Pierwsza obserwacja kompletu regul wyboru przejść gamma W pasmach chiralnych – ^{126}Cs

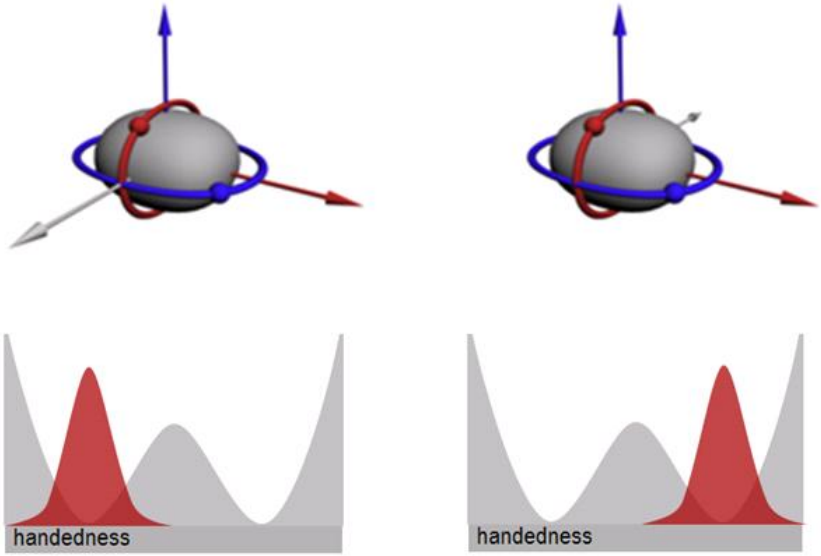
Zakład Fizyki Jądra Atomowego

EAGLE
OSIRIS
COLLABORATION

WYDZIAŁ FIZYKI

Spontaneous symmetry breaking
Breaking of the chiral symmetry in nuclear physics
Role of time reversal in description of chirality
DSA lifetime measurements
Results interpretation

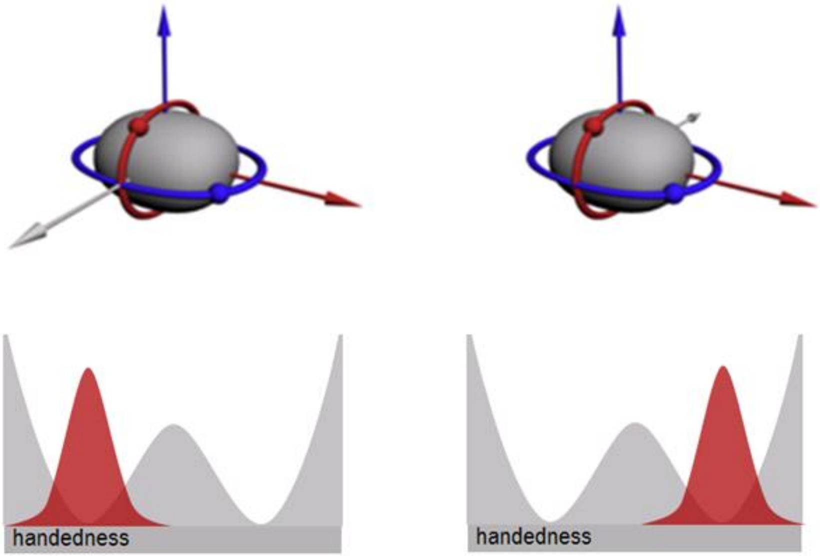
Introduction



Handedness of a nucleus

The ^{126}Cs nucleus can be described as coupling of three elements:
even-even core R, odd proton p and odd neutron n,
each with its own angular momentum j_{-R}, j_p, j_n , respectively.
In case of strong triaxial deformation of the core,
the three angular momenta vectors are mutually perpendicular
forming a system with **specified handedness**

Introduction



Spontaneous chiral symmetry breaking

There is a double potential well in the parameter of handedness and we create a nucleus in one of the potential minima being either left |L>- or right-handed |R>. The |L> and |R> are dynamical states and not eigenstates of the hamiltonian. The left-handed state is a wave packet that will tunnel to the right-handed one and vice-versa. Quickness of the tunneling process depends on width and height of the energy barrier between the two potential minima. In case of a large energy barrier the probability of the tunneling effect will be very low and negligible. In such situation the wave packet will remain only in one potential well although the hamiltonian is symmetric with respect to handedness reversion – fig. 1. This means **strong spontaneous chiral symmetry breaking**.

Introduction

The direct observation of the state with specified handedness in the presented experiments is impossible since the state is a dynamical one. The only properties of a nucleus that can be measured are related to eigenstates of the hamiltonian. Eigenstates can be found by utilizing the commutation relation between hamiltonian and chiral symmetry operator

$$[R_Y^T, H] = 0 \qquad (1)$$

Having an eigenstate the commutation relation leads to

$$H(R_Y^T \psi_E) = E(R_Y^T \psi_E)$$

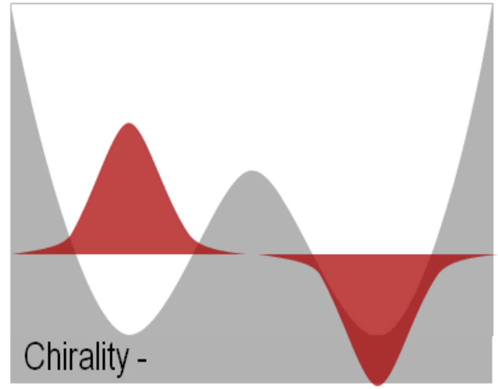
In default of degeneracy it means that if ψ_E is an eigenfunction with eigenvalue *E*, then $R_Y^T \psi_E$ is also an eigenfunction with the same eigenvalue. This is possible when the state represented by $R_Y^T \psi_E$ is also an eigenstate of the symmetry operator:

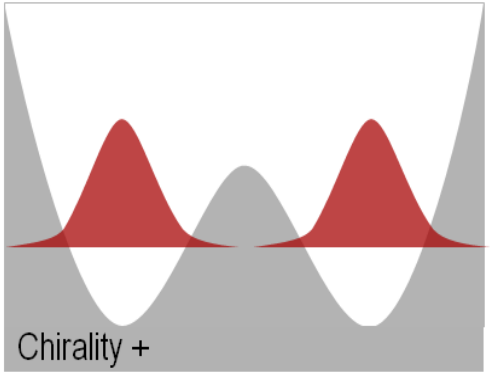
$$R_Y^T | \psi_E >= C | \psi_E > \qquad (2)$$

where $C = \mp 1$ since $(R_Y^T)^2 = identity.$

The symmetry operator reverses handedness – it transforms left handed state into right-handed one and vice versa. The |L> and |R> symmetry breaking states are not eigenstates of the symmetry operator. In contrast, equation (2) shows that the eigenstates of hamiltonian are either symmetric |+> or antisymmetric |-> in the parameter of handedness possessing definite **new quantum number C=+1, C=-1 called chirality**. These states conserve the symmetry since they are eigenstates of the symmetry operator. A nucleus is created in the dynamical state |L> (or |R>) that can be decomposed in the elements of the eigenstate basis : |L>=|+> + |->; (|R>=|+>-|->)

This leads finally to the conclusion that in case of chiral symmetry breaking (a nucleus is created either in the state |L> or |R>) doublet of states |+> and |-> conserving chiral symmetry will be observed experimentally.

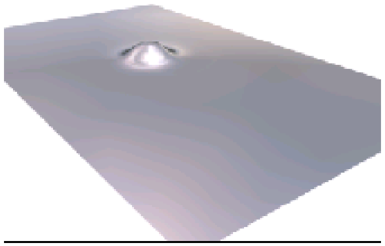




Introduction

SPONTANEOUS SYMMETRY BREAKING – OTHER EXAMPLES

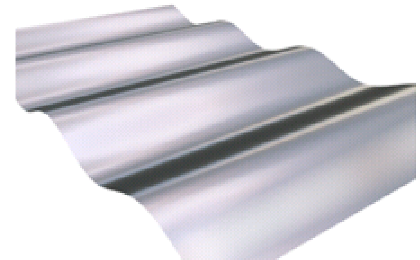
localized particle



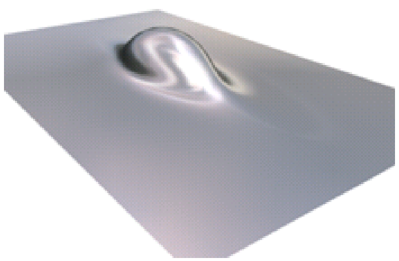
Translational Symmetry breaking

LAB

Translational states



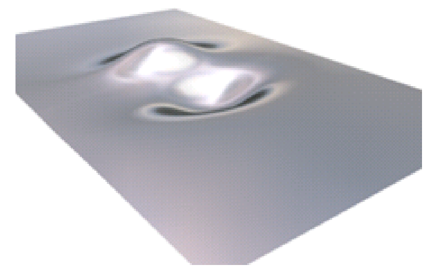
Deformed nucleus



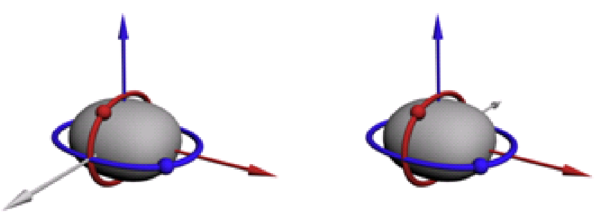
Rotational Symmetry breaking

LAB

Rotational states



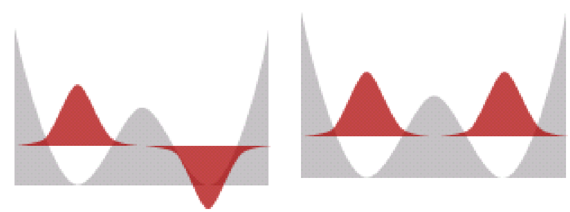
Specified handedness



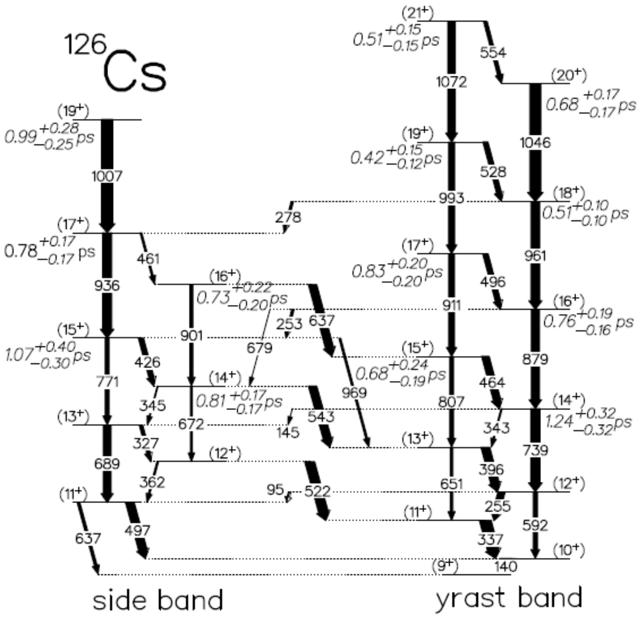
Chiral Symmetry breaking

LAB

Chiral dublets



Chiral partner bands Cs, La



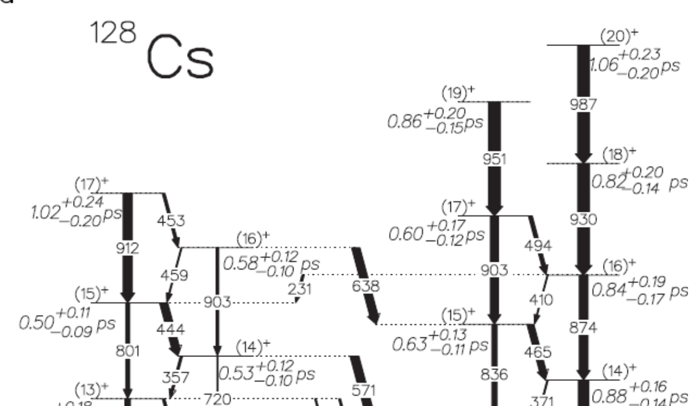
Lifetime results from the DSA experiments –warsaw cyclotron

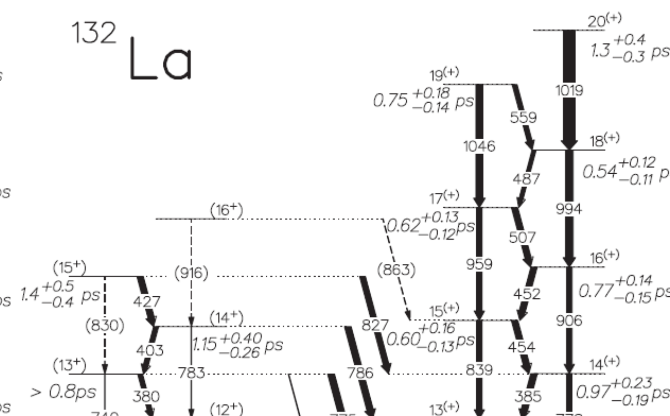
Partner bands populated in fusion evaporation reaction

M1 interband transitions yrast->side observed in ^{126}Cs

Energy separation in Cs Isotopes around 150 keV

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



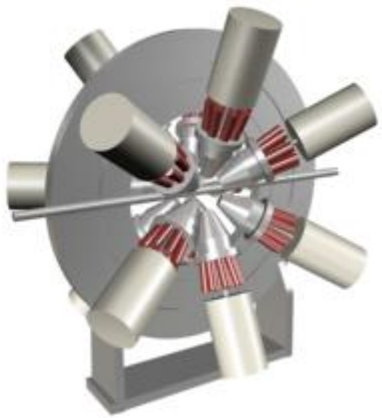


E.G. et al.,

^{128}Cs as the best example revealing the chiral symmetry breaking phenomenon

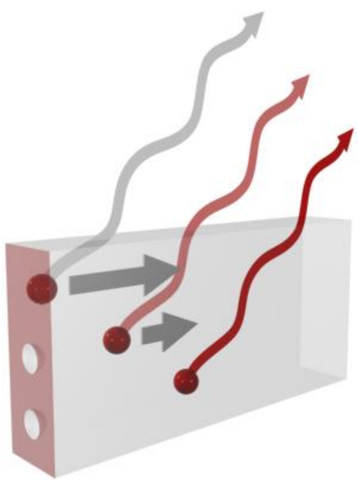
Phys. Rev. Lett. 97 (2006) 172501

DSA lifetime measurements



OSIRIS II

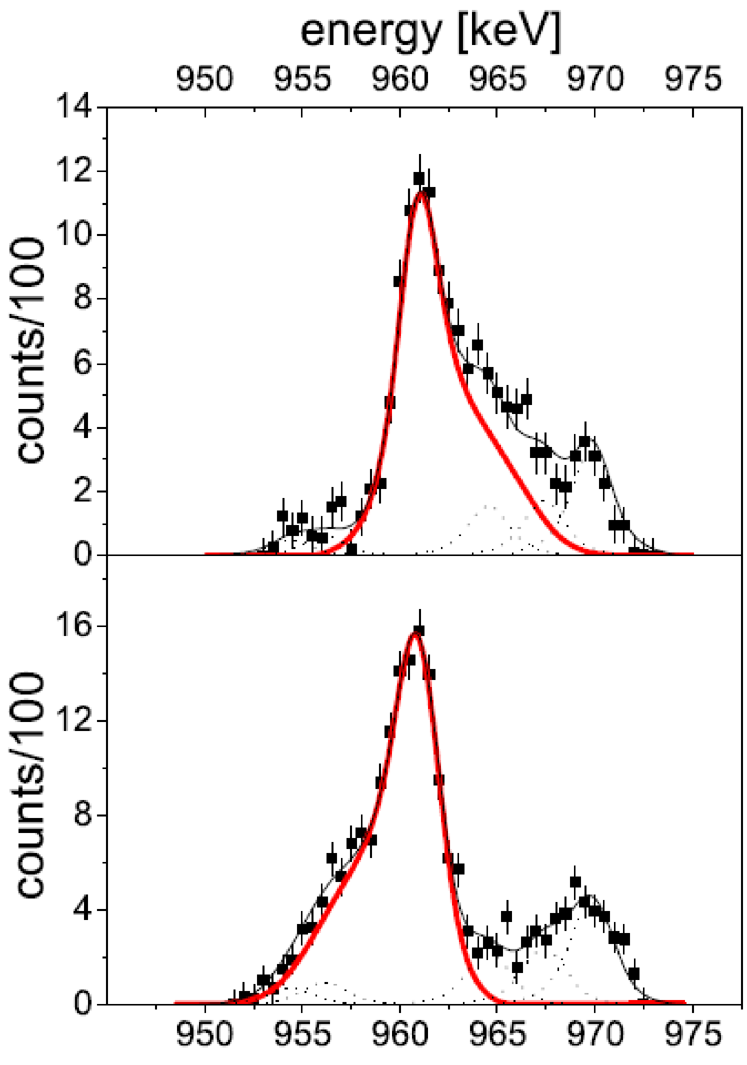
12 ACS detectors
Each around 30% efficiency
U200P warsaw cyclotron

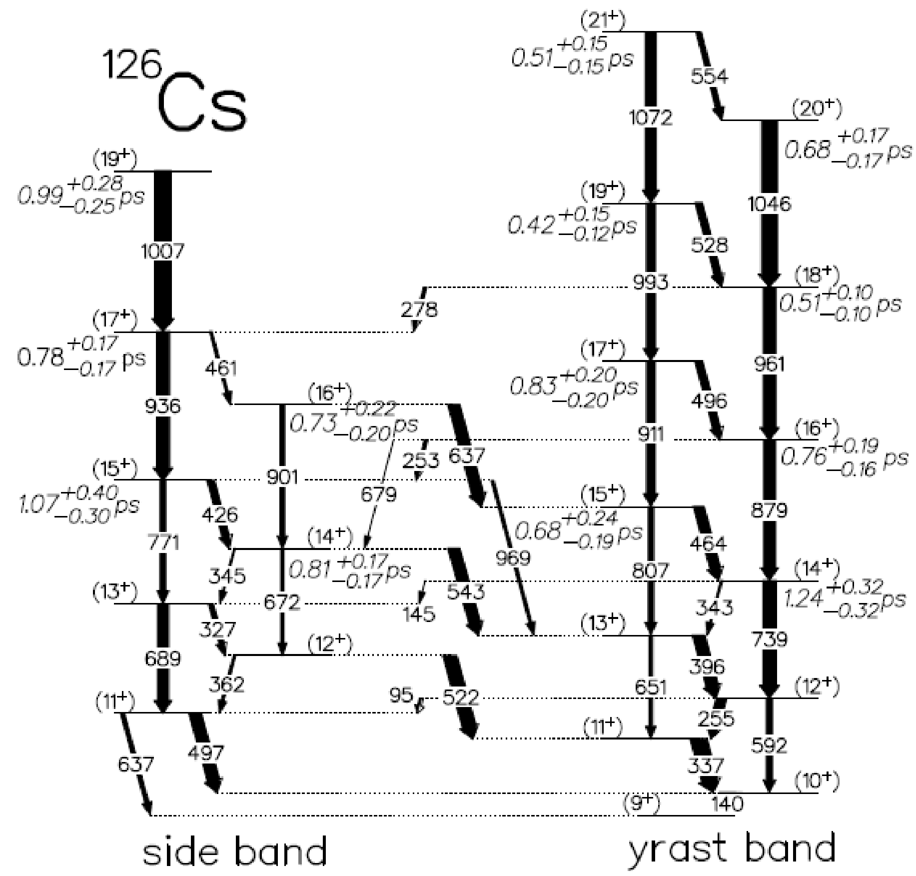


DSA

$^{120}Sn(^{10}B,4n)^{126}Cs$
0,01c initial velocity
Stopping time ~ 1ps

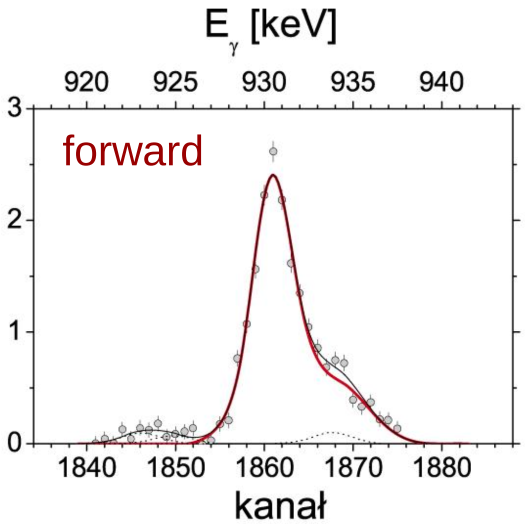
DSA lineshape examples

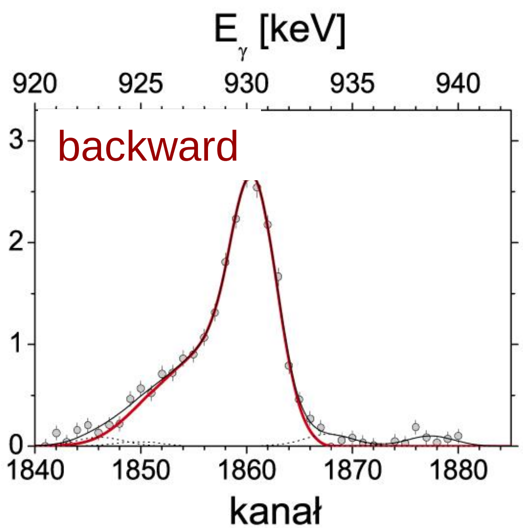


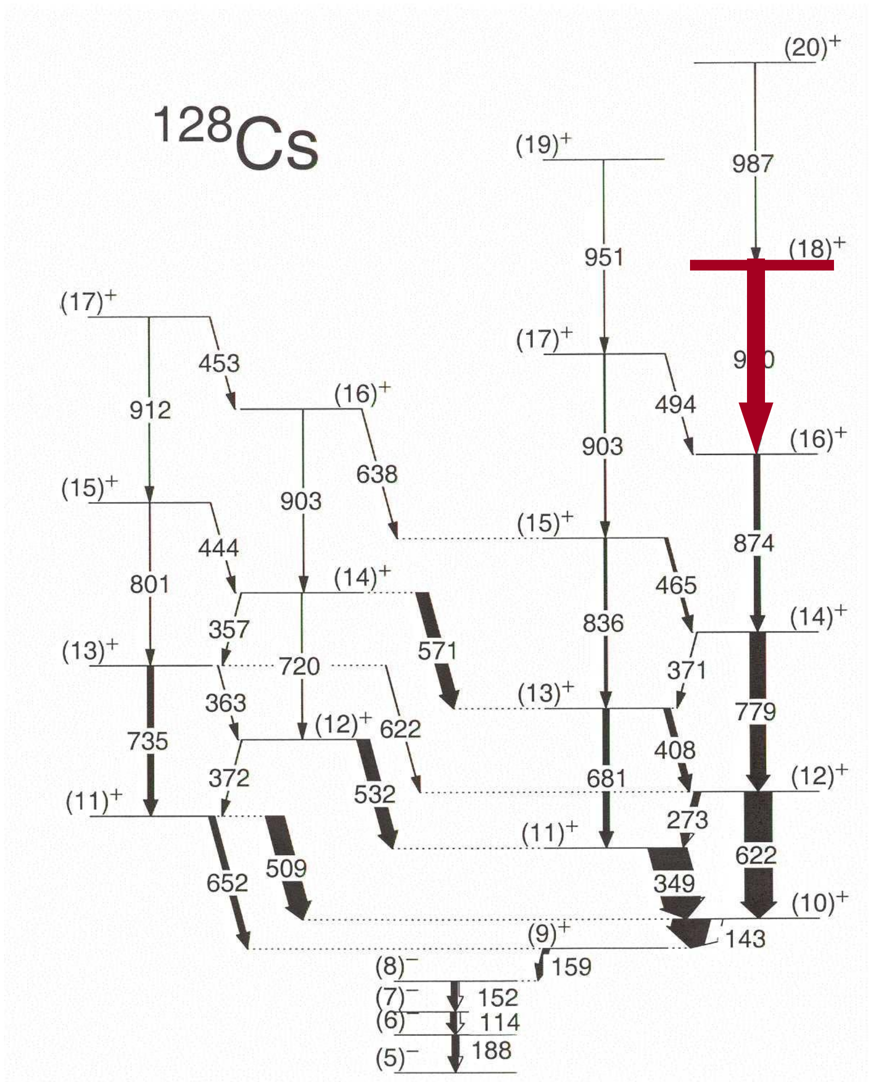


DSA lineshape examples

FIT TO EXPERIMENTAL DATA







Role of time reversal in chiral symmetry

TIME REVERSAL IN SCIENCE-FICTION LITERATURE

„Jedynymi , którzy dziwią się jednokierunkowości czasu, są fizycy. To dlatego, że żadne prawo fizyki nie wyróżnia jednego kierunku upływu czasu… Żadne nie wymaga tego, by czas płynął od przeszłości ku przyszłości, a nie odwrotnie.

W świecie, w którym strzałka termodynamiczna wskazywałaby drugą stronę, ludzie pamiętali by zdarzenia ze swej przyszłości, a nie przeszłości. Oznacza to, że wbrew pozorom ich postrzeganie świata nie różniłoby się wiele od naszego”

„Ważne są tylko dni, które już znamy”
Przekrój, 4.06.2009

„Podstawową cechą kwantowomechanicznego opisu układów fizycznych jest odwracalność w czasie: dla każdego procesu kwantowego mogącego zacierać informację istnieje proces odwrotny , który w zasadzie mógłby zostać wykorzystany do jej odtworzenia.

Natomiast w ogólnej teorii względności nie istnieje żaden proces pozwalający odzyskać coś, co wpadło pod horyzont zdarzeń czarnej dziury.”

„Portret czarnej dziury”
Świat Nauki, styczeń 2010.

Role of time reversal in chiral symmetry

TIME REVERSAL IN SCIENCE-FICTION LITERATURE

„Nieodwracalność czasu – oto naczelna nielojalność bytu.
Wszak wiadomo, że kto zaczyna żyć, sam sobie szkodzi nieobyciem w bycie,
a kto kończy, ten wprawdzie już wie, co do czego i jak, lecz na ogół za późno….”

„… Weźcie się do czasu, mówię wam. Kto raz upadnie, będzie to mógł anulować,
A jeśli się za pierwszym nawrotem nie poprawi, to po dwudziestym
czy po setnym znudzi się albo i wydobrzeje.”

Stanisław Lem,
„Cyberiada”

Intrinsic states (symmetry breaking)

TIME REVERSAL T

$$T|A\rangle = |A'\rangle$$

$$T|B\rangle = |B'\rangle$$

$$TMT^{+} = M'$$

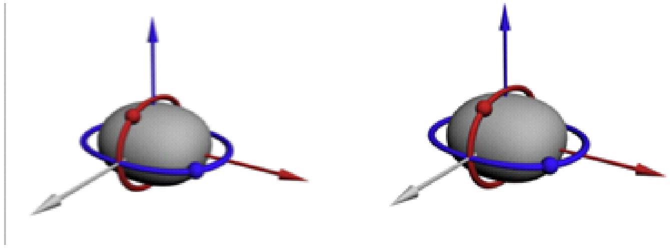
$$\langle A'| = (\langle A|T^{+})$$

$$\langle A|M|B\rangle^{*} = \langle A'|M'|B'\rangle$$

T-SIGNATURE $R_Y^T = R_Y T$

$$R_y^T|R\rangle = |L\rangle$$

$$R_y^T|L\rangle = |R\rangle$$



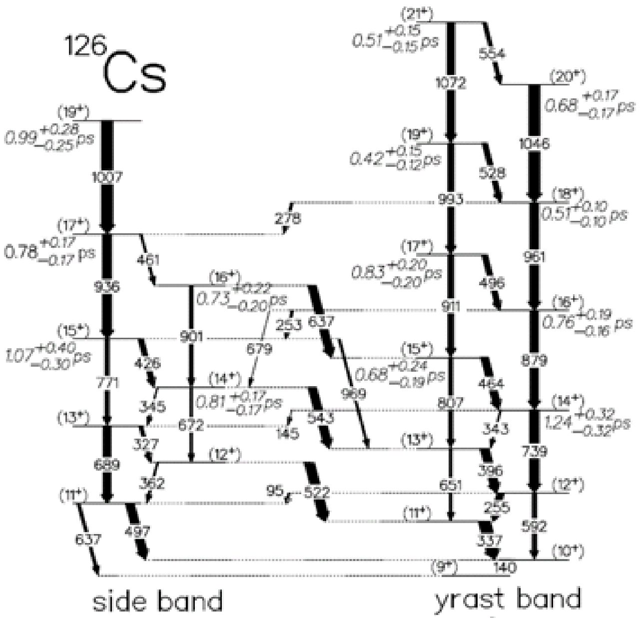
$$\langle L|M|R\rangle^{*} = \langle R|M|L\rangle$$

$$M(\sigma\lambda) = M1, E2, M3 \ldots$$

$$\left[R_y^T, M(\sigma\lambda)\right] = 0 \quad \Rightarrow M' = M$$

A. Bohr, B. Mottelson
Nuclear Structure
W.A. Benjamin (1969)

Laboratory states



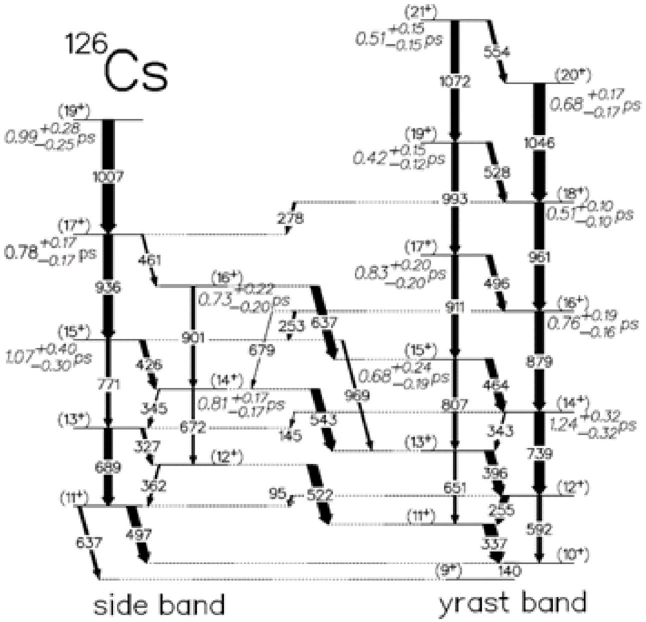
$$|I, M, +\rangle = \frac{1}{\sqrt{2}N_{I+}}\left(|I, M, L\rangle + |I, M, R\rangle\right)$$

$$|I, M, -\rangle = \frac{i}{\sqrt{2}N_{I-}}\left(|I, M, L\rangle - |I, M, R\rangle\right)$$

$$\langle I_2, + \| M \| I_1, + \rangle = \frac{1}{\sqrt{2}N_{I_2+}}\left(\langle I_2, L| + \langle I_2, R|\right)|M| \frac{1}{\sqrt{2}N_{I_2+}}\left(|I_1, L\rangle + |I_1, R\rangle\right)$$

$$\langle I_2, + \| M \| I_1, + \rangle = \frac{1}{2N_{I_2+}N_{I_1+}}\left(\langle I_2, L\| M \| I_1, L\rangle + \langle I_2, R \| M \| I_1, R\rangle + \langle I_2, L \| M \| I_1, R\rangle + \langle I_2, R \| M \| I_1, L\rangle\right)$$

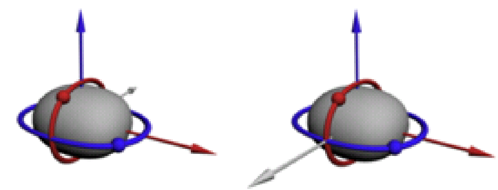
Laboratory states



$$|I,M,+\rangle = \frac{1}{\sqrt{2}N_{I+}}\left(|I,M,L\rangle + |I,M,R\rangle\right)$$

$$|I,M,-\rangle = \frac{i}{\sqrt{2}N_{I-}}\left(|I,M,L\rangle - |I,M,R\rangle\right)$$

$$\langle L|M|R\rangle^{*} = \langle R|M|L\rangle$$



$$\langle I_2,+\|M\|I_1,+\rangle = Re\langle I_2,L\|M\|I_1,L\rangle$$

$$\langle I_2,-\|M\|I_1,-\rangle = Re\langle I_2,L\|M\|I_1,L\rangle$$

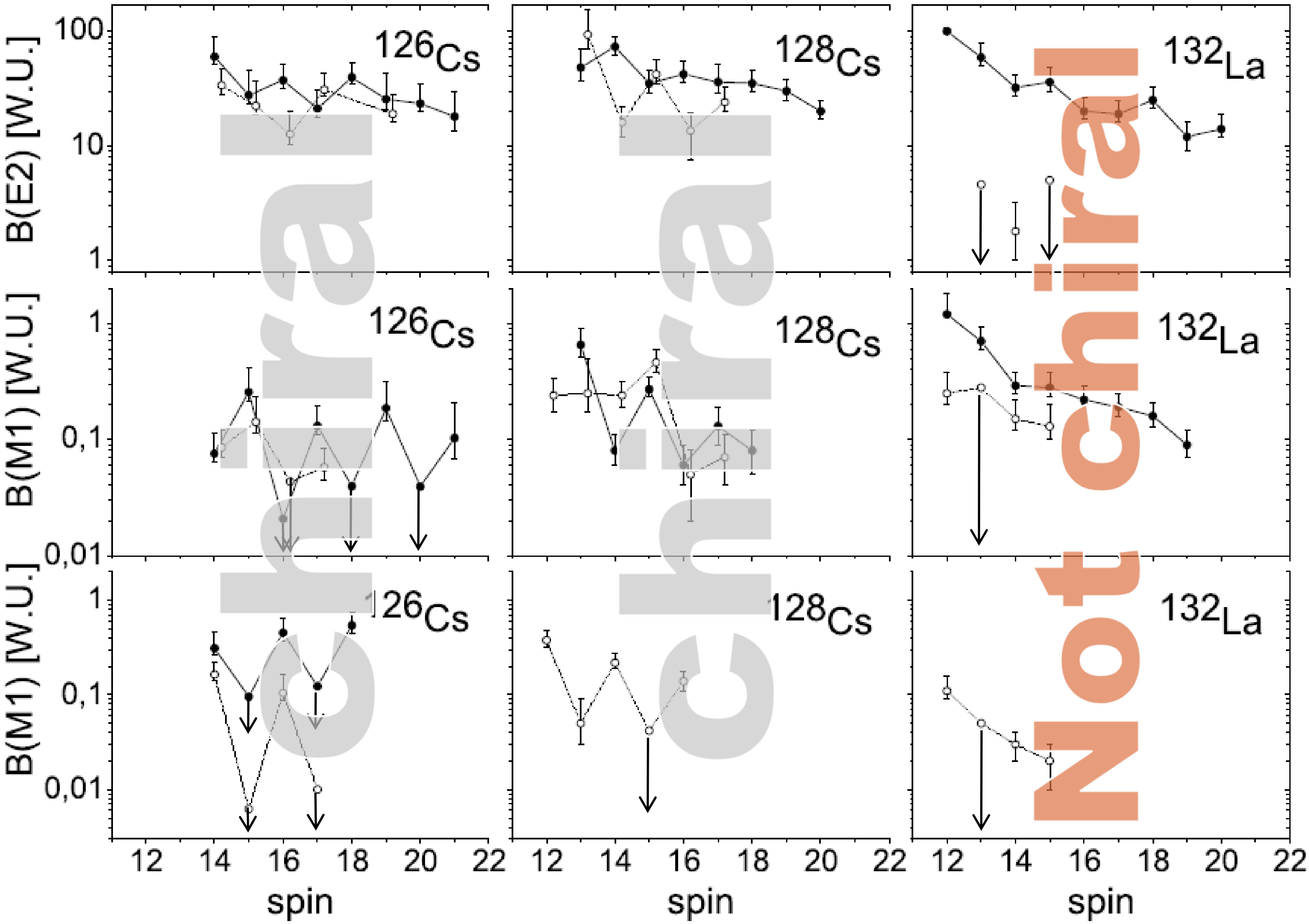
Inband transition probabilities Identical in both bands

$$\langle I_2,+\|M\|I_1,-\rangle = Im\langle I_2,L\|M\|I_1,L\rangle$$

$$\langle I_2,-\|M\|I_1,+\rangle = Im\langle I_2,L\|M\|I_1,L\rangle$$

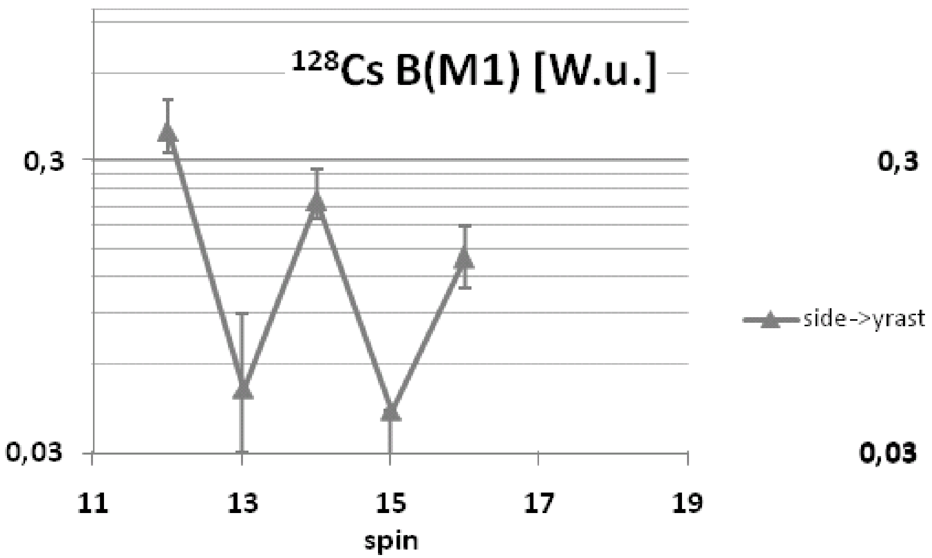
Interband transition probabilities Identical in both bands

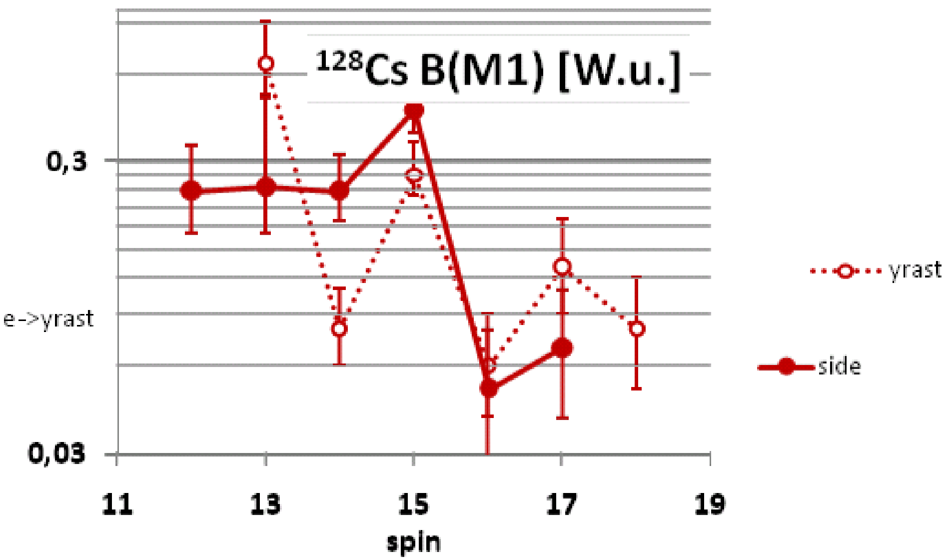
Experimental transition probabilities



Transition probabilities ^{128}Cs

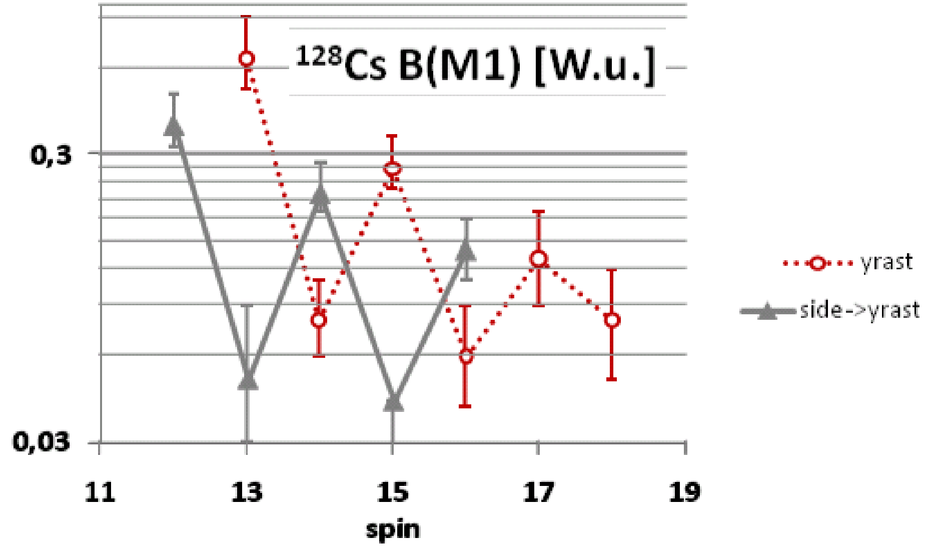
Transition probabilities similar in both bands



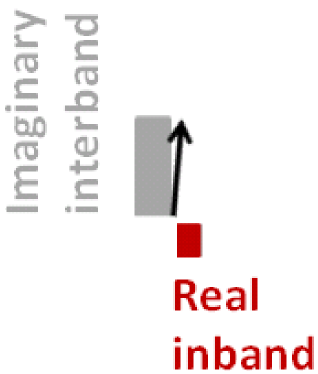


Transition probabilities ^{128}Cs

Transition probabilities similar in both bands
Inband transition strong => interband weak (vice-versa)



Transition probabilities ^{128}Cs



Transition probabilities similar in both bands

Inband transition strong => interband weak (vice-versa)

B(M1) staggerings correspond to ideal case of chirality:

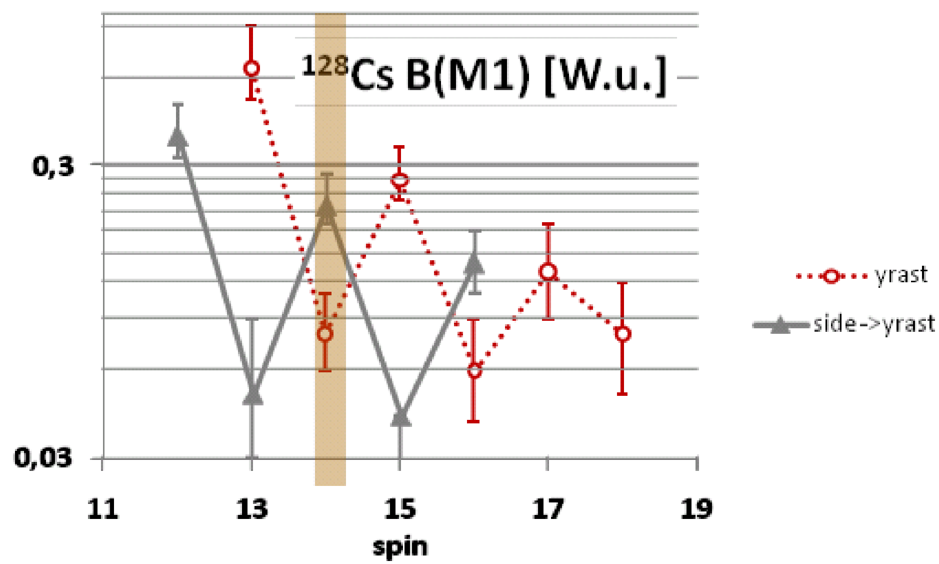
1)TRIAXIALITY $\gamma=30°$

2)THREE ANGULAR MOMENTUM VECTORS PERPENDICULAR

3)2qp SIGLE-J SHELL CONFIGURATION

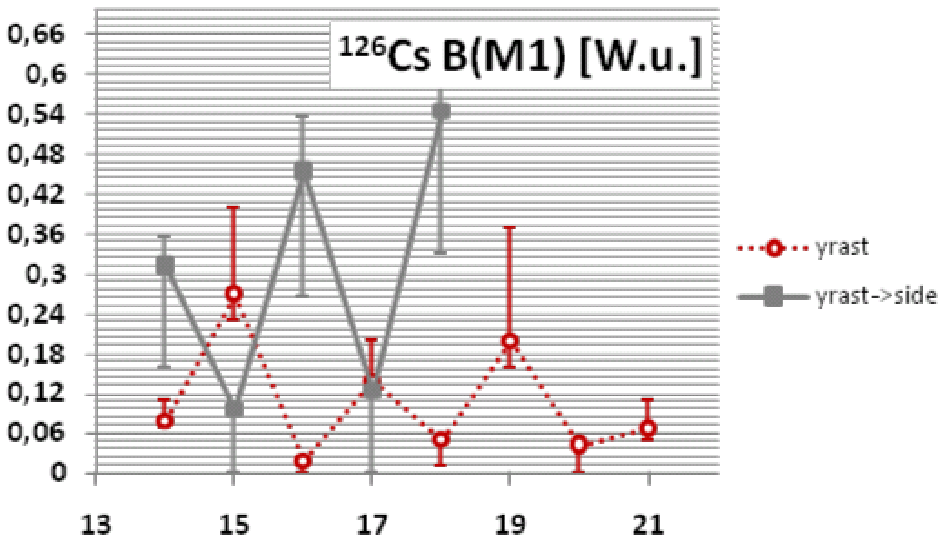
T. Koike et al.,
Phys. Rev. Lett. 93, 172502-1 (2004)

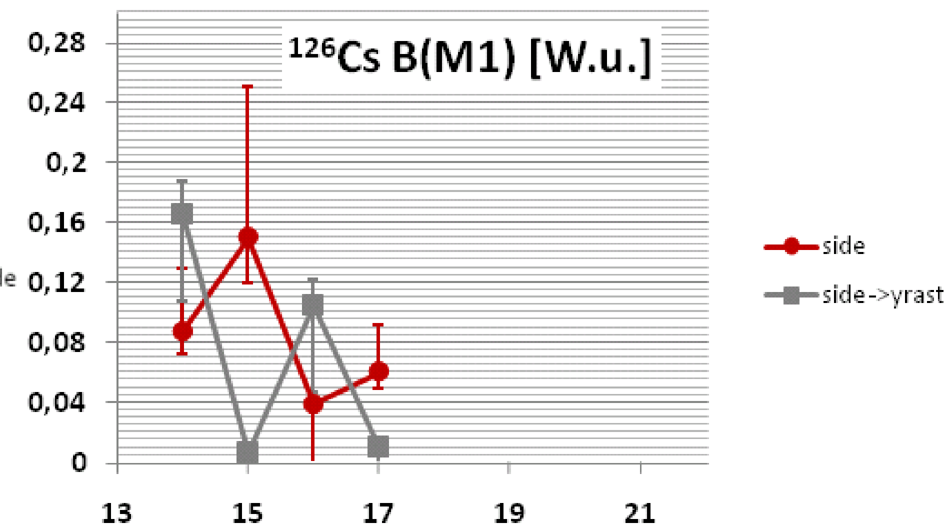
Yrast -> side transitions not observed



Transition probabilities ^{126}Cs

B(E2) transition probabilities similar in both bands
B(M1) transition probabilities similar in both bands
B(M1) staggering observed for M1 **inband** transitions
B(M1) staggering observed for M1 **interband** transitions
in both directions: **side->yrast & yrast ->side**
Interband B(M1) staggering has an opposite phase to the inband one

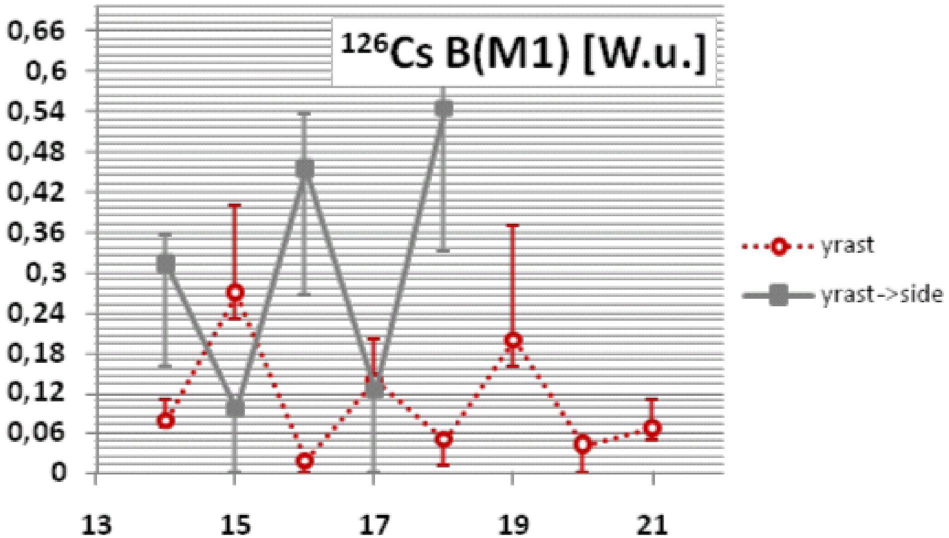


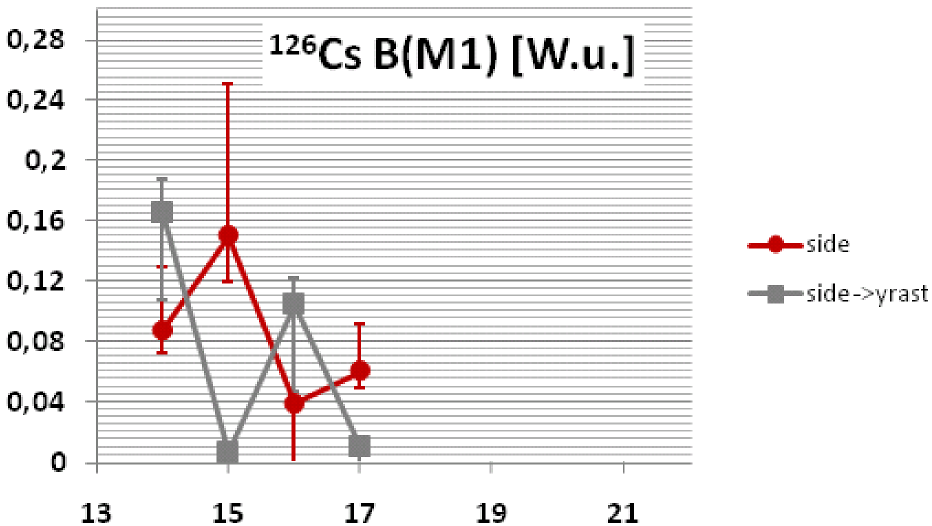


Transition probabilities ^{126}Cs

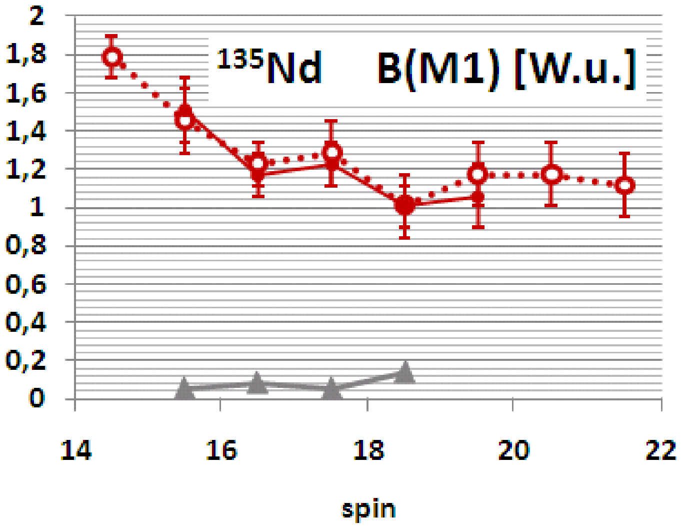
First experimental confirmation of the full set of chiral electromagnetic selection rules

Well separated left- and right-handed states
Strong triaxial deformation
Angular mommentum vectors mutually perpendicular
Partner bands built on 2qp single-j shell configuration





Chirality vs. Structural composition



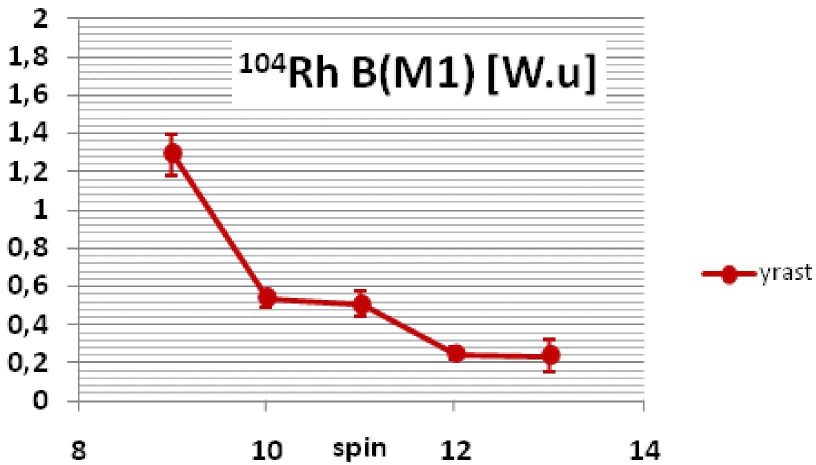
3qp configuration

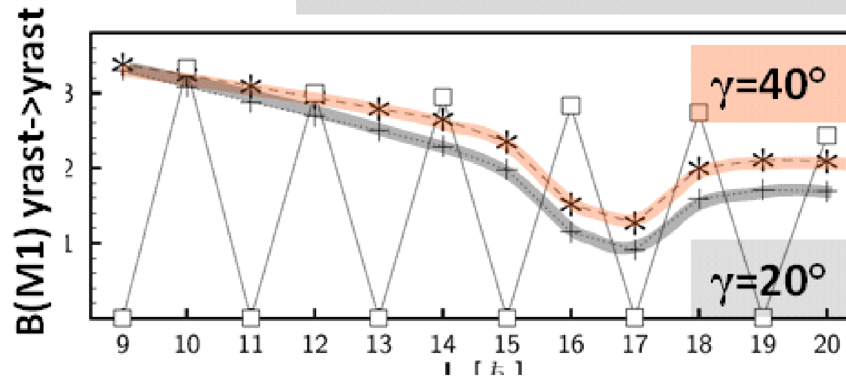
$$(\pi h_{11/2})^2 \otimes \nu h_{11/2}$$

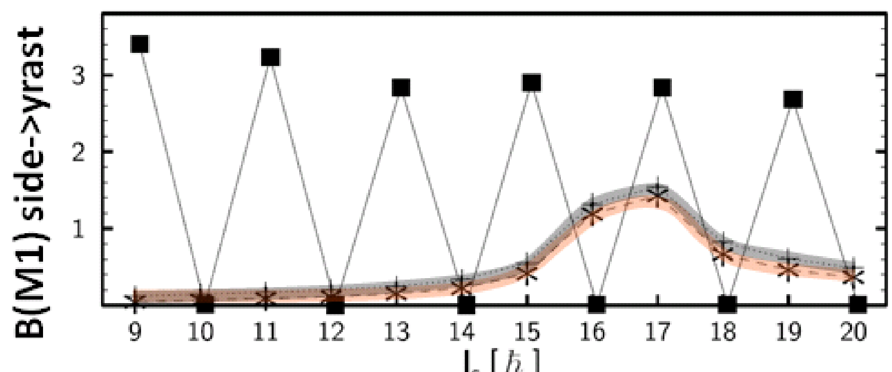
Single-j configuration
2qp configuration
Triaxiality γ=30°

Nonaxial deformation

$$\pi h_{11/2} \otimes \nu h_{11/2}$$



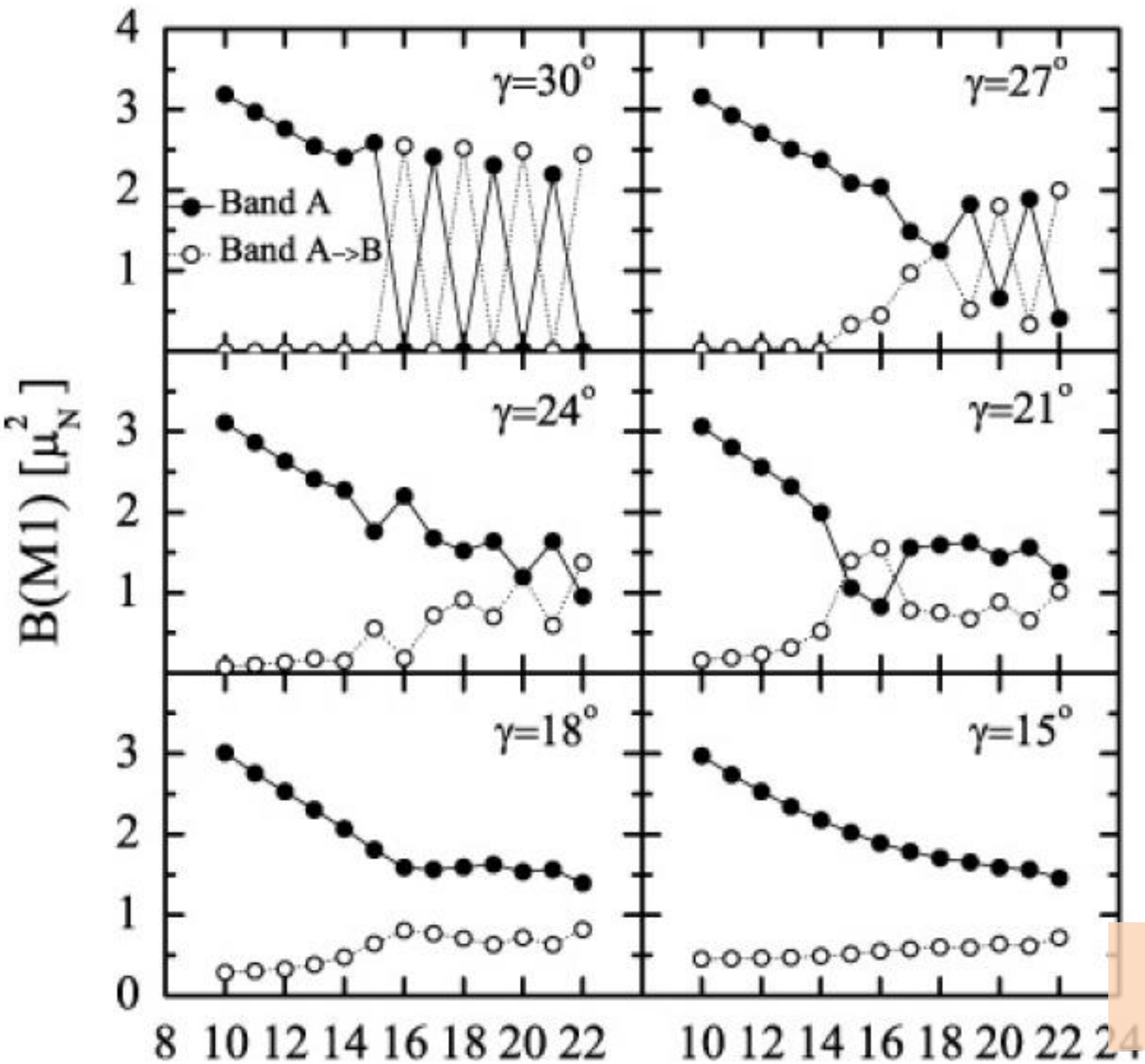




Different-j shell configuration

$$\pi g_{9/2} \otimes \nu h_{11/2}$$

Particle-Rotor Calculations



B. Qi et al.,
Phys. Rev. C79 (2009) 041302(R)

Conclusion

FIRST EXPERIMENTAL CONFIRMATION OF COMPLETE SET OF CHIRAL GAMMA SEL. RULES

Transition probabilities similar in both bands
Inband B(M1) staggering observed
Interband B(M1) staggering with opposite phase observed

^{126}CS

TWO GENERAL FEATURES OF GAMMA TRANSITION PROBABILITIES

CHIRALITY

Similar electromagnetic properties of both of the bands
Inband transition strong=>interband weak (vice-versa)

Characteristic B(M1) staggerings

STRUCTURAL COMPOSITION

NEW TERM

To distinguish the nuclear phenomenon
from the one in theory of fundamental interactions

SPIN-CHIRALITY

Collaboration

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