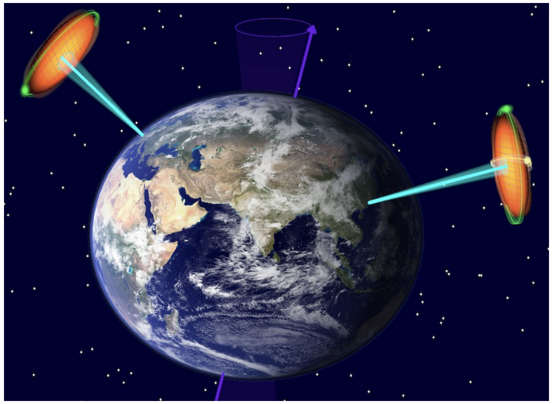
25 years of chirality in nuclei

Chirality and wobbling in nuclei from an experimental perspective

Plan of the talk

Review of the results on chiral bands
Recent results in the A=130 mass region
Review of the results on wobbling bands



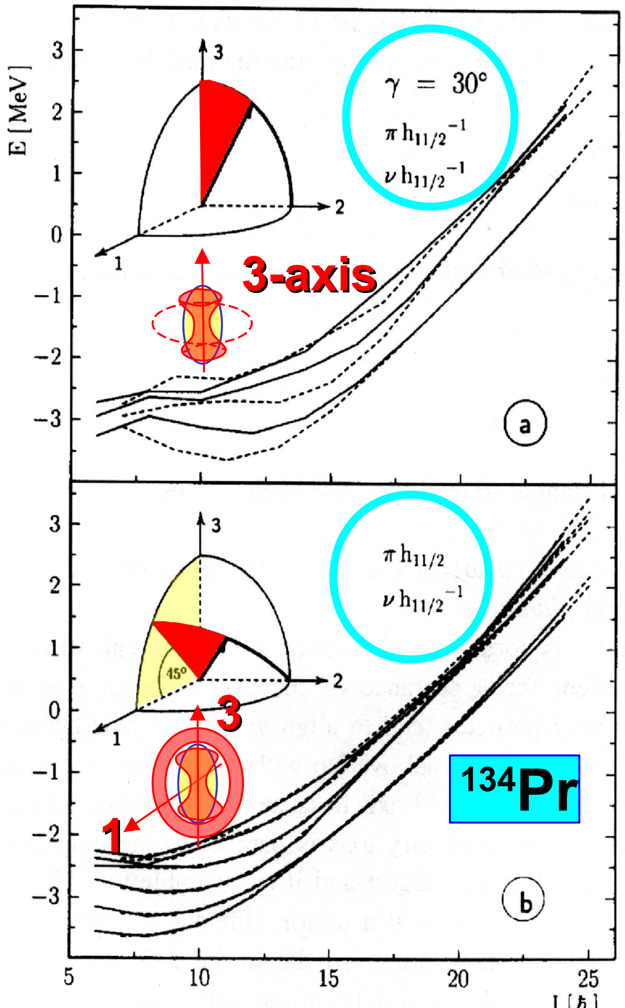
Isabelle Deloncle

中国科学院 CHINESE ACADEMY OF SCIENCES
国家自然科学基金委员会 National Natural Science Foundation of China
中国科学院近代物理研究所 Institute of Modern Physics, Chinese Academy of Sciences
université PARIS-SACLAY
IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

Chiral mode

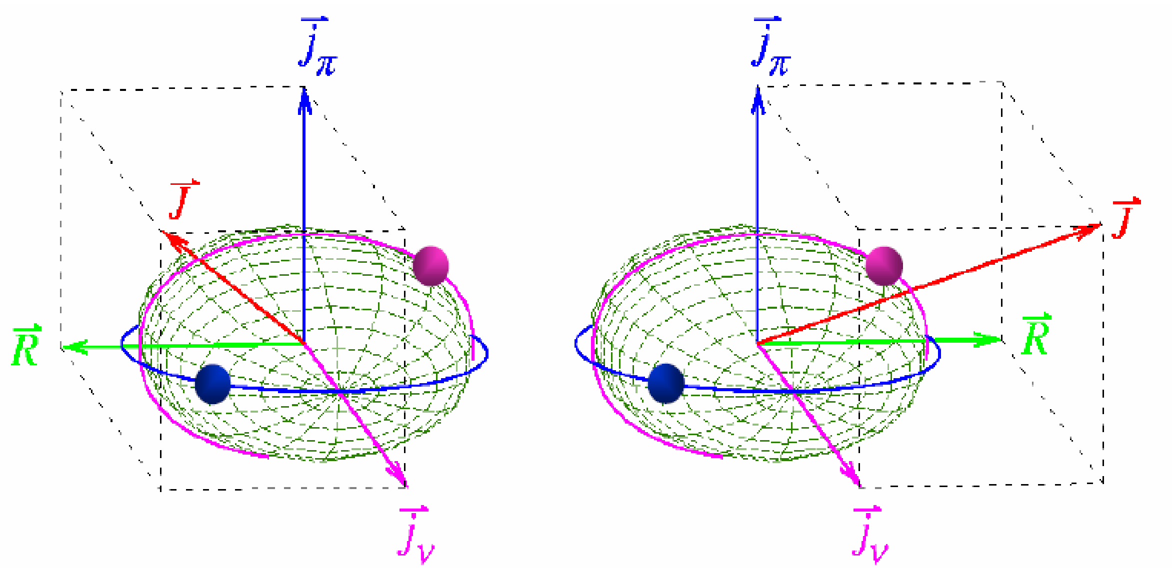
Frauendorf & Meng, NPA 617, 1997

C.P. et al, NPA 597, 1996



Chiral Geometry in Nuclei

Mutually orthogonal coupling of three angular momenta in odd-odd nuclei



History of chirality in nuclei - 1997

Theoretical paper (Frauendorf, Meng, Nucl. Phys. A 617) :

Tilted rotation of triaxial nuclei (^{134}Pr best candidate)

Abstract :

Conditions are discussed when the axis of rotation lies inside or outside the principal planes of the triaxial density distribution. The planar solutions represent ΔI=1 bands, whereas the aplanar solutions represent **pairs** of identical ΔI=1 bands with the same parity. The two bands differ by the chirality of the principal axes with respect to the angular momentum vector. The transition from planar to chiral solutions is evident in both the quantal and the mean field calculations. Its physical origin is discussed.

History of chirality in nuclei - 1996

Experimental paper on ^{134}Pr (C. Petrache et al., Nucl. Phys. A 597)

° ∩ΟΙΞ∃∪Π

ΔΙΡ ∫ΦΛΑΙΓ∫ $\pi\Gamma_{11/2}$[541]3/2 – $\nu\Gamma_{11/2}$[514]9/2 doublet bands.

The difference of 2 ħ in the experimental alignment of the bands based on the signature partners of the π[541]3/2 orbital is discussed in terms of shape coexistence and coupling with the γ phonon, but no consistent interpretation could be found.

R_{DCO} of the connecting transitions : 620 keV : 0.84(4) => δ ~ -0.15

624 keV : 0.76(5) => δ ~ -0.20

638 keV : 0.59(8) => δ ~ -0.35

History of chirality in nuclei - 2000

Theoretical paper (Dimitrov, Frauendorf, Dönau, PRL 84)

Chirality of nuclear rotation (^{134}Pr best candidate)

Abstract :

It is shown that the rotating mean field of triaxial nuclei can break the chiral symmetry. Two nearly degenerate $\Delta I=1$ rotational bands originate from the left-handed and right-handed solutions. The ^{134}Pr and ^{188}Ir were discussed.

History of chirality in nuclei - 2001

Experimental papers

- N=75 ^{130}Cs, ^{132}La,^{134}Pr, ^{136}Pm (Starosta, Koike et al., PRL 86)
- N=73 ^{128}Cs, ^{130}La,^{132}Pr (Koike, Starosta, et al., PRC 63)

History of chirality in nuclei - 2006-2015

Experimental papers

- ^{134}Pr (Tonev et al., PRL 96) – transition probabilities → chirality questioned
- ^{134}Pr (Petrache et al., PRL 96) – quadrupole moments → chirality questioned
- ^{128}Cs (Grodner et al., PRL 97) – transition probabilities → chirality confirmed
- ^{126}Cs (Wang et al., PRC 74)
- ^{103}Rh (Timar et al., PRCR 73)
- ^{103,104}Rh (Suzuki et al., PRCR 78) - lifetimes
- ^{136}Nd (Mukhopahyay et al., PRC 78, 2008) lifetimes → chiral doublets not confirmed
- ^{198}Tl (Lawrie et al., PRCR 78)
- ^{198}Tl (Lawrie et al., PRCR 78)
- ^{80}Br (Wang et al., PLB 703)
- ^{126}Cs (Grodner et al., PLB 703) – chiral transition rules
- ^{134}Pr (Timar et al., PRC 84, 2011) – high-spin bands, new chiral candidates

History of chirality in nuclei - 2016-2023

Experimental papers

- ^{78}Br (Liu et al., PRL 116)
- ^{128}Cs (Grodner et al., PRL 96) – g-factor → chiral only above a given spin
- ^{116}In (Xu et al., PLB 768)
- ^{81}Kr (Mu et al., PLB 827)
- ^{76}Br (Wu et al., PLB 833)
- ^{80}Br (Guo et al., PLB 833)
- ^{116}In (Xu et al., PLB 839)

Experimental and theoretical papers: 197

History of chirality in nuclei - 1996-2023

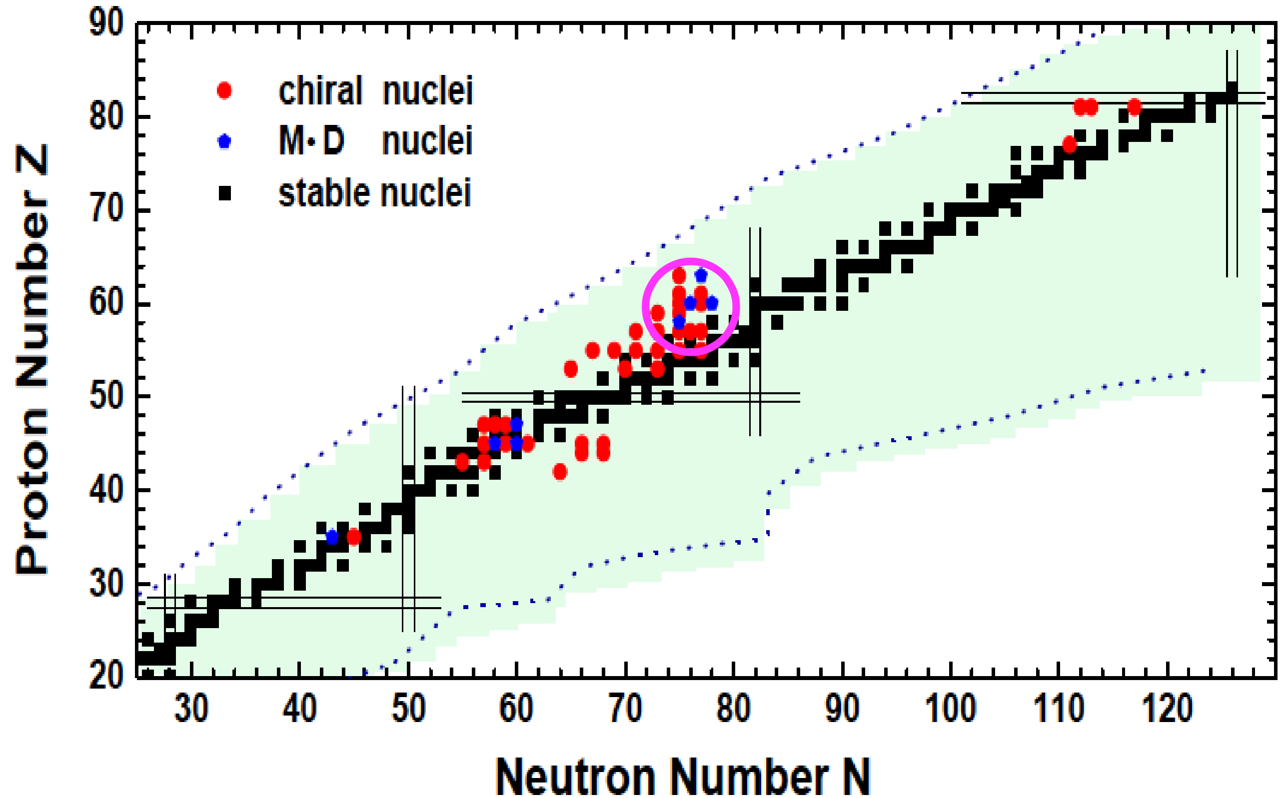
Experimental fingerprints :

- almost constant energy difference between partners
- similar intraband transitions probabilities
- similar single-particle alignments
- attenuated energy staggering
- B(M1) staggering (why only in Cs nuclei?)
- present in odd-odd, odd-A an even-even nuclei (^{136}Nd, ^{138}Nd)

Theoretical fingerprints :

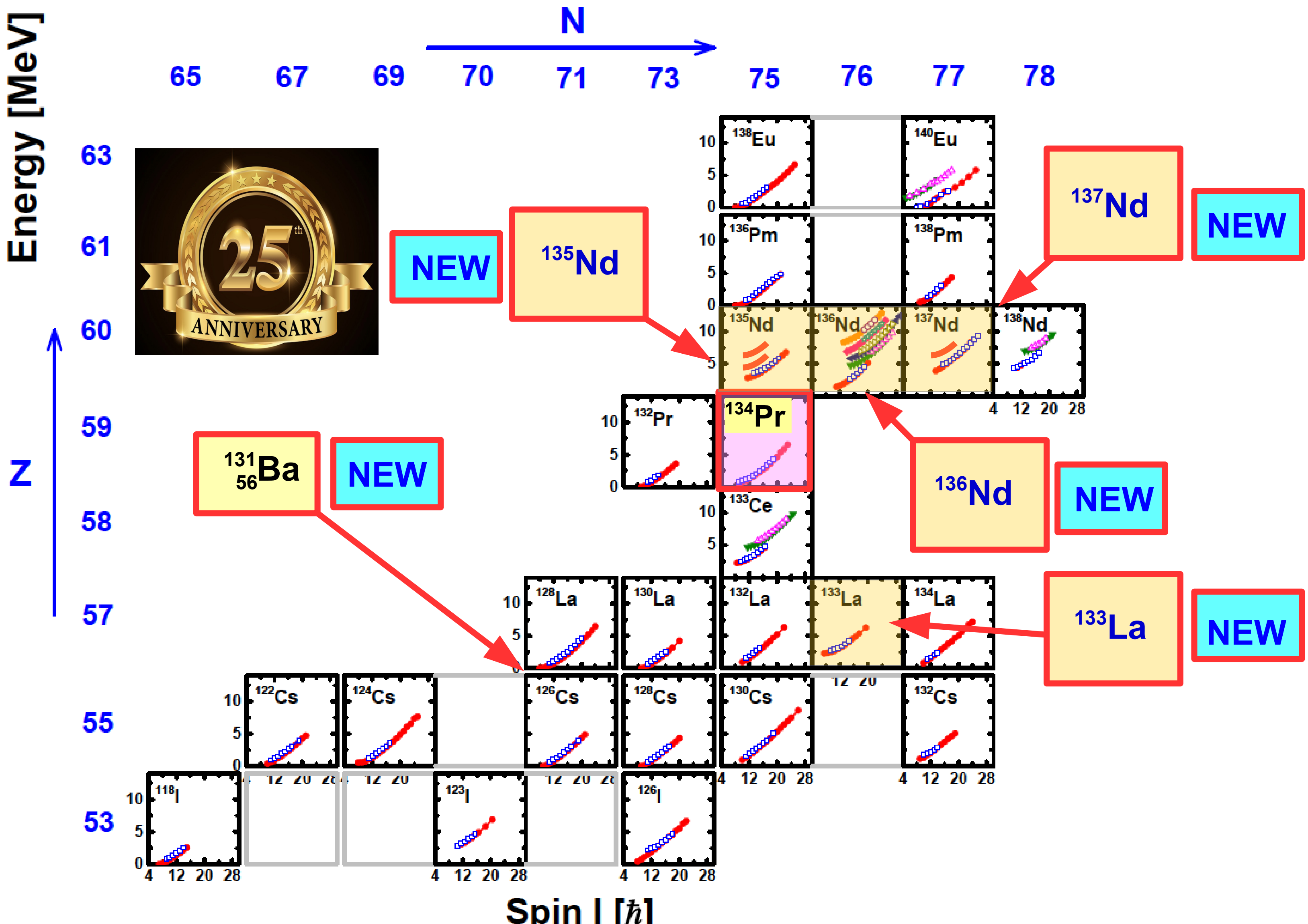
- similar expectation values of the angular momenta
- similar spin aligned along two perpendicular axes
- near maximal triaxiality
- present only above a critical frequency
- degeneracy over a limited spin range

Chiral bands on the nuclear chart



B.W. Xiong, Y.Y. Wang, ADNDT 125 (2018) 193: Nuclear chiral bands data tables

25 Anniversary of chiral bands



B.W. Xiong, Y.Y. Wang, ADNDT 125 (2018) 193: Nuclear chiral bands data tables

JUROGAM II + RITU, $^{40}Ar+^{100}Mo$
20 pnA, 1 week (October 2016)

JUROGAM II

24 Clovers HPGe

15 Coaxial HPGe

39 BGO shields

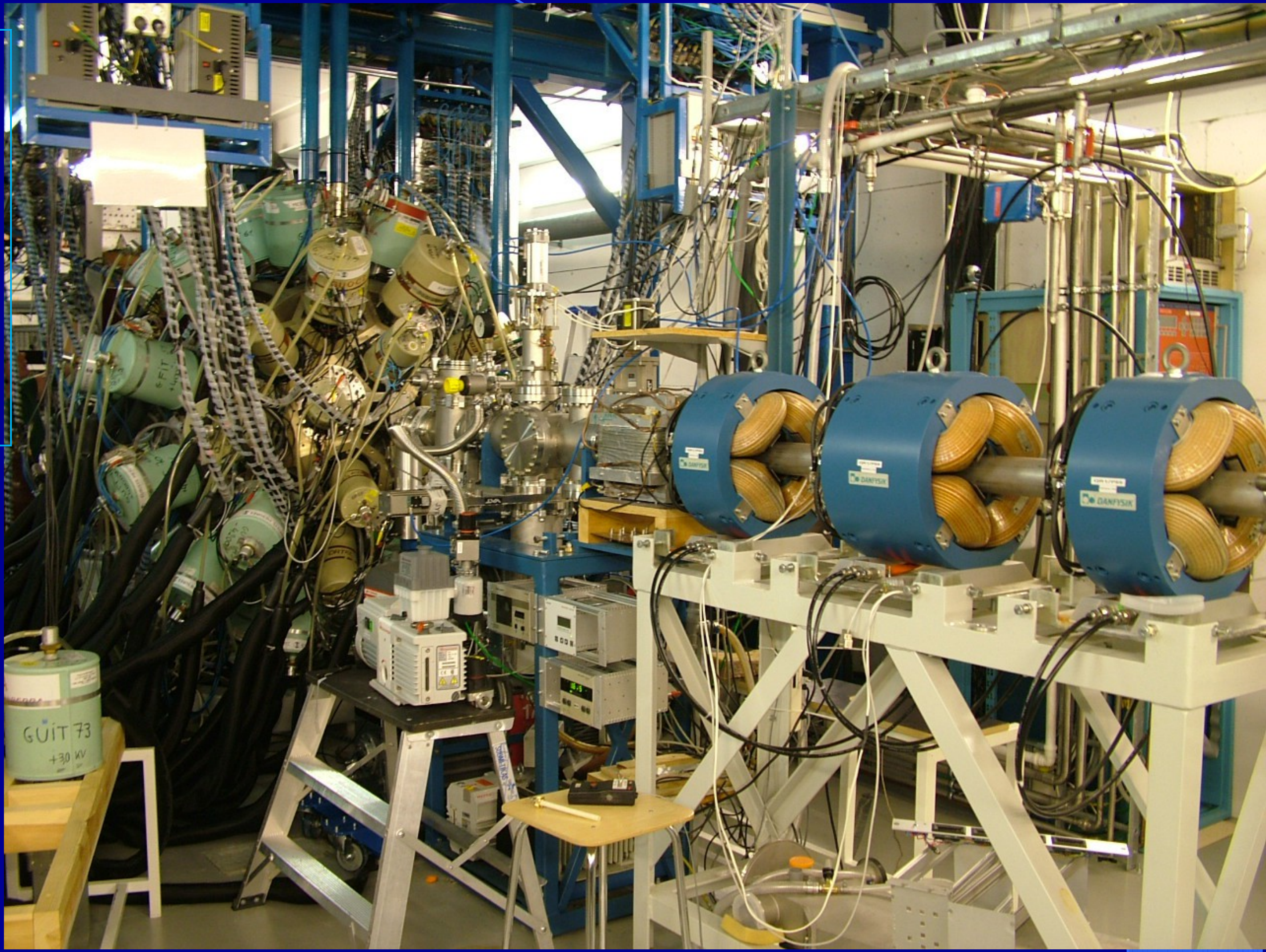
$\varepsilon_{tot} = 4$ %

RITU

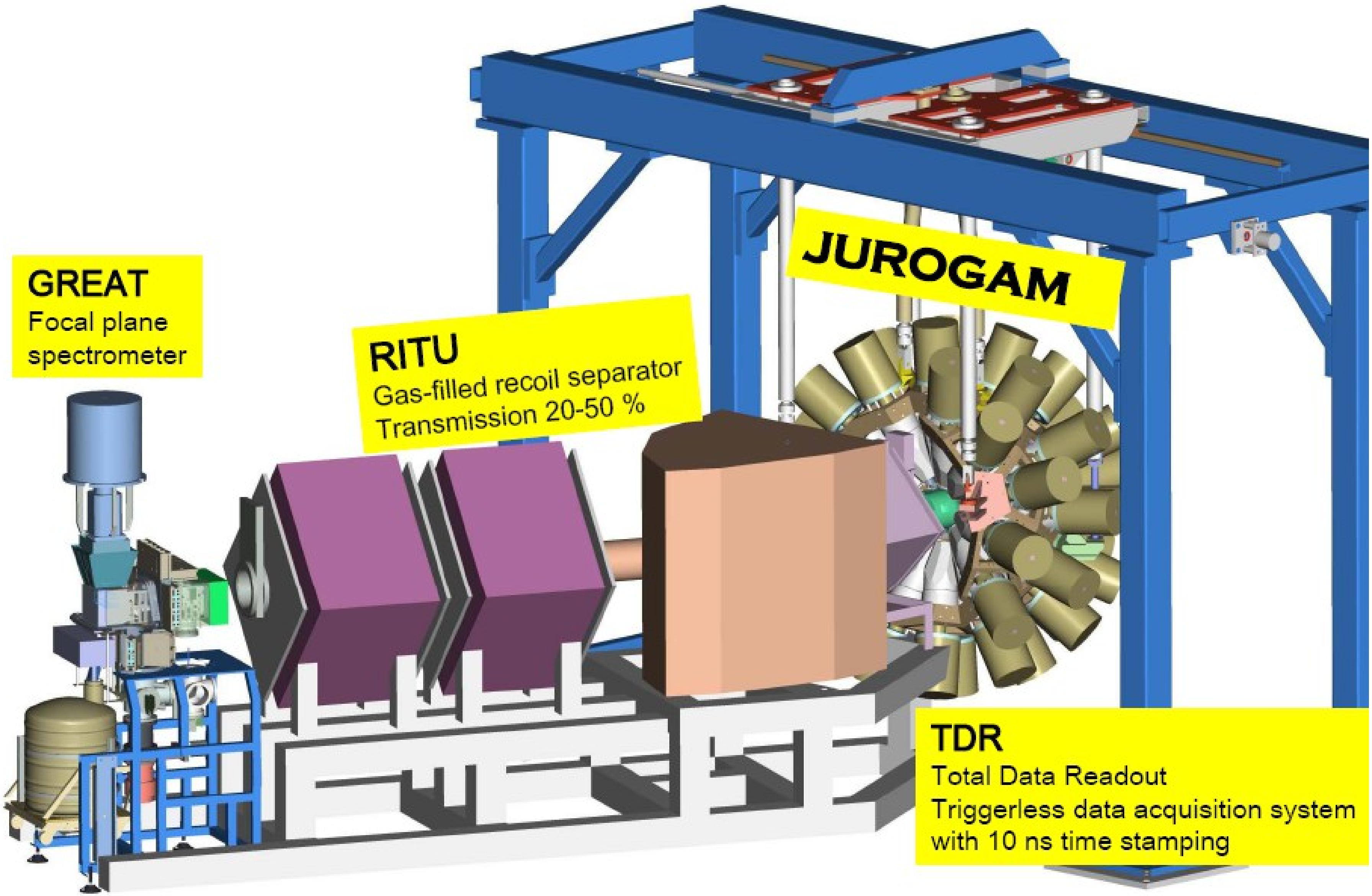
QHDQHQV

500 ns transport time

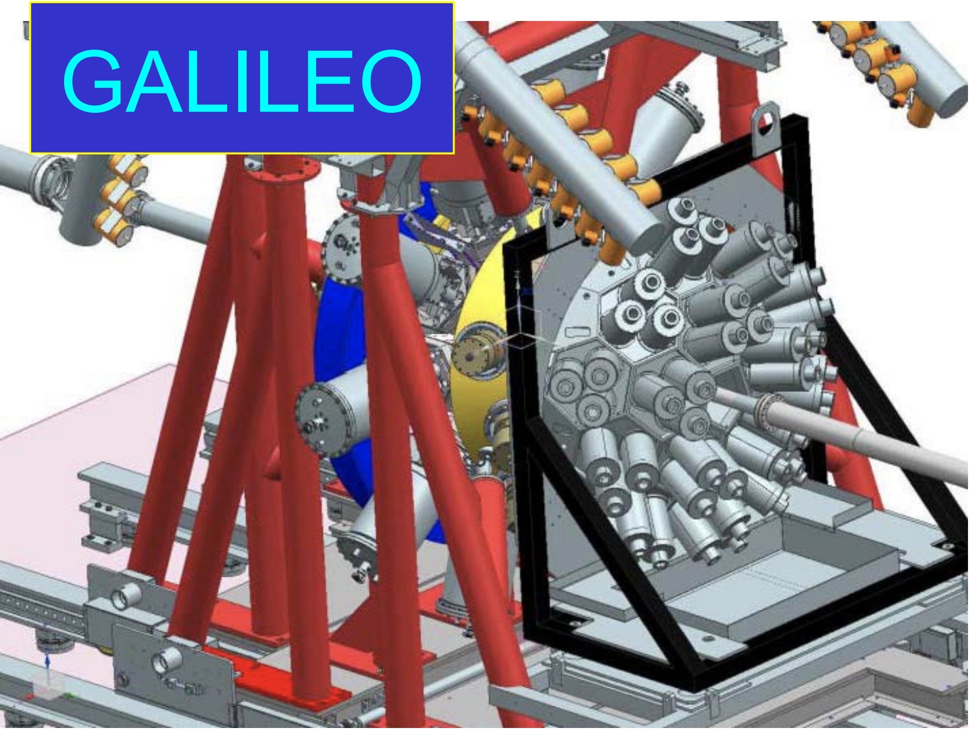
20-50% transmission

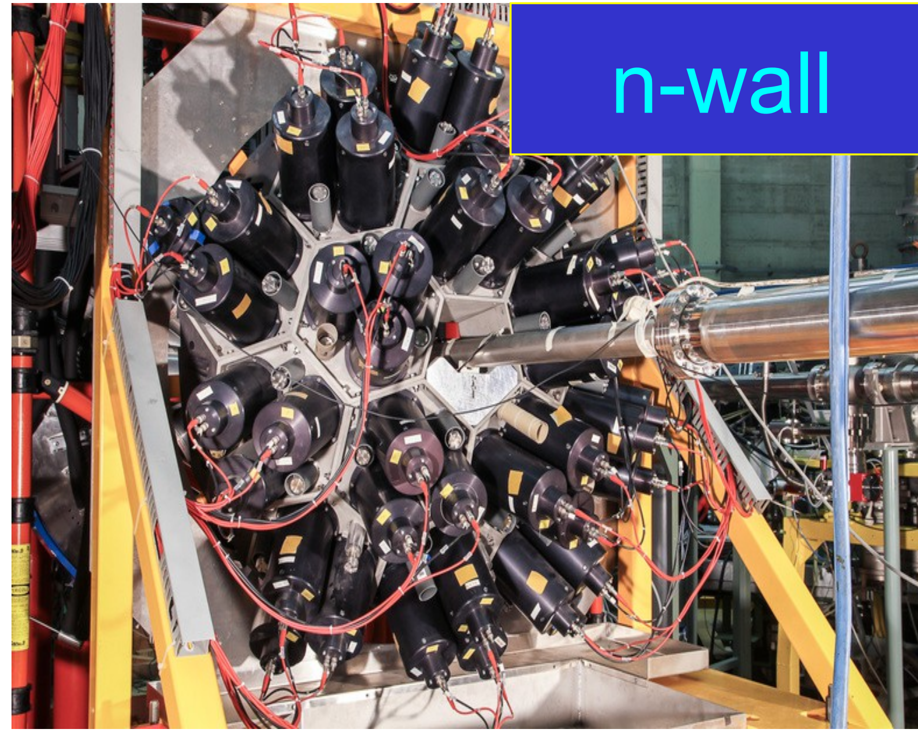


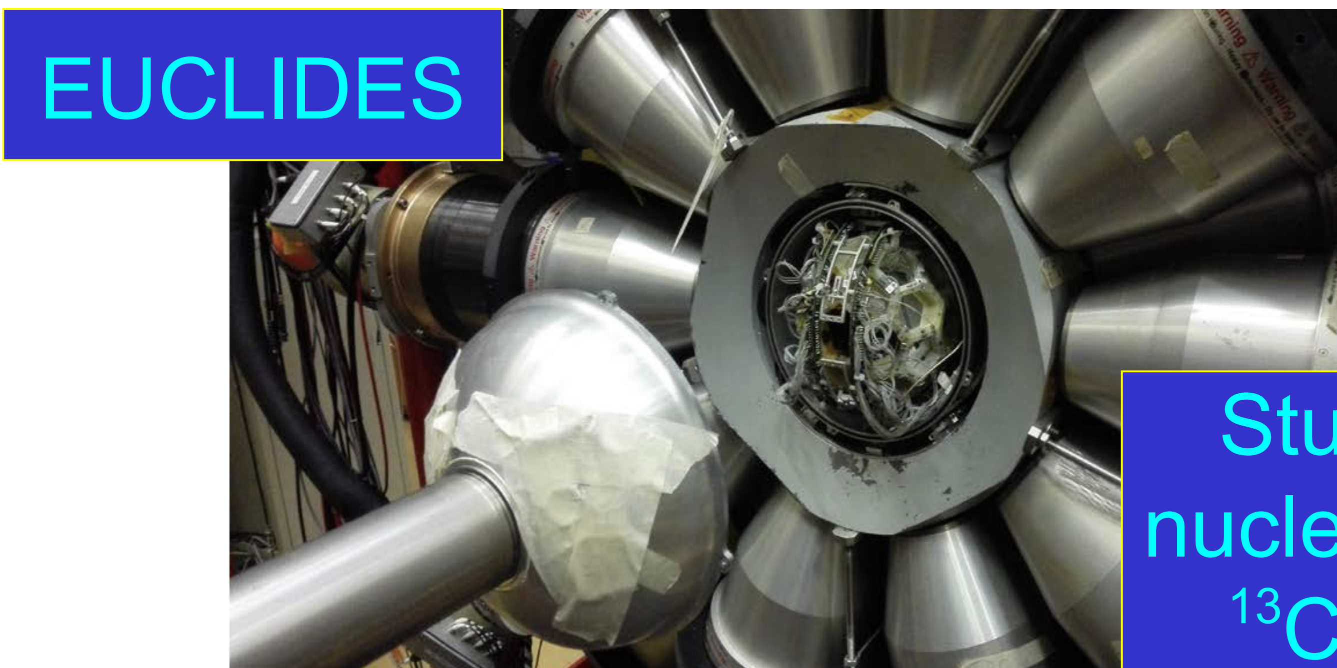
JUROGAM+RITU at Jyväskylä (^{48}Ca + ^{96}Zr)



Ga



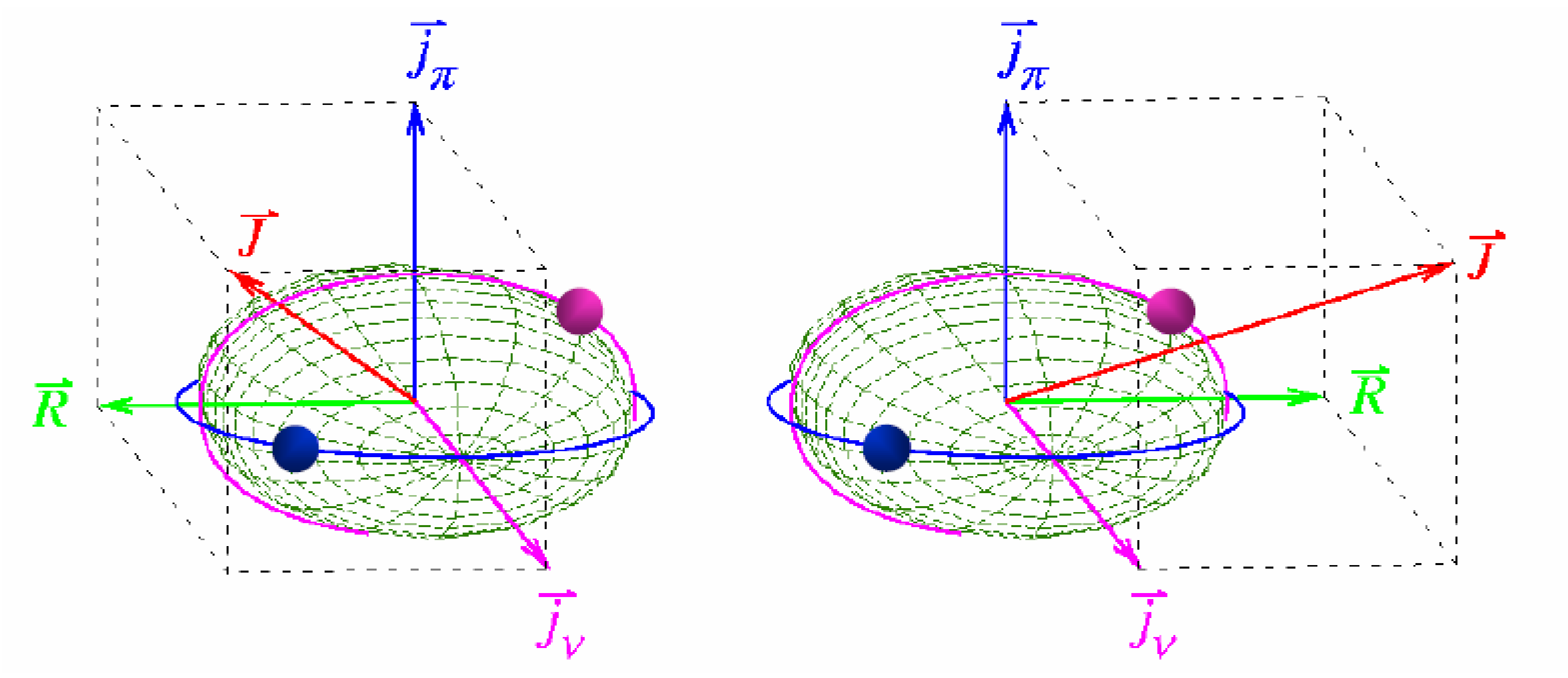




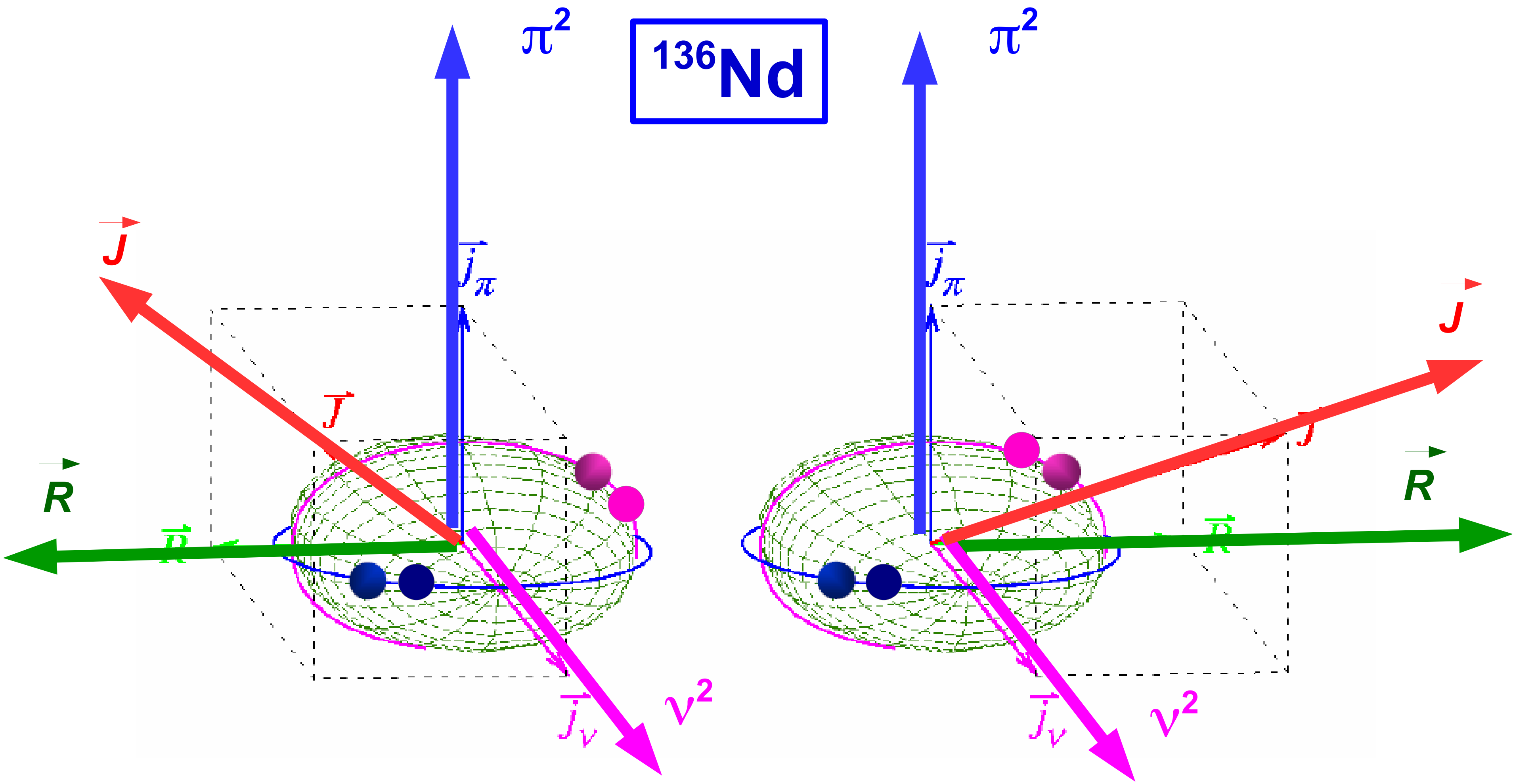
Study of Ba nuclei using the $^{13}C + ^{122}Sn$

Chirality in odd-odd nuclei : 2-qp configurations

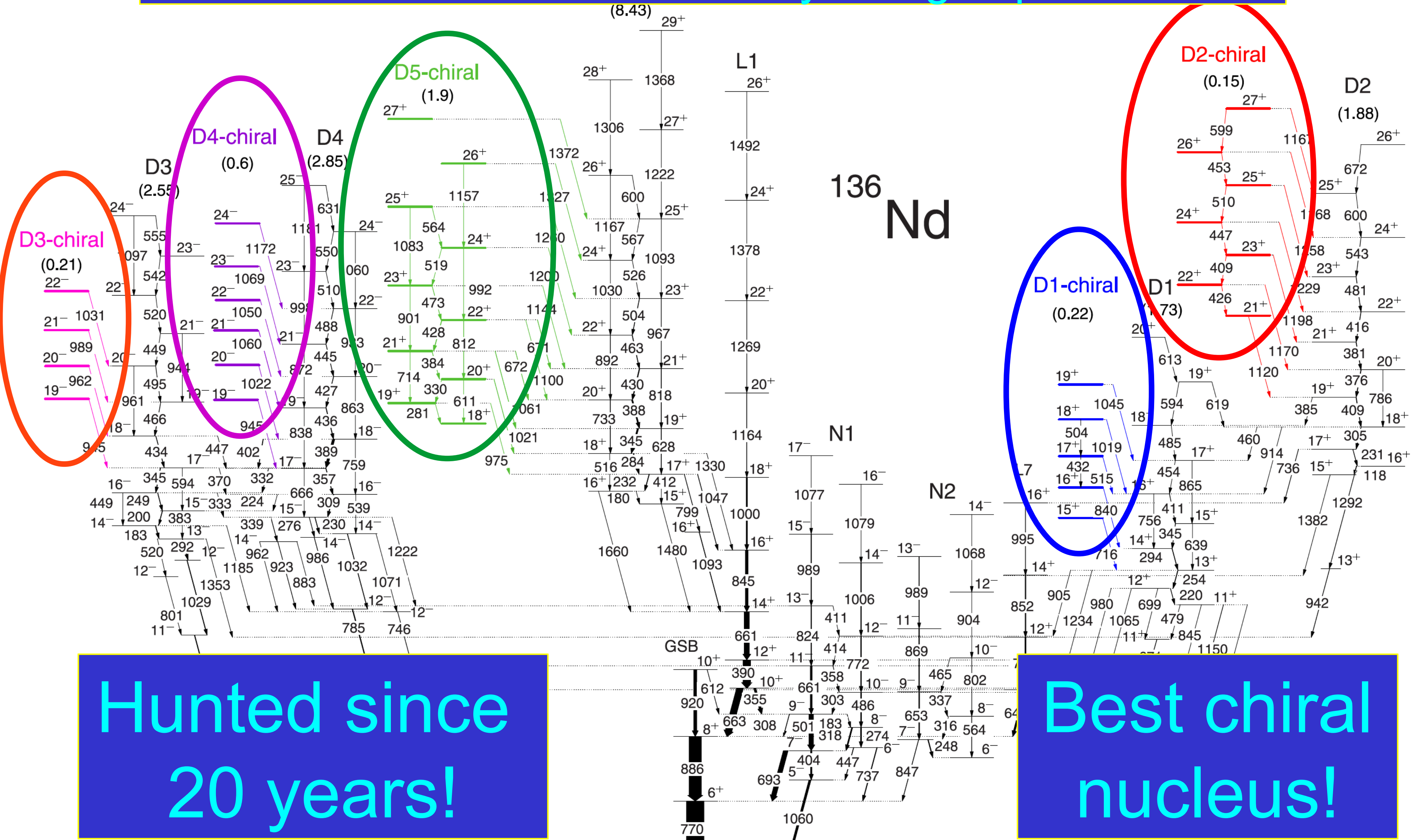
Cs, La, Pr, Pm, Eu



Chirality in even-even nuclei: 4-qp configurations



Ultimate chirality under best conditions:
stable maximal triaxiality at high spins



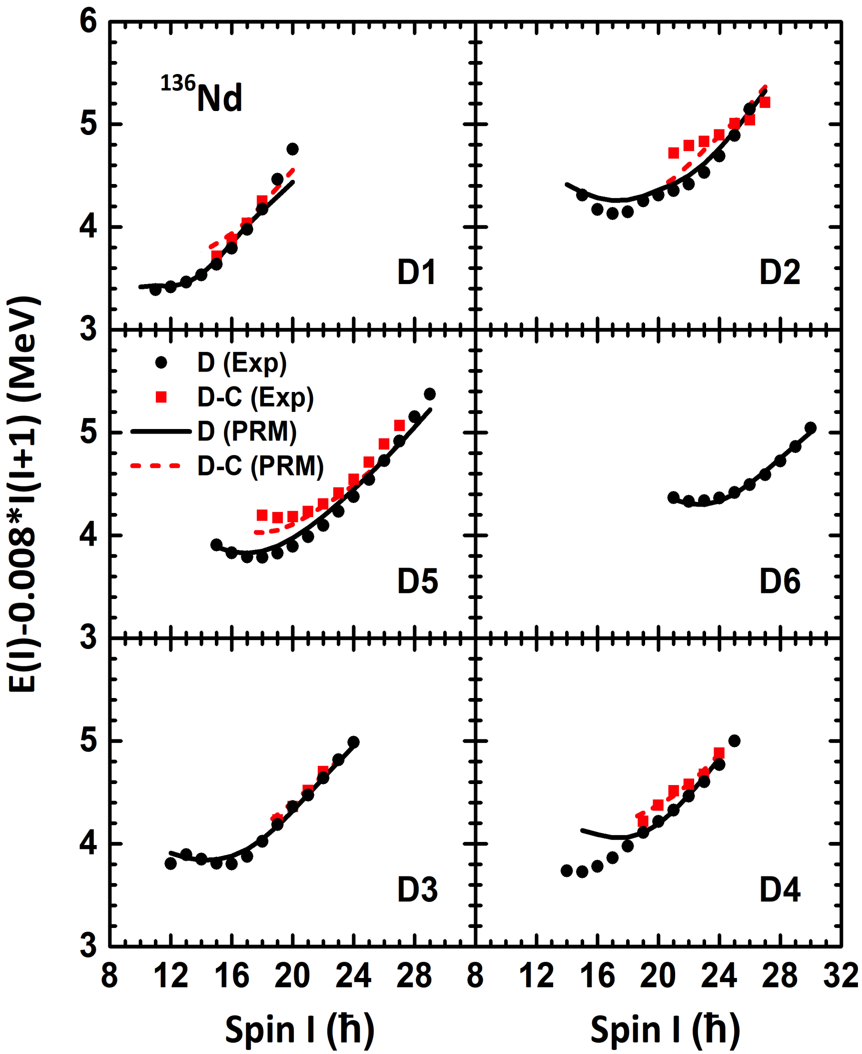
Hunted since 20 years!

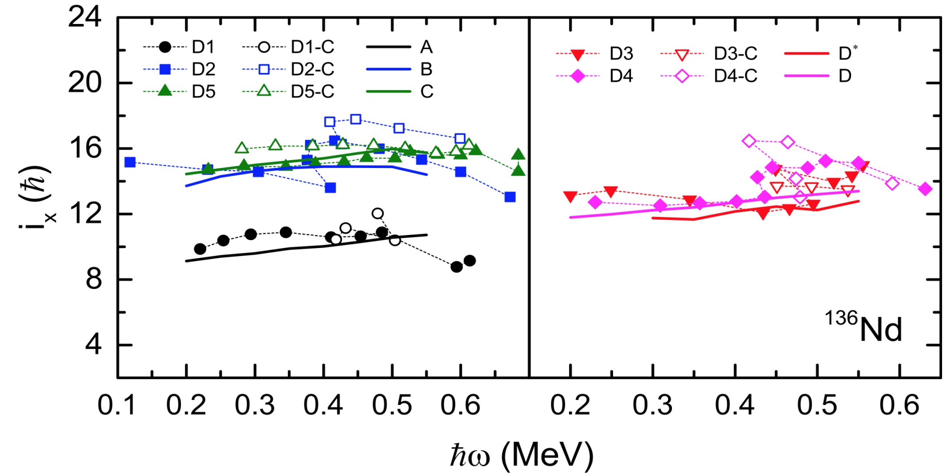
Best chiral nucleus!

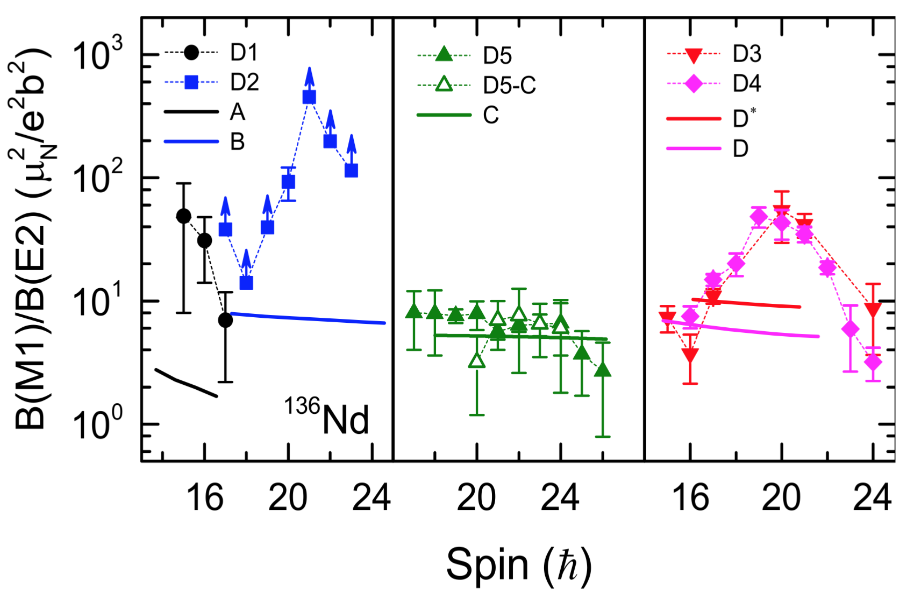
CP, B.F. Lv et al, PRC 97 (2018) 041304 (R)

Multi-j PTRM calculations for ^{136}Nd

Q. B. Chen, B.F. Lv, C.M. Petrache, J. Meng, PLB 782 (2018) 744



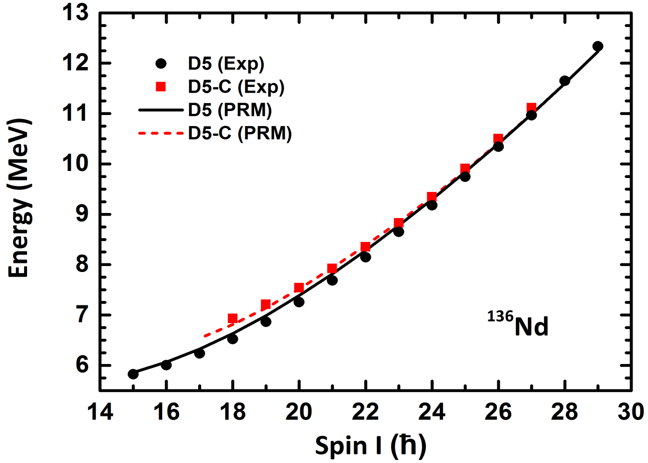


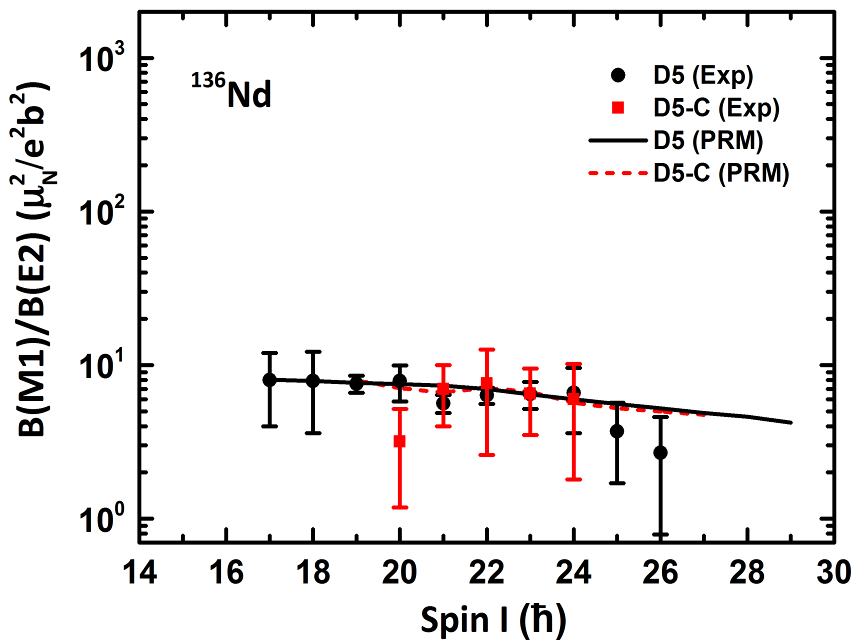


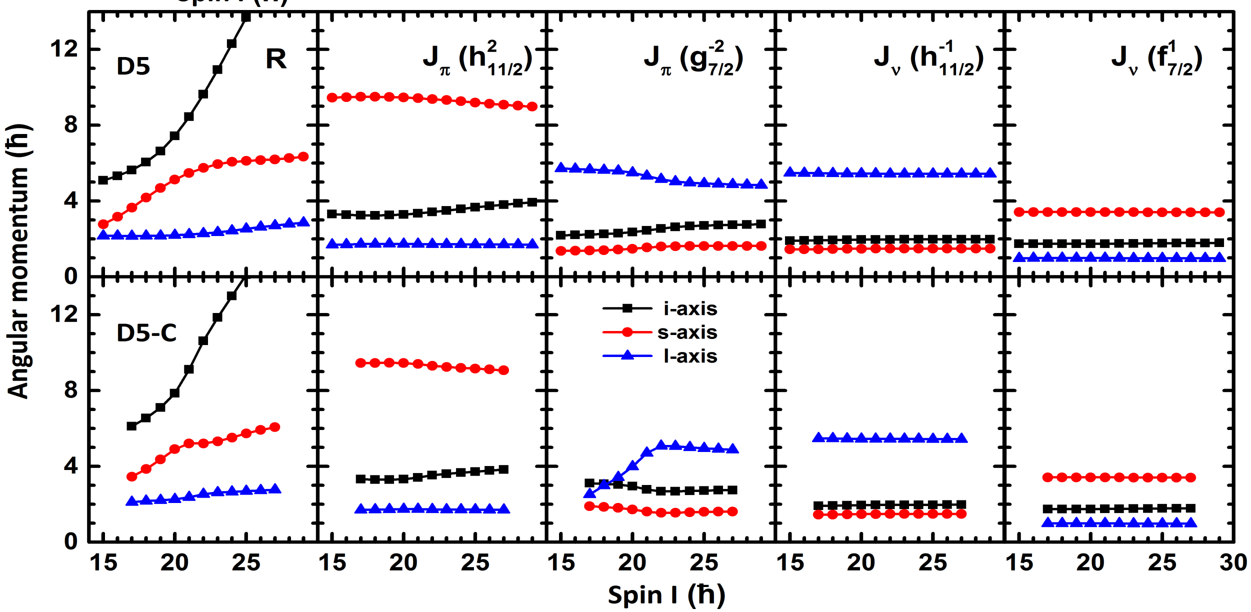
^{136}Nd – chiral doublet D5

Numerical details

- Configuration: $\pi (1h_{11/2})^2 (1g_{7/2})^{-2} \nu (1h_{11/2})^{-1} (1f_{7/2})^1$
- Deformation: ($\beta = 0.26$, γ=23.0°)
- Irr. MOI: $\Im$ = 40 MeV
- Coriolis attenuation factor: 0.93







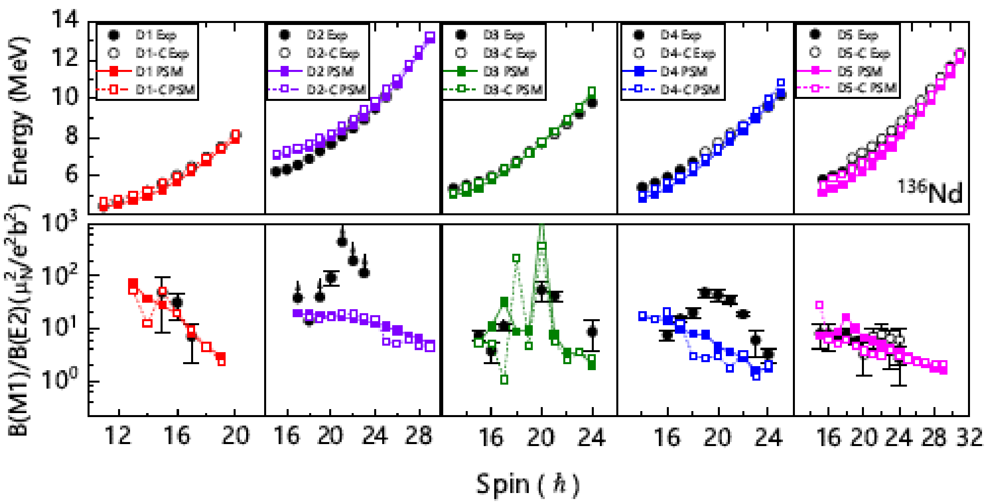
TPSM calculations for the 5 chiral bands of ^{136}Nd

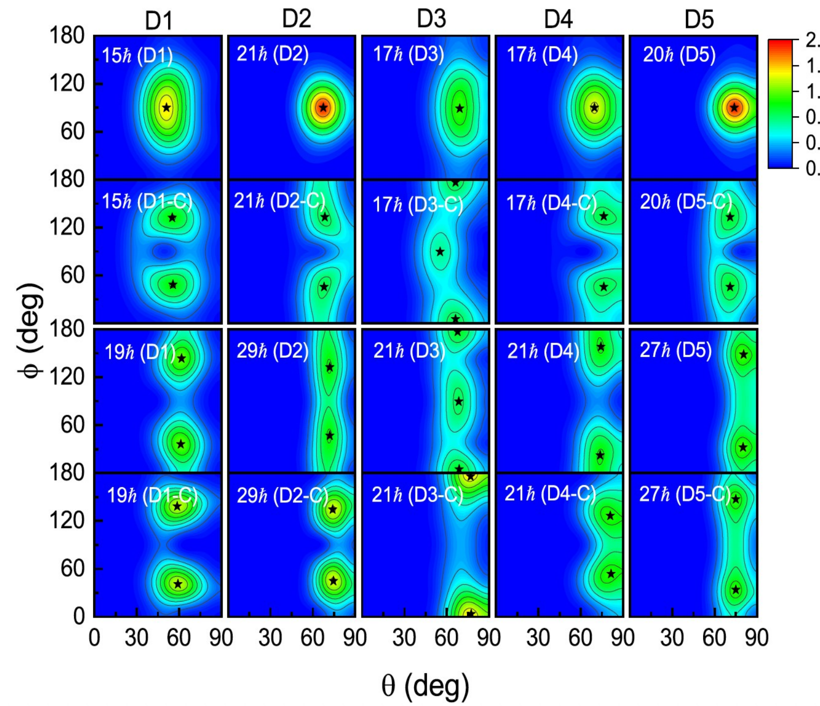
Y.K. Wang et al, PRC 99 (2019) 054303

Azimuthal plots : probability distribution of angular momenta

$$
\{|\Phi_0\rangle,\ \hat\beta^\dagger_{\nu_i}\hat\beta^\dagger_{\nu_j}|\Phi_0\rangle,\ \hat\beta^\dagger_{\pi_i}\hat\beta^\dagger_{\pi_j}|\Phi_0\rangle,\ \hat\beta^\dagger_{\pi_i}\hat\beta^\dagger_{\pi_j}\hat\beta^\dagger_{\nu_k}\hat\beta^\dagger_{\nu_l}|\Phi_0\rangle,\\
\hat\beta^\dagger_{\nu_i}\hat\beta^\dagger_{\nu_j}\hat\beta^\dagger_{\nu_k}\hat\beta^\dagger_{\nu_l}|\Phi_0\rangle,\ \hat\beta^\dagger_{\pi_i}\hat\beta^\dagger_{\pi_j}\hat\beta^\dagger_{\pi_k}\hat\beta^\dagger_{\pi_l}|\Phi_0\rangle,\\
\hat\beta^\dagger_{\nu_i}\hat\beta^\dagger_{\nu_j}\hat\beta^\dagger_{\nu_k}\hat\beta^\dagger_{\nu_l}\hat\beta^\dagger_{\nu_m}\hat\beta^\dagger_{\nu_n}|\Phi_0\rangle,\ \hat\beta^\dagger_{\pi_i}\hat\beta^\dagger_{\pi_j}\hat\beta^\dagger_{\pi_k}\hat\beta^\dagger_{\pi_l}\hat\beta^\dagger_{\pi_m}\hat\beta^\dagger_{\pi_n}|\Phi_0\rangle,\\
\hat\beta^\dagger_{\pi_i}\hat\beta^\dagger_{\pi_j}\hat\beta^\dagger_{\nu_k}\hat\beta^\dagger_{\nu_l}\hat\beta^\dagger_{\nu_m}\hat\beta^\dagger_{\nu_n}|\Phi_0\rangle,\ \hat\beta^\dagger_{\nu_i}\hat\beta^\dagger_{\nu_j}\hat\beta^\dagger_{\pi_k}\hat\beta^\dagger_{\pi_l}\hat\beta^\dagger_{\pi_m}\hat\beta^\dagger_{\pi_n}|\Phi_0\rangle\},
$$

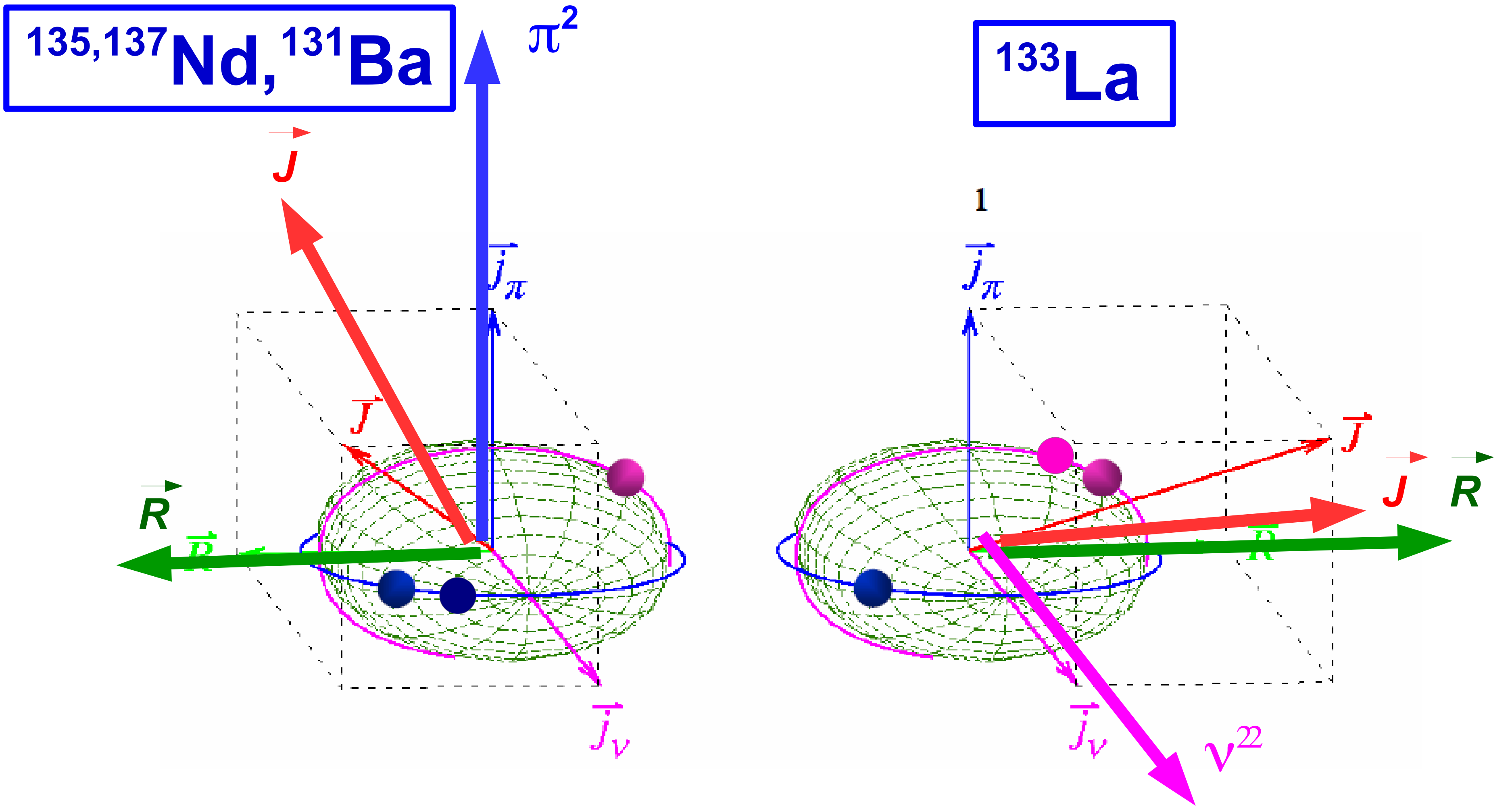
low spin





high spin

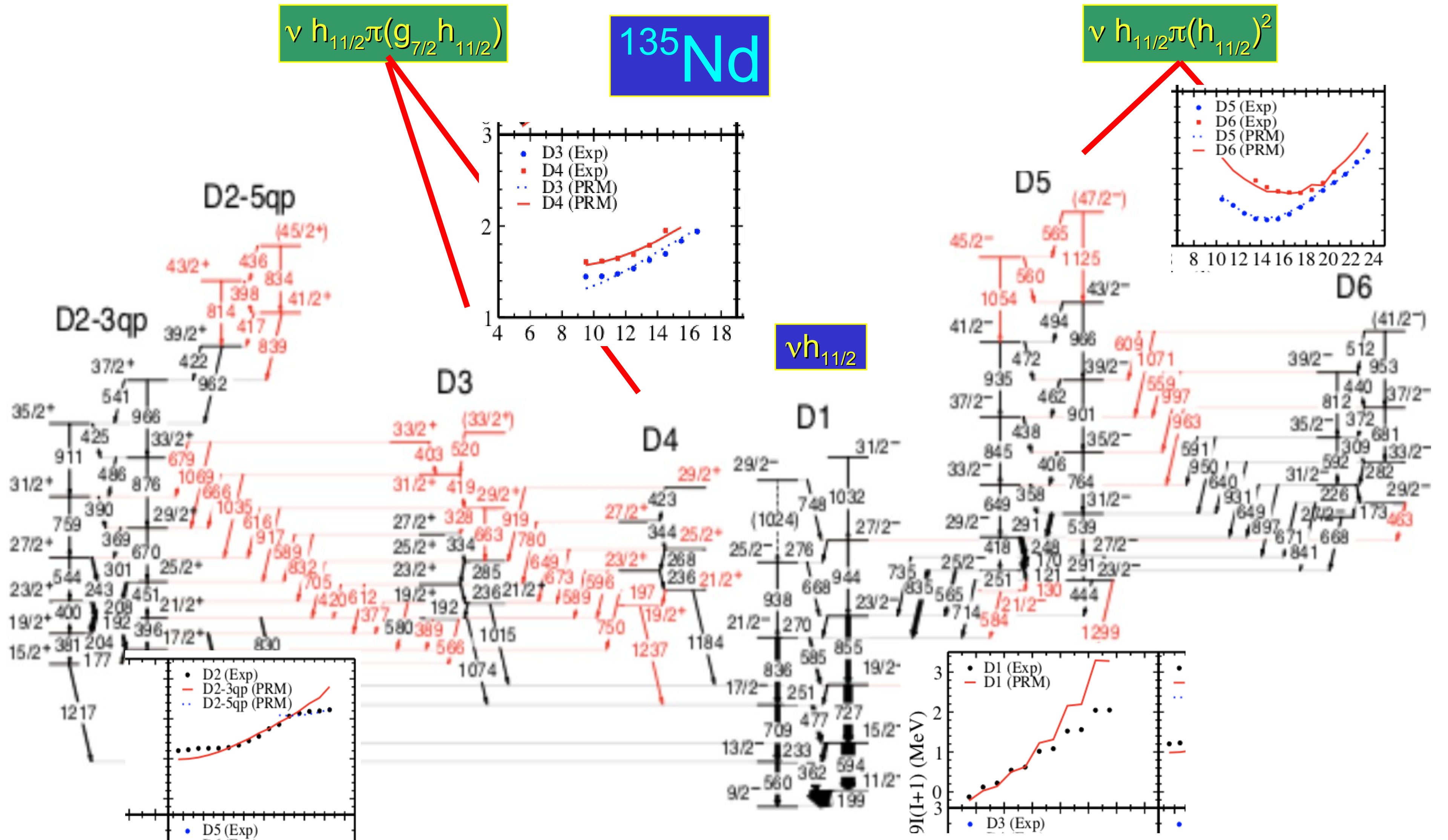
Chirality in odd-even nuclei: 3-qp (π^2&ν^{h1} or π^{h1}&ν^{h2}) configurations



B.F. Lv, C.M. Petrache, Q.B. Chen et al.

PRC 103, 019901 (2021)

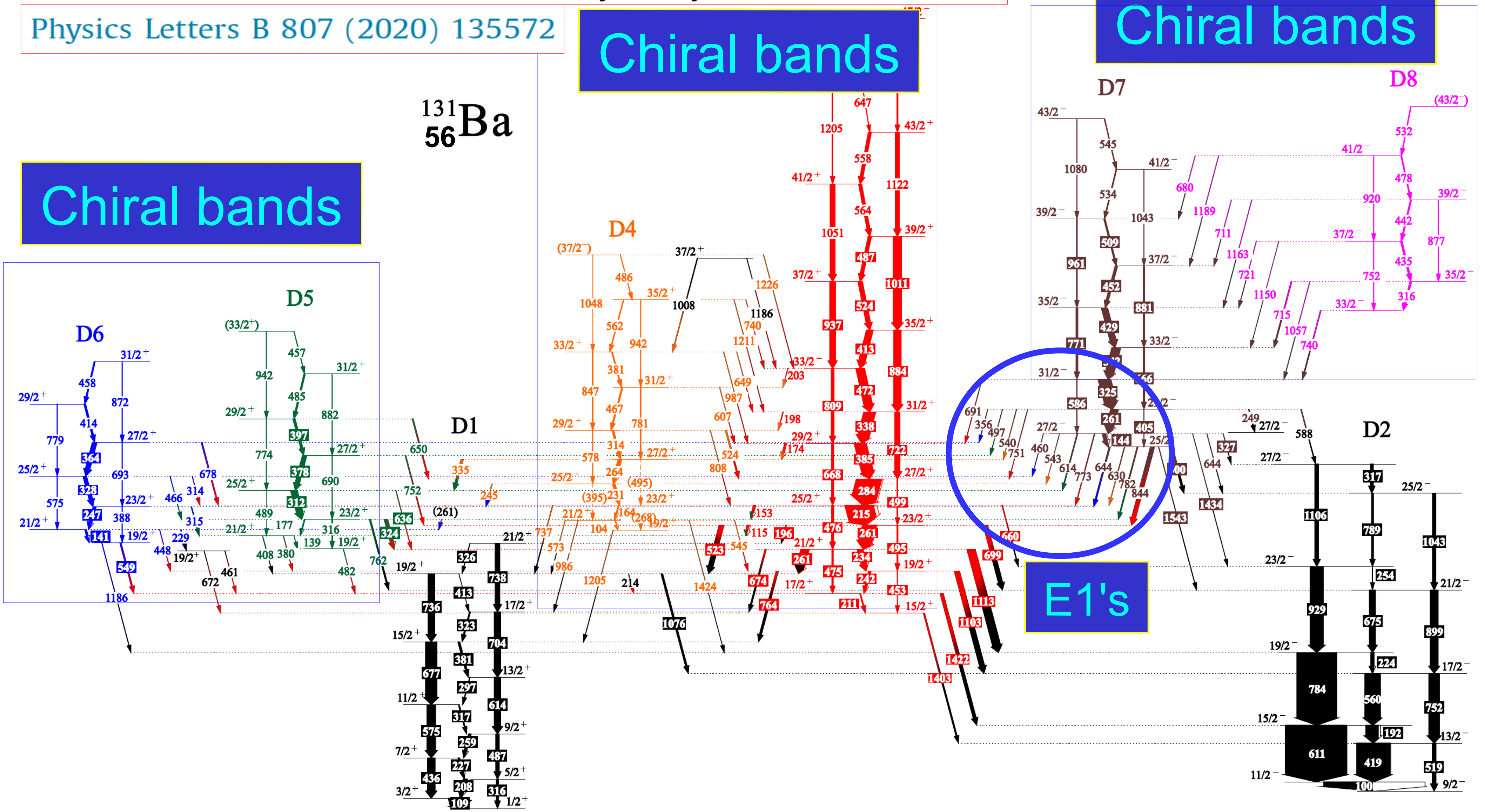
^{135}Nd



Evidence for pseudospin-chiral quartet bands in the presence of octupole correlations

S. Guo [a,b,*], C.M. Petrache [c,*], D. Mengoni [d,e], Y.H. Qiang [a], Y.P. Wang [f], Y.Y. Wang [f], J. Meng [f,g], Y.K. Wang [f], S.Q. Zhang [f], P.W. Zhao [f], A. Astier [c], J.G. Wang [a,b], H.L. Fan [a], E. Dupont [c], B.F. Lv [c], D. Bazzacco [d,e], A. Boso [d,e], A. Goasduff [d,e], F. Recchia [d,e], D. Testov [d,e], F. Galtarossa [h,i], G. Jaworski [h], D.R. Napoli [h], S. Riccetto [h], M. Siciliano [h], J.J. Valiente-Dobon [h], M.L. Liu [a,b], G.S. Li [a,b], X.H. Zhou [a,b], Y.H. Zhang [a,b], C. Andreoiu [j], F.H. Garcia [j], K. Ortner [j], K. Whitmore [j], A. Ataç-Nyberg [k], T. Bäck [k], B. Cederwall [k], E.A. Lawrie [l,m], I. Kuti [n], D. Sohler [n], T. Marchlewski [o], J. Srebrny [o], A. Tucholski [o]

Physics Letters B 807 (2020) 135572



Selection rules of electromagnetic transitions for chirality-parity violation in atomic nuclei

Yuanyuan Wang [a], Xinhui Wu [a], Shuangquan Zhang [a], Pengwei Zhao [a], Jie Meng [a, b, c]

ELSEVIER
Science Bulletin
Volume 65, Issue 23, 15 December 2020, Pages 2001-2006

Multiple chiral doublet bands with octupole correlations in reflection-asymmetric triaxial particle rotor model

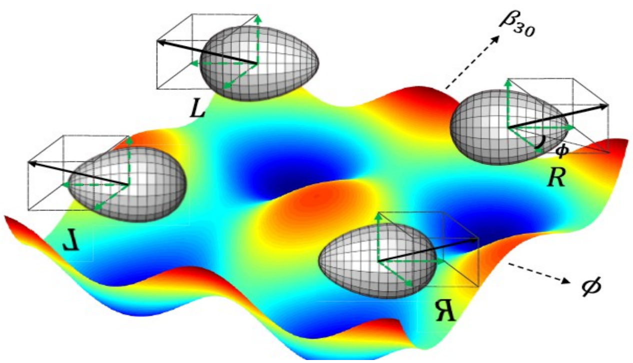
Y.Y. Wang (王媛媛)[a], S.Q. Zhang (张双全)[b], P.W. Zhao (赵鹏巍)[b], J. Meng (孟杰)[b,a,c,*]

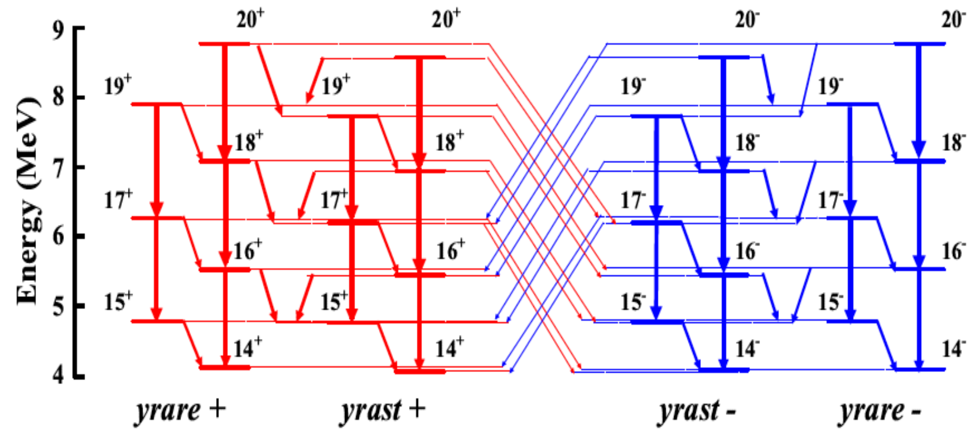
Physics Letters B 792 (2019) 454–460

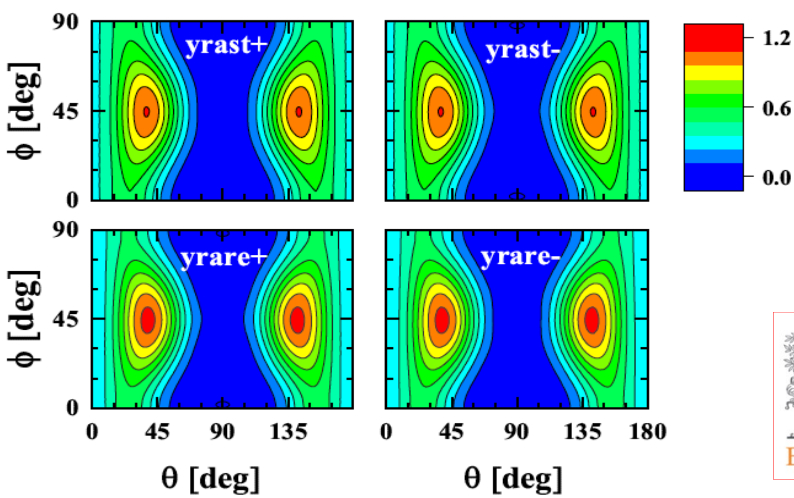
New quantum numbers

Chiture $\mathcal{A}$, similar to signature $\mathcal{R}$

Chiplex $\mathcal{B}=\mathcal{A}\mathcal{P}$, similar to simplex $\mathcal{S}=\mathcal{R}(\pi)\mathcal{P}$







Robustness of chiral symmetry in atomic nuclei with reflection-asymmetric shapes

Costel Marian Petrache

ELSEVIER
Science Bulletin
Volume 65, Issue 23, 15 December 2020, Pages 1956-1957

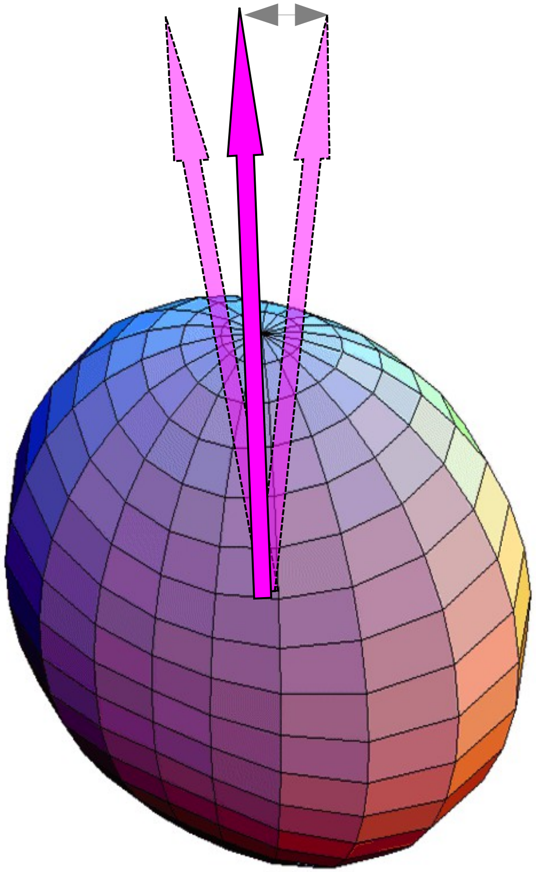
Conclusions, perspectives on chirality

→ Discovery of chiral rotation in even-even nuclei
^{136}Nd – bands based on 4qp an 6qp configurations.

→ Need of precise and complete experimental data
(intensities, angular correlations, lifetimes)

→ Search for chiral doublets in other mass regions

Wobbling mode



Approximation valide only when *I* >> *j*
and
fixed direction of *I*

$$E(I, n_{\text{wobb}}) = \frac{I(I+1)}{2\mathcal{J}_x} + \hbar\omega_{\text{wobb}}\left(n_{\text{wobb}} + \frac{1}{2}\right)$$

$$\hbar\omega_{\text{wobb}} = \hbar\omega_{\text{rot}}\sqrt{\frac{(\mathcal{J}_x - \mathcal{J}_y)(\mathcal{J}_x - \mathcal{J}_z)}{\mathcal{J}_y \mathcal{J}_z}}$$

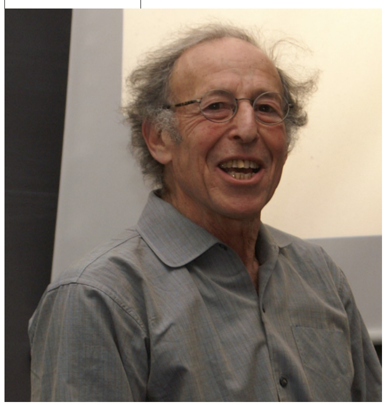
$$\hbar\omega_{\text{rot}} = \frac{I}{\mathcal{J}_x}$$

Wobbling bands: questions, new achievements and perspectives

1975, Bohr-Mottelson, Chapter 4,
States with large I ($I^2 >> I_2^{\,2}+I_3^{\,2}$)

$$E(I, n_{\rm wobb}) = \frac{I(I+1)}{2\mathcal{J}_x} + \hbar\omega_{\rm wobb}\left(n_{\rm wobb} + \frac{1}{2}\right)$$

1975 — 2001 — 2022

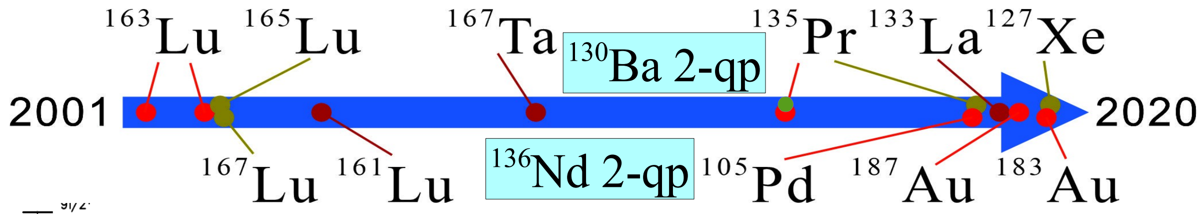




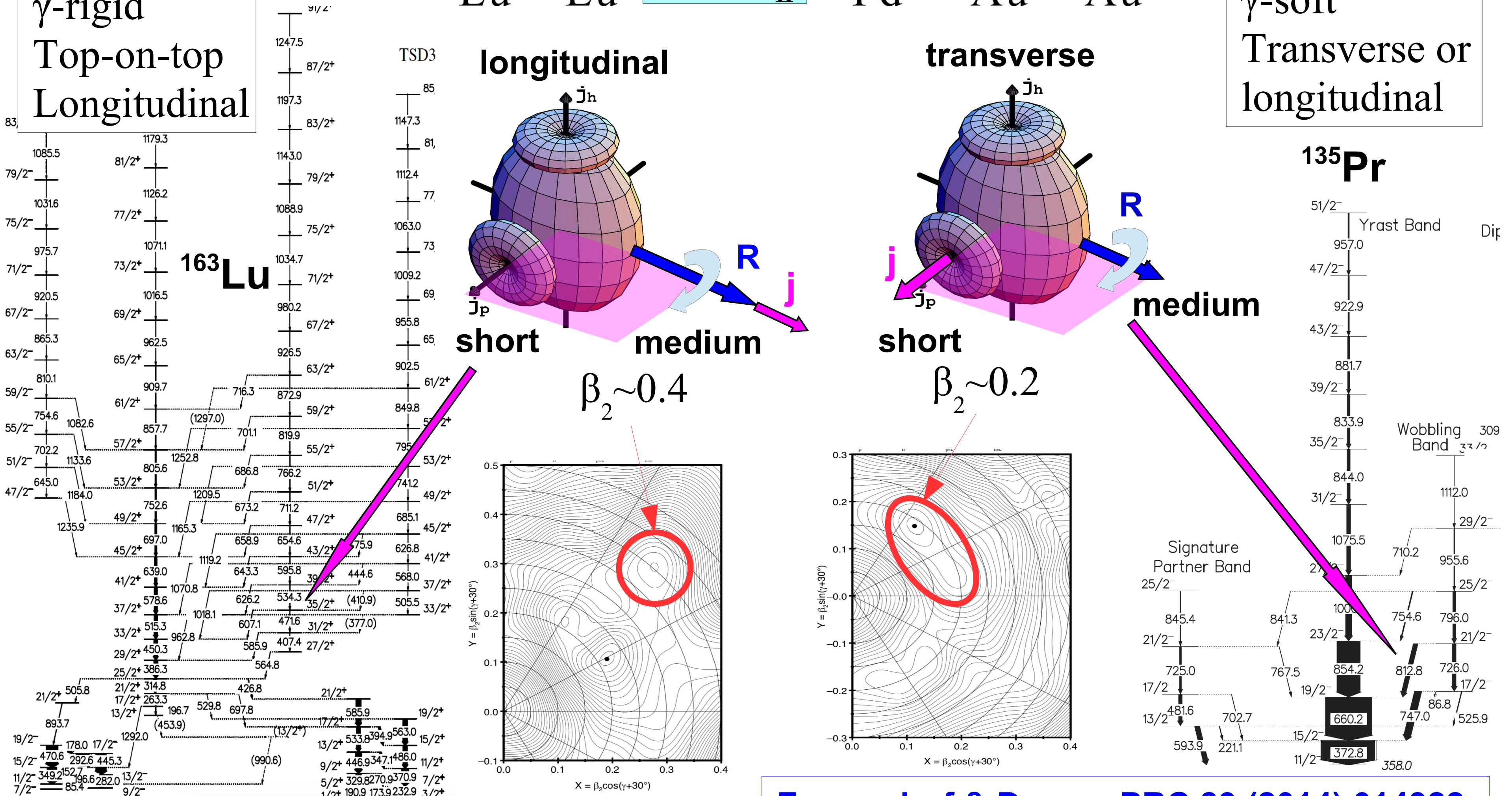



Reported wobbling bands

High spins
Large β_2
γ-rigid
Top-on-top
Longitudinal



Low spins
Moderate β_2
γ-soft
Transverse or
longitudinal



Frauendorf & Donau, PRC 89 (2014) 014322

PRL 114, 082501 (2015) PHYSICAL REVIEW LETTERS week ending 27 FEBRUARY 2015

February 2015

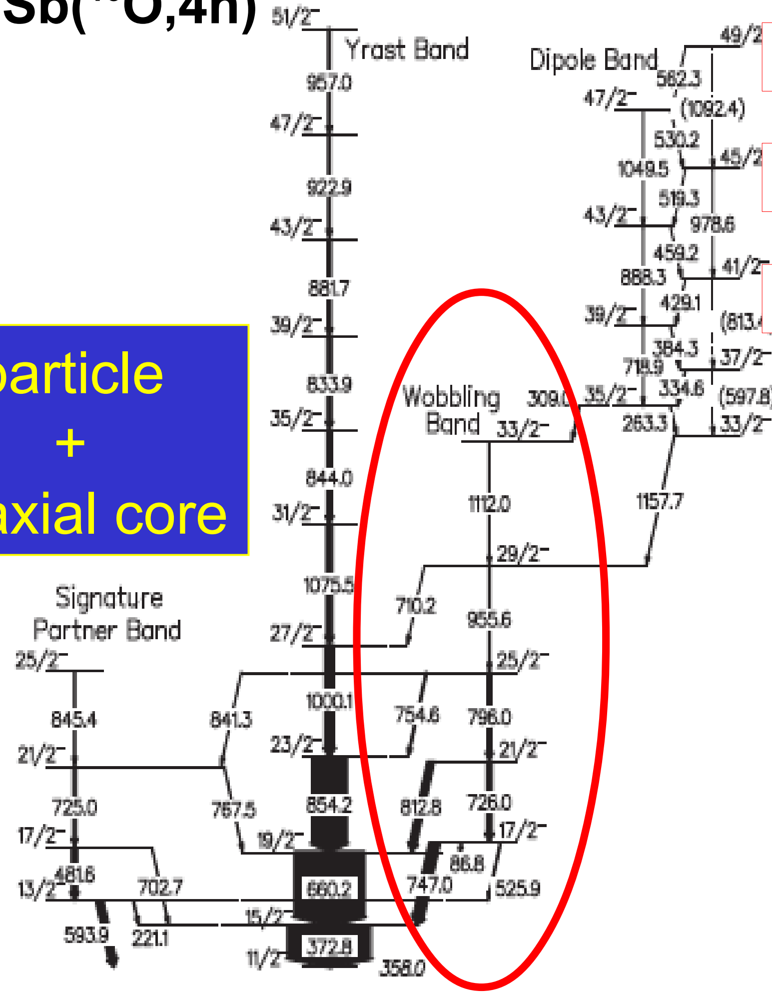
Transverse Wobbling in ^{135}Pr

J. T. Matta, U. Garg, W. Li, S. Frauendorf, A. D. Ayangeakaa,† D. Patel, and K. W. Schlax
C. M. Petrache
Centre de Sciences Nucléaires et Sciences de la Matière, Université Paris—Sud and CNRS/IN2P3, F-91405 Orsay, France

^{135}Pr

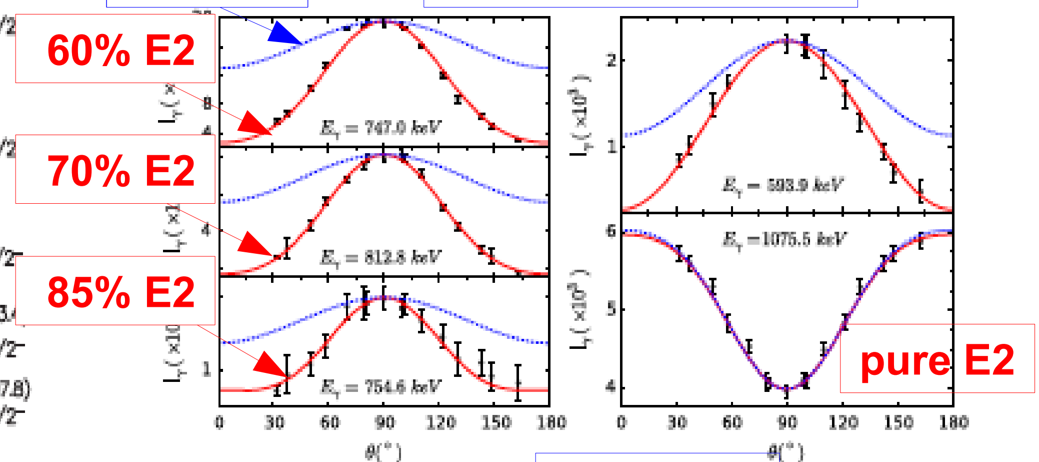
^{123}Sb(^{16}O,4n)

particle
+
triaxial core

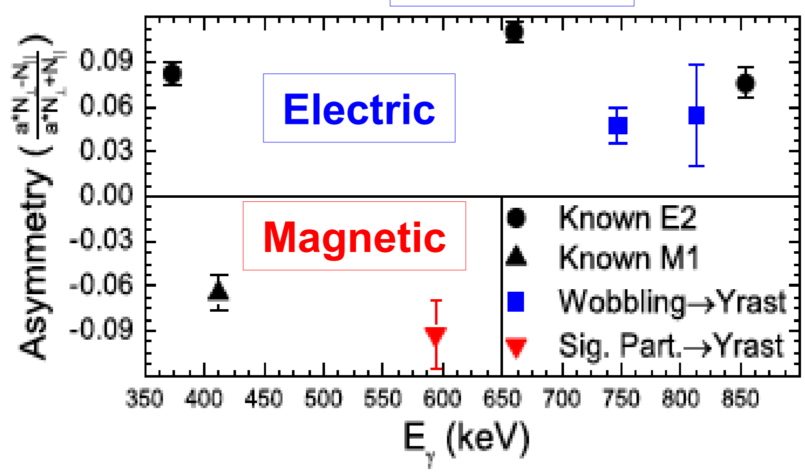


pure M1

Gammasphere data



INGA data



November 2015

PHYSICAL REVIEW C 92, 054325 (2015)

Negative-parity high-spin states and a possible magnetic rotation band in $^{135}_{59}Pr_{76}$

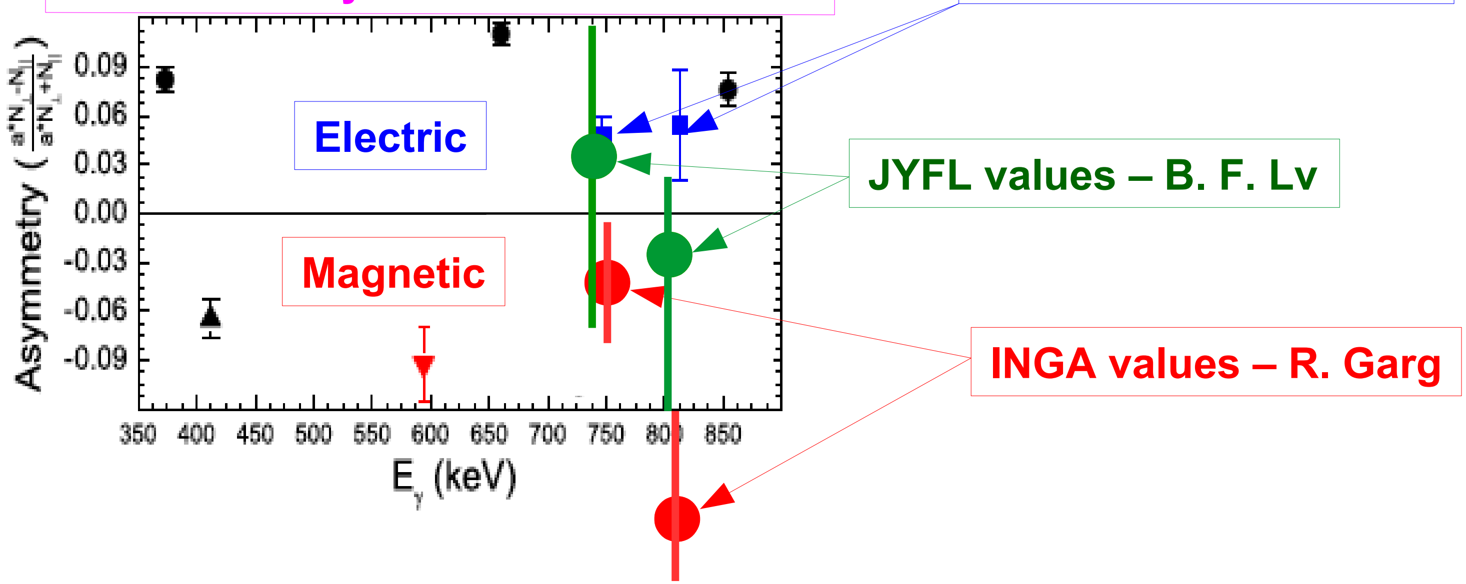
Ritika Garg,[1,2,*] S. Kumar,[1] Mansi Saxena,[1] Savi Goyal,[1] Davinder Siwal,[1] Sunil Kalkal,[3] S. Verma,[1] R. Singh,[4] S. C. Pancholi,[2] R. Palit,[5] Deepika Choudhury,[6] S. S. Ghugre,[7] G. Mukherjee,[8] R. Kumar,[2] R. P. Singh,[2] S. Muralithar,[2] R. K. Bhowmik,[2] and S. Mandal[1]

(Received 26 August 2015; published 30 November 2015)

1478.2	747.5	9.06(24)	0.25(1)^{Q}	−0.05(0.03)	$M1+E2$	$17/2^- \rightarrow 15/2^-$
3000.4	755.3	1.83(15)	0.46(4)^{Q}		D	$25/2^{(-)} \rightarrow 23/2^-$
4292.7	762.7	1.58(8)				$31/2^- \rightarrow 27/2^-$
3519.0	764.2	4.81(18)	2.13(37)^{D}		Q	$27/2^{(-)} \rightarrow 23/2^-$
2158.9	767.9	1.02(8)				$(21/2^-) \rightarrow 19/2^-$
3530.0	776.2	7.75(23)	0.83(6)^{Q}	0.1[illegible](12)	$E2$	$27/2^- \rightarrow 23/2^-$
3000.4	795.9	4.43(15)	0.98(10)^{Q}		Q	$25/2^{(-)} \rightarrow 21/2^-$
2204.4	813.3	5.96(18)	0.22(2)^{Q}	−0.2(0.08)	$M1+E2$	$21/2^- \rightarrow 19/2^-$

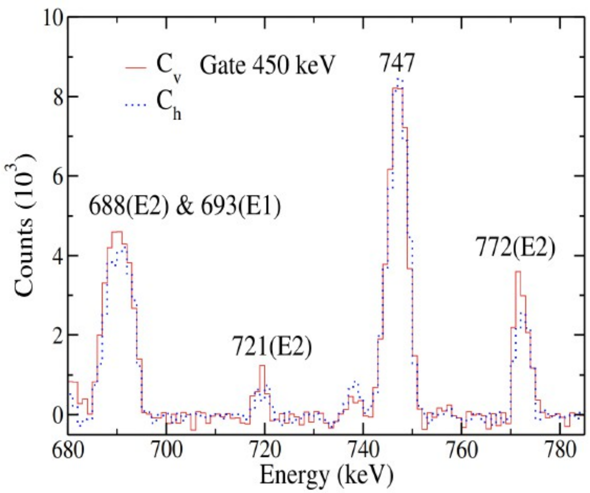
Magnetic

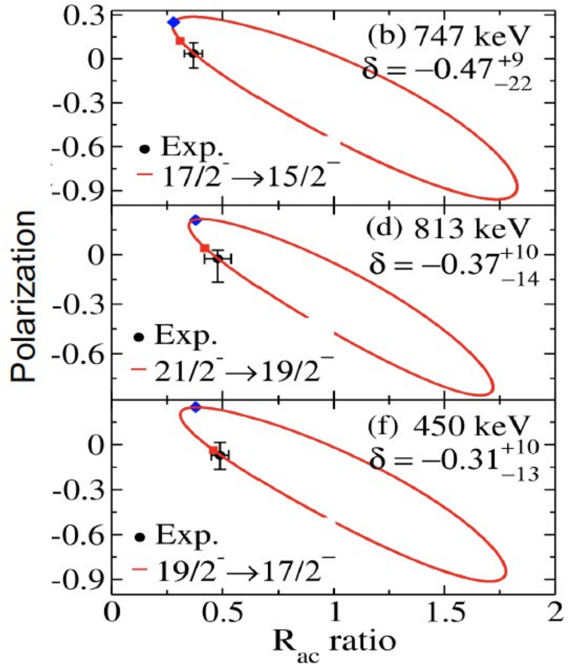
Contradicting results measured with the same array and same reaction!



Experimental evidence against wobbling interpretation

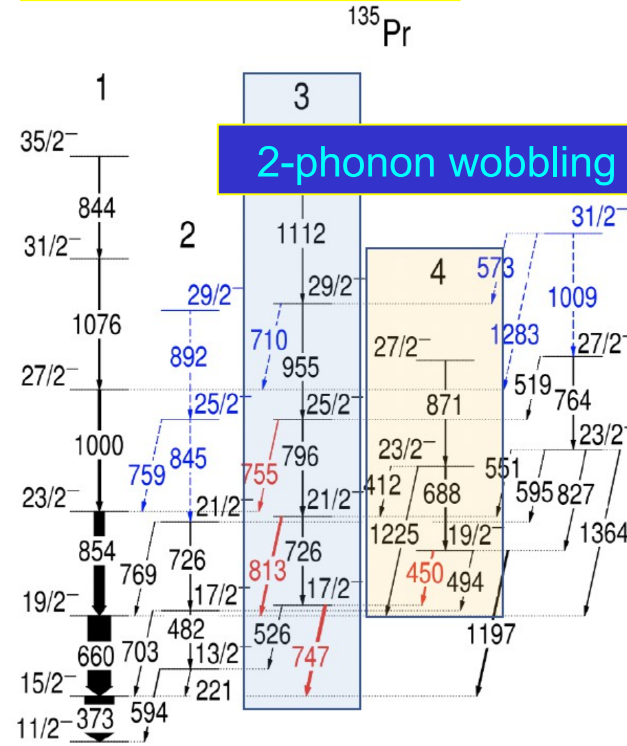
Experimental results





1-phonon wobbling

2-phonon wobbling



E_γ (keV)	P	R_{ac}	δ	$\frac{B(M1)_{out}}{B(E2)_{in}}$	$\frac{B(E2)_{out}}{B(E2)_{in}}$
747.3	0.04^{+8}_{-13}	0.37(4)	-0.47^{+9}_{-22}		
813.2	-0.03^{+5}_{-12}	0.48(6)	-0.37^{+10}_{-14}	0.4(3)	0.12(8)
755.1		0.50(6)			
450.2	-0.07^{+9}_{-10}	0.49(4)	-0.31^{+10}_{-13}		

Experimental results do not support the wobbling nature of the bands!

J. T. Matta, U. Garg, W. Li, et al., Phys. Rev. Lett. 114, 082501 (2015).
Sensharma, U. Garg, S. Zhu et al., Phys. Lett. B 792, 170 (2019).

B.F. Lv et al., PLB 824 (2022)136840

Theoretical evidence against wobbling interpretation

Discussion: Quasiparticle plus-triaxial-rotor calculations

QTR calculations: E. Lawrie, iThemba LABS, South Africa

In the present QTR calculations:

(i) Does not use the frozen approximation of the particle angular momentum.

(ii) Does not modify the relative magnitude of the irrotational-flow moments of inertia.

(iii) The single-particle degrees of freedom were considered, allowing effects such as Coriolis alignment of the valence nucleon, as well as single-particle excitations.

Physics Letters B 824 (2022) 136840

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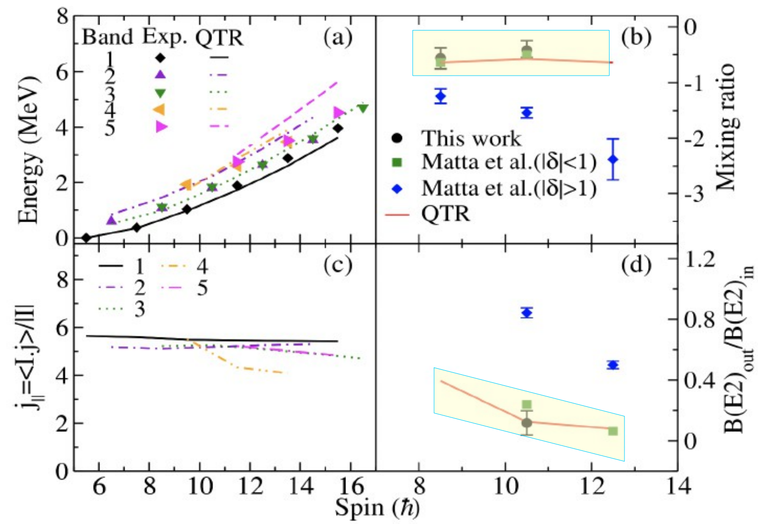
Evidence against the wobbling nature of low-spin bands in ^{135}Pr

B.F. Lv[a,b], C.M. Petrache[b,*], E.A. Lawrie[c,d], S. Guo[a,e], A. Astier[b], K.K. Zheng[a,b], H.J. Ong[a,e], J.G. Wang[a,e], X.H. Zhou[a,e], Z.Y. Sun[a,e], P.T. Greenlees[f], H. Badran[f], T. Calverley[f,g], D.M. Cox[f,h], T. Grahn[f], J. Hilton[f,g], R. Julin[f], S. Juutinen[f], J. Konki[f,i], J. Pakarinen[f], P. Papadakis[f,g], J. Partanen[f], P. Rahkila[f], P. Ruotsalainen[f], M. Sandzelius[f], J. Sarén[f], C. Scholey[f], J. Sorri[f,j], S. Stolze[f,k], J. Uusitalo[f], B. Cederwall[l], A. Ertoprak[l], H. Liu[l], I. Kuti[m], J. Timár[m], A. Tucholski[n], J. Srebrny[n], C. Andreoiu[o]



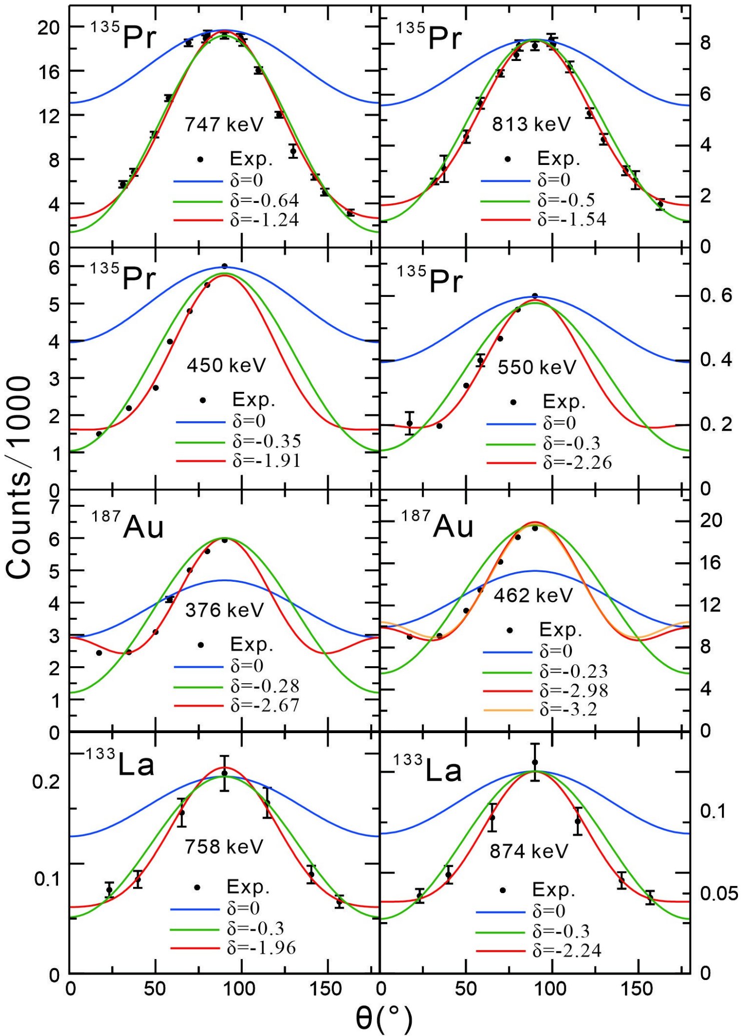
- Excitation energies, mixing ratio, and $B(E2)_{out}/B(E2)_{in}$ were well reproduced by QTR calculations.
- The nearly complete parallel orientation of the single-particle and the total angular momenta. **In contradiction with transverse wobbling geometry!**

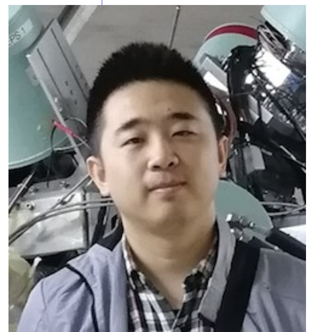
J. T. Matta, U. Garg, W. Li, et al., Phys. Rev. Lett. 114, 082501 (2015).
Sensharma, U. Garg, S. Zhu et al., Phys. Lett. B 792, 170 (2019).

Problems with experimental results for low-spin 1-qp bands

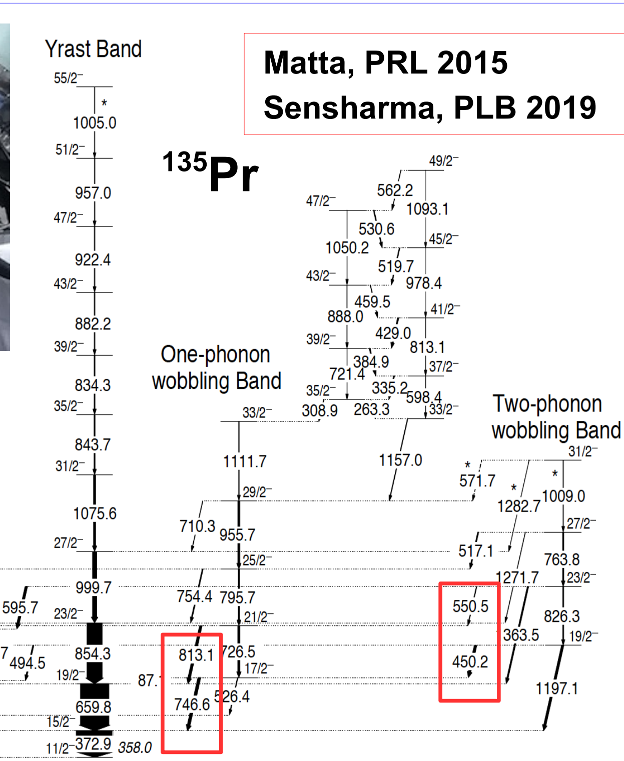
Not easy to extract convincing mixing ratios from angular distributions of transitions with 10% relative intensities!

Polarization asymmetry has very large errors for weak transitions!

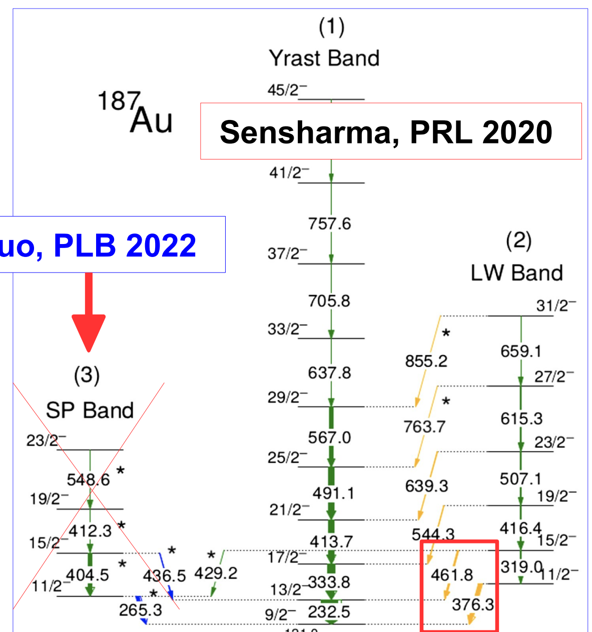




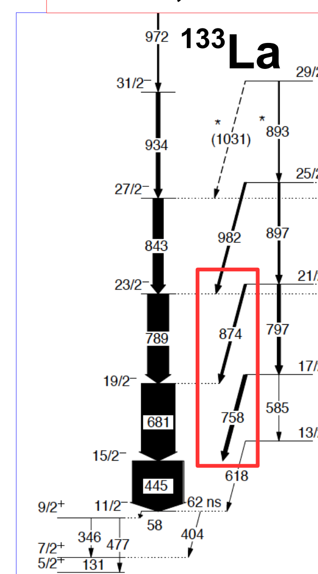
S. Guo



Guo, PLB 2022

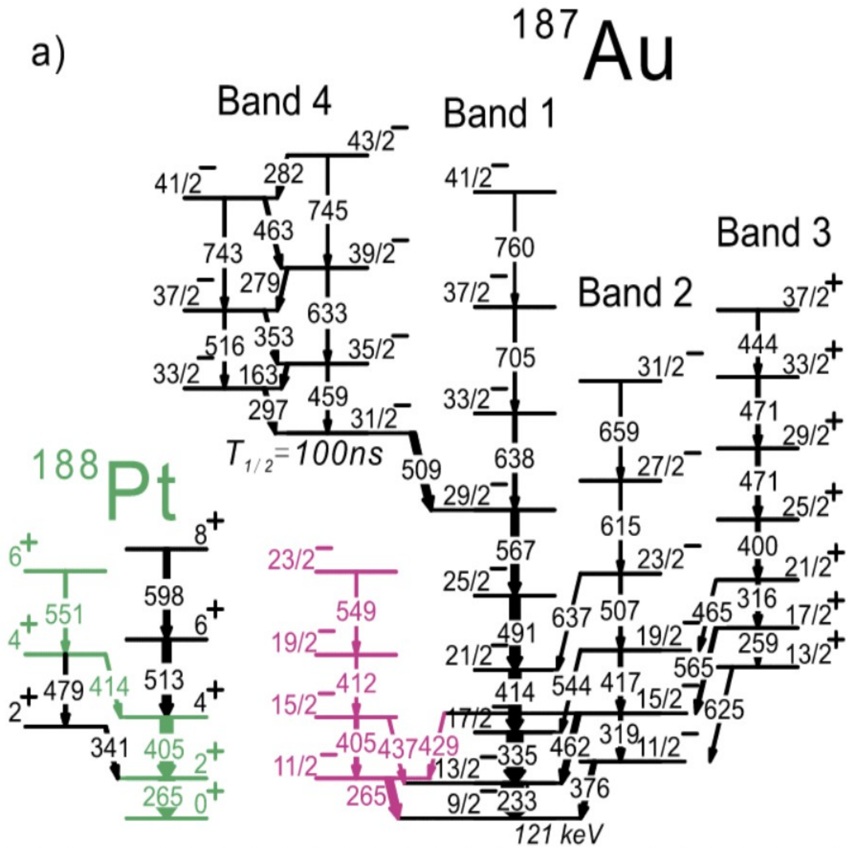


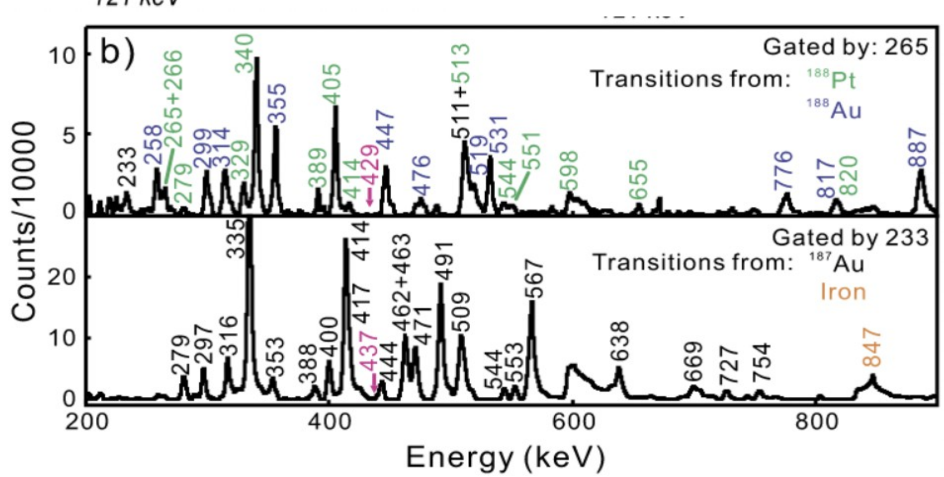
Biswas, EPJA 2019

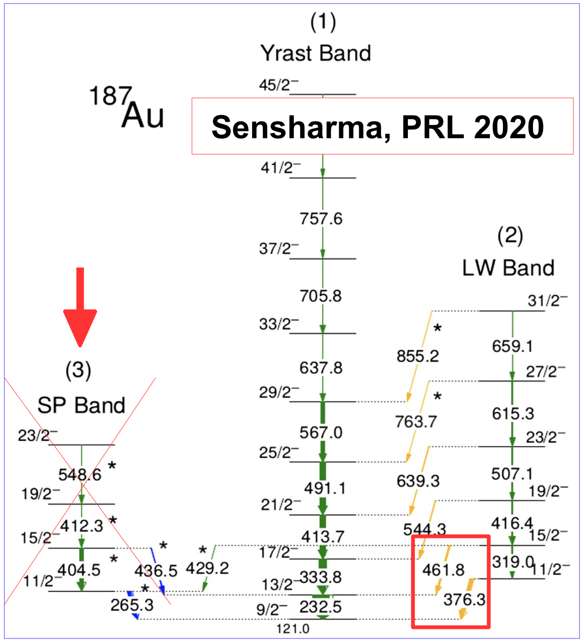


Physics Letters B 828 (2022) 137010

Sensharma, PhD thesis, 2021

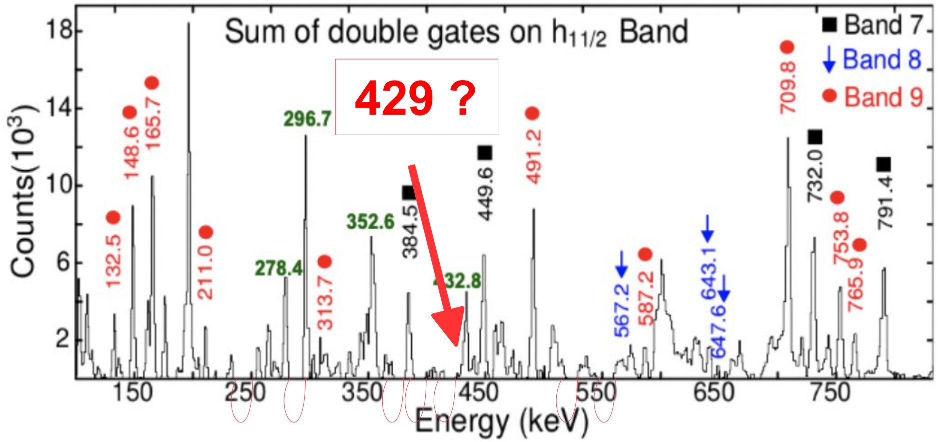


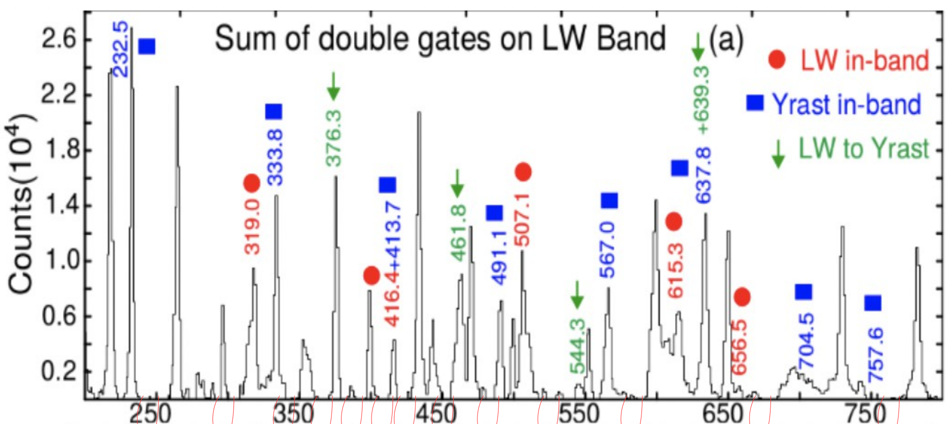


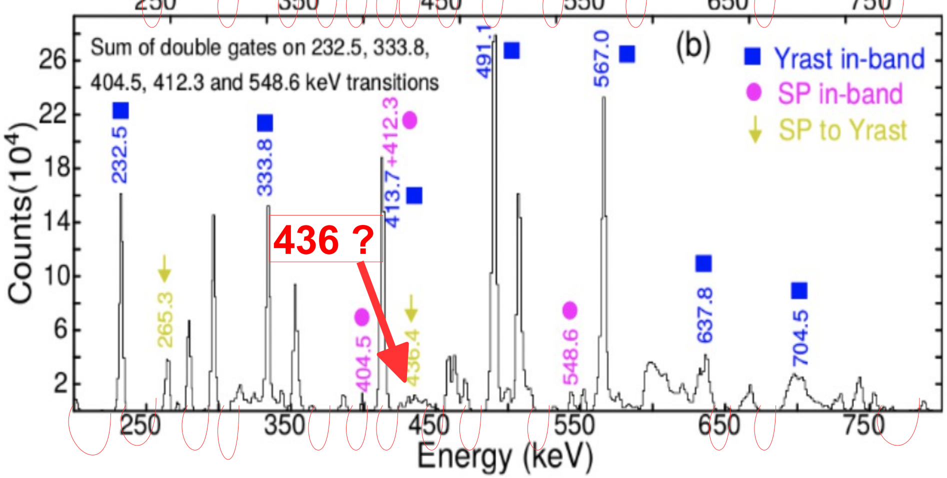


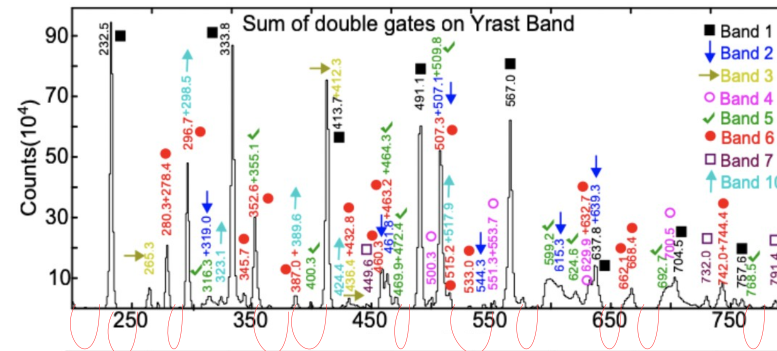
^{187}Au

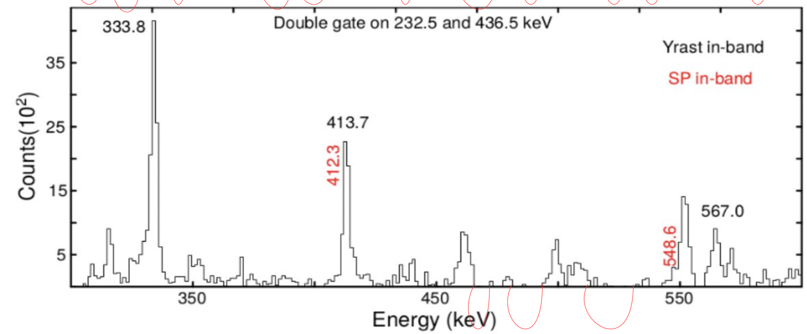
Sensharma, PhD thesis, 2021

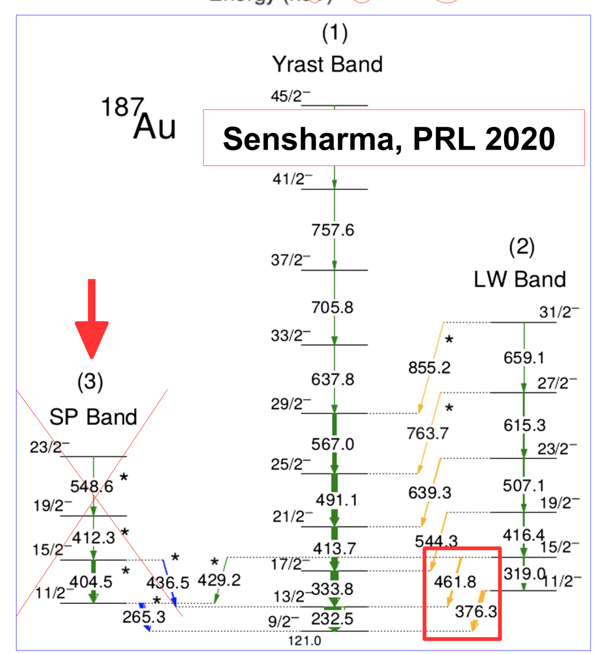








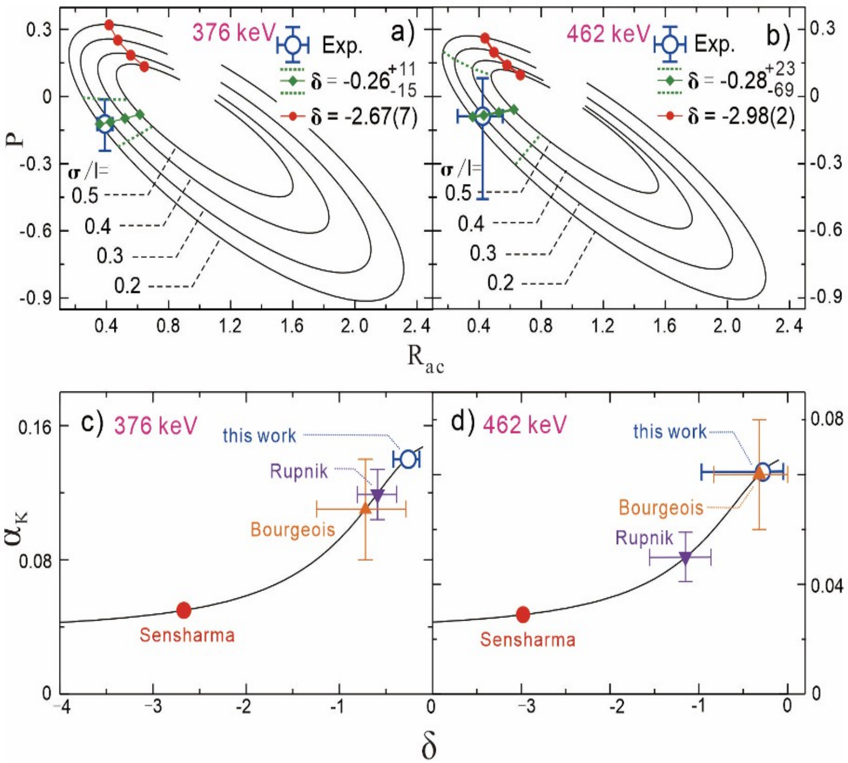




^{187}Au

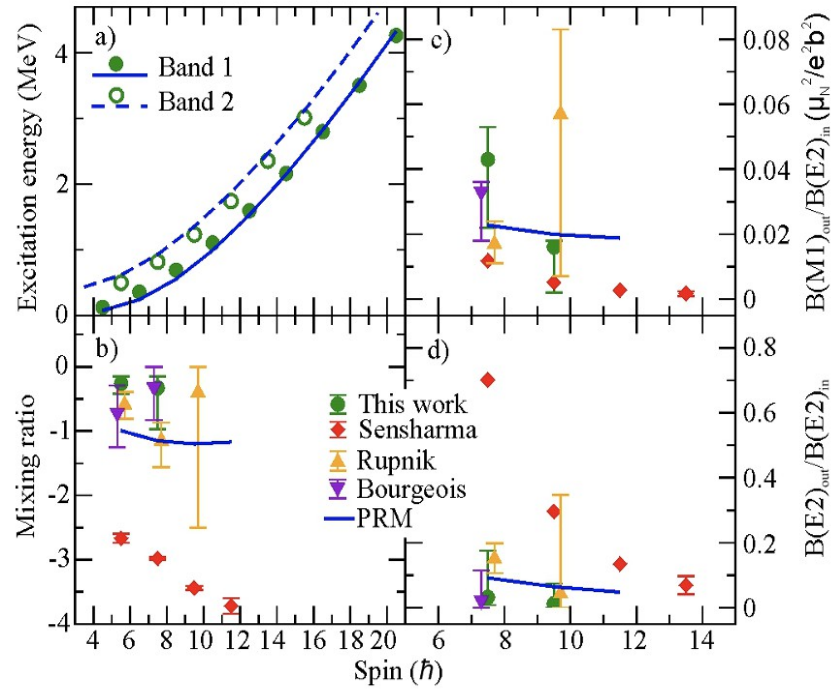
Mixing ratios

Sensharma, et al., PRL **124**, 052501 (2020)



Bourgeois, et al., NPA **295**, 424 (1978) Rupnik, et al., PRC **58**, 771 (1998)

QTR calculations



Deformation parameters: $\varepsilon = 0.21$, $\gamma = 12°$

S. Guo et al., PLB 828 (2022) 137010

Wobbling of low-spin 1-qp bands is questionable : the rotation axis is not fixed, high-spin condition not fulfilled!

PHYSICAL REVIEW C **101**, 034306 (2020)

Tilted precession and wobbling in triaxial nuclei

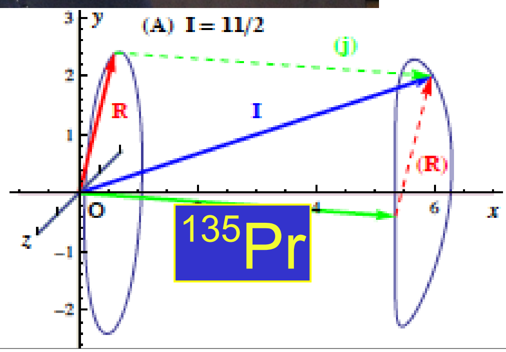
E. A. Lawrie,[1,2,*] O. Shirinda,[1,†] and C. M. Petrache[3,‡]

The wobbling approximation is valid if the rotational angular momenta around the two axes with lower MoI is small [16]:

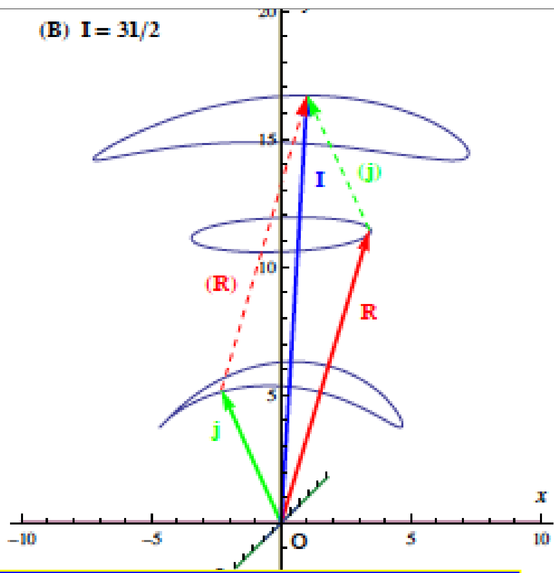
$$I_2^2 + I_3^2 \ll I^2, \quad (15)$$

a condition that can be rewritten as

$$f(n,I) = (2n+1)\frac{(A_2 + A_3 - 2A_1)}{2I\sqrt{(A_2 - A_1)(A_3 - A_1)}} \ll 1. \quad (16)$$

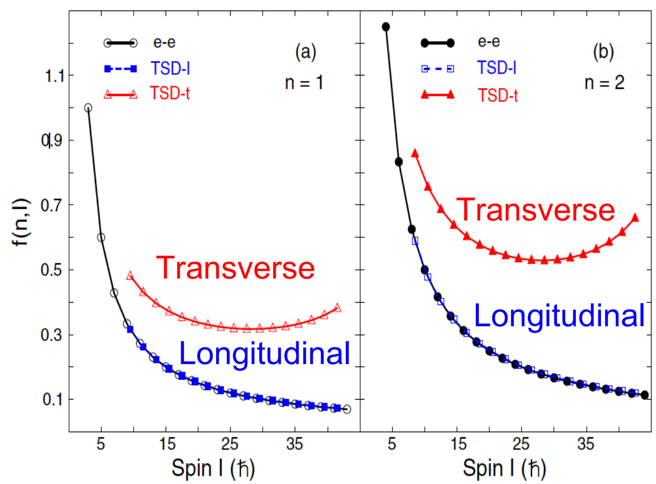


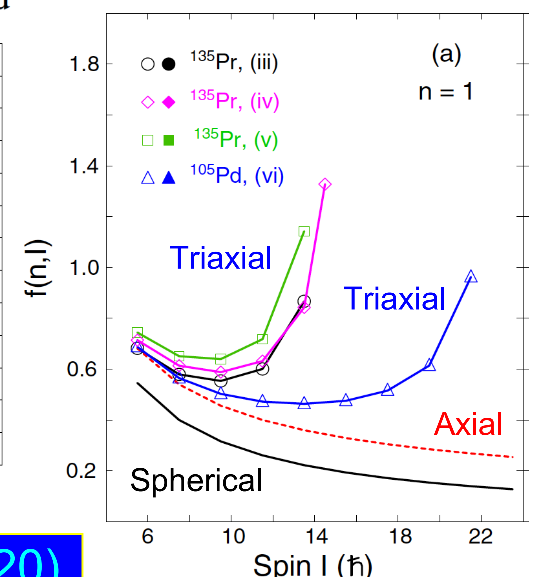
Revolving toward the medium axis
No stable transverse geometry !!!



Tanabe, PRC 95 (2017)

$A_1 = 1, A_2 = 4$, and $A_3 = 4$ are used





Lawrie, PRC 101 (2020)

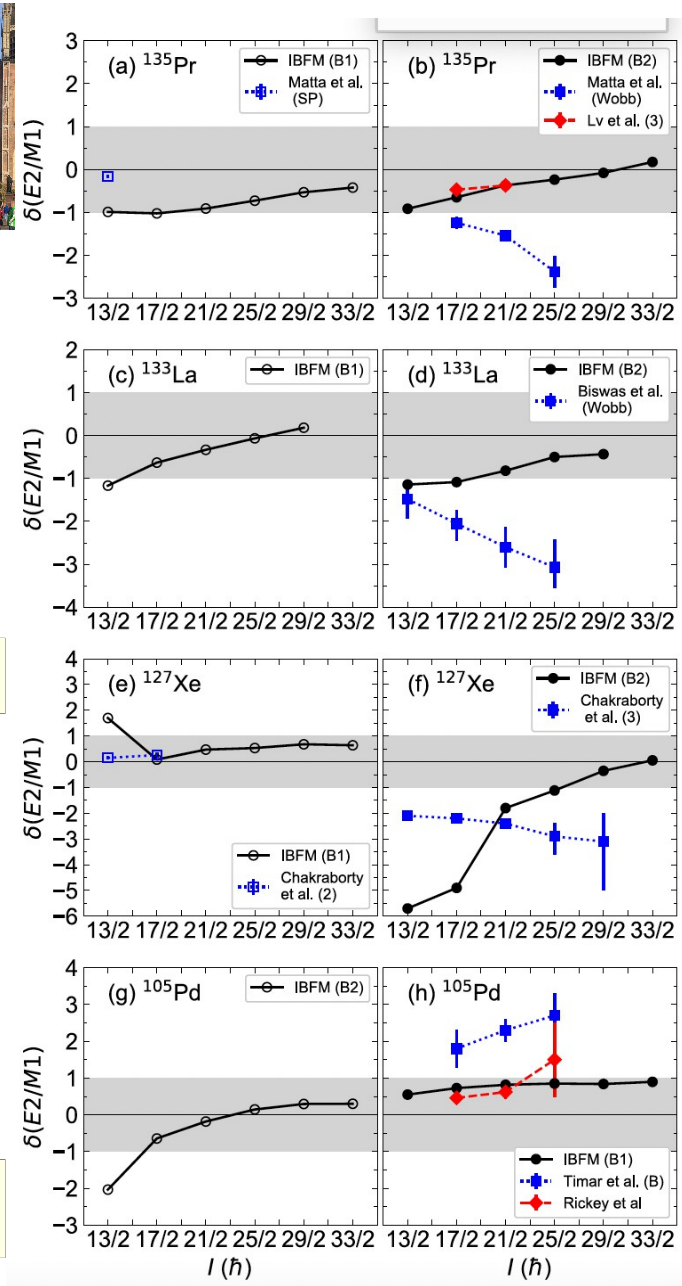
PHYSICAL REVIEW C **105**, 024320 (2022)

Questioning the wobbling interpretation of low-spin bands in γ-soft nuclei within the interacting boson-fermion model

K. Nomura[1,*] and C. M. Petrache[2]

TABLE II. Comparisons between the calculated and experimental $\delta(E2/M1)$ mixing ratios of the $\Delta I = 1$ interband transitions, and the ratios of the interband $B(M1; I \to I-1)_{\text{out}}$ and $B(E2; I \to I-1)_{\text{out}}$ to inband $B(E2; I \to I-2)_{\text{in}}$ transition rates, connecting the low-lying yrare bands to the yrast bands in ^{135}Pr, ^{133}La, ^{127}Xe, and ^{105}Pd.

Nucleus	E_γ (keV)	Spin	δ		$B(M1)_{\text{out}}/B(E2)_{\text{in}}$		$B(E2)_{\text{out}}/B(E2)_{\text{in}}$	
			EXP	IBFM	EXP	IBFM	EXP	IBFM
^{135}Pr [8]	747.0	$17/2^-_1$	$-1.24 + 0.13$	-0.646		0.078		0.034
	812.8	$21/2^-_1$	-1.54 ± 0.09	-0.368	0.164 ± 0.014	0.425	0.843 ± 0.032	0.040
	754.6	$25/2^-_1$	-2.38 ± 0.37	-0.236	0.035 ± 0.009	0.771	0.500 ± 0.025	0.028
	710.2	$29/2^-_1$		-0.078	$\leqslant 0.016 \pm 0.004$	0.387	$\geqslant 0.261 \pm 0.014$	0.0017
	593.9	$13/2^-_1$	-0.16 ± 0.04	-0.988		0.725		4.371
^{135}Pr [18]	747.3	$17/2^-_1$	$-0.47^{+0.09}_{-0.22}$	-0.646		0.078		0.034
	813.2	$21/2^-_1$	$-0.37^{+0.10}_{-0.14}$	-0.368	0.4 ± 0.3	0.425	0.12 ± 0.08	0.040
^{133}La [10]	618	$13/2^-_1$	$-1.48^{+0.45}_{-0.32}$	-1.167				
	758	$17/2^-_1$	$-2.05^{+0.39}_{-0.30}$	-0.630	$0.107^{+0.035}_{-0.028}$	0.232	$1.127^{+0.140}_{-0.130}$	0.683
	874	$21/2^-_1$	$-2.60^{+0.46}_{-0.47}$	-0.331	$0.056^{+0.018}_{-0.019}$	0.404	$0.716^{+0.079}_{-0.079}$	0.401
	982	$25/2^-_1$	$-3.07^{+0.47}_{-0.65}$	-0.065	$0.039^{+0.011}_{-0.015}$	1.646	$0.545^{+0.057}_{-0.059}$	0.443
^{127}Xe [12]	483	$13/2^-_1$	$-2.1^{+0.2}_{-0.2}$	-5.699		0.085		9.242
	639	$17/2^-_1$	$-2.2^{+0.2}_{-0.1}$	-4.901	0.138 ± 0.012	0.039	2.352 ± 0.565	1.874
	735	$21/2^-_1$	$-2.4^{+0.1}_{-0.1}$	-1.801	0.098 ± 0.005	0.037	1.500 ± 0.172	0.163
	800	$25/2^-_1$	$-2.9^{+0.7}_{-0.5}$	-1.117	0.071 ± 0.031	0.050	1.346 ± 0.879	0.064
	884	$29/2^-_1$	$-3.1^{+1.9}_{-1.1}$	-0.355	0.052 ± 0.044	0.103	0.922 ± 0.895	0.011
	651	$13/2^-_2$	$+0.15^{+0.05}_{-0.05}$	$+1.698$	0.180 ± 0.004	0.022	0.014 ± 0.009	0.329
	876	$17/2^-_2$	$+0.26^{+0.10}_{-0.10}$	$+0.085$	0.053 ± 0.002	0.462	0.007 ± 0.005	0.005
^{105}Pd [11]	991	$17/2^-_1$	$+1.8 \pm 0.5$	$+0.727$	0.162 ± 0.097	0.316	0.66 ± 0.18	0.389
	1034	$21/2^-_1$	$+2.3 \pm 0.3$	$+0.817$	0.089 ± 0.026	0.166	0.60 ± 0.09	0.236
	994	$25/2^-_1$	$+2.7 \pm 0.6$	$+0.851$	0.029 ± 0.057	0.101	0.34 ± 0.07	0.182
^{105}Pd [26]	991	$17/2^-_1$	$+0.46 \pm 0.10$	$+0.727$		0.316		0.389
	1034	$21/2^-_1$	$+0.62 \pm 0.18$	$+0.817$		0.166		0.236
	994	$25/2^-_1$	$+1.5 \pm 1.0$	$+0.851$		0.101		0.182



Conclusions on low-spin wobbling

- Experimental evidence against low-spin wobbling: the interband transitions have predominant M1 nature, not E2.
- The high-spin approximation of Bohr and Mottelson is not realized, which implies that the wobbling harmonic approximation is not adequate.
- The Coriolis force induces a rapid alignment of the particle angular momentum along that of the core.
- Other models, like IBFM, which consistently account for the γ-softness of the core, describe better the yrare low-spin bands.
- One should extend, generalize the concept of wobbling as proposed by Bohr and Mottelson, to something like «universal nuclear wobbling», by a consistent treatment of the anharmonicities, to account for predominantly M1 interband transitions.

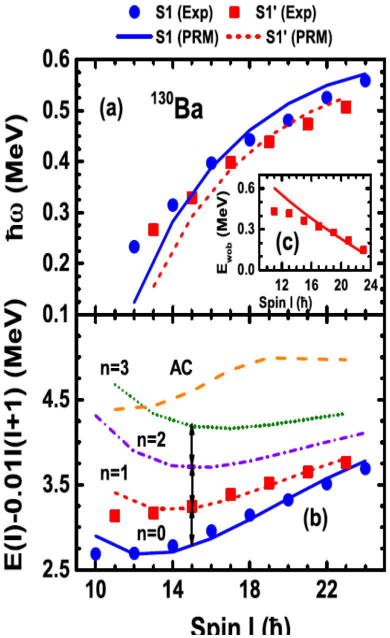
Evidence for wobbling in 2qp bands

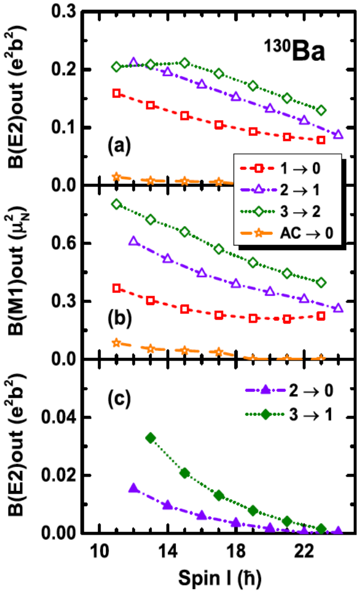
CDFT calculations

PHYSICAL REVIEW C 100, 061301(R) (2019)

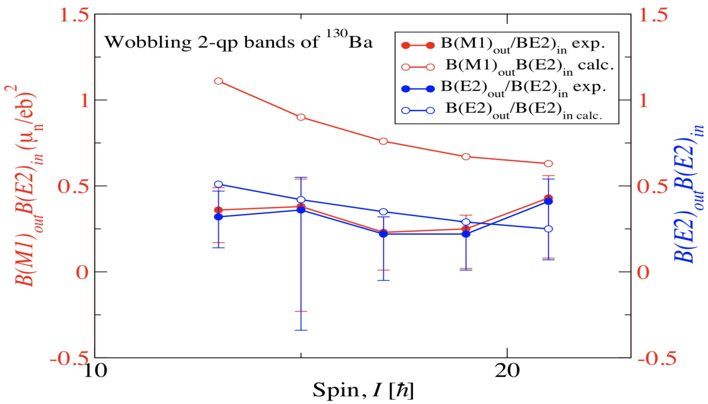
Transverse wobbling in an even-even nucleus ^{130}Ba

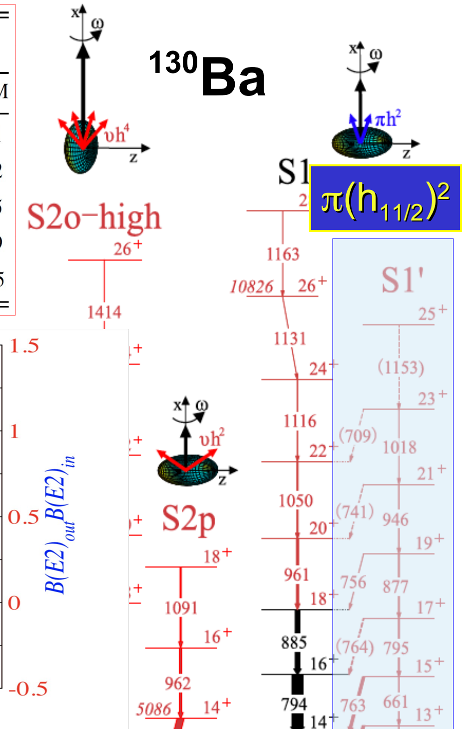
Q. B. Chen[1,*], S. Frauendorf,[2,†] and C. M. Petrache[3,‡]

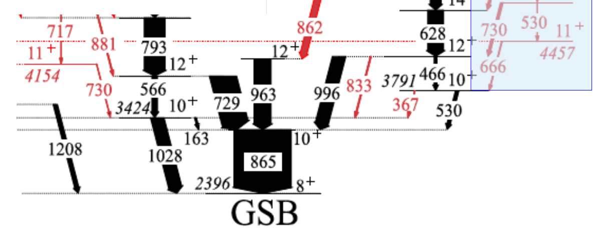


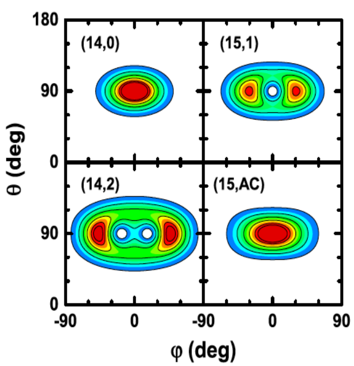


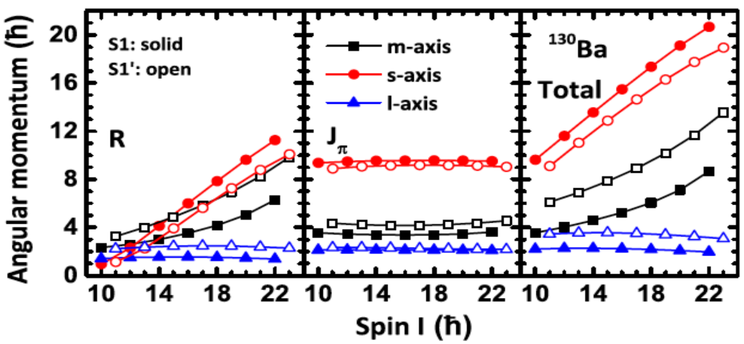
I (ħ)	δ Expt	δ PRM	$\frac{B(M1)_{out}}{B(E2)_{in}}\left(\frac{\mu_N^2}{e^2b^2}\right)$ Expt	$\frac{B(M1)_{out}}{B(E2)_{in}}$ PRM	$\frac{B(E2)_{out}}{B(E2)_{in}}$ Expt	$\frac{B(E2)_{out}}{B(E2)_{in}}$ PRM
13	-0.58^{+13}_{-13}	−0.67	0.36^{+19}_{-13}	1.11	0.32^{+18}_{-15}	0.51
15	-0.62^{+10}_{-10}	−0.68	0.38^{+61}_{-16}	0.90	0.36^{+70}_{-19}	0.42
17	-0.62^{+10}_{-10}	−0.68	0.23^{+22}_{-09}	0.76	0.22^{+27}_{-10}	0.35
19	−0.60	−0.66	0.25^{+23}_{-08}	0.67	0.22^{+21}_{-07}	0.29
21	−0.60	−0.63	0.43^{+35}_{-13}	0.63	0.41^{+34}_{-13}	0.25











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Diversity of shapes and rotations in the γ-soft ^{130}Ba nucleus: First observation of a t-band in the $A = 130$ mass region

C.M. Petrache[a,*], P.M. Walker[b], S. Guo[c,d,*], Q.B. Chen[e], S. Frauendorf[f], Y.X. Liu[g], R.A. Wyss[h], D. Mengoni[i], Y.H. Qiang[c], A. Astier[a], E. Dupont[a], R. Li[a], B.F. Lv[a], K.K. Zheng[a], D. Bazzacco[i], A. Boso[i], A. Goasduff[i], F. Recchia[i], D. Testov[i], F. Galtarossa[j], G. Jaworski[j], D.R. Napoli[j], S. Riccetto[j], M. Siciliano[j,k], J.J. Valiente-Dobon[j], M.L. Liu[c,d], X.H. Zhou[c,d], J.G. Wang[c], C. Andreoiu[l], F.H. Garcia[l], K. Ortner[l], K. Whitmore[l], T. Bäck[h], B. Cederwall[h], E.A. Lawrie[m], I. Kuti[n], D. Sohler[n], J. Timár[n], T. Marchlewski[o], J. Srebrny[o], A. Tucholski[o]

Two quasiparticle wobbling in the even-even nucleus ^{130}Ba

Y.K. Wang[a], F.Q. Chen[b], P.W. Zhao[a,*]

TPSM

Physics Letters B 802 (2020) 135246

Microscopic investigation on the existence of transverse wobbling under the effect of rotational alignment: the ^{136}Nd case

TPSM

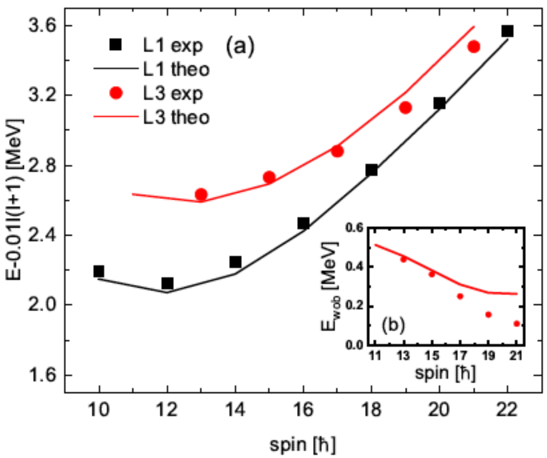
Fang-Qi Chen[1] and C. M. Petrache[2]

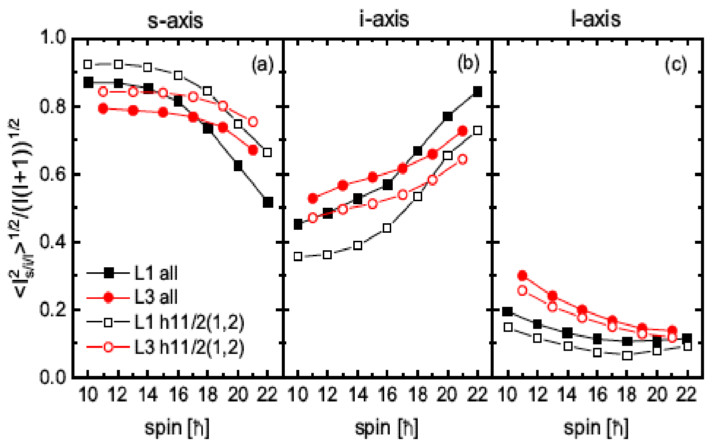
of Physical Science and Technology, Northwestern Polytechnical University, Xi'an 710129, China

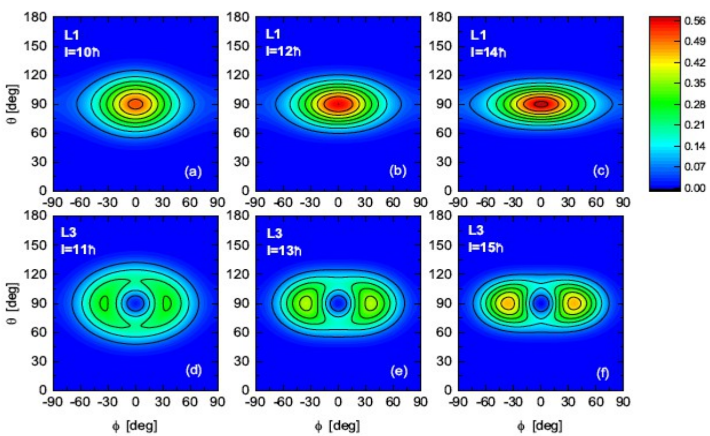
[2]Centre de Sciences Nucléaires et Sciences de la Matière, CNRS/IN2P3, Université Paris-Saclay, Bâtiment 104-108, 91405 Orsay, France

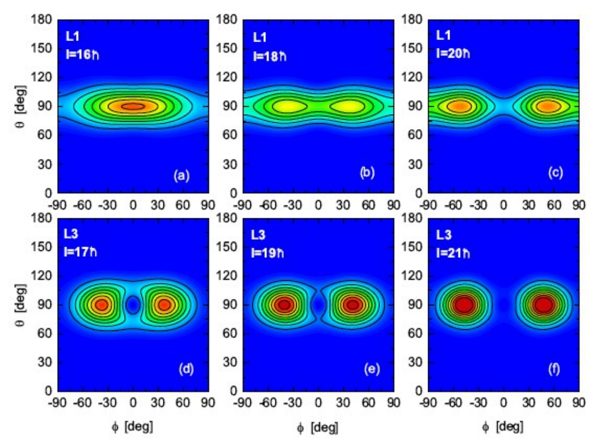
(Dated: November 11, 2020)

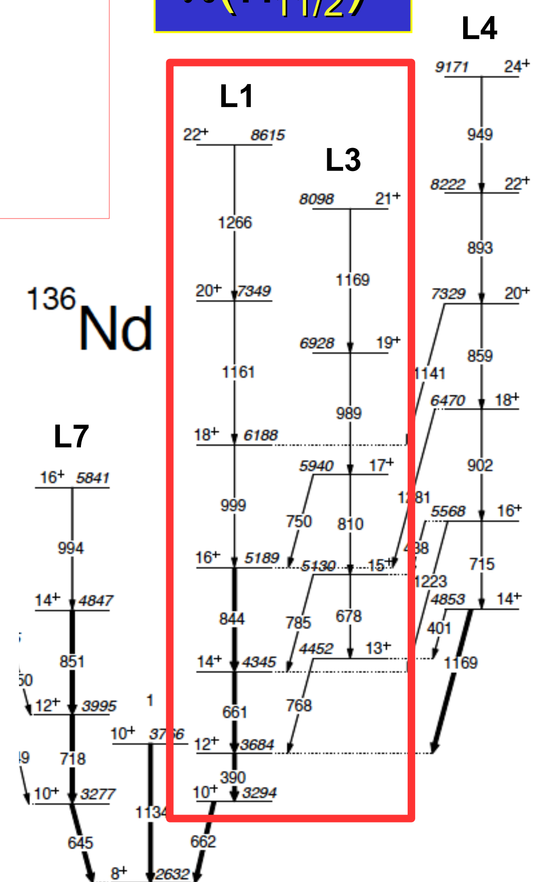
$\pi(h_{11/2})^2$











Evidence for wobbling interpretation of 2qp bands

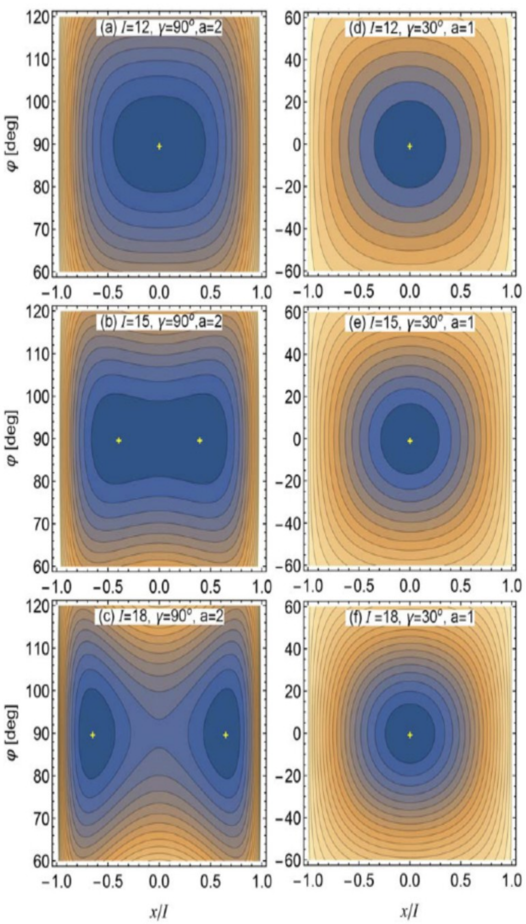
PHYSICAL REVIEW C **106**, 014313 (2022)

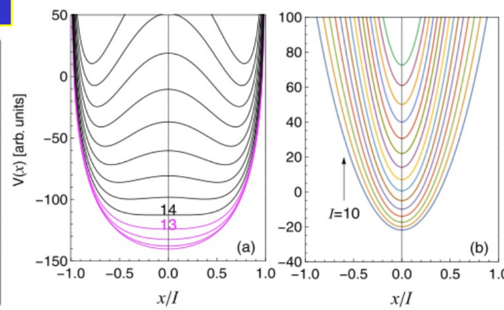
Beyond the harmonic approximation description of wobbling excitations in even-even nuclei with frozen alignments

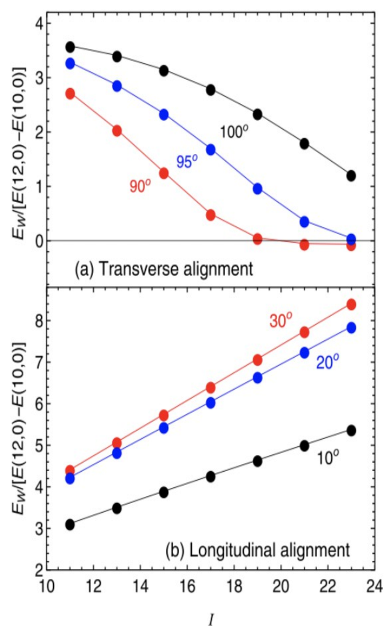
R. Budaca[1,2,*] and C. M. Petrache[3]

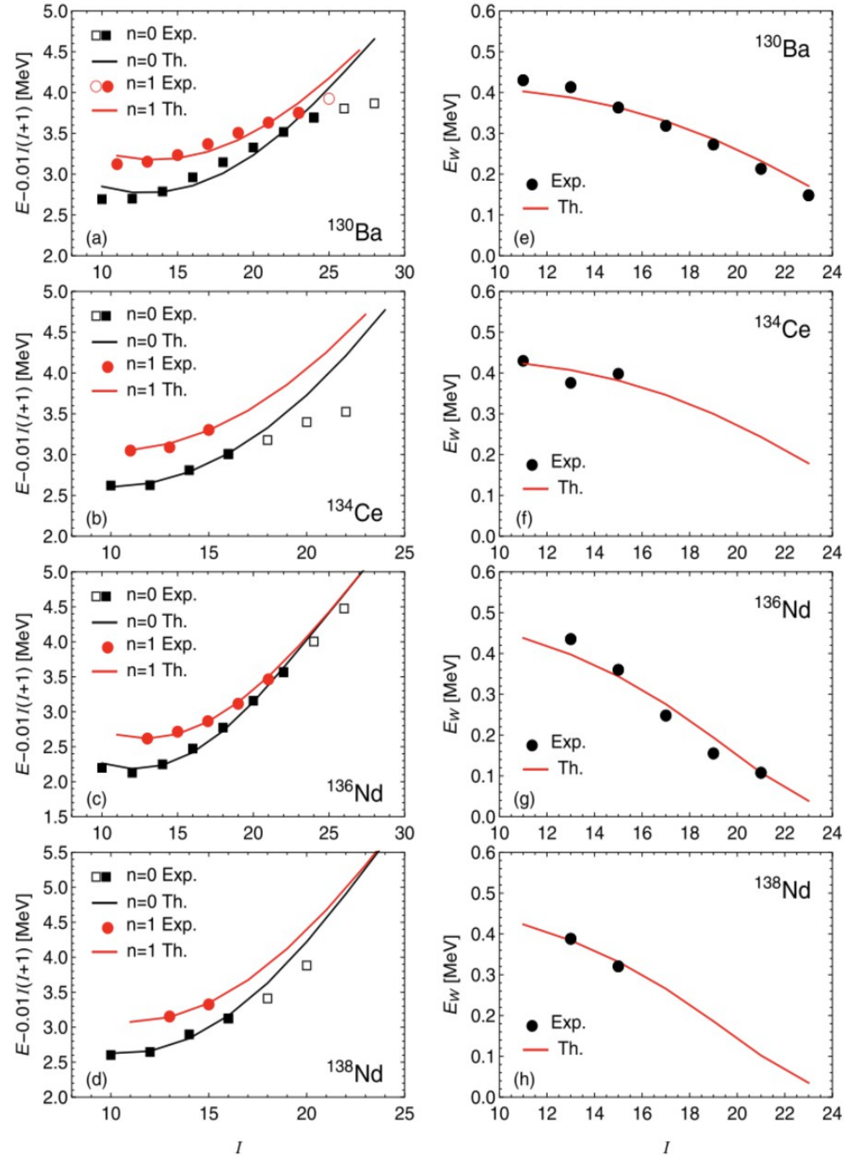
Collective Hamiltonian+2qp in frozen orthogonal geometry

transverse | longitudinal









Conclusions on wobbling interpretation outside the A=160 mass region

- high-spin 2qp bands: YES
- low-spin 1qp bands: NO

Collaboration

Experiment:

France: 6 PhD students

P. M. Jodidar, K.K. Zheng,

B.F. Lv, R. Leguillon,

T. Zerrouki, A. Vancrayenest

+ A. Astier, C. M. Petrache

Finland: R. Julin, P. Greenlees, J. Uusitalo

China: S. Guo, B.F. Lv, K. K. Zheng

Italy: D. Mengoni

South Africa: E. Lawrie

Canada: C. Andreoiu

Poland: J. Srebrny, A. Tucholski

Hungary: J. Timar, I. Kuti, D. Sohler

UK: R.D. Page, D.T. Joss

Theory:

China: 7 theorists

J. Meng (Peking),

Q.B. Chen (Shanghai),

Z.P. Li (Chonqing),

X.T. He (Nanjing),

F.Q. Chen (Lanzhou),

Z.H. Zhang (Peking),

Y. Liu (Huzhou),

P. W. Zhao (Peking)

USA: S. Frauendorf

Sweden: I. Ragnarsson

Japan: M. Matsuzaki

Croatia: K. Nomura

Romania: A.A. Raduta

R. Budaca

Thank you !