Searching for shape coexistence in Ca isotopes

Young GAMMA meeting

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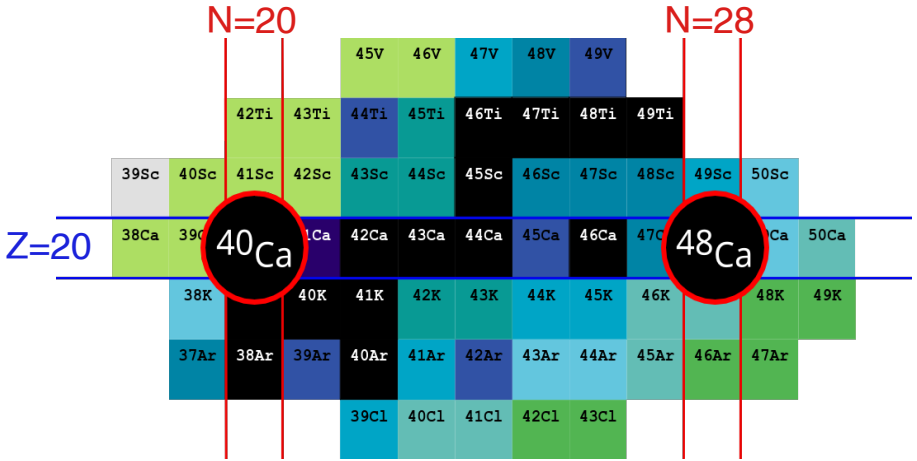
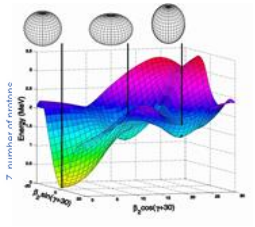
Physics case – Shape coexistence in Z=20 isotopes



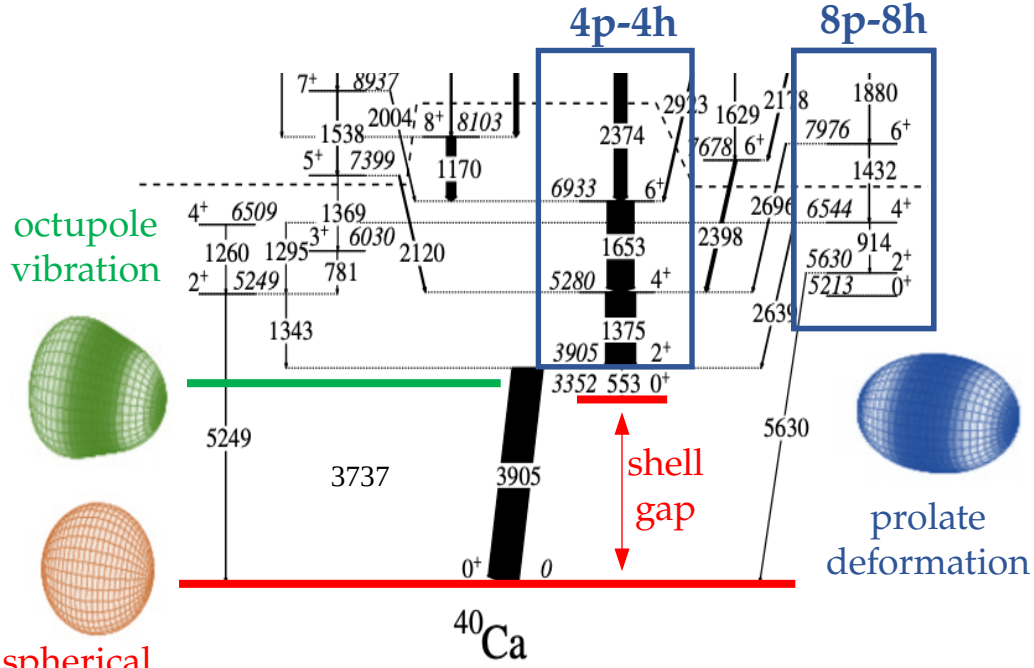
Shape coexistence across the nuclide chart



A.N. Andreyev *et al.*
Nature **405**, 430 (2000)

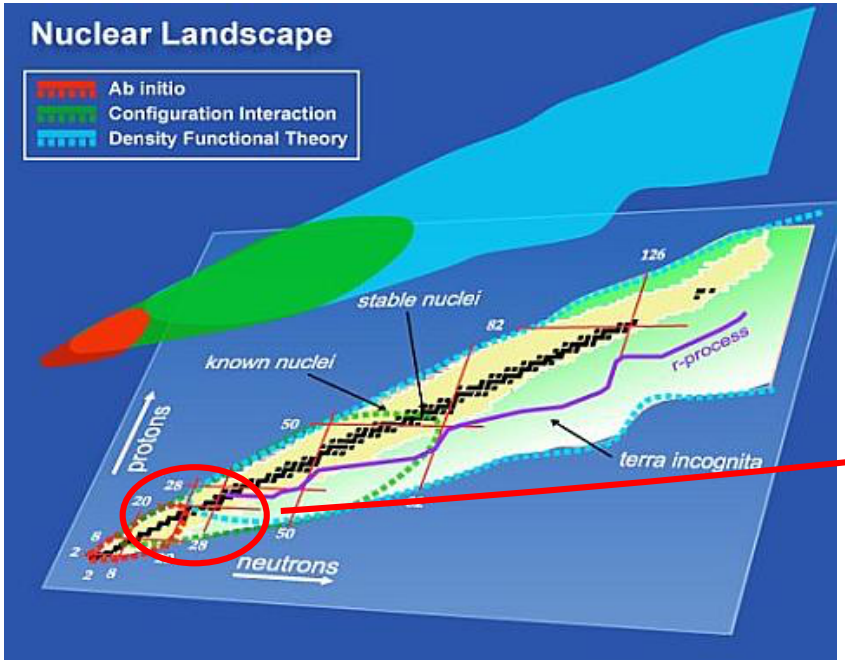
S. Leoni *et al.*
PRL **118**, 162502 (2017)

N. Marginean *et al.*
PRL **125**, 102502 (2020)



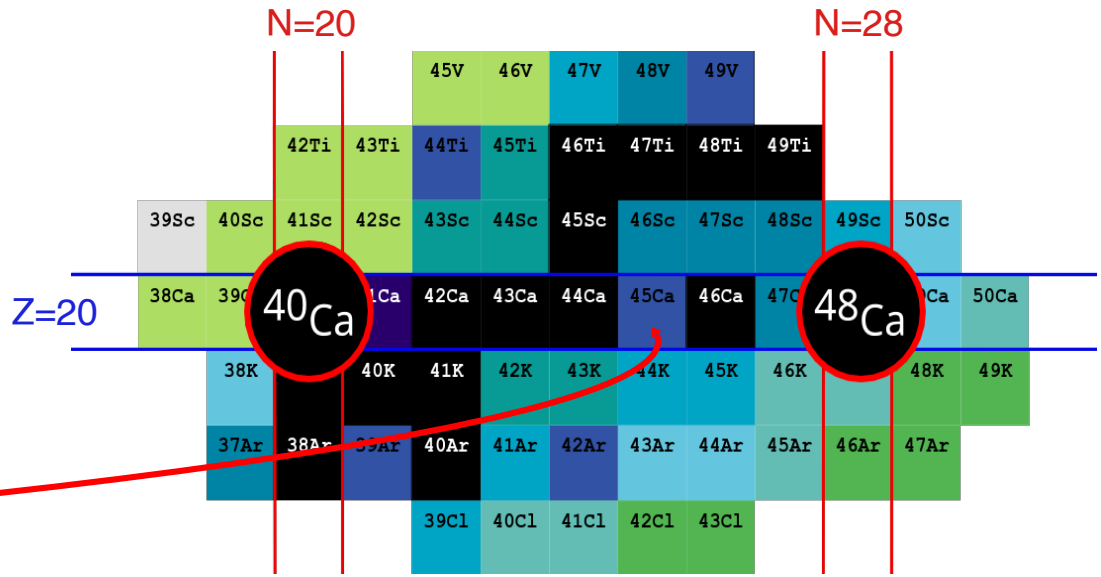
E. Ideguchi *et al.* Phys. Rev. Lett **87**, 222501 (2001)

The A~40 region of the nuclear chart is the meeting point of **several** theoretical approaches



- J. D. Holt, J. Menendez, J. Simonis, and A. Schwenk, Phys. Rev. C **90**, 024312 (2014)
- Y. Utsuno, T. Otsuka, B. A. Brown, M. Honma, T. Mizusaki, and N. Shimizu, Progr. Theor. Phys. Suppl. **196**, 304 (2012)
- M. Bender, P.-H. Heenen, P.-G. Reinhard, Rev. Mod. Phys. 75, 121 (2003)

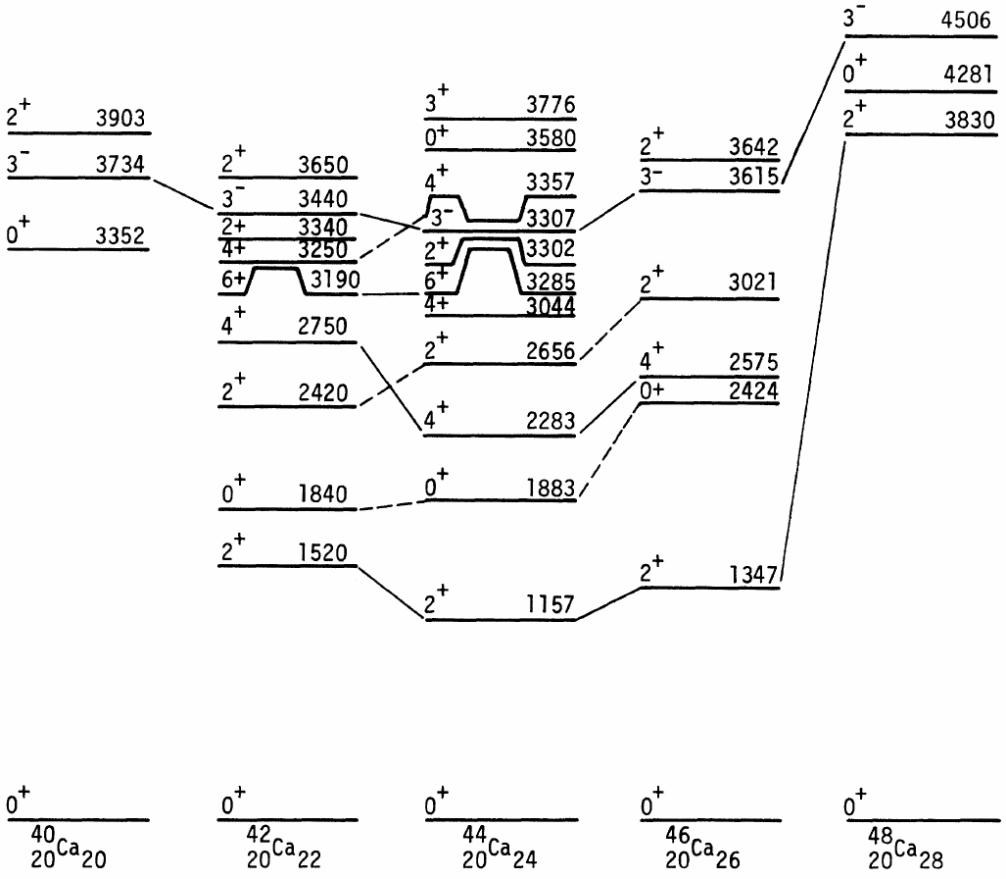
Study of the full Calcium chain



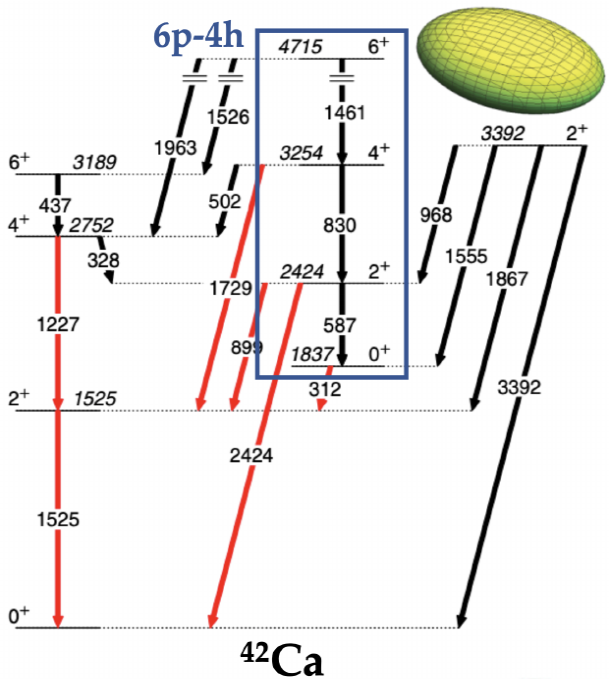
With ^{41,47,49}Ca already published

- S. Bottoni et al. Phys. Rev. C 103 (2021) - Low-spin particle-core and hole-core excitations in ^{41,47,49}Ca isotopes studied by cold-neutron-capture reactions

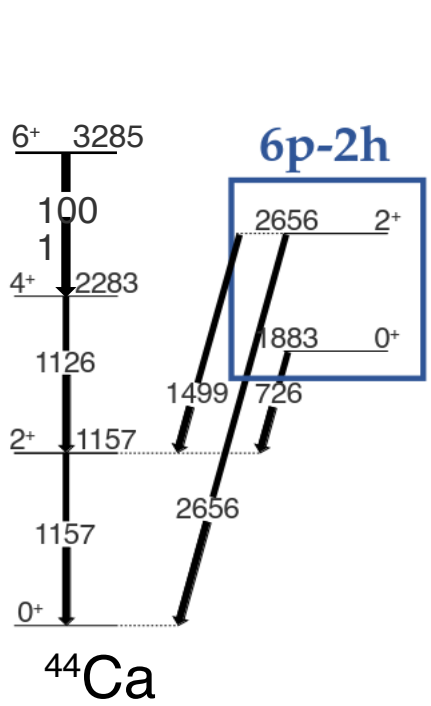
Physics case – The cases of ^{42}Ca and ^{44}Ca



- *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 deformed band reported by K. Hadyńska et al. – Phys. Rev. C 97 (2018)*



- *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)*
- *Configuration of 3.59 MeV 0^{+} state in ^{44}Ca – Phys. Let. 79B (1978)*

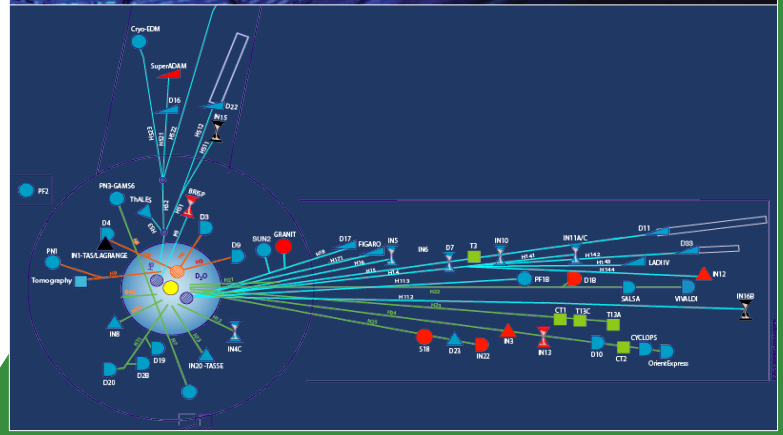
Experimental Setups - The ILL nuclear reactor

Institut Laue Langevin (ILL), Grenoble, France

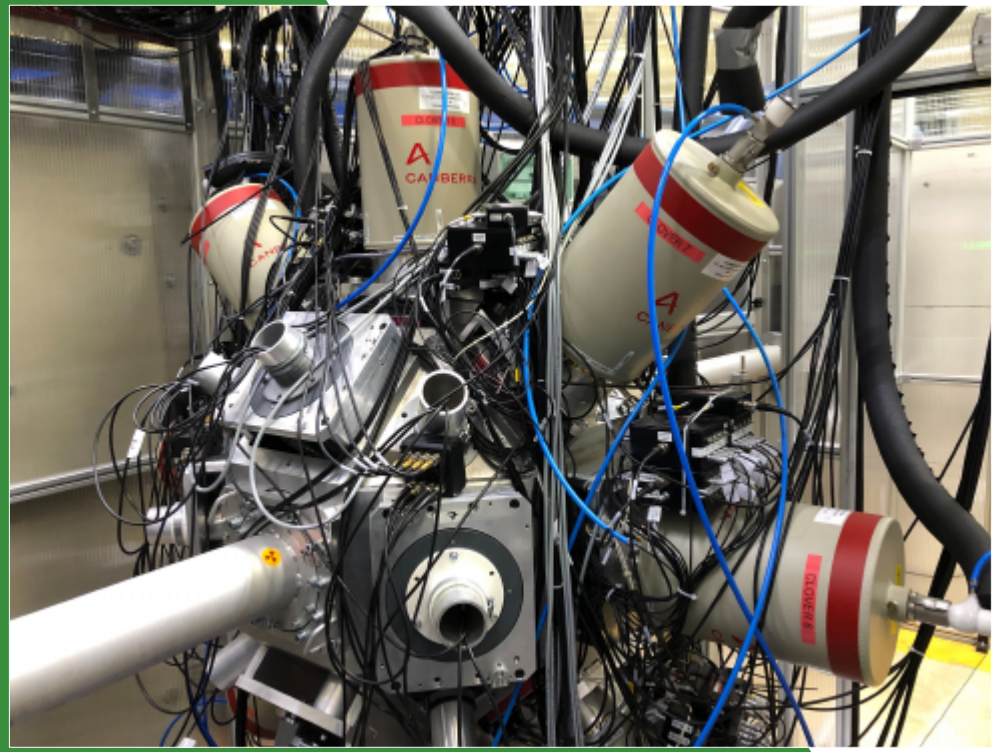
- Thermal Power: ~ 58 MW
- Neutron Flux: 1.5 x 10^{15} n cm^{-2} s^{-1}
- Neutron Flux at FIPPS: 10^{8} n cm^{-2} s^{-1}
- Bemalines: 40

Fundamental Science:

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



Experimental Setups - FIPPS



Reactions:

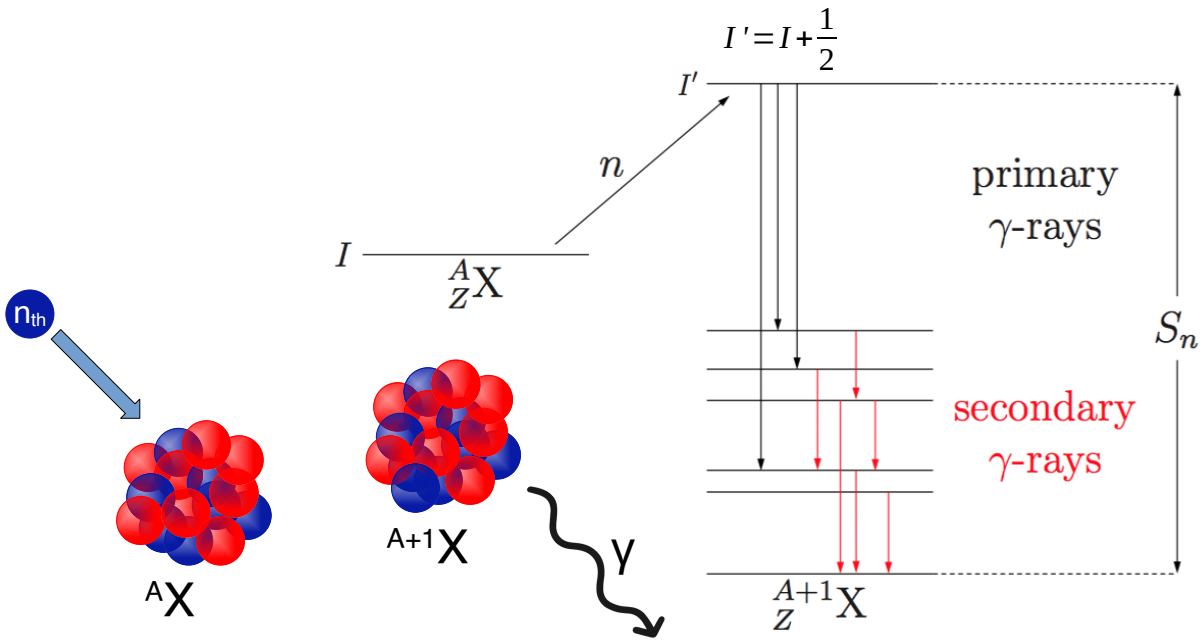
- $^{41}Ca(n,\gamma)^{42}Ca$
- $^{43}Ca(n,\gamma)^{44}Ca$

FIPPS:

- 32 HPGe (8 Clovers) + BGOs
- 8 $LaBr_3$:Ce

Targets:

- ^{41}Ca (Radioactive)
  - 2 Mbq / 600 µg / $\tau_{1/2} = 10^5$ years
  - Powder
- ^{43}Ca
  - 20 mg
  - Powder



From neutron binding energy to ground state

$$n + X = (X+1)$$

$$\underbrace{\cancel{T_n}}_{meV} + \underbrace{m_n c^2}_{GeV} + \underbrace{m_X c^2}_{GeV} = \underbrace{m_{X+1} c^2}_{GeV} + \underbrace{\cancel{T_{X+1}}}_{<<meV} + \underbrace{E^*_{X+1}}_{MeV}$$

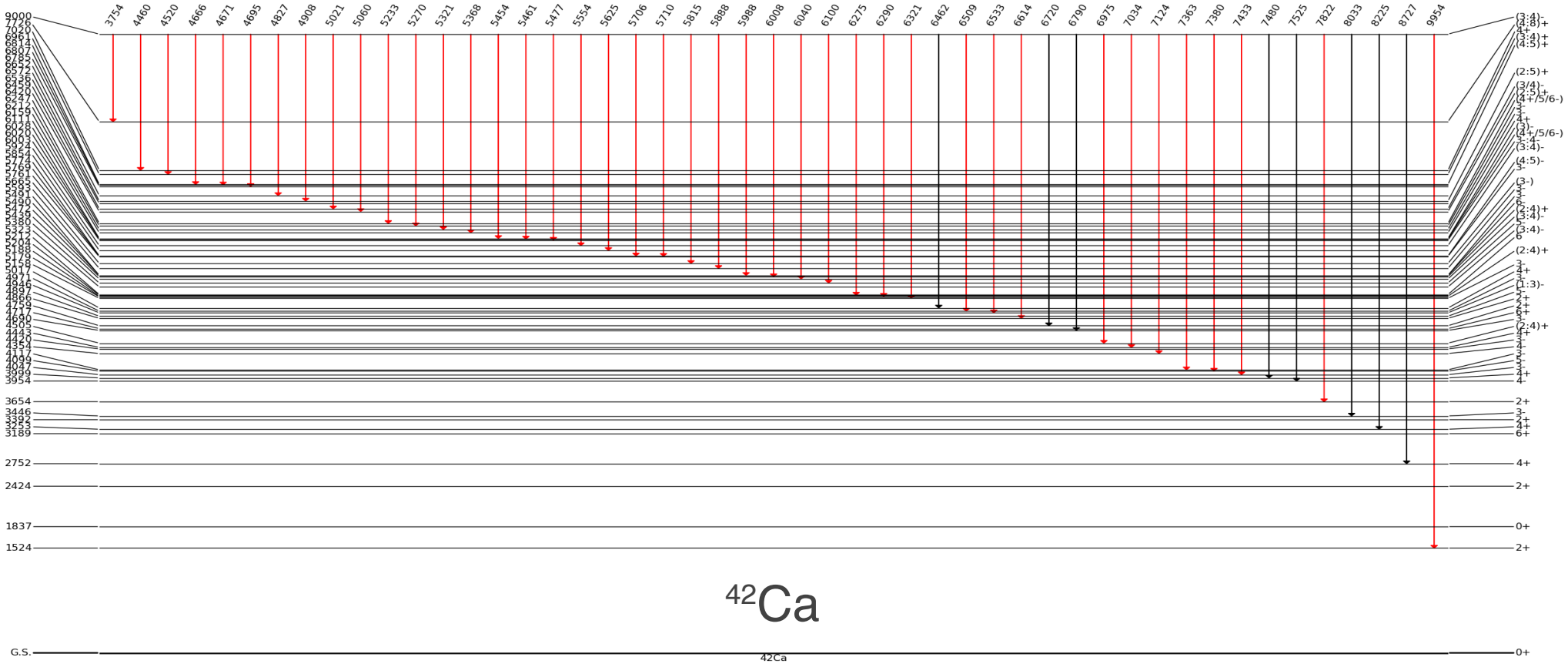
$$E^*_{X+1} = (m_n c^2 + m_X c^2) - m_{X+1} c^2 \equiv S_n$$

Complete low-spin spectroscopy

Possible techniques:

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

Experimental Results and Future Perspectives – Level Scheme

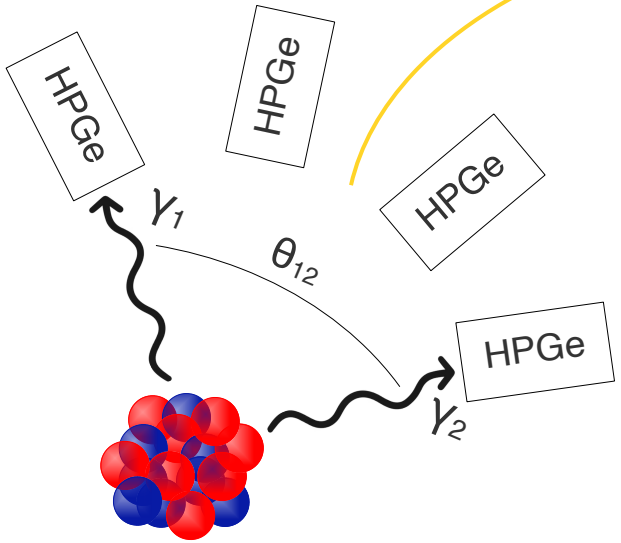


^{42}Ca

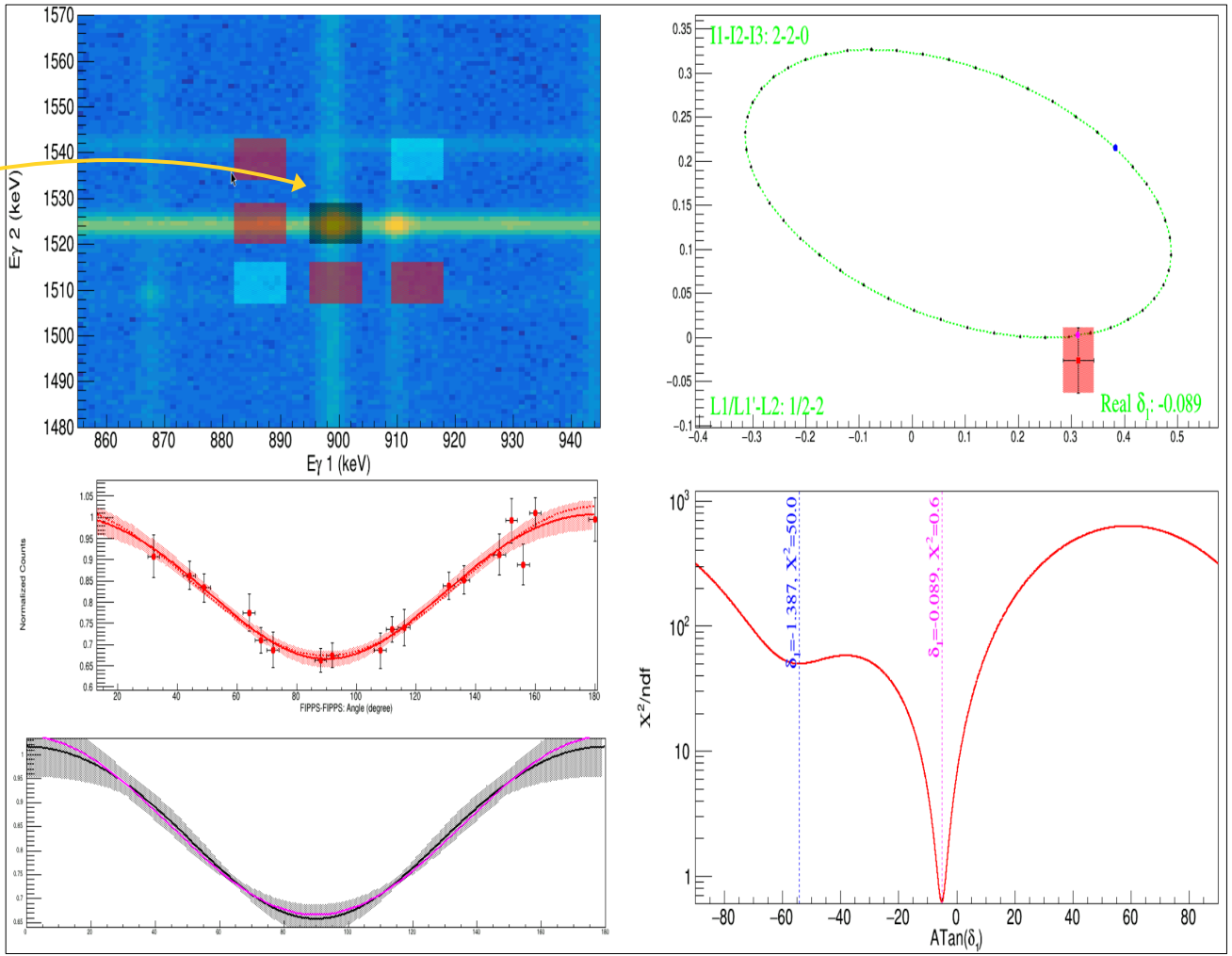
- More than 200 gamma ray transitions (~100 never observed before)
- More than 60 excited levels (~10 never observed before)

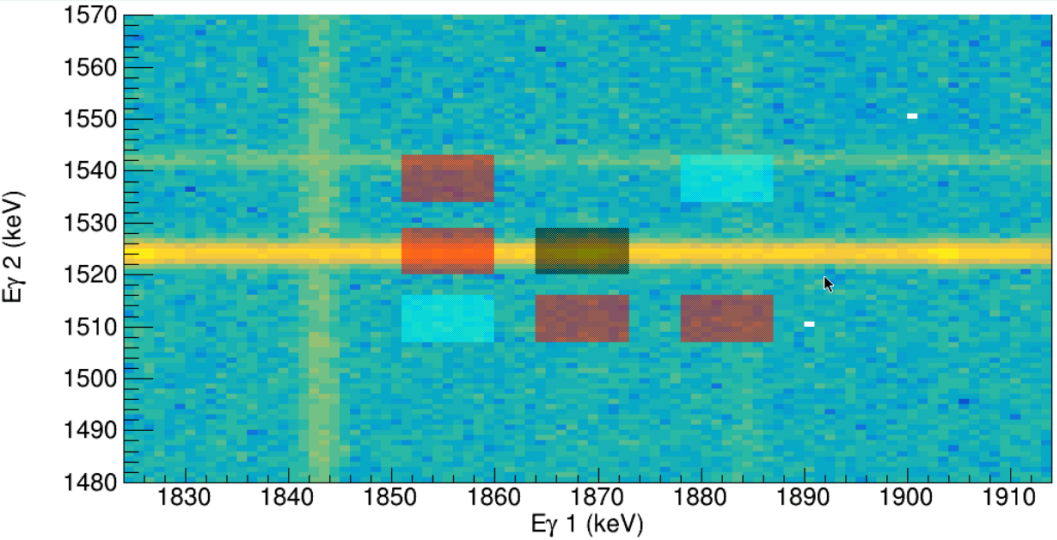
$$\delta_\gamma^2 = I_\gamma(\lambda+1)/I_\gamma(\lambda)$$

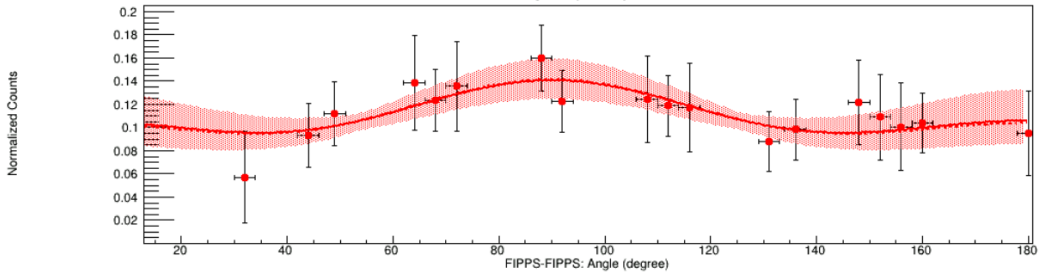
$$W(\theta) = \sum_k A_k Q_k P_k(\cos\theta)$$

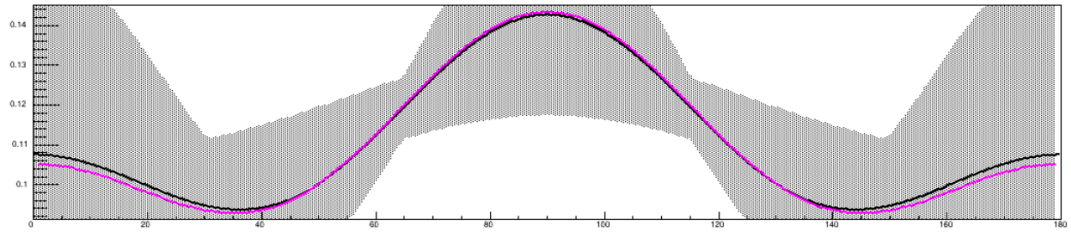


Spin assignment from transitions **multipolarity**

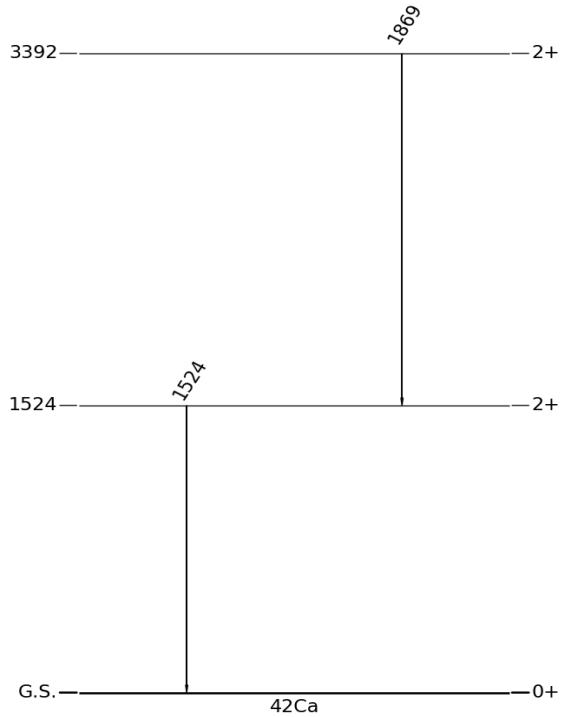






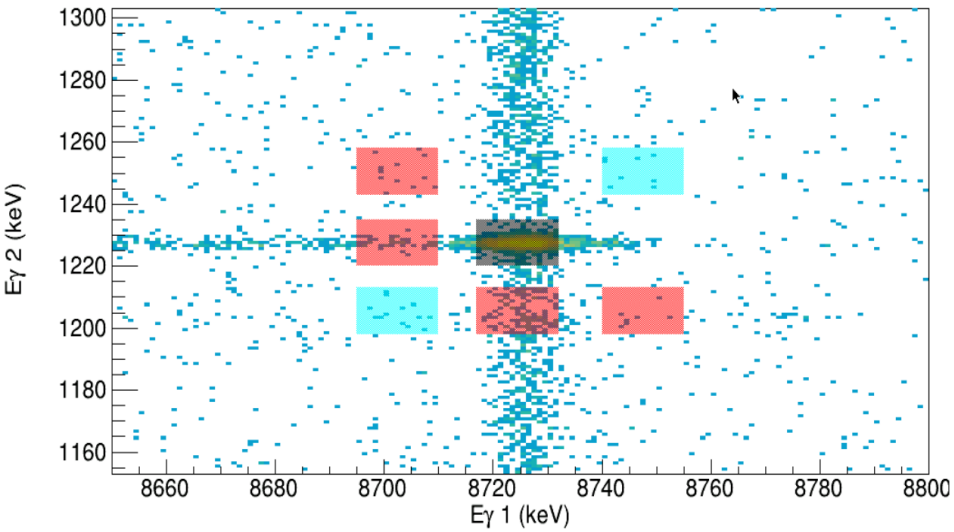


BENCHMARK

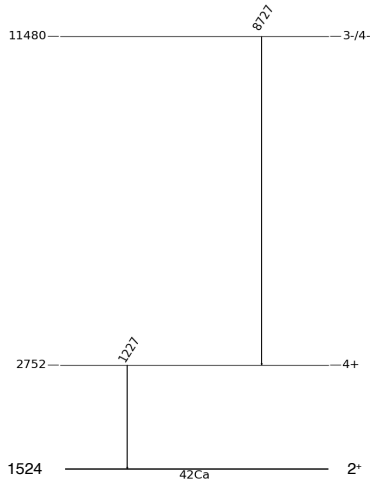


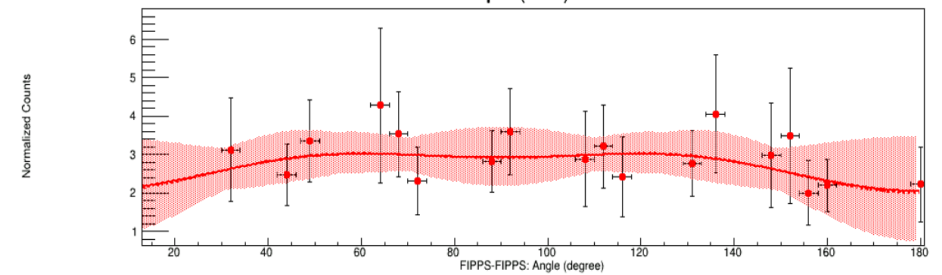
Litterature: M1+E2 \ δ= +1.7 (4)
Exp. Result: M1+E2 \ δ= +1.4 (6)

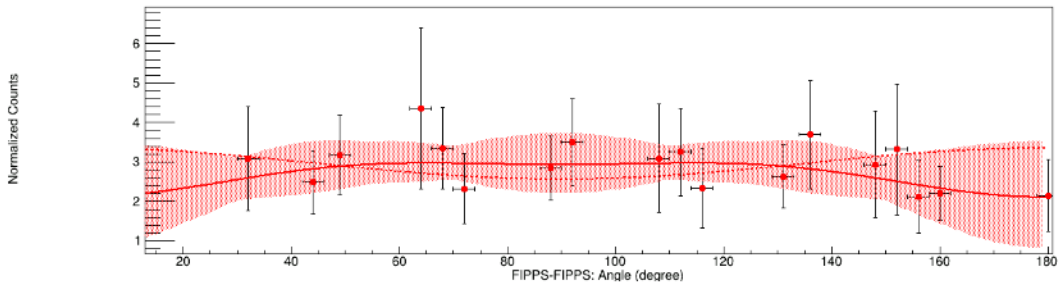
Experimental Results and Future Perspectives – Angular Correlation

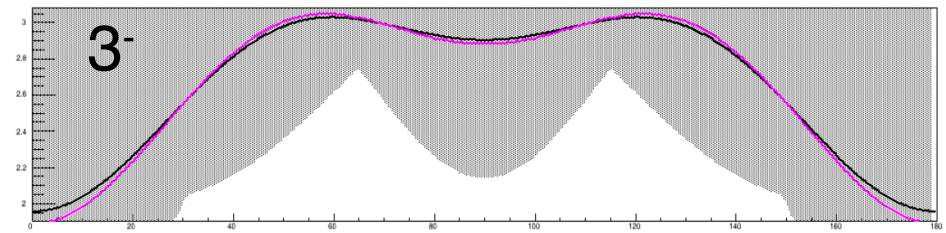


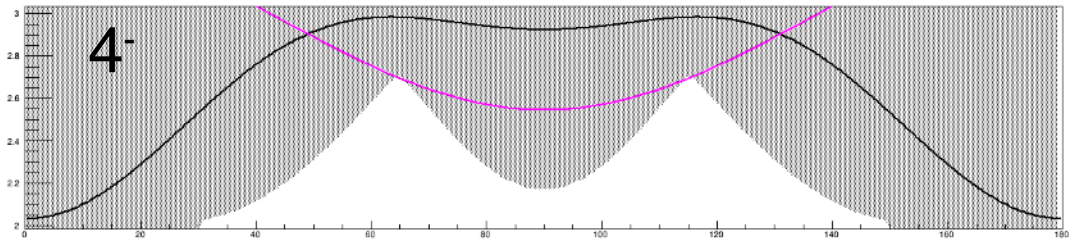
Exp. Result: δ= E1+M2 \ +4.7 (4)







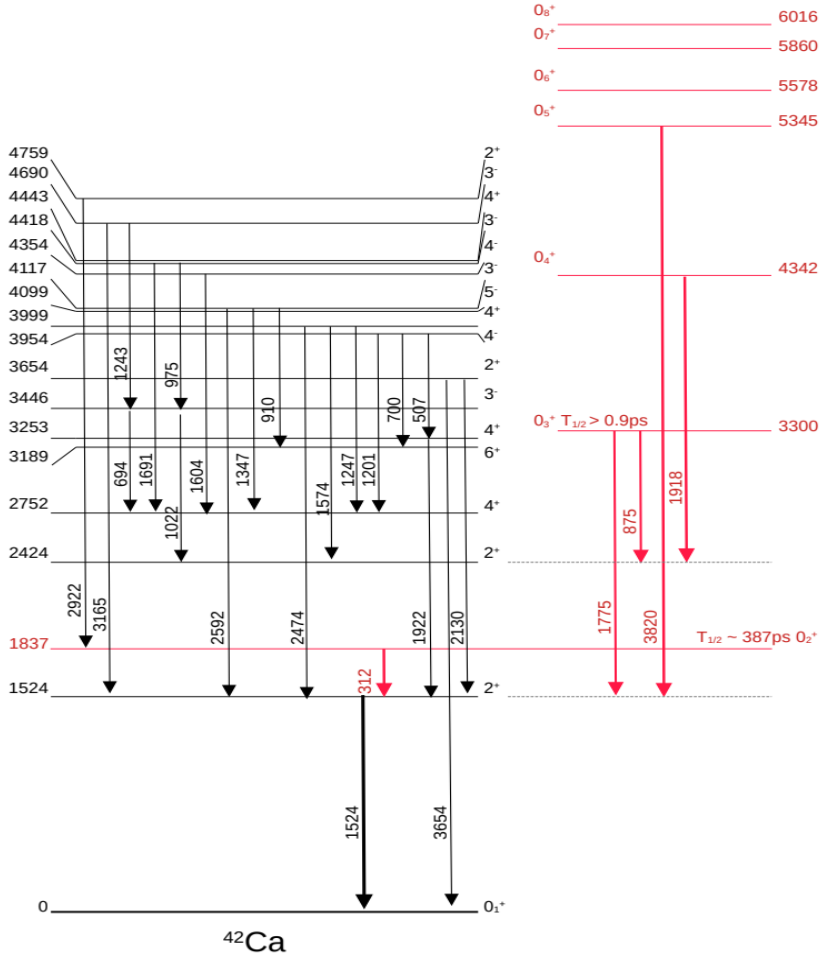




Level No.	Energy [keV]	J^π	Level No.	Energy [keV]	J^π
0	G.S.	0+	14	5201 ±5	
1	1523	2+	15	5366 ±9	
2	1837	0+	16	5471 ±9	4+
3	2423	2+	17	5779 ±11	
4	2751 ±4	4+	18	5863 ±10	0+
5	3186 ±6	6+	19	6015 ±9	0+
6	3253 ±5		20	6106 ±7	(4+)
7	3437 ±9	(3-)	21	6273 ±7	
8	3651 ±6	2+	22	6518 ±8	(0+)
9	4090 ±8		23	6723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

A **future experiment has already** been planned for October 2024 to further investigate 0^+ states of ^{42}Ca:

- **Reaction:** ^{40}Ca(^{18}O,^{16}O)^{42}Ca - 2n transfer
- **Targets:** 1 mg/cm^2 and 10 mg/cm^2 for DSAM technique

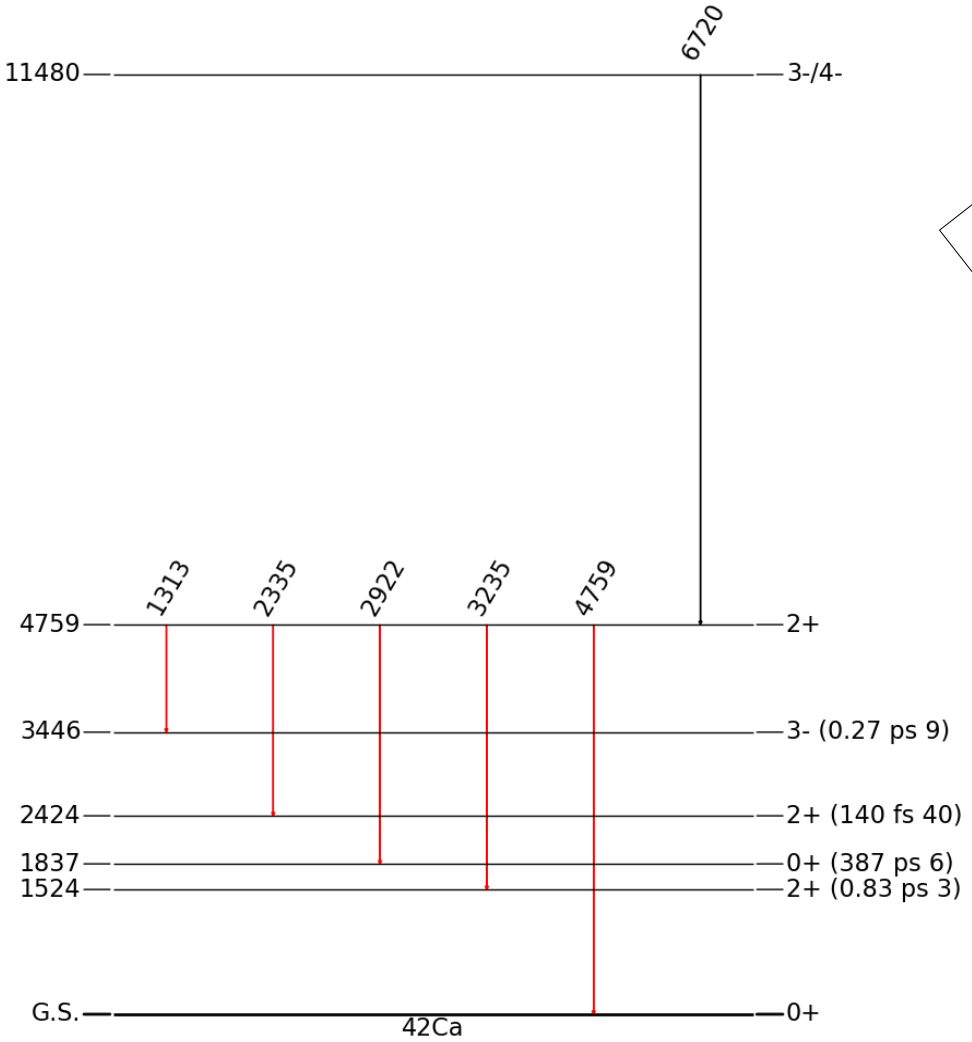


Study of shape coexistence in ^{42,44}Ca by means of n-gamma reactions

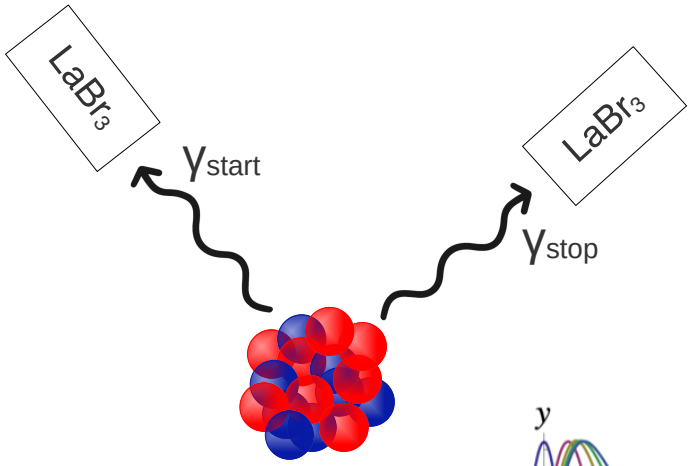
- (Complete) **low-spin spectroscopy** and **lifetimes measurements**,
- Gamma multipolarity asignment
- **Level scheme reconstruction** of ^{44}Ca,

- **Future experiment at IFIN-HH,** October 2024 ^{40}Ca(^{18}O,^{16}O)^{42}Ca

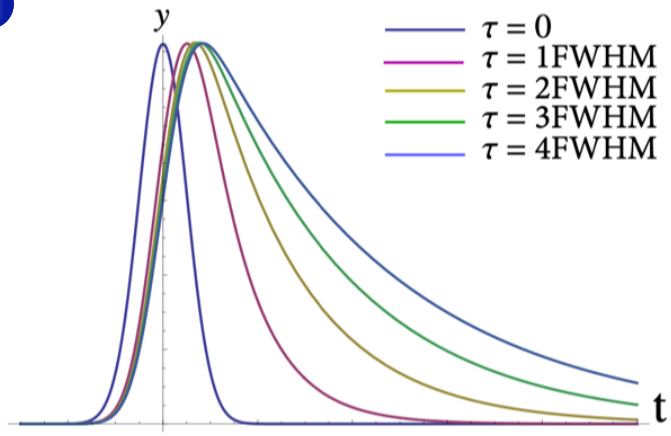
Thank you for your attention!



FAST-TIMING TECHNIQUE



$\tau_{1/2}$ > 10 ps



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

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

$$A_k(j_i \lambda \lambda' j_f) = \rho_k(j_i) \frac{1}{1+\delta^2} [F_k(j_f \lambda \lambda' j_i) + 2\delta F_k(j_f \lambda \lambda' j_i) + \delta^2 F_k(j_f \lambda \lambda' j_i)]$$