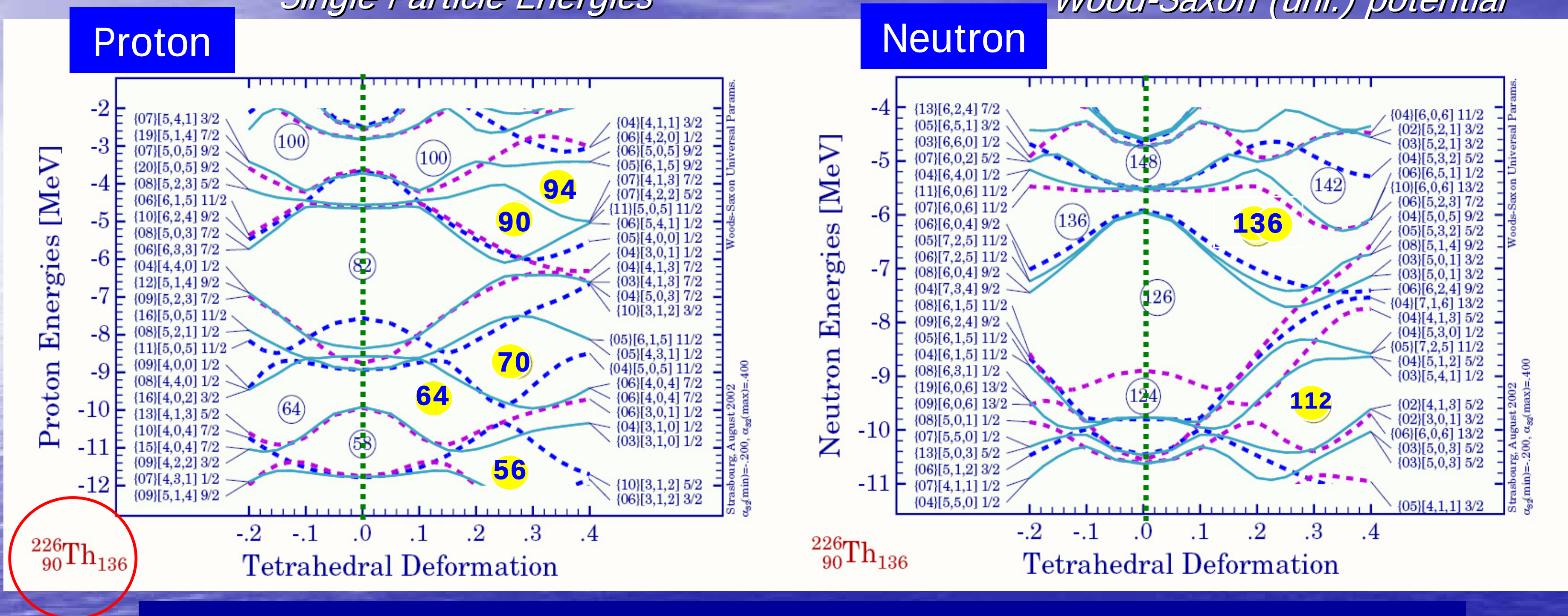
Tetrahedral Symmetry in the Actinides : *the ELMA project*

D. Curien *IPHC Strasbourg*
TetraNuc Collaboration

- Theoretical idea : combine the Group-Theory and Mean-Field formalism (*J. Dudek, A. Gozdz and collaborators): effect on nuclear stability?*
- Rare-Earth: first series of experiment started in 2006
  - still on-going at ANL, ILL & LNL
  - experimental criteria = branching ratio & transition probabilities
- Meanwhile : exploration the Actinides region
- *ELMA project* : first step with the ORGAM test-experiment

Point Groups Tetrahedral Symmetry

Single Particle Energies *Wood-Saxon (uni.) potential*

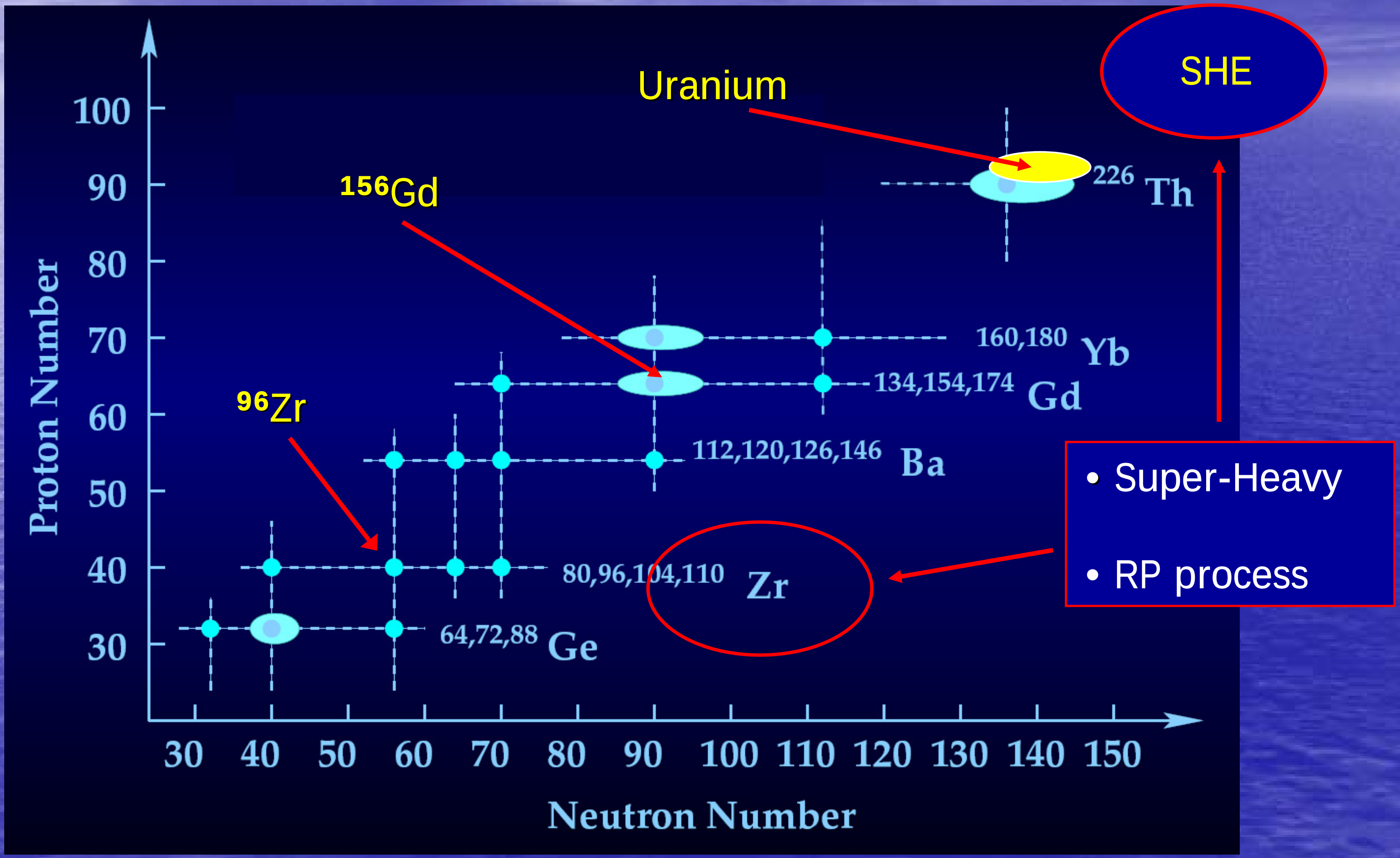


Full lines correspond to 4-fold degenerated orbitals consequence of large number of irreducible representations

Huge gaps around Z=90-94 and N=136.

They are comparable to the usual spherical gaps and often larger than the competing quadrupole shell gaps

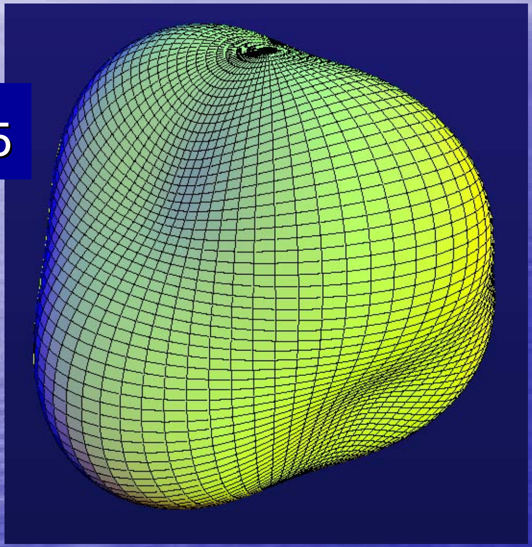
Tetrahedral Islands



Deformed Nuclei *(slightly exaggerated)*

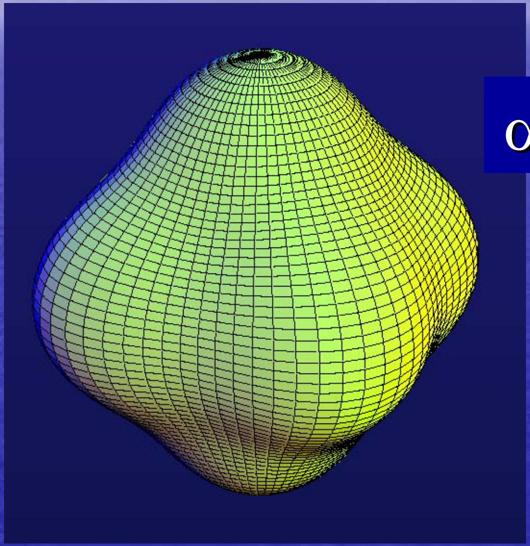
T_d -symmetry

α_{32}=0.15



O_h -symmetry

α_{40}=0.20



Spherical Harm. first non-zero order:

λ=3

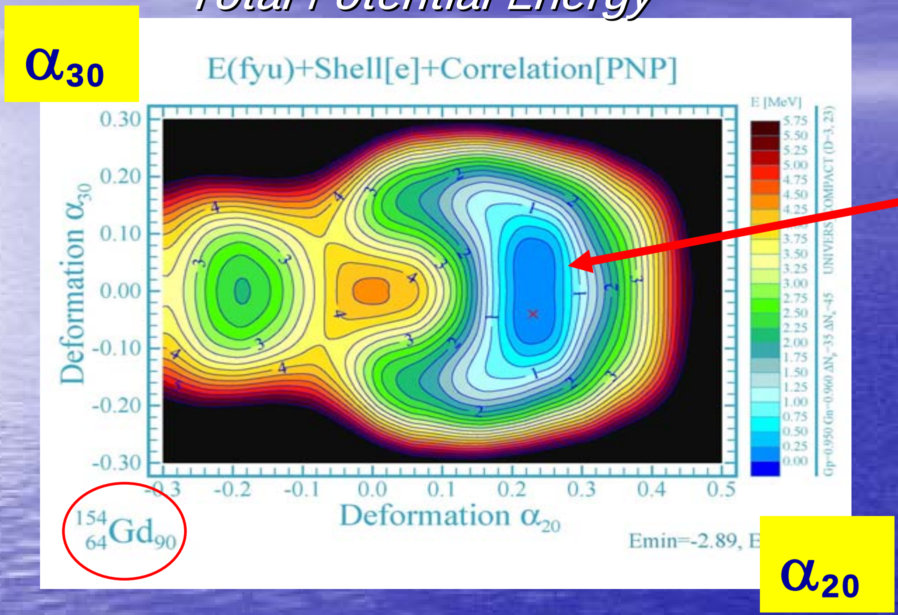
such as axial octupole

λ=4

Combining the two symmetries simultaneously strengthens the final tetrahedral symmetry effect *(at least ~ 1.5 MeV in the Actinides).*

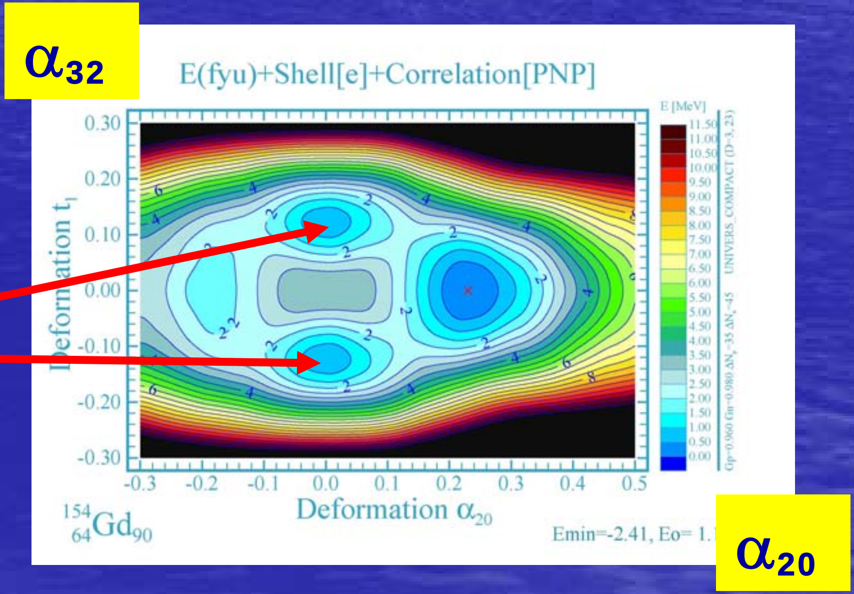
Question: *what about "classic" α_{30} axial octupole symmetry?*

Total Potential Energy



J. Dudek, K. Mazurek 2009

No minimum for usual Octupole deformation

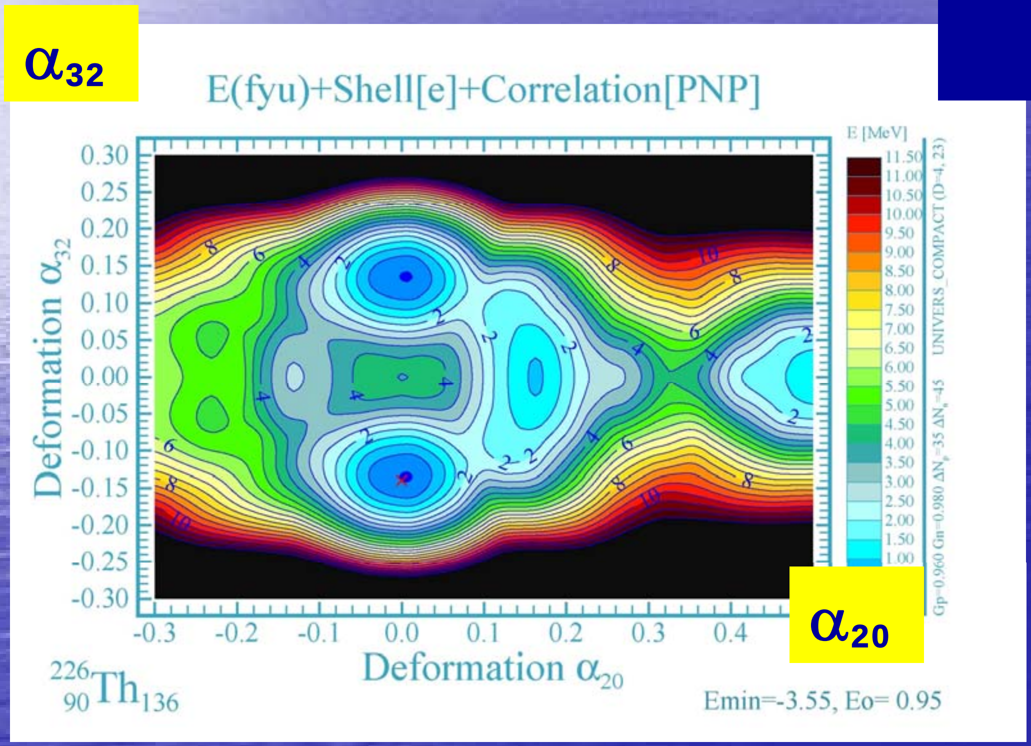


Clear low lying minima for Tetrahedral deformation

The Actinides:
a *more promising region?*

"magic numbers"
N,Z=90-94,136-142

<ins>Elements of interest:</ins>
thorium
uranium
plutonium



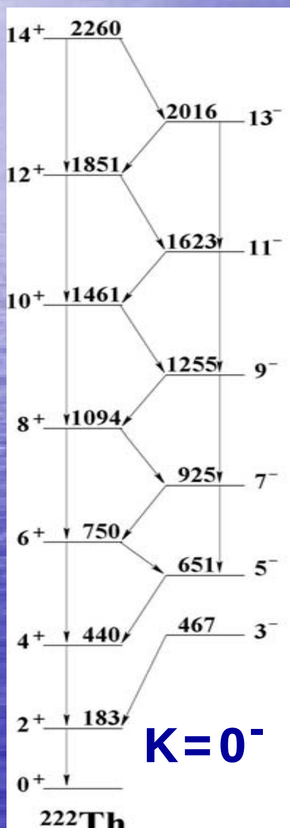
<ins>Tetrahedral minimum:</ins>

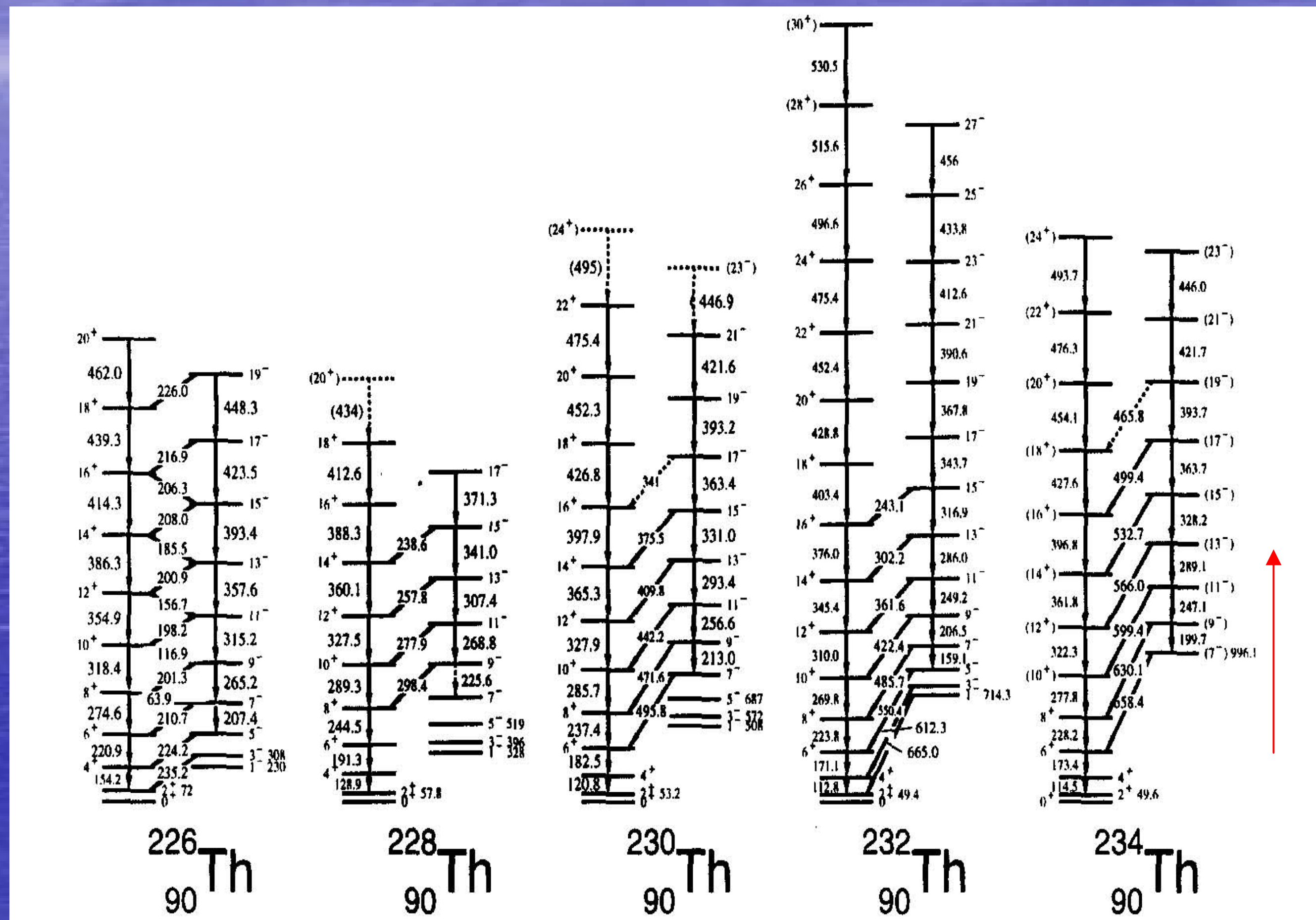
- 500 keV above GS
- significant barrier: 2.5 MeV
- maximum effect of octahedral symmetry

→ *Stronger stability than prolate/oblate/spherical shape coexistence*

Typical Decay Schemes

gsb npb





JFC Cocks et al. NPA 645 (1999) 61

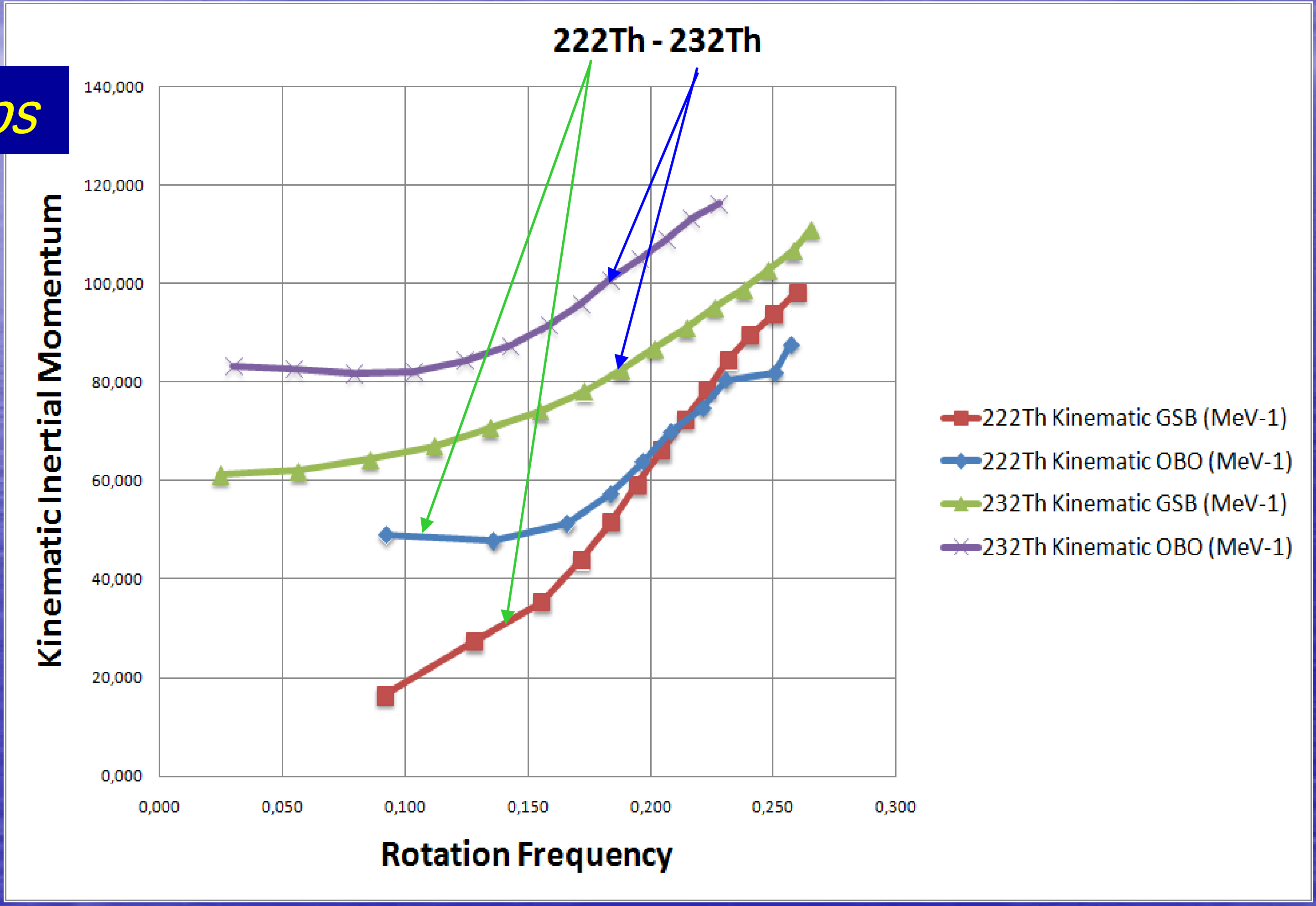
Branching Ratios In The Thorium

états	220Th (90,130)	222Th (90,132)	224Th (90,134)	226Th (90,136)	228Th (90,138)	230Th (90,140)	232Th (90,142)
21-		0.2(?)				-	-
19-	-	0.3(?)		2		-	-
17-	-	0.4(2)	?	2.3	-	-	-
15-	1.8 ?	0.4(2)	0.4	2	-	?	?
13-	?	0.3(2)	0.5	?	16	?	?
11-	0.4	0.4(2)	0.4	2	13	?	?
9-	0.3	0.4(2)	?	2	14	156 (64)	182 (41)
7-	0.4	0.4(3)	?	?	0	?	2264 (470)
5-	0	0	0	0	0	?	0
3-	0	0	0	0	0	0	0

*B(E**2**)**in**/B(E**1**)**out** * 10 **6***

Moment of Inertia : gs & np bands

→ 2 groups



Classical View of the 2 Groups

- Difference in aligned angular momentum *(from VMI)*

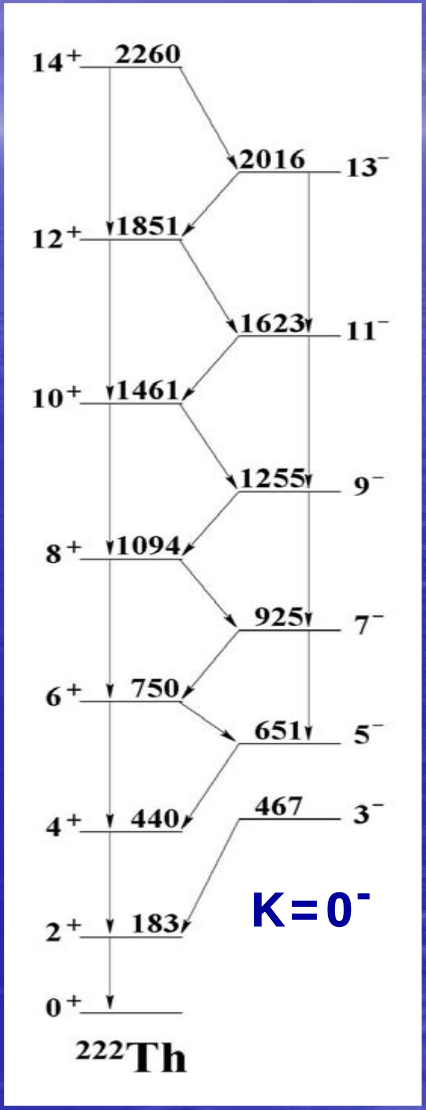
  $$\Delta i_x = i_x^- - i_x^+ \text{ at a given } \omega$$

- Two limits:
  - Permanent octupole deformation:

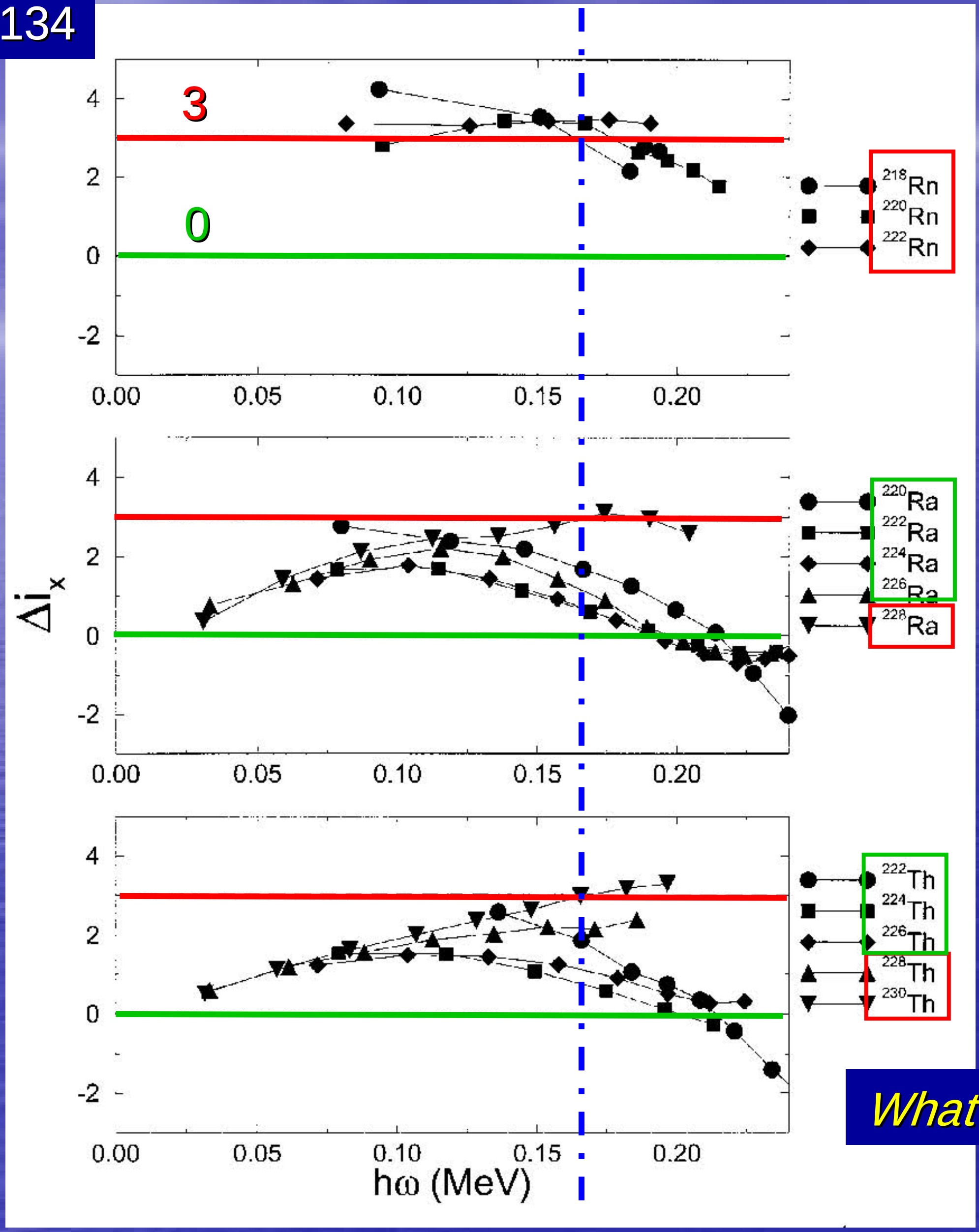
    $$i_x^- = i_x^+ = \mathcal{R} \qquad \Delta i_x = 0\hbar$$

  - Octupole vibration: *when the octupole phonon is aligned*

    $$\Delta i_x = 3\hbar$$



N ~ 134



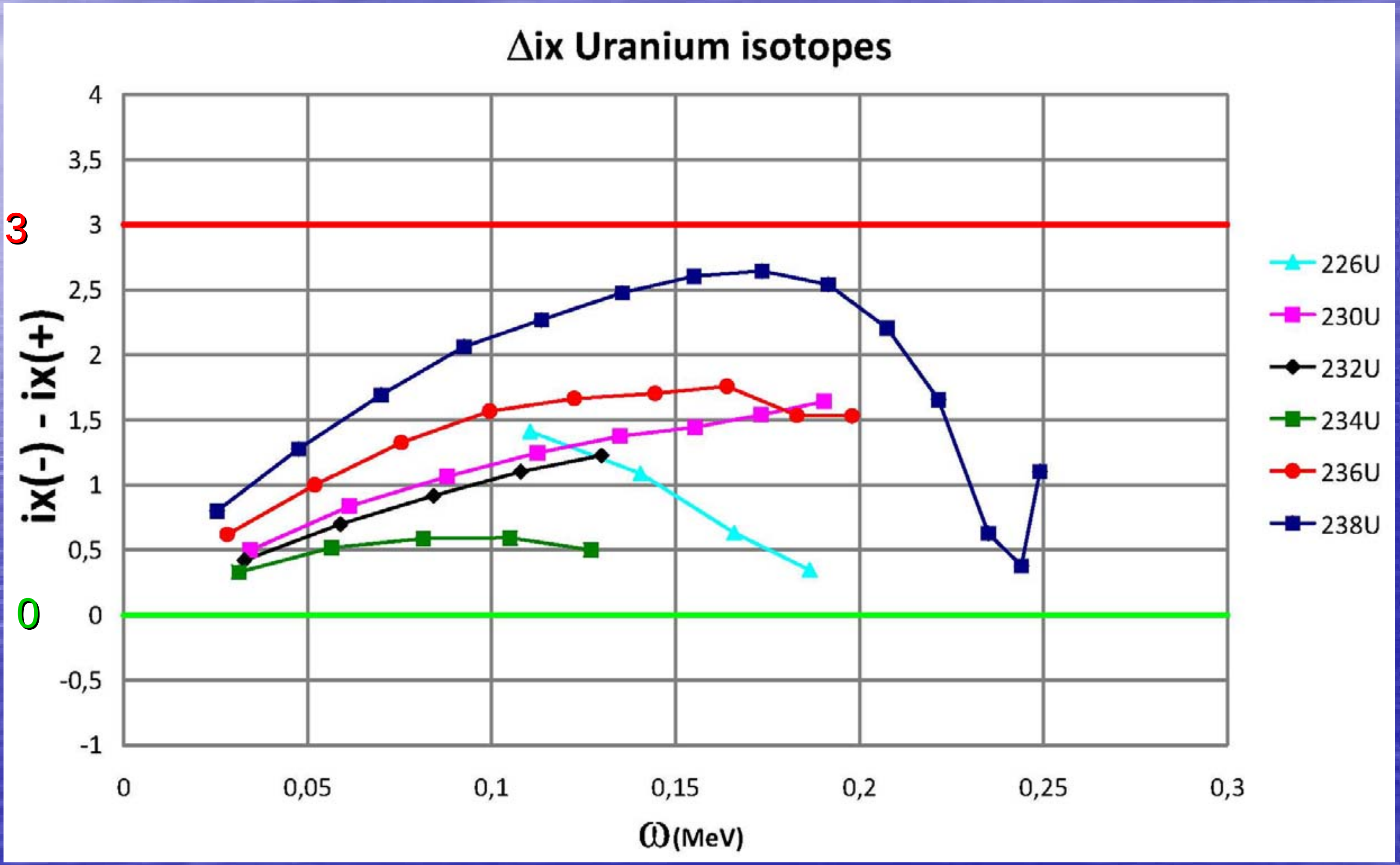
"vibrators"

"permanent"

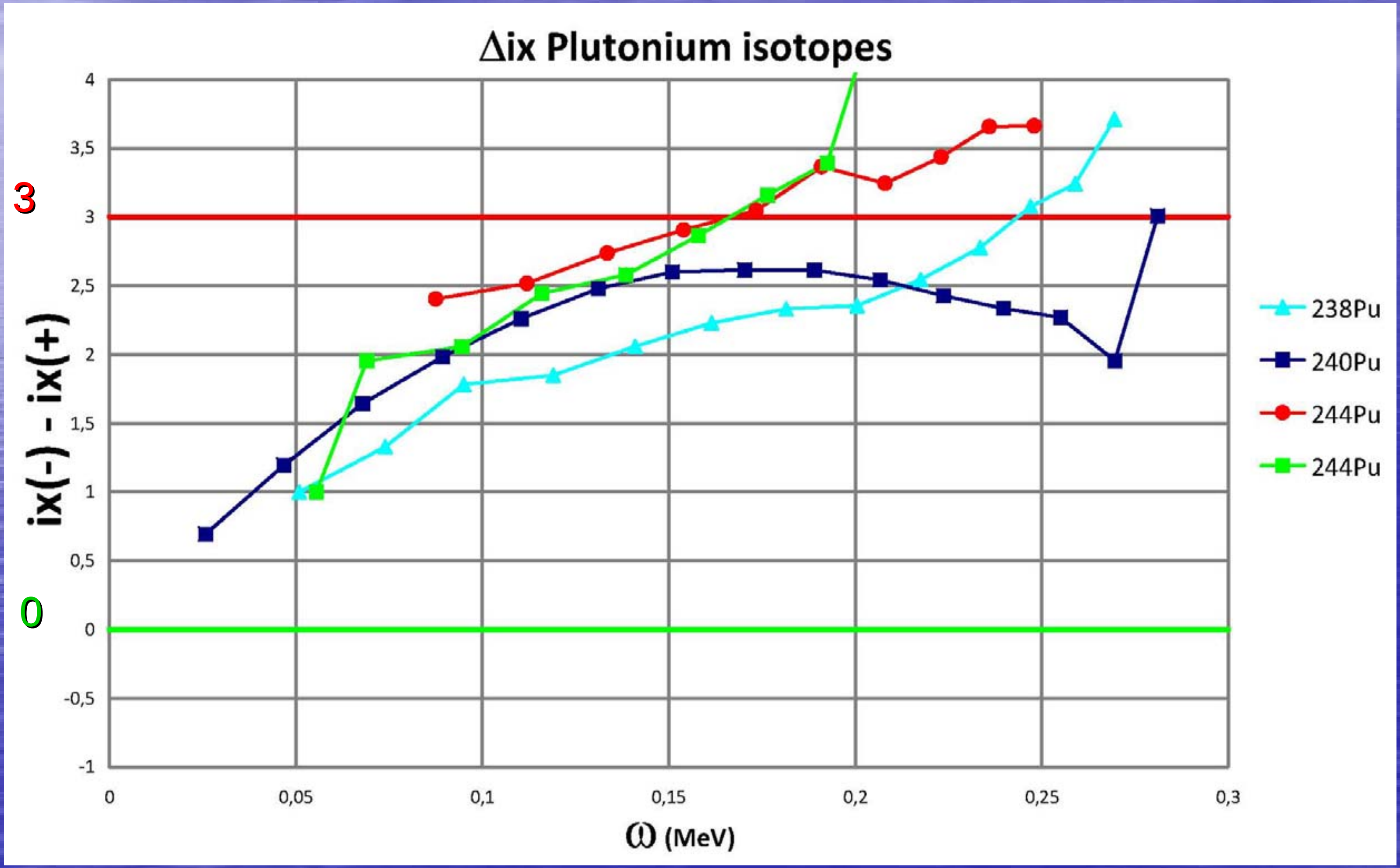
What about U & Pu?

P. Butler Phys. Scripta T88, 7, 2000

Differential Alignment: Uranium

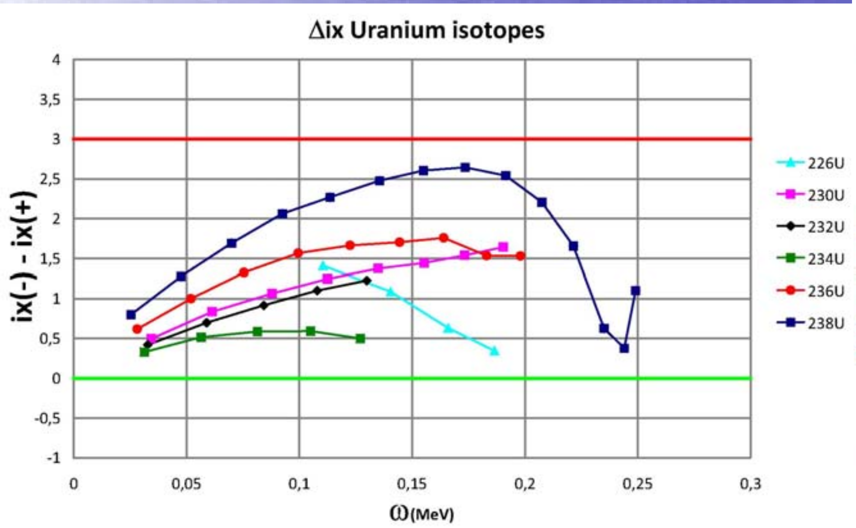


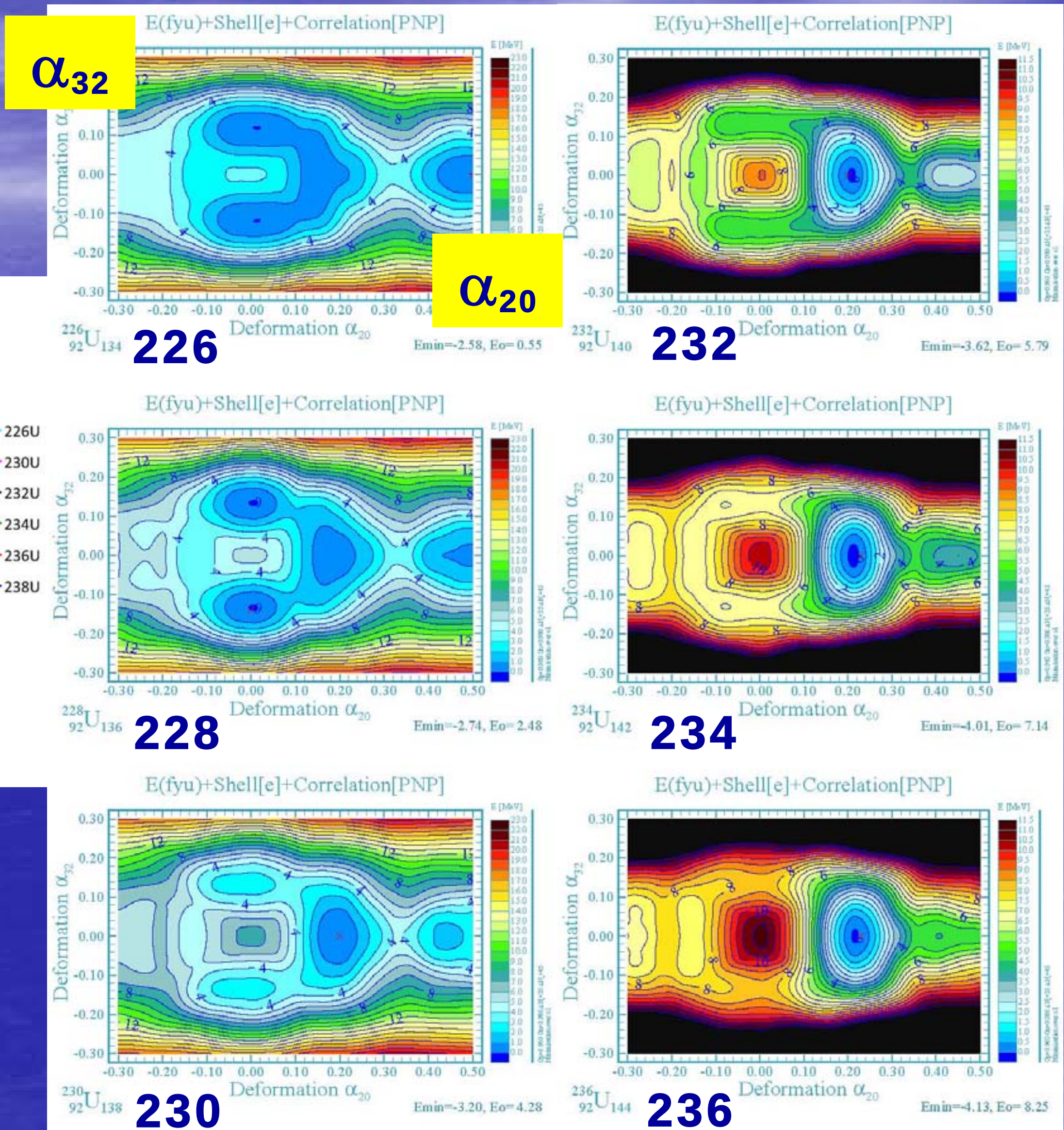
Differential Alignment: Plutonium



Comparisons With Mean Fields Predictions *1* :

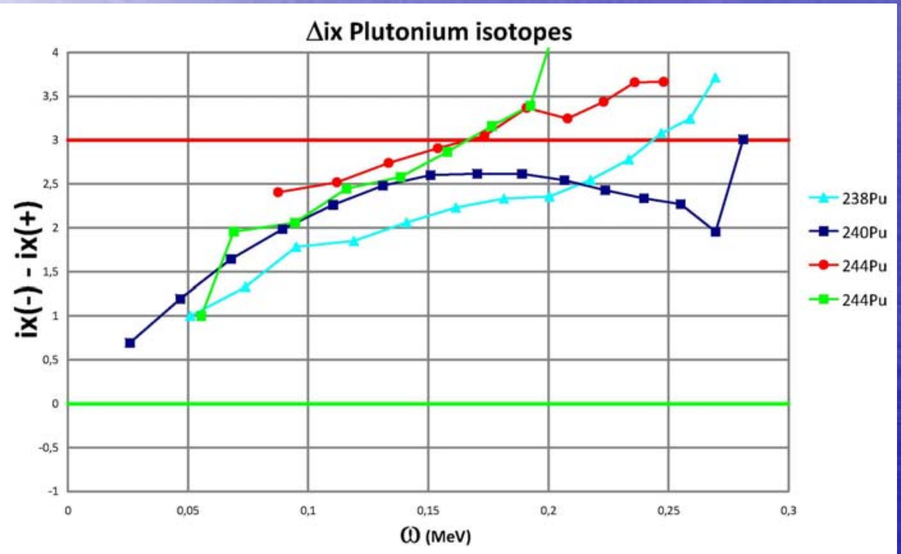
Uranium isotopes

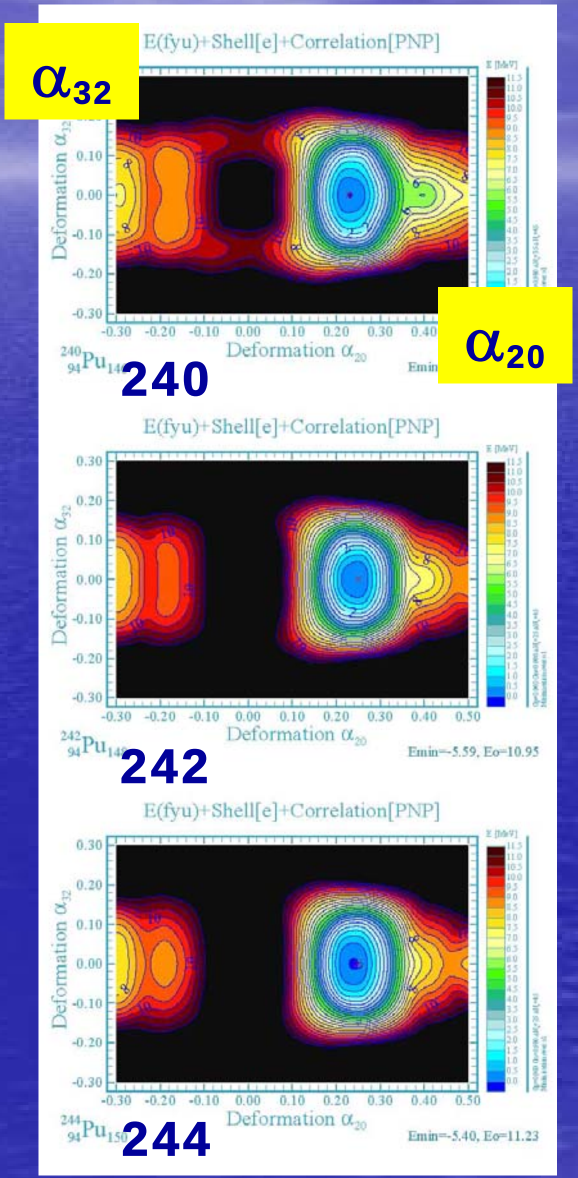




Comparisons With Mean Fields Predictions *2* :

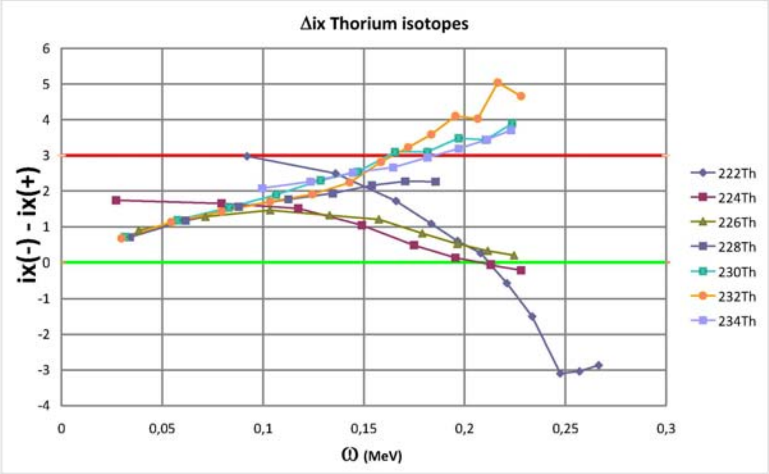
Plutonium isotopes

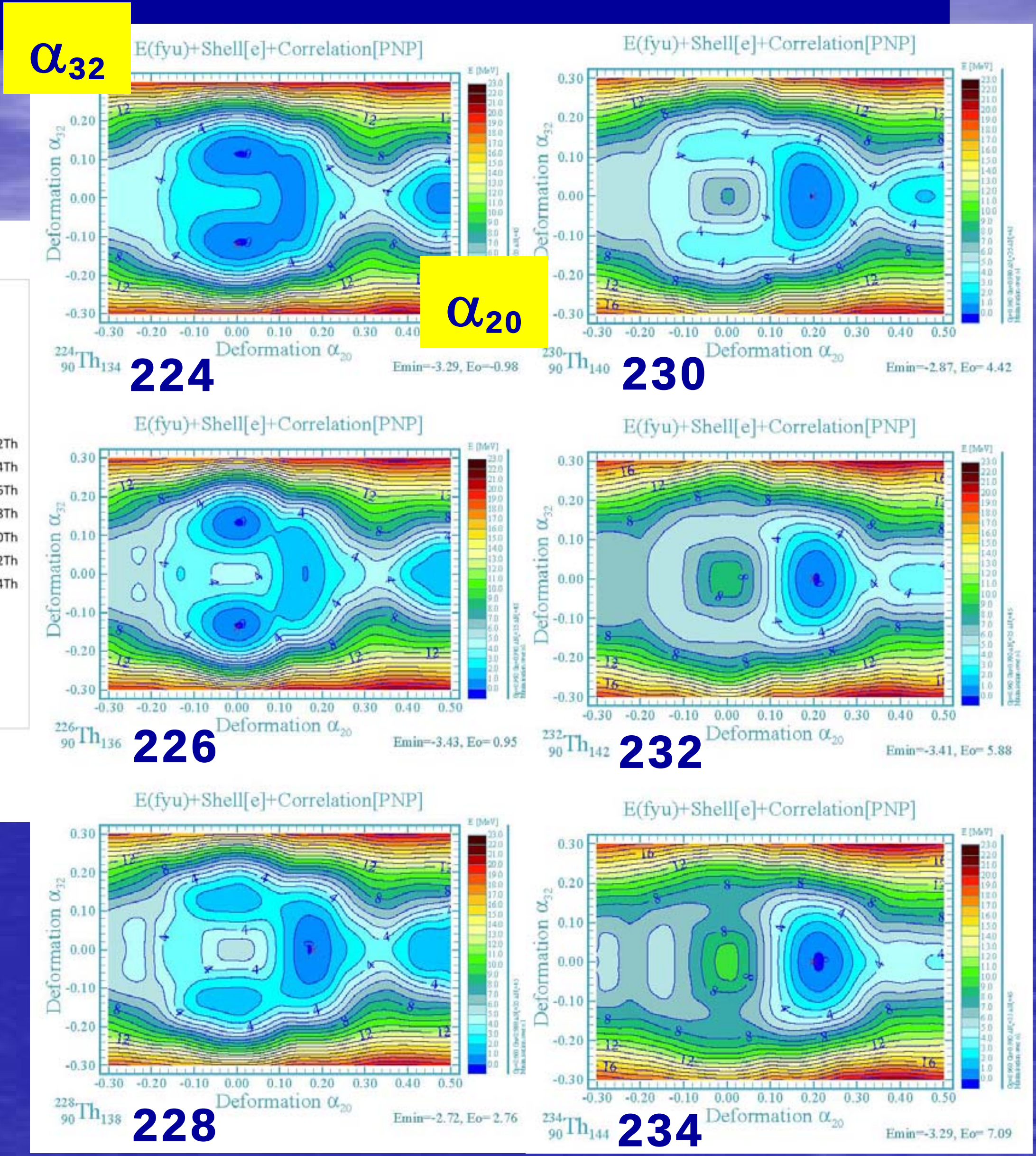




Comparisons With Mean Fields Predictions *3* :

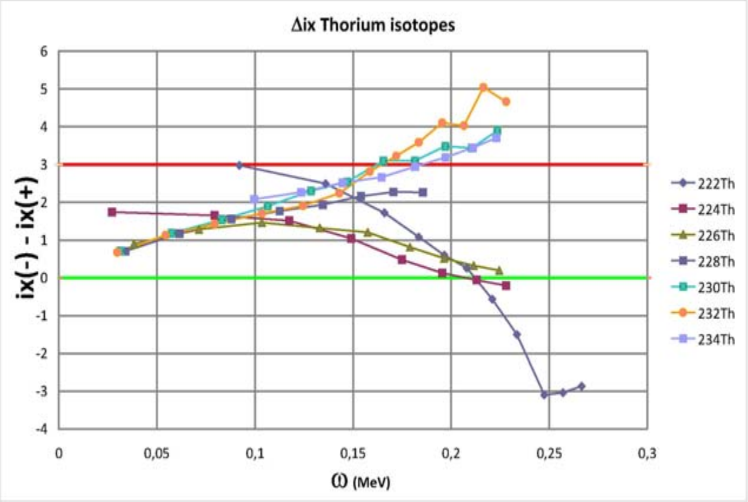
Thorium isotopes

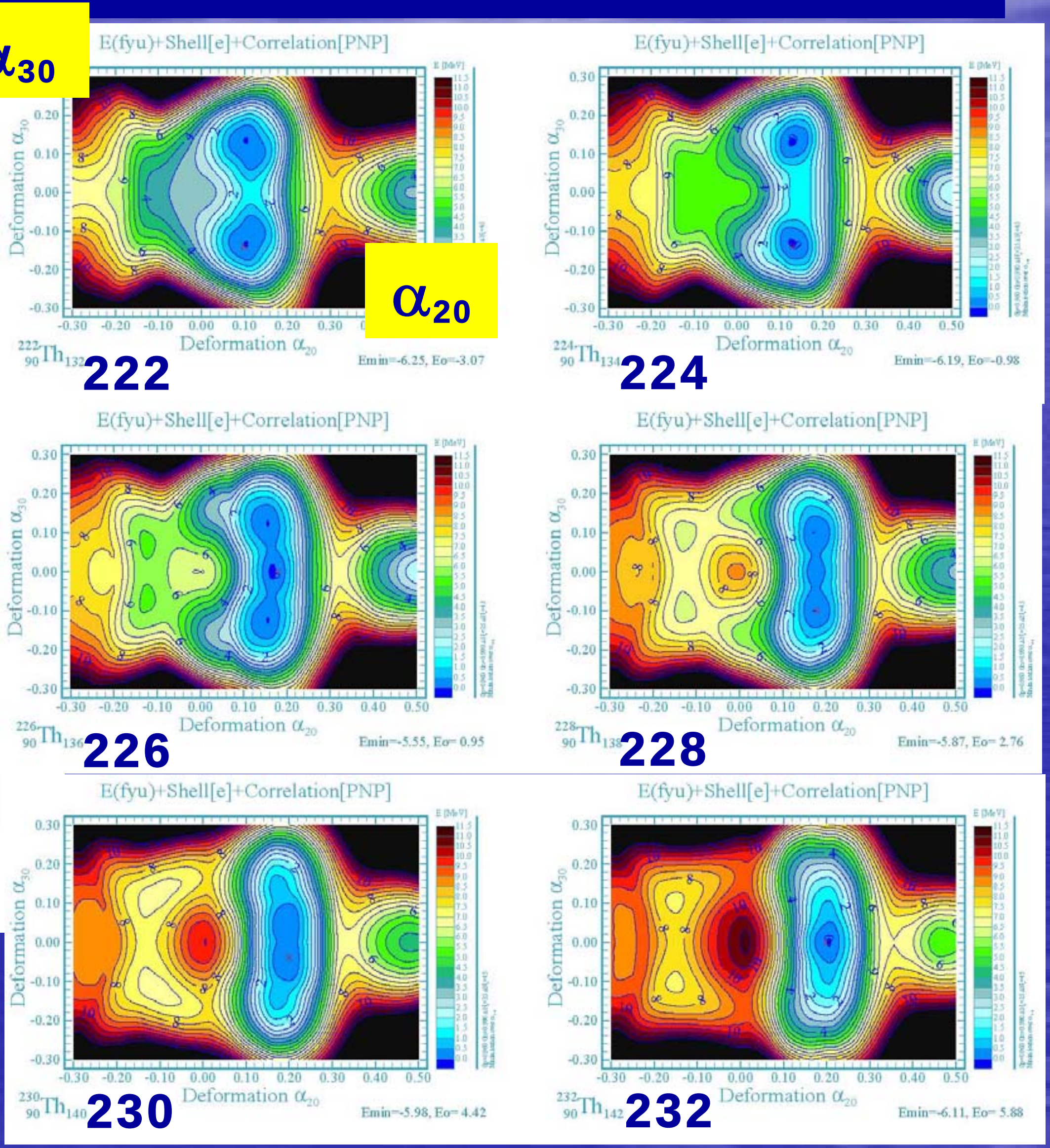




Axial Octupole: Permanent Def. versus Vib.

Thorium isotopes





Synthesis of The Comparison
A Possible Tetra-Island ?

Z/N	132	134	136	138	140	142	144	146	148	150
Pu							238	240	242	244
U		226	228	230	232	234	236	238		
Th	222	224	226	228	230	232	234			
Ra	220	222	224	226	228					
Rn		220	222							

Octupole permanent deformation

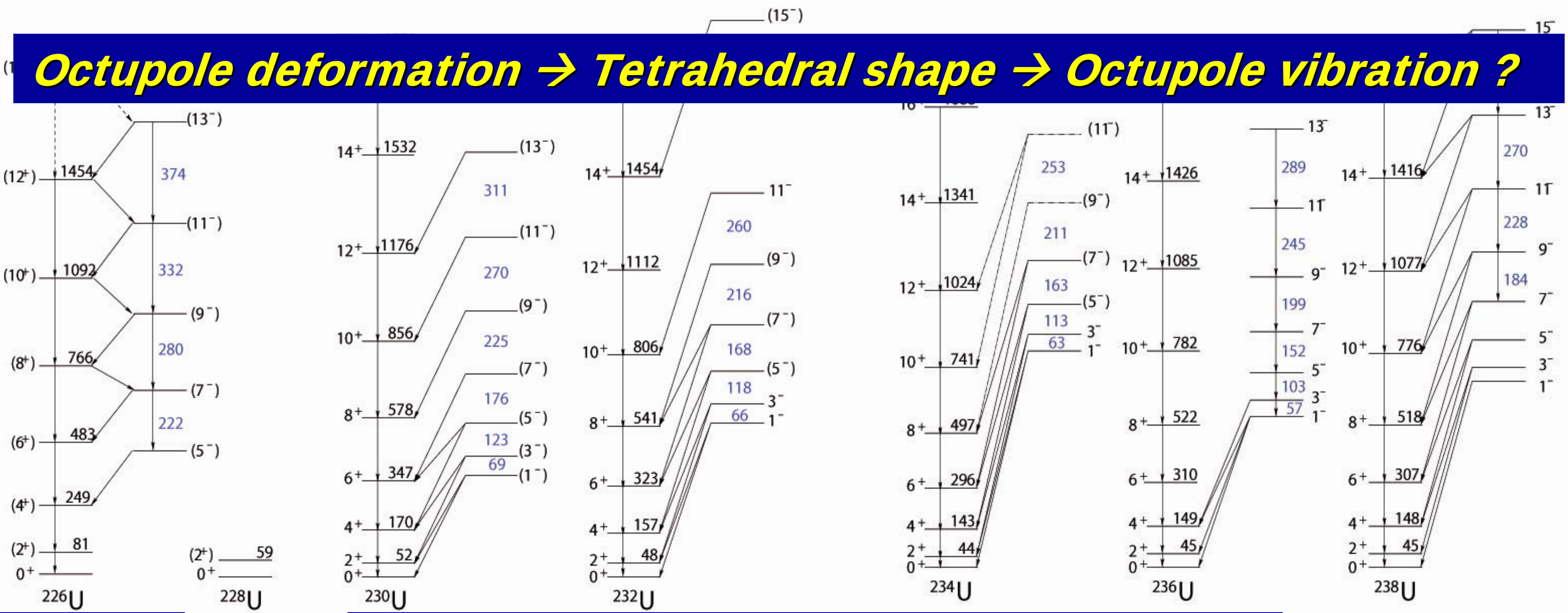
Tetrahedral deformation

Octupole vibration

Uranium Isotopes:

an new hypothesis on old measurements

Octupole deformation → Tetrahedral shape → Octupole vibration ?



1998
Jurosphere
P. Greenlees

1987 P. Zeyen e and 3 γ detectors

1996
8 π
D. Ward

→ More data requested !

What Can Be Done Experimentally Nowadays?

- Revisit the decay schemes to improve the branching ratio measurements: *$\gamma\gamma$-e coincidences*

- Measure the lifetime of the states of interest wherever possible to obtain the reduced transition probabilities for comparison with theoretical values *(range 1 to 100 ps)*

→ *ELMA project (Electron for Lifetimes Measurements in Actinides)*

How to Measure Lifetimes in Light U?

- With gamma? *impossible*

  Plunger : no recoil velocity with the α, p reactions

  Fast timing: gating not possible above the states of interest

- With conversion electrons?

  → *May Be! (and most probably the only possibility)*

NUCLEAR INSTRUMENTS AND METHODS **11** (1961) 29–38; NORTH-HOLLAND PUBLISHING CO.

The Microwave Method

EXPERIMENTS USING ULTRA-FAST PULSE TECHNIQUES

G. GOLDRING

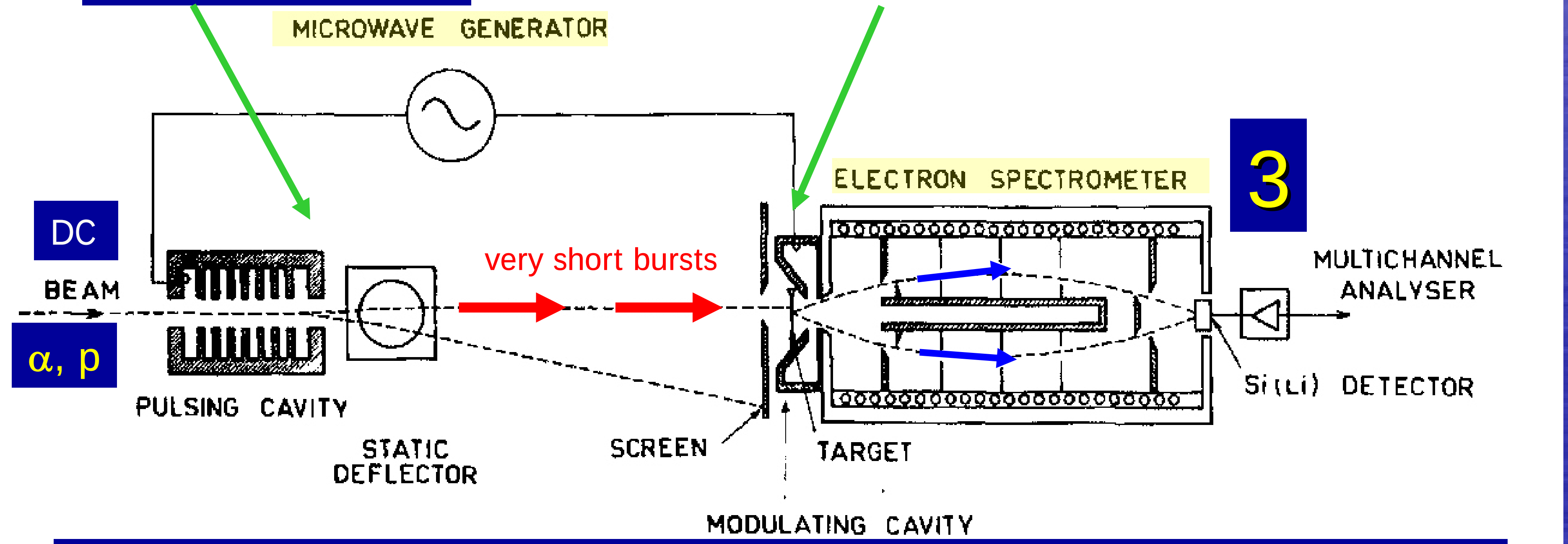
The Weizmann Institute of Science, Israel

Lifetime measurements were carried out at the Weizmann Institute for low-lying levels of a number of odd-*A* nuclei in the rare earth region. The mean lives are in the range of (3–20) $\times$ 10^{-11} sec and a special method was developed for the measurement of these short times. This consists of a microwave beam pulsing device which chops the charged particle beam producing the excited level at a frequency of 2500 Mc/sec, and a combination of a beta-ray spectrometer and a microwave cavity modulating the energy of the electrons and acting as a timed shutter for conversion electrons emitted in the decay of the excited state. The time resolution in these experiments was 7 $\times$ 10^{-11} sec. The ultimate time resolution that can be achieved is determined by the optical properties of the particle beam and the power available for the microwave deflection.

Goldring's Microwave Setup

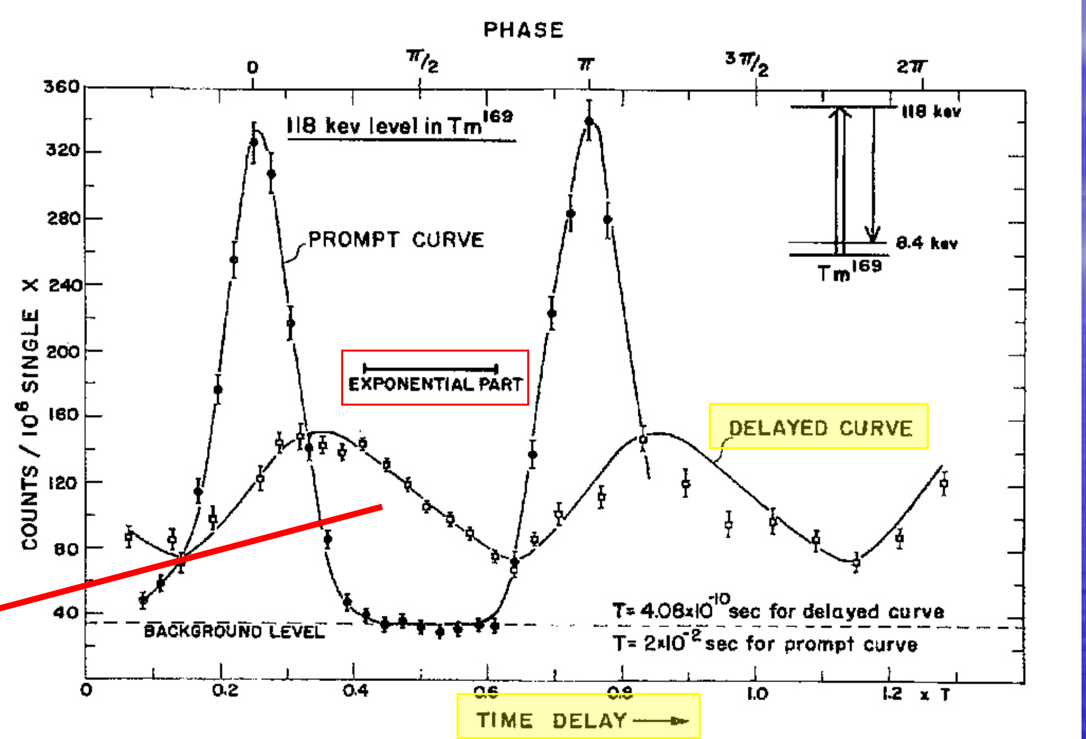
1 HF Beam chopper and beam sweeping cavity

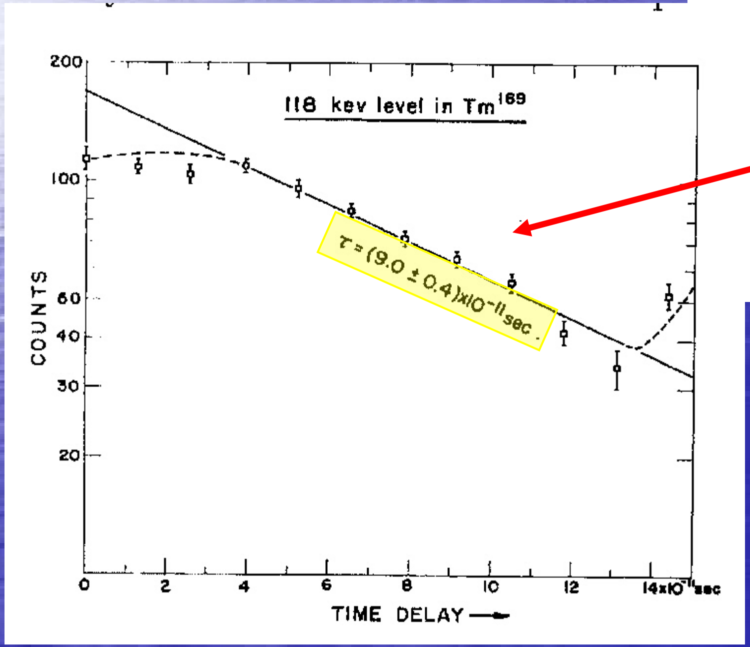
2 Electromagnetic shutter-like device: selection of electrons according to their time of emission



Changing relative phase between the 2 cavities = modulating the electron energy in function of time → variable time-scale between the production of excited states and their decay via conversion electrons

Recording the count rate in function of the phase gives a direct access to the lifetime of the excited state





Actual range of the method:
15-200 ps (+- 10%)
with microwave frequency 2.5 GHz

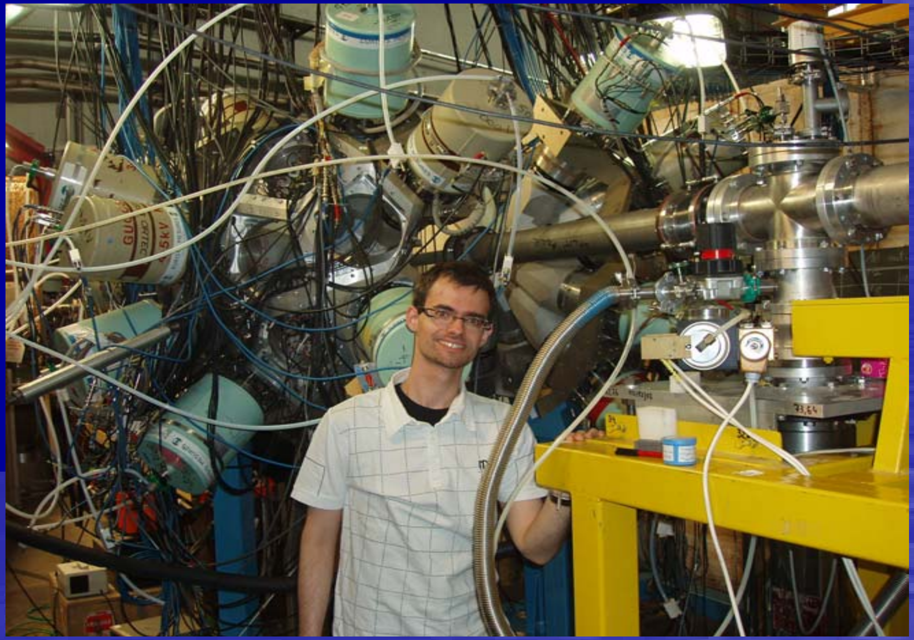
Goldring: "the ultimate time resolution is determined by optics of the line and the microwave power"

Test ELMA with ORGAM

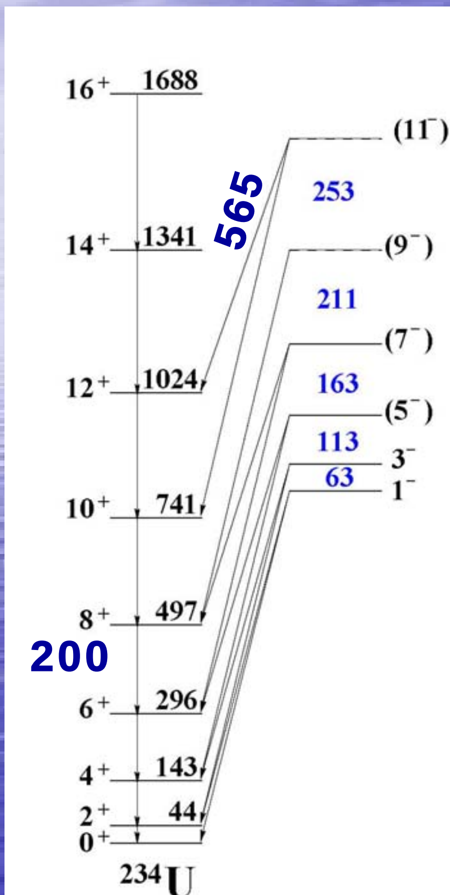
- Key issue : *final aim CE measurements not the γ*
- Main goals :
  - excitation function $^{232}Th(\alpha, 2n)\ ^{234}U$ @ 28MeV
  - test the filtering of the fission *(95% of the cross section)* with the $\gamma - \gamma$ coincidences
  - test the target quality

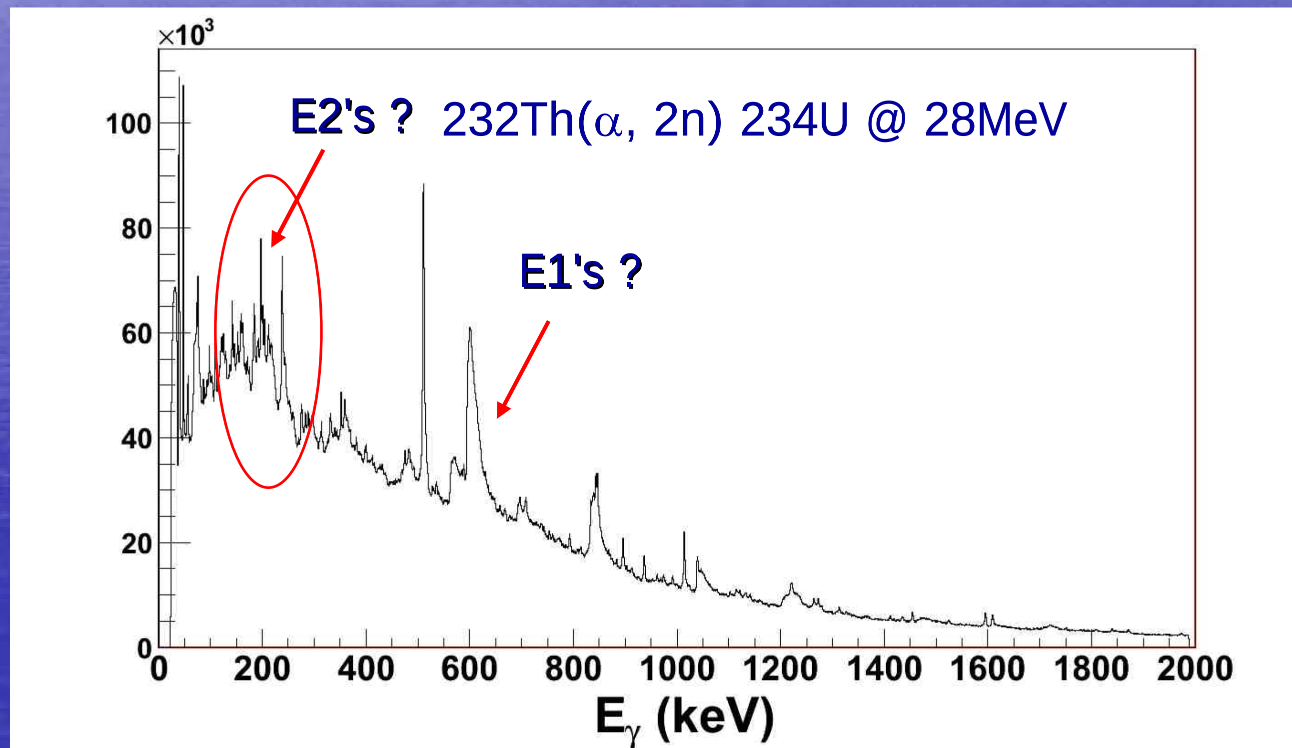
- ORGAM array + Si det.

L. Sengelé & G. Lehaut
(O. Stezowski)

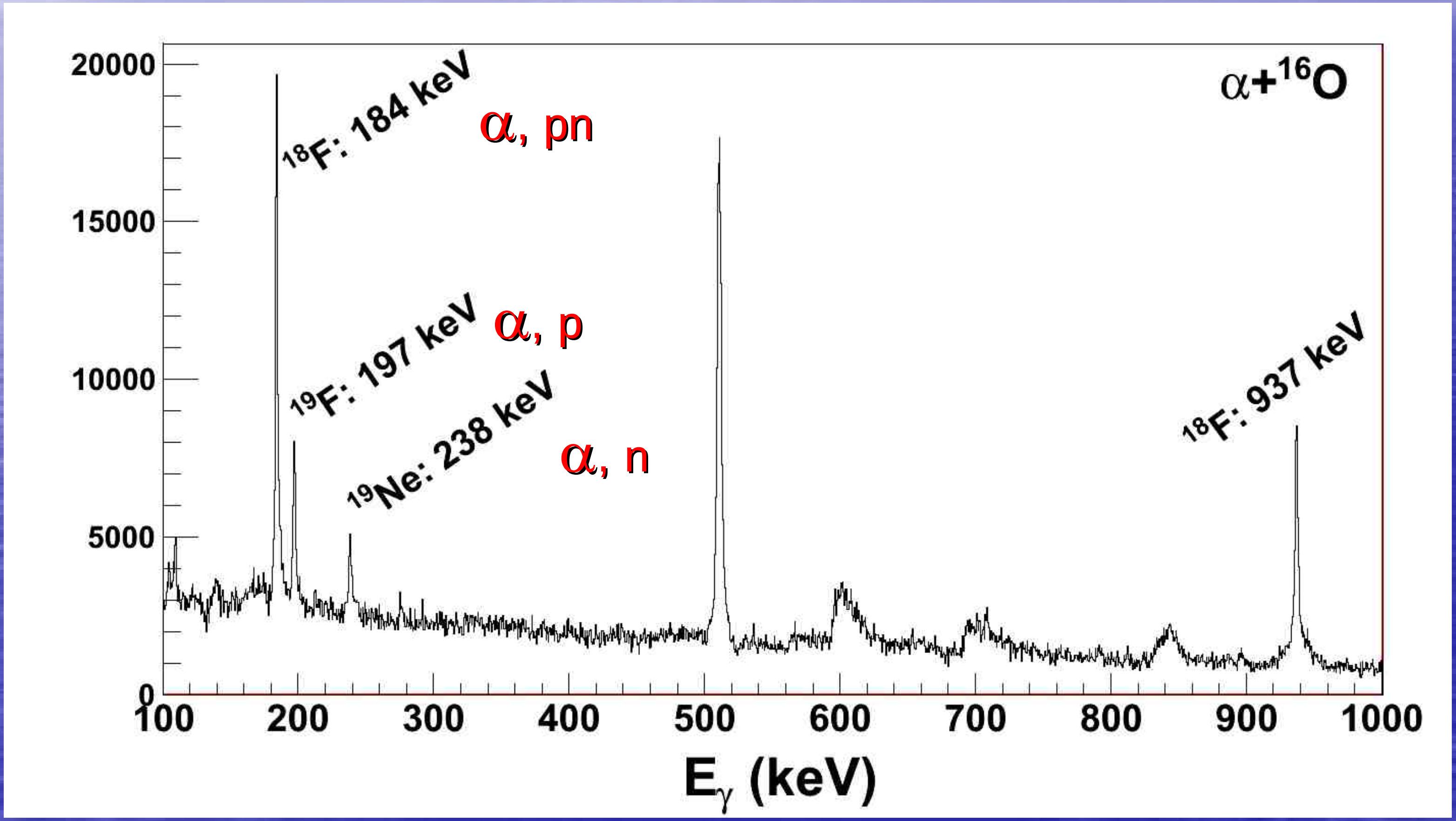


ELMA Test : gamma spectra

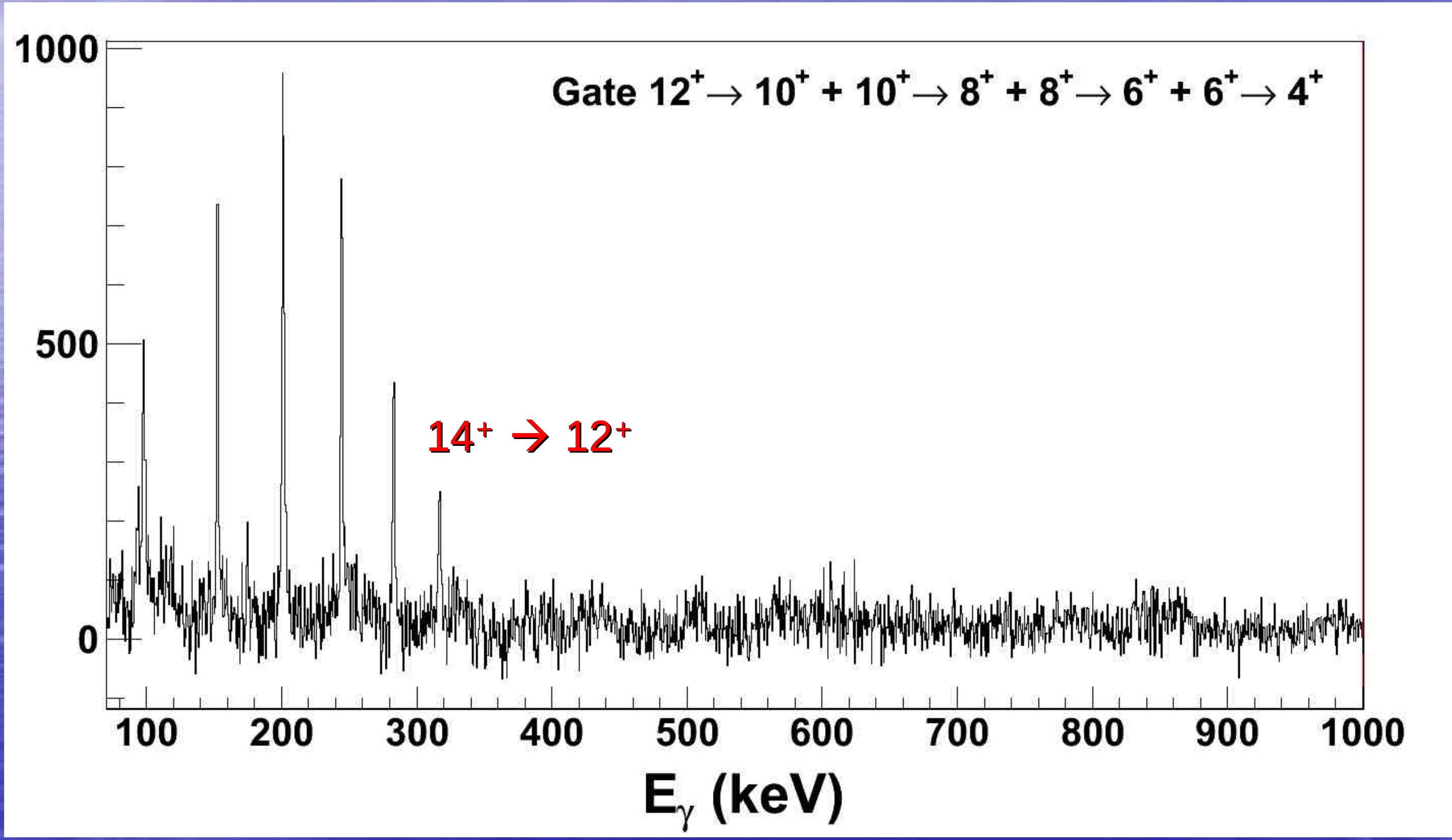




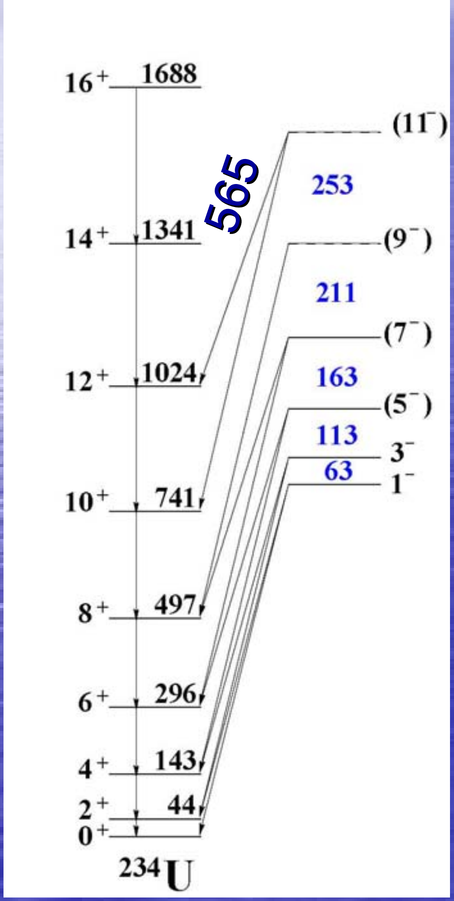
ELMA Test : oxygen contaminants

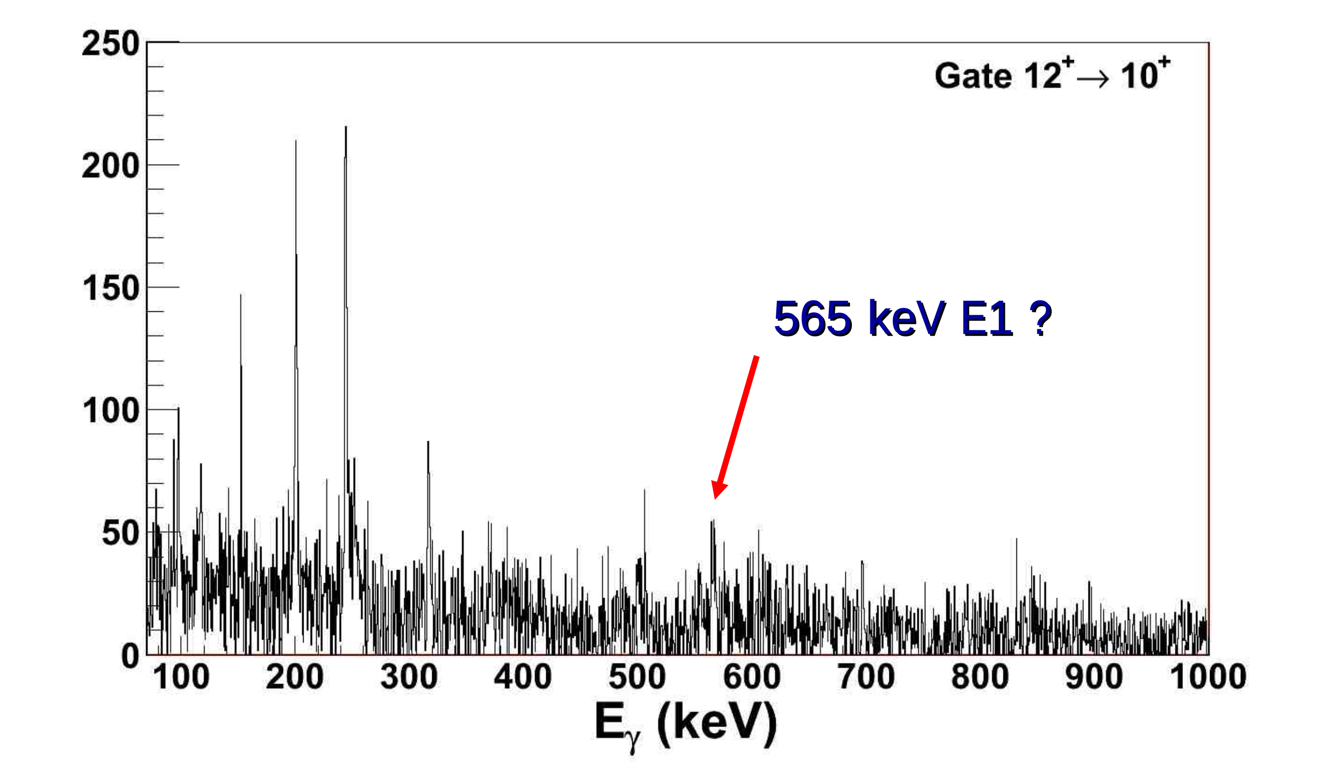


ELMA Test : ^{234}U gsb γ–γ only



ELMA Test : E1's ?





Summary & Conclusions

- Since the launch of the TetraNuc Collaboration important progresses have been made in the more promising region of the Actinides that shows the existence of a possible island of tetrahedral nuclei.
- This possibility is calling for the creation of a modern dedicated corpus of data
- A possible way to realize this corpus has been formulated through the ELMA project to measure the lifetimes of the state of interest through conversion electron
- A first experimental test was performed with the ORGAM array and turned to be encouraging
- Our next move will be two folds (JYFL):
  - Test the ^{231}Pa(p, 4n) ^{228}U reaction, ^{228}U is the most favourable case
  - Test the possibility to measure the E1's CE in ^{234}U with JUROGAM+SAGE
    (^{232}Th target 1,4e10y – CE ~ 2% for 400 keV E1)

List of main *TetraNuc* collaborators

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Thanks !