



IUPAP WG9, May 28th, 2025
Daejeon, Korea

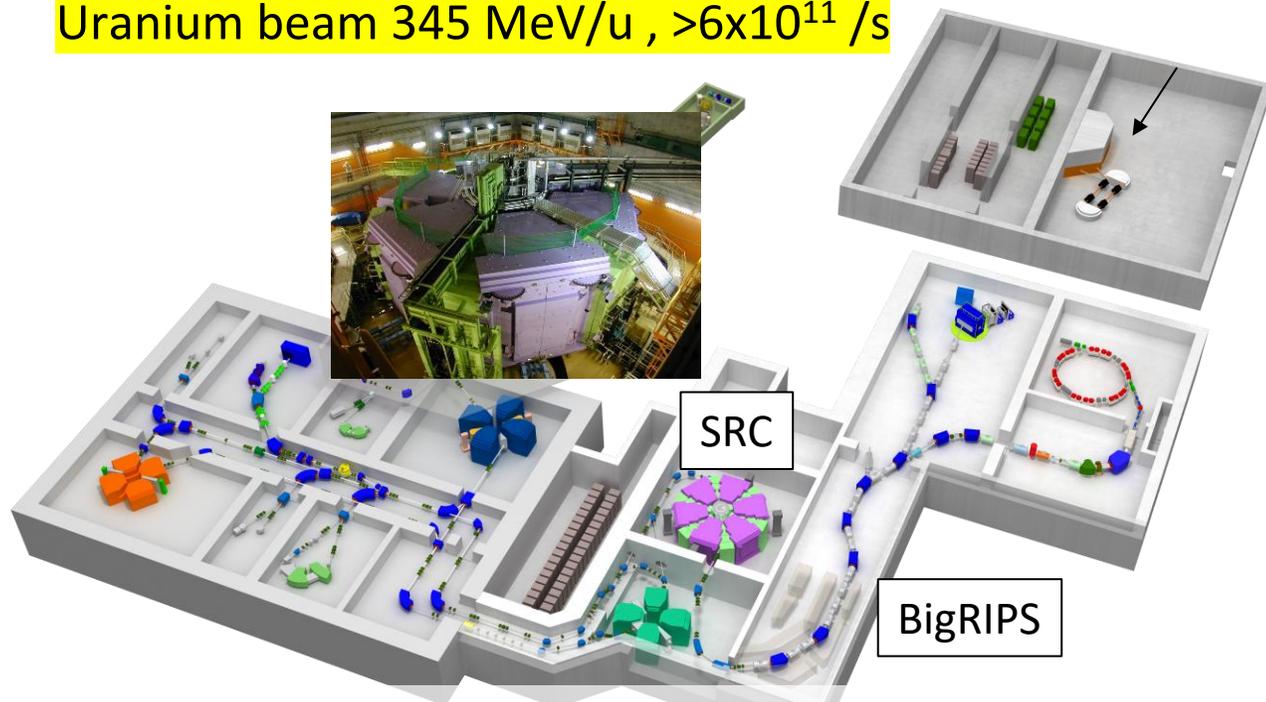
Report from RIKEN

1. Overview of RIBF
2. New results and news
3. Status of the RIBF upgrade project

Hiroyoshi Sakurai
RIKEN Nishina Center for Accelerator-Based Science

Radioactive-isotope (RI) Beam Factory (RIBF)

SRC: Superconducting Ring Cyclotron
World's First and Strongest K2600MeV
Uranium beam 345 MeV/u , $>6 \times 10^{11}$ /s



BigRIPS Superconducting RI beam Separator

In-flight separator

World's Largest Acceptance

High magnetic rigidity 9 Tm

~ 250 MeV/u



Three spectrometers

for reaction studies with fast RI beams

ZeroDegree



SAMURAI



SHARAQ + OEDO (univ. of Tokyo, CNS)



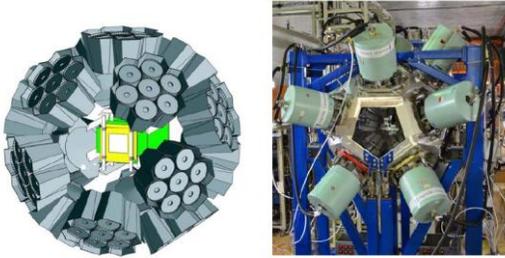
A storage ring (Rare RI Ring)

dedicated to mass measurement



Large-Size International Collaborations

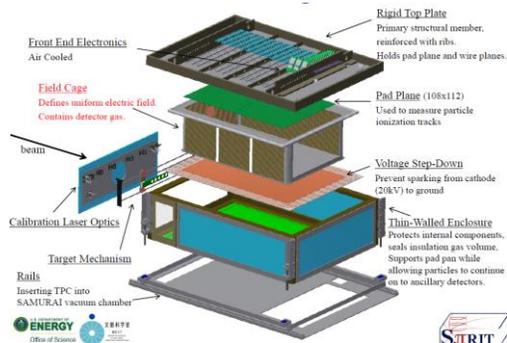
EURICA (2011-2016):
EUroball-RIKEN Cluster Array



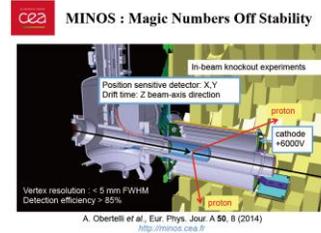
BRIKEN(2017-2021):
He-3 detector array for beta-delayed neutron



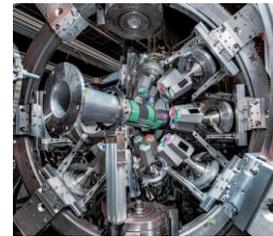
SpiRIT TPC (2015-):
heavy-ion collision program for EOS



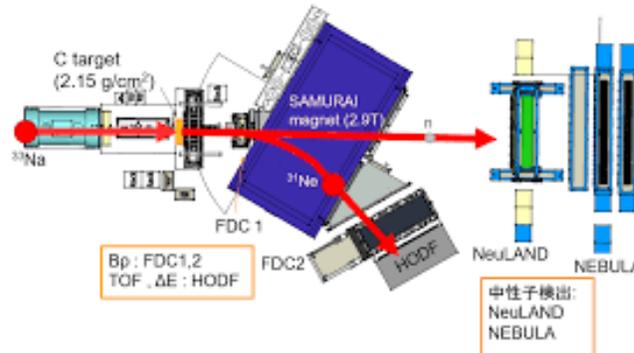
SEASTAR (2014-2017):
thick liq. H₂ + TPC+NaI
for in-beam gamma spectroscopy



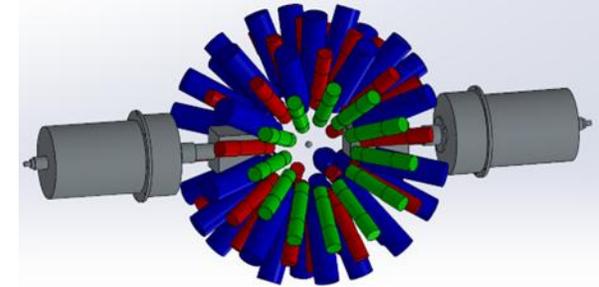
HiCARI (2019-2021):
Tracking Ge detectors
for in-beam gamma spectroscopy



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

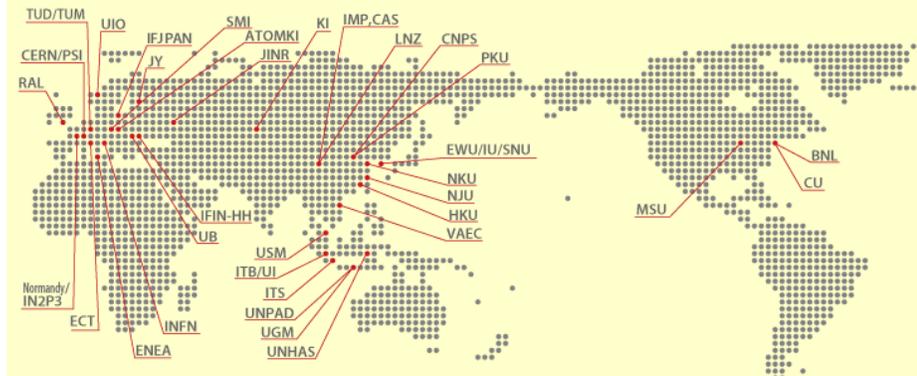


IDATEN (2021-):
84 LaBr₃ (Ce) + 2 Cover Ge detectors
to measure lifetime of excited states



EURICA-II, HYPATIA projects are on going!

MoUs with
48 institutions and universities in 20 countries

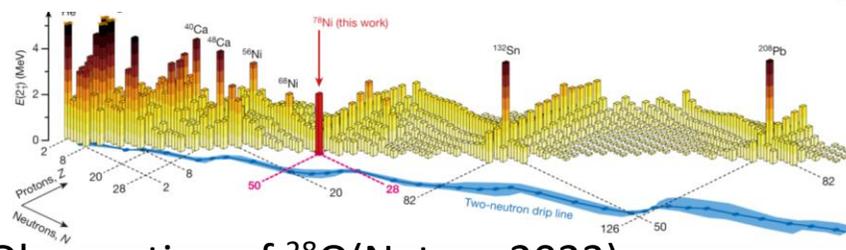


Very² selected highlights in 2007-2024

Shell-evolution: magicity loss and new magicity



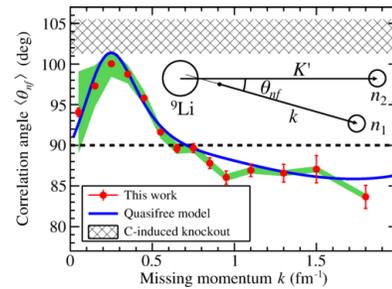
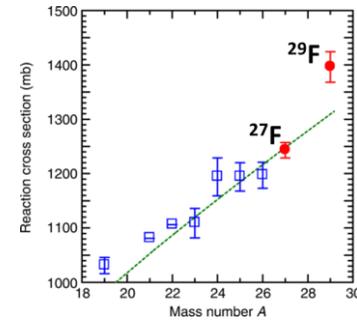
New magicity at N=34 (Nature 2013)
Double magicity of Ni-78 (Nature 2019)



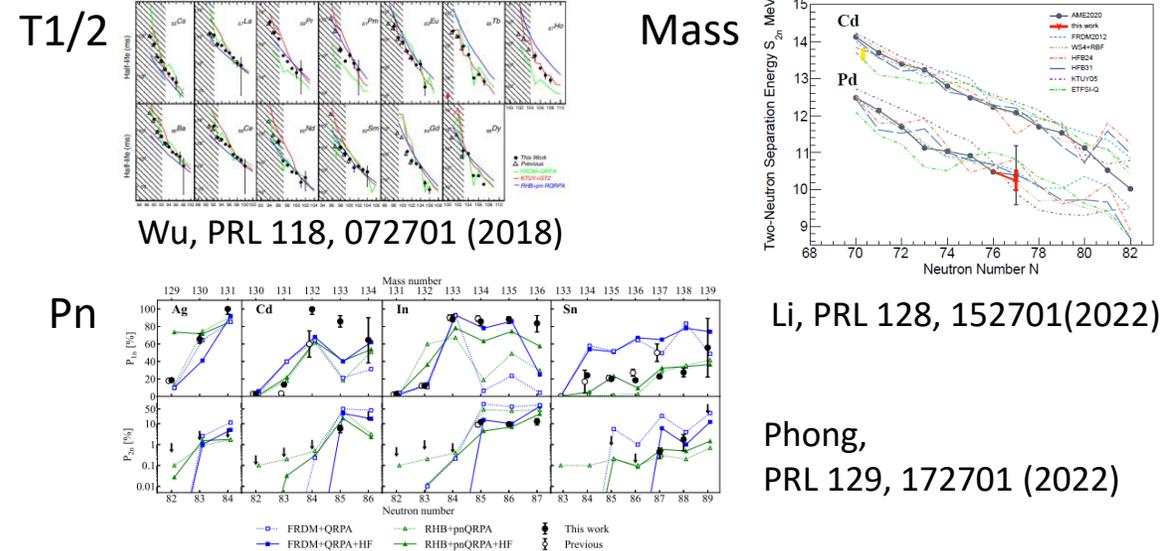
Observation of ²⁸O (Nature 2023)
Shell evolution in the Cu isotopes (Nature Physics 2019)

Neutron-neutron correlation in the vicinity of the dripline

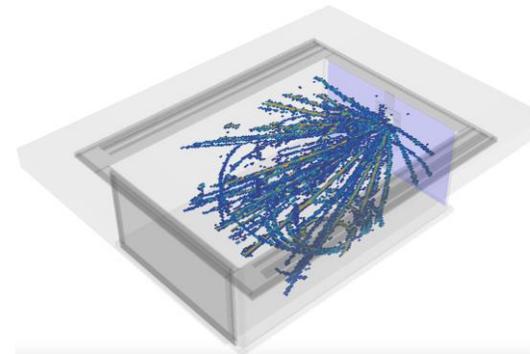
Two-neutron halo F-29 (PRL 2020)
Surface localization of dineutron in Li-11 (PRL 2020)
Tetra-neutron system (PRL 2016, Nature 2022)



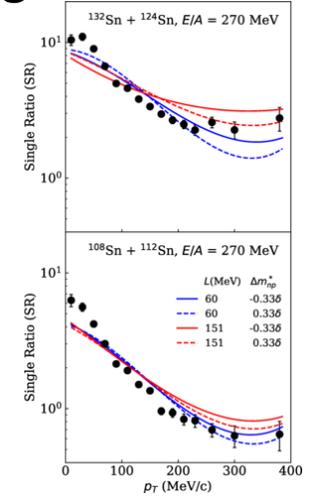
r-process path : nucleo-synthesis up to U



Equation-of-State in asymmetric nuclear matter SN explosion, neutron-star, gravitational wave



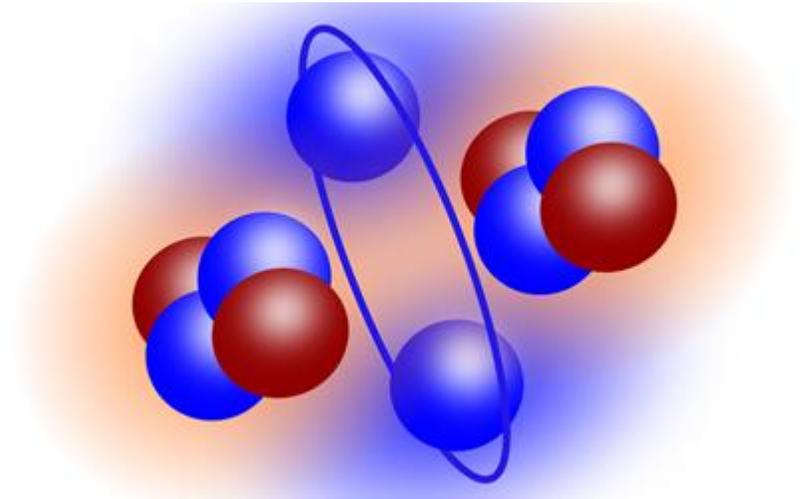
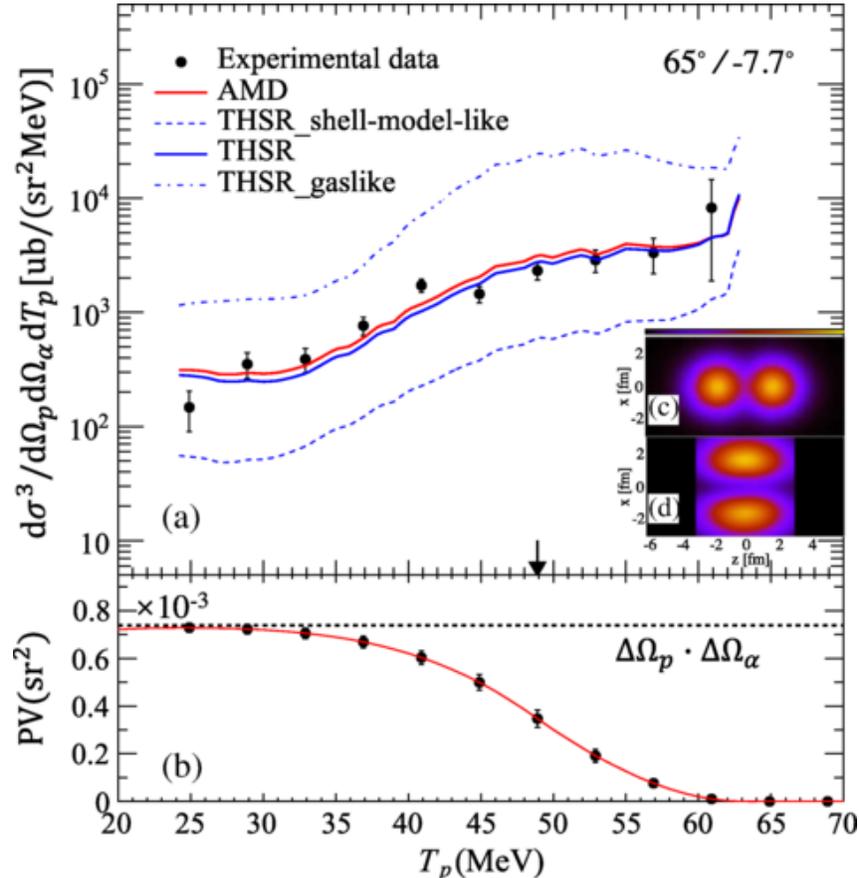
Estee, PRL 126, 162701 (2021)



Validation of the ^{10}Be Ground-State Molecular Structure Using $^{10}\text{Be}(p,p\alpha)^6\text{He}$ Tripple Differential Reaction Cross-Section Measurements

SAMURAI Collaboration

R. Li, D. Beaulme et al., PRL 131, 212501 (2023)



“Nuclear Ground State Has Molecule-Like Structure”

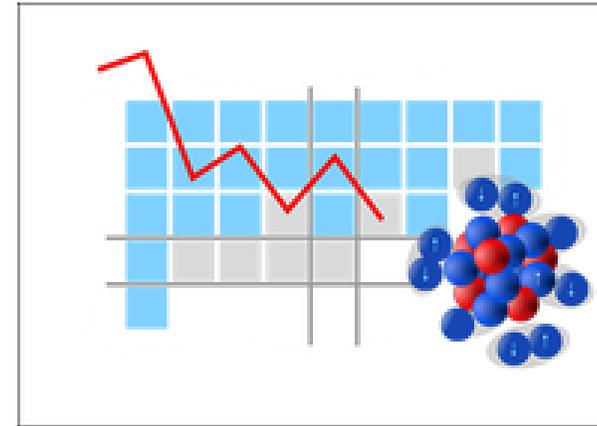
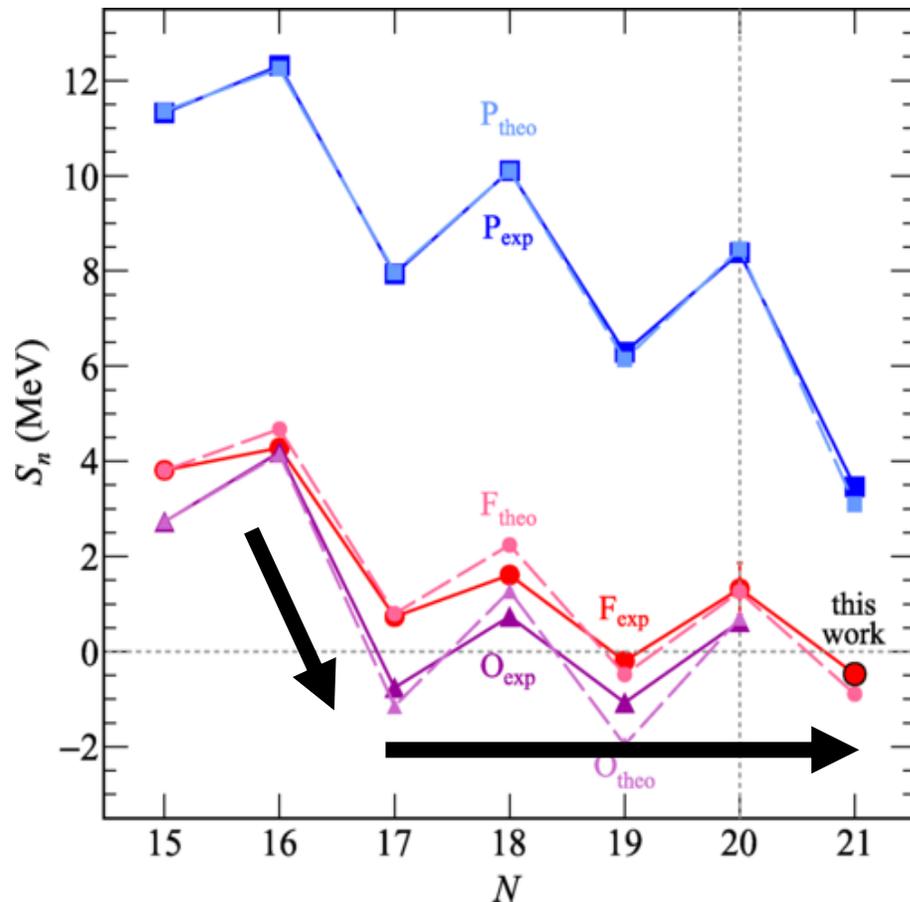
November 21, 2023, Physics 16, s167

David Ehrenstein

Magicity versus Superfluidity around ^{28}O viewed from the Study of ^{30}F

SAMURAI Collaboration

J. Kahlbow, T. Aumann, et al., PRL 133, 0 82501(2024)

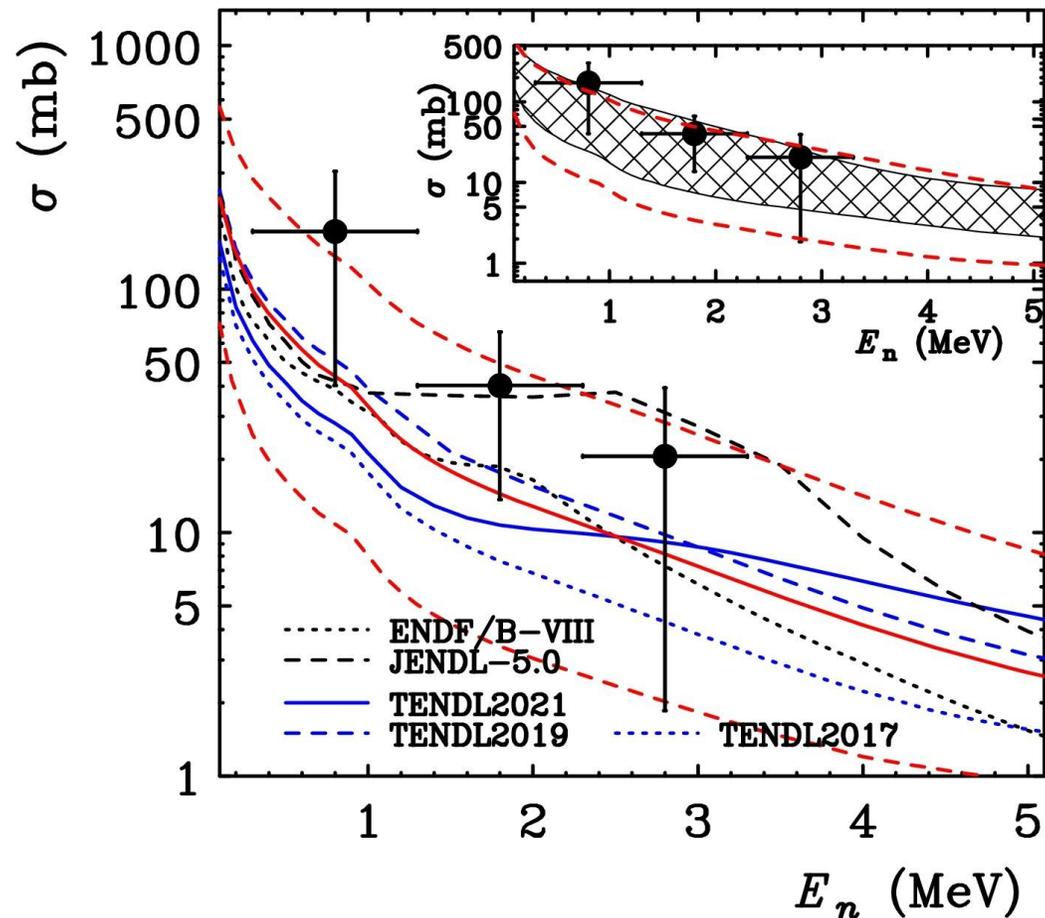


Large drop of stability at $N>16$
 S_n stays constant at $N>16$
Large mixing of sd and pf shells?

Neutron capture reaction cross-section of ^{79}Se through the $^{79}\text{Se}(d,p)$ reaction in inverse kinematics

SHARAQ/OEDO Collaboration

N. Imai et al., PLB 850, 138470(2024)

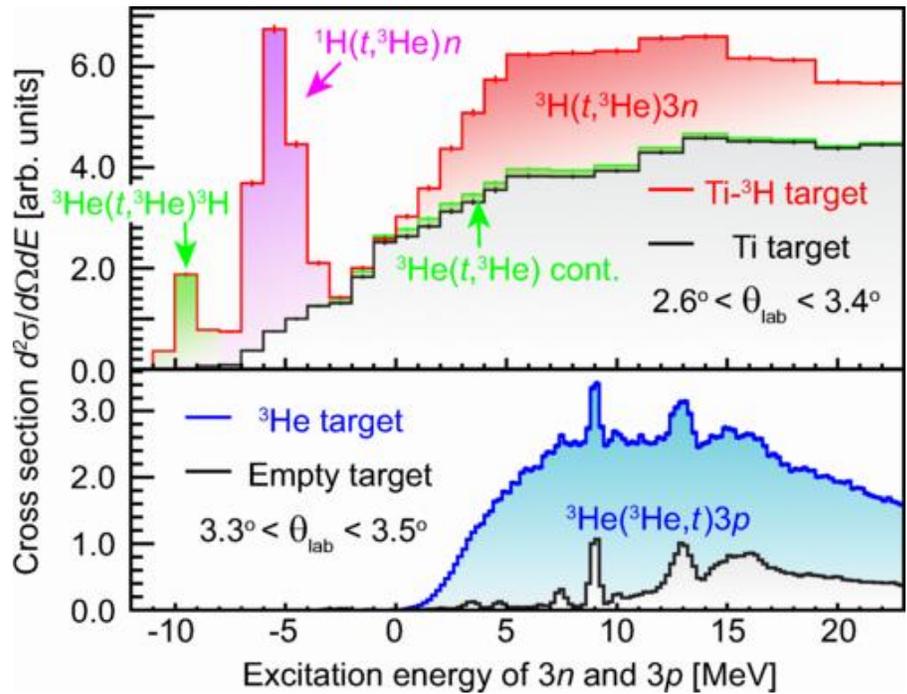


SHARAQ/OEDO, Univ. Tokyo, CNS

Precise spectroscopy of the $3n$ and $3p$ systems via ${}^3\text{H}(t, {}^3\text{He})3n$ and ${}^3\text{He}({}^3\text{He}, t)3p$ reactions at intermediate energies

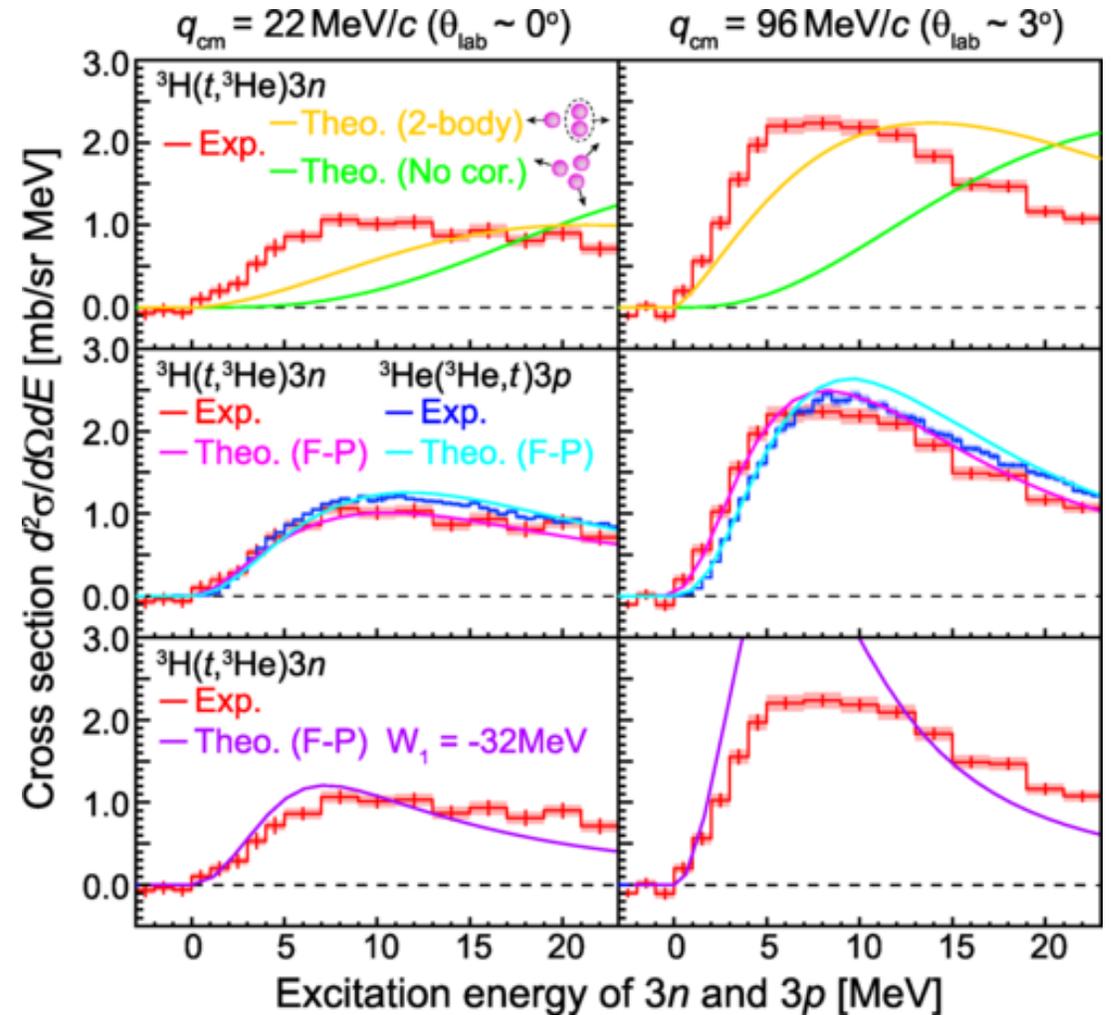
SHARAQ+RCNP Collaboration

K. Miki et al., PRL 133, 012501(2024)



Ti- ${}^3\text{H}$ target
(${}^3\text{H}$ 3mg/cm 2)
at SHARAQ

RCNP



Nishina Memorial Prize 2024

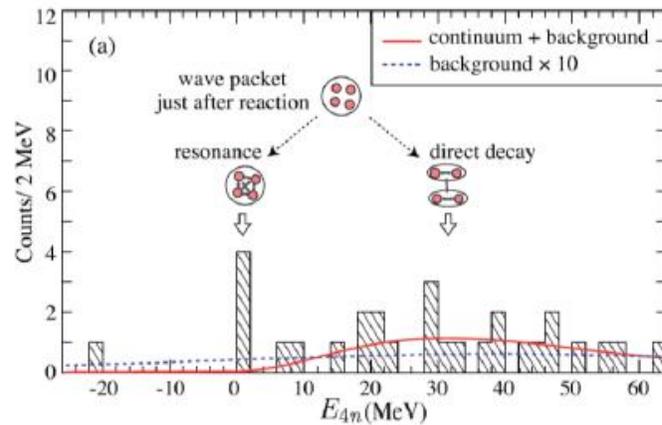
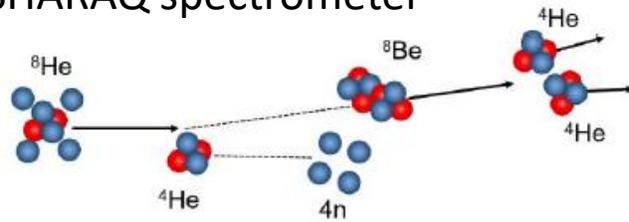
Nishina Memorial Prize is one of the prestigious award for physics in Japan, given by Nishina Memorial Foundation.

Given to Prof. Dr. Susumu Shimoura
for “Experimental study of four-neutron states”



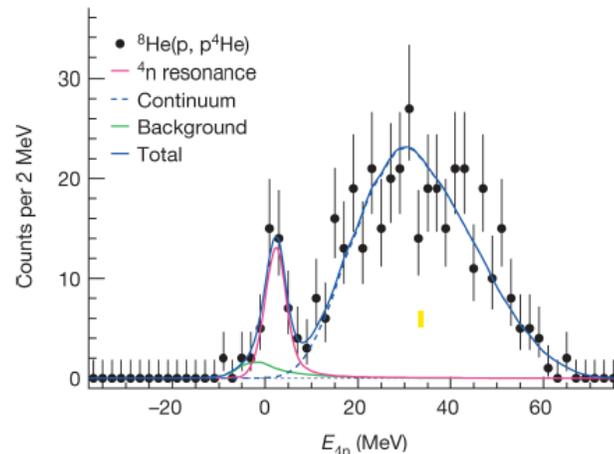
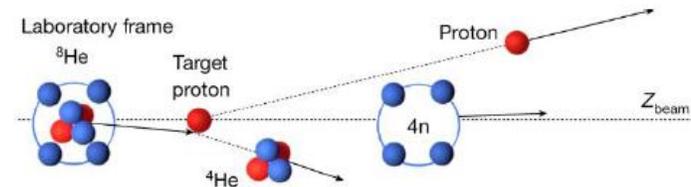
Award Ceremony
December 5, 2024 @ Tokyo

SHARAQ spectrometer



Phys. Rev. Lett. 116, 052501 (2016)

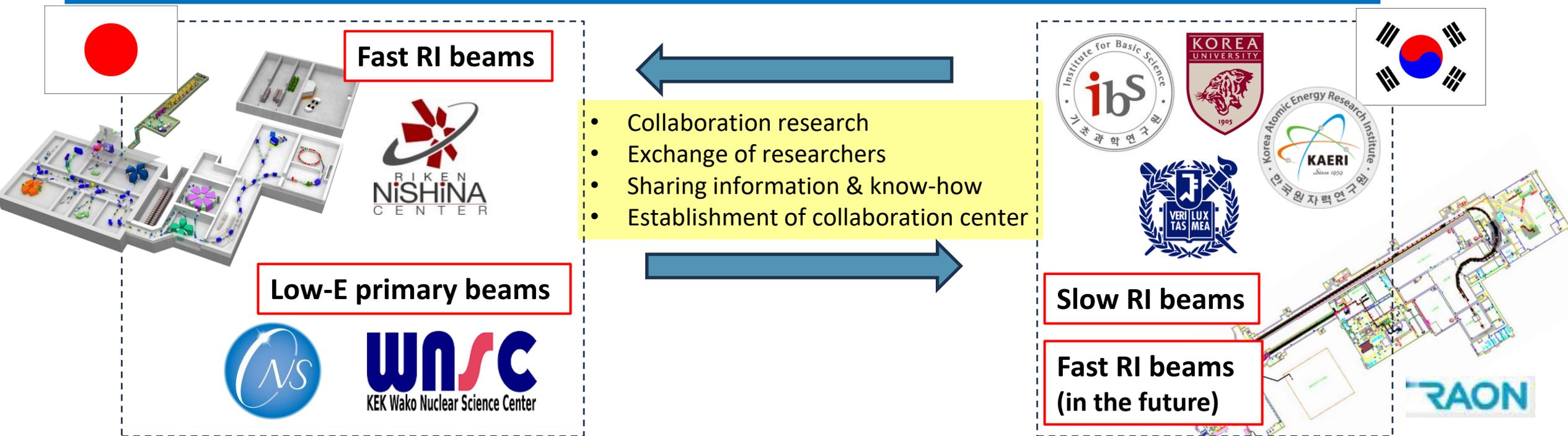
SAMURAI spectrometer



Nature 606, 678 (2022)



Korea-Japan Collaboration: Top-Tier Platform for Rare-Isotope Science



Top-Tier Platform is an NRF grant in Korea, to enhance international collaborations with foreign partners.

20B KRW for 10 years

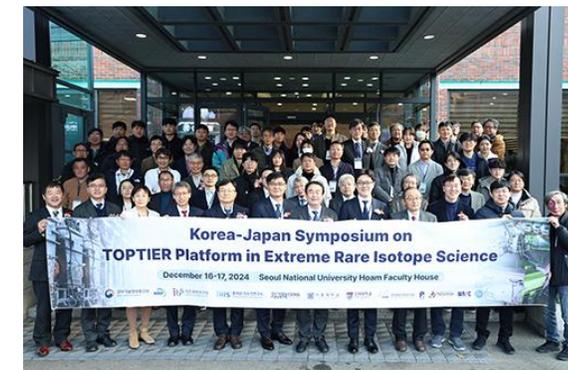
IBS Institute of Rare Isotope Science decided to submit a proposal with RIKEN Nishina Center

Korea : IBS, Seoul National University, Korea University, KAERI

Japan: RIKEN Nishina Center, Univ. of Tokyo CNS, KEK WNSC

The proposal was approved in this year to promote rare-isotope science.

The kick-off meeting in December 16-17, 2024



Moonshot Goal10

<https://www.jst.go.jp/moonshot/en/program/goal10/index.html>

Realization of a dynamic society in harmony with the global environment and free from resource constraints, through diverse applications of fusion energy, by 2050.

Development of High Intensity Neutron Source and Advanced Fusion System by Innovative Acceleration Technology

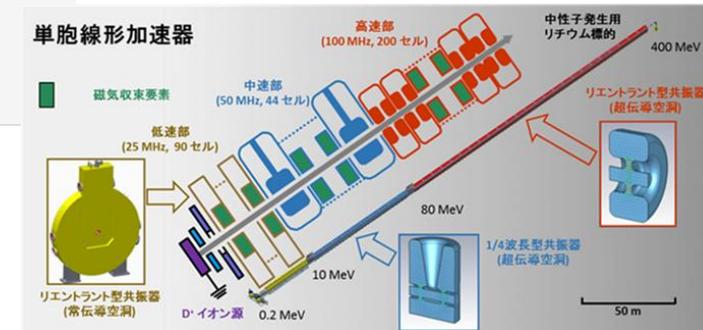
Project Manager

OKUNO Hiroki

Group Director, Nuclear Transmutation Technology Group, Nishina Center for Accelerator-Based Science, RIKEN



This project aims to revolutionize fusion energy development by introducing innovative accelerator technologies. By establishing high-energy, high-output ampere-class beam accelerator technology, we enable the generation of large quantities of neutrons, thereby accelerating the development of fusion reactor materials. Additionally, by using automated cyclotron resonance accelerators for ion injection and heating, we will verify the feasibility of small-scale fusion reactors. This will help us aim for a future with a self-sustaining fuel society, one that does not increase high-level radioactive waste, a society coexisting with fusion energy, and a future supporting activities in uncharted spaces such as deep-sea and interplanetary travel.



Okuno et al.
Proposal of a 1-ampere-class deuteron single-cell linac for nuclear transmutation
Proc. Jpn. Acad. Ser. B Phys. Iol. Sci. 95, 430, 2019

RIBF Upgrade Project

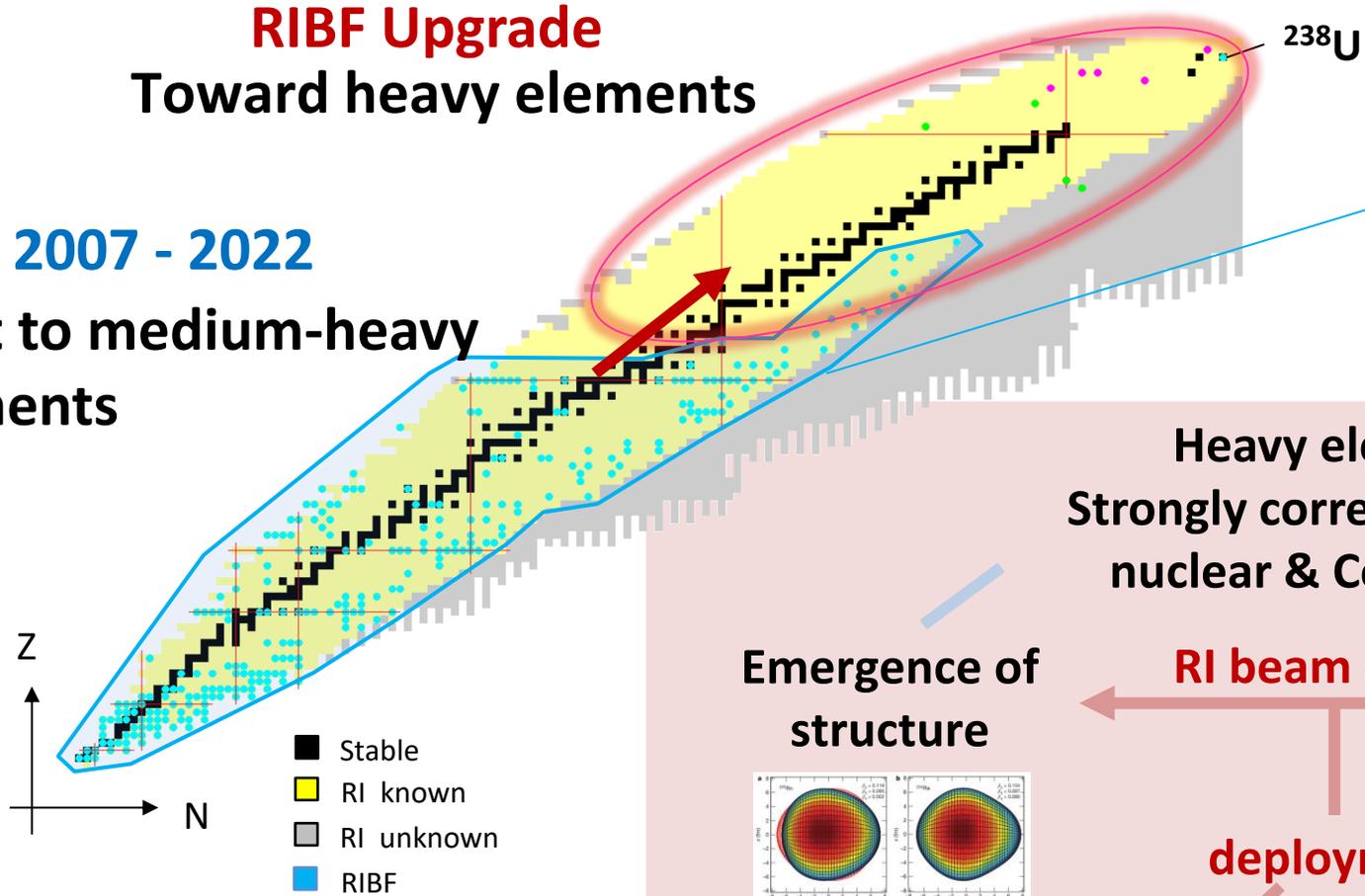
Courtesy of Daisuke Suzuki

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

RIBF Upgrade
Toward heavy elements

RIBF 2007 - 2022

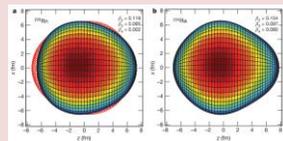
Light to medium-heavy elements



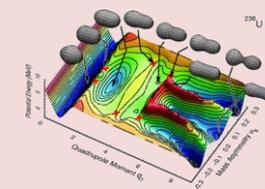
Nuclear force
Many-body correlations

Heavy element RI =
Strongly correlated system of
nuclear & Coulomb forces

Emergence of structure



Emergence of dynamics



RI beam studies

deployment

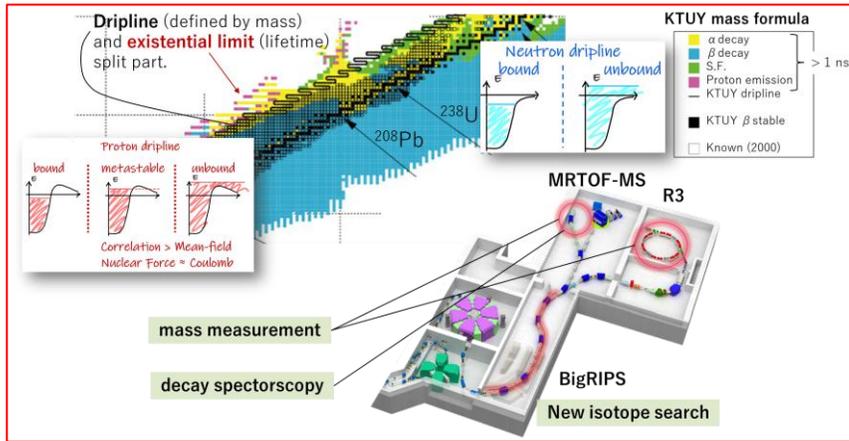
Evolution of matter
Nucleosynthesis
Neutron star structure

Nuclear energies
RI medicine applications
New energy cycle

Physics Cases

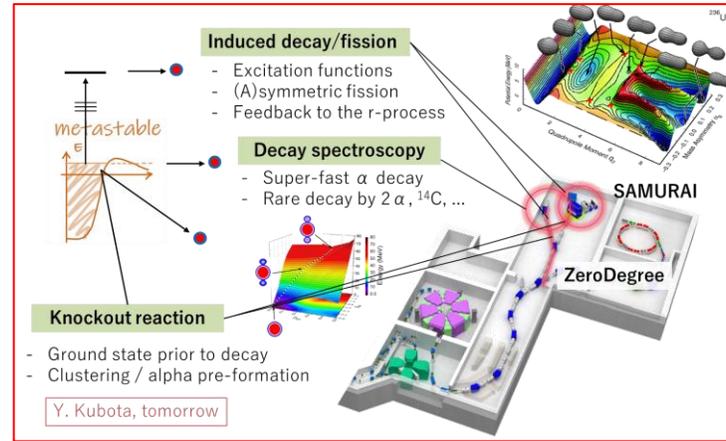
Proton dripline and limit of existence

Location of the driplines reflects complex interplay of structure and dynamics



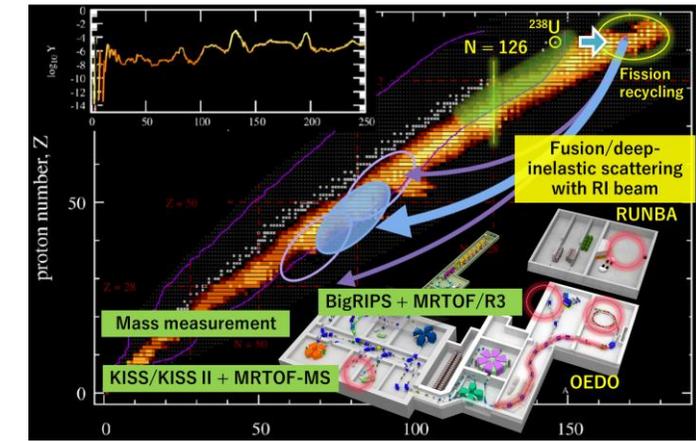
Alpha decay, rare decays to fission

Dynamics and structure behind can be studied in a unified way



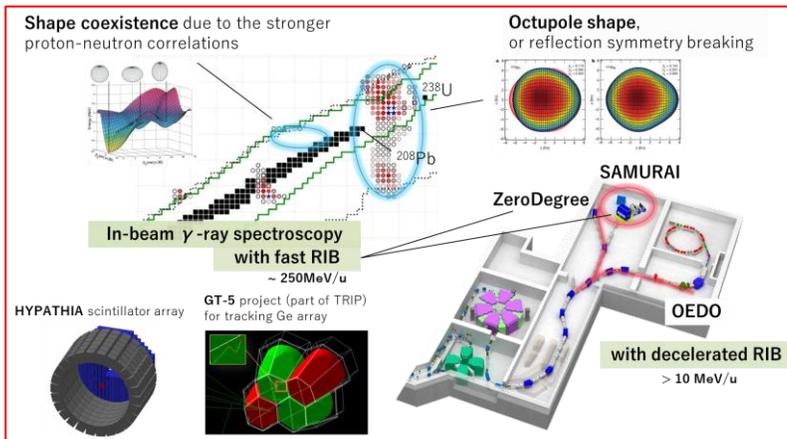
R-process path

Towards the end point of elements



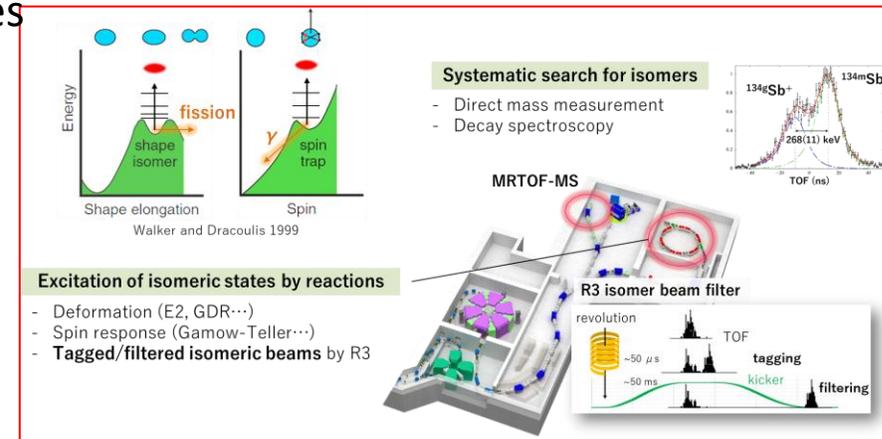
Exotic shapes

A variety of shapes expected in heavy element region



Isomerism

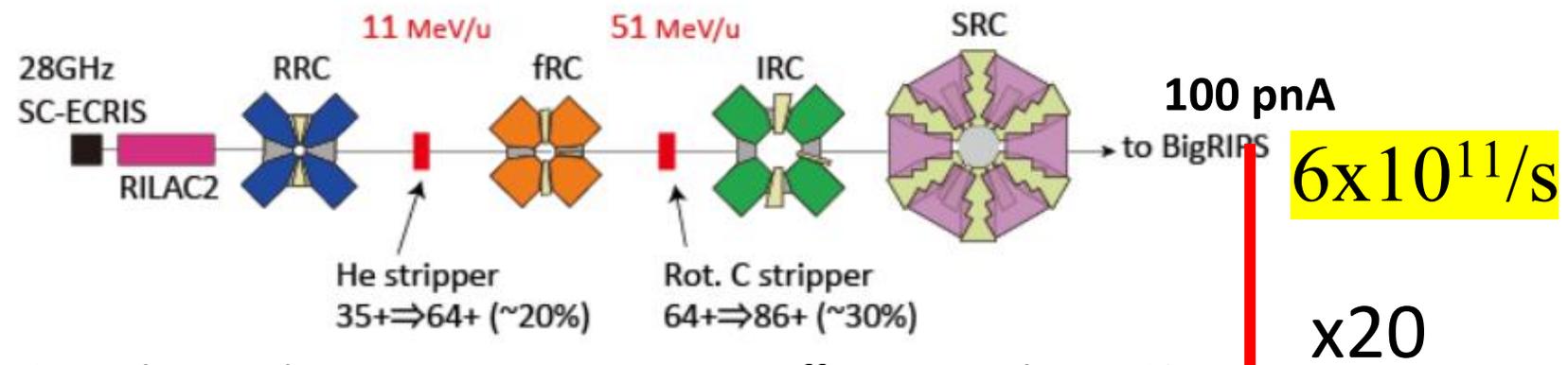
States with extreme deformation or spin, rarely met in ground states



RIBF upgrade plan to have more intense U beam

Courtesy of Imao

Present Acceleration Scheme



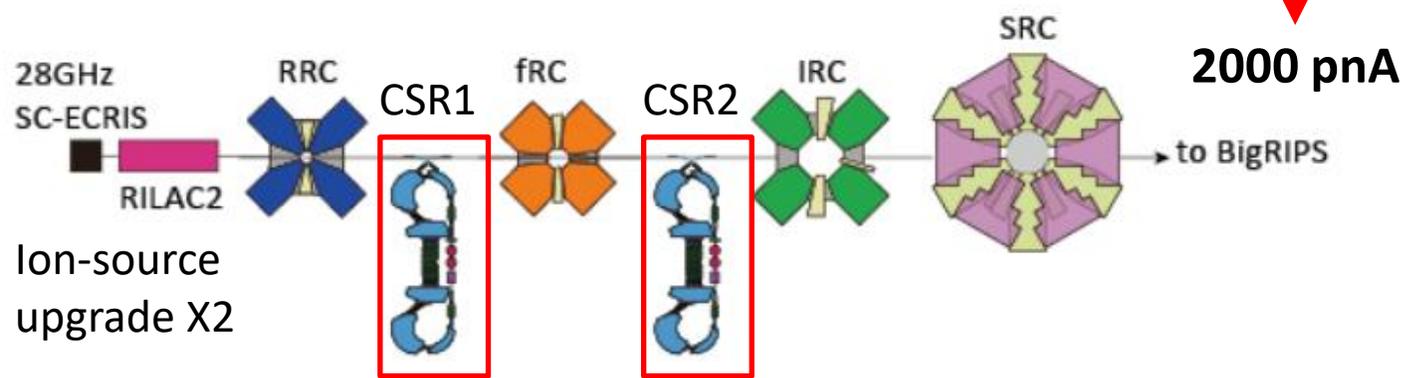
Large loss at the strippers : transmission efficiency is about 6%

1x10¹³/s

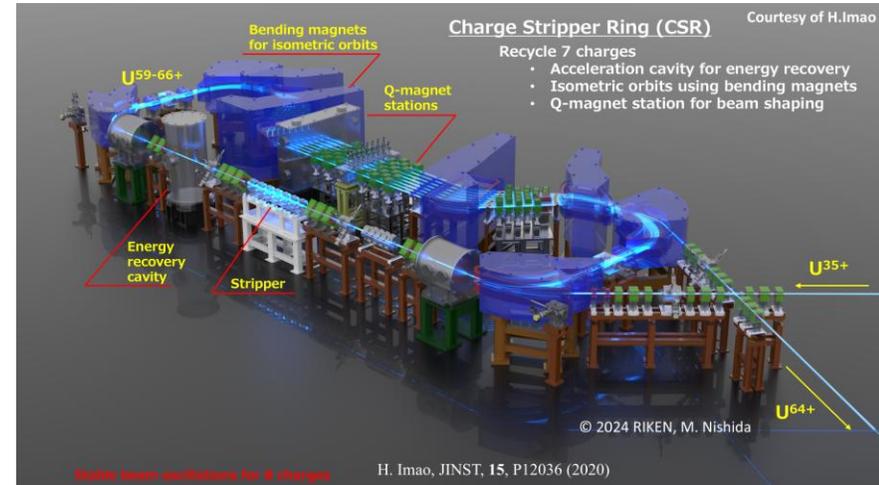
x20

“Recycling of heavy-ion beams”

Upgrade plan



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



“RIBF Facility Upgrade Project” issued in 2023

https://www.nishina.riken.jp/researcher/RIBFupgrade/RIBF_Upgrade_NCAC.pdf

- 8 year project.
- Year 1 to 5: construction of CSR1 for 500 pA
- Year 6 to 8: construction of CSR2 for 2,000 pA

Year	1	2	3	4	5	6	7	8	9
Injection system upgrade for IRC	design	construction	installation						
CSR1	design	design	construction	construction	installation				
ECR-IS upgrade	design	construction	construction	construction	installation				
SRC-RF upgrade	design	construction	construction	construction	installation				
fRC-RF upgrade		design	construction	construction	installation				
Infrasructure upgrade	design	construction	installation						
CSR2			design	design	design	construction	construction	installation	
BigRIPS first stage for high power beam			design	design	design	construction	construction	installation	
BigRIPS first stage for high purity beam	design	design	construction	construction	installation				
Spectrometer upgrade			design	design	design	construction	construction	installation	
Beam intensity						500 pA			2000 pA

Budget is being requested

In 2024, Int’l WS “Advancing physics at next RIBF (ADRIB24)”

In 2025, Int’l WS “Advancing physics at next RIBF (ADRIB25)”

more than 100 participants, 50% were young generations (20-30’s years old)

