

Recent activities and highlights at the RIBF

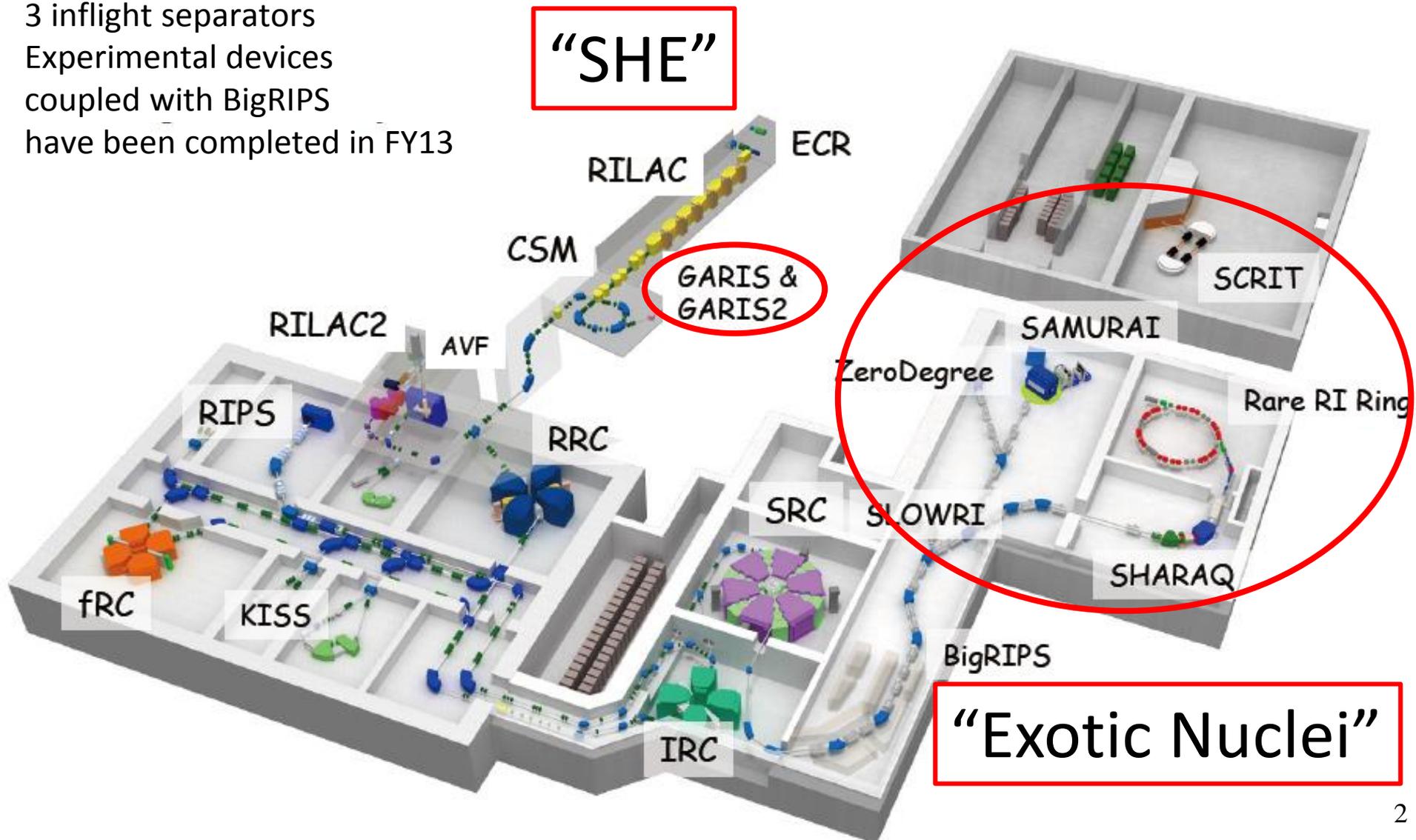
H. Sakurai

RIKEN Nishina Center / Dept. of Physics, Univ. of Tokyo

RI Beam Factory

5 cyclotrons + 2 linacs
3 inflight separators
Experimental devices
coupled with BigRIPS
have been completed in FY13

“SHE”



Prof. Arima and RIBF

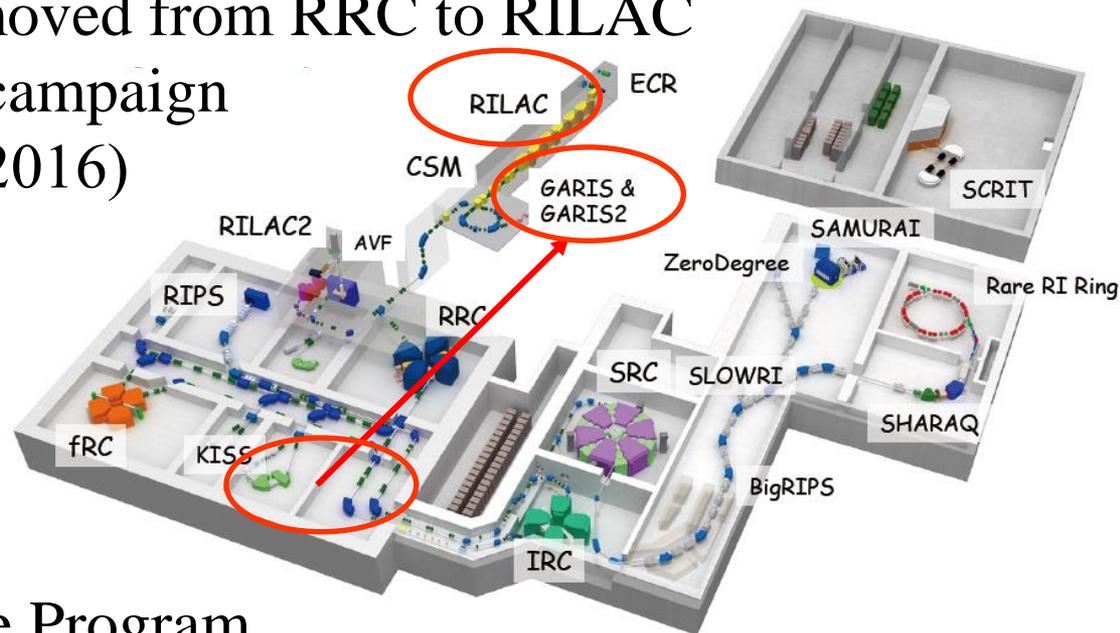
- 1992 Drs. Yano and Ishihara proposed the RIBF project
- 1993(-1998) Prof. Arima became the President of RIKEN
- 1994 International Advisory Committee for RIBF
- 1995 Government approval

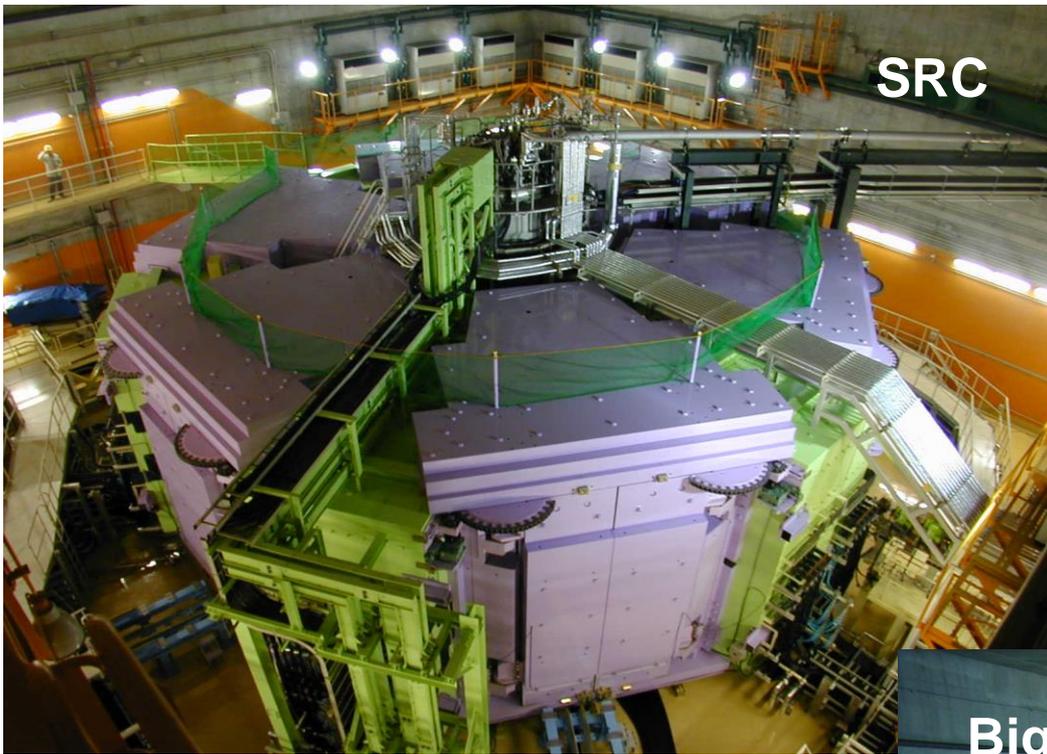
RILAC upgraded, UT-CNS RF-cavities installed
and GARIS moved from RRC to RILAC

- 2004(-2012) Element 113 campaign
“Nihonium”(2016)

- 2007 RIBF started
 $^{125,126}\text{Pd}$

- 2014 Nuclear Waste Program
started (ImPACT)





SRC

**World's First and Strongest
K2600MeV
Superconducting Ring Cyclotron**

400 MeV/u Light-ion beam
345 MeV/u Uranium beam

**World's Largest Acceptance
9 Tm
Superconducting RI beam Separator**

~250-300 MeV/nucleon RIB



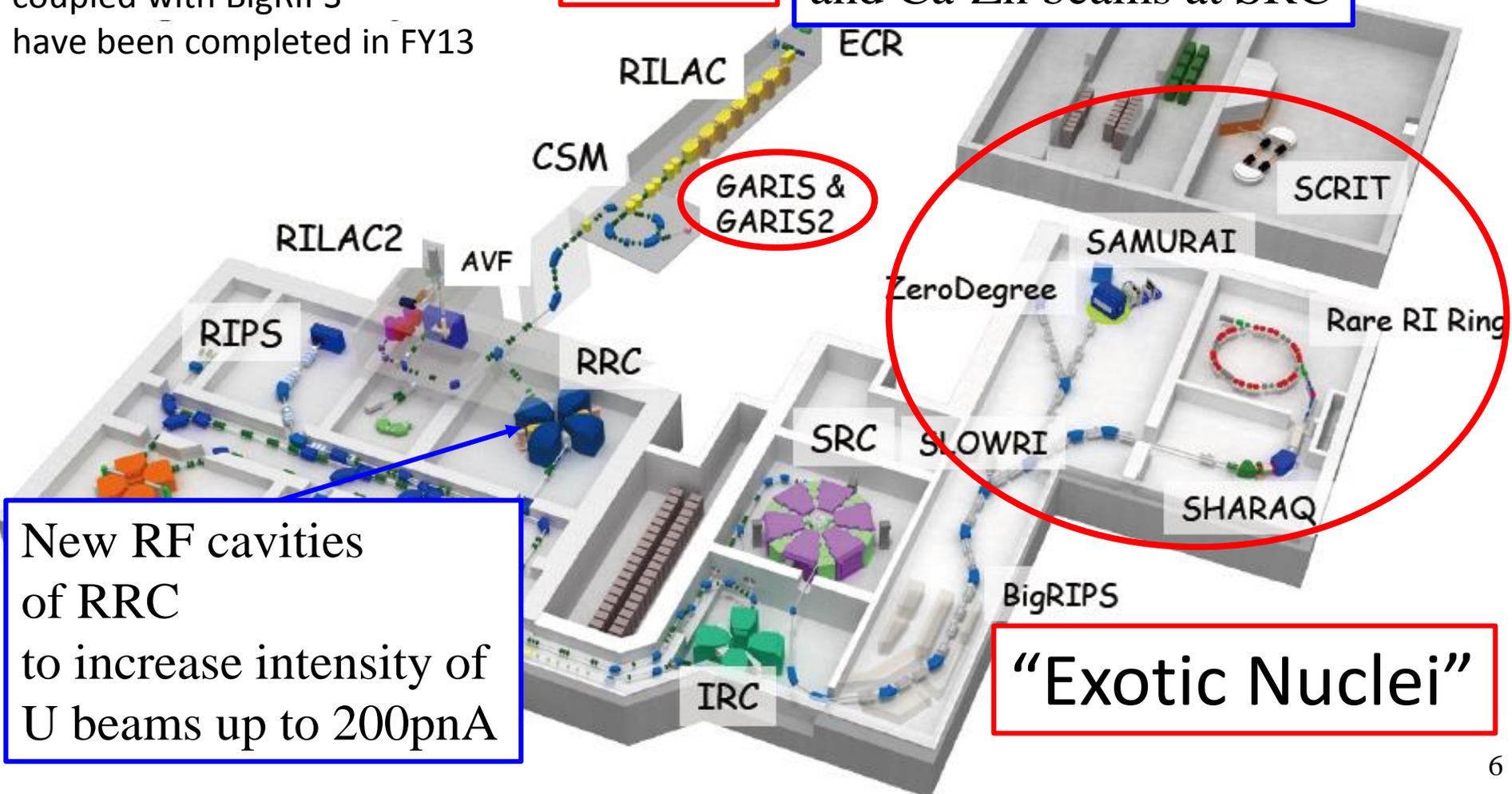
BigRIPS

Accelerator Upgrade in 2018-2019

5 cyclotrons + 2 linacs
3 inflight separators
Experimental devices
coupled with BigRIPS
have been completed in FY13

“SHE”

RILAC upgrade
for 119th and 120th
and Ca-Zn beams at SRC



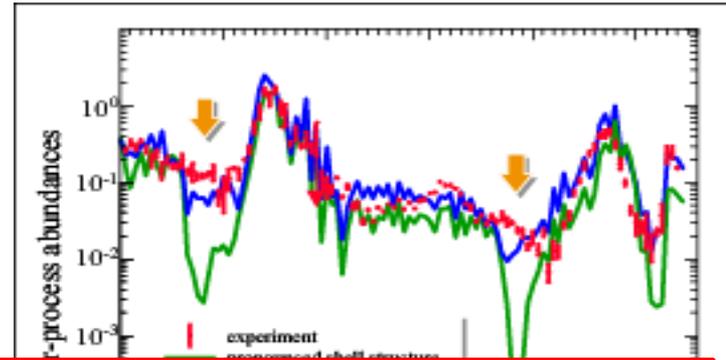
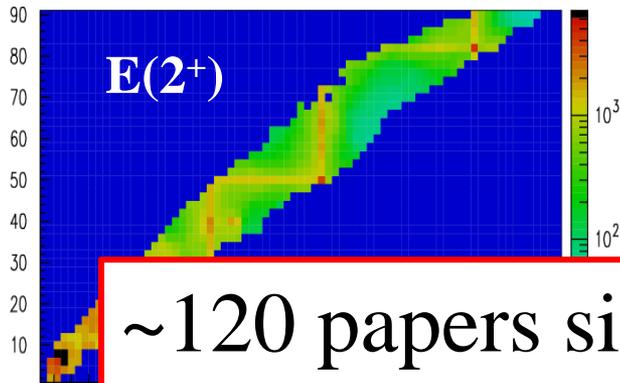
New RF cavities
of RRC
to increase intensity of
U beams up to 200pnA

“Exotic Nuclei”

Physics with Exotic Nuclei

Shell Evolution :
magicity loss and new magicity

R-process path: Synthesis up to U



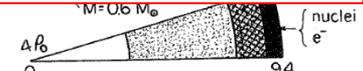
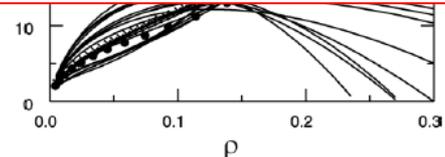
~120 papers since 2007
(References found in H.S., Front. Phys. 13, 13211 (2018))

Front. Phys. 13(6), 132111 (2018)
<https://doi.org/10.1007/s11467-018-0849-0>

REVIEW ARTICLE

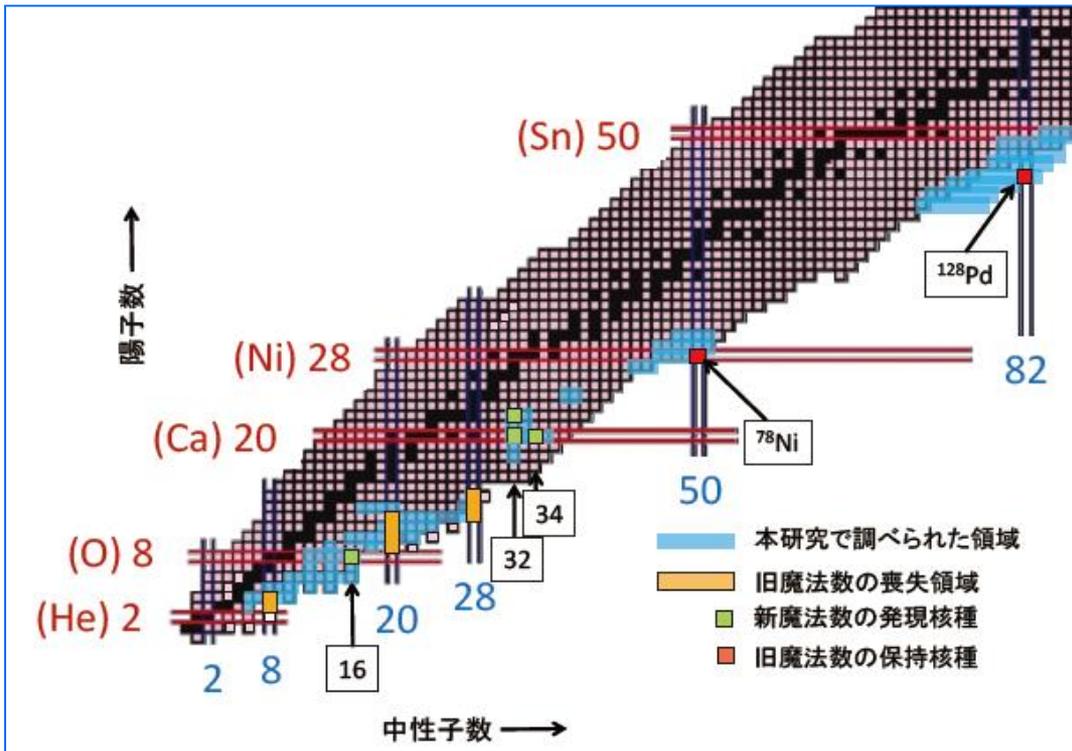
Nuclear physics with RI Beam Factory

Hiroyoshi Sakurai



Shell Evolution

In-beam gamma and decay spectroscopy



Magicity Loss at N=20、28

New magic number N=34

Double magicity of ^{78}Ni (Z=28, N=50)

Magicity at N=82 with Z>46...



New Magicity
of N=34

N=20-28

^{32}Ne : Doornenbal, PRL 103, 032501 (2009)

$^{36,38}\text{Mg}$: Doornenbal, PRL111, 212502 (2013)

^{42}Si : Takeuchi PRL109, 182501 (2012)

^{40}Mg : Crawford, in preparation

N=32, 34

^{54}Ca : Steppenbeck, Nature 502, 207 (2013)

^{50}Ar : Steppenbeck, PRL 114, 252501 (2015)

^{52}Ar : in preparation

N=50

^{78}Ni : Xu, PRL 113, 032505 (2014)

^{78}Ni : Taniuchi, in preparation

N=82, Z=50

^{126}Pd : Wang, PRC 88 054318 (2013)

^{136}Sn : Wang, PTEP 023D02 (2014)

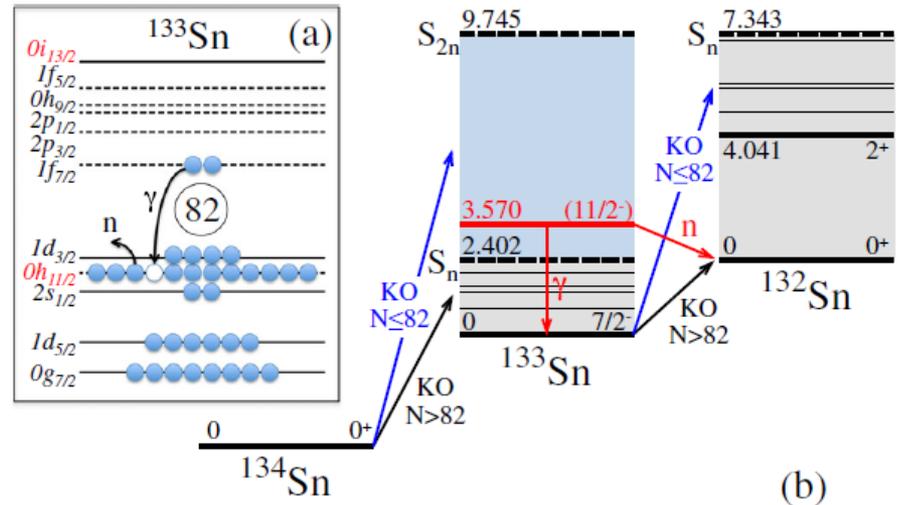
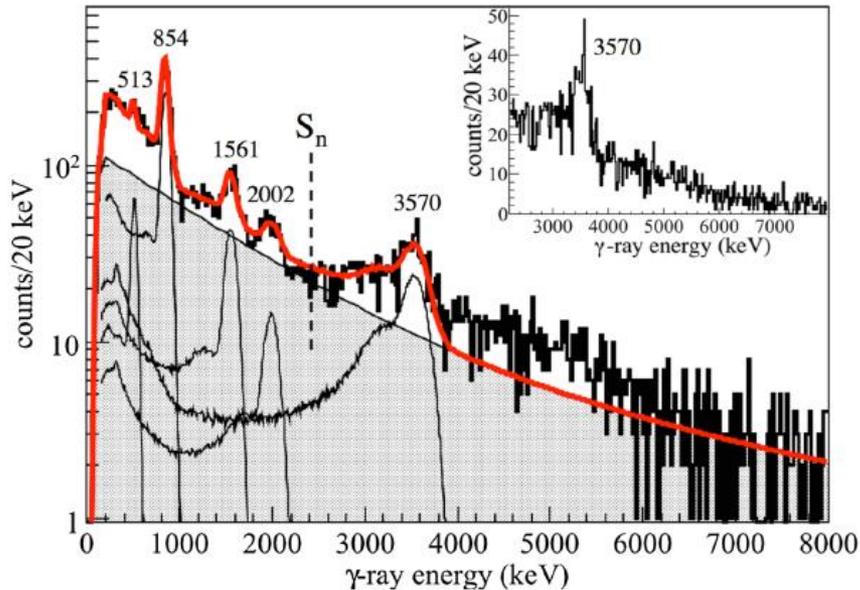
$^{126,128}\text{Pd}$: Watanabe, PRL 111, 152501 (2013)

$^{136,138}\text{Sn}$: Simpson, PRL113, 132502 (2014)



Gamma-decay of unbound neutron-hole states in ^{133}Sn

V. Vaquero, A. Jungclaus et al., PRL 118, 202502, 2017



A gamma-decay of a neutron-hole unbound state at 3.57 MeV in ^{133}Sn is observed. Neutron emission of a state at 3.66 MeV was observed at ISOLDE (PRL77, 1020, 1996)

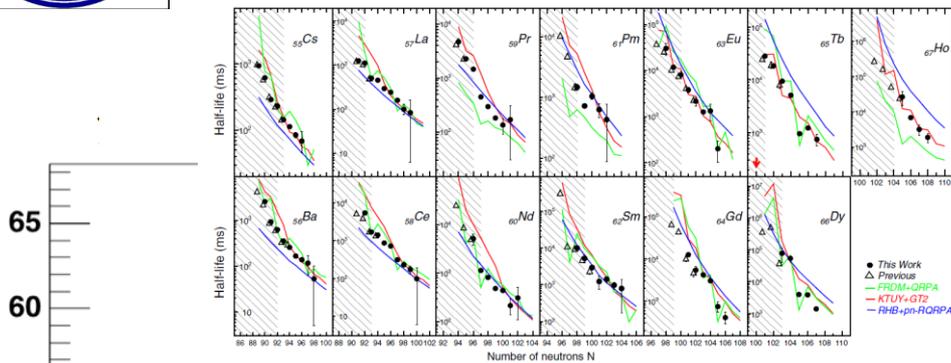
Very small overlap between the state of ^{133}Sn and the ground state of ^{132}Sn , because of double magicity of ^{132}Sn

Concerning the r-process path, not only beta-delayed emission but also gamma-decay should be considered in network calculation

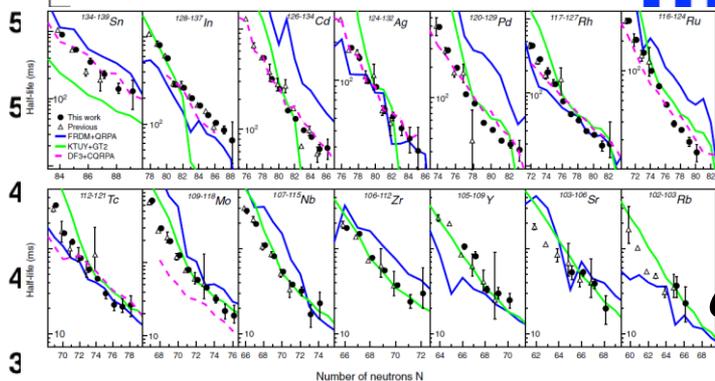


EURICA Achievements (2012-): Half-lives

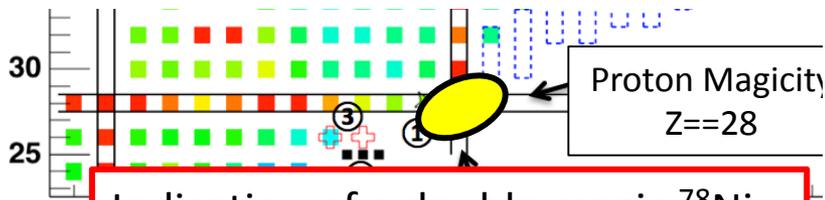
Proton number



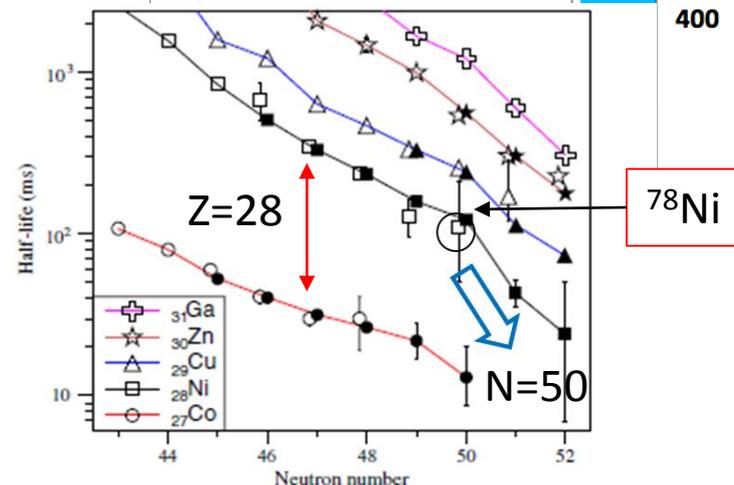
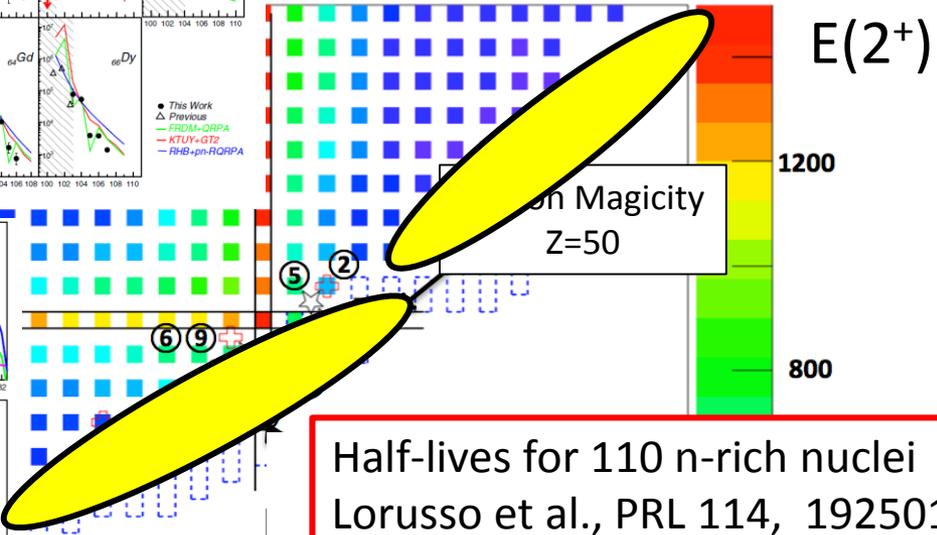
Half-lives for 94 n-rich nuclei
Wu et al., PRL 118, 072701 (2017)



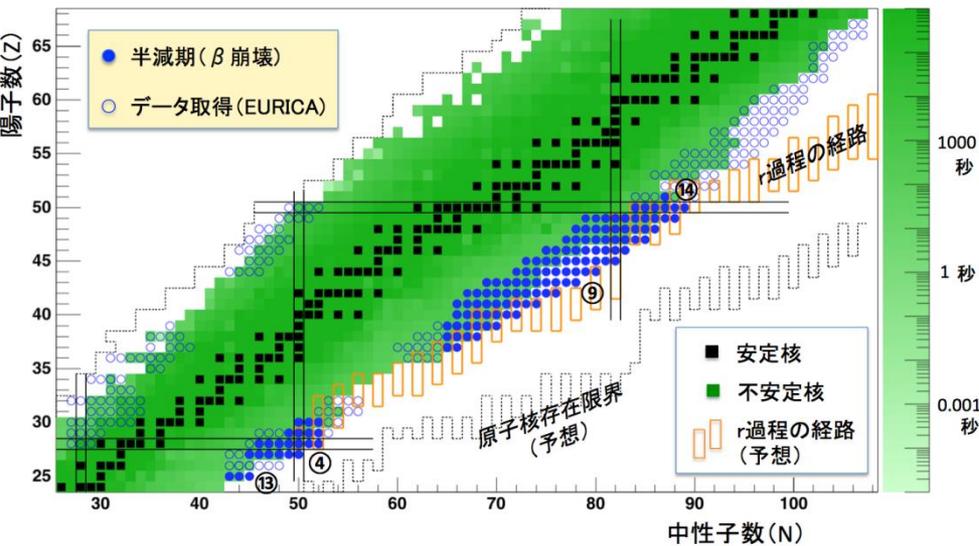
Half-lives for 110 n-rich nuclei
Lorusso et al., PRL 114, 192501 (2015)



Indication of a double magic ^{78}Ni
Xu et al., PRL 113, 032505 (2014)

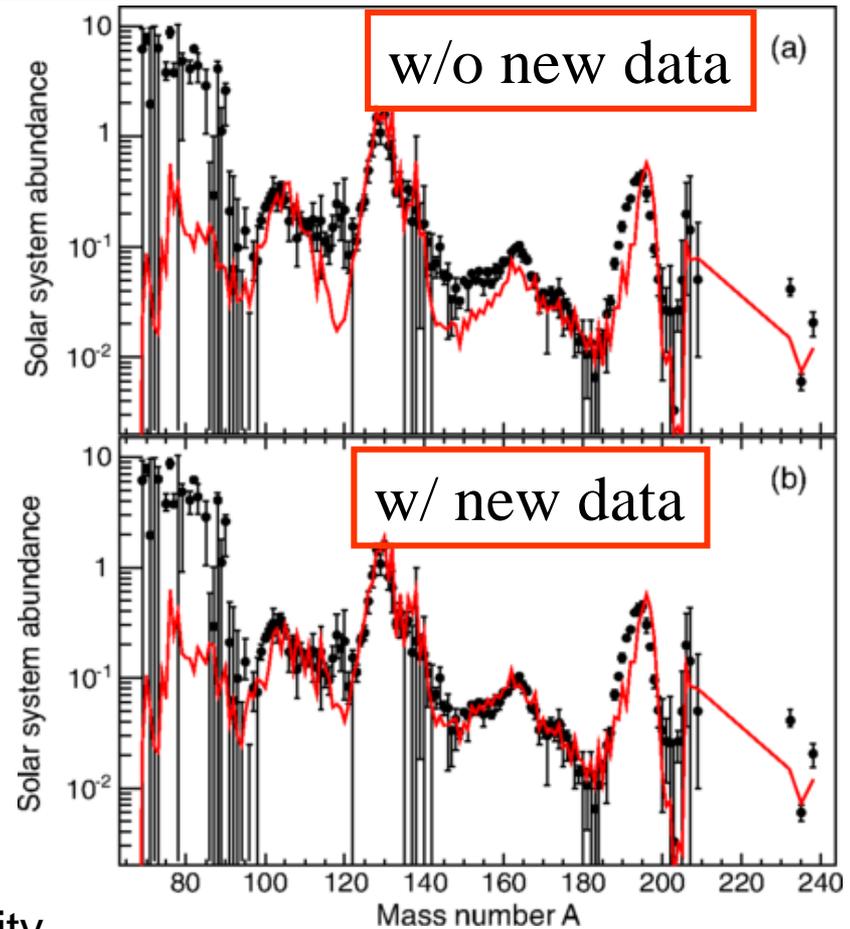


“Revolution” in the r-process research



Bunch of $T_{1/2}$ data for $A \sim 100$
 A standard model assuming (n, γ) equilibrium reproduces the r-abundance up to rare-earth region

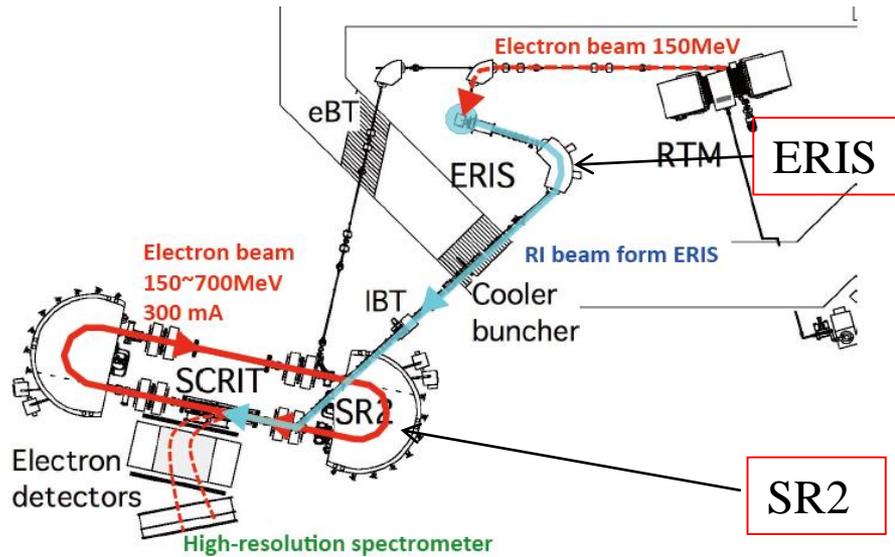
Mass, beta-delayed neutron emission probability measurement in future



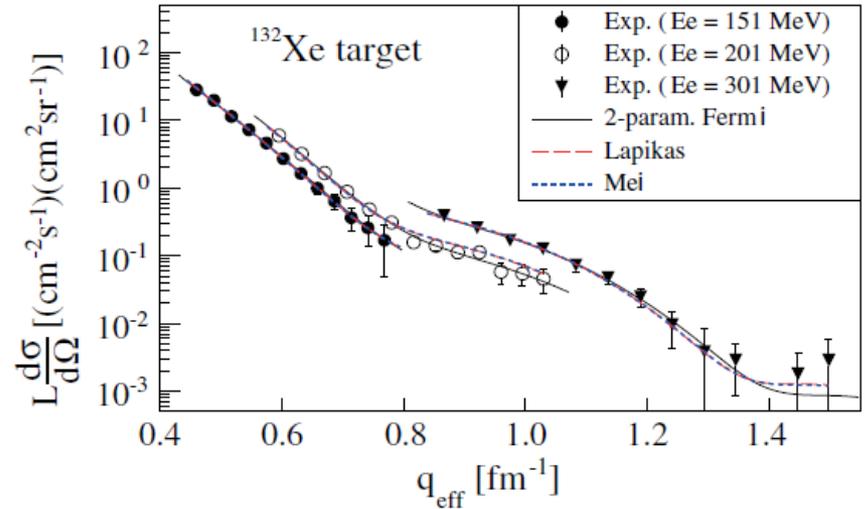
G. Lorusso, S. Nishimura *et al.* *PRL*. 114, 192501 (2015)

S. Nishimura *et al.*, *PRL*. 106, 052502 (2011)
 Z. Y. Xu, S. Nishimura *et al.*: *PRL*. 113, 032505 (2014)
 G. Lorusso, S. Nishimura *et al.*: *PRL*. 114, 192501 (2015)
 G. Benzoni, A.I. Morales, H. Watanabe *et al.*: *PRC* 92, 044320 (2015)
 P. Lee, C.-B. Moon, C. S. Lee, A. Odahara *et al.*: *PLB* 751, 107 (2015)

SCRIT Facility for e+RI scattering

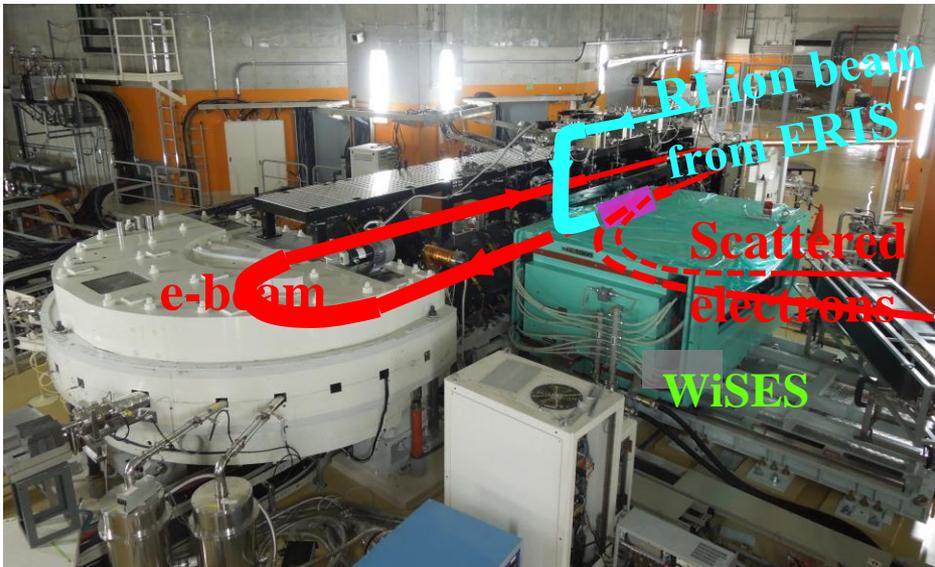


First elastic scattering from ^{132}Xe
Tsukada et al., PRL118, 262501 (2017)



Luminosity of $10^{27}/(\text{cm}^2\text{s})$ was achieved
at the e-beam current of 250mA.

Efficiency improvement
More high power beam 10W- \rightarrow 1kW
 $\rightarrow 10^{29}/\text{cm}^2/\text{s}$

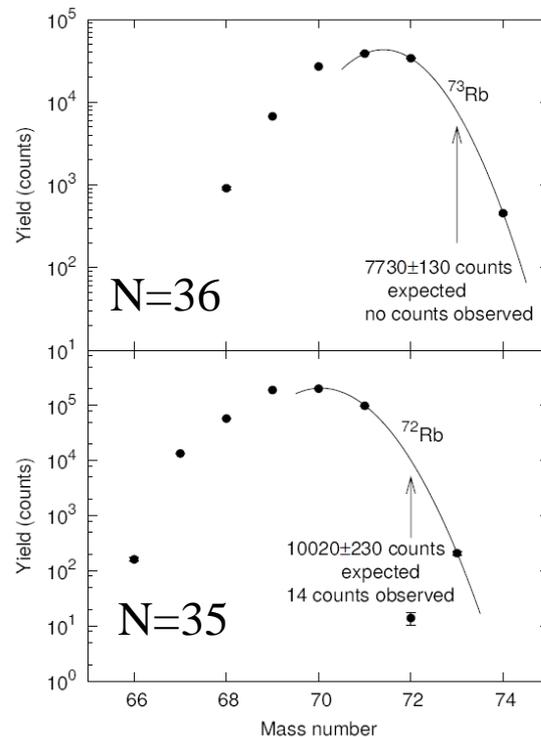
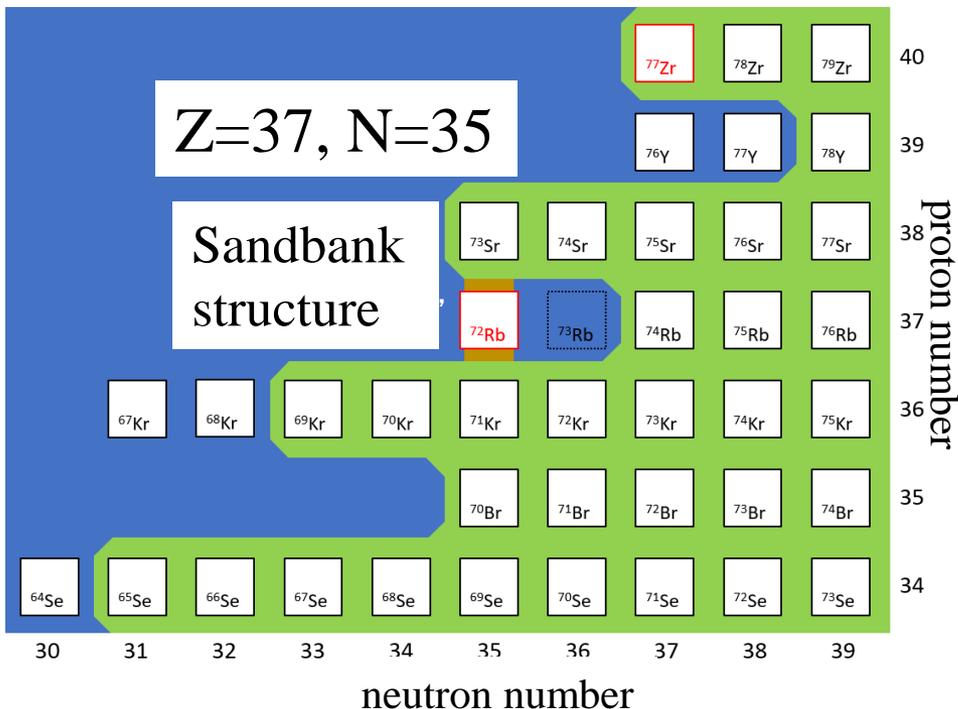




Discovery of ^{72}Rb :

H. Suzuki et al., PRL 119, 192503 (2017)

A nuclear sandbank beyond the proton drip-line

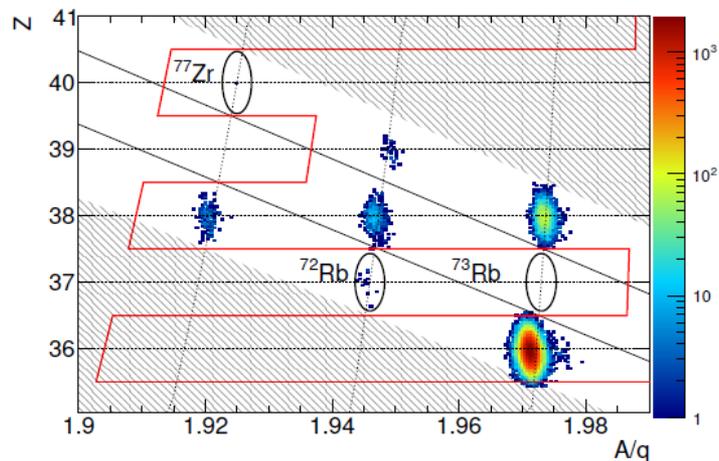


^{72}Rb : $T_{1/2} \sim 100$ ns

^{73}Rb : no events

$T_{1/2} < 80$ ns

^{77}Zr : one event



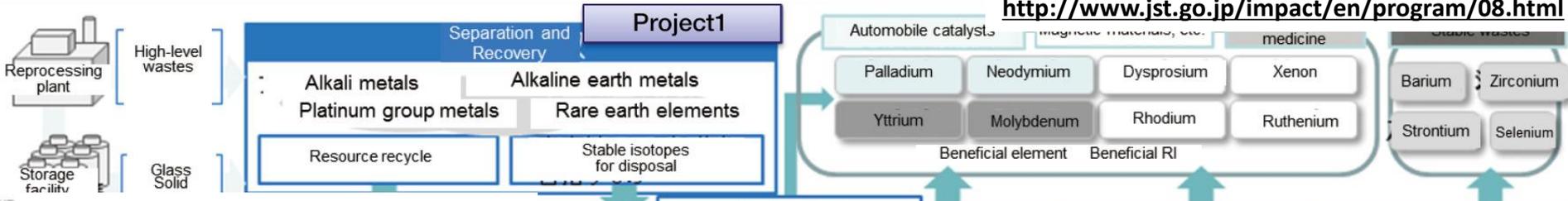
Mechanism of stability enhancement
for the odd-odd nucleus ?

Reduction and Resource Recycling of High-level Radioactive Wastes through Nuclear Transmutation

2014-2018

Program Manager
Reiko Fujita

<http://www.jst.go.jp/impact/en/program/08.html>

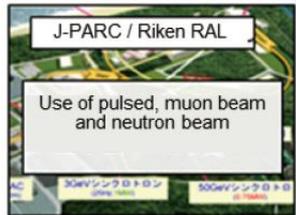


Nuclear Reaction Data

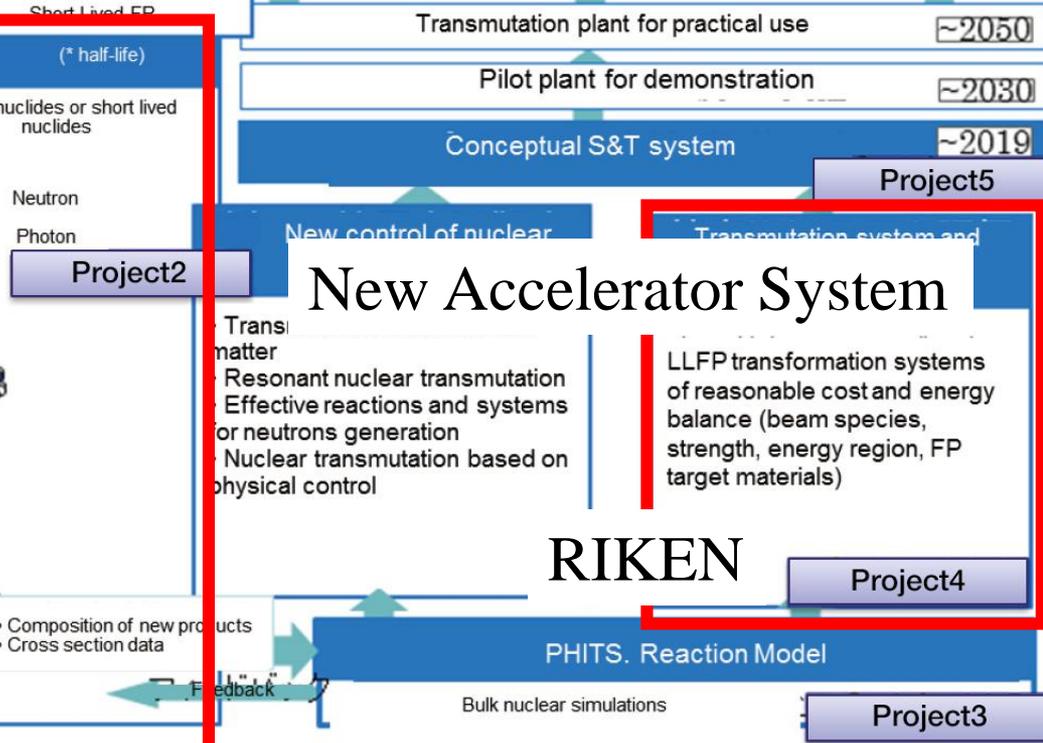
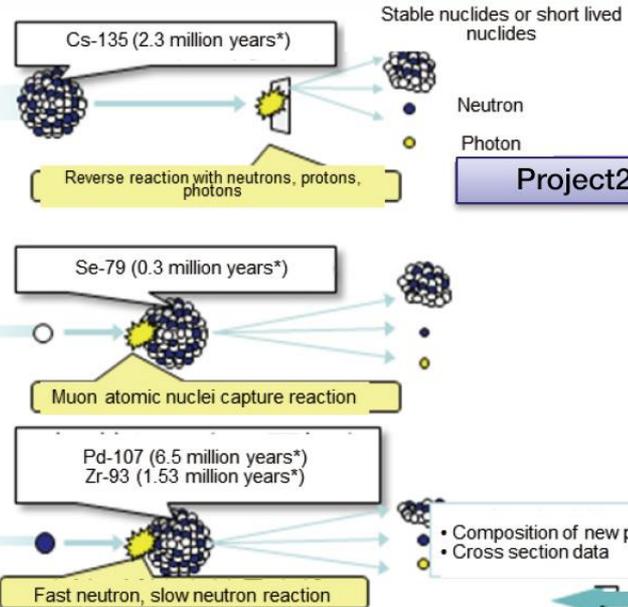
★ World's leading facilities enable world's first data acquisition



RI Beam Factory
Beam contained various nuclides including unstable nuclides



J-PARC / Riken RAL
Use of pulsed, muon beam and neutron beam



RIKEN+UT

RIKEN

Project4

PHITS. Reaction Model

Bulk nuclear simulations

Project3

Nuclear Reaction Data@RIBF

RIKEN-Kyushu-Tokyo-TITech-Niigata-Miyazaki

ZeroDegree Spectrometer



Spallation
 ^{107}Pd @ 50, 100, 200 MeV/u
 ^{93}Zr @ 50, 100 MeV/u
 ^{79}Se @ 200 MeV/u
 ^{126}Sn @ 200 MeV/u



SAMURAI Spectrometer

Spallation
 ^{79}Se , ^{93}Zr @ 110, 200 MeV/u
 Coulomb breakup (γ, n)
 $^{79,80}\text{Se}$, $^{93,94}\text{Zr}$ @ 200 MeV/u

Super Conducting Ring Cyclotron



K=2600MeV

Uranium beam
 (345 MeV/u)



Super-conducting in-flight separator

Beryllium target



LLFP beams
 ^{107}Pd , ^{93}Zr , ^{79}Se , ^{135}Cs

OEDO Device March 2017 completed

Efficient production of low-E RI beams.



Incomplete fusion reaction
 ^{107}Pd @ 20, 30 MeV/u
 ^{93}Zr @ 20, 30 MeV/u
 Neutron-capture (n, γ)
 Trojan horse method $^{77,79}\text{Se}(d, p)$ @ 20 MeV/u

平成30年度 全国発明表彰式

公益社団法人 発明協会



Ceremony at Hotel Okura, June 12th 2018

The 21st Century Invention Award, Japan Institute of Invention and Innovation (2018)