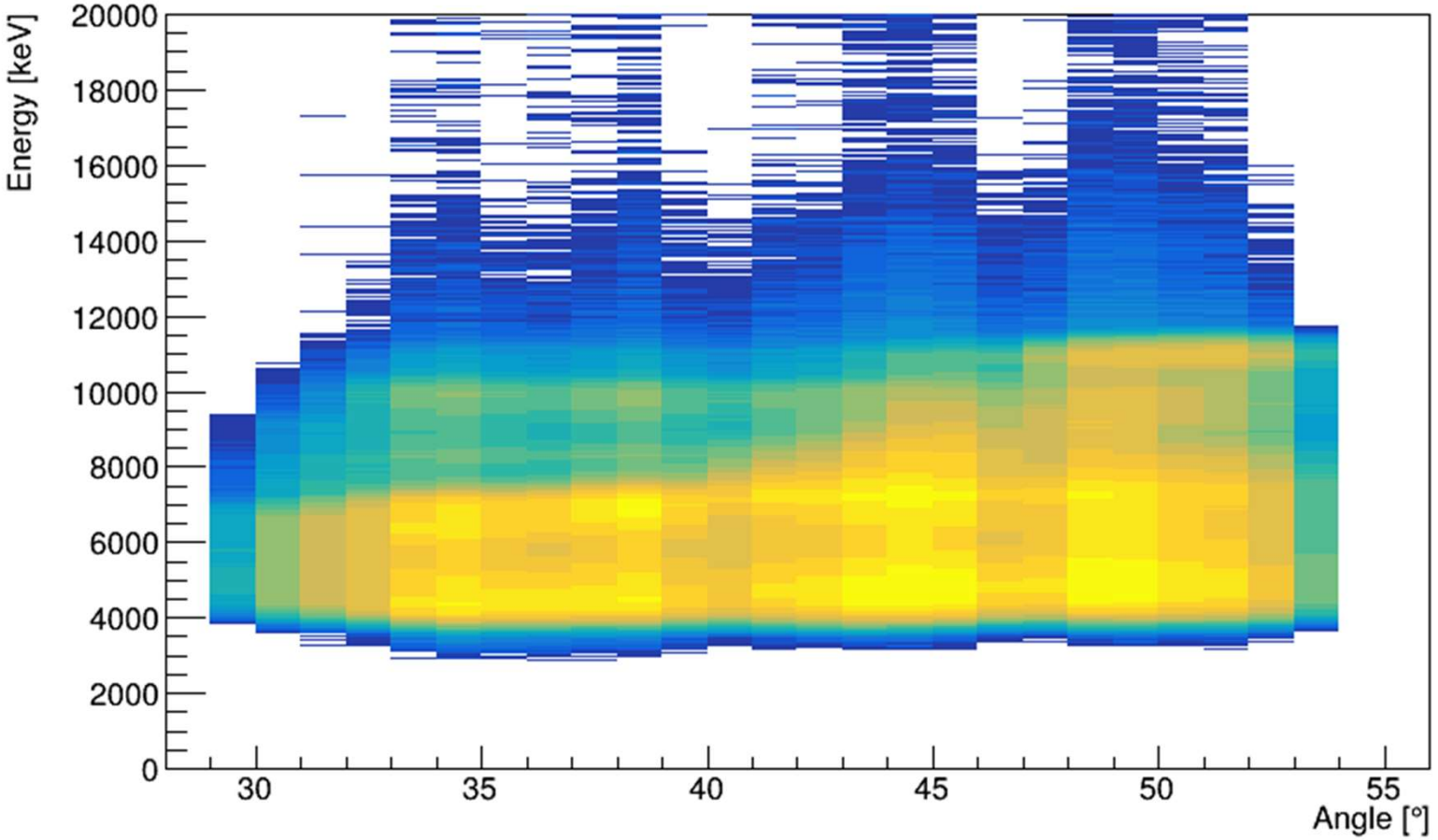
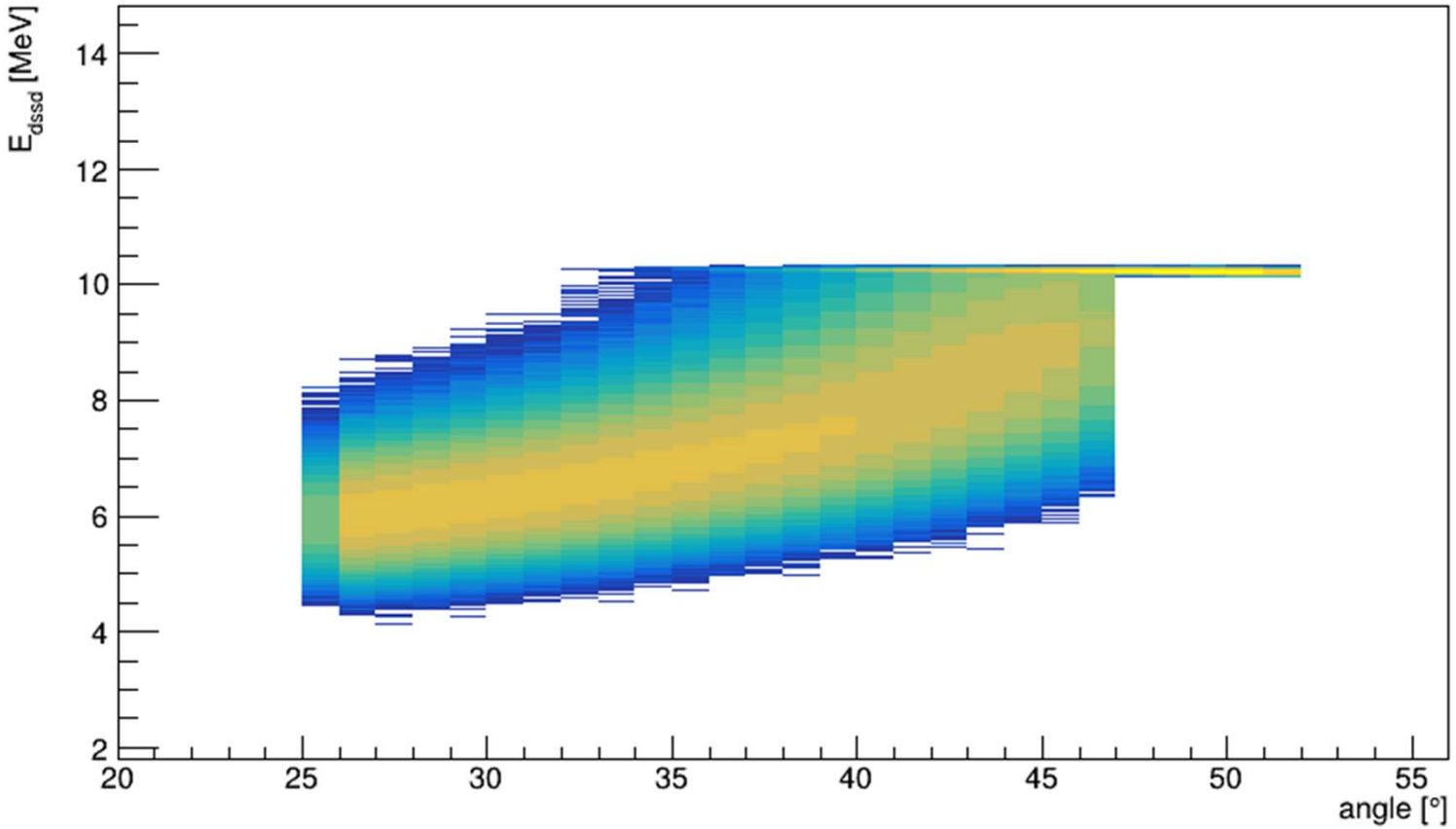
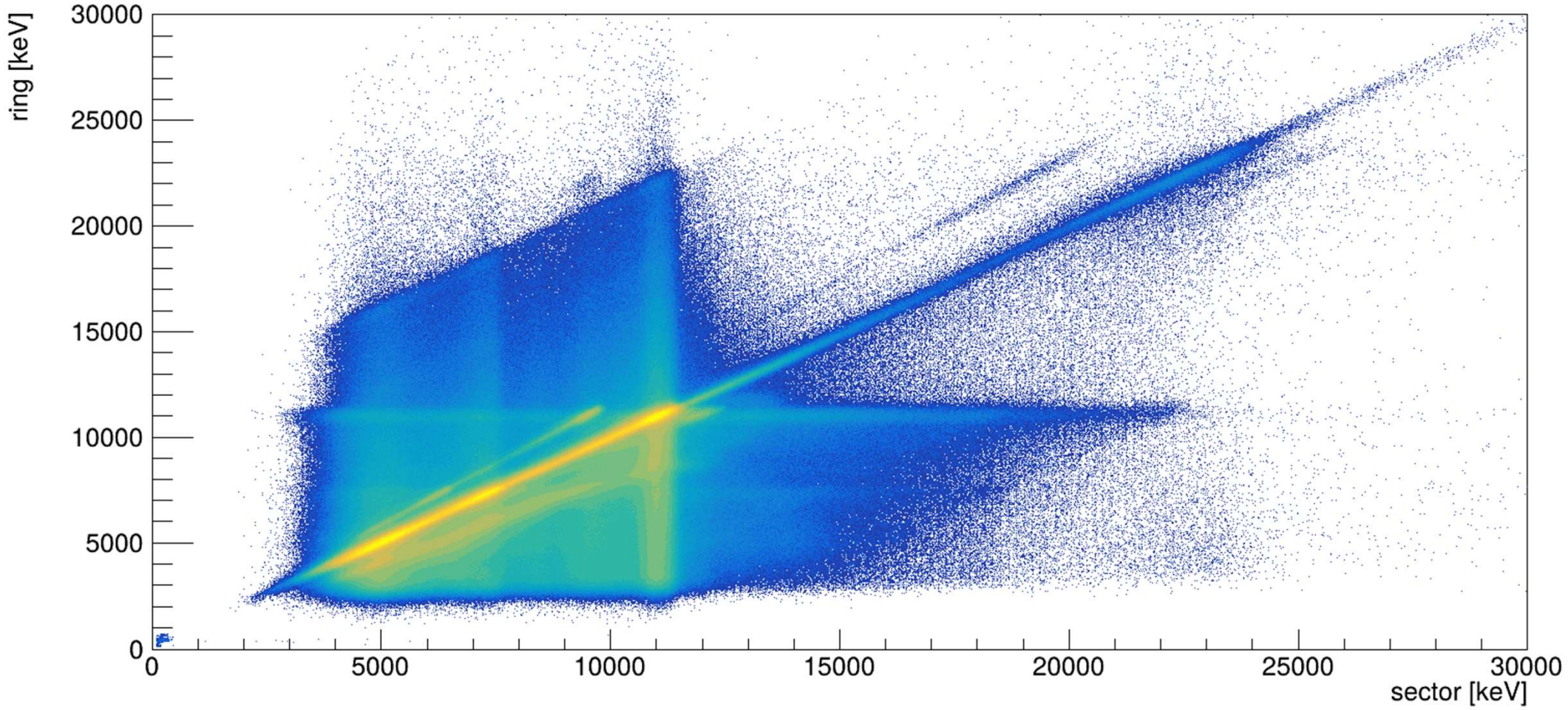


4. A word on the DSSD

Simulated energy deposited in the DSSD from ^{235}U(d,d')



4. A word on the DSSD



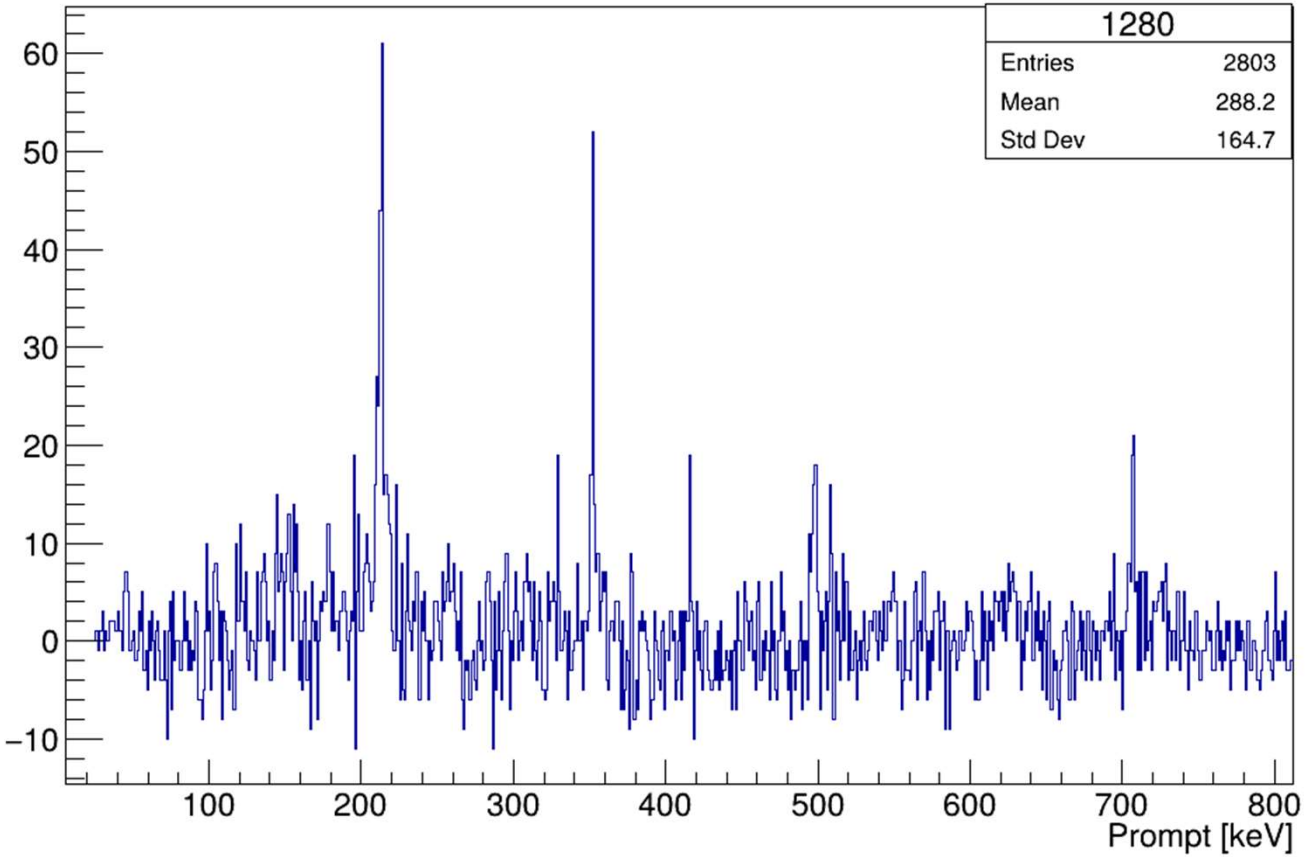
Conclusion

- Experiment with nu-Ball2 carried out under identical conditions with a more powerful array (Ge over NaI)
- We do not confirm the previous result and can't observe gamma back decay.
- We suggest a scenario where the previous result was in fact based on false random coincidences
- Back decay, if it exists, must be in the sub-microbarn range
- *Hence INNER BARRIER PENETRATION/HEIGHT PARAMETERS underpinning theory for the actinide region may well be DIFFERENT than those currently used*
- A more sensitive search for back-decay in gamma coincidence data for 236U and 233Th is ongoing
- New unknown states feeding the 4- isomer in 236U have been observed.

BACKUP

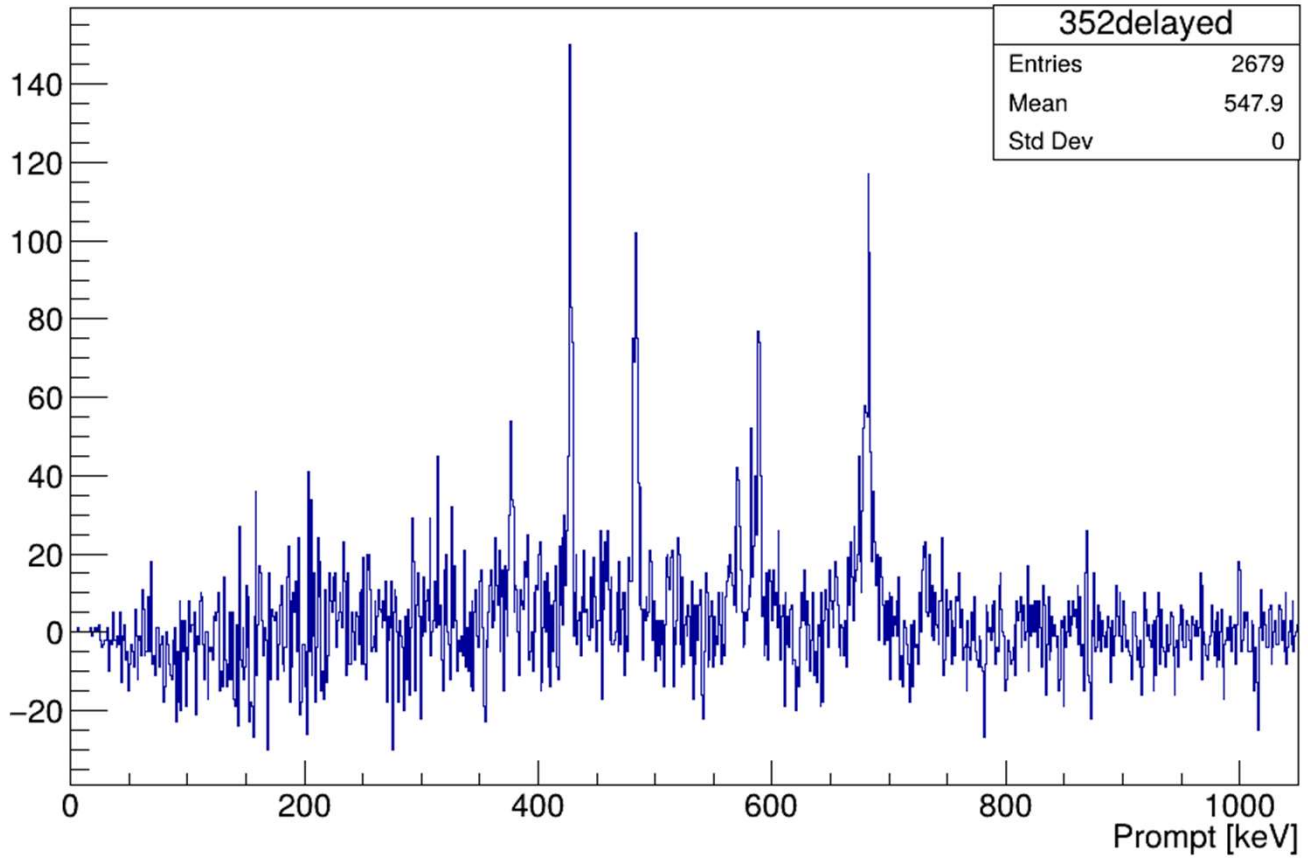
Prompt-delay spectroscopy

^{134}Xe



Prompt-delay spectroscopy

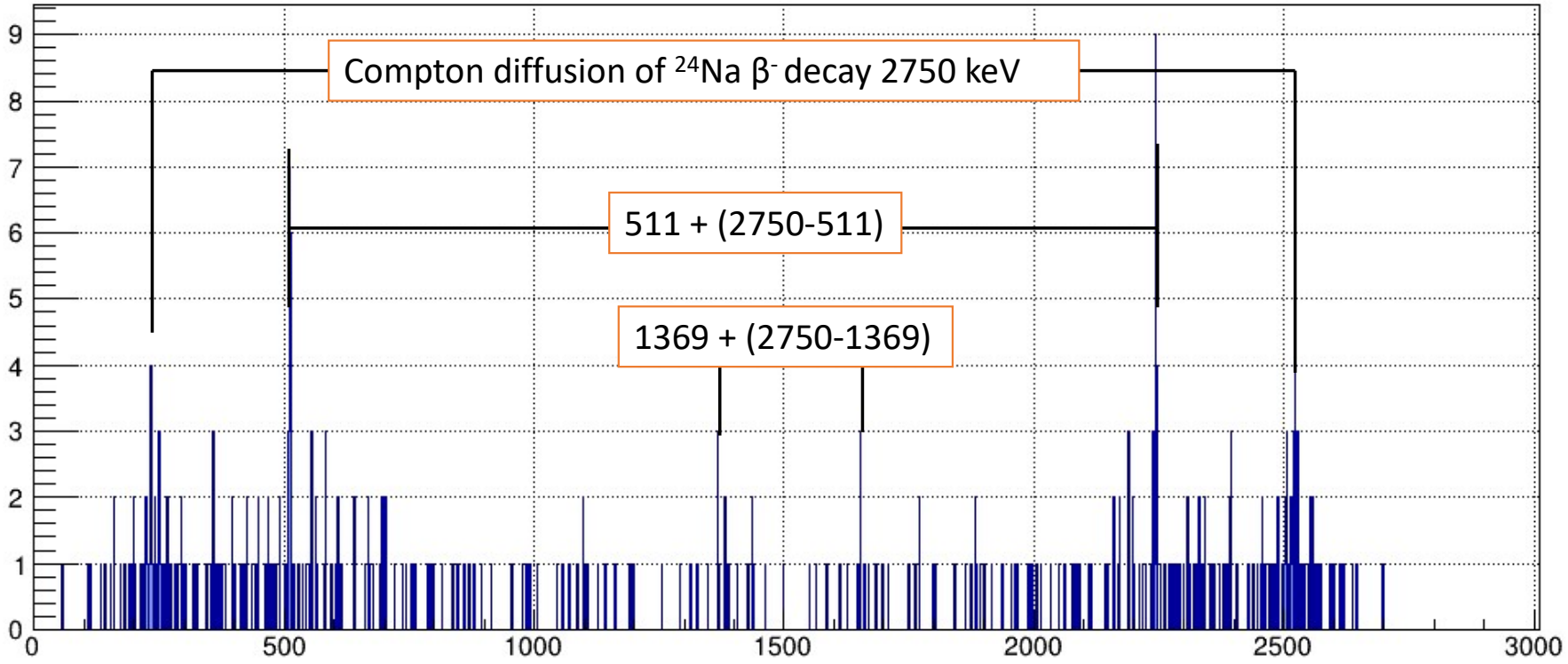
^{95}Sr



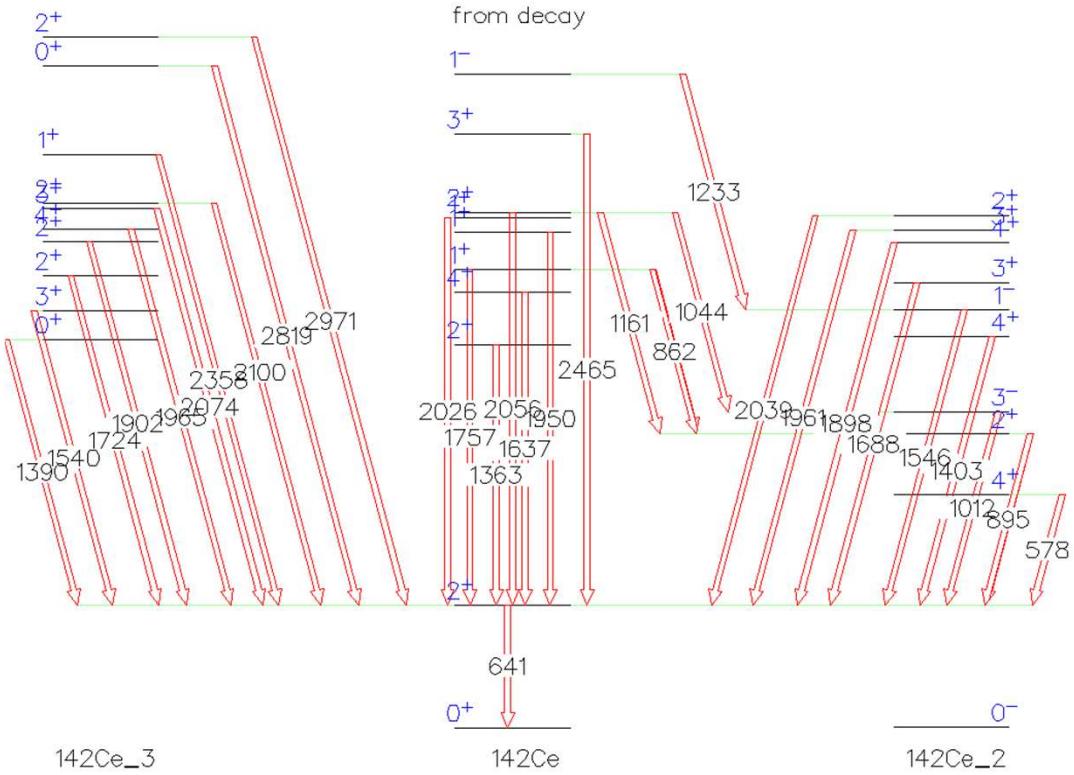
3. 2023, Orsay : High precision spectroscopy with Nuball2

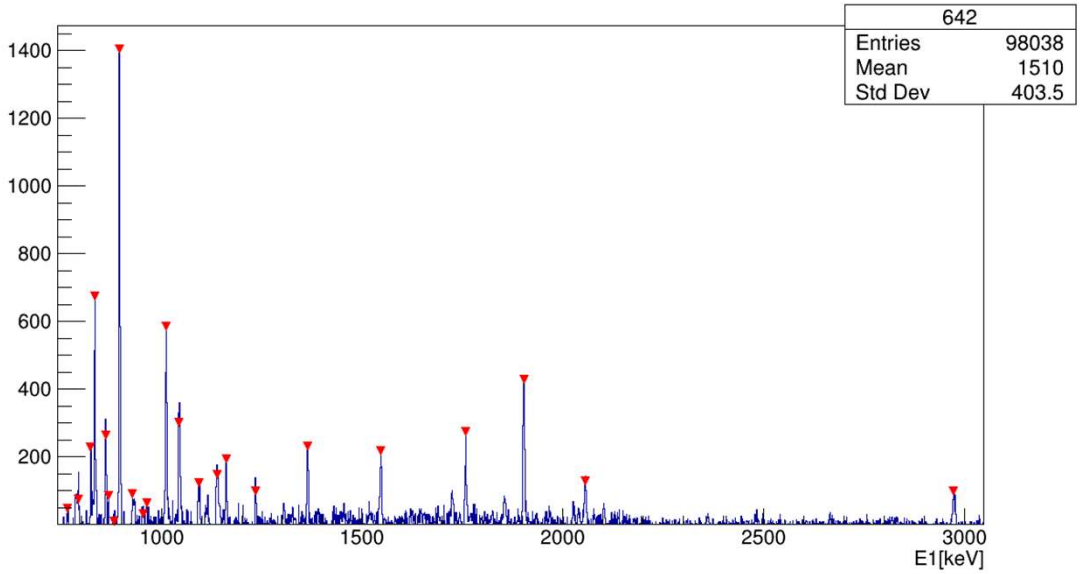
Gate ΣE = 2750

Beam off after the experiment :



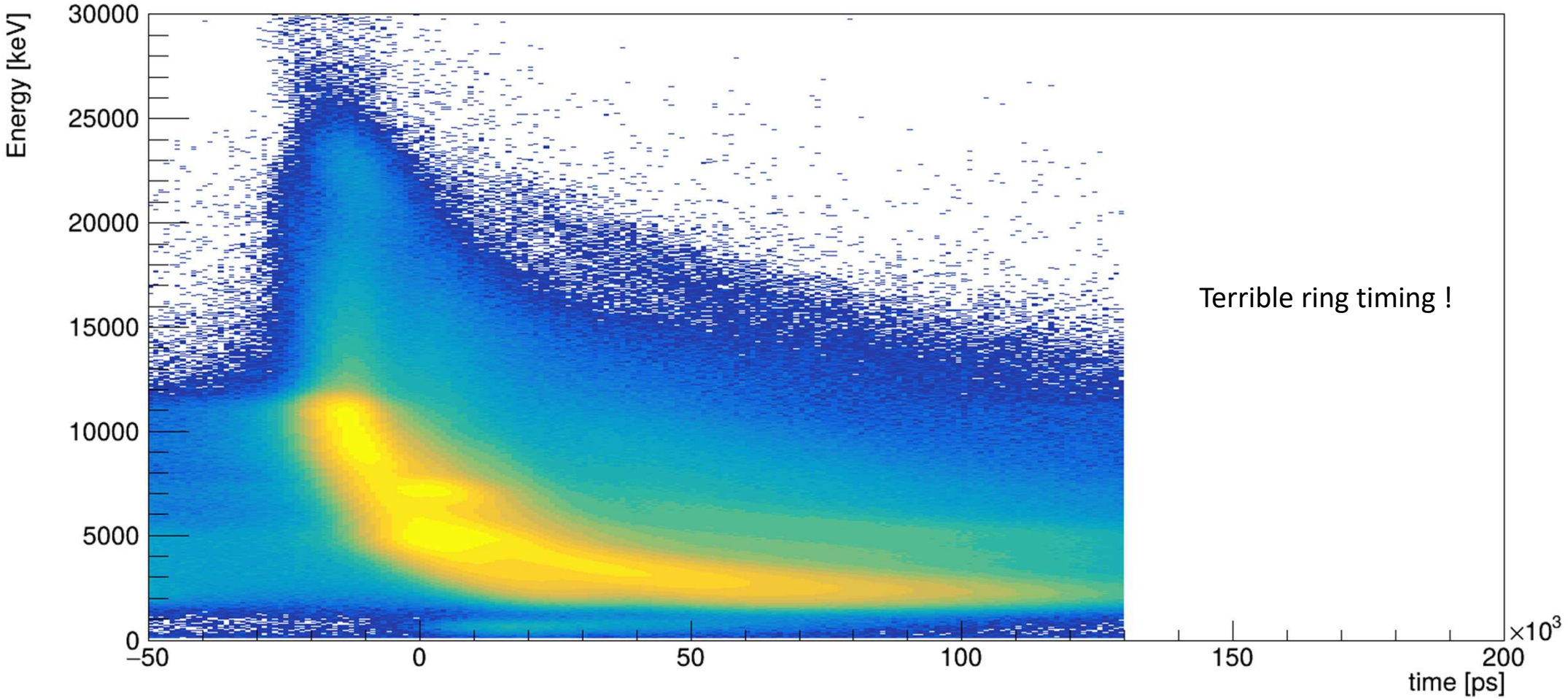
3. 2023, Orsay : High precision spectroscopy with Nuball2



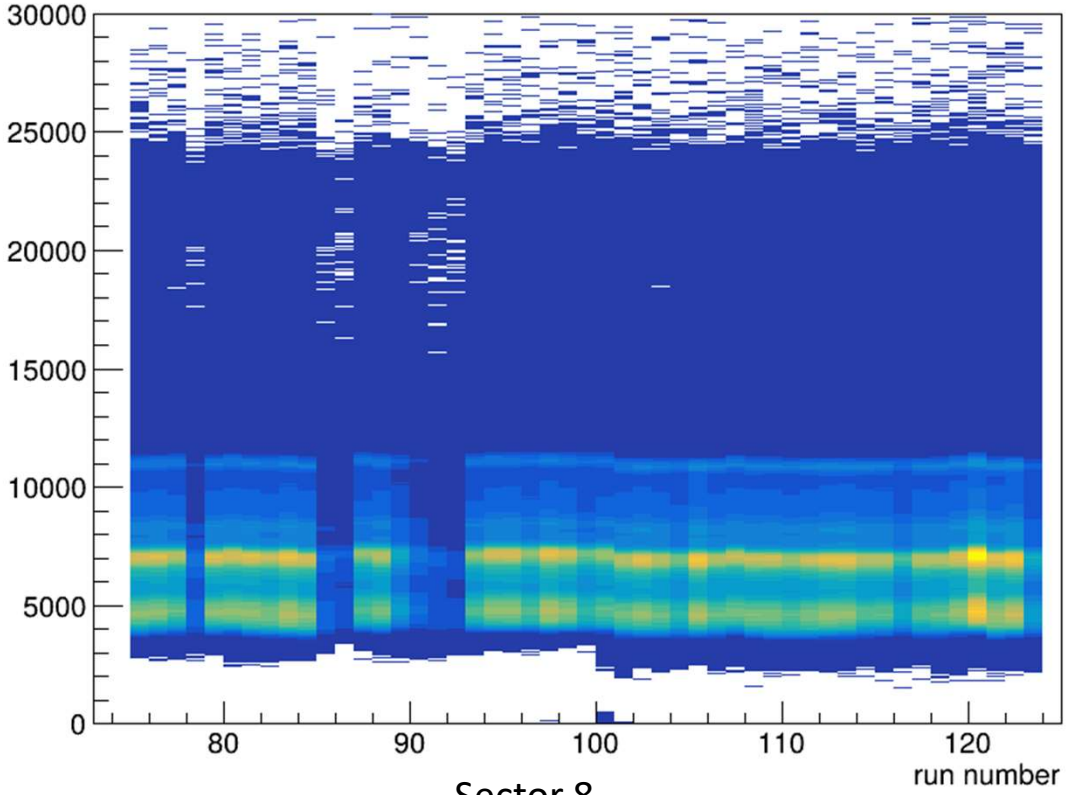


Huge contamination of ^{142}Ce above 500 keV !!!

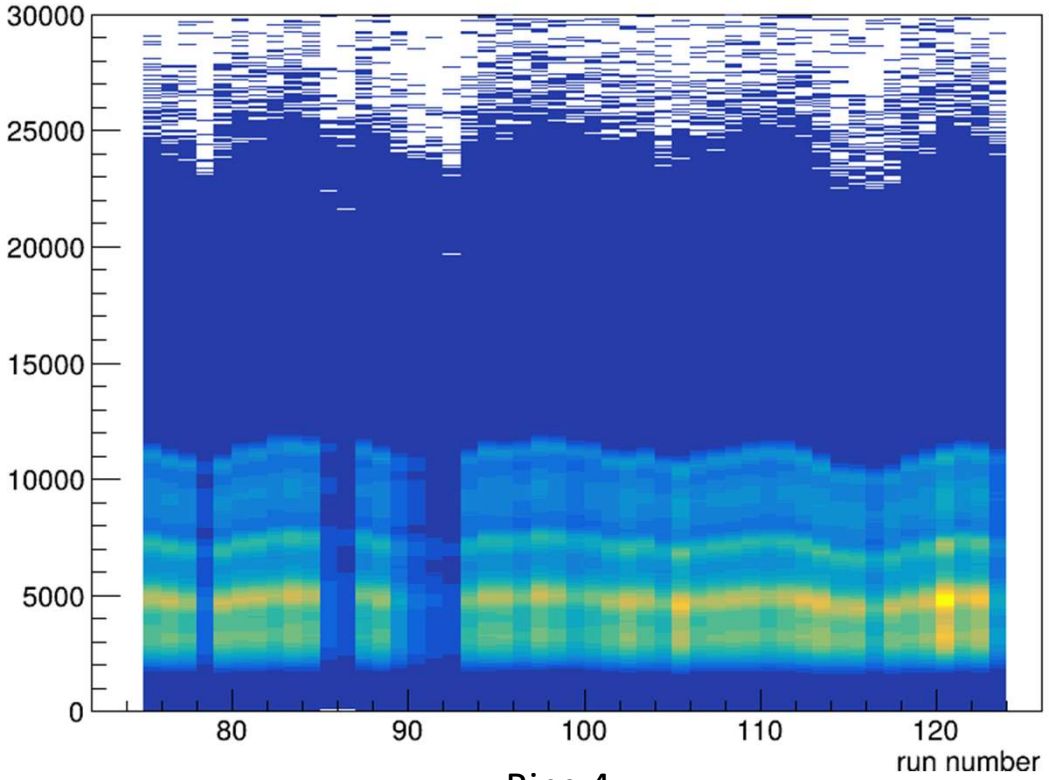
4. A word on the DSSD



Gain drift



Sector 8



Ring 4