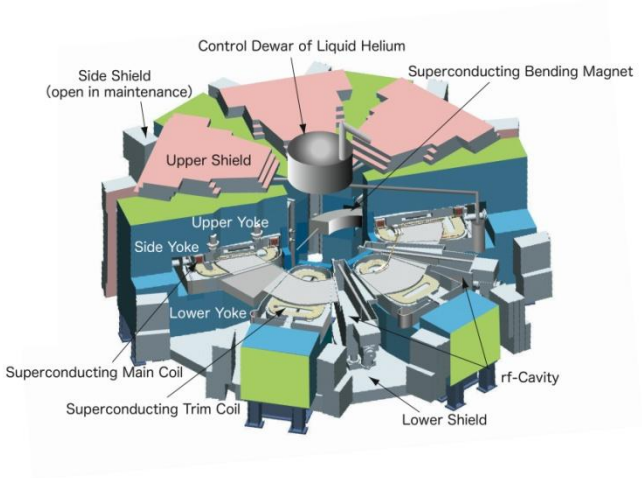
A New Possibility of Low-Z Gas Stripper for High-Power Uranium Beam Acceleration as Alternative to C Foil

Hiroki Okuno, Nobuhisa Fukunishi, Akira Goto, Hiroo Hasebe, Hiroshi Imao, Osamu Kamigaito, Masayuki Kase, Hironori Kuboki, Yasushige Yano
(RIKEN Nishina Center, Wako)
Ady Hershcovitch
(BNL, Upton, Long Island, New York),

Preview of the Talk

Introduction to RIBF



Upgrade programs
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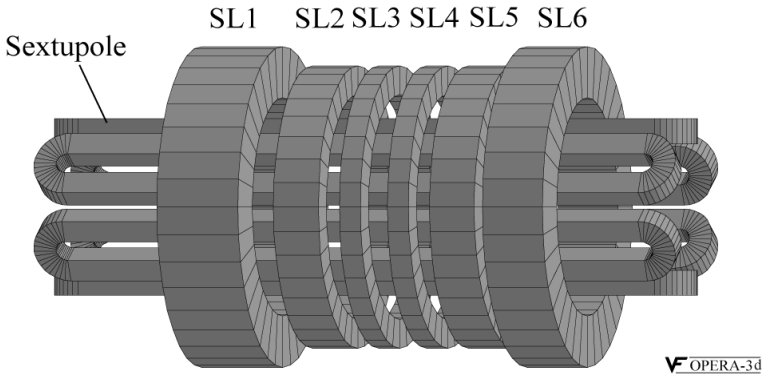

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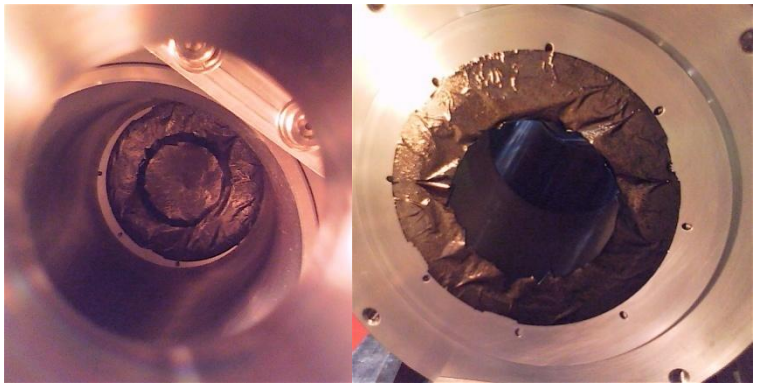
(C-foil on rotating cylinder and Gas (N_2))



Low-Z gas stripper

Introduction RIKEN RI Beam Factory (RIBF)

The Old Facility (1975~1990)

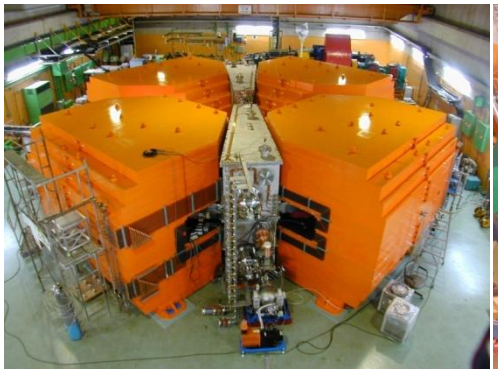
RRC

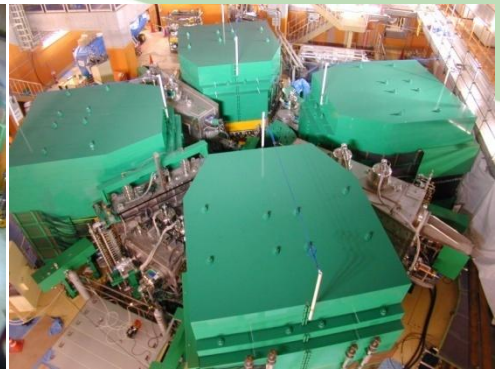
RILAC

ECRIS

RIBF

(1997~(2012))





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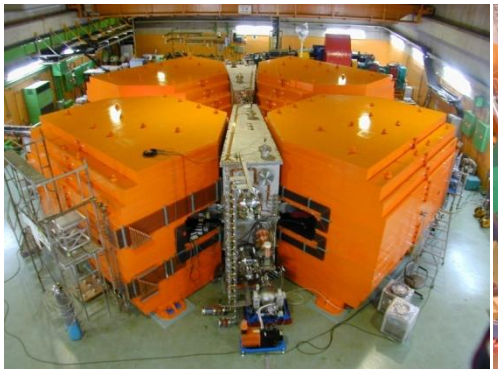


History of RIBF

1997-: Construction started.

2003 March: The building for the accelerator was completed. Installation was started.

2005 Nov.: Successful Excitation of the superconducting sector magnets for SRC

2006 28th Dec: The first beam from SRC

2007: 2008: 2009: 2010: Improvement, improvement, improvement…

Beam Intensities achieved so far (Goal 1 pμA)

• pol-d(250 MeV/u) :	120 pnA : May2009	Mode 3
• ^{4}He(320 MeV/u) :	1000 pnA : Oct2009	Mode 1
• ^{14}N(250 MeV/u) :	80 pnA : May2009	Mode 3
• ^{18}O(345 MeV/u) :	1000 pnA : June2010	Mode 1
• ^{48}Ca(345 MeV/u) :	230 pnA : May 2010	Mode 1
• ^{86}Kr(345 MeV/u) :	30 pnA(<1min) : Nov2007	Mode 1
• ^{238}U(345 MeV/u) :	0.8 pnA : Dec2009	Mode 2

Key issues to increase the intensity of U beam

- Increase the beam intensity from the ion source
  - New 28 GHz Superconducting ECR ion source
  - Goal intensity of U^{35+} >15 pμ A (1pμA @ SRC)
  - Developments for U beam are in progress.
- Improve transmission efficiency
  - New injector (Efficient acceleration in the low energy region)
  - Avoid the emittance growth due to the space charge.
- Make charge strippers with long lifetimes
  - The 1st stripper is critical.
  - Max. lifetime ~12 hrs @1000enA after RRC
  - R&D programs : Rotating, Gas

New 28 GHz Superconducting ECR ion source (Nakagawa et. al.)

Design:

Flat B_{min} configuration

Large plasma volume: 1100 cm^3

Construction:

started in Oct. 2007

Successfully excited to the designed field in October 2008.

Developments for U beam (18 GHz mode):

Dec. 2008 : Installation

April 2009-- : Start

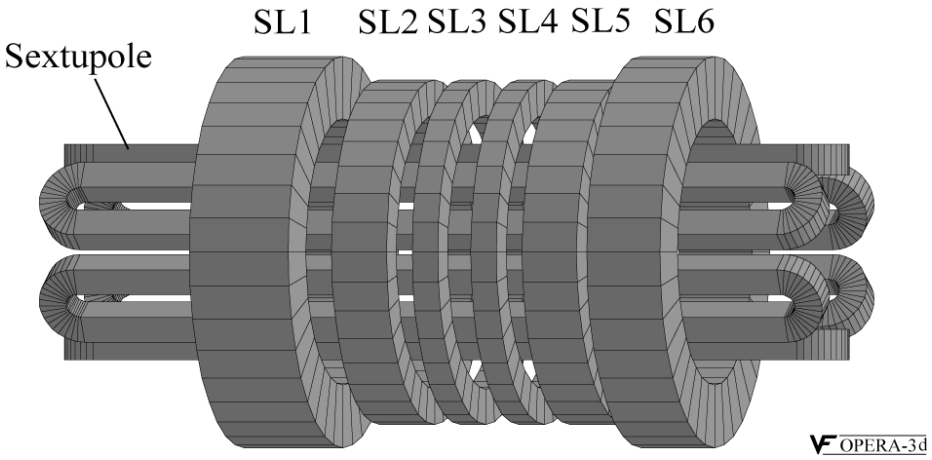
Nov. 2009 : U^{35+} 10 euA (~5 times)

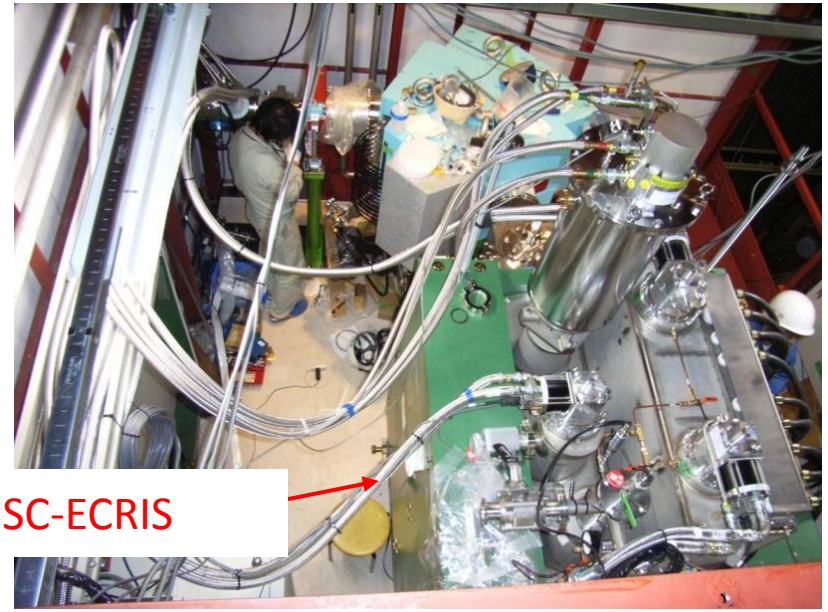
Move to the upstream of the New Injector:

Finished (Summer 2010)

Upgrade to 28 GHz

in progress (Autumn 2010).





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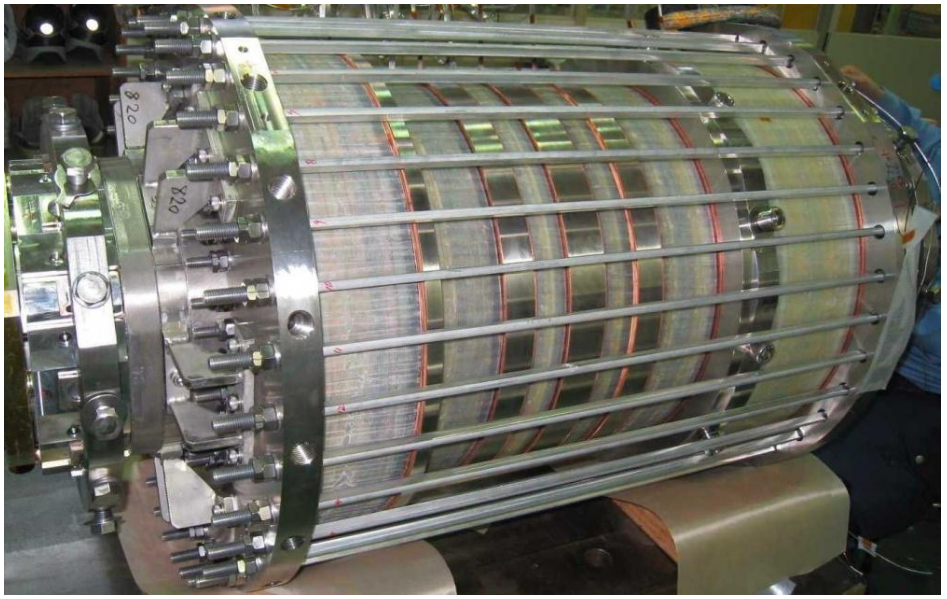

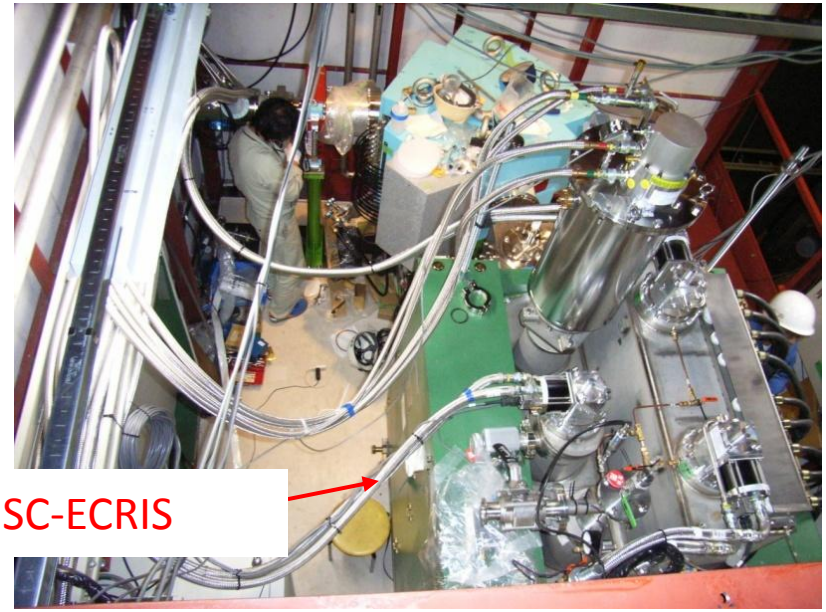

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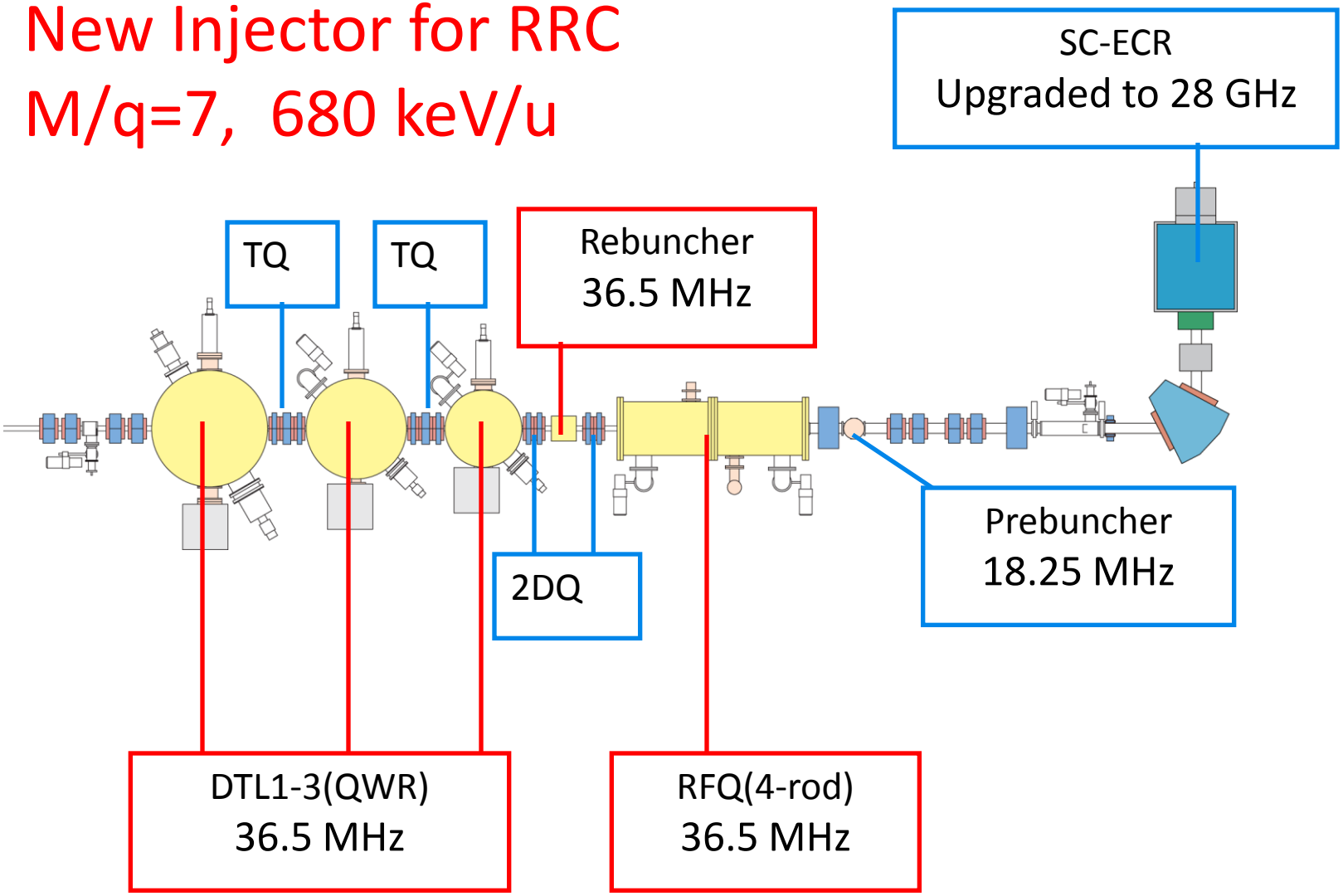
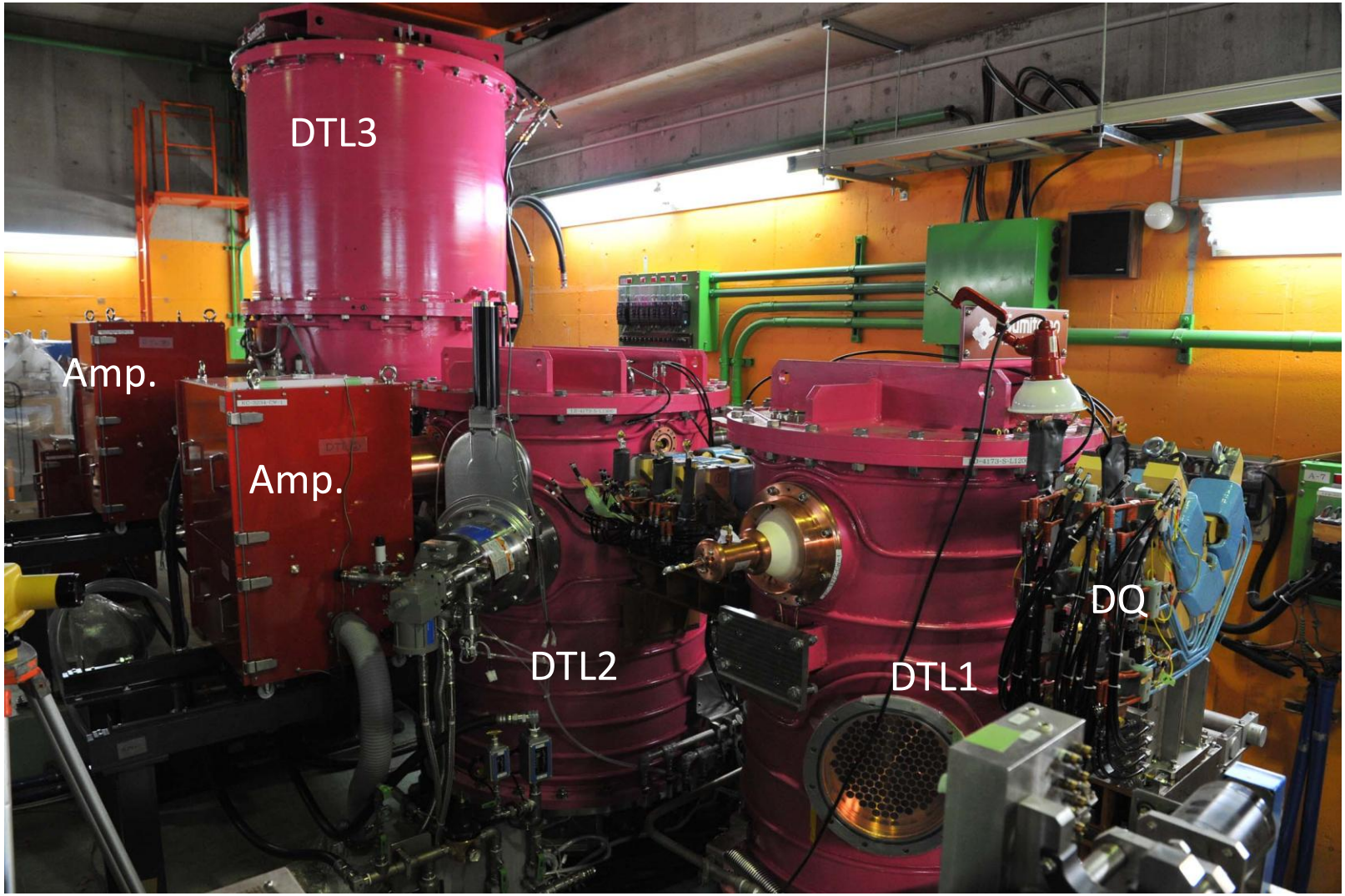
- Make charge strippers with long lifetimes
  - The 1st stripper is critical.
  - Max. lifetime ~12 hrs @1000enA after RRC
  - R&D programs (2008~): Rotating, Gas

New Injector for RRC
M/q=7, 680 keV/u



Fabrication of the main components was completed in FY2009.

New Injector (RILAC2) in the AVF room



Beam commissioning will start from Dec. 2010!

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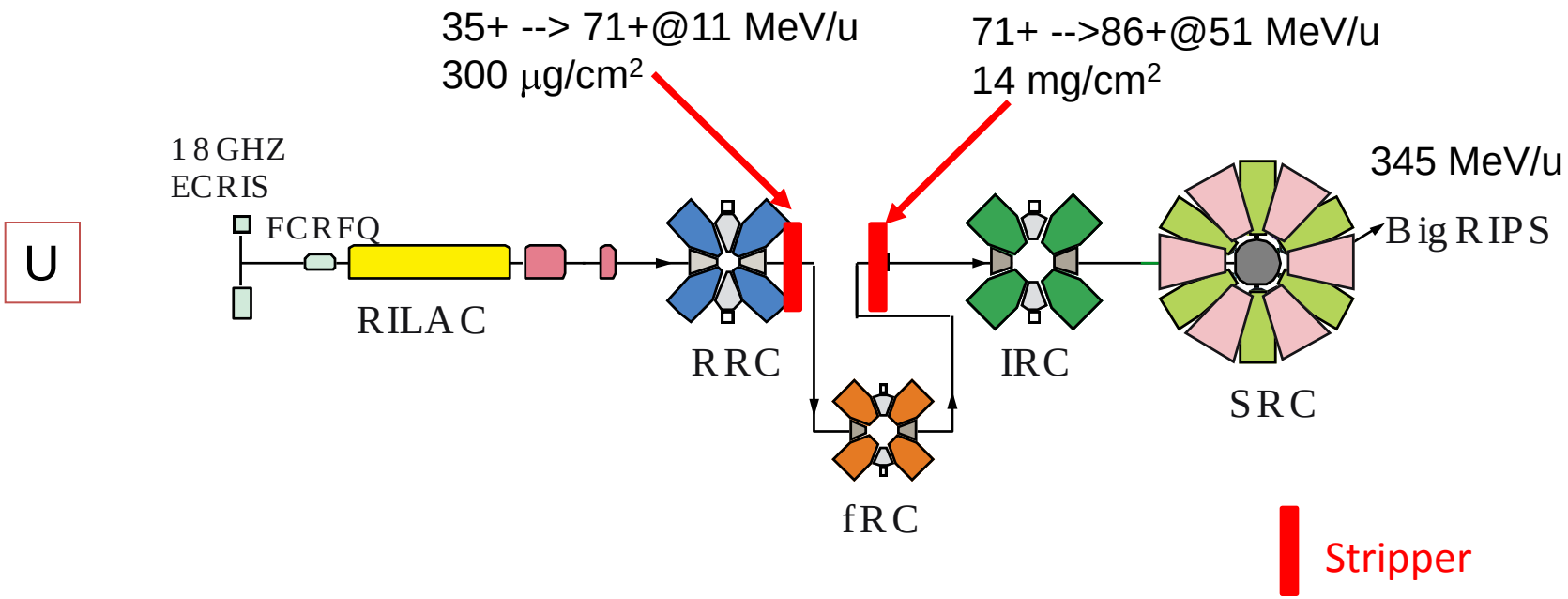
Charge strippers in Uranium Acceleration



The 1st stripper : Commercially available C-foils are usually used.

=> Lifetime: 12 hours (1.4 eμA)

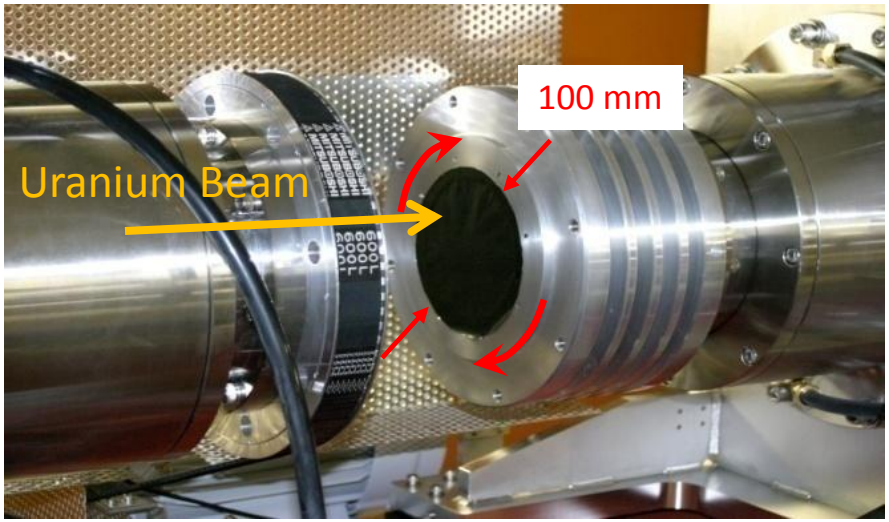
The present intensity	: No problem
>The present intensity x 100	: Serious Problem! → much stronger strippers

R&D programs for the 1st stripper (2008-)

Carbon foil:

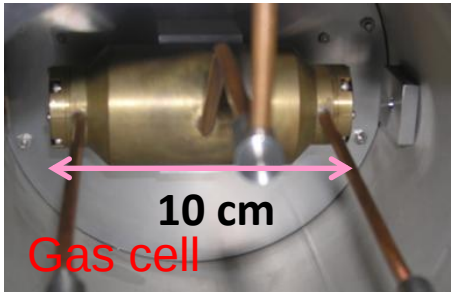
Large Carbon foils on a rotating cylinder.
60 times longer lifetimes than
that of the fixed foil.

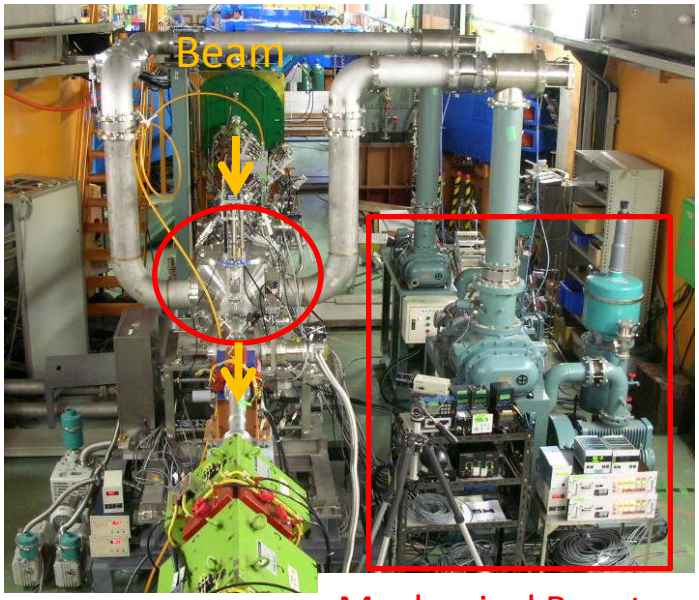
A opened view



Gas stripper (N_2):

1. Free from lifetime related problems.
2. Lower equilibrium charge state Qe.
(density effect)
3. Measurement of Qe using a gas target with differential pumping system.



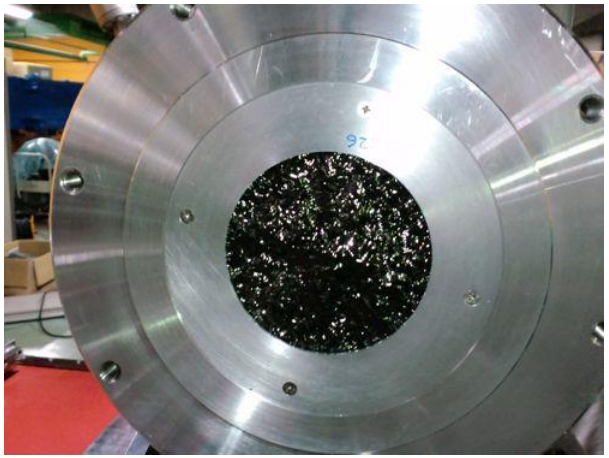


Mechanical Booster pumps

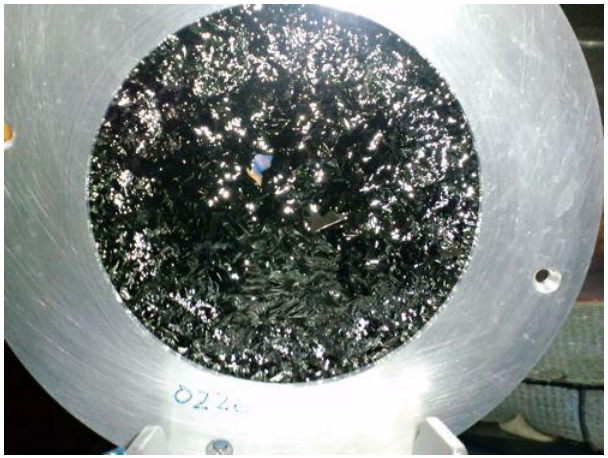
The first test of a rotating stripper (May 2008)

A foil on the rotating cylinder was tested in May 2008 => Broke shortly, 15 min
Rotation speed ~ 100 rpm

Slowly rotating (0.05 rpm) foil (Mar. 2010)



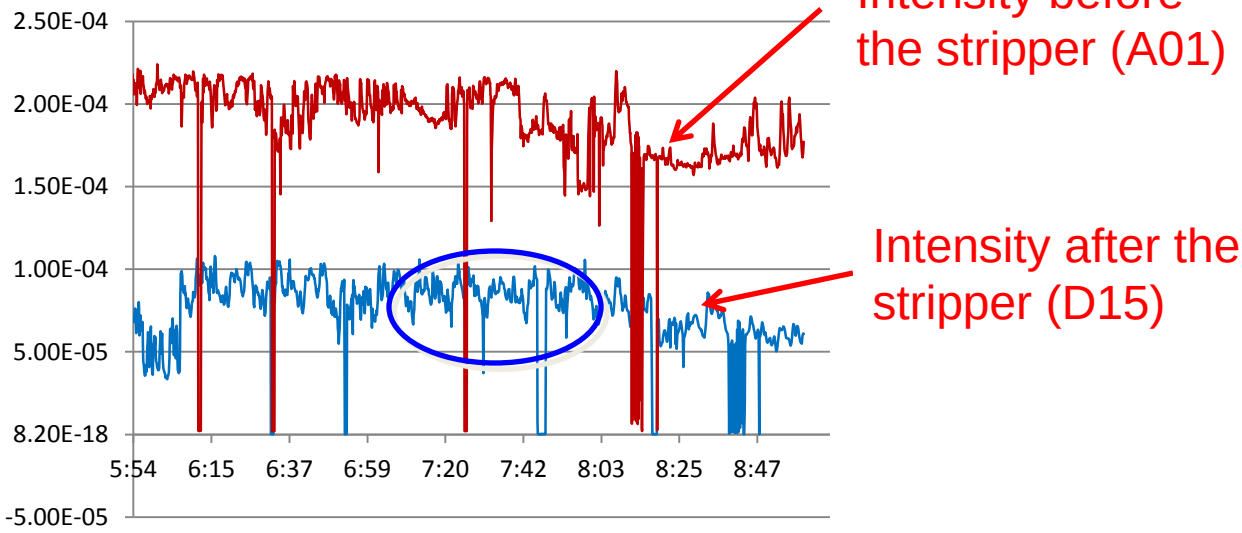
Before irradiation



After irradiation

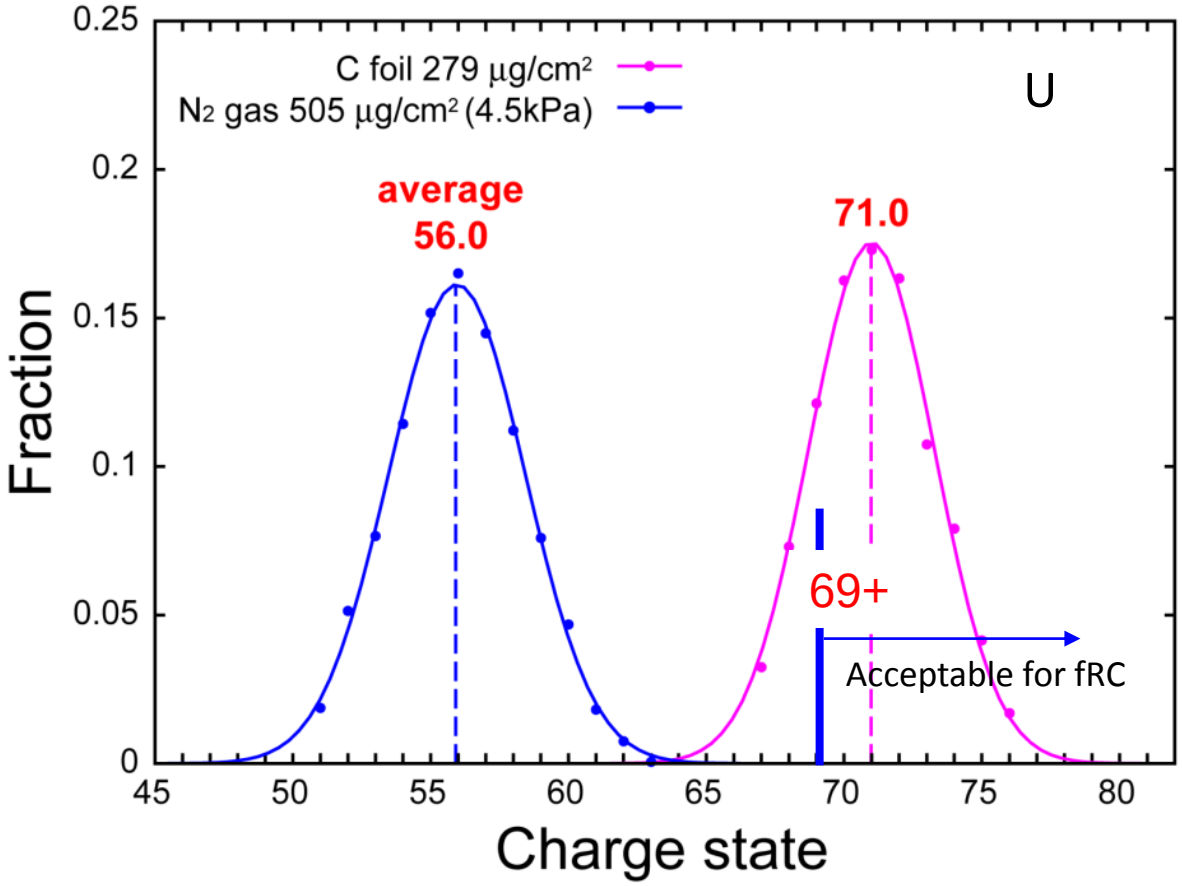
38 hours @ 1.7 eμA => Survived!

However,..



Test of the gas stripper (Feb./March 2009)

- U beam: The average charge state with the gas stripper was far below the acceptable state for the fRC.



Merits of gas stripper: long lifetime, uniform thickness →

What can we do to get higher charge state in gas?

- Higher stripping energy
  - Qe measurements at (11), 14 and 15 MeV/u.
  - Qe = 56 (11 MeV/u), 61 (14 MeV/u), 62 (15 MeV/u).
  - 22 MeV/u is necessary to get 69+ as Qe.

    (cf. The present stripping energy is 11 MeV/u)
  - Huge remodel of the accelerators before and after the stripper .
  - Such remodel will cost more than $ 10M.
- Different material
  - Low-Z gas (H_2 and He)

Examples of charge state of U in He or N_2 (50 MeV/u)

Effective charge

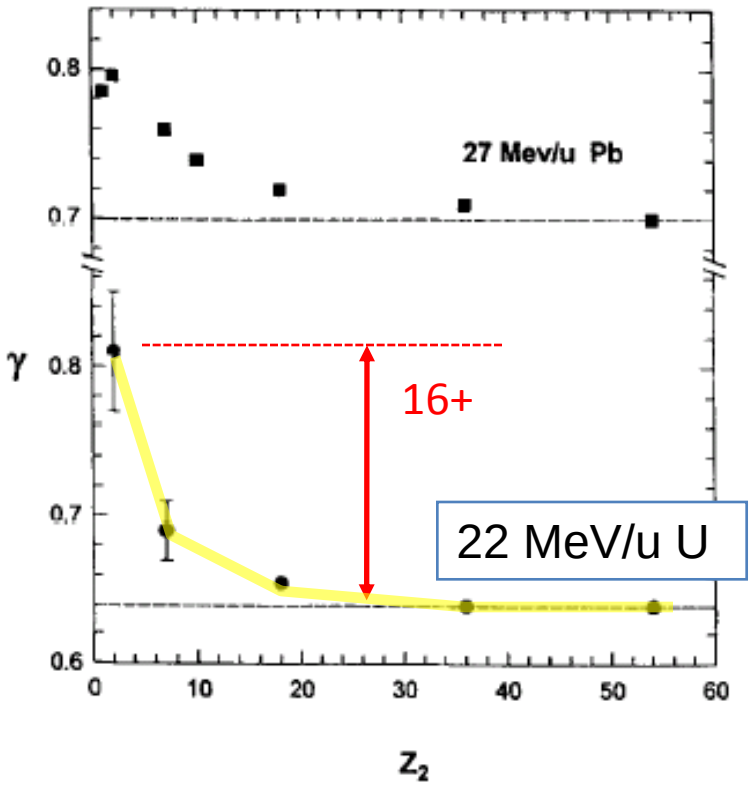


Fig. 6. Same as Fig. 3 for 27 MeV/u Pb and 22 MeV/u U ions.

NIMB 107 (1996) 9

Equilibrium charge state

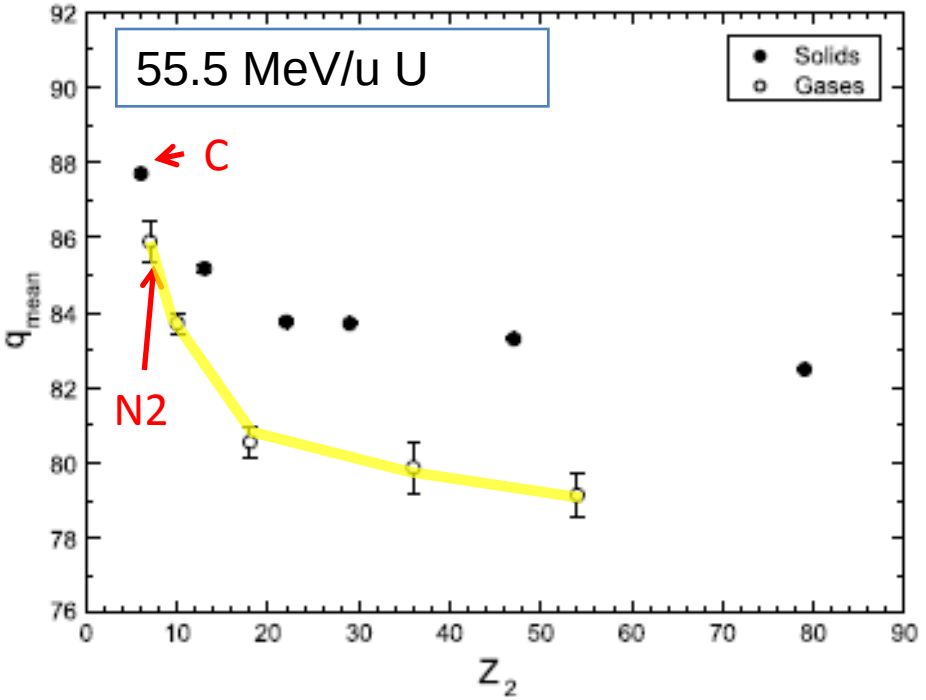


Fig. 2. Mean charge of uranium ions at 55.5 MeV/u passing through gases and solids as function of the target atomic number (Z_2). Note that not in all materials equilibrium was reached.

NIM B 245 (2006) 32

Mechanism to get higher charge state

1: Equilibrium charge state Qe is determined by competition between e-loss and e-capture.

2: Capture cross sections strongly depend on the Vp (ion velocity) compared with that of the target electrons.

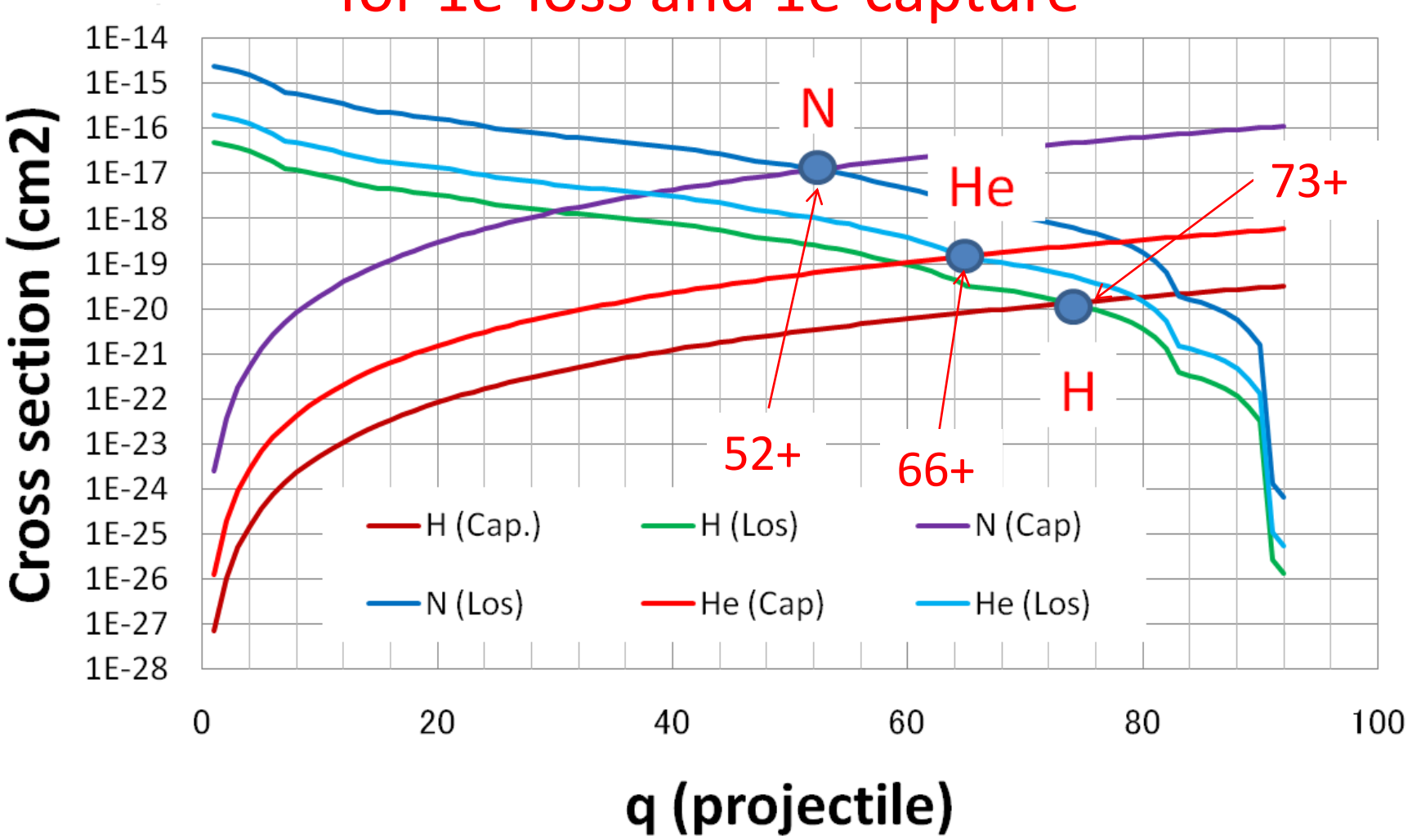
3: e-Capture is highly suppressed due to bad kinematical matching when Vp >> V1s (the fastest target electron).

4: Suppression of e-capture is expected in the case of low Z region or higher ion velocity because V1s ~ Z/137.

5: Qe will be higher in low-Z region.

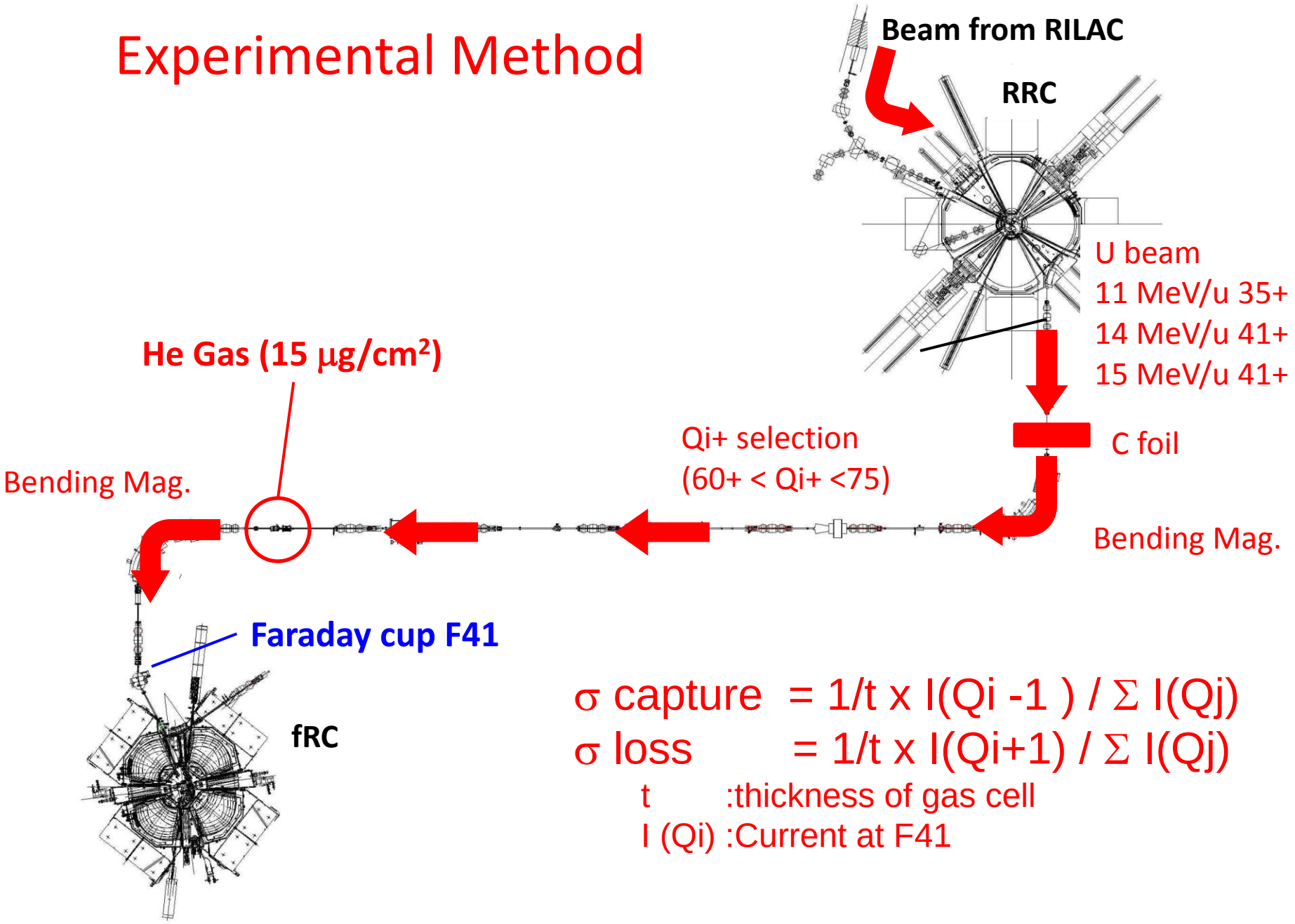
Case	Ion @ Energy (MeV/u)	Target	Vp/V1s	result
1	U @ 22	He	14.9	Qe (He) = Qe (Ar)+16
2	U @ 55.5	N_2	6.8	Qe (N_2) = Qe (C) - 2
3	U @ 11	He	10.4	Similar to Case 1,2?
4	U @ 11	N_2	3.0	Not similar to Case 1,2?

A simple estimation of cross section for 1e-loss and 1e-capture



Loss: M. Gryzinski, Phys. Rev. 138 (1965) A305. (Binary Encounter Model)
Capture: A.S. Schlachter, et. al., Phys. Rev. A 27 (1983) 3372.

Experimental Method



σ capture $= 1/t \times I(Qi-1) / \Sigma I(Qj)$

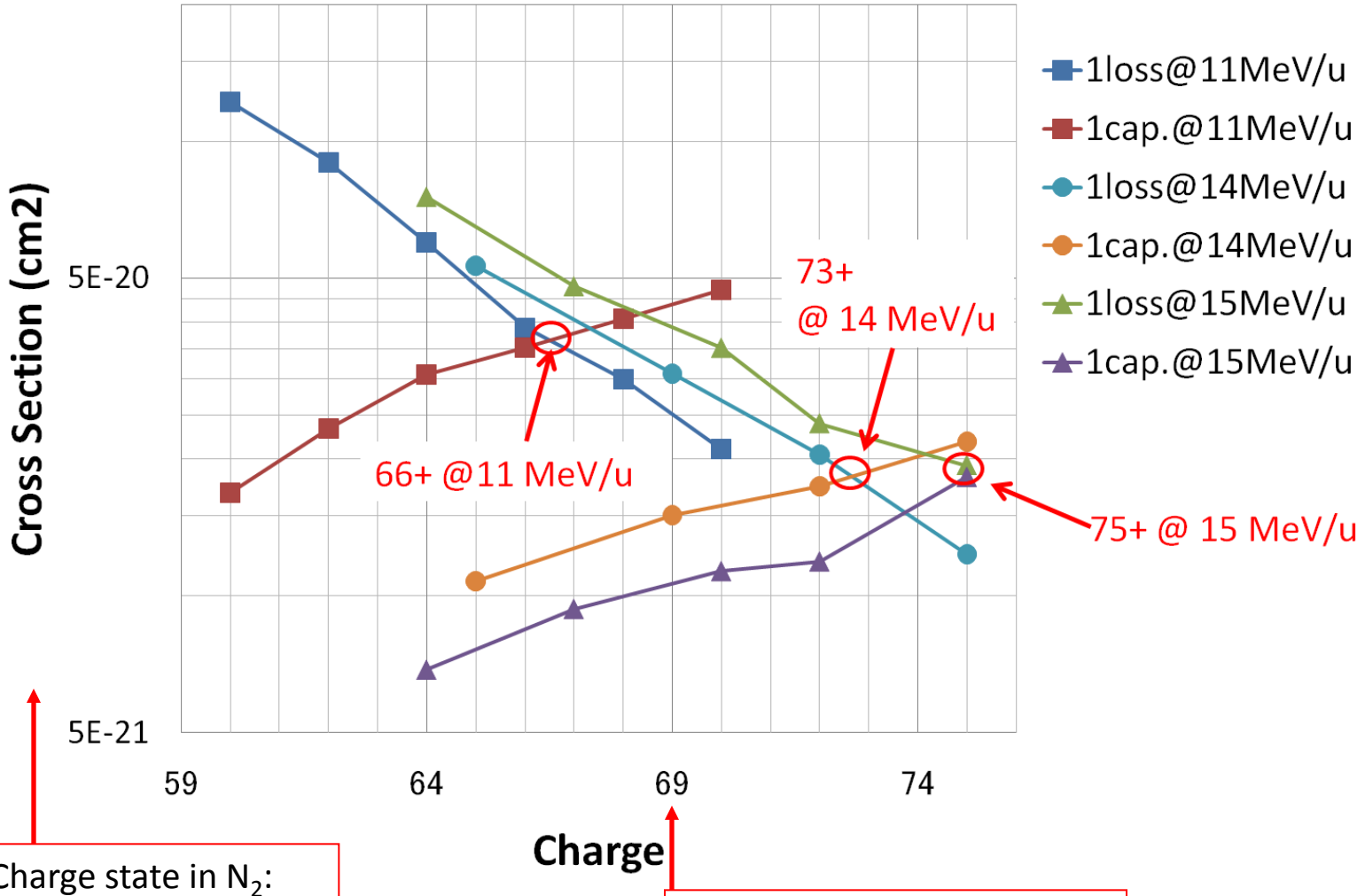
σ loss $= 1/t \times I(Qi+1) / \Sigma I(Qj)$

t :thickness of gas cell

I (Qi) :Current at F41

Measured Results

Electron capture and loss cross sections of U in He-gas were measured to estimate the equilibrium charge state.



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

Acceptable with fRC: 69+

Difficulty in accumulation of low-Z gas

The existing gas stripper : He ～15 μg/cm^2 (0.7 kPa)

(cf. N_2 1.3 mg/cm^2)

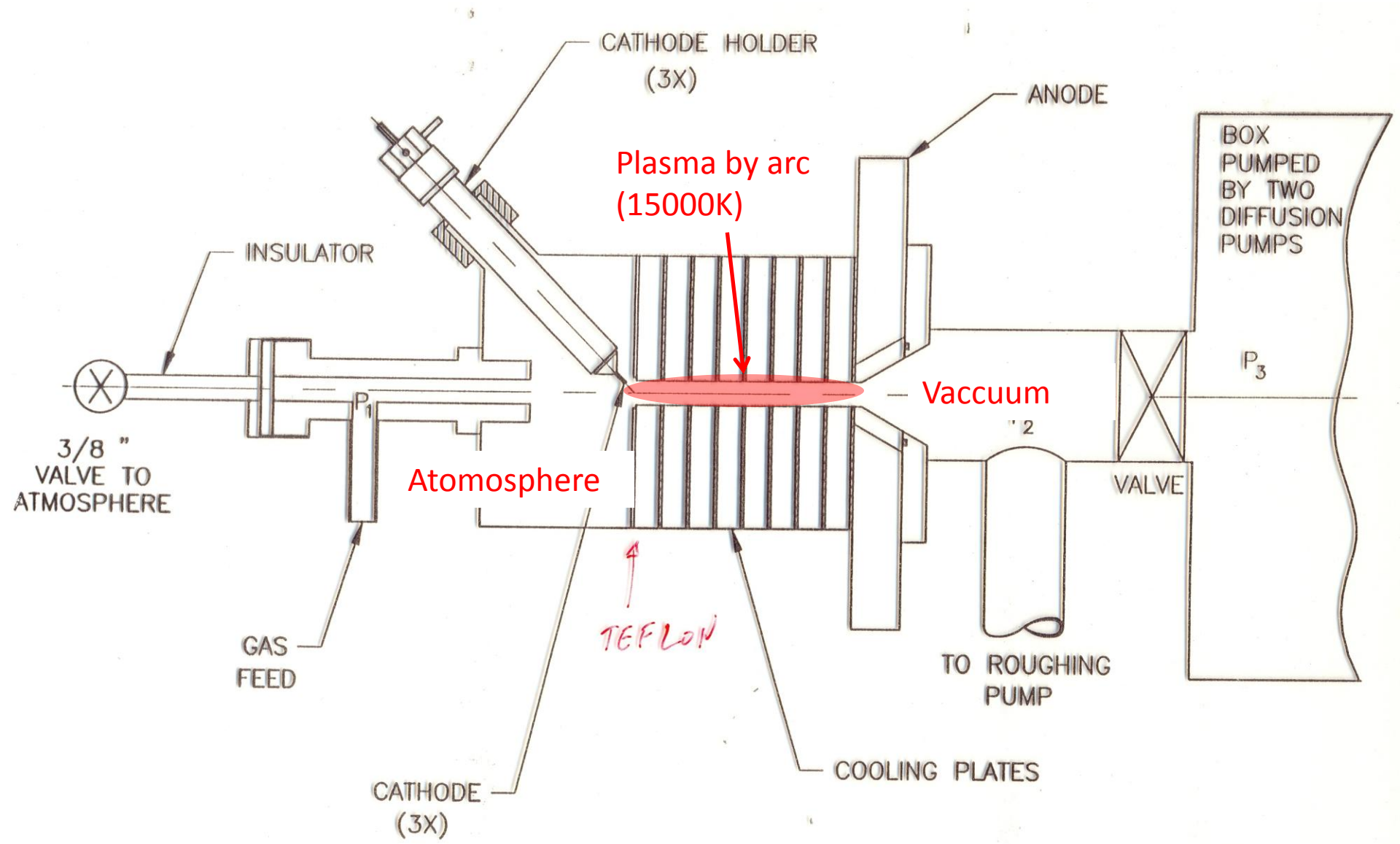
~1mg/cm^2 of low-Z gas is necessary to be accumulated to get higher charge state.

→ *A new device to make it possible …*

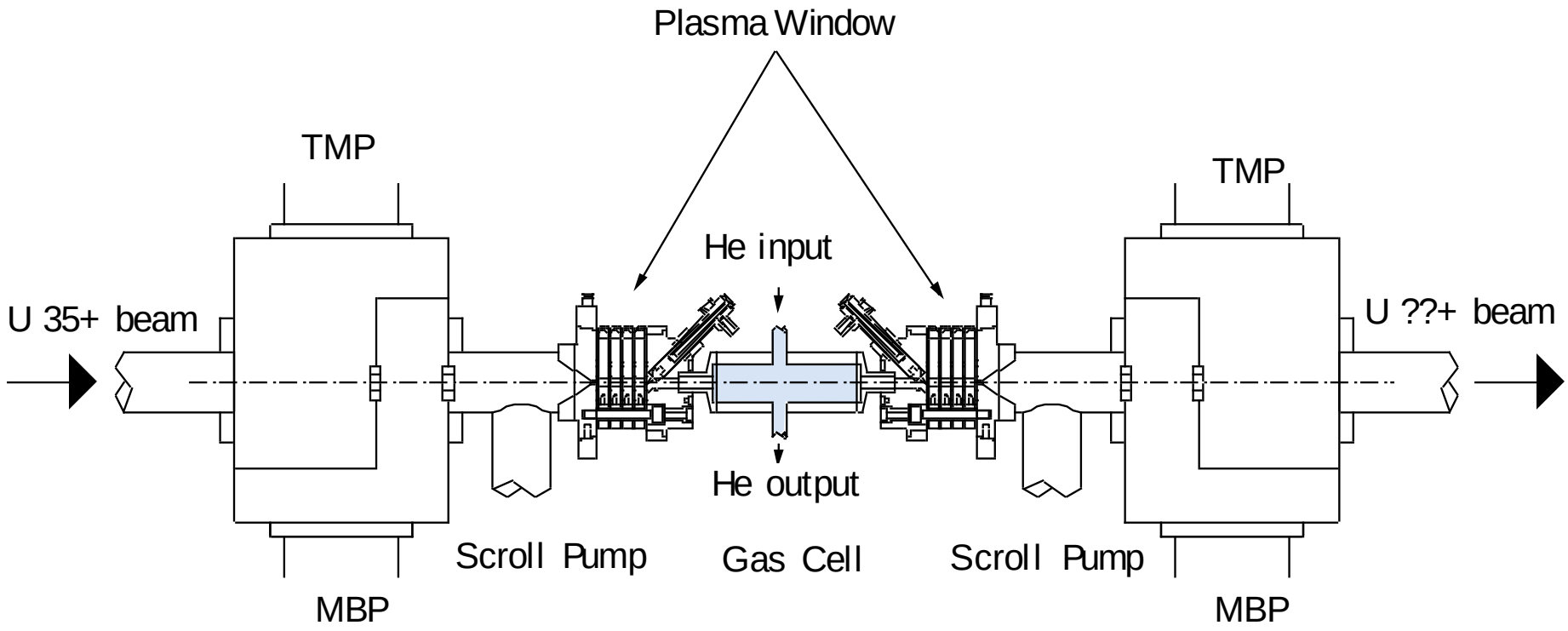
Plasma Window (1995-)

Inventor : Ady Hershcovitch (BNL)

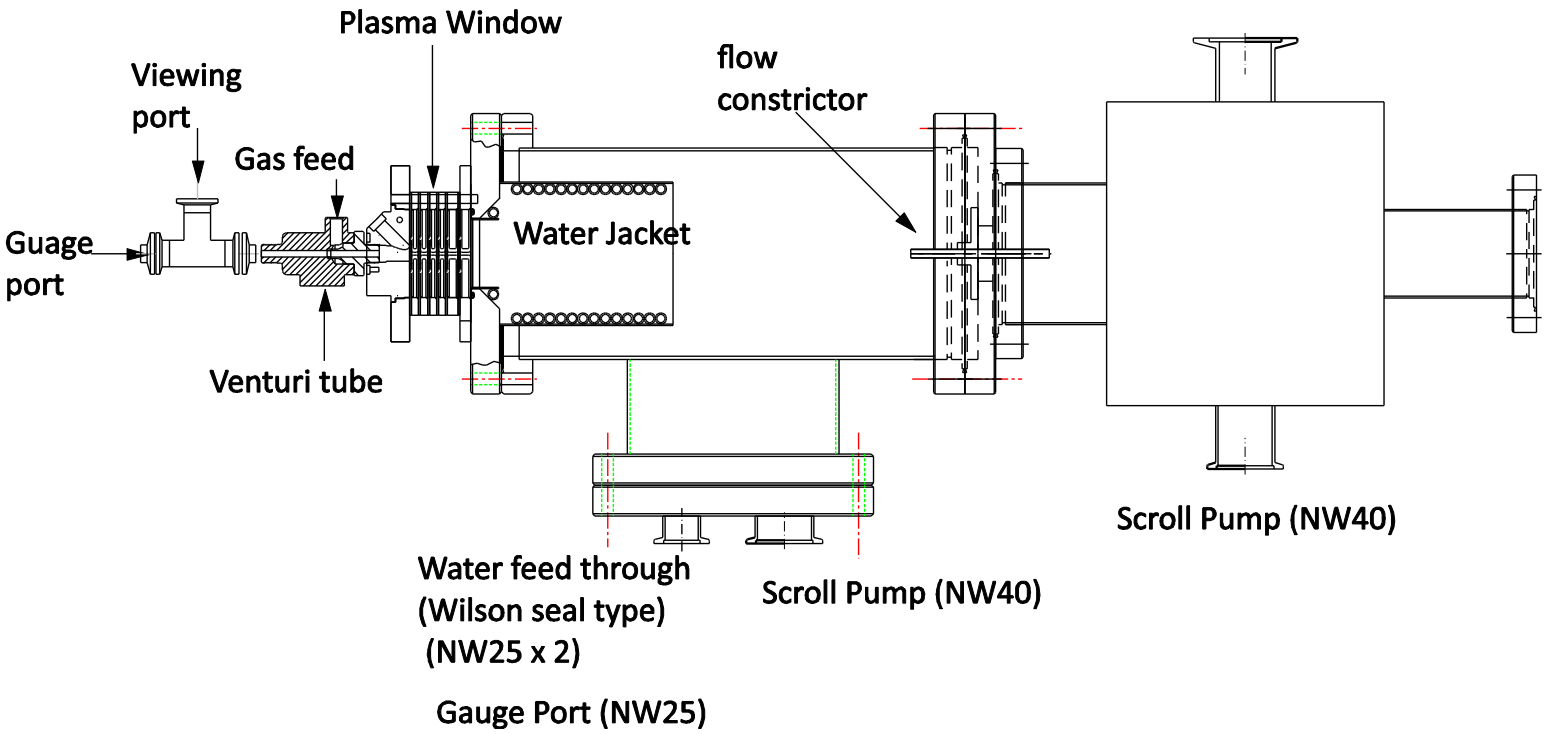
Plasma Window (Wall Stabilization Theory)



Schematic sketch of the low-Z gas stripper using two plasma windows



R&D 1: Plasma Window (-March 2011)



R&D 2 : Ar → He (H_2), d = 2 mm → 6 mm (2011)

R&D 3 : gas cell with the two plasma windows for offline test (2012)

Review of the Talk

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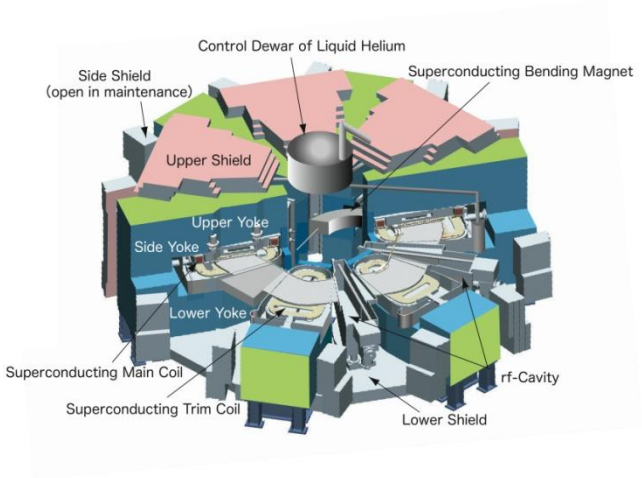

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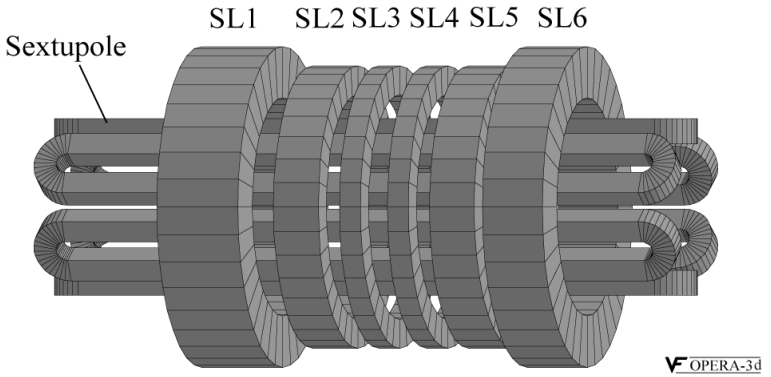

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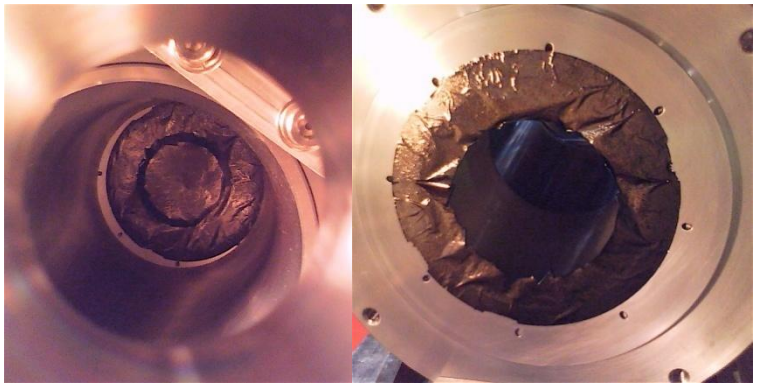
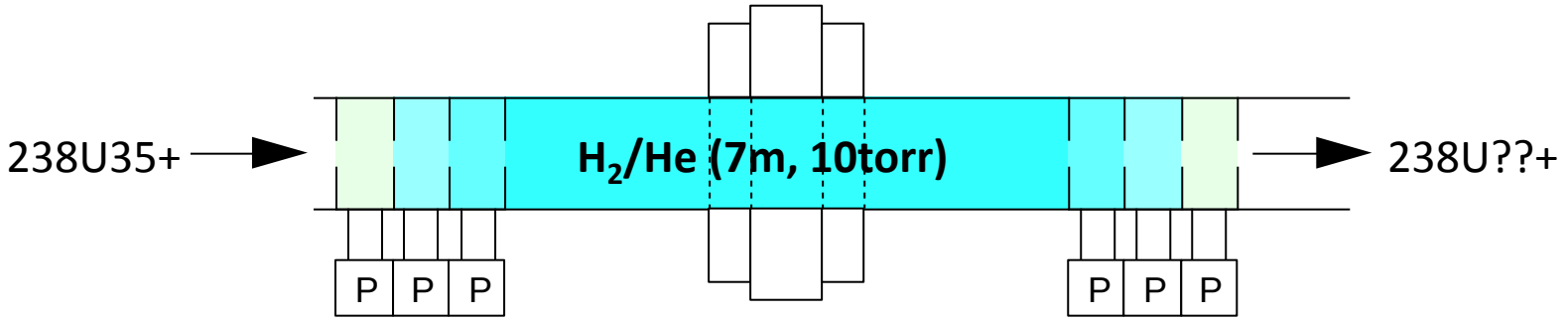


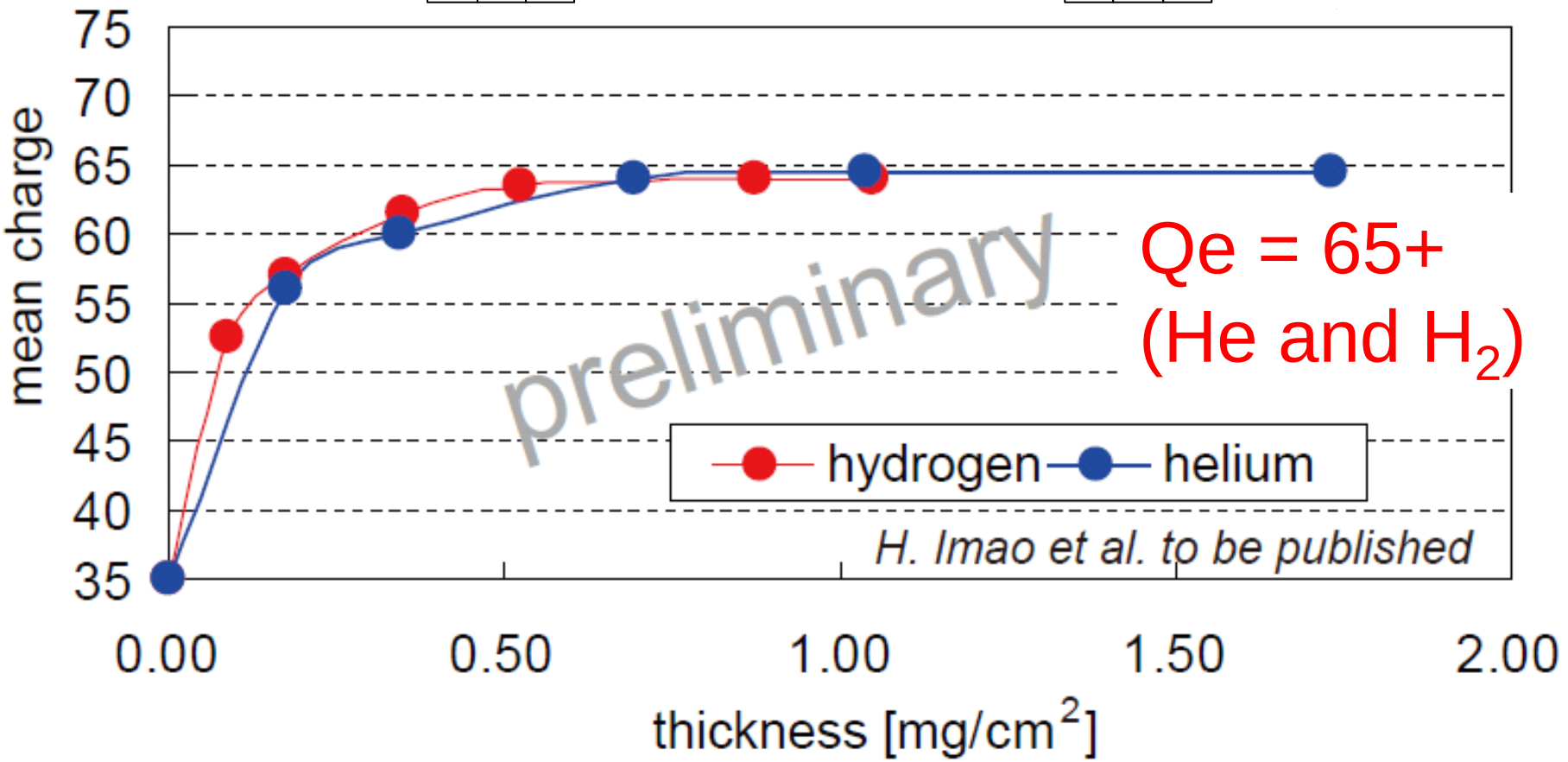
Low-Z gas stripper

Summary

- The operation of RIBF after the first beam was very successful from 2007 to 2010.
- The new 28 GHz superconducting ECR ion source and the new injector are now ready to increase intensity of uranium beam.
- Stripper problem is still open.:
  - large foil on rotation cylinder, N_2 gas stripper.
- Low-Z gas stripper is one of the candidates.
- We believe that the plasma window may solve difficulty in accumulation of low-Z gas.

Measurements of Equilibrium Charge State in Low-Z Gas using a Long Gas Stripper (9/24-9/26)





Qe = 65+
(He and H_2)