Chirality and wobbling in the ^{135,136,137}Nd and ^{135}Pr nuclei

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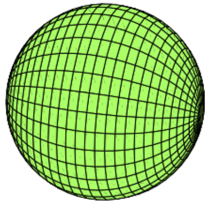
CWAN'23 Huizhou

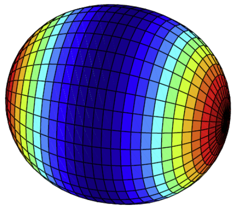
Outline

- **Introduction**
  - Nuclear chirality
  - Wobbling motion
- **Experimental details**
- **Results and discussion**
  - Chirality in $^{135,136,137}Nd$
  - Wobbling motion in ^{135}Pr and ^{136}Nd
- **Summary**

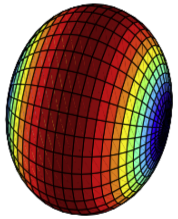
Introduction



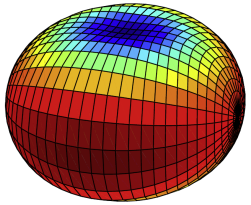
spherical



prolate



oblate

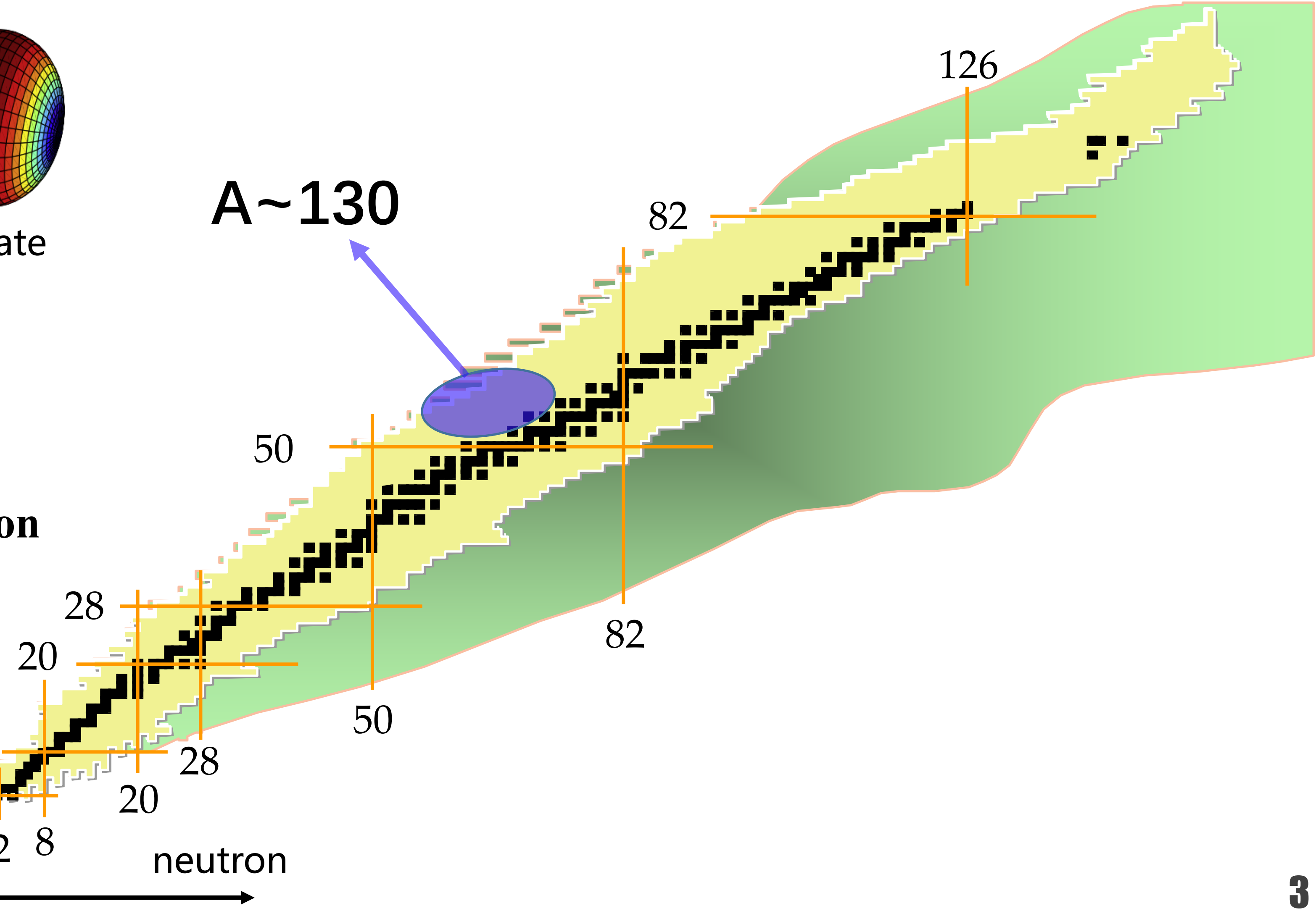


triaxial

Triaxiality is a very rare phenomenon

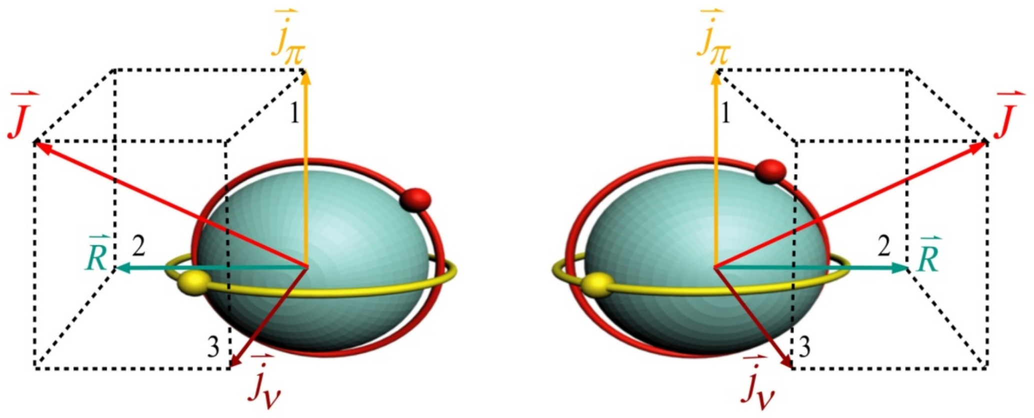
Fingerprint of triaxiality:

- Chirality
- wobbling



Introduction: Chirality

In nuclear physics, chirality was suggested in 1997 by Frauendorf and Meng.
It shows up in a triaxial nucleus which rotates about an axis out of the three principal planes.



Left-handed **Right-handed**

Collective core (**R**); Quasi-proton (**j_π**); Quasi-neutron (**j_ν**).

Odd-odd nucleus

There are three nearly **perpendicular** angular momenta:

j_π mainly along *short* axis,
j_ν mainly along *long* axis,
R mainly along *int.* axis.

The total angular momentum J is aplanar which can present chiral geometry

S.Frauendorf and J.Meng, Nucl. Phys. A617, 131(1997)

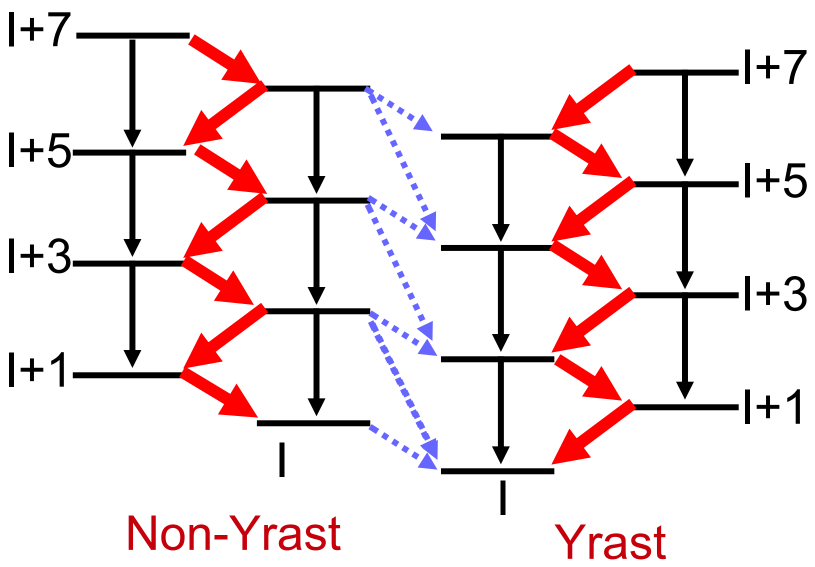
Introduction: Chirality

When chiral symmetry is broken in the body-fixed frame, the restoration of the symmetry in the lab frame is manifest as: two nearly degenerate ΔI =1 bands with the same parity, called chiral doublet bands.

Fingerprints

- ✓ Similar energy spectra and energy staggering;
- ✓ Similar B(M1)/B(E2) ratios;
- ✓ Similar angular momentum geometry.

Chiral doublet bands structure

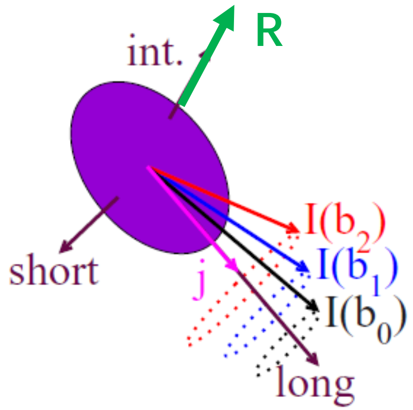


Introduction: Wobbling motion

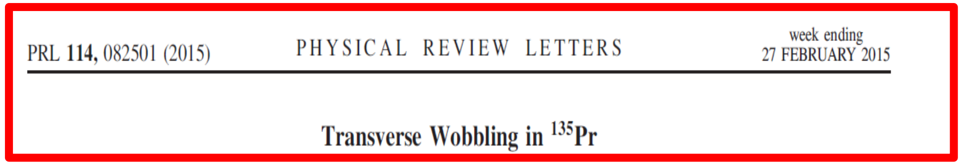
Initially proposed by Bohr and Mottelson for even-even nuclei at high spin.

Around 2001, the predicted wobbling motion was experimentally reported in some of nuclei of the A=160 mass region at high spin.

In 2014, a new type of wobbling motion, called transverse wobbling, was proposed by Frauendorf and Dönau.



In 2015, the first example of transverse wobbling bands was reported in ^{135}Pr.


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

Transverse Wobbling in ^{135}Pr

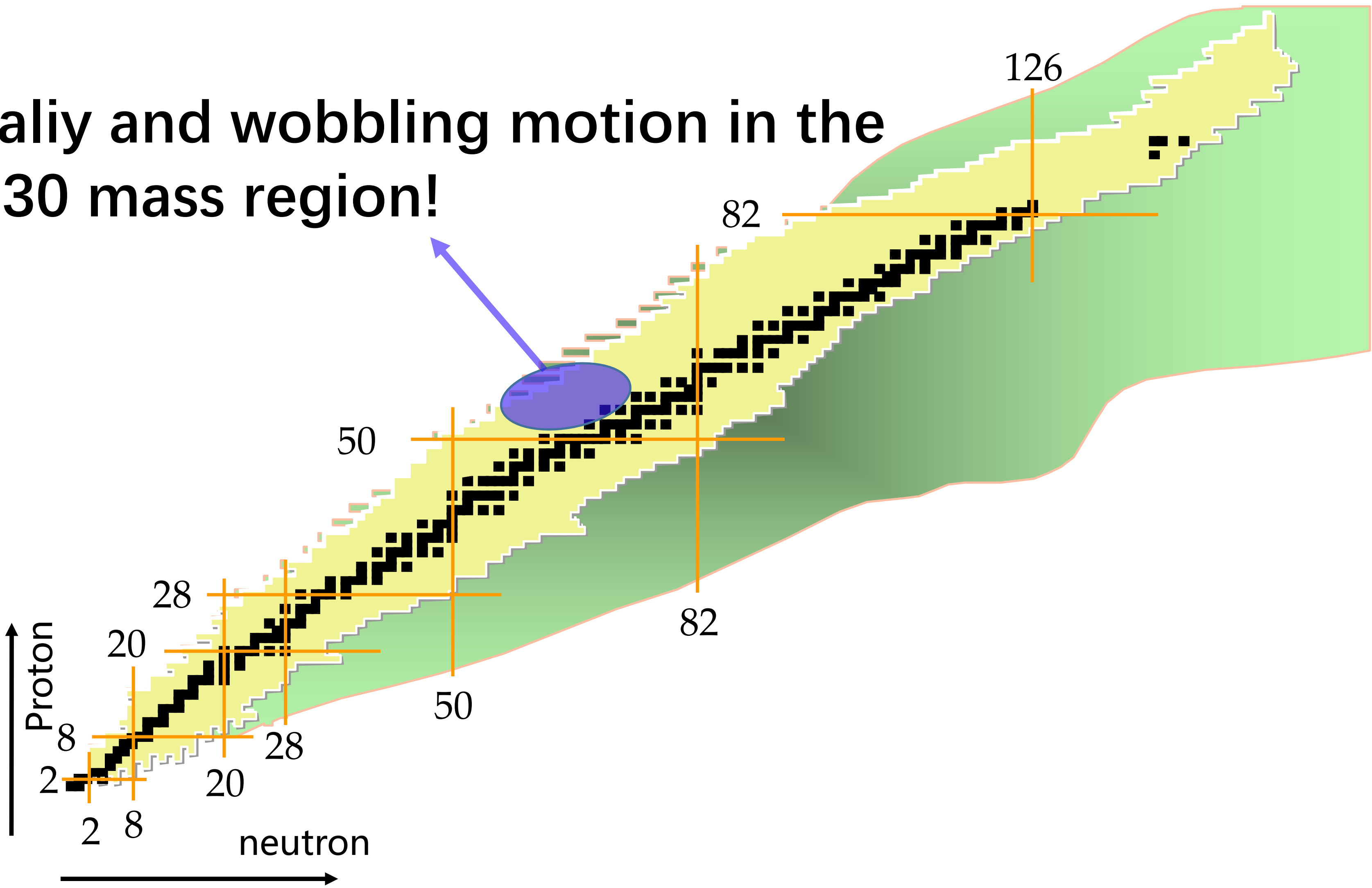
Recently, both transverse and longitudinal wobbling bands were reported at low spin in ^{105}Pd, ^{133}La, ^{127}Xe, ^{187}Au, and ^{183}Au nuclei et al.

Identified via the mixing ratio values of $\Delta I = 1$ transitions which are larger than one. Enchanced E2!

S. Frauendorf, and F. Dönau Phys. Rev. C **89**, 014322 (2014)

Introduction

Chiraliy and wobbling motion in the A~130 mass region!



Experimental details

Experimental details

University of Jyväskylä, Finland.

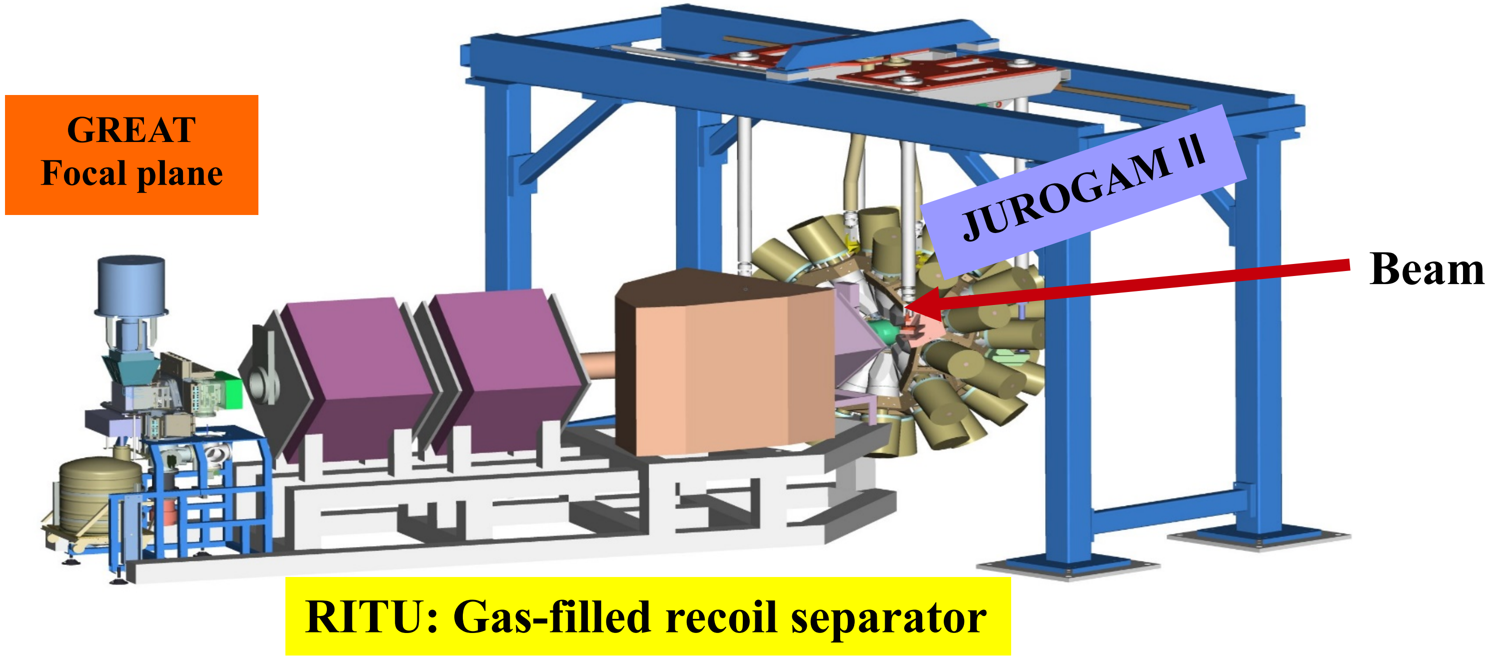
Beam: ^{40}Ar, 152 MeV;

Target: ^{100}Mo, 0.5 mg/cm^2.

Populated nuclei: ^{135,136,137}Nd and ^{135}Pr

Around 5.1 $\times$ 10^{10} (≥3 fold) coincidence events were collected

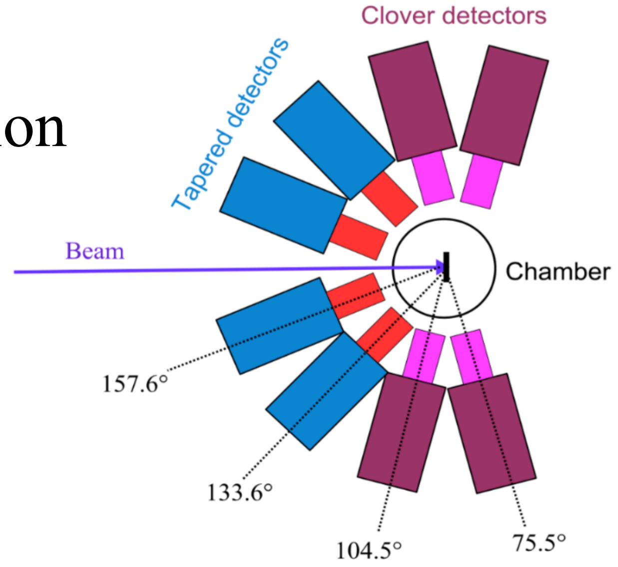
JUROGAM II + RITU + GREAT



Experimental details

JUORGAMMA: 15 tapered HPGe, 24 Clovers, 39 BGO shields, $\varepsilon_{tot} \approx 5$ % at 1.3 MeV.

Angular correlation R_{ac} (anisotropy) and linear polarization



In present work, angular correlation (R_{ac}) is defined as

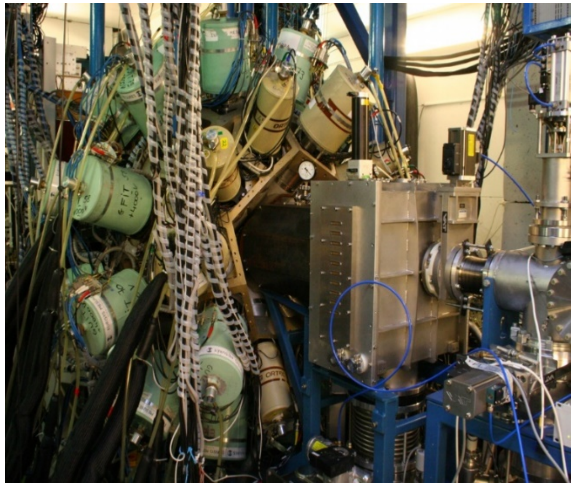
$$R_{ac} = \frac{I_\gamma(157.6^\circ + 133.6^\circ,\ \text{gated on all angles})}{I_\gamma(\approx 90^\circ,\ \text{gated on all angles})}$$

The R_{ac} values for stretched dipole and quadrupole transitions are ≈ 0.8 and ≈1.4, respectively.

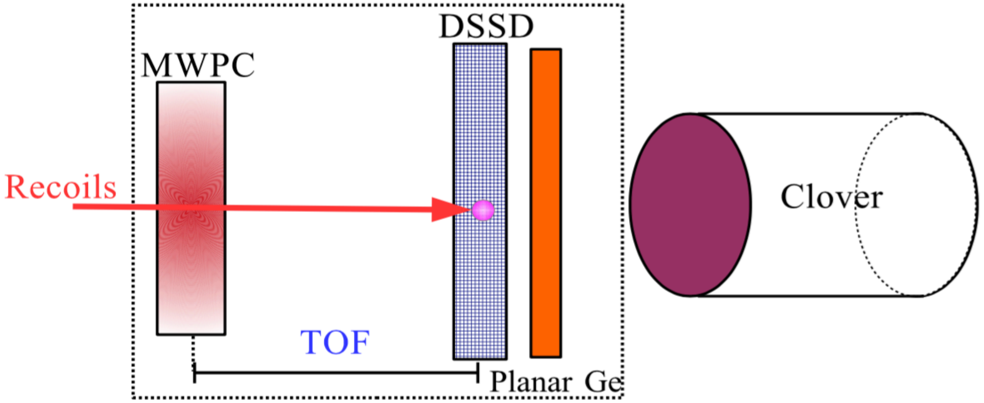
Linear polarization (P)

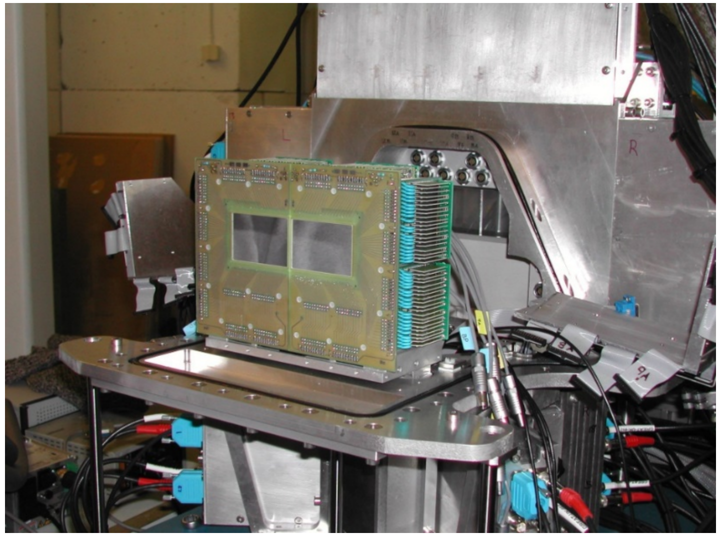
$$P = \frac{1}{Q(E_\gamma)} \frac{a(E_\gamma)N_\perp - N_\parallel}{a(E_\gamma)N_\perp + N_\parallel}$$

Compton scattering between two crystals which are perpendicular (parallel) to the beam direction.



Experimental details





MWPC: measure the position of the recoils, deliver the time reference for the delayed events and for the time of flight (TOF) of recoils.

DSSDs: measure the energies of ions, like emitted α, β, and proton.

3 Clovers, Planar Ge:
γ-rays, X-rays.

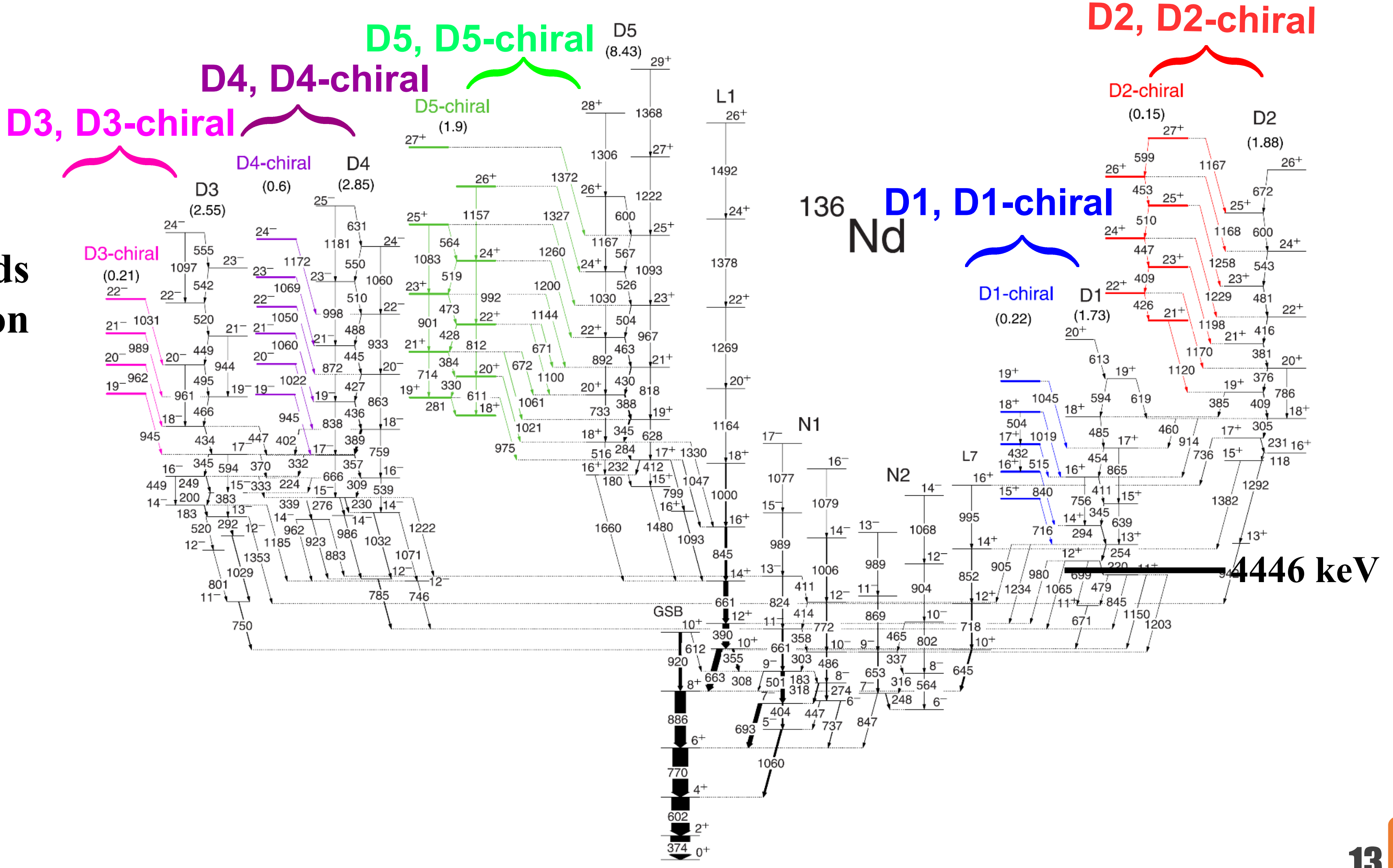
Recoil decay tagging (**RDT**)

Results and discussion

Results and discussion: ^{136}Nd

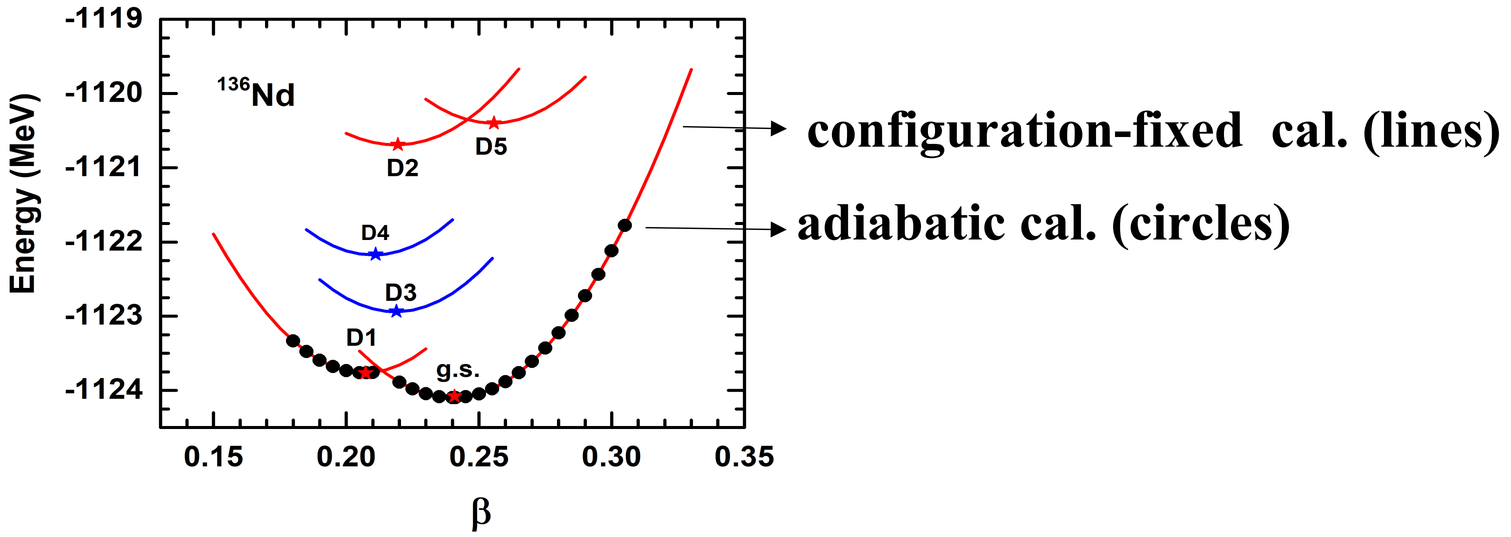
- Five new doublet bands were identified based on different configuration.

- positive parity: D1, D2, D5
- negative parity: D3, D4



Results and discussion: ^{136}Nd

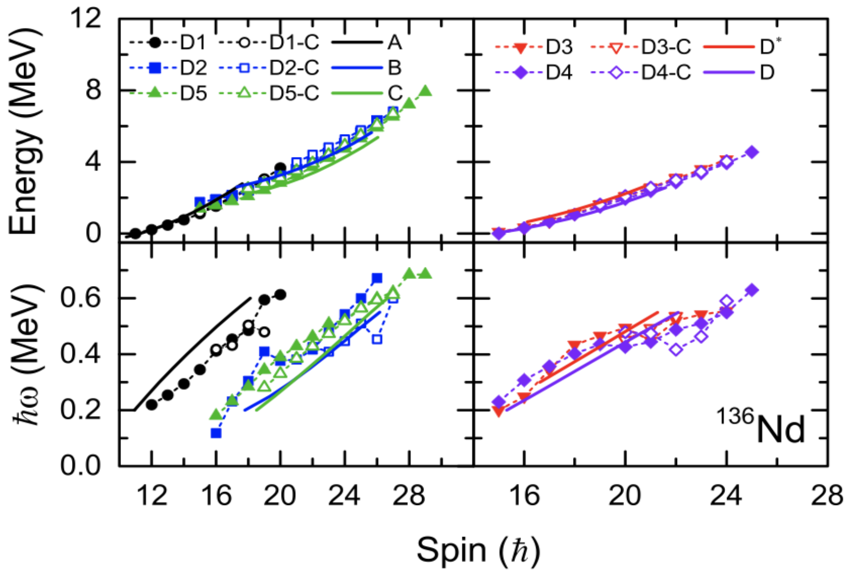
In order to understand the bands properties, Jie Meng group performed covariant density functional theory (CDFT) calculations.

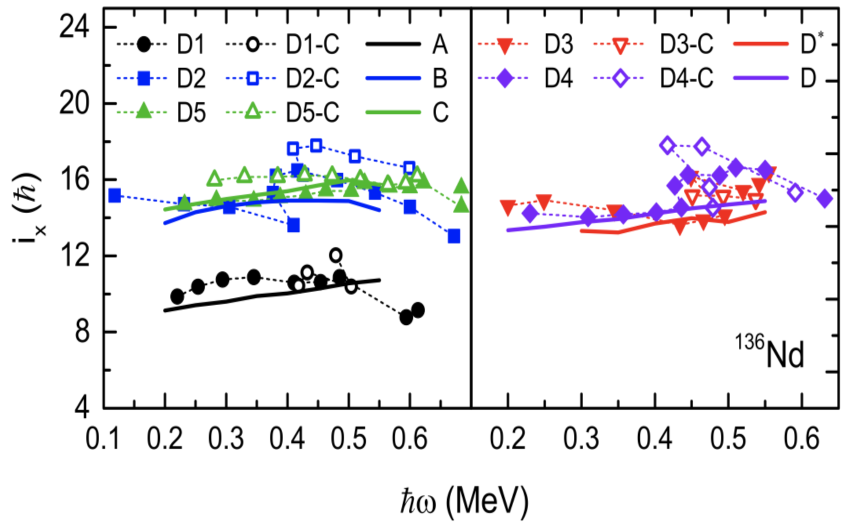


8 candidate configurations

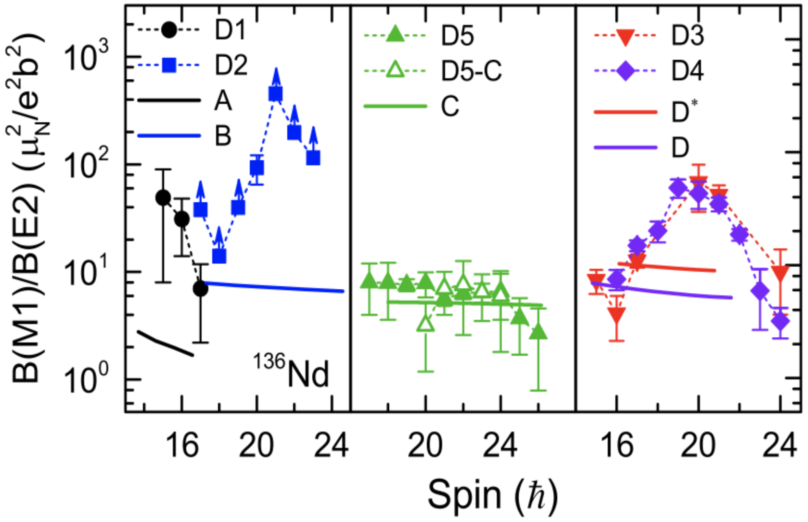
State	E_x	Parity	(β,γ)	Unpaired nucleons
G	0.000	+	(0.24, 27°)	-
A	0.335	+	(0.21, 21°)	$\pi(h_{11/2})^1(d_{5/2}g_{7/2})^{-1} \otimes \nu(h_{11/2})^{-1}(s_{1/2}d_{3/2})^{-1}$
B	3.419	+	(0.22, 19°)	$\pi(h_{11/2})^3(d_{5/2}g_{7/2})^{-1} \otimes \nu(h_{11/2})^{-1}(s_{1/2}d_{3/2})^{-1}$
C	3.704	+	(0.26, 23°)	$\pi(h_{11/2})^2(g_{7/2})^{-2} \otimes \nu(h_{11/2})^{-1}(f_{7/2}h_{9/2})^1$
D	1.173	−	(0.22, 19°)	$\pi(h_{11/2})^2 \otimes \nu(h_{11/2})^{-1}(s_{1/2}d_{3/2})^{-1}(\Omega \sim +\frac{3}{2})$
D*	1.346	−	(0.21, 22°)	$\pi(h_{11/2})^2 \otimes \nu(h_{11/2})^{-1}(s_{1/2}d_{3/2})^{-1}(\Omega \sim -\frac{3}{2})$
E	1.937	−	(0.21, 23°)	$\pi(h_{11/2})^2(d_{5/2}g_{7/2})^{-2} \otimes \nu(h_{11/2})^{-1}(s_{1/2}d_{3/2})^{-1}$
F	2.778	−	(0.20, 35°)	$\pi(h_{11/2})^1(d_{5/2}g_{7/2})^{-1} \otimes \nu(h_{11/2})^{-2}$
H	3.494	−	(0.20, 37°)	$\pi(h_{11/2})^1(d_{5/2}g_{7/2})^{-3} \otimes \nu(h_{11/2})^{-2}$

Results and discussion: ^{136}Nd





- ➢Excitation energies and frequency-versus-spin are nearly identical.
- ➢ The quasi-particle alignments are in good agreement with the results of CDFT calculations.
- ➢ Similar B(M1)/B(E2) ratios, well reproduced by CDFT calculations



C. M. Petrache, B. F. Lv, A. Astier *et al.*, Phys. Rev. C 97, 041304(R) (2018).

Results and discussion: ^{136}Nd

To further understanding the structure of ^{136}Nd

Particle rotor model calculations are used to:

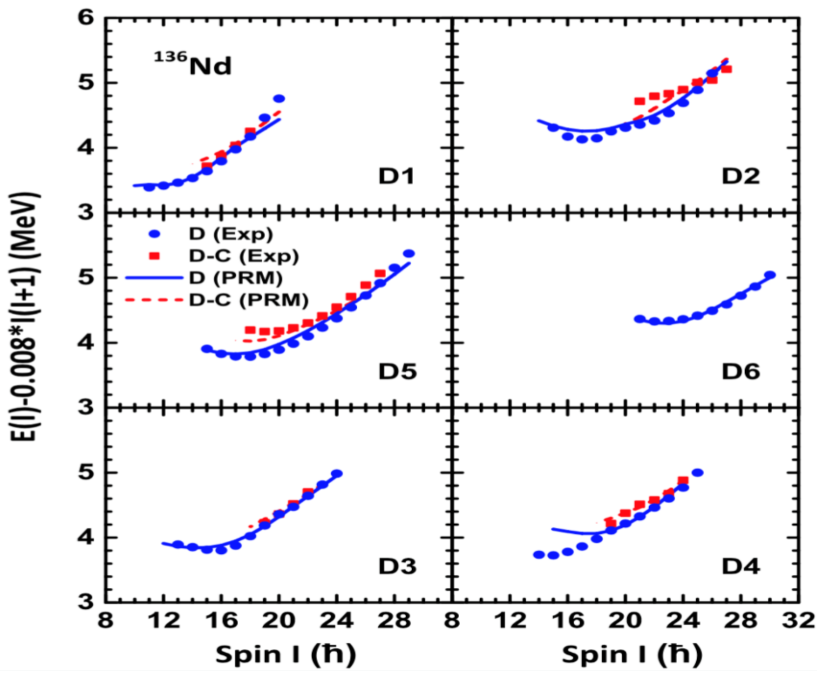
1. investigate in detail the five doublet bands
2. examine the chiral geometry

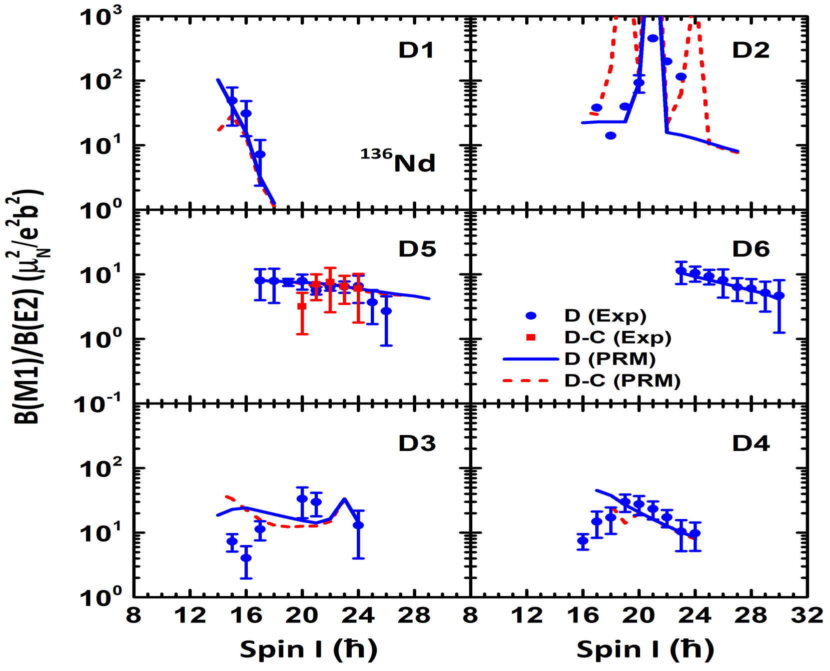
However, as the chiral bands of ^{136}Nd involve four different single-j shells, a multi-j PRM model was developed by Qibo Chen and applied to ^{136}Nd.

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

Results and discussion: ^{136}Nd

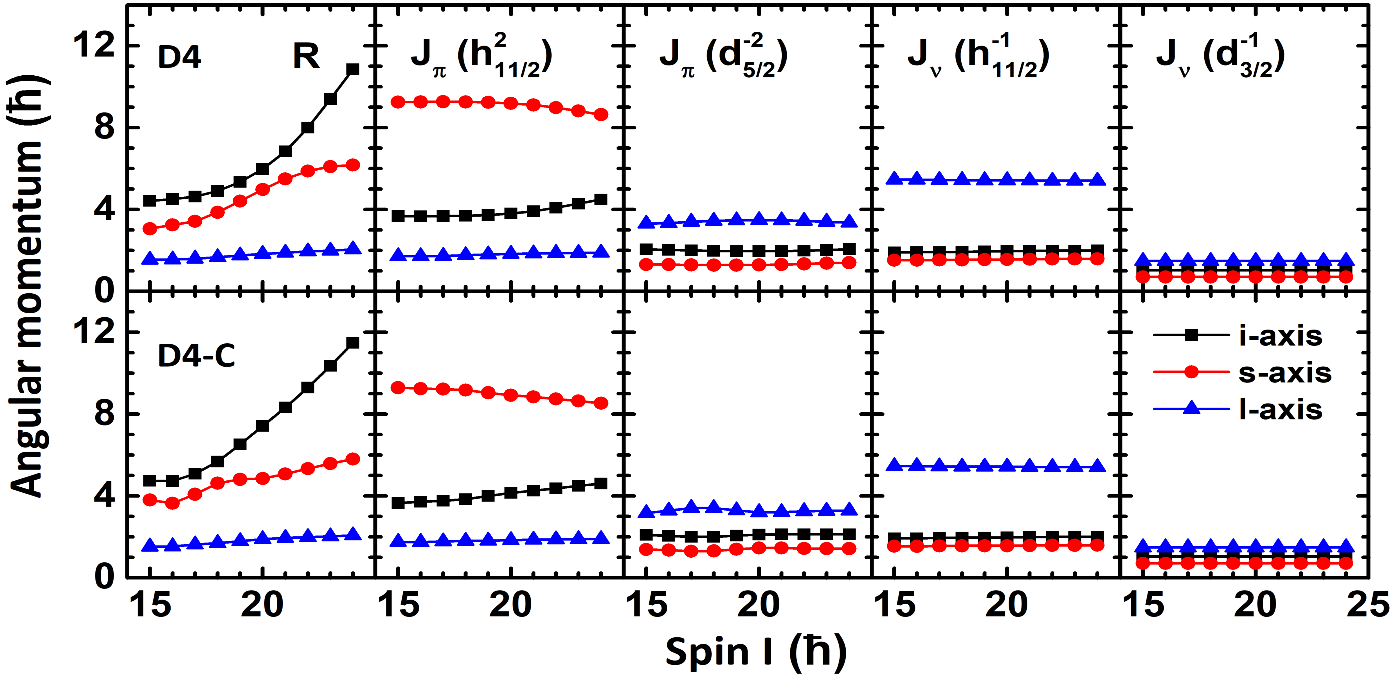
Band	Parity	Unpaired nucleons	(β, γ)
D1	+	$\pi(1h_{11/2})^1(2d_{5/2})^{-1} \otimes \nu(1h_{11/2})^{-1}(2d_{3/2})^{-1}$	(0.21, 21°)
D2	+	$\pi(1h_{11/2})^3(2d_{5/2})^{-1} \otimes \nu(1h_{11/2})^{-1}(2d_{3/2})^{-1}$	(0.22, 19°)
D5	+	$\pi(1h_{11/2})^2(1g_{7/2})^{-2} \otimes \nu(1h_{11/2})^{-1}(1f_{7/2})^1$	(0.26, 23°)
D3	–	$\pi(1h_{11/2})^2 \otimes \nu(h_{11/2})^{-1}(2d_{3/2})^{-1}$	(0.22, 19°)
D4	–	$\pi(1h_{11/2})^2(2d_{5/2})^{-2} \otimes \nu(h_{11/2})^{-1}(2d_{3/2})^{-1}$	(0.22, 19°)





Results and discussion: ^{136}Nd

In order to examine the 3D chiral geometry, we calculated angular momentum components along the three axes for each qp:



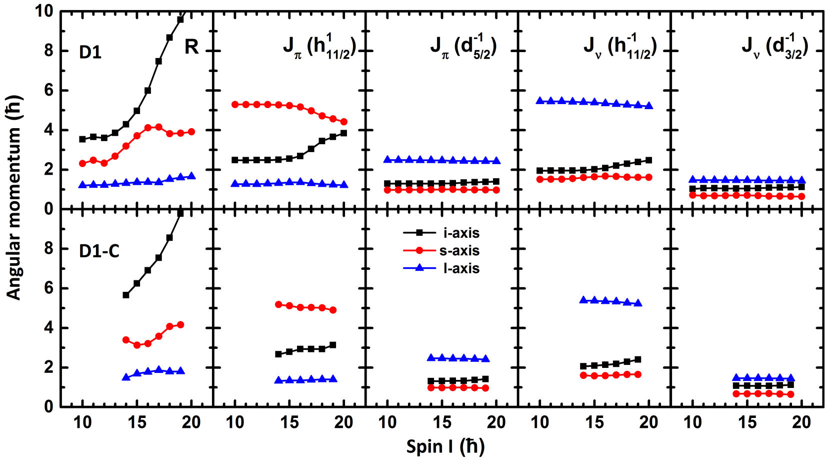
Rotor: **intermediate-axis**;

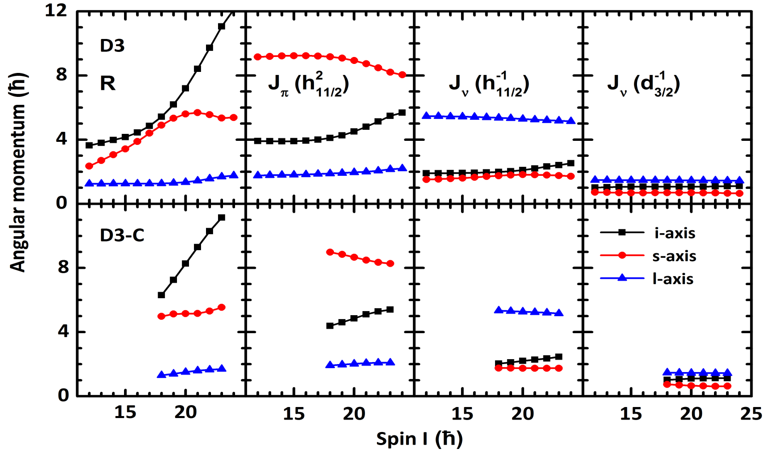
Proton $h_{11/2}$ particles: **short-axis**;

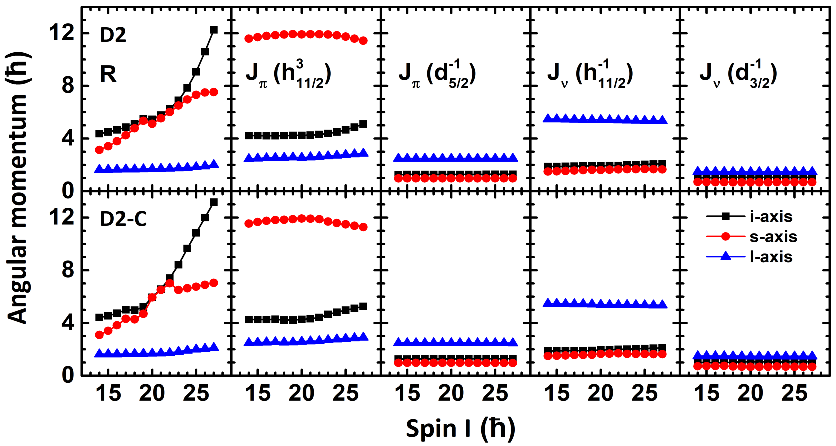
Proton $d_{5/2}$ hole, neutron $h_{11/2}$ and $d_{3/2}$ holes: **long-axis**.

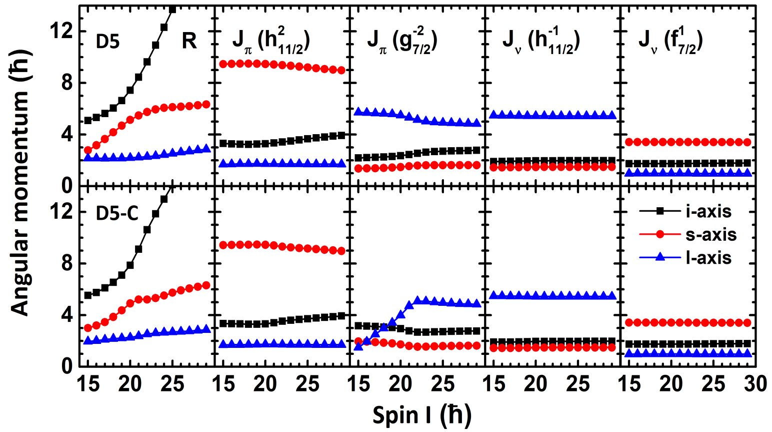
Results and discussion: ^{136}Nd

Angular momentum components along the three axes:D1, D2, D3, D5









Chiral geometry is confirmed for ALL doublet bands

Results and discussion: ^{136}Nd

PHYSICAL REVIEW C **99**, 054303 (2019)

Multichiral facets in symmetry restored states: Five chiral doublet candidates in the even-even nucleus ^{136}Nd

Y. K. Wang (王亚坤),[1] F. Q. Chen (陈芳祁),[2] P. W. Zhao (赵鹏巍),[1] S. Q. Zhang (张双全),[1] and J. Meng (孟杰)[1,3,4,*]

[1] *State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China*

[2] *School of Natural and Applied Sciences, Northwestern Polytechnical University, Xian 710129, China*

[3] *School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China*

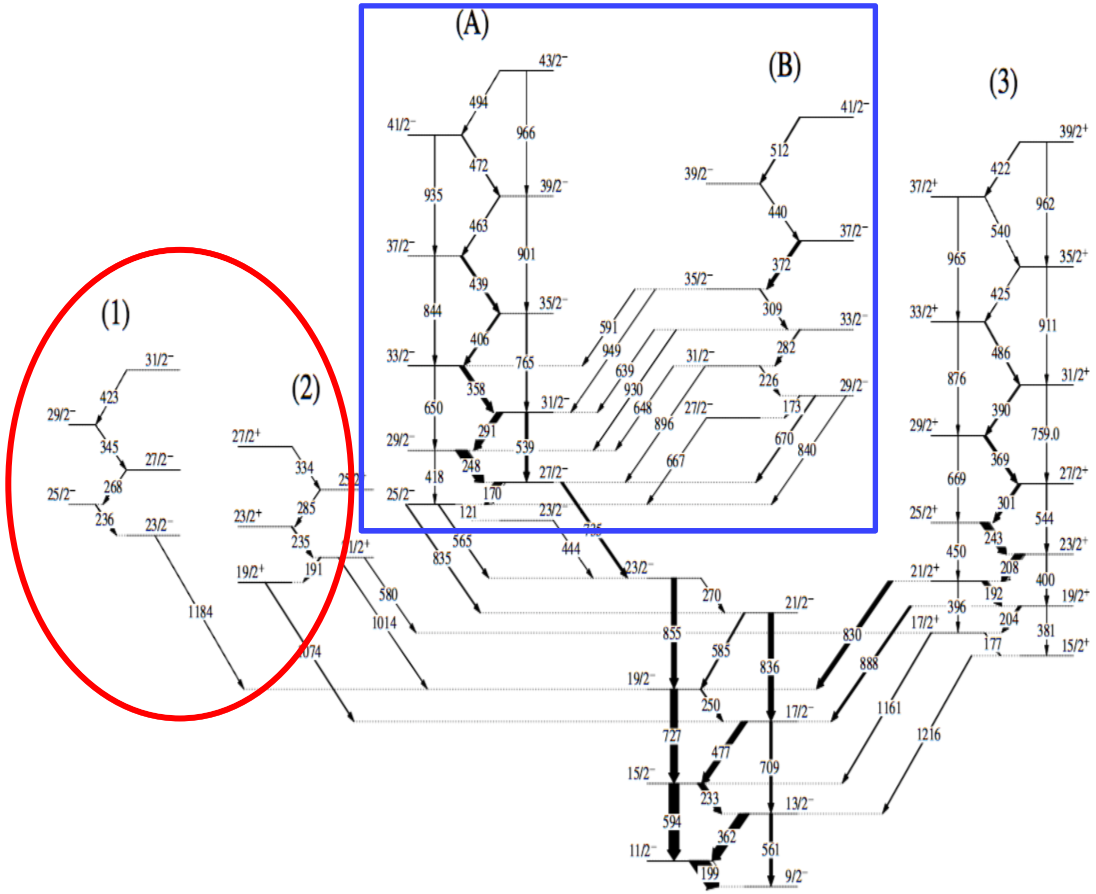
[4] *Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan*

A triaxial projected shell model（ TPSM) including configurations with more than four quasiparticles in the configuration space is developed.

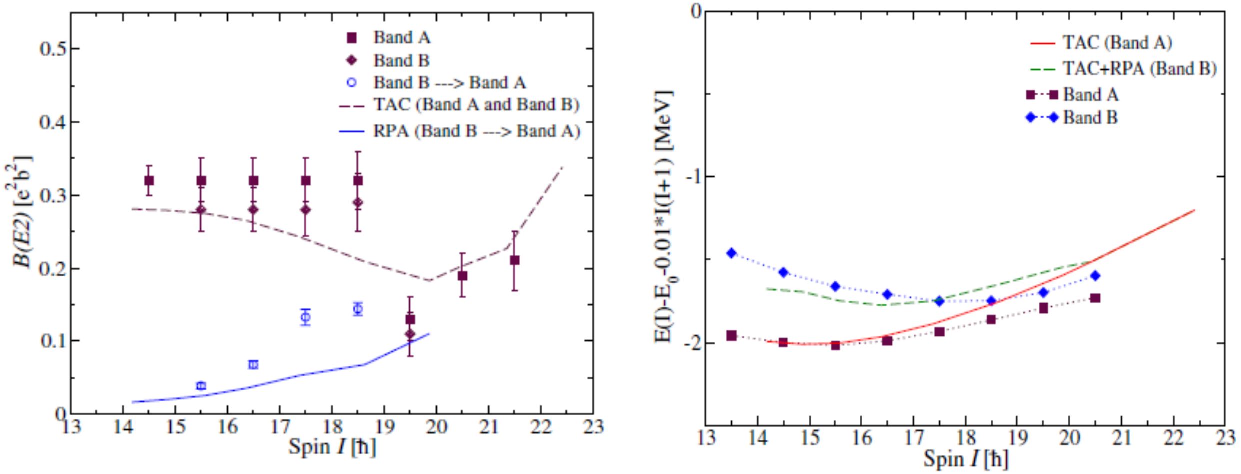
Chiral bands are confirmed for bands D1, D2, D4, D5, but not hard for D3.

Results and discussion: ^{135}Nd

$\pi h_{11/2}^{2} \otimes \nu h_{11/2}^{-1}$ Chiral bands



Transitions probabilities



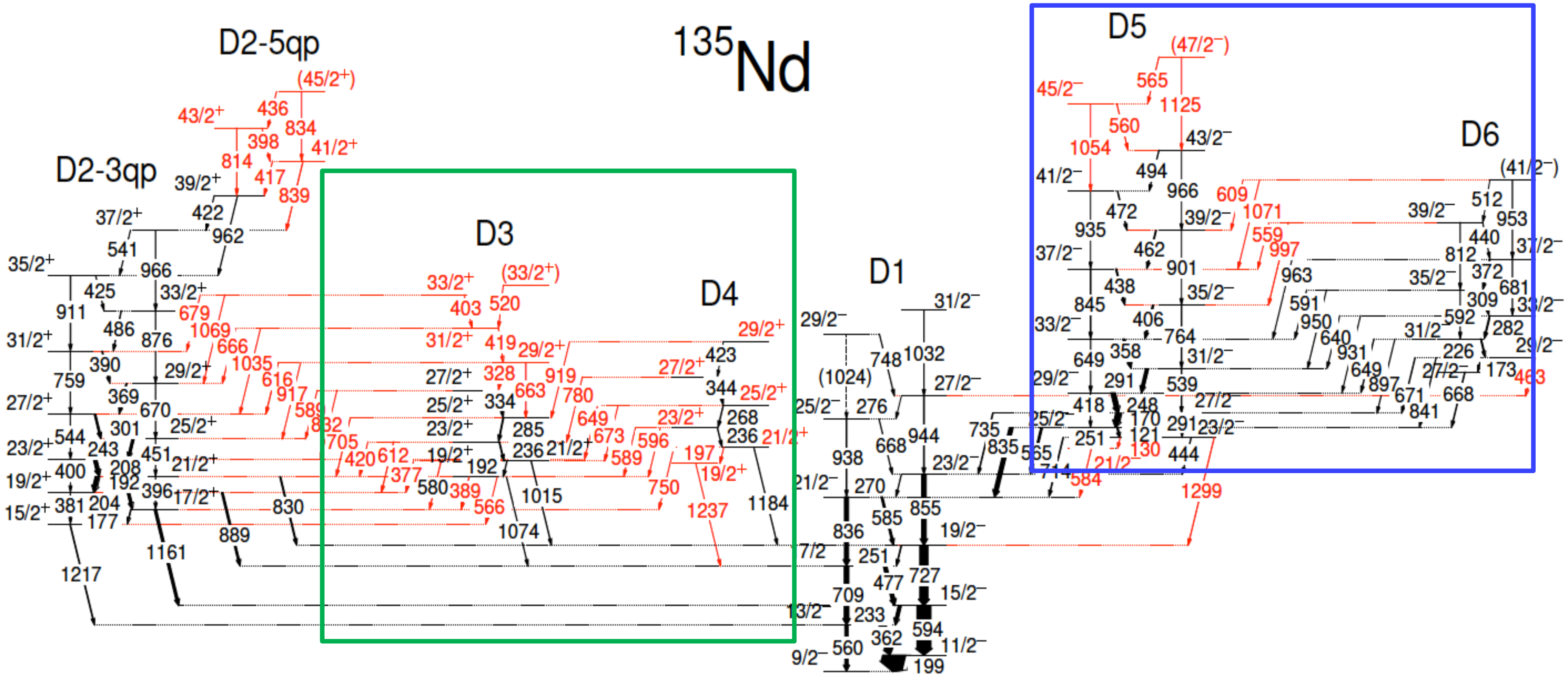
Lifetime measurement: the chiral bands are confirmed.

S.Zhu, Ph.D thesis, 2004. S. Zhu et al, PRL 91(2003)

Mukhopadyay et al, PRL 99 (2007)

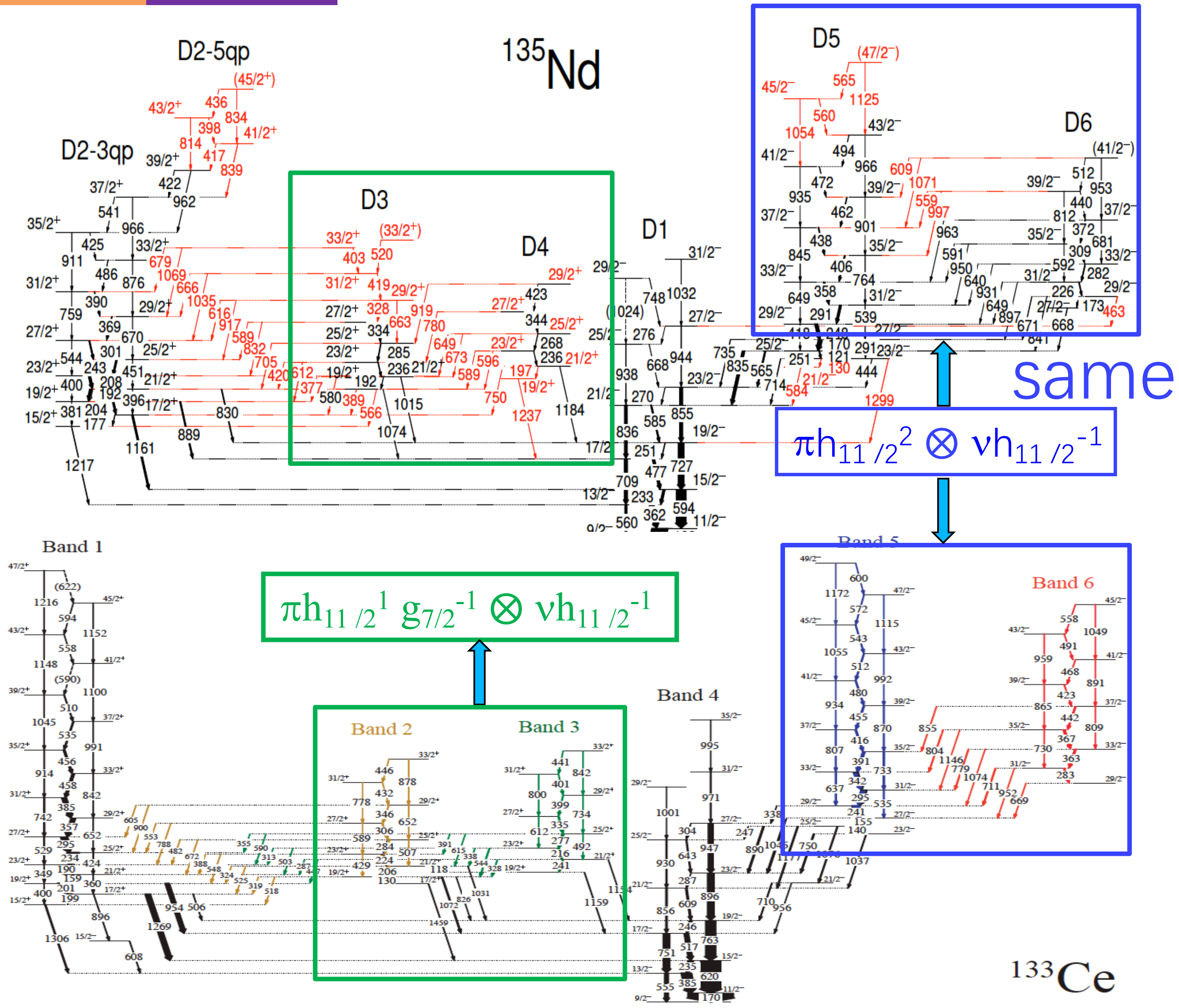
Results and discussion: ^{135}Nd

D5 and D6 were already known as chiral bands.



How about D3 and D4 bands ?

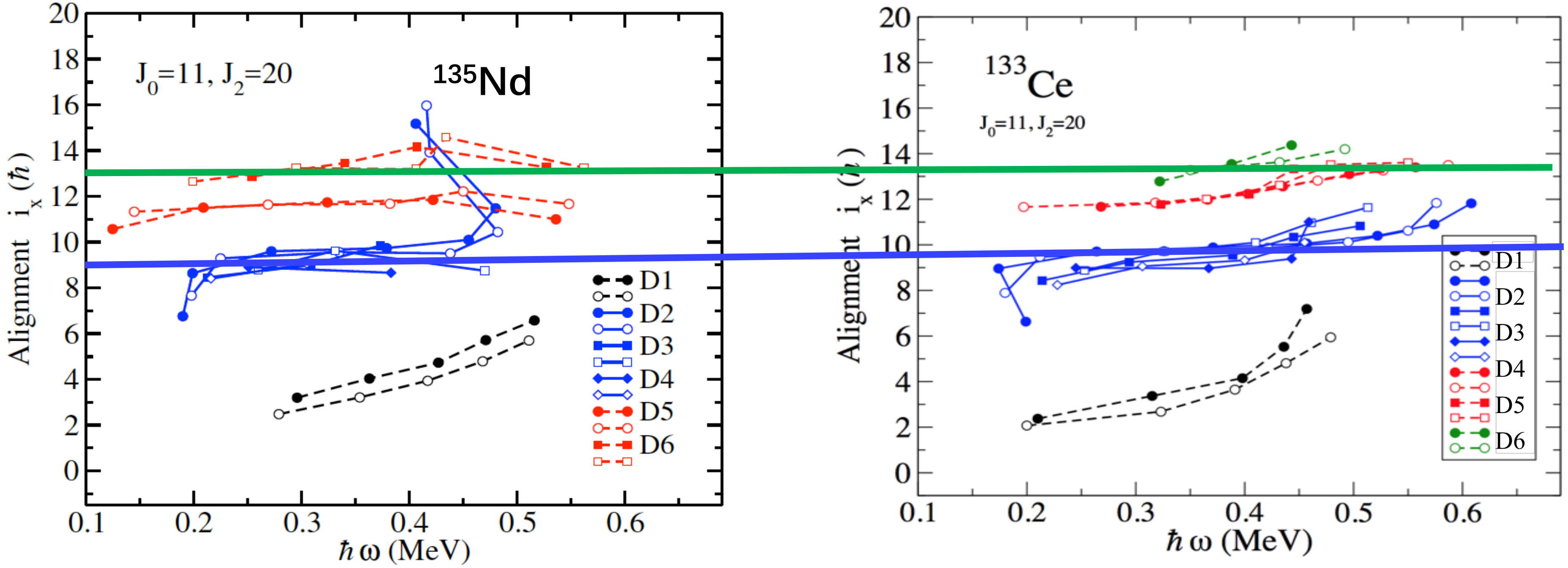
Results and discussion: ^{135}Nd



Comparison of ^{135}Nd with ^{133}Ce (N=75)

- **D5 and D6 have the same configuration in these two nuclei .**
- **D3 and D4?**

Results and discussion: ^{135}Nd



indicate

$\pi h_{11/2}^{1} (dg)^{-1} \otimes \nu h_{11/2}^{-1}$

$\pi h_{11/2}^{2} \otimes \nu h_{11/2}^{-1}$

Results and discussion: ^{135}Nd

PRM calculations results for ^{135}Nd（Q.B.Chen calculations）

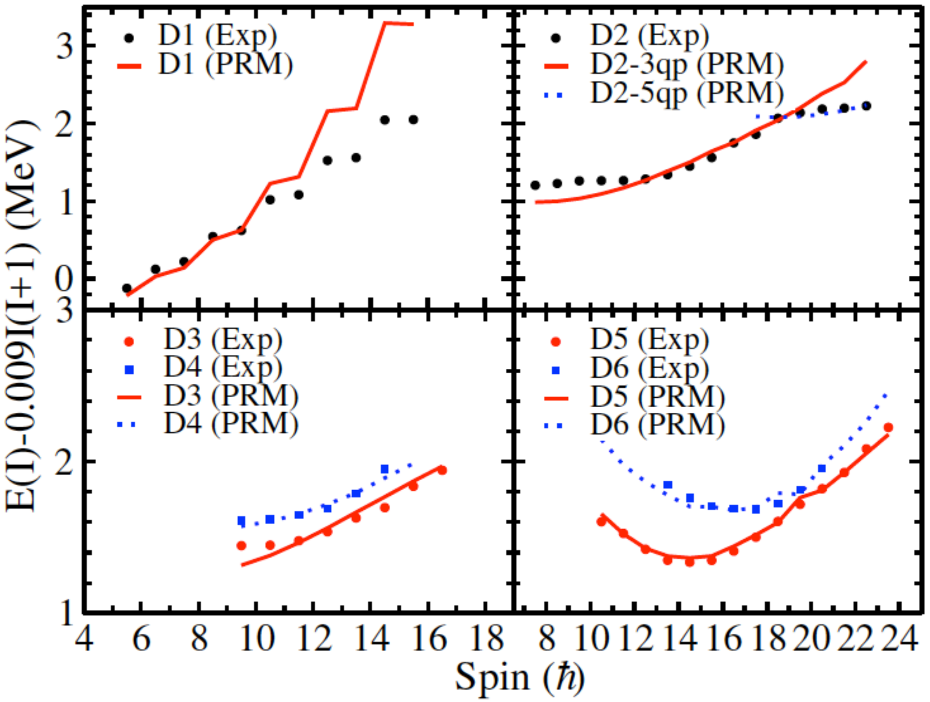
D1 : $\nu h_{11/2}^{-1}$

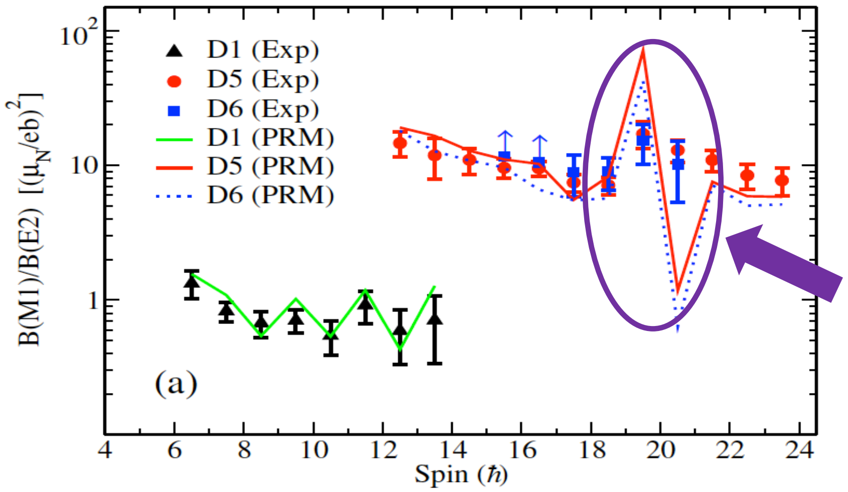
D2-3qp : $\pi h_{11/2}^{1} (d_{5/2})^{-1} \otimes \nu h_{11/2}^{-1}$

D2-5qp: $\pi h_{11/2}^{3} (d_{5/2})^{-1} \otimes \nu h_{11/2}^{-1}$

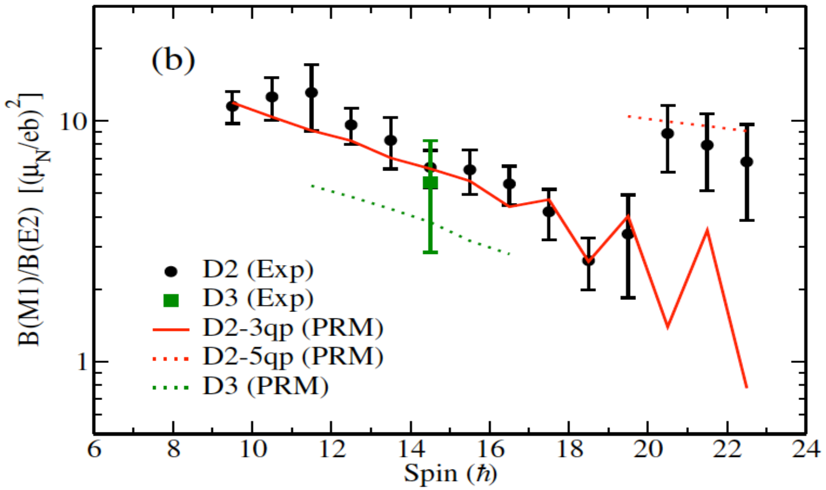
D3-D4 : $\pi h_{11/2}^{1} (g_{7/2})^{-1} \otimes \nu h_{11/2}^{-1}$

D5-D6: $\pi h_{11/2}^{2} \otimes \nu h_{11/2}^{-1}$





It could be a change from chiral vibration to static chirality or band crossing.



Similar B(M1)/B(E2);

B(M1)/B(E2) are well reproduced by model calc.

B. F. Lv, C. M. Petrache, Q. B. Chen *et al.*, Phys. Rev. C 100, 024314 (2019).

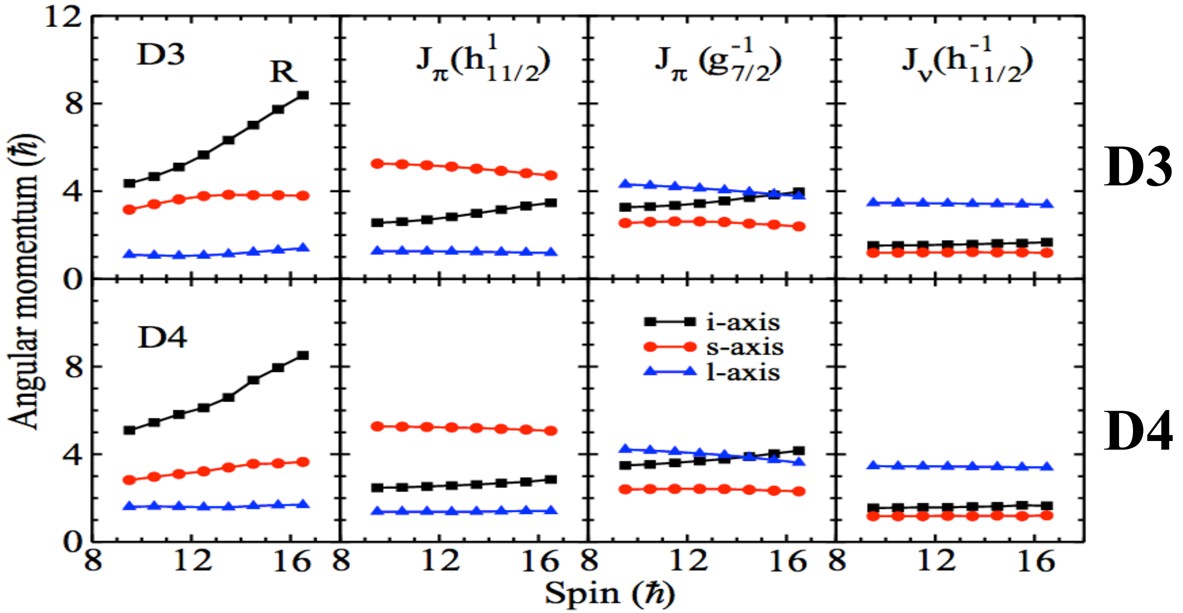
Results and discussion: ^{135}Nd

Angular momentum components along the three axes:

Rotor: **intermediate-axis**;

Proton $h_{11/2}$ particle: **short-axis**;

Neutron $h_{11/2}$ and proton $g_{7/2}$ holes : **long-axis**.



D3 and D4 are new chiral doublet bands.

Results and discussion: ^{135}Nd

Time-dependent and tilted axis cranking covariant density functional theory (TAC-CDFT) calculations results for ^{135}Nd

PHYSICAL REVIEW C **105**, L011301 (2022)

Letter

Dynamics of rotation in chiral nuclei

Z. X. Ren (任政学), P. W. Zhao (赵鹏巍),* and J. Meng (孟杰)†
State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China

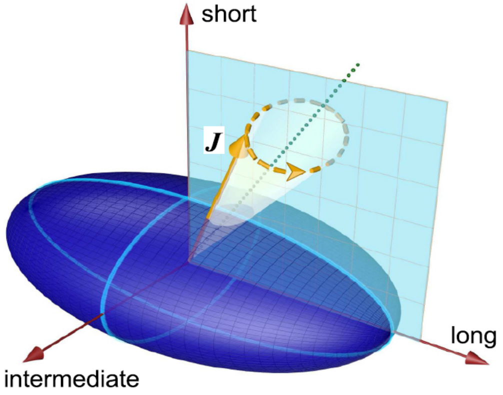
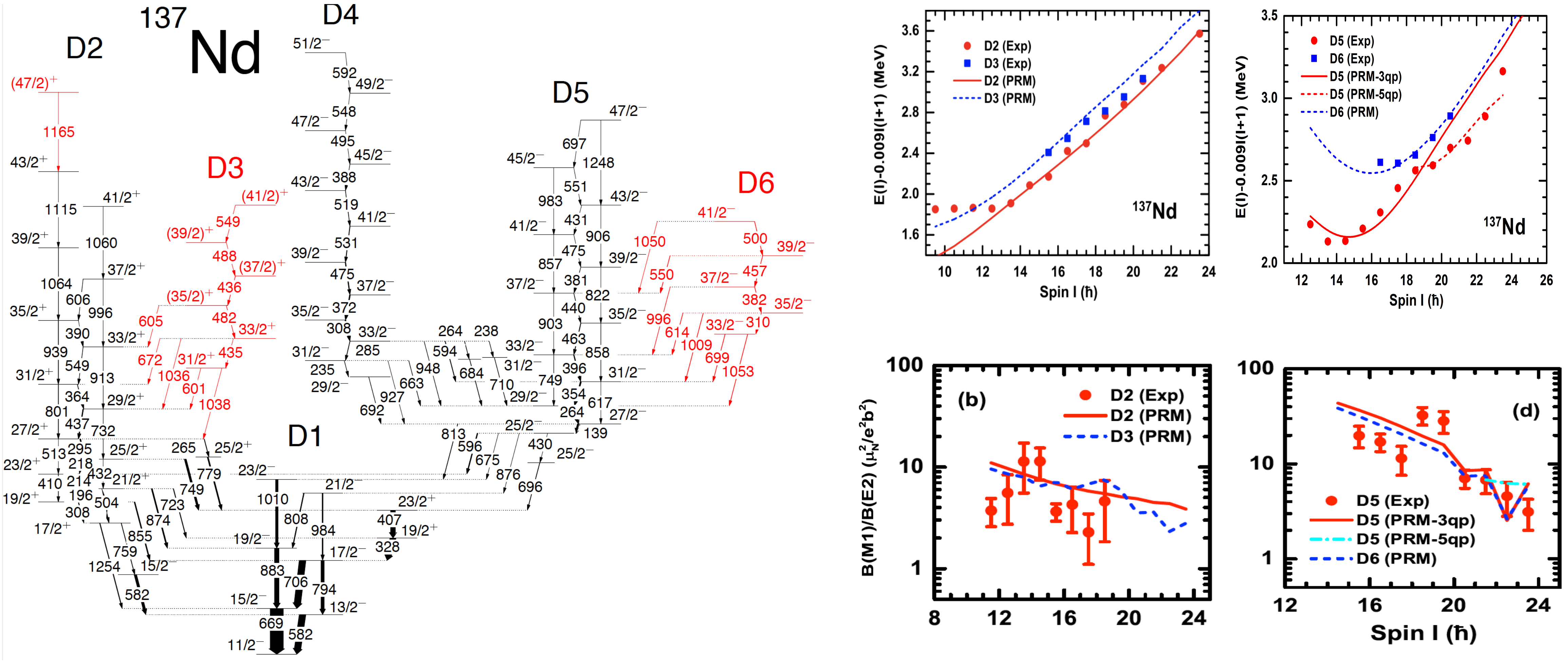


FIG. 1. A schematic picture for the "chiral precession" of a triaxial nucleus in the body-fixed frame, where the short, intermediate, and long axes are shown explicitly. The total angular momentum ***J*** of the nucleus is rotating about an axis (dotted line) in the body-fixed frame.

A novel mechanism, i.e., **chiral precession**, is revealed from the microscopic dynamics of the total angular momentum in the body-fixed frame, whose harmonicity is associated with a transition from the planar into aplanar rotations with the increasing spin

Results and discussion: ^{137}Nd

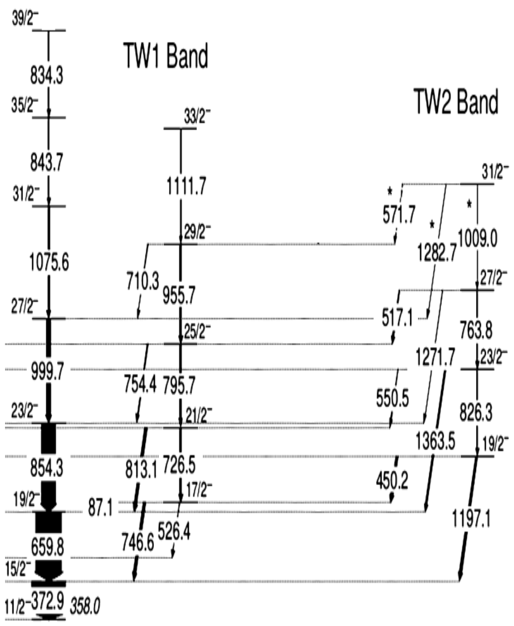


C. M. Petrache, B. F. Lv, Q. B. Chen et al., Eur. Phys. J. A 56 :208 (2020)

Wobbling motion in ^{135}Pr and ^{136}Nd

Results and discussion: ^{135}Pr

Previously reported negative-parity low-lying states in ^{135}Pr were re-interpreted as the first cases of one-phonon and two-phonon transverse wobbling bands.

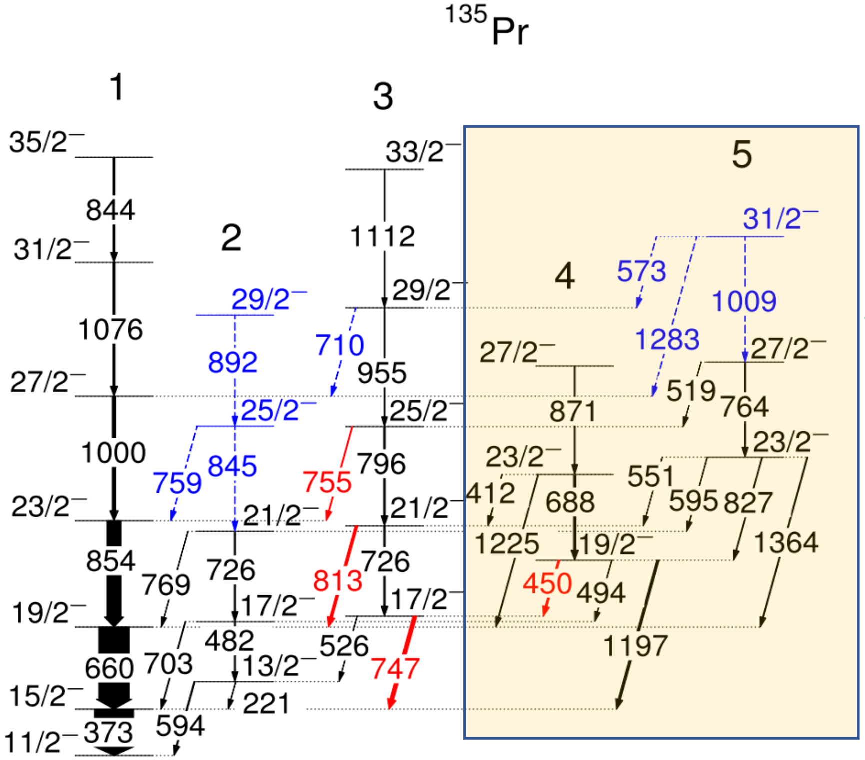


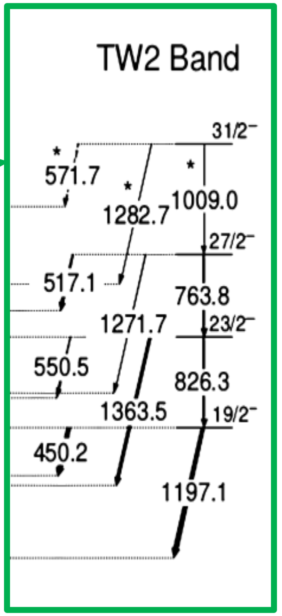
Gamma energy	linear Polarization (asymmetry)	Linear polarization (asymmetry)	Linear polarization (asymmetry)	mixing ratio	method
747	**0.047**	**-0.05(3)**	**0.03(3)**	-1.24(13)	angular distribution
813	**0.054**	**-0.20(8)**	**0.04(3)**	-1.54(9)	angular distribution
450	**no**	**no**	**no**	-1.91(5)	angular distribution
Refs	J. T. Matta et al., Phys. Rev. Lett. 114, 082501 (2015).	R. Garg et al., Phys. Rev. C 92, 054325 (2015).	Erratum: [Phys. Rev. C **92**, 054325 (2015)] **2019**	J. T. Matta et al., phys. Rev. Lett. 114, 82501 (2015).	

Same reaction and same setup

T. M. Semkow, D. G. Sarantites, K. Honkanen, Phys. Rev. C **34**, 523(1986)
J. T. Matta, U. Garg, W. Li, et al., Phys. Rev. Lett. 114, 082501 (2015).
R. Garg, S. Kumar, M. Saxena et al., Phys. Rev. C 92, 054325 (2015).
N. Sensharma, U. Garg, S. Zhu et al., Phys. Lett. B 792, 170 (2019).
S. Guo, C. M. Petrache https://doi.org/10.48550/arXiv.2007.10031, S. Guo https://doi.org/10.48550/arXiv.2011.14364

Results and discussion: ^{135}Pr





We can uniquely determine mixing ratio of ΔI = 1 transitions using combined linear polarization and angular correlation (P-R_{ac}) method.

J. T. Matta, U. Garg, W. Li, et al., Phys. Rev. Lett. 114, 082501 (2015).
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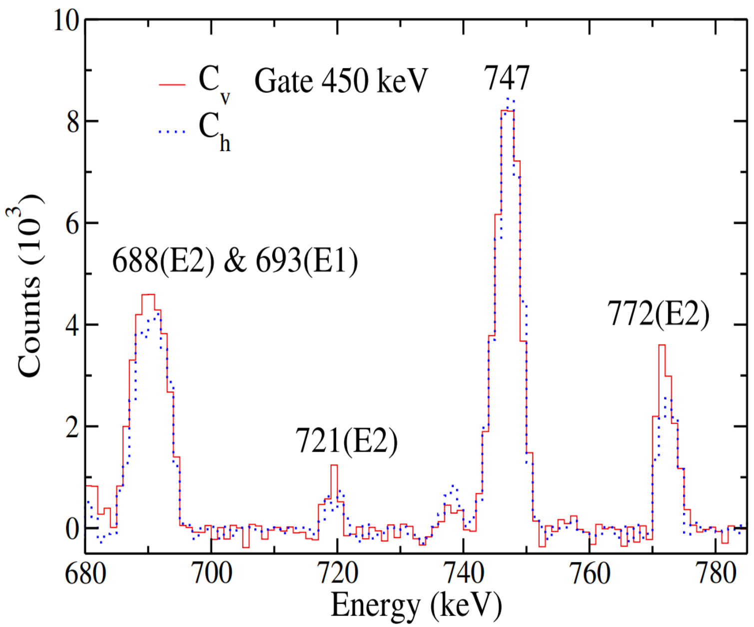
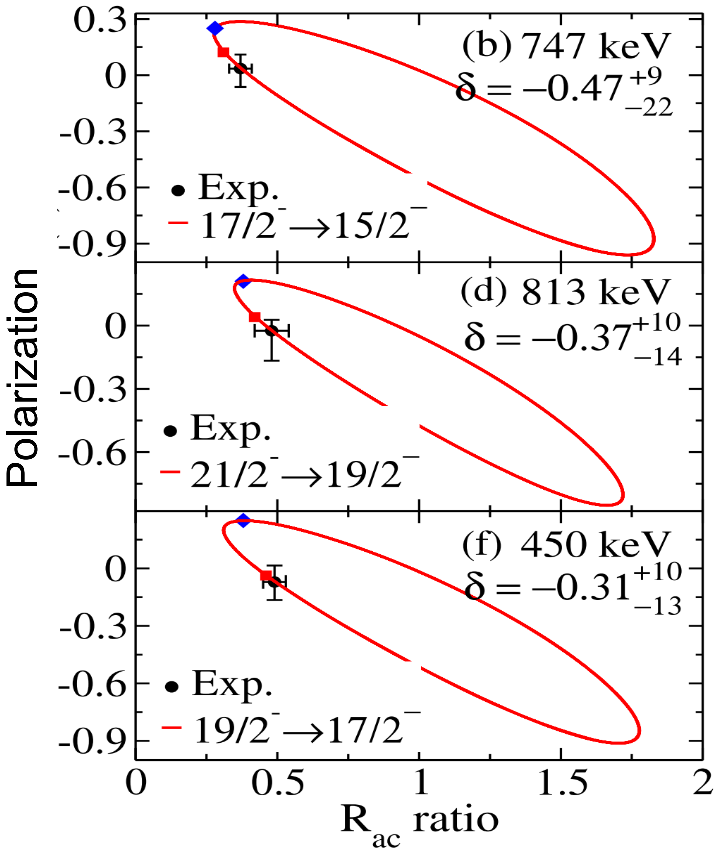
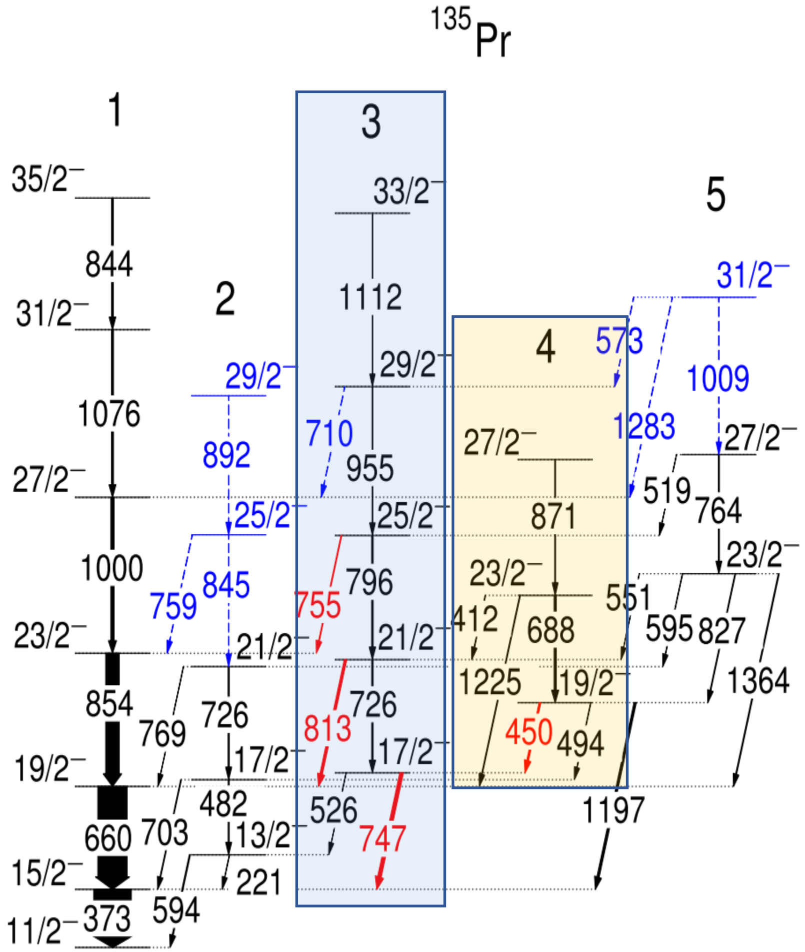
Results and discussion: ^{135}Pr







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!

Results and discussion:Quasiparticle plus-triaxial-rotor for ^{135}Pr

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

- **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!**

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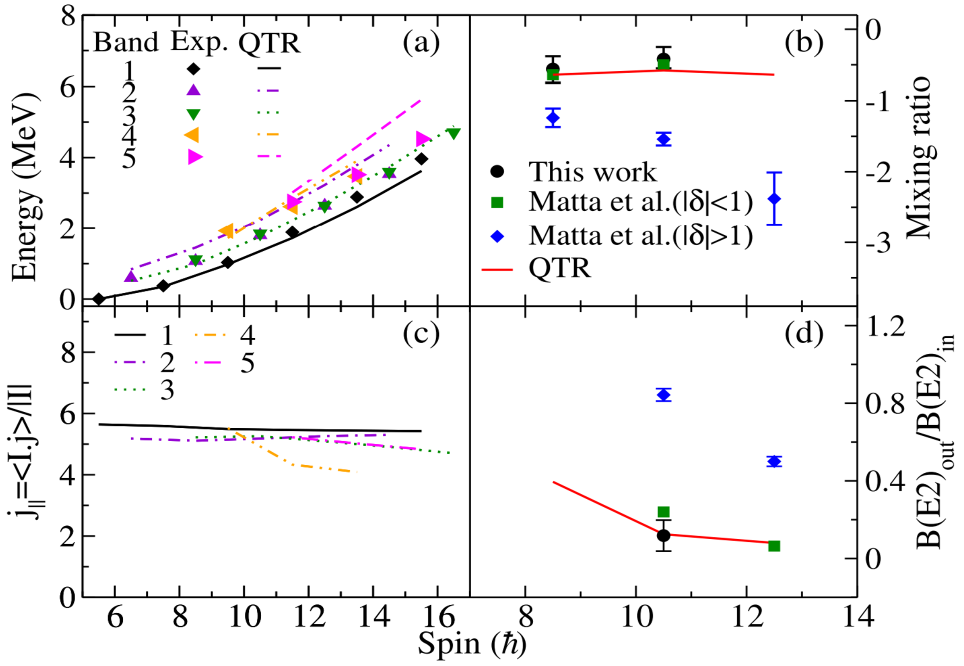
Evidence against the wobbling nature of low-spin bands in ^{135}Pr

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]



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Sensharma, U. Garg, S. Zhu et al., Phys. Lett. B 792, 170 (2019).

Results and discussion: Wobbling bands at high spin in ^{136}Nd

How about the transverse wobbling motion **at high spin**?

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

Rapid Communications

Transverse wobbling in an even-even nucleus

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

^{130}Ba
PRM

Physics Letters B 802 (2020) 135246
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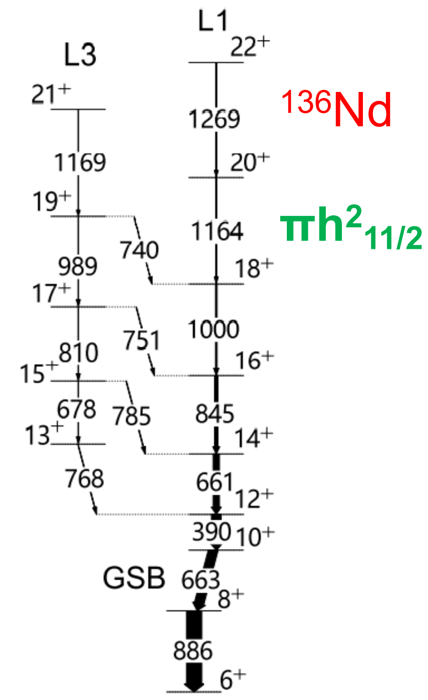
Two quasiparticle wobbling in the even-even nucleus ^{130}Ba

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

TPSM

Two high-spin bands in ^{136}Nd were predicted by the triaxial projected shell model as good candidates of transverse wobbling bands.



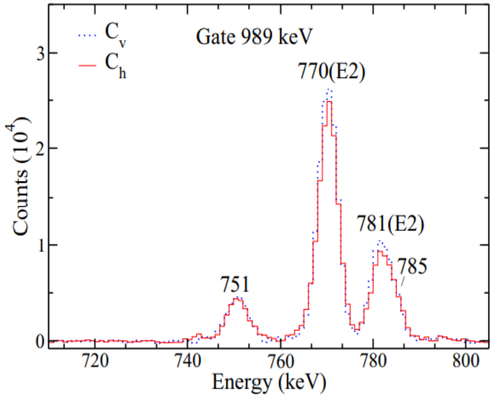
PHYSICAL REVIEW C **103**, 064319 (2021)

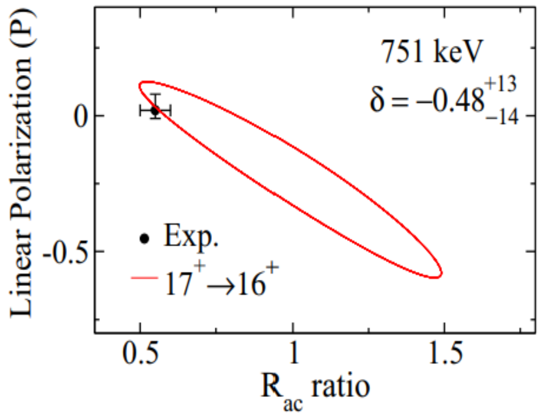
Microscopic investigation on the existence of transverse wobbling under the effect of rotational alignment: The ^{136}Nd case

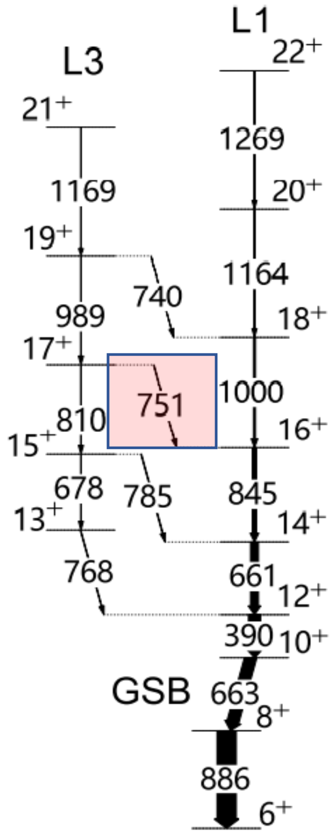
Fang-Qi Chen[1] and C. M. Petrache[2]

Results and discussion: Wobbling bands at high spin in ^{136}Nd

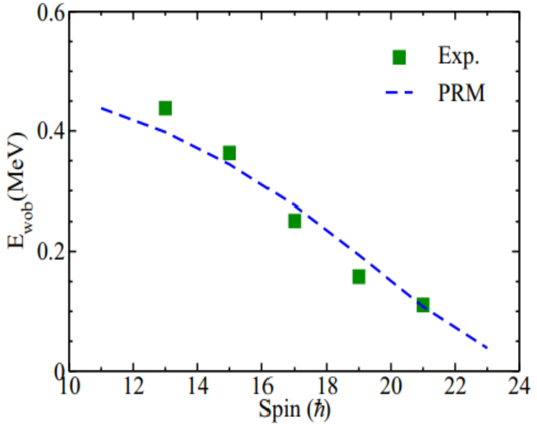
Experimental results

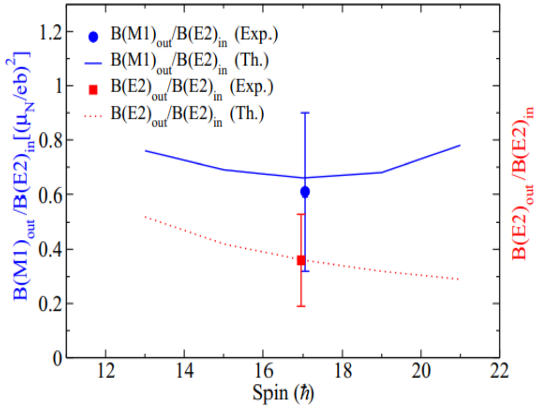






Experimental results Vs. PRM calculations (**R. Budaca**)





PHYSICAL REVIEW C **105**, 034302 (2022)

Experimental evidence for transverse wobbling bands in ^{136}Nd

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

Summary

- ✓ Five pairs of chiral bands were identified in ^{136}Nd. Calculations based on TAC-CDFT and PRM are in very good agreement with the experimental results. This is the first time observed MχD bands in the even-even nuclei.

- ✓ Observed MχD bands in ^{135,137}Nd, calculations based on PRM are in very good agreement with the experimental data.

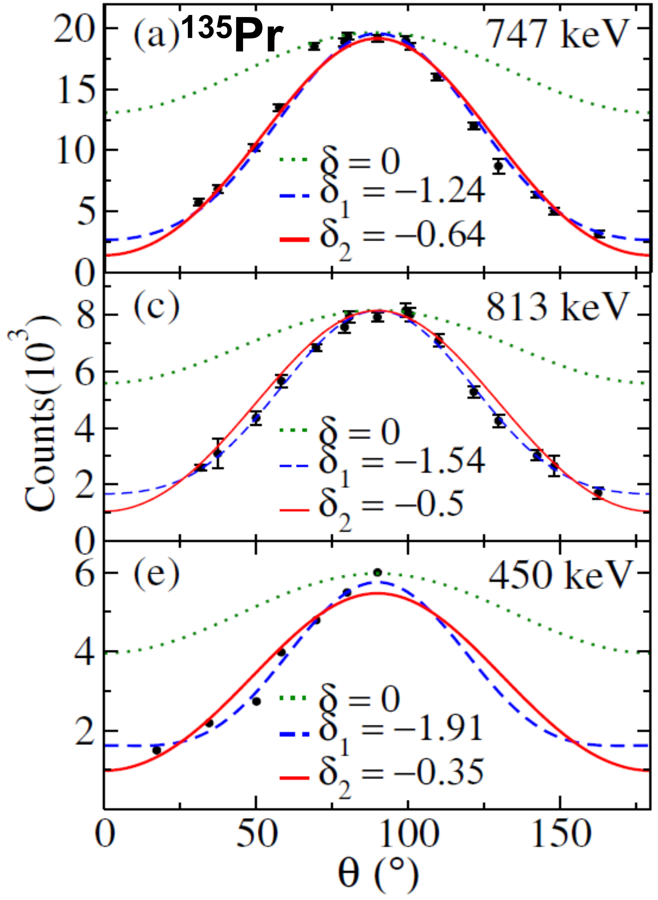
- ✓ Previously proposed one- and two-phonon wobbling bands in ^{135}Pr were studied. Our experimental results do not support the interpretation, and new calculations results based on QTR are in very good agreement with the experimental data, showing the bands are tilted precession bands based on the $\pi h_{11/2}$ configuration.

- ✓ We observed the transverse wobbling bands in ^{136}Nd.

Thanks for your attention!

Introduction: Motivation of the study of ^{135}Pr

One can not simply exclude solutions of mixing ratios higher and lower than one from only angular distribution measurement.



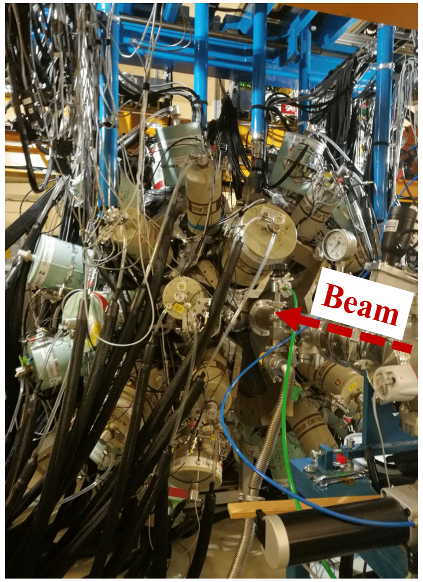
$$\chi^2 = \frac{\sum_{i=1}^{N}(\frac{\varepsilon_i}{\sigma_i})^2}{N-L}$$

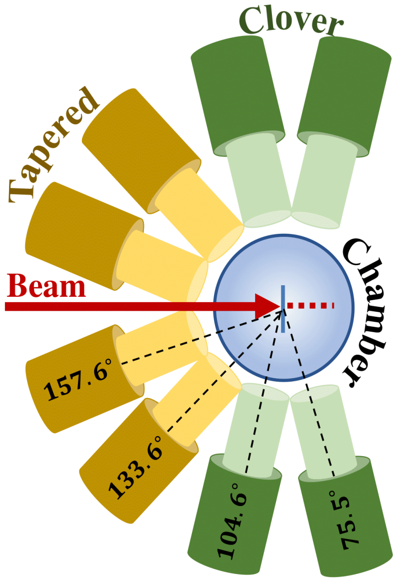
N-L: degree of freedom, here N-L=16-2=14
ε_i: the deviation of fitting and experimental central for point i
σ_i: error on point i

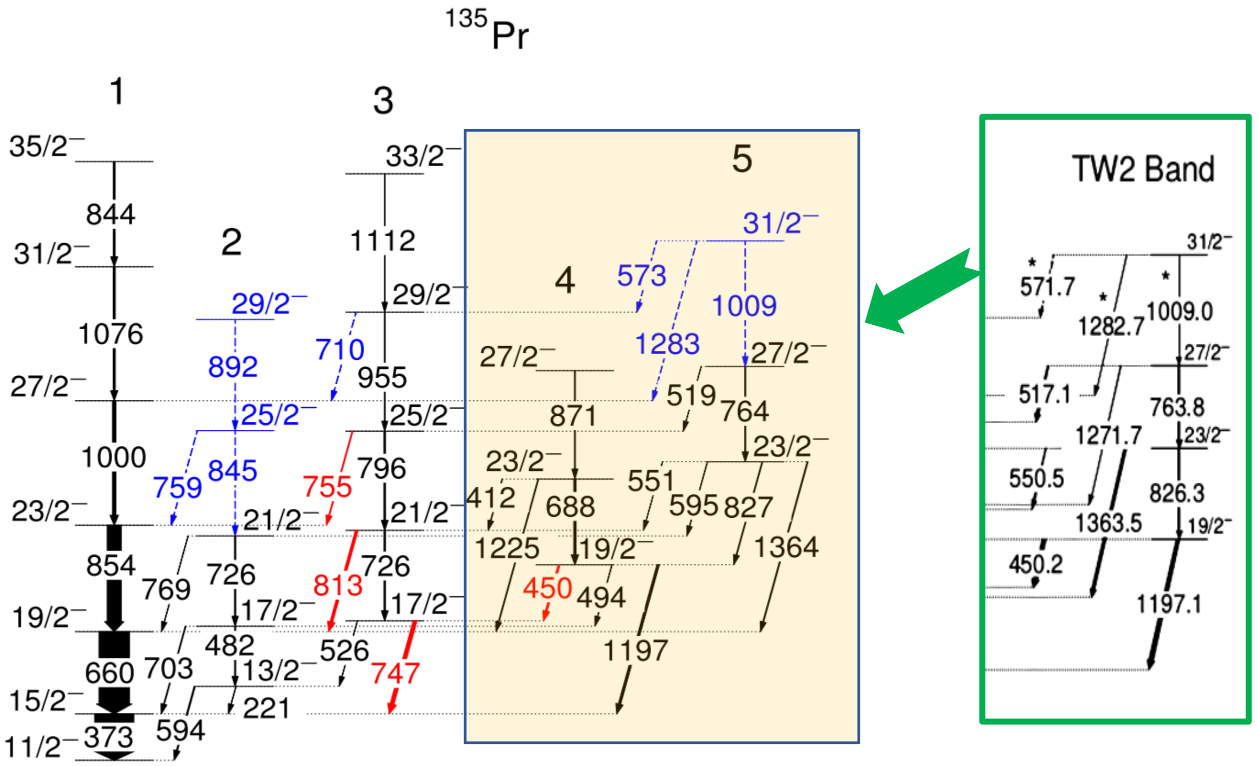
747 keV	δ = -1.24	δ = -0.64
χ^2	5.7	7.2

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

Experimental details







In present work, angular correlation (R_{ac}) is defined as

$$R_{ac} = \frac{I_\gamma(157.6^\circ + 133.6^\circ,\ \text{gated on all angles})}{I_\gamma(\approx 90^\circ,\ \text{gated on all angles})}$$

The R_{ac} values for stretched dipole and quadrupole transitions are ≈ 0.8 and ≈1.4, respectively.

Linear polarization (P)

$$P = \frac{1}{Q(E_\gamma)} \frac{a(E_\gamma)N_\perp - N_\parallel}{a(E_\gamma)N_\perp + N_\parallel}$$

Compton scattering between two crystals which are perpendicular (parallel) to the beam direction.

We can uniquely determine mixing ratio of ΔI = 1 transitions using combined linear polarization and angular correlation (P-R_{ac}) method.

J. T. Matta, U. Garg, W. Li, et al., Phys. Rev. Lett. 114, 082501 (2015).
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Results and discussion: ^{135}Pr Quasiparticle plus-triaxial-rotor

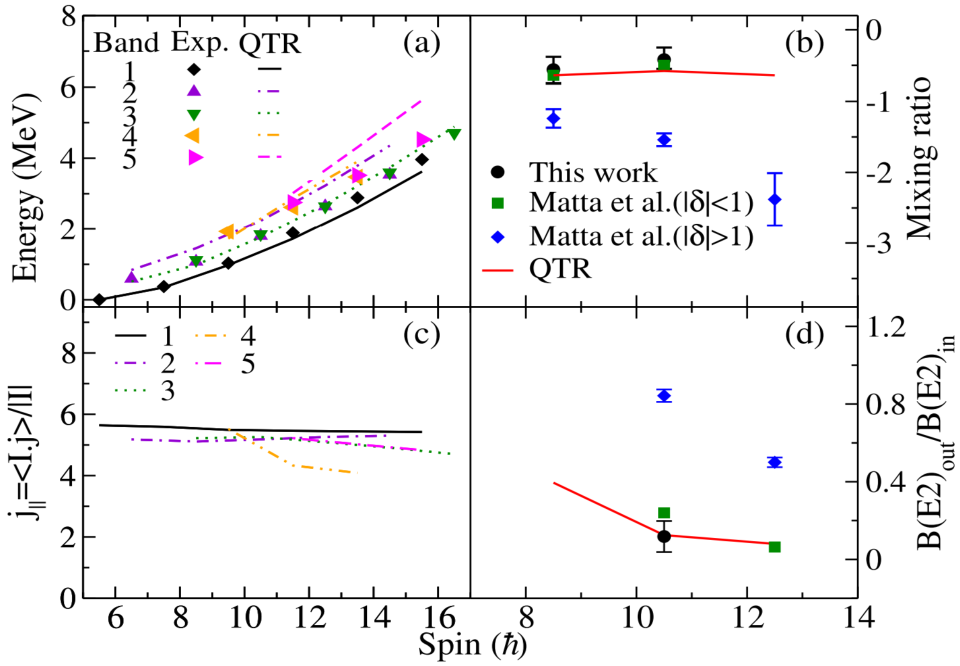
QTR calculations: E. Lawrie, iThemba LABS, South Africa

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.



- **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!**

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

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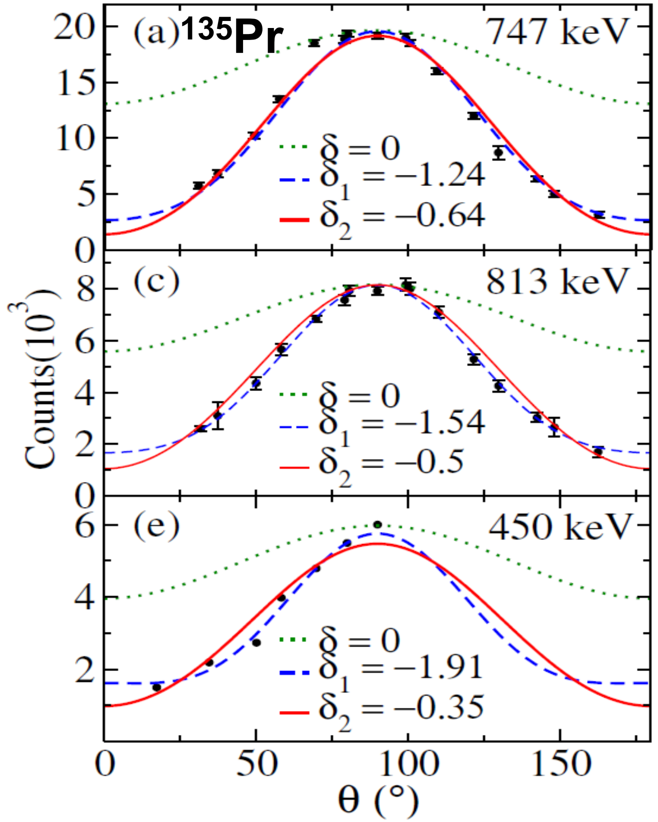


J. T. Matta, U. Garg, W. Li, et al., Phys. Rev. Lett. 114, 082501 (2015).
N. Sensharma, U. Garg, S. Zhu et al., Phys. Lett. B 792, 170 (2019).

Theoretically, a considerable debate about the validity of transverse wobbling motion in odd-mass nuclei is in course.

K. Tanabe and K. Sugawara-Tanabe, Phys. Rev. C 95, 064315 (2017).
K. Tanabe and K. Sugawara-Tanabe, Phys. Rev. C 97, 069802 (2018).
S. Frauendorf, Phys. Rev. C 97, 069801 (2018).
A. A. Raduta, R. Poenaru, and C. M. Raduta, Phys. Rev. C 101, 014302 (2020).
E. A. Lawrie, O. Shirinda, and C. M. Petrache, Phys. Rev. C 101, 034306 (2020).
K. Nomura and C. M. Petrache, Phys. Rev. C 105, 024320 (2022)
………

In present work, we measured the mixing ratios of transitions connecting low-lying states in ^{135}Pr, using both linear polarization and angular correlation analysis obtained from the same measurement.

Results and discussion: ^{135}Nd

Chirality in the odd –A nucleus $^{135}Nd_{75}$

Introduction

Prior to this work, a series of $\Delta I = 1$ chiral bands based on the $\pi h_{11/2}^{2} \otimes \nu h_{11/2}^{-1}$ configuration have been identified in the N = 75 nuclei in the A ≈ 130 mass region. Additionally, the MχD have been reported recently in the odd-A nucleus ^{133}Ce which is an isotone of ^{135}Nd.

Motivated by these observations, **we also expected to identify MχD in ^{135}Nd.**

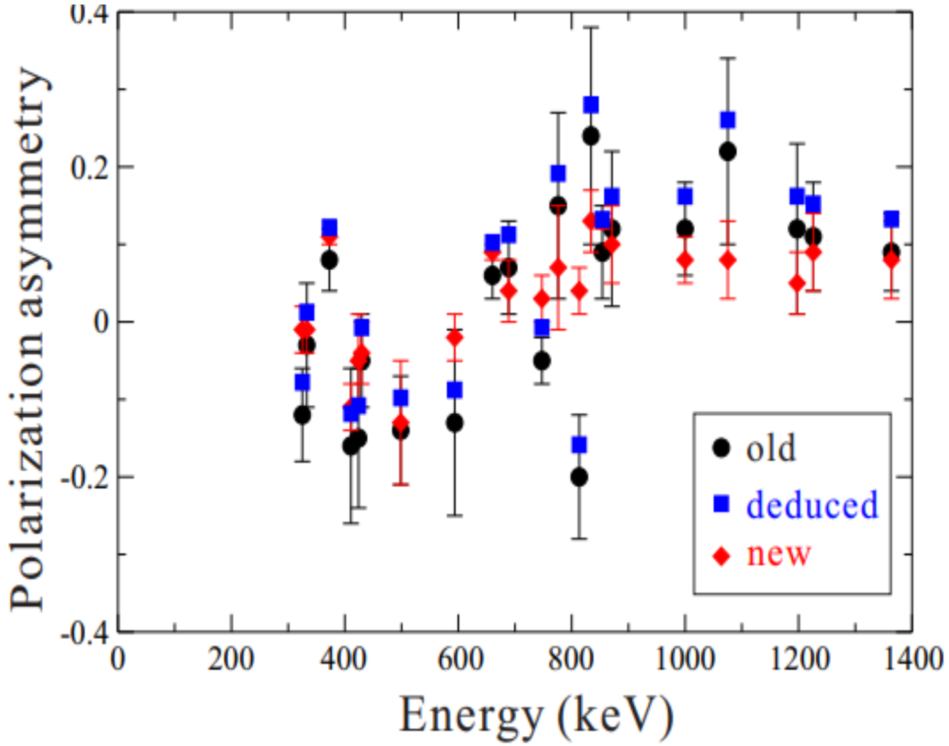


FIG. 2. (Color online) The old and new polarization asymmetry values, in comparison with the deduced ones assuming only the geometry asymmetry is changed.

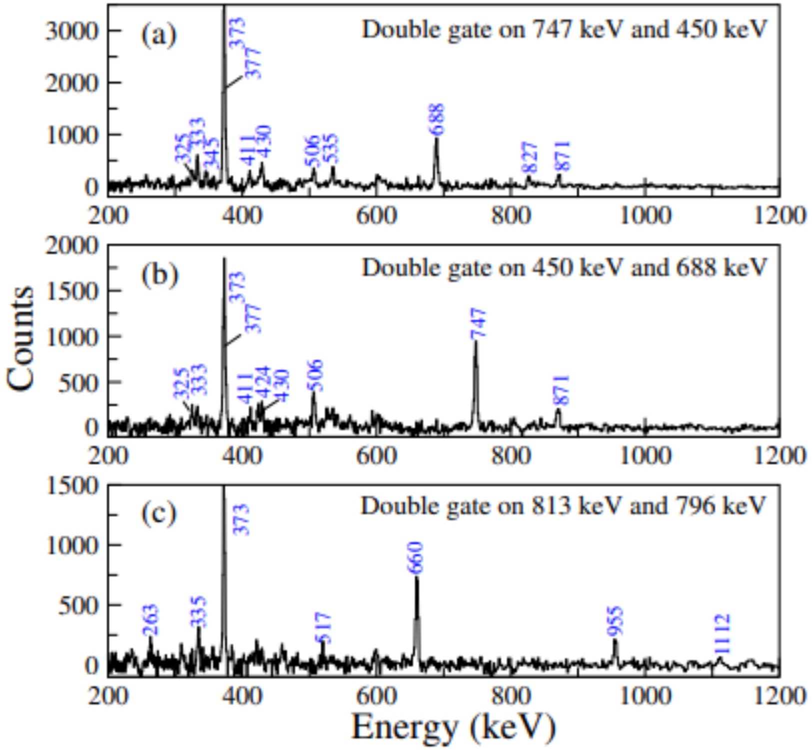
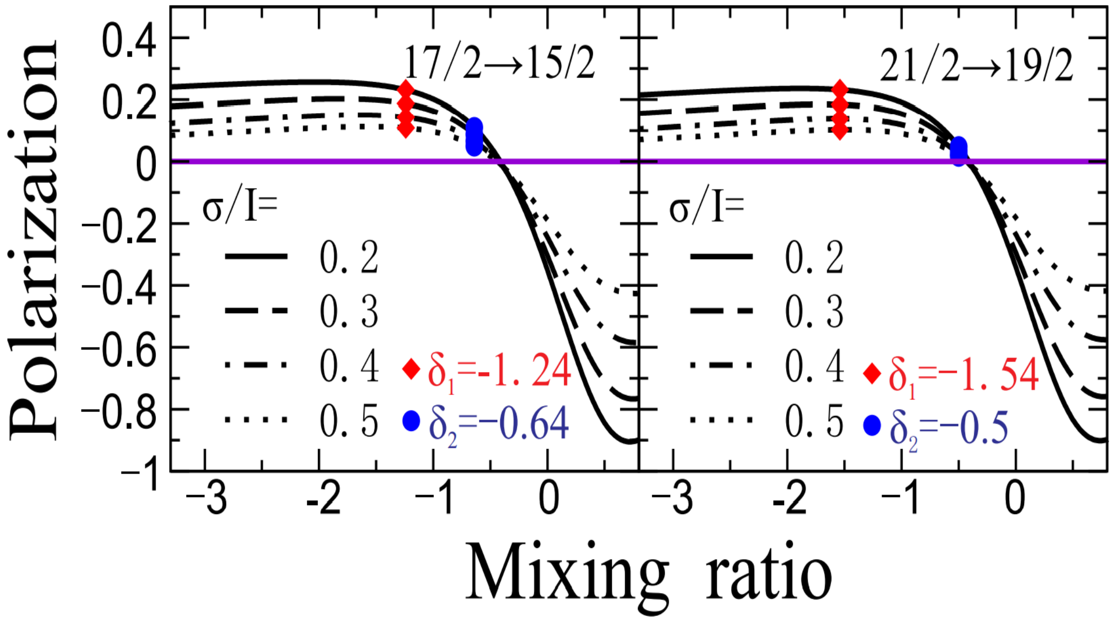


Figure 2: Representative double-gated spectra showing the low-lying structure of ^{135}Pr. (a) Double gated on the 747- and 450-keV transitions. (b) Double gated on the 450- and 688-keV transitions. (c) Double gated on the 813- and 796-keV transition.

2007.10031v1.pdf (arxiv.org)



from the INGA array. In the two cases where the data had sufficient statistics to reliably extract the asymmetries (see Ref. [24] for details), the asymmetry parameter is > 0, clearly identifying these transitions as predominantly electric in nature. The measured asymmetry parameters are presented in Fig. 3. We note that, in contrast, both the