Cyclotron Institute Texas A&M University
Nuclear Data Evaluation Center

Data-Based Research Project:

Could revisiting the Principles of a Level Scheme bring new Insight into High-Spin Physics?

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Content

I. Experimental Evidence

II. Level Scheme Re-Concept

III. Insight into High-Spin Physics

I. Experimental Evidence

Case study: ^{171}Yb nucleus high spin rotational bands

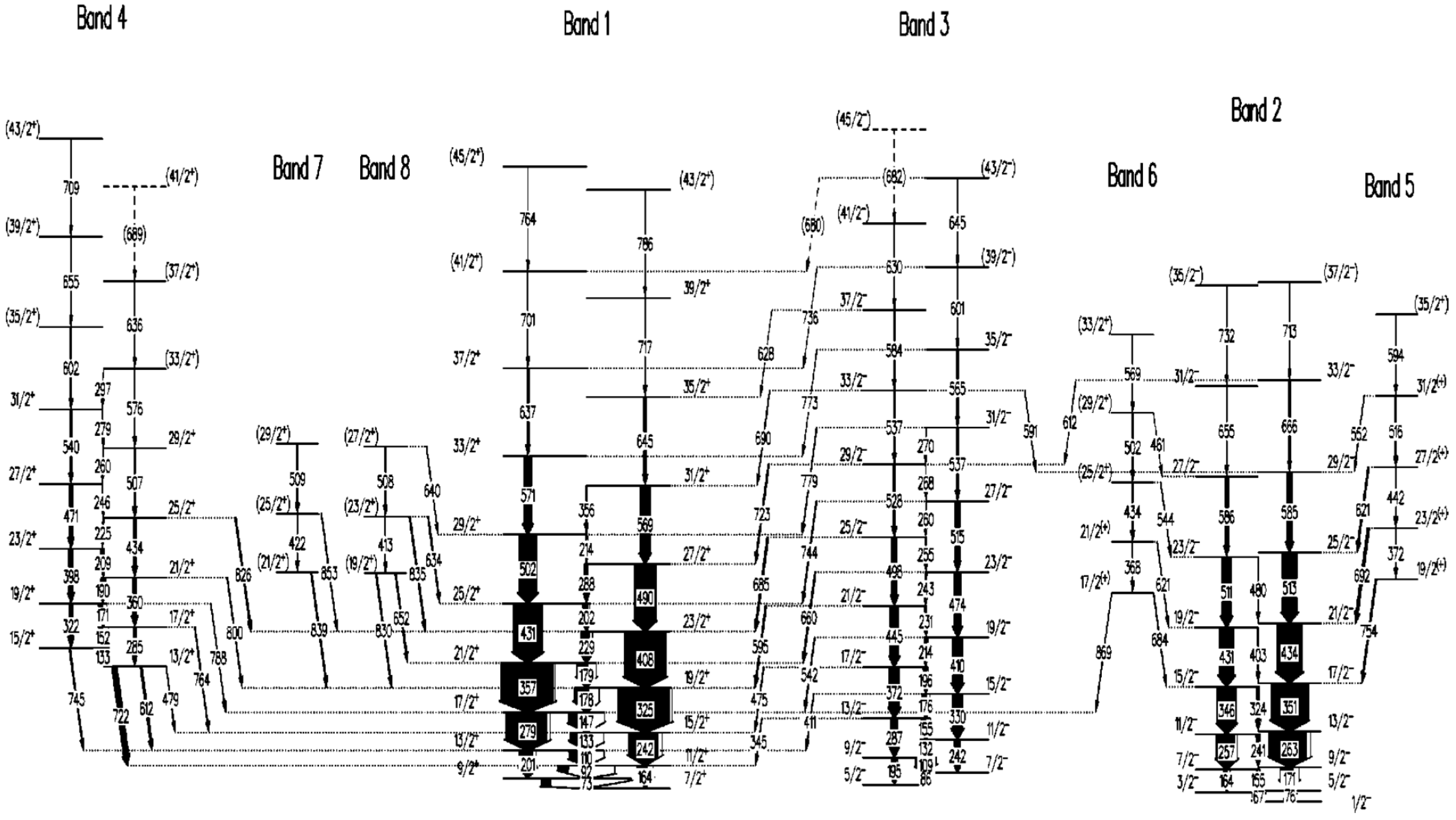


FIG. 5. Level scheme for ^{171}Yb.

D.E.Archer *et al*, Phys.Rev. C57, 2924 (1998)

How the bands can be described? *(ΔE_γ^x, ΔE_γ^y) Differential Coincidence Matrix*

Bohr-Mottelson Collective Rotor

$$E(I)=\frac{\hbar^2}{2\Im}I(I+1),\quad c=\frac{\hbar^2}{2\Im}$$

$$E_\gamma=E(I)-E(I-2)=\frac{\hbar^2}{2\Im}(4I-2)=2c(2I-1)$$

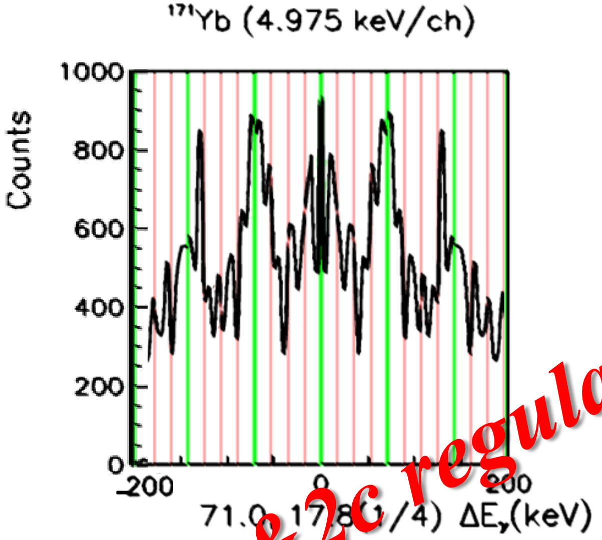
$$\Delta E_\gamma=E_\gamma(I)-E_\gamma(I-2)=8\frac{\hbar^2}{2\Im}=8c$$

New Parametrization (average behavior)

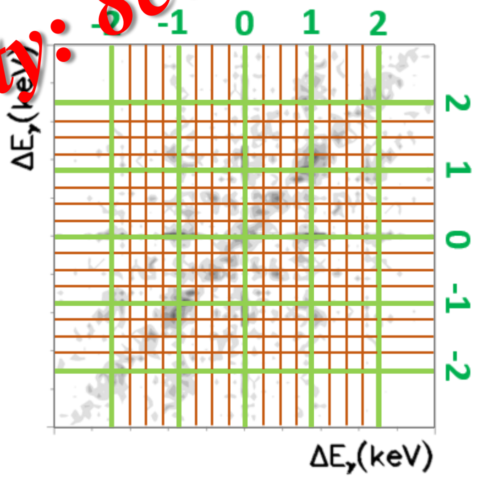
$$E_\gamma=2c(2I+k-1),\ k\ \text{integer}$$

- *2c Moment of Inertia, Real*
- (2*I*+*k*-1) *Angular Momentum, Integer*

Bitmap Distribution



Repeatability: 8c&2c regular grid !



How the bands can be described?

Bohr-Mottelson Collective Rotor

$$E(I) = \frac{\hbar^2}{2\Im} I(I+1), \quad c = \frac{\hbar^2}{2\Im}$$

$$E_\gamma = E(I) - E(I-2) = \frac{\hbar^2}{2\Im}(4I-2) = 2c(2I-1)$$

$$\Delta E_\gamma = E_\gamma(I) - E_\gamma(I-2) = 8\frac{\hbar^2}{2\Im} = 8c$$

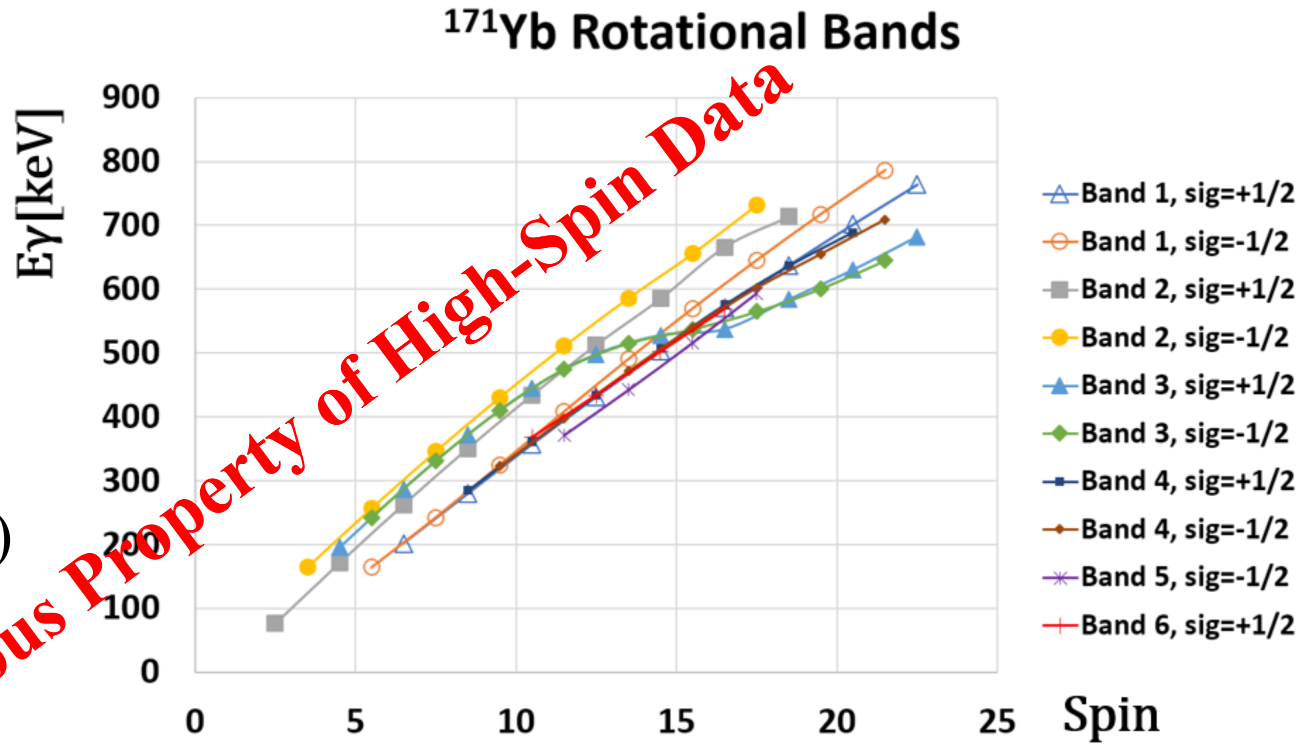


Fig. (Eγ's versus spins)

Repeatability is an Ubiquitous Property of High-Spin Data

New Parametrization (average behavior)

$$E_\gamma = 2c(2I + k - 1), \; k \text{ integer}$$

- *-Quasi-linear beam almost parallel and equidistant*
- *-Average behavior:* $2c(2I+k-1)$, *k integer*
- *-Determine from fit over all bands' γ rays:*

  $2c$, k's, *from* $\Sigma(E\gamma(I)/2c-(2I+k-1))^2 = \min$
- *- Same slope* ($2c$) *for all k-bands* ⇒ *same* $\mathcal{J}^{(2)}_{eff} = \frac{\hbar^2}{2c}$

- *2c Moment of Inertia, Real*
- $(2I+k-1)$ *Angular Momentum, Integer*

Case study: ^{171}Yb nucleus high spin rotational bands

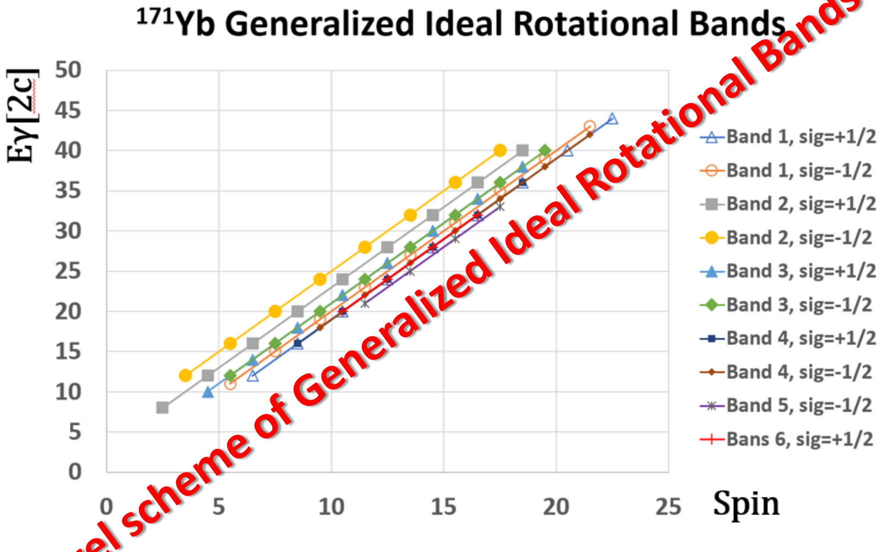


Fig. (Generalized Ideal Rotation Bands)

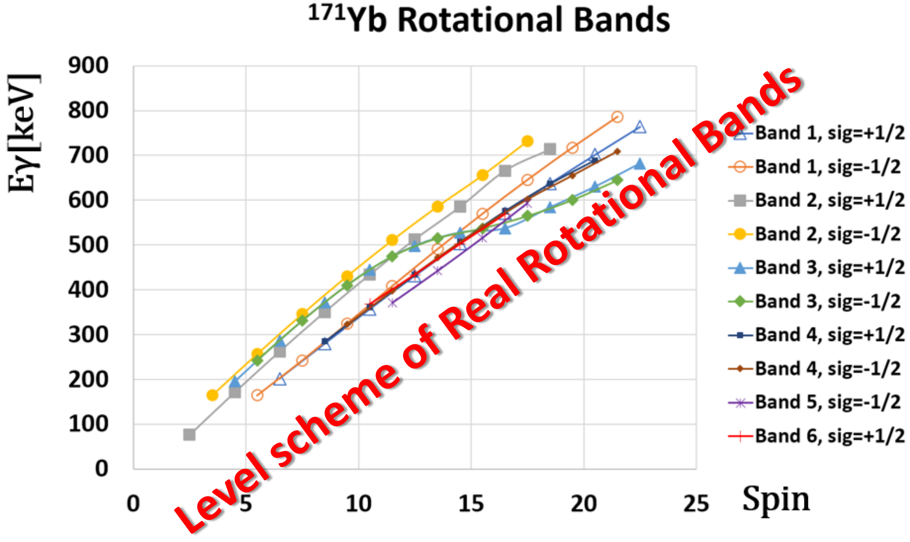


Fig. (Eγ's versus spins)

^{171}Yb band fits using $E_\gamma=2c(2I+k-1)$ parametrization, $\Sigma(E\gamma(I)/2c-(2I+k-1))^2=\min$

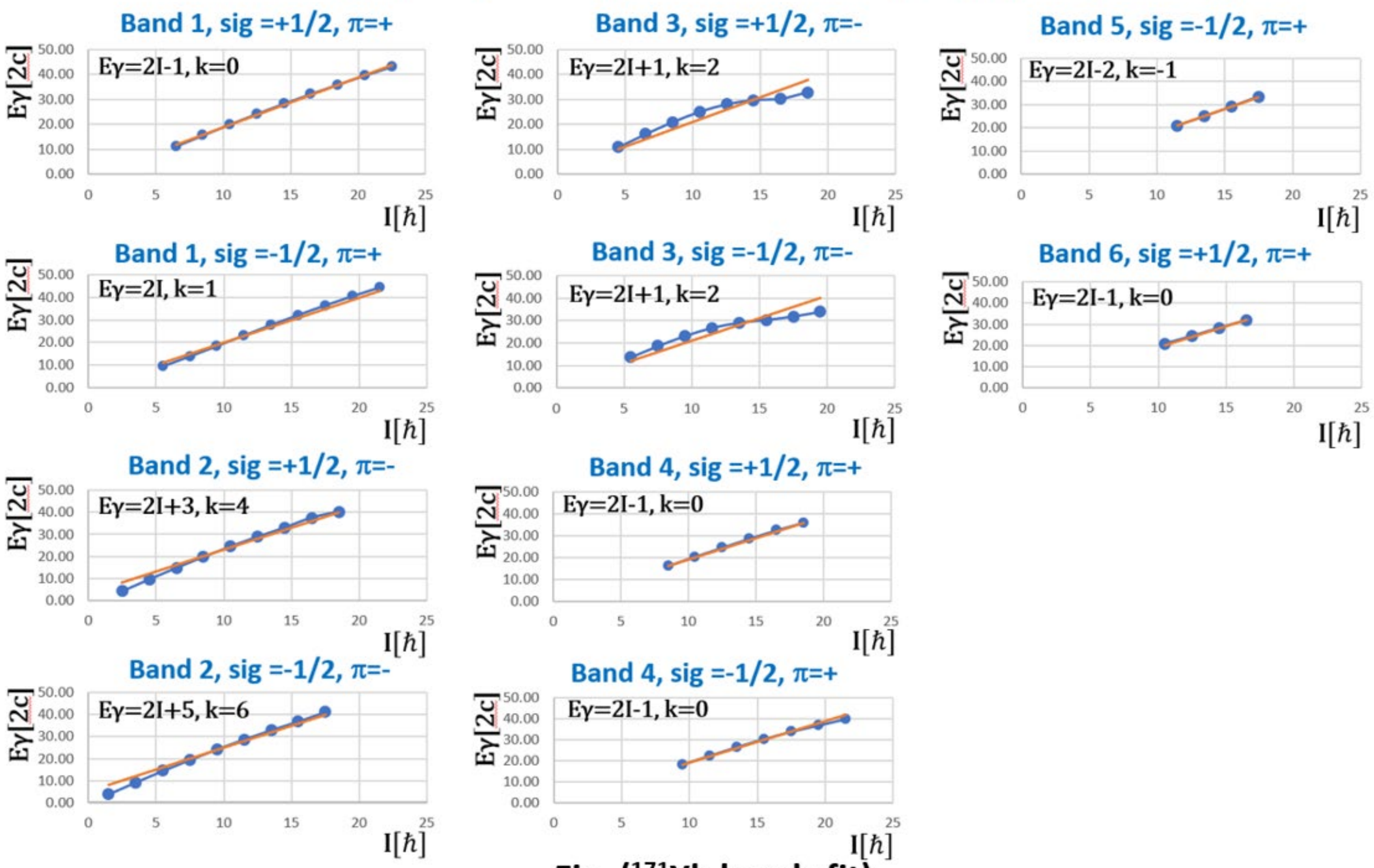


Fig. (^{171}Yb bands fit)

$$2c = 17.75 \text{ keV}$$

$$\mathcal{J}^{(2)}_{eff} = 56.34\ \hbar^2/\text{MeV}$$

II. Level Scheme Re-Concept

What we got for the average description of ^{171}Yb bands?

k-Generalized Ideal Rotor bands:

For **k=0**, **Bohr-Mottelson Ideal Rotor** bands: described by the 2cI(I+1) rule for even and odd spins

For **k≠0**, **k-Generalized Ideal Rotor** bands: have the same $\mathcal{J}^{(2)}_{eff}$ (same 2*c*) but are no longer described by the 2cI(I+1) rule.

Q: How to place the k-generalized ideal rotor bands in the level scheme?

A: By adding 2I+1 "stairs" of 2c levels to the k=0 band!

One gets a "***parabolic 2D building***" *on which:*

- ***k=0 bands are vertical paths***
- ***k≠0 bands are tilted paths***
- In general, the energy levels can be indexed by three **integer numbers**, **(I,m,n)**, where:
    - **I** is the nuclear spin,
    - **m** is the position of the "stair" level relative to the spin "floor",
    - **n** the energy of the level, which is a natural number in units of 2c.
- ***Triple coordinates suggest 3D level scheme***!

Quadratic (8c) + Linear (2c) Scales

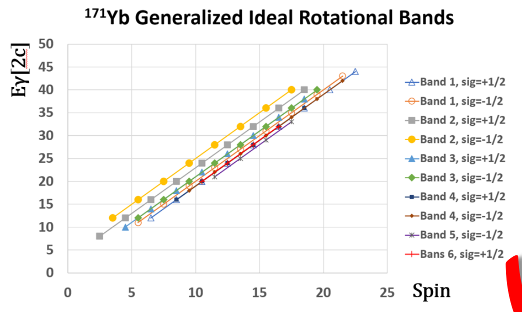


Fig. (Generalized Ideal Rotation Bands)

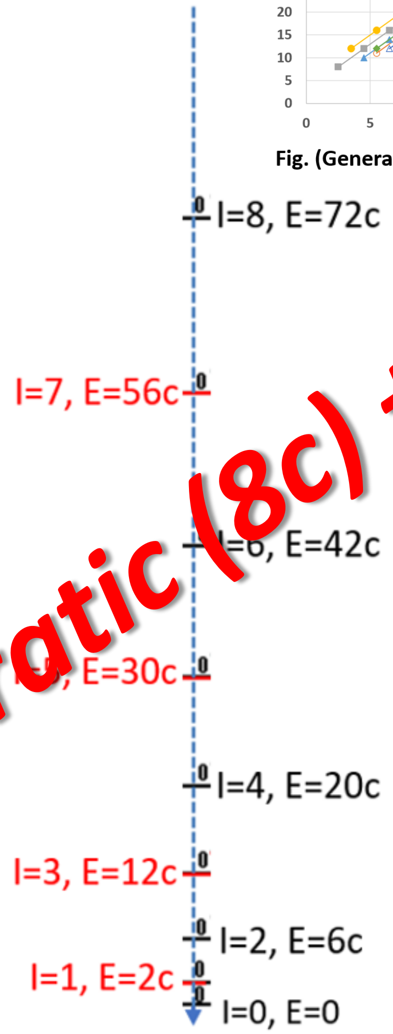


Fig. (Ideal rotor)

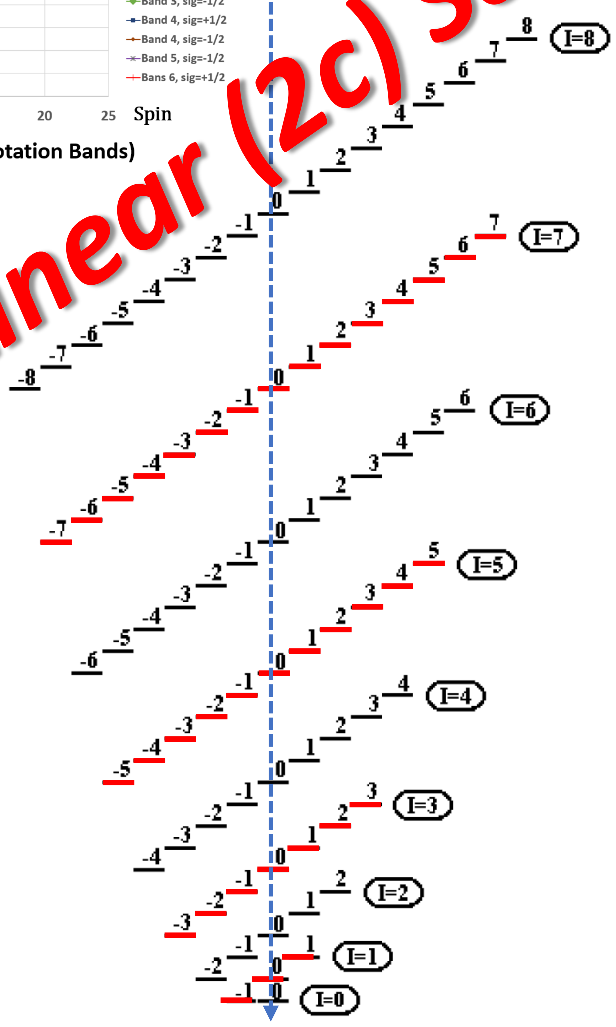
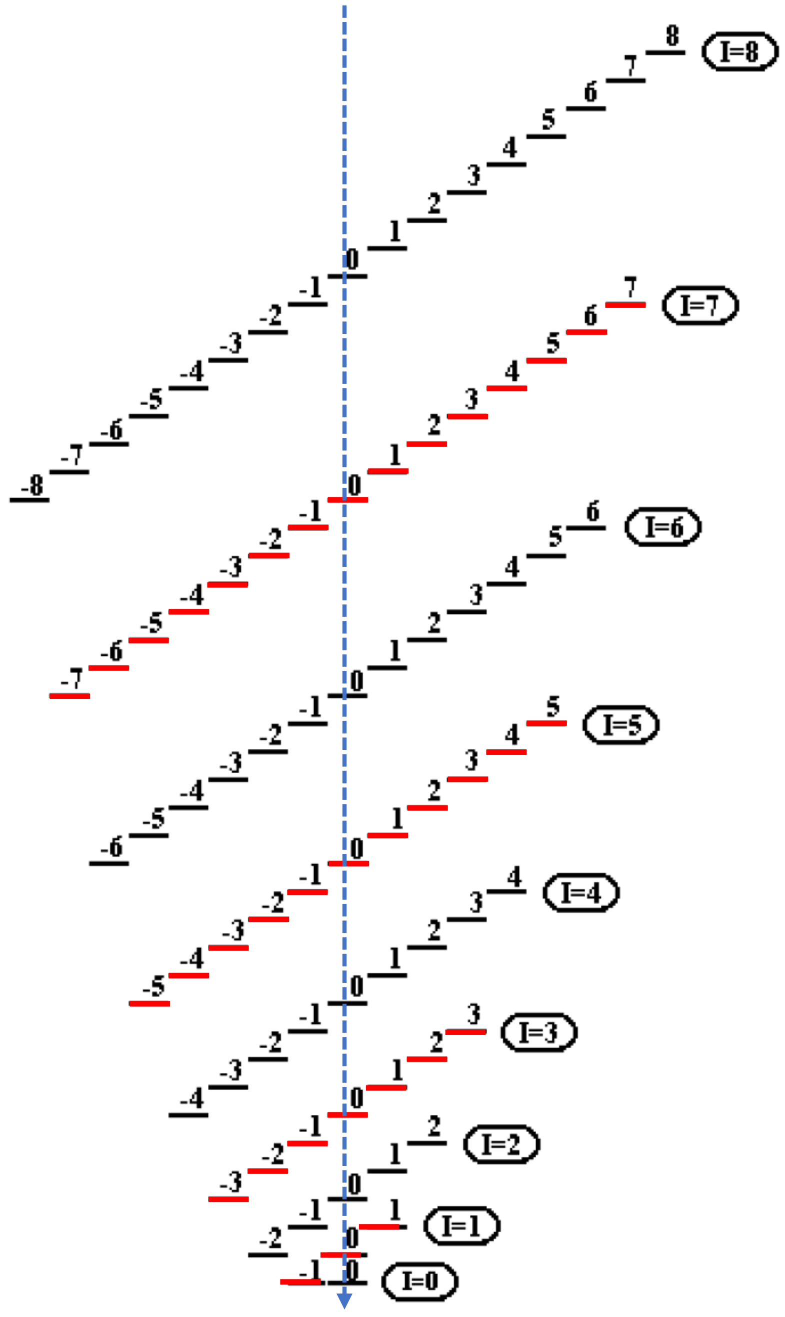


Fig. (Opened generalized ideal rotor)

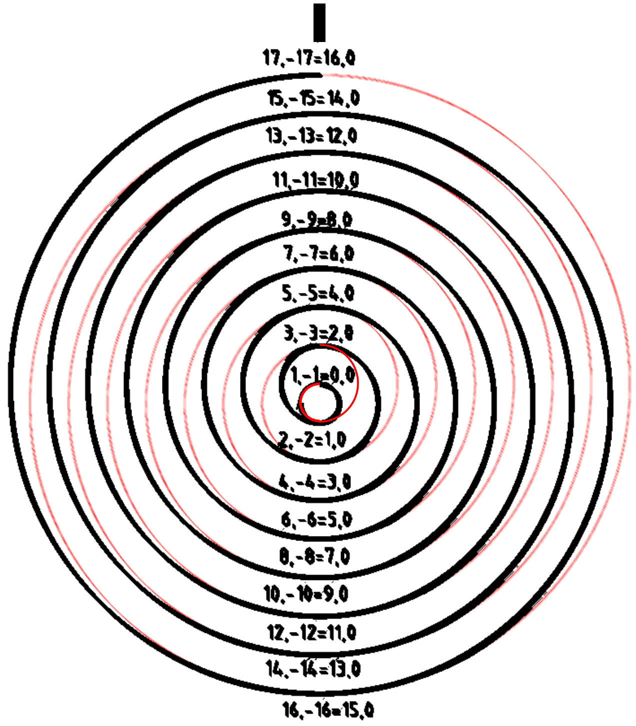
Parabolic Level Scheme for k bands

$$E_\gamma^{k}(I) = 2c\,(2I + k - 1),\ k=\pm1,\pm2,\ldots,I$$

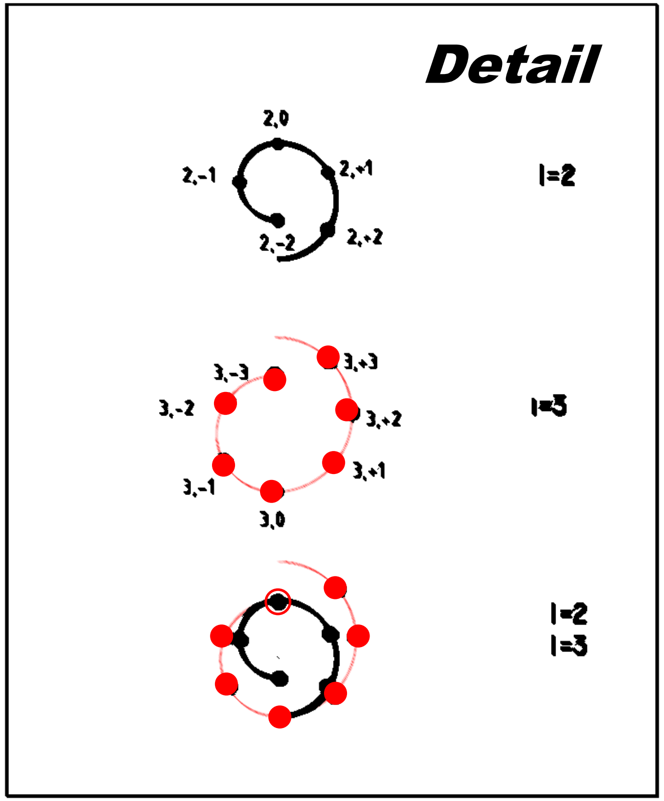
DOUBLE HELIX



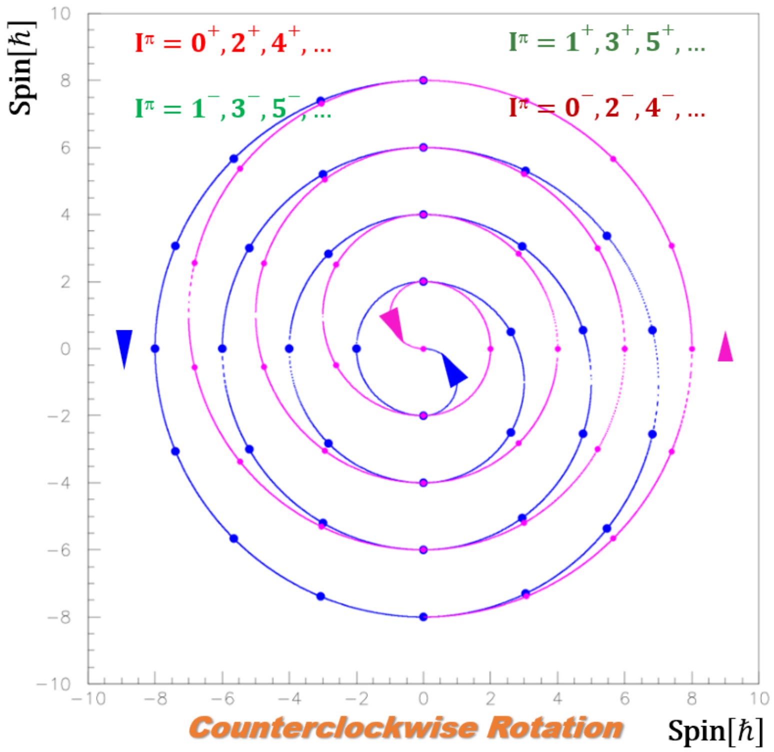
2D view



3D view (from above)



Double-Helix for even-A and odd-A Nuclei



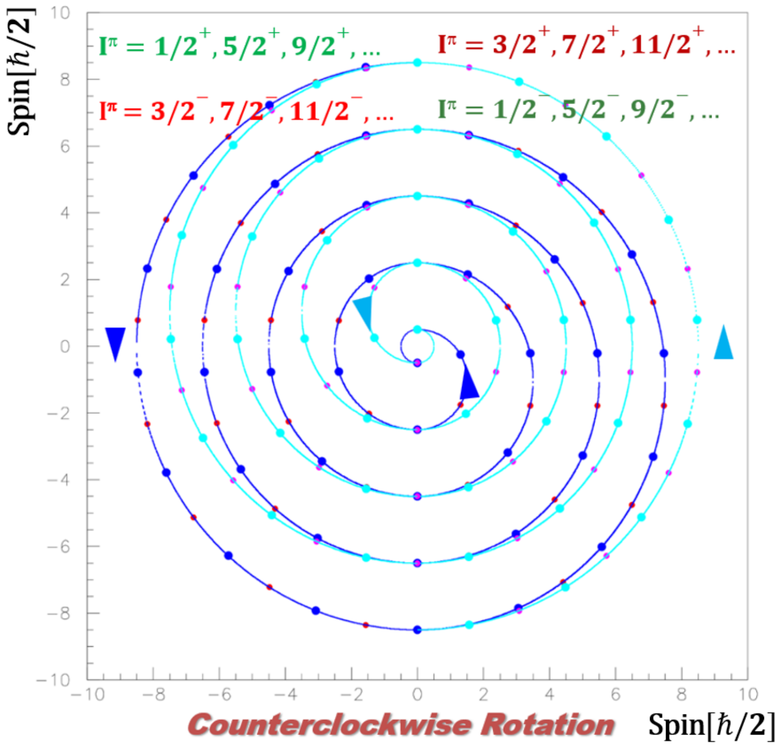


Fig. (Set of 2 helixes for integer spins)

Fig. (Set of 2 helixes for integer half-spins)

Double-Helix Level Scheme of ^{171}Yb nucleus

Decomposition of experimental $E\gamma$'s of all bands

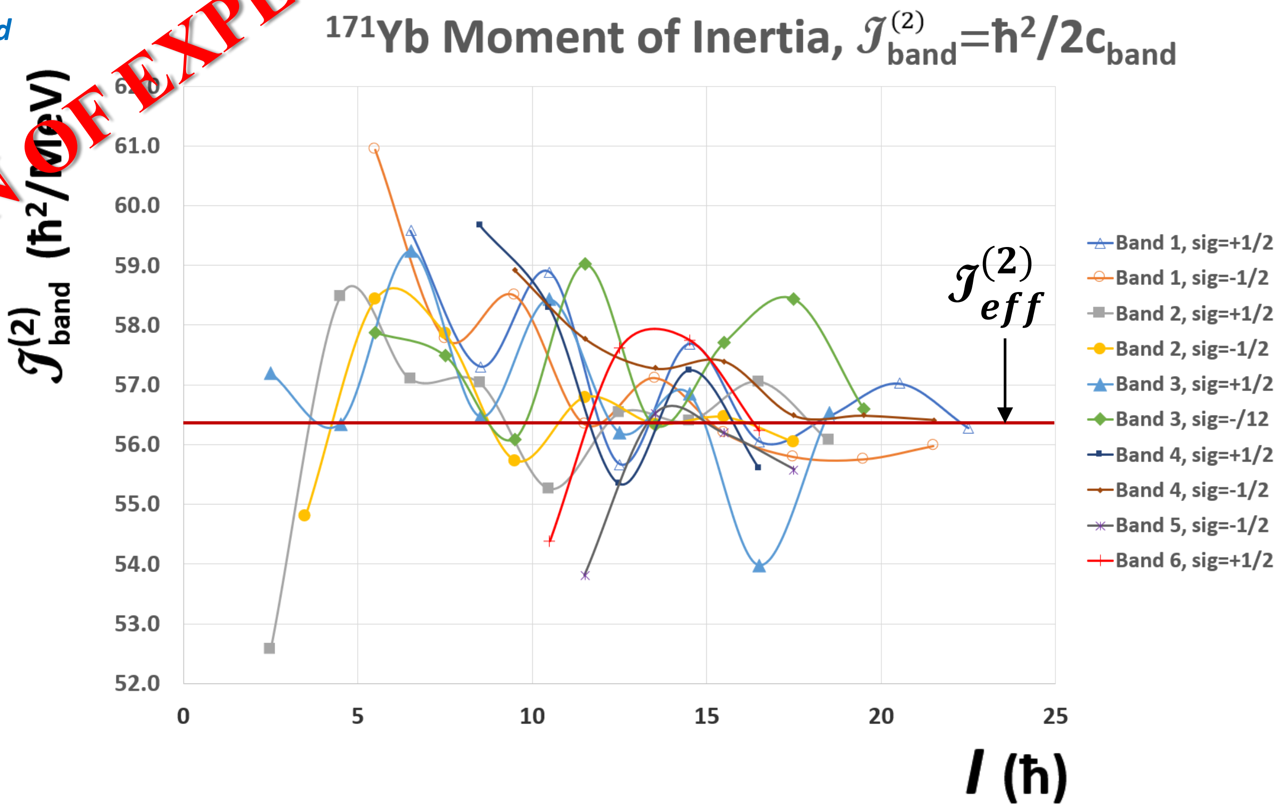
$E\gamma = 2c(2I+k-1 + k' + fn)$

$E\gamma = 2c_{band} \times (2I+k+k'-1)$, with $2c_{band} = 2c[1+fn/(2I+k+k'-1)]$,

with $2c_{band}$ ***real and*** $(2I+k+k'-1)$ ***integer***

- **$(2I+k+k'-1)$ generalized angular momentum**
- One gets ***Bands Moment of Inertia***, $\mathcal{J}^{(2)}_{band} = \hbar^2/2c_{band}$

COMPLETE DESCRIPTION OF EXPERIMENTAL BANDS



^{171}Yb nucleus Double Helix Level Scheme

Part I: Level scheme of Generalized Ideal Rotational Bands

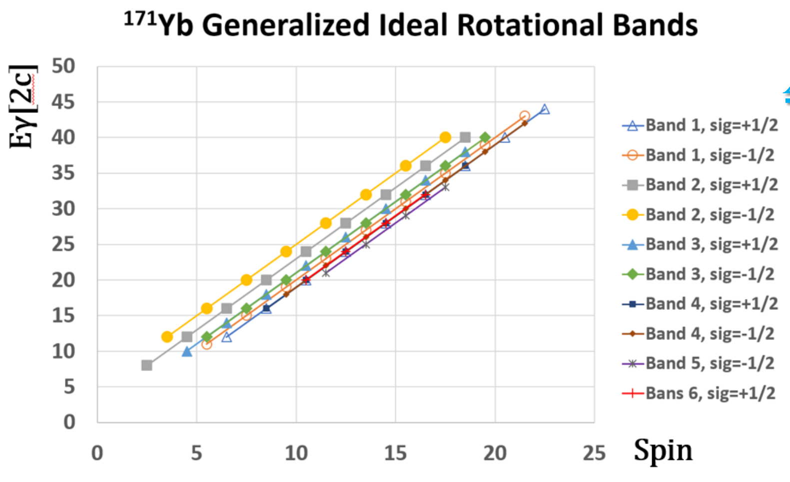


Fig. (Generalized Ideal Rotation Bands)

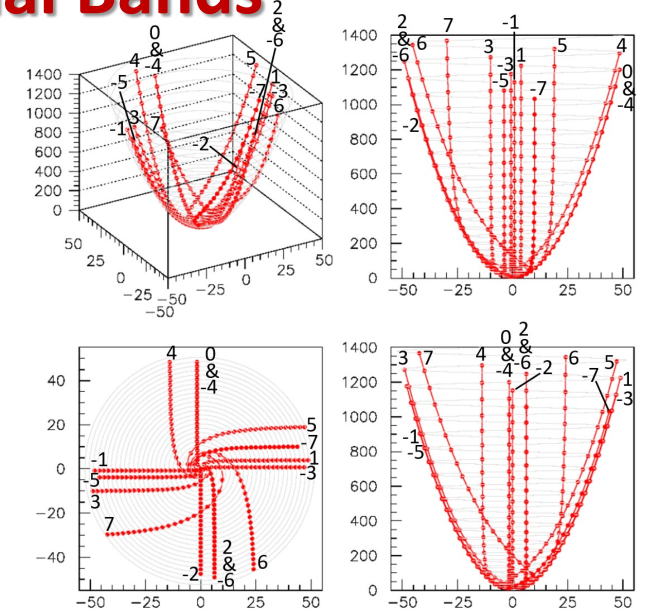
Average Ideal Rotational Description

Parametrization:

$E\gamma = 2c(2I+k-1)$

$2c$ ***Real***, $(2I+k-1)$ ***Integer***

2c, k from least-squares fit



Part II: Level scheme of Real Rotational Bands

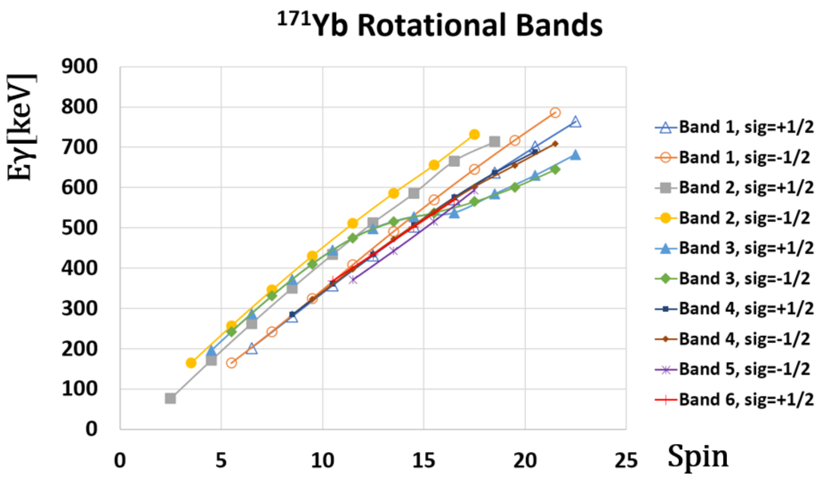


Fig. (Eγ's versus spins)

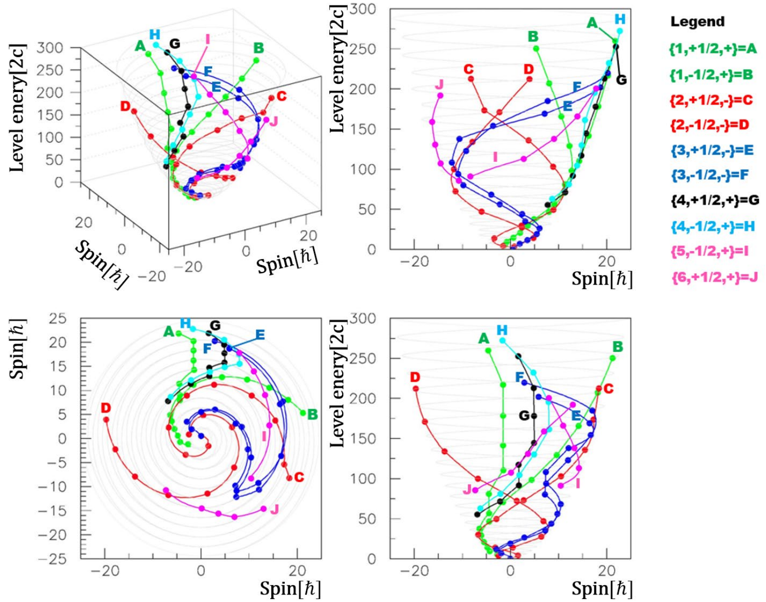
Real Bands Rotational Description

Decomposition:

$E\gamma = 2c_{band}(2I+k+k'-1)$

$2c_{band}$ ***Real***, $(2I+k+k'-1)$ ***Integer***

$2c_{band} = 2c[1+fn/(2I+k+k'-1)]$



III. Insight into High-Spin Physics

Elementary Helix Loop with γ transition

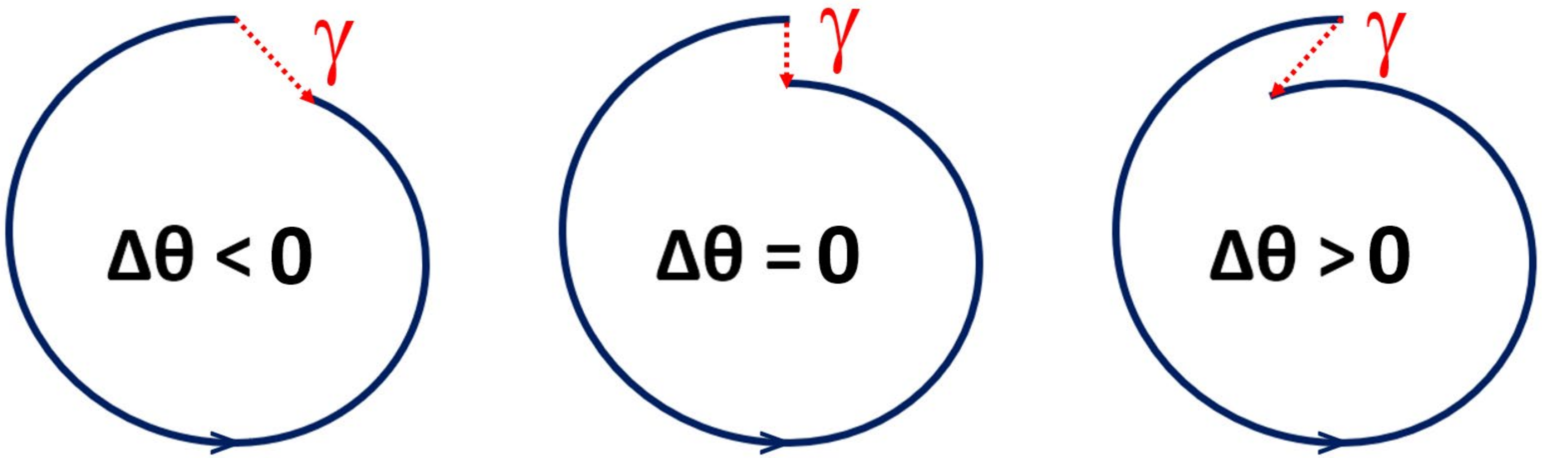
$E\gamma=2c_{band}(2I+k+k'-1)$:

Δθ=0, 2π Elementary Helix Loop Rotation ***due to 2I Macroscopic Collective Motion***

- ***γ-decay paths: along vertical diameter***

Δθ≠0 Band's Apparent Rotation on the Helix ***due to k+k' Microscopic S.P. Motion***

- ***γ-decay paths: Δθ<0 clockwise precession***
- ***γ-decay paths: Δθ>0 counterclockwise precession***



Phase angle of levels on helicoid: $\theta(\mathrm{I,m})=\sum_{I,m}(I+\frac{m}{I})\pi$

Phase shift between two consecutive band levels: $\Delta\theta(\mathrm{I})=\theta(\mathrm{I})-\theta(\mathrm{I-2})-2\pi$

Fig. (Δθ apparent band rotation on the helicoid)

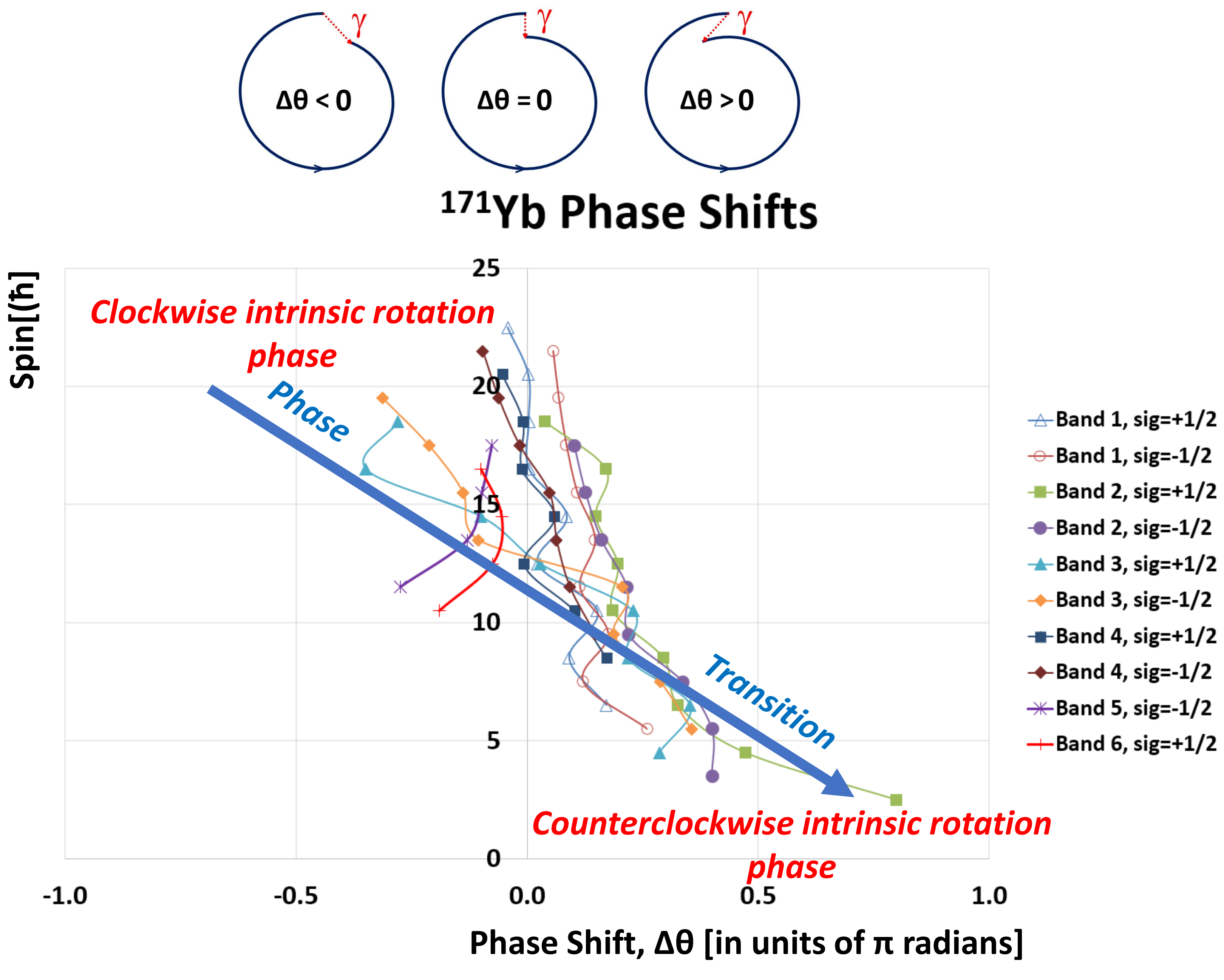
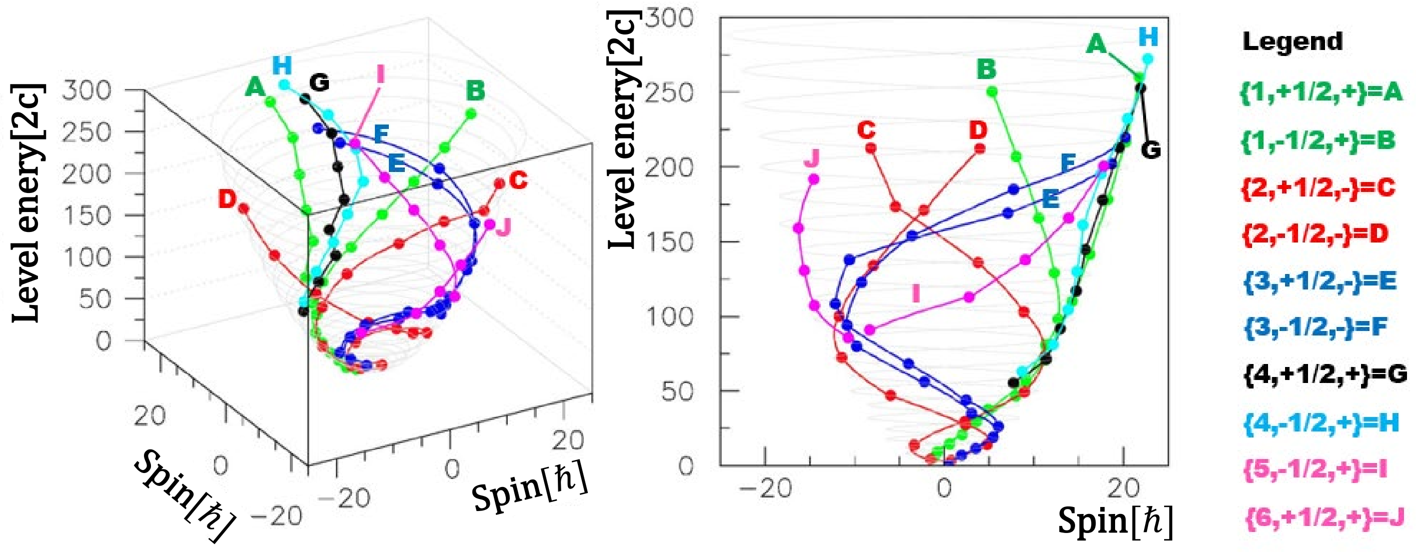


Fig. (^{171}Yb Phase Shifts)



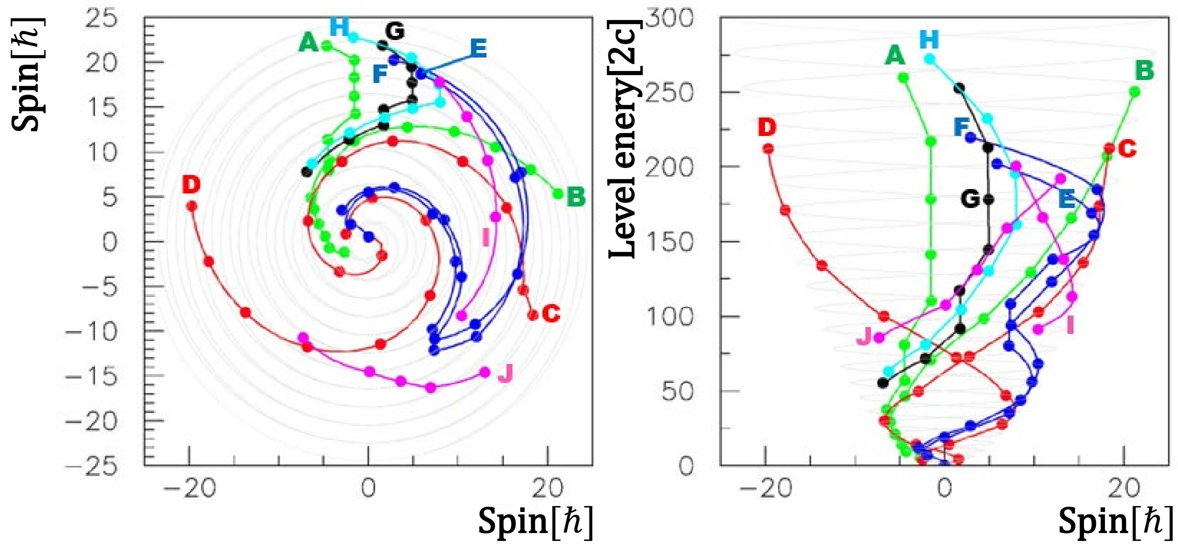
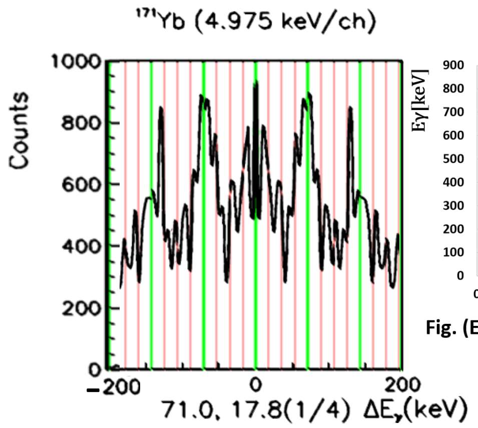


Fig. (Double helix of ^{171}Yb nucleus)

Double Helix Level Scheme Summary

I Repeatability



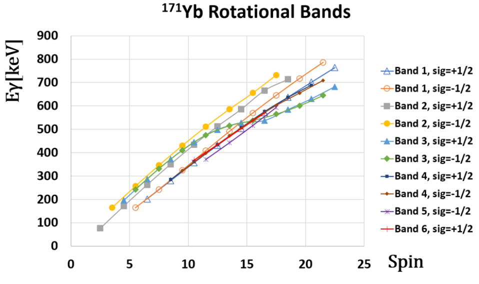
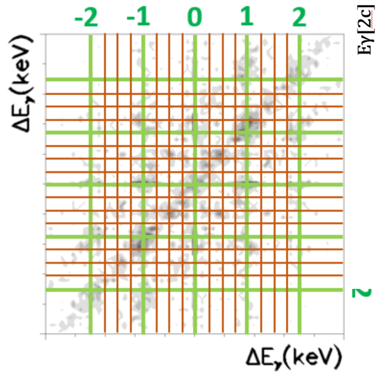


Fig. (Eγ's versus spins)



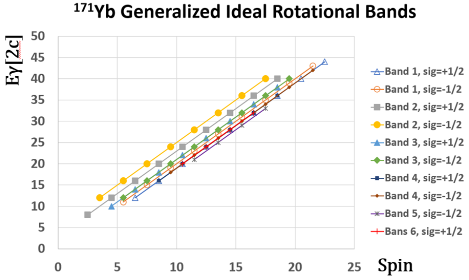
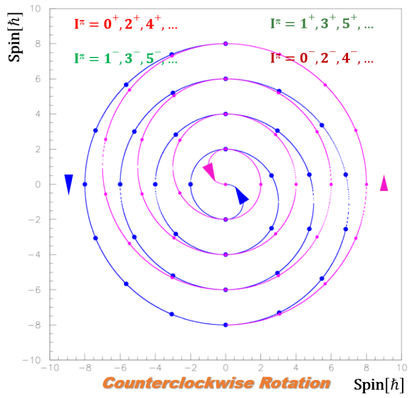
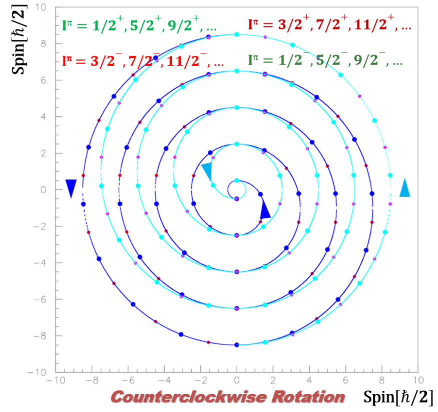


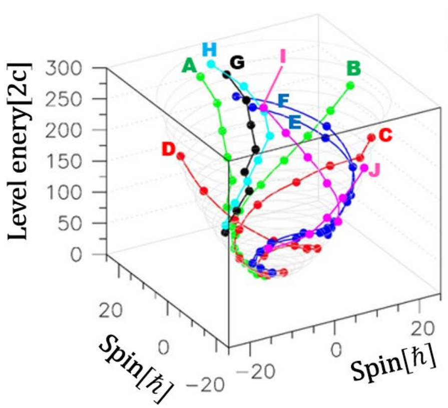
Fig. (Generalized Ideal Rotation Bands)

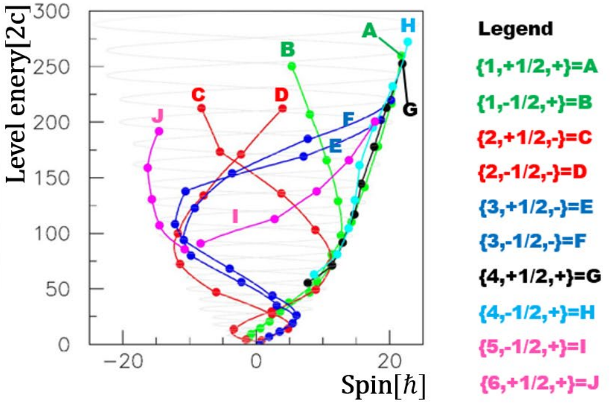
II Double Helix

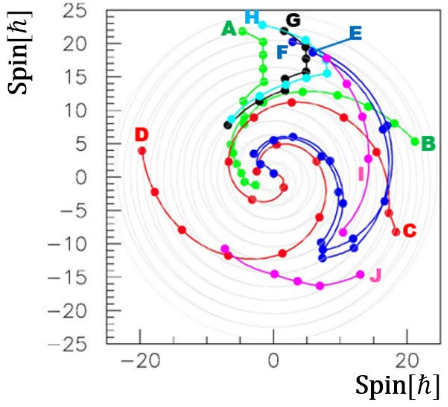


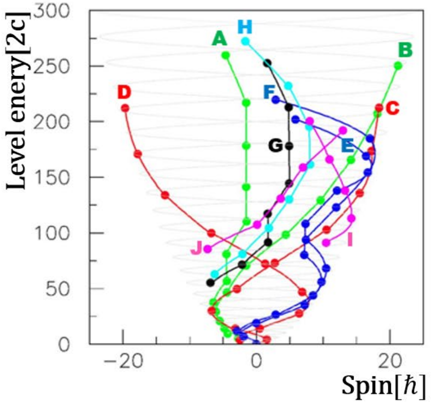


III Double Helix Level Scheme



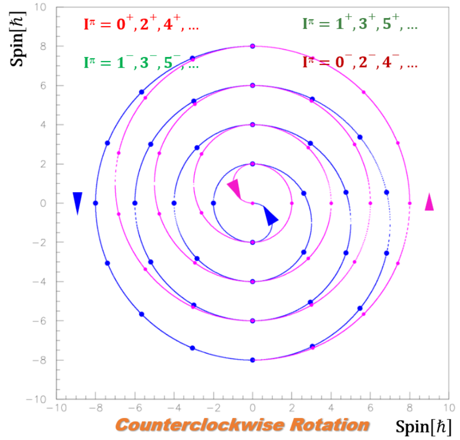


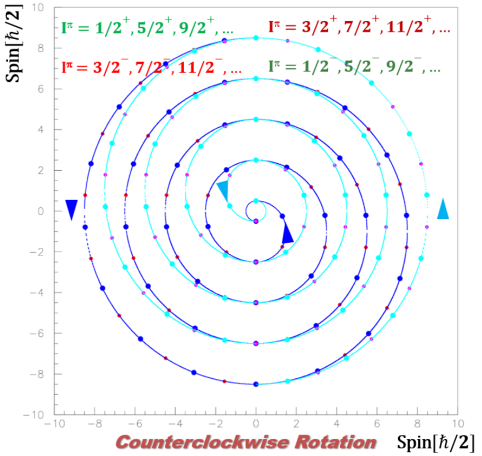




Double Helix Level Scheme Insight:
Investment in Nuclear Structure Building

- ***Double Helix** is the geometrical place of the discrete set of spin states available for the rotational motion of the nucleus, which defines a **Semiclassical Meta-Trajectory***
- ***On average, one can assume that Nuclear Matter itself follows the Semiclassical Meta-Trajectory on Double Helix, with the actual levels selected by the rotational bands' paths***
- ***Semi-classically, through Repeatability Nuclear Matter's Double Helix Motion <u>can be seen as a Vortex Motion</u>***
- ***This can indicate vorticity in the liquid drop and relax the irrotational flow hypothesis on Bohr-Mottelson model***





DOUBLE HELICOID LEVELS SCHEME (DHLS)