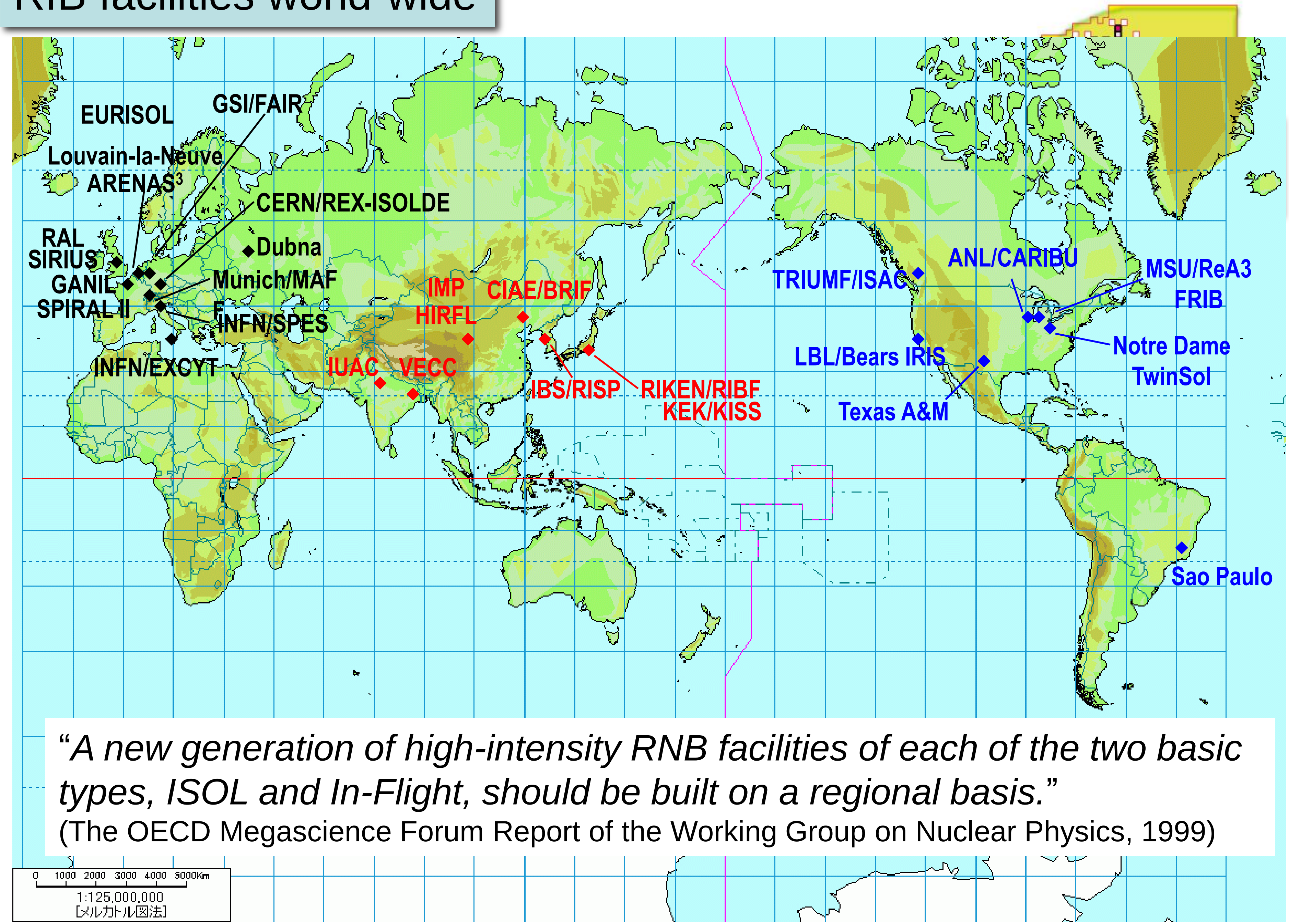
Rare-Isotope Beam Facilities in Asia

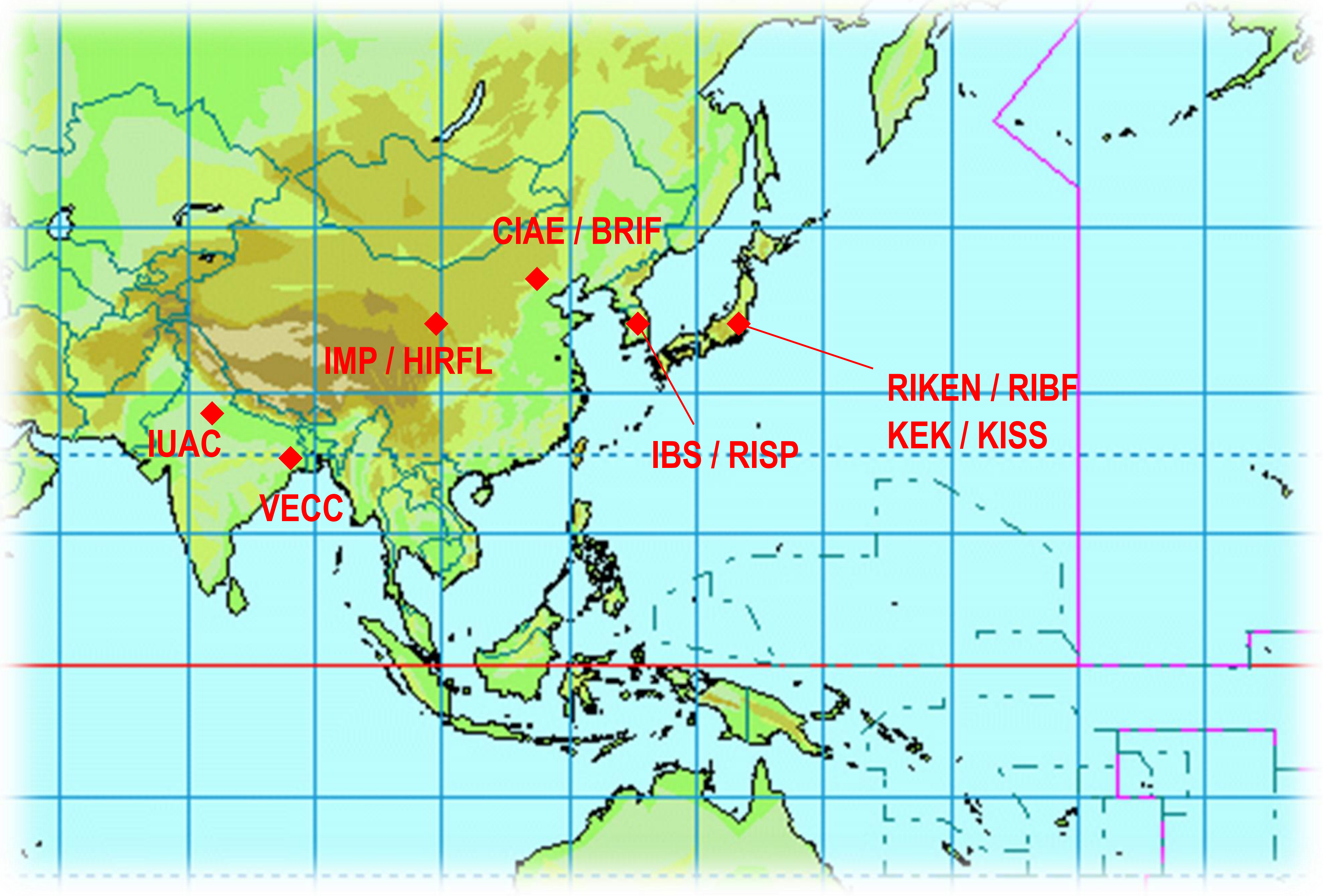
Osamu Kamigaito
RIKEN Nishina Center

RIB facilities world-wide



"A new generation of high-intensity RNB facilities of each of the two basic types, ISOL and In-Flight, should be built on a regional basis."
(The OECD Megascience Forum Report of the Working Group on Nuclear Physics, 1999)

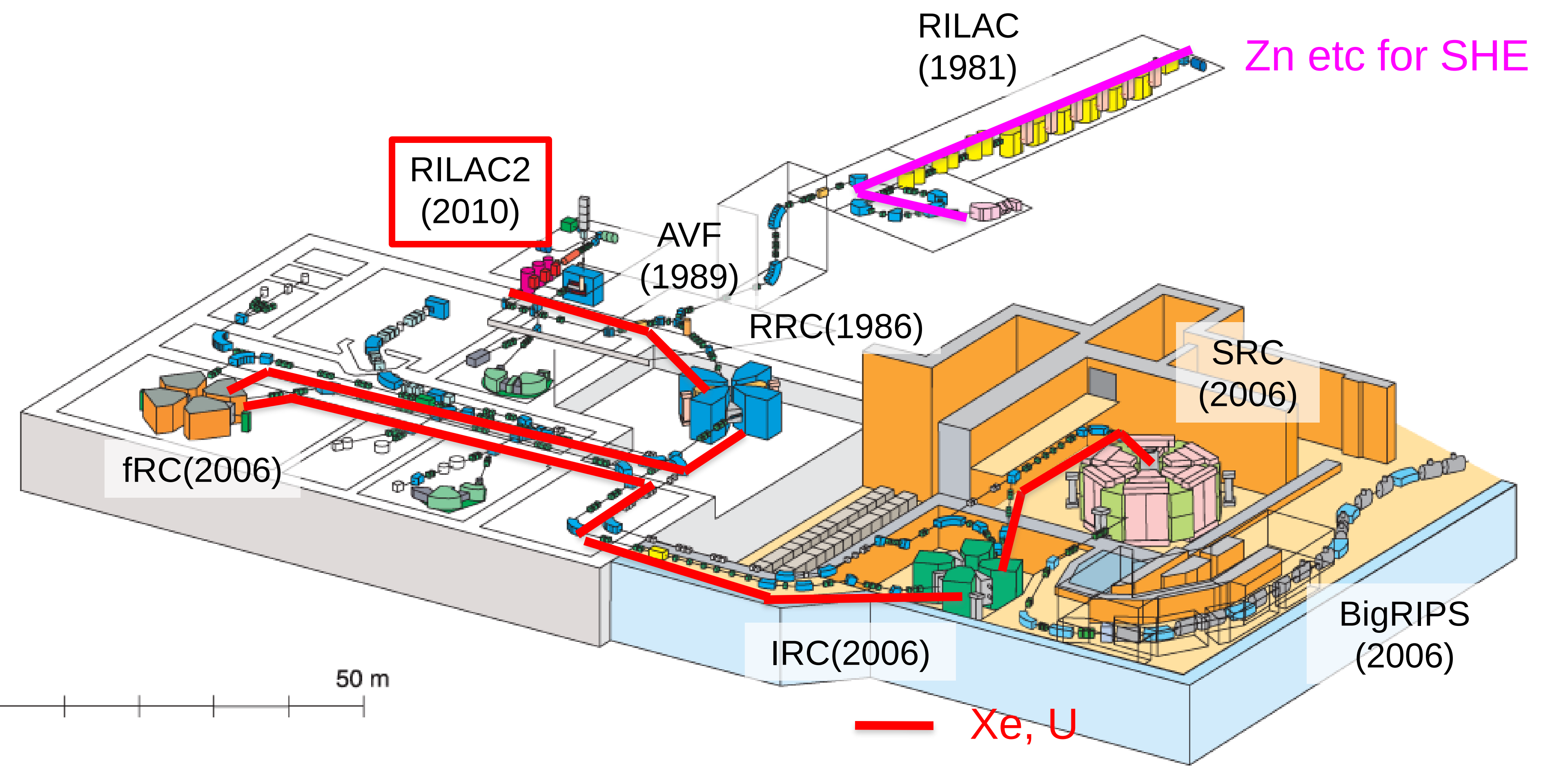
RIB facilities in Asia



RIKEN RIBF, Japan

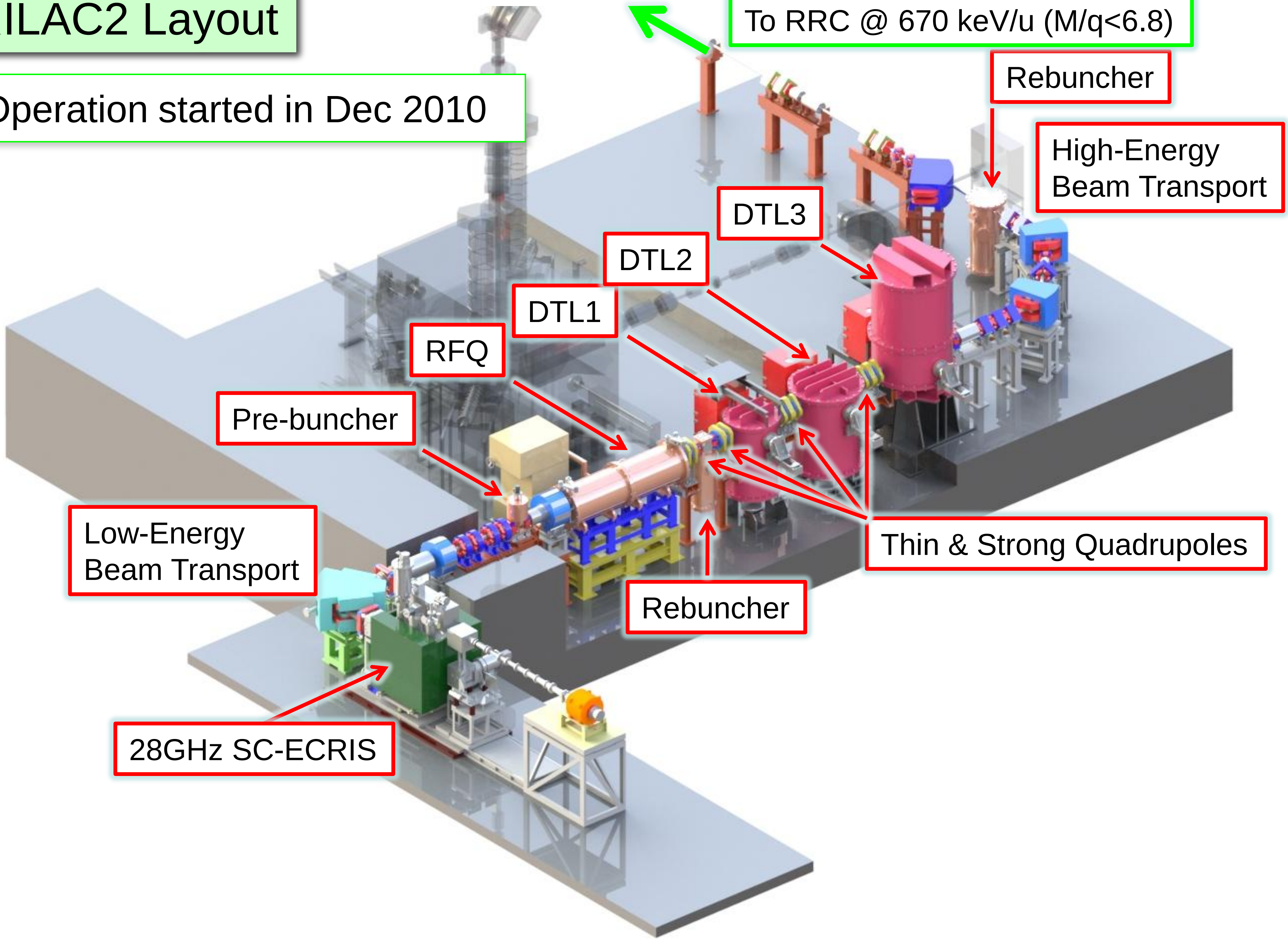
Y. Yano, NIM B261 (2007) 1009
(RIBF=Radioactive Isotope Beam Factory)

3 Injectors & 4 Booster cyclotrons
In-flight fragmentation / fission



RILAC2 Layout

Operation started in Dec 2010

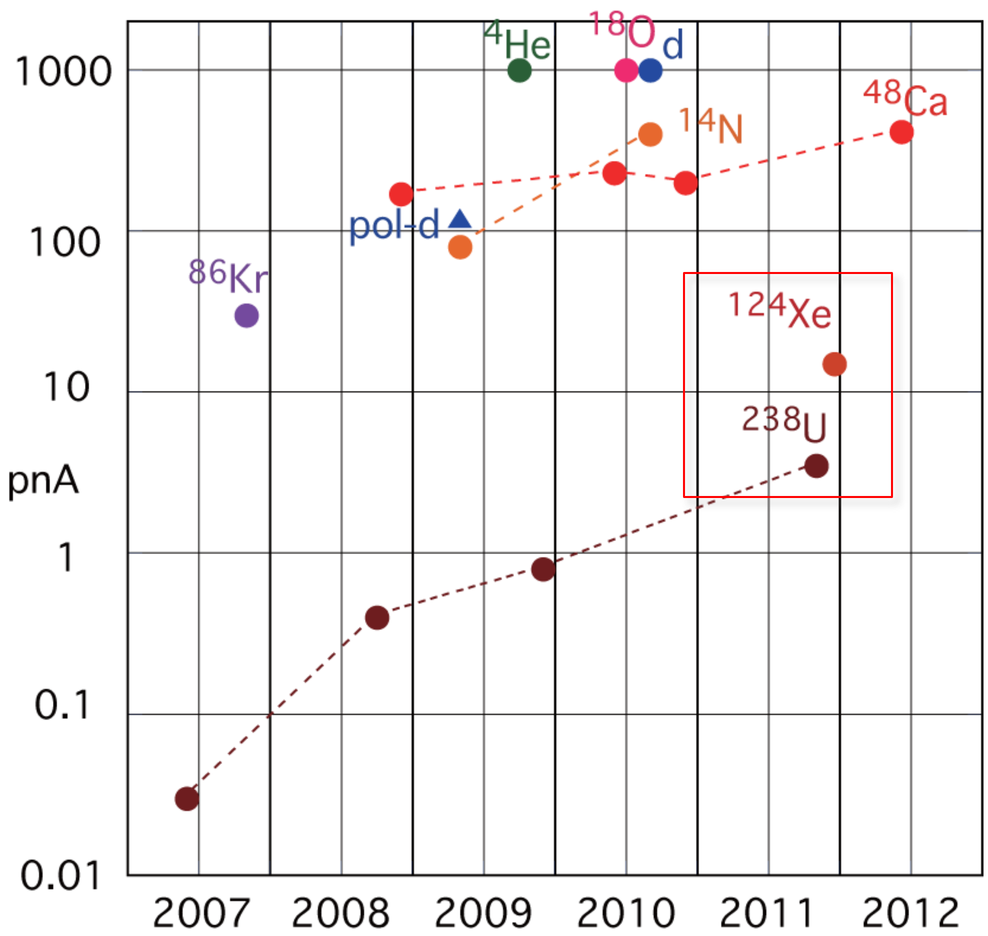


K. Yamada, IPAC2012

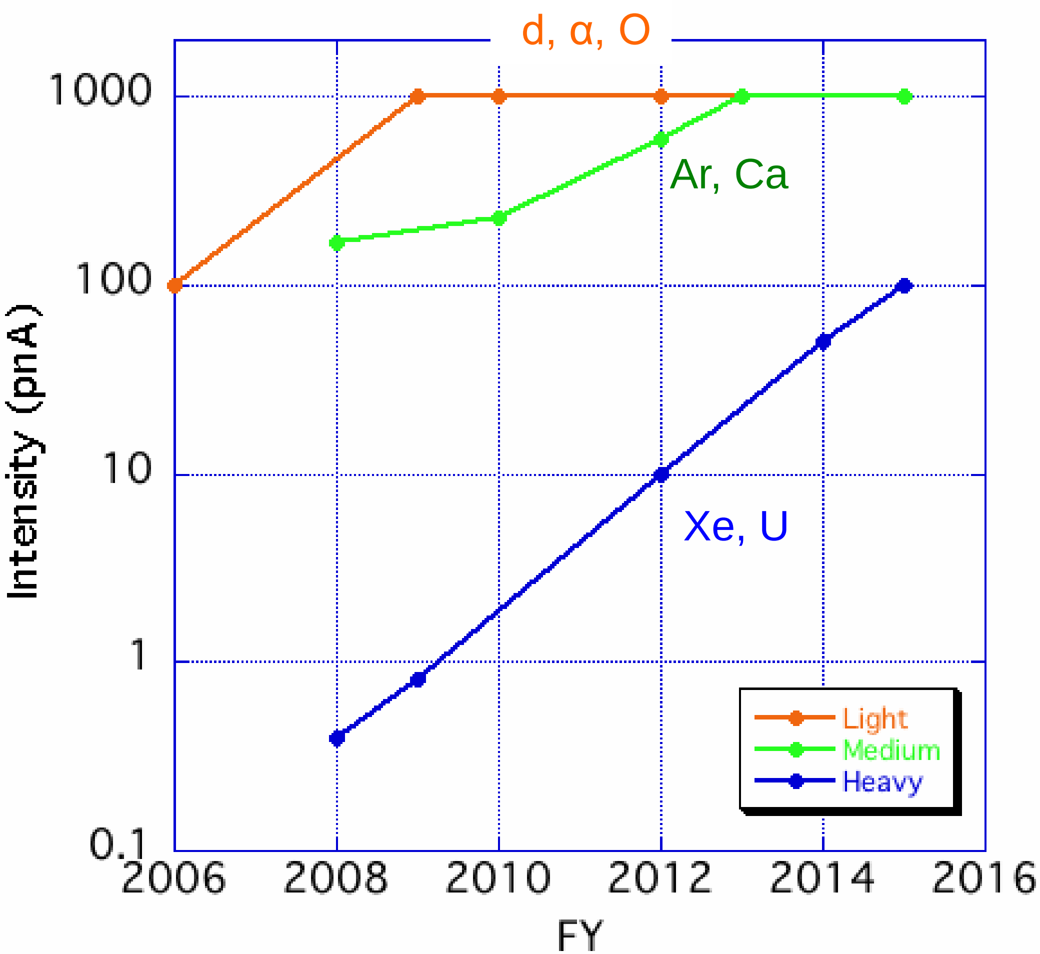
Achieved beam intensities at RIBF

• 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)	415 pnA
	(6.8 kW)
• ^{86}Kr(345 MeV/u)	30 pnA
• ^{124}Xe(345 MeV/u)	15 pnA
• ^{238}U(345 MeV/u)	3.5 pnA

=> 2×10^{10} pps



Intensity upgrade plan



R&Ds:

- Charge stripper

  => (Dr. Okuno's talk)

- Upgrade of fRC

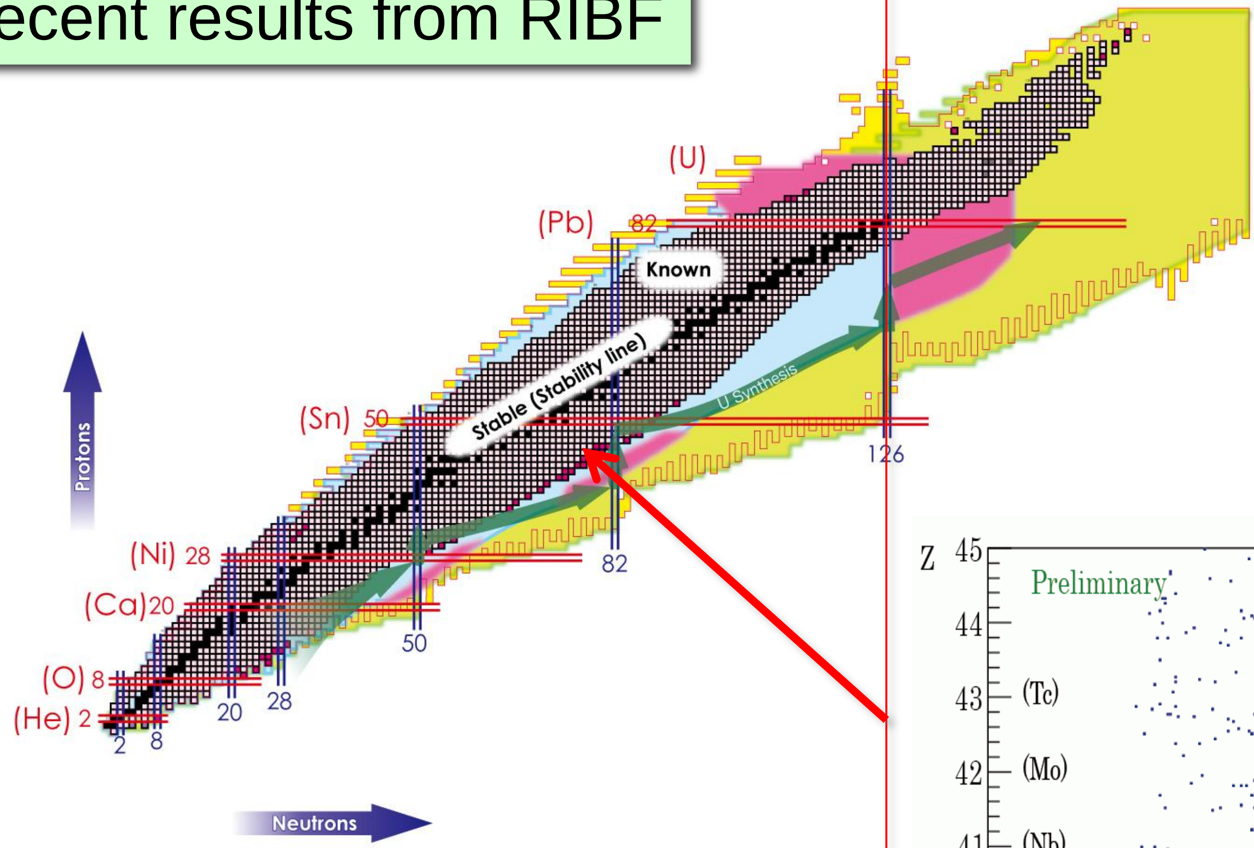
  => Waiting for beam test

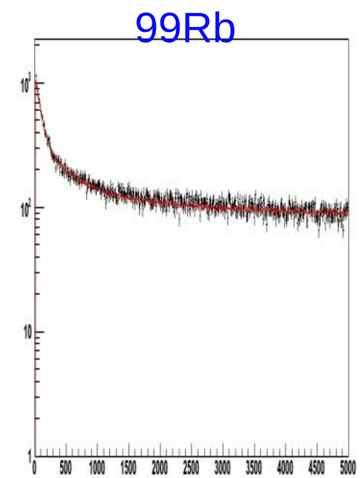
- UO_2 oven

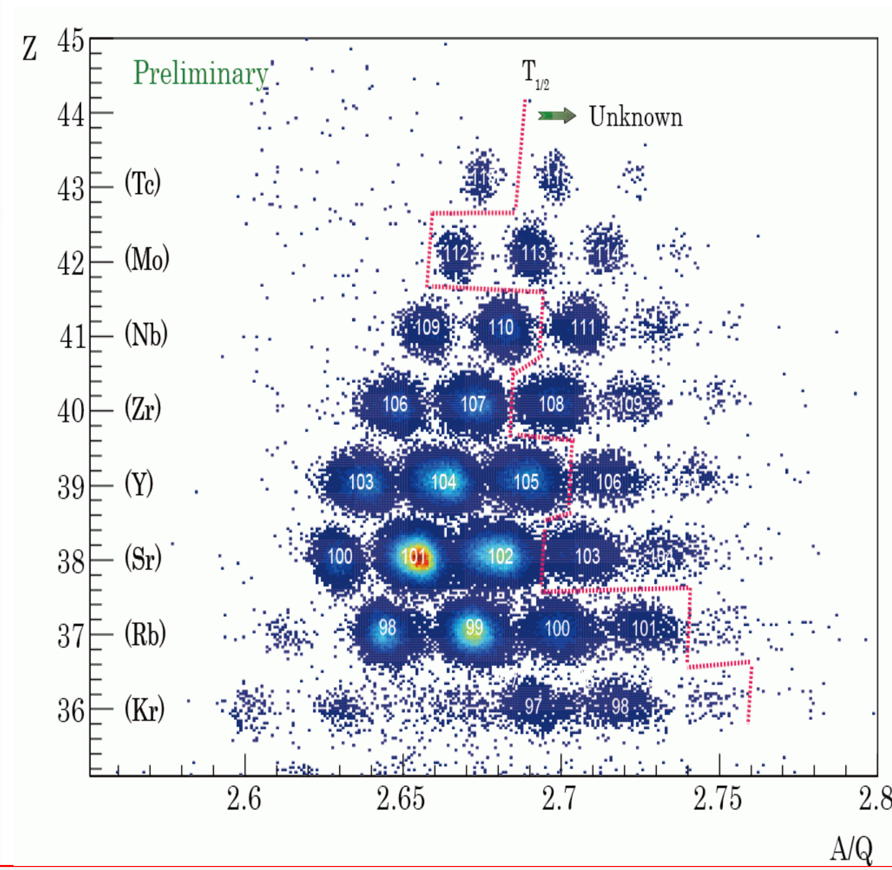
  => in progress

- Stabilization of temperature
- Dated components

Recent results from RIBF





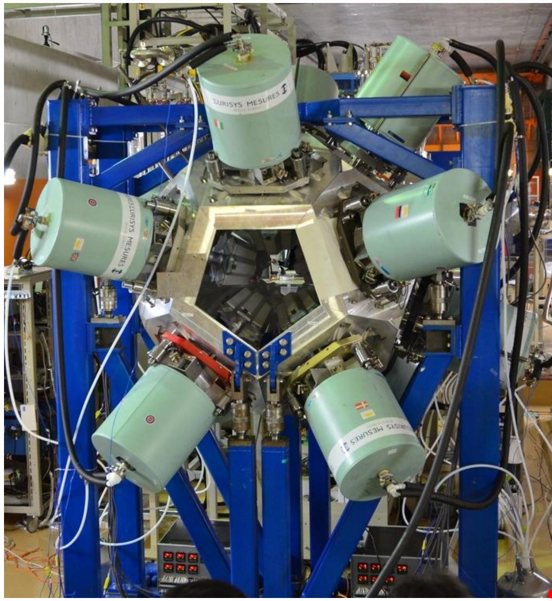


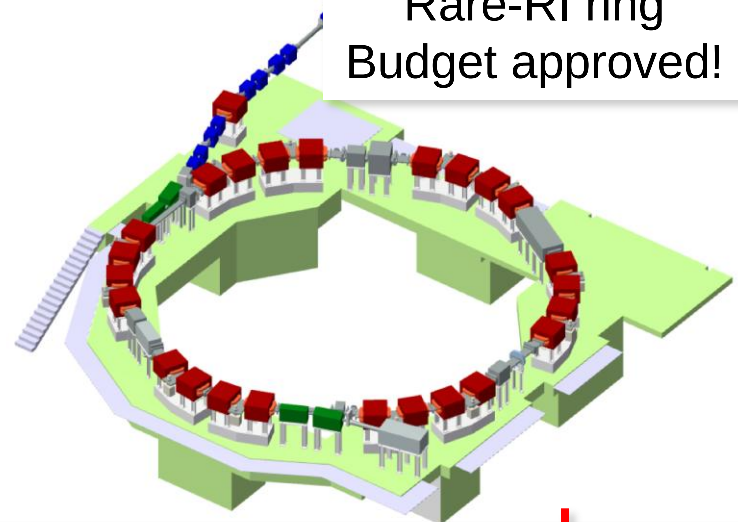
New $T_{1/2}$ measured !

S. Nishimura et al., PRL 106 (2011) 052502

5 PRL, 3 PLB, 2 PRC, 2 JPSJ ..

New experimental apparatus & Collaboration

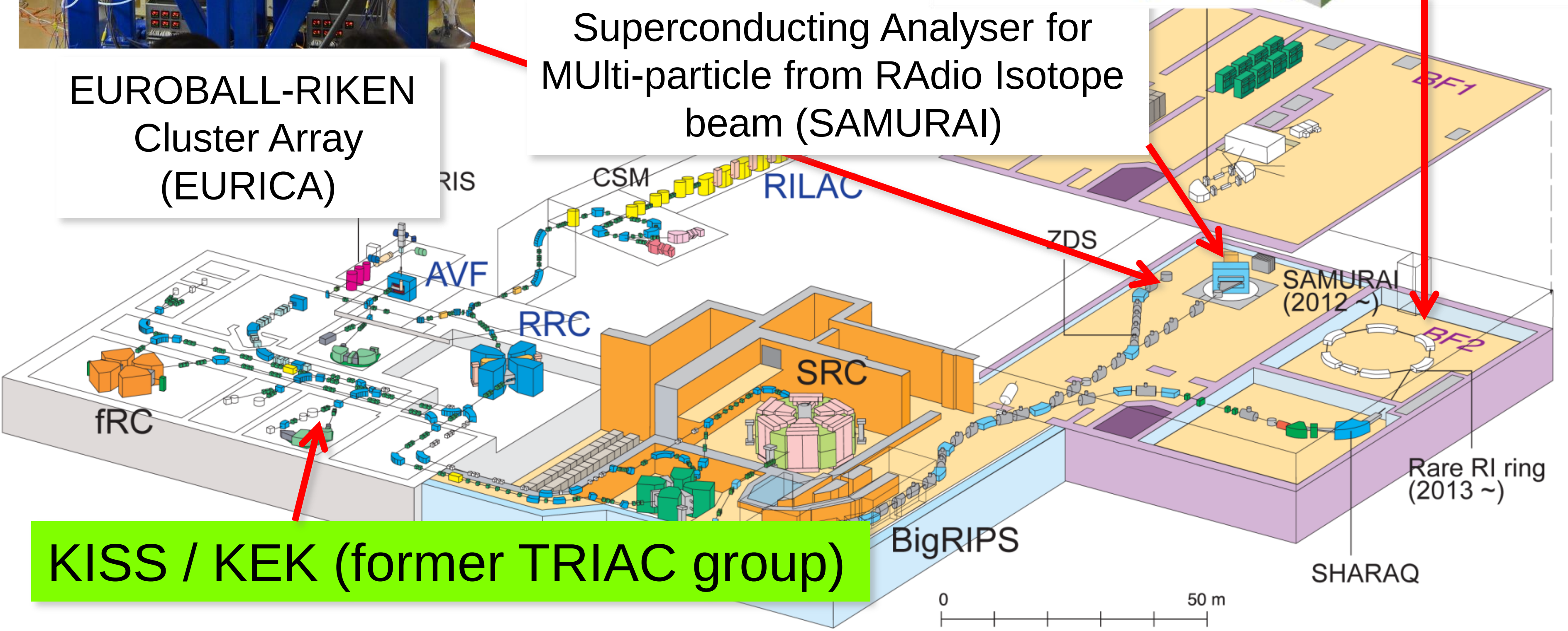




Rare-RI ring
Budget approved!

EUROBALL-RIKEN
Cluster Array
(EURICA)

Superconducting Analyser for
MUlti-particle from RAdio Isotope
beam (SAMURAI)

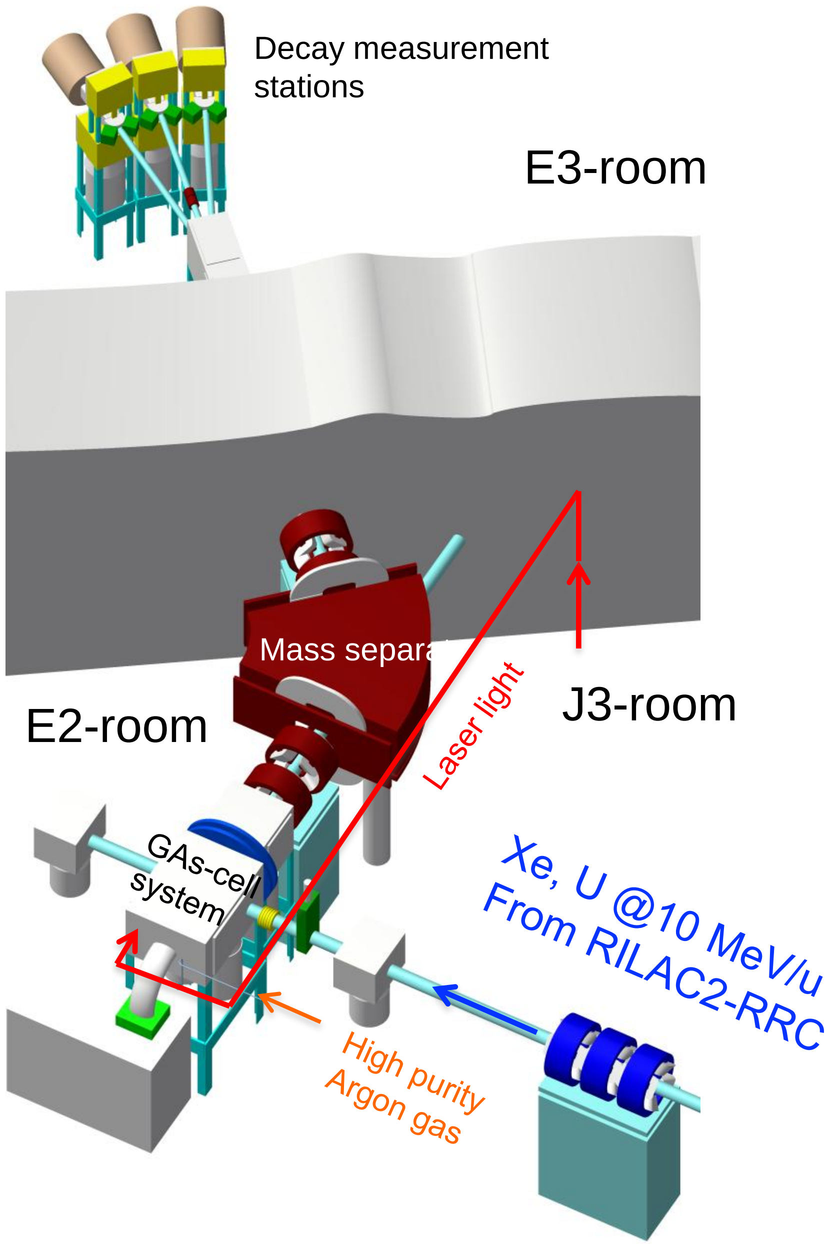


KISS / KEK (former TRIAC group)

KISS project by KEK at RIKEN

Courtesy of Prof. Miyatake (KEK)

(KISS : KEK Isotope Separation System)



Argon-gas catcher cell
+ Laser resonant ionization (Z)
+ Mass separation (A)
+ Low-background det. system

$\varepsilon_{tot.}$~ 7 % ($t_{1/2}$=500 ms)

R_Z~ 1000, R_A~ 840

$\tau_{extr.}$~ 240 ms

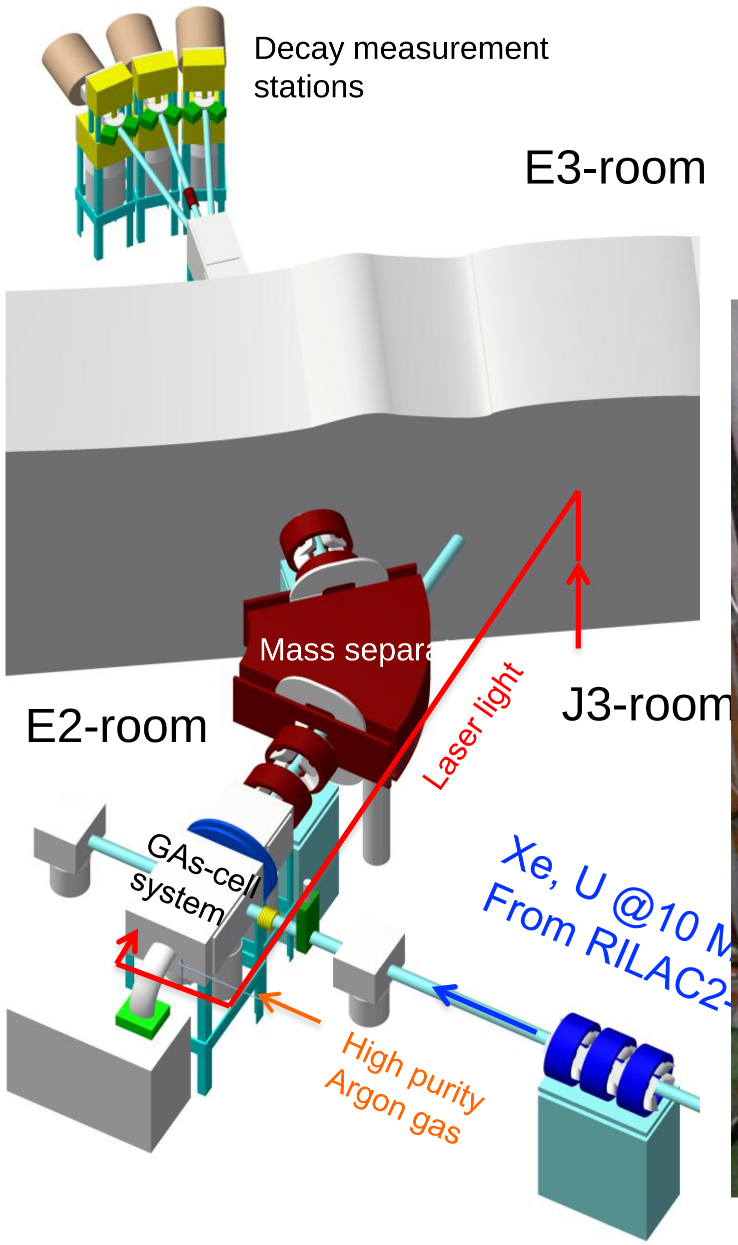
~3 day machine time for ^{200}W

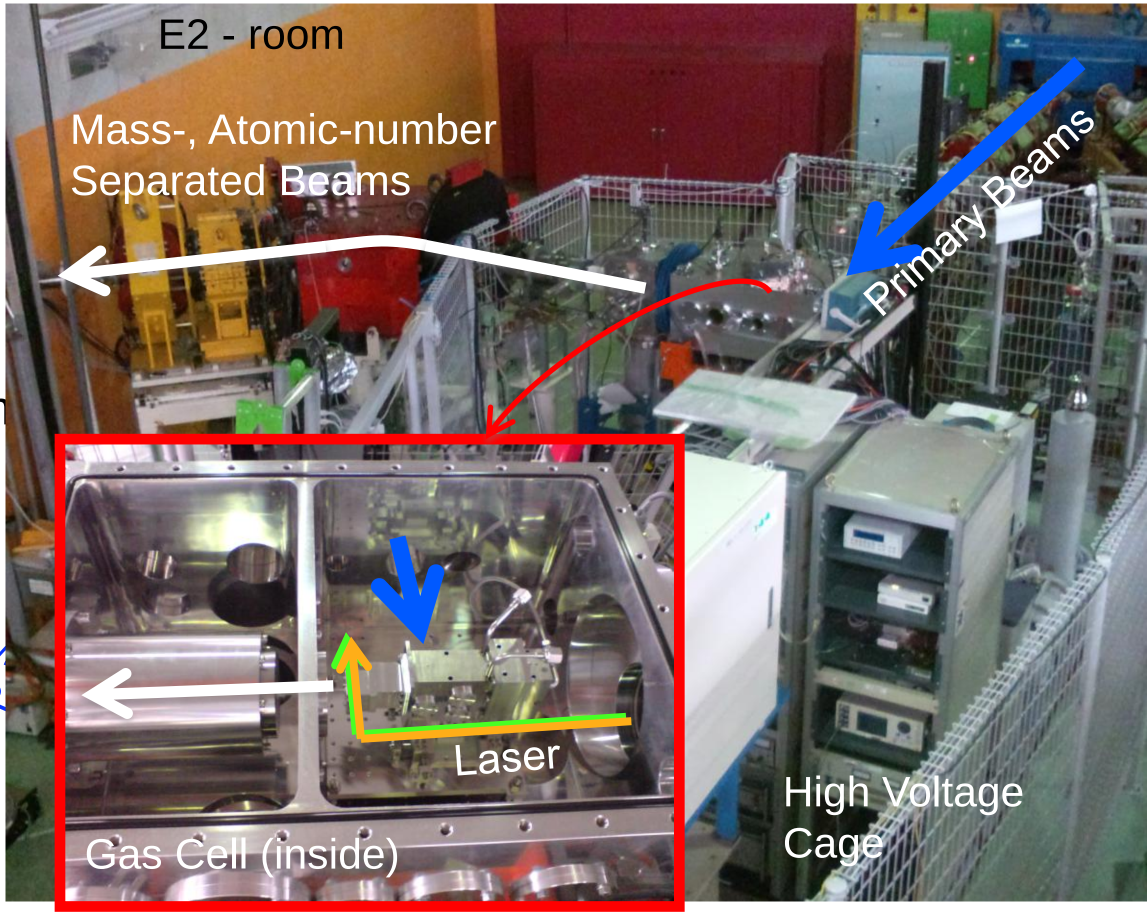
KISS project by KEK at RIKEN

Courtesy of Prof. Miyatake (KEK)

(KISS : KEK Isotope Separation System)

Argon-gas catcher cell
+ Laser resonant ionization (*Z*)
+ Mass separation (*A*)
+ Low-background det. system

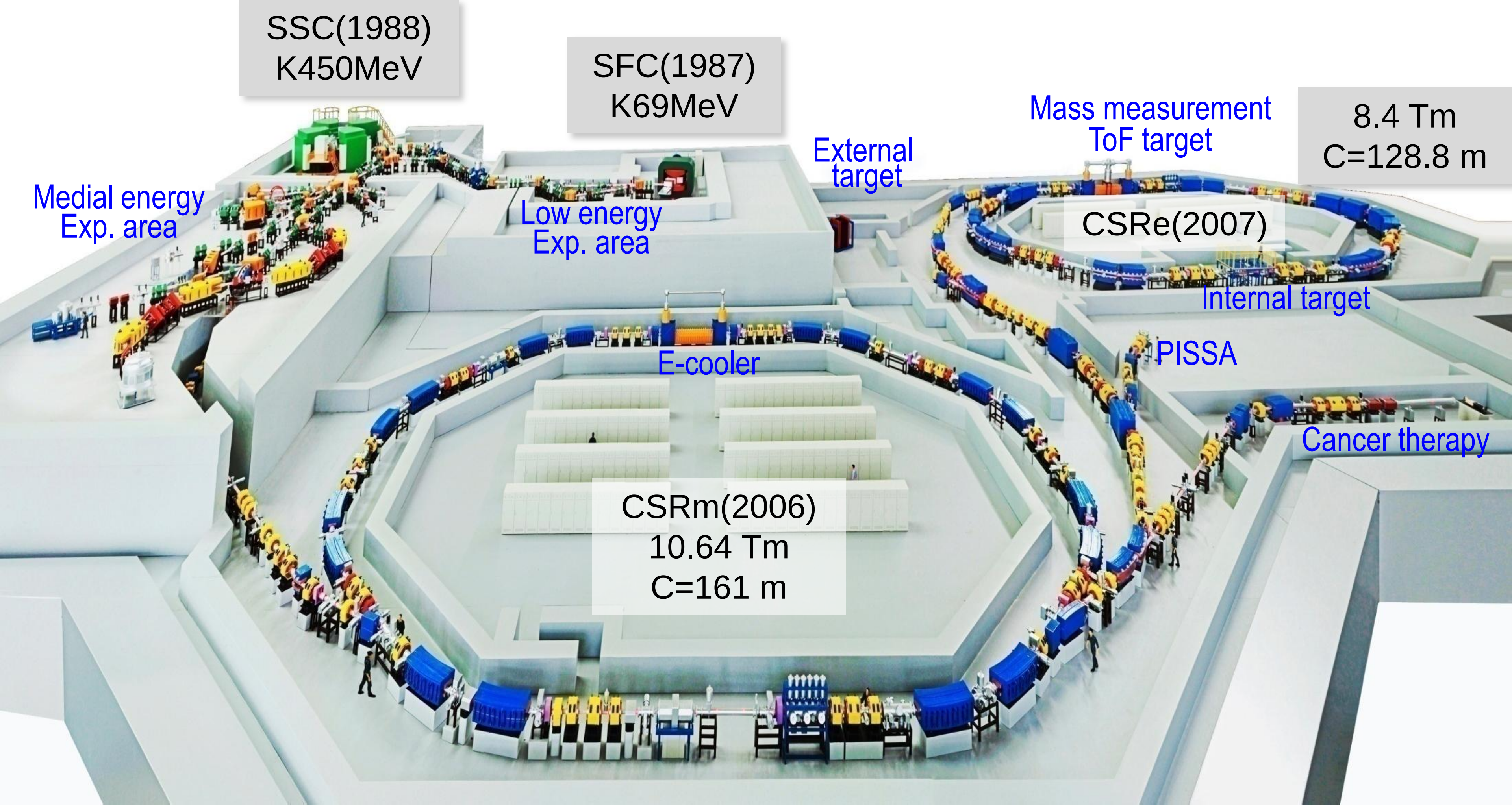




IMP-CAS HIRFL, China

Courtesy of Prof. Zhao (IMP)
(HIRFL = Heavy Ion Research Facility in Lanzhou)

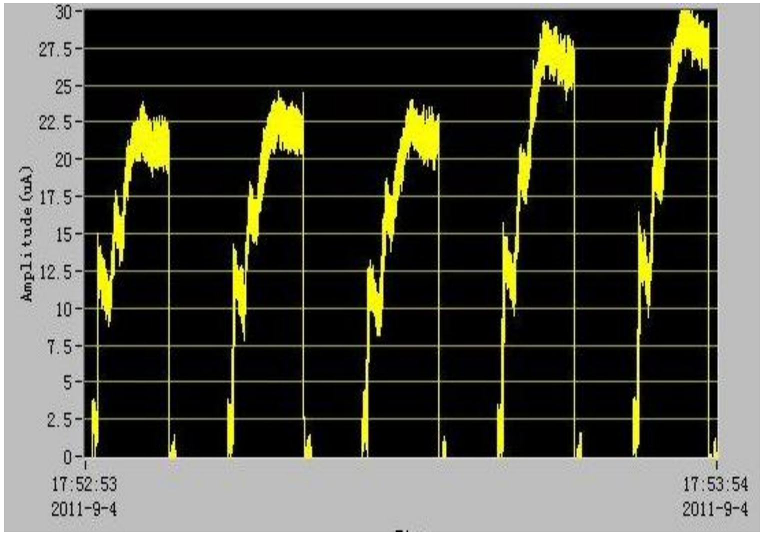
2 Cyclotrons + 2 Cooler-ring Synchrotron
In-flight fragmentation



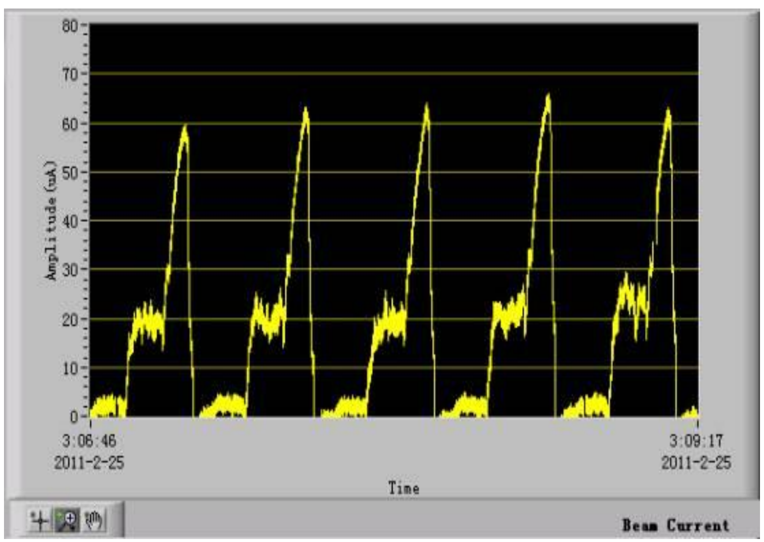
Layout of HIRFL

New beams in HIRFL

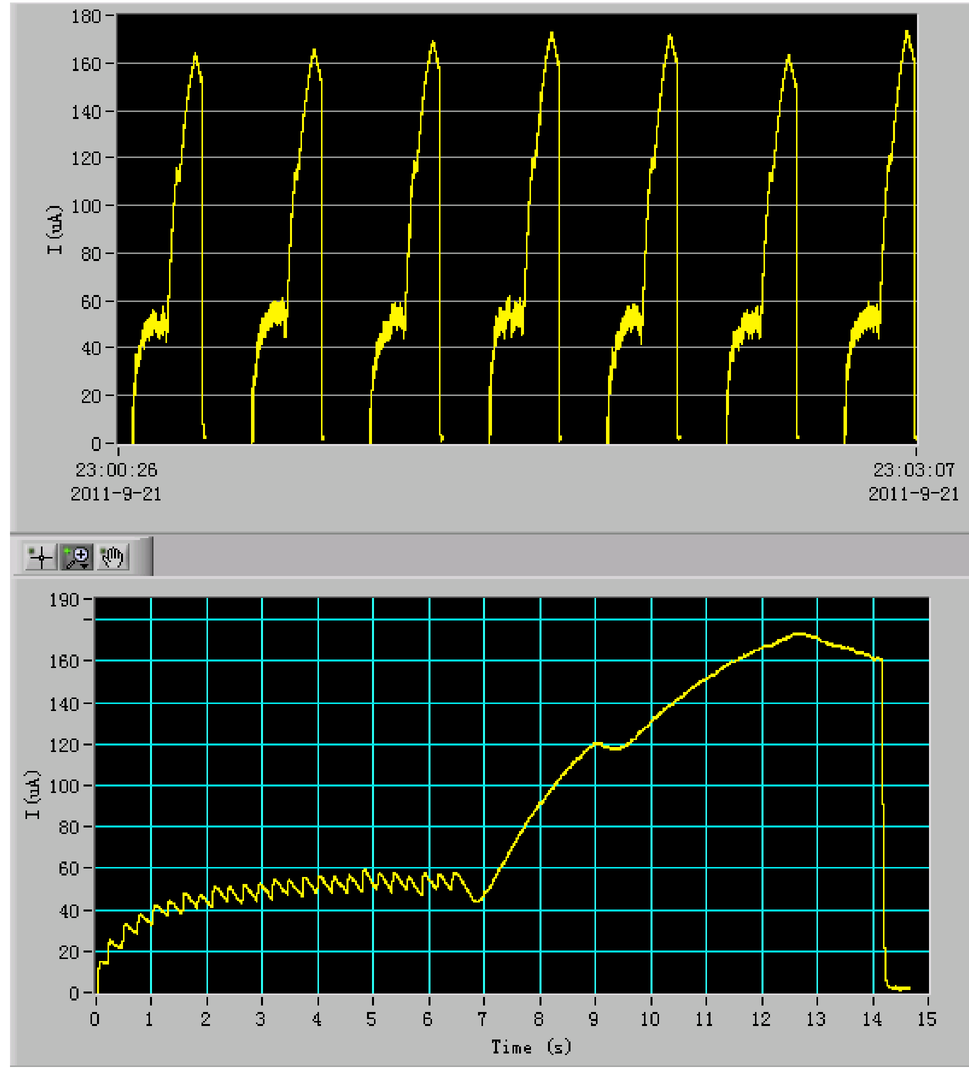
Courtesy of Prof. Zhao (IMP)



H_2^+, 400MeV/u



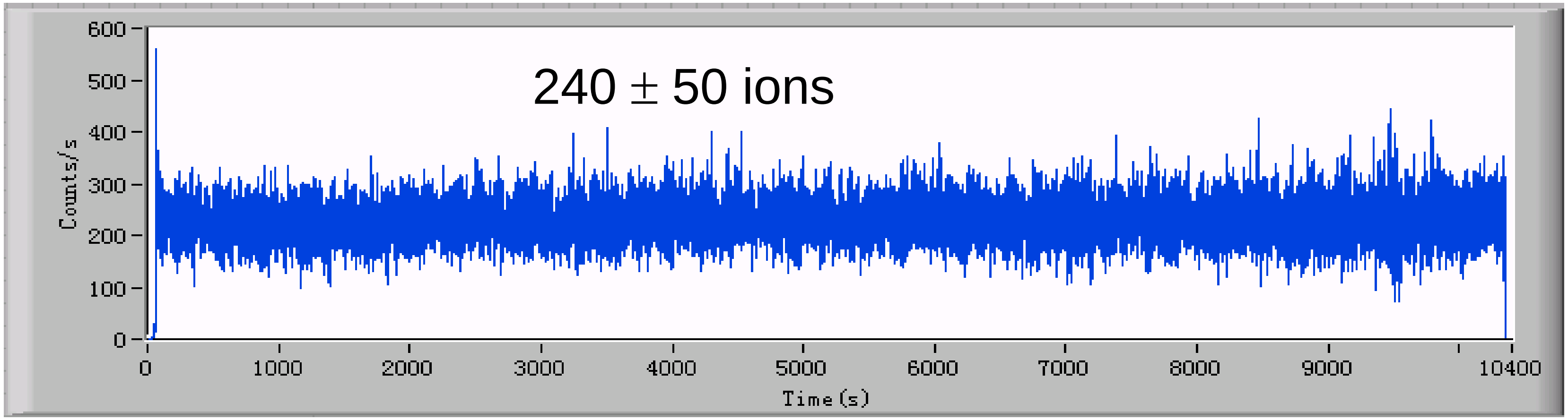
$^{209}Bi^{36+}$, 170MeV/u

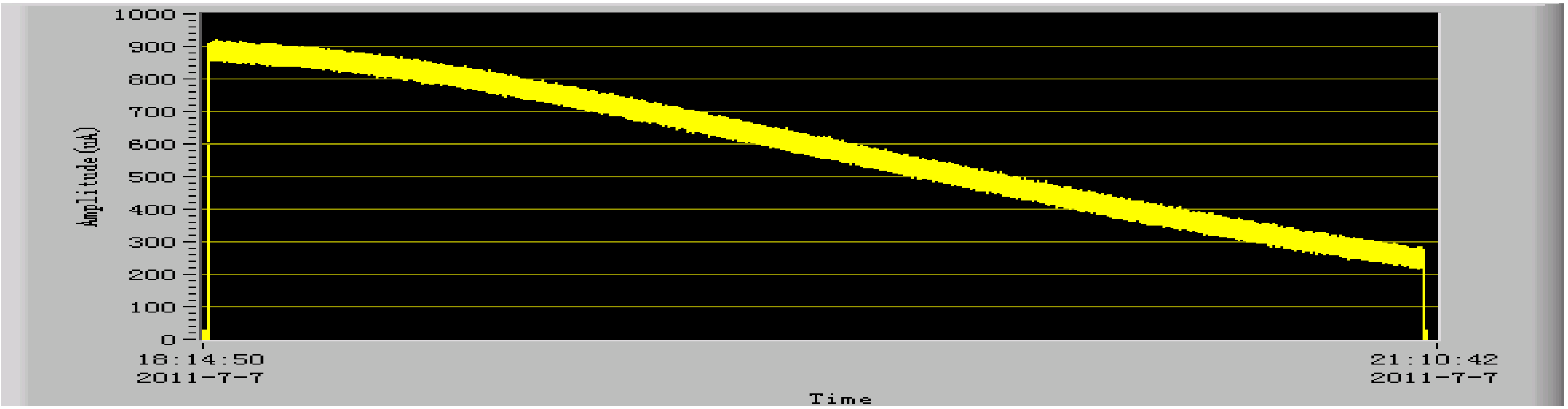


$^{238}U^{32+}$, 100MeV/u， 10^7ppp

Long pulse slow extraction in CSRm:10,000 s

Courtesy of Prof. Zhao (IMP)



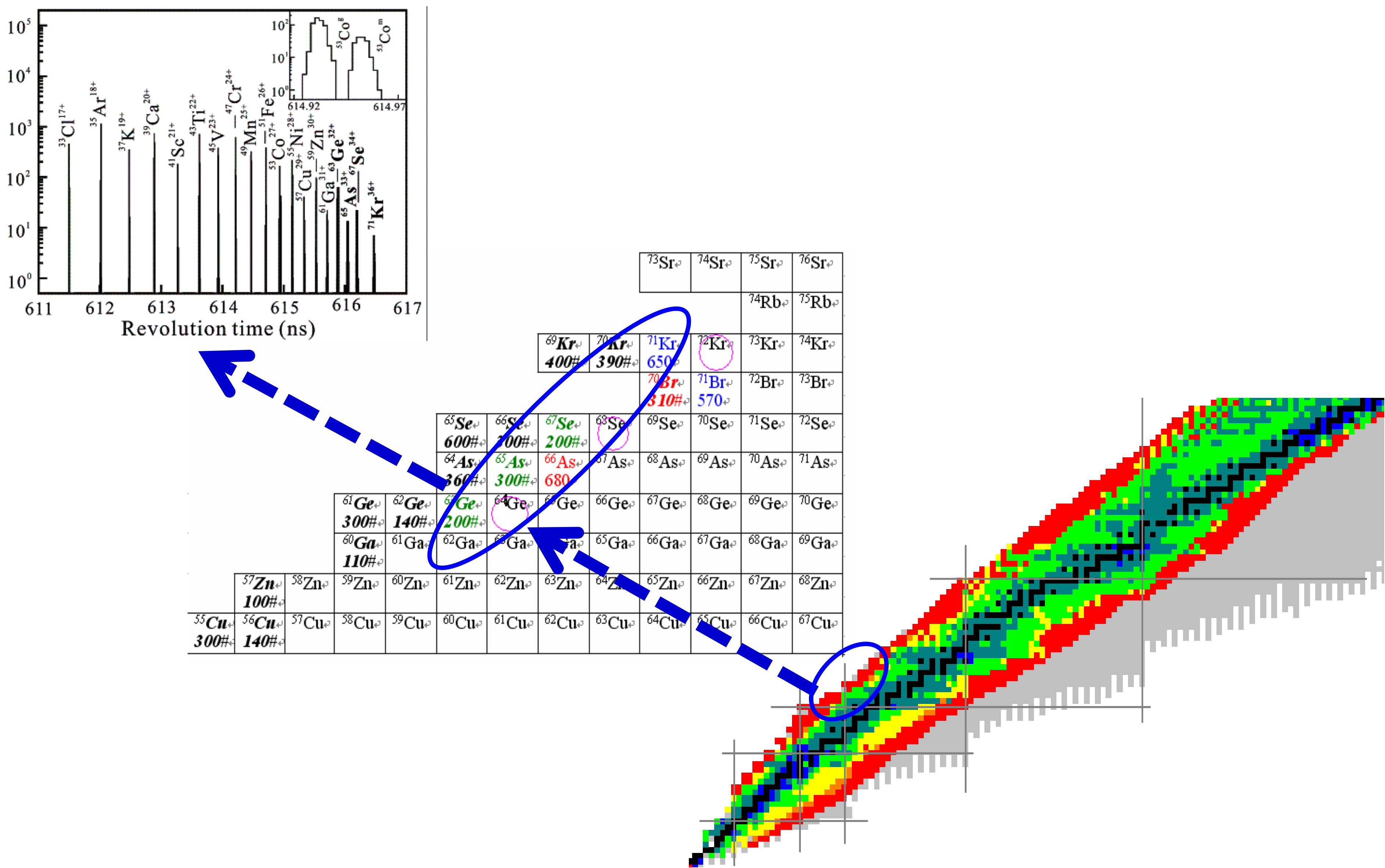


- 1/3 resonance slow extraction
- RF-Knockout exciting
- Feedback of extraction rates with fast Qs

Recent results from HIRFL

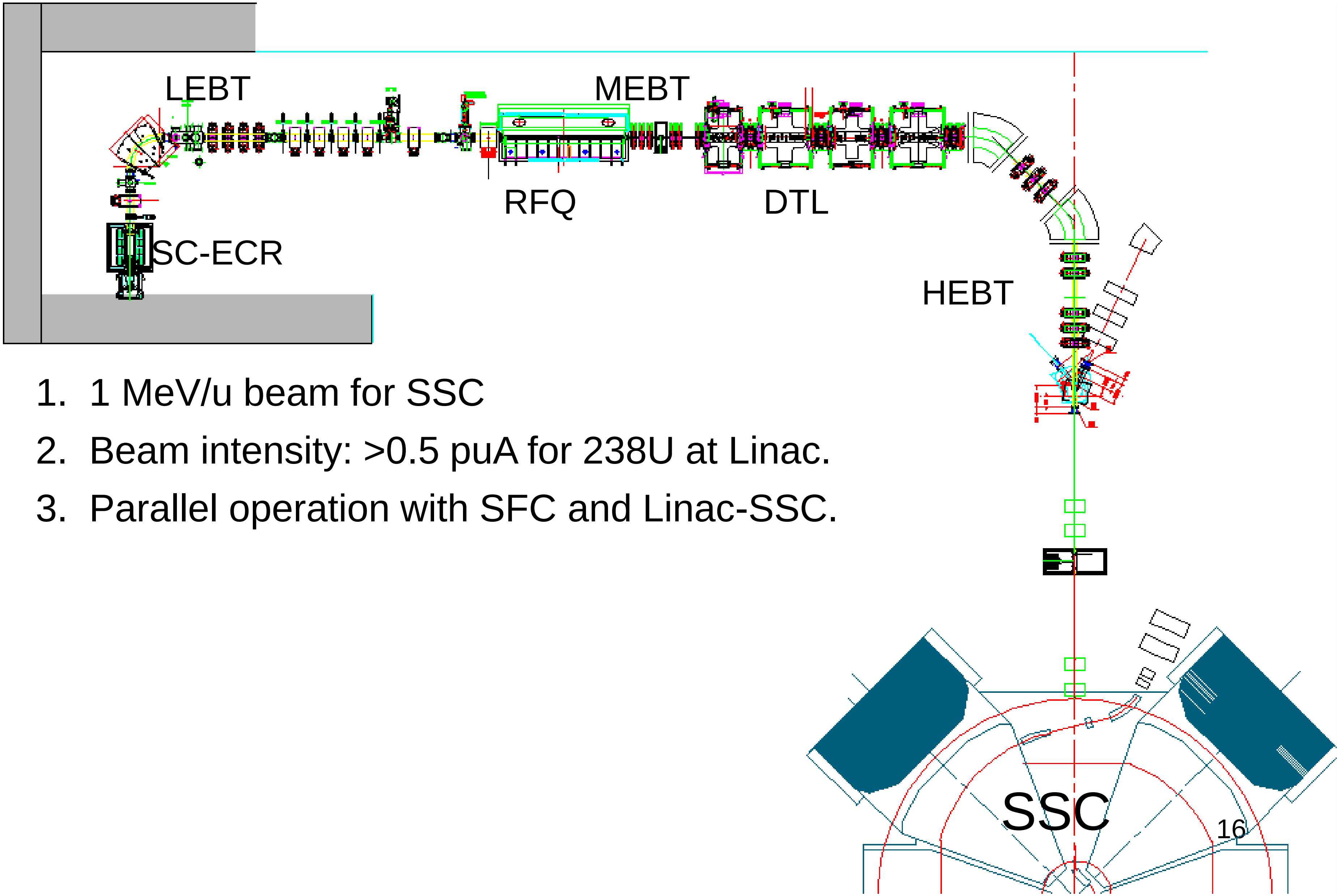
X. L. Tu, PRL 106 (2011) 112501

Mass measured for drip-line nuclei ^{63}Ge, ^{65}As, ^{67}Se, ^{71}Kr



Near-future plan (next 2~3 years): SSC-Linac

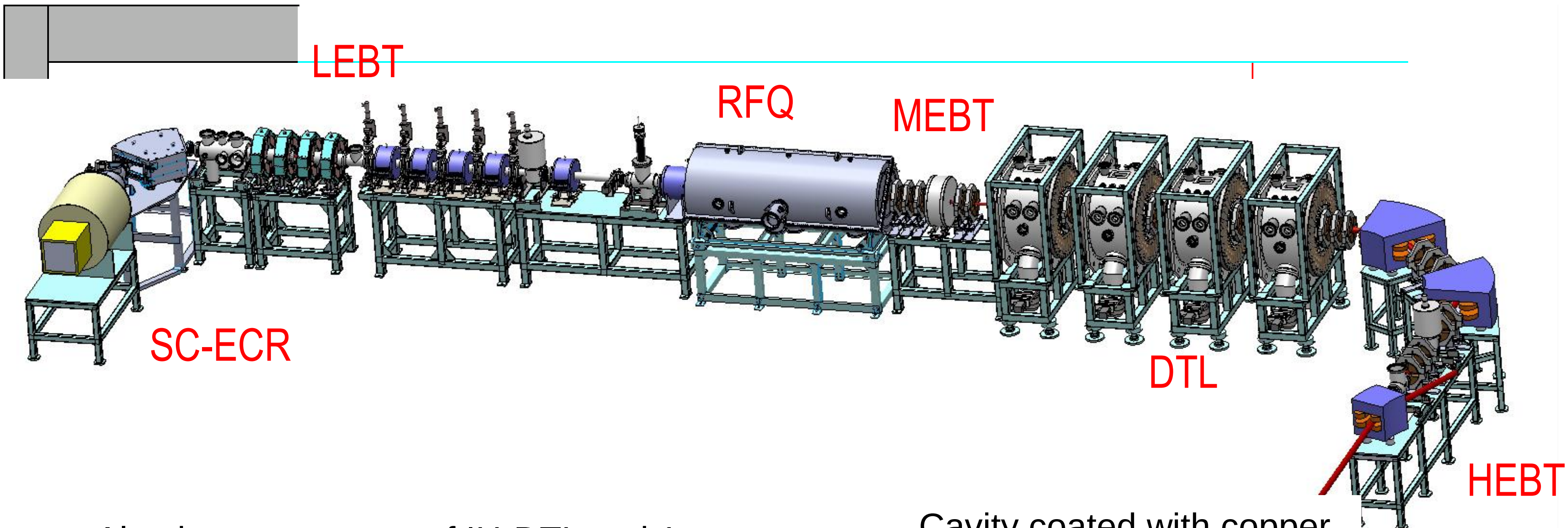
Courtesy of Prof. Zhao (IMP)



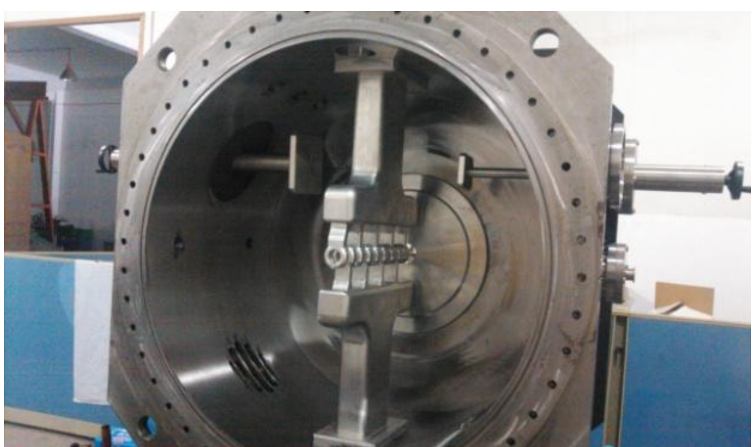
1. 1 MeV/u beam for SSC
2. Beam intensity: >0.5 puA for 238U at Linac.
3. Parallel operation with SFC and Linac-SSC.

Near-future plan (next 2~3 years): SSC-Linac

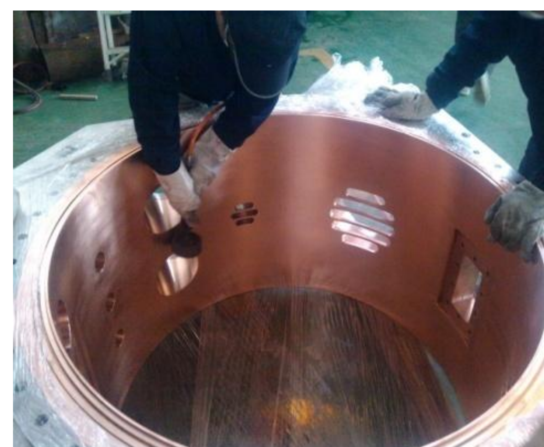
Courtesy of Prof. Zhao (IMP)



Aluminum prototype of IH-DTL tank1



Cavity coated with copper in inner surface

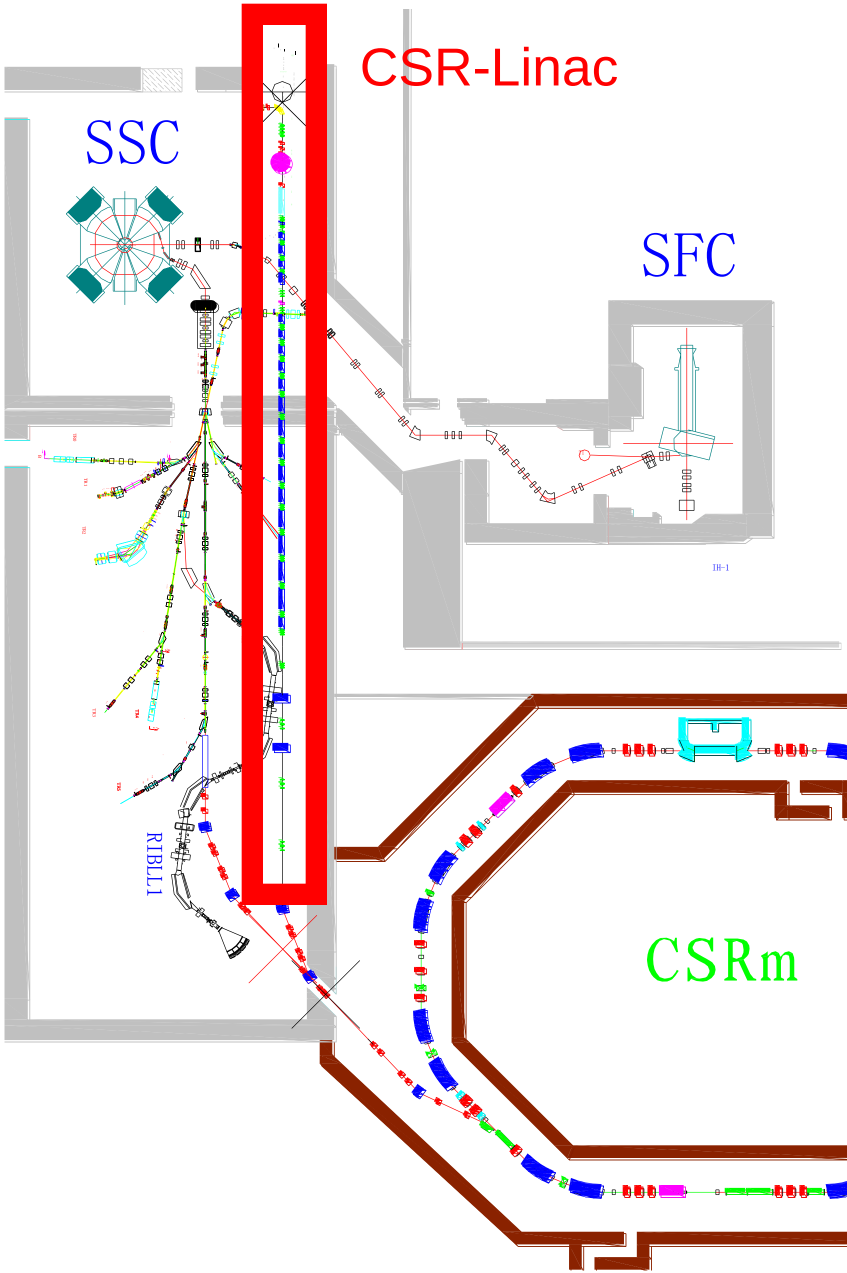


Near-future plan (next 3~5 years): CSR-Linac

Courtesy of Prof. Zhao (IMP)

1. 10 MeV/u beam for CSRm.
2. Beam intensity: >5 euA for 238U.
3. Parallel operation with SFC, SFC+SSC and Linac-CSR.

Element	Length [cm]	Frequency [MHz]	Energy [MeV/u]
LEBT	920	0→13.4167	0.00373
RFQ	252	53.6667	0.143
MEBT1	175	53.6667	0.143
DTL1	480	53.6667	1.025
MEBT2	400	161	1.025
DTL2	3000	161	10
HEBT	3300	161	10

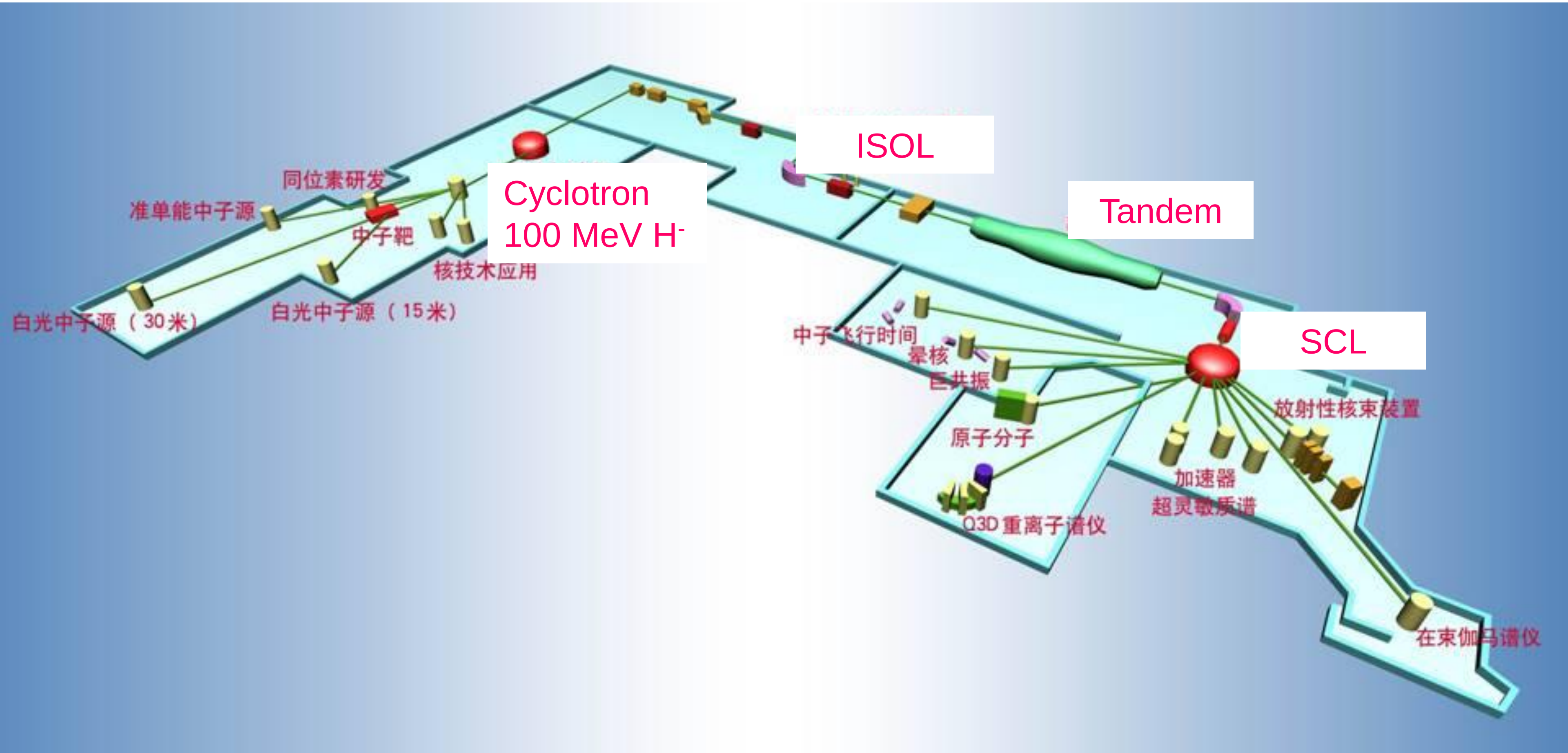


CIAE BRIF, China

Courtesy of Prof. Liu (CIAE)
(BRIF = Beijing Rare Ion beam Facility)

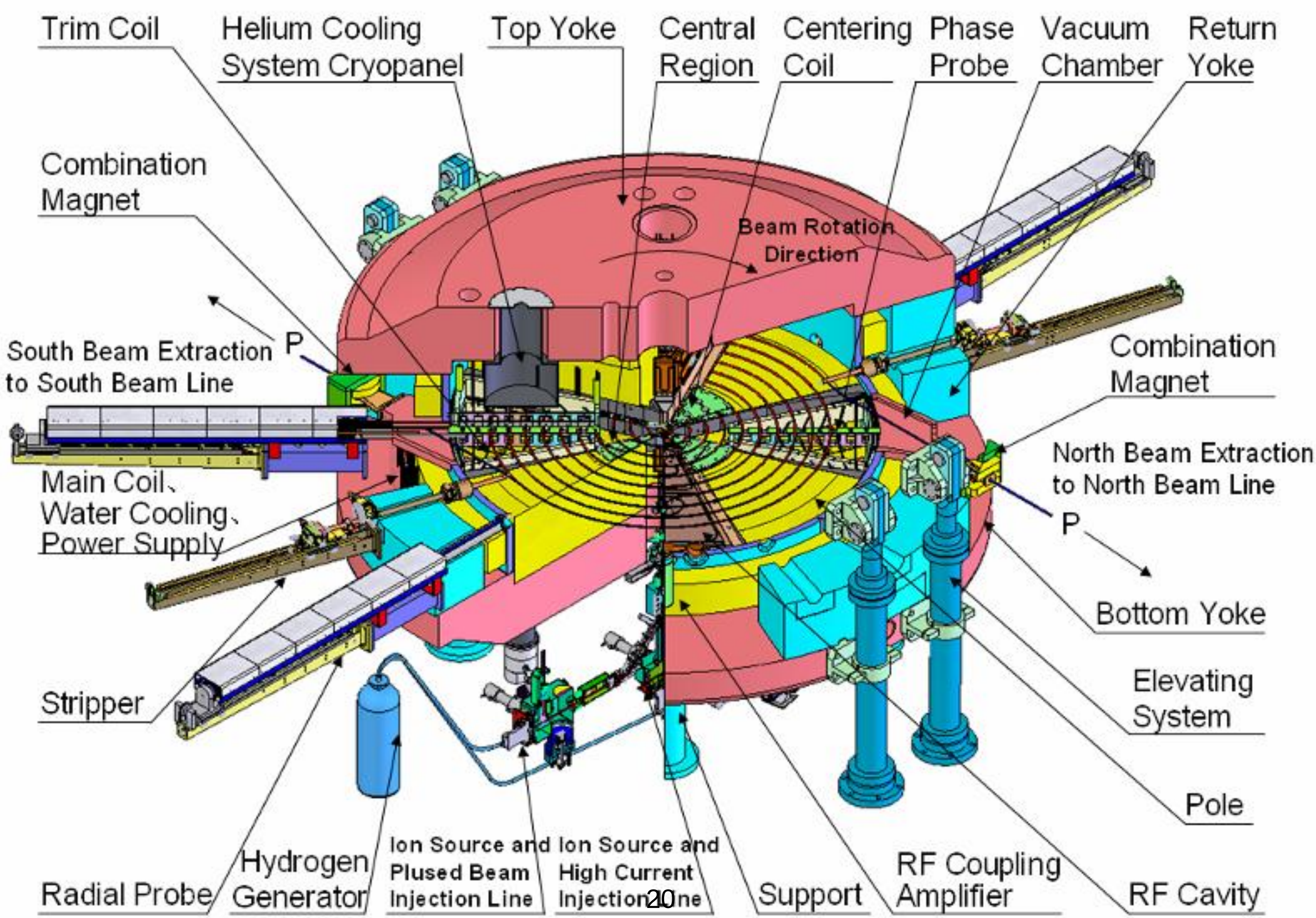
- ISOL / Driver = 100 MeV 200 μA compact H^- cyclotron
- 20000 mass resolution ISOL => Tandem => 2 MeV/q super-conducting LINAC

- Project approved in 2003 - 2004 / Revised plan approved in 2008 – 2009
- Civil engineering started in 2011 / Cyclotron fabrication completed in 2011



H- compact cyclotron (CYCIAE-100)

Courtesy of Prof. Liu (CIAE)



H- compact cyclotron (CYCIAE-100)

Courtesy of Prof. Liu (CIAE)

Superconducting linac in fabrication

Courtesy of Prof. Liu (CIAE)

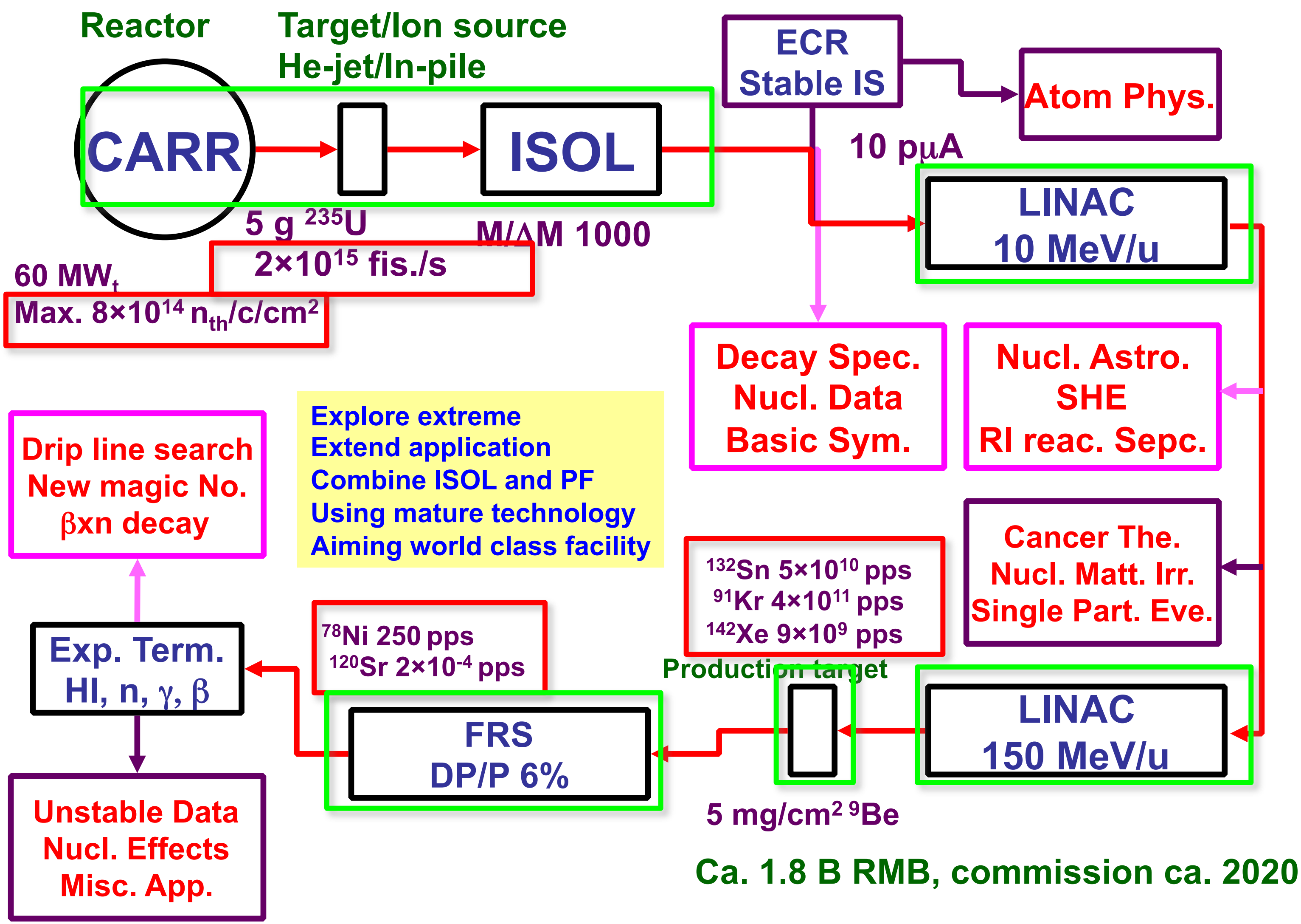
- BRIF will be commissioned in 2014.

Future plan : CARIF project at CIAE

Courtesy of Prof. Liu (CIAE)

- ISOL + PF scheme

CARIF (China Advanced Rare Ion-beam Facility)

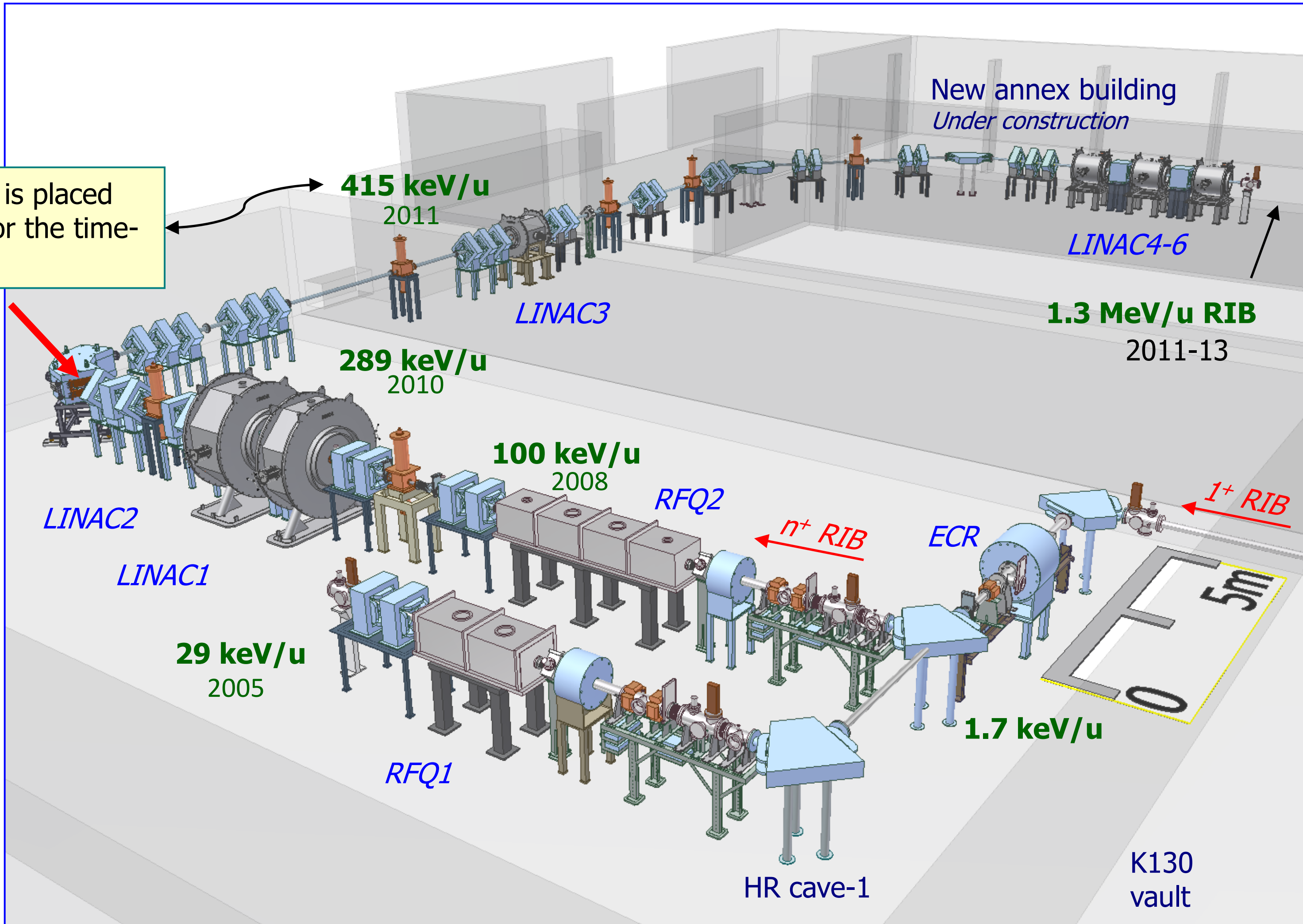


Ca. 1.8 B RMB, commission ca. 2020

RIB project – VECC, India

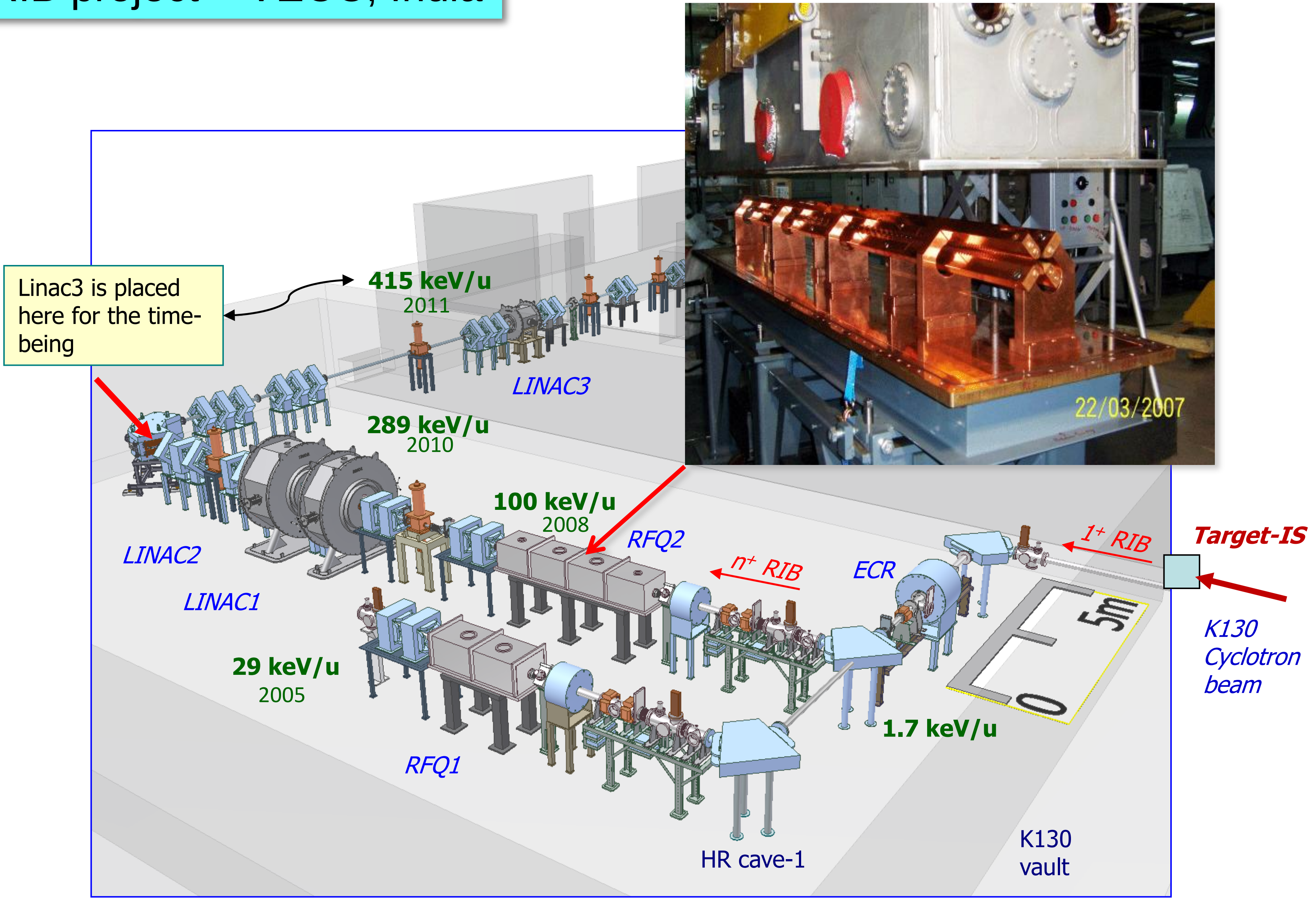
Courtesy of Prof. Chakrabarti (VECC)

Linac3 is placed here for the time-being



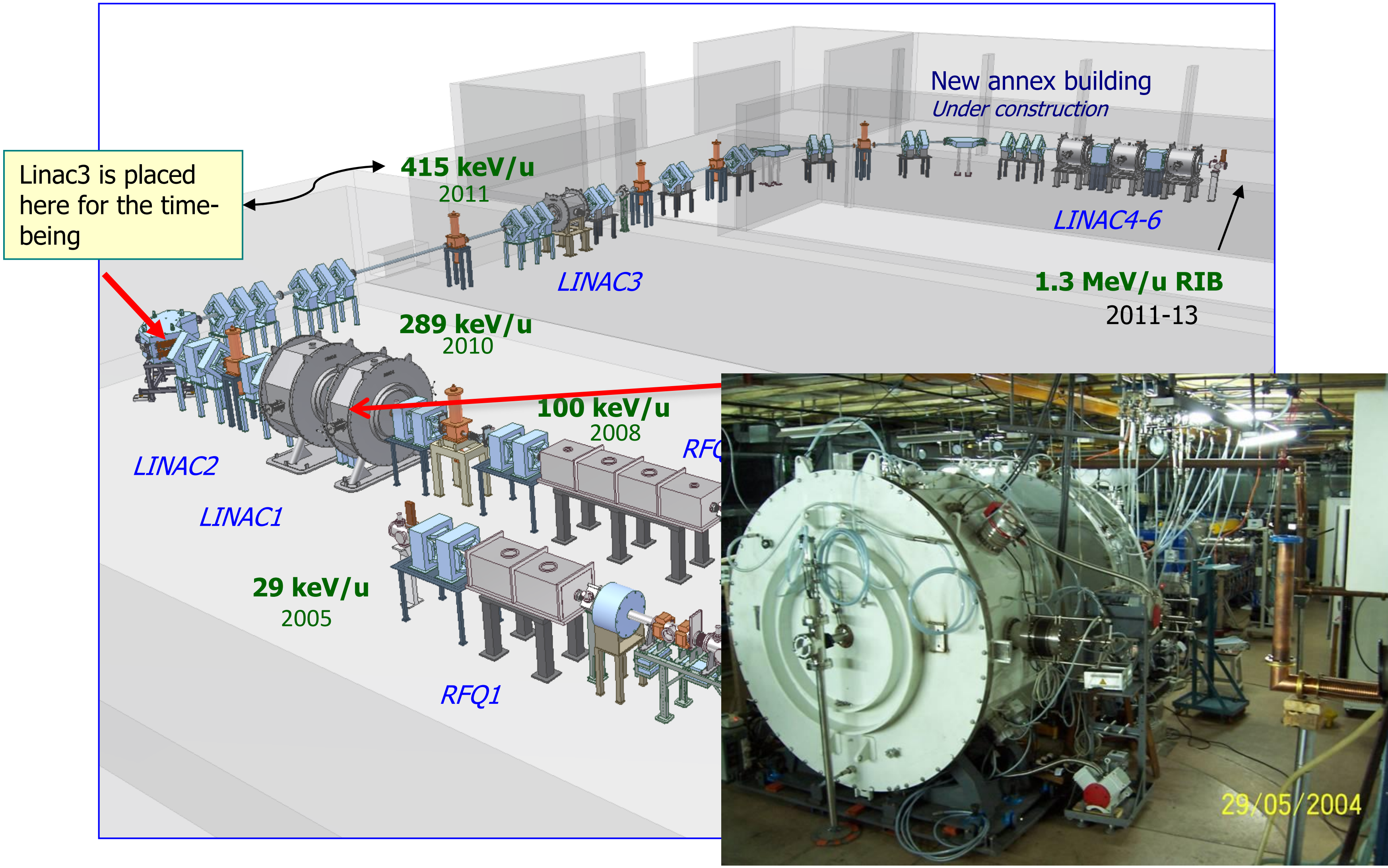
RIB project – VECC, India

Courtesy of Prof. Chakrabarti (VECC)



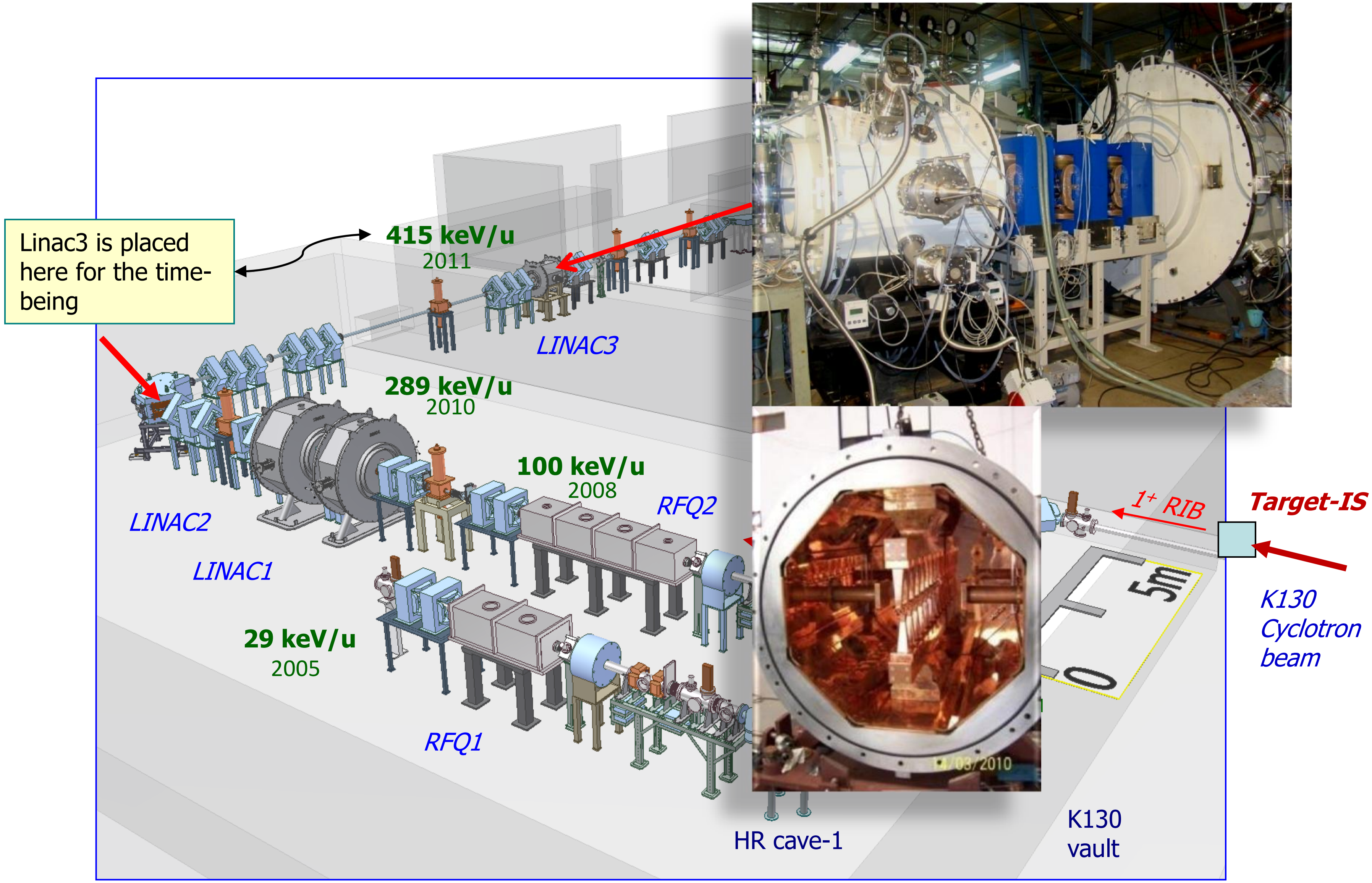
RIB project – VECC, India

Courtesy of Prof. Chakrabarti (VECC)



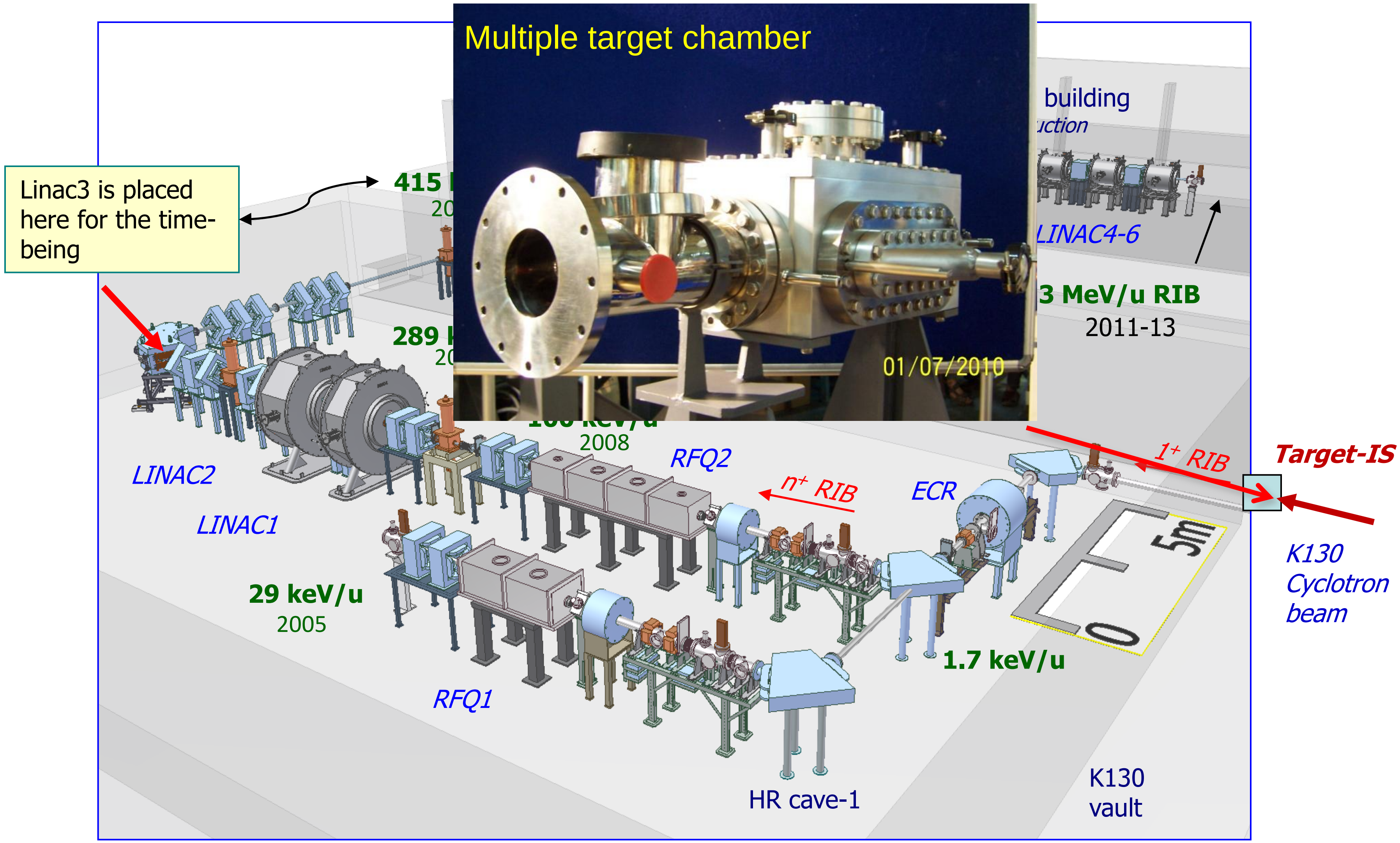
RIB project – VECC, India

Courtesy of Prof. Chakrabarti (VECC)



RIB project – VECC, India

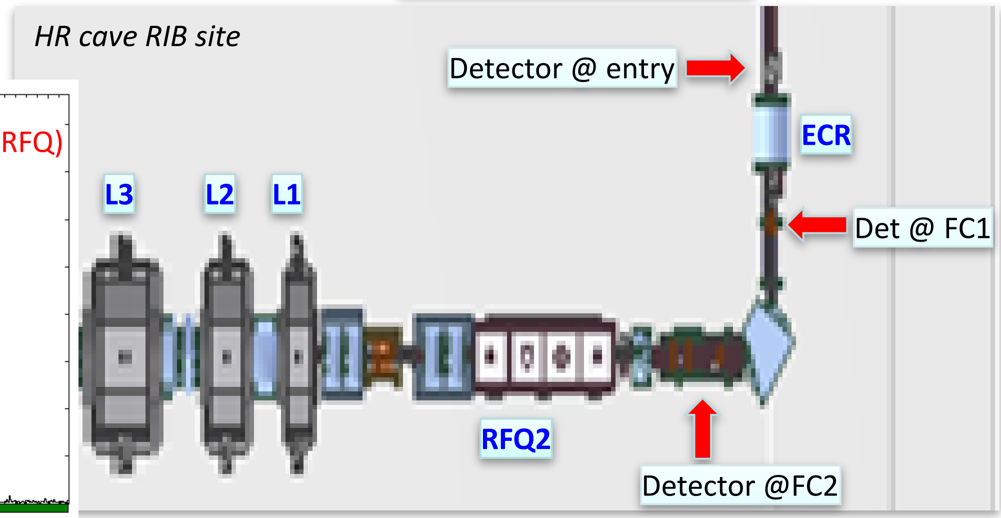
Courtesy of Prof. Chakrabarti (VECC)

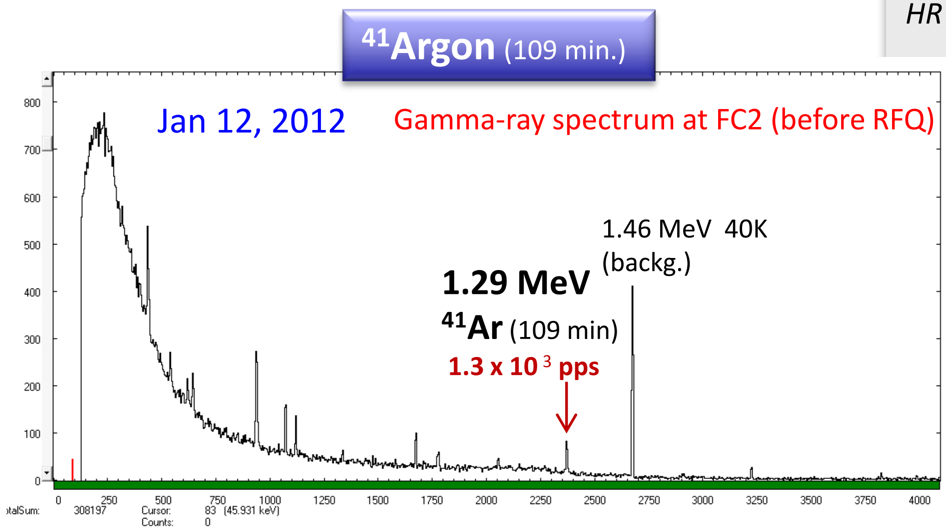


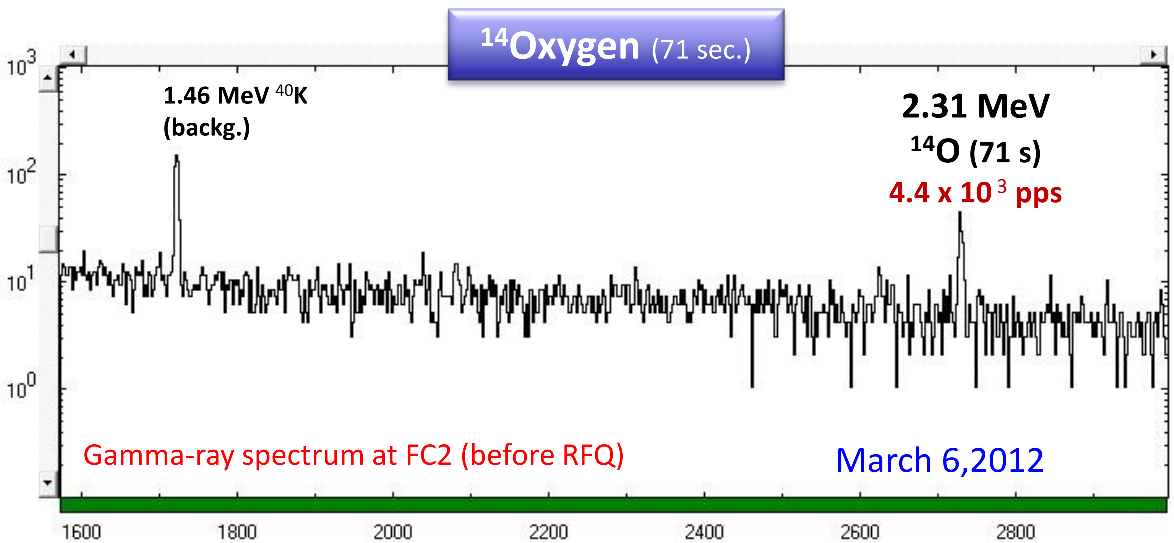
Measured RIB decay-spectra before RFQ2

Courtesy of Prof. Chakrabarti (VECC)

Radioactive atoms from target chamber placed in cyclotron vault



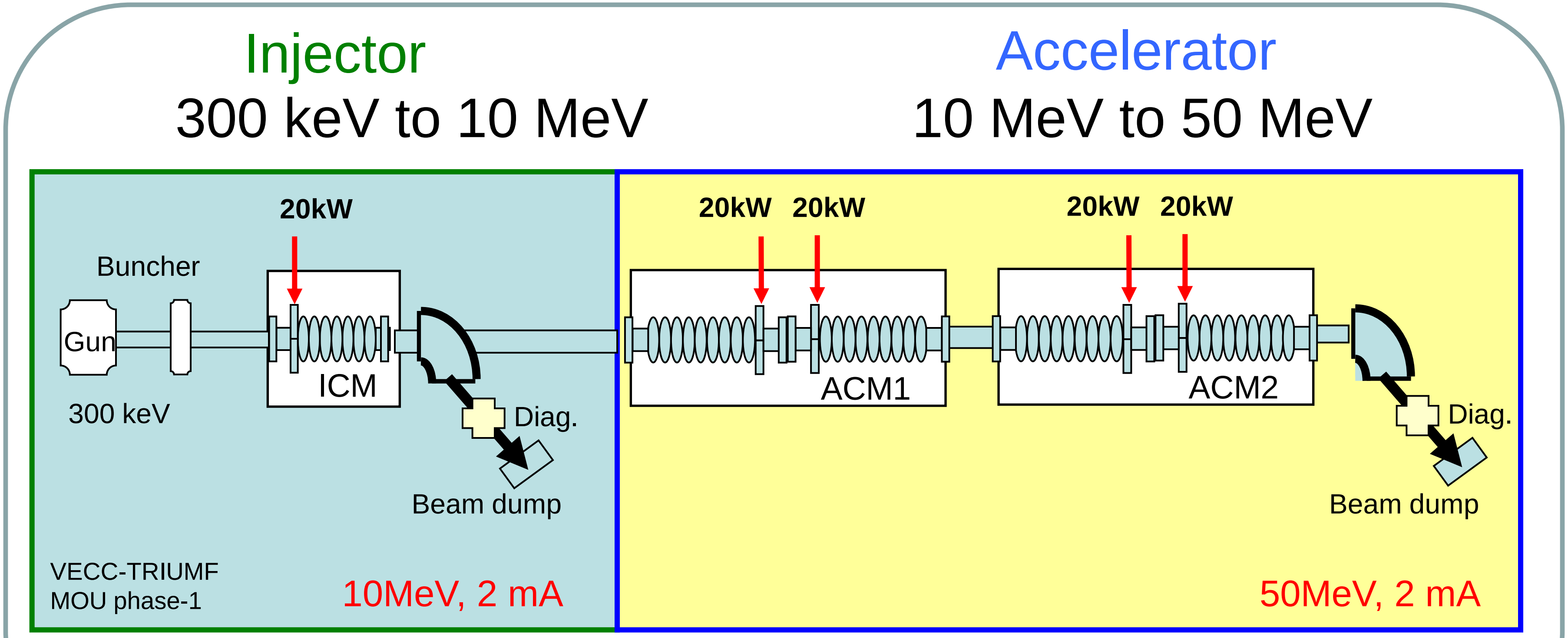




RIB	Prod. route	T1/2	pps @ FC2
^{14}O	^{14}N(p,n)	71 s	4.4×10^3
^{42}K	^{40}Ar(α,pn)	12.36 hr	2.7×10^3
^{41}Ar	^{40}Ar(α,2pn)	109 min	1.3×10^3

50 MeV superconducting e-linac (VECC-TRIUMF collaboration)

Courtesy of Prof. Chakrabarti (VECC)



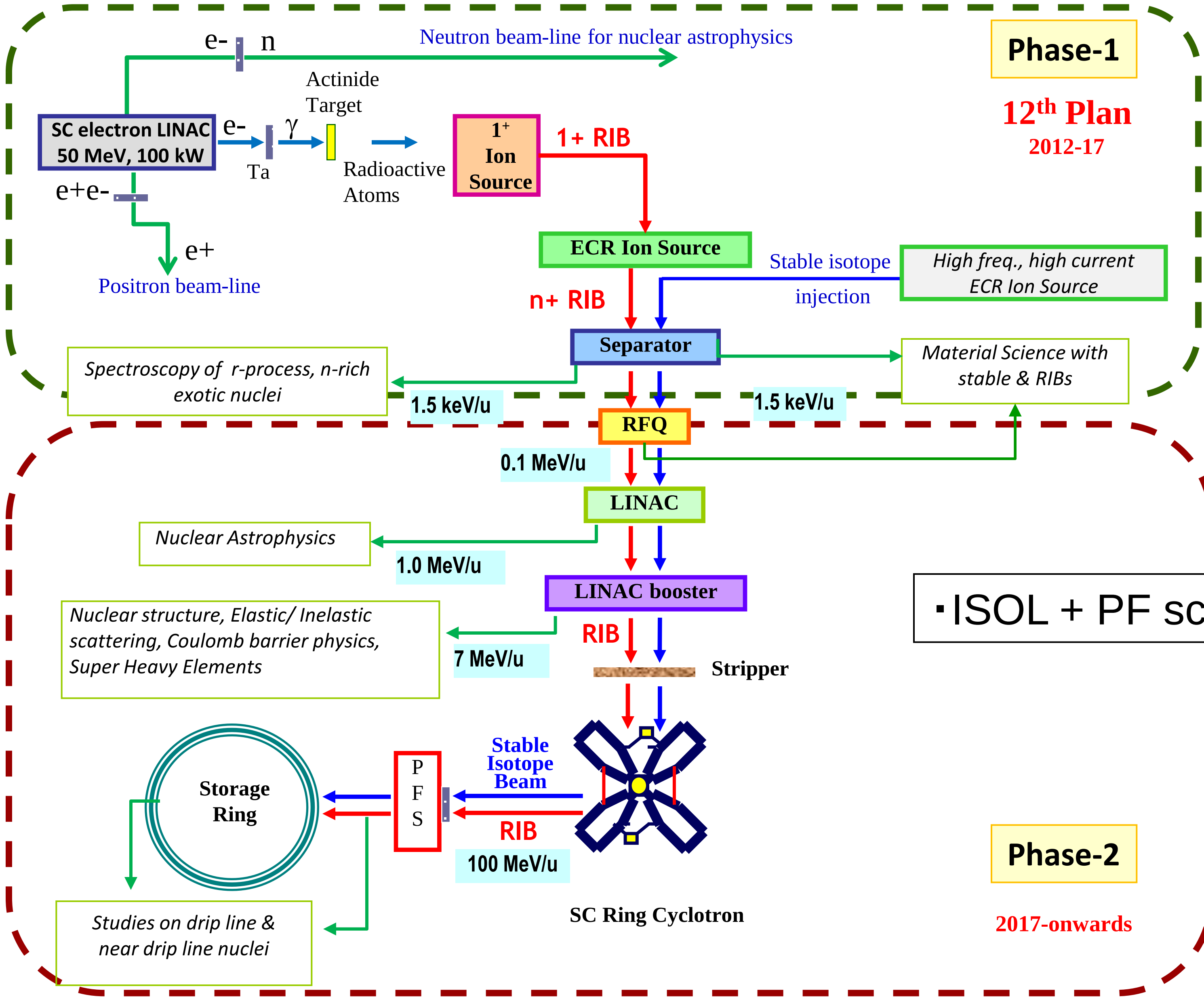
Phase-1 : 2009 – 2013

Phase-2 : 2013 – 2017

Future plan: ANURIB facility

Courtesy of Prof. Chakrabarti (VECC)

A National Facility for Unstable and Rare Isotope Beams



- ISOL + PF scheme

IUAC, India

Courtesy of Prof. Roy (IUAC)

Production of low energy ^{7}Be radioactive ion beam at IUAC using HIRA

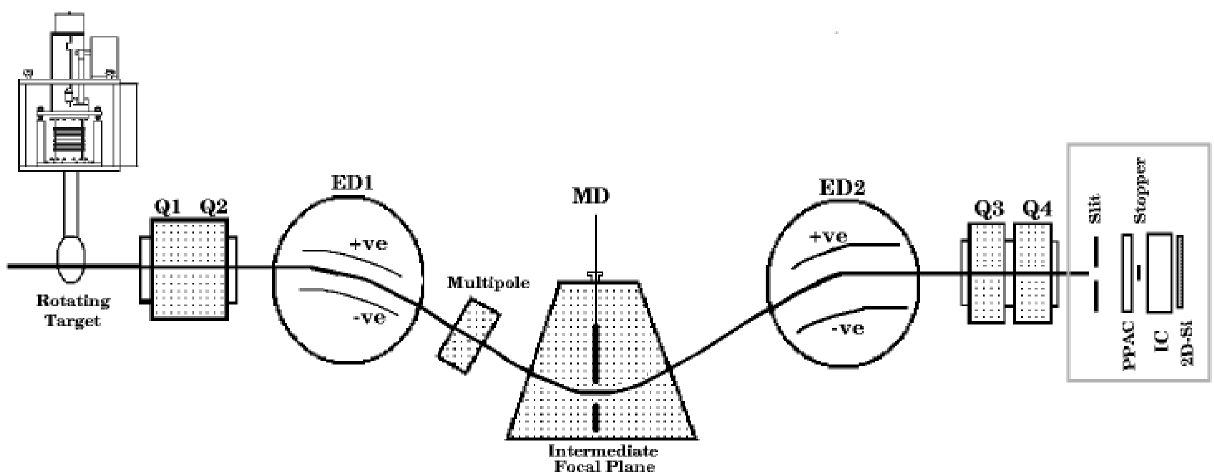
(HIRA: Heavy-Ion Reaction Analyzer)

^{7}Be radioactive ion beam (RIB) has been optimised

- Energy range of ^{7}Be RIB: 17 to 22 MeV
- Production reactions: (p,n),(d,n) type of reactions in inverse kinematics
- Filter + transporter: existing RMS, HIRA operated in new ion optics

Typical RIB parameters

- Size ~ 4 mm (fwhm), ♎ ❑ & ♎♐ = +/- 30 mrad, ♎E = +/- 0.5 MeV
- Purity > 99% , Intensity ~10^{4} pps



HYRA at IUAC, India

Courtesy of Prof. Roy (IUAC)

N. Madhavan et al., PRAMANA J. Phys. 75 (2010) 317

HYbrid Recoil mass Analyzer - *Unique dual-mode, dual-stage spectrometer with large acceptances and rigidity at IUAC, New Delhi*

(to fully exploit ECR + LINAC beams of higher energy and intensity)

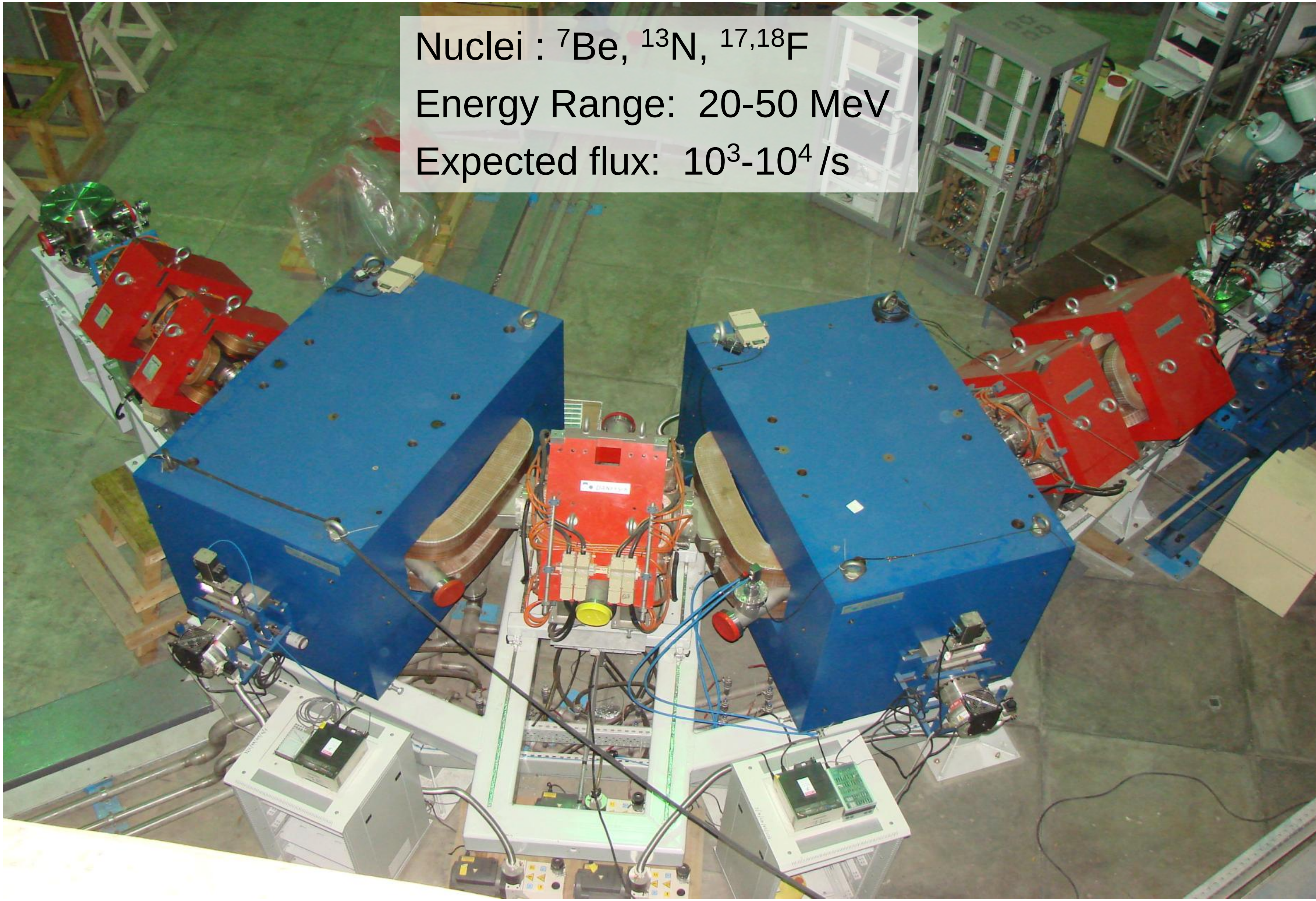
Useful to access heavy fusion evaporation residues with large efficiency along beam direction in gas-filled mode rejecting beam-like particles, target-like recoils and fission fragments – First stage only

(similar to Dubna, RIKEN, LBL, JYFL facilities but unique in design)

Useful to produce secondary radioactive beams (similar to ^{7}Be in HIRA but with higher energies and lesser purity) in momentum achromatic (vacuum) mode – First stage only

HYRA (Gas-Filled Separator / Vacuum Mode RMS) – First stage

Courtesy of Prof. Roy (IUAC)



IBS – RISP project, Korea

Courtesy of Prof. Kim (SNU/IBS)

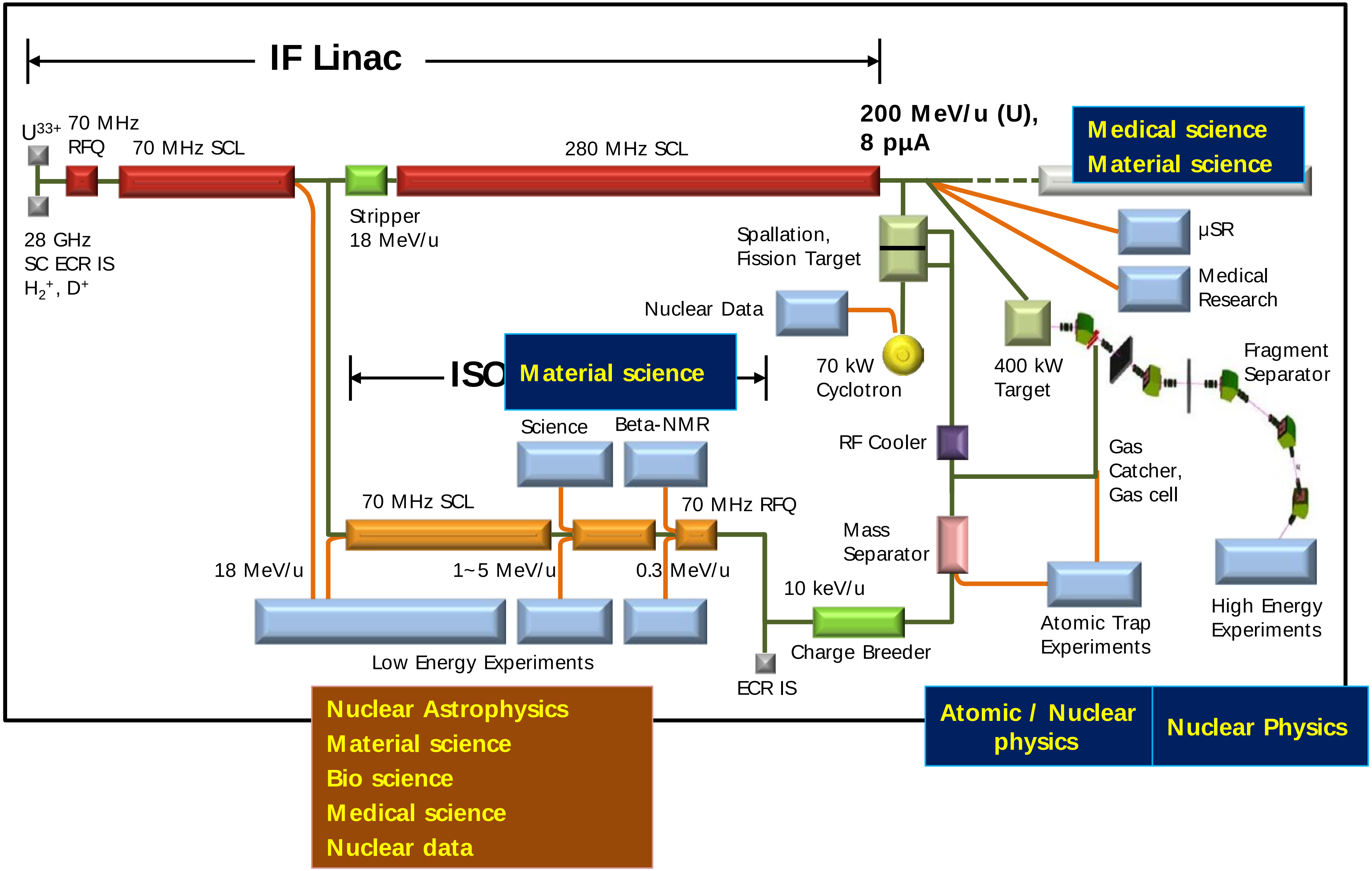
Science Business Belt

(RISP=Rare-Isotope Science Project)

IBS – RISP project, Korea

Courtesy of Prof. Kim (SNU/IBS)

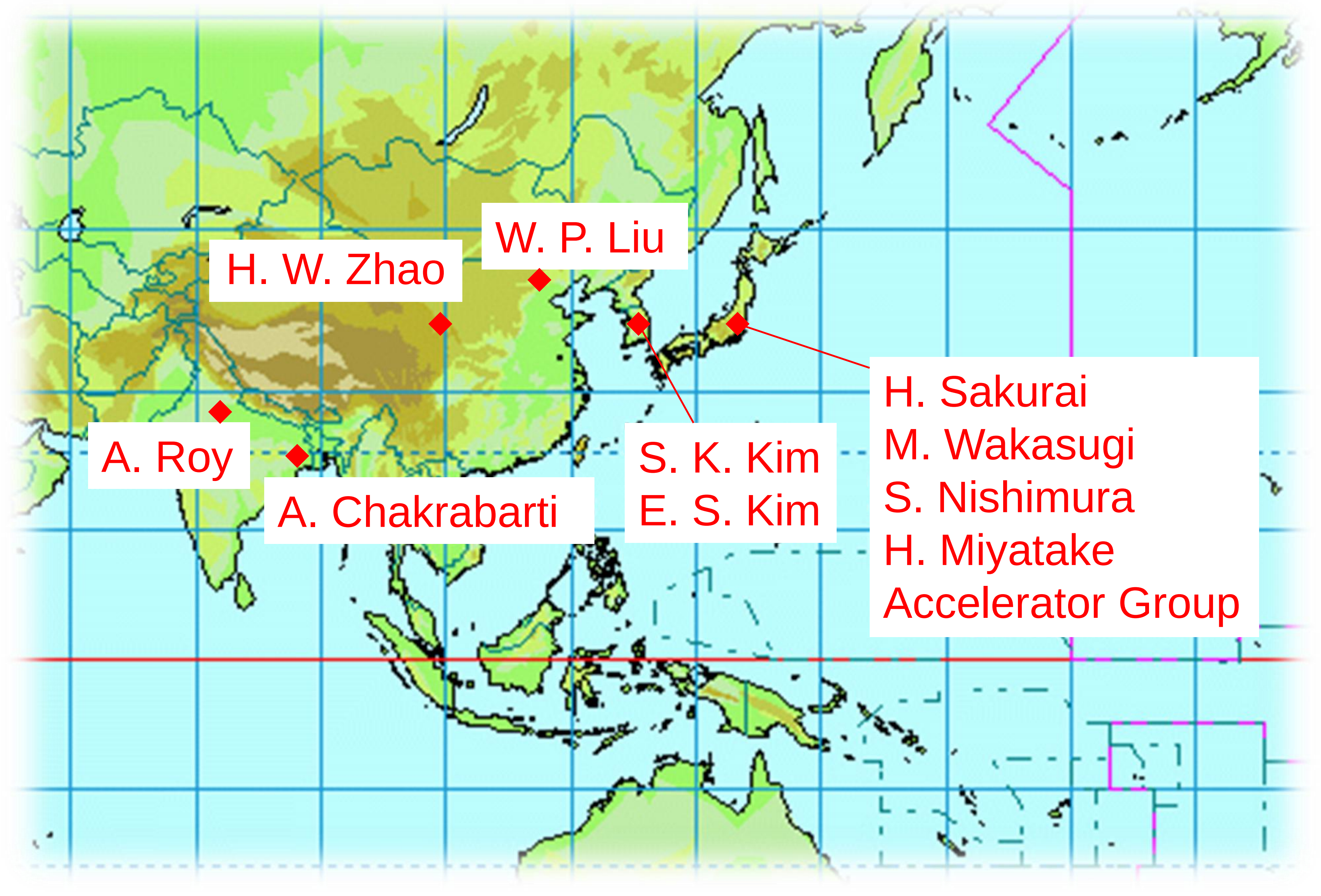
Concept of the Accelerator Complex



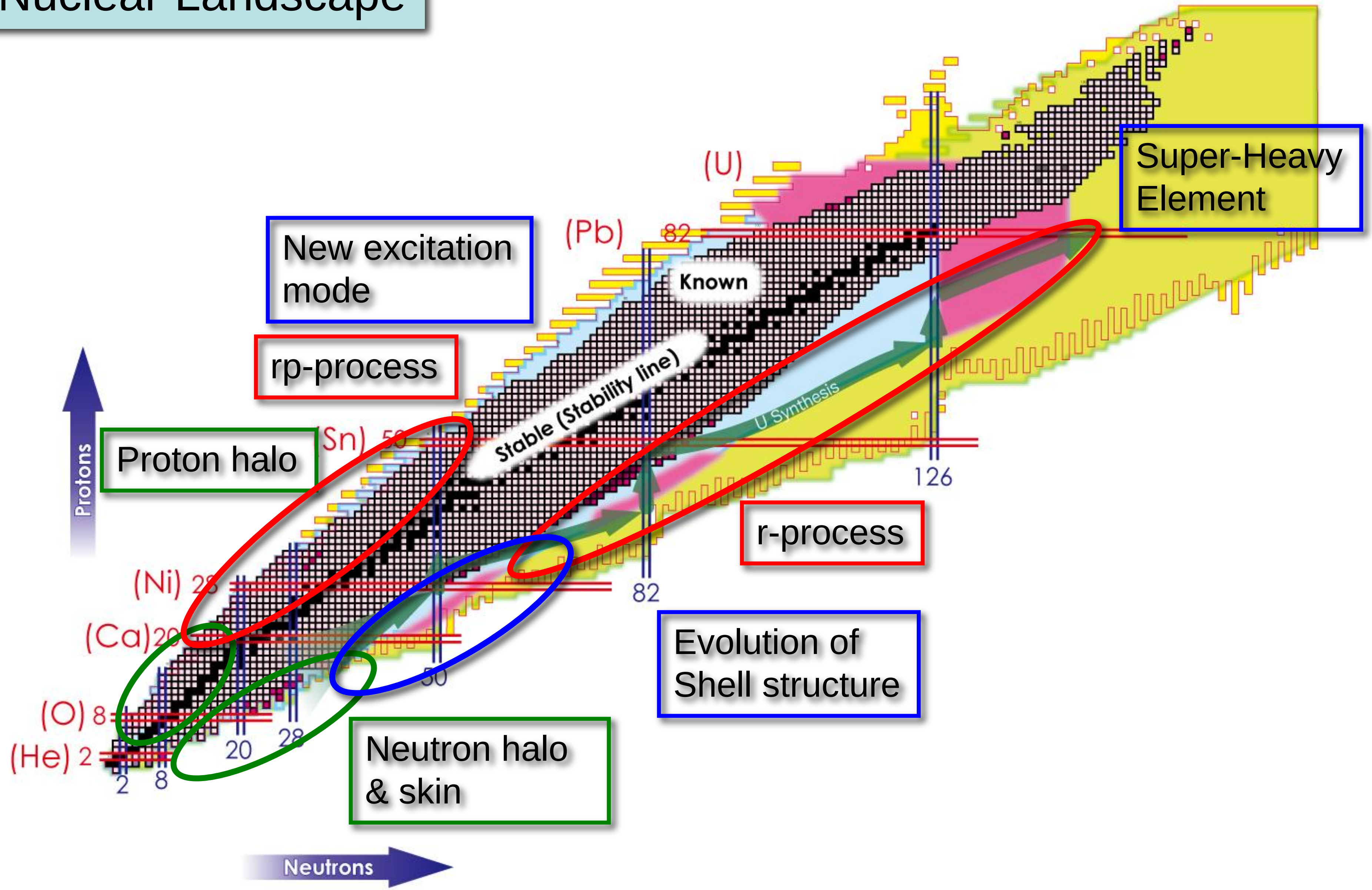
Summary

- R&Ds of RI-Beam facilities are very active in Asia.
- New facilities are planned to start in coming 10 years.
- Regional and international collaborations are important in various technical challenges.

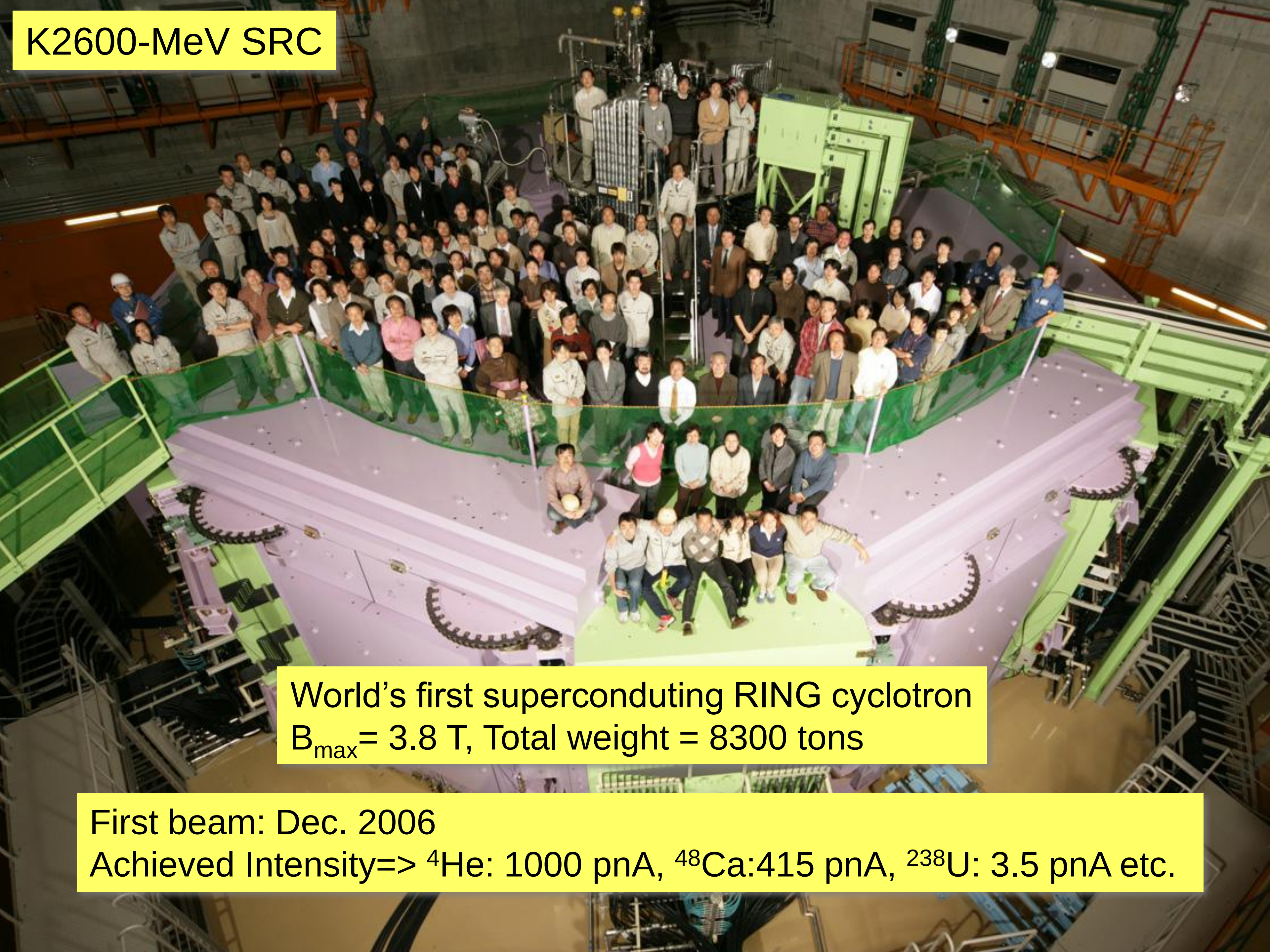
Many thanks to



Nuclear Landscape



K2600-MeV SRC



World’s first superconduting RING cyclotron
B_{max}= 3.8 T, Total weight = 8300 tons

First beam: Dec. 2006
Achieved Intensity=> ^{4}He: 1000 pnA, ^{48}Ca:415 pnA, ^{238}U: 3.5 pnA etc.

2007 BT

- T. Ohnishi et al., “Identification of New Isotopes 125Pd and 126Pd Produced by In-Flight Fission of 345 MeV/nucleon 238U: First Results from the RIKEN RI Beam Factory”, J. Phys. Soc. Jpn. 77 (2008) 083201. <= 238U 345 MeV/u

2008 BT

- T. Ohnishi et al., “Identification of 45 New Neutron-Rich Isotopes Produced by In-Flight Fission of a 238U Beam at 345 MeV/nucleon”, J. Phys. Soc. Jpn. 79 (2010) 073201. <= 238U 345 MeV/u
- T. Nakamura et al., “Halo Structure of the Island of Inversion Nucleus 31Ne”, Phys. Rev. Lett. 103 (2009) 262502. <= 48Ca 345 MeV/u
- P. Doornenbal et al., “Spectroscopy of 32Ne and the Insland of Inversion”, Phys. Rev. Lett. 103 (2009) 032501. <= 48Ca 345MeV/u.
- P. Doornenbal et al., “Exploring the “island of inversion” by in-beam γ -ray spectroscopy of the neutron-rich sodium isotopes 31,32,33Na”, Phys. Rev. C 81, (2010) 041305(R). <=48Ca 345 MeV/u
- M. Takechi et al., “Interaction cross sections for Ne isotopes towards the island of inversion and halo structures of Ne-29 and Ne-31”, Phys. Lett. B 707, (2012) 357. <=48Ca 345 MeV/u

2009 BT

- S. Nishimiura et al., “β-Decay Half-Lives of Very Neutron-Rich Kr to Tc Isotopes on the Boundary of the r-Process Path: An Indication of Fast r-Matter Flow”, Phys. Rev. Lett. 106 (2011) 052502. <= 238U 345 MeV/u
- T. Sumikama et al., “Structural Evolution in the Neutron-Rich Nuclei 106Zr and 108Zr” Phys. Rev. Lett. 106 (2011) 202501. <= 238U 345 MeV/u
- H. Watanabe et al., “Low-lying level structure of the neutron-rich nucleus 109Nb: A possible oblate-shape isomer”, Phys. Lett. B 696 (2011) 186. <= 238U 345 MeV/u
- H. Watanabe et al., “Development of axial asymmetry in the neutron-rich nucleus 110Mo”, Phys. Lett. B 704 (2011) 270. <= 238U 345 MeV/u
- K. Sekiguchi et al., “Three nucleon force effects in intermediate-energy deuteron analyzing powers for *d p* elastic scattering”, Phys. Rev. C 83 (2011) 061001(R). <=pol-d 250 MeV/u

2010 BT

- R. Chevrier et al., “Is the 7/2- Isomer State of 43S Spherical?”, Phys. Rev. Lett. 108 (2012) 162501. <= 48Ca 345 MeV/u