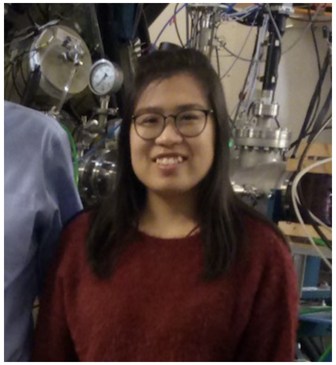
# Chirality and wobbling in nuclei: new achievements and perspectives



France: K.K. Zheng, A. Astier, CP
China: S. Guo, B.F. Lv (Lanzhou),
J. Meng, P. W. Zhao, Z. H. Zhang et al. (Peking),
Y. Liu (Huzhou),
F.Q. Chen (Xi'An),
Z. P. Li (Chongqing)
Finland: P. Greenlees, J. Uusitalo, J. Pakarinen et al.
Italy: D. Mengoni et al.
South Africa: E. Lawrie et al.
Poland: J. Srebrny, A. Tucholski et al.
Sweden: B. Cederwall et al.
Hungary: J. Timar, I. Kuti, D. Sohler
Canada: C. Andreoiu et al.
Germany: Q.B. Chen
USA: S. Frauendorf



# Three successful experiments

RITU + JUROGAM II – 2016 (12 articles: 10 published, 2 submitted)

$^{136}$Nd – chirality (3), triaxiality (1), HD bands (1), octupole correlations (1), 2-qp wobbling (1 submitted)

$^{135}$Nd – chirality (1), TiP (1 submitted)

$^{137}$Nd – chirality (1), oblate rotation at the highest spins (2)

GALILEO+EUCLIDES+N WALL - 2017 (7 articles: 4 published, 3 submitted)

$^{130}$Ba – diversity of shapes and rotations (1), high-K isomer (1), 2-qp wobbling (1), detailed spectroscopy (1 submitted)

$^{131}$Ba – chirality (1), detailed spectroscopy (2 to be submitted)

EAGLE+plunger – 2016 (1 article)

$^{136}$Nd – lifetime of the $10^{+}$ states

# JURO GAM II + RITU, $^{40}Ar + ^{100}Mo$ Nd

## 20 pnA, 1 week, October 2016

**JUROGAM II**

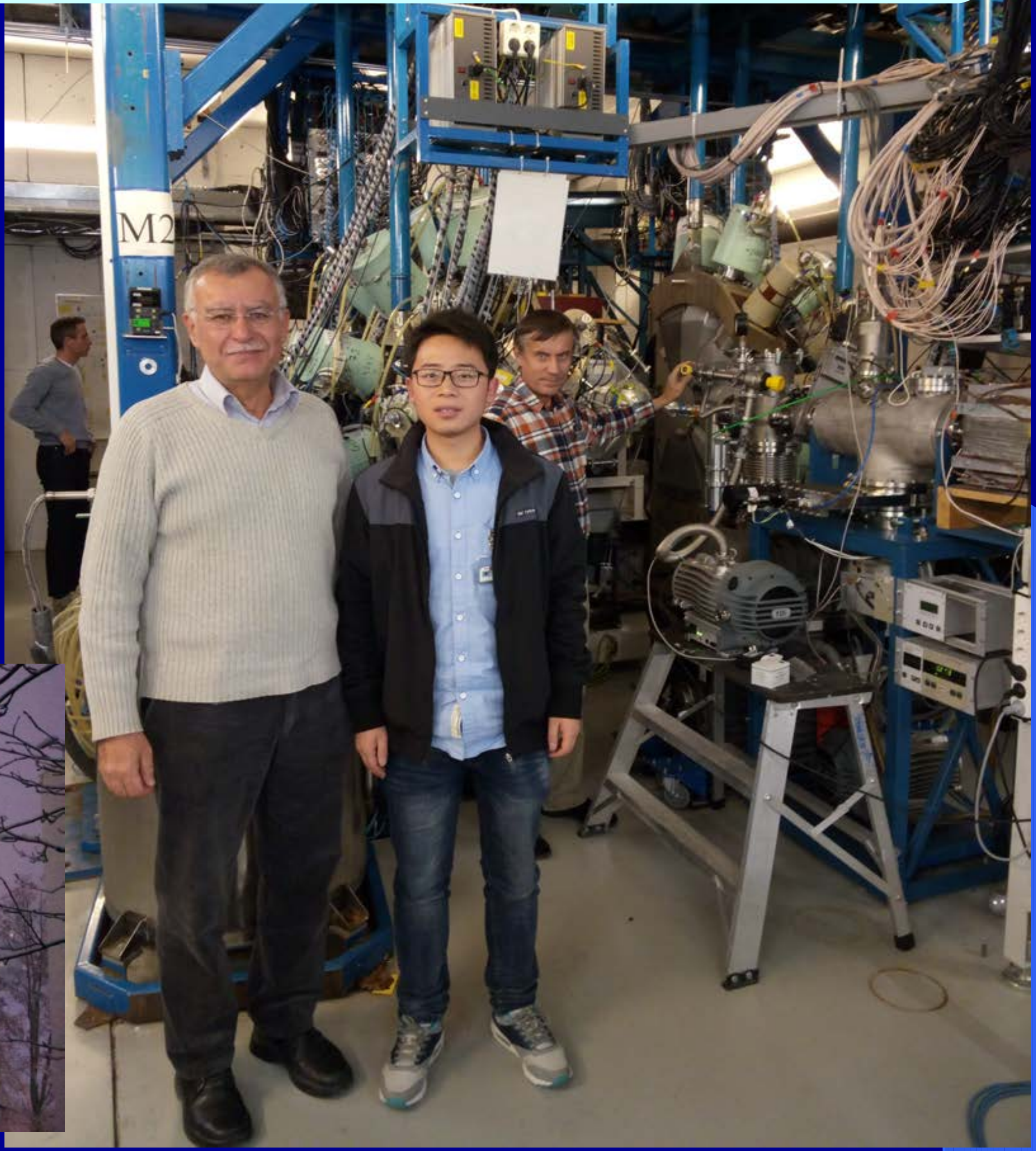
**24 Clovers HPGe**

**15 Coaxial HPGe**

**39 BGO shields**

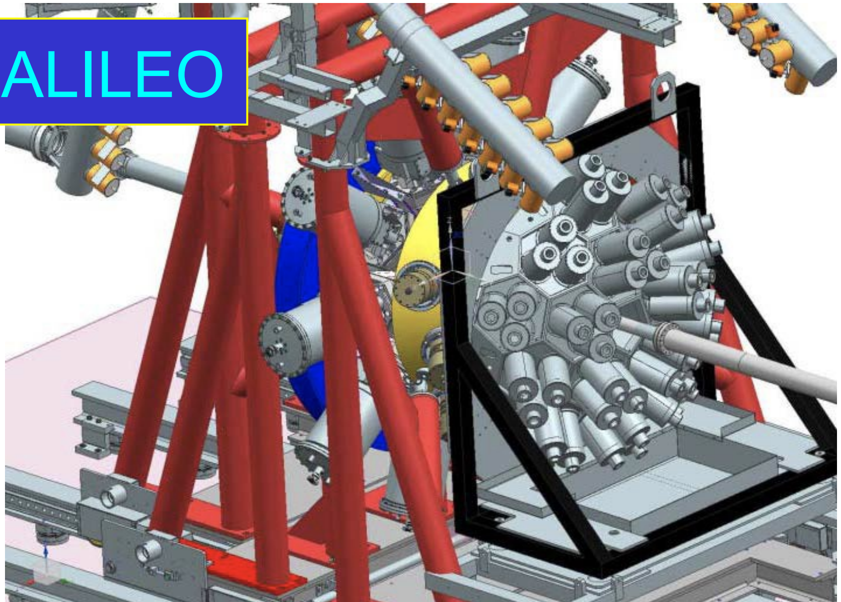
**$\varepsilon_{tot} = 4\ \%$**

**RITU**

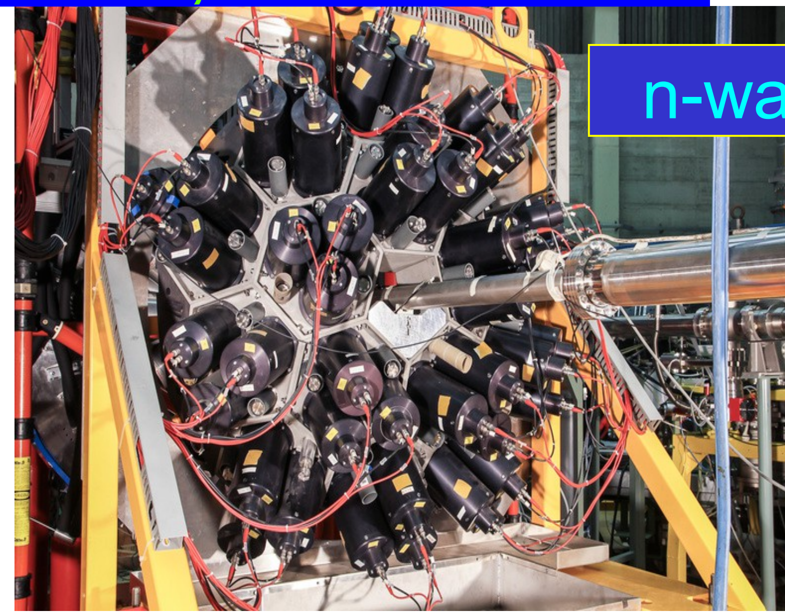



# GALILEO+EUCLIDES+n wall,
## $^{13}C + ^{122}Sn$ Ba,1 week, March 2017

GALILEO



n-wall

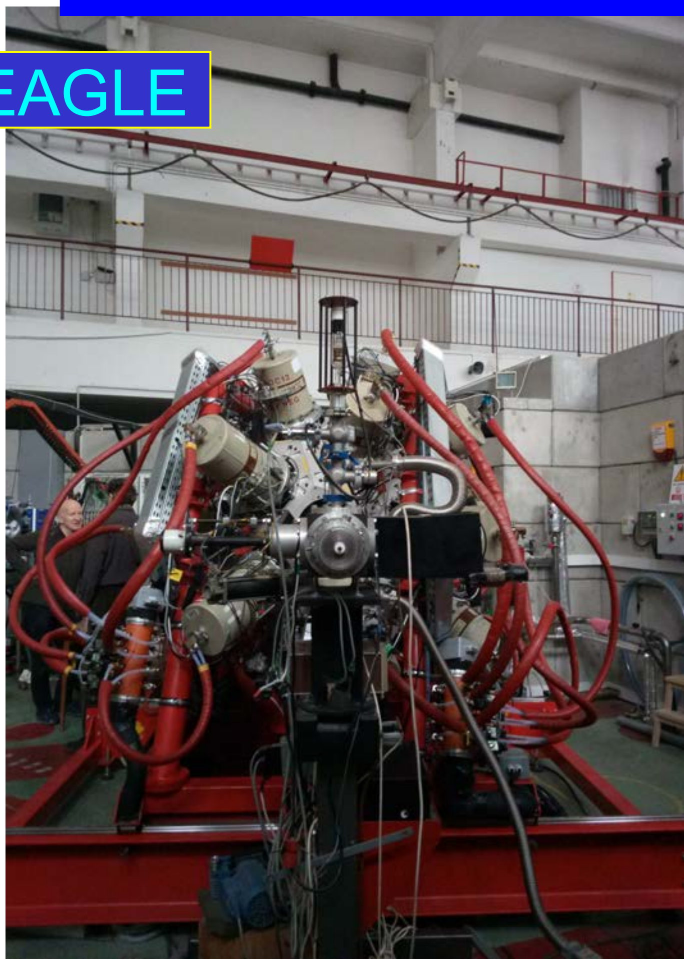


EUCLIDES

# EAGLE+plunger,

# $^{20}$Ne+$^{120}$Sn $^{136}$Nd, 1 week, December 2016

EAGLE



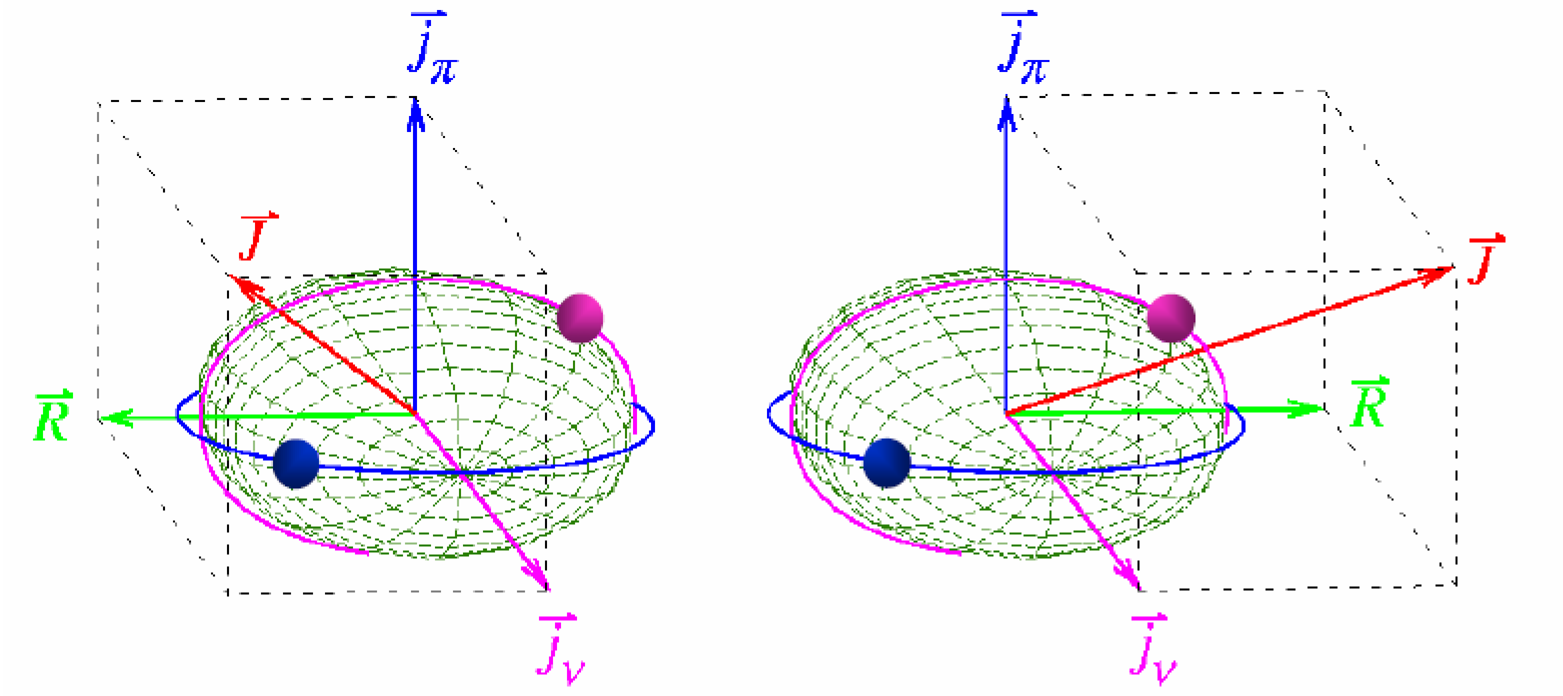
Plunger

Important collaborators

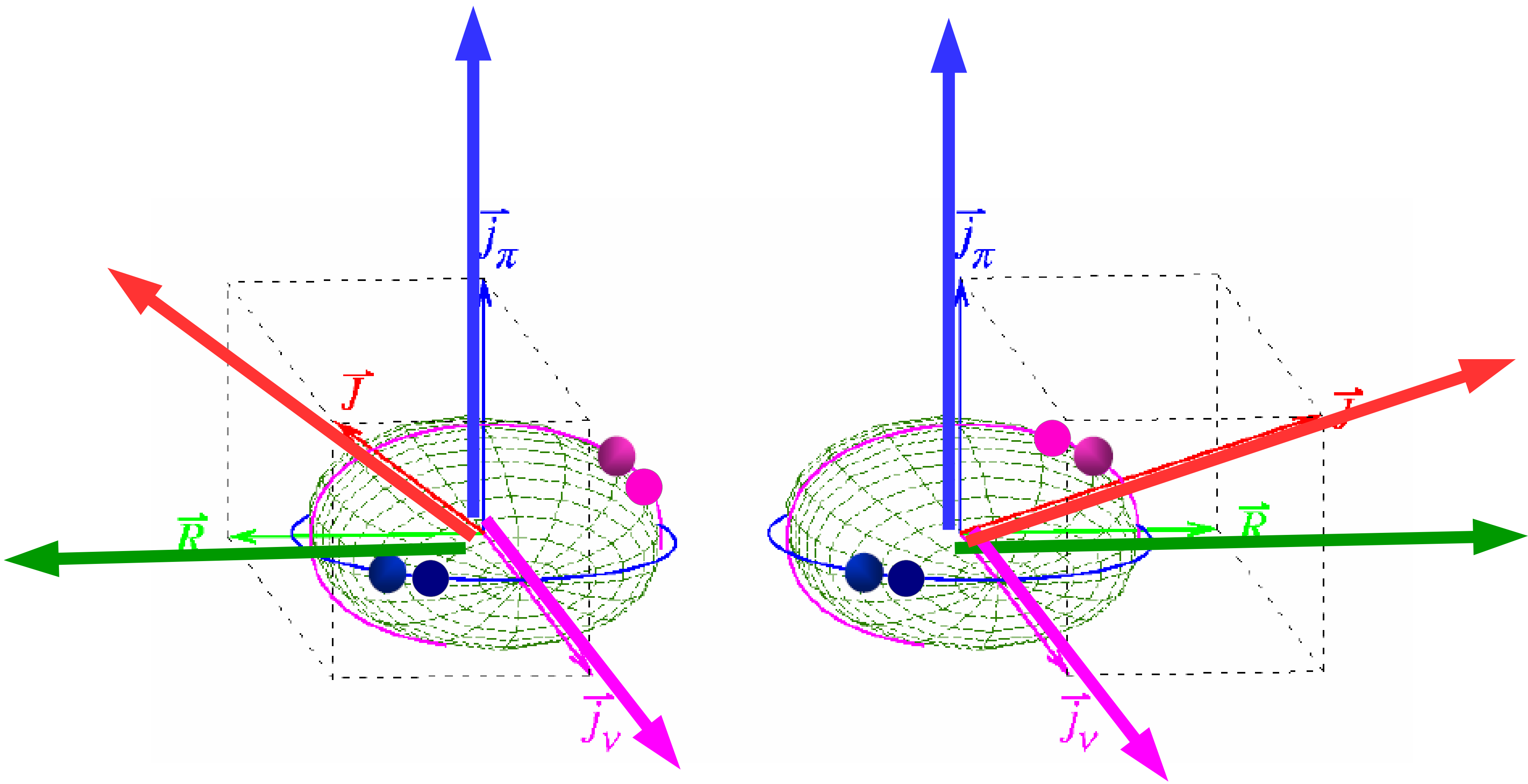
# Chiral mode

## Chiral Geometry in Nuclei

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



# NEW (2018):
# Chirality in even-even nuclei

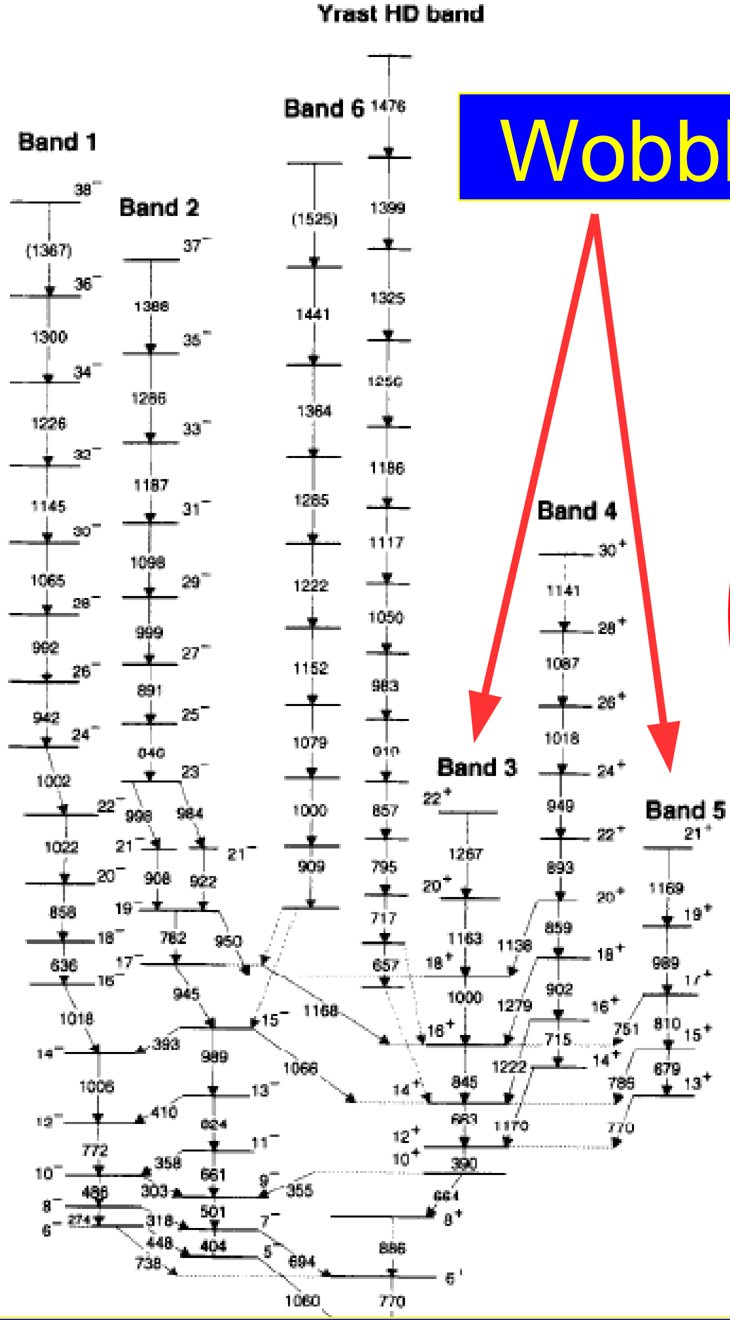


GASP data

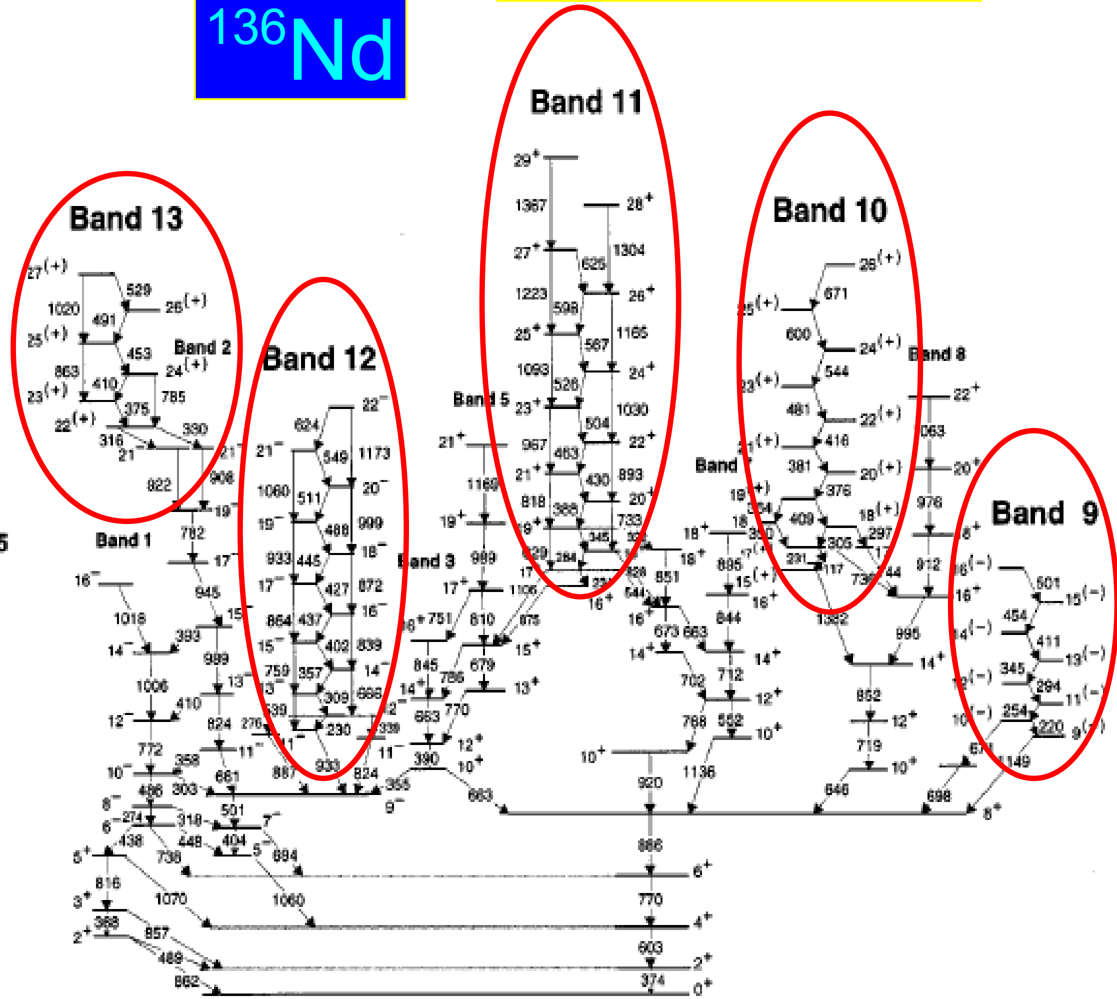
Wobbling?

No chiral!?

$^{136}$Nd




CP et al, PLB 373 (1996)



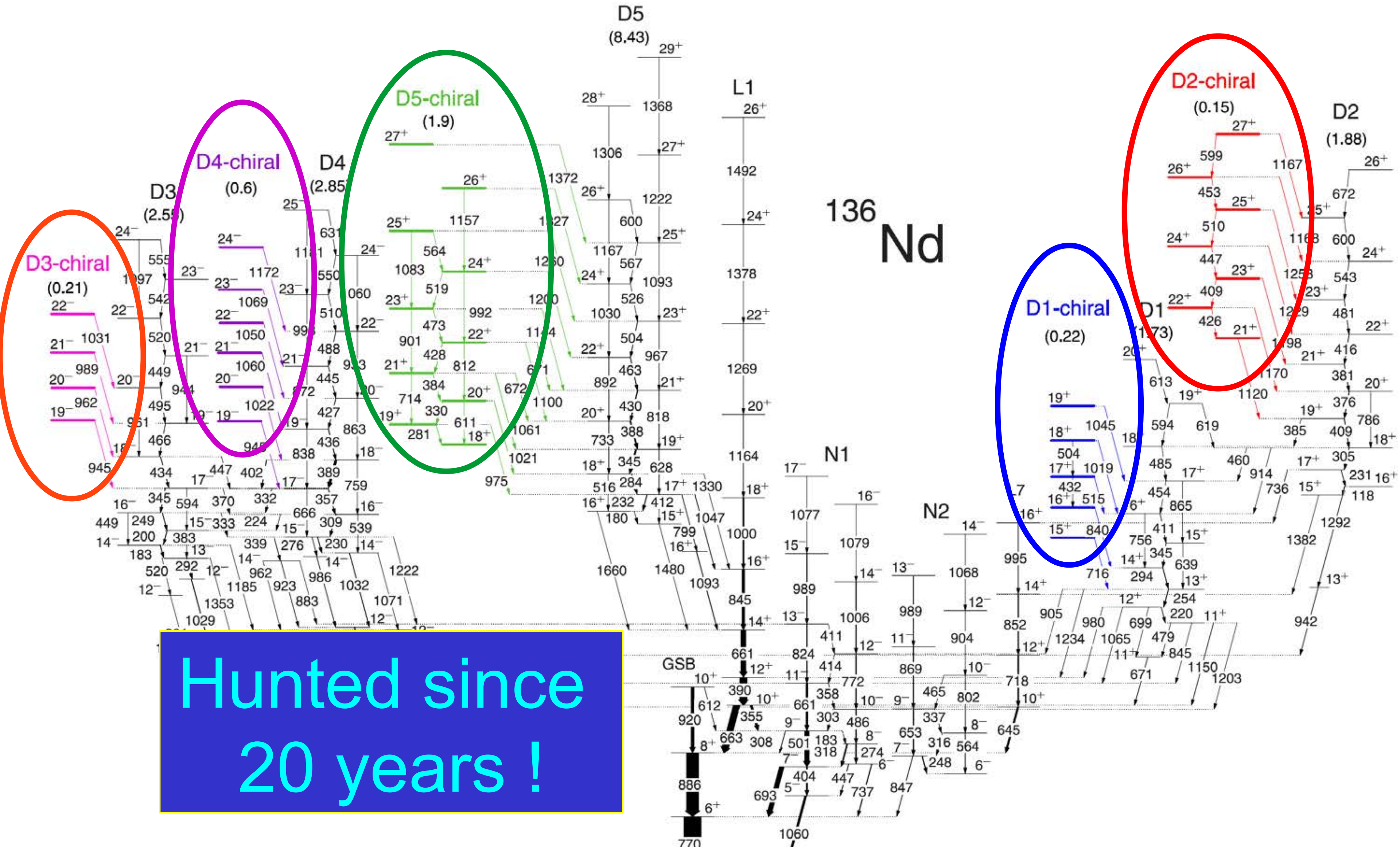

CP et al, NPA 617 (1997)

# First observation of five chiral doublets in one nucleus: apotheosis of chirality in the even-even $^{136}$Nd nucleus

CP, B.F. Lv, et al.

PRC 97 (2018) 041304(R)

# Ultimate chirality : clear evidence in even-even nuclei



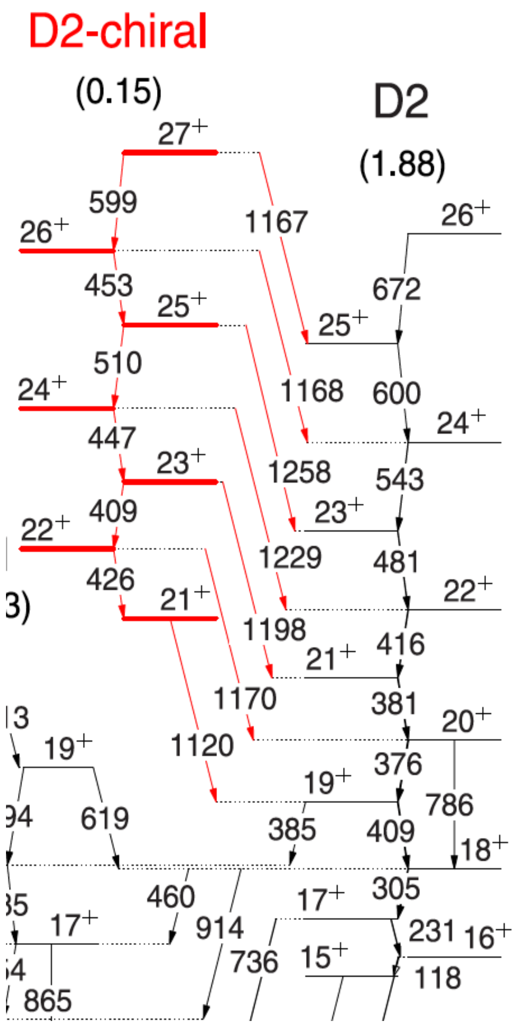

Hunted since 20 years !

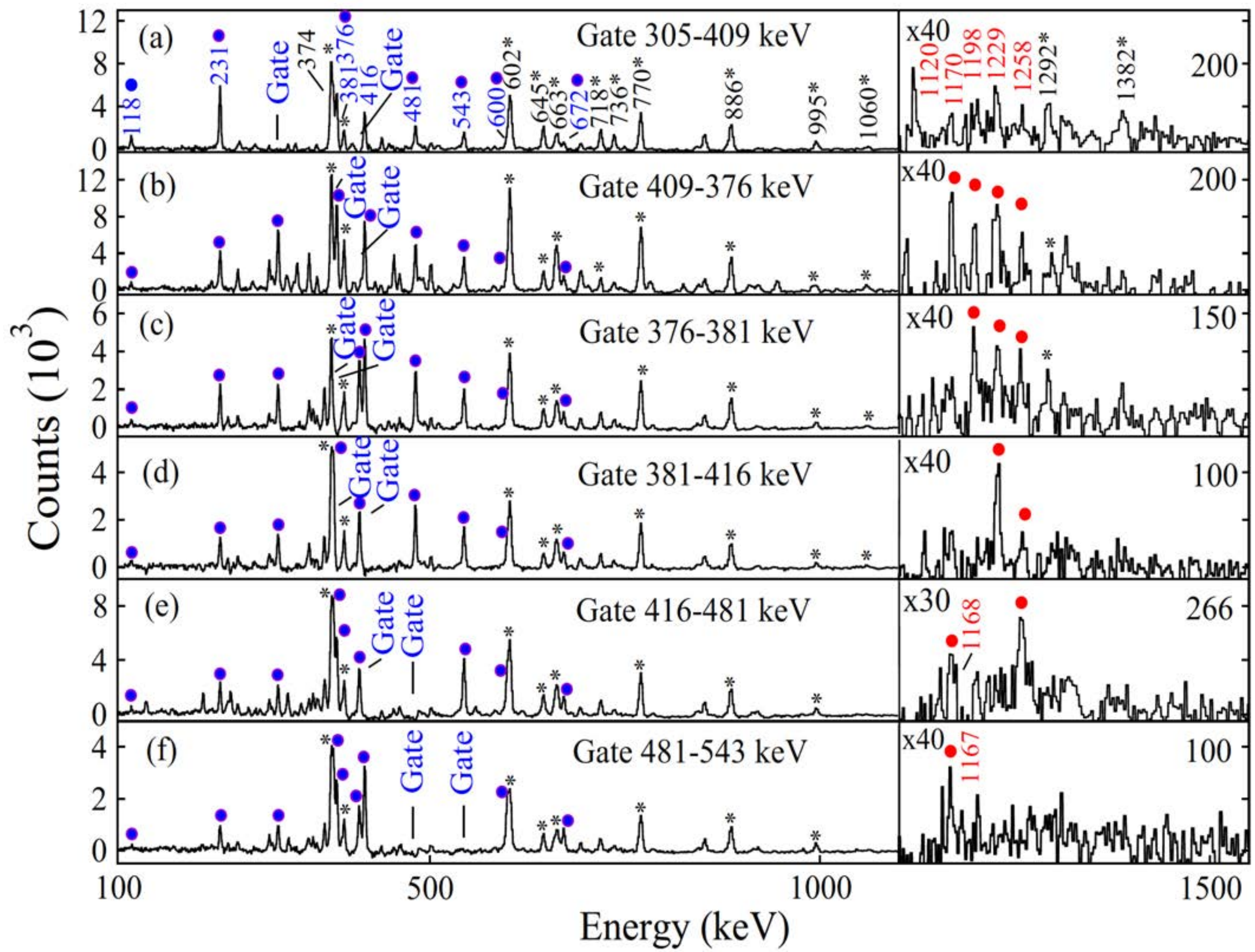
**CP, B.F. Lv et al, PRC 97 (2018) 041304(R)**

# $^{136}$Nd – D2 chiral doublet

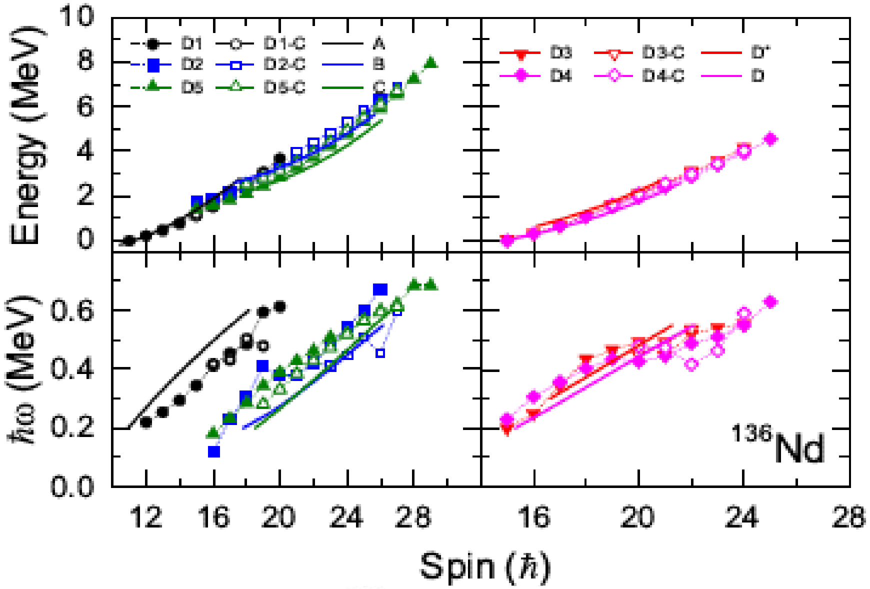
Chiral

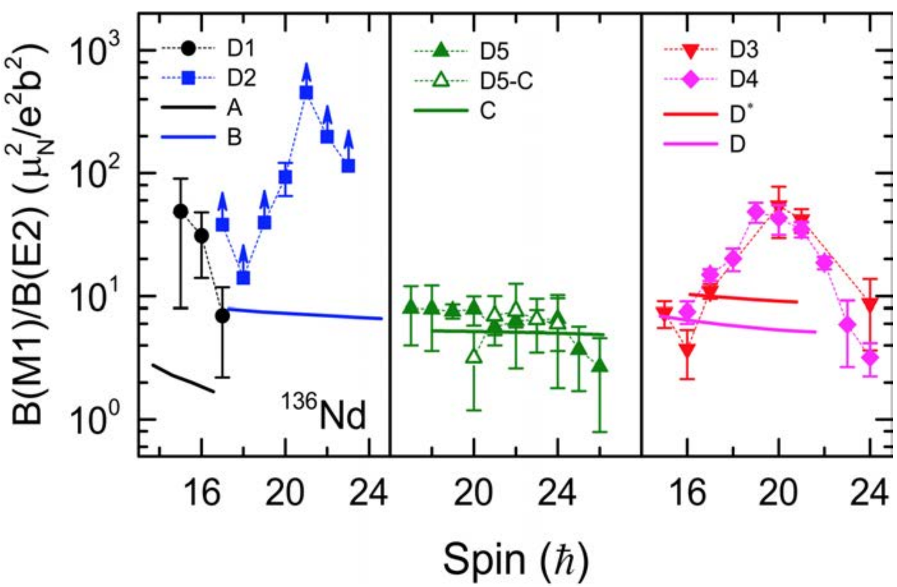
$\pi h^3 ( \int B)^{-1} \otimes \nu \Gamma^{21}(sd)^{-1}$

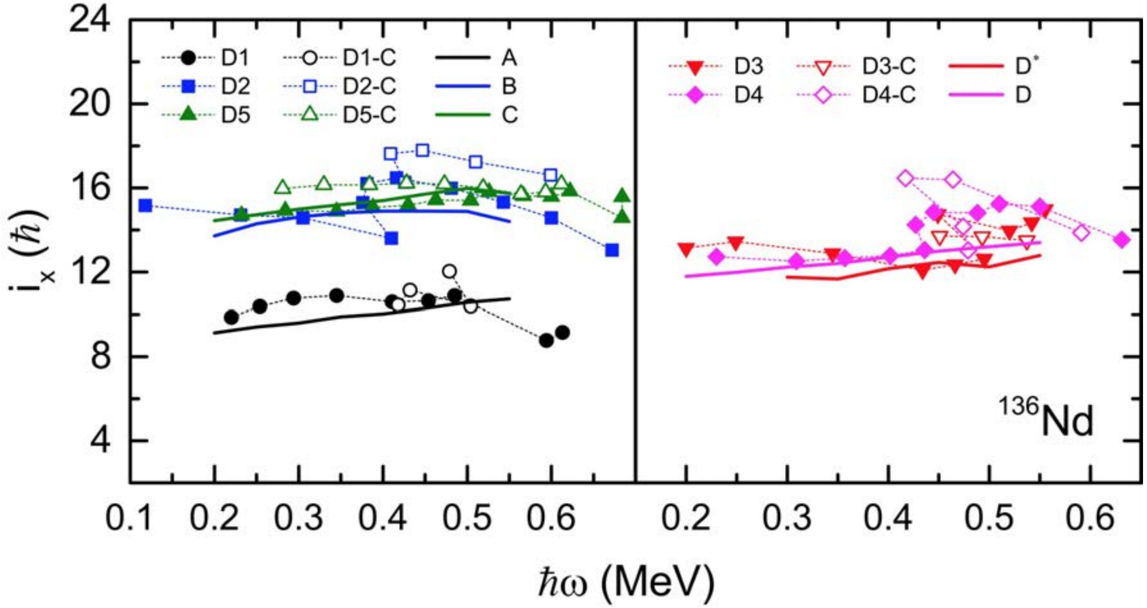


# $^{136}$Nd – TAC-CDFT calculations by Meng's group



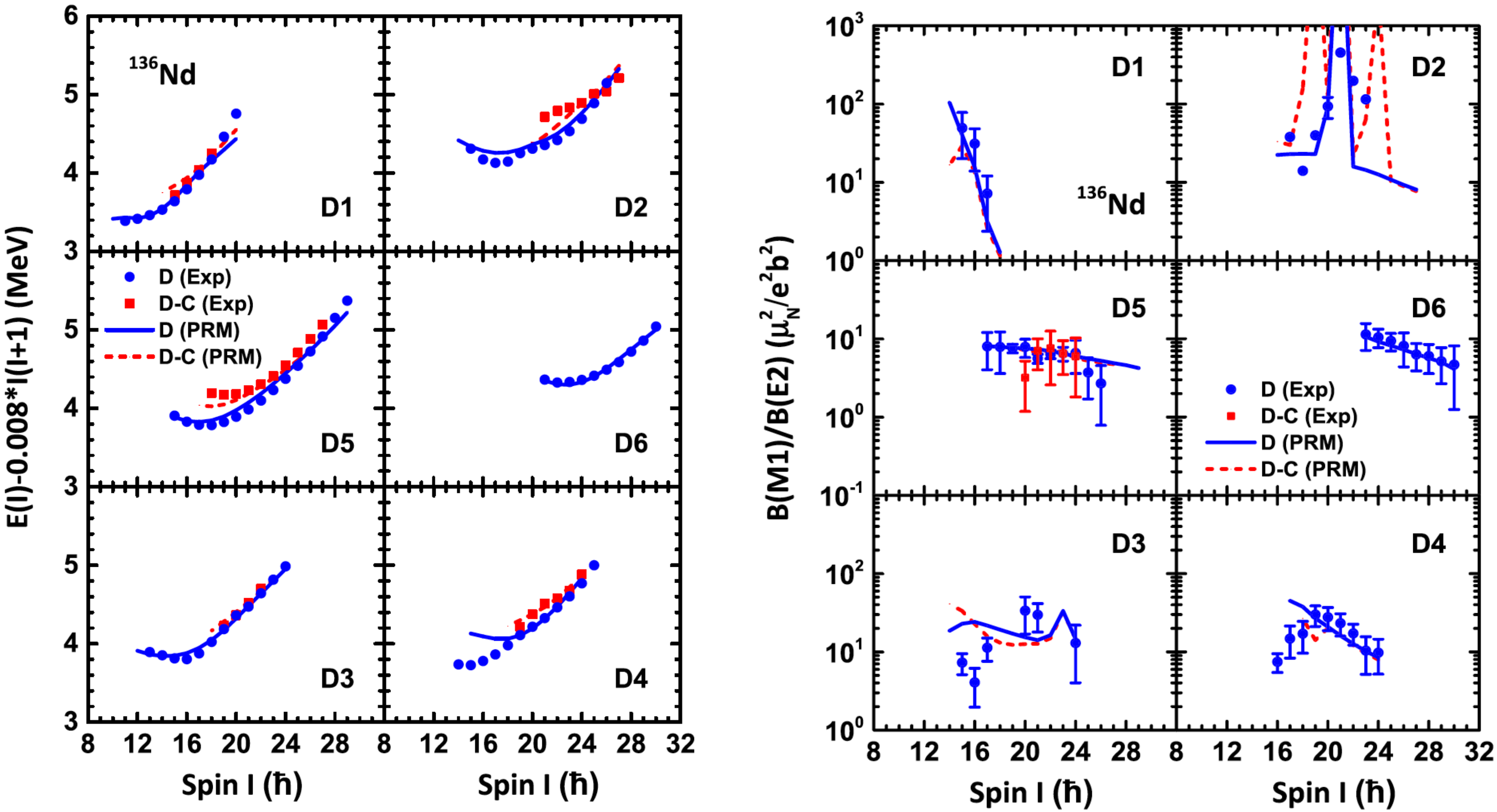



# Multiple chiral doublets in four-$j$ shells particle rotor model: Five possible chiral doublets in $^{136}_{60}Nd_{76}$

Q.B. Chen [a], B.F. Lv [b], C.M. Petrache [b], J. Meng [c,d,e,*]

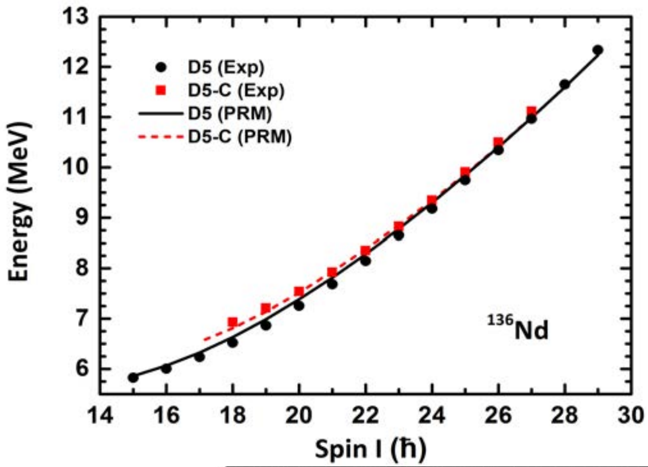
Physics Letters B 782 (2018) 744–749

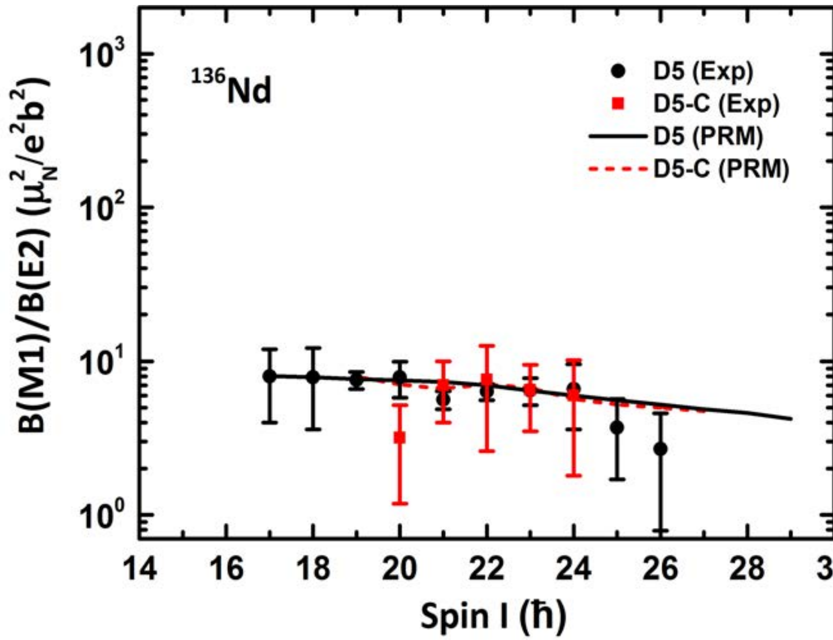


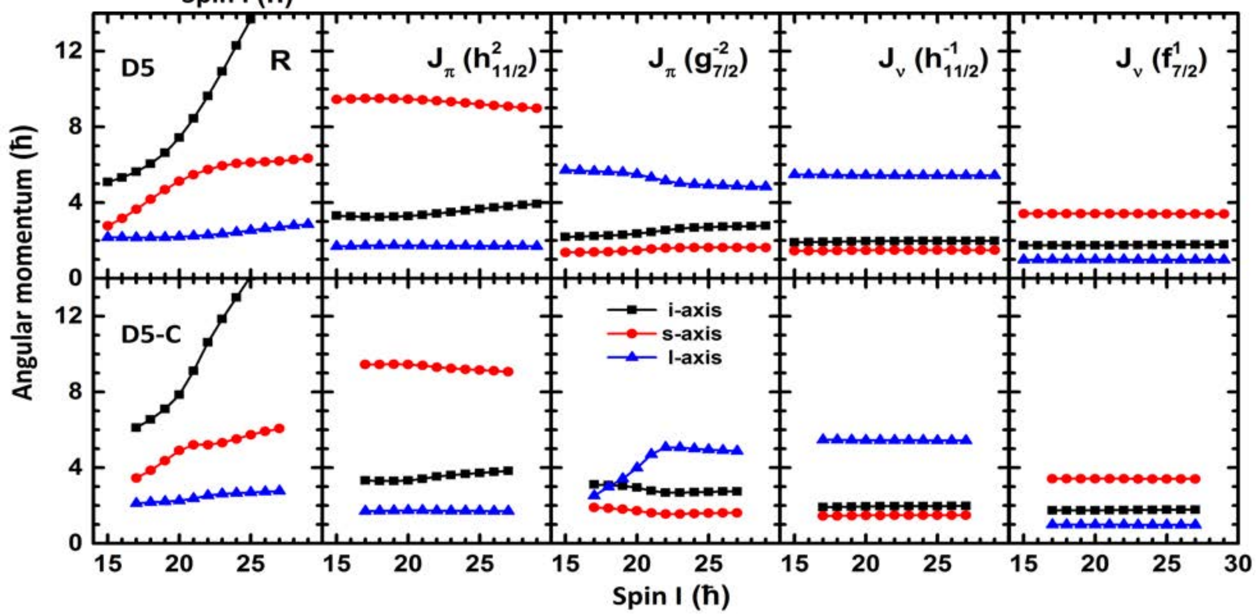
# $^{136}$Nd – chiral doublet D5

**Numerical details**

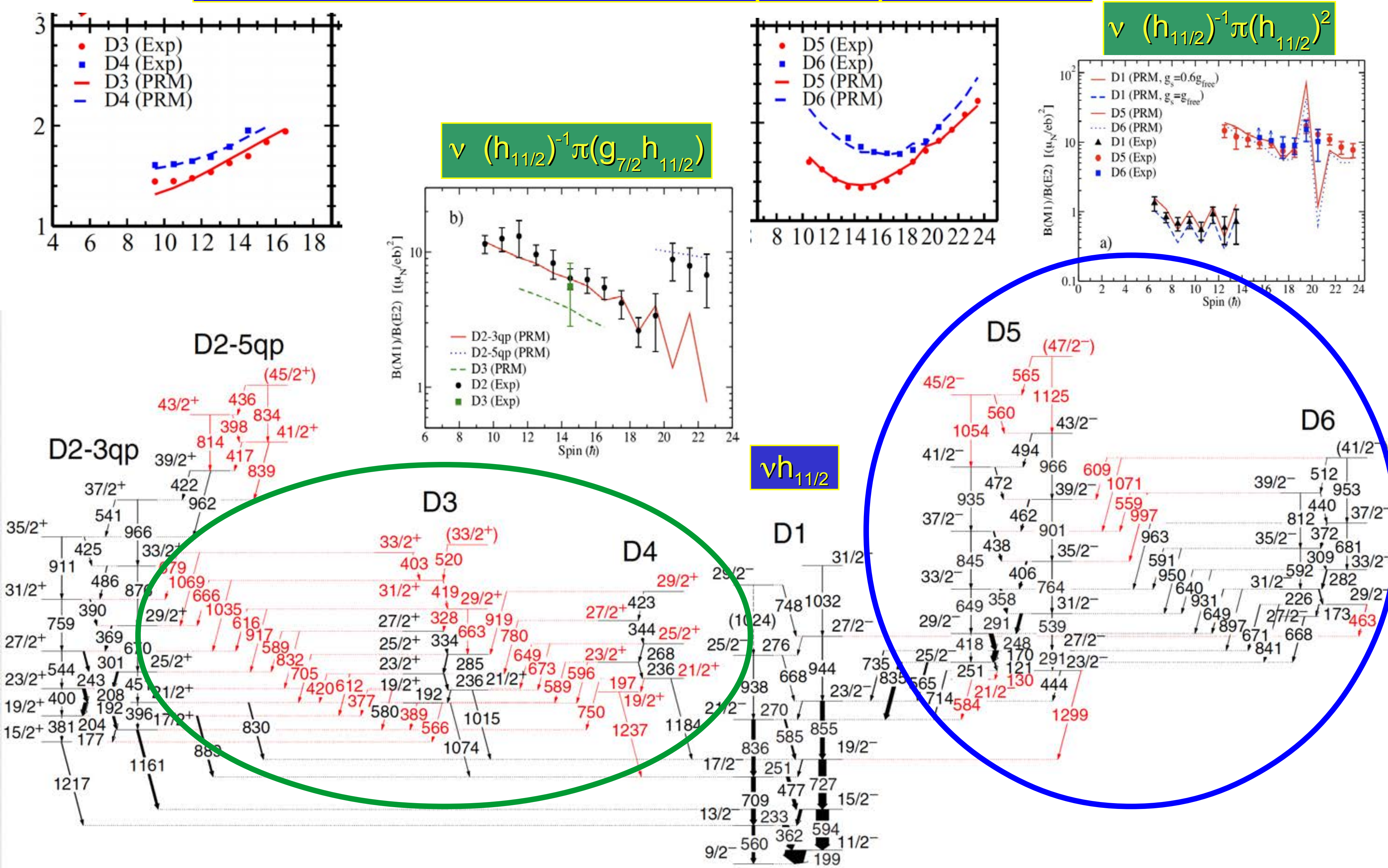
- Configuration: $\pi\,(1h_{11/2})^2\,(1g_{7/2})^{-2}\,\nu\,(1h_{11/2})^{-1}\,(1f_{7/2})^1$
- Deformation: ($\beta = 0.26$, $\gamma = 23.0^o$)
- Irr. MOI: $\Im = 40$ MeV
- Coriolis attenuation factor: 0.93



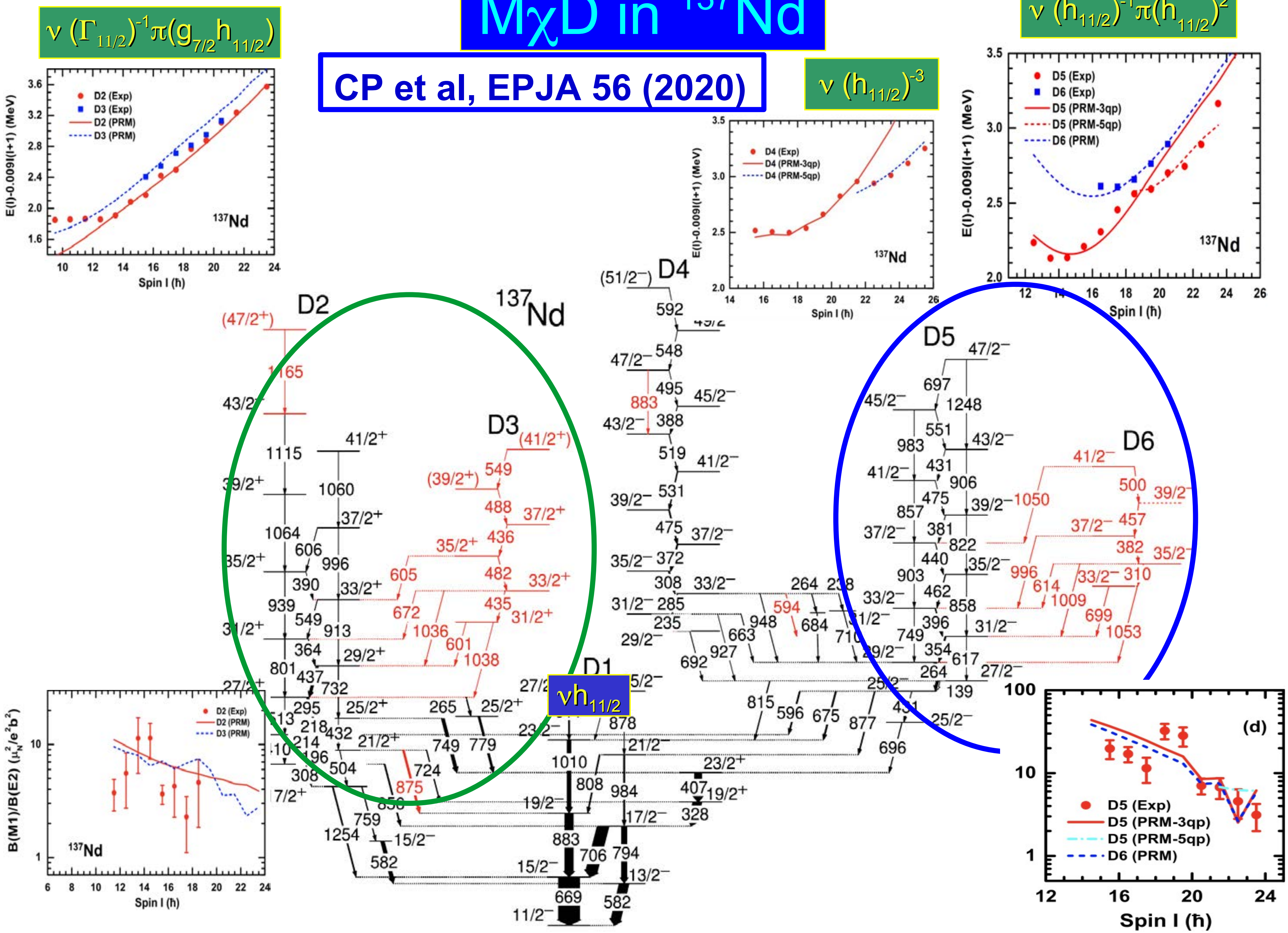



# Multiple chiral bands in $^{135}$Nd
# B.F. Lv et al - PRC 100 (2019) 024314



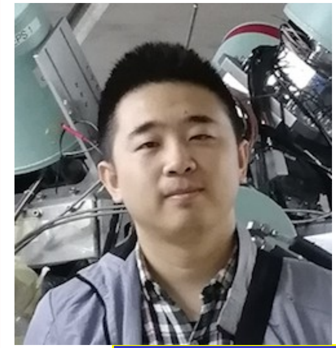
# MχD in $^{137}$Nd

**CP et al, EPJA 56 (2020)**

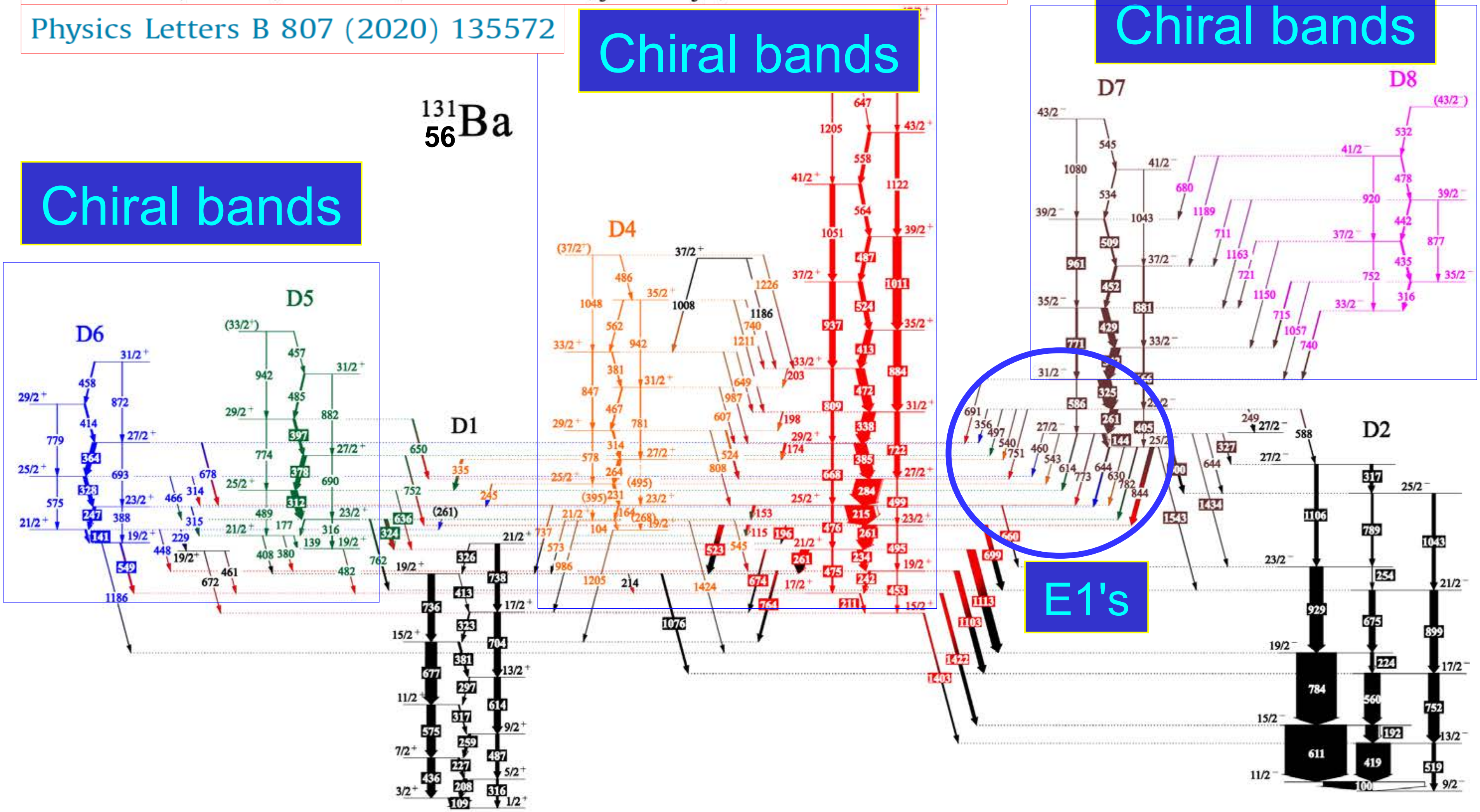


# Evidence for pseudospin-chiral quartet bands in the presence of octupole correlations

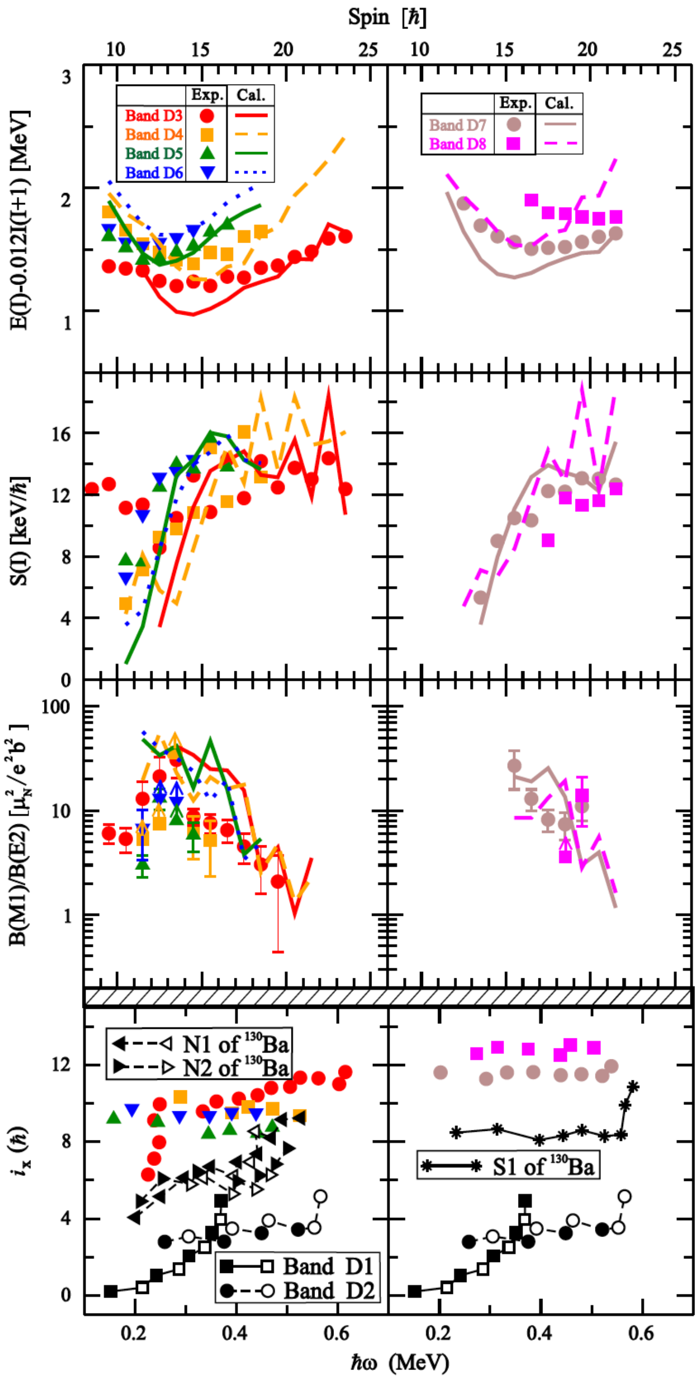
S. Guo[a,b,*], C.M. Petrache[c,*], D. Mengoni[d,e], Y.H. Qiang[a], Y.P. Wang[f], Y.Y. Wang[f], J. Meng[f,g], Y.K. Wang[f], S.Q. Zhang[f], P.W. Zhao[f], A. Astier[c], J.G. Wang[a,b], H.L. Fan[a], E. Dupont[c], B.F. Lv[c], D. Bazzacco[d,e], A. Boso[d,e], A. Goasduff[d,e], F. Recchia[d,e], D. Testov[d,e], 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]

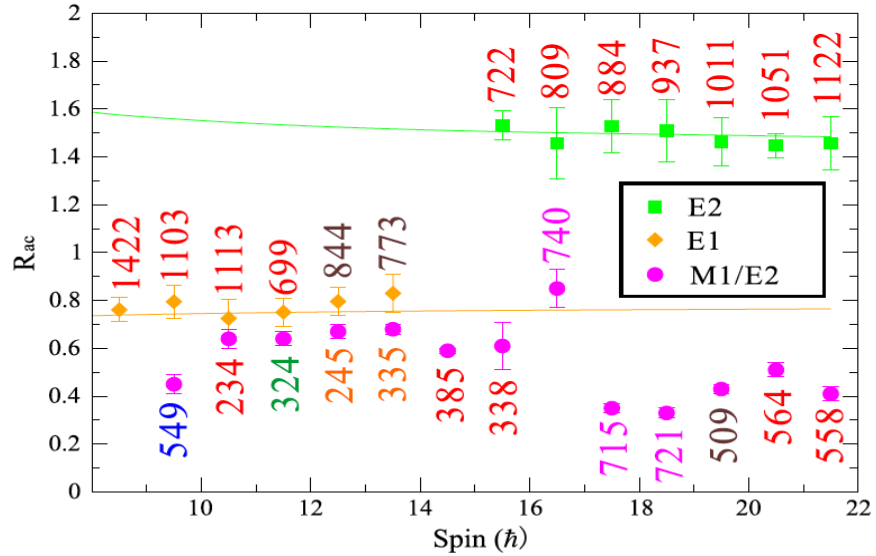


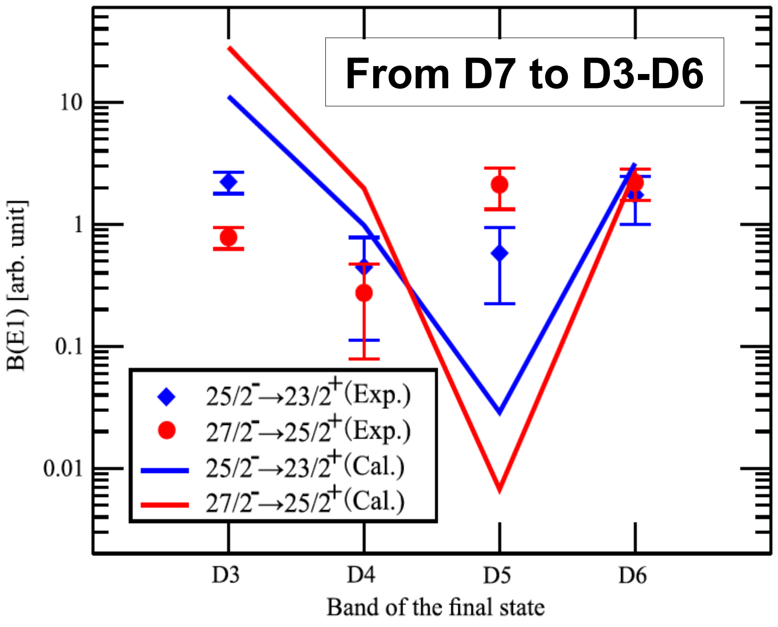
Physics Letters B 807 (2020) 135572



# Chiral bands of $^{131}$Ba



# 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]

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

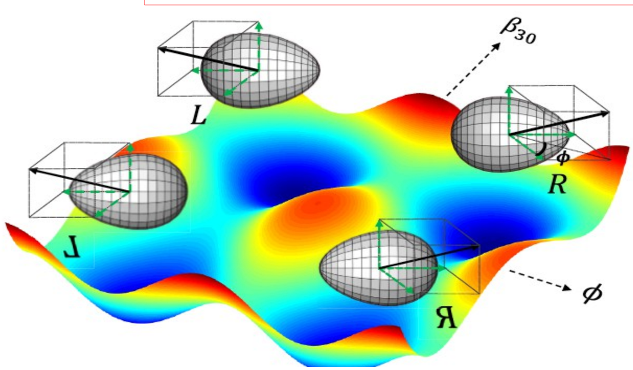
Y.Y. Wang (王媛媛)[a], S.Q. Zhang (张双全)[b], P.W. Zhao (赵鹏巍)[b], J. Meng (孟杰)[b,a,c,*]

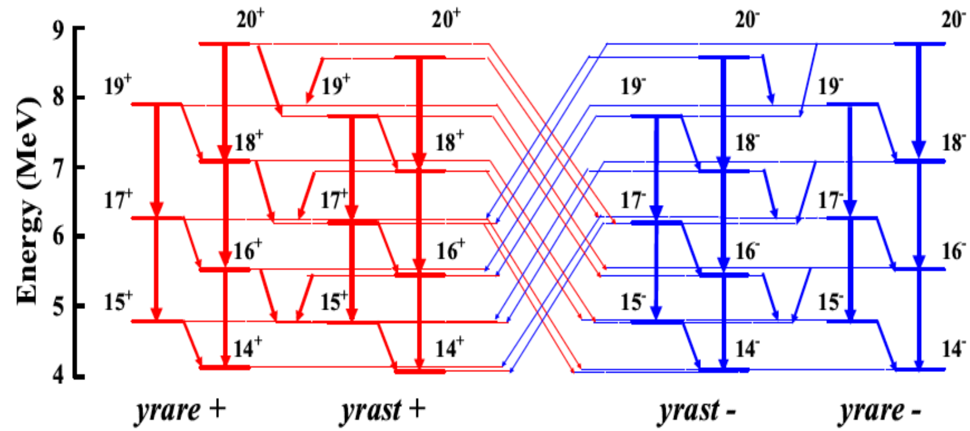
Physics Letters B 792 (2019) 454–460

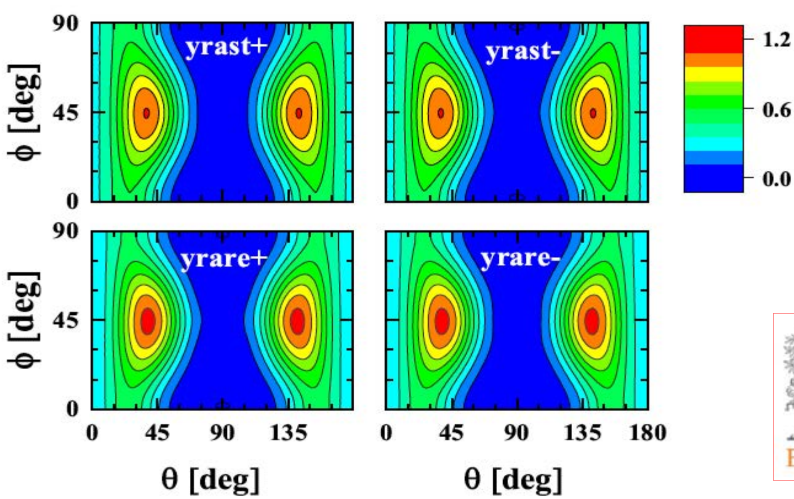
**New quantum numbers**

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

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



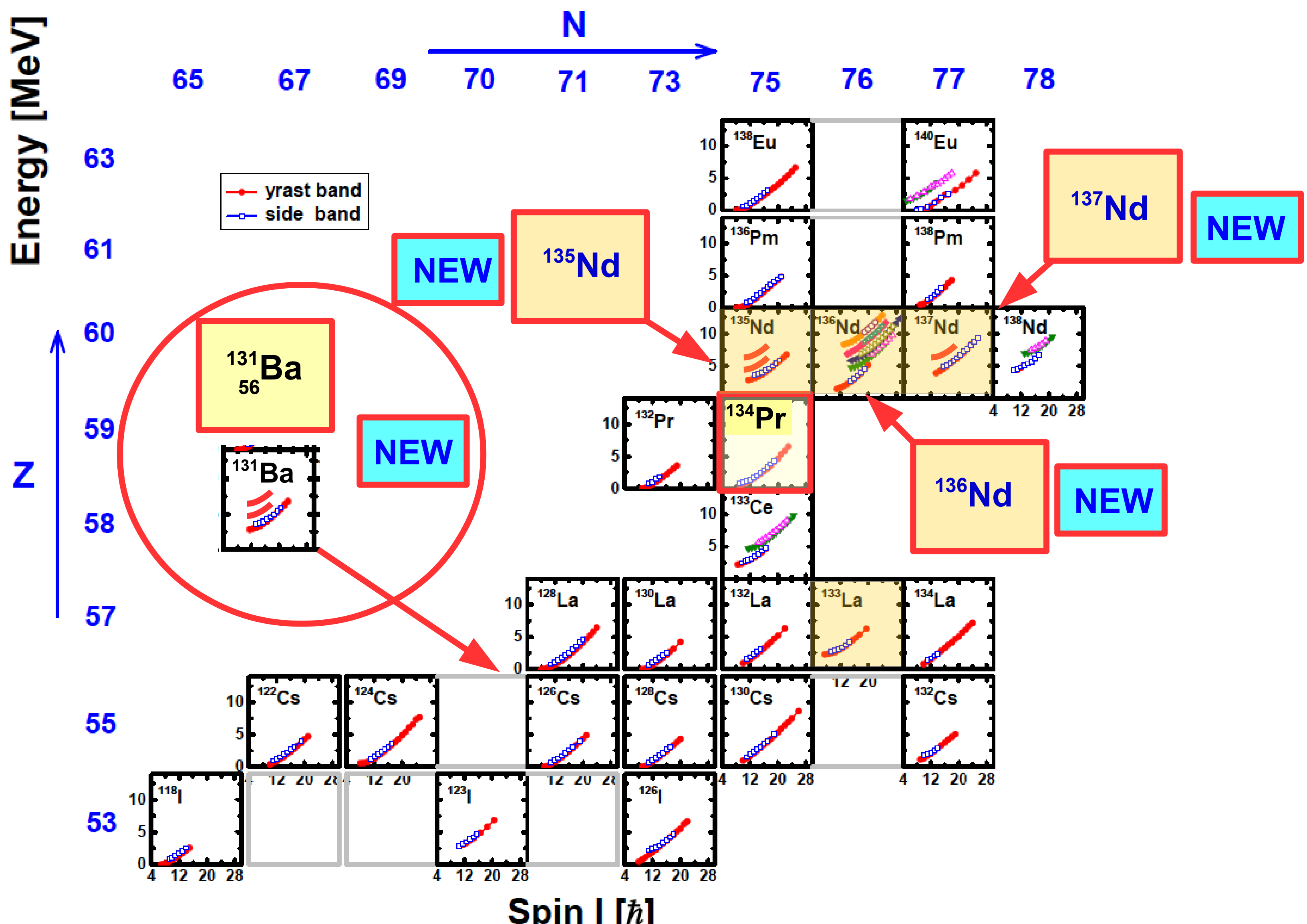




# Robustness of chiral symmetry in atomic nuclei with reflection-asymmetric shapes

Costel Marian Petrache

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

# New chiral bands in A=130 region




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

# Wobbling outside of the A=160 mass region

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

# Wobbling bands – theoretical predictions and calculations

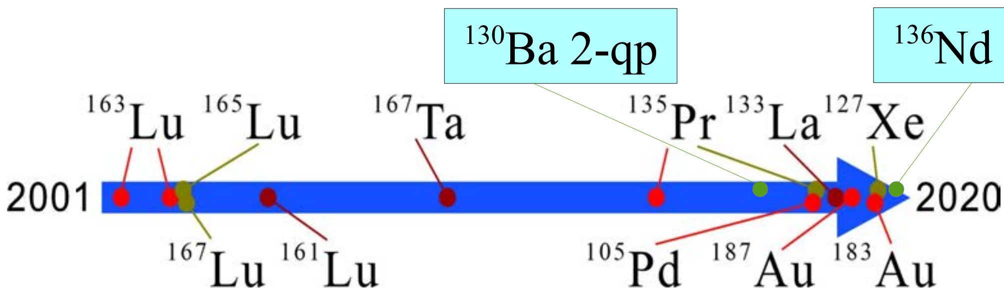
1975, Bohr-Mottelson, Chapter 4,
States with large I ($I^2 >> I_2^2 + I_3^2$)

1975 → 2001 → 2020

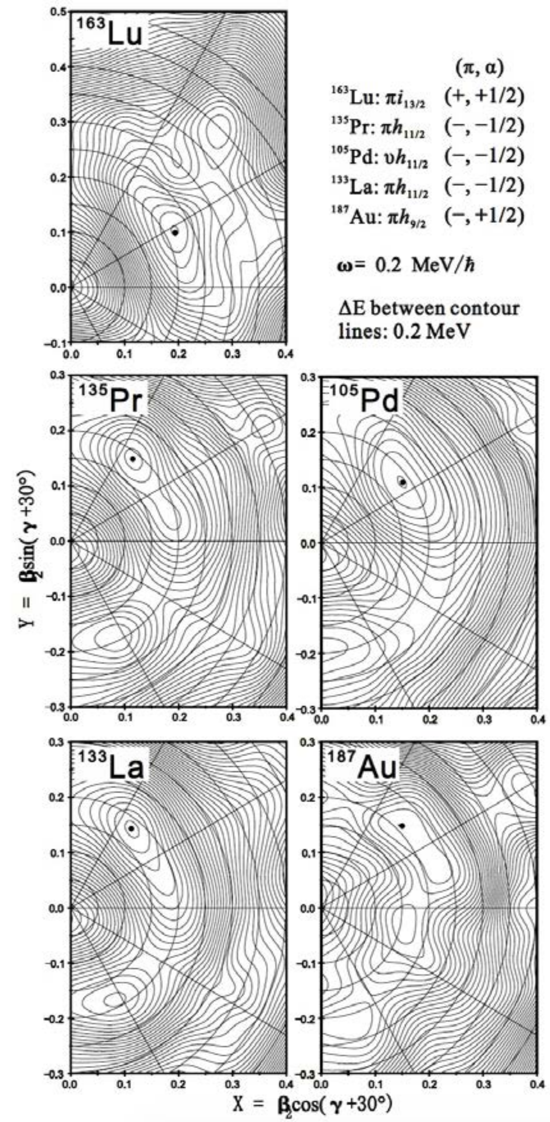
**High spins**
γ-rigid
Rigid MOI
Shimizu 1995
Hamamoto 2002
Matsuzaki 2003
Tanabe 2006
Oi 2006
Raduta 2020
…
and many others

**Low spins**
γ-rigid
Rigid & Hydrodynamic MOI
Frauendorf-Dönau 2014
Chen 2016
Tanabe 2017
Budaca 2018
Qi 2020
γ-soft
Casten 2003
…
and many others

# Reported wobbling bands




6 PRL
5 PLB
2 EPJ
2 PRC




High spins
Large quadrupole deformation (β~0.4)
γ-rigid
Interpreted by top-on-top with rigid MOI

Low-medium spins
Moderate quadrupole deformation (β~0.2)
γ-soft
Interpreted by transverse or longitudinal wobbling with hydrodynamic MOI

# Risk of misinterpretation of low-spin bands in odd-even nuclei as wobbling bands instead of Tilted Precession (TiP) bands

Wobbling at low spins? => questionable from both experimental and theoretical points of view

Tilted Precession at low spins – YES (1 PRC submitted)

$^{135}$Nd – TiP bands (1 PRC submitted)

$^{135}$Pr – questionable experimental results (1 PRC comment submitted)

$^{133}$La – questionable experimental results (1 comment in preparation)

$^{187}$Au – questionable experimental results (1 article in preparation)

$^{183}$Au, $^{127}$Xe, $^{105}$Pd – questionable wobbling interpretation

2-qp wobbling at high spins? => Maybe YES

$^{130}$Ba – 2-qp wobbling (1 PLB)

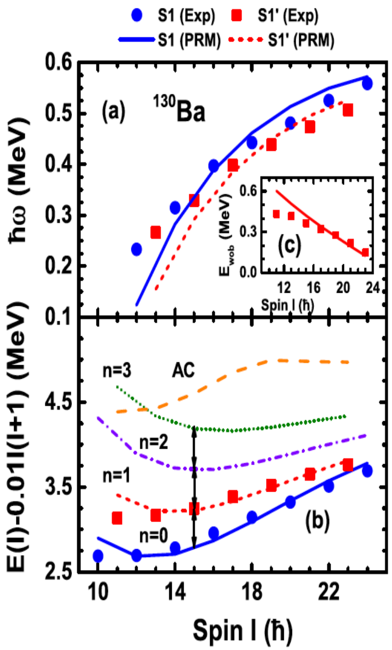
$^{136}$Nd – 2-qp wobbling (1 PRC submitted)

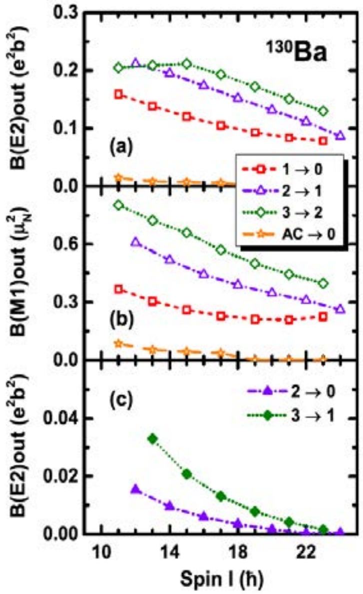
# Wobbling of 2-qp bands at high spins

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,‡]



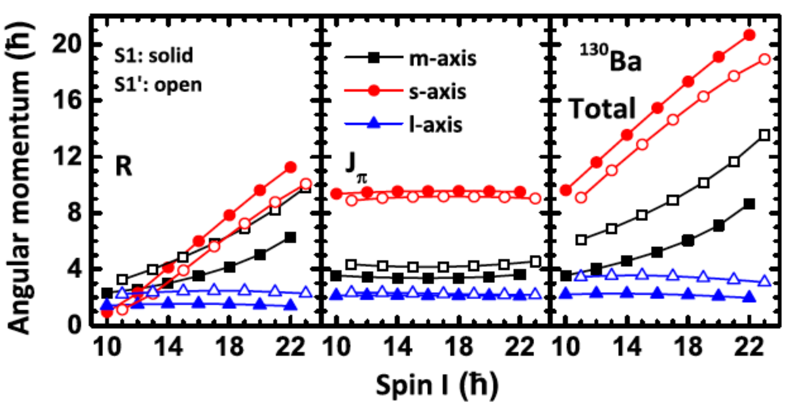
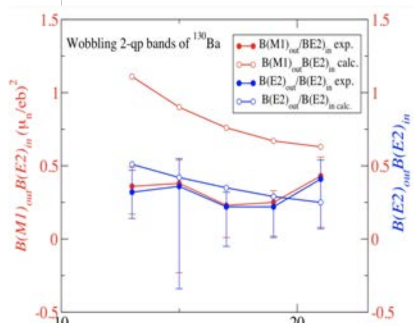
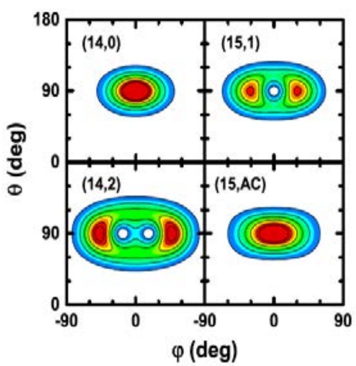
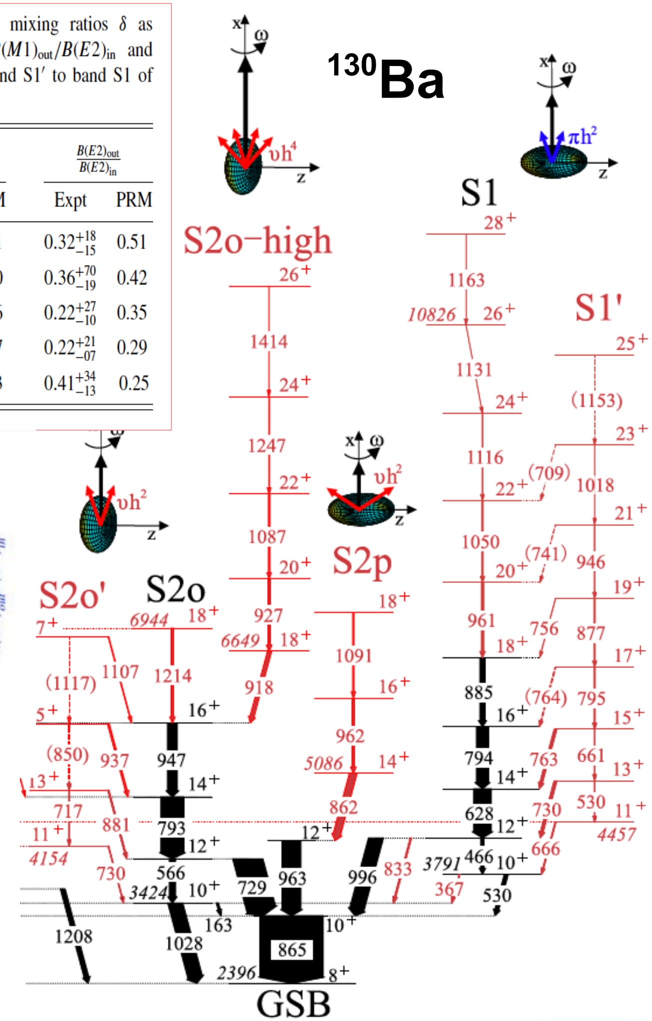




TABLE I. Experimental and theoretical mixing ratios $\delta$ as well as the transition probability ratios $B(M1)_{out}/B(E2)_{in}$ and $B(E2)_{out}/B(E2)_{in}$ for the transitions from band S1′ to band S1 of $^{130}$Ba.

| | $\delta$ | | $\frac{B(M1)_{out}}{B(E2)_{in}}\left(\frac{\mu_N^2}{e^2b^2}\right)$ | | $\frac{B(E2)_{out}}{B(E2)_{in}}$ | |
|---|---|---|---|---|---|---|
| $I$ (ħ) | Expt | PRM | Expt | PRM | Expt | 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 $\gamma$-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]

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


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

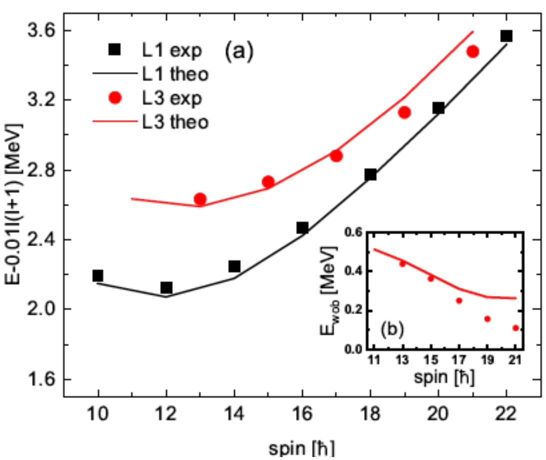
[1] *School of Physical Science and Technology, Northwestern Polytechnical University, Xi'an 710129, China*
[2] *Centre de Sciences Nucléaires et Sciences de la Matière, CNRS/IN2P3, Université Paris-Saclay, Bâtiment 104-108, 91405 Orsay, France*

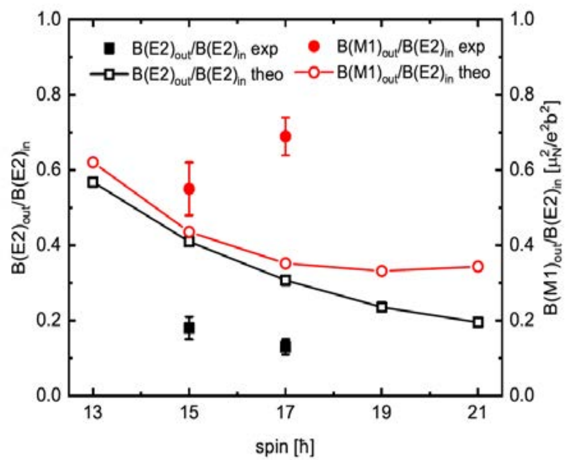


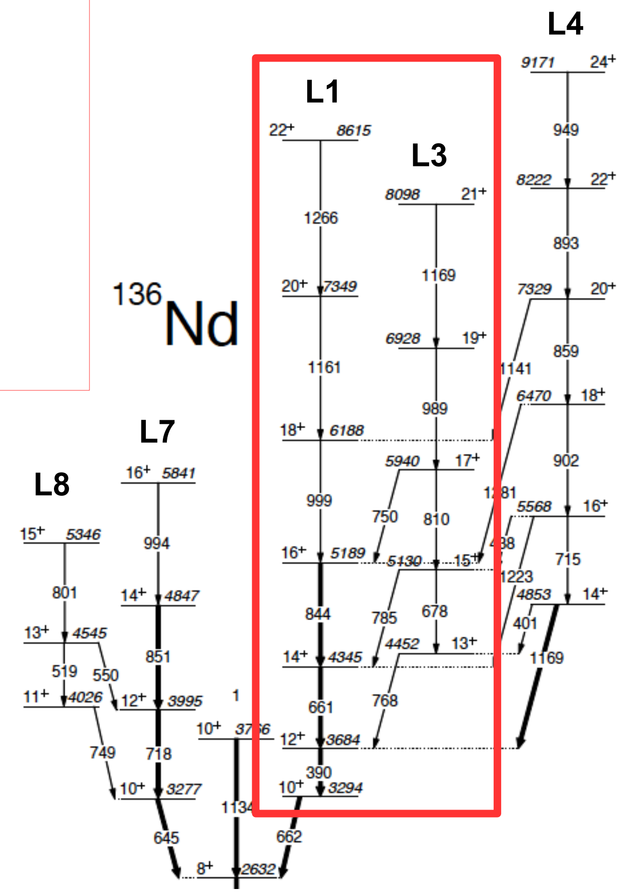
(Dated: November 11, 2020)

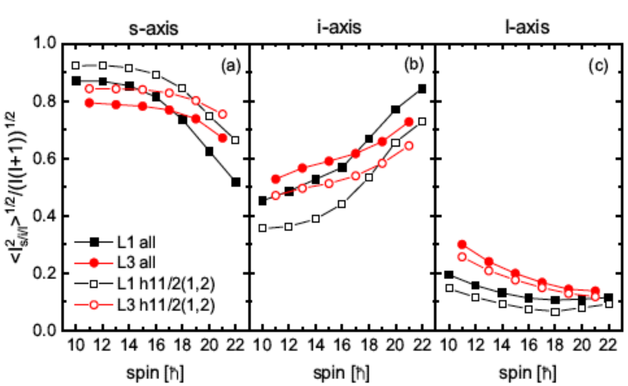


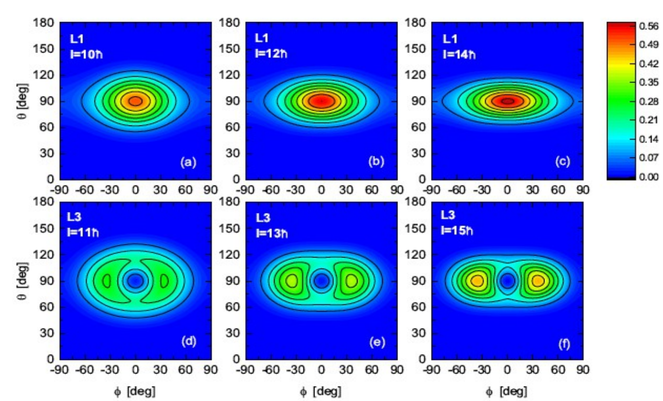
The even- and odd-spin two-quasiparticle yrast bands in $^{136}$Nd are investigated with the triaxial projected shell model, focusing on the possible interpretation as transverse wobbling. With the experimental observables reproduced reasonably, the conditions under which the wobbling approximation is valid are examined via the angular momentum geometry and the configuration components extracted from the microscopic wave functions. The impact of the rotational alignment of the quasiparticles on the scenario of transverse wobbling is emphasized. It turns out that the $n = 0$ band of the wobbling candidate is more affected than the $n = 1$ one, which tends to go against the decreasing trend of the wobbling energy expected in the transverse case.

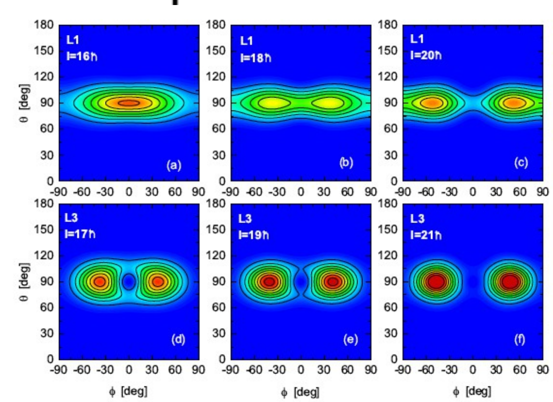



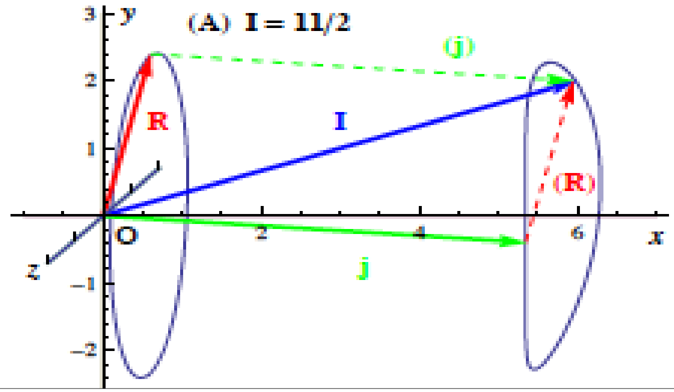
Wobbling 1-qp bands

at low spins

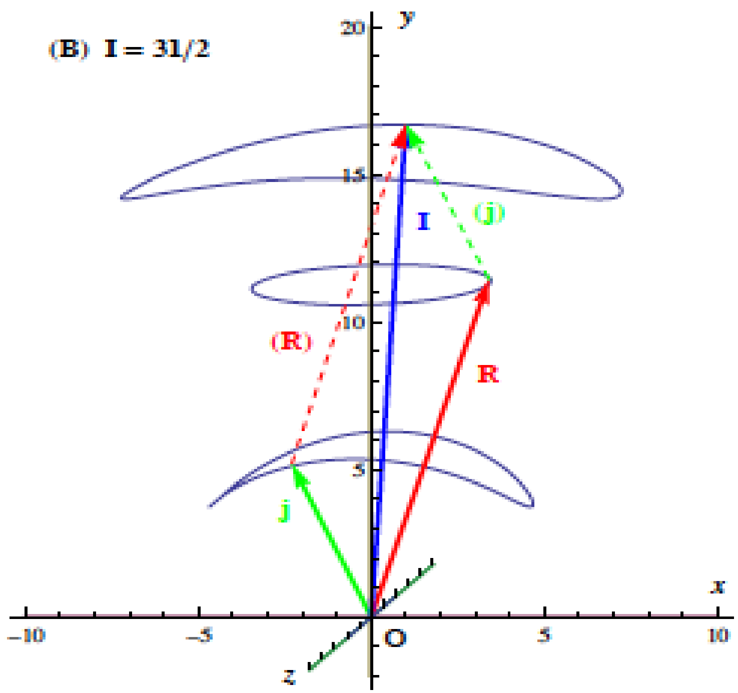
– questionable

– high risk of misinterpretation

# $^{135}Pr$




**Revolving towards the medium axis**
**No stable transverse geometry !!!**




Tanabe, PRC 95 (2017)

PHYSICAL REVIEW C 101, 034306 (2020)

# Tilted precession and wobbling in triaxial nuclei

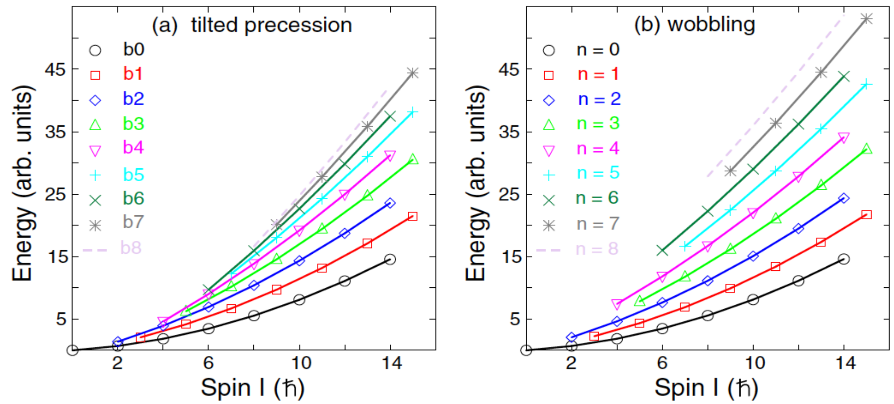
E. A. Lawrie,[1,2,*] O. Shirinda,[1,†] and C. M. Petrache[3,‡]

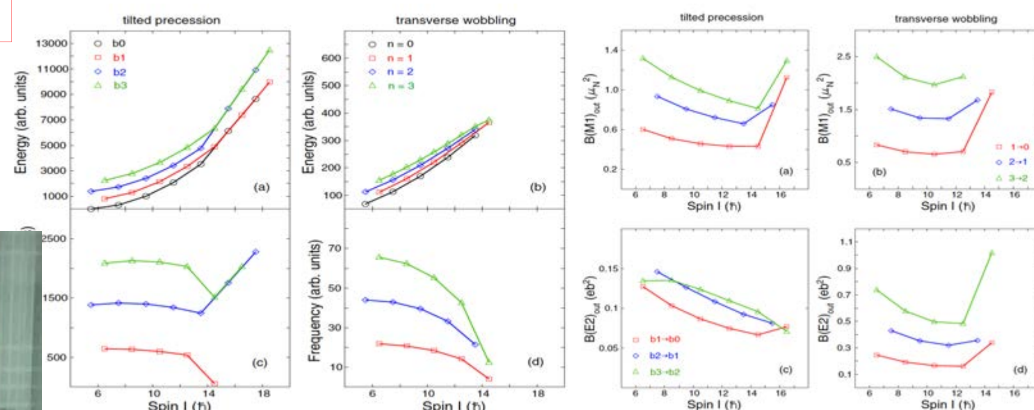
The wobbling approximation is valid if the rotational angular momenta around the two axes with lower MoI is small [16]:

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

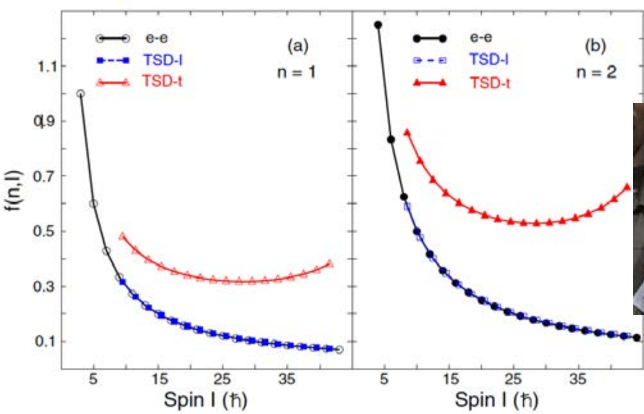
a condition that can be rewritten as

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

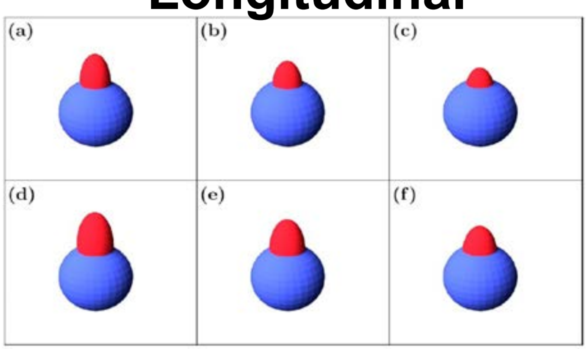


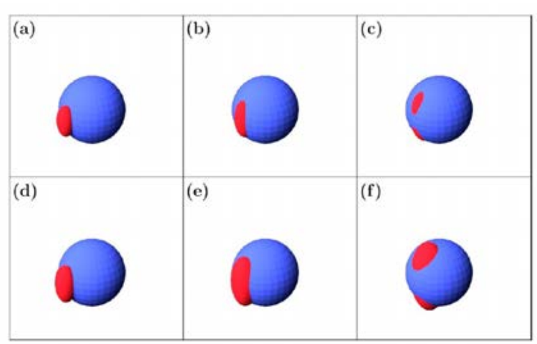

$A_1 = 1, A_2 = 4$, and $A_3 = 4$ are used

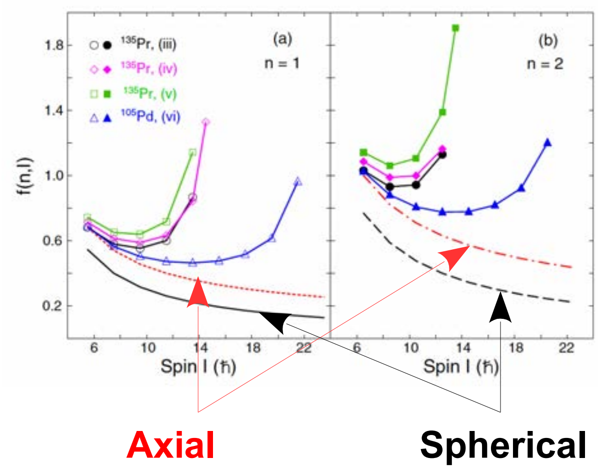



## Longitudinal




## Transverse

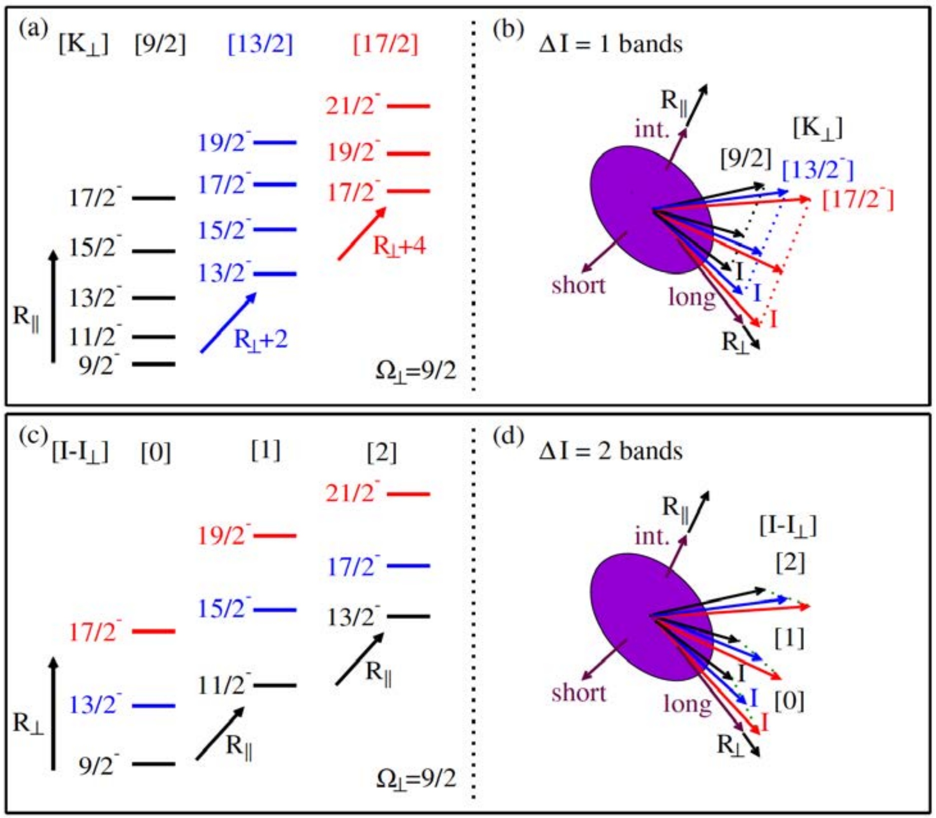


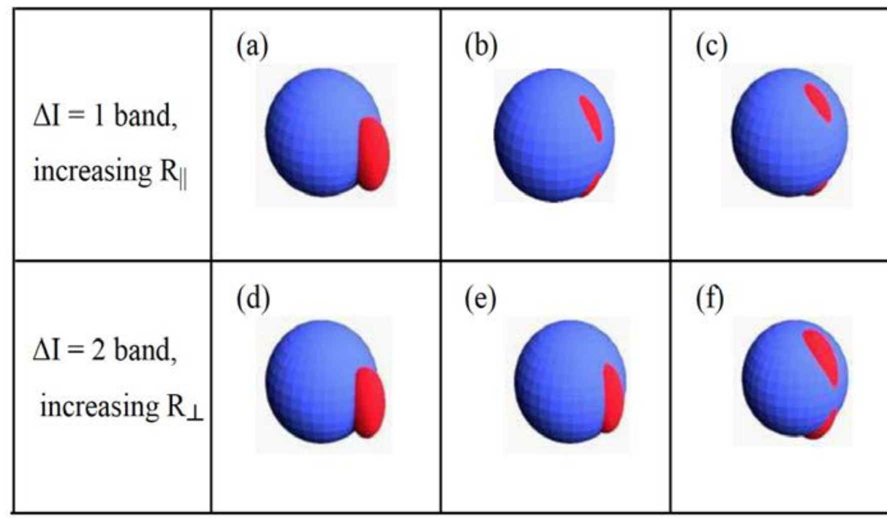



# Tilted precession bands in $^{135}$Nd

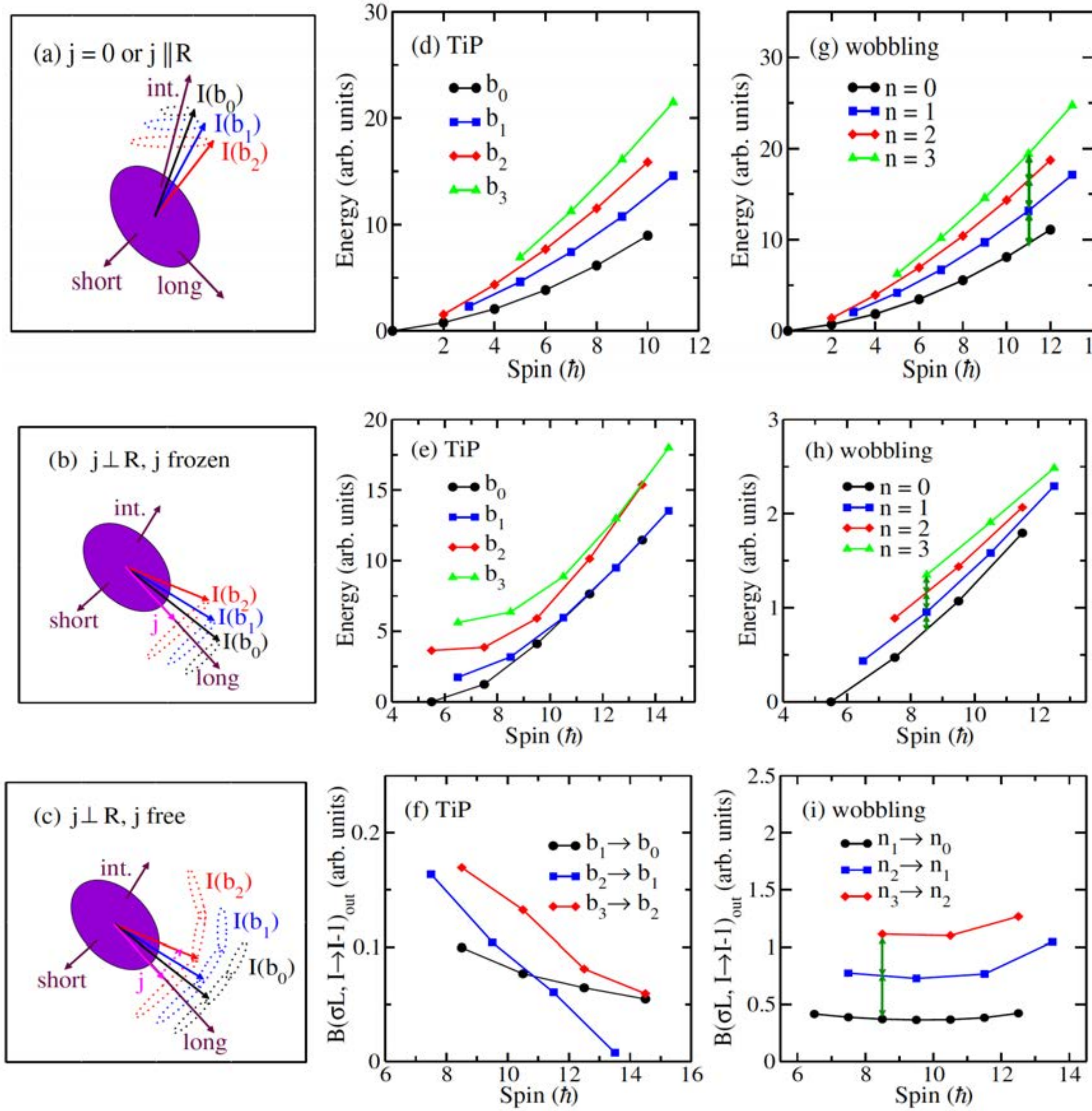
**Submitted to PRC**

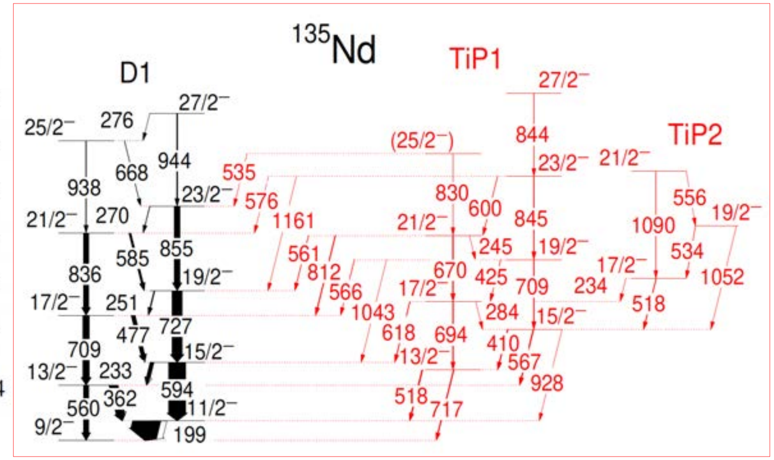
B. F. Lv,[1] C. M. Petrache,[2,*] E. A. Lawrie,[3,4] A. Astier,[2] E. Dupont,[2] K. K. Zheng,[1,2] P. Greenlees,[5] H. Badran,[5] T. Calverley,[5,6] D. M. Cox,[5,†] T. Grahn,[5] J. Hilton,[5,6] R. Julin,[5] S. Juutinen,[5] J. Konki,[5,‡] J. Pakarinen,[5] P. Papadakis,[5,§] J. Partanen,[5] P. Rahkila,[5] P. Ruotsalainen,[5] M. Sandzelius,[5] J. Saren,[5] C. Scholey,[5] J. Sorri,[5,7] S. Stolze,[5,¶] J. Uusitalo,[5] B. Cederwall,[8] A. Ertoprak,[8] H. Liu,[8] S. Guo,[1] J. G. Wang,[1] H. J. Ong,[1] X. H. Zhou,[1] I. Kuti,[9] J. Timár,[9] A. Tucholski,[10] J. Srebrny,[10] and C. Andreoiu[11]

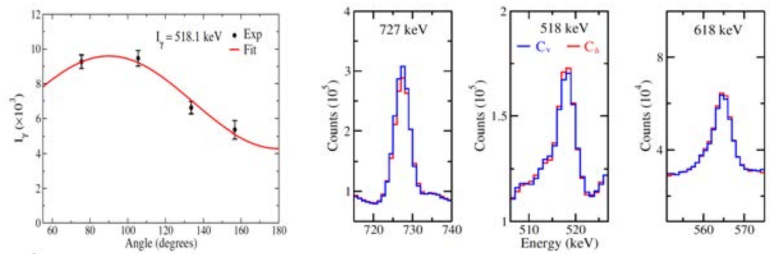


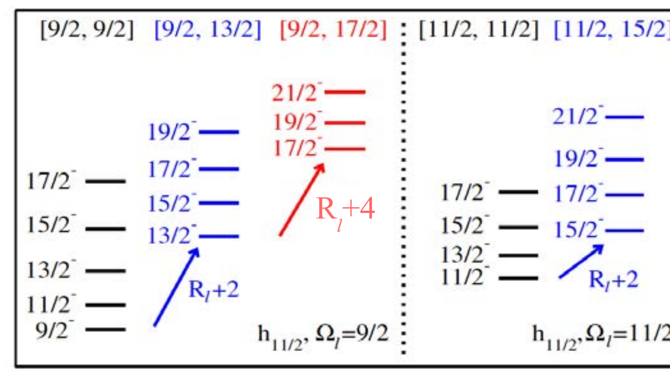



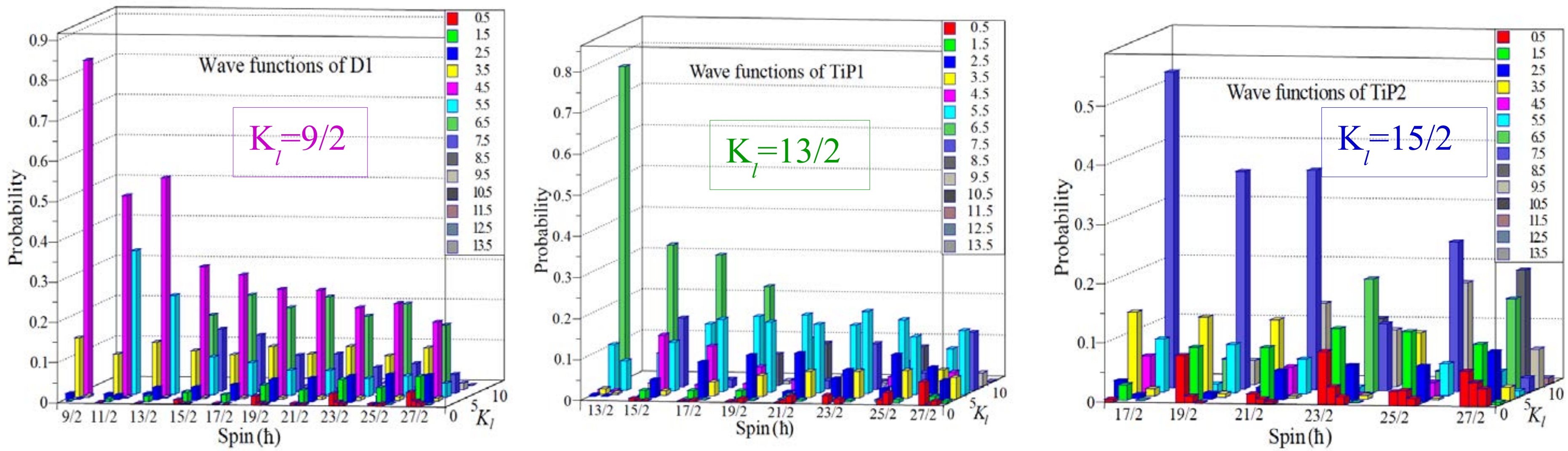
# PRM calculations by E. Lawrie

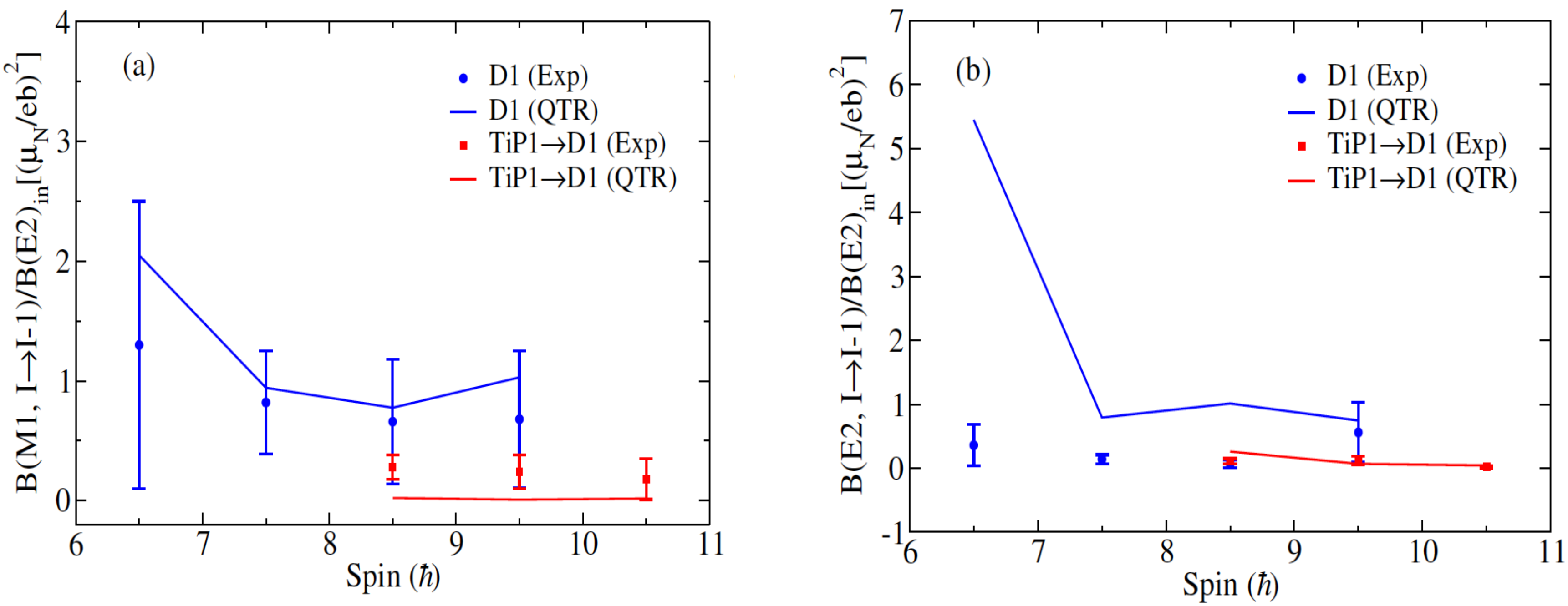


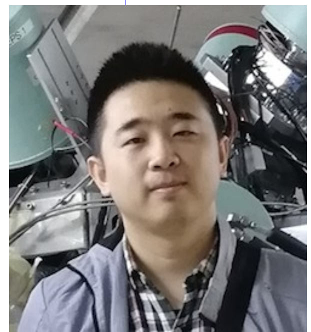

Wave functions of D1
$K_l$=9/2
Probability
Spin (ħ)
Wave functions of TiP1
$K_l$=13/2
Wave functions of TiP2
$K_l$=15/2
$K_l$
0.5
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5

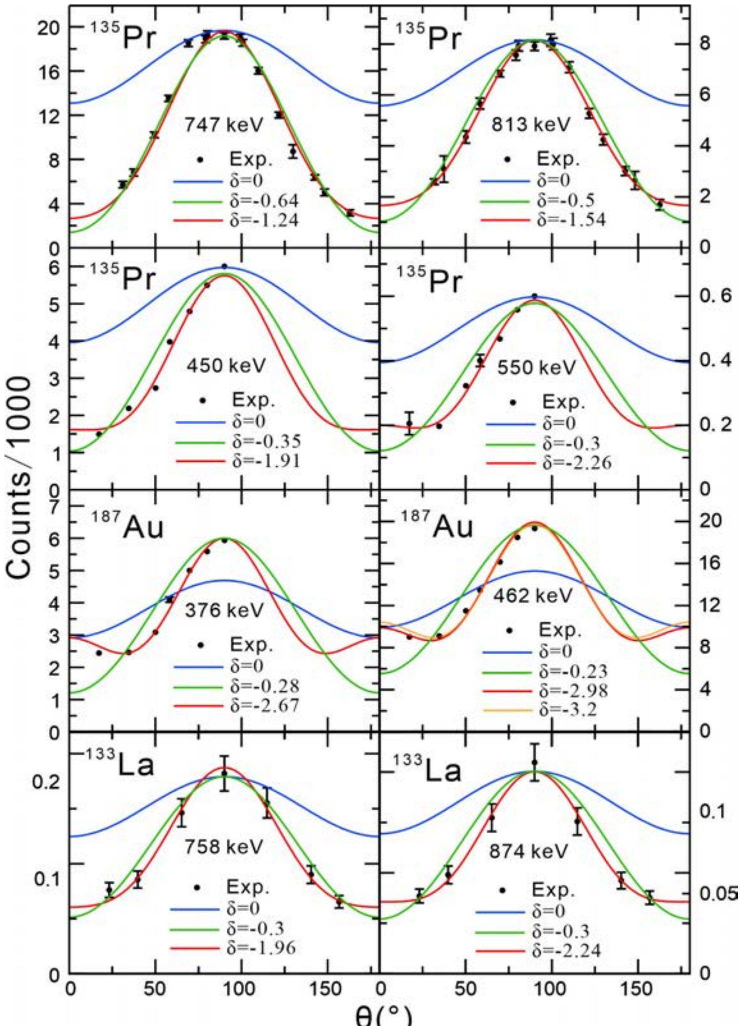

(a)
D1 (Exp)
D1 (QTR)
TiP1→D1 (Exp)
TiP1→D1 (QTR)
B(M1, I→I-1)/B(E2)$_{in}$[($\mu_N$/eb)$^2$]
Spin (ħ)
(b)
D1 (Exp)
D1 (QTR)
TiP1→D1 (Exp)
TiP1→D1 (QTR)
B(E2, I→I-1)/B(E2)$_{in}$[($\mu_N$/eb)$^2$]
Spin (ħ)

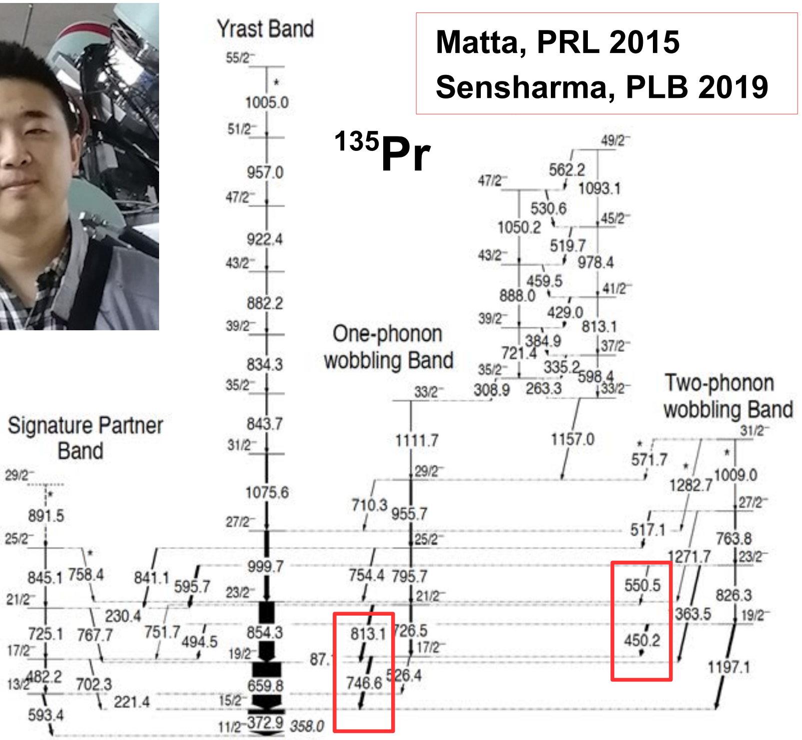
# Problems with experimental results

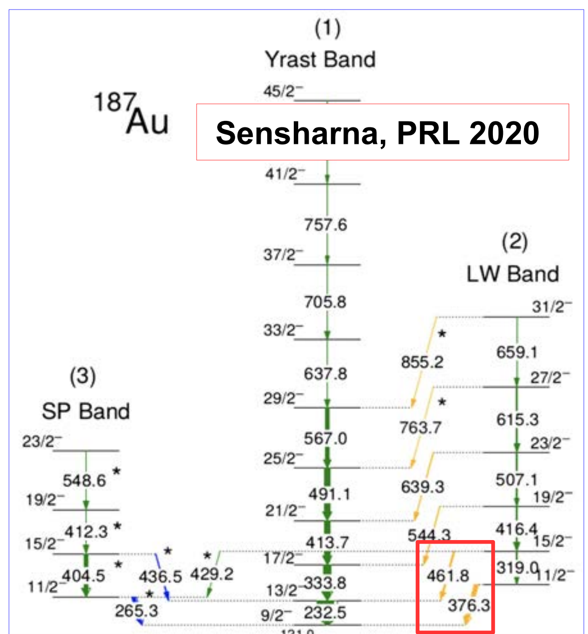
Not easy to extract convincing mixing ratios from angular distributions of transitions with 10% relative intensities!

Polarization asymmetry has very large errors for weak transitions!

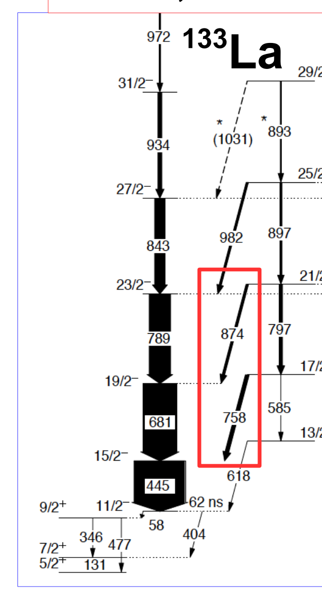





Biswas, EPJA 2019

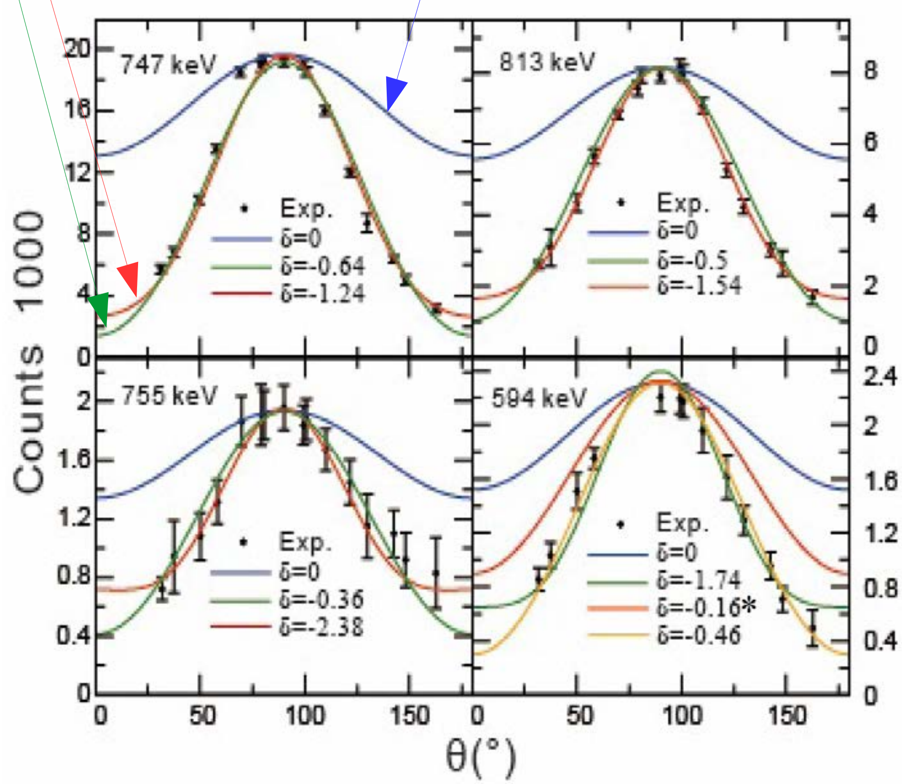


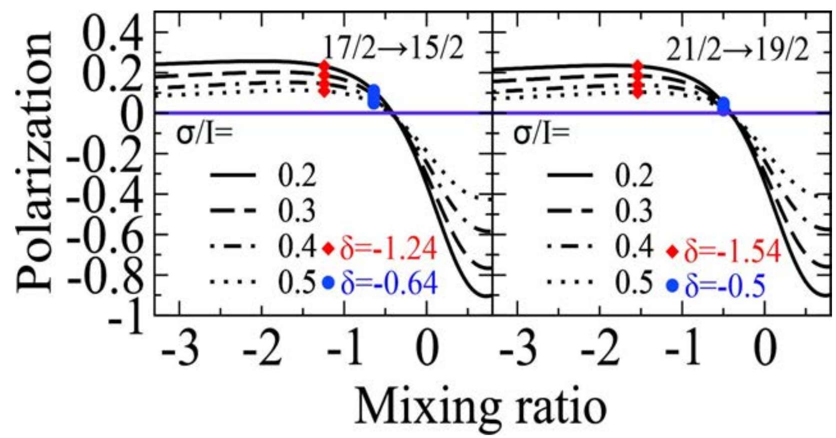
# Problems on $^{135}$Pr

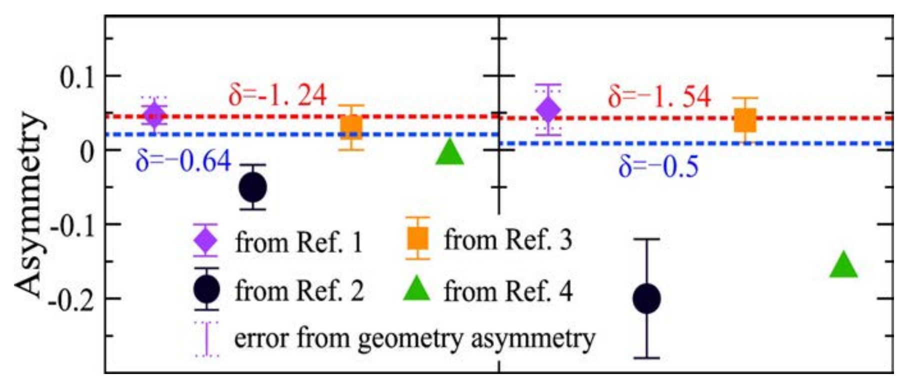
Credit to Guo Song, IMP Lanzhou

Very similar, not convincing!

Misleading!




* -0.16 was repoted in the text, but -0.46 is obtained by fitting the reported curve


1: PRL 114, 082501 (2015)
2: PRC 92, 054325 (2015)
3: PRC 100, 069901 (E) (2019)
4: arXiv: 2007.10031

# Comment on "Erratum: Negative-parity high-spin states and a possible magnetic rotation band in $^{135}_{59}Pr_{76}$ [Phys. Rev. C 92, 054325 (2015)]"

S. Guo (郭松)[1,2] and C. M. Petrache[3]

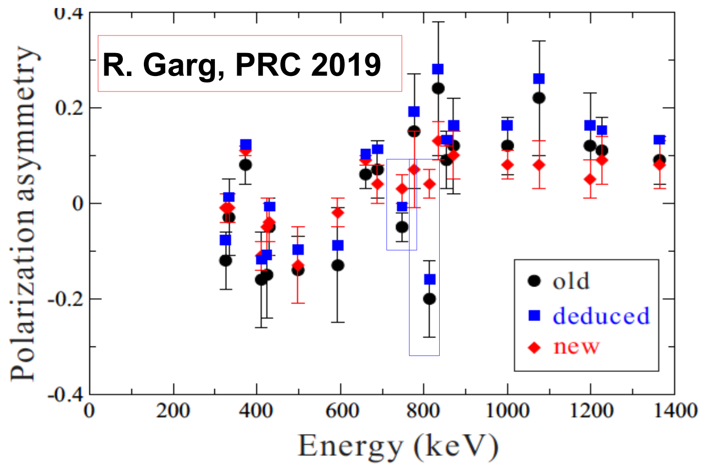



FIG. 2. (Color online) The old and new polarization asymmetry values, in comparison with the deduced ones assuming only the geometry asymmetry is changed.

$$\Delta = \frac{aN_{\perp} - N_{\parallel}}{aN_{\perp} + N_{\parallel}}$$

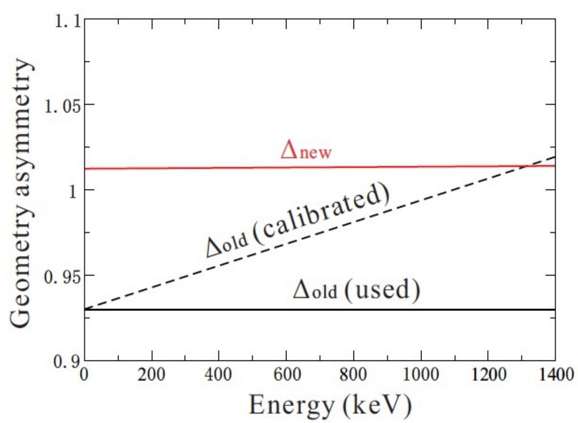


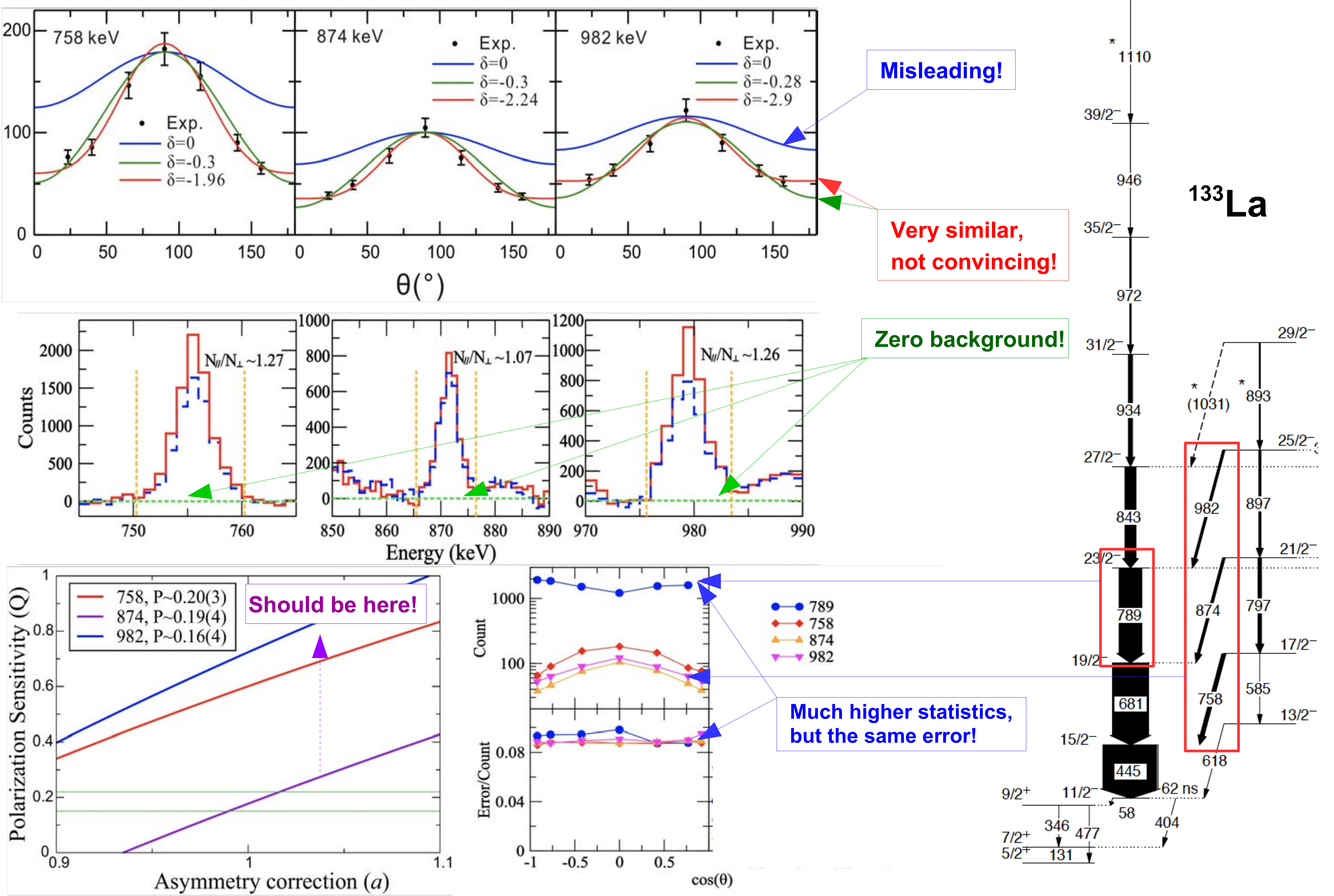

FIG. 1. (Color online) Geometry asymmetry as functions of transition energy.

ABLE I. $\gamma$-ray energy, polarization asymmetry ($\Delta$) rat
nd deduced ratios between the counts of parallel and p
endicular scattering (R).

| $E_\gamma$(keV) | $\Delta_{old}$ | $\Delta_{new}$ | $\Delta_{deduced}$ | $R_{old}$ | $R_{new}$ |
|---|---|---|---|---|---|
| 325.1 | -0.12(6) | -0.01(3) | -0.078 | 0.845 | 0.968 |
| 332.9 | -0.03(8) | -0.01(3) | 0.013 | 1.013 | 0.968 |
| 372.8 | 0.08(4) | 0.11(1) | 0.122 | 1.262 | 1.232 |
| 410.8 | -0.16(10) | -0.11(3) | -0.118 | 0.779 | 0.792 |
| 424.0 | -0.15(9) | -0.05(6) | -0.108 | 0.795 | 0.893 |
| 429.7 | -0.05(6) | -0.04(4) | -0.007 | 0.973 | 0.911 |
| 498.5 | -0.14(7) | -0.13(8) | -0.098 | 0.811 | 0.760 |
| 593.7 | -0.13(12) | -0.02(3) | -0.088 | 0.828 | 0.948 |
| 660.2 | 0.06(3) | 0.09(1) | 0.102 | 1.213 | 1.182 |
| 688.8 | 0.07(6) | 0.04(4) | 0.112 | 1.237 | 1.069 |
| 747.5 | -0.05(3) | 0.03(3) | -0.007 | 0.973 | 1.048 |
| 776.2 | 0.15(12) | 0.07(8) | 0.192 | 1.455 | 1.136 |
| 813.3 | -0.2(8) | 0.04(3) | -0.159 | 0.717 | 1.069 |
| 834.0 | 0.24(14) | 0.13(4) | 0.280 | 1.754 | 1.282 |
| 854.0 | 0.09(6) | 0.13(1) | 0.132 | 1.288 | 1.282 |
| 870.8 | 0.12(10) | 0.1(5) | 0.162 | 1.369 | 1.206 |
| 999.9 | 0.12(6) | 0.08(3) | 0.162 | 1.369 | 1.158 |
| 1075.2 | 0.22(12) | 0.08(5) | 0.261 | 1.682 | 1.158 |
| 1197.4 | 0.12(11) | 0.05(4) | 0.162 | 1.369 | 1.090 |
| 1225.9 | 0.11(7) | 0.09(5) | 0.152 | 1.341 | 1.182 |
| 1363.7 | 0.09(5) | 0.08(5) | 0.133 | 1.288 | 1.158 |

## Comment on "Longitudinal wobbling in $^{133}$La [Eur. Phys. J. A 55, 159 (2019)]"

W. Hua (滑伟),[1] S. Guo (郭松),[2,3,*] C. M. Petrache,[4]



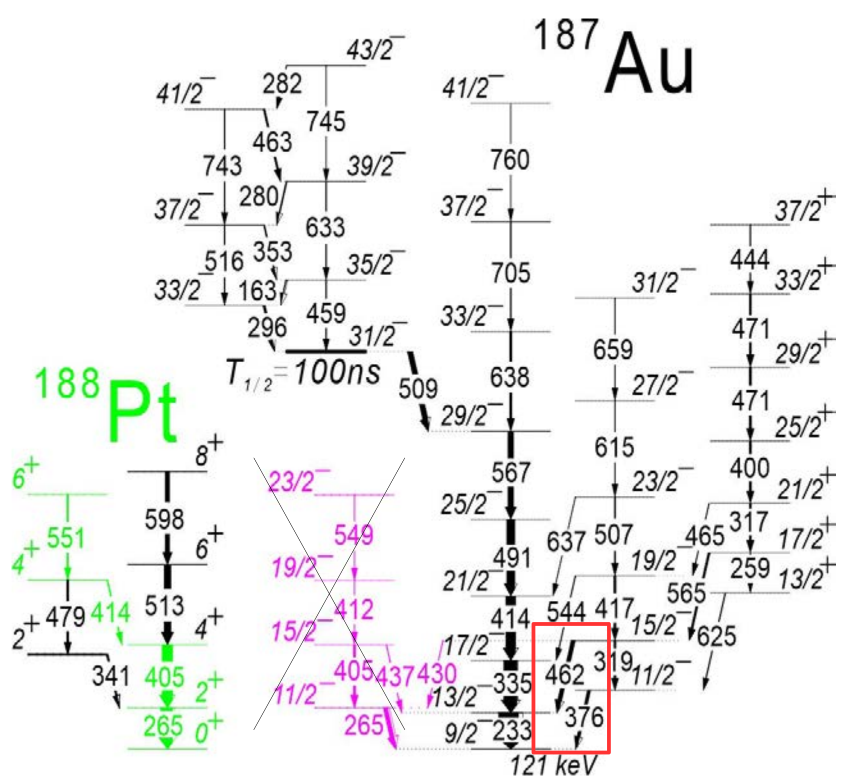
PHYSICAL REVIEW LETTERS **124,** 052501 (2020)

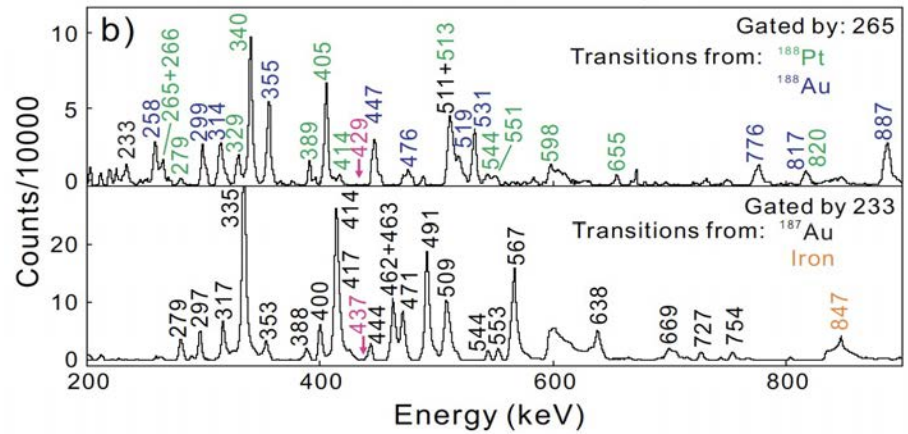
Editors' Suggestion | Featured in Physics

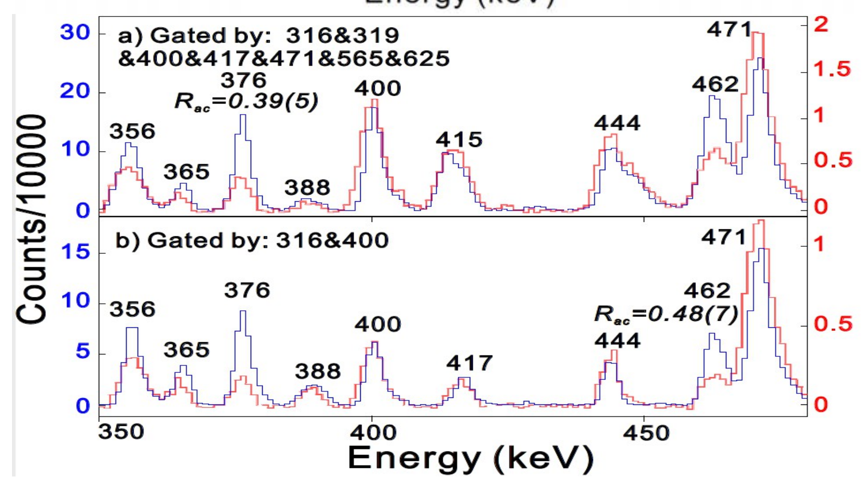
No wobbling in $^{187}$Au !

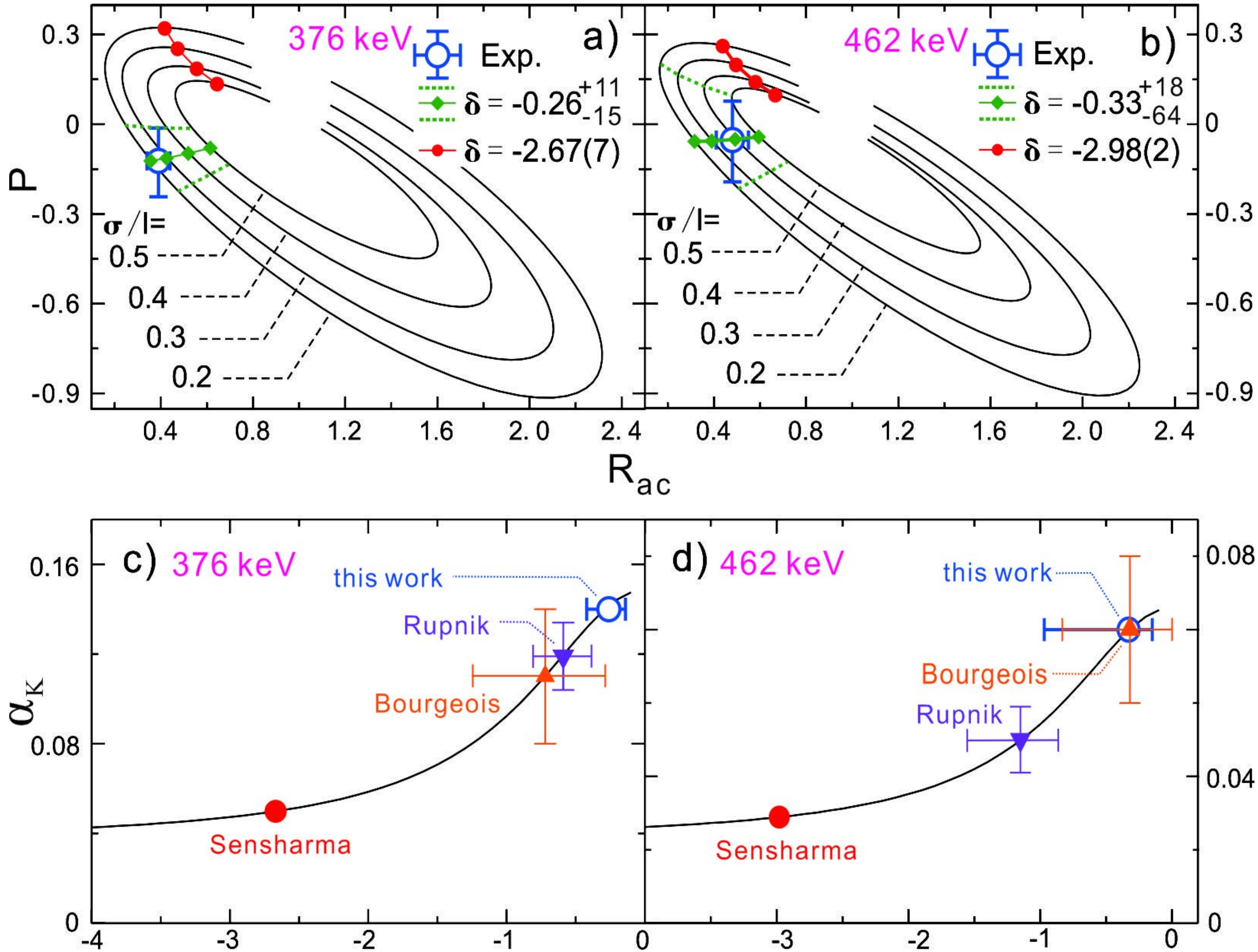
# Longitudinal Wobbling Motion in $^{187}$Au

N. Sensharma,[1] U. Garg,[1] Q. B. Chen,[2] S. Frauendorf,[1] D. P. Burdette,[1] J. L. Cozzi,[1] K. B. Howard,[1] S. Zhu,[10] M. P. Carpenter,[3] P. Copp,[3] F. G. Kondev,[3] T. Lauritsen,[3] J. Li,[3] D. Seweryniak,[3] J. Wu,[3] A. D. Ayangeakaa,[4] D. J. Hartley,[4] R. V. F. Janssens,[5,6] A. M. Forney,[7] W. B. Walters,[7] S. S. Ghugre,[8] and R. Palit[9]



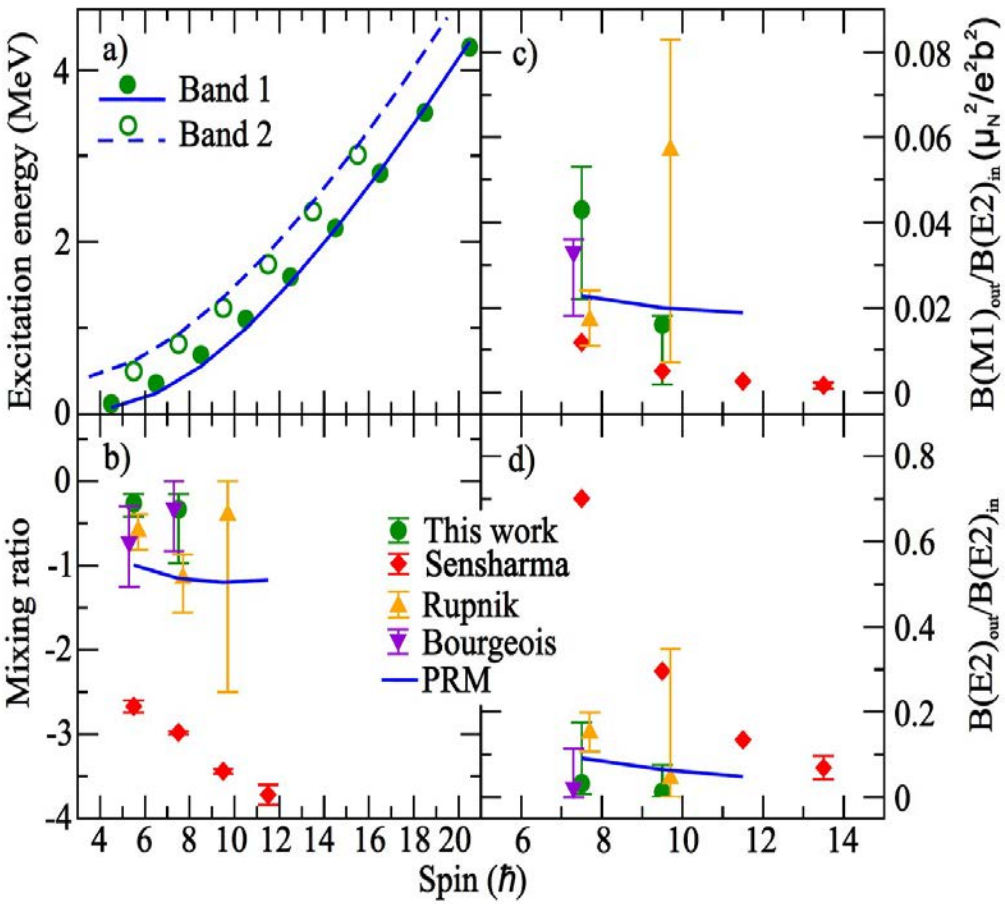



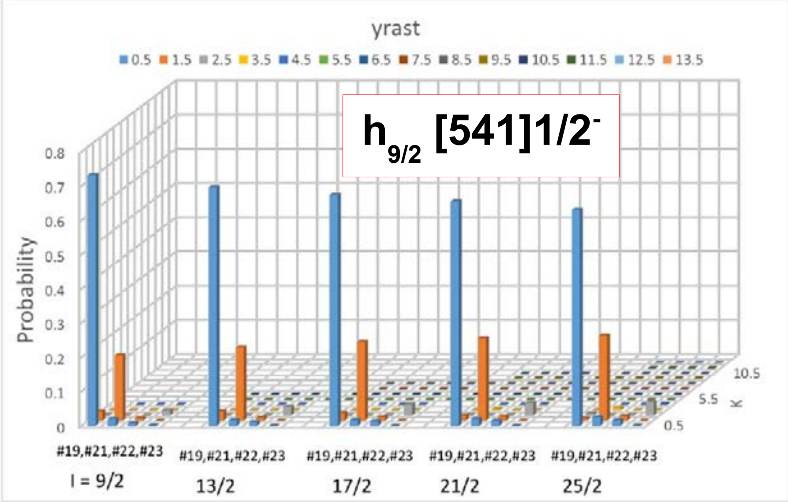



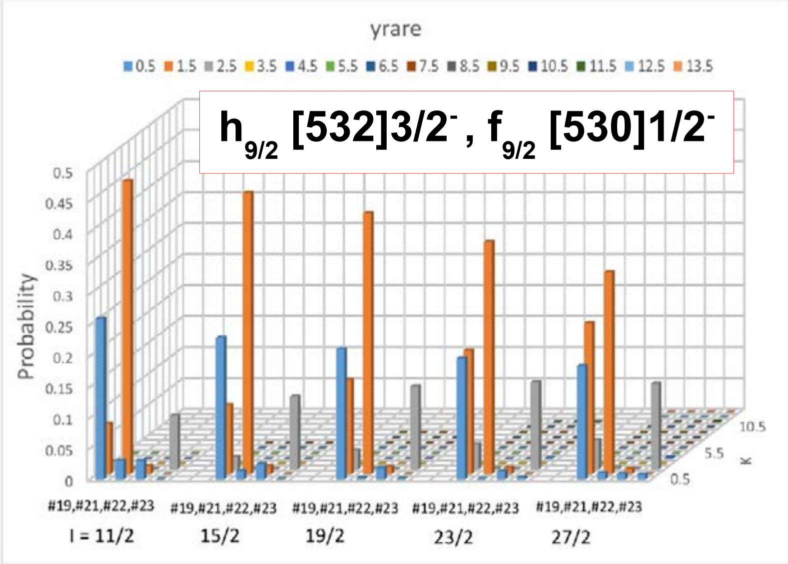


376 keV
a)
Exp.
δ = -0.26^{+11}_{-15}
δ = -2.67(7)
σ/I=
0.5
0.4
0.3
0.2
P
0.3
0
-0.3
-0.6
-0.9
462 keV
b)
Exp.
δ = -0.33^{+18}_{-64}
δ = -2.98(2)
0.4
0.8
1.2
1.6
2.0
2.4
R_ac
c) 376 keV
this work
Rupnik
Bourgeois
Sensharma
α_K
0.16
0.08
0
d) 462 keV
this work
Bourgeois
Rupnik
Sensharma
0.08
0.04
-4
-3
-2
-1
0

# PTRM calculations for $^{187}$Au : different 1-qp configurations, not wobbling bands!



Thank you !