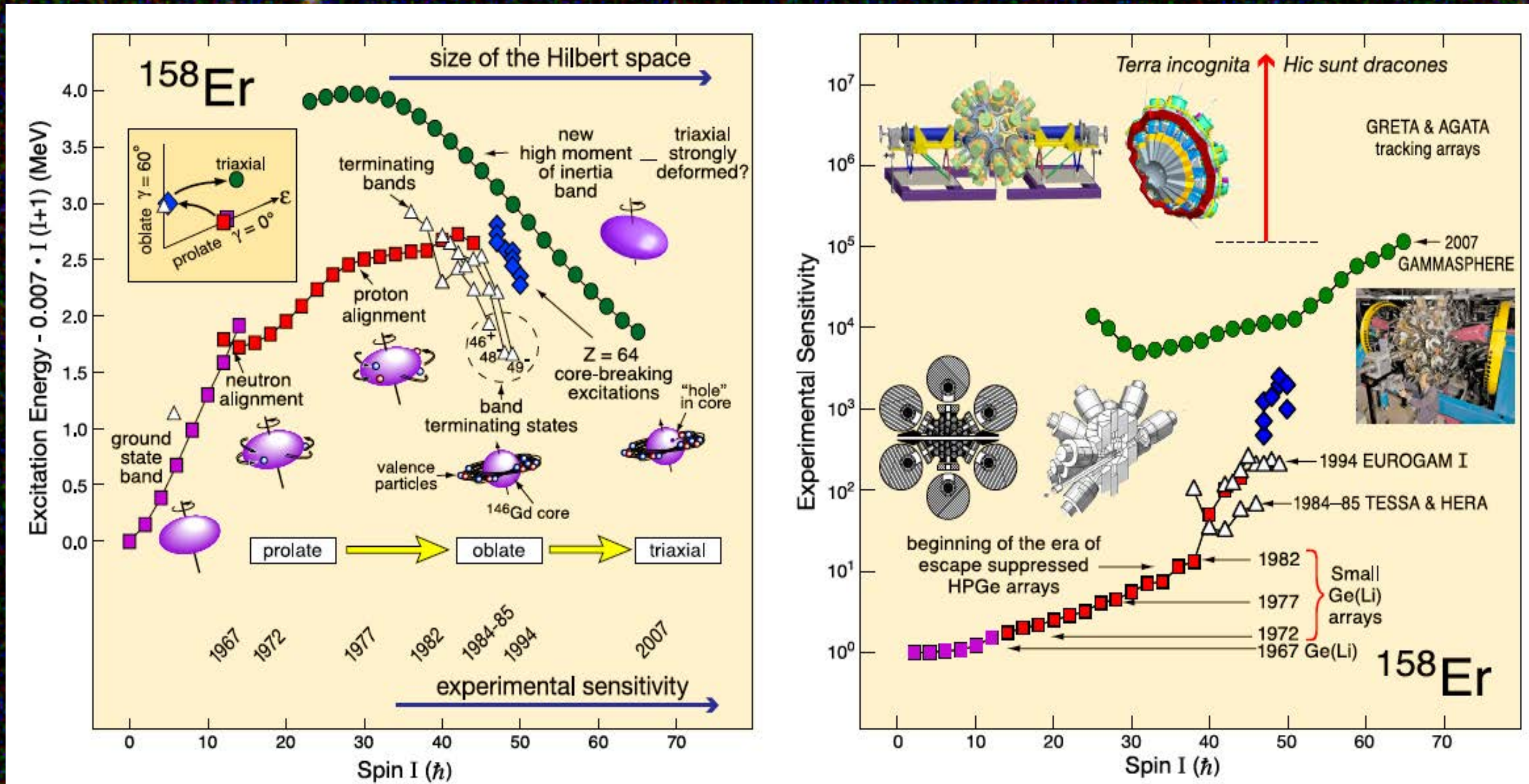
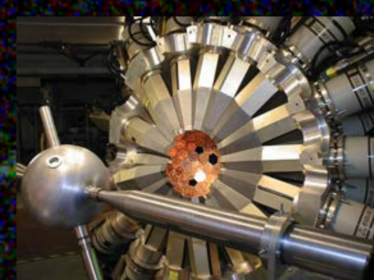
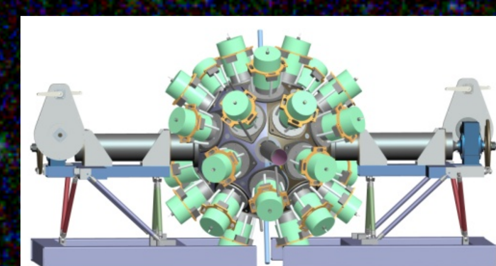


The evolution of shapes and collectivity with increasing angular momentum.

Mark A. Riley - Florida State University (+ LOTS OF FRIENDS!)

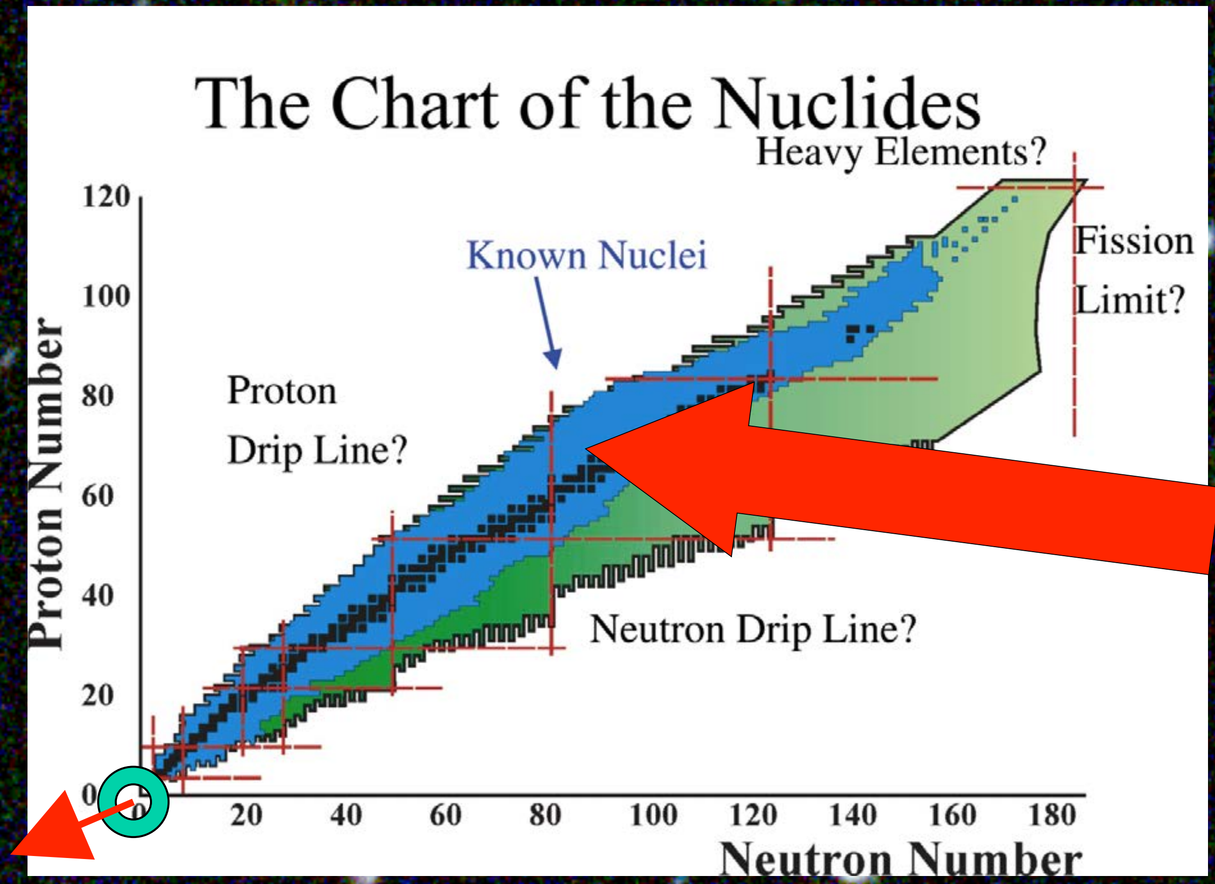




Video of Jerzy Dudek from 1989…. Classic stuff!

NUCLEI AT THE EXTREMES:

Pushing to the limits in N and Z is always good but looking at excited states in nuclei is important too, e.g. it allows us to EXTRAPOLATE how things will change further out.



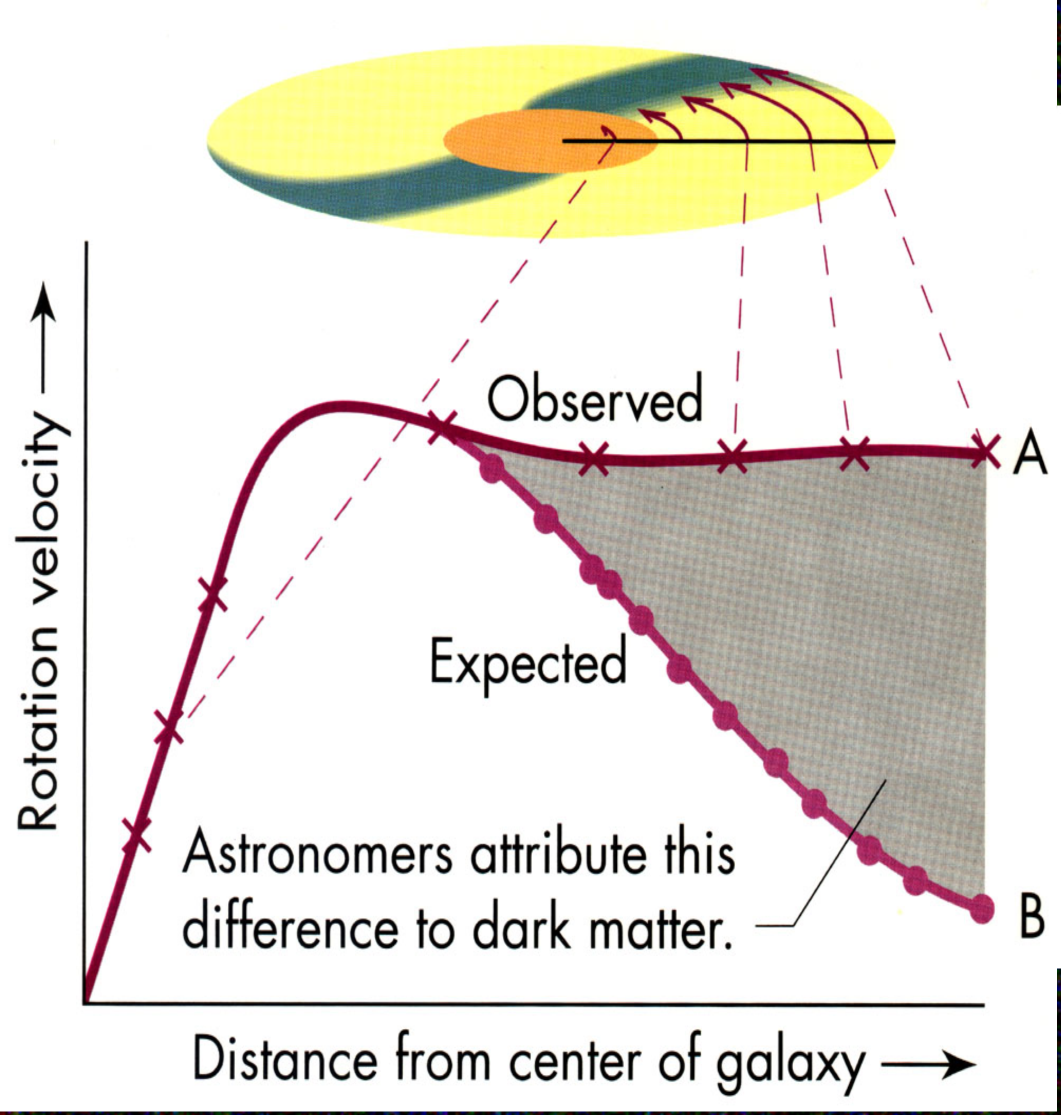
Increasing Angular Momentum and Excitation Energy:

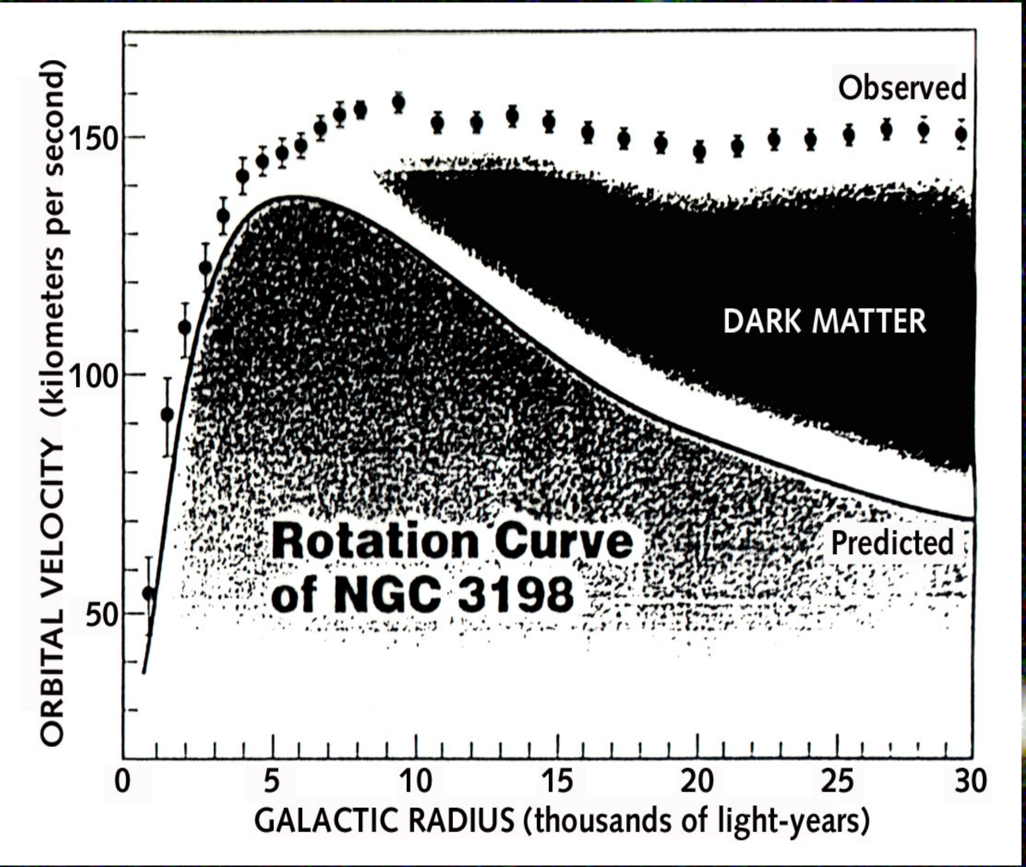
Excellent way to investigate nuclear structure. Remember these studies are ultra-sensitive to what the intruder shells are doing!

It is fun to look at rotating objects!

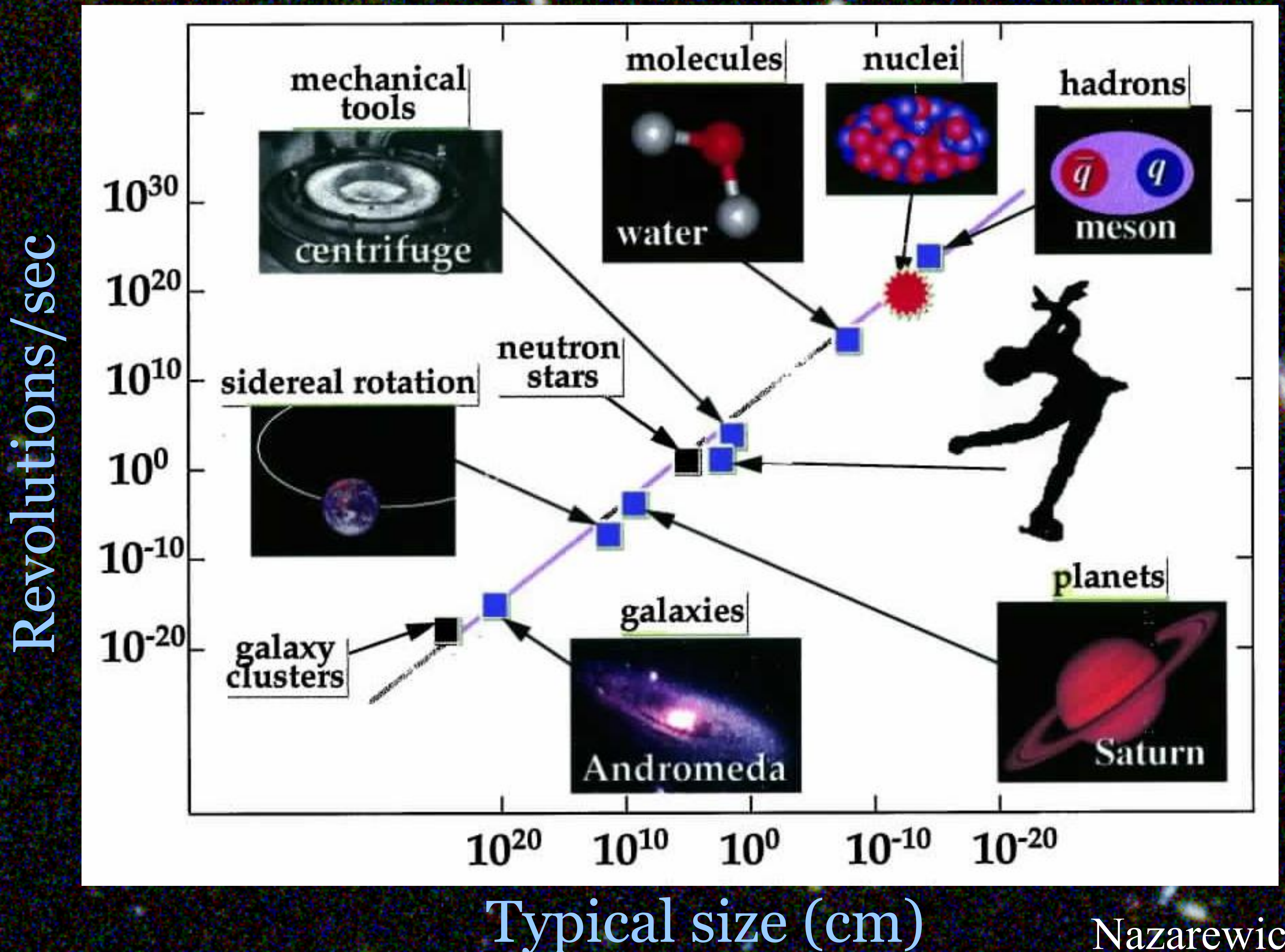
Large Rotating Body

Dark Matter in a Spiral Galaxy





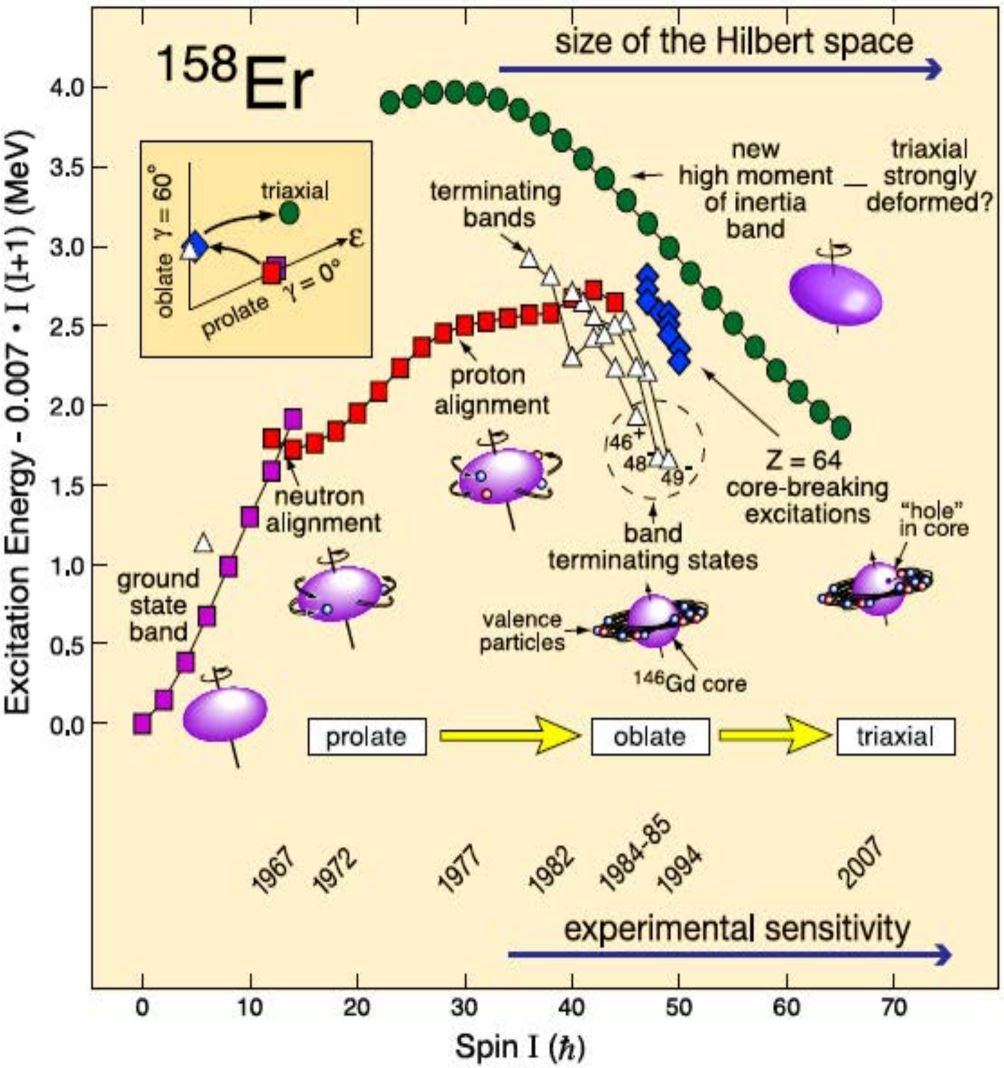
Rotations in the Universe

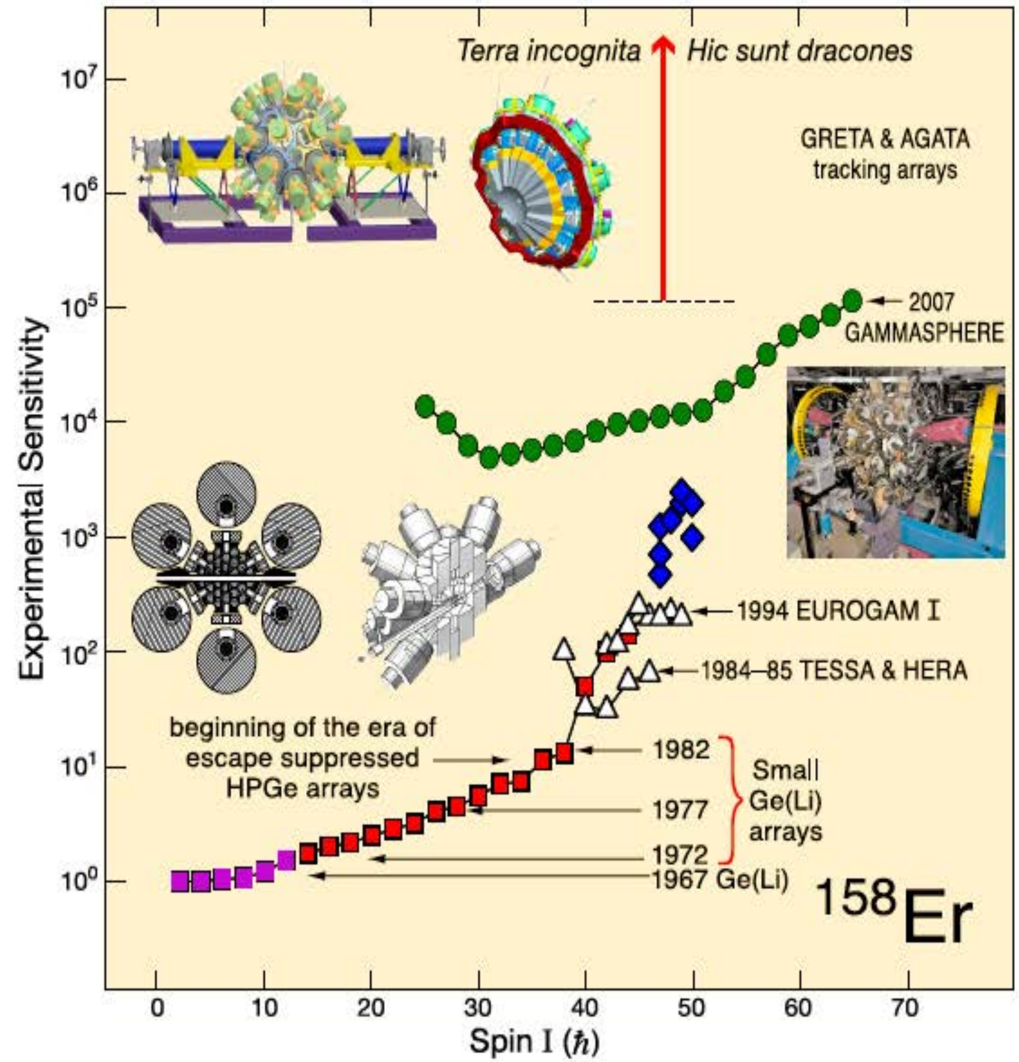


Nazarewicz

Evolution of Gamma-Ray Spectroscopy

New Detector Systems ⟺ New Physics





High-spin Study of ^{161}Lu: The Crossroads Between Lower Spin TSD Wobbling and Ultrahigh-Spin TSD Bands?

D.J. Hartley,[1] M.A. Riley,[2] J. Simpson,[3] E. S. Paul,[4] R. V. F. Janssens,[5] L.L. Riedinger,[6] A. D. Ayangeakaa,[5] J. Baron,[2] M. Benner,[1] A. Boston,[4], H. Boston,[4] M.P. Carpenter, [5] C.J. Chiara,[5,7] U. Garg,[8] S. Hallgren,[1] J. Harker,5,7 F.G. Kondev,[9] T. Lauritsen,[5] W.C. Ma,[10] P. Mason,[3] J. Matta,[8] S. Miller,[2] P. Nolan,[4] J.R. Vanhoy[1], K. Villafana,[2] X. Wang,[11] J. Wright,[4] and S. Zhu[5]

73	^{162}Ta	^{163}Ta	^{164}Ta	^{165}Ta	^{166}Ta	^{167}Ta	^{168}Ta	^{169}Ta
72	^{161}Hf	^{162}Hf	^{163}Hf	^{164}Hf	^{165}Hf	^{166}Hf	^{167}Hf	^{168}Hf
71	^{160}Lu	^{161}Lu ?	^{162}Lu	^{163}Lu	^{164}Lu	^{165}Lu	^{166}Lu	^{167}Lu
70	^{159}Yb	^{160}Yb	^{161}Yb	^{162}Yb	^{163}Yb	^{164}Yb	^{165}Yb	^{166}Yb
69	^{158}Tm	^{159}Tm	^{160}Tm	^{161}Tm	^{162}Tm	^{163}Tm	^{164}Tm	^{165}Tm
68	^{157}Er	^{158}Er	^{159}Er	^{160}Er	^{161}Er	^{162}Er	^{163}Er	^{164}Er
67	^{156}Ho	^{157}Ho	^{158}Ho	^{159}Ho	^{160}Ho	^{161}Ho	^{162}Ho	^{163}Ho
Z / N	89	90	91	92	93	94	95	96

Ultra high-spin TSD   Wobbling   TSD

High-spin Study of ^{161}Lu: The Crossroads Between Lower Spin TSD Wobbling and Ultrahigh-Spin TSD Bands?

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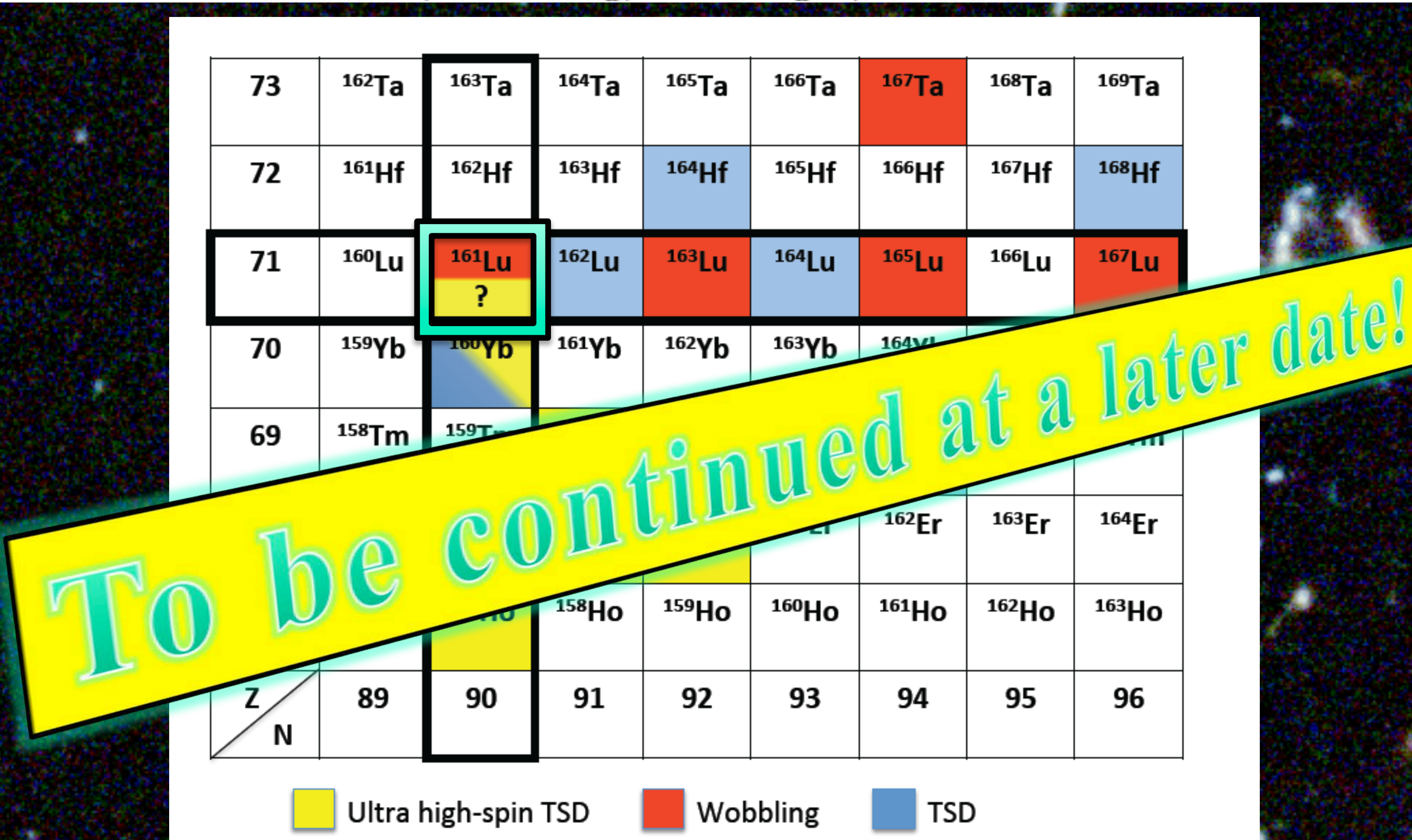


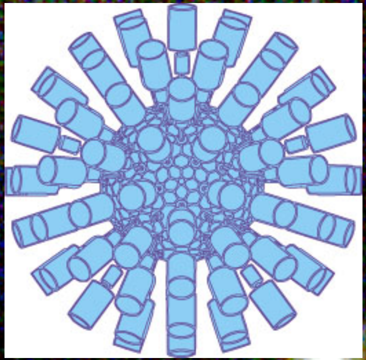
Orbital Dynamics of Triaxial Nuclei

Triaxial Black-Hole Galactic Nuclei: M. Y. Poon & D. Merritt

Department of Physics and Astronomy, Rutgers University, New Brunswick, NJ 08855

Astrophysical Journal, Vol. 549, Number 1, Part 1, Page 192

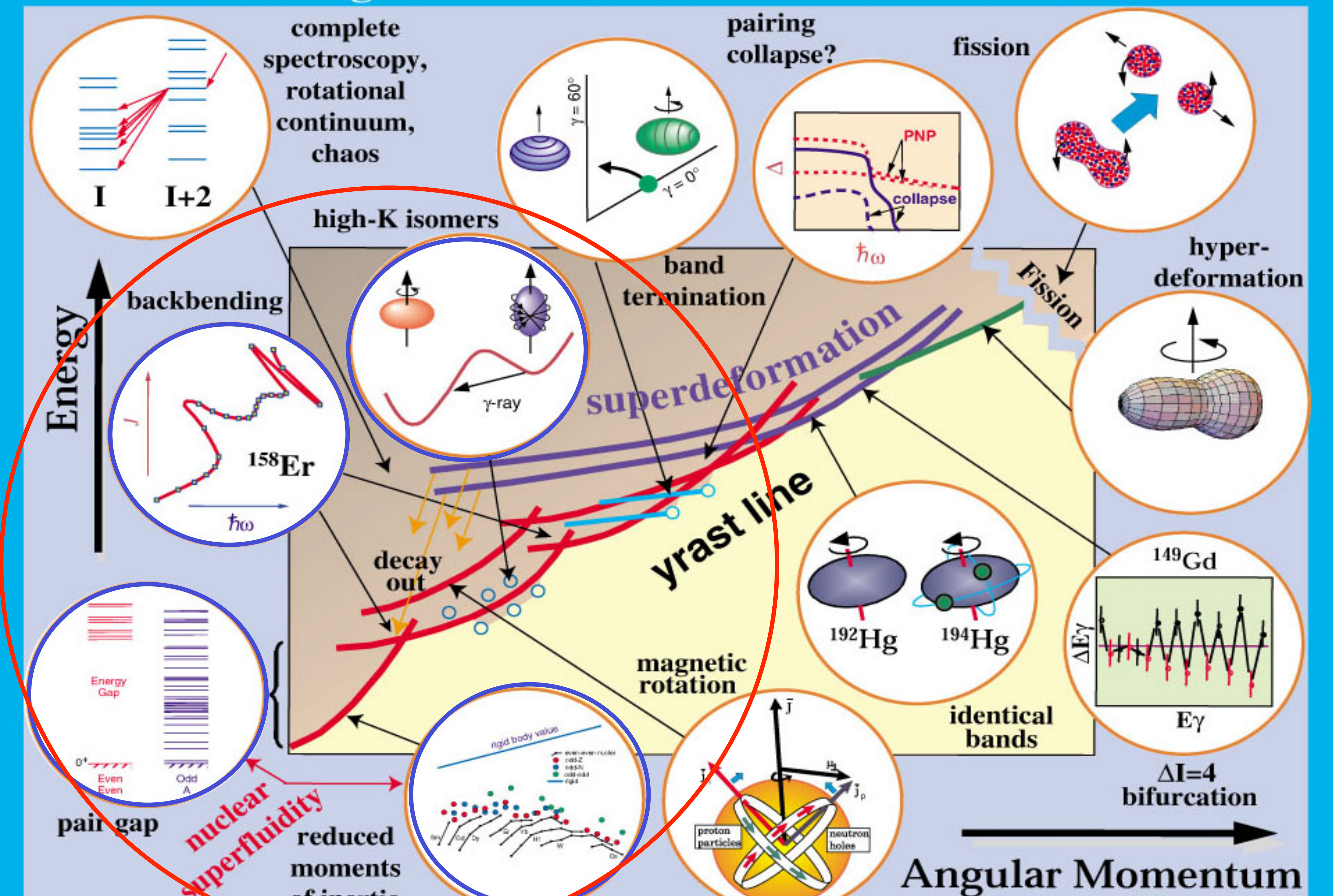
"We construct models of triaxial galactic nuclei containing central black holes using the method of orbital superposition, …. We consider three triaxial shapes : almost prolate, almost oblate and maximally triaxial. …… low angular momentum orbits. ….."



Outline of Talk

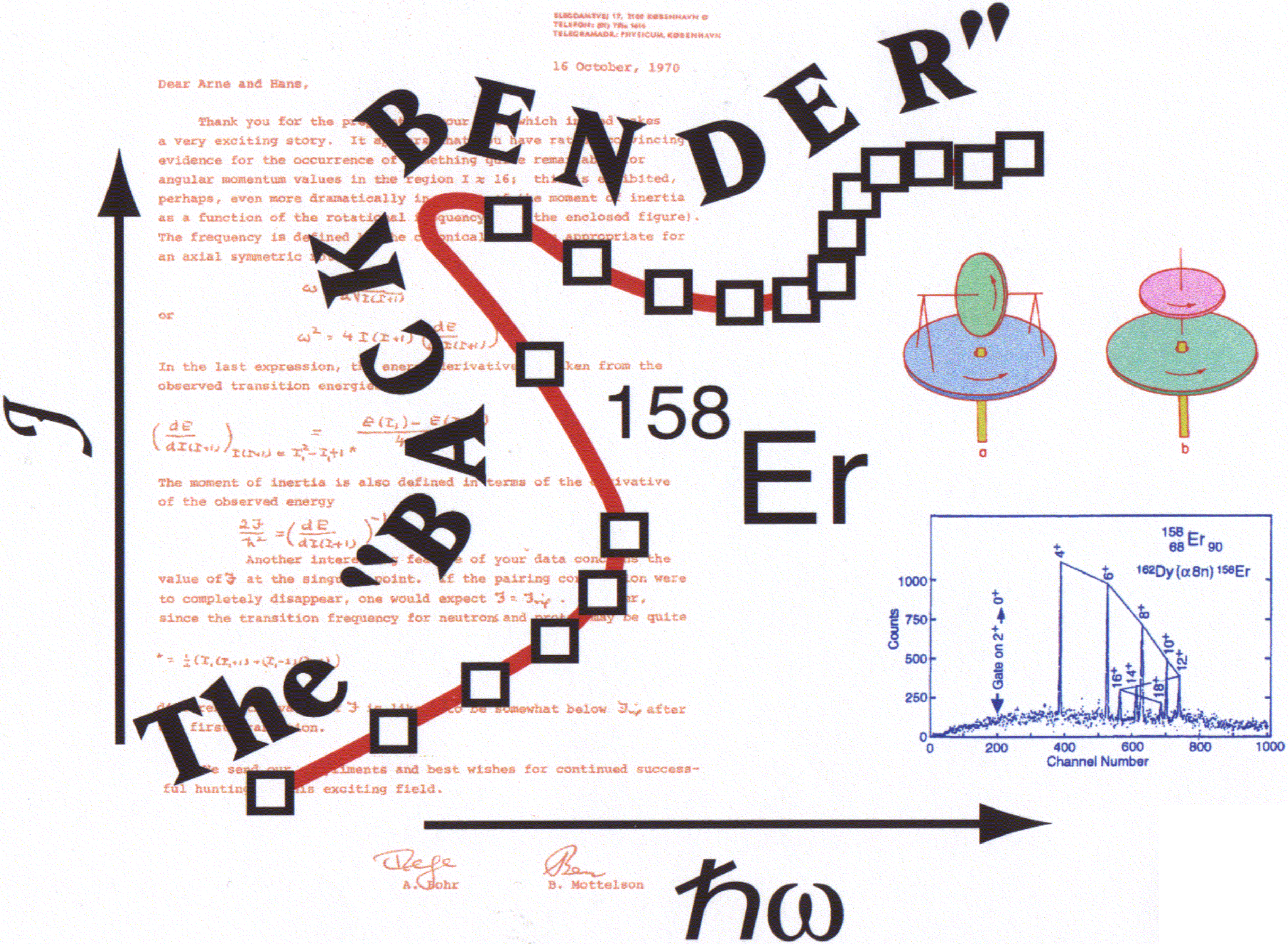
- Search for Wobbling modes in A~170 Re and W nuclei.
- Expts using Gammasphere at ANL.
- Detailed Spectroscopic Study $^{168,169,170,171}W$.
- Backbending in nuclei. A shameful advertisement. Many people in the room have participated in this great adventure!
- Good for students to know some history. ☺
- Systematic Examination of Band Crossing Frequencies in the A≈170 Region. Continuing on from where Jerry Garrett left off.
- The effect of seniority on pairing correlations from band crossing frequencies and comparisons to moment-of-inertia results from high-seniority high-K isomer studies.

The Angular Momentum World of the Nucleus

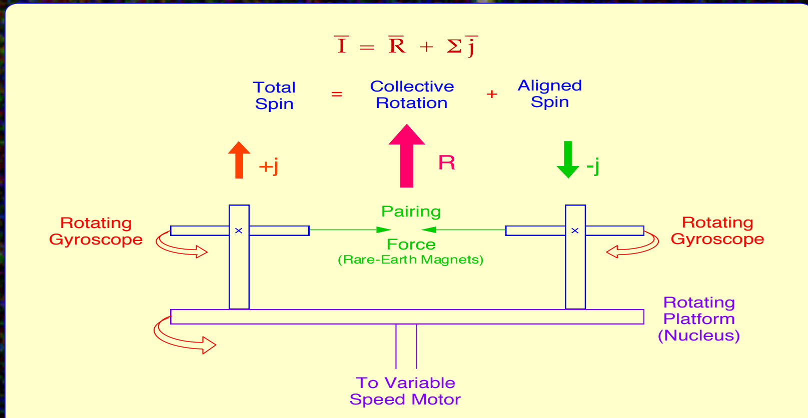


Riley, Simpson & Paul, Phys.Scripta, in press

http://www.physics.fsu.edu/TheBackBender



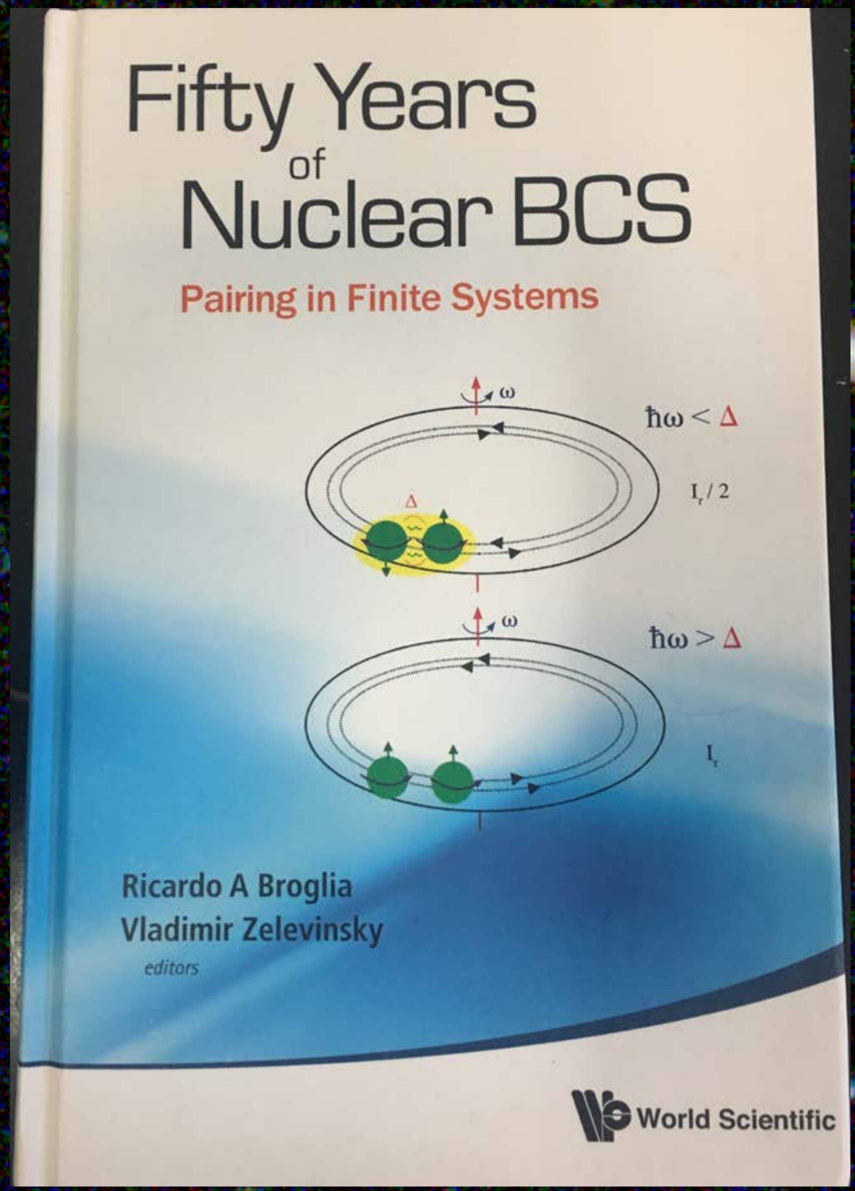
The "BACKBENDER"
158
Er
ℏω
16 October, 1970
Dear Arne and Hans,
A. Bohr
B. Mottelson
158 68 Er 90
162Dy(α8n)158Er
Counts
Channel Number
Gate on 2+ → 0+
4+
6+
8+
10+
12+
14+
16+
18+
a
b



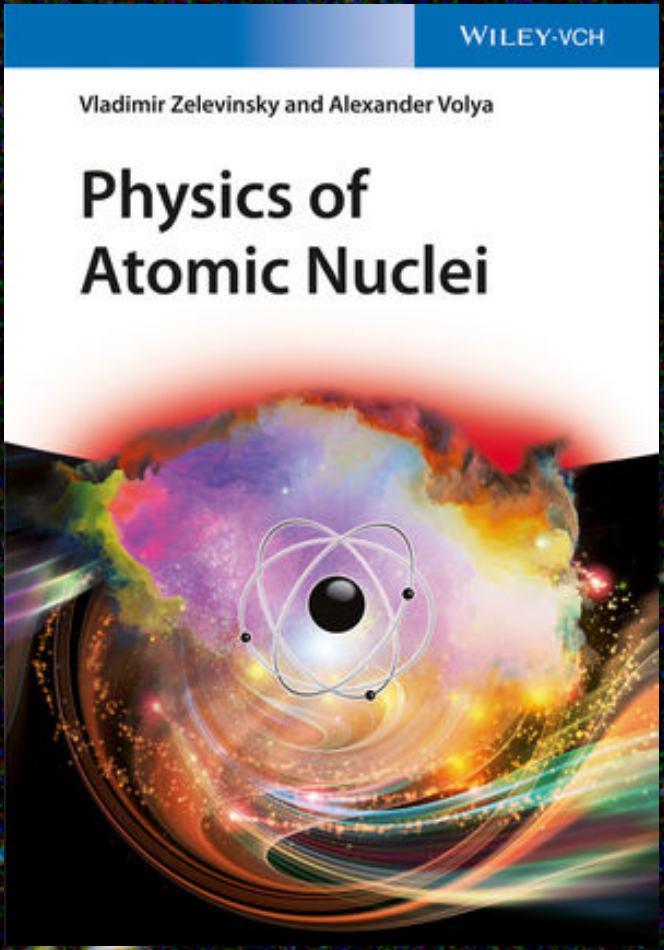
"Backbending" Demonstration Schematic

Bob Schrieffer and yours truly plus "The Backbender"!

Backbending on the cover!



New book out Feb 2017!

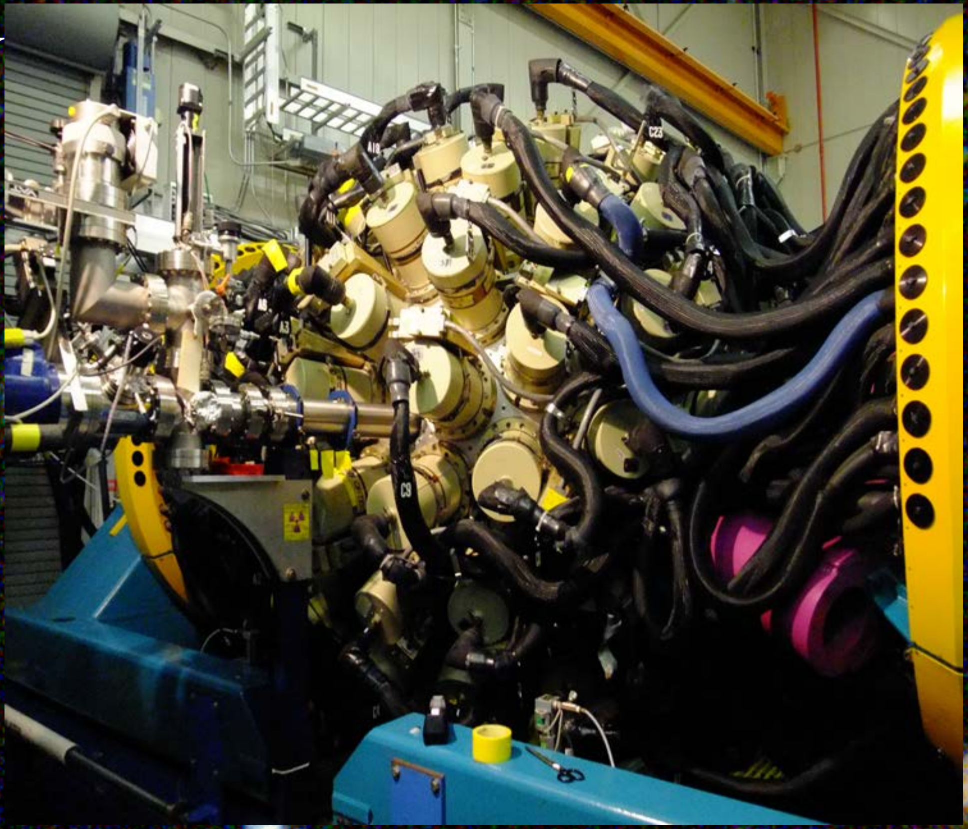


http://www.wiley.com/WileyCDA/WileyTitle/productCd-3527413502.html

Table of Contents

GSFMA247 (Experiment 1)

- ^{55}Mn + ^{118}Sn at 260 MeV
- ATLAS accelerator at Argonne National Lab
- 2.3x10^{9} four-fold or higher events, detected using Gammasphere
- Search for wobbling modes in ^{169}Re
- TSD candidates in ^{168,169}W?



GSFMA281 (Expt 2)

- ^{55}Mn + ^{120}Sn at 257 MeV
- ATLAS accelerator at Argonne Nat. Lab
- 2.0x10^{9} three-fold or greater events using Gammasphere
- Search for wobbling modes in ^{171}Re
- TSD candidates in ^{170,171}W?

No evidence for TSD or Wobbling bands? ☹

But what to do with all these bands?

Scott Miller

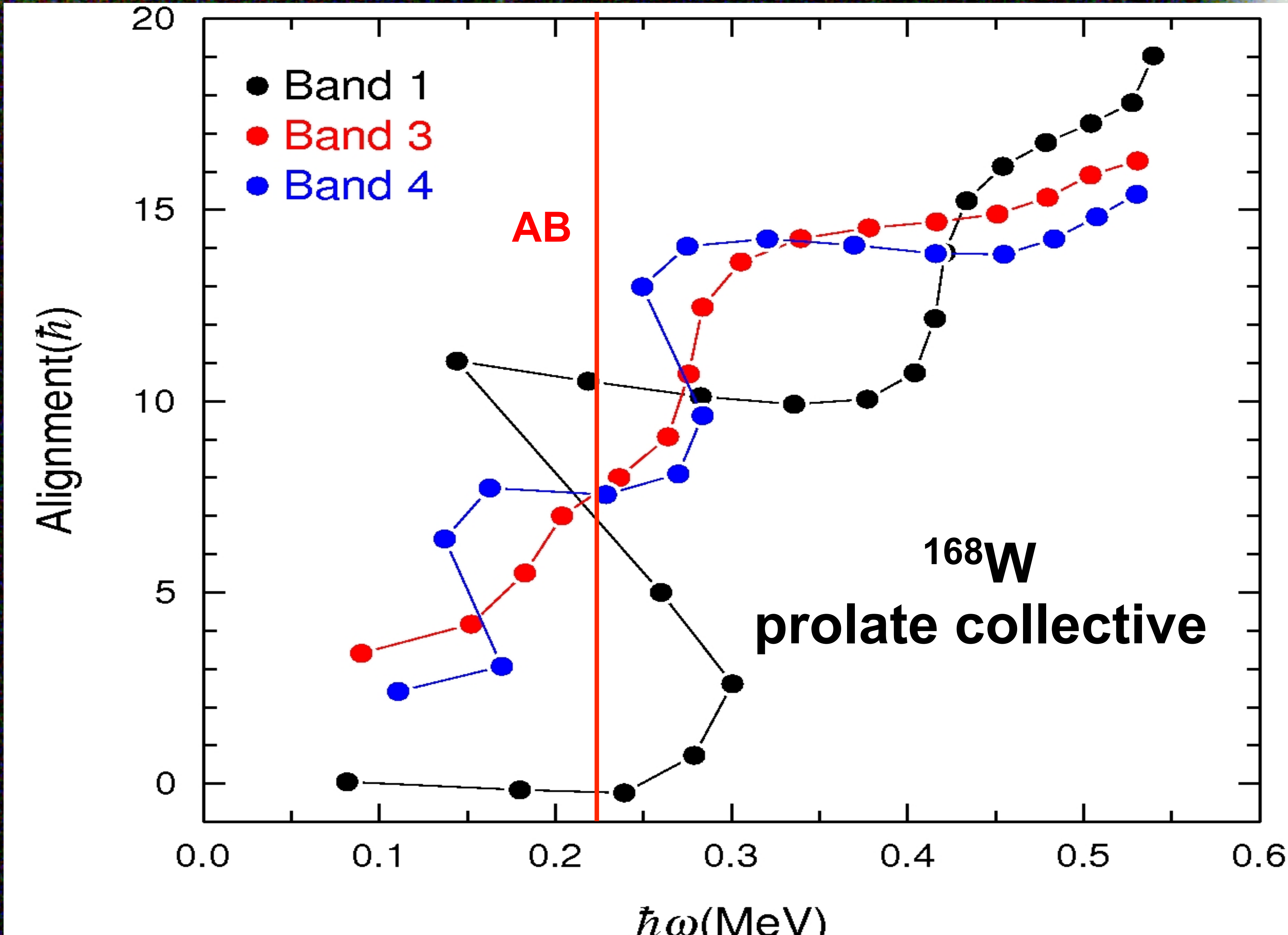
"A pessimist sees the difficulty in every opportunity; an optimist sees the opportunity in every difficulty."

Winston Churchill

What to do with all these bands?

Scott Miller
FSU Grad Student
Did all the work!

Have some fun looking at their backbending properties, e.g. alignments and figure out their configurations etc etc ! ☺

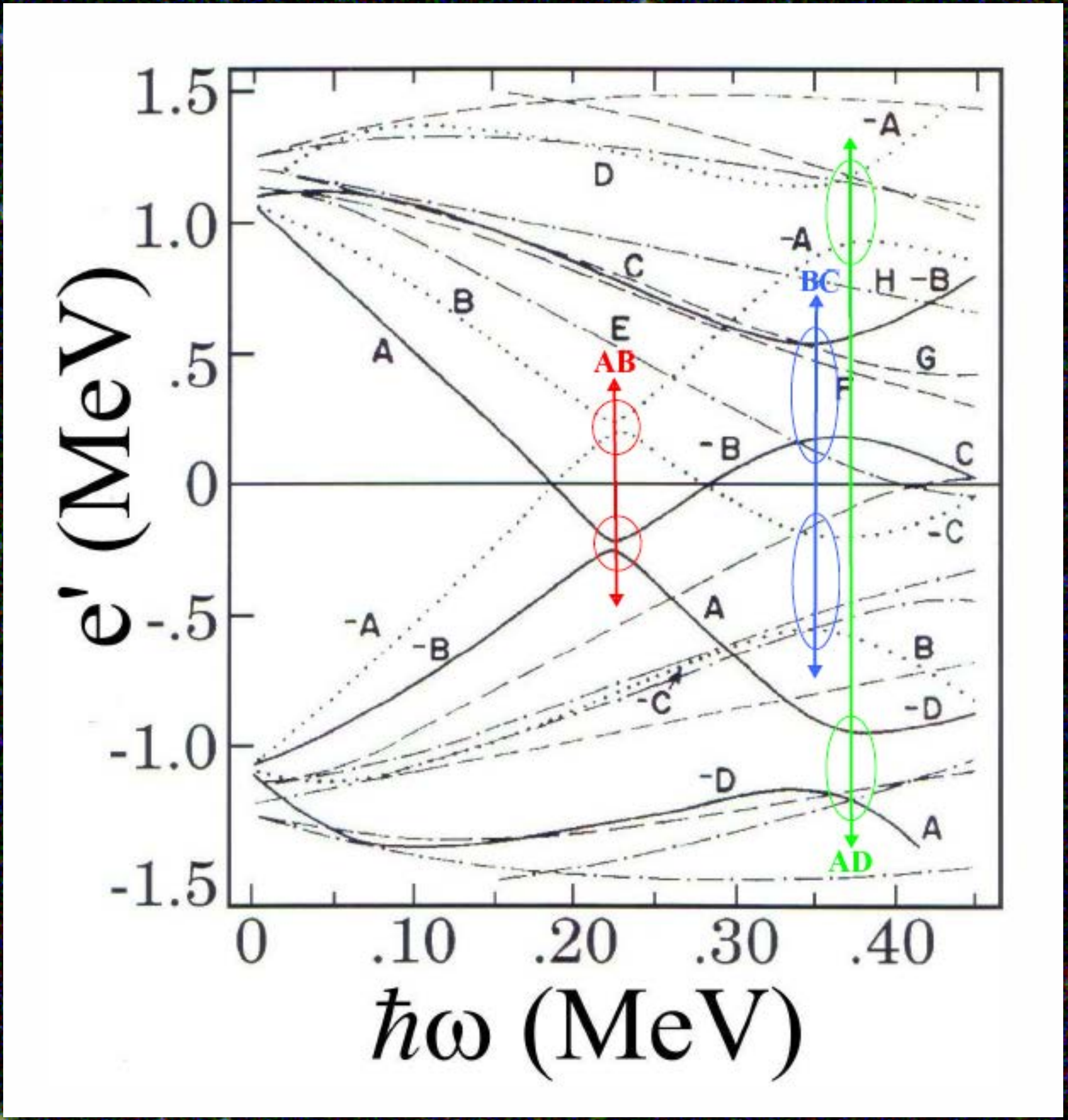

Band 1
Band 3
Band 4
AB
^{168}W
prolate collective
Alignment($\hbar$)
$\hbar\omega$(MeV)
0
5
10
15
20
0.0
0.1
0.2
0.3
0.4
0.5
0.6

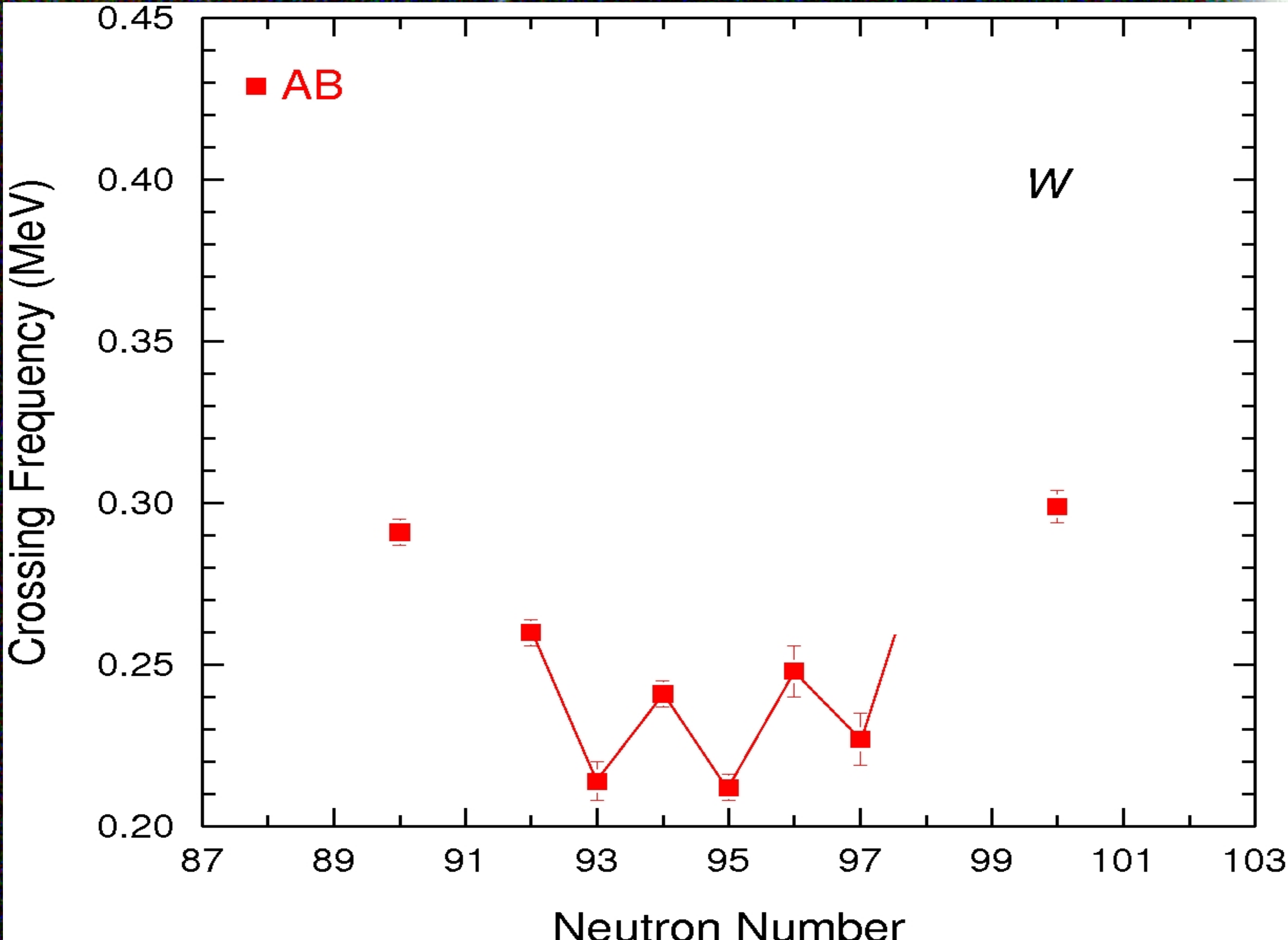
Cranked Shell Model Quasi-particle diagram or Spagetti plot!

See

Bengtsson, Frauendorf, May, At. Data and Nuc. Data Tables Vol 35, 15-122, 1986

And references therein





AB
W
Crossing Frequency (MeV)
0.45
0.40
0.35
0.30
0.25
0.20
87
89
91
93
95
97
99
101
103
Neutron Number

Classic Paper!

VOLUME 47, NUMBER 2 PHYSICAL REVIEW LETTERS 13 JULY 1981

Evidence for Decreased Pairing Energies in Odd-N Nuclei from Band-Crossing Frequencies

J. D. Garrett, O. Andersen, J. J. Gaardhøje, G. B. Hagemann, B. Herskind, J. Kownacki,[a] J. C. Lisle,[b] and L. L. Riedinger[c]
The Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark

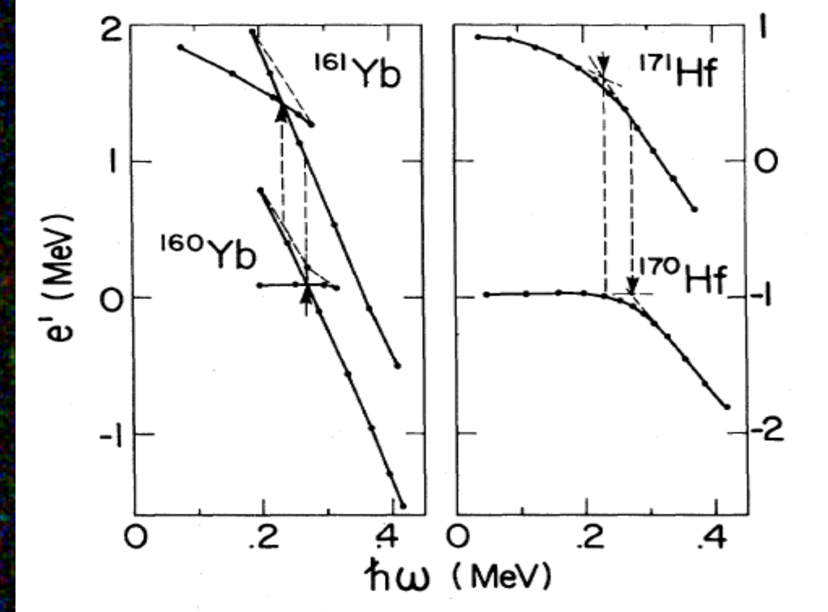
and

W. Walús,[d] N. Roy, S. Jönsson, and H. Ryde
Department of Physics, University of Lund, S-223 Lund, Sweden

and

M. Guttormsen and P. O. Tjøm
Institute of Physics, University of Oslo, N-1000 Oslo, Norway
(Received 23 March 1981)

An odd-even neutron-number dependence of the alignment frequency of the first pair of $i_{13/2}$ quasineutrons in rare-earth nuclei is established. This effect is explained by a reduction of the neutron pairing-correlation parameter Δ_n for odd-N systems as compared to seniority-zero configurations in even-N nuclei.



Garrett et al Phys. Rev. Lett 47:75 (1981)

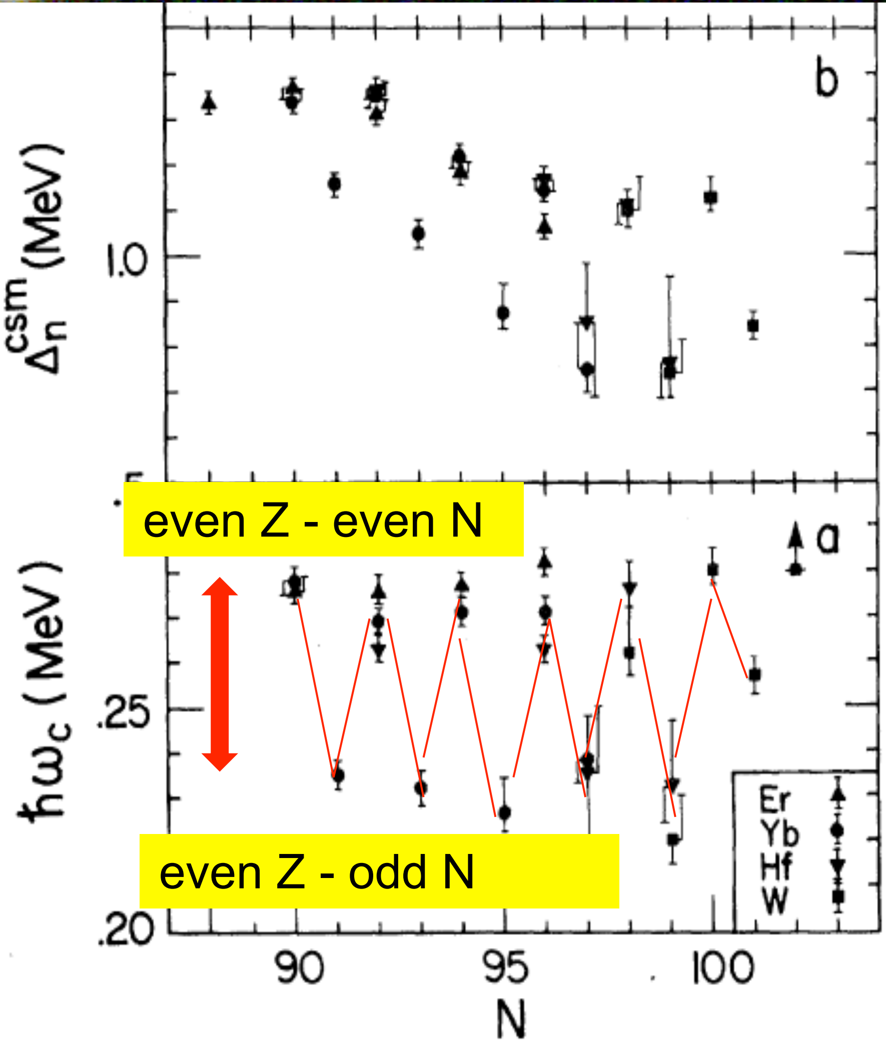


FIG. 2. (a) Systematics of $\hbar\omega_c$ for yrast bands in even-mass nuclei and for the lowest negative-parity band in odd-N nuclei. (b) Values of Δ_n^{CSM} necessary to reproduce the $\hbar\omega_c$'s in CSM calculations. The error

VOLUME 47, NUMBER 2 PHYSICAL REV

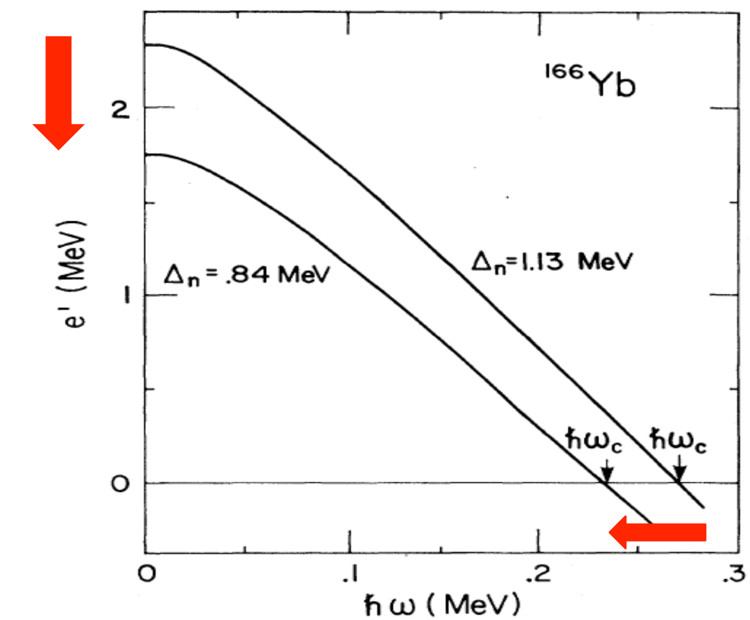
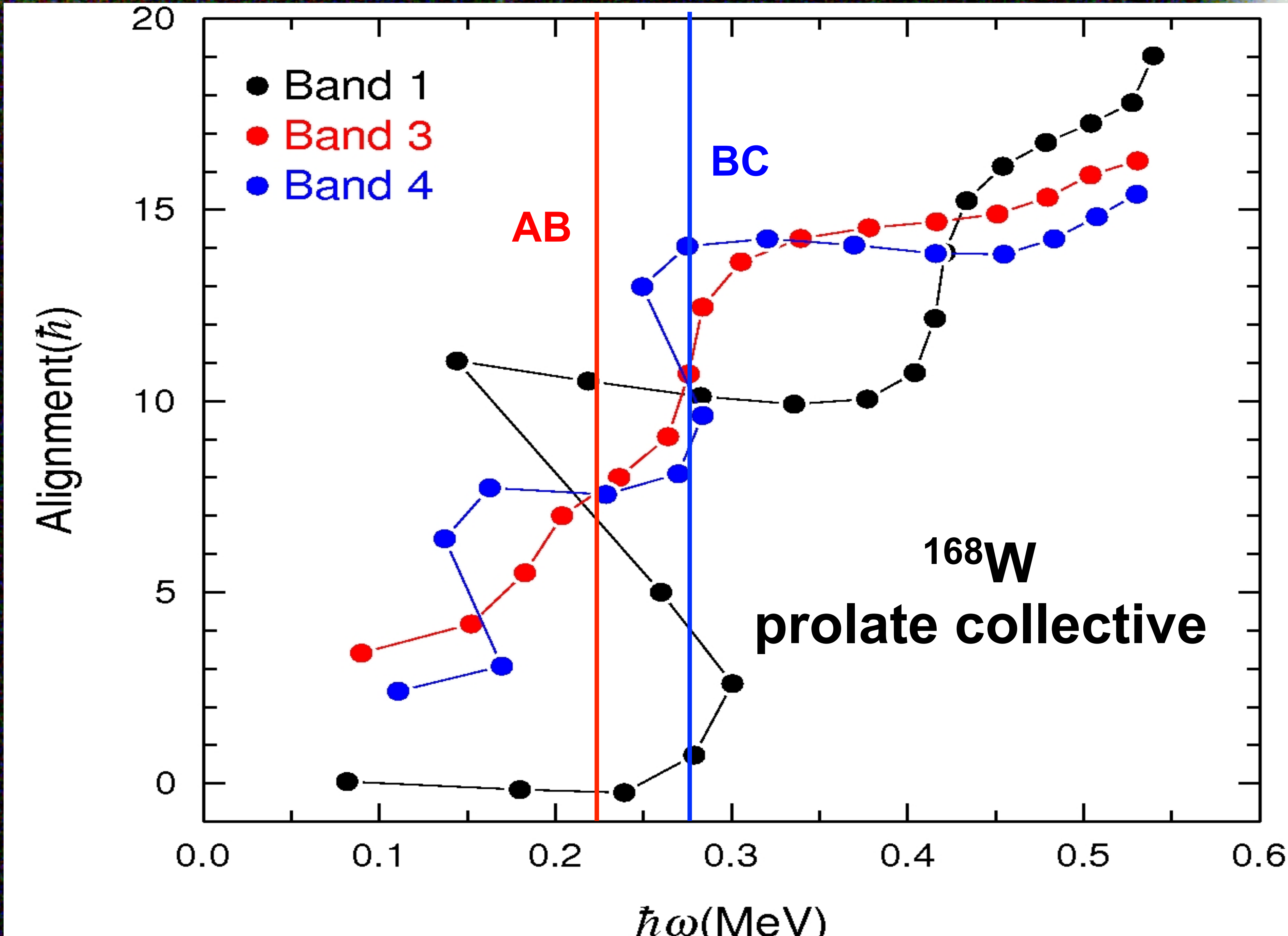


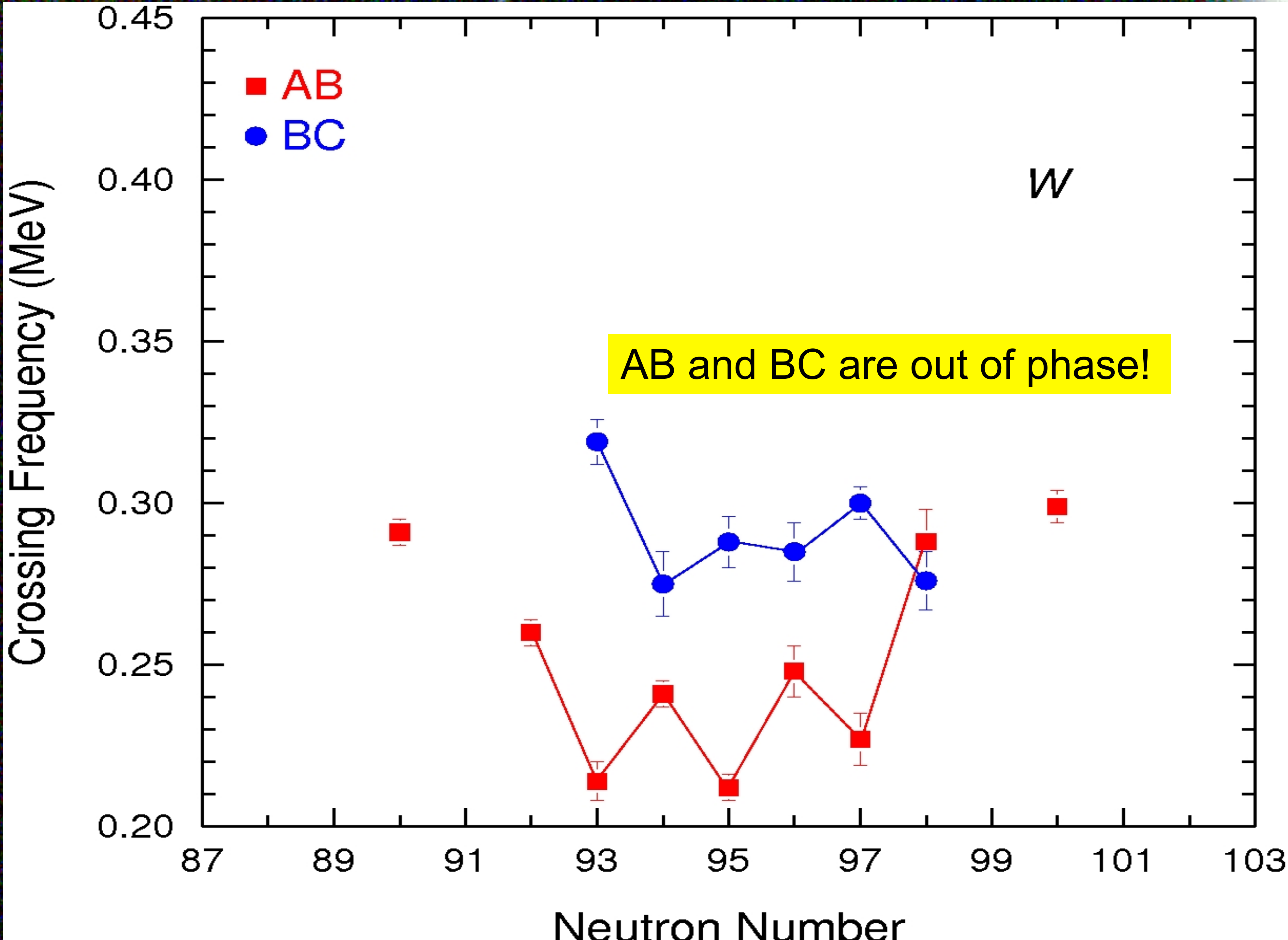
FIG. 4. Cranked shell-model two-quasiparticle Routhians as a function of $\hbar\omega$ for ^{166}Yb calculated with two different values Δ_n, indicating the shift in $\hbar\omega_c$ for a change in Δ_n.

Jerry and IY in 1987!

duction of the neutron pairing-correlation parameter Δ_n for odd-N systems as compared to seniority-zero configurations in even-N nuclei.

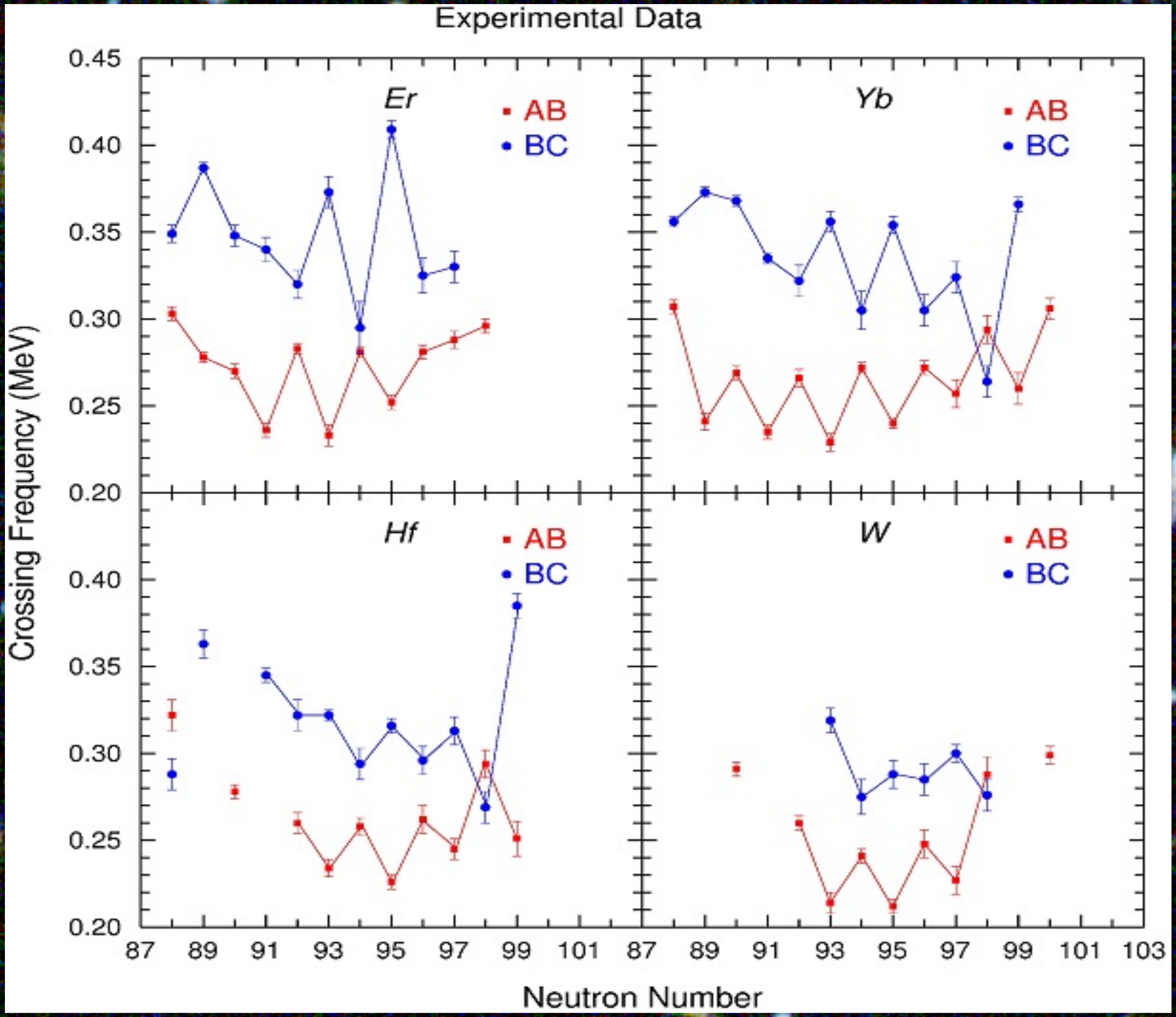


Band 1
Band 3
Band 4
AB
BC
168W
prolate collective
Alignment(ħ)
ħω(MeV)
0
5
10
15
20
0.0
0.1
0.2
0.3
0.4
0.5
0.6

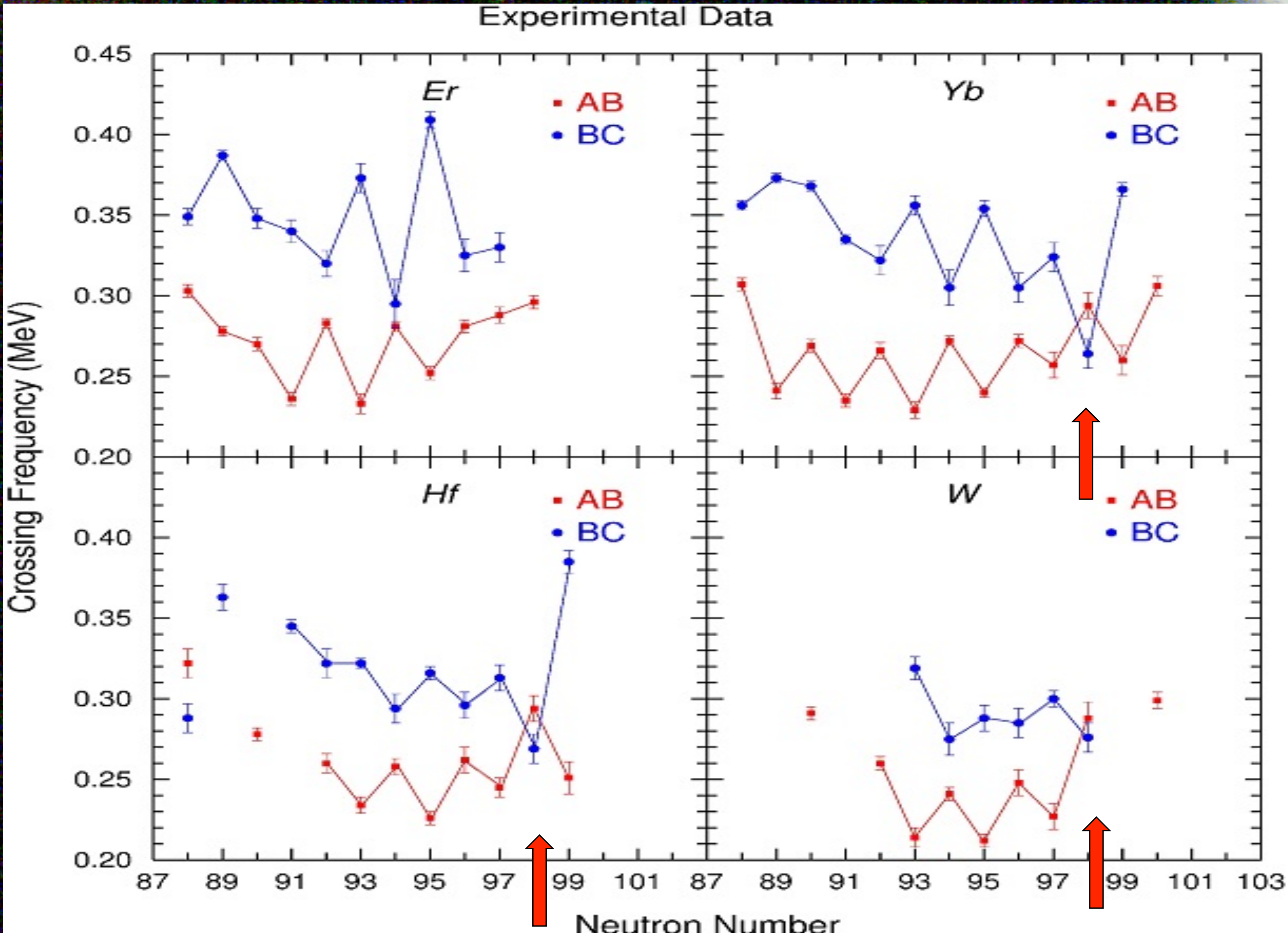


AB
BC
W
AB and BC are out of phase!
Crossing Frequency (MeV)
0.45
0.40
0.35
0.30
0.25
0.20
87
89
91
93
95
97
99
101
103
Neutron Number

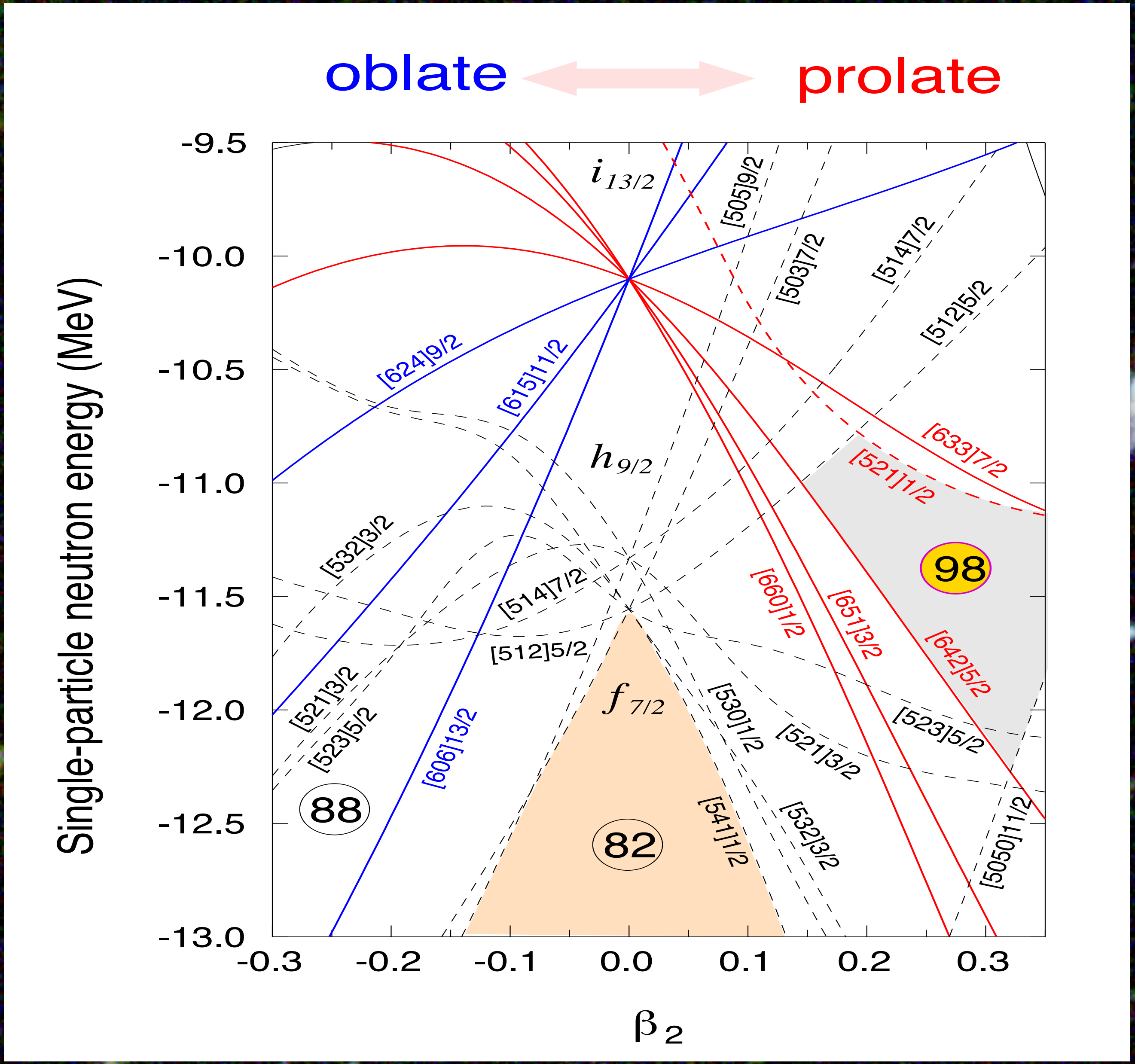
AB & BC Band Crossing Frequencies

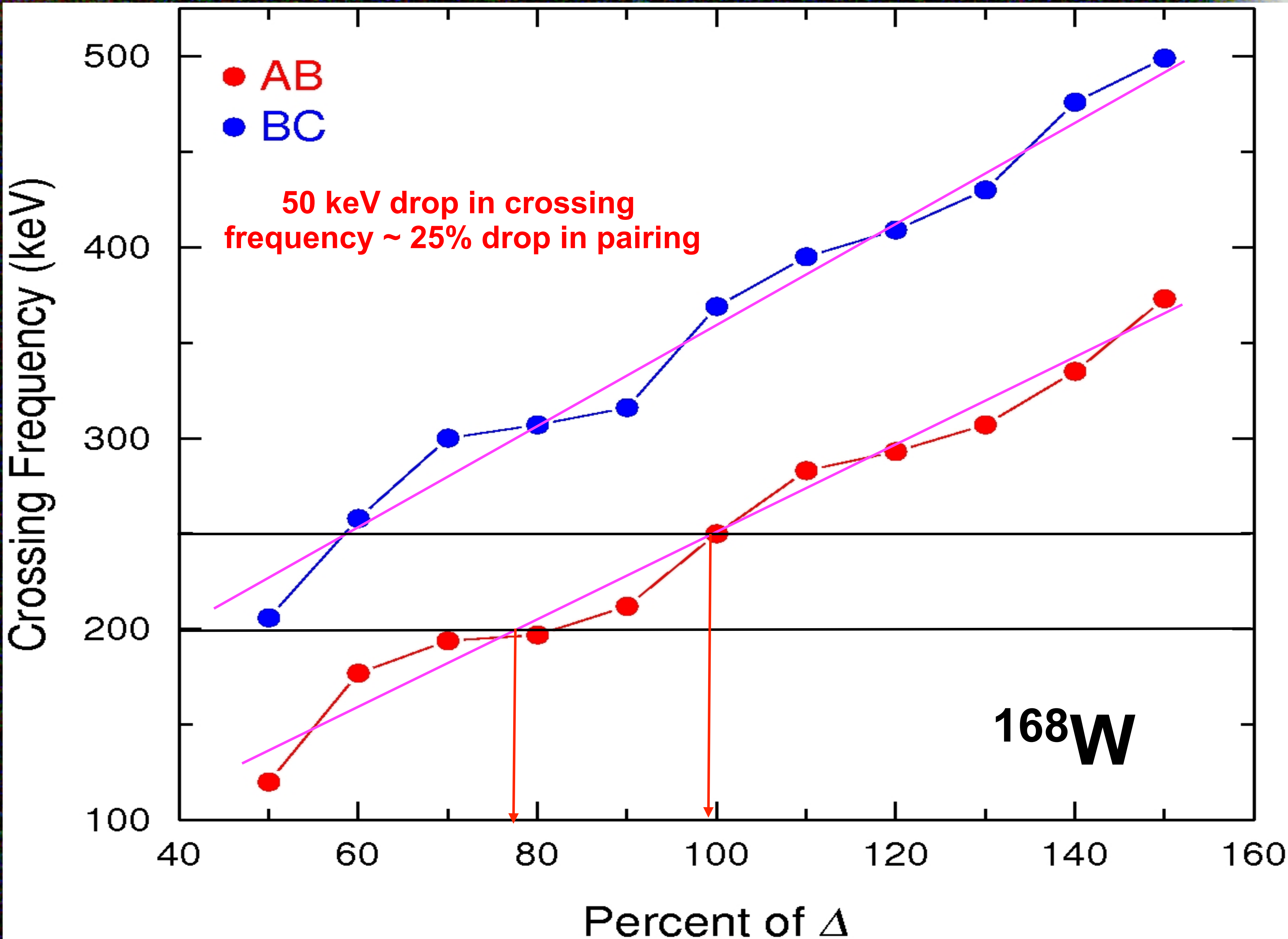


Trend observed by Garret et. al. for the AB crossing: Phys. Rev. Lett 47:75 (1981)
Trend observed by Miller et. al. for the BC crossing: to be published


Experimental Data
Er
AB
BC
Yb
AB
BC
Hf
AB
BC
W
AB
BC
Crossing Frequency (MeV)
0.45
0.40
0.35
0.30
0.25
0.20
0.40
0.35
0.30
0.25
0.20
87
89
91
93
95
97
99
101
87
89
91
93
95
97
99
101
103
Neutron Number

Nilsson Diagram for Neutrons showing N=98 deformed gap:Thanks Filip ☺

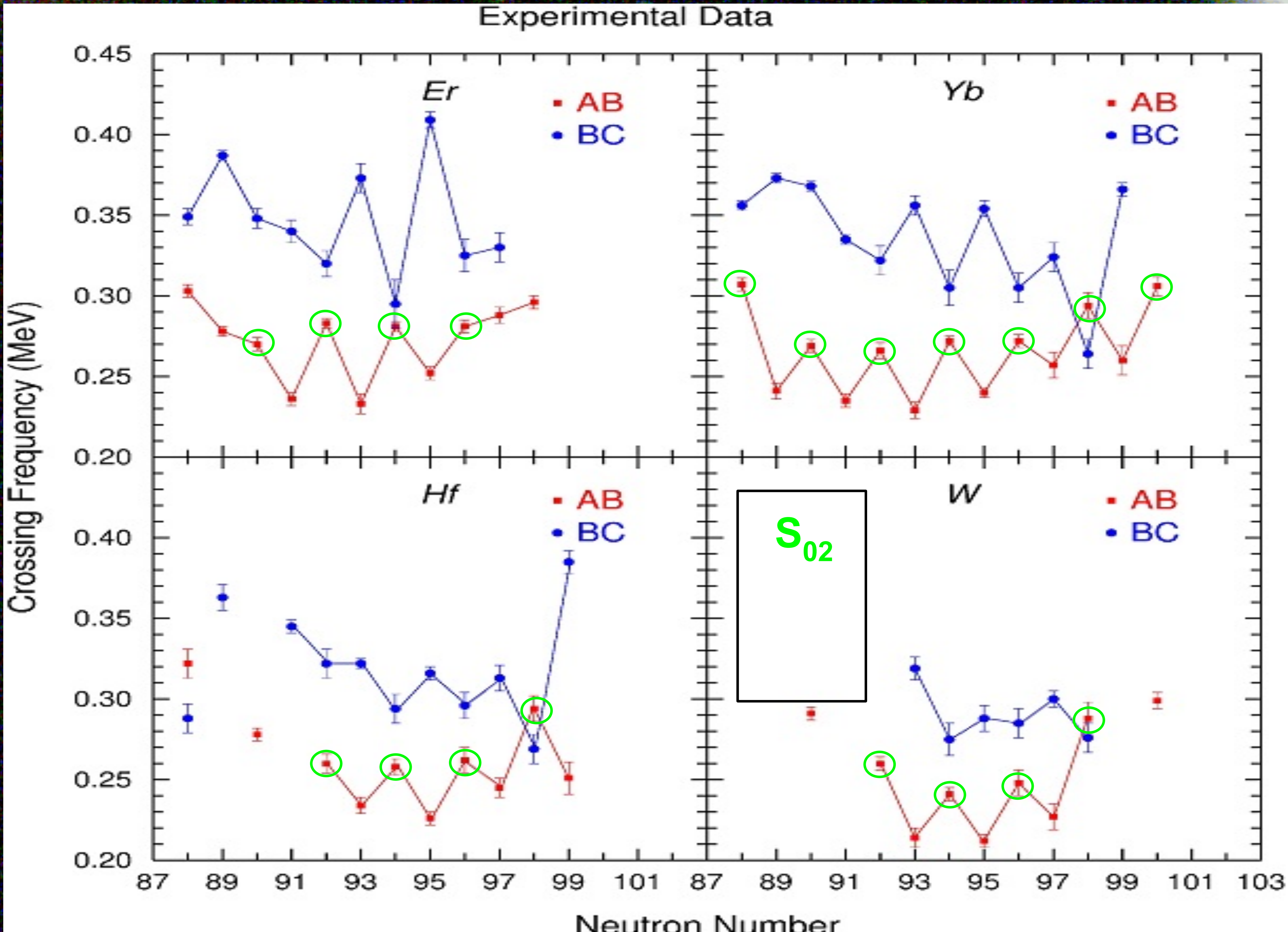




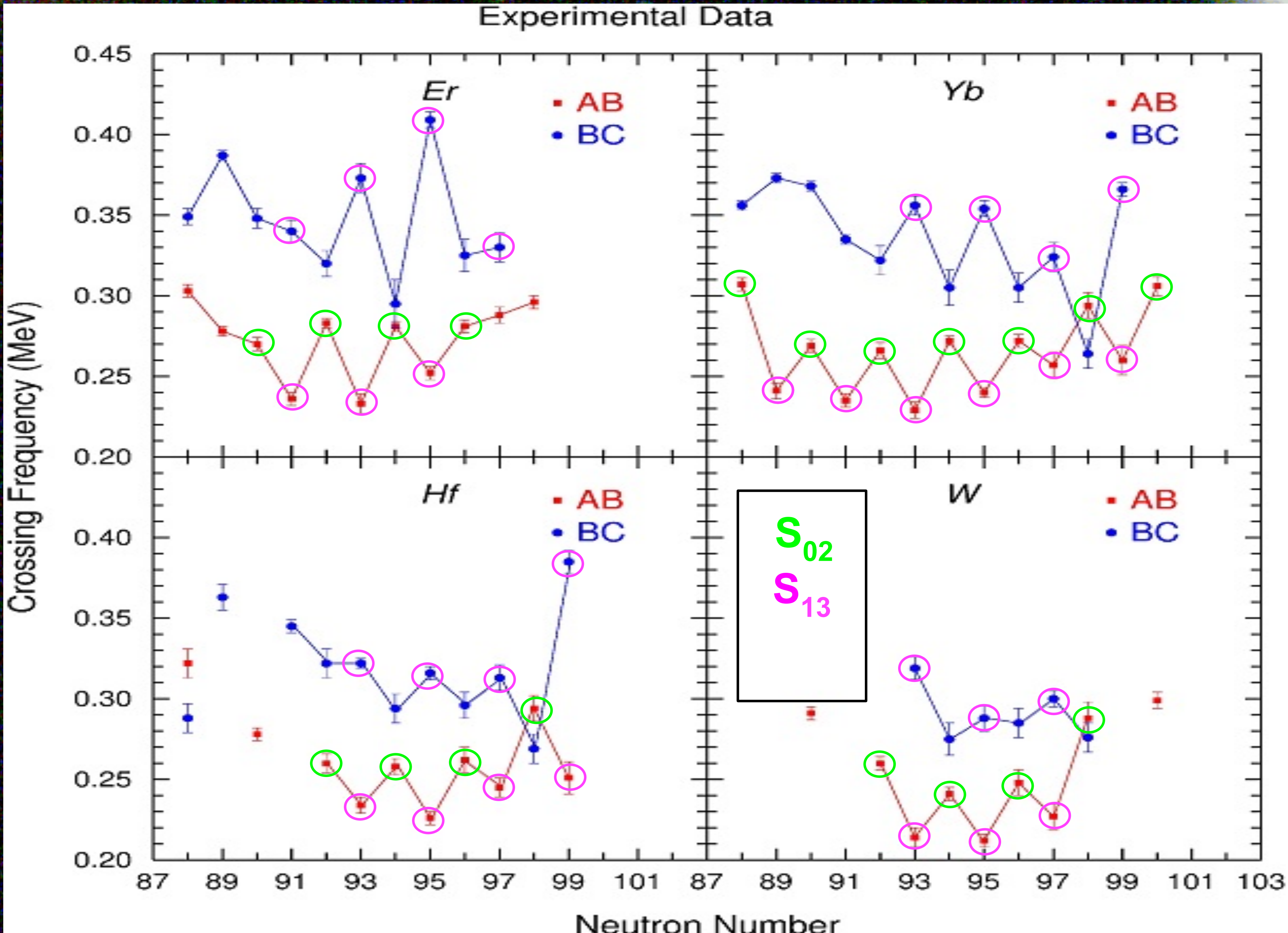
AB
BC
50 keV drop in crossing
frequency ~ 25% drop in pairing
Crossing Frequency (keV)
500
400
300
200
100
40
60
80
100
120
140
160
Percent of Δ
168W

Seniority labels for band crossings

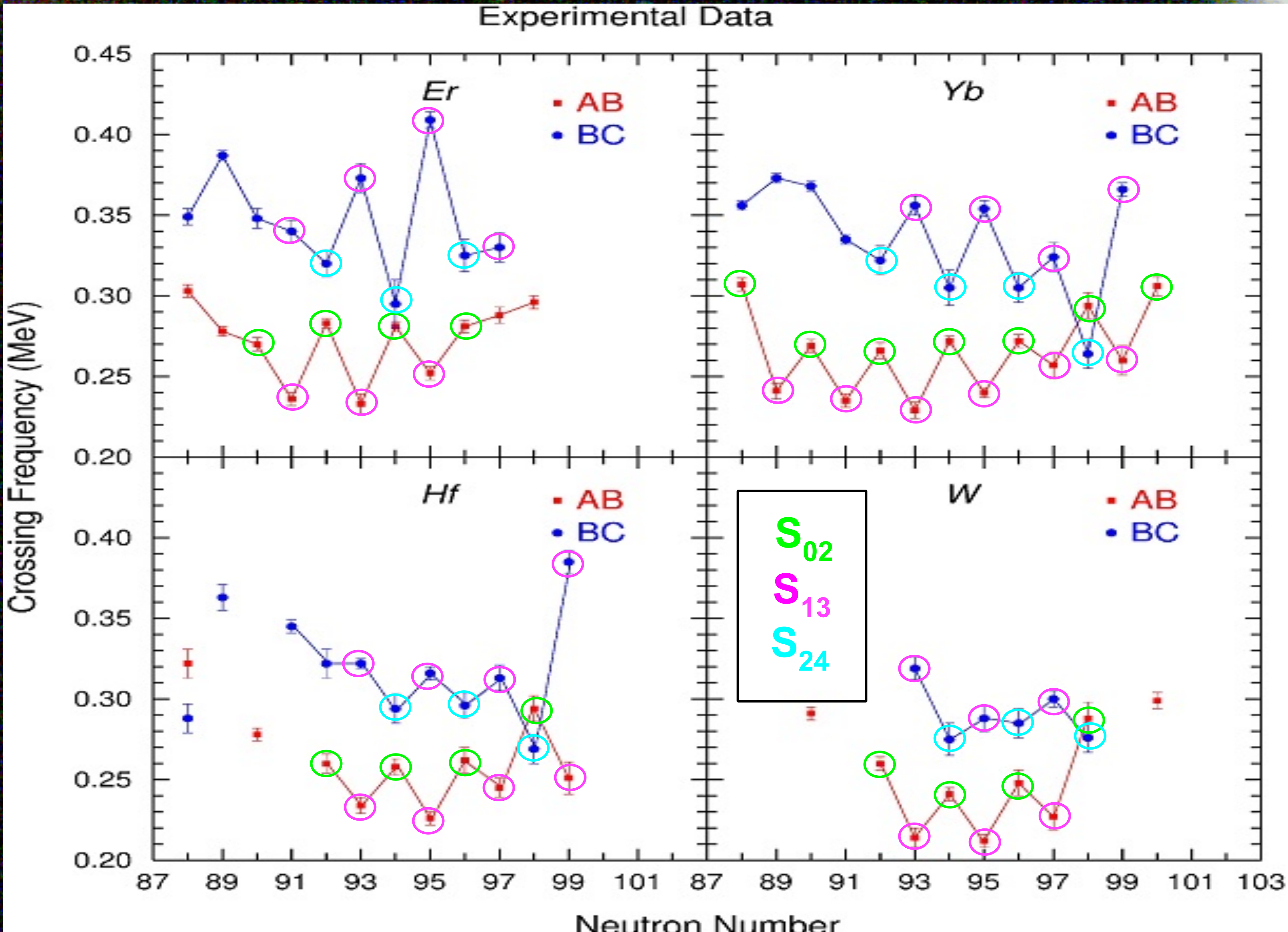
- 0 >2 quasiparticles = S_{02}
- 1>3 quasiparticles = S_{13}
- 2>4 quasiparticles = S_{24}
- Higher Seniority => Higher reduction in pairing due to Pauli Blocking
- Lower pairing => Lower crossing frequency



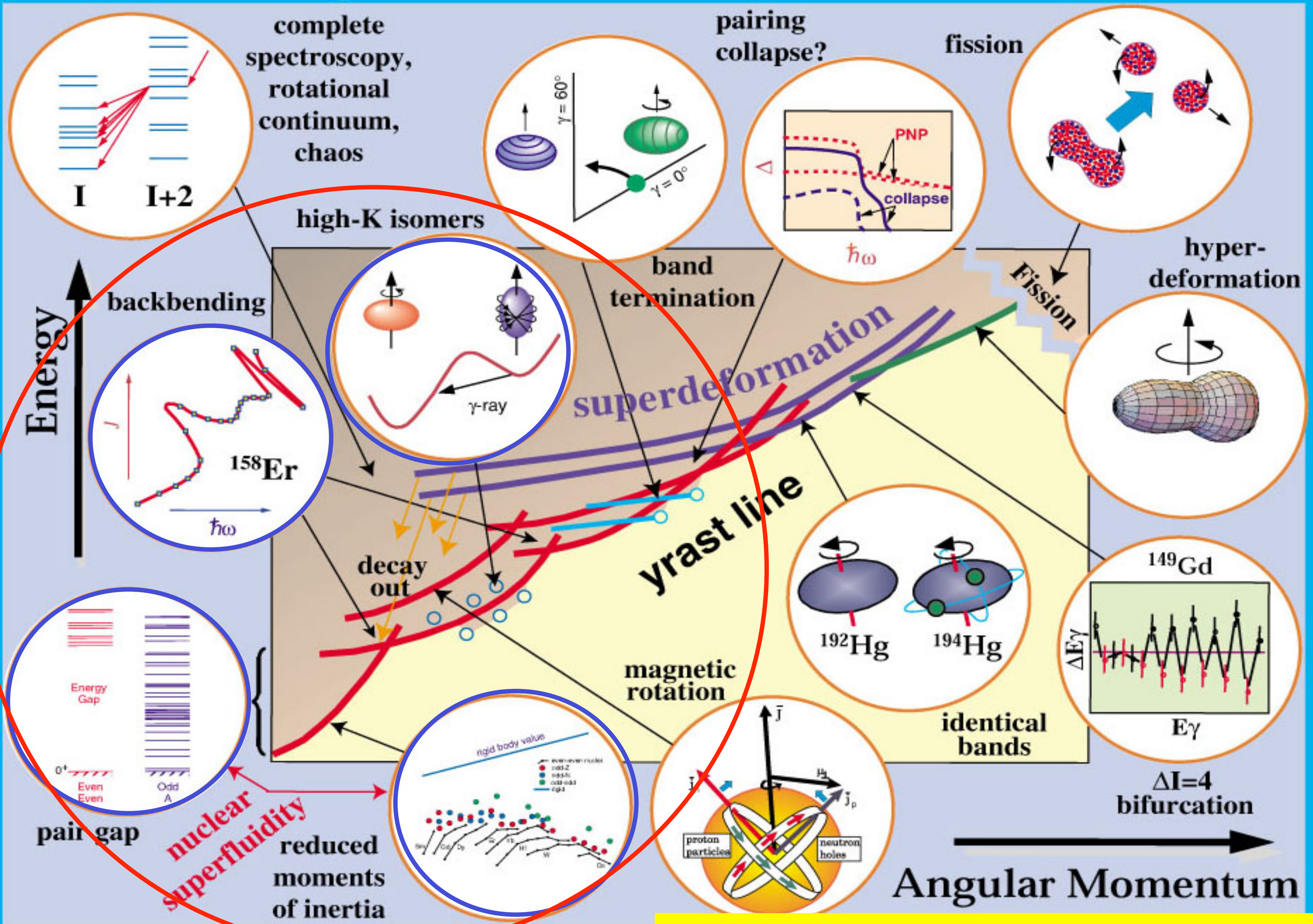
Experimental Data
Er
Yb
Hf
W
AB
BC
S02
Crossing Frequency (MeV)
Neutron Number



Experimental Data
Er
Yb
Hf
W
AB
BC
S_{02}
S_{13}
Crossing Frequency (MeV)
Neutron Number
0.45
0.40
0.35
0.30
0.25
0.20
87
89
91
93
95
97
99
101
103


Experimental Data
Er
Yb
Hf
W
AB
BC
S02
S13
S24
Crossing Frequency (MeV)
Neutron Number
0.20
0.25
0.30
0.35
0.40
0.45
87
89
91
93
95
97
99
101
103

The Angular Momentum World of the Nucleus



Riley, Simpson & Paul, Phys.Scripta, in press

12 February 1998

PHYSICS LETTERS B

ELSEVIER

Physics Letters B 419 (1998) 7–13

Pairing reduction and rotational motion in multi-quasiparticle states

G.D. Dracoulis [a], F.G. Kondev [a], P.M. Walker [a,b]

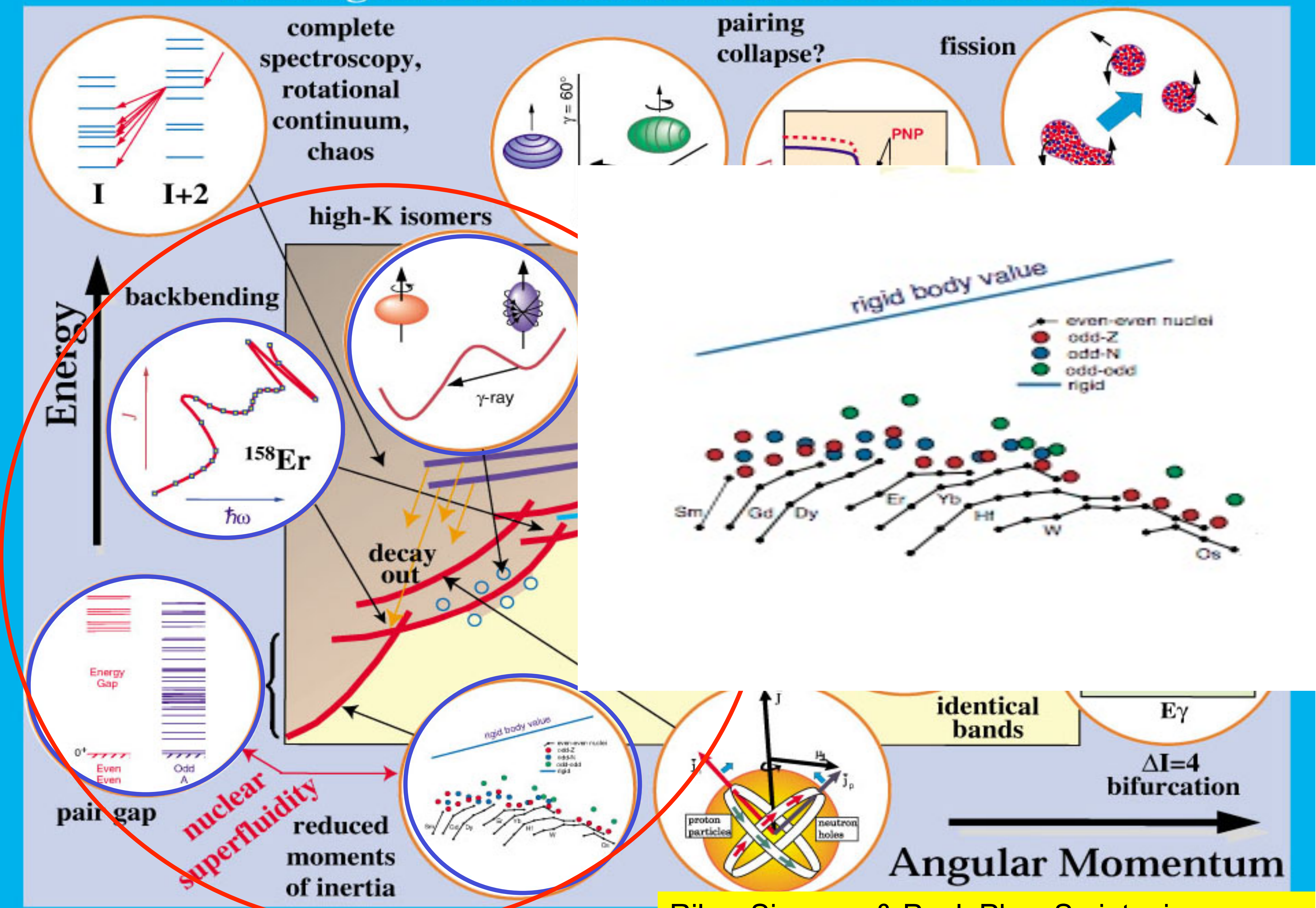
[a] *Department of Nuclear Physics, RSPhysSE, Australian National University, Canberra ACT, 0200, Australia*
[b] *Department of Physics, University of Surrey, Guildford, Surrey, GU2 5XH, UK*

Received 28 March 1997; revised 8 September 1997
Editor: J.-P. Blaizot

Abstract

Calculations of pairing energies in multi-quasiparticle states using the Lipkin-Nogami prescription predict a discrete reduction in pairing with a geometric dependence on seniority. An abrupt transition from superfluid to normal motion is therefore not expected, even with a large number of orbits blocked. Recent experimental results on rotational bands associated with multi-quasiparticle intrinsic states allow comparisons to be made for a subset of orbitals as a function of seniority. Approximate agreement is obtained between the observed moments-of-inertia and calculated values supporting the view that for the highest seniority states identified so far, the pairing persists at nearly half of the full value.

The Angular Momentum World of the Nucleus



Riley, Simpson & Paul, Phys.Scripta, in press

Reduction of Pairing with Seniority from high-K isomer band studies

Dracoulis, Kondev and Walker Phys. Lett. B 419 (1998)

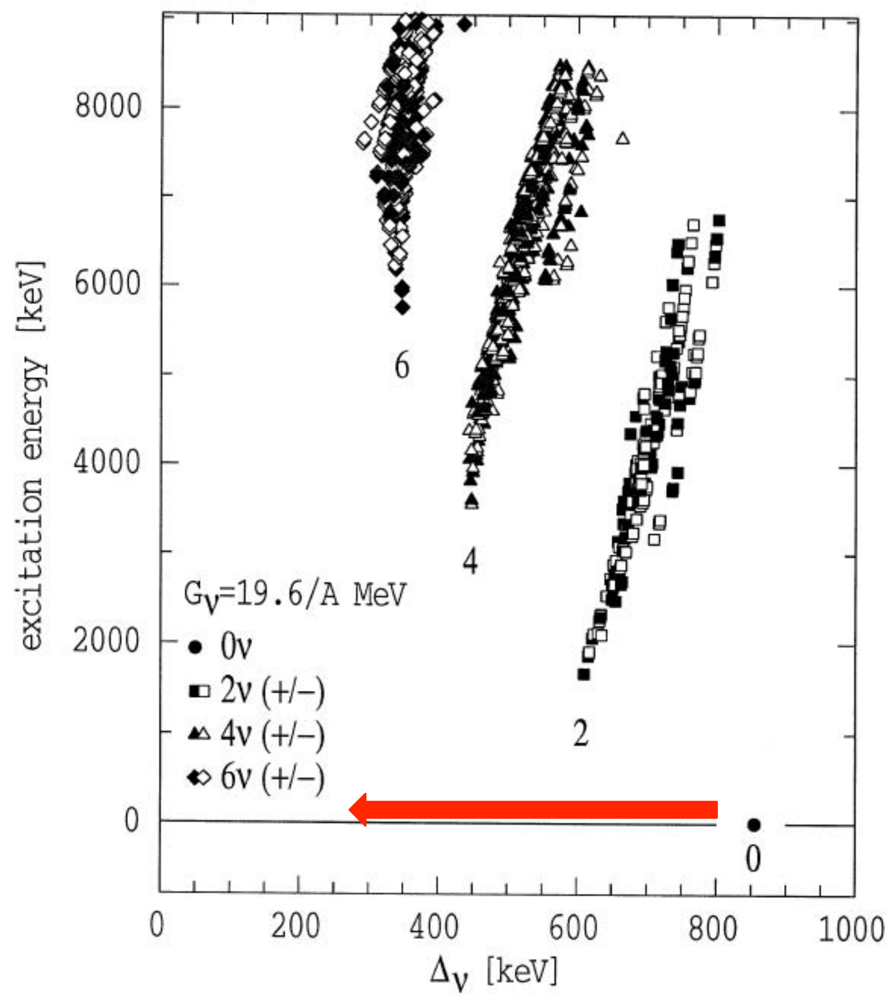


Fig. 1. Predicted neutron pairing for intrinsic states of different seniority in ^{178}W.

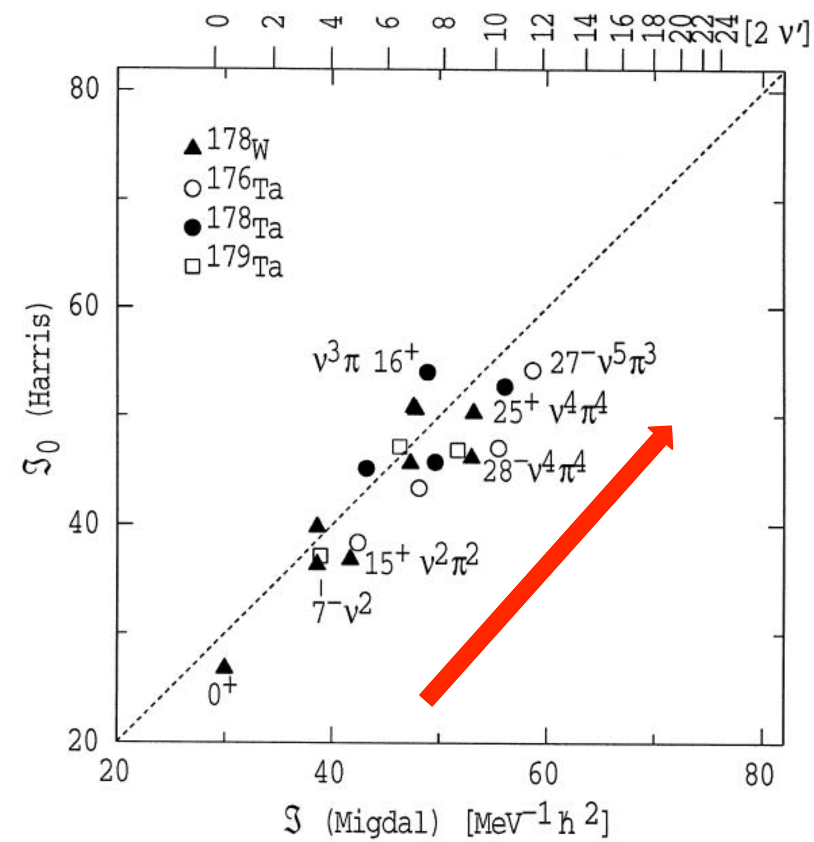


Fig. 4. The moment-of-inertia parameter $\Im_0$ deduced from a fit to rotational bands using the modified Harris parameterisation given in the text, plotted against the values using the Migdal formula with pairing values calculated for each configuration. The bars on the upper border indicate the expected dependence of the moment-of-inertia for equal proton and neutron seniority (giving a total $2\times\nu'$) and a geometric pairing dependence.

Physics Letters B 726 (2013) 675–679

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Quasi-particle and collective magnetism: Rotation, pairing and blocking in high-K isomers

N.J. Stone [a,b], J.R. Stone [a,b], P.M. Walker [c], C.R. Bingham [b,d]

[a] Department of Physics, University of Oxford, Oxford, OX1 3PU, UK
[b] Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA
[c] Department of Physics, University of Surrey, Guildford, Surrey, GU2 7XH, UK
[d] Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

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ABSTRACT

For the first time, a wide range of collective magnetic g-factors g_R, obtained from a novel analysis of experimental data for multi-quasi-particle configurations in high-K isomers, is shown to exhibit a striking systematic variation with the relative number of proton and neutron quasi-particles, $N_p - N_n$. Using the principle of additivity, the quasi-particle contribution to magnetism in high-K isomers of Lu–Re, $Z = 71$–75, has been estimated. Based on these estimates, band-structure branching ratio data are used to explore the behavior of the collective contribution as the number and proton/neutron nature (N_p, N_n), of the quasi-particle excitations, change. Basic ideas of pairing, its quenching by quasi-particle excitation and the consequent changes to moment of inertia and collective magnetism are discussed. Existing model calculations do not reproduce the observed g_R variation adequately. The paired superfluid system of nucleons in these nuclei, and their excitations, present properties of general physics interest. The new-found systematic behavior of g_R in multi-quasi-particle excitations of this unique system, showing variation from close to zero for multi-neutron states to above 0.5 for multi-proton states, opens a fresh window on these effects and raises the important question of just which nucleons contribute to the 'collective' properties of these nuclei.

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Review

Review of metastable states in heavy nuclei

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Abstract

The structure of nuclear isomeric states is reviewed in the context of their role in contemporary nuclear physics research. Emphasis is given to high-spin isomers in heavy nuclei, with $A \gtrsim 150$. The possibility to exploit isomers to study some of the most exotic nuclei is a recurring theme. In spherical nuclei, the role of octupole collectivity is discussed in detail, while in deformed nuclei the limitations of the K quantum number are addressed. Isomer targets and isomer beams are considered, along with applications related to energy storage, astrophysics, medicine, and experimental advances.

Backbending Today and Summary

- What was once a surprise and a mystery is now a beautiful diagnostic instrument!
- Very sensitive to changes in pairing, deformation and what the intruder orbitals are doing.
- Systematic analysis of crossing frequencies near A ~ 170. We have extended the classic work of Garrett et al to higher seniority BC crossing frequencies.
- We have super systematics on the p-rich side and a good understanding ….. Or so we think.
- Is the n-rich side the same where pairing may be very different?
- To be continued! ☺

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Plus one more item …..

Mega-Congrats to John and I-Yang: 2016 Rutherford and Bonner Prize Winners!


THANK YOU!