

Isomer Studies

with RI-beam Induced Fusion Reactions
and In-Flight Fission Reactions

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Isomer :

one of good probes to obtain information
for change of nuclear structure

ex. shape isomer :

caused by the sudden shape change

We apply isomer spectroscopy to study **shape evolution**.



as function of **spin** and **isospin**

How does nuclear **shape change**

by **increasing angular momentum**

and/or

by **increasing neutron or proton number?**

High-spin shape isomers in $N=83$ isotones

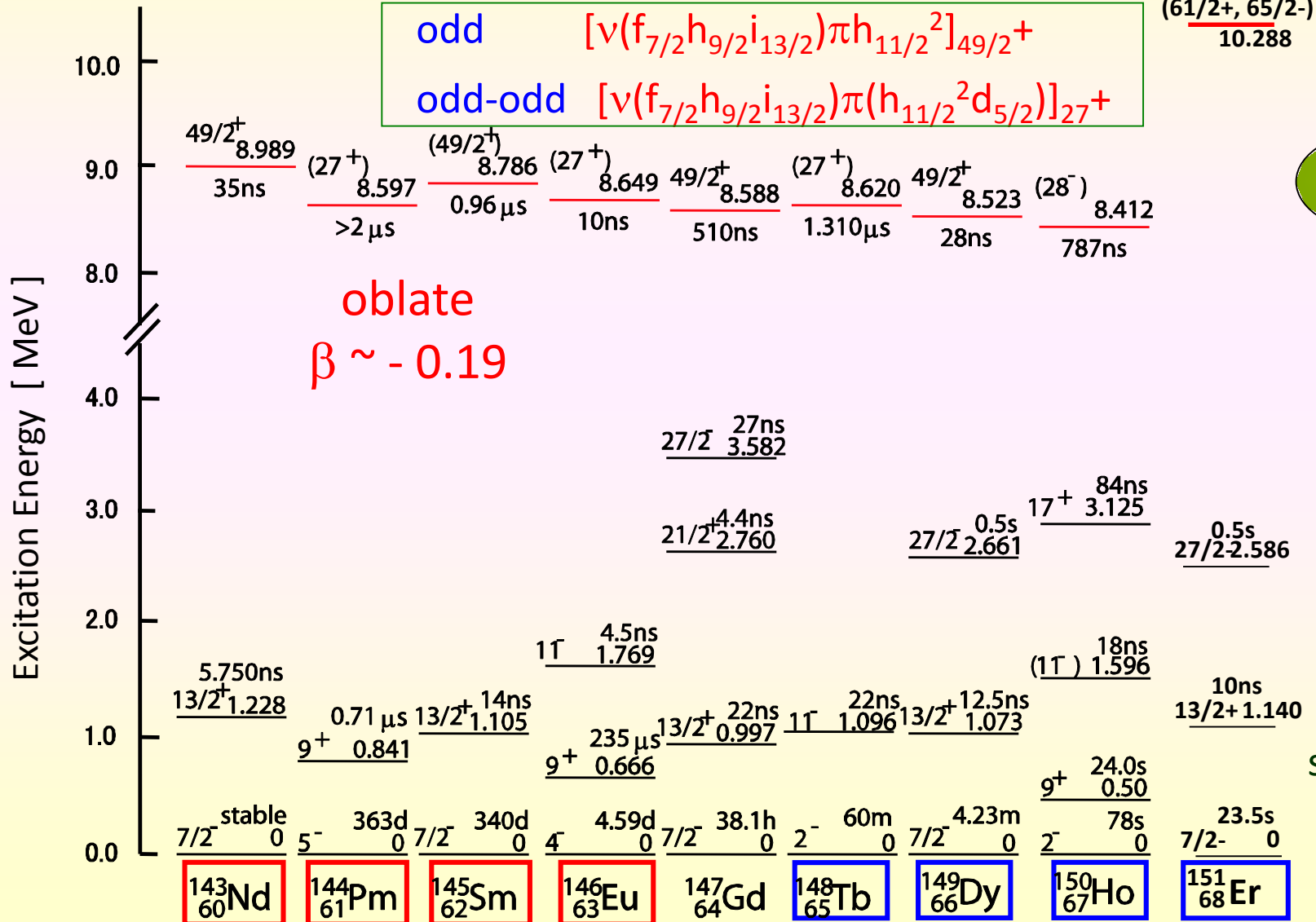
$$^{152}\text{Er} : [\nu(f_{7/2}h_{9/2}i_{13/2})\pi(h_{11/2}^4)]_{61/2^+}$$

$$^{151}\text{Ho} : [\nu(f_{7/2}h_{9/2}i_{13/2})\pi(h_{11/2}^3)]_{28^-}$$

$$\text{odd } [\nu(f_{7/2}h_{9/2}i_{13/2})\pi h_{11/2}^2]_{49/2^+}$$

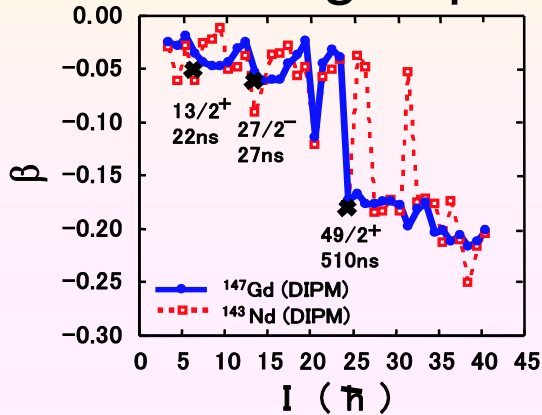
$$\text{odd-odd } [\nu(f_{7/2}h_{9/2}i_{13/2})\pi(h_{11/2}^2d_{5/2})]_{27^+}$$

420ns
(61/2+, 65/2-)
10.288



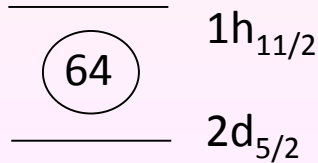
Results by the systematic study of high-spin shape isomers in $N=83$ isotones

1. shape isomer with high-spin



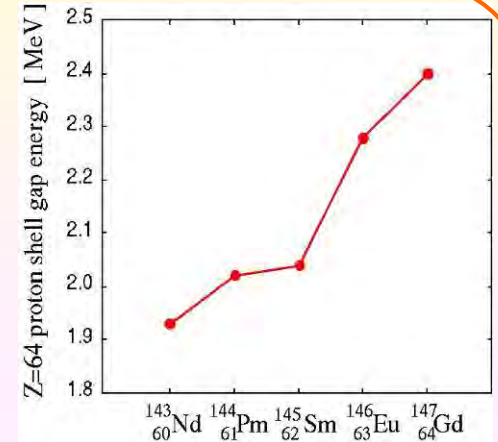
A. Odahara et al.,
J. Phys. Soc. Jpn **77** (2008) 114201

2. change of the $Z=64$ sub-shell gap energy



deformed independent particle model (DIPM)
by H. Sagawa

A. Odahara et al., Nucl. Phys. **A620** (1997) 363



3. experimental pairing interaction in high-spin states

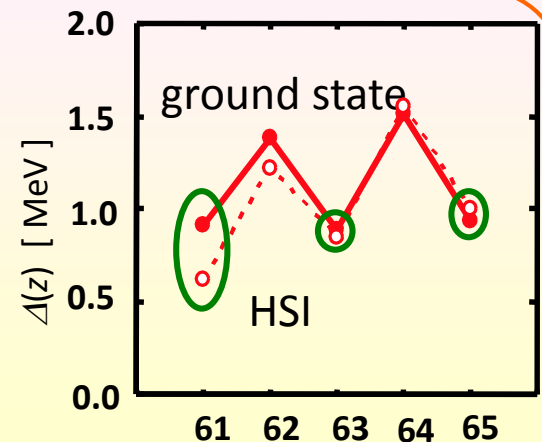
odd-even mass difference

$B(Z)$: binding energy

$E(Z)$: excitation energy
of the HSI

$$\Delta(Z) = \frac{\pi Z}{2} [\{B(Z-1) + E(Z-1)\} + \{B(Z+1) + E(Z+1)\} - 2\{B(Z) + E(Z)\}]$$

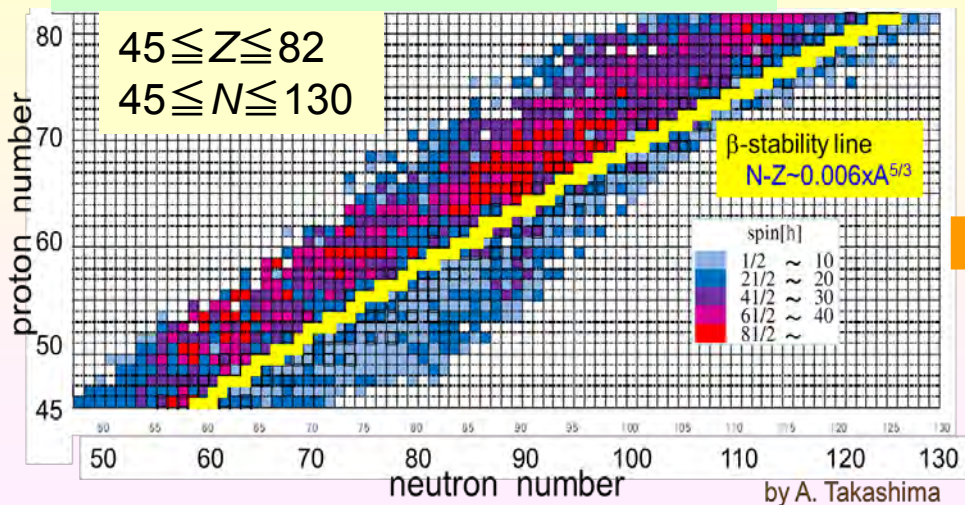
A. Odahara et al., Phys. Rev. C **72** (2005) 061303



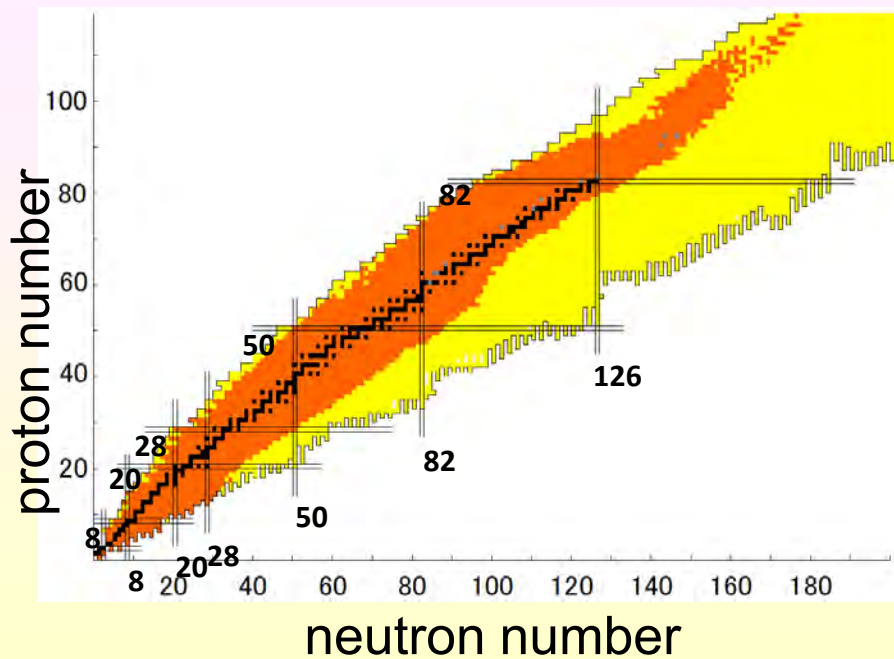
Nuclear Chart :
Experimental maximum spins
reported in NNDC (-2008)

except for SD spins
 which are mostly
 not confirmed

to search for
 high-spin shape isomers



We developed
 γ-ray spectroscopy method
 using **low-energy RI beam**
 (around 5 - 10 MeV/u)
fusion reaction
 at RCNP, Osaka University.



to search for isomers
 in neutron-rich nuclei

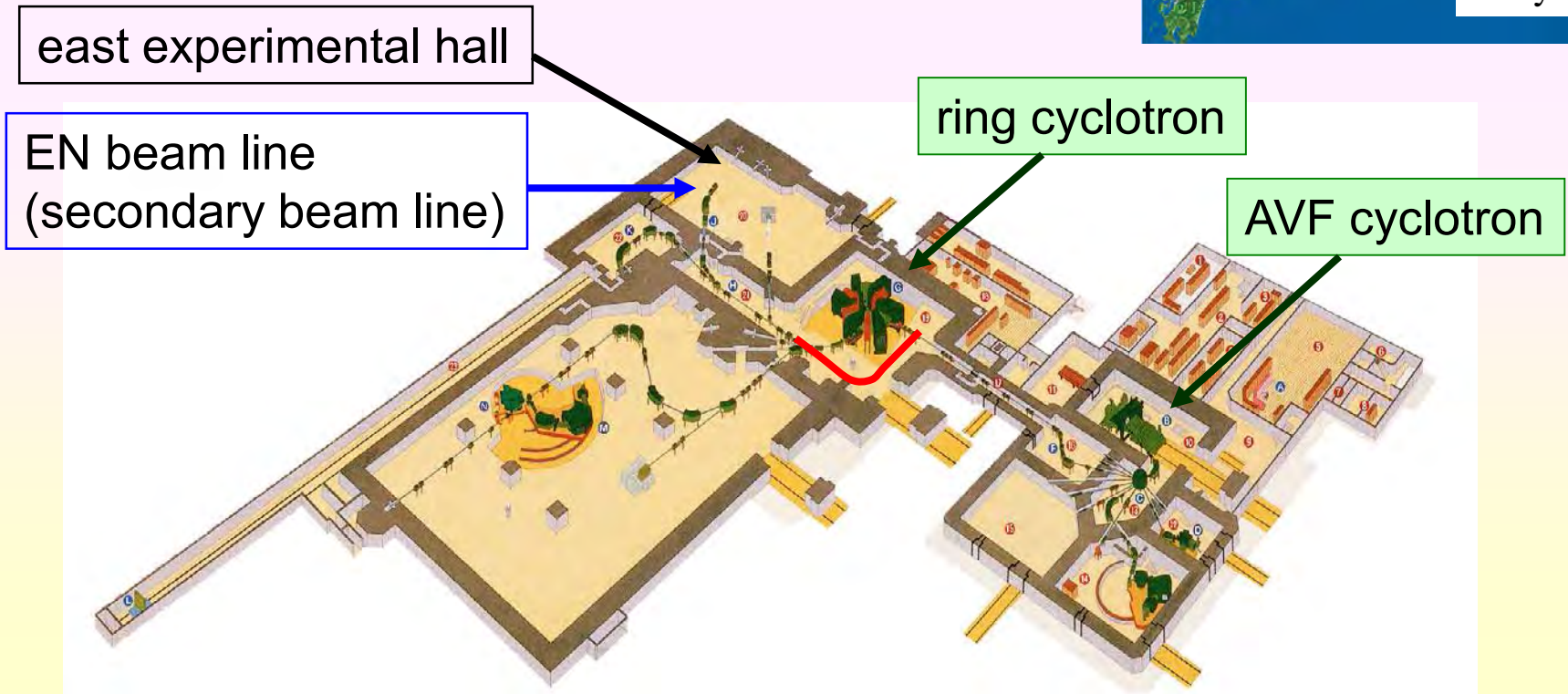
in-flight fission reaction
 - **EURICA campaign** -
 at RIBF, RIKEN

Isomer Studies

with RI-beam Induced Fusion Reactions
and In-Flight Fission Reactions

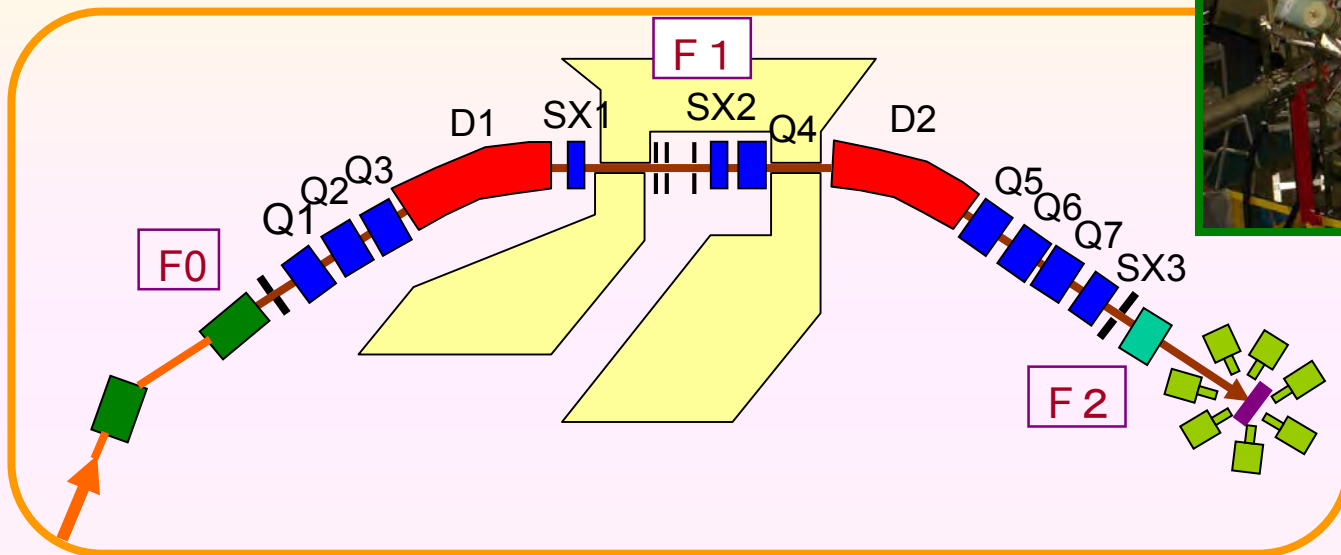
1. Isomer study in **high-spin** region
using **RI-beam Induced Fusion Reaction**
at **RCNP, Osaka University**
2. Isomer study in **neutron-rich isotopes**
using **In-Flight Fission Reactions**
- experiment in EURICA campaign –
at **RIBF, RIKEN**

1. Isomer study in high-spin region using RI-beam Induced Fusion Reaction at RCNP, Osaka University



EN beam line

RCNP secondary beam line



T. Shimoda et al., NIM B70 (1992) 320.
S. Mitsuoka et al., NIM A372 (1996) 489.

RI beam with beam energy
from low (\sim MeV/u)
to high (\sim several tens MeV/u)
can be delivered.

Maximum rigidity	3.2 Tm
Energy acceptance	$\Delta E/E = 16 \%$
Angular acceptance	$\Delta\theta = 40$ mrad
	$\Delta\phi = 28$ mrad
Path length	16.8 m

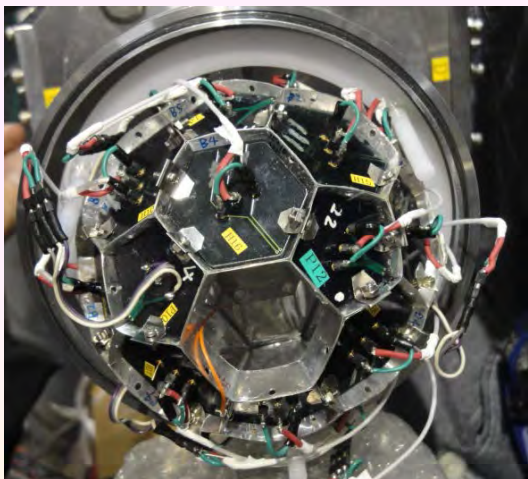
Study of high-spin states of nuclei in transitional mass region with $Z \sim 57$ and $A \sim 130$

primary reaction : ${}^9\text{Be}({}^{18}\text{O}, {}^{17}\text{N}){}^{10}\text{B}$

9.3 MeV/u, 1.5 pμA

secondary reaction : ${}^{124}\text{Sn} + {}^{17}\text{N} \rightarrow {}^{135}\text{La} (6n), {}^{136}\text{La} (5n)$

5.5 MeV/u, 1.2×10^5 pps, around 60%



Si-ball
170 μm ΔE type
by Kyushu Univ.
& CNS, U. of Tokyo

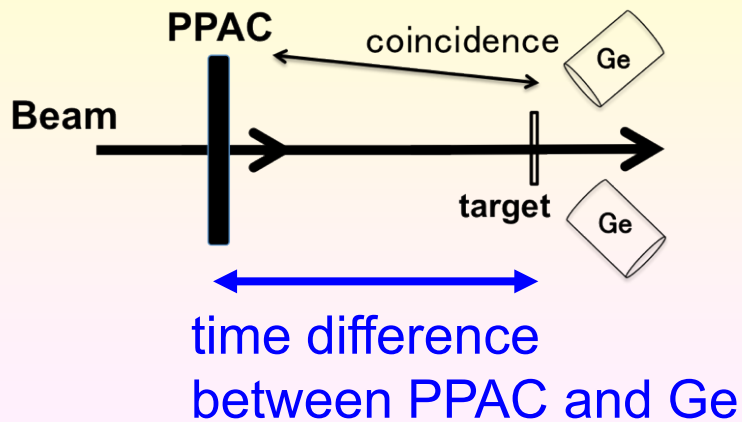


Ge detector array
12 tapered Ge
+ 8 BGOACS
(co-axial Ge det.
used in EUROBALL)
from gamma pool

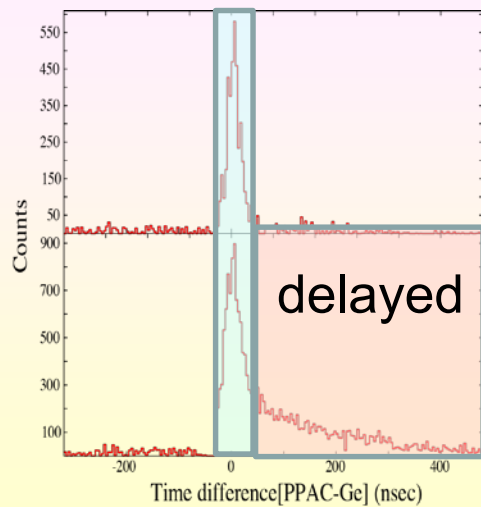
total efficiency :
around 3 %
at 1.3 MeV

collaboration with
French group
(IPN, CNSMS, Orsay
& Universite Paris Sud XI)

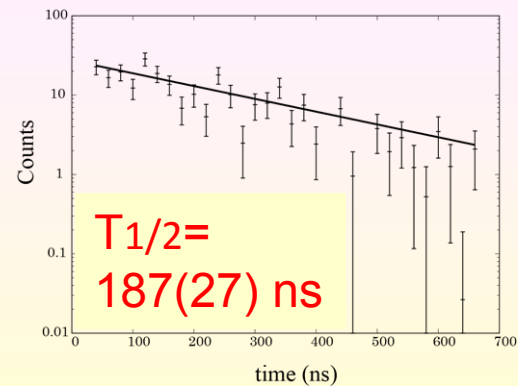
new isomer in ^{136}La



prompt

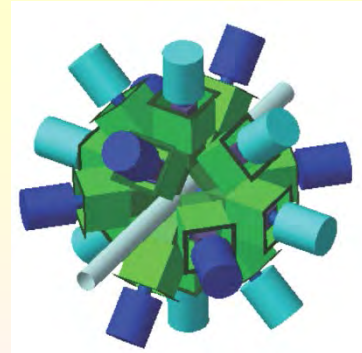


new isomer in ^{136}La



RCNP
future plan

Clover Array Gamma-ray spectrometer
at RCNP/RIBF for Advanced research
(CAGRA)



10 clovers + Compton suppression shields
from CloverShare in USA

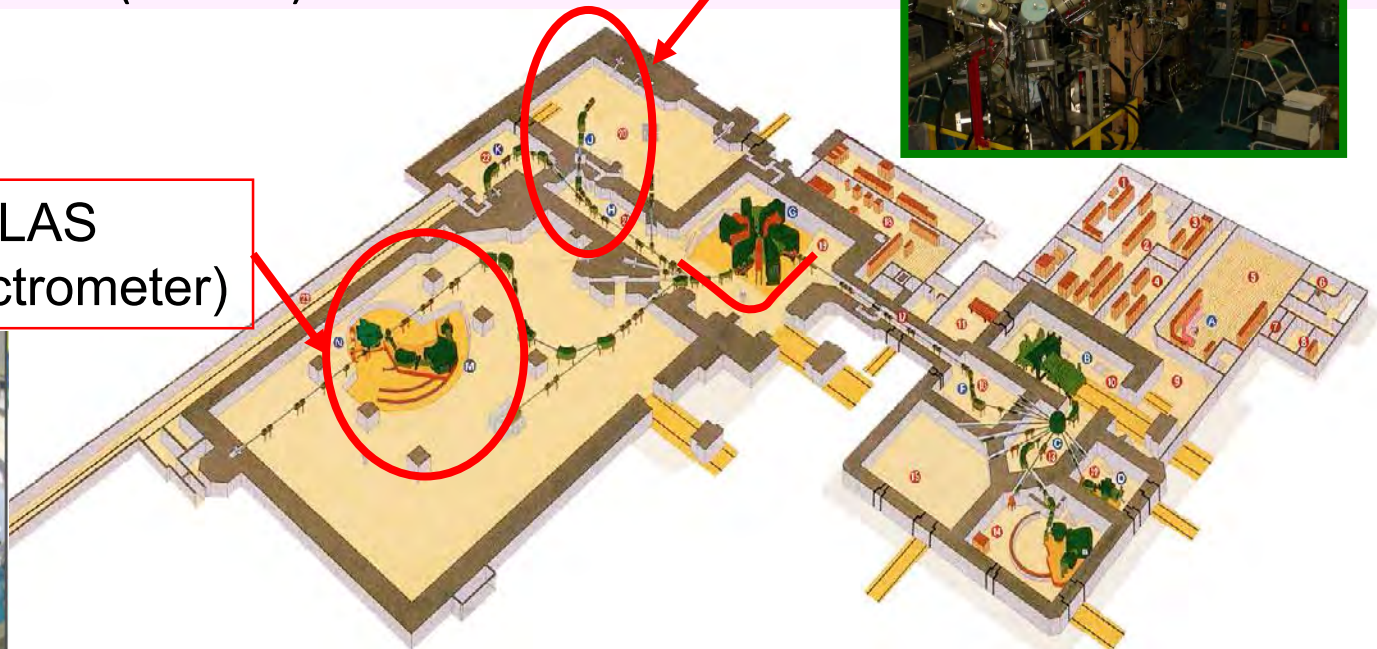
6 clovers + Compton suppression shields
from Tohoku University.

N. Aoi (RCNP), E. Ideguchi (RCNP), A. Tamii (RCNP),
M.P. Carpenter (ANL), V. Werner (Yale),
P. Fallon (LBNL), T. Koike (Tohoku)

EN beam line
(secondary beam line)



Grand Raiden & LAS
(double arm spectrometer)



Search for high-spin states in transitional nuclei
with $Z \sim 57$ and $A \sim 130$

Dep. of Phys., Osaka Univ.

Univ. of Paris Sud, France

CNS, Univ. of Tokyo

RCNP, Osaka Univ.

RIKEN

Tokyo Univ. of Sci.

IPN Orsay, France

IPN Lyon, France

CSNSM Orsay, France

IPHC Strasbourg, France

H. Nishibata, A. Odahara, T. Shimoda,
Y. Ito, K. Tajiri, J. Takatsu

R. Leguillon, C. Petrache (CSNSM Orsay)

R. Yokoyama

E. Ideguchi, N. Hamatani, T. Suzuki

H. Watanabe, Y. Wakabayashi,

S. Nishimura, Y. Gono

K. Yoshinaga

D. Beaumel

G. Lehaut, D. Guinet

P. Desesquelles

D. Curien

Isomer Studies

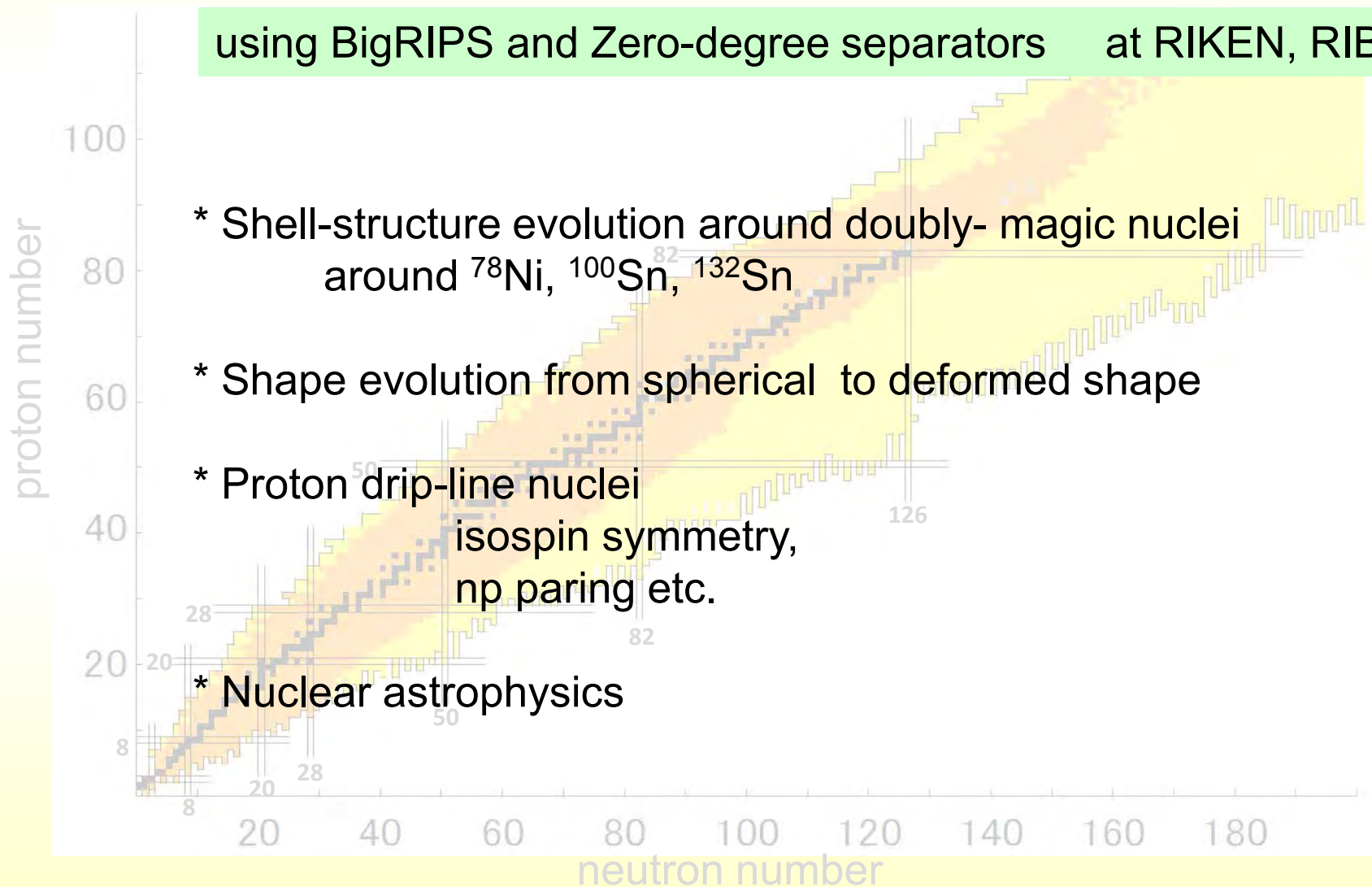
with RI-beam Induced Fusion Reactions
and In-Flight Fission Reactions

1. Isomer study in **high-spin** region
using **RI-beam Induced Fusion Reaction**
at **RCNP, Osaka University**
2. Isomer study in **neutron-rich isotopes**
using **In-Flight Fission Reactions**
- experiment in EURICA campaign –
at **RIBF, RIKEN**

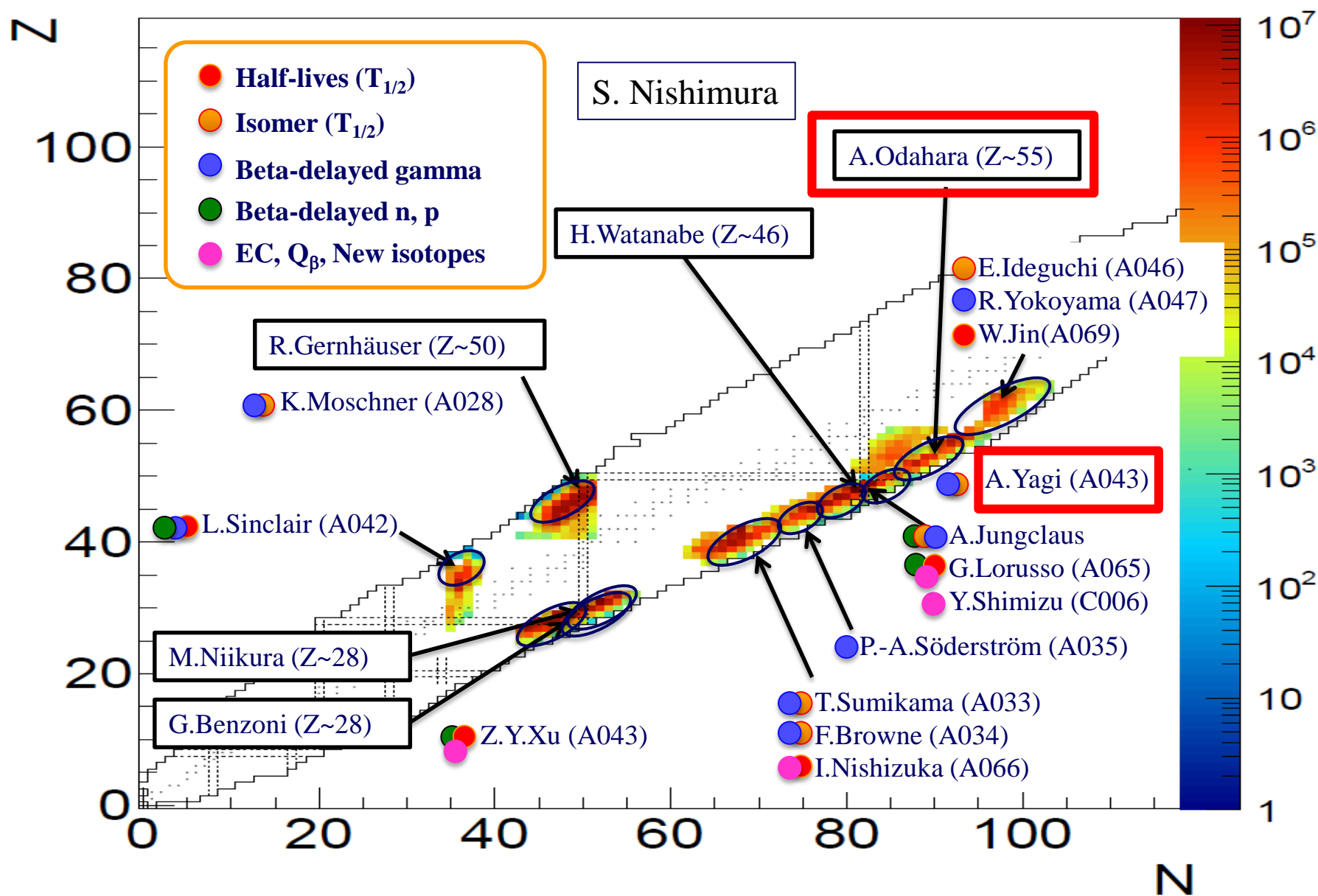
EURICA (EUroball-RIKEN Cluster Array) project

decay spectroscopy : β -decay and isomer decay of nuclei far from stability line

using BigRIPS and Zero-degree separators at RIKEN, RIBF



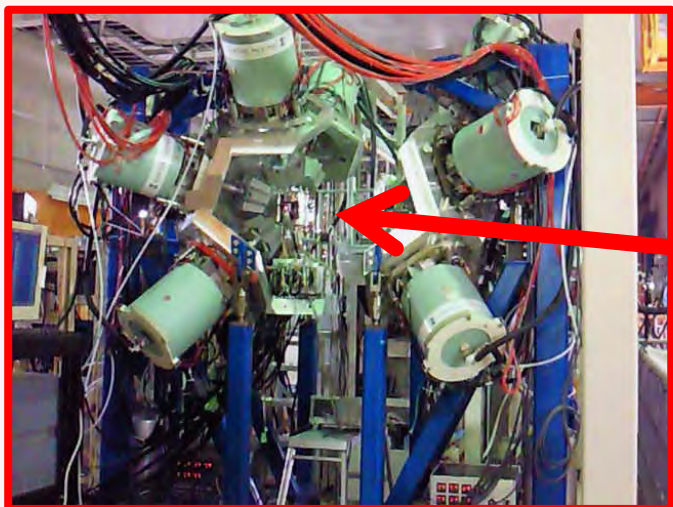
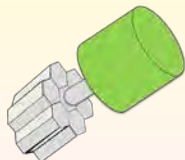
Survey of Decay Properties with EURICA



EURICA

(Euroball-RIKEN Cluster Array)

12 EUROBALL
Cluster Ge detectors
for γ ray

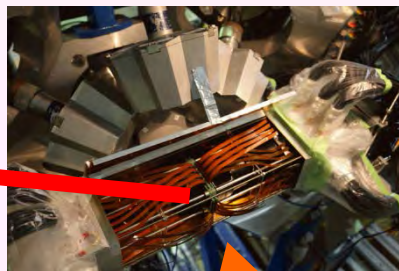


Detectors used in EURICA project

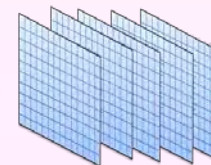
WAS3ABi

(Wide-range Active Silicon Strip Stopper
Array for Beta and Ion detection)

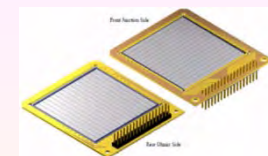
5 DSSSDs (Double Sided Silicon Strip Detector)
for RI beam and β ray



Beam



40x60x1 mm
(40x60 strips)



18 LaBr₃ detectors

$\phi 1.5 \times 2''$

for short life time
measurement



plastic scintillator

for β ray
as time reference



NP1112-RIBF87

Shape evolution in neutron-rich $A \sim 140$ nuclei beyond the doubly-magic nucleus ^{132}Sn

Spokespersons :

Atsuko Odahara
Radomira Lozeva
Changbum Moon

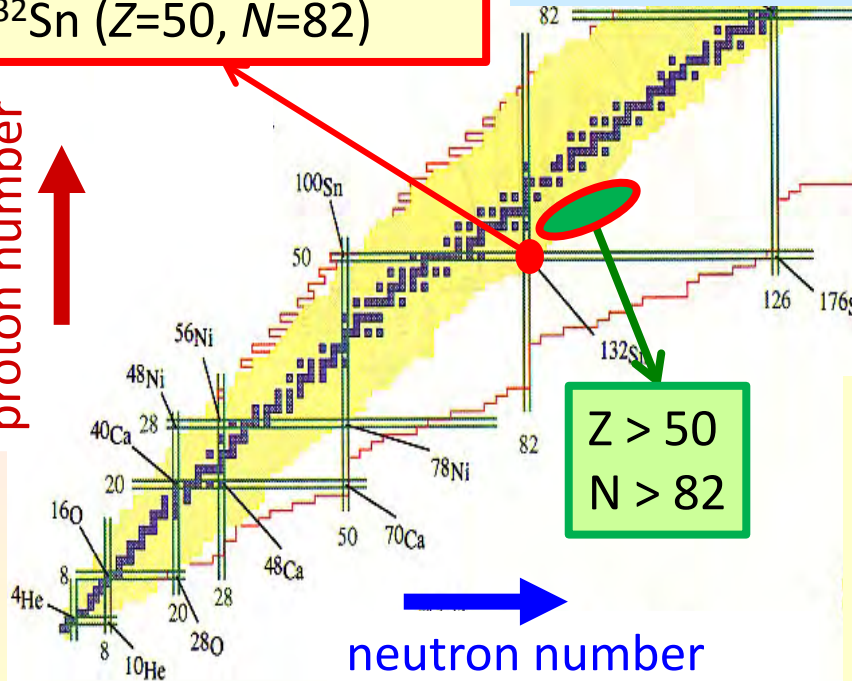
Osaka Univ., Japan
IPHC, Strasbourg, France
Hoseo Univ., Korea

EURICA U beam campaign :
 β - γ spectroscopy
isomer spectroscopy

doubly-magic nucleus
 ^{132}Sn ($Z=50, N=82$)

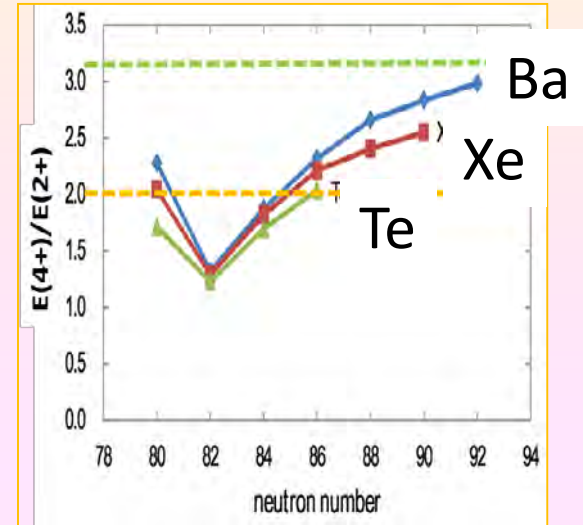
experiment :
30 April – 5 May, 2013
(Live time : 3.5 days)

proton number



$Z > 50$
 $N > 82$

neutron number



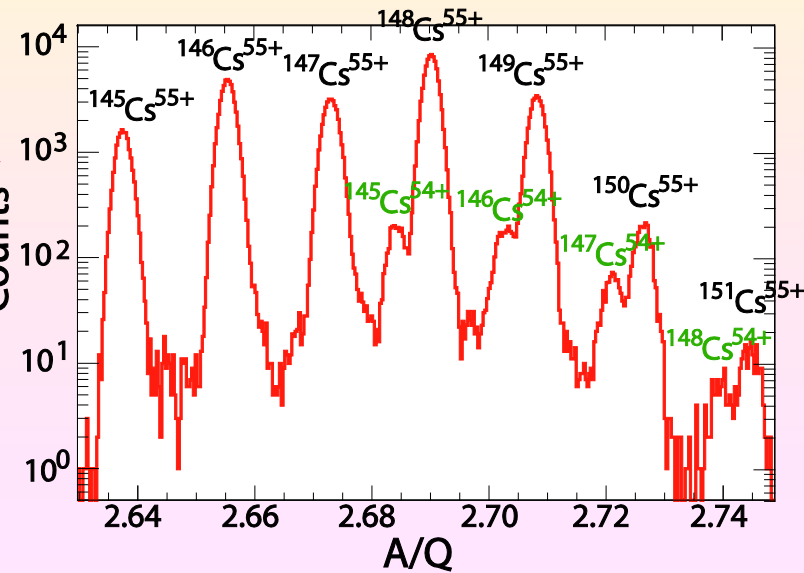
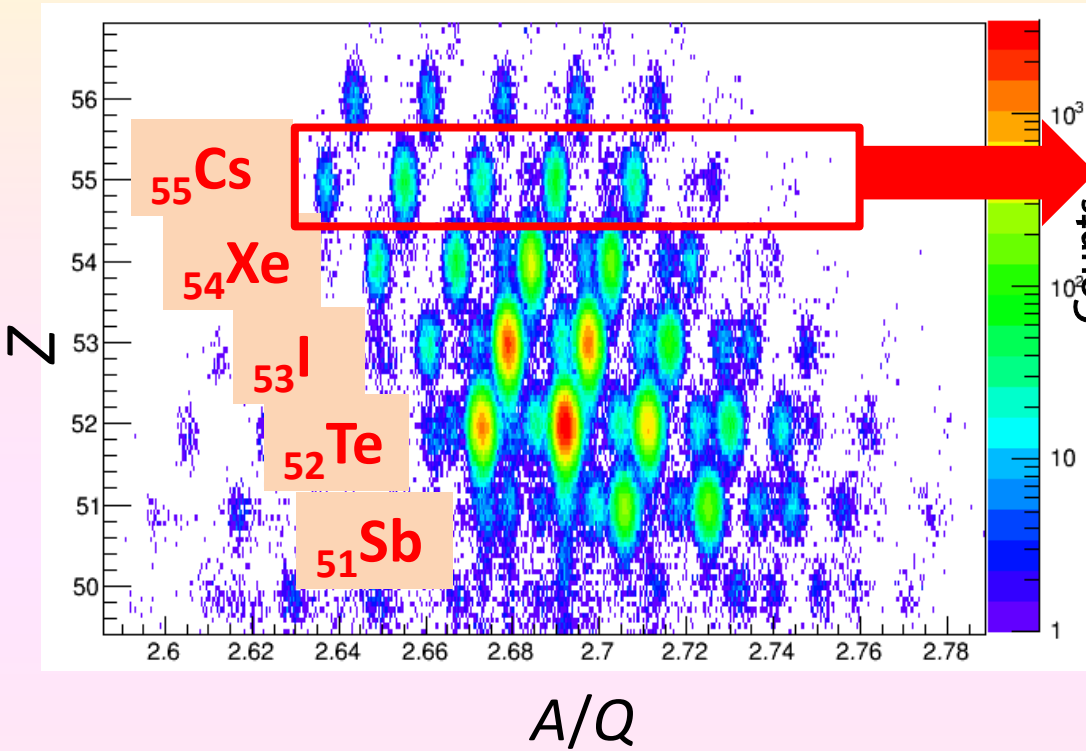
Systematic study of
shape evolution
from spherical to prolate shape
as increase of neutron number

Octupole correlations
is expected in this mass region.

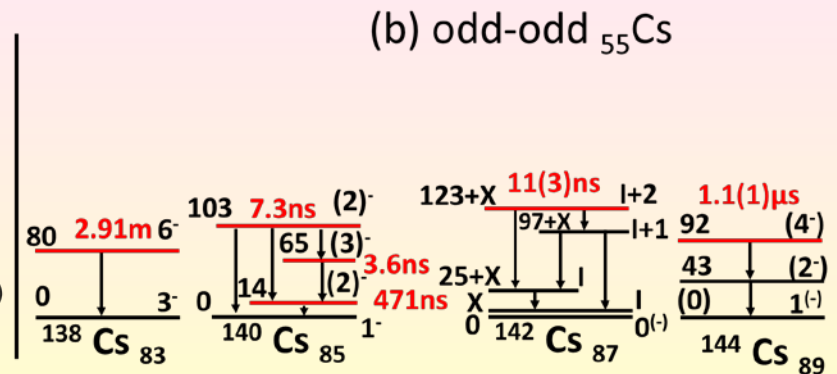
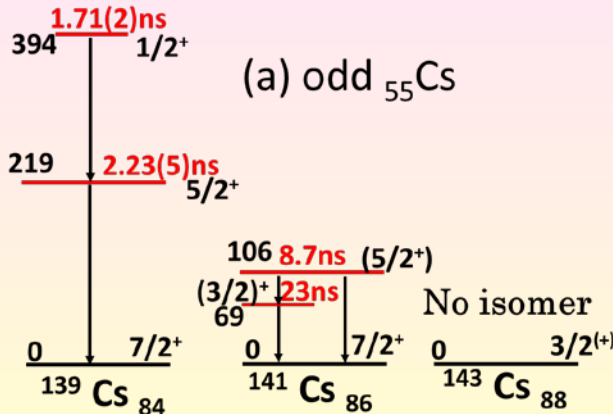
well known in ^{146}Ba ($Z=56, N=90$)

Search for isomers in n-rich Cs isotopes

by Osaka group
A. Yagi



Systematics
of known isomers
in Cs isotopes

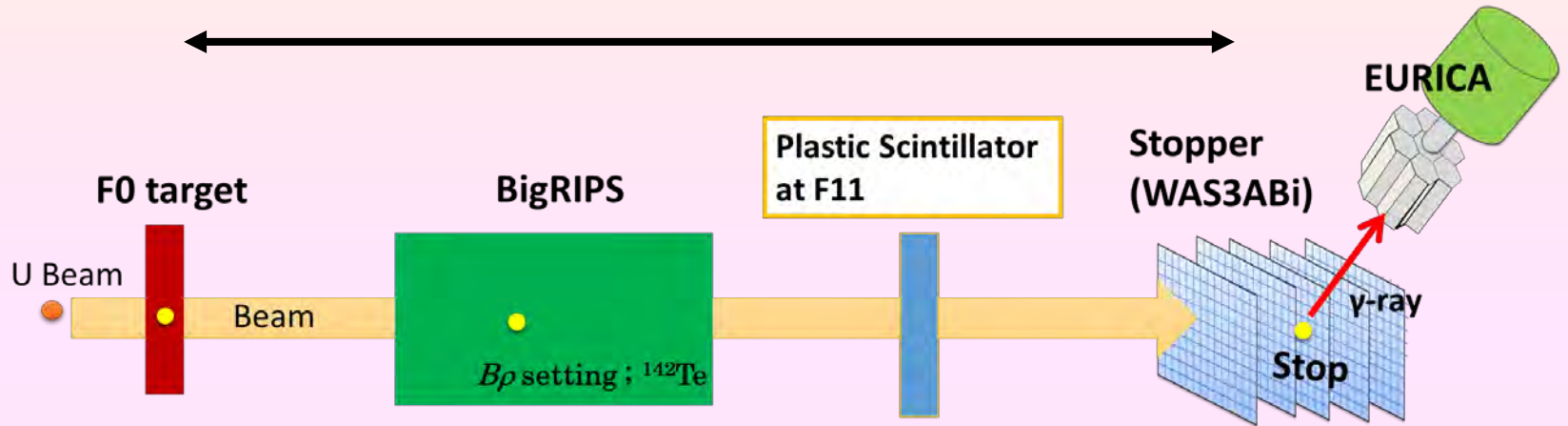


ref : NNDC

Search for isomers in n-rich Cs isotopes

We can search isomers with $T_{1/2} > \text{hundreds ns}$.

flight time [F0 target – WAS3ABi] : around 650 ns

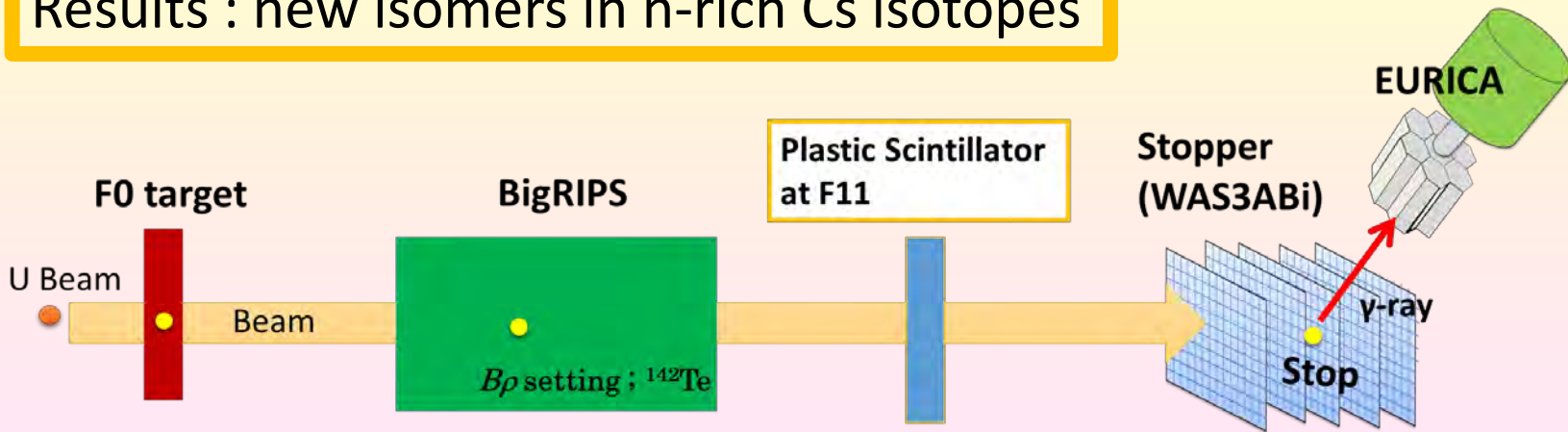


time information to search for isomer

start :
beam at F11

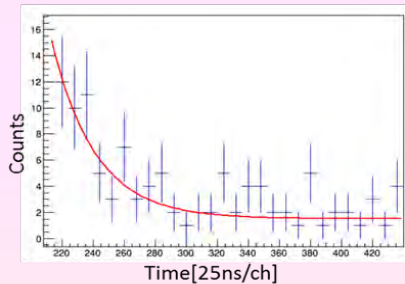
stop :
 γ -ray
by EURICA

Results : new isomers in n-rich Cs isotopes



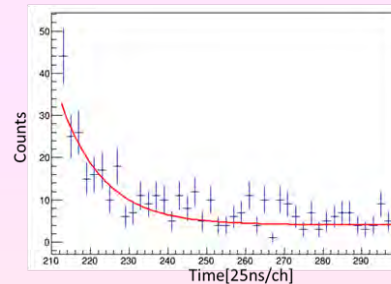
by A. Yagi

^{145}Cs ($N=90$)



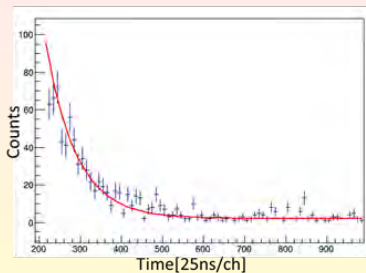
$$T_{1/2} = 0.5(1) [\mu\text{s}]$$

^{147}Cs ($N=92$)



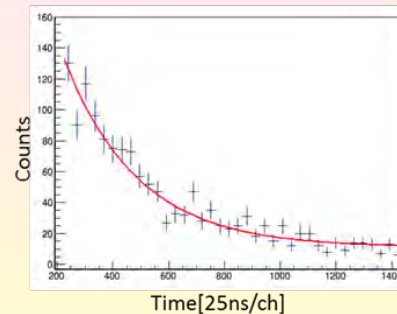
$$T_{1/2} = 0.19(2) [\mu\text{s}]$$

^{146}Cs ($N=91$)



$$T_{1/2} = 1.25(5) [\mu\text{s}]$$

^{148}Cs ($N=93$)



$$T_{1/2} = 4.8(2) [\mu\text{s}]$$

Discussion : isomers in n-rich Cs isotopes

(1) isomers in odd-odd Cs

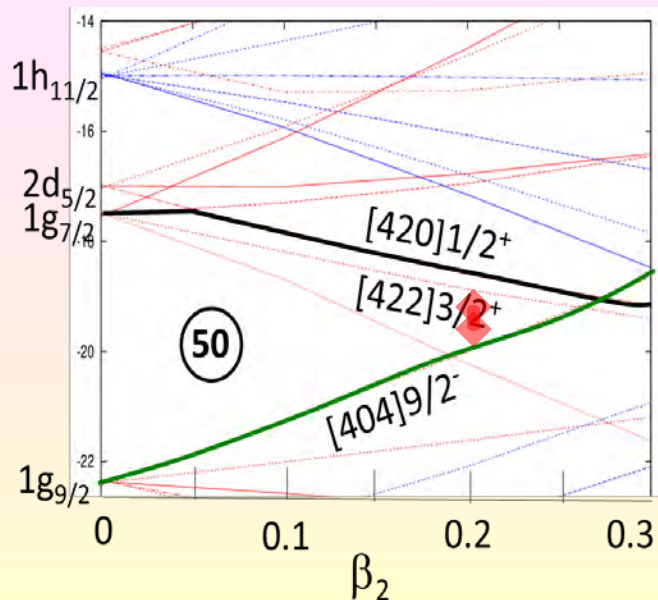
new isomers

low-energy transition
directly emitted
from the isomers

(2) isomers in odd Cs

new isomers

K isomer ?



Woods-Saxon
calculation code
by M. Yamagami

K isomer
 $[404]9/2^-$?

from the *Ex*
of isomers

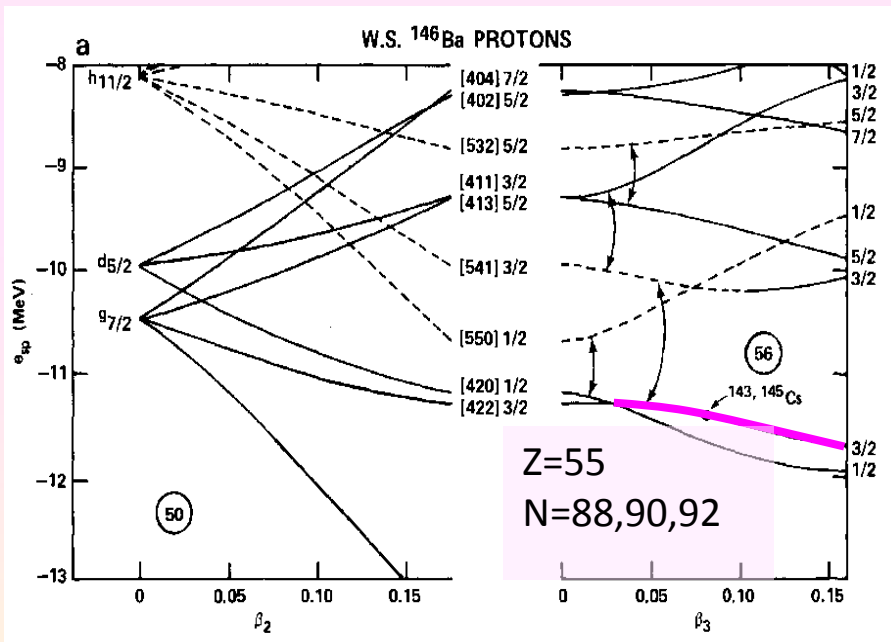
$\beta_2 > 0.2$?

Discussion : new isomers in n-rich Cs isotopes

Spins and parities of the ground states

Z \ N	82	84	86	88	90	92
Cs 55	7/2+	7/2+	7/2+	3/2+	3/2+	(3/2+)

NNDC



spin-parity $3/2^+$ of ground state in Cs isotopes with $N=88, 90, 92$

It is difficult to explain it simply by single-particle level.

octupole collectivity ?

G.A. Leander et al.,
Phys. Lett. B 152 (1985) 284

A. Odahara¹, R. Lozeva², C.-B. Moon³, A. Yagi¹, R. Daido¹, Y. Fang¹, H. Nishibata¹, S. Nishimura⁴, P. Doornenbal⁴, G. Lorusso⁴, P.-A. Soderstrom⁴, T. Sumikama⁵, H. Watanabe⁶, T. Isobe⁴, H. Baba⁴, H. Sakurai^{7,4}, F. Browne^{8,4}, Z. Patel^{9,4}, S. Rice^{9,4}, L. Sinclair^{10,4}, J. Wu^{11,4}, Z.Y. Xu⁷, R. Yokoyama¹², T. Kubo⁴, N. Inabe⁴, H. Suzuki⁴, N. Fukuda⁴, D. Kameda⁴, H. Takeda⁴, D.S. Ahn⁴, D. Murai¹³, F.L. Bello Garrote¹⁴, J.M. Daugas¹⁵, F. Didierjean², E. Ideguchi¹⁶, T. Ishigaki¹, H.S. Jung¹⁷, T. Komatsubara¹⁸, Y.K. Kwon¹⁸, C.S. Lee¹⁹, S. Morimoto¹, M. Niikura^{7,4}, I. Nishizuka⁵, T. Shimoda¹, K. Tshoo¹⁸, P. Lee¹⁹

1 Department of Physics, Osaka University
2 IPHC/CNRS and University of Strasbourg
3 Hoseo University, 4 RIKEN Nishina Center
5 Department of Physics, Tohoku University
6 Beihang University
7 Department of Physics, University of Tokyo
8 University of Brighton, 9 Surry University
10 University of York, 11 Peking University
12 CNS, University of Tokyo
13 Rikkyo University, 14 University of Oslo
15 CEA/DAM, 16 RCNP, Osaka University
17 University of Notre Dame, 18 IBS
19 Chung-Ang University



Summary

1. Isomer study was performed to reveal **shape evolution** as a function of spin and isospin.
2. Isomer study was carried out in **high-spin** region using **RI-beam induced fusion reaction** at **RCNP, Osaka University**.
 - (1) We developed γ -ray spectroscopy method using low-energy RI beam (around 5-10 MeV/u) fusion reaction .
 - (2) We found the exotic isomer in ^{136}La which locates transitional and triaxial deformed region.
3. Isomer study was carried out in **neutron-rich isotopes** using **in-flight fission reactions** as one of experiments in **EURICA campaign** at **RIBF, RIKEN**.
 - (1) We found 4 new isomer in n-rich Cs isotopes.
 - (2) New isomers in odd-Cs supposed be candidate of *K* isomer.