Quest for the chiral symmetry breaking in atomic nuclei

Ernest Grodner

XXX Mazurian Lakes Conference on Physics
08.09.2007

Main subjects

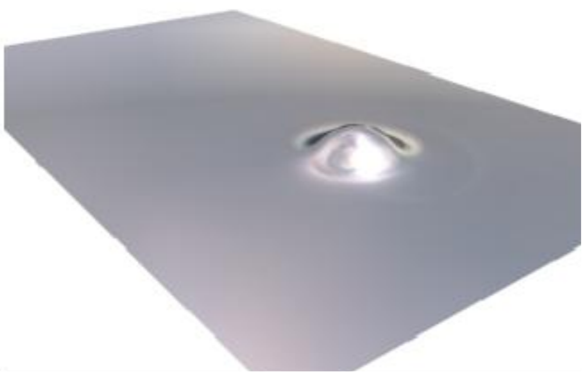
Introduction
- Examples of symmetry breaking
- Chiral symmetry breaking

Search for nuclear chirality
- Level scheme
- Brief theoretical description
- Transition probabilities

Results and discussion
- Level scheme interpretation
- Transition probabilities interpretation

Breaking of the symmetry

BROKEN SYMMETRY | **SYMMETRY CONSERVED**

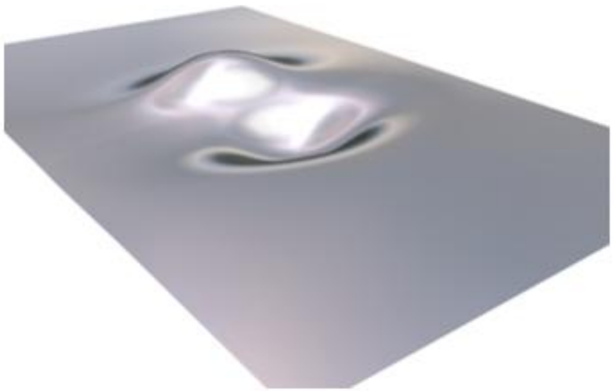


Defined position (localized)

Defined momentum

Translational symmetry

Defined orientation (localized)

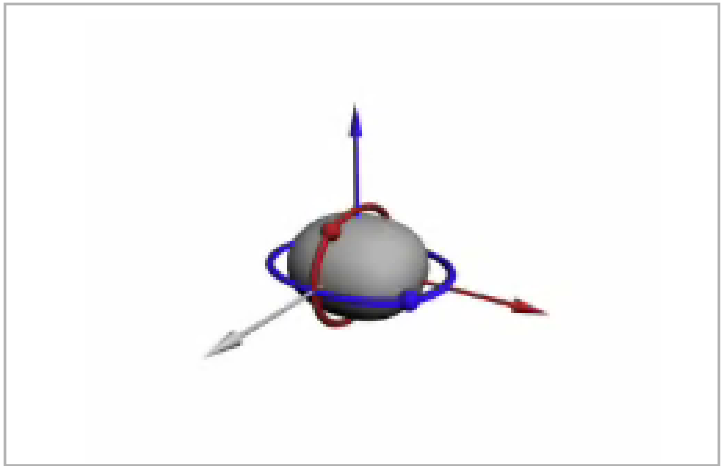


Defined angular momentum

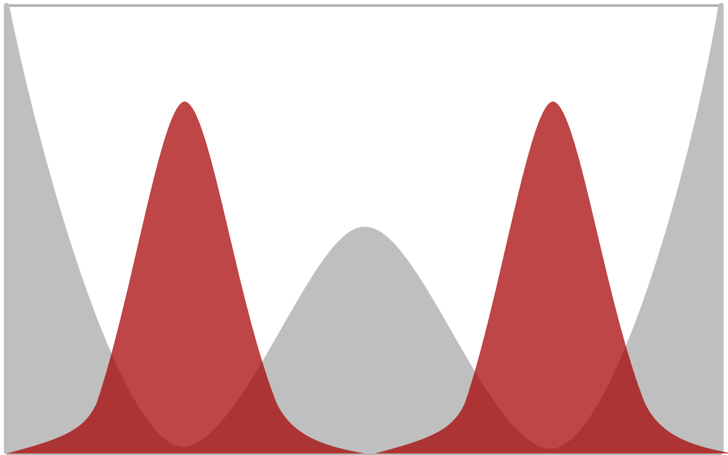
Rotational symmetry

Breaking of the chiral symmetry

LOCALIZATION IN THE HANDEDNESS PARAMETER



Defined handedness



handedness

Chiral symmetry

Three mutually perpendicular angular momenta vectors forming the reference frame with defined handedness

Chiral symmetry operator $R_Y T$

Changes left-handed state to right-handed one and vice versa

$$R_Y T|L\rangle = |R\rangle$$

$$R_Y T|R\rangle = |L\rangle$$

Localized states

are not observed in the laboratory reference frame

Experimental observation of handedness

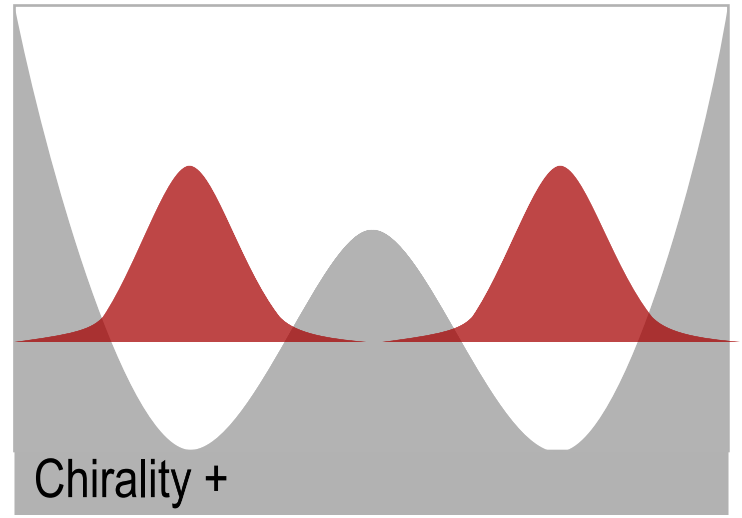
is imposible in laboratory reference frame.

Breaking of the chiral symmetry

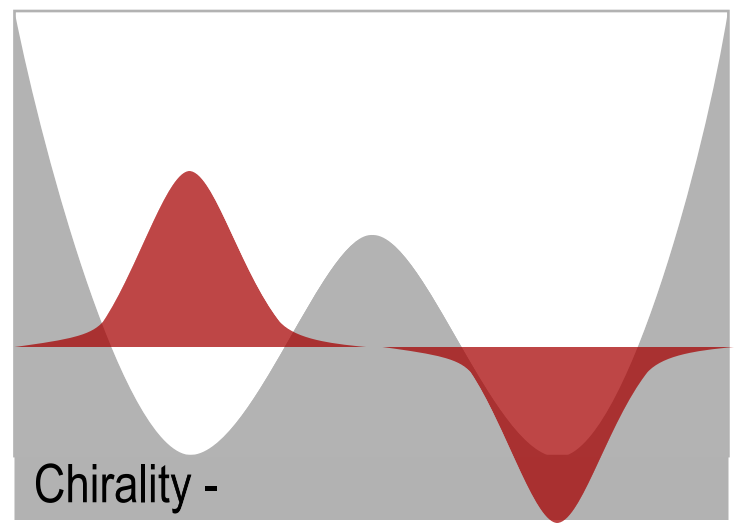
EXPECTED PROPERTIES IN LAB FRAME

Two close lying |+> and |-> states

with restored symmetry (defined chirality) and undefined handedness are expected to be observed



$$\left|+\right\rangle = \frac{1}{\sqrt{2}}\frac{\left|L\right\rangle + \left|R\right\rangle}{\sqrt{1+\varepsilon}}$$



$$\left|-\right\rangle = \frac{i}{\sqrt{2}}\frac{\left|L\right\rangle - \left|R\right\rangle}{\sqrt{1-\varepsilon}}$$

Breaking of the chiral symmetry

EXPECTED PROPERTIES IN LAB FRAME

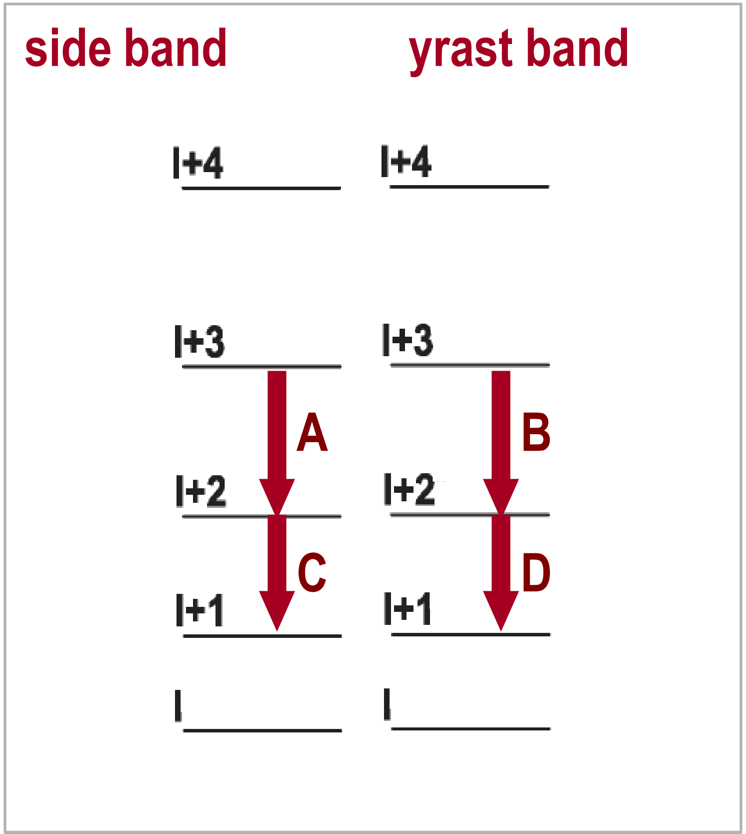
Chiral partner bands

Two rotational bands with similar energy levels, same spins and parity.

Similar electromagnetic properties

The same transition probabilities between corresponding levels

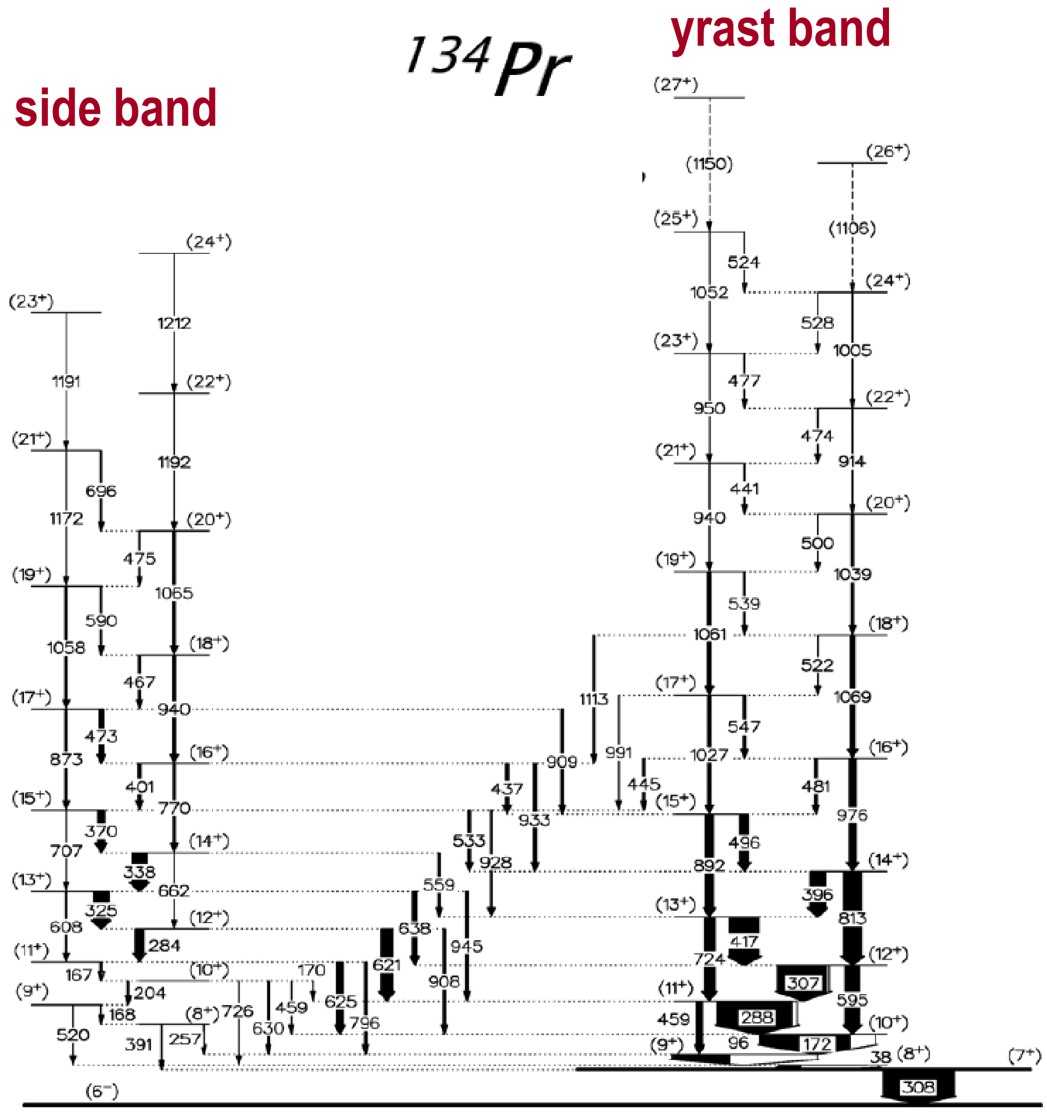
A=B
C=D
...



Chiral partner bands

Breaking of the chiral symmetry

FIRST OBSERVATION OF THE CHIRAL PARTNER BANDS



C.M. Petrache et al..

Nucl. Phys. A597, 106, (1996)

Main subjects

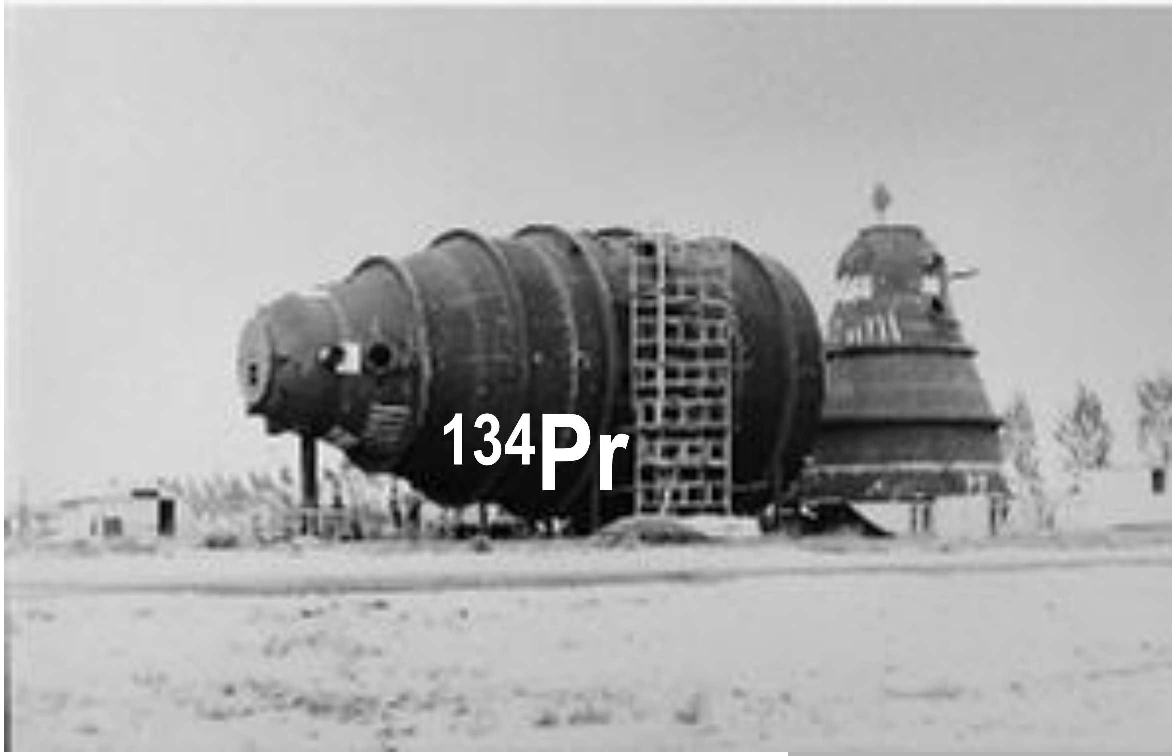
Introduction
- Examples of symmetry breaking
- Chiral symmetry breaking

Search for nuclear chirality
- Level scheme
- Brief theoretical description
- Transition probabilities

Results and discussion
- Level scheme interpretation
- Transition probabilities interpretation

Breaking of the chiral symmetry

EXPERIMENTAL PREMISES



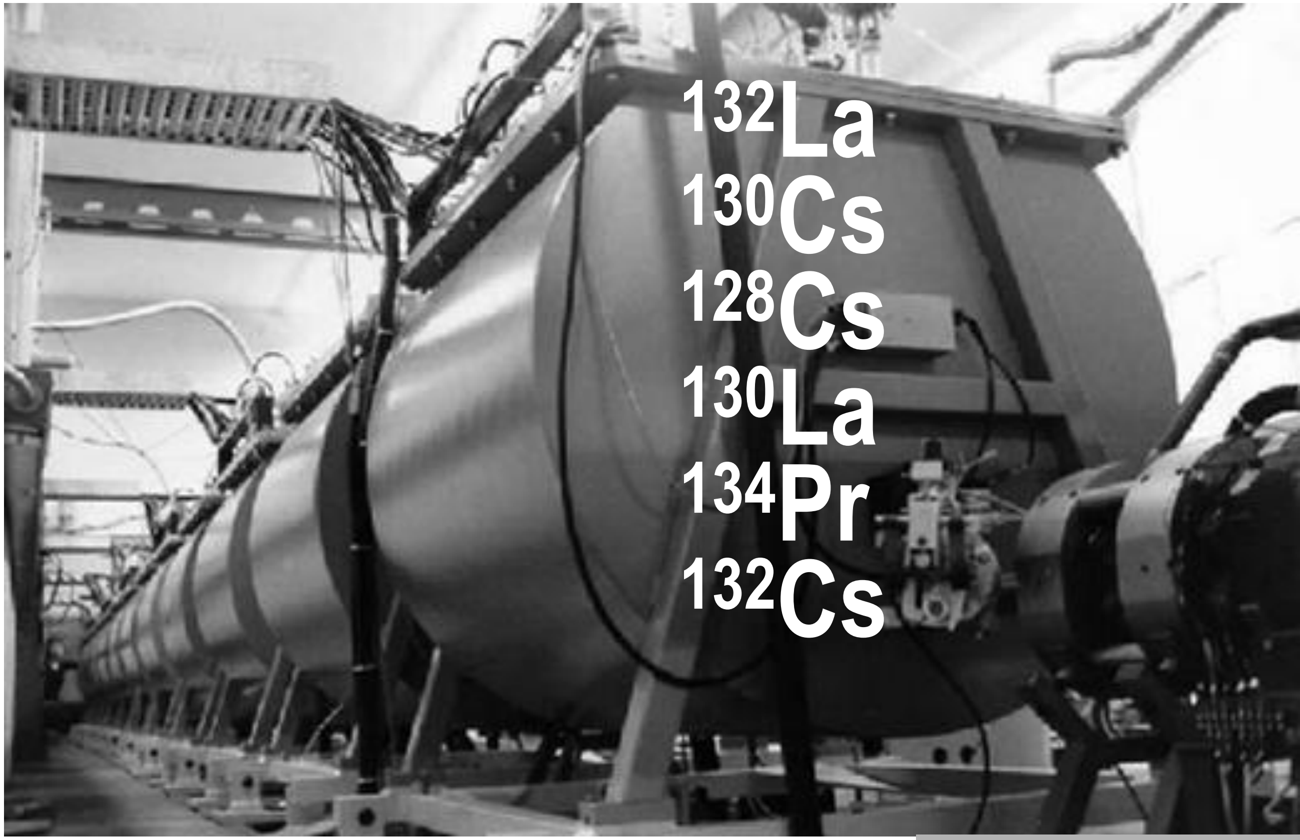
Structure of the level scheme

two similar rotational bands

Legnaro

Breaking of the chiral symmetry

EXPERIMENTAL PREMISES



Structure
of the level scheme
two similar rotational bands

Stony Brook

Breaking of the chiral symmetry

EXPERIMENTAL PREMISES

Structure of the level scheme

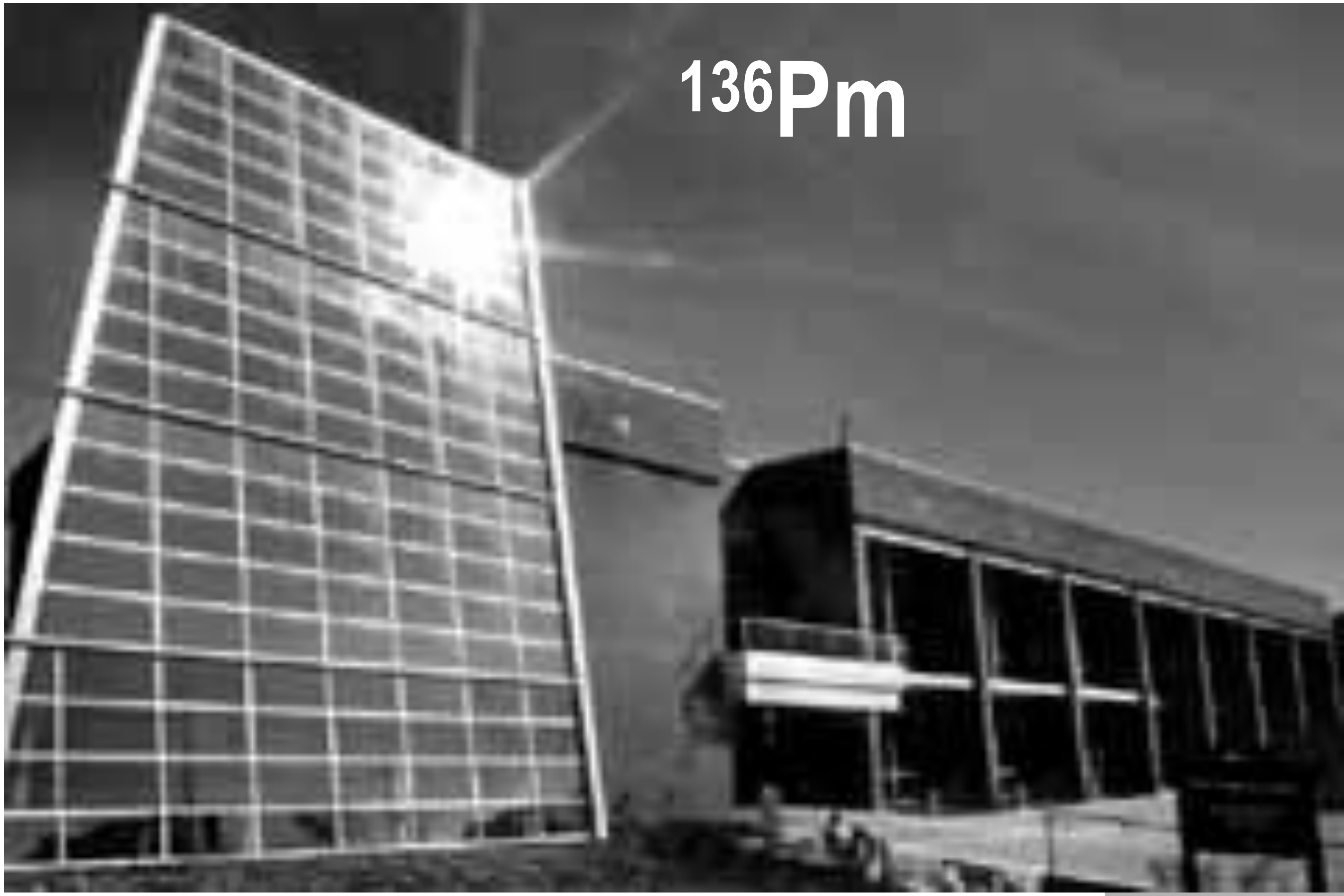
two similar rotational bands

Yale

Breaking of the chiral symmetry

EXPERIMENTAL PREMISES

Structure
of the level scheme
two similar rotational bands



Tennessee

Structure

of the level scheme

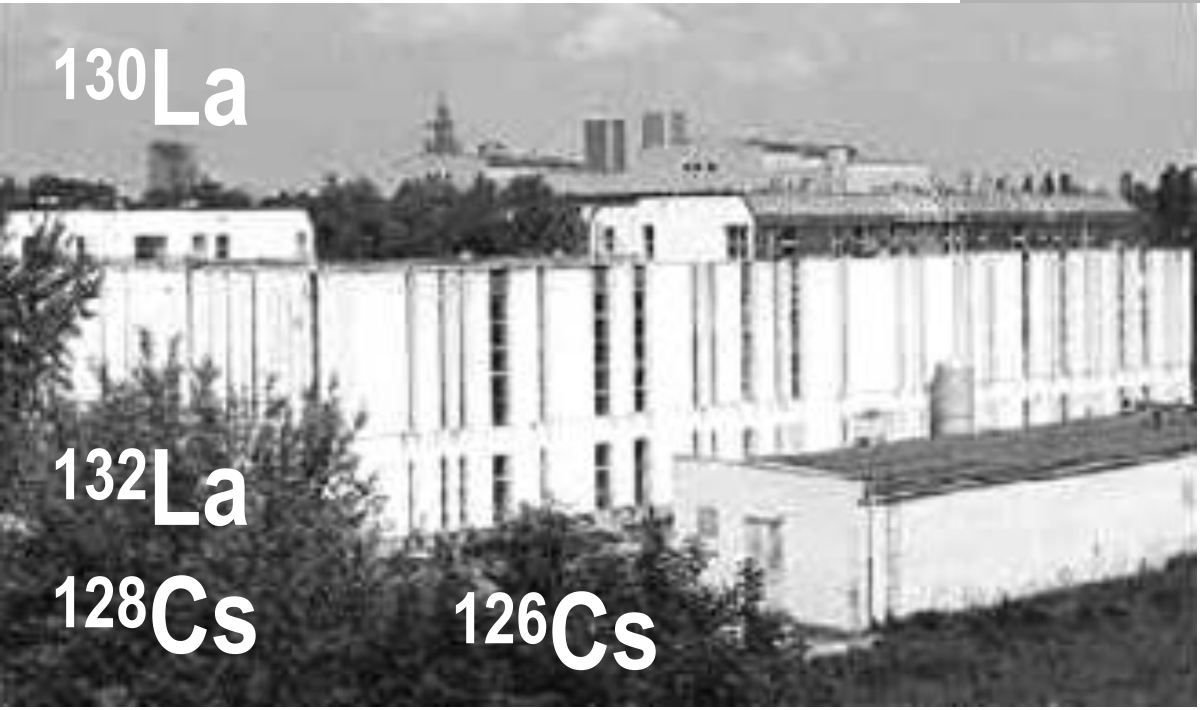
two similar rotational bands

Berkeley

Breaking of the chiral symmetry

EXPERIMENTAL PREMISES

Warsaw



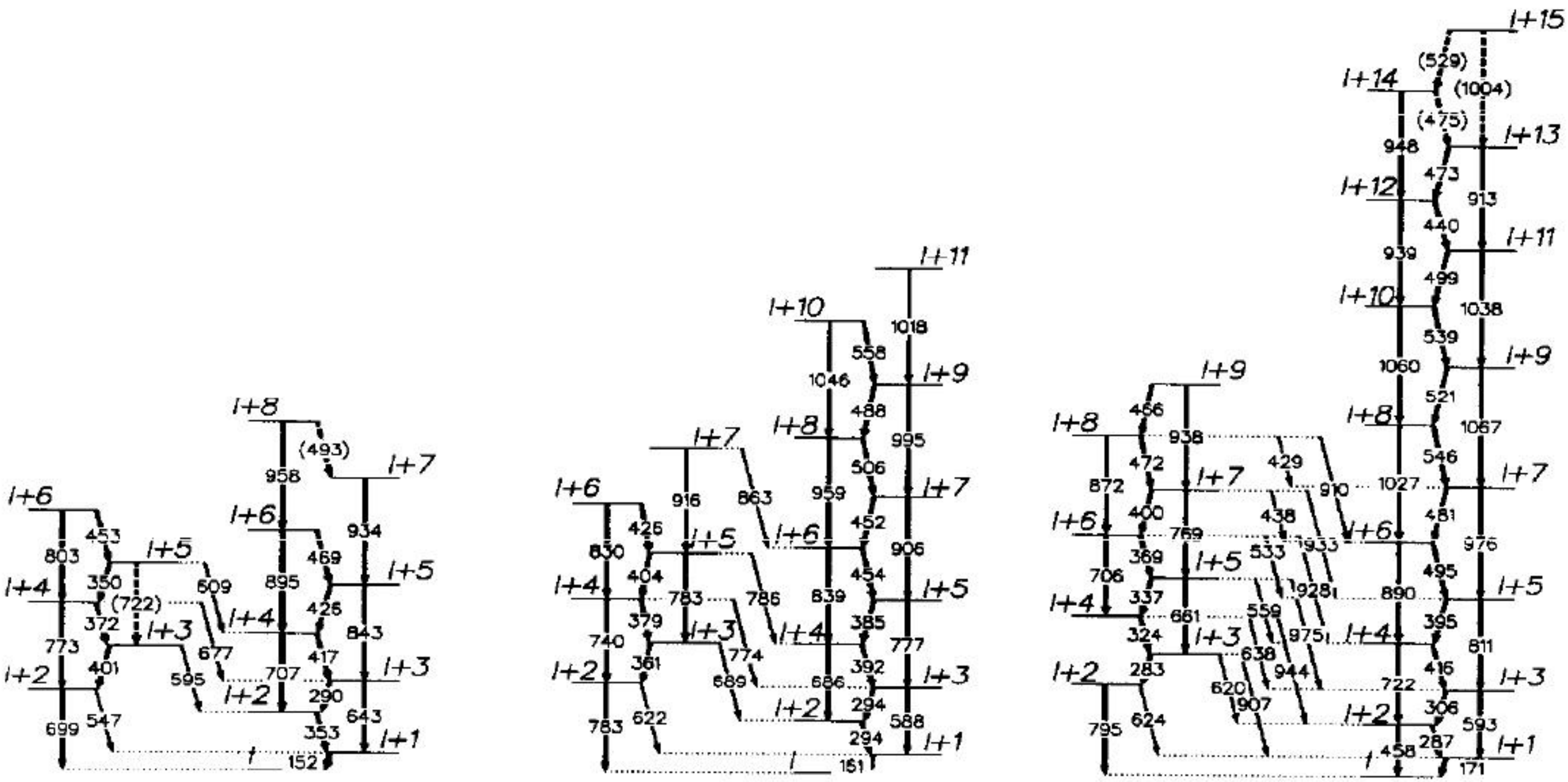
Structure

of the level scheme

two similar rotational bands

Breaking of the chiral symmetry

EXAMPLES OF THE PARTNER BANDS



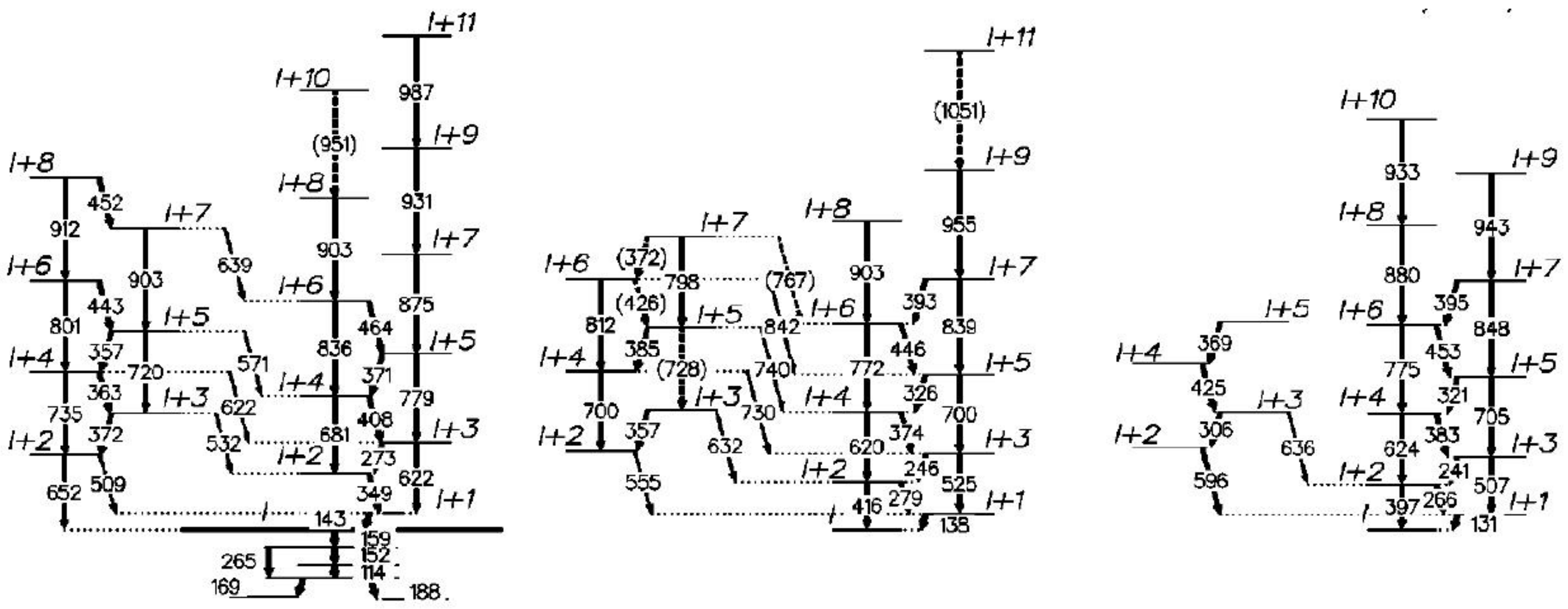
^{130}Cs

^{132}La

^{134}Pr

Breaking of the chiral symmetry

EXAMPLES OF THE PARTNER BANDS



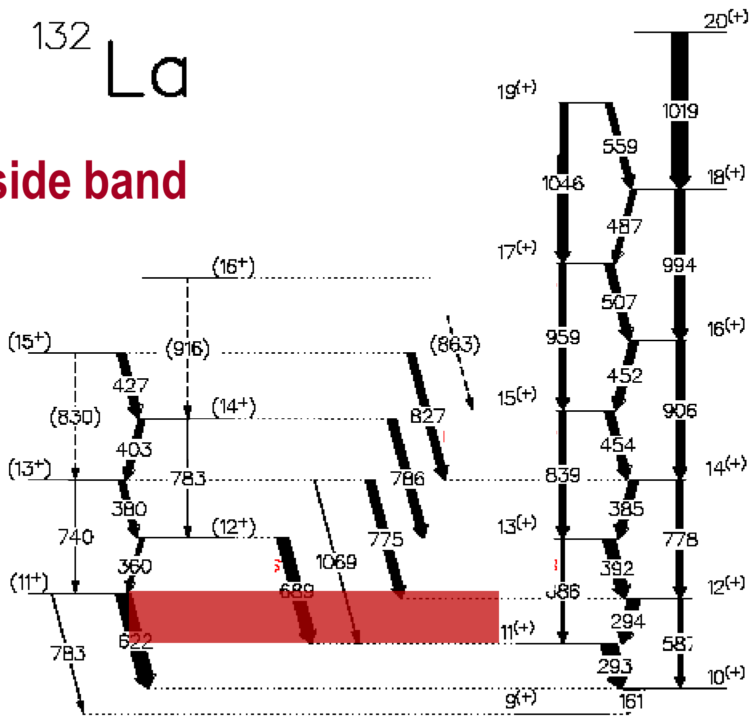
$^{128}_{55}Cs_{73}$ $^{130}_{57}La_{73}$ $^{132}_{59}Pr_{73}$

Breaking of the chiral symmetry

EXAMPLES OF THE PARTNER BANDS

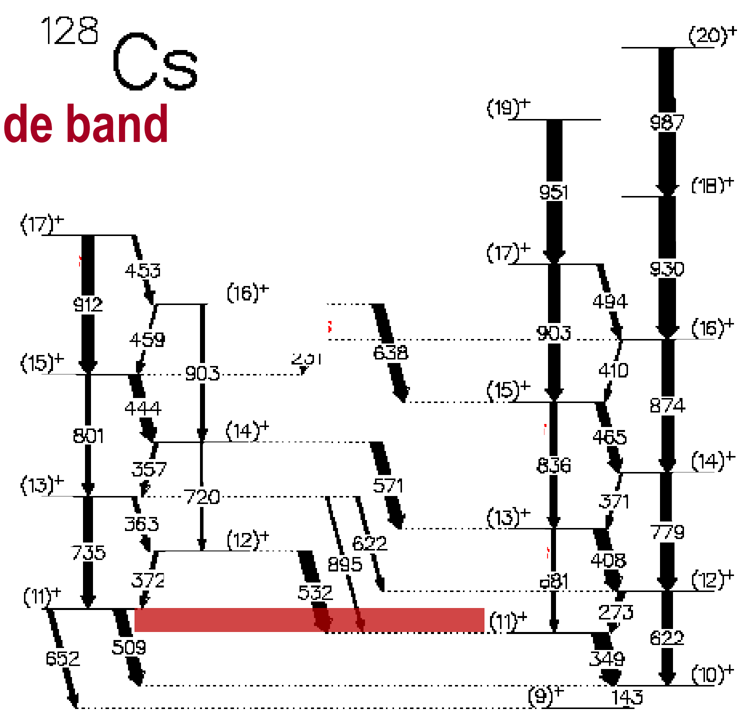
yrast band

side band



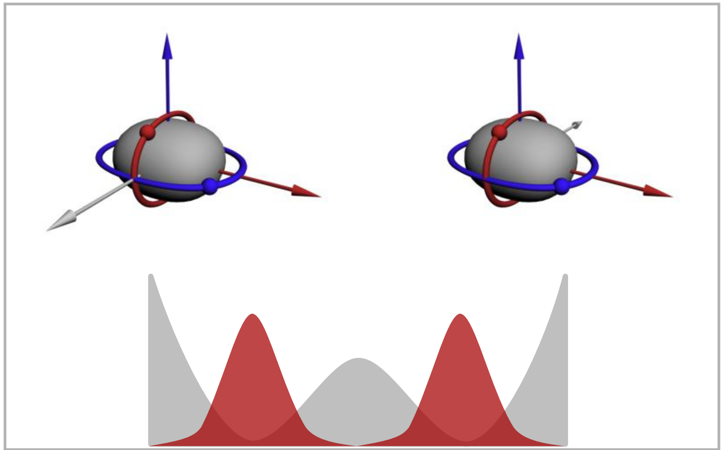
yrast band

side band

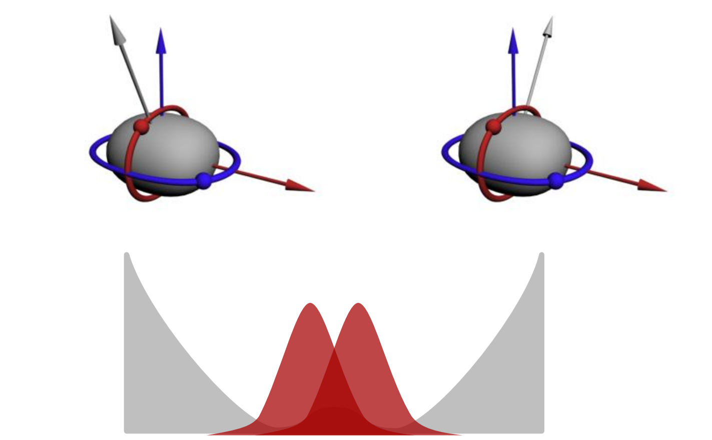


Chiral symmetry breaking limits

DIFFERENCES OBSERVED IN LAB SYSTEM



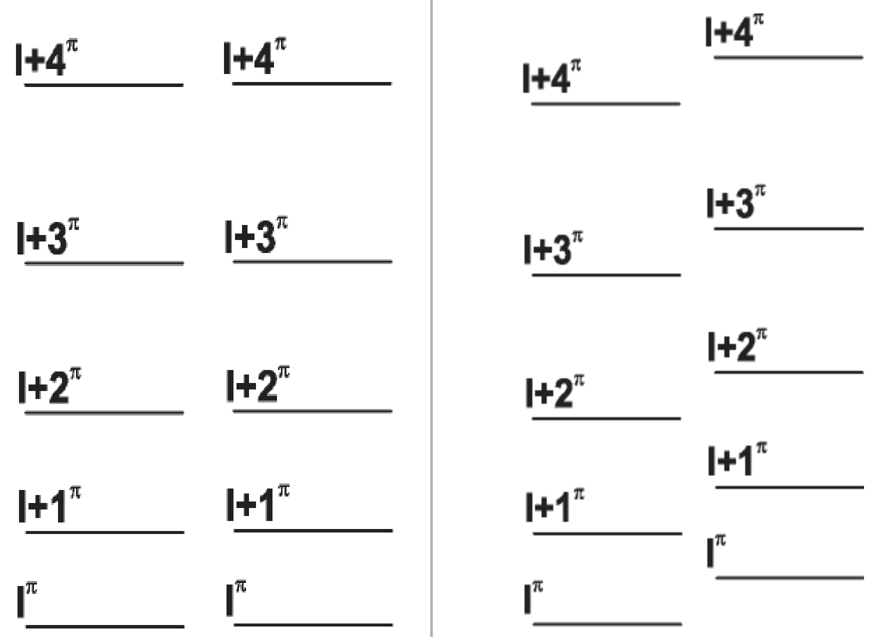
Strong limit of chiral sym. breaking



Weak chiral symmetry breaking

Chiral partner bands can differ in each element
depending on the limit of the symmetry breaking

Strong symmetry breaking limit	Weak symetry breaking



Brief theoretical description

ENERGIES AND TRANSITION PROBABILITIES

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

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

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

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 $B_0 = \mathrm{Re}\langle L | B | L \rangle$

Lifetime measurements

EXPERIMENTAL SETUP

Multidetector array OSIRIS II

12 HPGe detectors (currently)

BGO anticompton shields

Beam

U200P cyclotron

Nuclear reactions

^{122}Sn(^{14}N,4n)^{132}La E=70 MeV

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

Heavy Ion Laboratory

University of Warsaw

OSIRIS II

Principles of the lifetime measurement

DOPPLER EFFECT

Required

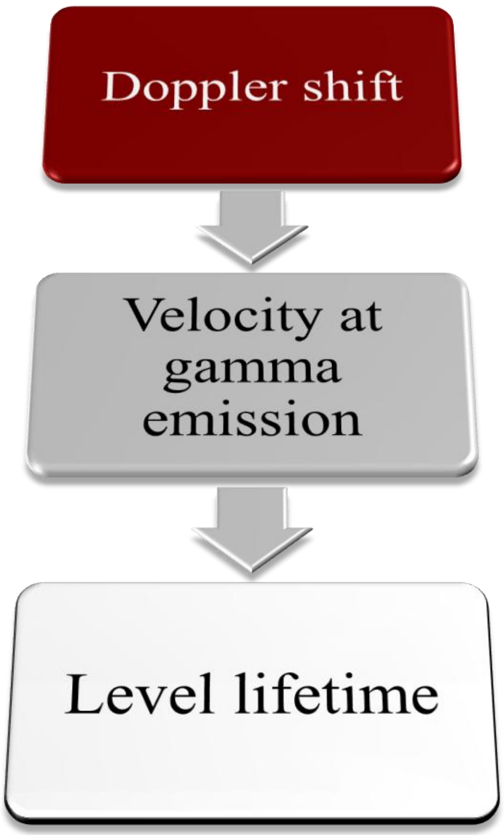
good energy resolution

excellent apparatus lineshape (gaussian and symmetric)

Required

time-velocity correlation for the recoils

feeding time distribution



Method of the lifetime measurement

DOPPLER SHIFT ATTENUATION 0.2 – 1.5 ps

Doppler effect

$E=E_0(1+\beta\cos\theta)$

Initial velocity

0.01c

Gamma emission

w during the slowing down process in the target

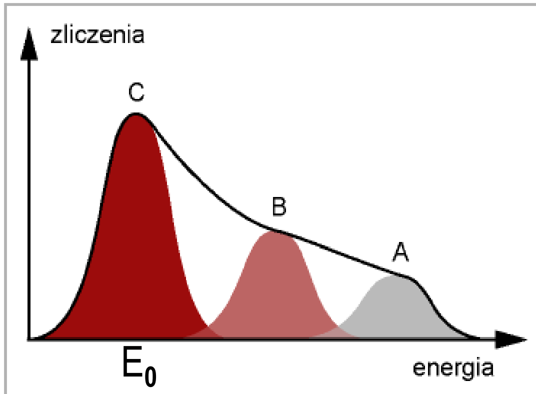
lifetime

Determined from the Doppler disturbed gamma lineshape

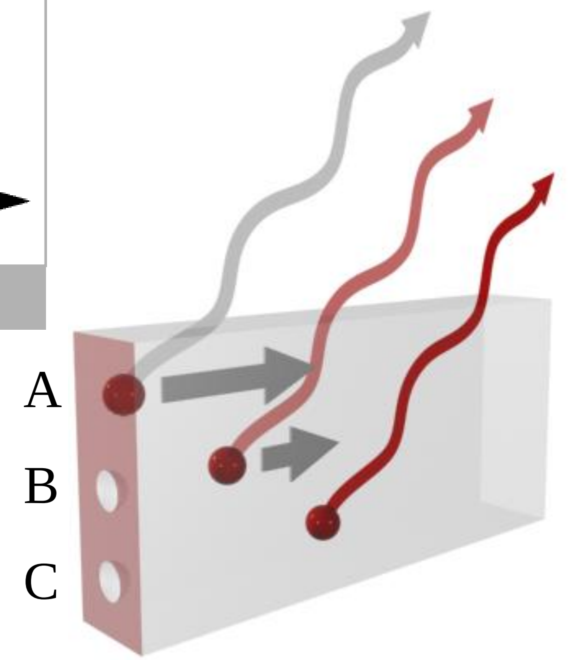
Doppler disturbed gamma lineshape

Gamma emission at different velocities of the recoils

Velocity distribution – lineshape – depends on the lifetime



Energy spectrum



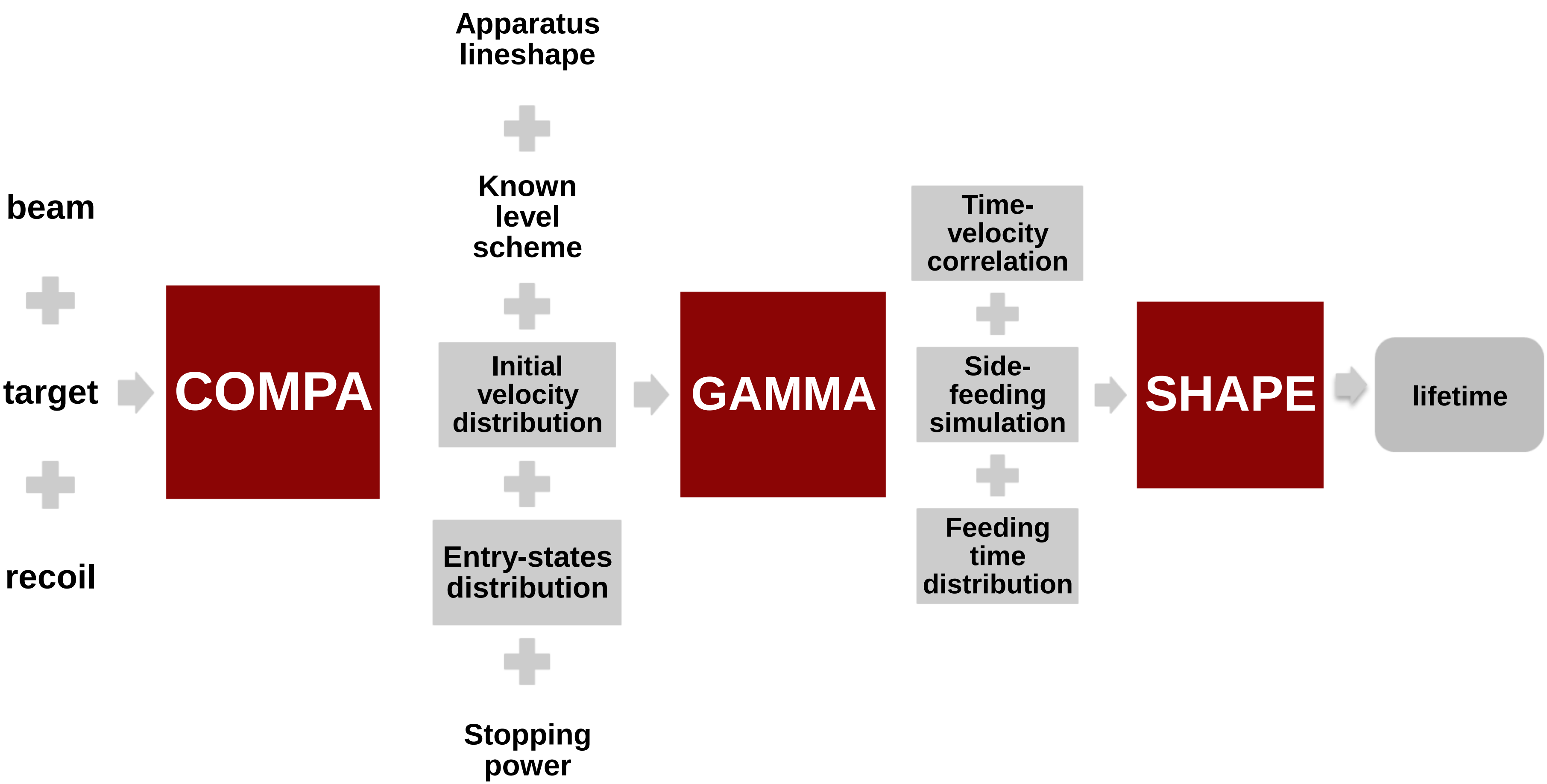
Gamma emission during the slowing down process

E. G. et al..

Eur. Phys. Jour. A27, 325-340 (2006)

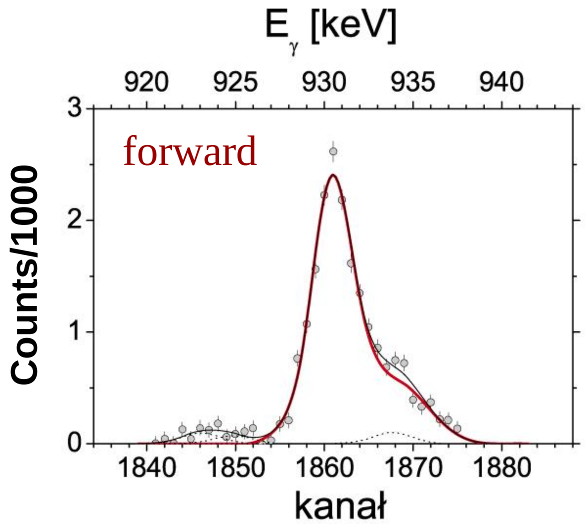
Data analysis process

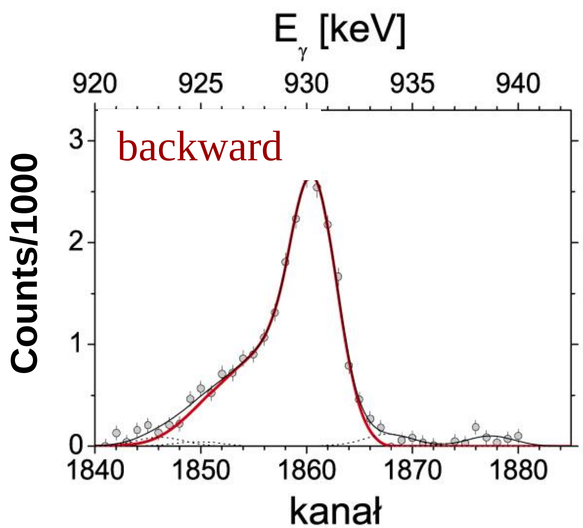
A.A. PASTERNAK - MONTECARLO SIMULATIONS

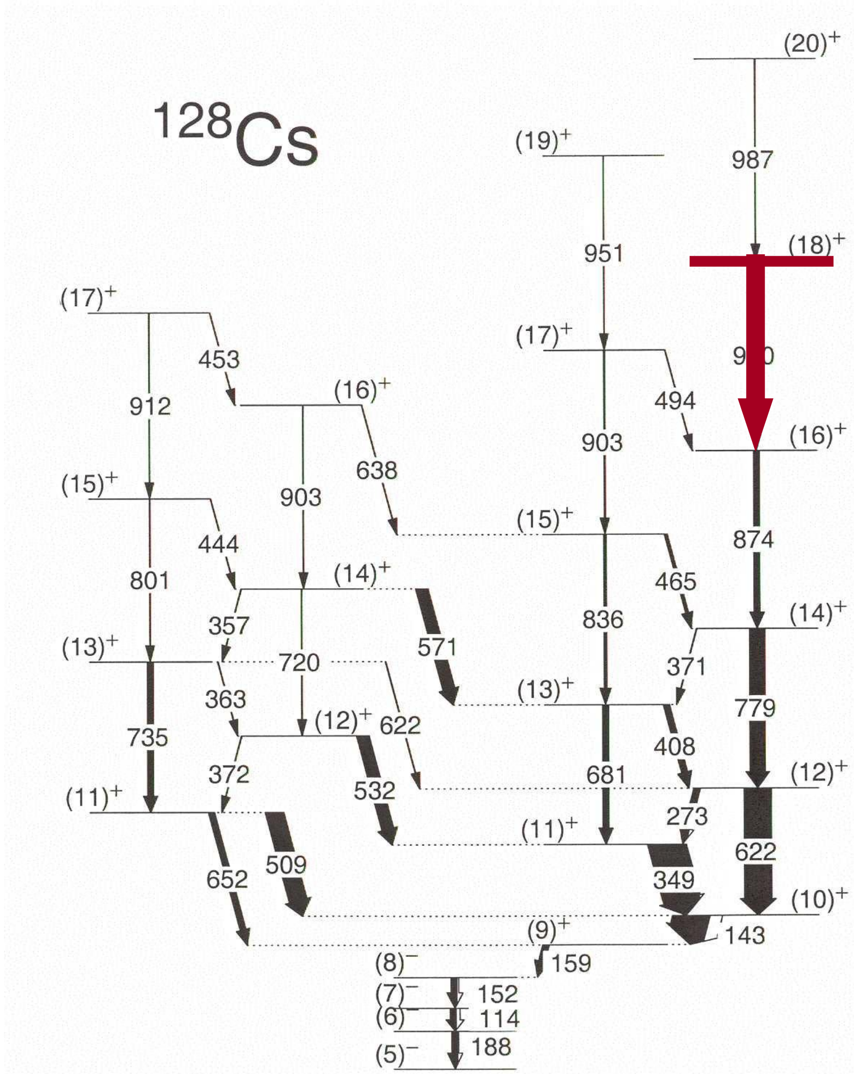


Data analysis process

FIT TO EXPERIMENTAL DATA





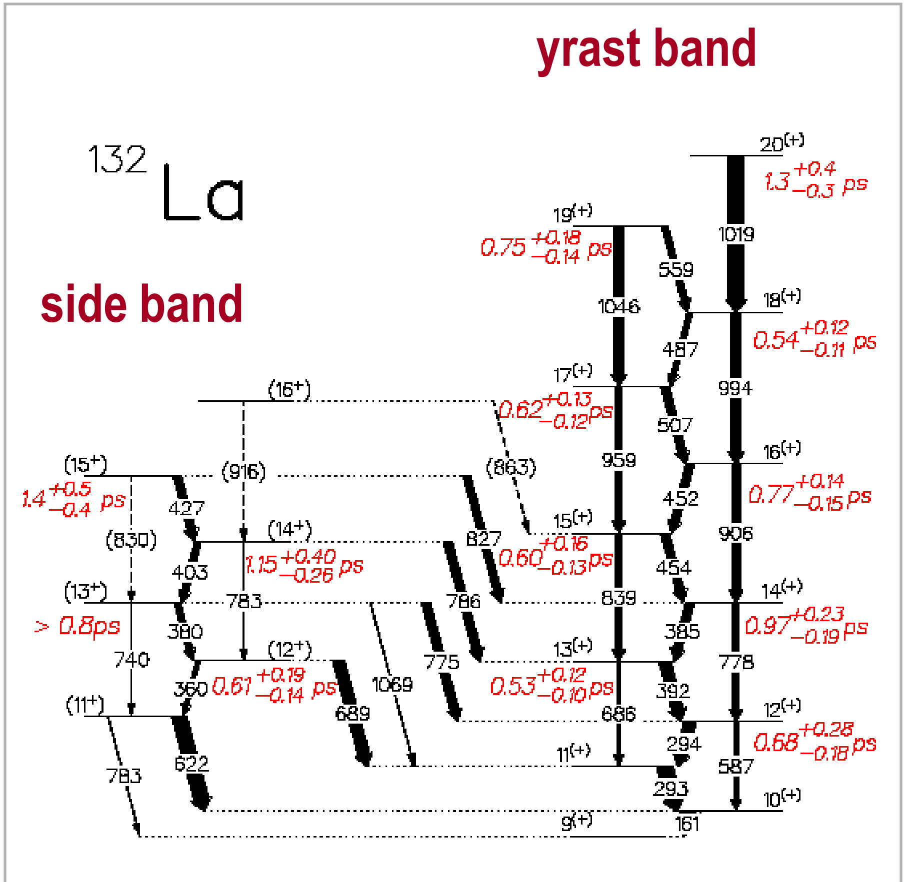


Results

LIFETIMES OF THE EXCITED STATES OF ^{132}La i ^{128}Cs

E. G. et al..

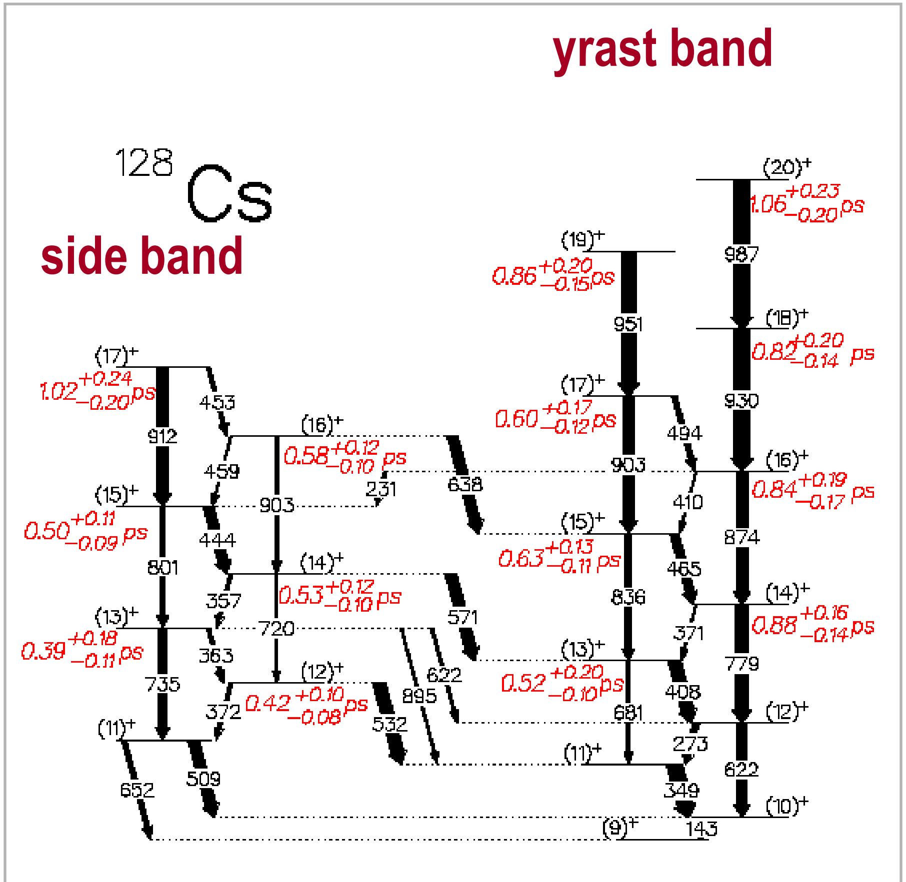
Int. Jour. Of Mod. Phys. E13, 243, (2004)



Partner bands in ^{132}La

E. G. et al..

Int. Jour. Of Mod. Phys. E14, 347, (2005)



Partner bands in ^{128}Cs

Lifetime results

CALCULATED IN TO THE GAMMA PROBABILITIES

$$B(E2) = \frac{1}{\tau} \cdot \frac{4\pi}{1.2^4}\left(\frac{5}{3}\right)^2 A^{-4/3}\frac{1}{1.22 \cdot 10^{-3}}E^{-5}$$

$$B(M1) = \frac{1}{\tau} \cdot \frac{\pi}{10}\left(\frac{4}{3}\right)^2 \frac{1}{17.6}E^{-3}$$

A. Bohr, B. Mottelson

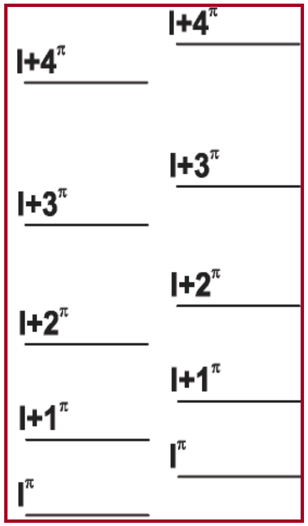
Nuclear Structure, Benjamin, New York (1969)

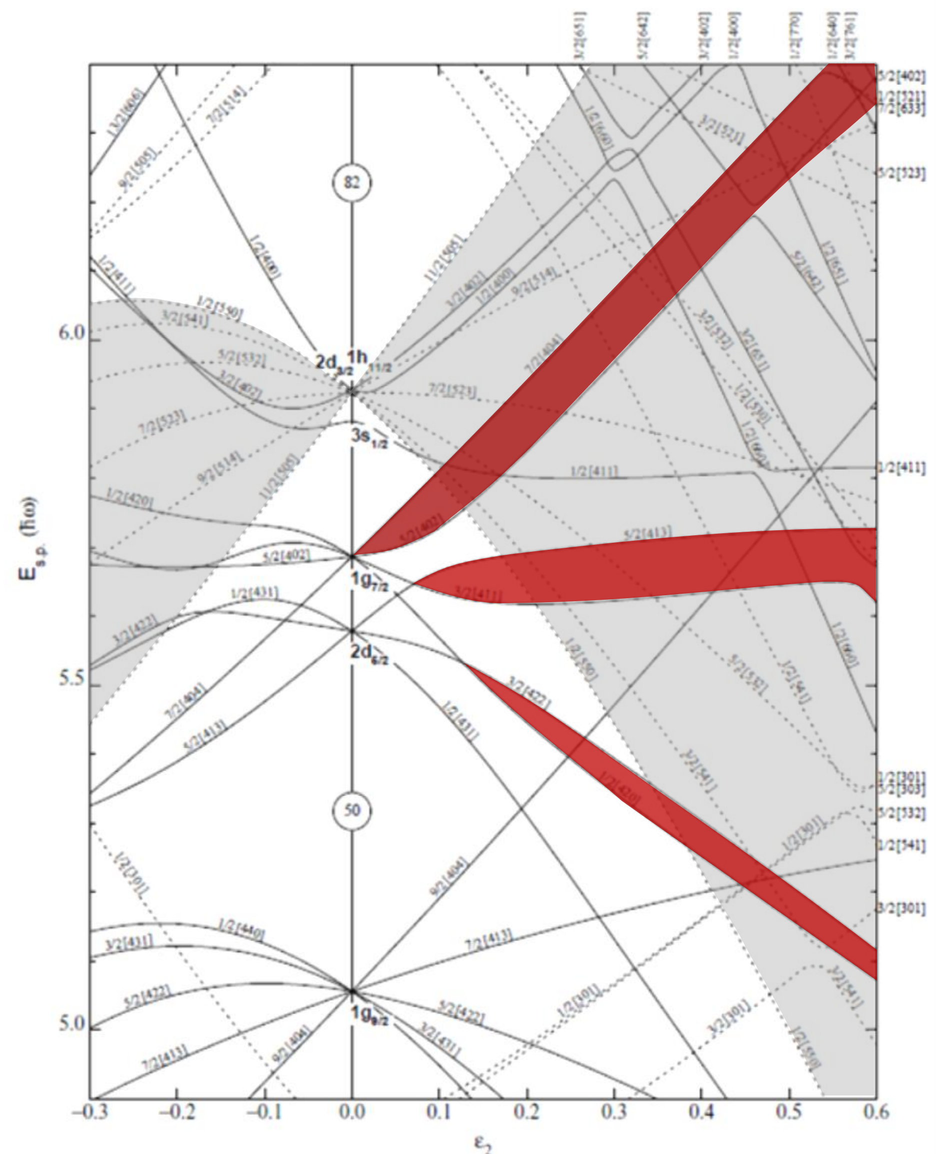
Main subjects

- **Introduction**
  - Examples of symmetry breaking
  - Chiral symmetry breaking
- **Search for nuclear chirality**
  - Level scheme
  - Brief theoretical description
  - Transition probabilities
- **Results and discussion**
  - Level scheme interpretation
  - Transition probabilities interpretation

Pseudo-spin concept

LEVEL ENERGIES



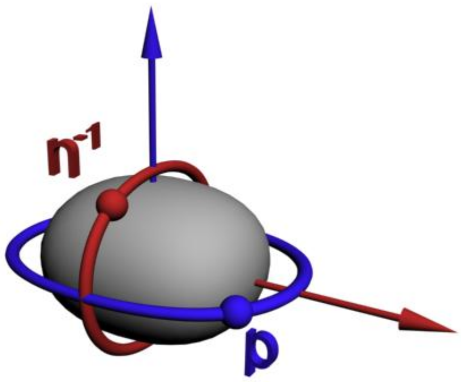


pseudo-spin transformation

Unitary transformation U relabeling physical states into their pseudo counterparts. The transformed hamiltonian UHU^{+} has reduced spin-orbit term.

Signature splitting

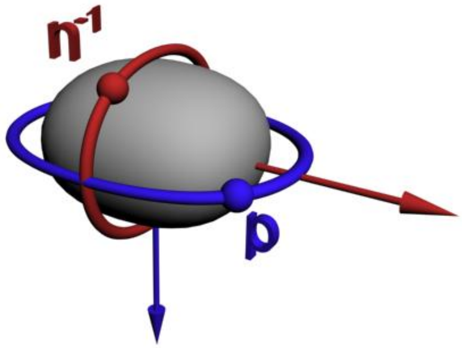
LEVEL ENERGIES



(non-rotating) Nilsson potential

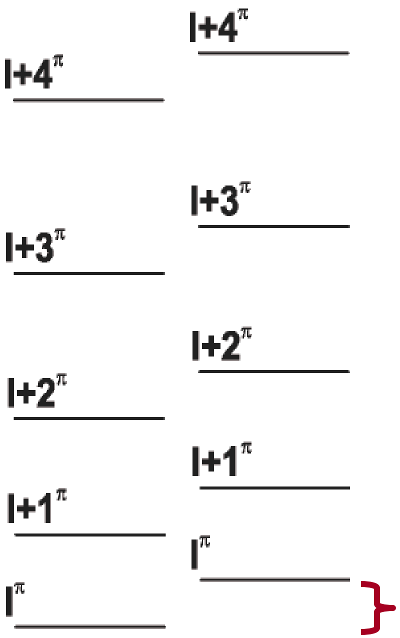
Single particle basis $|k,\Omega_k\rangle$ doubly degenerated.

The $|k,\Omega_k\rangle$ state and time reversed one $|k,\overline{\Omega}_k\rangle$ have the same energy

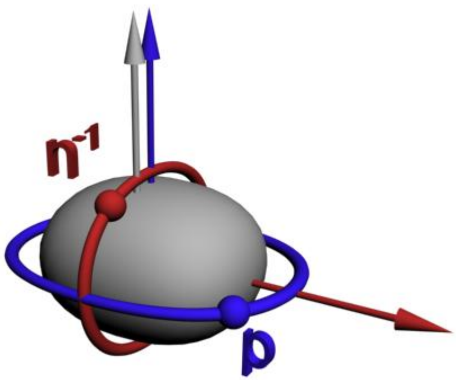


Signature splitting

LEVEL ENERGIES

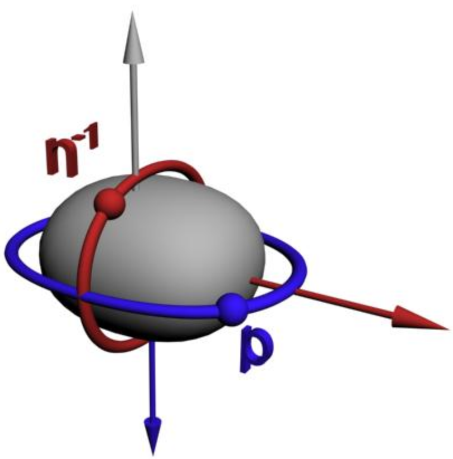


Signature splitting coused by the odd proton



rotating potential

Coriolis interaction ωI_x split the time reversed states. The $|k,\Omega_k\rangle$ state and time reversed one $|k,\overline{\Omega}_k\rangle$ have different energies



Results and discussion

ELECTROMAGNETOC PROPERTIES OF ^{132}La

Transition probabilities

$$\frac{B(E2)_{side}}{B(E2)_{yrast}} \sim \frac{1}{20}$$

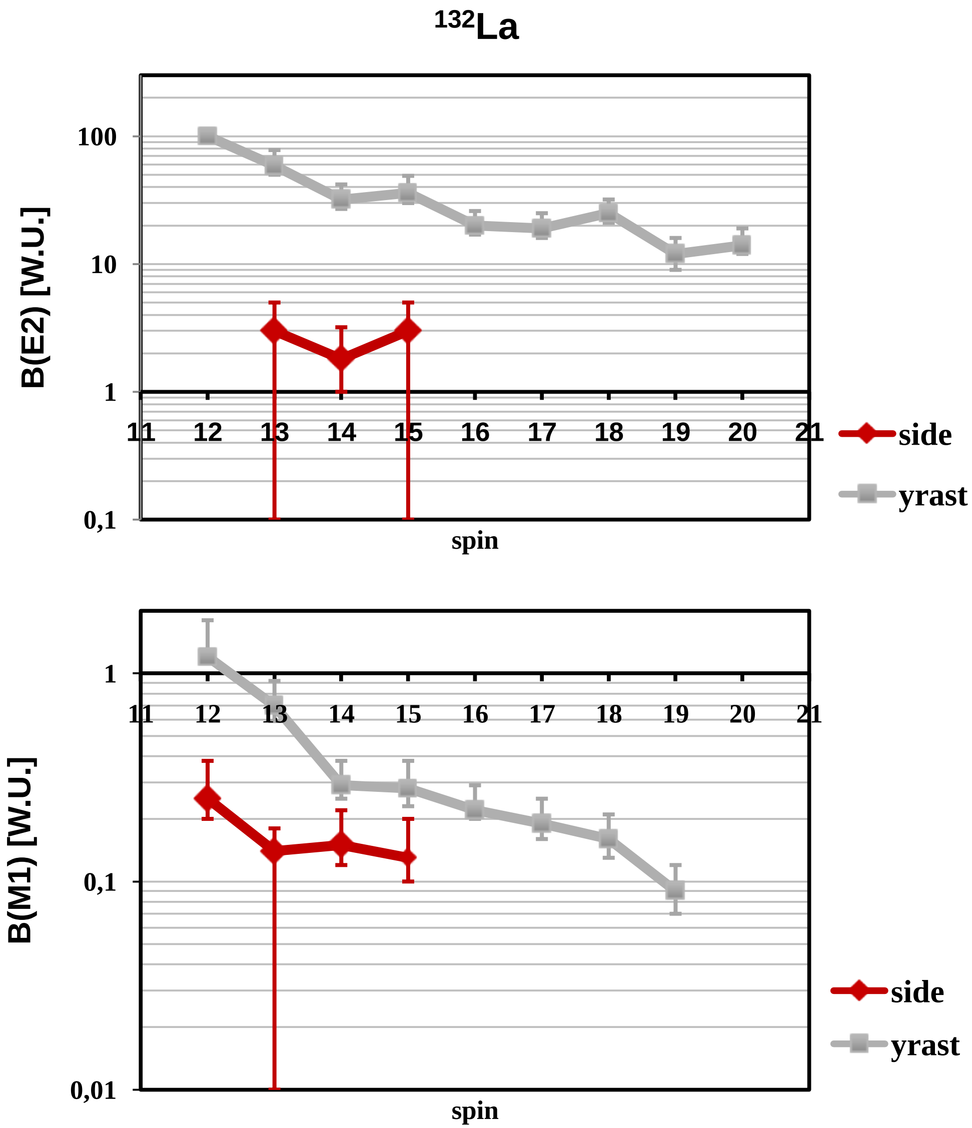
$$\frac{B(M1)_{side}}{B(M1)_{yrast}} < \frac{1}{3}$$

conclusion

The electromagnetic properties of ^{132}La do not support the chiral symmetry breaking

E. G. et al..

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



Results and discussion

ELECTROMAGNETIC PROPERTIES OF ^{128}Cs

PIASKI 2007

Transition probabilities

$$\frac{B(E2)_{side}}{B(E2)_{yrast}} \sim 1 \qquad \frac{B(M1)_{side}}{B(M1)_{yrast}} \sim 1$$

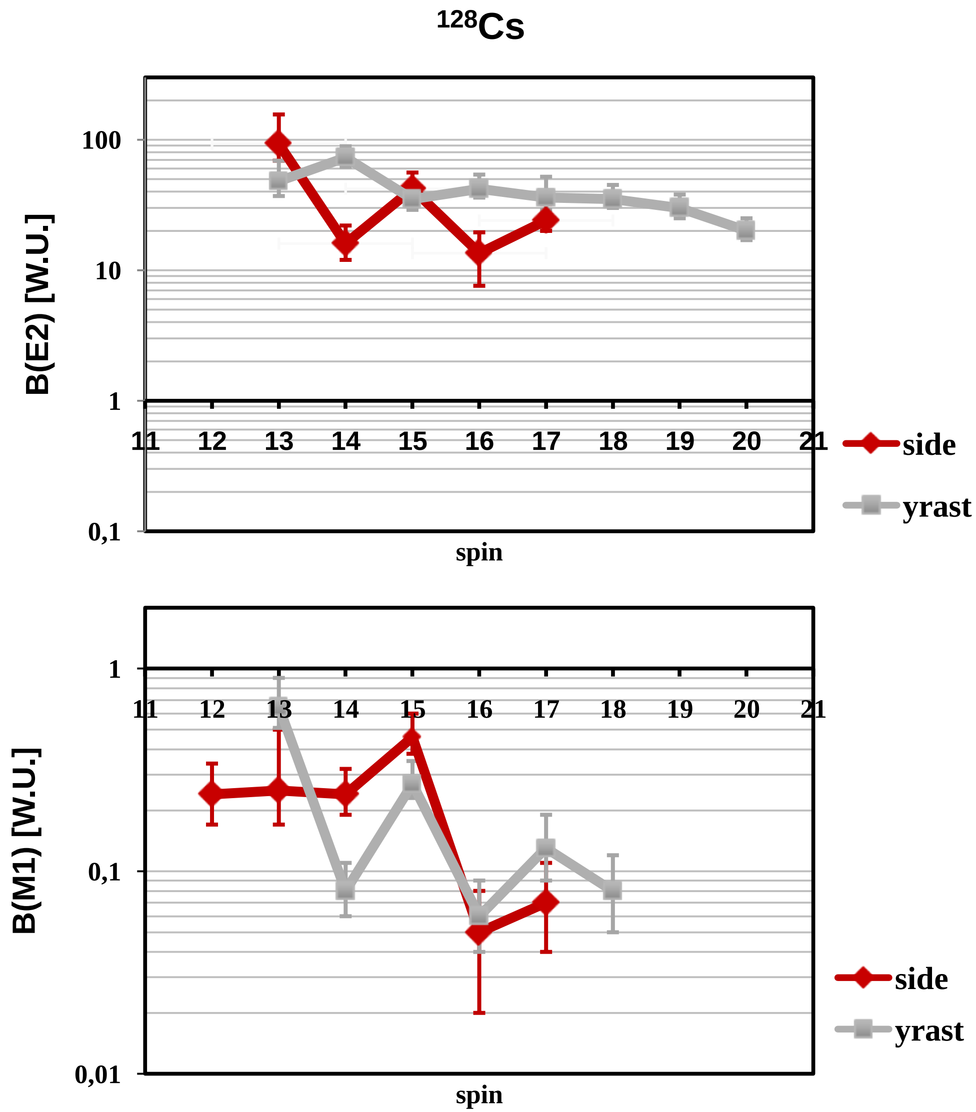
B(M1) staggering

Predicted for strong limit

of the chiral symmetry breaking

T. Koike et al..

Phys. Rev. Lett. 93, 172502, (2004)



conclusion

Electromagnetic properties of ^{128}Cs confirm the chiral symmetry breaking phenomenon

E. G. et al..

Int. Jour. Of Mod. Phys. E15, 548, (2006)

E. G. et al..

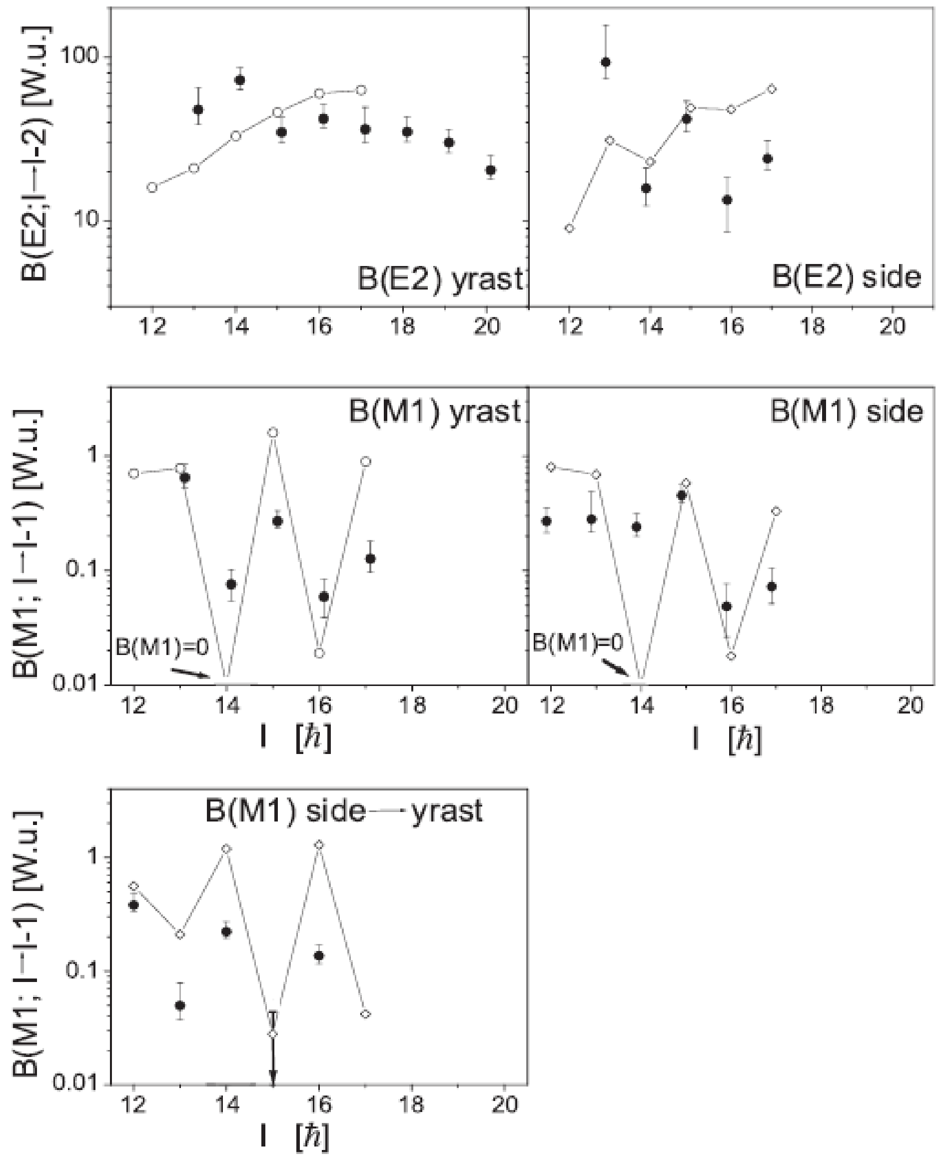
Phys. Rev. Lett. 97, 172501, (2006)

Results and discussion

^{128}Cs COMPARISON WITH THEORETICAL CALCULATIONS

Calculations done in frame of CQPC model

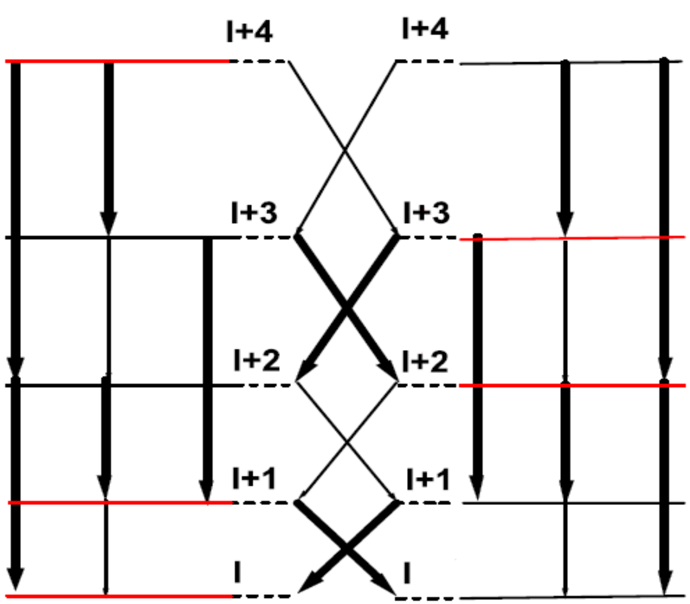
Chiral symmetry breaking in ^{128}Cs predicted

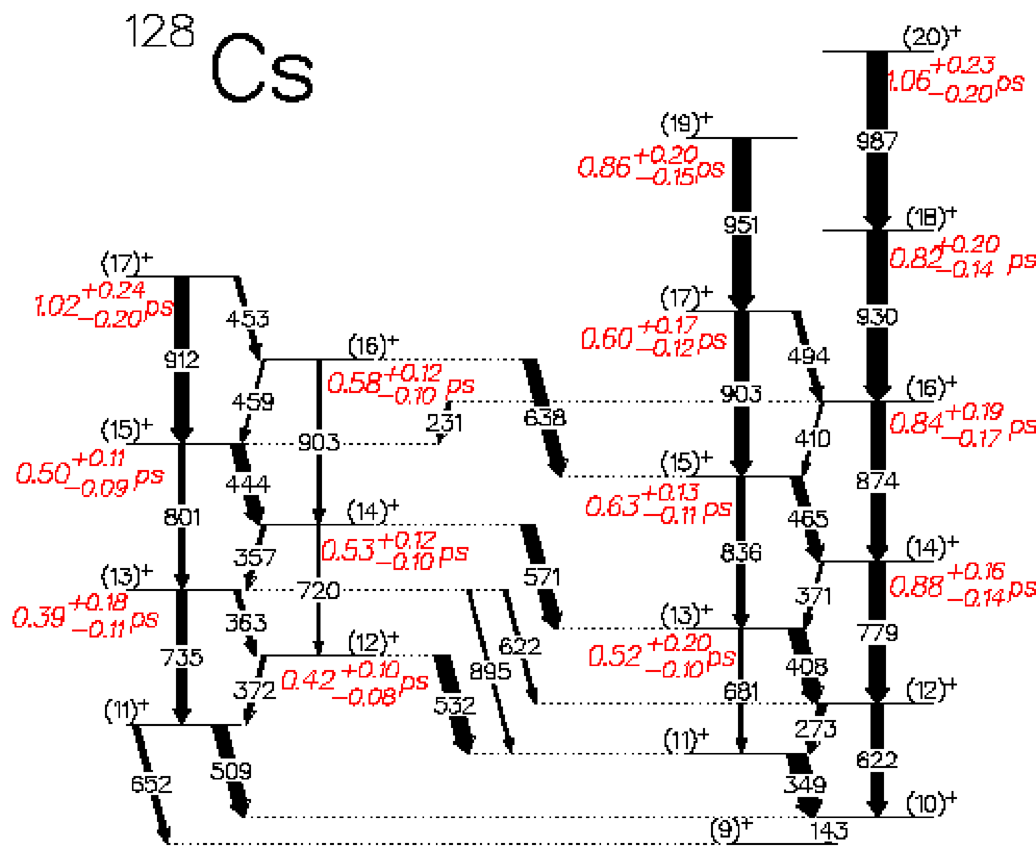


T. Koike et al..

Phys. Rev. C67, 044319, (2003)

Gamma Selection rules





cooperation

E. Grodner, I. Zalewska, T. Morek, J. Srebrny, Ch. Droste, M. Kowalczyk, J. Mierzejewski, M. Sałata.

Institute of Experimental Physics, Warsaw University, Warsaw, Poland

A. A. Pasternak

A. F. Ioffe Physical Technical Institute RAS, St. Petersburg, Russia

S. G. Rohoziński, J. Dobaczewski, P.Olbratowski, W. Satuła

Institute of Theoretical Physics, Warsaw University, Warsaw, Poland

J. Kownacki, M. Kisieliński, A. Kordyasz, P. Napiorkowski, M.Wolińska-Cichocka

Heavy Ion Laboratory of Warsaw University, Warsaw, Poland

L. Nowicki, R. Ratajczak, R. Kaczarowski, W. Płóciennik, E. Ruchowska, A. Wasilewski

The Andrzej Sołtan institute for Nuclear Studies, Otwock-Świerk, Poland

summary

research subject

Experimental search for chiral symmetry breaking in atomic nuclei

method

DSA lifetime measurements

experiment

Cyclotron U200P , OSIRIS II multidetector array

results

First lifetime measurements in nuclei supposed of the chirality phenomenon

^{132}La – chiral symmetry breaking not confirmed

^{128}Cs – all observables agree with chiral interpretation – first chiral nucleus

^{126}Cs – propably the second chiral nucleus

conclusion

Lifetime measurements are necessary for study of the chirality

New dynamic variable (handedness) needed to be introduced for proper quantum mechanical description

Future – new facility at HIL Wrasaw

WARS – NEW MULTIDETECTOR ARRAY

Study Center of Electromagnetic Transition Probabilities
based on Warsaw Array for γ-Ray Spectrometry (WARS)