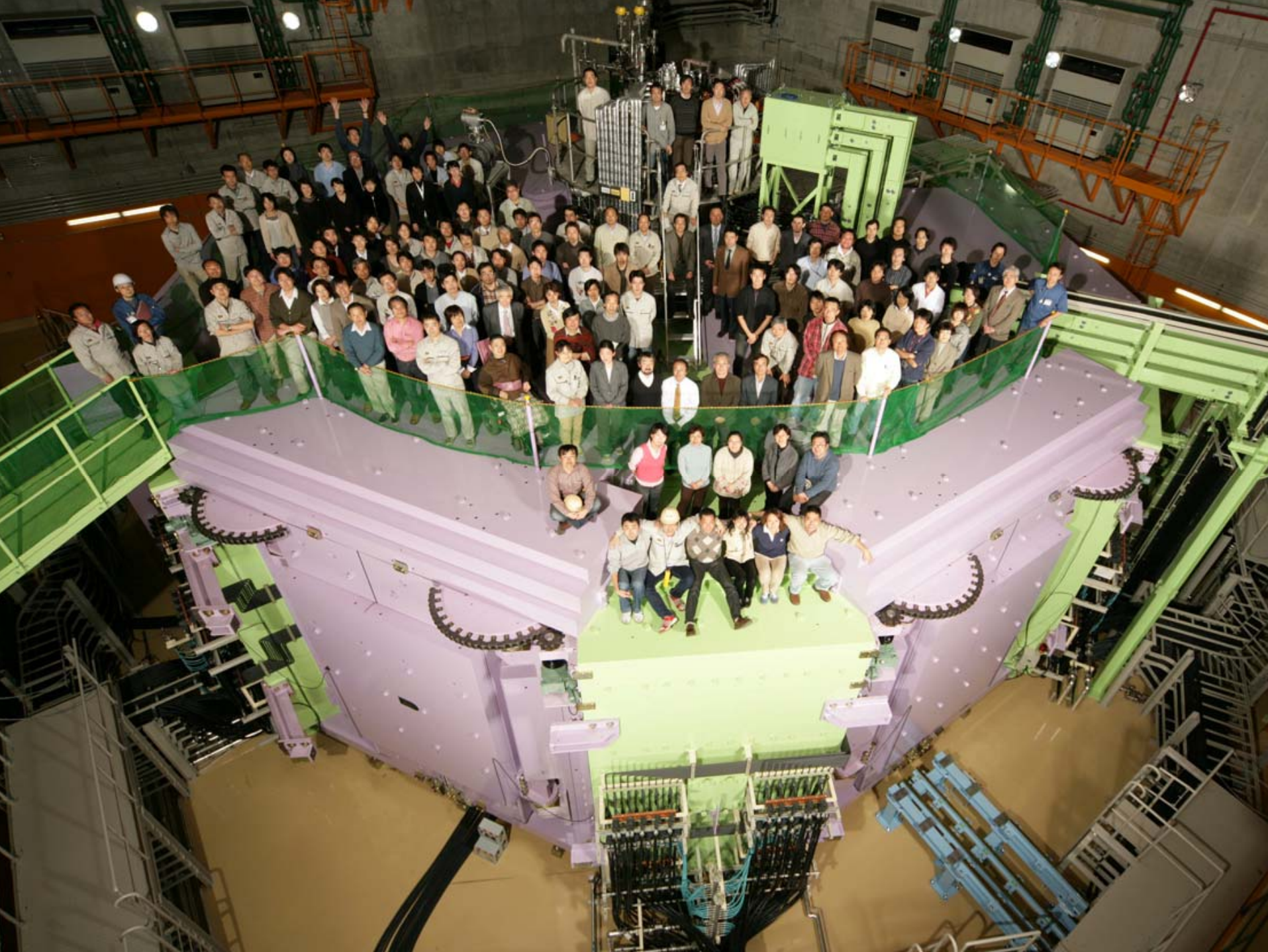
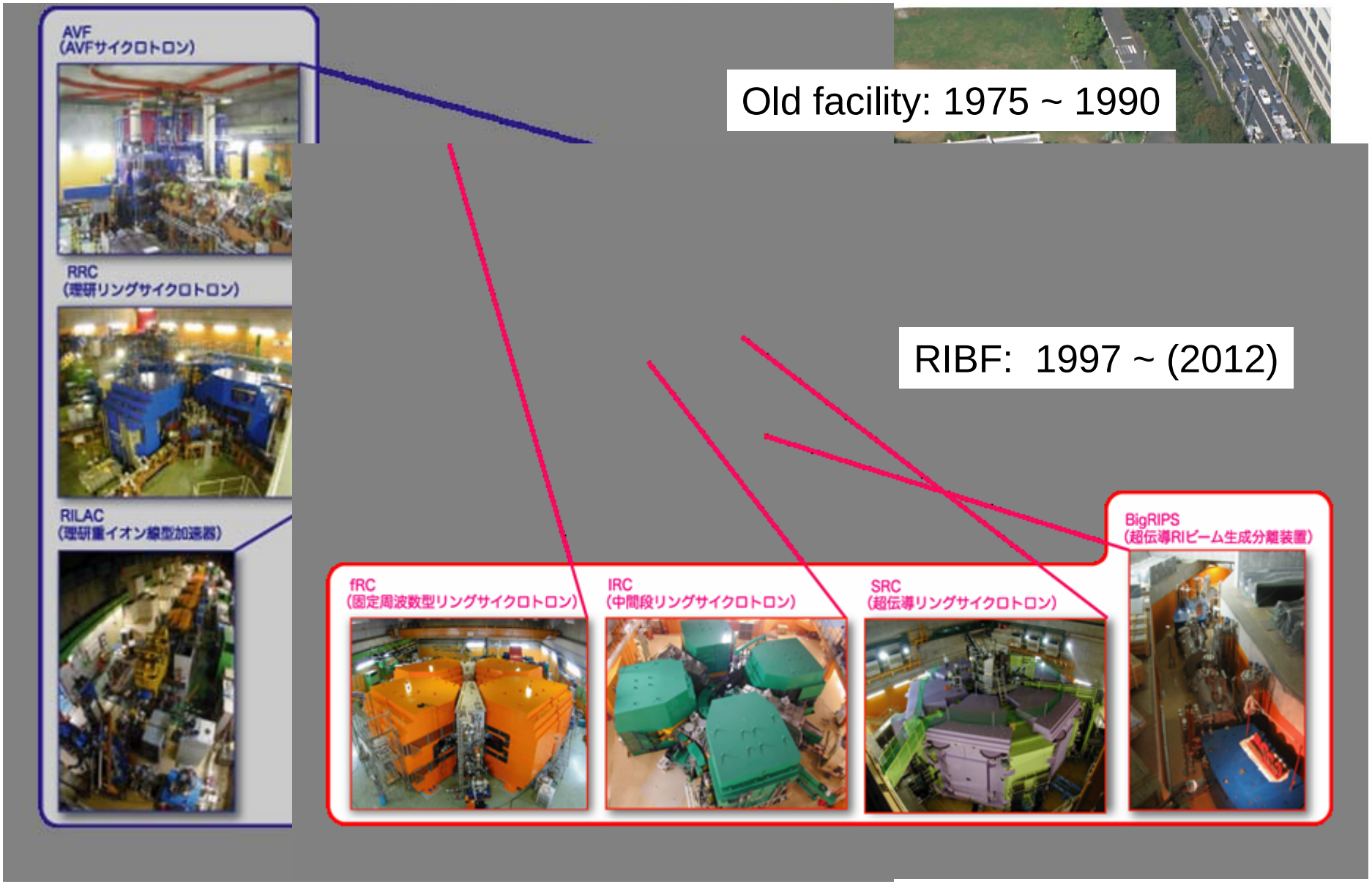


Present status of RIBF accelerators at RIKEN

1) Introduction to RIBF (- 2007)
2) Improvements & Present status (2008 - 2010)
3) Recent results from RIBF (2008 - 2010)
4) Further developments & Plans (2009 - 2010)
   a: SC-ECR
   b: New Injector (RILAC2)
   c: Charge Strippers

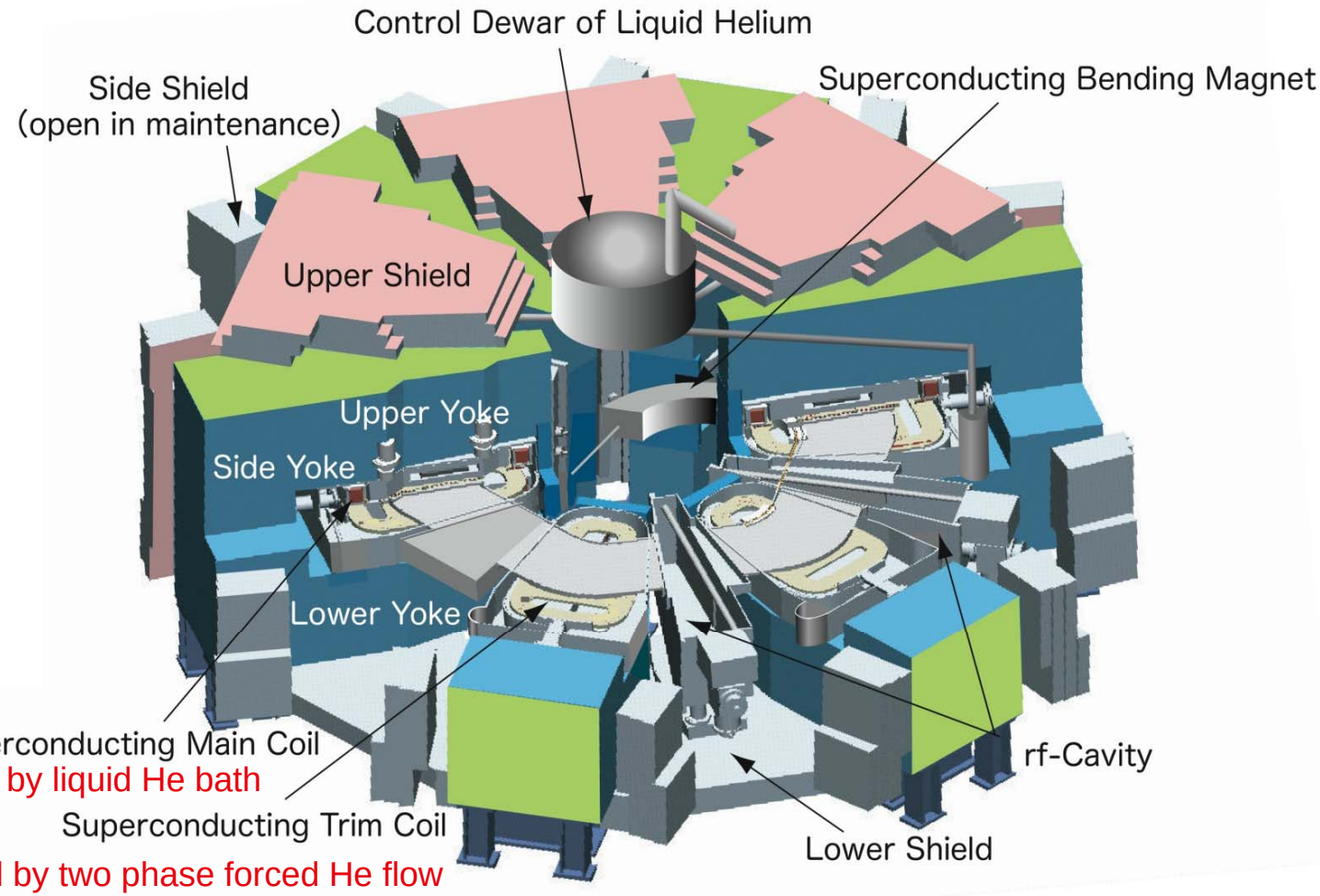
O. Kamigaito
Accelerator Group, RIKEN Nishina Center

RIKEN RI Beam Factory (RIBF)



SRC (Superconducting Ring Cyclotron) => World's first!

K = 2,600 MeV
Self Magnetic Shield
Self Radiation Shield
3.8T (240 MJ)
18-38 MHz
8,300 tons



SRC (Superconducting Ring Cyclotron) => World's first!

K = 2,600 MeV
Self Magnetic Shield
Self Radiation Shield
3.8T (240 MJ)
18-38 MHz
8,300 tons

First beam of 345 MeV/u $^{27}Al^{10+}$ extracted from SRC on Dec. 28, 2006 at 16:00
(A. Goto, Cyclotrons2007)

Superconductor
Cooled by liquid He bath
Superconducting Trim Coil
Indirectly cooled by two phase forced He flow
Lower Shield

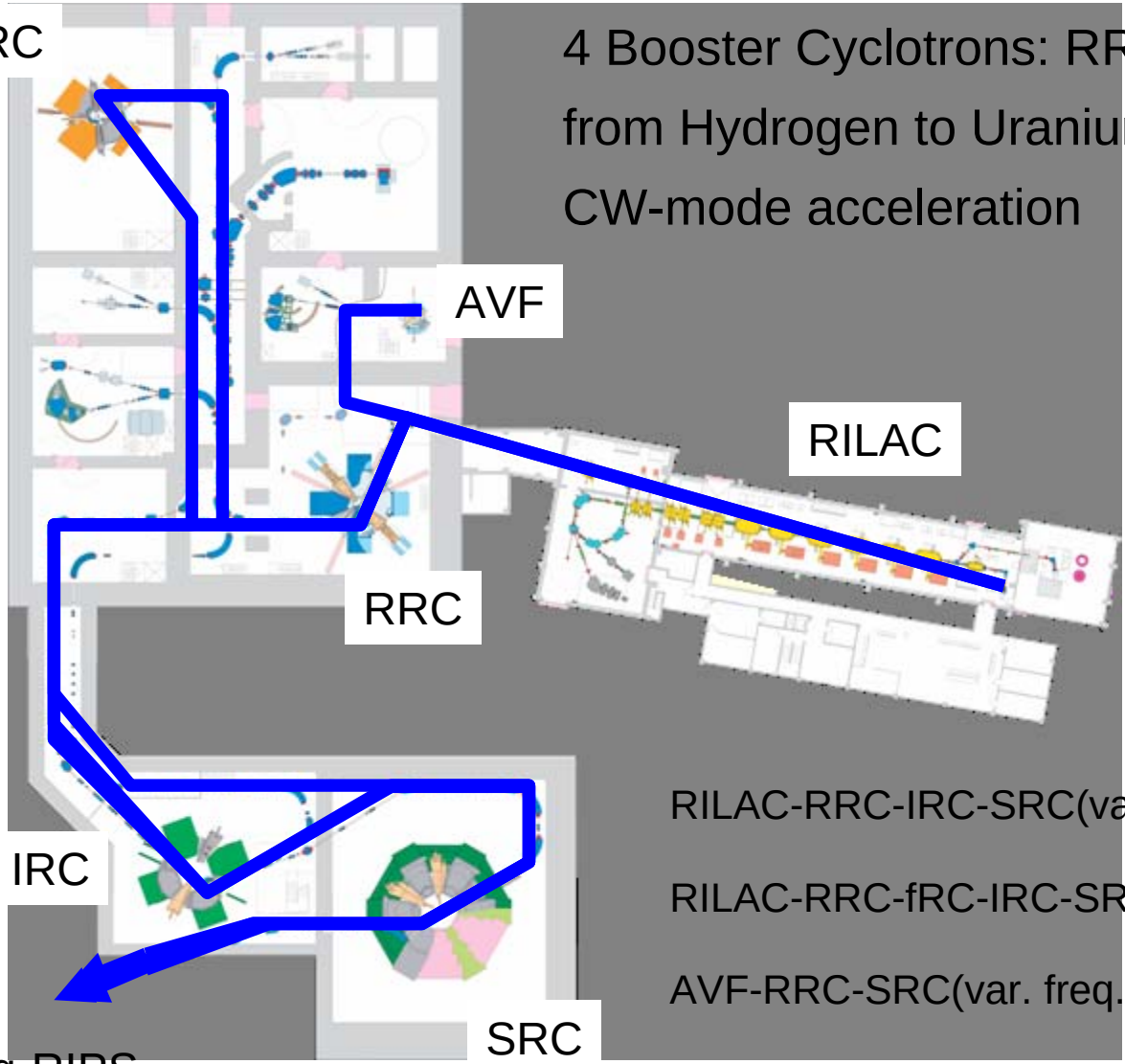
RIBF Accelerators

2 Injectors: RILAC & AVF

4 Booster Cyclotrons: RRC, fRC, IRC, SRC

from Hydrogen to Uranium => 345MeV/u

CW-mode acceleration

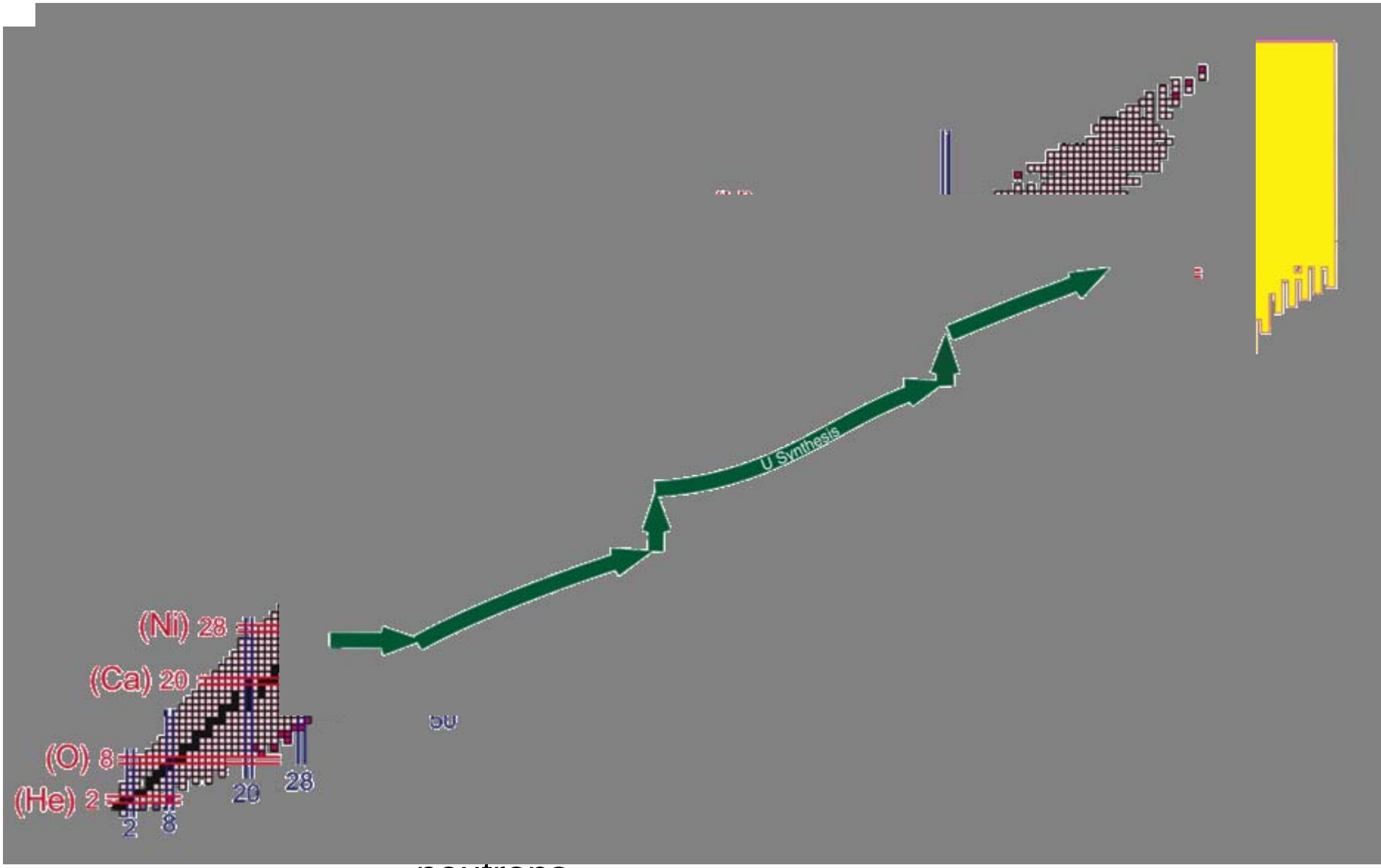


RILAC-RRC-IRC-SRC(var. freq.) : Max 400 MeV/u

RILAC-RRC-fRC-IRC-SRC(fixed freq.) : 345 MeV/u

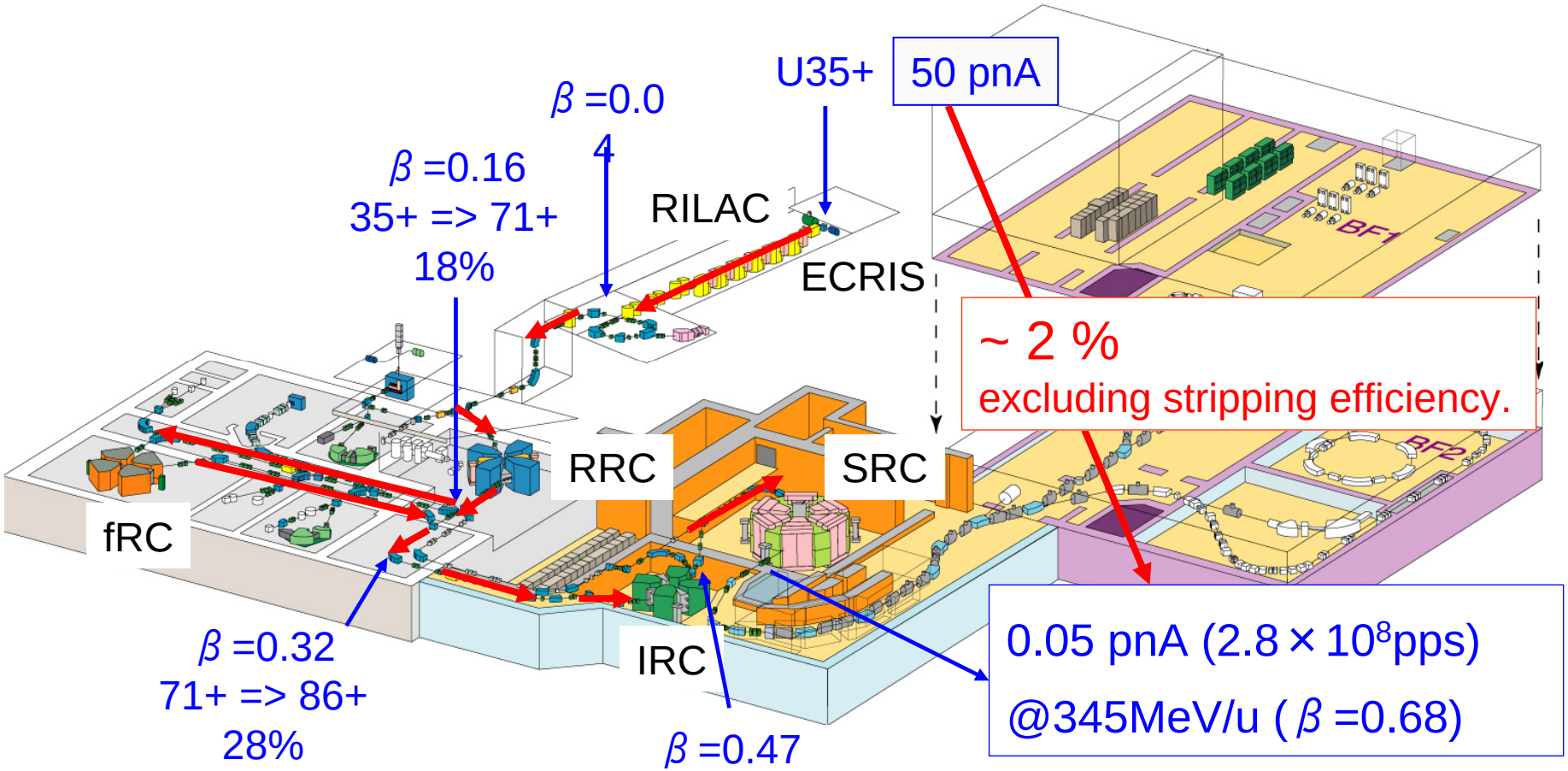
AVF-RRC-SRC(var. freq.) : Max 440 MeV/u

Expansion of nuclear world by RIBF



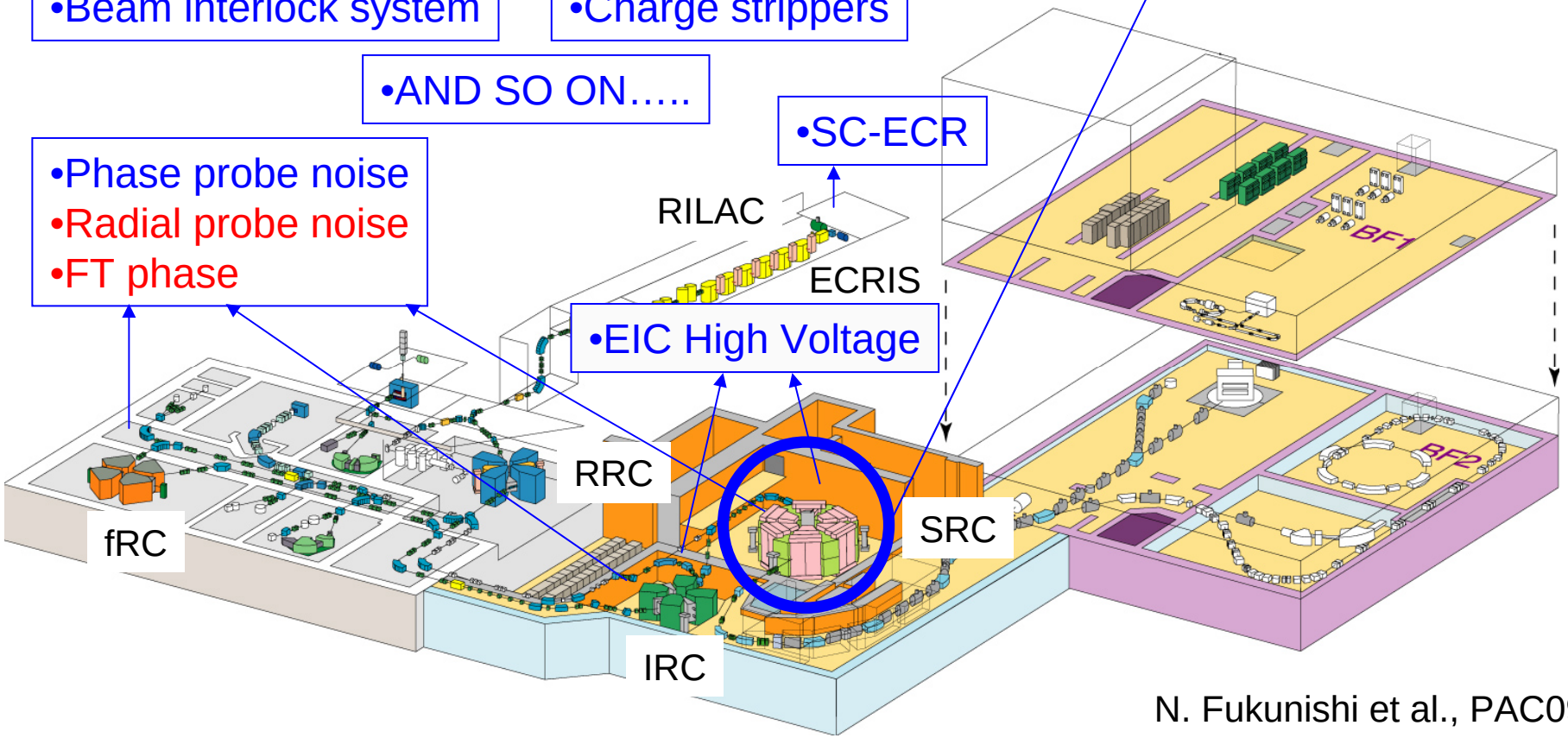
U-beam intensity and transmission in 2007

Improvement plan was started, but not fully executed due to lack of operation time in FY2007…



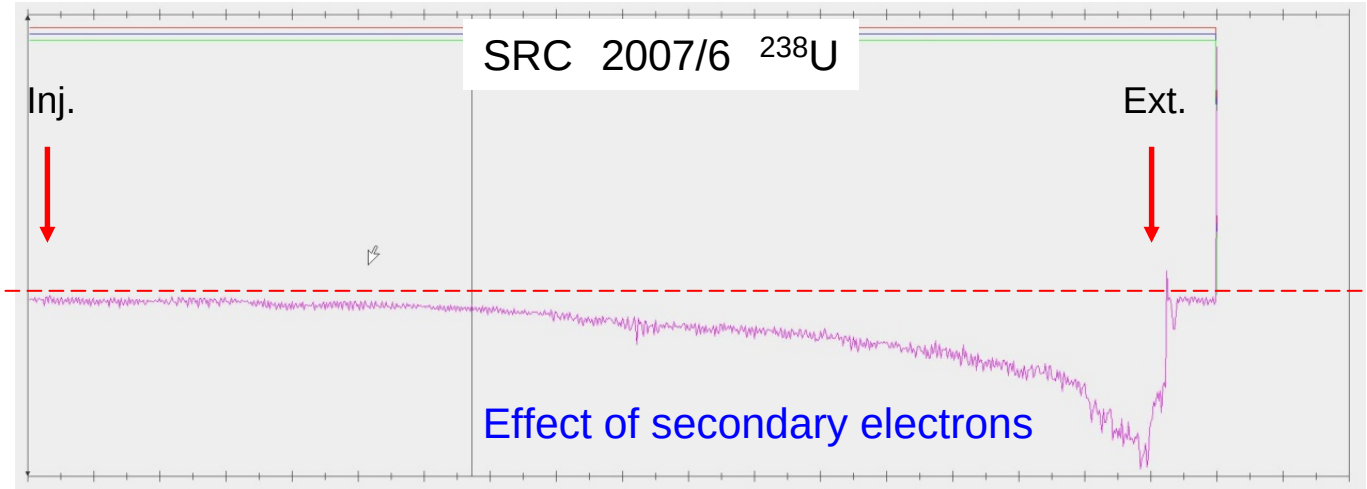
2) Improvements (08 - 10)

- Beam phase stability
- RF stability
- Noise in phase probes
- Beam interlock system
- Accurate Faraday cups
- TOF monitors
- Actual value of RF voltage
- Charge strippers
- AND SO ON…..
- Oil contamination in refrigerators
- SC-ECR
- Phase probe noise
- Radial probe noise
- FT phase
- EIC High Voltage

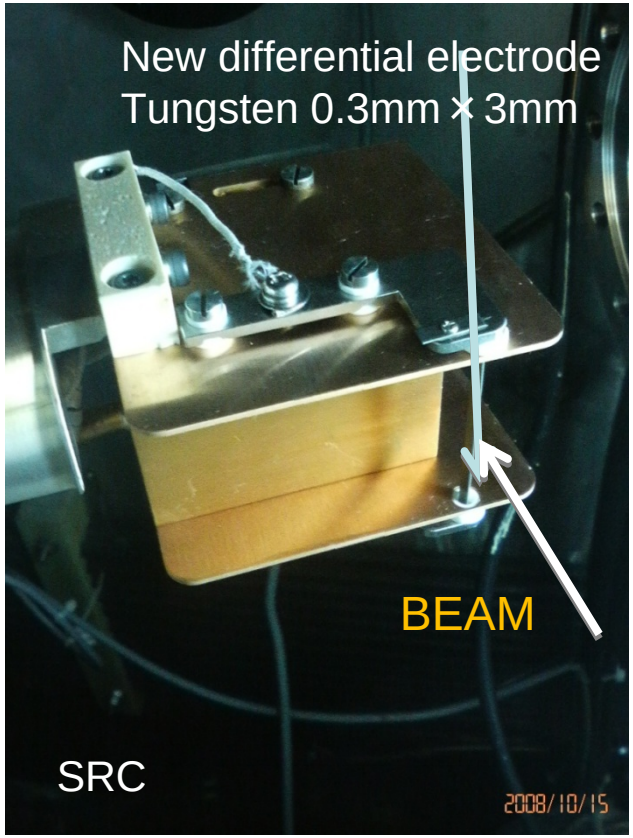


N. Fukunishi et al., PAC09
K. Yamada et al., HIAT09

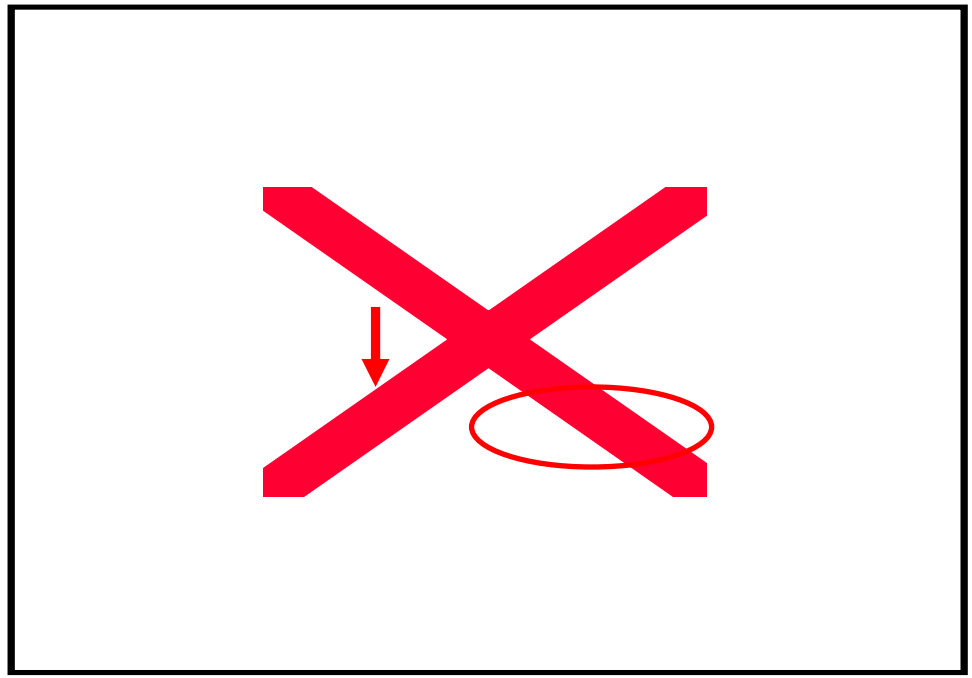
Radial probe problems



Radial probe improvements



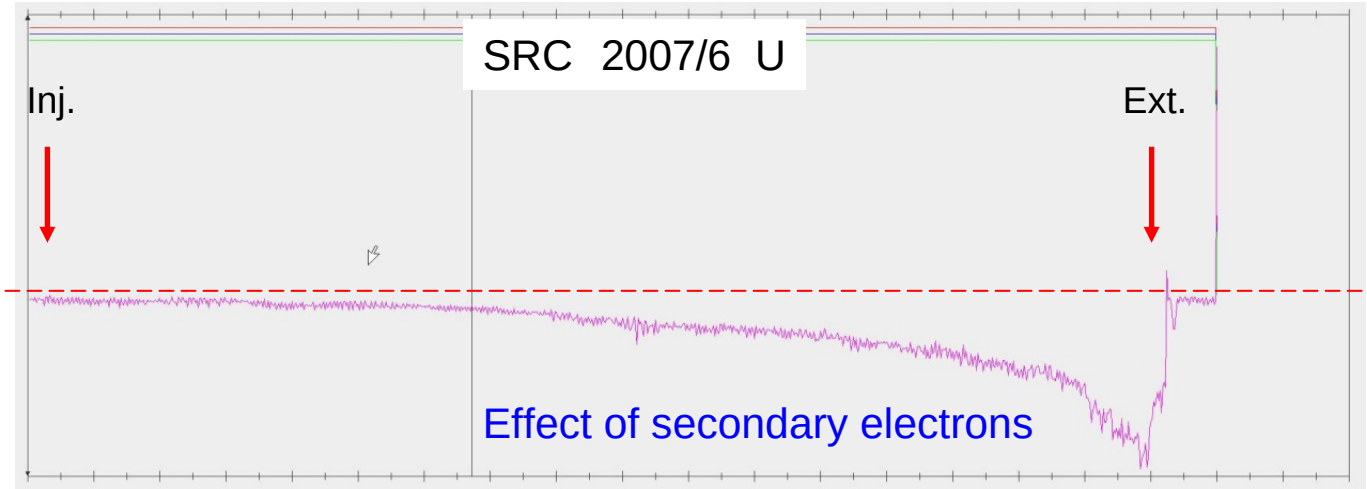
Differential probe modified
SRC (,fRC)



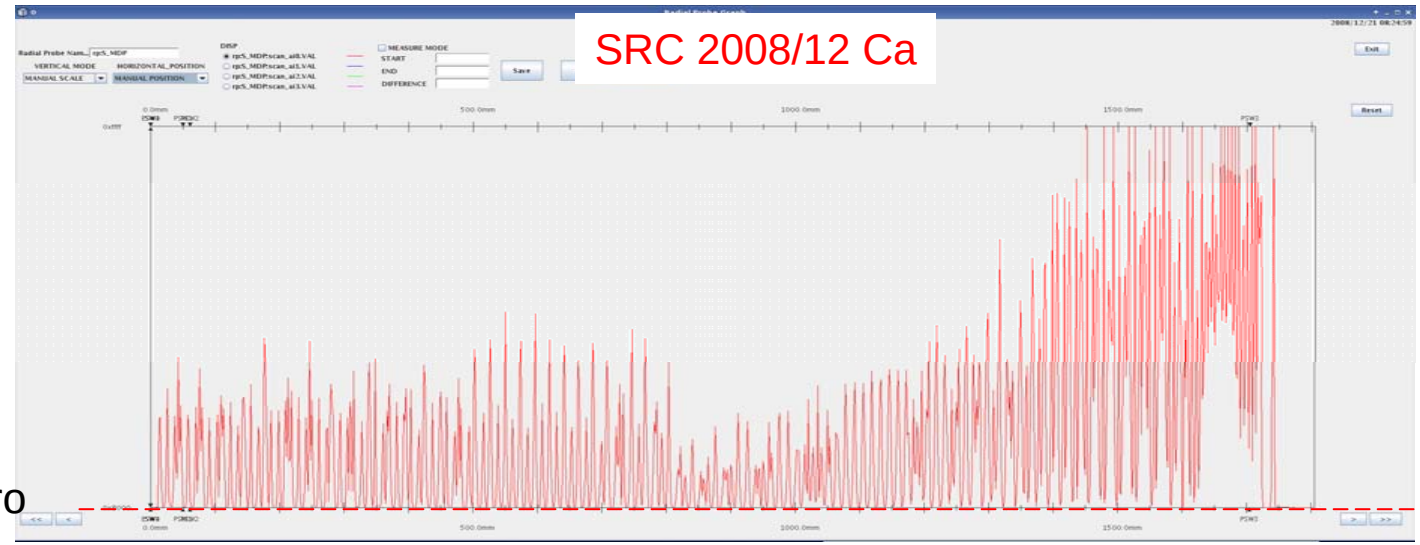
Probe-shaft grounded on both sides
IRC, SRC

Solved!

Radial probe problems

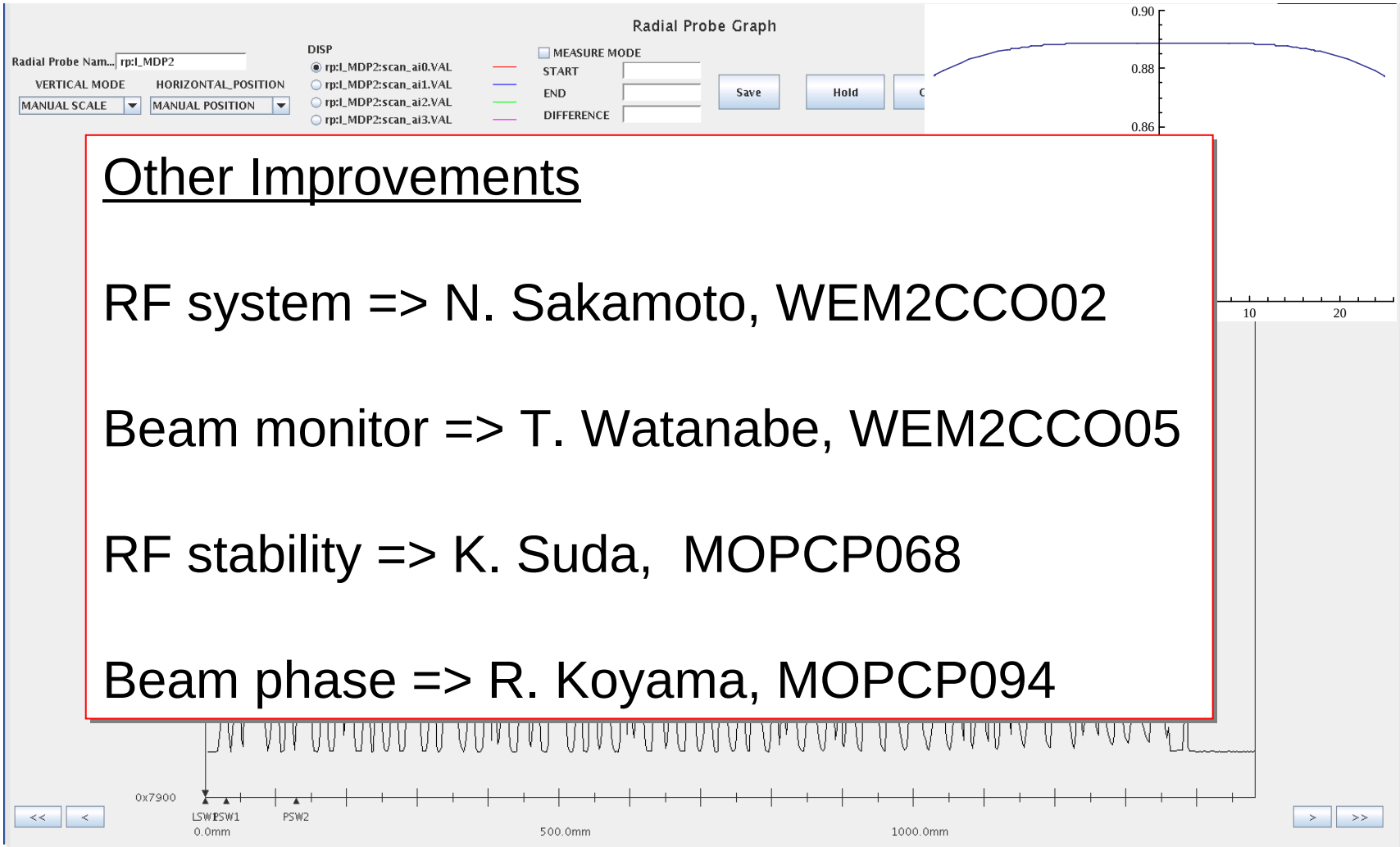


+ FT Noise



Turn pattern in IRC

FT-phase : 0deg



Other Improvements

RF system => N. Sakamoto, WEM2CCO02

Beam monitor => T. Watanabe, WEM2CCO05

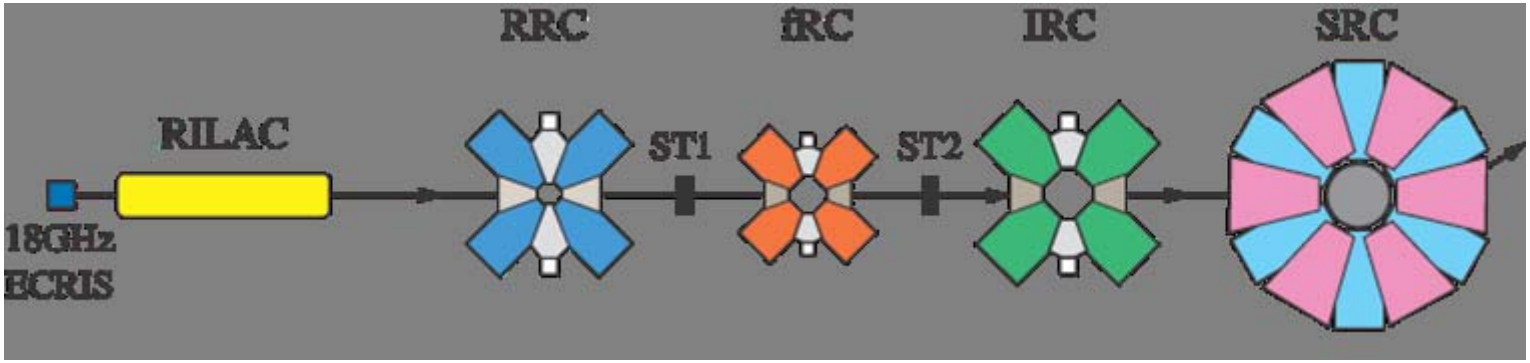
RF stability => K. Suda, MOPCP068

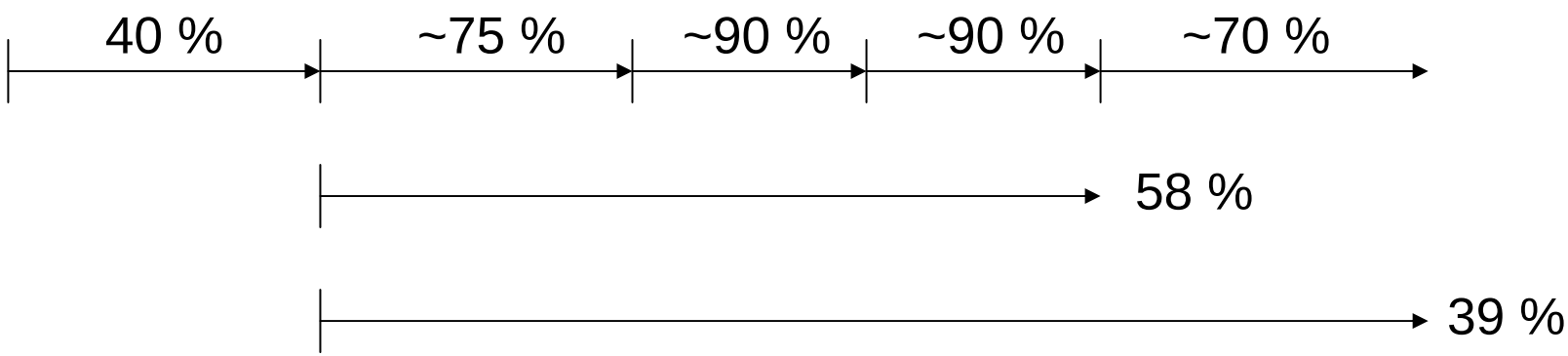
Beam phase => R. Koyama, MOPCP094

in out

Single turn extraction => High quality beams

Transmission efficiencies for U beam
(stripping efficiency exculded)

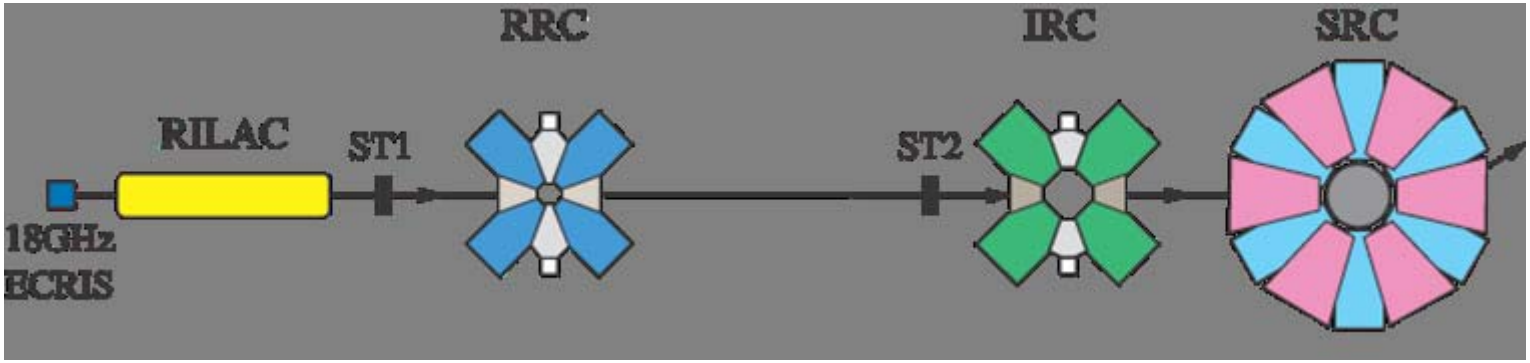




N. Fukunishi et al., PAC09

Transmission efficiencies for Ca beam
(stripping efficiency exculded)

N. Fukunishi et al., LINAC10



62 % → ~100 % → 85 % → 80 %

~100 % → ~70 %

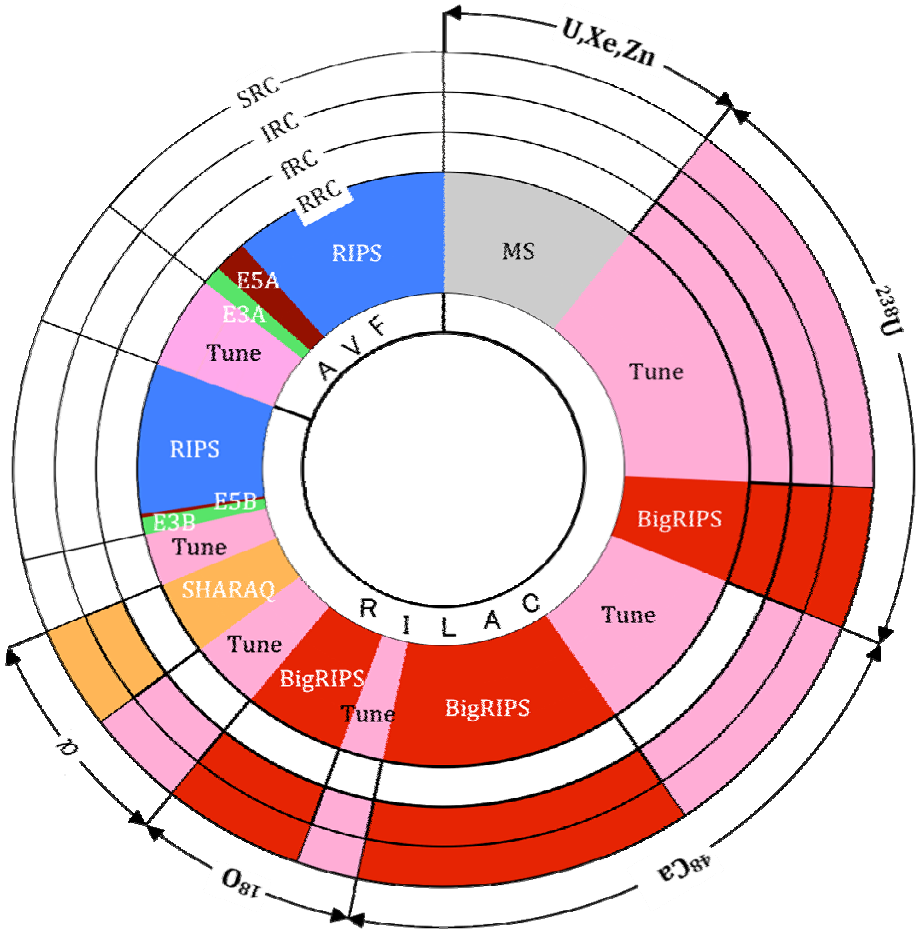
Transmission efficiencies for O beam in Jul. 2010
(stripping efficiency exculded)

~85 %

Achieved beam intensities

- pol-d(250 MeV/u)：120 pnA：May2009
- ^{4}He(320 MeV/u)：1000 pnA：Oct2009
- ^{14}N(250 MeV/u)：80 pnA：May2009
- ^{18}O(345 MeV/u)：1000 pnA：Jul2010 => 6.2 kW
- ^{48}Ca(345 MeV/u)：230 pnA：Jun2010 => 3.8 kW
- ^{86}Kr(345 MeV/u)：30 pnA(<1min)：Nov2007
- ^{238}U(345 MeV/u)：0.8 pnA：Dec2009

Operational statistics of RIBF



(c. f.RRC operation: 5238 hours)

Jul. 09 - Jul. 10

U238: Exp 287 h + Tuning 801 h

Ca48: Exp 663 h + Tuning 490 h

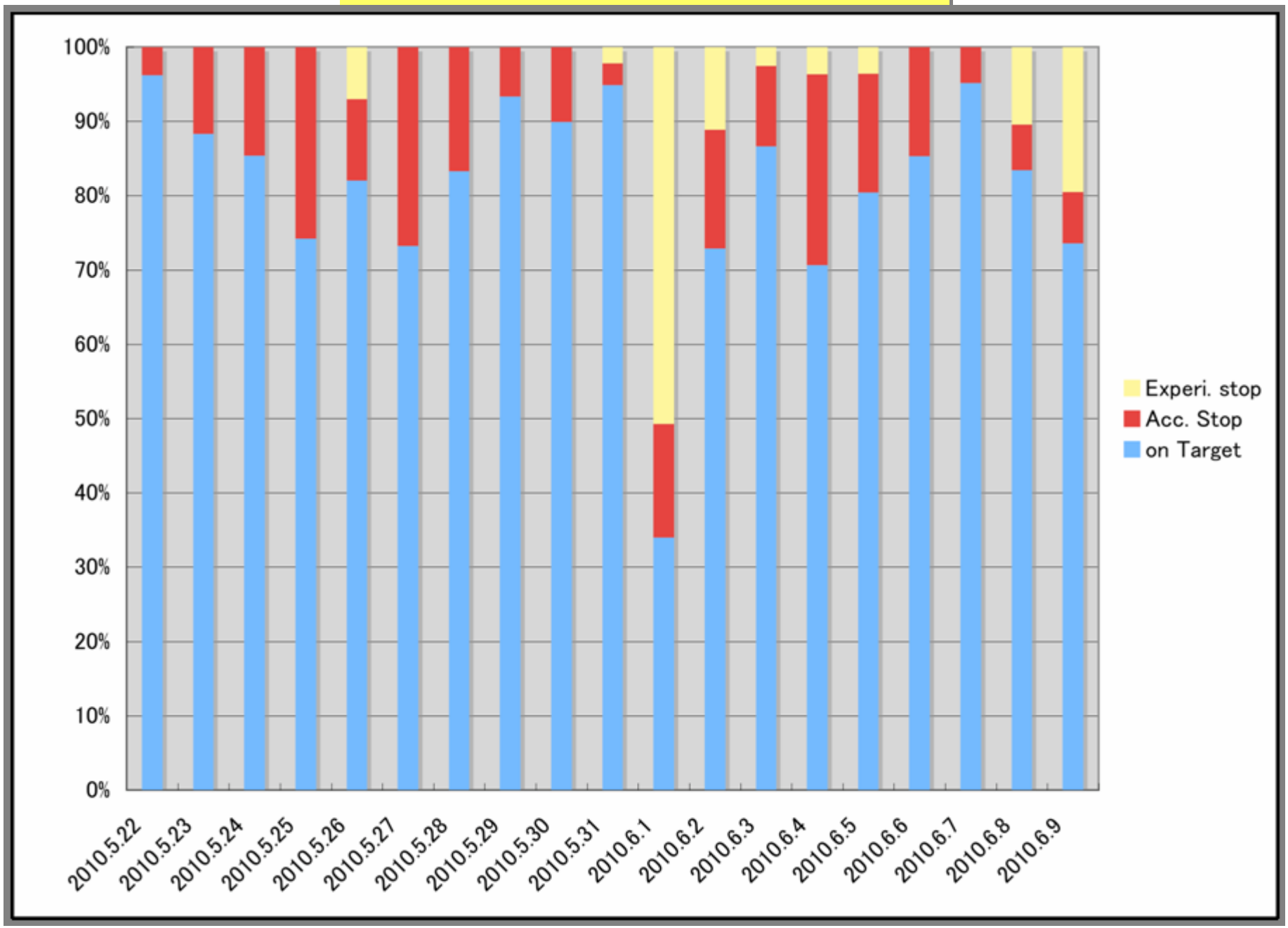
O18: Exp 310 h + Tuning 96 h

He4: Exp 280 h + Tuning 121 h

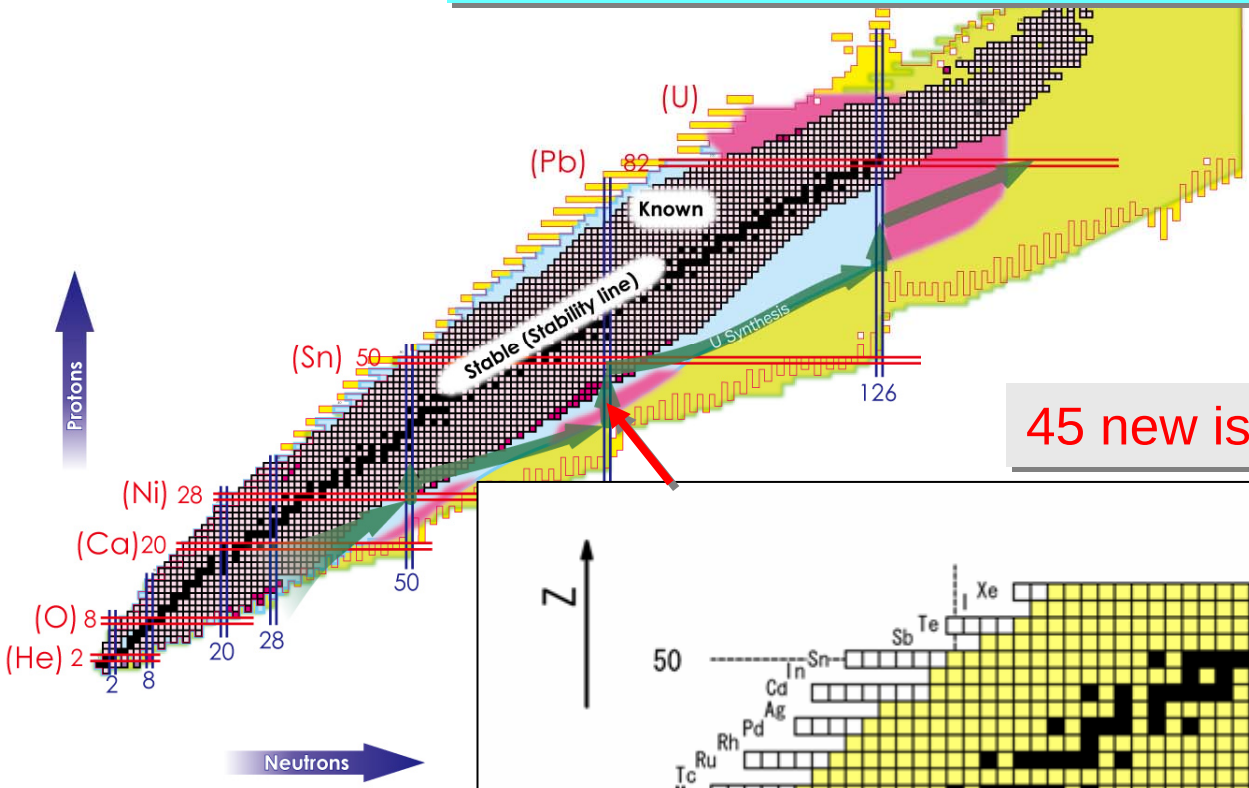
Machine Study:

- U238: 343 h (to RRC & fRC)
- Xe136: 154 h (to RRC & fRC)
- Zn70: 49 h (to RRC)

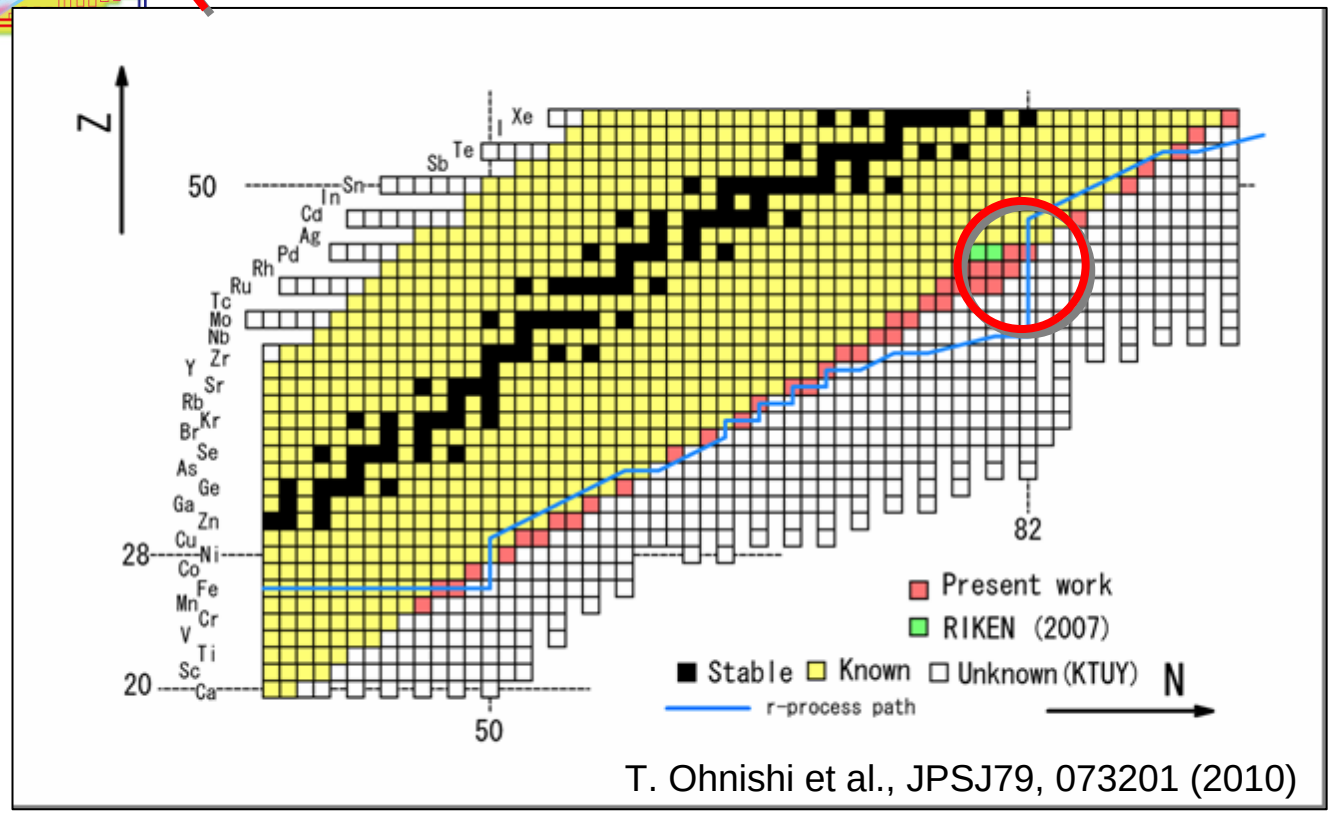
Operational statistics of RIBF



3) Recent results from RIBF



45 new isotopes from U-fission



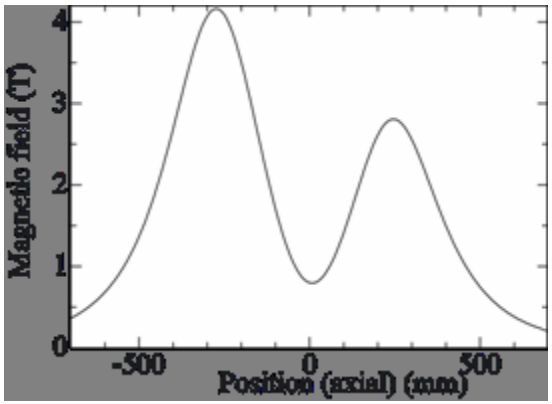
T. Ohnishi et al., JPSJ79, 073201 (2010)

4) Developments - a: SC-ECRIS

- Large plasma volume: 1100 cm^3
- Flat B_{min} configuration

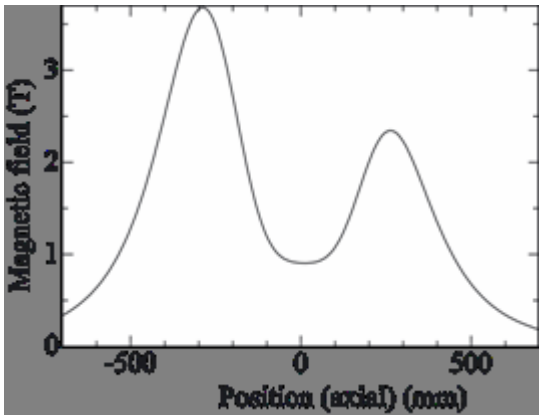
Construction started in October 2007.

Successfully excited to the designed field in October 2008.

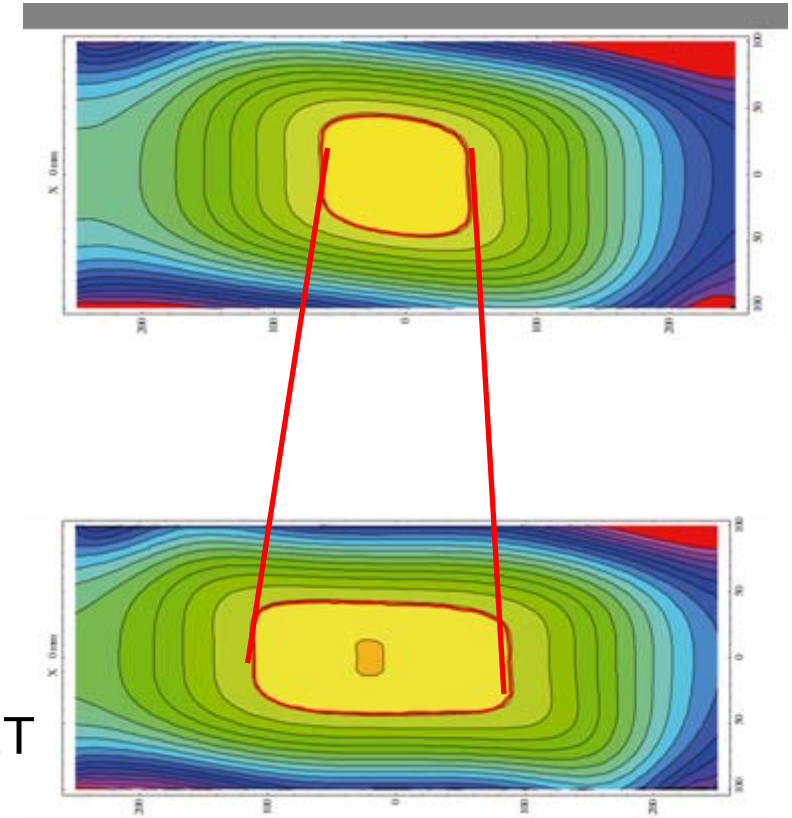


Classical B_{min}

Flat B_{min}



Mirror Filed：3.8T/2.2T



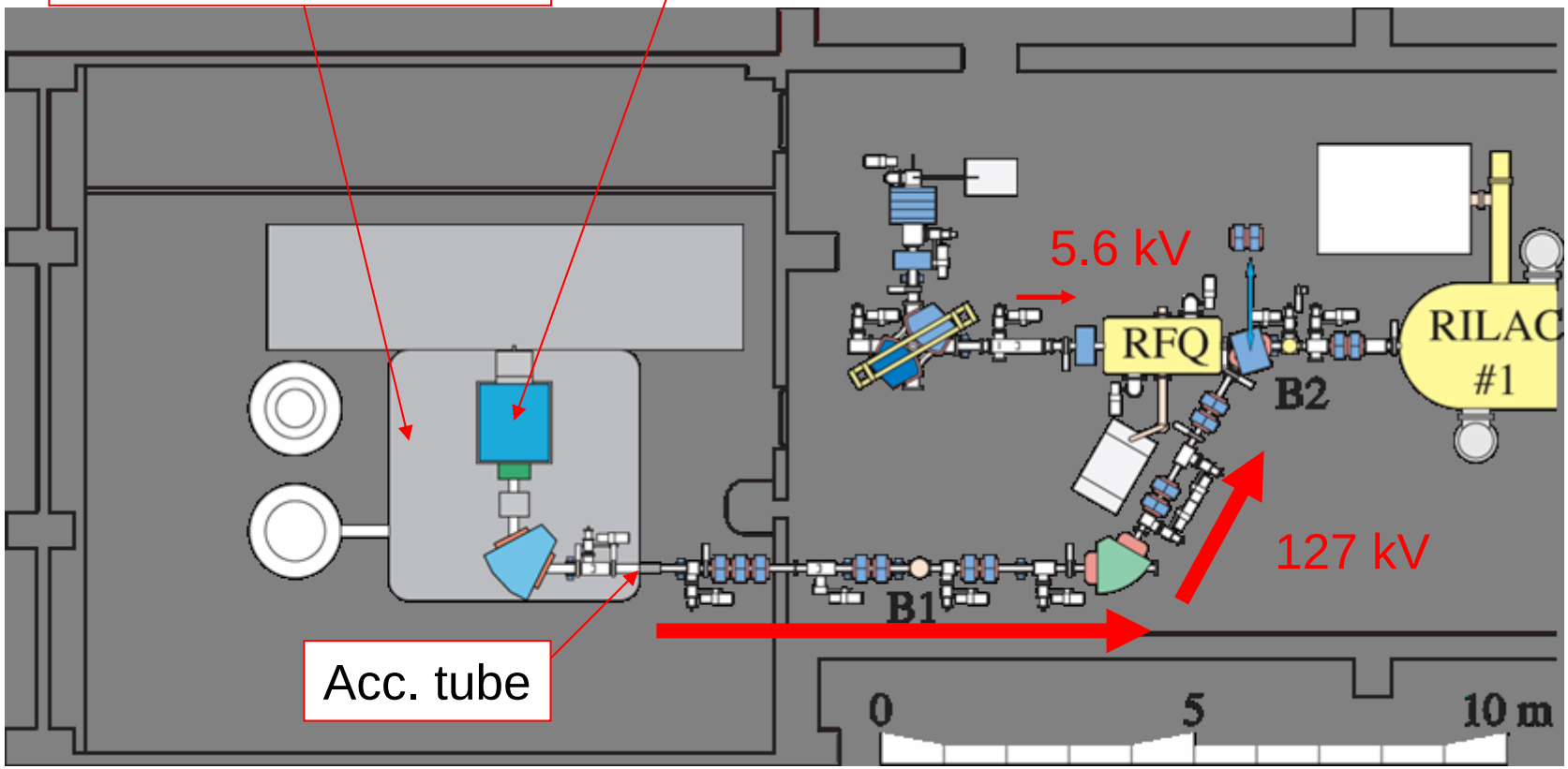
T. Nakagawa, ECRIS'08

SC-ECRIS on Cockcroft-Walton injector for RILAC (Dec. 2008)

SC- ECR(15 kV)

HV terminal (112 kV)

Higher extraction voltage =>
- Higher current is expected.
- Space-charge effect will be reduced.

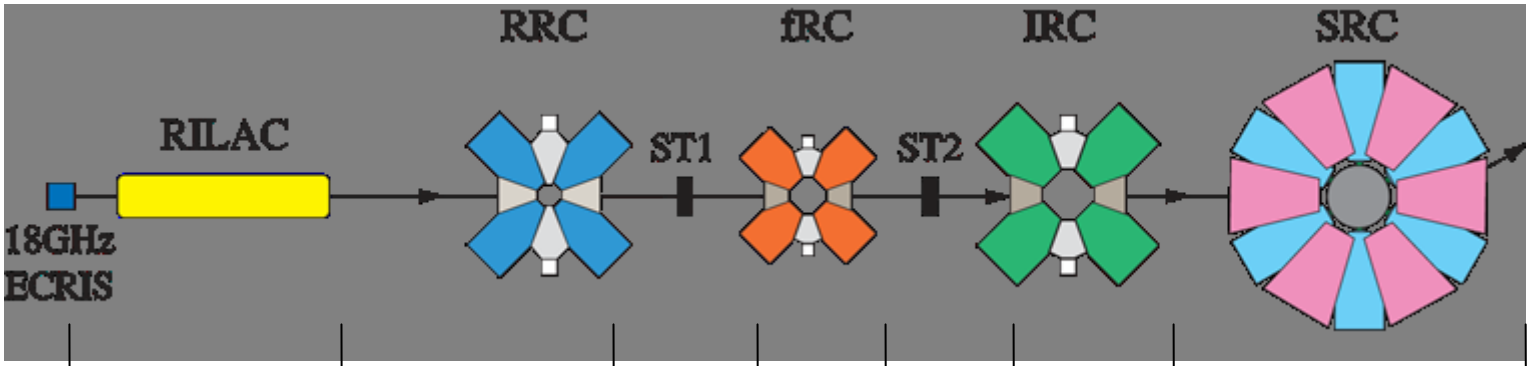


Developments for U beam from SC-ECRIS in 2009

Apr 7:	Evacuation of SCECR started
May 11:	First beam
Jul 1:	O6+ 150 euA
Jul 14:	Xe20+ 63 euA
Sep 11:	MEBT + RILAC acc. test

Oct 16:	Au30+ 17 euA
Oct 29:	Au30+ 30euA
Oct 30:	U test started
Nov 9:	U35+ 9 euA
Nov 13 -:	U35+ 10 euA

U beam intensity in Nov. 2009



(2008 /enA)	2000	870	870	240	240	80	70	35
(2009 /enA)	12600	3800	3400**	670	480*	150*	130*	72

*: FC's have been improved. **: Overestimated.

Developments for U beam from SC-ECRIS in 2009

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Oct 29:	Au30+ 30euA
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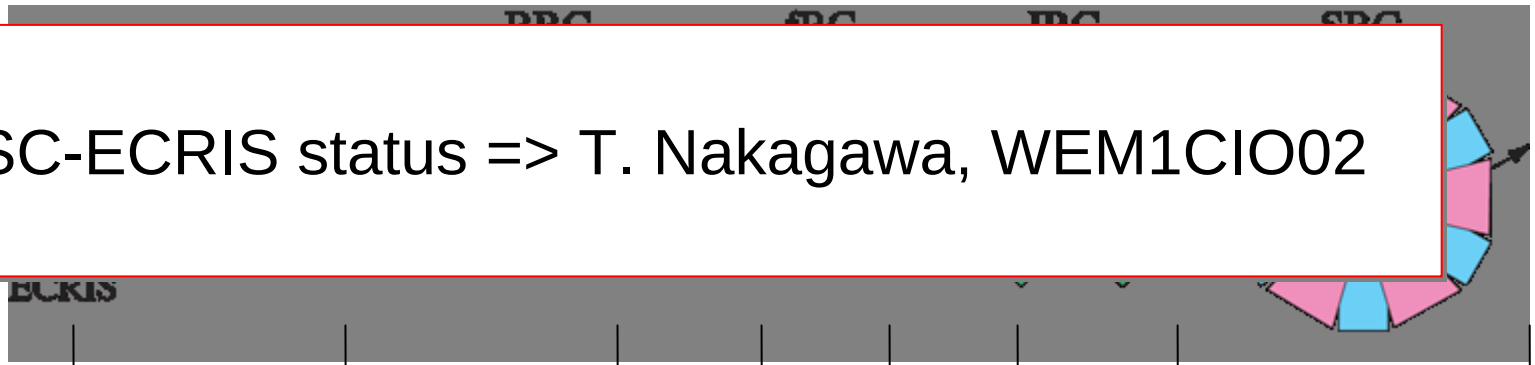
Nov 13 -:	U35+ 10 euA

U beam intensity in Nov. 2009

SC-ECRIS status => T. Nakagawa, WEM1CIO02



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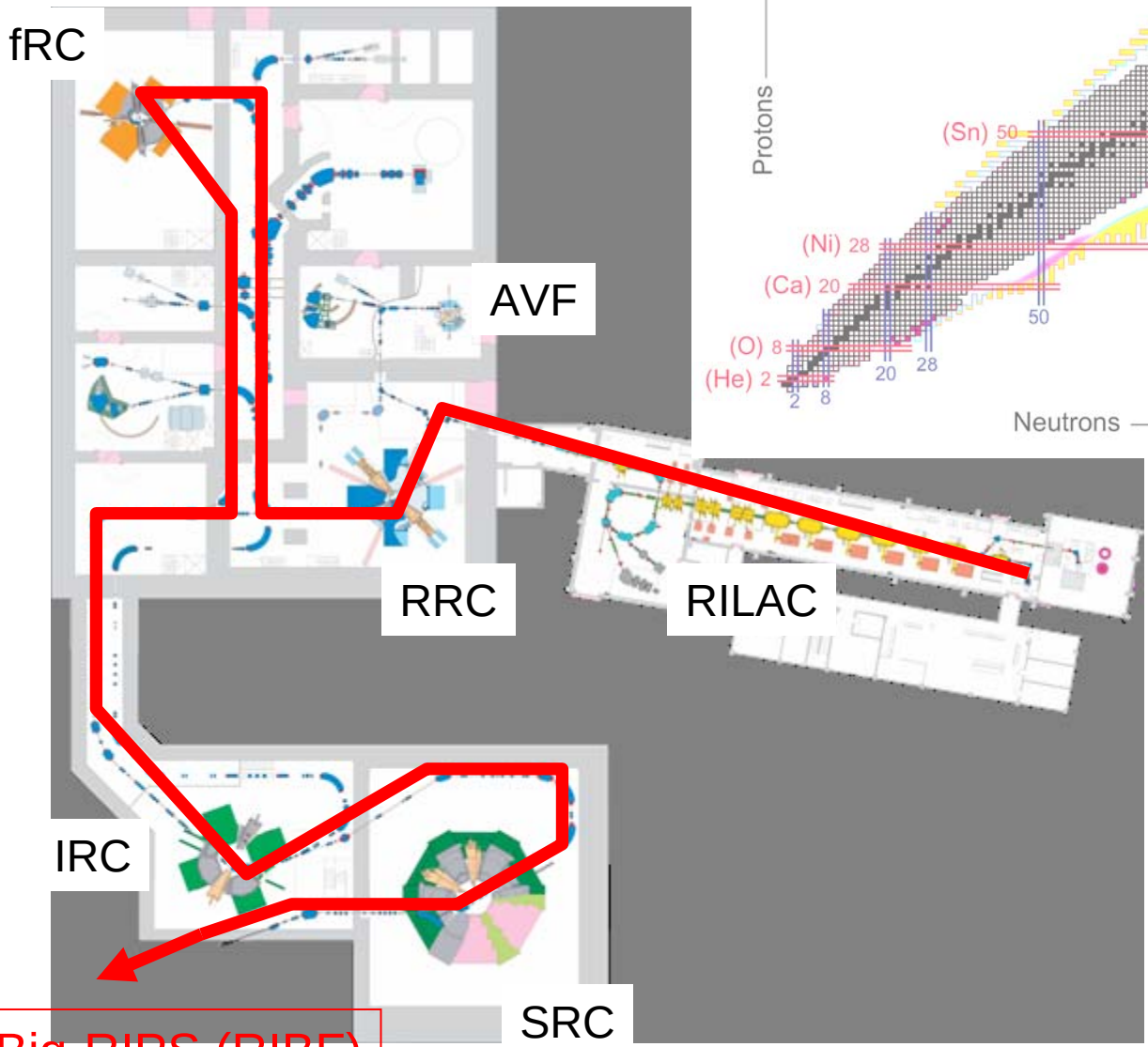
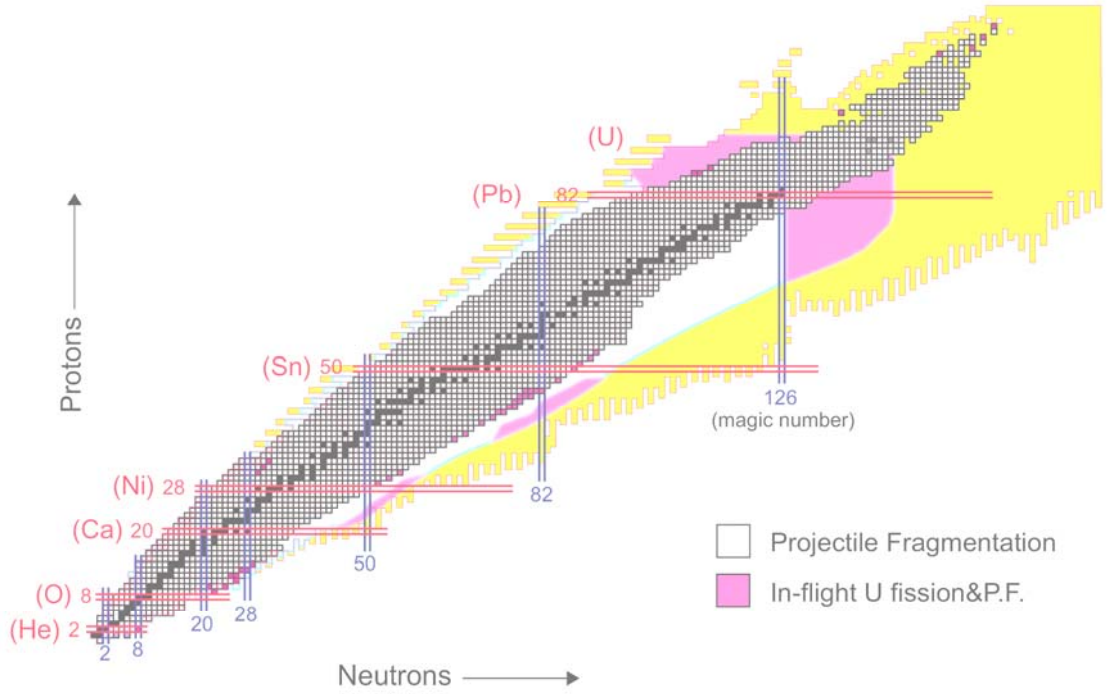
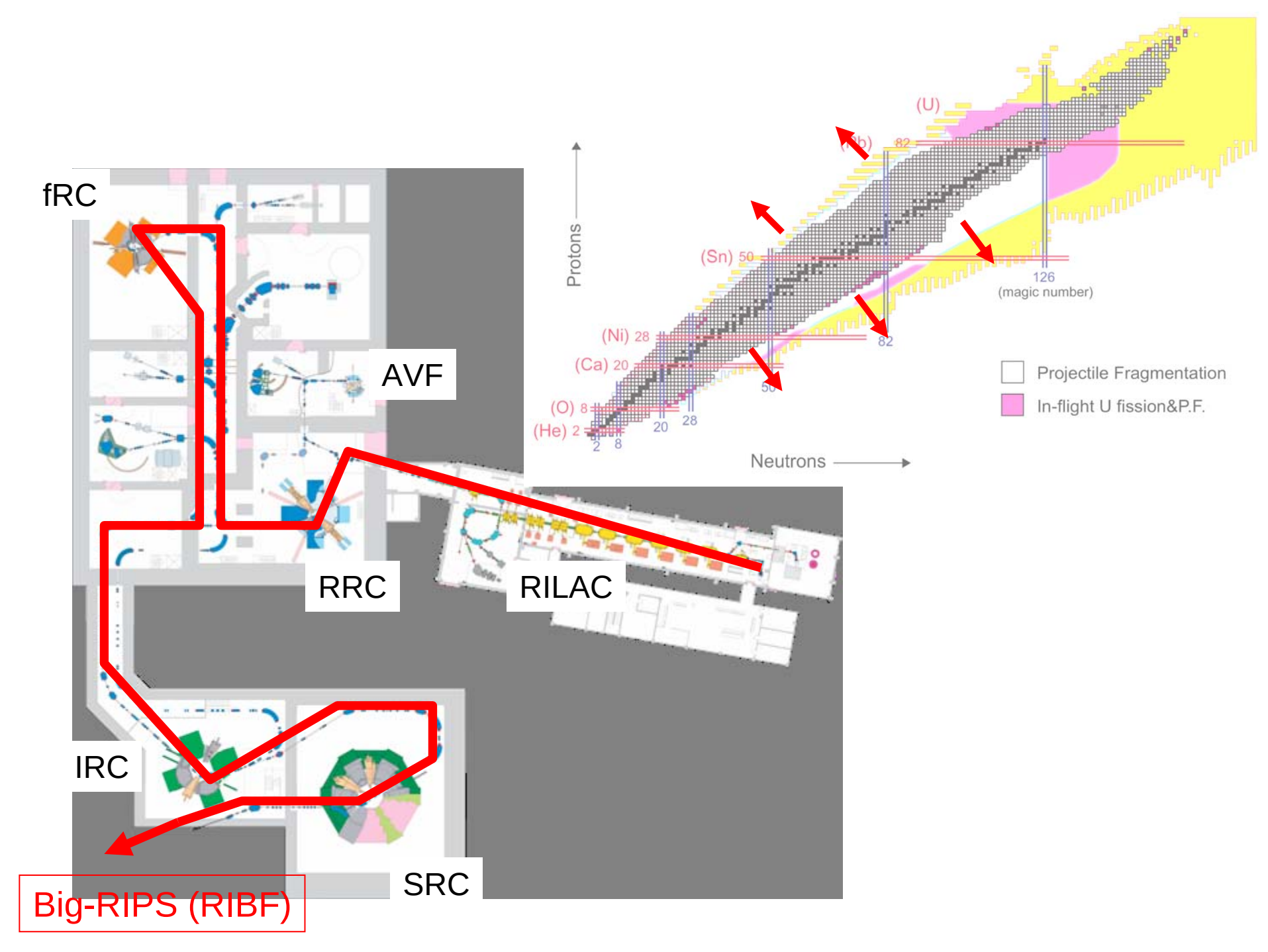

fRC
AVF
RRC
RILAC
IRC
SRC
Big-RIPS (RIBF)


(U)
(Pb)
82
(Sn) 50
126
(magic number)
(Ni) 28
82
(Ca) 20
50
(O) 8
(He) 2
20
28
2
8
Protons
Neutrons
Projectile Fragmentation
In-flight U fission&P.F.


fRC
AVF
RRC
RILAC
IRC
SRC
Big-RIPS (RIBF)
Protons
Neutrons
(U)
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82
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(Ni) 28
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2
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28
50
Projectile Fragmentation
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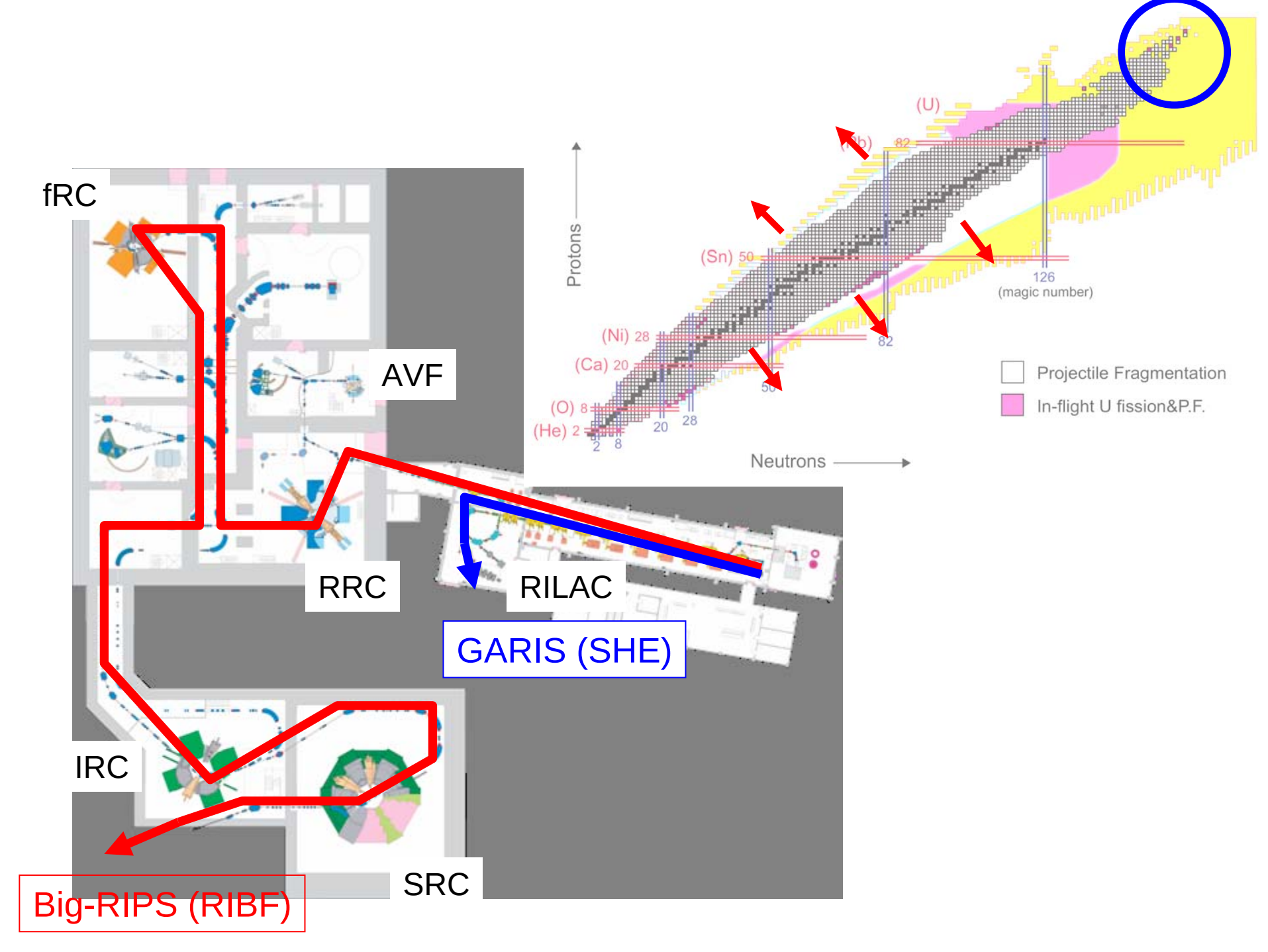
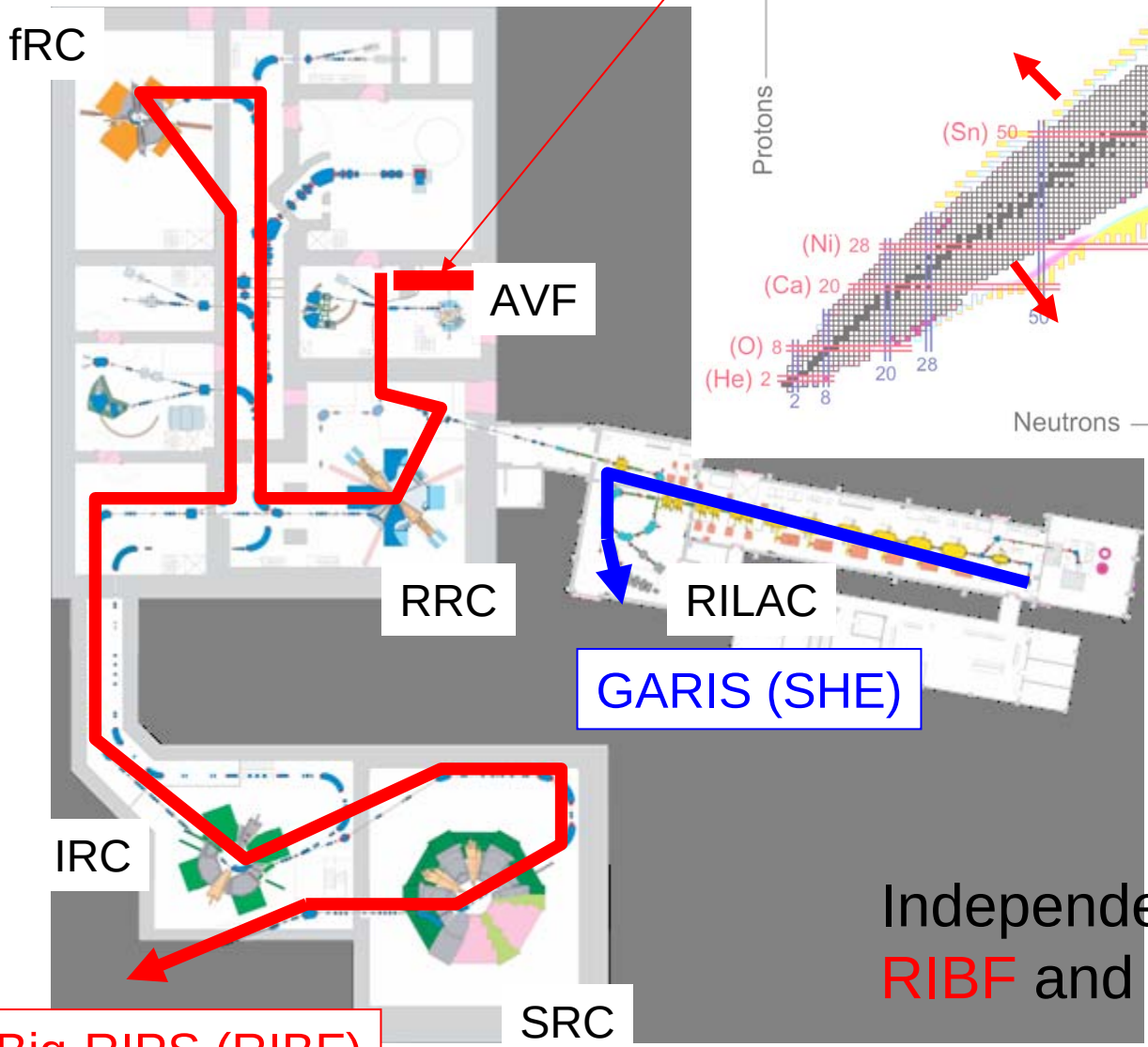
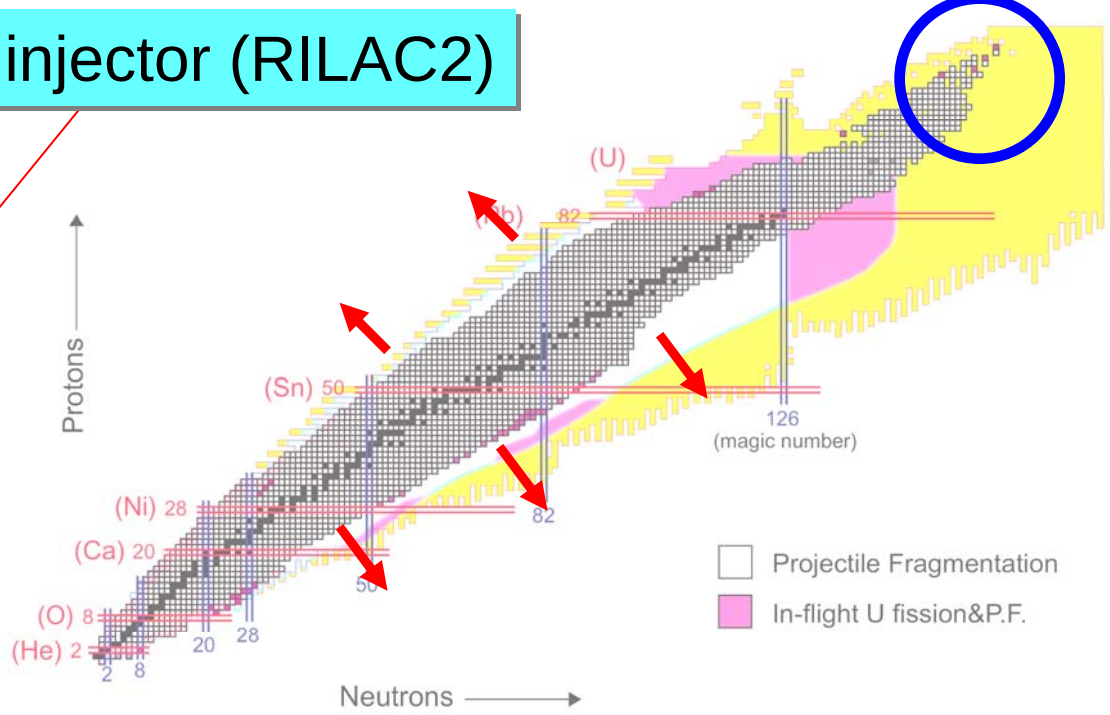
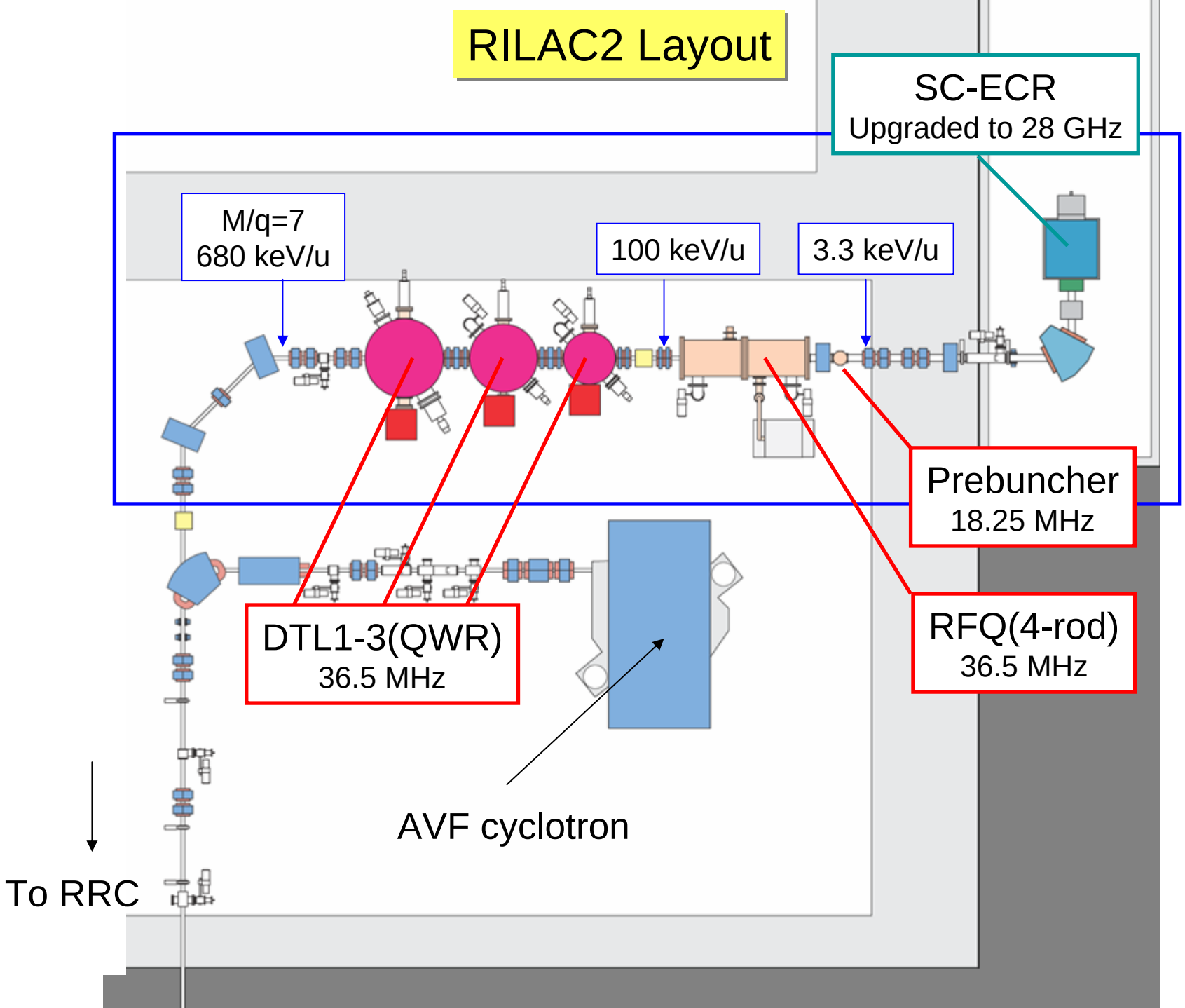

fRC
AVF
RRC
RILAC
GARIS (SHE)
IRC
SRC
Big-RIPS (RIBF)
Protons
Neutrons
(U)
(Pb) 82
(Sn) 50
(Ni) 28
(Ca) 20
(O) 8
(He) 2
2
8
20
28
50
82
126
(magic number)
Projectile Fragmentation
In-flight U fission&P.F.

b: New injector (RILAC2)

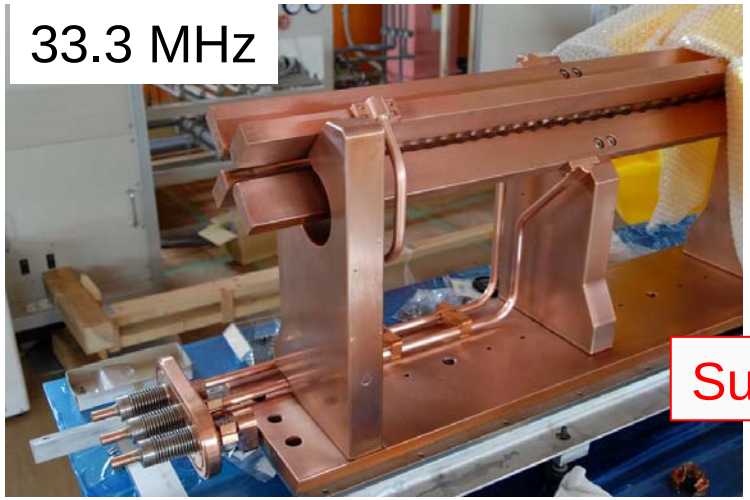




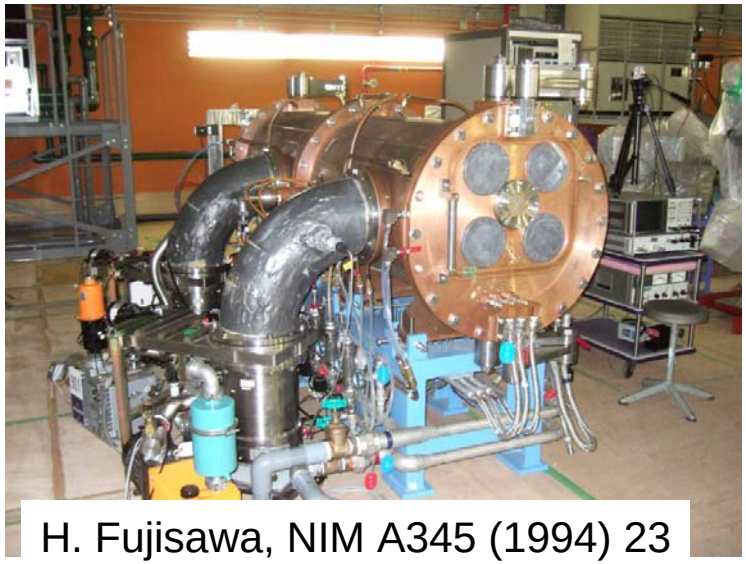
Independent operation of
RIBF and SHE research


RILAC2 Layout
SC-ECR
Upgraded to 28 GHz
M/q=7
680 keV/u
100 keV/u
3.3 keV/u
Prebuncher
18.25 MHz
DTL1-3(QWR)
36.5 MHz
RFQ(4-rod)
36.5 MHz
AVF cyclotron
To RRC

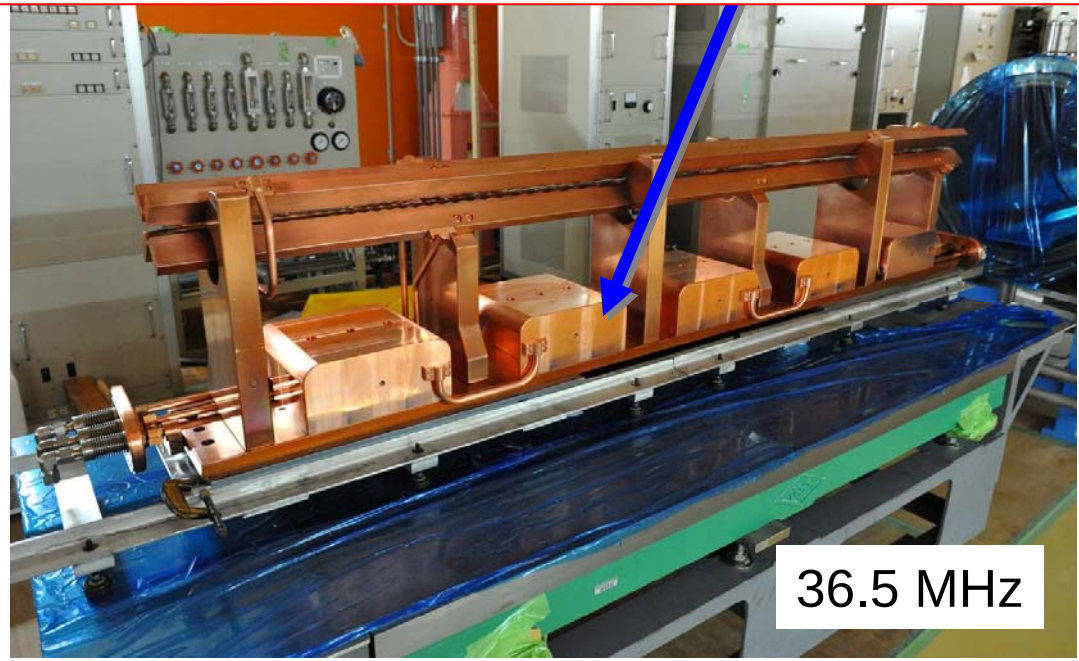
4-rod RFQ



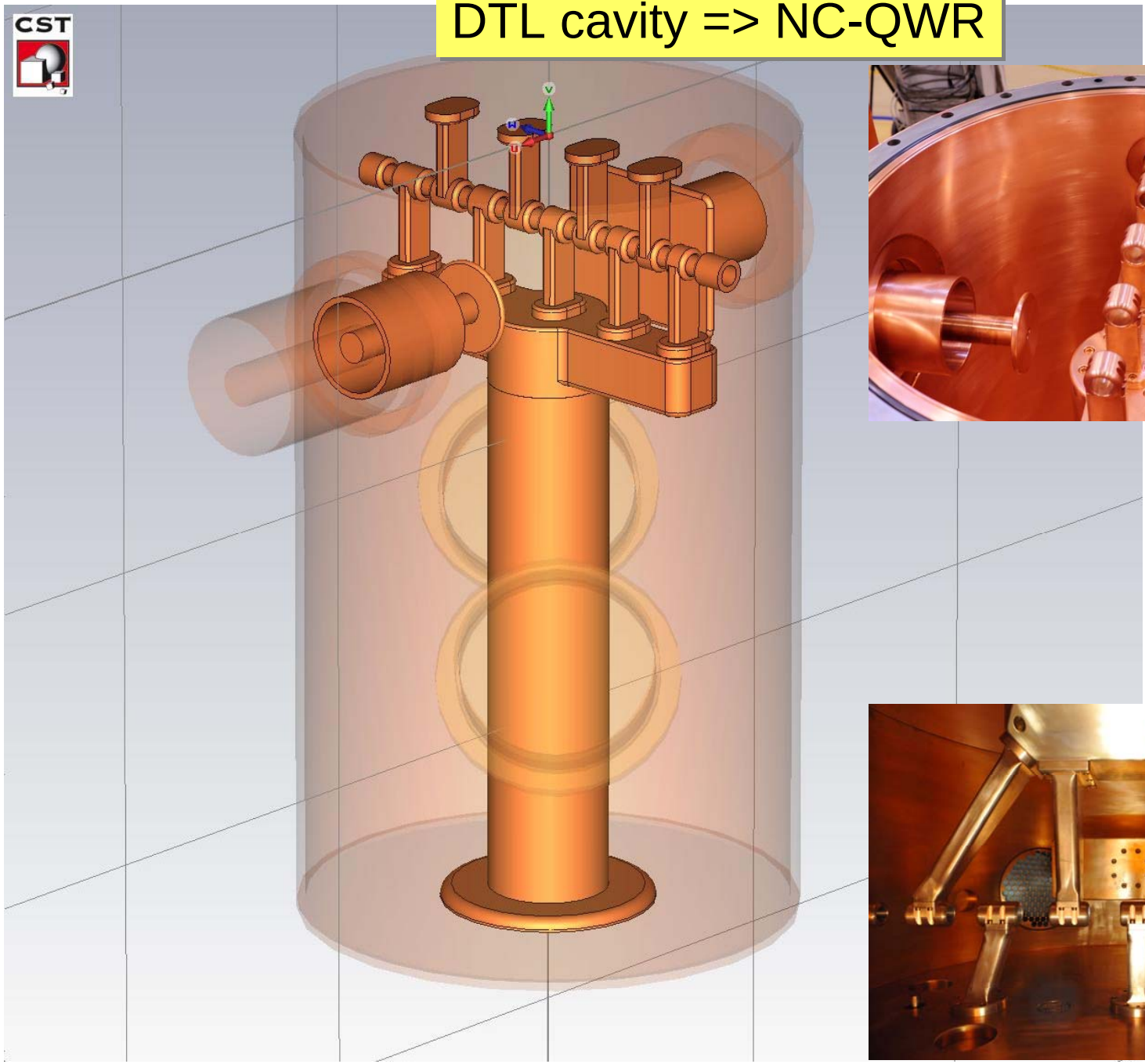
Successfully excited at designed power in August.



H. Fujisawa, NIM A345 (1994) 23



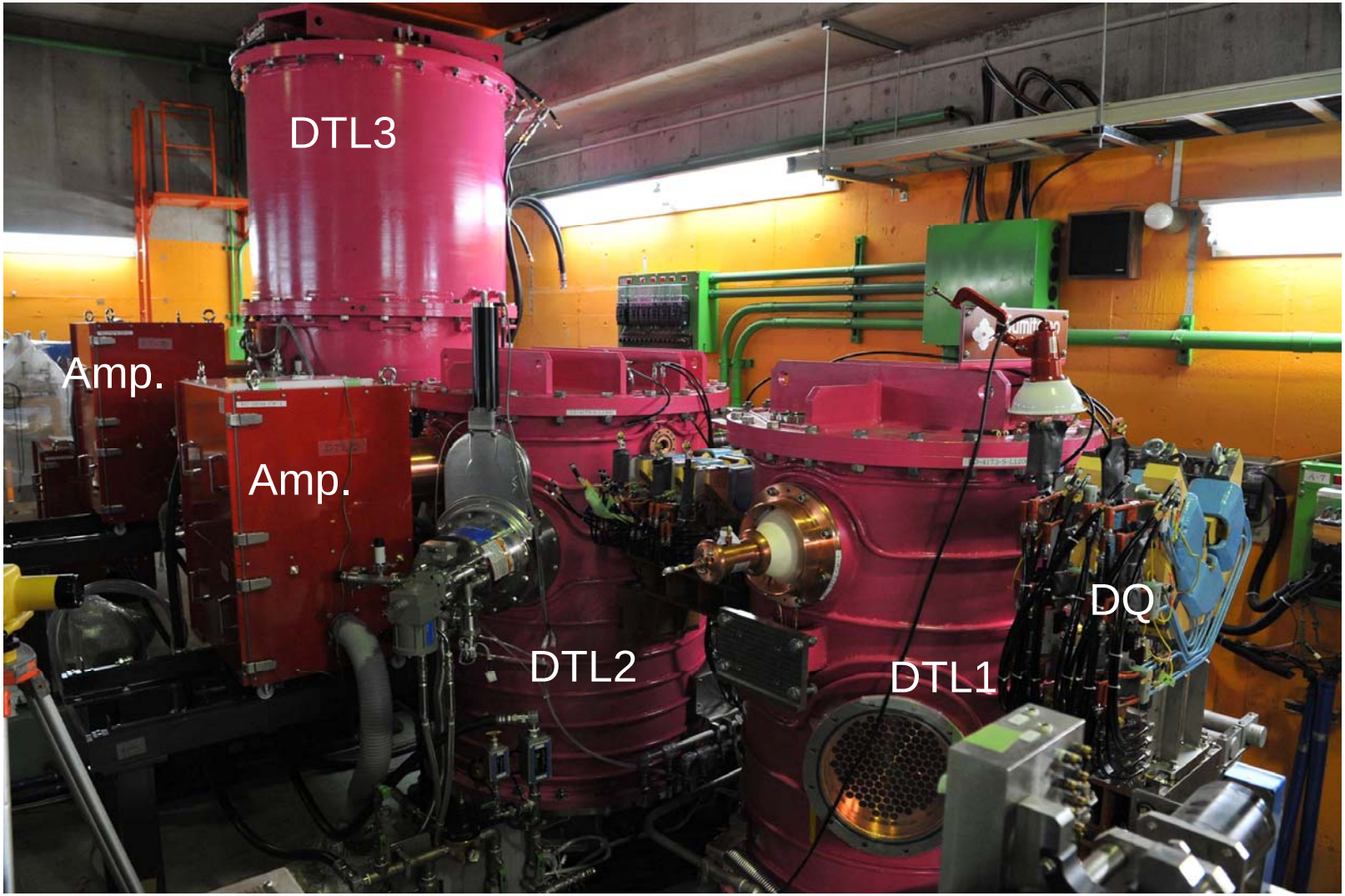
DTL cavity => NC-QWR



DTL1

DTL3

RILAC2 in the AVF room



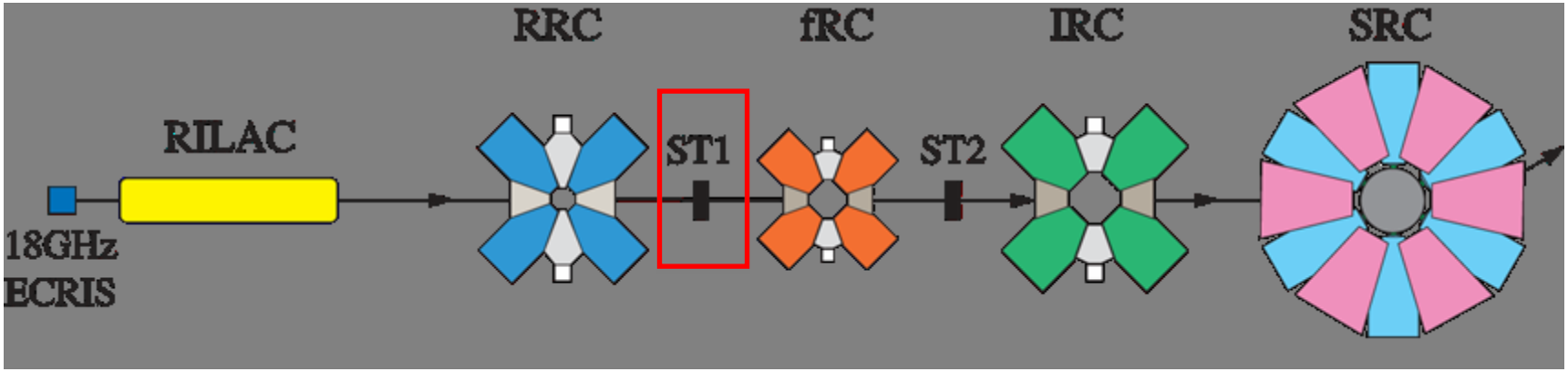
RILAC2 in the AVF room

RILAC2 status => K. Yamada, MOPCP025

Commissioning will start in December. => 5 pnA of U beam in FY2011

4) Developments - c: Charge stripper for U beam

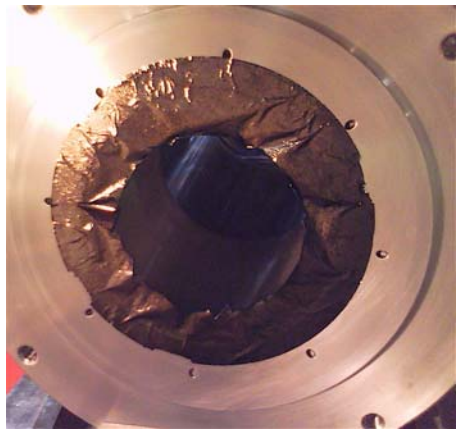
345 MeV/u



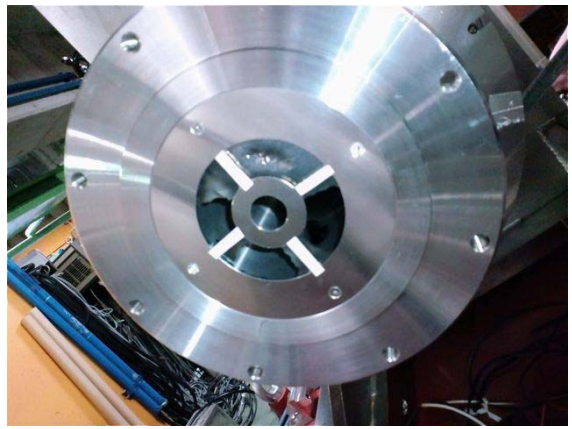
U 35+ ➔ 71+ ➔ 86+

Carbon Foil 300 μg/cm^2 => Lifetime < 12 hours

Lifetime of fast rotating foil (100 rpm) < several min.

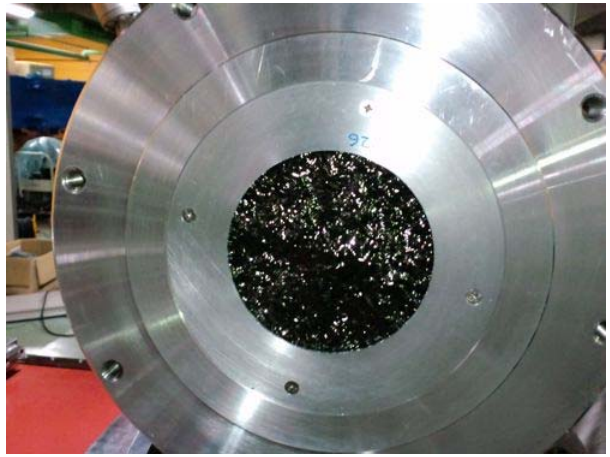


2008

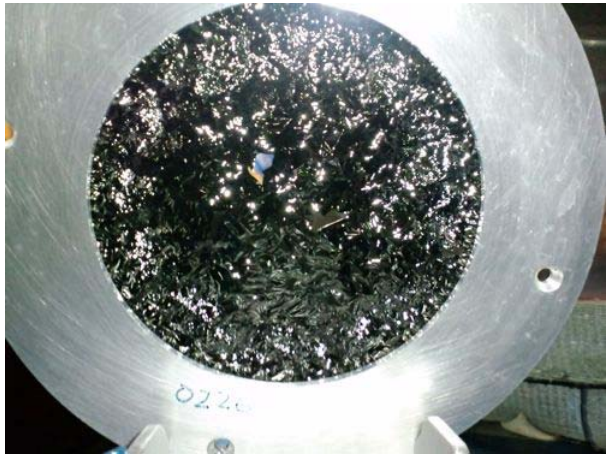


2009

Slowly rotating stripper (Apr. 2010)

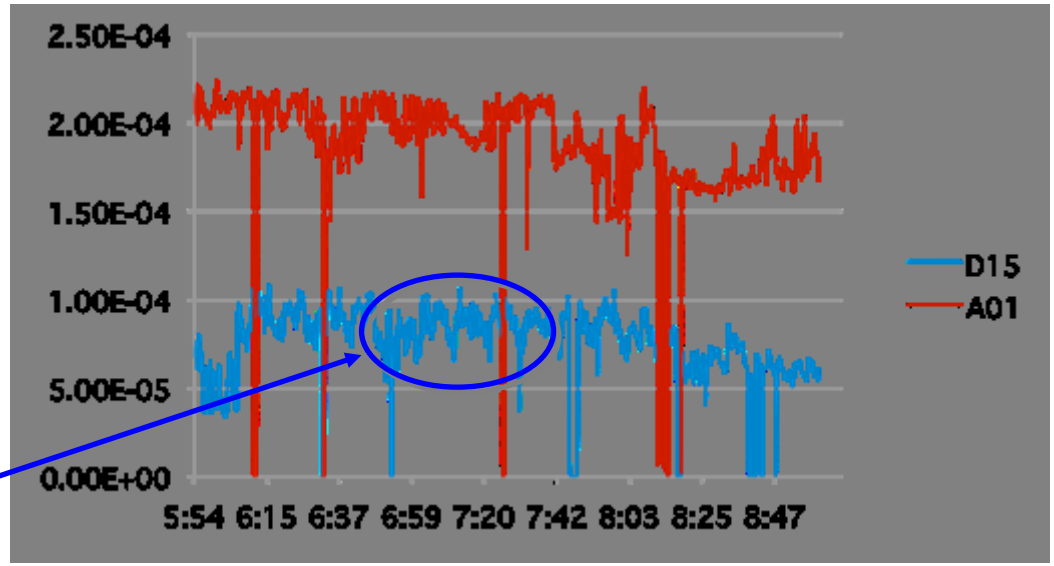


Before irradiation



After irradiation

0.05 rpm, 38 hours @ 1.4 eμA => Survived!

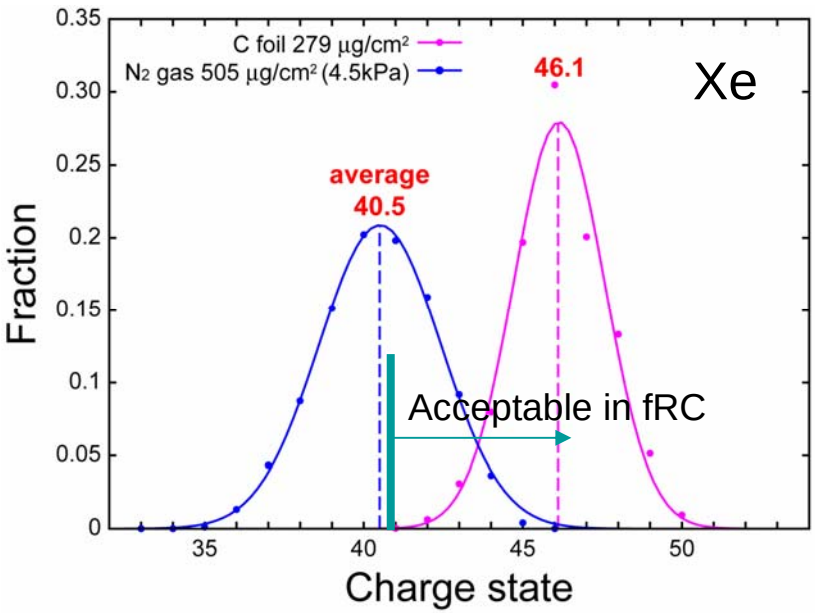


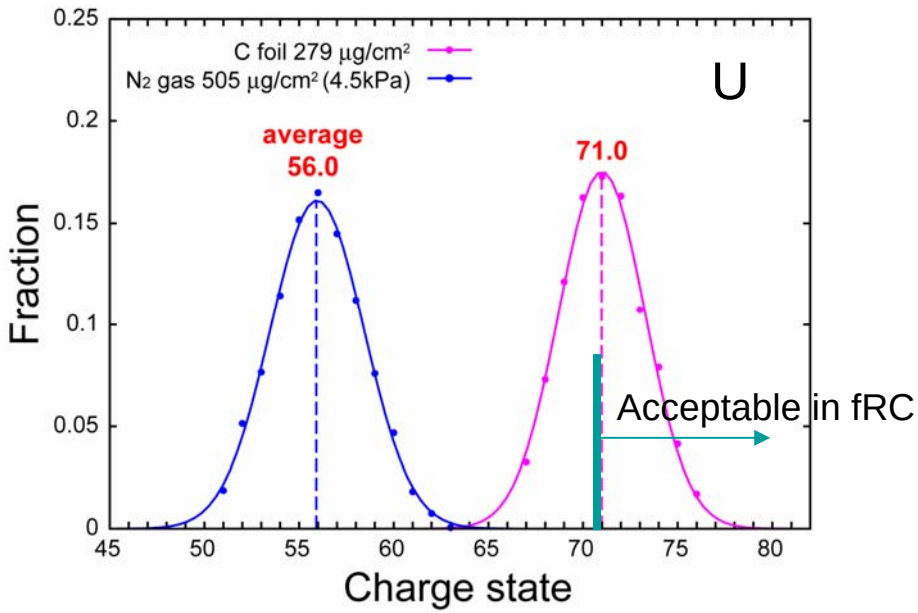
Fluctuation observed

Gas stripper (2009)

- Xe beam => N_2-gas stripper can be used.

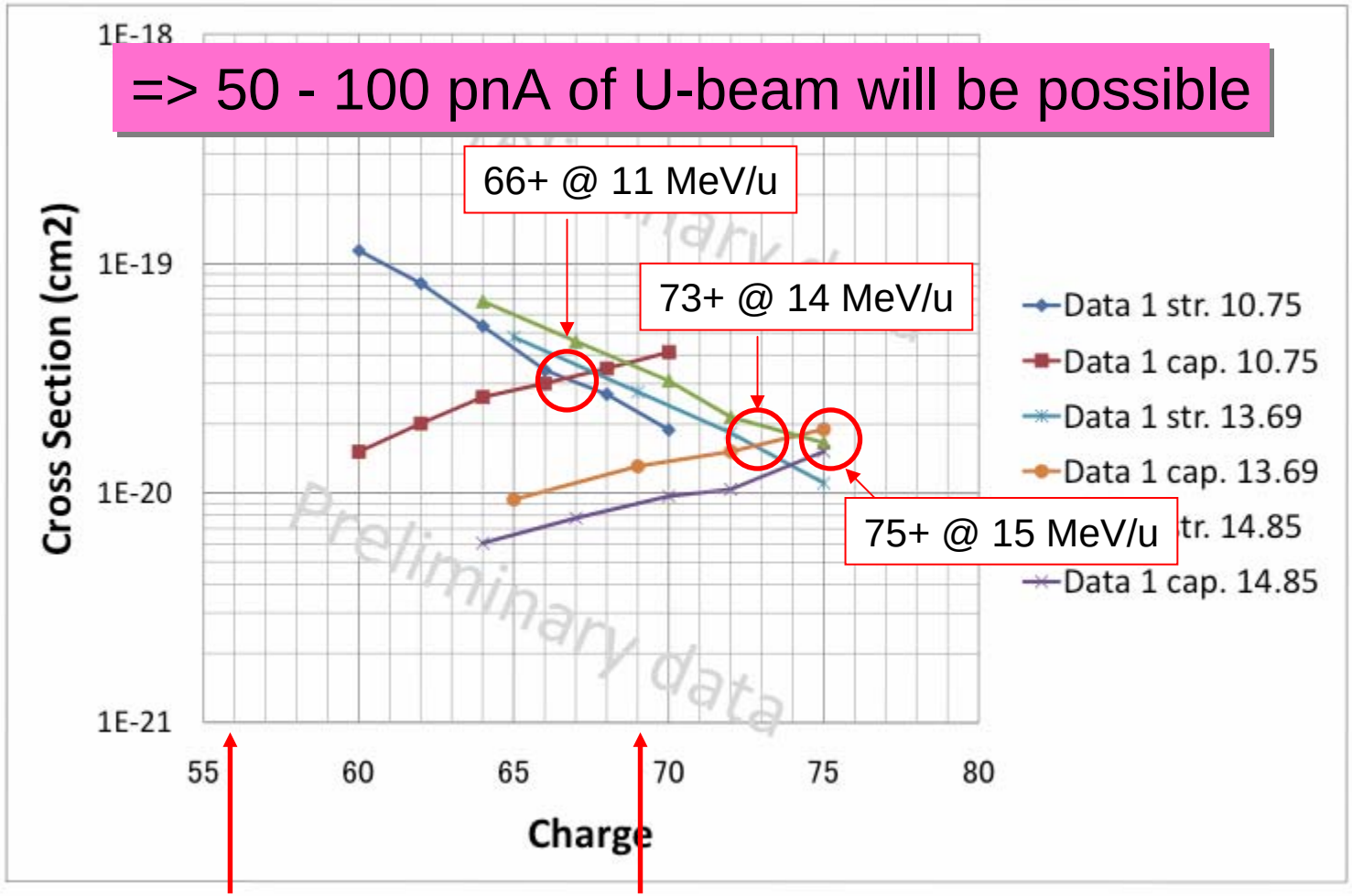
- U beam => The average charge state in the N_2-gas stripper was far below the acceptable state in the fRC.





Electron capture and stripping of U in He gas (Apr. 2010)

Low-Z gas stripper with high pressure!



Eq. Charge state in N_2:
56+ @ 11 MeV/u

Acceptable with fRC: 69+

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Thank you for your attention!

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