March 2-6, 2015

New Isotope Search with BigRIPS

T. Kubo, RIKEN Nishina Center

Conducted at RIKEN RI Beam Factory (RIBF) using the BigRIPS separator in order to expand the frontier of nuclear chart

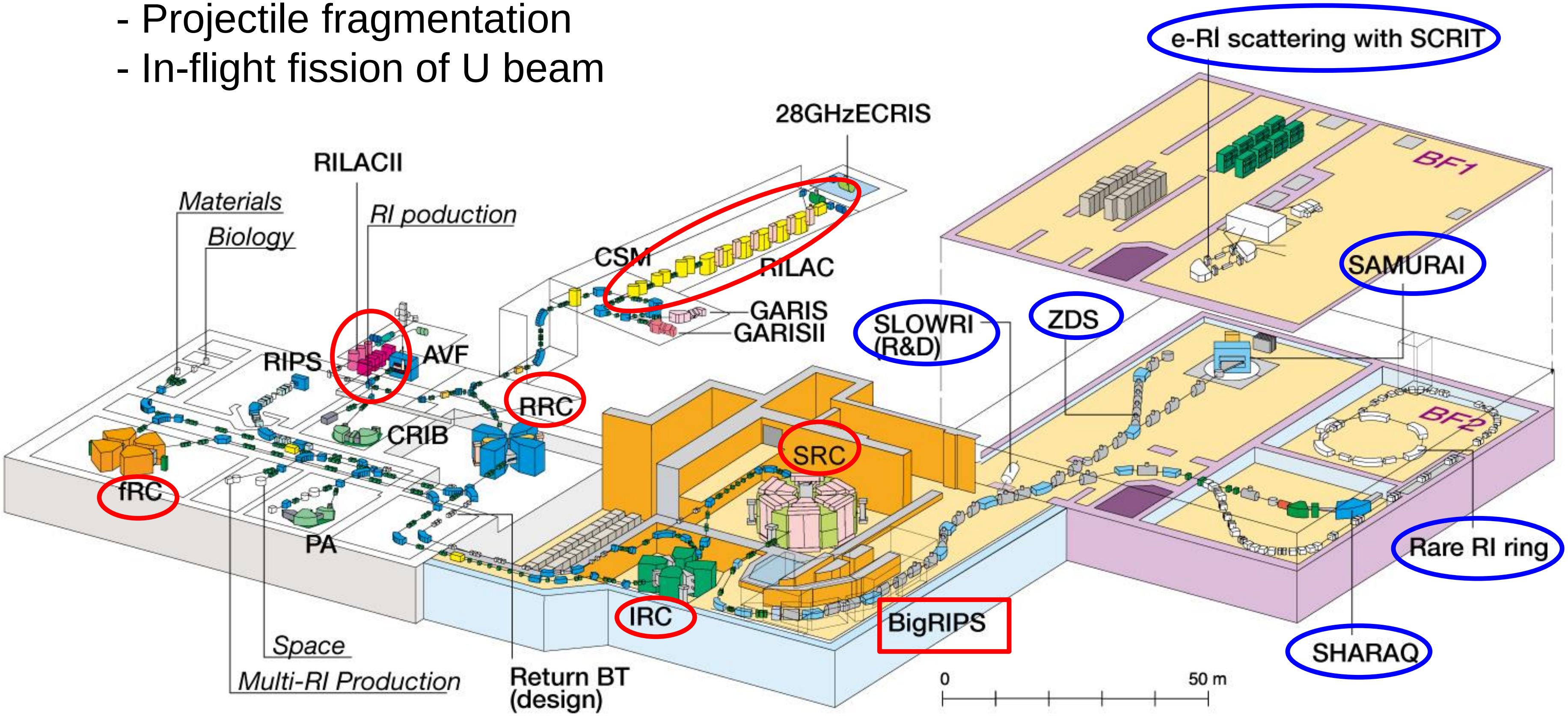
Outline of my talk

- Brief introduction of RIKEN RIBF and BigRIPS separator
- Neutron drip-line search using a ^{48}Ca beam: search for ^{33}F, ^{36}Ne and ^{39}Na.
- Overview of search for a wide range of new isotopes using in-flight fission of a ^{238}U beam
- Production rate measurements
- Summary and perspective

Presented at GSI NUSTAR 2015 annual meeting on March 4, 2015, GSI, Darmstadt, Germany

RI Beam Factory (RIBF) at RIKEN

A next-generation in-flight RI beam facility
- Projectile fragmentation
- In-flight fission of U beam



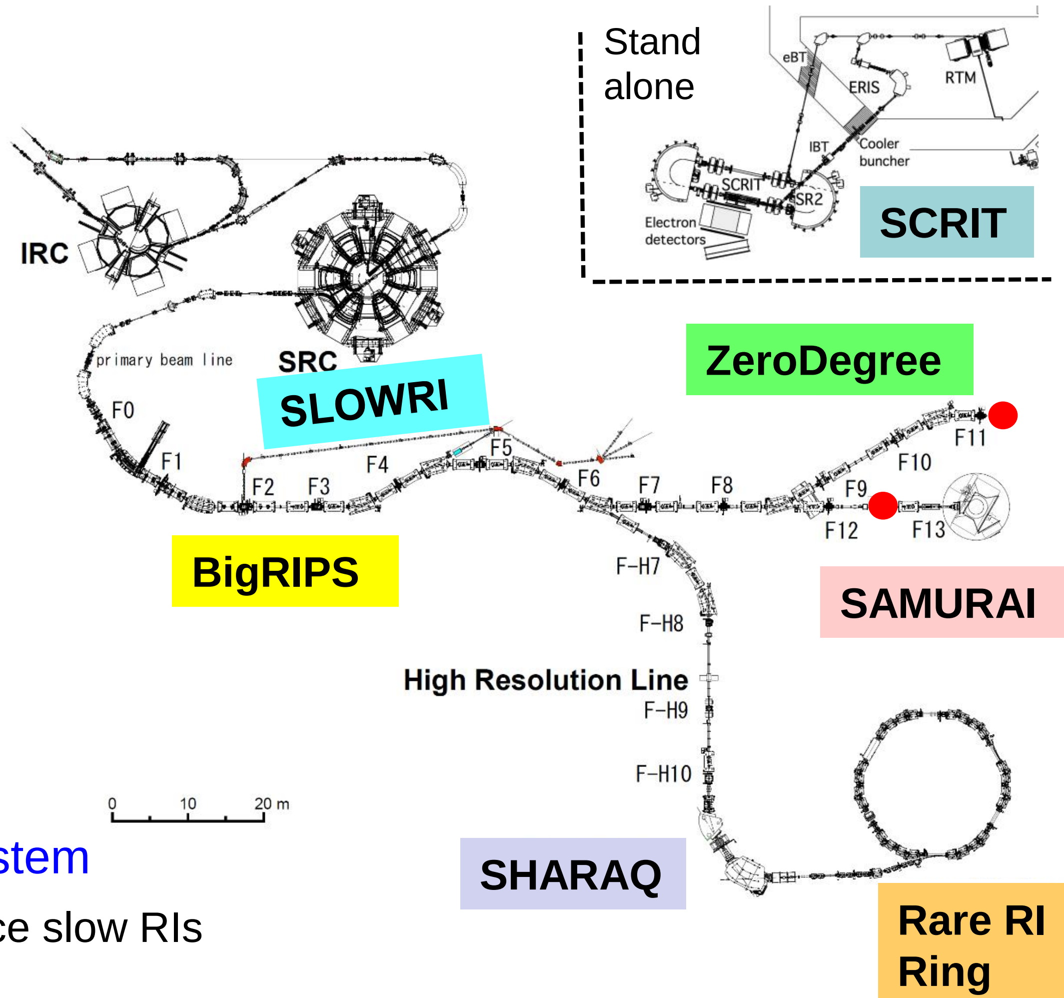
- ➢ RIBF accelerator system consists of linacs and cyclotrons.
- ➢ Maximum energy is ~345 MeV/u for heavy ions up to U ions.
- ➢ Goal beam intensity is 1 pμA (6 x 10^{12} particles/sec).

RRC, fRC, IRC & SRC cyclotrons

- ➢ BigRIPS separator: used for RI-beam production
- ➢ Major experimental facilities

Major experimental facilities at RIBF: designed & built for RI beam experiments

- **BigRIPS separator**
  Also used as a spectrometer
- **ZeroDegree spectrometer: ZDS**
  Forward spectrometer fixed at 0 degrees and provides nice PID
- **SAMURAI spectrometer**
  Very large acceptances allowing kinematically complete measurement
- **SHARAQ spectrometer (by CNS) and high-resolution beam line**
  High-resolution measurement by momentum dispersion matching
- **SLOWRI & PALIS gas catcher system**
  Combines in-flight and ISOL to produce slow RIs
- **Rare RI Ring : isochronous mass ring** TOF mass measurement (~ppm)
- **SCRIT (Self-Confining RI target)**
  Electron-RI scattering using electron storage ring and ISOL system



- **Decay stations for β-γ and β-n measurements** ● : EURICA, BRIKEN
- **Various large-scale detectors :** DALI2, GRAPE, EUROBALL, ESPRI, MUST2, MINOS, SAMURAI TPC, …

Photos

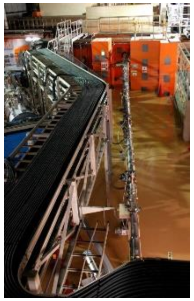
RIPS

25 years!

RRC

RILAC

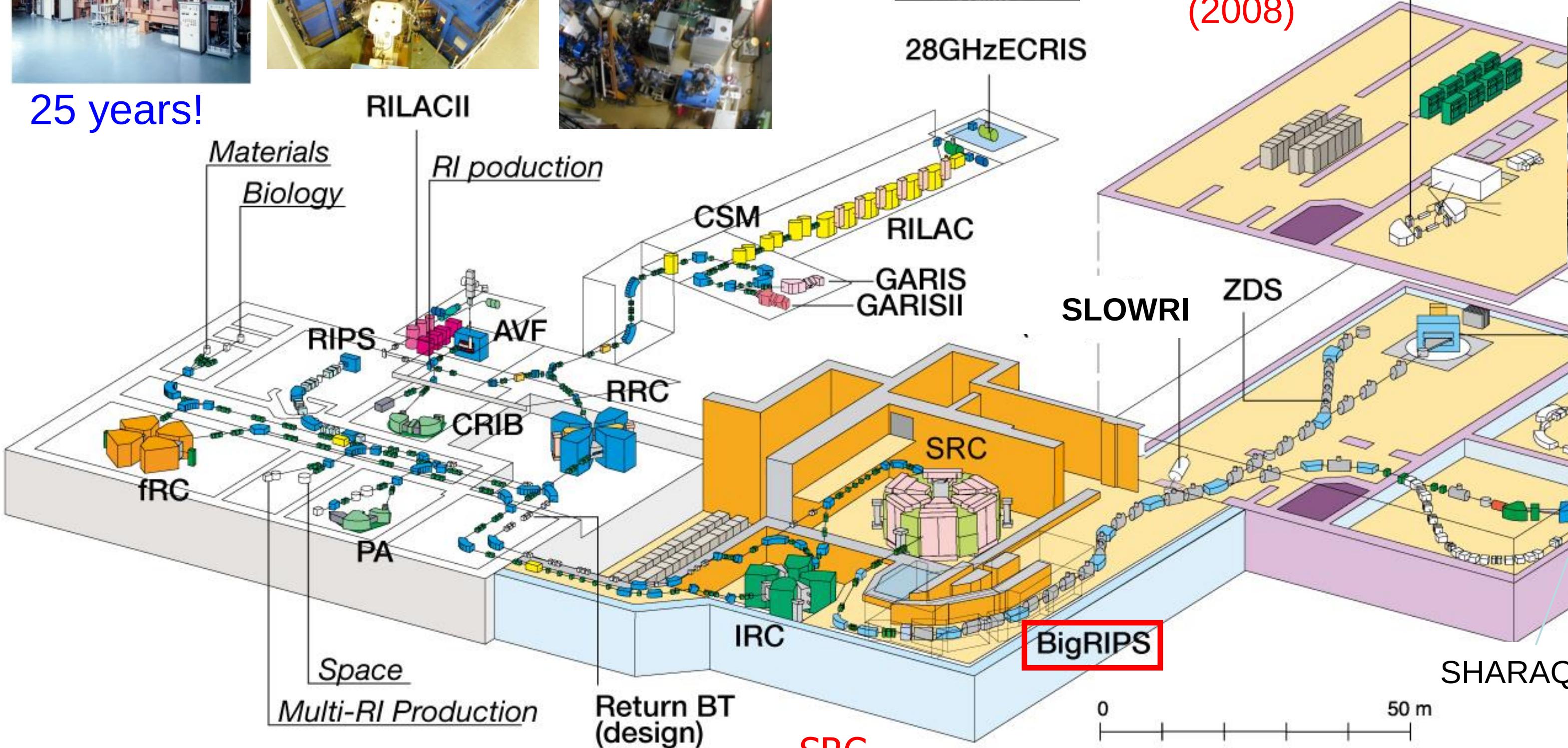
SLOWRI
(2015)



ZeroDegree: ZDS
(2008)

SCRIT (2011)

SAMURAI
(2012)



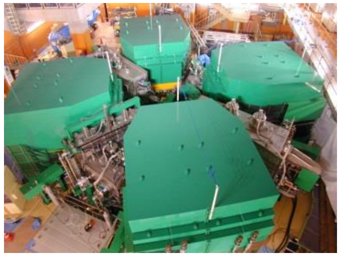
(2015)
Rare RI Ring

SRC

BigRIPS (2007)

fRC

IRC



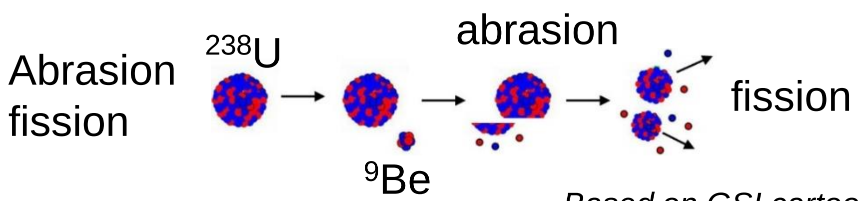
SHARAQ (2009)

BigRIPS separator (since March 2007)

- **Large acceptances**

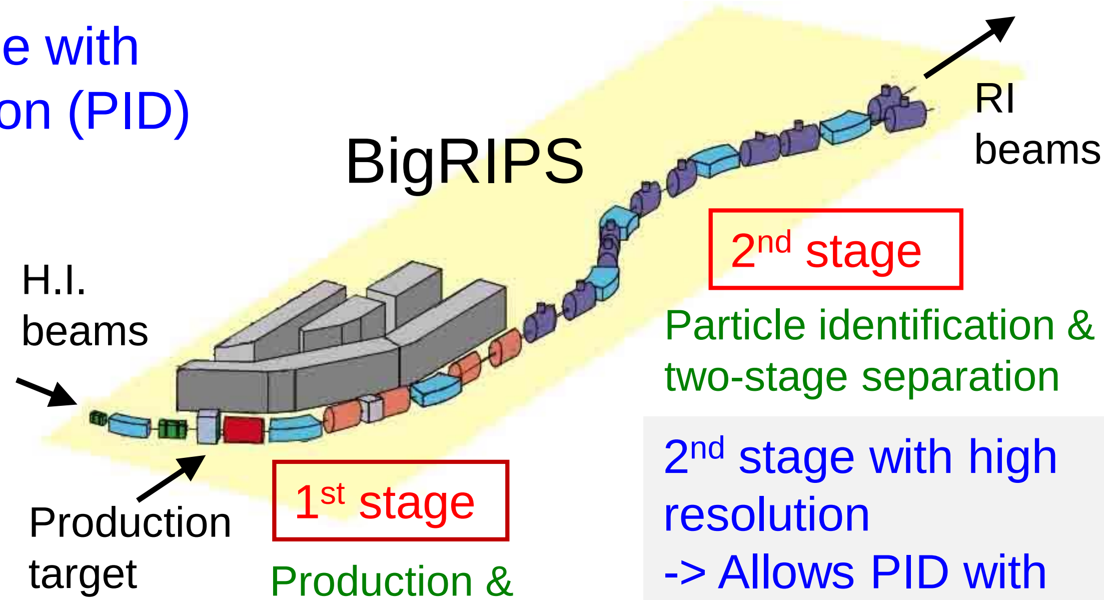
  Comparable with spreads of in-flight fission of U beam at RIBF energies, allowing efficient production of RI beams

$\Delta\theta$ = 80 mr
$\Delta\phi$ = 100 mr
$\Delta p/p$ = 6 %
$B\rho$ = 9 Tm
L = 78.2 m



Based on GSI cartoons

- **Two-stage separator scheme with excellent particle identification (PID)**



Production & separation

Particle identification & two-stage separation

2nd stage with high resolution
-> Allows PID with charge states

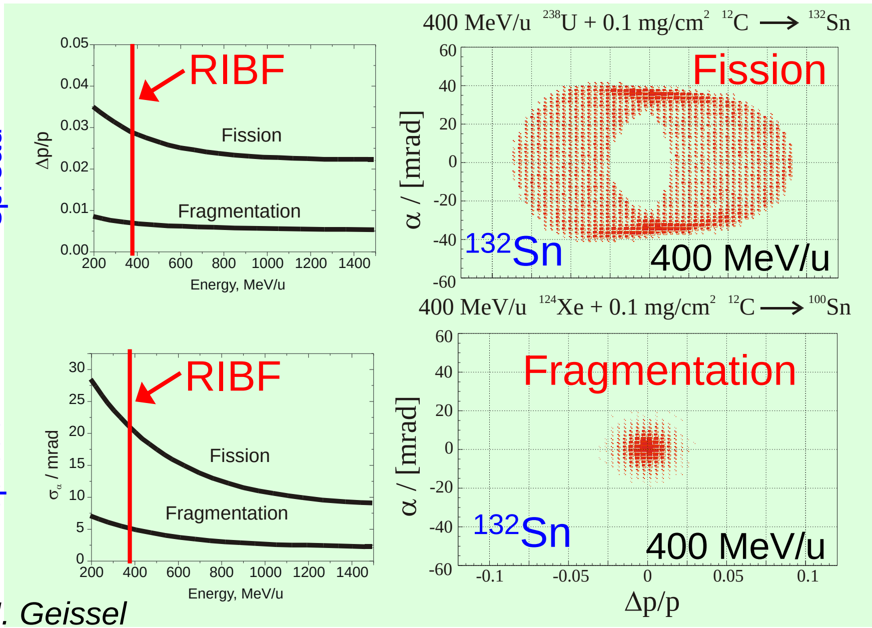
- PID: based on TOF-$B\rho$-ΔE method with track reconstruction and made by Z vs. A/Q
- A/Q resolution is high enough to identify charge state events without measuring TKE

Reaction kinematics (angle and momentum spreads) and collection efficiency of fragments: demonstrates large acceptances of BigRIPS

Well cover the spreads of fission fragments!

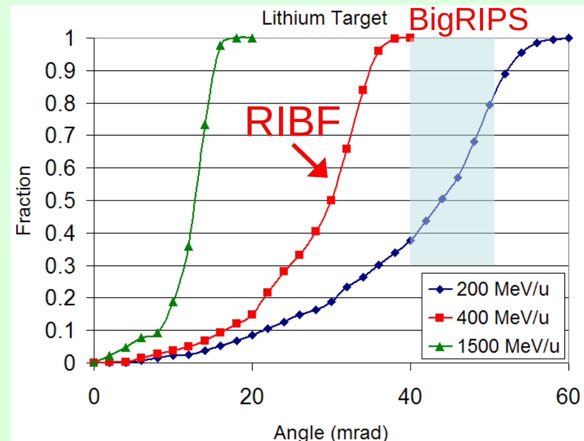
Momentum spread

Angular spread



From H. Geissel

Fraction of ^{132}Sn contained in a cone of the respective angle

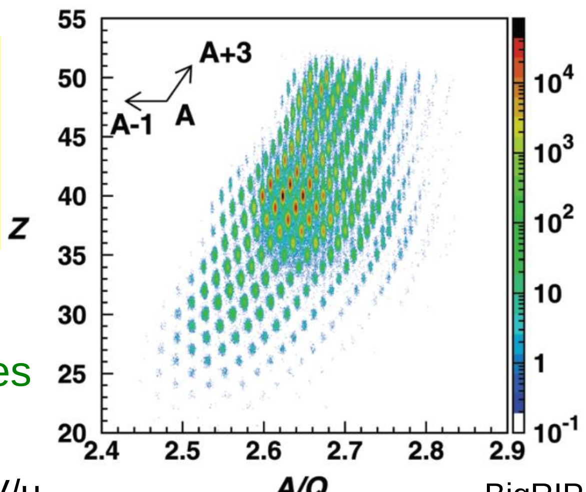


Fission

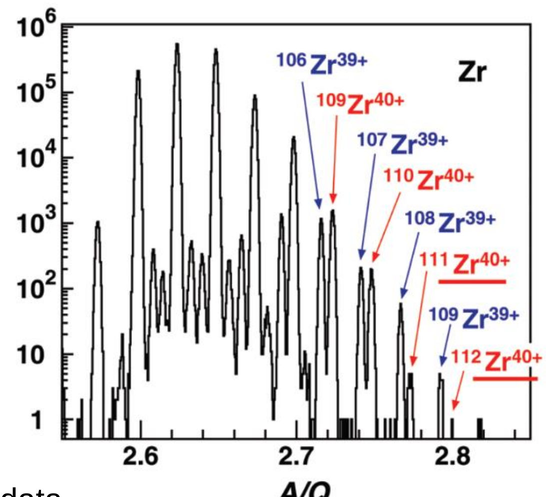
From J. Nolen

Excellent PID for fission fragments

High enough to identify charge states



^{238}U+Be at 345 MeV/u

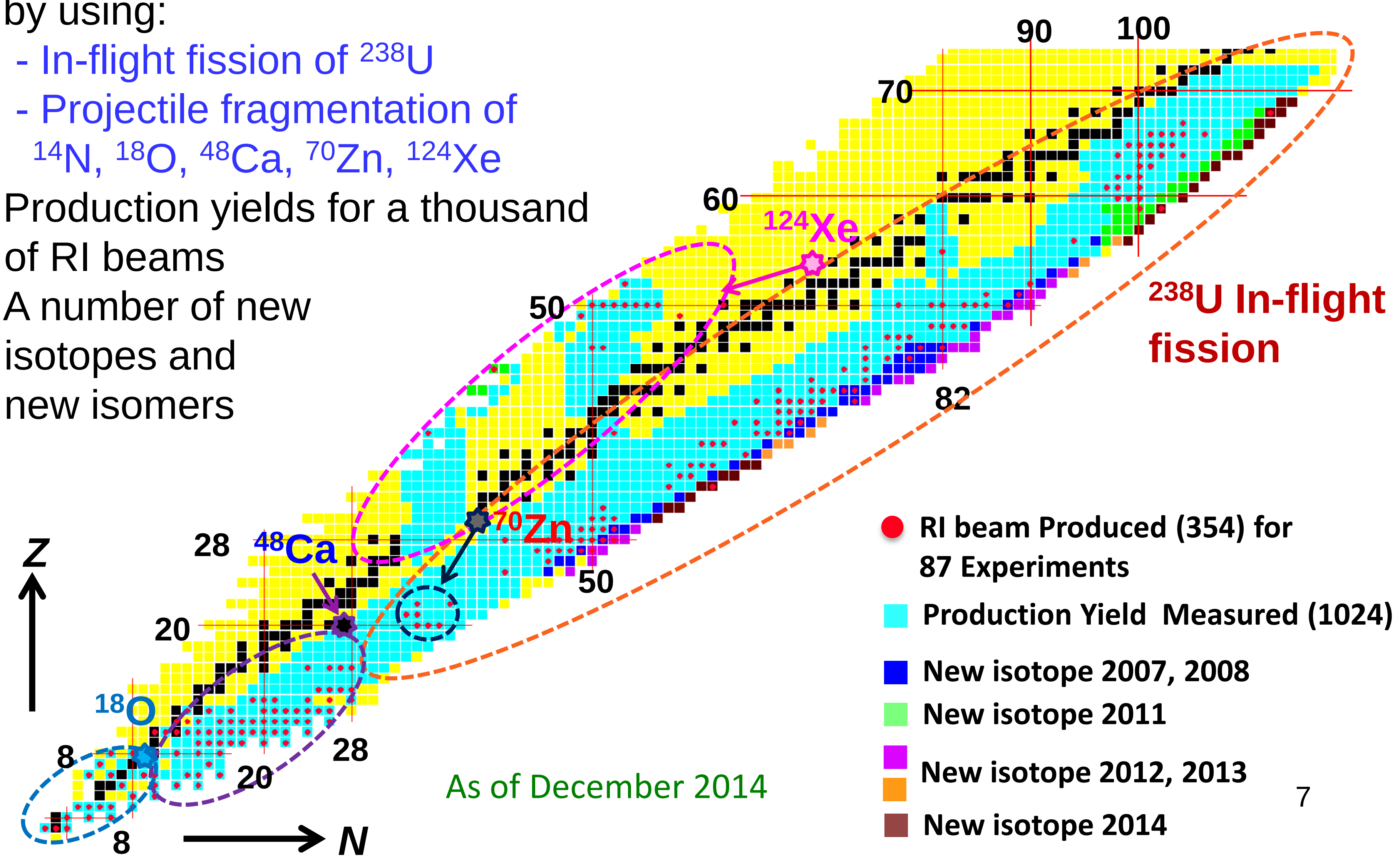


BigRIPS data

Neighboring fully-stripped and hydrogen-like peaks clearly identified

RI beams produced at BigRIPS (May 2007 – Dec. 2014)

- We have produced a total of 354 RI beams and delivered to 87 experiments.
- by using:
  - In-flight fission of ^{238}U
  - Projectile fragmentation of ^{14}N, ^{18}O, ^{48}Ca, ^{70}Zn, ^{124}Xe
- Production yields for a thousand of RI beams
- A number of new isotopes and new isomers



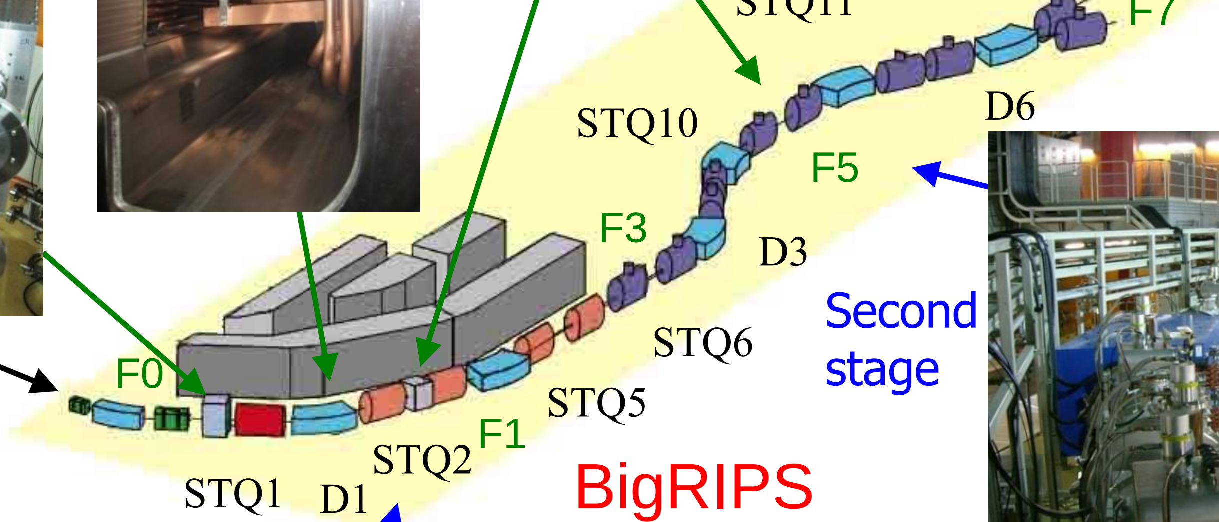
Photos

High-power production target

High-power beam dump

Energy degraders

PID detectors



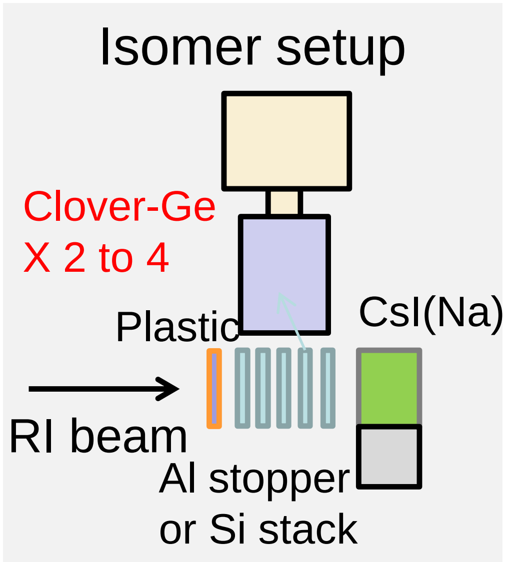
Second stage

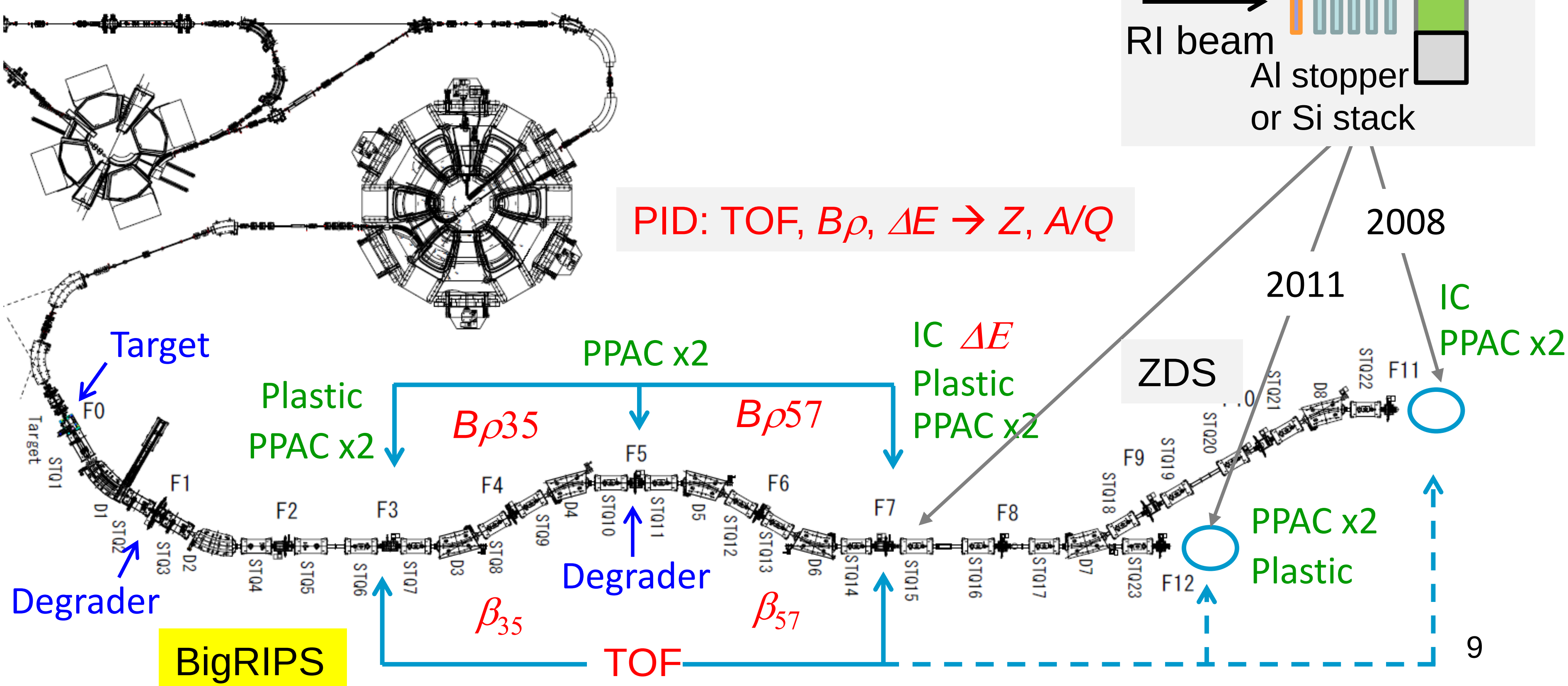
First stage

Large-aperture superconducting quadrupole triplets: STQ

Our experimental setups for new isotope search

- Standard beam-line detectors at BigRIPS for TOF, $B\rho$, ΔE measurement for PID of new isotopes
- Clover-type Ge detectors for isomer tagging for PID calibration and also isomer measurement (which was simultaneously conducted while searching for new isotopes)





Particle identification (PID) scheme at BigRIPS

TOF-Bρ-ΔE method with track reconstruction

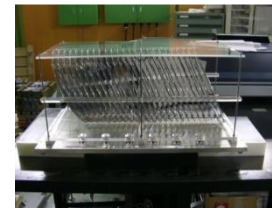
Measure TOF, Bρ, ΔE at 2nd stage

Bρ, β, ΔE ↓ + isomeric *γ*-rays

Z, A/Q

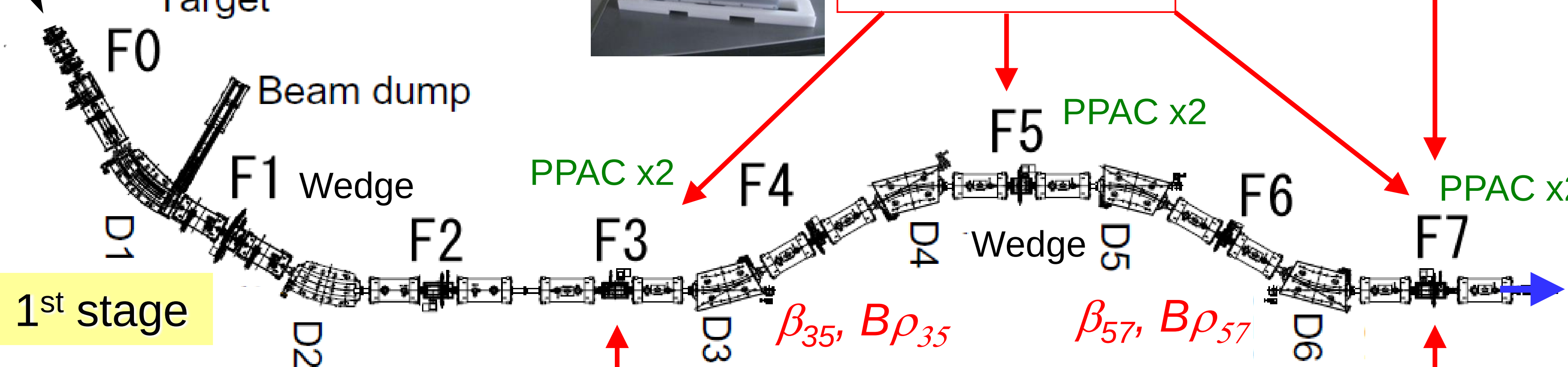
$$Z \leftarrow -dE/dx = f(Z,\beta)$$

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



ΔE: MUSIC, Si
Isomer γ-ray: Ge

Bρ with track reconstruction



1st stage

2nd stage

Measure trajectories at focuses for track reconstruction by using PPACs to improve A/Q resolution

TOF: *β*

Plastic scinti.

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Conducted Dec. 2014!

Neutron drip-line for low Z nuclei

^{36}Ca	^{37}Ca	^{38}Ca	^{39}Ca	^{40}Ca	^{41}Ca	^{42}Ca	^{43}Ca	^{44}Ca	^{45}Ca	^{46}Ca	^{47}Ca	^{48}Ca	^{49}Ca	^{50}Ca	^{51}Ca	^{52}Ca
^{35}K	^{36}K	^{37}K	^{38}K	^{39}K	^{40}K	^{41}K	^{42}K	^{43}K	^{44}K	^{45}K	^{46}K	^{47}K	^{48}K	^{49}K	^{50}K	^{51}K
^{34}Ar	^{35}Ar	^{36}Ar	^{37}Ar	^{38}Ar	^{39}Ar	^{40}Ar	^{41}Ar	^{42}Ar	^{43}Ar	^{44}Ar	^{45}Ar	^{46}Ar	^{47}Ar	^{48}Ar	^{49}Ar	^{50}Ar
^{33}Cl	^{34}Cl	^{35}Cl	^{36}Cl	^{37}Cl	^{38}Cl	^{39}Cl	^{40}Cl	^{41}Cl	^{42}Cl	^{43}Cl	^{44}Cl	^{45}Cl	^{46}Cl	^{47}Cl	^{48}Cl	^{49}Cl
^{32}S	^{33}S	^{34}S	^{35}S	^{36}S	^{37}S	^{38}S	^{39}S	^{40}S	^{41}S	^{42}S	^{43}S	^{44}S	^{45}S	^{46}S	^{47}S	^{48}S
^{31}P	^{32}P	^{33}P	^{34}P	^{35}P	^{36}P	^{37}P	^{38}P	^{39}P	^{40}P	^{41}P	^{42}P	^{43}P	^{44}P	^{45}P	^{46}P	
^{30}Si	^{31}Si	^{32}Si	^{33}Si	^{34}Si	^{35}Si	^{36}Si	^{37}Si	^{38}Si	^{39}Si	^{40}Si	^{41}Si	^{42}Si	^{43}Si	^{44}Si		
^{29}Al	^{30}Al	^{31}Al	^{32}Al	^{33}Al	^{34}Al	^{35}Al	^{36}Al	^{37}Al	^{38}Al	^{39}Al	^{40}Al	^{41}Al	^{42}Al	^{43}Al		
^{28}Mg	^{29}Mg	^{30}Mg	^{31}Mg	^{32}Mg	^{33}Mg	^{34}Mg	^{35}Mg	^{36}Mg	^{37}Mg	^{38}Mg		^{40}Mg				
^{27}Na	^{28}Na	^{29}Na	^{30}Na	^{31}Na	^{32}Na	^{33}Na	^{34}Na	^{35}Na		^{37}Na						
^{26}Ne	^{27}Ne	^{28}Ne	^{29}Ne	^{30}Ne	^{31}Ne	^{32}Ne		^{34}Ne								
^{25}F	^{26}F	^{27}F		^{29}F		^{31}F										
^{24}O		^{26}O		^{28}O												

Nuclear chart from Thomas Baumann, Dave Morrissey, Oleg Tarasov

Most neutron-rich isotopes observed so far (the year and facility shown)

2007 NSCL-A1900

2007 NSCL-A1900

2002 RIKEN-RIPS

2002 RIKEN-RIPS

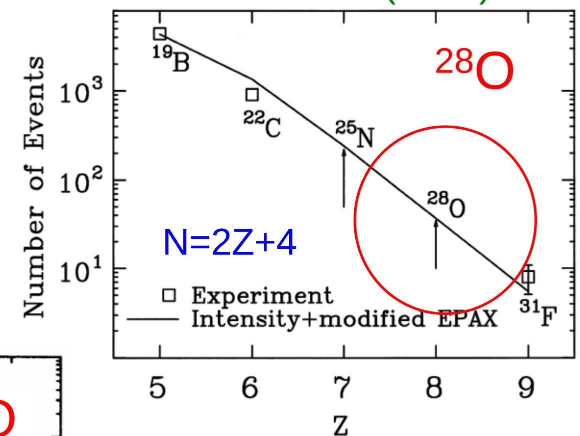
1999 RIKEN-RIPS

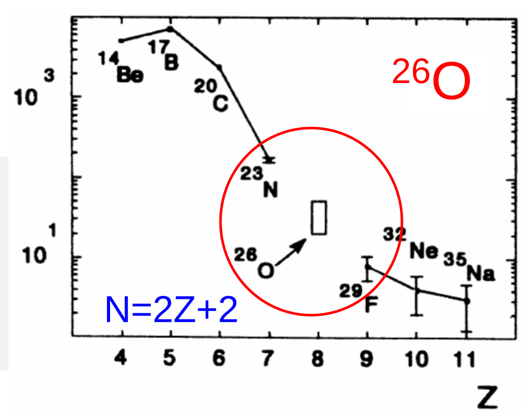
1970 FLNR

1990 GANIL-LISE

1997 GANIL-LISE RIKEN-RIPS

H. Sakurai et al.: PLB 448 (1999)180





The location of the neutron drip line is only known up to Oxygen, which is ^{24}O !

(Established more than 15 years ago)

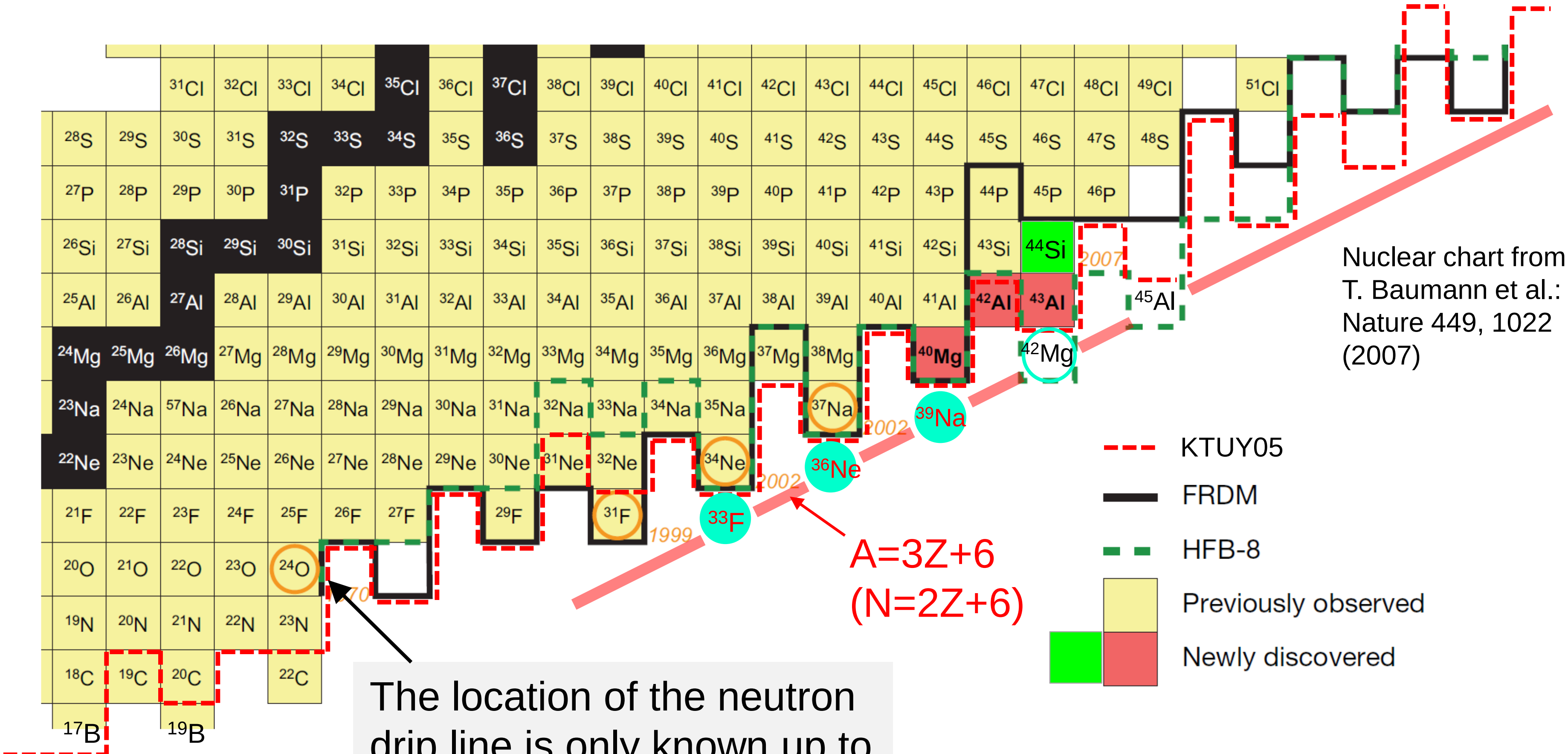
Non-existence of ^{26}O and ^{28}O established long time ago

D. Guillemaud-Mueller et al.: PRC 41 (1990) 937

Neutron drip-line search using a ^{48}Ca beam at RIKEN RIBF

We have recently searched for the drip-line nuclei: ^{33}F, ^{36}Ne, ^{39}Na (Dec 2014)

- using an intense ^{48}Ca beam (400 - 500 pnA (3x10^{12} pps) at 345 MeV/u)
- in order to determine existence/non-existence of ^{33}F, ^{36}Ne, and ^{39}Na with A = 3Z+6 and to locate the neutron drip-line



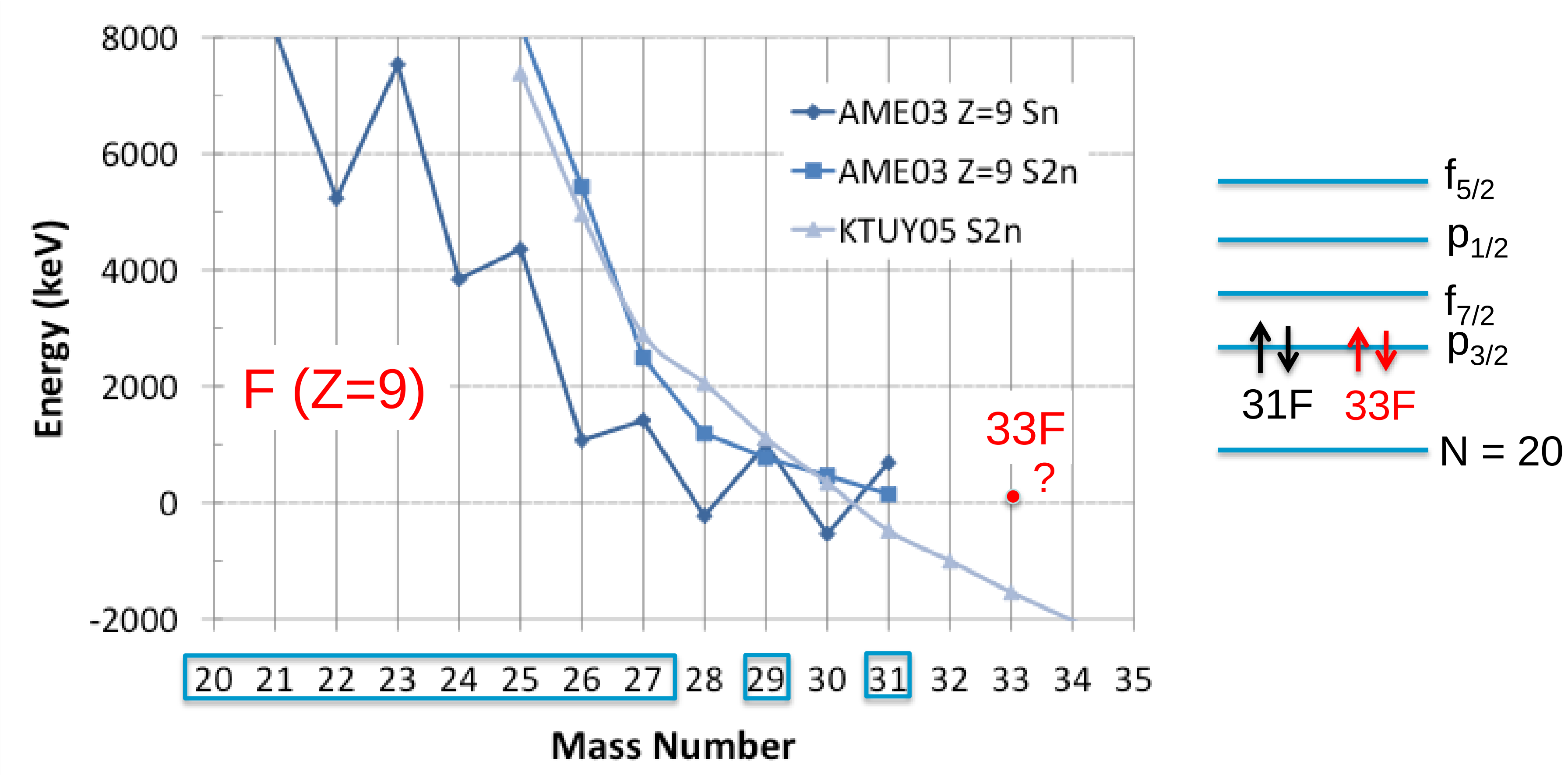
The location of the neutron drip line is only known up to Oxygen: ^{24}O.

Plan presented by T.K. at NSCL User Meeting in August 2010.

Systematics of neutron separation energy for F isotopes and the drip lines

Courtesy of Brad M. Sherrill (collaborator)

From systematics it is possible that ^{33}F (and ^{36}Ne, ^{39}Na) are bound.



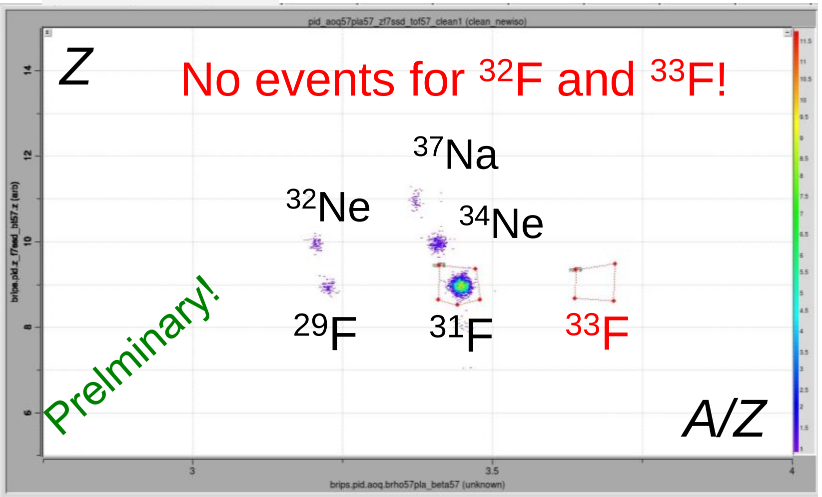
Determination of drip lines provides us with a key benchmark for nuclear model and mass model. It does not matter if it is bound or not.

KTUY05 : Koura-Tachibana-Uno-Yamada, Prog Theor Phys 113 (2005) 305

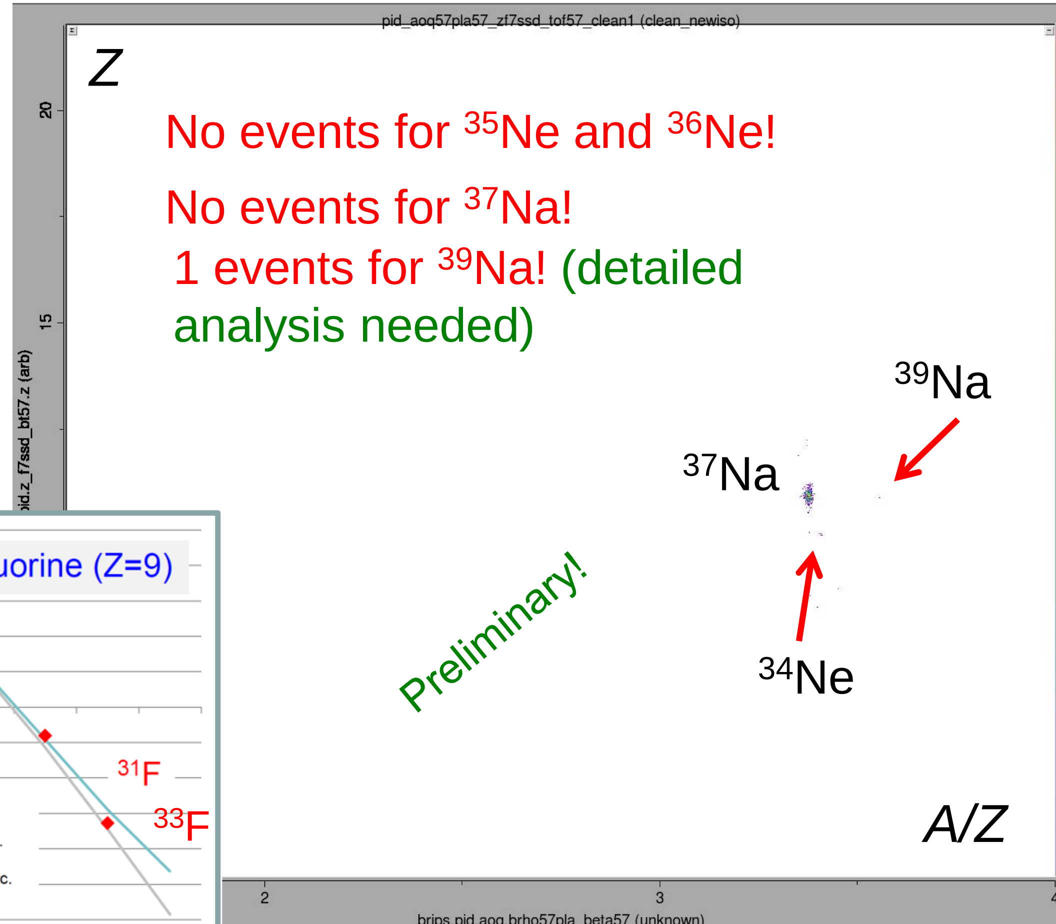
Preliminary results from our on-line analysis

^{48}Ca + Be at 345 MeV/u

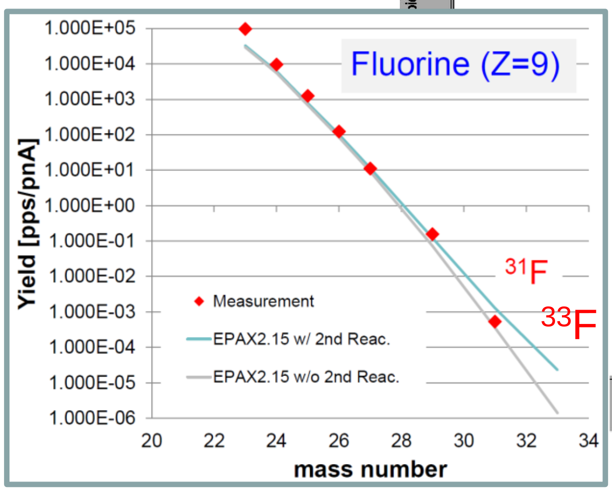
^{33}F run 415 pnA (ave.), 14.3 h



$^{36}Ne+^{39}Na$ run 440 pnA (ave.), 9.4 h



Measured yield systematics for F isotopes along with EPAX2.15 LISE++ predictions



Expected counts of 33F assuming EPAX2.15 (without secondary reactions) -> 20.7 counts -> Give very high probability that 33F is not bound: 99.999999897%

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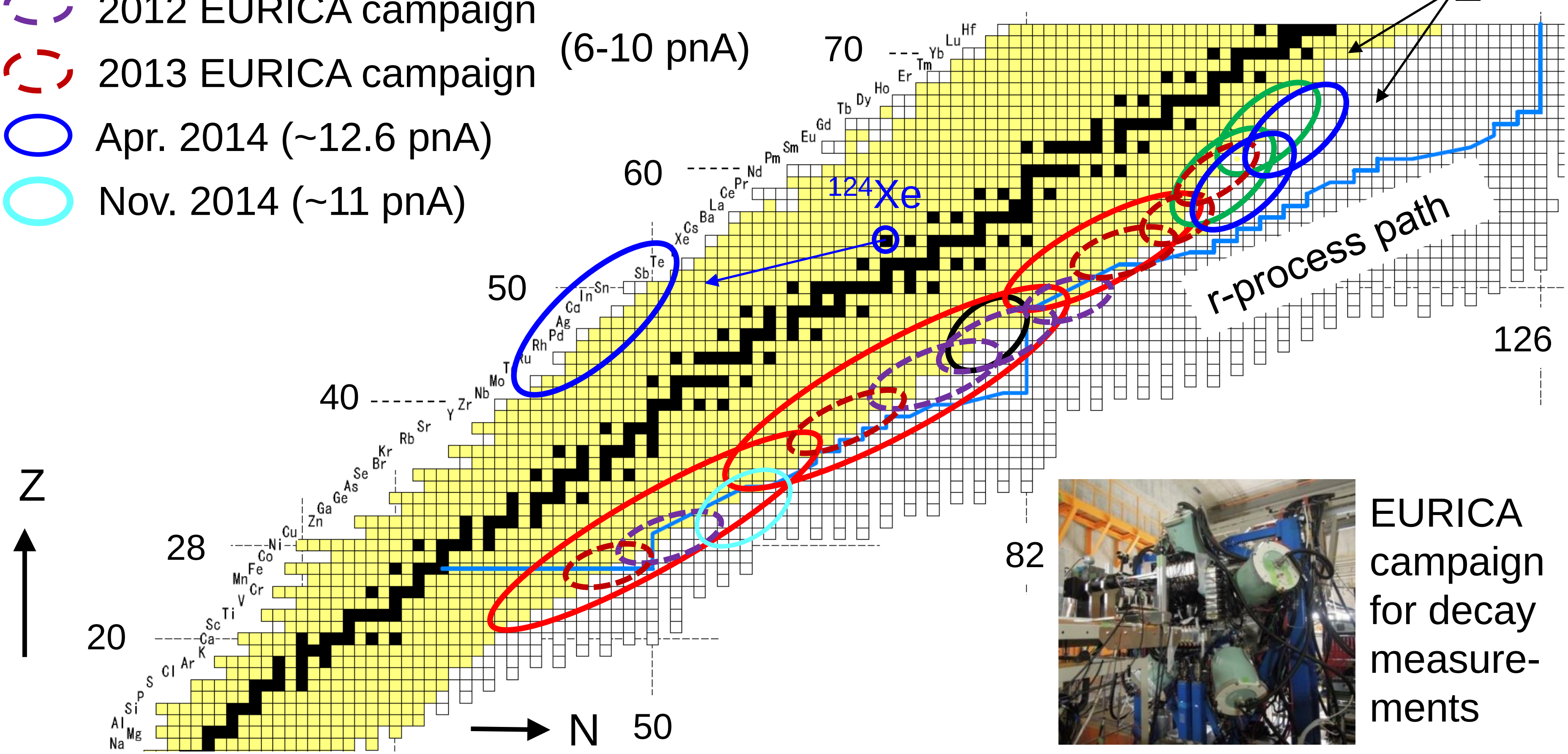
- Overview of search for a wide range of new isotopes using in-flight fission of a ^{238}U beam at 345 MeV/u

  Conducted several times from May 2007 till Dec. 2014
- Production rate measurements
- Summary and perspective

New isotope runs at BigRIPS since 2007

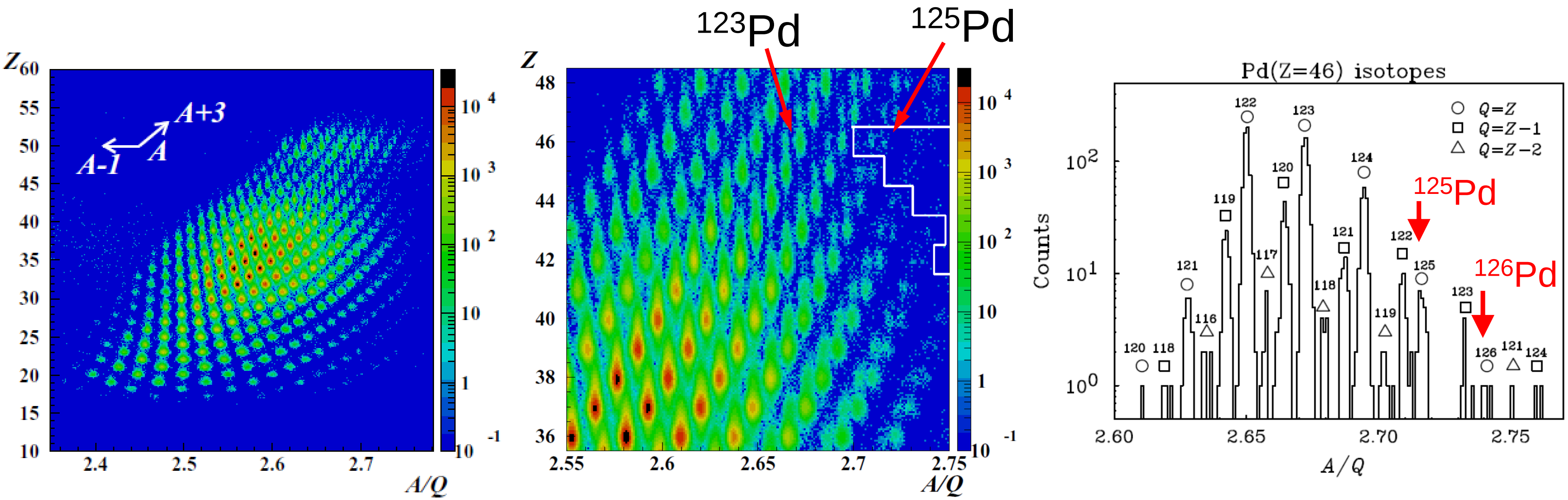
- Neutron-rich new isotopes using in-flight fission of ^{238}U at 345 MeV/u
  - May 2007 (~0.007 pnA, 4x10^{7}pps)
  - Nov. 2008 (~0.22 pnA, 1x10^9 pps)
  - Oct. 2011 (~0.3 pnA, 2x10^9 pps)
  - 2012 EURICA campaign
  - 2013 EURICA campaign (6-10 pnA)
  - Apr. 2014 (~12.6 pnA)
  - Nov. 2014 (~11 pnA)
- Proton-rich new isotopes using ^{124}Xe at 345 MeV/u
  Dec. 2011 (~9 pnA), 2013 (~35 pnA)
- Neutron drip-line search using ^{48}Ca at 345 MeV/u
  Dec. 2014 (400-500 pnA)



EURICA campaign for decay measure-ments

2007 U experiment

- First experiment at RIBF!
- $^{238}U^{86+}$ + Be at 345 MeV/u
- Two new isotopes ^{125}Pd and ^{126}Pd identified!
- U intensity very low ~0.007 pnA (4 x 10^7 pps), running time: ~1 day
- demonstrated the potential of BigRIPS separator

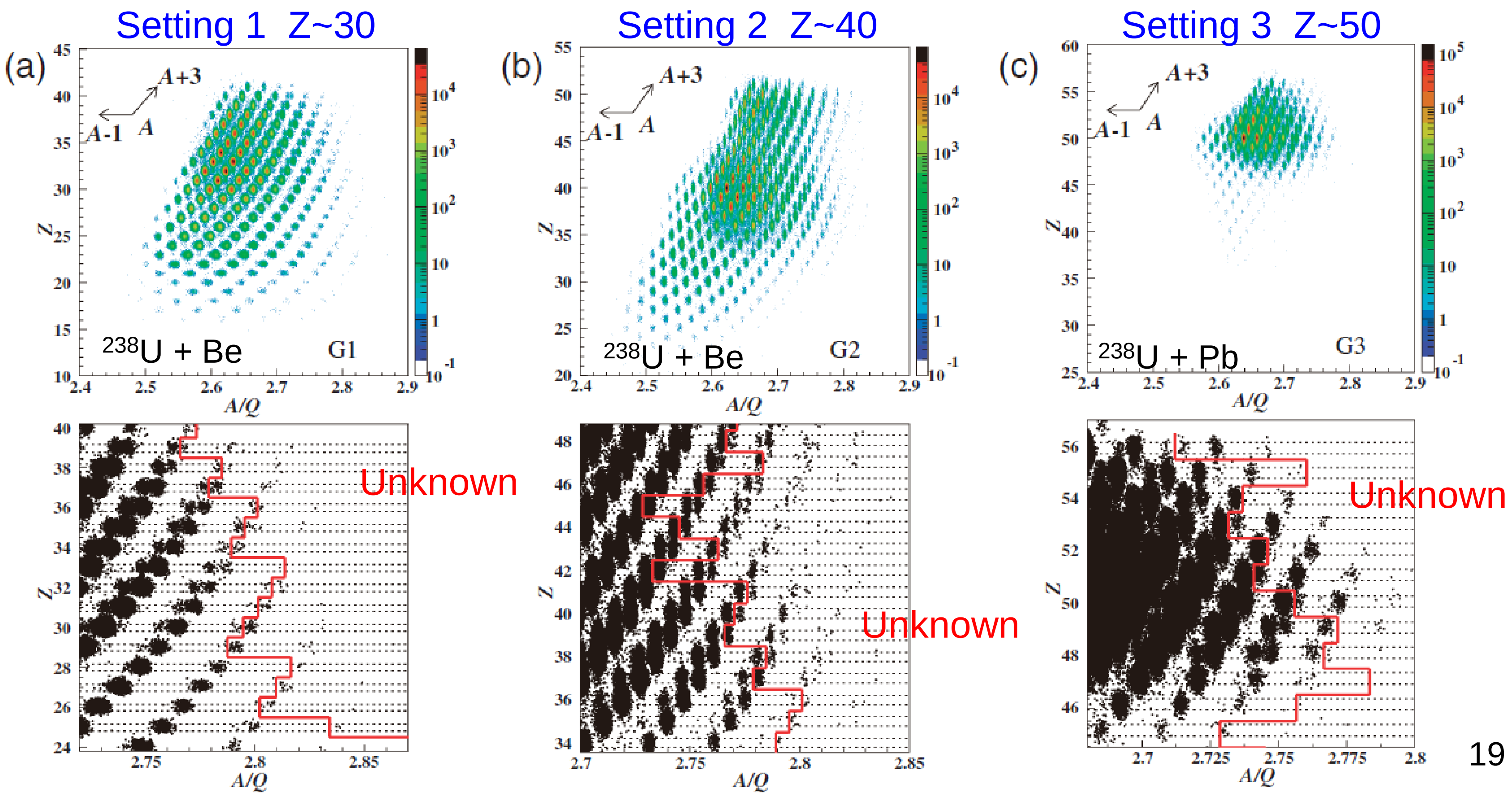


T. Ohnishi et al.: J. Phys. Soc. Jpn. **77** (2008) 083201.

2008 U experiment

- Ran three different settings targeting Z ~30, Z ~40 and Z ~50 region
- ^{238}U + Be/Pb 345MeV/u, ~4 days
- U intensity ~30 times higher than in 2007, but still low: ~0.22 pnA (1 x 10^9 pps)

- A total of 45 new isotopes over a wide range of neutron-rich exotic nuclei!
  - demonstrates the capability of BigRIPS separator

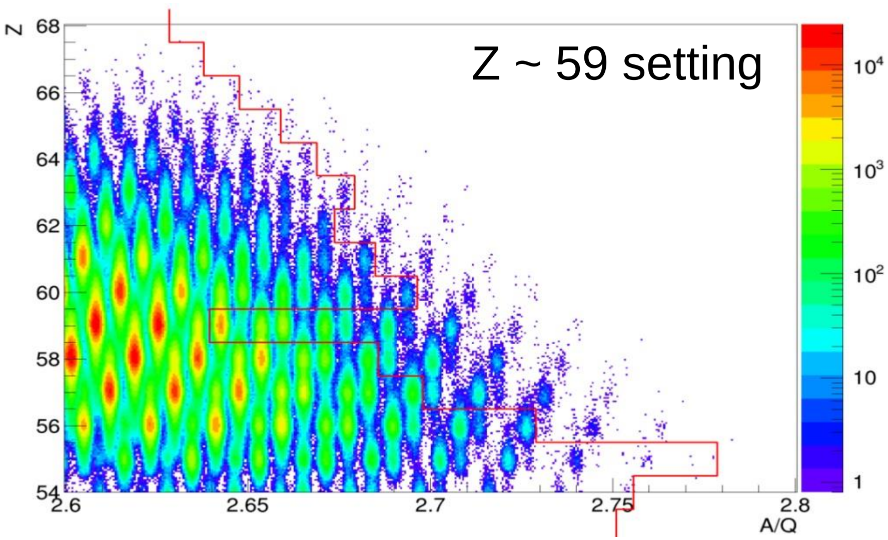


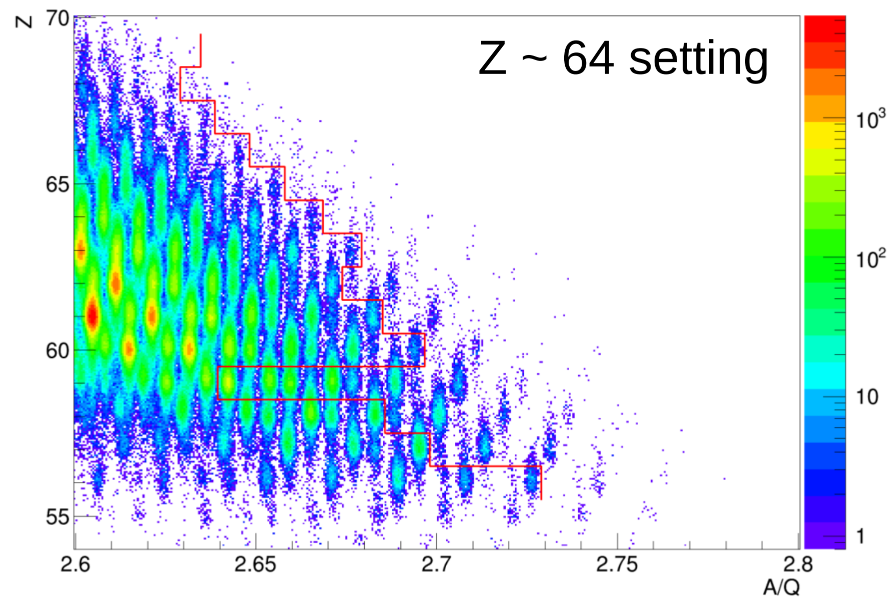
T. Ohnishi et al.: J. Phys. Soc. Jpn. **79** (2010) 073201.

2011 Oct U experiment

- Searched for new isotopes in neutron-rich rare earth region
- Ran two settings: Z ~59 and ~64, $^{238}U^{86+}$ + Be at 345 MeV/u
- U intensity still low: ~0.3 pnA (2 x 10^9 pps), running time ~4 days

- 26 new isotopes over a wide range of neutron-rich rare earth nuclei!
  - again demonstrates the capability of BigRIPS separator





D. Kameda, N. Fukuda et al., to be submitted.

New isotope search during EURICA campaign (2012 & 2013)

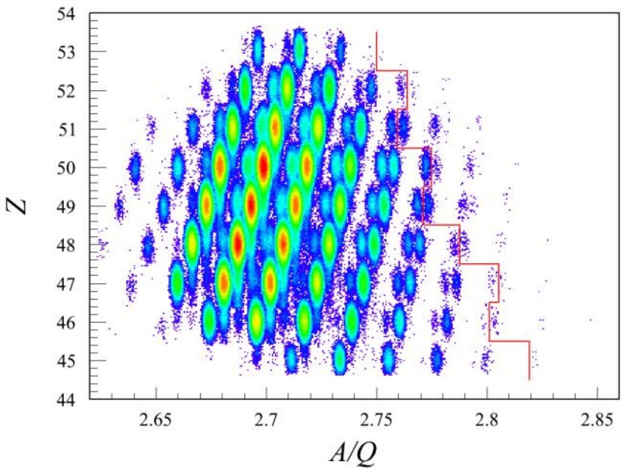
- Ran several settings for various regions
  - ^{238}U + Be at 345 MeV/u
- Intensity increased a lot: 6 -10 pnA

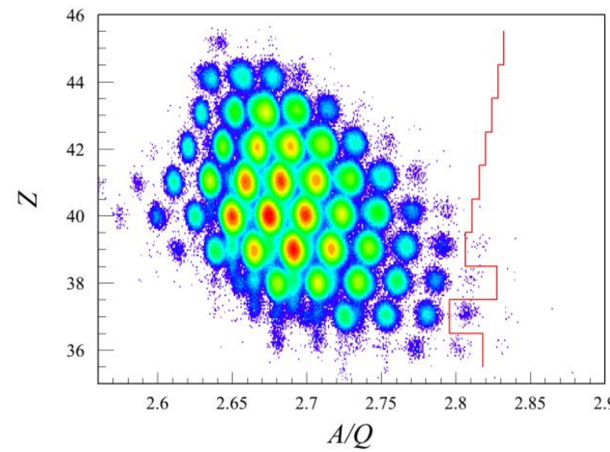
- A number of new isotopes observed!

2013 ~6 pnA 8 (3+5) (preliminary)

2012 ~10 pnA 26 (19+7) (preliminary)

Z ~50 setting (2012)

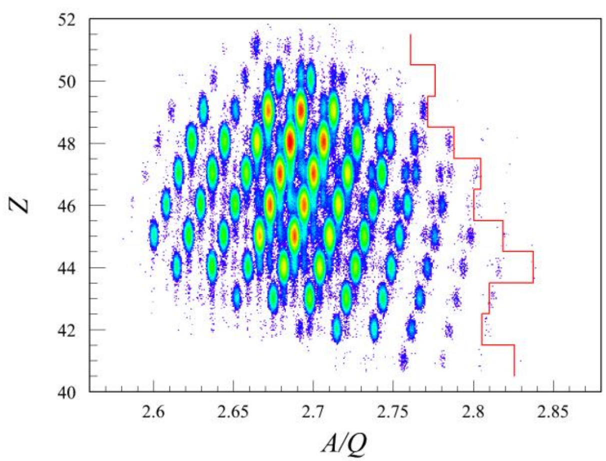


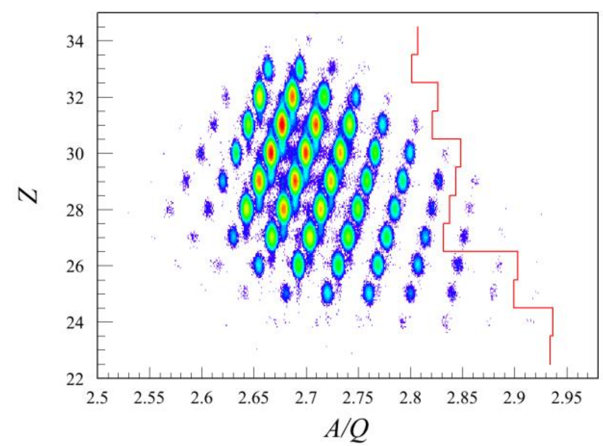


Z ~40 setting (2013)

Examples of PID plots

Z ~46 setting (2012)





Z ~28 setting (2012)

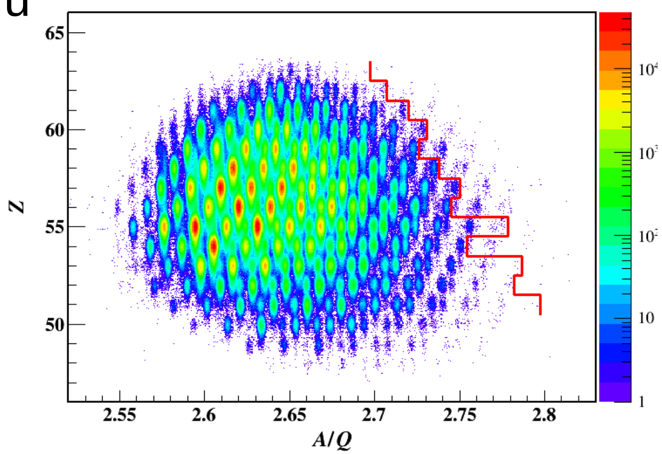
Y. Shimizu et al., to be submitted. T. Sumikama et al., to be submitted.

2014 April U experiment

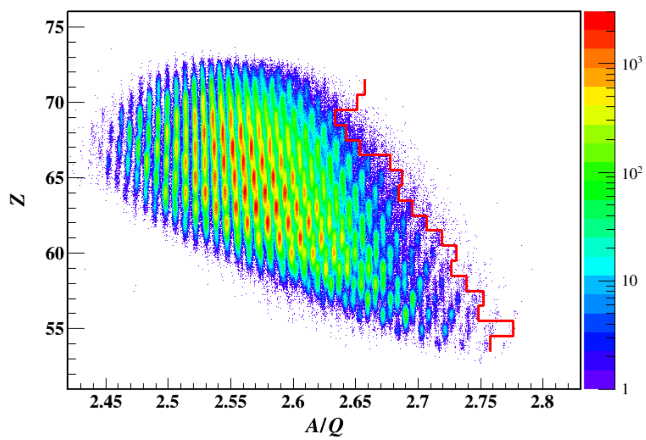
- ^{238}U + Be at 345 MeV/u
  ~ 12.6 pnA
- Ran two settings
- Neutron-rich rare earth region again

18 new isotopes
(preliminary)

Z ~59 setting



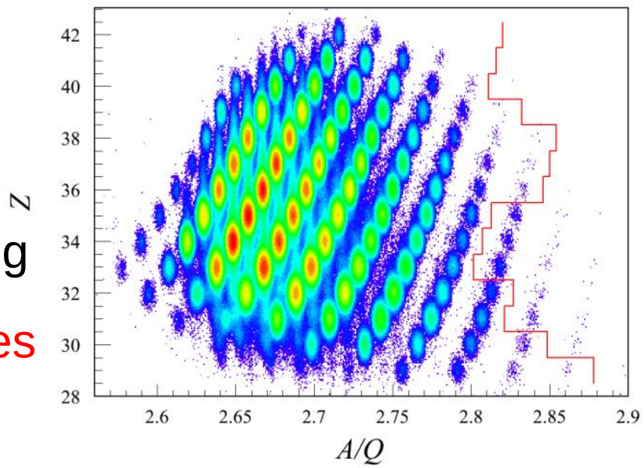
Z ~68 setting



2014 Nov U experiment

- ^{238}U + Be
  345 MeV/u
  ~11 pnA
- *Z* ~35 setting

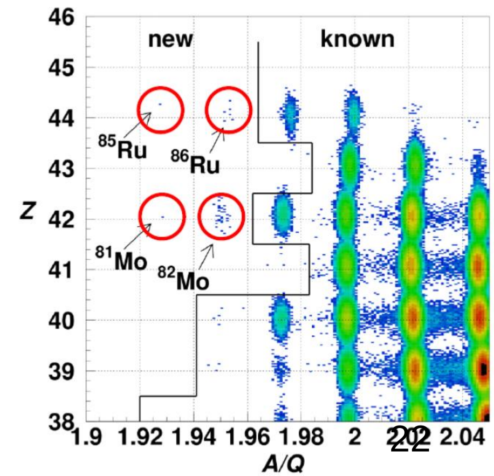
10 new isotopes
(preliminary)



2011 Nov Xe experiment

- ^{124}Xe + Be
  345 MeV/u
  ~9 pnA

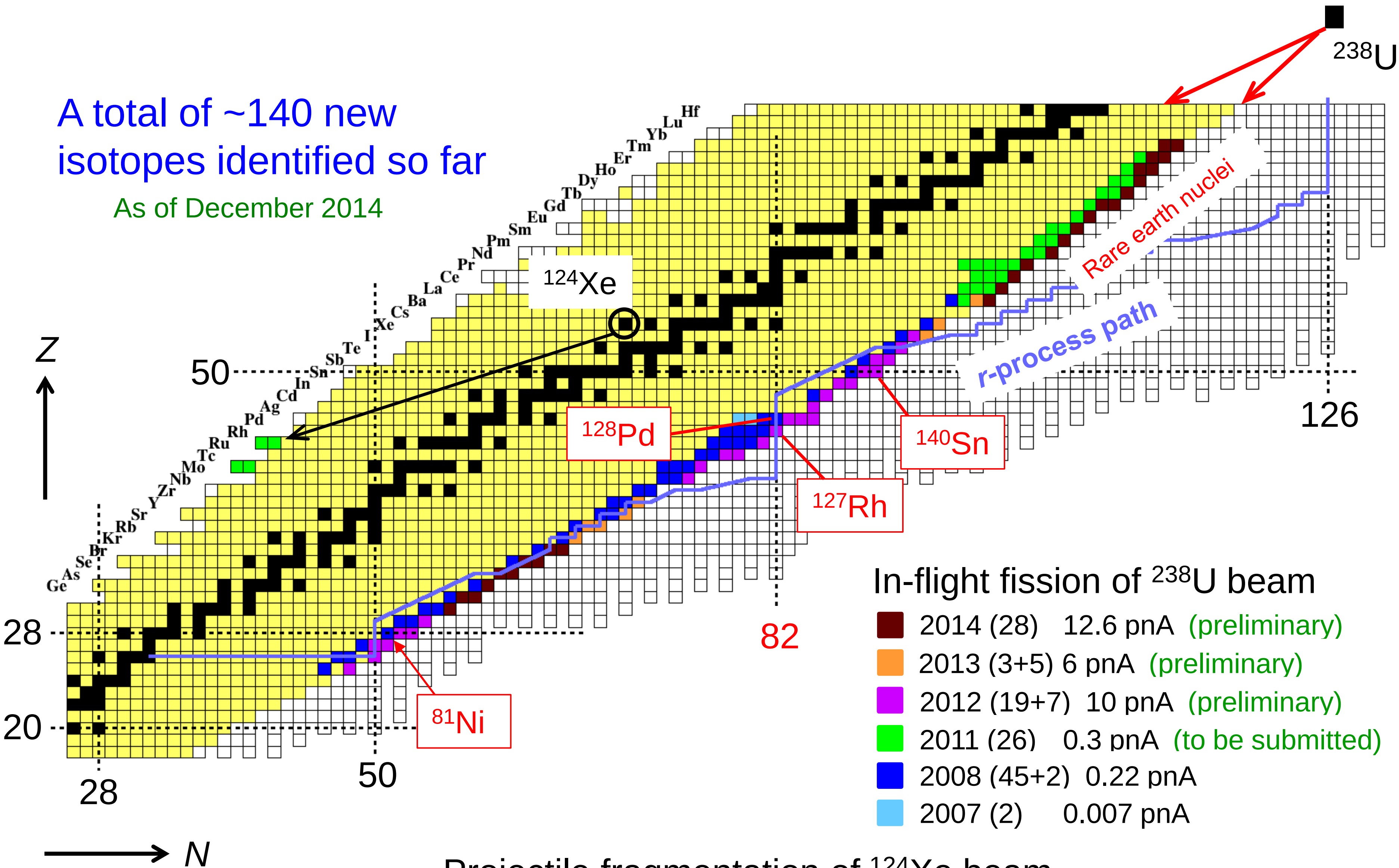
4 new
isotopes



Summary of new isotopes observed at RIBF

A total of ~140 new isotopes identified so far

As of December 2014



In-flight fission of ^{238}U beam

- 2014 (28) 12.6 pnA (preliminary)
- 2013 (3+5) 6 pnA (preliminary)
- 2012 (19+7) 10 pnA (preliminary)
- 2011 (26) 0.3 pnA (to be submitted)
- 2008 (45+2) 0.22 pnA
- 2007 (2) 0.007 pnA

Projectile fragmentation of ^{124}Xe beam

- 2011 (4) ^{124}Xe: 9 pnA

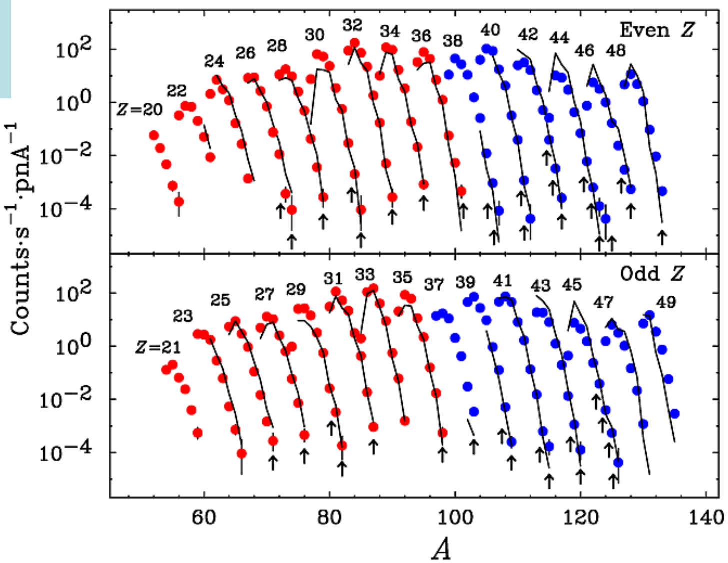
Outline of my talk

- Brief introduction of RIKEN RIBF and BigRIPS separator
- Neutron drip-line search using a ^{48}Ca beam at 345 MeV/u: search for ^{33}F, ^{36}Ne and ^{39}Na
- Overview of search for a wide range of new isotopes using in-flight fission of a ^{238}U beam at 345 MeV/u
- Production rate measurements Comparison with predictions
- Summary and perspective

Measured production yields compared with LISE++ AF-model predictions

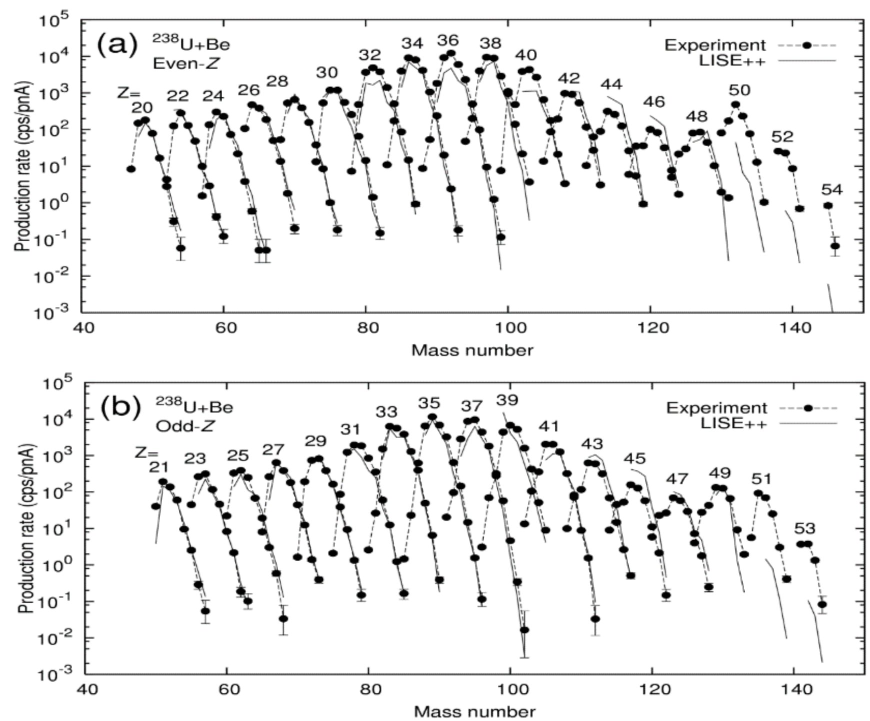
Fission fragments

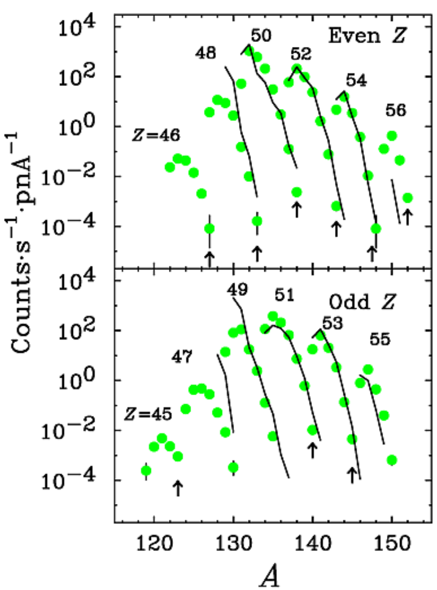
^{238}U 345MeV/u + Be (Abrasion fission)
2008 experiment



● Z~30 setting
● Z~40 setting

^{238}U 345MeV/u + Be (Abrasion fission)
2007 experiment





^{238}U 345MeV/u + Pb
(Coulomb fission)
2008 experiment

● Z~50 setting

—— LISE++(ver. 8.4.1)

Fairly good agreement with LISE++ Abrasion Fission (AF) model except for heavy regions with Z > 50
→ Improvement is needed

Measured production cross sections of P.F. compared with EPAX predictions

EPAX3.01	——
EPAX2.15	----

^{48}Ca + Be at 345 MeV/u

- EPAX 2.15 better
- EPAX 3.01 underestimates

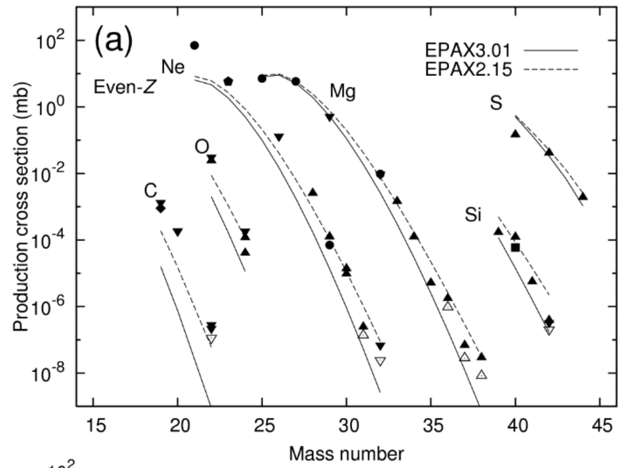
^{70}Zn + Be at 345 MeV/u

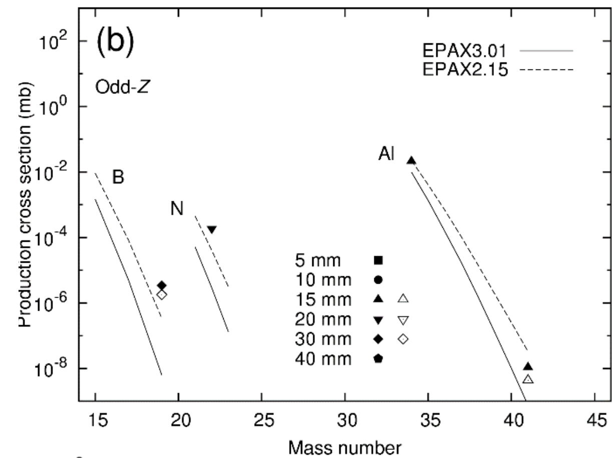
- For Z < 20, EPAX 2.15 better
  EPAX 3.01 underestimates
- For Z > 20, EPAX 3.01 better

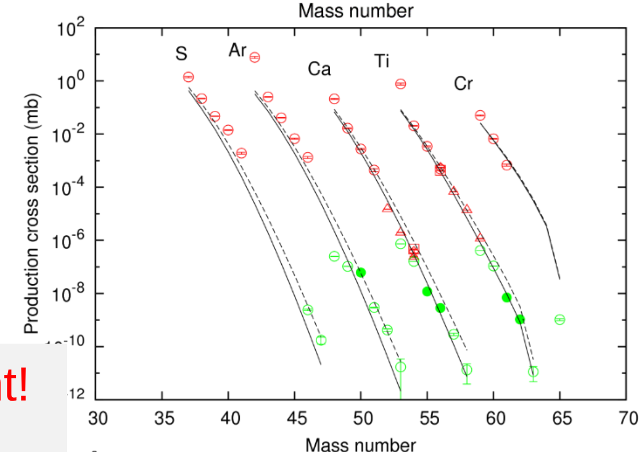
Overall fairly good agreement!
EPAX 2.15: better for lower Z
EPAX 3.01: better for higher Z

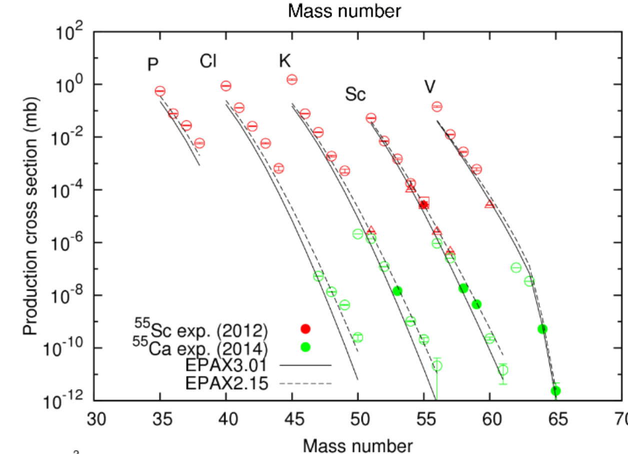
^{124}Xe + Be at 345 MeV/u

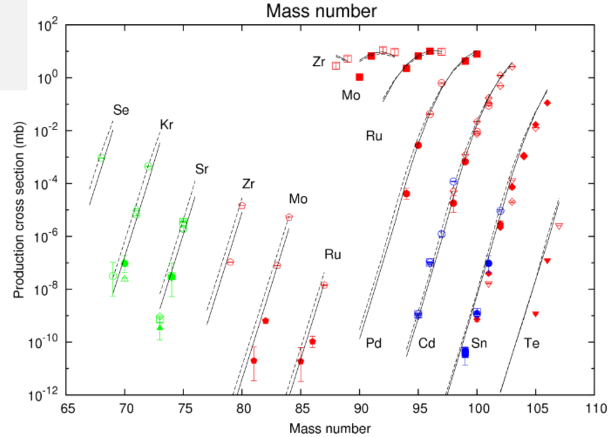
- EPAX 3.01 better
- Large discrepancy for very proton-rich isotopes: *e.g.* ^{100}Sn ~1/6, ^{73}Sr ~1/3

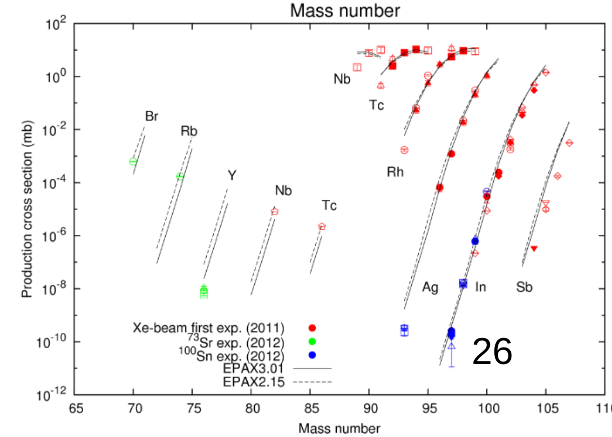




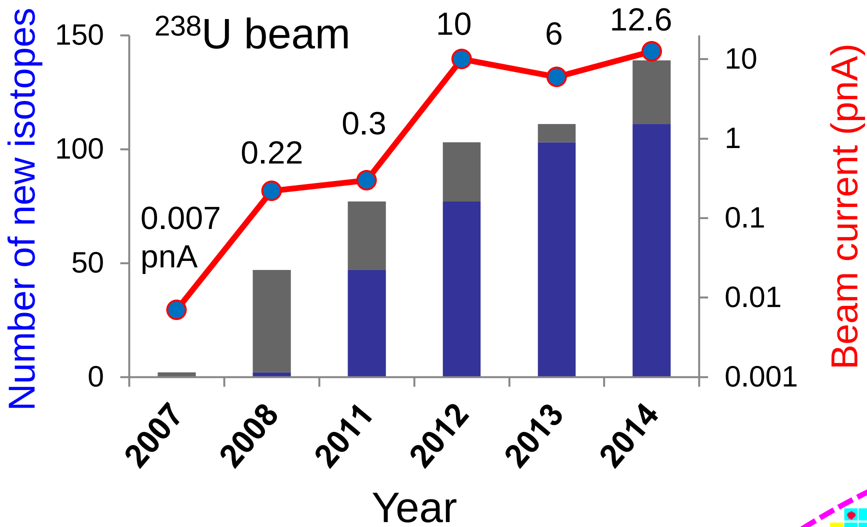






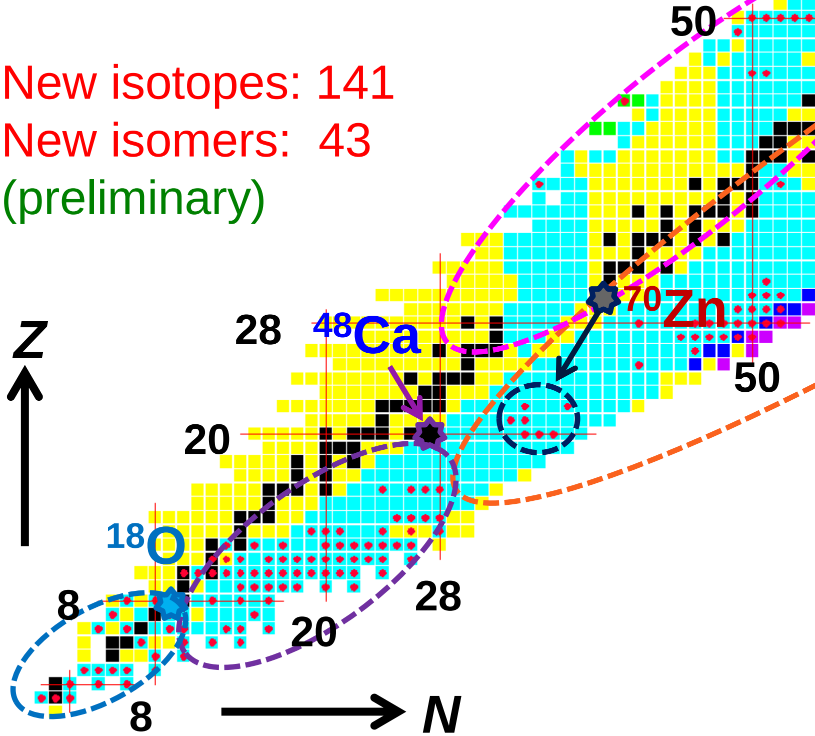
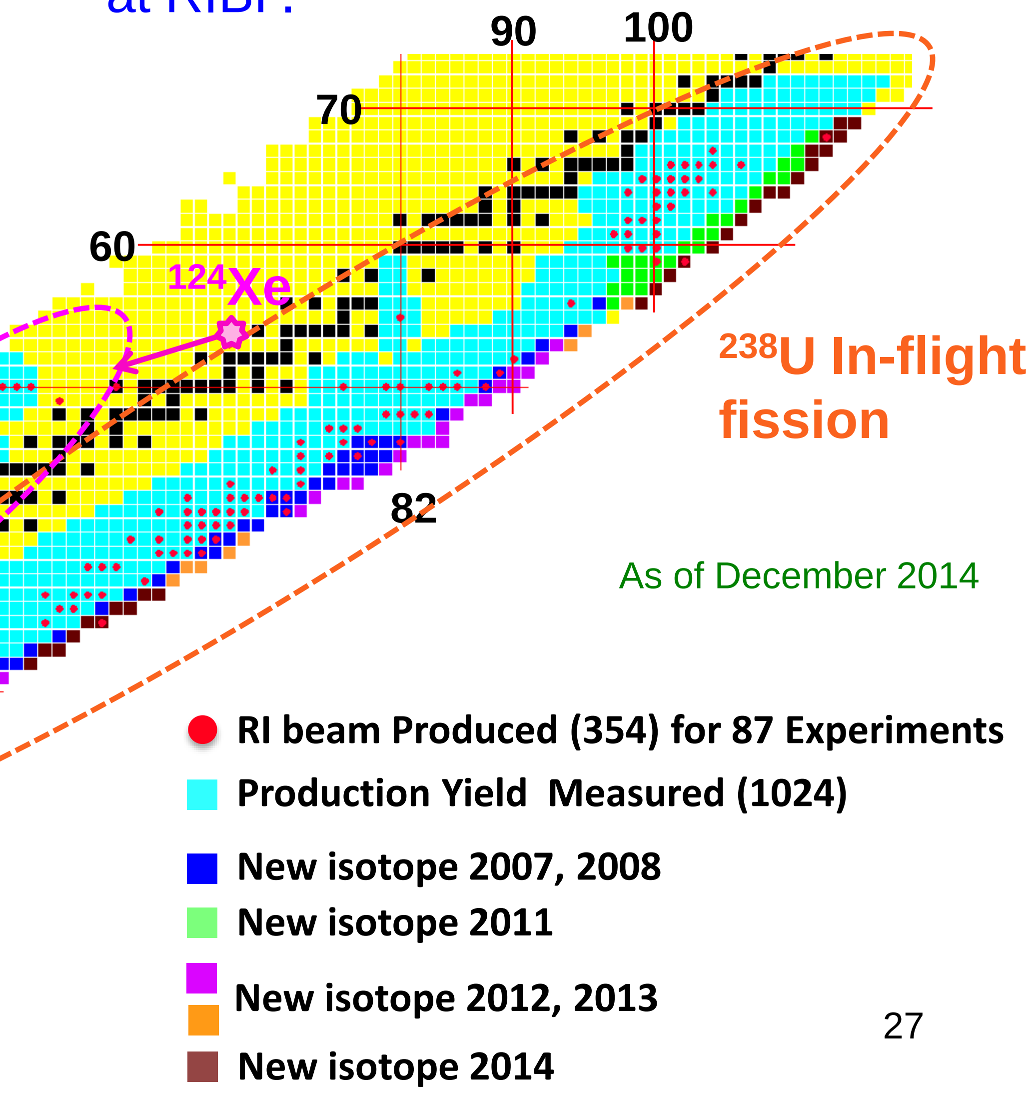


Summary



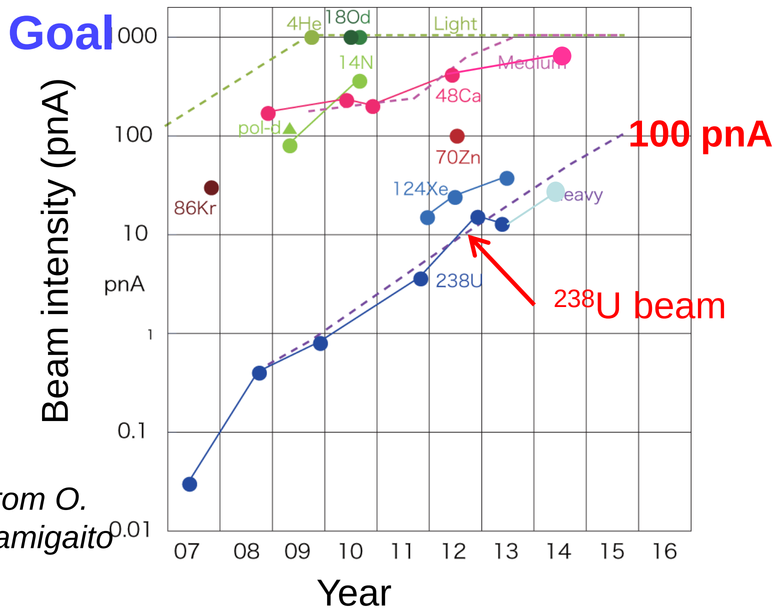
The frontiers of nuclear chart is expanding with the upgraded features at RIBF.

New isotopes: 141
New isomers: 43
(preliminary)

Perspective

Planned schedule of intensity upgrade

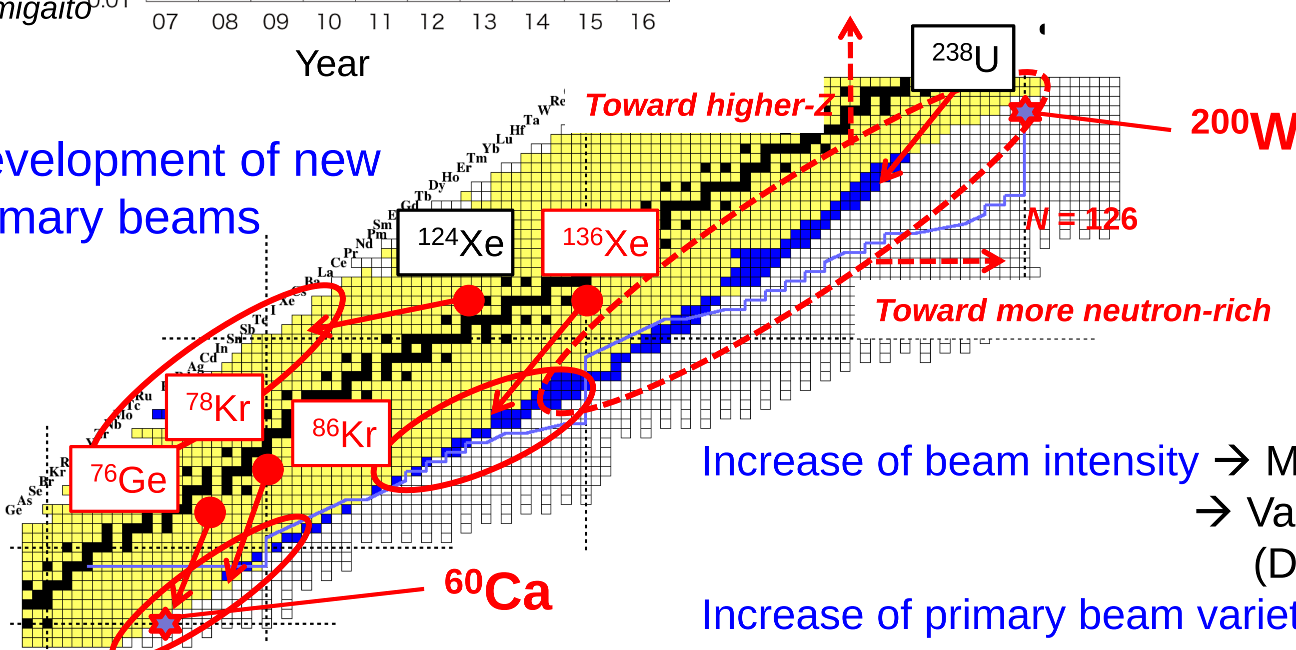


From O. Kamigaito

Present status of primary beams

Beam particle	E/A(MeV)	Beam current (pnA) Maximum record	Beam current (pnA) Expected ¶	Injector
d	250	1000	200	AVF
d(pol.)	250	120	30	AVF
^{4}He	320	1000	1000	AVF
^{14}N	250	400	400	RILAC
^{18}O	345	1000	500	RILAC
^{48}Ca	345	500-600	150	RILAC
^{70}Zn	345	123	100	RILAC
^{76}Ge	345	not tested	N/A	RILAC
^{78}Kr	345	under development	50	RILAC
^{86}Kr	345	30	50	RILAC
^{136}Xe	345	not tested	20	RILAC2
^{124}Xe	345	38	20	RILAC2
^{238}U	345	25	15	RILAC2

Development of new primary beams



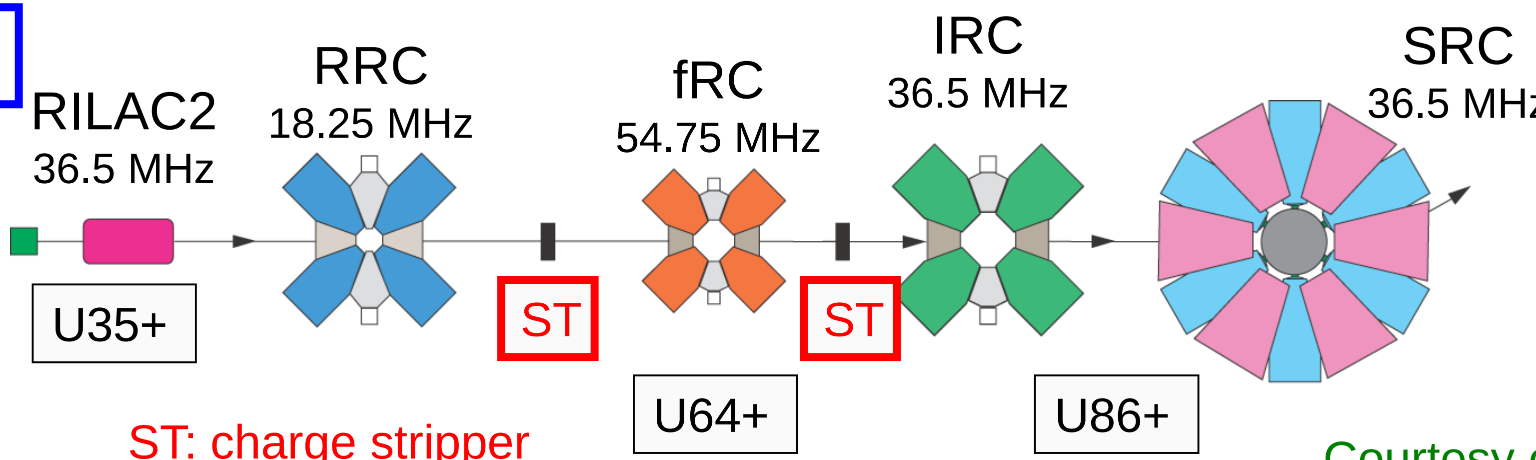
Increase of beam intensity → Much further from stability
→ Various types of experiments
(Decay → Reaction)

Increase of primary beam variety → Variety of RI beams

Long-term upgrade program at RIKEN RIBF

planned to further increase the beam intensity by skipping one charge stripper

Present

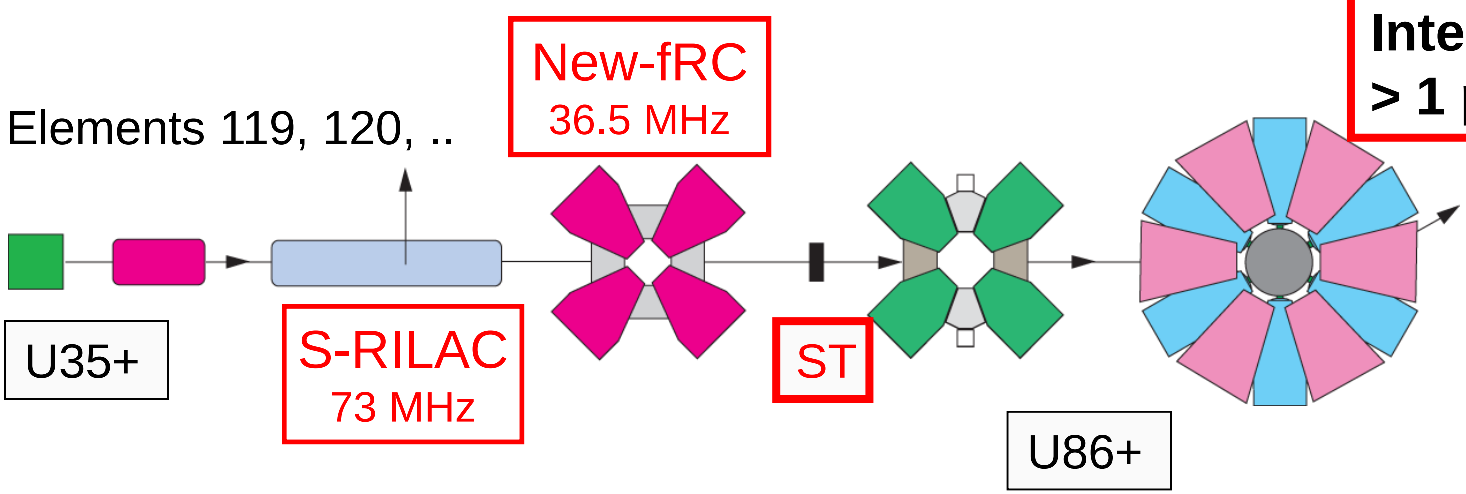


ST: charge stripper

Courtesy of O. Kamigaito, RIKEN

Upgrade plan

- Single stripping stage => New fRC
- Supercondcuting linac injector



Intensity > 1 pμA

Collaboration

2007 U experiment

T. Ohnishi, T. Kubo, K. Kusaka, A. Yoshida, K. Yoshida, N. Fukuda, M. Ohtake, Y. Yanagisawa, H. Takeda, D. Kameda, Y. Yamaguchi, N. Aoi, K. Yoneda, H. Otsu, S. Takeuchi, T. Sugimoto, Y. Kondo, H. Scheit, Y. Gono, H. Sakurai, T. Motobayashi, H. Suzuki, T. Nakao, H. Kimura, Y. Mizoi, M. Matsushita, K. Ieki, T. Kuboki, T. Yamaguchi, T. Suzuki, A. Ozawa, T. Moriguchi, Y. Yasuda, T. Nakamura, T. Nannichi, T. Shimamura, Y. Nakayama, H. Geissel, H. Weick, J.A. Nolen, O.B. Tarasov, A.S. Nettleton, D.P. Bazin, B.M. Sherrill, D.J. Morrissey, W. Mittig

2008 U experiment

T. Ohnishi, T. Kubo, K. Kusaka, A. Yoshida, K. Yoshida, M. Ohtake, N. Fukuda, H. Takeda, D. Kameda, K. Tanaka, N. Inabe, Y. Yanagisawa, Y. Gono, H. Watanabe, H. Otsu, H. Baba, T. Ichihara, Y. Yamaguchi, M. Takechi, S. Nishimura, H. Ueno, A. Yoshimi, H. Sakurai, T. Motobayashi, T. Nakao, Y. Mizoi, M. Matsushita, K. Ieki, N. Kobayashi, K. Tanaka, Y. Kawada, N. Tanaka, S. Deguchi, Y. Satou, Y. Kondo, T. Nakamura, K. Yoshinaga, C. Ishii, H. Yoshii, Y. Miyashita, N. Uematsu, Y. Shiraki, T. Sumikama, J. Chiba, E. Ideguchi, A. Saito, T. Yamaguchi, I. Hachiuma, T. Suzuki, T. Moriguchi, A. Ozawa, T. Ohtsubo, M.A. Famiano, H. Geissel, A.S. Nettleton, O.B. Tarasov, D.P. Bazin, B.M. Sherrill, S.L. Manikonda, J.A. Nolen

2011 U experiment

D. Kameda, T. Kubo, N. Inabe, N. Fukuda, H. Takeda, H. Suzuki, K. Yoshida, K. Kusaka, K. Tanaka, Y. Yanagisawa, M. Ohtake, H. Sato, Y. Shimizu, H. Baba, M. Kurokawa, D. Nishimura, T. Ohnishi, S. Go, R. Yokoyama, T. Fujii, E. Ideguchi, A. Chiba, T. Yamada, N. Iwasa, D. Murai, K. Ieki, S. Momota, H. Nishibata, O. B. Tarasov, D. J. Morrissey, B. M. Sherrill, J. Hwang, S. Kim, Y. Sato, G. Simpson

2011 Xe-124 experiment

D. Kameda, T. Kubo, N. Inabe, N. Fukuda, H. Takeda, H. Suzuki, K. Yoshida, K. Kusaka, K. Tanaka, Y. Yanagisawa, M. Ohtake, H. Sato, Y. Shimizu, H. Baba, M. Kurokawa, D. Nishimura, S. Go, R. Yokoyama, T. Fujii, E. Ideguchi, A. Chiba, Y. Okoda, N. Iwasa, D. Murai, K. Ieki, S. Momota, H. Nishibata, M. Lewitowicz, G. de France, I. Celikovic, K. Steiger, D. Bazin, O. B. Tarasov, D. J. Morrissey, B. M. Sherrill

2012 & 2013 EURICA U experiment

Y. Shimizu, T. Kubo, N. Inabe, N. Fukuda, H. Takeda, D. Kameda, H. Suzuki, K. Yoshida, K. Kusaka, Y. Yanagisawa, M. Ohtake, D. Murai,

<u>G.S. Simpson</u>, <u>A. Jungclaus</u>, G. Gey, J. Taprogge, S. Nishimura, P. Doornenbal, G. Lorusso, P.-A. Soederstroem, T. Sumikama, and Z. Xu (Exp# RIBF85)

<u>G. Lorusso</u>, <u>H. Watanabe</u>, H. Baba, F. Browne, P. Doornenbal, G. Gey, T. Isobe, Z. Li, S. Nishimura, P.-A. Soderstrom, T. Sumikama, J. Taprogge, Zs. Vajta, J. Wu Z.Y. Xu (Exp# RIBF60&62R1)

Collaboration (cont.)

2014 April U experiment

N. Fukuda, N.Inabe, T.Kubo, D.Kameda, H.Suzuki, H.Takeda, D.S.Ahn, D.Murai, K.Yoshida, K.Kusaka, Y.Yanagisawa, M.Ohtake, Y.Shimizu, Y.Sato, H.Sato, Y.Sato, H.Otsu, H.Baba, G. Lorusso, P.-A.Söderström, T.Isobe, N.Imai, M.Mukai, S.Kimura, H.Miyatake, N.Iwasa, A.Yagi, R.Yokoyama, O.B.Tarasov, H.Geissel

2014 Oct U experiment

Y. Shimizu, T. Kubo, N. Inabe, D.S. Ahn, N. Fukuda, K. Kusaka, D. Murai, M. Ohtake, H. Suzuki, H. Takeda, Y. Yanagisawa, K. Yoshida, Y. Hirayama, Y. Ichikawa, N. Imai, T. Isobe, N. Iwasa, S.A. Jeong, D. Kim, E.H. Kim, H. Miyatake, M. Mukai, S. kimura, H. Otsu, H. Sato, Y. Sato, T. Sonoda, A. Yagi

2014 Dec Ca-48 experiment

N. Inabe, N. Fukuda, H. Takeda, H. Suzuki, D.S. Ahn, Y. Shimizu, D. Murai, H. Sato, Y. Sato, K. Kusaka, Y. Yanagisawa, M. Ohtake, K. Yoshida, H. Otsu, N. Iwasa, T. Nakamura, O. Tarasov, B. Sherrill, D. Morrissey, H. Geissel, T. Kubo

Thank you for your attention!

LISE++ abrasion-fission model: for predicting cross sections

By Oleg Tarasov

Three excitation energy regions (3 EERs) method

- Low excitation region: fission barrier < E^* < 40 MeV
- Middle excitation region: 40 MeV < E^* < 180 MeV
- High excitation region: 180 MeV < E^*

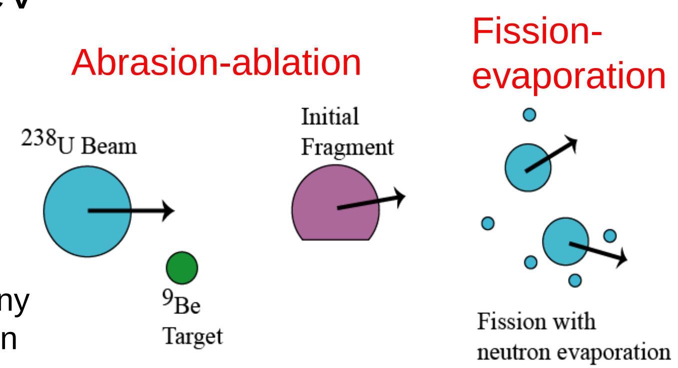
Parameters for ^{238}U + Be

	Low	Middle	High
fissile	$^{236}_{92}$U	$^{226}_{90}$Th	$^{220}_{84}$Ra
E^* MeV	23.5	100	250
σ mb	200	500	350

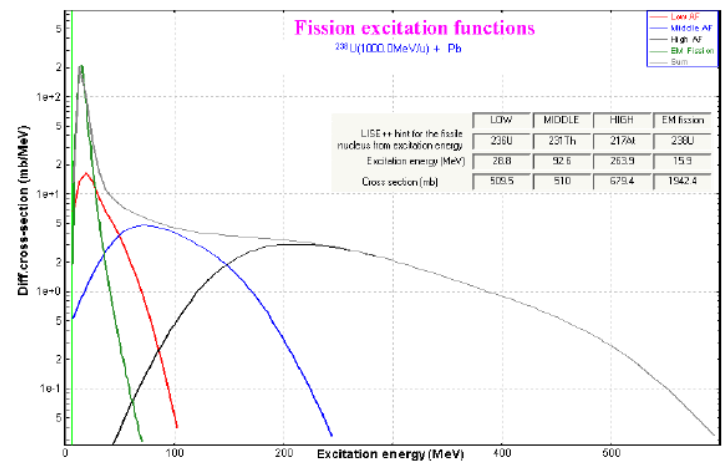
Parameters for ^{238}U + Pb

	Low	Middle	High
fissile	$^{238}_{92}$U	$^{230}_{90}$Th	$^{214}_{84}$Po
E^* MeV	17.3	100	300
σ mb	2280*	500	1300

* includes coulomb fission cross section



from Tony Nettleton



The parameters here are the standard ones in the LISE++ manual, and determined so as to fit the GSI cross section data.