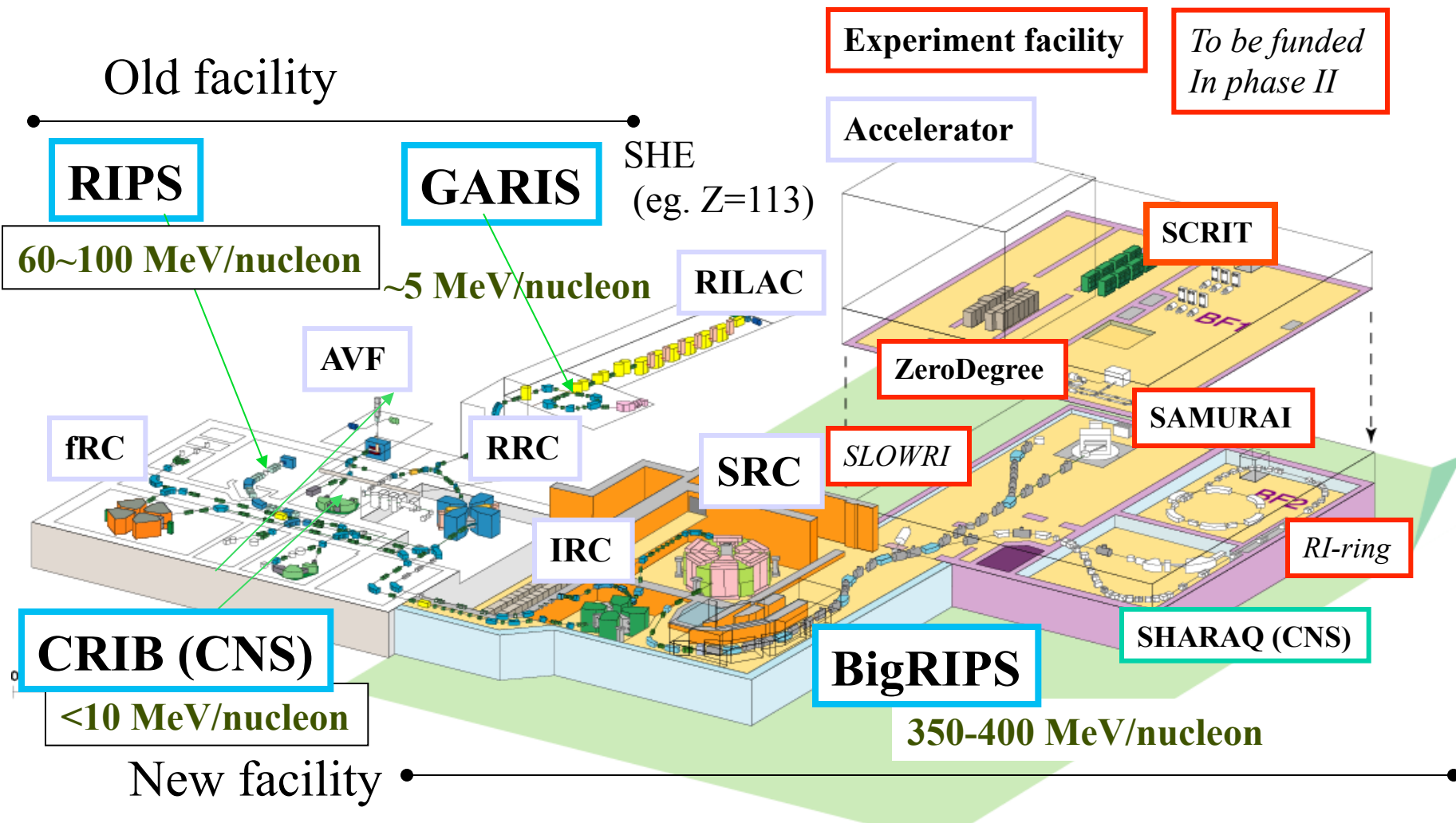




RIBFでの戦略

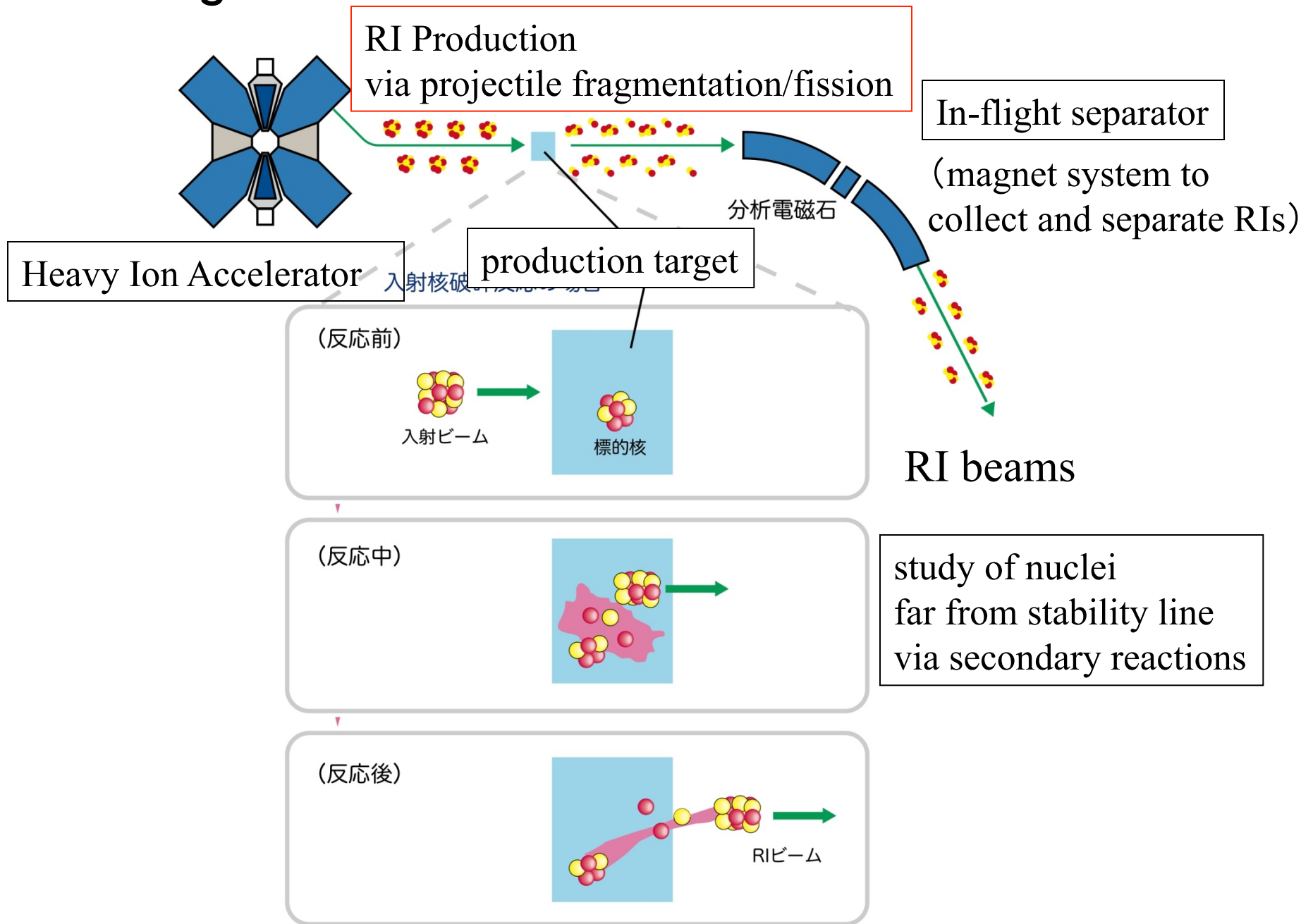
櫻井博儀

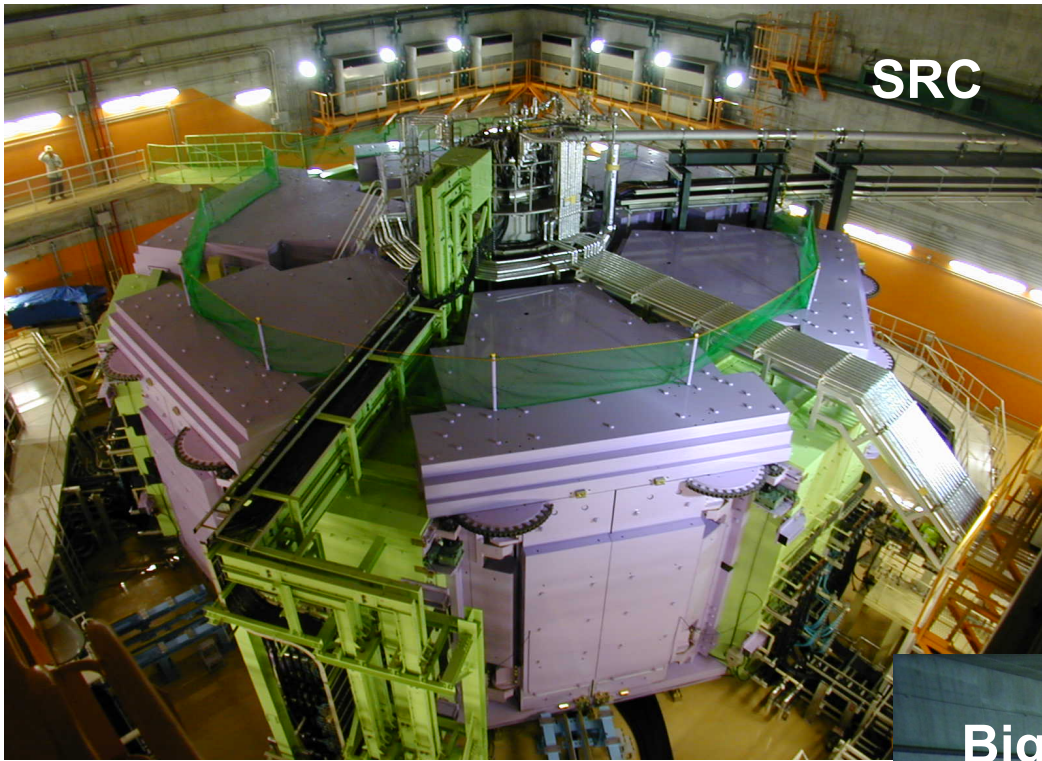
RIKEN RI Beam Factory (RIBF)



Intense (80 kW max.) H.I. beams (up to U) of 345A MeV at SRC
Fast RI beams by projectile fragmentation and U-fission at BigRIPS
Operation since 2007

In-flight Production Method of RI beam





SRC

Superconducting Ring Cyclotron

**World's First and Strongest
K2600MeV**

400 MeV/u Light-ion beam

345 MeV/u Uranium beam

BigRIPS In-flight Separator

**World's Largest Acceptance
9 Tm**

Superconducting RI beam Separator

~250-300 MeV/nucleon RIB



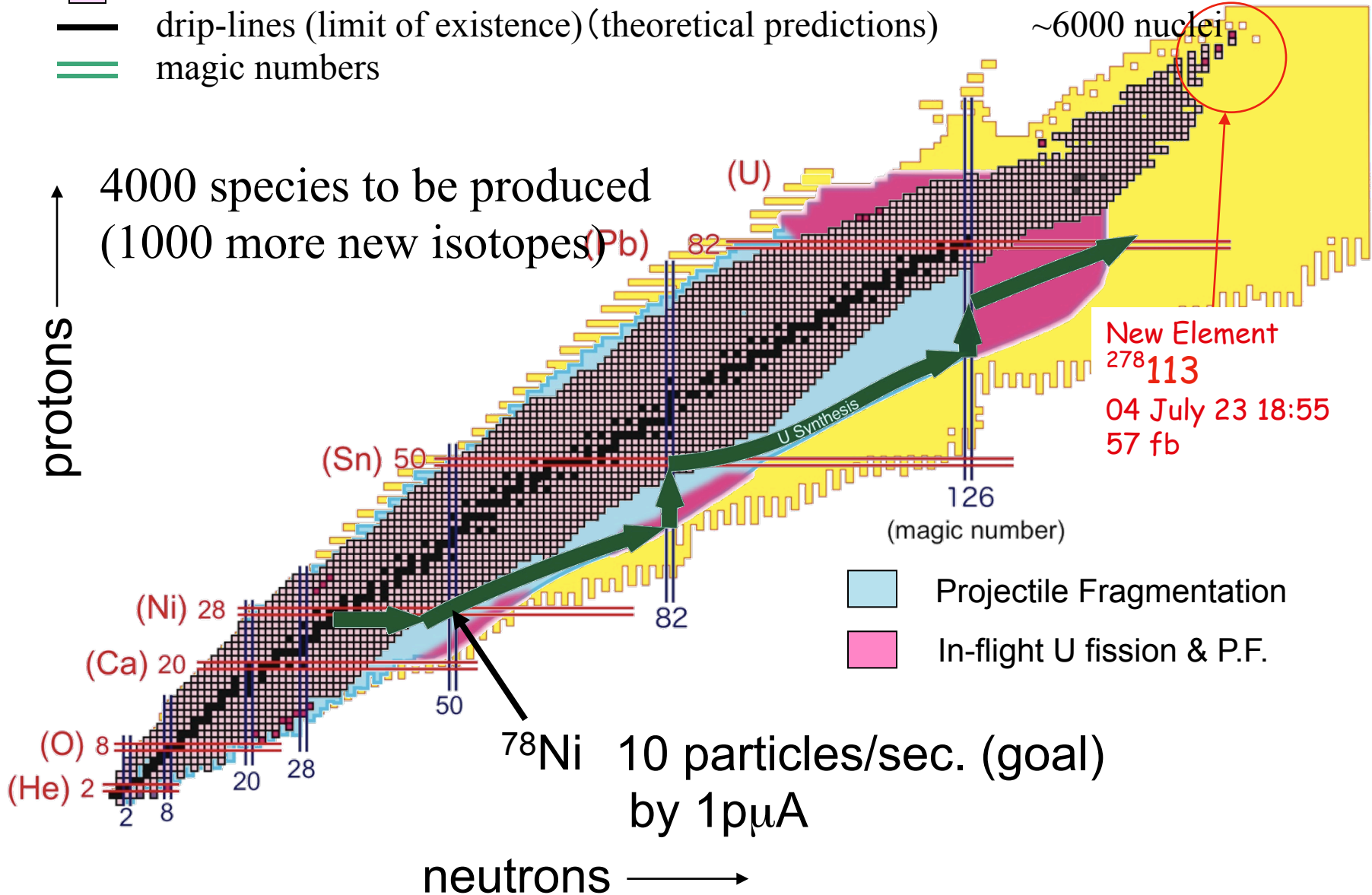
BigRIPS

Exploration of the Limit of Existence

- stable nuclei
- unstable nuclei observed so far
- drip-lines (limit of existence) (theoretical predictions)
- magic numbers

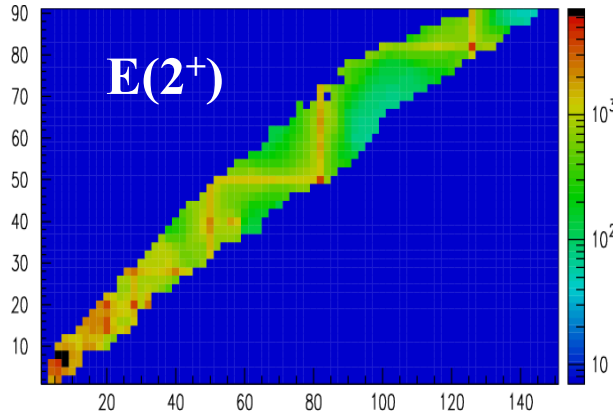
~300 nuclei
 ~2700 nuclei
 ~6000 nuclei

↑ 4000 species to be produced
 (1000 more new isotopes)



Liberation from Stable Region and Exotic Nuclei

Shell Evolution : magicity loss and new magicity



Shape ?
 Shell gap ?
 Single particle level ?
 Cluster formation ?
 Role of 3NF ?
 Magicity loss ?

50, 82, 126, 184

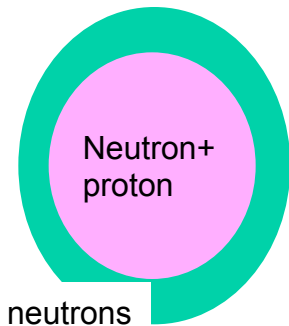
Spherical



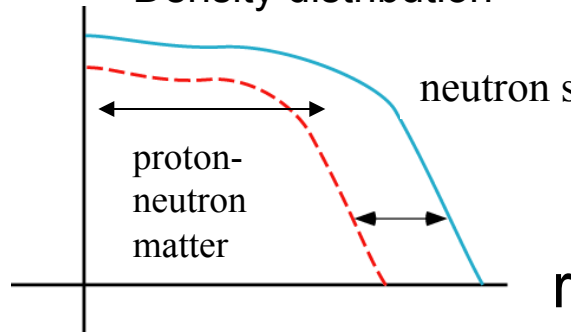
Deformed



Dynamics of new "material" : Neutron-skin (halo)



Density distribution



Skin thickness ? Density distribution ?
 Role of skin in reactions ?
 Pairing in skin ? di-neutrons ?
 Exotic modes of skin ?

RIBF provides data for nuclei far from the stability line

Challenges in establishing new frame work of nuclear physics

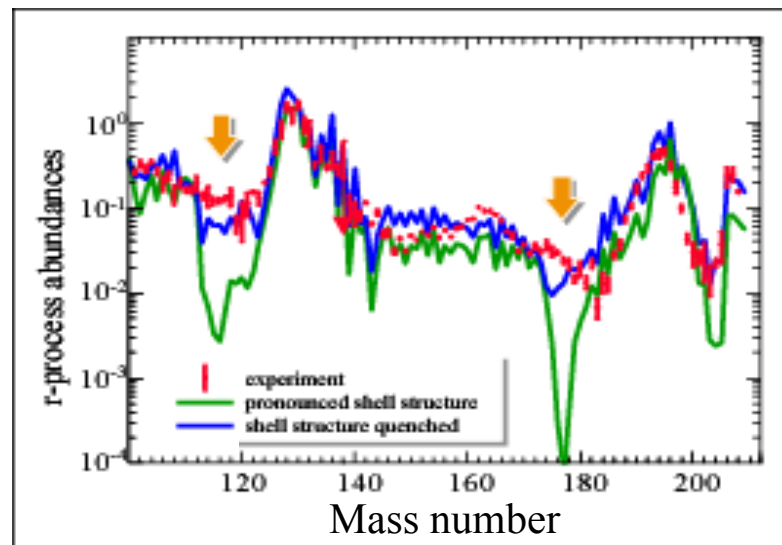
Challenge for r-process path and explosion in supernovae

Synthesis up to U (r-process)

unknown neutron-rich nuclei
theoretical predictions only

Necessary of experimental investigation
for nuclear properties of heavy and
neutron-rich nuclei

Mass, life-time, decay mode

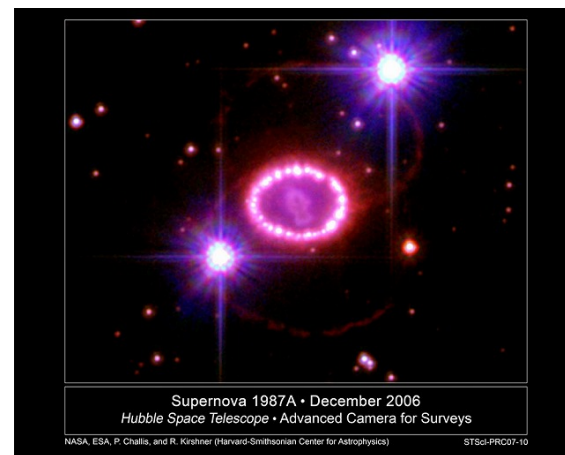


Explosion mechanism of supernova

No explosion in theoretical works

Outer crust of neutron star

Necessary of experimental study for
Equation-of-State for nuclear matter



1987A

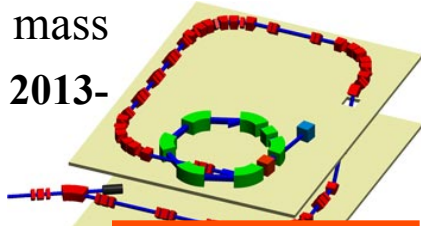
New Experimental Devices of RIBF

To maximize the potentials of intense RI beams available at RIBF

for several 100 – 1000 species

Rare RI ring

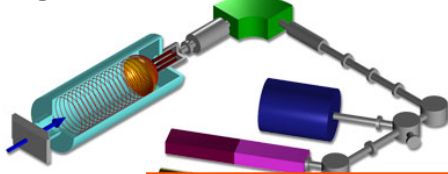
mass
2013-



Funded 2012

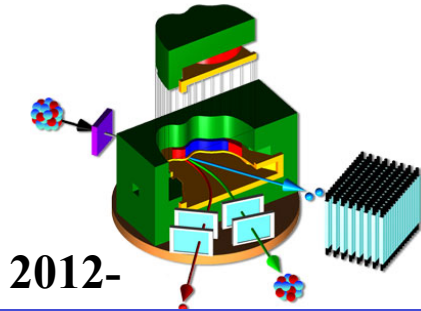
SLOWRI

gas-catcher



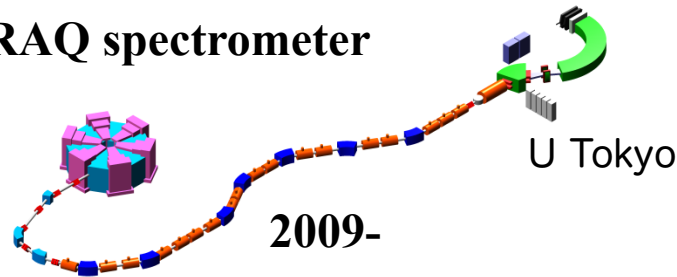
to be funded

SAMURAI



2012-

SHARAQ spectrometer



2009-

U Tokyo

ZeroDegree

2008-

IRC-to-RIPS BT

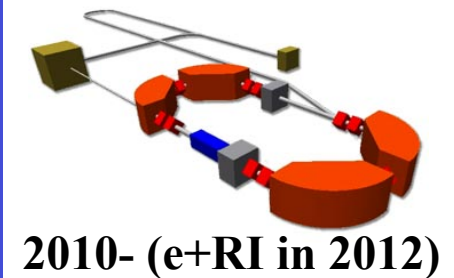
multi-use

2012-



to be funded

SCRIT



2010- (e+RI in 2012)

mass
half-life
excited states
deformation
charge radii
matter radii
charge distribution
matter distribution
EM moments
single particle states
astrophysical reactions
giant resonances
exotic modes
HI collisions (EOS)

“Rare RI Ring” for mass measurement

Construction started in April 2012!

Ozawa, Wakasugi, Uesaka et al.

Specialized to mass measurements
of r-process nuclei
Low production rate ($\sim 1/\text{day}$)
Short life time ($< 50\text{ms}$)

Key technologies:

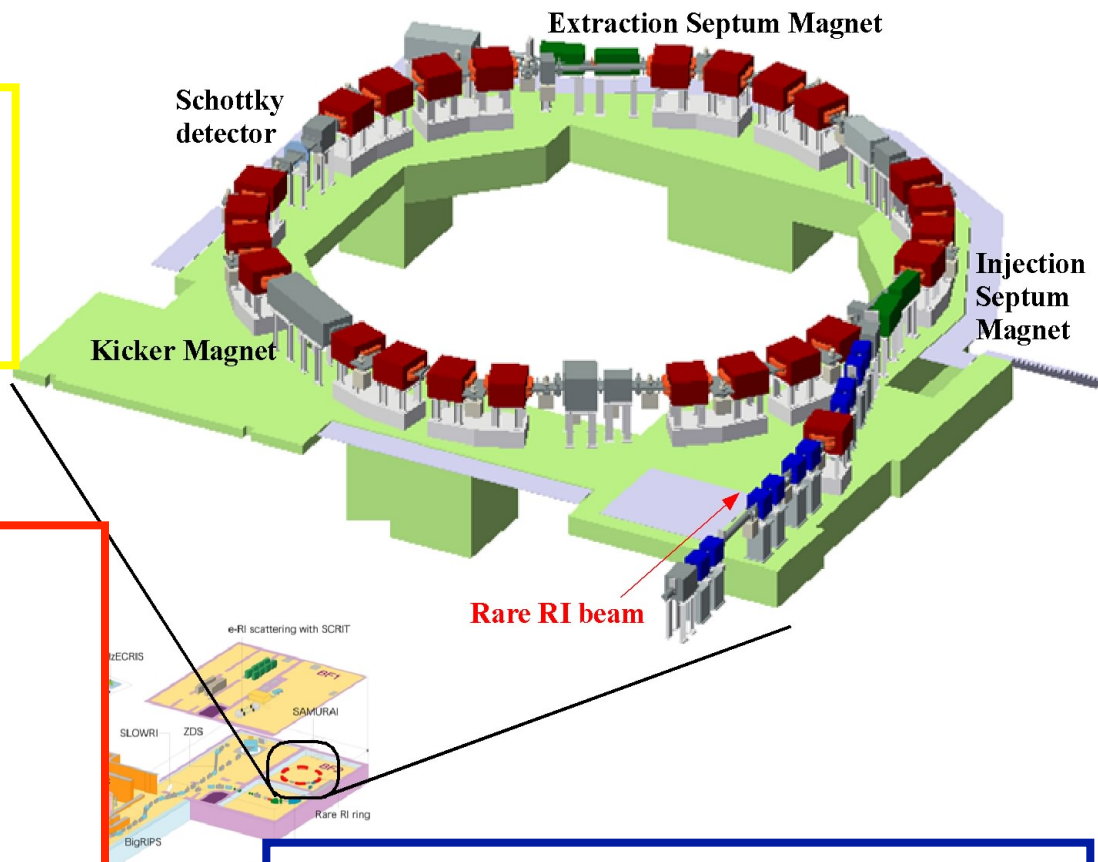
Isochronous ring

$$\Delta T/T < 10^{-6} \text{ for } \delta p/p = \pm 0.5\%$$

Individual injection triggered by
a detector at BigRIPS

efficiency $\sim 100\%$

even for a “cyclotron” beam



Schedule:

2014 Commissioning run

2015~ Mass measurements of RI

SCRIT Electron Scattering Facility

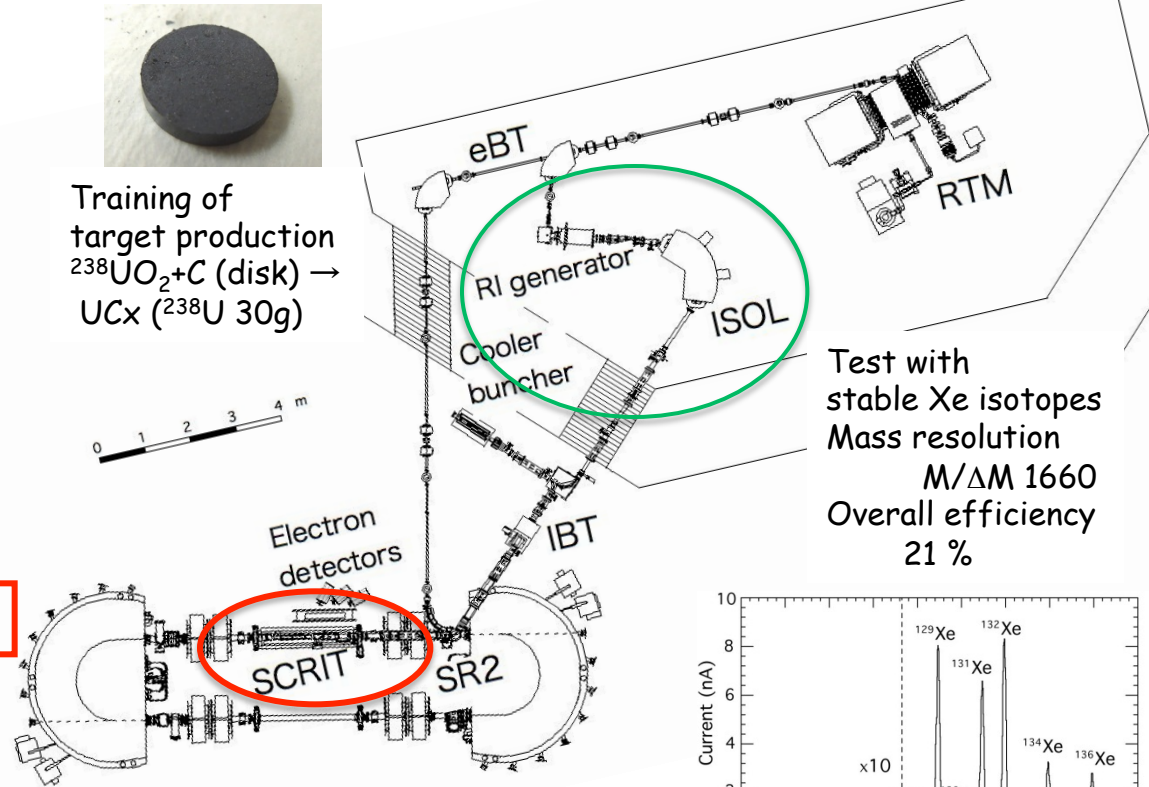
Wakasugi et al.

- 2009 Facility constructions
- 2010 Tuning of accelerators
Installation of SCRIT
- 2011 SCRIT performance test
ISOL commissioning
- 2012 Test of RI production
Tuning of ISOL
- 2013 Upgrade RTM
Construction e-Spectromete
Full-scale RI production
Start Experiments for RI's

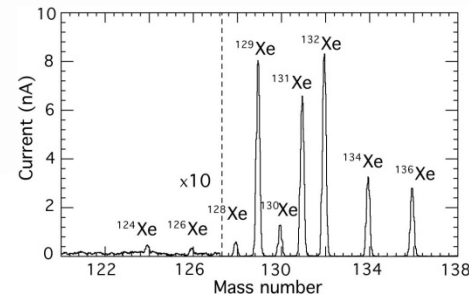
Commissioning of ISOL and preparation of UCx target



Training of
target production
 $^{238}\text{UO}_2 + \text{C} (\text{disk}) \rightarrow$
 $\text{UCx} (^{238}\text{U} \text{ 30g})$

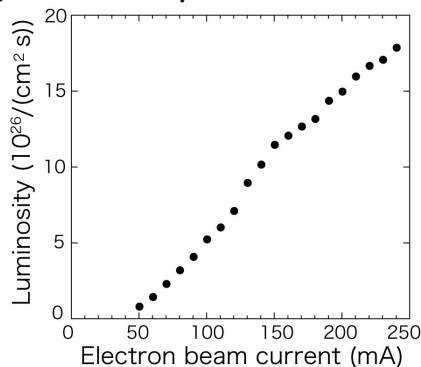


Test with
stable Xe isotopes
Mass resolution
 $M/\Delta M$ 1660
Overall efficiency
21 %



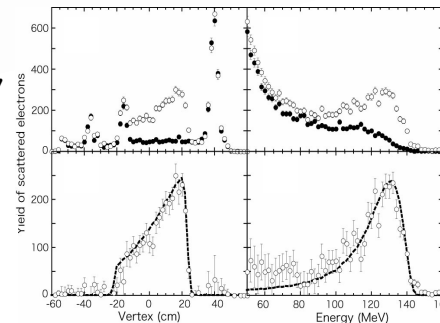
Test Experiments using Stable ^{133}Cs

Achieved luminosity $1.8 \times 10^{27} / (\text{cm}^2 \text{s})$
Ion trapping efficiency 85 %
at 240 mA



Measurements of
Electrons elastically
scattered from
trapped Cs ions
in SCRIT

- with Cs
- without Cs



SAMURAI Spectrometer

Kobayashi et al 2012-

versatile spectrometer with a large superconducting magnet

Spectroscopy of

Unbound States e.g. (γ, n)

$(p, 2p)$ Missing Mass

Nucl. Astrophys. (p, γ)

Deuteron expts for 3NF

EoS in HIC

March Commissioning
May B-19, C-22 etc.

\vec{d} setup

(not shown in picture)

NSCL, Liverpool, TA&M joining this project

Proton

Bending Magnet

Superconducting

Large $B \cdot L$ (7Tm)

Large pole gap (80cm)

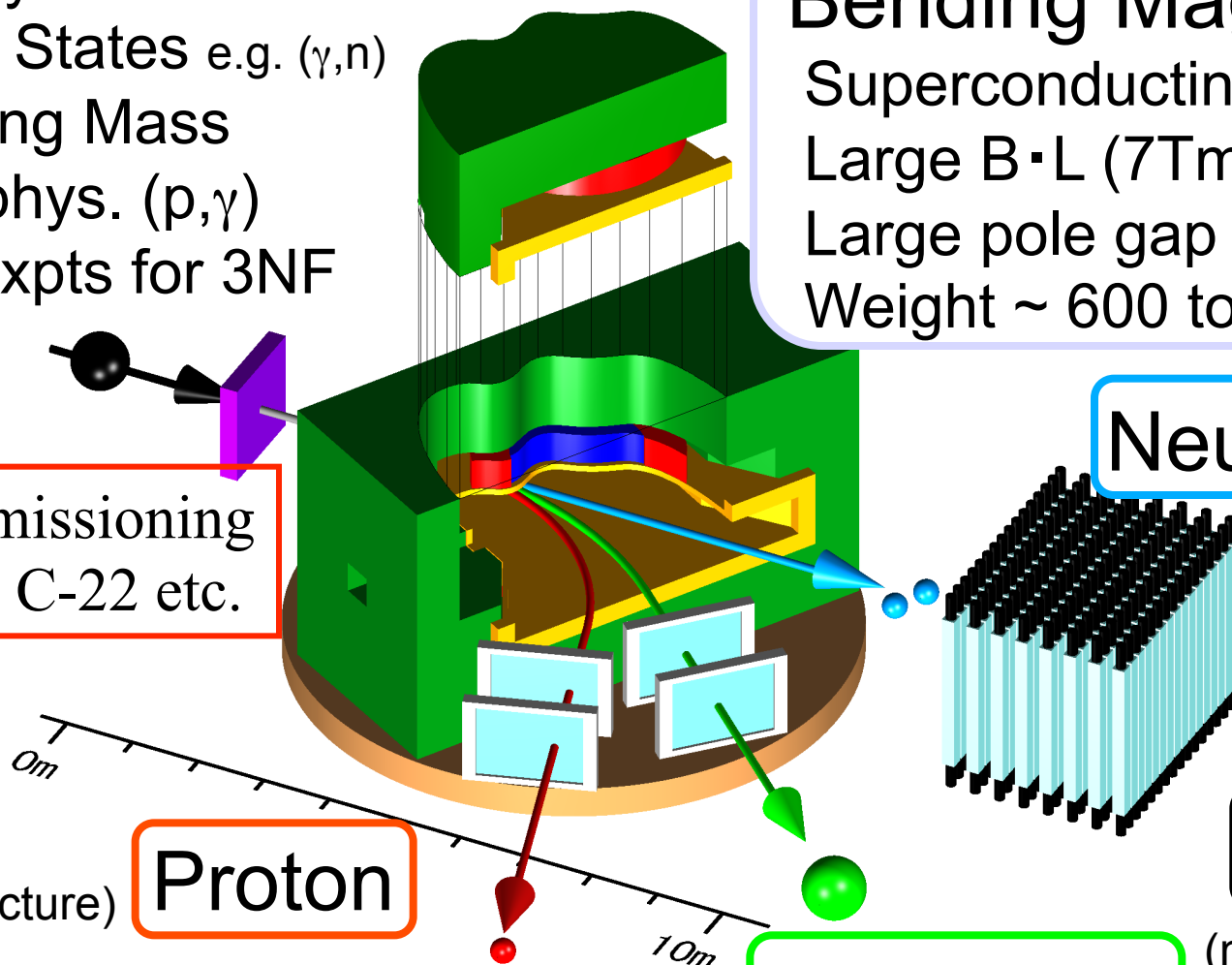
Weight \sim 600 ton

Neutron

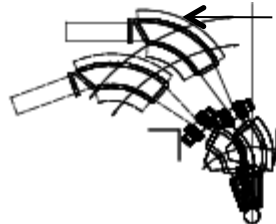
TPC

(not shown
in picture)

Heavy Ion



Experimental Devices available at the new facility

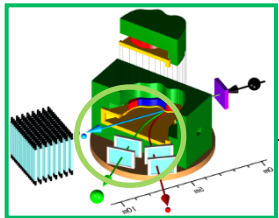


SHARAQ(2009~) CNS-UT

High resolution spectrometer

Miki et al., PRL 108, 262503 (2012)
IVSMR in Zr-90 and Pb-208 via (t,He3)

SAMURAI (2012~)



BigRIPS (2007~)

2nd

1st

production target

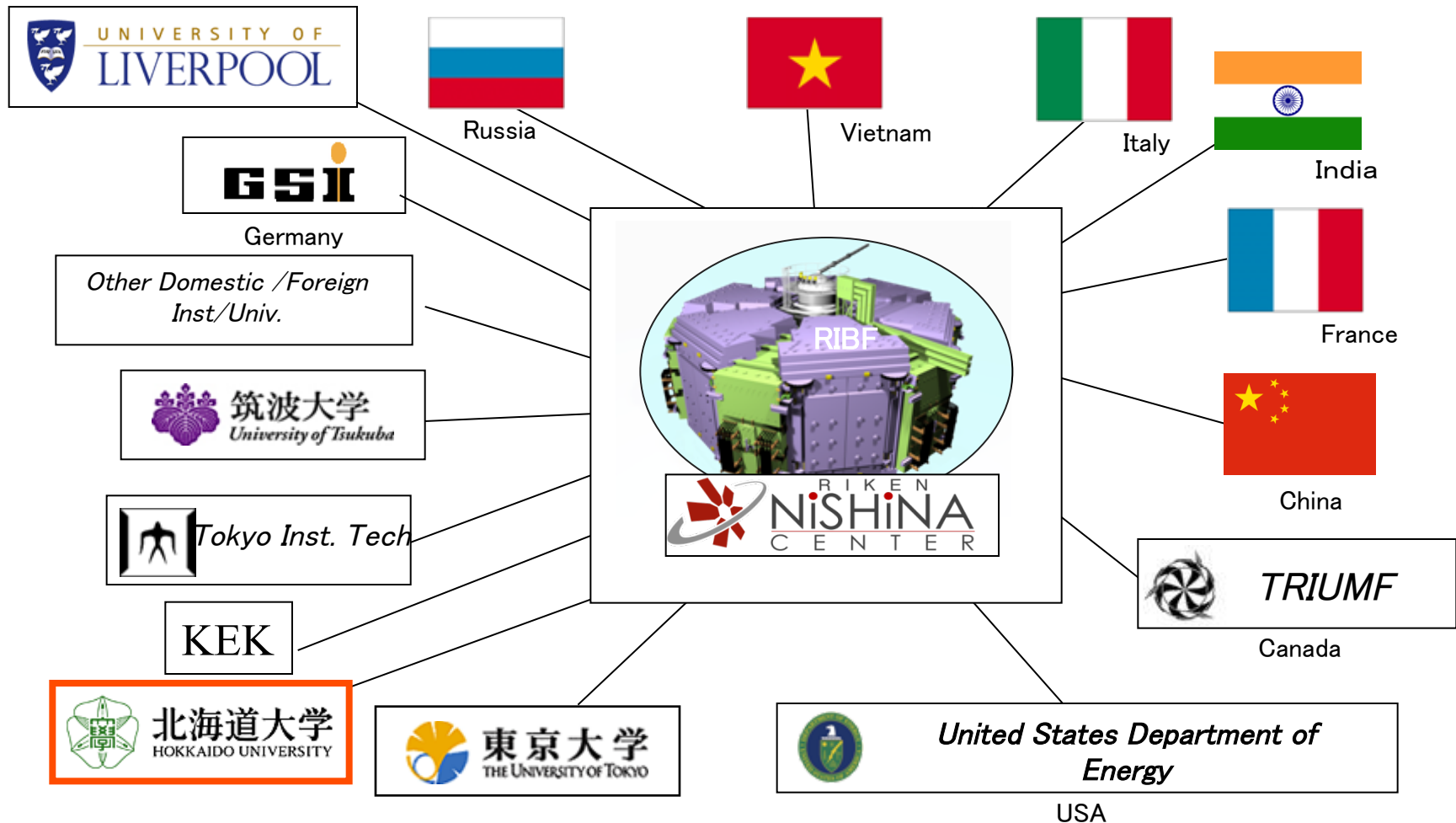
ZeroDegree (2008~)

BigDpol(2009~)

For polarized deuteron only
SRC



Promotion of Nuclear Science Programs Under Domestic/International Collaborations



Country-based; France, China, Italy...

Institute/university-based: US, UK, Germany, India, Russia, Canada, Hungary, Bulgaria...

Co-organization of PAC with CNS, Univ. of Tokyo

External investment by CNS: SHARAQ, CRIB, GRAPE

Charged particle nuclear reaction data



RIBF

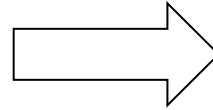
Direct reactions

Elastic (p,p), ...
Inelastic (p,p'), (α , α')...
Coulomb Excitation
Coulomb Dissociation
Quasi-elastic (p,2p), (p,pn)
Transfer (d,p), (d,n), ...
Charge exchange (p,n), (n,p), ...
Double charge exchange
3-N forces d+p elastic
pionic atom (d, ^3He)

Heavy ion induced reactions

Total reaction c.s.
One-, two-nucleon knock-out
reaction
Fragmentation reaction
Fission reaction
Fusion reaction
Central collisions
.....

reaction
data



Nuclear Reaction
Data Center (JCPRG)

compilation
evaluation (light mass)

Jan 10-11th, 2006

Possible programs for nuclear data via inverse reactions with stable and primary beams upto 350A MeV??

Two contributions from Nuclear Data Community

Fukahori (JAEA)

“Review on nuclear reaction data at intermediate and high energy”

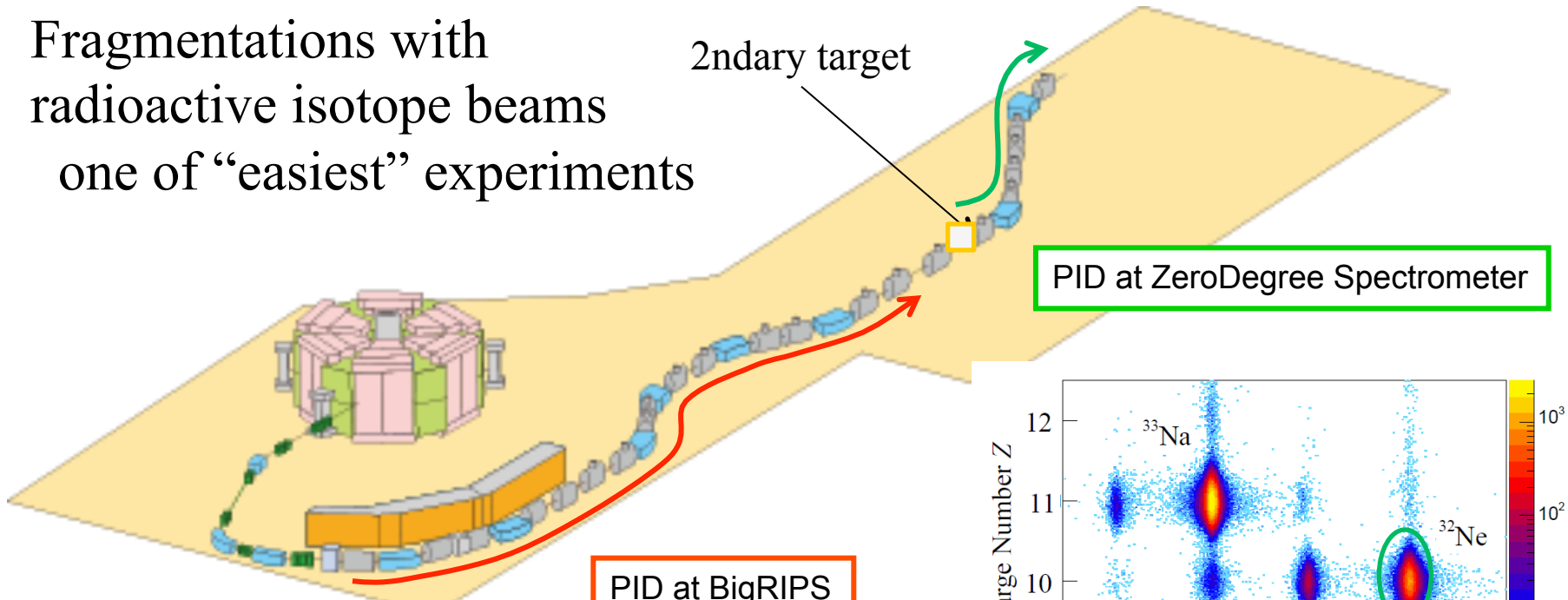
Uozumu (Kyushu Univ.)

“Double differential cross sections for particle production data at intermediate and high energy”

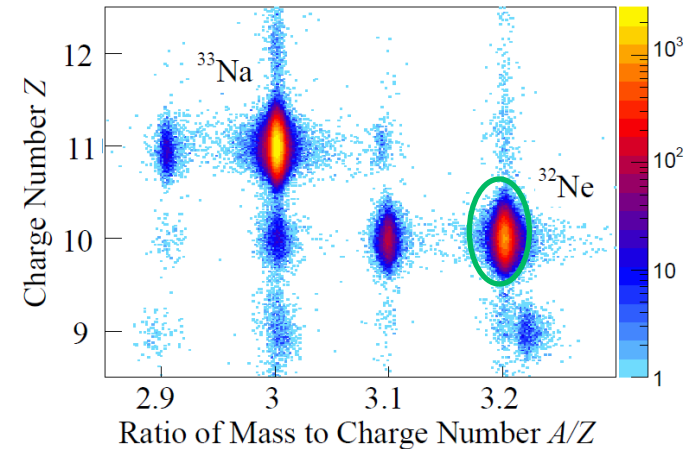
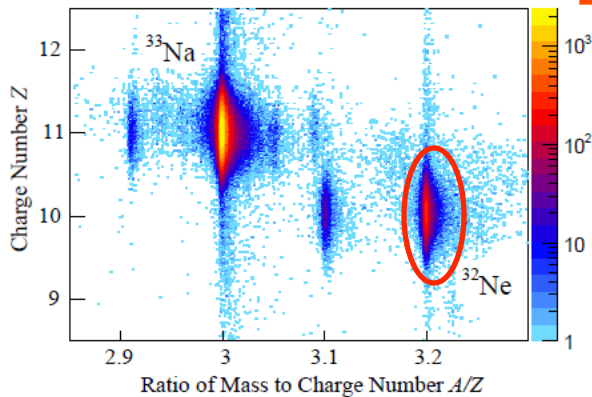
Forming a nuclear data collaboration and making a master plan??

Nuclear data programs with secondary beams ??

Fragmentations with radioactive isotope beams
one of “easiest” experiments



PID at BigRIPS



Summary

RIBF is the world leading facility for radioactive isotope beams

Bunch of nuclear reaction and structure data are being produced.

Concerning nuclear data...

A joint reaction database program with Hokkaido U, Japan

It is good chance to form a nuclear data collaboration with major institutes/univ. in Japan

More collaborations with nuclear data group in Asia??

A lot of opportunities in inverse reactions