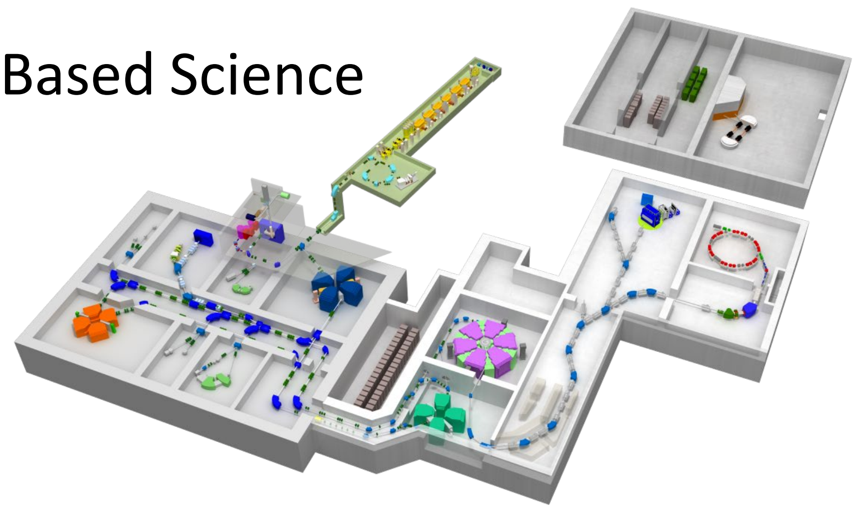
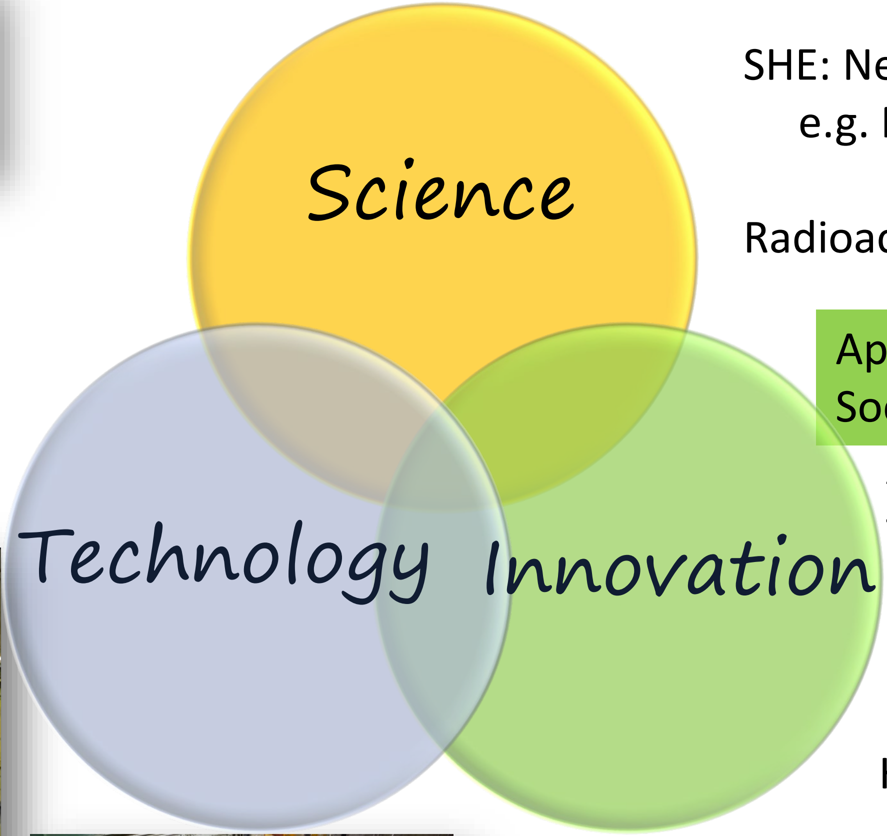
Research activities in nuclear physics and engineering with RIBF

Hiroyoshi Sakurai
RIKEN Nishina Center for Accelerator-Based Science



Science, Technology and Innovation at RIBF

Origin of Elements



Artificial transmutation of elements

SHE: New Elements
e.g. Nihonium Z=113

Radioactive waste problem

Applications for Social Benefits

Alpha-emitter productions for medical application

Heavy-ion breeding

Electronics test for space application

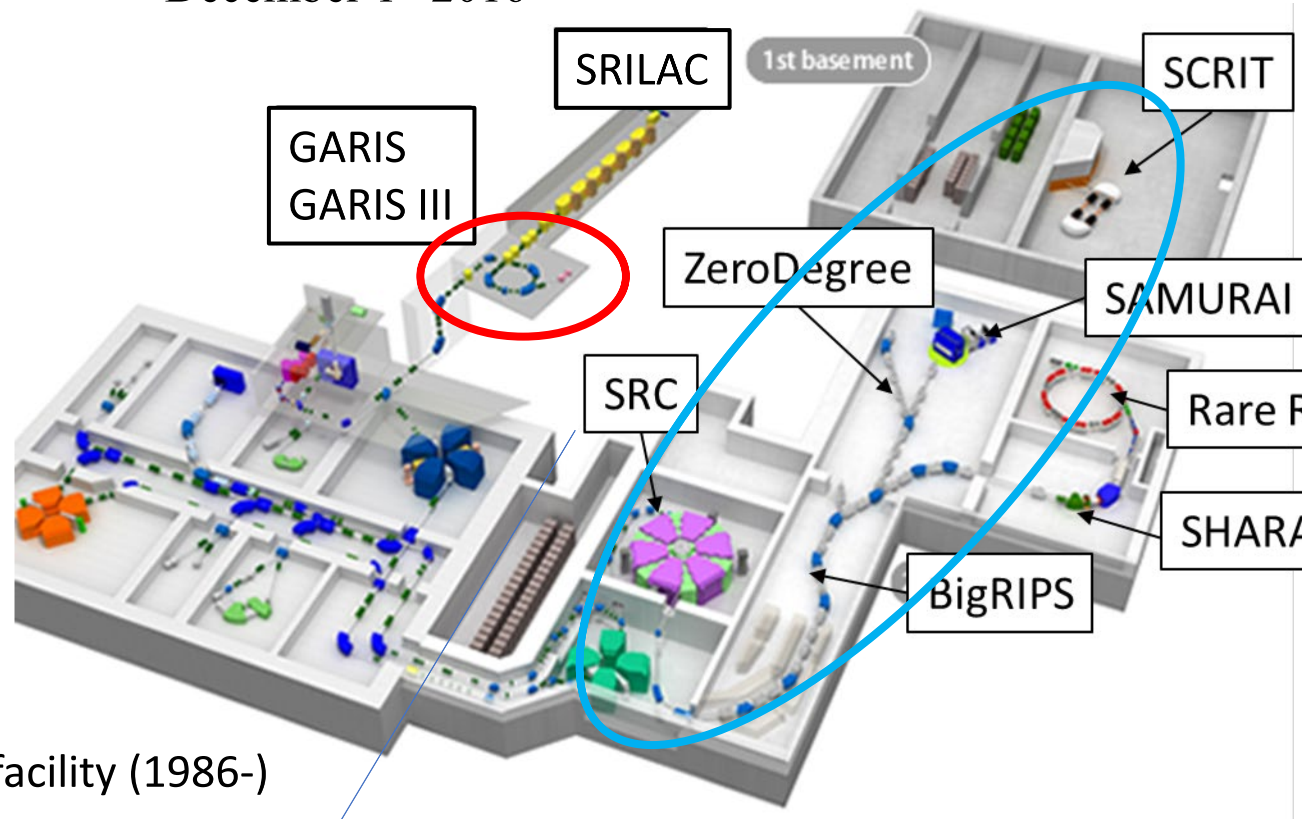
Heavy-Ion Accelerator
Isotope Separation

RI Beam Factory

“Super-Heavy Elements”

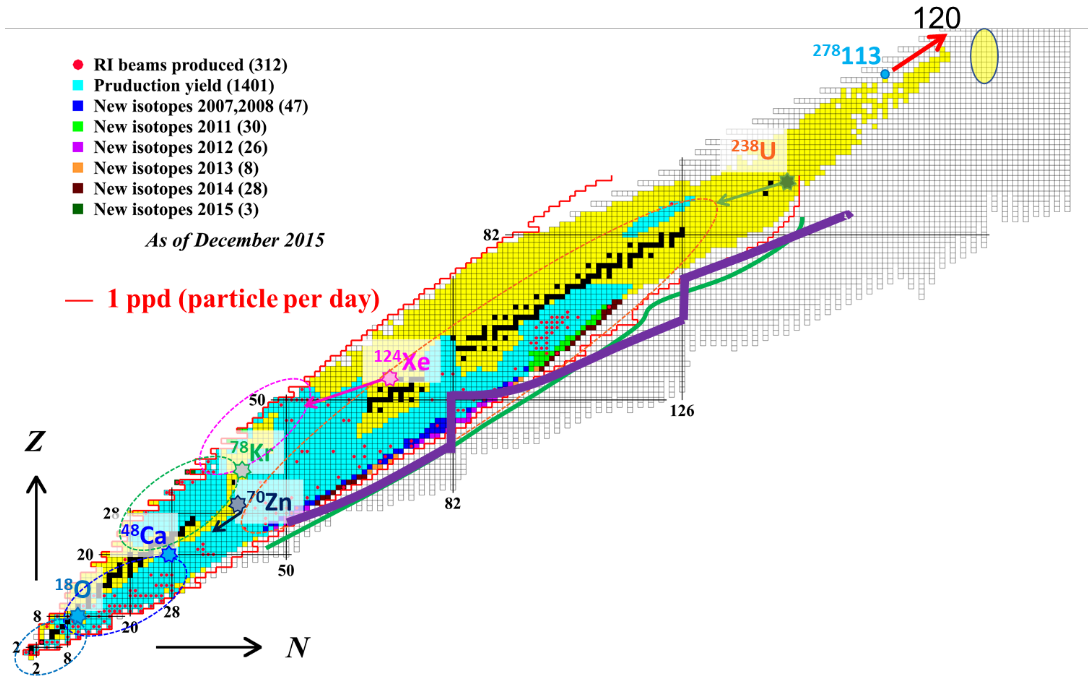
Z

Element 113th “Nihonium”
December 1st 2016



Old facility (1986-)

New facility (2006-)



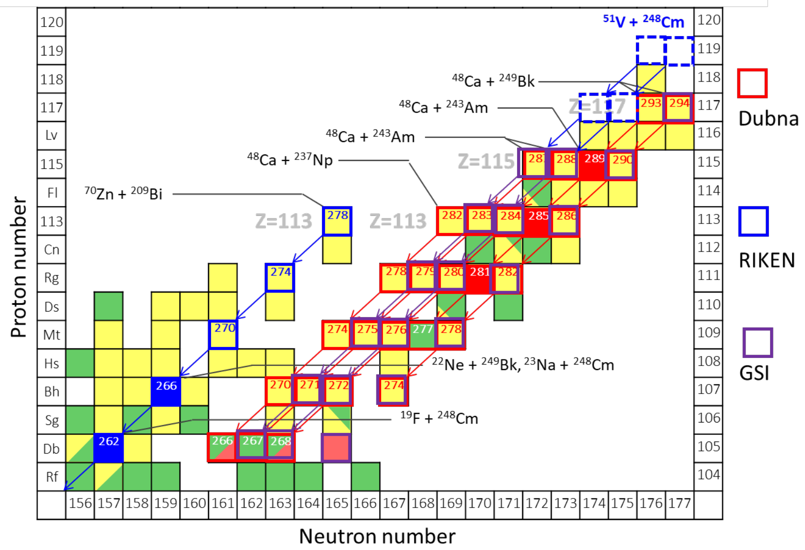
N

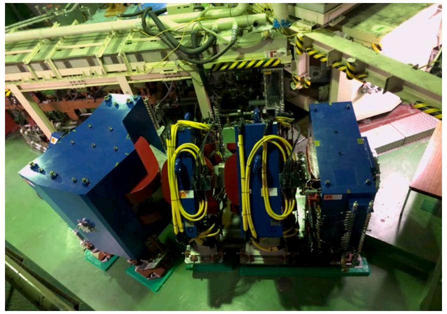
“Exotic Nuclei”

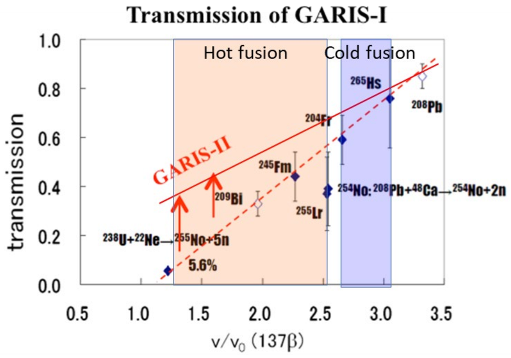
New Setup towards new elements

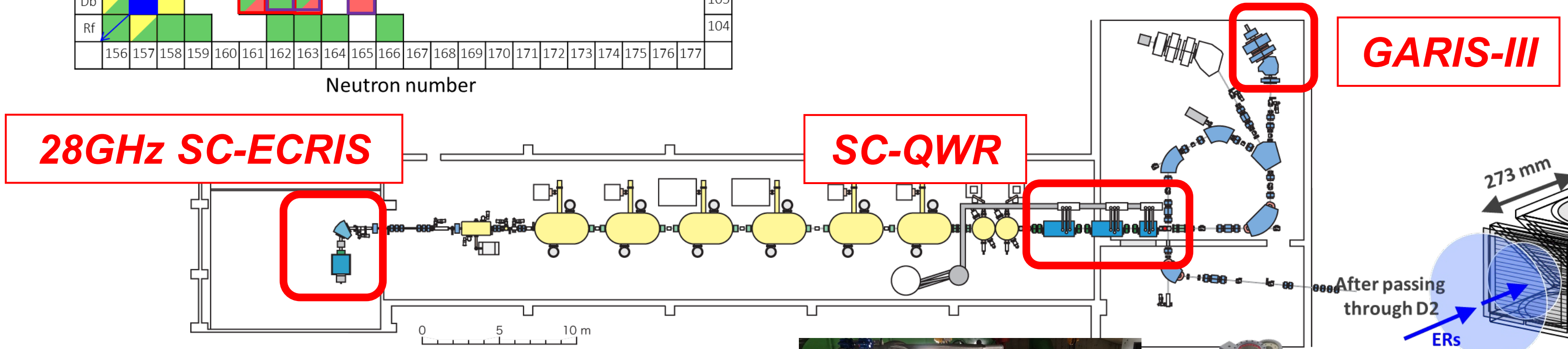
RILAC upgraded by 28GHz ECRIS and SC-QWR (first beam, Jan. 2020!)

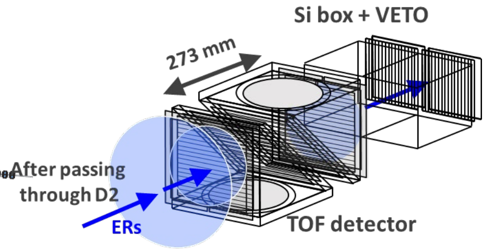
New gas-filled recoil separator for hot-fusion: GARIS-III

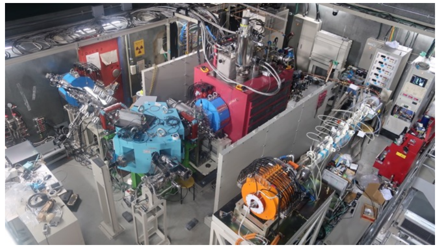


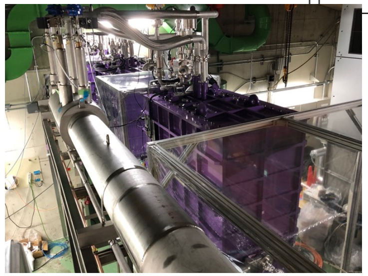


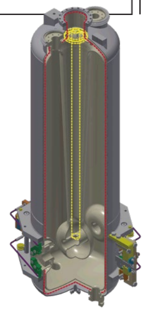




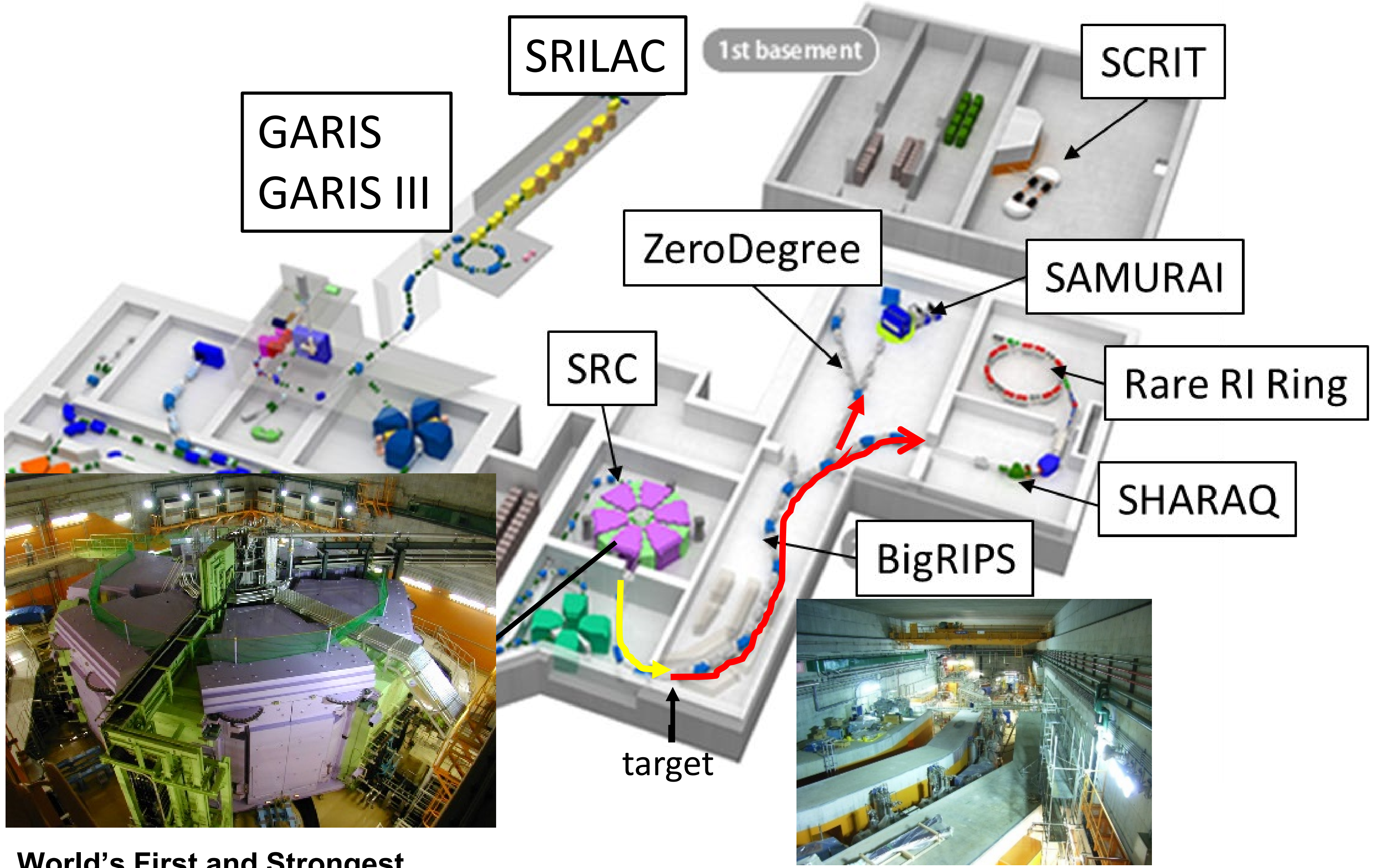








Production and delivery of radioactive isotope beams



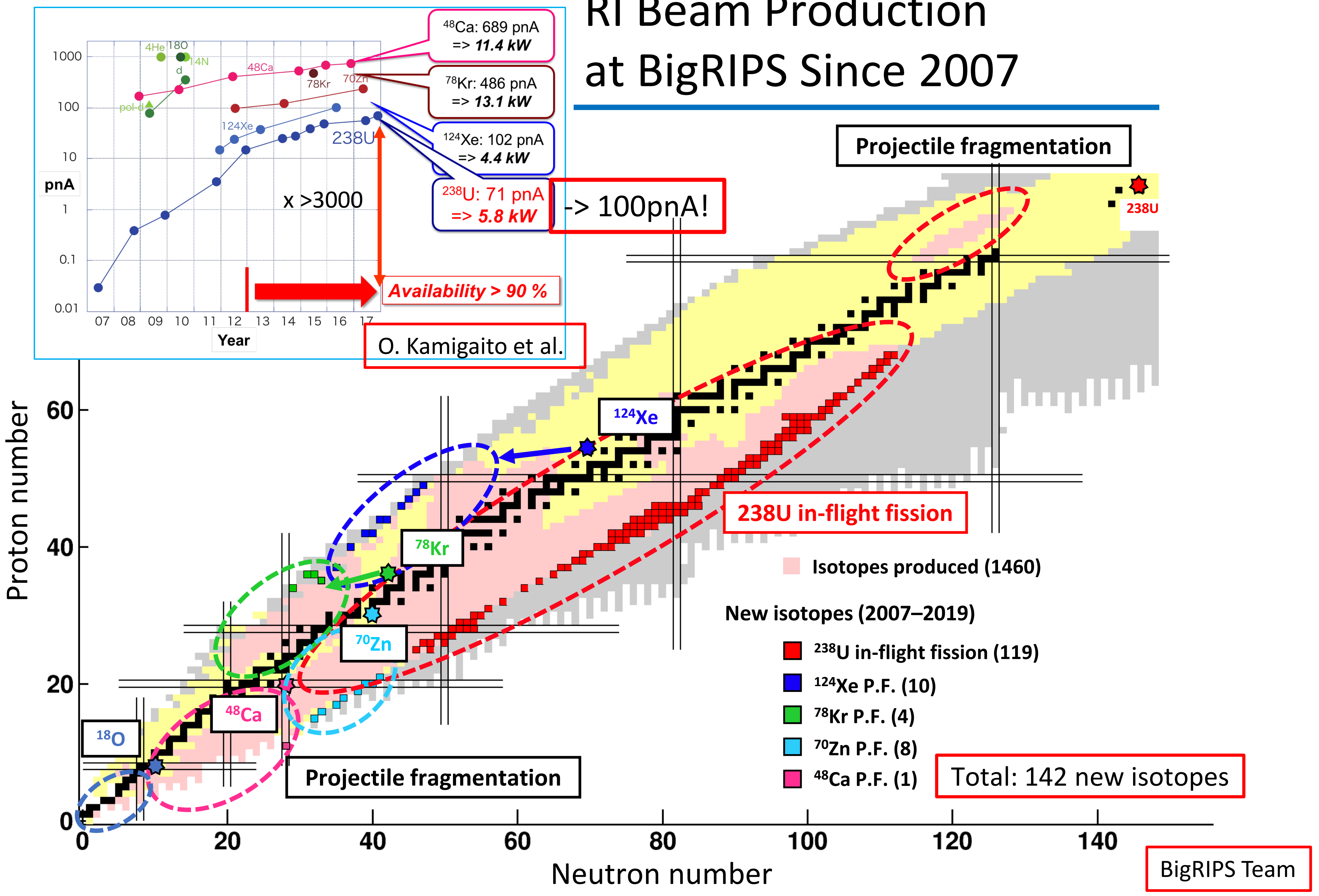
World's First and Strongest
K2600MeV
Superconducting
Ring Cyclotron

Light ions at 400 MeV/u
U beam at 345 MeV/u

World's Largest Acceptance
High magnetic rigidity 9 Tm
Superconducting RI beam Separator

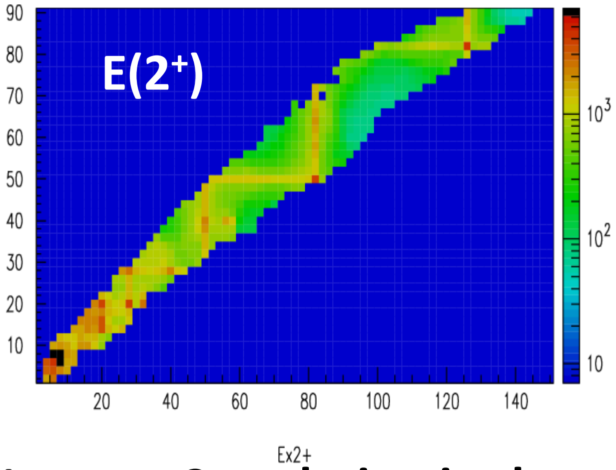
200-250 MeV/u

RI Beam Production at BigRIPS Since 2007

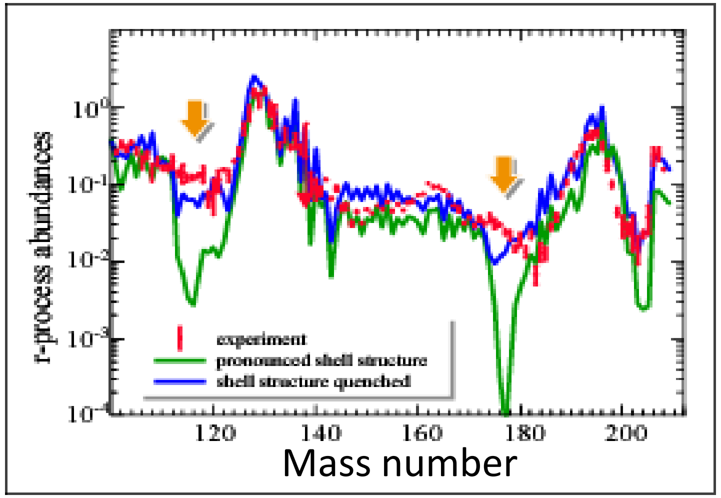


Nuclear Physics with Exotic Nuclei

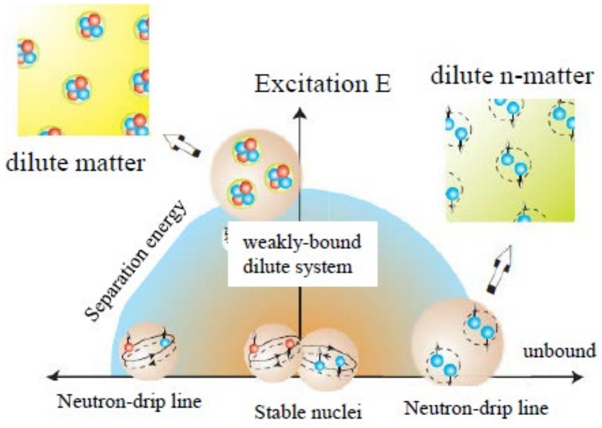
Shell Evolution :
magicity loss and new magicity



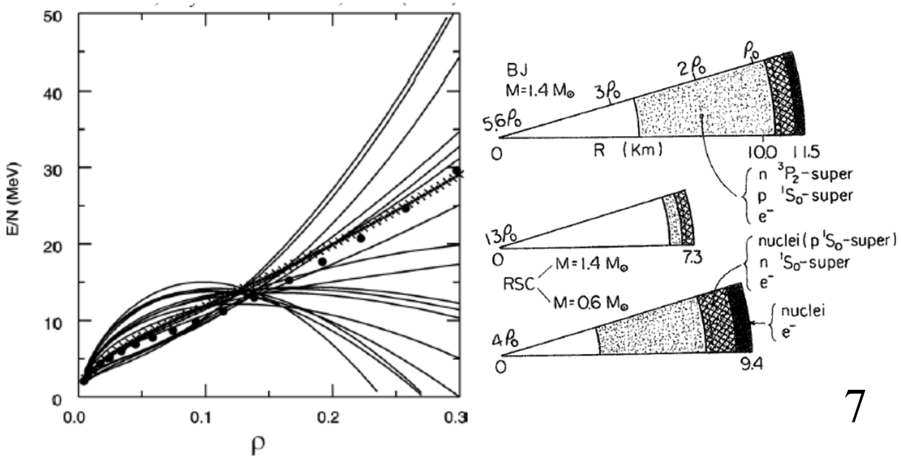
R-process path: Synthesis up to U



Neutron Correlation in the vicinity of the Drip-line

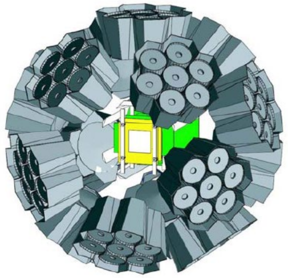


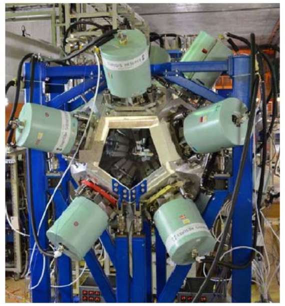
EOS: asymmetric nuclear matter
SN explosion, neutron-star, gravitational wave



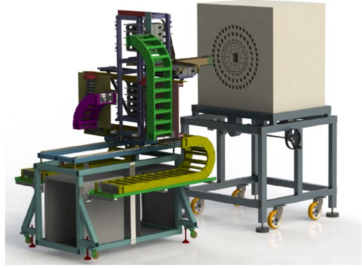
Large-Size International Collaborations

EURICA (2011-2016):
Ge detector array for beta-delayed gamma

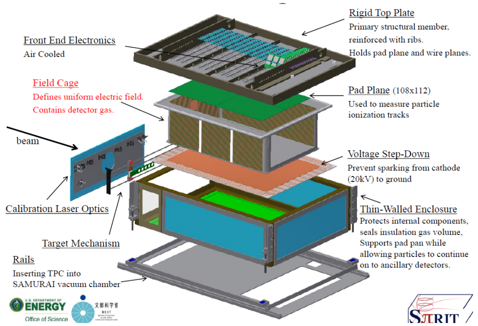




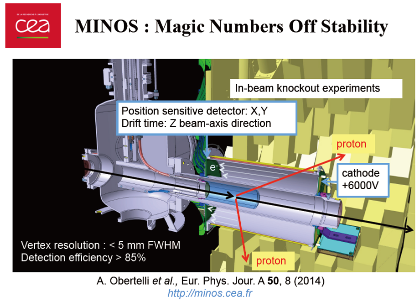
BRIKEN(2017-2021):
He-3 detector array for beta-delayed neutron



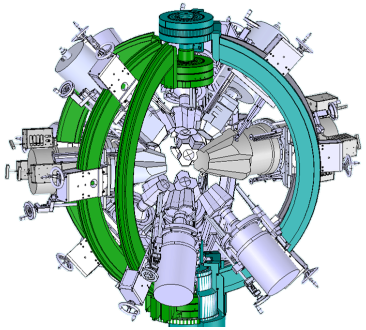
SpiRIT TPC (2015-):
heavy-ion collision program for EOS



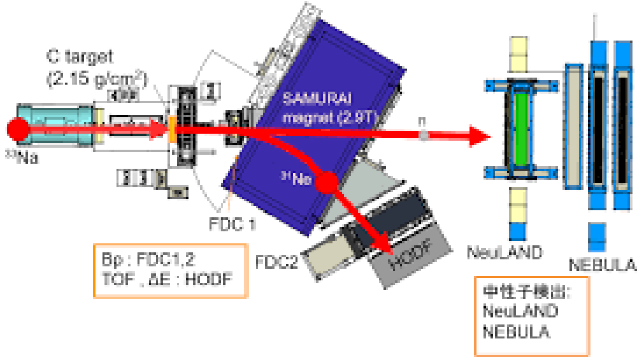
SEASTAR (2014-2017):
thick liq. H2 +TPC+NaI
for in-beam gamma
spectroscopy



HiCARI (2019-2020):
Tracking Ge detectors
for in-beam gamma
spectroscopy



SAMURAI (2012-):
neutron detectors + CsI+…for neutron correlation



Very Selected Highlights at RIBF

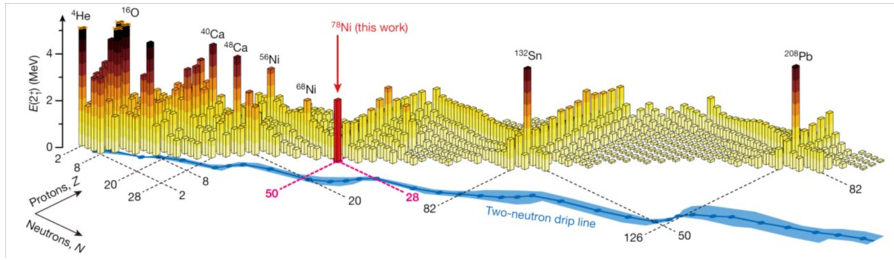
Shell Evolution :

magicity loss and new magicity

New magicity at N=34 (Nature 2013)

Double magicity of ^{78}Ni (Nature 2019)

^{78}Ni revealed as a doubly magic stronghold against nuclear deformation



First spectroscopy of ^{40}Mg at N=28 (PRL 2019)

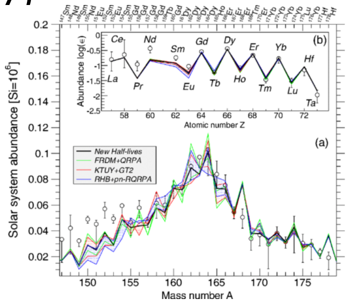
Shell evolution and shape deformation in ^{75}Cu (Nature Physics 2019)

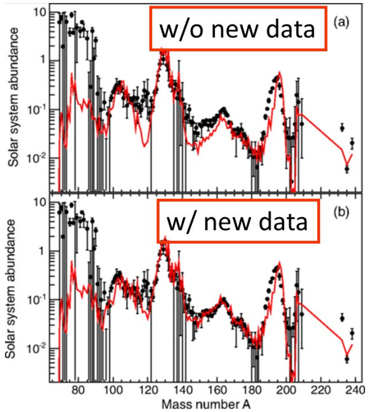
r-process nucleosynthesis:

Impact of T1/2 data

the 2nd peak (PRL 2011, 2015)

the rare earth peak (PRL 2017)





Neutron correlation:

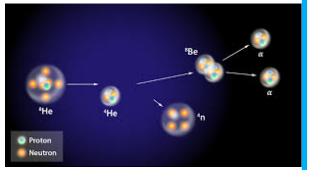
Deformed halo nuclei ^{31}Ne ^{37}Mg (PRL2009, 2014)

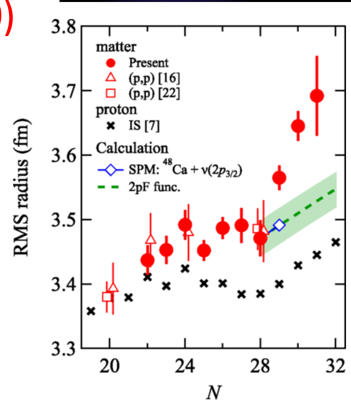
Two-neutron halo ^{29}F (PRL 2020)

Barely unbound nucleus ^{26}O (PRL 2016)

Tetraneutron state (PRL 2015)

Swelling of double magic ^{48}Ca core (PRL2020)





EOS:

3NF with polarized deuteron beams (PRC 2017)

GT in ^{132}Sn (PRL 2018)

Probing the Symmetry Energy with the Spectral Pion Ratio Heavy-ion collisions (PLB 2020, 2021, PRL 2021)

Vietnamese Activity at RIBF

PHYSICAL REVIEW C **100**, 011302(R) (2019)

Rapid Communications

Observation of a μs isomer in $^{134}_{49}In_{85}$: Proton-neutron coupling "southeast" of $^{132}_{50}Sn_{82}$

VNU
Univ. of Science

V. H. Phong,[1,2] G. Lorusso,[1,3,4,*] T. Davinson,[5] A. Estrade,[6] O. Hall,[5] J. Liu,[1,7] K. Matsui,[1,8] F. Montes,[9] S. Nishimura,[1] A. Boso,[3] P. H. Regan,[3,10] R. Shearman,[3] Z. Y. Xu,[11] J. Agramunt,[12] J. M. Allmond,[13] D. S. Ahn,[1] A. Algora,[12,14] H. Baba,[1] N. T. Brewer,[11,15] C. G. Bruno,[5] R. Caballero-Folch,[16] F. Calvino,[17] M. Wolińska-Cichocka,[18] G. Cortes,[17] I. Dillmann,[16,19] C. Domingo-Pardo,[12] A. Gargano,[20] S. Go,[1] C. J. Griffin,[5] R. K. Grzywacz,[11,15] L. Harkness-Brennan,[21] T. Isobe,[1] A. Jungclaus,[22] D. Kahl,[5] L. H. Khiem,[23,24] G. Kiss,[1,14] A. Korgul,[25] S. Kubono,[1] K. Miernik,[25] A. I. Morales,[12] N. Nepal,[6] M. Piersa,[25] Zs. Podolyák,[10] B. C. Rasco,[11,15] K. P. Rykaczewski,[13] H. Sakurai,[1,8] Y. Shimizu,[1] D. W. Stacener,[13] T. Sumikama,[1] H. Suzuki,[1] H. Takeda,[1] J. L. Tain,[12] A. Tarifeño-Saldivia,[12,17] A. Tolosa-Delgado,[12] V. Vaquero,[22] P. J. Woods,[5] R. Yokoyama,[11] and C. Yuan[26]

PHYSICAL REVIEW C **104**, 044331 (2021)

Investigation of the ground-state spin inversion in the neutron-rich ^{47,49}Cl isotopes

VINATOM

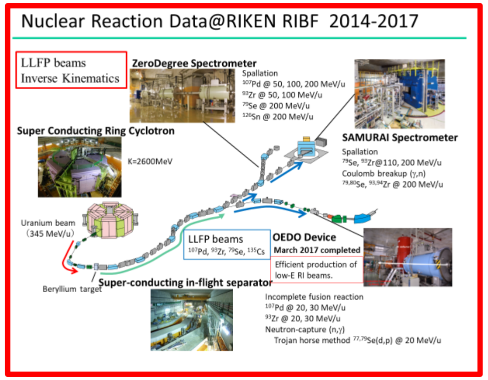
B. D. Linh,[1] A. Corsi,[2] A. Gillibert,[2,*] A. Obertelli,[2,3,4] P. Doornenbal,[3] C. Barbieri,[5,6,7] S. Chen,[8,3,9] L. X. Chung,[1] T. Duguet,[2,10] M. Gómez-Ramos,[4,11] J. D. Holt,[12,13] A. Moro,[11] P. Navrátil,[12] K. Ogata,[14,15] N. T. T. Phuc,[16,17] N. Shimizu,[18] V. Somà,[2] Y. Utsuno,[18,19] N. L. Achouri,[20] H. Baba,[3] F. Browne,[3] D. Calvet,[2] F. Château,[2] N. Chiga,[3] M. L. Cortés,[3] A. Delbart,[2] J.-M. Gheller,[2] A. Giganon,[2] C. Hilaire,[2] T. Isobe,[3] T. Kobayashi,[21] Y. Kubota,[3,18] V. Lapoux,[2] H. N. Liu,[2,4,22] T. Motobayashi,[3] I. Murray,[23,3] H. Otsu,[3] V. Panin,[3] N. Paul,[2,24] W. Rodriguez,[3,25,26] H. Sakurai,[3,27] M. Sasano,[3] D. Steppenbeck,[3] L. Stuhl,[18,28,29] Y. L. Sun,[2,4] Y. Togano,[30] T. Uesaka,[3] K. Wimmer,[27,3] K. Yoneda,[3] O. Aktas,[22] T. Aumann,[4,31] F. Flavigny,[23,20] S. Franchoo,[23] I. Gašparić,[32,4,3] R.-B. Gerst,[33] J. Gibelin,[20] K. I. Hahn,[34,29] N. T. Khai,[35] D. Kim,[34,3,29] T. Koiwai,[27] Y. Kondo,[36] P. Koseoglou,[4,31] J. Lee,[8] C. Lehr,[4] T. Lokotko,[8] M. MacCormick,[23] K. Moschner,[33] T. Nakamura,[36] S. Y. Park,[34,29] D. Rossi,[4] E. Sahin,[37] D. Sohler,[28] P.-A. Söderström,[4] S. Takeuchi,[36] N. D. Ton,[1] H. Törnqvist,[4,31] V. Vaquero,[38] V. Wagner,[4] H. Wang,[39] V. Werner,[4] X. Xu,[8] Y. Yamada,[36] D. Yan,[39] Z. Yang,[3] M. Yasuda,[36] and L. Zanetti[4]

Challenge to solve the radioactive waste problem

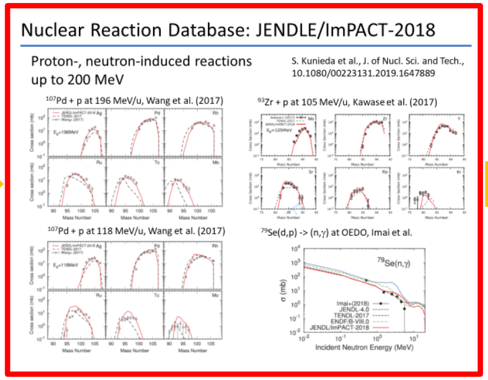
ImPACT (2014-2018) R&D grant under the Cabinet in Japan
"Reduction and Resource Recycling of High-level Radioactive Wastes through Nuclear Transmutation"
(https://www.jst.go.jp/impact/en/program/08.html)

How to reduce long-lived fission products with accelerators?

Nuclear Data at RIBF

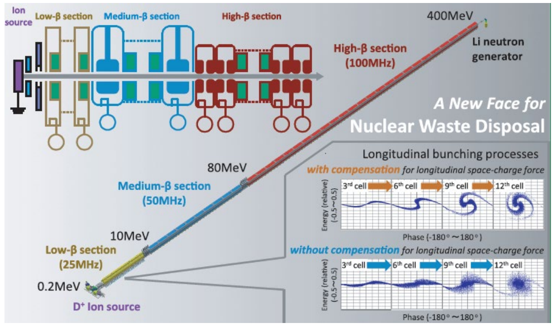


Database at JAEA



Simulation with PHITS code

Transmutation Strategy
Accelerator performance required



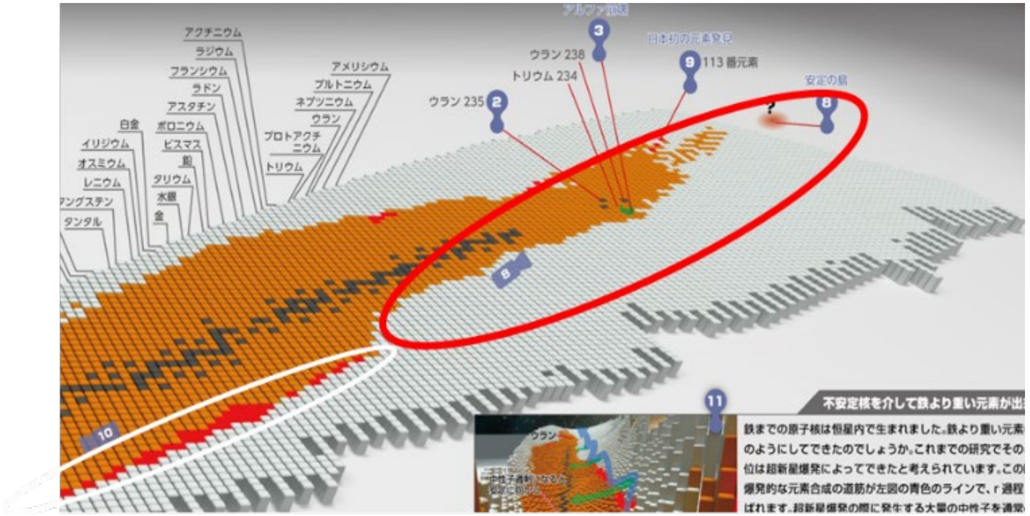
1-ampare deuteron linac
to produce high-energy neutrons

Okuno et al., Proc. Jpn. Acad., Ser. B 95 (2019), 430

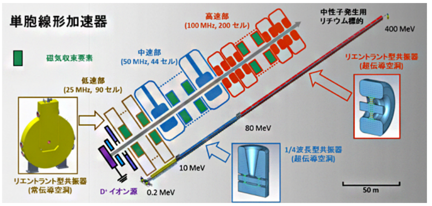
HS, "ImPACT under RIKEN Nishina Center", Nuclear Physics News 31, issue 3, 26-29
http://www.nupecc.org/npn/npn313.pdf

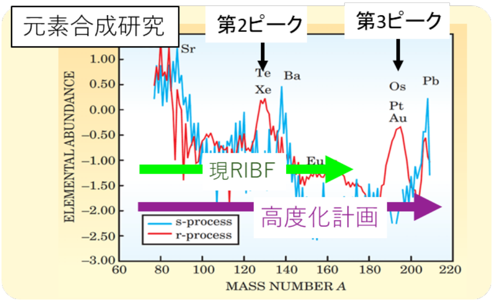
Can human beings freely recreate elements?

The nuclear chart explored by RIBF intensity-upgrade



Expansion of the nuclear chart
with
both intense
Fast radioactive beams +
Low-energy radioactive beams

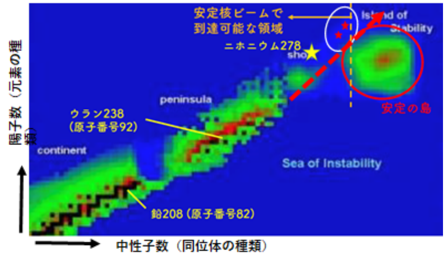




Challenge 1: Pathway towards reduction of the radioactive waste
not only long-lived fission fragments but also minor actinides

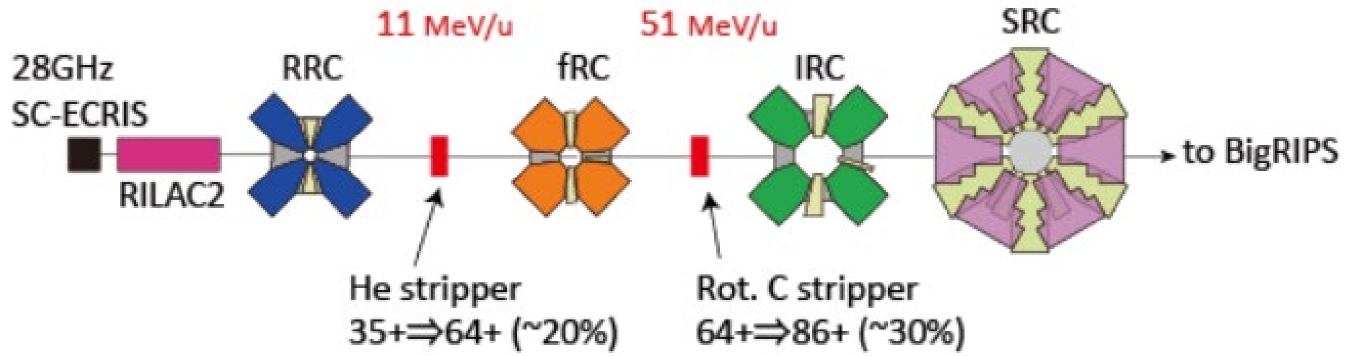
Challenge 2: Pathway towards Uranium in the r-process path
the 3rd peak of the r-process and the termination

Challenge 3: Pathway towards the Island of Stability



RIBF upgrade for higher U intensity

Present Acceleration Scheme

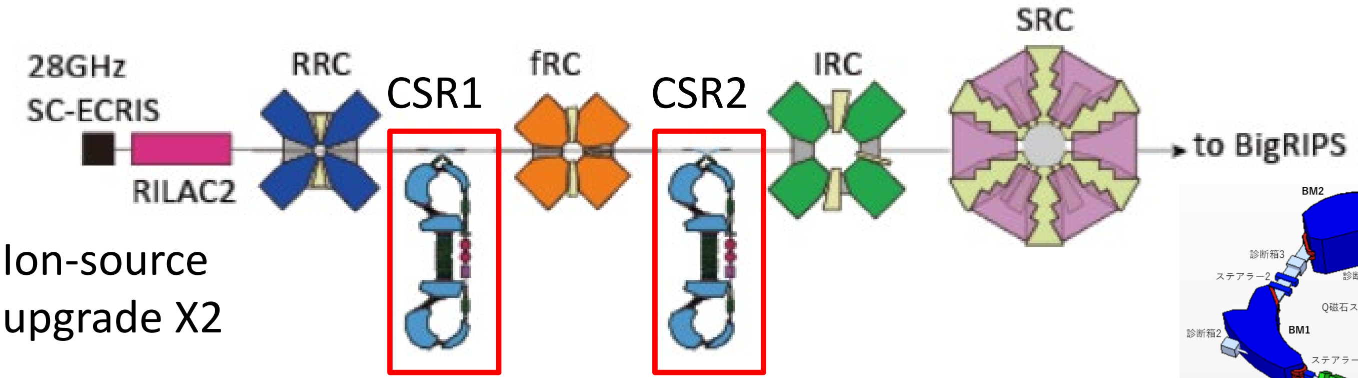


100 pnA

Large loss at the strippers : transmission efficiency is about 6%

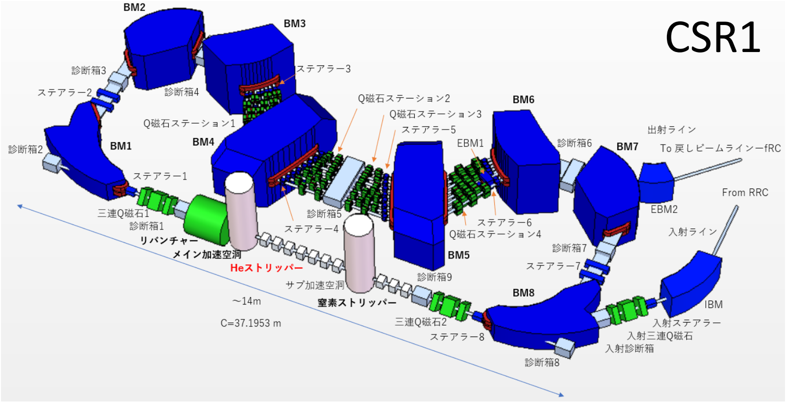
x20

Upgrade plan



2000 pnA

Ion-source upgrade X2



CSR1

Charge Stripper Rings : beam recycling technology to increase transmission efficiency by a factor of 10

Requesting the construction budget now

Summary

RIBF is one of the world leading facilities in low energy nuclear physics

RIBF is maximizing discovery potentials and research opportunities in low-energy nuclear physics as well as nuclear engineering, especially for the radioactive waste problem

RIBF intensity upgrade plan is at the top priority of Nishina Center to further strengthen the RIBF facility