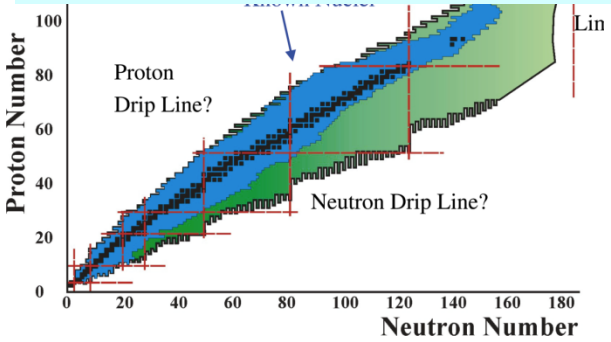
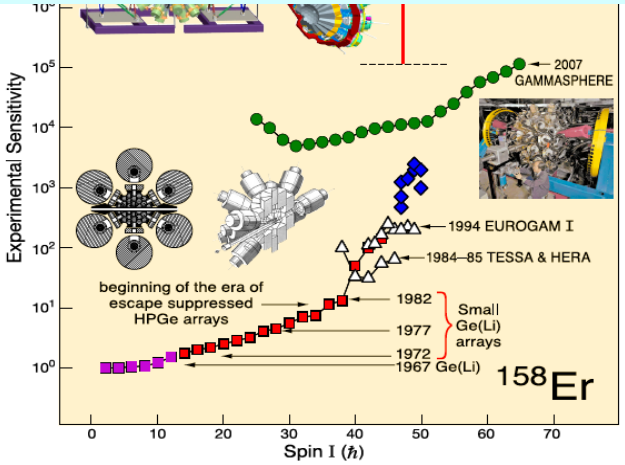
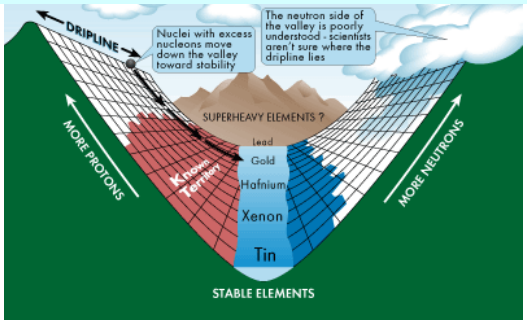
Collective Structures at Ultrahigh Spin in the Rare Earth Region: A New Chapter in the Story of Rapid Nuclear Rotation and A New Challenge for Understanding Triaxiality in Nuclei

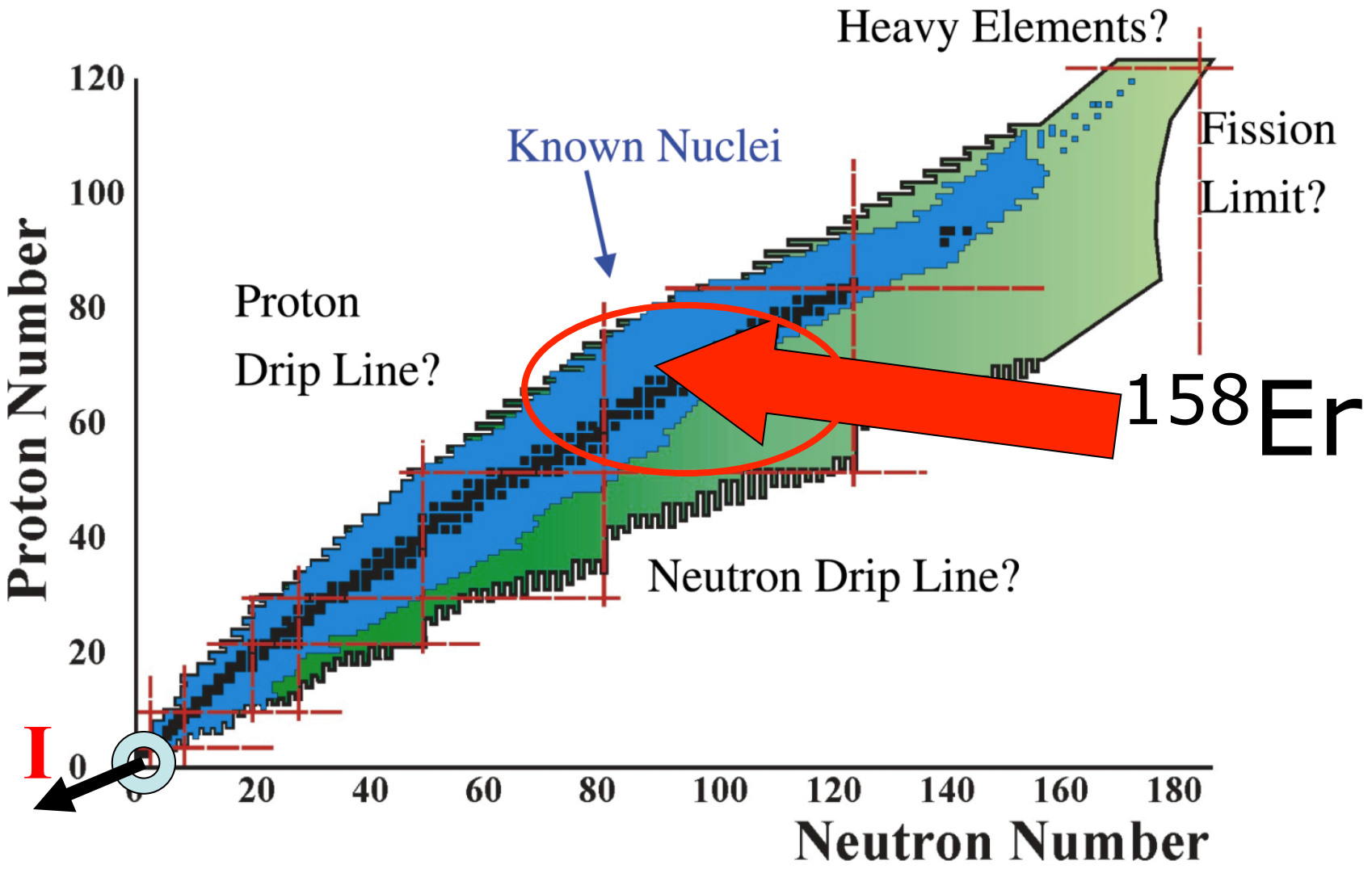






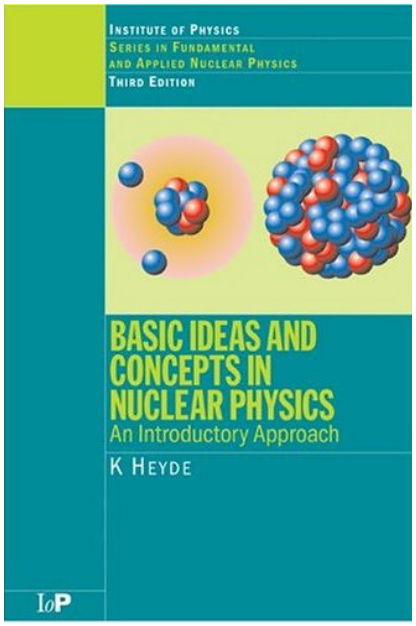
Nuclear Structure 2012 Conference

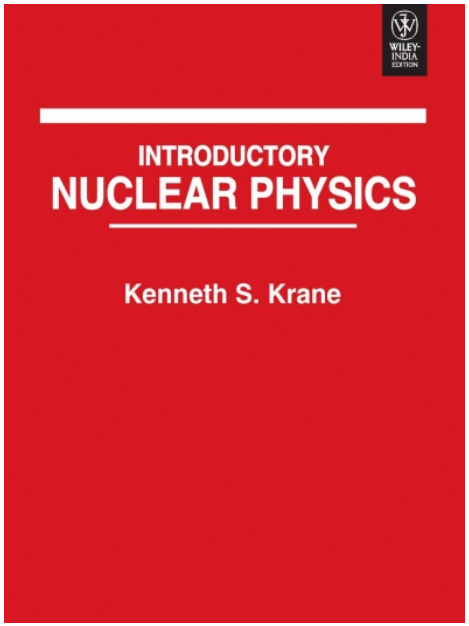
Where are the limits and what happens on the way?

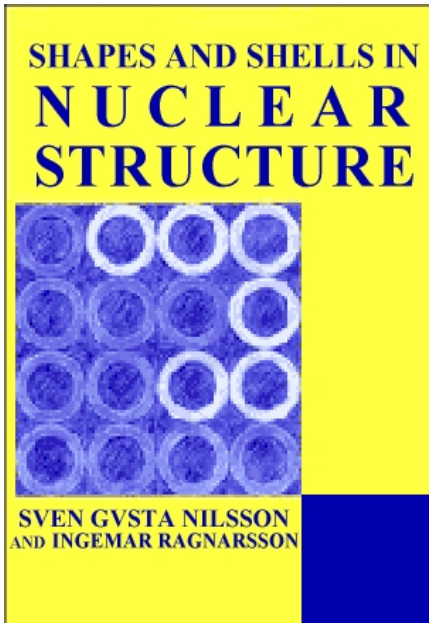


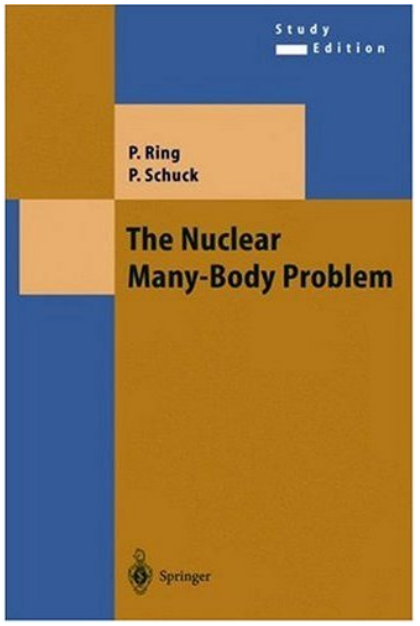
Increasing Angular Momentum and Excitation Energy: An excellent way to investigate nuclear structure, especially to see what the critically important intruder orbitals are doing.

In fact, the ^{158}Er nucleus is widely acknowledged as a textbook example in high-spin nuclear physics.









Z. Physik 257, 147—176 (1972)
© by Springer-Verlag 1972

1st alignment

Experimenta
of High Spin States in the
of ^{158,160}Er, ^{164,166}Y

R. M. Lieder, H. Beuscher, W
H.-J. Probst, and C. I
Institut für Kernphysik der Kern

VOLUME 38, NUMBER 25 PHYSICAL REVI

After the alignments were found in ^{158}Er, soon backbendings were everywhere! This was the dawn of a golden age for the Cranked Shell Model : *Bengtsson and Frauendorf*

VOLUME 48, NUMBER 8 PHYSICAL REVI

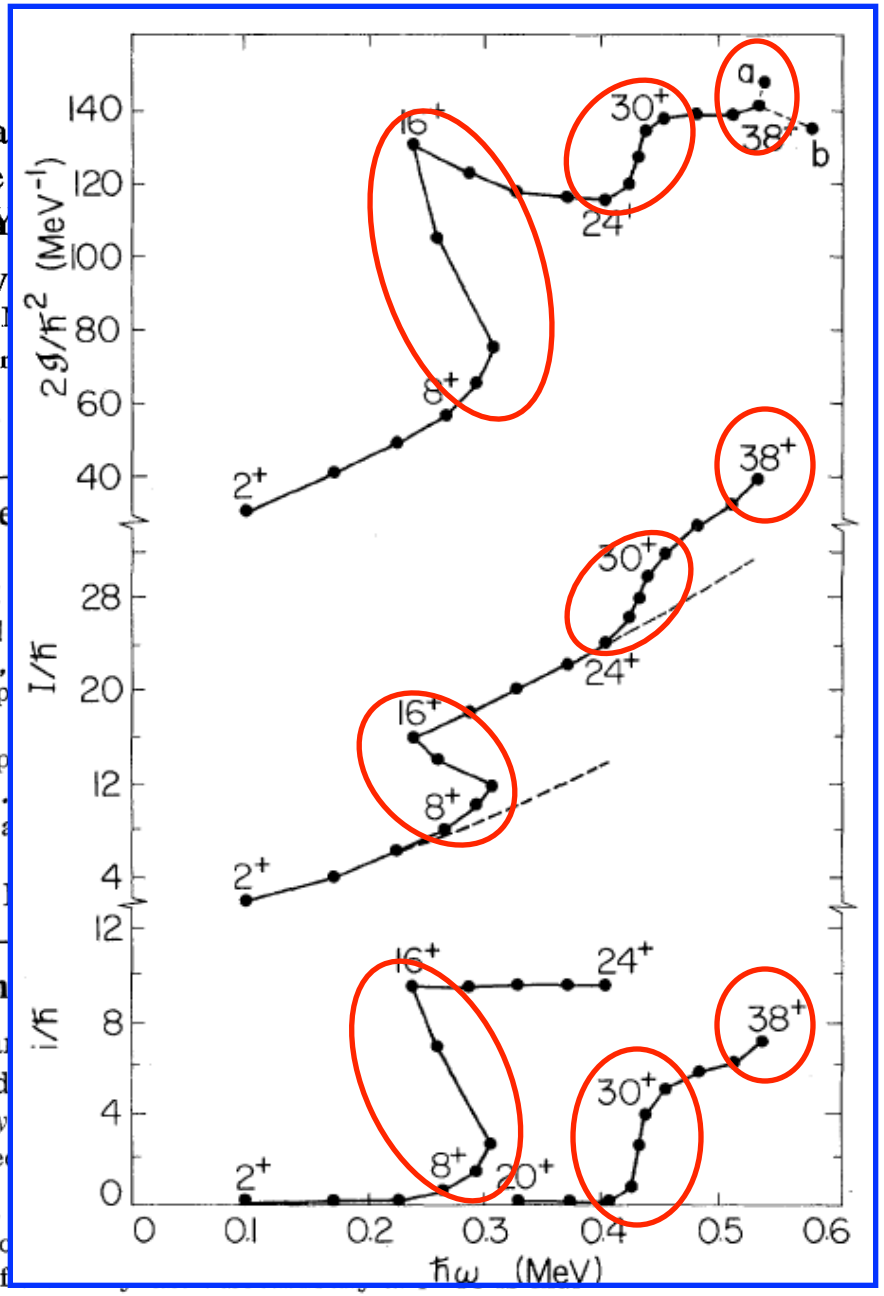
Third Discontinuity in th

J. Burde,[a] E. L. Dines,[b] S. Shih,[c] R. M. Dia
C. Schück,[e] and
Nuclear Science Division, Lawrence Berkeley Laboratory

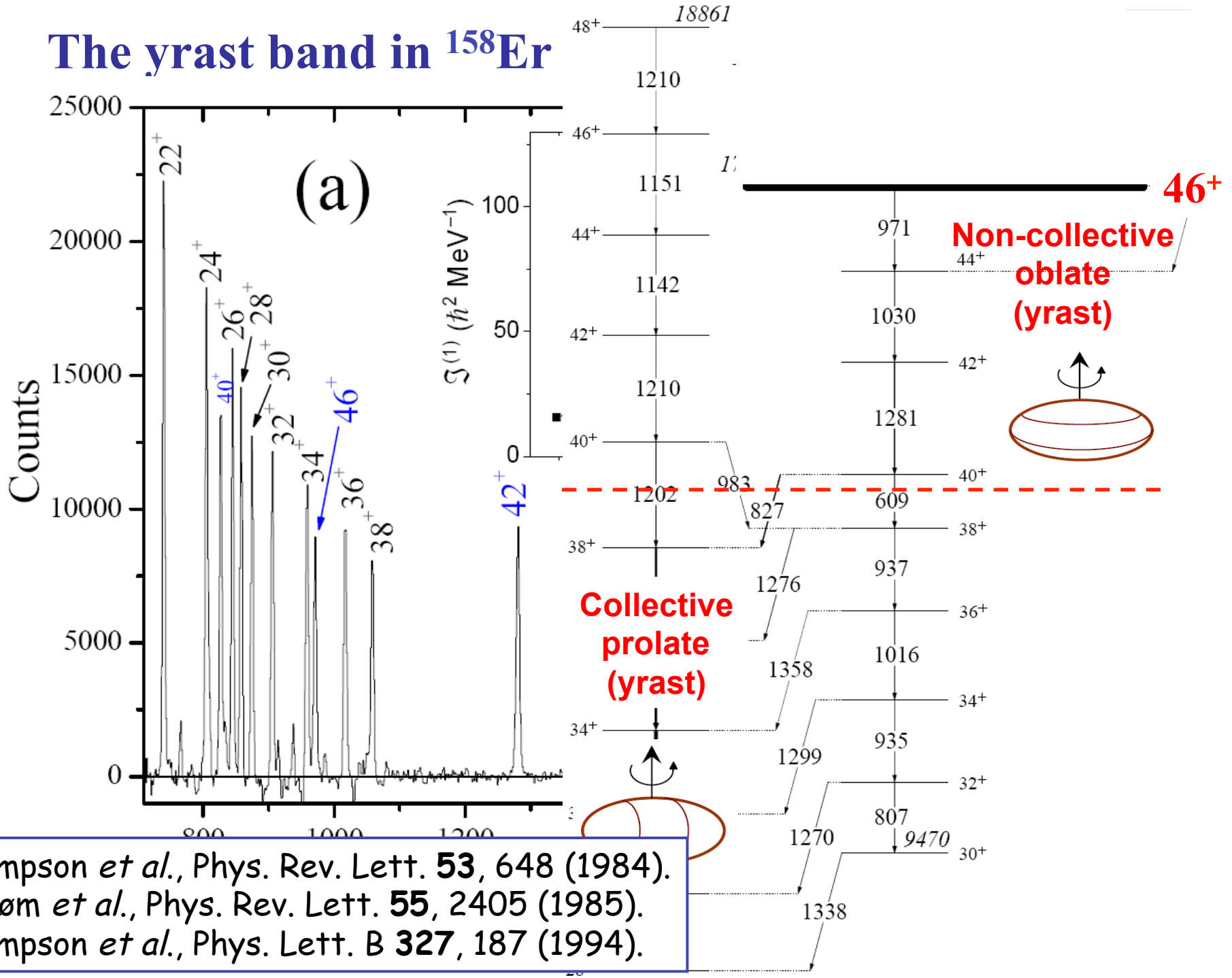
(Received 7 De

3rd alignment

transitions from states with
^{122}Sn(^{40}Ar, 4$n\gamma$). In addition to
upbend at $I=28$ previously known, the start of
cated. Candidates for the $I=40$ state are suggested and possible causes of the yrast discontinuity are discussed.



The yrast band in ^{158}Er



Simpson *et al.*, Phys. Rev. Lett. **53**, 648 (1984).
Tjøm *et al.*, Phys. Rev. Lett. **55**, 2405 (1985).
Simpson *et al.*, Phys. Lett. B **327**, 187 (1994).

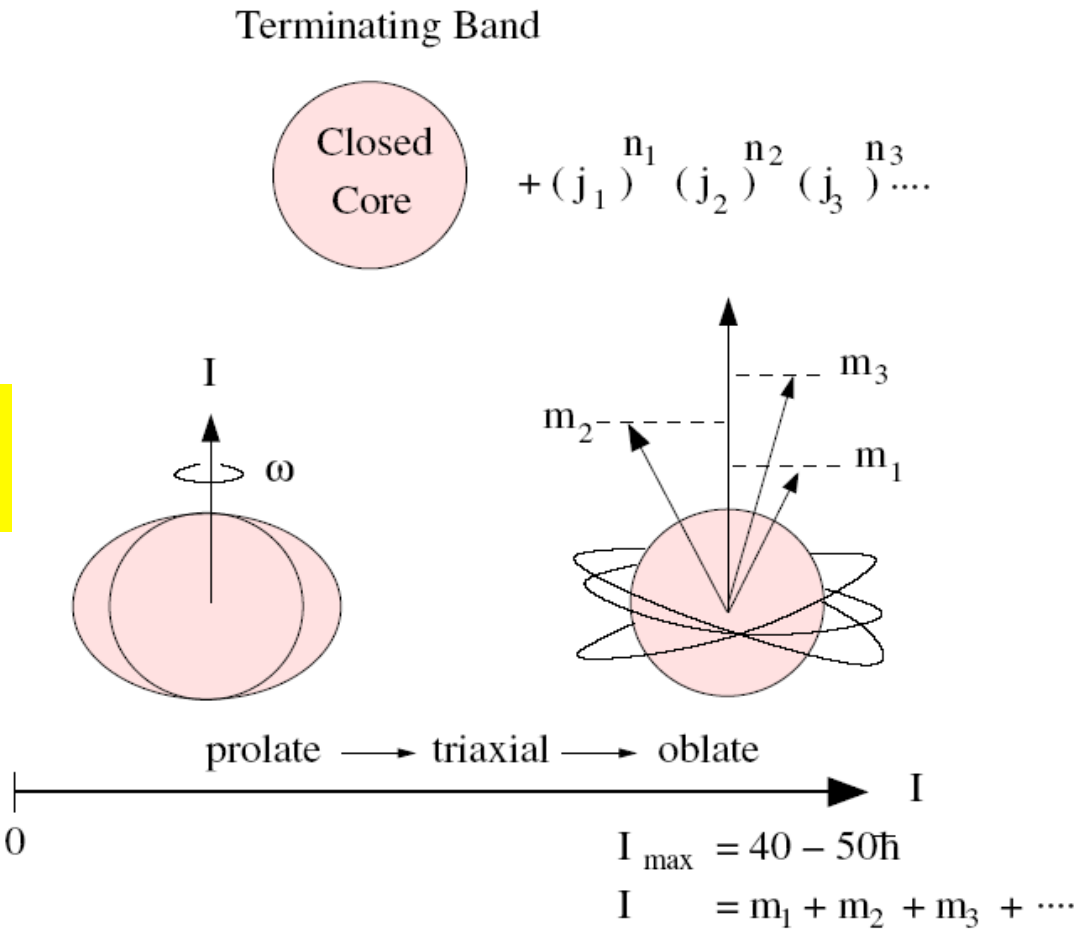
Band Termination in ^{158}Er

- Valence nucleons (4 valence protons, 8 valence neutrons) in ^{158}Er are counted with respect to :

$$^{146}_{64}Gd_{82}$$ **core**

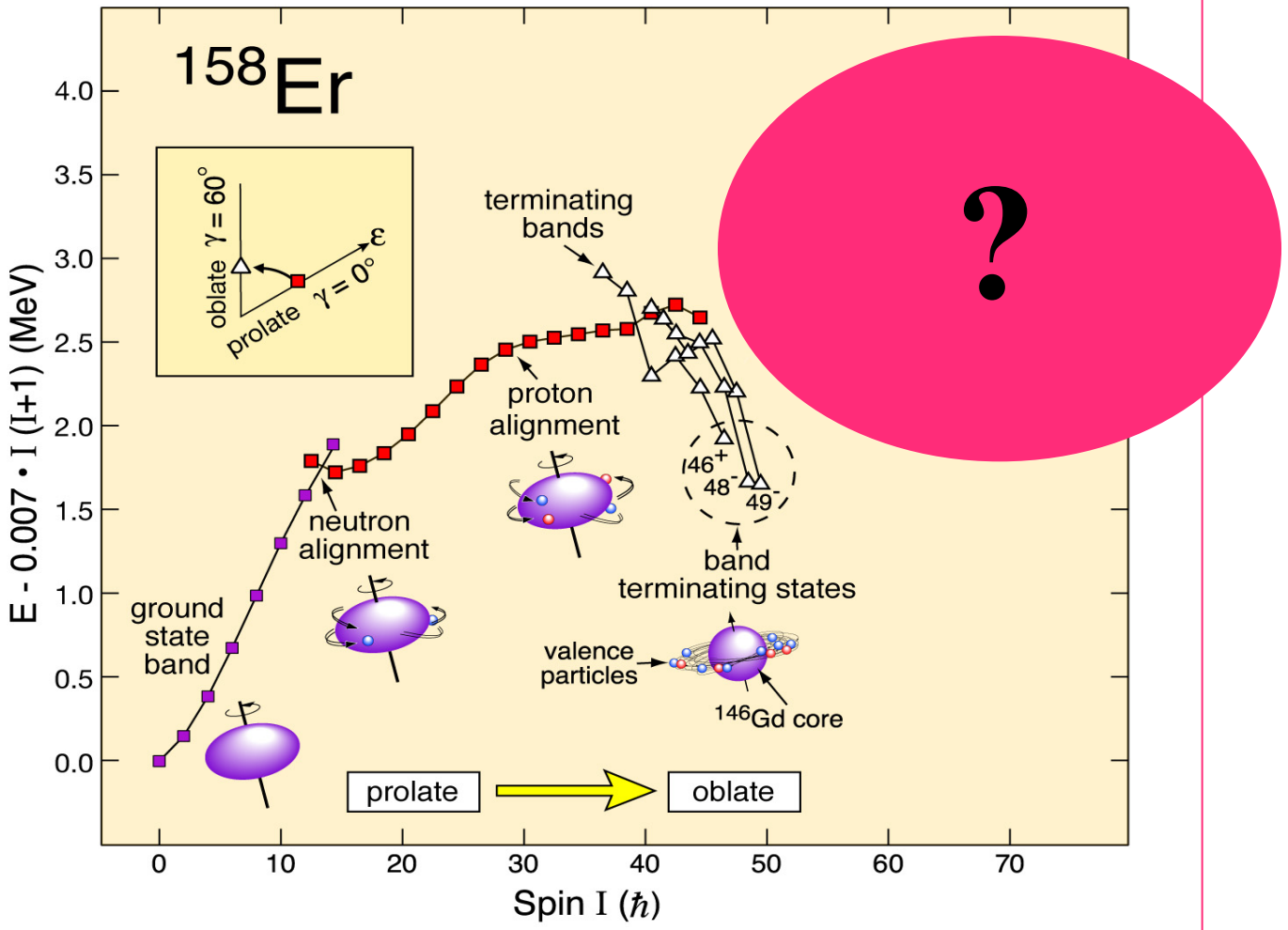
Band termination occurs when the valence nucleons outside the core are fully aligned with the axis of rotation.

46^+: $\pi(h_{11/2})^4\ \nu(f_{7/2})^3(h_{9/2})^3(i_{13/2})^2$ fully aligned



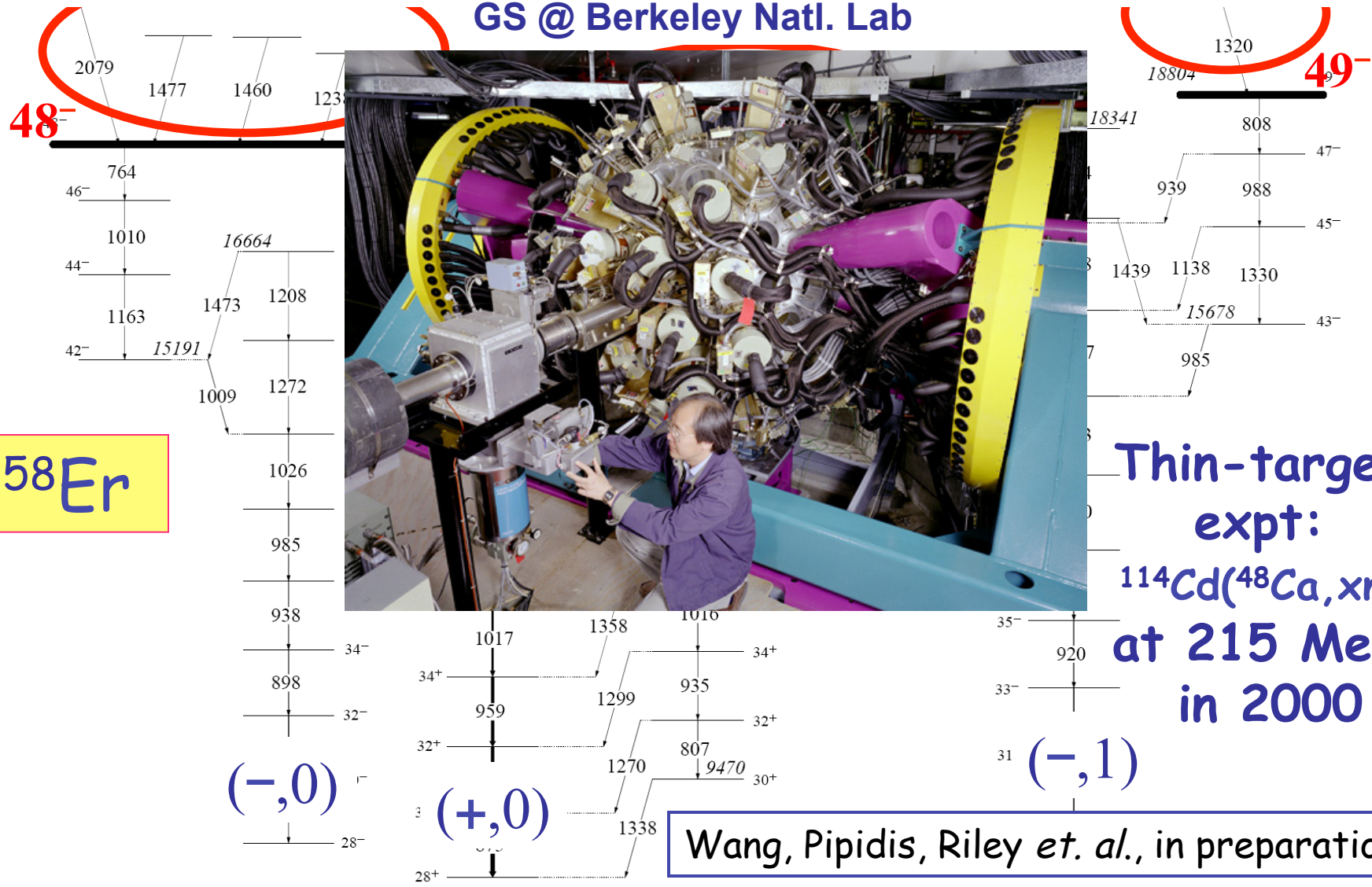
Bengtsson and Ragnarsson, Physica Scripta **T5**, 165 (1983).
Ragnarsson *et al.*, Phys. Rev. Lett. **54**, 982 (1985).
Ragnarsson *et al.*, Phys. Scripta **34**, 651 (1986).

WHAT LIES ABOVE BAND TERMINATION? - Searching for the states beyond BT had been a goal for decades.



The very weak feeding transitions above BT originate from the levels of weakly-deformed, core-breaking configurations.

GS @ Berkeley Natl. Lab

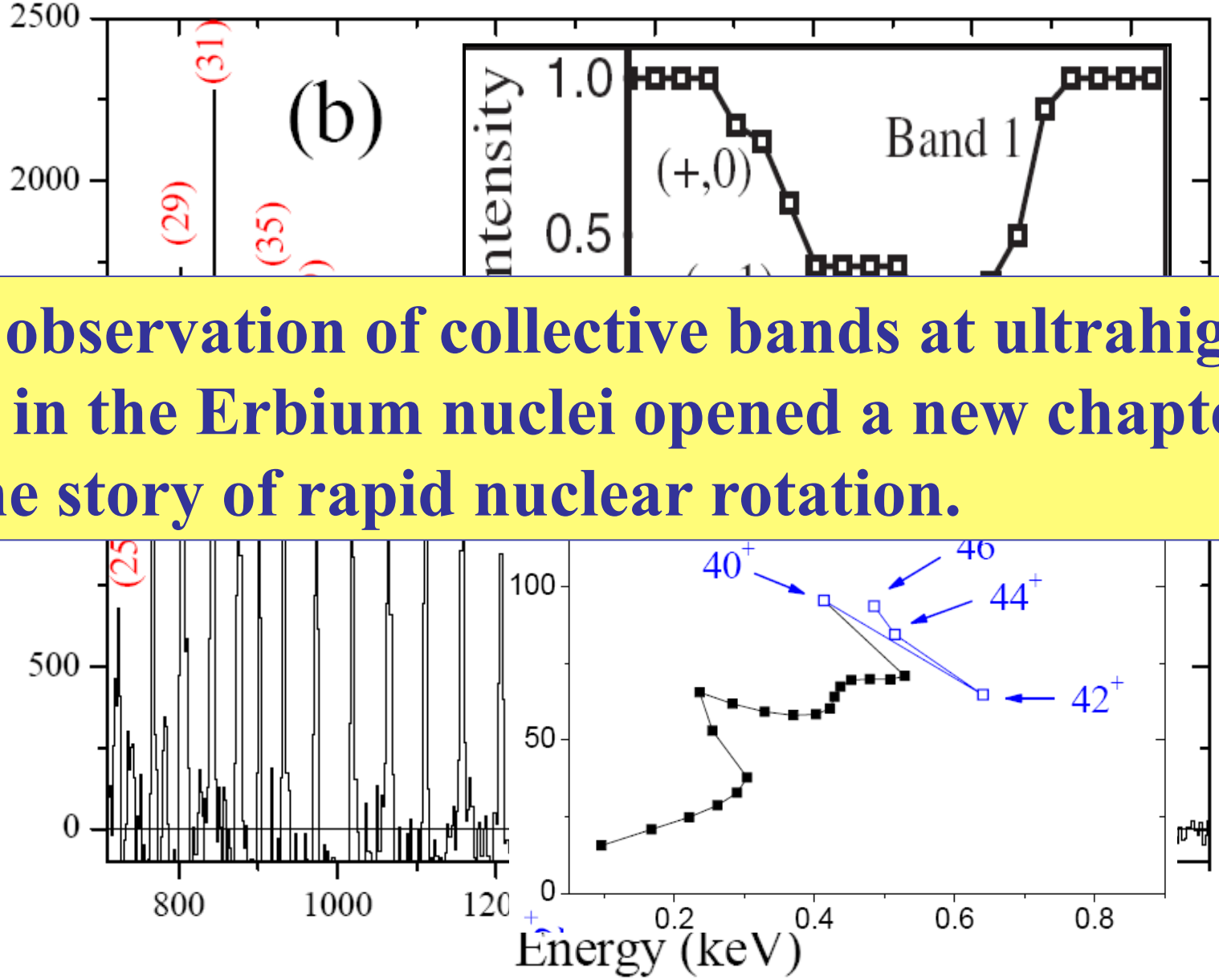


^{158}Er

Thin-target expt:
^{114}Cd(^{48}Ca,xn)
at 215 MeV
in 2000

Wang, Pipidis, Riley *et. al.*, in preparation.

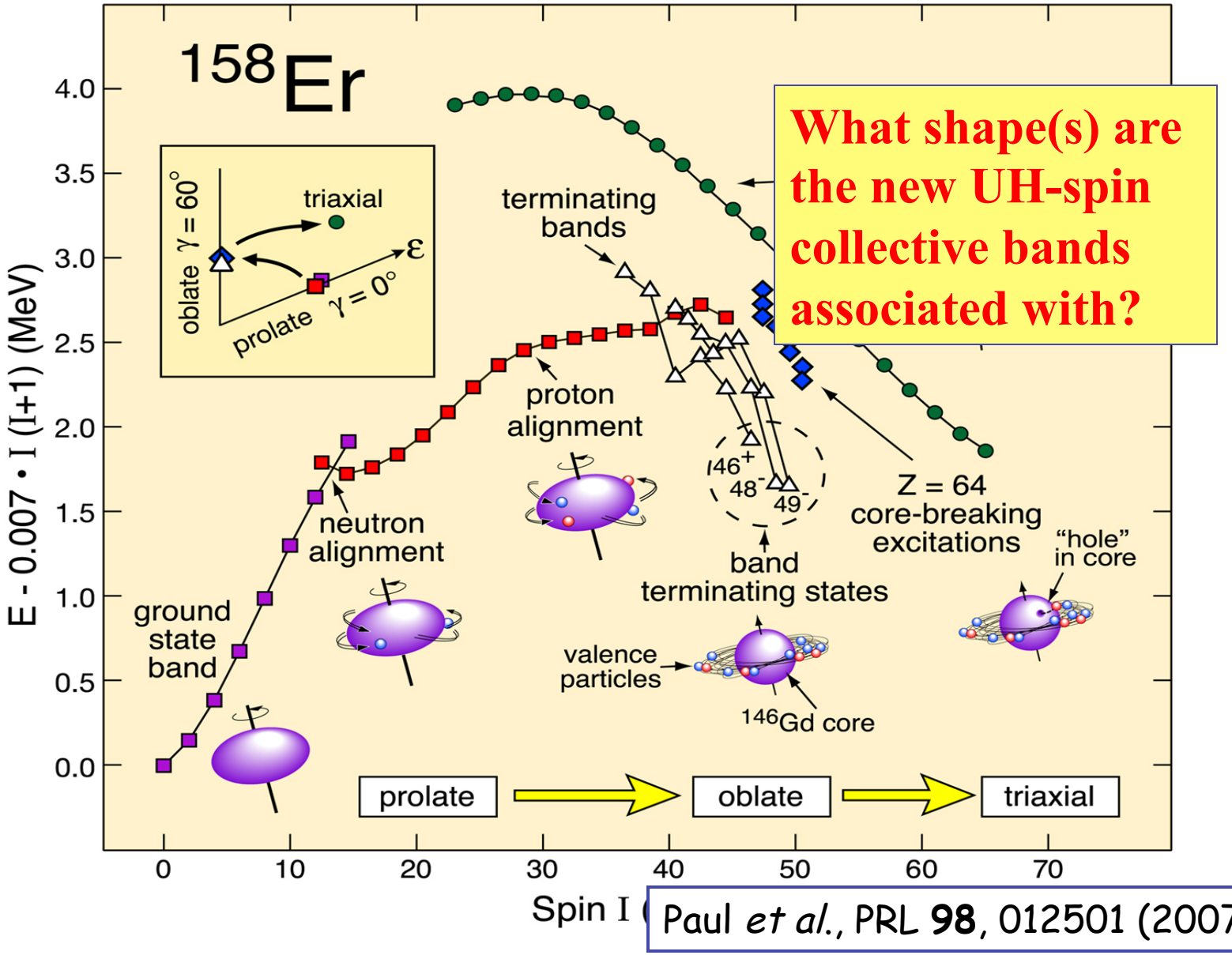
The 1st ultrahigh spin band in ^{158}Er



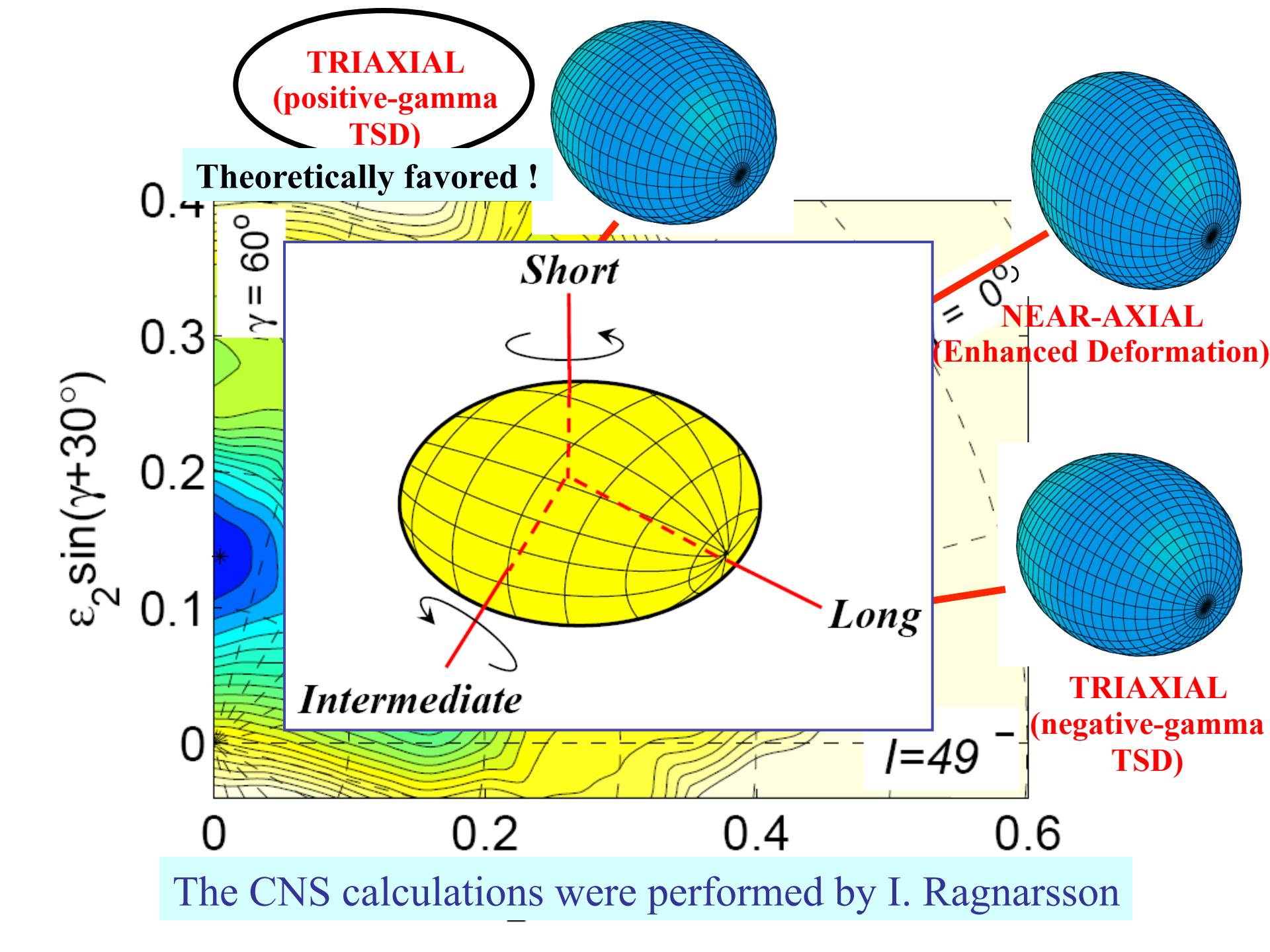
The observation of collective bands at ultrahigh spin in the Erbium nuclei opened a new chapter in the story of rapid nuclear rotation.

Paul *et al.*, PRL **98**, 012501 (2007).

Along the Yrast Line in ^{158}Er



Paul *et al.*, PRL **98**, 012501 (2007).



The CNS calculations were performed by I. Ragnarsson

Asymmetric shapes in nature

Typical size of diameter (unit: meter)

10^{20}

10^{8}

10^{7}

10^{6}

10^{5}

10^{2}

10^{0}

10^{-5}

10^{-6}

10^{-7}

10^{-8}

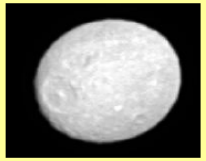
10^{-9}

10^{-14}

10^{-15}

Galaxy

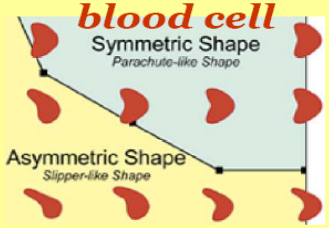
Planet



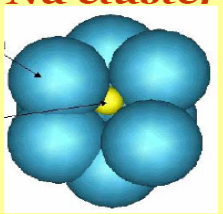
Asteroid

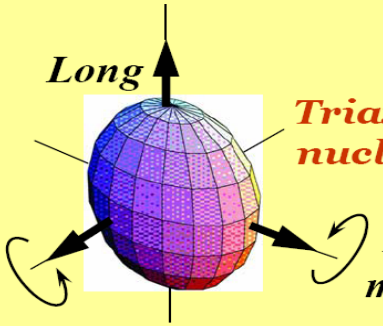
The "bean" in Chicago Millennium park

Human red blood cell



Na cluster

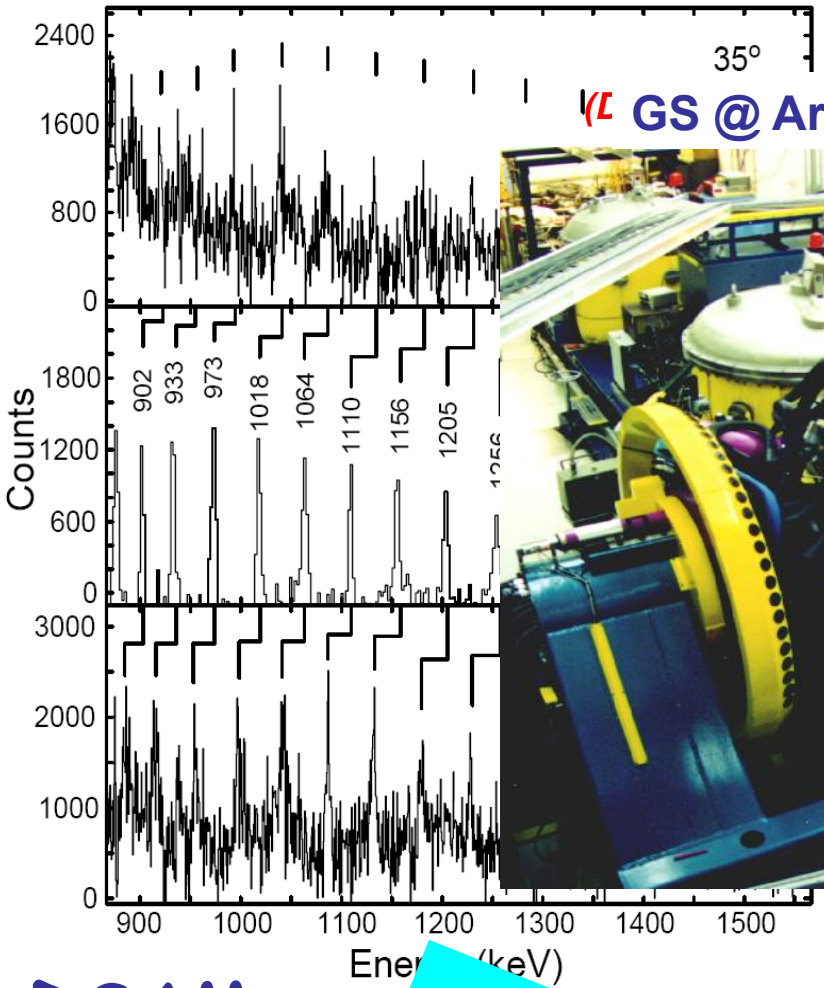




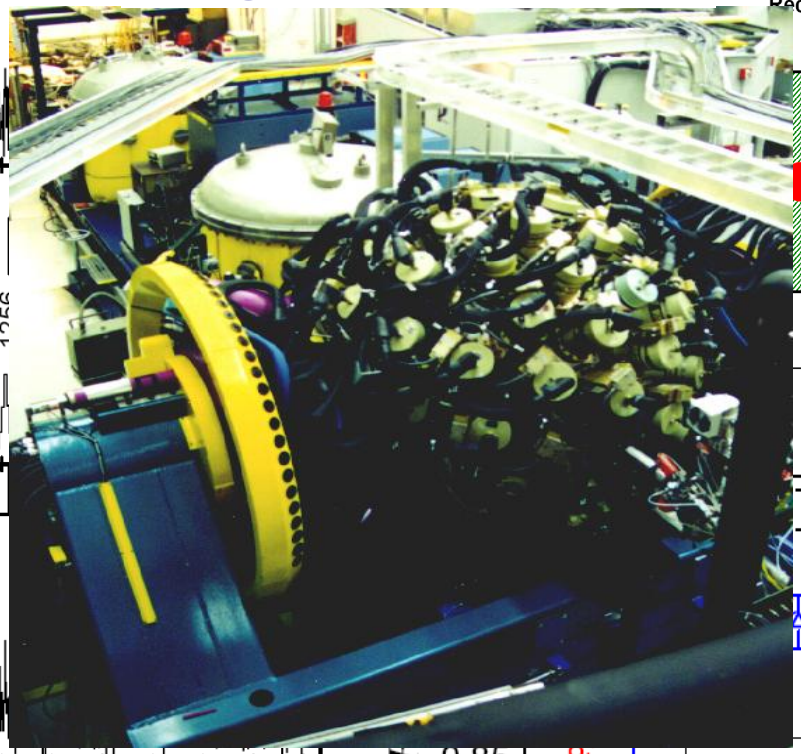
Wang, Riley et al.

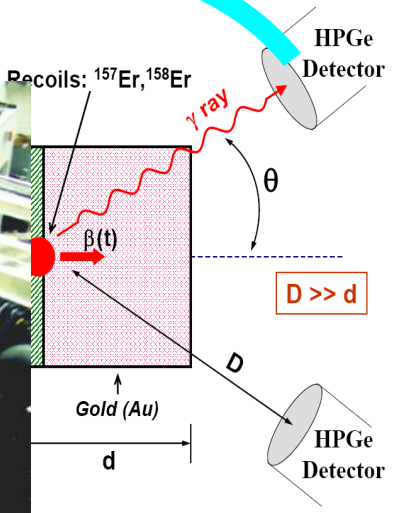
Wang *et al.*, Phys. Lett. B **702**, 127 (2011).

^{158}Er UH band 1

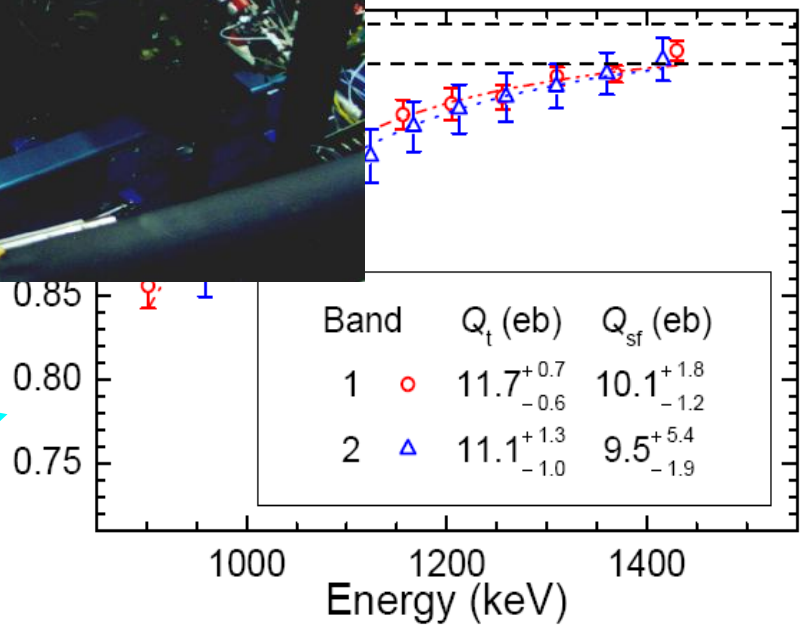


GS @ Argonne Natl. Lab



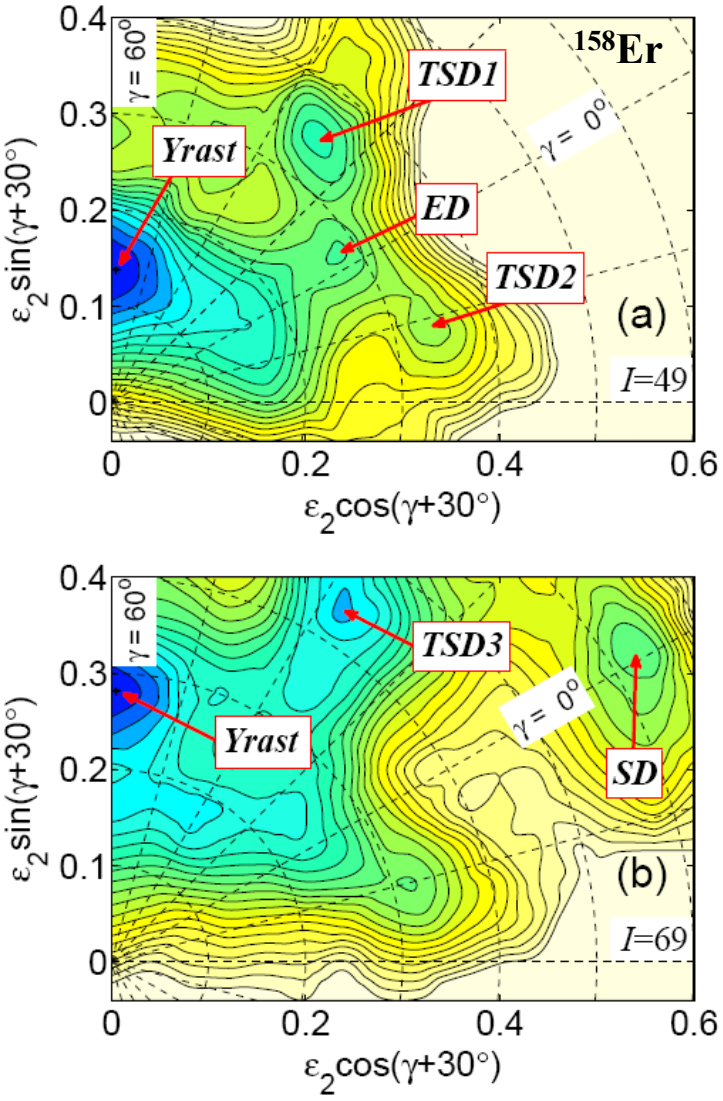


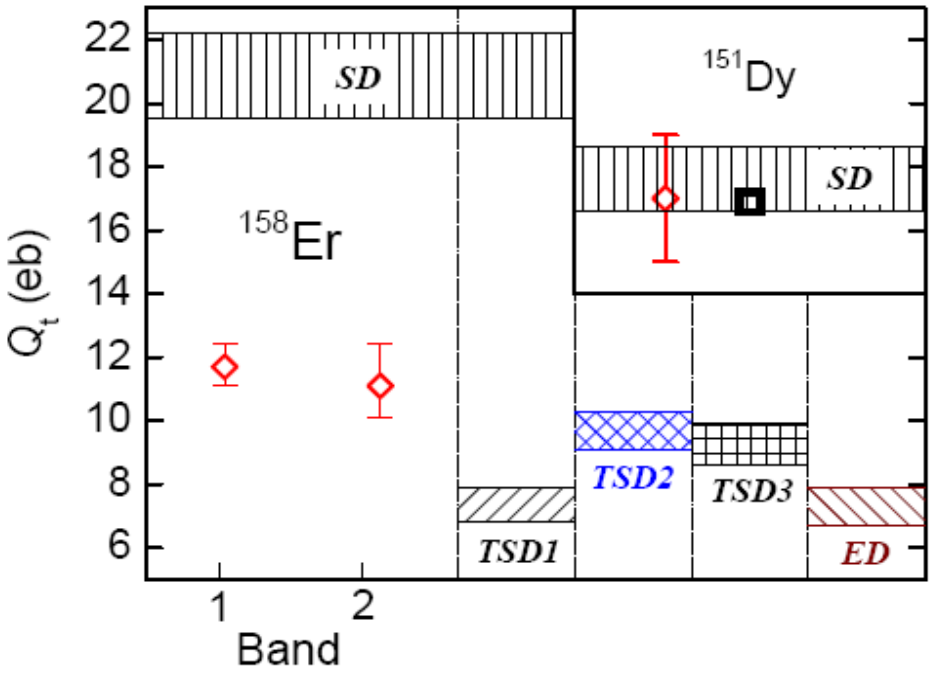
DSAM expt in 2009



CNS calculations

Wang *et al.*, Phys. Lett. B **702**, 127 (2011).





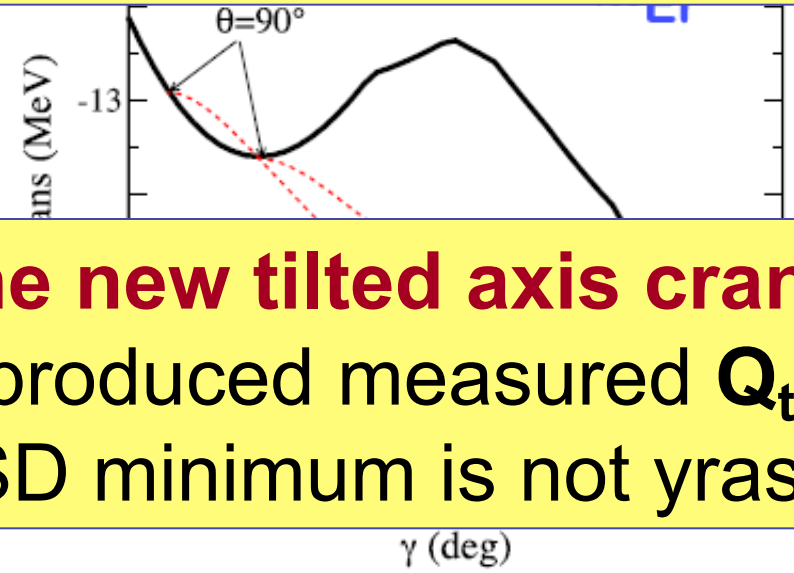
Measured Q_t values in ^{158}Er too large!

....

Hence, ^{154}Er expt – ^{151}Dy SD values and more…

- ***The CNS calculations do not account for the Q_t data satisfactorily.***
- *What do other theoretical approaches predict?*

The puzzling observations in our Erbium-158 work have recently motivated more theoretical studies.



The TSD minimum of rotation about the intermediate

The new tilted axis cranking (TAC) calculations reproduced measured Q_t (10.5 eb), but the related TSD minimum is not yrast until spin **~ 70hbar.**

considered.

FIG. 2 (color online). Lowest Routhians in ^{158}Er calculated by means of SCTAC (Nilsson potential) at fixed ε_2 and ω as a function of γ for rotation about the x axis (solid line) compared to those calculated at $\gamma = 15°$ and $22°$ as functions of θ (dashed lines). In the latter case, the Routhians are drawn by uniformly scaling the range of $0° \leq \theta \leq 90°$ into the corres of γ.

shape. The is) and α The short, spectively;

Shi *et al.*, Phys. Rev. Lett. **108**, 092501 (2012).

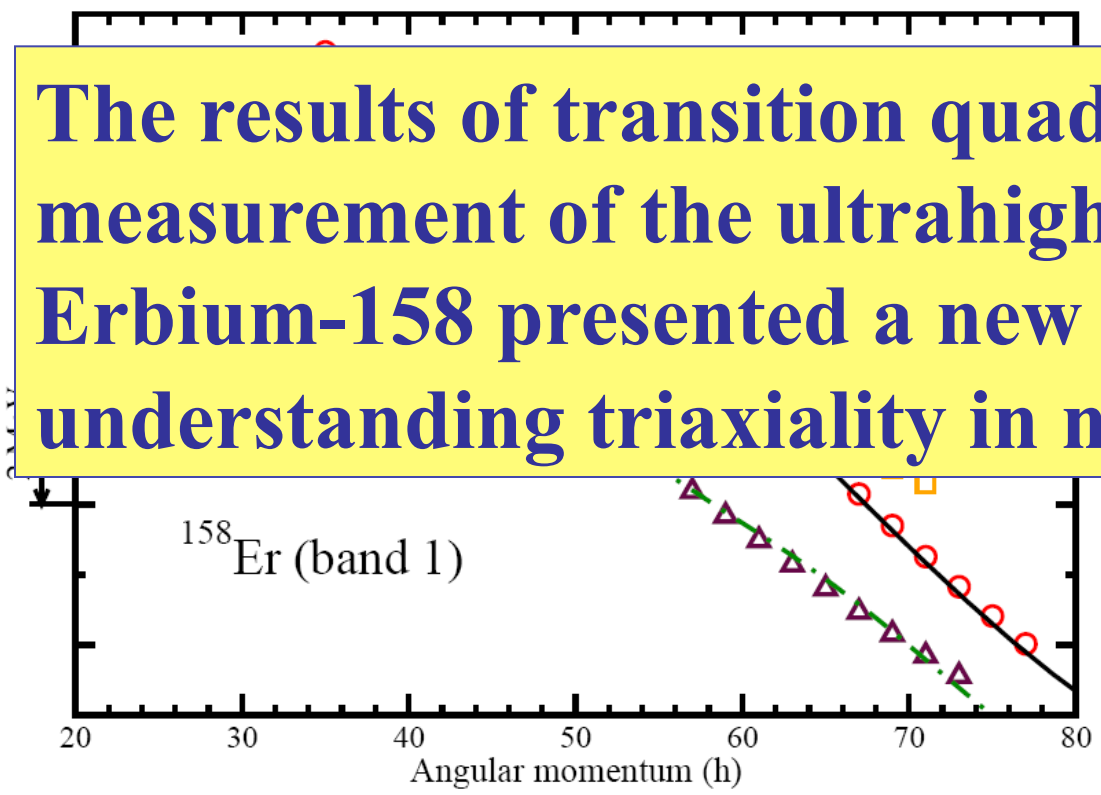
Rotating nuclei at ultrahigh spin: density functional theoretical analysis of ^{158}Er.

A. V. Afanasjev,[1,2] Yue Shi,[3] and W. Nazarewicz[2,4,5]

[1] *Department of Physics and Astronomy, Mississippi State University, MS 39762*

Where are the band structures associated with the most energetically favored TSD minimum in the spin range **30 – 60hbar?**

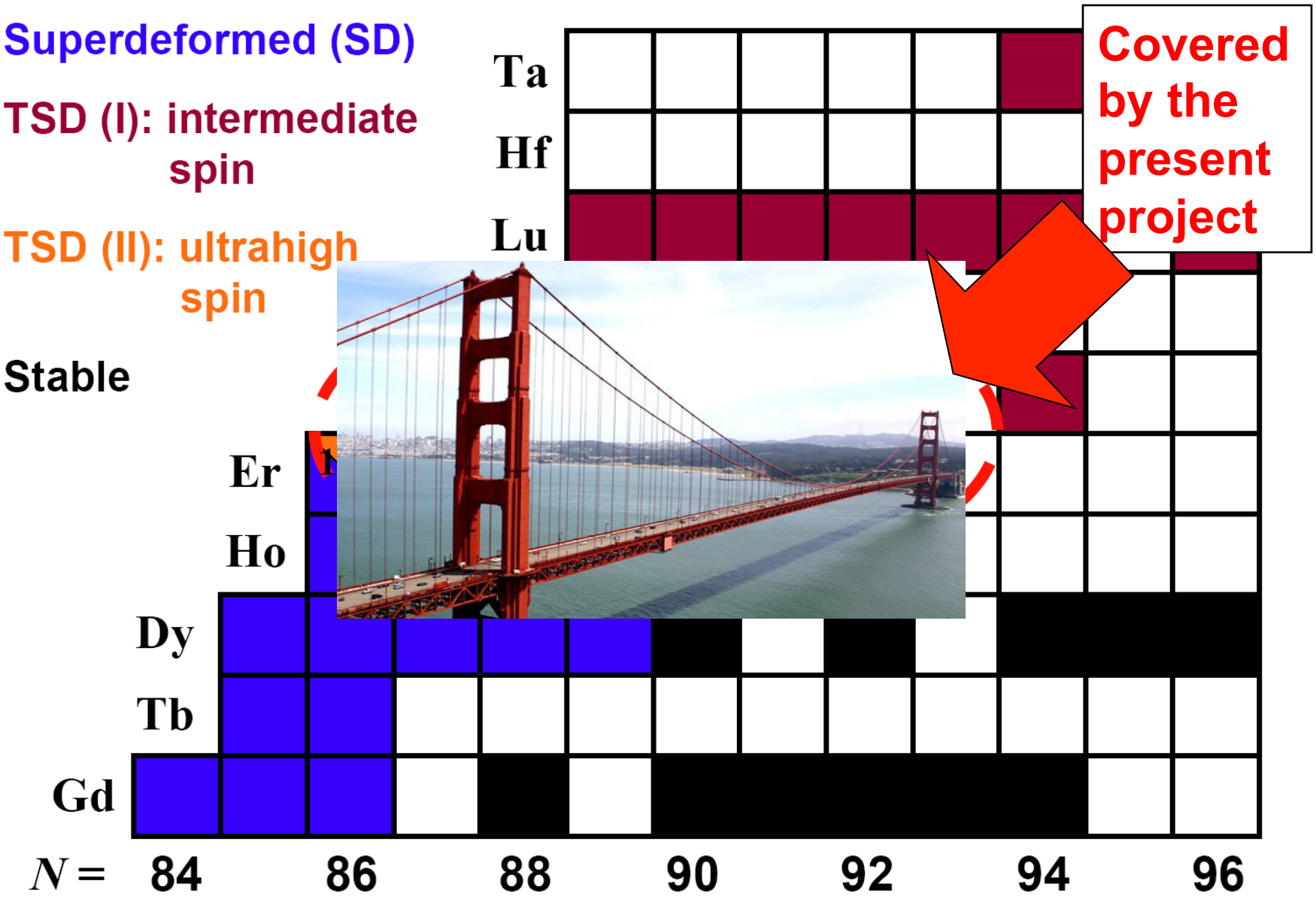
The results of transition quadrupole moment measurement of the ultrahigh spin bands in Erbium-158 presented a new challenge for understanding triaxiality in nuclei.



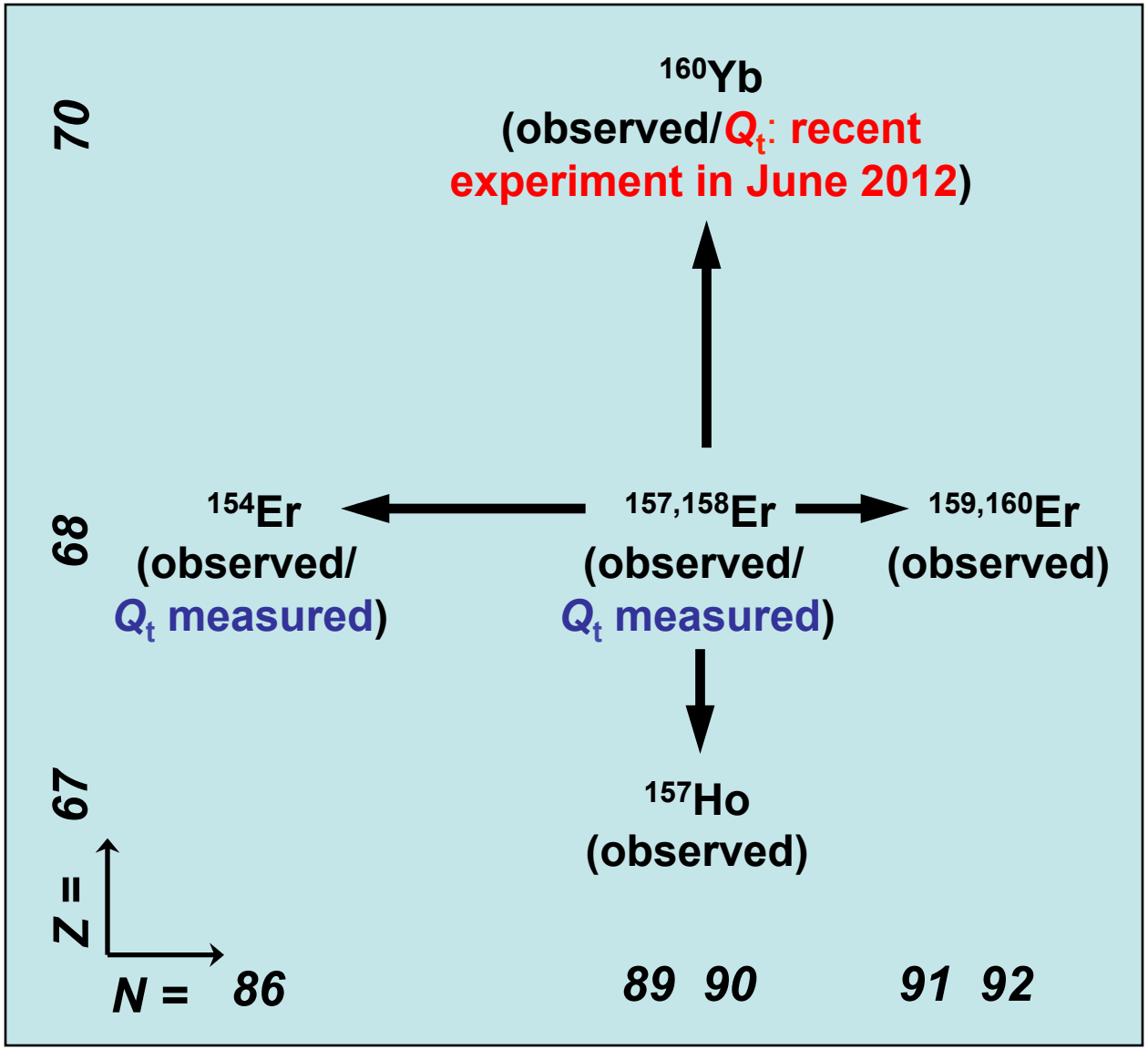
Courtesy of Anatoli Afanasjev

Cranked relativistic mean field (CRMF) and cranked Skyrme Hartree-Fock (CSHF) theories are employed.

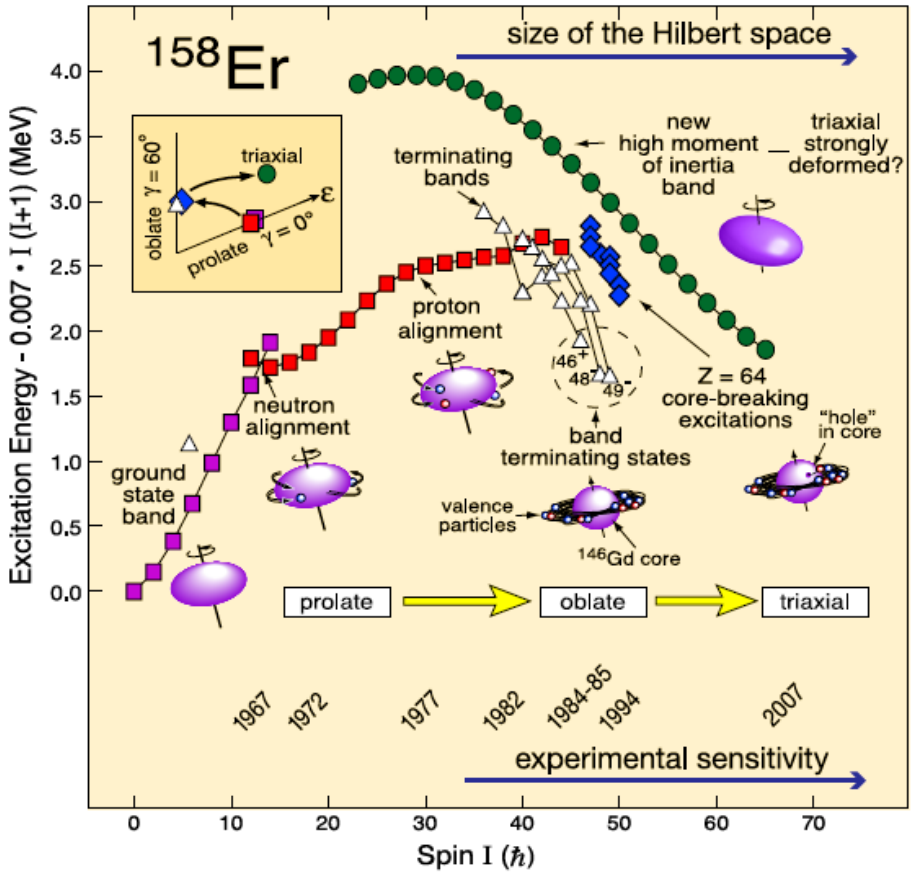
Perspective: An extended study of collective bands at spins beyond band termination in the rare earth region

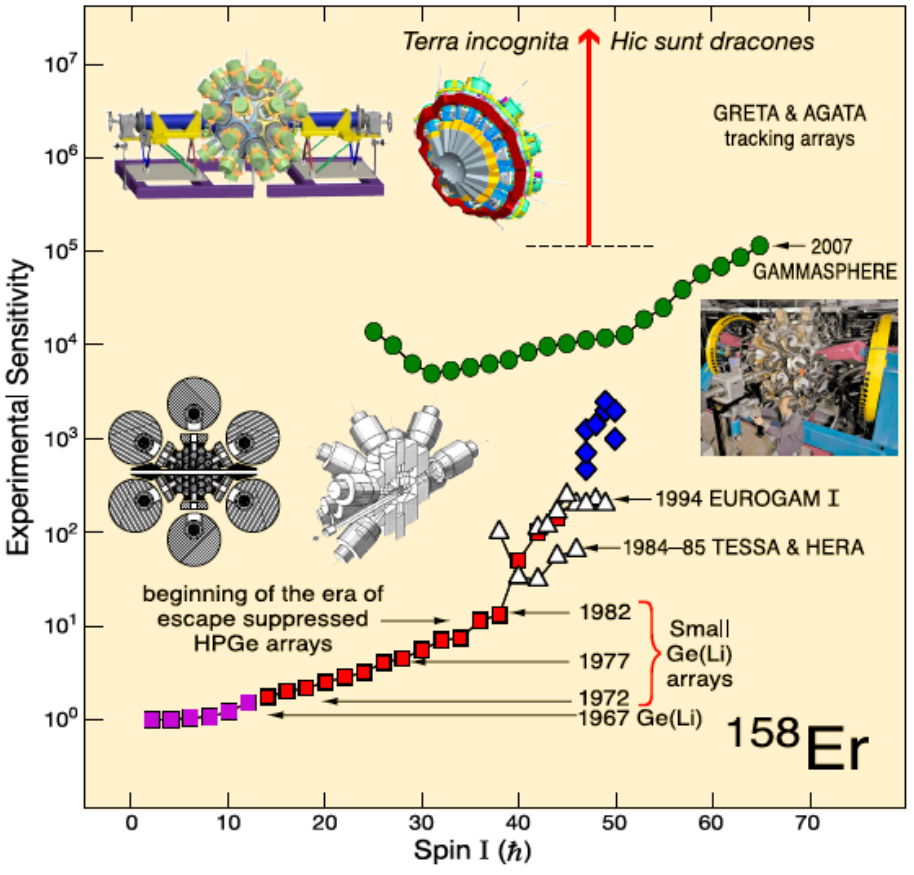


Status of the project



The Structural Evolution of ^{158}Er in Excitation Energy, Spin, Intensity and Time





Embodied in *"Nuclear Physics: Exploring the Heart of Matter": National Academies Decadal Survey of Nuclear Physics (NP 2010)*

ACKNOWLEDGEMENT

North America

FSU: X. Wang, M. A. Riley, S. M. Miller, J. S. Baron;
ANL: M. P. Carpenter, C. J. Chiara, R. V. F. Janssens, F. G. Kondev, T. Lauritsen, S. Zhu; ***USNA***: D. J. Hartley; ***UTK***: L. L. Riedinger;
ND: U. Garg, J. Matta, A. D. Ayangeakaa; ***ORNL***: D. C. Radford;
ARL: J. J. Carroll, J. Gaison; ***LBNL***: P. Fallon, M. K. Petri

Europe

Liverpool: E. S. Paul, A. J. Boston, H. C. Boston, P. Hampson, D. Judson, P. J. Nolan, J. Rees, J. Revill, S. V. Rigby, C. Unsworth;
Daresbury: J. Simpson, J. Ollier; ***Lund***: I. Ragnarsson

Thank you!

The story is continuing…