LINAC12
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XXVI Linear Accelerator Conference

Commissioning of a New Injector for the RIKEN RI-Beam Factory

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A) RIKEN NISHINA CENTER
B) SUMITOMO ACCELERATOR SERVICE LTD.

Contents

- Introduction of RIBF accelerators
- Design and performance of RILAC2
- Results of beam commissioning
- Summary and plans

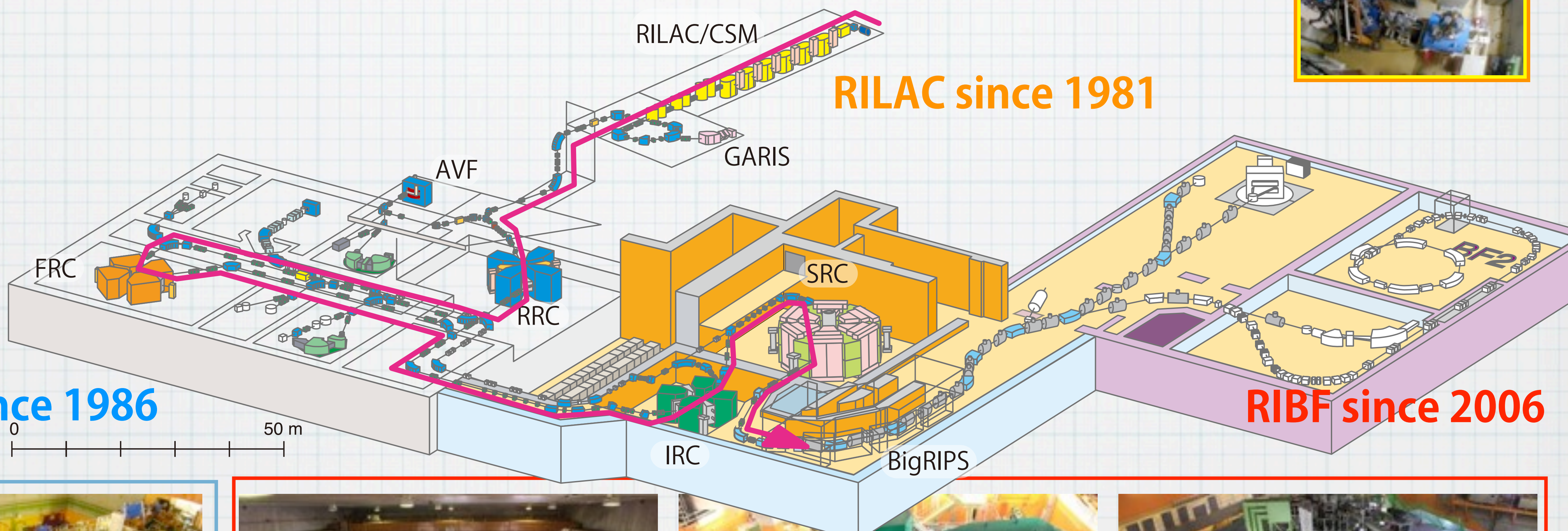
RIKEN RIB-Factory Overview

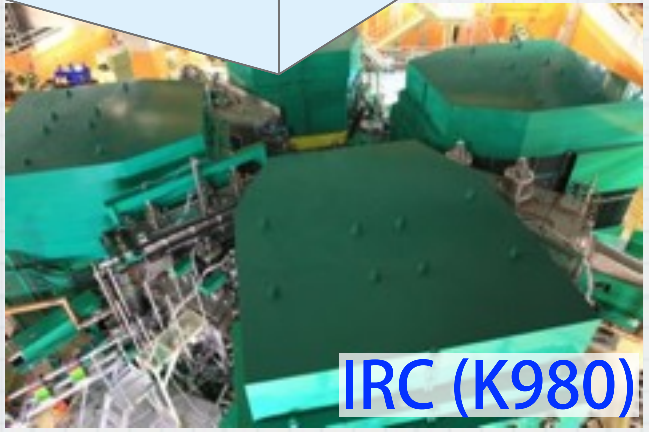
AVF

Mission: Expand the availability of heavier RIB

Beams:
- Wide Mass Range — deuteron ～uranium
- Energy to produce RIB — ～400 MeV/u
- High Power — 1 particle μA

RILAC





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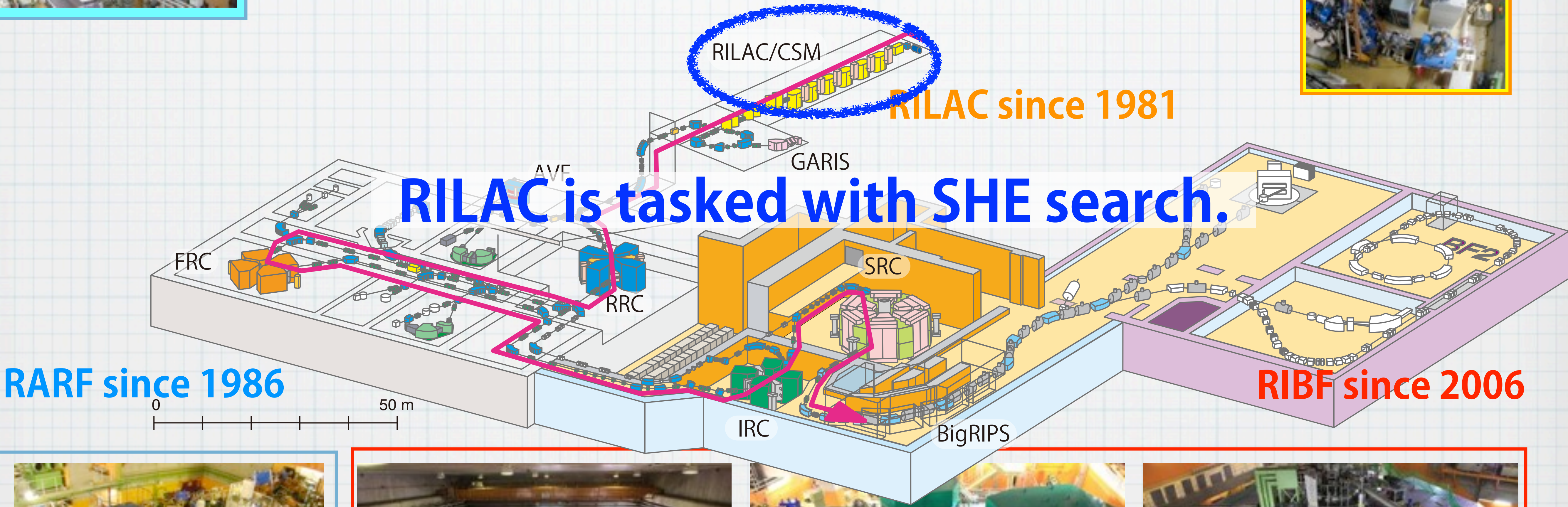

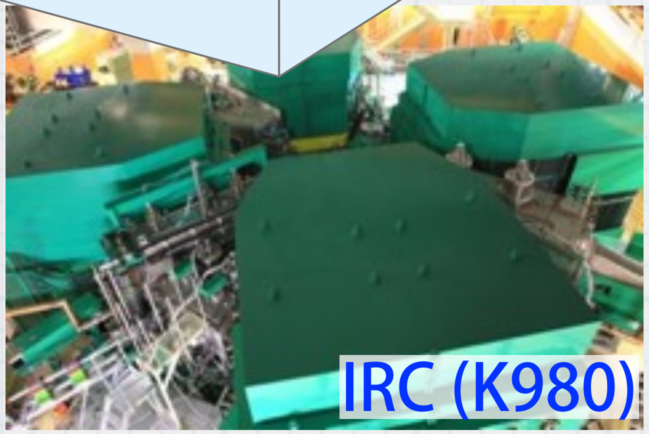

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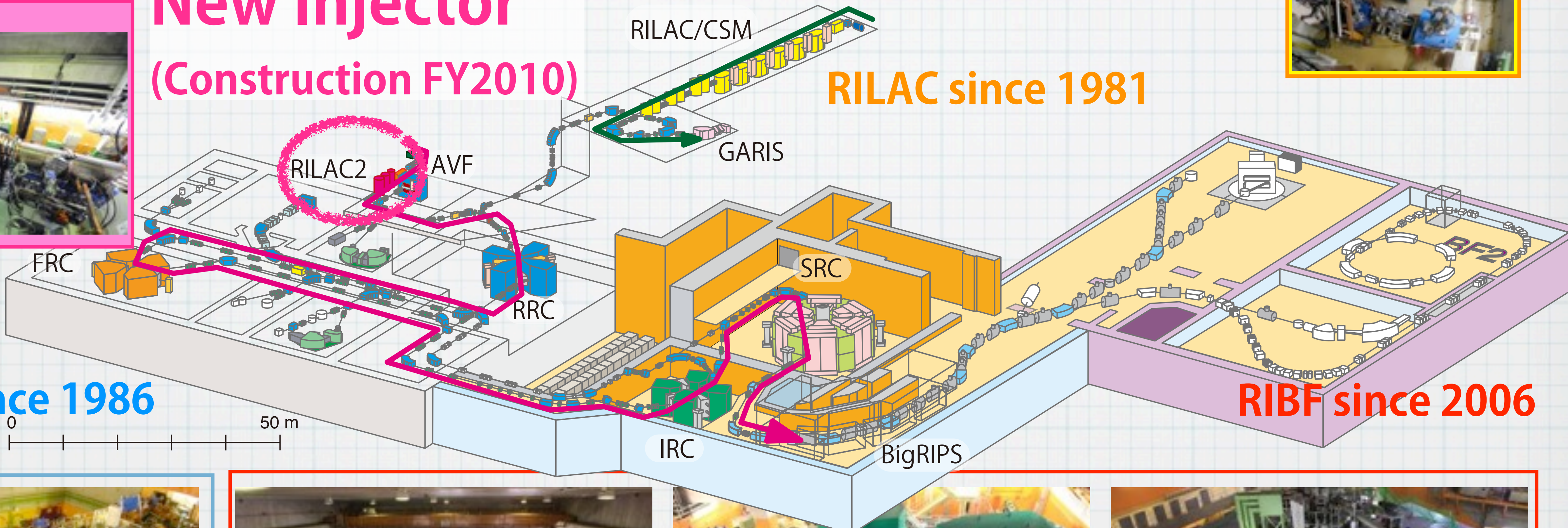
AVF

RILAC2

RILAC

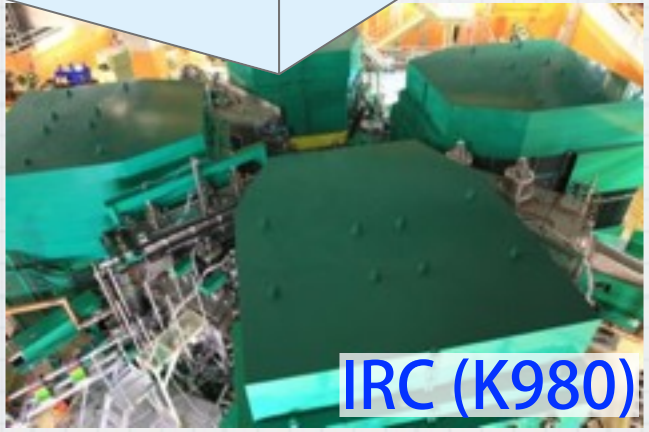
New Injector

(Construction FY2010)



RRC (K540)

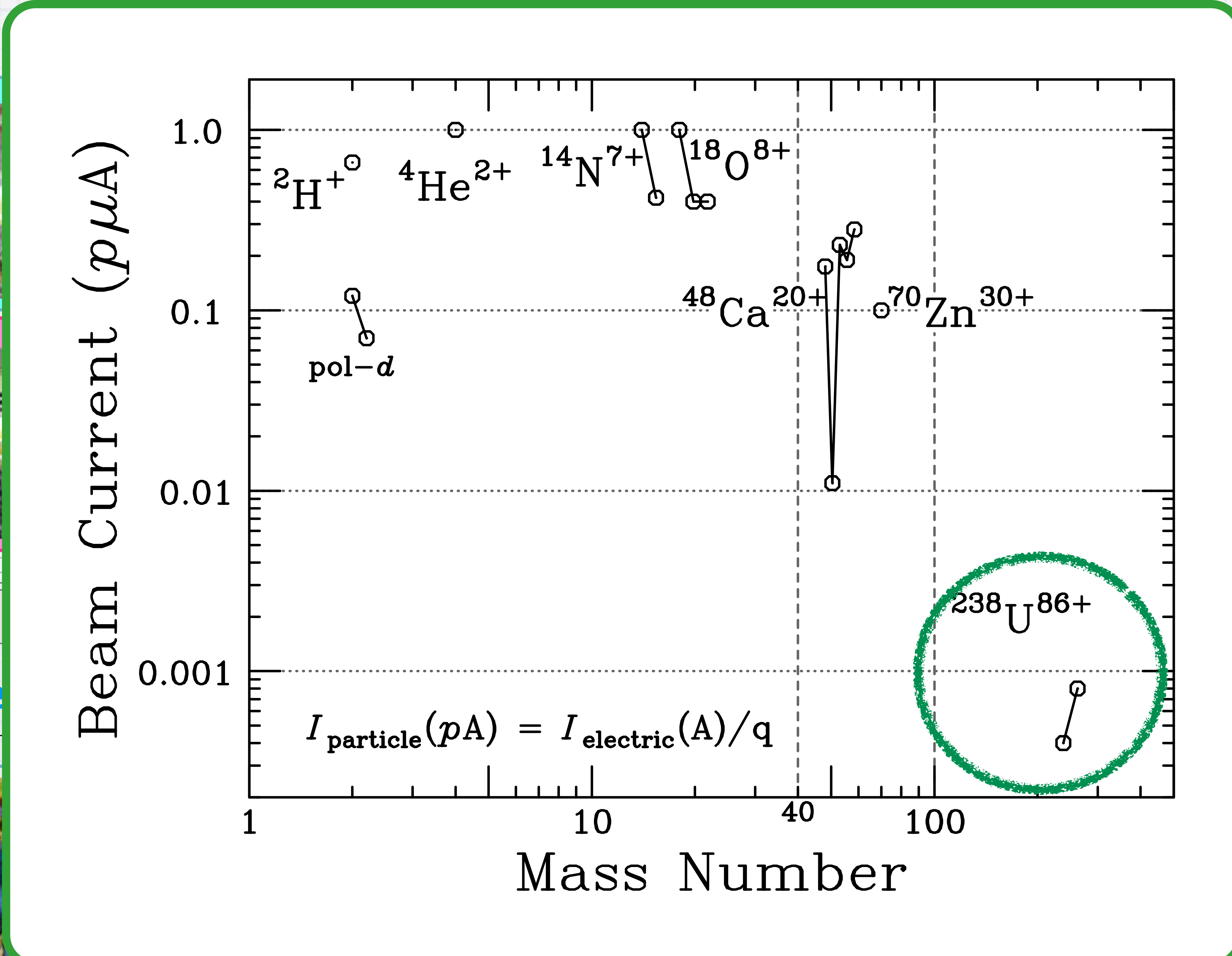
FRC (K570)

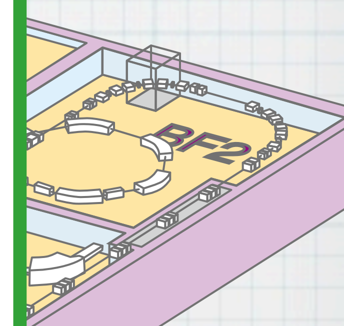


IRC (K980)

SRC (K2600)

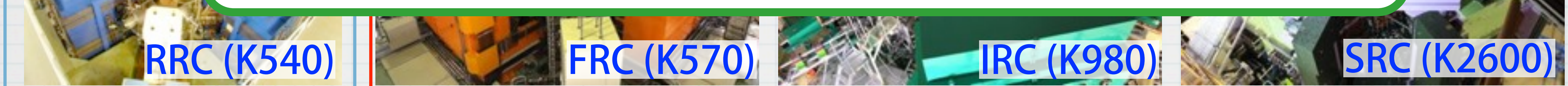
RIKEN RIB-Factory Overview





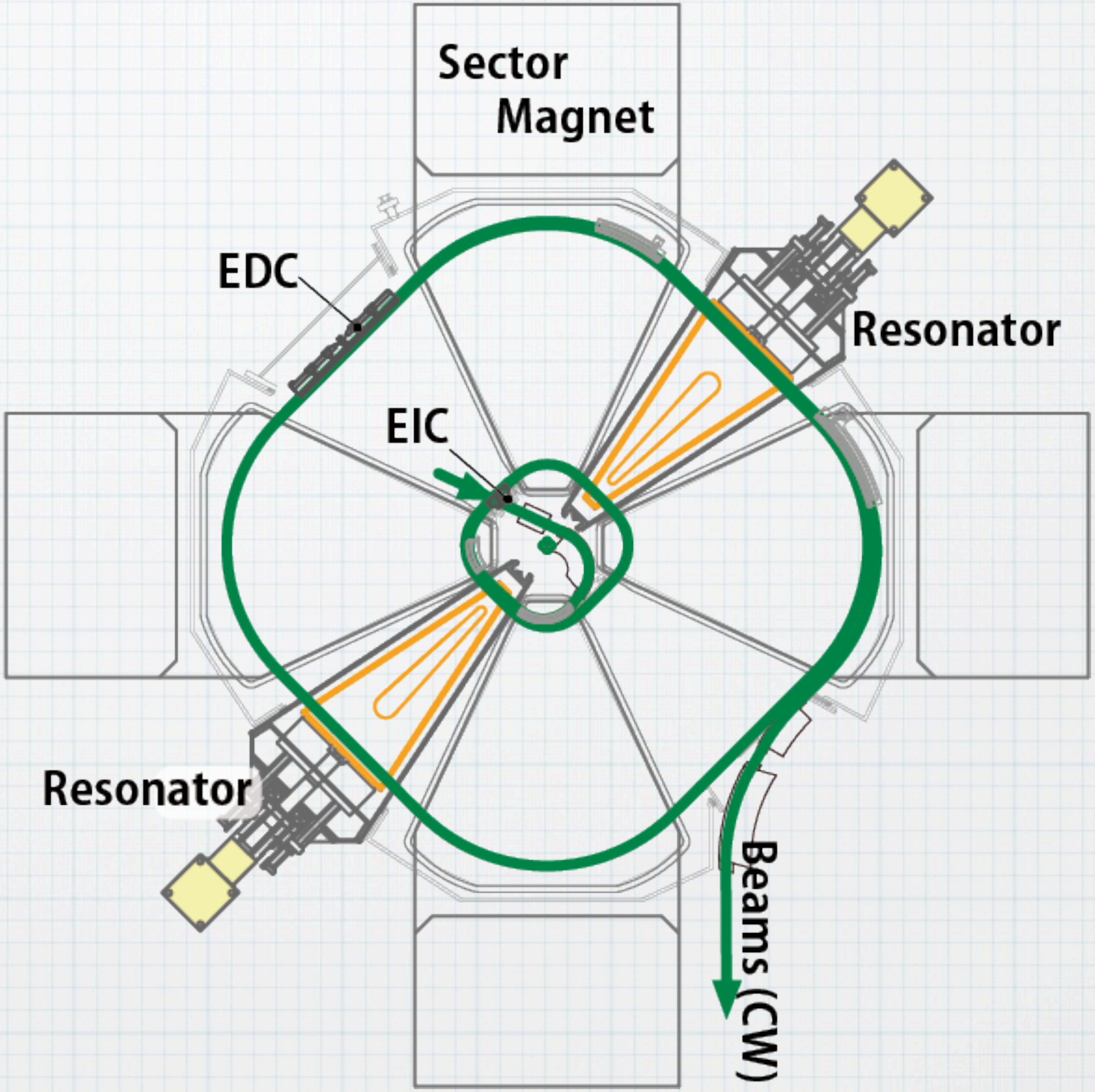
RARF since

nce 2006



Injection to RRC

- CW mode operation
- Isochronous magnetic field
  - Acceleration at the top of the RF
  - longitudinal acceptance ±3°
- RF fixed frequency operation
  - Frequency 18.25 MHz
  - Harmonic 9
  - Voltage 230 kV/turn
  - Number of turns ～325
- Extraction
  - Electric Deflection Channel
  - Turn gap ～ 5.5 mm
  - Beam Loss at EDC
- Diagnostics for elaborate tuning
  - MDP: Main and Differential Probes
    - → Turn pattern
  - PP: Phase Probes
    - → Isochronism



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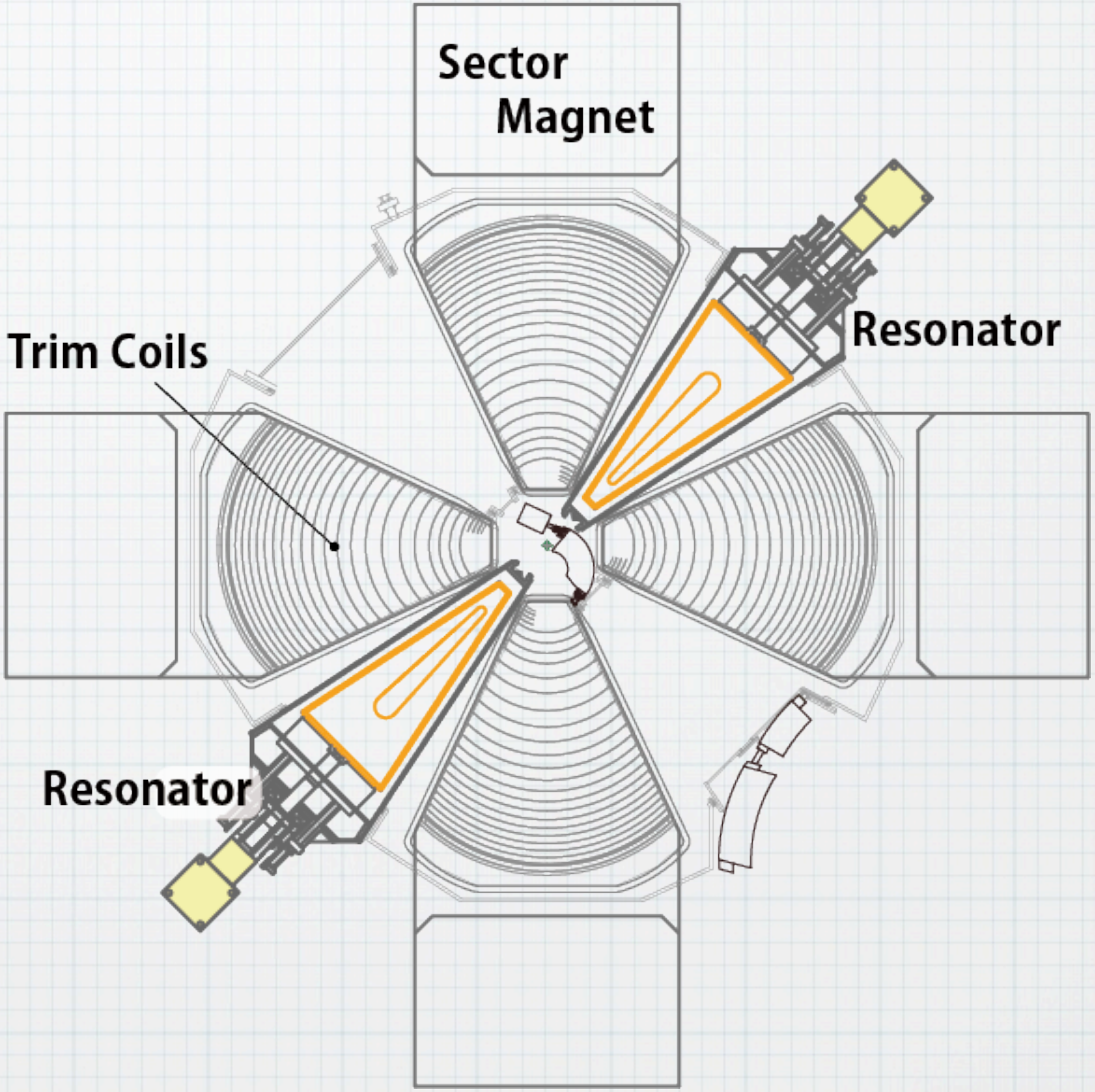

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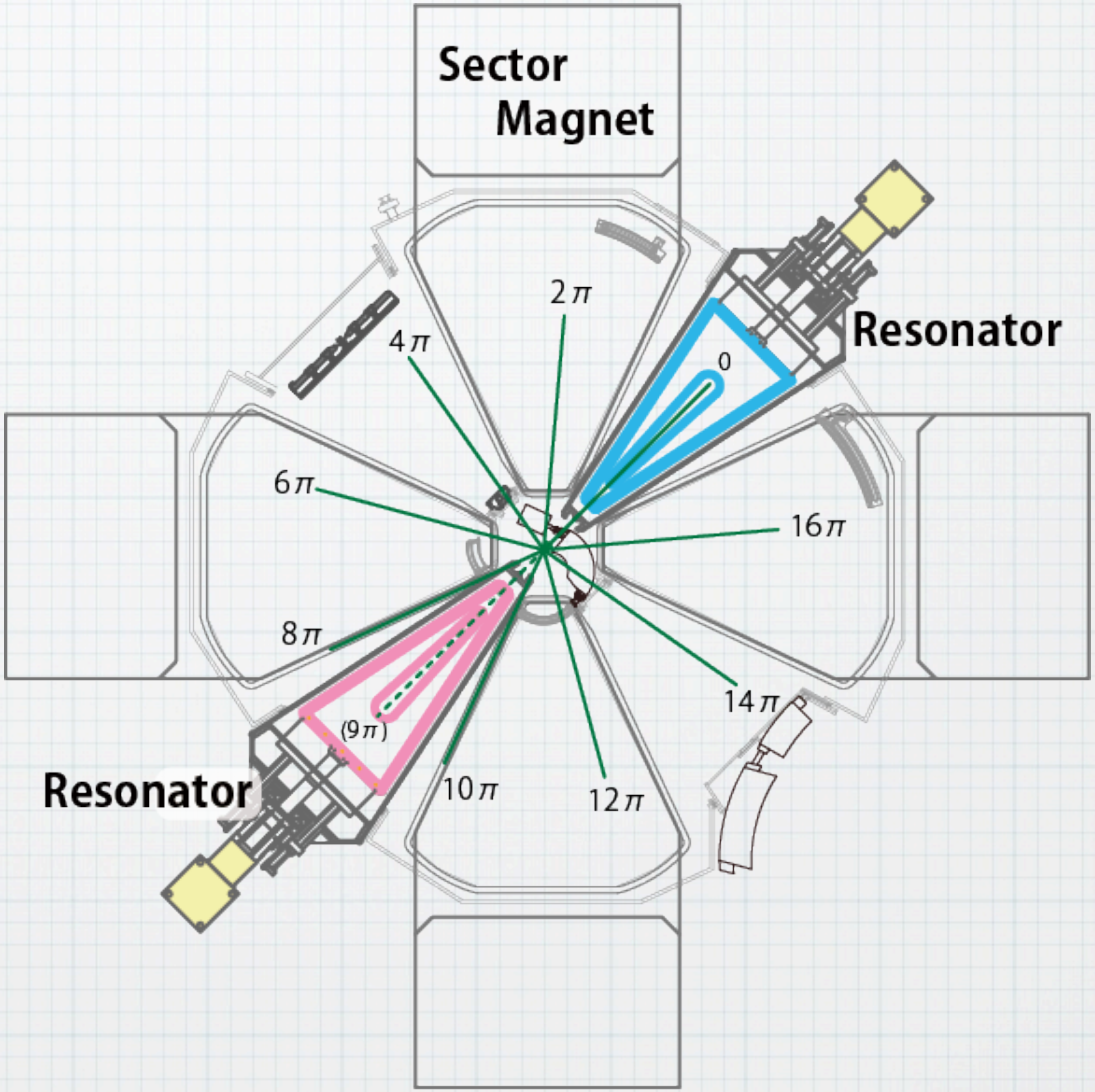

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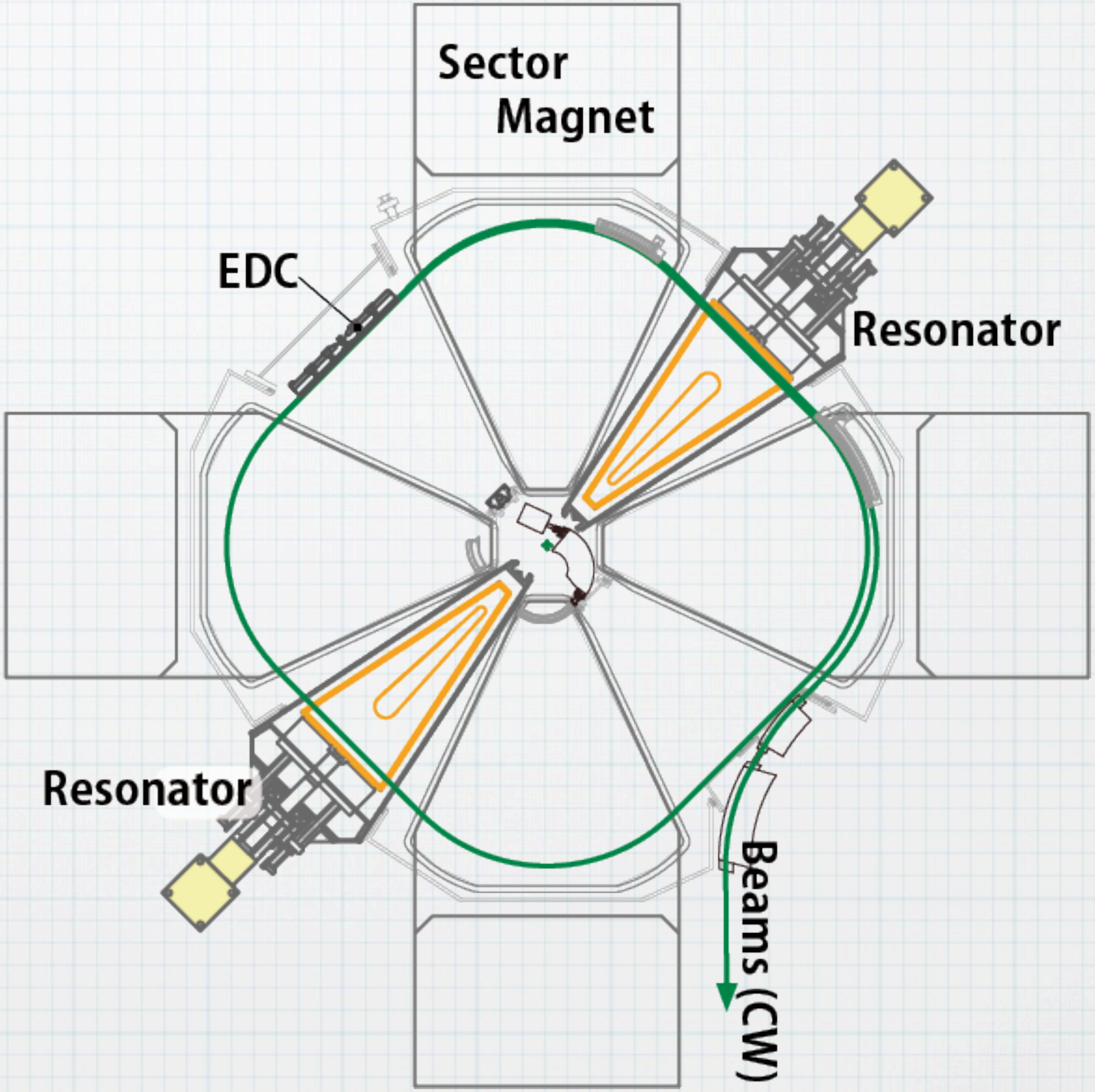

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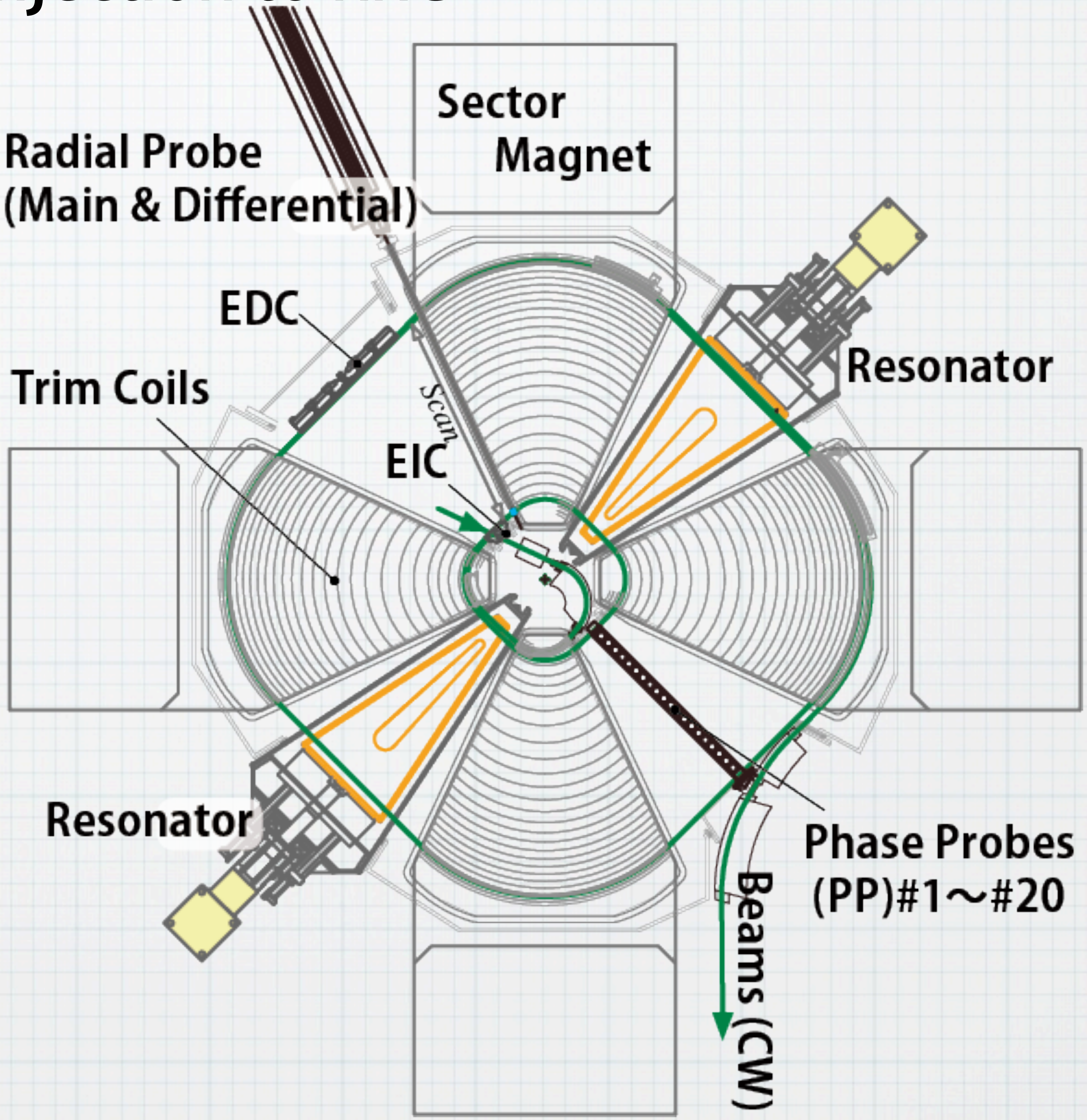


Requirement for the injector

- Bunched beam

  18.5 MHz (CW)

- Ions

  $^{238}U^{35+}$ and $^{124}Xe^{20+}$ (q/m〜6.8)

- Energy

  0.67 MeV/u

- RF errors

  $|\Delta V/V| < 0.1\ \%$, $|\Delta \Phi| < 0.1^{o}$

- Beam stability

  $|\Delta T| << 0.2$ ns (= 3deg. of 18.25 MHz)

Contents

- ☑ Introduction of RIBF accelerators
- ☐ **Design and performance of RILAC2**
- ☐ Results of beam commissioning
- ☐ Summary and Plans

Overview of RILAC2

- Construction: FY2009, Installation: FY2010
- Beams: Xe and U, 0.67 MeV/u

First Beam: 2010/12/21 ^{124}Xe

Beam Service: 2011/12, 2012/6 ^{124}Xe, 2012/12 ^{238}U

- Main Components

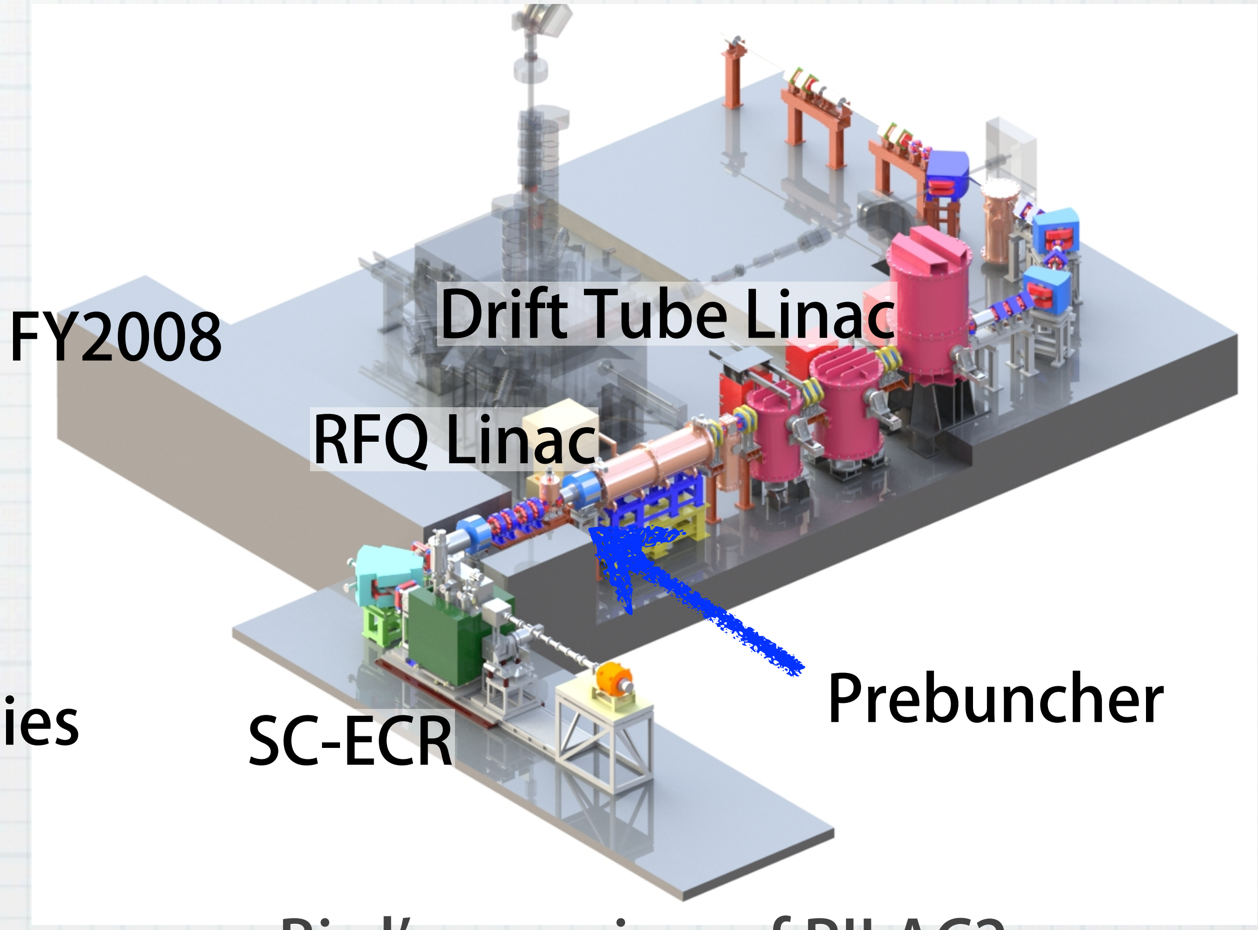
Ion Source: Superconducting Magnet

w/ 28 GHz Gyrotron constructed in FY2008

Prebuncher (BUN): 18.25 MHz (CW)

4-Rod RFQ Linac: 36.5 MHz (CW)

Drift Tube Linac: 36.5 MHz (CW), 3 Cavities



Bird’s-eye view of RILAC2

SC-ECR

- 100 times more intense $^{238}U^{35+}$ than those from RIKEN 18GHz-ECRIS.
- Set of six superconducting trim coils:

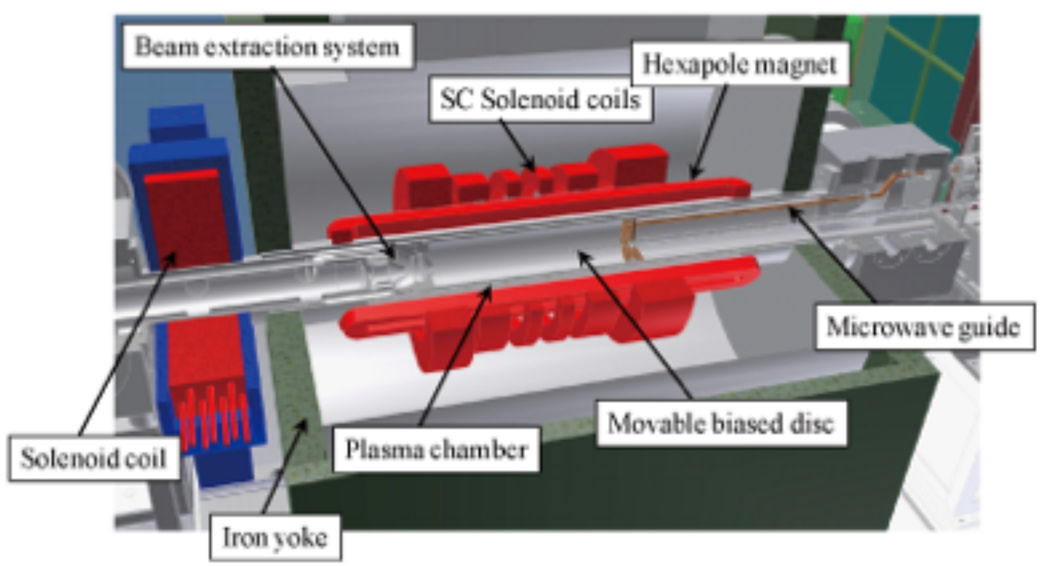
  Large plasma volume 1100 cm^3

  Flexibility of various magnetic field distribution on axis

  from classical B_{min} to so-called "flat B_{min}" *

*G. D. Alton and D. N. Smithe, Rev. Sci. Instrum. 65 (1994) 775

Schematic drawing of SC-ECRIS



Main parameters of Ion source

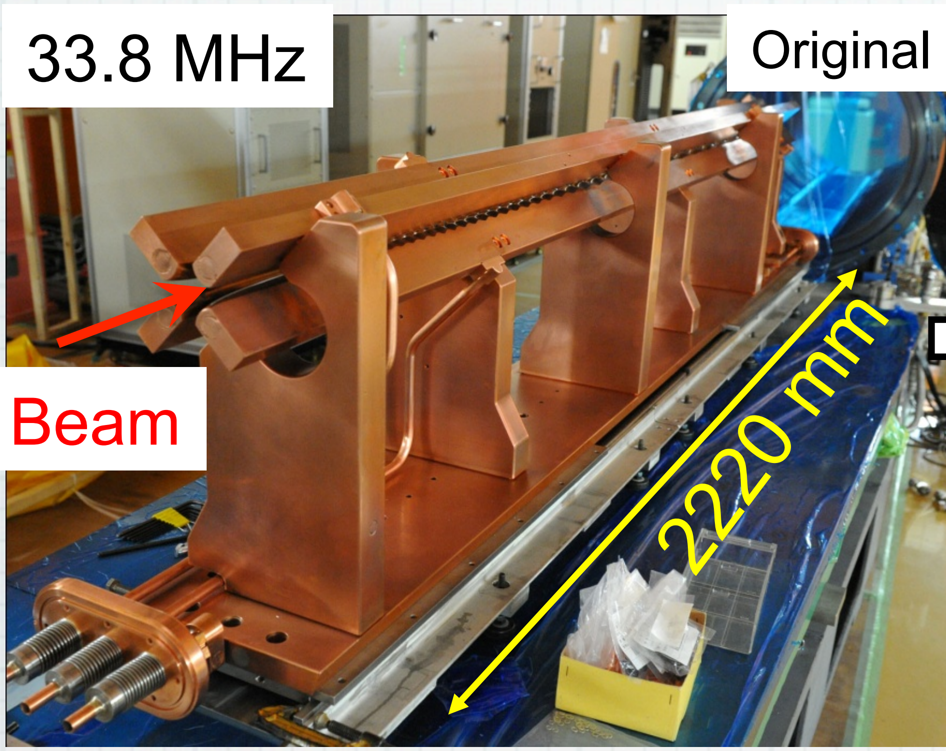
Maximum B_{inj}		3.8T
B_{min}		<1.0T
B_r		2.2T
B_{ext}		2.3T
RF frequency		28GHz
max. power		10kW
Plasma chamber	diameter	15cm
	length	52cm
Typical base vacuum		$1x10^{-5}$Pa
extraction voltage		22kV

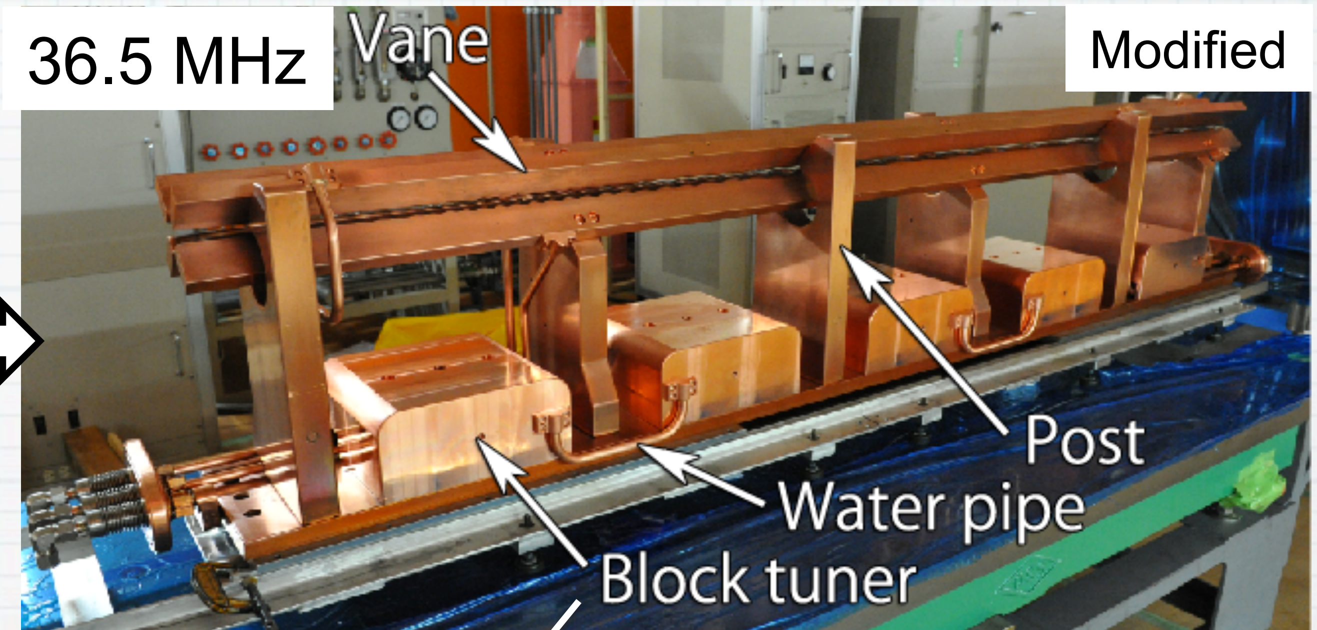
$^{238}U^{35+}$ ~60 eμA, $^{124}Xe^{25+}$ ~250 eμA (July 2012)

RFQ

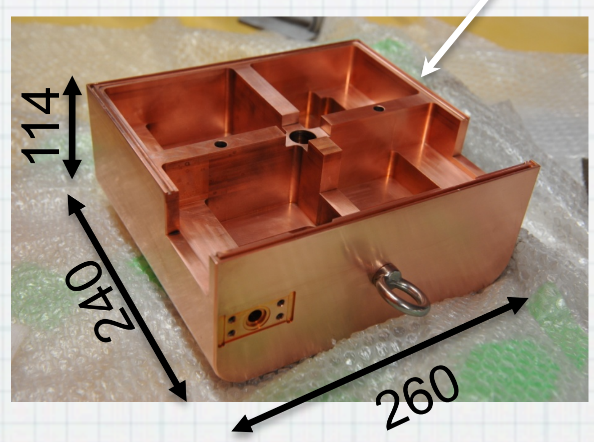
K. Yamada et al., LINAC10

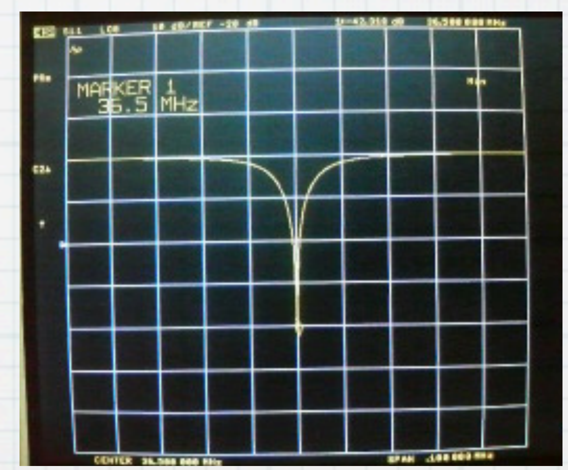
Recycled a 4-rod RFQ linac kindly provided by Kyoto University.





Frequency	36.5 MHz
Duty	100 %
m/*q* ratio	7
Input energy	3.28 keV/u
Output energy	100.3 keV/u
Input emittance	200π mm·mrad
Vane length	225.6 cm
Intervane voltage	42.0 kV
Mean aperture (r_0)	8.0 mm
Max. modulation (m)	2.35
Focusing strength (B)	6.785
Final synchronous phase	-29.6°
Unloaded Q	5000
Shunt impedance	~50 kΩ
Required rf power	~18 kW

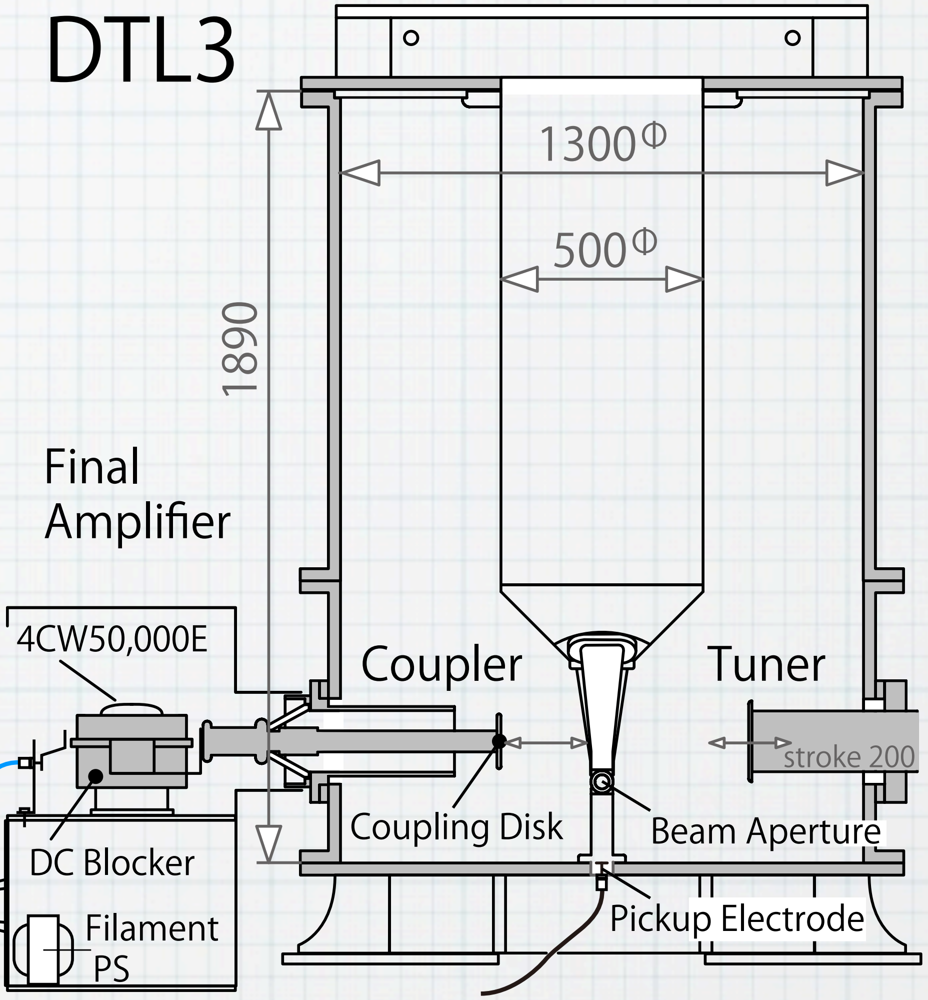


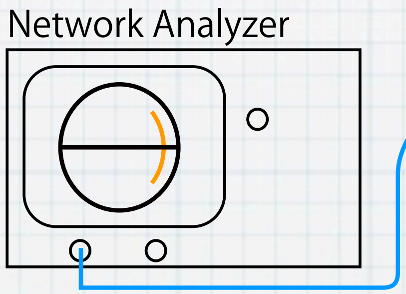


Resonant frequency f_0 : 33.8 MHz → 36.5 MHz
m/q ≈ 7 ions accelerated to 100 keV/u without changing vane electrodes.
Unloaded Q : 5400 → 5000 (measured)

DTL

- 36.5 MHz (CW)
  - QWR
  - Low- β : 0.015-0.038
  - Capacitive Coupler, directly coupled with the amplifier
- Low-power tests
  - Q: 78 % of ideal
  - Resonant Frequency was 0.2 % higher than MWS
  - K. Suda et al., TUPB095
- Amplifier:
  - based on Tetrode (EIMAC 4CW50,000E)
  - load resistance of the tube →700 Ω





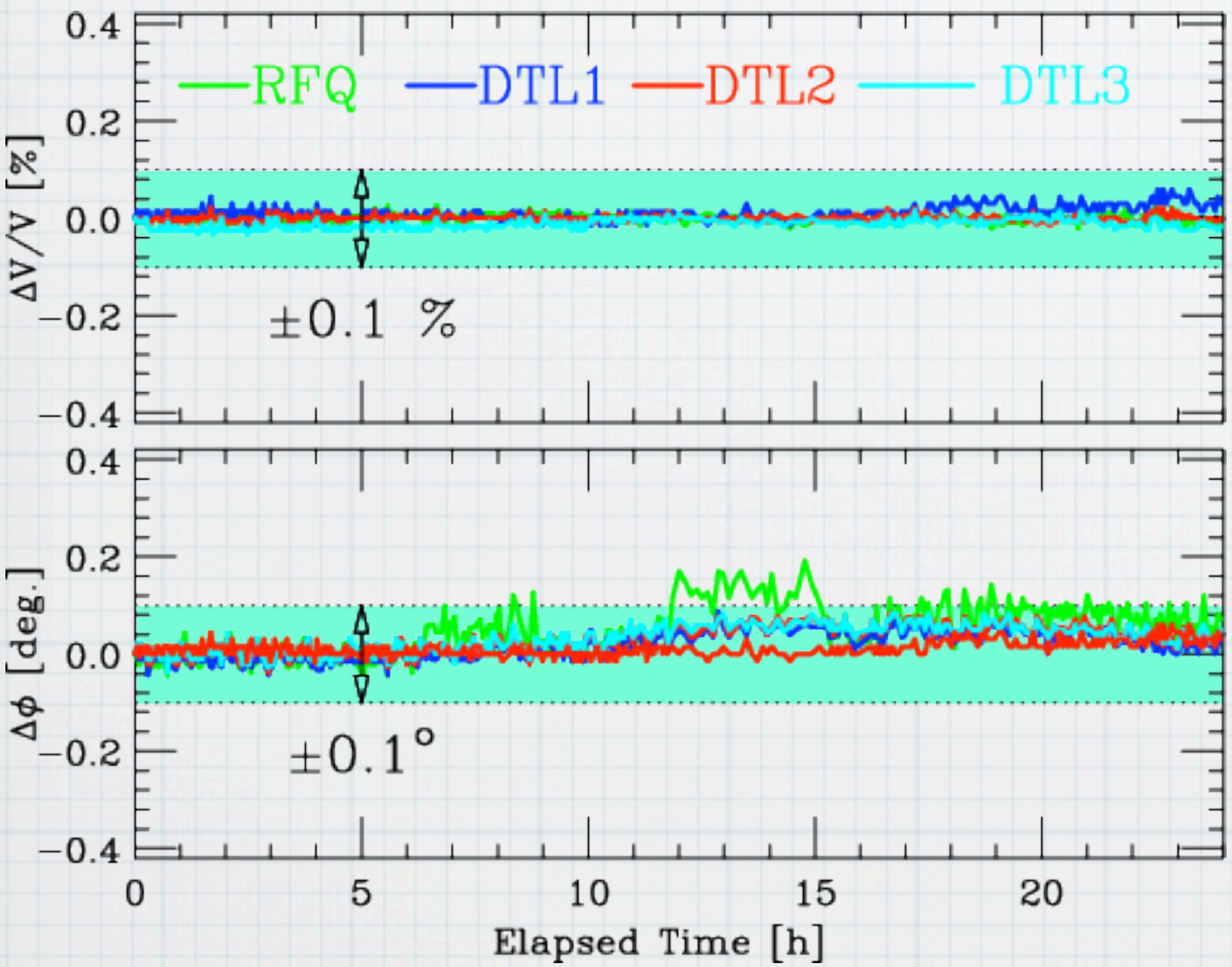
DTL1 Cavity

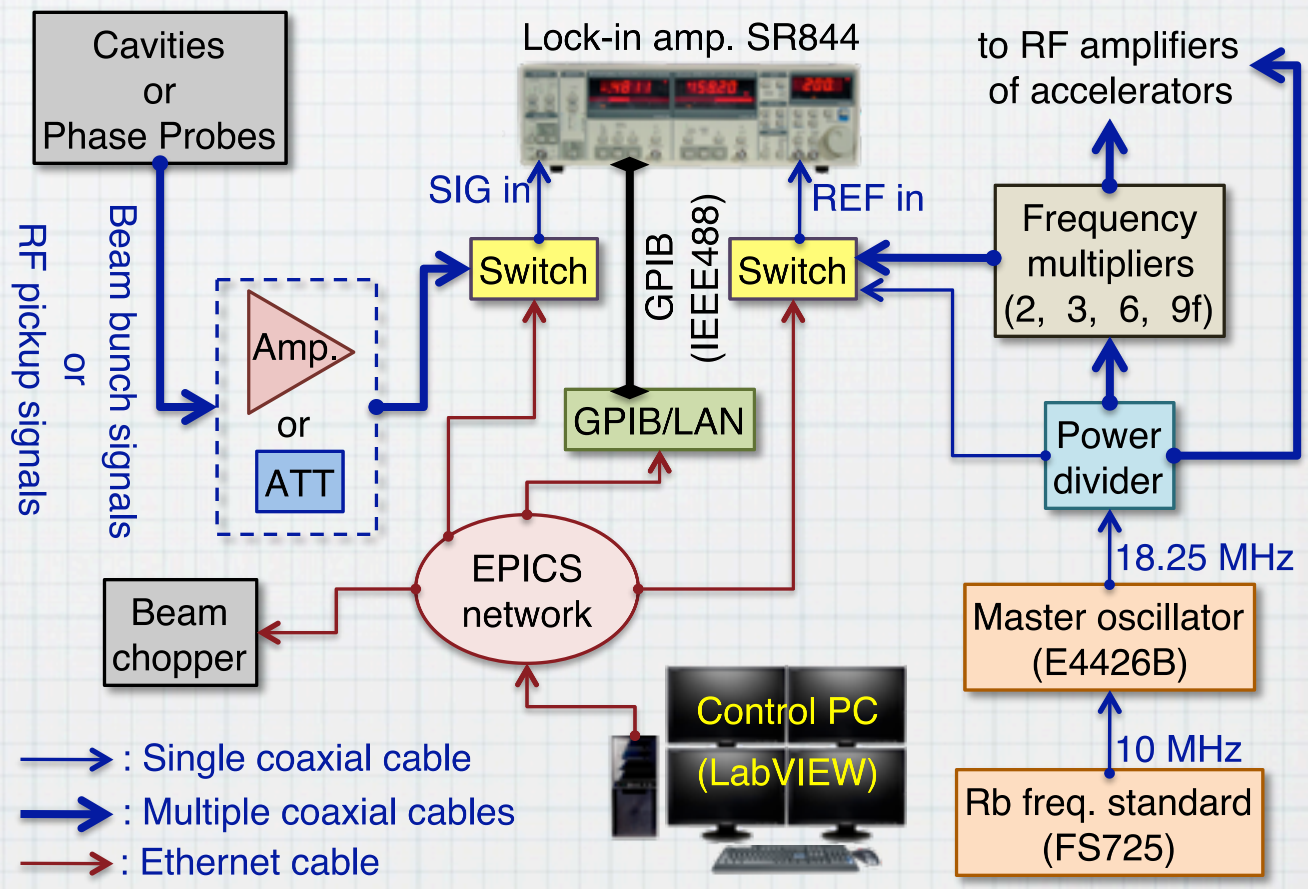
RF errors

- Long-term operation test
- RF errors

  |Δ V/V| < 0.1 %, |Δ Φ|<0.1°, stable operation with high reliability
- Analogue feedback:

  Auto Gain Control, Auto Phase Lock, Auto Frequency Tuning
- Monitoring system based on the RF Lock-in amp, SR844





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- [x] Introductionof RIBF accelerators
- [x] New Injector RILAC2
- [ ] **Beam Commissioning**
- [ ] Summary and Plans

Repair to Main Coil of RRC Sector Magnet

Beam Commissioning

- Acceleration test (RILAC2 stand alone)

  First Beam:

  2010/12/21 ^{124}Xe

  Beam Energy and Transmission Efficiency

  Beam Stability

- Commissioning to RIBF (injection to RRC)

  Beam Service:

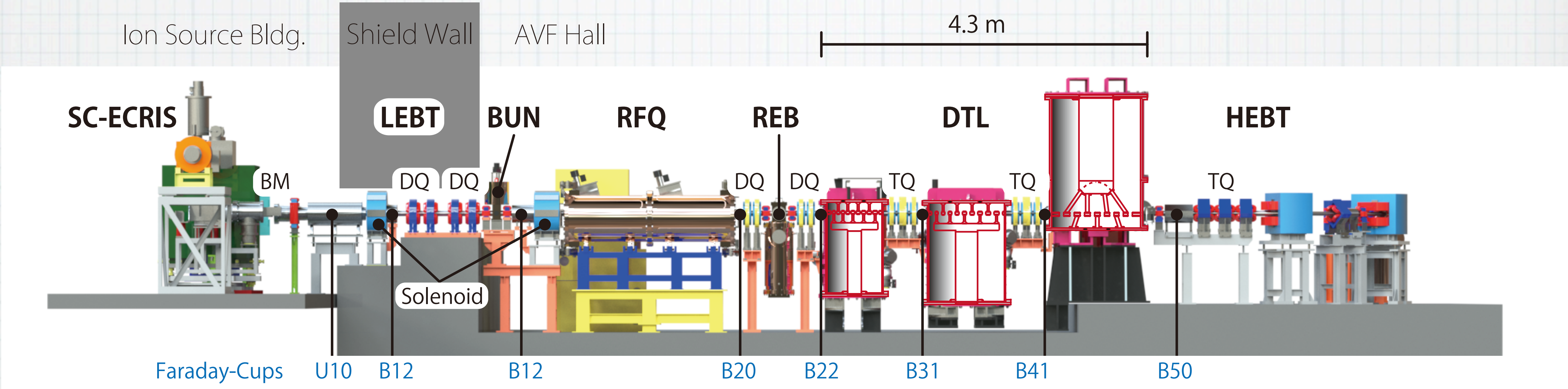
  2011/12, 2012/6 ^{124}Xe,

  2012/12 ^{238}U

  Acceleration Efficiency of RRC

  Short life time of charge stripper

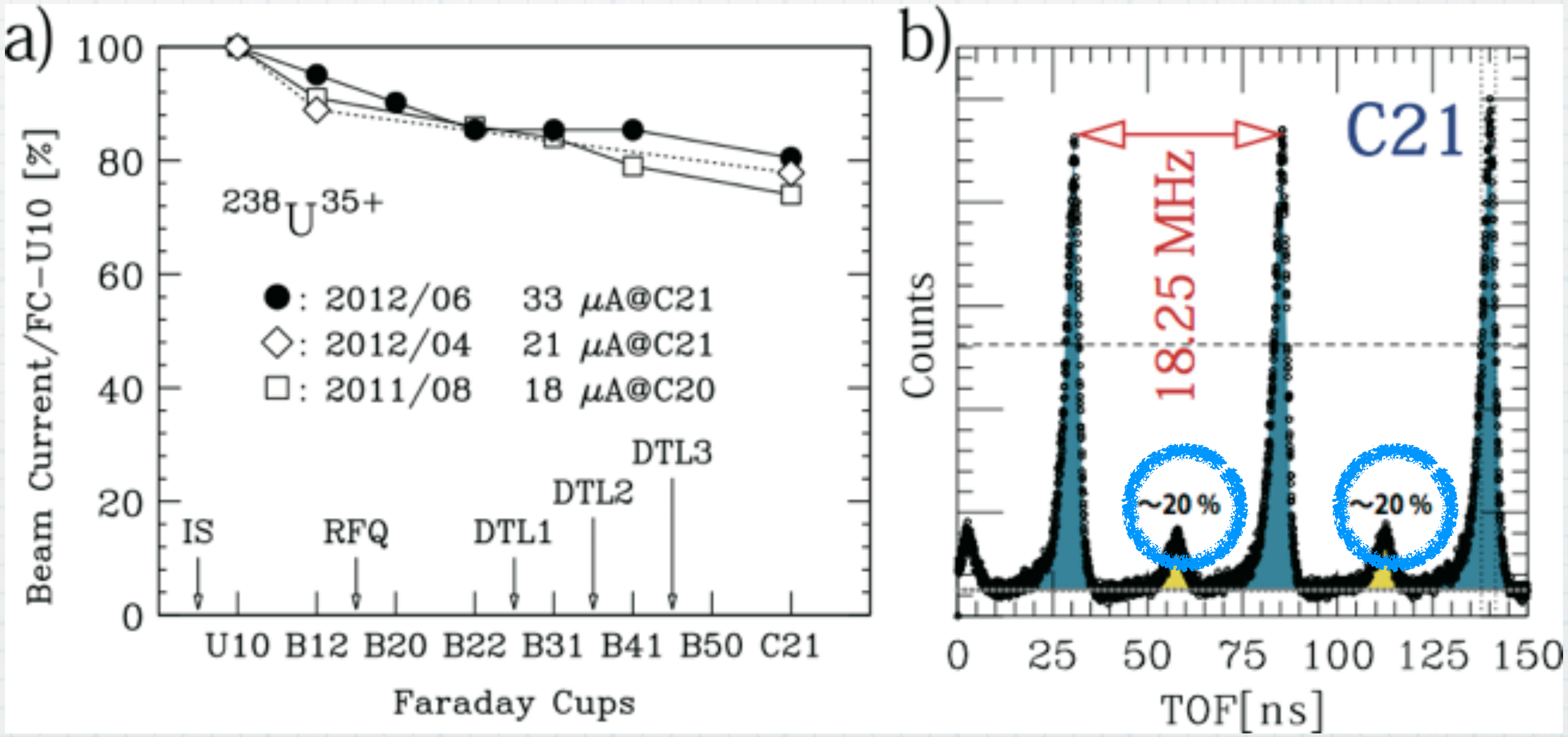
Acceleration Test (Energy and Transmission Efficiency)



Transmission: ~75 %

TOF: 0.67 MeV/u

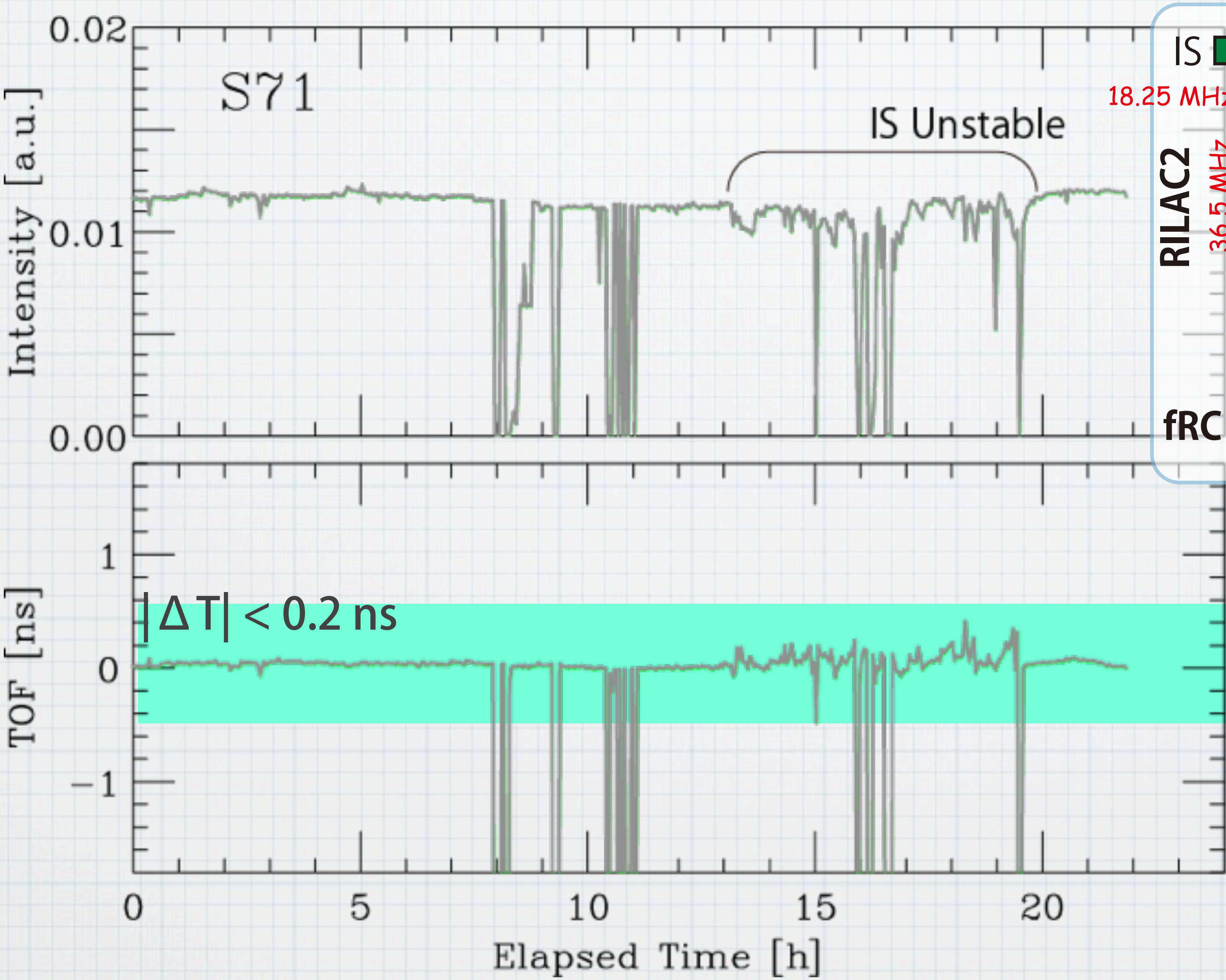
Bunching Efficiency: 80 %

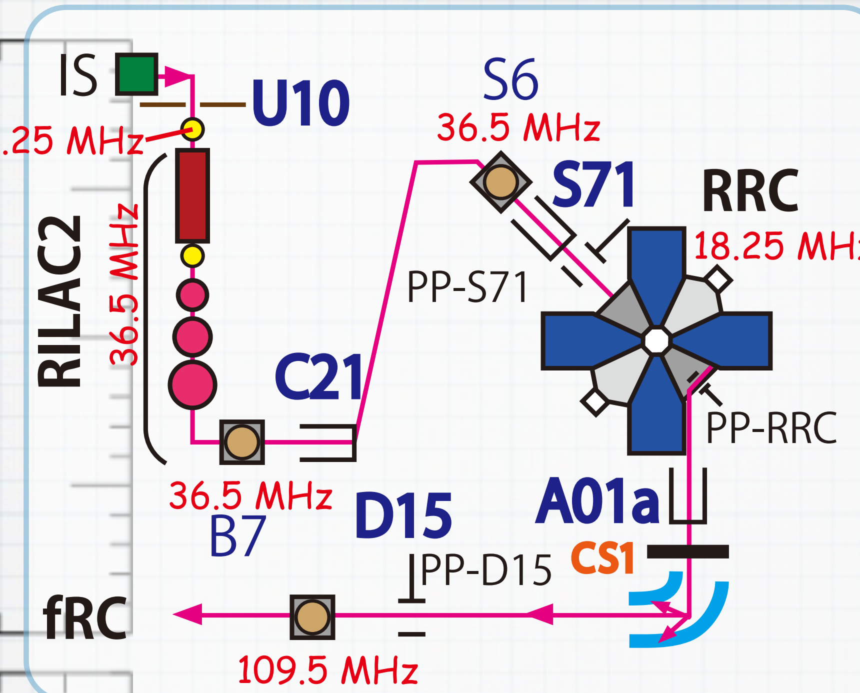


Acceleration Test (Stability)

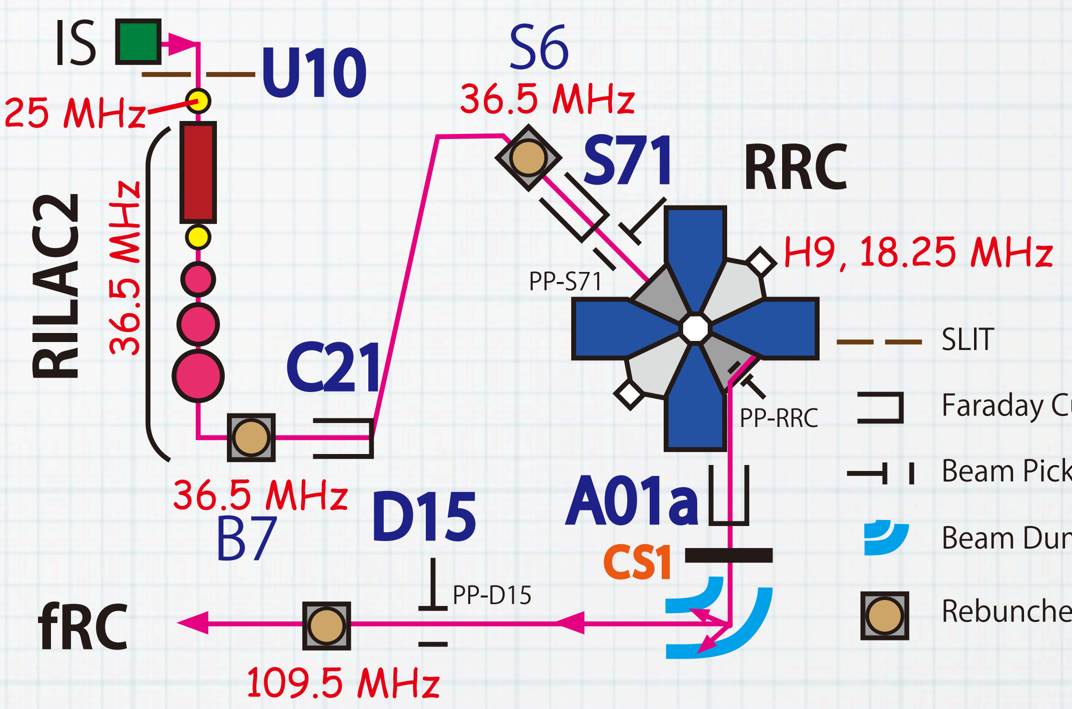
Beam intensity and Injection timing of the beam accelerated by RILAC2

RF Stability, Double-Rebuncher → Stable enough for injection to the RRC





Injection to RRC (Acceleration Efficiency)



Acceleration Efficiency = 50 ～ 60 %

Why?

1. Bunching efficiency ～ 80 %
2. Poor Turn separation

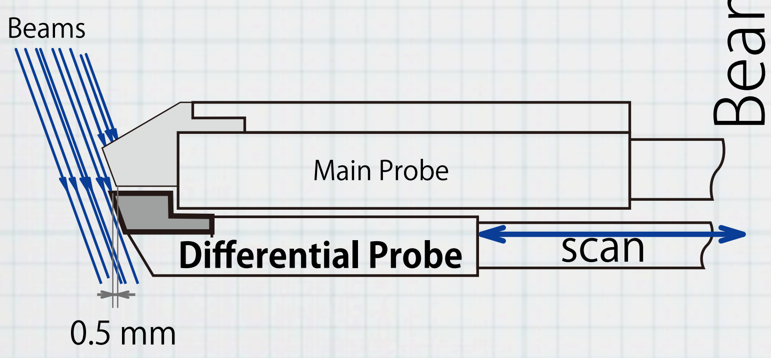
→Low Acc. Voltage

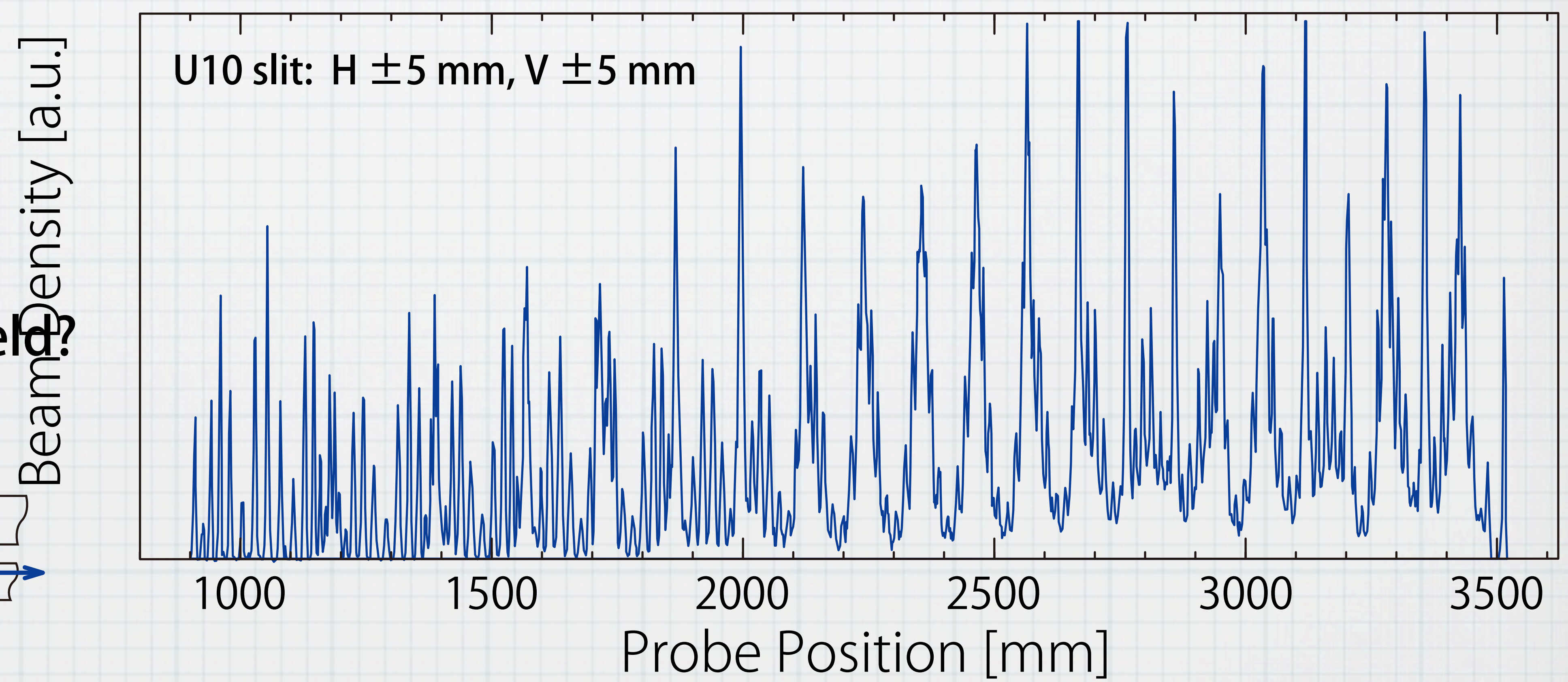
→Emittance mismatch?

Transverse?

Longitudinal?

→Imperfect Magnetic field?





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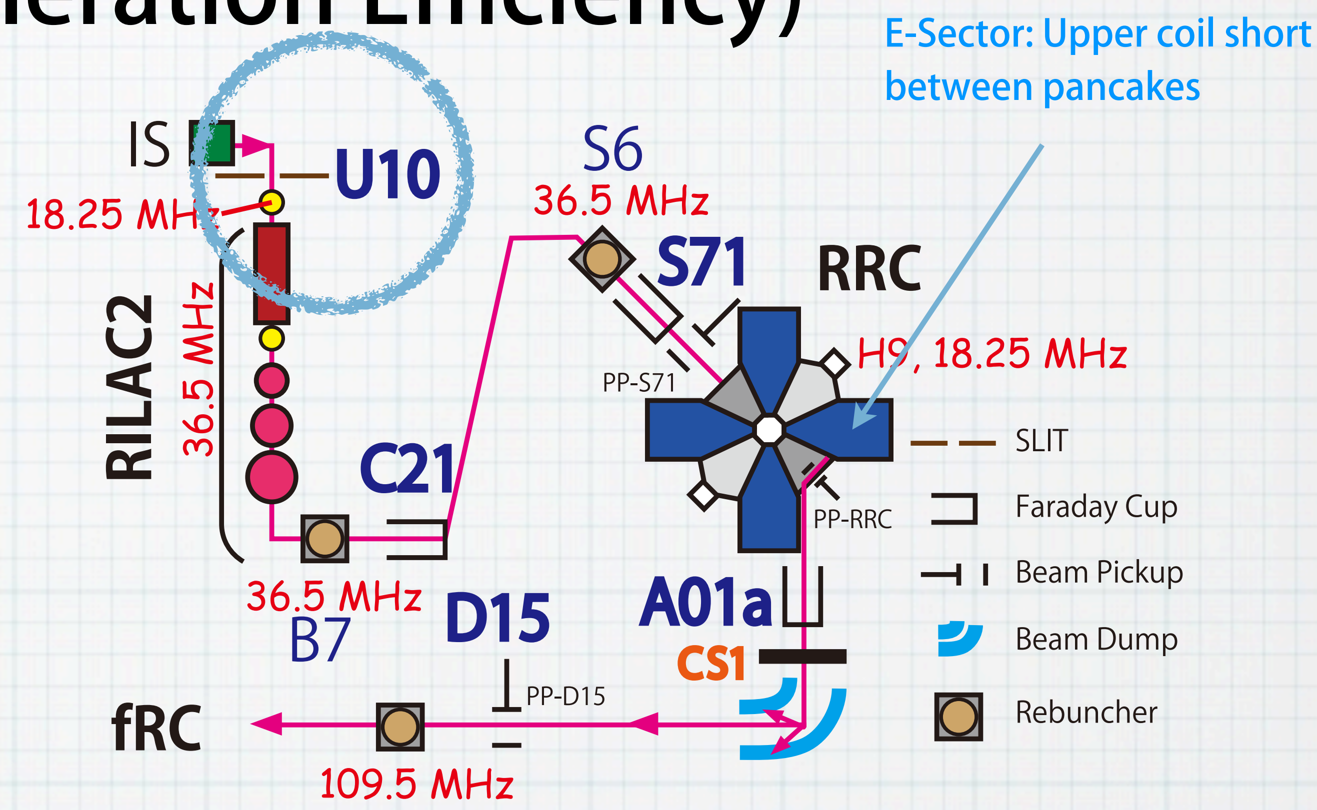

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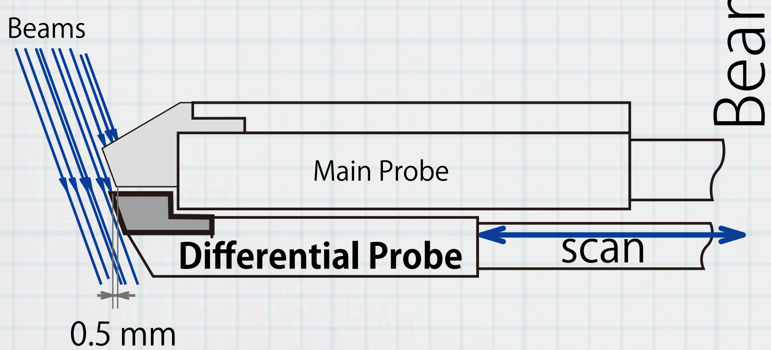
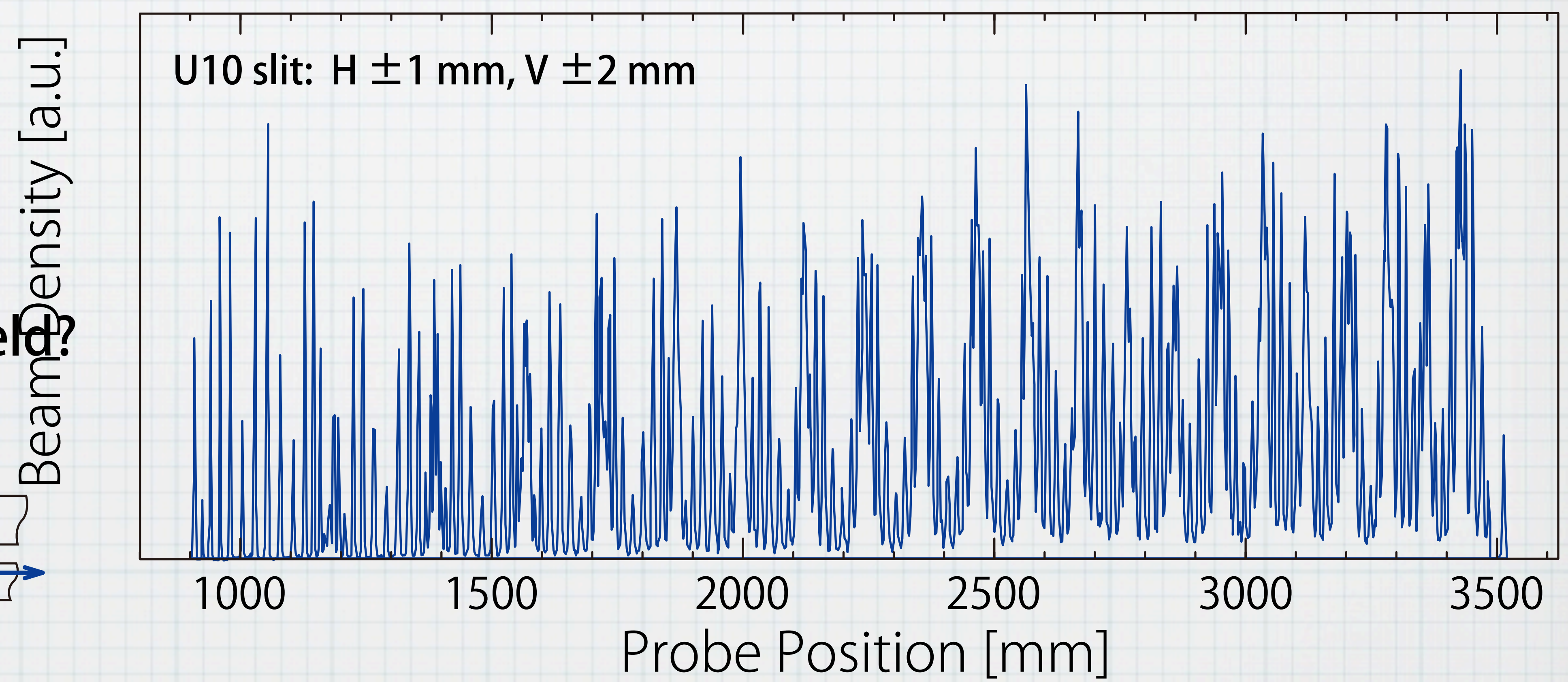


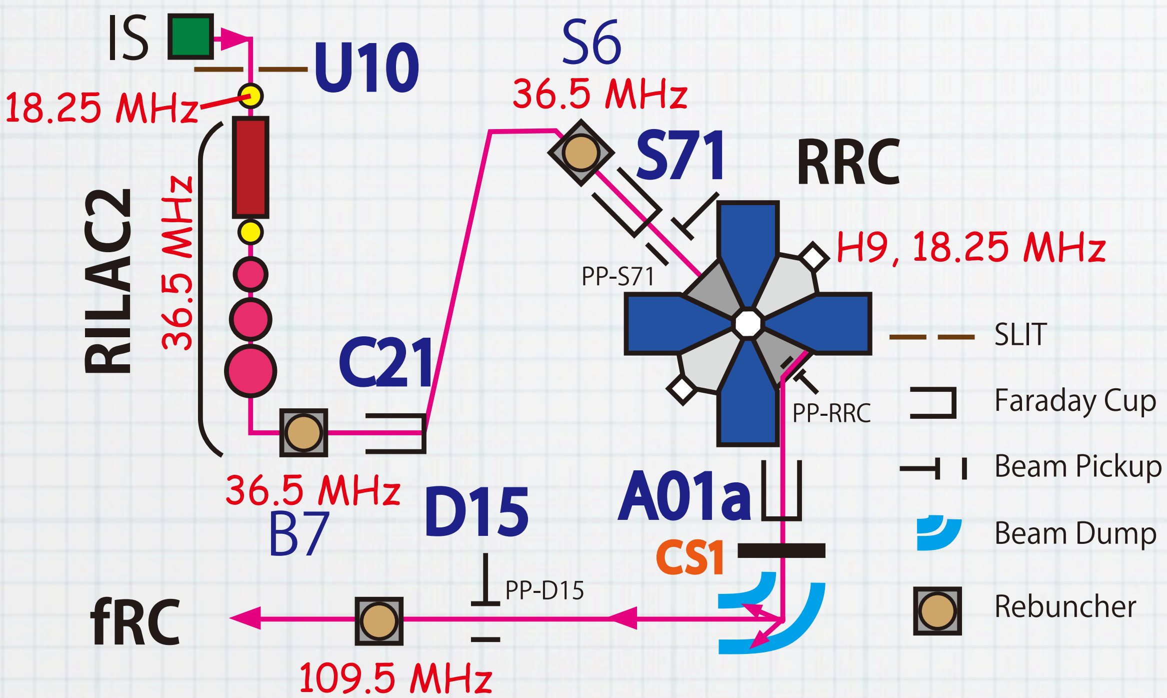


Lifetime of the stripper foil

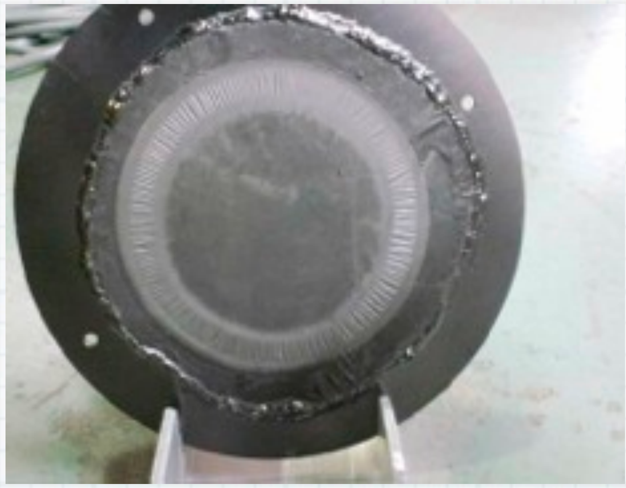
U **DEC2011**

～10 eμA@FCA0a1

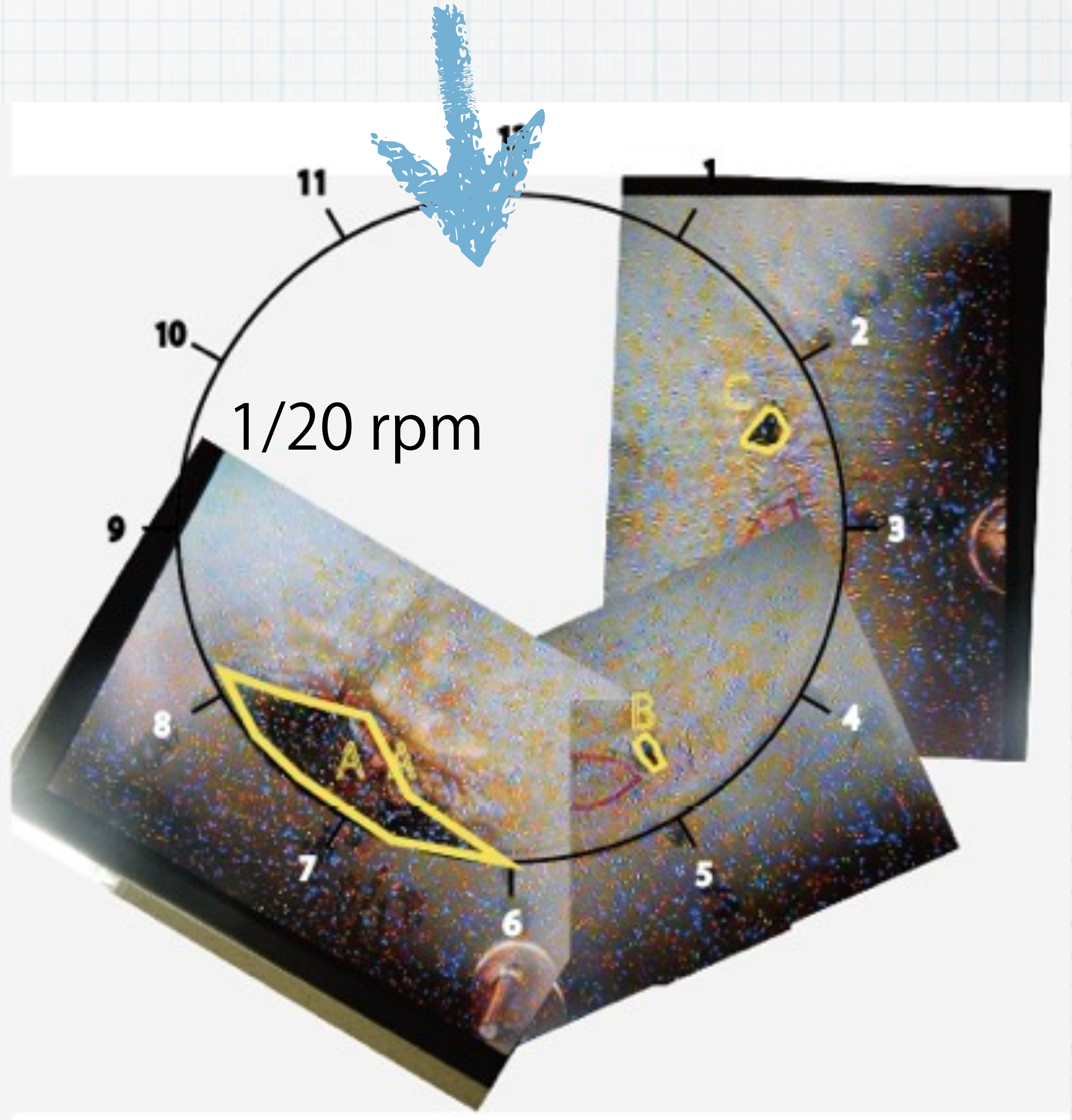
- Lifetime in MT(Nov, 2009) 12hrs@1pnA



CS1



0.35 mg/cm²



- Rotating Stripper

H. Ryuto, et al., Nucl. Instru. Meth. A569(2006)697.

- CNT-SDC

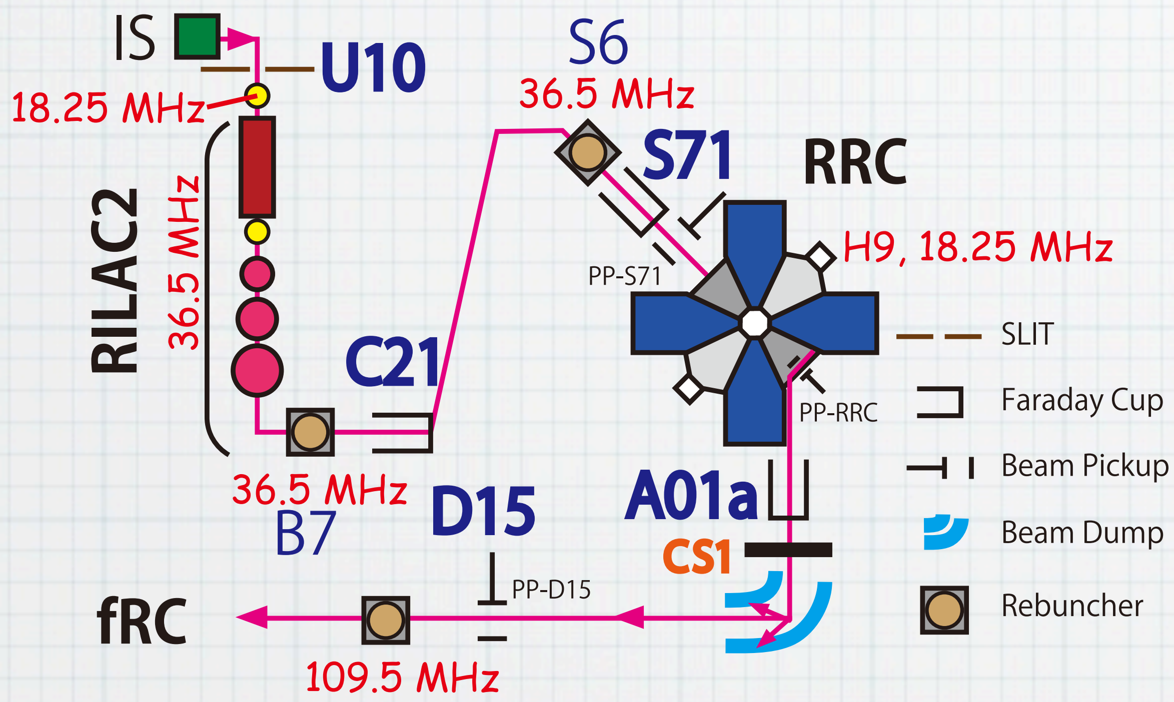
Carbon nanotube/sputter deposited carbon

Frequency of exchange : 1 time/4-5days providing ～3.5 pnA

Lifetime of the stripper foil

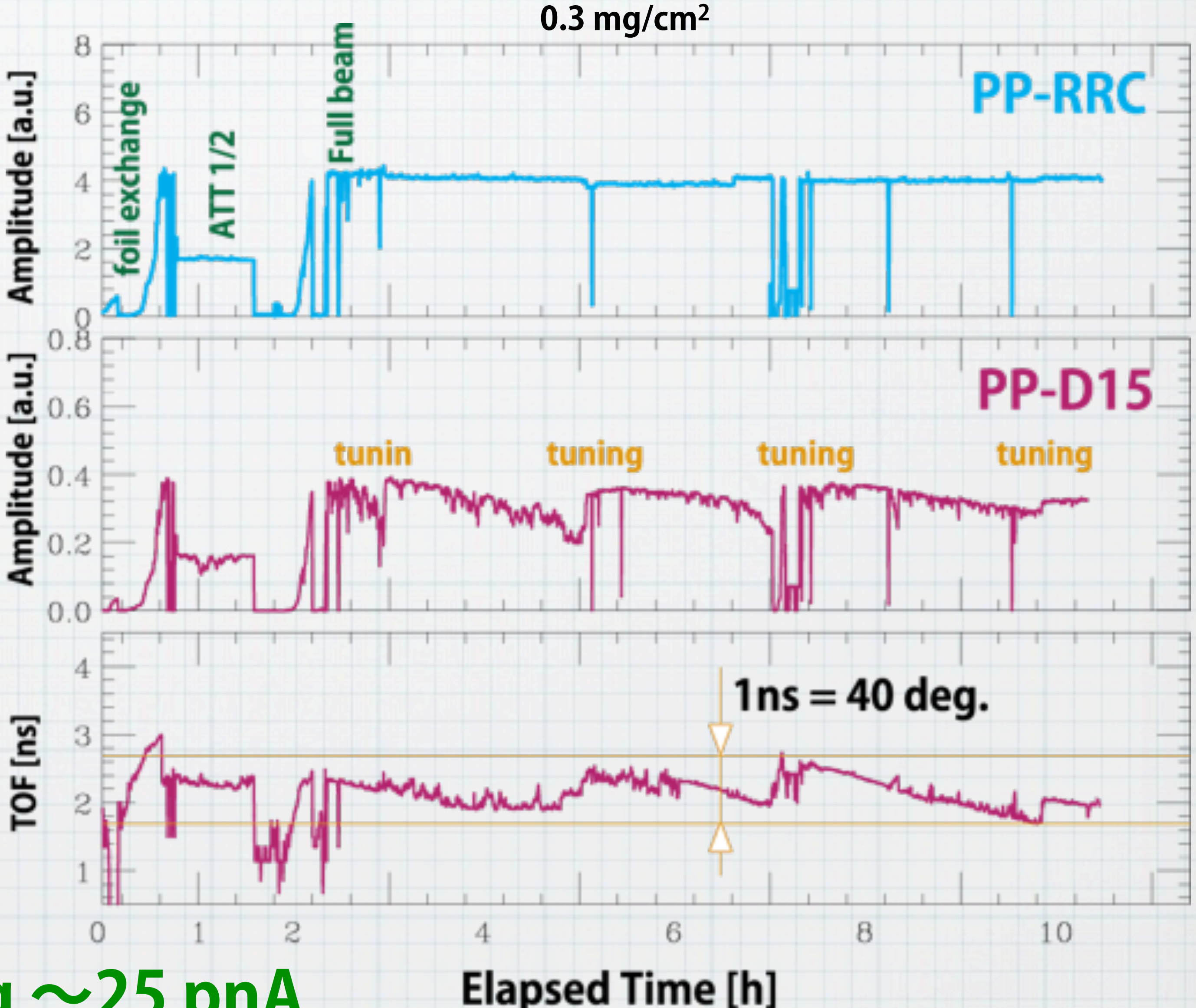
Xe ~33 eμA@FCA0a1

JUNE2012



CS1

0.3 mg/cm²



- Carbon foil became significantly thinner due to the heat load.

Exchange : 2-3 times/day providing ~25 pnA

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Summary

- RILAC2 was successfully commissioned

RF errors , $|\Delta V/V| < 0.1$ %, $|\Delta \Phi| < 0.1^{o}$

High Reliability, down time due to the RILAC2 RF was < 0.3 %

- Acceleration test

Transmission efficiency (RILAC2) ～75 %

Stable beams were provided as an injector to cyclotron ($|\Delta T| < 0.2$ ns)

- Beam commissioning to RRC

Acceleration efficiency of RRC is 50-60 %

- Beam Intensity at SRC (345 MeV/u) was greatly increased as:

^{238}U : 3.5 pnA, ^{124}Xe : 24 pnA

- Synthesis of SHE and RIBF experiments were performed simultaneously.

Plans

U and Xe Beam Service scheduled (Oct-Dec, 2012)

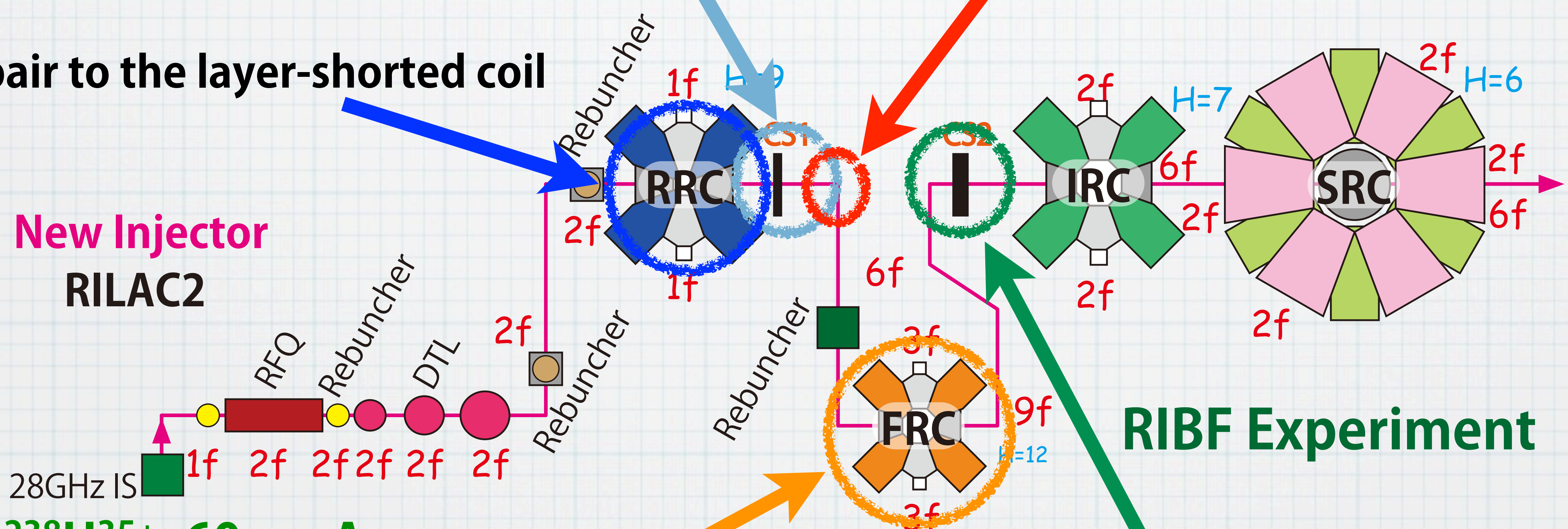
CS1: He Gas Stripper (<0.7 mg/cm²)

$^{238}U^{35+} \rightarrow {}^{238}U^{65+}$

10 kW Beam Dump inside the analyzer magnet

Repair to the layer-shorted coil

New Injector
RILAC2



IS: $^{238}U^{35+}$, 60 eμA

RIBF Experiment

K upgrade of fRC

CS2: Rotation foil for U
N_2 gas for Xe

Beam current(Oct- , 2012): ^{238}U > 5 pnA, ^{124}Xe > 30 pnA

Plans

CS

Repair to th

New Inj

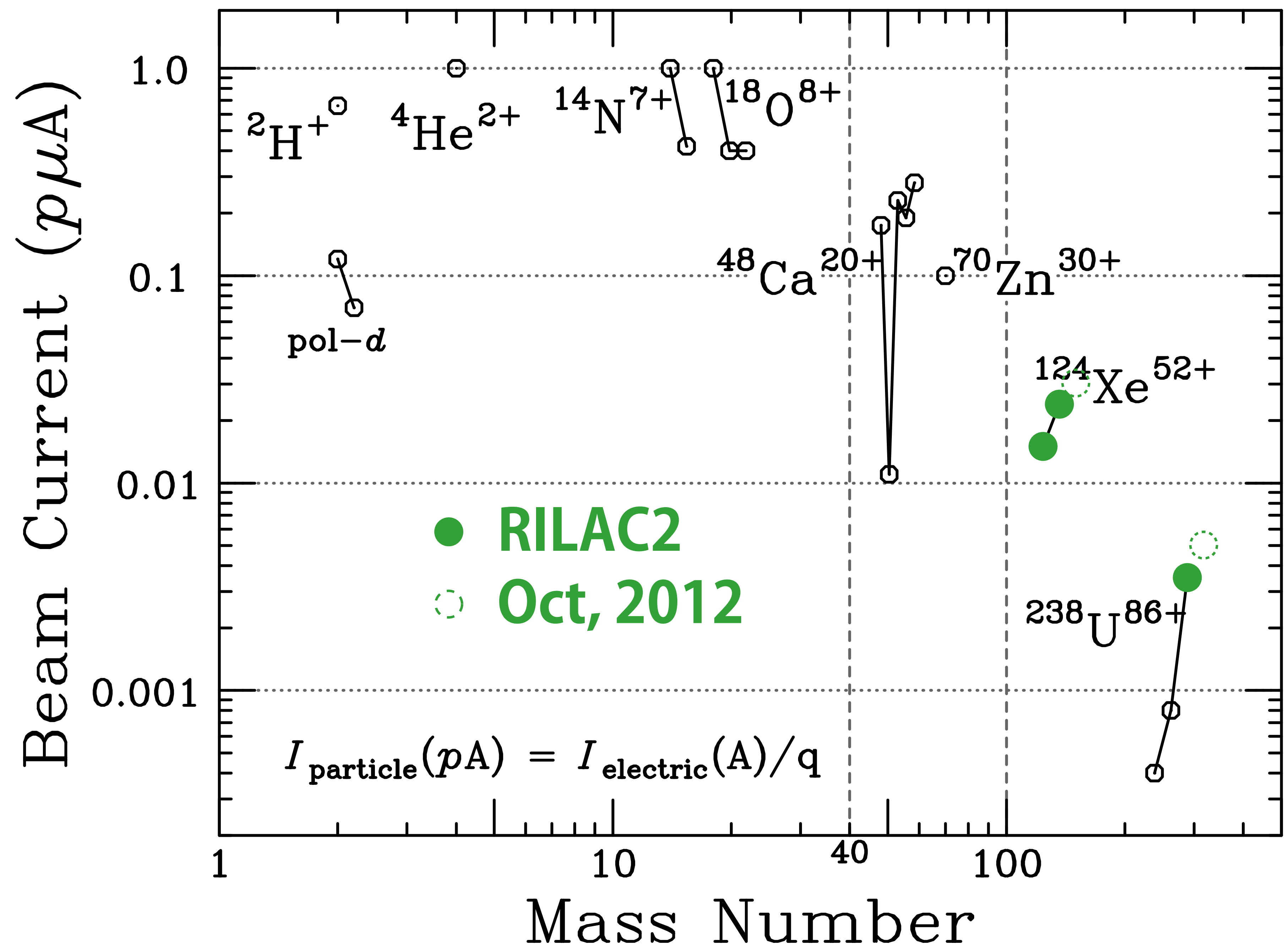
RILAC

28GHz IS

IS: $^{238}U^{35+}$,

net

or U



Beam current(Oct- , 2012): ^{238}U > 5 pnA, ^{124}Xe > 30 pnA


HIAT2015
(The 13th Heavy Ion Accelerator Technology Conference)
September 6 -11, 2015
YOKOHAMA, JAPAN
RIKEN Nishina Center
RIKEN NiSHiNA CENTER

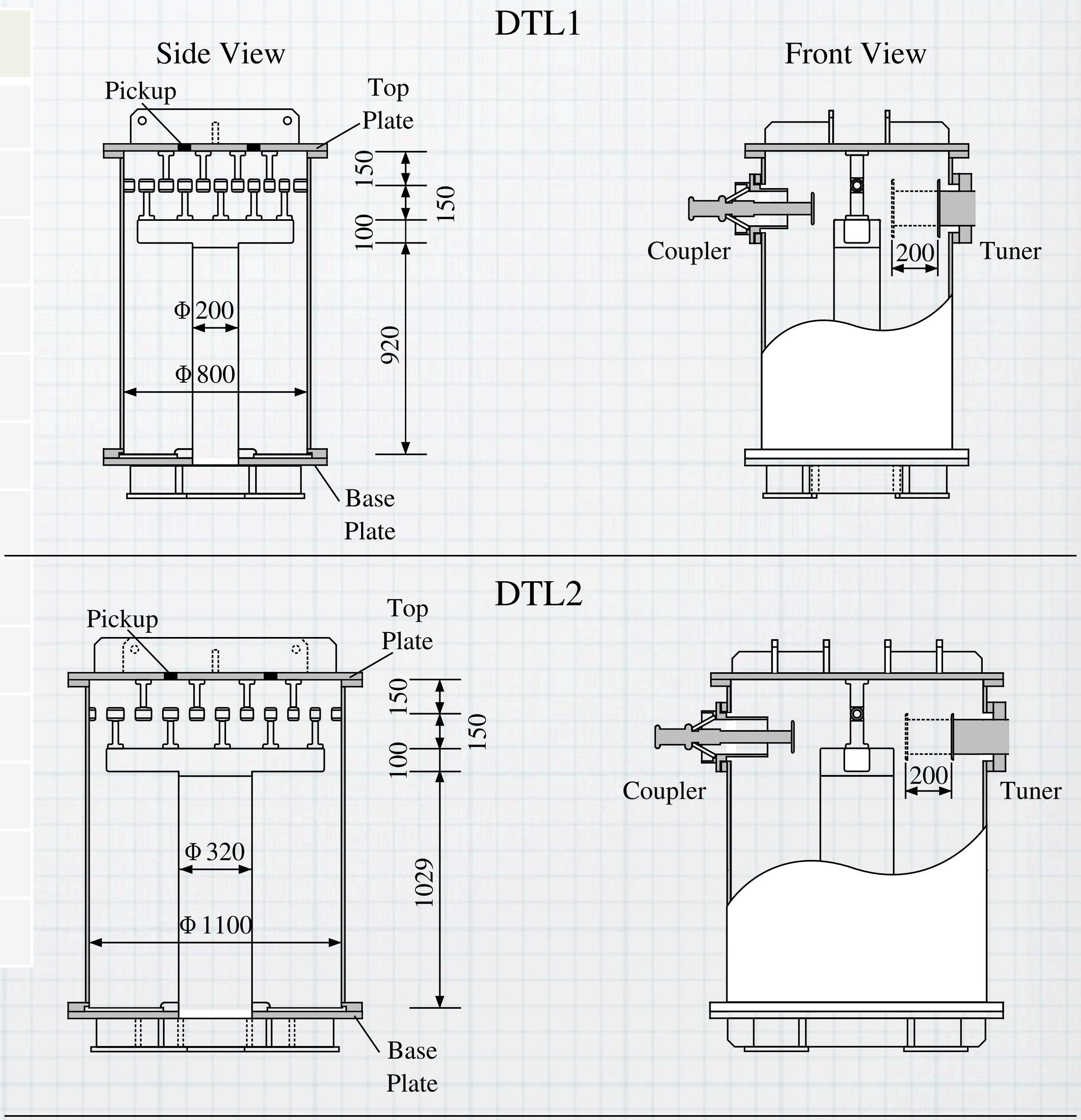
Thank you.

DTL

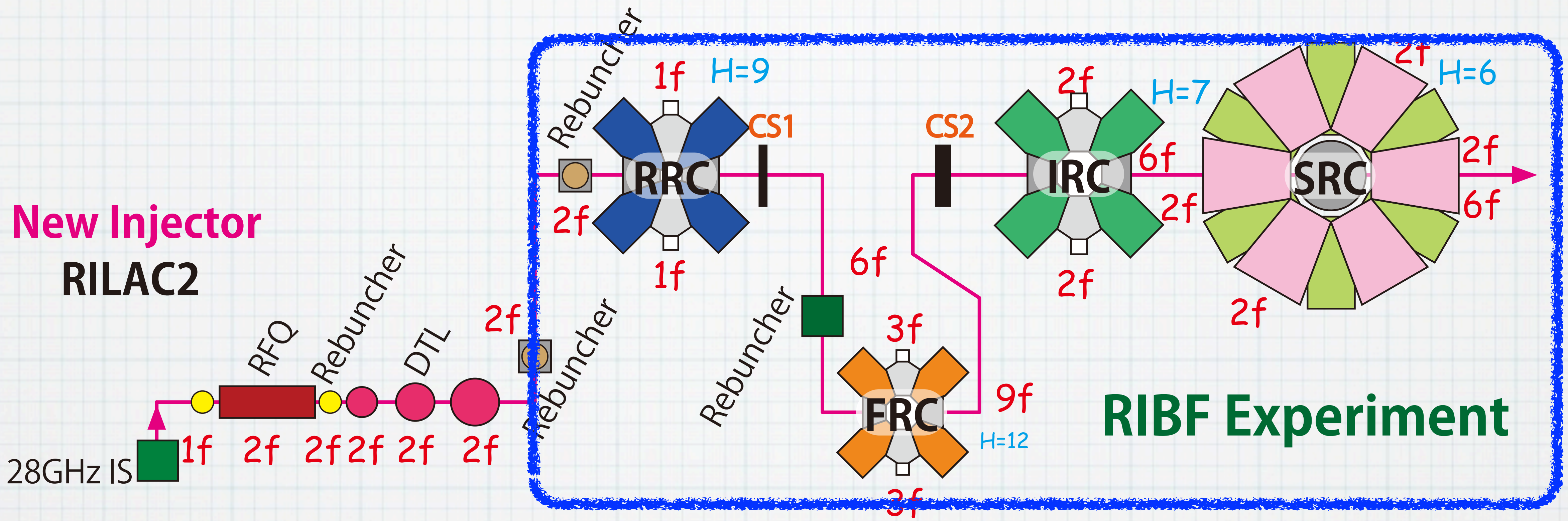
Design Parameters of DTL

	DTL1	DTL2	DLT3
Frequency (MHz)	36.5	36.5	36.5
Duty (%)	100	100	100
m/q ratio	7	7	7
Input energy (keV/u)	100	220	450
Output energy (keV/u)	220	450	680
Length (cm)	80	110	130
Height (mm)	1320	1429	1890
Gap number	10	10	8
Gap length (mm)	20	50	65
Gap voltage (kV)	110	210	260
Drift tube aperture (mm)	17.5	17.5	17.5
Peak surface field (MV/m)	8.9	9.4	9.7
Synchronous phase (deg.)	-25	-25	-25

Schematic of DTL1 and DTL2 cavities.



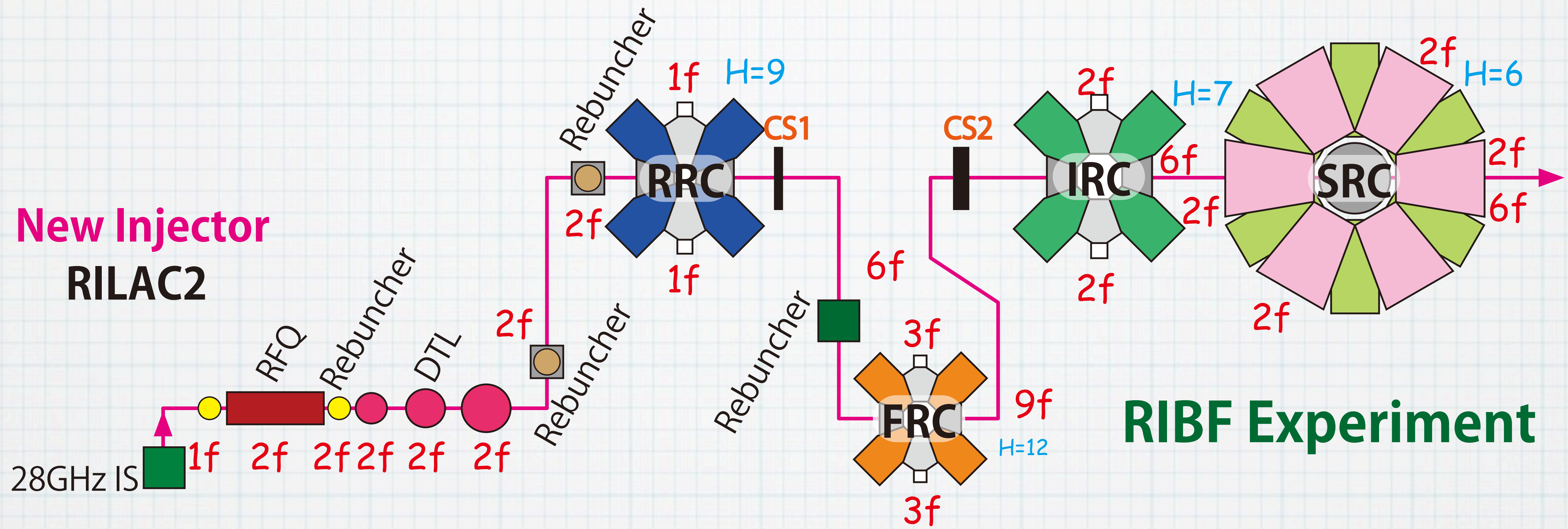
Xe and U acceleration



1. Cyclotron cascades consist of RRC, and new booster cyclotrons with an injector linac.

	RRC	fRC	IRC	SRC
K (MeV)	540	570	980	2600
Number of Sectors	4	4	4	6
Velocity Gain	4	2.1	1.5	1.5

Xe and U acceleration

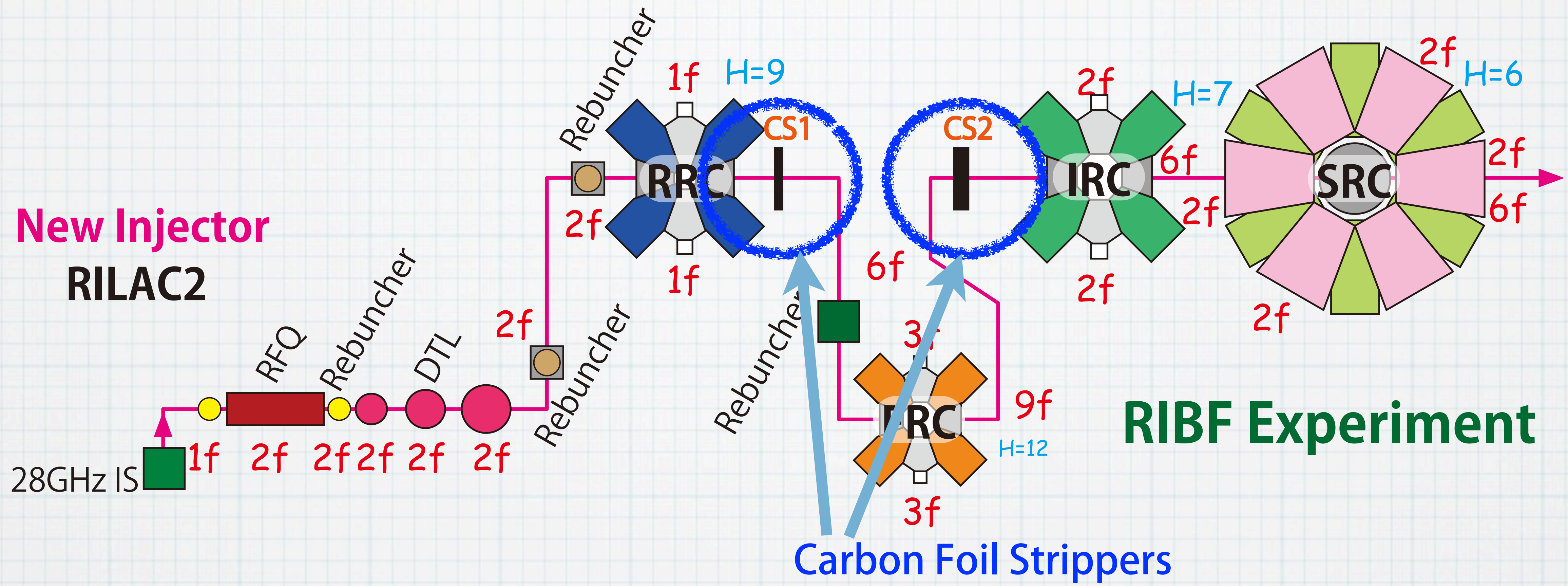


1. Cyclotron cascades consist of RRC, and new booster cyclotrons with an injector linac.

2. Fixed energy mode dedicated for the acceleration of U and Xe to 345 MeV/u.

	RILAC2	RRC	fRC	IRC	SRC
Energy (MeV/u)	0.67	10.75	51	114	345

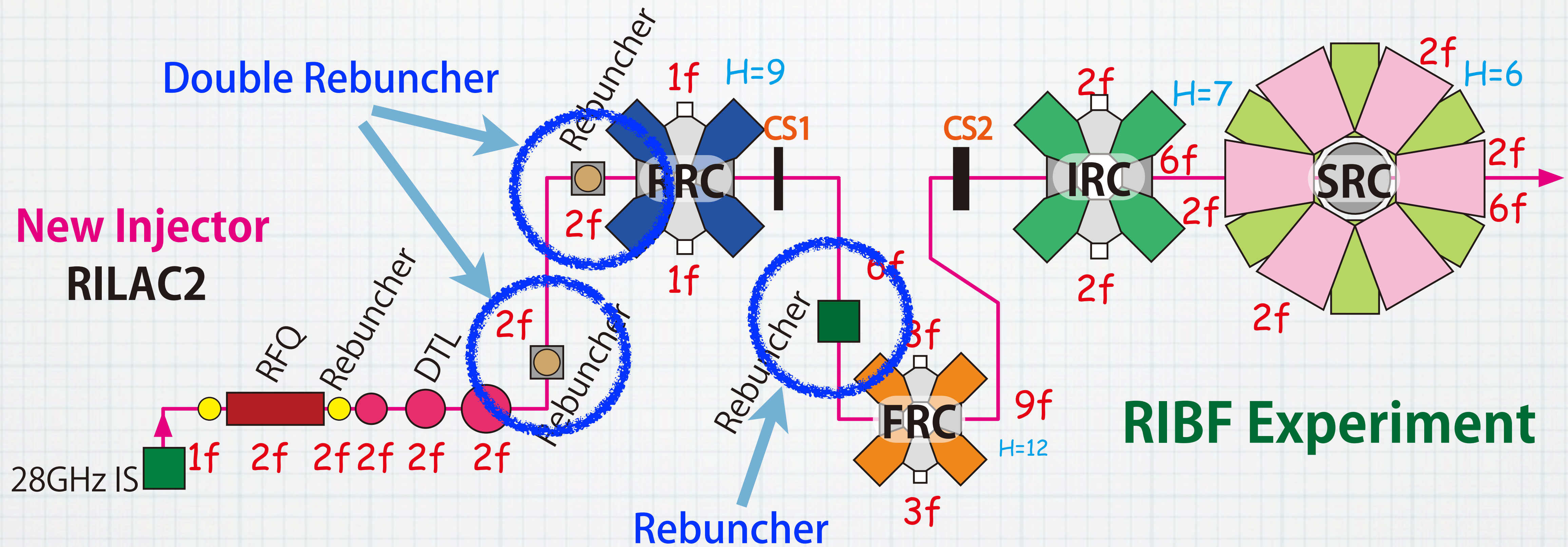
Xe and U acceleration



1. Cyclotron Cascades consist of RRC, and new booster cyclotrons with an injector linac.
2. Fixed energy mode dedicated for the acceleration of U and Xe to 345 MeV/u.
3. Charge Stripping is made twice at the injection to FRC and the injection to SRC.

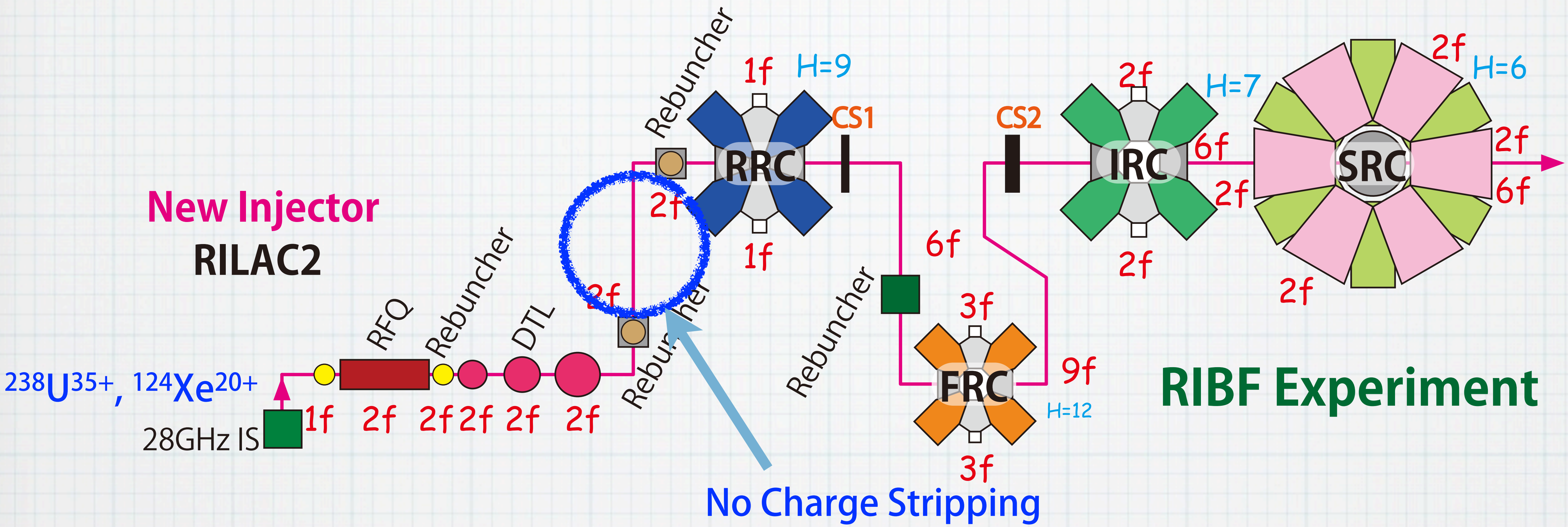
	IS	RILAC2	RRC	fRC	IRC	SRC
U	35	←	←	71	86	←
Xe	20	←	←	46	52	←

Xe and U acceleration



1. Cyclotron cascades consist of RRC, and new booster cyclotrons with an injector linac.
2. Fixed energy mode dedicated for the acceleration of U and Xe to 345 MeV/u.
3. Charge Stripping is made twice at the injection to FRC and the injection to SRC
4. Rebunchers compensate the beam energy error keeping the injection timing constant.

Xe and U acceleration



1. Cyclotron cascades consist of RRC, and new booster cyclotrons with an injector linac.
2. Fixed energy mode dedicated for the acceleration of U and Xe to 345 MeV/u.
3. Charge Stripping is made twice at the injection to FRC and the injection to SRC
4. Rebunchers compensate the beam energy error keeping the injection timing constant.
5. Intense uranium and Xe beams from IS are accelerated by RRC without charge stripping before injection.