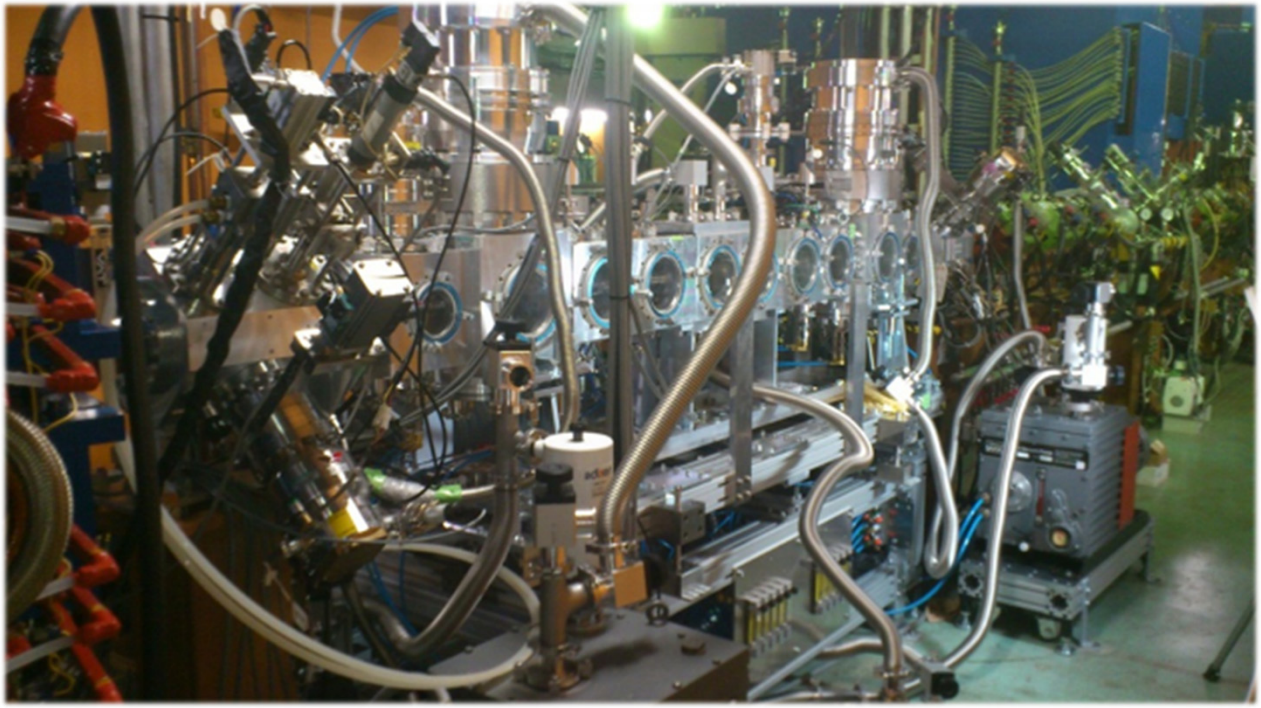
ACFA/IPAC'13 Prize

Realization of New Charge-state Stripper for High-power Uranium Ion Beams



Hiroshi Imao

RIKEN NiSHiNA CENTER

RIKEN

^{238}U

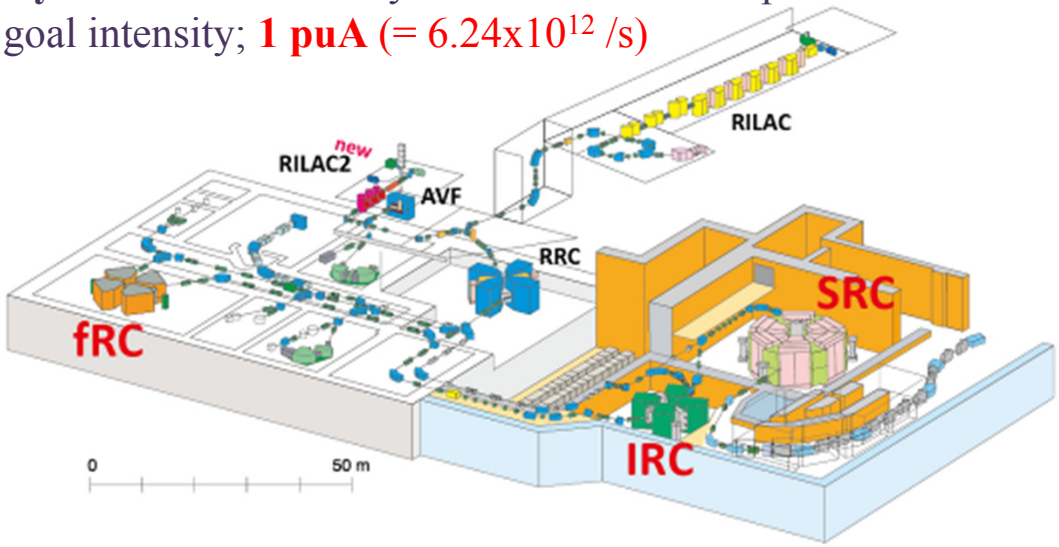
Outline

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

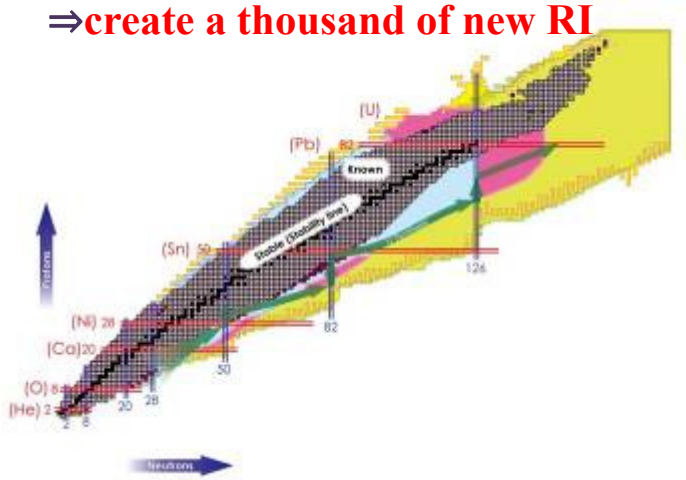
Riken RI Beam Factory (RIBF)

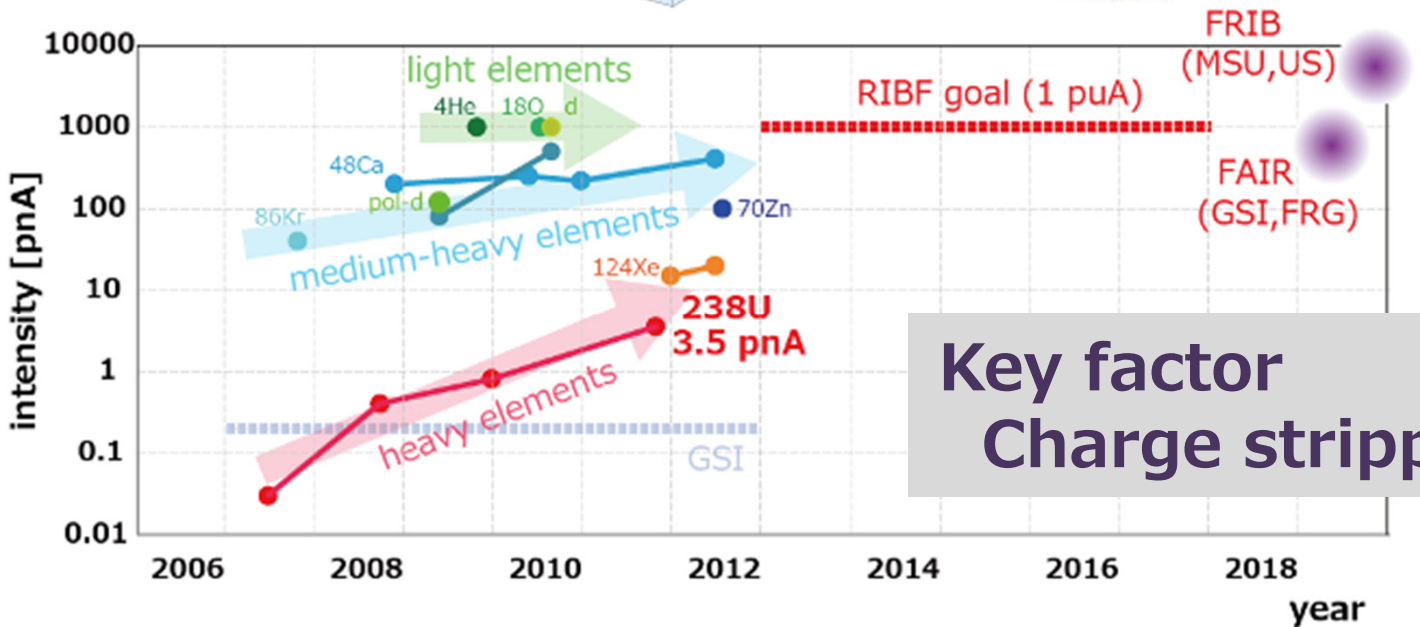
Cyclotron-based heavy-ion accelerator complex
goal intensity; **1 puA** (= 6.24×10^{12} /s)



Upgrading of ^{238}U intensity

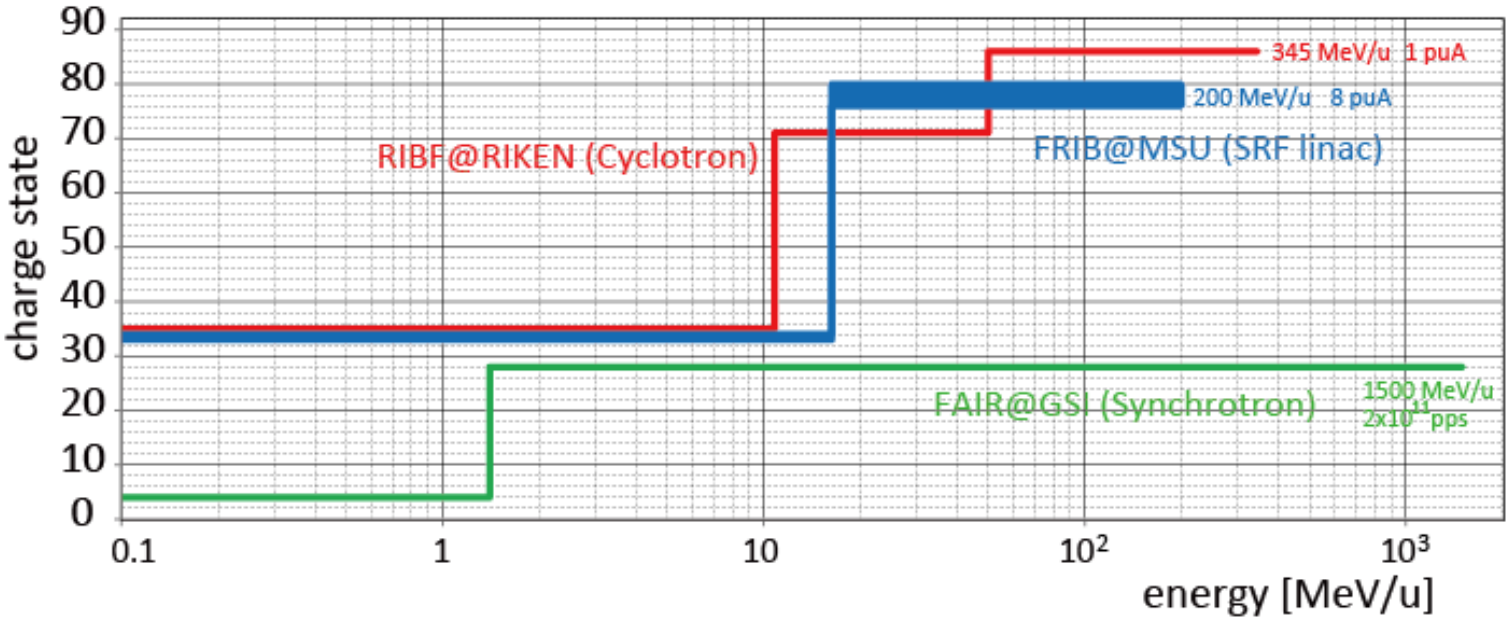
RI beams via in-flight fission
Expansion of nuclear chart
⇒**create a thousand of new RI**





Key factor
Charge stripper

Charge stripping in inflight-RI facilities



Heavy ion accelerator → flexibility of charge state

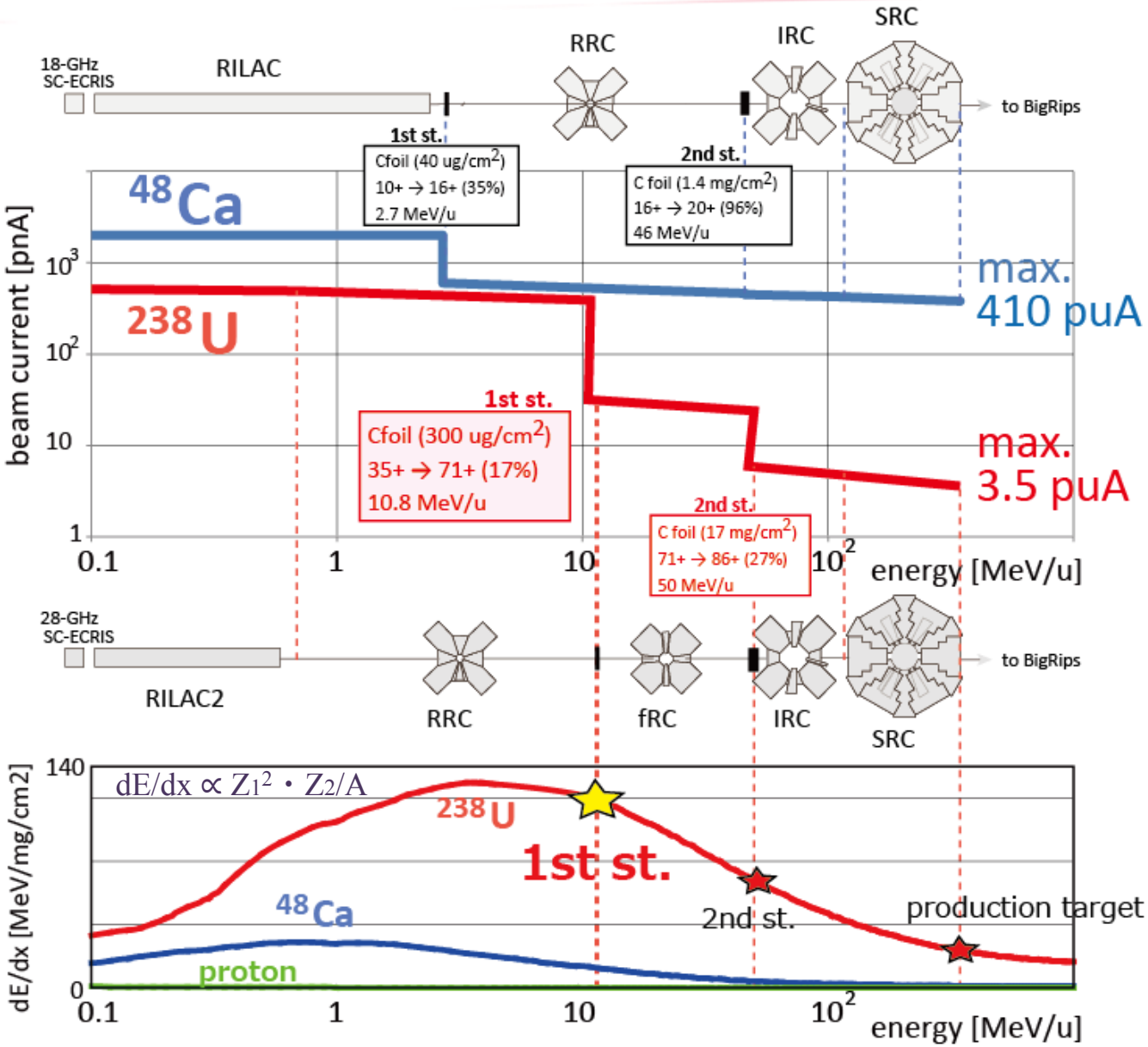
controlled by Ion source & Charge-state stripper

- **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.)

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**
- fragile, thickness non-uniformity, poor thermal conductivity

Bottleneck of ^{238}U acceleration at RIBF

C-foil: <0.02 puA

Rotating CNT-foil: <~0.3 puA

Goal: 10 puA ⇒ New stripper is required

Low-Z gas stripper

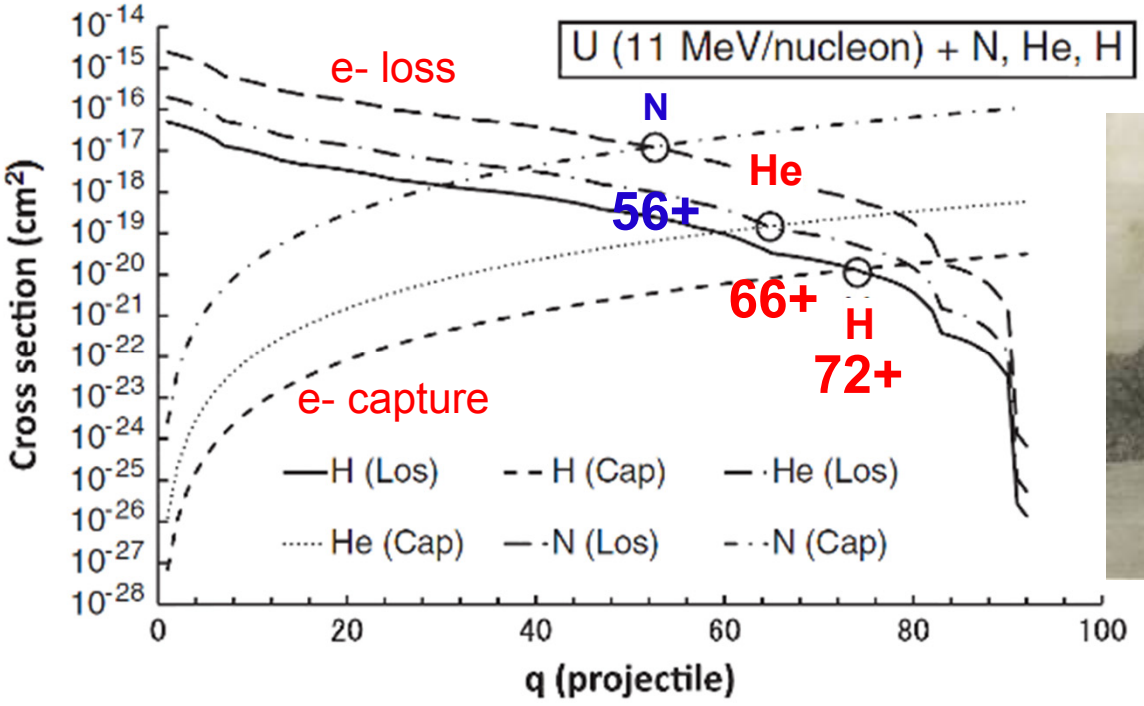
Low-Z (Z; atomic number) gas（e.g., H_2・He)

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

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

⇒suppression of e- capture

Calculation



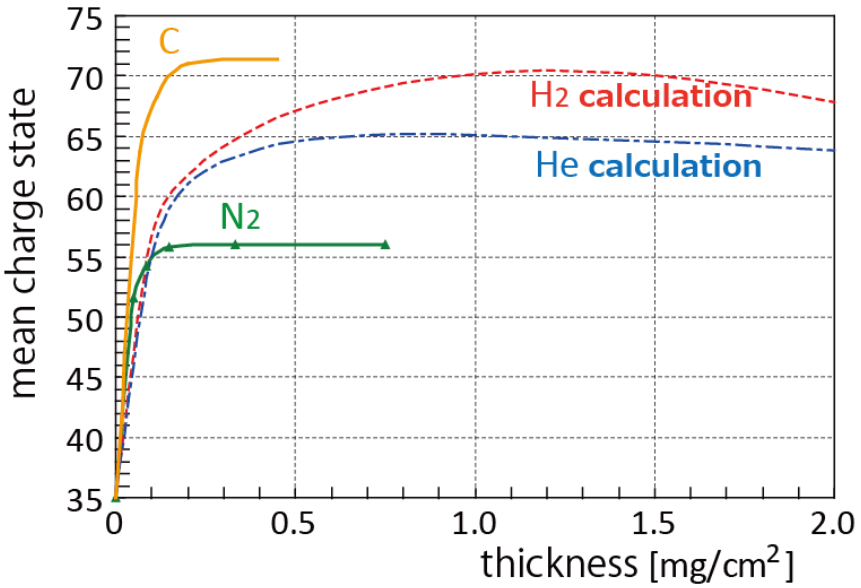
H. Okuno et al., PRST-AB 14, 033503 (2011)

Prototype development

Technical challenge

Windowless confinement

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



Prototype systems

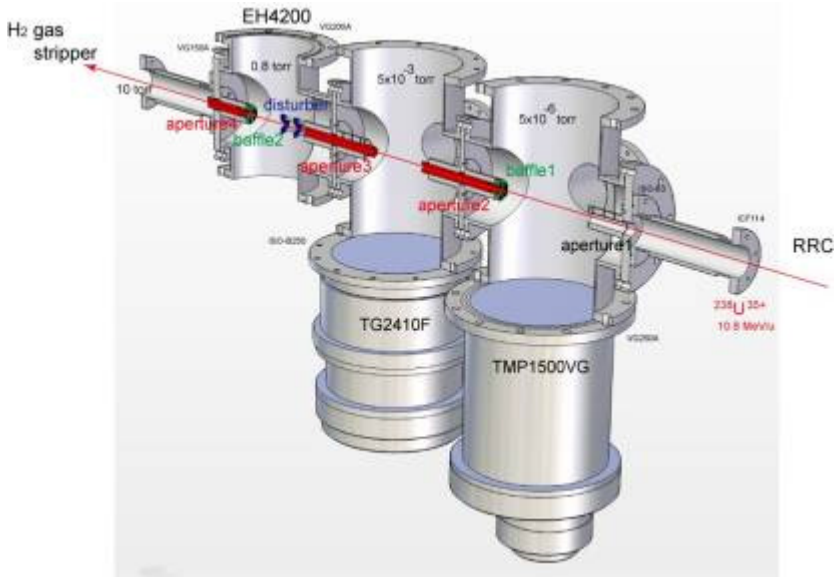
Feasibility of gas confinement

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

  ⇒conductance suppression

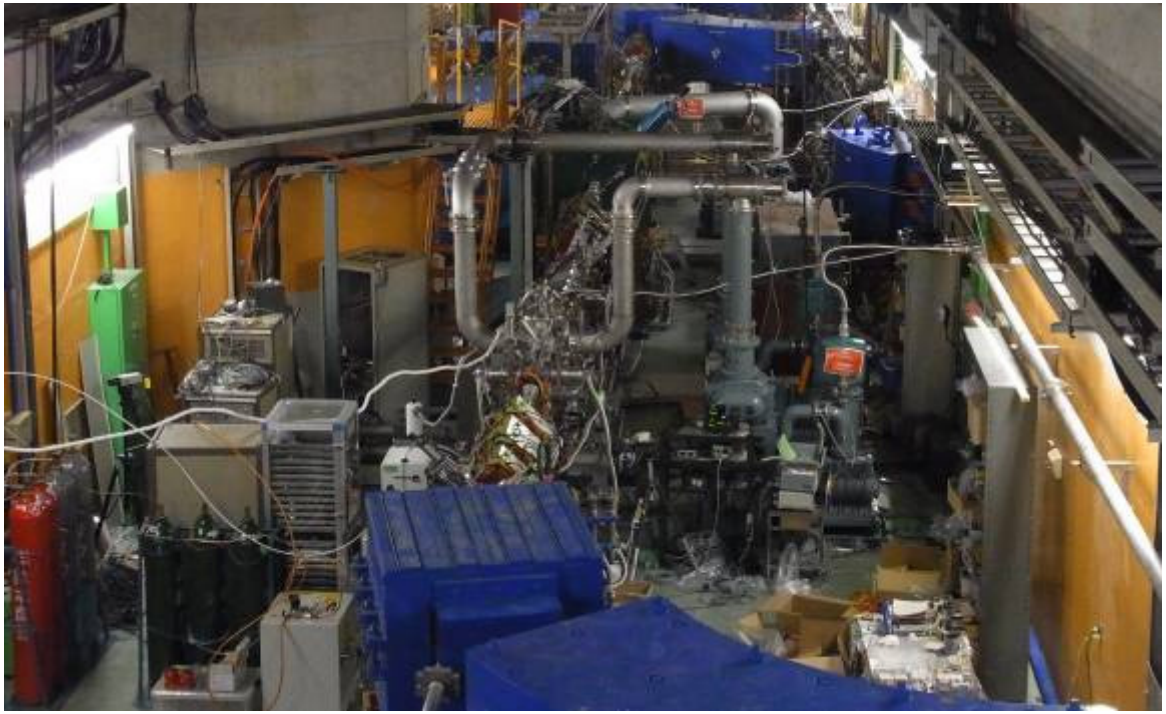
Fundamental data

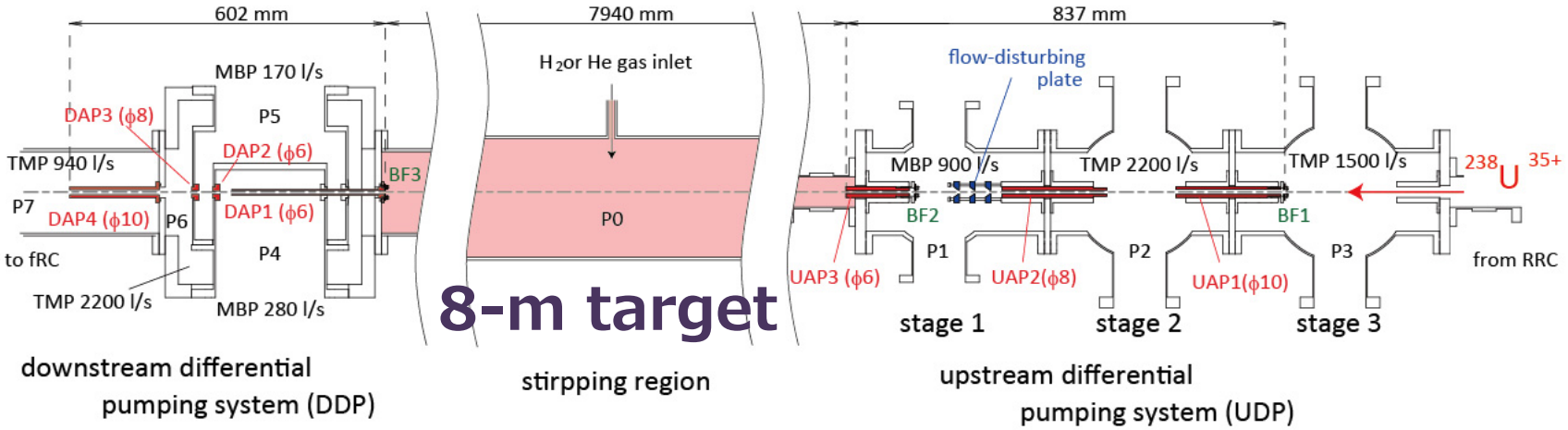
- Charge distribution
- Energy spread
- Beam transmission



2. He stripper development

Prototype 8-m strippers

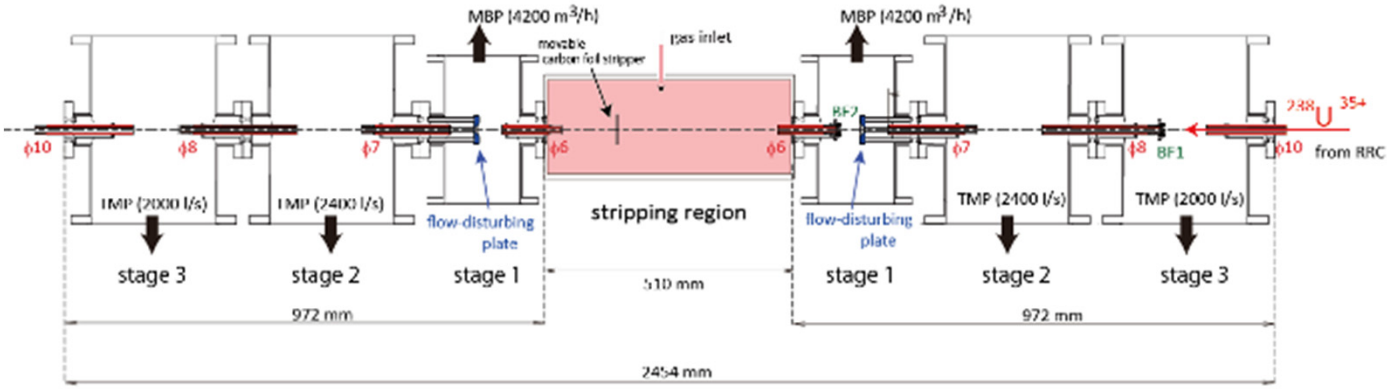




Gas was directly confined within **beamline** (**H_2 1 mg/cm^2, He 3 mg/cm^2**)

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**

Fundamental data and strategy

•Charge evolution

mean charge state 65+ for H_2 and He

acceptable state of fRC 69+（C 71+、N_2～56+）

•Energy spread

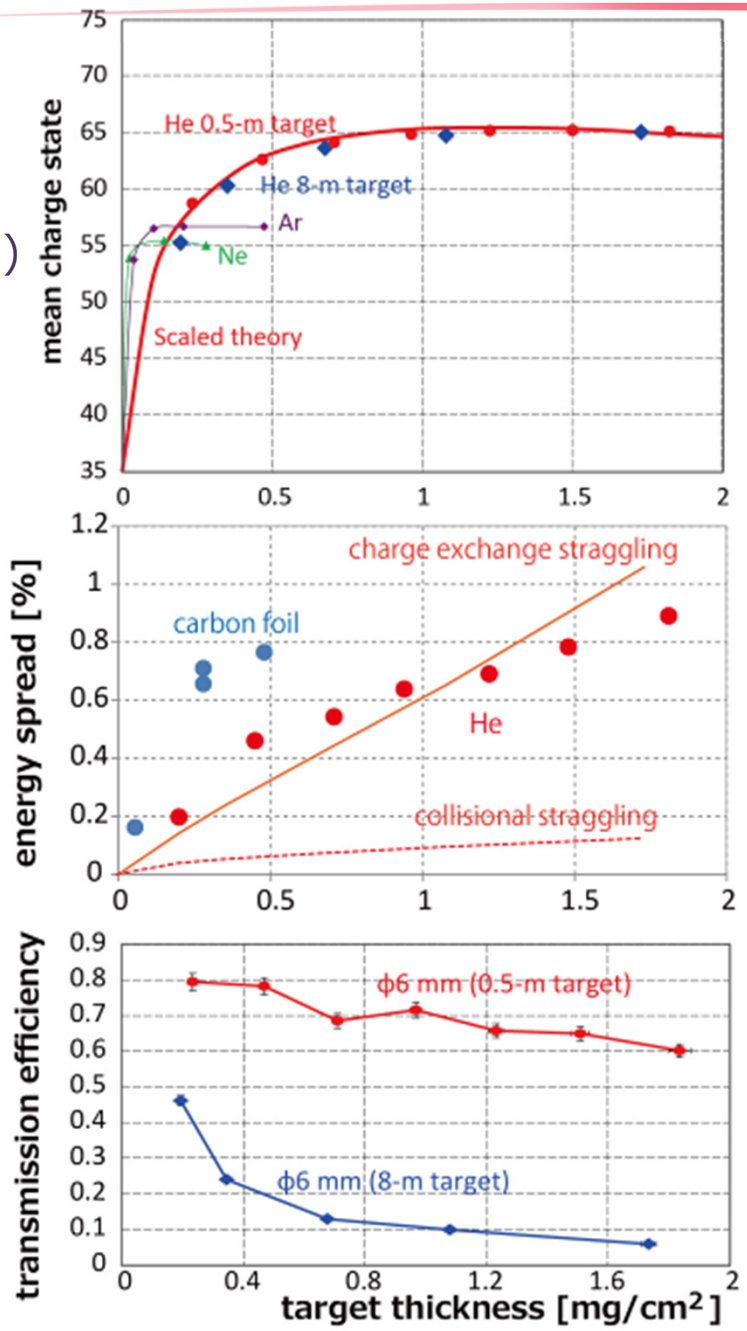
Time distribution measured w/ scinti.

Half of spread for C-foil (thickness uniformity)

•Transmission

50cm target, φ6mm aperture ⇒70%

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



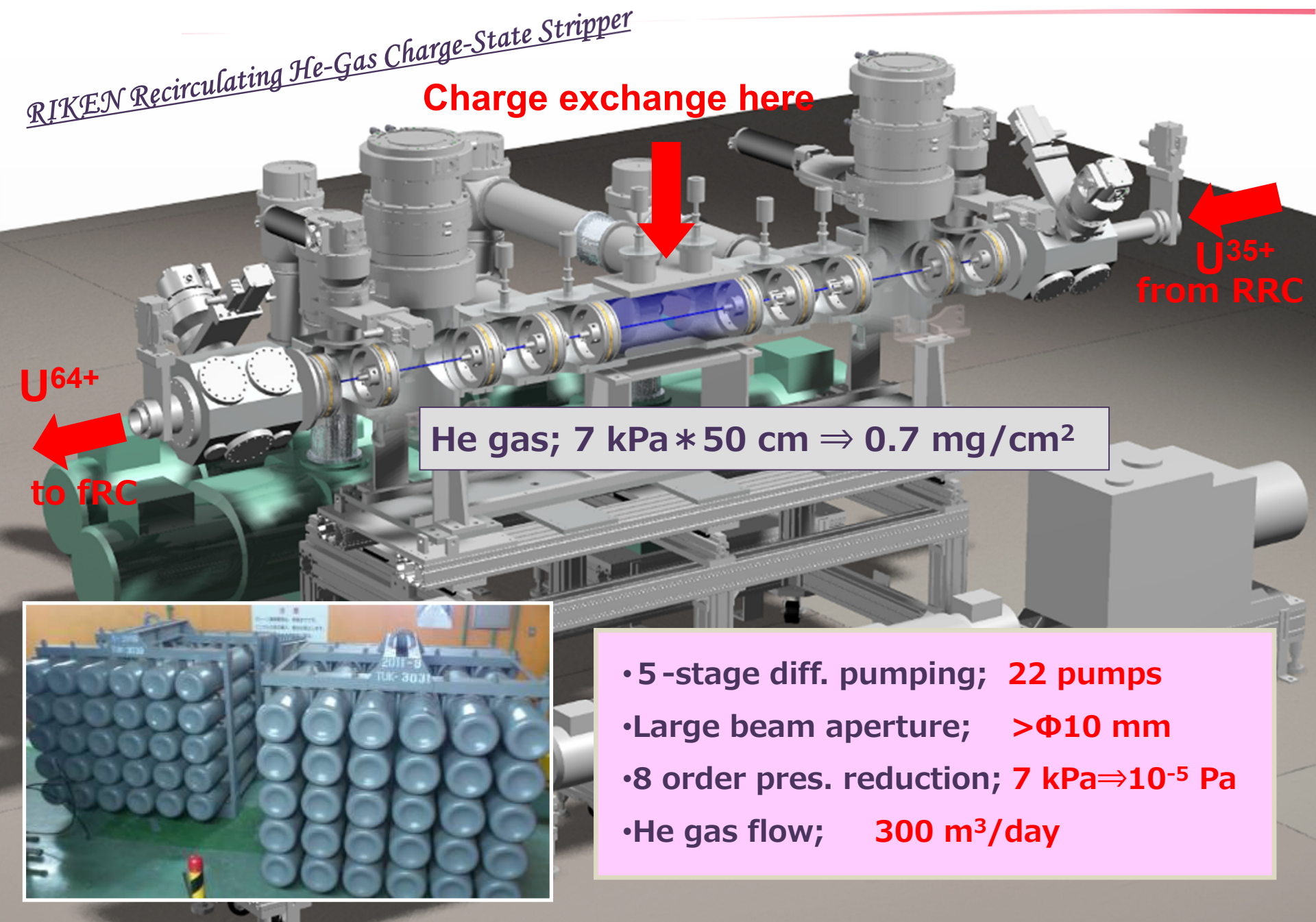
Strategies for practical system

- **acceleration for 64+ w/ fRC modification**
- target thickness reduced (**0.5-0.7 mg/cm²**)
- beam orifice enlarged (Φ6mm⇒**Φ10mm**)

2. He stripper development

Design of He gas stripper

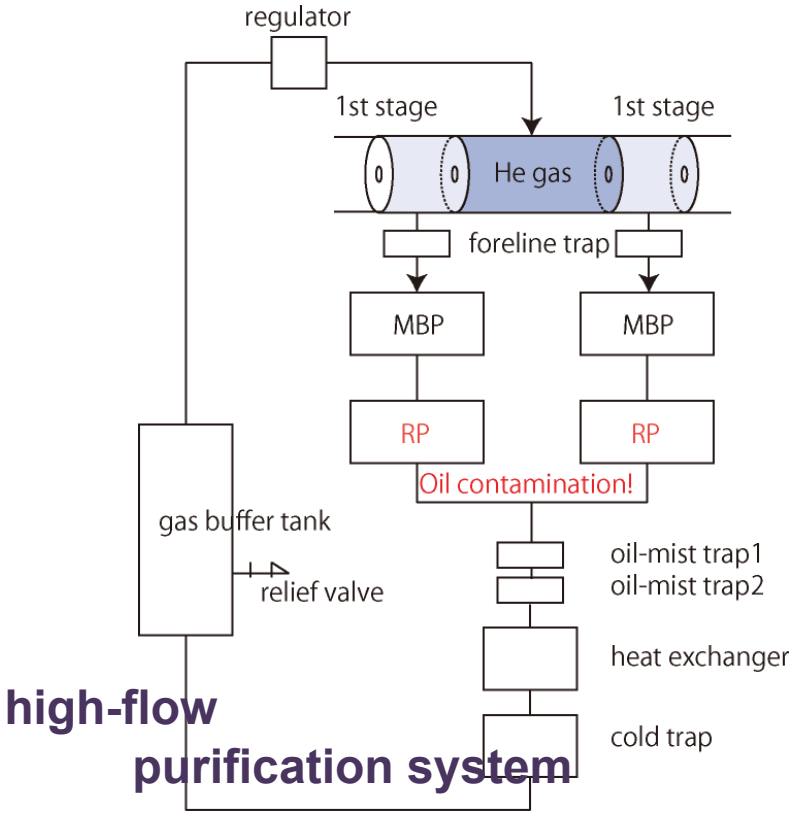
RIKEN Recirculating He-Gas Charge-State Stripper



- 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

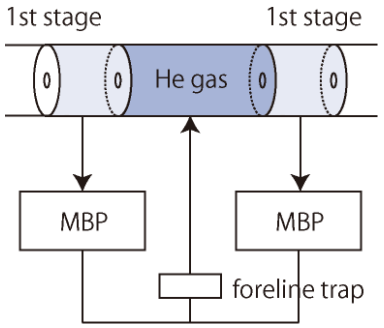
Gas recirculation with MBP

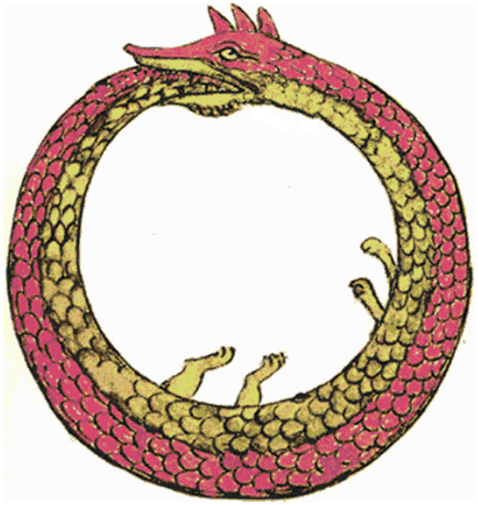
Gas recirculation w/ rotary pumps



high-flow purification system

Only w/ Mechanical booster pumps

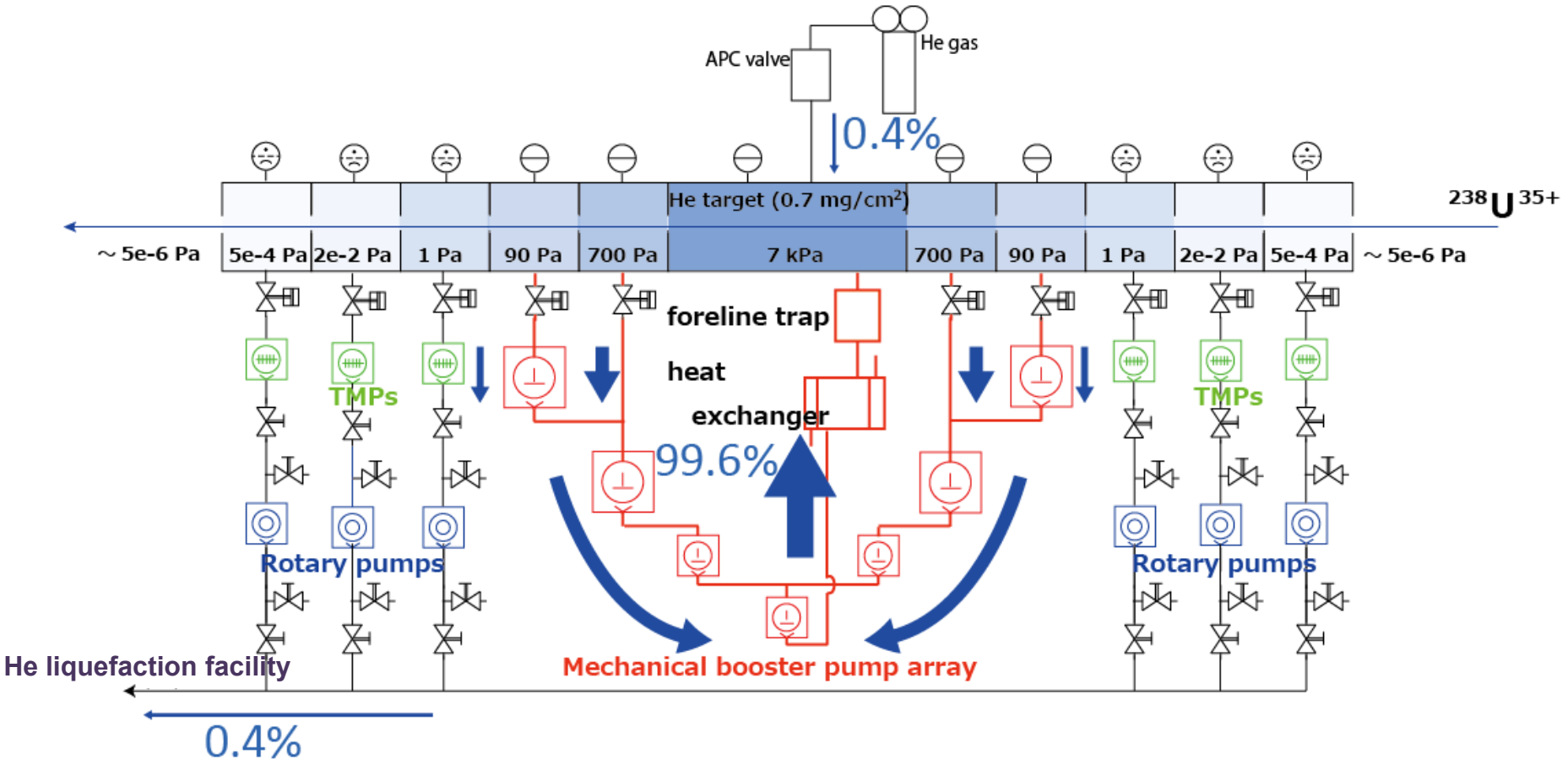




Reduce complexity of purification system

- Cost reduction
- Stable target and reliable system

Design of recirculation system



- **Multi-stage MBP array** (7 units, 12000 m^3/h)
- **Recycling rate < 99.6%**
- Target refilling rate > 0.4% （impurity、activation)
- Auto pressure control for gas supply

2. He stripper development

R&D works in 2012

High duty line & limited time !

2012 Jan. Installation

Mar. Offline tests

thickness <1 mg/cm^2

Recycle rate <99.6%

Apr.-Oct. Online tests

fRC upgrade

new beam dump

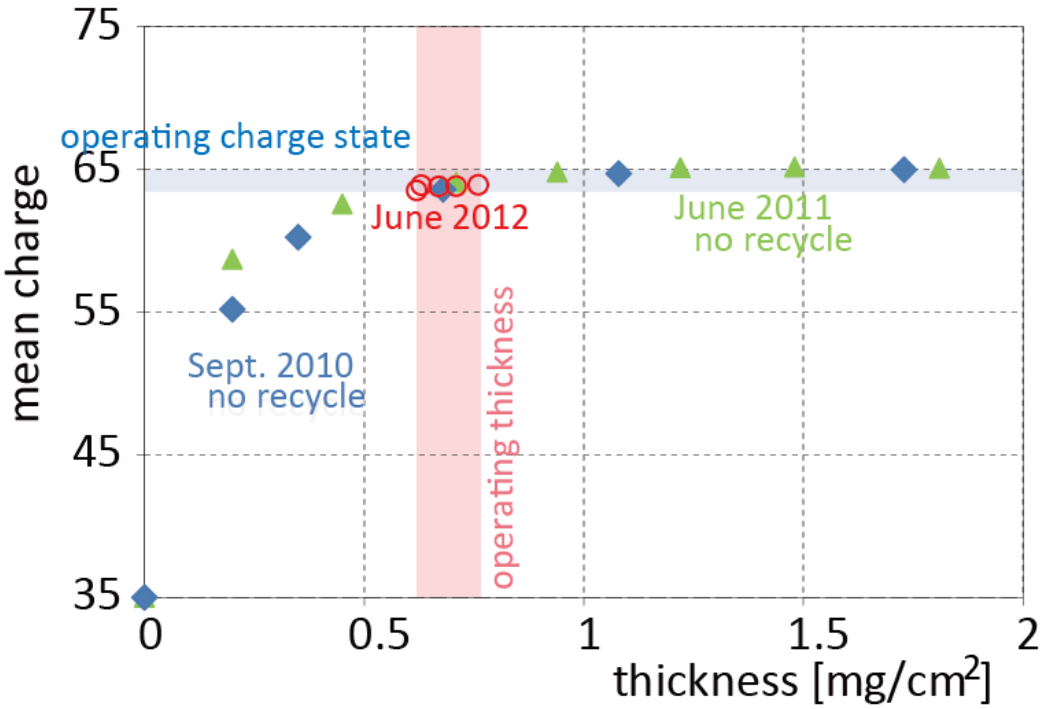
Nov.-Dec. User runs

Effect of impurity

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

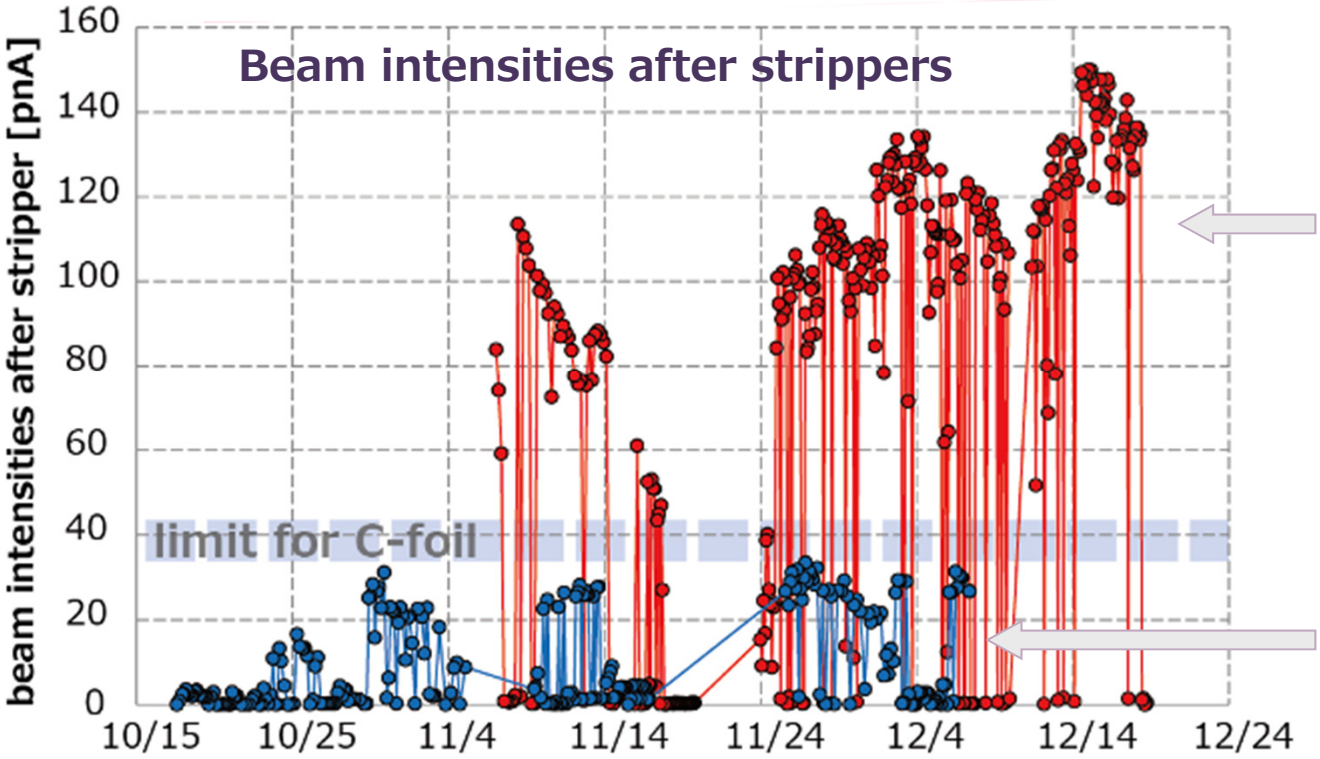
$\sigma_{cap} \propto Z^{4.2}$ (less than 100 ppm of impurity is required)

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)

User runs w/ He stripper



2012: w/ He stripper

Stably operated!

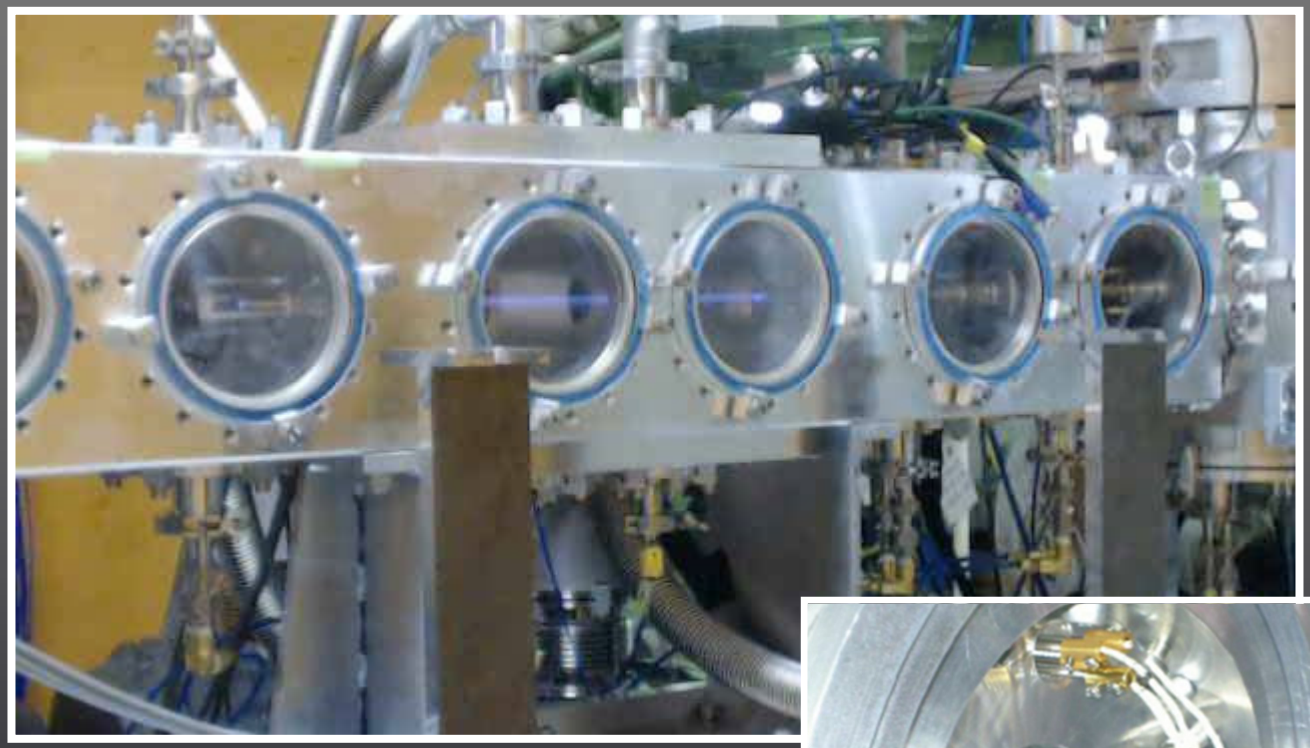
2011: w/ rot. C-foil

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



Summary

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

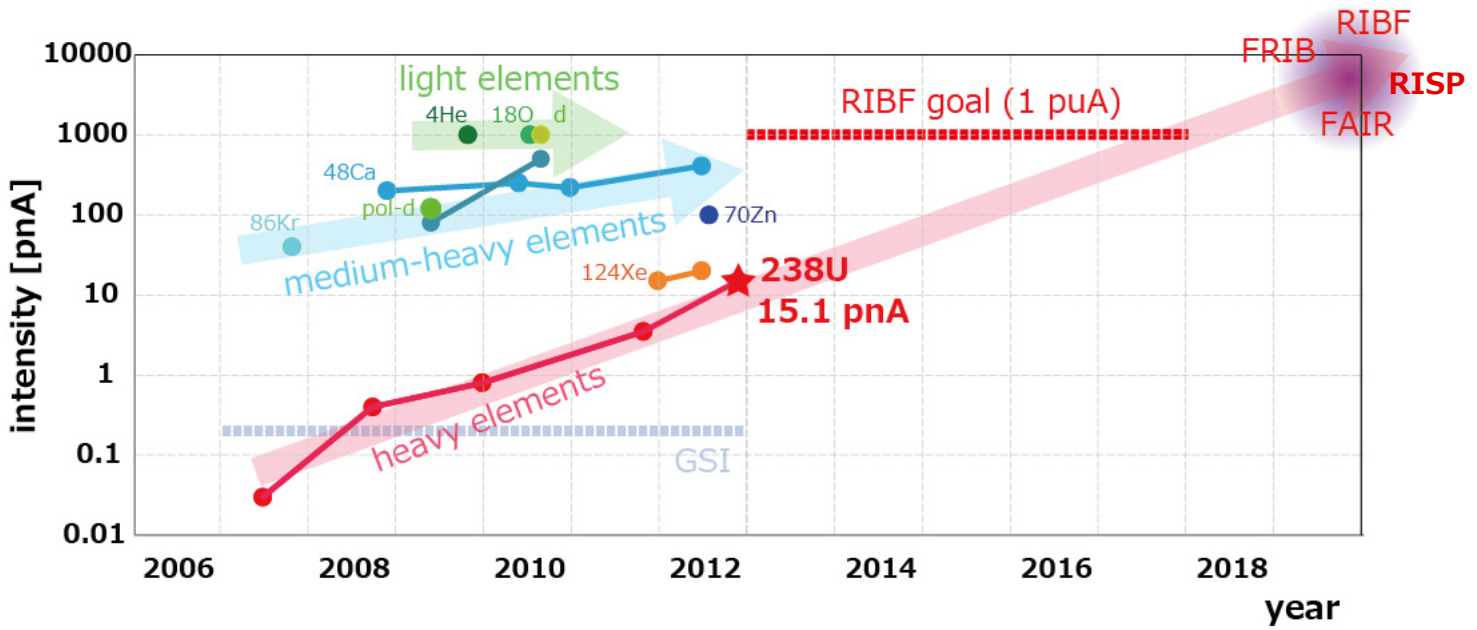
Tenfold increase of average output intensity of ^{238}U in 2012

- 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, K700-fRC, high-power beam dump, 2nd Be disk stripper etc.)



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Y. Kanai, Y. Enomoto, N. Kuroda, Y. Nagata, H.A. Torii,
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Acknowledgement

New addition is born to my family
(4 days ago during conference reception!!)

Thank you very much!

Let's discuss in poster session today THPW0038