First results of $\beta-\gamma$ spectroscopy for neutron-rich nuclei around A=110 at RIBF

Kenta Yoshinaga

Tokyo University of Science

23, May, 2011, E(U)RICA WS

Collaborators

- RIKEN Nishina Center
  - S. Nishimura, H. Watanabe, Z. Li, H. Baba, M. Nishimura, T. Isobe, H. Scheit, P. Doornenbal, D. Steppenbeck, H. Sakurai
- Tokyo University of Science
  - T. Sumikama, K. Yoshinaga, Y. Miyashita, T. Nakano, K. Sugimoto, S. Takano, J. Chiba
- Osaka University
  - K. Yamaguchi, A. Odahara, A. Takashima, Y. Ito, K. Tajiri, T. Shimoda, H.J. Ong
- Tokyo Institute of Technology
  - N. Kobayashi, Y. Kawada, Y. Kondo, T. Nakamura
- CNS
  - E. Ideguchi, S. Go, S. Ota, S. Kubono, H. Yamaguchi, T. Hashimoto, S. Hayakawa
- Japan Atomic Energy Agency
  - Y. Wakabayashi
- Kyushu University
  - T. Teranishi
- Technishe Universität München
  - C. Hinke, K. Steiger, R. Kruecken
- Michigan State University
  - G. Lorusso,
- Lawrence Berkeley National Laboratory
  - J.S. Berryman
- INFN
  - O. Wieland, N. Blasi
- Università di Milano
  - A. Bracco, F. Camera
- University of Surrey
  - Zs. Podolyák, P.M. Walker

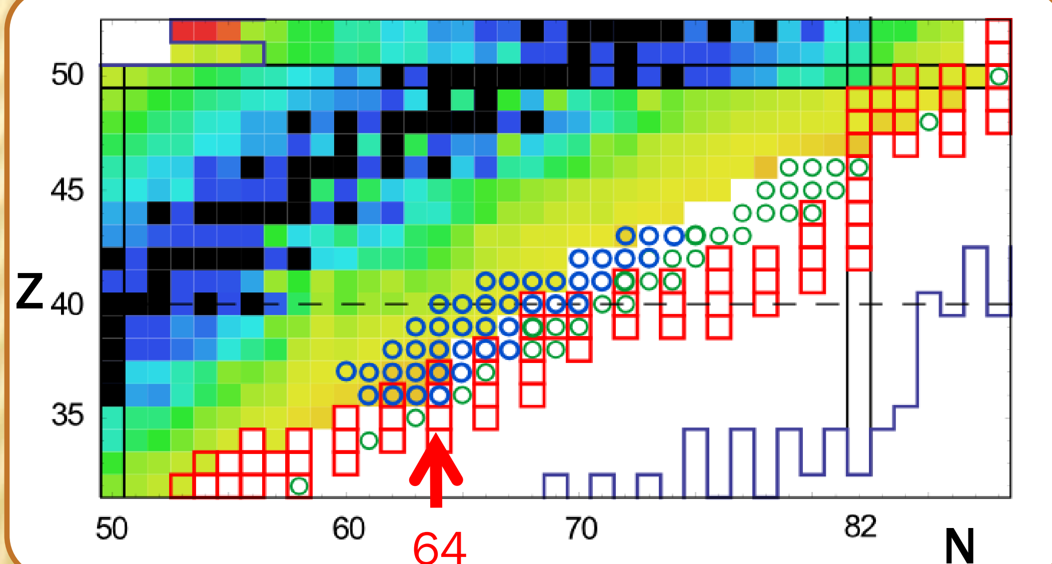
Contents

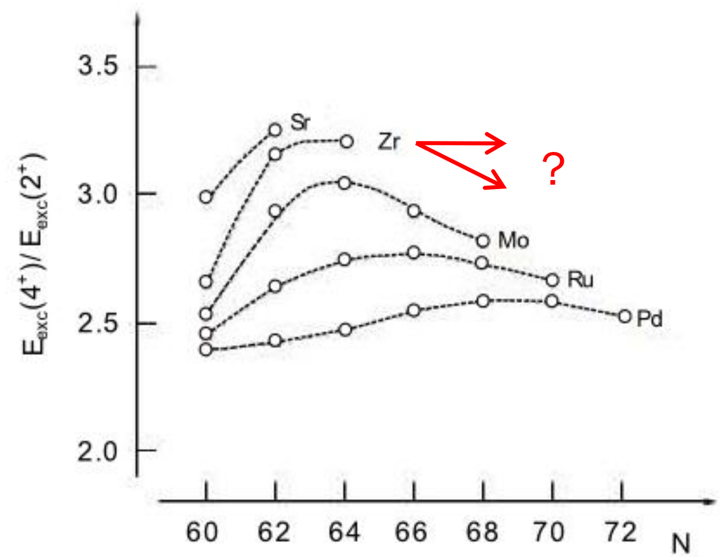
- Motivation
- Experiment
  - Beam production
  - Detectors for $\beta-\gamma$ spectroscopy
  - 100MHz Time stamp DAQ system
  - Data analysis with Time-Stamp
- Result
  - Shape evolution of neutron-rich even-even Zr isotopes
  - A possible oblate-shape isomer in ^{109}Nb
  - β-decay half-lives of neutron-rich Kr to Tc isotopes
- Summary

Motivation

Motivation

A drastic shape evolution is predicted in neutron-rich nuclei around A=110.
For the Zr isotopes, a deformation may reach a maximum by a deformed shell-closure.
However, the maximization of the deformation has not been observed as a function of neutron numbers.

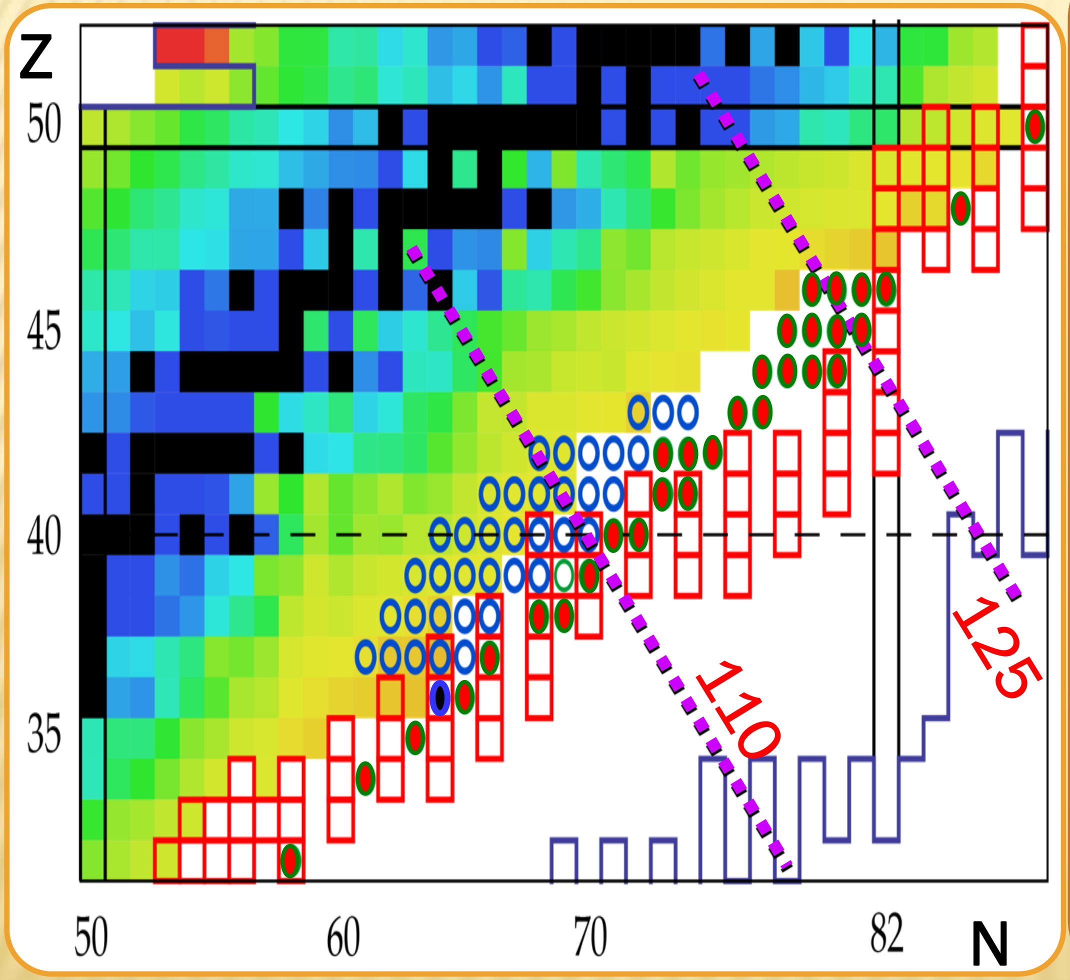


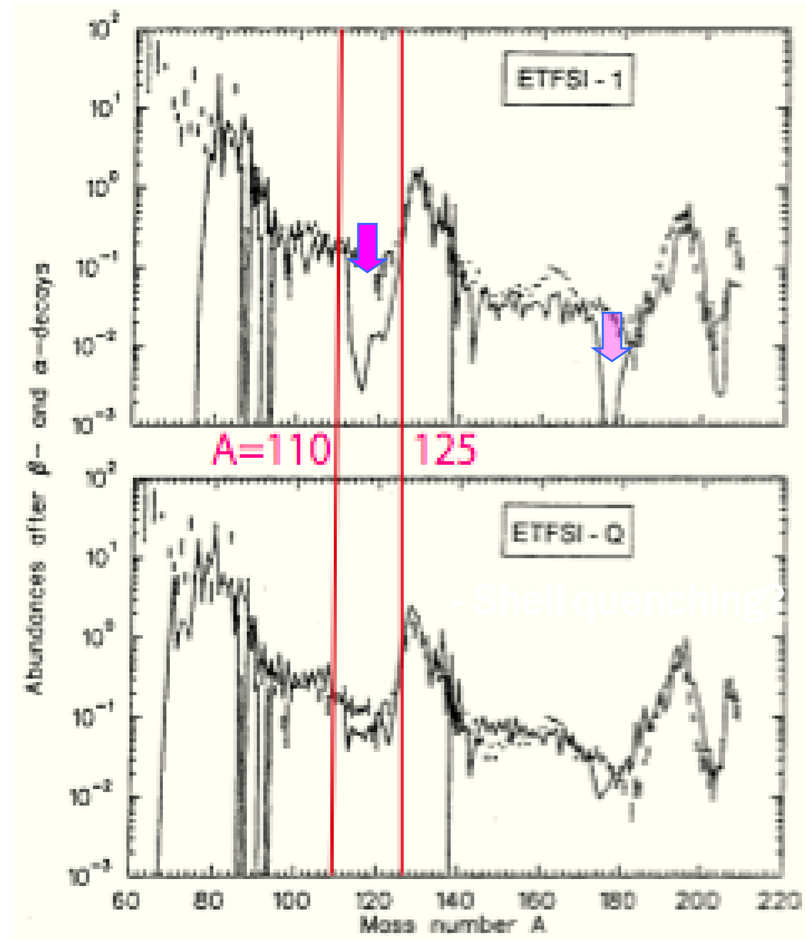


Blue : Measurement Region @ Decay Exp.
Green: T.Ohnishi, JPSJ 79 (2010).. 45 new isotopes

$$R_{4/2} = E(4_1^+)/E(2_1^+)$$

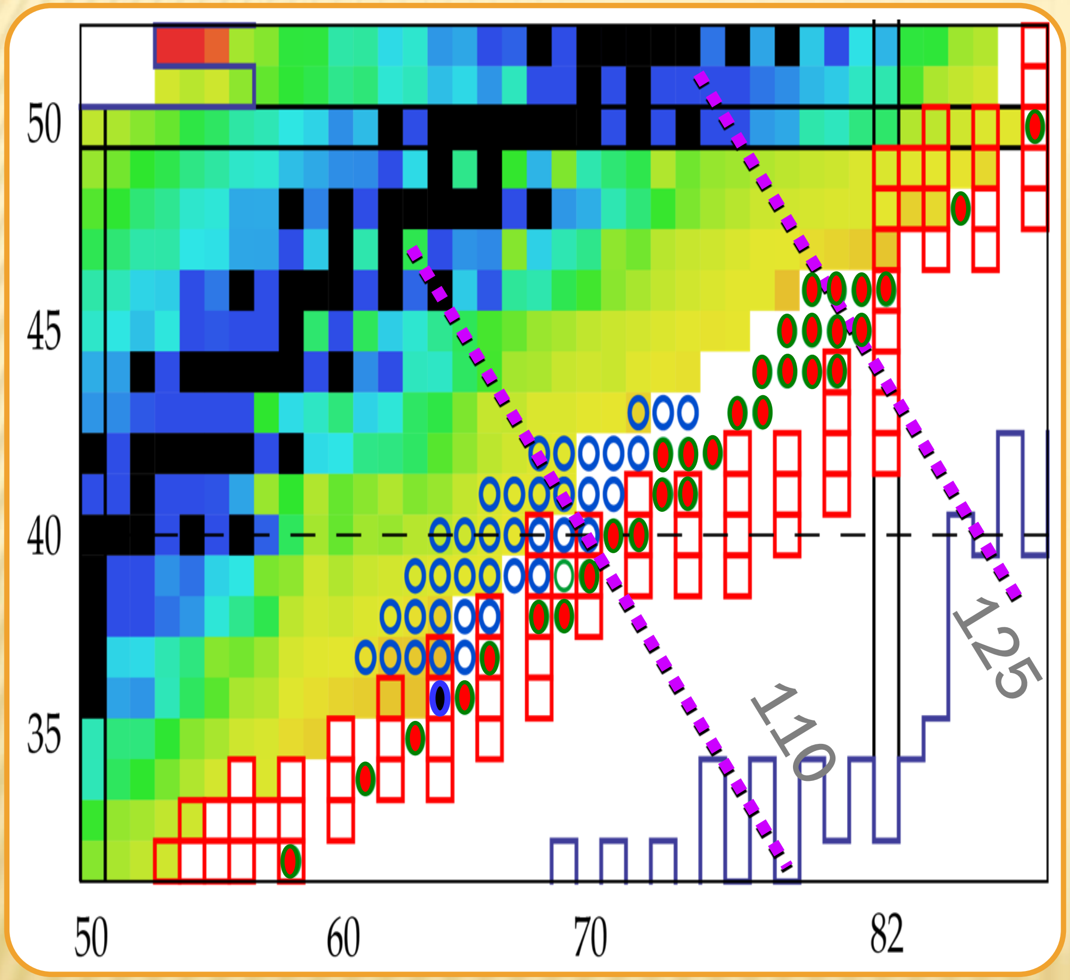
Nucleosynthesis on r-Process





B.Pfeiffer et al. ZPA 357 (1997)

Nucleosynthesis on R-Process



☆ Half-lives （T $_{1/2}$)
→ abundance
→ process speed

☆ Masses (A, Q_β, S_n)
→ location of the path

☆ β-delayed neutron （P_n）
→ final abundances

☆ν ($\bar{\nu}$) catupures

Purpose : To study the low-lying excited state of such nuclei,
and β-decay half-life measurement

Experiment

1. $\beta-\gamma$ spectroscopy at RIBF
2. Beam production
3. Detectors for $\beta-\gamma$ spectroscopy
4. 100MHz Time stamp DAQ system
5. Data analysis with Time-Stamp

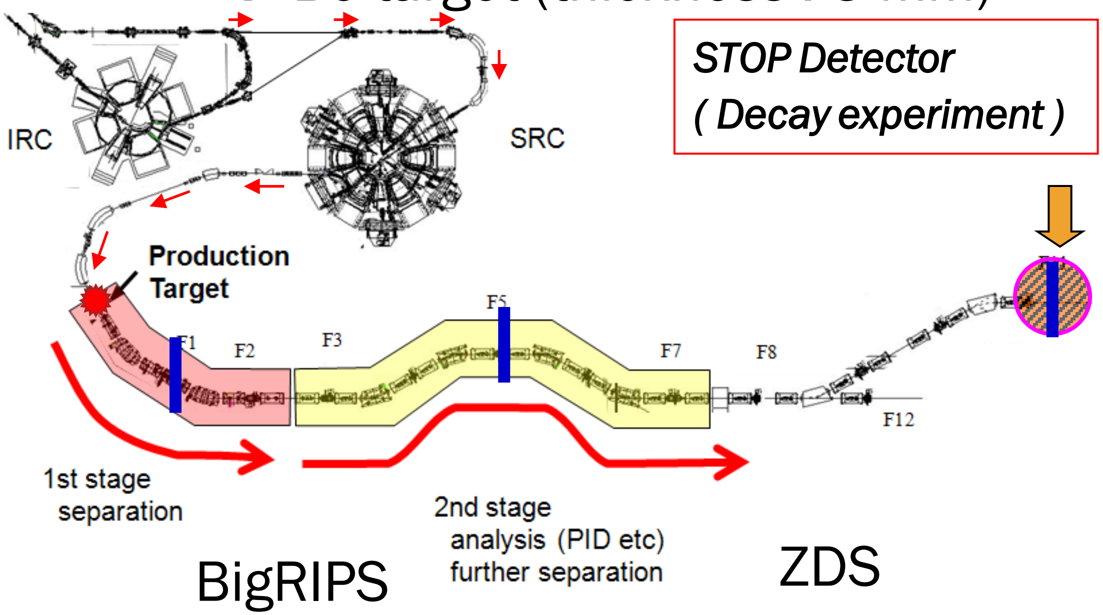
$\beta-\gamma$ spectroscopy at RIBF

- Beam time : Dec., 2009. 3 days
  ($T_{1/2}$ measurement : 8 hours)
- Primary beam: ^{238}U at 345 MeV/A
  ~ 0.3 pnA on average
- Objective isotopes :
  Neutron-rich A = 110 nuclei
- Experimental method :
  Decay spectroscopy with stopped beam

Beam production

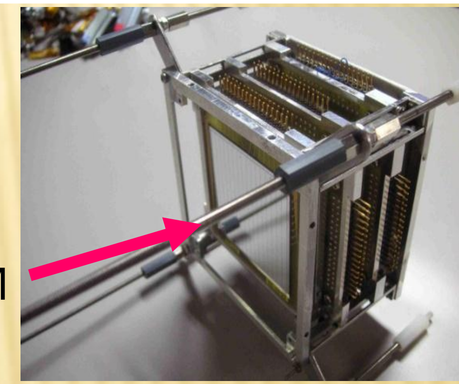
^{238}U @ 345 MeV/u

→ Be target (thickness : 3 mm)



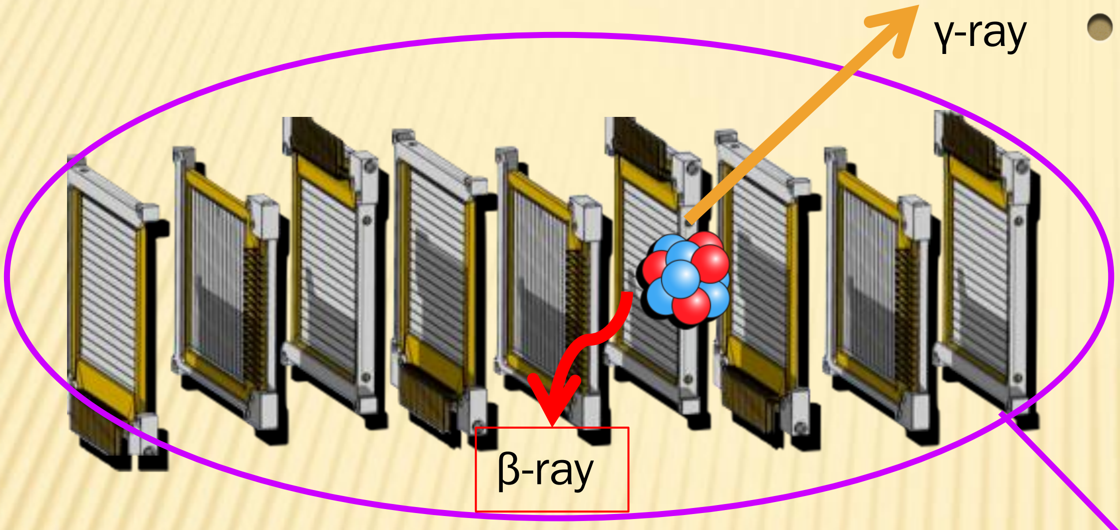
- Wedge Al degrader @ F1
- Charge stripper @ F5
- Al Degrader @ F11

Double sided Silicon strip detector (DSSD)

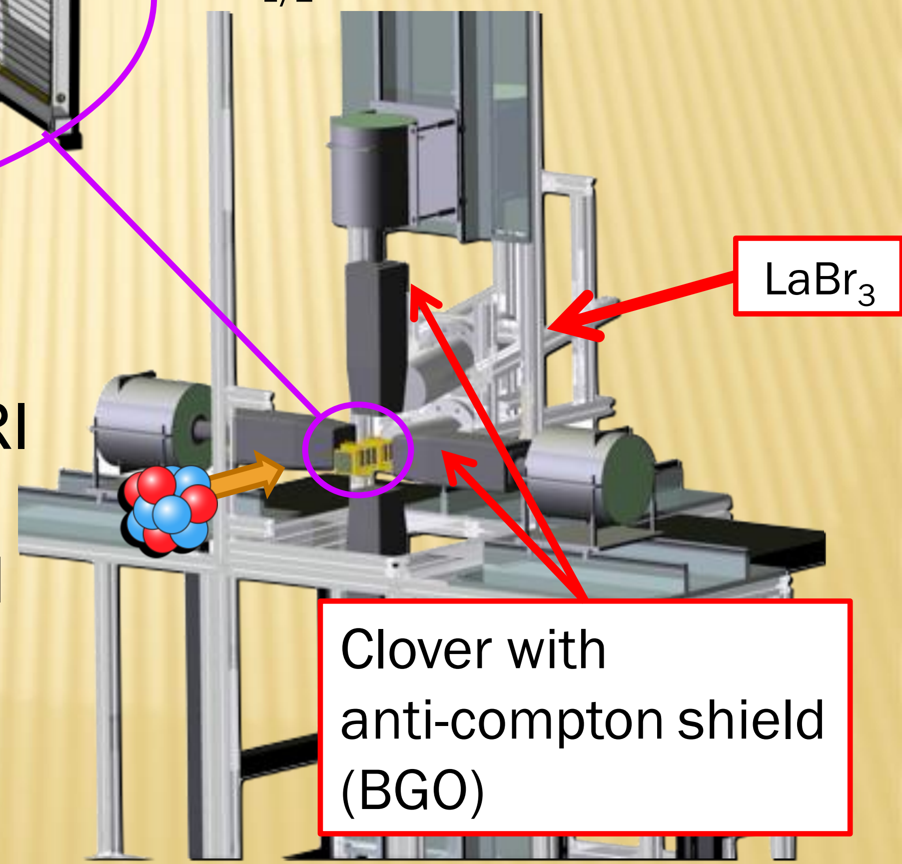


- Sensitive area : 50 x 50 mm
- Strip : 16 x 16
- Strip width : 3 mm
- Thickness : 1000 μm

Detectors for β−γ spectroscopy



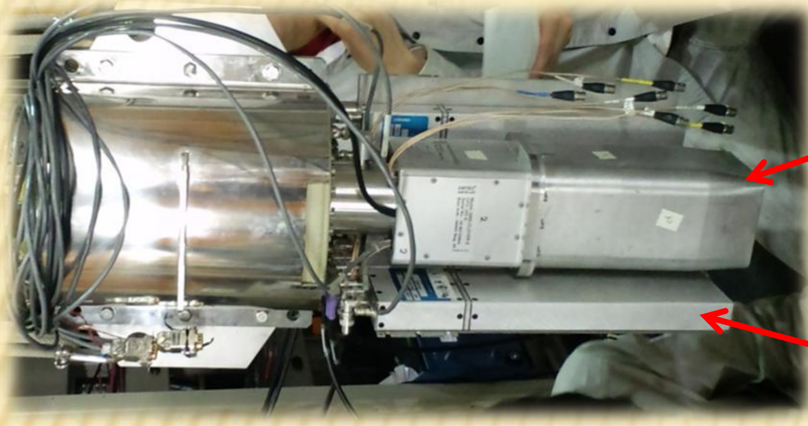
- RI & β-ray detection
  - 9 DSSDs
  - ~ 2000 pixels in total
  - Implant rate ~ 100 cps
    $T_{1/2}$ measurement : ~ 10cps



- The implantation of an identified RI is associated with the following β-decay events that are detected in the same DSSD pixel

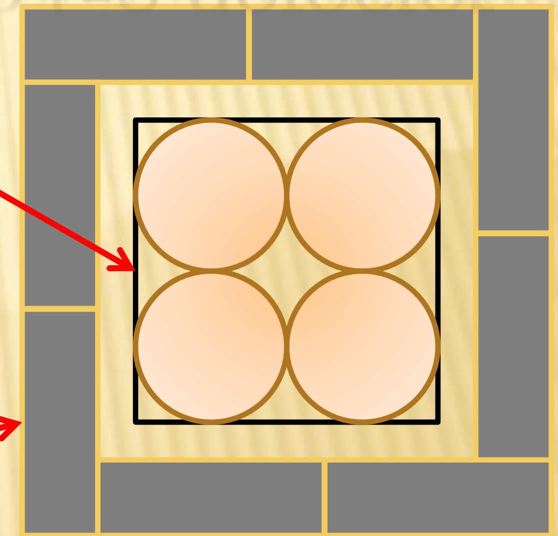
Y. Miyashita, Master thesis(2011)

Compton-suppressed Clover-type Ge detector



Clover

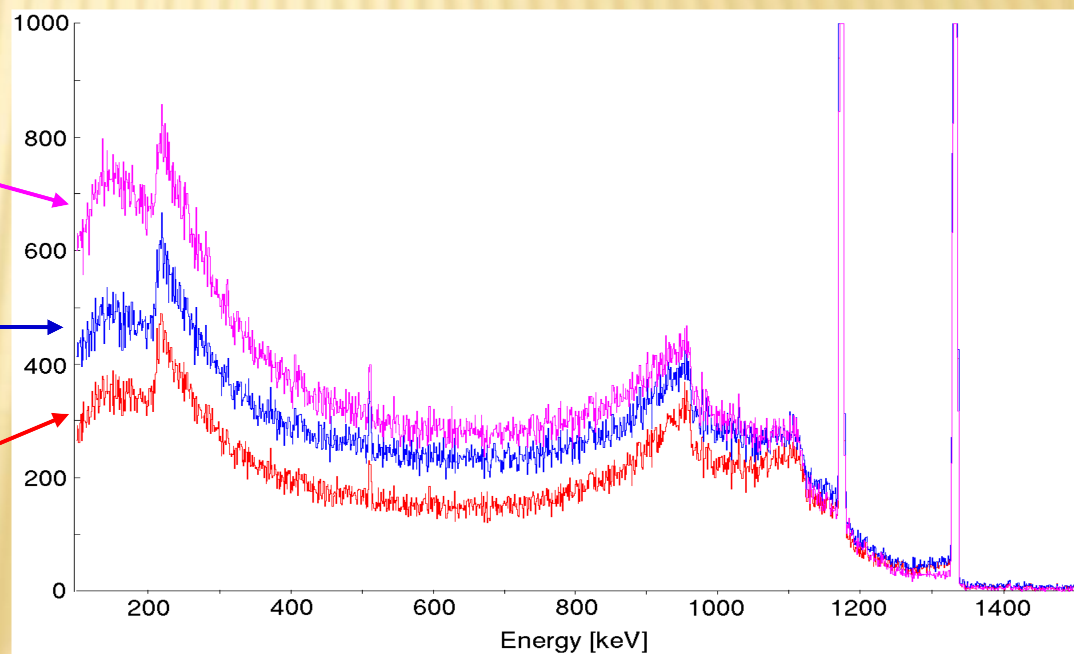
BGO



Sum of 4 crystals
(P/T ~ 0.1)

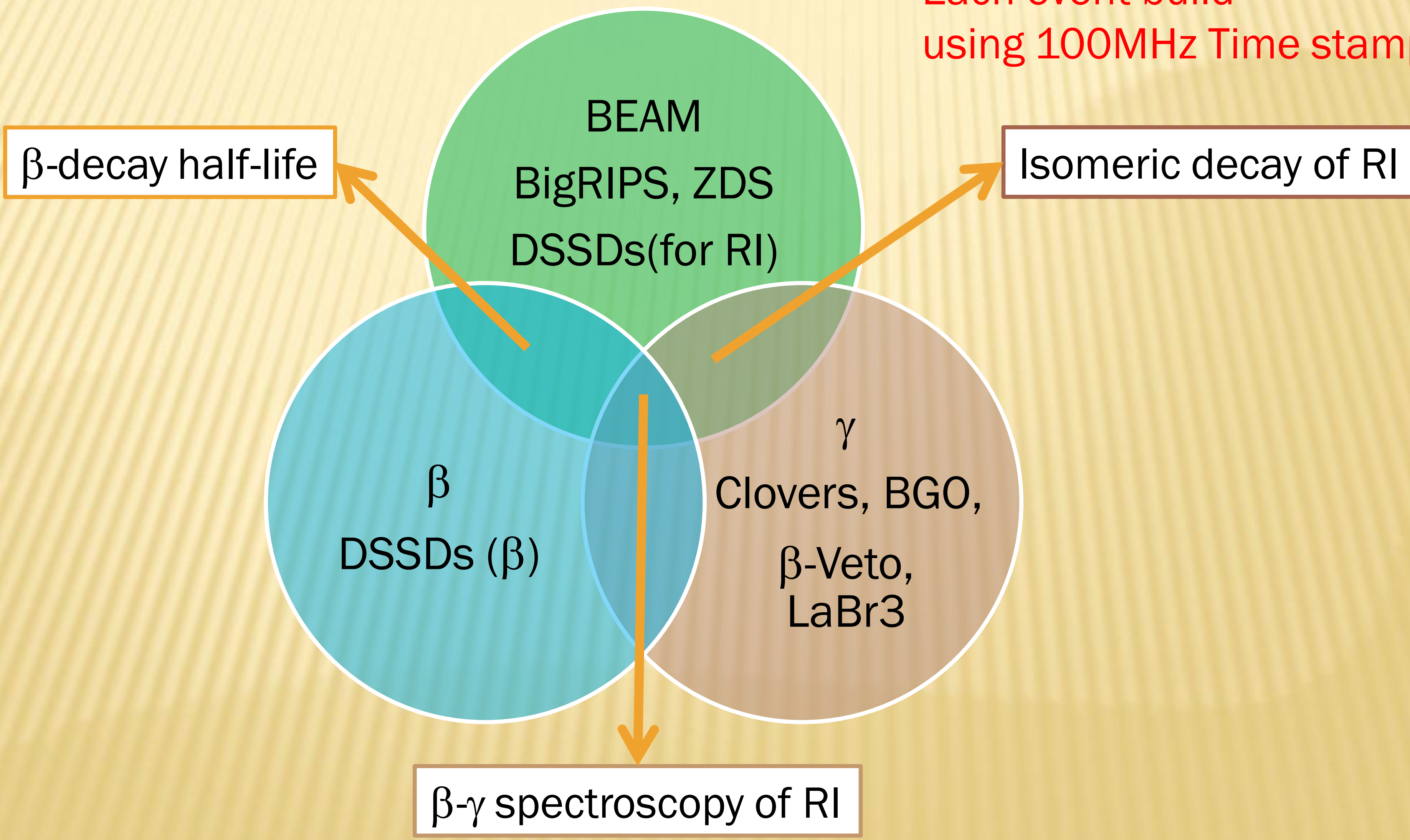
Add-back
(P/T ~ 0.2)

Add-back + Suppression
(P/T ~ 0.3)



100MHz Time stamp DAQ system

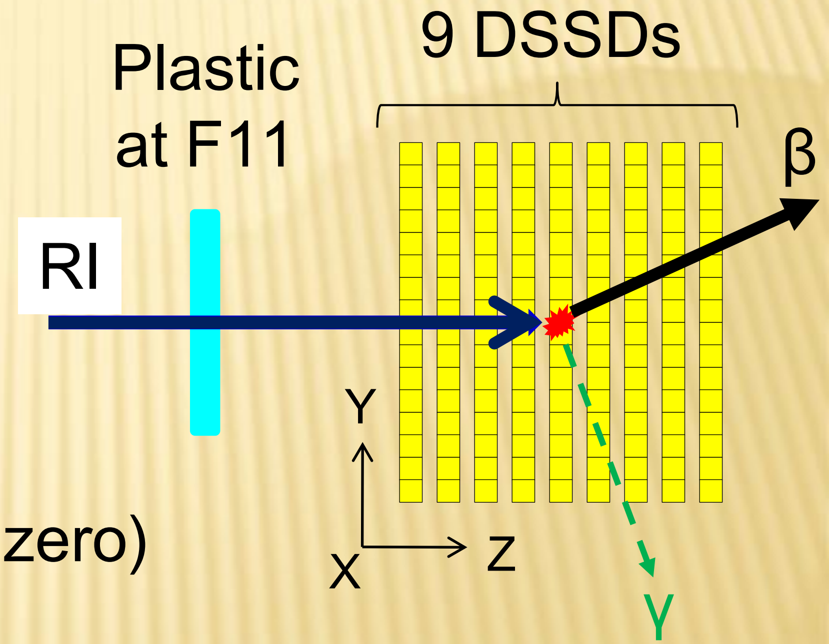
Each event build
using 100MHz Time stamp



Data analysis with time stamp

Particle identification (PID)

- ΔE-TOF-Bρ method using the focal plane detectors in BigRIPS and ZDS



Isomeric decay of RI

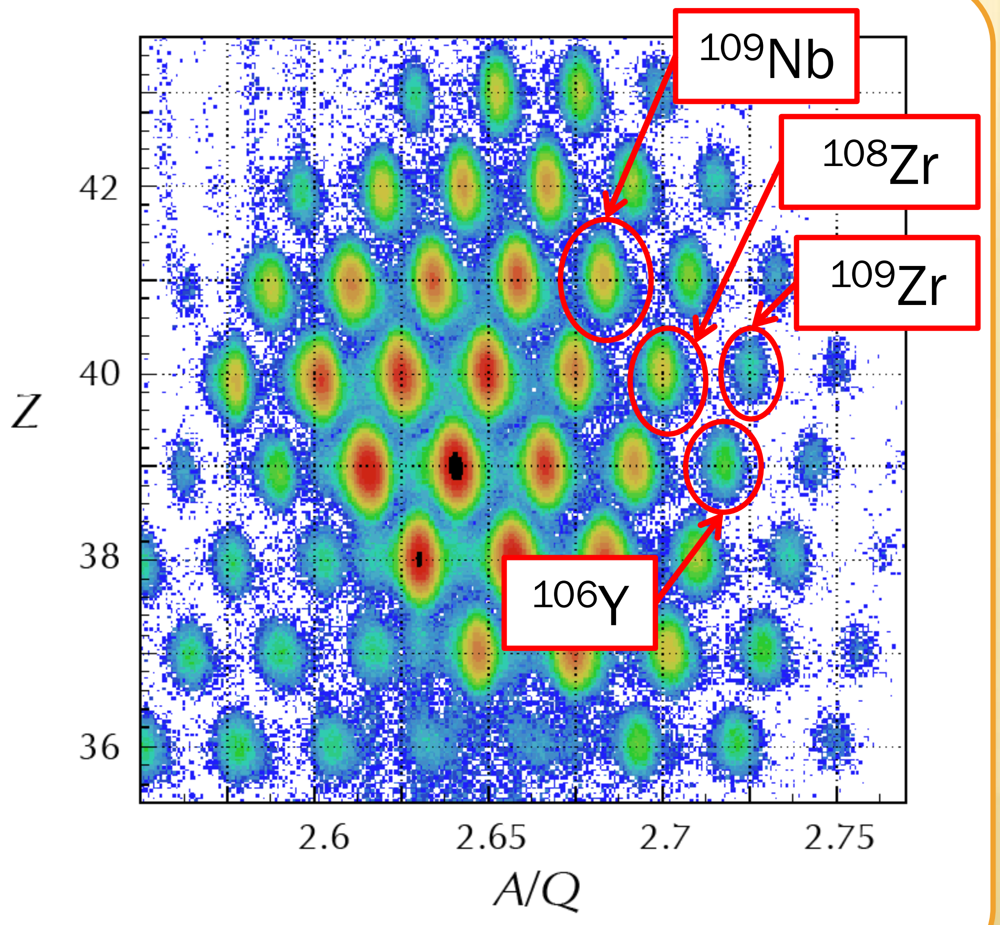
- Delayed coincidence (up to 50 μs) between
  - F11 plastic: Identified RI (time zero)
  - Clover Ge: γ rays

β-decay half-life **β-γ spectroscopy**

- The implantation of an identified RI is associated with the following β-decay events that are detected in the same DSSD pixel

Position of RI stopped
- DSSD strip → X, Y
- DSSD layer → Z

Particle Identification



RI	Yield [count]	Purity [%]
^{106}Y	6.8 x 10^3	0.11
^{108}Zr	2.9 x 10^4	0.45
^{109}Zr	2.1 x 10^3	0.03
^{109}Nb	2.3 x 10^5	3.02

Total count : 6.3 x 10^6

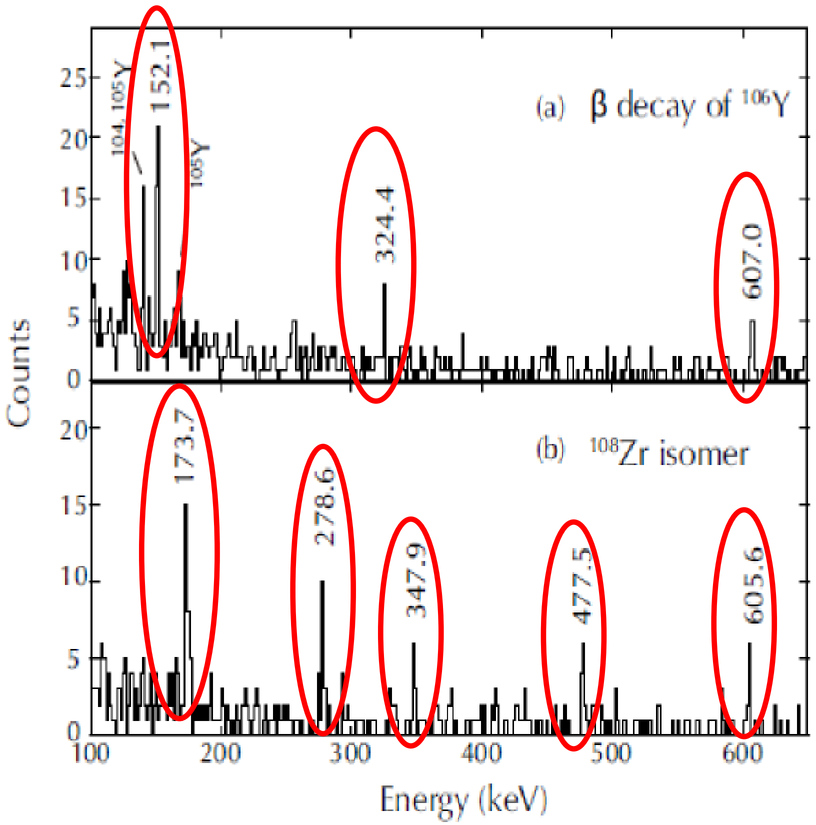
1. Shape evolution of neutron-rich even-even Zr isotopes
2. Possible oblate-shape isomer in ^{109}Nb
3. β-decay half-lives of neutron-rich Kr to Tc isotopes

Result

1. Shape evolution of neutron-rich even-even Zr isotopes
2. Possible oblate-shape isomer in ^{109}Nb
3. β-decay half-lives of neutron-rich Kr to Tc isotopes

Result

Shape evolution of neutron-rich even-even Zr isotopes



T. Sumikama et. al.,
PRL 106, 202501 (2011)

In coincidence with β-decay of ^{106}Y ,
- new 3 peaks observed

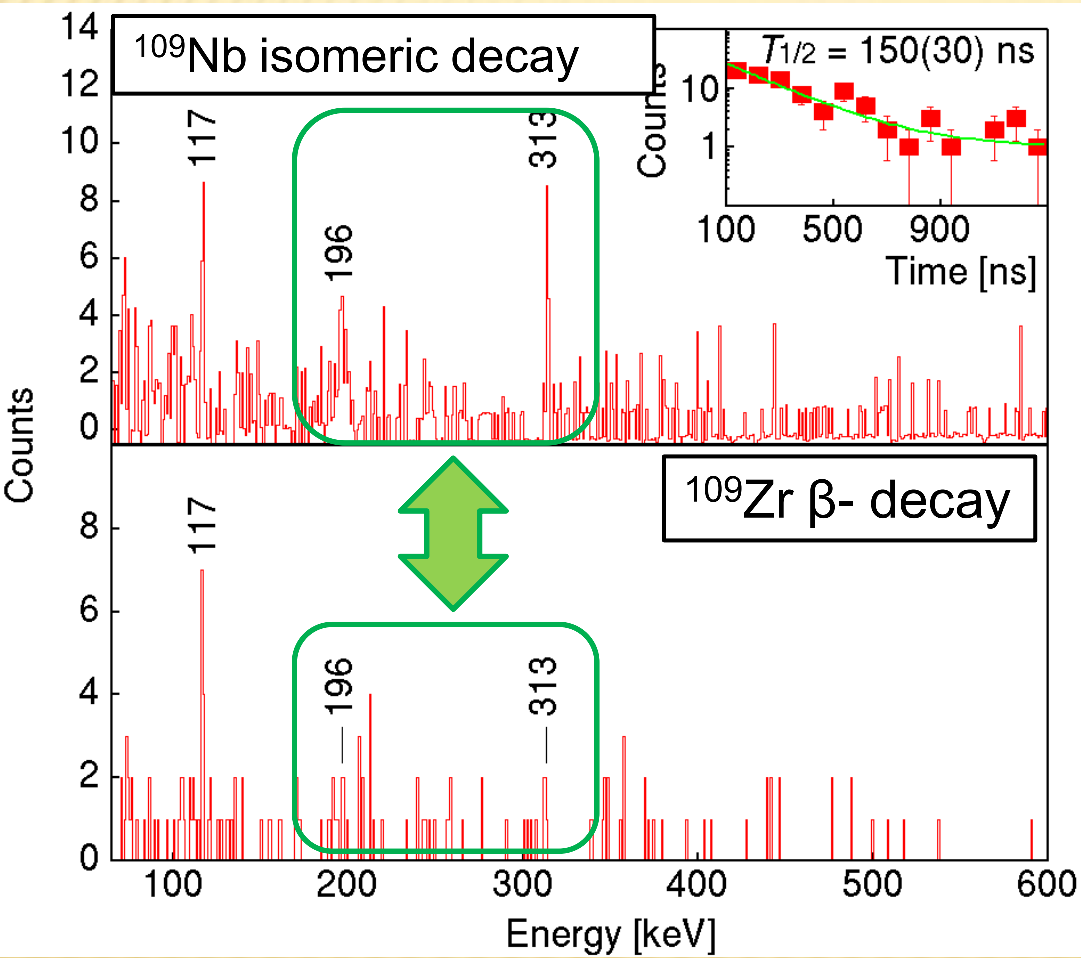
In coincidence with
isomeric-decay of ^{108}Zr,
- new 5 peaks observed

Detail of these results is going to be shown in Dr. Sumikama's talk.

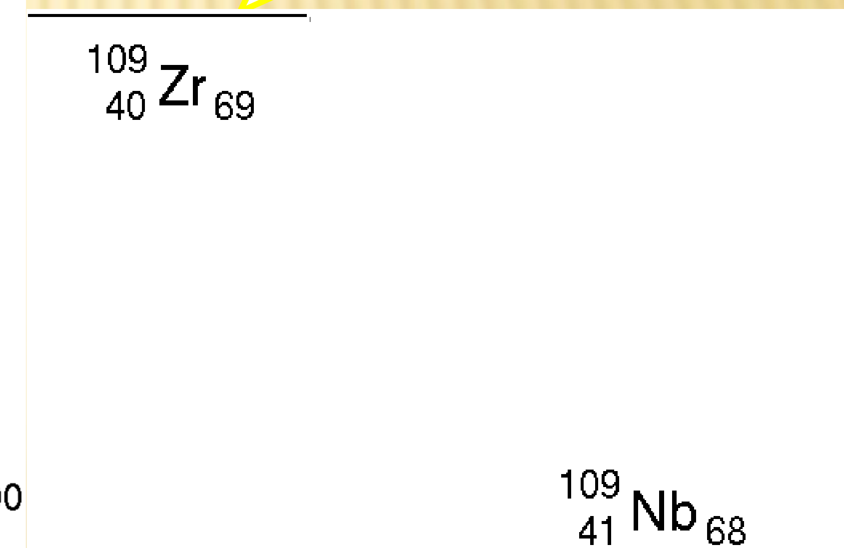
1. Shape evolution of neutron-rich even-even Zr isotopes
2. Possible oblate-shape isomer in ^{109}Nb
3. β-decay half-lives of neutron-rich Kr to Tc isotopes

Result

Possible oblate-shape isomer in ^{109}Nb

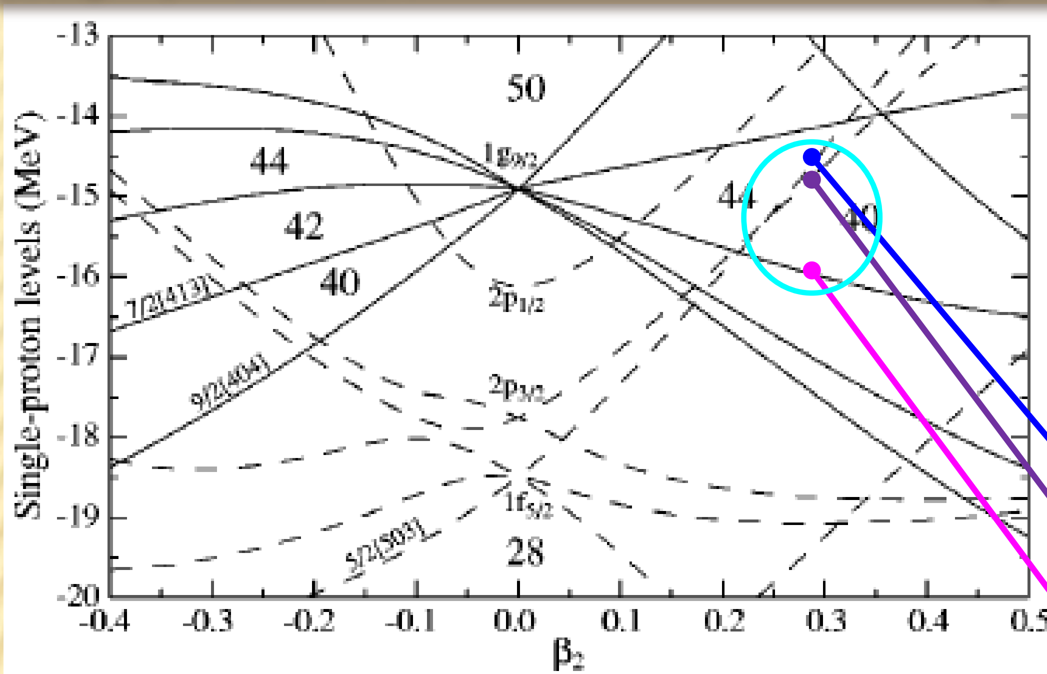


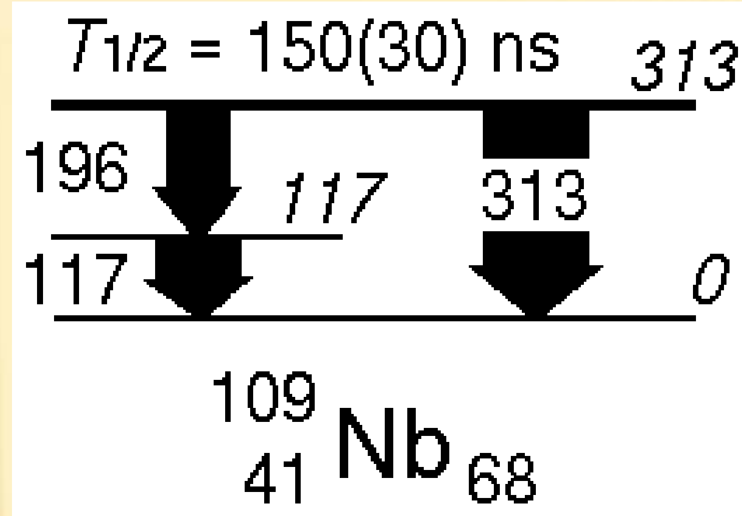
β-decay halfl-ife:
$T_{1/2} = 63^{+38}_{-17}$ ms
S. Nishimura et al.,
PRL 106, 052502 (2011)



H. Watanabe et al., PLB 696, 186 (2011)

Single-proton levels calculated for the ^{110}Zr region





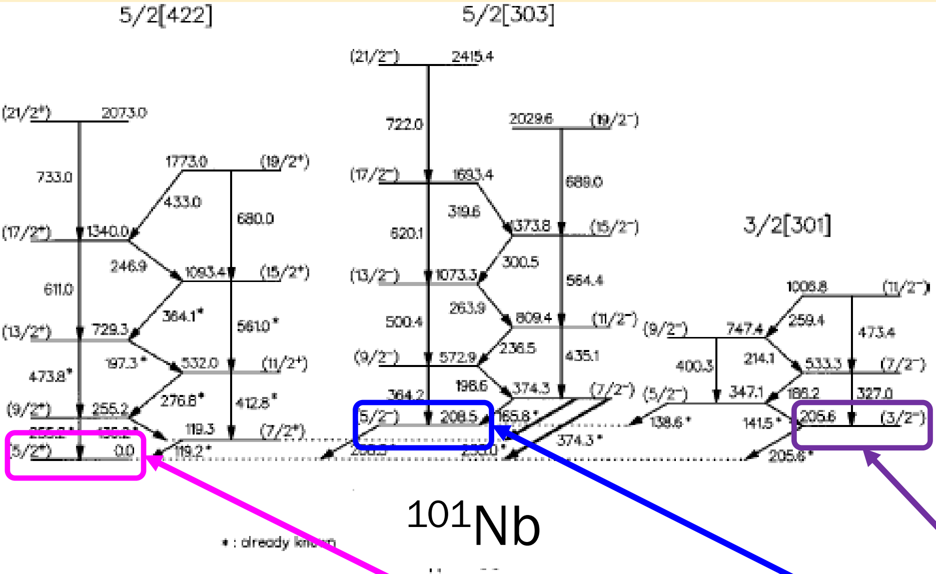
Prolate

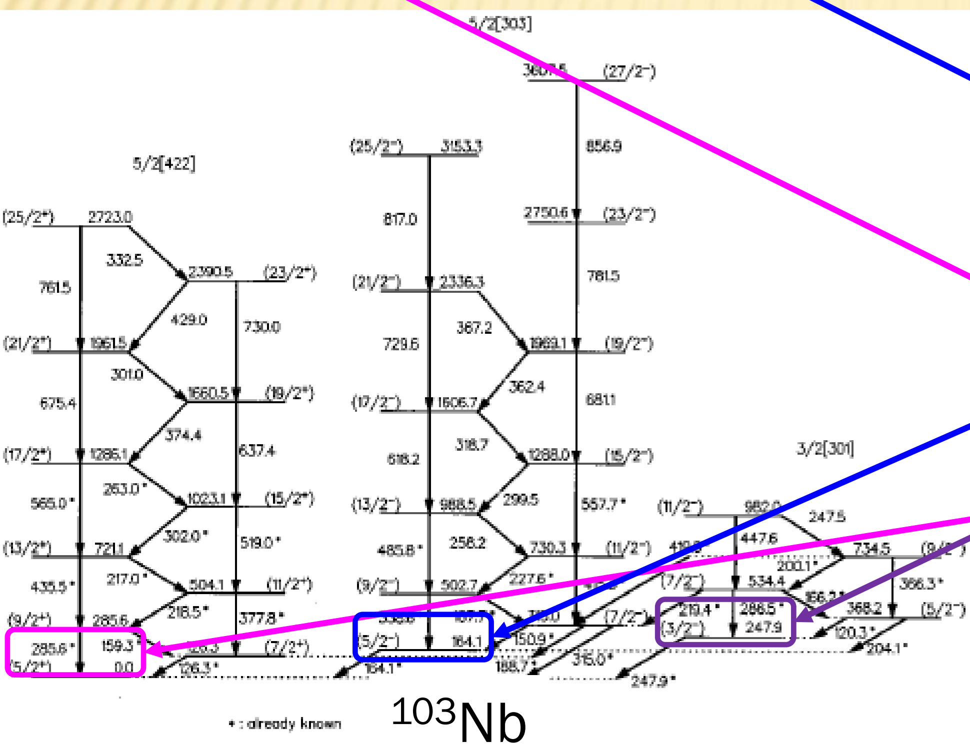
- [303] $5/2^-$
- [301] $3/2^-$
- [422] $5/2^+$

Properties of the $T_{1/2}$ = 150 ns isomer

- E_{ex} = 313 keV much below the pairing gap energies
  - **Single-quasiproton configuration**
- Isomeric ratio ~ 10 %
  - **Yrast trap** ⇒ Spin^{isomer} > Spin$^{g.s.}$

2Δn = 2.1 MeV
2Δp = 2.5 MeV





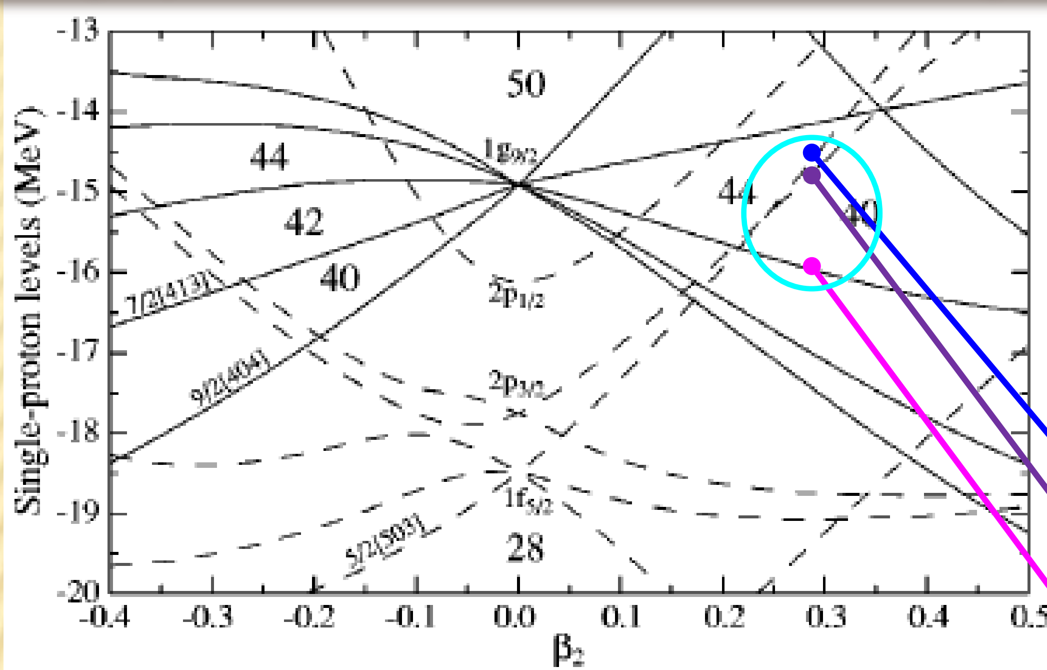
	E_γ [keV]	Transition	B(E1) [W.u.]
^{101}Nb	205.3	**$3/2^- \rightarrow 5/2^+$**	**1.9×10^{-5}**
	208.4	**$5/2^- \rightarrow 5/2^+$**	**4.2×10^{-5}**
^{103}Nb	164.1	**$5/2^- \rightarrow 5/2^+$**	**1.3×10^{-5}**
	247.6	**$3/2^- \rightarrow 5/2^+$**	**1.6×10^{-5}**

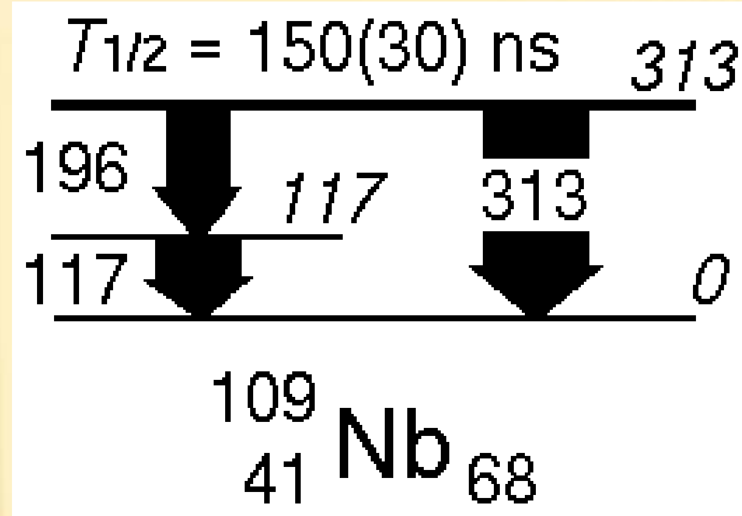
Prolate

- [303] $5/2^-$
- [301] $3/2^-$
- [422] $5/2^+$

J. K. Hwang et al., PRC 58, 3252 (1998)

Single-proton levels calculated for the ^{110}Zr region





Prolate

- [303] $5/2^-$
- [301] $3/2^-$
- [422] $5/2^+$

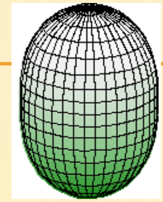
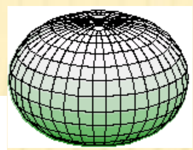
Isomeric decays in ^{109}Nb

Strongly hindered

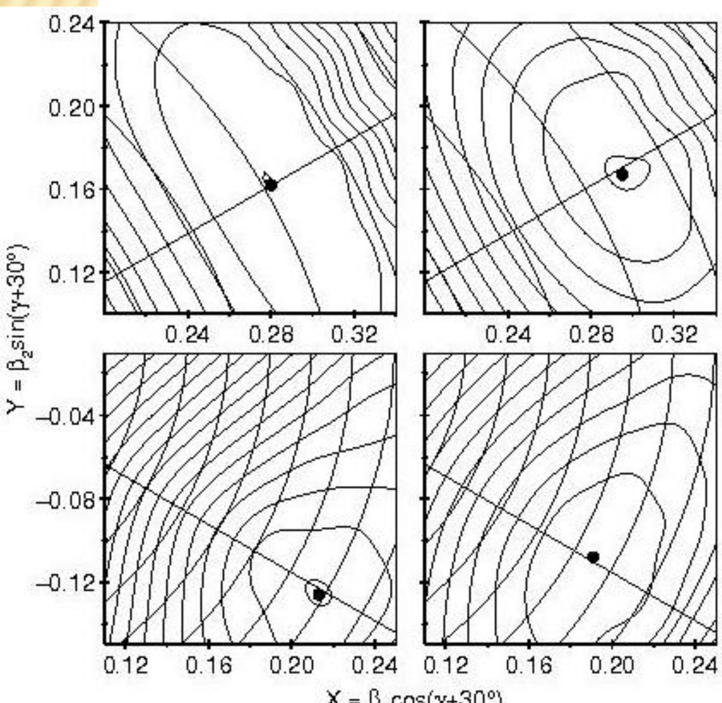
E_γ (keV)	I_γ[%] (relative)	B(σλ) [W.u.]			
		E1	M1	E2	M2
313.1	62(20)	3.9×10^{-8}	2.9×10^{-6}	2.4×10^{-2}	~~1.8~~
196.3	38(14)	1.0×10^{-7}	7.2×10^{-6}	1.5×10^{-1}	~~11~~

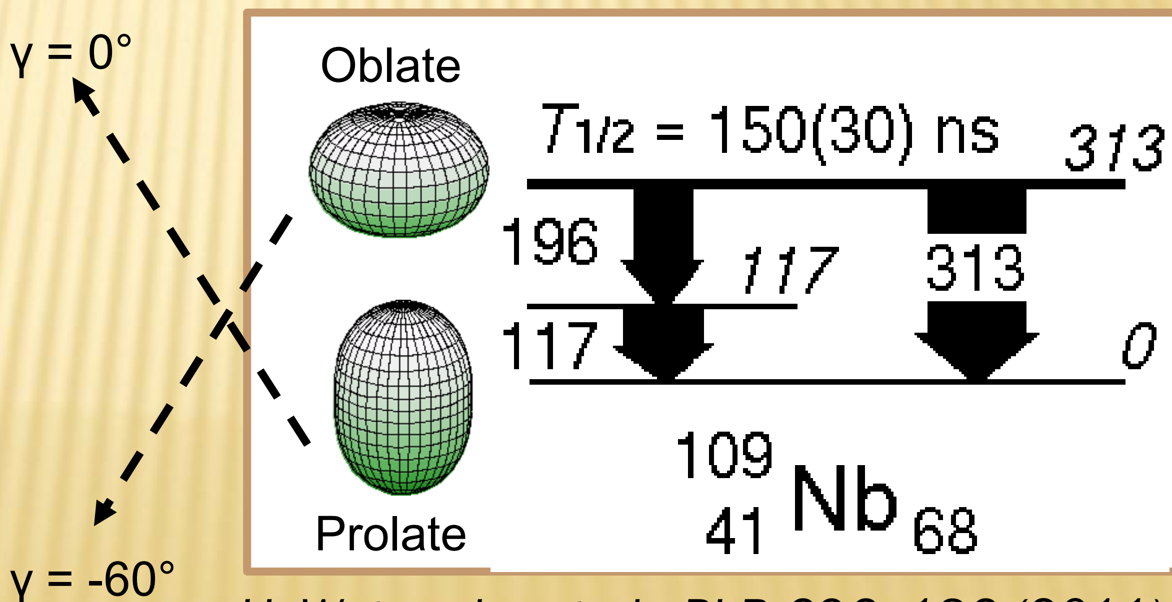
Another possible explanation for this strong hindrance is Prolate-oblate shape coexistence

courtesy of
Y. Shi and F.R. Xu,
Peking University Gr.

	K^{π}	$\Omega[Nn_z\Lambda]$	β_2	β_4	γ	E_{ex}
Prolate	$3/2^-$	3/2[301]	0.324	- 0.030	0°	0
	$1/2^+$	1/2[431]	0.364	- 0.028	0°	96
	$5/2^-$	5/2[303]	0.313	- 0.026	0°	310
	$7/2^+$	7/2[413]	0.339	- 0.046	0°	388
	$5/2^+$	5/2[422]	0.312	- 0.023	0°	398
Oblate	$7/2^+$	7/2[413]	0.219	- 0.035	- 60°	301
	$1/2^-$	1/2[321]	0.251	- 0.031	- 51°	554
	$3/2^-$	3/2[321]	0.247	- 0.030	- 61°	804
	$9/2^+$	9/2[404]	0.211	- 0.043	- 60°	1051

$K^{\pi} = 3/2^-$ $K^{\pi} = 7/2^+$





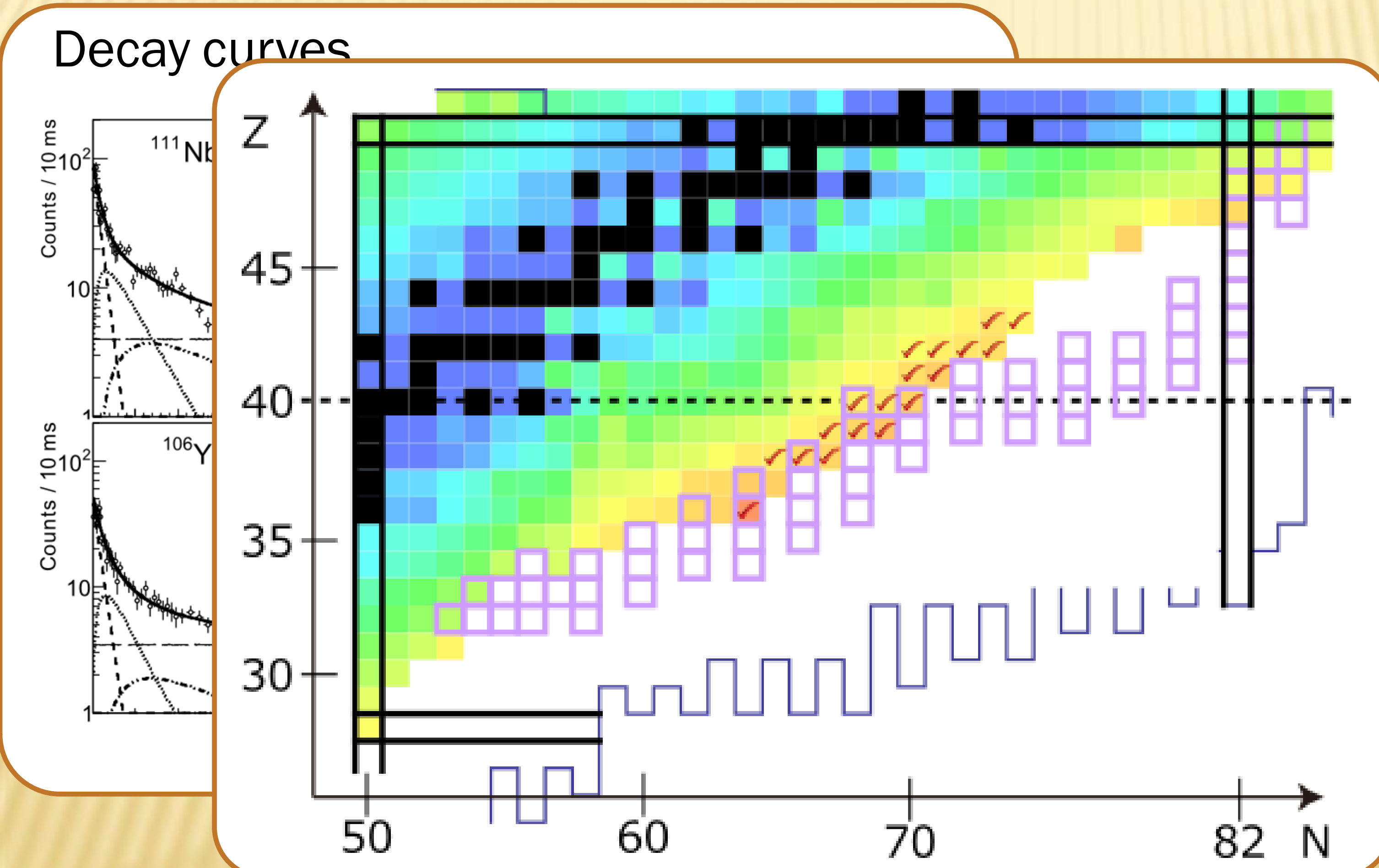
H. Watanabe et al., PLB 696, 186 (2011)

1. Shape evolution of neutron-rich even-even Zr isotopes
2. Possible oblate-shape isomer in ^{109}Nb
3. β-decay half-lives of neutron-rich Kr to Tc isotopes

Result

β-decay half-lives on r-process path

Decay curves



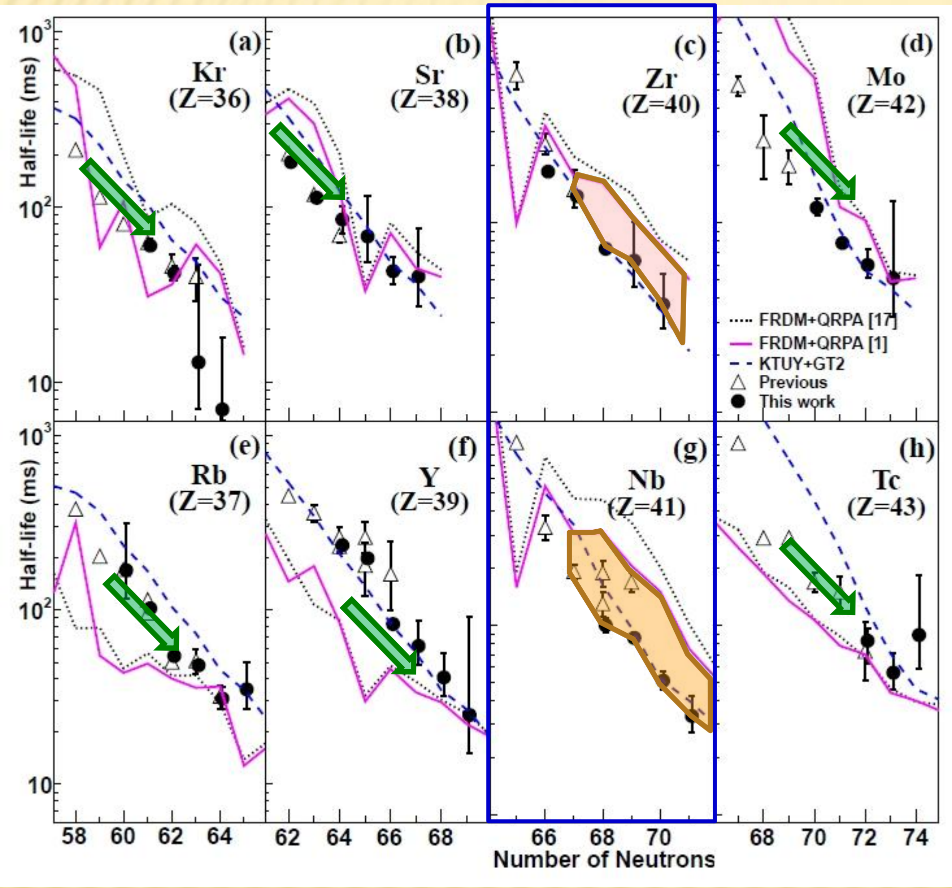
38 half-lives

18 half-lives

A
7 ~ 100
7 ~102
0 ~ 105
3 ~ 108
6 ~ 110
9 ~ 112
2 ~ 115
5 ~ 117

S. Nishimura et al., PRL 106, 052502 (2011)

Compare with theoretical values



Zr and Nb decay faster than expected by FRDM+QRPA ($T_{1/2}$: 1/2 ~ 1/3 ~)

S. Nishimura et al., PRL 106, 052502 (2011)

Summary

- First $\beta-\gamma$ spectroscopy experiment
  with 345 MeV/A U-beam at RIBF
- Results
  - Shape evolution of neutron-rich even-even Zr isotopes
  - Oblate shape isomer of ^{109}Nb isotopes
  - The half-lives of 18 nuclei are newly obtained.
- In progress
  - Analysis and study for neutron-rich Sr, Y, Zr, Mo isotopes

Thank you for your attention