Experience of RIB research at RIKEN
(short retrospective review to look in future...)

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[(3)] Visiting researcher at RIKEN Nishina Center, Wako, Japan
(1993-1995, 2000-2001, 2003-2013)

OUTLINE

- Old RIKEN Accelerator Facility (1989-2007)
  - Production of RI beams: RIPS, CRIB
  - Examples of experimental setups and new fundamental results
- New RIBF Facility (2007-…)
  - Fragment separator BigRIPS
  - Spectrometers and Setups: ZeroDegree, SAMURAI, SHARAQ, EURICA+WASABI
  - Discovery of new isotopes, new data on exotic nuclei
  - New setups: OEDO, RI Ring, SCRIT
- Summary

Radioactive Isotope Beams World-Wide (middle 2018)

by K. Knie, GSI

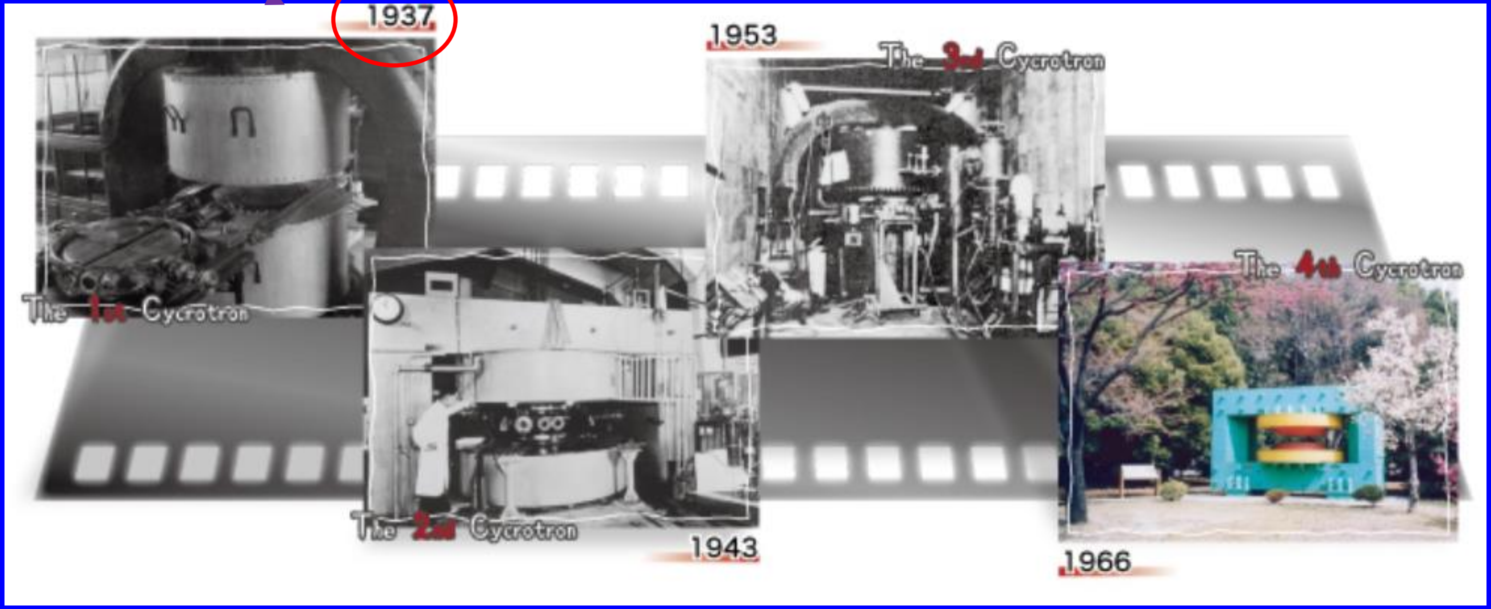
RIKEN (RIKagaku KENkyusho = Institute of Physical and Chemical Research)

founded in 1917 as the first private scientific foundation in Japan
with the financial support by the imperial Household, the Government and private organization

1st Cyclotron in Japan
2nd Cyclotron in the world

4 first cyclotrons in 1937–1966

Yoshio Nishina (1890-1951)

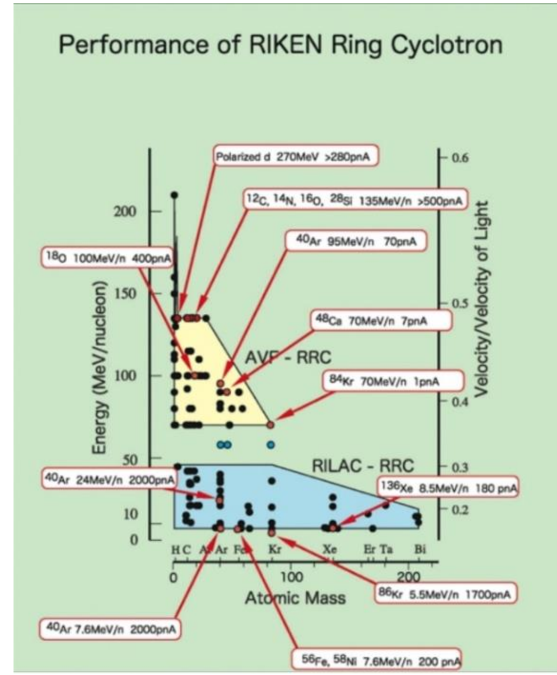


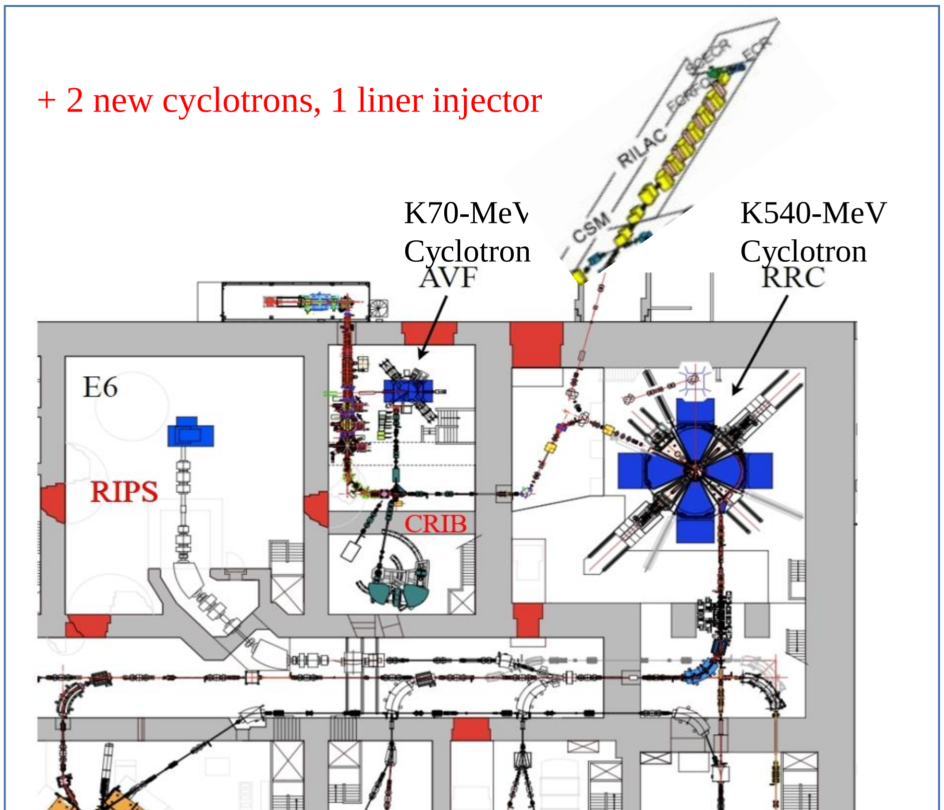
Old RIKEN Accelerator Research Facility (1986-2007) up to 135 A MeV

Yasushige Yano

Isao Tanihata

Toshiyuki Kubo



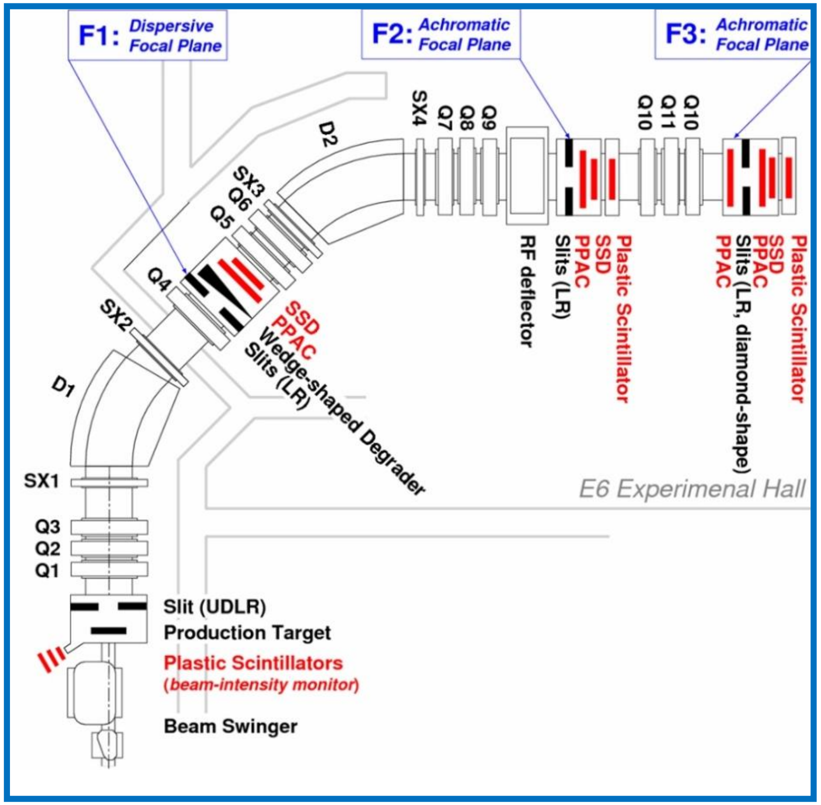


Some important RRC beams:

Beam particle	E/A (MeV)	Current (pnA)	Injector
^{14}N	135	500	AVF
^{18}O	100	1000 (500)	AVF
^{22}Ne	100	360	AVF
^{40}Ar	95 / 63	80 / 800	AVF / RILAC
^{48}Ca	63	250	RILAC
^{136}Xe	11	250	RILAC2
^{238}U	11	500	RILAC2

T.Kubo et al., NIM **B** 70, (1992) 309

RIPS



Basic characteristics of RIPS

Configuration	Q-Q-Q-SX-D-SX-Q (First section)
	Q-Q-SX-D-SX-Q-Q-Q (Second section)
	Q-Q-Q (Third section)
Angular acceptance	60 mrad × 60 mrad
Momentum acceptance	6%
Solid angle	5 msr
Focus	F1, dispersive, end of first section
	F2, double achromatic, end of second section
	F3, double achromatic, end of third section
Momentum dispersion at F1	$(x/\delta) = 24$ mm/%

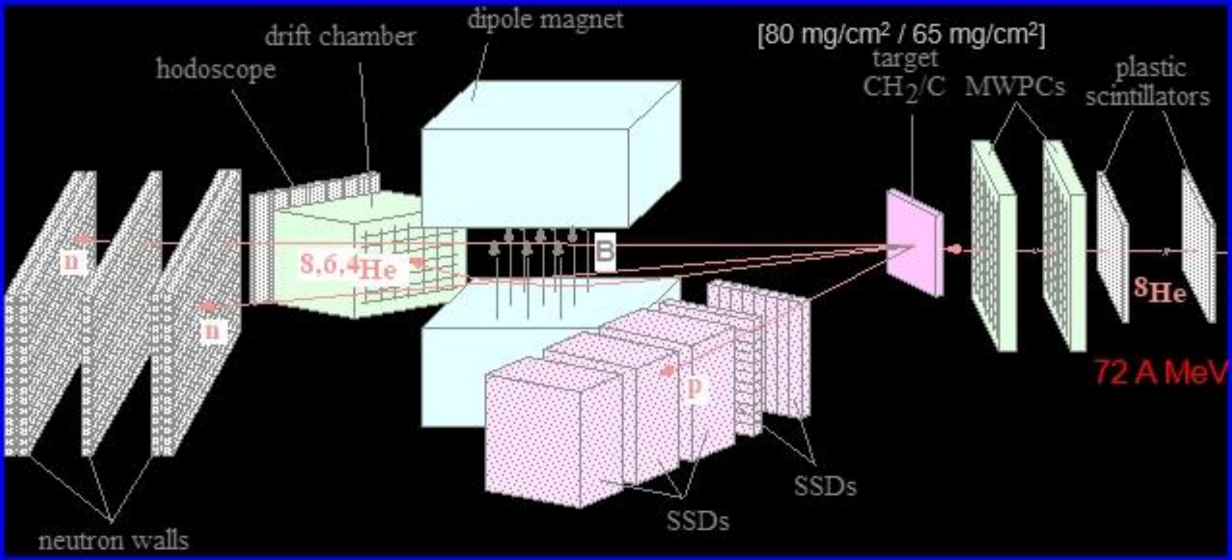
In the '90s world record RIBs intensities of exotic nuclei:

Secondary-beam production rates

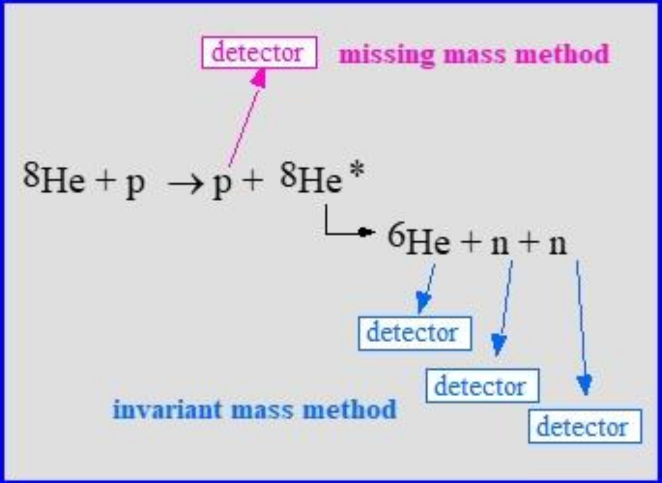
Isotope	Rate (particle/s)	Putity (%)	
6He	5.36E+06	100.0	
8He	1.77E+05	100.0	!!
11Li	7.57E+04	100.0	
10Be	4.13E+07	100.0	
11Be	1.15E+07	100.0	
12Be	2.26E+06	99.4	!!
14Be	3.94E+04	100.0	

The first study of ^{8}He scattering
Search for excited states of ^{8}He

N/Z = 3 !!



RIPS, RIKEN

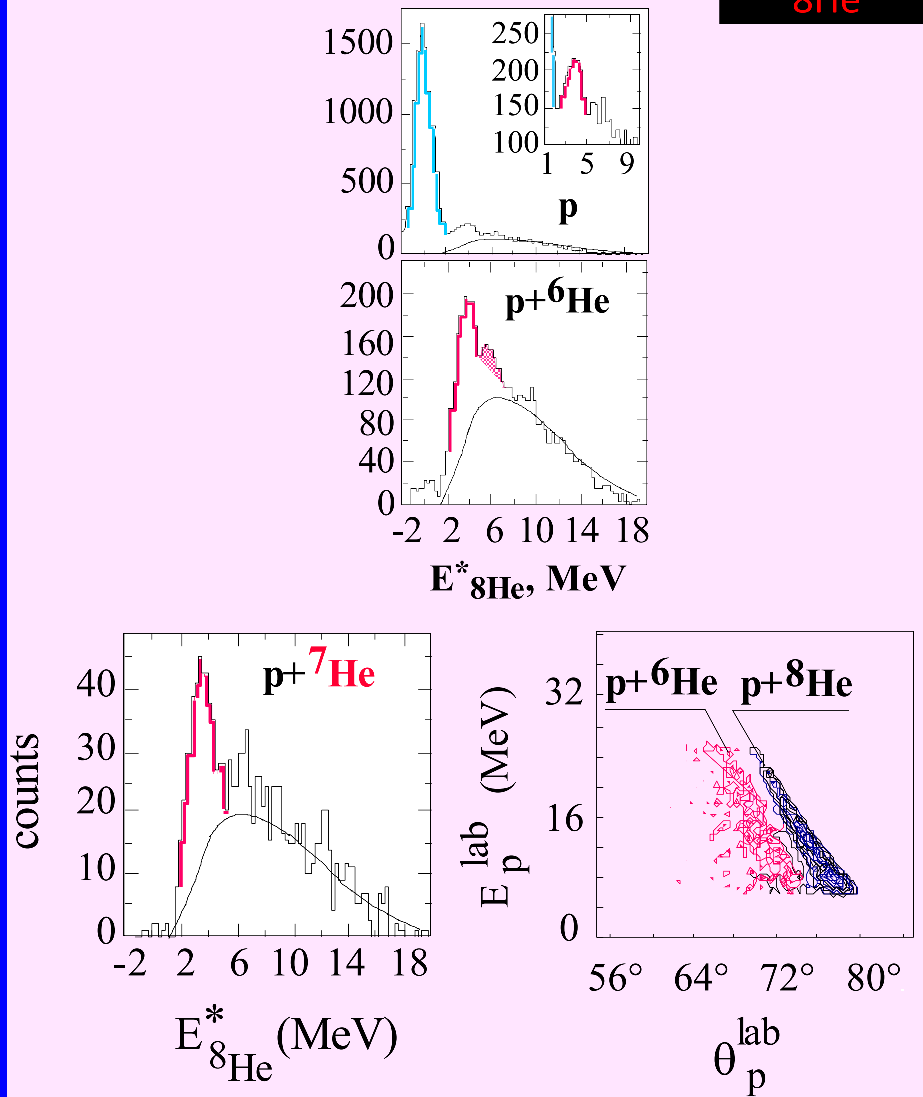


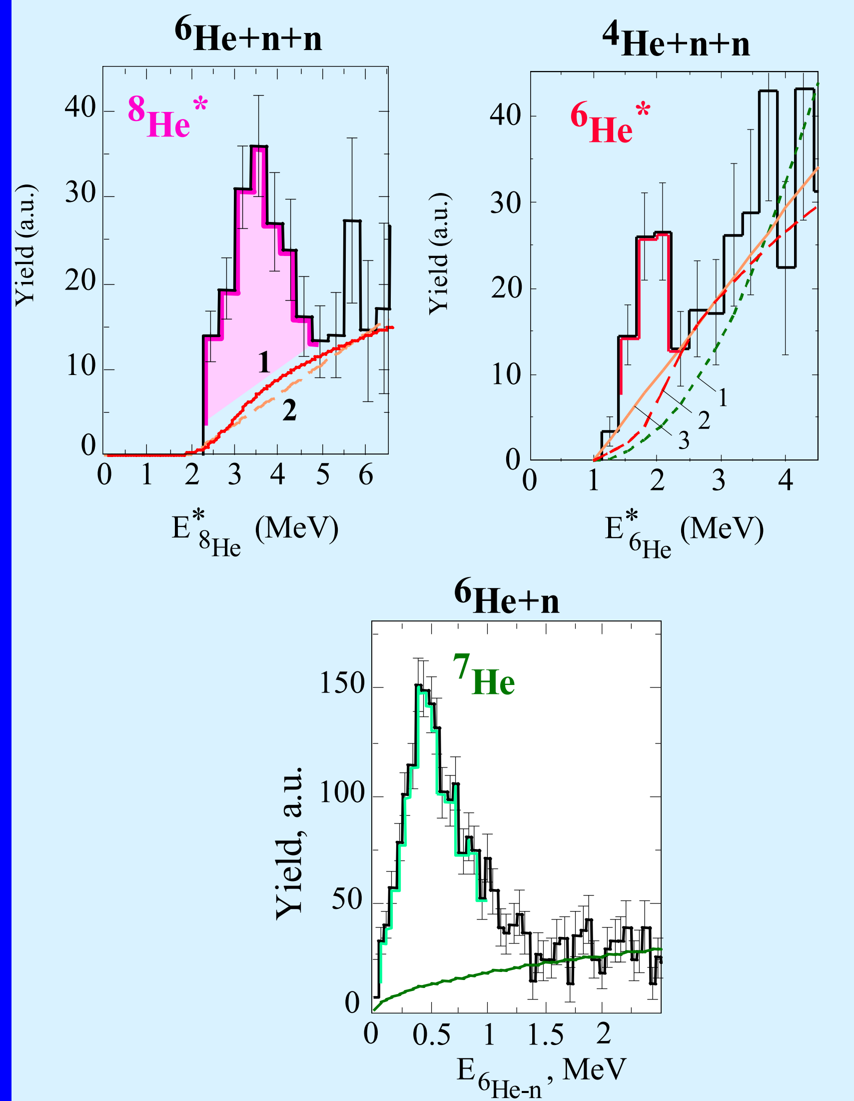
Missing mass method

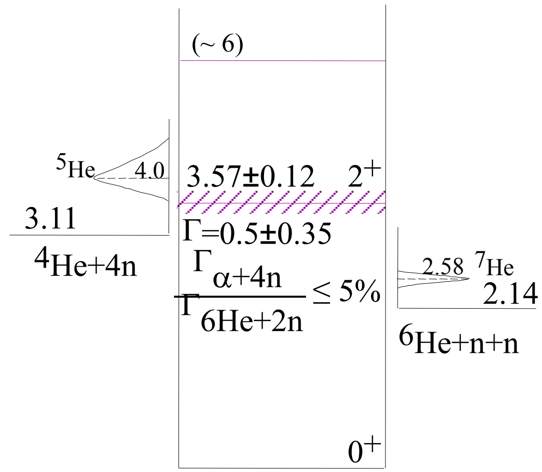
A. A. Korsheninnikov et al.
Phys. Lett. B **316**, 38 (1993)

Invariant mass method

$E^{*}_{8He} \approx 3.6$ MeV

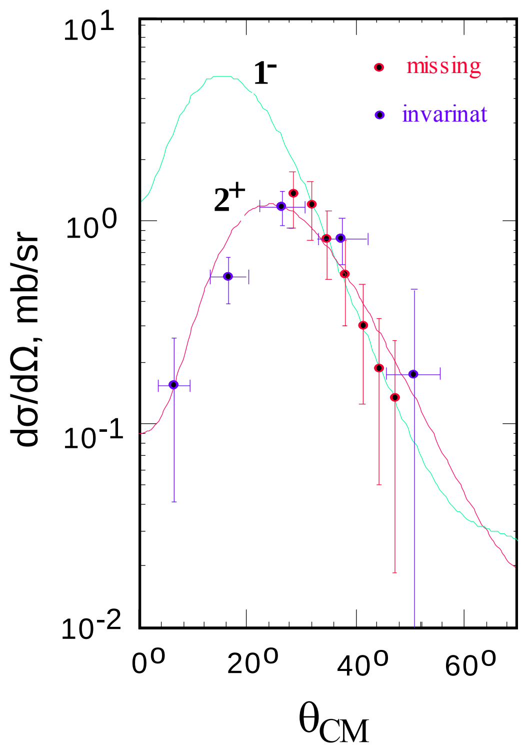




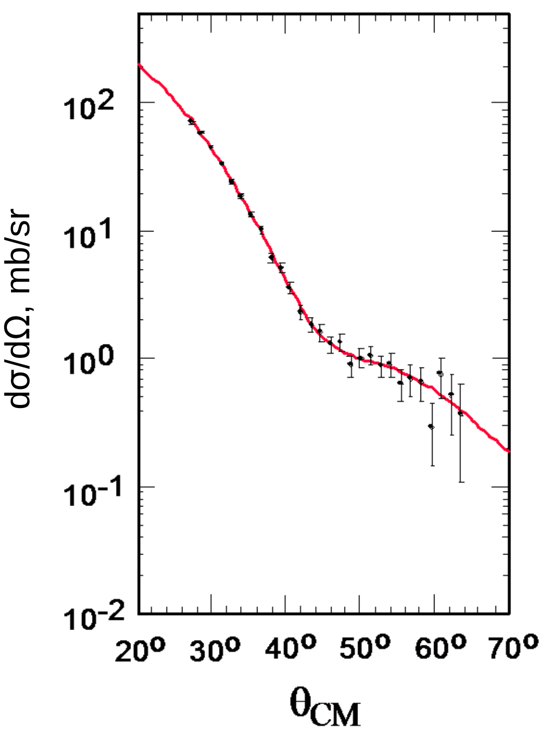


^{8}He

Inelastic scattering ^{8}He + p



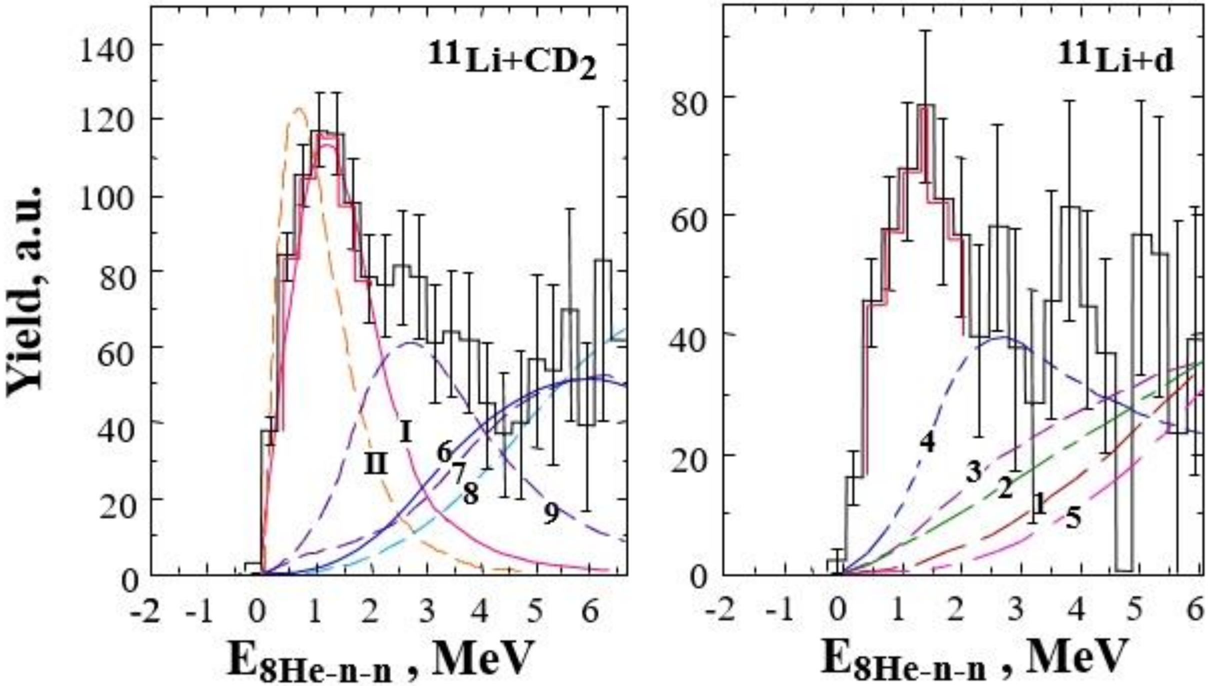
Elastic scattering ^{8}He + p



Observation of ^{10}He

A. A. Korsheninnikov et al. Phys. Lett. B **326**, 31 (1994)

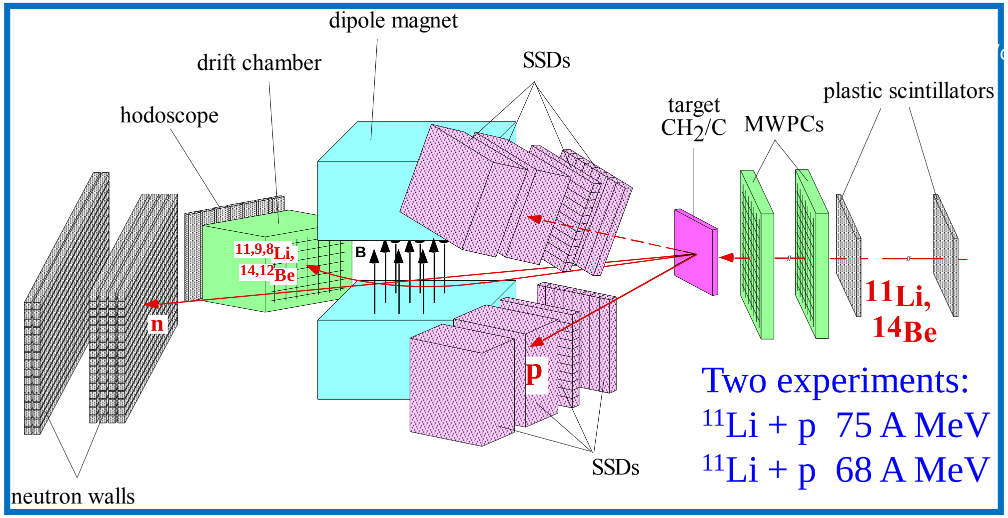
^{8}He+n+n :



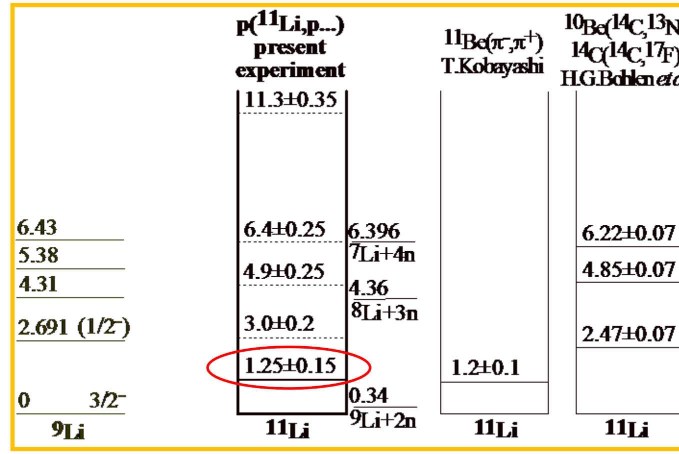
$E_{^8He-n-n} = 1.2 \pm 0.3$ MeV , $\Gamma \leq 1.2$ MeV

26 years ago…

Spectroscopy of ^{11}Li by proton scattering



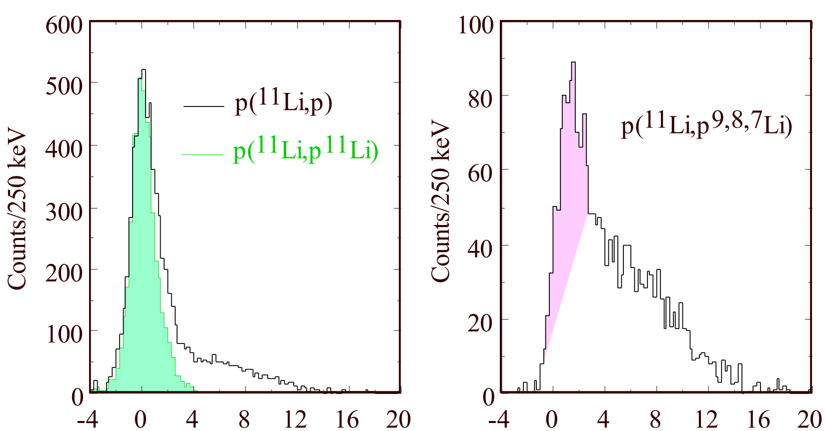
A. A. Korsheninnikov et al.
Phys. Rev. C **53**, R537 (1996)

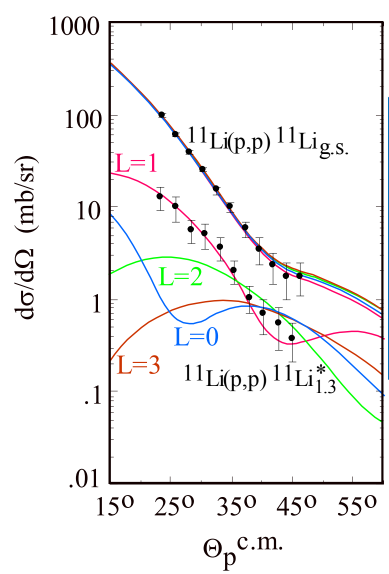


A. A. Korsheninnikov et al.
Phys. Rev. Lett. **78**, 2317 (1997)

Observation of dipole nature of 1.3 MeV state of ^{11}Li

^{11}Li + p, 68 *A* MeV





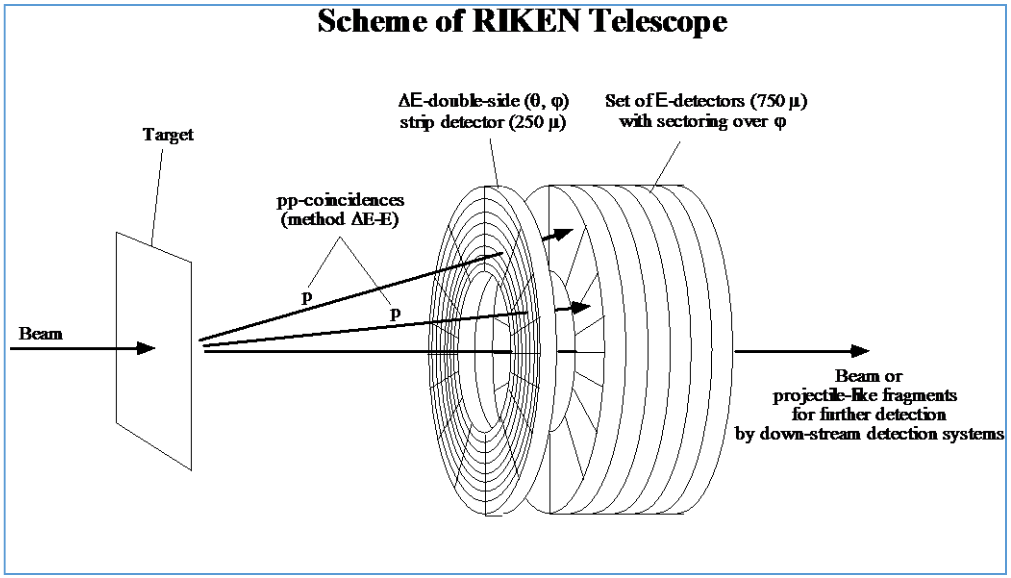
Triple state S_{nn}=1 of valence neutrons in ^{11}Li*

Conclusion:

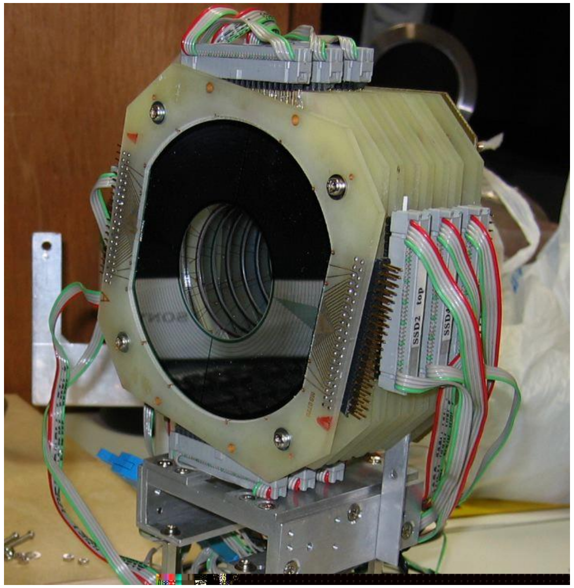
Valence neutrons in ^{11}Lig.s. should have significant component of p1/2 state ! (not pure s-orbital)

Switch to the transfer reactions with exotic beams…

$p(^8He,d)^7He$, $p(^6He,pp)^5H$, $p(^8He,pp)^7H$, $d(^8He,^3He)^7H$



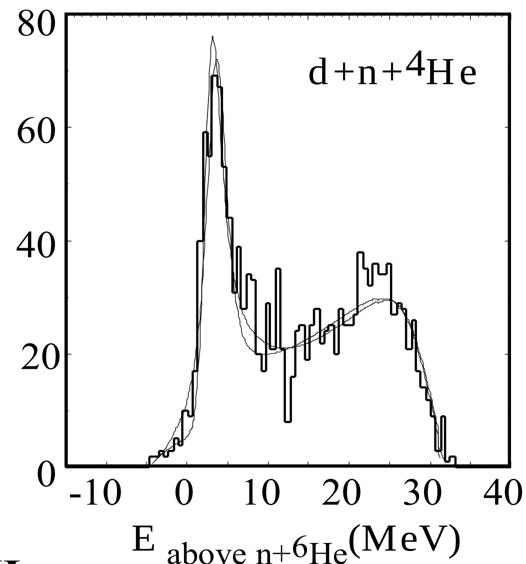
"RIKEN Telescope"
DSSSD (250 um) + 6 SSSD (750 um) + 1 SSSD veto
192 channels
(produced by Micron Ltd.)

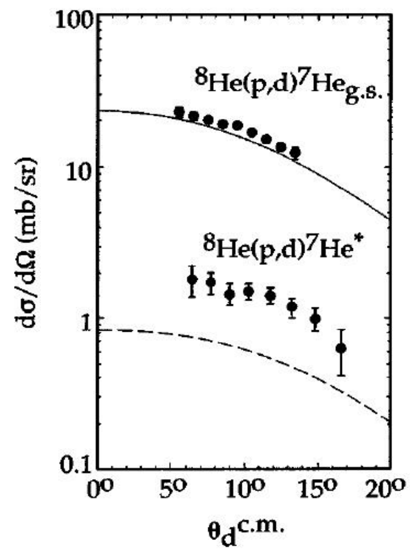


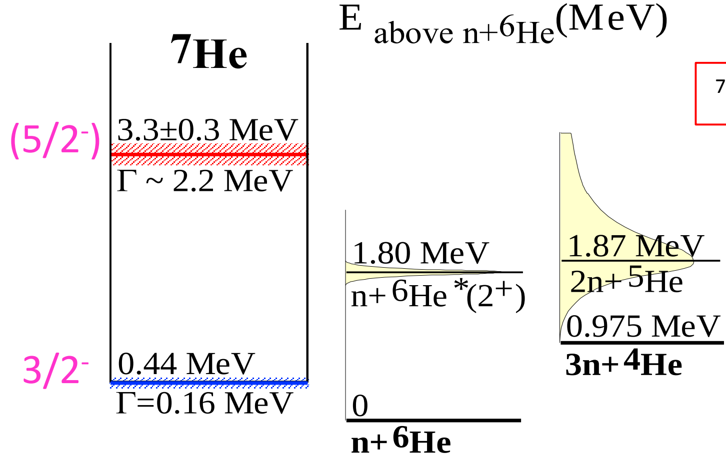
^{7}He excited state 3.3 MeV with unusual structure

$p(^{8}He,d)^{7}He$

A. A. Korsheninnikov. *et al*. Phys. Rev. Lett. **82**, 3581 (1999)







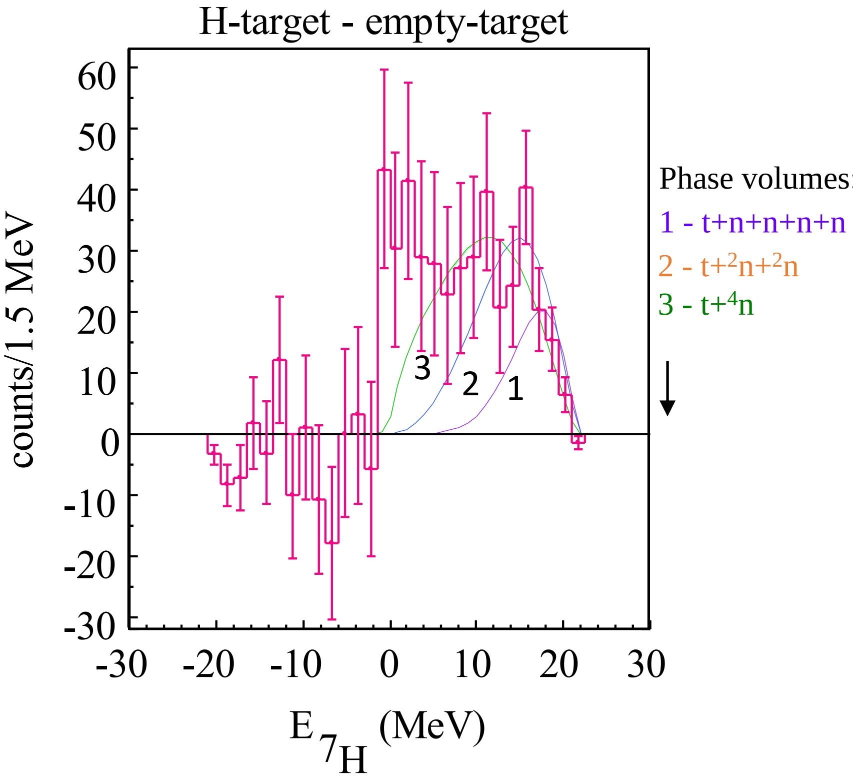
$^{7}He^{*} = {}^{6}He(2^{+})+n(P_{1/2})$

Evidence for the existence of superheavy ^{7}H state near t+4n threshold !

First RIKEN experiment to search for ^{7}H

A. A. Korsheninnikov et al.
Phys. Rev. Lett. **90**, 082501 (2003)

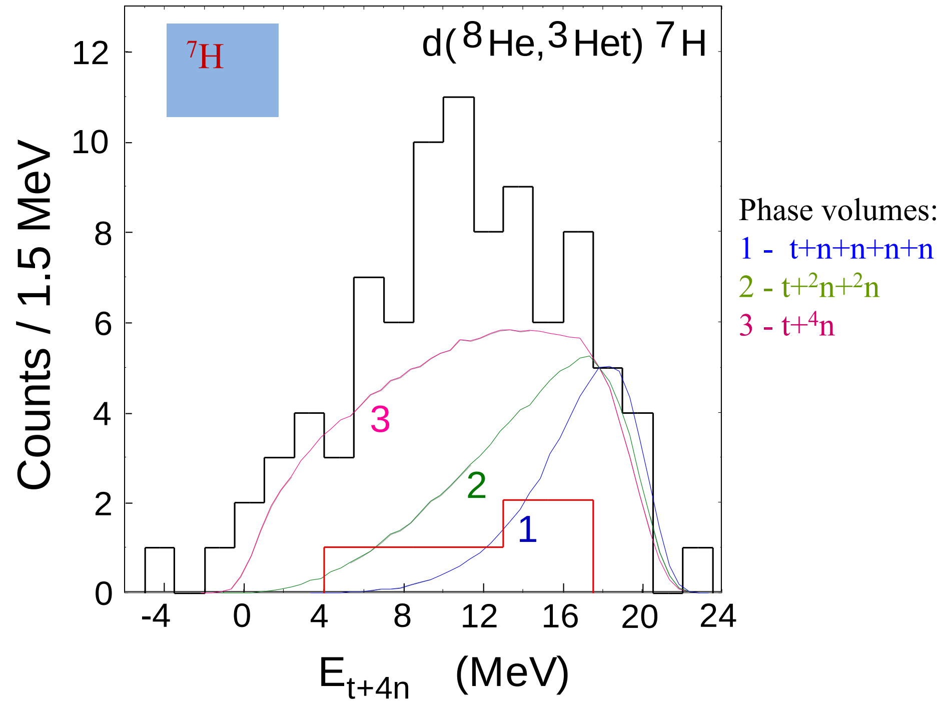
p(^{8}He,pp)^{7}H   61 A MeV@8He



Second experiment

E.Yu.Nikolskii *et al*., Phys. Rev. C **81,** 064606 (2010)

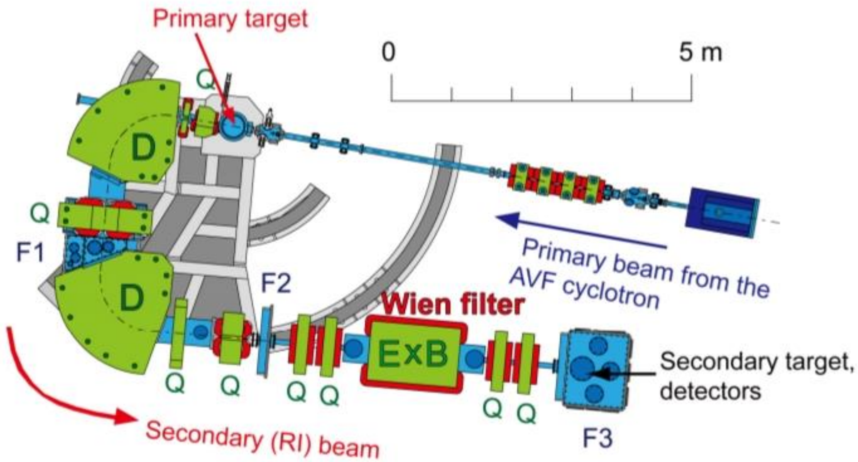
42 *A* MeV ^{8}He 140 000 pps



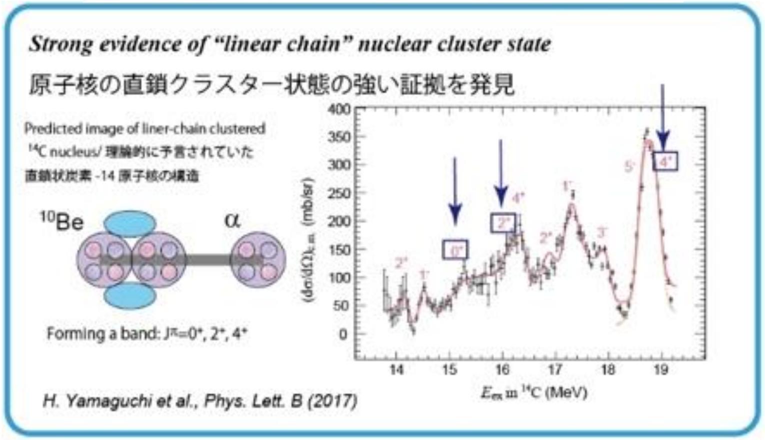
Cross section $_{E=0÷3\ MeV}$ ~ 30 μb/sr

CRIB

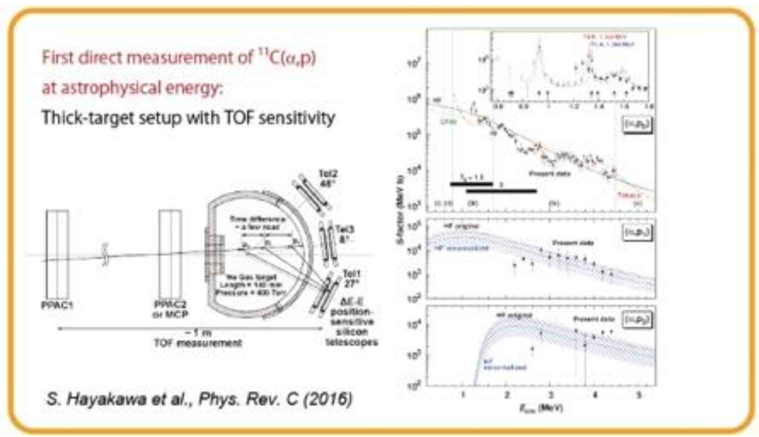
- CNS Radio-Isotope Beam separator , operated by CNS (Univ. of Tokyo), located at RIBF (RIKEN Nishina Center).
  - Low-energy(<10MeV/u) RI beams by in-flight method.
  - Primary beam from K=70 AVF cyclotron.
  - Momentum (Magnetic rigidity) separation by "double achromatic" system, and velocity separation by a Wien filter.
  - Orbit radius: 90 cm, solid angle: 5.6 msr, momentum resolution: 1/850.



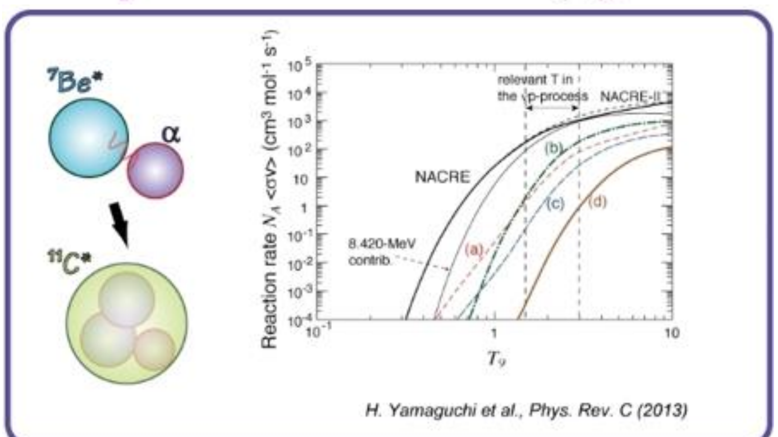
Linear-chain cluster states in ^{14}C nucleus



First direct measurement of the steller ^{11}C(α, p)^{14}N reaction

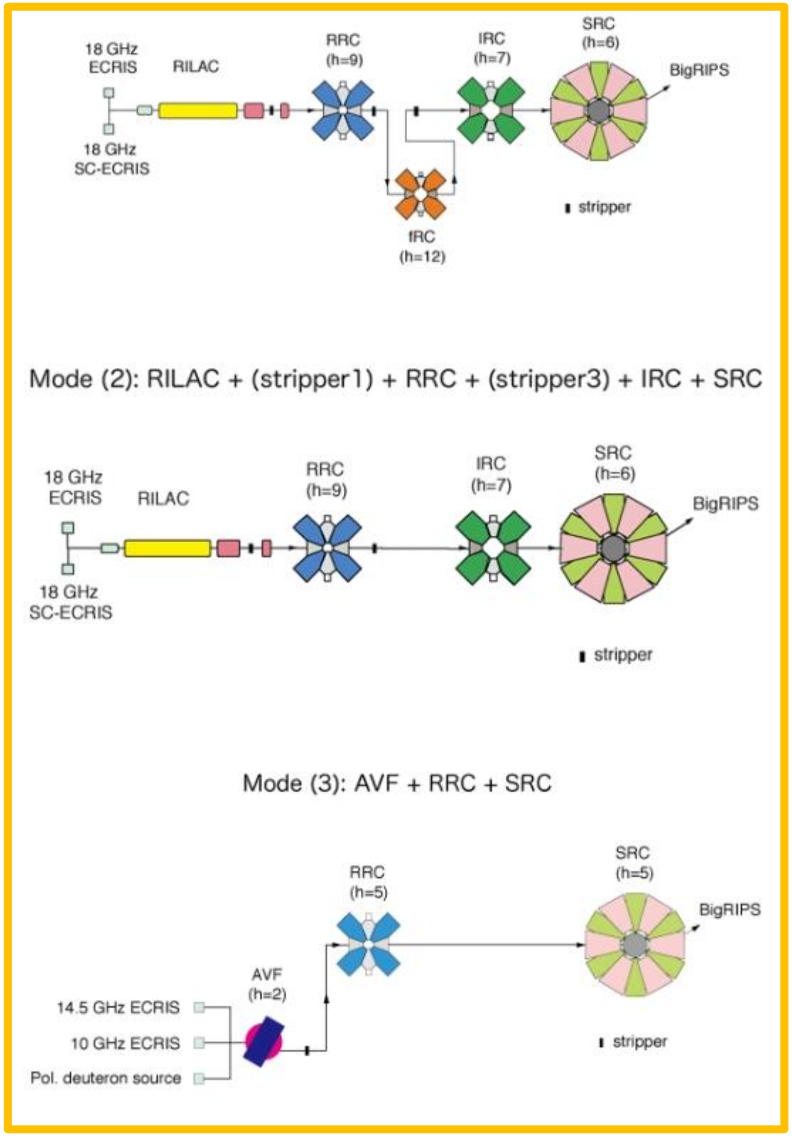


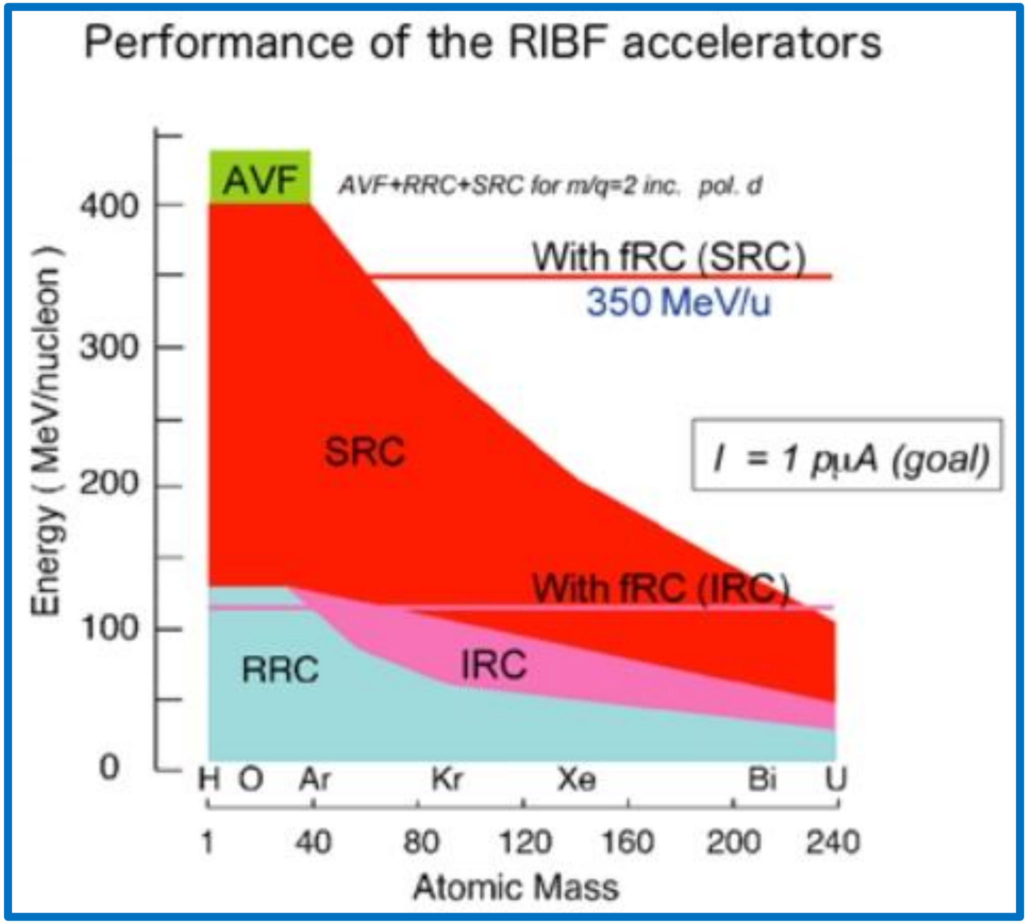
Alpha resonances in ^{11}C and ^{7}Be(α,γ) reaction



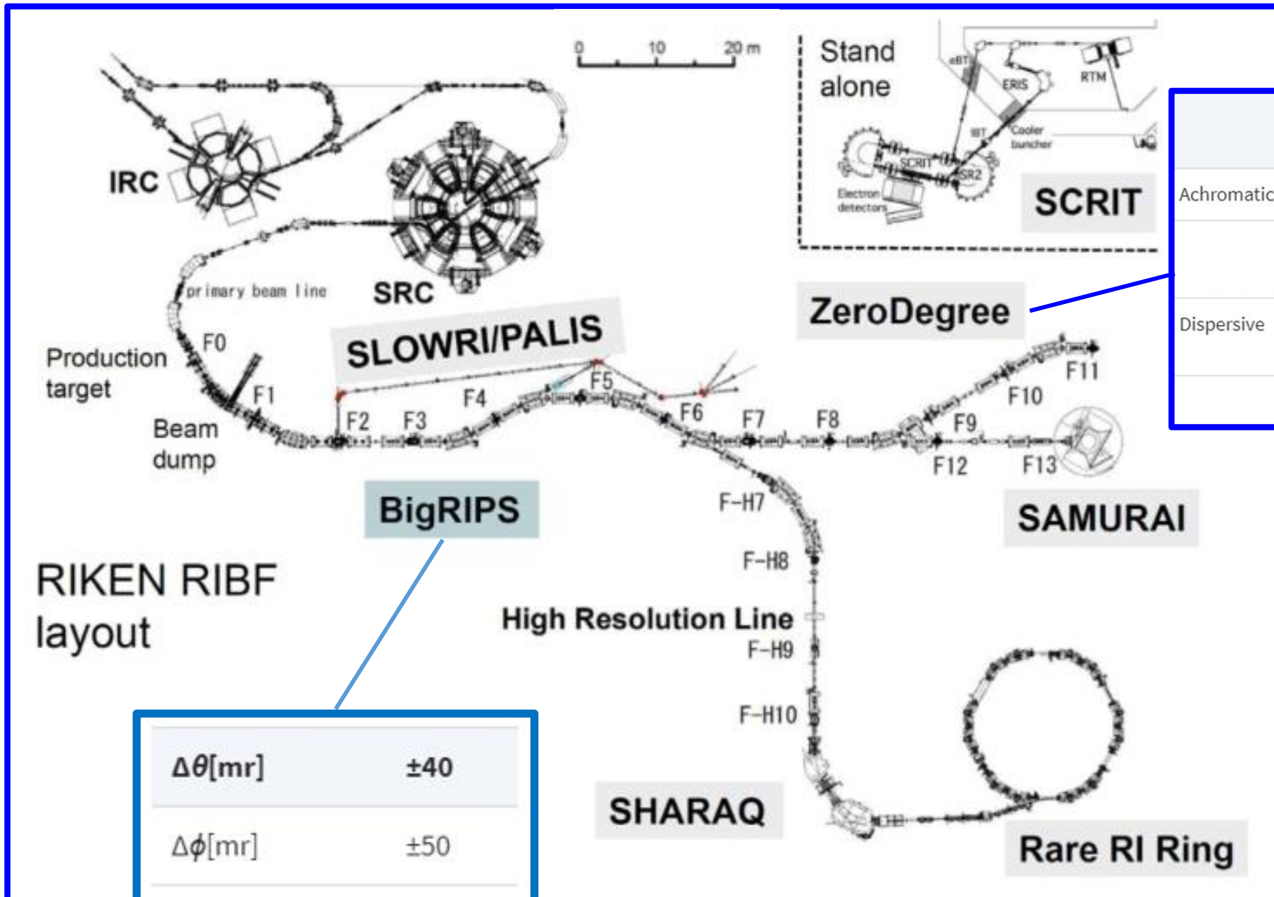
New RIBF Facility (since 2007)

Modes of acceleration





BigRIPS separator & ZeroDegree spectrometer



	Optics modes	Δθ[mr]	Δϕ[mr]	δ[%]	P/ΔP*	Max.Bρ[Tm]
Achromatic	Large acc.	±45	±30	±3	1240	8.1
	Medium Res.	±20	±30	±3	2080	9.7
Dispersive	Medium Res.	±20	±30	±2	4070	9.8
	High Res.	±15	±15	±1	6410	10.2

Δθ[mr]	±40
Δϕ[mr]	±50
δ[%]	± 3
P/ΔP(1st)*	1260
P/ΔP(2nd)**	3420
Max.Bρ[Tm]***	9.5/8.8
Length[Tm]	78.2

Particle identification at BigRIPS

ΔE-TOF-Bρ method with track reconstruction → Improve Bρ and TOF resolution

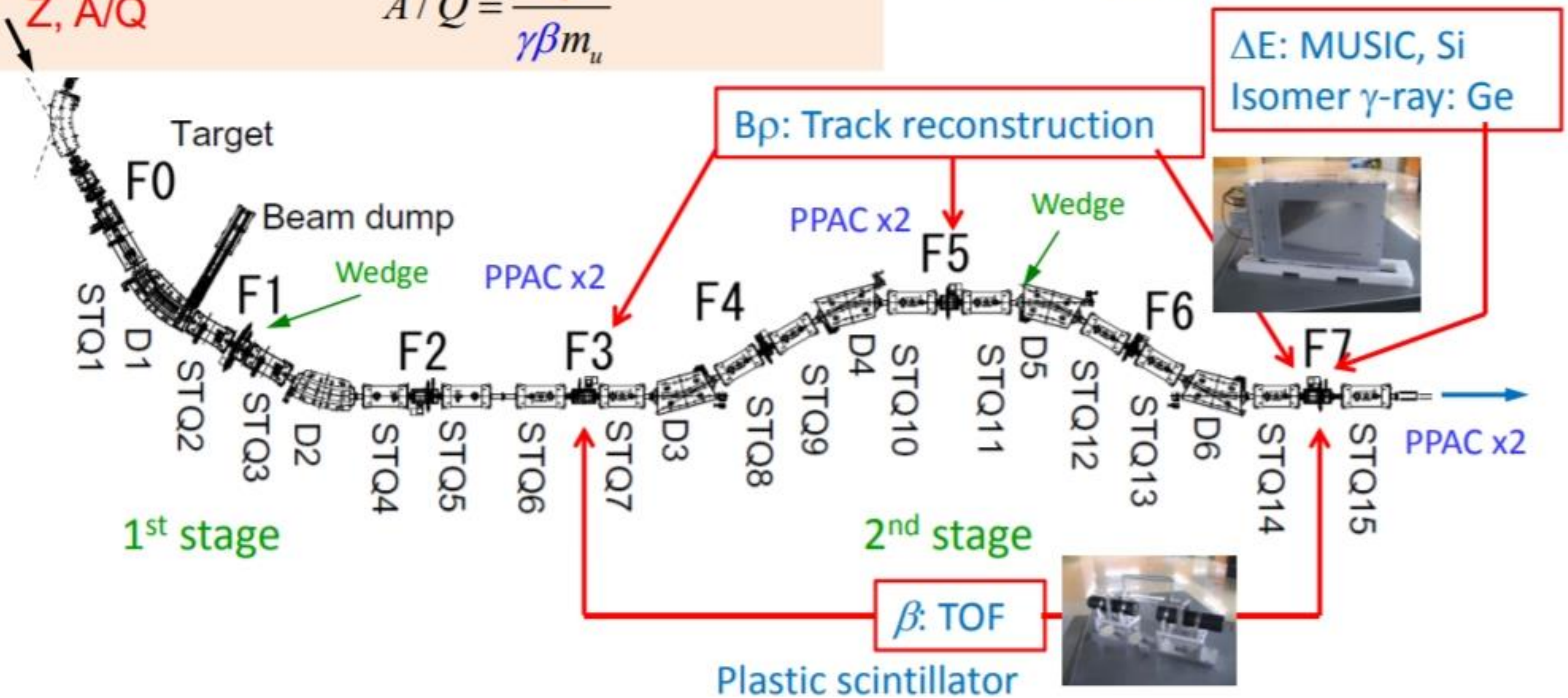
Measure ΔE,TOF, Bρ @ 2nd stage

↓ + isomeric γ-ray

Z, A/Q

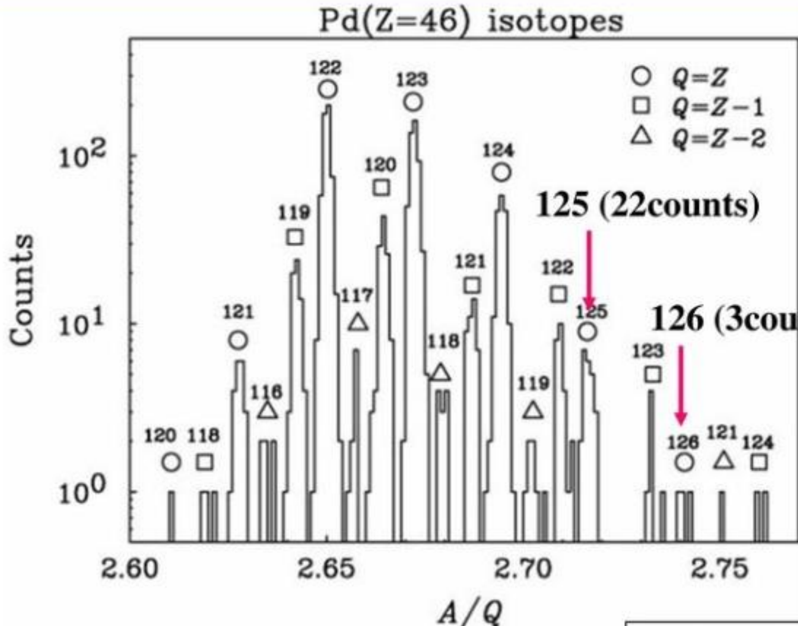
$$Z \leftarrow -dE/dx = f(Z, \beta)$$

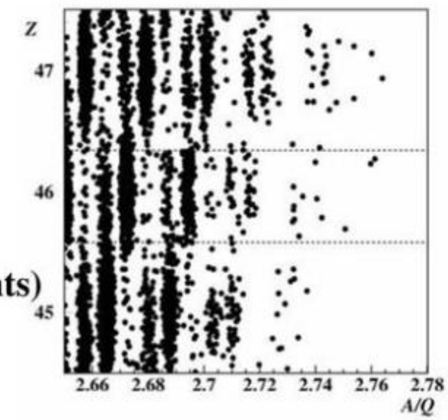
$$A/Q = \frac{B\rho}{\gamma\beta m_u}$$



Identification of new isotopes ^{125,126}Pd

T. Onishi et al, JPSJ 77 (08)083201.



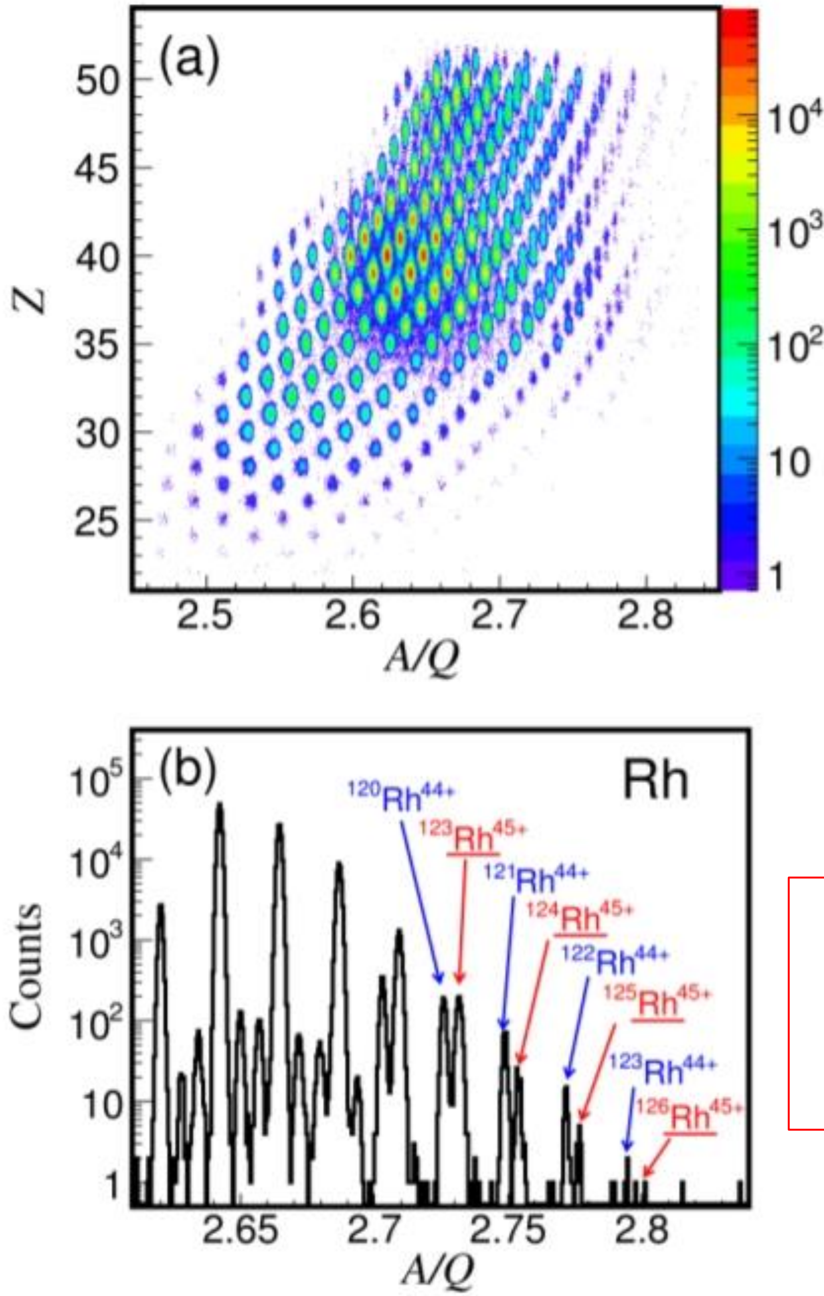


Total dose 3.6x10^{12} for 25 hrs
I ~0.01 pnA on average

A/Q resolution(r.m.s): 0.041% at Z=46
Bρ resolution (r.m.s): 0.02%
ΔT resolution (r.m.s.): 40 psec

Cf. ^{124}Pd 19 counts, ^{125}Pd(cand.) 1count at GSI, 1997
PLB 415, 111 (97); total dose ~1x10^{12}

Slide by H.Sakurai



Identification the new isotopes:

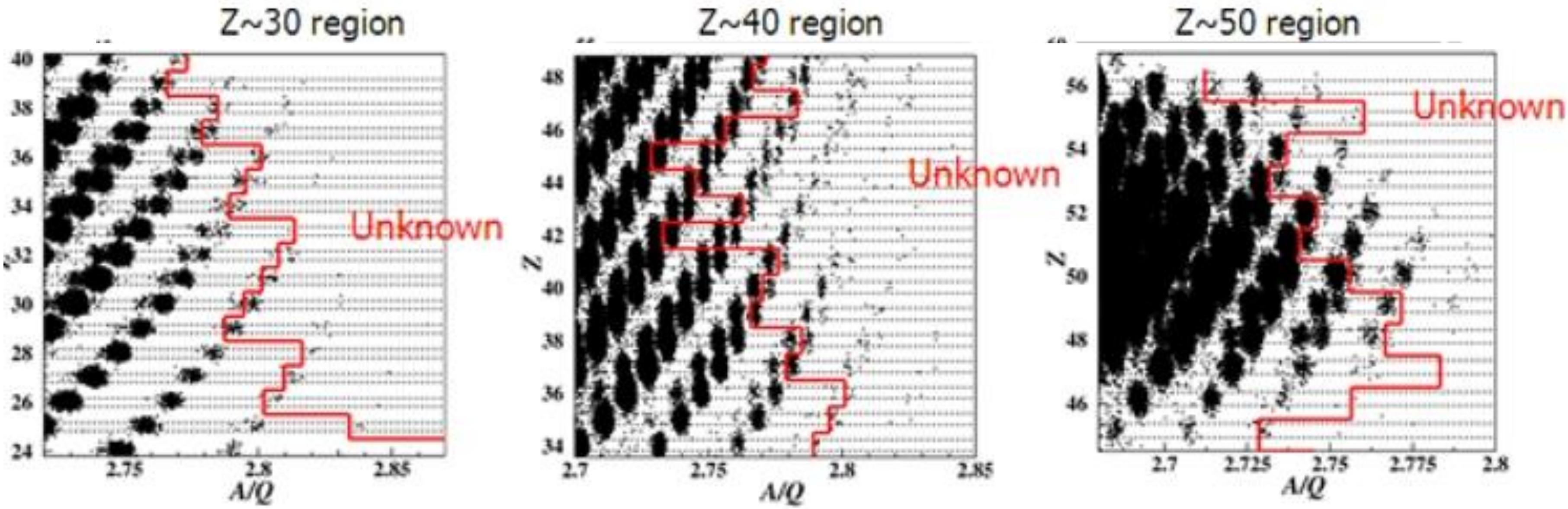
^{123,124,125,126}Rh

^{238}U (345 AMeV) + ^{9}Be

A/Q RMS resolution = 9.2×10^{-4}

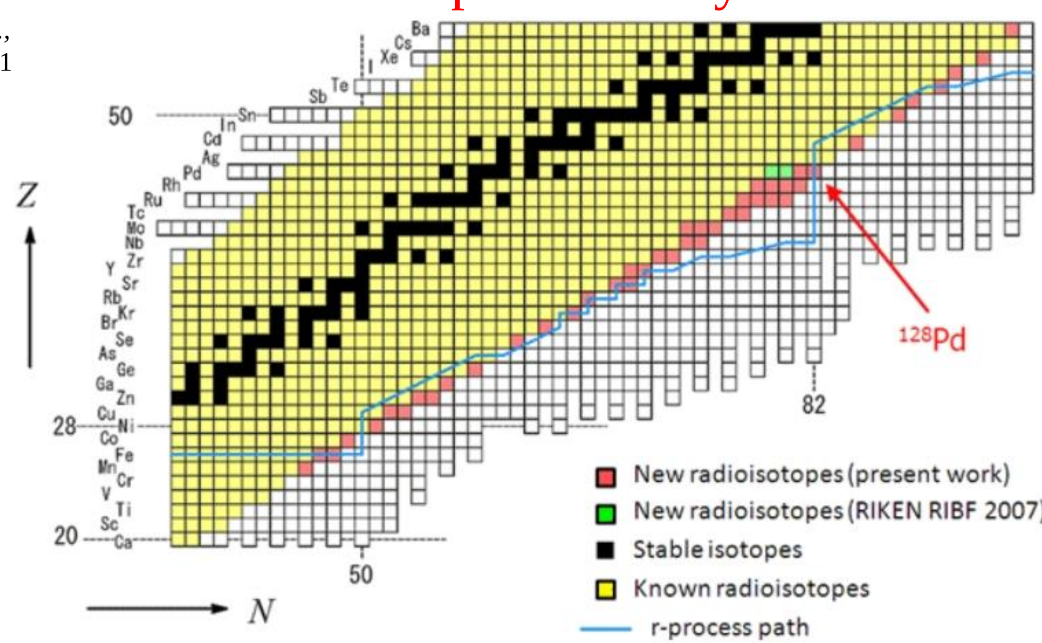
A/Q difference between $^{123}Rh^{45+}$ and $^{120}Rh^{44+}$ = 5.6×10^{-3} ($6.1\sigma_{A/Q}$)

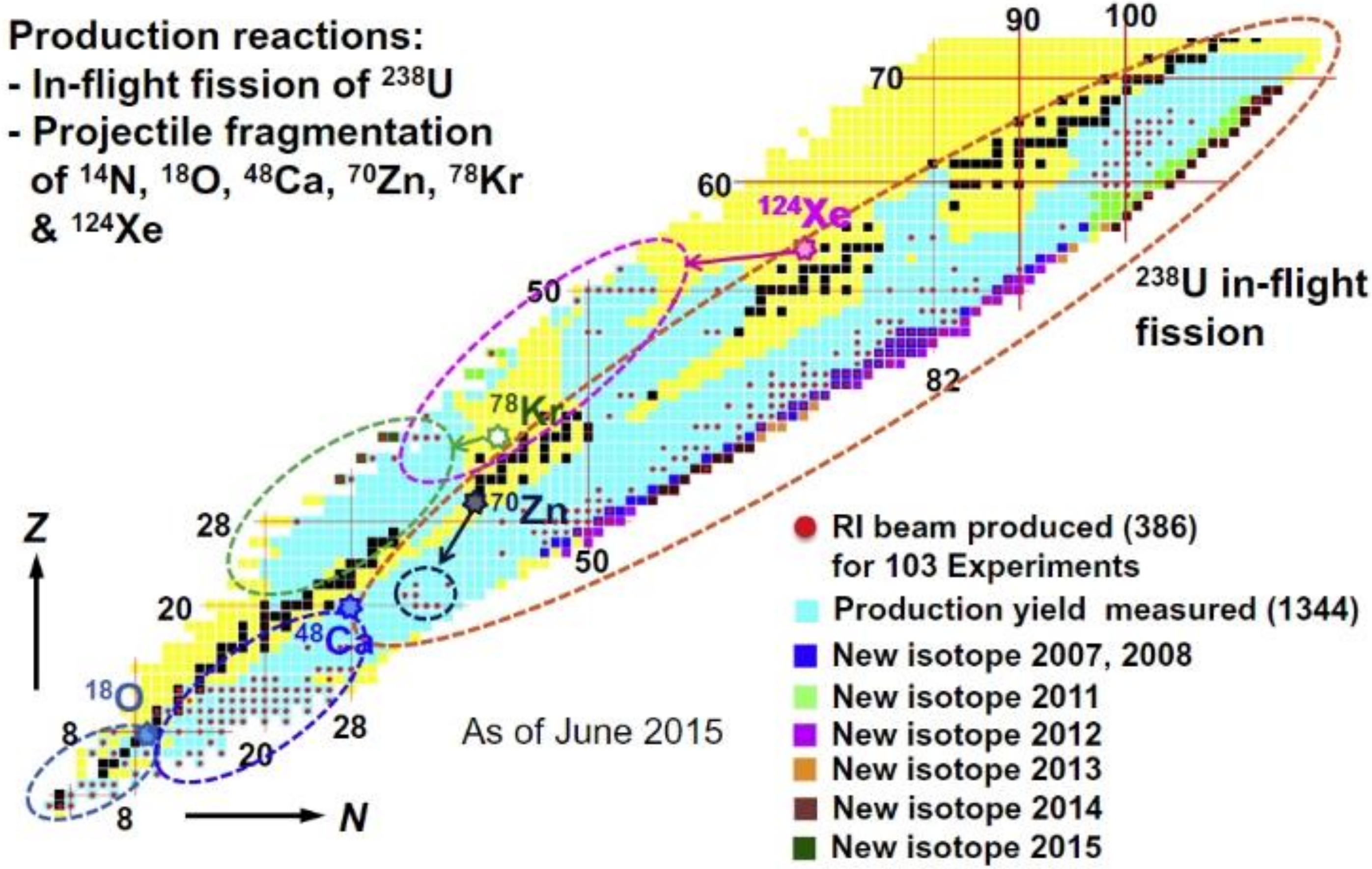
In-flight fission ^{238}U (345 AMeV) + ^{9}Be



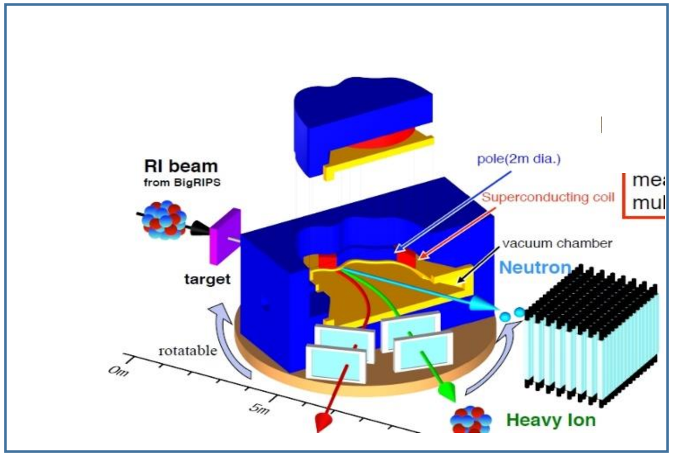
45 new isotopes for 4 days measurements !

T. Ohnishi et al, *J. Phys. Soc. Jpn.*, Vol. 79, No. 7, July, 2010, 073201



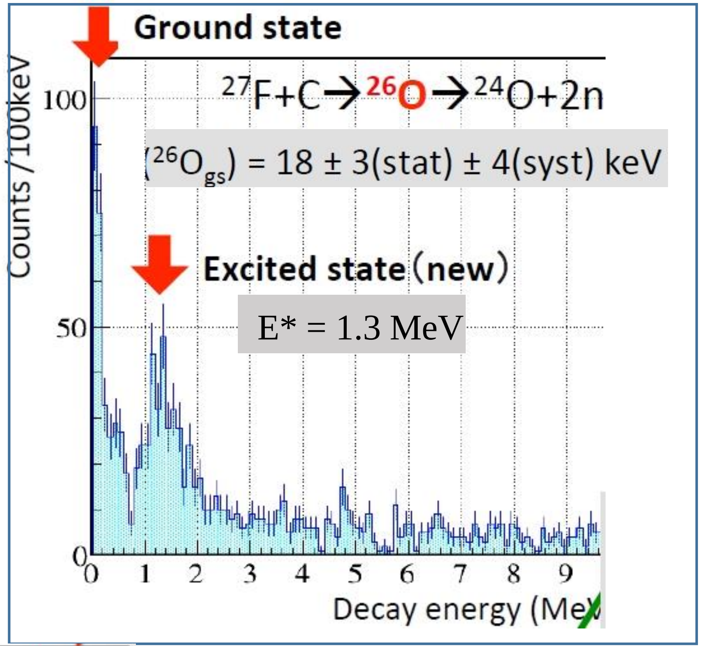

Production reactions:
- In-flight fission of 238U
- Projectile fragmentation
of 14N, 18O, 48Ca, 70Zn, 78Kr
& 124Xe
90
100
70
60
124Xe
50
78Kr
70Zn
28
20
48Ca
18O
8
28
20
8
50
82
Z
N
238U in-flight
fission
As of June 2015
RI beam produced (386)
for 103 Experiments
Production yield measured (1344)
New isotope 2007, 2008
New isotope 2011
New isotope 2012
New isotope 2013
New isotope 2014
New isotope 2015

SAMURAI: 7 Tm bending power



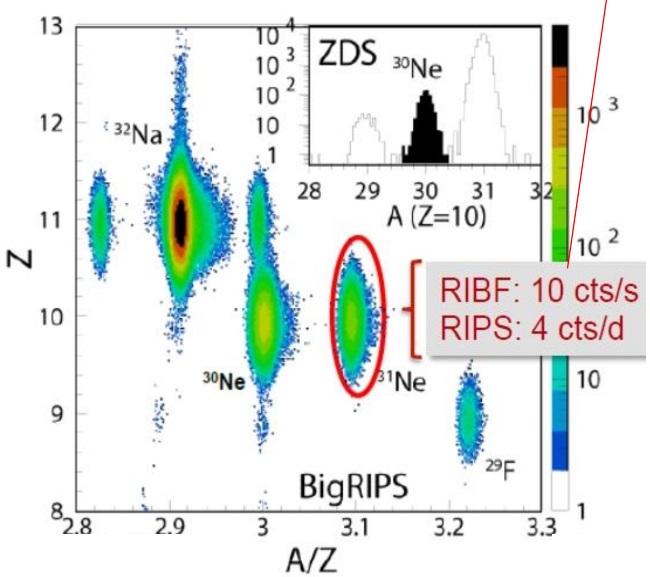
Spectroscopy of unbound ^{26}O

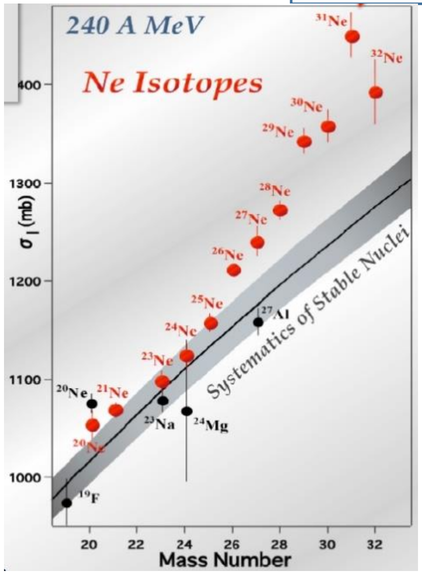
Kondo et al, *PRL* 116 (2016)

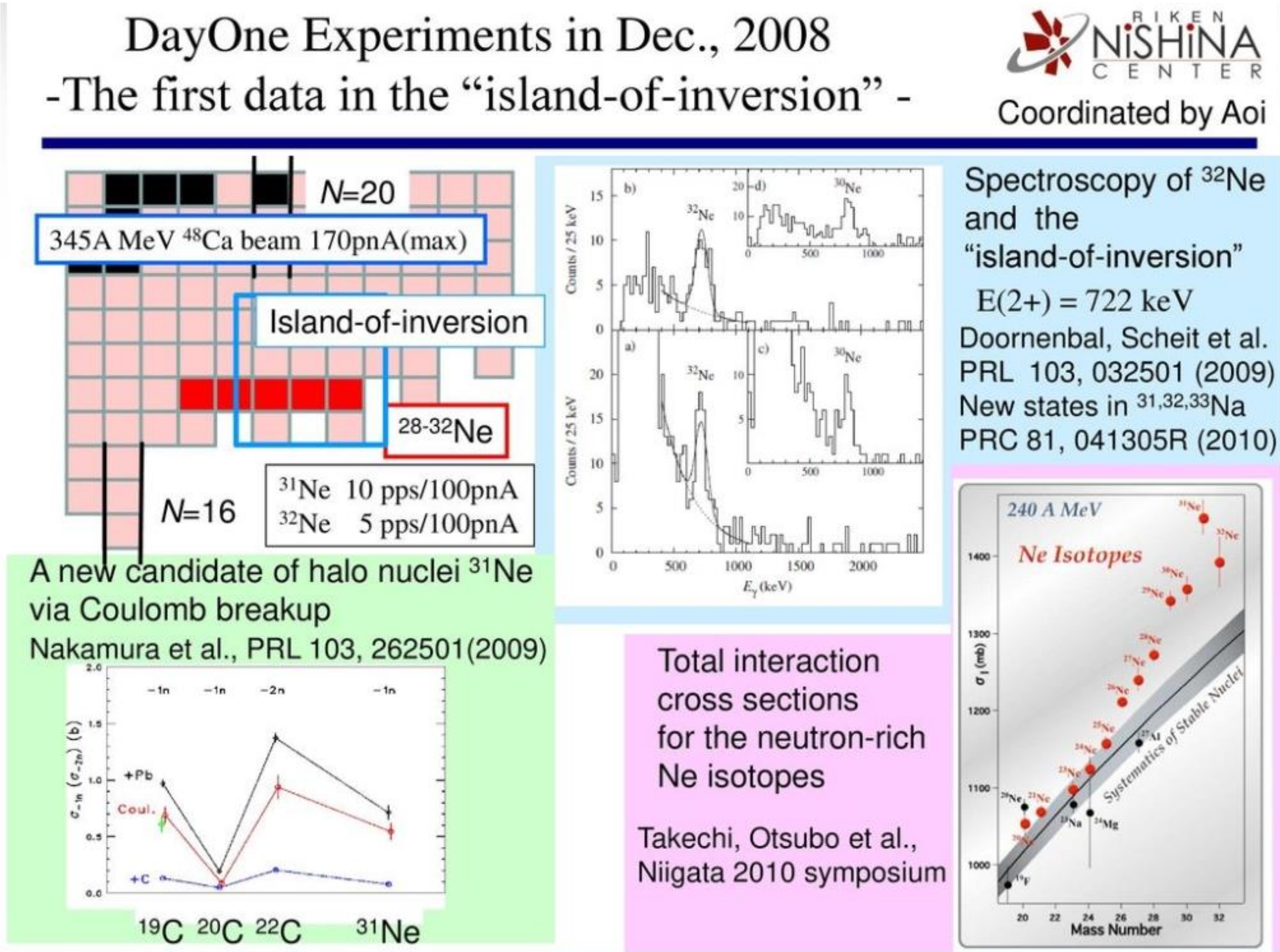


RIBF / RIPS ^{31}Ne Intensity = 2 x 10^5 !!!

Takechi et al. Phys. Lett. **B707** (2012)







Slide by H.Sakurai

(^{24}O + p) experiment with unique intensity of ^{24}O beam (260 AMeV) of 2 000 s^{-1}

Low-lying Excited States in ^{24}O via (p,p')
- The First Missing Mass Spectroscopy at RIBF -

RIKEN NiSHiNA CENTER

Spokespersons : Valerie Lapoux and Hideaki Otsu

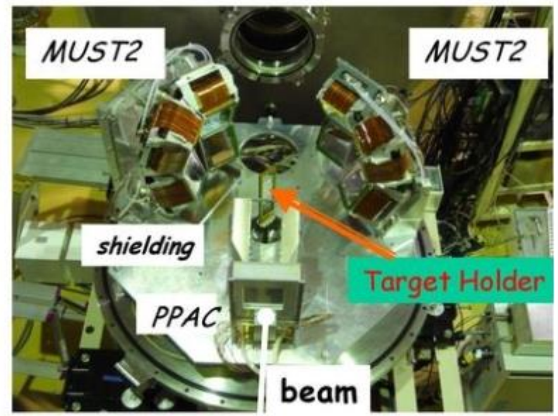
May, 2010

The state-of-art detector MUST2 from France coupled with BigRIPS/ZDS setup

GOAL

Characteristics of the N=16 new magic number ?
… in O isotopes
Structure of a drip-line nucleus,
possible neutron-skin or halo

EXCITATION ENERGY SPECTRUM
FOR ^{24}O → ^{24}O(p,p')^{24}O*



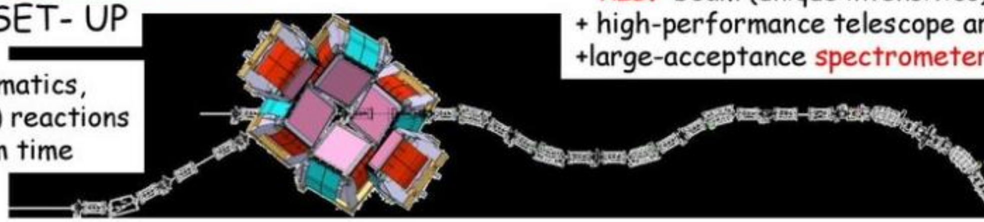
TOOLS

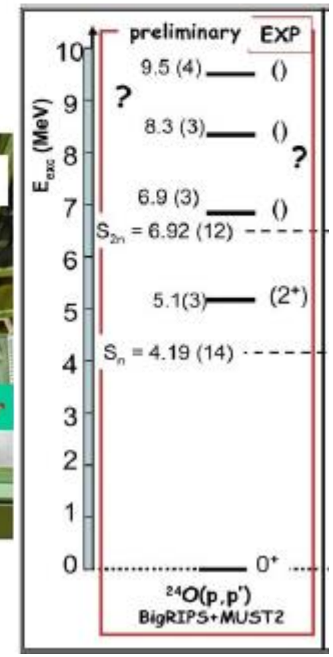
Particle spectroscopy of UNBOUND states

SET- UP

Kinematics,
(p,p') reactions
Beam time

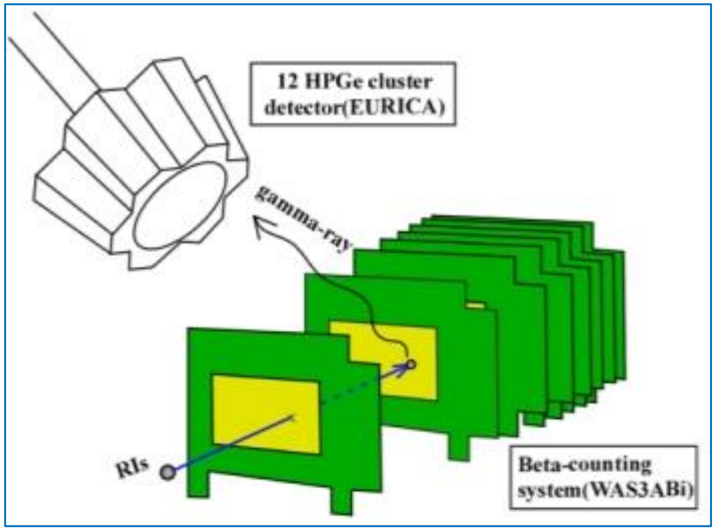
RIBF beam (unique intensities)
+ high-performance telescope array
+large-acceptance spectrometer





EURICA + WASABI setups

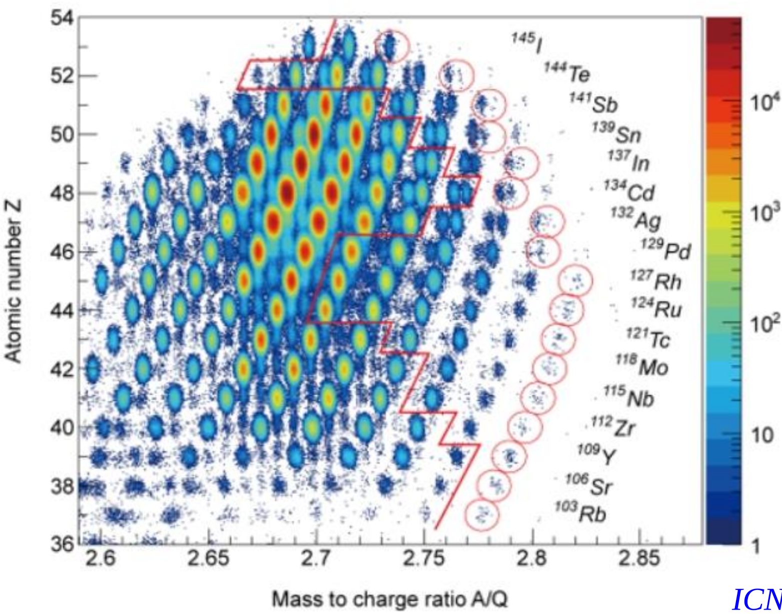
G. Lorusso et al. *PRL* **114** (2015)

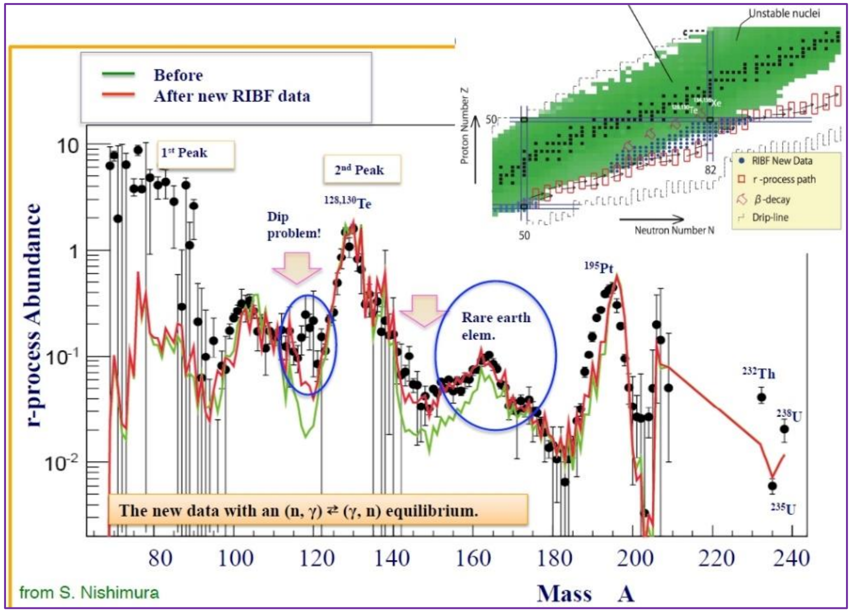


12 EUROBALL clusters at RIKEN

Data have direct implications for r-process calculations for abundances of elements in A ~110 and A ~ 130 peaks

110 (40 new) half lives measured

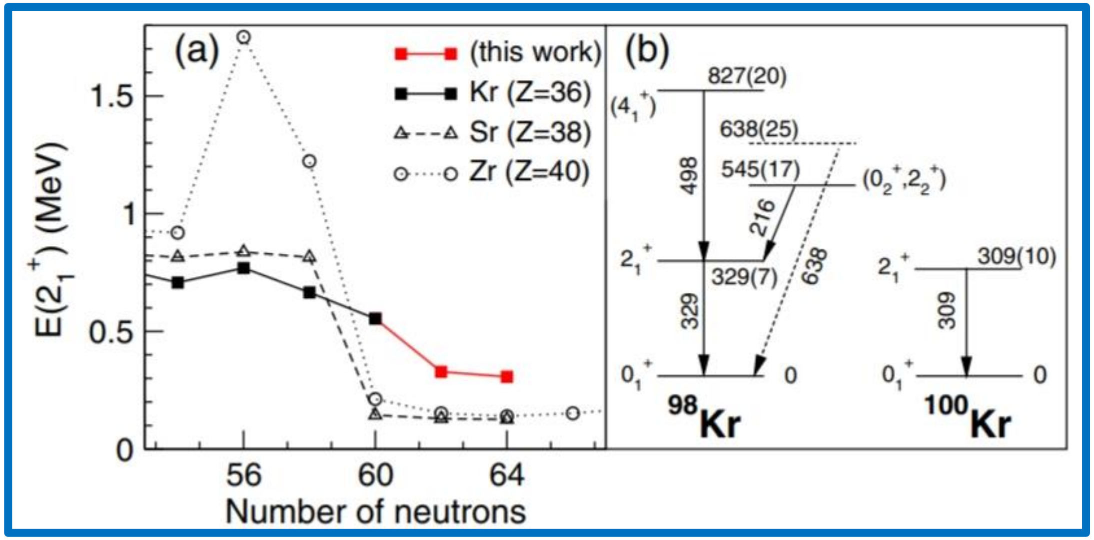


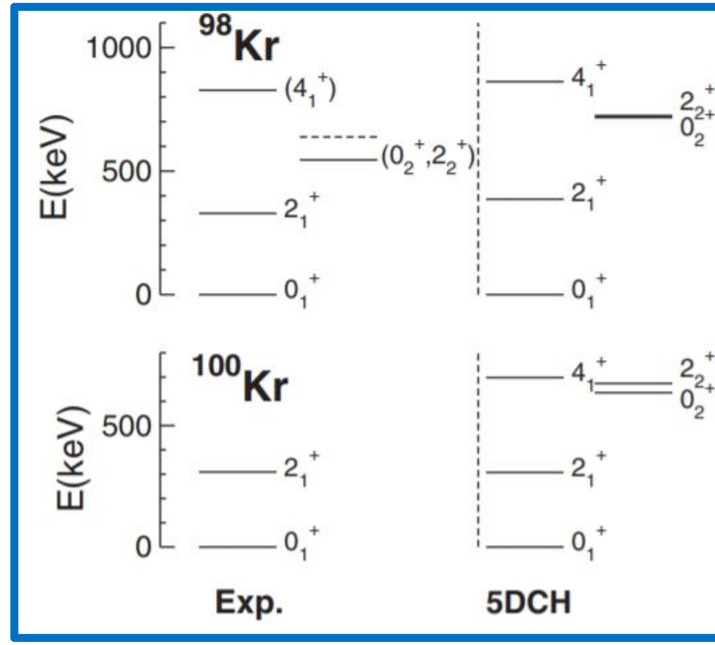


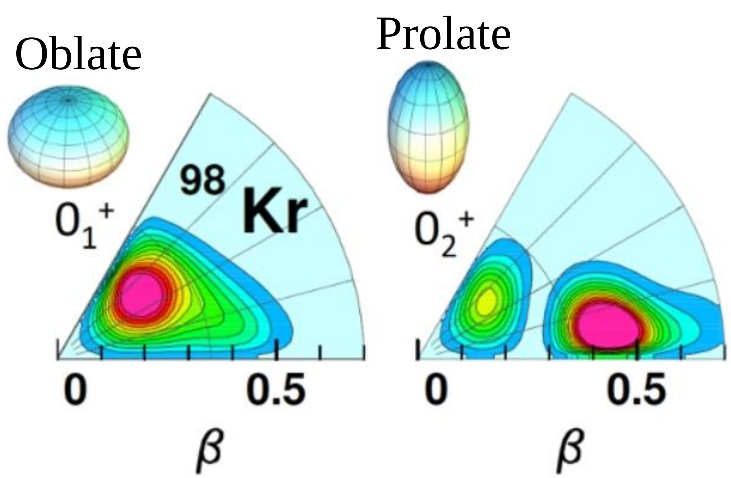
Shape Evolution in Neutron-Rich Krypton Isotopes Beyond N = 60: First Spectroscopy of ^{98,100}Kr

F. Flavigny et al, PRL **118** (2017)

^{99,101}Rb(p,2p) reactions at 220 MeV/nucleon

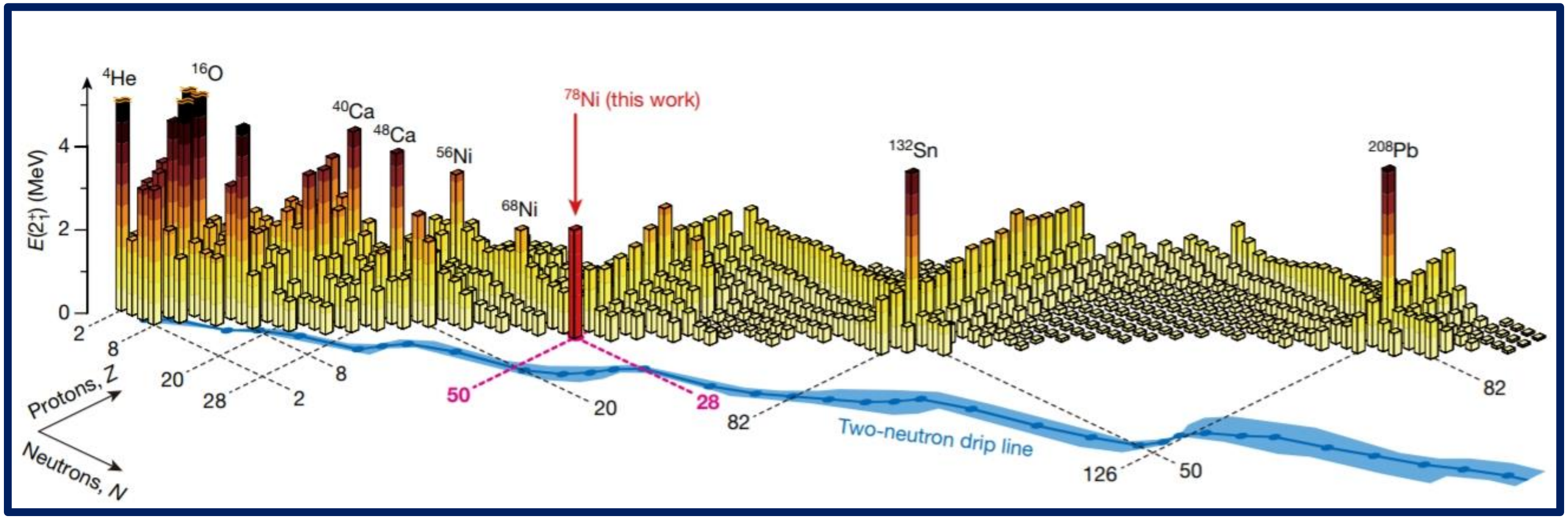


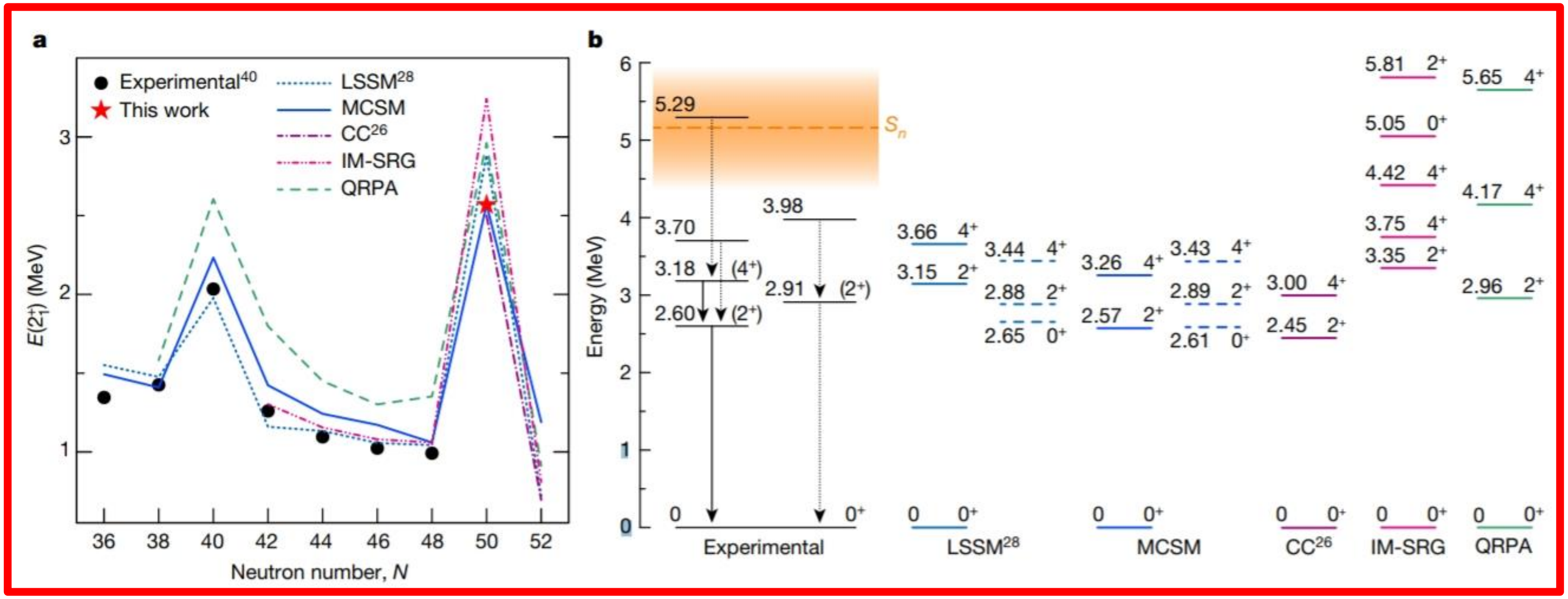




^{78}Ni revealed as a doubly magic stronghold against nuclear deformation

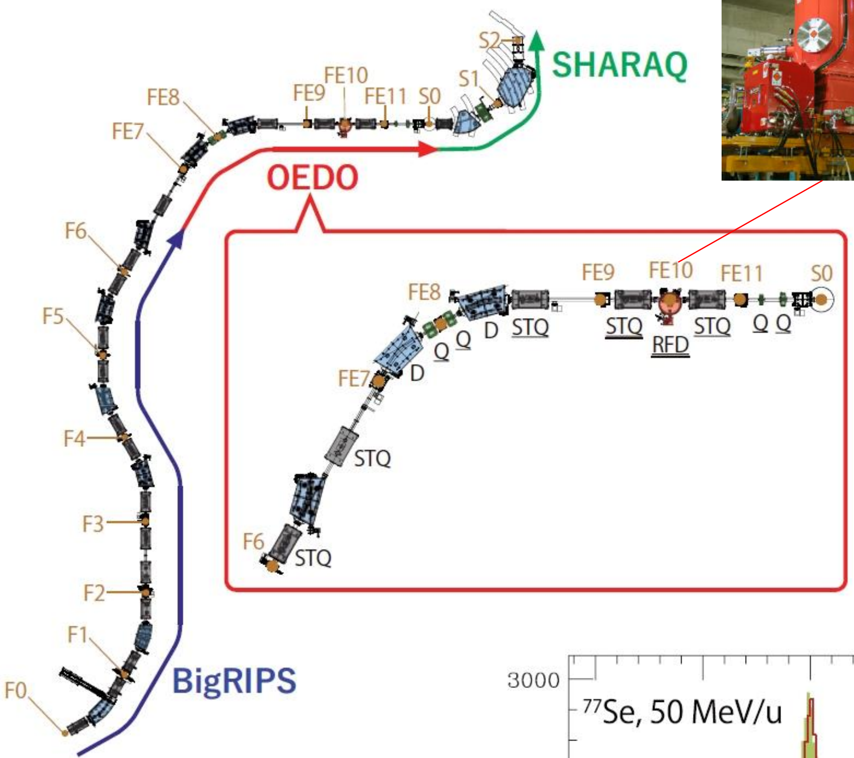
R. Taniuchi et al., *Nature* ***569*** *(2019)*





RF deflector

S.Michimasa et al., Prog. Theor. Exp. Phys. 2019, 043D01



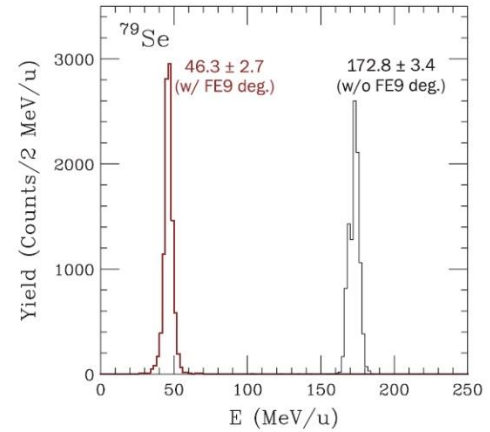
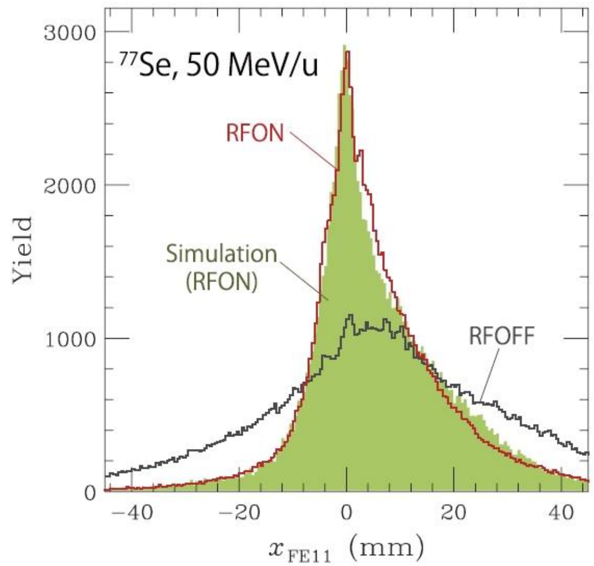
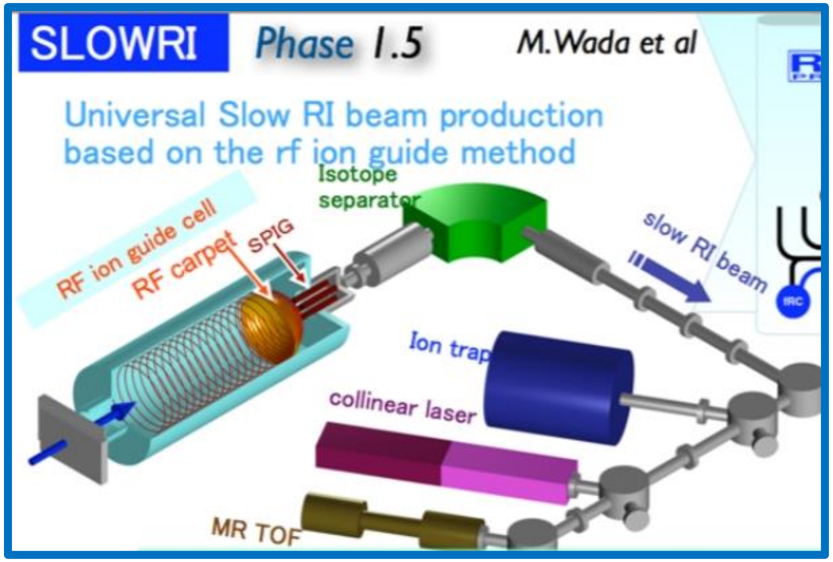


Fig. 12. Energy compression from 172 to 45 MeV/u by using a wedge-shaped degrader. The red (black) histogram shows the energy distribution of the ^{79}Se beam with (without) the FE9 degrader. The thickness and angle of the degrader were set to be 6 mm and 25 mrad, respectively.

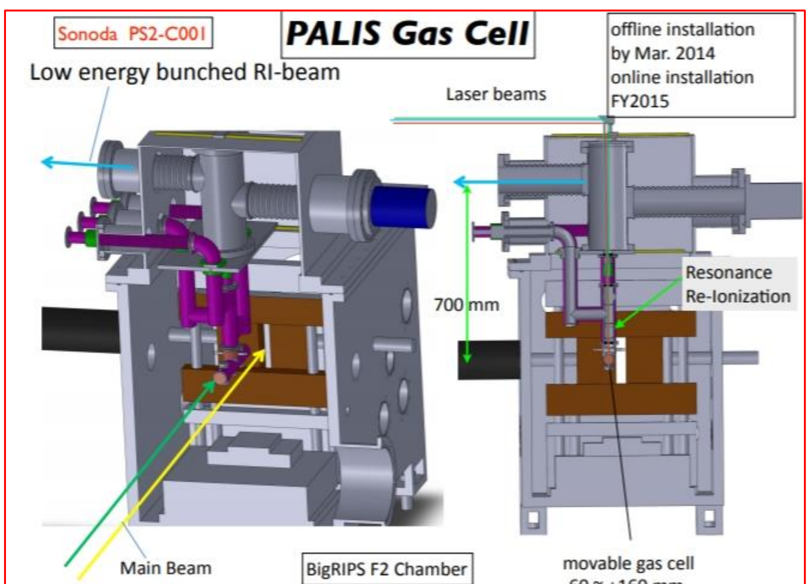


Beam spot of 13.5mm FWHM at the achromatic focus FE11 with transmission of 54%.

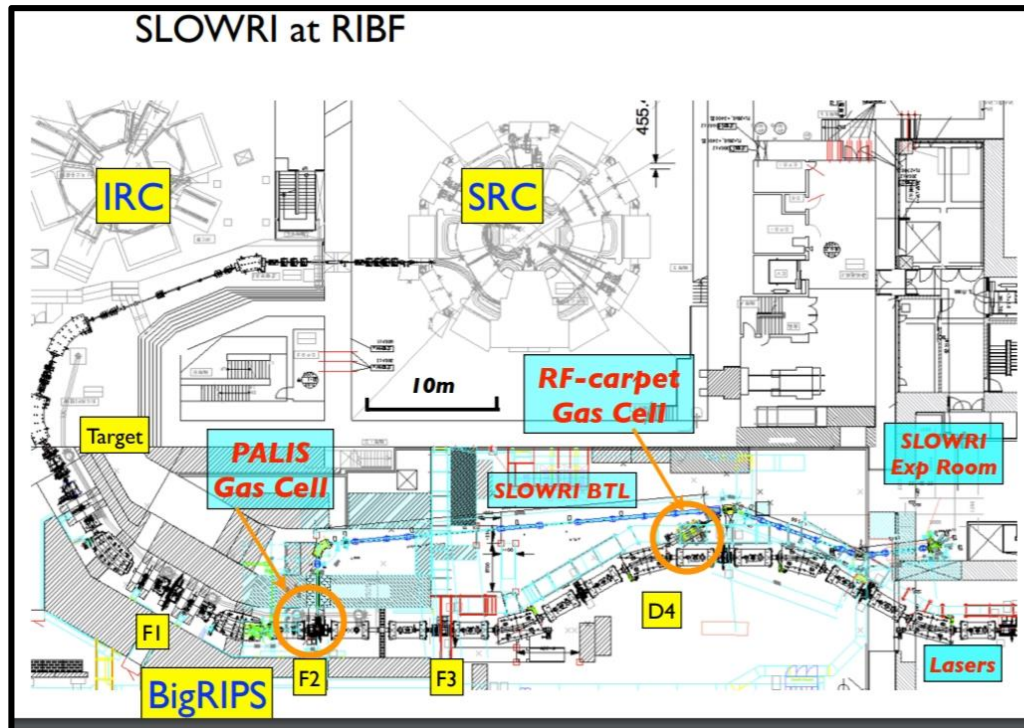
SLOWRI



SLOWRI
Phase 1.5
M.Wada et al
Universal Slow RI beam production
based on the rf ion guide method
Isotope separator
RF ion guide cell
RF carpet
SPIG
slow RI beam
Ion trap
collinear laser
MR TOF

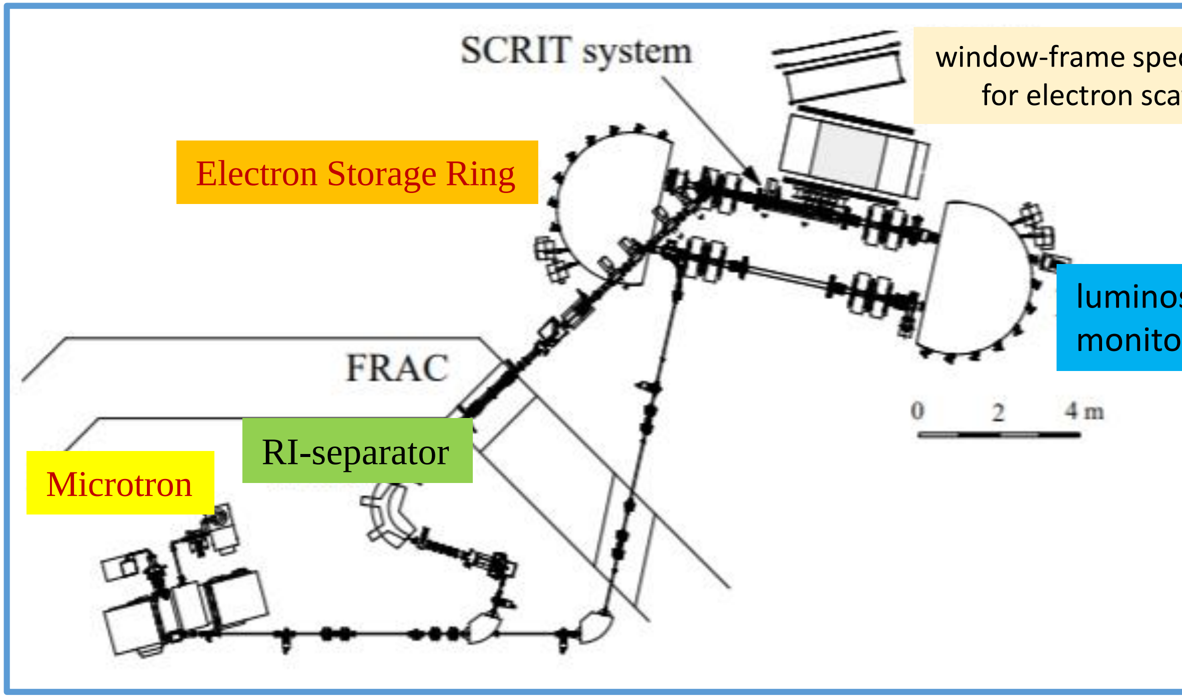


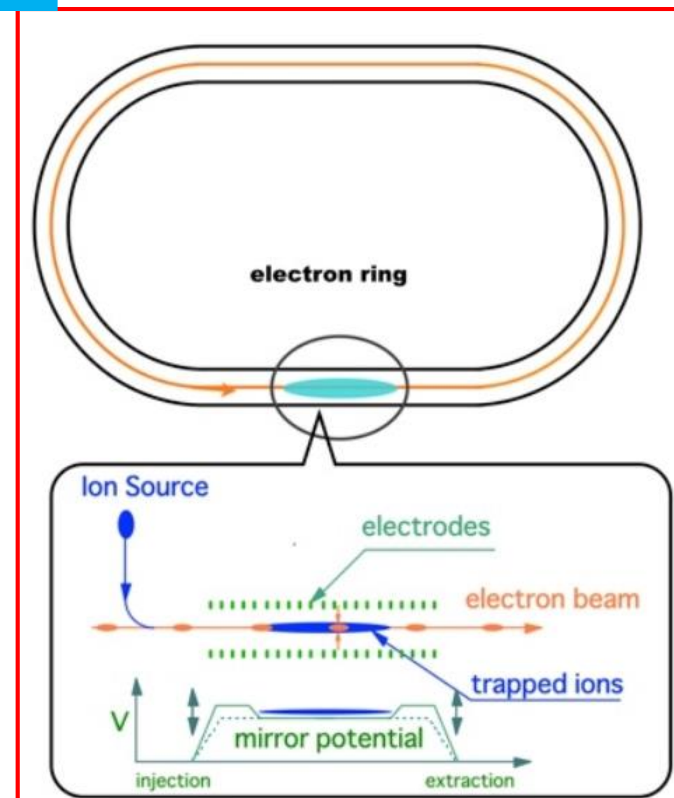
Sonoda PS2-C001
PALIS Gas Cell
offline installation
by Mar. 2014
online installation
FY2015
Low energy bunched RI-beam
Laser beams
700 mm
Resonance
Re-Ionization
Main Beam
BigRIPS F2 Chamber
movable gas cell
-60 ~ +160 mm



SLOWRI at RIBF
IRC
SRC
10m
RF-carpet
Gas Cell
Target
PALIS
Gas Cell
SLOWRI BTL
SLOWRI
Exp Room
D4
F1
F2
F3
BigRIPS
Lasers

SCRIT project





SUMMARY

- In 1989-2007 at "old" RIKEN accelerator facility (AVF, RILAC+RRC) with primary beams up to 135 AMeV a number of secondary beams (^{6,8}He, ^{9,11}Li, ^{7,10,12,14}Be, …) with world record intensities were produced at RIPS and CRIB separators.
  - Unique RIB's parameters of this facility made it possible to perform world class experiments for studying structure of exotic nuclei, such as ^{7}H, ^{8}He, ^{11}Li, $^{12-14}$Be etc.
- From 2007 a new Radioactive Ion Beam Factory (RIBF) at RIKEN have been constructed. Three new cyclotrons, including world-largest superconducting cyclotron SRC provide primary beams from proton to uranium up to 400 AMeV energy.
  - New BigRIPS fragment separator provides unique intensities of secondary beams. Spectrometers and setups ZeroDegree, SAMURAI, SHARAQ, EURICA, SLOWRI opened incredible possibilities for physicists including discovering new elements and isotopes, studying properties of nuclei lying near and above lines of stability.
  - New setups at RIBF like OEDO, RI Ring, SCRIT are very promising tools to study low-energy reactions, to perform mass measurements of rare nuclei and obtain their charge form factors.

Hope DERICA project will be big step in future soaking up best features of RIKEN facilities !!

Thank you for your attention!

Key point in particle identification

- ✓ $B\rho$ measurement is made by trajectory reconstruction at the 2nd stage.

- ✓ Velocity β of RI beams are derived from TOF(F3-F7) in combination with Twofold measurement of $B\rho_{35}$ and $B\rho_{57}$ in order to include energy loss in F5 materials, which provides high accuracy in β determination.

$$\begin{cases} \dfrac{B\rho_{35}}{B\rho_{57}} = \dfrac{(\gamma\beta)_{35}}{(\gamma\beta)_{57}} \\ TOF_{37} = \dfrac{L_{35}}{\beta_{35}c} + \dfrac{L_{57}}{\beta_{57}c} \end{cases} \qquad \frac{A}{Q} = \frac{B\rho_0(1+\delta_{57})}{(\gamma\beta)_{57}} \cdot \frac{c}{m_u}, \quad m_u = 931.49432 \text{ MeV/c}^2$$

- ✓ The *A/Q* resolution is high enough to identify both *A* and *Q* without measuring total kinetic energy.

- ✓ Nuclear charge *Z* is derived from ΔE measured at F7 and β_{57}.

$$\Delta E \propto \frac{4\pi e^4 Z^2}{m_e v_{57}^2} Nz \left[\ln\frac{2m_e v_{57}}{I} - \ln\left(1-\beta_{57}^2\right) - \beta_{57}^2 \right], \quad v_{57} = \beta_{57} c$$

- ✓ PID is confirmed by detecting delayed γ-rays emitted from short-lived isomeric states of the fragments.

Track reconstruction

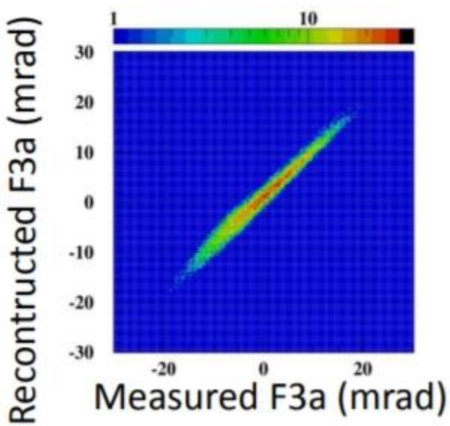
by using the position and angle measured at the focuses (such as F5x, F5a, F3x) and the experimentally determined transfer matrices as follows:

$$F5x = (x|x)F3x + (x|a)F3a + (x|\delta)\delta$$

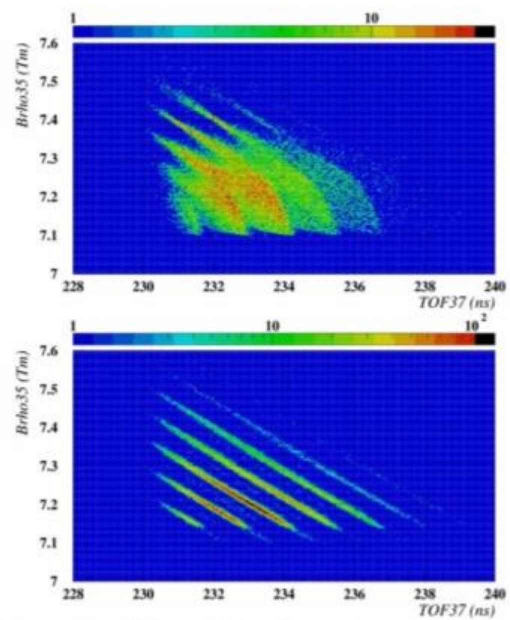
$$F5a = (a|x)F3x + (a|a)F3a + (a|\delta)\delta$$

$$B\rho = B\rho_0(1+\delta)$$

Measured F5x, F5a, F3x
→ deduce δ, F3a

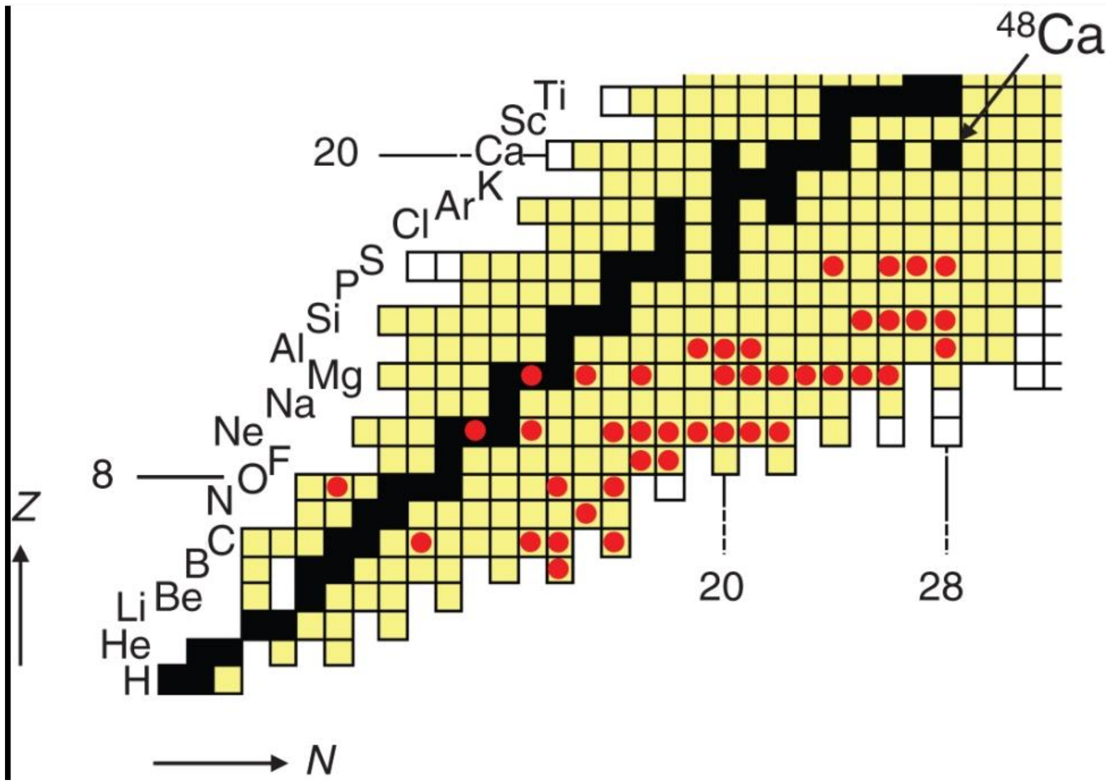


For $Z = 50$ isotopes produced by in-flight fission of a ^{238}U beam at 345 MeV/u.
$\Delta p/p = 6\%$



← **Without track reconstruction**
(from the position at dispersive focus)

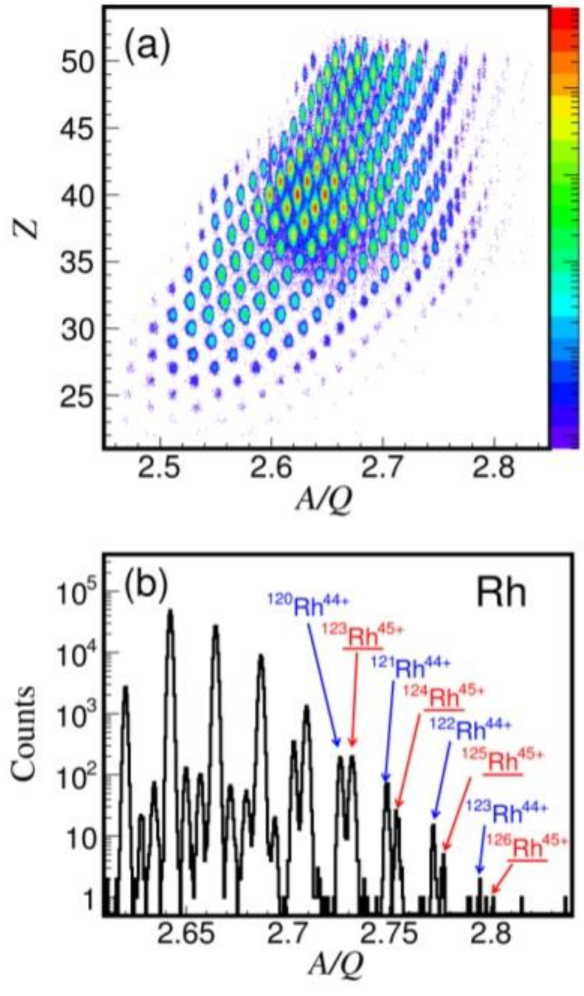
← **With track reconstruction**

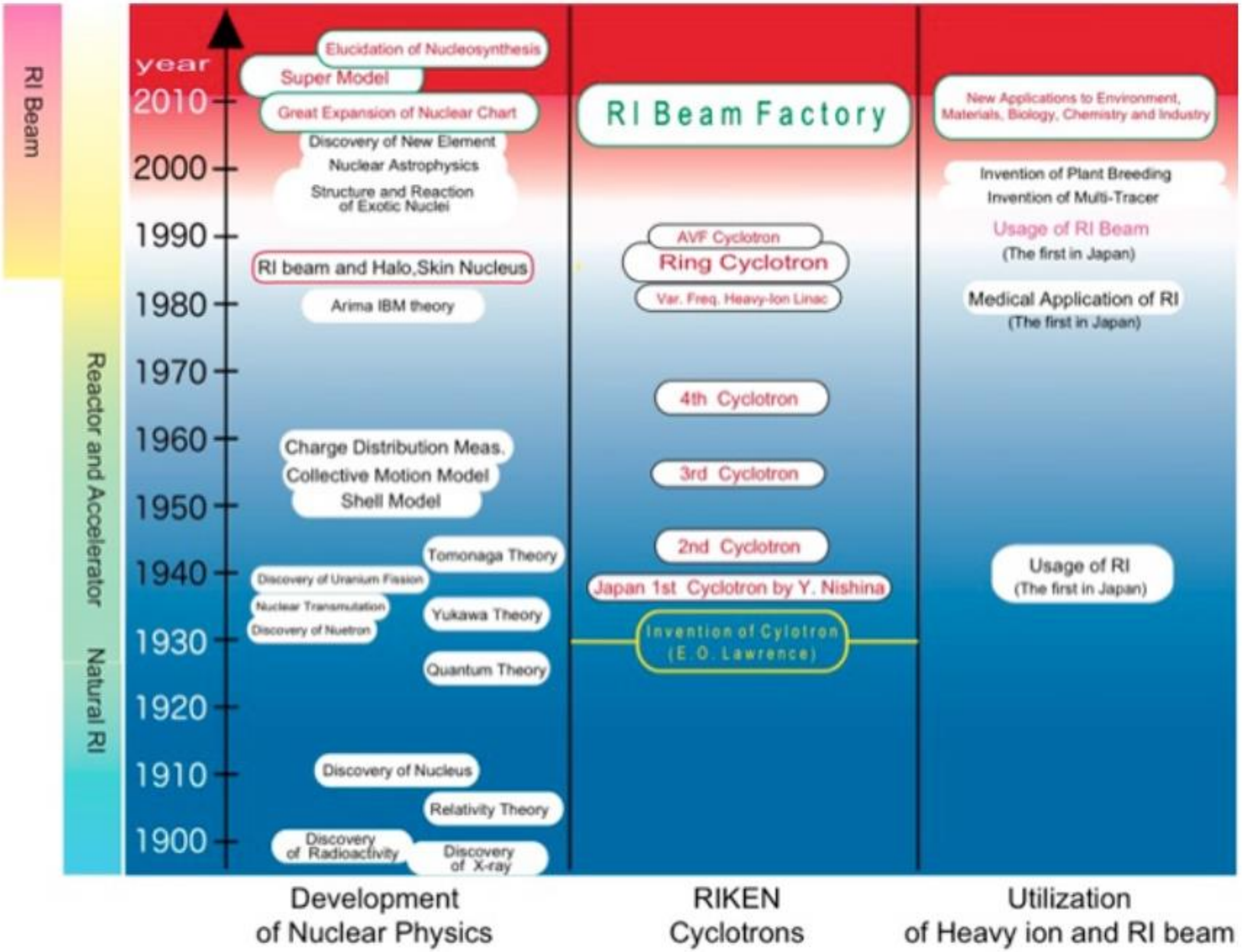


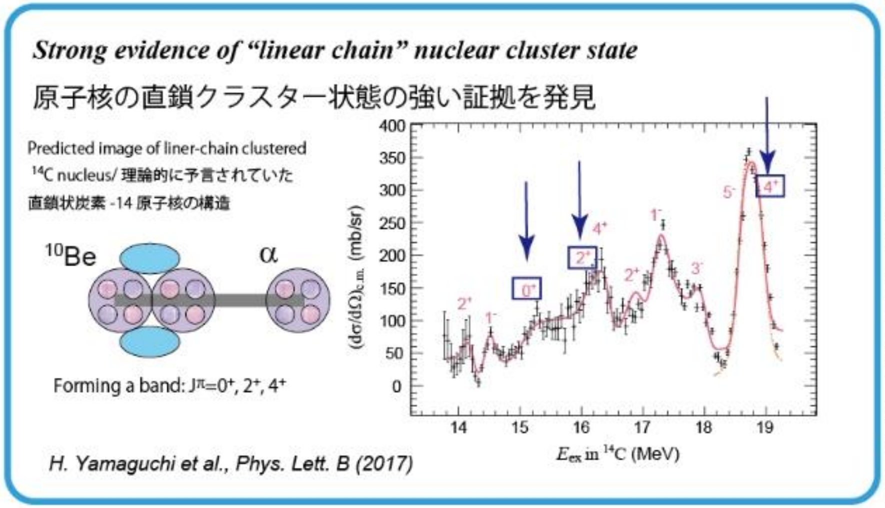
48Ca
Ti
Sc
20
Ca
K
Ar
Cl
S
P
Si
Al
Mg
Na
Ne
F
8
O
N
C
B
Be
Li
He
H
Z
N
20
28

Beam particle	*E/A*(MeV)	Beam current (pnA)		Injector
		Maximum (instantaneous) achieved so far	Expected ¶ (for exp. planning in your proposal)	
d	250	1000	200	AVF
d(pol.)	250	120	30	AVF
^{4}He	320	1000	1000	RILAC
^{14}N	250	400	400	AVF
^{18}O	220	550	400	AVF
^{18}O	230	400	400	AVF
^{16}O	250	200	200	AVF
^{18}O	250	200	200	AVF
^{18}O	345	1000	500	RILAC
^{48}Ca	345	730	500	RILAC
^{70}Zn	345	250	200	RILAC2
^{76}Ge	345	not tested	N/A	RILAC
^{78}Kr	345	486	300	RILAC2
^{86}Kr	345	30	200	RILAC
^{136}Xe	345	not tested	20	RILAC2
^{124}Xe	345	178	140	RILAC2
^{238}U	345	72	60	RILAC2

¶ Some intensities are limited by shielding requirements

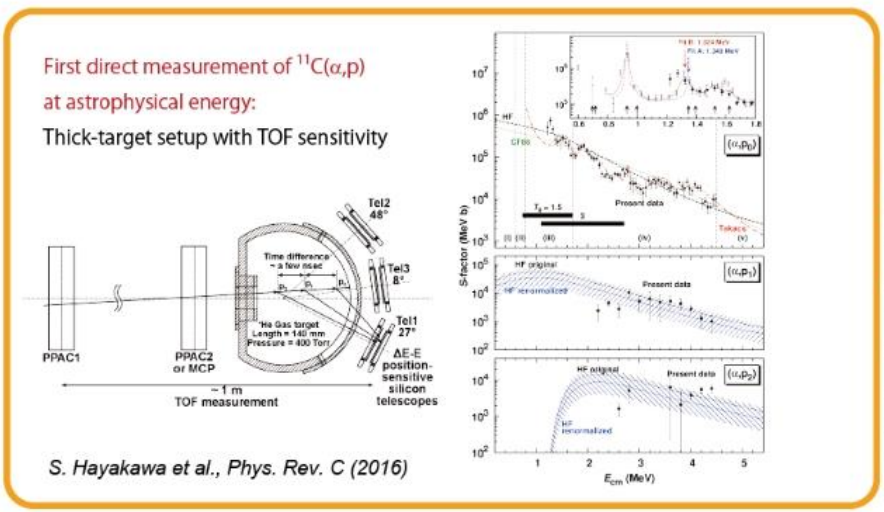

(a)
Z
A/Q
(b)
Rh
Counts
A/Q
120Rh44+
123Rh45+
121Rh44+
124Rh45+
122Rh44+
125Rh45+
123Rh44+
126Rh45+


RI Beam
Reactor and Accelerator
Natural RI
year
2010
2000
1990
1980
1970
1960
1950
1940
1930
1920
1910
1900
Elucidation of Nucleosynthesis
Super Model
Great Expansion of Nuclear Chart
Discovery of New Element
Nuclear Astrophysics
Structure and Reaction of Exotic Nuclei
RI beam and Halo,Skin Nucleus
Arima IBM theory
Charge Distribution Meas.
Collective Motion Model
Shell Model
Tomonaga Theory
Discovery of Uranium Fission
Nuclear Transmutation
Discovery of Nuetron
Yukawa Theory
Quantum Theory
Discovery of Nucleus
Relativity Theory
Discovery of Radioactivity
Discovery of X-ray
RI Beam Factory
AVF Cyclotron
Ring Cyclotron
Var. Freq. Heavy-Ion Linac
4th Cyclotron
3rd Cyclotron
2nd Cyclotron
Japan 1st Cyclotron by Y. Nishina
Invention of Cylotron (E.O. Lawrence)
New Applications to Environment, Materials, Biology, Chemistry and Industry
Invention of Plant Breeding
Invention of Multi-Tracer
Usage of RI Beam (The first in Japan)
Medical Application of RI (The first in Japan)
Usage of RI (The first in Japan)
Development of Nuclear Physics
RIKEN Cyclotrons
Utilization of Heavy ion and RI beam



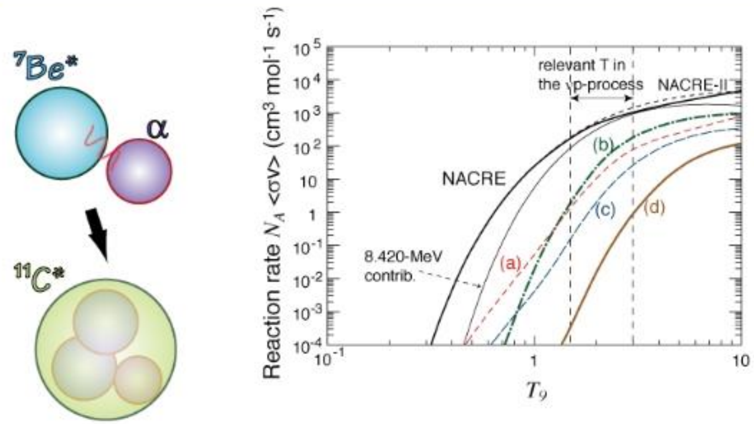
Linear-chain cluster states in ^{14}C nucleus

It is a well-known fact that a cluster of nucleons can be formed in the interior of an atomic nucleus, and such clusters may occupy molecular-like orbitals, showing characteristics similar to normal molecules consisting of atoms. Chemical molecules having a linear alignment are commonly seen in nature, such as carbon dioxide. A similar linear alignment of the nuclear clusters, has been studied since the 1950s, however, there has been no clear experimental evidence demonstrating the existence of such a state. Recently, it was predicted that an excess of neutrons may offer a stabilizing mechanism, and linear-chained ^{14}C (Carbon-14) can be formed. Using the ^{10}Be+α resonant scattering method with radioactive beam, w we observed a series of levels which completely agree with theoretically predicted linear-chain cluster states . We regard this as the first strong evidence of the linear-chain clustered nucleus. This work can be considered as an important step as a new technique in the alignment and morphology of the atomic nucleus.



First direct measurement of the steller ^{11}C(α, p)^{14}N reaction

The ^{11}C(α, p)^{14}N reaction is an important α-induced reaction competing with hydrogen-burning processes in high-temperature explosive stars, such as x-ray bursters and supernovae. We directly measured its reaction cross sections both for the ground-state transition (α, p_0) and the excited-state transitions (α, p_1) and (α, p_2) at relevant stellar energies 1.3-4.5 MeV by an extended thick-target method featuring time of flight for the first time. We revised the reaction rate including the (α, p_1) and (α, p_2) contributions and also low-lying resonances of (α,p_0) using both the present and the previous experimental data which were totally neglected in the previous compilation works.

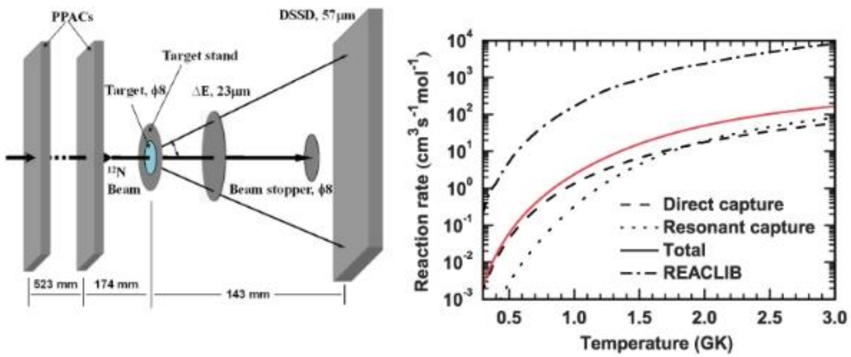


H. Yamaguchi et al., Phys. Rev. C (2013)

Alpha resonances in ^{11}C and $^7Be(\alpha,\gamma)$ reaction

The nuclear resonances in ^{11}C were studied using ^7Be RI beam at CRIB. The $^7Be(\alpha,\gamma)$ reaction is known to play important roles in the synthesis of nuclei heavier than carbon. Especially, it produces carbon as much as the triple-alpha process, which was considered to be the most dominant process, in a nucleosynthesis process in supernovae, called νp-process. The reaction rate at high temparature is dominated by resonant reaction, but not much information on higher-lying resonances had been known. From our measurement, a more precise evaluation of the reaction rate at the supernova temperature became possible. The resonances are also important for understanding the alpha cluster structure in ^{11}C nucleus. (See $^7Li+\alpha$ study below.)

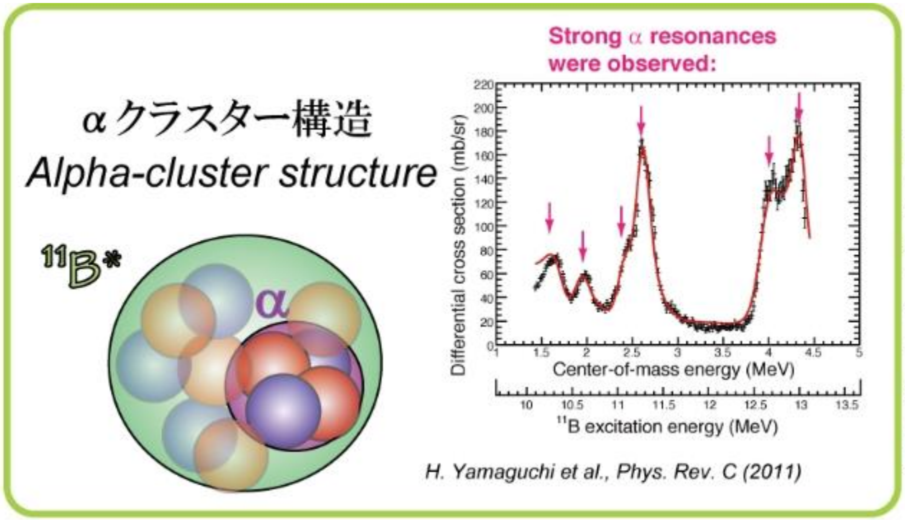
Measurement of $^{12}N(d, n) \rightarrow {}^{12}N(p, \gamma)$ rate



B. Guo et al., Phys. Rev. C (2013)

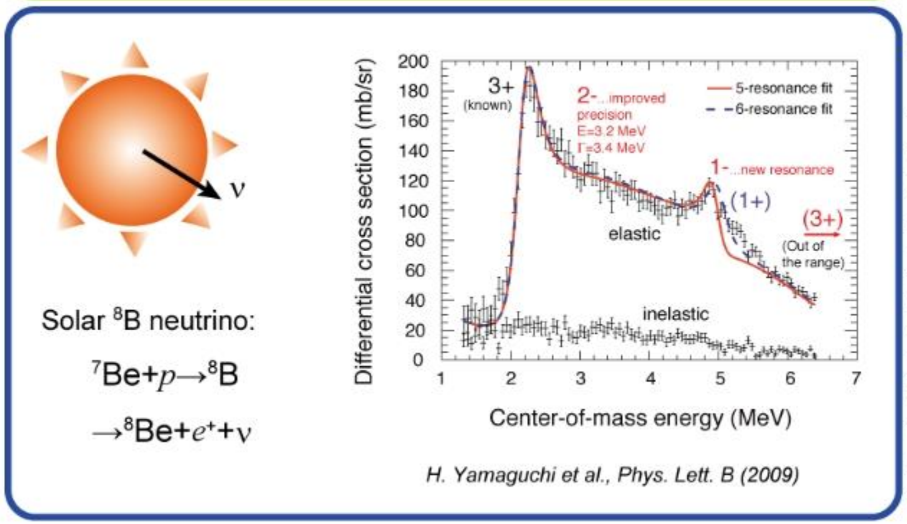
Study on astrophysical $^{12}N(p, \gamma)$ reaction with ANC method

The astrophysical reaction $^{12}N(p, \gamma)$, a key reaction to produce nuclei heavier than carbon, was studied using an indirect method. We measured the angular distribution of a similar reaction, the d(^{12}N, ^{13}O) proton transfer reaction. By using a special analysis method called the asymptotic normalization coefficient (ANC) method, the reaction rate was successfully deduced. The new rate is two orders of magnitude slower than that from the REACLIB compilation.



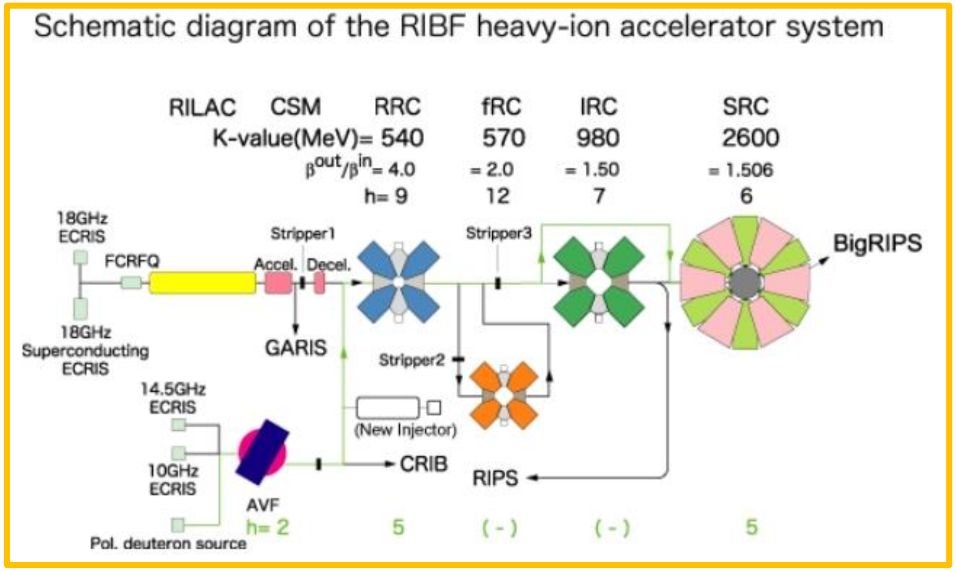
Alpha cluster structure in ^{11}B, studied by ^{7}Li+α scattering

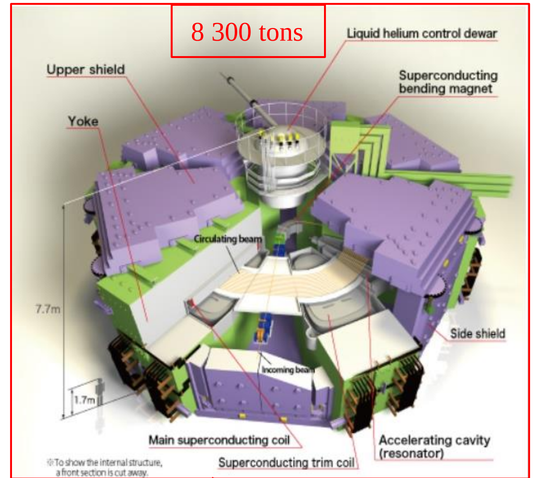
In relatively light nuclei, a structure called as α-cluster structure is often observed. Nuclei consist of protons and neutrons. In some cases, however, an α particle, which consists of 2 protons and 2 neutrons, acts as an independent particle in the nucleus. This can be called as an α-cluster state. There are also cases in which such α-cluster states forms a band structure, with a series of α-cluster states in the excited levels of a nucleus. We have observed many α-cluster like resonant states in ^{11}B (Boron-11) nucleus, formed by a ^{7}Li (Lithium-7) nucleus and an α particle, and we proposed a new α-cluster band structure. The information we obtained is valuable for a profound understanding of the nuclear cluster structure.

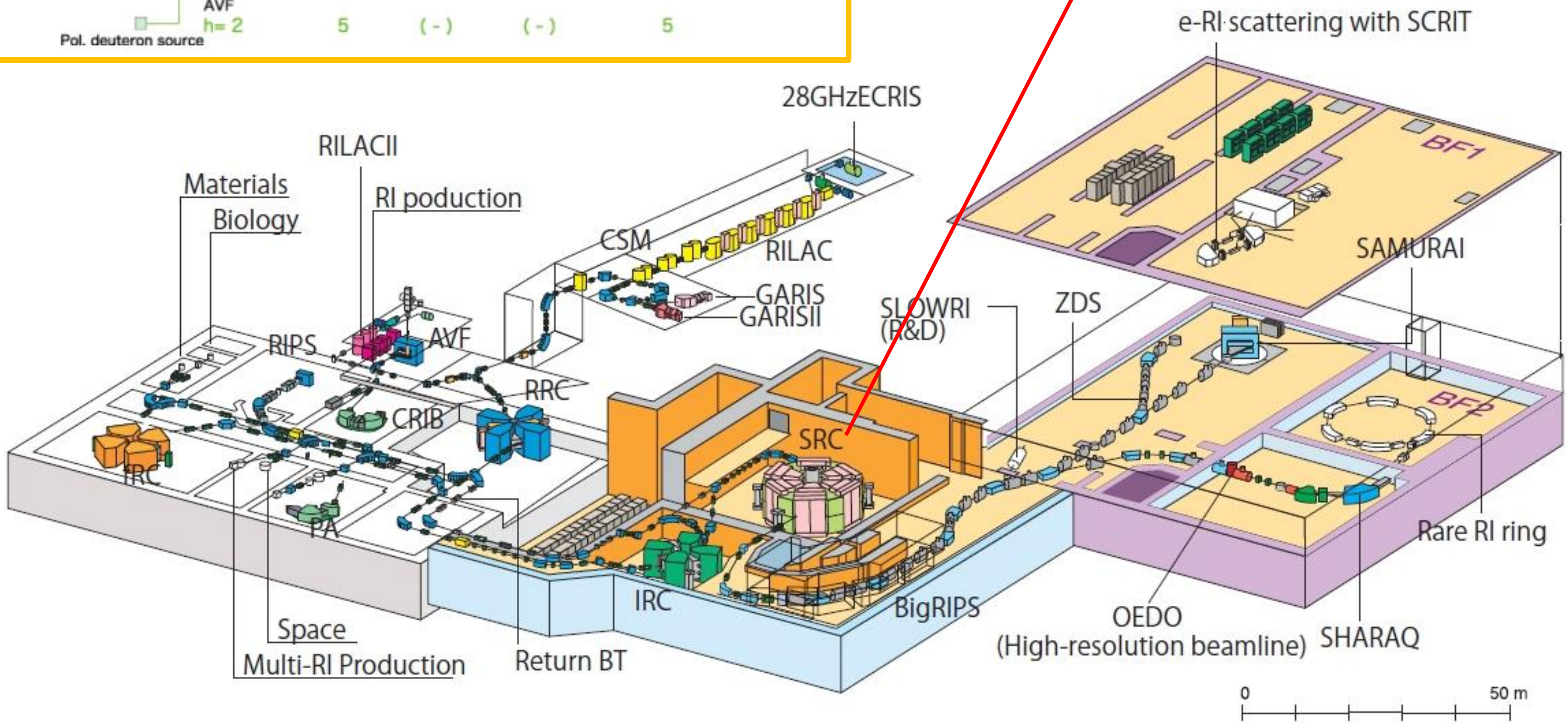


Studying resonant states formed by ^{7}Be+p

The unstable ^{7}Be (Beryllium-7) nucleus can make a reaction with hydrogen in the sun, forming a ^{8}B (Boron-8) nucleus. Eventually, the ^{8}B nucleus emits a neutrino on its beta-decay. The neutrino with that origin has relatively high energies and most frequently detected on the earth. To have a precise knowledge of the interior of the sun, there have been many studies to determine the rate how much ^{7}Be are converted into ^{8}B (reaction rate). In our study, we observed a very broad resonant state, which was said to be possibly influential for the reaction rate of the solar neutrino. Even the existense of the state was not certain with previous measurements, however, we observed the broad resonance state and determined its resonant parameters. We concluded the broad resonance makes negligible effect on the reaction rate.


Schematic diagram of the RIBF heavy-ion accelerator system
RILAC
CSM
RRC
fRC
IRC
SRC
K-value(MeV)= 540
570
980
2600
β^{out}/β^{in}= 4.0
= 2.0
= 1.50
= 1.506
h= 9
12
7
6
18GHz ECRIS
FCRFQ
Stripper1
Accel.
Decel.
Stripper3
BigRIPS
18GHz Superconducting ECRIS
GARIS
Stripper2
14.5GHz ECRIS
(New Injector)
10GHz ECRIS
CRIB
RIPS
AVF
h= 2
5
(-)
(-)
5
Pol. deuteron source


8 300 tons
Liquid helium control dewar
Upper shield
Superconducting bending magnet
Yoke
Circulating beam
7.7m
Side shield
1.7m
Incoming beam
Main superconducting coil
Accelerating cavity (resonator)
Superconducting trim coil


e-RI scattering with SCRIT
28GHzECRIS
RILACII
Materials
Biology
RI poduction
CSM
RILAC
GARIS
GARISII
SLOWRI (R&D)
ZDS
SAMURAI
BF1
BF2
RIPS
AVF
RRC
CRIB
SRC
fRC
PA
IRC
BigRIPS
Rare RI ring
OEDO (High-resolution beamline)
SHARAQ
Space
Multi-RI Production
Return BT
0
50 m