Complete Low-Spin Spectroscopy and Shape Coexistence in ^{44}Ca via the (n,γ) Reaction

GAMMA Science, Collaboration Workshop
Milano 9th-10th April 2026

Massimiliano Luciani - Università degli Studi di Milano

Collaboration

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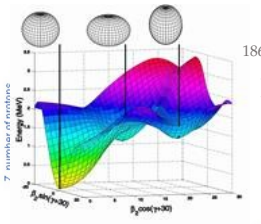
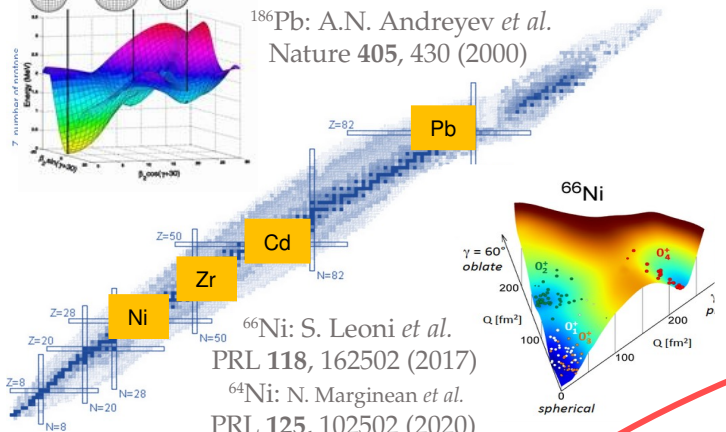
Institut für Kernphysik, Univsersität zu Köln, Köln, Germany

Shape coexistence across the nuclide chart



^{186}Pb: A.N. Andreyev *et al.*
Nature **405**, 430 (2000)



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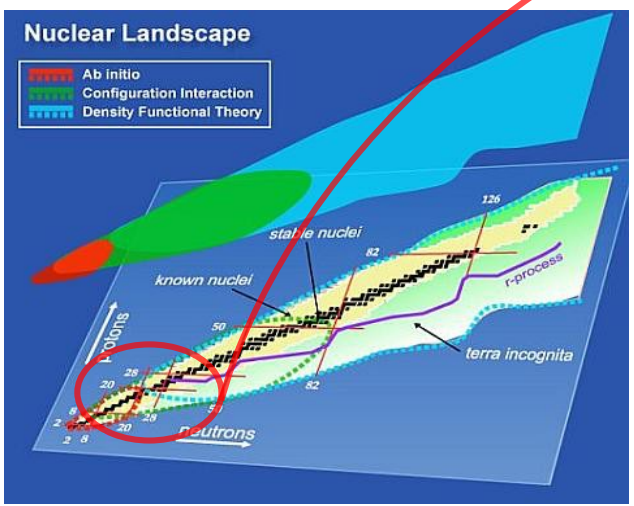
^{39}Ca β+	^{40}Ca 2β+	^{41}Ca e- capture	^{42}Ca Stable	^{43}Ca Stable	^{44}Ca Stable	^{45}Ca β-	^{46}Ca 2β-	^{47}Ca β-	^{48}Ca 2β-	^{49}Ca β-
^{38}K β+	^{39}K Stable	^{40}K β-	^{41}K Stable	^{42}K β-	^{43}K β-	^{44}K β-	^{45}K β-	^{46}K β-	^{47}K β-	^{48}K β-



The **A~40** region of the nuclear chart is the common ground of **several** theoretical approaches

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- Y. Utsuno, T. Otsuka, B. A. Brown, M. Honma, T. Mizusaki, and N. Shimizu, Progr. Theor. Phys. Suppl. **196**, 304 (2012)
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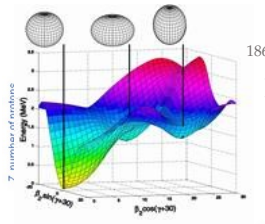

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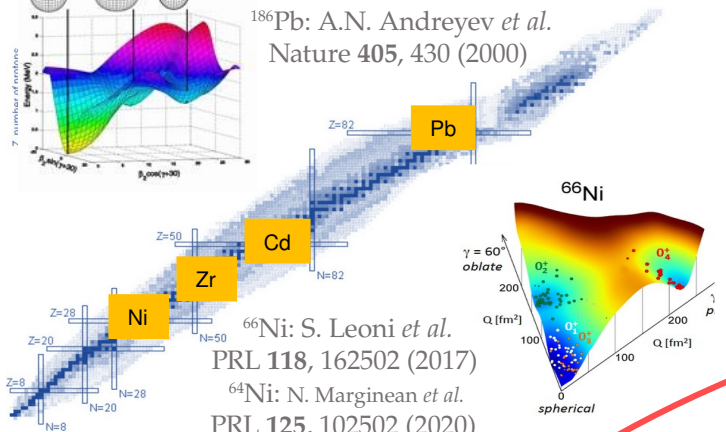

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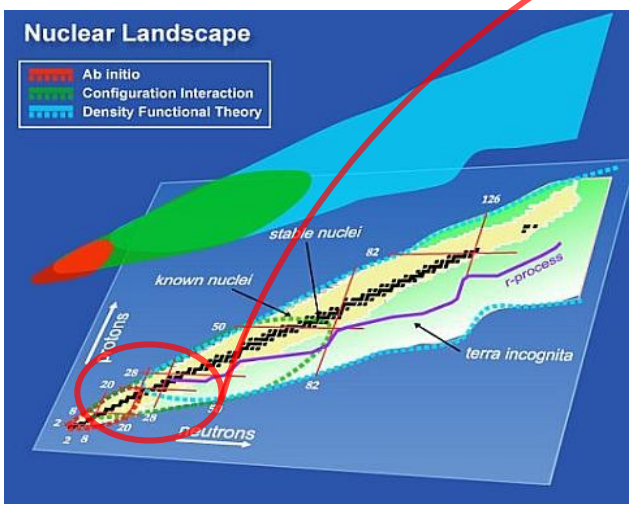

Already published

S. Bottoni *et al.*
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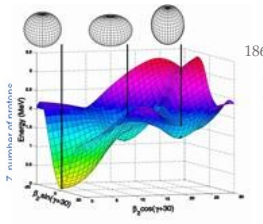

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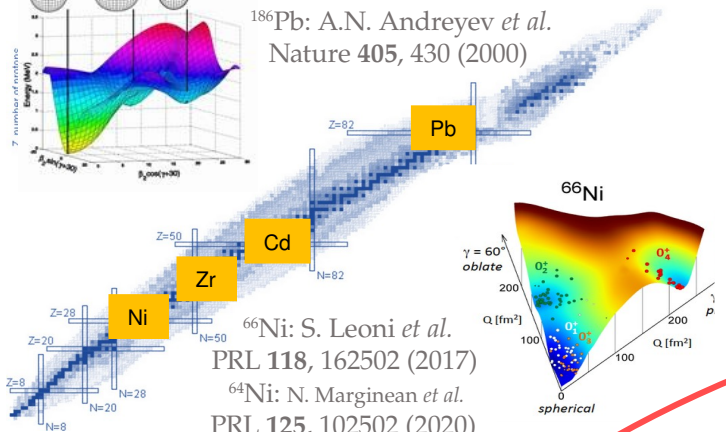

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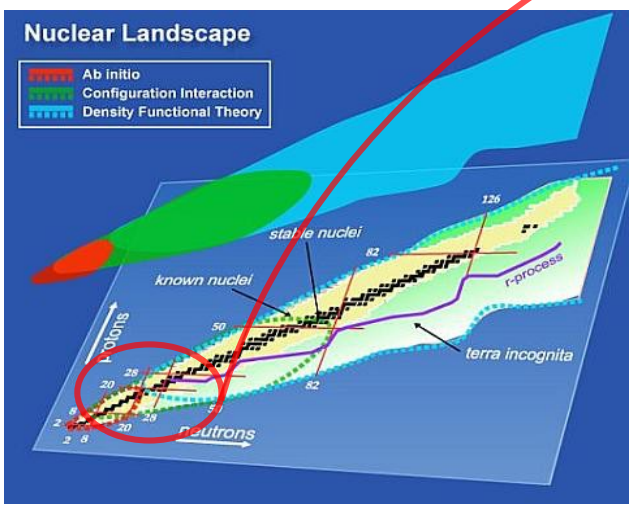

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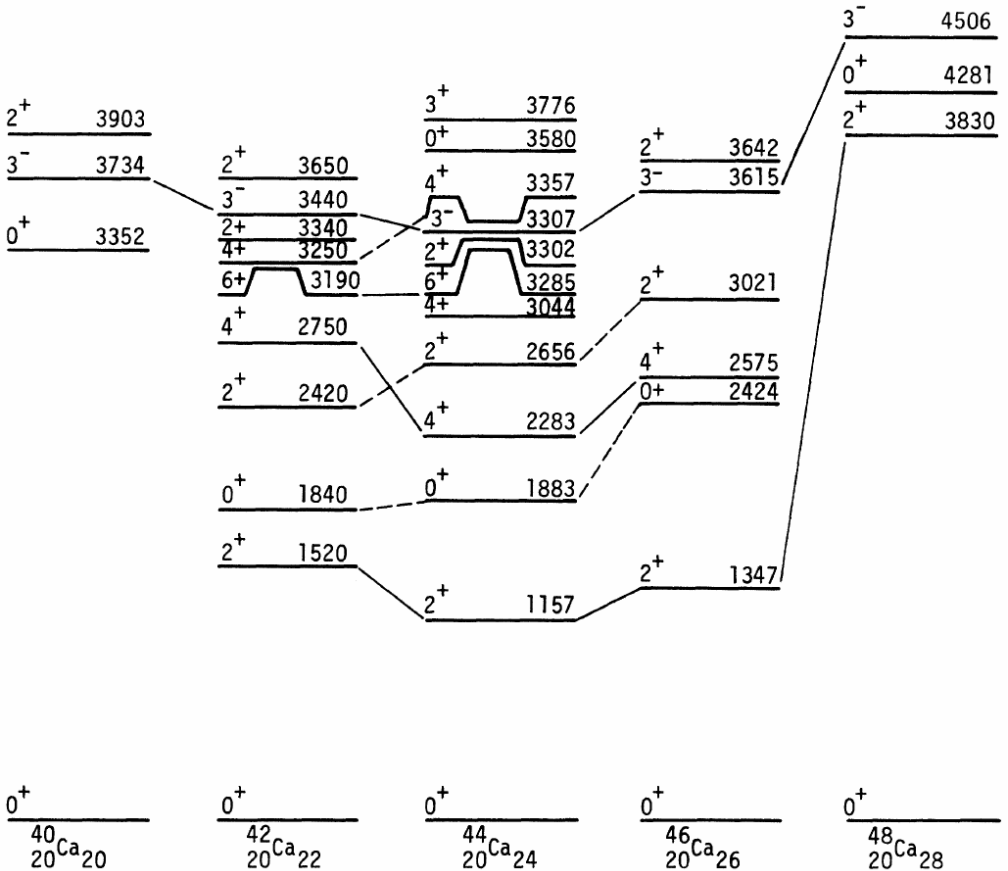
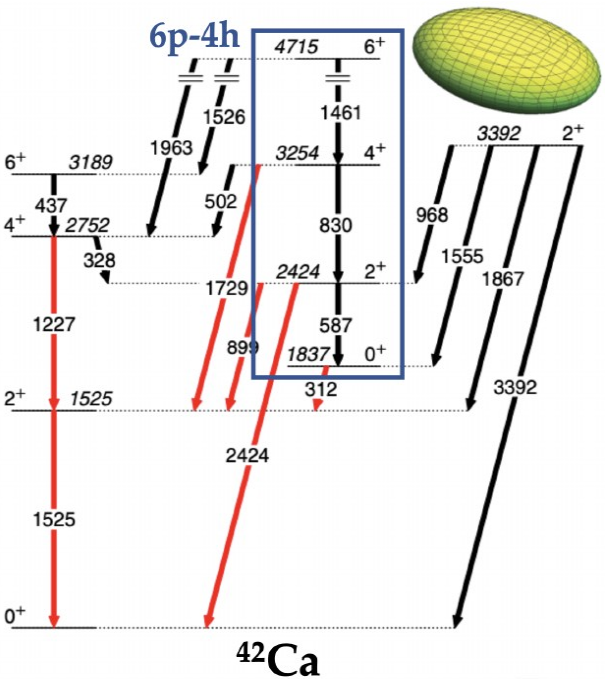


- *Coupled quadrupole-octupole excitations in ^{44}Ca and the decay of ^{44}K, ^{44}Sc^{m} and ^{44}Sc^{g} – Phys. Rev. C 13 (1976)*

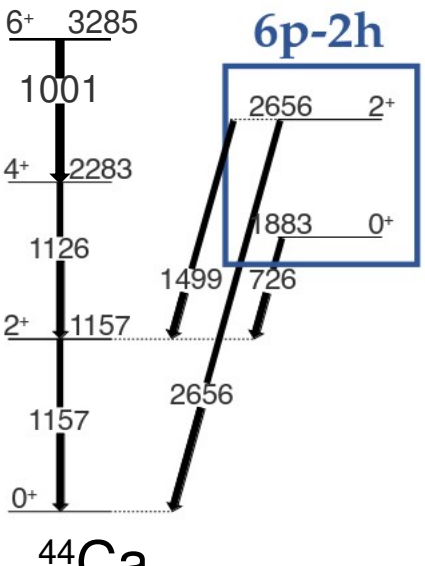
^{42}Ca



^{42}Ca

- *^{42}Ca deformed band reported by K. Hadyńska et al. – Phys. Rev. C 97 (2018)*

^{44}Ca



^{44}Ca

- *The even parity spectrum of ^{44}Ca by L. D. Skouras et al. – Nuc. Phys. A220 (1974)*
- *Alpha pickup to low-lying levels of ^{42,44}Ca – Phys. Rev. C 11 (1975)*
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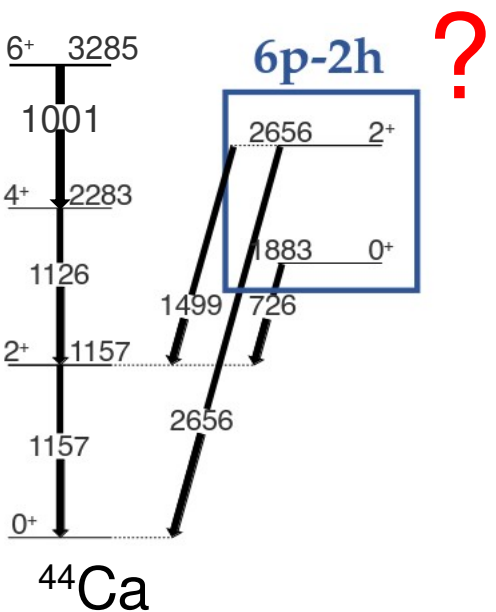
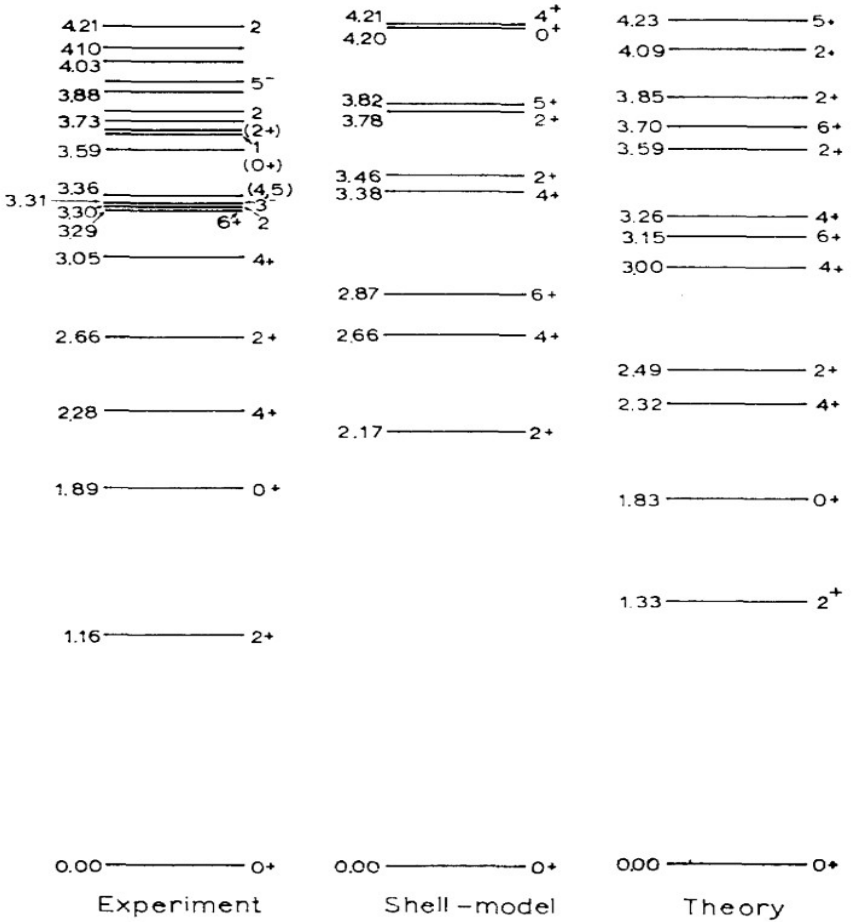
^{44}Ca





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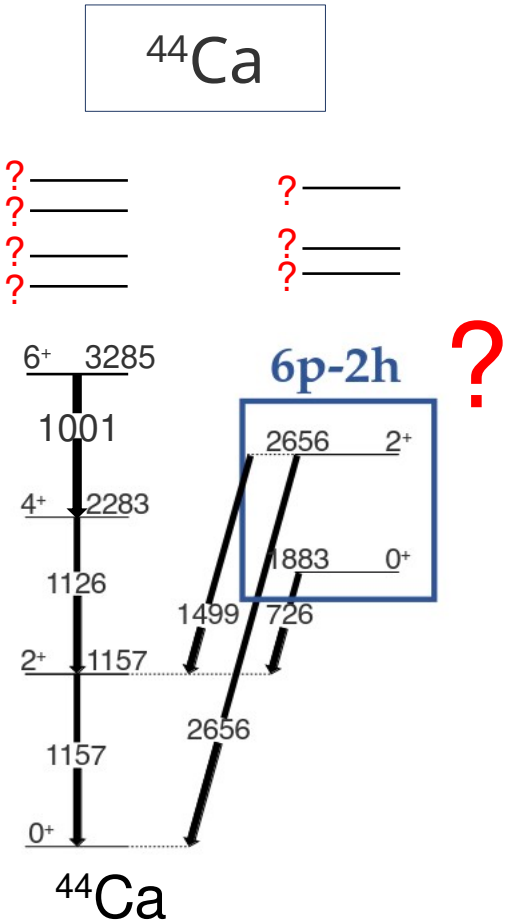

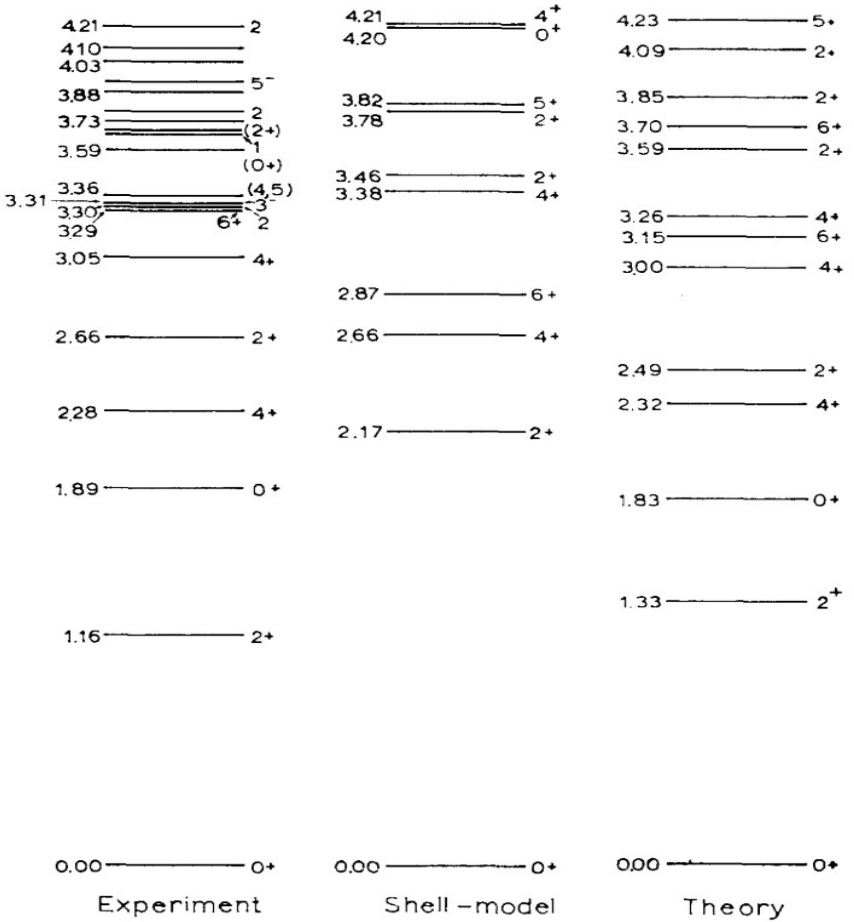

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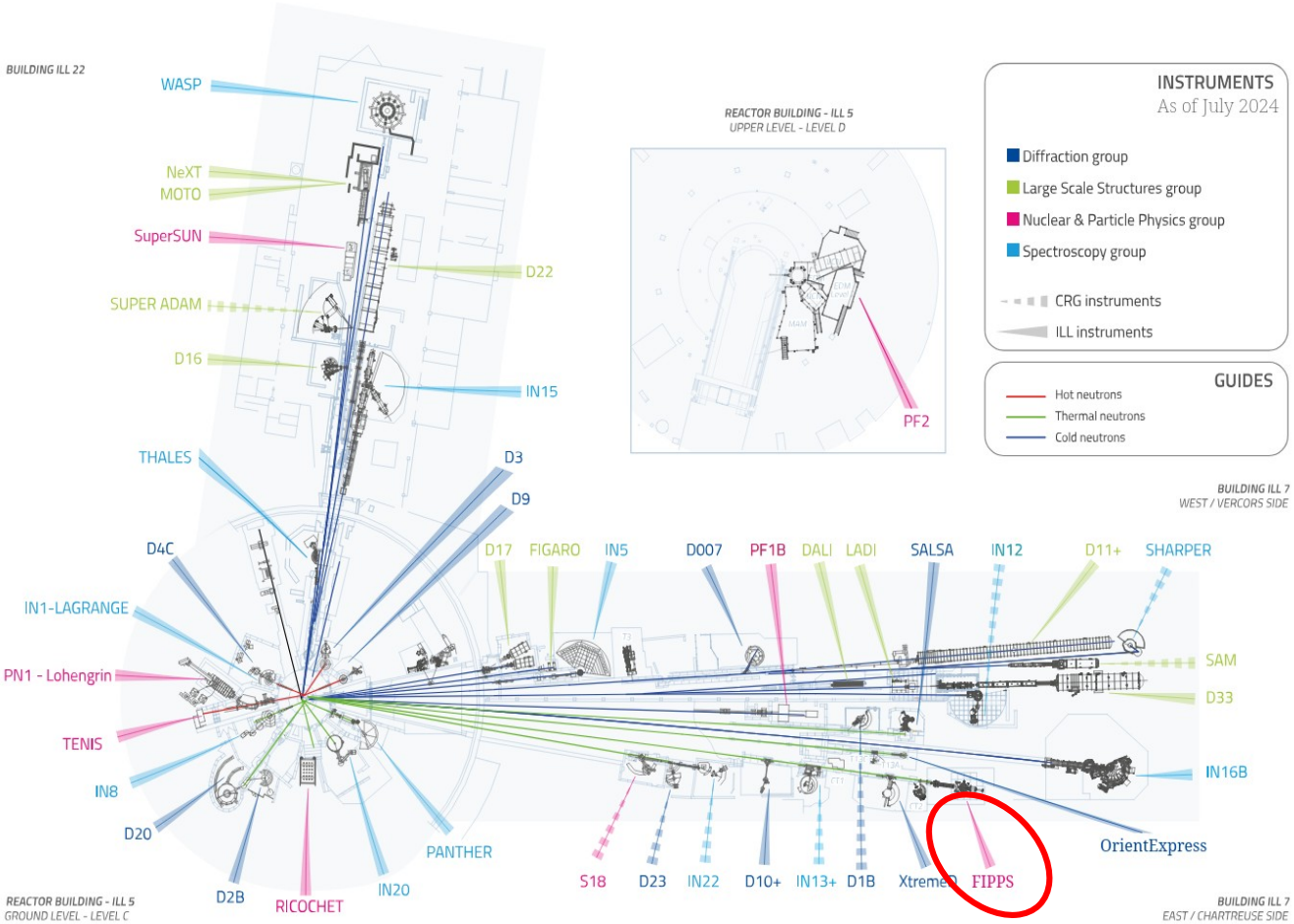
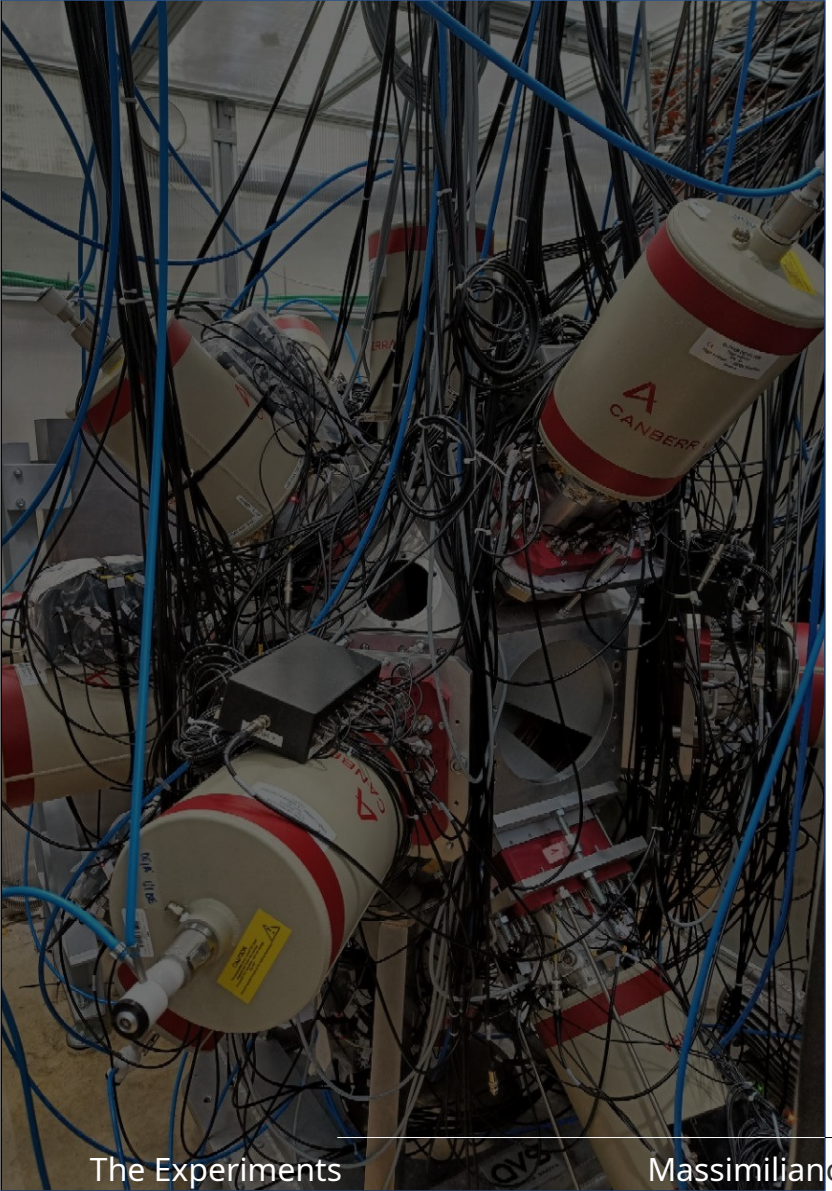


Institut Laue Langevin (ILL) Grenoble (Fr)

- Thermal Power: ~ 58 MW
- Neutron Flux: 1.5 x 10^{15} n cm^{-2} s^{-1}
- Neutron Flux at FIPPS: 10^{8} n cm^{-2} s^{-1}
- Beamlines: 40

Fundamental Science:

- Condensed Matter Physics
- Material Science
- Chemistry
- Biology
- Nuclear and Particle Physics



Reactions:

- $^{43}Ca(n_{th},\gamma)^{44}Ca$

FIPPS:

- 32 HPGe (8 Clovers) + BGOs

Coupled to:

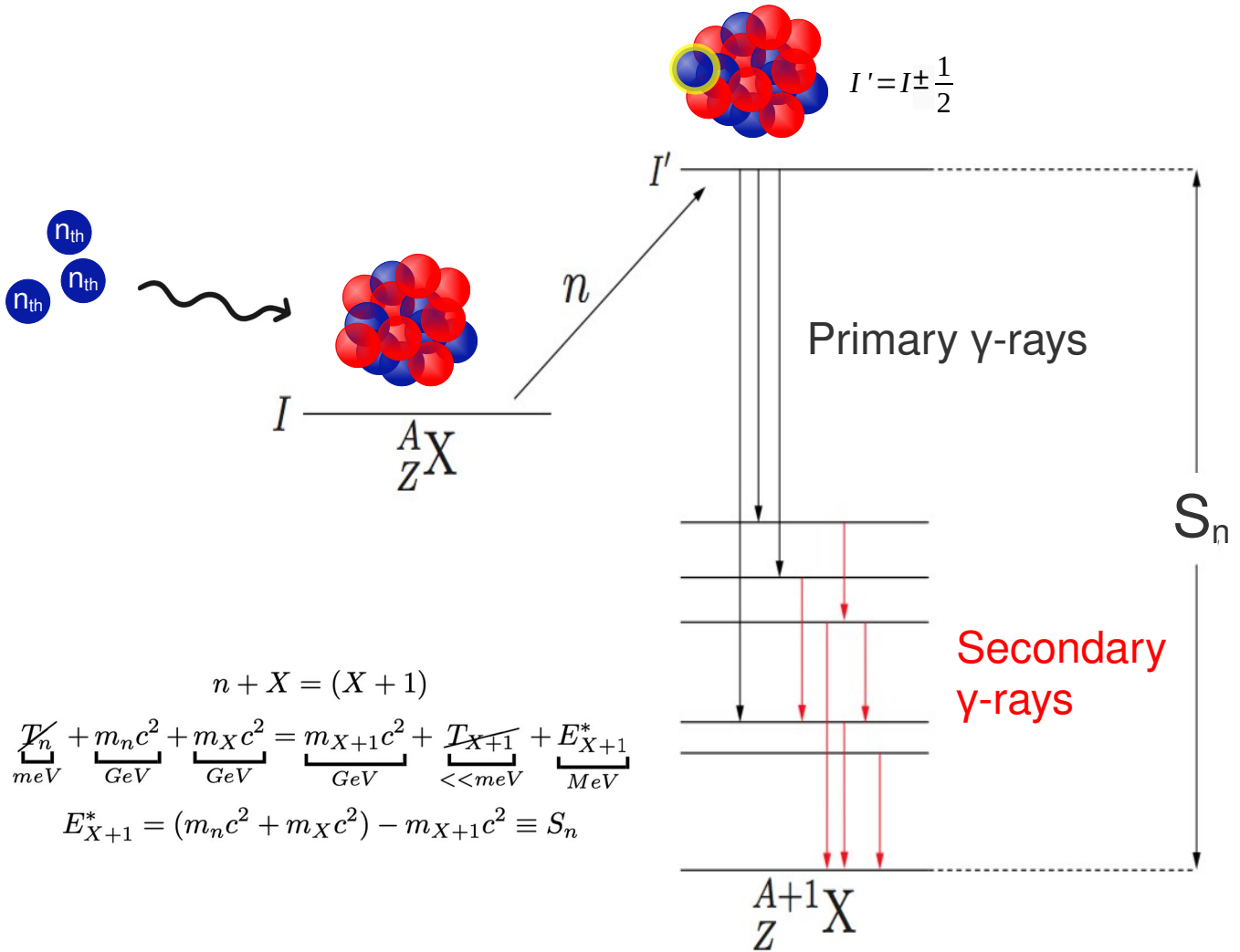
- 16 $LaBr_3$:Ce

or

- 32 HPGe + BGOs

Targets:

- ^{43}Ca
  - 20 mg



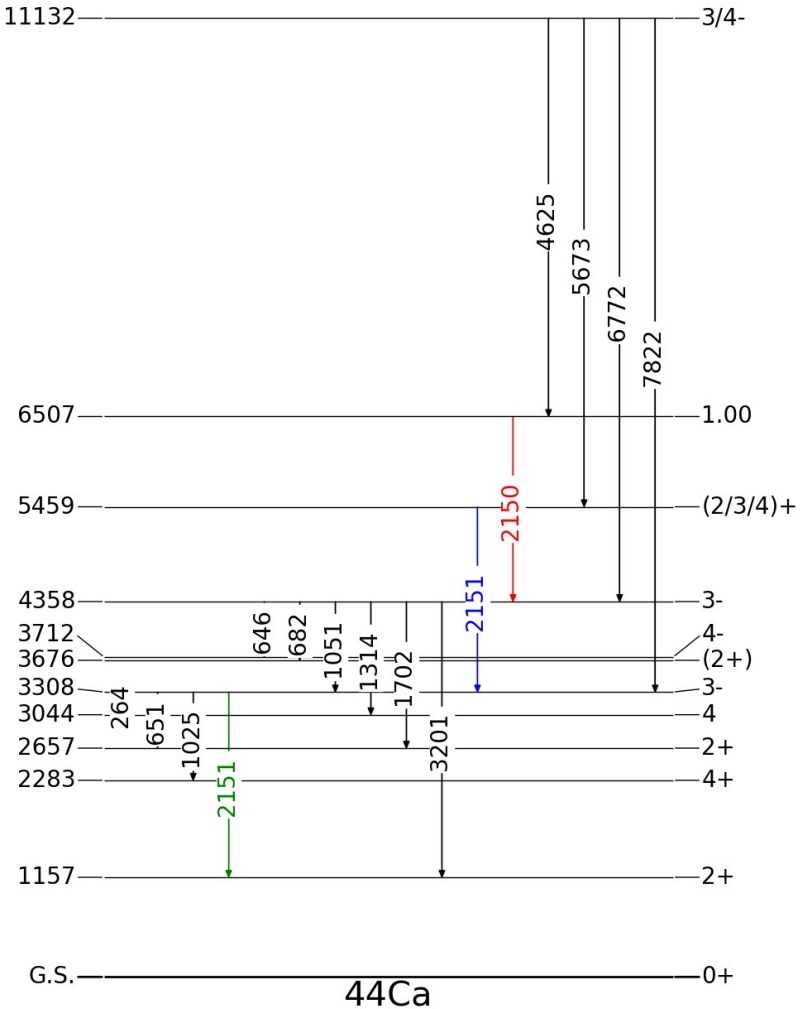
Complete low-spin spectroscopy

from neutron binding energy S_n to the ground state

Possible techniques:

- γ-γ and γ-γ-γ coincidences
  - Angular correlations
- Lifetimes measurements

Level scheme reconstruction – 2150 keV triplet



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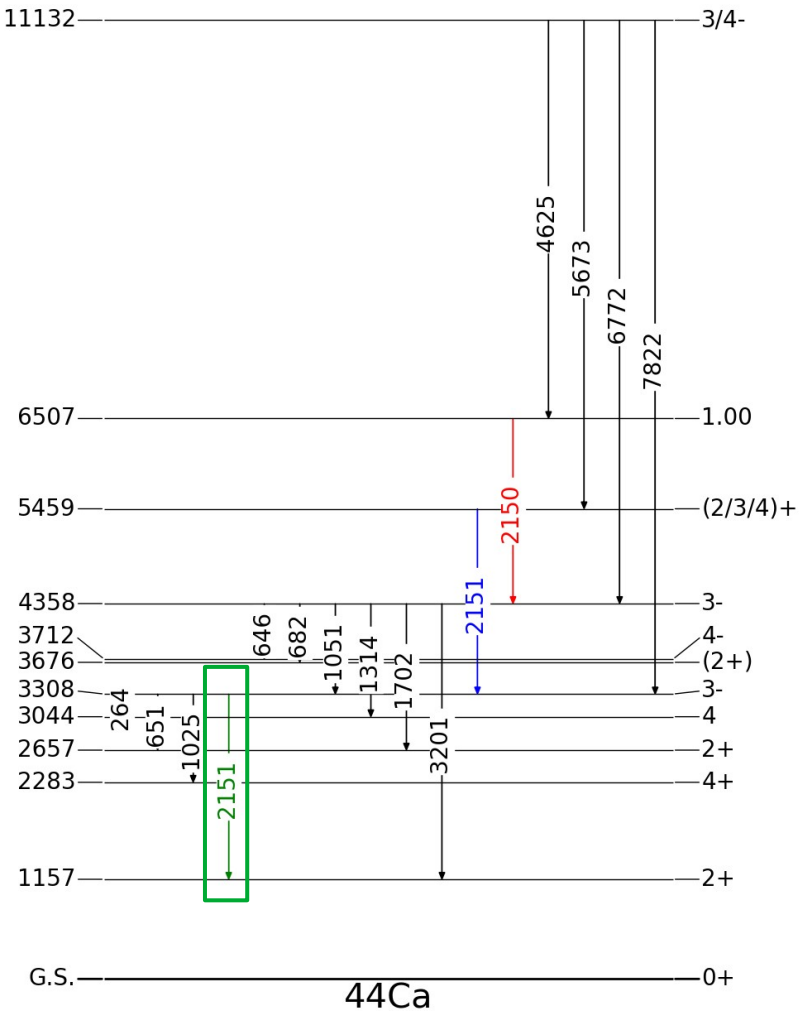

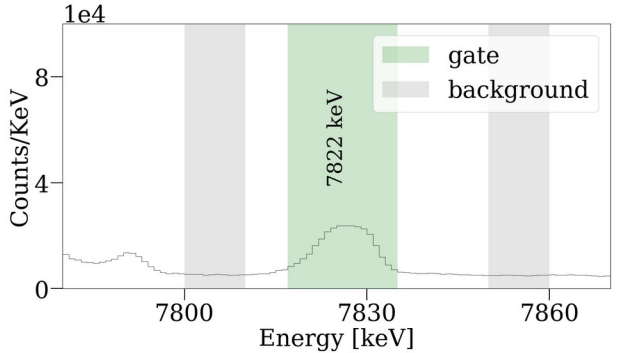

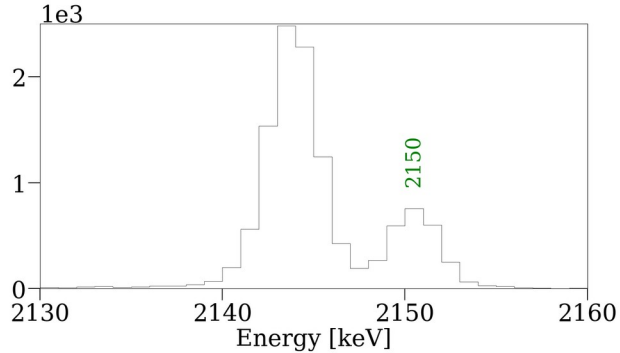

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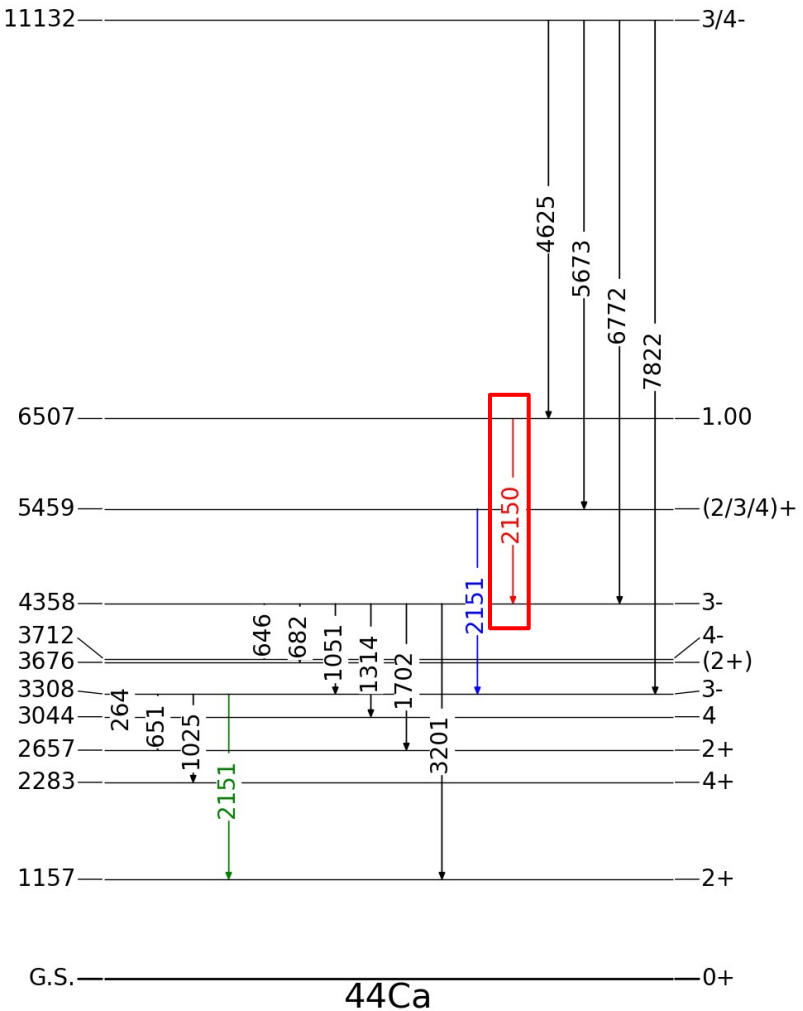

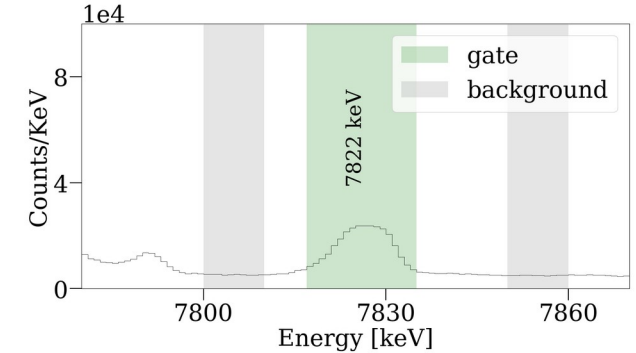

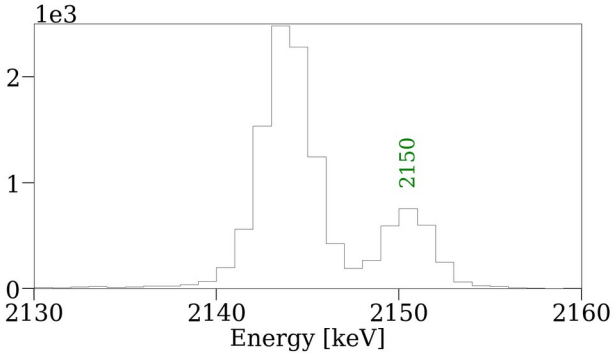

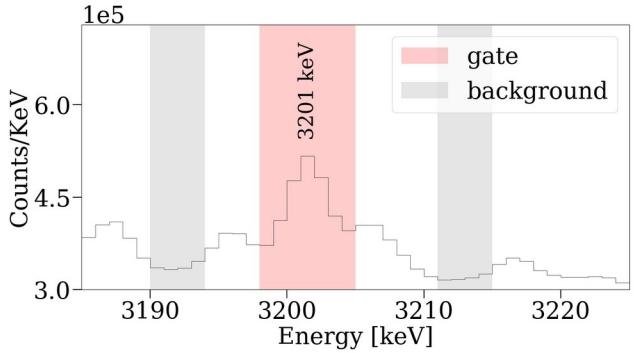

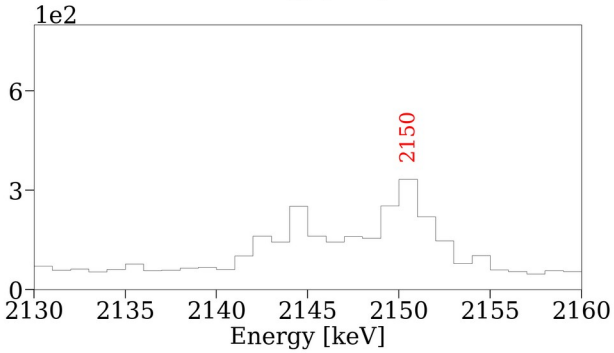

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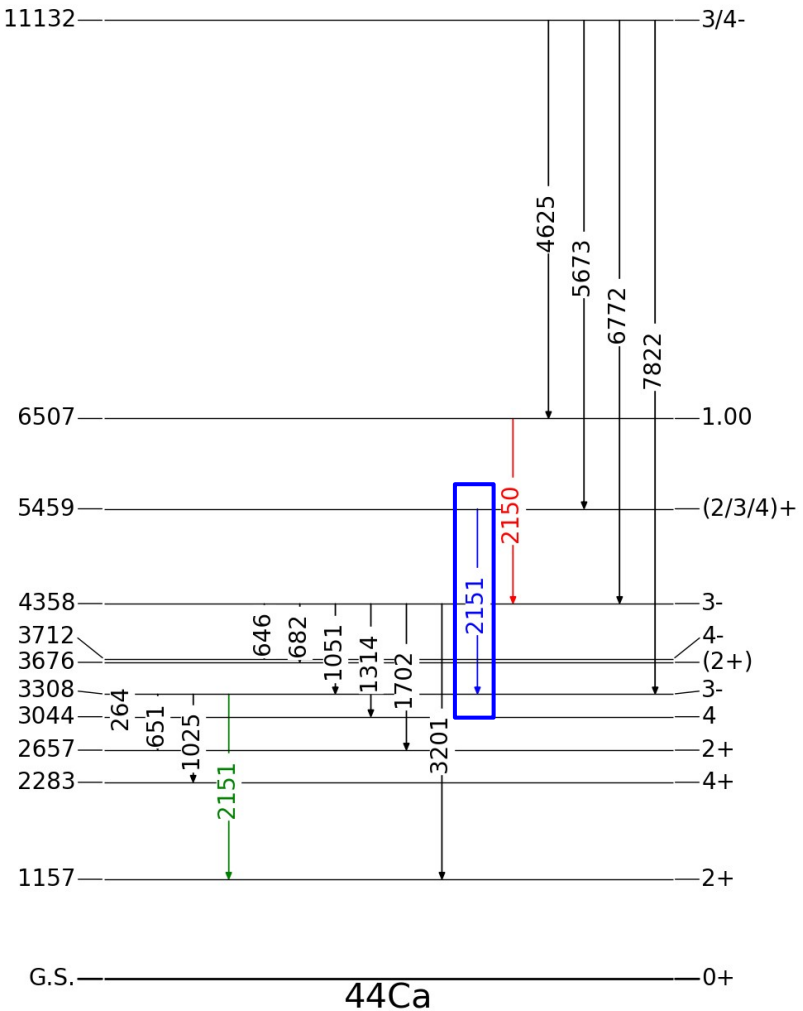

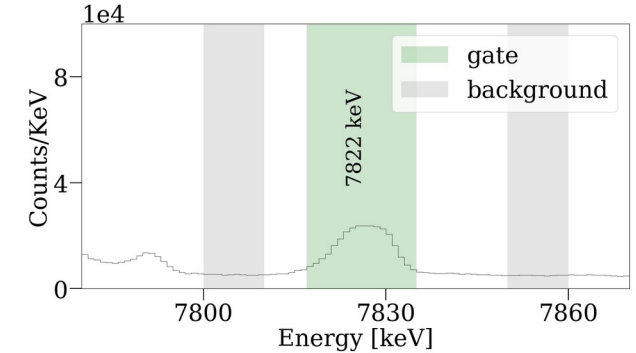

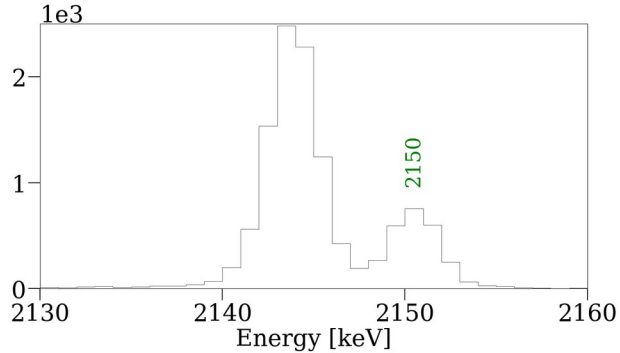

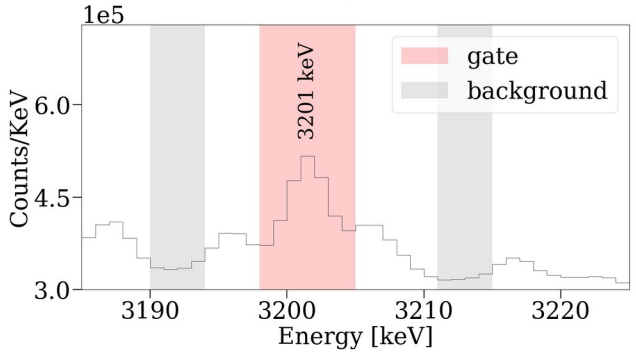

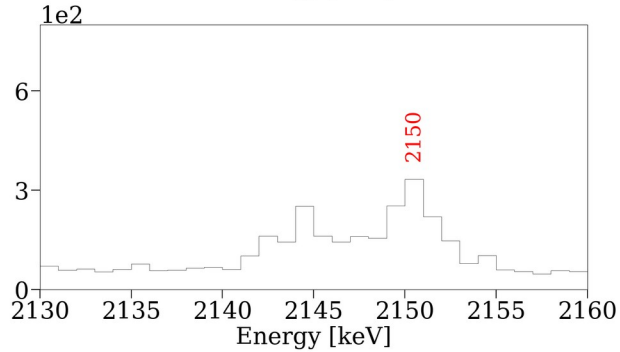

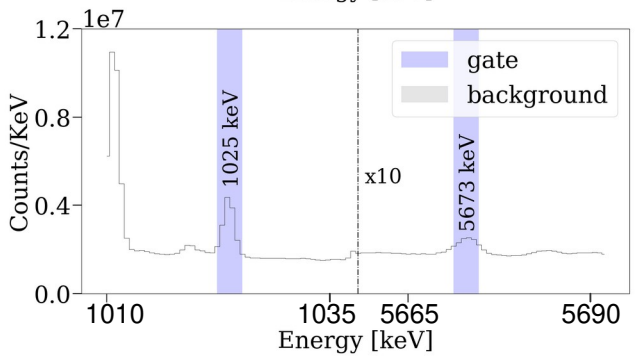

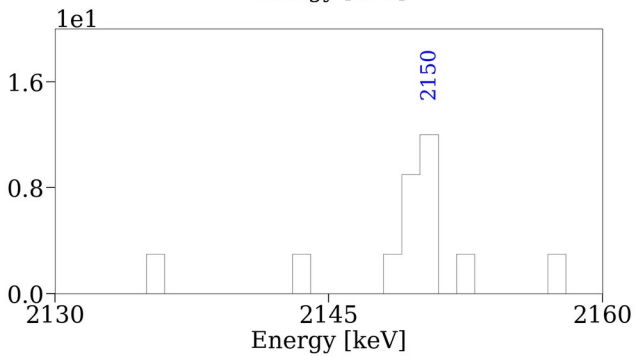

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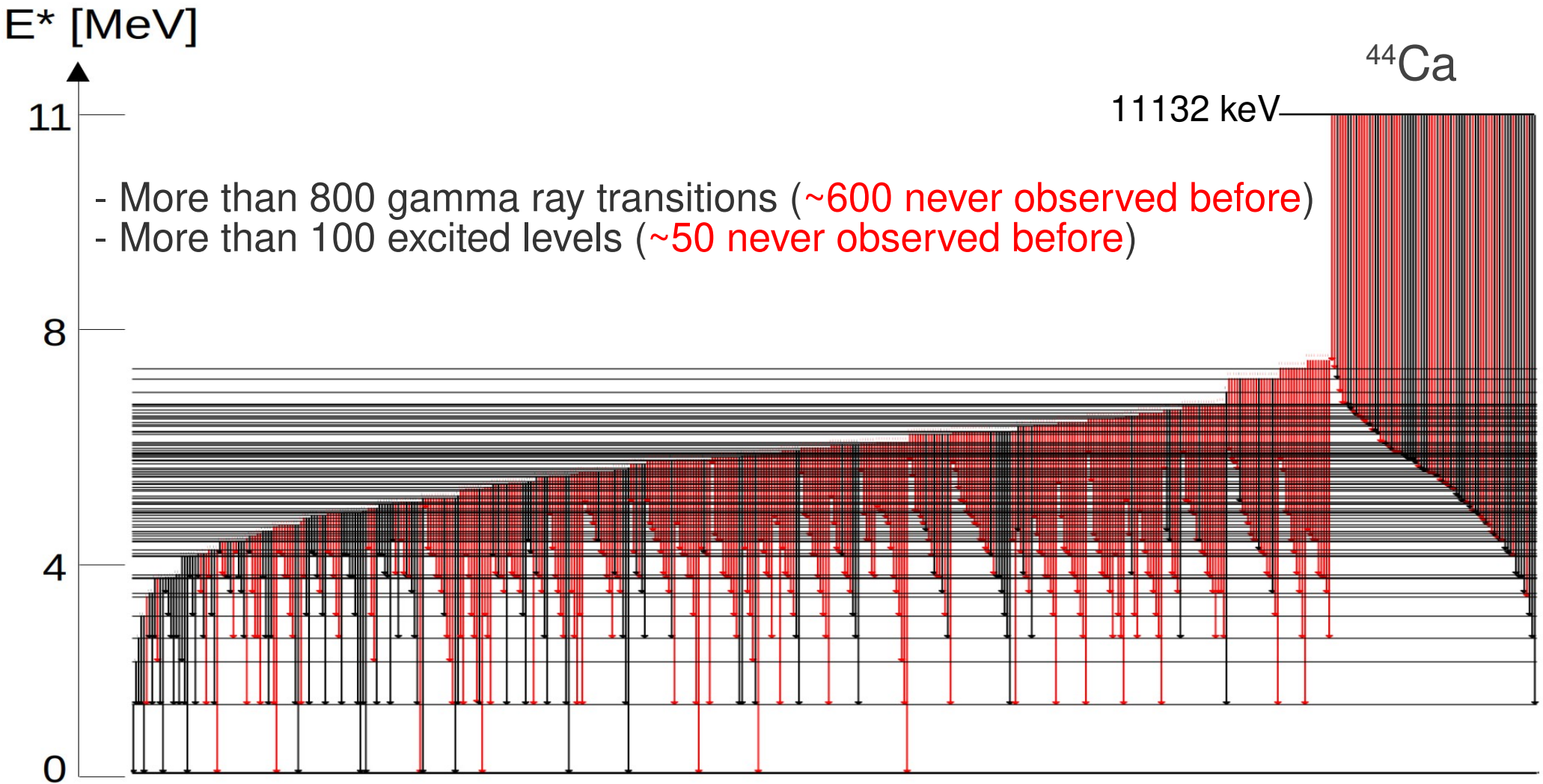

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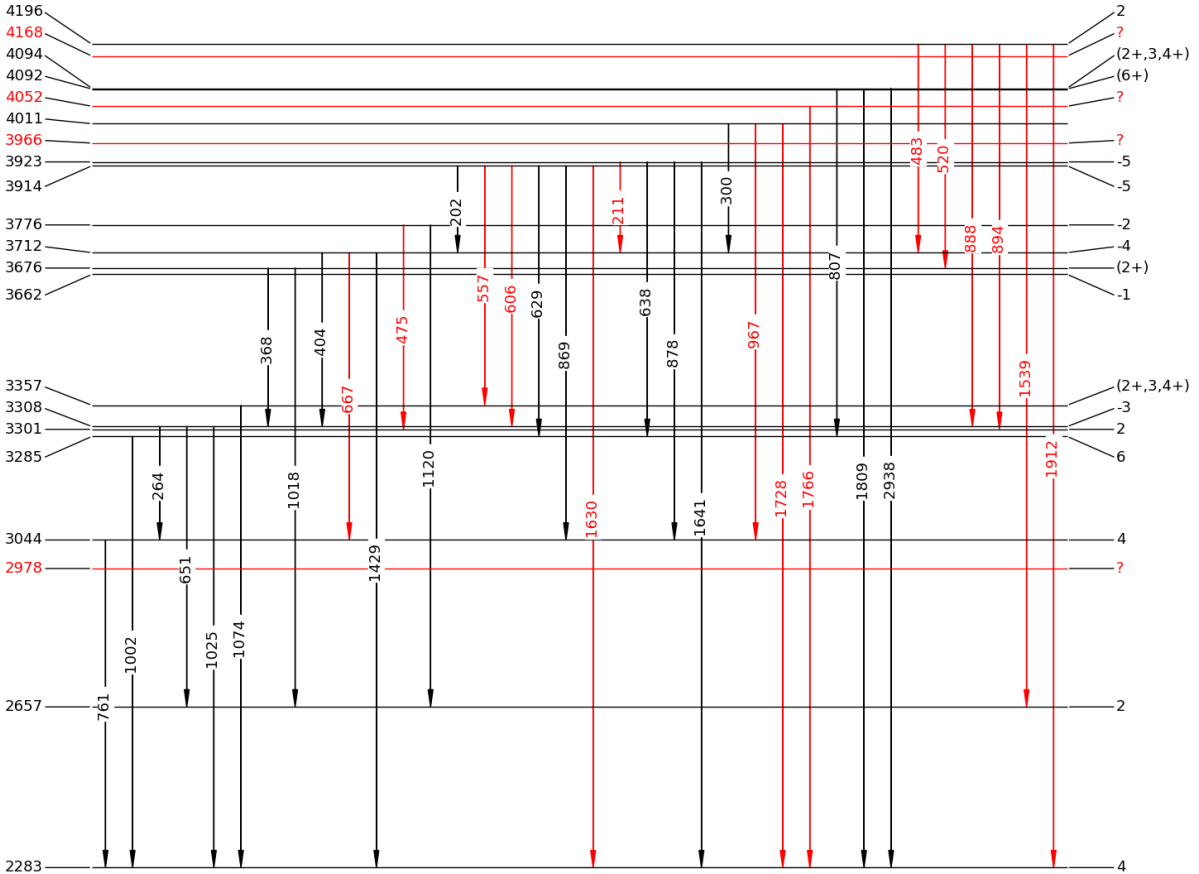

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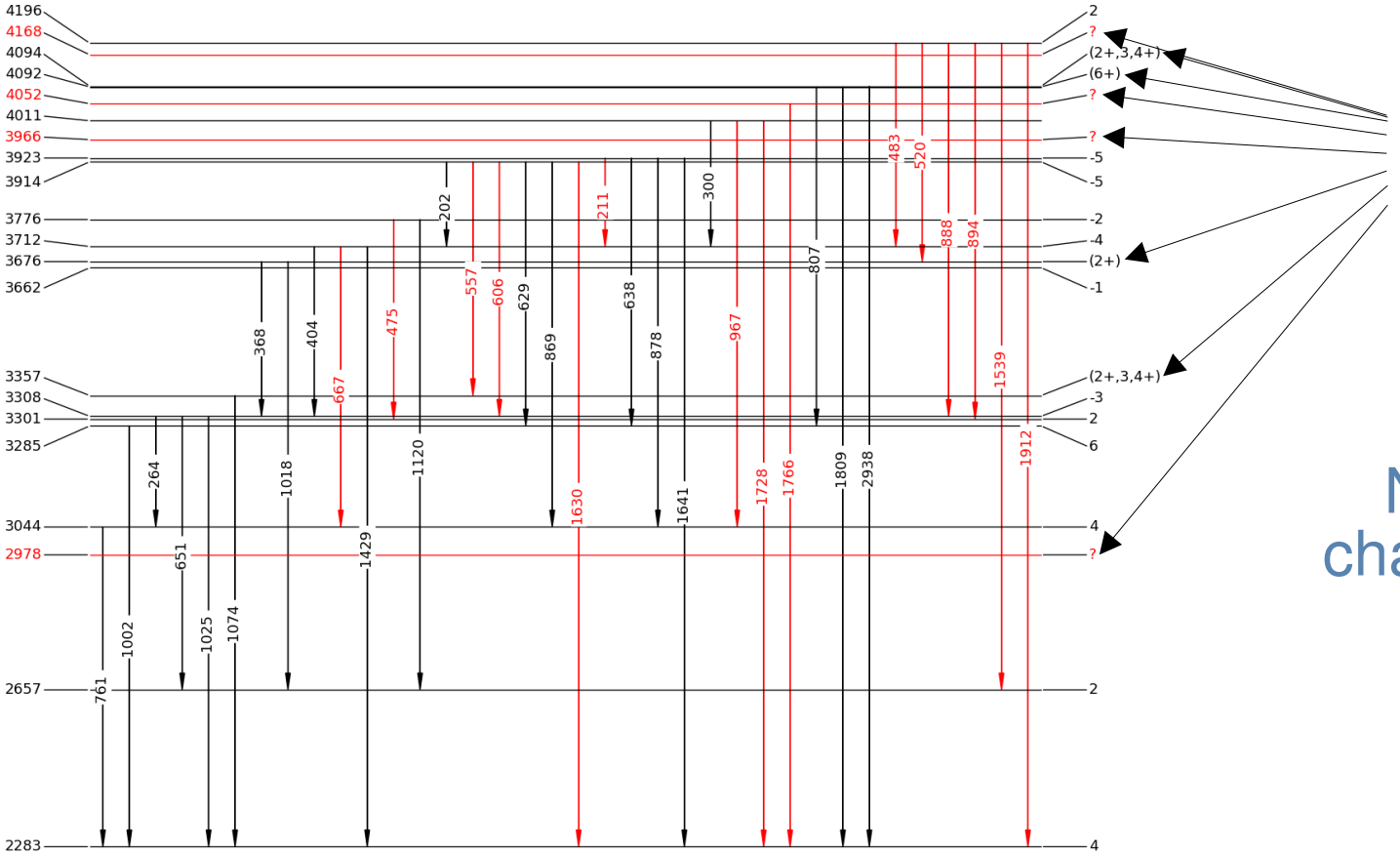


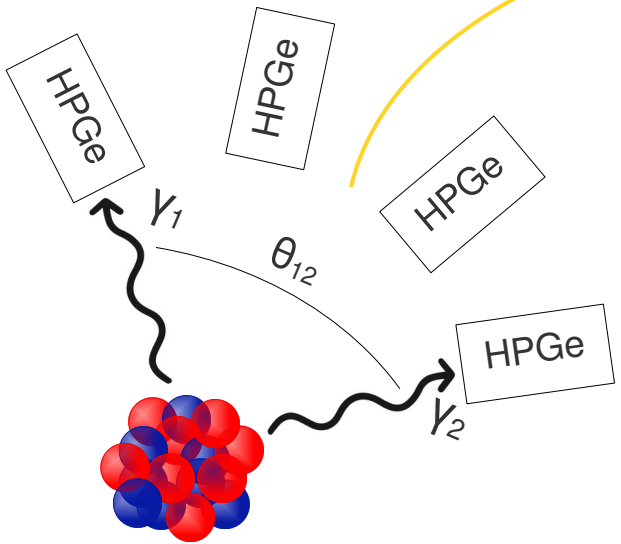
Many unknown spins and parities

Need precise characterization !!

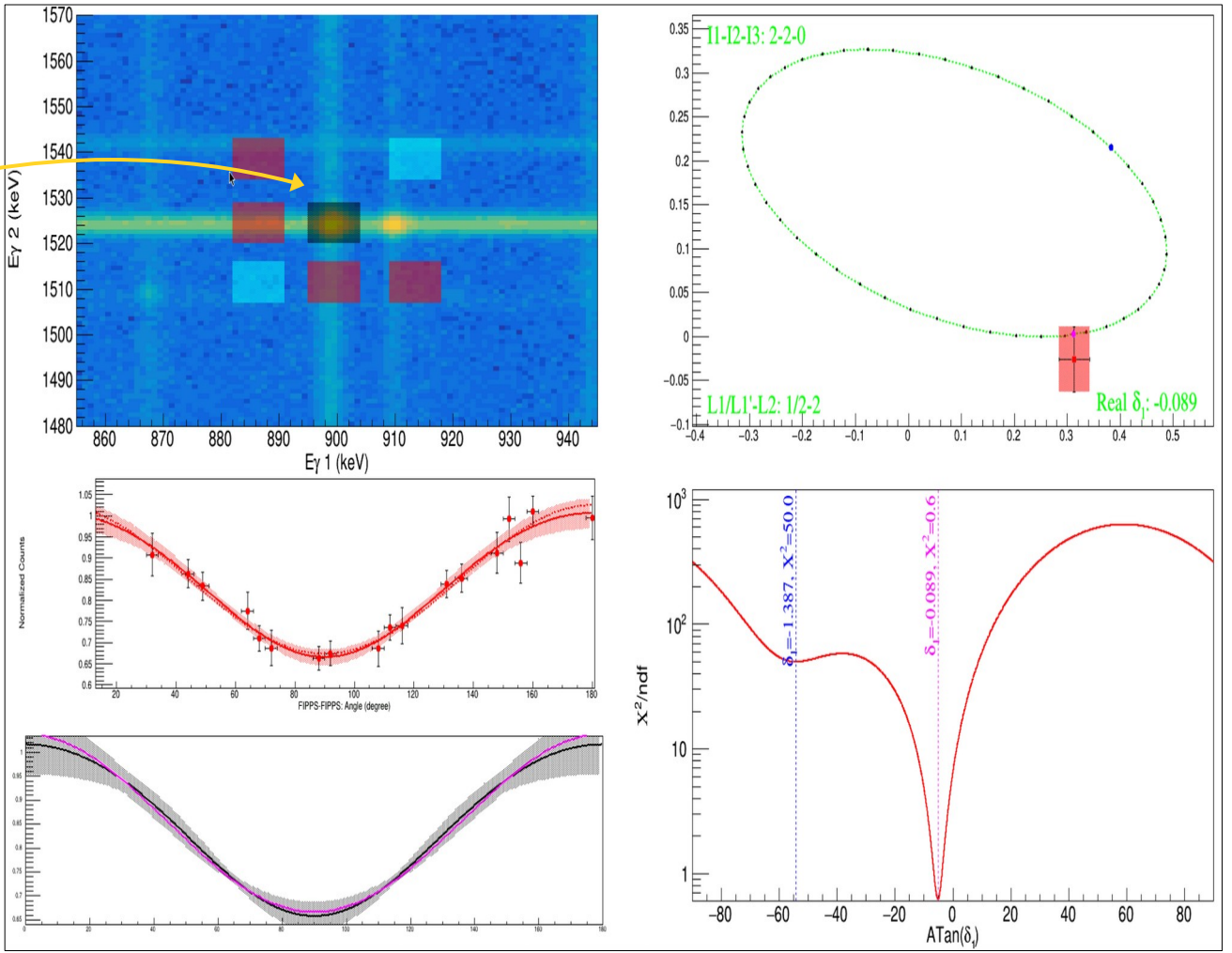
Angular correlation and distribution analysis

$$\delta_\gamma^2 = I_\gamma(\lambda+1)/I_\gamma(\lambda)$$

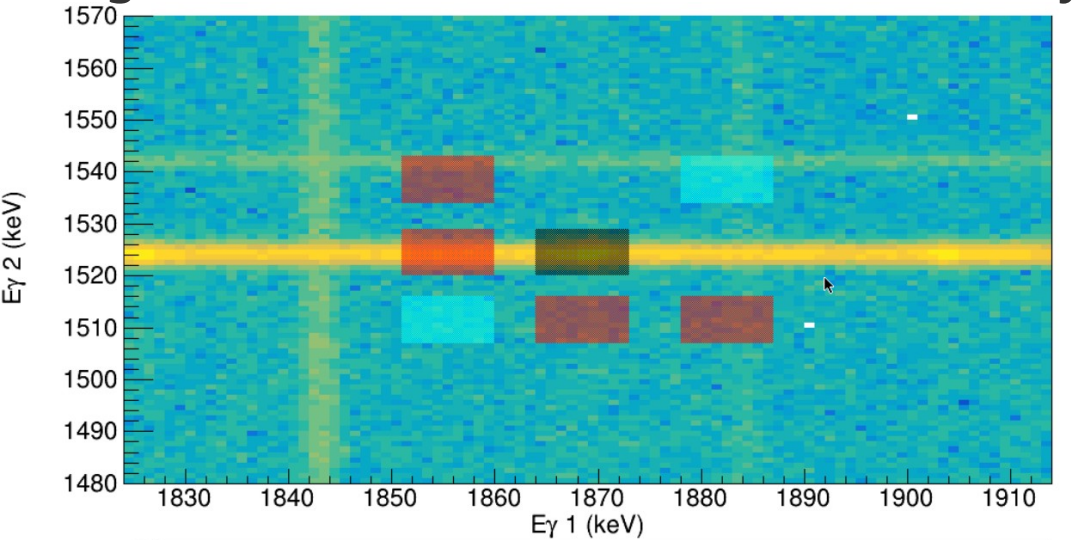
$$W(\theta) = \sum_k A_k Q_k P_k(\cos\theta)$$

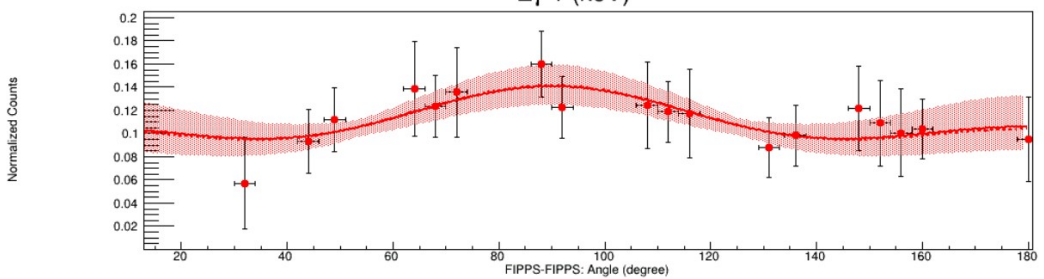


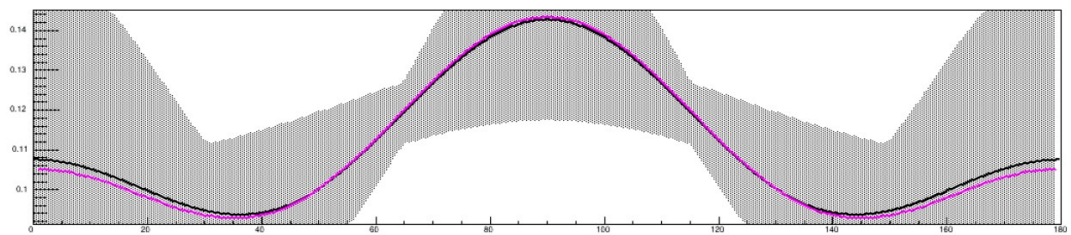
Spin assignment from transitions **multipolarity**



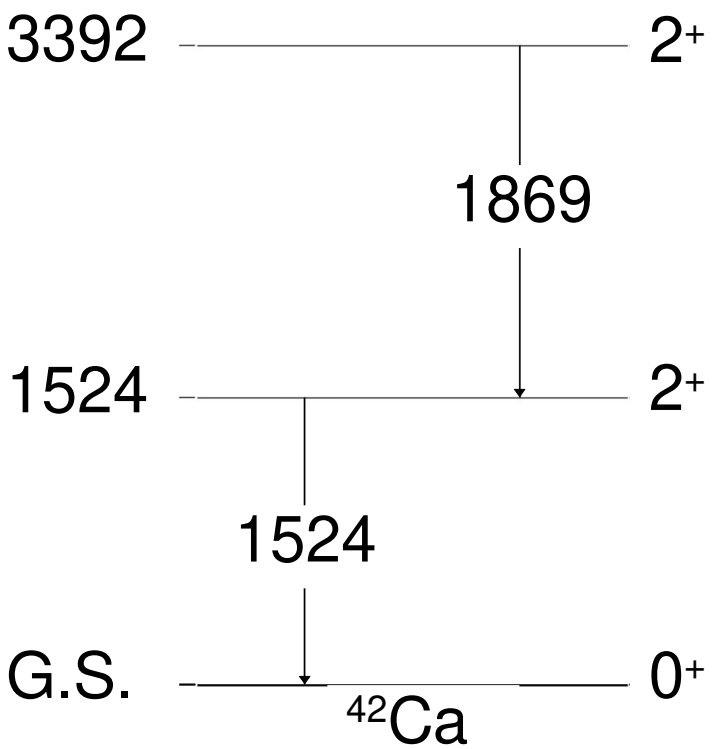
Angular correlation and distribution analysis





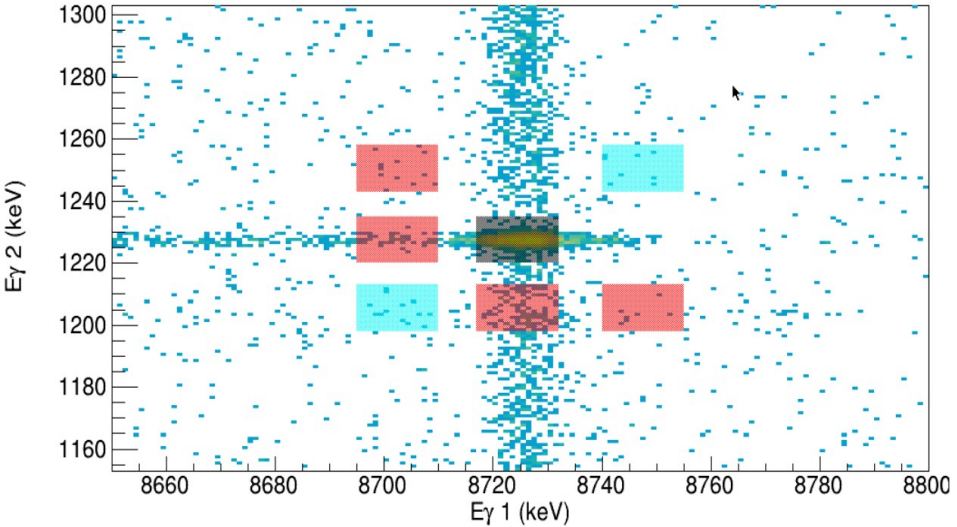


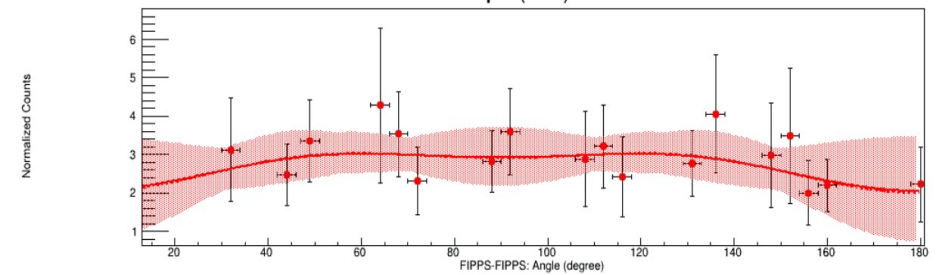
BENCHMARK

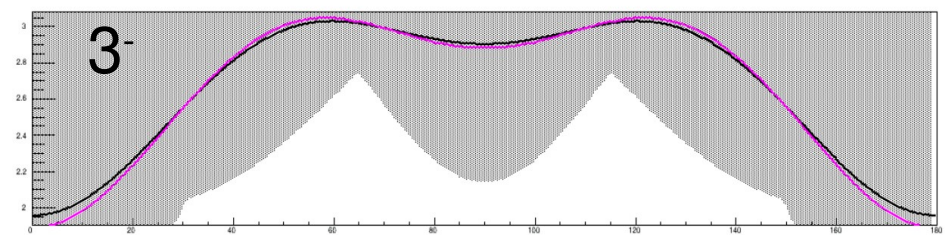


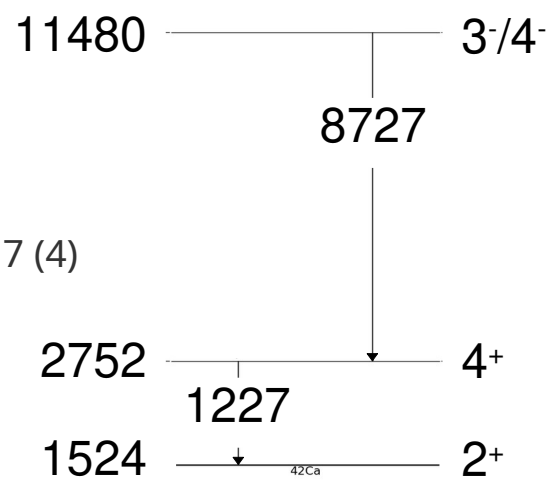
Litterature: M1+E2 \ δ= +1.7 (4)
Exp. Result: M1+E2 \ δ= +1.4 (6)

Angular correlation and distribution analysis

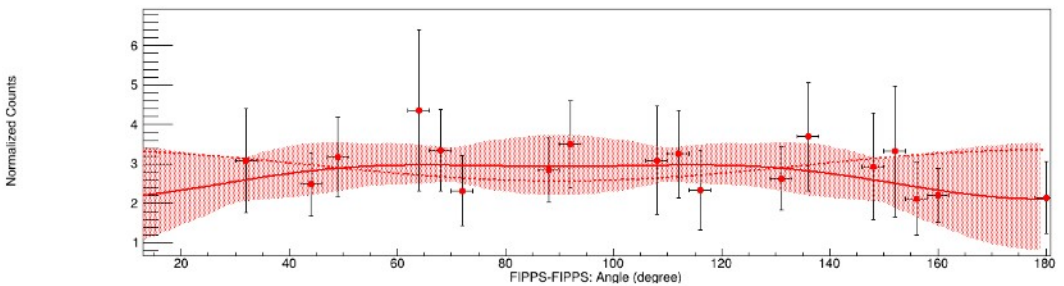


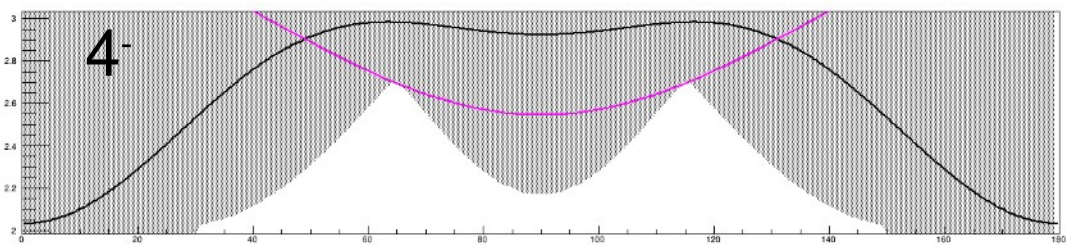






Exp. Result: δ= E1+M2 \ +4.7 (4)





Study of shape coexistence in ^{44}Ca by means of (n,ɣ) reactions

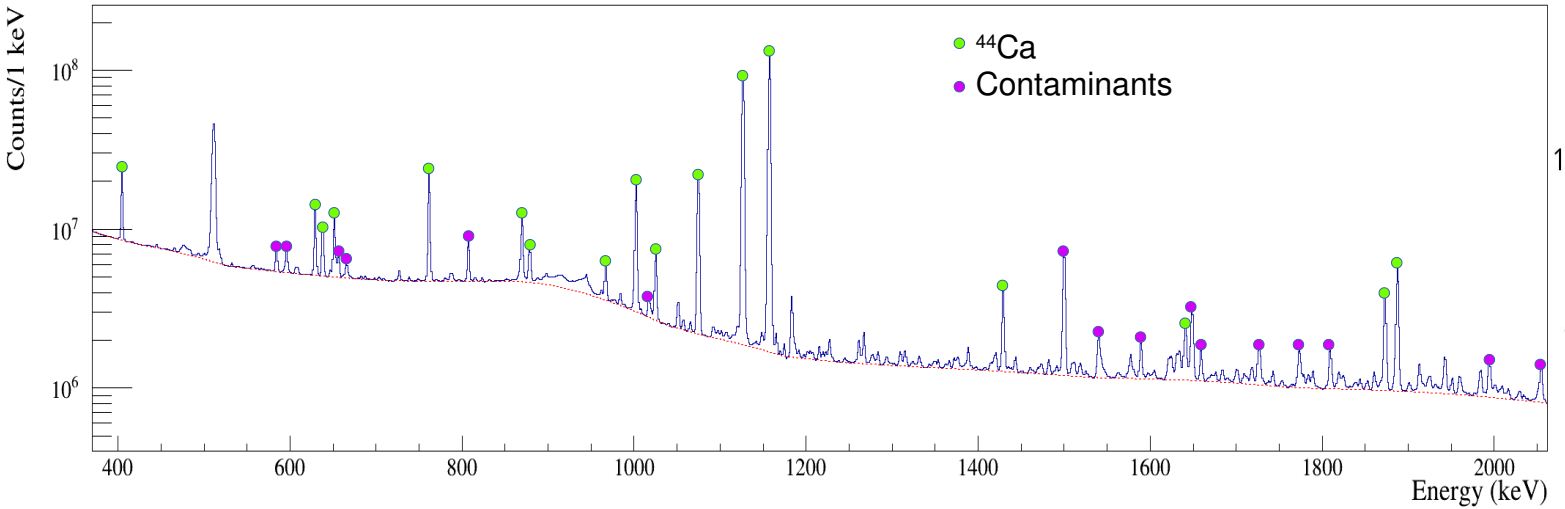
- Complete **low-spin spectroscopy** of ^{44}Ca,
- **Level scheme reconstruction** of ^{44}Ca.

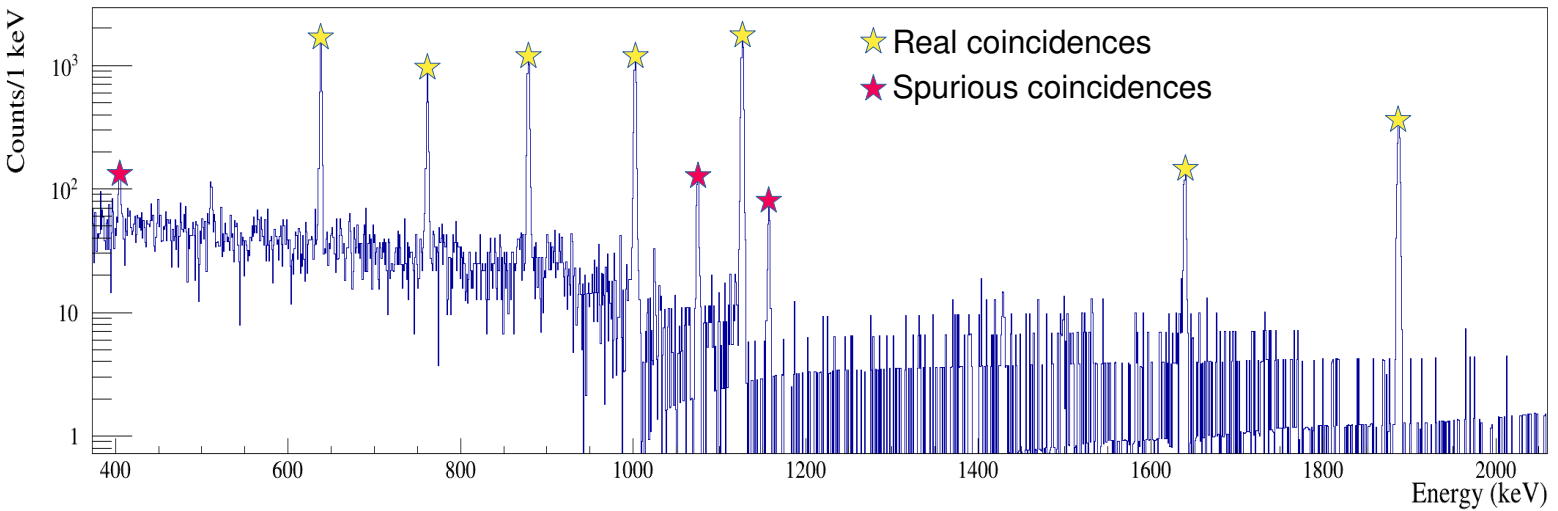
Next steps

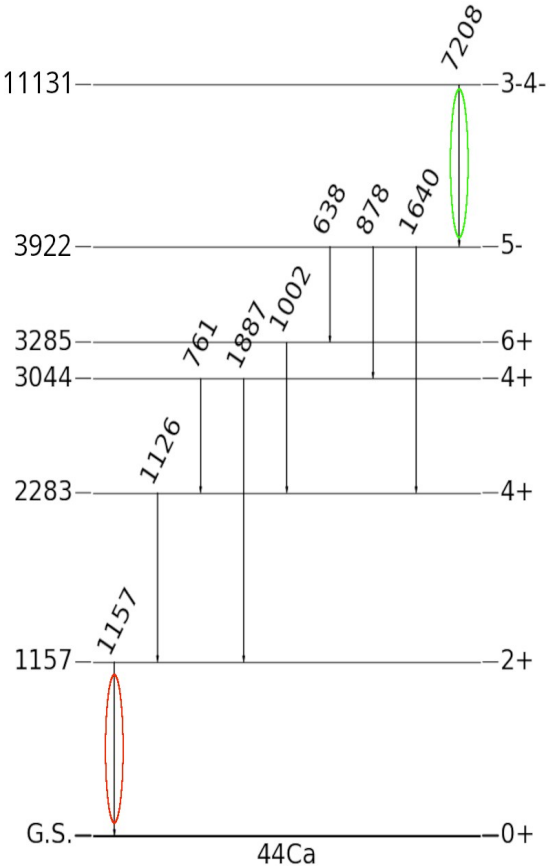
- Gamma **multipolarity** asignment
- **0^+ states** search to find candidates for deformed configurations **(fingerprints of shape coexistence)**.
- Comparison with Shell-Model predictions


Thank you for your attention!

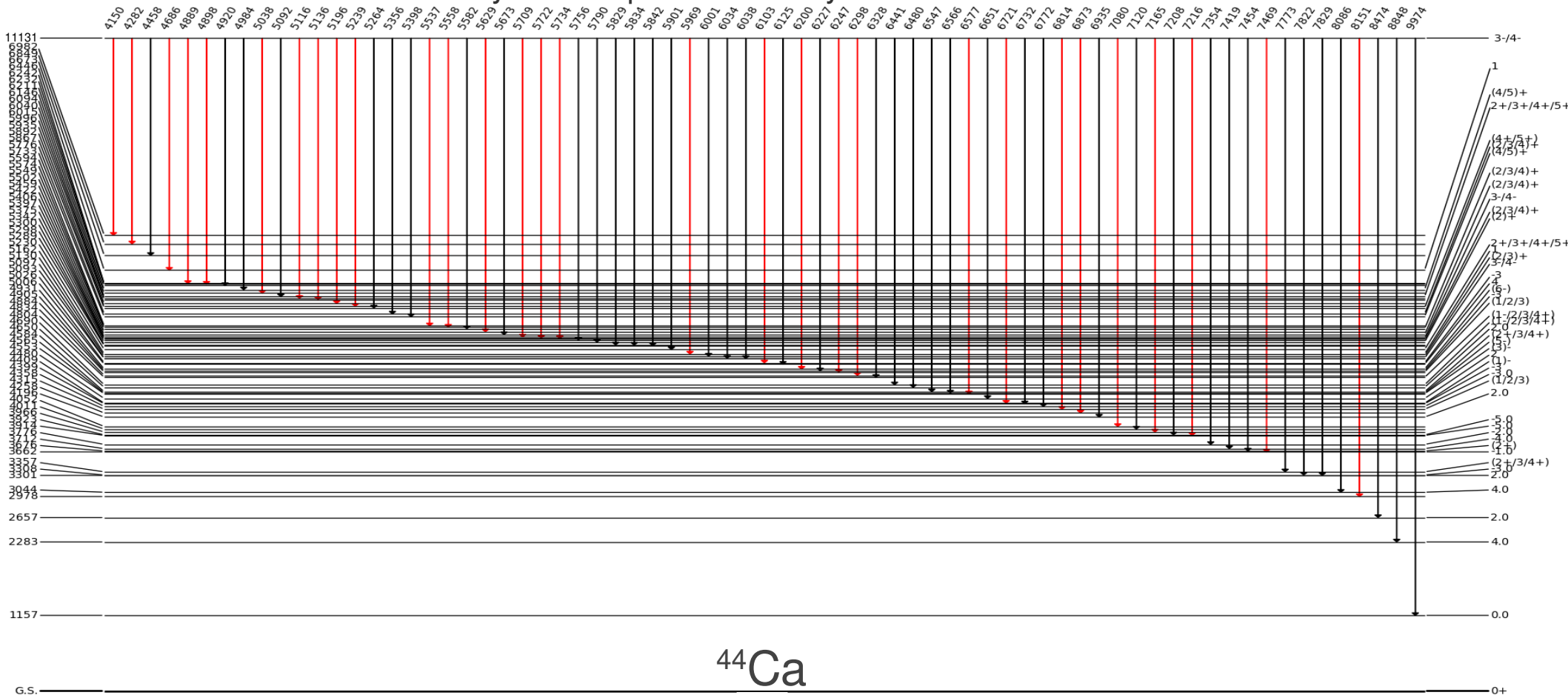
Level scheme reconstruction - Contaminats







Partial level scheme – decay from Capture state only



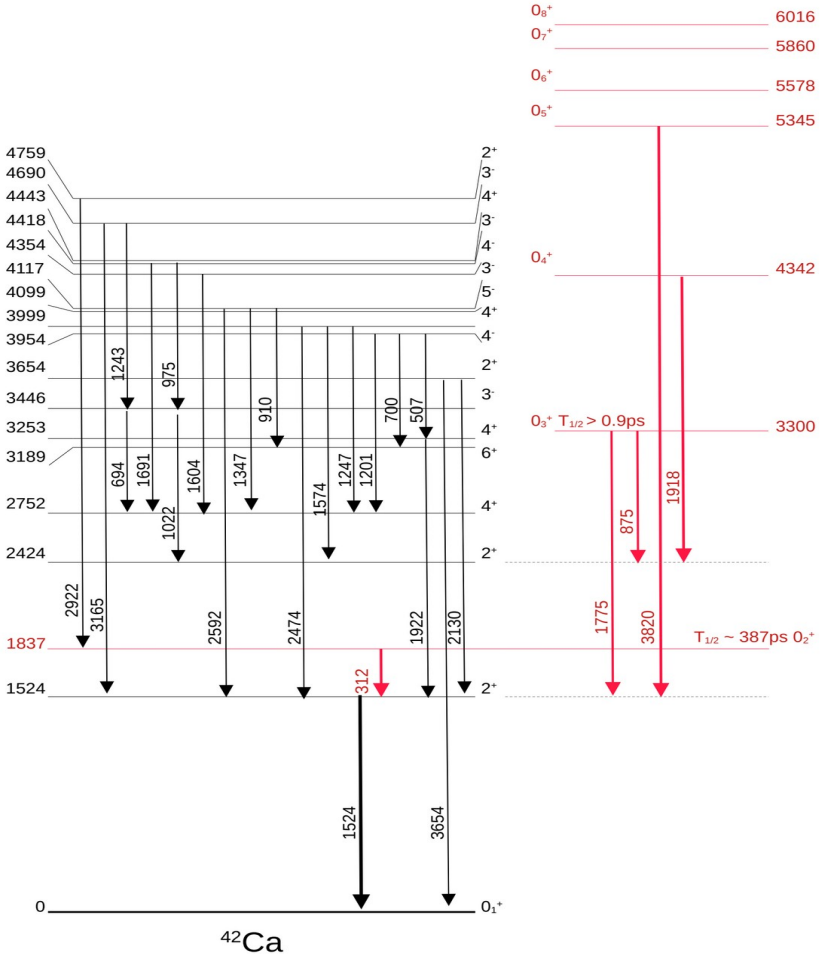
^{44}Ca

- More than 800 gamma ray transitions (~600 never observed before)
- More than 100 excited levels (~50 never observed before)

^{42}Ca comparison with previous works

Level No.	Energy [keV]	J^π	Level No.	Energy [keV]	J^π
0	G.S.	0+	14	5201 ±5	
1	1523	2+	15	5366 ±9	
2	1837	0+	16	5471 ±9	4+
3	2423	2+	17	5779 ±11	
4	2751 ±4	4+	18	5863 ±10	0+
5	3186 ±6	6+	19	6015 ±9	0+
6	3253 ±5		20	6106 ±7	(4+)
7	3437 ±9	(3-)	21	6273 ±7	
8	3651 ±6	2+	22	6518 ±8	(0+)
9	4090 ±8		23	6723 ±8	
10	4448 ±11	2+	24	6920 ±4	2+
11	4757 ±9	2+	25	7134 ±8	
12	4869 ±7	2+	26	7259 ±7	
13	5011 ±7	4+	27	7358 ±5	2+

D. C. Williams *et al.* Phys. Rev. **164** (1967)



Only the first excited 0^+ at 1837 keV was populated during our experiment

Capture state $J^\pi = 3^-/4^-$ → direct decay from capture state S_n extremely hindered