Isomeric Decay Spectroscopy at RIKEN RI Beam Factory

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Presentation for **Workshop on Nuclear Isomers: Structure and Applications**
19 – 21 May at the University of Surrey

Outline

- RI Beam Factory (RIBF) facility
  - Accelerators
  - Projectile Fragment Separator
    (BigRIPS/ZeroDegree)
- Decay spectroscopy at RIBF
  - Experimental setup and procedure
  - Outlook of isomeric decay spectroscopy
    - ^{132}Sn region
    - ^{70}Fe region
- Summary

RIKEN RIBF facility

Old accelerators
(since 1986)

RILAC

RRC

AVF

Old facility

New facility

BF1

BF2

0

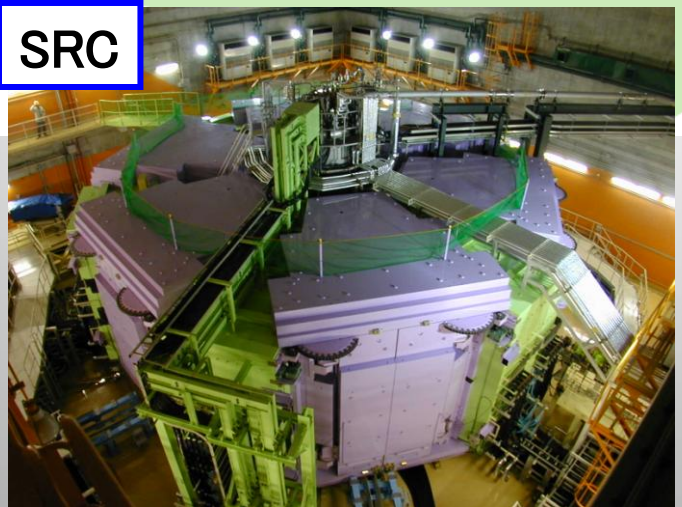
50 m

fRC

IRC

SRC

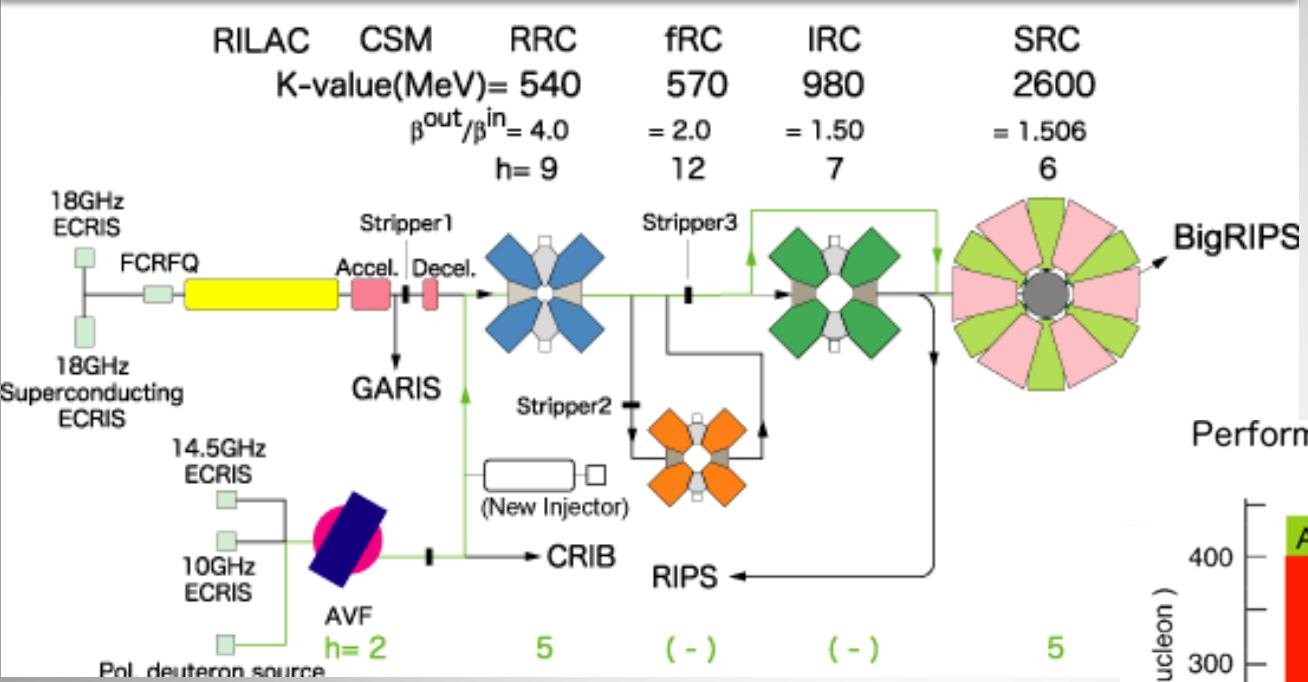
BigRIPS

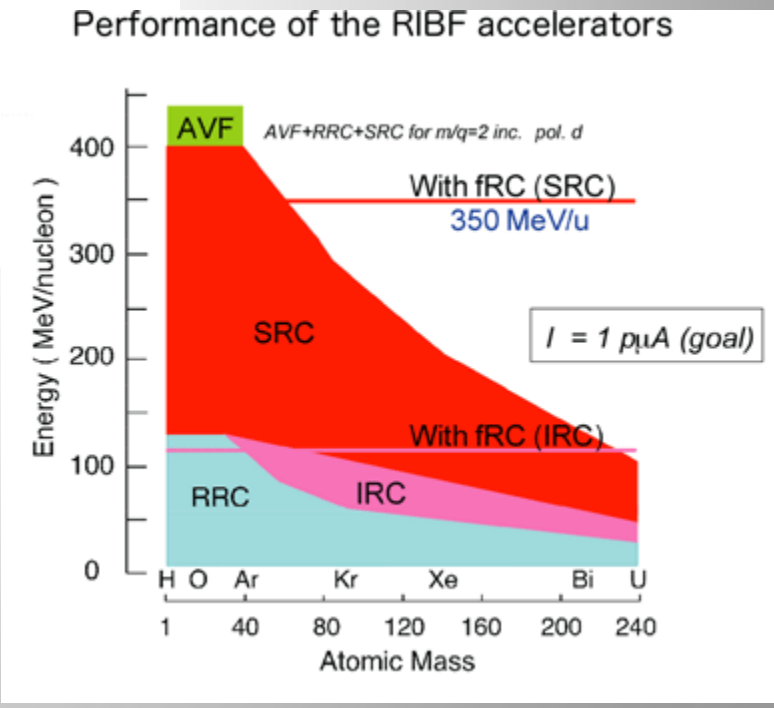


New accelerators
(since 2006)

RIBF accelerator system

Operation mode for 345 MeV/u H.I. beams





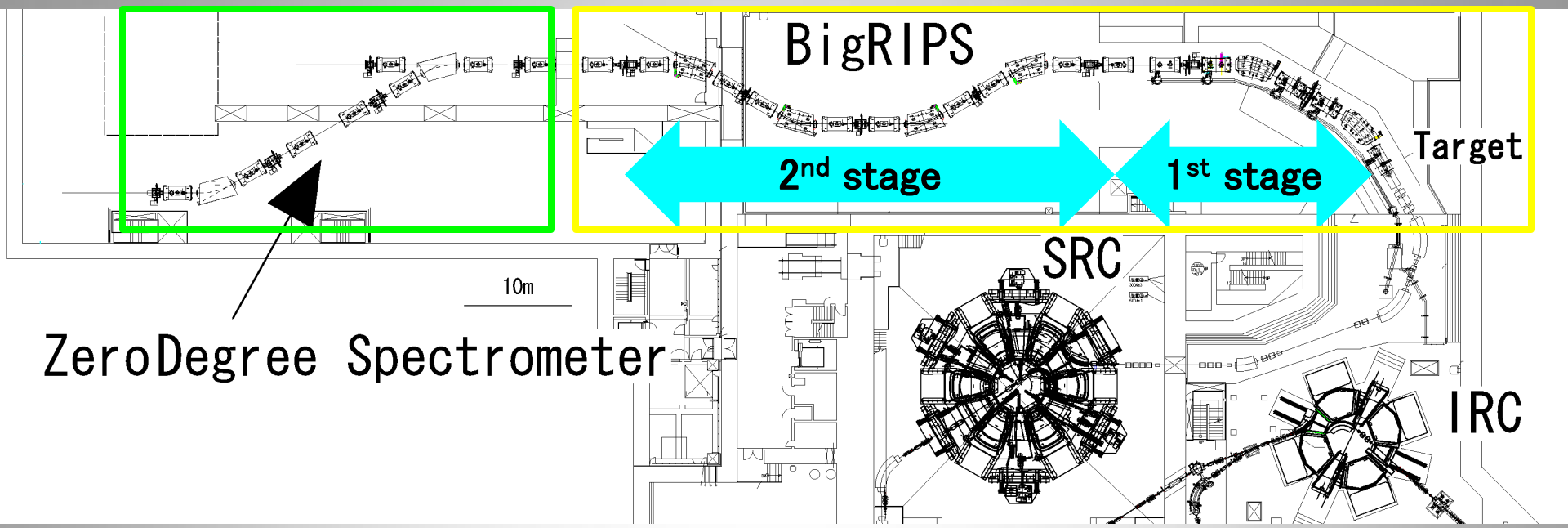
◆ Intensity of 345 MeV/u ^{238}U beam

Present: 0.3 pnA (November 2008)

Final goal: 1 pμ A (within 4–5 years)

For more information → **http://www.nishina.riken.jp/Eng/index.html**

BigRIPS/ZeroDegree spectrometer



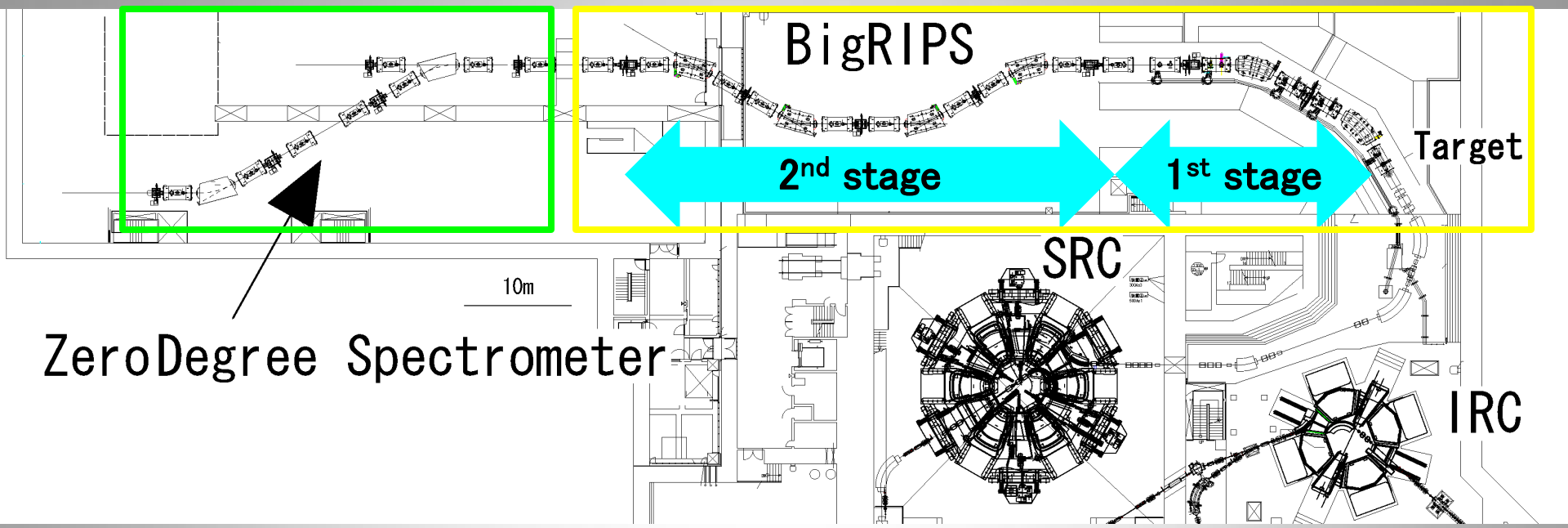
BigRIPS

- Two-stage fragment separator ($B\rho_{max}$ = 9 Tm)
  - 1st stage : production & separation
  - 2nd stage : identification

ZeroDegree

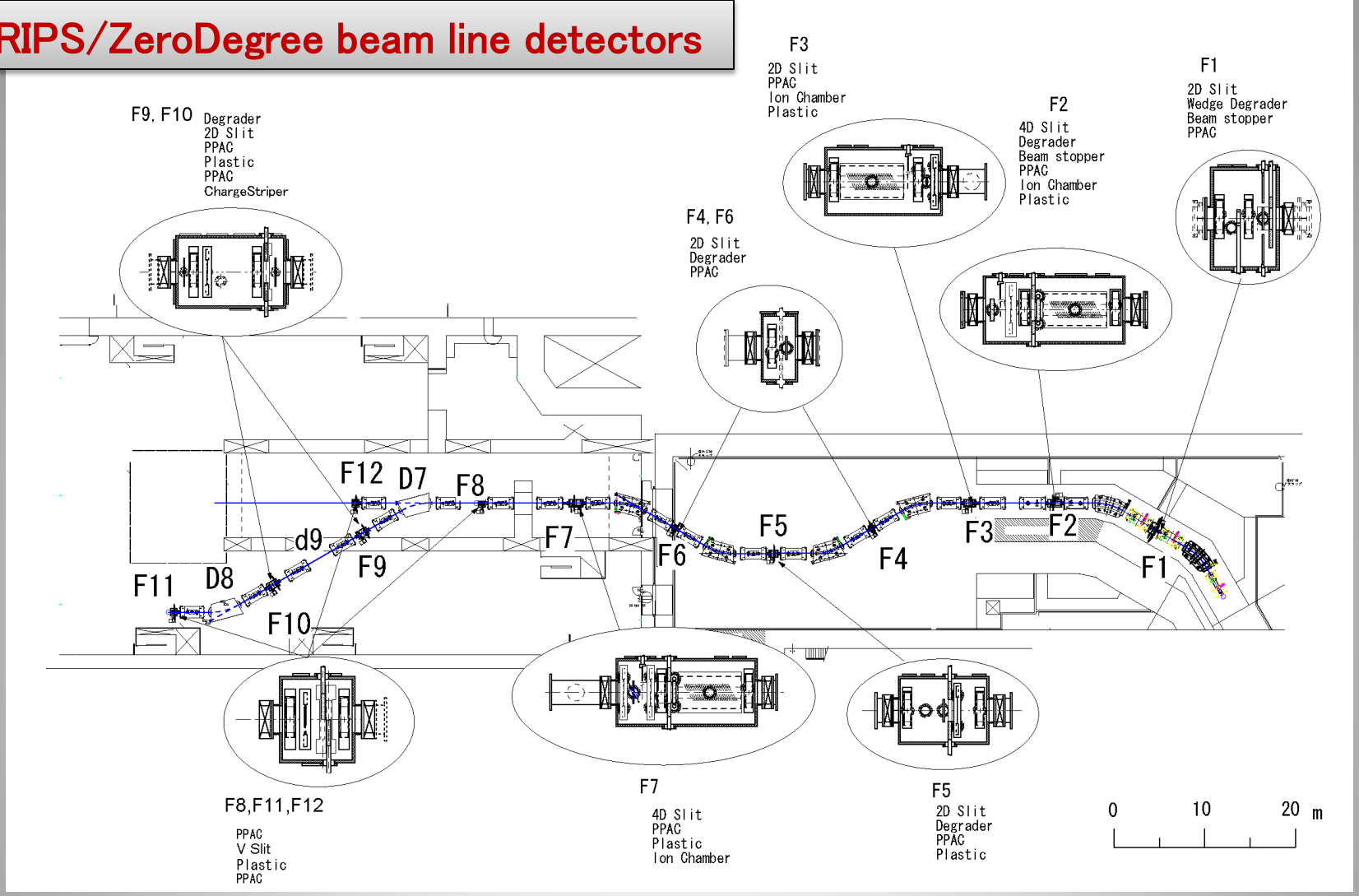
- Multi-function spectrometer
  - Tagging of secondary reaction products
  - Momentum distribution measurement

BigRIPS/ZeroDegree spectrometer



	Δ θ	Δ φ	Δ p/p	Momentum resolution (1st order)
BigRIPS	80 mr	100 mr	6 %	1300, First stage
				3300, Second stage
ZeroDegree	90 mr	60 mr	6 %	1240, Achromatic (Large acceptance)
	40 mr	60 mr	6 %	2100, Achromatic (High resolution)
	40 mr	60 mr	4 %	4100, Dispersive

BigRIPS/ZeroDegree beam line detectors

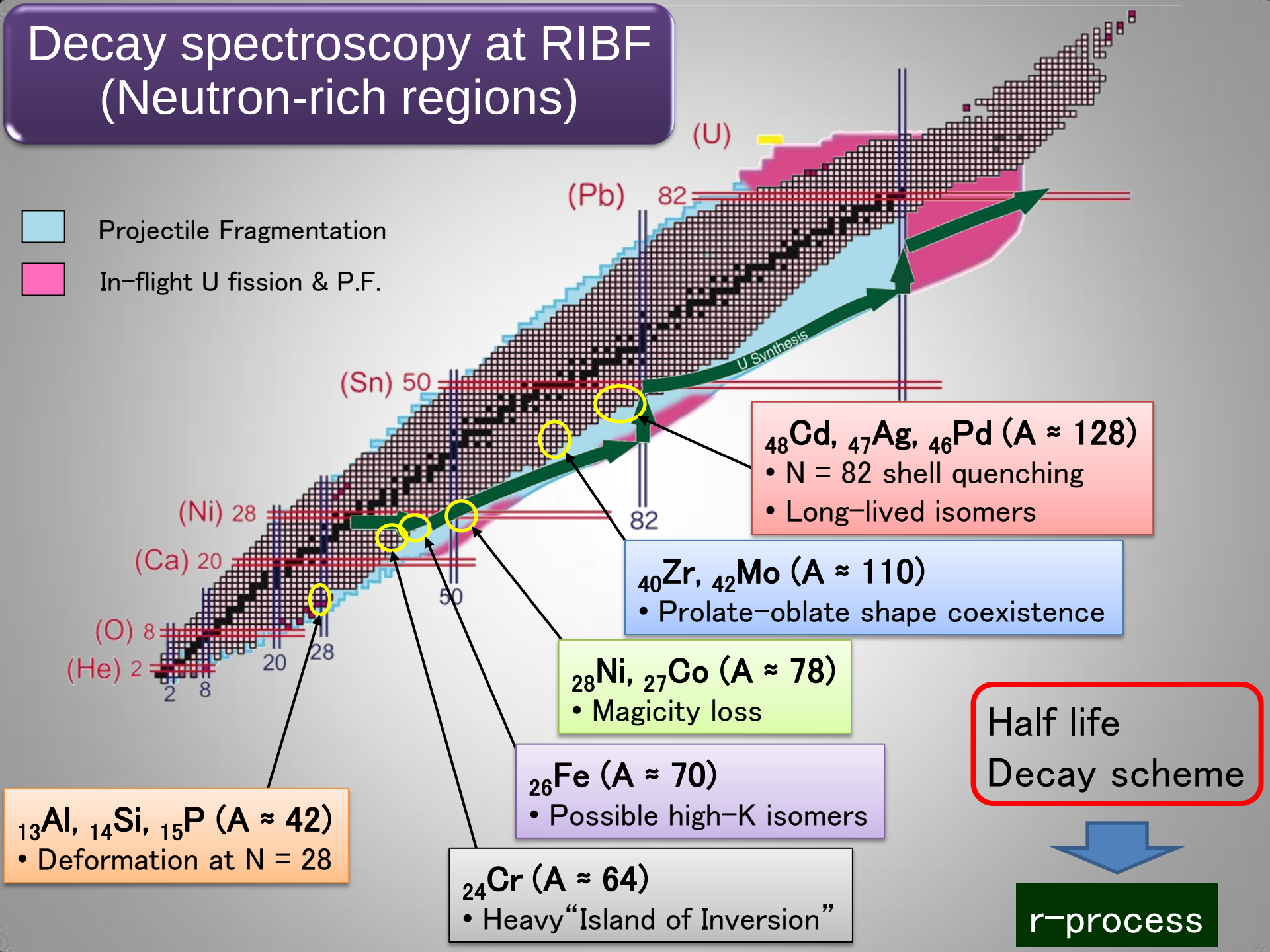


Particle identification (PID)

PPAC : Position
Plastic : Time of flight
I.C. or Si : Energy loss

A/Q
Z

Decay spectroscopy at RIBF (Neutron-rich regions)



NP-26 Collaboration

RIKEN Nishina Center	S. Nishimura, H. Watanabe, Z. Li, H. Sakurai, H. Baba M. Nishimura, T. Isobe, H. Scheit , P. Doornenbal, D. Steppenbeck
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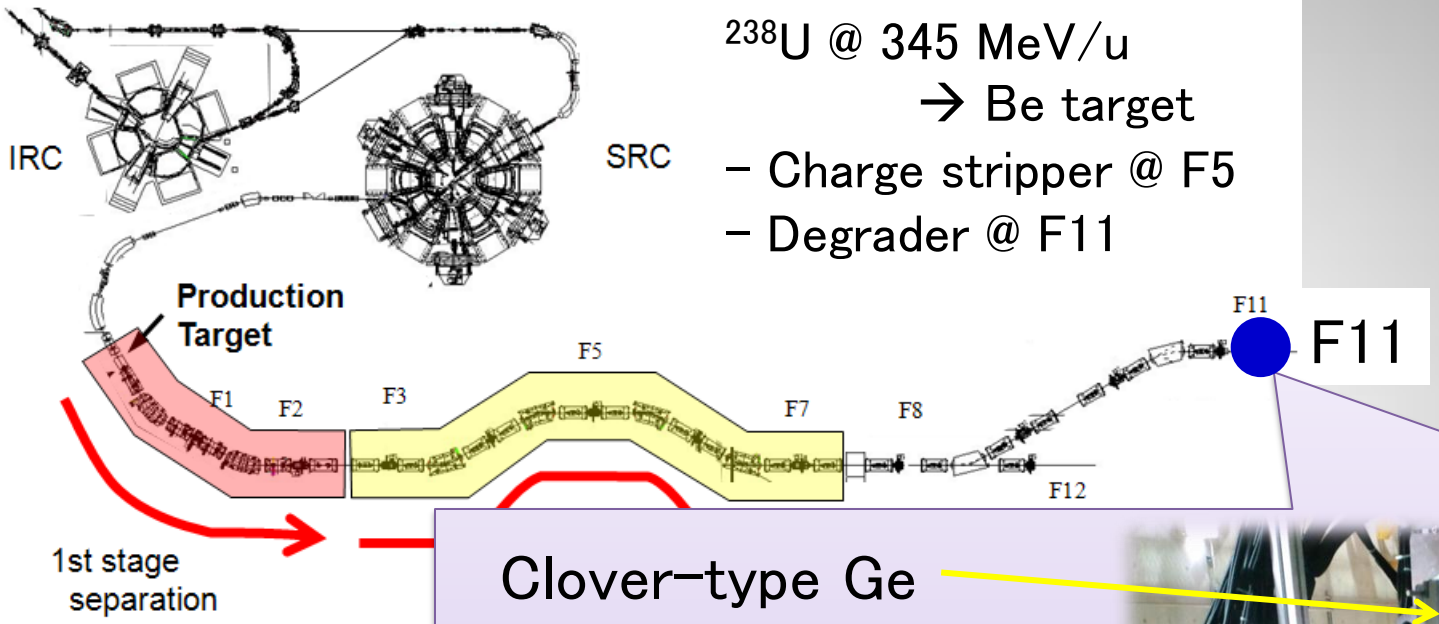
Osaka Univ.	K. Yamaguchi, A. Odahara, A. Takashima, Y. Ito, K. Tajiri, T. Shimoda
RCNP Osaka Univ.	H.J. Ong
Tokyo Inst. Tech.	N. Kobayashi, Y. Kawada, Y. Kondo, T. Nakamura
CNS Tokyo Univ.	E. Ideguchi, S. Go, S. Ota, S. Kubono, H. Yamaguchi T. Hashimoto, S. Hayakawa
JAEA	Y.Wakabayashi
Kyushu Univ.	T.Teranishi
MSU	G. Lorusso
TU München	C. Hinke, K. Steiger, R. Kruecken
INFN	O. Wieland, N. Blasi
Milano	A. Bracco, F. Camera
Surrey	Z. Podolyák, P. Walker
LBNL	J. Berryman

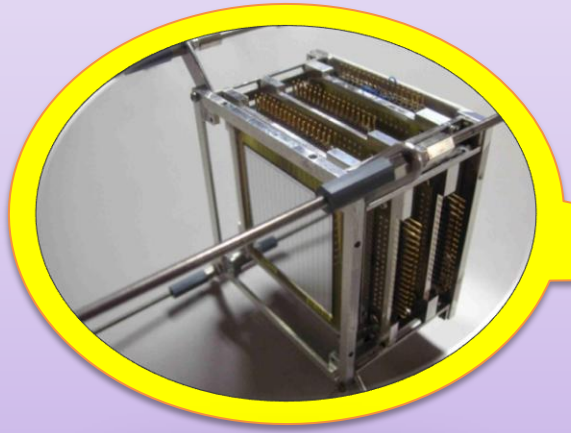
Experimental setup for decay spectroscopy



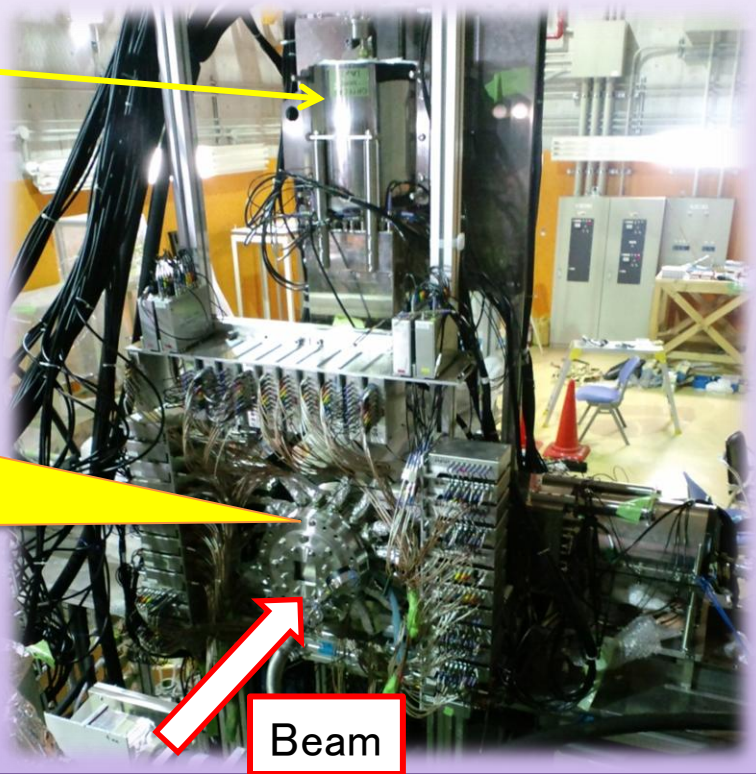
^{238}U @ 345 MeV/u
→ Be target
– Charge stripper @ F5
– Degrader @ F11

F11

Clover-type Ge



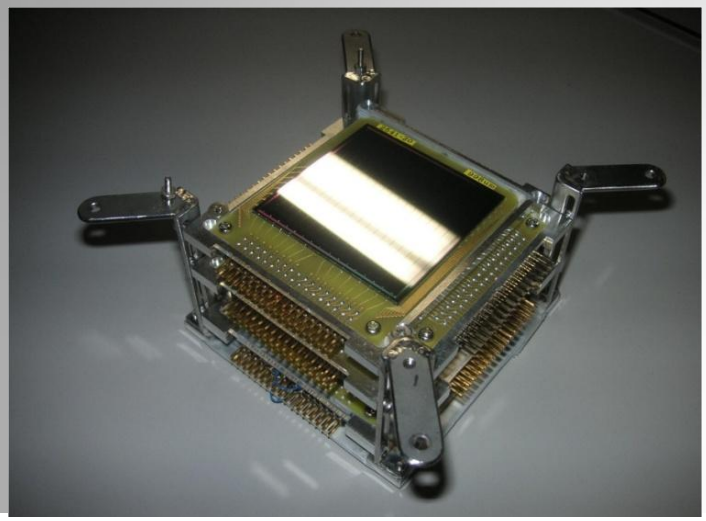
Stacked DSSSDs

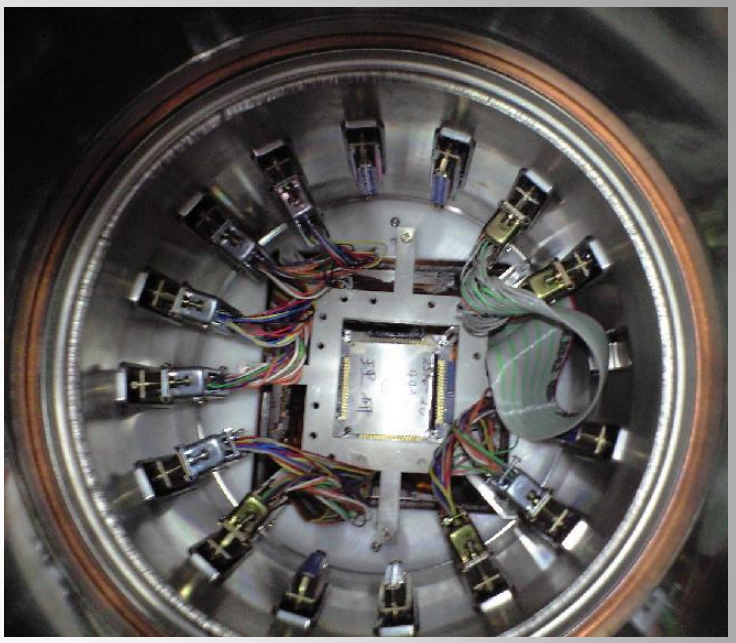


Beta counting system : DSSSD

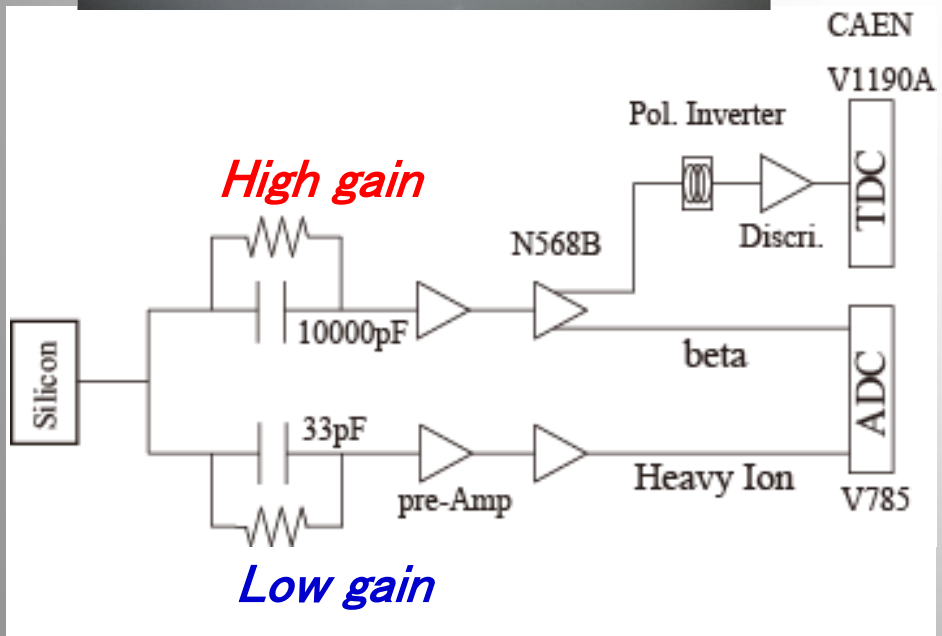
9 stacked Double-Sided-Silicon-Strip-Detectors

Micron W1 (16 x 16 strips)





Courtesy of S. Nishimura

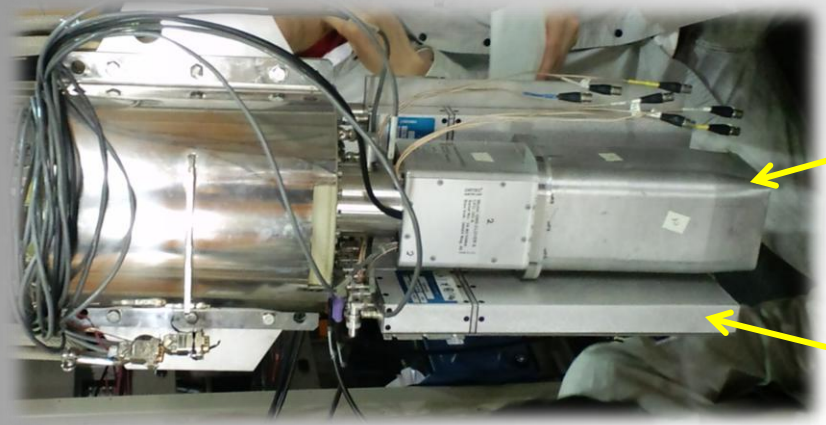


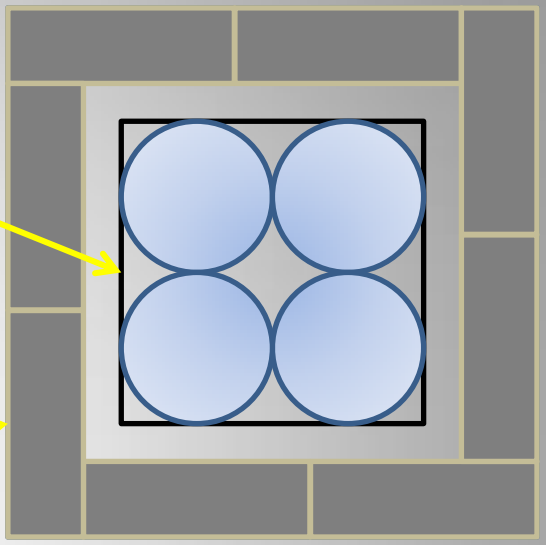
NEEDS

Very wide dynamic range

- ✓ Incident beam : ～ 5 GeV
- ✓ Energy threshold : ～ 20 keV

Compton-suppressed Clover-type Ge detector

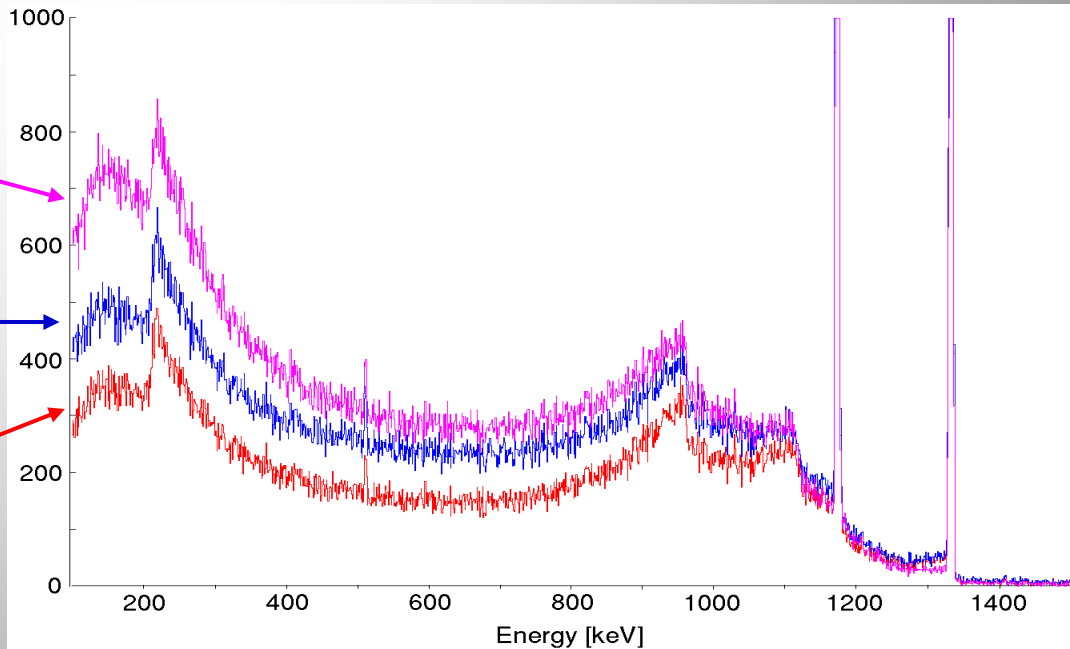




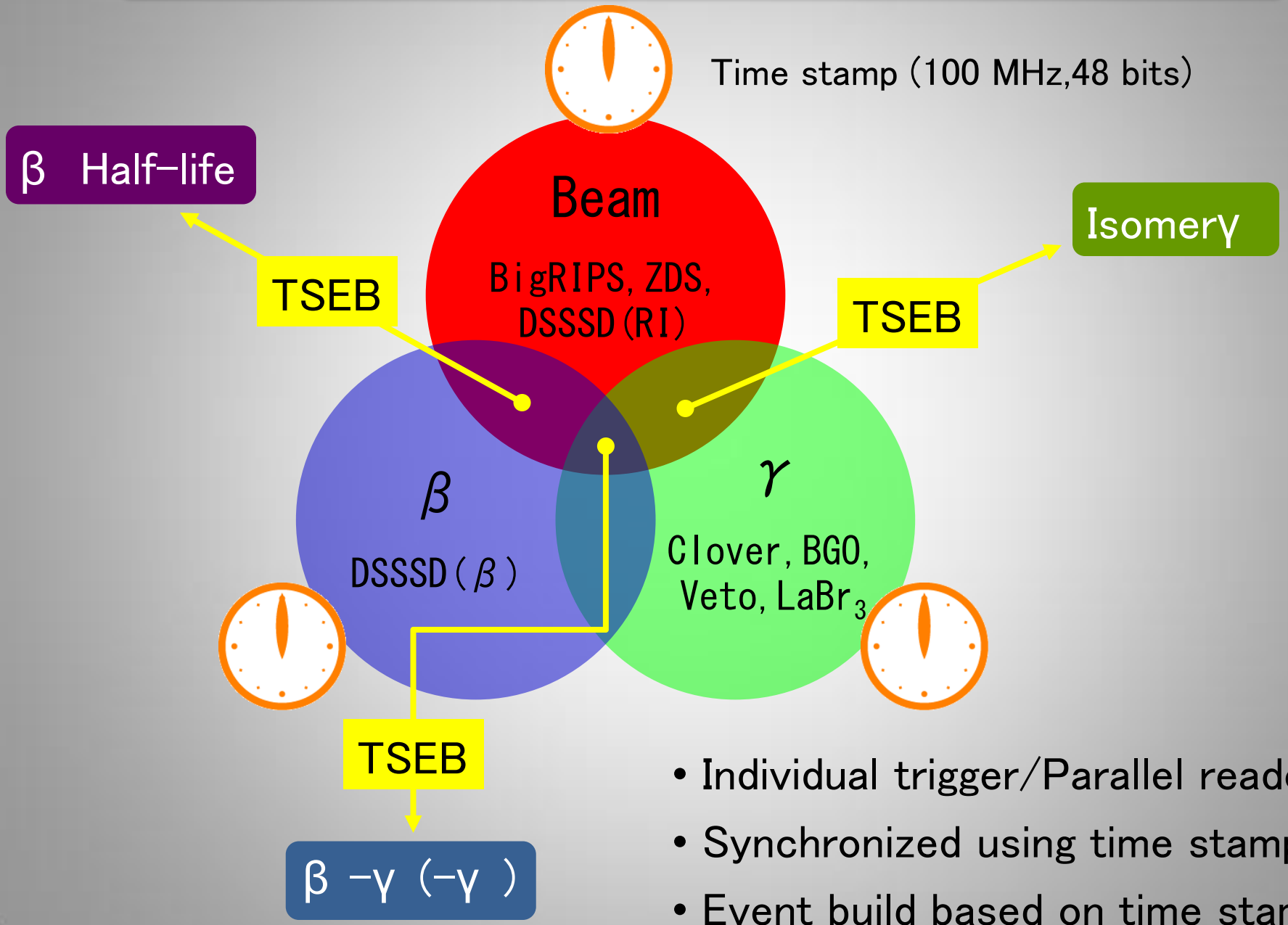
Sum of 4 crystals
(P/T～0.1)

Add-back
(P/T～0.2)

Add-back + Suppression
(P/T～0.3)



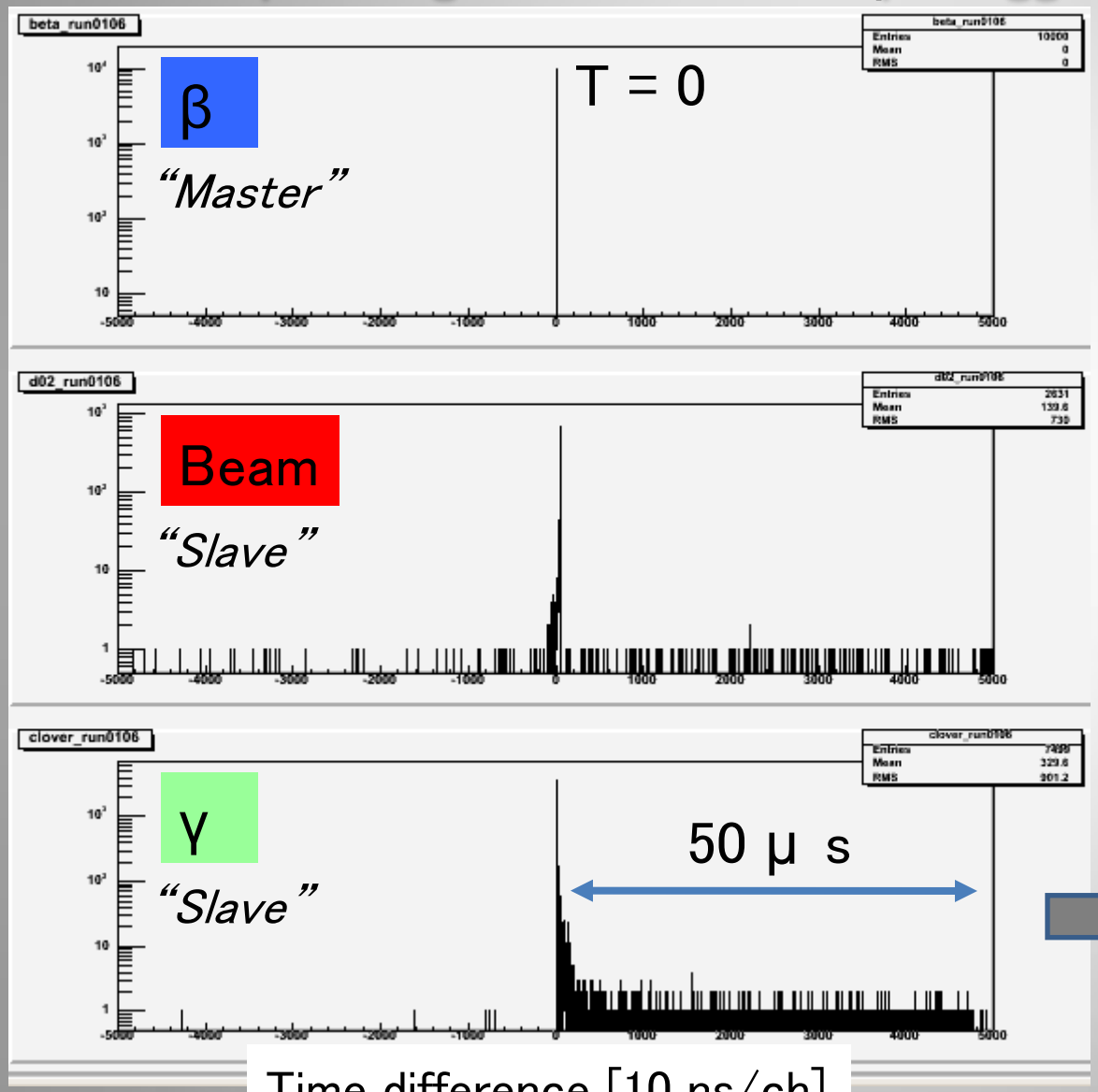
DAQ for decay spectroscopy experiment



- Individual trigger/Parallel readout
- Synchronized using time stamp
- Event build based on time stamp

Time stamp based event build for β-γ analysis

Time stamp histograms relative to β trigger

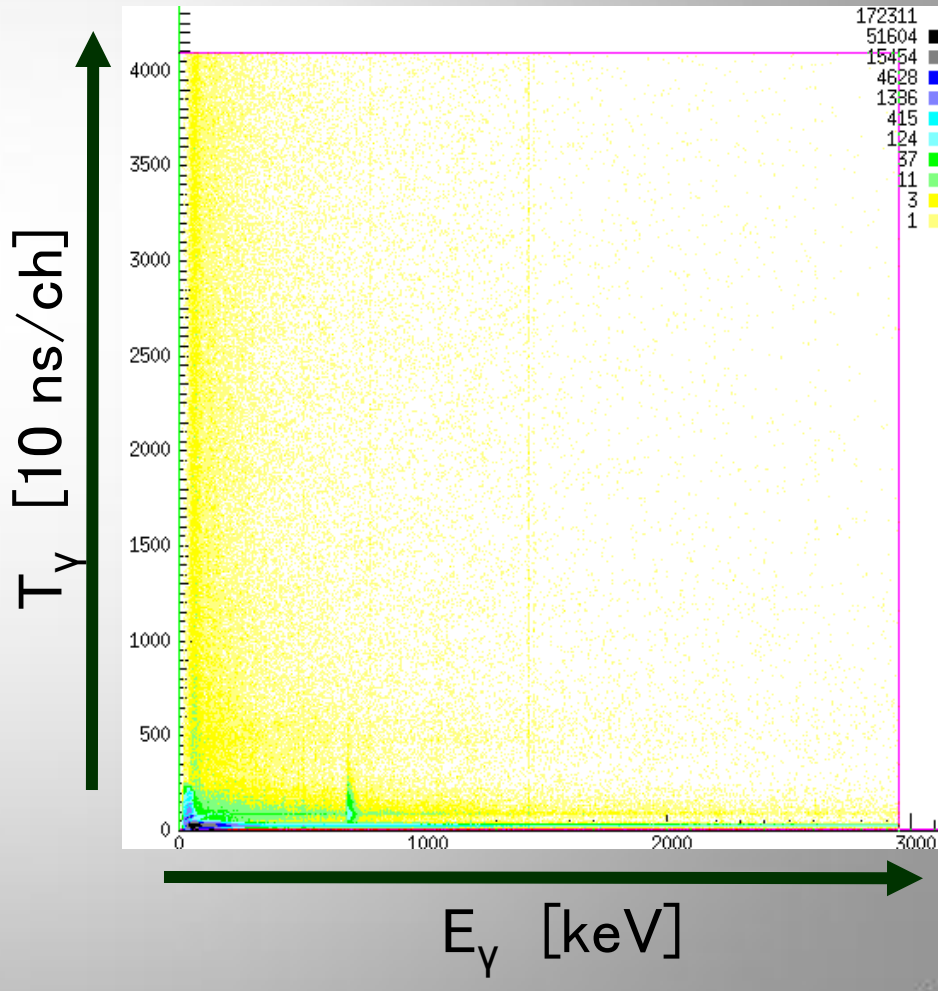


Width and Offset adjusted to analysis

Measurement of isomeric γ rays ($T_{1/2}$ ~ μs)

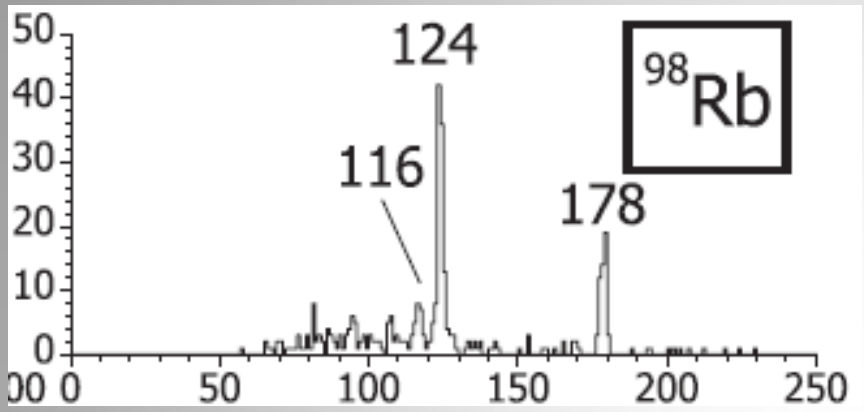
- Delayed γ -ray coincidence (up to 50 μ s) with beams

Identification of isomers in the μ s range



Time difference between Clover and Plastic at F11 (time-walk corrected)

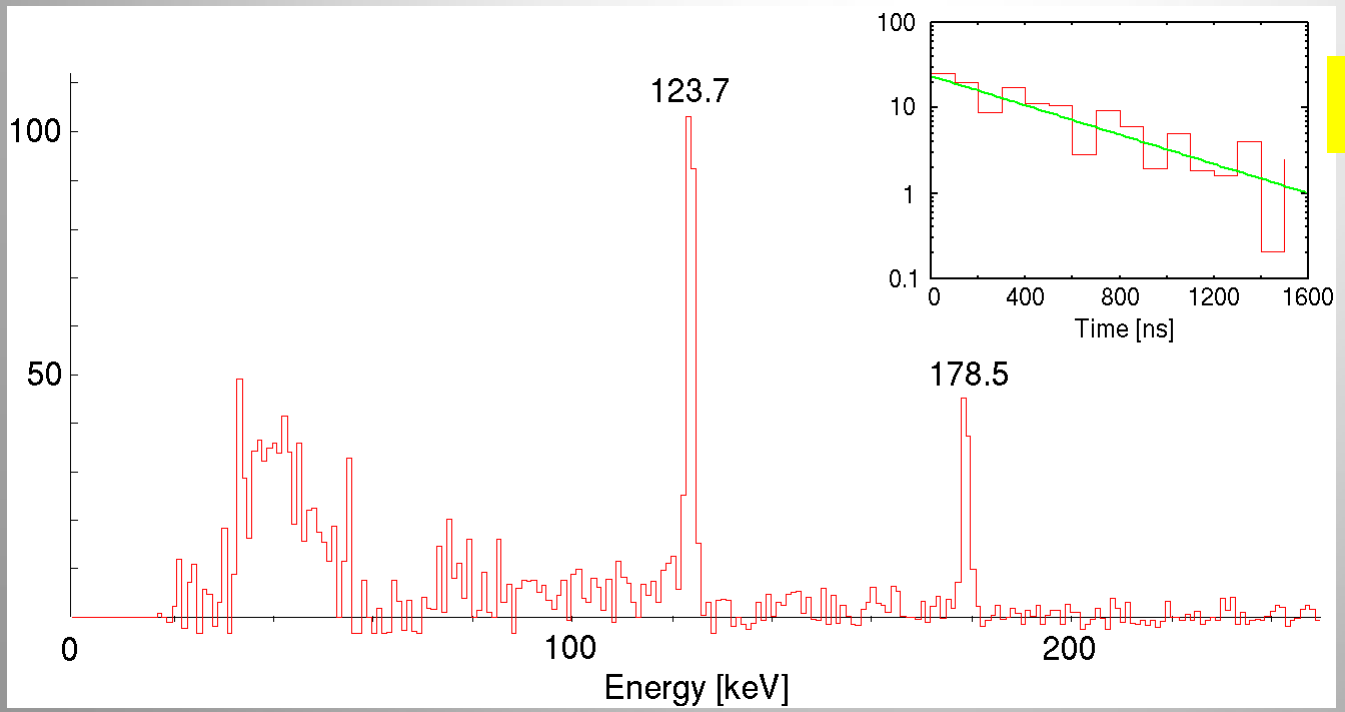
Measurement of isomeric γ rays ($T_{1/2}$ ~ μs)



Example

Identified by MSU group (2009)

$T_{1/2}$ = 700(50) ns

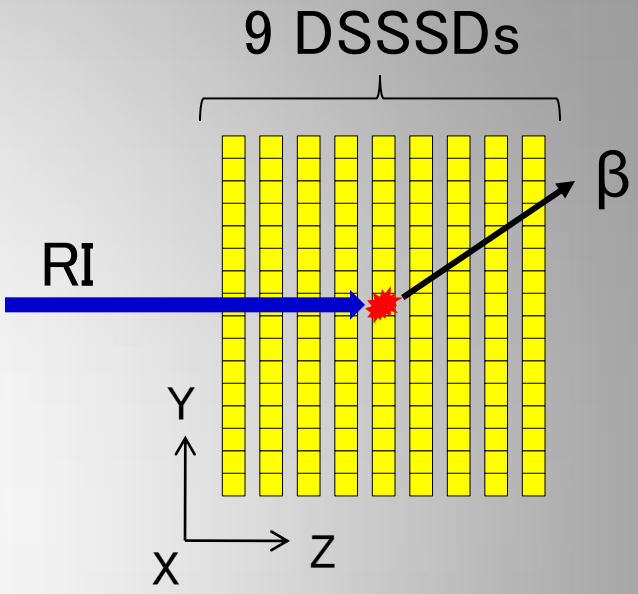


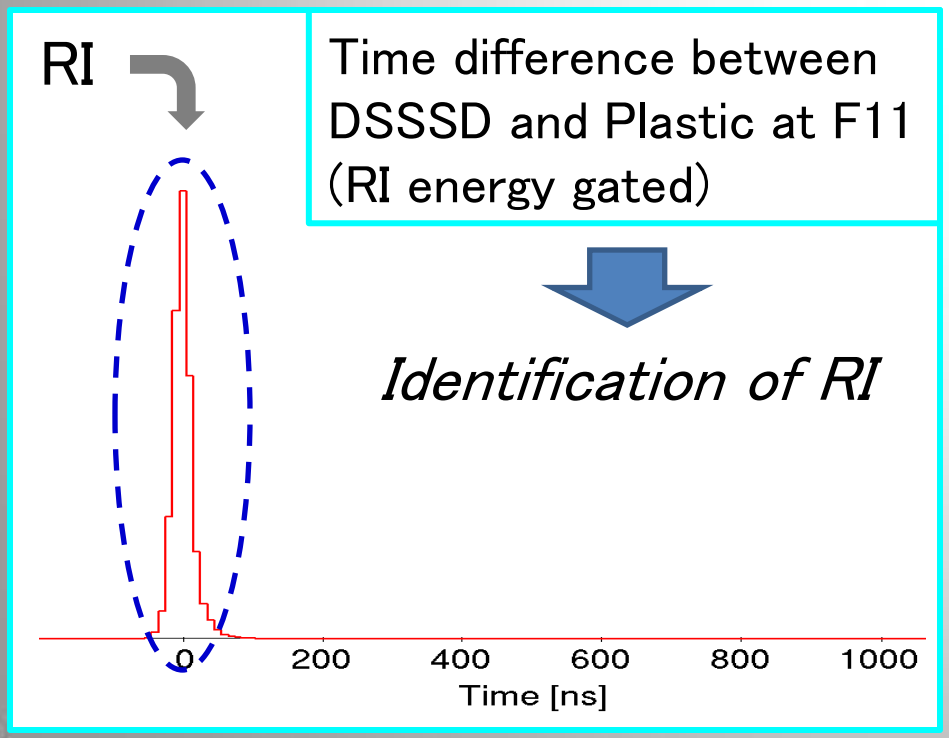
$T_{1/2}$ = 350(50) ns

β-γ spectroscopy

POINT

Associate preceding RI implantations with the following β decay in the **millisecond** range





Time difference between DSSSD and Plastic at F11 (RI energy gated)

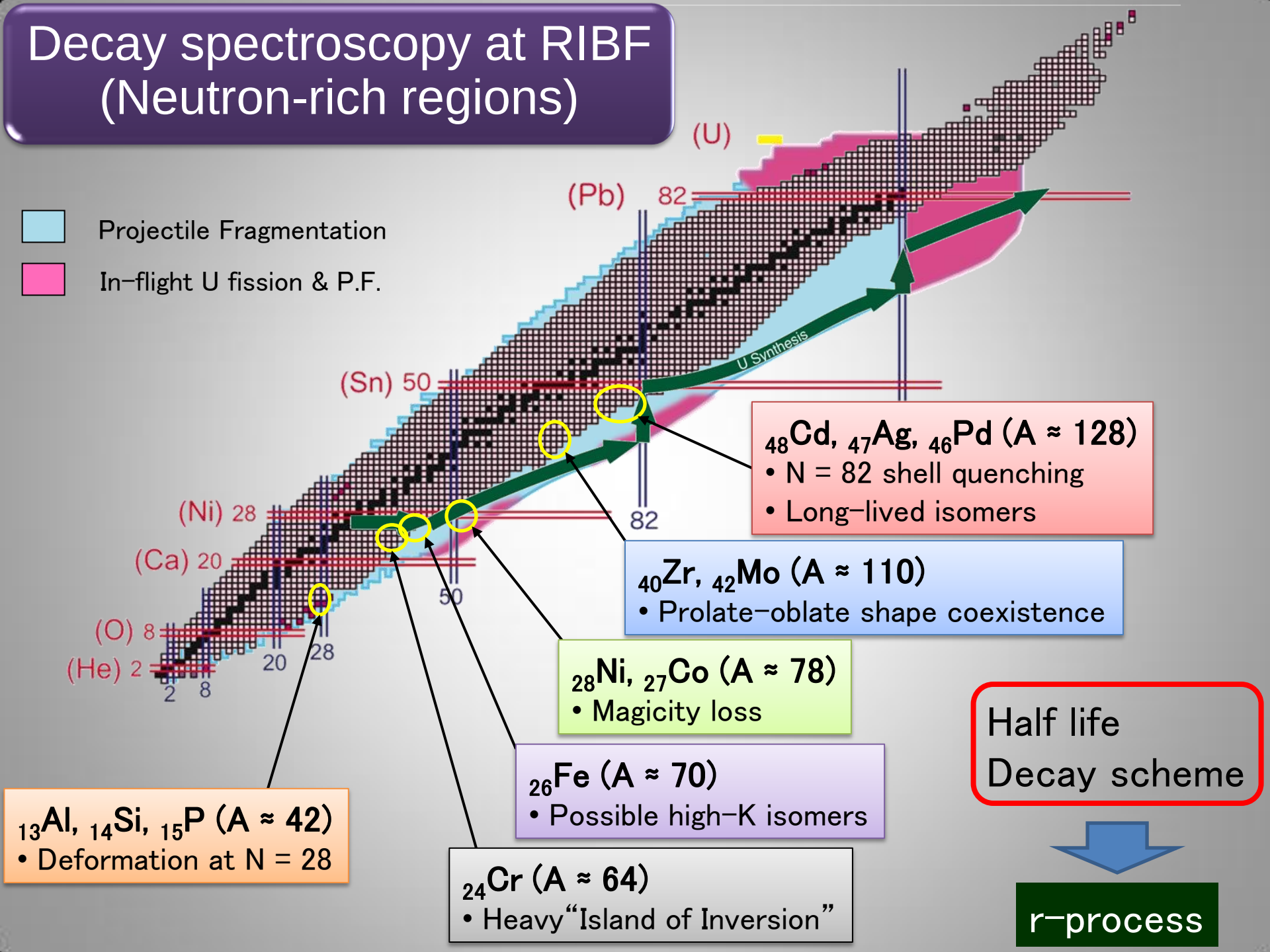
Identification of RI

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

Time stamp difference between RI and β

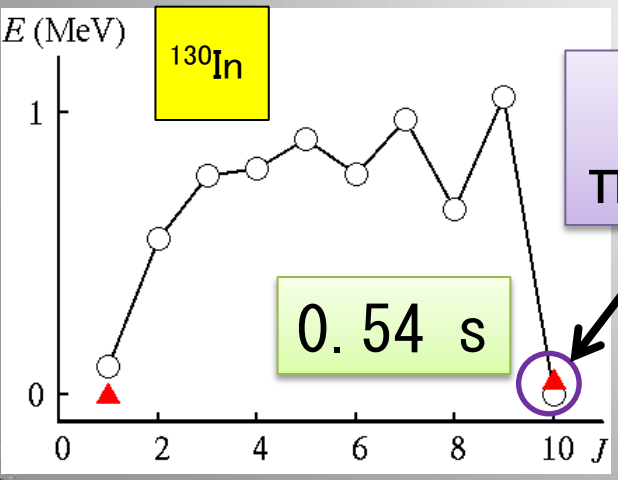
Half-life (～ms)

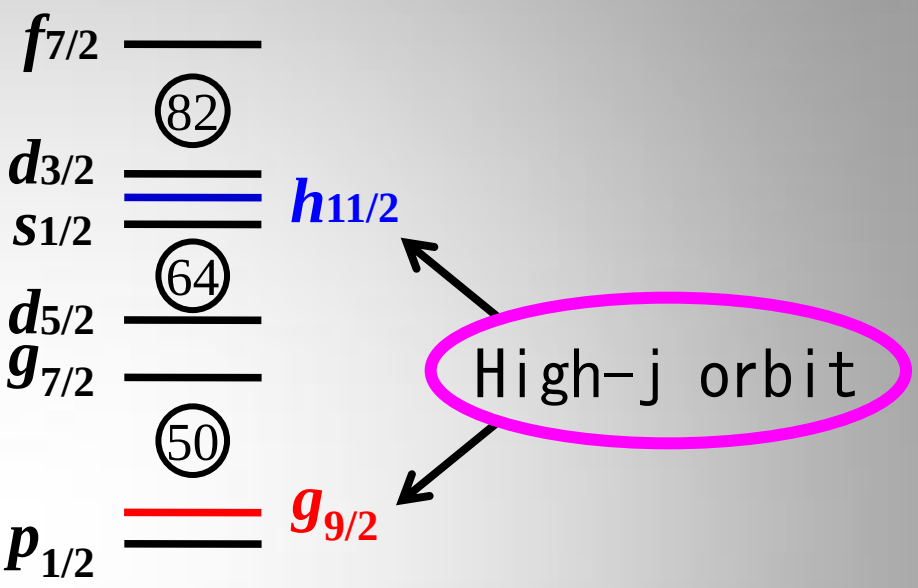
Decay spectroscopy at RIBF (Neutron-rich regions)



Level properties around ^{132}Sn (Z≦50, N≦82)

Proton \ Neutron	79	80	81	82	83
51	^{130}Sb	^{131}Sb	^{132}Sb	^{133}Sb	^{134}Sb
50	^{129}Sn	^{130}Sn	^{131}Sn	^{132}Sn	^{133}Sn
49	^{128}In	^{129}In	^{130}In	^{131}In	^{132}In
48	^{127}Cd	^{128}Cd	^{129}Cd	^{130}Cd	^{131}Cd
47	^{126}Ab	^{127}Ag	^{128}Ag	^{129}Ag	^{130}Ag





Attractive proton–neutron interactions depress the stretch-aligned configuration

$J^{\pi} = 10^{-}$

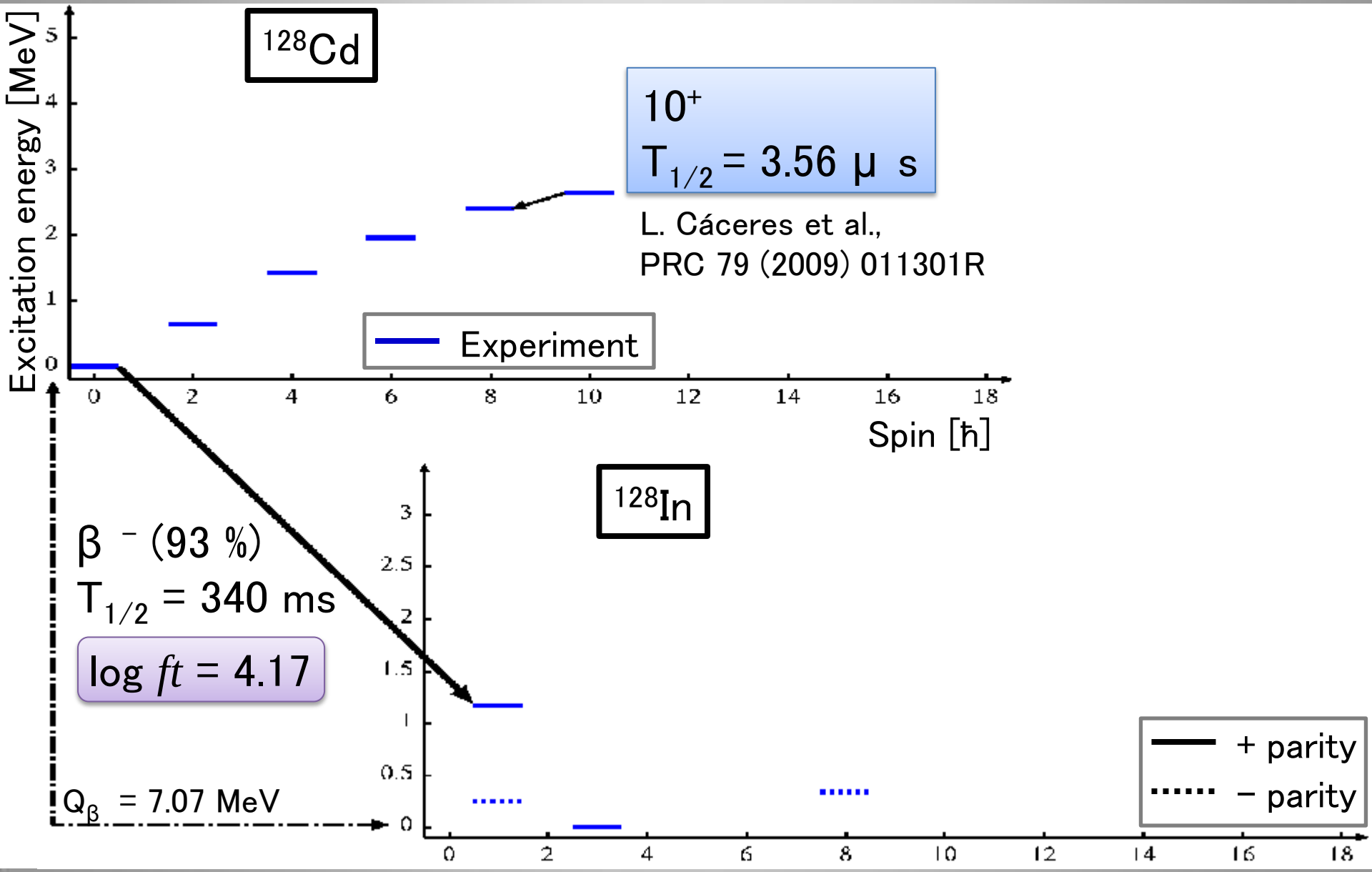
$\pi\, g_{9/2}^{-1} \nu\, h_{11/2}^{-1}$

^{128}Cd

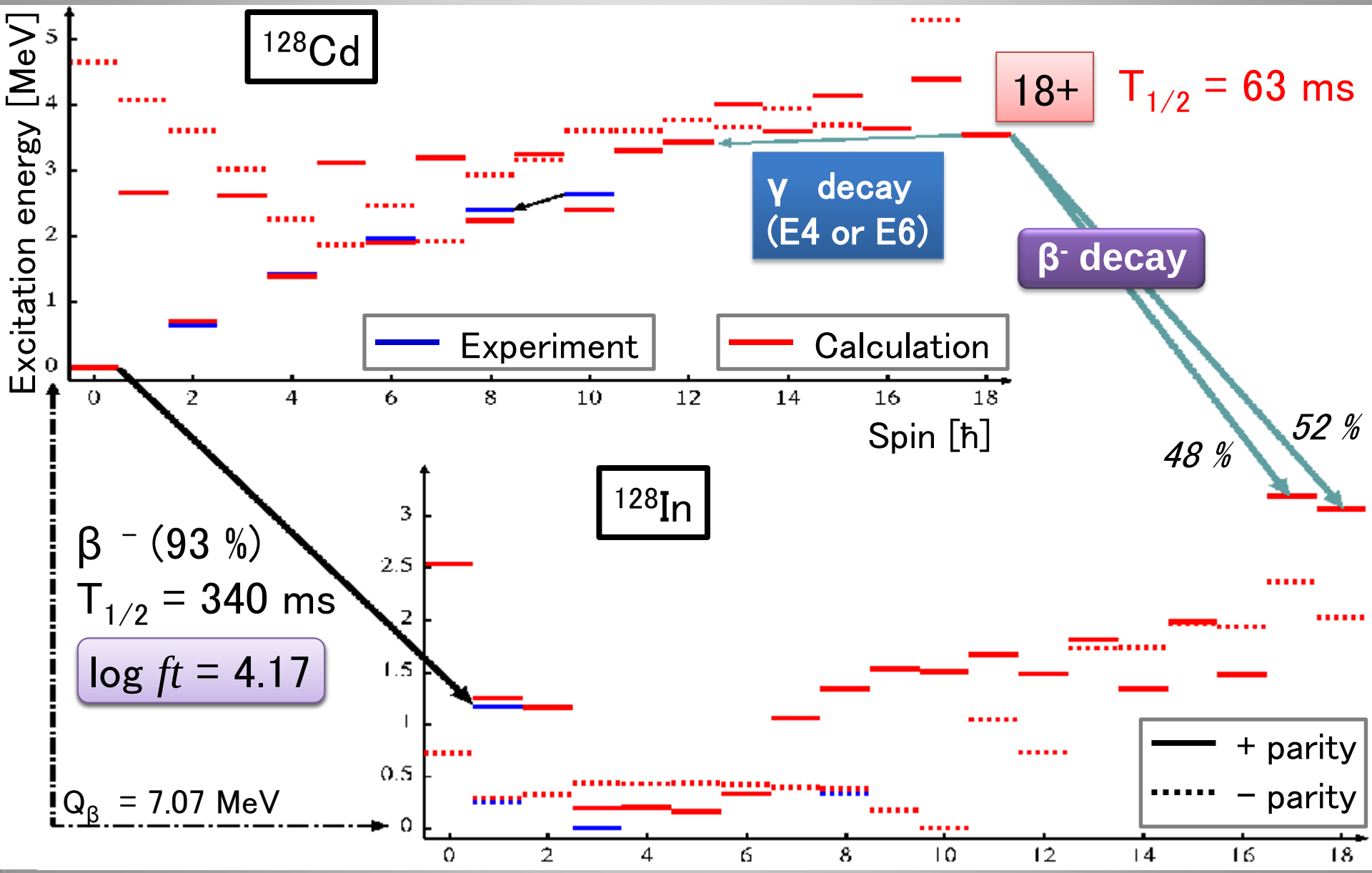
$J^{\pi} = 18^{+}$

$\pi\, (g_{9/2}^{-2})_{8+}\ \nu\, (h_{11/2}^{-2})_{10+}$

Spin-gap isomer in ^{128}Cd

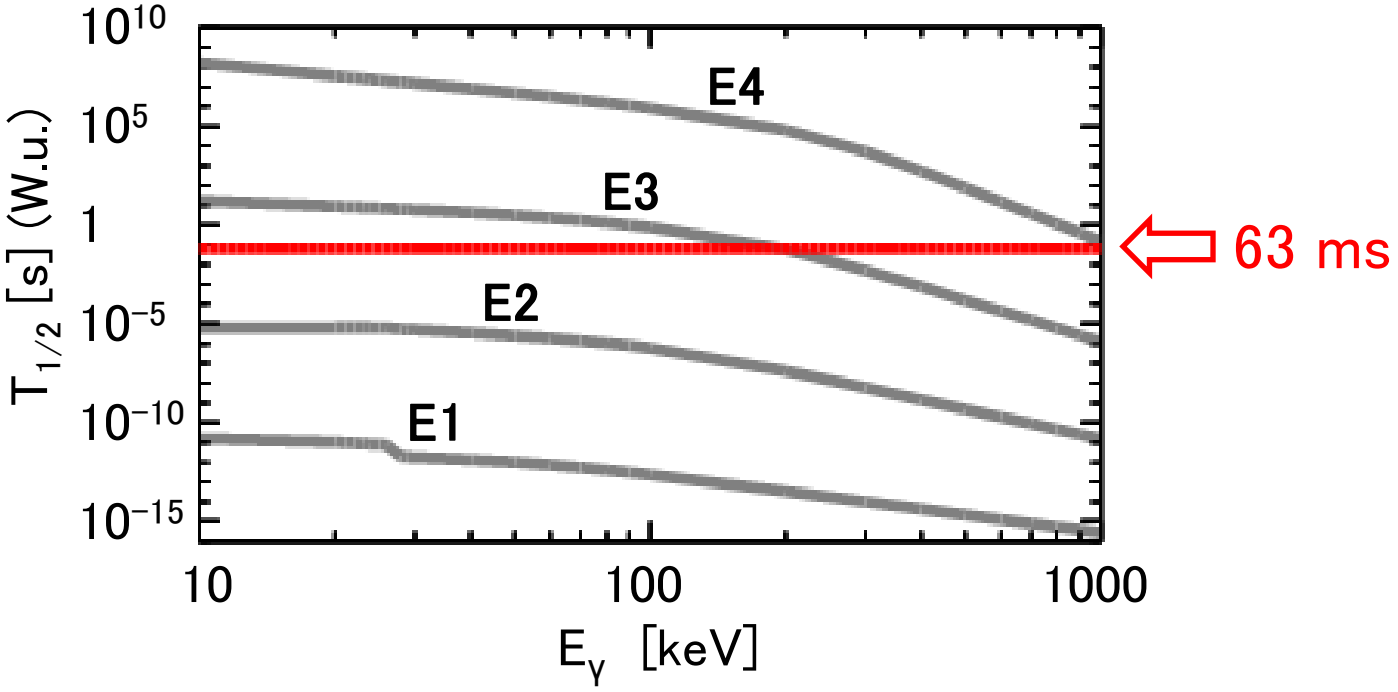


Spin-gap isomer in ^{128}Cd



Spin-gap isomer in ^{128}Cd

Transition half-lives (Weisskopf estimate) calculated for ^{128}Cd



Decay from the 18^+ state in ^{128}Cd

$T_{1/2}$(E4 and higher) > $T_{1/2}$(GT β^-) = 63 ms

	GSI		RIBF
Primary beam	^{136}Xe	^{238}U	^{136}Xe
Energy	750 AMeV	650AMeV	345 AMeV
Intensity	～7.4×10^{8} /s	～2.7×10^{8} /s	1 pnA
Target	Be, 4 g/cm^{2}	Be, 1 g/cm^{2}	Be, 1 g/cm^{2}
Setting	^{130}Cd		^{126}Pd
Yield (^{128}Cd)	**3.3×10^{5}** / ? days		**7.4×10^{6}** / 6 days

Approved by RIBF PAC

L. Cáceres et al.,
PRC 79 (2009) 011301R

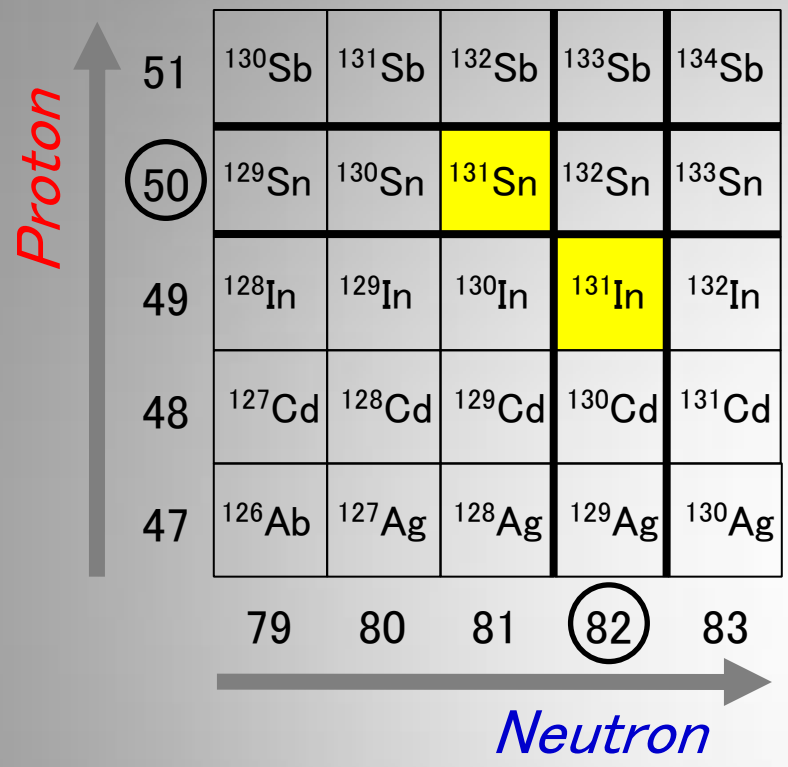
Estimation (LISE++)

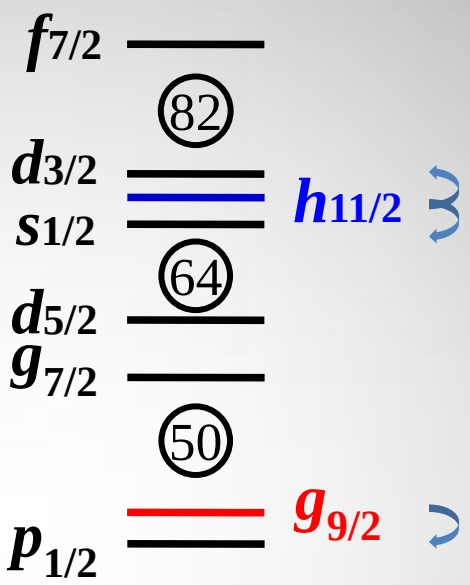
^{125}In	^{126}In	^{127}In	^{128}In 3.39e-3 0%	^{129}In 3.57e+0 1.057%	^{130}In 1.17e+1 16.101%	^{131}In 4.19e+0 34.858%
^{124}Cd	^{125}Cd 2.35e-3 0%	^{126}Cd 4.37e+0 0.965%	^{127}Cd 2.25e+1 17.464%	^{128}Cd 1.43e+1 48.136%	^{129}Cd 3.57e+0 67.999%	^{130}Cd 5.08e-1 74.056%
^{123}Ag 6.74e-2 0.014%	^{124}Ag 1.61e+1 9.358%	^{125}Ag 2.15e+1 40.599%	^{126}Ag 8.78e+0 64.636%	^{127}Ag 2.09e+0 75.613%	^{128}Ag 3.27e-1 76.539%	^{129}Ag 3.64e-2 76.543%
^{122}Pd 2.34e-1 0.38%	^{123}Pd 7.68e+0 37.53%	^{124}Pd 4.32e+0 73.325%	^{125}Pd 1.08e+0 76.401%	^{126}Pd 2.06e-1 76.698%	^{127}Pd 2.89e-2 75.471%	^{128}Pd 2.42e-3 62.593%
^{121}Rh 3.74e-2 0.548%	^{122}Rh 1.06e+0 48.314%	^{123}Rh 4.65e-1 76.694%	^{124}Rh 1.04e-1 73.915%	^{125}Rh 1.6e-2 62.106%	^{126}Rh 1.56e-3 43.716%	^{127}Rh 8.25e-5 23.736%
^{120}Ru 2.67e-3 0.416%	^{121}Ru 8.29e-2 40.722%	^{122}Ru 3.11e-2 55.476%	^{123}Ru 5.34e-3 41.614%	^{124}Ru 6.41e-4 27.094%	^{125}Ru 3.35e-5 10.161%	^{126}Ru 3.65e-7 1.12%

Total beam rate : ～ 130 /s

Acceptable rate for position correlation

Level properties around ^{132}Sn (Z≦50, N≦82)





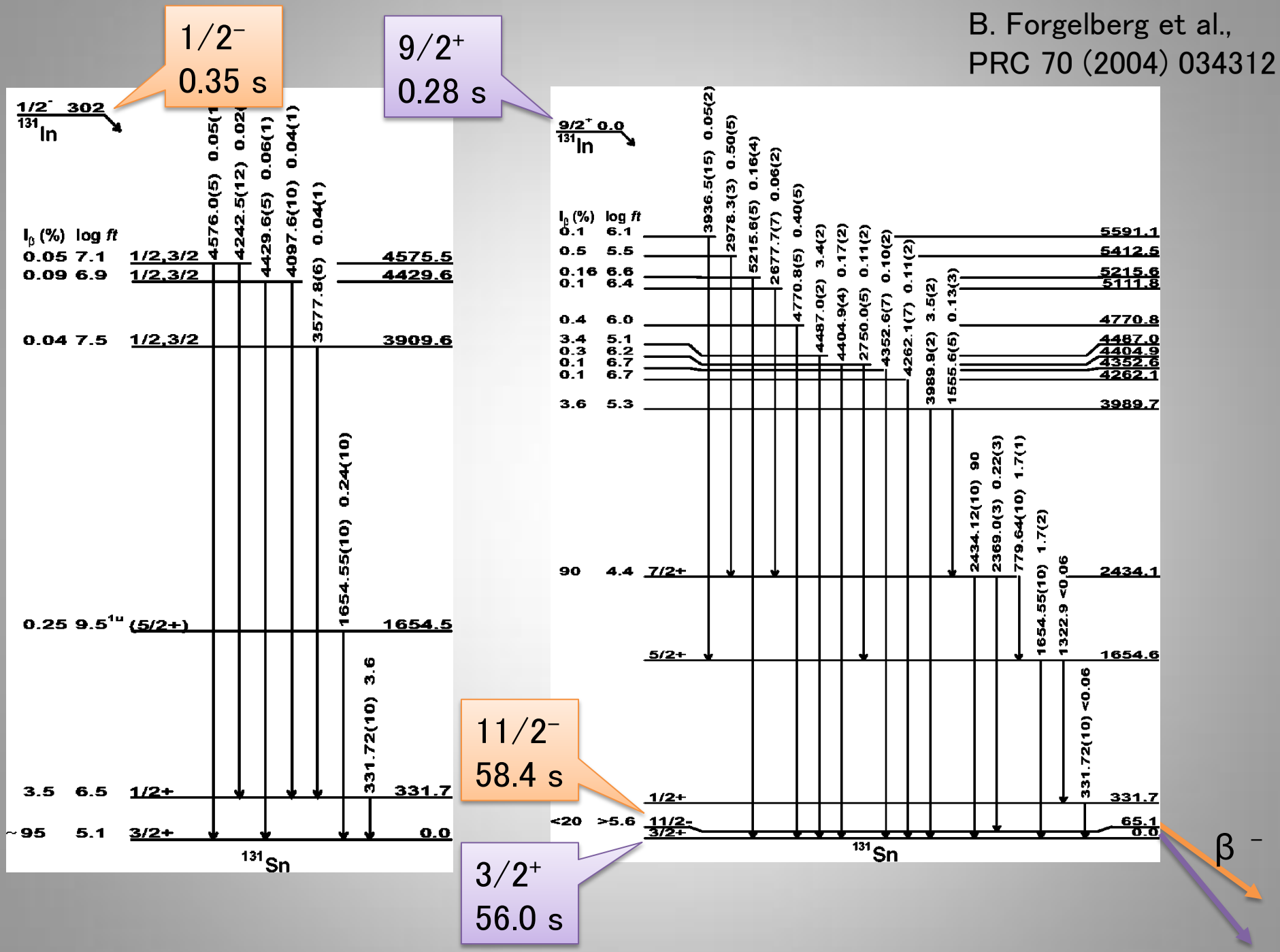
Neutron Spin gap

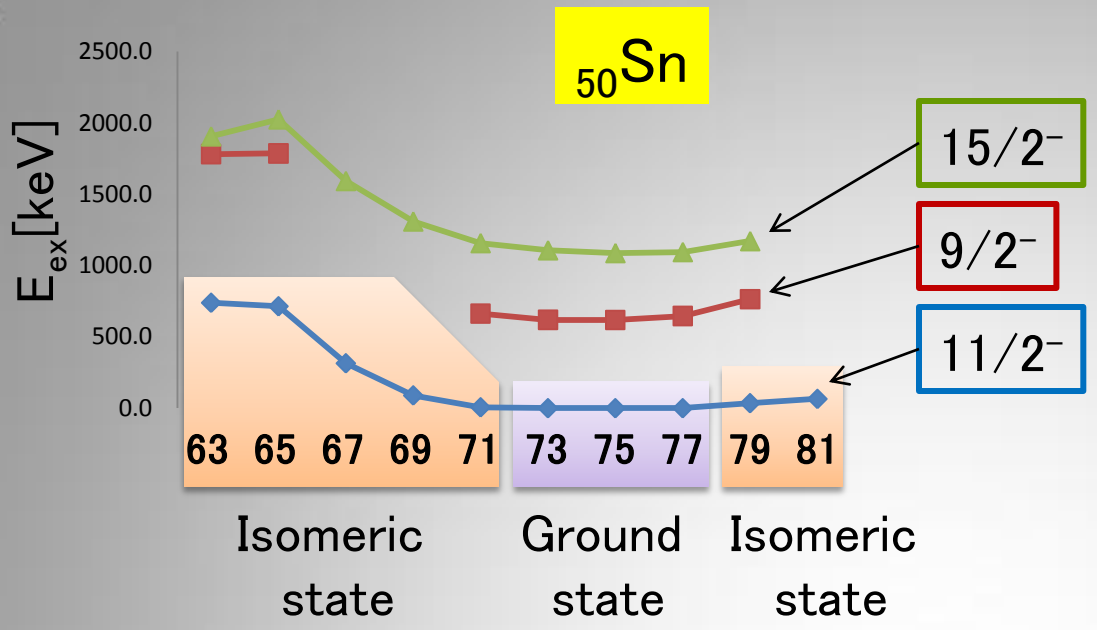
Proton Spin gap

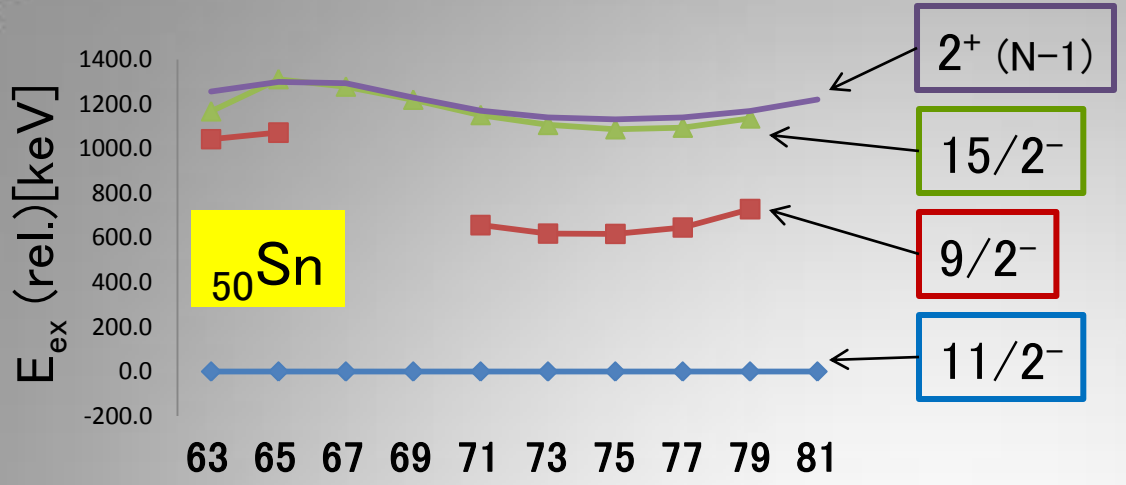
In odd-A nuclei

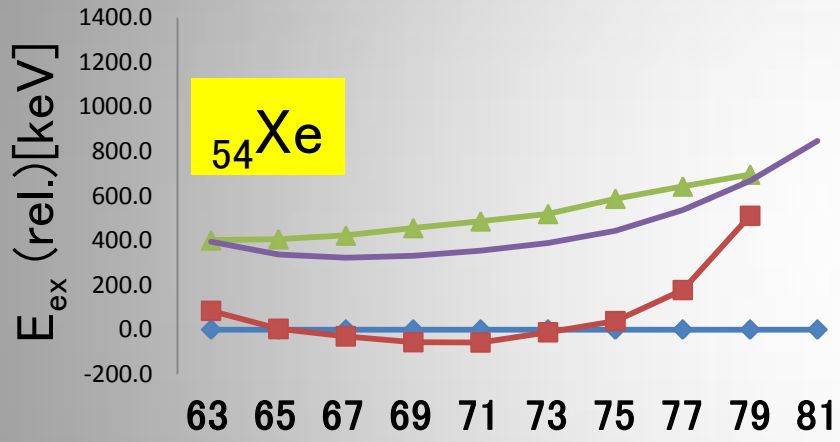
Single particle (hole) isomers at low excitation energies

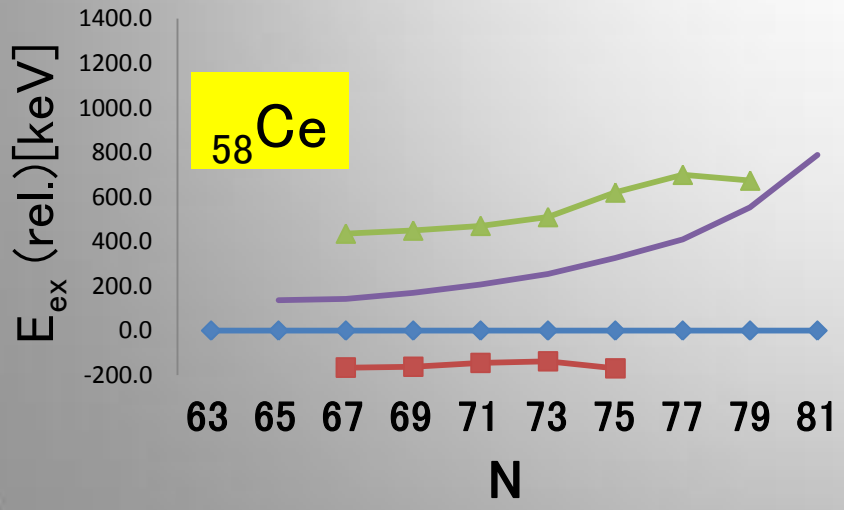
B. Forgelberg et al.,
PRC 70 (2004) 034312




$_{50}$Sn
E_{ex}[keV]
2500.0
2000.0
1500.0
1000.0
500.0
0.0
15/2⁻
9/2⁻
11/2⁻
63 65 67 69 71
73 75 77
79 81
Isomeric state
Ground state
Isomeric state







Spherical

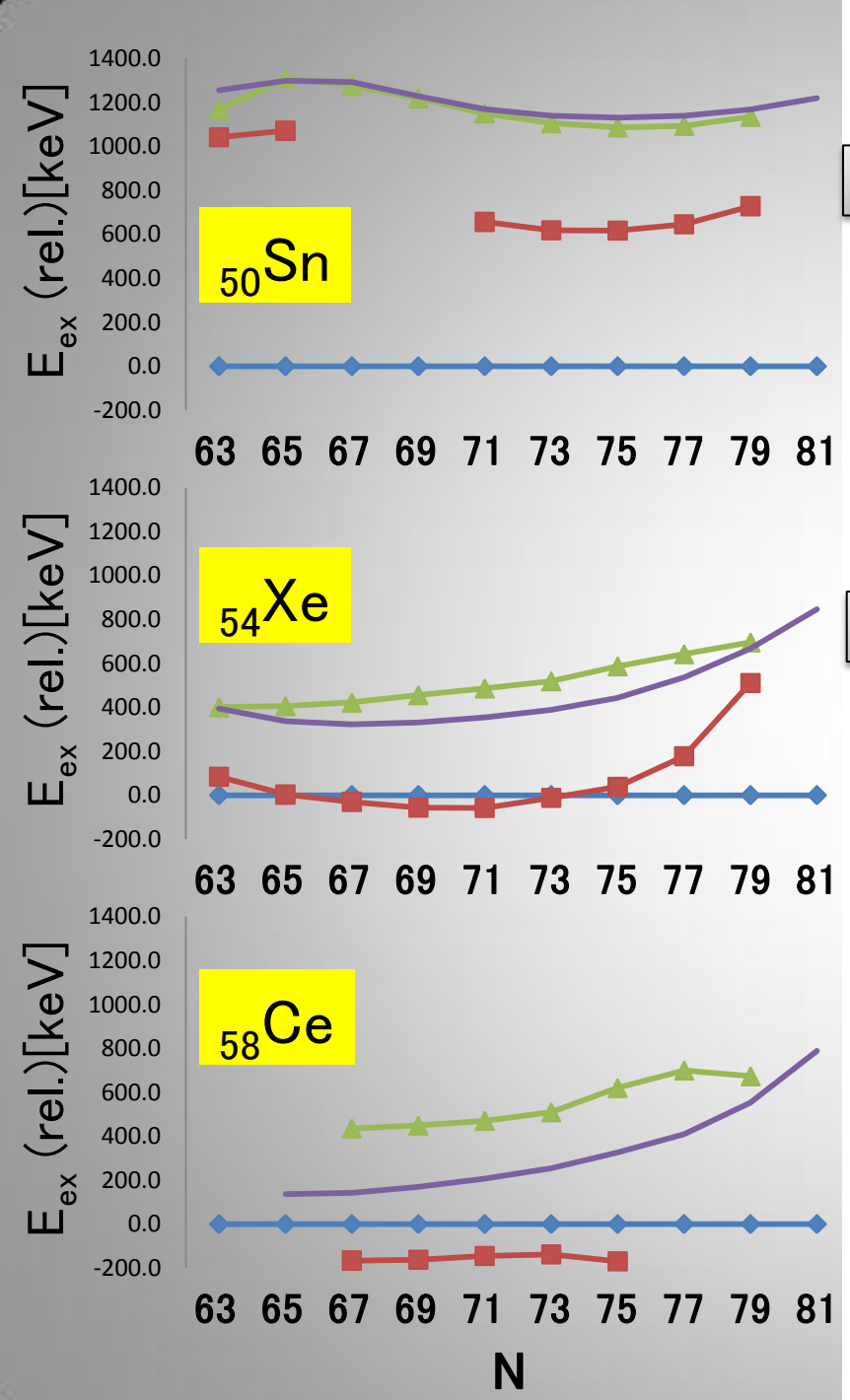
$E(9/2^-) > E(11/2^-)$

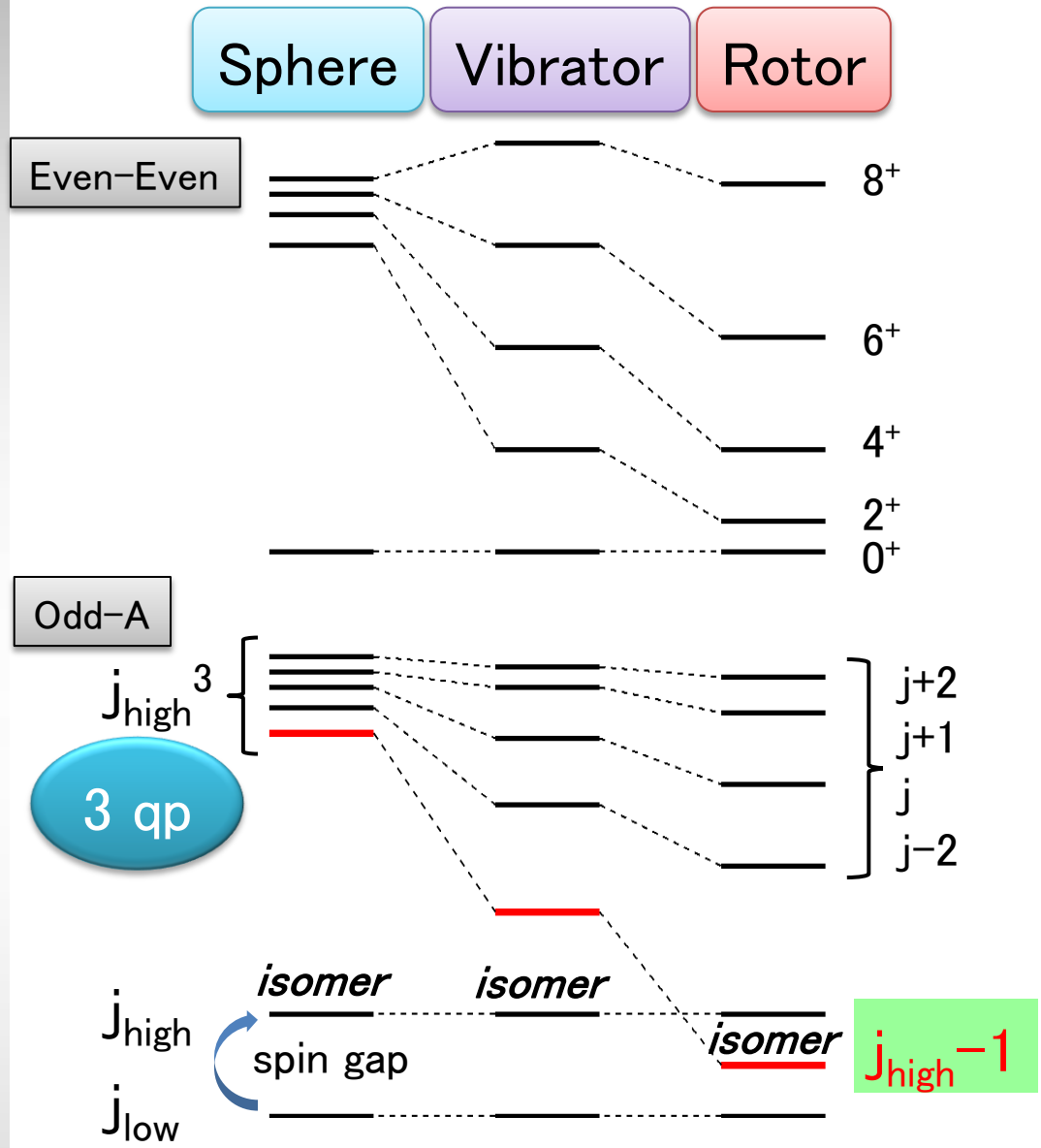
Vibrational

$E(9/2^-) \sim E(11/2^-)$

Deformed

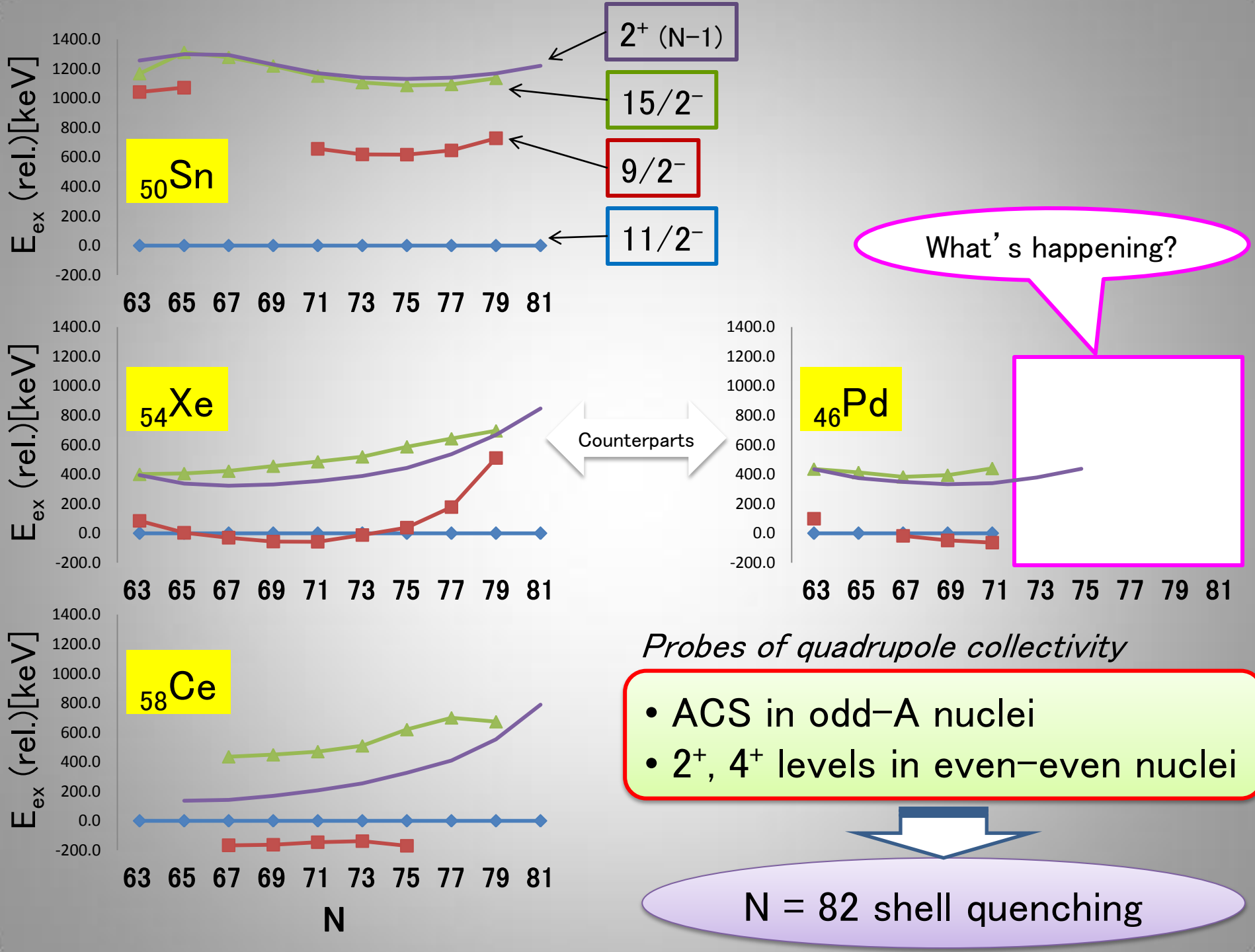
$E(9/2^-) < E(11/2^-)$





Anomalous coupling state (ACS)

Collective effect of three identical nucleons

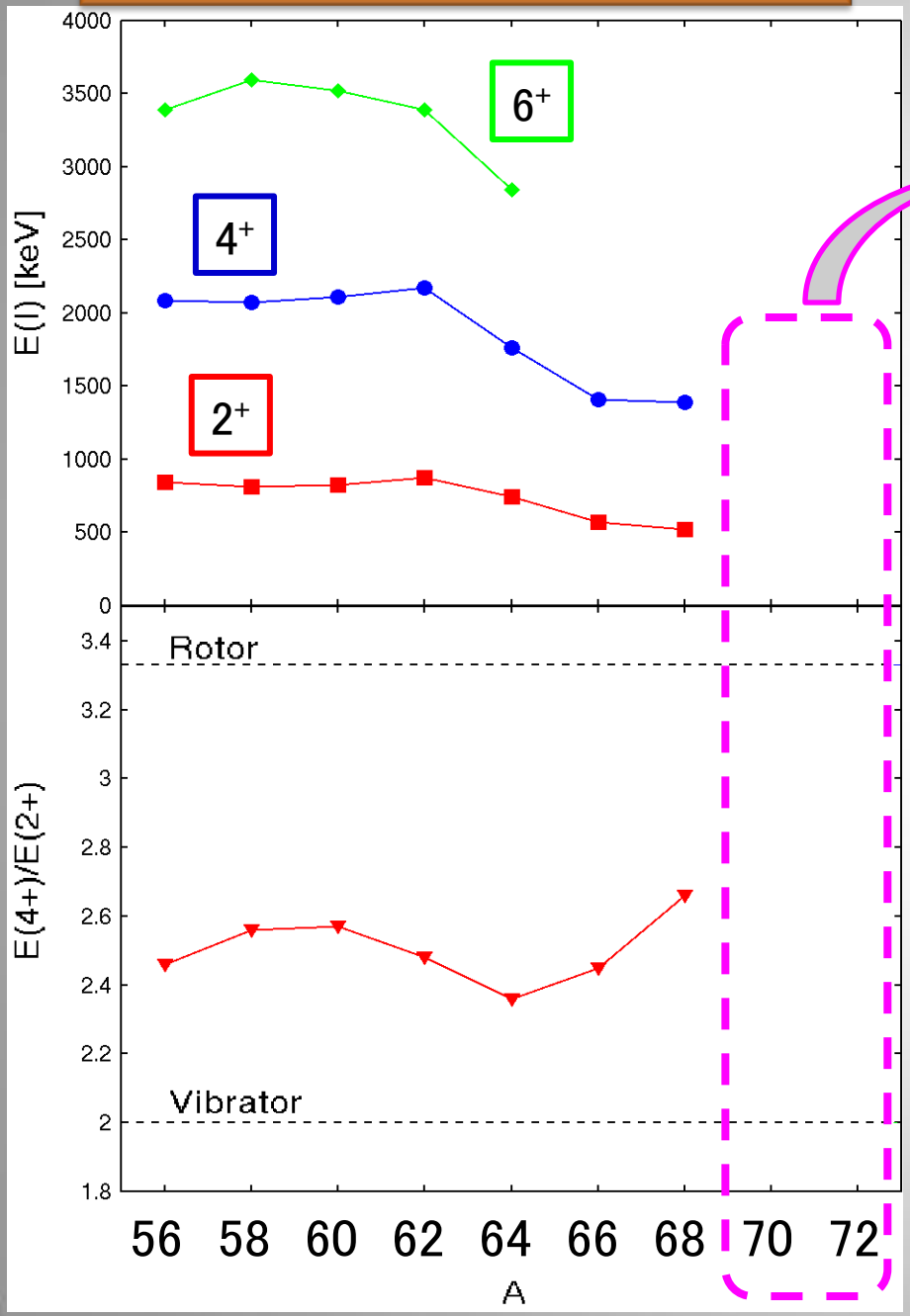


Probes of quadrupole collectivity

- ACS in odd-A nuclei
- 2^+, 4^+ levels in even-even nuclei

N = 82 shell quenching

Systematics of Fe isotopes



What's going on in ^{70,72}Fe?

?

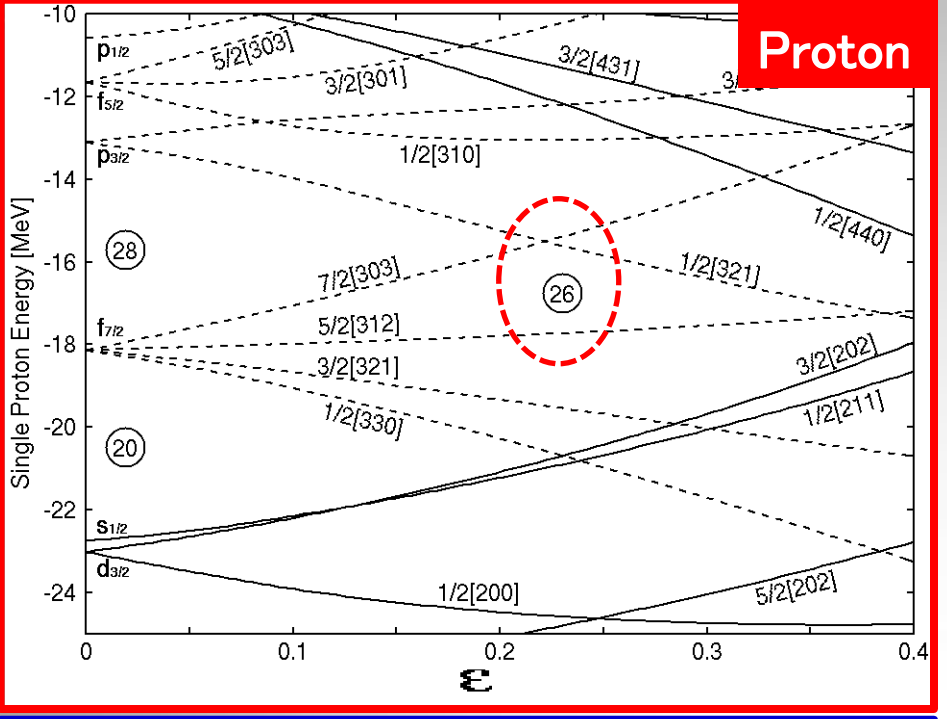
Rotation or Vibration

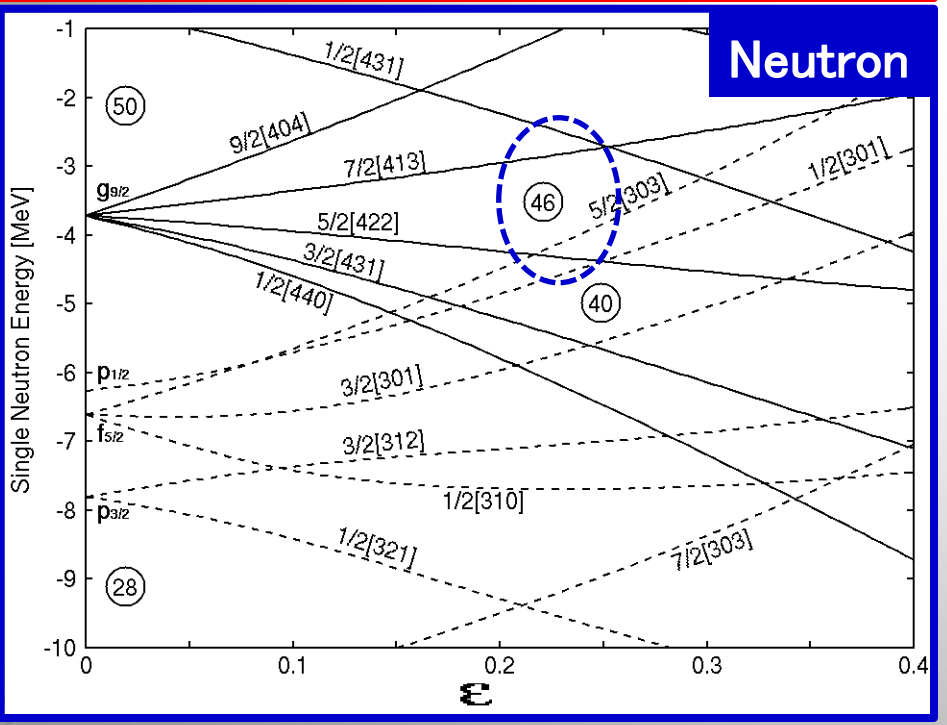
?

If statically deformed

High-K isomer

⇒CHECK





Possible high-K isomers in neutron-rich Fe isotopes

Nuclei	K^π	Configurations	
		Neutrons	Protons
^{70}Fe	0^+	g.s.	
	6^+	$(\frac{7}{2}^+[413], \frac{5}{2}^+[422])$	
	6^+		$(\frac{5}{2}^-[312], \frac{7}{2}^-[303])$
	12^+	$(\frac{7}{2}^+[413], \frac{5}{2}^+[422])$	$(\frac{5}{2}^-[312], \frac{7}{2}^-[303])$
^{72}Fe	0^+	g.s.	
	6^+	$(\frac{7}{2}^+[413], \frac{5}{2}^+[422])$	
	6^+		$(\frac{5}{2}^-[312], \frac{7}{2}^-[303])$
	12^+	$(\frac{7}{2}^+[413], \frac{5}{2}^+[422])$	$(\frac{5}{2}^-[312], \frac{7}{2}^-[303])$

Calculated by Furong

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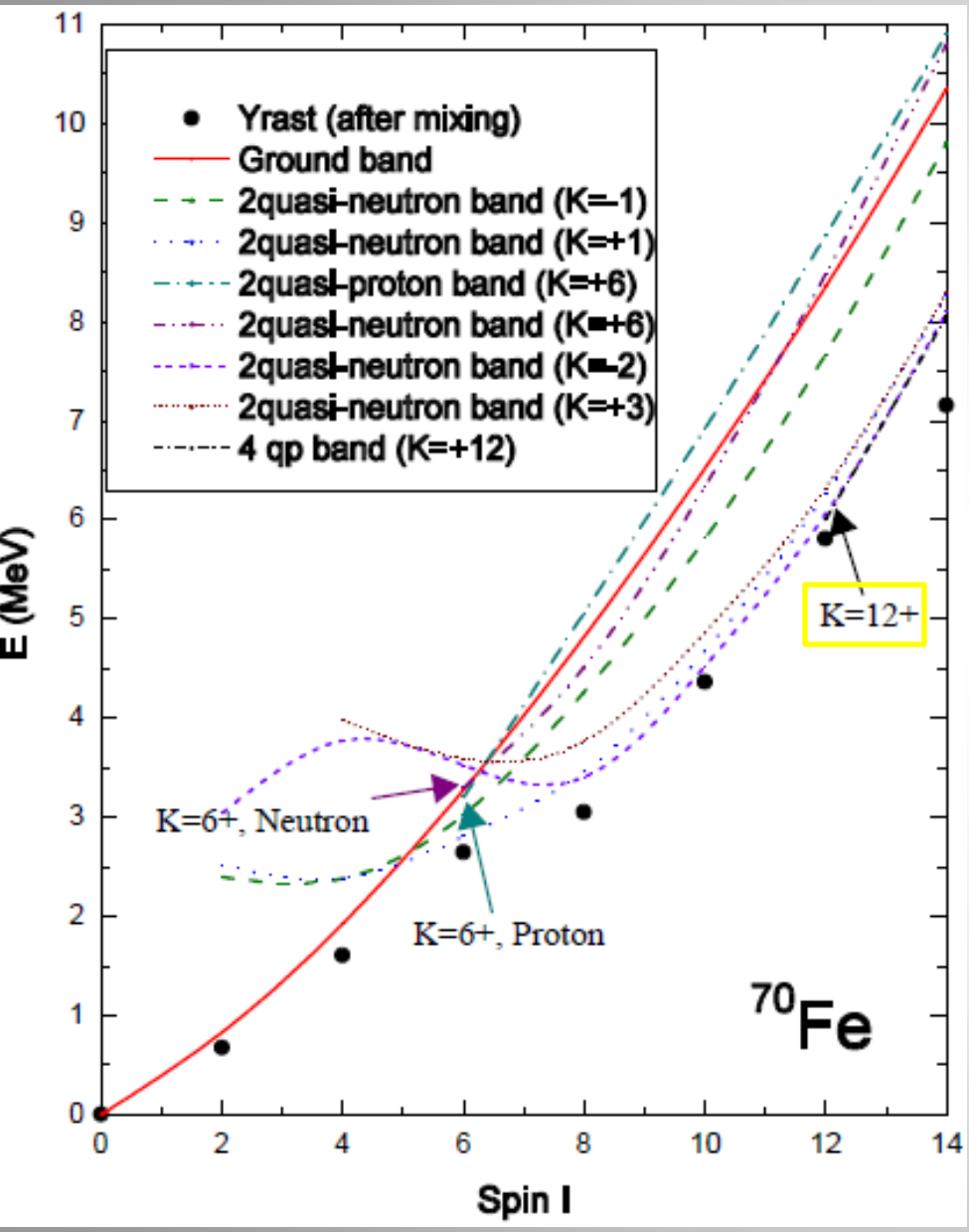

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Calculated by Furong

Production yield

LISE++ estimation

	^{70}Fe	^{72}Fe
Primary beam	^{76}Ge	^{238}U
Intensity	1 pnA	1 pnA
Target	Be, 2 g/cm^2	Be, 1 g/cm^2
Production rate	**1.5 /s**	**0.01 /s**
Purity (Total rate)	3.1 % (49 /s)	0.02 % (64 /s)

RIBF is capable of **1 pμ A** U beams

Upgrade

NEEDS

Severe for γ -ray measurement

- Study of ^{70}Fe is feasible with 1pnA ^{76}Ge beams
  - → To be proposed in the next RIBF PAC (Nov. 2010)
- Upgrade of U beams is required for ^{72}Fe production

Summary

RIBF is ready for decay spectroscopy experiments

- Accelerators
  - Intensity of U beams is now ～0.3 pnA ➡ Goal : 1 pμ A
- BigRIPS/ZeroDegree spectrometers
  - Good separation and PID achieved
- Decay spectroscopy setup
  - Active stopper (9 stacked DSSSDs)
  - γ -ray detector array
  - DAQ based on Time stamp

The first decay spectroscopy experiment has been carried out

- Zr (A～110) region
  - Particle-γ (delayed) coincidence for isomeric γ -ray measurement
  - Position correlation for β -γ spectroscopy

Analysis is ongoing

Isomer spectroscopy will be launched soon

- Spin-gap (β -decaying) isomers around ^{132}Sn
- High-K isomers around ^{70}Fe