ANPhA symposium 2025
28−29, November 2025

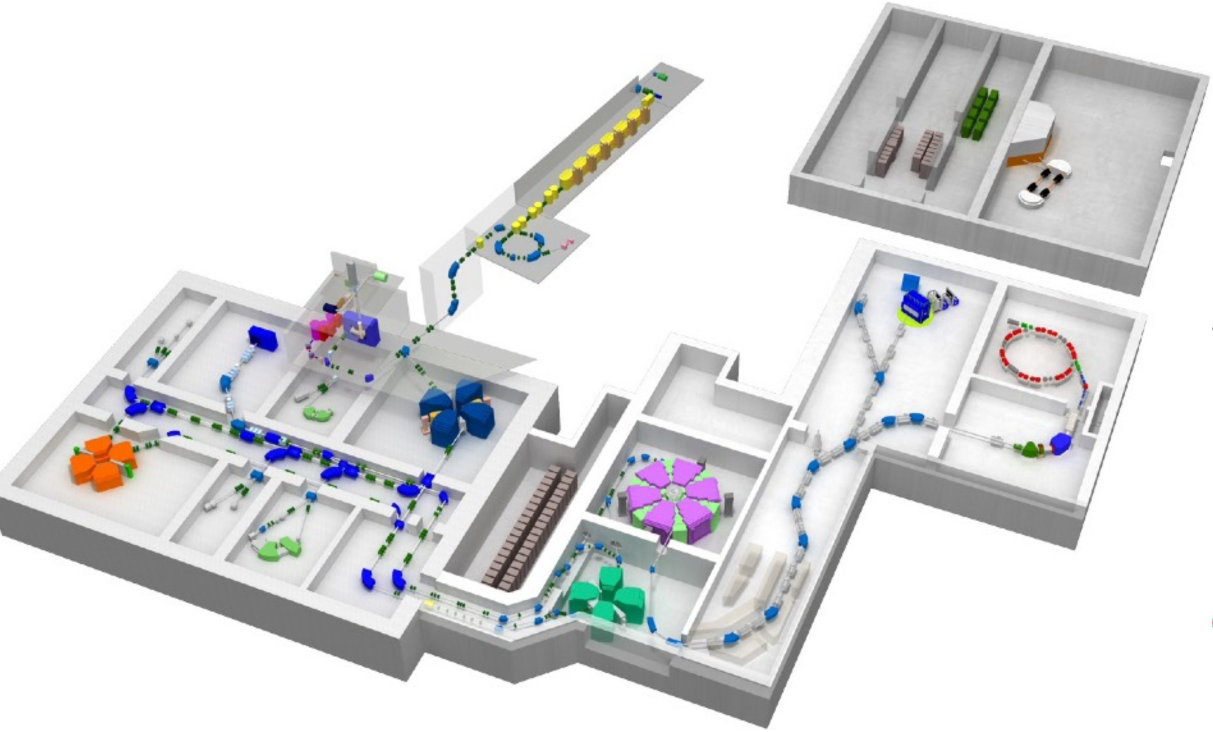
The RIBF Facility and Its Upgrade Project

Tomohiro Uesaka
on behalf of Hiro Sakurai
RIKEN Nishina Center for Accelerator-Based Science

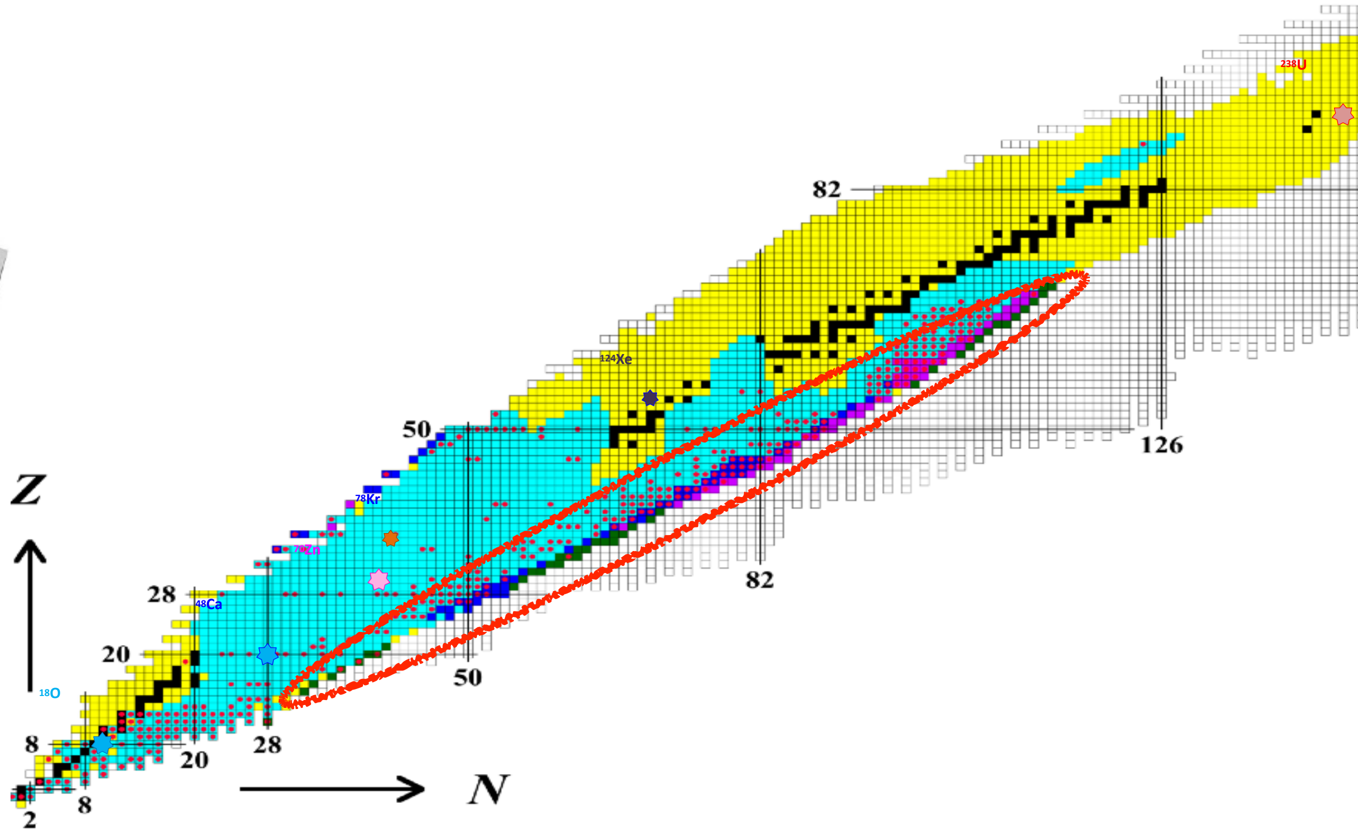
RI Beam Factory at RIKEN

Heavy-ion accelerator that provides high intensity radioactive isotope (RI) beams at 60−70% of the light speed.

Nuclei in a wide isospin chain are delivered.

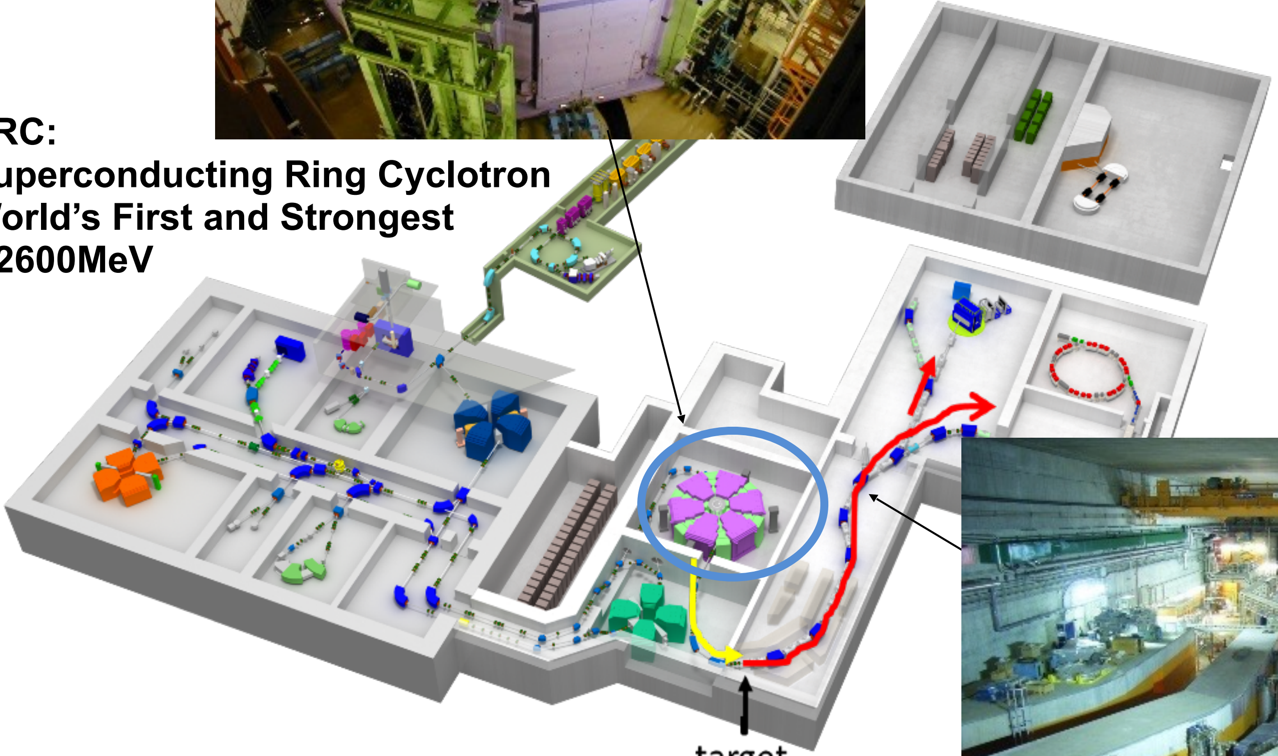


Nuclear chart

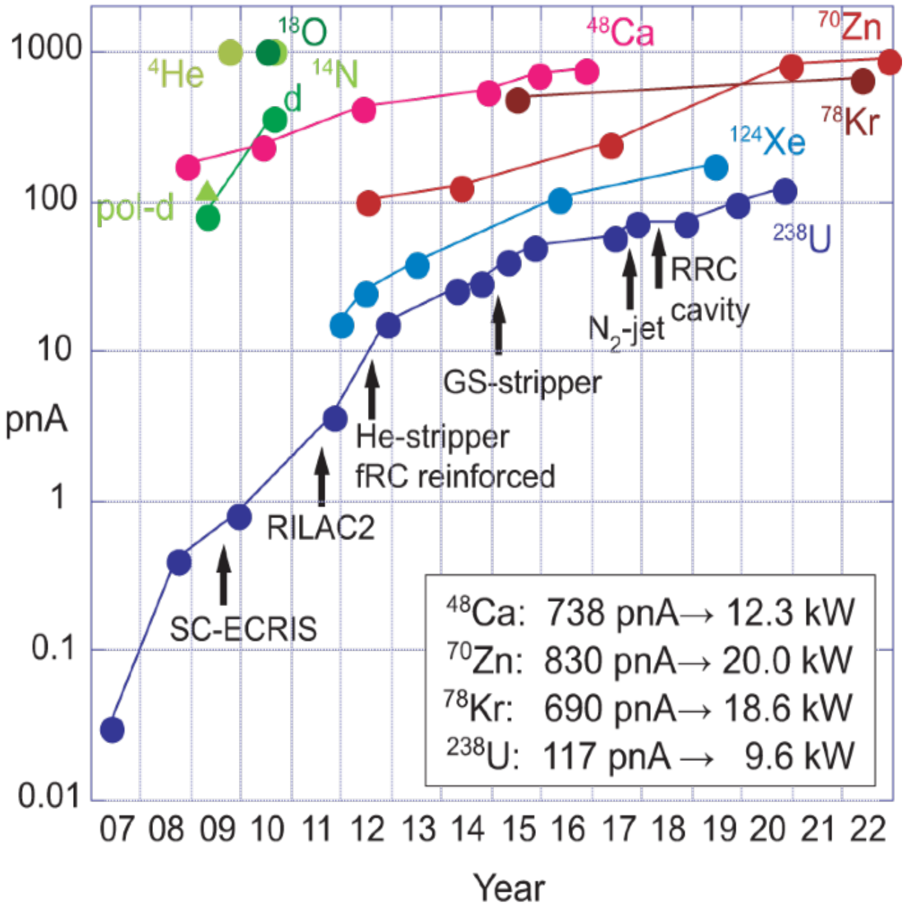


Accelerators and In-flight Separator at RIBF

SRC:
Superconducting Ring Cyclotron
World's First and Strongest
K2600MeV

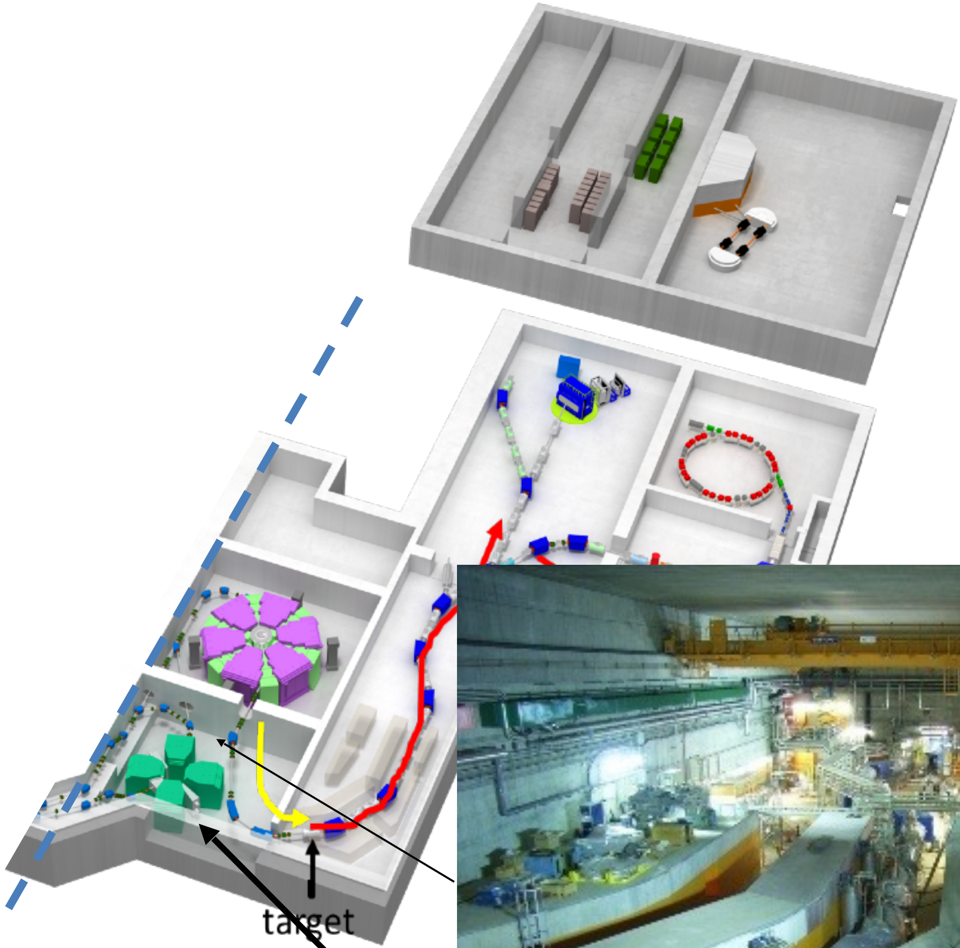


Beam Intensity of SRC as a function of year



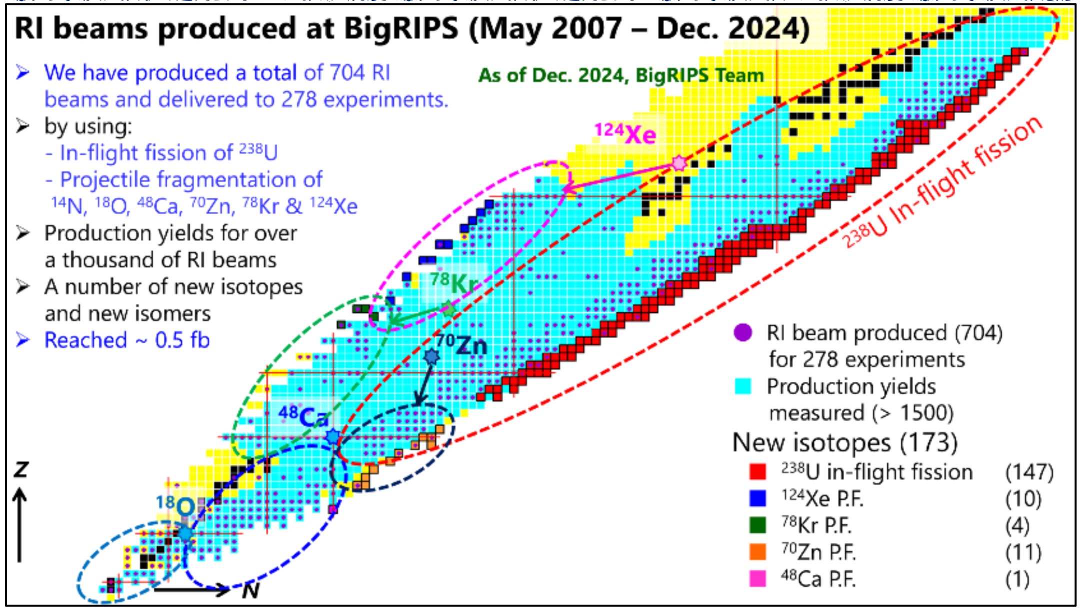
BigRIPS:
Superconducting RI beam Separator
In-flight separator
World's Largest Acceptance
High magnetic rigidity 9 Tm

In-flight Separator at RIBF



New facility (2006-)

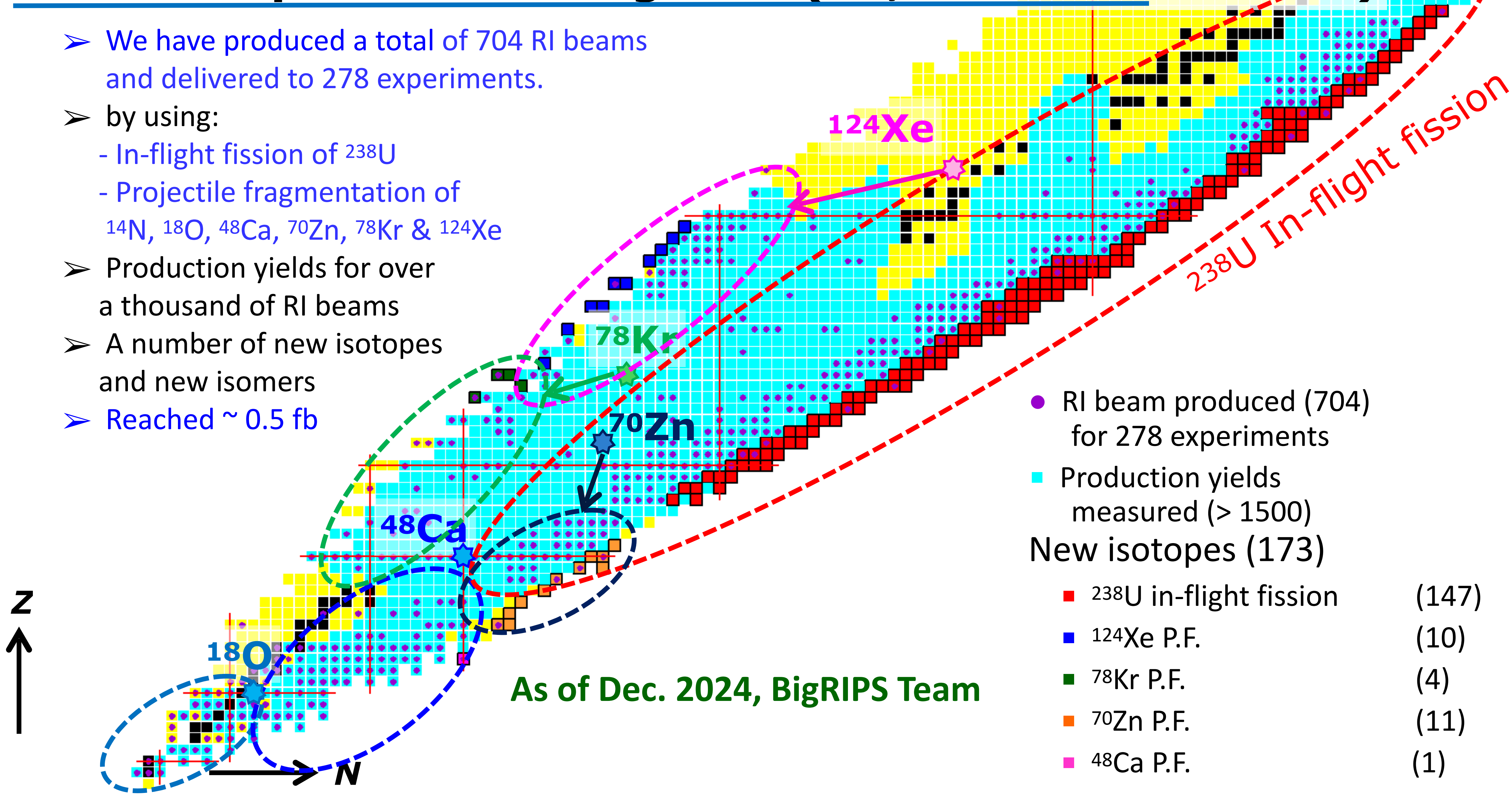
RI be
at ~2



BigRIPS:
Superconducting RI beam Separator
In-flight separator
World's Largest Acceptance
High magnetic rigidity 9 Tm

RI beams produced at BigRIPS (May 2007 – Dec. 2024)

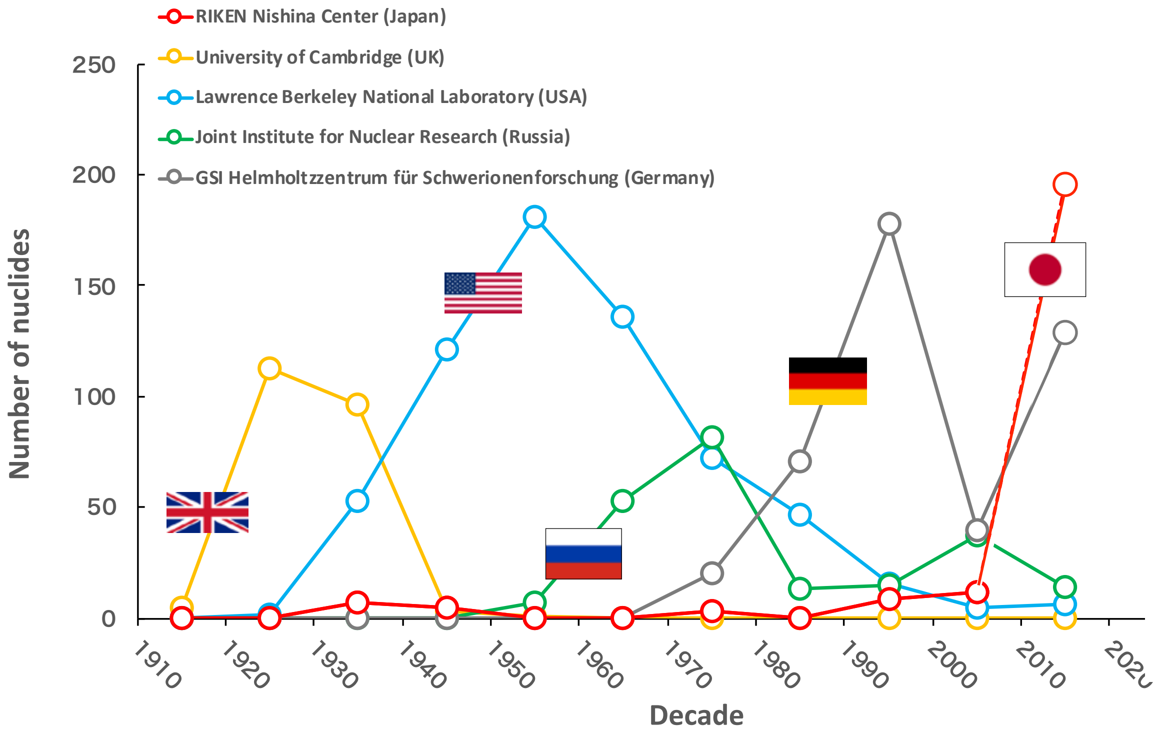
- We have produced a total of 704 RI beams and delivered to 278 experiments.
- by using:
  - In-flight fission of ^{238}U
  - Projectile fragmentation of ^{14}N, ^{18}O, ^{48}Ca, ^{70}Zn, ^{78}Kr & ^{124}Xe
- Production yields for over a thousand of RI beams
- A number of new isotopes and new isomers
- Reached ~ 0.5 fb



As of Dec. 2024, BigRIPS Team

Production of new isotopes: measure of the discovery potential

# of new isotopes discovered at RIBF as of May 2025: 183



PTEP

Prog. Theor. Exp. Phys. **2025** 113D01 (13 pages)
DOI: 10.1093/ptep/ptaf149

Discovery of Proton-Rich Radioactive Isotopes in the $Z = 60$ Region Produced by the Projectile Fragmentation of a 345-MeV/Nucleon ^{238}U Beam

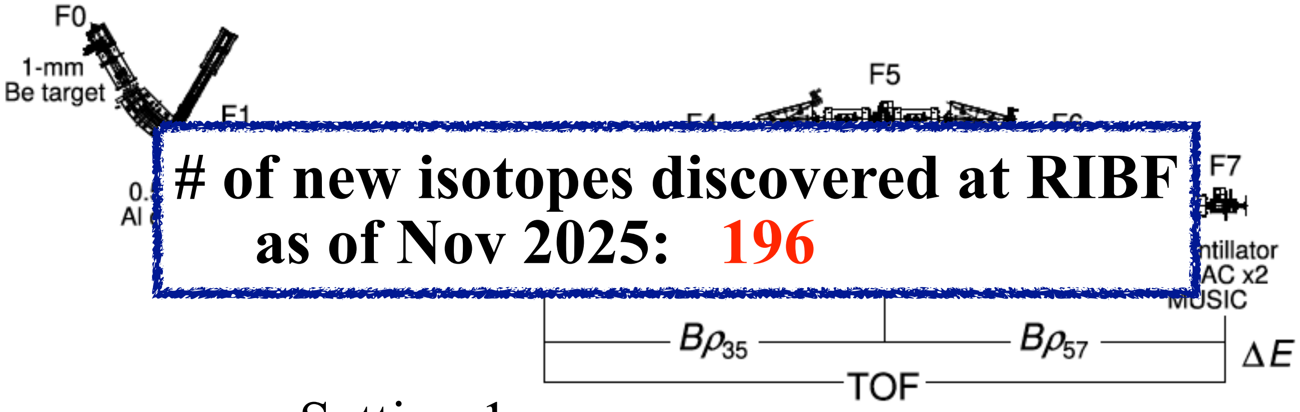
H. Suzuki[1,*], N. Fukuda[1], H. Takeda[1], Y. Shimizu[1], M. Yoshimoto[1], Y. Togano[1], H. Sato[1], N. Kitamura[2], S. Hanai[2], S. Momota[3], K. Kusaka[1], Y. Yanagisawa[1], M. Ohtake[1], T. Sumikama[1], N. Fukunishi[1], and S. Michimasa[1]

[1] *RIKEN Nishina Center for Accelerator-Based Science, RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*
[2] *Center for Nuclear Study, The University of Tokyo, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*
[3] *School of Engineering Science, Kochi University of Technology, 185 Miyanokuchi, Tosayamada, Kami City, Kochi 782-8502, Japan*

Received June 6, 2025; Revised October 5, 2025; Accepted October 6, 2025; Published October 15, 2025

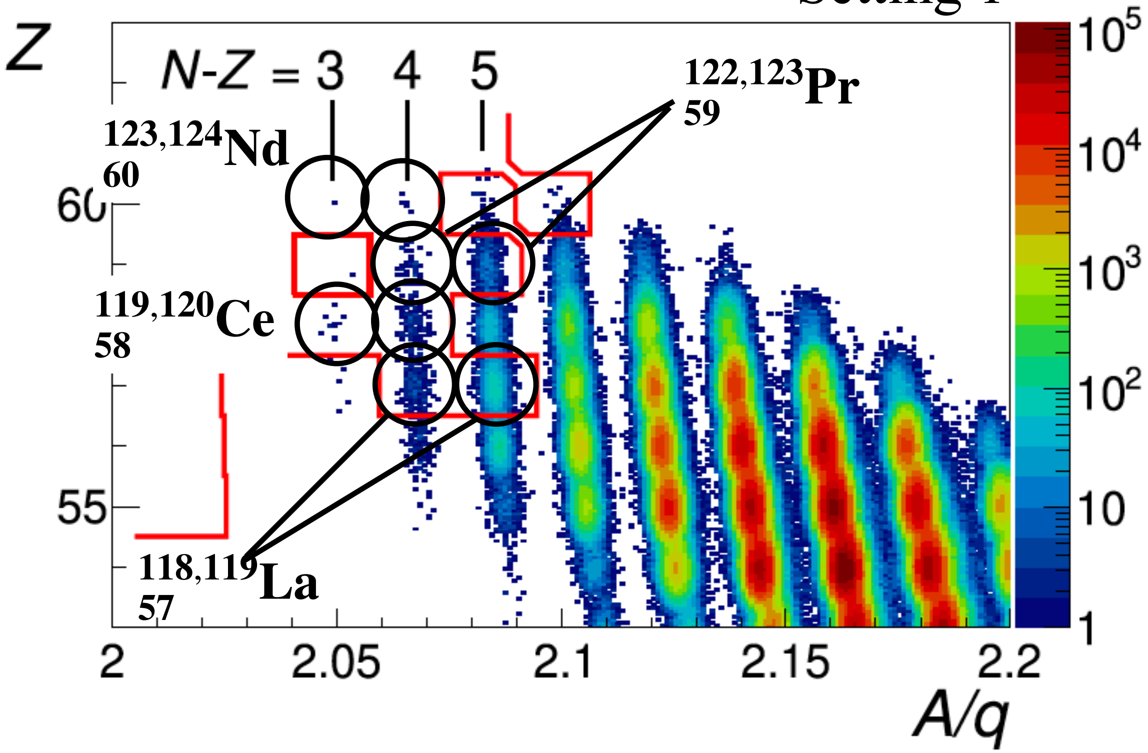
Production of new isotopes: measure of the discovery potential

U beam at 345 MeV/u
~ 60 pnA

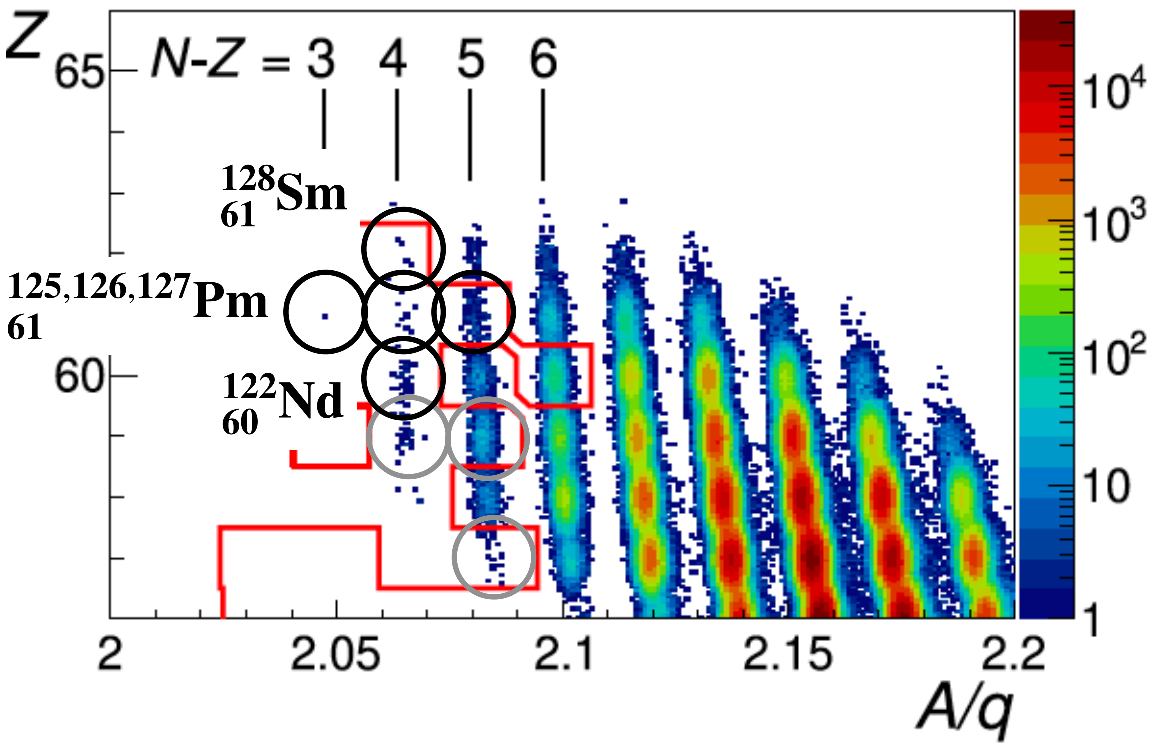


# of new isotopes discovered at RIBF as of Nov 2025: 196

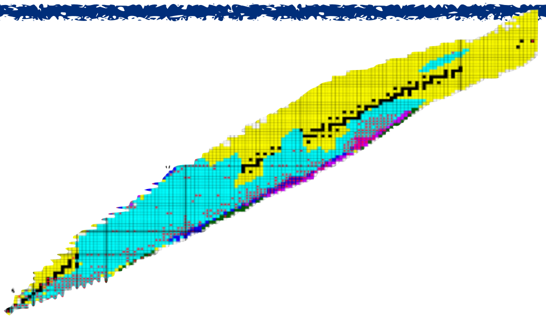
Setting 1

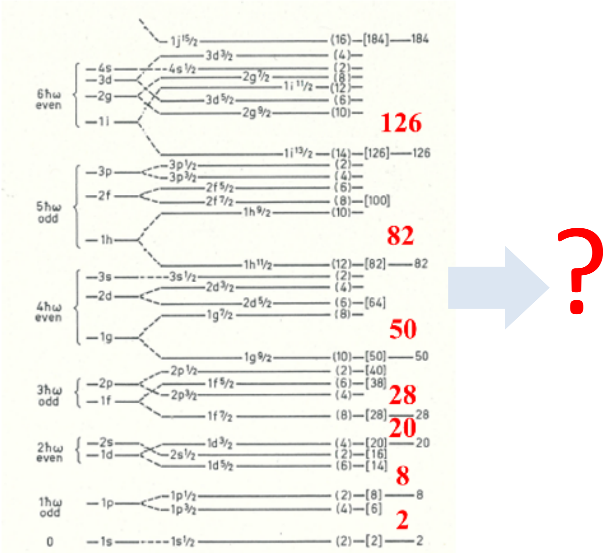


Setting 2



Physics with nuclei far from the stability line

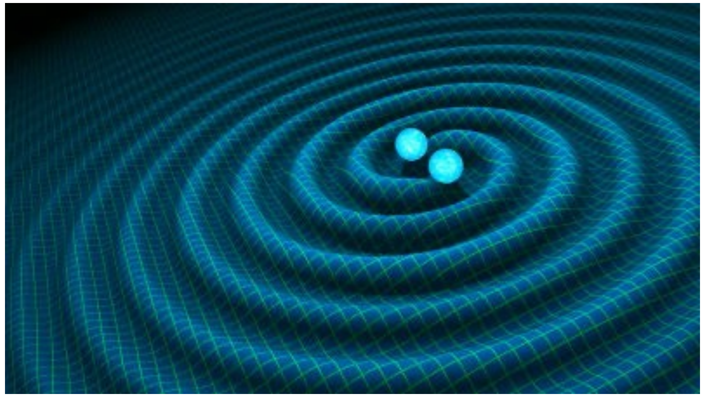




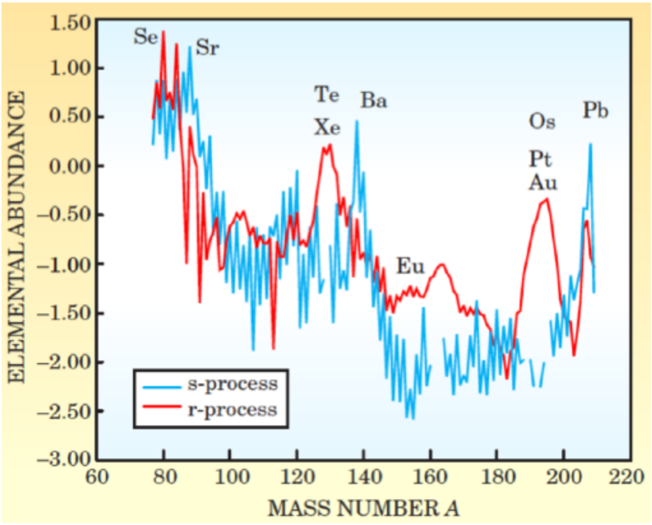
Where is the limit of nuclear stability?

How does nuclear shell structure evolve in the region far from the β stability line?

How are nuclei stabilized near and beyond the drip-line?



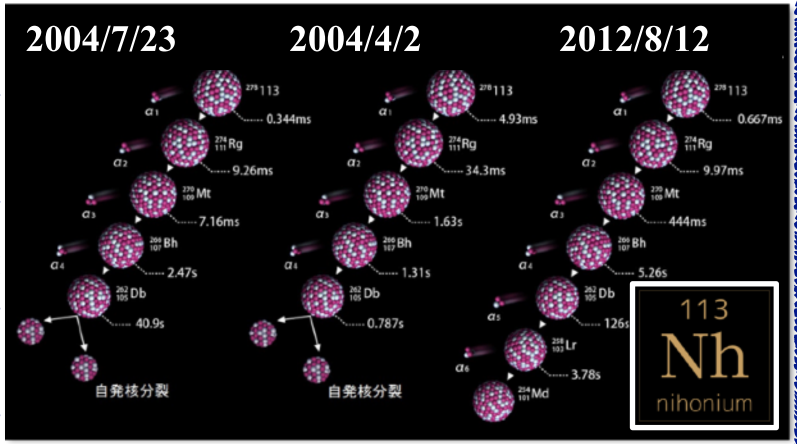
How stiff is the neutron matter?



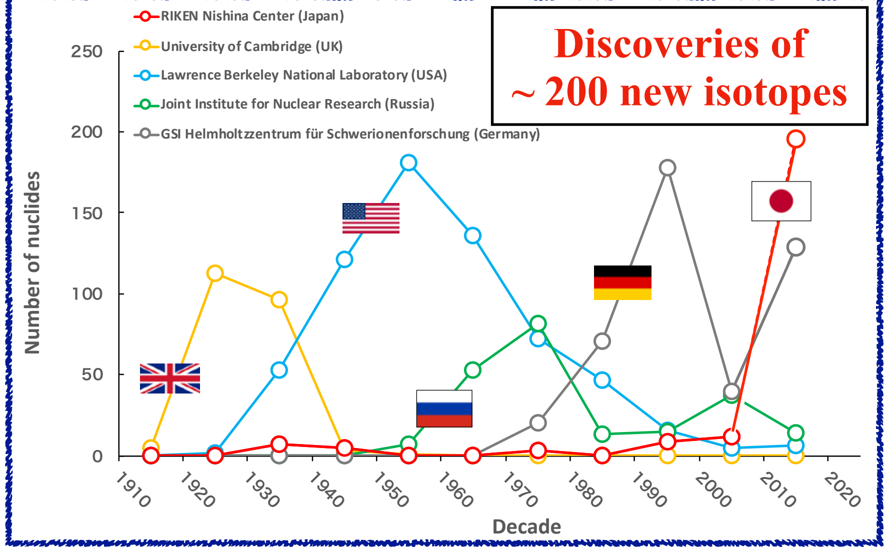
How and where are elements heavier than iron formed?

Selected Achievements at RIBF

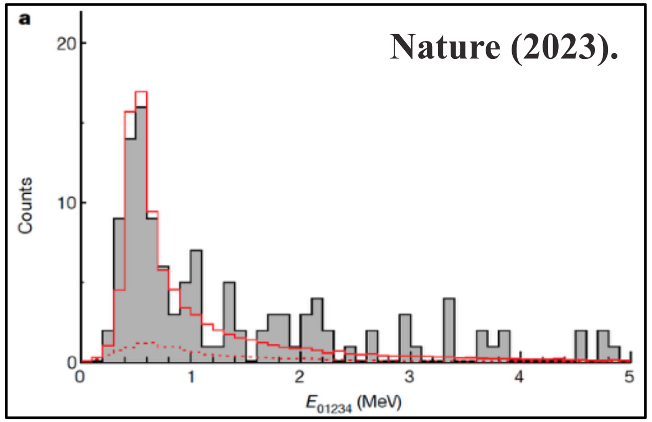
Discovery of Nihonium (Z=113)



Discoveries of ~ 200 new isotopes

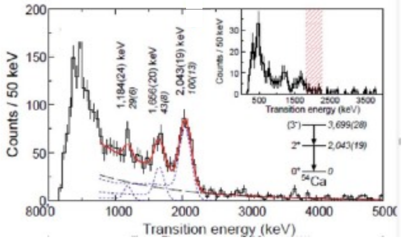


Discoveries of ^{28}O

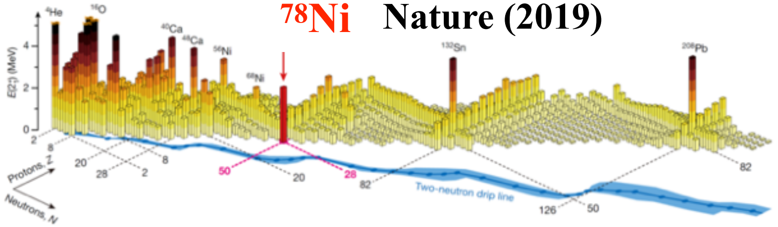


Evolution of nuclear magicity far from the stability line

N=34, Nature (2013)



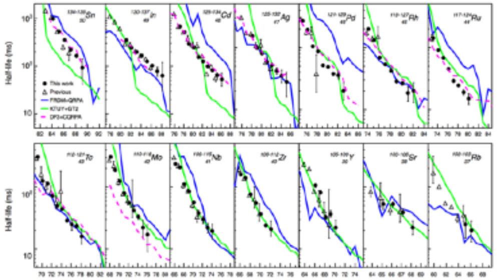
^{78}Ni Nature (2019)



Data crucial for understanding the origin of heavy elements

EURICA

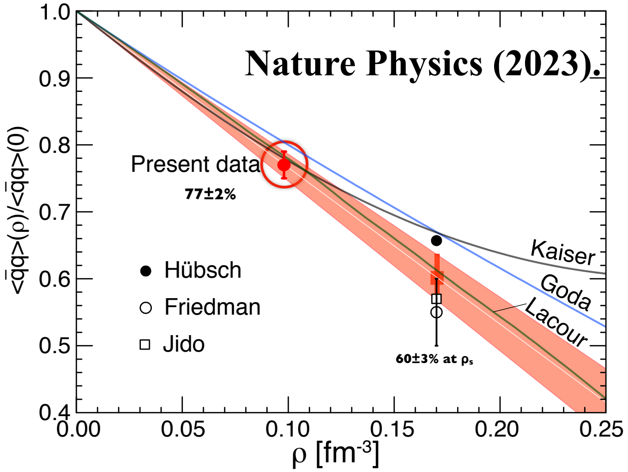
Lifetime
PRL (2015) etc.



Mass
PRL (2023) etc.

P_{xn}, PRL (2022)

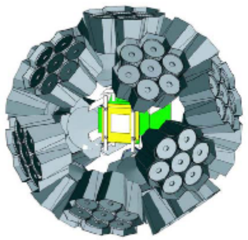
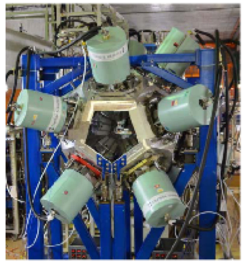
Partial restoration of chiral symmetry observed in pionic atoms



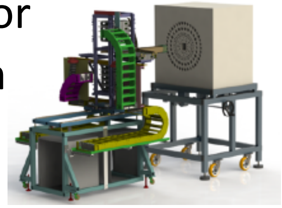
Large-Size International Collaborations

MoUs with
48 institutions and universities in 20 countries

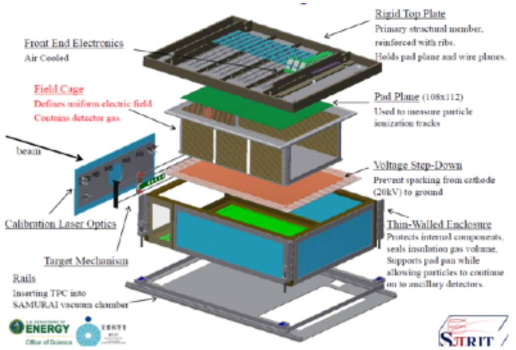
<u>EURICA (2011-2016):</u>
EUroball-RIKEN Cluster Array

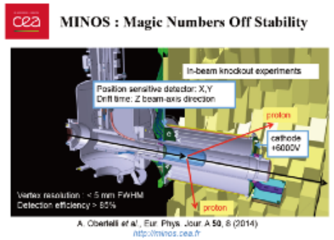
<u>BRIKEN(2017-2021):</u>
He-3 detector array for
beta-delayed neutron



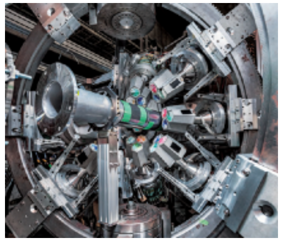
<u>SpiRIT TPC (2015-):</u>
heavy-ion collision program for EOS



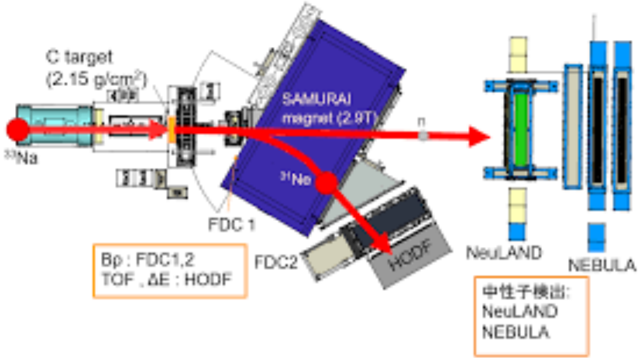
<u>MINOS & SEASTAR (2014-2017):</u>
thick liq. H_2 +TPC+NaI
for in-beam gamma
spectroscopy



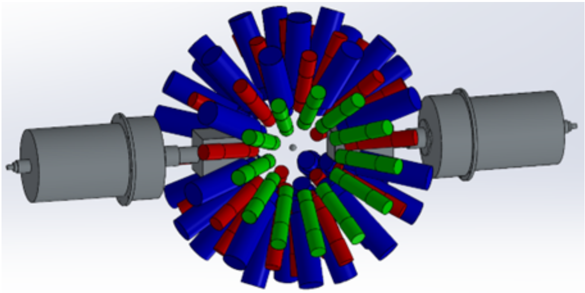
<u>HiCARI (2019-2020):</u>
Tracking Ge detectors
for in-beam gamma
spectroscopy



<u>SAMURAI (2012-):</u>
neutron detectors + CsI+…
for neutron correlation



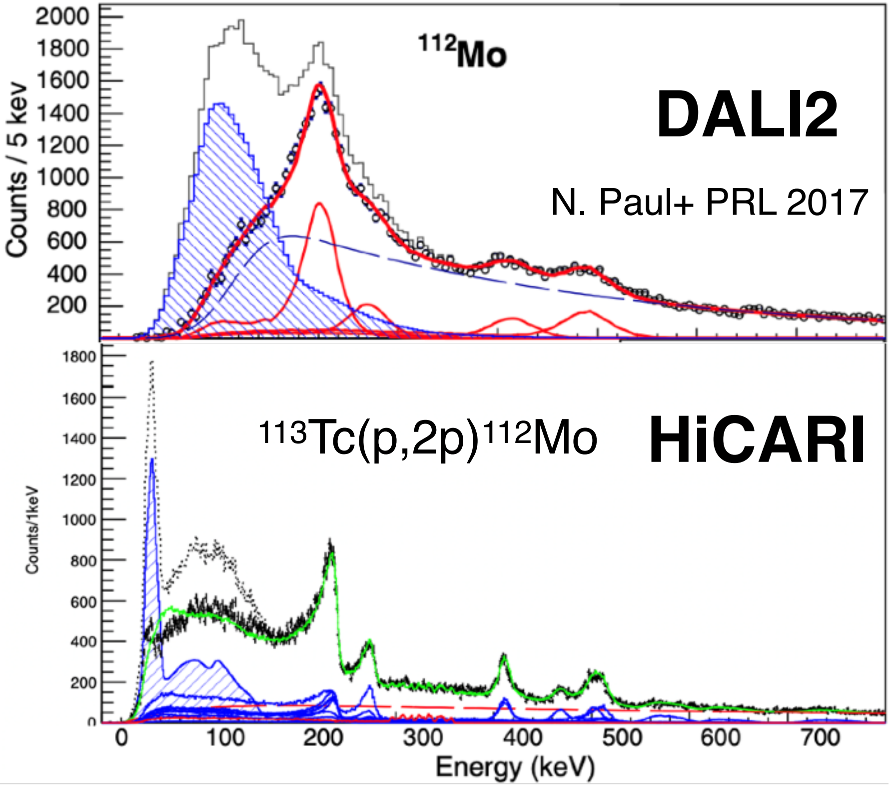
<u>IDATEN (2021-):</u>
84 $LaBr_3$ (Ce) + 2 Cover Ge detectors
to measure lifetime of excited states

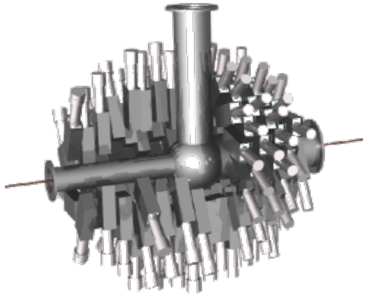


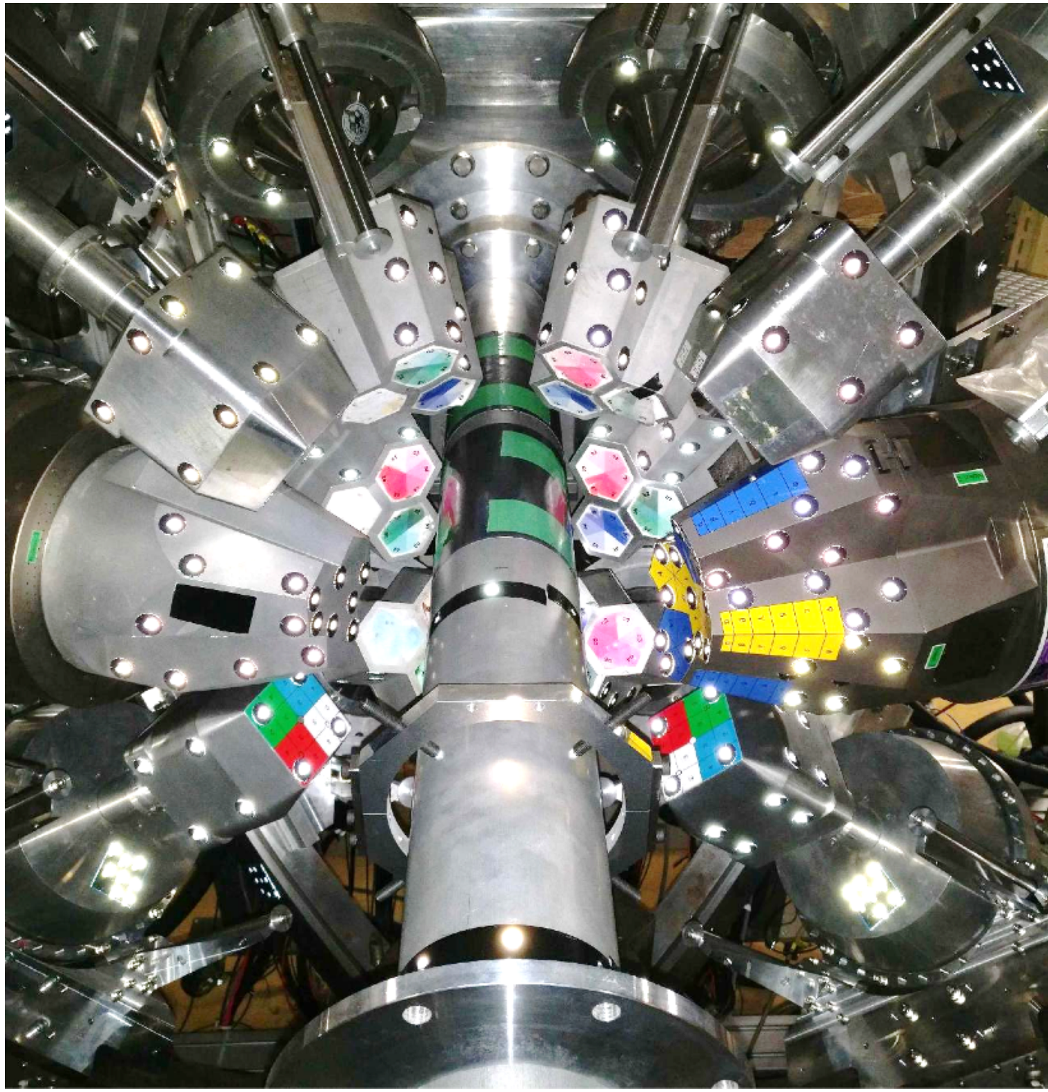
High-resolution Cluster Array at RIBF (HiCARI) project

Composite HPGe array based on

- 8 **Miniball triple-cluster** from CERN/Univ. Köln
- 1 **GRETINA Quad cluster** from RCNP
- 1 **GRETINA P3 clsuter** from LBNL
- 4 **Clover clusters** from IMP







Exotic nuclear shape near neutron-rich ^{110}Zr

- ^{110}Zr with Z = 40 and N = 70

  (harmonic oscillator magic numbers)

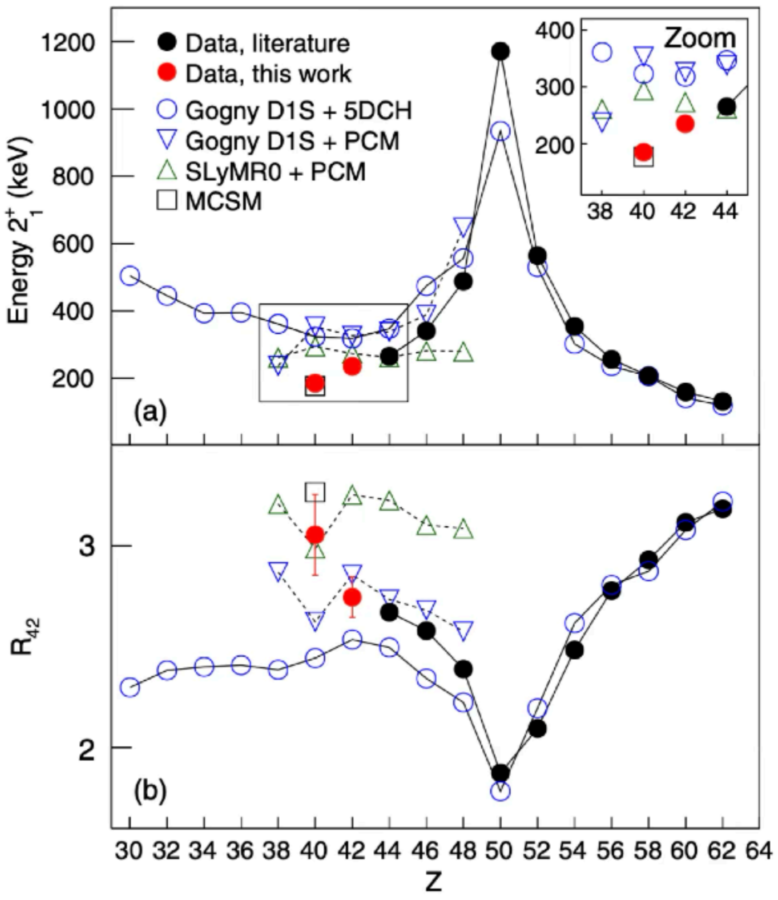
- The previous experimental work suggested “no magic character” when analyzed with BMF and MCSM.

- Interpretations of BMF and MCSM are very different.

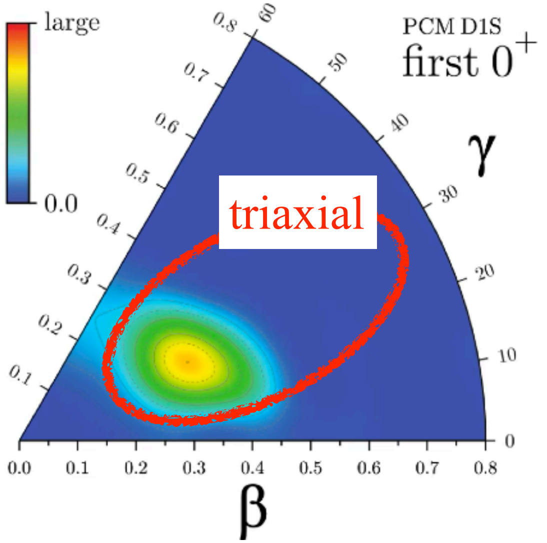
  BMF: triaxial deformation

  MCSM: prolate deformation

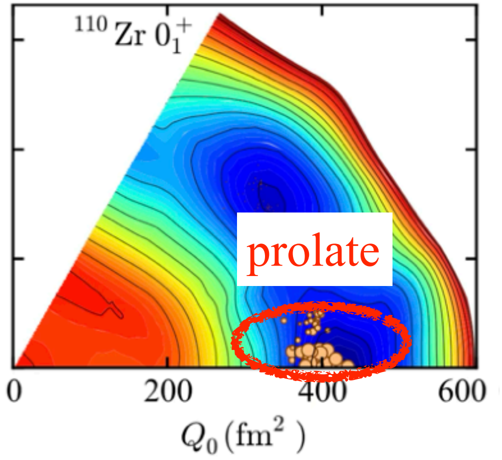
- ^{110}Zr is revisited with high-resolution γ-arrays for the lifetime measurement.



N. Paul et al.,
PRL 118, 032501 (2017)



N. Paul et al., PRL 118, 032501 (2017)

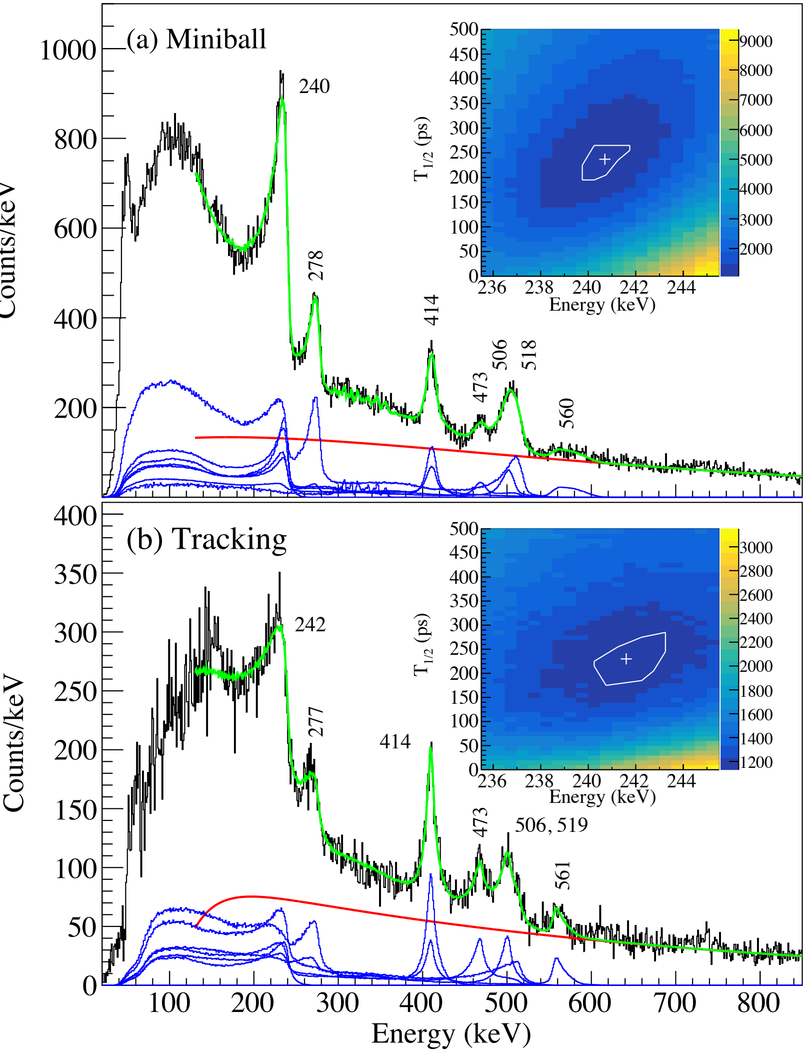


T. Togashi et al., PRL 117, 172502 (2016)

Triaxial deformation in Zr and Mo

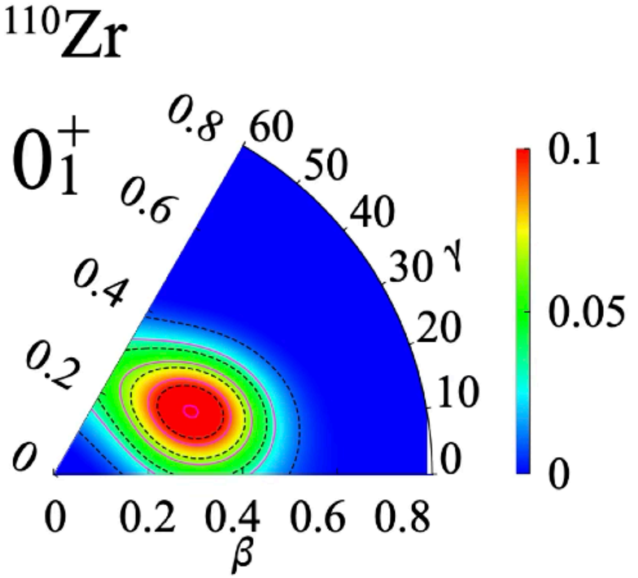
B. Moon et al., PLB 858, 139047 (2024)
B. Moon *et al.*, PLB 870, 139904 (2025)

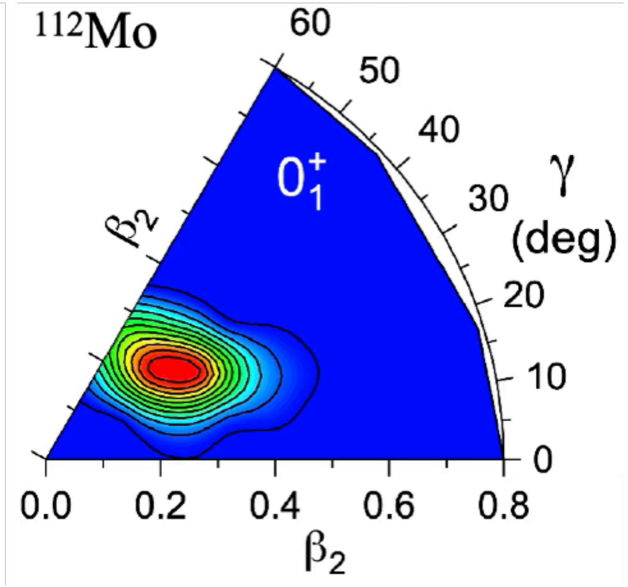
^{112}Mo Doppler-corrected γ-ray energy spectrum from ^{113}Mo(^{9}Be, Xγ)



Nucleon removal reactions at 200 – 250 AMeV

Energy and lifetime are simultaneously obtained by doppler correction & line shape analysis method.

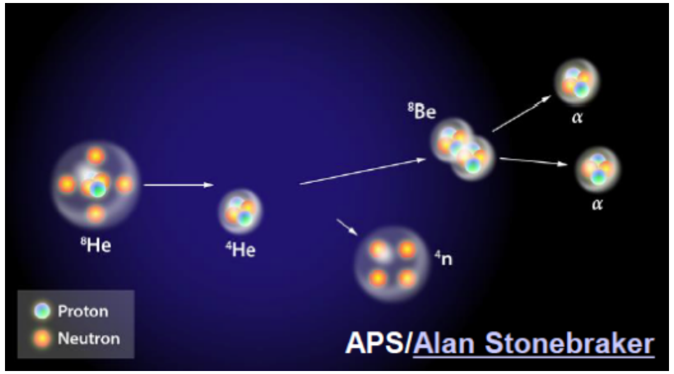


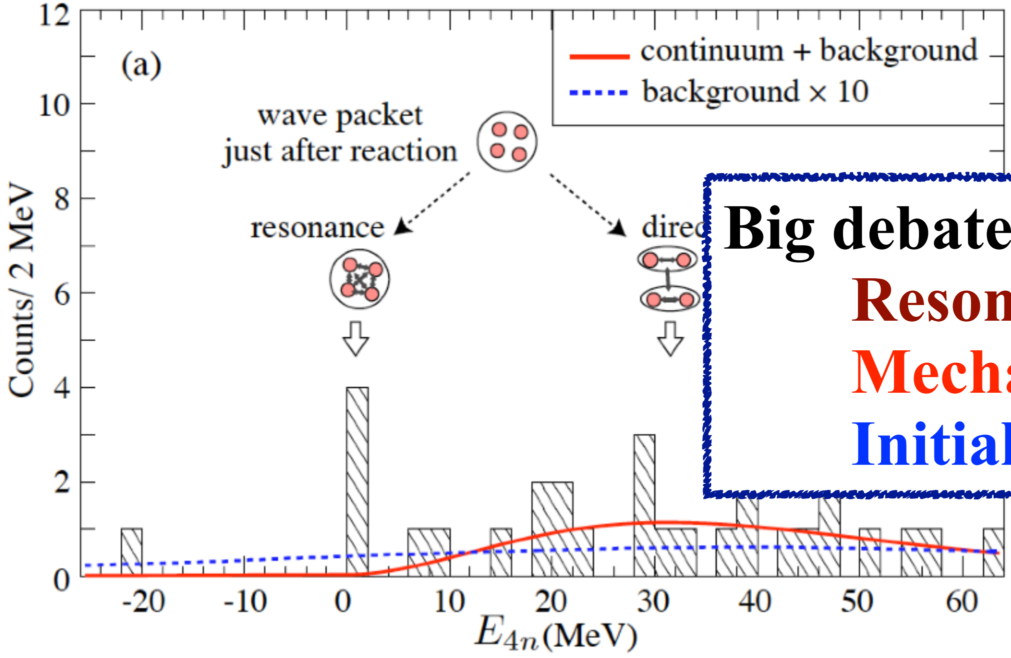


Triaxial deformation in ^{108,110}Zr and ^{110,112}Mo (N = 68, 70) is suggested by HiCARI data in line with theoretical predictions (HFB-SCCM with Gogny interaction).

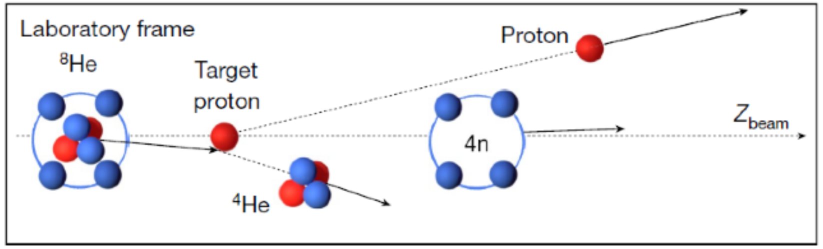
Toward establishment of Element # Zero : Tetraneutron

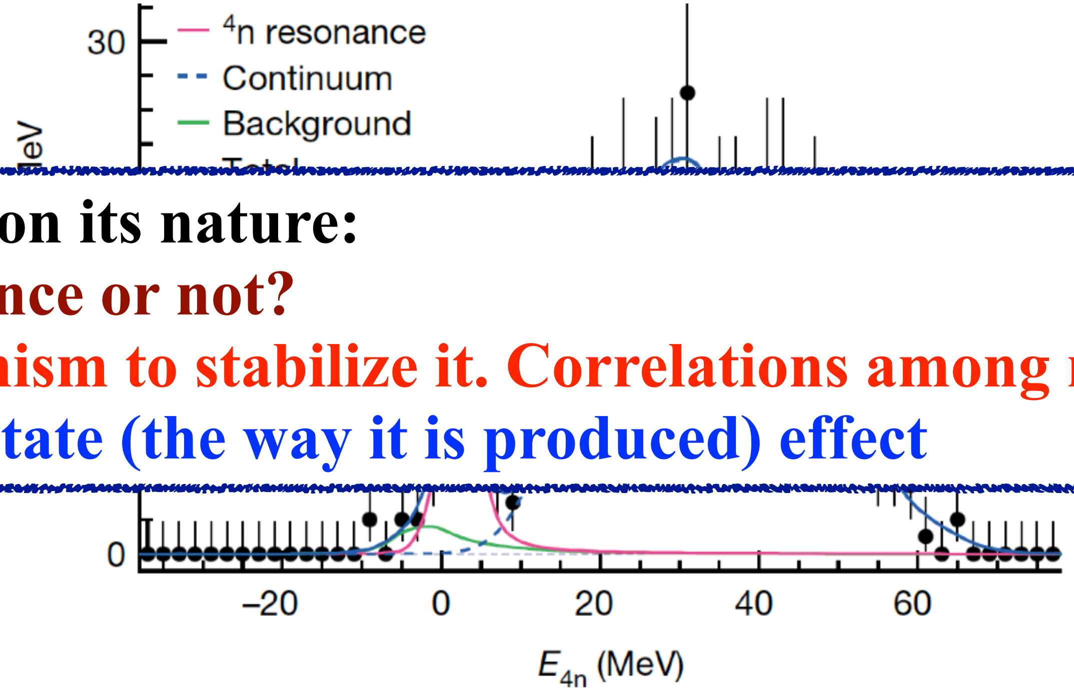
Kisamori, Shimoura et al., PRL 116 (2016)
^{4}He(^{8}He,^{8}Be)^4n @SHARAQ





M. Duer et al., Nature 606 (2022)
^{8}He(p,$p\alpha$)^4n @ θ_{CM}=180deg

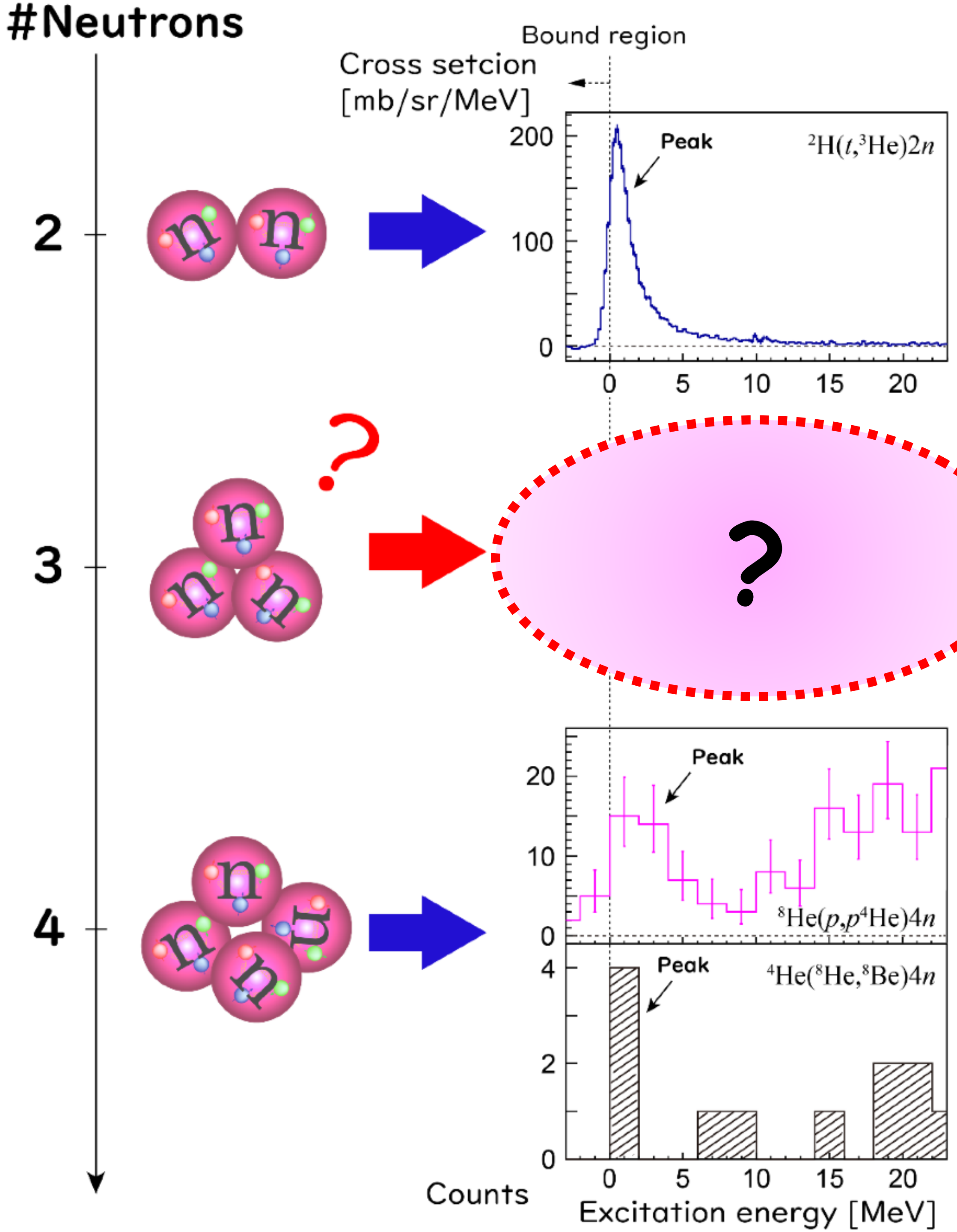




Big debates on its nature:

- **Resonance or not?**
- **Mechanism to stabilize it. Correlations among neutrons?**
- **Initial state (the way it is produced) effect**

Courtesy of
K. Miki



"Virtual state"

Not bound
but very close to.

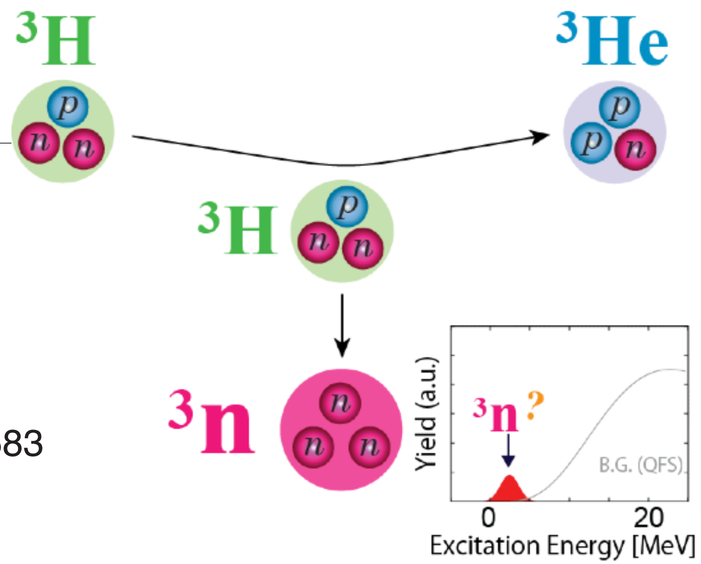
Unknown origin

M. Duer et al.,
Nature,
606, 678 (2022)

K. Kisamori et al.,
Phys. Rev. Lett.
116, 052501 (2016)

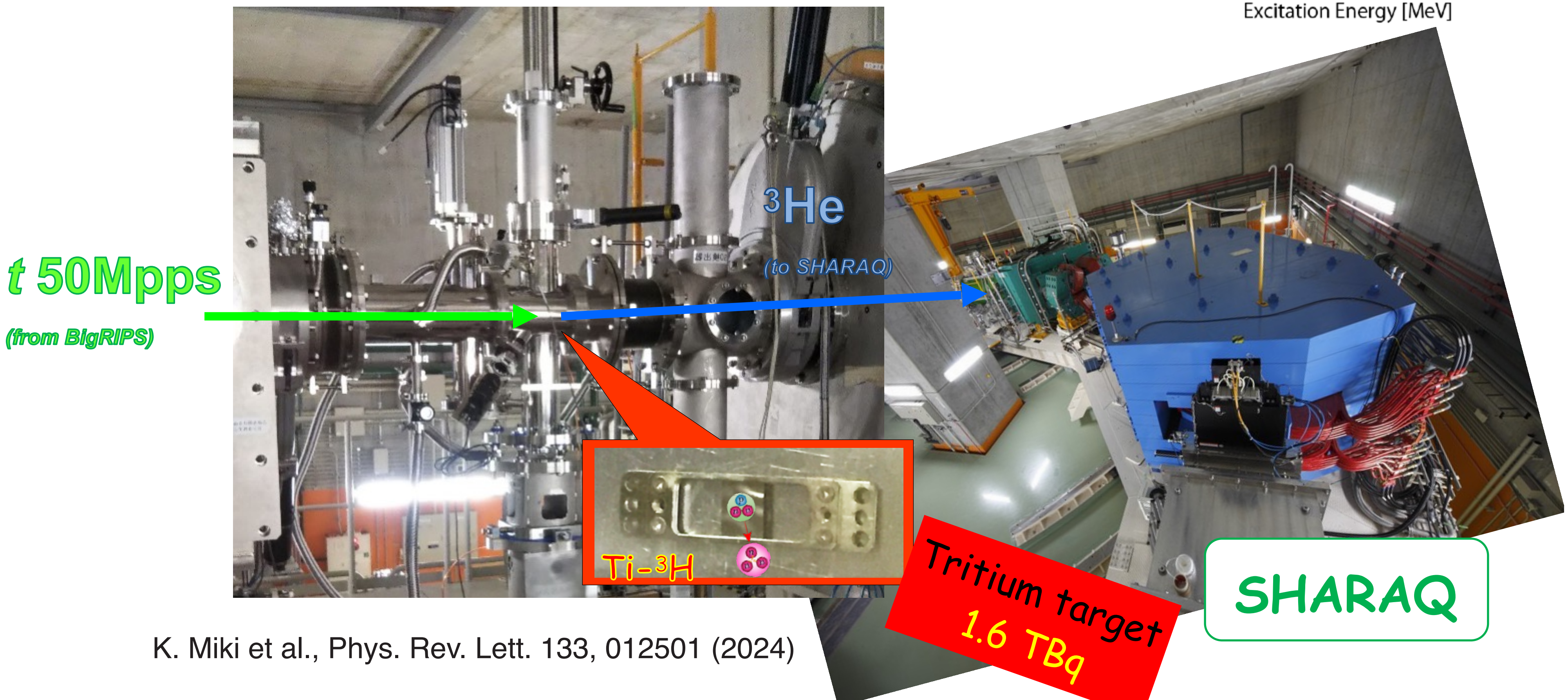
3n experiments at RIBF

Courtesy of K. Miki

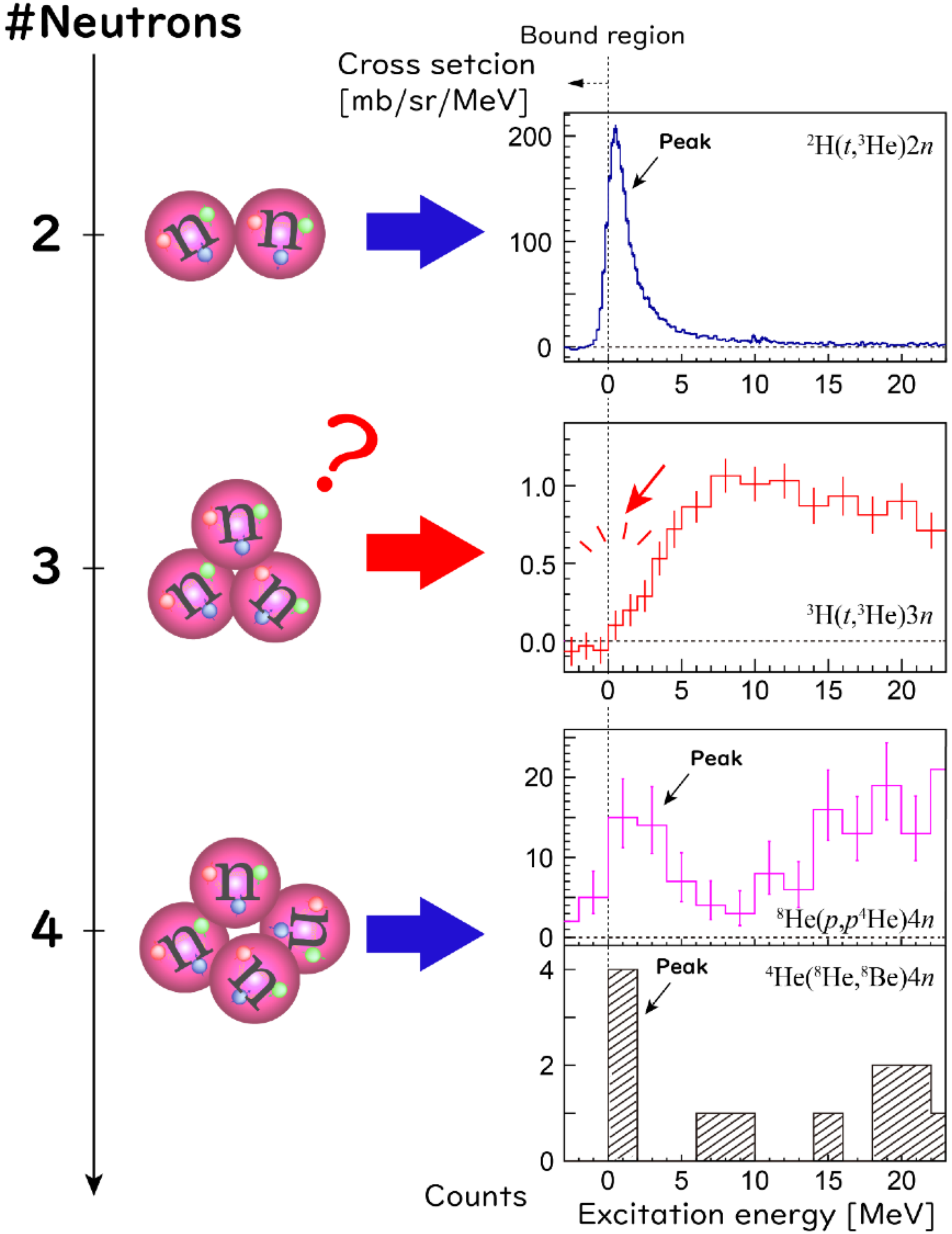


- 3n production by ^{3}H(t,^{3}He)3n reaction
  - Realized by newly developed tritium target

    K. Miki et al., Nucl Instrum. Meth. A 1056 (2023) 168583



K. Miki et al., Phys. Rev. Lett. 133, 012501 (2024)



K. Miki et al., PRL <u>133</u>, 012501 (2024)

"Virtual state"

Not bound
but very close to.

No peak !!

3n is more unstable.

First indication of the odd-even effect in multi-neutron systems.

Unknown origin

M. Duer et al., Nature, 606, 678 (2022)

K. Kisamori et al., Phys. Rev. Lett. 116, 052501 (2016)

High-statistics $^{8}He(p,p\alpha)^{4}n$ and $^{6,8}He(p,3p)^{4,6}n$ planned in 2026.
Collaboration with IBS under the TOPTIER project

The FIRST e-RI scattering at SCRIT

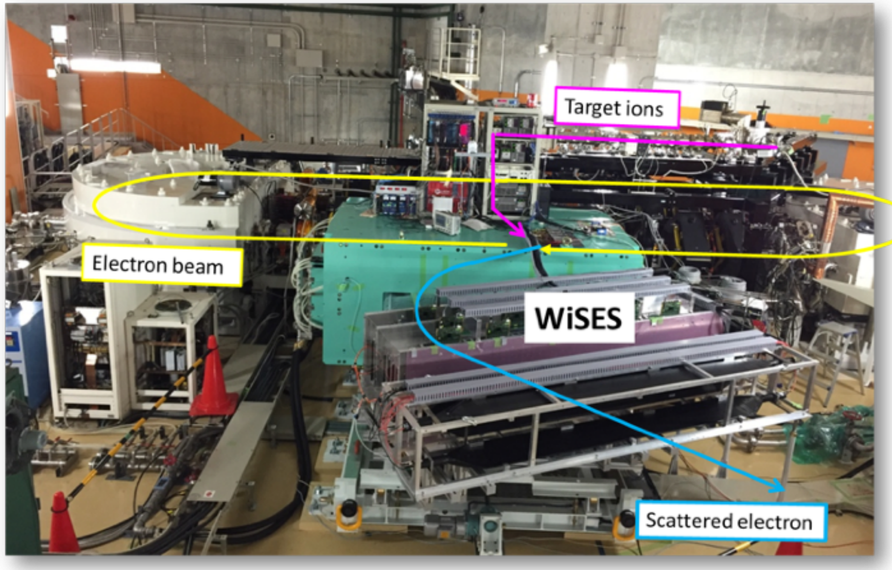
Featured in Physics | Editors' Suggestion

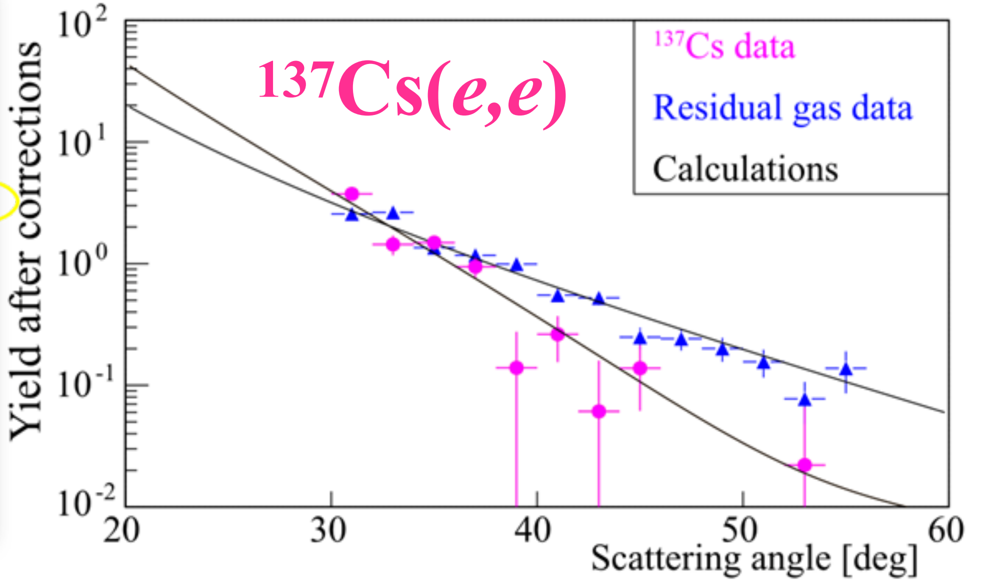
First Observation of Electron Scattering from Online-Produced Radioactive Target

K. Tsukada, Y. Abe, A. Enokizono, T. Goke, M. Hara, Y. Honda, T. Hori, S. Ichikawa, Y. Ito, K. Kurita, C. Legris, Y. Maehara, T. Ohnishi, R. Ogawara, T. Suda, T. Tamae, M. Wakasugi, M. Watanabe, and H. Wauke

Phys. Rev. Lett. **131**, 092502 (2023) – Published 30 August 2023

Challenges toward ^{132}Sn(*e*,*e*) is ongoing.





Courtesy of K. Tsukada

π-atom spectroscopy and chiral symmetry

T. Nishi, K. Itahashi et al.,
Nature Physics 19, 788 (2023).

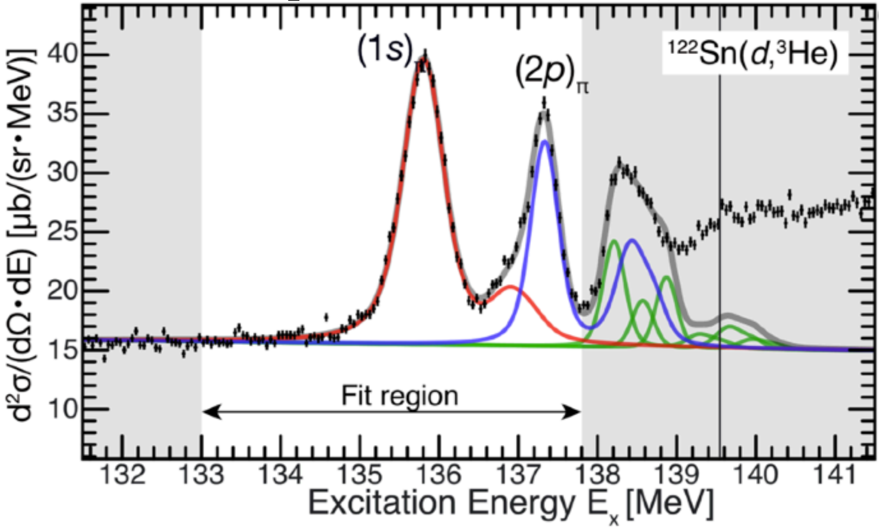

nature physics

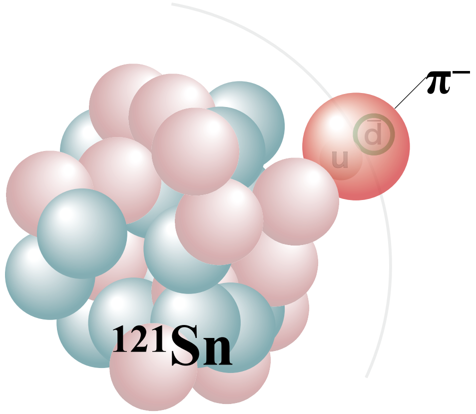
Article

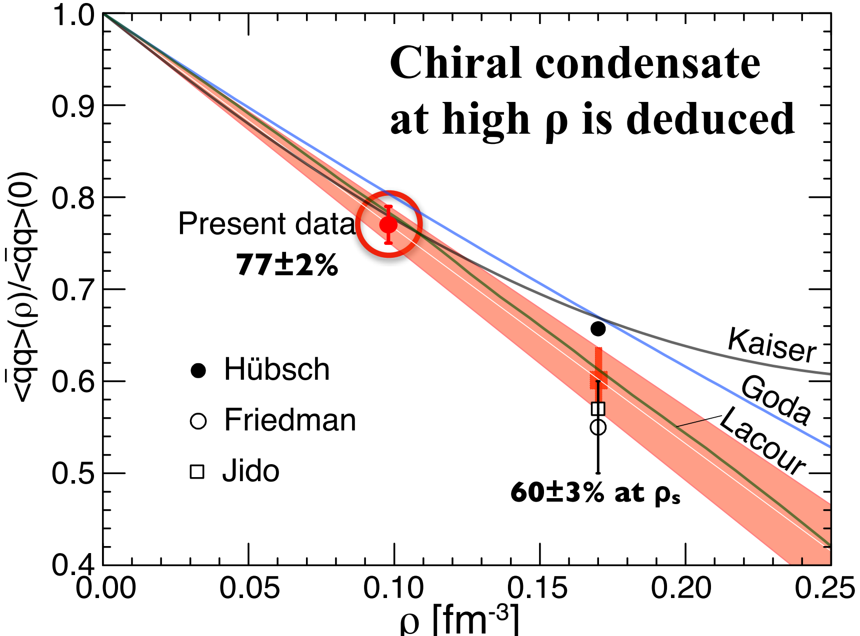
https://doi.org/10.1038/s41567-023-02001-x

Chiral symmetry restoration at high matter density observed in pionic atoms

Pionic 1s, 2p observed in (d,^{3}He) reactions







Chiral condensate at ρ_e is deduced to be 77±2% at nuclear density ~0.10 fm^{-3} by using the pion as a probe

Dispersion matching of the beam-line and BigRIPS

RIBF Upgrade Project

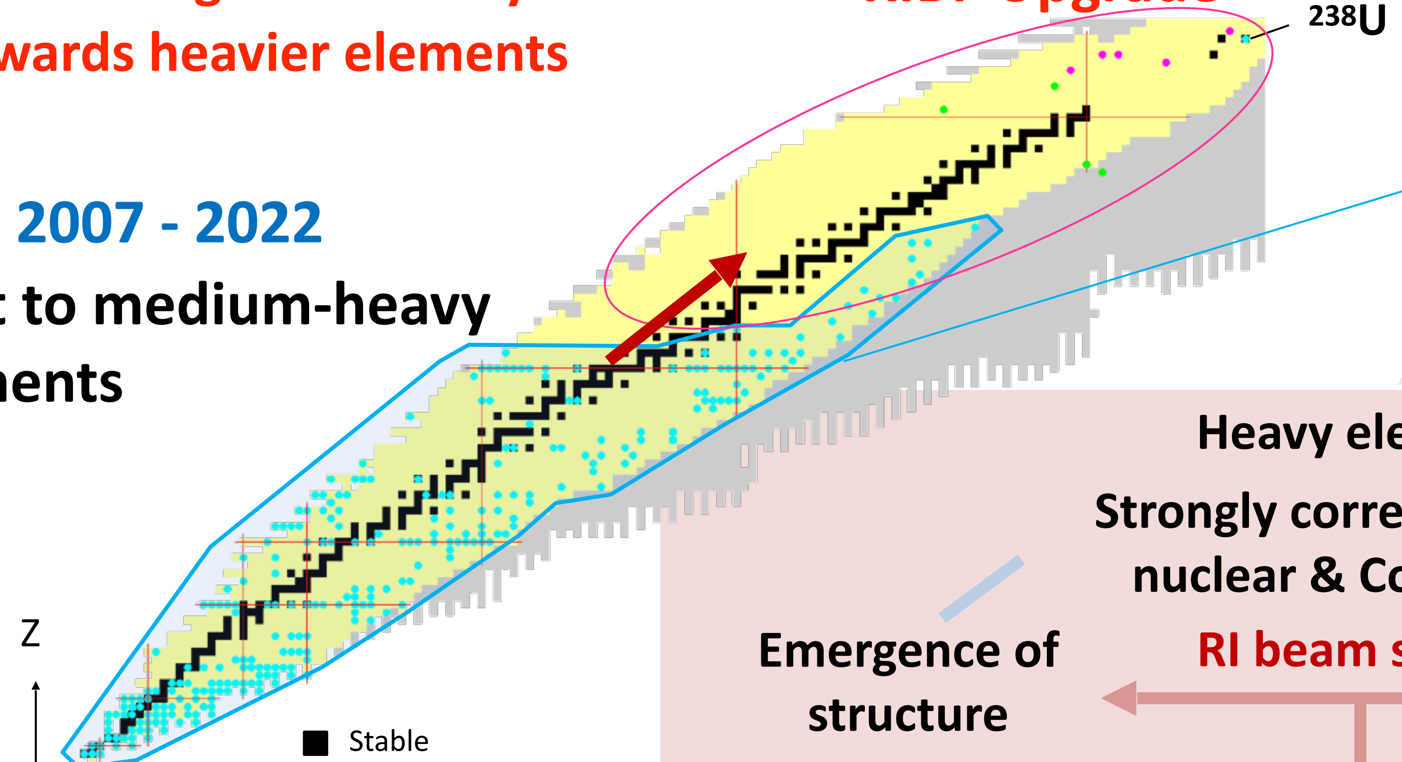
Courtesy of Daisuke Suzuki

Towards higher intensity
Towards heavier elements

RIBF Upgrade

RIBF 2007 - 2022

Light to medium-heavy elements



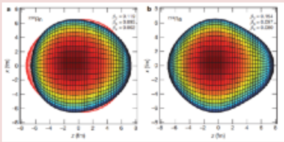
Nuclear force

Many-body correlations

Heavy element RI＝

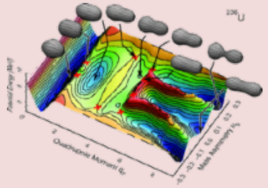
Strongly correlated system of nuclear & Coulomb forces

Emergence of structure



RI beam studies

Emergence of dynamics



deployment

Evolution of matter
Nucleosynthesis
Neutron star structure

Nuclear energies
RI medicine applications
New energy cycle

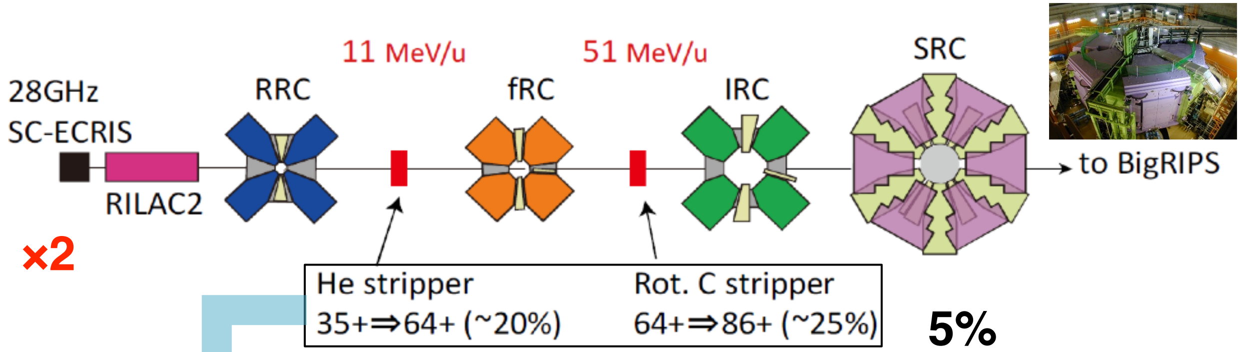
Science of heavy element RI
will be opened by fast RI beams

RIBF Facility Upgrade Project

Courtesy of H.Imao

Major facility upgrade of RIBF to **increase U beam intensity to 2,000 pnA (×20)**

Present



×2

100 pnA

×20

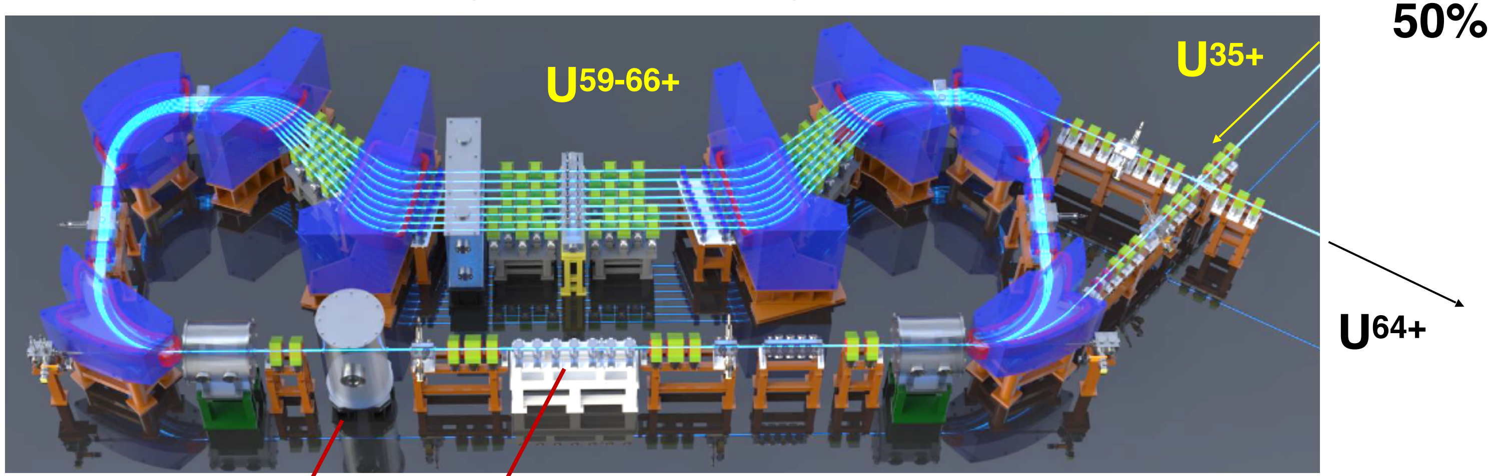
2,000 pnA

5%

×10

50%

Charge **S**tripper **R**ing (**CSR**)



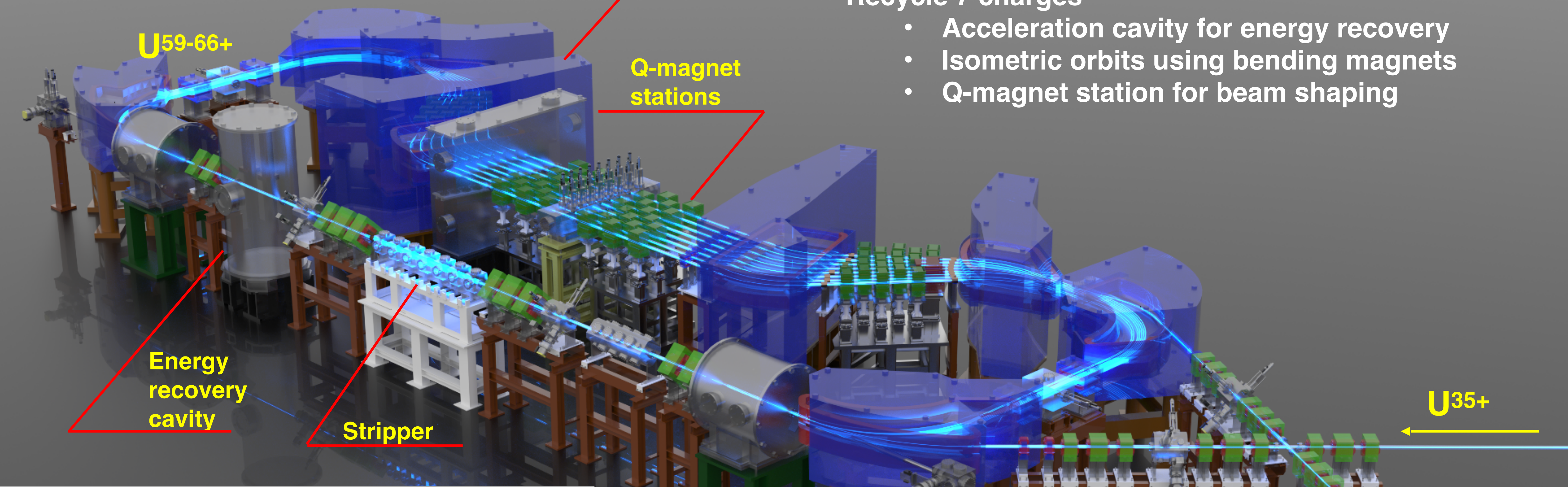
- Store **up to 7 charge states** in one ring.
- Economical solution compared to replacing fRC.
- **Luminosity obtained by the upgrade is more than 2-3 times higher than in other existing facilities.**

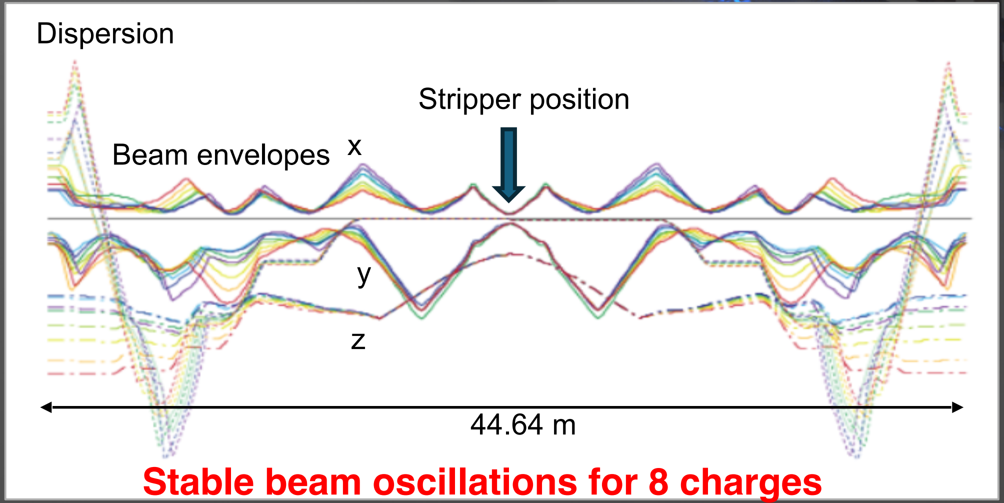
Courtesy of H.Imao

Charge Stripper Ring (CSR)

Recycle 7 charges

- Acceleration cavity for energy recovery
- Isometric orbits using bending magnets
- Q-magnet station for beam shaping





H. Imao, JINST, **15**, P12036 (2020)

Summary and Future Perspectives

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.

Limit of nuclear stability, shell evolution, nuclei beyond the drip-line, neutron-matter EoS, origin of elements. . . .

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