Lifetime measurement of candidate chiral doublet bands in the ^{103,104}Rh isotopes with the RDDS method in inverse kinematics

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Nuclear Chirality (Chiral Doublet)

Three perpendicular angular momenta can be formed into two system of handedness, the right-handed or the left-handed system

From S. Frauendorf and J. Meng, Nucl. Phys. A 617, 131 (1997).

For mass 100 region $\pi g_{9/2}^{-1} \otimes \nu h_{11/2}$

1-axis: long axis of the triaxial shape

j_n: proton-hole in a high-j shell

2-axis: short axis of the triaxial shapeL

j_p: neutron-particle in a high-j shell

3-axis: intermidiate axis of the triaxial shape

R: core rotation

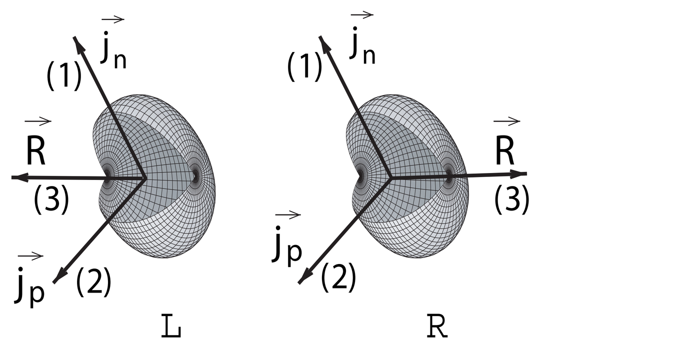
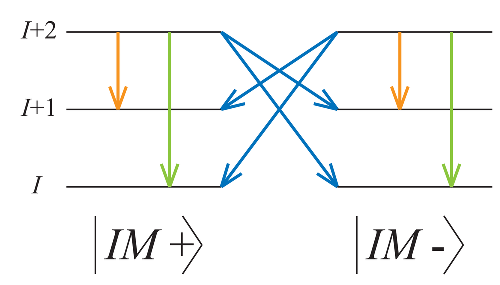


Figure from T. Koike, K. Starosta, and I. Hamamoto, Phys. Rev. Lett. 93, 172502 (2004).



$$[O, H] = 0$$

$$O = TR(\pi)$$

$|IM+\rangle$ $|IM-\rangle$

$$H\,|IR\rangle = \epsilon_R\,|IR\rangle\,, \quad H\,|IL\rangle = \epsilon_L\,|IL\rangle$$

$$O\,|IR\rangle = |IL\rangle\,, \quad O\,|IL\rangle = |IR\rangle$$

$$\epsilon_R = \epsilon_L$$

$$\begin{cases} |IM+\rangle = \frac{1}{\sqrt{2}}\left(|L\rangle + |R\rangle\right) \\ |IM-\rangle = \frac{i}{\sqrt{2}}\left(|L\rangle - |R\rangle\right) \end{cases}$$

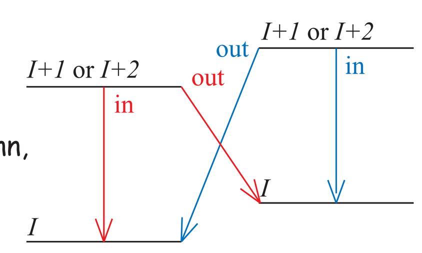
$$H\,|IM\pm\rangle = \epsilon\,|IM\pm\rangle$$

$$O\,|IM\pm\rangle = |IM\pm\rangle$$

two major experimental criteria

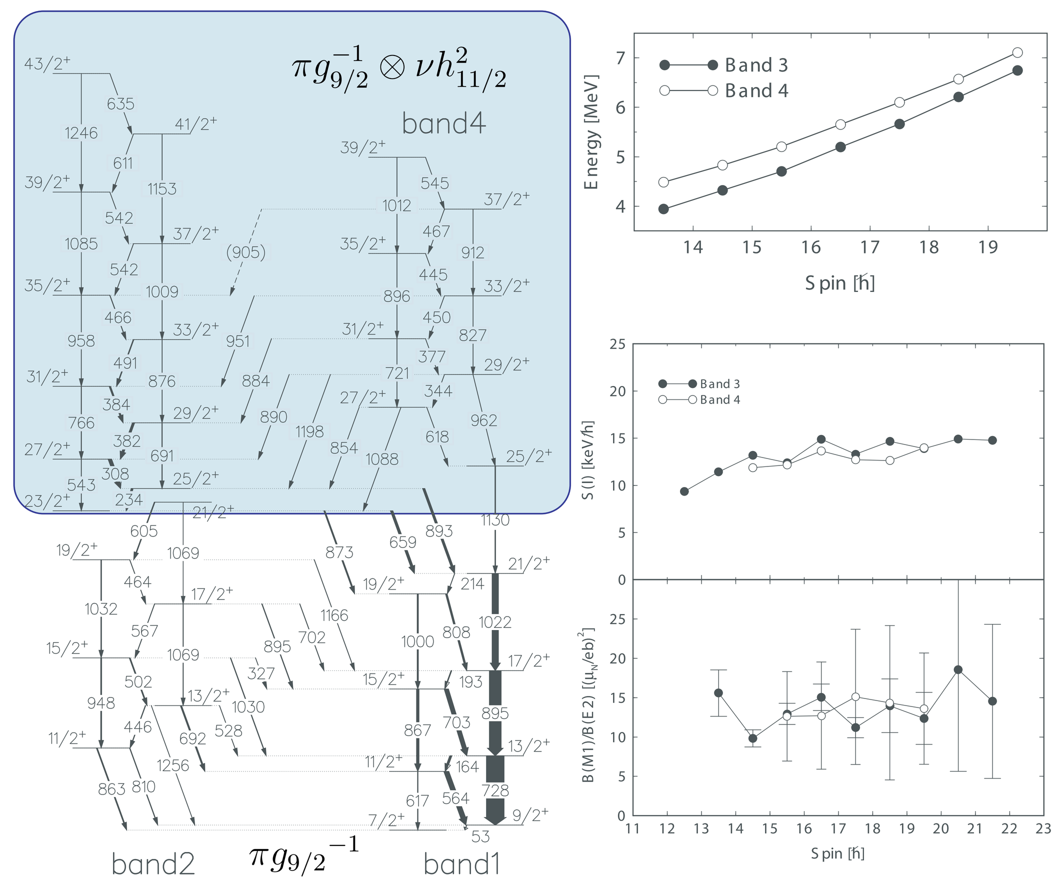
(i) the observation of nearly degenerate $\Delta I = 1$ twin bands built on the same single particle configuration

(ii) identical electromagnetic properties --- similar B(E2) and B(M1) values of in-band and inter-band transitions

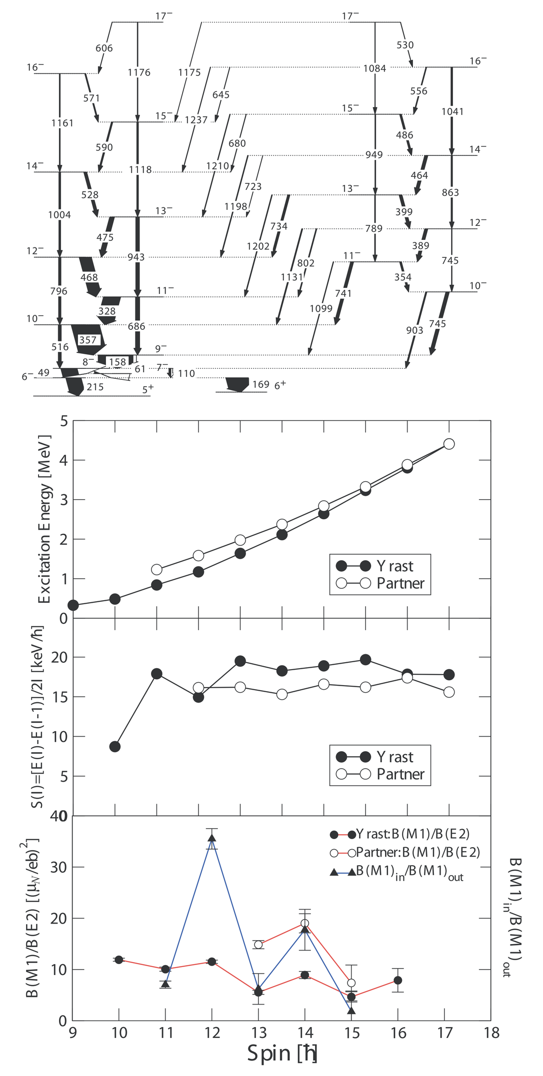


From C. M. Petrache, G. B. Hagemann, I. Hamamoto, and K. Starosta, Phys. Rev. Lett. 96, 112502 (2006).

Chiral Doublet Structures in ^{103}Rh and ^{104}Rh



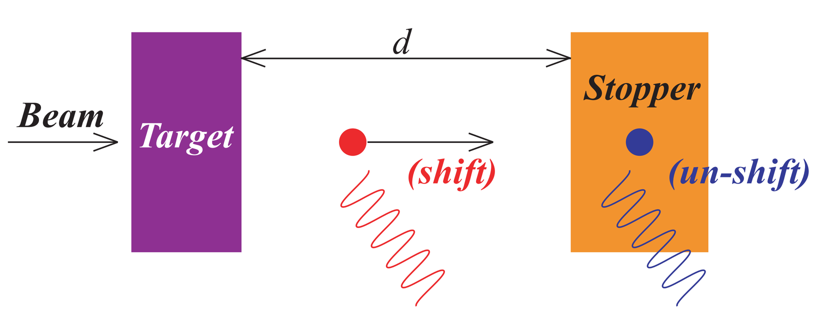
From J. Timar, C. Vaman, K. Starosta, D. B. Fossan, T. Koike, D. Sohler, I. Y. Lee, and A. O. Macchiavelli, Phys. Rev.C 73, 011301 (2006).

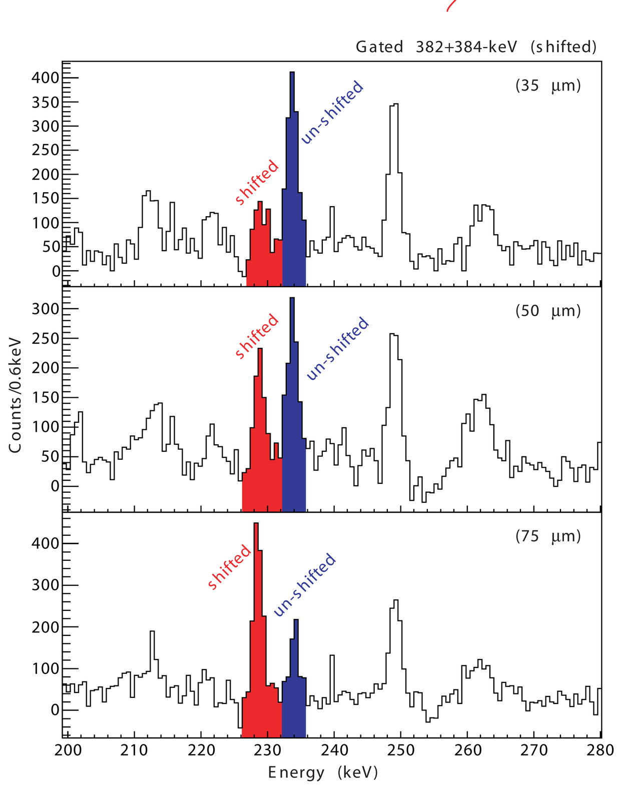


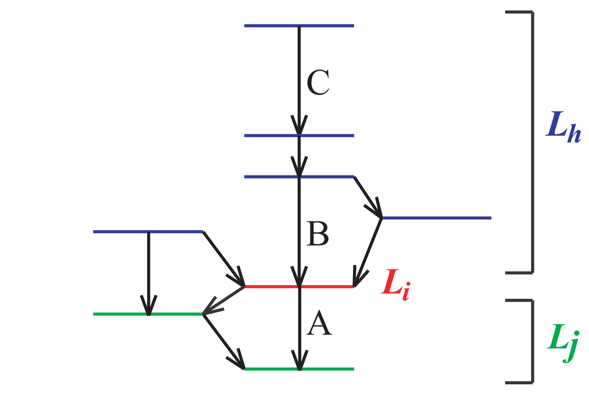
From C. Vaman, D. B. Fossan, T. Koike, K. Starosta, I. Y. Lee, and A. O. Macchiavelli, Phys. Rev. Lett. 92, 032501 (2004).

Coincidence Recoil Distance Doppler Shift Method (RDDS)

and Differential Decay-Curve Method (DDCM)







$$\frac{dn_i}{dt} = -\lambda_i n_i(t) + \sum_h \lambda_h n_h(t) b_{hi}$$

$$\tau_i = \frac{-N_{ij}(t) + b_{ij}\sum_h N_{hi}(t)}{\frac{dN_{ij}(t)}{dt}}$$

$$\tau_i = \frac{I^{\rm BA}_{\rm s,u}(x)}{I^{\rm BA}_{\rm s,s}(x+\Delta x) - I^{\rm BA}_{\rm s,s}(x-\Delta x)}\,\frac{2\Delta x}{v}$$

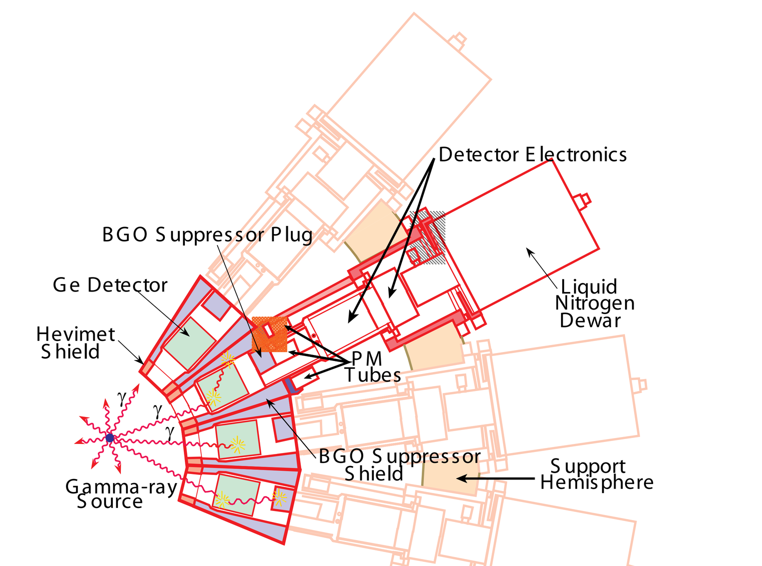
$$\tau_i = \frac{I^{\rm CA}_{\rm s,u}(x) - \alpha I^{\rm CB}_{\rm s,u}(x)}{I^{\rm CA}_{\rm s,s}(x+\Delta x) - I^{\rm CA}_{\rm s,s}(x-\Delta x)}\,\frac{2\Delta x}{v}, \quad \alpha = \frac{I^{\rm CA}}{I^{\rm CB}}$$

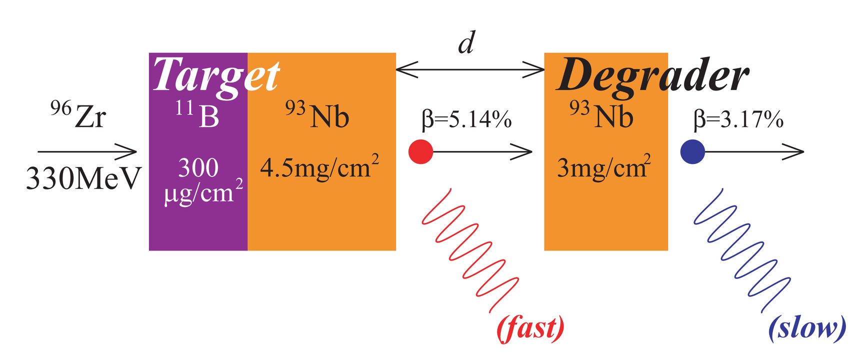
From A. Dewald, S. Harissopulos, and P. von Brentano, Z. Phys. A 334, 163 (1989).

ANL GSFMA169 Experiment

Lifetime measurement of chandidate chiral members in the A~100 region

- Recoil Distance Doppler Shift Methods
  - emitted gamma-ray was detected by Gammasphere array (Total 16 rings, 101 detectors with BGO-ACS were used.)
  - Cologne univ. plunger device was used
- Inverse Kinematics Reaction
  - ^{11}B(^{96}Zr,xn)^{104,103}Rh(x=3,4)
  - E(^{96}Zr) = 330 MeV from ATLAS accelerator at ANL, USA
  - 7 RDDS Distances (8,15,23,35,50,75,100 μm)





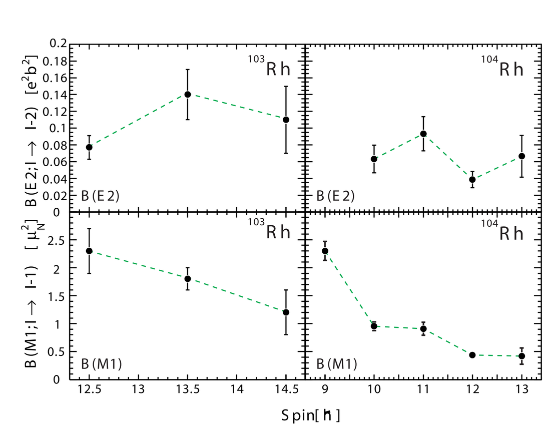
Front ring angle	Front ring N_{det}	Back ring angle	Back ring N_{det}
		121.72	5
35.26	8	129.93	10
50.07	10	145.45	10
58.28	5	162.73	5

the detectors placed in the forward and the backward directions were used for lifetime extraction.

Total 82 matrices are created ring by ring for each distances.

Gammaspere + Cologne plunger device

Results



The behavior as well as absolute values, of the B(E2) and B(M1) values between the two nuclei are similar;

- the B(E2) values exhibit weak staggering
- the B(M1) values decrease monotonically with increasing spin

Chiral Doublet → B(M1) staggering

B(E2) staggering → What?

Staggering pattern compaired between other chiral candidates

	configuration	$I-I_0$= even	$I-I_0$= odd	I_0^π	
odd-odd	$\pi h_{11/2} \otimes \nu h_{11/2}{}^{-1}$	large	small	9$^+$	^{124,126,128,130,132}Cs, ^{134}La
odd-odd	$\pi g_{9/2}{}^{-1} \otimes \nu h_{11/2}$	large	small	8$^-$	^{100}Tc, ^{104,106}Rh
odd-A	$\pi h_{11/2}{}^2 \otimes \nu h_{11/2}{}^{-1}$	small	large	25/2$^-$	^{135}Nd
odd-A	$\pi g_{9/2}{}^{-1} \otimes \nu h_{11/2}{}^2$	small	large	23/2$^+$	^{103,105}Rh

$I-I_0$	B(E2) even	B(E2) odd	B(M1) even	B(M1) odd
^{128}Cs	small	large	large	small
^{104}Rh	small	large	none	none
^{135}Nd	none	none	small	large
^{103}Rh	small	large	none	none

But, any theoretical calculation for any other nuclei indicates, chiral geometry is expected higher spin states.

ex.

J. Timar, P. Joshi, K. Starosta, V. Dimitrov, D. Fossan, J. Molnar, D. Sohler, R. Wadsworth, A. Algora, P. Bednarczyk, et al., Phys. Lett. B 598, 178 (2004),
S. Y. Wang, S. Q. Zhang, B. Qi, J. Peng, J. M. Yao, and J. Meng, Phys. Rev. C 77, 034314 (2008),
T. Koike, K. Starosta, and I. Hamamoto, Phys. Rev. Lett. 93, 172502 (2004).

Summary

- The lifetimes at the bottom of the three- or two-quasiparticle bands in ^{103}Rh and ^{104}Rh have been measured, respectively, via the recoil distance Doppler shift method. (The first measurements in this mass region for a pair of bands considered as chiral doublets.)

- The staggering observed in B(M1)/B(E2) ratios is caused by the B(E2) values.
  - The behavior of the B(E2) and B(M1) values in both nuclei is similar; the B(E2) values exhibit an odd-even spin dependence and the B(M1) values decrease with increasing spin.

- The staggering in the B(E2) values is not yet understood and demands theoretical interpretation.

- At the same time, it is absolutely necessary to measure the lifetimes of levels at higher spin together with those for the yrare partner band where the energy degeneracy is small.