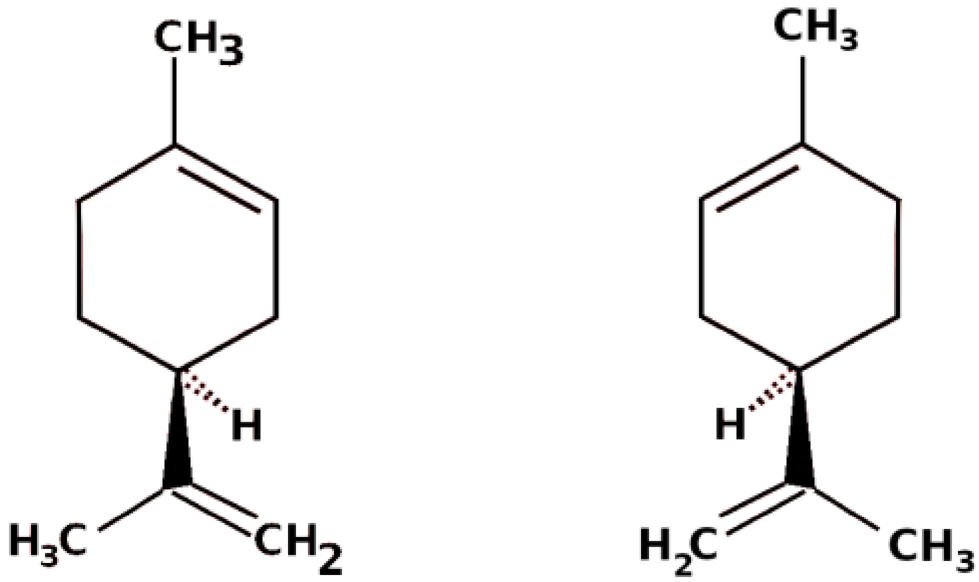
Ernest Grodner
BP1 Division
National Centre For Nuclear Research, Poland

Nuclear chirality
from a curiosity to mainstream research.

Konwersatorium im. Jerzego Pniewskiego i Leopolda Infelda

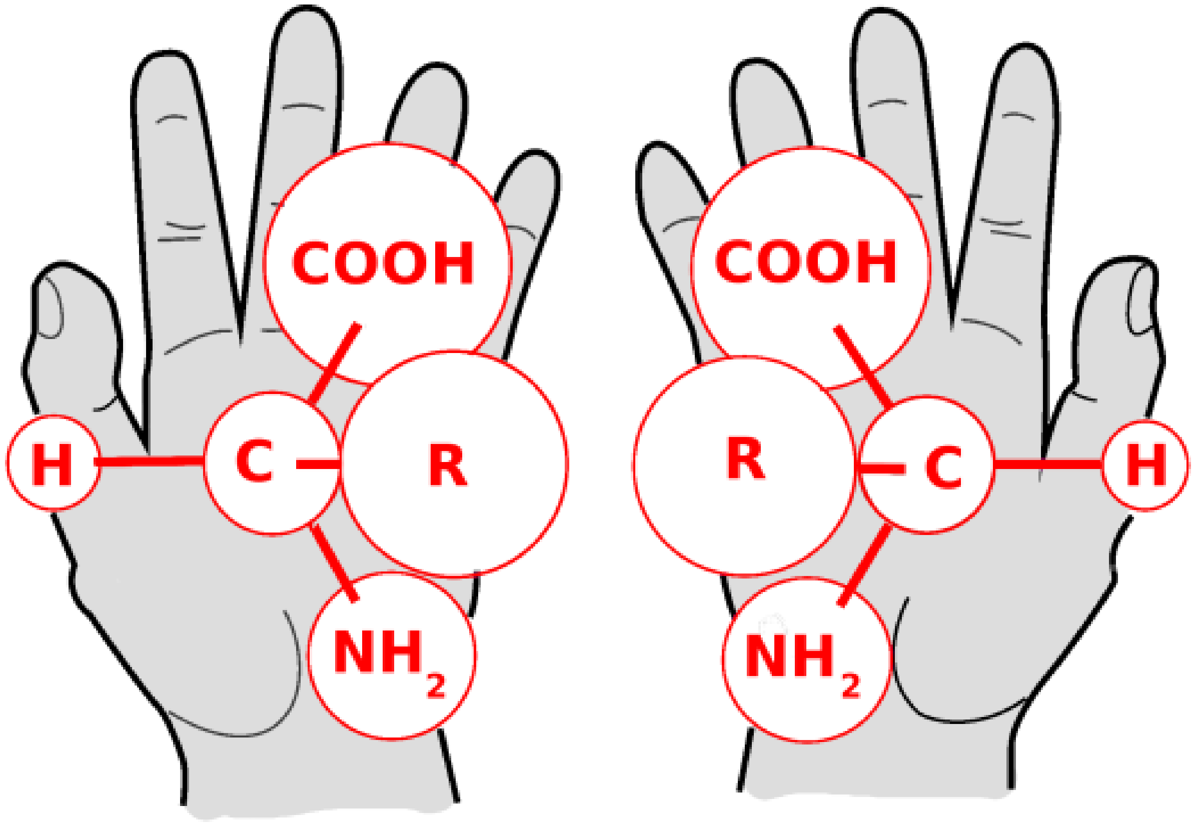


Citrus fruits aroma molecule
The right-handed molecules |R> - fresh fruits smell
The left-handed molecule |L> - petrol, turpentine smell

Mans H. Boelens, Harrie Boelens & Leo J. van Gemert, Perfumer & Flavorist, Vol.**18**, No. 6, 1-15 (1993)

Left- and right-handed molecules
The same chemical composition
Handedness reversion not possible with rotation only

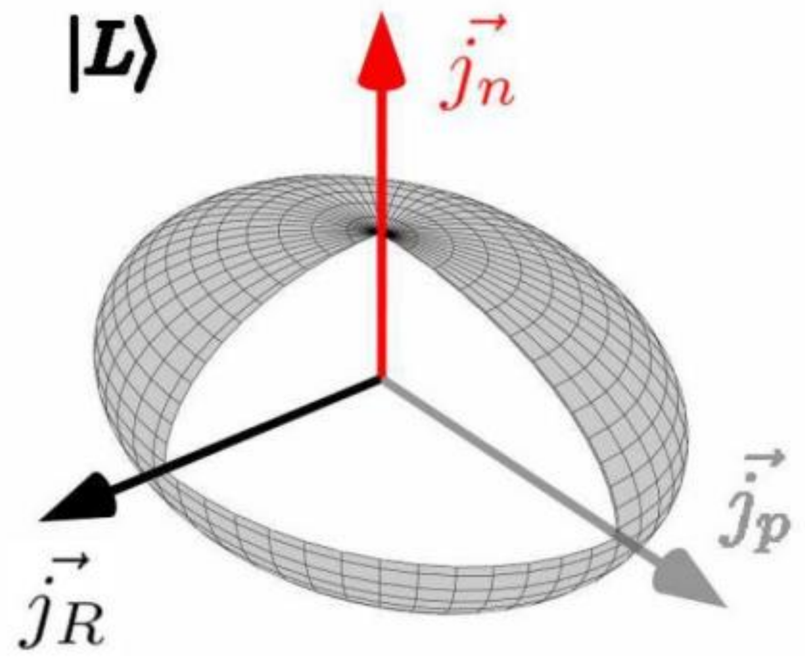
$$R_\pi P|L\rangle = |R\rangle$$

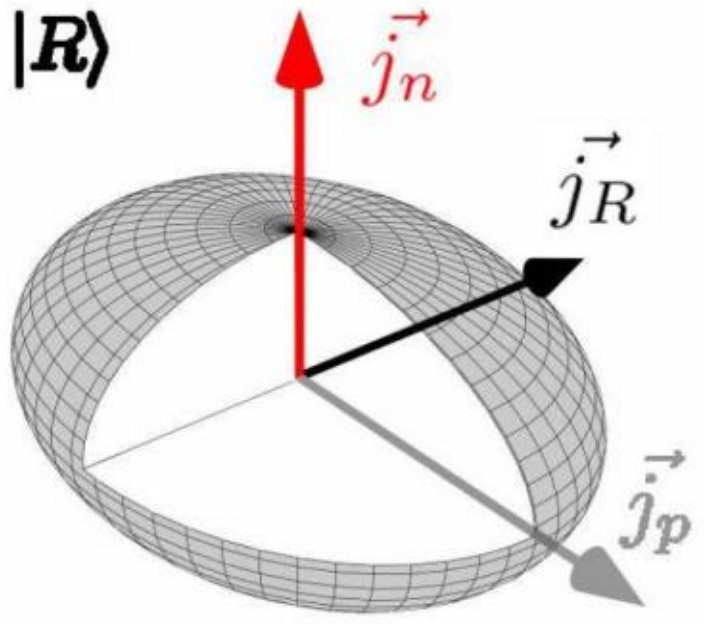


Nuclear chirality

$$R_\pi T|L\rangle = |R\rangle$$

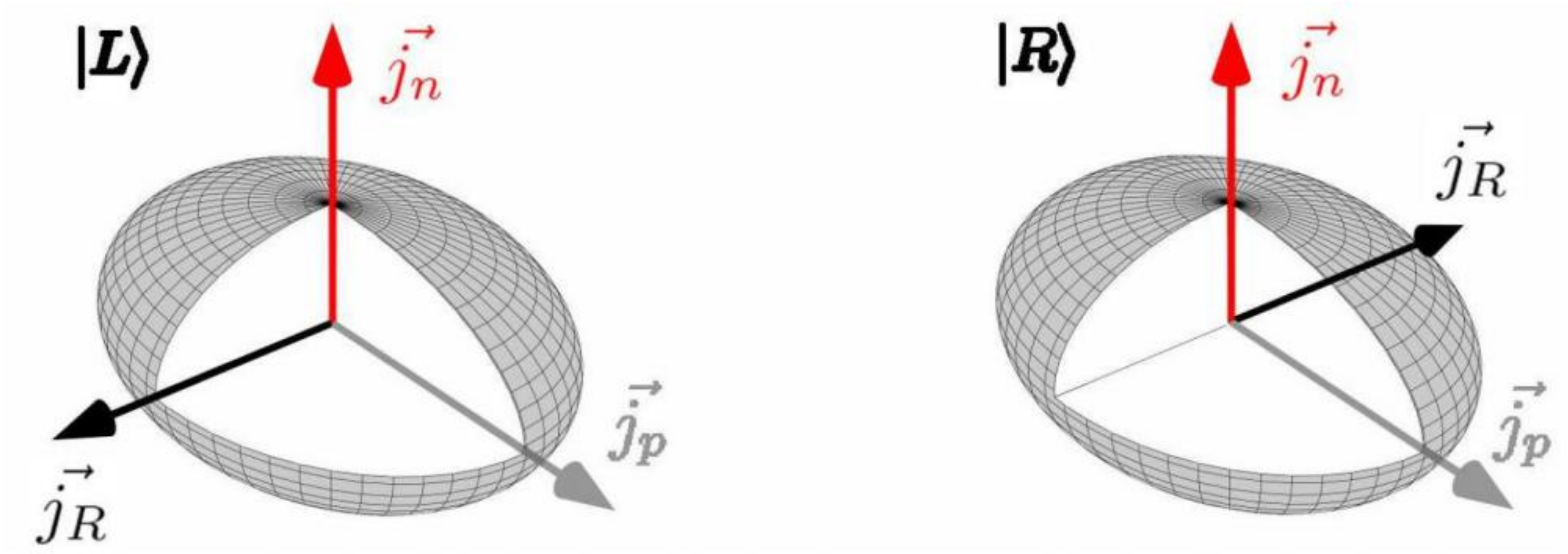
odd-odd nuclei
even-even core (triaxially deformed)
odd proton (particle)
odd neutron (hole)



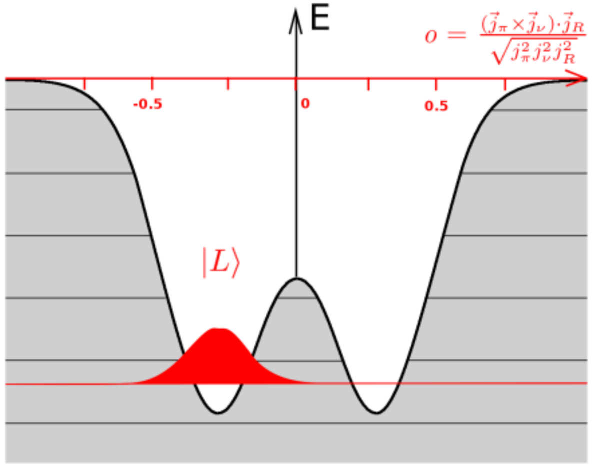


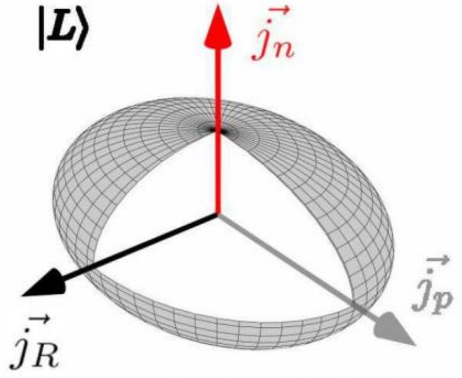
$$O = \frac{(\vec{j}_\pi \times \vec{j}_\nu)\cdot\vec{j}_R}{\sqrt{j_\pi^2 j_\nu^2 j_R^2}}$$

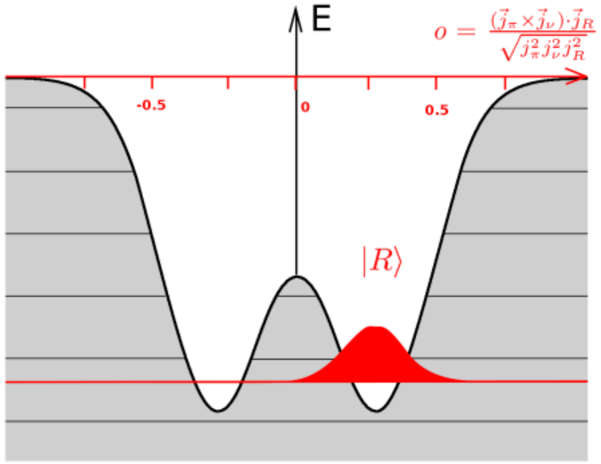
Negative value zero positive value

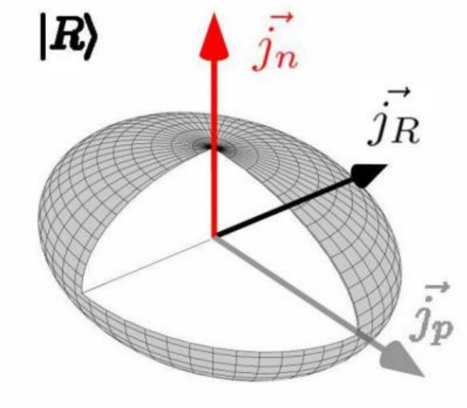


The experimenter's perspective

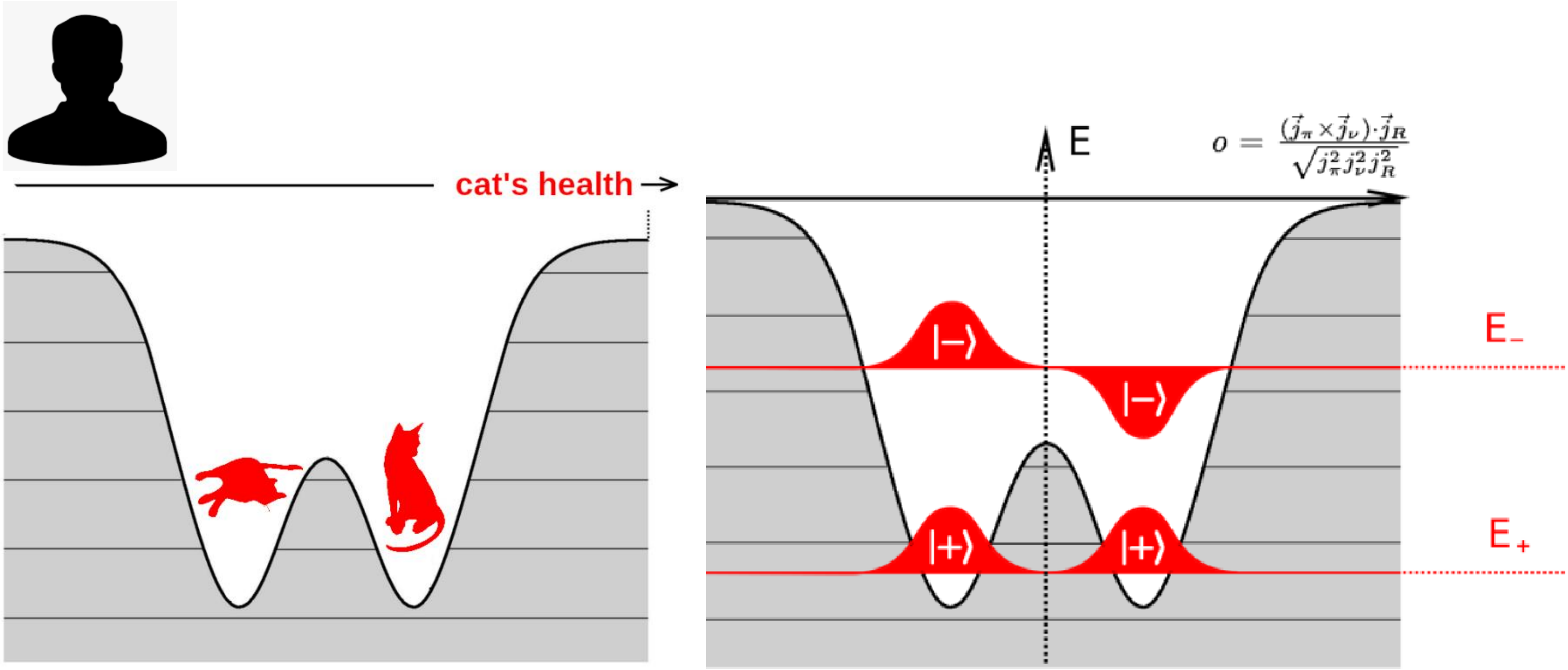








The experimenter's perspective



Chiral doublet structures in level schemes expected

$$[R_y T, H] = 0$$

$$|+\rangle = \frac{1}{\sqrt{2}} \frac{|L\rangle + |R\rangle}{\sqrt{1+\varepsilon}} \qquad \langle + | H | + \rangle = \frac{E_0 + \Delta E}{1+\varepsilon}$$

$$|-\rangle = \frac{i}{\sqrt{2}} \frac{|L\rangle - |R\rangle}{\sqrt{1-\varepsilon}} \qquad \langle - | H | - \rangle = \frac{E_0 - \Delta E}{1-\varepsilon}$$

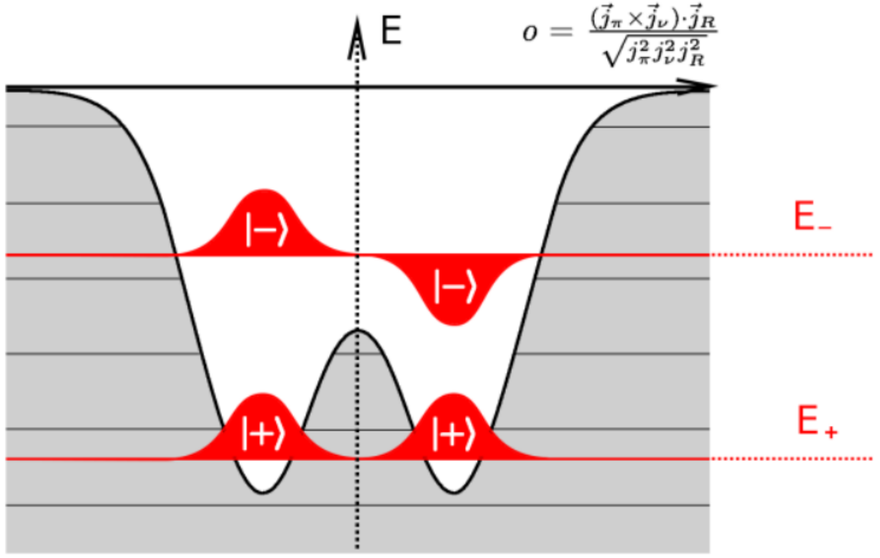
Doubling of the energy for LAB states

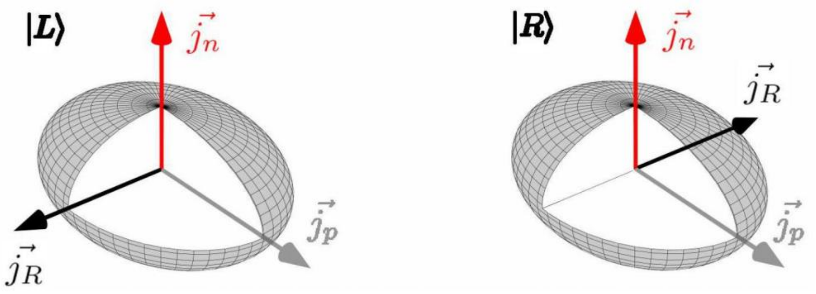
Parameters

Overlap $\varepsilon = \mathrm{Re}\langle L | R \rangle$

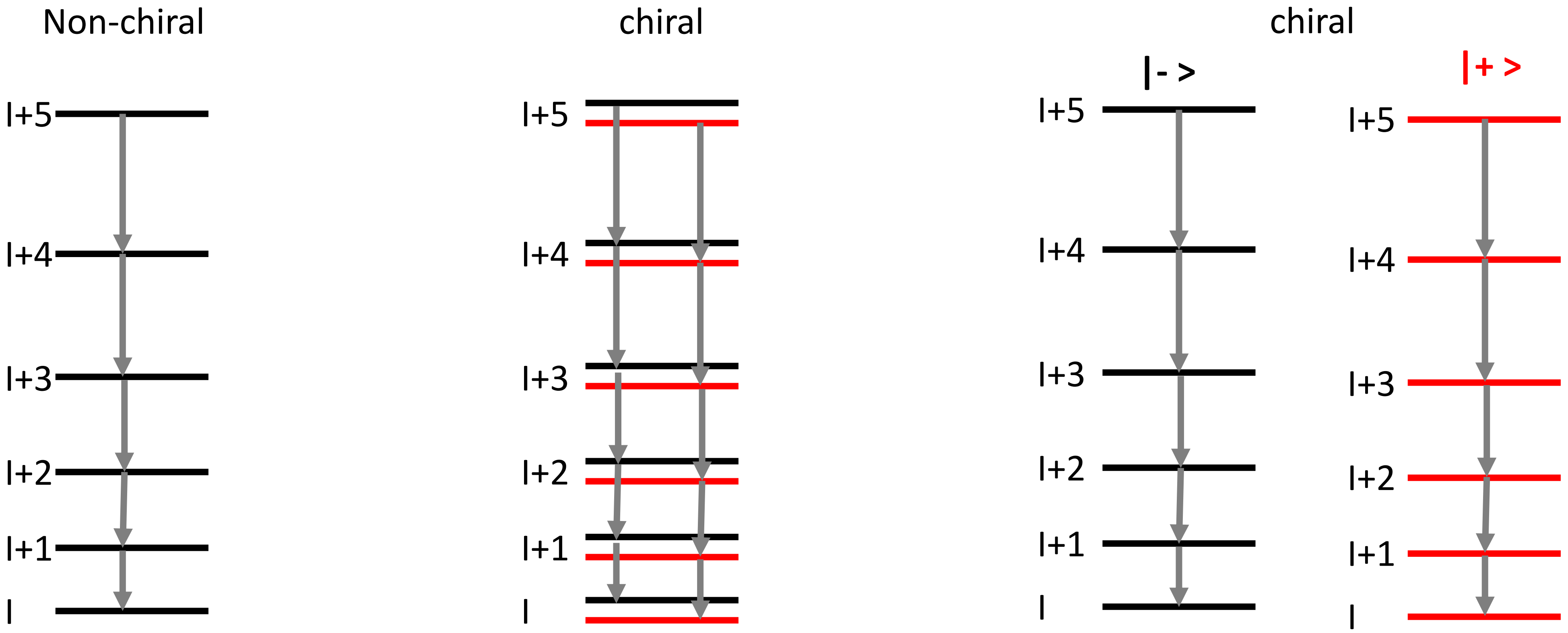
Tunneling effect $\Delta E = \mathrm{Re}\langle L | H | R \rangle$

Diagonal mat. element $E_0 = \mathrm{Re}\langle L | H | L \rangle$





Chiral rotational bands expected



Chiral Doublet Structures in Odd-Odd $N = 75$ Isotones: Chiral Vibrations

K. Starosta,[1,*] T. Koike,[1] C. J. Chiara,[1] D. B. Fossan,[1] D. R. LaFosse,[1] A. A. Hecht,[2] C. W. Beausang,[2] M. A. Caprio,[2] J. R. Cooper,[2] R. Krücken,[2] J. R. Novak,[2] N. V. Zamfir,[2,†] K. E. Zyromski,[2] D. J. Hartley,[3] D. L. Balabanski,[3,‡] Jing-ye Zhang,[3] S. Frauendorf,[4] and V. I. Dimitrov[4,‡]

[1]Department of Physics and Astronomy, SUNY at Stony Brook, Stony Brook, New York 11794
[2]Wright Nuclear Structure Laboratory, Yale University, New Haven, Connecticut 06520
[3]Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996
[4]Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556
and Institute for Nuclear and Hadronic Physics, Research Center Rossendorf, 01314 Dresden, Germany

(Received 24 July 2000)

New sideband partners of the yrast bands built on the $\pi h_{11/2} \nu h_{11/2}$ configuration were identified in $_{55}$Cs, $_{57}$La, and $_{61}$Pm $N = 75$ isotones of ^{134}Pr. These bands form with ^{134}Pr unique doublet-band systematics suggesting a common basis. Aplanar solutions of 3D tilted axis cranking calculations for triaxial shapes define left- and right-handed chiral systems out of the three angular momenta provided by the valence particles and the core rotation, which leads to spontaneous chiral symmetry breaking and the doublet bands. Small energy differences between the doublet bands suggest collective chiral vibrations.

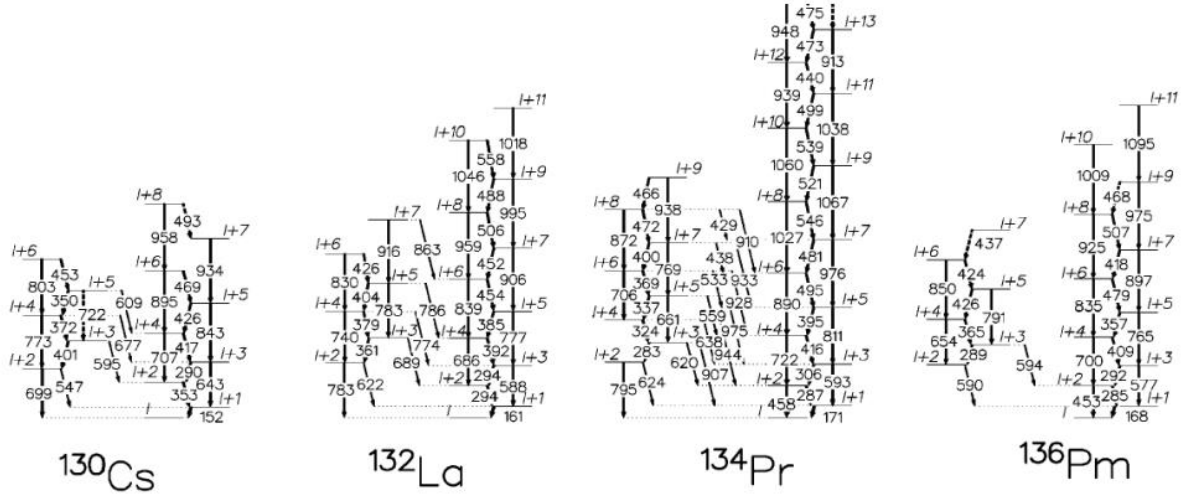


FIG. 2. Partial level schemes presenting the $\pi h_{11/2} \nu h_{11/2}$ bands and newly identified sidebands of ^{130}Cs, ^{132}La, and ^{136}Pm from the current study, and for ^{134}Pr from Ref. [3]. For each $N = 75$ isotone, the yrast $\Delta I = 1$ $\pi h_{11/2} \nu h_{11/2}$ band is shown on the right while the $\Delta I = 1$ sideband is shown on the left side of each level scheme.

Prof. Krystyna Siwek-Wilczyńska

Prof. Chrystian Droste

First electromagnetic transition probabilities measurement ^{132}La (2002)

$$[R_Y T, H] = 0$$

$$|+\rangle = \frac{1}{\sqrt{2}} \frac{|L\rangle + |R\rangle}{\sqrt{1+\varepsilon}} \qquad \langle +|H|+\rangle = \frac{E_0 + \Delta E}{1+\varepsilon}$$

$$|-\rangle = \frac{i}{\sqrt{2}} \frac{|L\rangle - |R\rangle}{\sqrt{1-\varepsilon}} \qquad \langle -|H|-\rangle = \frac{E_0 - \Delta E}{1-\varepsilon}$$

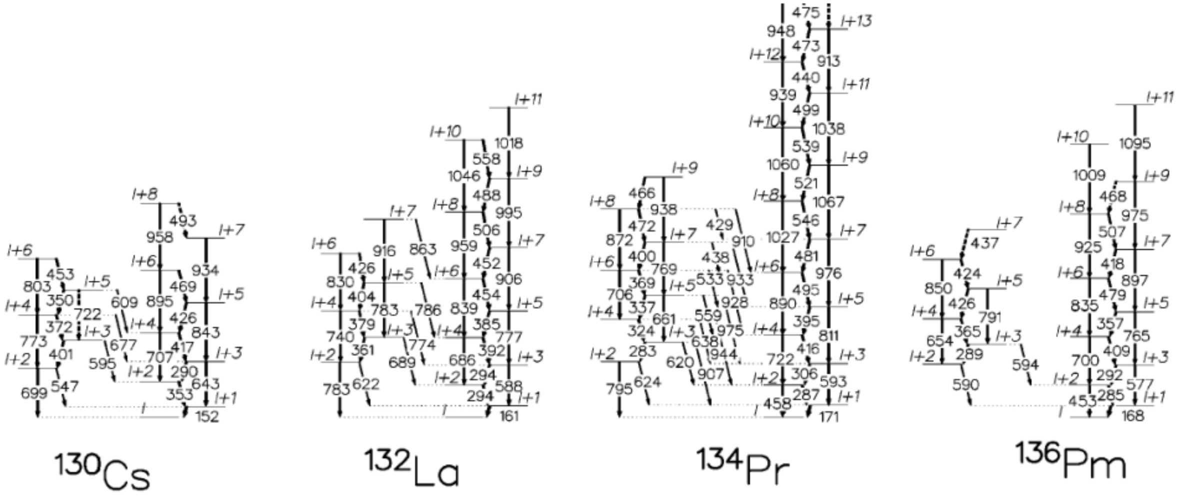
Doubling of the energy for LAB states

Parameters

Overlap $\varepsilon = \mathrm{Re}\langle L|R\rangle$

Tunneling effect $\Delta E = \mathrm{Re}\langle L|H|R\rangle$

Diagonal mat. element $E_0 = \mathrm{Re}\langle L|H|L\rangle$



First electromagnetic transition probabilities measurement ^{132}La (2002)

$$[R_Y T, H] = 0$$

$$|+\rangle = \frac{1}{\sqrt{2}} \frac{|L\rangle + |R\rangle}{\sqrt{1+\varepsilon}} \qquad \langle + | H | + \rangle = \frac{E_0 + \Delta E}{1+\varepsilon}$$

$$|-\rangle = \frac{i}{\sqrt{2}} \frac{|L\rangle - |R\rangle}{\sqrt{1-\varepsilon}} \qquad \langle - | H | - \rangle = \frac{E_0 - \Delta E}{1-\varepsilon}$$

Doubling of the energy for LAB states

Parameters

Overlap $\varepsilon = \mathrm{Re}\langle L | R \rangle$

Tunneling effect $\Delta E = \mathrm{Re}\langle L | H | R \rangle$

Diagonal mat. element $E_0 = \mathrm{Re}\langle L | H | L \rangle$

Prof. Brunon Sikora

First electromagnetic transition probabilities measurement ^{132}La (2002)

$$[R_Y T, H] = 0$$

$$|+\rangle = \frac{1}{\sqrt{2}} \frac{|L\rangle + |R\rangle}{\sqrt{1+\varepsilon}} \qquad \langle + |H| + \rangle = \frac{E_0 + \Delta E}{1+\varepsilon}$$

$$|-\rangle = \frac{i}{\sqrt{2}} \frac{|L\rangle - |R\rangle}{\sqrt{1-\varepsilon}} \qquad \langle - |H| - \rangle = \frac{E_0 - \Delta E}{1-\varepsilon}$$

Doubling of the energy for LAB states

Parameters

Overlap $\varepsilon = \mathrm{Re}\langle L | R \rangle$

Tunneling effect $\Delta E = \mathrm{Re}\langle L | H | R \rangle$

Diagonal mat. element $E_0 = \mathrm{Re}\langle L | H | L \rangle$

$$[R_Y T, B(\sigma\lambda)] = 0 \qquad \sigma\lambda = M1, E2, M3, E4, \ldots$$

$$\langle + |B(\sigma\lambda)| + \rangle = \frac{B_0 + \Delta B}{1+\varepsilon}$$

$$\langle - |B(\sigma\lambda)| - \rangle = \frac{B_0 - \Delta B}{1-\varepsilon}$$

Doubling of the transition probabilities

Parameters

Overlap $\varepsilon = \mathrm{Re}\langle L | R \rangle$

non-diagonal element $\Delta B = \mathrm{Re}\langle L | B | R \rangle$

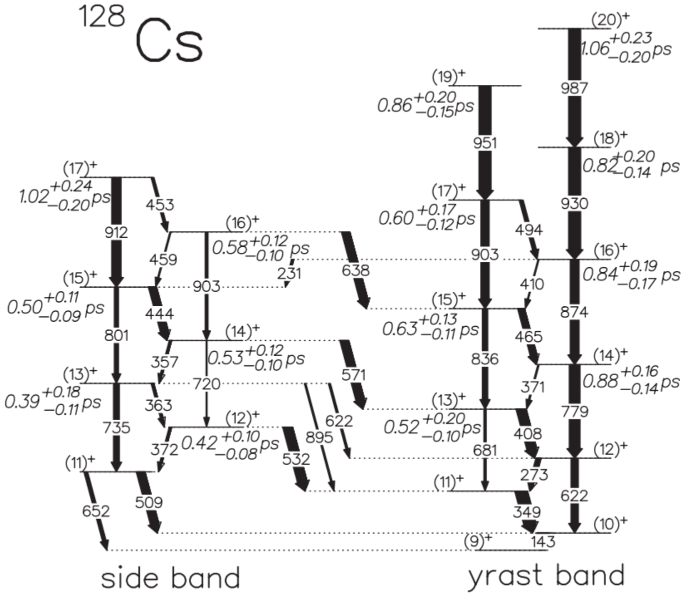
diagonal mat. element $B_0 = \mathrm{Re}\langle L | B | L \rangle$

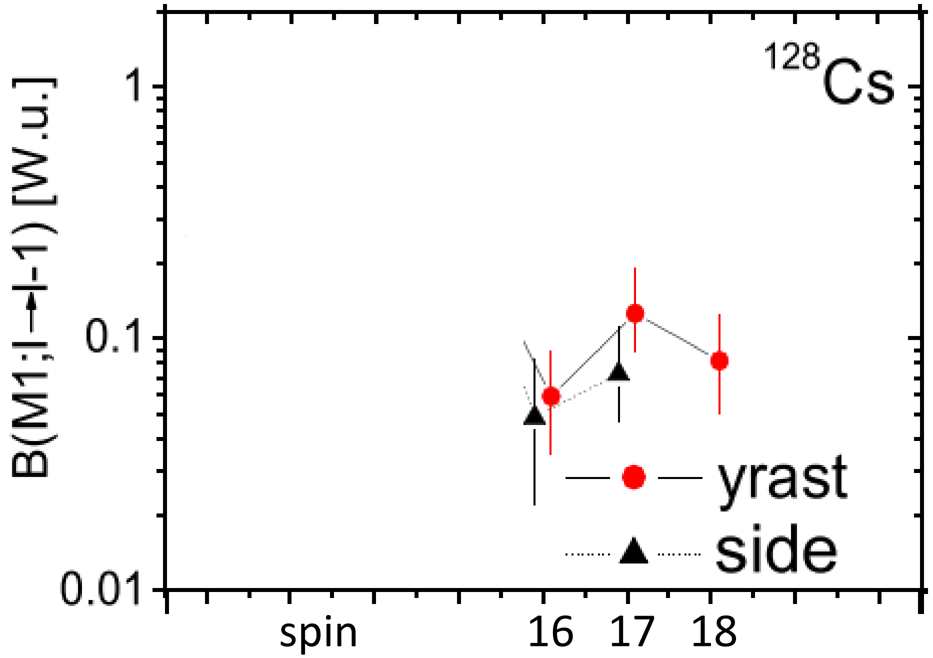
128Cs first experimental confirmation of chirality 2003-2005

PRL **97,** 172501 (2006) PHYSICAL REVIEW LETTERS week ending 27 OCTOBER 2006

^{128}Cs as the Best Example Revealing Chiral Symmetry Breaking

E. Grodner,[1] J. Srebrny,[1,2] A. A. Pasternak,[1,2,3] I. Zalewska,[1] T. Morek,[1] Ch. Droste,[1] J. Mierzejewski,[2] M. Kowalczyk,[1,2] J. Kownacki,[2] M. Kisieliński,[2,4] S. G. Rohoziński,[5] T. Koike,[6] K. Starosta,[7] A. Kordyasz,[2] P. J. Napiorkowski,[2] M. Wolińska-Cichocka,[2] E. Ruchowska,[4] W. Płóciennik,[4,*] and J. Perkowski[8]





dr Julian Srebrny

prof. Alexander Pasternak

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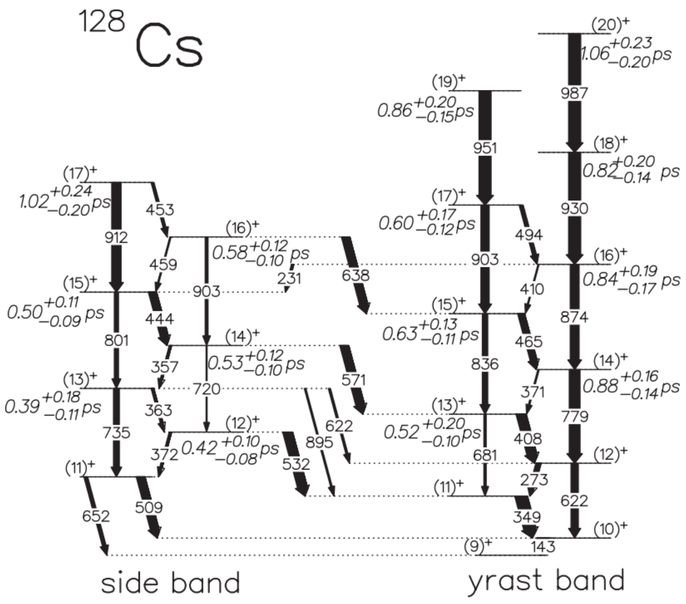

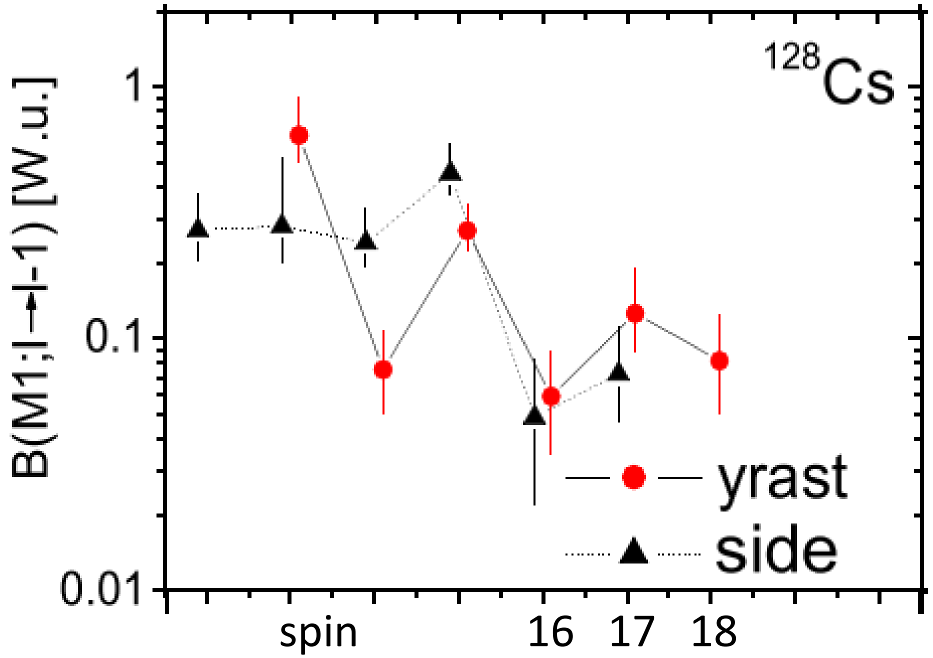

VOLUME 93, NUMBER 17 PHYSICAL REVIEW LETTERS week ending 22 OCTOBER 2004

Chiral Bands, Dynamical Spontaneous Symmetry Breaking, and the Selection Rule for Electromagnetic Transitions in the Chiral Geometry

T. Koike,[1] K. Starosta,[1,2] and I. Hamamoto[3,4]

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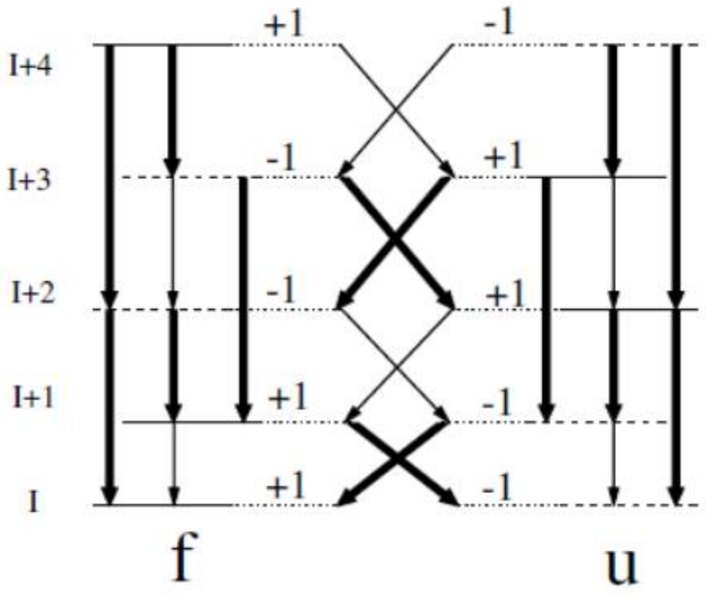
[2]Department of Physics and Astronomy and National Superconducting Cyclotron Laboratory, MSU, East Lansing, Michigan 48824, USA
[3]Division of Mathematical Physics, LTH, Un
[4]The Niels Bohr Institute, Blegdamsvej 17, Copen

(Received 16 March 2004; revised manuscript received 29

A model for a special configuration in triaxial odd-od
degenerate chiral bands with a sizable rotation, a manifestat
breaking. A quantum number obtained from the invaria
characterizes observable states, is given and selection rules fc
in chiral bands is derived in terms of this quantum number. T
indeed obtained in the numerical diagonalization of the Ha
over which electromagnetic transitions follow exactly the
geometry.

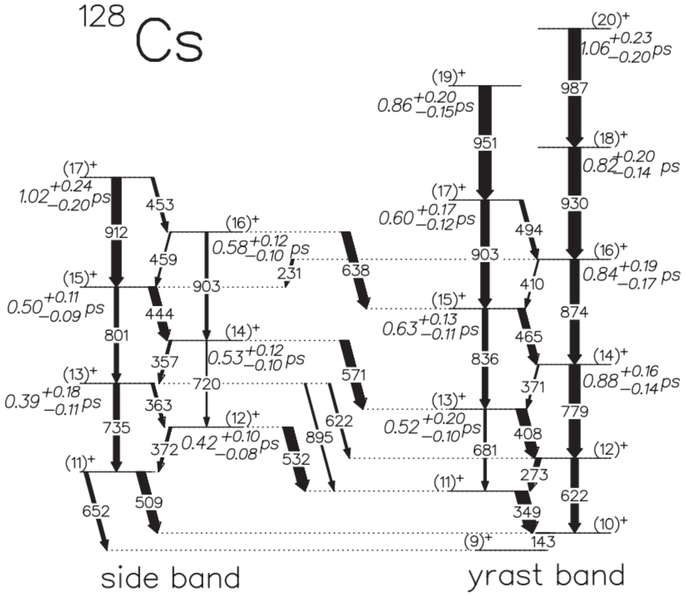


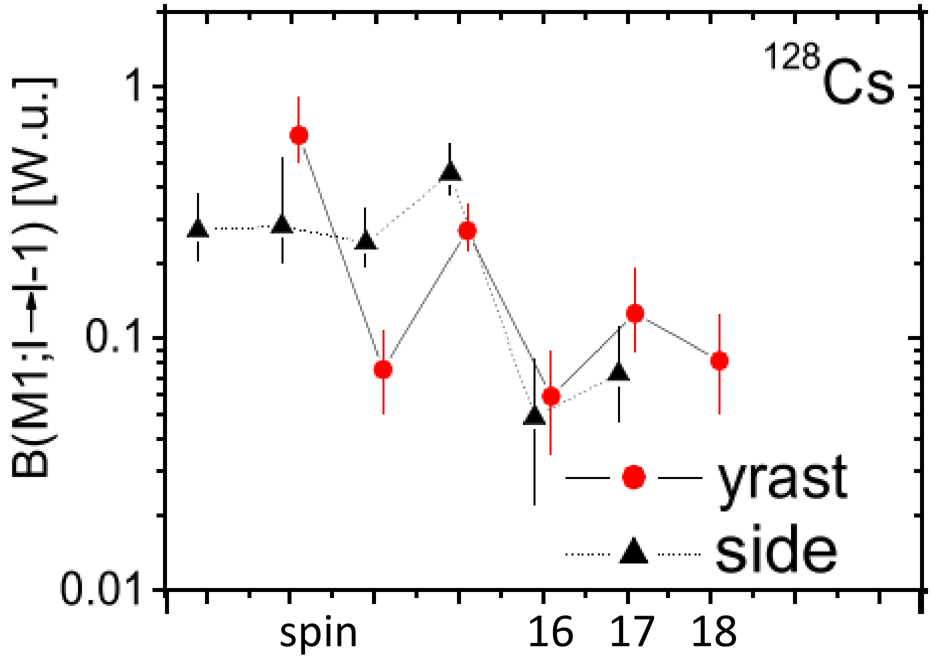
128Cs first experimental confirmation of chirality 2003-2005

PRL **97,** 172501 (2006) PHYSICAL REVIEW LETTERS week ending 27 OCTOBER 2006

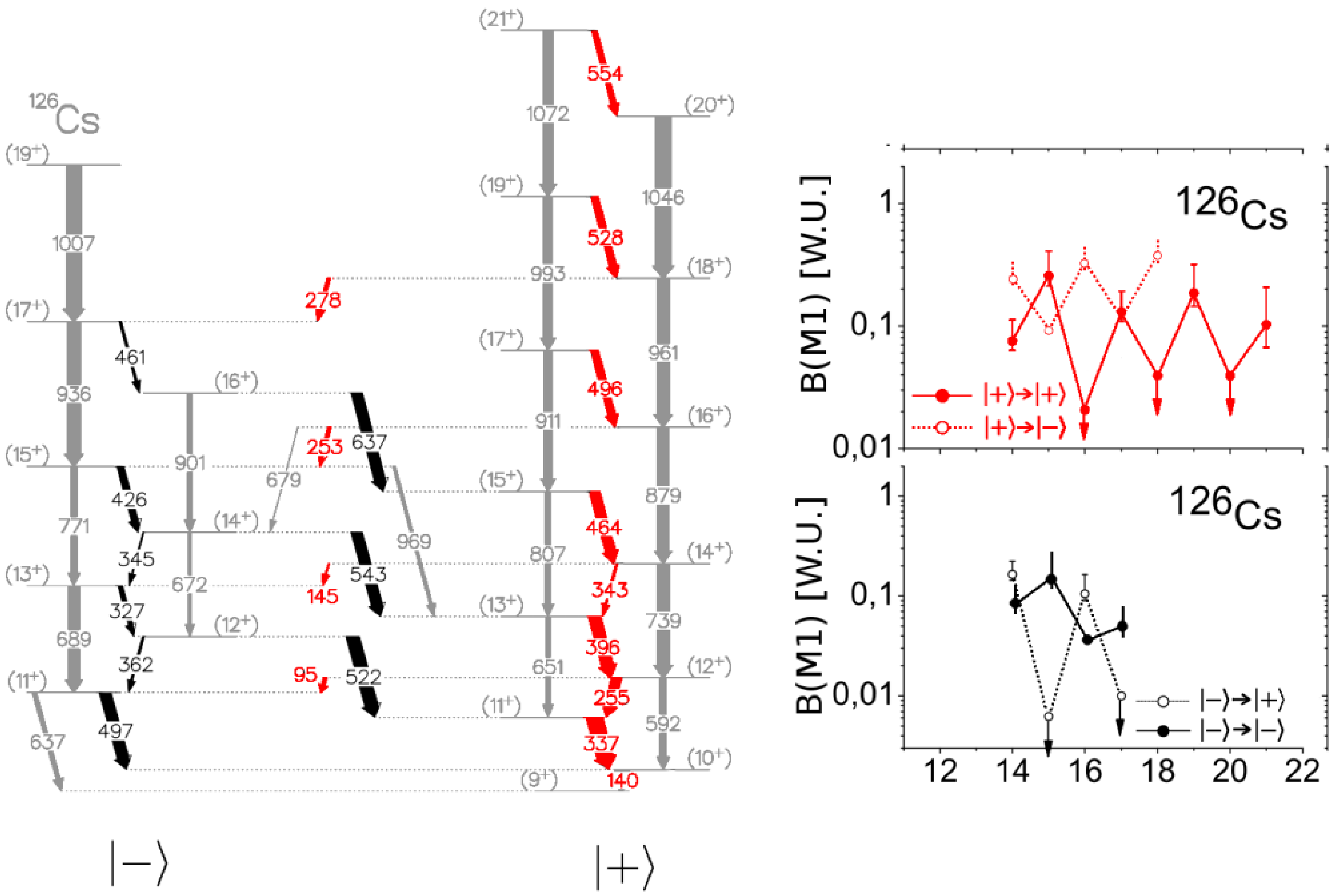
^{128}Cs as the Best Example Revealing Chiral Symmetry Breaking

E. Grodner,[1] J. Srebrny,[1,2] A. A. Pasternak,[1,2,3] I. Zalewska,[1] T. Morek,[1] Ch. Droste,[1] J. Mierzejewski,[2] M. Kowalczyk,[1,2] J. Kownacki,[2] M. Kisieliński,[2,4] S. G. Rohoziński,[5] T. Koike,[6] K. Starosta,[7] A. Kordyasz,[2] P. J. Napiorkowski,[2] M. Wolińska-Cichocka,[2] E. Ruchowska,[4] W. Płóciennik,[4,*] and J. Perkowski[8]





126Cs complete set of EM chiral selection rules observed for the first time.



Physics Letters B 703 (2011) 46–50

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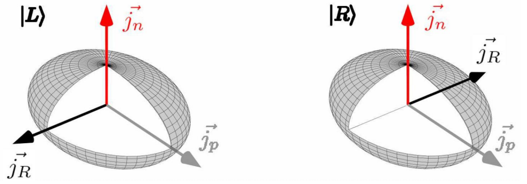
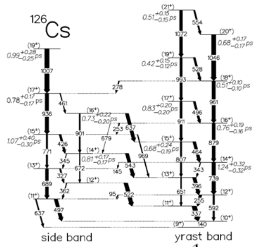
Partner bands of ^{126}Cs – first observation of chiral electromagnetic selection rules

E. Grodner [a,*], I. Sankowska [a,g], T. Morek [a], S.G. Rohoziński [b,c], Ch. Droste [a], J. Srebrny [c], A.A. Pasternak [d,c], M. Kisieliński [c,e], M. Kowalczyk [a,c], J. Kownacki [c,e], J. Mierzejewski [a,c], A. Król [f], K. Wrzosek [a,c]

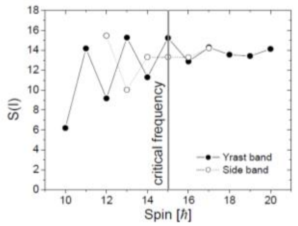
[a] Institute of Experimental Physics, Faculty of Physics, University of Warsaw, ul. Hoża 69, PL-00681, Warsaw, Poland
[b] Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, ul. Hoża 69, PL-00681, Warsaw, Poland
[c] Heavy Ion Laboratory, University of Warsaw, ul. Pasteura 5A, 02-093 Warsaw, Poland
[d] A.F. Ioffe Physical Technical Institute, 194021 St. Petersburg, Russia
[e] A. Sołtan Institute for Nuclear Studies, 05-400, Świerk, Poland
[f] Division of Nuclear Physics, University of Łódź, 90-236 Łódź, Poland
[g] Institute of Electron Technology, Al. Lotników 32/46, 02-668, Warsaw, Poland

Indirect signatures of chirality

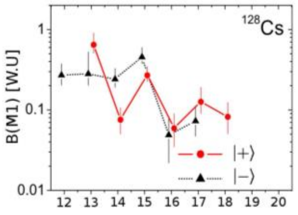




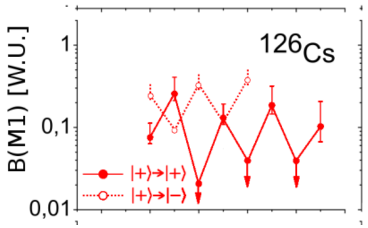
- 1. two nearly degenerated rotational bands with same I and parities



- 2. No energy staggering



- 3. Nearly the same EM transition probabilities in both bands
- 4. B(M1) staggering (in some isotopes only)



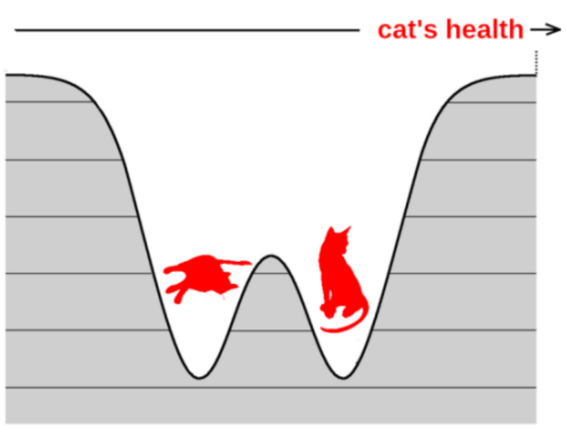
- 5. Opposite B(M1) staggering for inband and intraband transitions

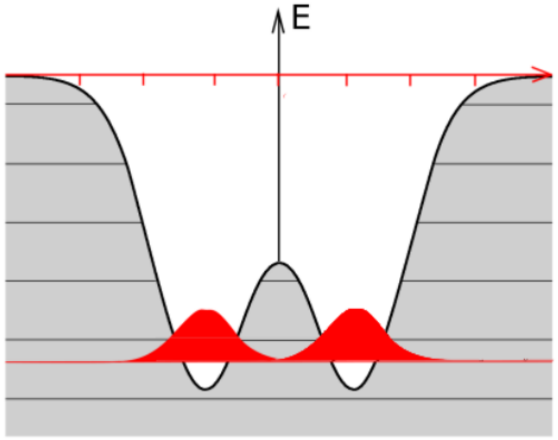
Attention!

Now the clue!

Superimposed states of a cat in the box

Symmetry braking cat inside

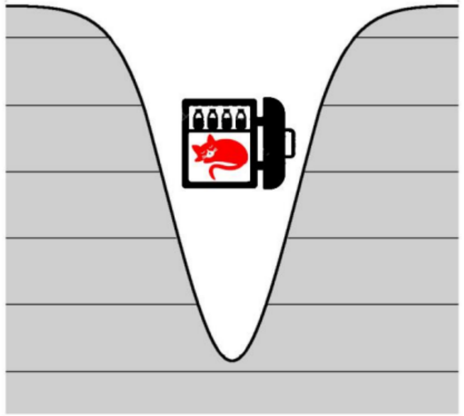


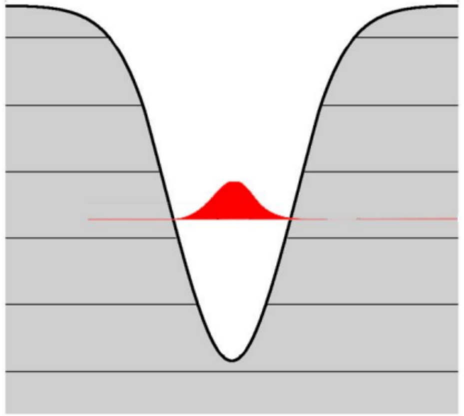


Measured cat's health:
hibernated

But what if we put a hibernated cat in the box in a first place?

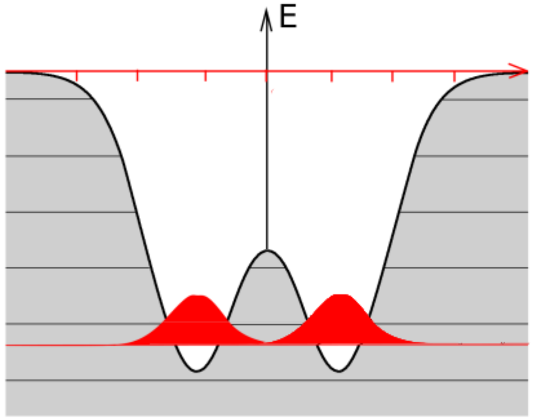
Symmetry conserving cat inside



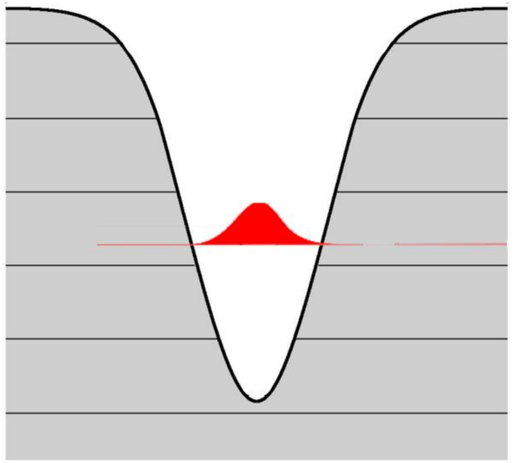


Measured cat's health:
hibernated

Chiral nucleus



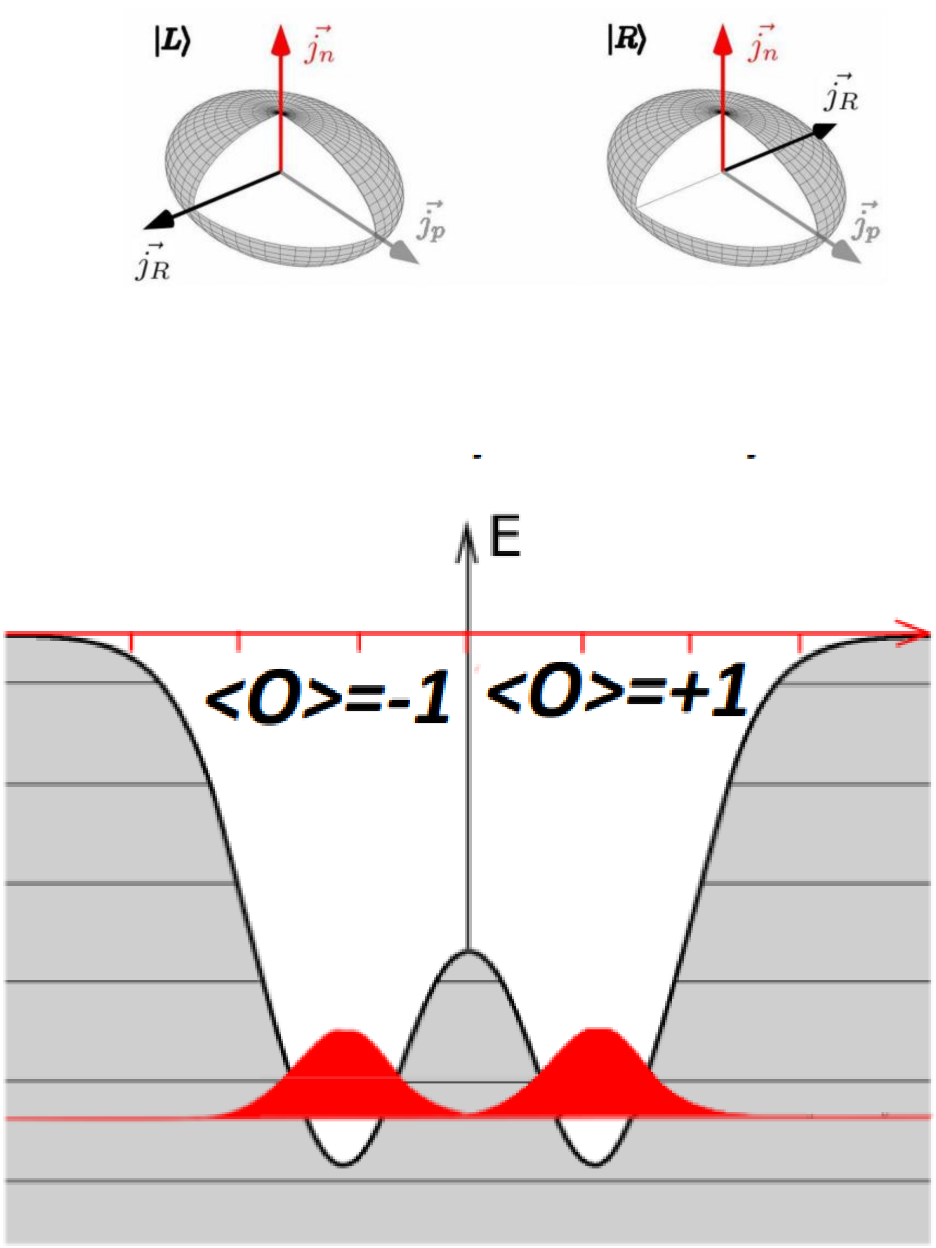
Non-chiral nucleus

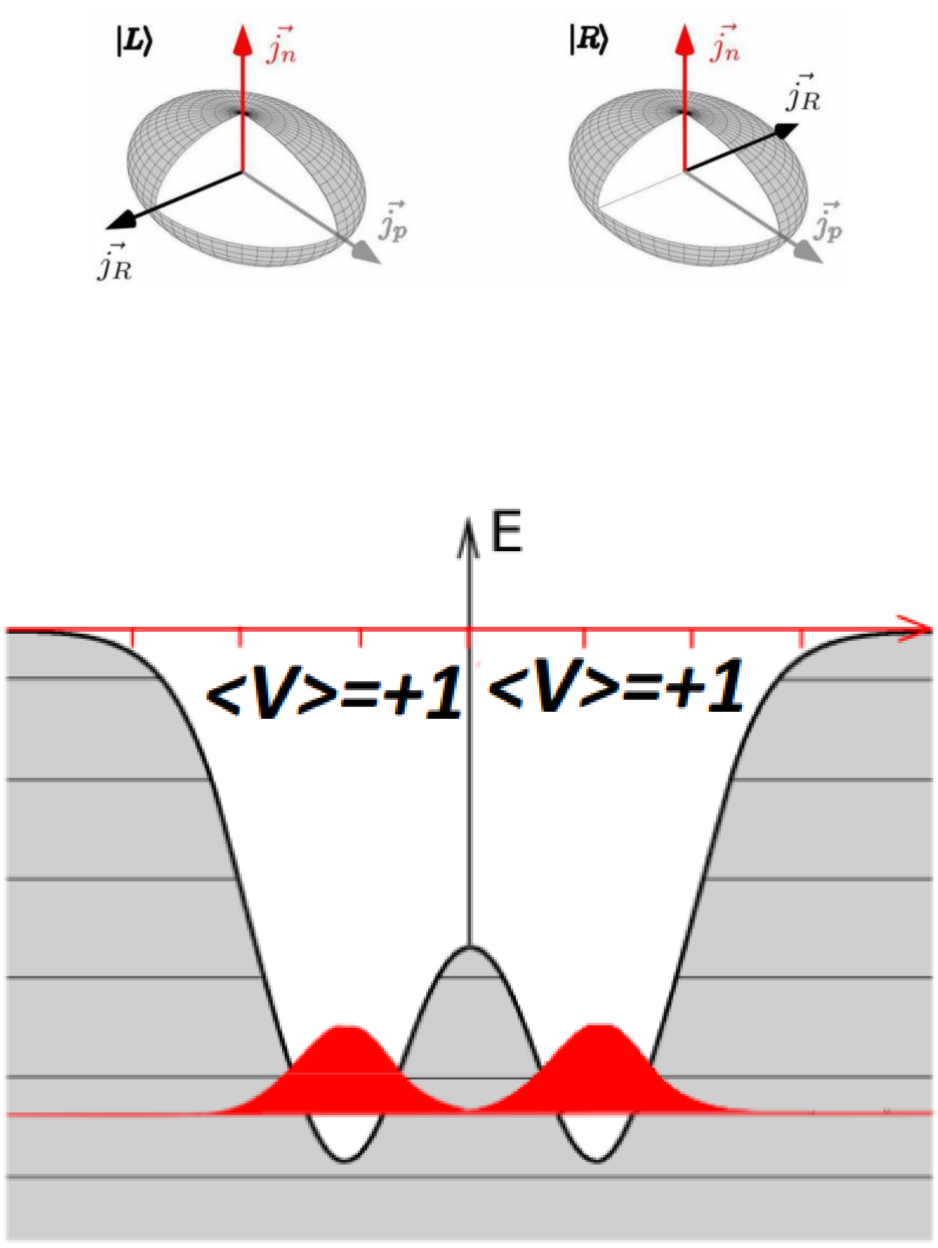


In both cases the same measured handedness value =0.0
(a hibernated cat again !)

$$<O> = \frac{(\vec{j}_\pi \times \vec{j}_\nu)\cdot \vec{j}_R}{\sqrt{j_\pi^2 j_\nu^2 j_R^2}} = 0.0$$

Expectation value of handedness
does not distinguish
the chiral and non-chiral
nucleus since handedness is a signed value.


|L⟩
|R⟩
$\vec{j}_n$
$\vec{j}_R$
$\vec{j}_p$
E
<O>=-1
<O>=+1


|L⟩
|R⟩
$\vec{j}_n$
$\vec{j}_R$
$\vec{j}_p$
E
<V>=+1
<V>=+1

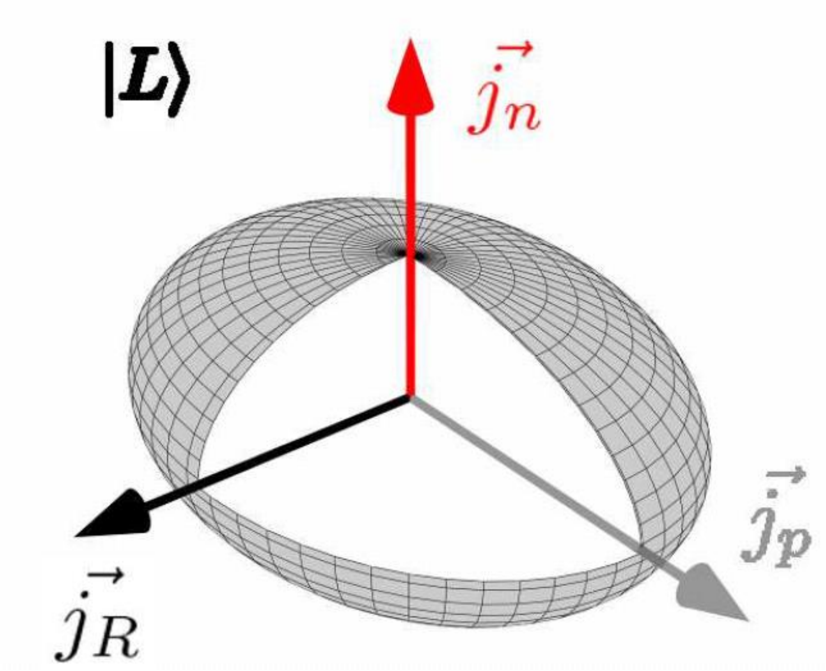
Magnetic dipole moment is a hit! Measured value: the g-factor

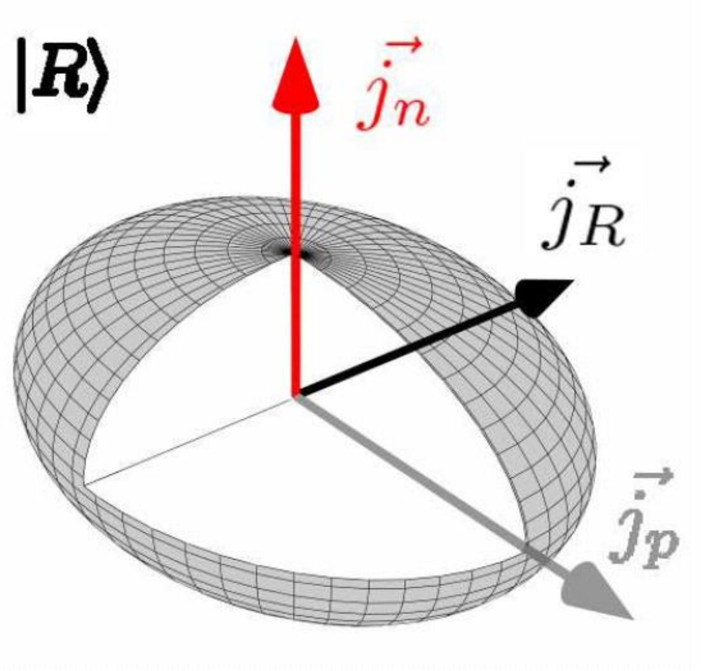
$$\frac{1}{\langle J^2 \rangle}\left(g_p\langle \vec{j}_n \cdot \vec{j}_R\rangle + g_n\langle \vec{j}_p \cdot \vec{j}_R\rangle + g_R\langle \vec{j}_p \cdot \vec{j}_n\rangle\right)$$

<g>=0 — Left handed

<g>=+0.1 — planar

<g>=0 — Right handed





First Measurement of the *g* Factor in the Chiral Band: The Case of the ^{128}Cs Isomeric State

E. Grodner,[1,2] J. Srebrny,[3] Ch. Droste,[2] L. Próchniak,[3] S. G. Rohoziński,[2] M. Kowalczyk,[3] M. Ionescu-Bujor,[4] C. A. Ur,[5] K. Starosta,[6] T. Ahn,[7] M. Kisieliński,[3] T. Marchlewski,[3] S. Aydin,[8,10] F. Recchia,[9] G. Georgiev,[11] R. Lozeva,[11] E. Fiori,[11] M. Zielińska,[3] Q. B. Chen,[12] S. Q. Zhang,[12] L. F. Yu,[12] P. W. Zhao,[12] and J. Meng[12,13]

[1]*National Centre for Nuclear Research, 05-540 Świerk, Poland*
[2]*Faculty of Physics, University of Warsaw, 02-093 Warsaw, Poland*
[3]*Heavy Ion Laboratory, University of Warsaw, 02-093 Warsaw, Poland*
[4]*Horia Hulubei National Institute for Physics and Nuclear Engineering, 077125 Bucharest, Romania*
[5]*Extreme Light Infrastructure, IFIN-HH, 077125 Bucharest, Romania*
[6]*Simon Fraser University, V5A 1S6 Vancouver, British Columbia, Canada*
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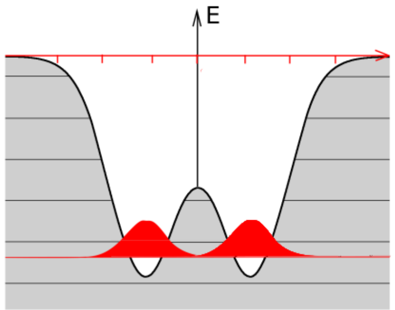
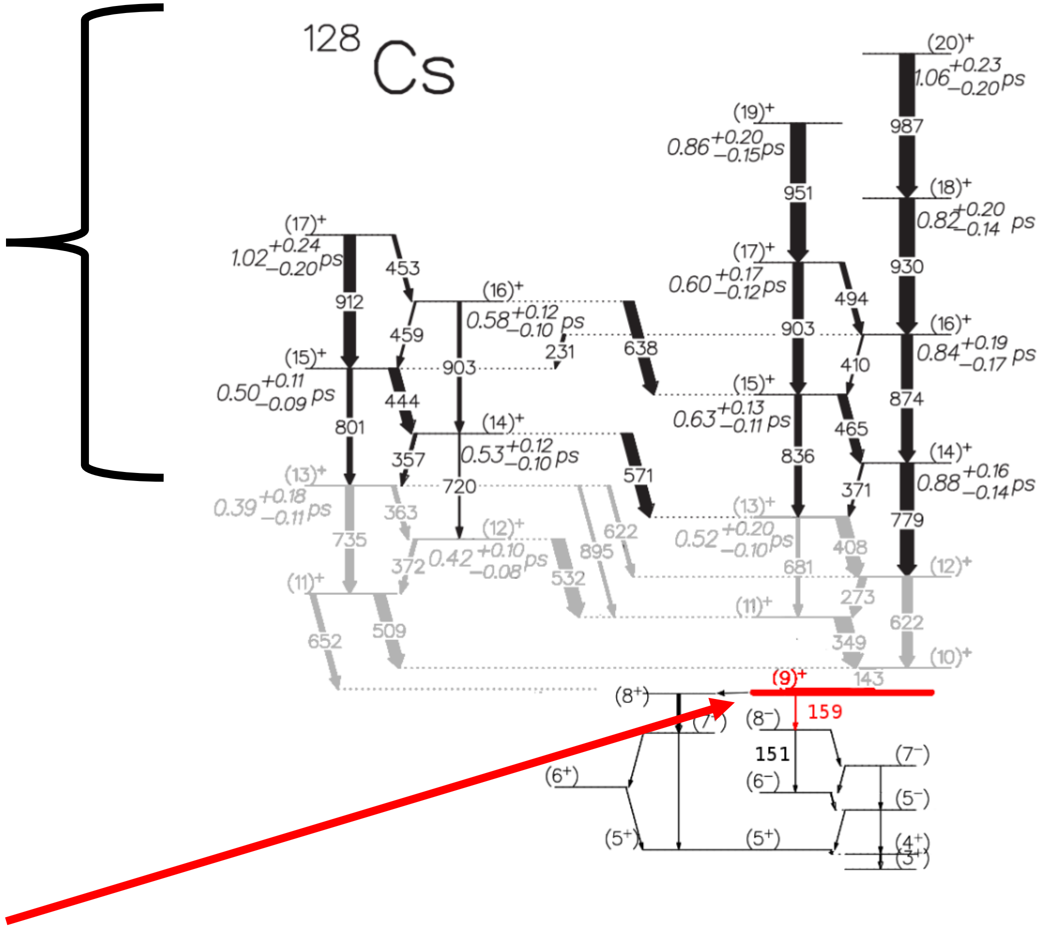
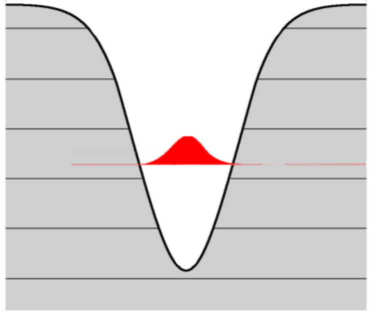
[9]*Dipartimento di Fisica dell'Università di Padova and INFN sez. Padova, I-35131 Padova, Italy*
[10]*Department of Physics, Aksaray University, 68100 Aksaray, Turkey*
[11]*CSNSM, Univ. Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, 91405 Orsay, France*
[12]*State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China*
[13]*Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan*

Chiral





Non-chiral



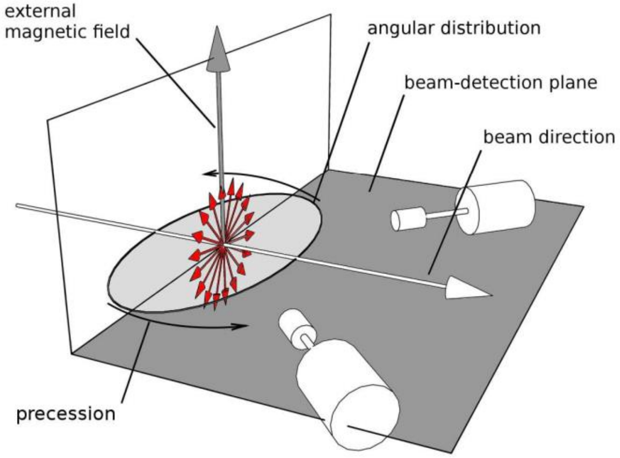
PHYSICAL REVIEW C
covering nuclear physics

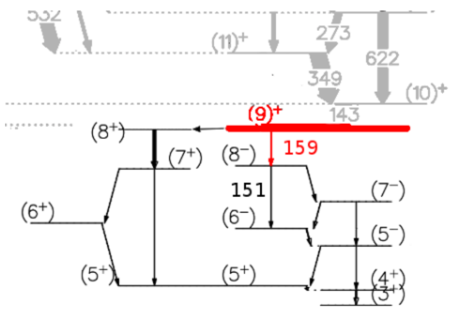
Examination of nuclear chirality with a magnetic moment measurement of the $I = 9$ isomeric state in $^{128}\mathrm{Cs}$

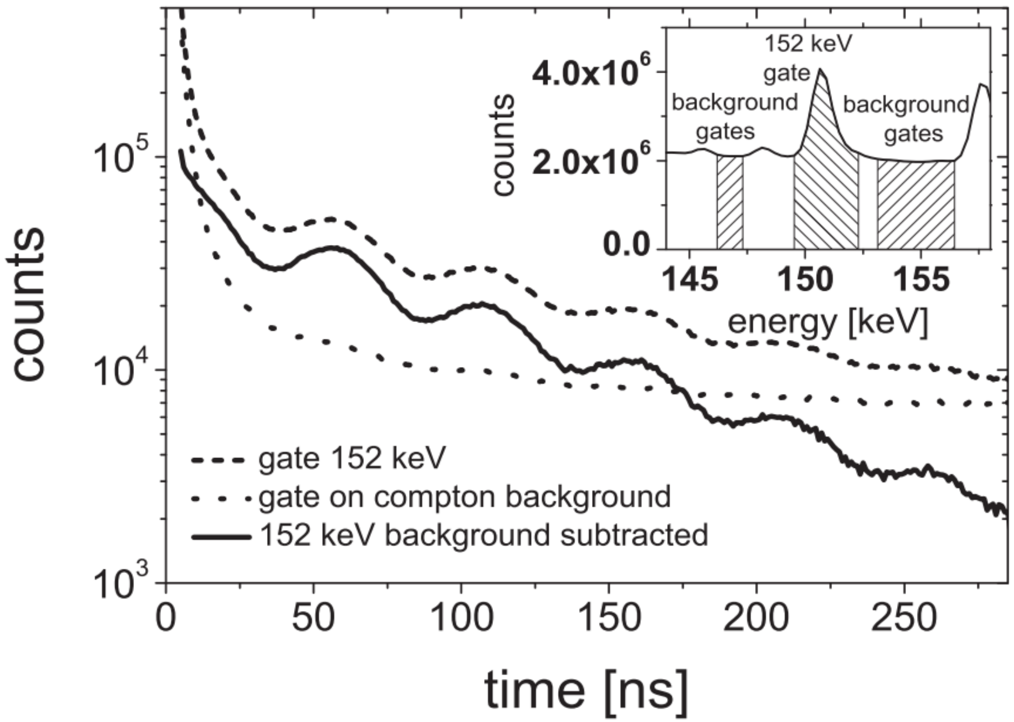
E. Grodner, M. Kowalczyk, M. Kisieliński, J. Srebrny, L. Próchniak, Ch. Droste, S. G. Rohoziński, Q. B. Chen, M. Ionescu-Bujor, C. A. Ur, F. Recchia, J. Meng, S. Q. Zhang, P. W. Zhao, G. Georgiev, R. Lozeva, E. Fiori, S. Aydin, and A. Nałęcz-Jawecki

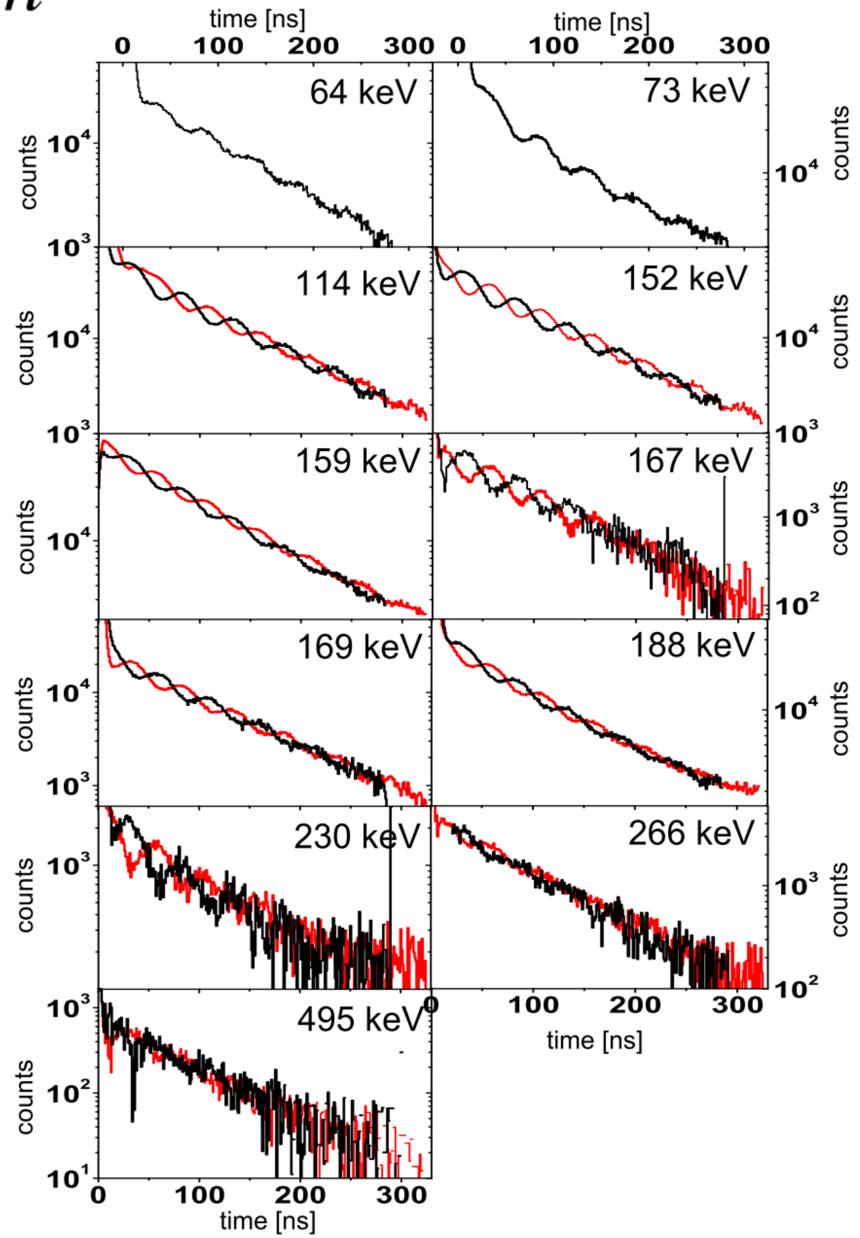
Phys. Rev. C **106**, 014318 – Published 28 July 2022

$$\omega_L = -g\mathbf{B}\mu_N/\hbar$$









FRONTIERS OF PHYSICS

TOPICAL REVIEW
Volume / Issue / / 2024

The *g*-factor measurement as an ultimate test for nuclear chirality

Ernest Grodner[1,†], Michał Kowalczyk[2,‡], Julian Srebrny[2,§], Leszek Próchniak[2,¶], Chrystian Droste[3,**], Jan Kownacki[2], Maciej Kisieliński[2,††], Krzysztof Starosta[4,‡‡], Takeshi Koike[5]

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5 Department of Physics, Tohoku University, Sendai, Miyagi 980-8577, Japan
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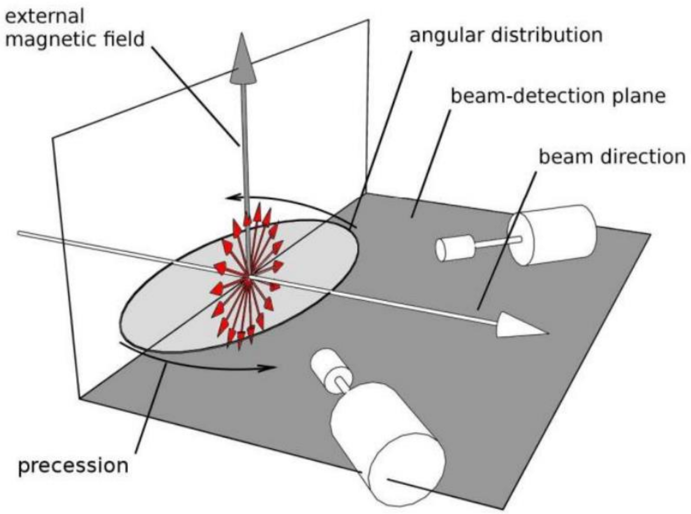
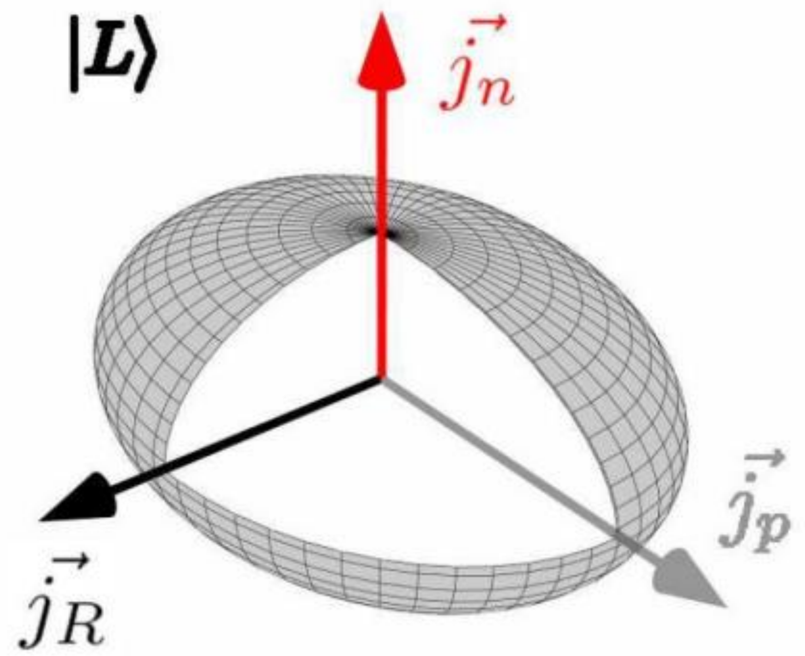
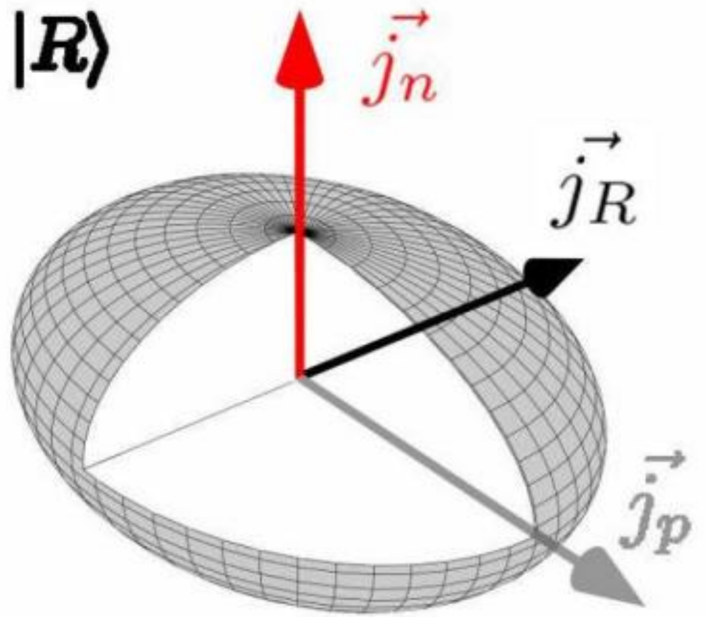


Nuclear chirality

$$R_\pi T|L\rangle = |R\rangle$$

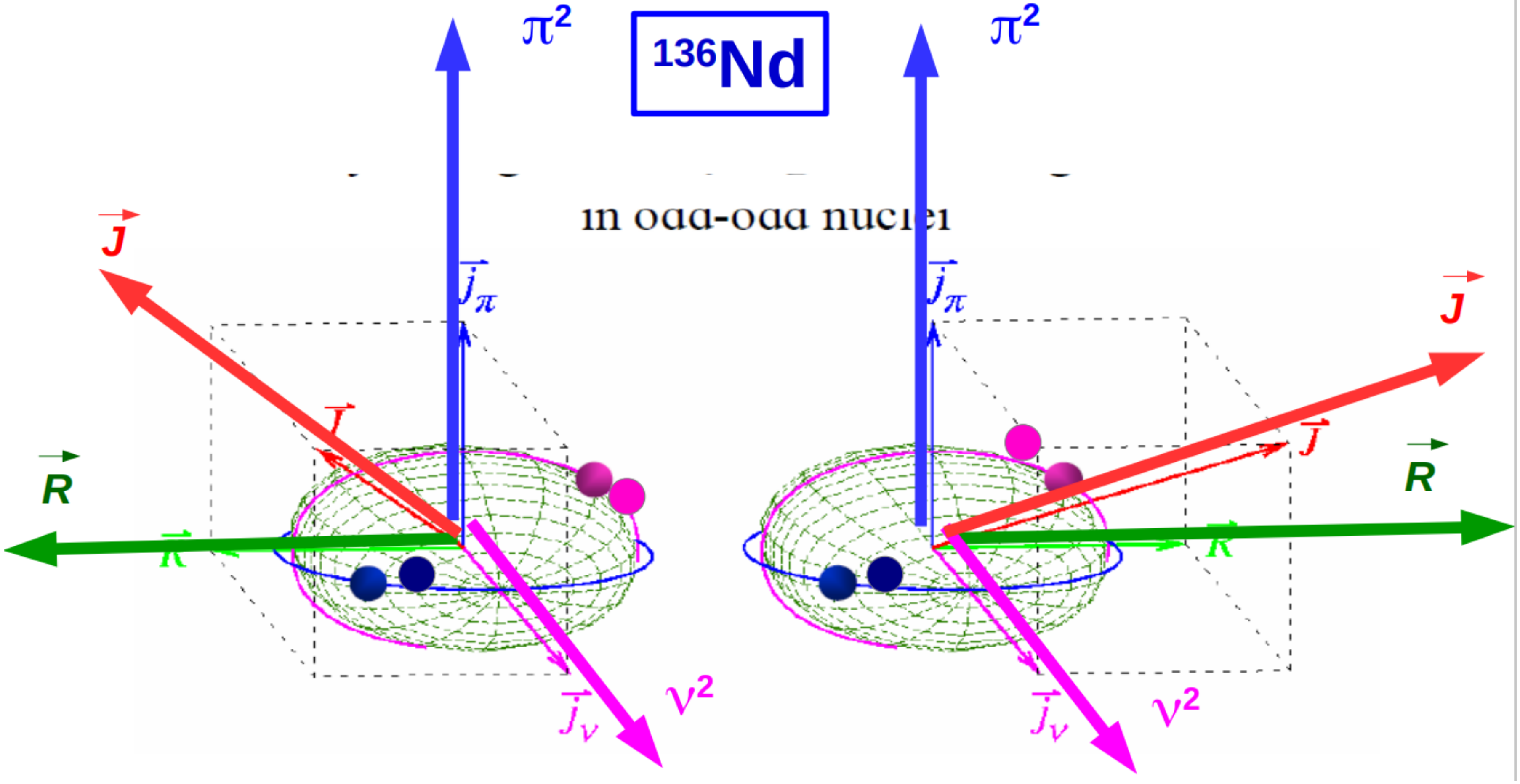
odd-odd nuclei
even-even core (triaxially deformed)
odd proton (particle)
odd neutron (hole)





Credit:
C. Petrache

Chirality in even-even nuclei: 4-qp configurations

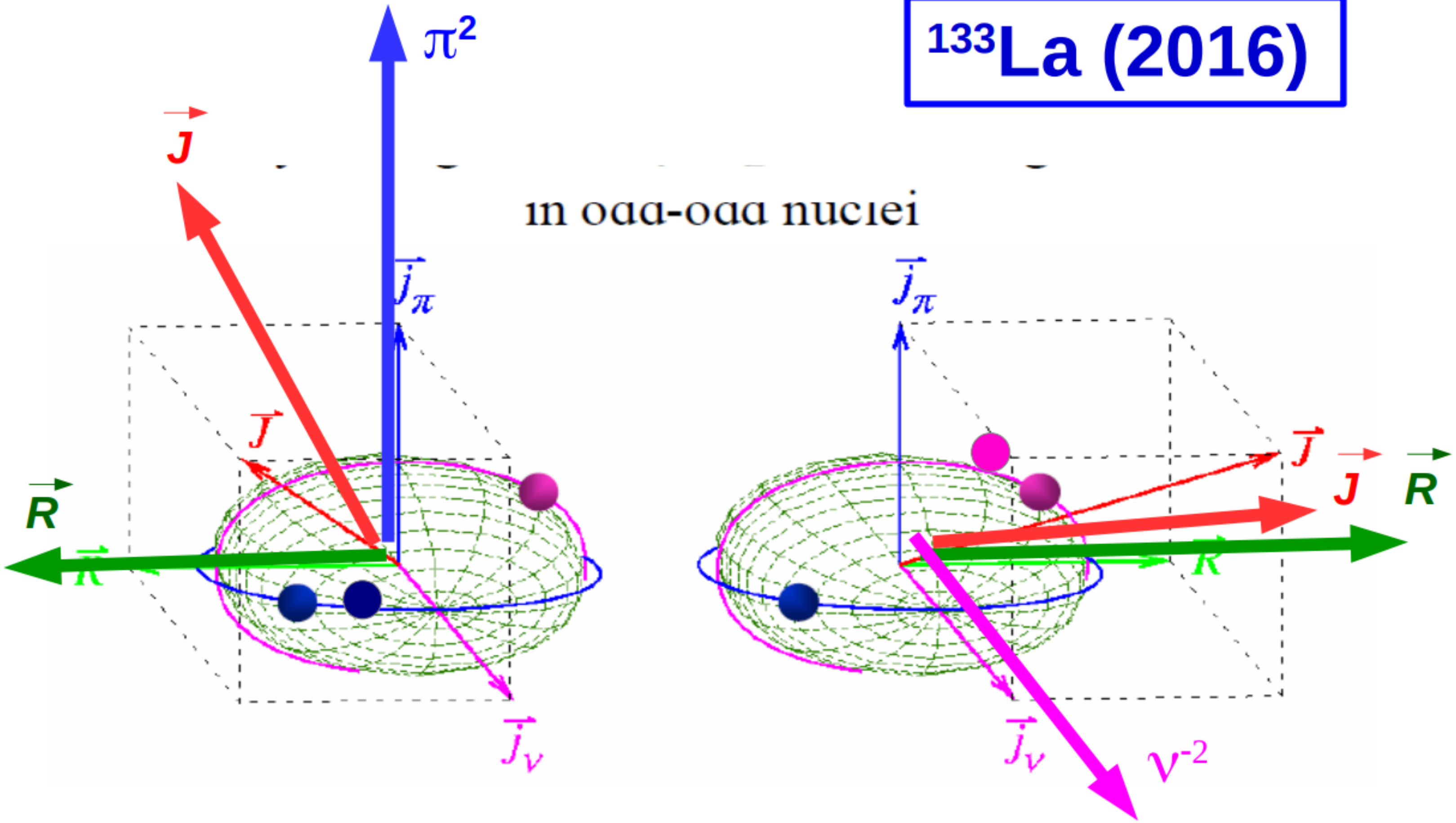


Credit:
C. Petrache

Chirality in odd-even nuclei: 3-qp (π^2&ν^{-1} or π^1&ν^{-2}) configurations

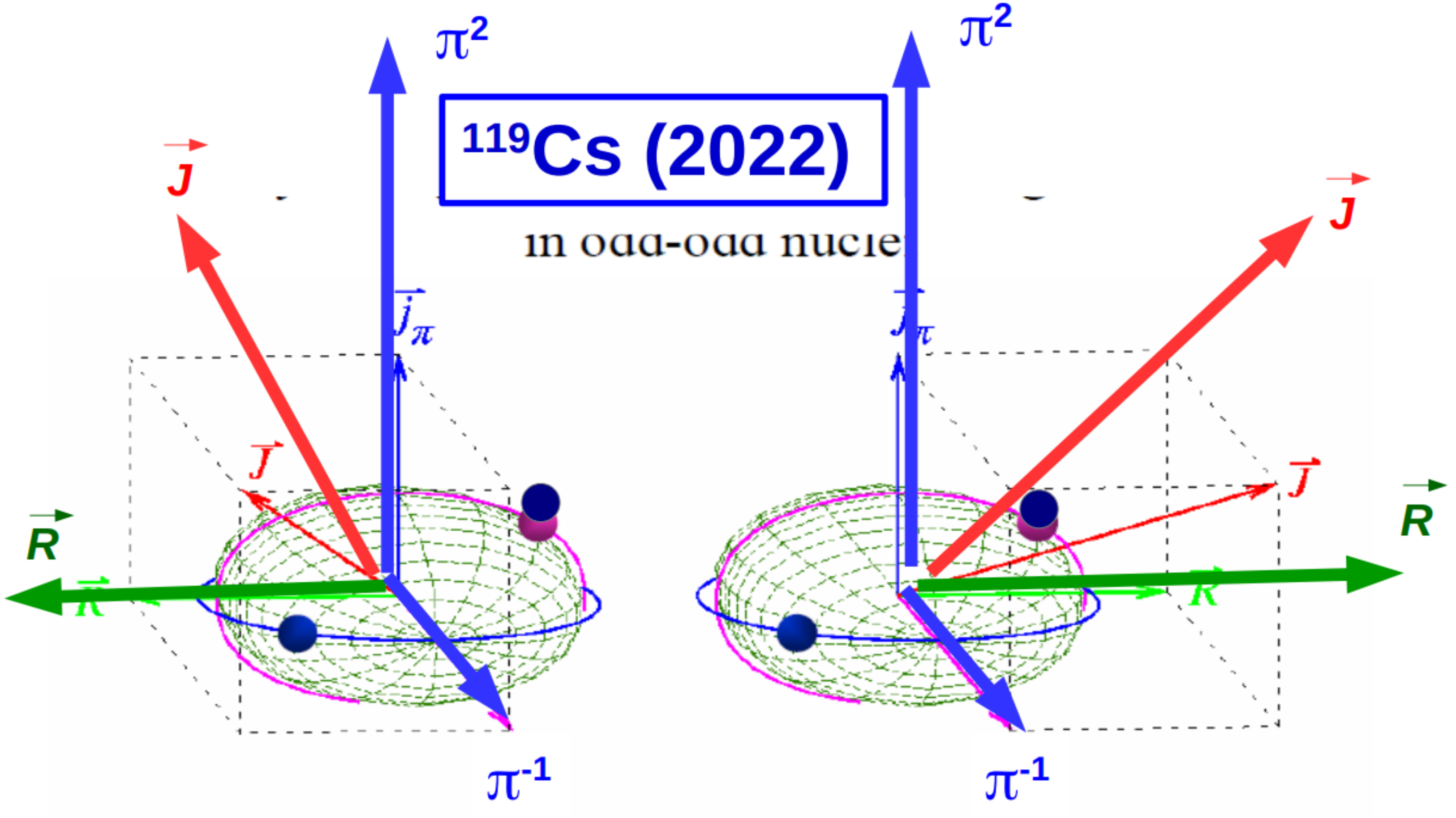
^{135,137}Nd (2019), ^{131}Ba (2020)

^{133}La (2016)



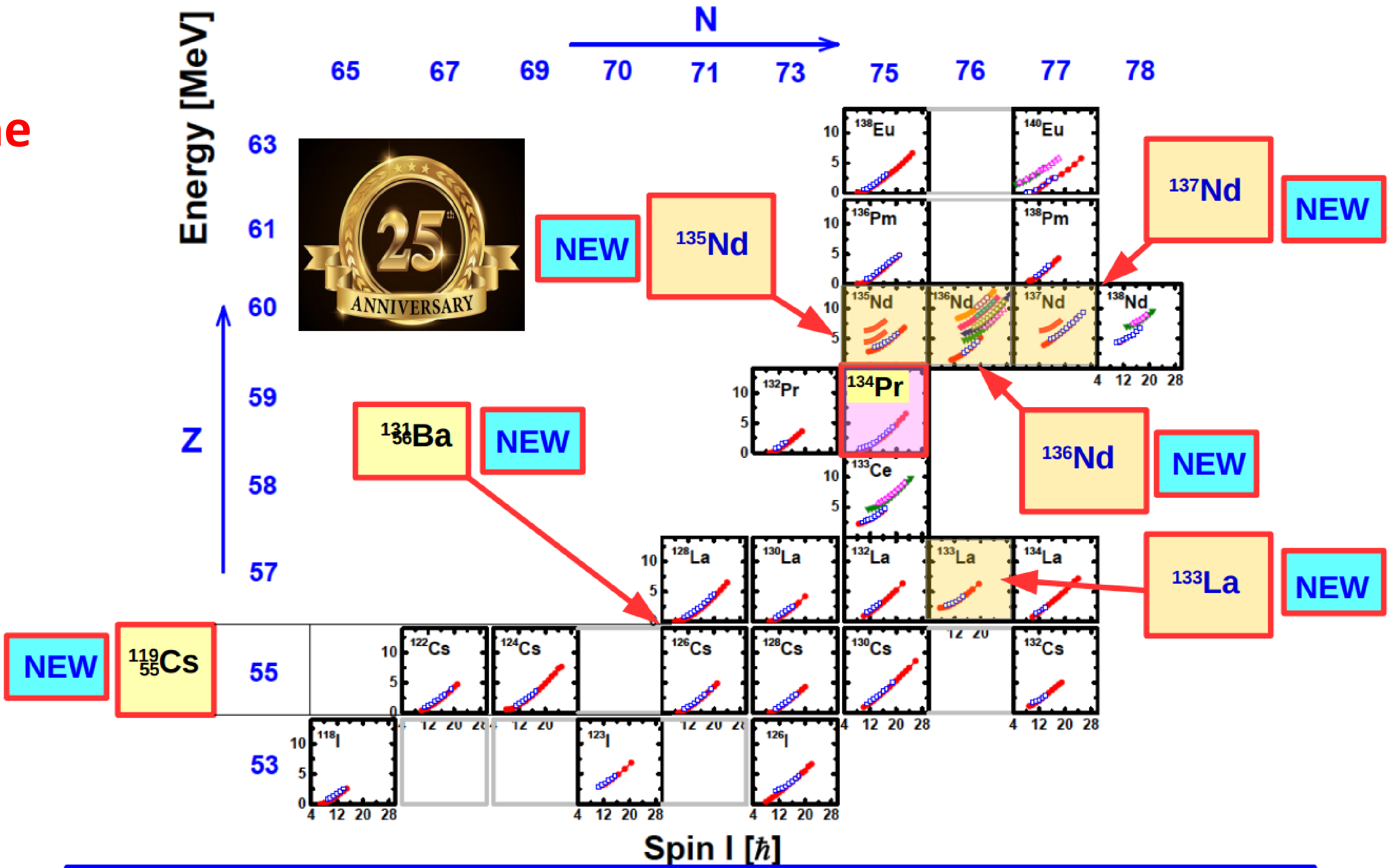
Credit:
C. Petrache

Chirality with identical particles: 3-protons (π^2& π^{-1})

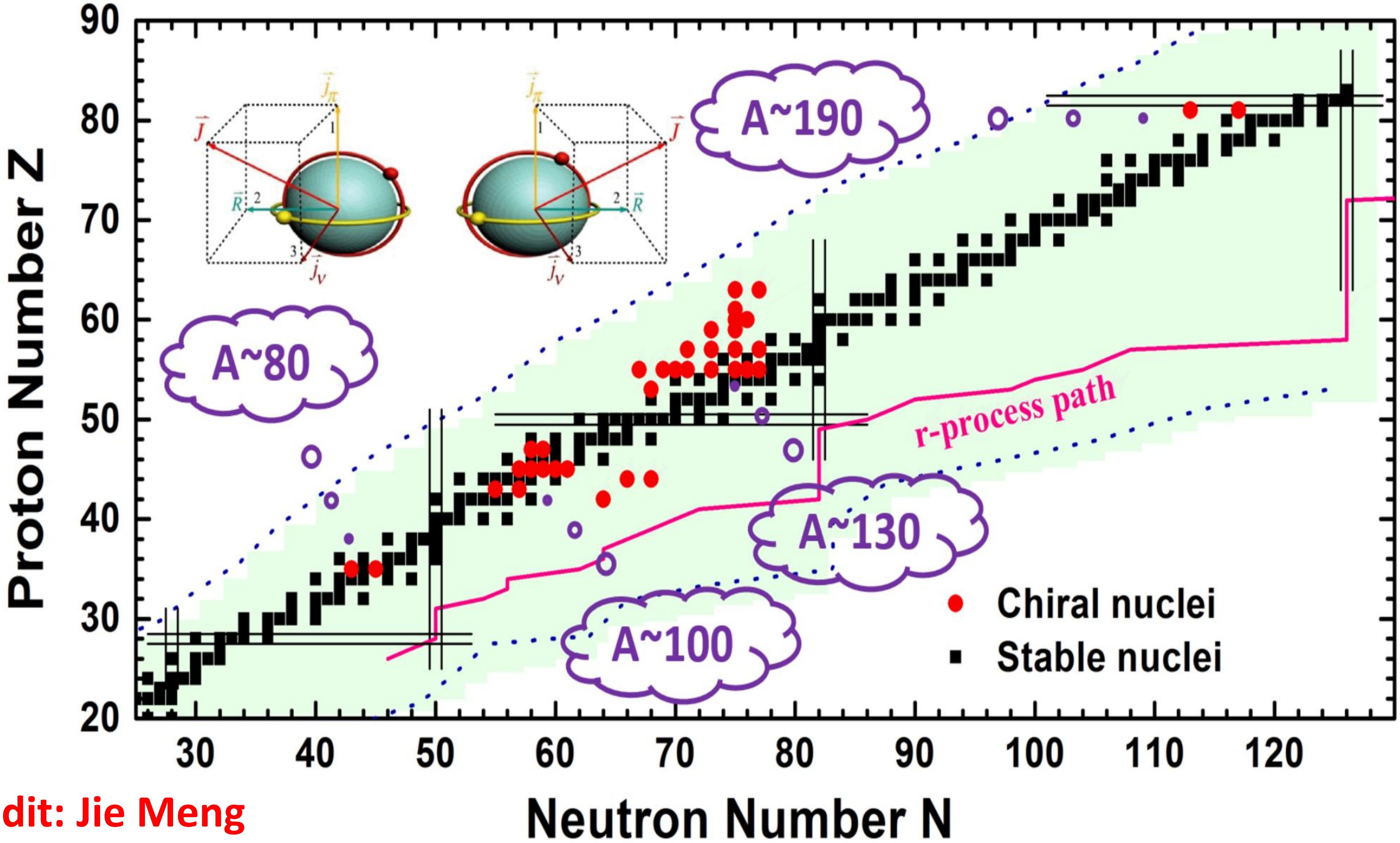


25 Anniversary of chiral bands (1997-2022)

Credit:
C. Petrache



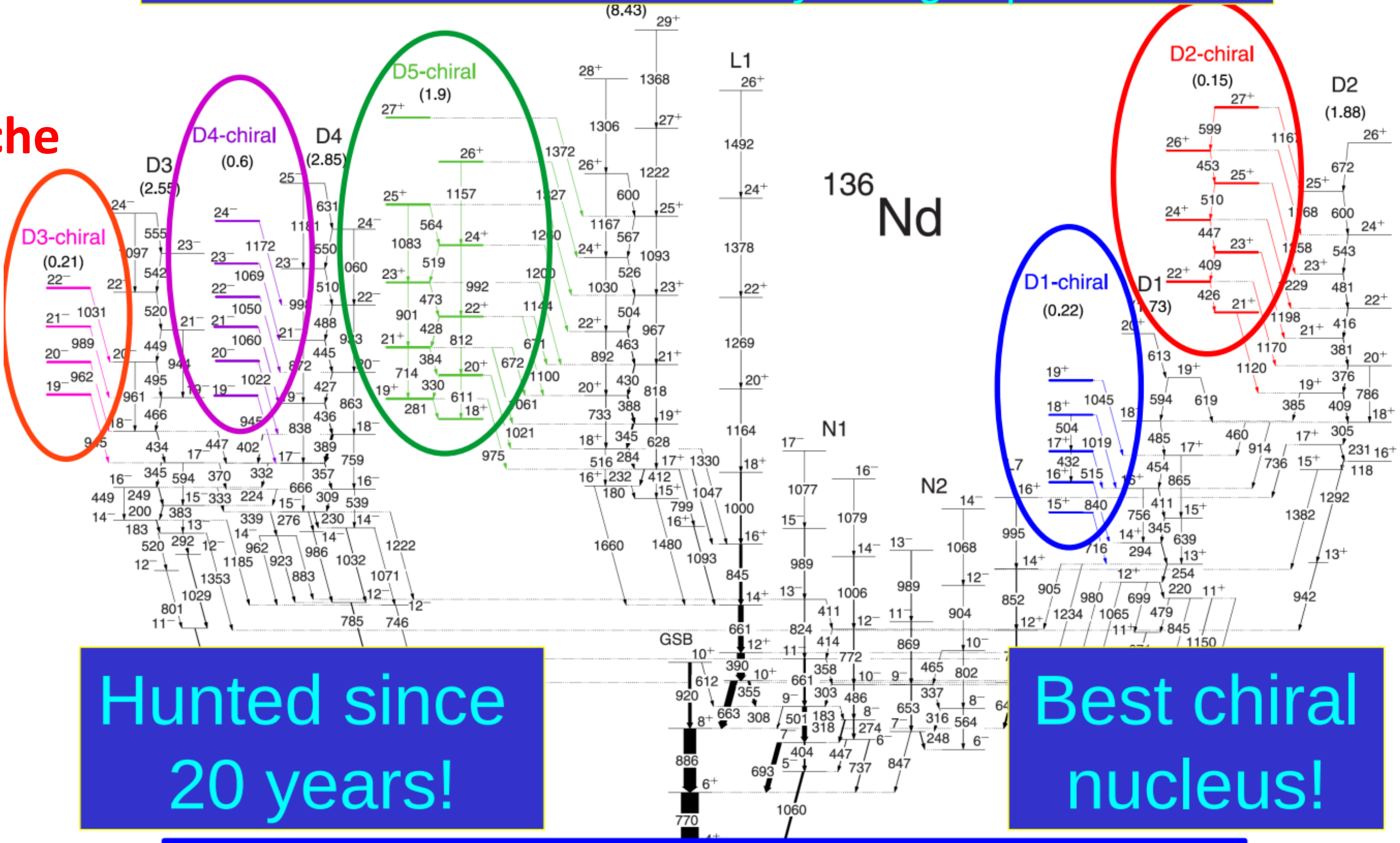
B.W. Xiong, Y.Y. Wang, ADNDT 125 (2018) 193: Nuclear chiral bands data tables



Credit: Jie Meng

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

Credit:
C. Petrache



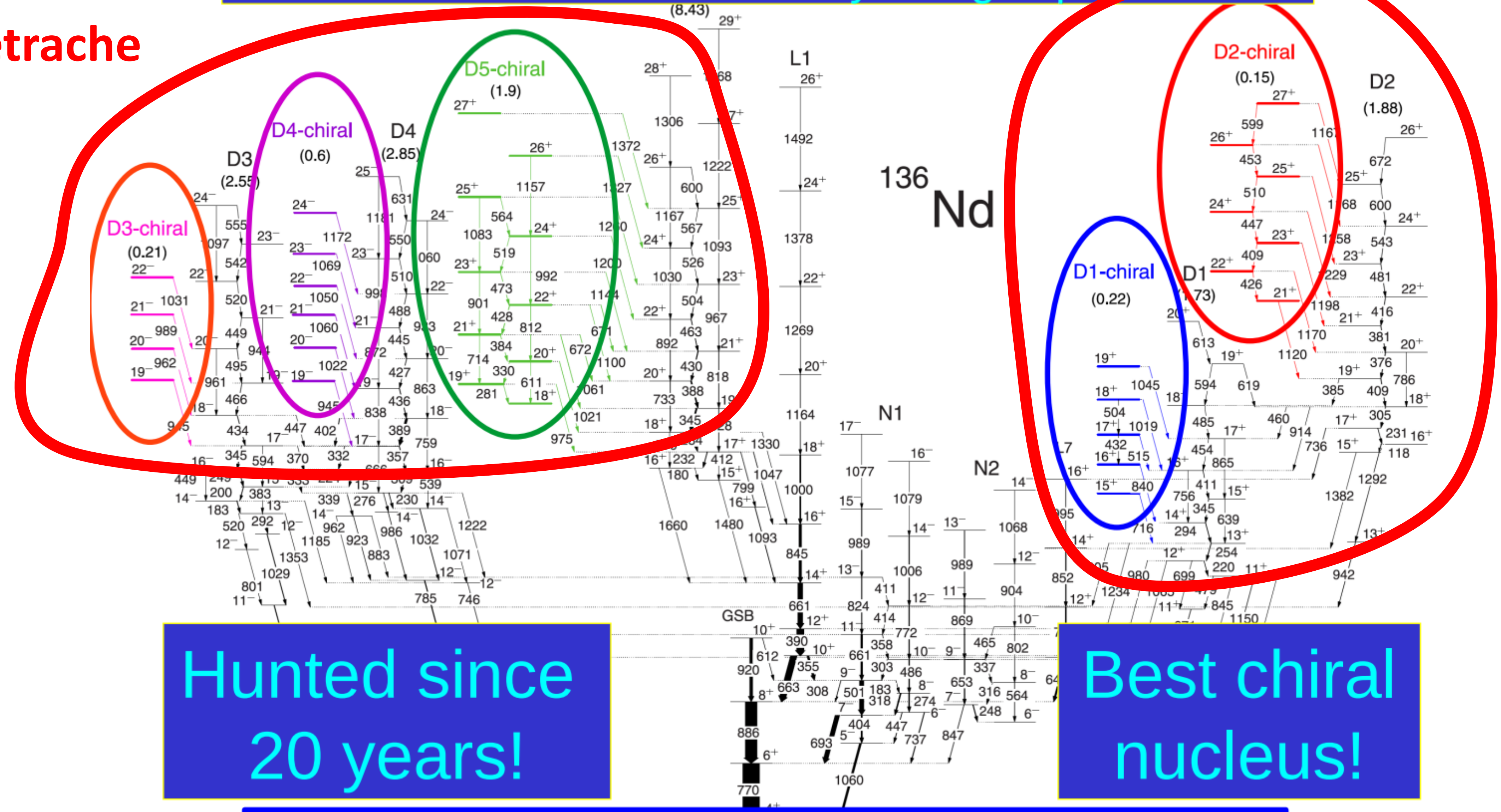
Hunted since 20 years!

Best chiral nucleus!

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

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

Credit:
C. Petrache



Hunted since 20 years!

Best chiral nucleus!

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

北京大學 PEKING UNIVERSITY

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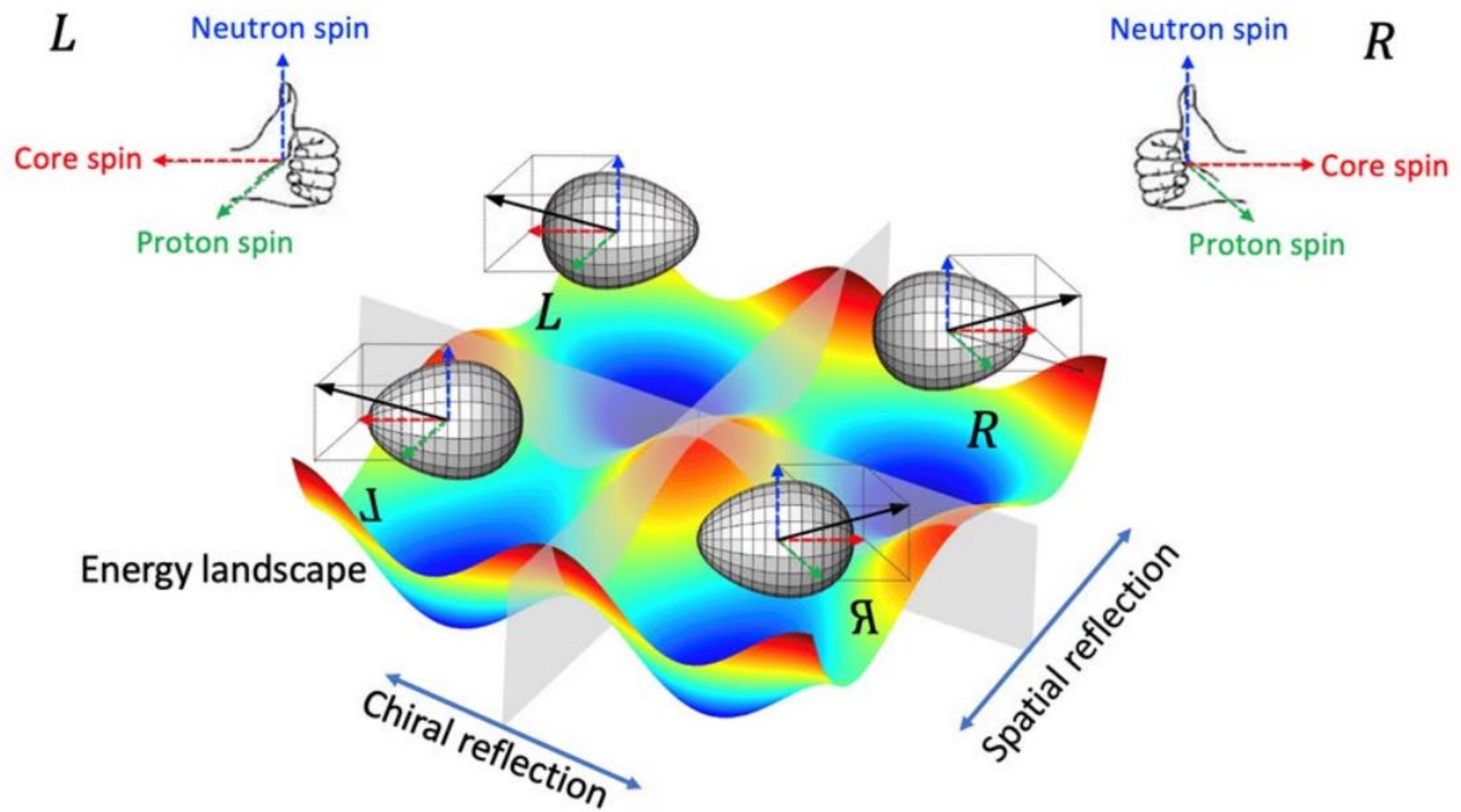
Article

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]

[a] State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China
[b] School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China
[c] Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan

Credit:
Jie Meng

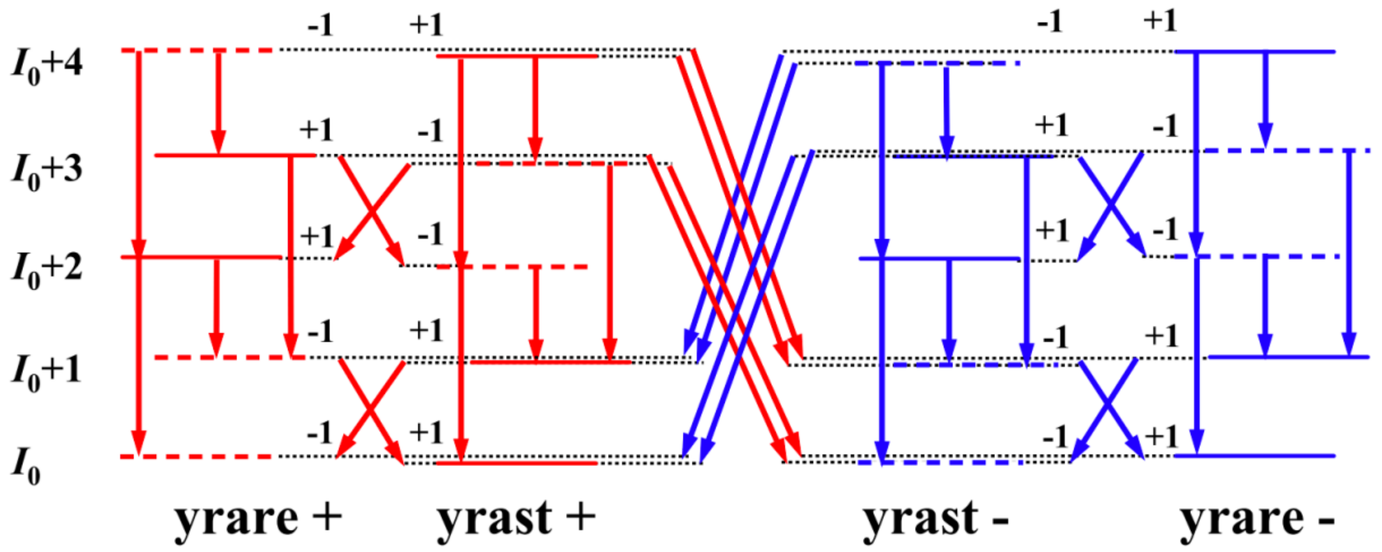


Nuclear Chirality-Parity (ChP) violation

ChP 四重带

Credit:
Jie Meng

从角动量 I_0 下的正、负宇称能量最低态（yrast state）和次低态（yrare state）出发，根据带内 $E2$ 连接得到两对宇称相反的手征双重带，即**ChP** 四重带



- ✓ 自旋增加 $2\hbar$，$\mathcal{B}$ 变号：带内 $E2$ 允许、带间 $E2$ 禁戒
- ✓ 带内和带间的 $M1$ 均随自旋增加交替出现
- ✓ $E3$ 跃迁随自旋增加交替出现，即 yrast+ ↔ yrast-，yrare+ ↔ yrare- 和 yrast+ ↔ yrare-, yrare+ ↔ yrast-


CWAN'23
International Conference on
Chirality and Wobbling in Atomic Nuclei
Huizhou (China), July 10 - 14, 2023
Theme of the Conference
Dynamics and statics of nuclear triaxiality
Topics:
Chirality and Wobbling:
Theoretical approaches
Experimental evidence
Collective modes:
Nature of triaxiality
Large scale diagonalization
Very neutron rich nuclei
Organizing Committee
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Advisory Committee
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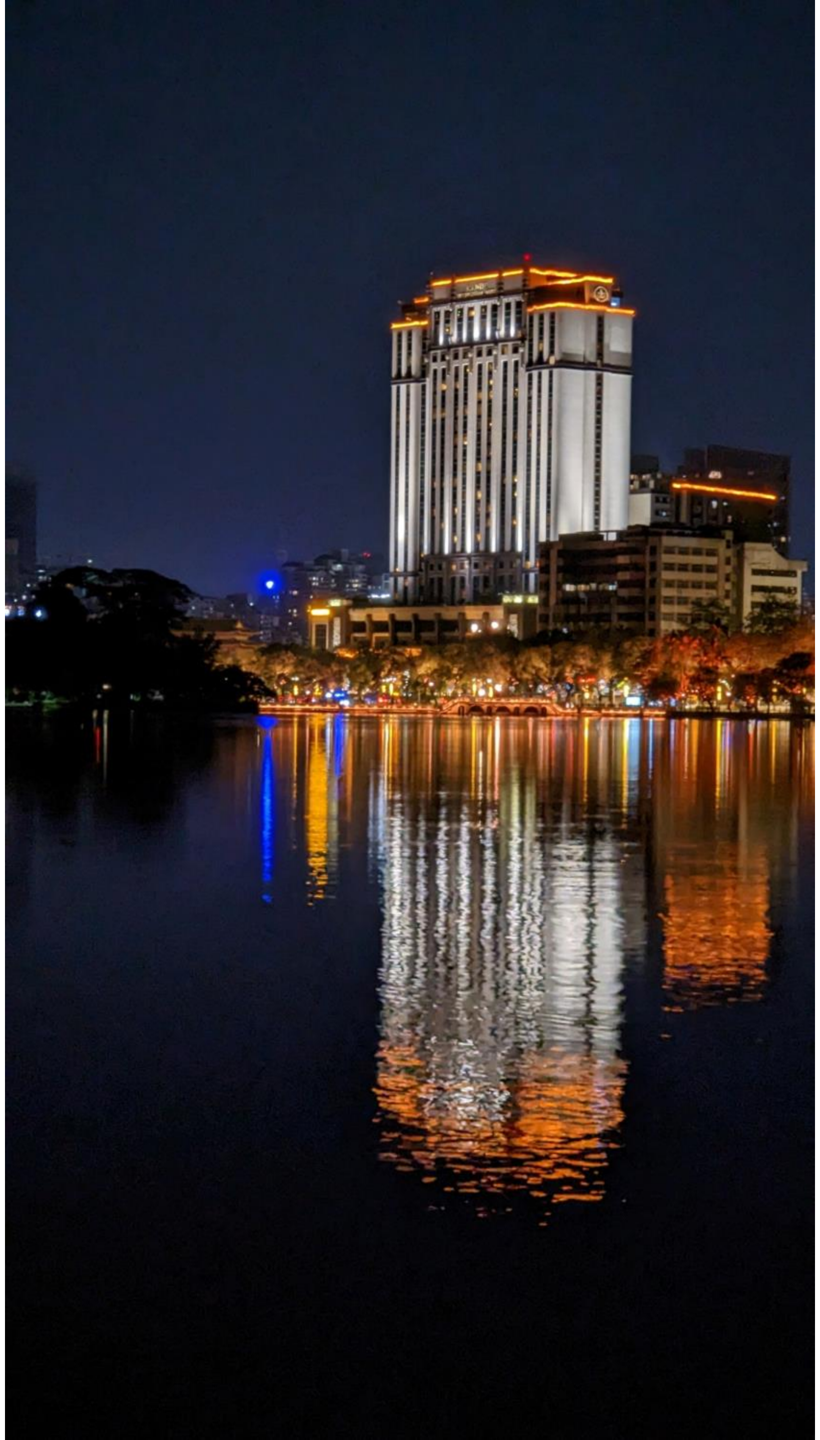
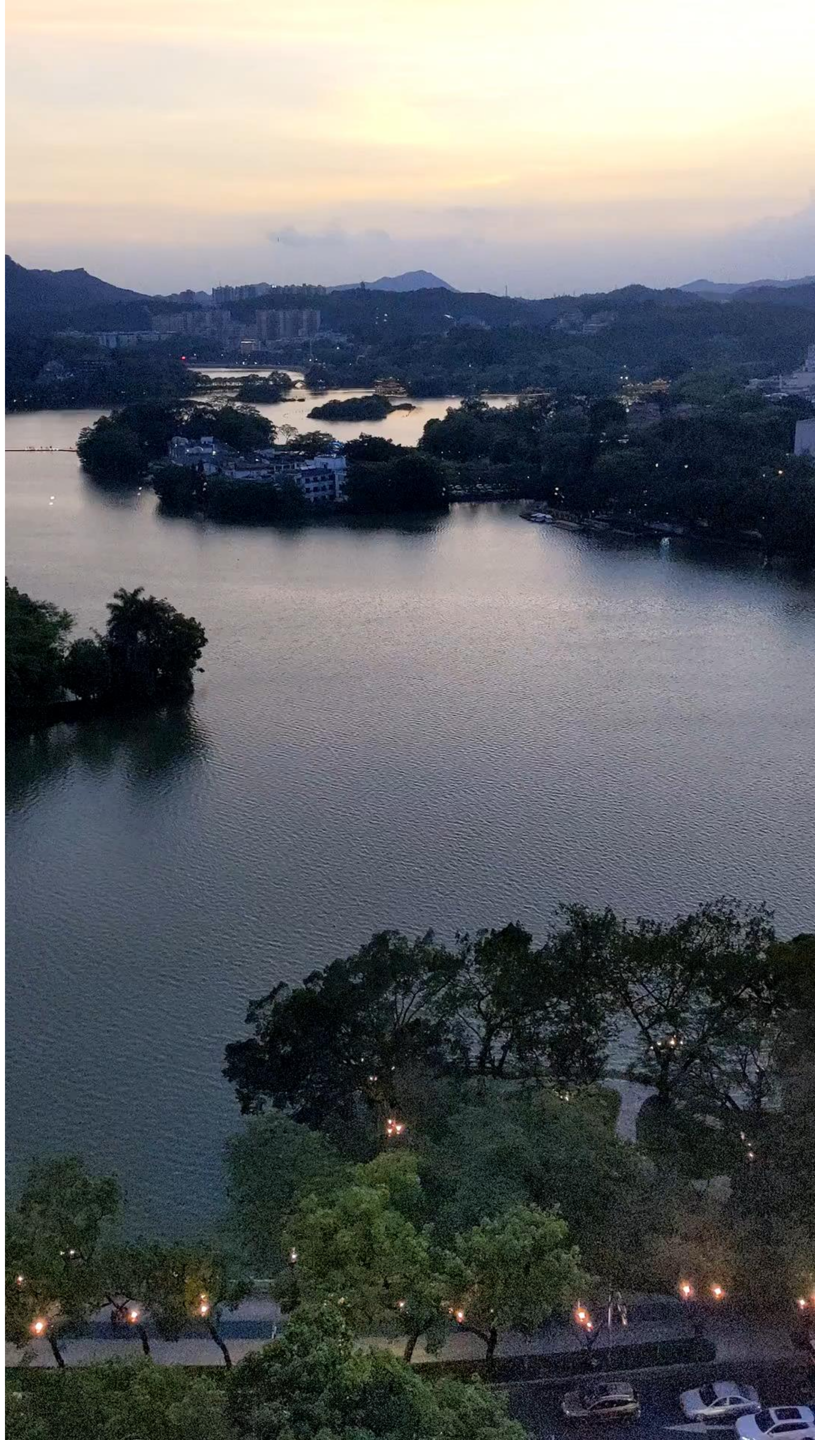

Credit:
Jie Meng

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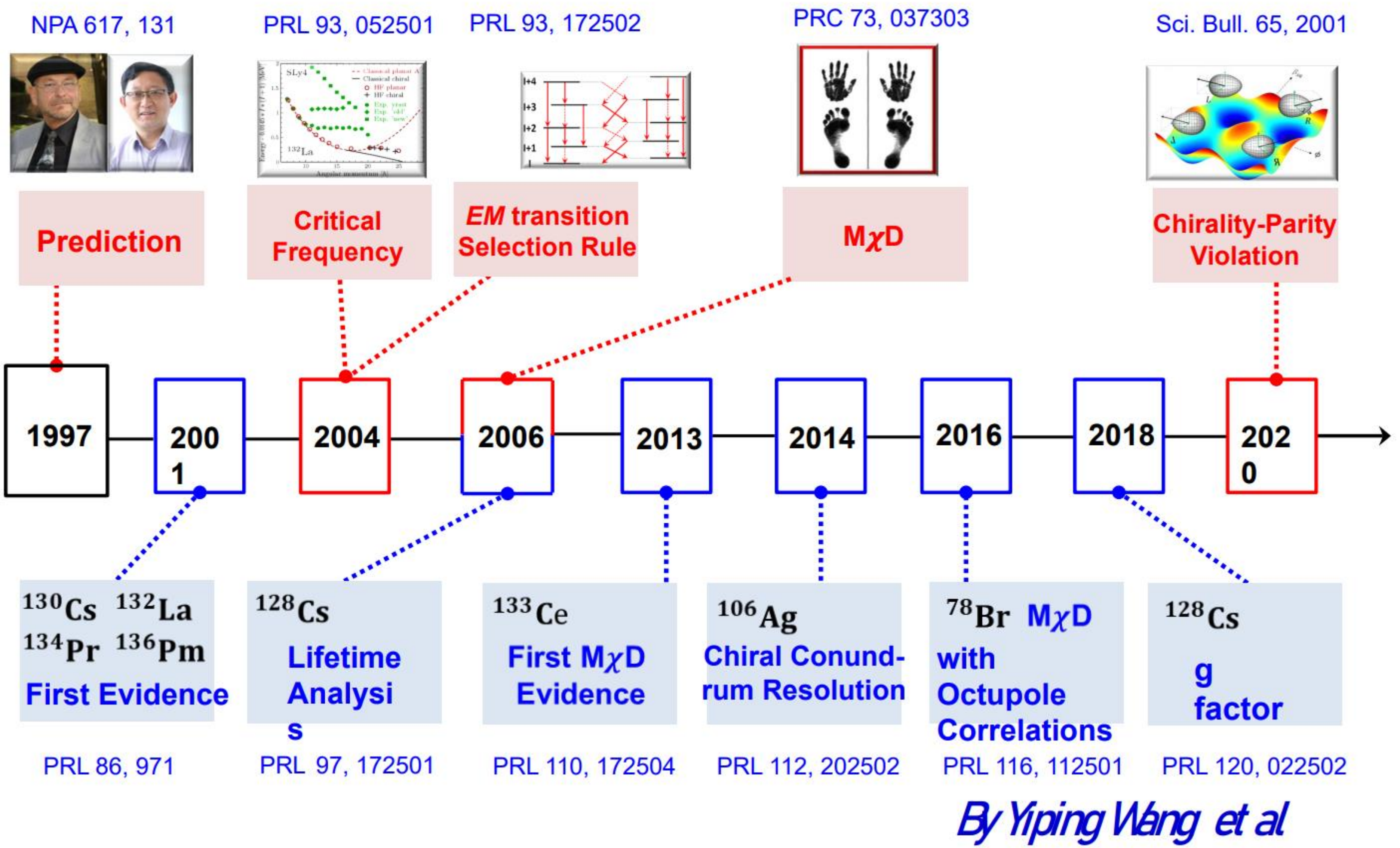
Timeline for nuclear chirality

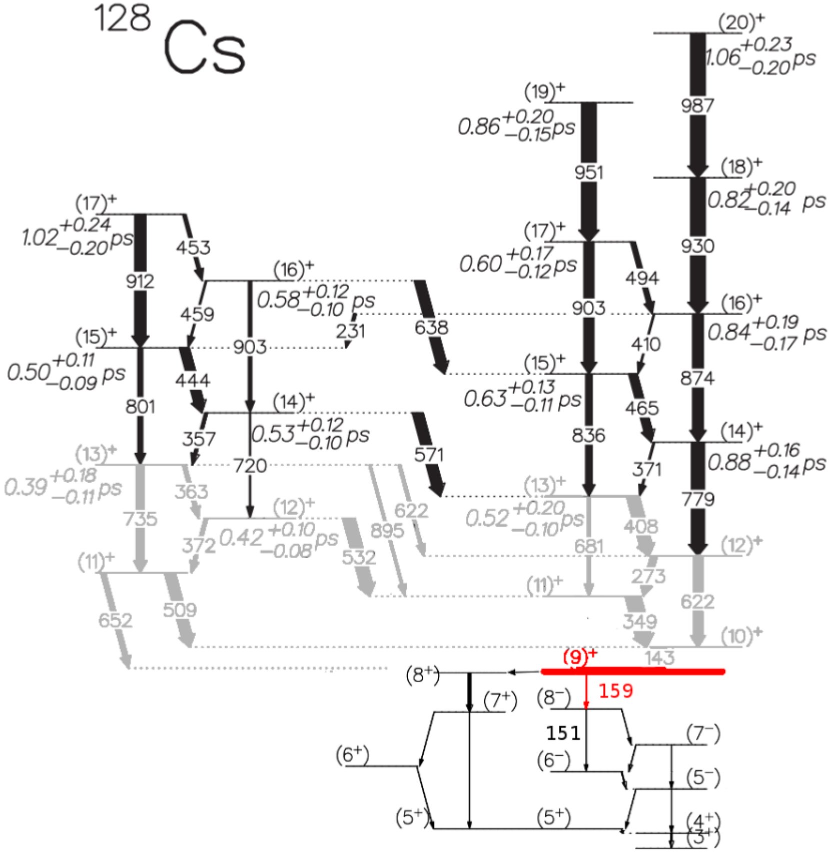


Future:

How chirality emerges?

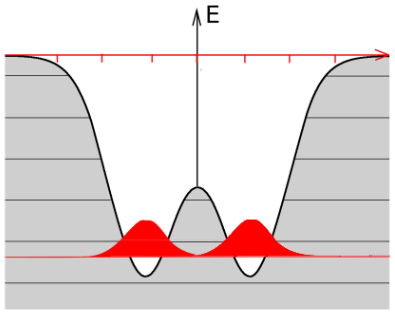
Non-chiral to chiral transition as a function of spin

Plunger experiments in low spin chiral bands

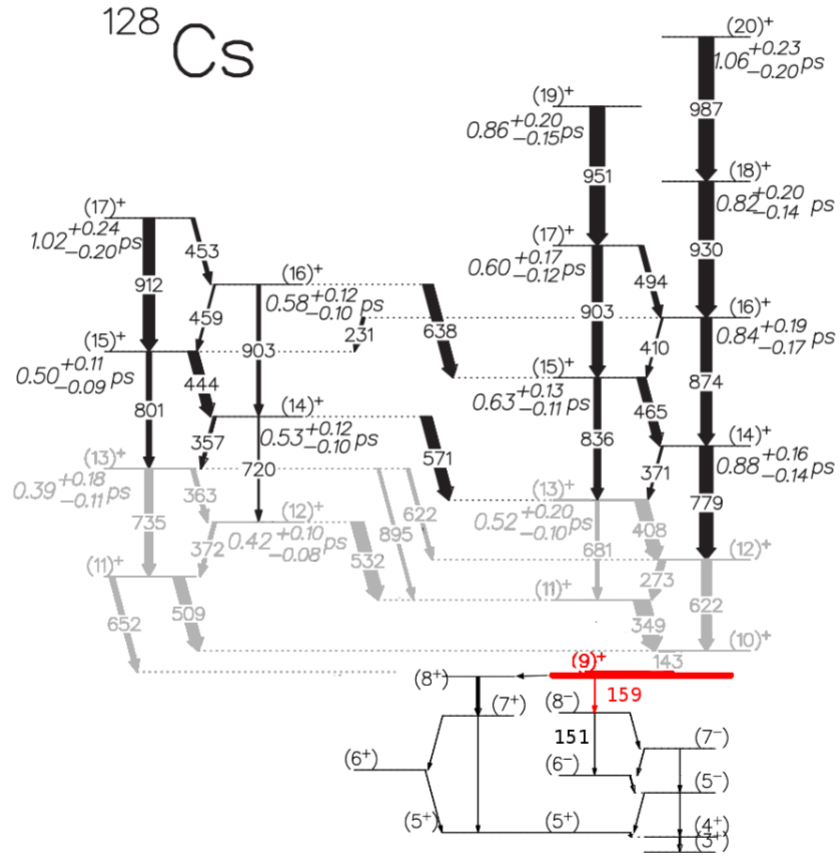


128Cs
(20)+
1.06 +0.23 −0.20 ps
987
(19)+
0.86 +0.20 −0.15 ps
951
(18)+
0.82 +0.20 −0.14 ps
930
(17)+
1.02 +0.24 −0.20 ps
912
453
(17)+
0.60 +0.17 −0.12 ps
494
(16)+
0.58 +0.12 −0.10 ps
459
903
231
638
903
(16)+
0.84 +0.19 −0.17 ps
410
(15)+
0.50 +0.11 −0.09 ps
444
(15)+
0.63 +0.13 −0.11 ps
874
465
801
(14)+
0.53 +0.12 −0.10 ps
357
720
571
836
(14)+
0.88 +0.16 −0.14 ps
371
(13)+
0.39 +0.18 −0.11 ps
363
(13)+
0.52 +0.20 −0.10 ps
779
735
622
(12)+
0.42 +0.10 −0.08 ps
372
532
895
408
681
(12)+
(11)+
273
(11)+
622
652
509
349
(10)+
143
(9)+
(8+)
159
(7+)
(8−)
151
(7−)
(6+)
(6−)
(5−)
(5+)
(5+)
(4+)
(3+)

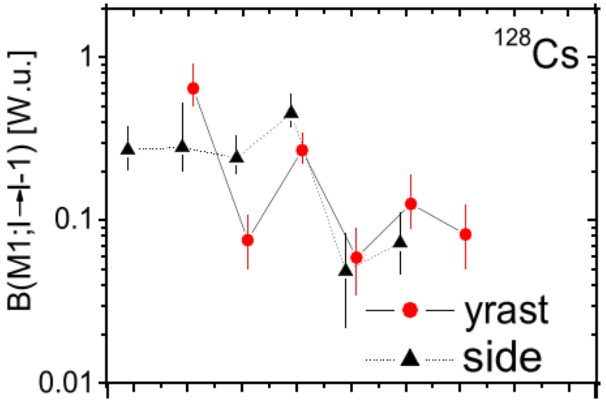
Chiral



E

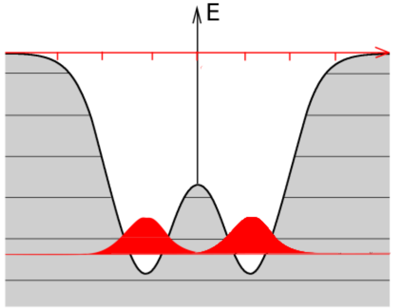


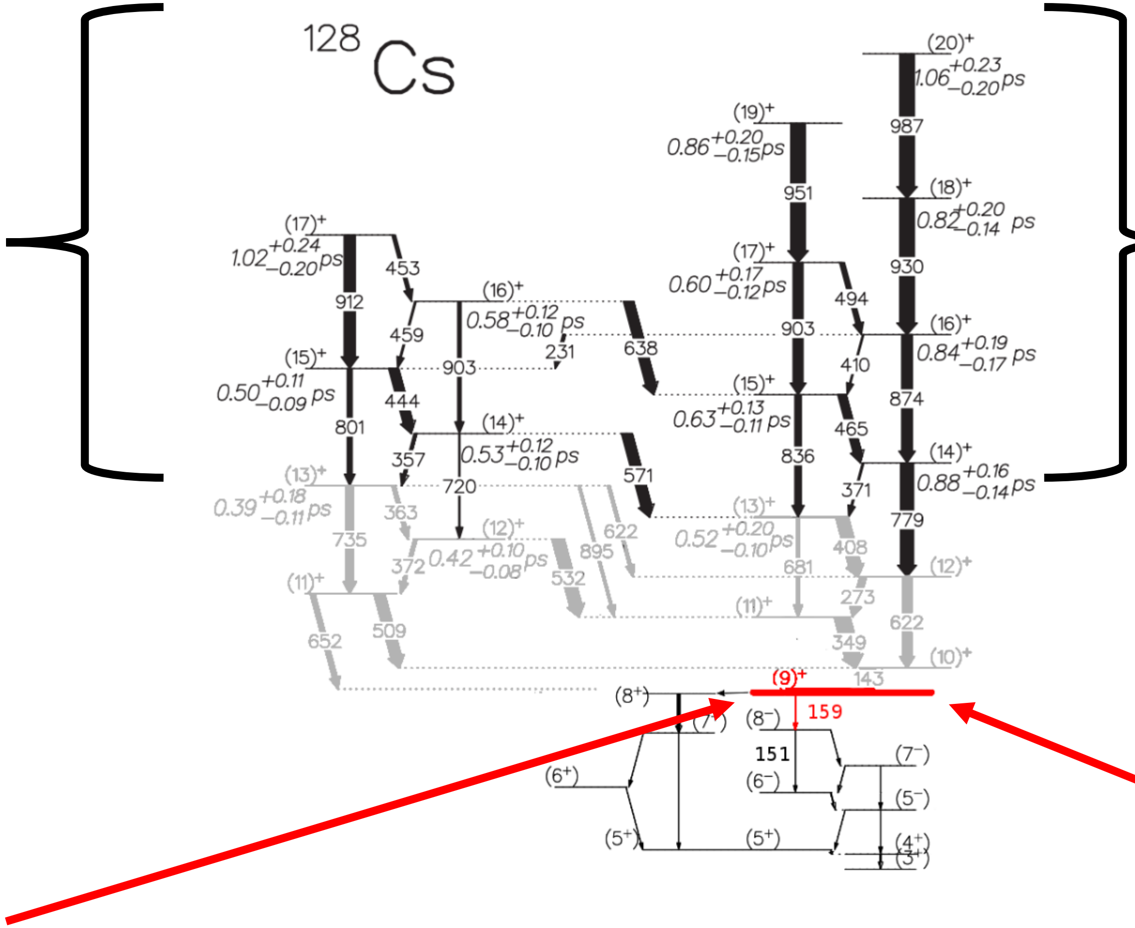
128Cs
(17)+
(16)+
(15)+
(14)+
(13)+
(12)+
(11)+
(10)+
(9)+
(8+)
(7+)
(6+)
(5+)
(8−)
(7−)
(6−)
(5−)
(4+)
(3+)
(18)+
(19)+
(20)+
159
151

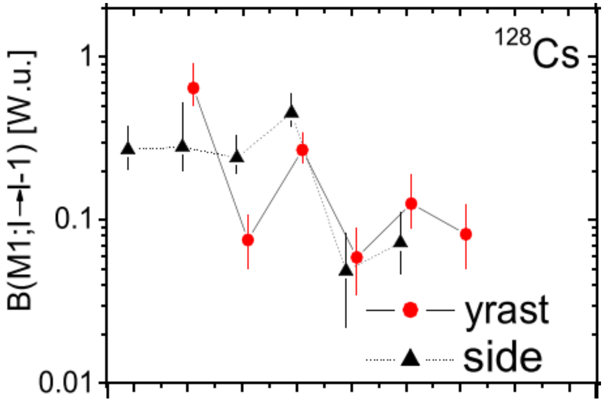


128Cs
B(M1;I→I-1) [W.u.]
1
0.1
0.01
yrast
side

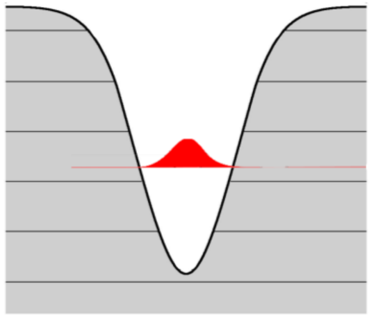
Chiral

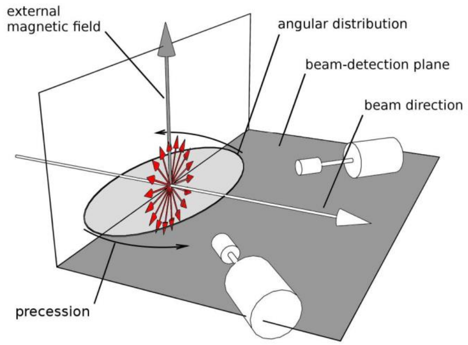




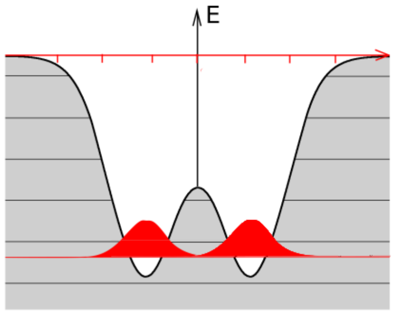


Non-chiral

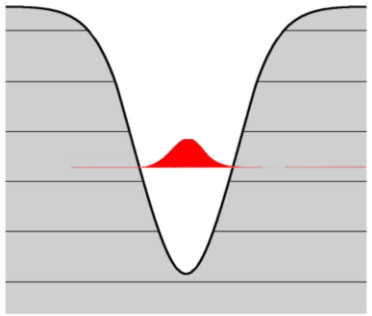


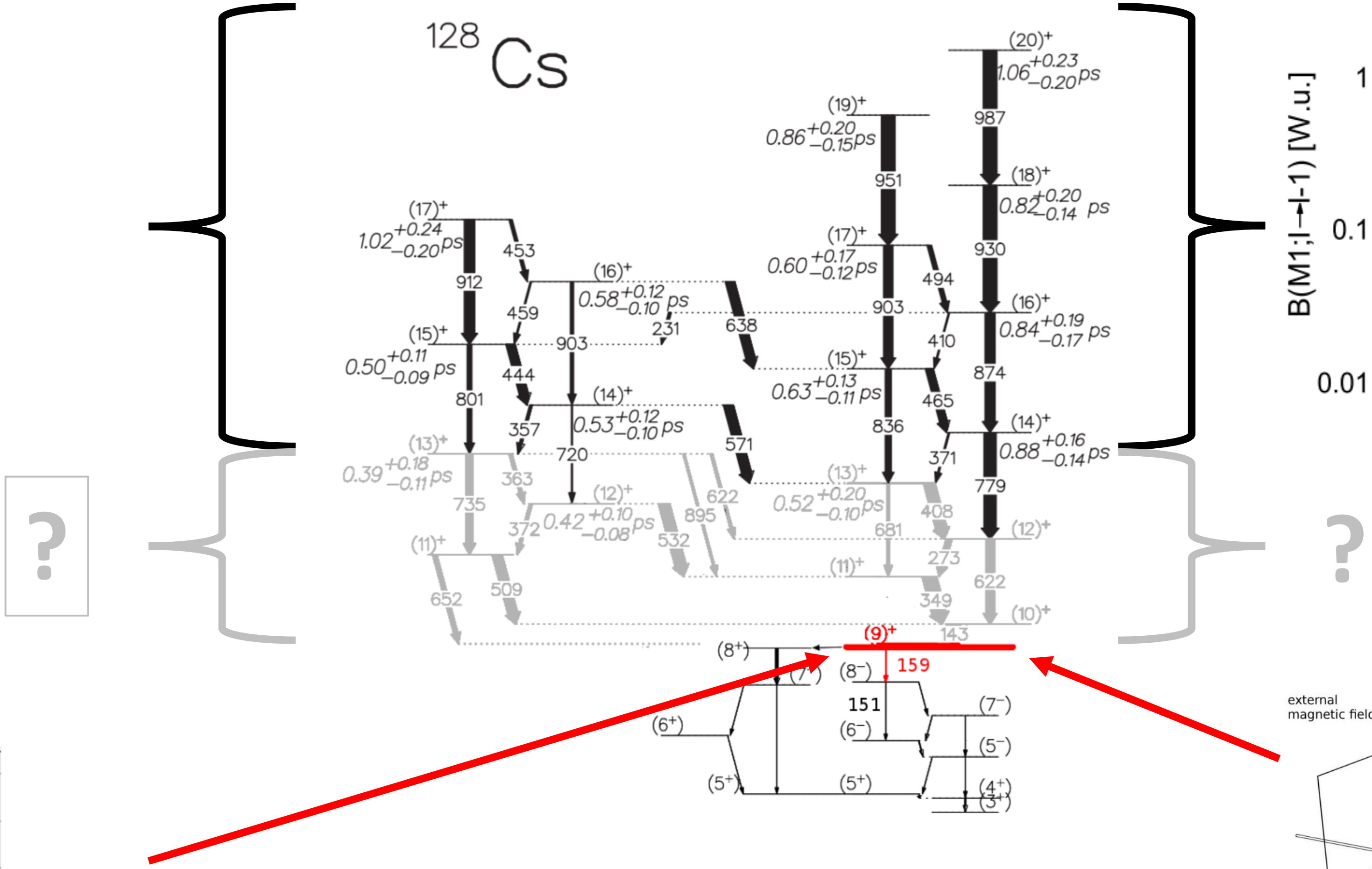


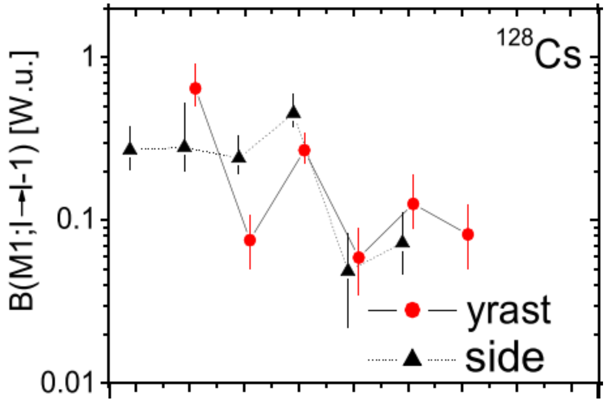
Chiral

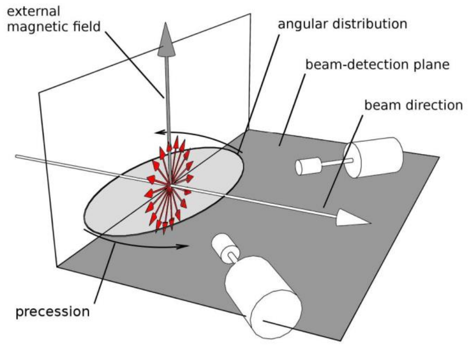


Non-chiral



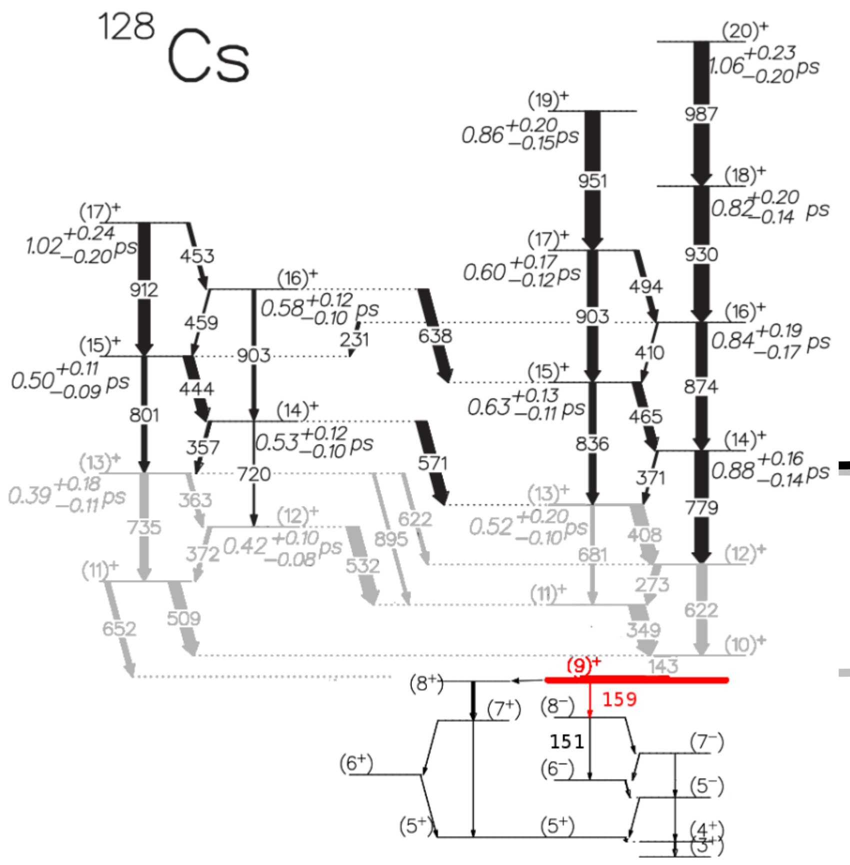


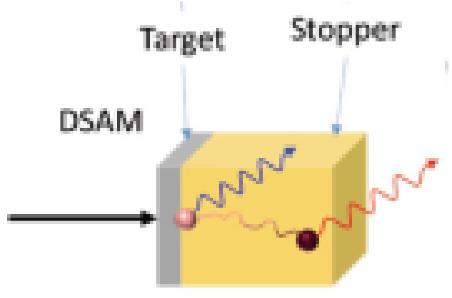




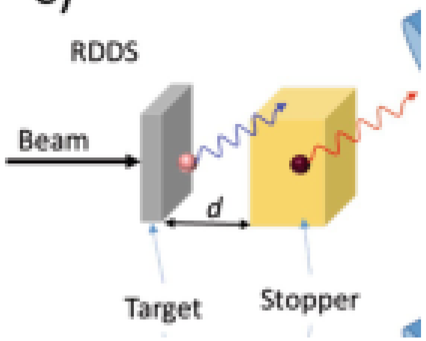
0.2 – 2.0 ps

2 – 500 ps





c)



Proposal to the HIL Programme Advisory Committee

Search for transition between chiral and non-chiral configuration in ^{128}Cs by lifetime measurement of I=11^{+}, 12^{+} states with a plunger technique

A. Nałęcz-Jawecki[1], E. Grodner[1], J. Srebrny[2], Ch. Fransen[3], Ch. Droste[4], L. Prochniak[2], Q. B. Chen[5], C. Petrache[6], G. Zhang[7], J. Samorajczyk-Pyśk[2], A. Stolarz[2], M. Komorowska[2], M. Kowalczyk[2], M. Palacz[2], G. Jaworski[2], P. Napiorkowski[2]

[1] *National Centre for Nuclear Research, Poland*

[2] *Heavy Ion Laboratory, University of Warsaw, Poland*

[3] *Institute of Nuclear Physics, University of Cologne, Germany*

[4] *Faculty of Physics, University of Warsaw, Poland*

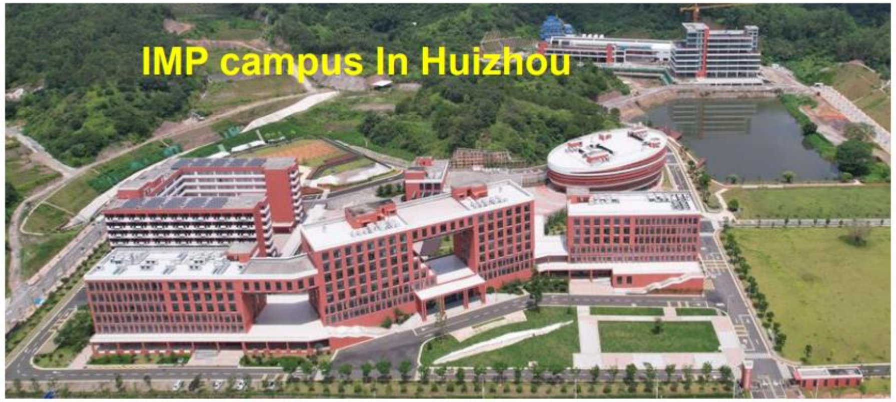
[5] *Department of Physics, East China Normal University, Shanghai 200241, China*

[6] *IJCLab, Université Paris-Saclay, 91400 Orsay, France*

[7] *Sun yat-sen University, Guangdong province, China*

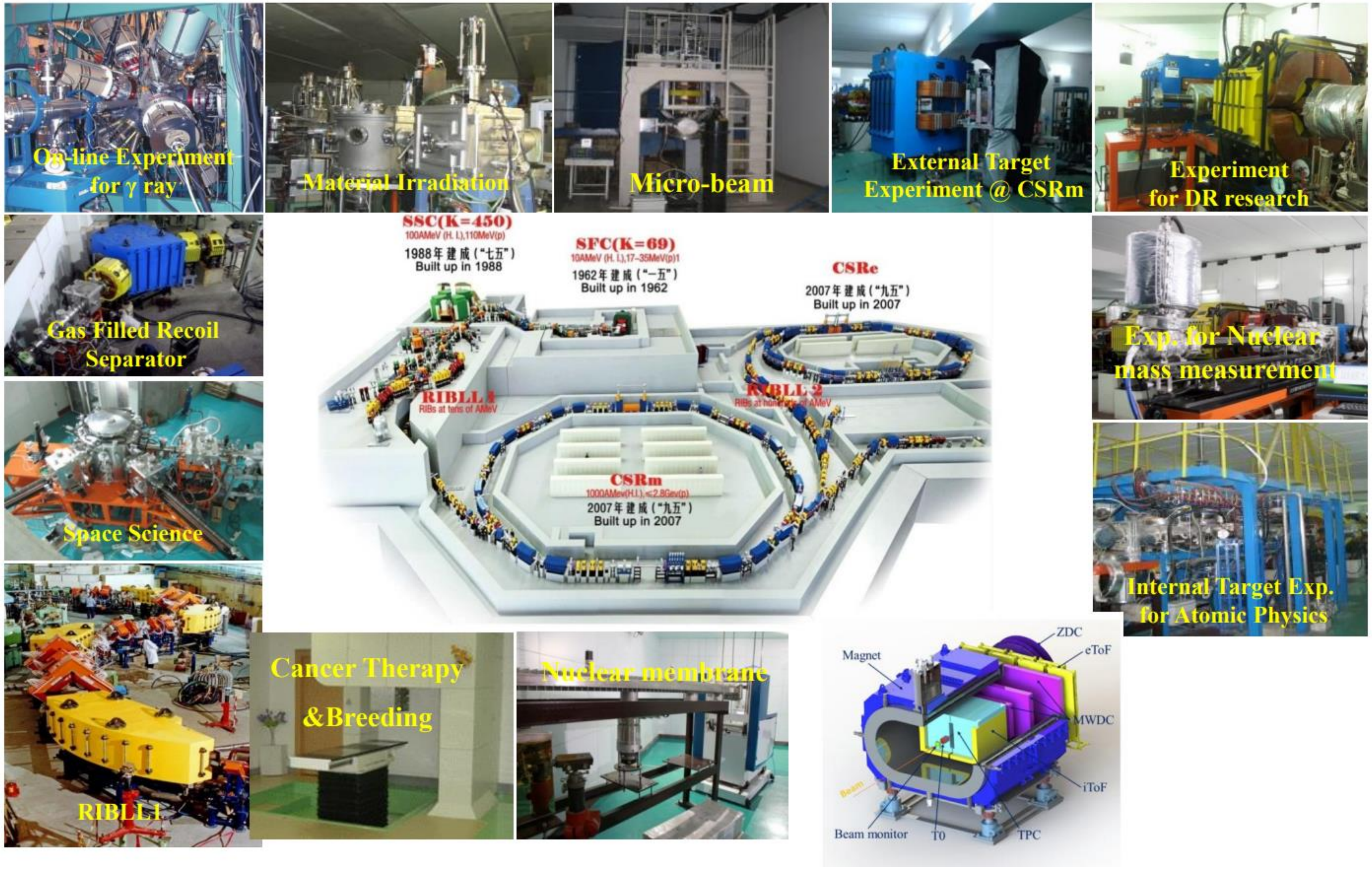
Credit:
Hongwei Zhao

Institute of Modern Physics (IMP), Chinese Academy of Sciences
Lanzhou/Huizhou, China



HIRFL : Experimental setups

Credit:
Hongwei Zhao



Acknowledgements

Exceptional lecturer

Collective nuclear theory specialist.

prof. Stanisław Grzegorz Rohoziński

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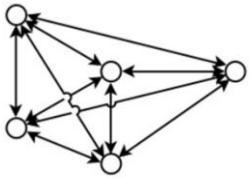

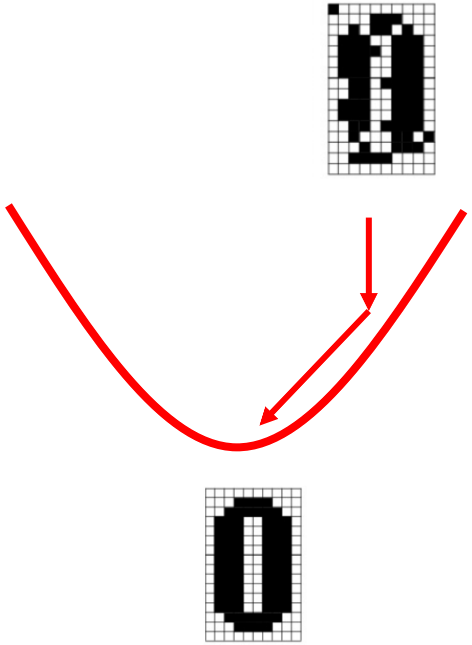

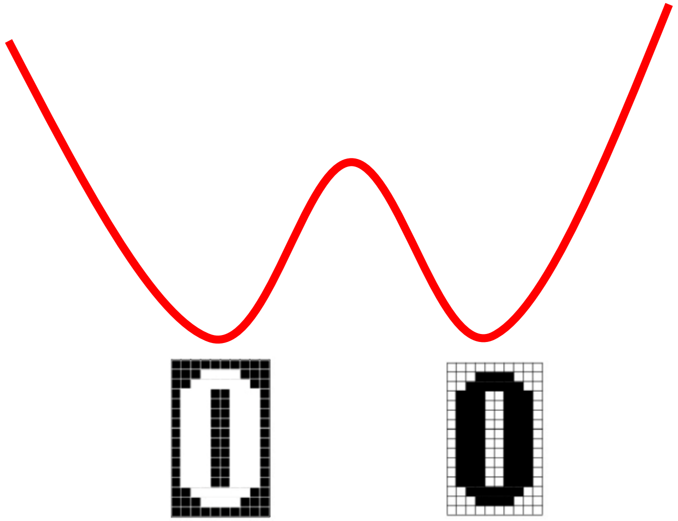

prof. Stanisław Grzegorz Rohoziński

Thank You