Nuclear structure of ^{122}Xe studied via β^+/EC decay

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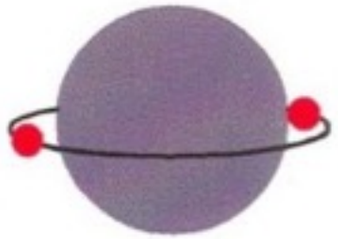
CAP Congress
2016-06-14

Evolution of Nuclear Shape



Shell Model

Spherical

Single particle

Collective Model

Nearly spherical

Surface Vibrate

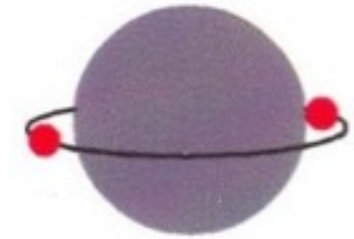
Ellipsoidal

Deformed

Surface Rotate

Nearly spherical

Surface Vibrate



Shell Model

Spherical

Single particle

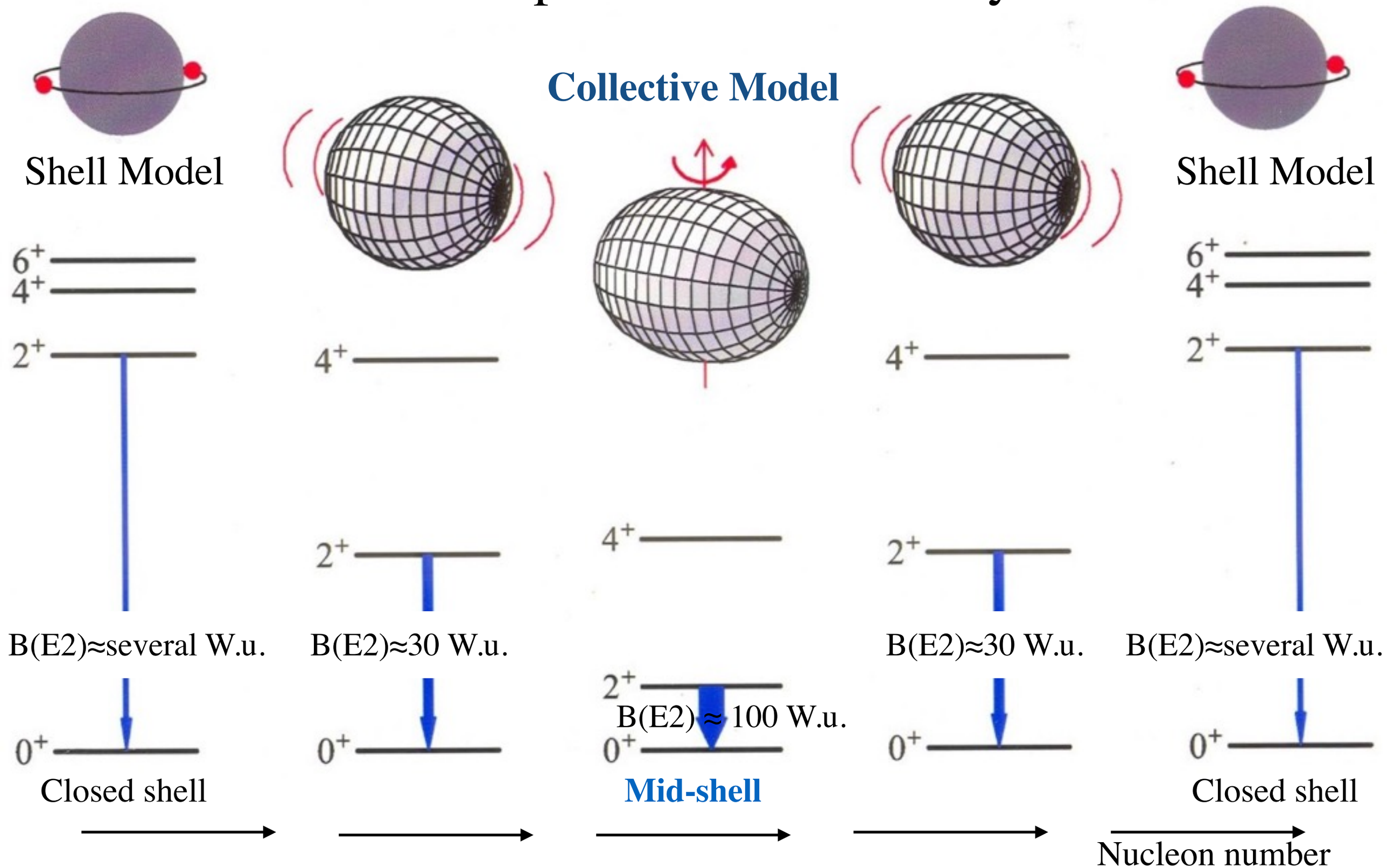
Shape changes

More valence nucleons

Closed shell → → **Mid-shell** → → Closed shell

Nucleon number

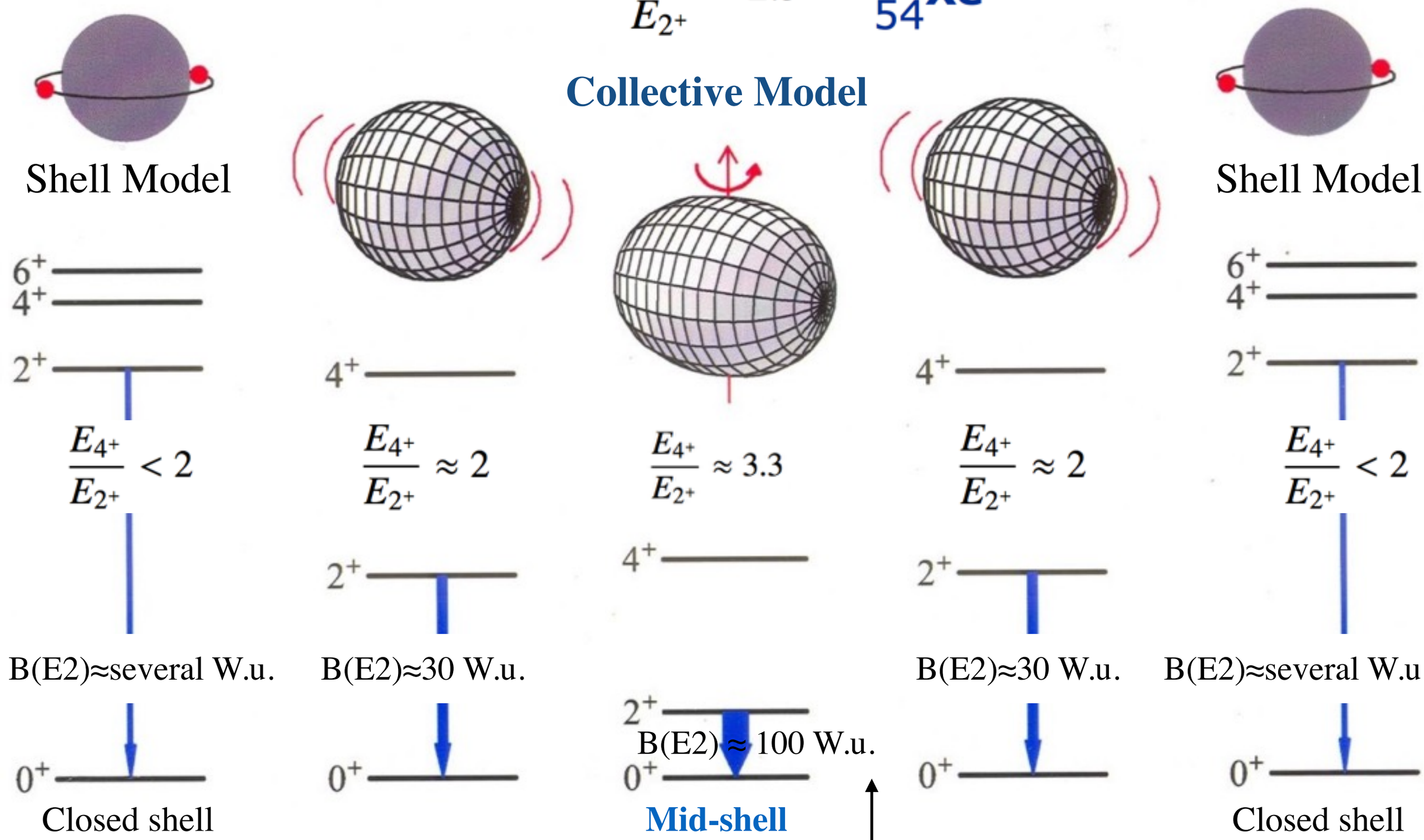
Development of Collectivity



- Enhanced B(E2) rates
- Lowering of the collective states

$$\frac{E_{4^+}}{E_{2^+}} \approx 2.5 \qquad {}^{122}_{54}\mathrm{Xe}$$

Collective Model

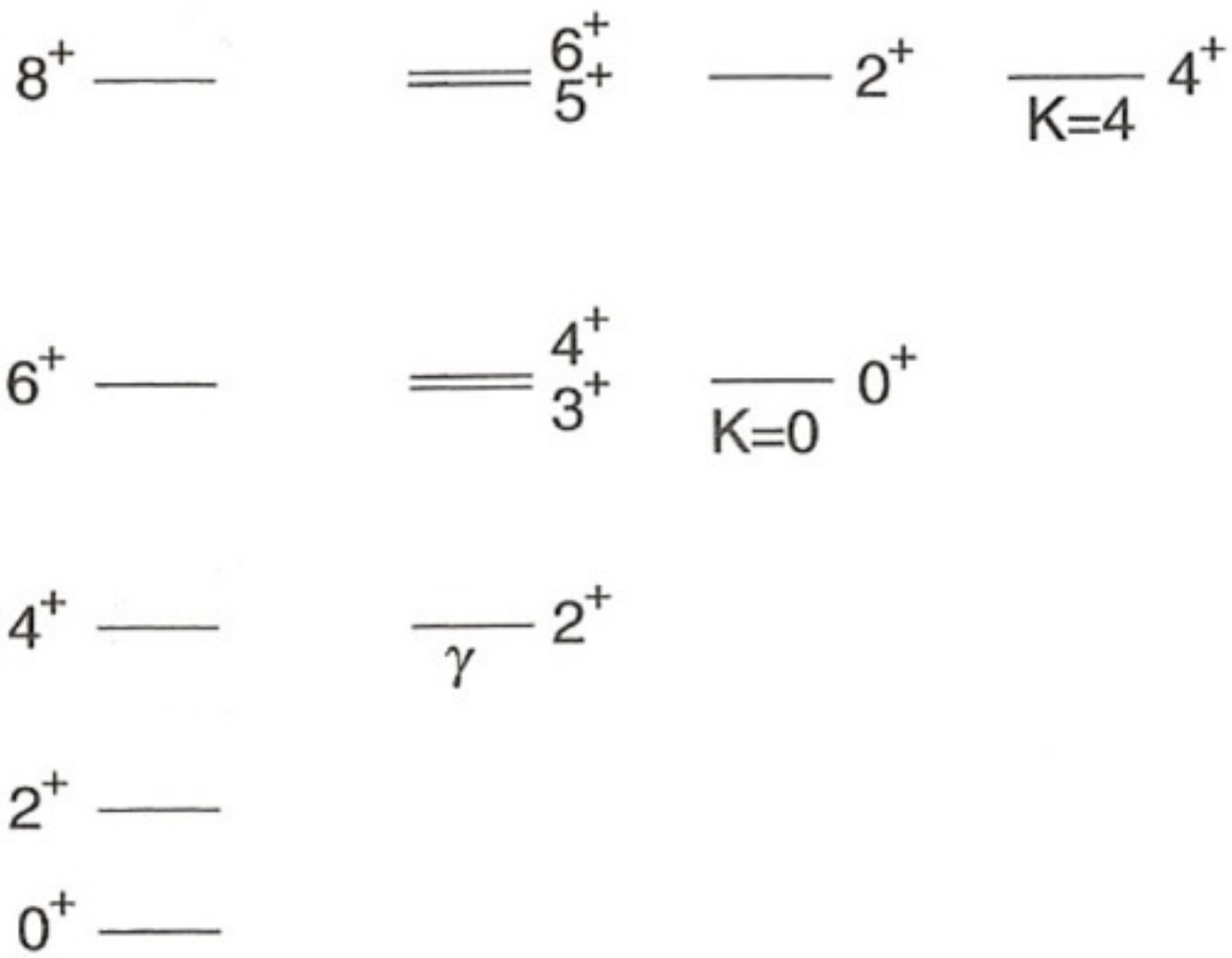


^{122}Xe falls in transitional region.

What kind of collective model can describe such nucleus?

γ-soft (in IBM O(6) symmetry)

γ-soft, O(6) symmetry (theo)



- Recent work on ^{124}Xe
- Showed $O(6)$ broken

G. Rainovski, N. Pietralla, T. Ahn, L. Coquard, C.J. Lister, R.V.F. Janssens, and M.P. Carpenter, Phys. Lett. B683, 11_(2010).

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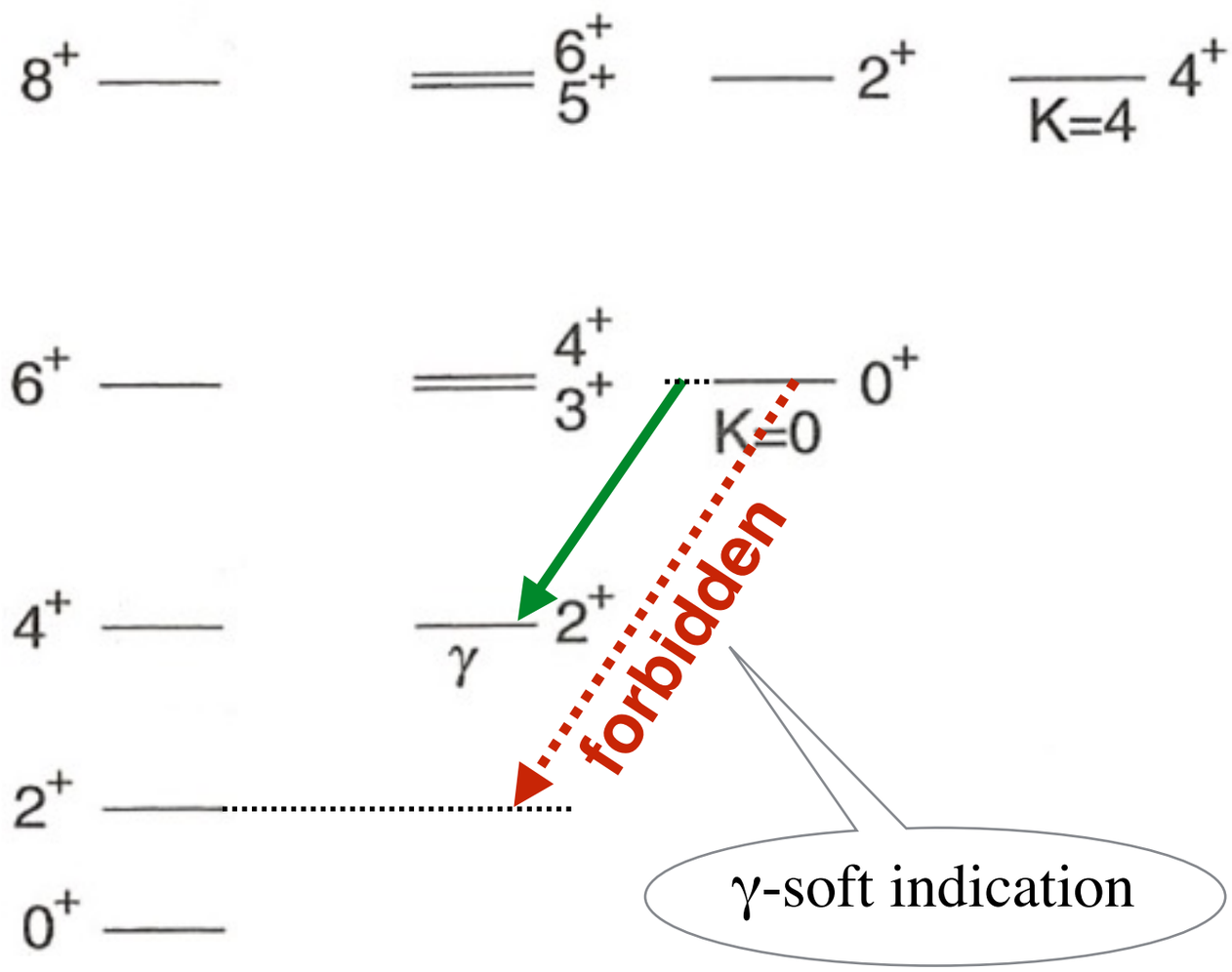
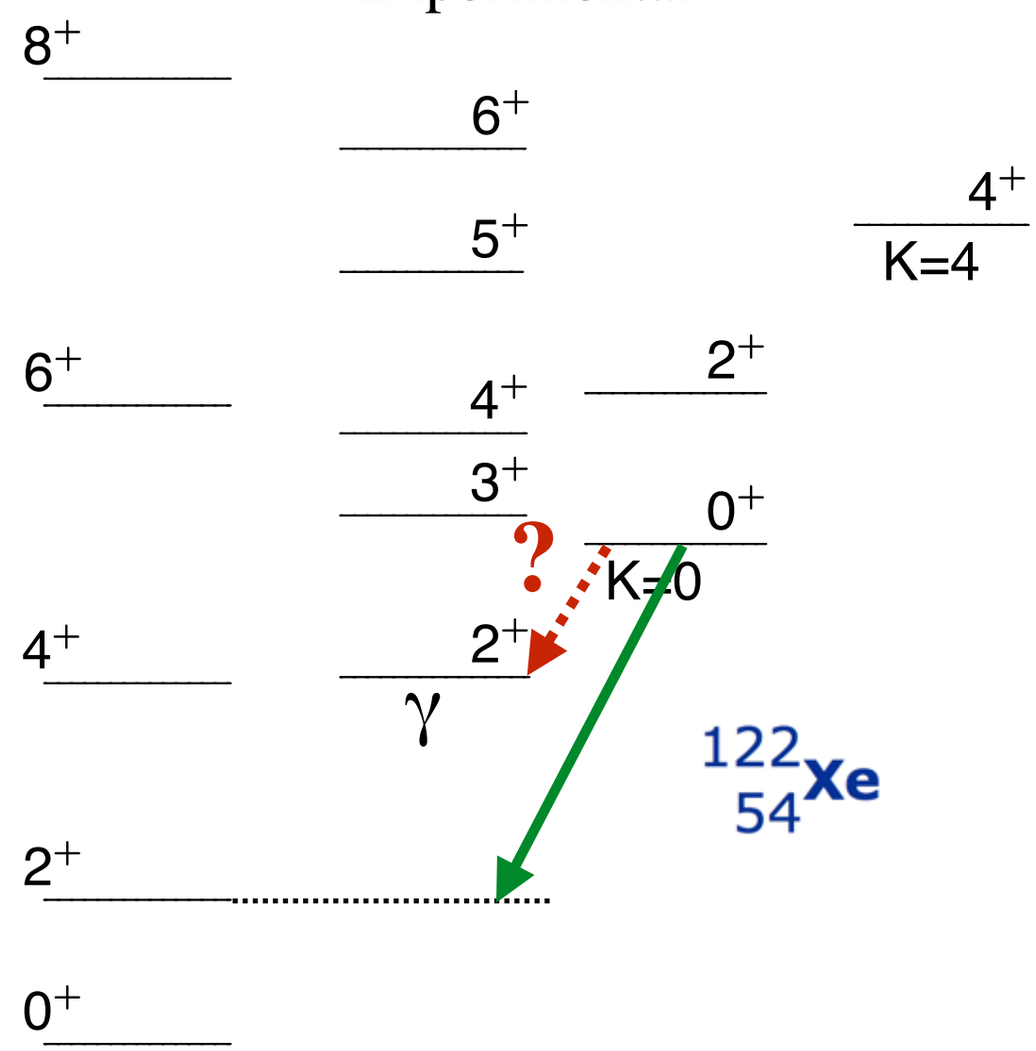


Experimental



- Recent work on ^{124}Xe
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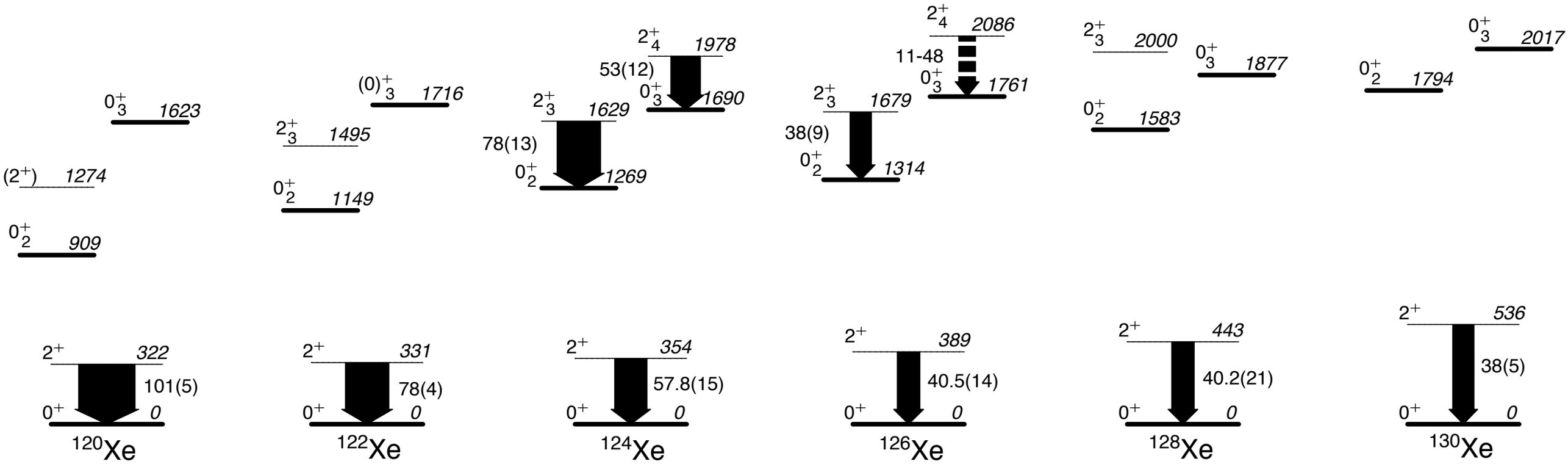
- No favoured transition
- Violates indication

Is ^{122}Xe still γ-soft nucleus and does it possess $O(6)$ symmetry?

E2 transitions in collective nuclei

University of Guelph

A.J. Radich *et al.*, Phys. Rev. C **91**, 044320 (2015)



Systematics of the low-lying 0+ states in the ^{120}Xe –^{130}Xe isotopes.

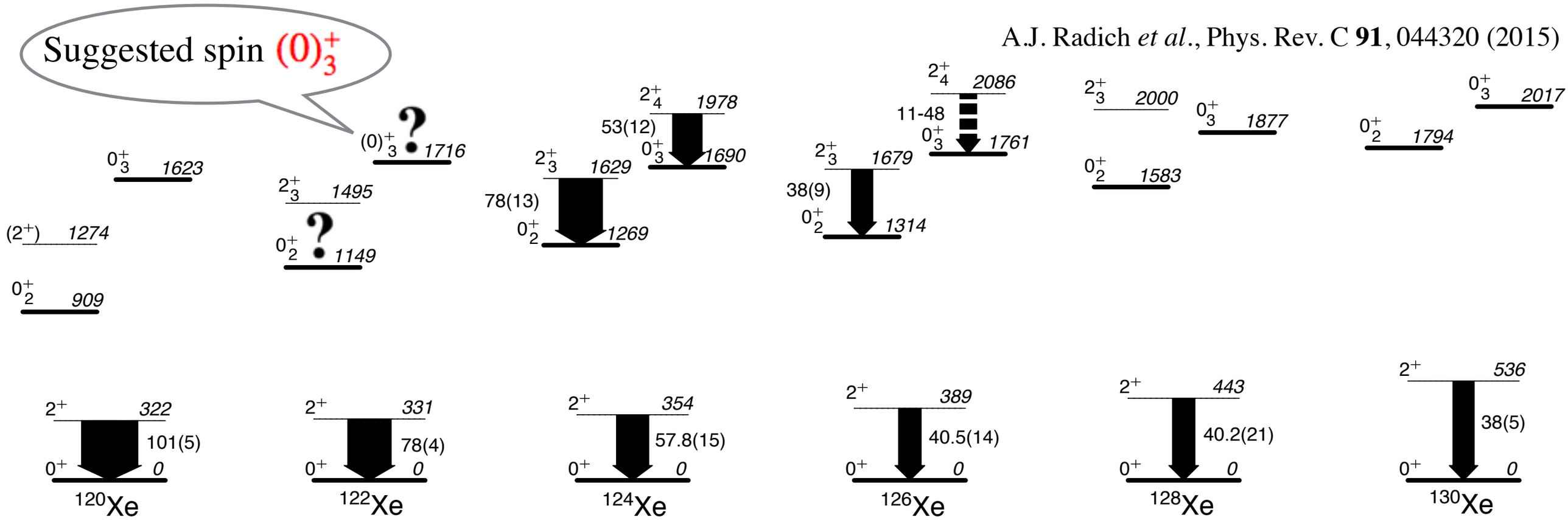
Collectivity in Xe isotopes is actually rather poorly characterized!

- Collective nuclei have to have these bands
- In-band E2 transitions strong
- Their B(E2) values (quadrupole collectivity)

E2 transitions in Xe-122

University of Guelph

A.J. Radich *et al.*, Phys. Rev. C **91**, 044320 (2015)



Systematics of the low-lying 0+ states in the ^{120}Xe –^{130}Xe isotopes.

Collectivity in Xe isotopes is actually rather poorly characterized!

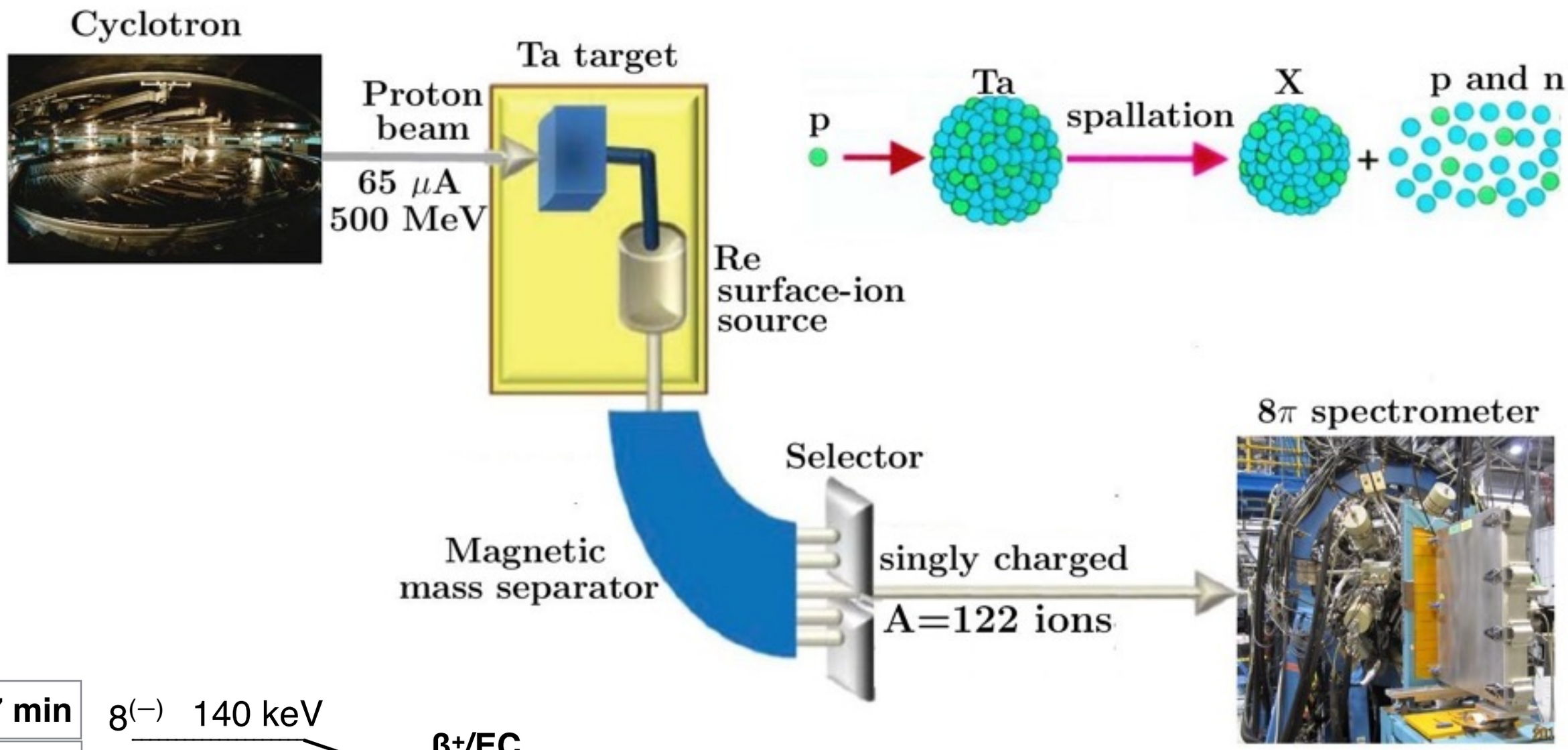
- Third 0^+ state not confirmed
- Band member 2^+ state missing
- Important E2 transitions missing

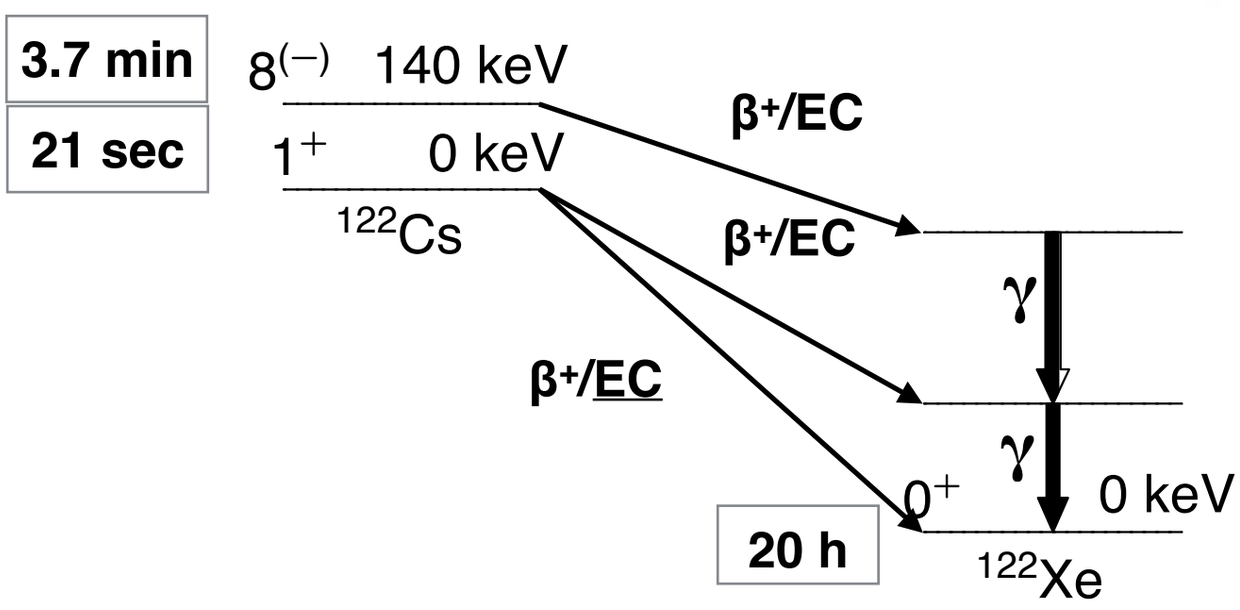
Important in-band E2 transitions are missing for ^{122}Xe?

To answer need to investigate ^{122}Xe

Experimental setup

TRIUMF-ISAC facility located in Vancouver, Canada.

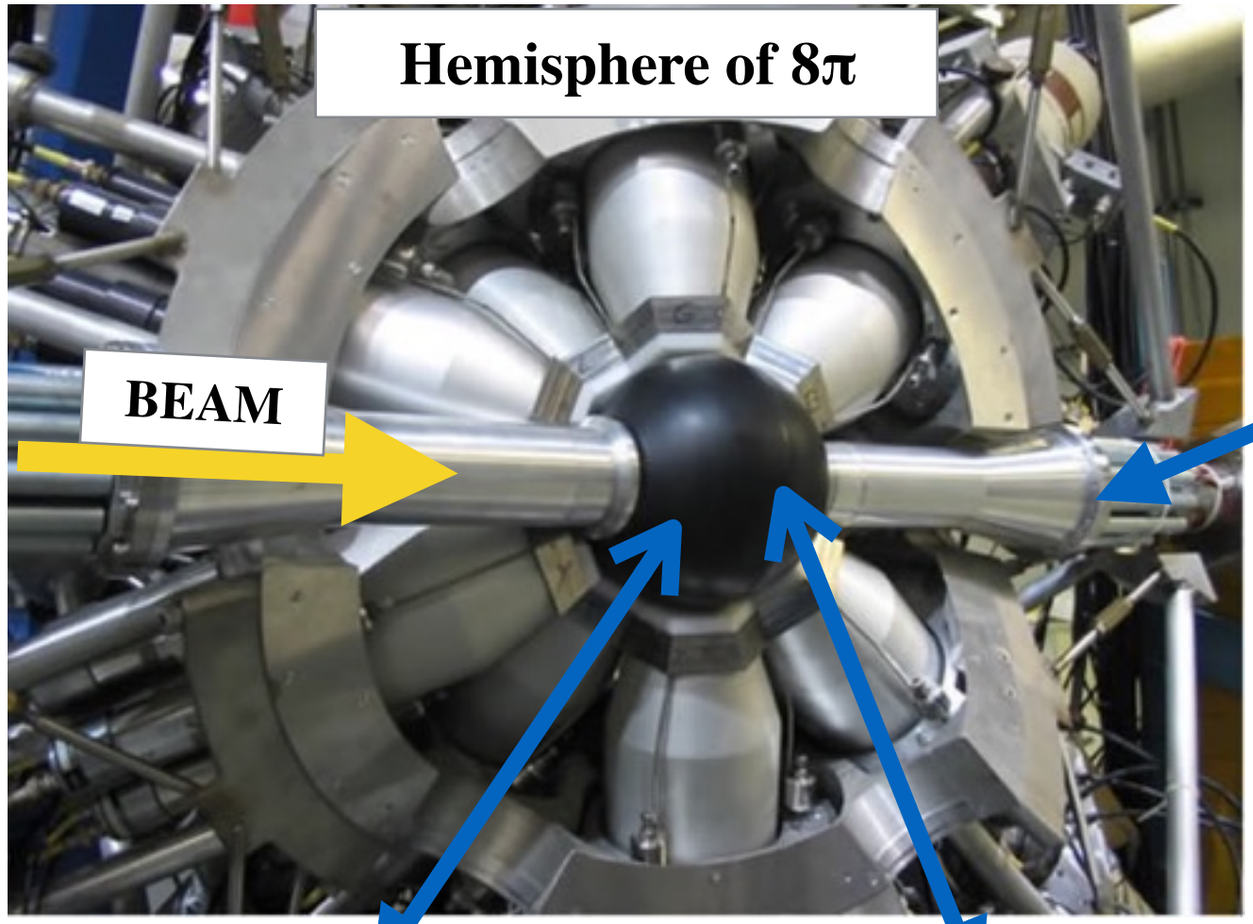


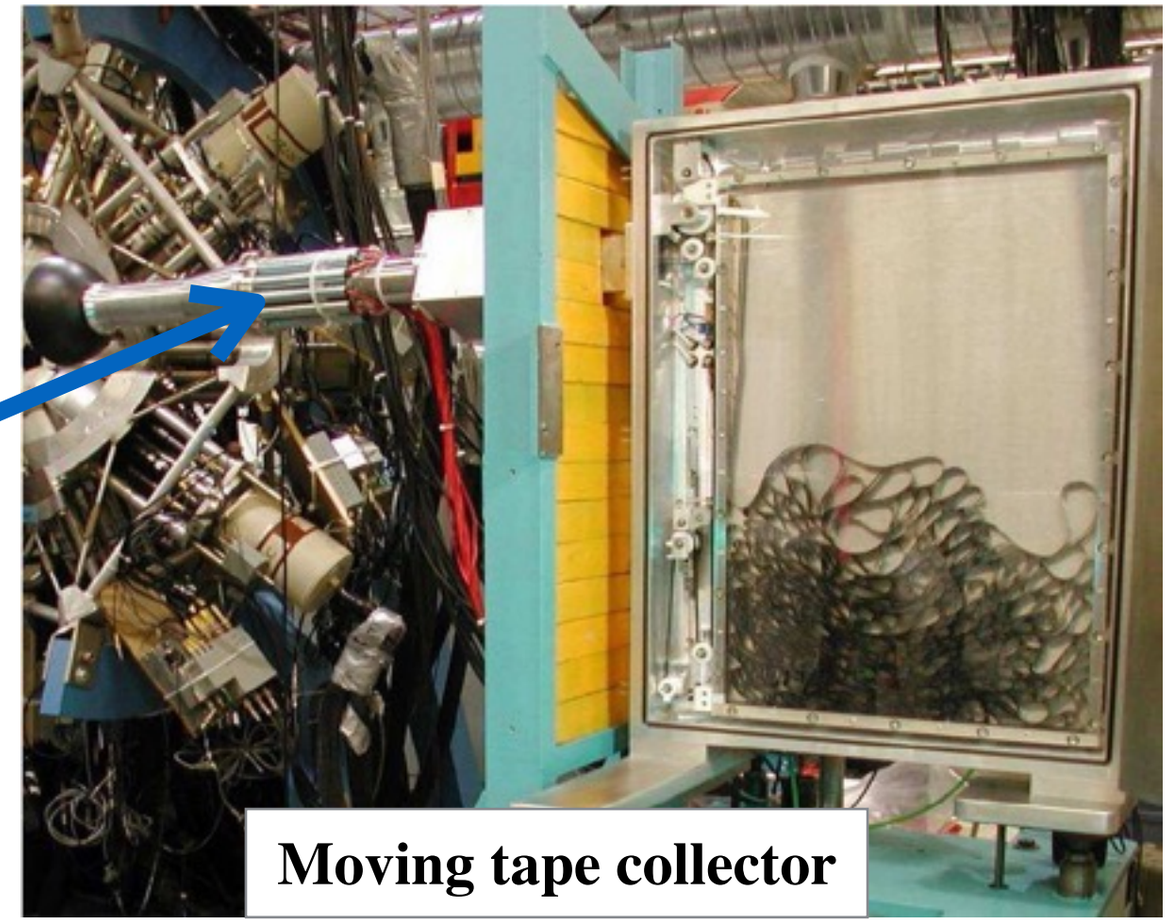


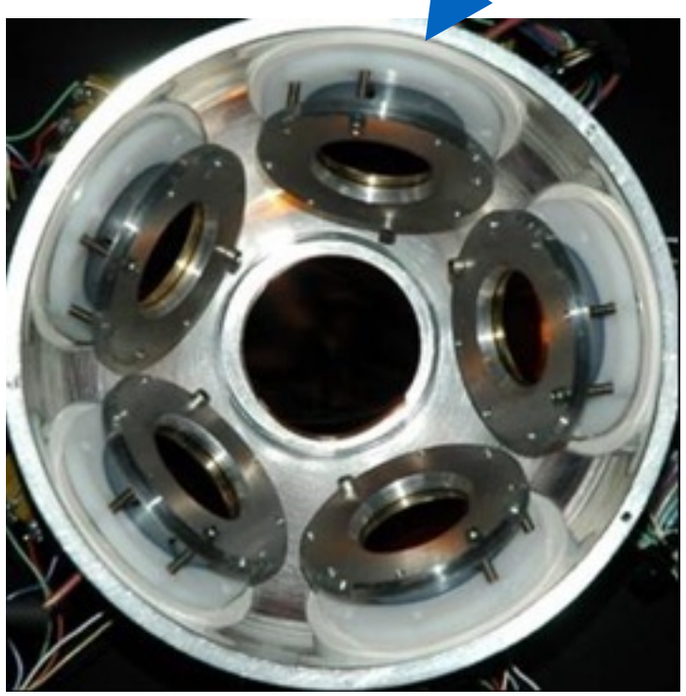
Two sets of data were collected for short- and long-half-life decays in repeated cycles.

- short cycle run 2s, 20s, 20s, and 0.75s
- long cycle run 20s, 450s, 450s, and 1.5s

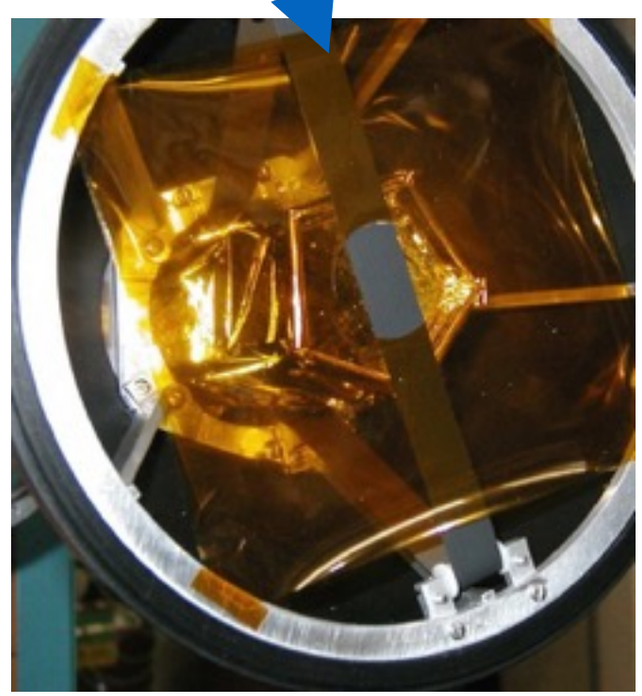
8π spectrometer







PACES



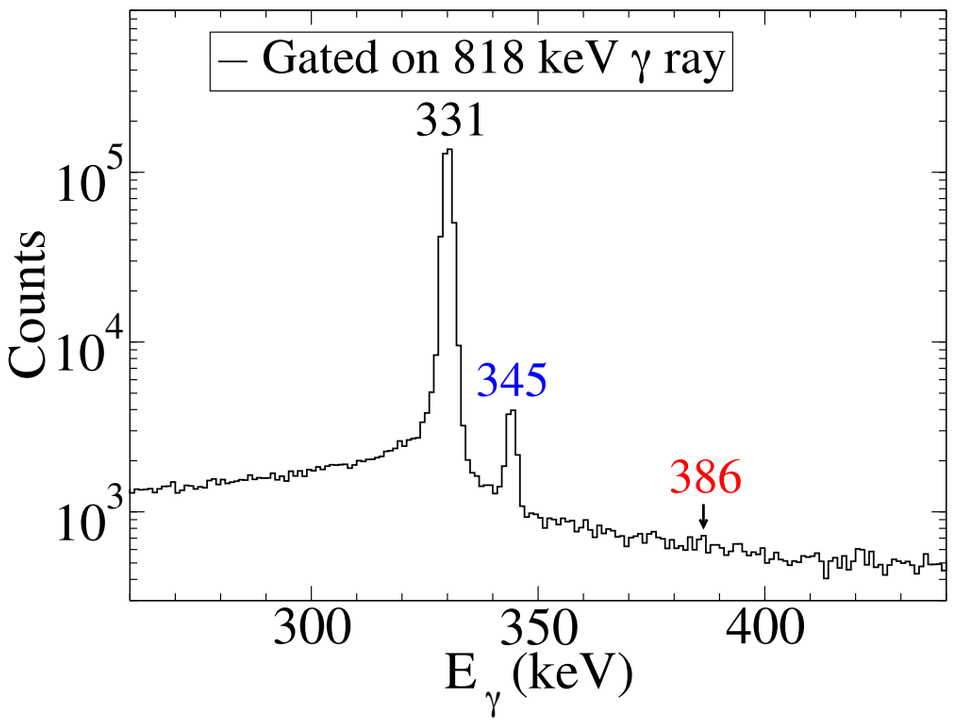
SCEPTAR

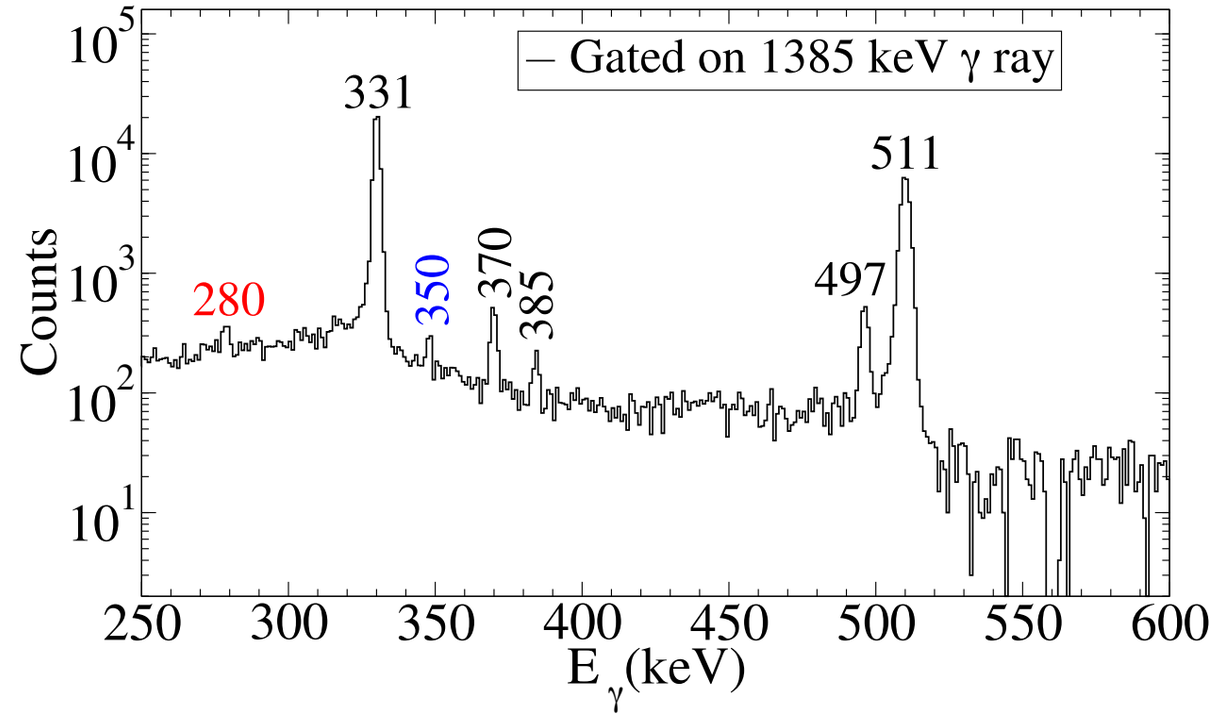
- 20 HP Ge detectors for γ-ray
- 5 Si(Li) detectors (PACES) for e^-'s
- Moving tape collector used to transport the beam deposit spot

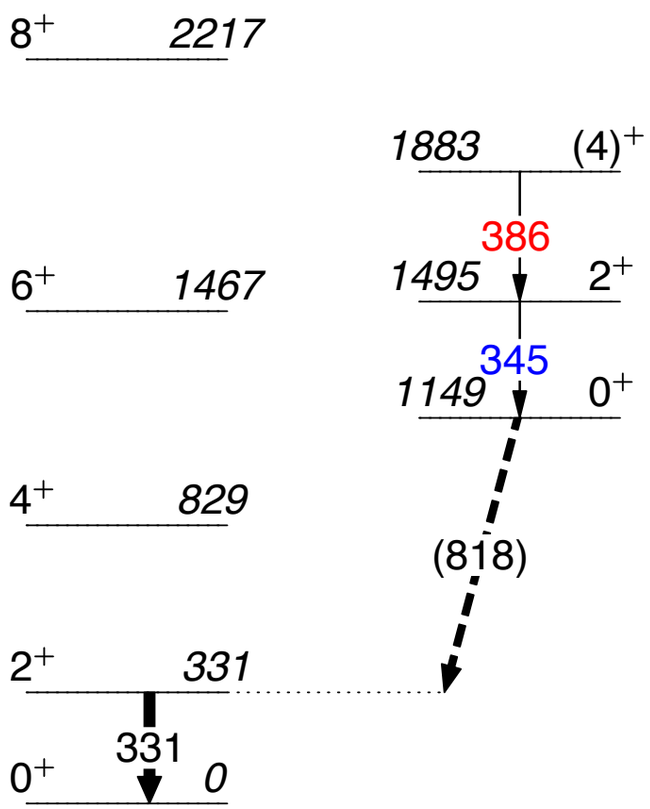
γγ coincidence data allowed

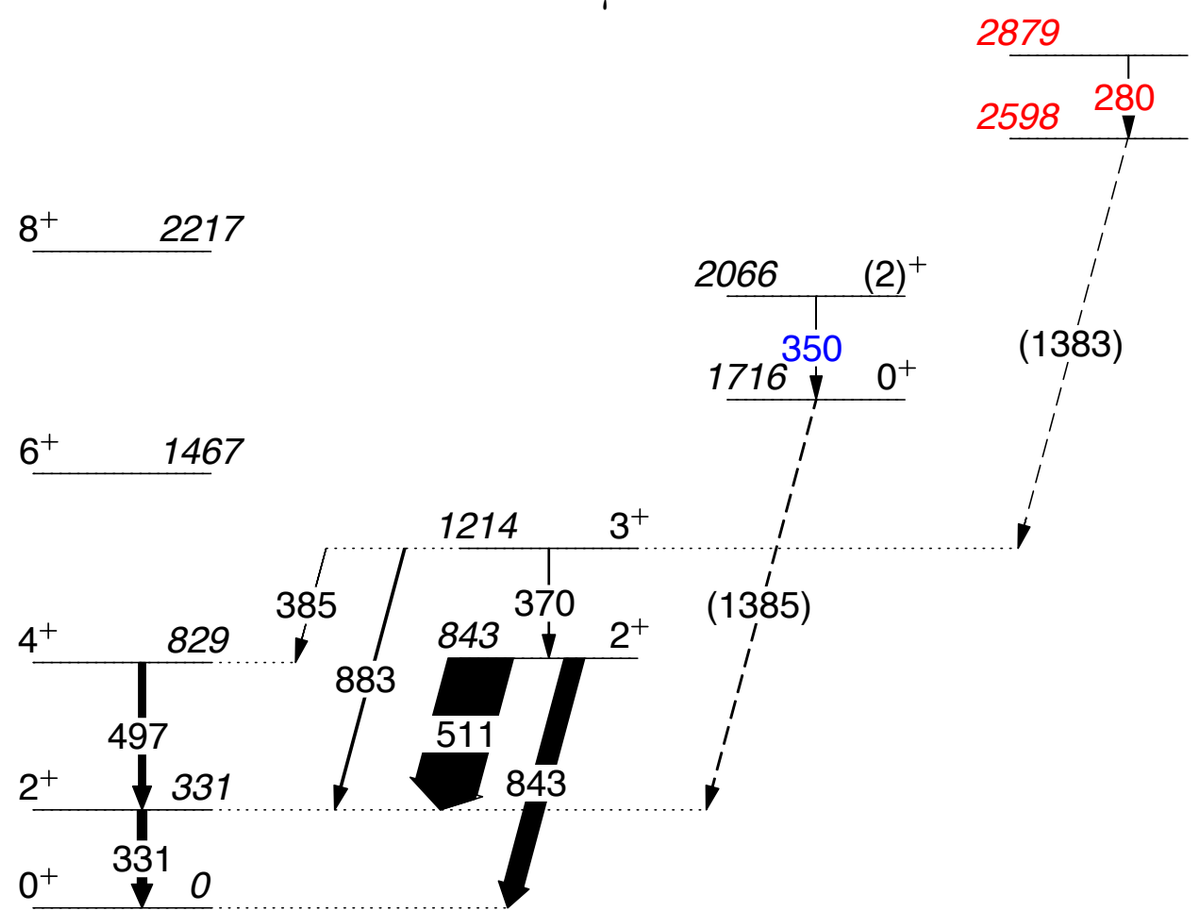
- 160 new transitions
- more than 100 new levels

Results: Important E2 transitions

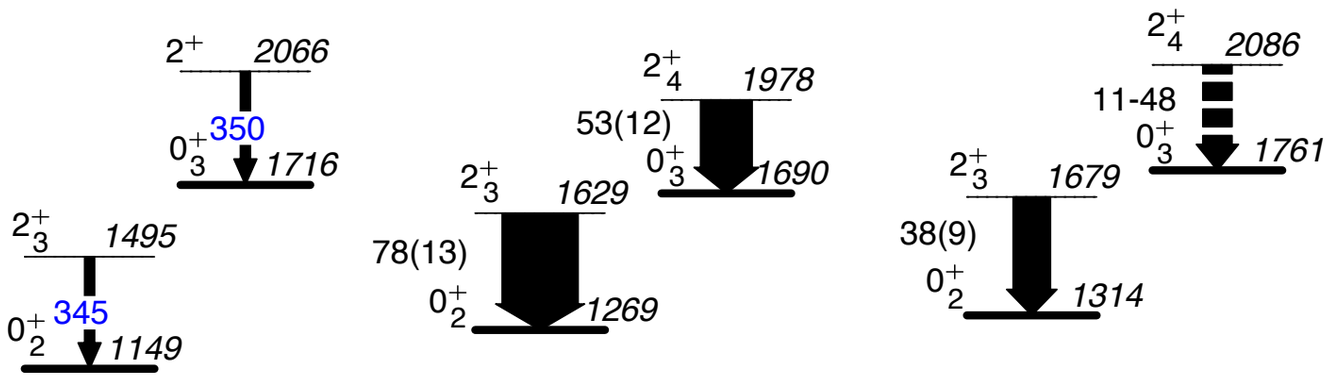


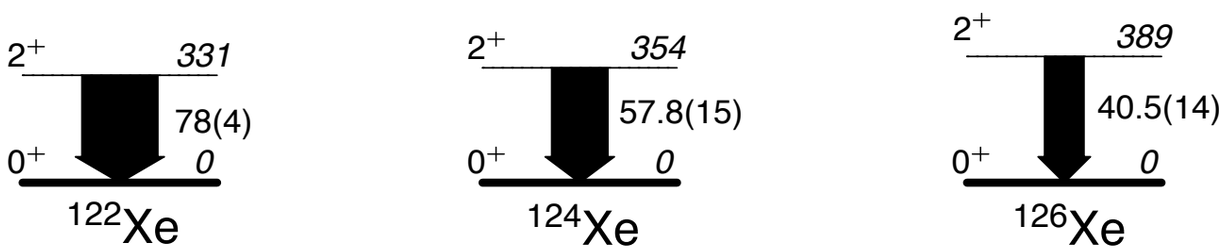




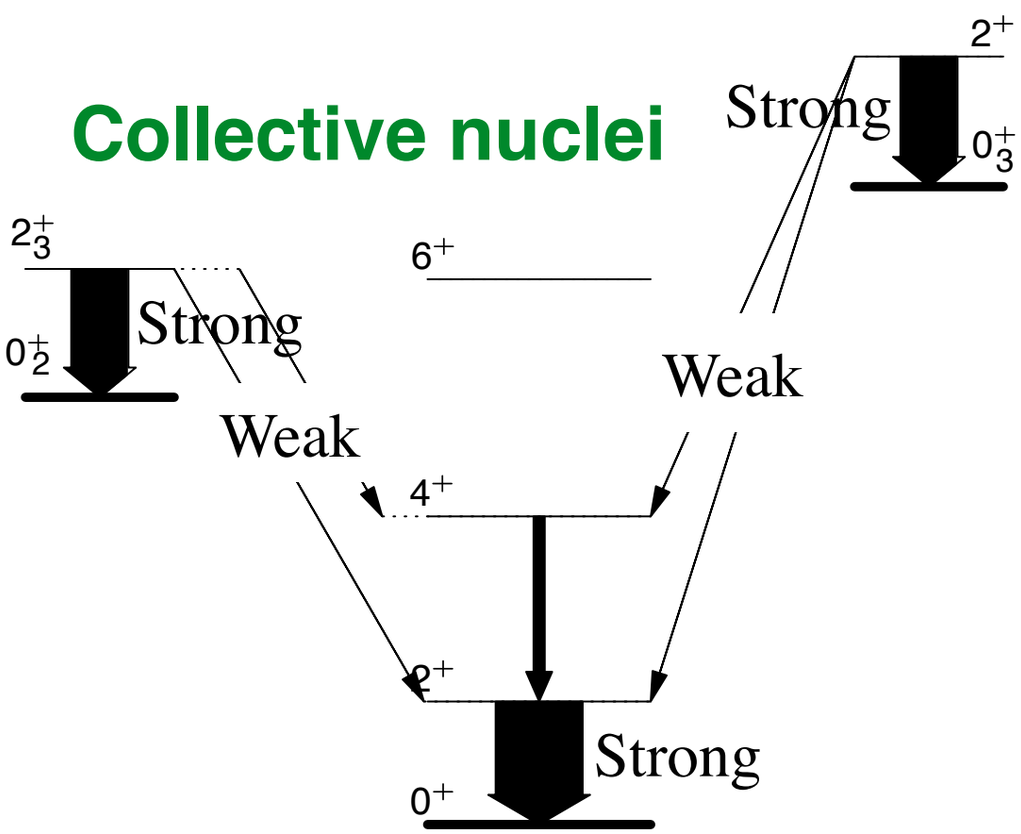


Results: E2 transitions

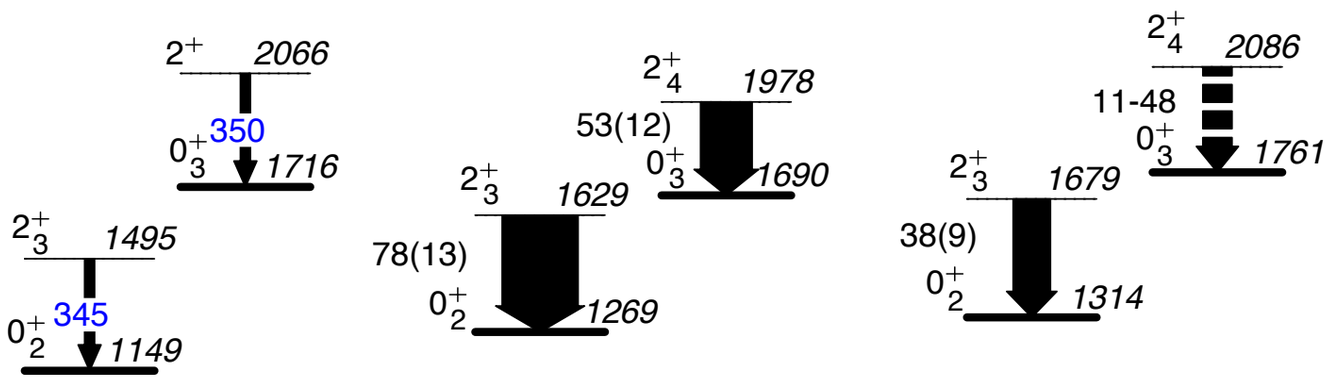




Systematics of the low-lying 0+ states.



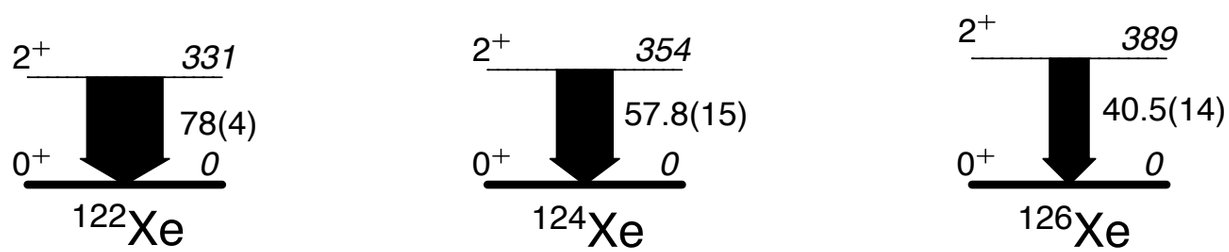
Results: Relative B(E2) values



$$B(E2) = \frac{9.527 \times 10^6}{E_{\gamma_i}^5 A^{4/3}} \frac{BR_{\gamma_i}}{T_{1/2}^{level}(1+\alpha_i)}$$

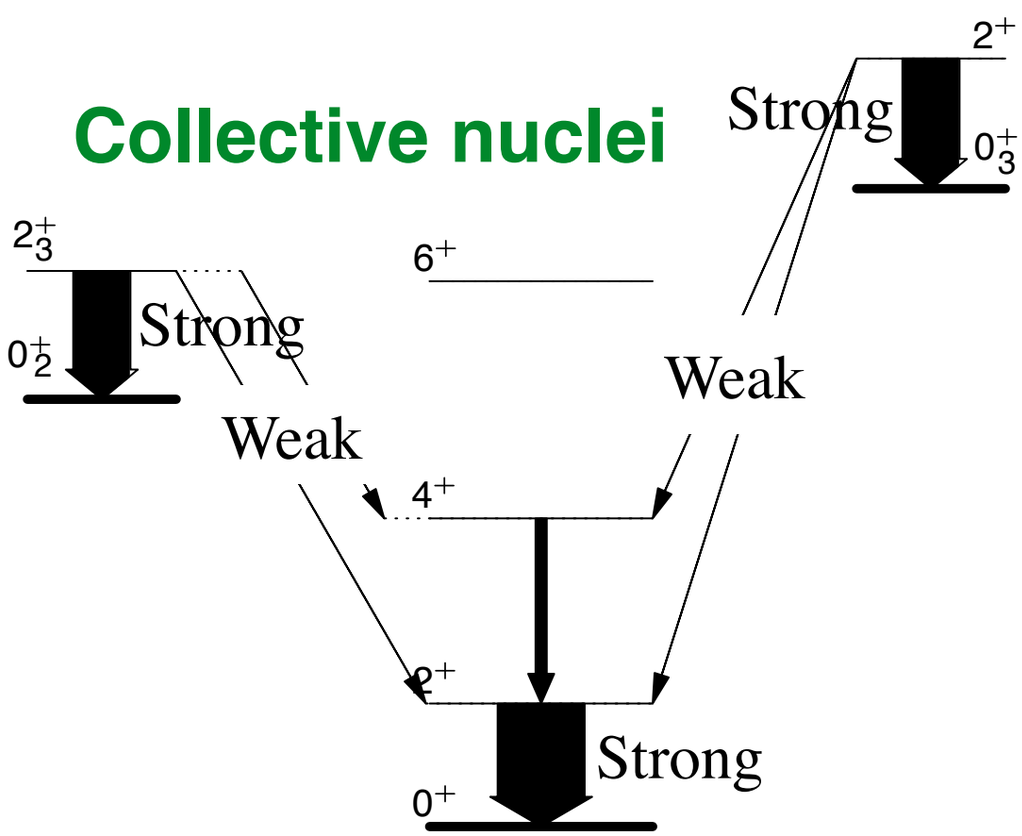
$T_{1/2}$ the half-life of the levels missing,

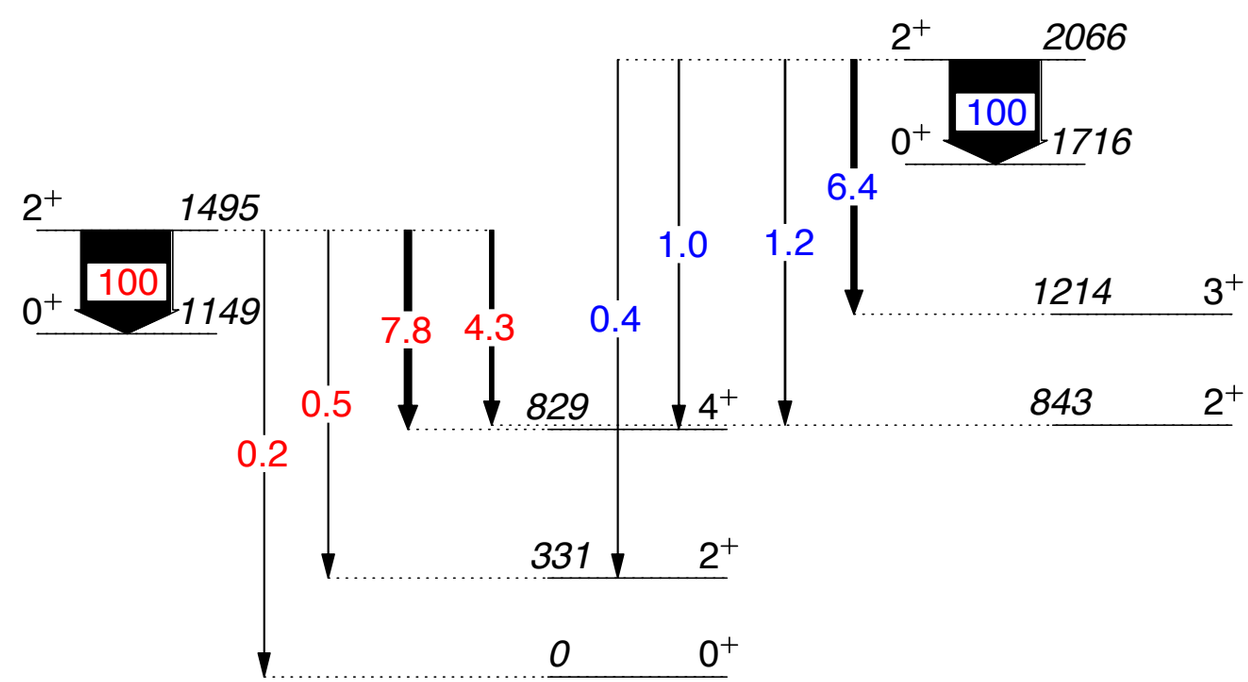
The relative $B(E2)$ values for the key transitions



$$\frac{B(E2)}{B(E2)_{ref}} = \frac{E_{\gamma_{ref}}^5}{E_\gamma^5} \frac{BR}{BR_{ref}}$$

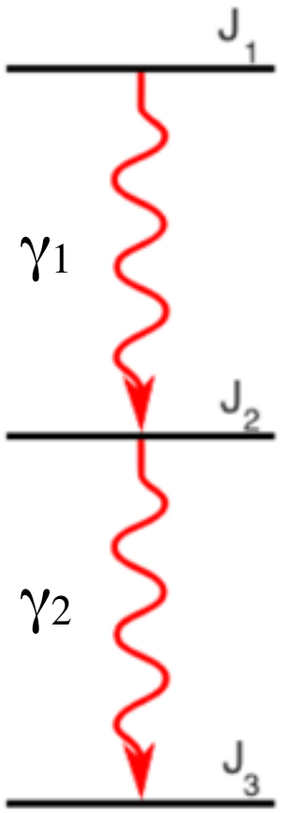
Systematics of the low-lying 0+ states.

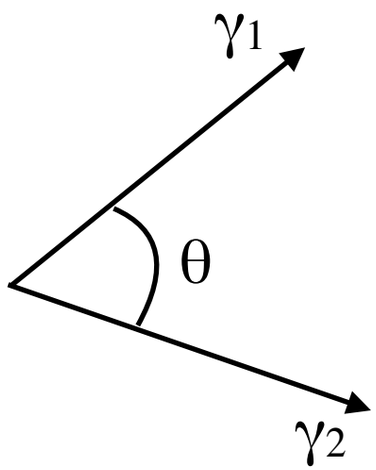




- Agrees collective behaviour
- Firmly establishes 2+ band members
- First critical piece of information

Results: Angular Correlation



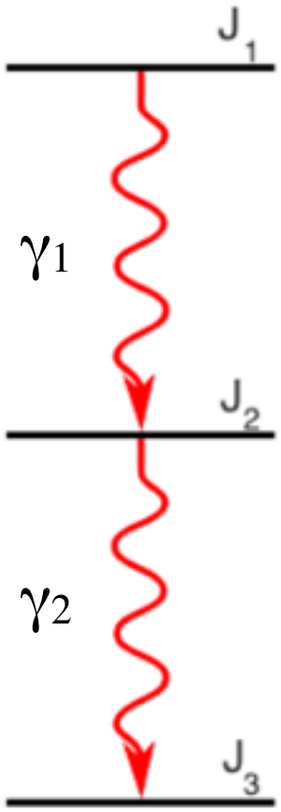


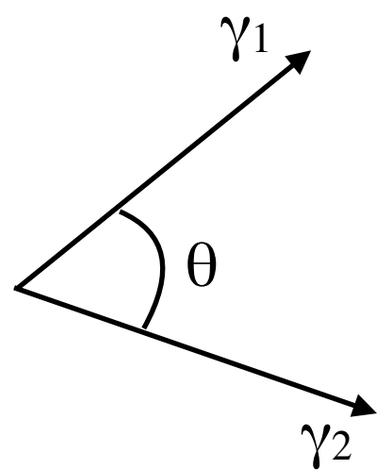
The probability, per unit solid angle, that two gamma-rays are emitted at an angle θ is proportional to.

$$W(\theta) = 1 + A_{22}P_2(cos(\theta)) + A_{44}P_4(cos(\theta)) + ...$$

$A_{22}(J_1, J_2, J_3)$ and $A_{44}(J_1, J_2, J_3)$

Results: Angular Correlation





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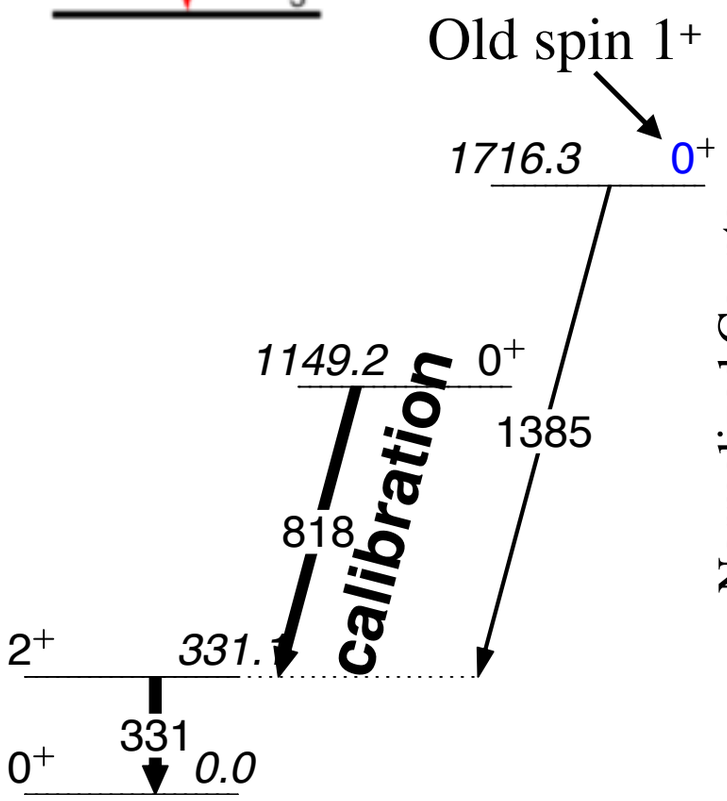
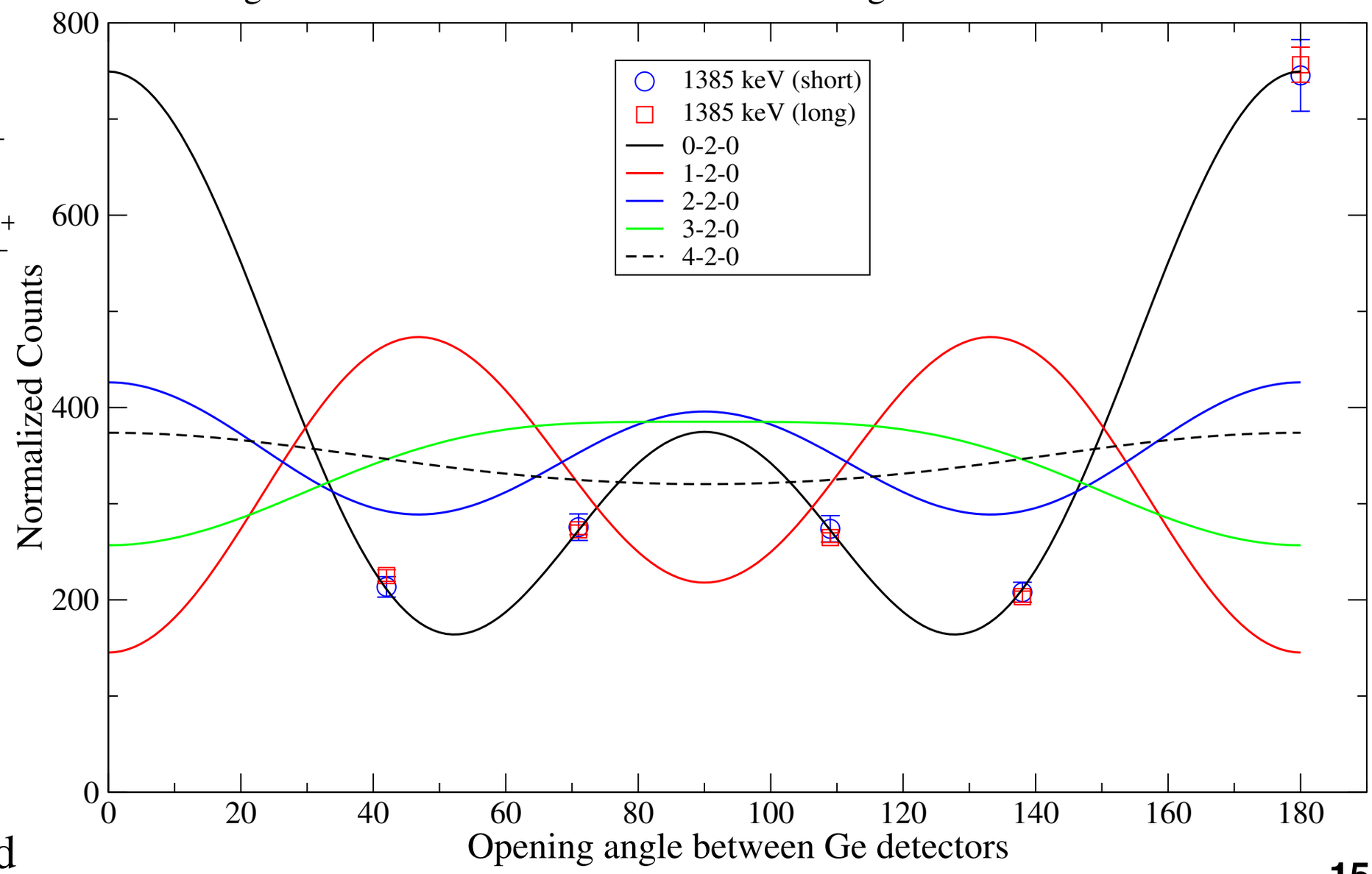


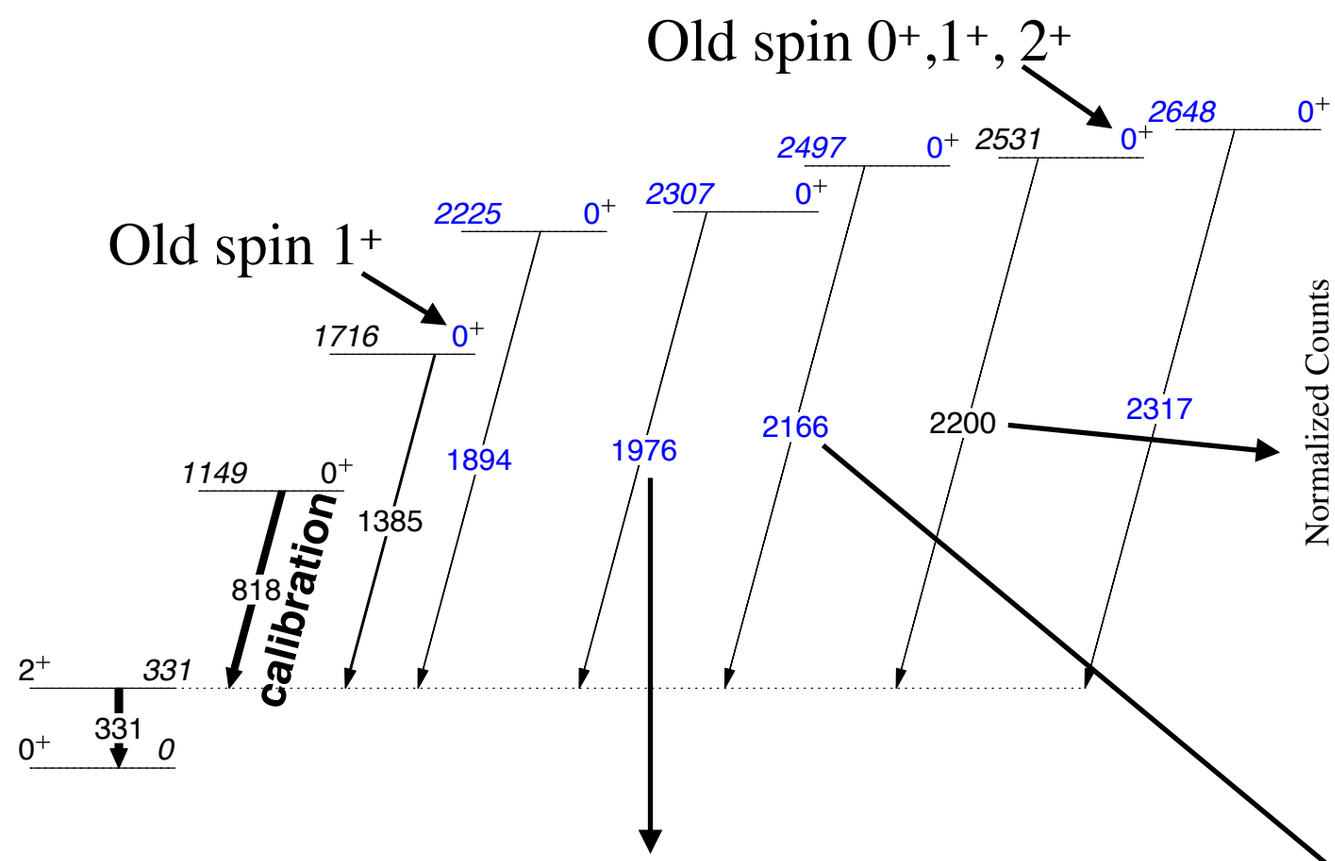
Angular correlations of 1385 keV transitions gated on 331 keV transition

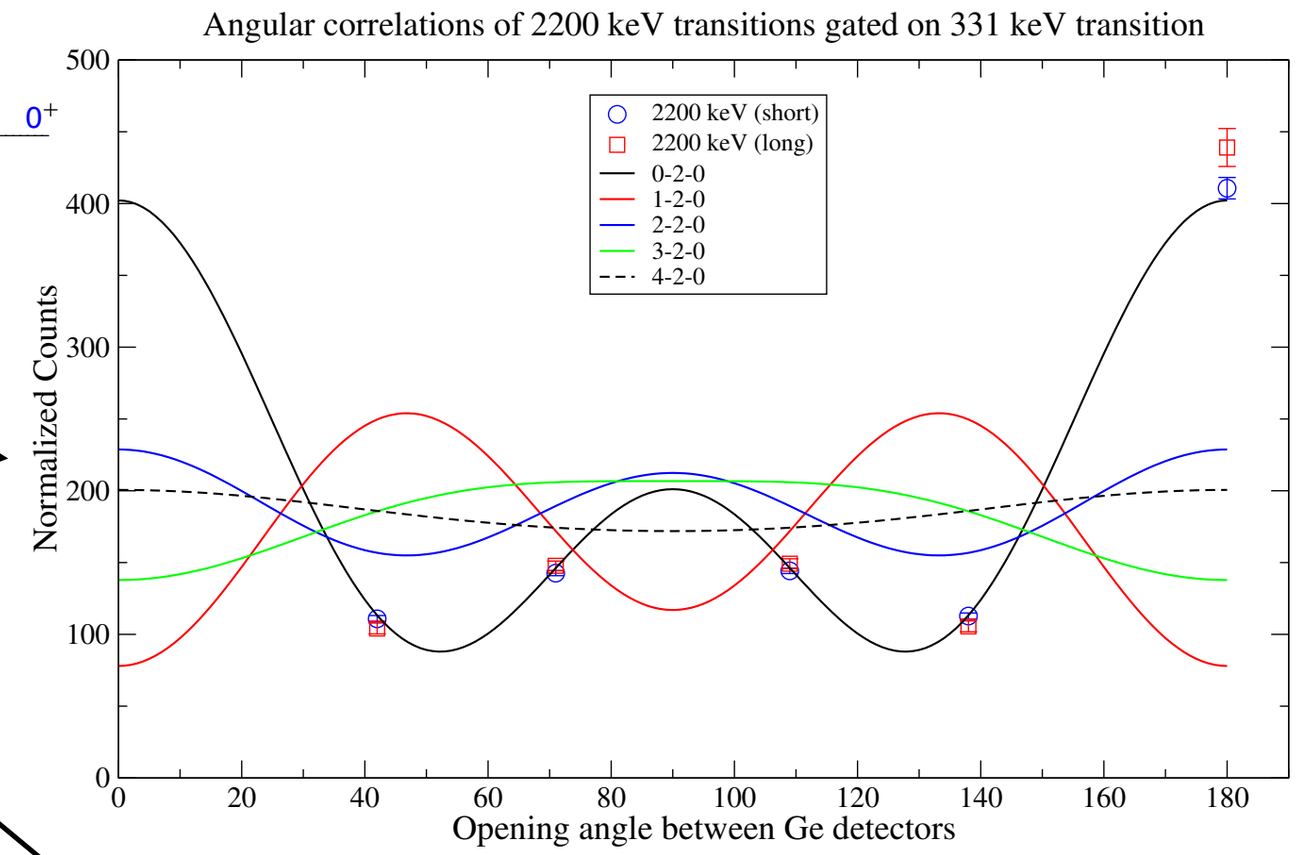


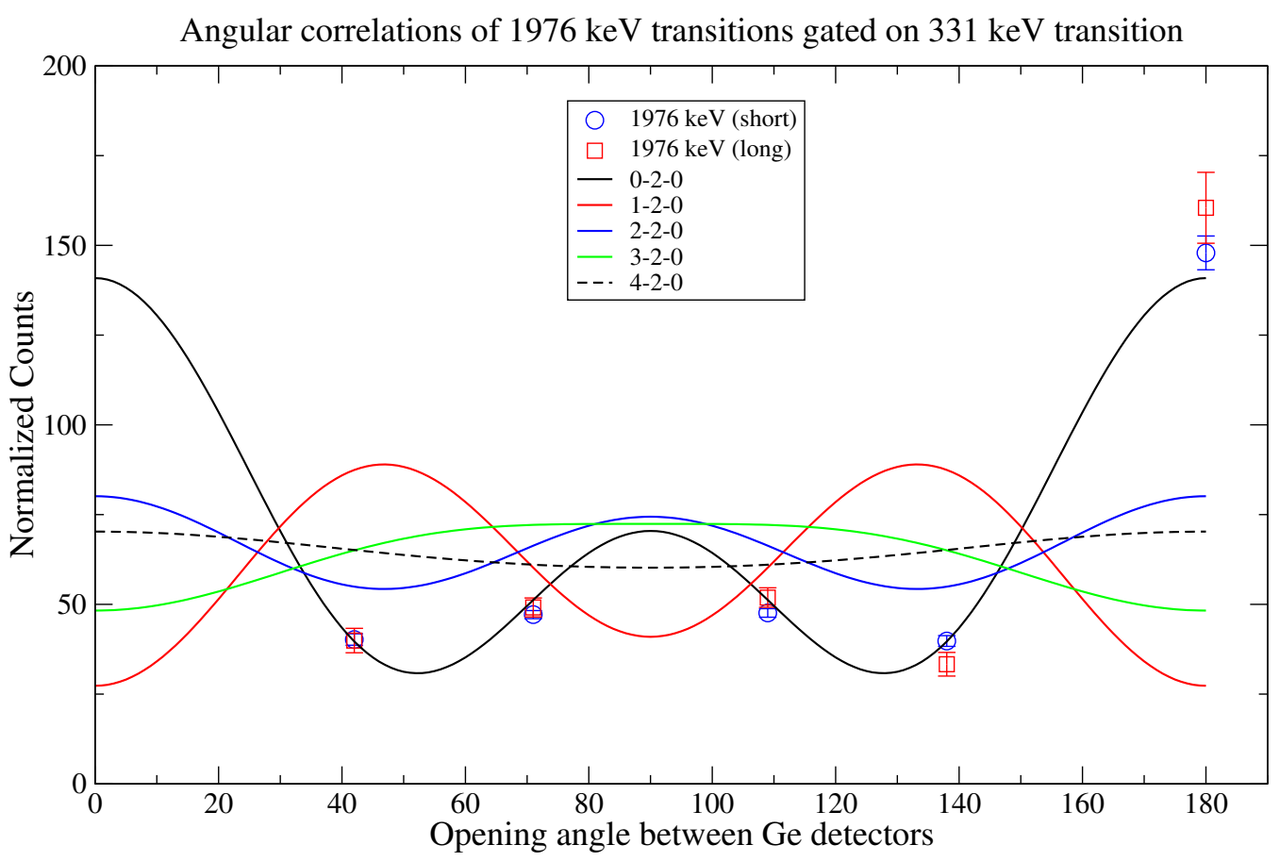
- Calibration made
- Third 0+ state confirmed

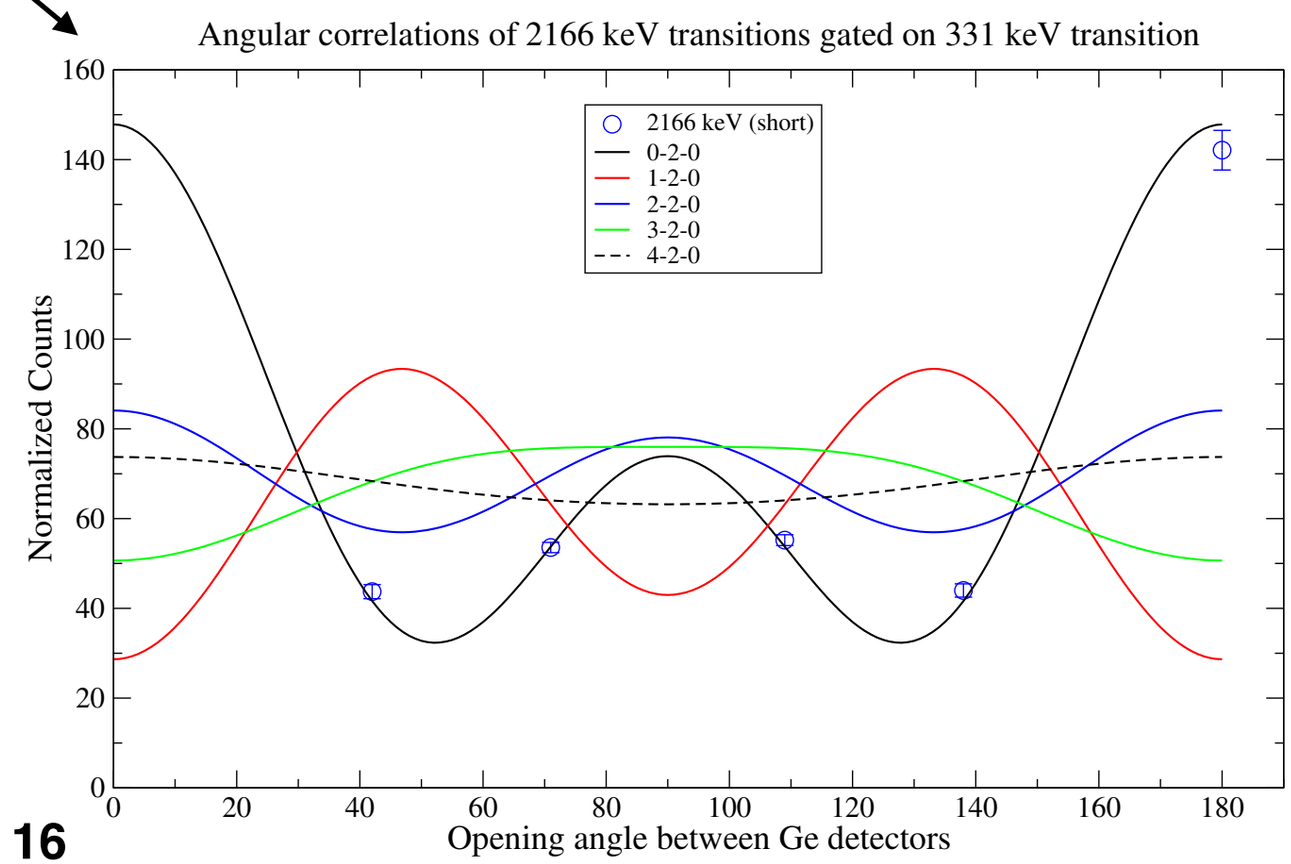
Results: Angular Correlation

University of Guelph

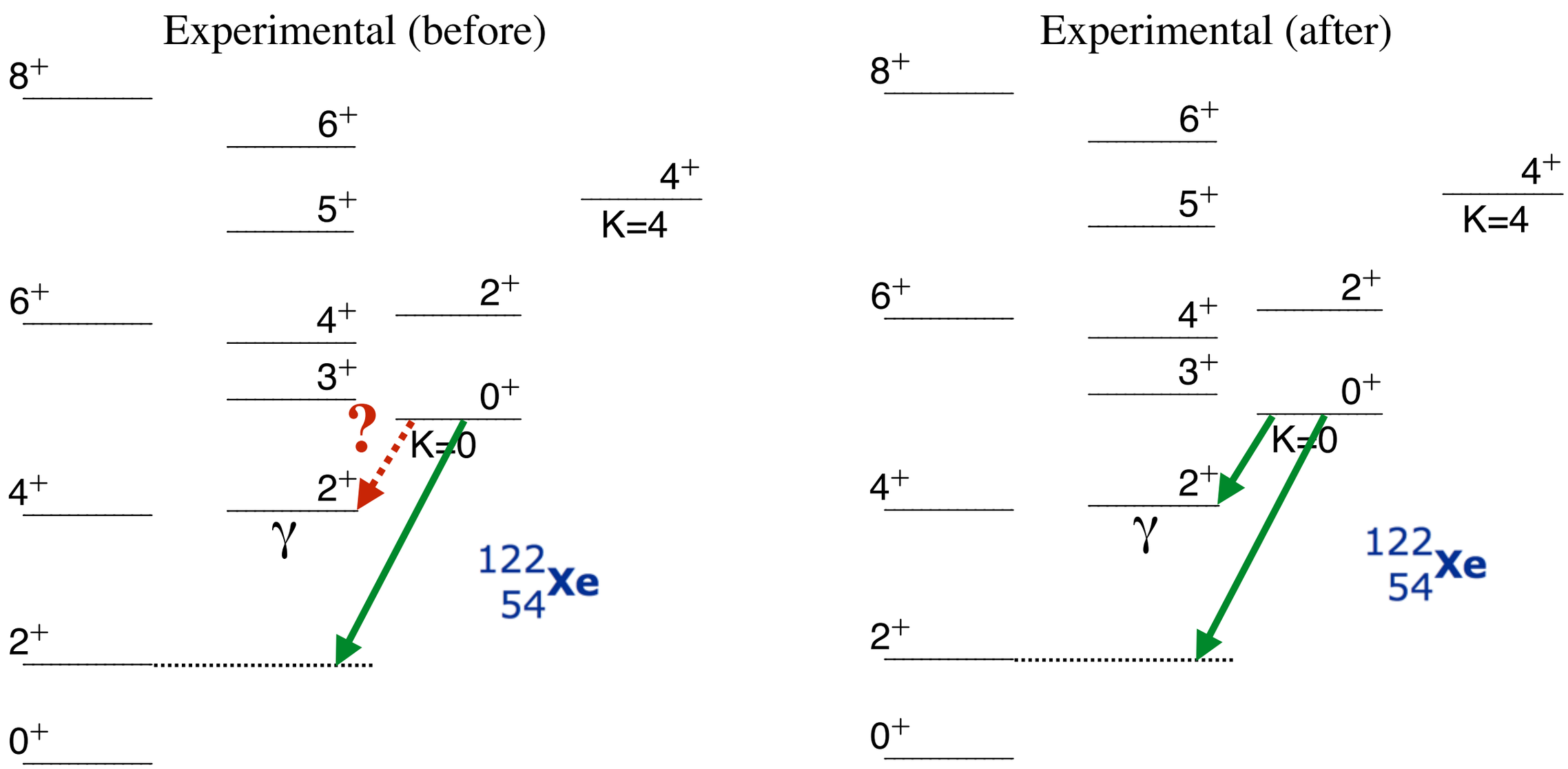






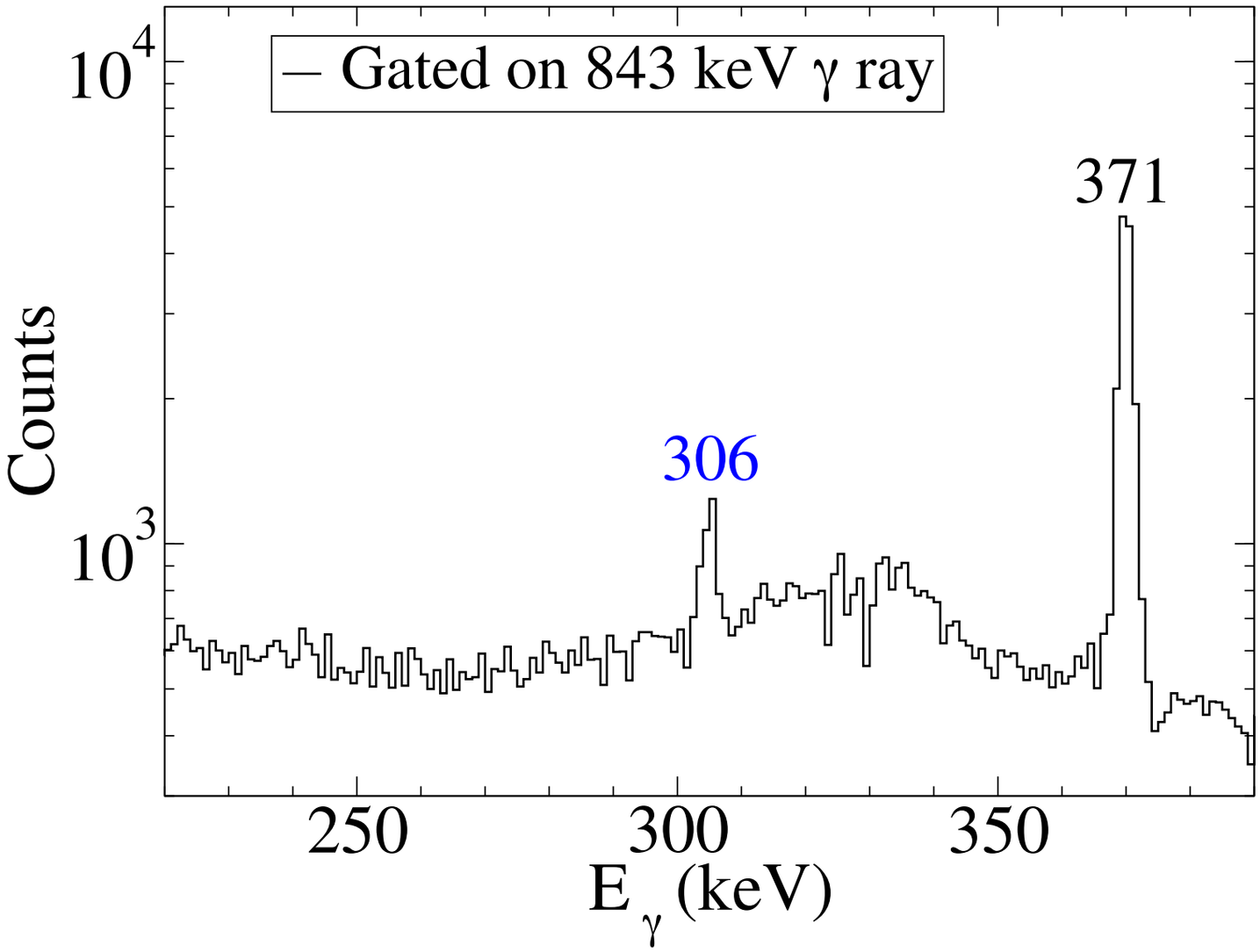


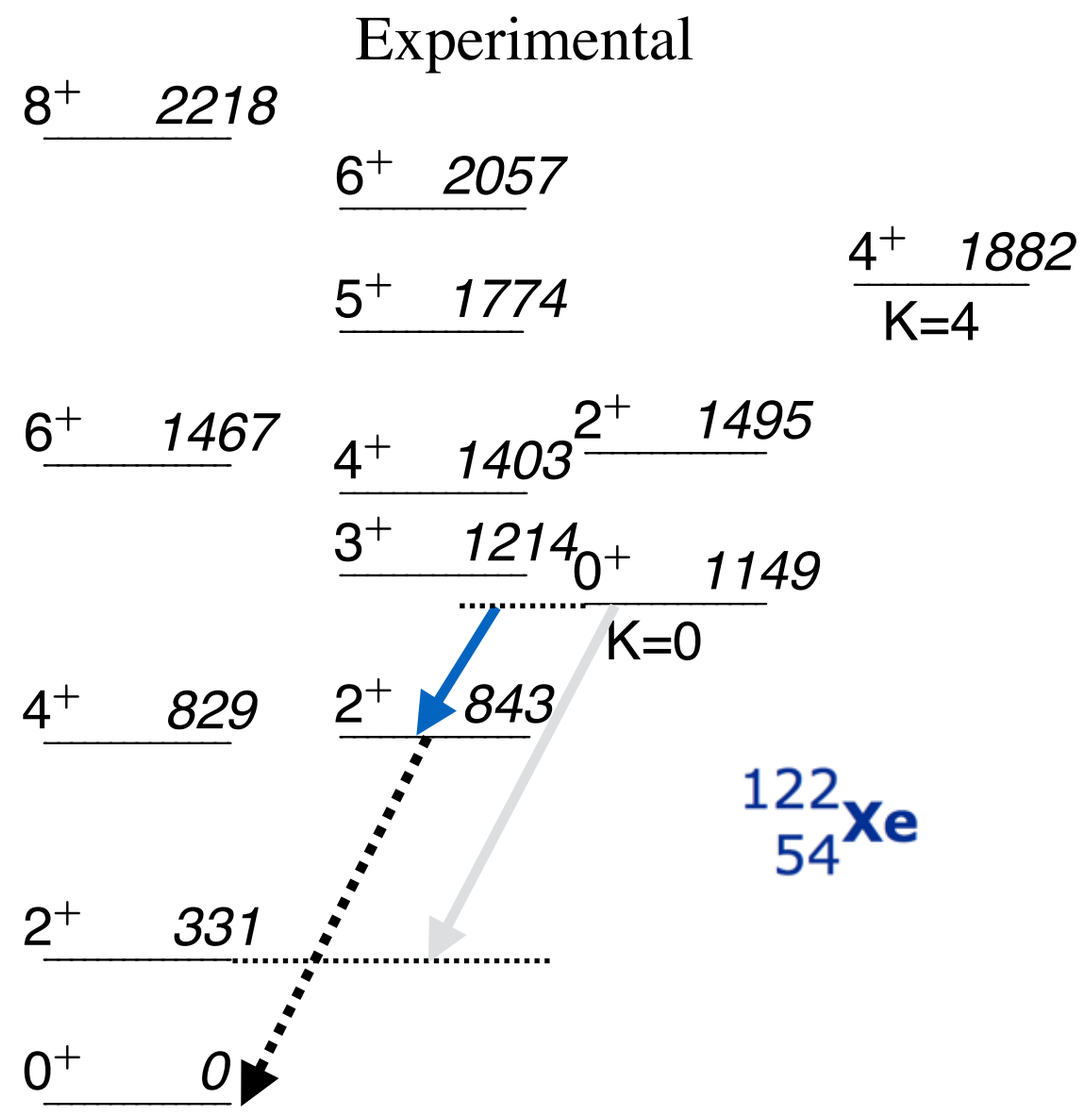
Key transition to γ-soft nuclei



- Key transition observed first time
- They will decide γ-softness

γ-soft (in IBM O(6) symmetry)





- Not ready to say some thing about γ-softness

Need to work on transition rate and branching ratio

Conclusion

160 new transitions and 100 new levels have been observed along with the 2^+ members of β-vibrational bands. Relative B(E2) values firmly establish the 2^+ band members.

We have firmly assigned spin value of 0 for 5 new states.

We have observed the key transition which will help to test γ-softness.

Angular correlation analysis will be continued for all new states.

The conversion electron data will be also analyzed.

Acknowledgements

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UNIVERSITY OF KENTUCKY

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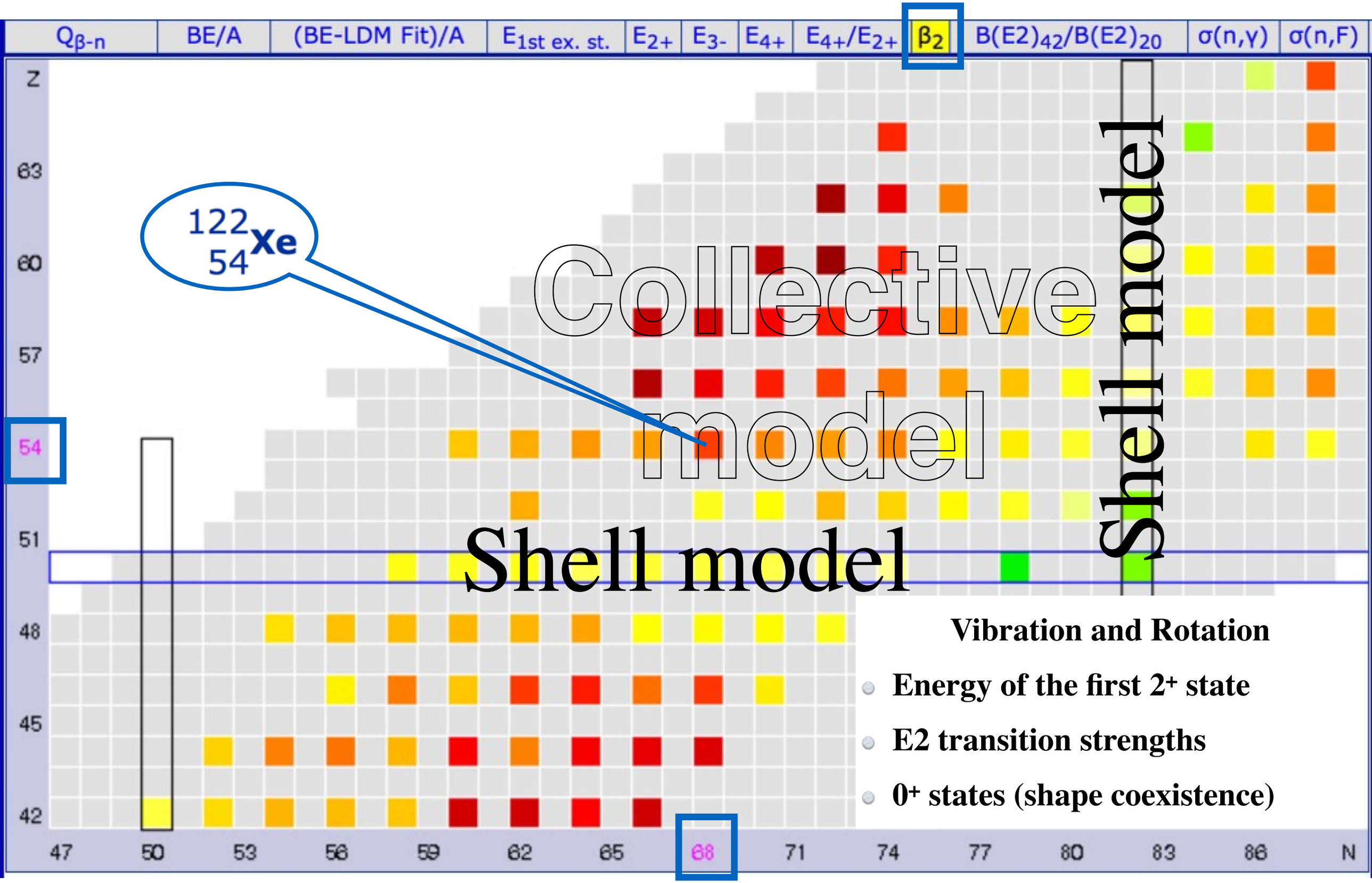
NRC·CNRC

NSERC CRSNG

Introduction

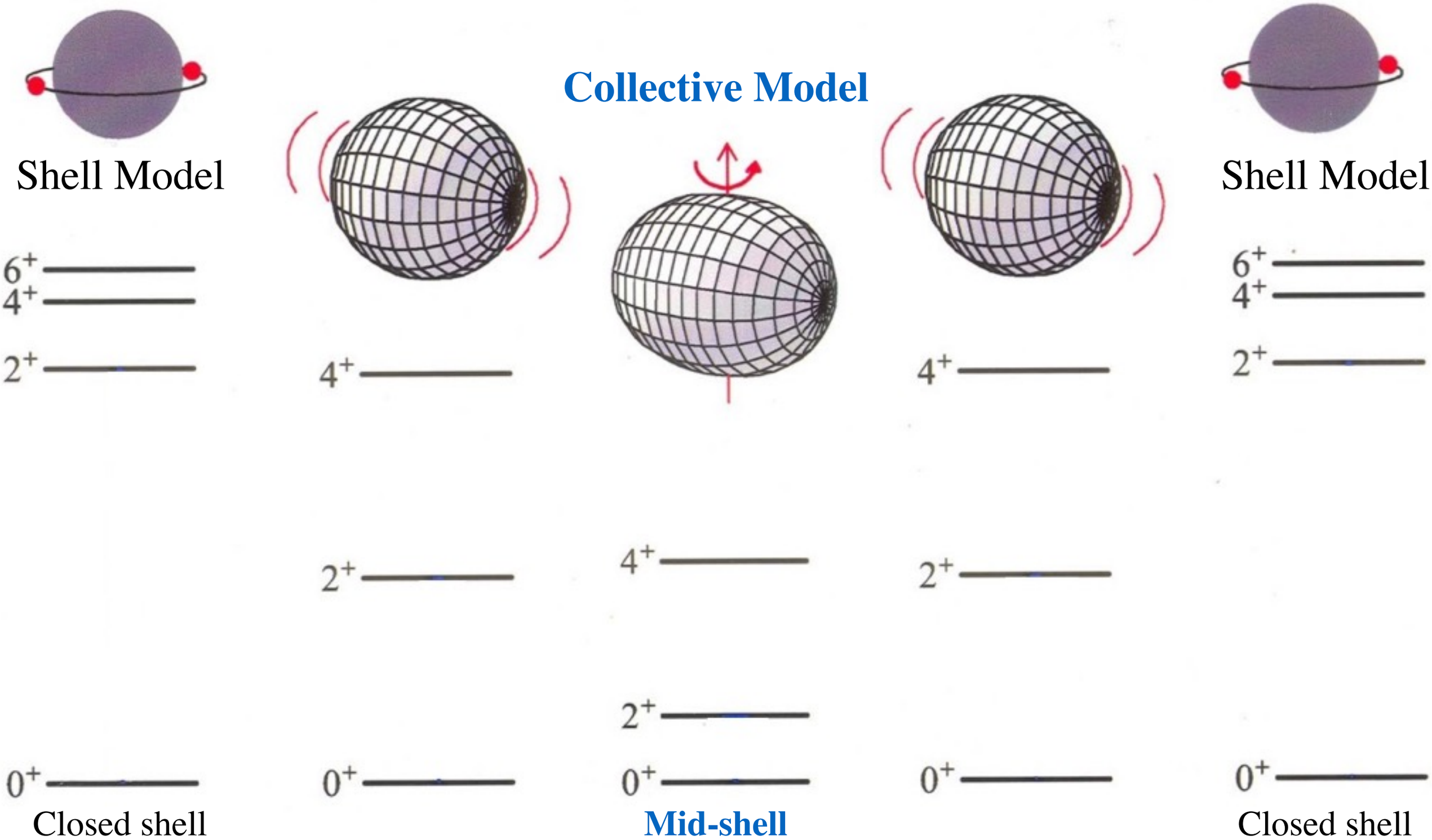


Vibration and Rotation

- **Energy of the first 2^+ state**
- **E2 transition strengths**
- **0^+ states (shape coexistence)**

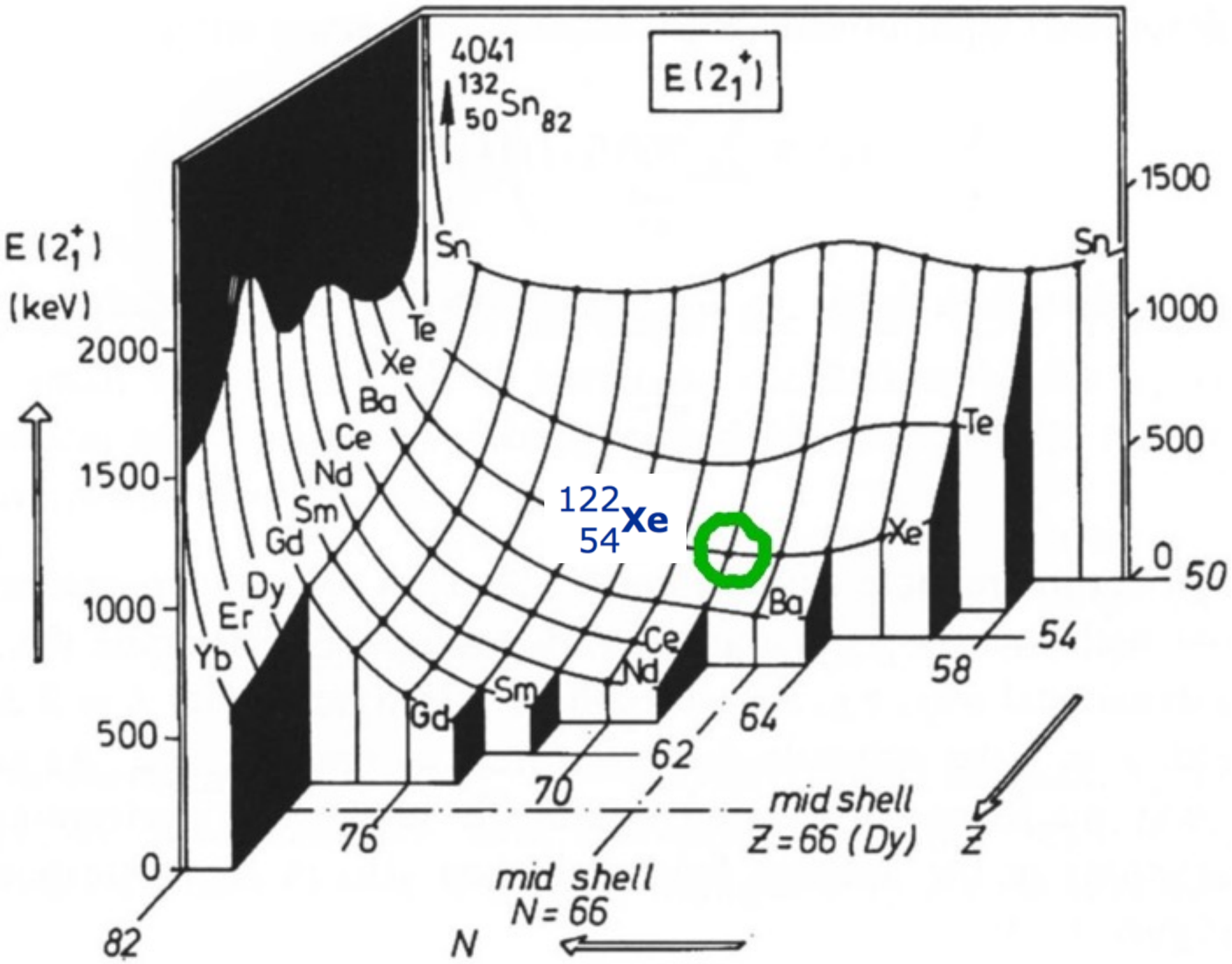
^{122}Xe is even-even deformed collective nucleus

Evolution of Nuclear Structure



Lowering of the collective states

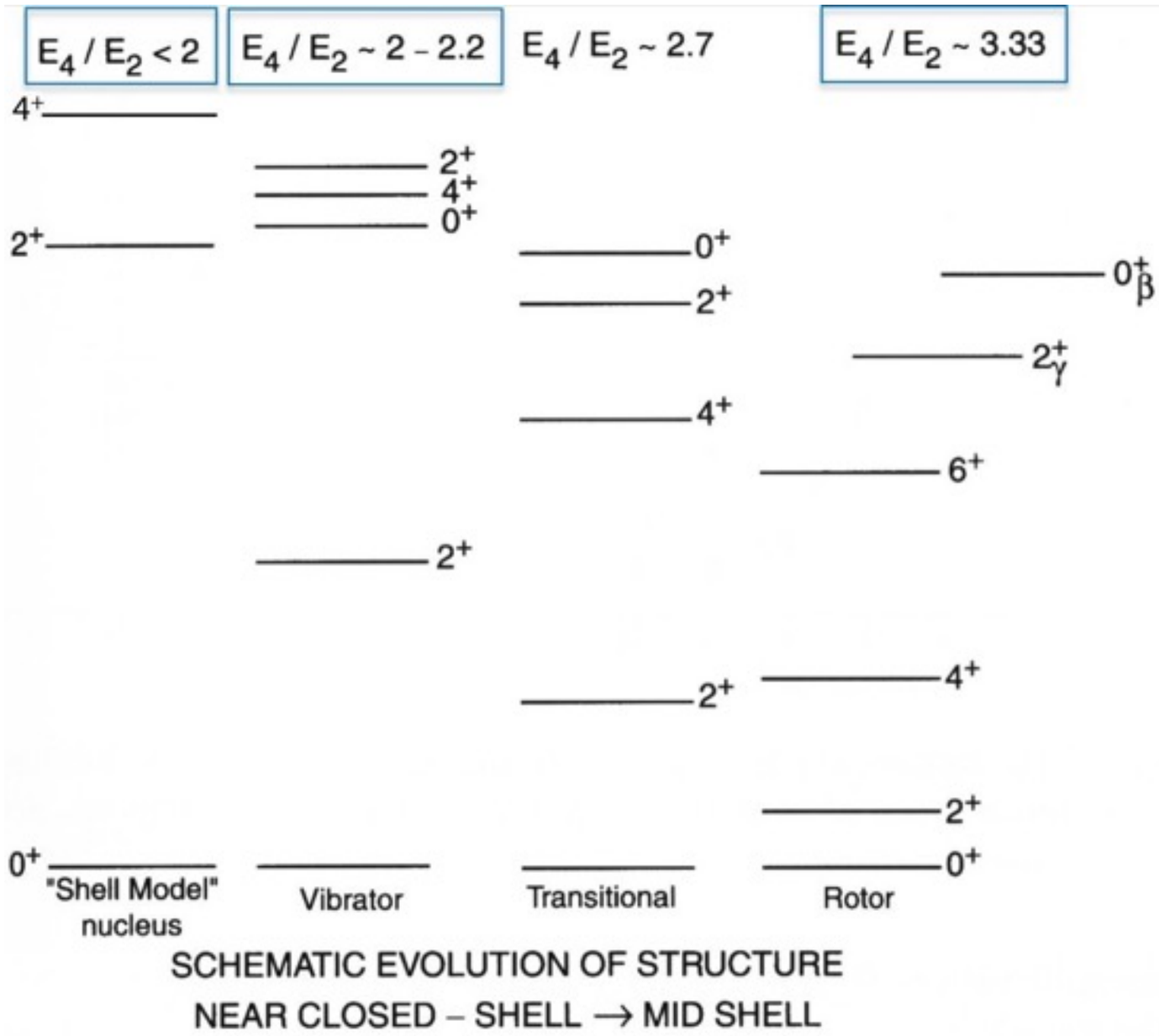
Evolution of collectivity



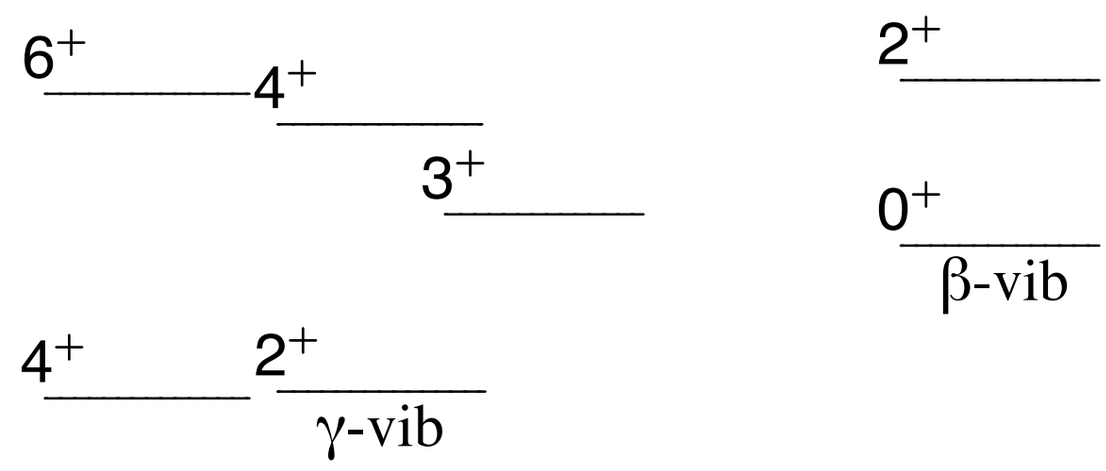
- 3D landscape plot
- First 2^+ state energy
- Xe centrally located
- Smooth evolution of collectivity
- Z>50 and N<82

However collectivity in this region is actually rather poorly characterized!

Energy ratio of the first 2^+ and 4^+ states



E4/E2 = 2.5



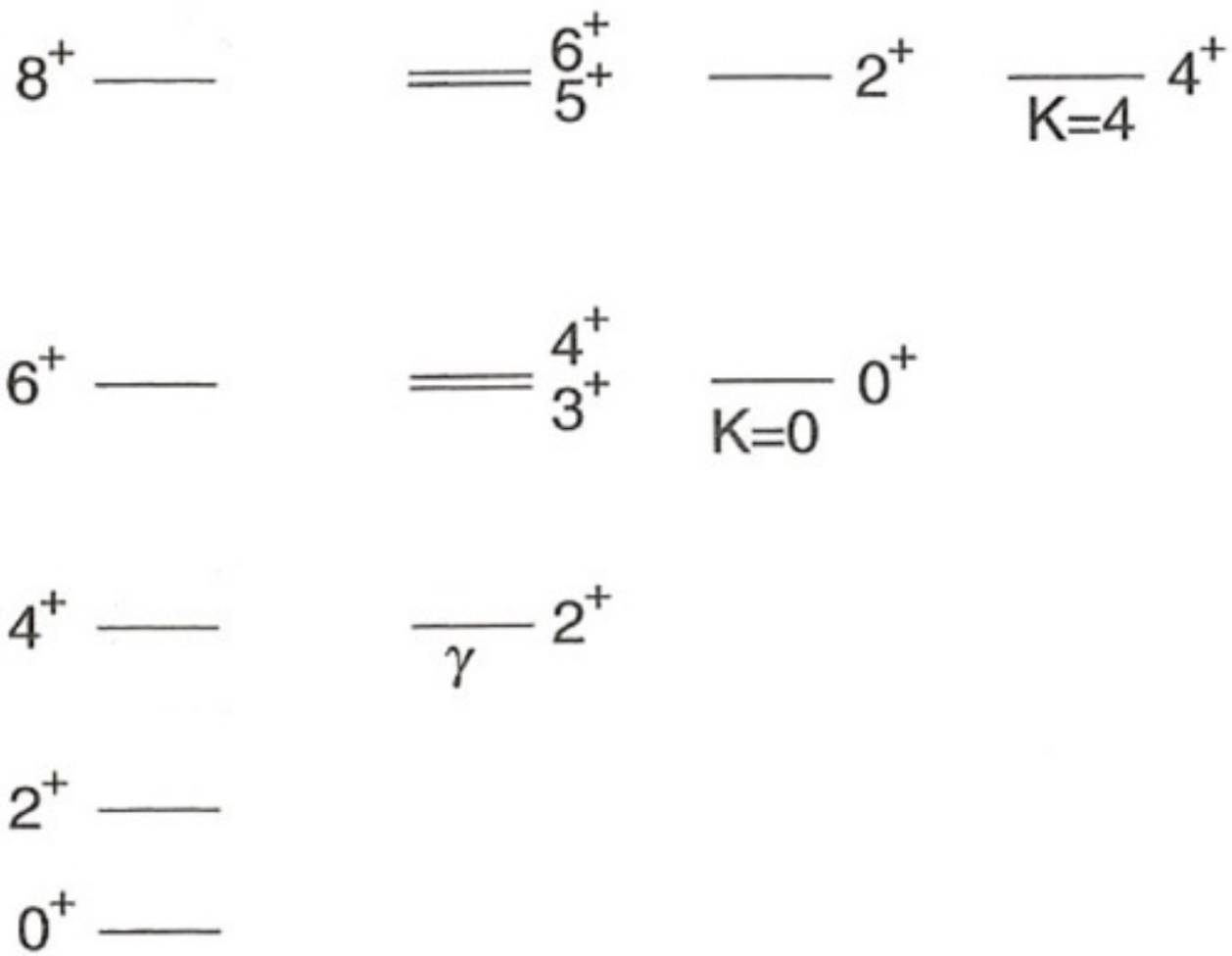
$^{122}_{54}$Xe

- The β vibration corresponds to fluctuations in the quadrupole deformation β.
- The γ vibration corresponds to oscillations in γ.

^{122}Xe is in transitional region from vibrational toward rotational.

γ-soft (in IBM O(6) symmetry)

γ-soft, O(6) symmetry (theo)



$$E_{rot}(J) = \frac{\hbar^2}{2I}[J(J+1) - K(K+1)]$$

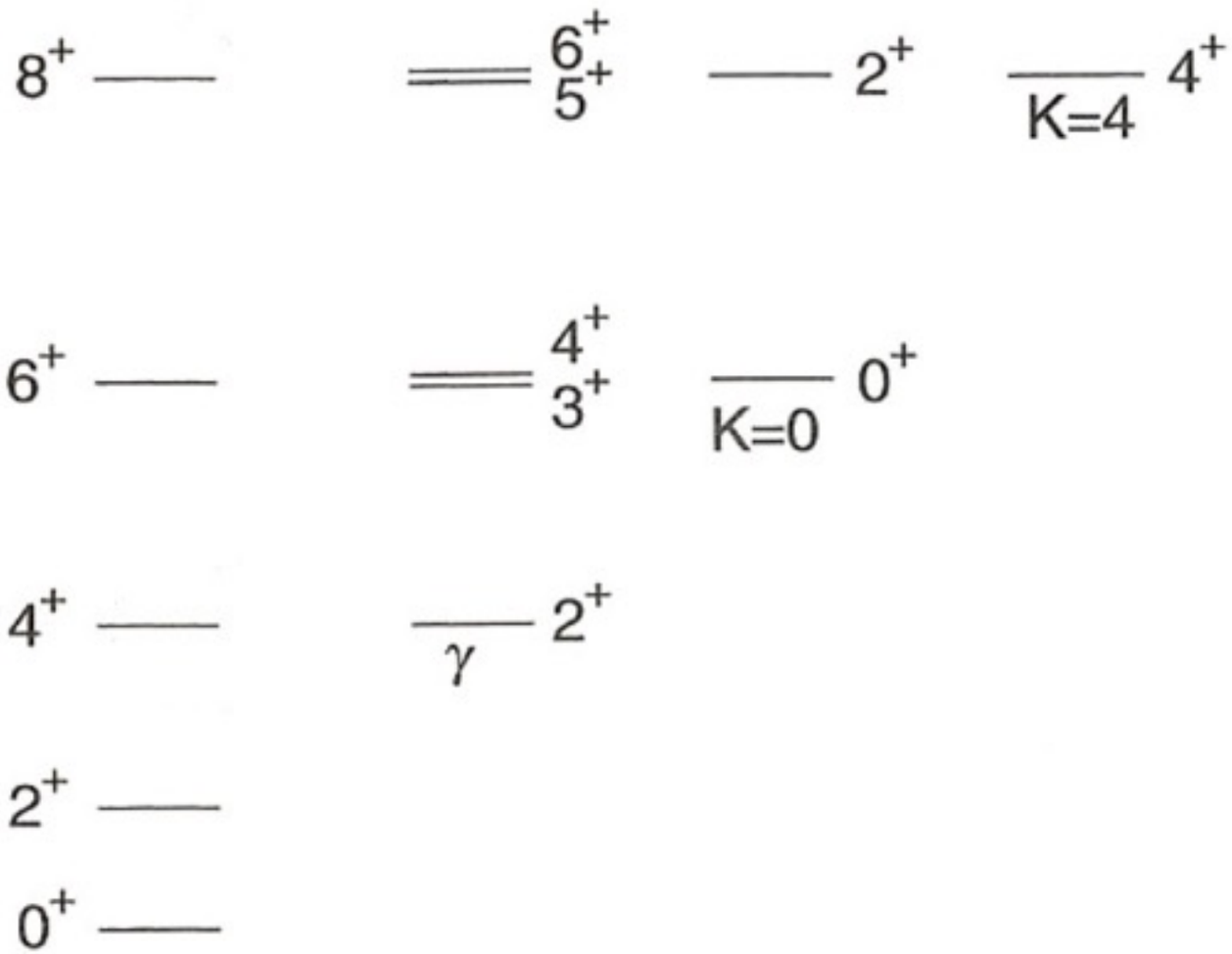
J=K, K+1, K+2, …

E2:E4:E6:E8= 1 : 2.5 : 4.5 : 7

L. Wilets, M. Jean, Phys. Rev. C102 (1956) 788.

γ-soft (in IBM O(6) symmetry)

γ-soft, O(6) symmetry (theo)



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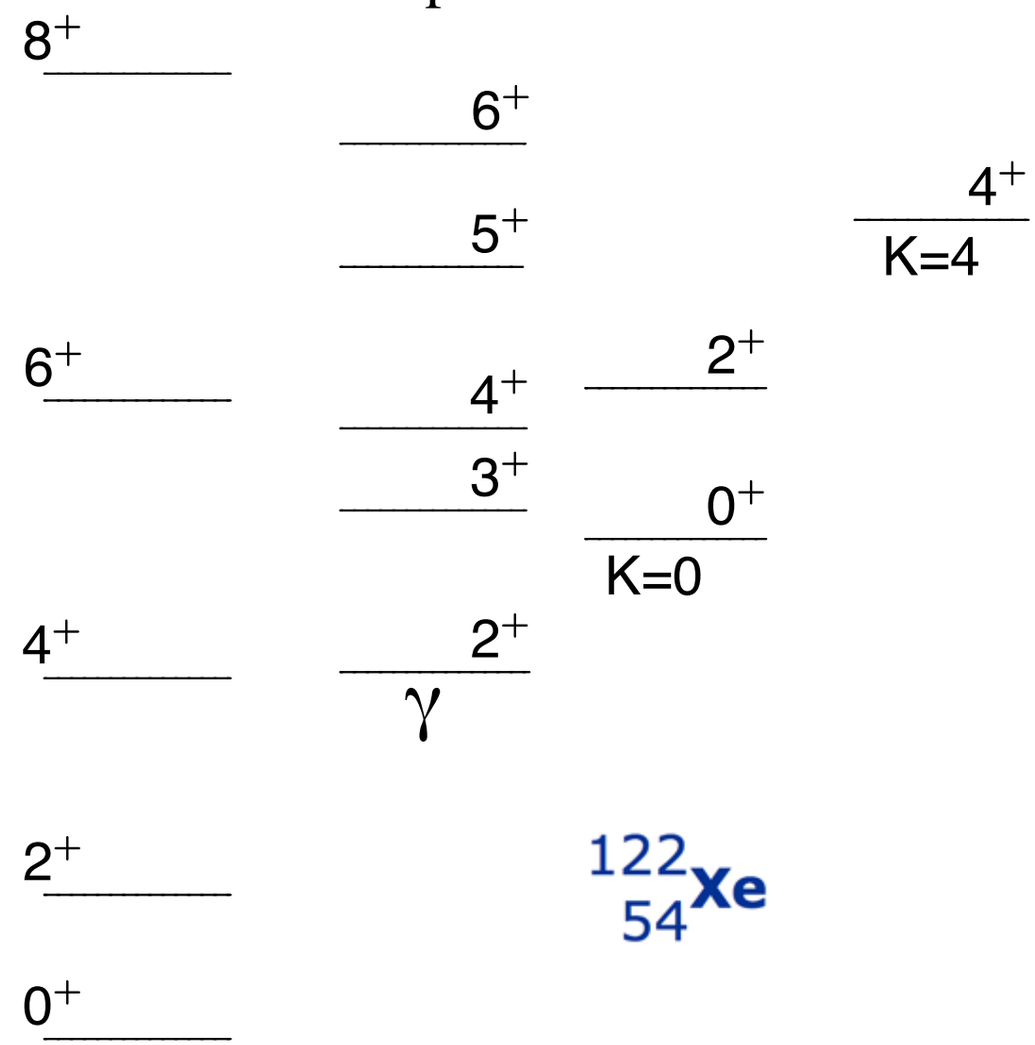

$$E_{rot}(J) = \frac{\hbar^2}{2I}[J(J+1) - K(K+1)]$$

J=K, K+1, K+2, …

E2:E4:E6:E8= 1 : 2.5 : 4.5 : 7

- Energy levels agree
- Levels spacing matches very good
- E2:E4:E6:E8= 1 : 2.5 : 4.4 : 6.7
- But third 2^+ state of K=0 band lower

L. Wilets, M. Jean, Phys. Rev. C102 (1956) 788.

R.F. Casten and P. von Brentano, Phys. Lett. 152 (1985) 22.

Xe isotopes manifest O(6) symmetry

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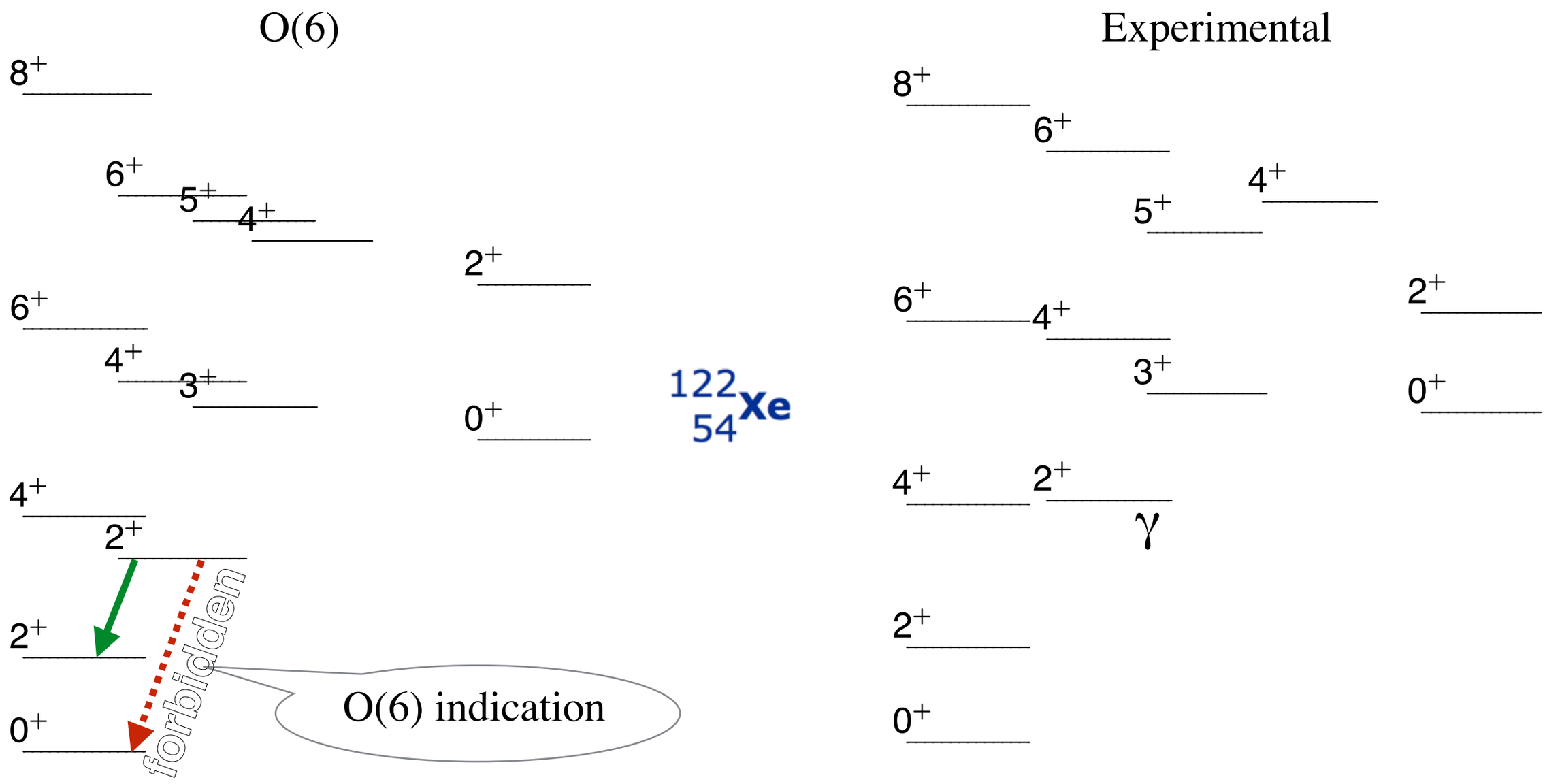


- IBM version of deformed, axially-asymmetric but γ-soft rotor
- IBM (Algebraic model)
- Energies and interactions of fermion pairs

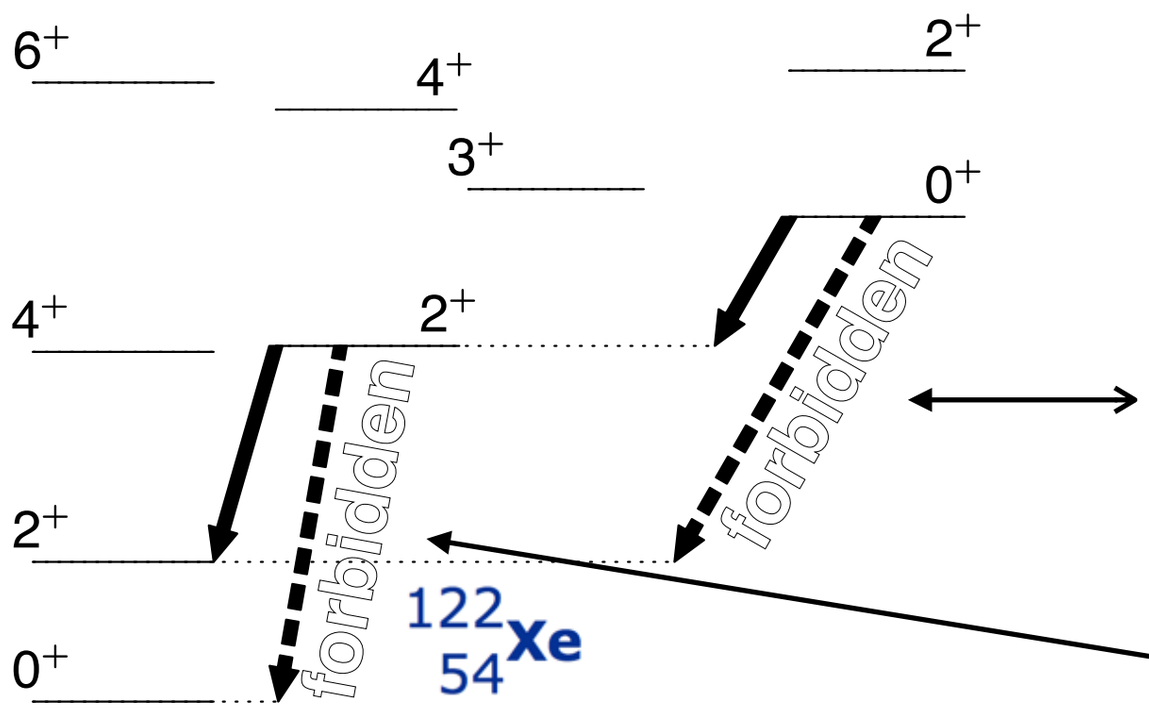
- Recent work on ^{124}Xe
- Showed *O*(6) broken

G. Rainovski, N. Pietralla, T. Ahn, L. Coquard, C.J. Lister, R.V.F. Janssens, M.P. Carpenter,Phys. Lett. B683, 11_(2010).

Is ^{122}Xe still γ-soft nucleus and does it possess *O*(6) symmetry?

How do we test γ-softness

γ-soft or *O*(6) nucleus



Alaga rule

$$\frac{B(E2: J_i \to J_f)}{B(E2: J_i \to J'_f)} = \frac{\langle J_i K_i 2\Delta K | J_f K_f \rangle^2}{\langle J_i K_i 2\Delta K | J'_f K_f \rangle^2}$$

$$\frac{B(E2: 2_2^+ \to 2_1^+)}{B(E2: 2_2^+ \to 0_1^+)} \to \infty$$

$$\frac{B(E2: 0_2^+ \to 2_2^+)}{B(E2: 0_2^+ \to 2_1^+)} \to \infty$$

Deformation parameters

- β extend of quadrupole deformation β.
- γ gives the degree of axial asymmetry.

Alaga rule can be used to

- assign K quantum numbers to different intrinsic excitations
- account band mixing effects

- Either both intra-band or both inter-band with the same initial and final bands.
- Intrinsic matrix element will clearly be identical for both transitions

Results: Level scheme extension

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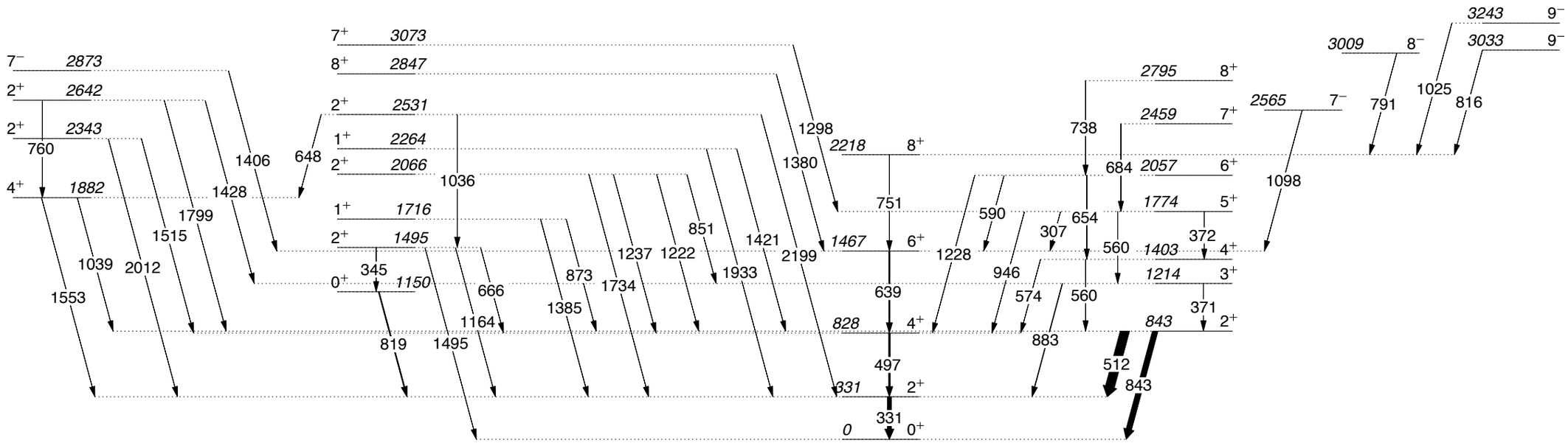
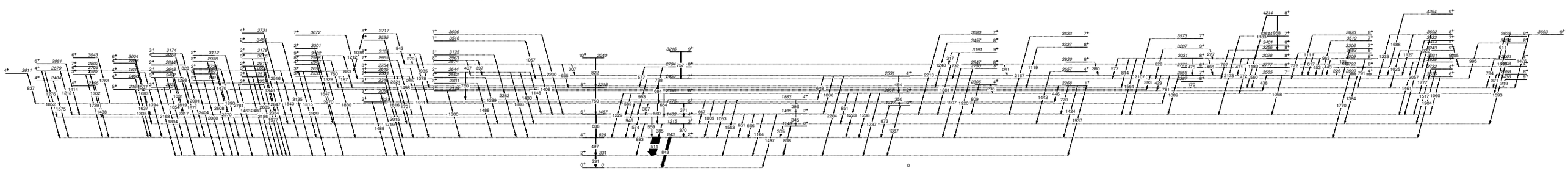
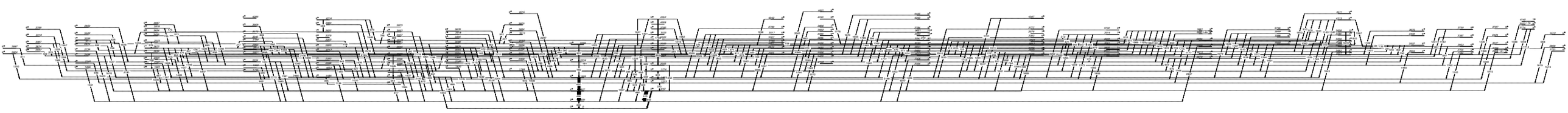
Old level scheme of ^{122}Xe



Preliminary level scheme of ^{122}Xe from short runs of this work



Preliminary level scheme of ^{122}Xe from long runs of this work



- 160 new transitions
- 100 new levels

Results: Angular Correlation