The RI Beam Factory (RIBF) at RIKEN – Status and Future Prospects

Walter F. Henning
RIKEN Nishina Center

EURORIB12, Abano Terme, May 21-25, 2012

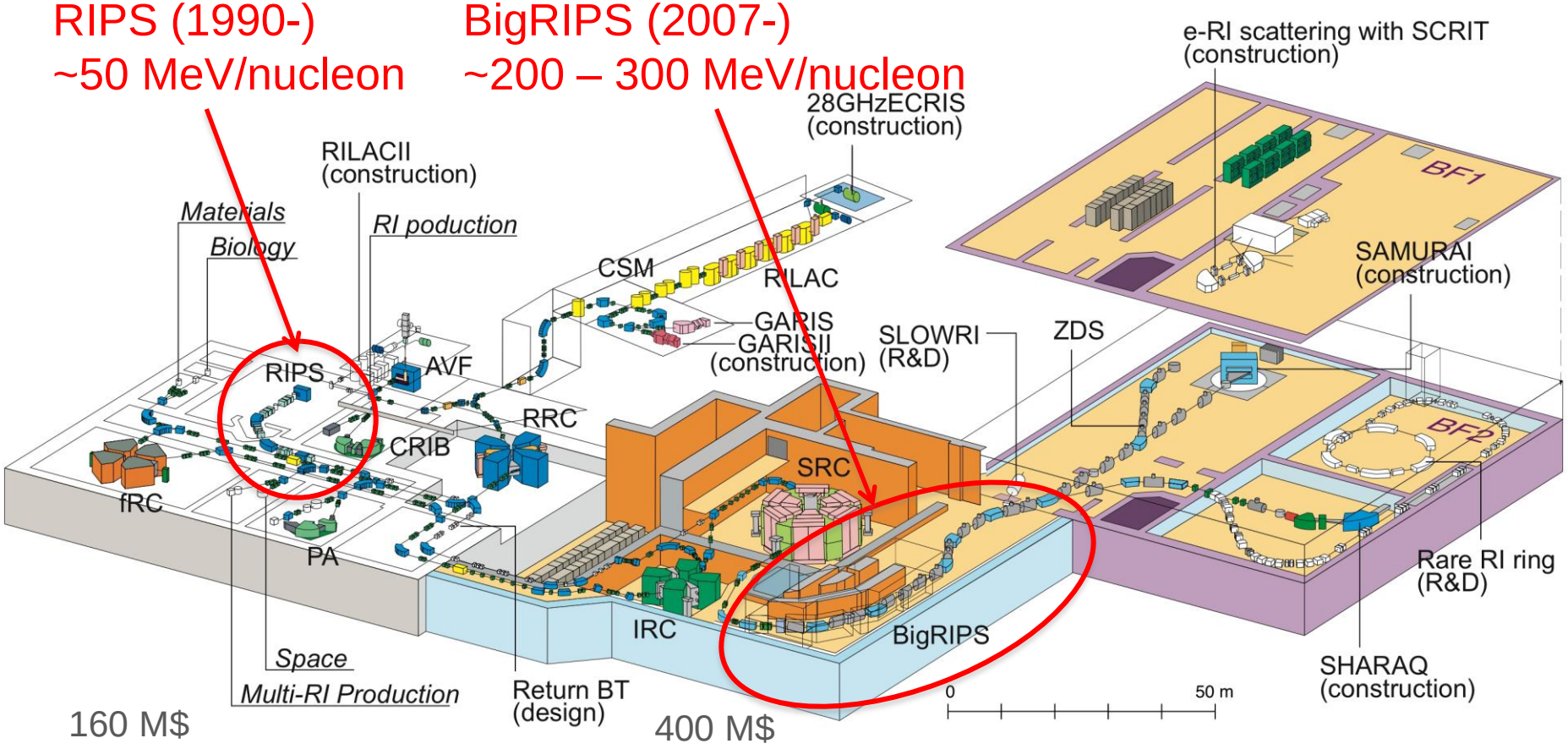
Outline

1. Status of RIBF
   - Facility and RIB capabilities
   - Present program
   - Recent results
2. New Initiatives in Experimental Facilities
   - SAMURAI
   - EURICA
   - Mass Ring
   - SCRIT
3. Accelerator Improvements & Extensions
   - Short-term upgrades
   - Long-term conceptual considerations
4. Outlook

RIBF (RI Beam Factory) – Layout

RIPS (1990-)
~50 MeV/nucleon

BigRIPS (2007-)
~200 – 300 MeV/nucleon



160 M$

135 MeV/nucleon
for light nuclei (1986-)

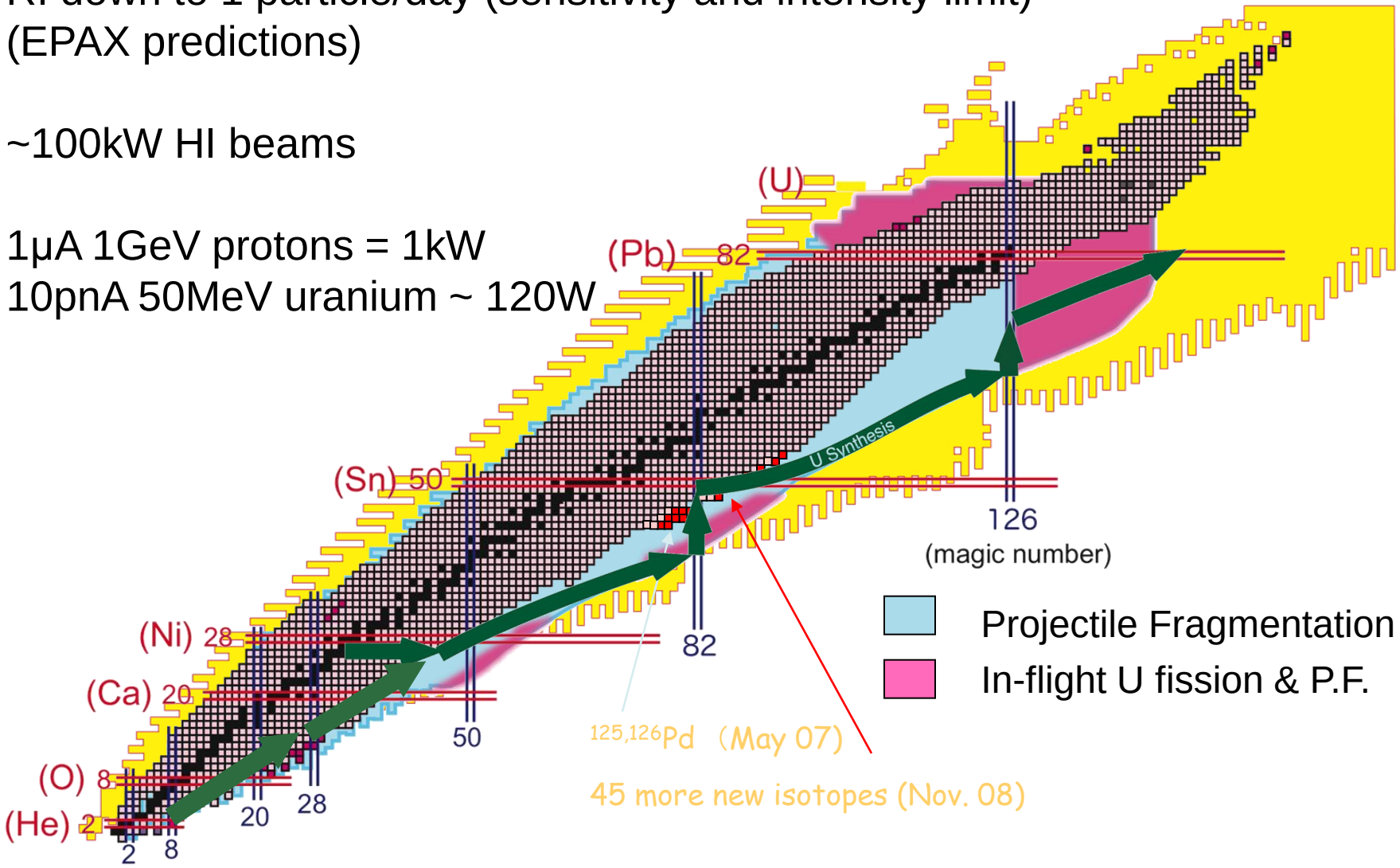
400 M$

345 MeV/nucleon
up to U (2006-)

Facility Goals:
RI down to 1 particle/day (sensitivity and intensity limit)
(EPAX predictions)

~100kW HI beams

1μA 1GeV protons = 1kW
10pnA 50MeV uranium ~ 120W



RIBF Layout

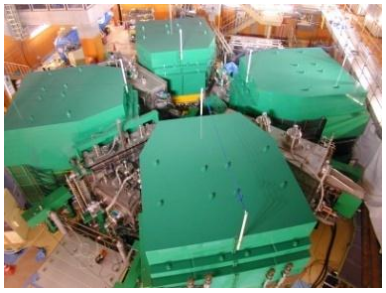
RILAC

RRC

RIPS

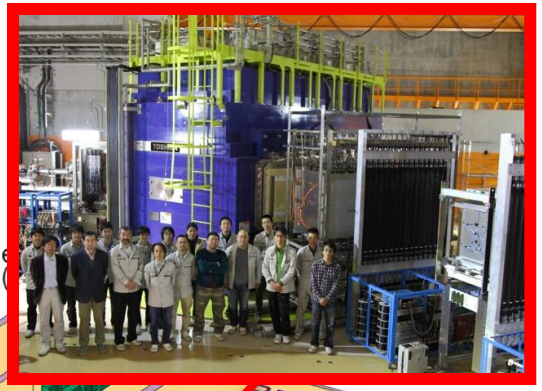
fRC

IRC

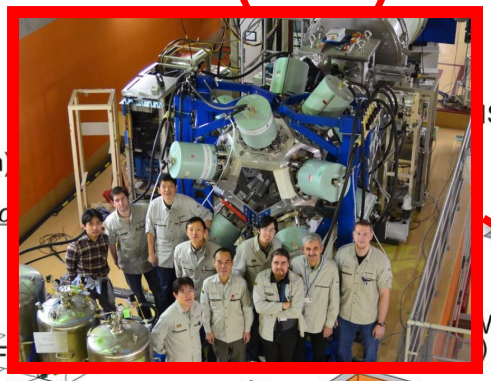


ZeroDegree (ZDS) (2008)

SAMURAI



EURICA (2012)



SRC (2007)

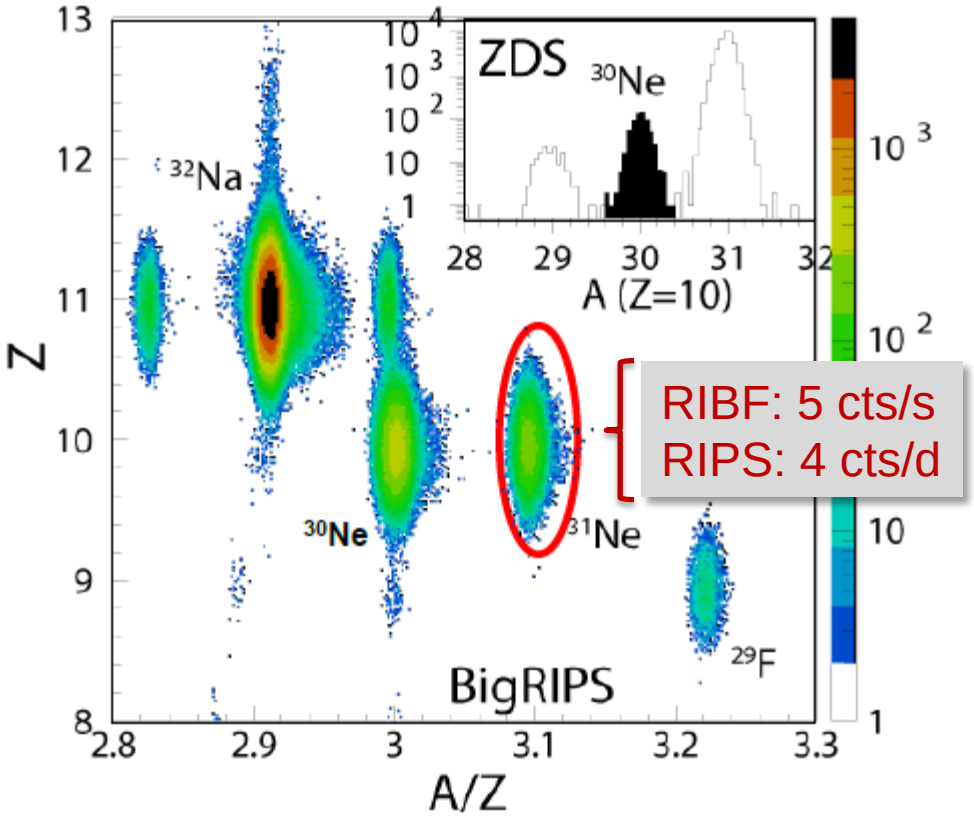
BigRIPS
(2007)

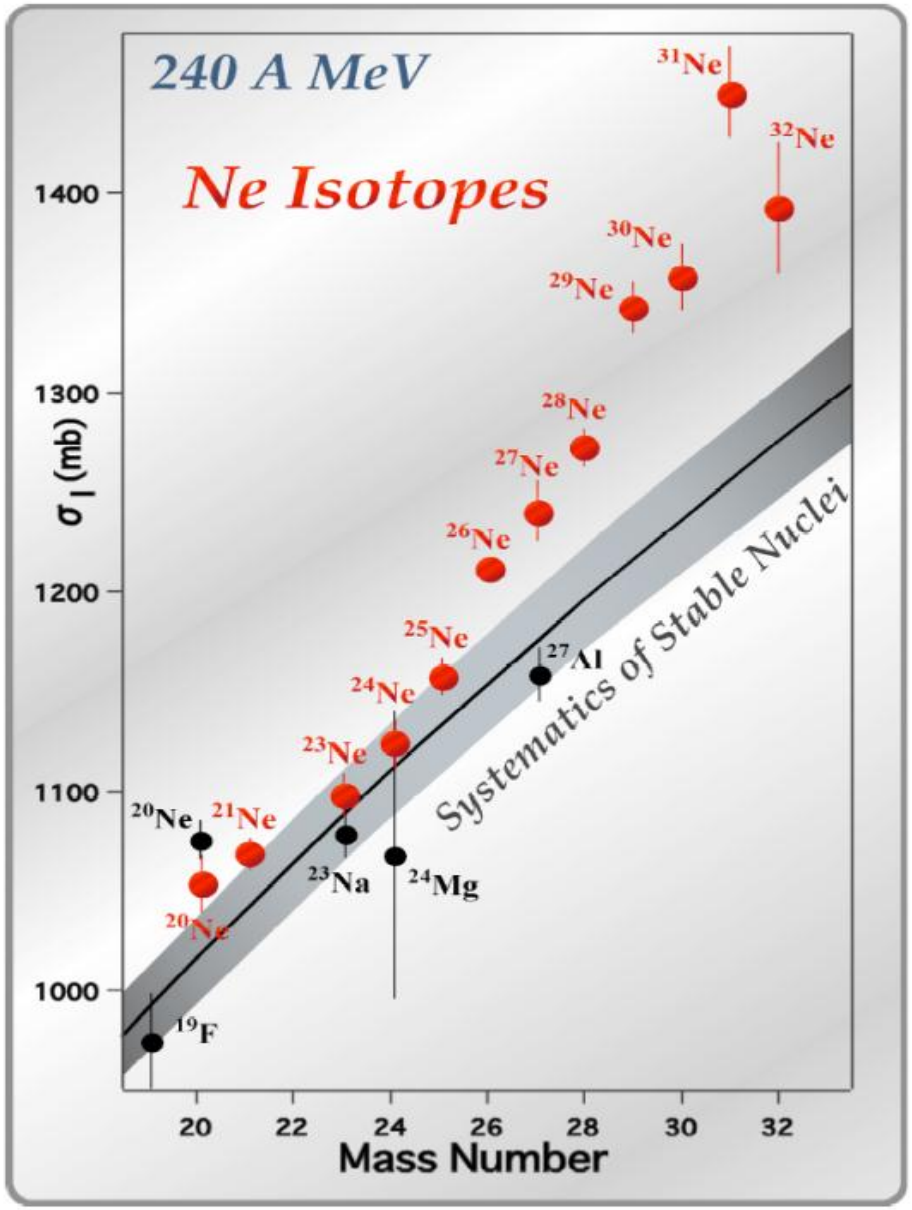
SHARAQ
(2009)

Approaching the Neutron-Dripline: Ne- Isotopes

Transmission & Interaction Cross Section Measurements

M. Takechi et al., Nucl. Phys. A 834 (2010) 412



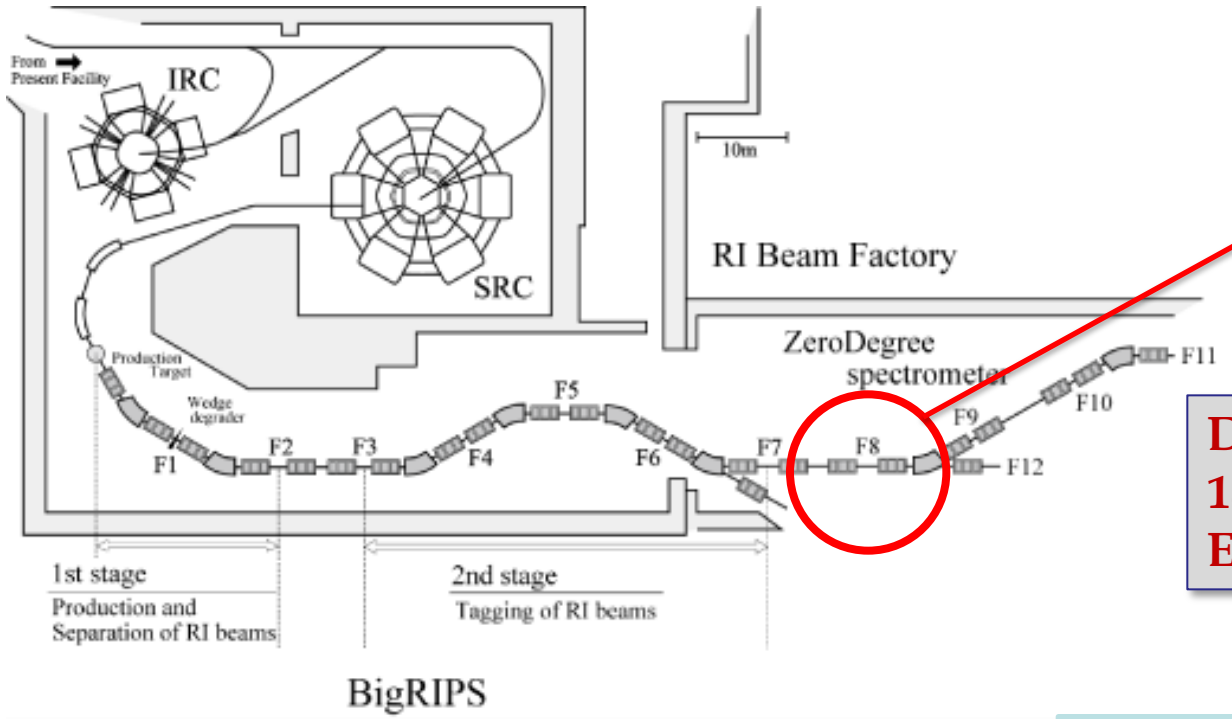


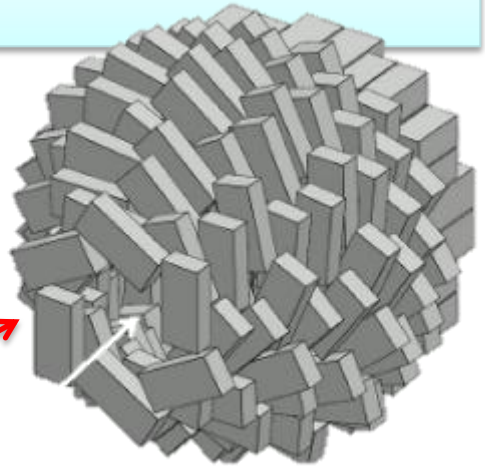
Spectroscopy in the Island of Inversion: ^{42}Si structure via gamma-ray spectroscopy following two-proton removal reaction

(Courtesy Satoshi Takeuchi)

Primary beam: ^{48}Ca 345*A* MeV -- Primary beam intensity: ~70 pnA (average)

Primary target: Be 15mm

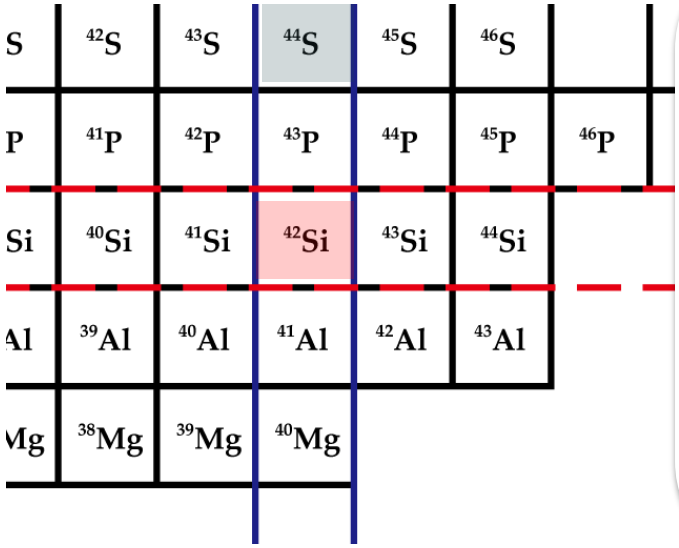


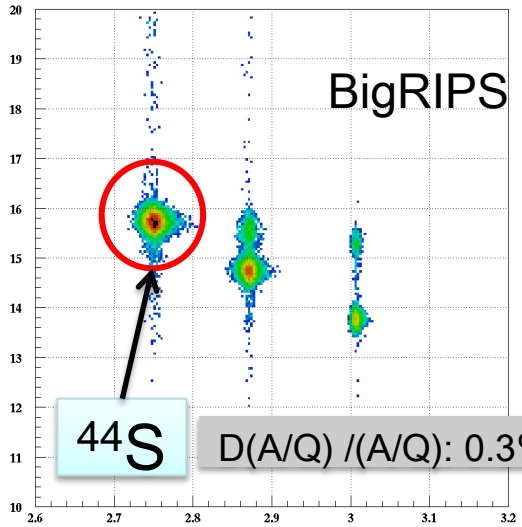


DALI2
186 NaI(Tl) crystals
Eff. : ~ 20% for 1 MeV (β~0.6)

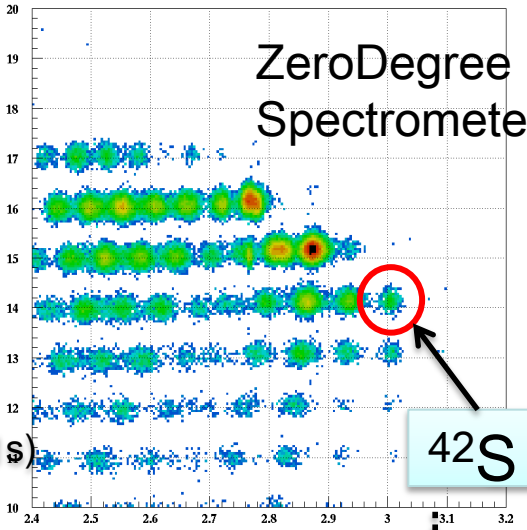
Secondary beam:	^{44}S 200*A* MeV
Beam intensity:	40k pps (average)
Reaction targets:	C 2.54g/cm^2

BigRIPS&ZDS
T. Kubo *et al.*, IEEE Trans. Appl. Supercond. **17**, 1069 (2007)
Y. Mizoi et al., RIKEN Accel. Prog. Rep. 38, 297 (2005)
DALI2
S. Takeuchi et al., RIKEN Accel. Prog. Rep. 36, 148 (2003)
S. Takeuchi et al., Phys.Rev. C, 79:054319, 2009.



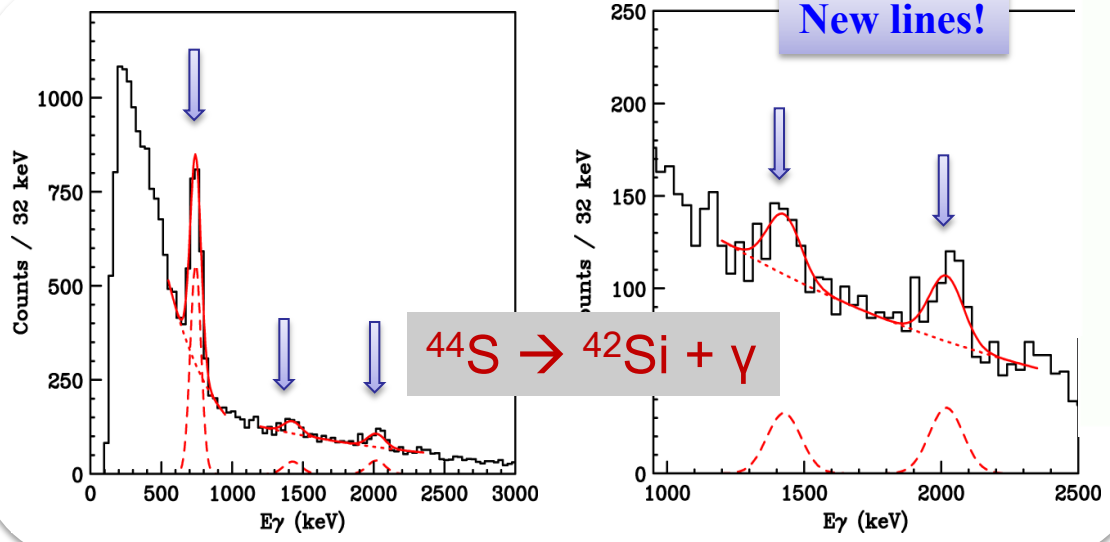


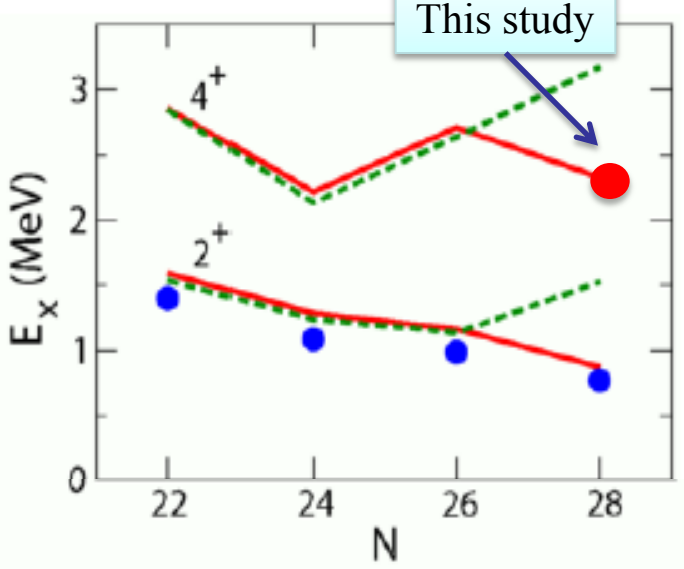
D(A/Q) /(A/Q): 0.3% (1s)



This study

$E_\gamma(2^+ \rightarrow 0^+) = 742(14)$ keV





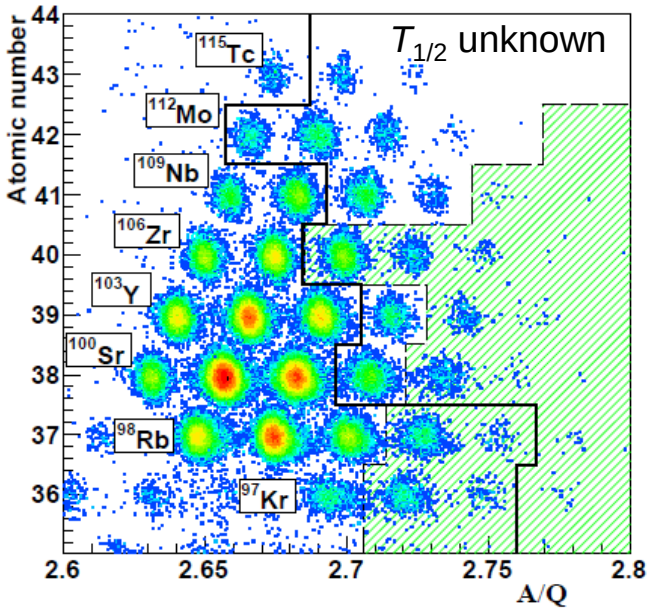
-- without tensor force → spherical min.
-- with tensor force → oblate min.

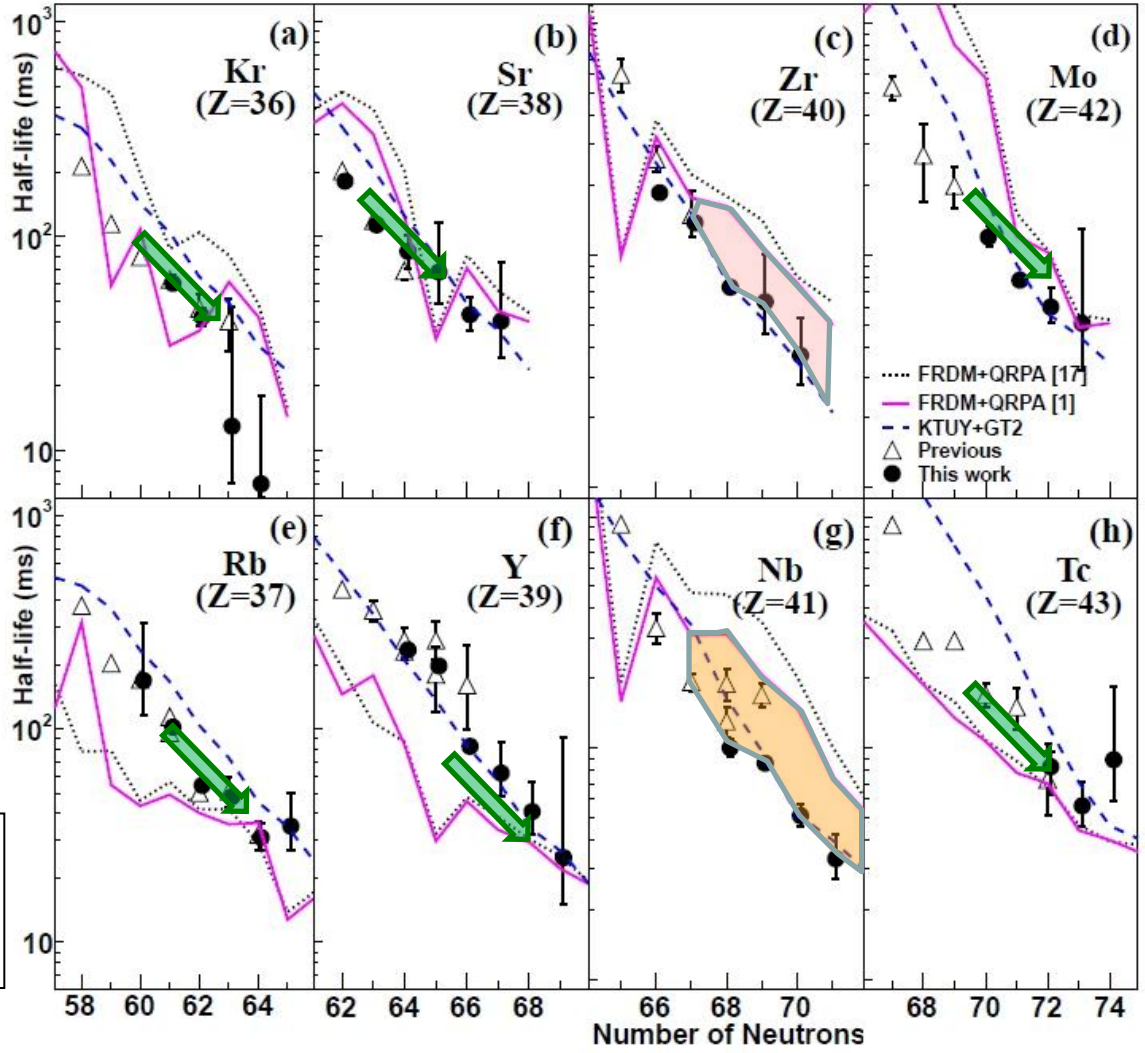
T.Otsuka et al., NPA 805 (2008) 127c

Toward the r-process path - β-decay half-lives (*A*~110)

Systematic studies of $T_{1/2}$ ←→ Mass, Q_β, S_n

Nishimura *et al.* PRL106, 052502 (2011)





- 8 hours data acquisition
- $T_{1/2}$ data of 38 isotopes including **first data for 18 isotopes**

$T_{1/2}$ are shorter for Zr/Nb compared with FRDM theories
→ more rapid r-process flow

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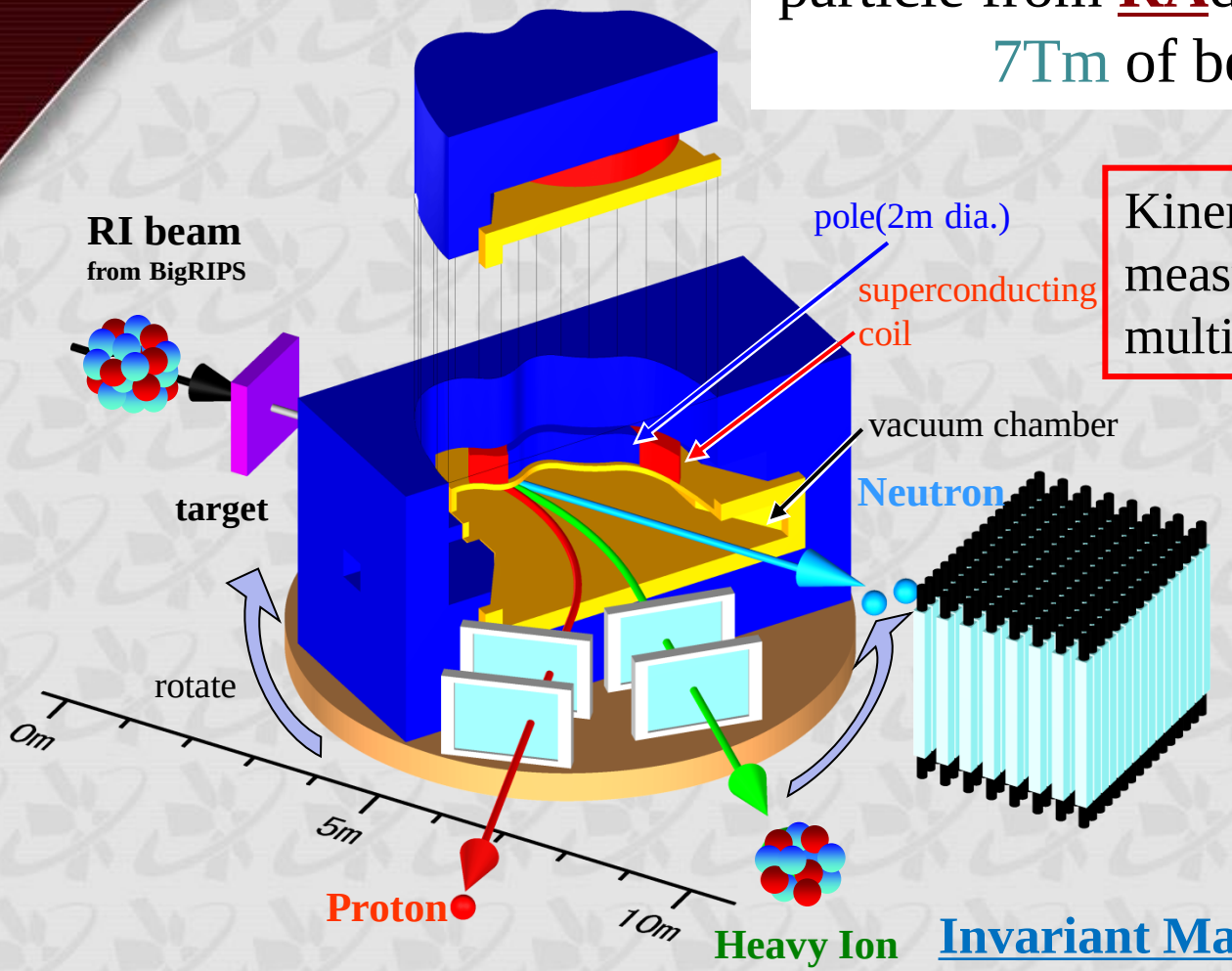
SAMURAI ~ A new spectrometer at RIBF ~

Superconducting **A**nalyzer for **MU**lti-particle from **RA**dio **I**sotope Beam with 7Tm of bending power



Kinematically complete measurements by detecting multiple particles in coincidence

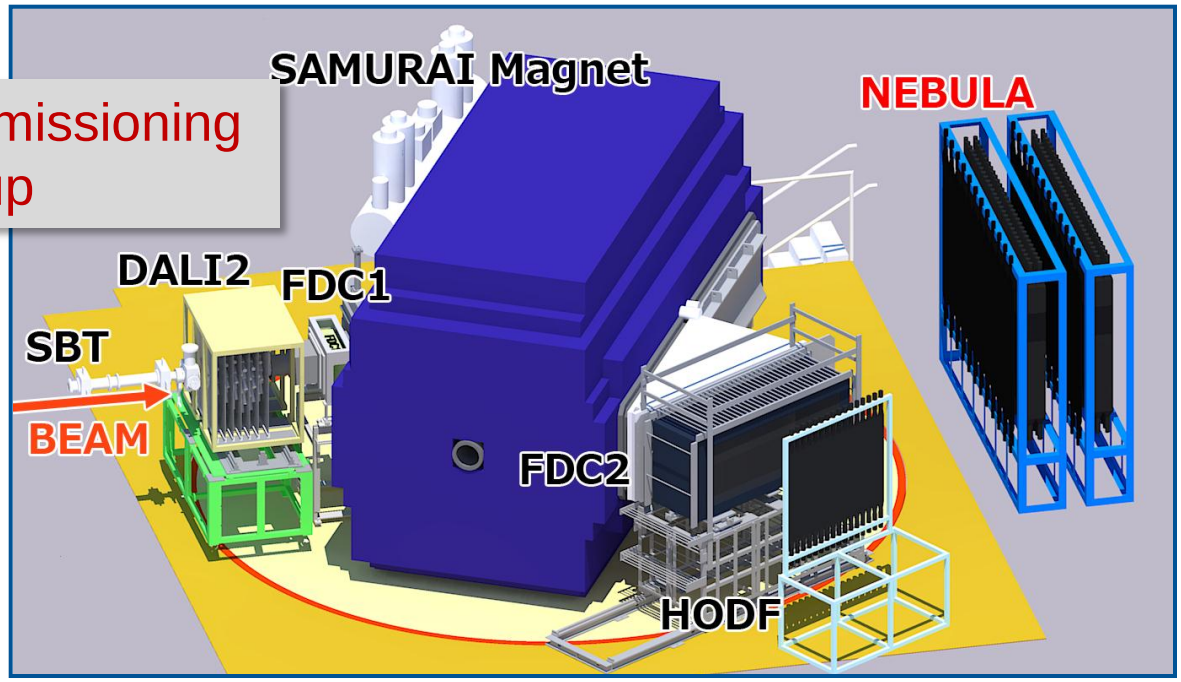
- Superconducting Magnet
  3T with 2m dia. pole
  (designed resolution 1/700)
  80cm gap (vertical)
- Heavy Ion Detectors
- Proton Detectors
- Neutron Detectors
- Large Vacuum Chamber
- Rotational Stage

Invariant Mass Measurement
Missing Mass Measurement

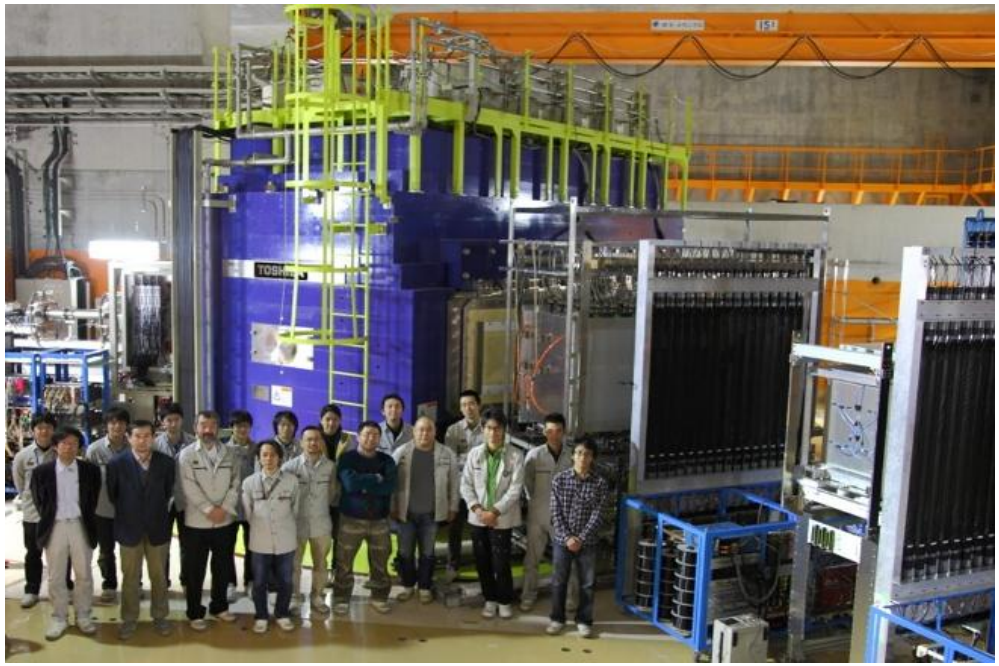
Courtesy of Yoneda

SAMURAI Commissioning
May 2012

Commissioning Set-up



- All the detectors and DAQ commissioned with beam and calibrated
- HI-neutron coincidences
  - $^{17}C \rightarrow {}^{16}C+n$ $^{15}B+n$
  - $^{15}C \rightarrow {}^{14}C+n$
  - $^{14}Be \rightarrow {}^{12}Be+2n$

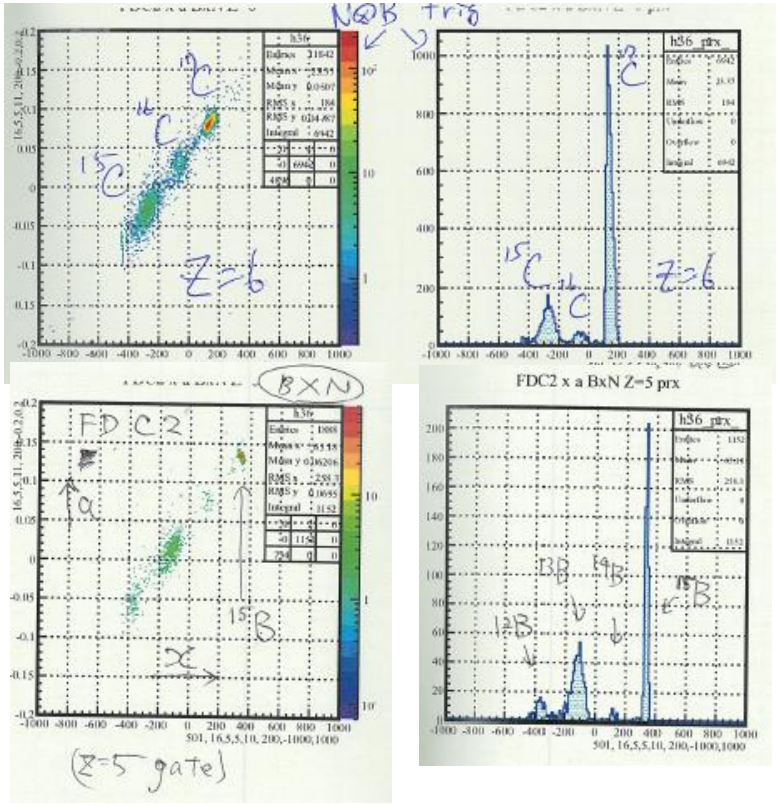


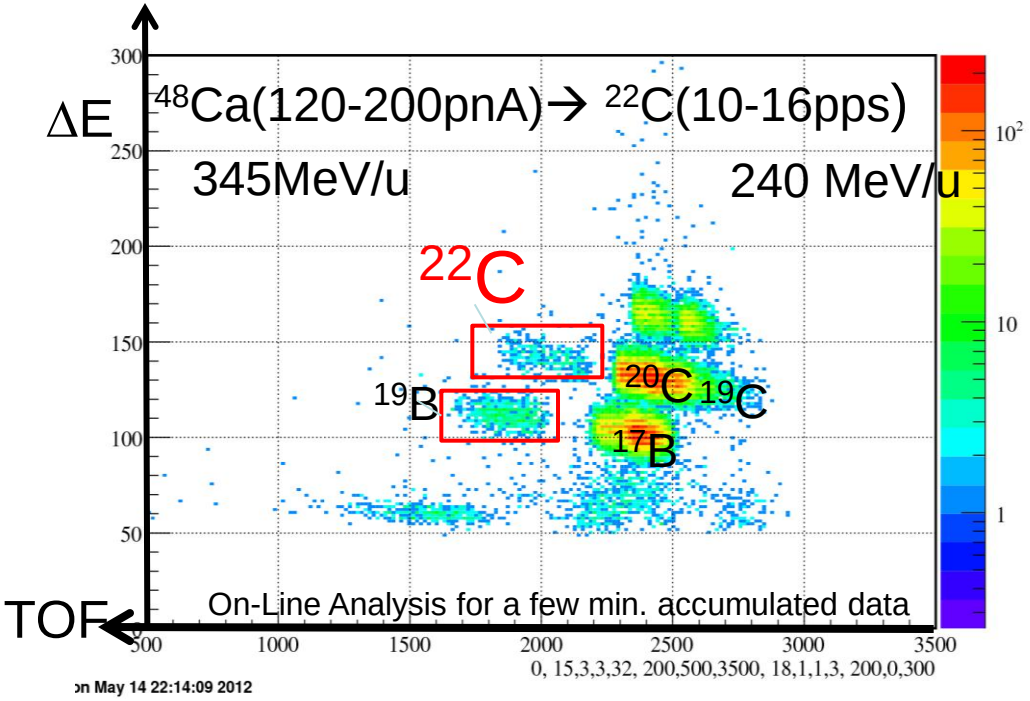
- **RIKEN**: K. Yoneda, N. Fukuda, N. Inabe, T. Isobe, T. Kubo, K. Kusaka, T. Motobayashi, J. Ohnishi, H. Otsu, H. Sato, Y. Shimizu, H. Suzuki, H. Takeda, S. Takeuchi
- **Tohoku U**: T. Kobayashi, K. Takahashi, K. Sekiguchi
- **Tokyo Tech**: T. Nakamura, N. Kobayashi, Y. Kondo, R. Minakata, S. Nishi, S. Ogoshi, T. Sako, R. Tanaka
- **Kyoto U**: Y. Matsuda, T. Murakami
- **Kyushu U**: T. Teranishi
- **France**: F. Delaunay, J. Gibelin, M. Miguel
- **Germany**: T. Aumann, Y. Togano
- **Korea**: Y. Sato, J. Hwang, S. Kim

RIKEN NiSHiNA CENTER

Courtesy
K. Yoneda
T. Nakamura

- "Spectroscopy of unbound oxygen isotopes"
  - Spokesperson: Yosuke Kondo (Tokyo Tech)
  - Observation of unbound oxygen isotopes
- "Exclusive Coulomb Breakup of neutron drip-line Nuclei"
  - Spokesperson: Takashi Nakamura (Tokyo Tech)
  - Coulomb breakup of neutron-rich boron and carbon isotopes
- "Structure of ^{18,19}B and ^{21,22}C"
  - Spokesperson: Nigel Orr/Julien Gibelin (LPC-Caen)
  - Observation of unbound states in neutron-rich boron and carbon isotopes

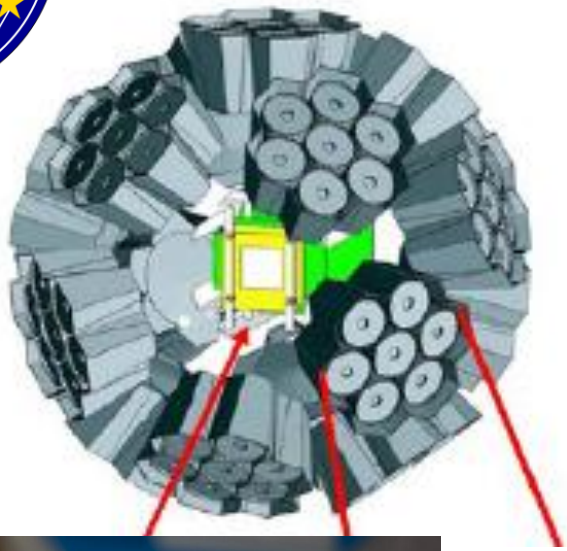


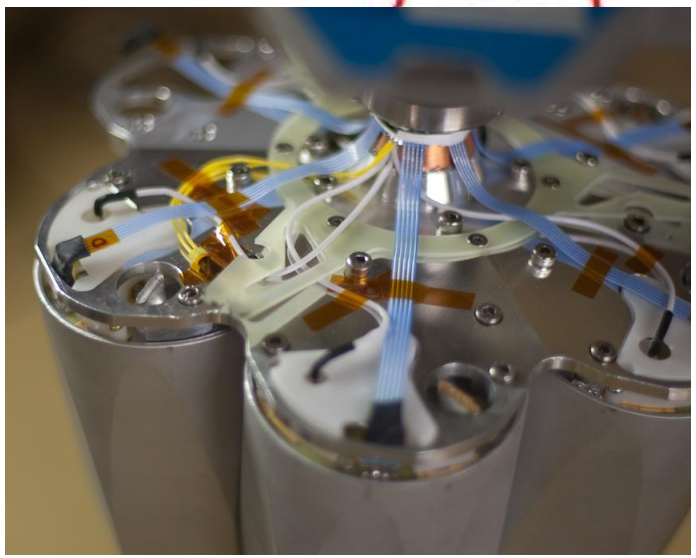


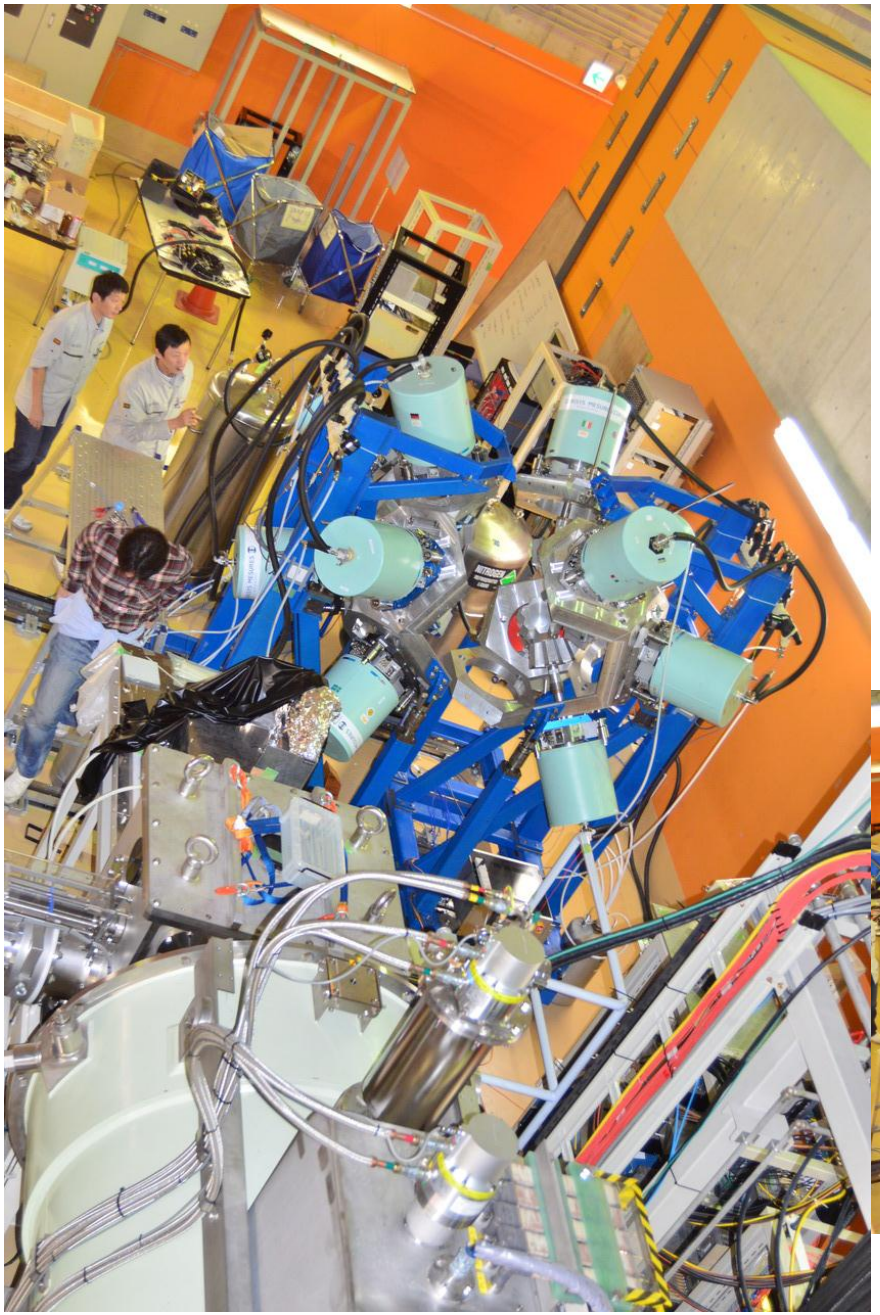
EUROBALL
RIKEN
Cluster
Array

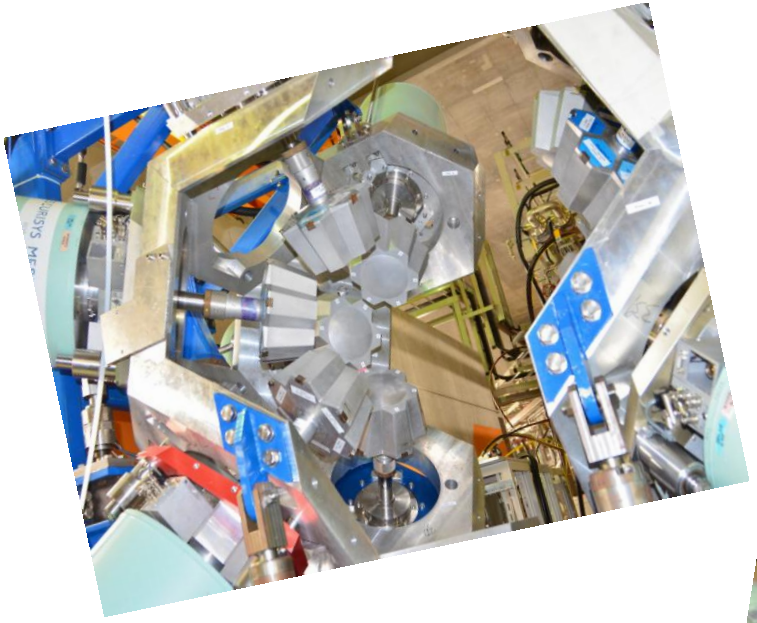
- Collaboration that uses high-efficiency Ge-spectrometer for isomeric and β-delayed spectroscopy at RIKEN
- 12 Cluster detectors
  - 84(88) crystals
    - High granularity
    - 15 % photopeak efficiency at 662 keV
- Ancillary detectors, e.g. the SIMBA array

EURICA Installation



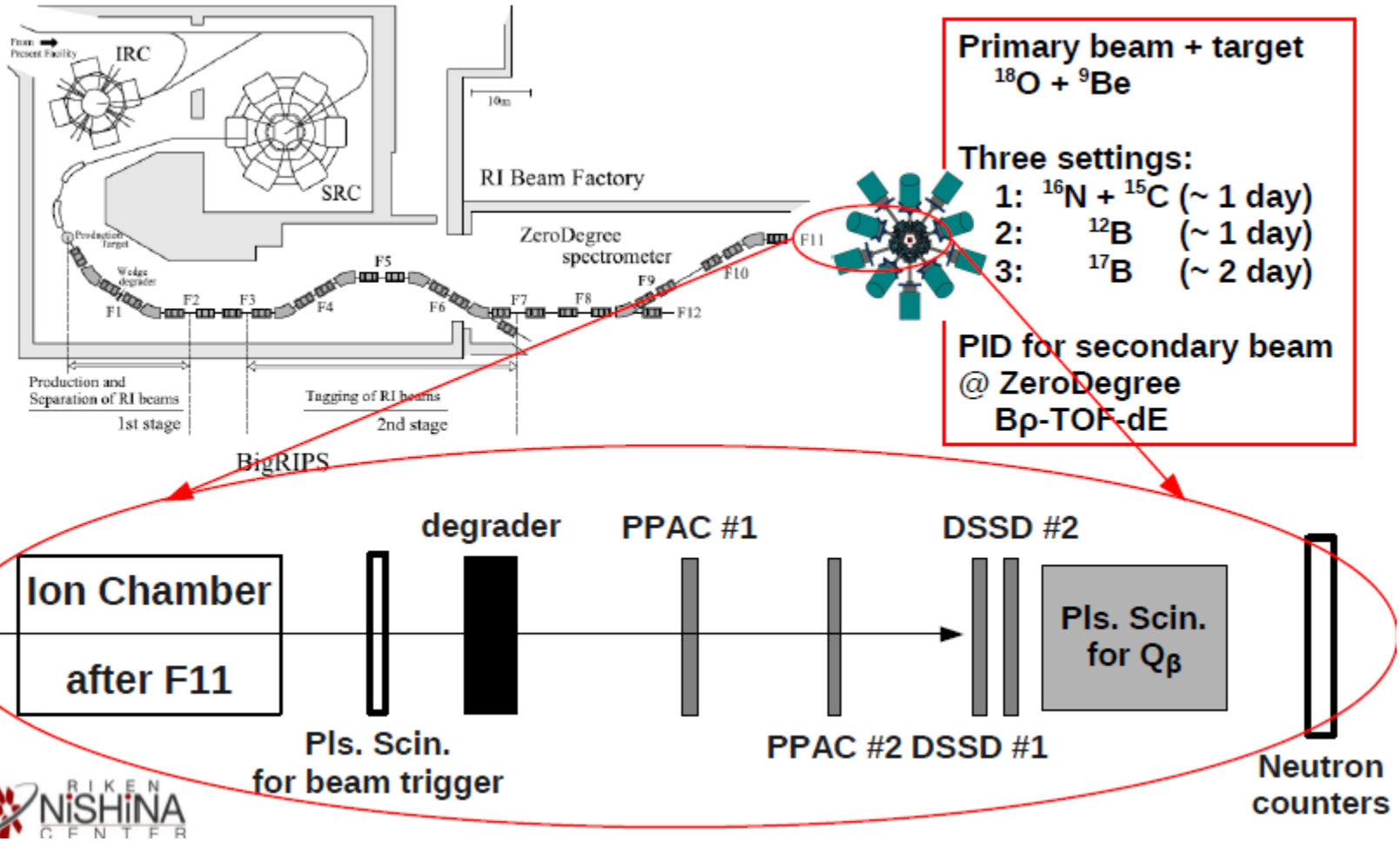




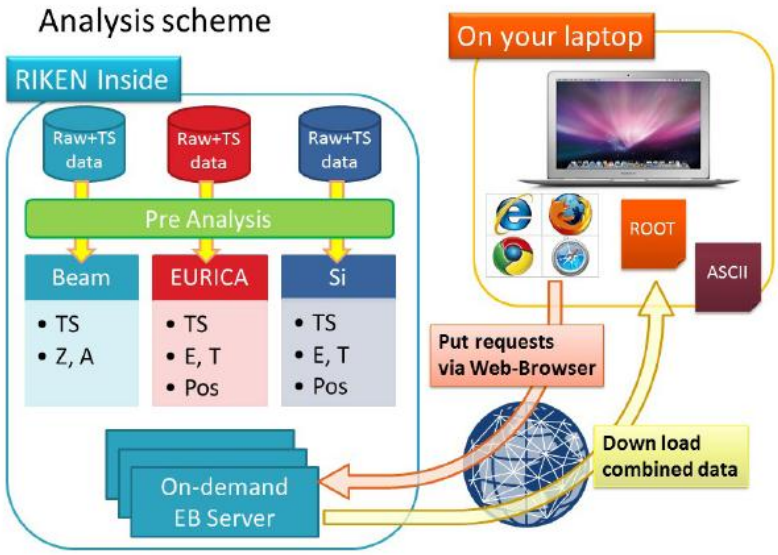


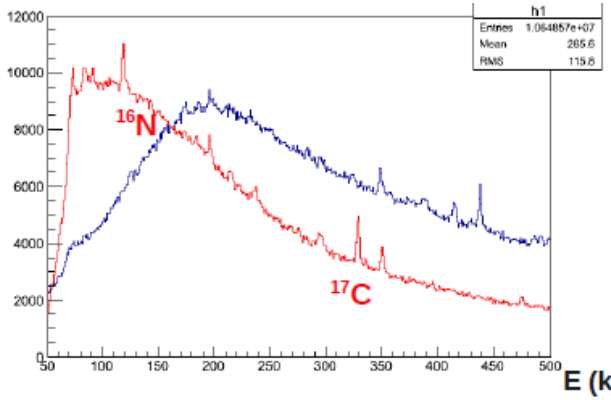

NIPPON
EXPRESS

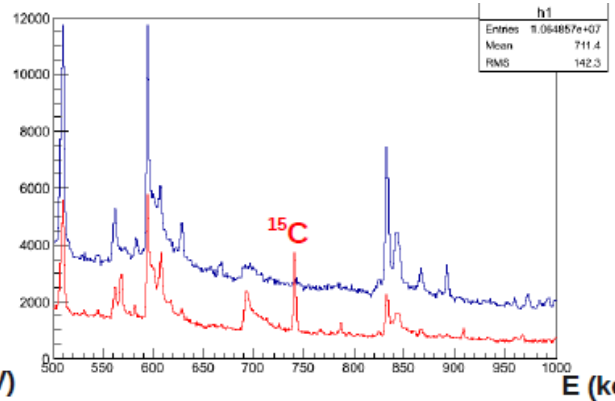
EURICA : Assembly and Commissioning

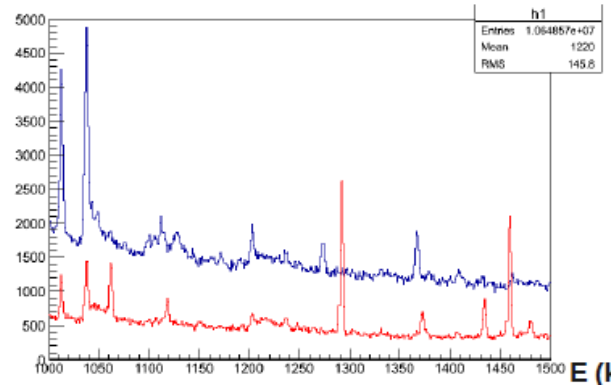


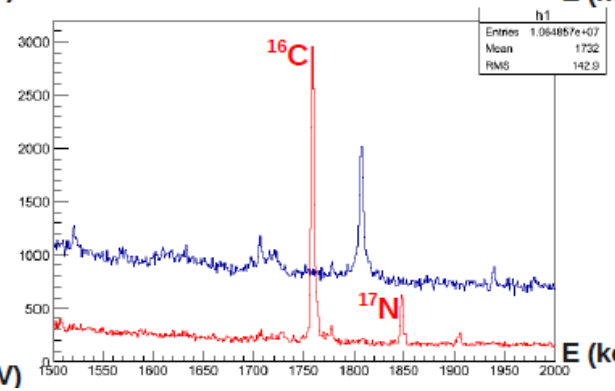
EURICA Commissioning



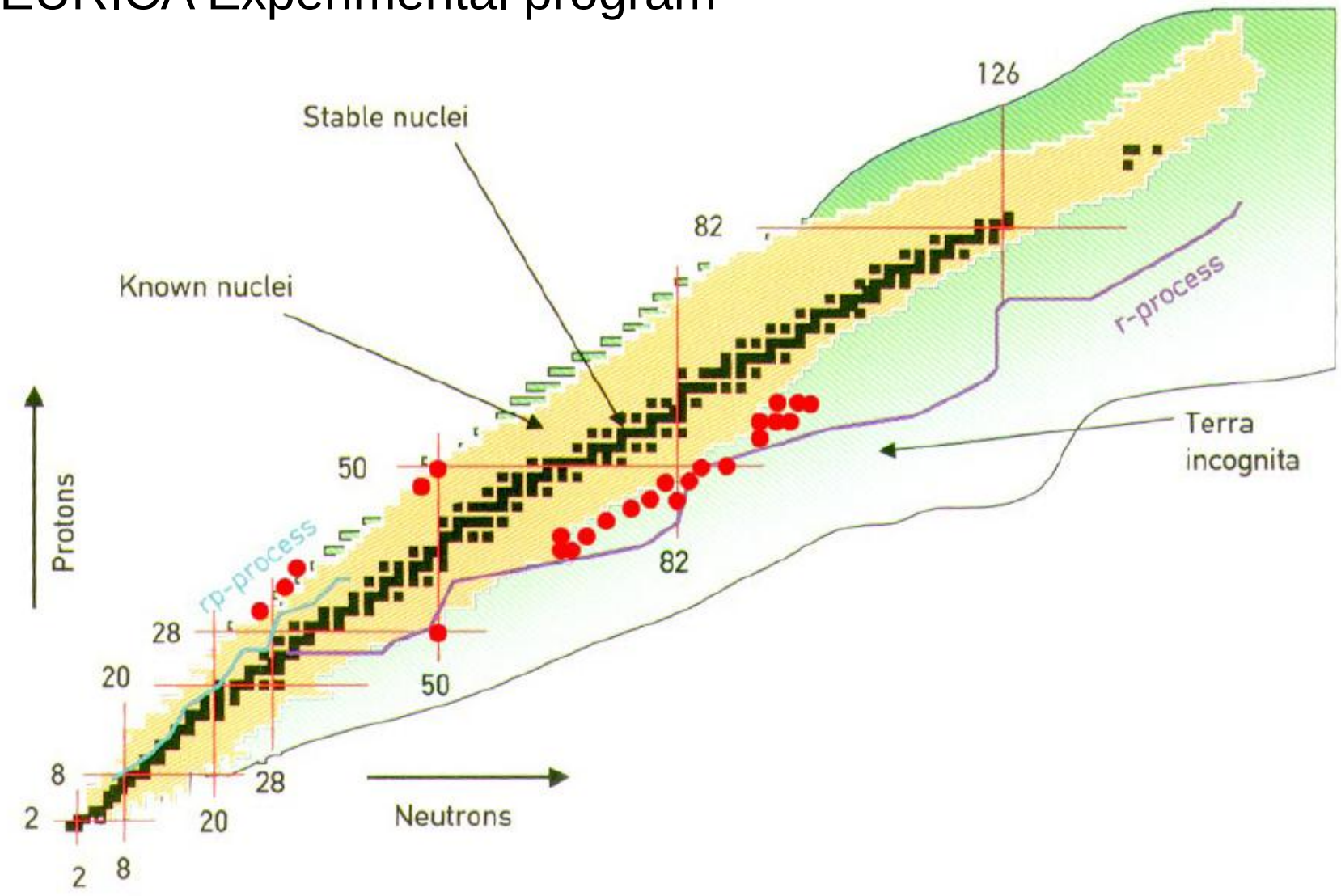








EURICA Experimental program



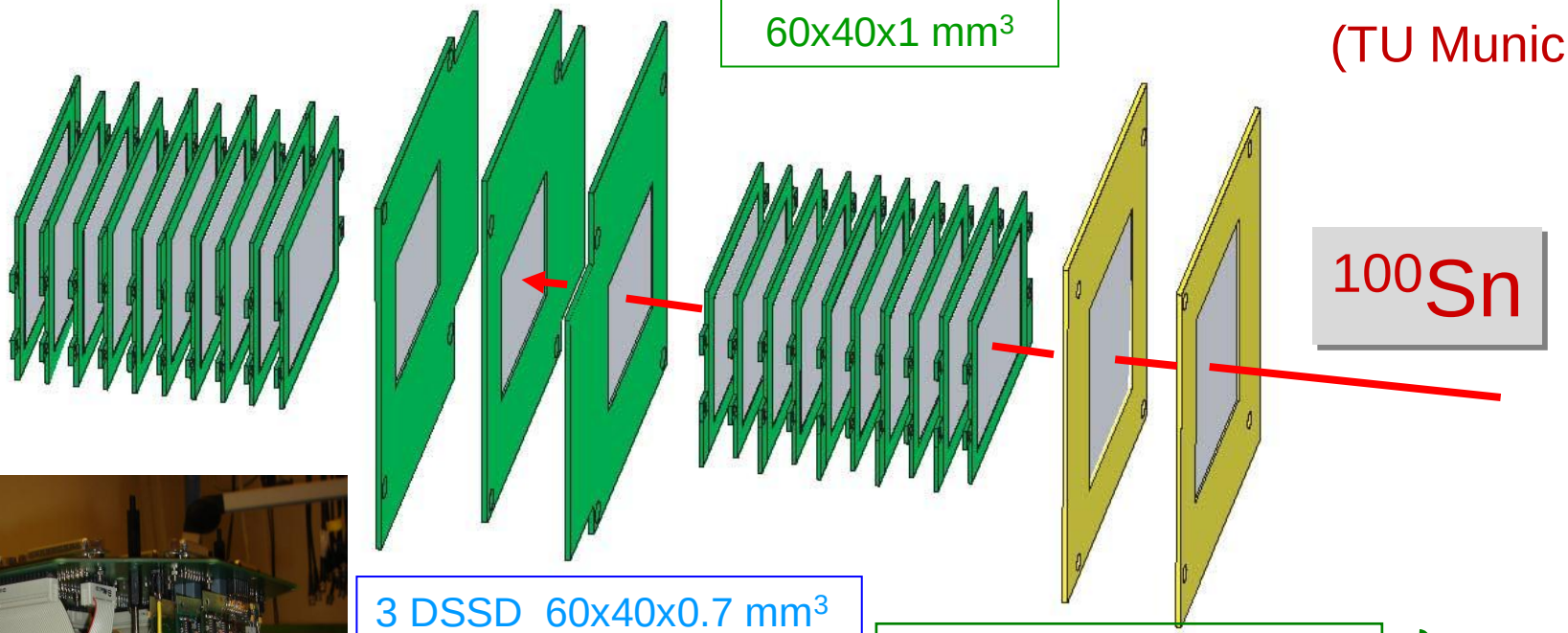
Silicon Implantation Detector and Beta Absorber **SIMBA** (TU Munich)

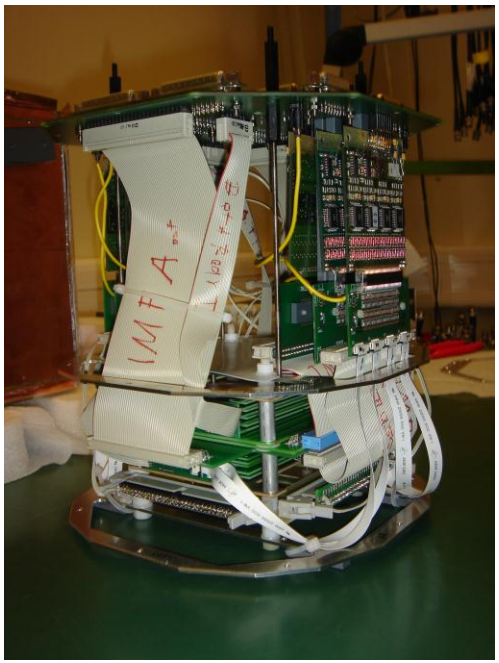
7 x-strips

10 SSSD
60x40x1 mm^3

7 x-strips

10 SSSD
60x40x1 mm^3





3 DSSD 60x40x0.7 mm^3

Gassiplex+ Mesytec

X SSSD 60x60x0.3 mm^3
Y SSSD 60x60x0.3 mm^3

} R - chain

Pixels in implantation zone:
3x60x40 = 7200

The EURICA Collaboration

A. Algora[1], N. Aoi[2], H. Baba[3], T. Bäck[4], Ch. Bauer[37], G. Benzoni[5], N. Blasi[5], A. Blazhev, M. Bostan[6], P. Boutachkov[19], A. Bracco[5,7], S. Brambilla[7], F. Browne[44], A. Bruce[44], L. Cáceres[8], B. Cakirli[39], F. Camera[5,7], W.N. Catford[18], I. Celikovic[8,9], J. Chiba[10], E. Clément[8], F. Crespi[5,7], P.V. Cuong[46], G. de Angelis[11,12], G. de France[8], N. de Séréville[13], F. Didierjean[14], Zs. Dombradi[40], C. Domingo-Pardo[1], M. Doncel[15], P. Doornenbal[3], G. Duchêne[14], T. Engert[19], N. Erduran[16], Th. Feastermann[20], E. Farnea[11,12], S. Franchoo[13], Y. Fujita[2], A. Gadea[1], U. Garg[50], A. Garnsworthy[17], W. Gelletly[18], J. Gerl[19], R. Gernhäuser[20], S. Go[21], A. Gottardo[11,12], E. Gregor[19], S. Grévy[22], G. Hackman[17], F. Hammache[13], T. Hayakawa[23], Ch. Hinke[20], Y. Hirayama[24], H. Hua[25], L.T.Q. Huong[46], T. Hüyük[1], F. Ibrahim[13], Y. Ichikawa[3], E. Ideguchi[21], N. Imai[24], N. Inabe[3], H. Ishiyama[24], T. Isobe[3], S. Jeong[24], H. Jung[52], A. Jungclaus[26], D. Kameda[3], L.H. Khiem[46], T. Koike[38], I. Kojouharov[19], K. Kolos[13], T. Komatsubara[27], A. Korichi[28], W. Korten[51], R. Krücken[17], T. Kubo[3], N. Kurz[19], A. Kusoglu[6], S. Lalkovski[47], F. Le Blanc[13], J. Lee[3], S. Leoni[5,7], M. Lewitowicz[8], Z.H. Li[3,25], X. Li[25], Zh. Li[41], M. Liu[42], W. Liu[41], Zh. Liu[43], G. Lorusso[3], R. Lozeva[14], S. Lunardi[11,12], P. Mason[18], I. Matea[13], D. Mengoni[11,12], C. Michelagnoli[11,12], B. Million[5], H. Miyatake[24], V. Modamio[11,12], C.B. Moon[29], A. Morales[7], K. Morimoto[3], K. Moschner[53], T. Motobayashi[3], T. Nagatomo[3,30], T. Nakamura[31], T. Nakao[3], M. Nakhoshtin[18], D. Napoli[11], M. Niikura[13], H. Nishibata[32], D. Nishimura[3], M. Nishimura[3], S. Nishimura[3], F. Nowacki[14], J. Nyberg[33], A. Odahara[32], R. Orlandi[26], S. Orrigo[1], J. Philip[11] N. Pietralla[37], S. Pietri[19], A. Pipidis[11], Zs. Podolyak[18], B. Quintana[15], M. Ramdhane[34], F. Recchia[12], P. Regan[18], S. Rice[18], O. Roberts[44], B. Rubio[1], E. Sahin[11,12], M. Sako[3,35], H. Sakurai[3,36], H. Schaffner[19], H. Scheit[37], T. Shimoda[32], P. Shury[3,27], K. Sieja[14], G. Simpson[34], P.A. Söderström[3], D. Sohler[40], T. Sonoda[3], O. Sorlin[8], I. Stefan[13], K. Steiger[20], D. Steppenbeck[3], T. Sumikama[10], B. Sunchan[48,49], H. Suzuki[3], J. Taprogge[26], J. Takatsu[32], H. Takeda[3], S. Takeuchi[3], D. Testov[13], G. Thiamova[34], J.C. Thomas[8], T.D. Trong[46], H. Ueno[3], C. Ur[11,12], Zs. Vajta[40], J. Valiente Dobon[11,12], D. Verney[13], Y. Wakabashi[23], T. Wakui[38], Y. Wang[41], H. Watanabe[3], Y. Watanabe[24], V. Werner[45], O. Wieland[5], H.J. Wollersheim[19], Z. Xu[36], A. Yagi[32], M. Yalcinkaya[6], H. Yamaguchi[21], Y. Ye[25], A. Yoshimi[3], K. Yoshinaga[3,10], Y. Zhang[42], Y. Zheng[42], and X. Zhou[42]

[1] University of Valencia, Spain
[2] RCNP, Japan
[3] RIKEN, Wako, Japan
[4] Royal Institute of Technology, Stockholm, Sweden
[5] INFN, Milano, Italy
[6] University of Istanbul, Turkey
[7] University of Milano, Italy
[8] GANIL, Caen, France
[9] VINCA, Belgrade, Yugoslavia
[10] Tokyo University of Science, Japan
[11] LNL, Legnaro, Italy
[12] University of Padova, Italy
[13] IPN Orsay, France
[14] IPHC, Strasbourg, France
[15] LRI - University of Salamanca, Spain
[16] University of Akdeniz, Antalya, Turkey
[17] TRIUMF, Vancouver, Canada
[18] University of Surrey, Guildford, UK
[19] GSI, Darmstadt, Germany
[20] TU München, Germany
[21] CNS, University of Tokyo, Japan
[22] CENBG Bordeaux, France
[23] JAEA, Tokai, Japan
[24] KEK, Tokai, Japan
[25] Peking University, China
[26] CSIC, Madrid, Spain
[27] University of Tsukuba, Japan
[28] CSNSM Orsay, France
[29] Hoseo University, Chun-Nam, Korea
[30] ICU, Tokyo, Japan
[31] Tokyo Institute of Technology, Japan
[32] Osaka University, Japan
[33] Uppsala University, Sweden
[34] LPSC Grenoble, France
[35] Kyoto University, Japan
[36] University of Tokyo, Hongo, Japan
[37] TU Darmstadt, Germany
[38] Tohoku University, Japan
[39] MPI Heidelberg, Germany
[40] ATOMKI, Debrecen, Hungary
[41] CIAE, Peking, China
[42] IMP Lanzhou, China
[43] University of Edingburgh, UK
[44] University of Brighton, UK
[45] Yale University, USA
[46] Vietnam Academy for Science and Technology, Hanoi, Vietnam
[47] University of Sofia, Bulgaria
[48] Beihang University, Beijing, China
[49] Justus-Liebig-University, Giessen, Germany
[50] University of Notre Dame, USA
[51] CEA Saclay, France
[52] Chung-Ang University, Seoul, Korea
[53] University of Cologne, Germany

Collaborations for RIBF

Workshops for collaborations held and planned:

SAMURAI (Superconducting Analyzer for Multi-particle from Radio Isotope Beams):

Nov. 2010 – SAMURAI TPC

Nov. 2010 – construction proposal to the RIBF PAC (local)

Mar. 2011 – day-one experiments / formation of “SAMURAI Collaboration”

EURICA (Campaign with the Euroball clusters at RIKEN):

May 2011 – physics cases in the campaign planned in 2012

E(U)RICA proposal to the Gamma Pool Committee

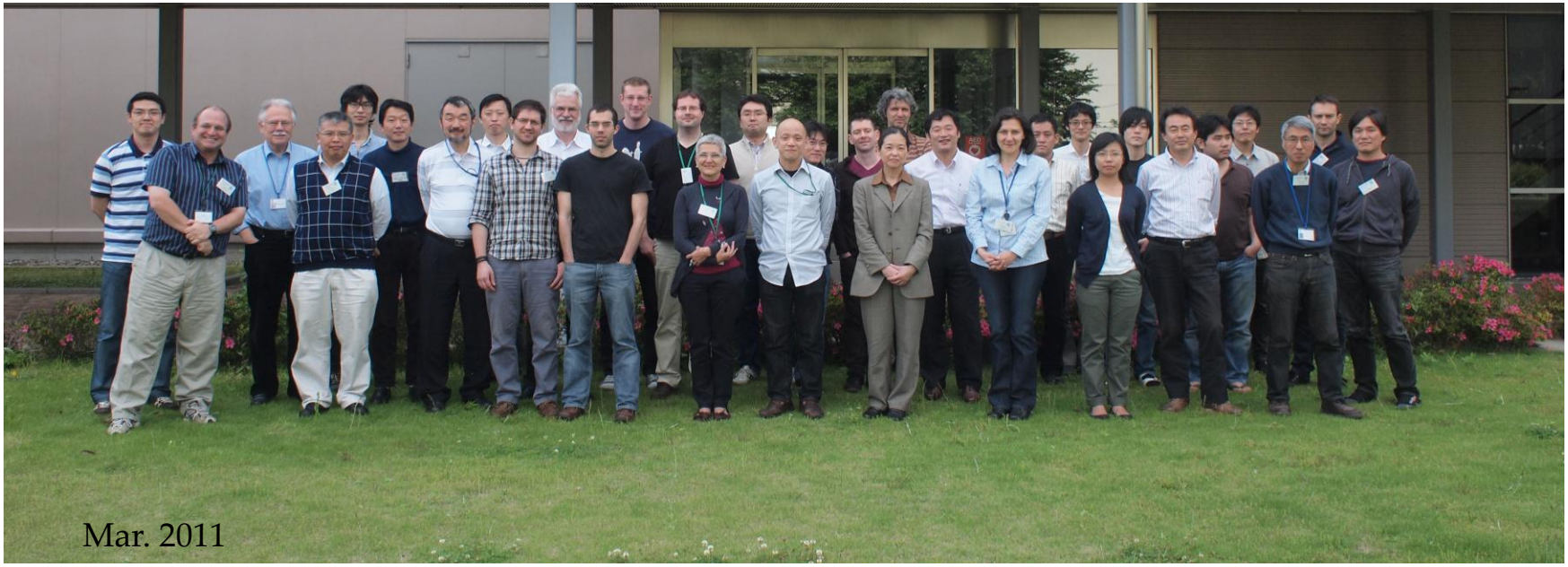
formation of collaboration

DALI2 and GRAPE (experiments with NaI(Tl) and Ge detector arryas):

July 2011 (in the “Gamma11” Symposium)

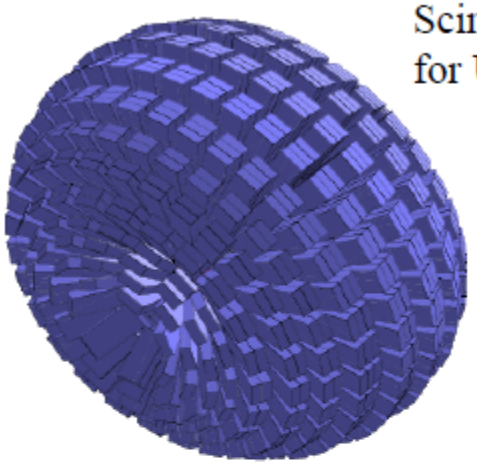
– physics cases for fast beam experiments at RIBF

formation of “SUNFLOWER Collaboration”



Mar. 2011

Next Generation Gamma-Detector System SHOGUN



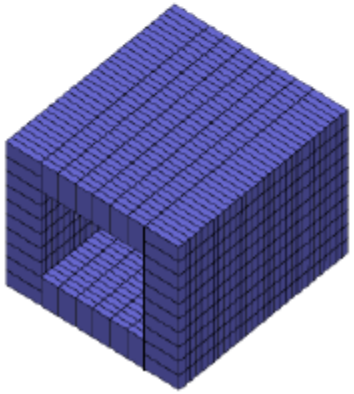
Scintilator based High resOlution Gamma-ray spectrometer for Unstable Nuclei

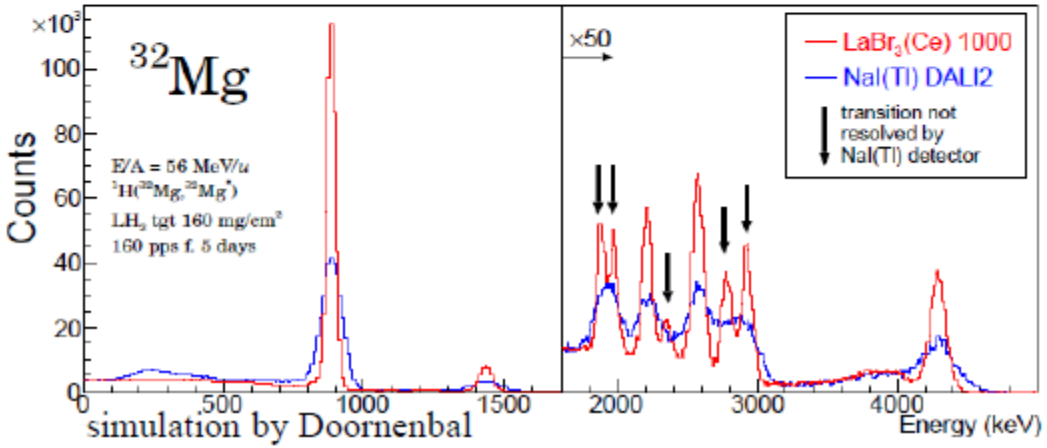
Scheit et al.

fast beam setup ($v = 0.6c$			
	$\frac{\Delta E}{E}$ (%)	ϵ_γ (%)	$\epsilon_{\gamma\gamma}$ (%)
NaI(Tl) DALI2	10.0	23.5	5.5
RISING	1.9	2.8	0.08
$LaBr_3$(Ce) 1000	**3.2**	**42.0**	**17.6**

slow/stopped beam setup			
	$\frac{\Delta E}{E}$ (%)	ϵ_γ (%)	$\epsilon_{\gamma\gamma}$ (%)
RISING	0.2	15.0	2.25
$LaBr_3$(Ce) 1000	2.4	**56.0**	**31.3**

$8 \times 4 \times 1.5$ cm^3

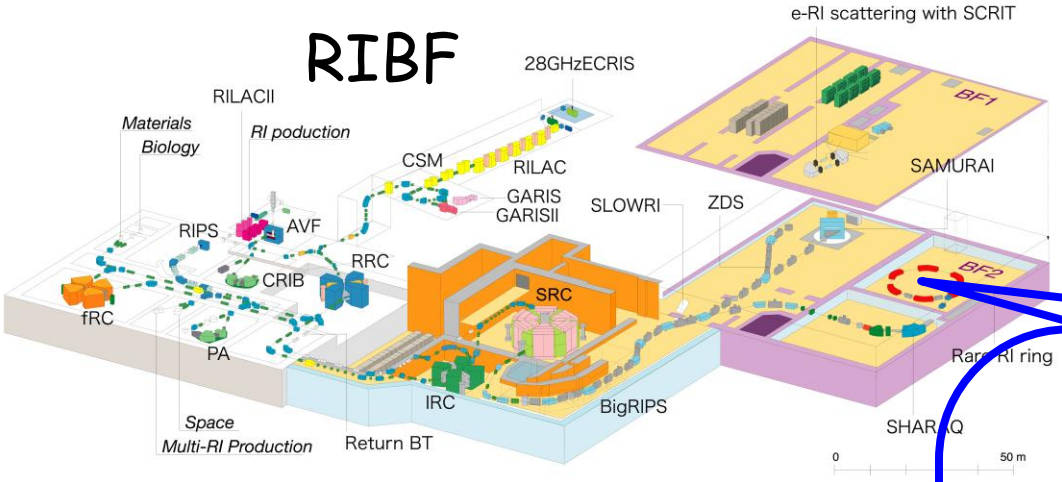




Cooperation with PARIS Collaboration

Construction of Rare RI Ring

FY2011.3 : President's Discretionary Budget was approved

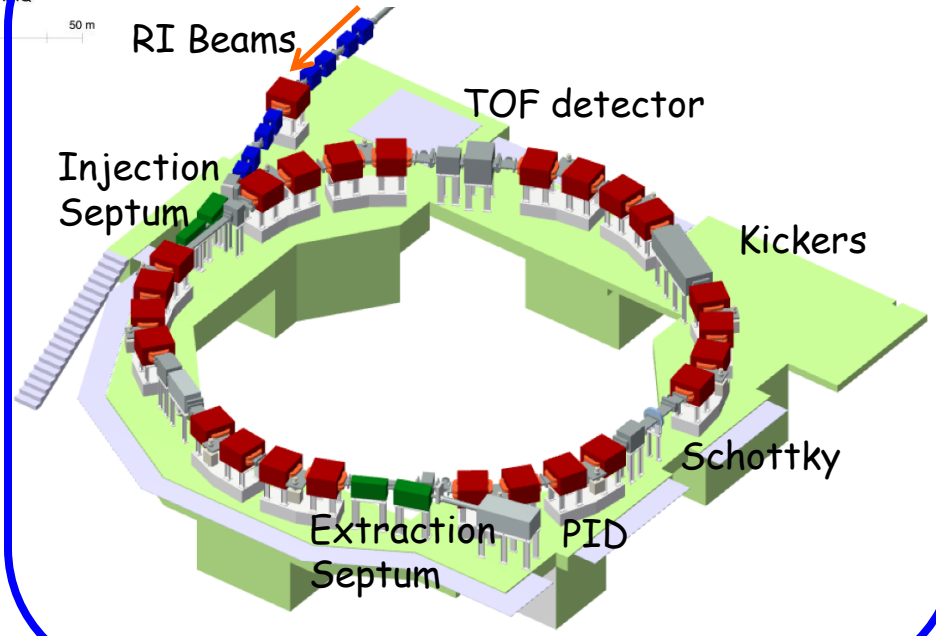


precision mass measurements
for extremely rare RI's

2012 ┐
2013 ┘ Construction

2014 Commissioning
Tuning
2015 Start mass measurement

Isochronous Storage Ring



Key technologies:

Isochronous ring

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

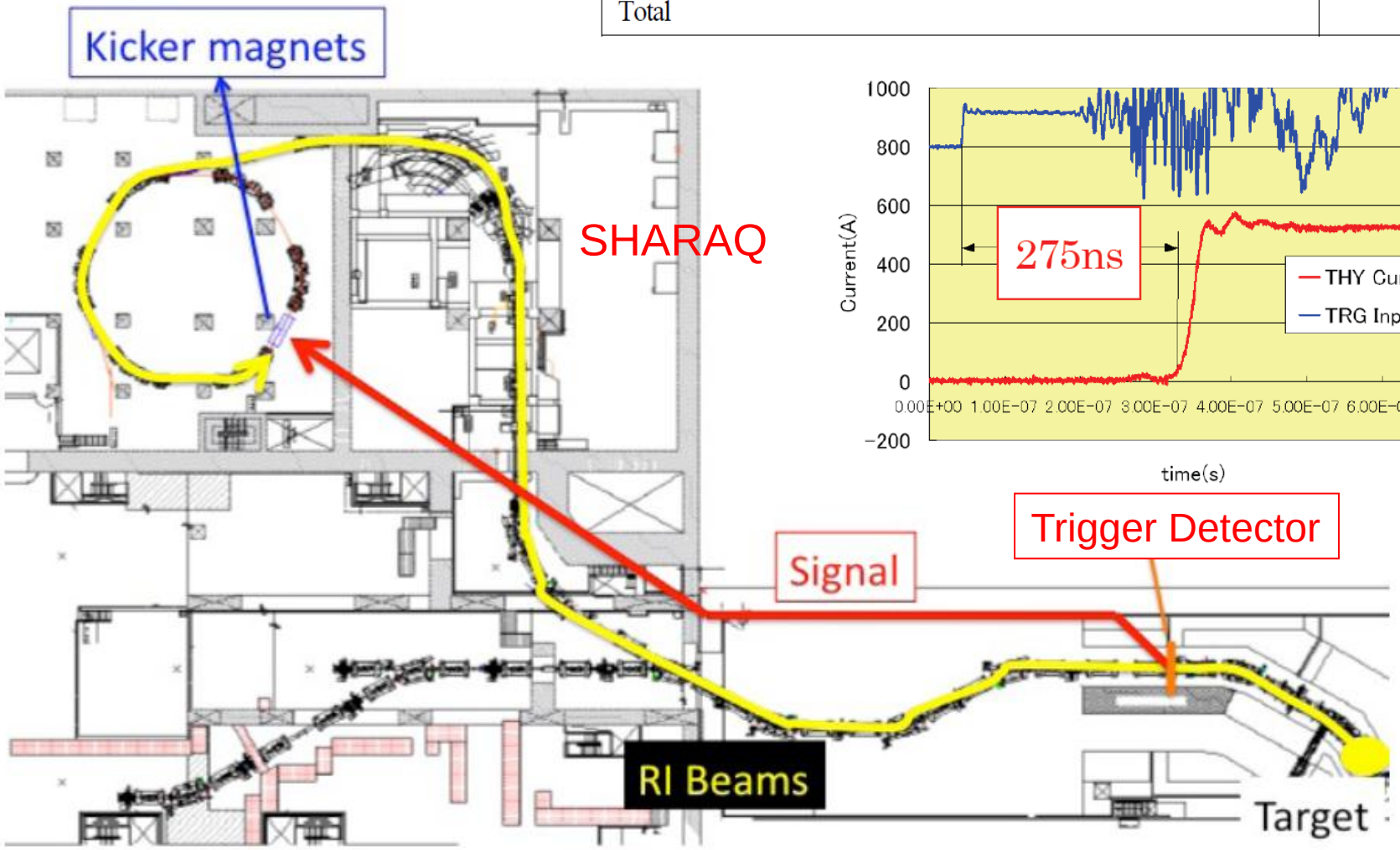
Individual injection

efficiency ~ 100%

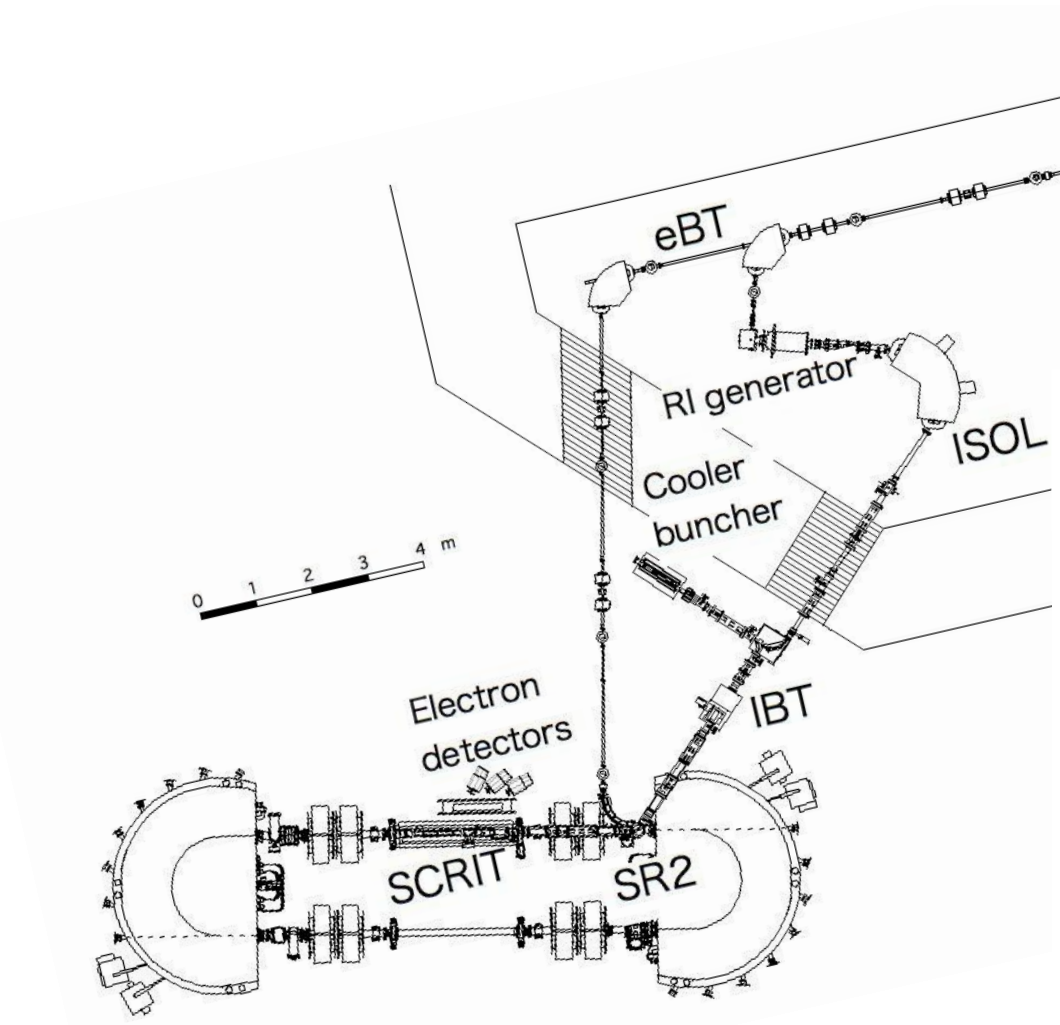
even for a “cyclotron” beam

Table 3 Delay time for Individual injection in Rare-RI Ring.

	Delay time (ns)
Trigger detector (Plastic+PMT) at F3	50
Transport cable from F3 to Kicker (~105 m length)	370
Power-supply device for thyratron	275
Thyratron to flat-top center in kicker magnetic filed	230
Total	925

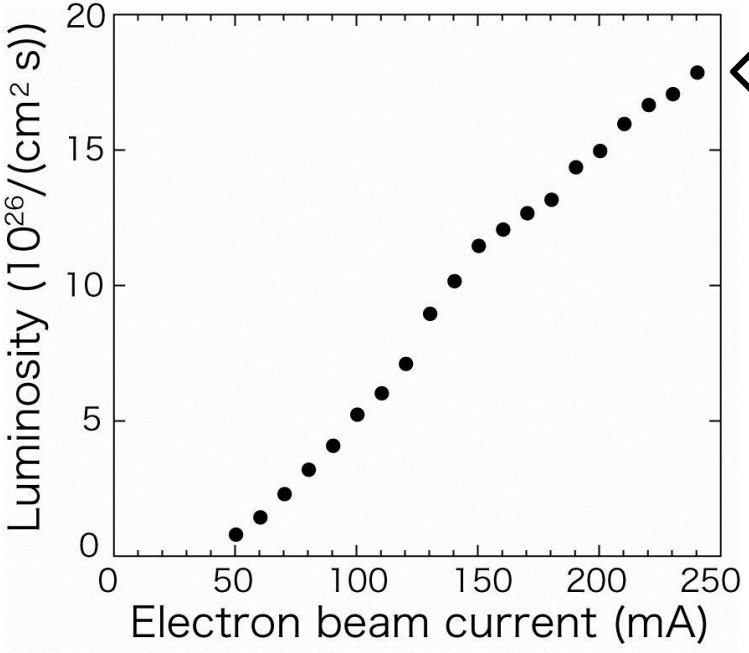


Status of the SCRIT Electron Scattering Facility



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-Spectrometer Full-scale RI production
2014	Start Experiments for RI's

Performances of the SCRIT and Test Experiments using Stable ^{133}Cs

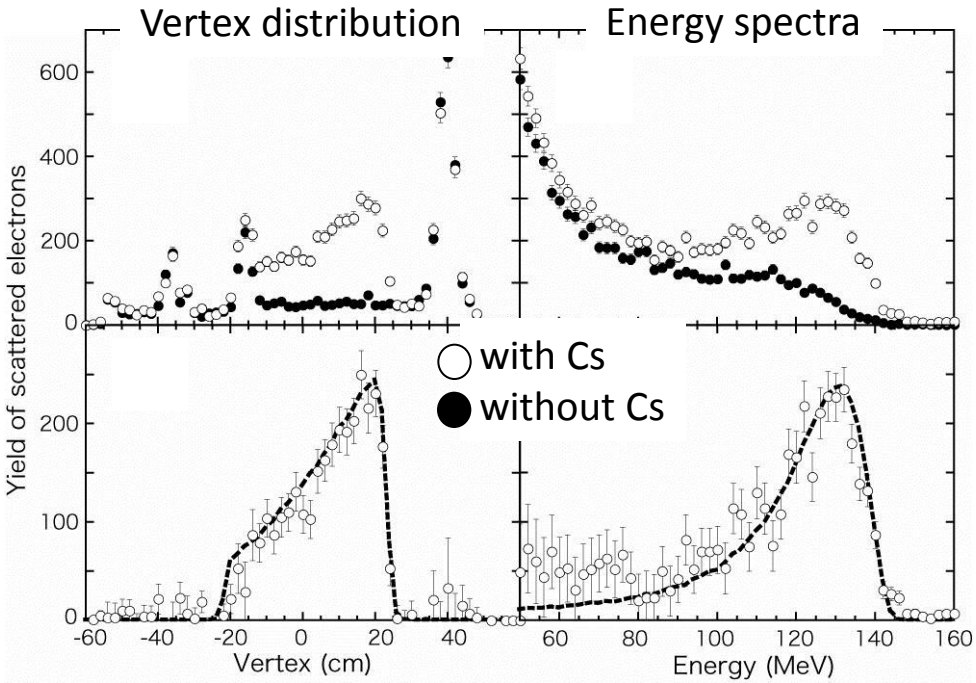


⇦ Achieved luminosity 1.8×10^{27} /(cm^{2}s)

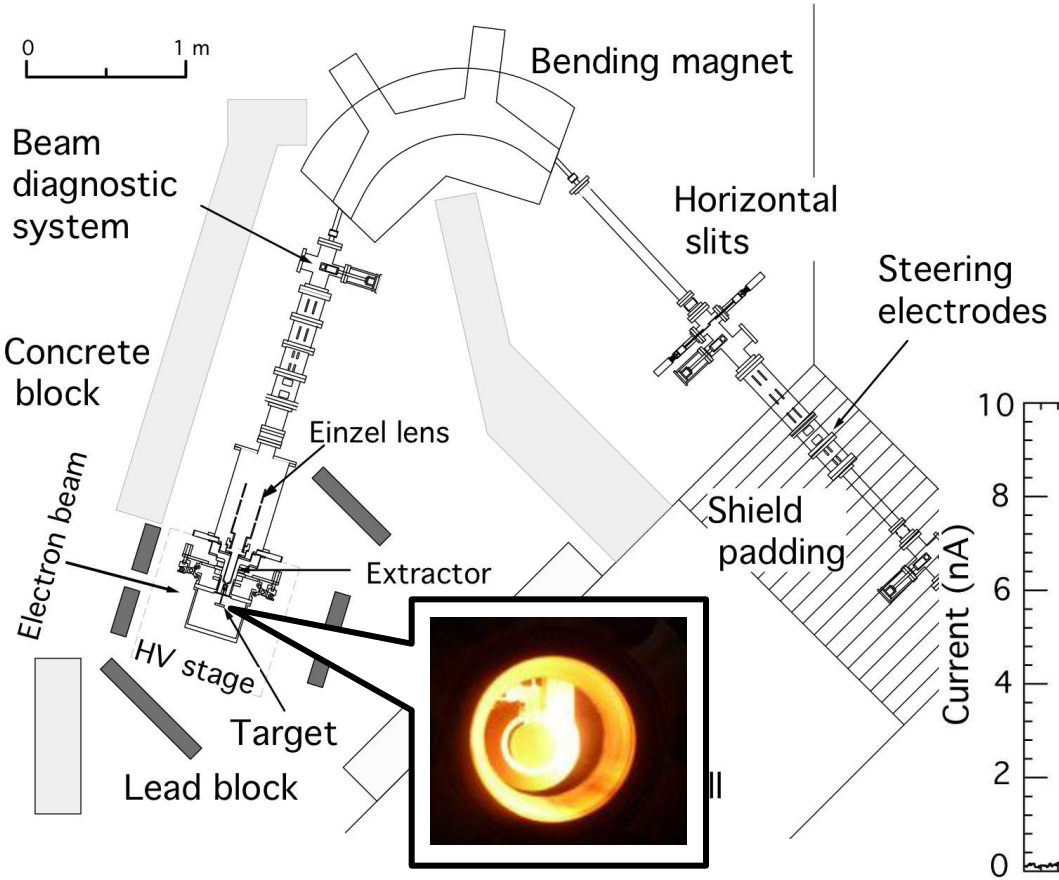
Ion trapping efficiency 85 %

at 240 mA

Measurements of electrons elastically scattered from trapped Cs ions in SCRIT ⇨



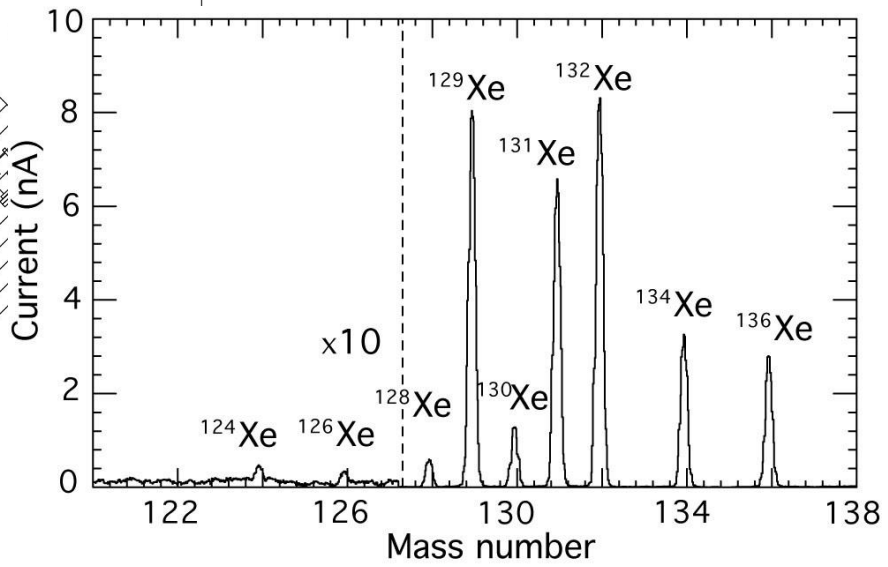
Commissioning of ISOL and preparation of UCx target

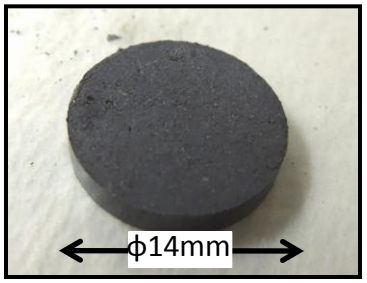


Test using stable Xe isotopes

Mass resolution M/ΔM 1660

Overall efficiency 21 %





Training of target production

$^{238}UO_2$+C (disk) → UCx (^{238}U 30g)

RIBF Layout

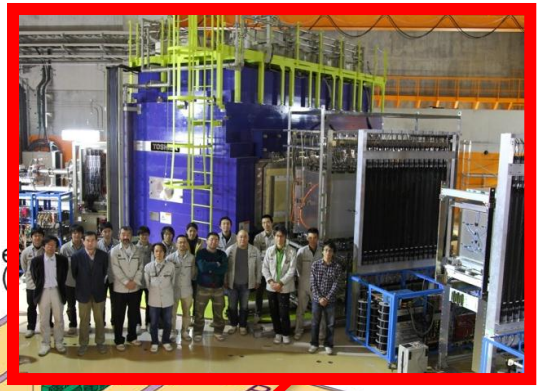
RILAC

RRC

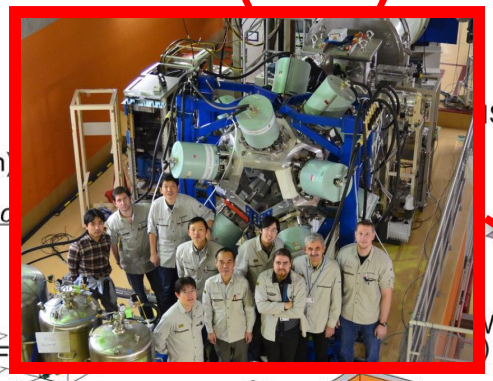
RIPS

ZeroDegree (ZDS) (2008)

SAMURAI



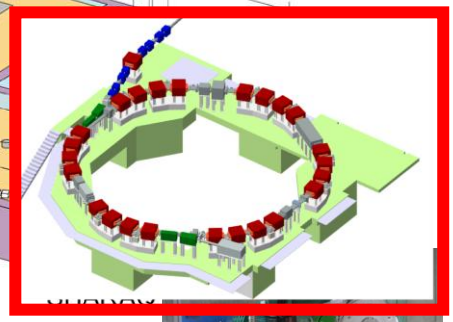
EURICA (2012)



SCRIT

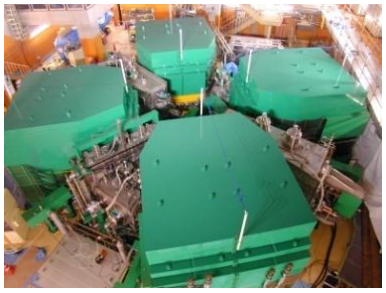
(2011)

RI Ring



fRC

IRC



SRC (2007)

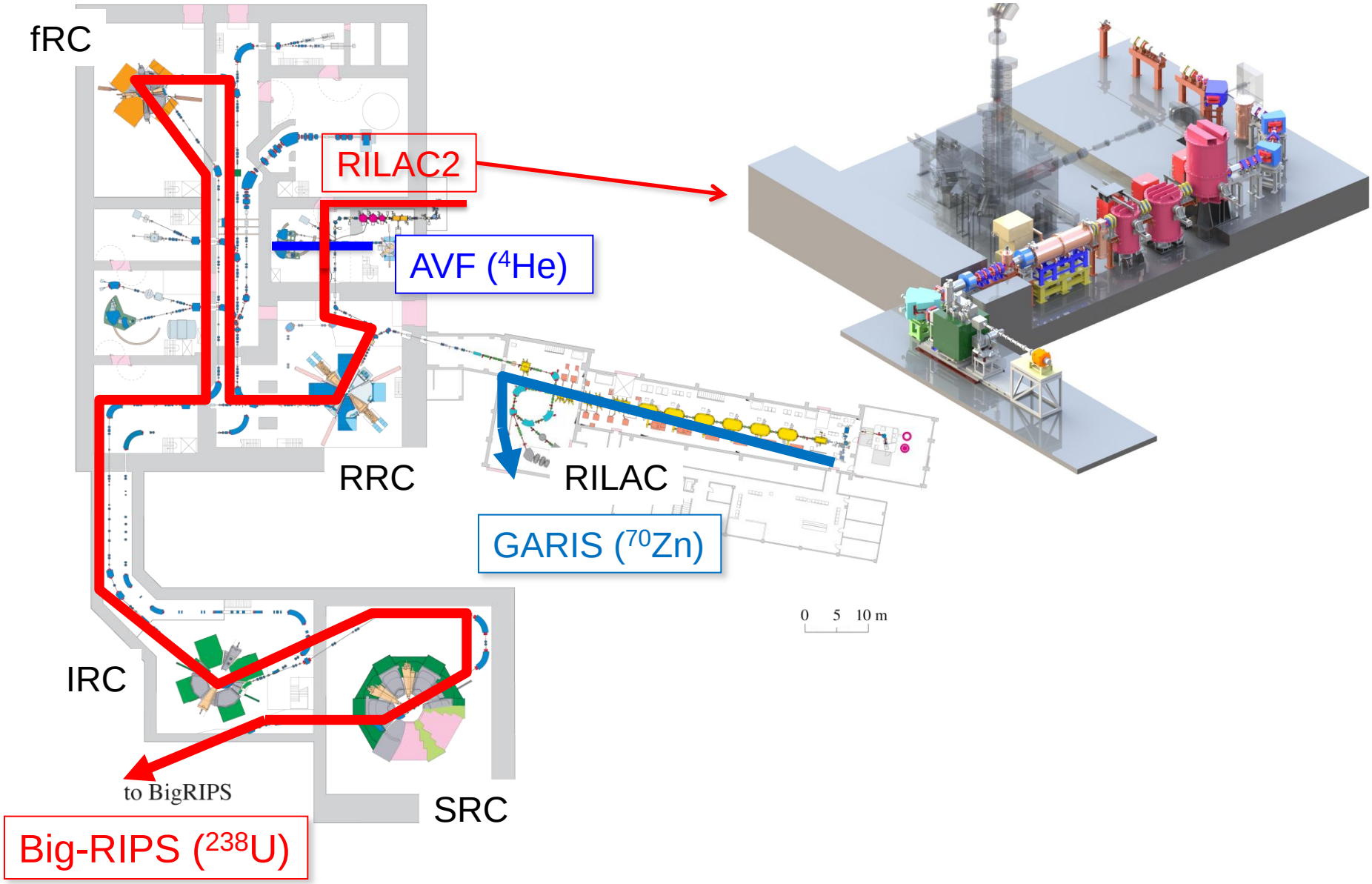
BigRIPS
(2007)

SHARAQ
(2009)

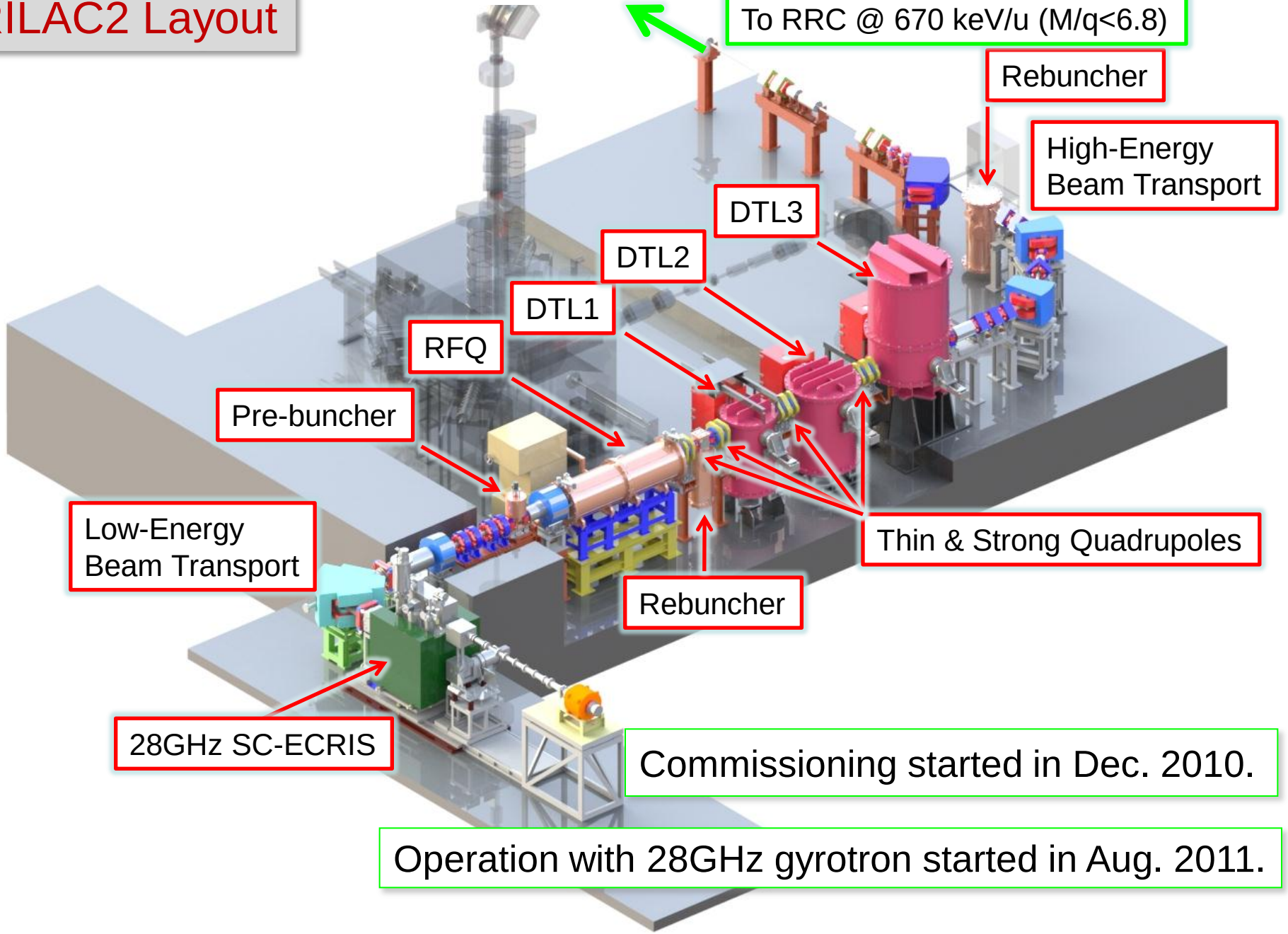
Outline

1. Status of RIBF
   - Facility and RIB capabilities
   - Present program
   - Recent results
2. New Initiatives in Experimental Facilities
   - SAMURAI
   - EURICA
   - Mass Ring
   - SCRIT
3. Accelerator Improvements & Extensions
   - Short-term upgrades
   - Long-term conceptual considerations
4. Outlook

Simultaneous operation of 3 accelerators



RILAC2 Layout



Commissioning started in Dec. 2010.

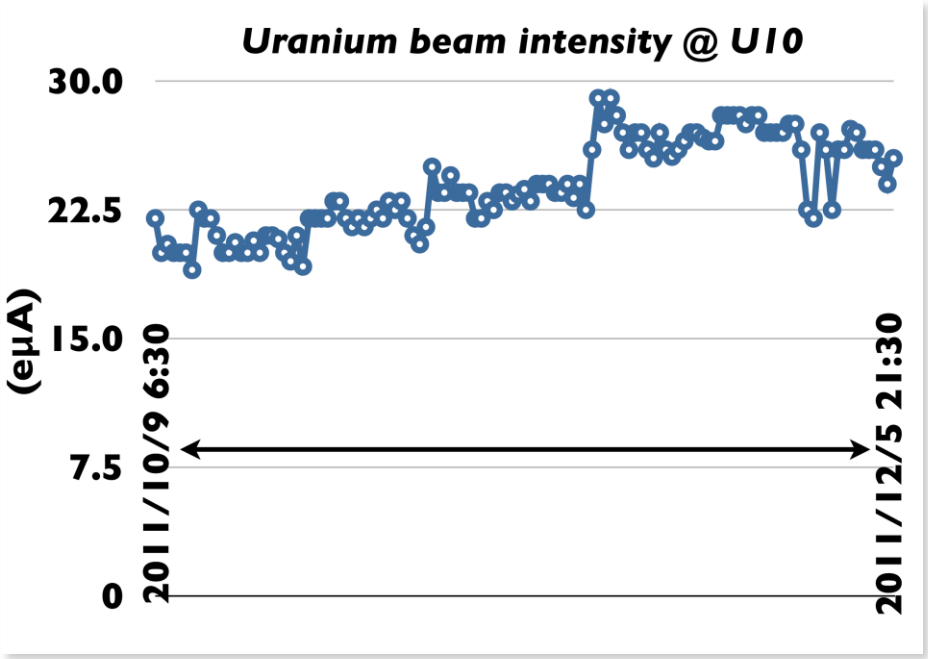
Operation with 28GHz gyrotron started in Aug. 2011.

(Drawing: Nishida/SAS)

U beam from 28GHz SC-ECRIS

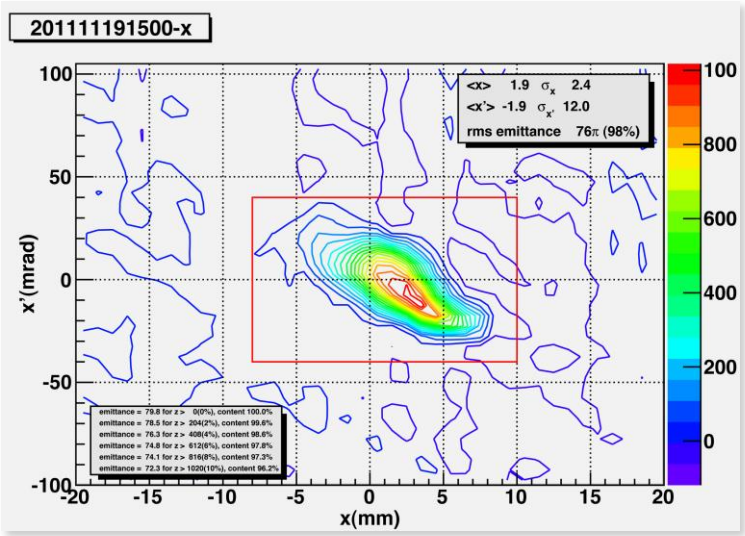
(Higurashi, Ohnishi, Nakagawa)

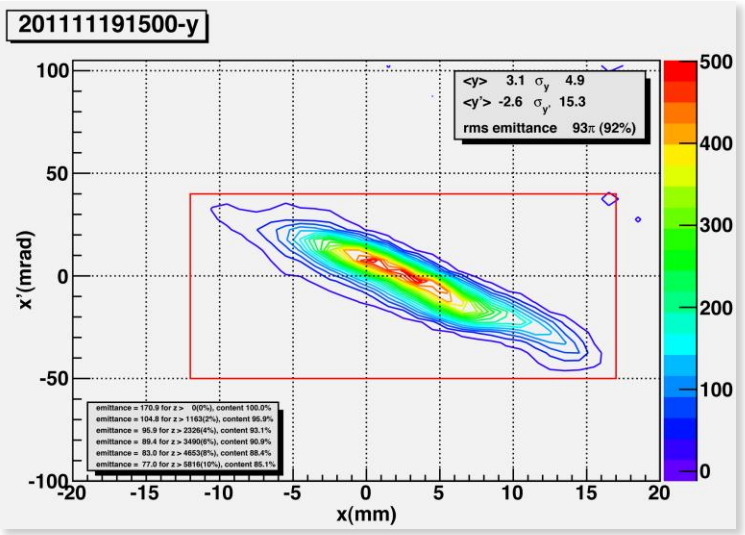
Intensity of U35+



- 20~30 e-micro-A.
- Stable.
- U-rod lasted ~1 month.

Emittance



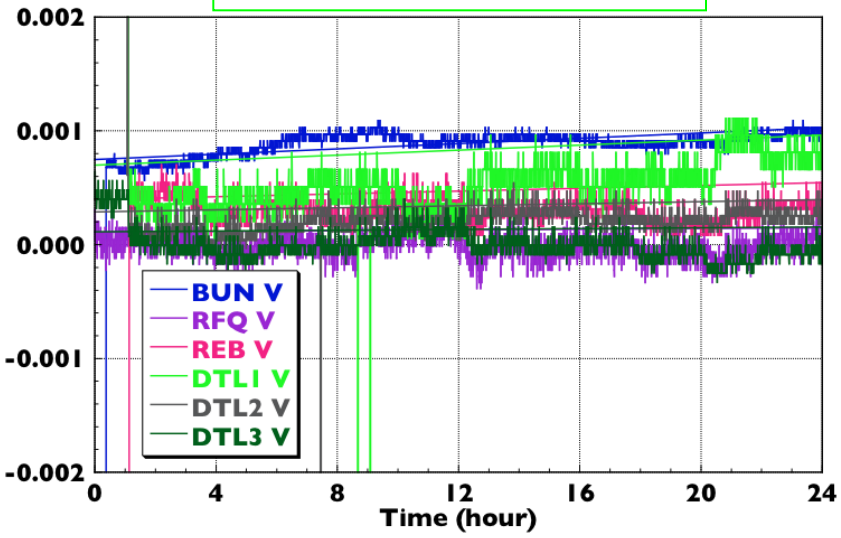


- 70~100 (π) mm-mrad @4-rms.
- Better than expected.

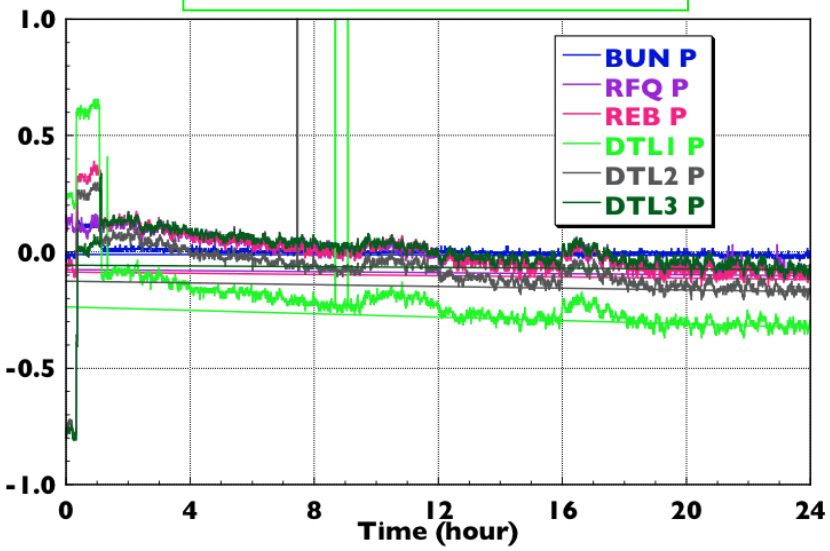
Stability of RILAC2 injector

(Suda, Yamada)

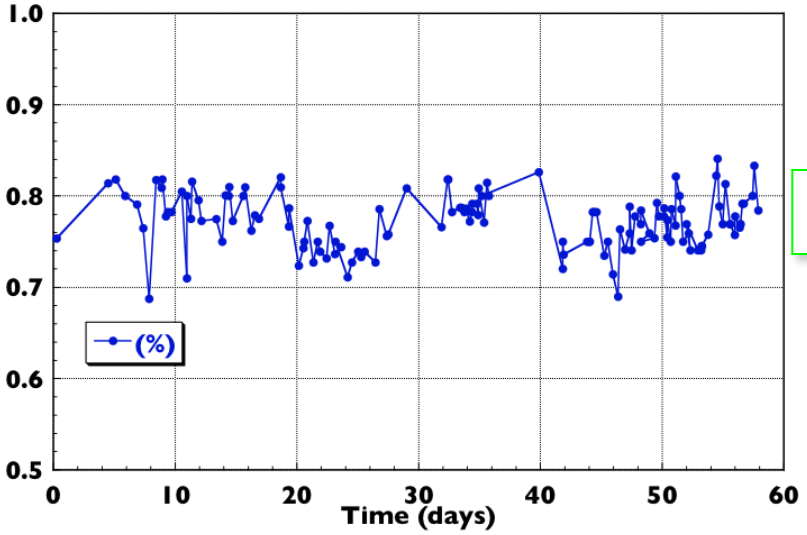
ΔV/V < 0.1 % (24hrs)



Δϕ < 0.2 deg. (24hrs)



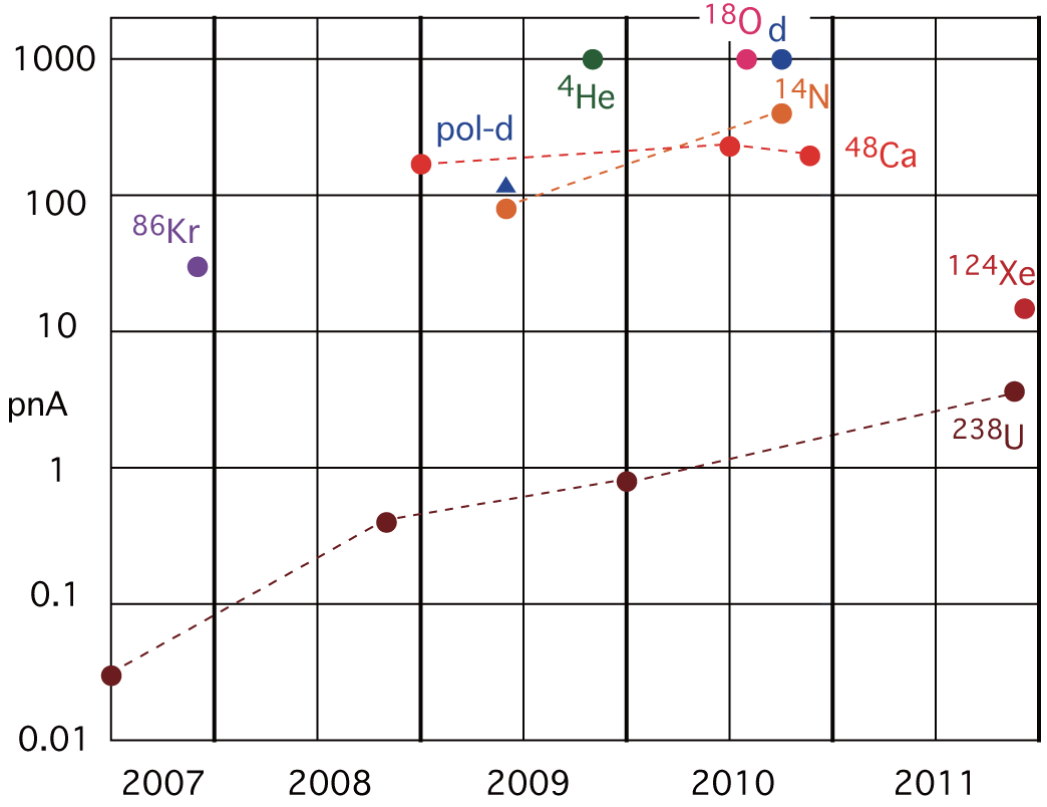
ε ~75 % (2 month)



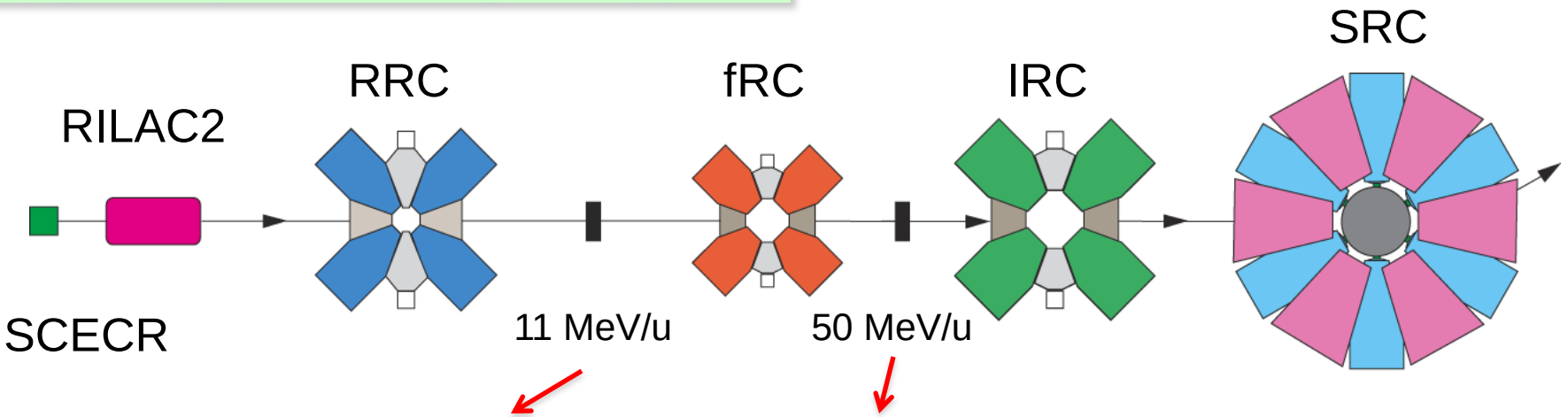
•Worked stably for 2 month, as expected…

Achieved beam intensities

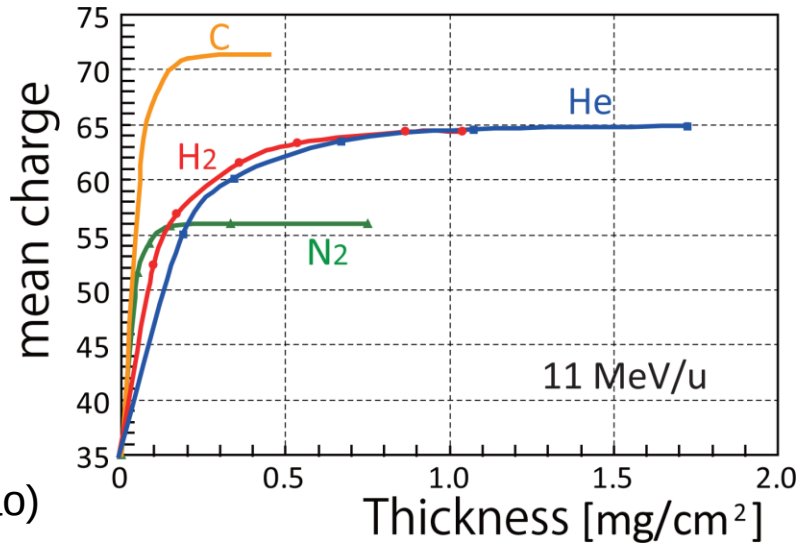
- pol-d(250 MeV/u) 120 pnA
- d(250 MeV/u) 1000 pnA
- ^{4}He(320 MeV/u) 1000 pnA
- ^{14}N(250 MeV/u) 400 pnA
- ^{18}O(345 MeV/u) 1000 pnA
- ^{48}Ca(345 MeV/u) 230 pnA
- ^{86}Kr(345 MeV/u) 30 pnA
- ^{124}Xe(345 MeV/u) 16 pnA
- ^{238}U(345 MeV/u) 3.8 pnA



Upgrade plan: Charge strippers



Atom	Q1	CS1	Q2	CS2	Q3	Available @	Intensity
^{238}U	35	CNT+EV	71	C	86	Present	3.5
	35	He gas	65	C	86	Oct 2012	(5)



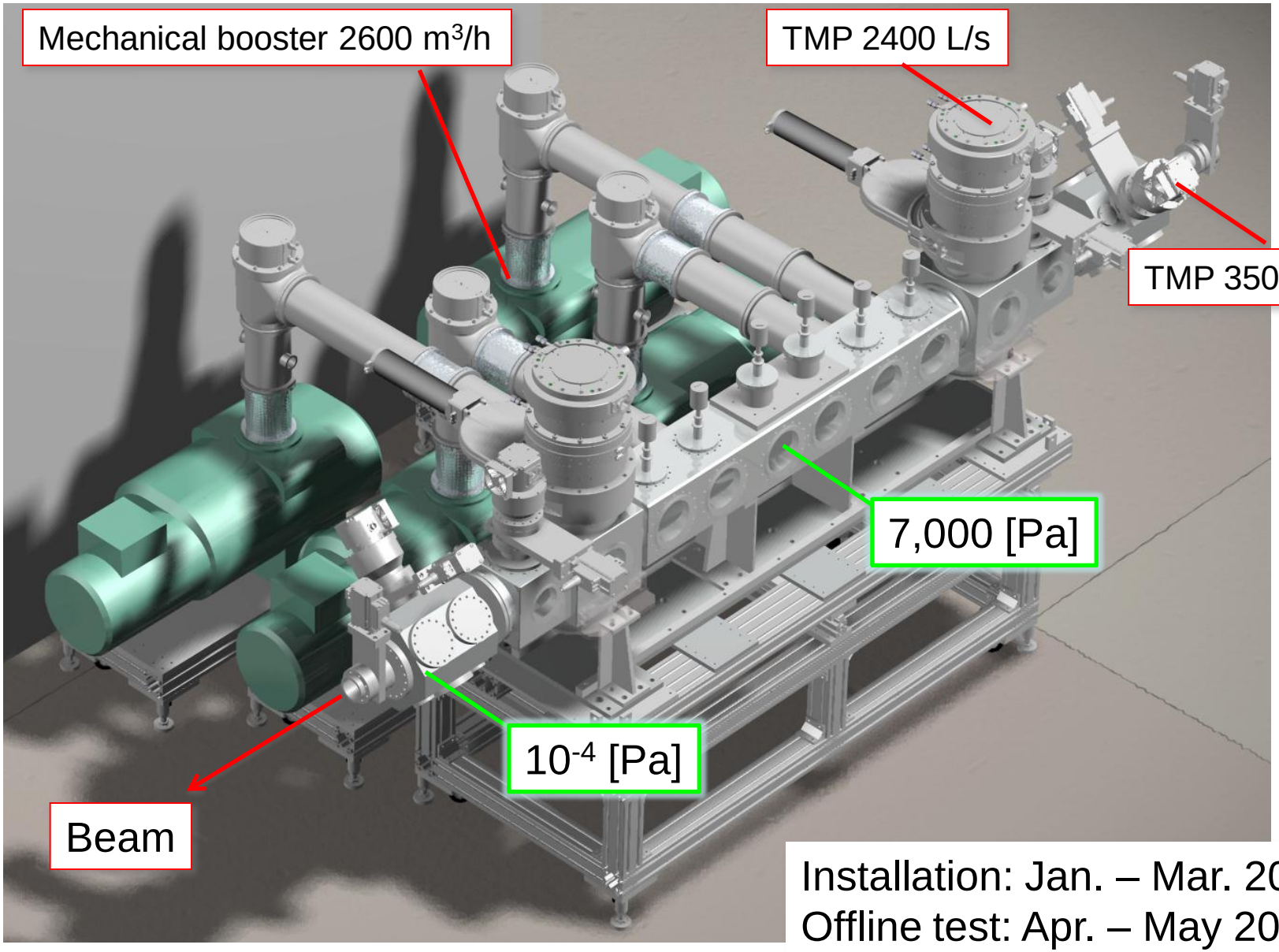
(Imao)

Present fRC: 69+

Upgraded fRC: 65+

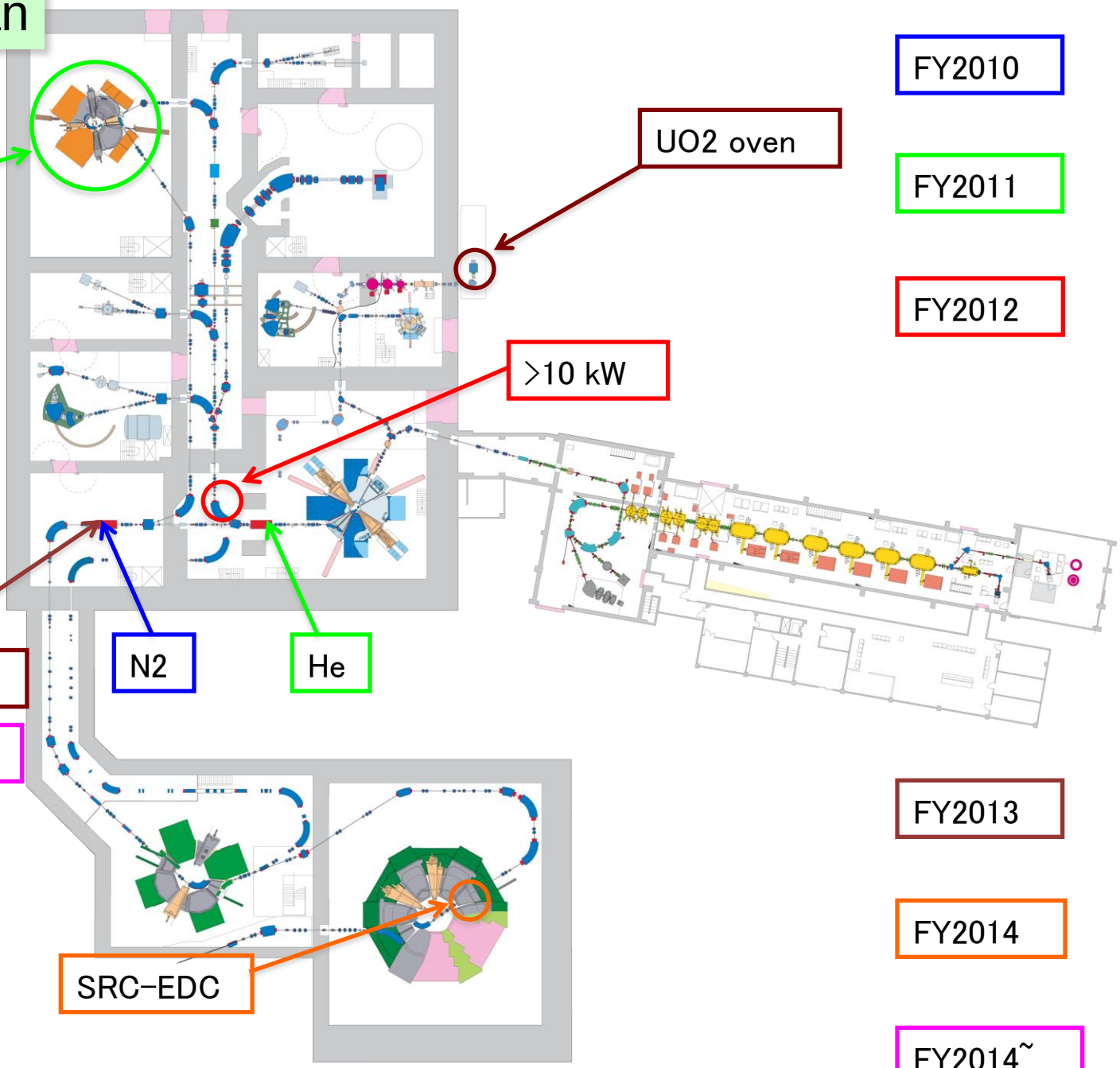
Acceptable charge state of U

Helium gas stripper @ 11 MeV/u

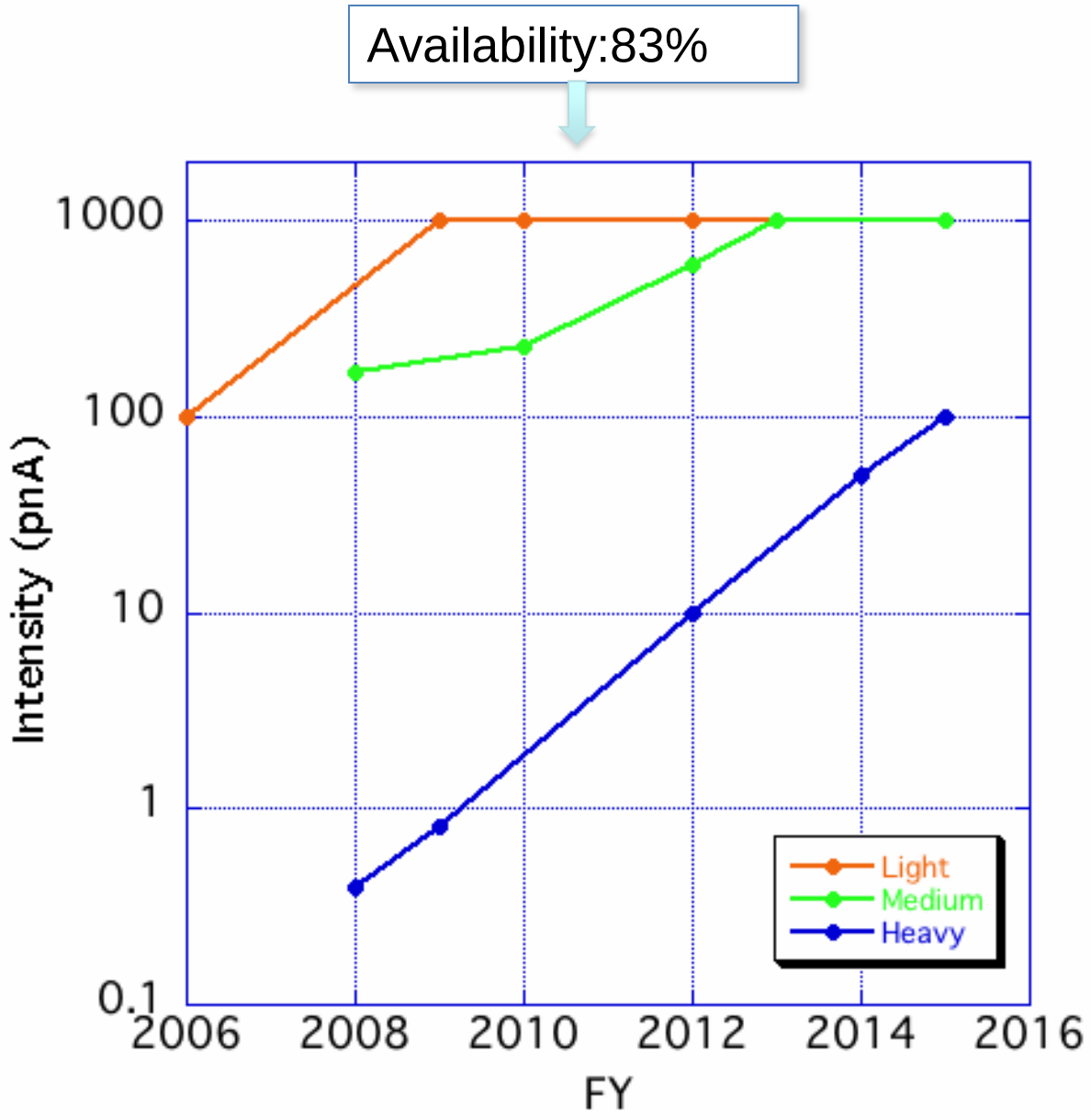


Installation: Jan. – Mar. 2012
Offline test: Apr. – May 2012
Beam test: Apr. – Sep. 2012

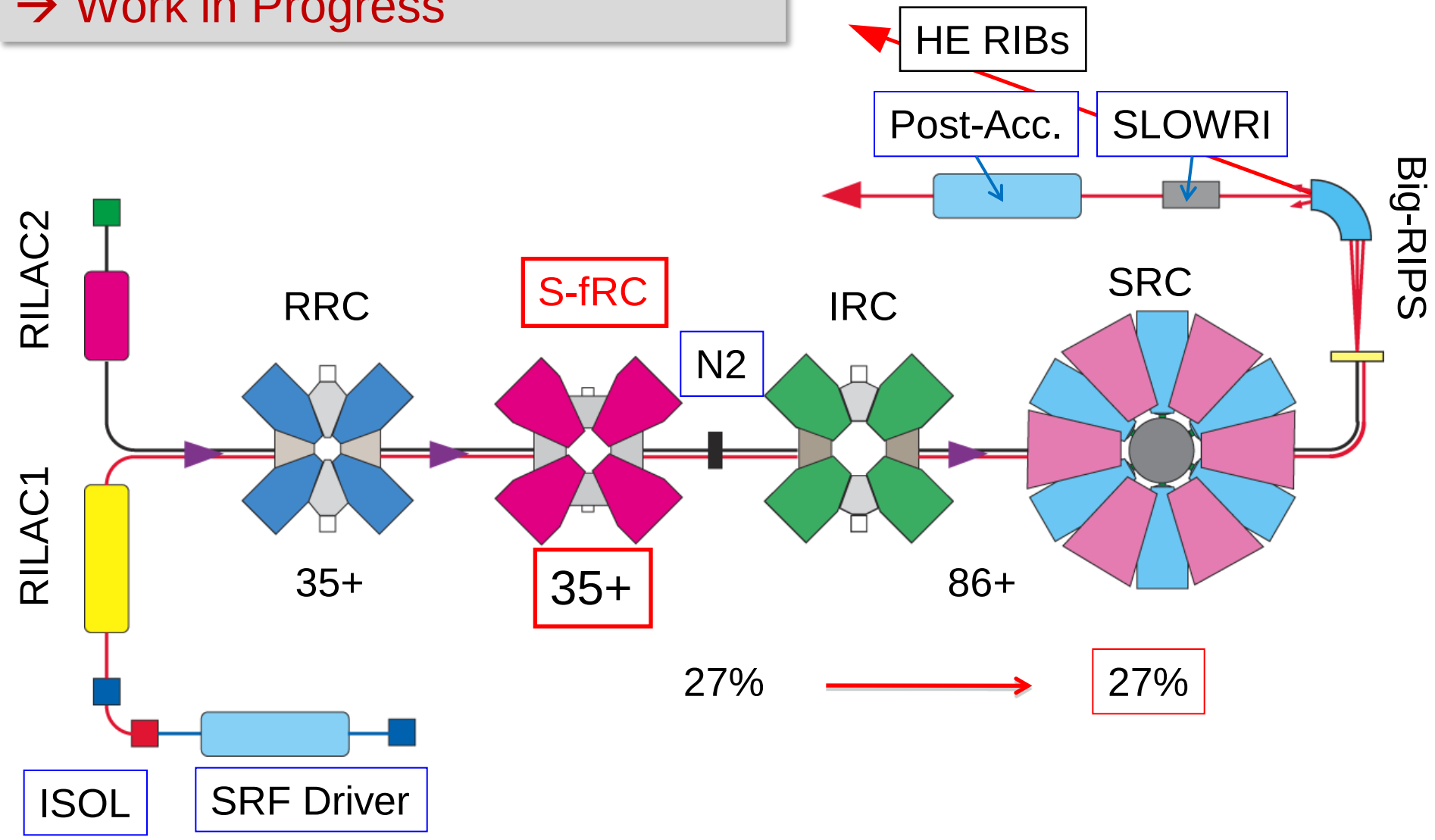
Upgrade plan



Upgrade plan



Long-Term RIBF Upgrade Options
→ Work in Progress



The RI Beam Factory (RIBF) at RIKEN – Status and Future Pro

Thank you for your attention !!!

Walter F. Henning
RIKEN Nishina Center

EURORIB12, Abano Terme, May 21-25, 2012