"Spontaneous symmetry breaking in nuclear physics"

20-lecie badań zjawiska chiralnosci w jadrach atomowych

XXIV NPW Kazimierz Dolny 20-23 IX 2017

Julian Srebrny 23 listopada 2017 Seminarium Fizyki Jądrowej

Katedra Fizyki Teoretycznej
UMCS Lublin

Środowiskowe Laboratorium
Ciężkich Jonów UW

XXIV Nuclear Physics Workshop Kazimierz Dolny 20-23 IX 2017

The general subject of the Workshop this year is:
"Spontaneous symmetry breaking in nuclear physics"

The special session will be devoted to **the 20th anniversary of the research of spontaneous chiral symmetry breaking** in nuclear structure physics started by the paper
Stefan Frauendorf and Jie Meng Nucl. Phys. A 617, 131 (**1997**)

It includes also all aspects of nonaxiality in nuclear shapes and Time reversal spontanous symmetry breaking.

北京大學 PEKING UNIVERSITY

I. September 14 to 20, 2003, workshop on symmetries of the rotating mean field, ECT* in Trento (www.ect.it).

II. September 22 to 26, 2010, XVII Nuclear Physics Workshop Marie and Pierre Curie on Symmetry and symmetry breaking in nuclear physics, Kazimierz Dolny, Poland.

III. October 27 to 30, 2013, The Seventh International Symposium on Chiral Symmetry in Hadrons and Nuclei, Beijing, China

IV. April 20 to 22, 2015, workshop on Chiral Bands in Nuclei, Nordita, Stockholm, Sweden.

V. September 20 to 24, 2017, XXIV Nuclear Physics Workshop "Marie & Pierre Curie" Kazimierz Dolny, Poland.

VI. …

http://kft.umcs.lublin.pl/wfj/2017/index.php/program/

ok. 60 uczestników

ORGANIZING COMMITTEE:

- Andrzej Baran
- Artur Dobrowolski
- Jerzy Dudek
- Andrzej Góźdź
- Marek Góźdź
- Jerzy Kraśkiewicz
- Krzysztof Pomorski
- Julian Srebrny (Co-Chairman, HIL UW)
- Michał Warda (Co-Chairman)
- Anna Wielgus
- Krystyna Zając
- Anna Zdeb

Breaking of the symmetry

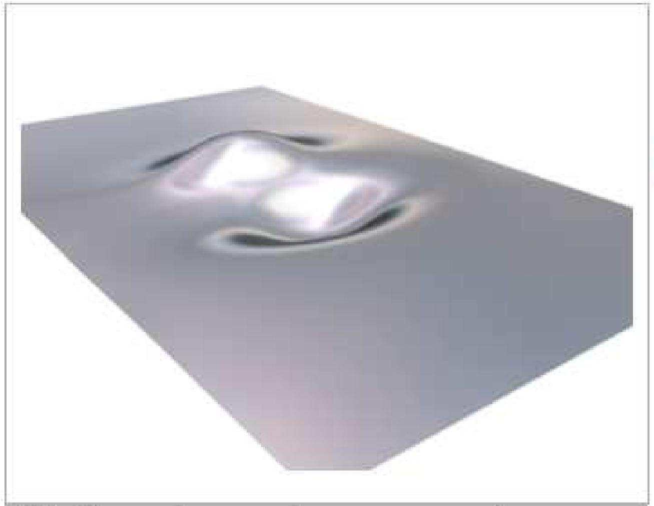
BROKEN SYMMETRY | **SYMMETRY CONSERVED**

Defined position (localized)

Defined momentum

Translational symmetry

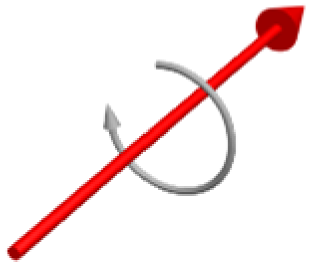
Defined orientation (localized)



Defined angular momentum

Rotational symmetry

CHIRALNOŚĆ JĄDROWA

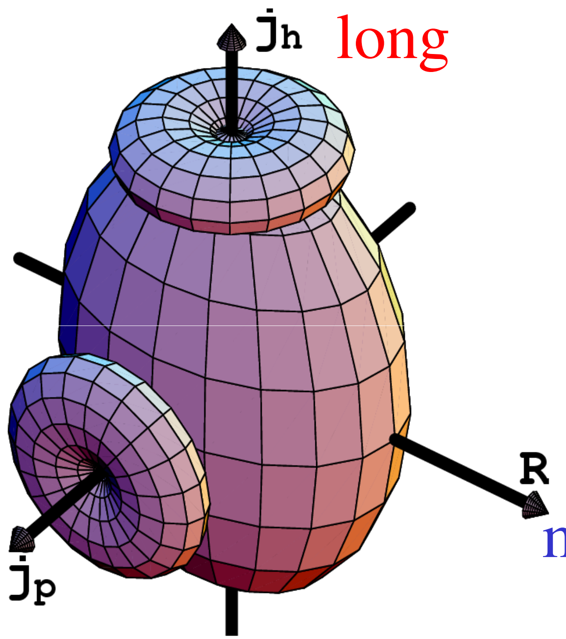
T |  > = |  >

Kluczowy wektor momentu pędu.

Odwracanie czasu zamienia wektor momentu pędu na przeciwny.

Combination of unpaired quasiparticles with Collective Triaxial Rotor

three dimensional(aplanar)

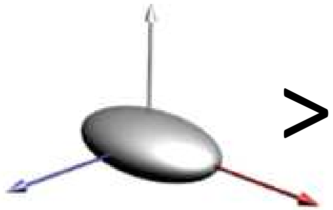
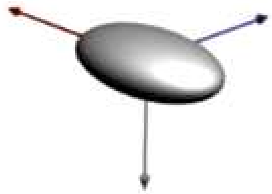
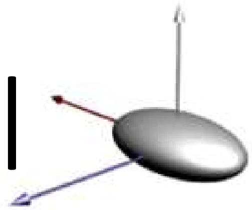


$\Theta_m > \Theta_s > \Theta_l$

typical case	$^{128}_{55}Cs_{73}$
rotor	$^{128}_{54}Xe_{74}$
low and high	$h_{11/2}$
proton particle	neutron hole

inne nasze: ^{126}Cs, ^{124} Cs

UKŁAD |L>, |R>

$R_Y T$ |  > = R_Y |  > = |  >

R_Y obrot o 2π wokół osi Y

T time reversal

$R_Y T$ | L > = I R >

$R_Y T$ | R > = I L >

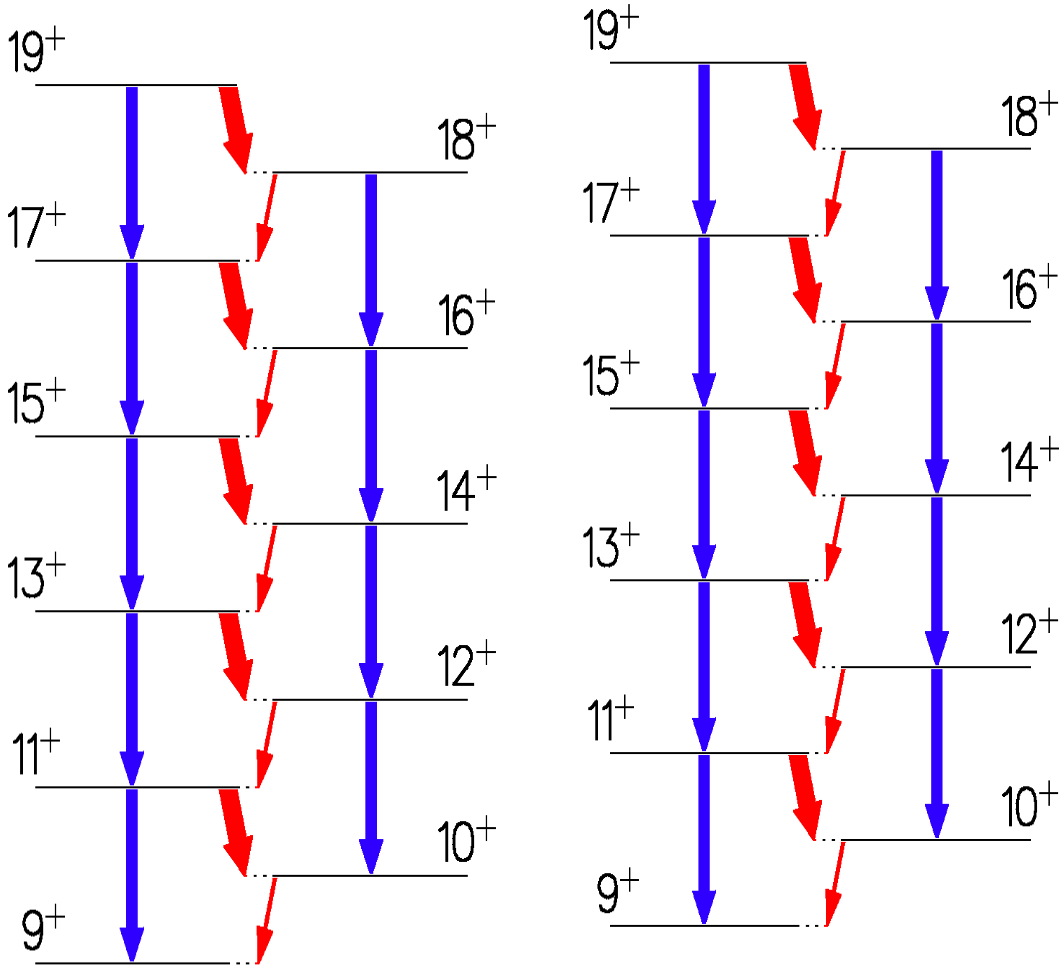
Jądro atomowe stygnie
i spontanicznie tworzy układ:
lewoskrętny |L> *lub*
prawoskrętny |R>

Przywracamy symetrie przez znalezienie dobrych funkcji własnych

$R_Y T$ (I L > + I R >) = (I L > + I R >)

$R_Y T$ (I L > - I R >) = c (I L > - I R >)

OCZEKIWANE WŁASNOŚCI



pasmo +

I L > + I R >

pasmo -

I L > - I R >

Dublety poziomów.

Ta sama parzystość.

Ten sam spin.

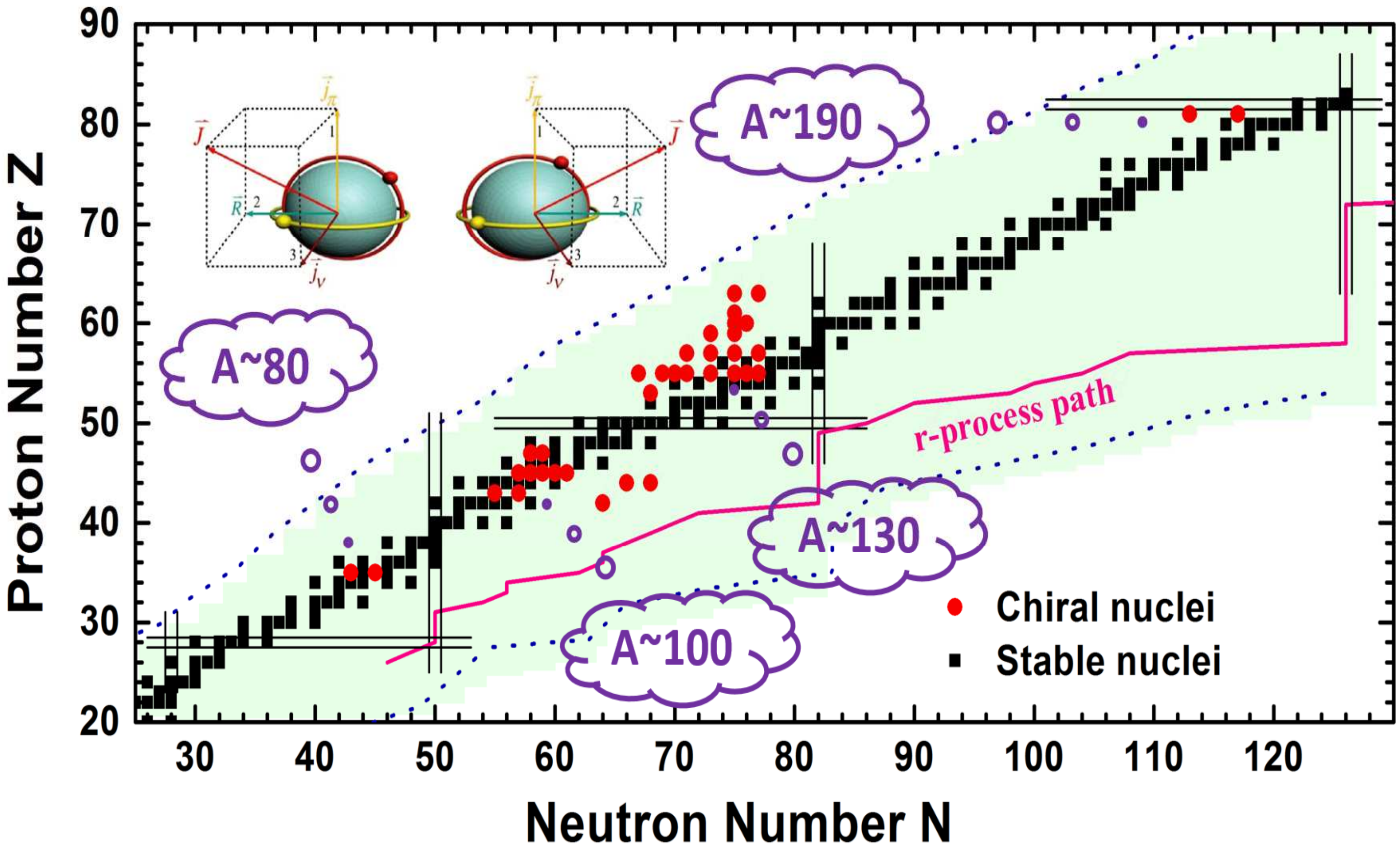
Dwa pasma rotacyjne.

Podobne B(E2).

Charakterystyczne B(M1).

Chiral nuclei observed

- **So far, more than 30 candidate have been reported in the A~80, 100, 130, and 190 mass regions. 【 Meng and Zhang2010JPG 】**
- **MχD predicted in 2006 is experimentally observed in 2013**



Spontaniczne łamanie symetrii chiralnej,

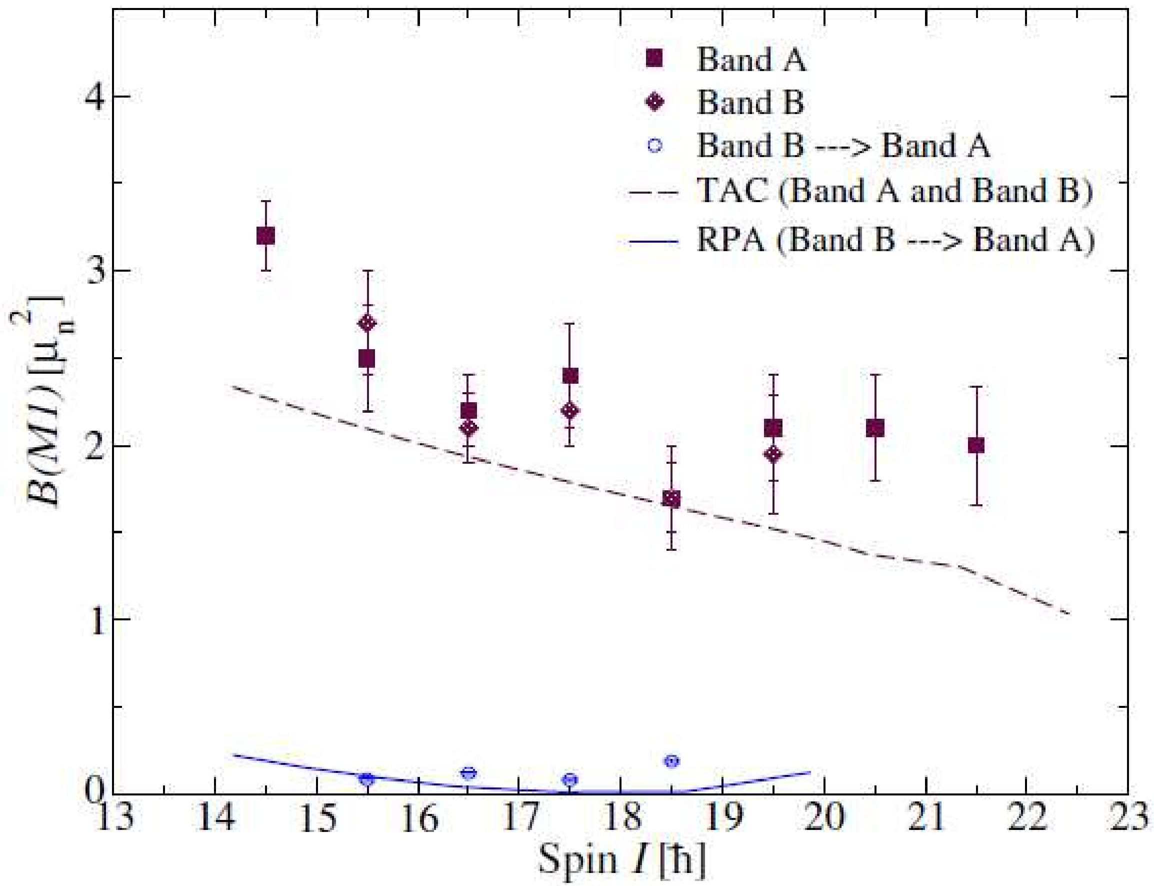
fundamentalne naruszenie symetrii T , Chiral QCD i nukleony

Stefan Frauendorf
Jie Meng
Costel Petrache
Kris Starosta
Ernest Grodner
Elena Lurie

Paweł Moskal *Experimental studies of time reversal symmetry breaking in decays of mesons and positronium atoms*

Evgeny Epelbaum QCD *chiral symmetry and nuclear physics* n-p, p-p scattering

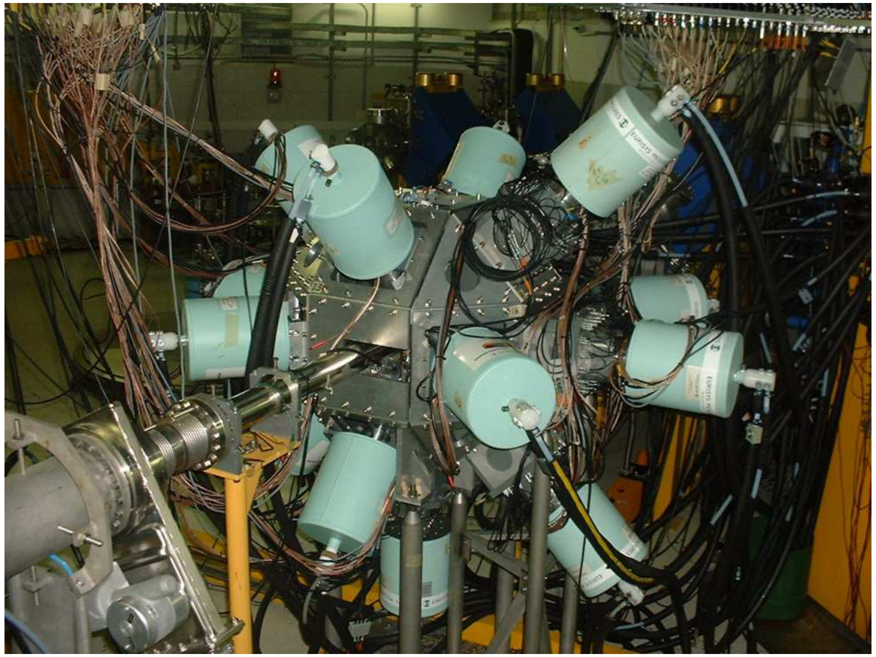
Krzysztof Pomorski, Andrzej Góźdź, Jerzy Dudek,…..



GAMMASPHERE
ATLAS- Argone NL
Notre Dame
S. Frauendorf; U. Garg

FIG. 2 (color online). Evolution of the $B(M1)$ transition rates with spin for the two chiral partner bands in ^{135}Nd. A comparison with the calculations described in the text is shown as well.

Studying the Tl isotopes:
^{194}Tl DSAM lifetimes



AFRODITE array at iThemba LABS, South Africa

9 HpGe clover detectors (7 cm x ∅5 cm),

Compton suppressed with BGO shields

efficiency of 1.8% at 1.3 MeV

8 HpGe LEPS detectors (1 cm x ∅ 6 cm)

^{181}Ta(^{18}O,5n)^{194}Tl at energy E(^{18}O)=92 MeV

Target: ^{181}Ta foil of 1mg/cm^{2,} onto thick backing of Bi, initial recoil velocity of v/c ~ 0.9 %

Beam time → 3 weekends for experiment A and B respectively

DSAM analysis – using the programs COMPA, GAMMA and SHAPE (analysis led by Prof. A. Pasternak)

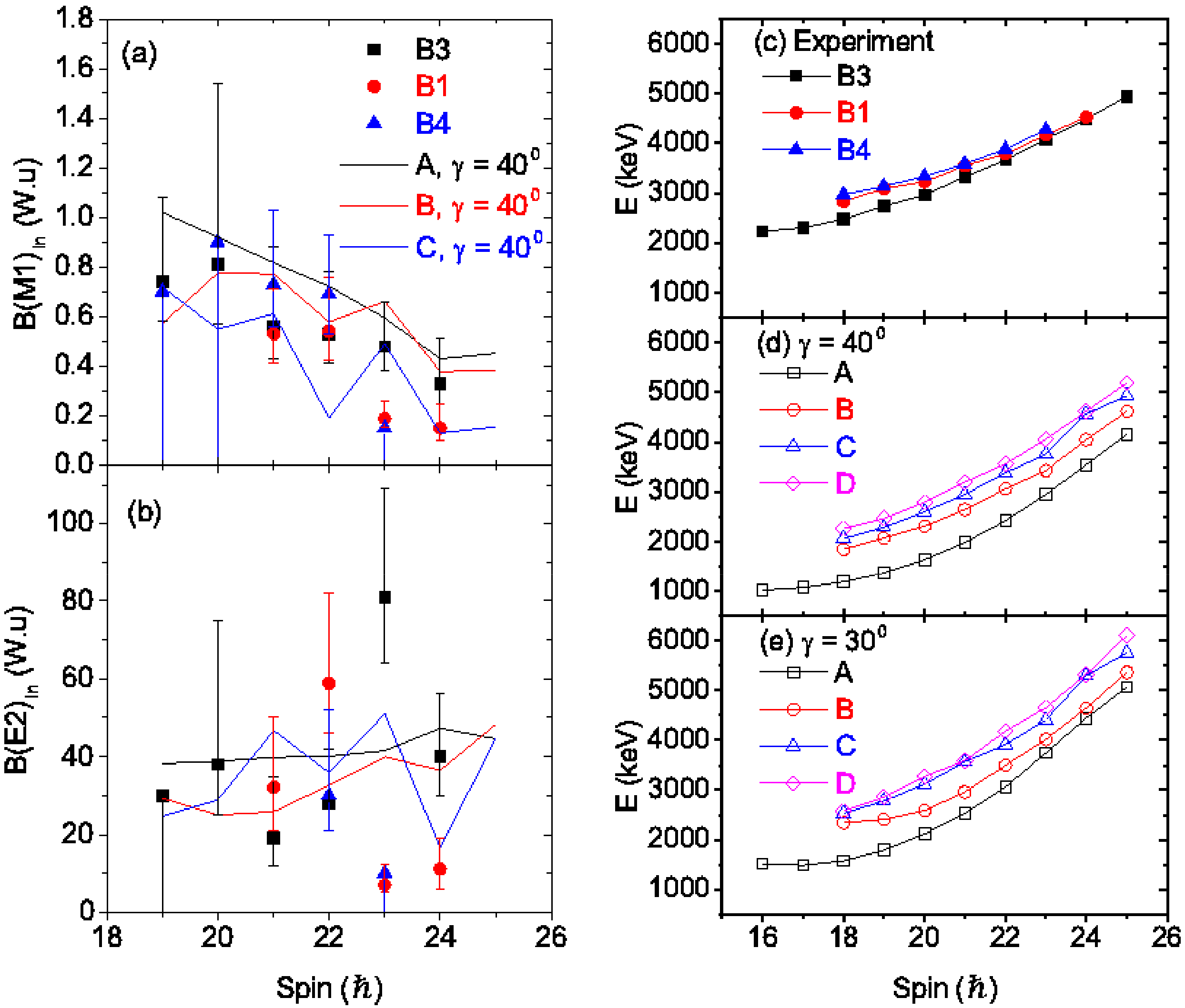
Monte-Carlo methods to simulate the entry states in ^{194}Tl and the decay (statistical decay, superdeformed bands, stretched M1 bands, known discrete levels)

The lifetimes are extracted step by step starting with the highest-energy level of a band.

Multi-particle Rotor Model calculations for the $\pi h_{9/2} \times \nu i_{13/2}^{-3}$ bands

Exp:
Chiral pair
B1 and B4

Third band
B3



(C,D) yrare chiral pair

(A,B) yrast chiral pair

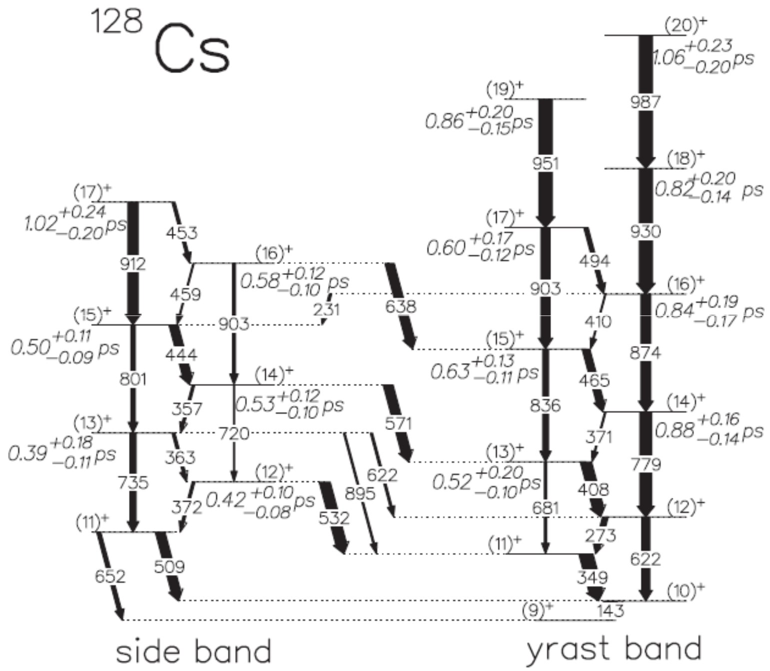
Non-chiral to chiral phase transition in ^{128}Cs based on magnetic moment measurements.

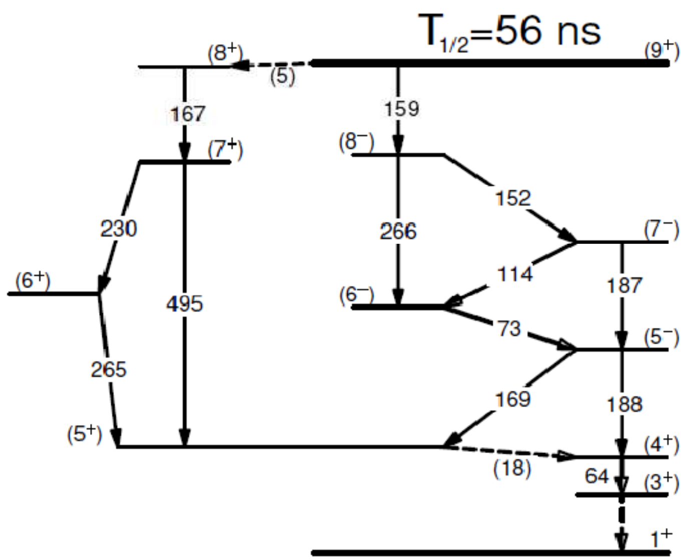
Ernest Grodner NCBJ

HIL (POLAND) LNL INFN (ITALY) BEIHANG (CHINA)
ORSAY (FRACNE) NIPNE (ROMANIA) NCBJ (POLAND)

First measurement of the *g*-factor in the chiral band: the case of the ^{128}Cs isomeric state

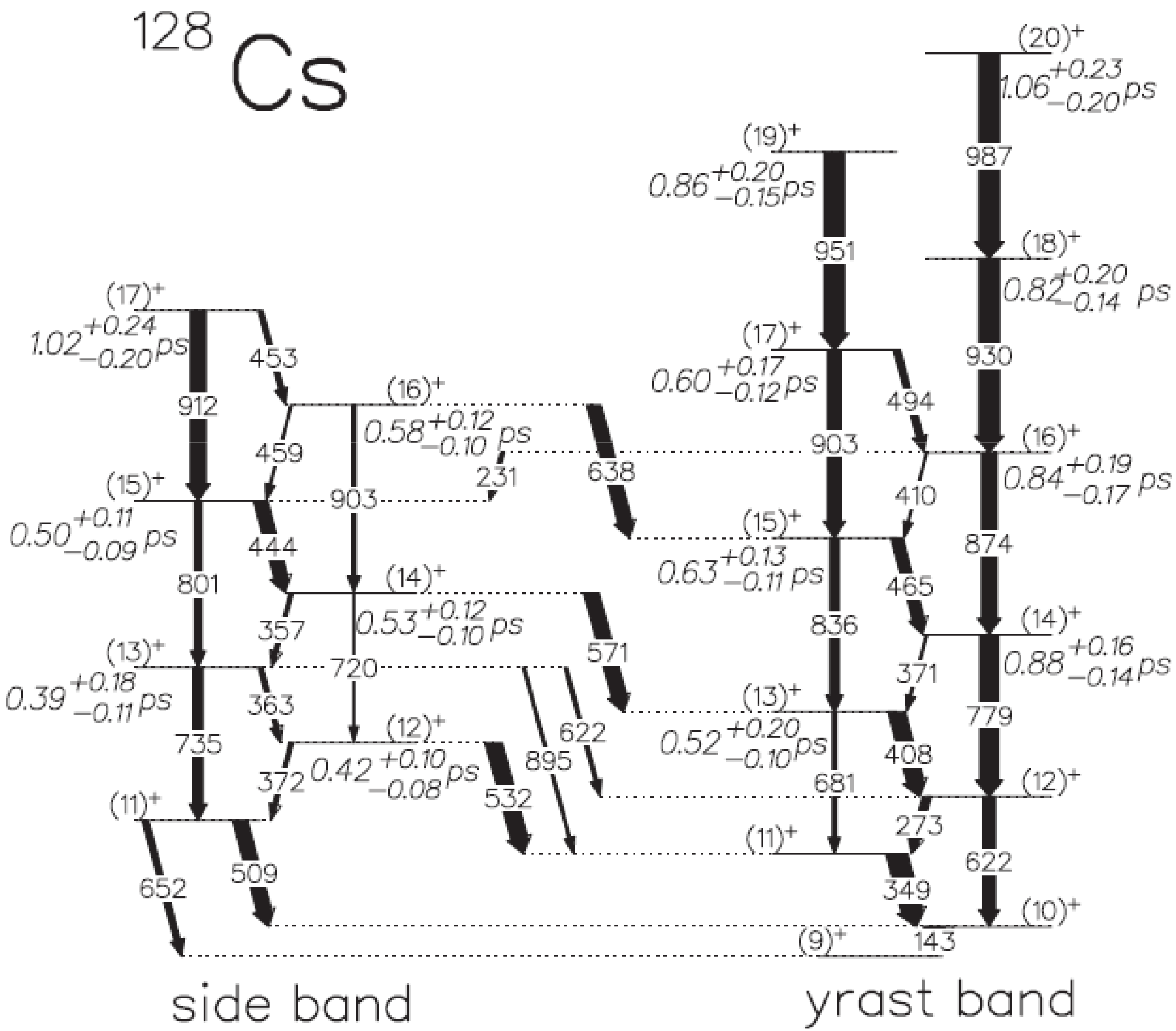
E. Grodner,[1,2] J. Srebrny,[3] Ch. Droste,[2] L. Próchniak,[3] S.G. Rohoziński,[2] M. Kowalczyk,[3] M. Ionescu-Bujor,[4]





Time-Dependent Perturbated Angular Distribution TDPAC g= +0.59(1)

Chiral g=0.51 planar g= 0.60 where is phase transition ?

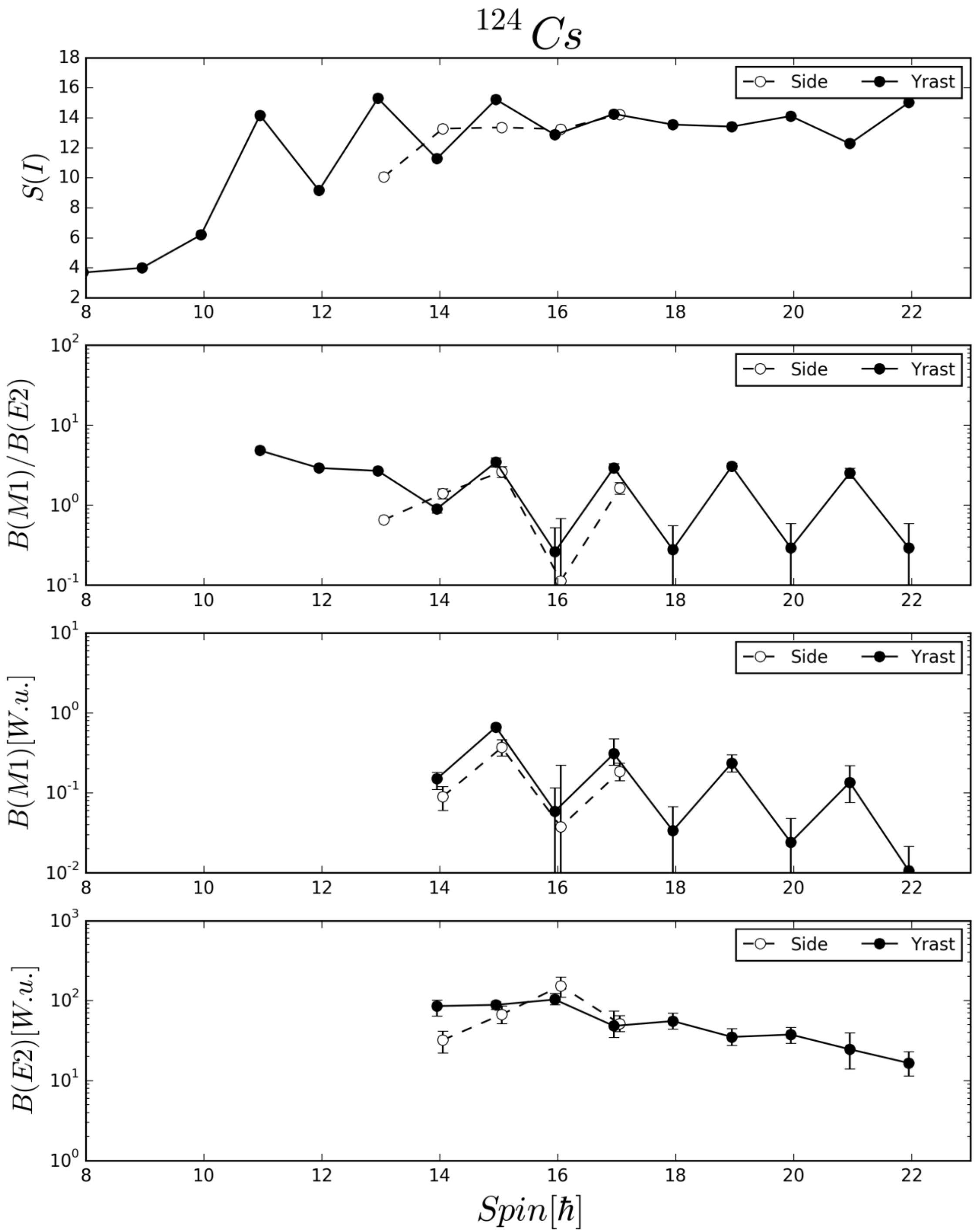


chiral

phase transition ?

planar

Tomasz Marchlewski



Challenges

- Clear signal for chirality in EM transitions
- Identify chiral sisters with longer legs (2qp+2qh)
- Neutron-rich region around ^{114}Ru
- Find chiral bands at high spin – "strongly deformed triaxial nuclei" around A=163
- Interpretation of TPSM (chiral sisters vs. qp. configurations)
- Dynamics of γ degree of freedom (BH vs. TPSM, effective rotor)

Spontaniczne łamanie symetrii chiralnej,
fundamentalne naruszenie symetrii T , Chiral QCD i nukleony

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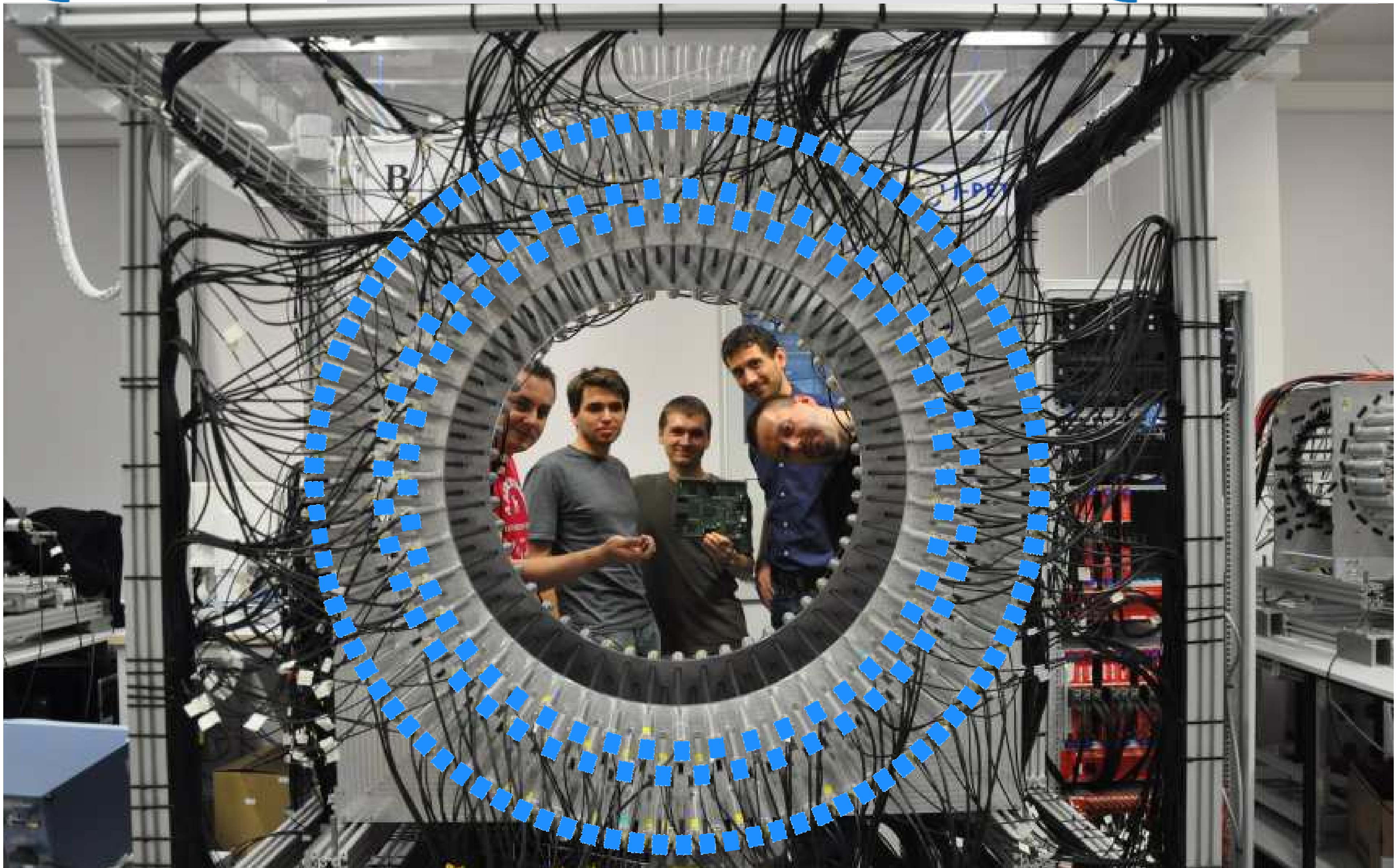
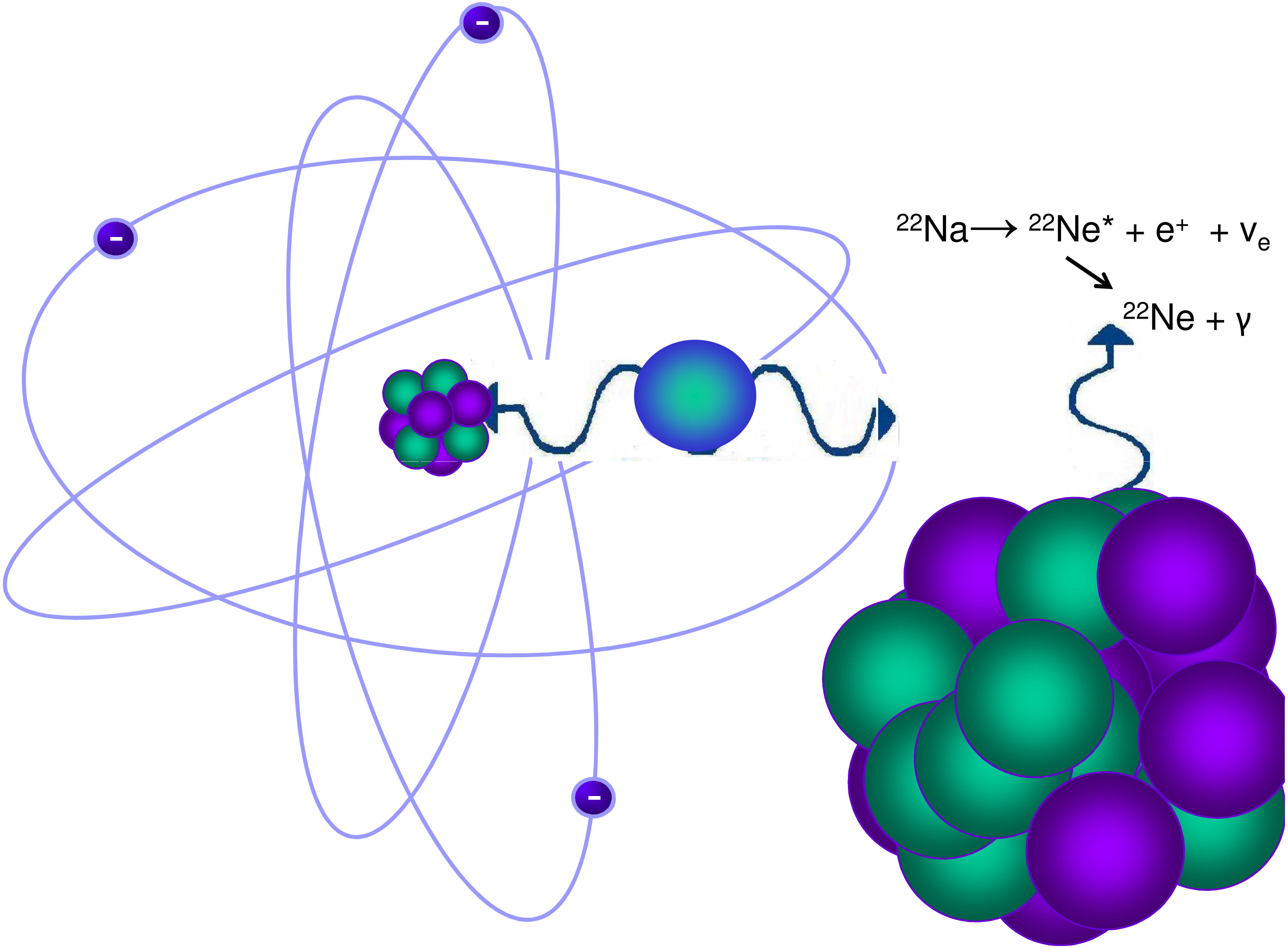
J-PET

Jagiellonian PET

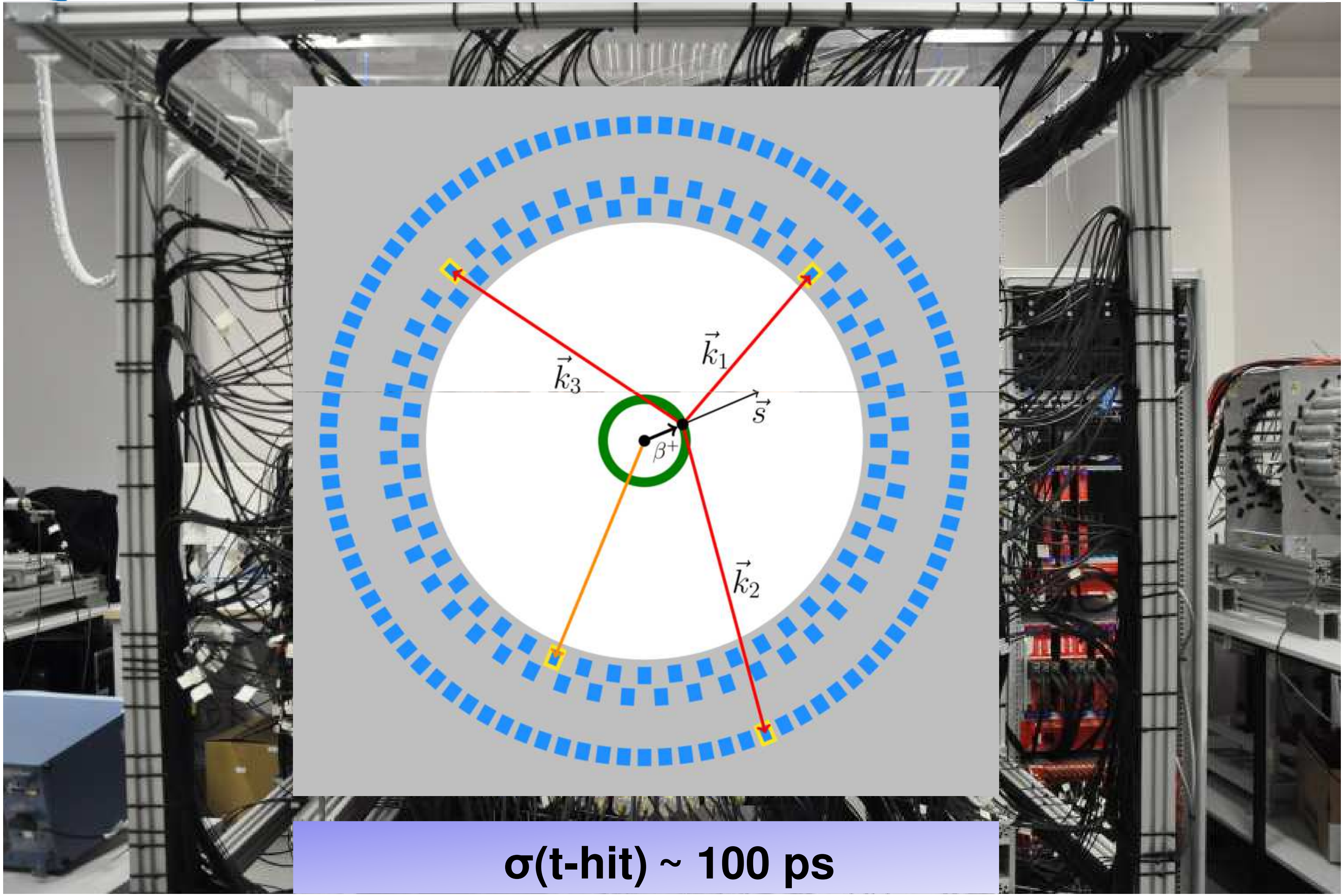
J-PET



AFOV: 50 cm ; TOF < 500 ps (FWHM)


$^{22}Na \longrightarrow {}^{22}Ne^{*} + e^{+} + \nu_e$
$^{22}Ne + \gamma$

J-PET Jagiellonian PET J-PET



σ(t-hit) ~ 100 ps

P. Moskal et al., Acta Phys. Polon. B 47, 509 (2016

Naruszenie symetrii CPT z pomiaru rozpadu ortopozytronium

- czas zycia pozwala wyroznic
  ortopozytronium - 140 ns, parapozytronium– 0.125 ns
- uklad orto rozpada sie na 3 kwanty gamma .
- dobrze zmierzone katy tych rozpadow moga dawac korelacje lub antykorelacje z kierunkiem spinu ortopozytonium (jest wyznaczony z kierunku lotu pozytonu)

I ta roznica moze byc czule zmierzona i dac wynik na zachowanie lub nie zachowanie CPT lepszy niz dotychczas zmierzony w 2003 - CPT = 0.0071(62)

Pawel Moskal szacuje, ze w rok pomiaru moze uda się zwiekszyc dokładnosć az do $10^{-5.}$

Rich experimental data on ^{119}I :
γ - soft or γ-rigid and possible wobbling

Julian Srebrny, HIL UW

XXIV Nuclear Physics Workshop Kazimierz Dolny 2017

20-th anniversary of chirality in nuclear structure physics

Transition probabilities in negative parity bands of the ^{119}I nucleus

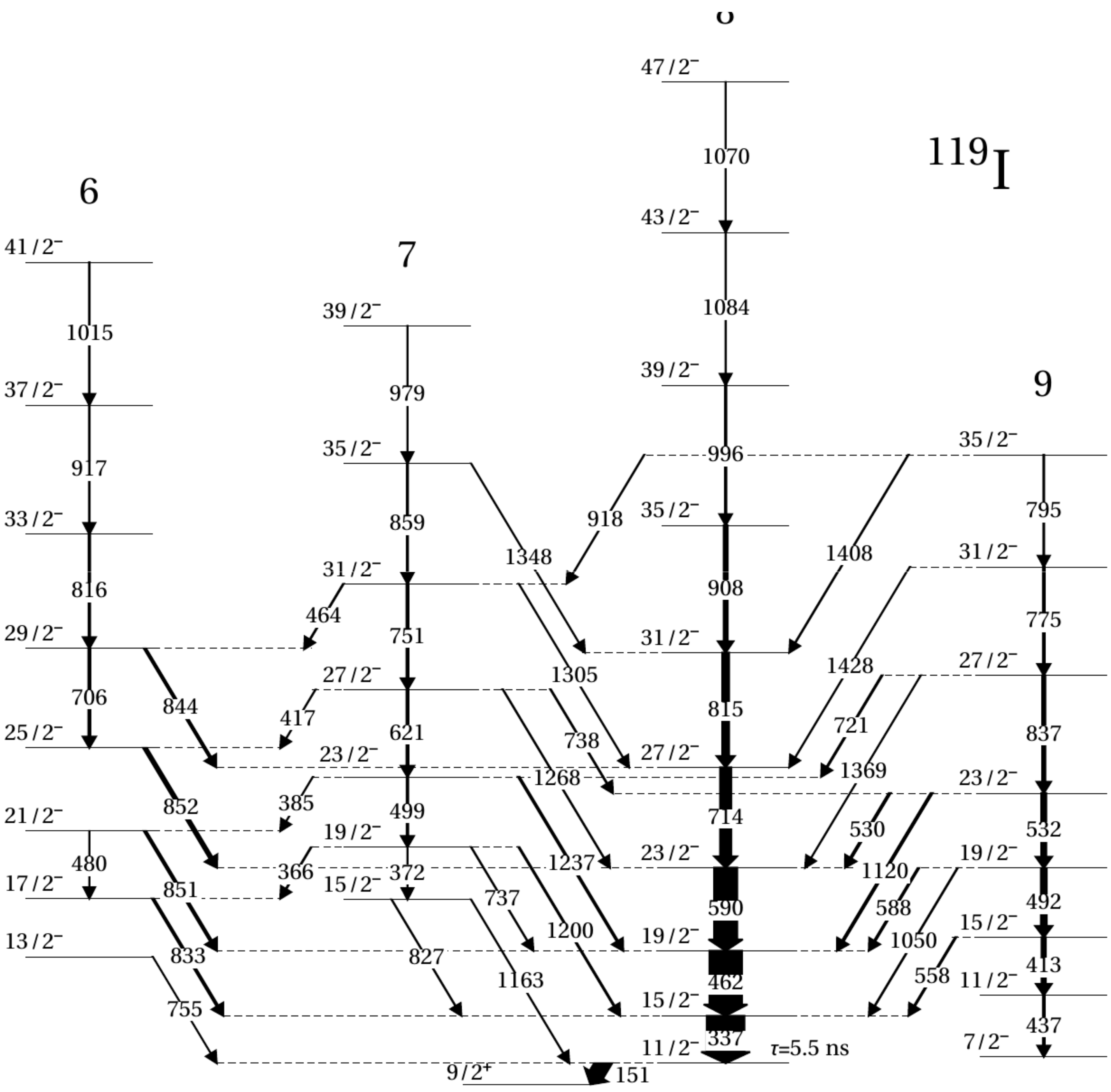
4 negative parity bands $\pi\ (h_{11/2})$

from 31 measured lifetimes, 39 values of *B*(E2) were established,
the reachest lifetime information

TAL NBI NORDBALL M. Piiparinen PLUNGER
Recoil Distanse Doppler Shift Attenuation Methods and DSAM

^{109}Ag(^{13}C,3n)^{119}I E(^{13}C) = 54 MeV

J. Srebrny , Ch. Droste , T. Morek, K. Starosta, A.A. Wasilewski,
A.A. Pasternak , E.O. Podsvirova , Yu.N. Lobach , G.H. Hagemann ,
S. Juutinen , M. Piiparinen , S. Törmänen, A. Virtanen
Nuclear Physics A 683 (2001) 21–47



119I
6
7
8
9
47/2⁻
43/2⁻
41/2⁻
39/2⁻
37/2⁻
35/2⁻
33/2⁻
31/2⁻
29/2⁻
27/2⁻
25/2⁻
23/2⁻
21/2⁻
19/2⁻
17/2⁻
15/2⁻
13/2⁻
11/2⁻
9/2⁺
7/2⁻
1070
1084
996
908
815
714
590
462
337
1015
917
816
706
480
979
859
751
621
499
372
795
775
837
532
492
413
437
918
1348
1305
1268
1237
1200
1163
737
827
1408
1428
1369
1120
1050
721
530
588
558
464
417
385
366
844
852
851
833
755
738
151
τ=5.5 ns

Phenomenological way of testing features of a quadrupole core by comparing various core models to the experimental results of odd-even nuclei - energy pattern and B(E2)

Core QusiParticle Coupling – CQPC

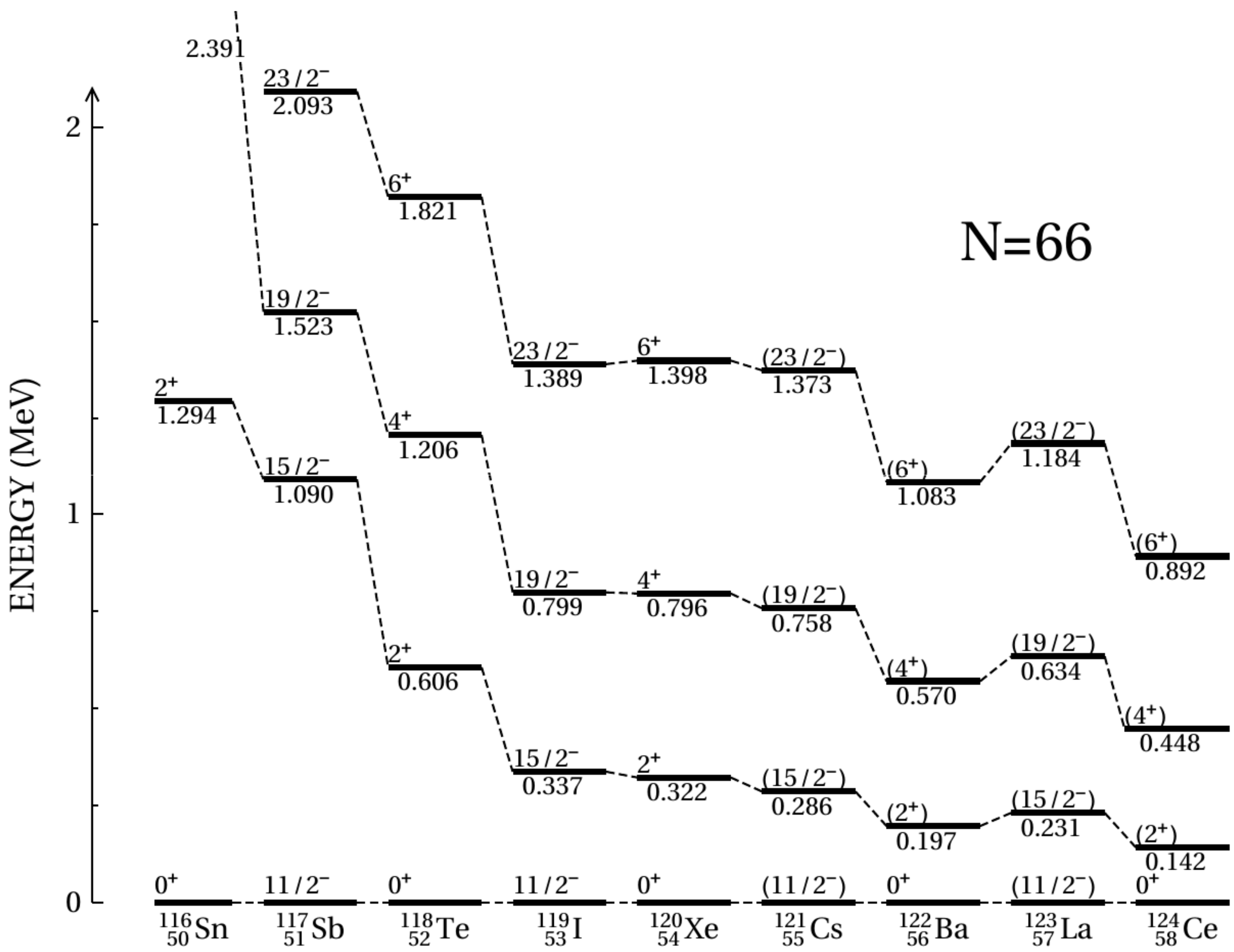
Qudrupole intereaction between collective core Q

and particle(quasiparticle) q with pairing included.

$$H = H_{sp} - \tfrac{1}{2}\ \chi\, Q \cdot q - \tfrac{1}{4}\, \Sigma G\, P^{\dagger} P$$

INPUT

1. Level energies and E2 matrix elements of the A-1 and A+1 cores model
   a) gamma-soft model
   b) gamma-rigid DF model



N=66
ENERGY (MeV)
0
1
2
2.391
0+
2+
1.294
116 50 Sn
11/2−
15/2−
1.090
19/2−
1.523
23/2−
2.093
117 51 Sb
0+
2+
0.606
4+
1.206
6+
1.821
118 52 Te
11/2−
15/2−
0.337
19/2−
0.799
23/2−
1.389
119 53 I
0+
2+
0.322
4+
0.796
6+
1.398
120 54 Xe
(11/2−)
(15/2−)
0.286
(19/2−)
0.758
(23/2−)
1.373
121 55 Cs
0+
(2+)
0.197
(4+)
0.570
(6+)
1.083
122 56 Ba
(11/2−)
(15/2−)
0.231
(19/2−)
0.634
(23/2−)
1.184
123 57 La
0+
(2+)
0.142
(4+)
0.448
(6+)
0.892
124 58 Ce

The γ-soft core of the ^{119}I nucleus – ^{120}Xe

Wilets–Jean model [Phys. Rev. 102 (1956) 788] in the extended version
J. Dobaczewski, S.G. Rohozinski, J. Srebrny, Z. Phys. A 282 (1977) 203

The following approximations were made:

(a) the rotational inertial functions $Bx = By = Bz = B\gamma\gamma = B =$ const,

(b) the vibrational inertial functions $B_{\beta\beta}$ = const, $B_{\beta\gamma} = 0$,

(c) the potential energy surface (PES) gamma-independent

$$V(\beta) = \tfrac{1}{2} C_2 \beta^2 + C_8 \beta^8 + G[\exp(-\beta^2/\alpha^2) - 1]$$

to obtain better agreement with the experimental B(E2) values in ^{120}Xe as well as in ^{119}I
a large value of C_8 was introduced: $C_2 = 0.01$ MeV, $C_8 = 1.5\text{x}10^4$ MeV,

equilibrium deformation $\boldsymbol{\beta_0} = 0.276$, the depth of potential $\boldsymbol{D} = 7.6$MeV,
Inertial functions: $\boldsymbol{B} = 110\ h^2$/MeV, $\boldsymbol{B_{\beta\beta}} = 1000\ h^2$/MeV,

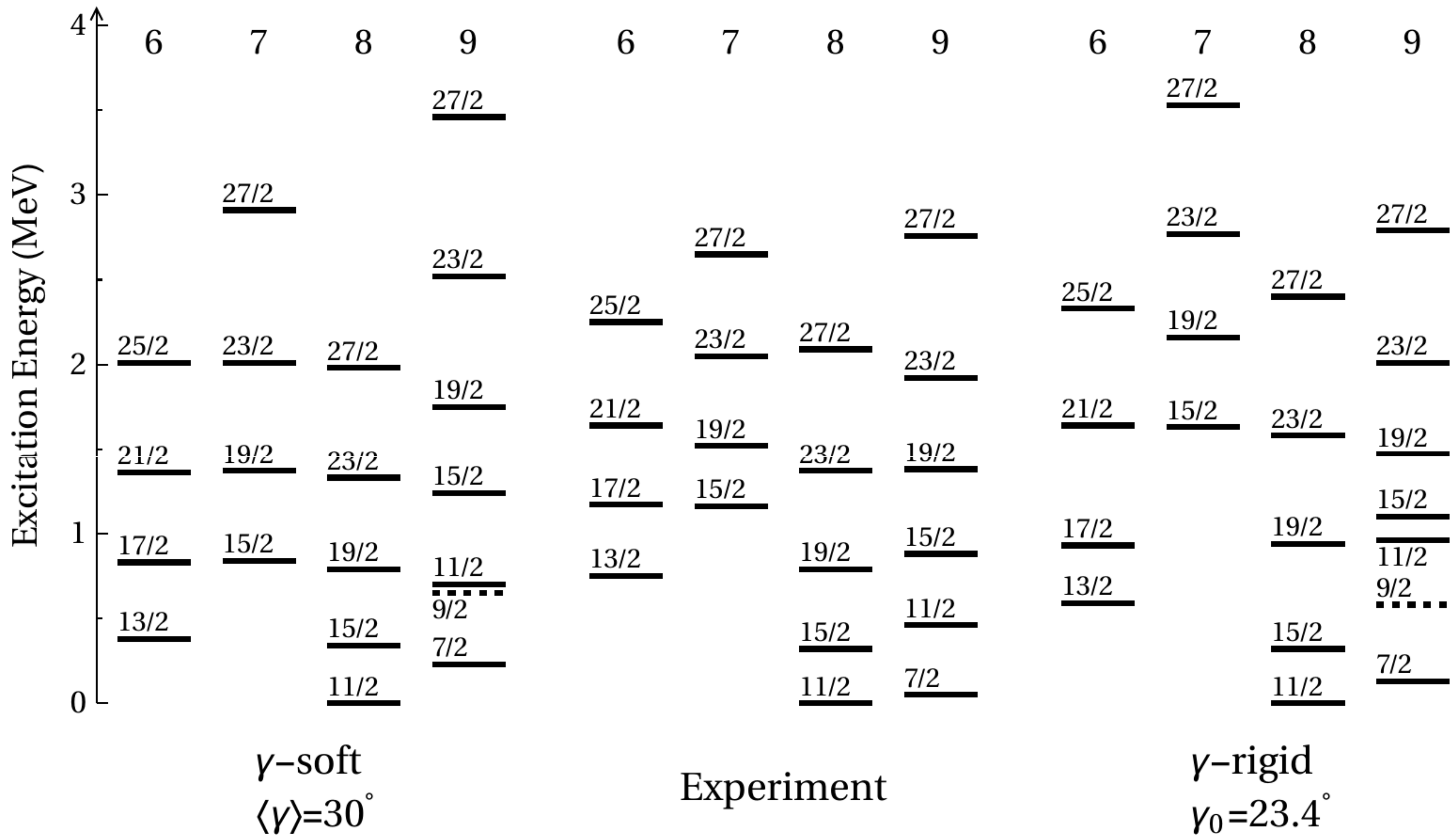
parameters for rigid cores

	DF-A	DF-B	DF-C
γ_0	23.4°	30°	37°
β_0	0.29	0.31	0.36
$E(2^+)$ (keV)	322.4	200	130

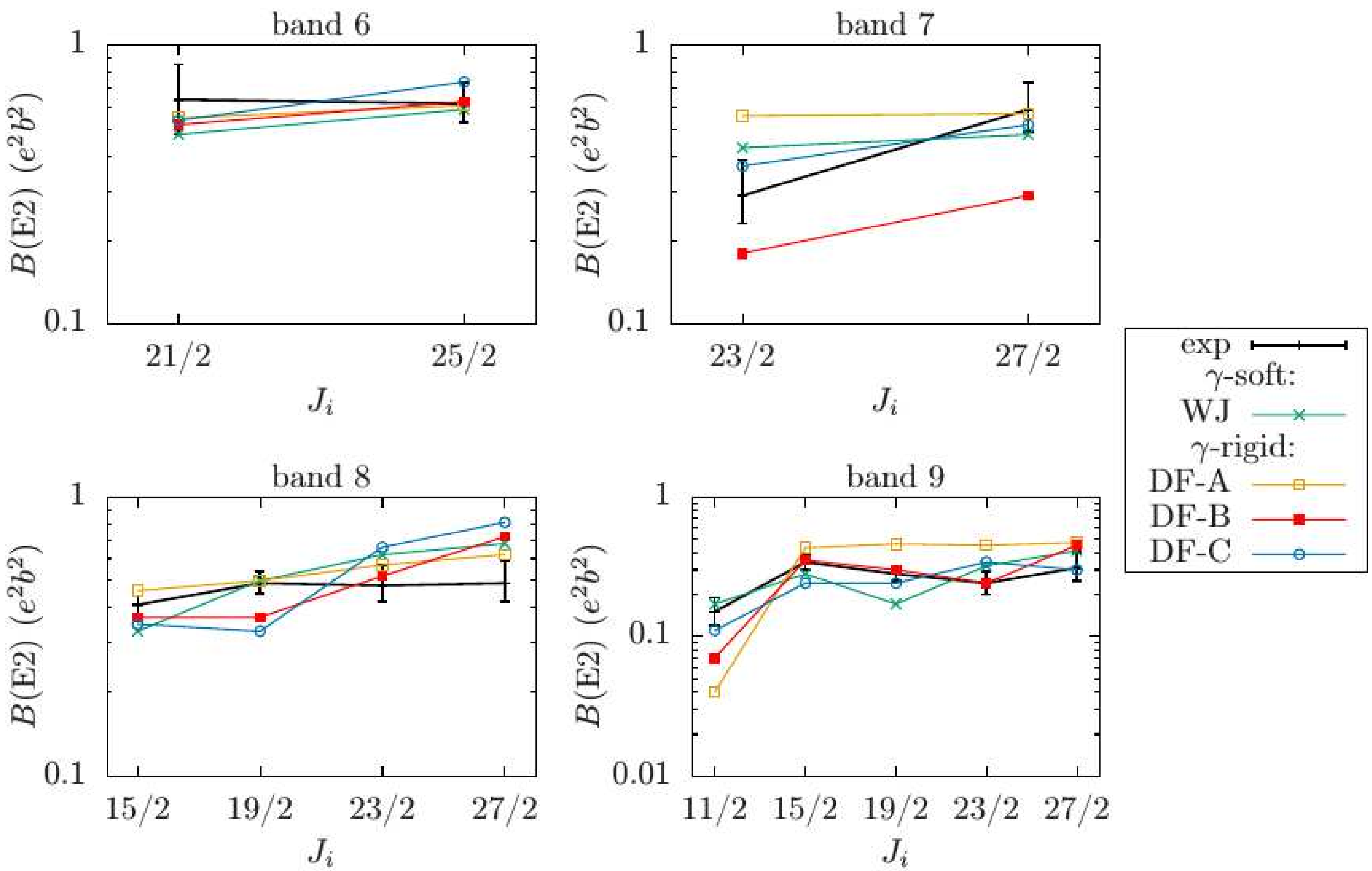
DF-A — the properties of the core taken from the experimental data of ^{120}Xe,

DF-B — γ_0 =30˚,corresponds to < γ > = 30˚ in the γ-soft core
the rest of the parameters were adjusted to reproduce ^{119}I

DF-C — all parameters were adjusted to reproduce the properties of ^{119}I,
particularly transition probabilities in band 9



Excitation Energy (MeV)
0
1
2
3
4
6
7
8
9
6
7
8
9
6
7
8
9
25/2
21/2
17/2
13/2
27/2
23/2
19/2
15/2
27/2
23/2
19/2
15/2
11/2
27/2
23/2
19/2
15/2
11/2
9/2
7/2
γ−soft
⟨γ⟩=30°
Experiment
25/2
21/2
17/2
13/2
27/2
23/2
19/2
15/2
27/2
23/2
19/2
15/2
11/2
27/2
23/2
19/2
15/2
11/2
7/2
γ−rigid
γ0=23.4°
25/2
21/2
17/2
13/2
27/2
23/2
19/2
15/2
27/2
23/2
19/2
15/2
11/2
27/2
23/2
19/2
15/2
11/2
9/2
7/2


band 6
band 7
band 8
band 9
B(E2) (e^2b^2)
J_i
1
0.1
0.01
21/2
25/2
23/2
27/2
15/2
19/2
11/2
exp
γ-soft:
WJ
γ-rigid:
DF-A
DF-B
DF-C

SUMMARY

I.

The lifetimes of 31 negative-parity levels were determined, 39 values of *B*(E2) . That is one of the largest set of electromagnetic transition probabilities for an odd-A nucleus from the 50 < *Z; N* < 82 region yet obtained.

III.

Level scheme and E2 transition probabilities for three bands – 8,7 and 6 **do not show big difference between γ– soft and γ-rigid interpretation.**

It indicates that at the first order approximation only < cos3γ> is important, not γ-softness or γ-ridigity.

IV.

The same as in the case of chiral structure with S-symmetry

Ch. Droste, S.G. Rohozinski, K. Starosta, L. Prochniak, and E. Grodner
Chiral bands in odd-odd nuclei with rigid or soft cores ***Eur. Phys. J. A 42, 79(2009)***

„ …. The results of calculations for the two different cores are compared. The properties of the nucleus with the rigid, maximally triaxial (γ= 30◦) and with the entirely γ-soft core are qualitatively very similar. … „