Octupole bands in the mass 160 region

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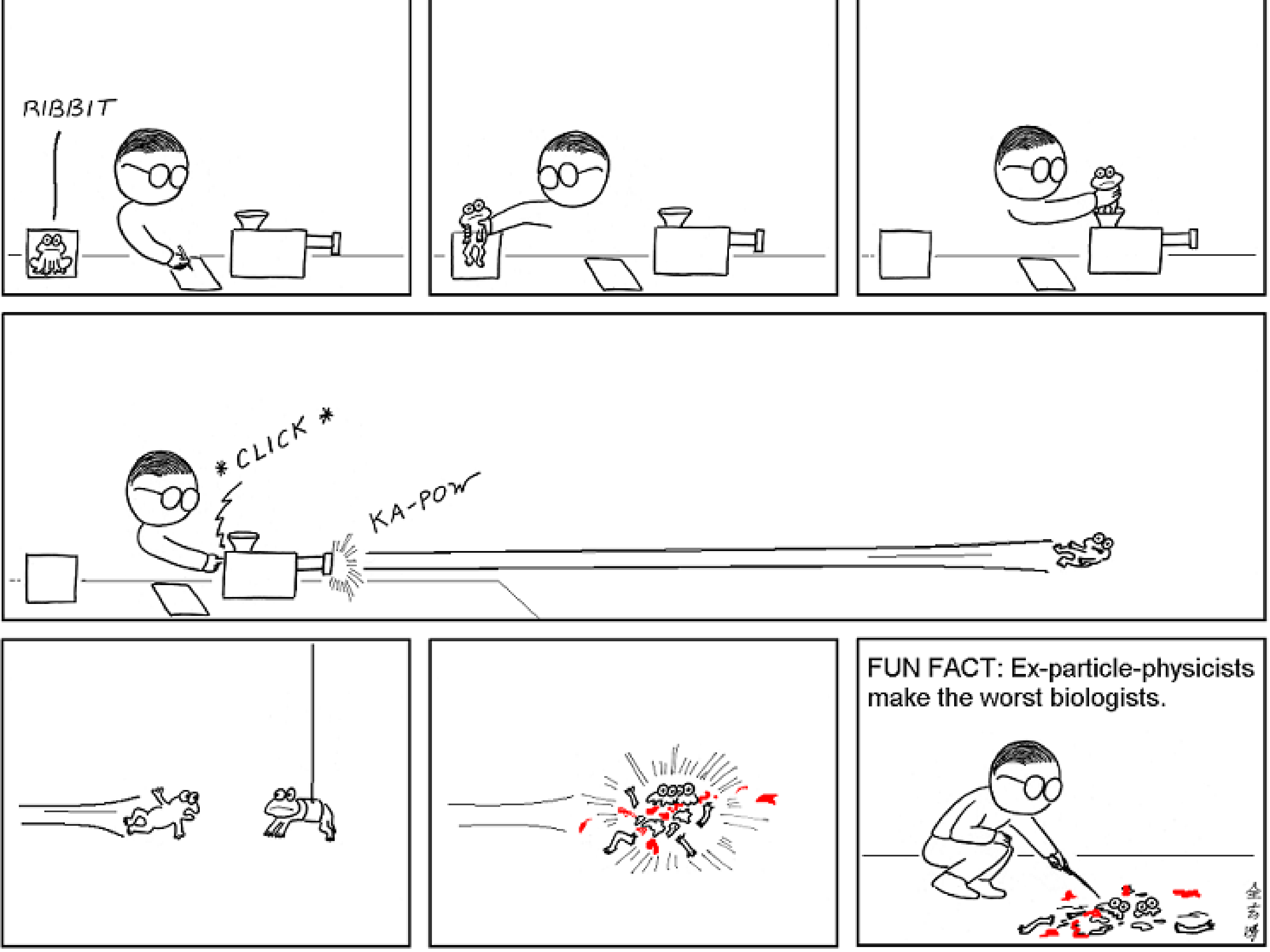

RIBBIT
CLICK
KA-POW
FUN FACT: Ex-particle-physicists make the worst biologists.

Nuclear deformations

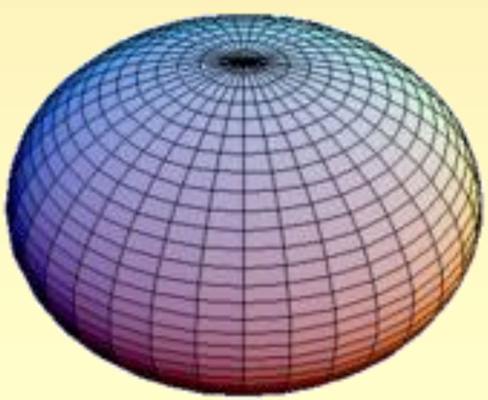
- Have ~150 body problem, with two sets of fermions. Use collective approach
- Apply liquid drop model to surface
- General expansion:

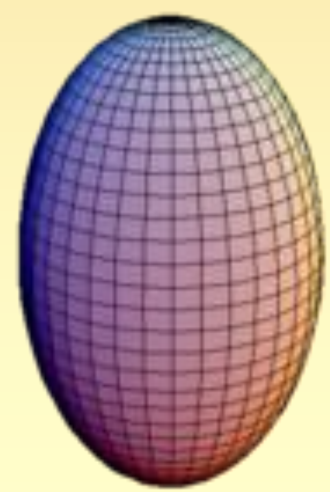
$$R(\theta,\phi,t) = R_0\left(1+\sum_{\lambda=0}^{\infty}\sum_{\mu=-\lambda}^{\lambda}\alpha_{\lambda\mu}(t)Y_{\lambda\mu}(\theta,\phi)\right)$$

$$R(\theta,\phi) = R_0\left(1+\sum_{\lambda=0}^{4}\sum_{\mu=0}^{\lambda}\alpha_{\lambda\mu}Y_{\lambda\mu}(\theta,\phi)\right)$$

Nuclear deformations

- The monopole and dipole deformations are scaling and translational – do not effect shape
- Ground state, most even-even nuclei are quadrupole-deformed:

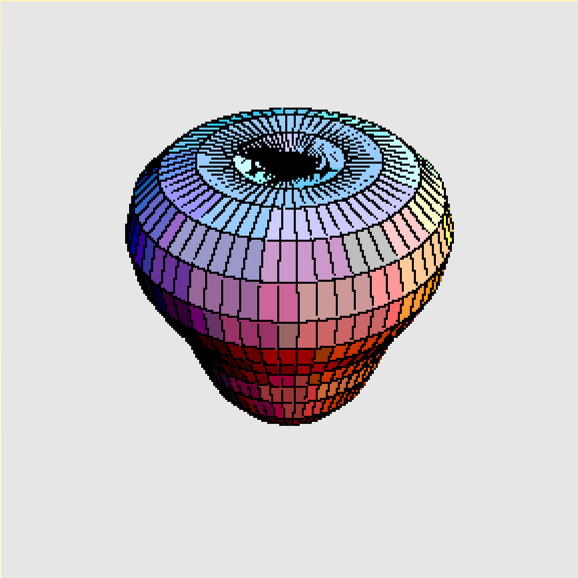




Octupole deformations

- Standard octupole deformation is $\alpha_{30} \neq 0$
- Corresponds to 'pear' shape:

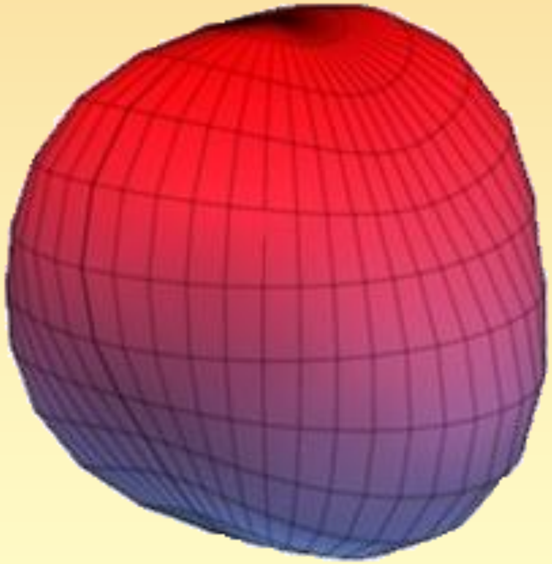
- Onto this we can superimpose a vibration:



Tetrahedral deformations

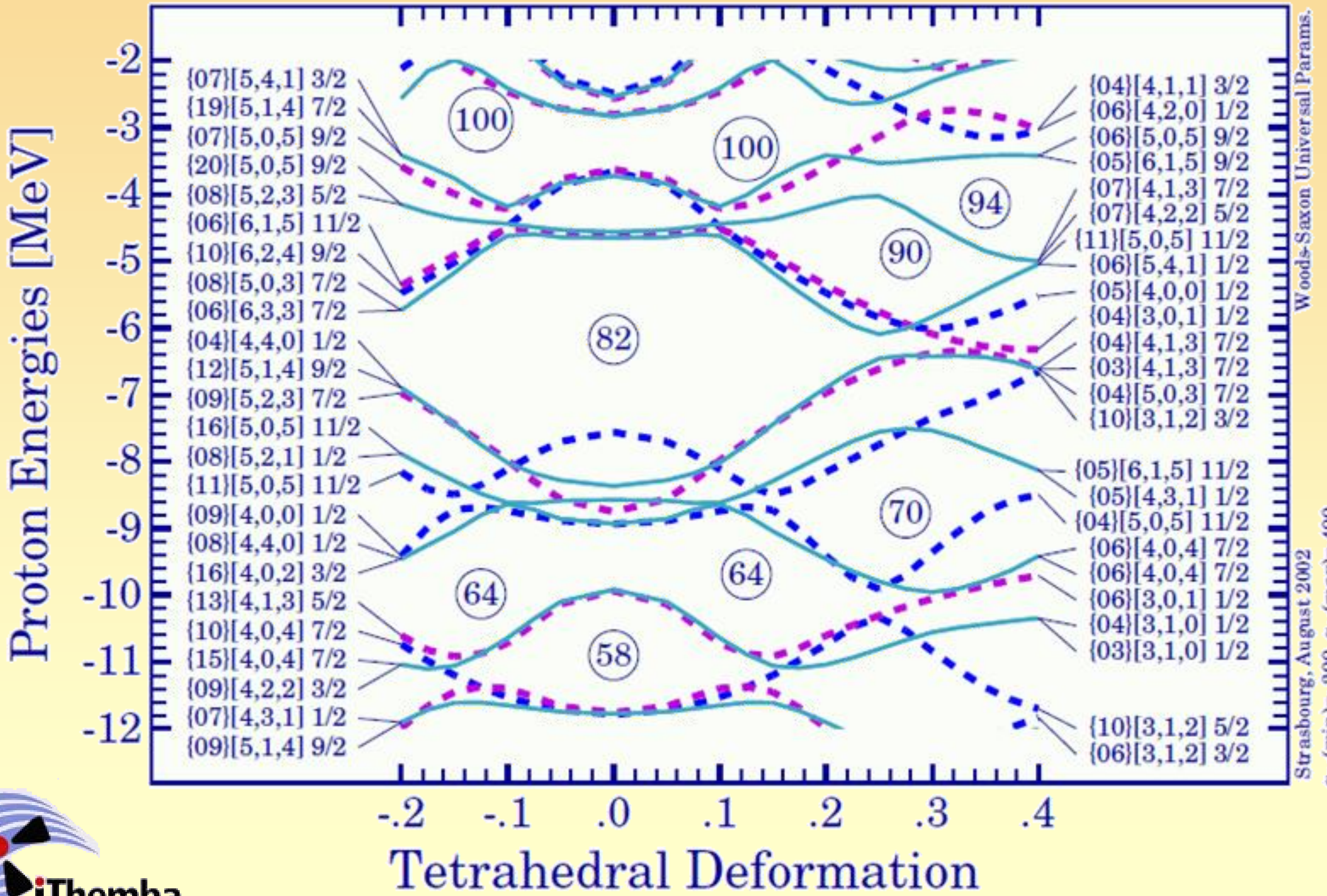
- It is also possible to have $\alpha_{32} \neq 0$

- However, for this to exist, cannot have a quadrupole moment.



So $\alpha_{20} = 0$

Where to find them?



Look for doubly-magic nuclei

- Looking for shell-gaps in the tetrahedral nucleon energies.
- There are some at 64 and 70, then 90 and 94
- So focus in the A~160 region:

  ^{154}Gd, ^{158}Gd, ^{160}Yb, ^{164}Yb
- Next deformed shell gaps are 112, 136, 142, so can look in ^{232}Th region.

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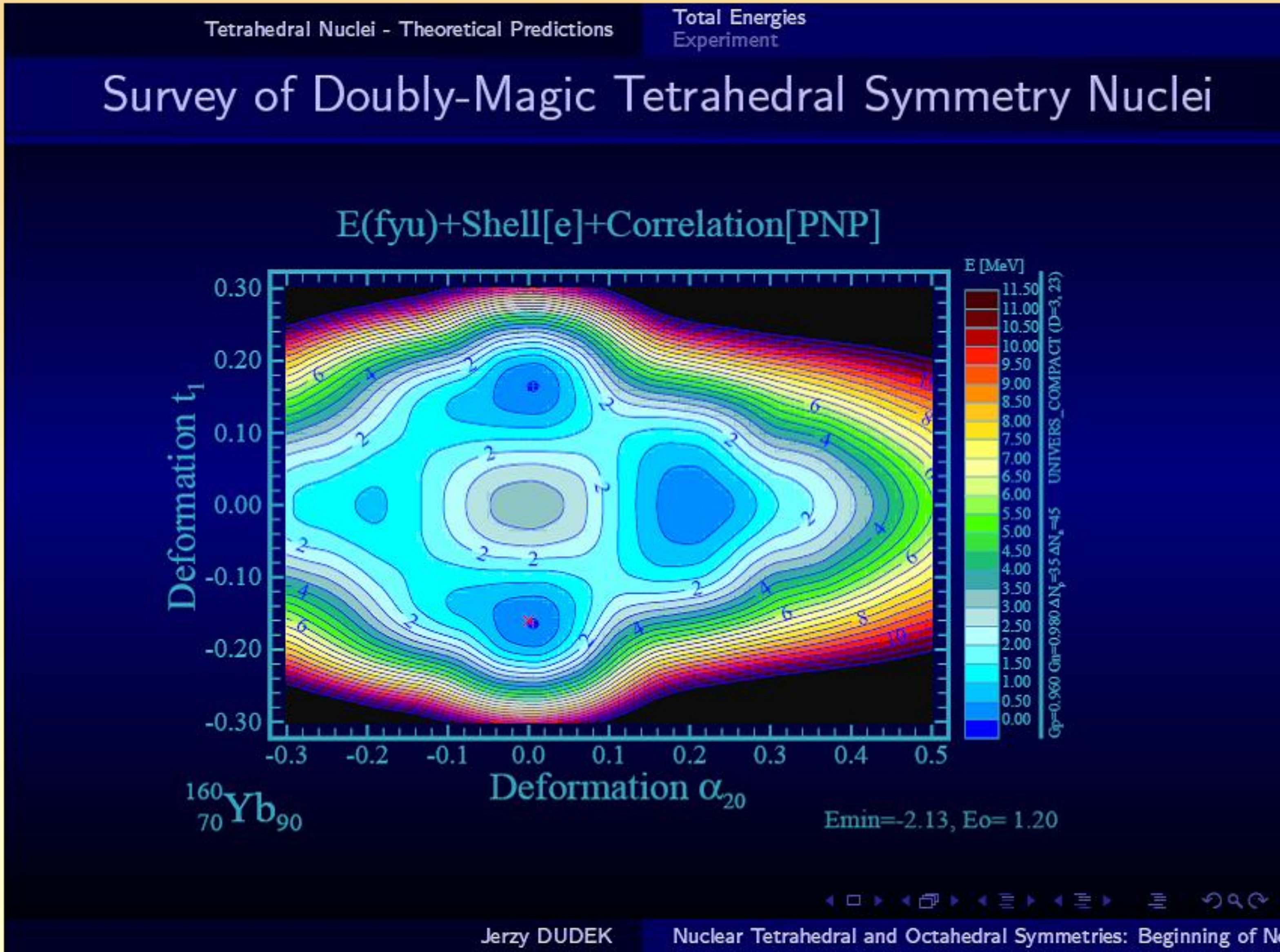
Calculations were promising:



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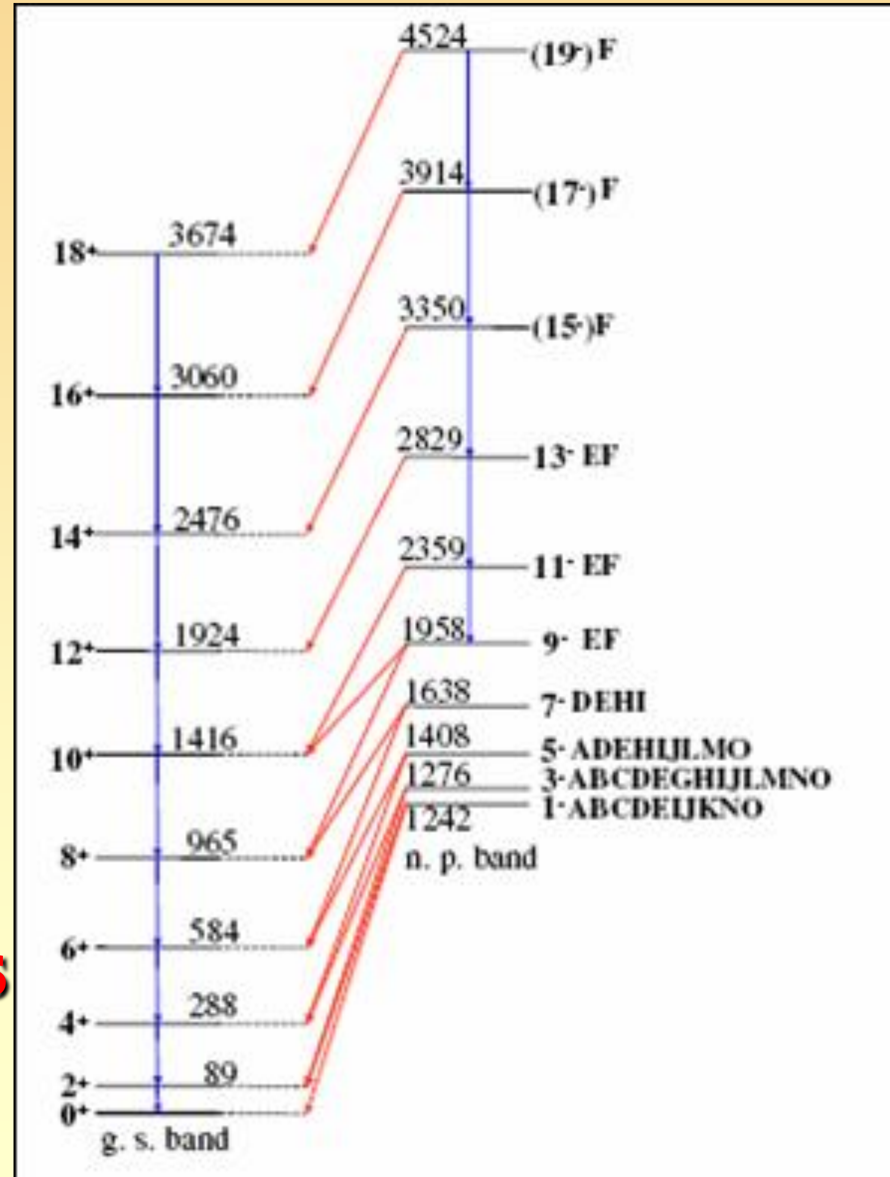
What to look for?

- With zero quadrupole moment, there will be no in-band E2 transitions

Generally thought of as octupole vibrations,

but now:

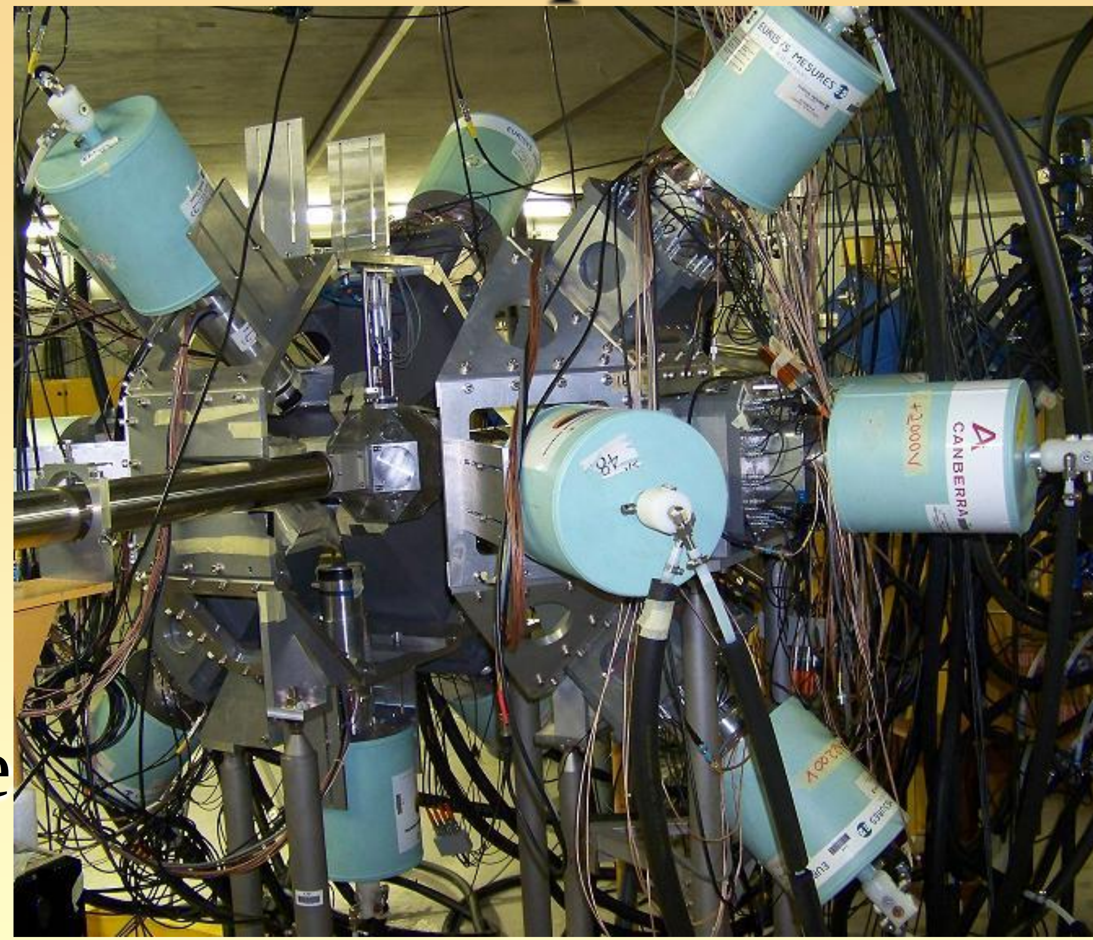
Tetrahedral candidates



AFRODITE setup

- HPGe detectors:
  9 Clover and
  up to 8 LEPS

- Collect up to
  10^9 $\gamma\gamma$ coincidence
  events / weekend



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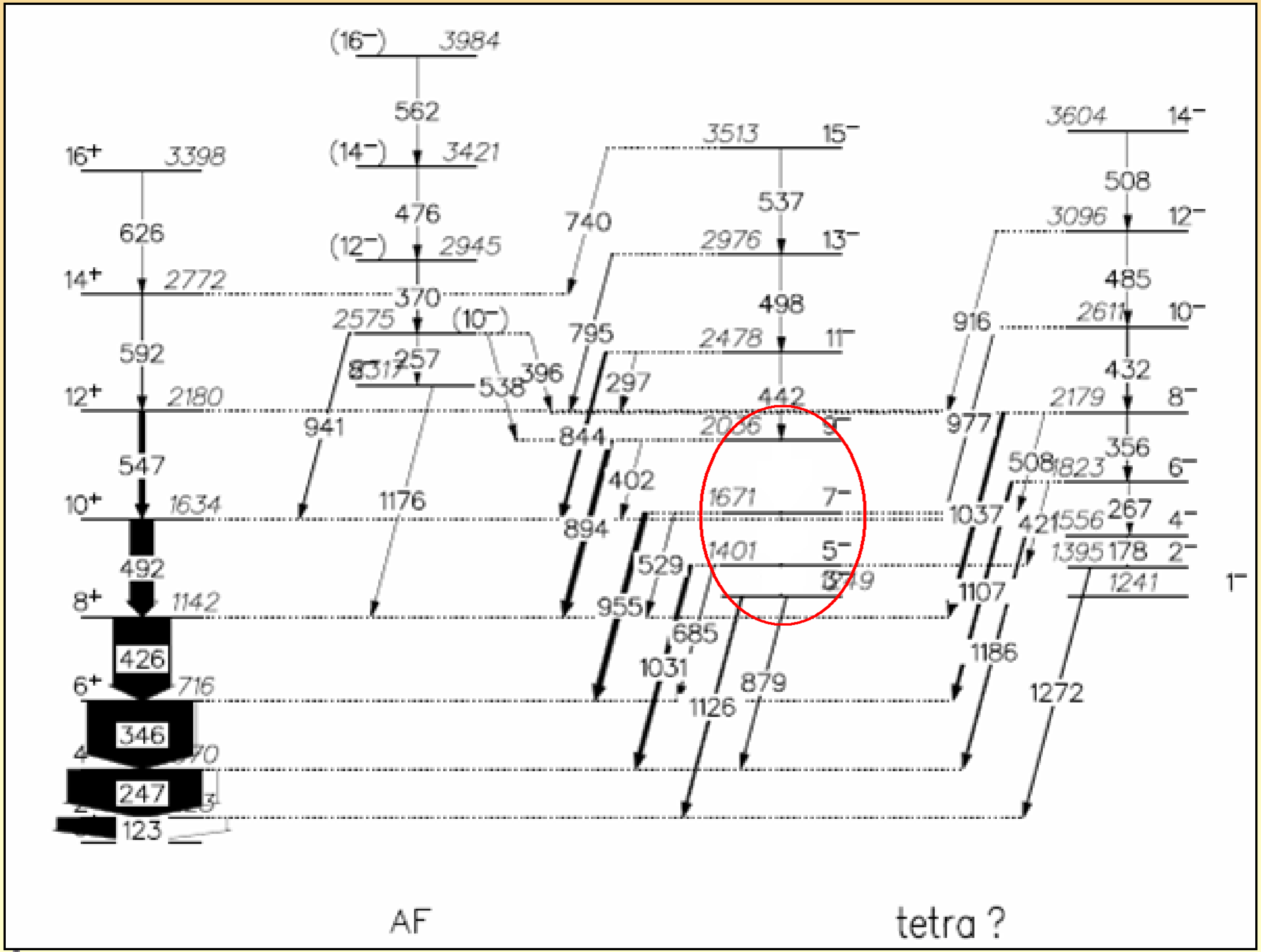
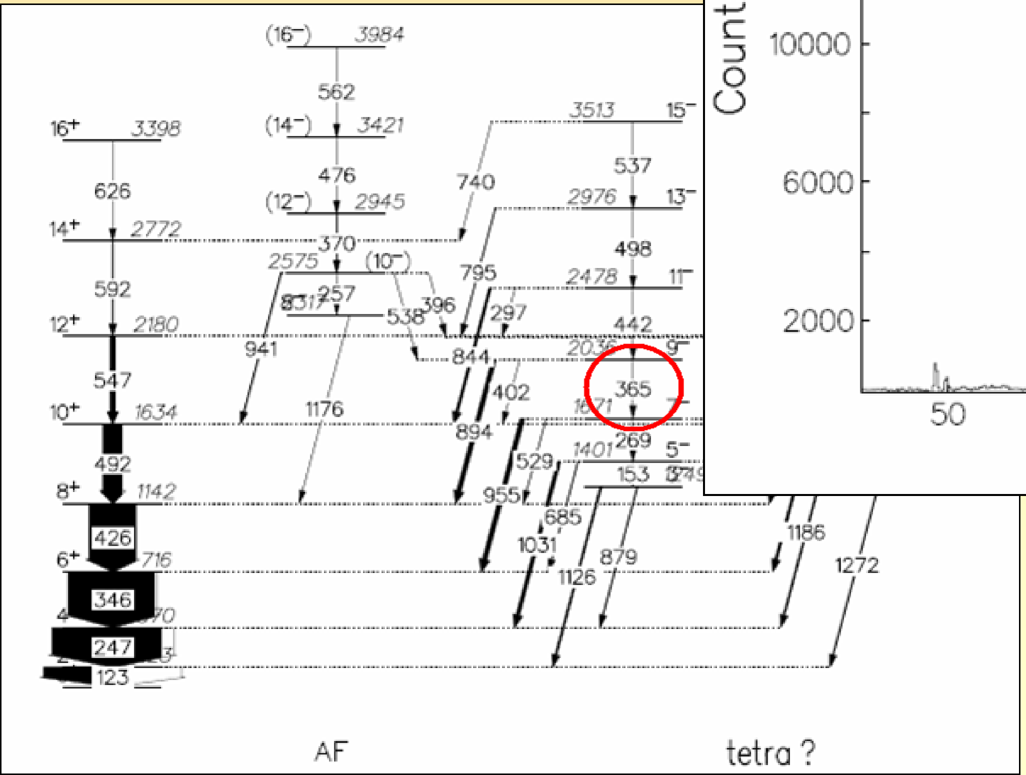
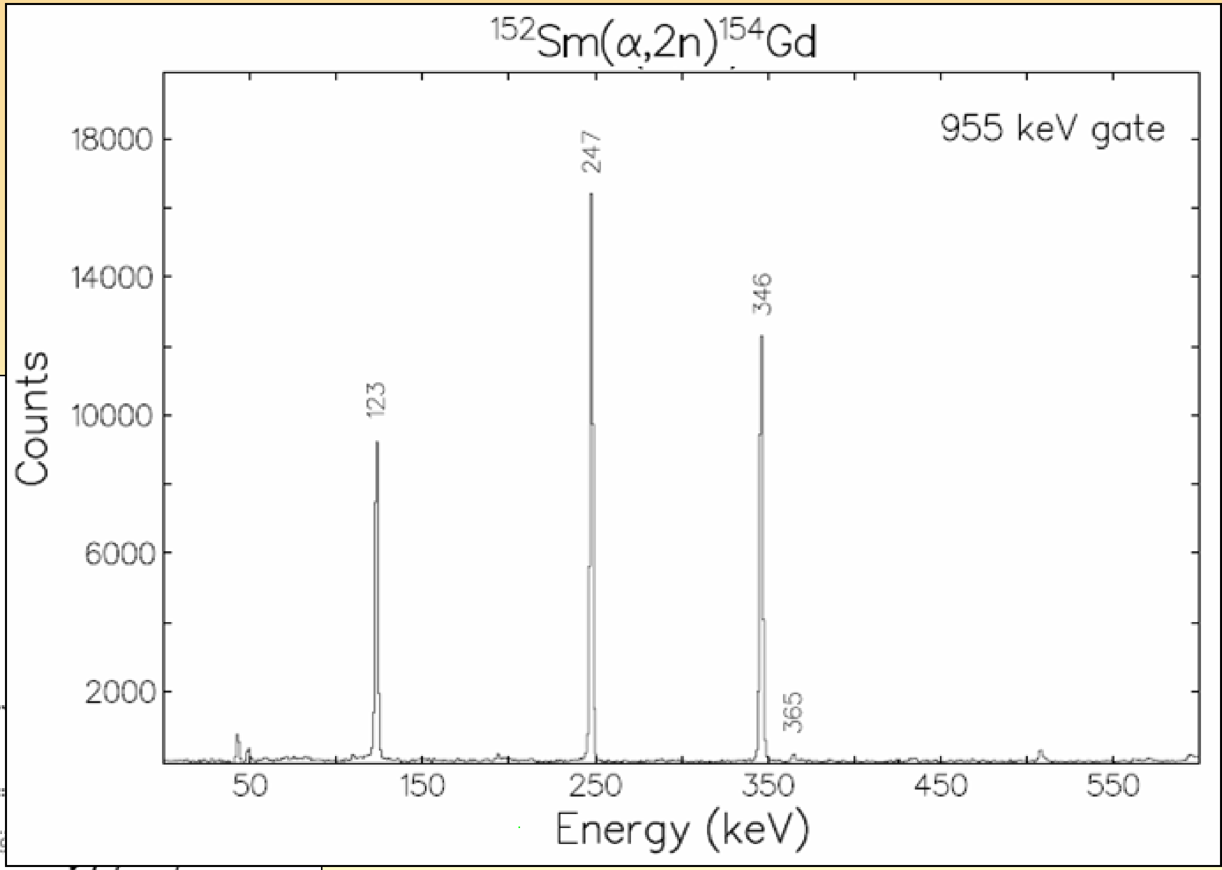
$^{152}Sm(\alpha,2n)^{154}Gd$:



Missing transitions?

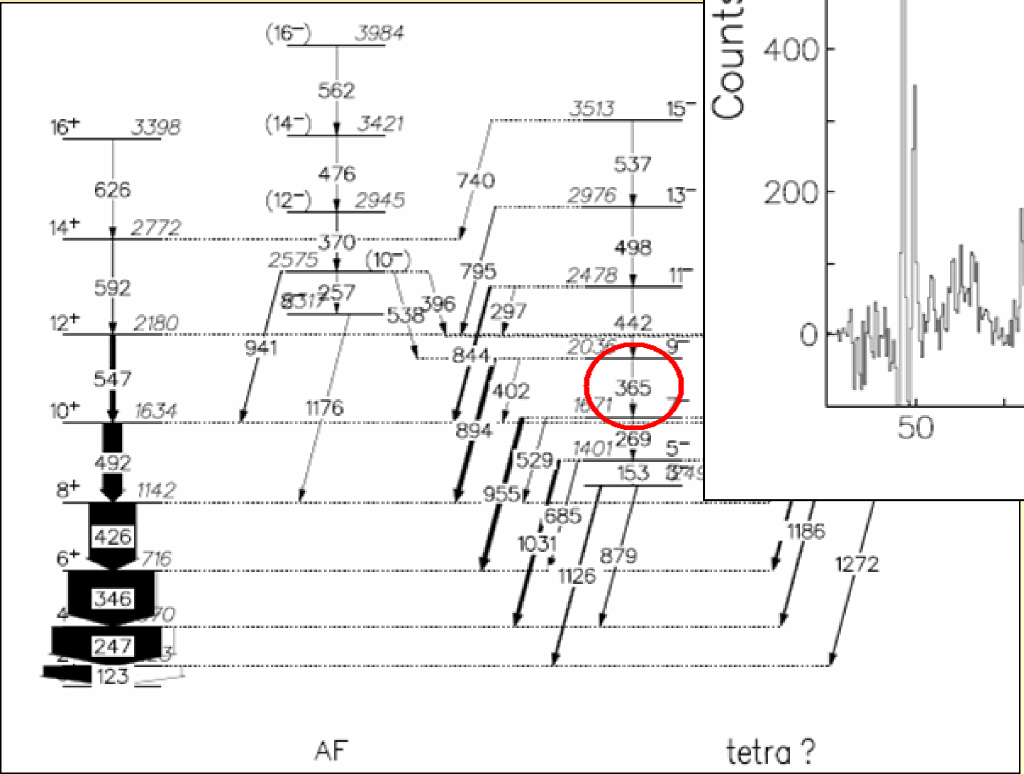
- Is there a 9 → 7?

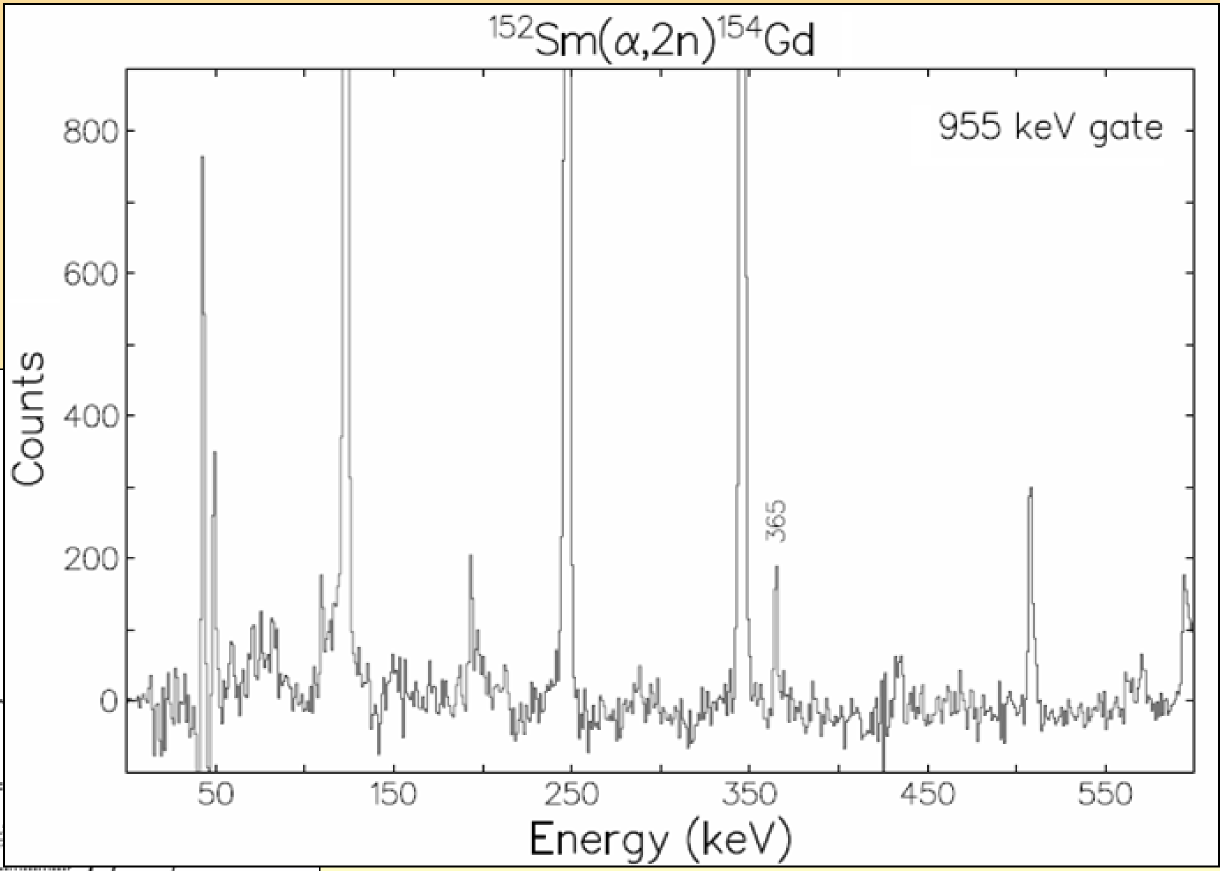




Missing transitions…

- Yes!

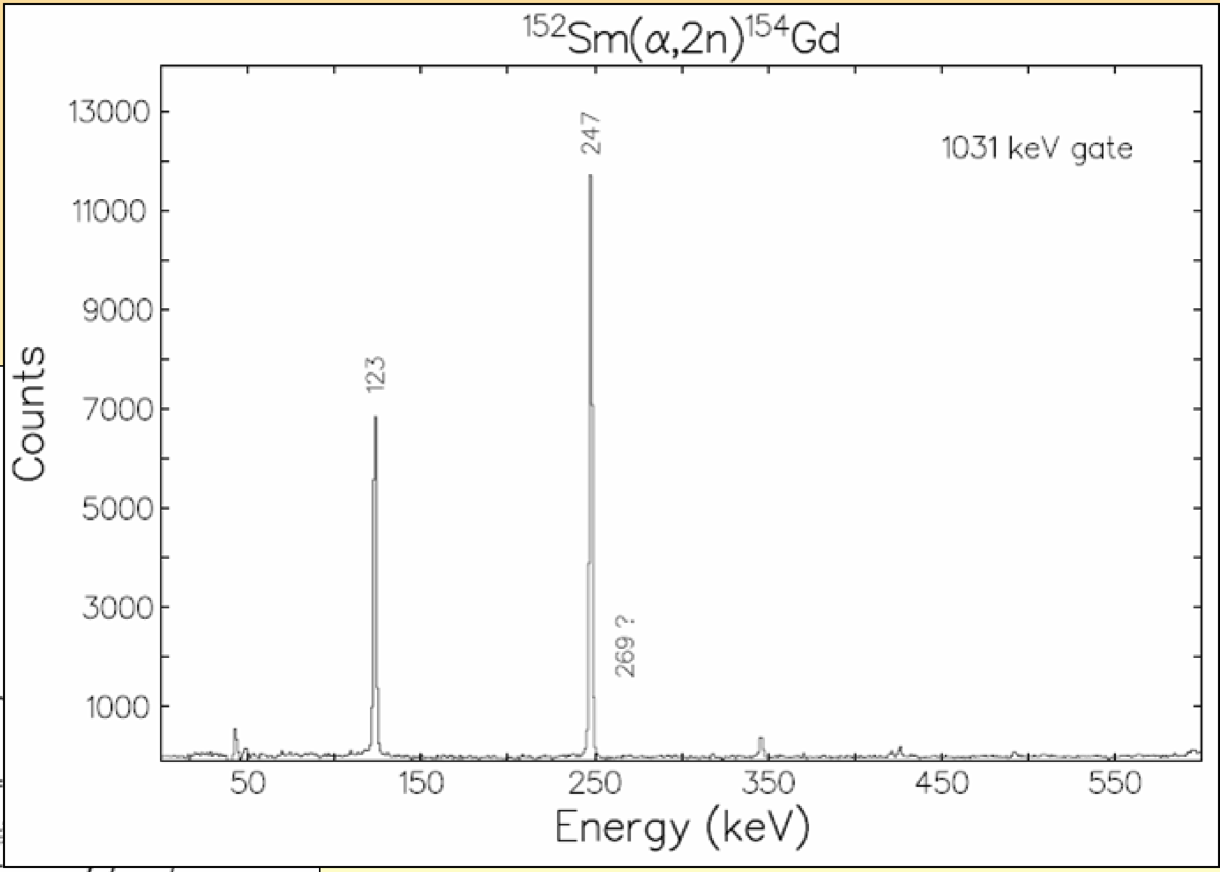


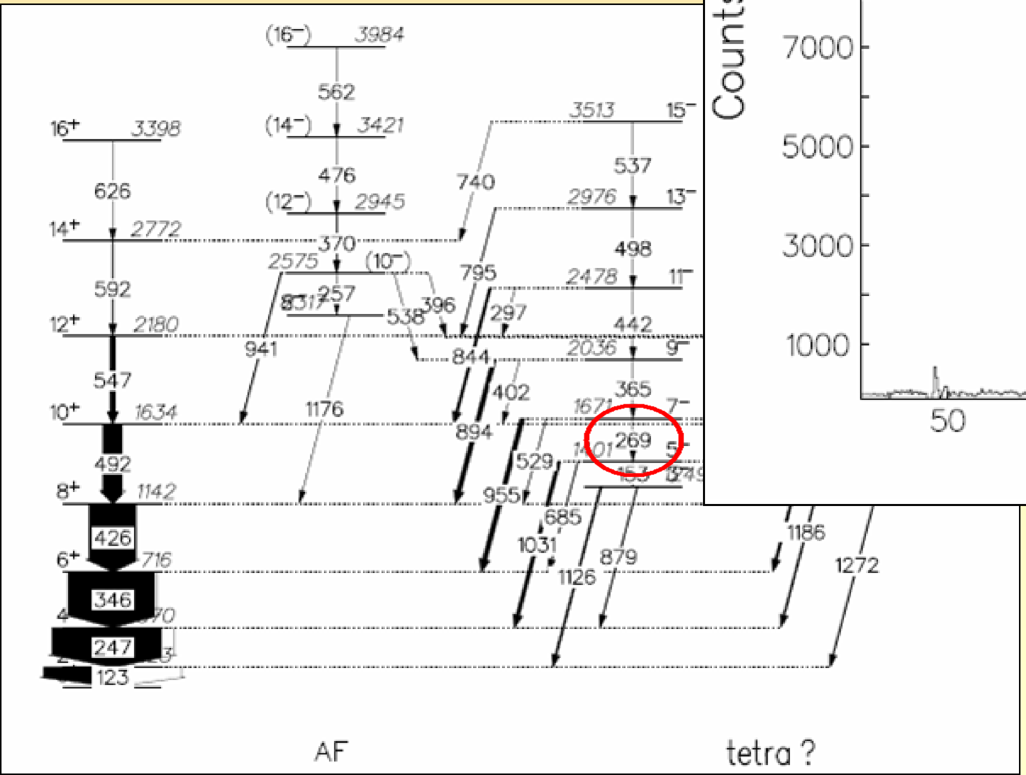


Let’s try again:

- How about

  7 → 5?

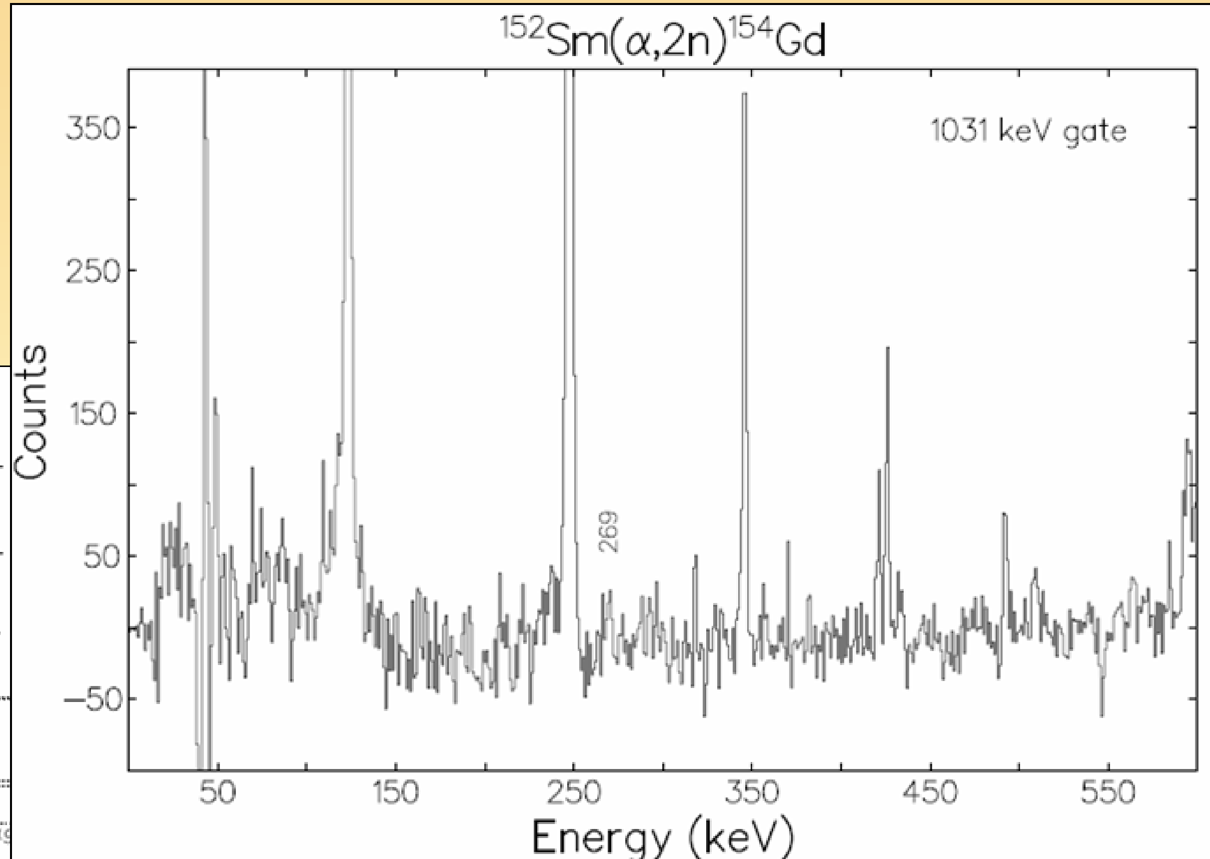


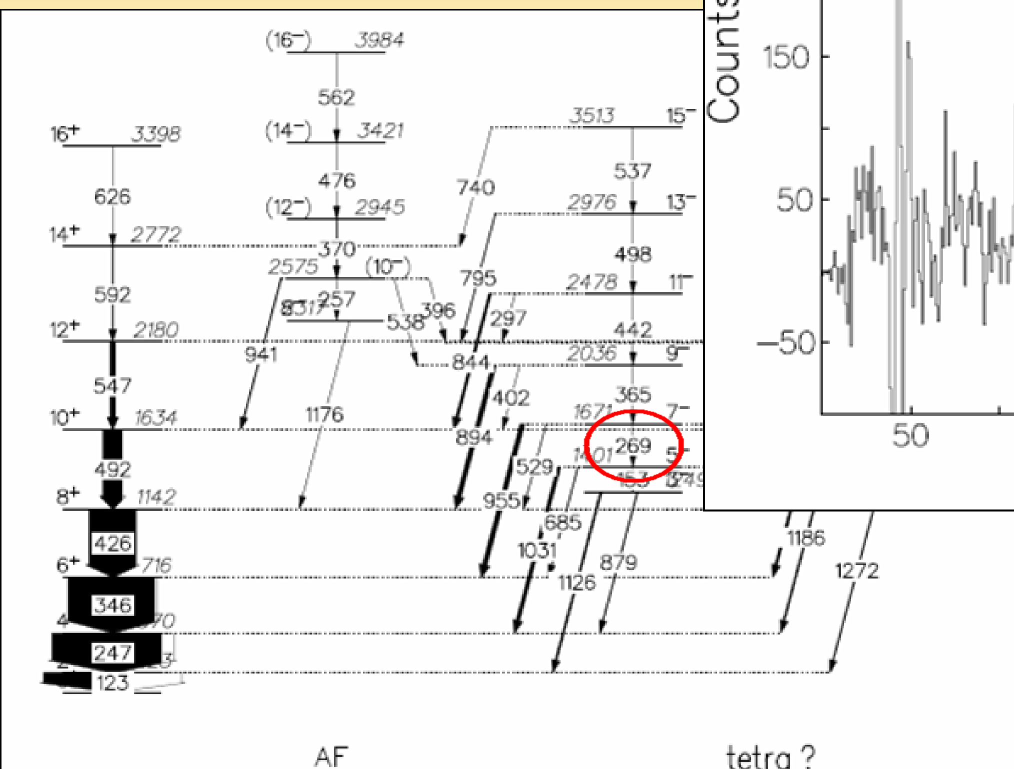


And it seems we have it:

- Well, sort of

  Much fainter



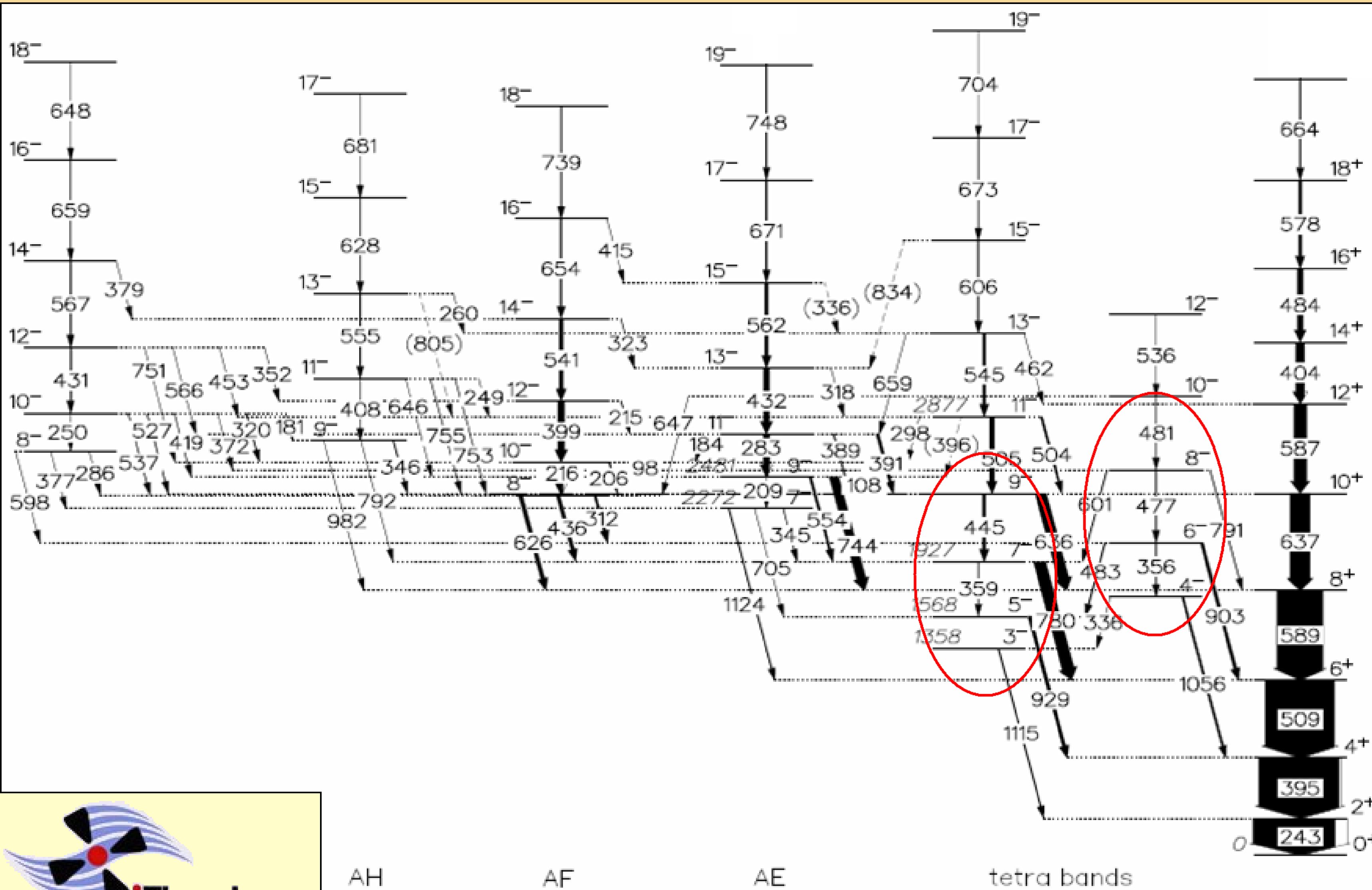


^{154}Gd update

- There are in-band E2 transitions
- The $9 \rightarrow 7$ and $7 \rightarrow 5$ transitions found, but getting very weak.
- $5 \rightarrow 3$ and $3 \rightarrow 1$ unobserved

- Unlikely to be tetrahedral

Next: ^{160}Yb



AH
AF
AE
tetra bands
18⁻ 16⁻ 14⁻ 12⁻ 10⁻ 8⁻
648 659 567 379 431 751 566 453 352 250 527 419 320 372 181 537 286 377 598
17⁻ 15⁻ 13⁻ 11⁻ 9⁻
681 628 555 408 346 792 982
18⁻ 16⁻ 14⁻ 12⁻ 10⁻ 8⁻
739 654 415 541 260 (805) 323 646 249 755 753 399 215 216 206 98 626 436 312
19⁻ 17⁻ 15⁻ 13⁻ 11⁻ 9⁻ 7⁻
748 671 562 (336) (834) 432 318 647 184 283 389 2481 209 2272 554 345 744 705 1124
19⁻ 17⁻ 15⁻ 13⁻ 11⁻ 9⁻ 7⁻ 5⁻ 3⁻
704 673 606 545 462 659 2877 298 (396) 505 504 391 108 445 1927 359 1568 1358 636 730 929 1115
12⁻ 10⁻ 8⁻ 6⁻ 4⁻
536 481 477 601 356 791 483 336 903 1056
18⁺ 16⁺ 14⁺ 12⁺ 10⁺ 8⁺ 6⁺ 4⁺ 2⁺ 0⁺
664 578 484 404 587 637 589 509 395 243
0

^{160}Yb, continued

- Evidence of the in-band E2 transitions
- Again, have transitions down to 5^- (and 4^-), but transitions very weak.
- Why?

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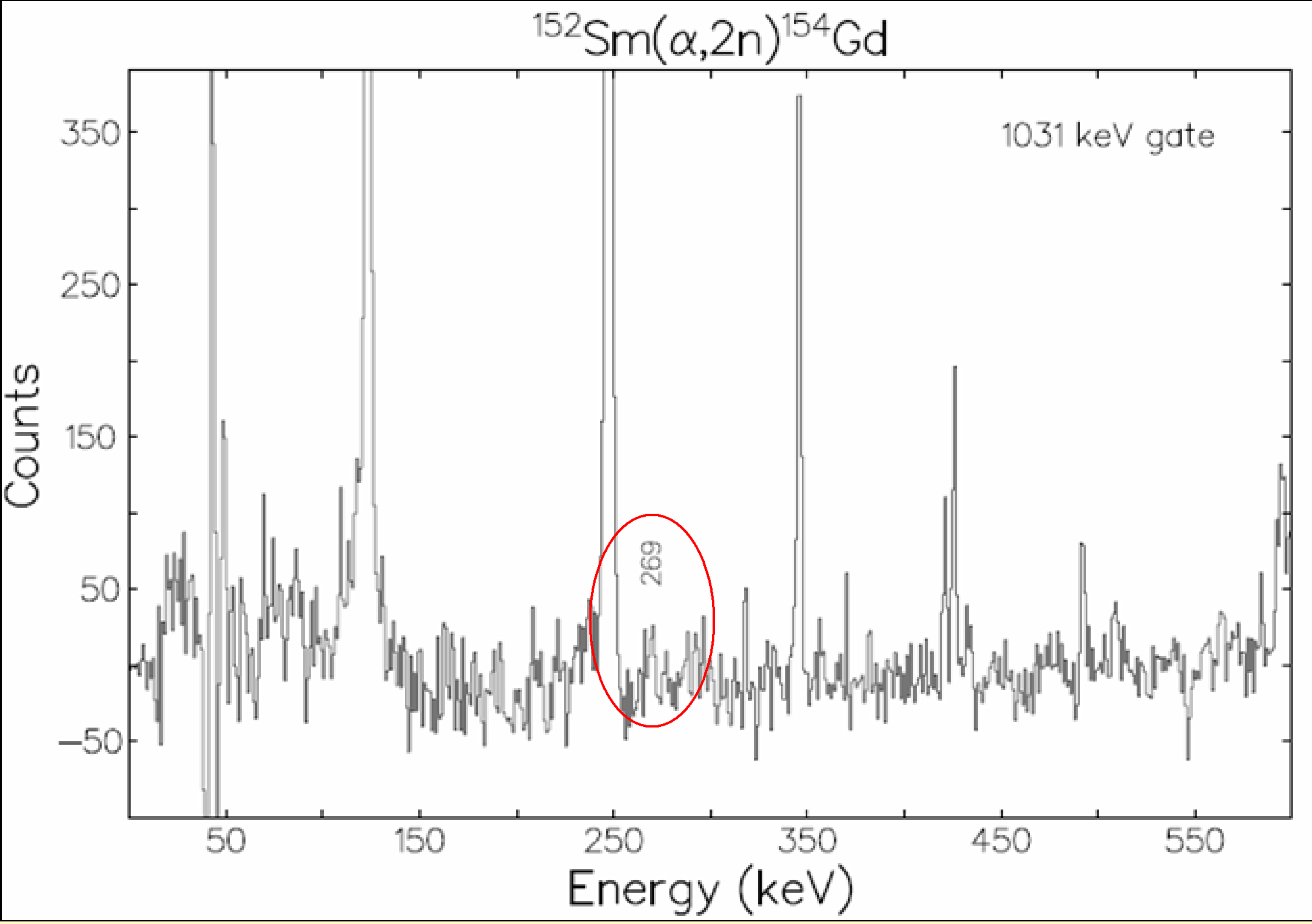
Branching ratios

- Choice in staying in-band or going to yrast
- Observed branching ratio (counts)

$$\lambda = \frac{P_\gamma(\mathrm{E2}, I \rightarrow I-2)}{P_\gamma(\mathrm{E1}, I \rightarrow I-1)} \sim \frac{E_\gamma(\mathrm{E2}, I \rightarrow I-2)^5}{E_\gamma(\mathrm{E1}, I \rightarrow I-1)^3}$$

- Low-energies gammas are suppressed, given preferential other option.



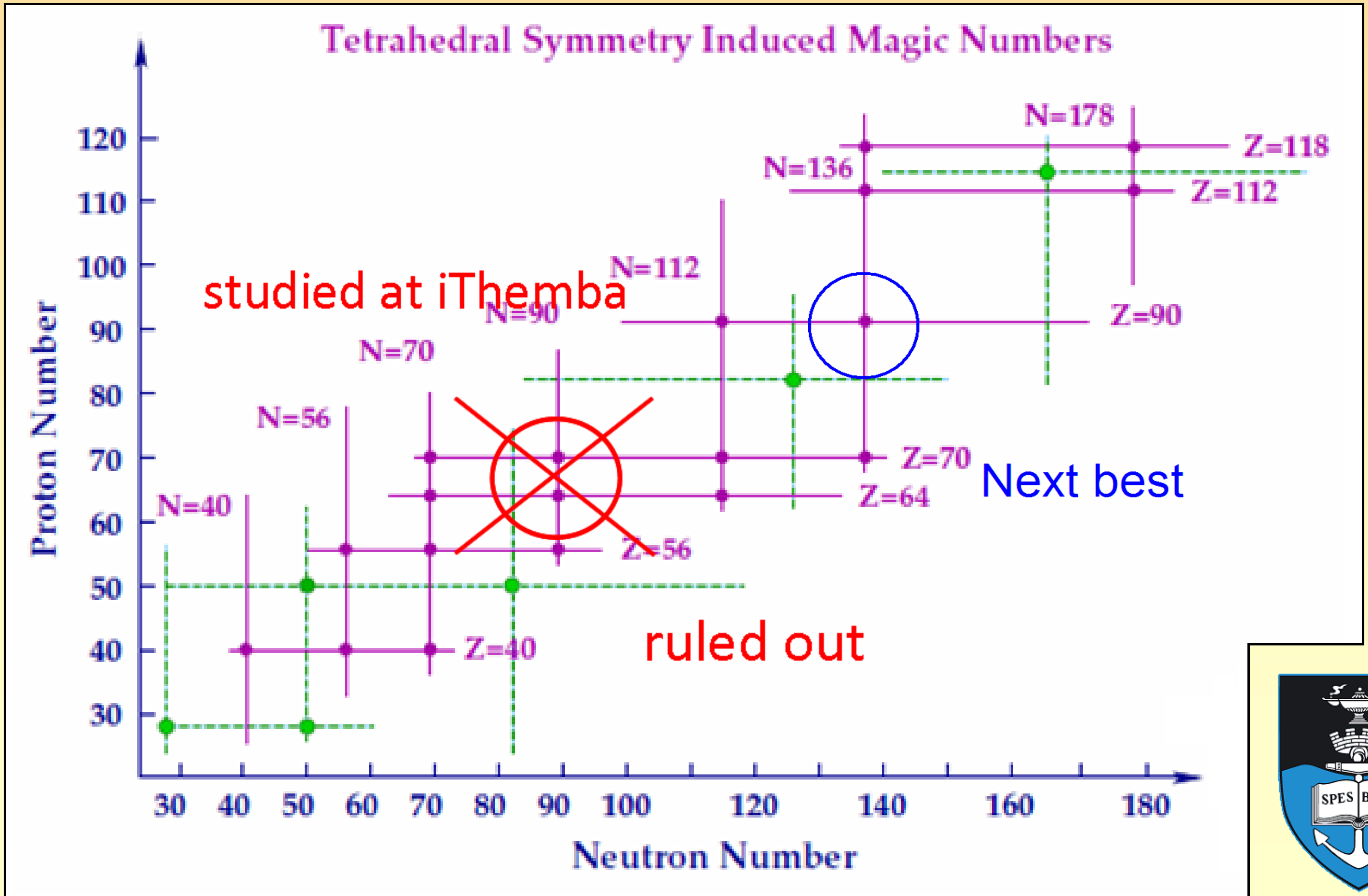
n a

~ 0.08

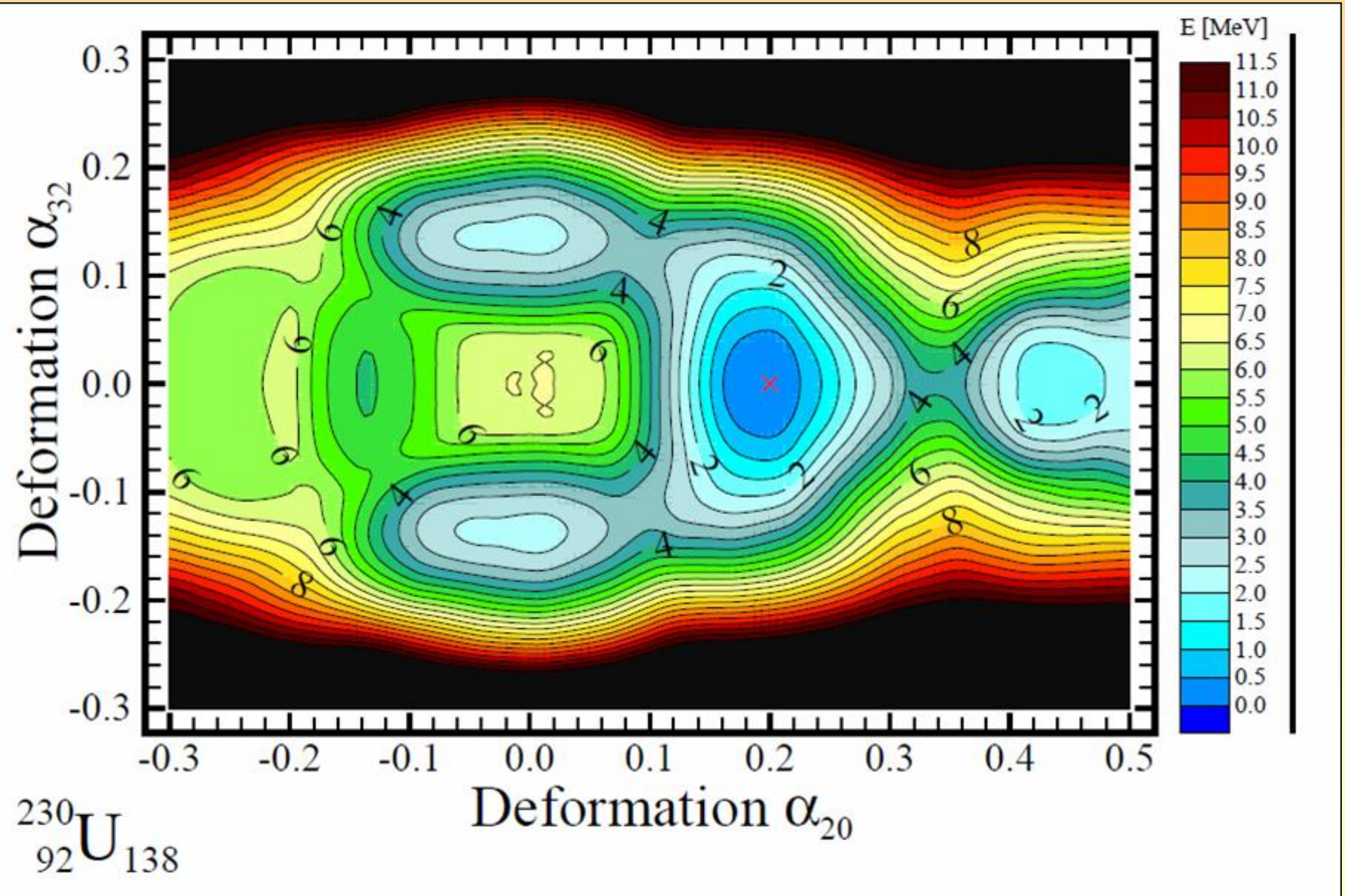
- Do not expect to be able to see it.

Where to next?

- There are other doubly-magic points:



Try look at region Z ~ 90



Lack of in-band E2's

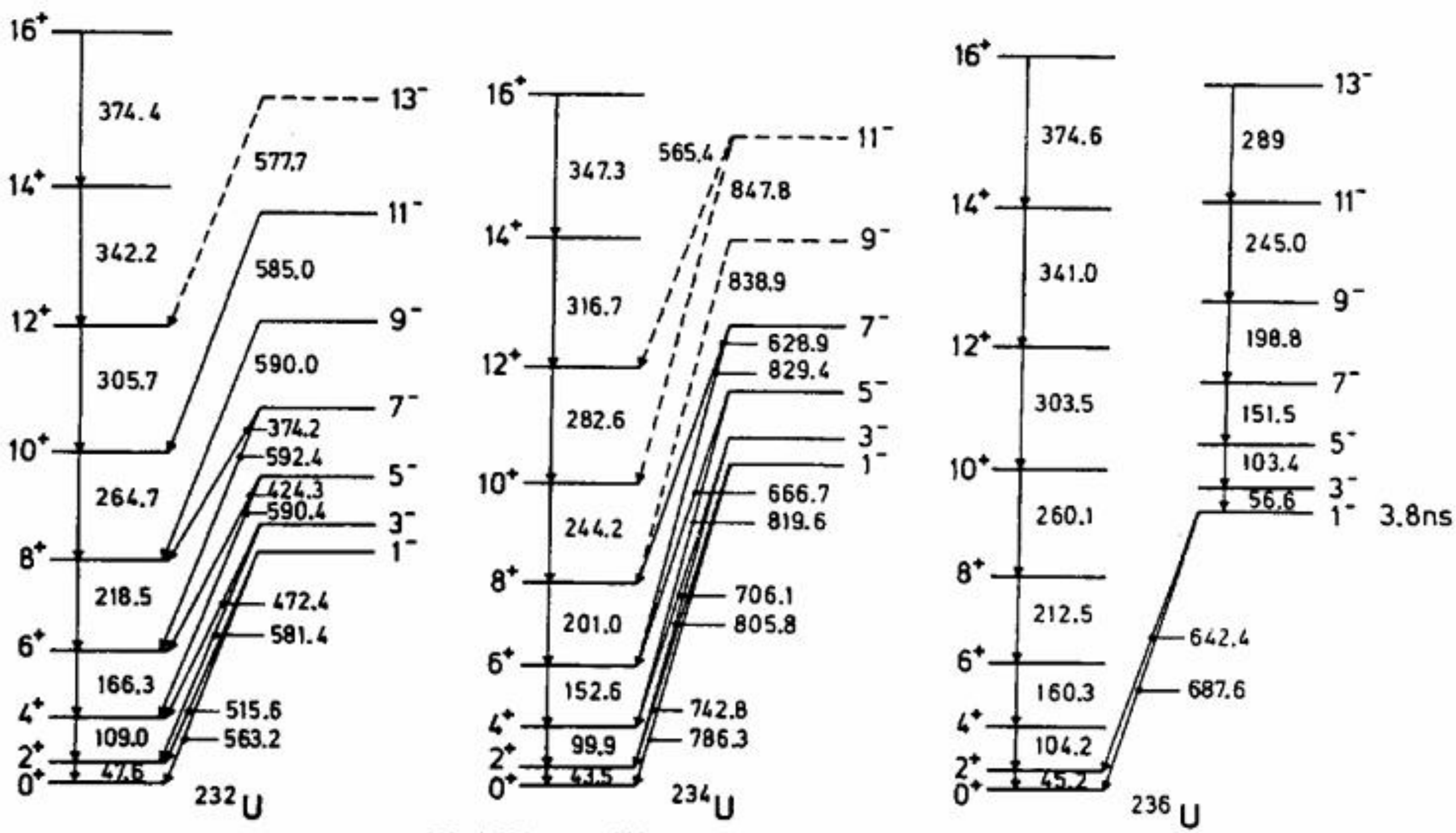
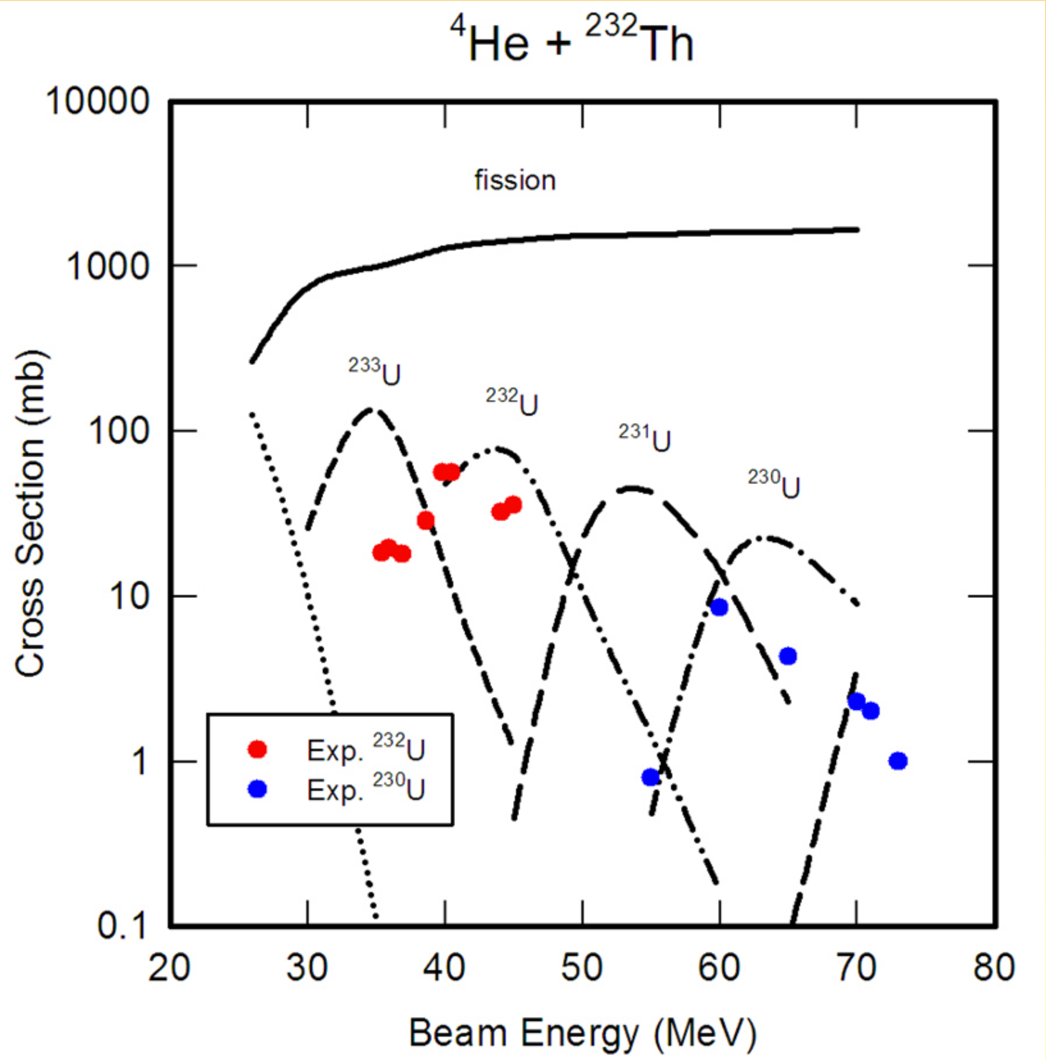


Fig. 9. Level schemes of the isotopes ^{232}U, ^{234}U and ^{236}U

Making U by fusion

$^{232}Th(\alpha,xn)$ reactions

Have very low cross-sections



Recoil detector

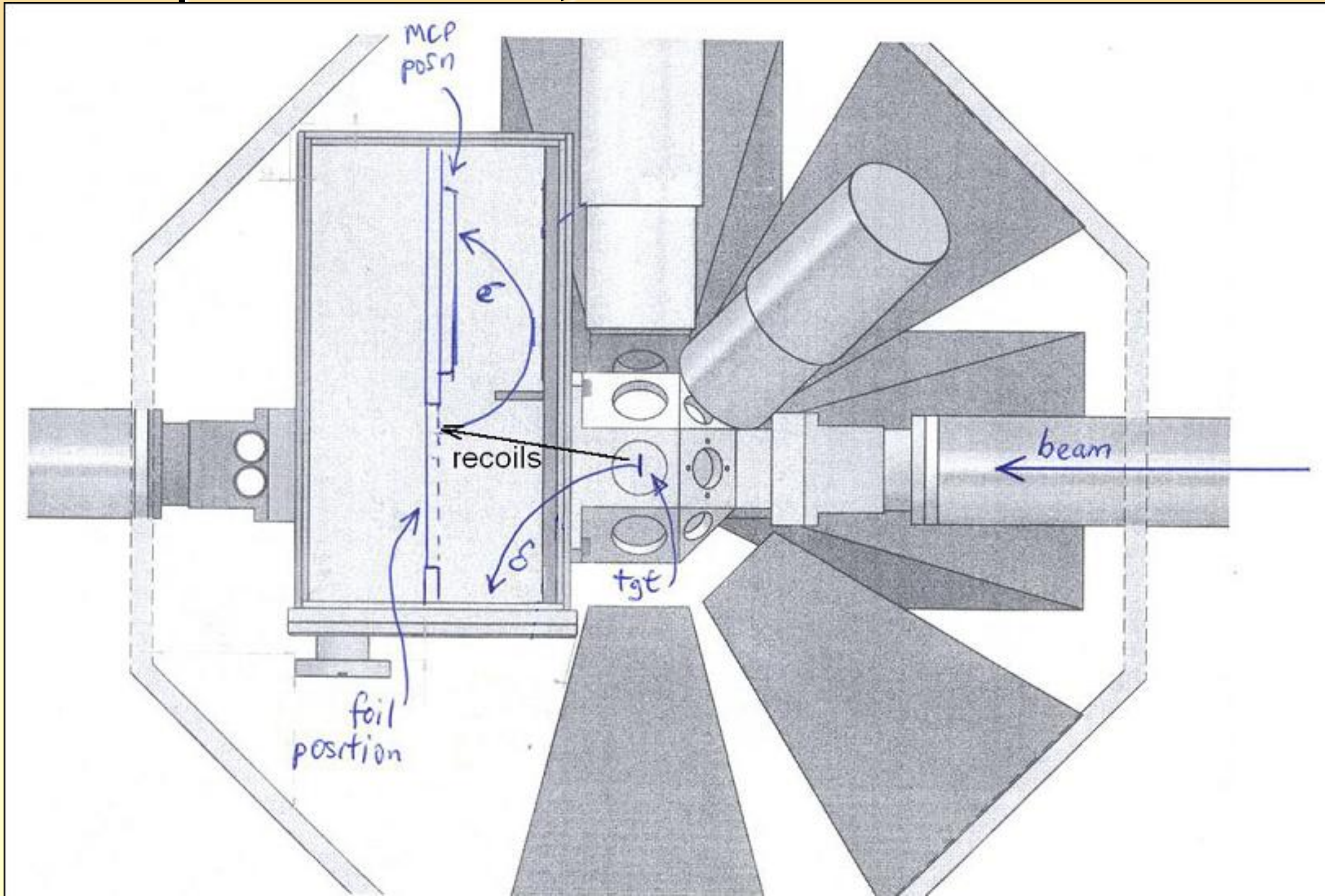
- Work with a pulsed beam, and careful TOF

Beam @

340 ns

Recoils

~150 ns



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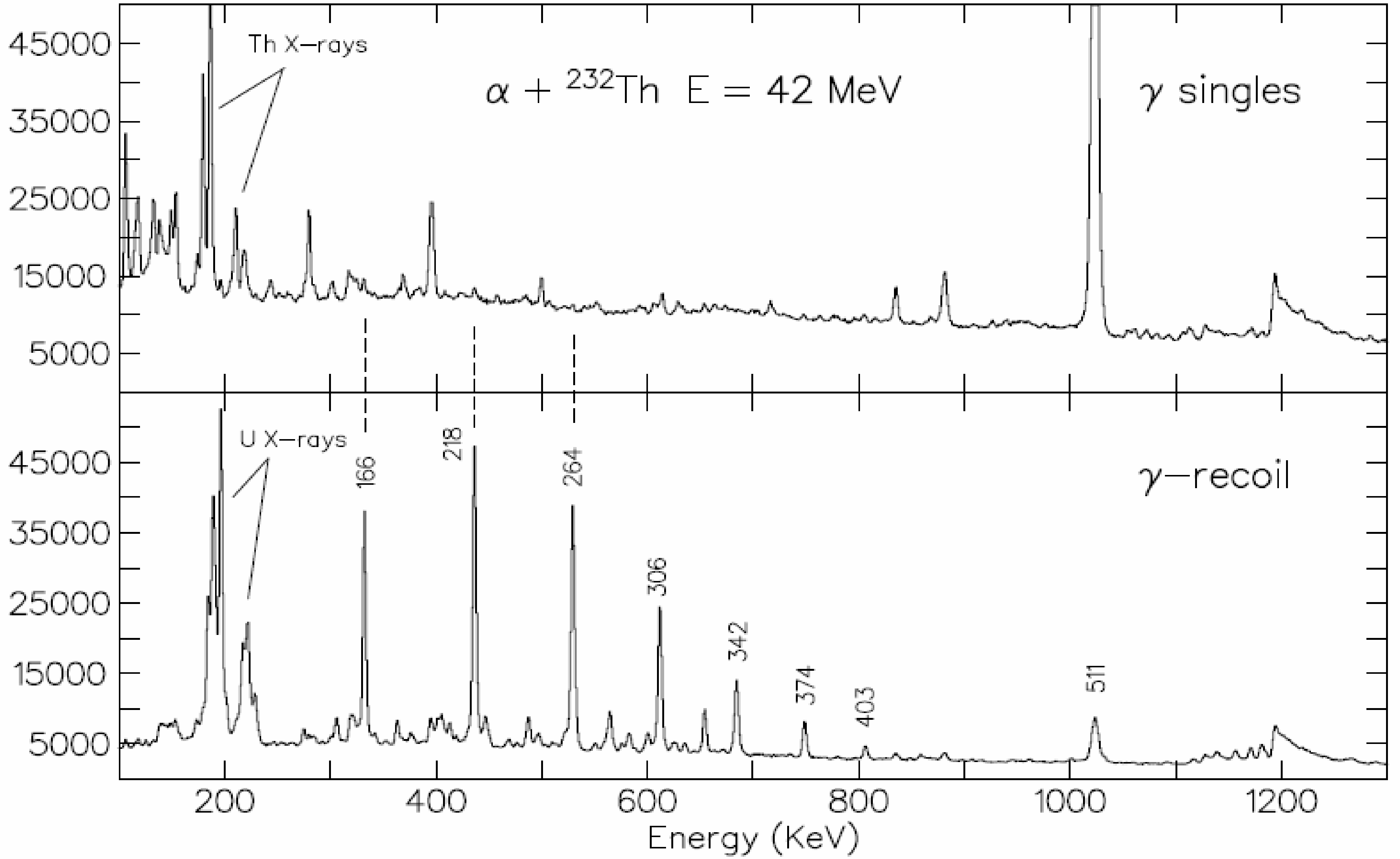
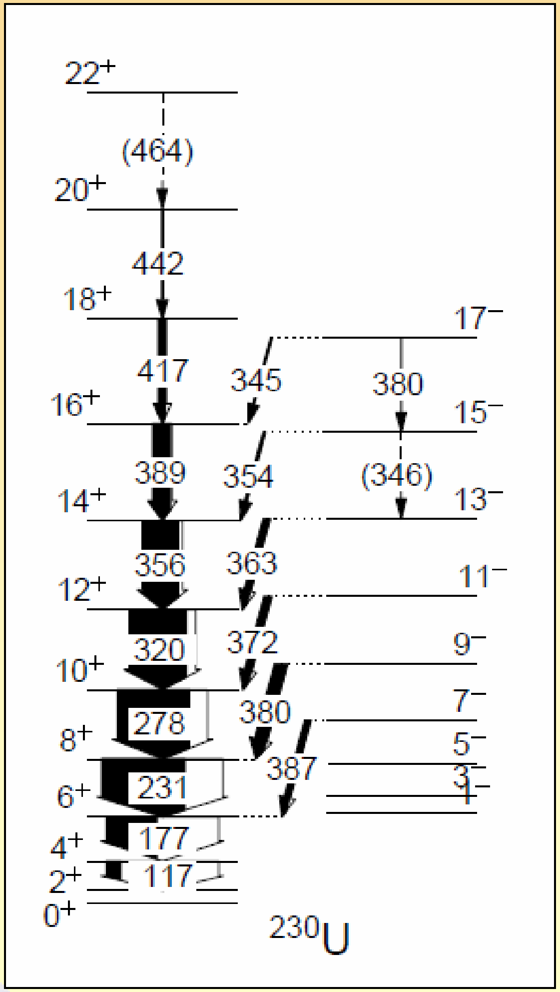
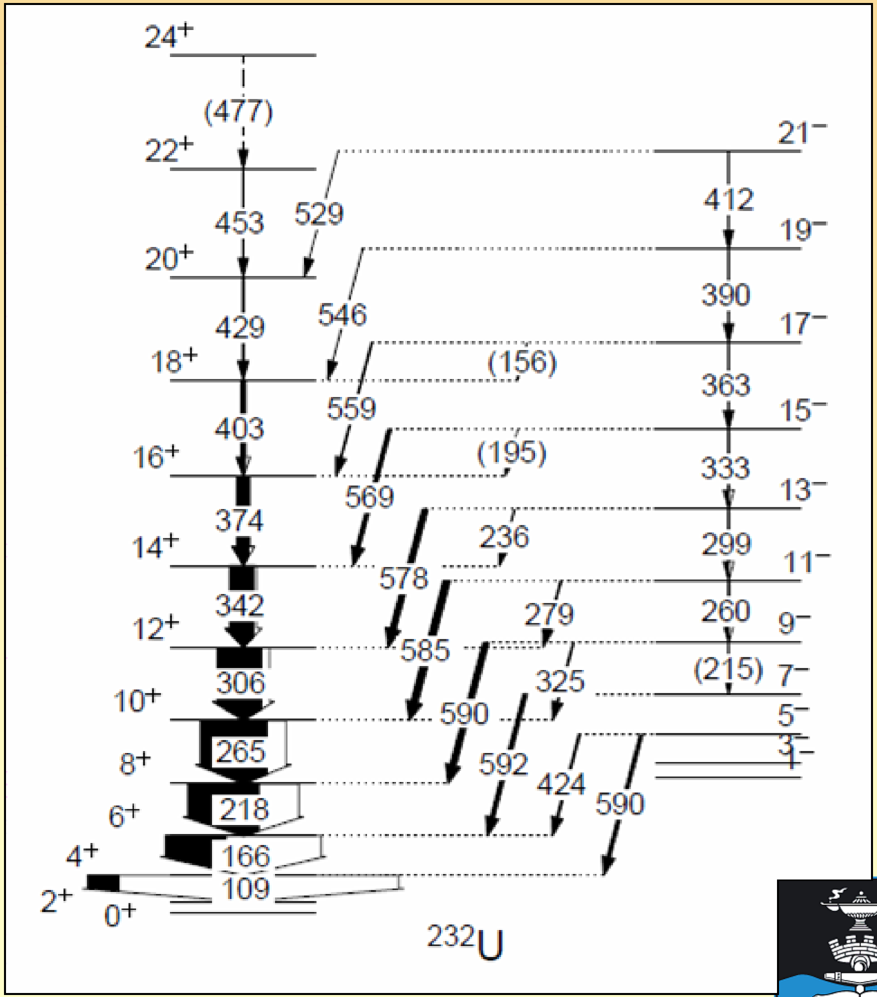
Recoil gate invaluable



Study ^{230}U, ^{232}U with AFRODITE





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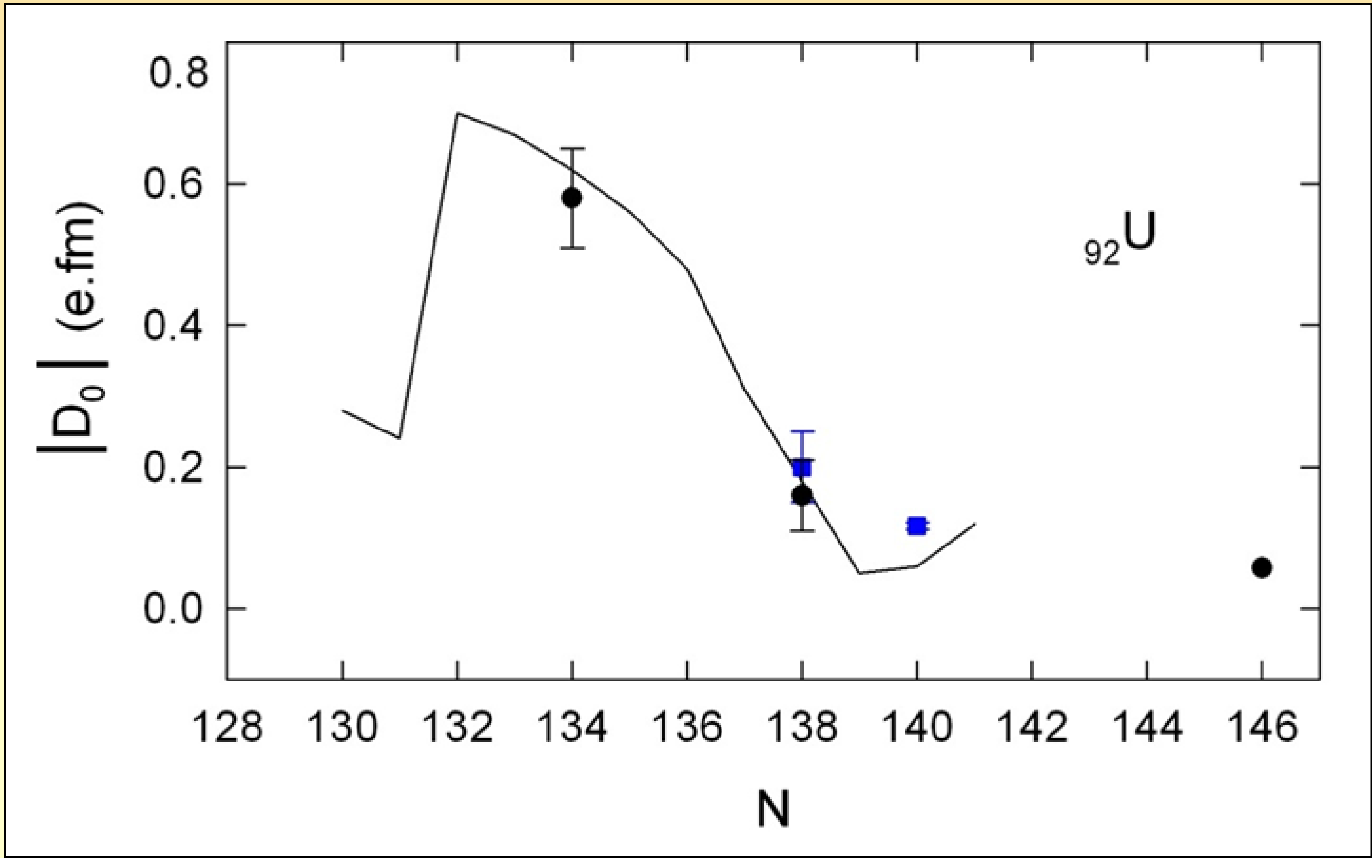
U octupole bands

- ^{232}U there are known in band transitions
- ^{230}U has only a couple weak transitions



- Compare to Skyrme mean-field results

Tsvetkov et al. (2002)

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Summary

- The octupole bands around A~160 have been studied, but do not support the tetrahedral idea
- The octupole bands in uranium have been studied, a little inconclusive. However, an indirect measurement of the dipole moment fits well with non-tetrahedral models.

No evidence found

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Way forward

- The iThemba LABS have array of tools for observing nuclear reactions
- Positive results for theory are best
- Octupole bands not tetrahedral
  - Still need to be understood
  - What is best way forward?
  - Currently working on RPA

References

- Dudek et al., Phys. Rev. Lett. 88, 252502 (2002)
- Dudek et al., Phys. Rev. Lett. 97, 072501(2006)
- Schunck et al., Phys. Rev. C69, 061305 (2004)
- Bark et al., Phys. Rev. Lett., 104, 022501 (2010)
- Ntshangase et al., to be published
- Tsvetkov et al., J. Phys. G28, 2187 (2002)

- Thanks to Rob Bark for use of his presentations at Nuclear Structure 2009 and 2010.

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The End

(No frogs were harmed in these experiments)

To the best of my knowledge