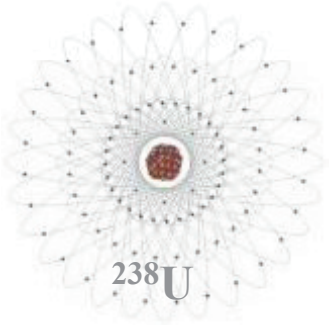
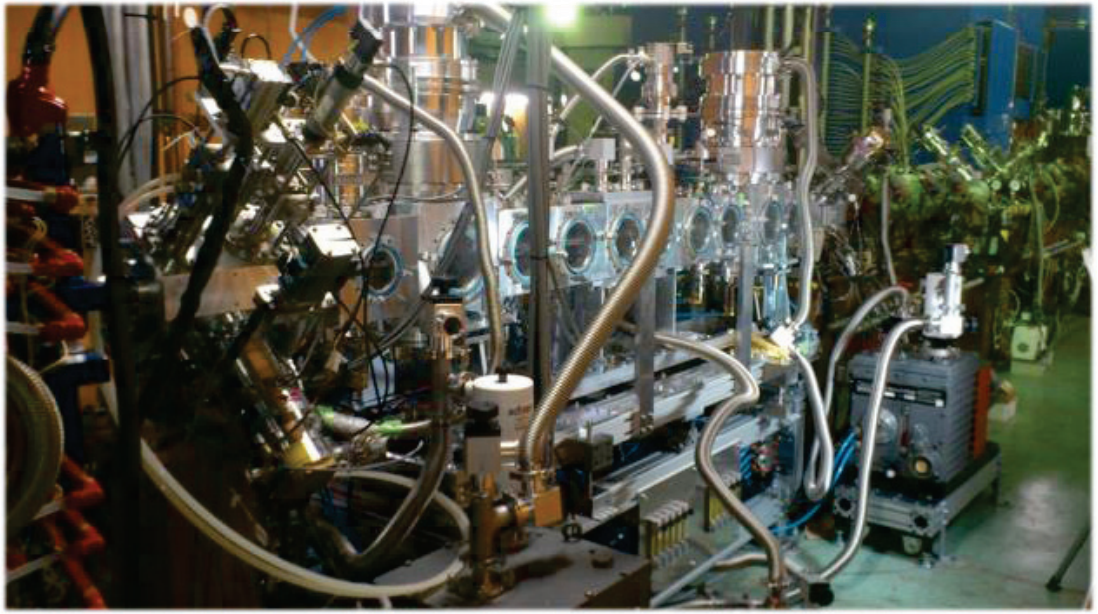


R&D of helium gas stripper for intense uranium beams



H. Imao, H. Okuno, H. Kuboki, O. Kamigaito,
H. Hasebe, N. Fukunishi, Y. Watanabe, M. Fujimaki,
T. Maie, T. Dantsuka, K. Kumagai, K. Yamada,
T. Watanabe, M. Kase, Y. Yano

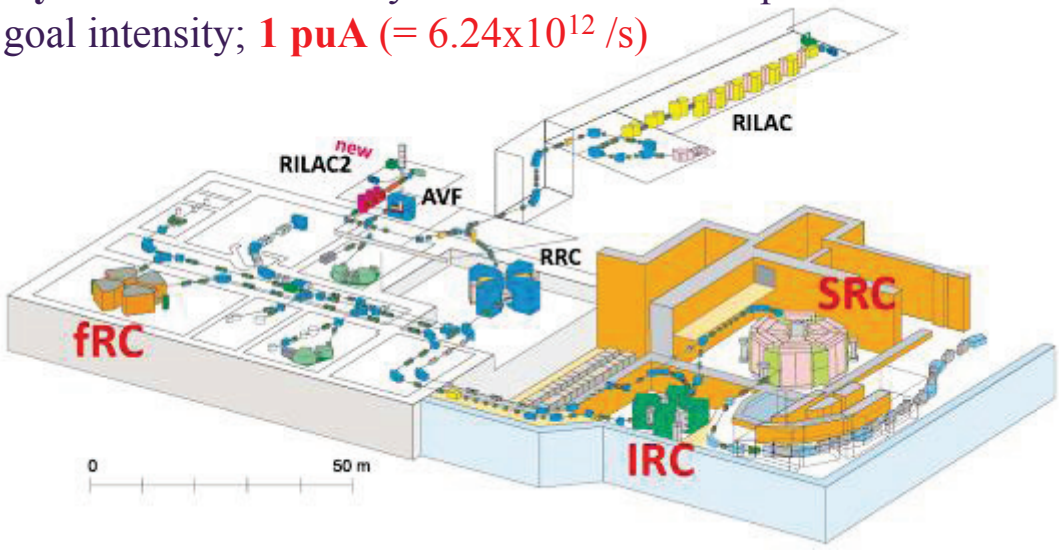
Outline

1. Uranium acceleration
   - Problem in charge stripper
2. He stripper development
   - Technical issues & prototype tests
   - Practical system development
3. Highlight data
   - Performance and highlight data
4. Summary and future prospects

Intensity upgrade of U beams at RIBF

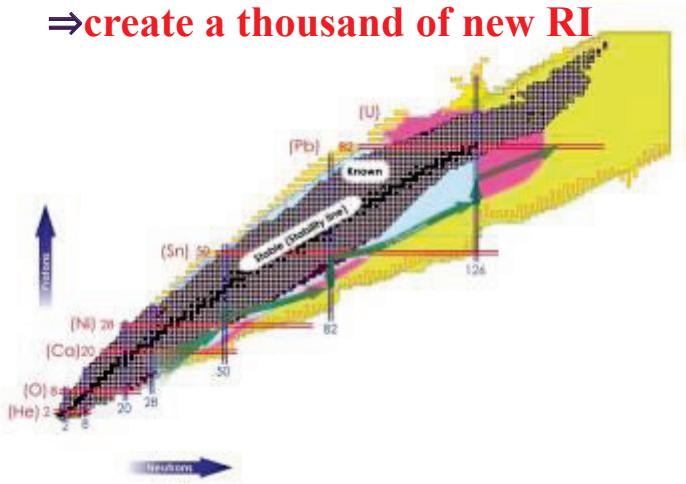
Riken RI Beam Factory (RIBF)

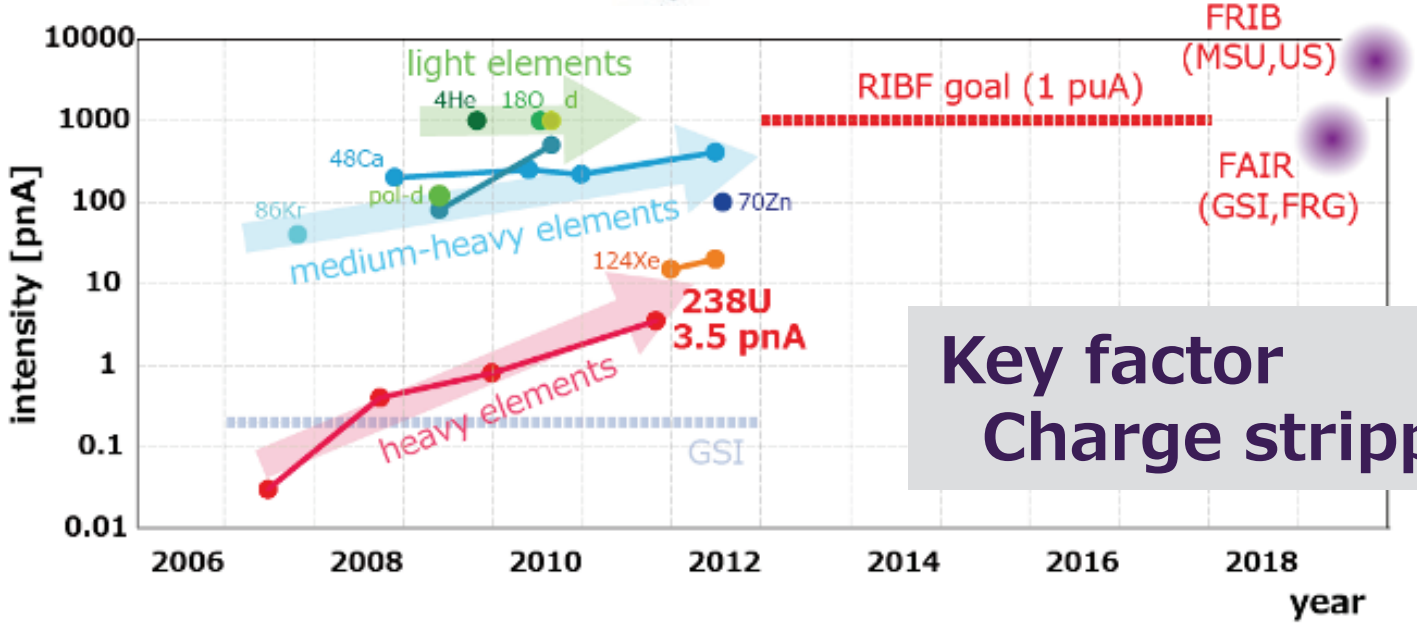
Cyclotron-based heavy-ion accelerator complex
goal intensity; **1 puA** (= 6.24×10^{12} /s)



Upgrading of ^{238}U intensity

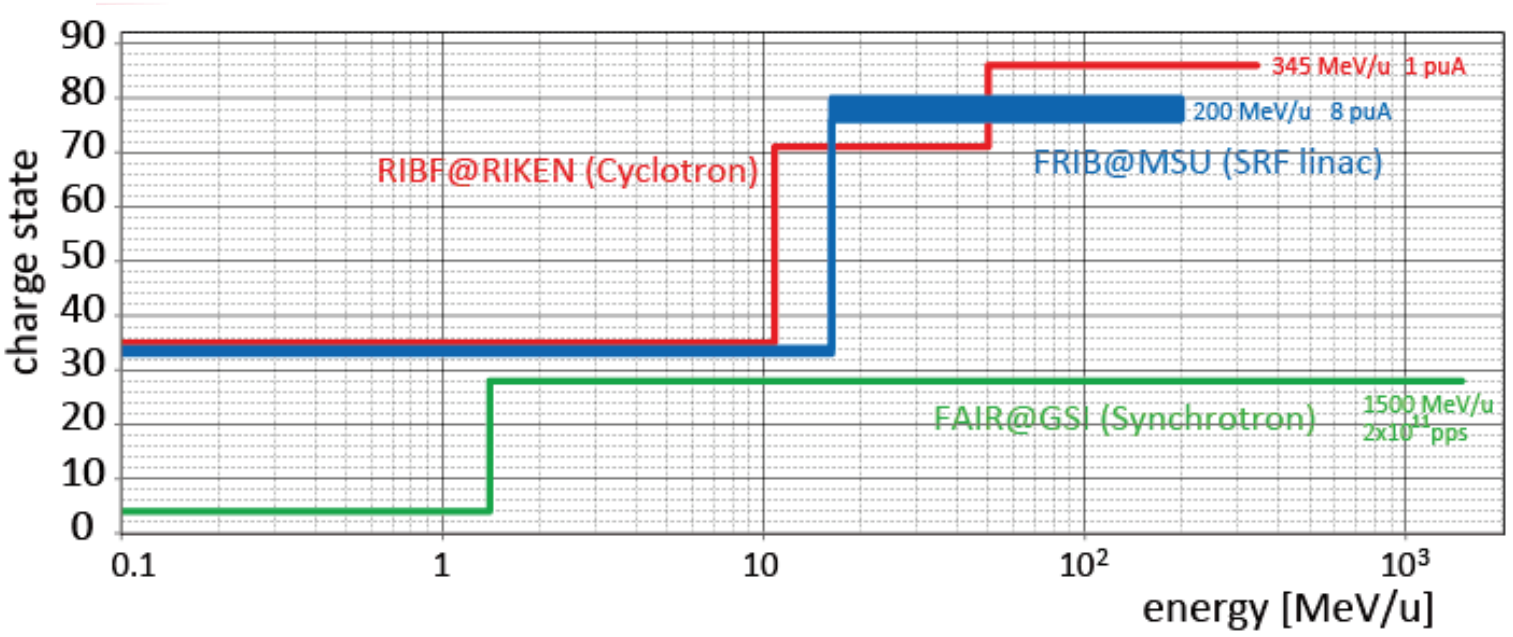
RI beams via in-flight fission
Expansion of nuclear chart
⇒**create a thousand of new RI**





Key factor
Charge stripper

Charge stripping in inflight-RI facilities



Heavy ion accelerator → flexibility of charge state

controlled by Ion source & Charge-state stripper

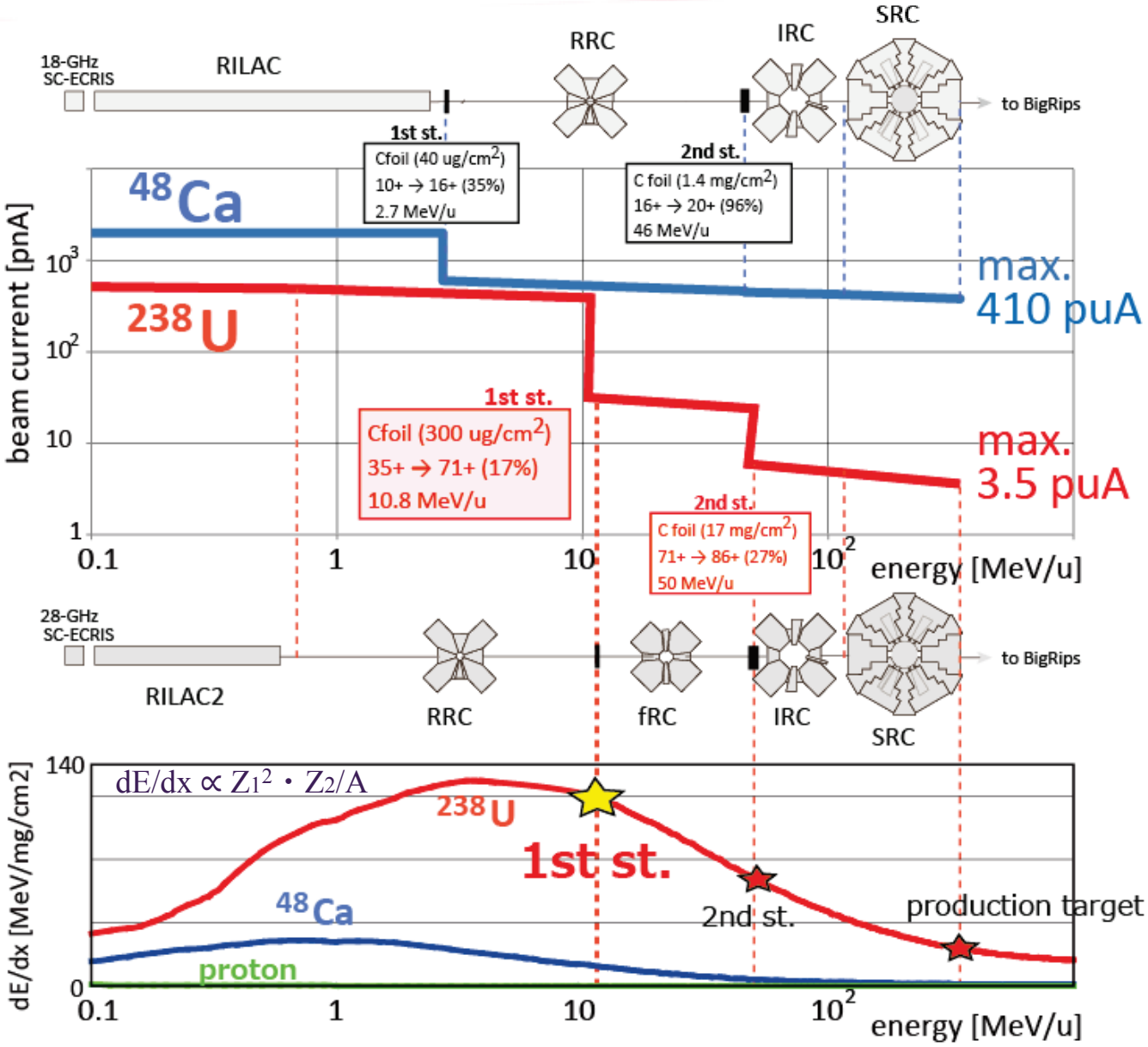
- **FAIR(Synchrotron, PLS)**
  Low charge state to avoid space charge

- **RIBF(Cyclotron, DC), FRIB(SRF linac, DC)**
  Highly charged ions
  Charge stripping at intermediate energies⇒outstanding issue!!
  ⇒**No established ways for high-power beams**

(Low-Z gas, liq-Li, plasma strippers etc.)

1. U acceleration

Original acceleration scheme at RIBF



11 MeV/u **10 puA** ^{238}U ～ 400 MeV **500 mA** proton!!!

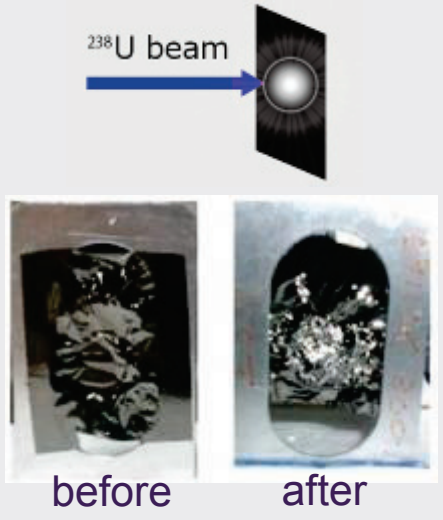
Bottleneck of RIBF

1st. Stripper at 11 MeV/u

- foil thickness less than **1 um**
- fragility, thickness non-uniformity, poor thermal conductivity

Bottleneck for ^{238}U acceleration

C-foil: <0.02 puA



Rotating CNT-foil: <~0.3 puA

Goal: 10 puA ⇒ New stripper is required

Low-Z gas stripper

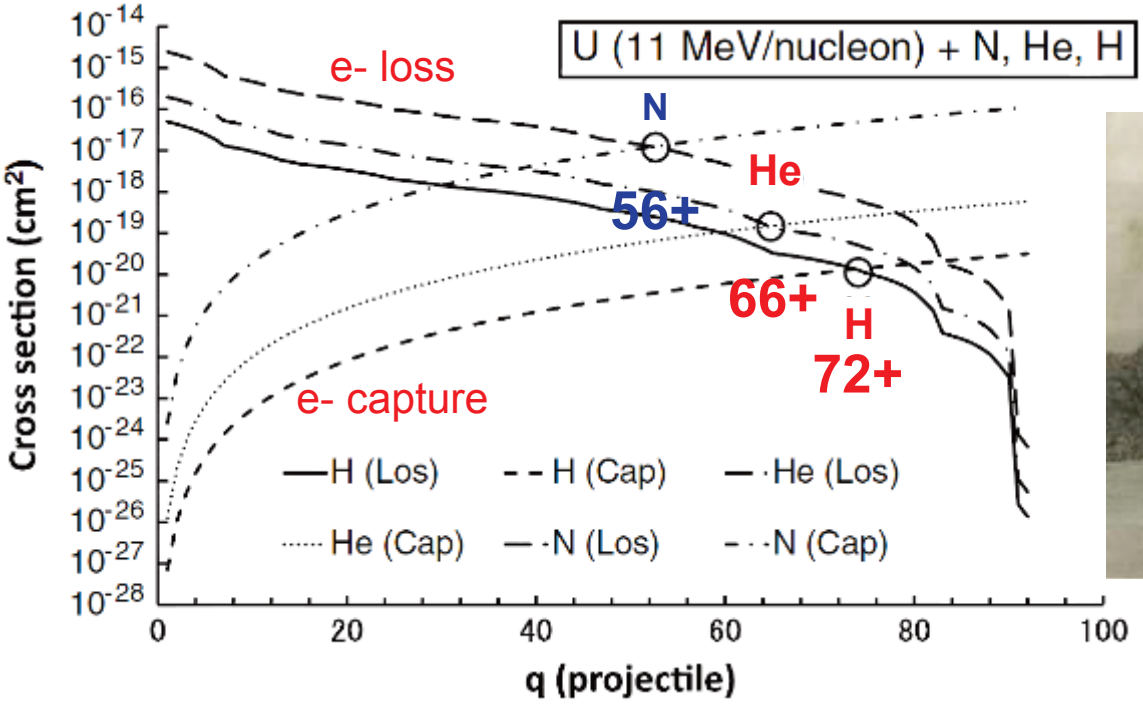
Low-Z (Z; atomic number) gas (e.g., H_2 · He)

- **Non destructive & uniform thickness**
- **High charge state equilibrium**

slow velocity of electrons ($v_{1s} \propto Zc/137$)

⇒suppression of e- capture

Calculation



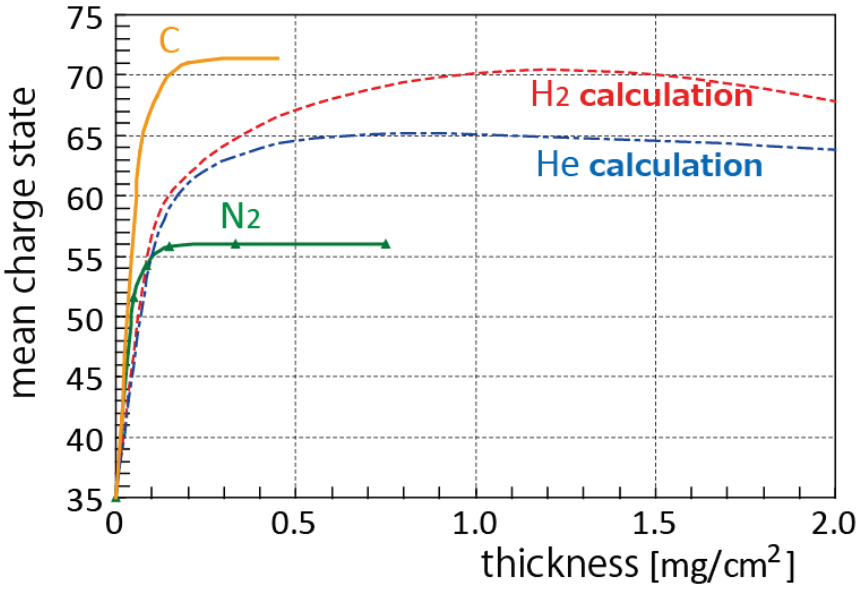
H. Okuno et al., PRST-AB 14, 033503 (2011)

Prototype development

Technical challenge

Windowless confinement

- Diffusiveness ($\propto\sqrt{m}$)
- Slow equilibrium



Prototype systems

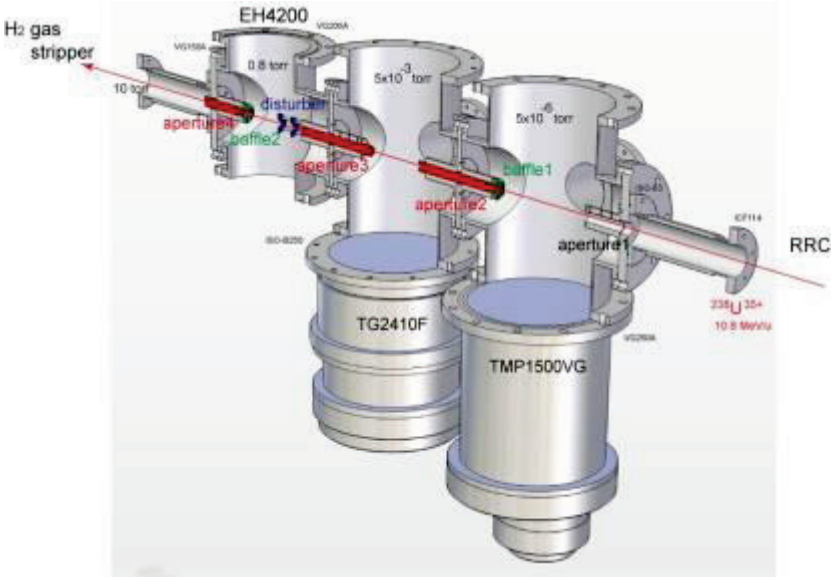
Feasibility of gas confinement

- Diff. pumpings w/ huge pumps
- Gas flow-disturber

  ⇒conductance suppression

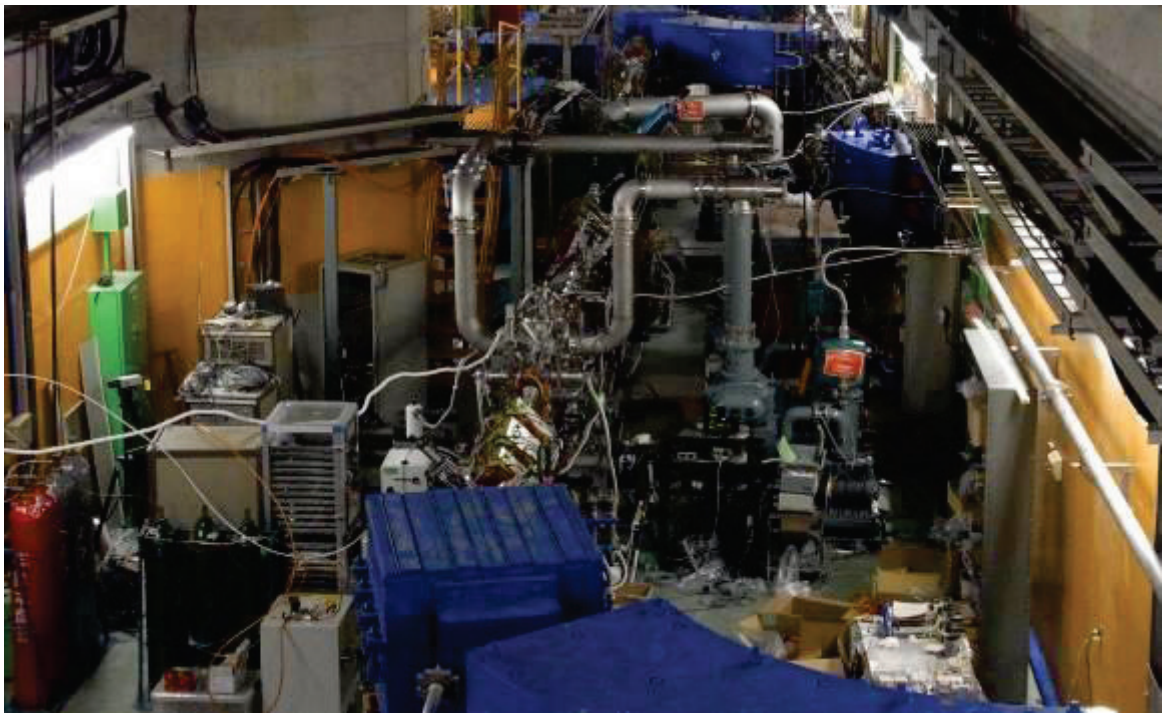
Fundamental data

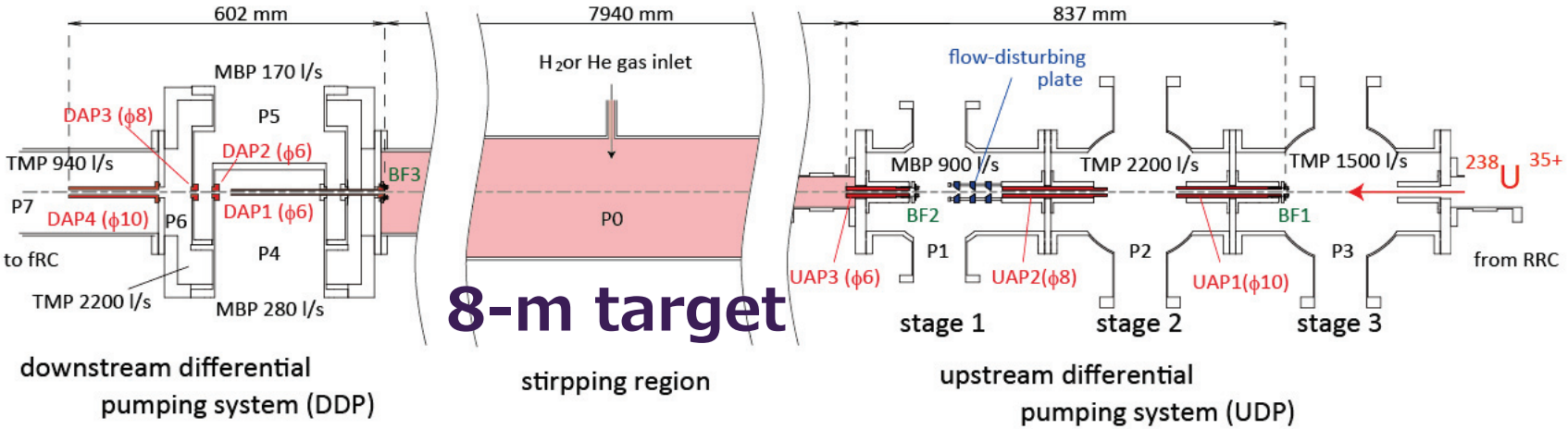
- Charge distribution
- Energy spread
- Beam transmission



2. He stripper development

Prototype 8-m strippers



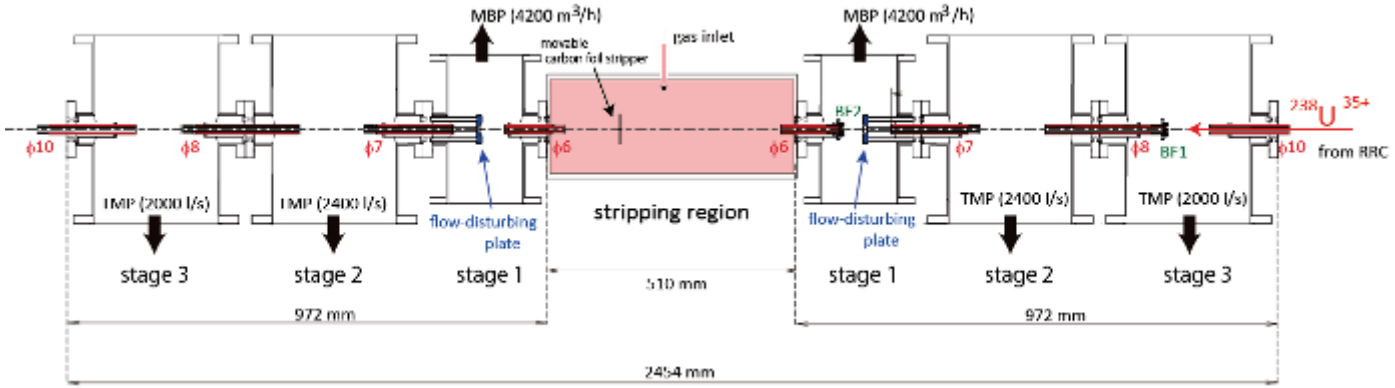


Gas was directly confined within **beamline** (**H_2 1 mg/cm^2, He 3 mg/cm^2**)

2. He stripper development

Prototype 0.5-m strippers

He; 2 mg/cm^2
N2; 30 mg/cm^2

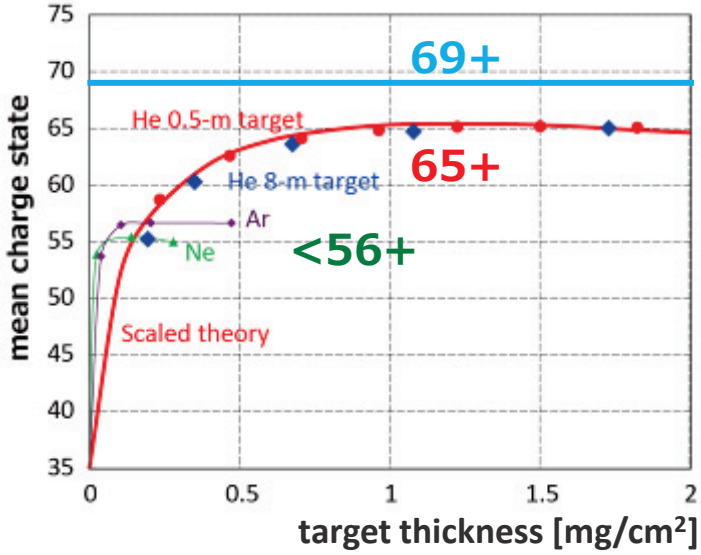


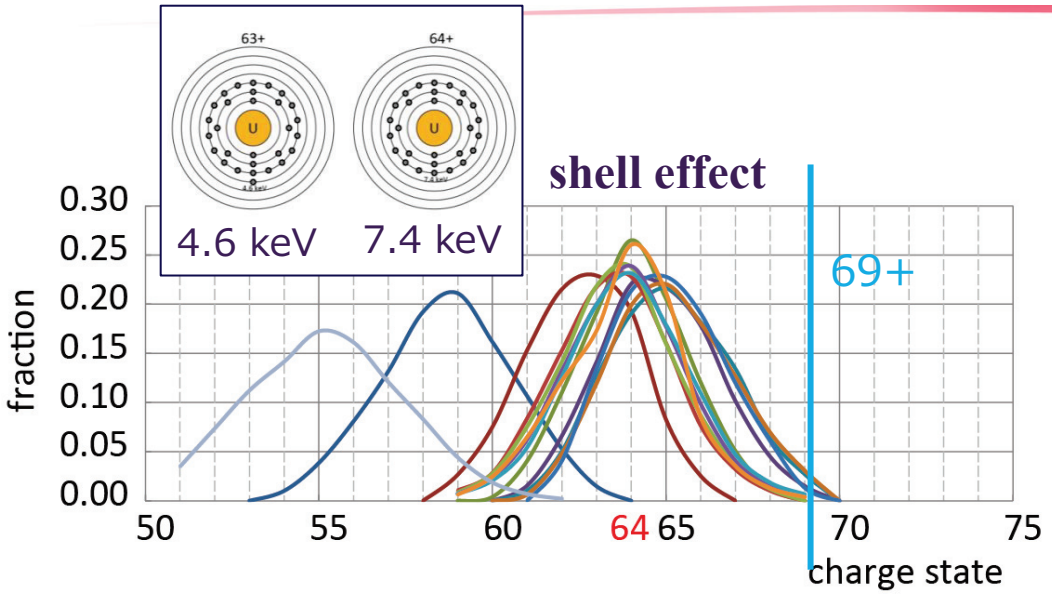
He gas w/ thickness of **2 mg/cm^2** was confined in **0.5-m target region**

2. He stripper development

Fundamental data

•Charge evolution

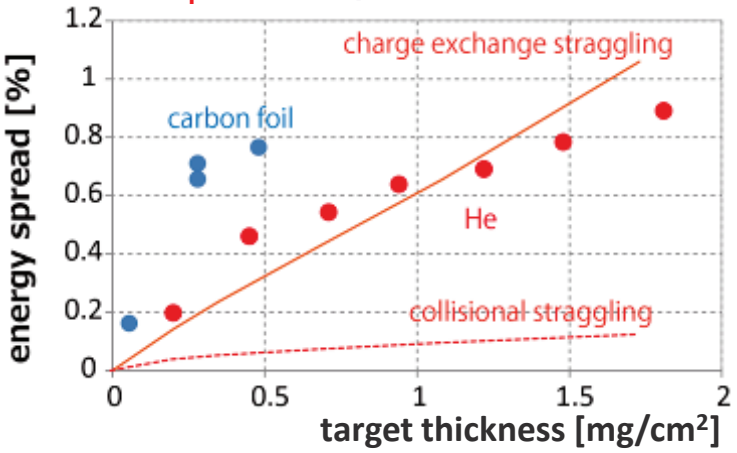




•Energy spread

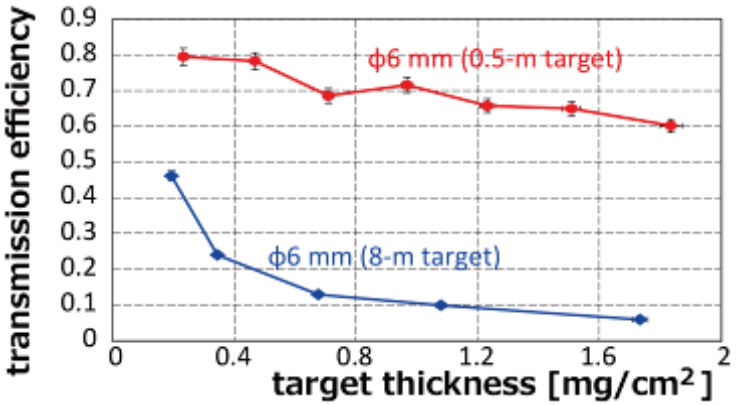
Time distribution measured w/ scinti.

Half of spread (thickness uniformity)



•Transmission

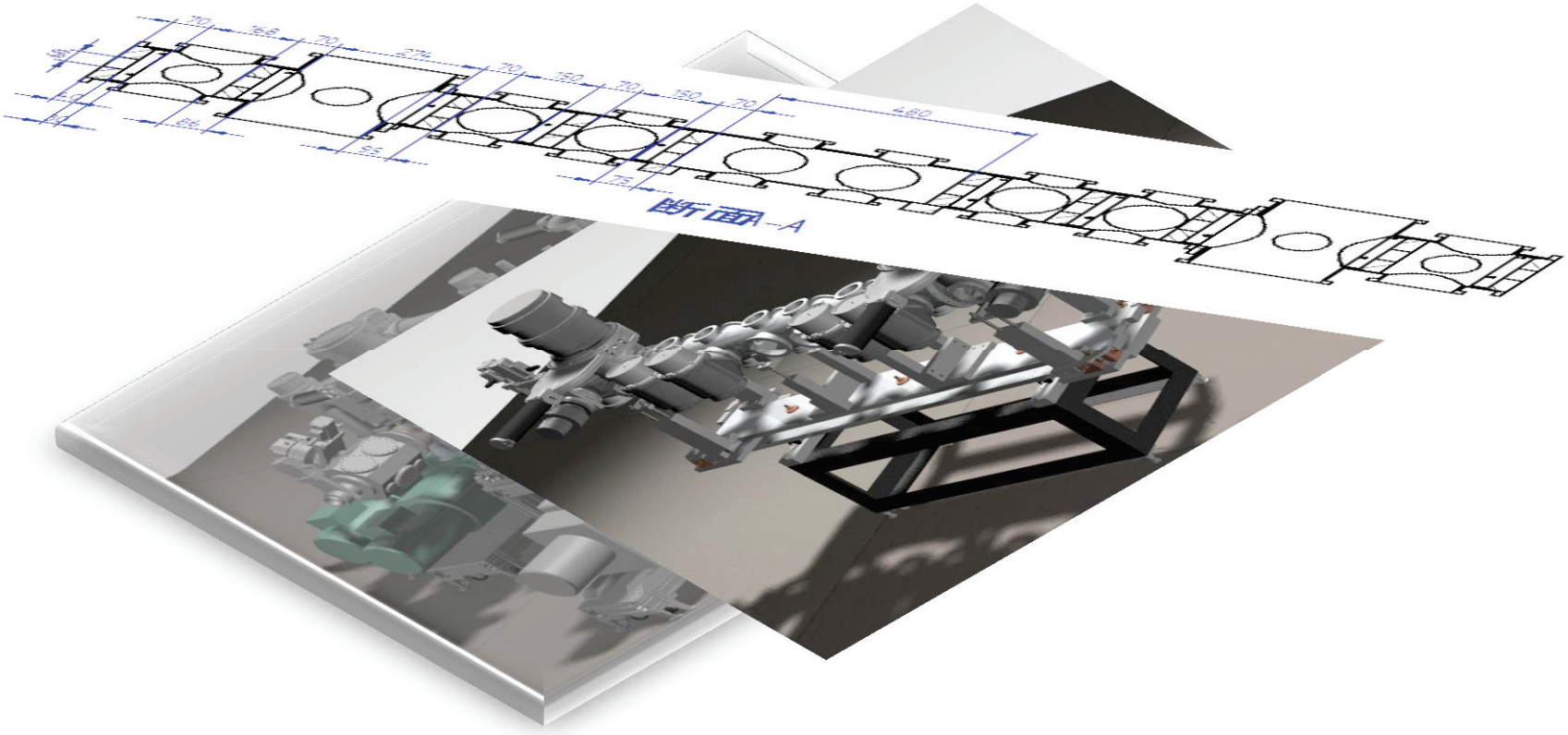
50cm target, φ6mm aperture ⇒70%



H. Imao et al., PRST-AB 15, 123501 (2012)

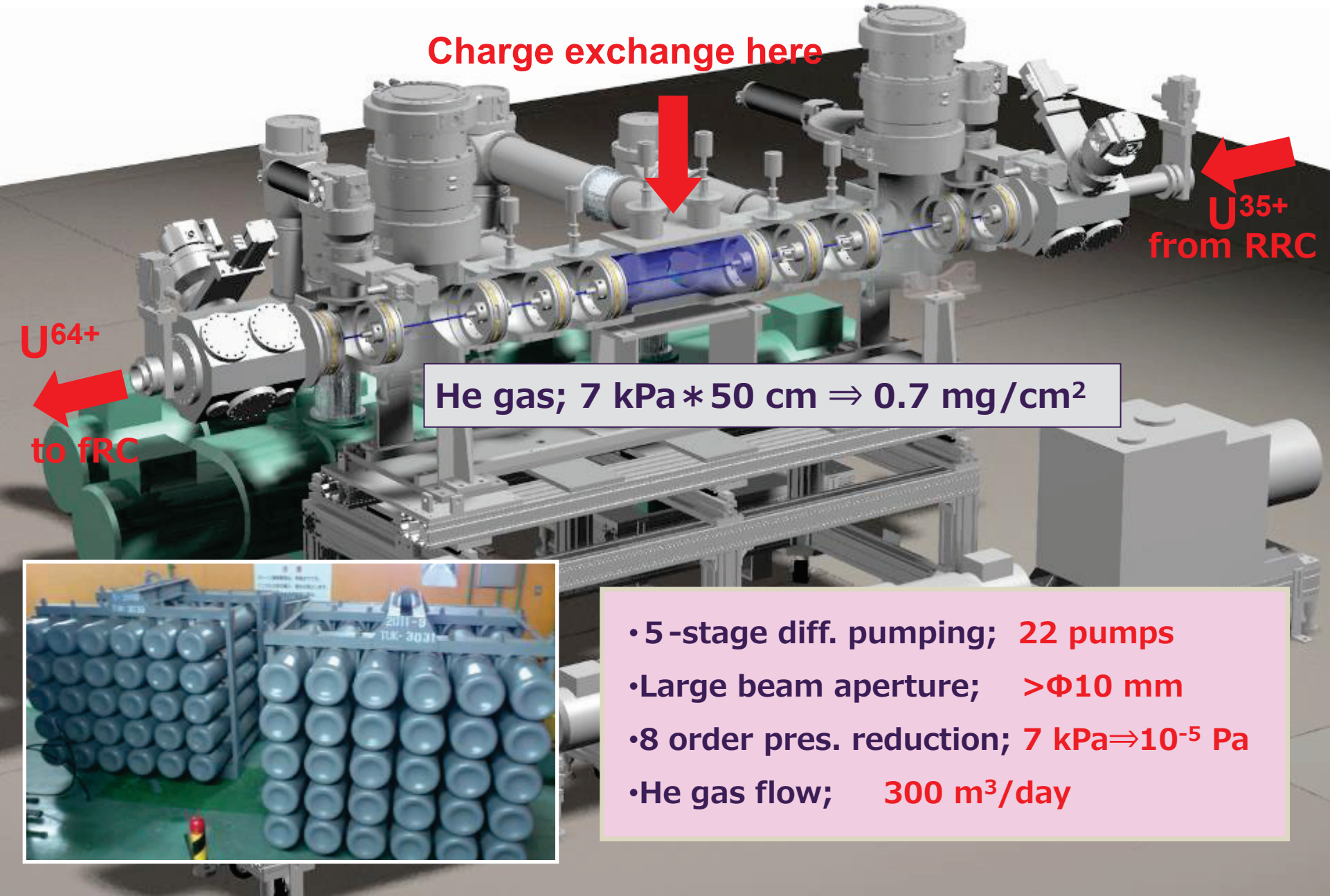
Strategies for practical system

- acceleration for 64+ w/ fRC modification (*Fukunishi et al.*)
- target thickness reduced (0.5-0.7 mg/cm^2)
- beam orifice enlarged (Φ6mm⇒Φ10mm)



2. He stripper development

Design of He gas stripper

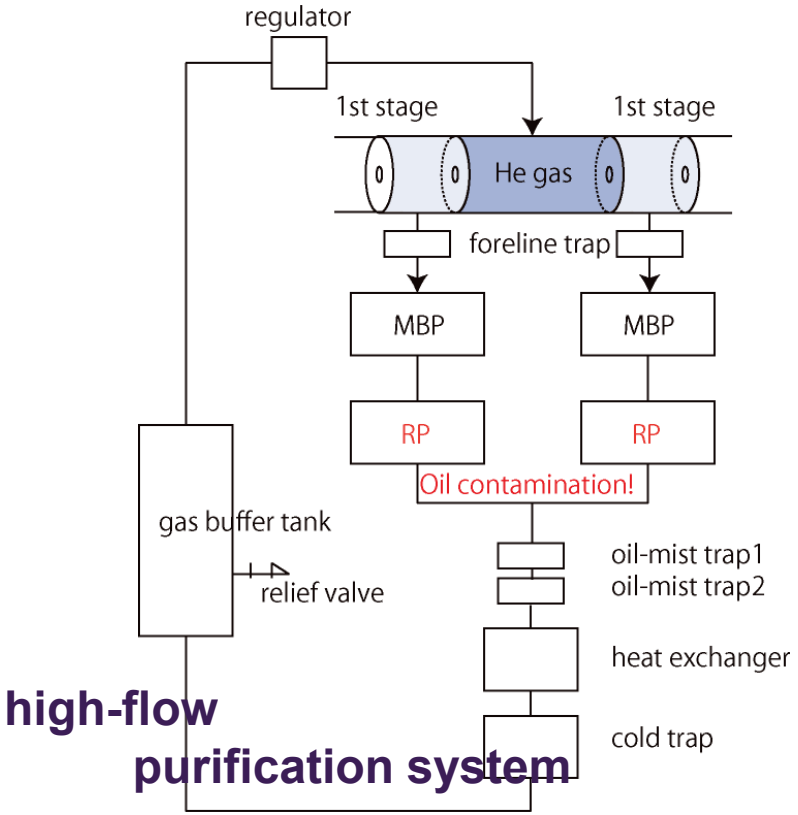


- 5-stage diff. pumping; 22 pumps
- Large beam aperture; >Φ10 mm
- 8 order pres. reduction; 7 kPa⇒10^{-5} Pa
- He gas flow; 300 m^3/day

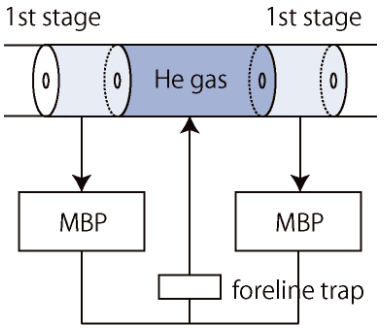
2. He stripper development

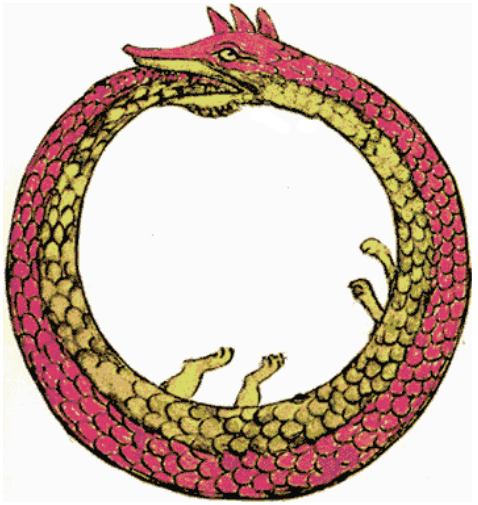
Gas recirculation with MBP

Gas recirculation w/ rotary pumps



Only w/ Mechanical booster pumps



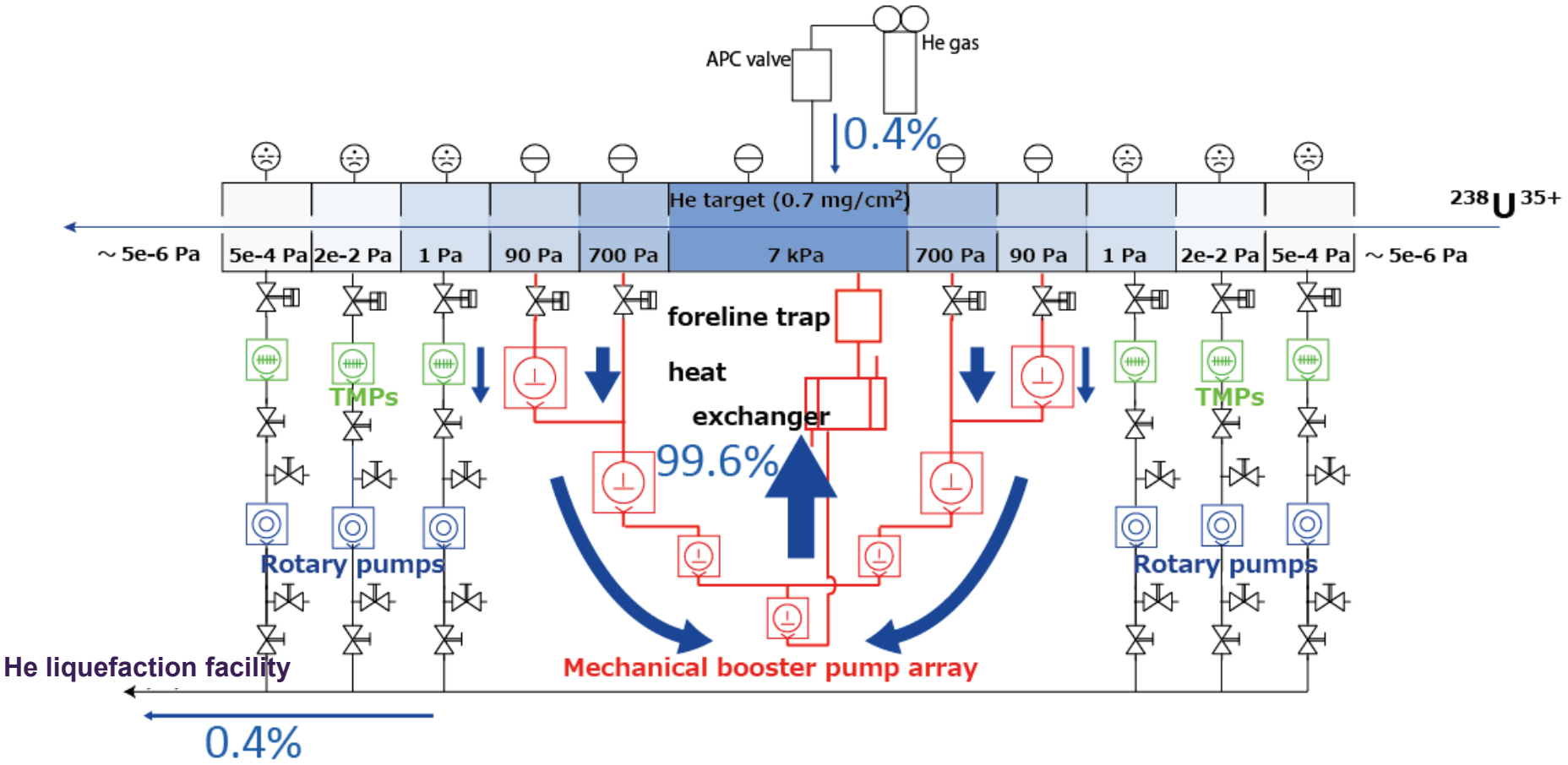


Reduce complexity of purification system

- Cost reduction
- Stable target and reliable system

2. He stripper development

Design of recirculation system



- **Multi-stage MBP array** (7 units, 12000 m^3/h)
- **Recycling rate < 99.6%**

2. He stripper development

R&D works in 2012

2012 Jan. Installation

Mar. Offline tests

thickness <1 mg/cm^2

Recycle rate <99.6%

Apr.-Oct. Online tests

fRC upgrade

new beam dump

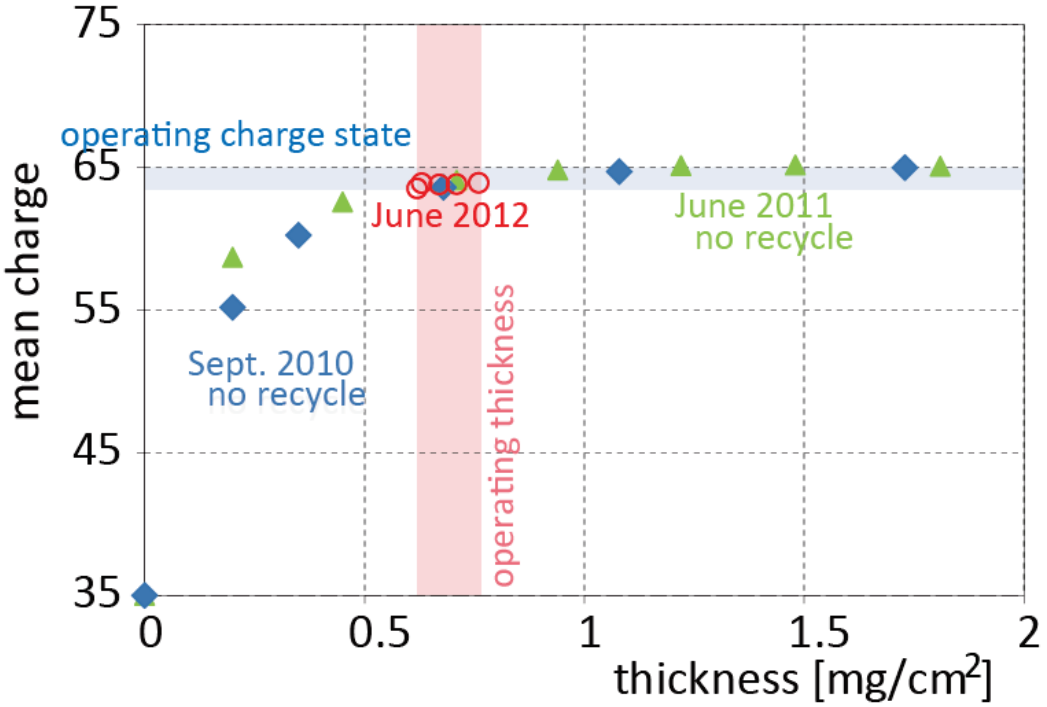
Nov.-Dec. User runs

Effect of impurity

Effect of impurity (Air, H_2O, HC) on charge state

$\sigma_{cap} \propto Z^{4.2}$ (less than 100 ppm of impurity is required)

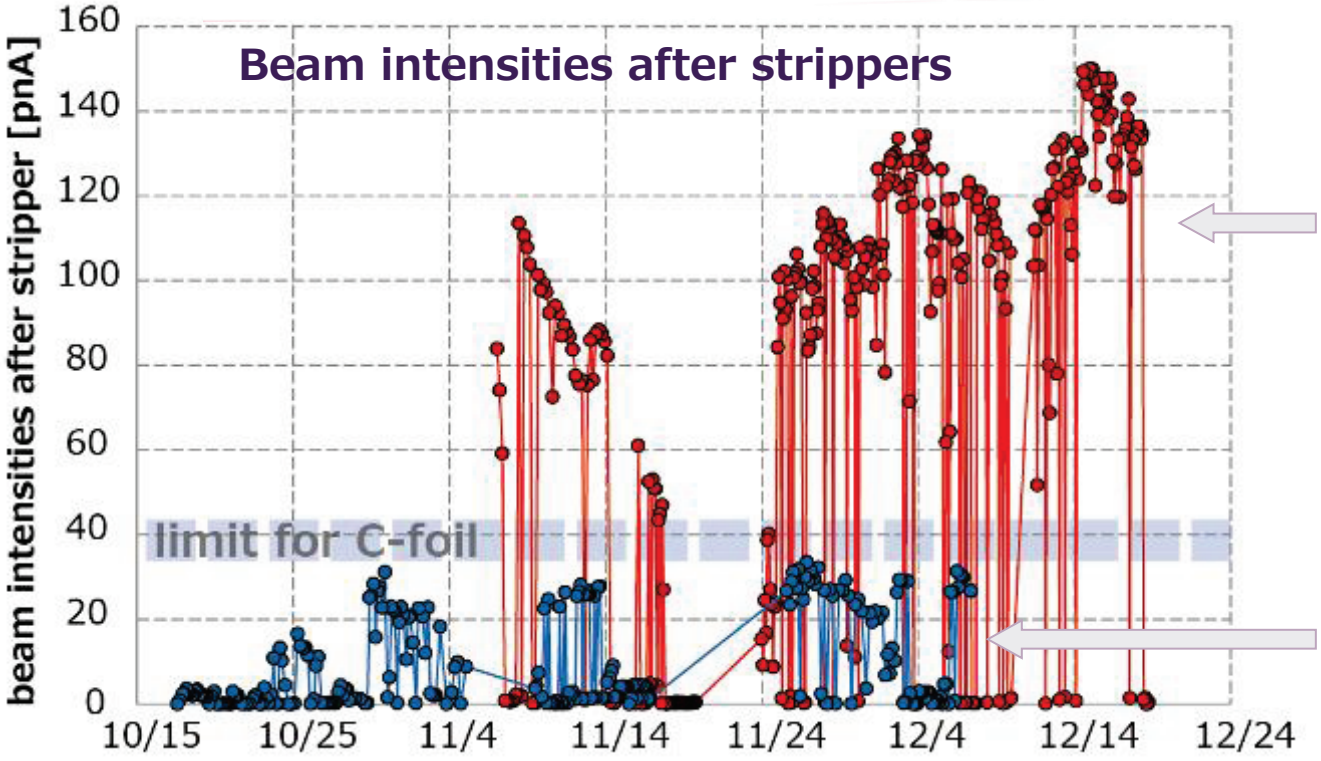
Charge state distribution is the most sensitive test!



mean charge state **64+ w/** recycling rate of **99.6%**
(equivalent to the value 64+ w/o recycling)

3. Highlight data

User runs w/ He stripper



2012: w/ He stripper

Stably operated!

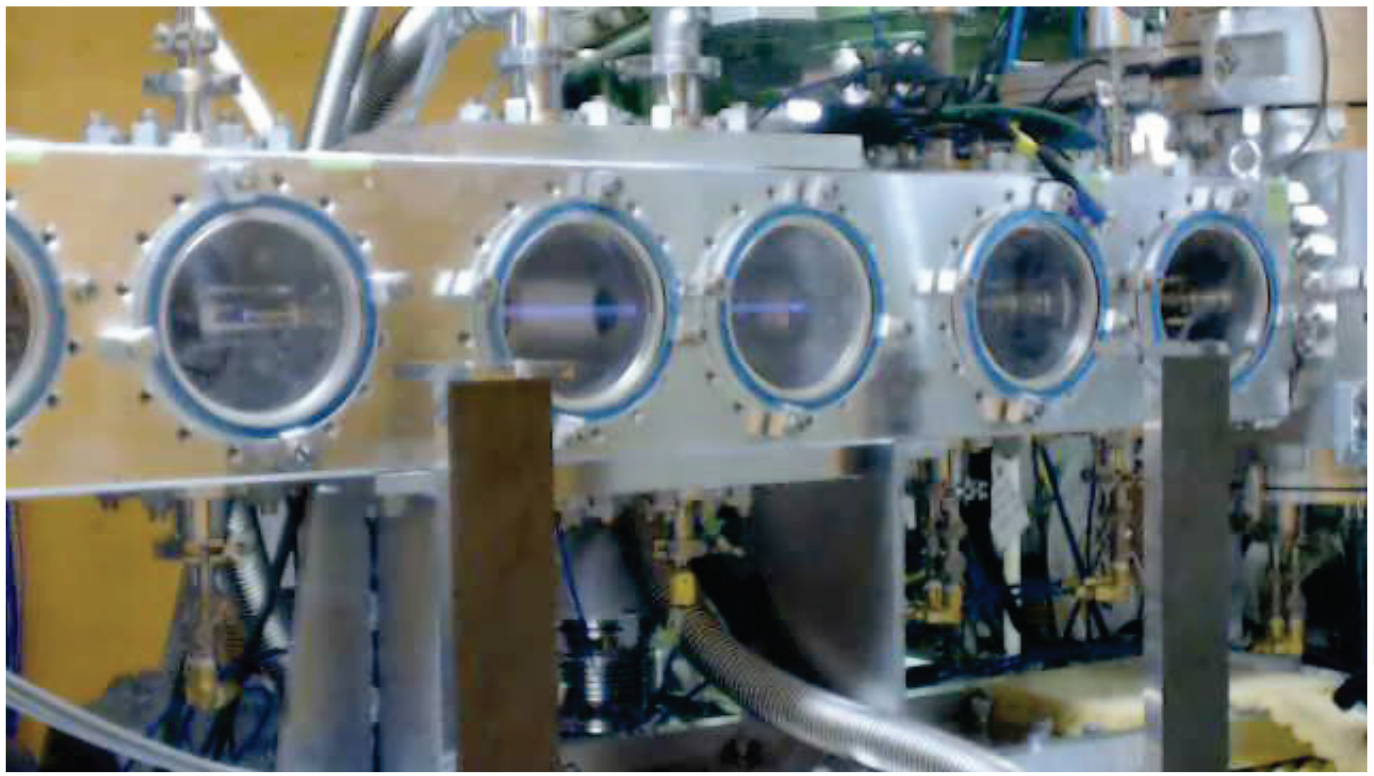
2011: w/ rot. C-foil

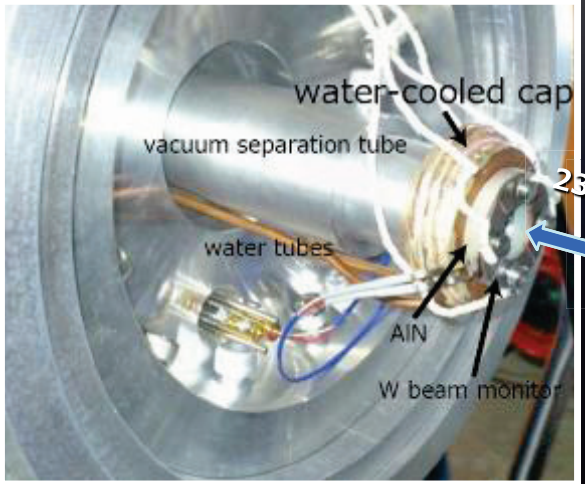
Beam after SRC	2011	2012	
Peak intensity [pnA]	3.6	**15.1**	**~10^{11} /s**
Service rate [%]	56.7	80.3	
Mean intensity [pnA]	1.6	10.2	

[Mean intensity x service rate] ⇒ **10 times ! !**

3. Highlight data

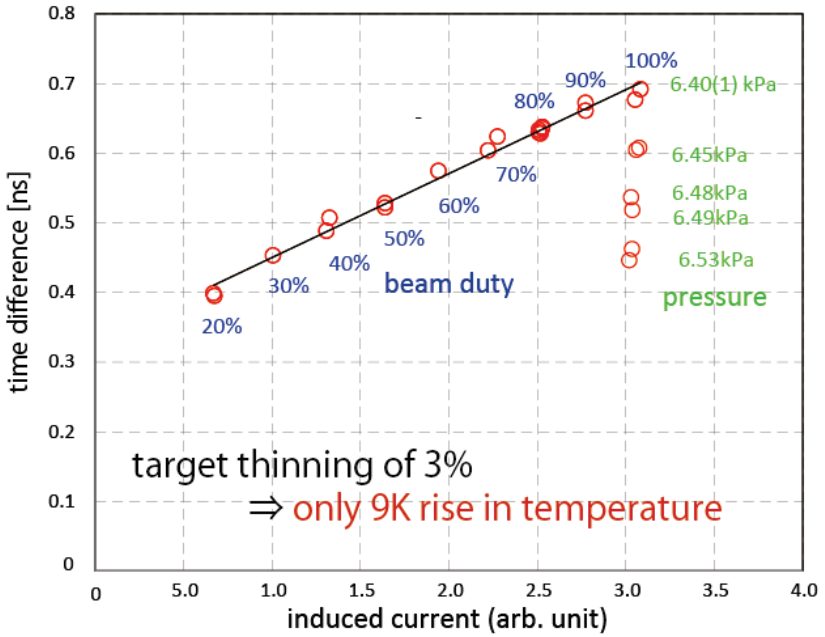
Glow of uranium beams

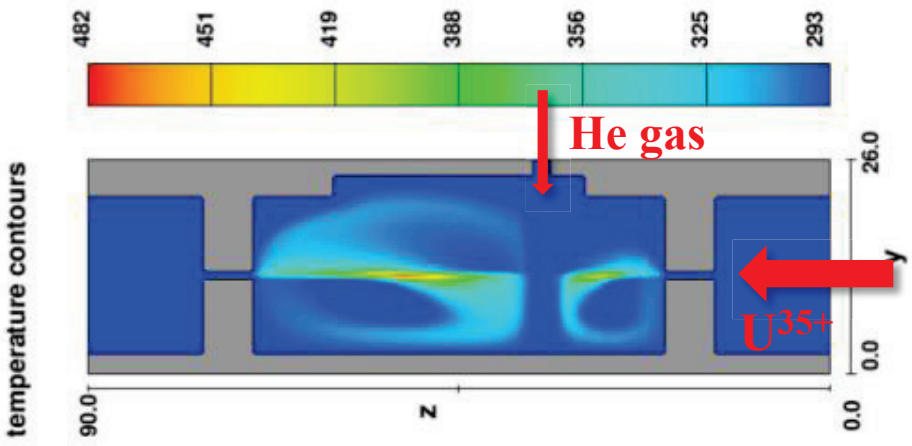




Target thinning

Target thinning caused by the heat load due to uranium beams will determine the application limit of gas stripper





The TOF of U^{64+} beams as a function of the beam intensity using phase probes.

Calculation

- flow3D (K. Ogata)
- SW flow simulation (H. Imao)

1 pμA⇒80 W energy deposit

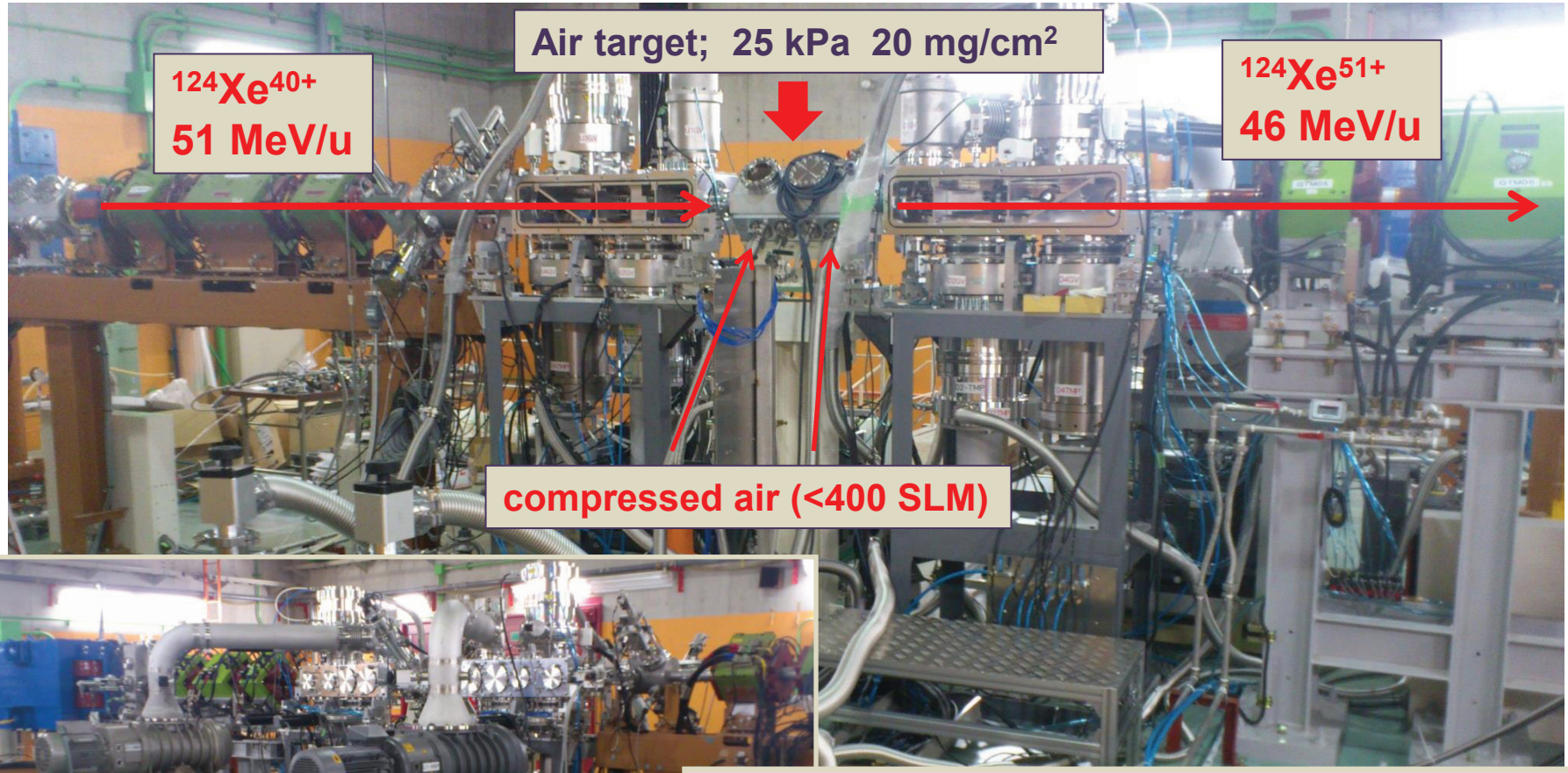
Heating efficiency is only 20%

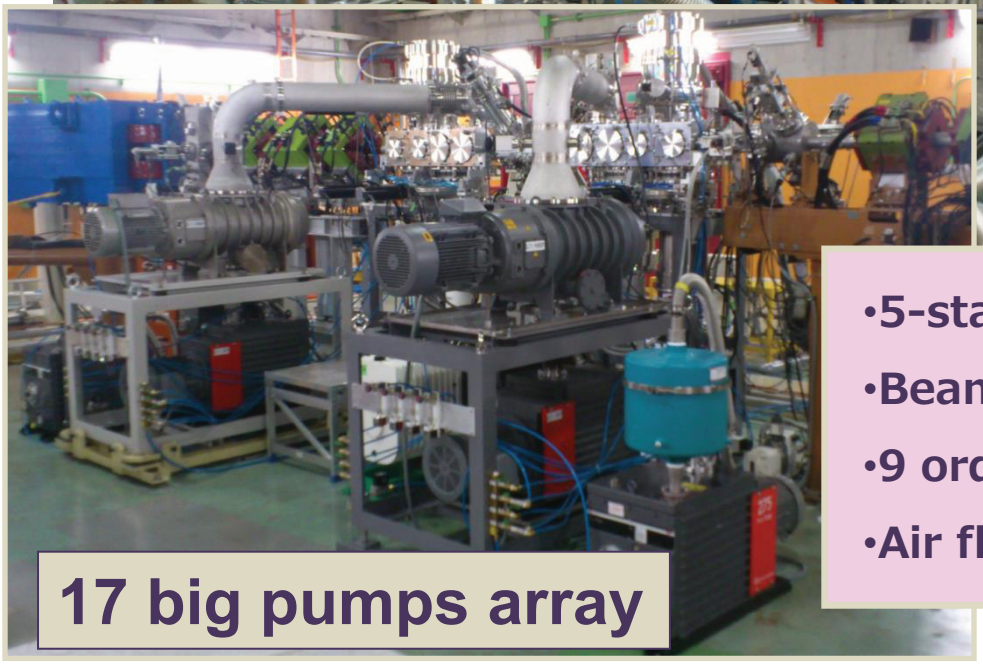
Some suppression mechanisms?

(VUV emission, energetic δ electrons emissionetc.)

3. Highlight data

Air stripper for 50-MeV/u Xe beams



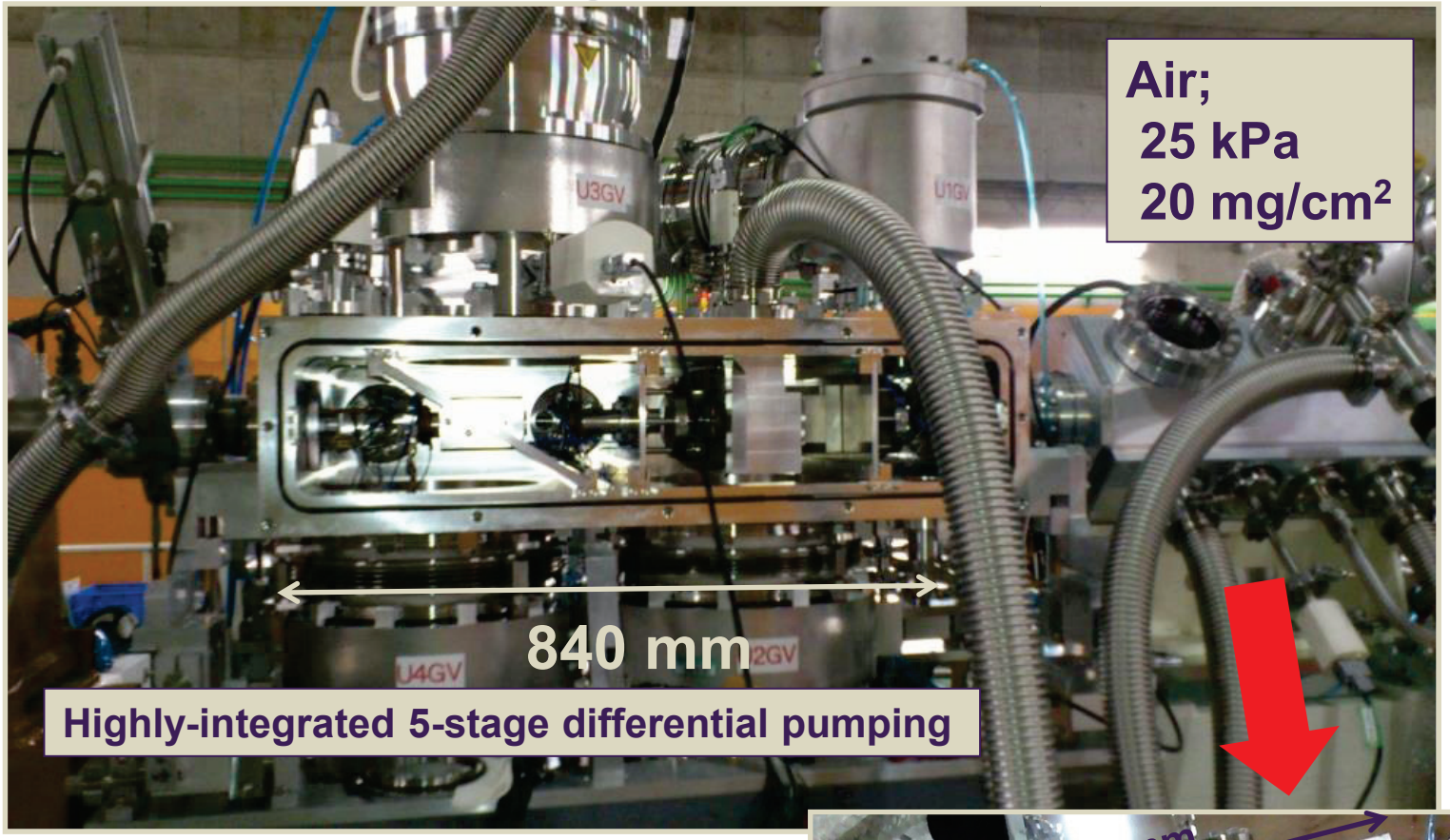


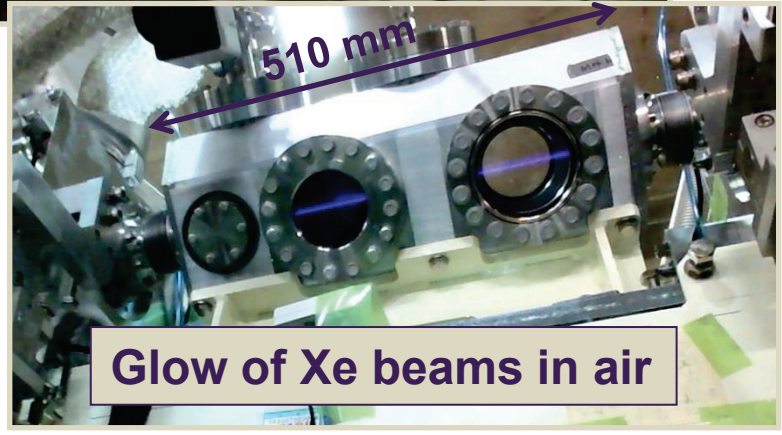
- 5-stage diff. pumping; 17 pumps
- Beam aperture; >Φ8.5 mm
- 9 order pres. reduction; 25 kPa⇒10^{-5} Pa
- Air flow; <400 SLM

3. Highlight data

Air stripper for 50-MeV/u Xe beams

Constructed this March and operated this June





Service rate 91% (77% in 2012)

[Mean intensity x service rate]
⇒ 3.8 times

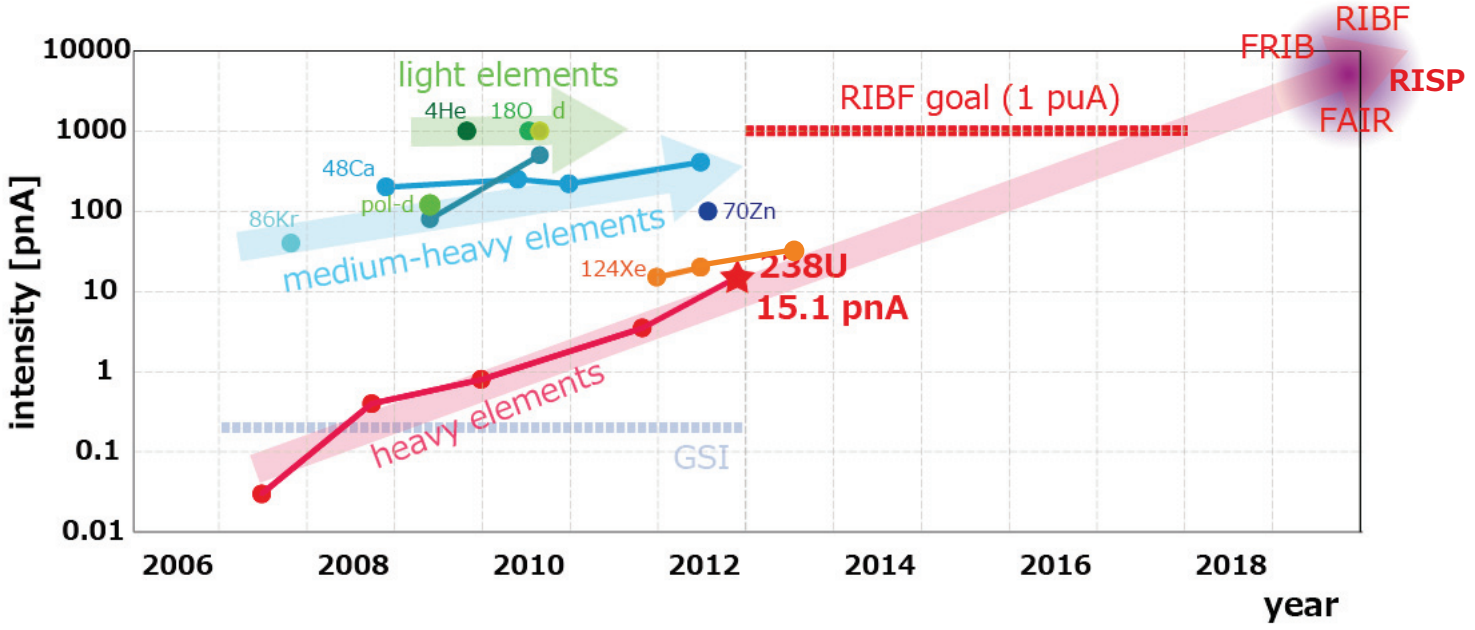
•C-foil was replaced every 8h in 2012
•Air stripper have infinite lifetime

Summary

New acceleration scheme with recirculating He gas stripper for high-power ^{238}U is realized

Tenfold increase of average output intensity of ^{238}U in 2012

- He stripper removed primary bottleneck
  (Operated without any deterioration w/ ^{238}U beams during 1.5 months)
- Success of some other remarkable accelerator upgrades
  (Ion source [*Higurashi et al.*], K700-fRC, high-power beam dump, 2nd Be stripper etc.)



Acknowledgement

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