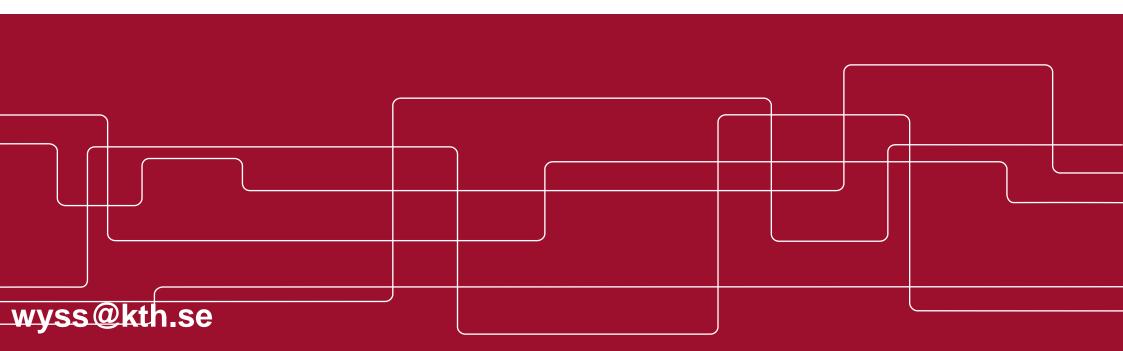


# Discoveries that change the course of a field

#### **Ramon Wyss**



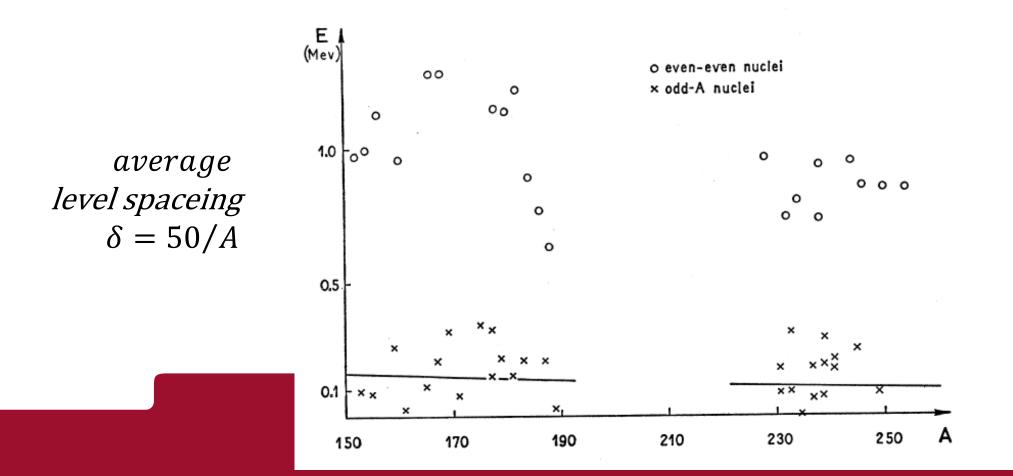
#### Possible Analogy between the Excitation Spectra of Nuclei and Those of the Superconducting Metallic State

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(Received January 7, 1958)

The evidence for an energy gap in the intrinsic excitation spectrum of nuclei is reviewed. A possible analogy between this effect and the energy gap observed in the electronic excitation of a superconducting metal is suggested.





## Possible Analogy between the Excitation Spectra of Nuclei and Those of the Superconducting Metallic State

The evidence for an energy gap in the intrinsic excitation spectrum of nuclei is reviewed. A possible analogy between this effect and the energy gap observed in the electronic excitation of a superconducting metal is suggested.



## Start of BCS and Hartree Fock Bogolyubov theory of nuclei

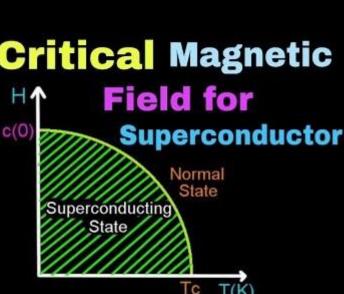


#### EFFECT OF NUCLEAR ROTATION ON THE PAIRING CORRELATION

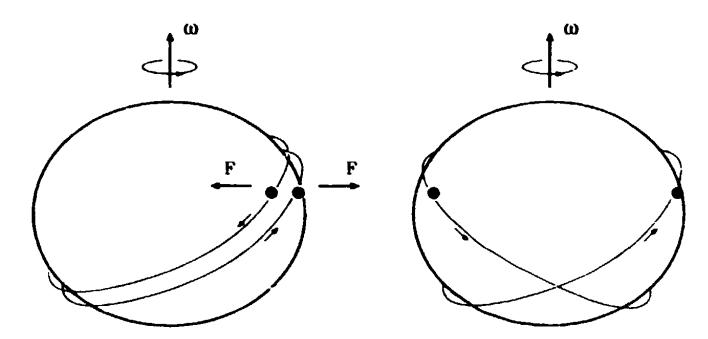
Ben R. Mottelson and J. G. Valatin\*

NORDITA and The Institute for Theoretical Physics, University of Copenhagen, Copenhagen, Denmark (Received November 8, 1960)

An analogy with the correlations in superconductors has proved to be rather fruitful in interpreting the nuclear features mentioned above. ' Pursuing this analogy, the close formal correspondence of the equations of motion in a constant magnetic field and in a rotating reference system suggests that the critical magnetic field phenomena of superconductors should also have their counterpart in the rotational spectra of nuclei.







Indeed, the pairing force couples two particles in time- reversed single-particle states, and a rotation has an opposite effect on the particles forming the pair. The Coriolis forces act in opposite directions and tend to decouple the pairing correlations. This is in analogy with the effect of the magnetic forces in a metal, which act with a different sign on electrons moving in opposite directions and destroy the pairing when the field reaches a critical value. The observation or nonobservation of this effect in the rotational spectra of nuclei could serve as a test of the description of the pairing correlations in nuclei.



## Mottelson-Valatin effect (nuclear Meissner effect)

#### Estimation of the critical spin ('frequency')

• 'For Ic> 12 in A=180 and Ic>18 for A=238'

#### And

• The moment of inertia **J** will approach **J**\_rigid

## Inspiration from studies at Berkley...

- 1963-65 Hans Ryde was on sabbatical at Cal Tech
- He visited Dick Diamond and Frank Stephens, world leaders in studying 'high-spin' states using heavy ions from the HILAC and various detectors: conversion electron, Nal, early small Ge(Li)
- Ground-state bands in deformed nuclei had regular spacings, evidence for *centrifugal stretching -* physics in I = 12 - 18 range

Transition	Yb1**	Yb1**	HCI00	H(1++	Hfute	Hfm	WW	WIN	W
$2 \rightarrow 0$	122.5 A	101.8 A	158.7 A	123.9 A	100.0 A	94.5 A	122.9 A	111.9 A	108.7
$4 \rightarrow 2$	261.5 A	227.9 A	311.0 A	261.1 A	220.6 A	213.4 A	254.0 A	243.1 A	239.8
$6 \rightarrow 4$	374.0 A	337.4 A	426.9 A	371.1 A	320.5 A	319.1 A	350.3 A	349.2 A	350.9
8 -+ 6	461.3 A	430.0 A	509.5 A	456.1 A	400.2 A	408.8 A	419.3 A	432.5 A	440.6
$10 \rightarrow 8$	528.4 A	506.8 A	564.0 A	522.0 A	462.0 A	483.6 A	469.6 A	498.0 A	508.2
$12 \rightarrow 10$	574.5 B	567.8 A	593.8 A	569.4 A	510.0 A	543.1 A	512.5 A	551.2 A	557.3
$14 \rightarrow 12$	606 C	602.7 C	613.4 C	606.5 C	550.3 A	588.6 A	548.5 A	594.0 B	595.1
$16 \rightarrow 14$		627.8 C			583.7 A	621.9 B	576.2 B		624.2
$18 \rightarrow 16$					614.3 B	641.8 B	596.8 C		
$20 \rightarrow 18$					652 C				*
		Stephens	s, Lark, Di	amond, N	ucl. Phys.	<b>63</b> , 82 (1	965)		KTI KTI
				NCNP 2	011				VETENSK OCH KON

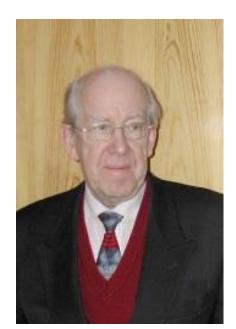
Ground-state rotational band transitions



8

### Stockholm - 1968

- Hans came back to Stockholm in 1965
- Led the effort to extract an α beam from the 225 cm cyclotron at the Institute of Physics
- March, 1968 started working with a young grad student, Arne Johnson (14 years younger than Hans)
- Performed experiments with two 43 cm<sup>3</sup> Ge(Li) detectors and the reaction <sup>160</sup>Gd(α,Xn)<sup>160</sup>Dy, <sup>161</sup>Dy





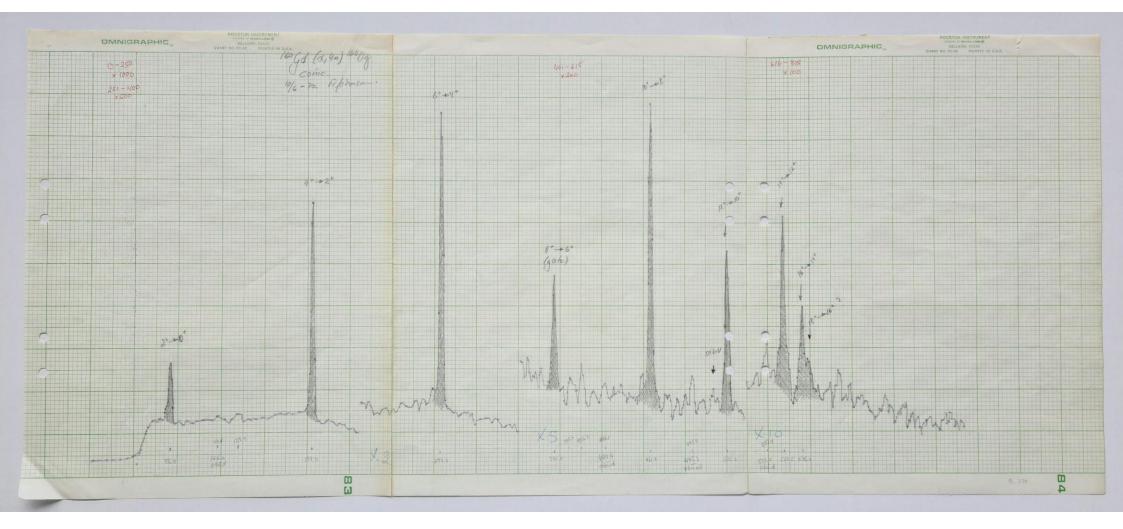




## Program to study odd-A nuclei



## Arne Johnson original spectrum 160Gd(alpha,4n)160Dy

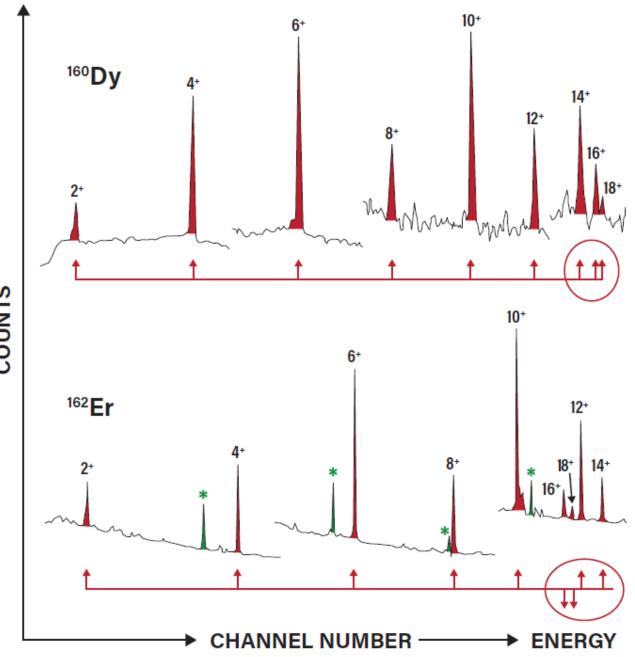


160 Dy- Original plat June 10, 1870 OMNIGRAPHIC.

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he 이제는 등은 특별 위원은 문질 모든을 연합했습니 것을 분석할 <u>방문을 받는 방문을 받</u> 을 만을 받을 것을 받았다. 한 방문을 받을 것을 받을 것을 한 것을 하는 것을 하는 것을 하는 것을 받았다. 한 방문을 받을 것을 하는 것을 수 있다. 것을 하는 것을 수 있는 것을 수 있다. 것을 수 있는 것을 수 있는 것을 수 있는 것을 수 있는 것을 수 있다. 것을 수 있는 것을 수 있다. 것을 수 있는 것을 수 있다. 것을 수 있는 것을 수 있다. 것을 수 있는 것을 수 있다. 것을 것 같은 것을 것 같이 것을 수 있는 것을 수 있다. 것을 것 같이 것 같이 같이 것 같이 것 같이 것 같이 것 같이 같이 것 같이 않는 것 같이 않는 것 같이 같이 않는 것 같이 않는 것 것 것 것 같이 것 같이 것 같이 것 같이 않는 것 같이 않는 것 않는 것 같이 않는 것 같이 않는 것 같이 않는 것 않는 것 같이 않는 것 않는 것 않으니 않은 것 않는 것 않은 것 않는 것 않으니 않는 것 않는 것 않는 것 않는 것 않은 않다. 것 않 것 같이 않 않은 것 않이 않 않 않 않 않 않은 것 않았다. 것 않은 것 않은 것 않 않았다. 것 것		김 동물 관광적	글글글등리		
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Firme Johnson





COUNTS

Dear Arne and Hans,

Thank you for the preprint of your note which indeed makes a very exciting story. It appears that you have rather convincing evidence for the occurrence of something quite remarkable for angular momentum values in the region I  $\approx$  16; this is exhibited, perhaps, even more dramatically in a plot of the moment of inertia as a function of the rotational frequency (see the enclosed figure). The frequency is defined by the canonical relation appropriate for an axial symmetric rotor

$$\omega = \frac{dE}{d\sqrt{1}(1+1)}$$

OF

1-1

 $\omega^2 = 4 \mathbf{I}(\mathbf{r}_{+1}) \left(\frac{d\mathbf{\tilde{e}}}{d\mathbf{r}(\mathbf{r}_{+1})}\right)^2$ 

In the last expression, the energy derivative is taken from the observed transition energies

- --- .

$$\left(\frac{d\varepsilon}{dI(I+i)}\right)_{I(I+i)} = \frac{\varepsilon(I_i) - \varepsilon(I_i-2)}{4I_i - 2}$$

The moment of inertia is also defined in terms of the derivative of the observed energy

$$\frac{23}{\pi^2} = \left(\frac{dE}{dI(I+1)}\right)^2$$

Another interesting feature of your data concerns the value of 3 at the singular point. If the pairing correlation were to completely disappear, one would expect  $3 = 3_{\tau_{eff}}$ . However, since the transition frequency for neutrons and protons may be quite

 $\overset{*}{=} \frac{1}{\mathcal{I}} \left( \mathbb{I}_{i} (\mathcal{I}_{i}(i) + (\mathcal{I}_{i}^{-2}) (\mathcal{I}_{i}(i)) \right)$ 

KØBENHAVNS UNIVERSITET MIELS BOHR INSTITUTET 16 October, 1970

Forskningsinstitutet för Atomfysik

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Stockholm

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Ryde

Johnson and Dr. H.

Dr. A.

BLEGDAMSVEJ 17, 2100 KØBENHAVN Ø TELEFON: (M) TKA 1616 TELEGRÅMADR.; PHYSICUM, KØBENHAVN different, the value of  $\exists$  is likely to be somewhat below  $\exists \downarrow$  after the first transition.

As a very minor point, it would seem that in referring to the pair correlated state, it would be more appropriate to use the more general expression superfluid rather than superconducting. Also, as you mentioned, the suggested title may be somewhat too general. Another possibility might be "Evidence for a "Singularity" in the Nuclear Rotational Band Structure".

We note that you quote the old article with Pines as a reference for the suggestion of a phase transition; however, this point was first discussed in a paper with Valatin (B.R. Mottelson and J.G. Valatin, Phys.Rev. Lett. 5, 511 (1960)). There is a large subsequent literature on the subject, but it may be difficult to select any particular paper.

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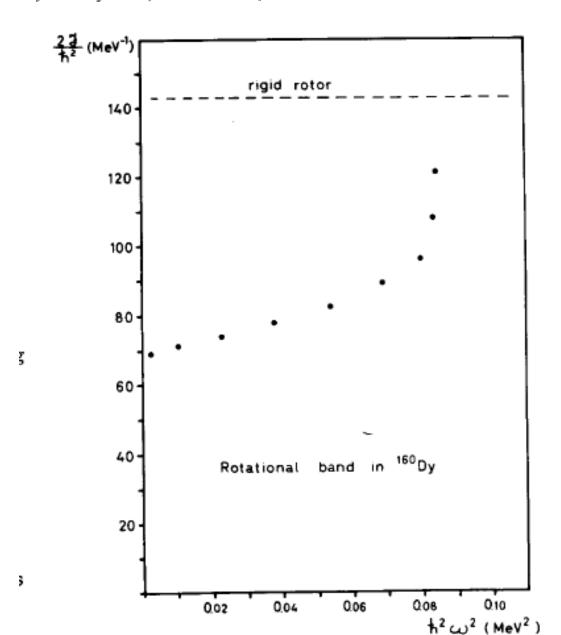
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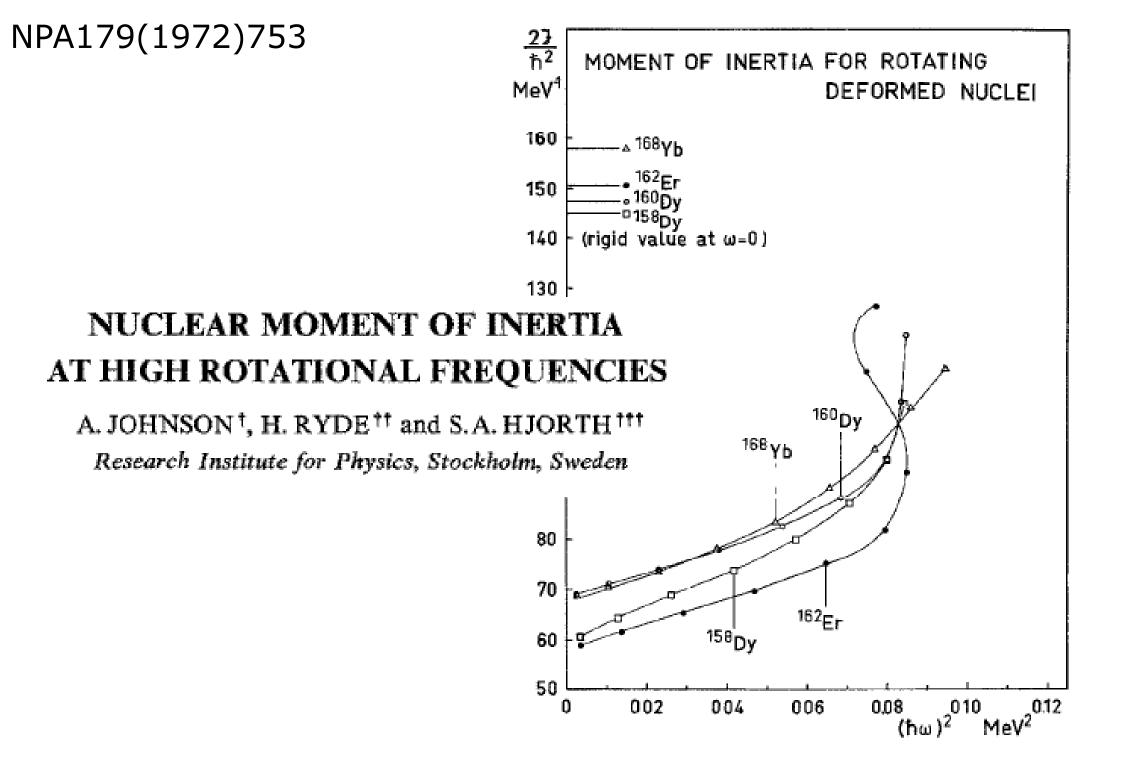
We send our compliments and best wishes for continued successful hunting in this exciting field.

ottelson

#### EVIDENCE FOR A "SINGULARITY" IN THE NUCLEAR ROTATIONAL BAND STRUCTURE PLB34 (1971)605

A. JOHNSON, H. RYDE\* and J. SZTARKIER Research Institute for Physics, Stockholm, Sweden







# Was this the observation of the Mottelson Valatin effect?

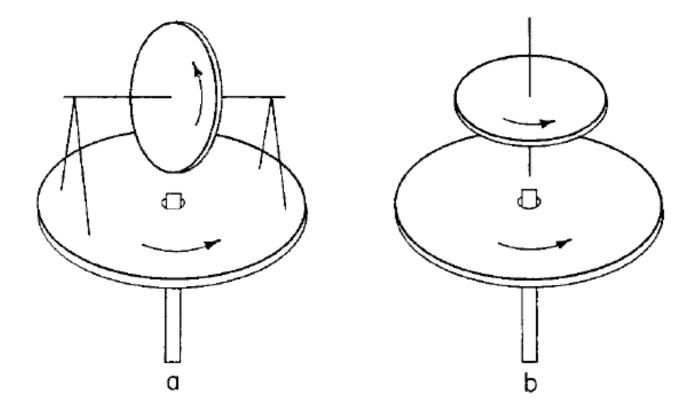
## **CORIOLIS EFFECTS IN THE YRAST STATES**

## F. S. STEPHENS<sup>†</sup> and R. S. SIMON Sektion Physik, Universität München, München, Germany<sup>††</sup>

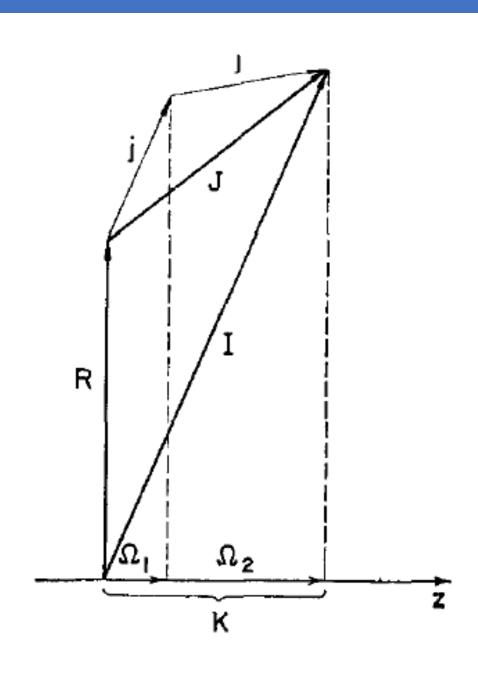
NPA183(1972)157

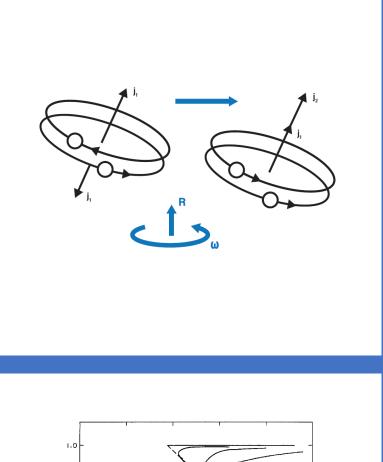
Very recently Johnson et al. have found some irregularities in the rotational energy spacings of rare-earth nuclei just in the region of spin where they are populated heavily in these (HI, Xn) reactions. It is too early to say how general this behaviour is, but it lends very strong support to the previous proposal that a major change is occurring in the **yrast** levels near this point. Johnson *et al.* suggest that this change is due to the phase transition associated with the loss of pairing correlations predicted by Mottelson and Valatin ") to occur at around this spin value.

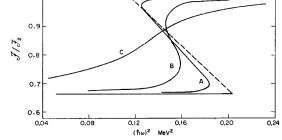
 $H_{\rm c} = -\frac{\hbar^2}{2\mathscr{I}} \langle \Omega \pm 1 | j_{\pm} | \Omega \rangle \sqrt{(I \mp K)(I \pm K + 1)} f(U, V),$ 



#### Coriolis effect on a spinning wheel

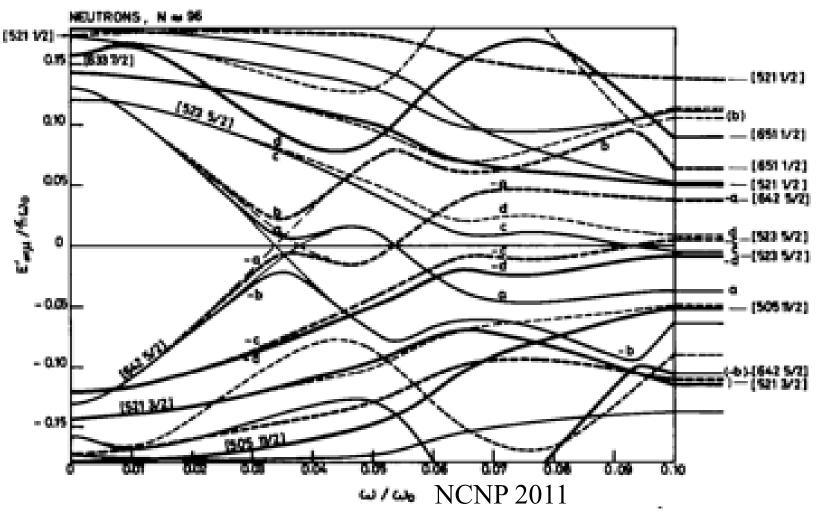




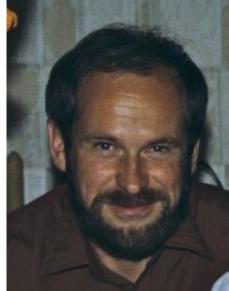


### **Cranked Shell Model - huge success**

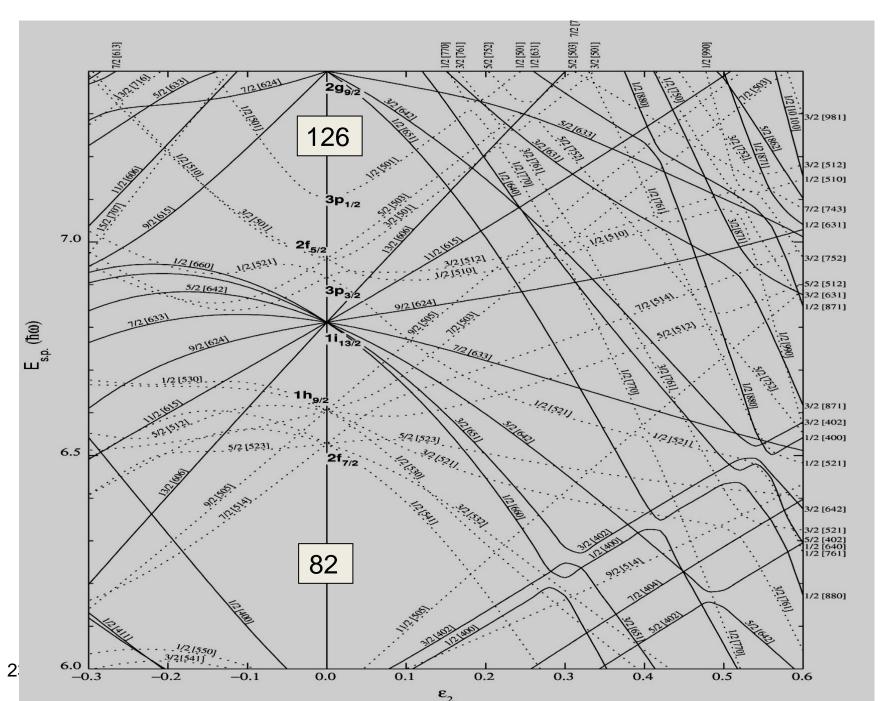
- Ragnar Bengtsson and Stefan Frauendorf, Nucl. Phys. A314, 27; A327, 139 (1979)
- This formalism explained many bands and crossings at high spins in many nuclei







#### **CSM built on deformed single-particle model of Sven Gösta Nilsson from 1950s**

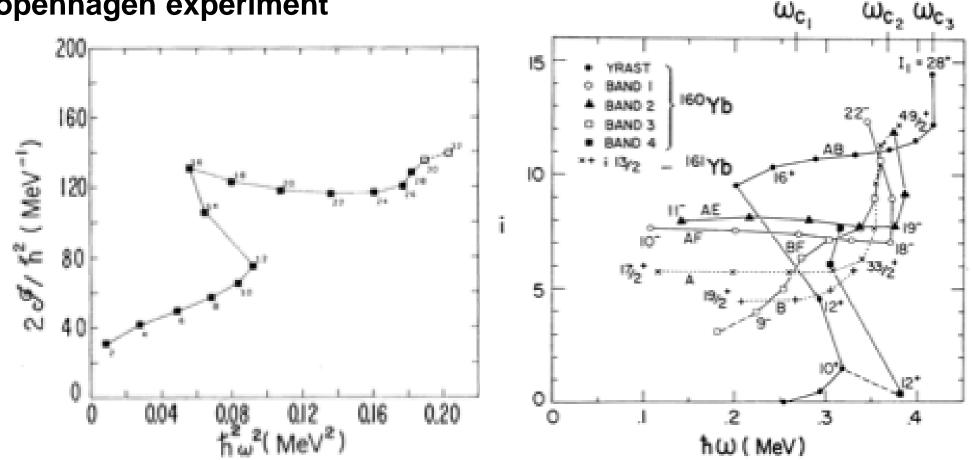






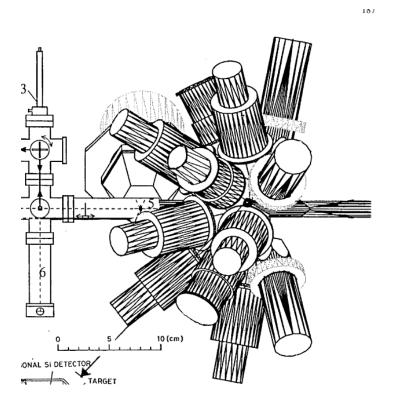
## **1970s - push to I = 20 to 30 regime**

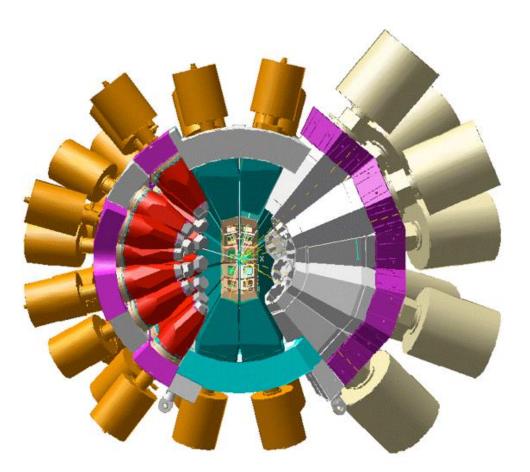
- First case of a second backbend: "Second Discontinuity in the Yrast Levels of <sup>158</sup>Er - I. Y. Lee et al, PRL 38, 1454 (1977) -Berkeley experiment
- Also present in isotone <sup>160</sup>Yb Beck et al., PRL 42, 493 (1979)
  Strasbourg experiment not an isolated occurrence
- Blocking experiment Riedinger et al., PRL 44, 568 (1980) -Copenhagen experiment ω<sub>c.</sub>





## **Unprecedented detector development**





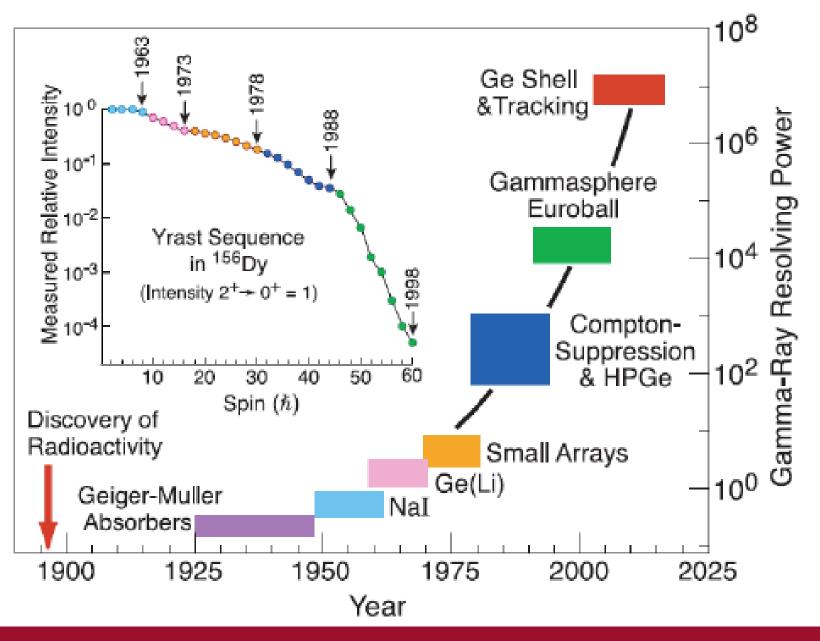
Nordball Pex Array

Euroball

>700 backbends now observed. Lots of important theory work



Huge progress in 40 years in resolving power of γ-ray detector systems and the high-spin states that can be accessed







Nuc Phys. A503 (1989)244

#### SPECTROSCOPY OF <sup>123</sup>La AND CONFIGURATION DEPENDENT PROTON PAIRING

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Manne Siegbahn Institute of Physics, Frescativägen 24, S-104 05 Stockholm, Sweden and

The Royal Institute of Technology, Physics Department I, S-100 44 Stockholm, Sweden

D.J.G. LOVE, A.H. NELSON<sup>2</sup>, D.W. BANES<sup>3</sup> and J. SIMPSON

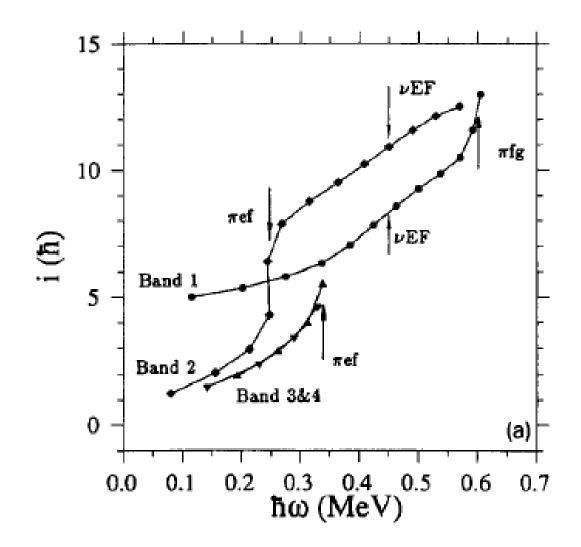
SERC, Daresbury Laboratory, Warrington WA4 4AD, UK

#### A. KIRWAN<sup>4</sup>

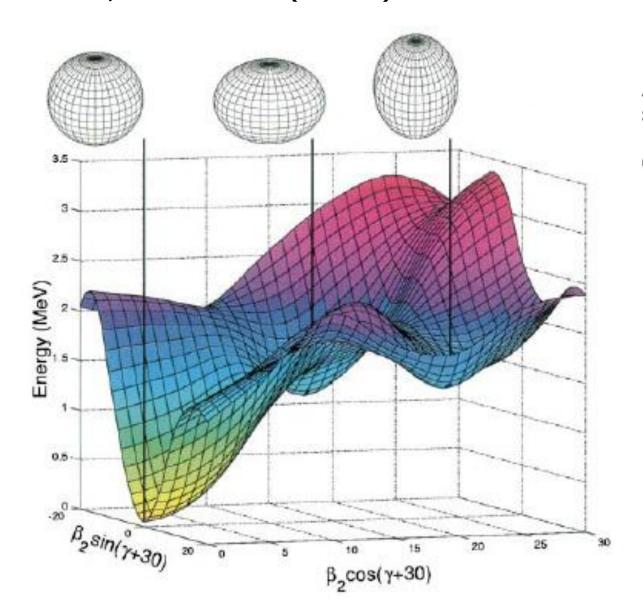
Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 3BX, UK

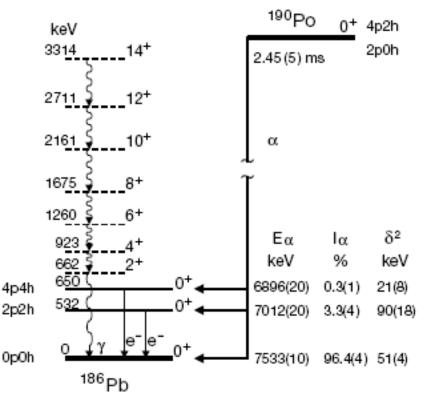
**R. BENGTSSON** 





'The discovery of a prolate-oblatespherical shape triplet of spin \$0^+\$ states in the atomic nucleus \$^{186}\$Pb', A.N. Andreyev, et.al Nature, Vol. 405 (2000) 430





PES calculations with WS potential -> TRS calculations



## **Extended TRS - Model**

- Deformed single particle WS potential
- Liquid drop and Strutinsky shell correction (Wigner Kirkwood)
- Developped symmetry restauration particle number fluctuation via Lipking Nogami correction and gauge symmetry restauration of pairing field via double stretched QQ pairing interaction
- Minimized in deformation space
- Application to high-spin, superdeformed, shape coexistence, high-K isomers, odd-even mass differences, radii, masses, N=Z nuclei, competition of T=1 and T=0 pairing
- Collaborators: W Satula, F Xu, P Magierski, A Bhagwatt



## **HFB-LNC equations**

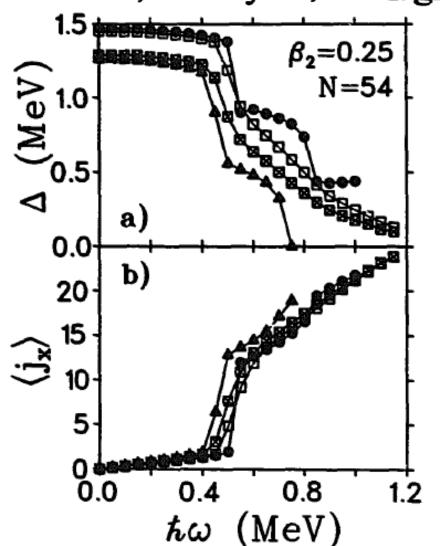
$$\begin{pmatrix} h & \Delta - 4\lambda_2 \kappa \\ -\Delta^* + 4\lambda_2 \kappa^* & -h^* \end{pmatrix} \begin{pmatrix} U \\ V \end{pmatrix} = (\mathscr{E} + \lambda_2) \begin{pmatrix} U \\ V \end{pmatrix},$$

$$\begin{split} h_{\alpha\beta} &= (e_{\alpha} - \lambda)\delta_{\alpha\beta} - \omega j_{\alpha\beta}^{(\alpha)} + \Gamma_{\alpha\beta}, \quad \Gamma_{\alpha\beta} = \sum_{\gamma\delta} \bar{v}_{\alpha\gamma\delta\delta} \rho_{\delta\gamma}, \\ \Delta_{\alpha\beta} &= \frac{1}{2} \sum_{\gamma\delta} \bar{v}_{\alpha\beta\gamma\delta} \kappa_{\gamma\delta}. \end{split}$$

$$\begin{split} \bar{v}_{\alpha\beta\gamma\delta}^{(\lambda\mu)} &= -G_{\lambda\mu} g_{\alpha\beta}^{(\lambda\mu)} g_{\gamma\delta}^{*(\lambda\mu)}, \\ g_{\alpha\beta}^{(\lambda\mu)} &= \begin{cases} \delta_{\alpha\bar{\beta}} & \hat{\lambda} = 0, & \mu = 0, \\ \langle \alpha | \tilde{Q}_{\mu} | \bar{\beta} \rangle, & \hat{\lambda} = 2, & \mu = 0, 1, 2. \end{cases} \end{split}$$

Physica Scripta. Vol. T56, 159-166, 1995

## The Lipkin–Nogami formalism for the cranked mean field



NPA578(1994)45

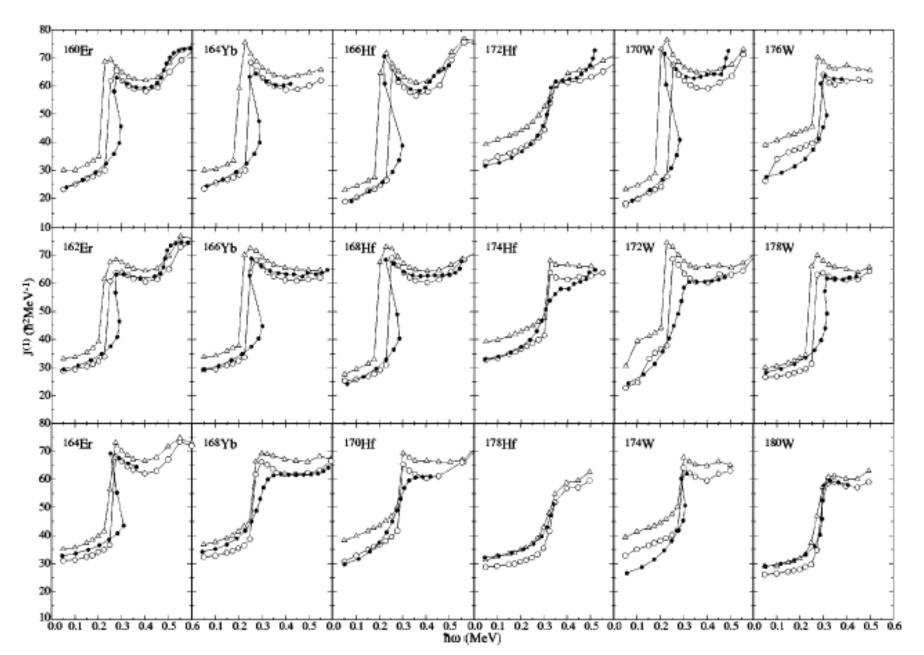
W. Satuła<sup>a,1</sup>, R. Wyss<sup>a</sup>, P. Magierski<sup>b</sup>

Comparision between HFBC, LN and PNP

Mean-field and blocking effects on odd-even mass differences and rotational motion of nuclei

F. R. Xu,<sup>1,\*</sup> R. Wyss,<sup>2</sup> and P. M. Walker<sup>1</sup>

PRC51 (1999)051301





## Is there a Meissner effect in Nuclei?



## Iso cranking hamiltonian

$$\hat{H}^{\omega_{\tau}} = \hat{h}_{\rm sp} - G_{t=1}\hat{P}_{1}^{\dagger}\hat{P}_{1} - G_{t=0}\hat{P}_{0}^{\dagger}\hat{P}_{0} - \vec{\omega}_{\tau}\vec{t},$$

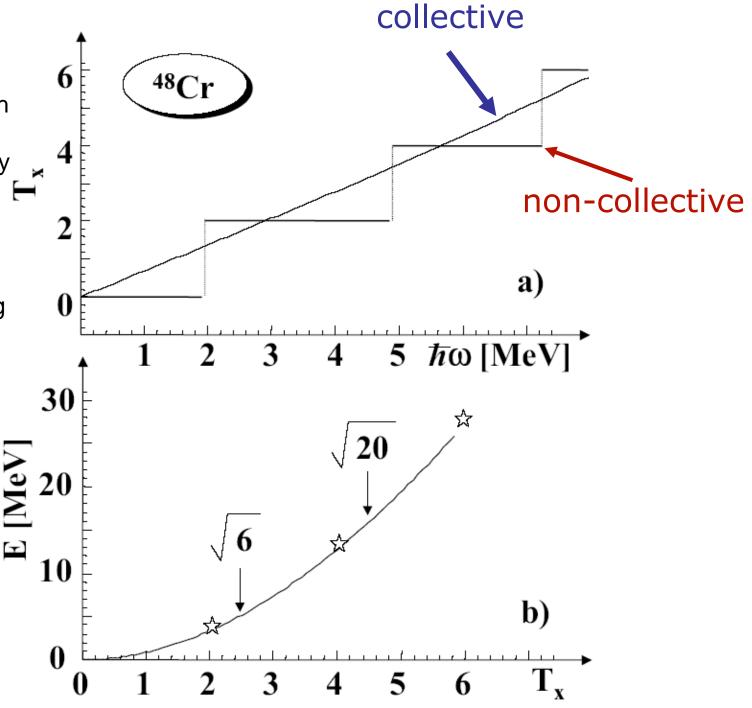
$$\hat{P}_{1\pm1}^{\dagger} = \sum_{i>0} \hat{a}_{in(p)}^{\dagger} \hat{a}_{\bar{i}n(p)}^{\dagger} \quad \hat{P}_{10}^{\dagger} = \frac{1}{\sqrt{2}} \sum_{i>0} (\hat{a}_{in}^{\dagger} \hat{a}_{\bar{i}p}^{\dagger} + \hat{a}_{ip}^{\dagger} \hat{a}_{\bar{i}n}^{\dagger}) \quad P_{0}^{\dagger} = \frac{1}{\sqrt{2}} \sum_{i>0} (a_{in}^{\dagger} a_{\bar{i}p}^{\dagger} - a_{ip}^{\dagger} a_{\bar{i}n}^{\dagger}).$$

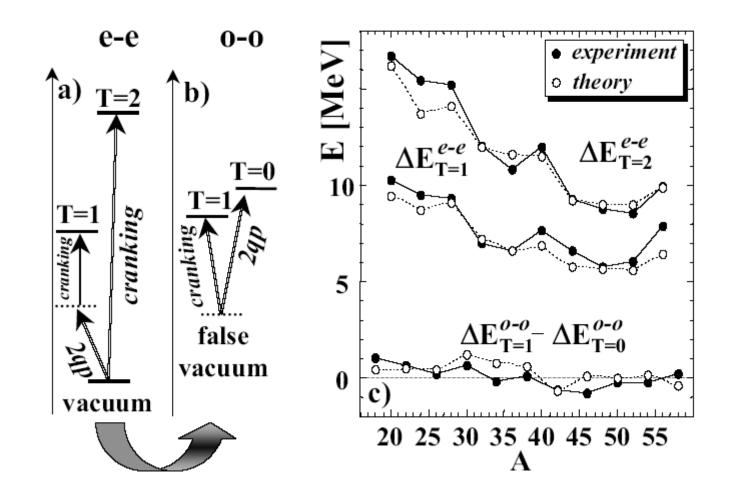
$$\sqrt{\langle \hat{t}_x \rangle^2 + \langle \hat{t}_y \rangle^2} = \sqrt{T(T+1)}.$$

WWW.KTH.SE

In the s.p. Model, one deals with 'non' collective rotations – the values of Tx jump discontinously at the crossing frequencies.

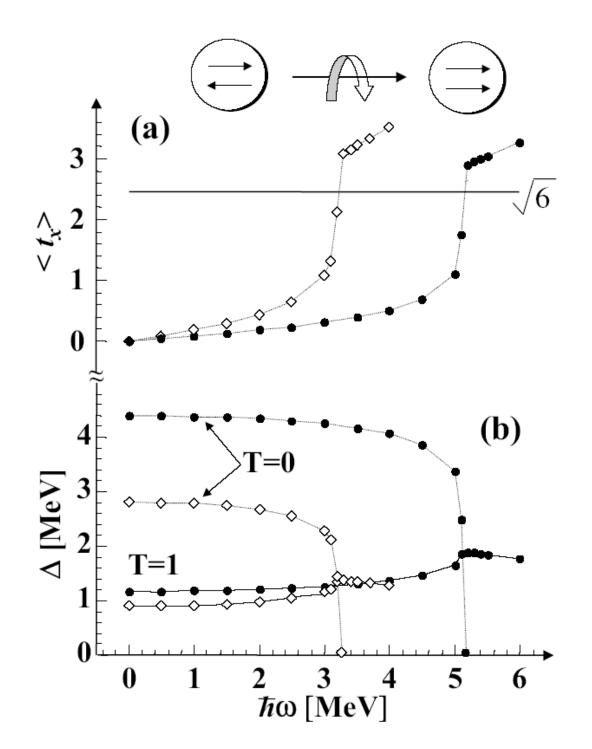
When T=1 pairing is switched on, the rotation is collective (smooth) and the corresponding values for iso spin excitations are given by the cranking condition, <Tx>=sqrt(T(T+1))(taking into account quantum fluctuations)





The alignment in iso space *tx* and the respons of T=1 and T=0 pair field. Calculations for 24Mg and 48Cr.

Meissner effect in isospace!





## Nuclear Physics News 32, 2022 - Issue 2

https://www.tandfonline.com/doi/full/10.1080/10619127.2022.2063000

feature article

## **Fifty Years of Backbending**

R. WYSS<sup>1</sup> D AND M. A. RIIEY<sup>2</sup> <sup>1</sup>KTH Royal Institute of Technology, Alba Nova, 10691 Stockholm, Sweden <sup>2</sup>Department of Physics, Florida State University, Tallahassee, Florida 32306, USA

Thanks for slides from Mark Riley and Lee Riedinger

#### Arne is elegant and he is fun!



From Lee Riedinger, thank you very much!

