17th Nuclear Physics Workshop
"Marie & Pierre Curie"
Kazimierz 2010-9-24

Chiral symmetry in atomic nuclei

Jie Meng 孟 杰

北京大学物理学院
School of Physics
Peking University (PKU)

北京航空航天大学物理与核能工程学院
School of Physics and Nuclear Energy Engineering
Beihang University (BUAA)

Outline

- ☐ Introduction
- ☐ Chirality in atomic nuclei
- ☐ Experimental progress
- ☐ Theoretical progress
- ☐ Summary and perspectives

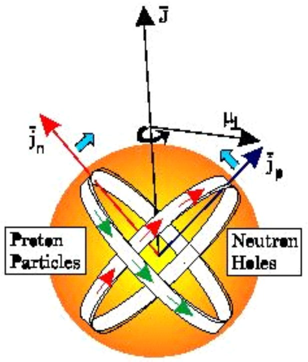
Chiral symmetries exist commonly in nature

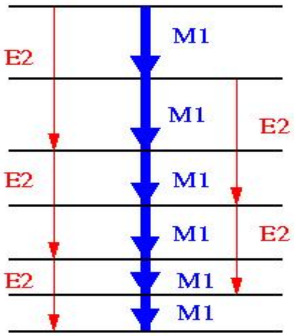
- ☐ Macroscopic spirals of snail shells and the Human hands...
- ☐ In geometry, a figure is chiral if it is not identical to its mirror image, or it cannot be mapped onto its mirror image by rotations and translations alone
- ☐ Particle physics, chirality is a dynamic property distinguishing between the parallel and anti-parallel orientations of the intrinsic spin with respect to the momentum of the massless particle.
- ☐ Chemistry, the study of chirality is a very active in inorganic, organic, physical, biochemistry and supramolecular chemistry.
- ☐ Nobel Prize in Chemistry for 2001: the development of catalytic asymmetric synthesis
- ☐ …

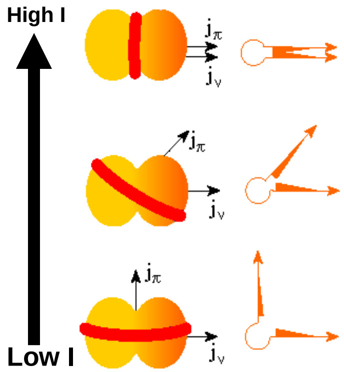
Chirality in atomic nucleus: short history

Magnetic Rotation: Hot topics of high spin physics in 1990s

- Near spherical nucleus
- $\Delta I=1$ bands with strong BM1
- Orientation of valence p and n provides spin



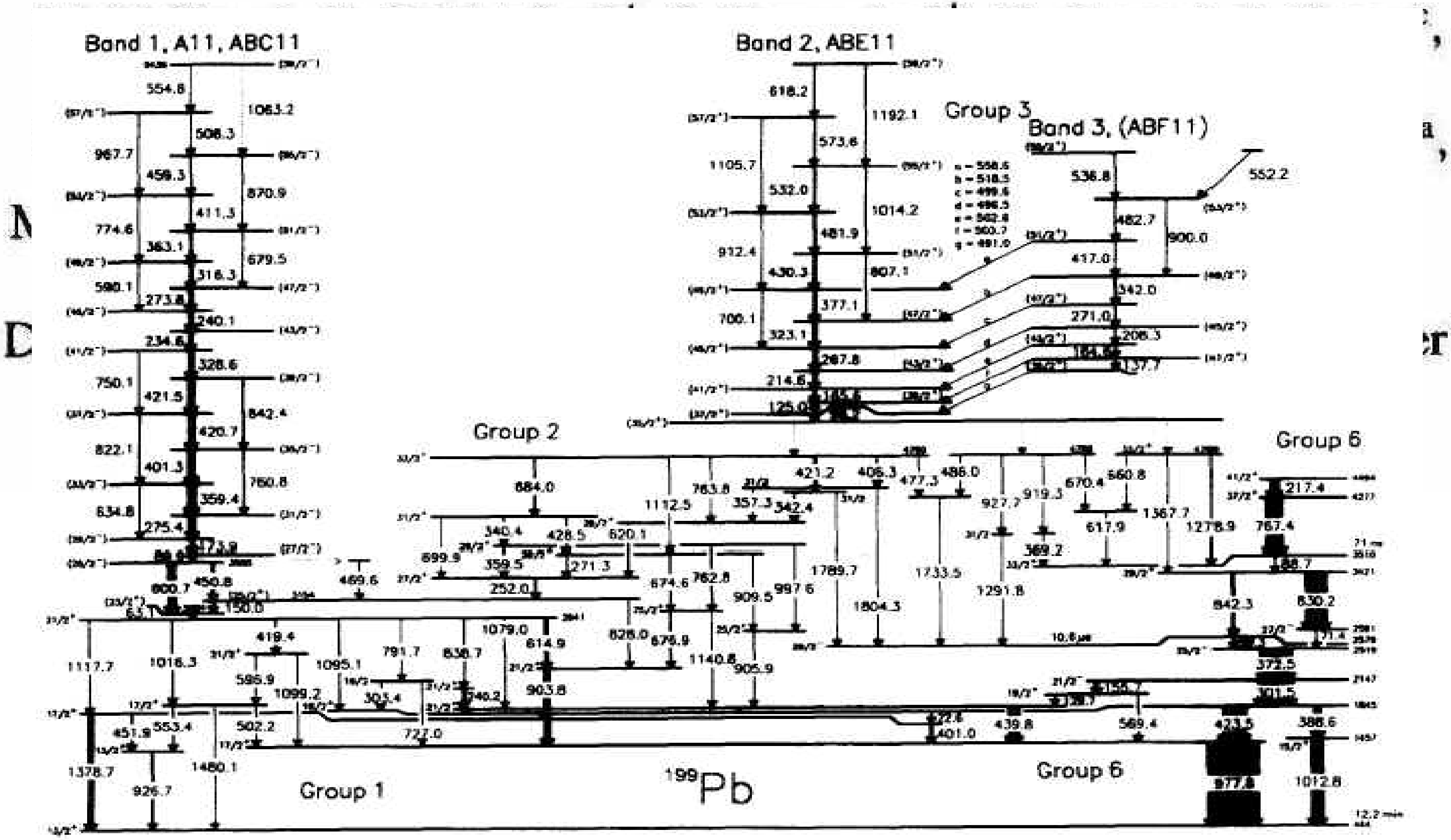




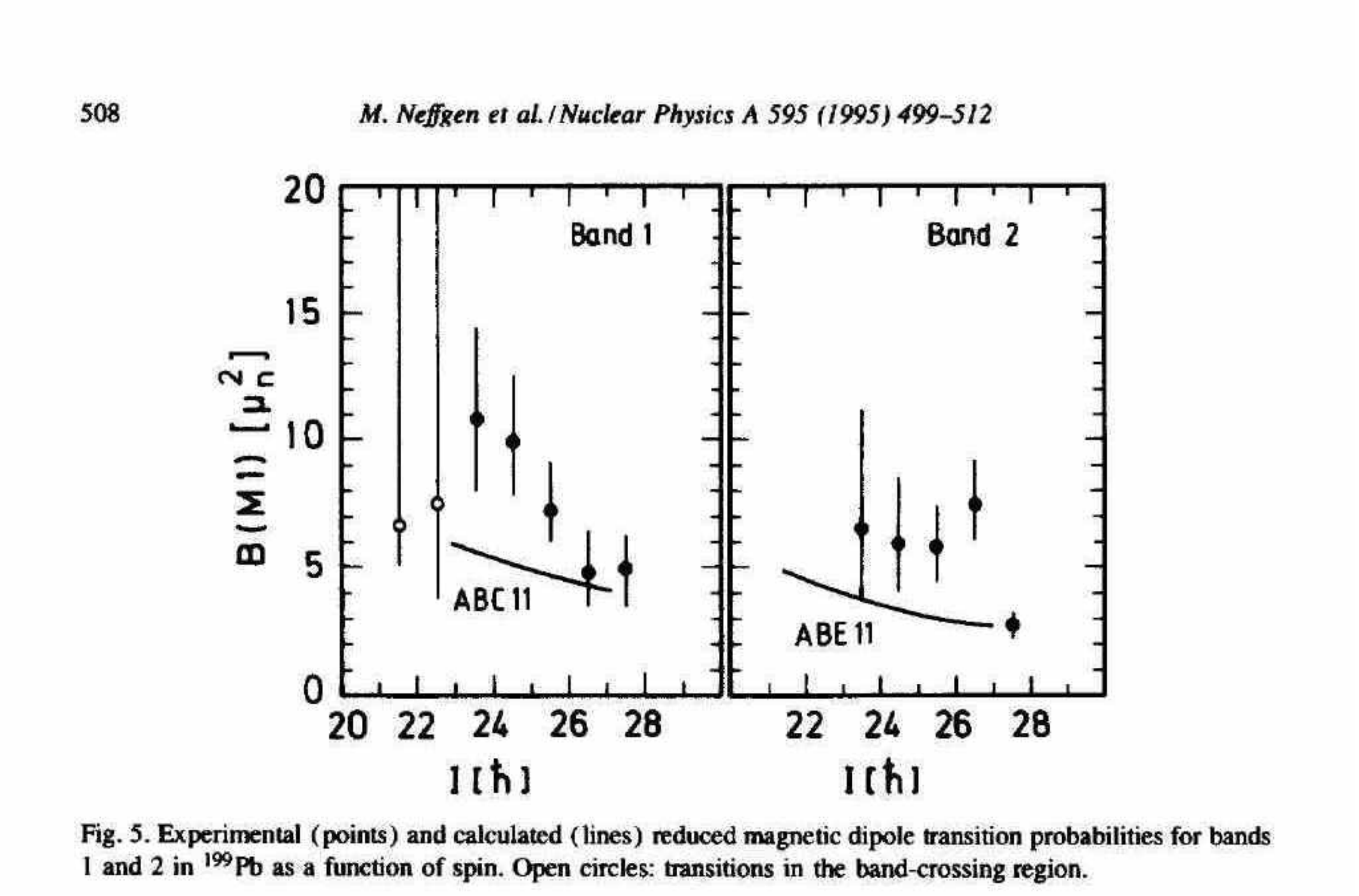
ELSEVIER

Nuclear Physics A 595 (1995) 499–512

Lifetimes of shears bands in ^{199}Pb



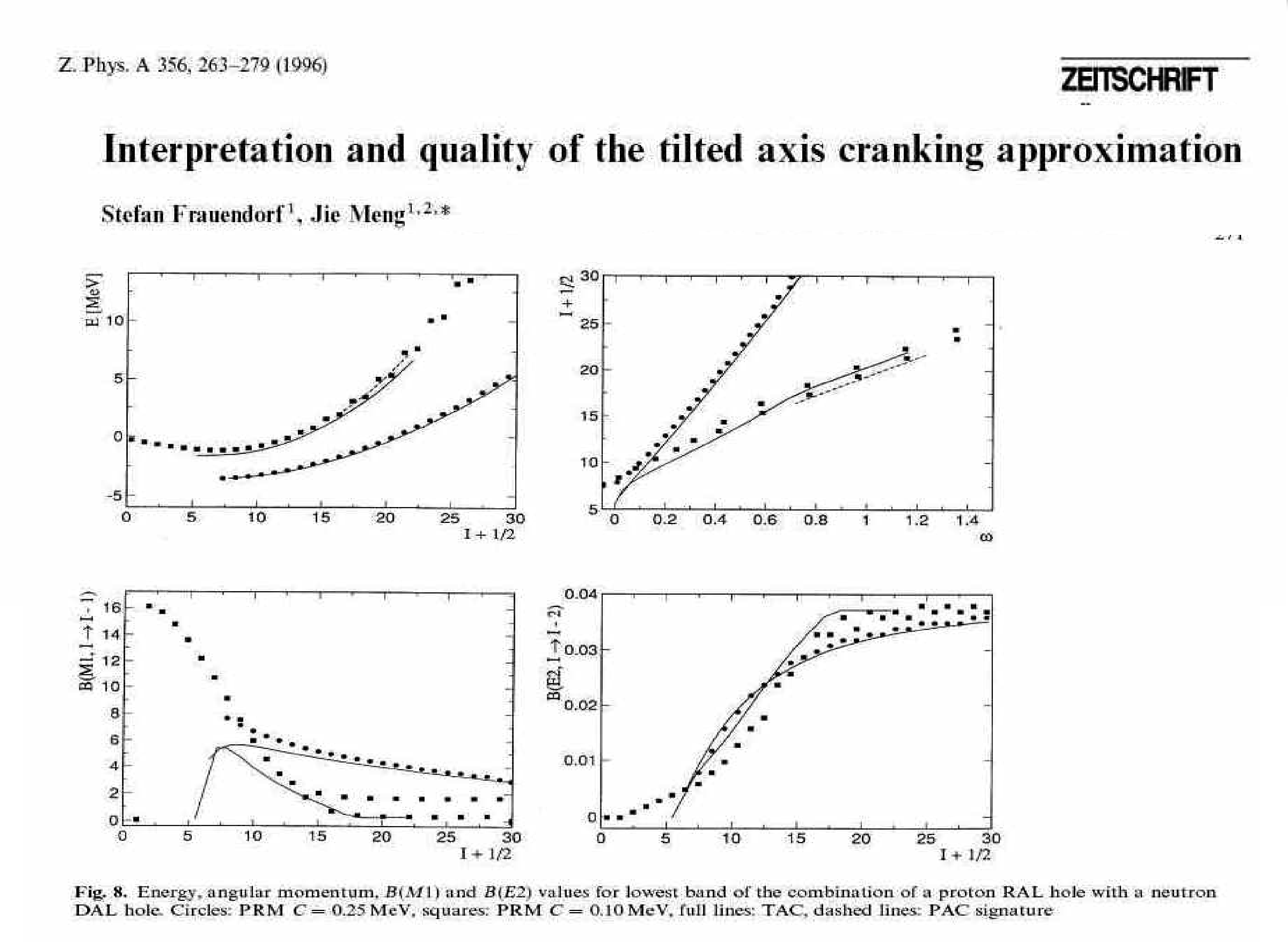
Δ I = 1 Enhanced magnetic dipole transition



508 *M. Neffgen et al. / Nuclear Physics A 595 (1995) 499–512*

Fig. 5. Experimental (points) and calculated (lines) reduced magnetic dipole transition probabilities for bands 1 and 2 in ^{199}Pb as a function of spin. Open circles: transitions in the band-crossing region.

How does B(M1) change with spin I ?



Z. Phys. A 356, 263–279 (1996)

ZEITSCHRIFT

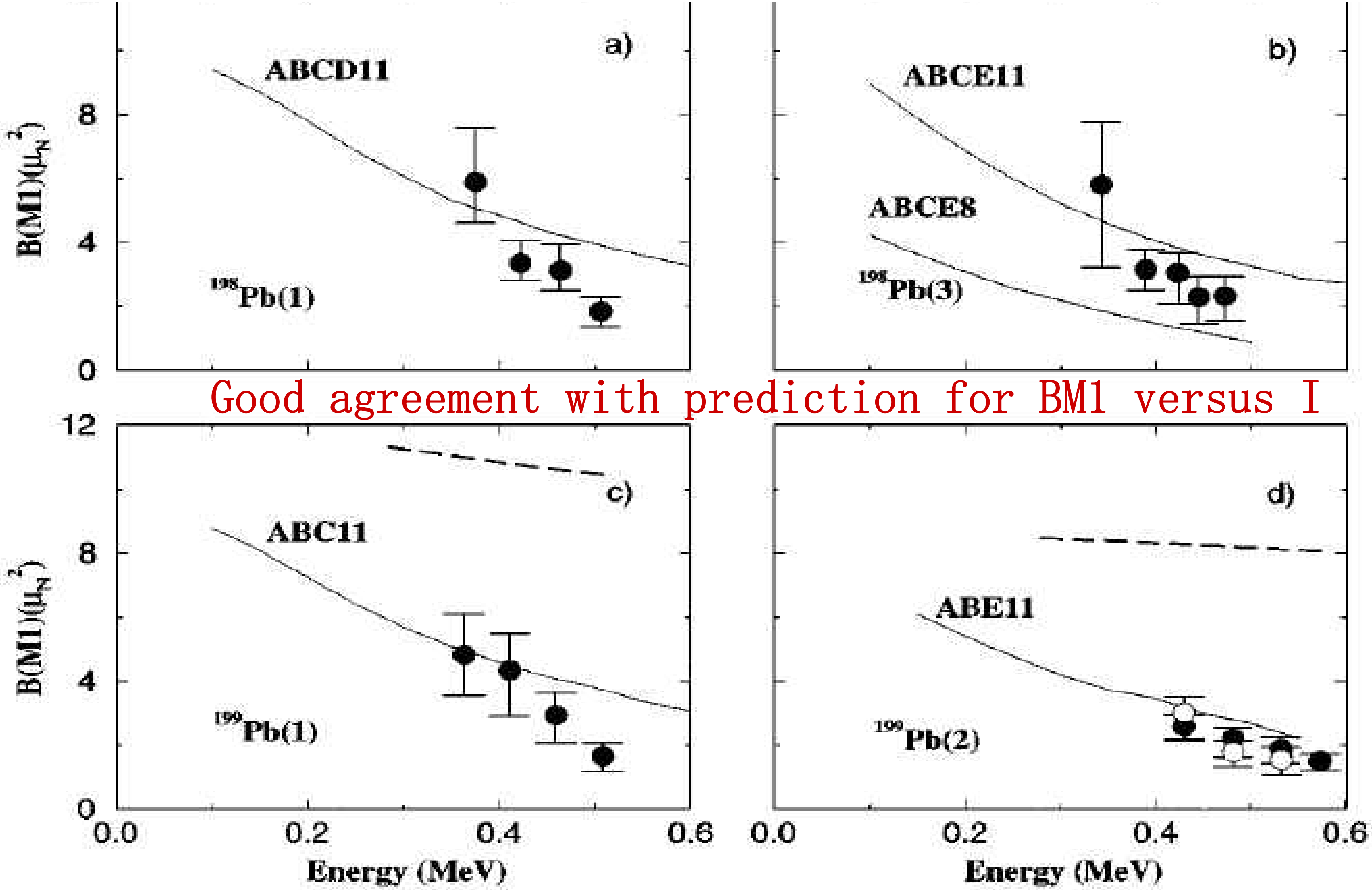
Interpretation and quality of the tilted axis cranking approximation

Stefan Frauendorf[1], Jie Meng[1,2,*]

Fig. 8. Energy, angular momentum, $B(M1)$ and $B(E2)$ values for lowest band of the combination of a proton RAL hole with a neutron DAL hole. Circles: PRM $C = 0.25$ MeV, squares: PRM $C = 0.10$ MeV, full lines: TAC, dashed lines: PAC signature

VOLUME 78, NUMBER 10 PHYSICAL REVIEW LETTERS 10 MARCH 1997

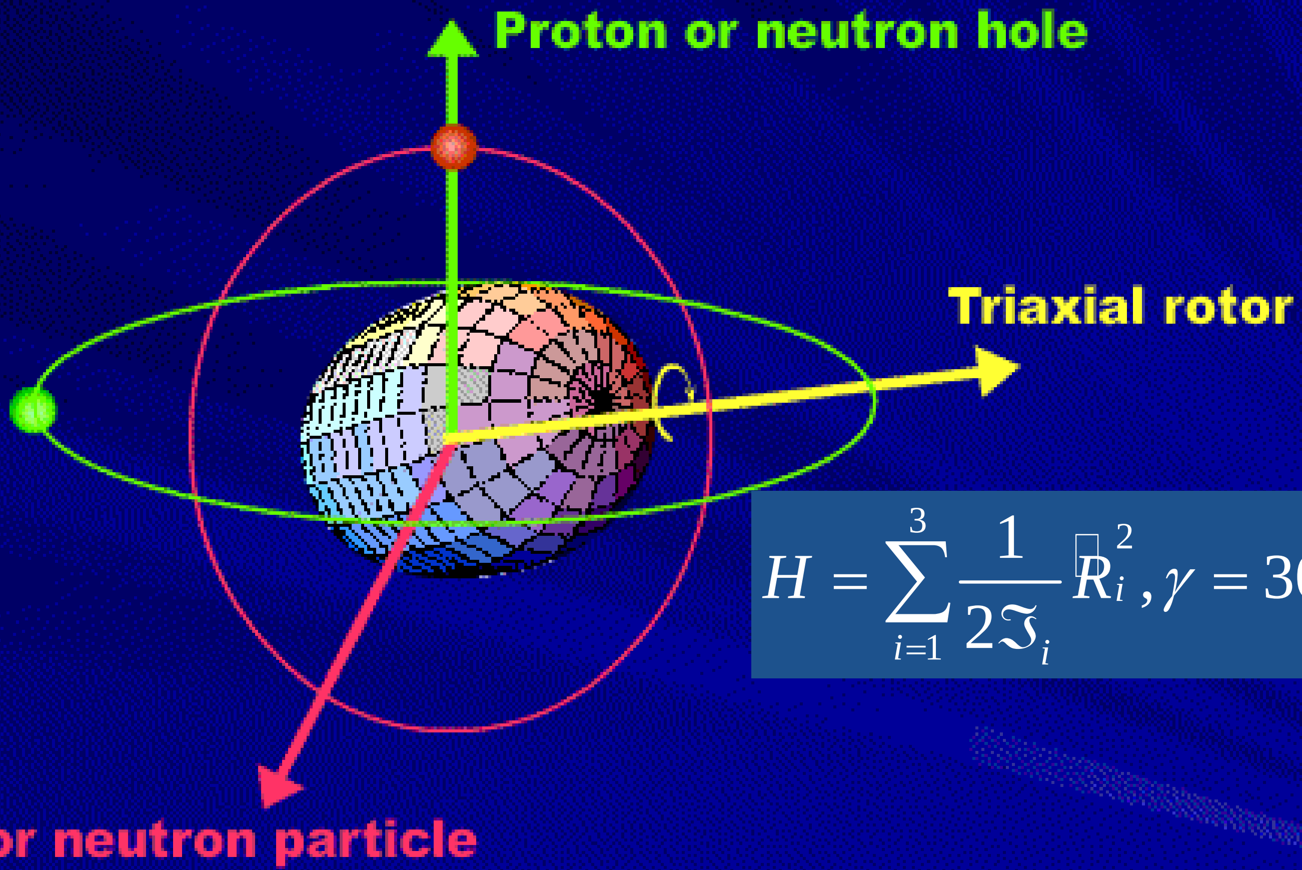
Evidence for "Magnetic Rotation" in Nuclei: Lifetimes of States in the M1 bands of ^{198,199}Pb



Good agreement with prediction for BM1 versus I

Generalizing to triaxial deformed case

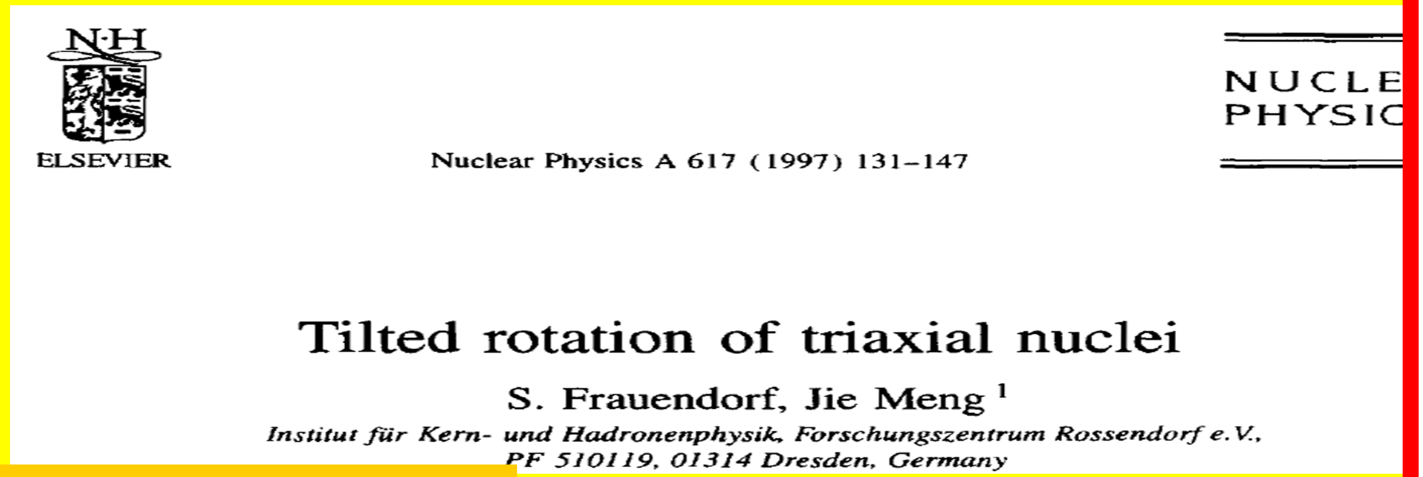
$$H_{sp} = -\frac{1}{2}C\left\{\cos\gamma\left\{j_3^2 - \frac{j(j+1)}{3}\right\} + \frac{\sin\gamma}{2\sqrt{3}}\left(j_+^2 + j_-^2\right)\right\}$$



$$H = \sum_{i=1}^{3}\frac{1}{2\mathfrak{J}_i}R_i^2, \gamma = 30^o$$

$$H_{sp} = \frac{1}{2}C\left\{\cos\gamma\left\{j_3^2 - \frac{j(j+1)}{3}\right\} + \frac{\sin\gamma}{2\sqrt{3}}\left(j_+^2 + j_-^2\right)\right\}$$

Chiral symmetry in atomic nuclei



N·H
ELSEVIER

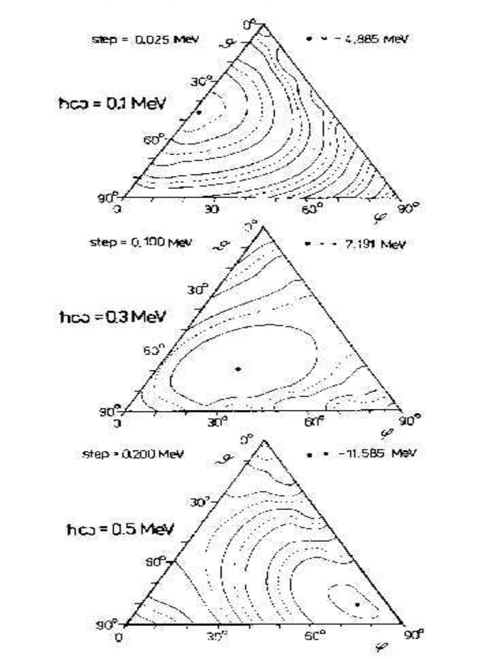
Nuclear Physics A 617 (1997) 131–147

NUCLE
PHYSIC

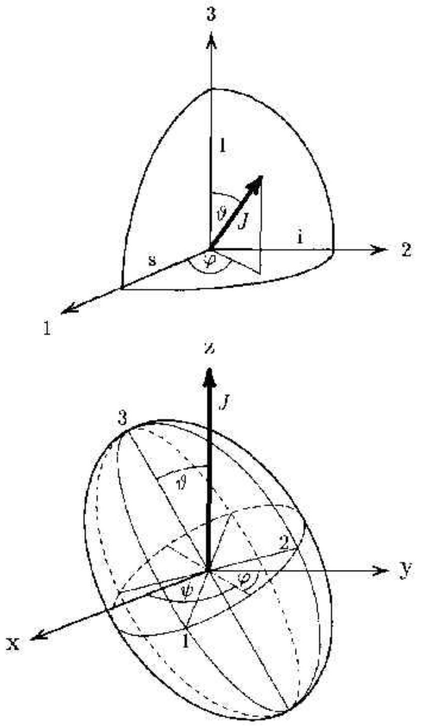
Tilted rotation of triaxial nuclei

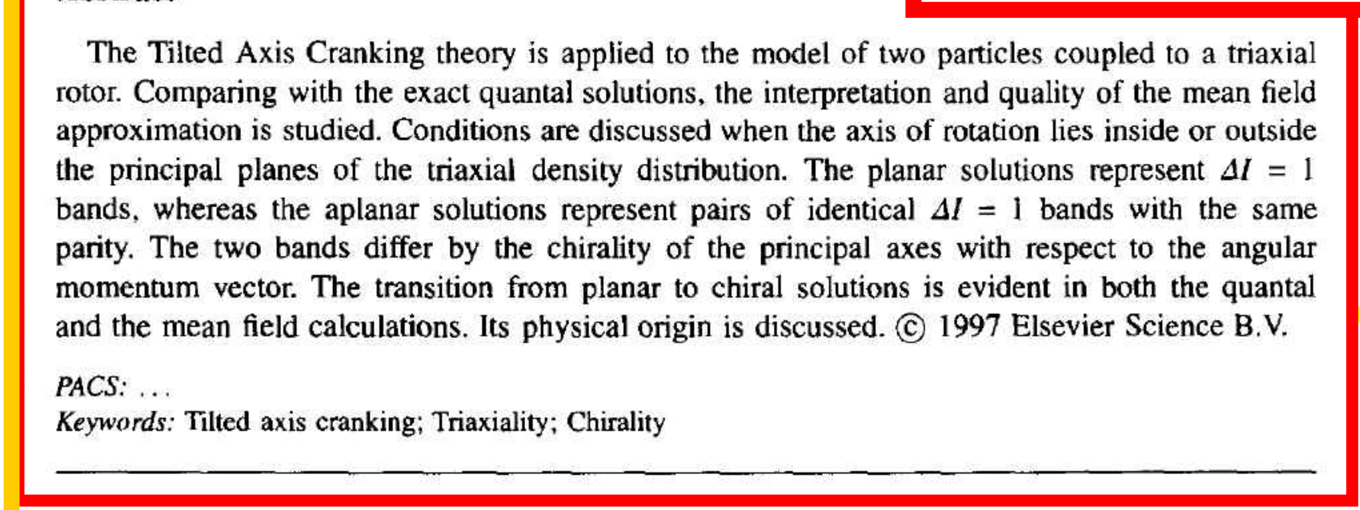
S. Frauendorf, Jie Meng [1]

Institut für Kern- und Hadronenphysik, Forschungszentrum Rossendorf e.V., PF 510119, 01314 Dresden, Germany



S. Frauendorf, J. Meng/Nuclear Physics A 617 (1997) 131–147





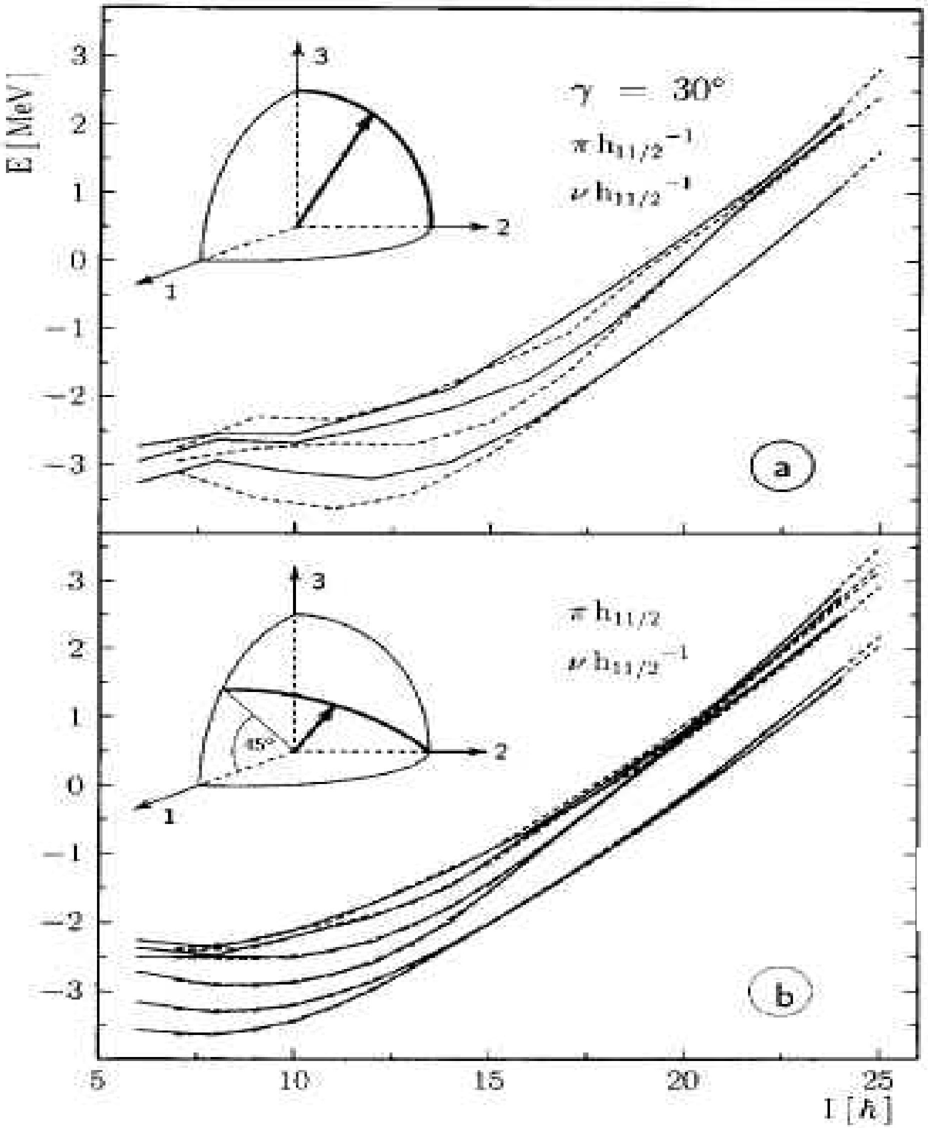
Abstract

The Tilted Axis Cranking theory is applied to the model of two particles coupled to a triaxial rotor. Comparing with the exact quantal solutions, the interpretation and quality of the mean field approximation is studied. Conditions are discussed when the axis of rotation lies inside or outside the principal planes of the triaxial density distribution. The planar solutions represent $\Delta I = 1$ bands, whereas the aplanar solutions represent pairs of identical $\Delta I = 1$ bands with the same parity. The two bands differ by the chirality of the principal axes with respect to the angular momentum vector. The transition from planar to chiral solutions is evident in both the quantal and the mean field calculations. Its physical origin is discussed. © 1997 Elsevier Science B.V.

PACS: . . .
Keywords: Tilted axis cranking; Triaxiality; Chirality

Chiral doublets bands: experimental signal

S. Frauendorf, J. Meng/Nuclear Physics A 617 (1997) 131–147

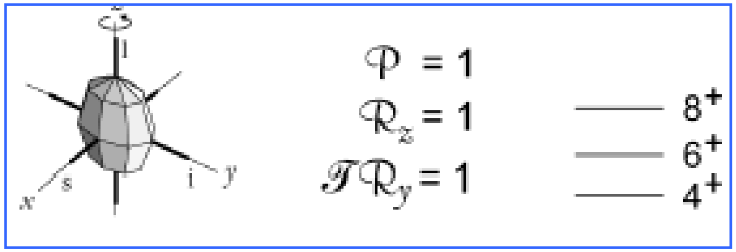


hh+triaxial rotor=MR

ph+triaxial rotor=Chiral doublets

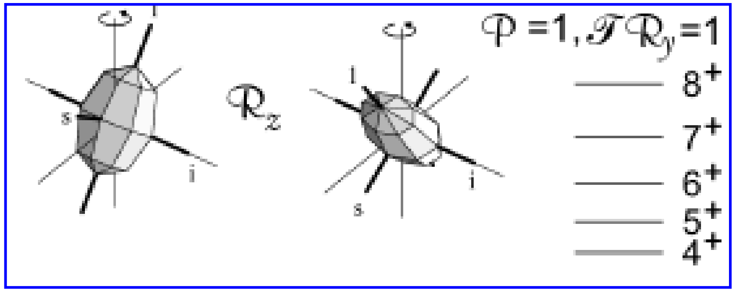
Chiral doublets bands, Why ?

1. J lies along a principal axis



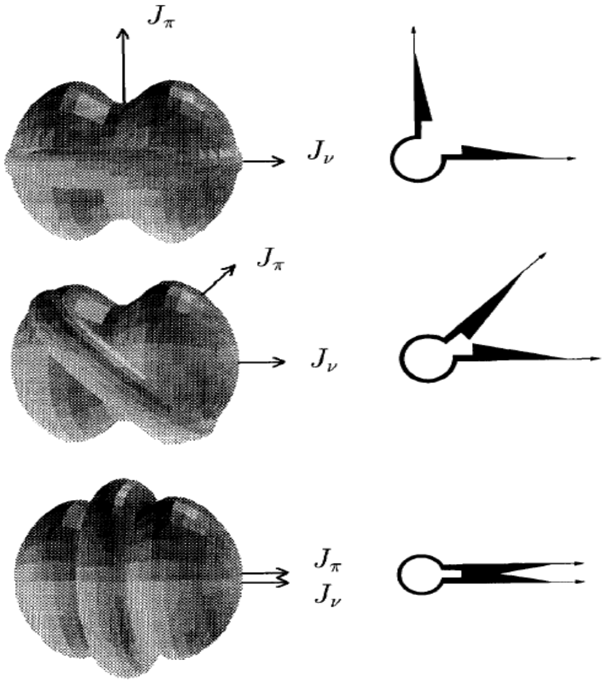
△I=2 rotational bands

2. J lies in a principal plane



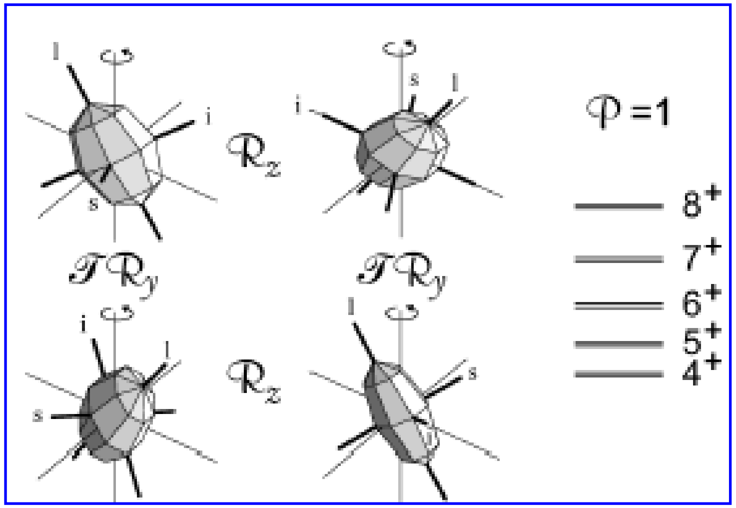
△I= 1 magnetic rotational bands

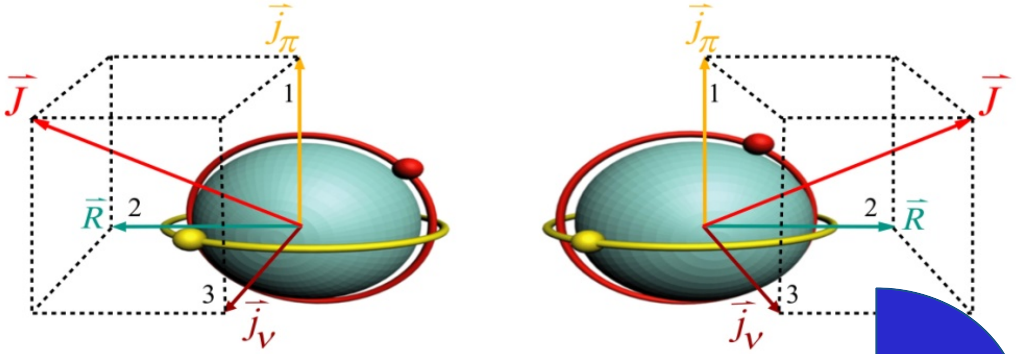
Shears bands



Chiral doublets bands, Why ?

3. J does not lie in any of principal plane





Chiral bands
Experimental signature:
Degenerate pairs of △ I=1 bands

$\Xi = T Py(\pi)$

Frauendorf, Meng, Nucl. Phys. A 617, 131(1997)

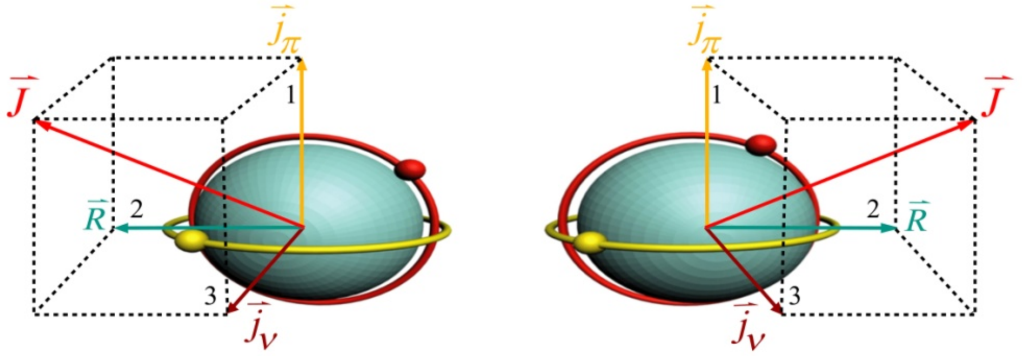
Spontaneous Symmetry Breaking of Chiral symmetry

$$[\chi, H] = 0, \chi = TR_y(\pi)$$

$$H|R\rangle = \varepsilon_R|R\rangle, H|L\rangle = \varepsilon_L|L\rangle$$

$$|R\rangle = \chi|L\rangle, |L\rangle = \chi|R\rangle$$

$$\varepsilon_R = \varepsilon_L$$



Ground State (vacuum) ⇛ Chiral

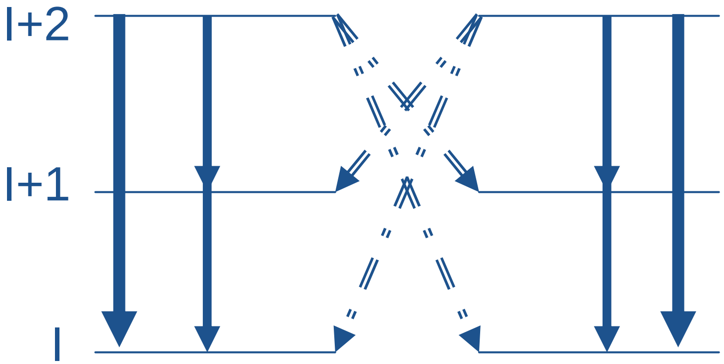
$$|IM+\rangle = \frac{1}{\sqrt{2}}(|R\rangle + |L\rangle)$$

$$|IM-\rangle = \frac{i}{\sqrt{2}}(|R\rangle - |L\rangle)$$

$$H|IM\pm\rangle = \varepsilon^{IM}_{\pm}|IM\pm\rangle$$

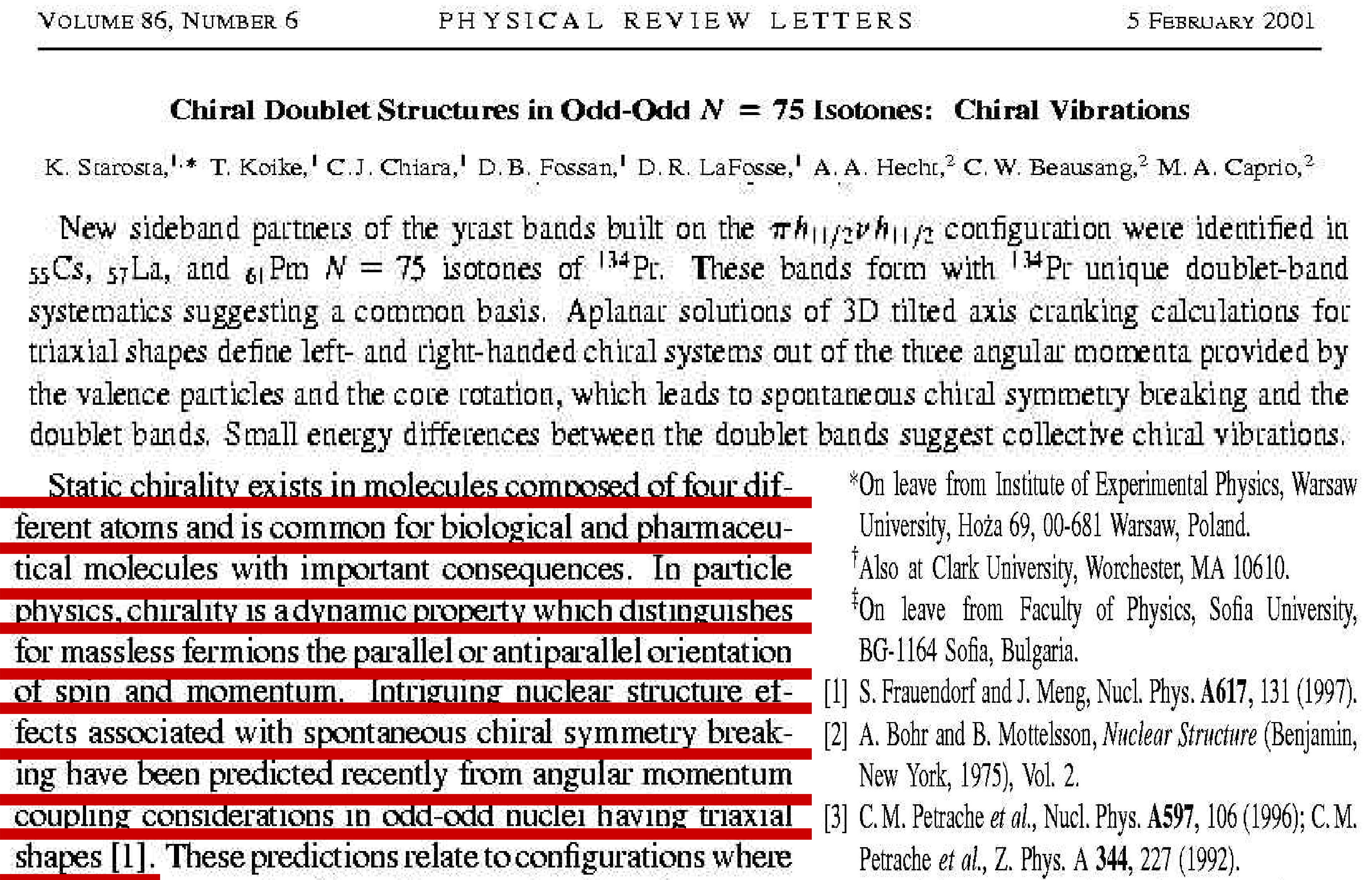
$$\chi|IM\pm\rangle = |IM\pm\rangle$$

$$\varepsilon^{IM}_{+} = \varepsilon^{IM}_{-}.$$



Chiral doublet ⇛ Restoration

First Observations of the Chiral doublets bands



VOLUME 86, NUMBER 6 PHYSICAL REVIEW LETTERS 5 FEBRUARY 2001

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]

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.

Static chirality exists in molecules composed of four different atoms and is common for biological and pharmaceutical molecules with important consequences. In particle physics, chirality is a dynamic property which distinguishes for massless fermions the parallel or antiparallel orientation of spin and momentum. Intriguing nuclear structure effects associated with spontaneous chiral symmetry breaking have been predicted recently from angular momentum coupling considerations in odd-odd nuclei having triaxial shapes [1]. These predictions relate to configurations where

---

[*] On leave from Institute of Experimental Physics, Warsaw University, Hoża 69, 00-681 Warsaw, Poland.

[†] Also at Clark University, Worchester, MA 10610.

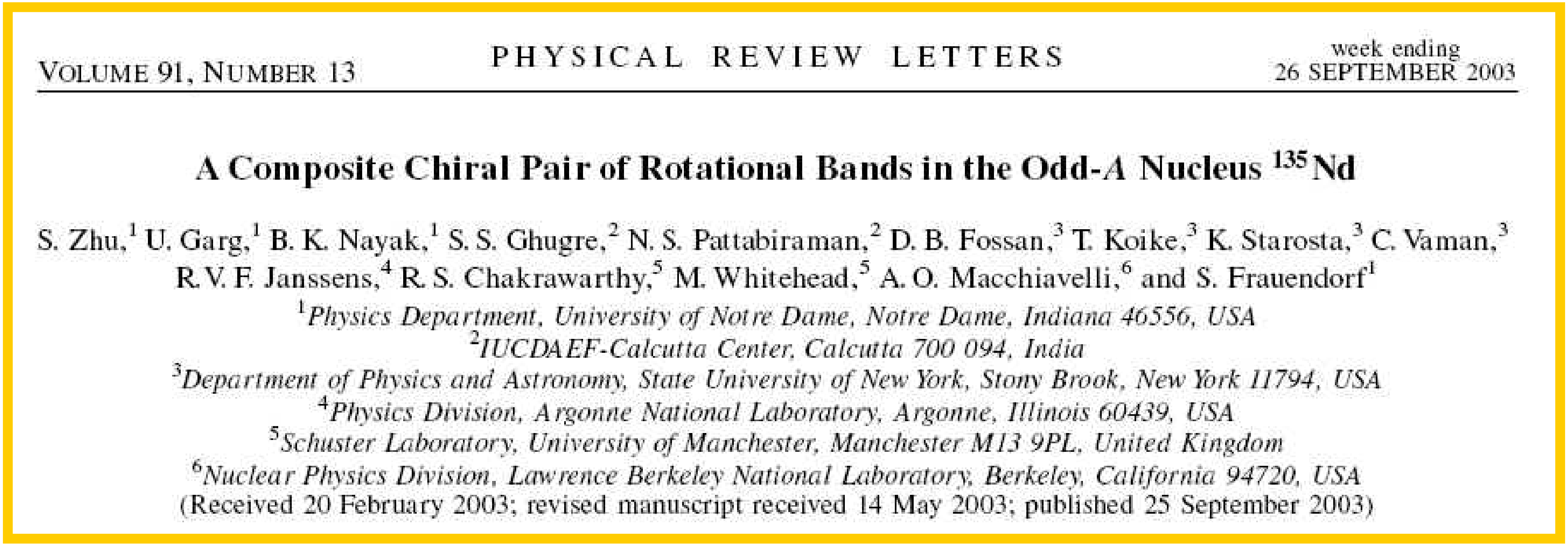
[‡] On leave from Faculty of Physics, Sofia University, BG-1164 Sofia, Bulgaria.

[1] S. Frauendorf and J. Meng, Nucl. Phys. **A617**, 131 (1997).

[2] A. Bohr and B. Mottelsson, *Nuclear Structure* (Benjamin, New York, 1975), Vol. 2.

[3] C. M. Petrache *et al.*, Nucl. Phys. **A597**, 106 (1996); C. M. Petrache *et al.*, Z. Phys. A **344**, 227 (1992).

Observations in Odd-A Nucleus



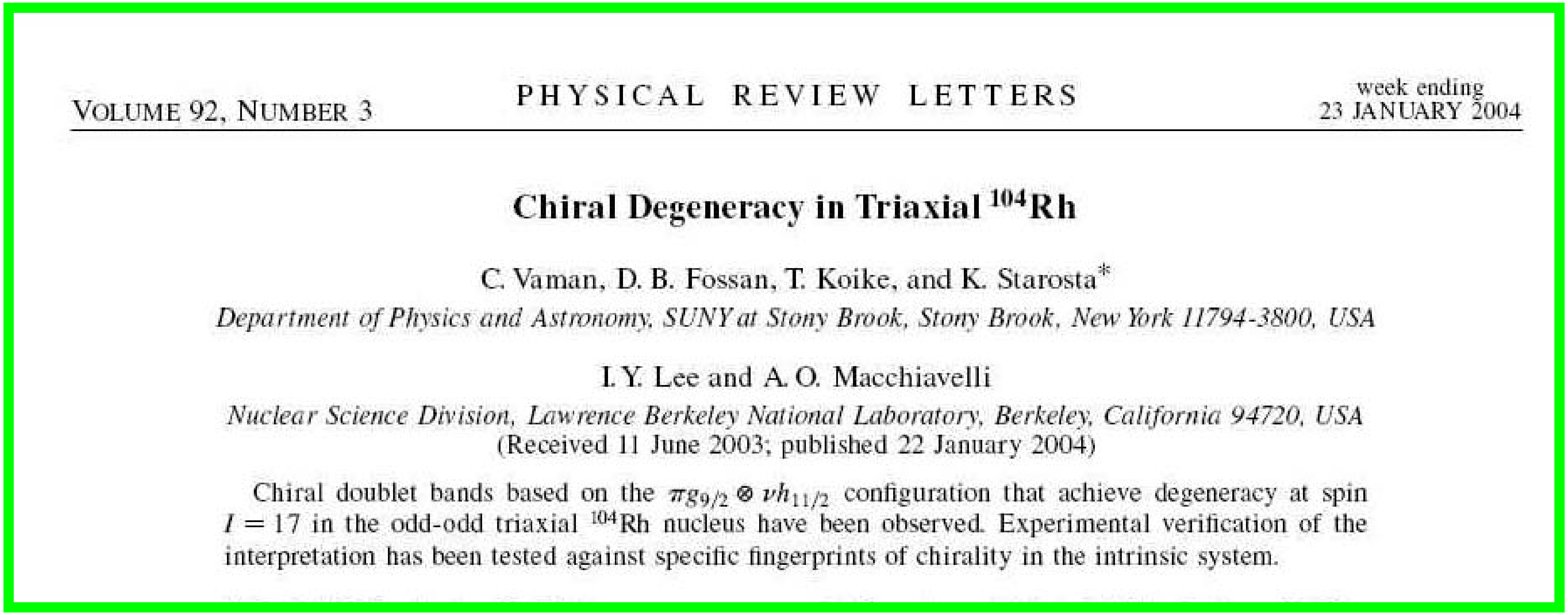
VOLUME 91, NUMBER 13 PHYSICAL REVIEW LETTERS week ending 26 SEPTEMBER 2003

A Composite Chiral Pair of Rotational Bands in the Odd-*A* Nucleus ^{135}Nd

S. Zhu,[1] U. Garg,[1] B. K. Nayak,[1] S. S. Ghugre,[2] N. S. Pattabiraman,[2] D. B. Fossan,[3] T. Koike,[3] K. Starosta,[3] C. Vaman,[3]
R. V. F. Janssens,[4] R. S. Chakrawarthy,[5] M. Whitehead,[5] A. O. Macchiavelli,[6] and S. Frauendorf[1]
[1]*Physics Department, University of Notre Dame, Notre Dame, Indiana 46556, USA*
[2]*IUCDAEF-Calcutta Center, Calcutta 700 094, India*
[3]*Department of Physics and Astronomy, State University of New York, Stony Brook, New York 11794, USA*
[4]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*
[5]*Schuster Laboratory, University of Manchester, Manchester M13 9PL, United Kingdom*
[6]*Nuclear Physics Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*

(Received 20 February 2003; revised manuscript received 14 May 2003; published 25 September 2003)

Observations in A~100 Nucleus



VOLUME 92, NUMBER 3 PHYSICAL REVIEW LETTERS week ending 23 JANUARY 2004

Chiral Degeneracy in Triaxial ^{104}Rh

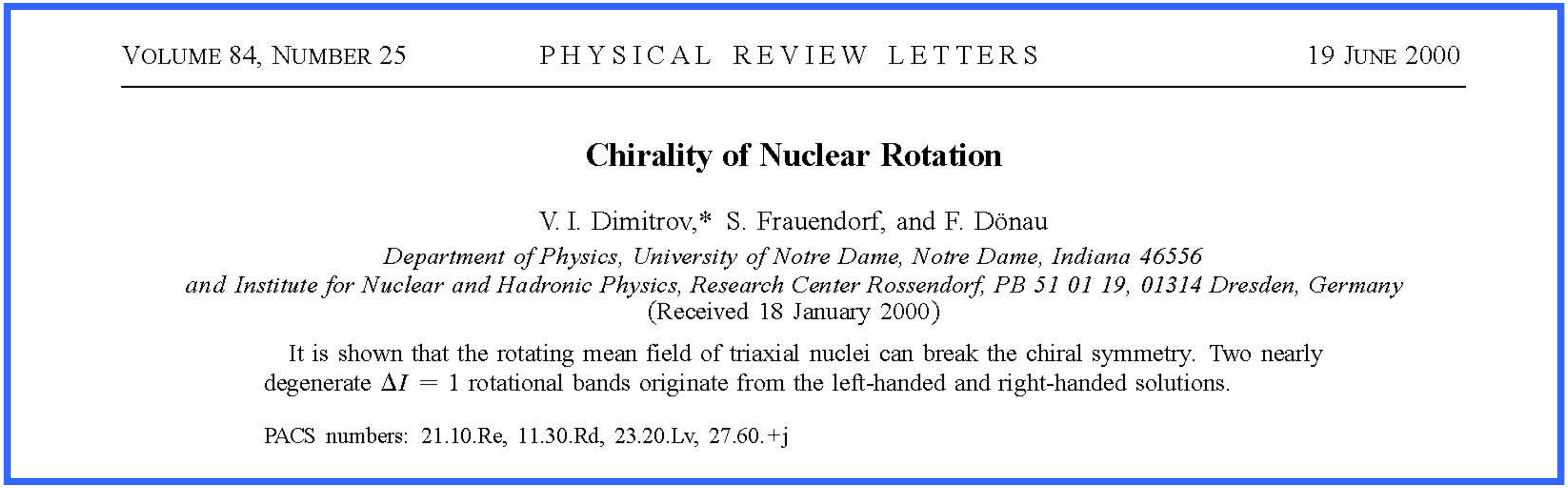
C. Vaman, D. B. Fossan, T. Koike, and K. Starosta*
Department of Physics and Astronomy, SUNY at Stony Brook, Stony Brook, New York 11794-3800, USA

I. Y. Lee and A. O. Macchiavelli
Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA

(Received 11 June 2003; published 22 January 2004)

Chiral doublet bands based on the $\pi g_{9/2} \otimes \nu h_{11/2}$ configuration that achieve degeneracy at spin $I = 17$ in the odd-odd triaxial ^{104}Rh nucleus have been observed. Experimental verification of the interpretation has been tested against specific fingerprints of chirality in the intrinsic system.

Self- consistent rotating mean field chiral solutions



VOLUME 84, NUMBER 25 PHYSICAL REVIEW LETTERS 19 JUNE 2000

Chirality of Nuclear Rotation

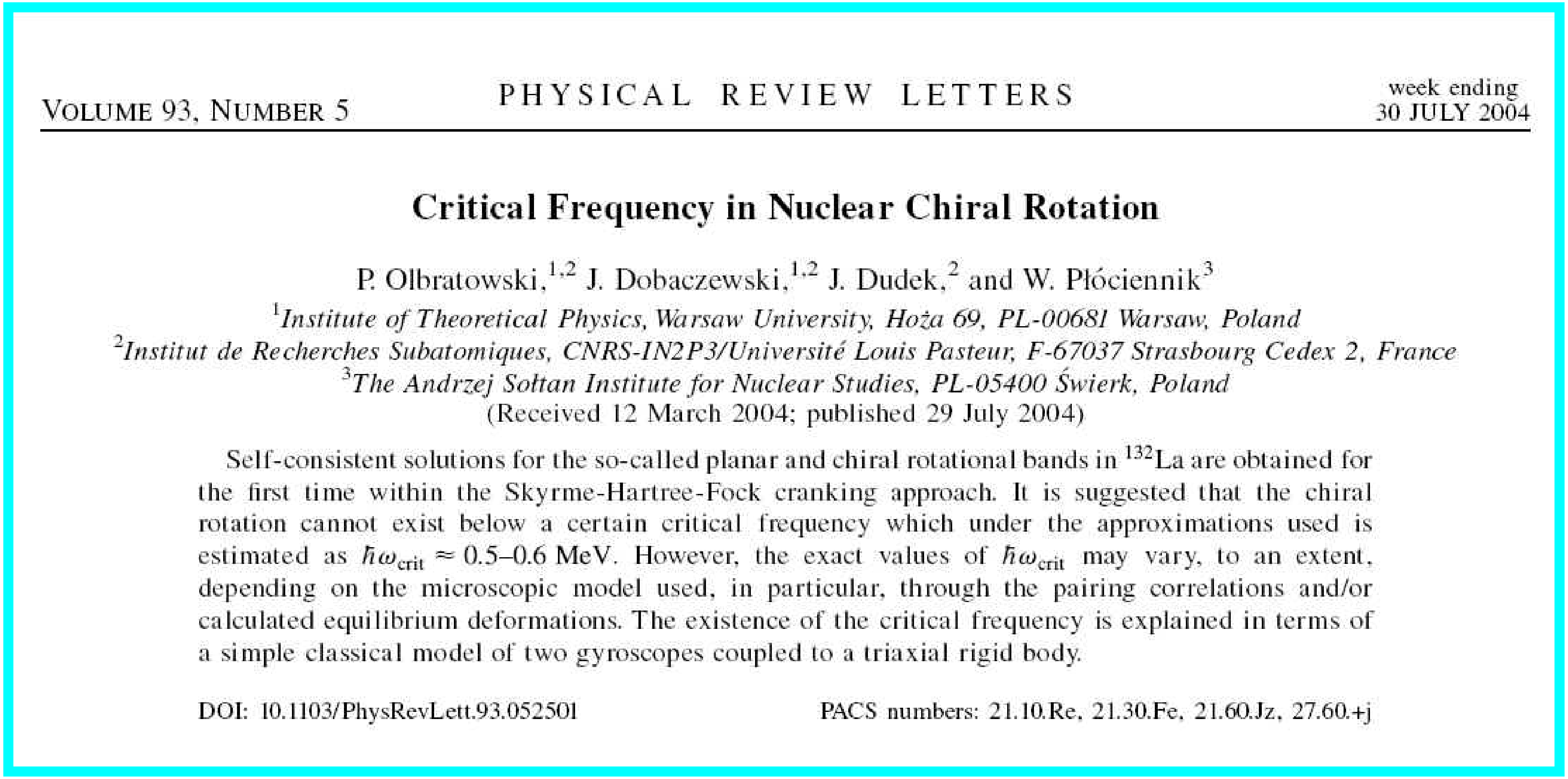
V. I. Dimitrov,* S. Frauendorf, and F. Dönau
Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556
and Institute for Nuclear and Hadronic Physics, Research Center Rossendorf, PB 51 01 19, 01314 Dresden, Germany

(Received 18 January 2000)

It is shown that the rotating mean field of triaxial nuclei can break the chiral symmetry. Two nearly degenerate $\Delta I = 1$ rotational bands originate from the left-handed and right-handed solutions.

PACS numbers: 21.10.Re, 11.30.Rd, 23.20.Lv, 27.60.+j

Critical frequency in Chiral rotations



VOLUME 93, NUMBER 5 PHYSICAL REVIEW LETTERS week ending 30 JULY 2004

Critical Frequency in Nuclear Chiral Rotation

P. Olbratowski,[1,2] J. Dobaczewski,[1,2] J. Dudek,[2] and W. Płóciennik[3]

[1]*Institute of Theoretical Physics, Warsaw University, Hoża 69, PL-00681 Warsaw, Poland*

[2]*Institut de Recherches Subatomiques, CNRS-IN2P3/Université Louis Pasteur, F-67037 Strasbourg Cedex 2, France*

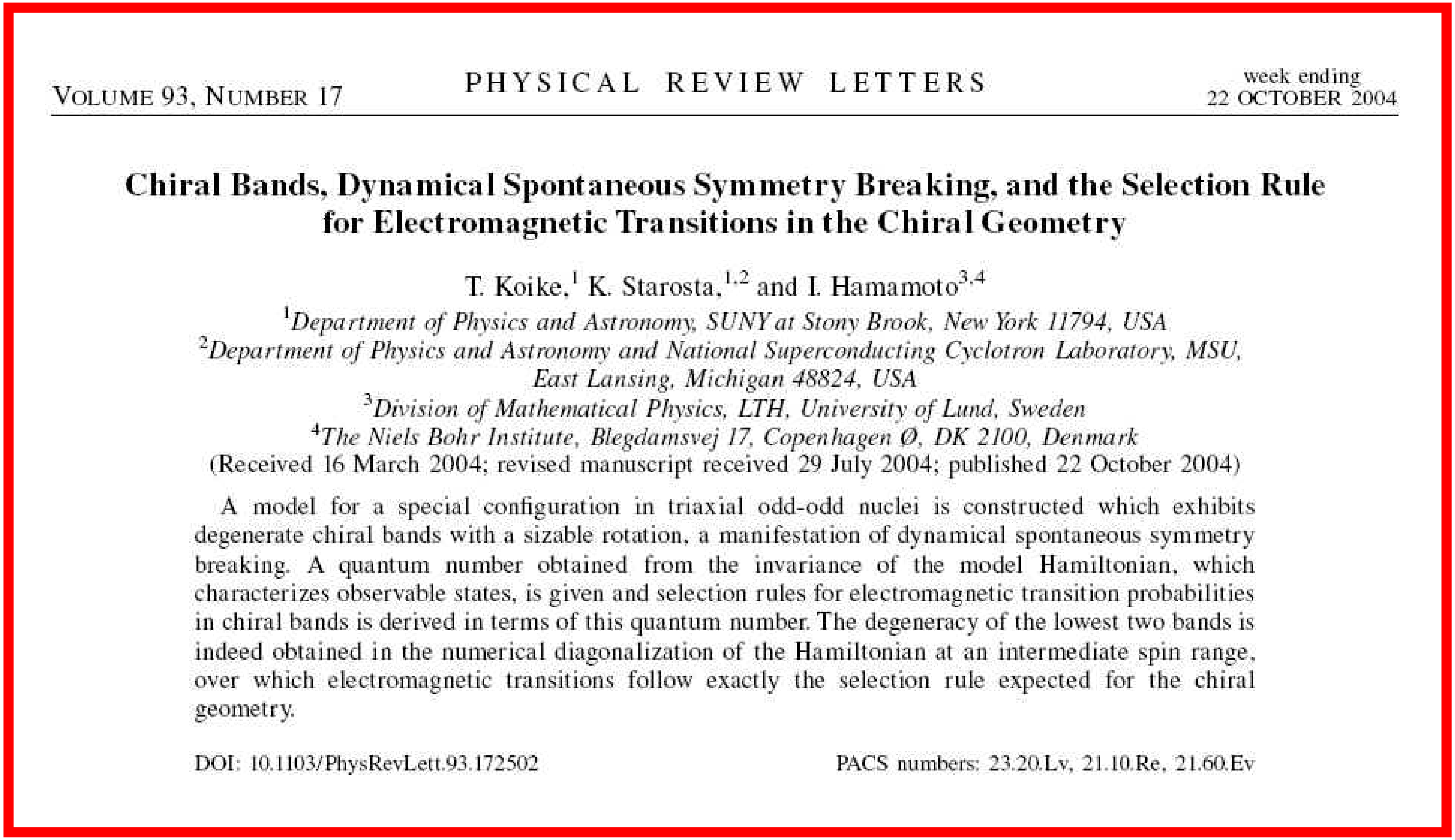
[3]*The Andrzej Sołtan Institute for Nuclear Studies, PL-05400 Świerk, Poland*

(Received 12 March 2004; published 29 July 2004)

Self-consistent solutions for the so-called planar and chiral rotational bands in ^{132}La are obtained for the first time within the Skyrme-Hartree-Fock cranking approach. It is suggested that the chiral rotation cannot exist below a certain critical frequency which under the approximations used is estimated as $\hbar\omega_{\rm crit} \approx 0.5$–$0.6$ MeV. However, the exact values of $\hbar\omega_{\rm crit}$ may vary, to an extent, depending on the microscopic model used, in particular, through the pairing correlations and/or calculated equilibrium deformations. The existence of the critical frequency is explained in terms of a simple classical model of two gyroscopes coupled to a triaxial rigid body.

DOI: 10.1103/PhysRevLett.93.052501 PACS numbers: 21.10.Re, 21.30.Fe, 21.60.Jz, 27.60.+j

Selection rule of EM transitions in Chiral rotations



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

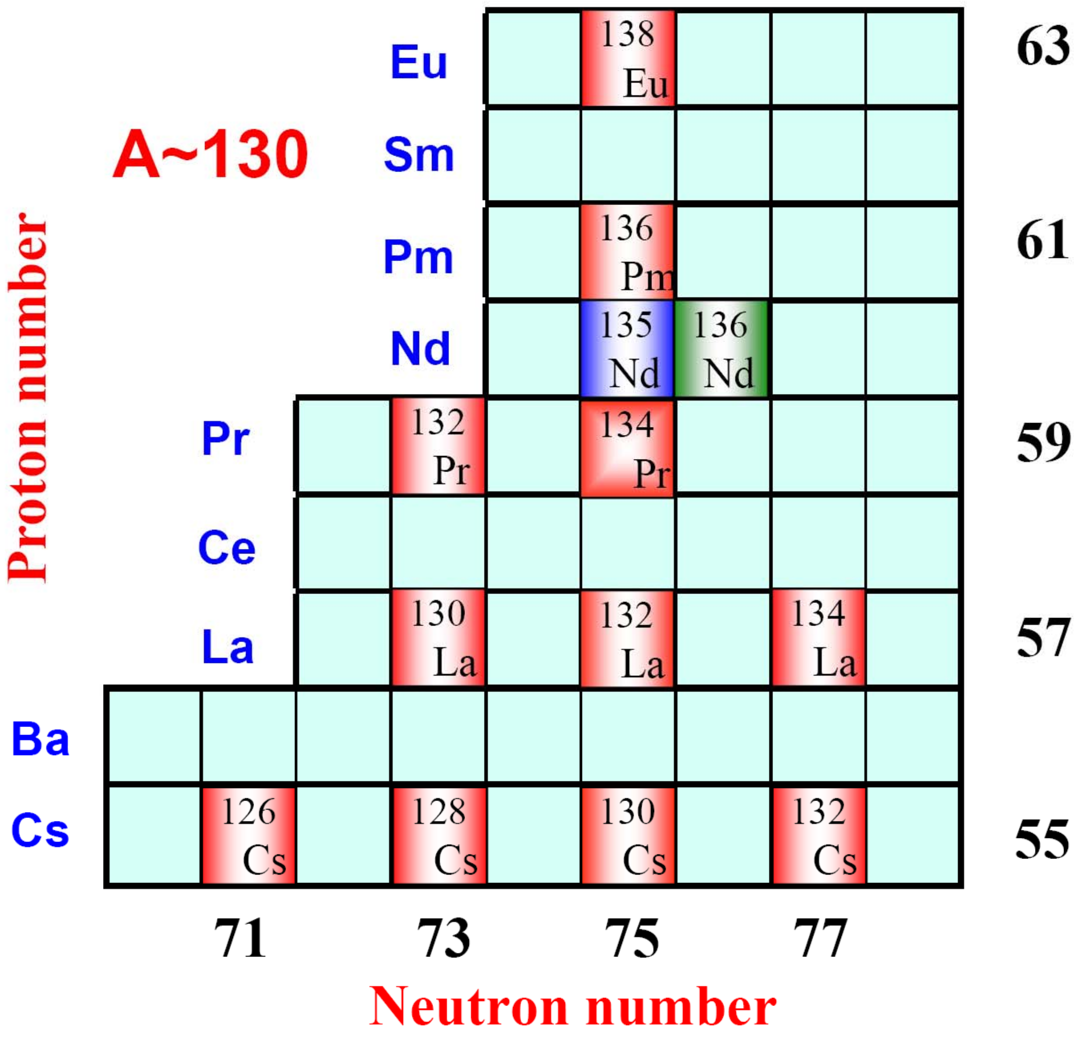
T. Koike,[1] K. Starosta,[1,2] and I. Hamamoto[3,4]
[1]*Department of Physics and Astronomy, SUNY at Stony Brook, New York 11794, USA*
[2]*Department of Physics and Astronomy and National Superconducting Cyclotron Laboratory, MSU, East Lansing, Michigan 48824, USA*
[3]*Division of Mathematical Physics, LTH, University of Lund, Sweden*
[4]*The Niels Bohr Institute, Blegdamsvej 17, Copenhagen Ø, DK 2100, Denmark*

(Received 16 March 2004; revised manuscript received 29 July 2004; published 22 October 2004)

A model for a special configuration in triaxial odd-odd nuclei is constructed which exhibits degenerate chiral bands with a sizable rotation, a manifestation of dynamical spontaneous symmetry breaking. A quantum number obtained from the invariance of the model Hamiltonian, which characterizes observable states, is given and selection rules for electromagnetic transition probabilities in chiral bands is derived in terms of this quantum number. The degeneracy of the lowest two bands is indeed obtained in the numerical diagonalization of the Hamiltonian at an intermediate spin range, over which electromagnetic transitions follow exactly the selection rule expected for the chiral geometry.

DOI: 10.1103/PhysRevLett.93.172502 PACS numbers: 23.20.Lv, 21.10.Re, 21.60.Ev

Candidate Chiral bands in *A~130 region*



^{138}Eu: Hecht 2001

^{136}Pm: Starosta 2001
Hecht 2001

^{135}Nd: Zhu 2003

^{136}Nd: Mergel 2002

^{132}Pr: Koike 2001

^{134}Pr: Petrache 1996

^{130}La: Koike 2001

^{132}La: Starosta 2001

^{134}La: Bark2001

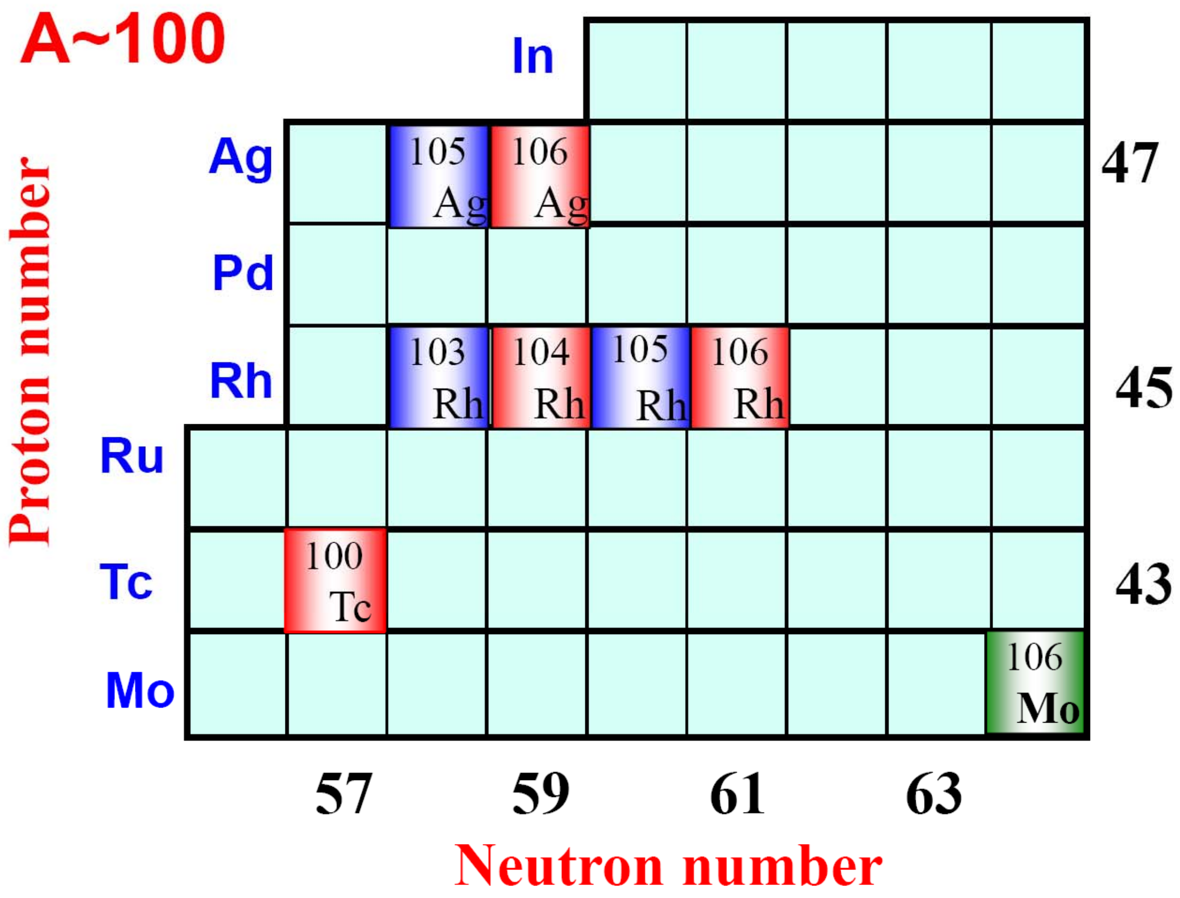
^{126}Cs: Li 2002
Wang 2006

^{128}Cs: Koike 2001

^{130}Cs: Starosta 2001

^{132}Cs: Koike 2003
Rainovski 2003

Candidate Chiral bands in *A~100 region*



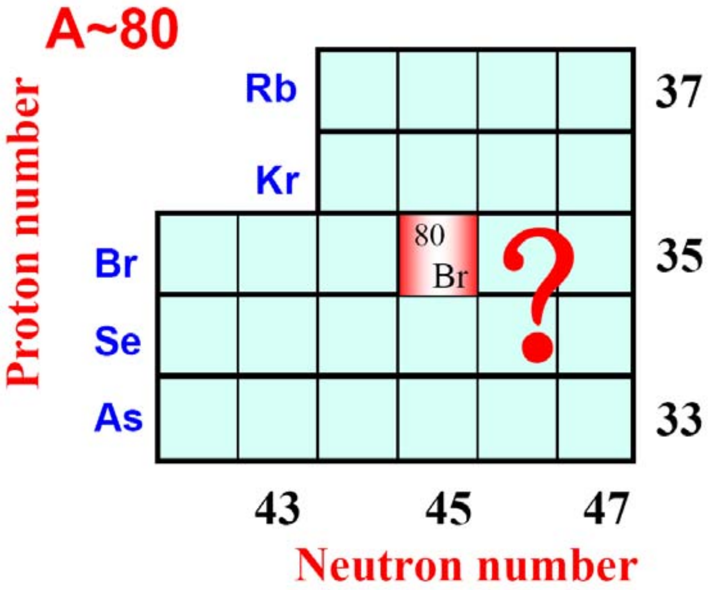
^{105}Ag: Timár 2007
^{106}Ag: He 2006
Joshi 2007
^{103}Rh: Timár 2006
^{104}Rh: Vaman 2004
^{105}Rh: Alcátara 2004
Timár 2004
^{100}Tc: Joshi 2005
^{106}Mo: Zhu 2005

Candidate Chiral bands in *other region*

Candidate Chiral bands in *A~190 region*

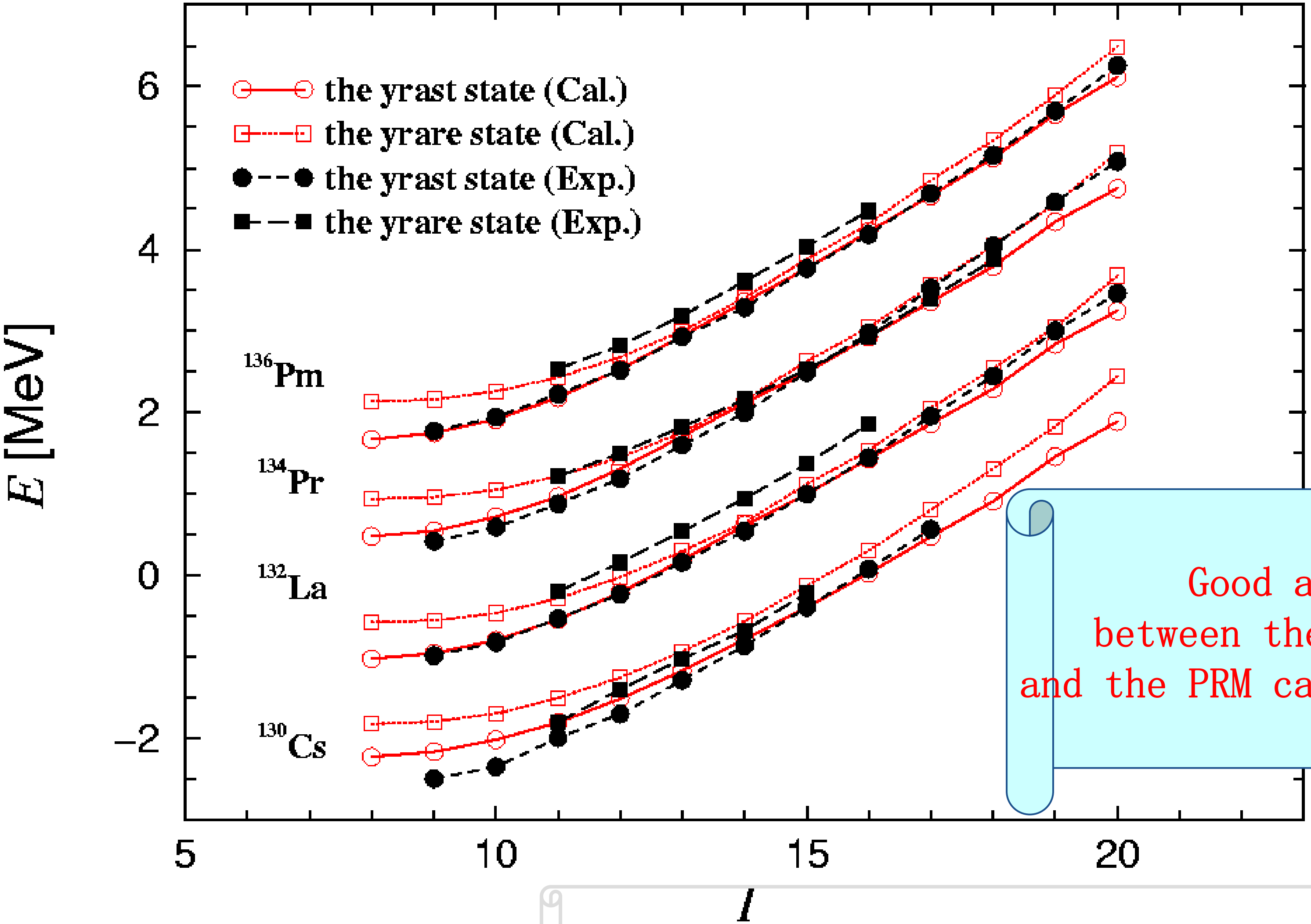
^{188}Ir: Balabanski 2004
^{198}Tl: Lawrie2008

Candidate Chiral bands in *A~80 region?*



China & South Africa
& Hungary
Mar.20-29 2009
@ iThemba Labs!

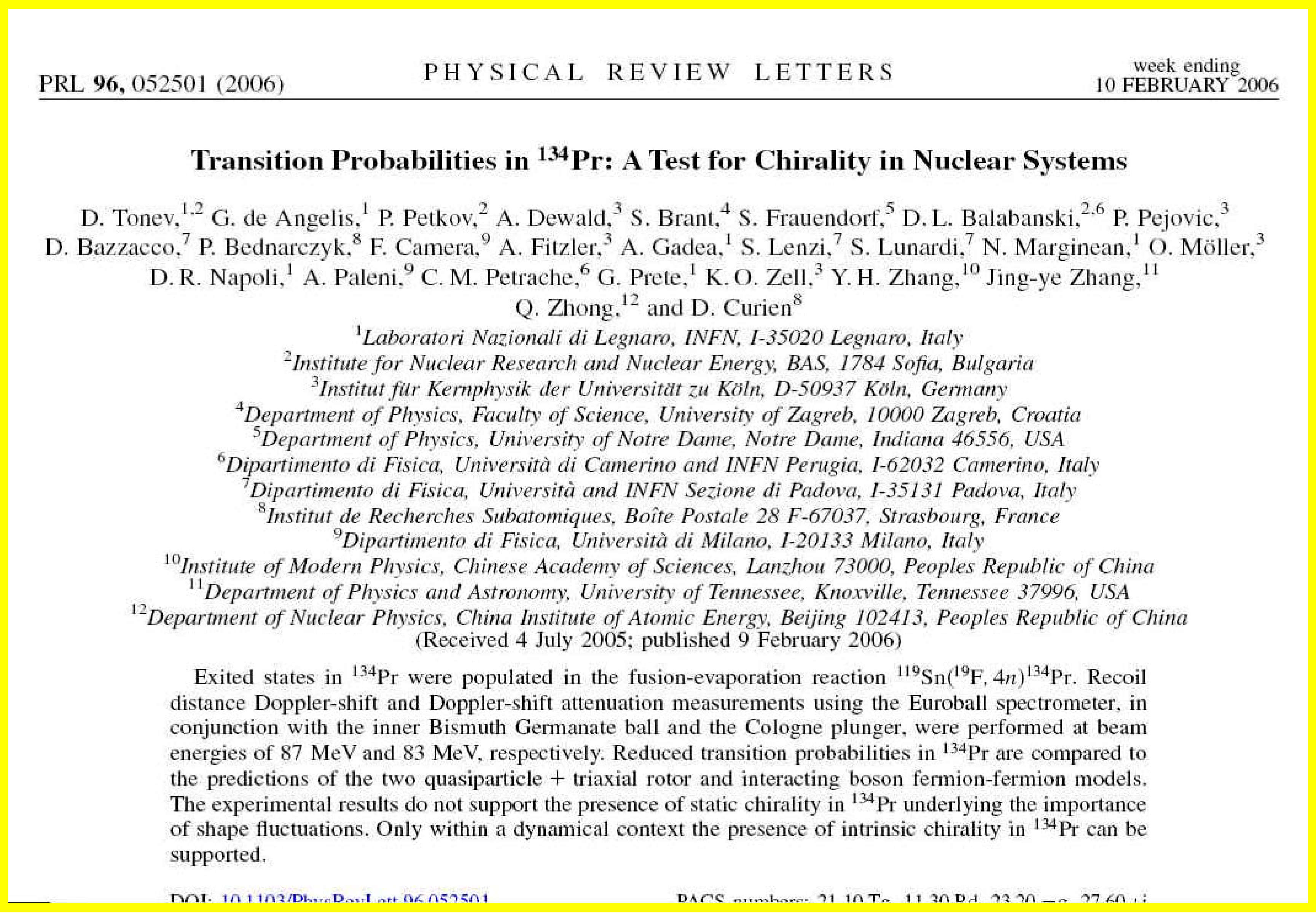
Near energy degeneracy: easy !



Good agreement between the experimental and the PRM calculated results

Peng, Meng, Zhang,Phys. Rev.C68, 044324 (2003)

Near energy degeneracy – chirality?



PRL **96,** 052501 (2006) PHYSICAL REVIEW LETTERS week ending 10 FEBRUARY 2006

Transition Probabilities in ^{134}Pr: A Test for Chirality in Nuclear Systems

D. Tonev,[1,2] G. de Angelis,[1] P. Petkov,[2] A. Dewald,[3] S. Brant,[4] S. Frauendorf,[5] D. L. Balabanski,[2,6] P. Pejovic,[3] D. Bazzacco,[7] P. Bednarczyk,[8] F. Camera,[9] A. Fitzler,[3] A. Gadea,[1] S. Lenzi,[7] S. Lunardi,[7] N. Marginean,[1] O. Möller,[3] D. R. Napoli,[1] A. Paleni,[9] C. M. Petrache,[6] G. Prete,[1] K. O. Zell,[3] Y. H. Zhang,[10] Jing-ye Zhang,[11] Q. Zhong,[12] and D. Curien[8]

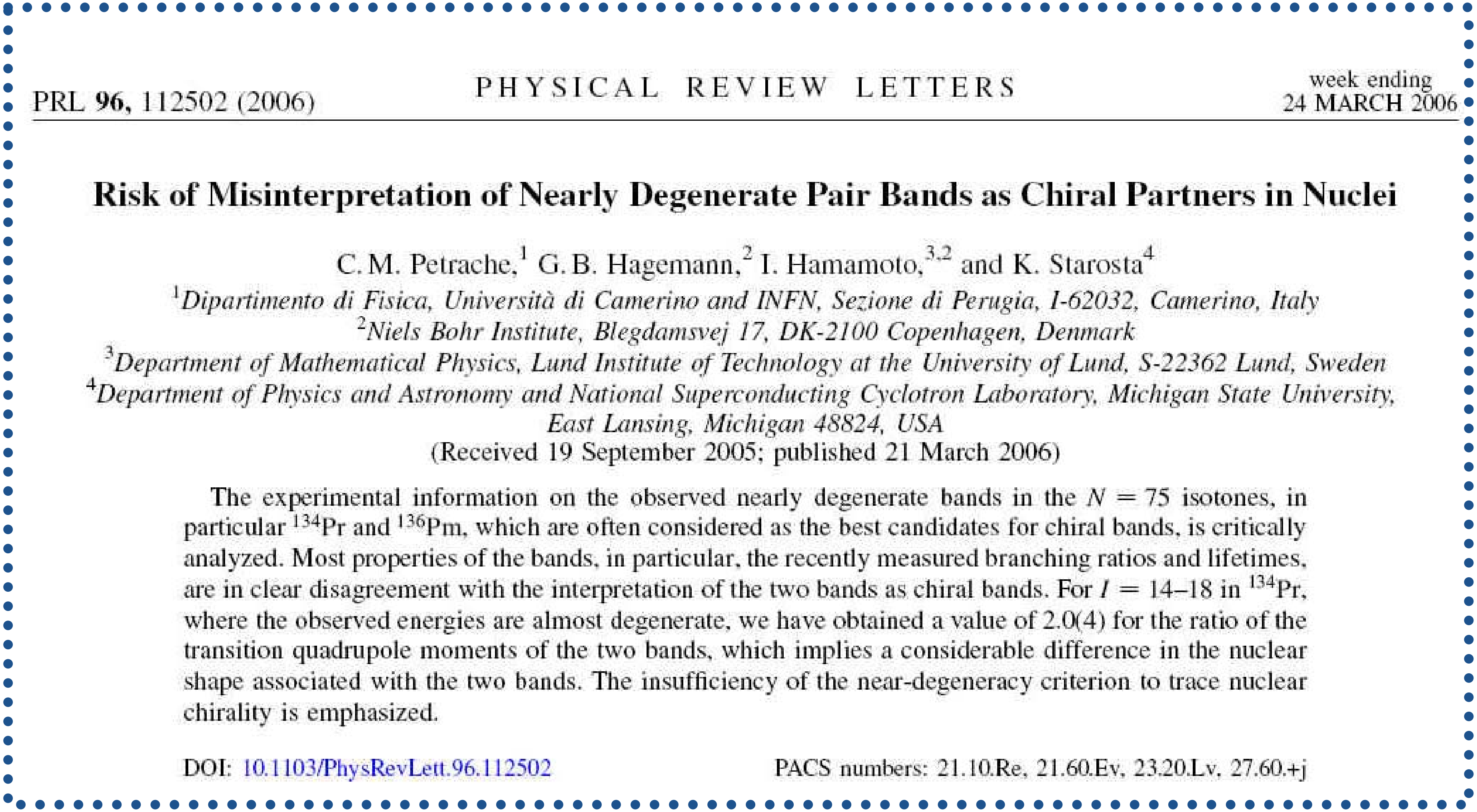
[1]*Laboratori Nazionali di Legnaro, INFN, I-35020 Legnaro, Italy*
[2]*Institute for Nuclear Research and Nuclear Energy, BAS, 1784 Sofia, Bulgaria*
[3]*Institut für Kernphysik der Universität zu Köln, D-50937 Köln, Germany*
[4]*Department of Physics, Faculty of Science, University of Zagreb, 10000 Zagreb, Croatia*
[5]*Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556, USA*
[6]*Dipartimento di Fisica, Università di Camerino and INFN Perugia, I-62032 Camerino, Italy*
[7]*Dipartimento di Fisica, Università and INFN Sezione di Padova, I-35131 Padova, Italy*
[8]*Institut de Recherches Subatomiques, Boîte Postale 28 F-67037, Strasbourg, France*
[9]*Dipartimento di Fisica, Università di Milano, I-20133 Milano, Italy*
[10]*Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 73000, Peoples Republic of China*
[11]*Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA*
[12]*Department of Nuclear Physics, China Institute of Atomic Energy, Beijing 102413, Peoples Republic of China*

(Received 4 July 2005; published 9 February 2006)

Exited states in ^{134}Pr were populated in the fusion-evaporation reaction ^{119}Sn(^{19}F, $4n$)^{134}Pr. Recoil distance Doppler-shift and Doppler-shift attenuation measurements using the Euroball spectrometer, in conjunction with the inner Bismuth Germanate ball and the Cologne plunger, were performed at beam energies of 87 MeV and 83 MeV, respectively. Reduced transition probabilities in ^{134}Pr are compared to the predictions of the two quasiparticle + triaxial rotor and interacting boson fermion-fermion models. The experimental results do not support the presence of static chirality in ^{134}Pr underlying the importance of shape fluctuations. Only within a dynamical context the presence of intrinsic chirality in ^{134}Pr can be supported.

DOI: 10.1103/PhysRevLett.96.052501 PACS numbers: 21.10.Tg, 11.30.Rd, 23.20.−g, 27.60.+j

^{134}Pr – Chiral candidate ? ? ?



PRL **96,** 112502 (2006) PHYSICAL REVIEW LETTERS week ending 24 MARCH 2006

Risk of Misinterpretation of Nearly Degenerate Pair Bands as Chiral Partners in Nuclei

C. M. Petrache,[1] G. B. Hagemann,[2] I. Hamamoto,[3,2] and K. Starosta[4]

[1]*Dipartimento di Fisica, Università di Camerino and INFN, Sezione di Perugia, I-62032, Camerino, Italy*
[2]*Niels Bohr Institute, Blegdamsvej 17, DK-2100 Copenhagen, Denmark*
[3]*Department of Mathematical Physics, Lund Institute of Technology at the University of Lund, S-22362 Lund, Sweden*
[4]*Department of Physics and Astronomy and National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*

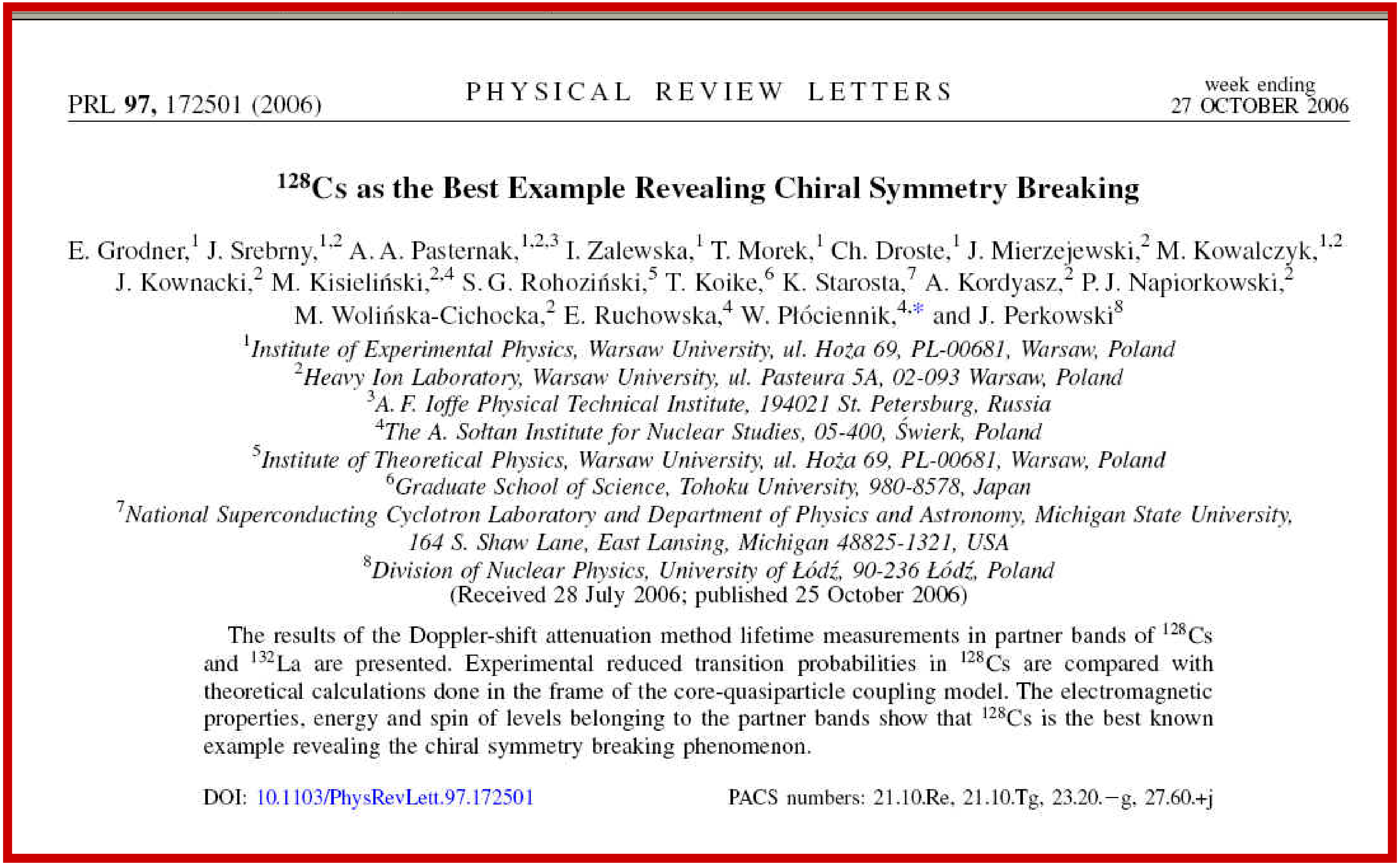
(Received 19 September 2005; published 21 March 2006)

The experimental information on the observed nearly degenerate bands in the $N = 75$ isotones, in particular ^{134}Pr and ^{136}Pm, which are often considered as the best candidates for chiral bands, is critically analyzed. Most properties of the bands, in particular, the recently measured branching ratios and lifetimes, are in clear disagreement with the interpretation of the two bands as chiral bands. For $I = 14$–18 in ^{134}Pr, where the observed energies are almost degenerate, we have obtained a value of 2.0(4) for the ratio of the transition quadrupole moments of the two bands, which implies a considerable difference in the nuclear shape associated with the two bands. The insufficiency of the near-degeneracy criterion to trace nuclear chirality is emphasized.

DOI: 10.1103/PhysRevLett.96.112502 PACS numbers: 21.10.Re, 21.60.Ev, 23.20.Lv, 27.60.+j

End of the story ?

手征原子核： another best example！？



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]

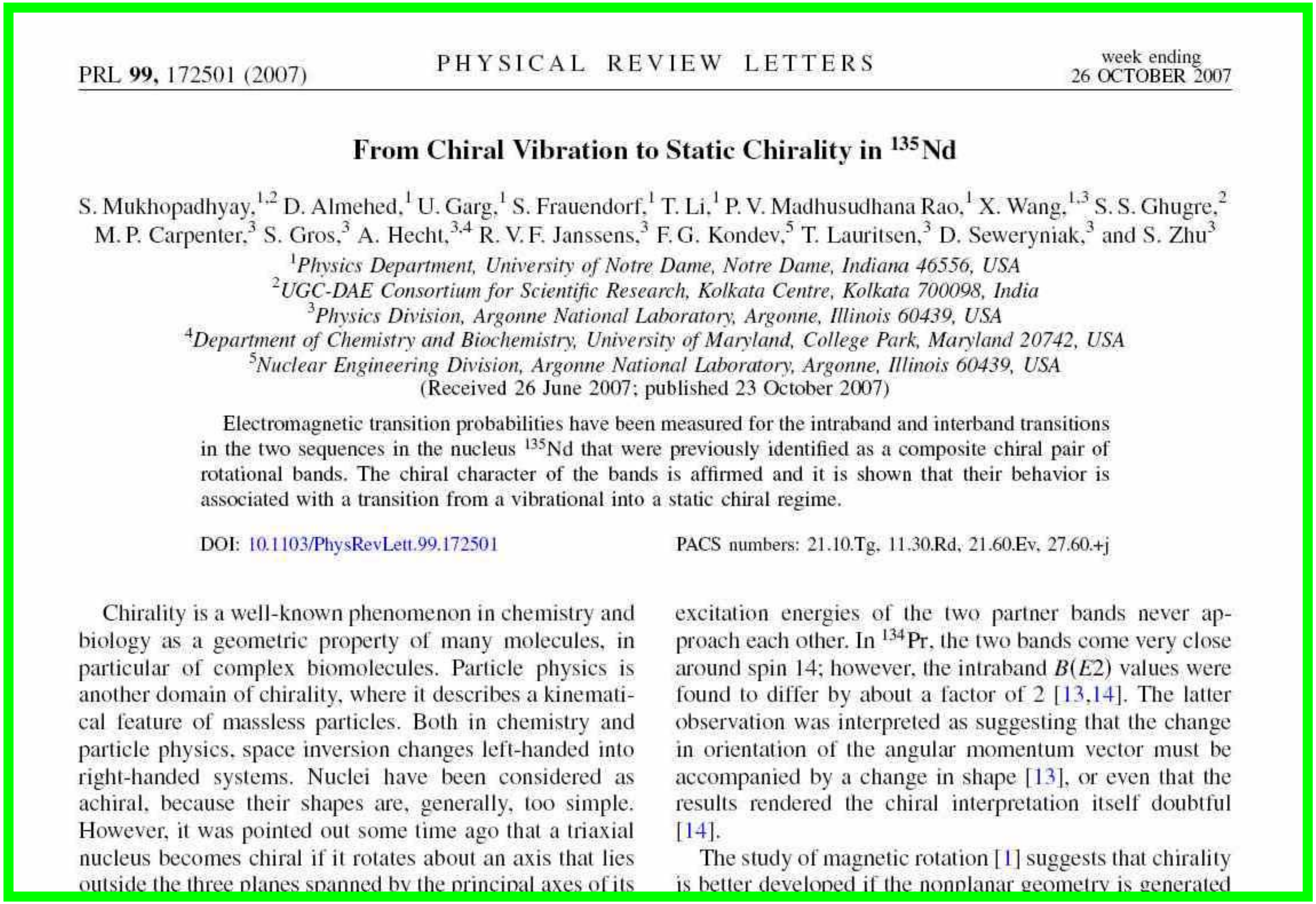
[1]*Institute of Experimental Physics, Warsaw University, ul. Hoża 69, PL-00681, Warsaw, Poland*
[2]*Heavy Ion Laboratory, Warsaw University, ul. Pasteura 5A, 02-093 Warsaw, Poland*
[3]*A. F. Ioffe Physical Technical Institute, 194021 St. Petersburg, Russia*
[4]*The A. Sołtan Institute for Nuclear Studies, 05-400, Świerk, Poland*
[5]*Institute of Theoretical Physics, Warsaw University, ul. Hoża 69, PL-00681, Warsaw, Poland*
[6]*Graduate School of Science, Tohoku University, 980-8578, Japan*
[7]*National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, 164 S. Shaw Lane, East Lansing, Michigan 48825-1321, USA*
[8]*Division of Nuclear Physics, University of Łódź, 90-236 Łódź, Poland*

(Received 28 July 2006; published 25 October 2006)

The results of the Doppler-shift attenuation method lifetime measurements in partner bands of ^{128}Cs and ^{132}La are presented. Experimental reduced transition probabilities in ^{128}Cs are compared with theoretical calculations done in the frame of the core-quasiparticle coupling model. The electromagnetic properties, energy and spin of levels belonging to the partner bands show that ^{128}Cs is the best known example revealing the chiral symmetry breaking phenomenon.

DOI: 10.1103/PhysRevLett.97.172501 PACS numbers: 21.10.Re, 21.10.Tg, 23.20.−g, 27.60.+j

手征原子核： another best example！？



PRL **99,** 172501 (2007) PHYSICAL REVIEW LETTERS week ending 26 OCTOBER 2007

From Chiral Vibration to Static Chirality in ^{135}Nd

S. Mukhopadhyay,[1,2] D. Almehed,[1] U. Garg,[1] S. Frauendorf,[1] T. Li,[1] P. V. Madhusudhana Rao,[1] X. Wang,[1,3] S. S. Ghugre,[2] M. P. Carpenter,[3] S. Gros,[3] A. Hecht,[3,4] R. V. F. Janssens,[3] F. G. Kondev,[5] T. Lauritsen,[3] D. Seweryniak,[3] and S. Zhu[3]

[1]*Physics Department, University of Notre Dame, Notre Dame, Indiana 46556, USA*
[2]*UGC-DAE Consortium for Scientific Research, Kolkata Centre, Kolkata 700098, India*
[3]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*
[4]*Department of Chemistry and Biochemistry, University of Maryland, College Park, Maryland 20742, USA*
[5]*Nuclear Engineering Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*

(Received 26 June 2007; published 23 October 2007)

Electromagnetic transition probabilities have been measured for the intraband and interband transitions in the two sequences in the nucleus ^{135}Nd that were previously identified as a composite chiral pair of rotational bands. The chiral character of the bands is affirmed and it is shown that their behavior is associated with a transition from a vibrational into a static chiral regime.

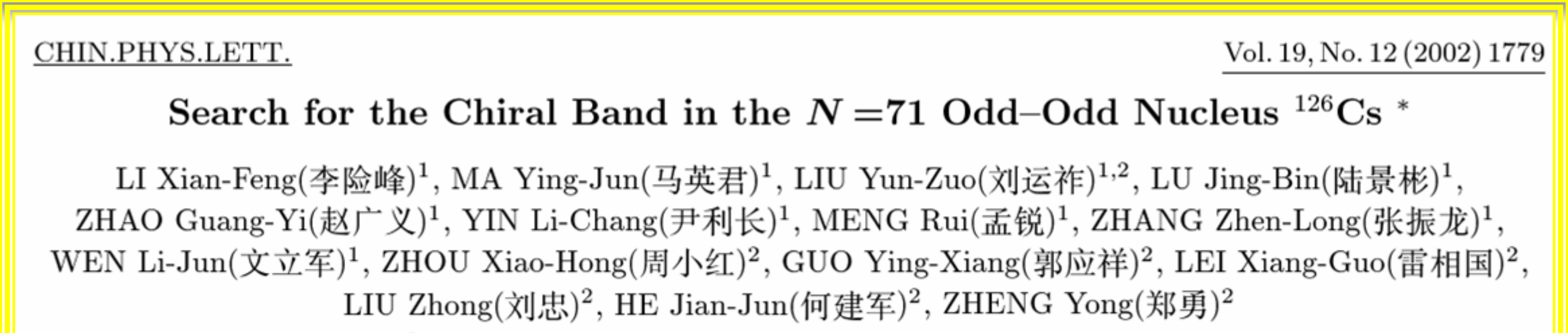
DOI: 10.1103/PhysRevLett.99.172501 PACS numbers: 21.10.Tg, 11.30.Rd, 21.60.Ev, 27.60.+j

Chirality is a well-known phenomenon in chemistry and biology as a geometric property of many molecules, in particular of complex biomolecules. Particle physics is another domain of chirality, where it describes a kinematical feature of massless particles. Both in chemistry and particle physics, space inversion changes left-handed into right-handed systems. Nuclei have been considered as achiral, because their shapes are, generally, too simple. However, it was pointed out some time ago that a triaxial nucleus becomes chiral if it rotates about an axis that lies outside the three planes spanned by the principal axes of its

excitation energies of the two partner bands never approach each other. In ^{134}Pr, the two bands come very close around spin 14; however, the intraband $B(E2)$ values were found to differ by about a factor of 2 [13,14]. The latter observation was interpreted as suggesting that the change in orientation of the angular momentum vector must be accompanied by a change in shape [13], or even that the results rendered the chiral interpretation itself doubtful [14].

The study of magnetic rotation [1] suggests that chirality is better developed if the nonplanar geometry is generated

Observations of the Chiral doublets bands in China



CHIN.PHYS.LETT. Vol. 19, No. 12 (2002) 1779

Search for the Chiral Band in the $N=71$ Odd–Odd Nucleus ^{126}Cs *

LI Xian-Feng(李险峰)[1], MA Ying-Jun(马英君)[1], LIU Yun-Zuo(刘运祚)[1,2], LU Jing-Bin(陆景彬)[1],
ZHAO Guang-Yi(赵广义)[1], YIN Li-Chang(尹利长)[1], MENG Rui(孟锐)[1], ZHANG Zhen-Long(张振龙)[1],
WEN Li-Jun(文立军)[1], ZHOU Xiao-Hong(周小红)[2], GUO Ying-Xiang(郭应祥)[2], LEI Xiang-Guo(雷相国)[2],
LIU Zhong(刘忠)[2], HE Jian-Jun(何建军)[2], ZHENG Yong(郑勇)[2]
[1]Department of Physics, Jilin University, Changchun 130023

PHYSICAL REVIEW C **74**, 017302 (2006)

Candidate chiral doublet bands in the odd-odd nucleus ^{126}Cs

Shouyu Wang,[1] Yunzuo Liu,[1,2] T. Komatsubara,[3] Yingjun Ma,[1] and Yuhu Zhang[2]
[1]*Department of Physics, Jilin University, Changchun 130021, People's Republic of China*
[2]*Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, People's Republic of China*
[3]*Institute of Physics, Tandem Accelerator Center, University of Tsukuba, Ibaraki 305, Japan*

(Received 28 November 2005; published 7 July 2006)

The candidate chiral doublet bands recently observed in ^{126}Cs have been extended to higher spins, several new

Question: Chiral bands ?

Reproduction of Spectra & transition in 2qp coupled with triaxial rotor ! Examine the orientation of the AM

Nuclear Chirality: Based on the geometry for one particle and one hole coupled to a triaxial rotor with gamma=30^0

1. nearly degenerate doublet bands

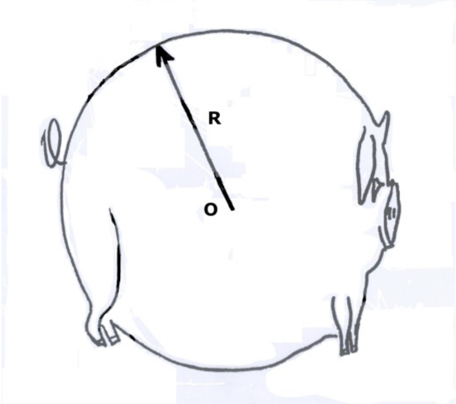
2. S(I) independent of spin

3. identical spin alignments

4. identical B(M1), B(E2) values

5. staggering of B(M1)/B(E2) ratios

6. interband B(E2)=0 at high spin



chiral bands

It is necessary to have a model with many-particles plus many-holes coupled with triaxial rotor!

S.Y. Wang, S.Q. Zhang, B. Qi, and J. Meng, Examining the Chiral Geometry in ^{104}Rh and ^{106}Rh, Chinese Physics Letters 2007 24 (3): 664-667

Theoretical Progress

- **3D Tilted Axis Cranking**
  - –S.Frauendorf and J.Meng, Nucl. Phys. A420, 173 (1984)
- **Relativistic Mean Field**
  - -Madokoro, Meng, Matsuzaki, Yamaji, Phys. Rev. C 62 (2000) 061301
  - –Peng et al., Phys. Rev. C 77, 024309 (2008)
- self- consistent rotating mean field solutions
  - –Dimitrov, Frauendorf, and F. Doenau, Phys. Rev. Lett. 84, 5732 (2000)
- **Skyrme-Hatree-Fock Cranking**
  - –P. Olbratowski et al., Phys. Rev. Lett. 93 052501 (2004)
- **TAC+RPA** (^{135}Nd) Phys. Rev. Lett. 99, 172501 (2007)

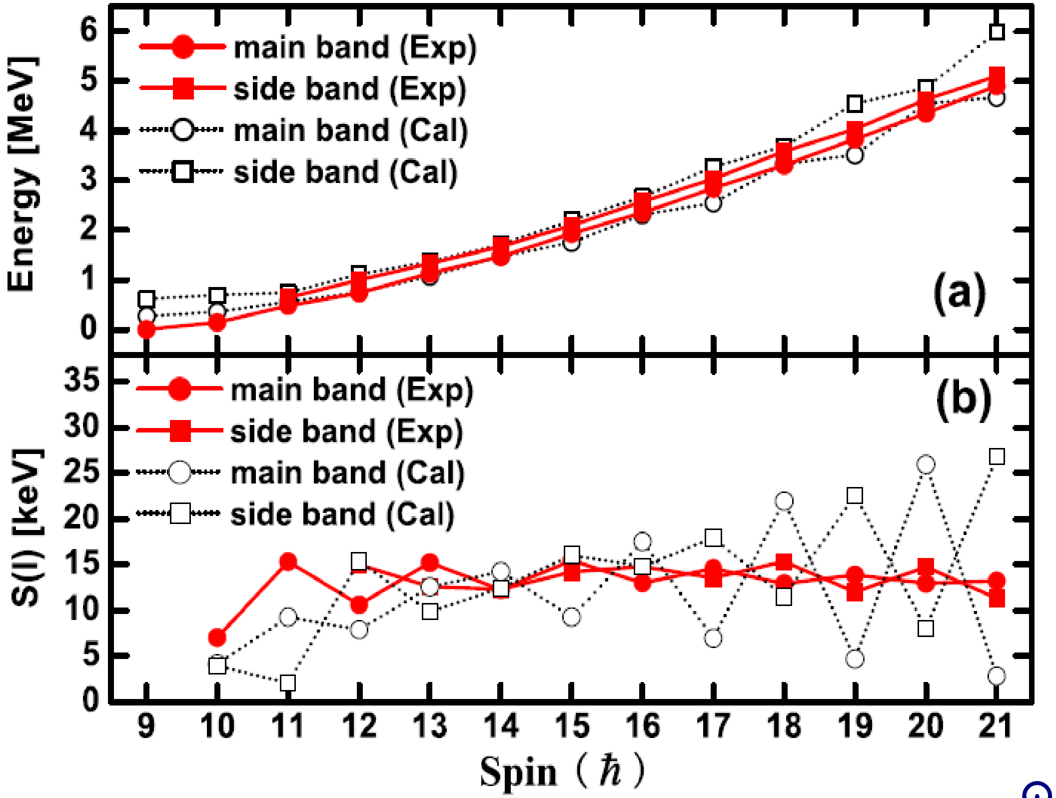
- **Particle-hole plus triaxial rotor model**
  - –S.Frauendorf and J.Meng, Nucl. Phys. A420, 173 (1984)
  - –T. Koike, K. Starosta, and I. Hamamoto, Phys. Rev. Lett. 93, 172502 (2004)
  - –K. Starosta et al., Phys. Rev. C65 044328 (2004)
  - –S.Q.Zhang et al., Phys. Rev. C75, 044307 (2007)
  - –B. Qi et al., Phys. Lett. B675 175 (2009)
  - –E. A. Lawrie et al., Phys. Rev. C 78021305 (2008)
- **Pair Truncated Shell Model / Quadrupole Coupling Model**
  - –K. Higashiyama, N. Yoshinaga, and K. Tanabe, Phys. Rev. C 72, 024315 (2005)
  - –N. Yoshinaga and K. Higashiyama, Eur. Phys. J A 30,343 (2006)
- **Interacting Boson Fermion Fermion Model (IBFFM)**
  - –S. Brant, D. Vretenar, and A. Ventura, Phys. Rev. C 69, 017304 (2004)
- **Interacting Vector Boson Model (IVBM)**
  - –H. G. Ganev, A. I. Georgieva, S. Brant, and A. Ventura, Phys. Rev. C 79, 044322 (2009)

Simulating n-particles-n-holes by pairing

configuration:

one proton in $h_{11/2}$

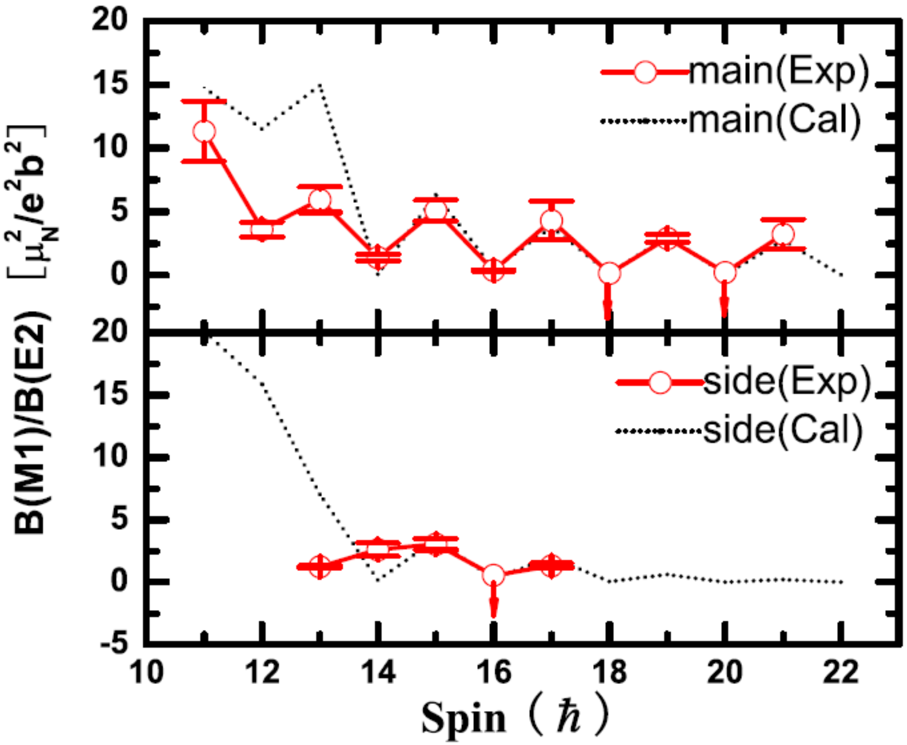
one quasi-neutron in $h_{11/2}$: simulate n-neutron holes



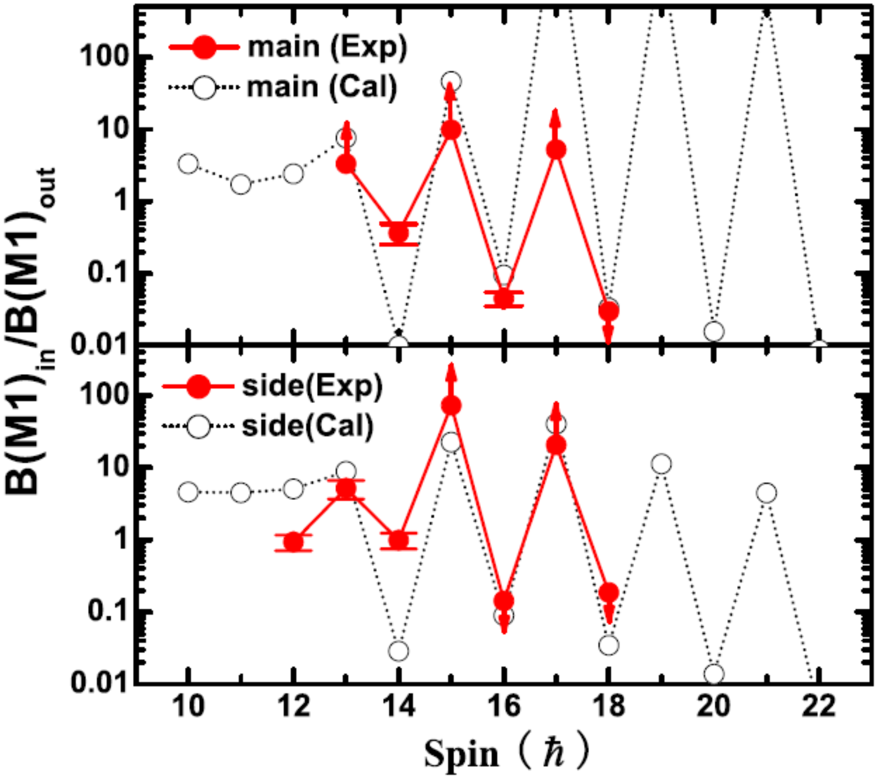
Energy spectra of ^{126}Cs

S.Y. Wang, S.Q. Zhang, B. Qi, and J. Meng, Phys. Rev. C 75, 024309 (2007)

Simulating n-particles-n-holes by pairing



S.Y. Wang, S.Q. Zhang, B. Qi, J. Meng, Phys. Rev. C 75, 024309 (2007)



Electromagnetic properties of ^{126}Cs

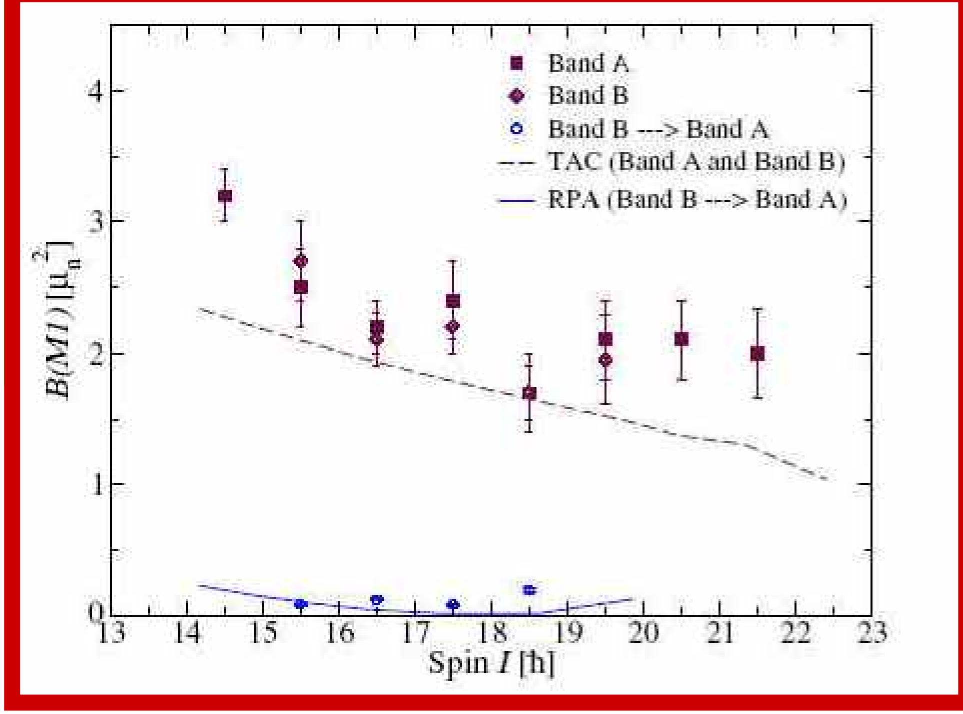
^{135}Nd as an example

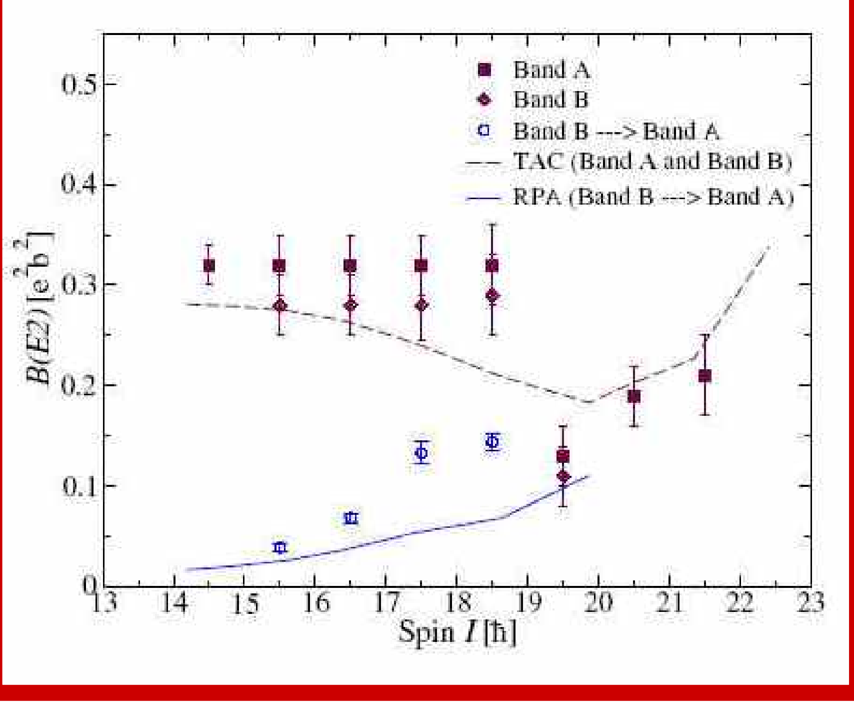
PRL **99**, 172501 (2007) PHYSICAL REVIEW LETTERS week ending 26 OCTOBER 2007

From Chiral Vibration to Static Chirality in ^{135}Nd

S. Mukhopadhyay,[1,2] D. Almehed,[1] U. Garg,[1] S. Frauendorf,[1] T. Li,[1] P. V. Madhusudhana Rao,[1] X. Wang,[1,3] S. S. Ghugre,[2] M. P. Carpenter,[3] S. Gros,[3] A. Hecht,[3,4] R. V. F. Janssens,[3] F. G. Kondev,[5] T. Lauritsen,[3] D. Seweryniak,[3] and S. Zhu[3]

[1]*Physics Department, University of Notre Dame, Notre Dame, Indiana 46556, USA*
[2]*UGC-DAE Consortium for Scientific Research, Kolkata Centre, Kolkata 700098, India*
[3]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*





Odd-A Chiral Nucleus ^{135}Nd

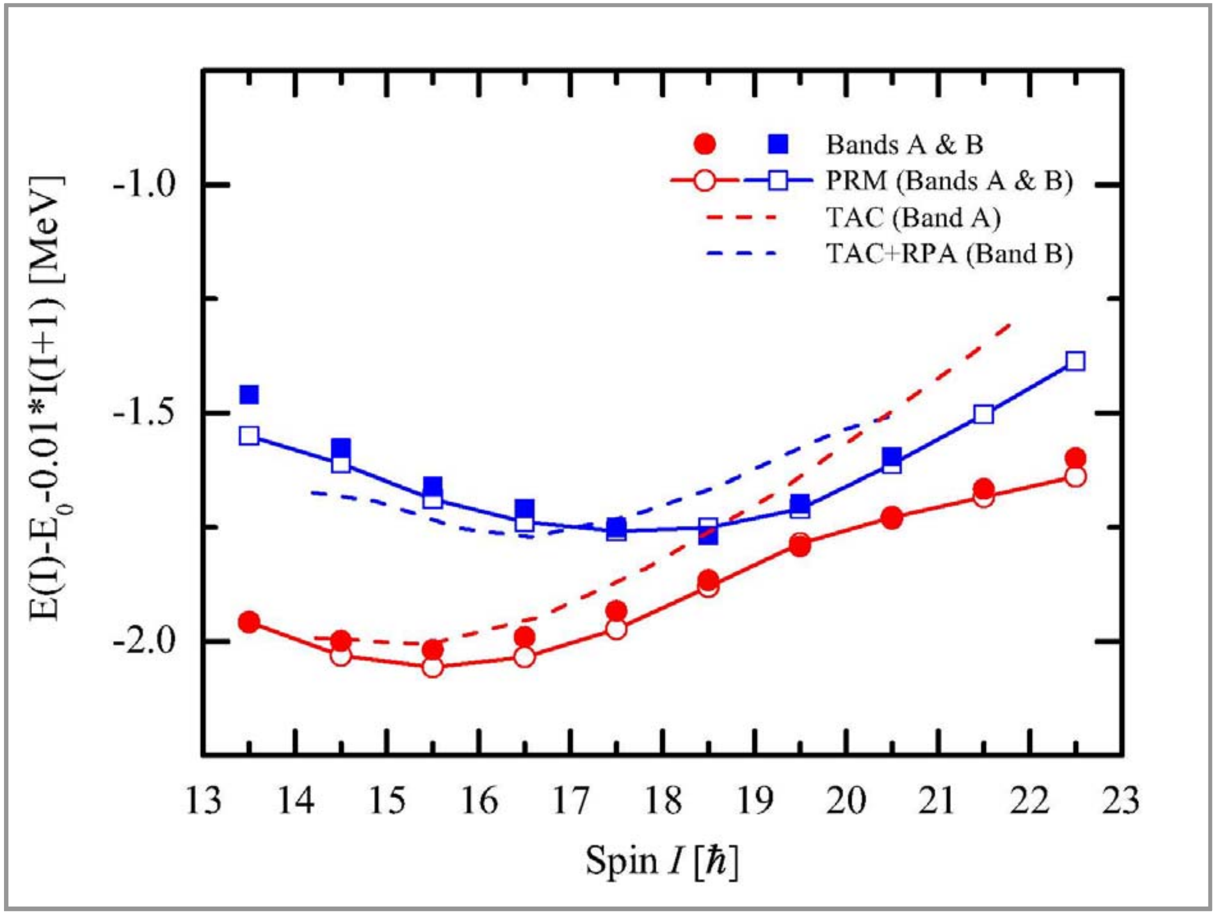
Many-particle-many-hole & triaxial rotor

Numerical details

- Config: $\pi h_{11/2}^{2} \otimes \nu h_{11/2}^{-1}$
- deformation $\beta = 0.235,\quad \gamma = 22.4^{\circ}$ with RMF
- MOI $29\hbar^{2}/MeV$ justified by data
- intrinsic Q $Q_0 = (3/\sqrt{5\pi})R_0^{2} Z\beta = 4.0eb$
- g-factor $g_R = Z/A,\quad g_p = 1.21,\quad g_n = -0.21$

Odd-A Chiral Nucleus ^{135}Nd

奇-A 核^{135}Nd中候选手征带的能谱

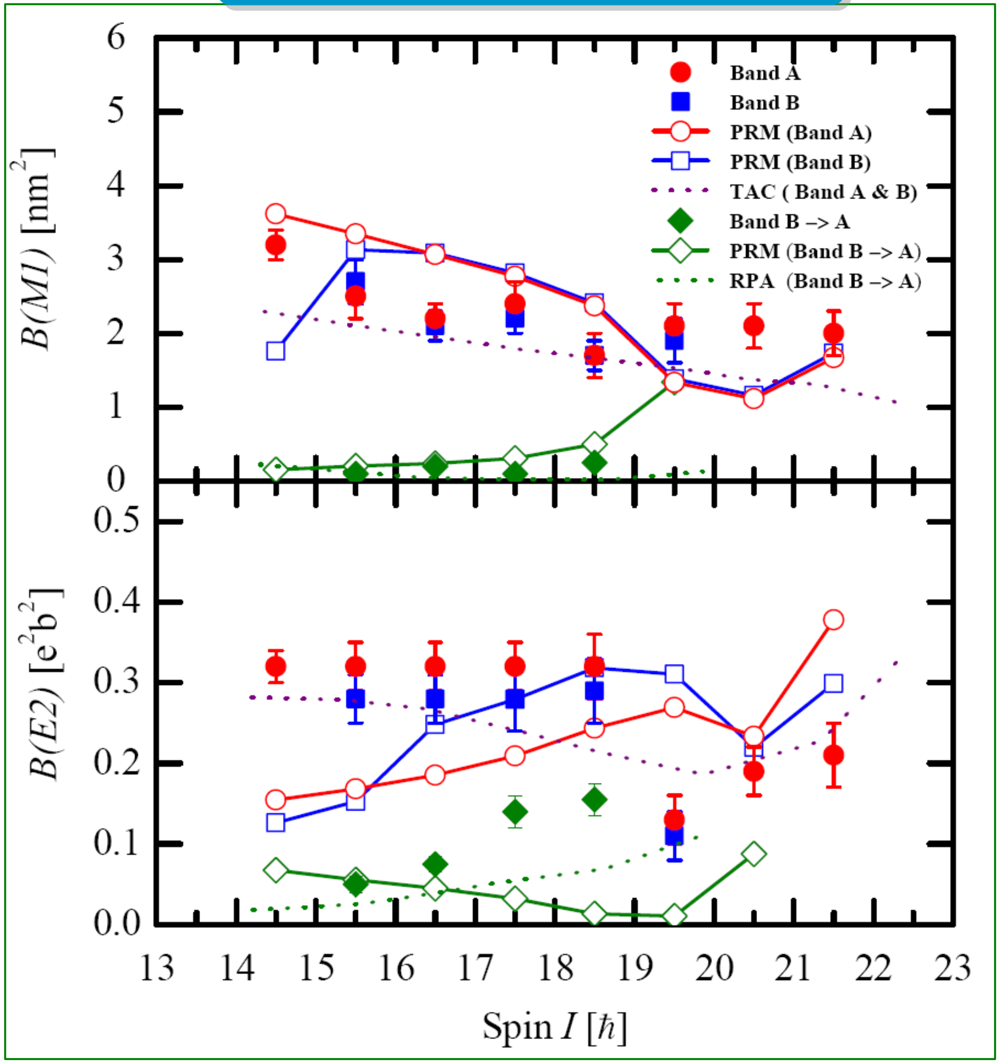


Data: Zhu *PRL* 2003
TAC: Mukhopahyay *PRL* 2007

Chirality in odd-A nucleus ^{135}Nd in particle rotor model,
B.Qi, S.Q. Zhang, J. Meng, S.Y. Wang, S. Frauendorf, Phys. Lett. B 675 (2009) 175–180

Odd-A Chiral Nucleus ^{135}Nd

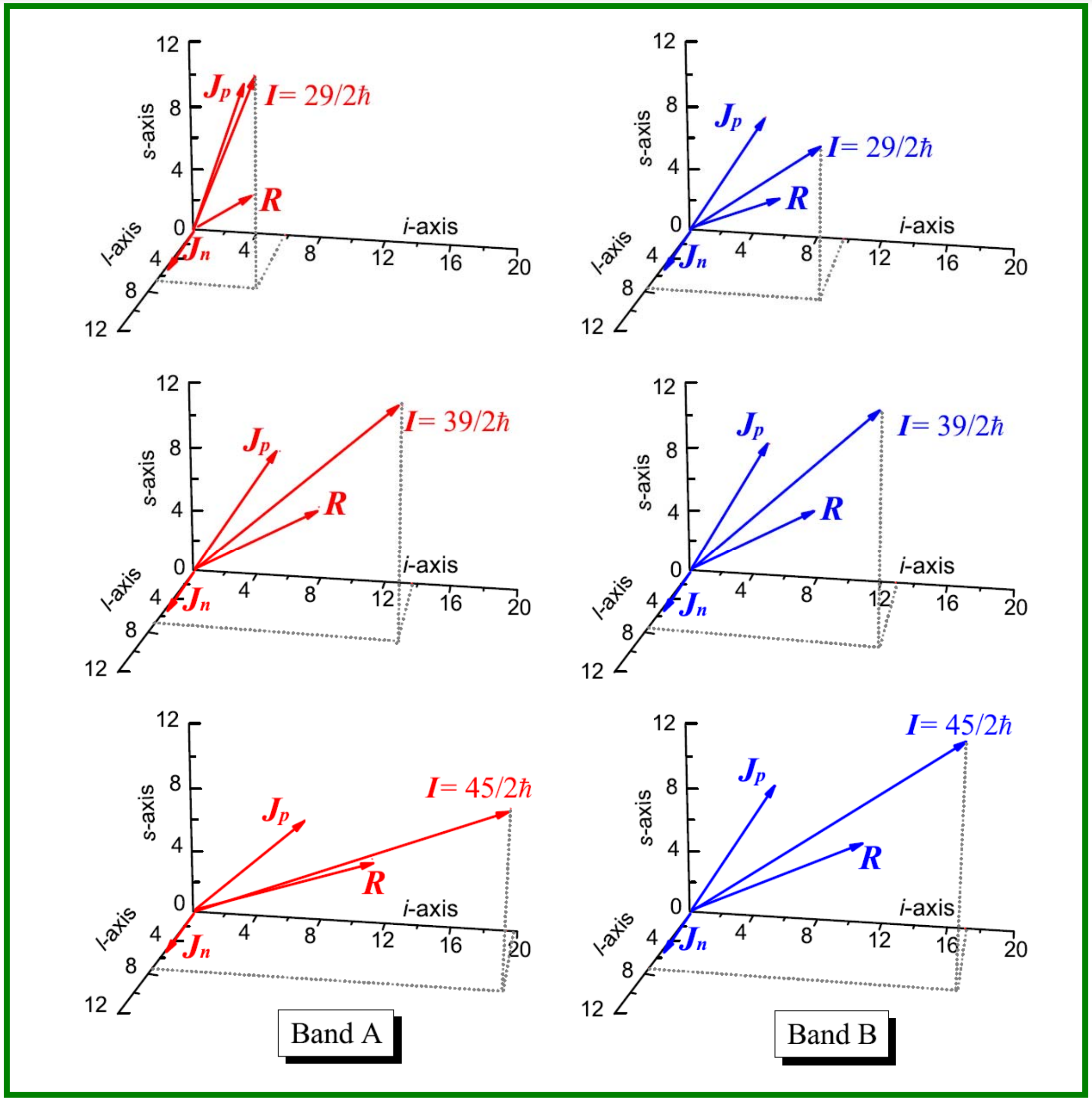
B(M1) & B(E2)



B(M1) & B(E2)的实验特征被很好的再现

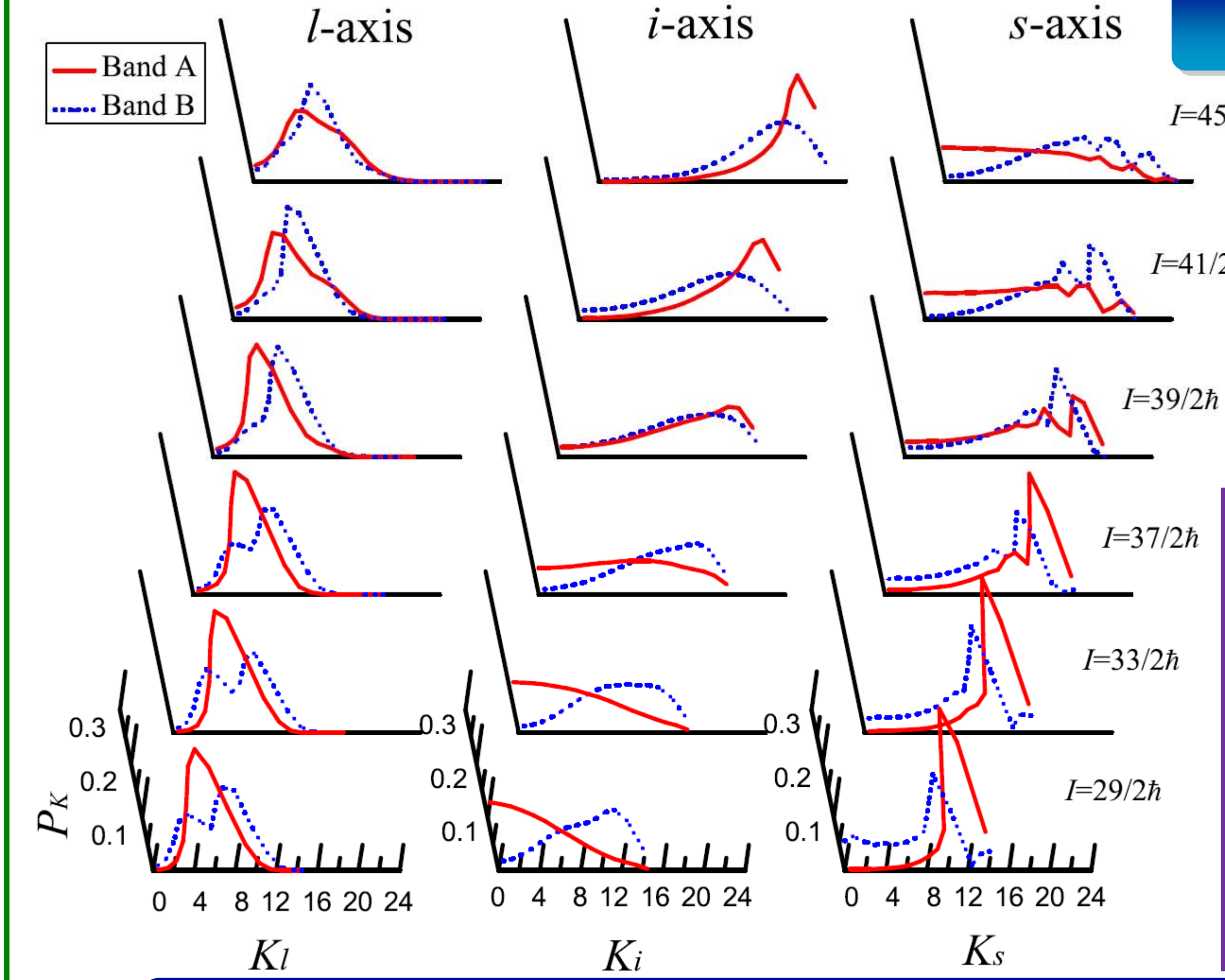
Odd-A Chiral Nucleus ^{135}Nd

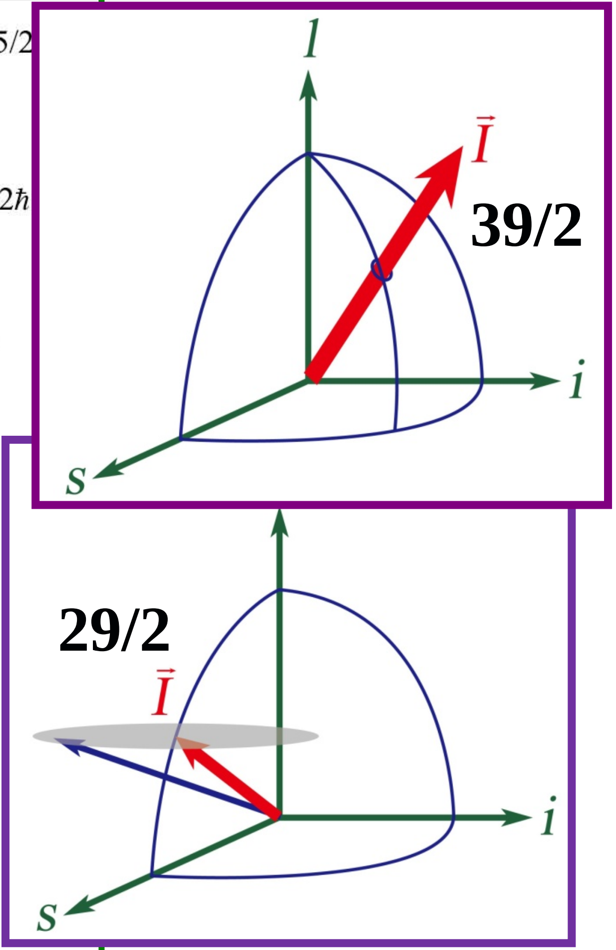
角动量期待值



Odd-A Chiral Nucleus ^{135}Nd

角动量投影值





动态手性 → I=39/2附近的静态手性 → 动态手性

Microscopic deformation calculation for chiral

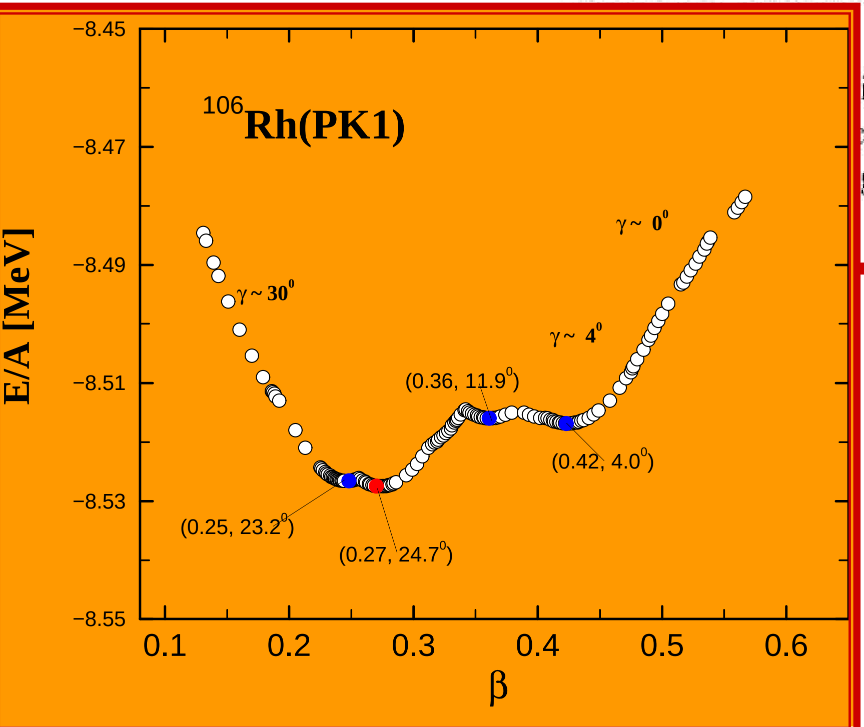
PHYSICAL REVIEW C **73**, 037303 (2006)

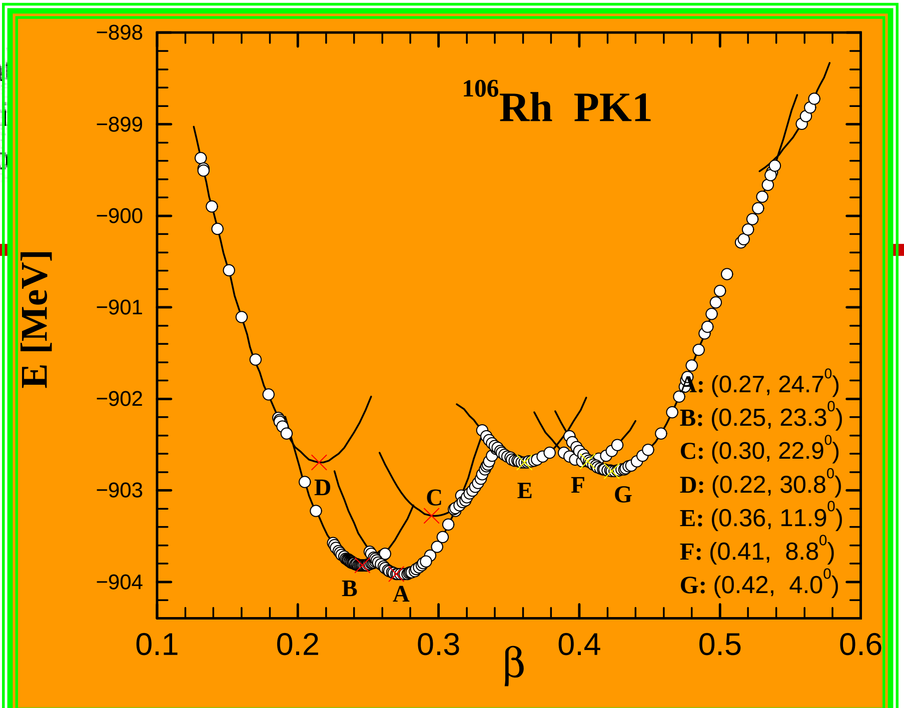
Possible existence of multiple chiral doublets in ^{106}Rh

J. Meng,[1,2,3,*] J. Peng,[1] S. Q. Zhang,[1] and S.-G. Zhou[2,3]
[1] *School of Physics, Peking University, Beijing 100871, China*
[2] *Institute of Theoretical Physics, Chinese Academy of Science, Beijing 100080, China*
[3] *Center of Theoretical Nuclear Physics, National Laboratory of Heavy Ion Accelerator, Lanzhou 730000, China*
(Received 30 March 2005; published 15 March 2006)

MχD

iaxial rela
ce of multi
ggested fo





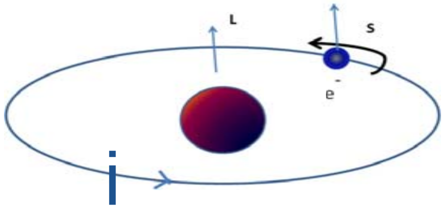
Relativistic description of magnetic moment

- Nuclear magnetic moment is ontained from the effective electromagnetic current

$$j_i^{\mu}(x) = \underset{\substack{\downarrow \\ j_D}}{Q\overline{\psi}_i\gamma^{\mu}\psi_i} + \frac{\lambda_a}{2M}\partial_{\nu}(\underset{\substack{\downarrow \\ j_A}}{\overline{\psi}_i}\sigma^{\mu\nu}\psi_i)$$

- Static magnetic dipole moment is determined by

$$\vec{\mu} = \sum_i \frac{1}{2}\int d^3 r[\vec{r}\times\vec{j}_i]$$



- Nuclear magnetic moment can naturally be divided into the Dirac and anomalous parts,

$$\mu = \begin{cases} \mu_D, & \text{for a relativistic point particle} \\ \mu_A, & \text{from intrinsic structure} \end{cases}$$

Isoscalar magnetic moment

- The enhanced isoscalar magnetic moment: the over-enhancement for the Dirac magnetic moment

$$\vec{\mu}_D = \frac{1}{2}\int d^3r\ \vec{r}\times\vec{j}_D = \frac{1}{2}\int d^3r\ \frac{1}{M^*}\bar{\psi}\left(\vec{L}+\vec{\Sigma}\right)\psi$$

With $M^* \approx 0.6M$

- Time-odd RMF approach: the space-like components of vector meson field leads to non-vanishing current

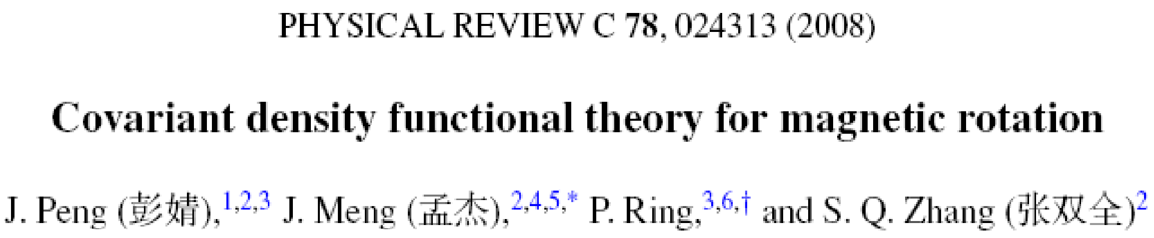
Isoscalar magnetic moment (μ_N) $\mu_s = [\mu(Z,N) + \mu(Z+1,N-1)]/2$

A	Exp.	Tri.	Axi.	Sph.	Sch.
15	0.22	0.19	0.18	0.32	0.19
17	1.41	1.45	1.48	1.57	1.44
39	0.71	0.67	0.64	0.94	0.64
41	1.92	1.96	1.97	2.21	1.94

The isoscalar magnetic moment can be reproduced quite well

Yao, et al., PRC 74, 024307 (2006).

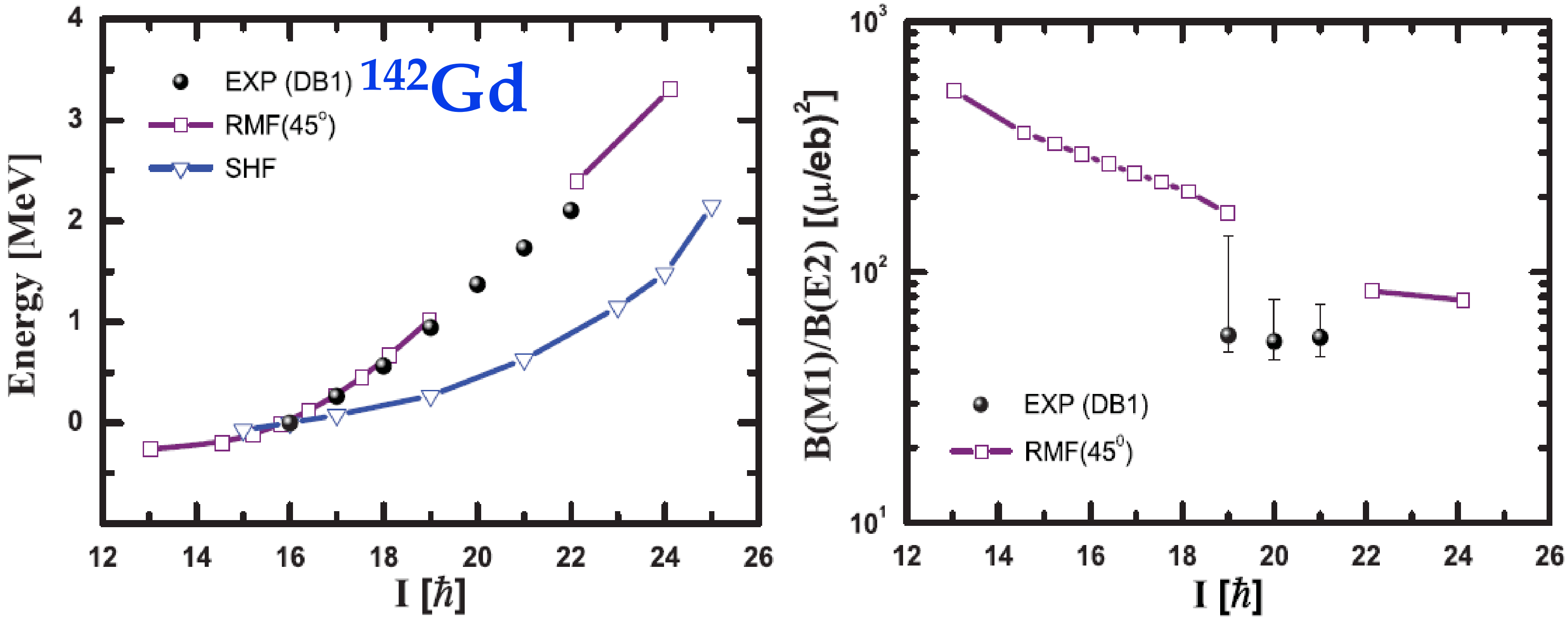
Magnetic Rotation(MR)



PHYSICAL REVIEW C **78**, 024313 (2008)

Covariant density functional theory for magnetic rotation

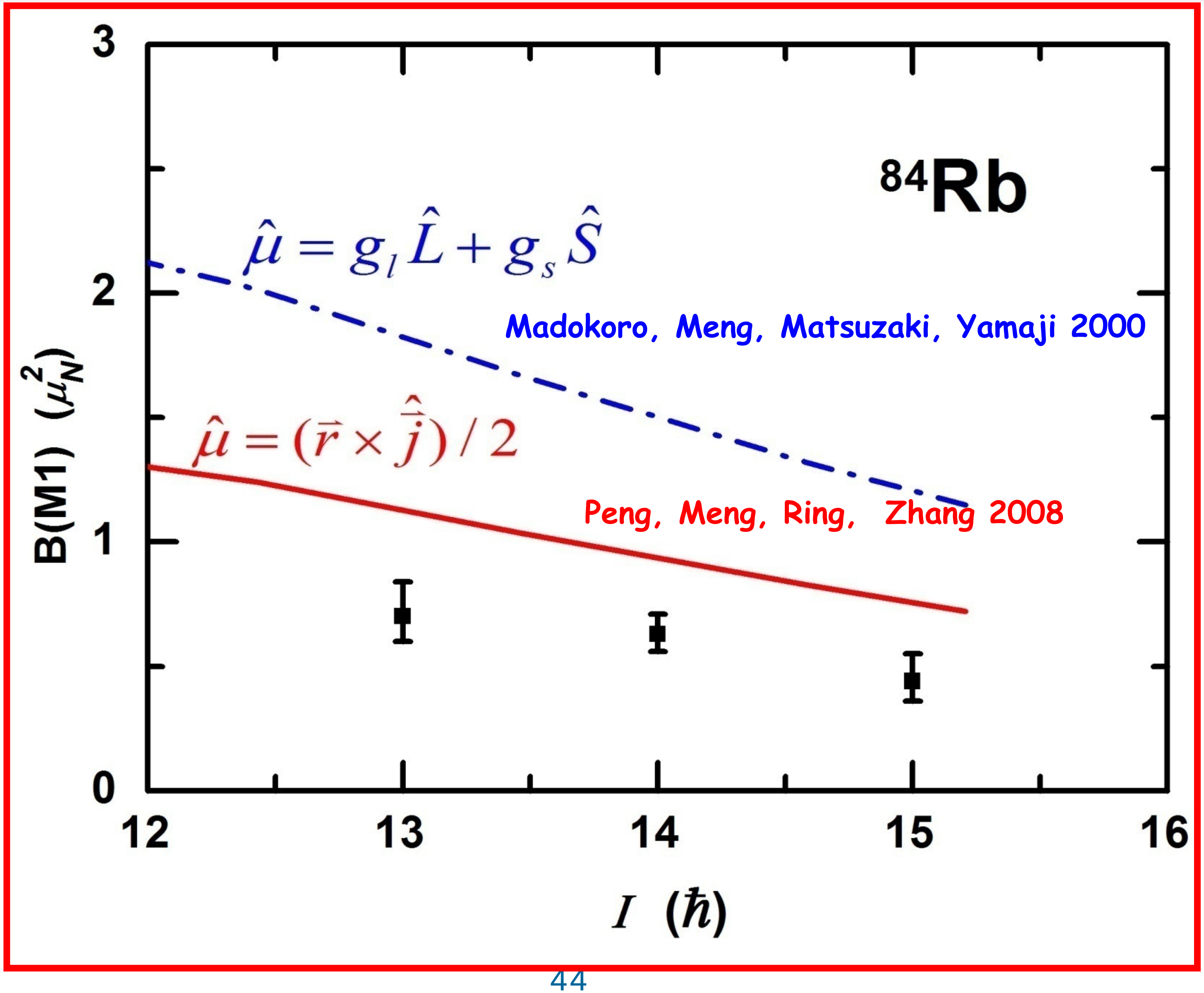
J. Peng (彭婧),[1,2,3] J. Meng (孟杰),[2,4,5,*] P. Ring,[3,6,†] and S. Q. Zhang (张双全)[2]



$$\mu = \sum_{i=1}^{A}\int d^3r\left[\frac{Mc^2}{\hbar c}Q\psi_i^\dagger(\mathbf{r})\mathbf{r}\times\boldsymbol{\alpha}\psi_i(\mathbf{r})+\kappa\psi_i^\dagger(\mathbf{r})\beta\boldsymbol{\Sigma}\psi_i(\mathbf{r})\right]$$

$$B(M1)=\frac{3}{8\pi}(\mu_x\sin\theta_J-\mu_z\cos\theta_J)^2,$$

Relativistic description for B(M1)

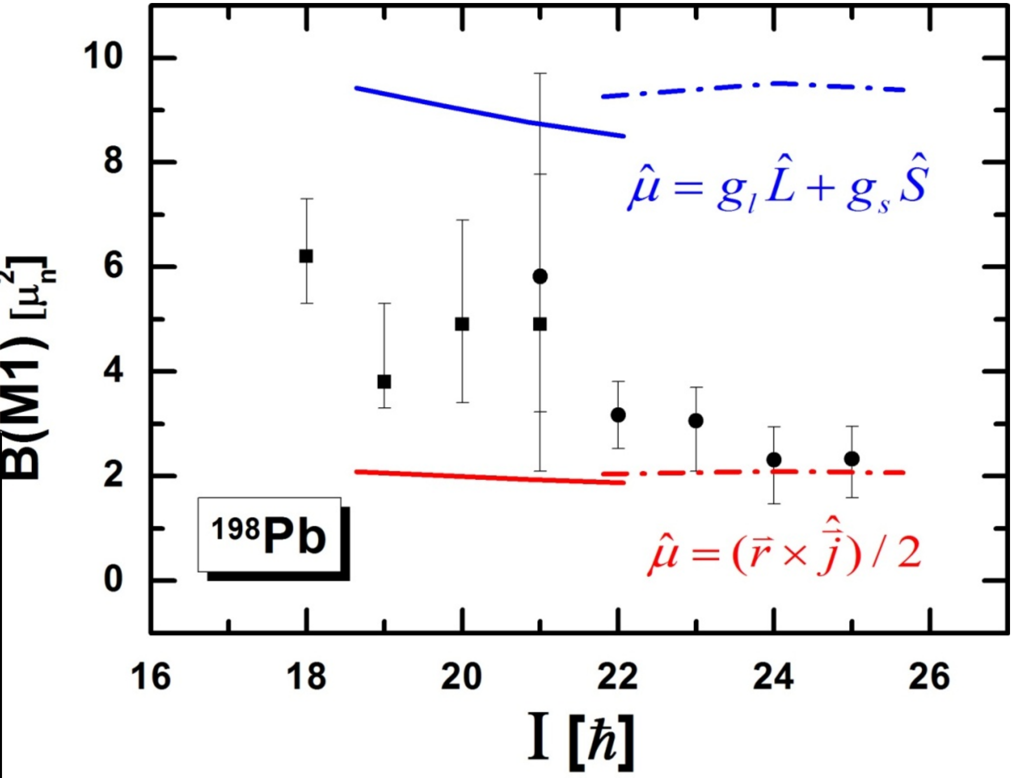


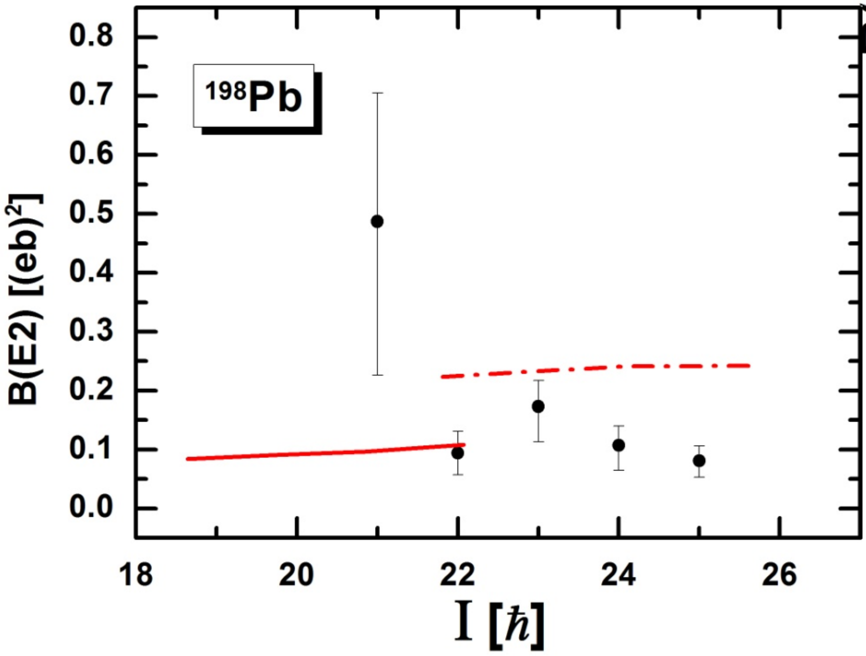
Relativistic description for B(M1) in ^{198}Pb

PC-PK1

Nf=12

$\nu i_{13/2}^{-2} \otimes \pi h_{9/2} i_{13/2}$ $\nu i_{13/2}^{-4} \otimes \pi h_{9/2} i_{13/2}$





Summary & Perspectives

IOP PUBLISHING JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICS

J. Phys. G: Nucl. Part. Phys. 37 (2010) 064025 (11pp) doi:10.1088/0954-3899/37/6/064025

Open problems in understanding the nuclear chirality

Jie Meng[1,2,3] **and S Q Zhang**[2]

[1] School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, People's Republic of China
[2] State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, People's Republic of China
[3] Department of Physics, University of Stellenbosch, Stellenbosch, South Africa

E-mail: mengj@pku.edu.cn

- Chirality in atomic nuclei is a hot topic
- Lots of theoretical and experimental progress on chirality in atomic nuclei are achieved
- Efforts to understand nuclear chirality more are appreciated

Thank You!