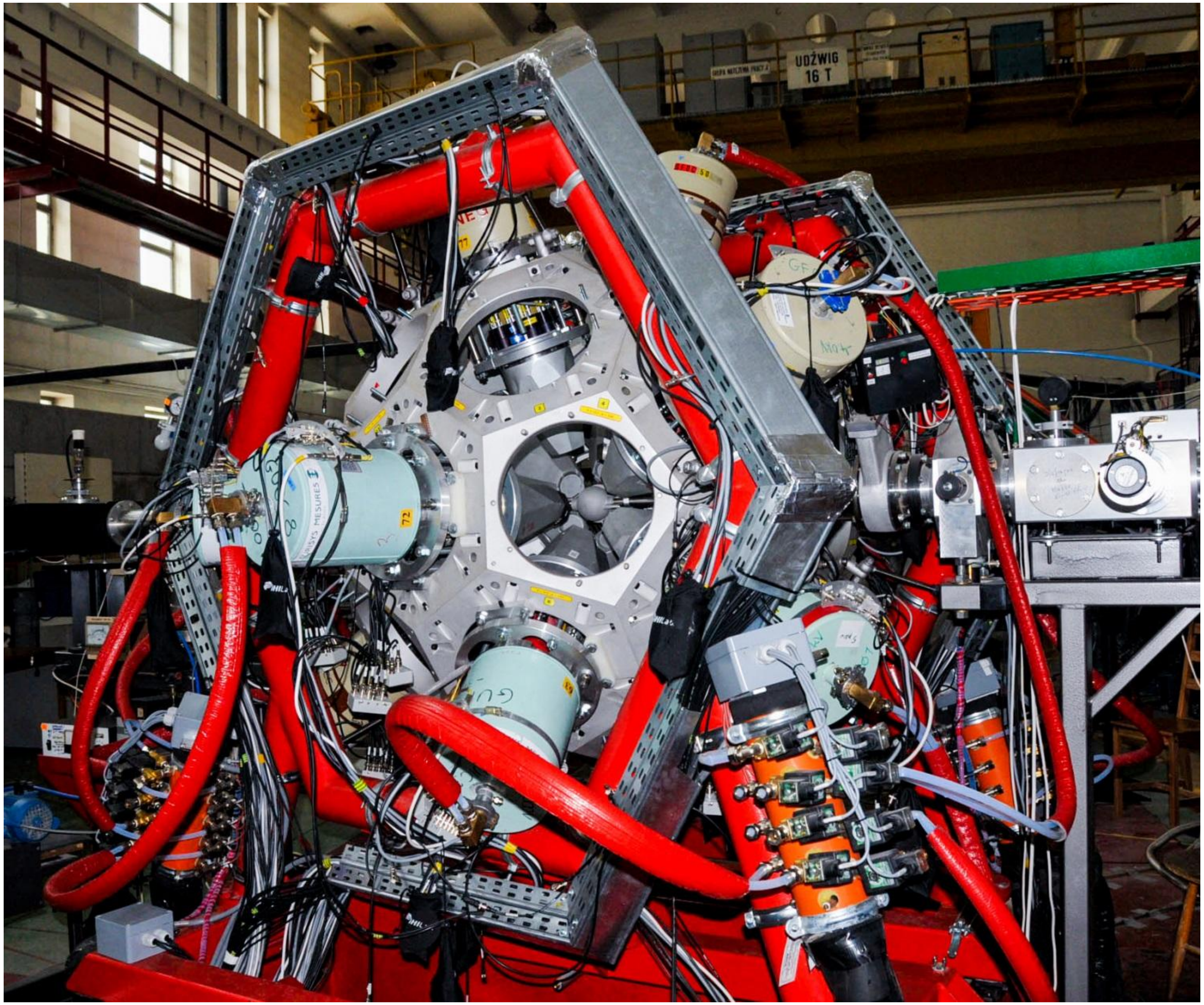
EAGLE (OSIRIS II) – czego nauczyliśmy się dzięki naszym eksperymentom

Julian Srebrny, Seminarium środowiskowe - Warszawa 28 III 2019



OUTLINE

1. **Short informations on EAGLE** (central European Array for Gamma Levels Evaluation) **collaboration .**

Our main experimental as well as theoretical conclusions :

2. K-isomers: not weakening of K-quantum numer conservation

   but important role of small K-admixture

3. COULEX :

   The measure of quadrupole and triaxial shapes by Sum Rules method

   < Q**2 > , < cos3δ >

4. Chirality study for A=130 region:

   how our experiments were a little ahead of theory

EAGLE –OSIRIS II

J. Andrzejewski[4], F. Bello[17], A. Bruce[14], G. Cata-Danil[10], J. Cedercall[11], Bo Cederwall[17], J. Choiński[1], E. Clement[15], W. Czarnacki[6], A. Dewald[5], J. Dobaczewski[3], Ch. Droste[2], C. Fahlander[11], A. Goergen[17], E. Grodner[6], J. Iwanicki[1], A. Jakubowski[1], Ł. Janiak[6], K. Hadyńska-Klęk[1], M. Kicińska-Habior[2], **M. Kisieliński[1]**, M. Klintefiord[17], M. Komorowska[1], A. Kordyasz[1], A. Korman[6], W. Korten[9], **M. Kowalczyk[1], J. Kownacki[1]**, S. Lalkovski[12], P. Magierski [13], T. Marchlewski[1], H. Marginean[10], T. Matulewicz[2], P. Matuszczak[1], M.Matejska-Minda[1,8]W. Męczynski[8], C. Mihai[10], P.J. Napiorkowski[1], M. Palacz[1], J. Perkowski[4], J. Pluta[13], B. Pomorska[7], L. Próchniak[1], G. Rainovski[12], S.G. Rohoziński[3], T. Rząca-Urban[2], J. Samorajczyk[1], M.Saxena [1],W. Satuła[3], S. Siem[17], J. Srebrny[1], J. Timar[16], A. Trzcińska[1], A. Tucholski[1], W. Urban[2], M. Wolińska-Cichocka[1], K. Wrzosek-Lipska[1], N.V. Zamfir[10], M. Zielińska[9], A. Krasznahorkay[16], B. Nyako[16] , A. Korgul [2], A. Synfelt-Każuch [6], S.Pascu [10], A.Turturica[10], R. Mihai [10] , M. Ionescu-Bujor [10],

EAGLE Collaboration Member Institutes

1. Heavy Ion Laboratory , University of Warsaw, Poland
2. Nuclear Physics Division, Institute of Experimental Physics , University of Warsaw, Poland
3. Institute of Theoretical Physics, University of Warsaw, Poland
4. Faculty of Physics and Applied Informatics, University of Lodz, Poland
5. Institute fur Kernphysik, Universitat zu Koln, Germany
6. National Center for Nuclear Research, Poland
7. Department of Theoretical Physics, Institute of Physics, M. Curie Skłodowska University, Poland
8. The Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Poland
9. IRFU/SPhN, CEA Saclay, Gif-sur-Yvette, France
10. Horia Hulubei National Institute of Physics and Nuclear Engineering – IFIN HH, Romania
11. Faculty of Physics, University of Sofia "St.Kliment Ohridski", Bulgaria
12. Faculty of Physics, Warsaw University of Technology, Poland
13. School of Environment and Technology, University of Brighton, United Kingdom
14. GANIL, Caen, France
15. Division of Nuclear Physics, Institute of Nuclear Research (ATOMKI), Hungary
16. Department of Physics, Royal Institute of Technology (KTH) Stockholm, Sweden
17. Department of Physics, LUND, Sweden
18. Department of Physics, University of Oslo, Norway

EAGLE specialities

Our team specializes in precise measurements and comprehensive analysis of the following quantities that give insight into the internal structure of atomic nuclei:

- \- magnetic dipole moments,
- \- electric quadrupole moments,
- \- lifetimes of nuclear states in a broad range from 10^{-13} to 10^{-2} s, measured by various methods, in particular by using the Doppler shift of a gamma radiation (DSAM and RDM),
- \- multipolarity of electromagnetic transitions determined by simultaneous measurement of internal conversion electrons (ULESE) and gammas and by γ-γ angular correlations
- \- reduced E2, M1 and E3 matrix elements which bring information on nuclear shapes and collectivity

Studied nuclei : ^{42}Ca, ^{45}Sc, ^{104}Pd , ^{107}Ag , ^{110}Cd, ^{110}Sn, ^{111}Sn, ^{112}Sn, ^{118}Sn, ^{120}Te, ^{124}Cs, ^{126}Cs, ^{128}Cs, ^{130}Ba, ^{132}Ba, ^{129}La, ^{131}La, ^{132}La, ^{132}Ce, ^{134}Nd, ^{136}Nd, ^{140}Sm, ^{148}Ho, ^{149}Ho, ^{184}Pt

Quantum system of finite number of fermions

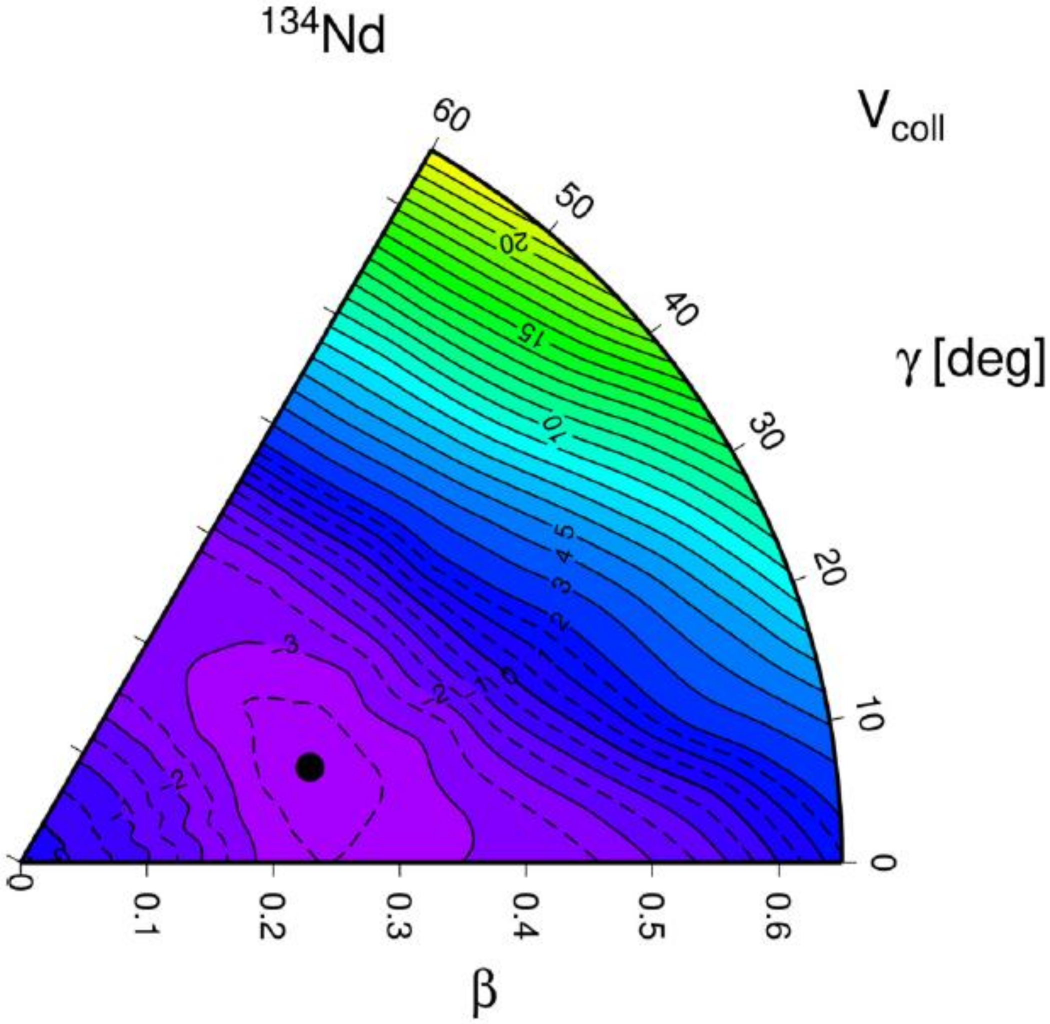


FIG. 11. Mean-field collective potential energy (

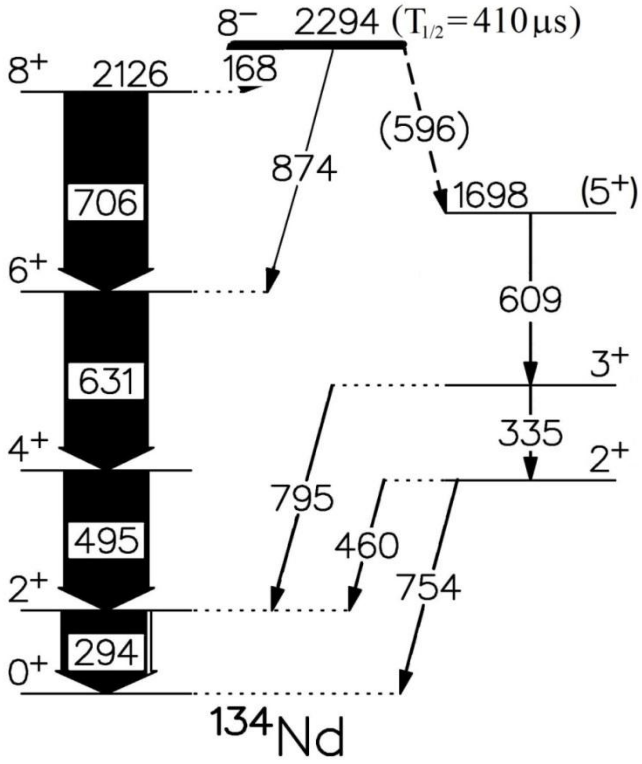
L. Próchniak

II. K-isomer decay: not weakening of K-quantum numer conservation, but important role of a small K-admixture

J. Perkowski, …..

$^{122}Te(^{16}O,4n)^{134}Nd$

E (^{16}O) = 90 MeV



Podobne dane o; **^{130}Ba, ^{132}Ce, ^{184}Pt**

.

Standard way of hindrance evaluation is too general.

hindrance factor $F = T^{p} / T^{W}$,

$$\nu = | K_i - K_f | - \lambda$$

hindrance per degree of K- forbiddenness $f_{\nu} = (F)^{1/\nu}$

It is not important informations ?!

Important are only small admixtures.

Decay of the $I^{\pi} = 8^{-}$ isomeric state in ^{134}Nd and ^{184}Pt studied by electron and γ spectroscopy

J. Perkowski, J. Andrzejewski, Ch. Droste, Ł. Janiak, E. Grodner, S. G. Rohozinski, L. Próchniak, J. Srebrny, J. Samorajczyk-Pysk, T. Abraham, K. Hadynska-Klek, M. Kisielinski, M. Komorowska, M. Kowalczyk, J. Kownacki, T. Marchlewski, J. Mierzejewski, P. Napiorkowski, A. A. Korman, M. Zielinska

PHYSICAL REVIEW C 95, 014305 (2017)

^{134}Nd

K	Isomeric State* $I^{\pi}=K^{\pi}=8^{-}$	Triaxiality, model D-F			Coriolis	
		5^{+}	6^{+}	8^{+}	6^{+}	8^{+}
0	0	–	61.3	52.4	99.1	97.7
1	0	–	–	–	0.33	0.89
2	0	96.4	37.5	44.1	0.25	0.67
3	0	–	–	–	0.154	0.41
4	6.3×10^{-4}	3.6	1.2	3.4	0.077	0.21
5	0.014	–	–	–	0.031	0.082
6	0.35	–	2.5×10^{-3}	0.05	9.6×10^{-3}	0.026
7	7	–	–	–	–	6.0×10^{-3}
8	92.6	–	–	5×10^{-5}	–	1.0×10^{-3}

[*] G. D. Dracoulis, et al., Phys. Rev. C **79**, 061303 (2009).

^{134}Nd

K amplitudes product

Transition	Triaxiality, model D-F		Coriolis	
E1, $8^- \rightarrow 8^+$ K = 8 0	K=7 → K=6	0.32	K=8 → K=7	0.56
	K=5 → K=4	0.047	K=7 → K=6	0.18
E3, $8^- \rightarrow 6^+$ K = 8 0	K=7→ K=4	8.4	K=8 → K=5	2.9
	K=5 → K=2	0.54	K=7 → K=4	0.54
M2, $8^- \rightarrow 6^+$ K = 8 0	K=8 → K=6	0.24	K=7 → K=5	0.89
	K=6 → K=4	0.42	K=6 → K=4	0.22
E3, $8^- \rightarrow 5^+$ K = 8 2	K=7 → K=4	25.2	–	–
	K=5 → K=2	1.35	–	–

^{134}Nd *K amplitudes product*

Przejście	Triaxiality, model D-F		Coriolis	
E1, $8^- \to 8^+$ K = 8 0	K=7 → K=6	0.32	K=8 → K=7	0.56
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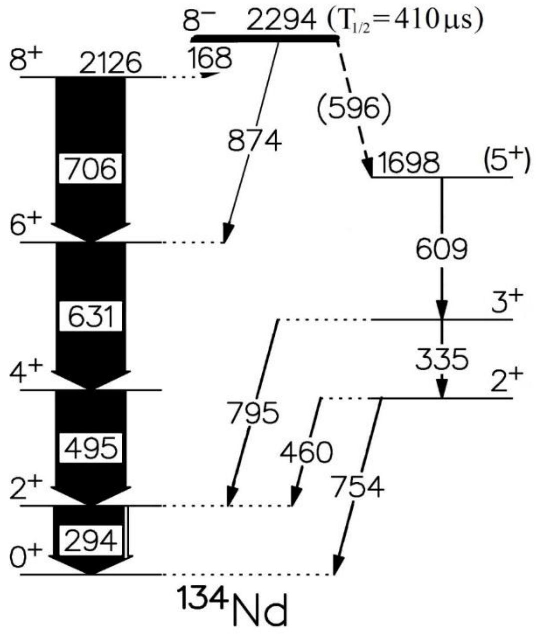


III. COULEX and nuclear quadrupole shapes

P. Napiorkowski, K. Wrzosek-Lipska , K. Hadynska-Klęk,…….

Quadrupole collectivity produces strong correlations of the E2 matrix elements and the number of significant collective variables is much lower than the number of matrix elements.

Such model independent collective variables are e.g. quadrupole charge deformation parameters: < Q**2 > , < cos3δ >

They can be obtained using rotationally invariant products of the quadrupole operators.

Those SUM RULES of products of reduced E2 matrix elements are corelated directly with expectation values of charge shape in specific level.

It can be obtained experimentaly and **theoreticaly**

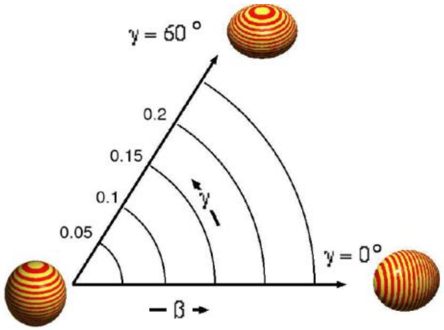
K. Kumar *Phys. Rev. Lett. 28 (1972) 249.*

D. Cline *Annual Rev. Nucl. Part. Sci. 36 (1986) 683.*

J. Srebrny and D. Cline *Int. J. Mod. Phys. E 20, 422 (2011).*

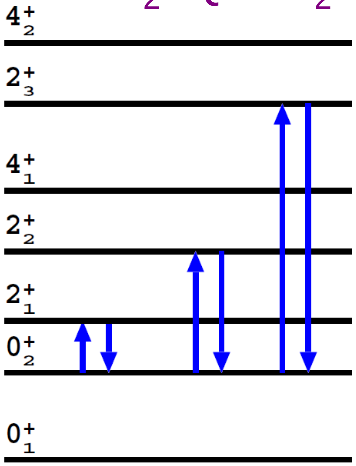
CoulEx and nuclear deformation

Quadrupole invariants method ➔ nuclear shape from matrix elements. The only quantal measure of nuclear charge deformation



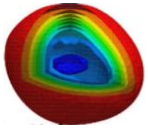
→ overall deformation (analogous to *β* Bohr's parameter)

$\langle 0^+_2 | Q^2 | 0^+_2 \rangle$

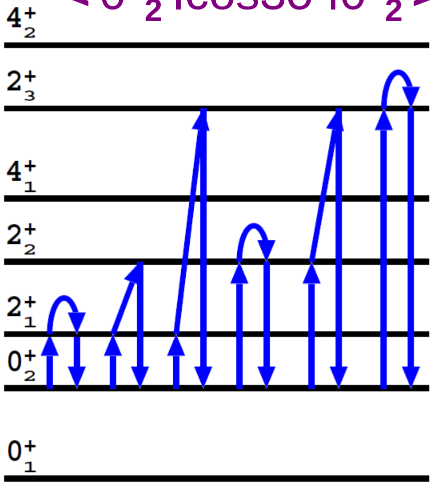


$$\frac{\langle Q^2\rangle}{\sqrt{5}} = \langle i|\,[\mathrm{E2}\times \mathrm{E2}]^0\,|i\rangle = \frac{1}{\sqrt{(2I_i+1)}}\sum_t \langle i\|\mathrm{E2}\|t\rangle\langle t\|\mathrm{E2}\|i\rangle \begin{Bmatrix} 2 & 2 & 0\\ I_i & I_i & I_t \end{Bmatrix}$$

→ triaxiality (analogous to *γ* Bohr's parameter)



$\langle 0^+_2 | \cos 3\delta | 0^+_2 \rangle$



$$\sqrt{\frac{2}{35}}\langle \mathrm{Q}^3\cos 3\delta\rangle = \langle i|\{[\mathrm{E2}\times \mathrm{E2}]^2\times \mathrm{E2}\}^0|i\rangle$$

$$= \frac{1}{(2I_i+1)}\sum_{t,u}\langle i\|\mathrm{E2}\|u\rangle\langle u\|\mathrm{E2}\|t\rangle\langle t\|\mathrm{E2}\|i\rangle \begin{Bmatrix} 2 & 2 & 2\\ I_i & I_t & I_u \end{Bmatrix}$$

D. Cline, Ann. Rev. Nucl. Part. Sci. 36 (1986)
K. Kumar, PRL 28 (1972)

Courtesy K. Wrzosek-Lipska

Quadrupole invariants calculated by theoretical models

and by experimental data < Q**2 > and < cos3δ >

Our data induced : quadrupole invariants became standard way even in model calculations

1. J. Dobaczewski, S.G. Rohozinski , J. Srebrny *Z. Physik A 282, 203(1977)*

   Nuclei from the Barium Region: Nonaxial or Gamma-Soft ?

   theoretical invariants by phenomenological model

2. J. Srebrny,…….*Nucl. Phys. A766 (2006)25* *COULEX* ^{104}Ru

microscopic calculations General Bohr Hamiltonian(GBH)

J. Srebrny, T. Czosnyka, Ch. Droste, S.G. Rohozinski, L. Prochniak, K. Zajac, K. Pomorski, D. Cline, C.Y. Wu, A. Backlin, L. Hasselgren, R.M. Diamond, D. Hans, H.J. Korner, F.S. Stephens, C. Baktash, R.P. Kostecki

3. *K. Wrzosek,……Phys. Rev. C86(2012)064305* *COULEX* ^{100}Mo

microscopic calculations GBH

K. Wrzosek-Lipska, L. Prochniak, M. Zielinska, J. Srebrny, K. Hadynska-Klek, J. Iwanicki, M. Kisielinski, M. Kowalczyk, P. J. Napiorkowski, D. Pietak and T. Czosnyka

4. *K. Hadynska,……Phys. Rev. C97(2018)024326* *COULEX* ^{42}Ca

microscopic calculations, including large scale shell model

K. Hadynska-Klek, P. Napiorkowski, M. Zielinska, J. Srebrny,… M. Kicinska –Habior,.. T. Abraham,.. J. Iwanicki, J. Jaworski, ..M. Kisielinski, …..

M. Komorowska, M. Kowalczyk, …M. Palacz, L. Prochniak, ….K. Rusek…, K. Wrzosek-Lipska,..

4. K. Hadynska,……Phys. Rev. C97(2018)024326 COULEX ^{42}Ca

microscopic calculations, including large scale shell model

K. Hadynska-Klek, P. Napiorkowski, M. Zielinska, J. Srebrny,… M. Kicinska –Habior,.. T. Abraham,.. J. Iwanicki, J. Jaworski, ..M. Kisielinski, …..

M. Komorowska, M. Kowalczyk, …M. Palacz, L. Prochniak, ….K. Rusek…, K. Wrzosek-Lipska,..

5. S. Quan, Q. Chen, Z. P. Li, T. Nikšić, and D. Vretenar *Phys. Rev. C **95**, 054321 (2017)*

Global analysis of quadrupole shape invariants based on covariant energy density functionals

Conclusions: The present analysis has shown that, when based on a universal and consistent microscopic framework of nuclear density functionals, shape invariants provide distinct indicators and reliable predictions for the occurrence of low-energy coexisting shapes. This method is particularly useful for studies of shape coexistence in regions far from stability where few data are available.

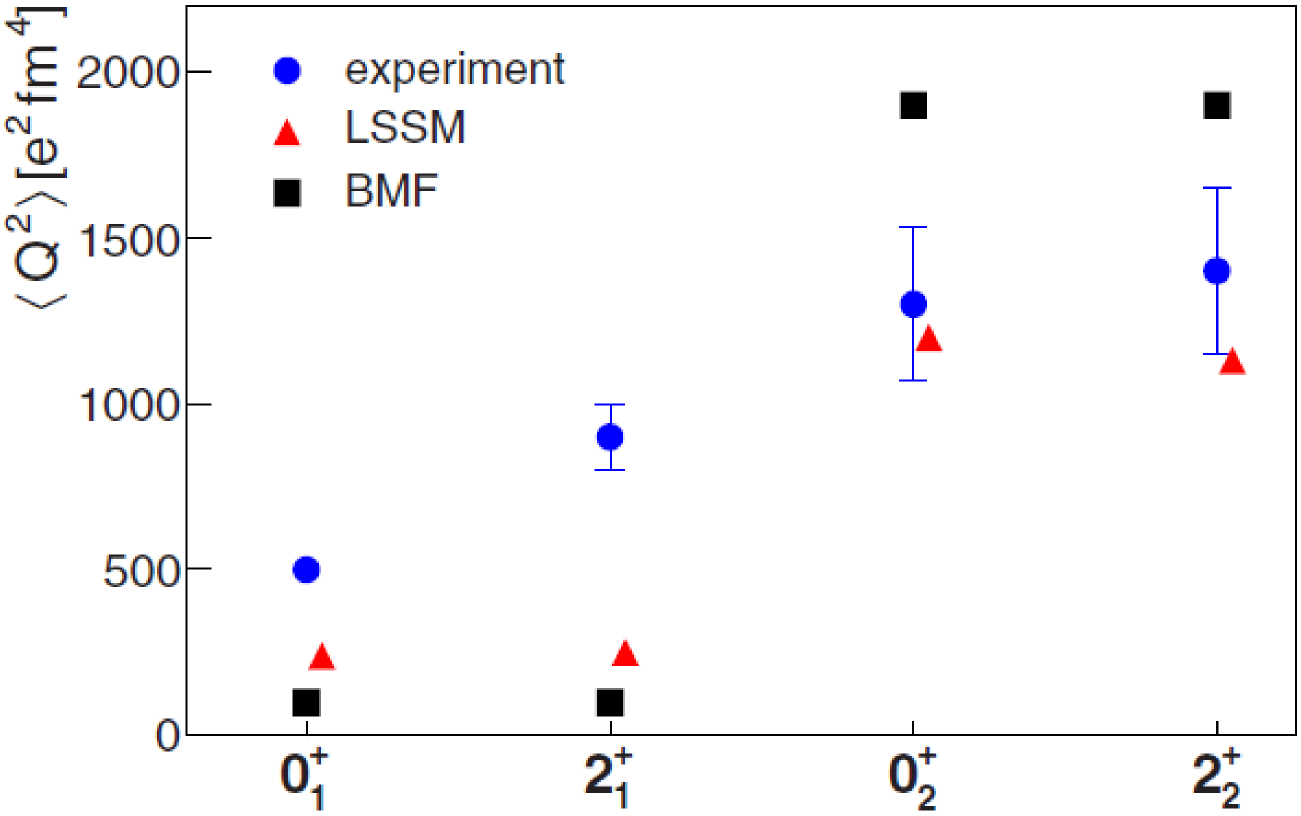


FIG. 11. Experimental and theoretical $\langle Q^2 \rangle$ invariants for the $0^+_{1,2}$ and $2^+_{1,2}$ states in ^{42}Ca.

K. Hadynska,……Phys. Rev. C97(2018)024326 *COULEX* ^{42}Ca

Higher order invariants allow to measure a softness of Q^2 and $\cos 3\delta$

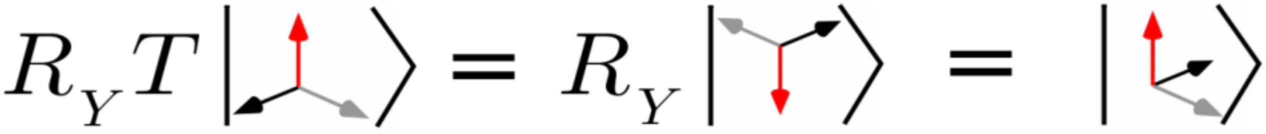
$$\sigma(Q^2) = \left(\langle Q^4\rangle - \langle Q^2\rangle^2\right)^{1/2} \qquad \sigma(\cos 3\delta) = \left[\frac{\langle Q^6 \cos 3^2\delta\rangle}{\langle Q^6\rangle} - \left(\frac{\langle Q^3 \cos 3\delta\rangle}{\langle Q^2\rangle^{3/2}}\right)^2\right]^{1/2}$$

the need of longer excitation pass:

3 intermediate states for *σ(Q2)* and 5 intermediate states for *σ(cos3δ)*

$$\begin{aligned}
&[[\mathcal{M}(\mathrm{E2}) \times \mathcal{M}(\mathrm{E2})]_0[\mathcal{M}(\mathrm{E2}) \times \mathcal{M}(\mathrm{E2})]_0]_0 \\
&\quad = \frac{1}{5}(Q_0^4 + 2Q_0^2Q_2^2 + Q_2^4) = \frac{1}{5}Q^4, \\
&[[\mathcal{M}(\mathrm{E2}) \times \mathcal{M}(\mathrm{E2})]_0[[\mathcal{M}(\mathrm{E2}) \times \mathcal{M}(\mathrm{E2})]_2 \times \mathcal{M}(\mathrm{E2})]_0]_0 \\
&\quad = -\sqrt{\frac{2}{175}}(Q_0^5 - 2Q_0^3Q_2^2 - 3Q_0Q_2^4) = -\sqrt{\frac{2}{175}}Q^5 \cos 3\delta, \\
&[[\mathcal{M}(\mathrm{E2}) \times \mathcal{M}(\mathrm{E2})]_0[\mathcal{M}(\mathrm{E2}) \times \mathcal{M}(\mathrm{E2})]_0[\mathcal{M}(\mathrm{E2}) \times \mathcal{M}(\mathrm{E2})]_0]_0 \\
&\quad = \frac{1}{5\sqrt{5}}(Q_0^6 + 3Q_0^4Q_2^2 + 3Q_0^2Q_2^4 + Q_2^6) = \frac{1}{5\sqrt{5}}Q^6, \\
&[[[\mathcal{M}(\mathrm{E2}) \times \mathcal{M}(\mathrm{E2})]_2 \times \mathcal{M}(\mathrm{E2})]_0[[\mathcal{M}(\mathrm{E2}) \times \mathcal{M}(\mathrm{E2})]_2 \times \mathcal{M}(\mathrm{E2})]_0]_0 \\
&\quad = \frac{2}{35}(Q_0^6 - 6Q_0^4Q_2^2 + 9Q_0^2Q_2^4) = \frac{2}{35}Q^6 \cos^2 3\delta.
\end{aligned}$$

IV. Chirality study for A ≈130 region



I R >

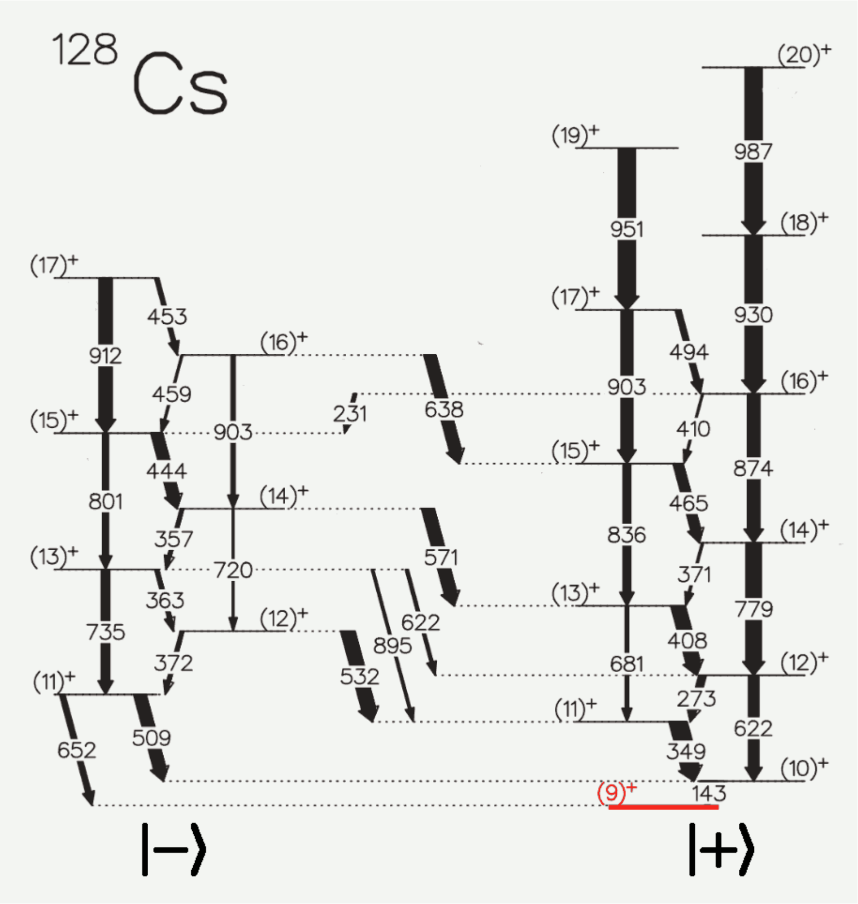
I L >

|+> = N+ (|R > + |L >)

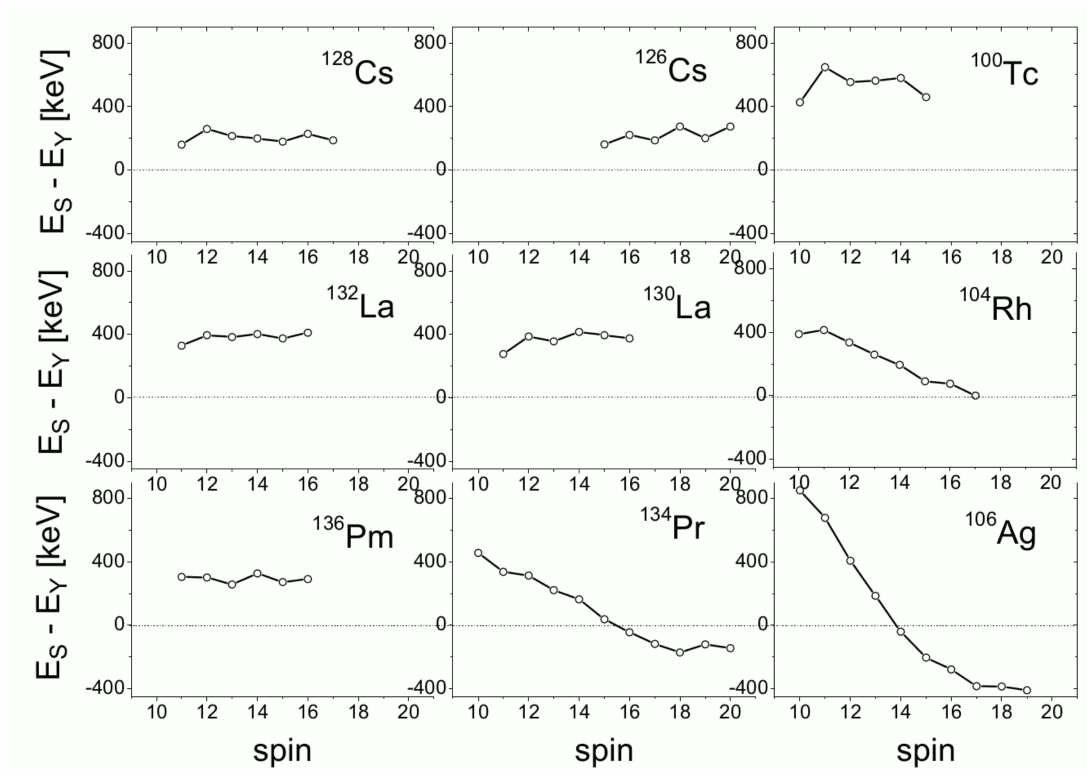
I−> = N- (IR > − IL >)

$^{122}Sn(^{10}B, 4n)^{128}Cs$ $E_{^{10}B} = 55$ MeV

partner bands- close in energy

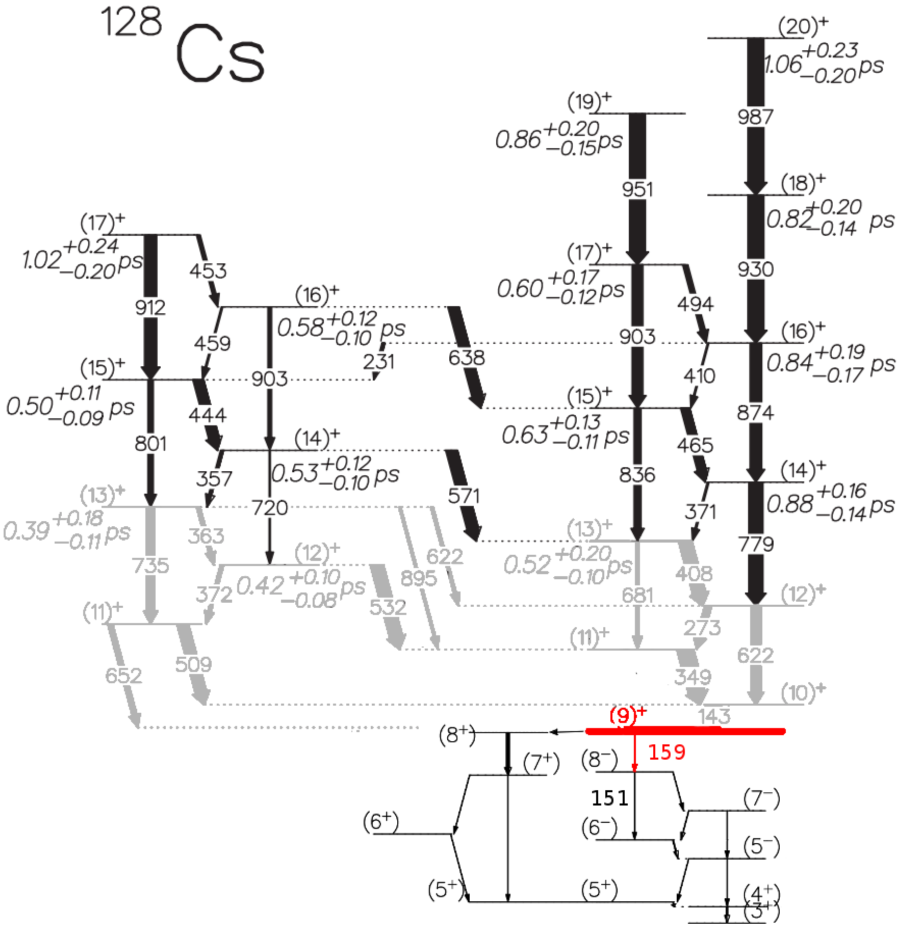


E. Grodner,
Acta Phys. Pol. B39(2008) 531



C. M. Petrache, G. B. Hagemann, I. Hamamoto, and K. Starosta PRL 96, 112502(2006)

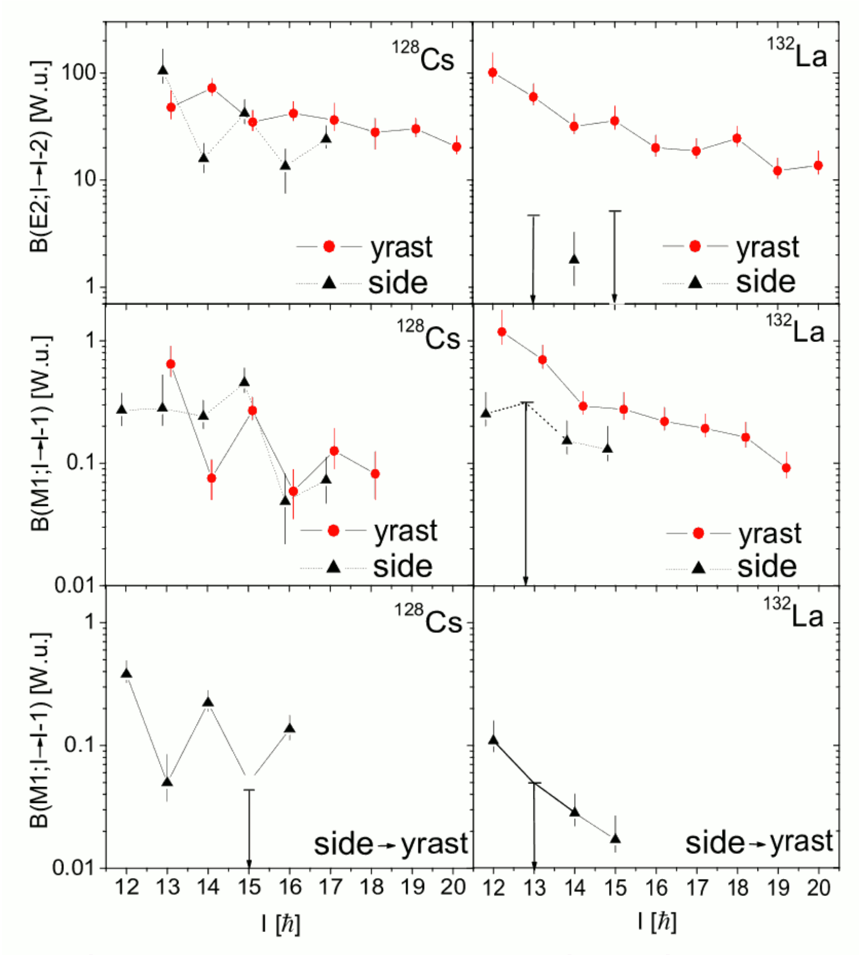
"Risk of Misinterpretation of Nearly Degenerate Pair Bands as Chiral Partners in Nuclei. The insufficiency of the near-degeneracy criterion to trace nuclear chirality is emphasized."



Phys.Rev.Let. 97, 172501 (2006)

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

E. Grodner, J. Srebrny, A. A. Pasternak, I. Zalewska, T. Morek, Ch. Droste, J. Mierzejewski, M. Kowalczyk, J. Kownacki, M. Kisielinski, S. G. Rohozinski, T. Koike, K. Starosta, A. Kordyasz, P. J. Napiorkowski, M. Wolinska-Cichocka, E. Ruchowska, W. Płociennik, and J. Perkowski



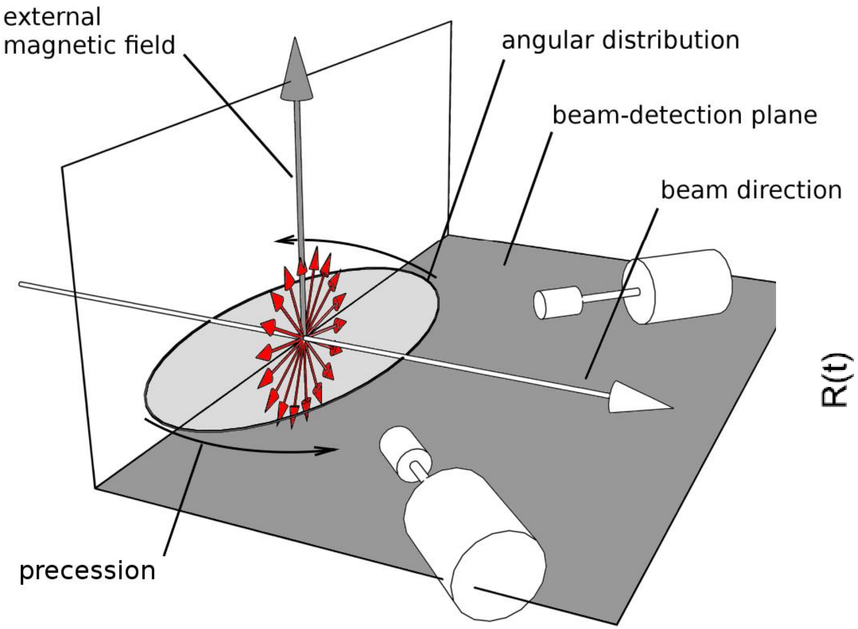
Level lifetimes important factor for chirality experimental proof

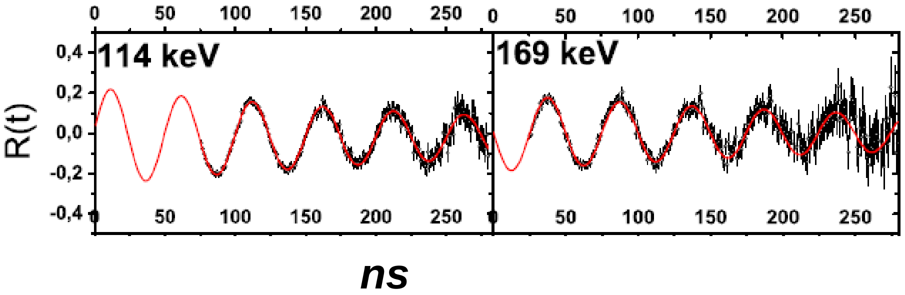
Phys.Rev.Let. 97, 172501 (2006)

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

magnetic moment measurements

Time Differential Perturbed Angular Distribution - TDPAC

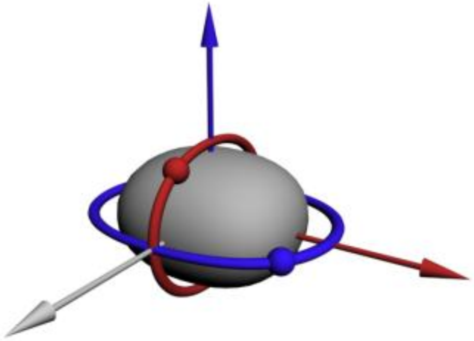




First Measurement of the g Factor in the Chiral Band: the Case of the ^{128}Cs Isomeric State
Phys. Rev. Let. 120, 022502 (2018)

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

$$g = g_{\text{chiral}} - \frac{1}{J(J+1)}\left(g_p \vec{J}_n \cdot \vec{J}_R + g_n \vec{J}_p \cdot \vec{J}_R + g_R \vec{J}_p \cdot \vec{J}_n\right)$$



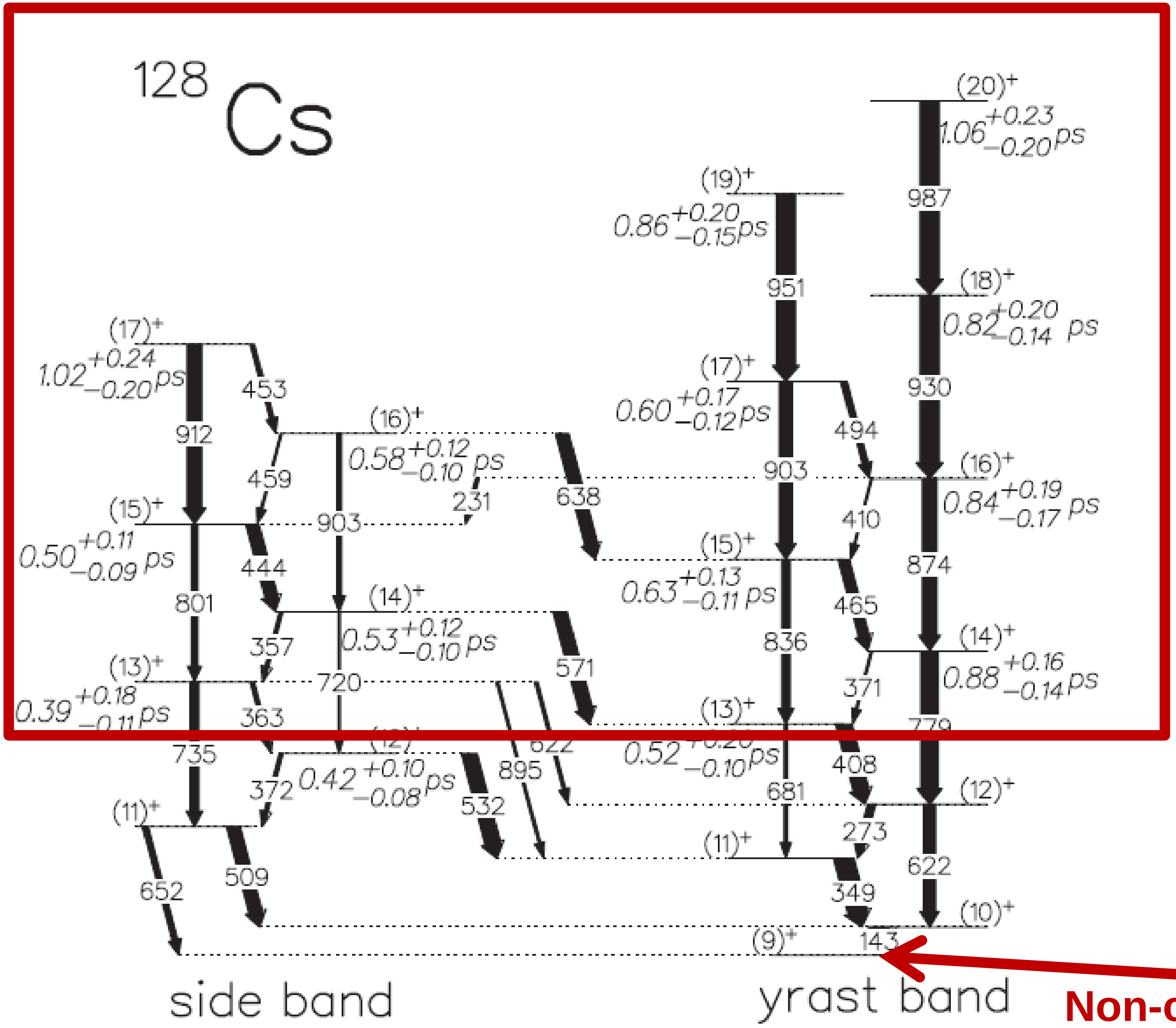
left and right handedness

$g_{\text{chiral}} = 0.5$

$g_{\text{non-chiral}} = 0.6$

$g_{\text{exp}} = 0.59(1)$

E. Grodner et al. *Phys. Rev. Lett* ***97***, *172501(2006),*



Chiral character

Non-chiral character

E. Grodner et al. *Phys.Rev.Let.****120****, 022502(2018)*

E. Grodner, M. Kowalczyk

$LaBr_3$ – troubles for Eγ < 300 keV and τ < 200 ps

SUMMARY

Important conlusions based on our experimental data, together with theoretical interpretations

1.K-isomers,
standard ΔK – λ not important,
additional K-components in isomer as well as in final levels
- important even smal amount

2. COULEX
expectation value of two Quadrupole invariants -
the only measure of the Quadrupole deformation and the triaxiality;
experimental as well as **theoretical**.
Tomasz Czosnyka: quantal nuclear microscope.

3. Chirality in A ≈ 130 region
   a) partner bands – not enough
   b) B(M1) and B(E2) close in both bands
   c) g-factor of chiral bands-head = planar (not chiral) configuration
   in ^{128}Cs- not chiral to chiral phase transition ?
   d) EAGLE – EYE new experiment to measure 10^+ lifetime by
   16 Ge + 24 FATIMA $LaBr_3$