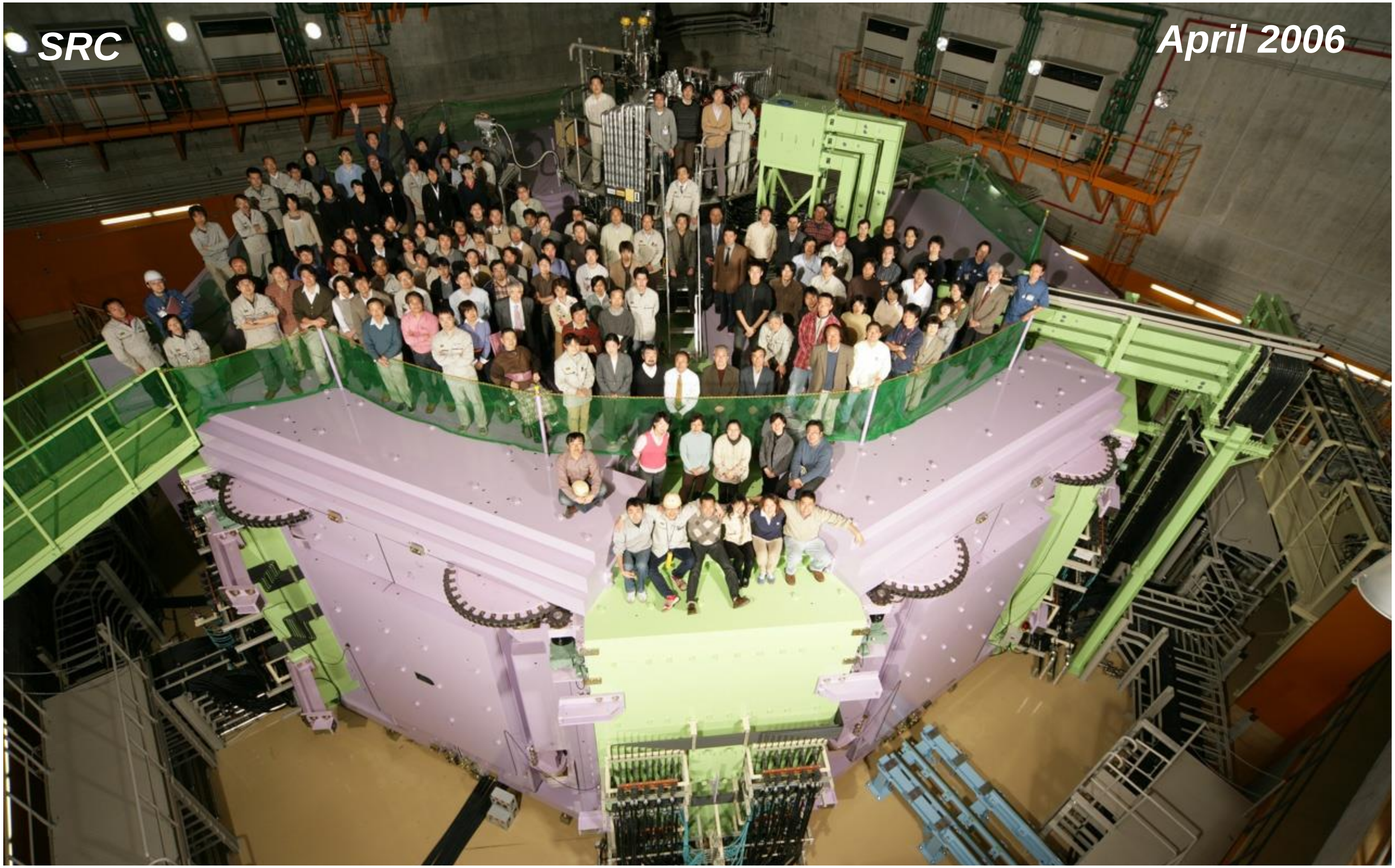
Charge strippers and target for Radioactive Ion Beam Factory (RIBF)



RIKEN Nishina Center for Accelerator-Based Science

Hiroki Okuno

Charge strippers and target for Radioactive Ion Beam Factory (RIBF)

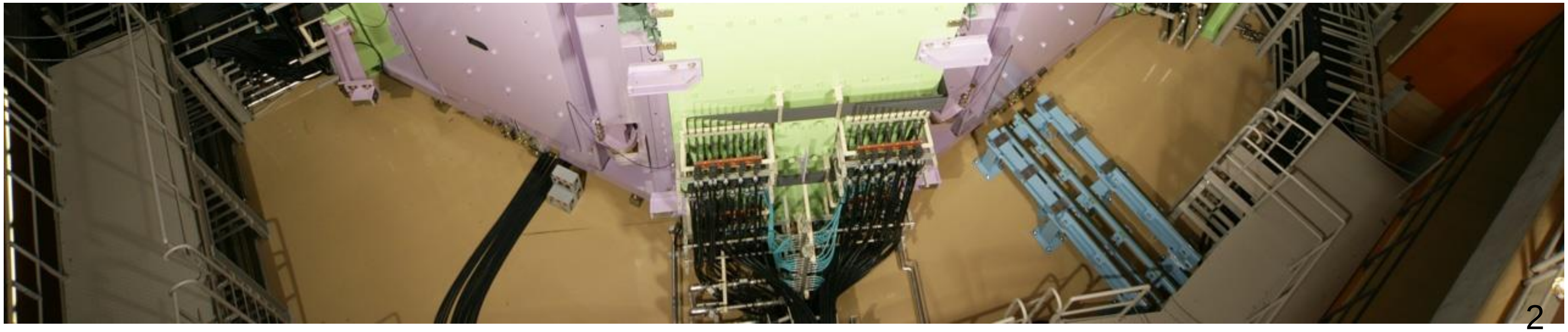
Co-authors

Cyclotrons, Stripper: Hiroki Okuno

He gas stripper: Hiroshi Imao

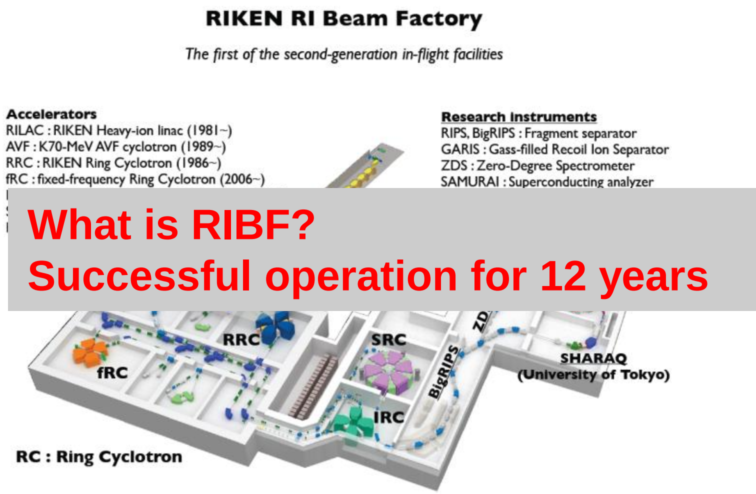
Carbon foil stripper: Hiroo Hasebe

BigRIPS team leader: Koichi Yoshida



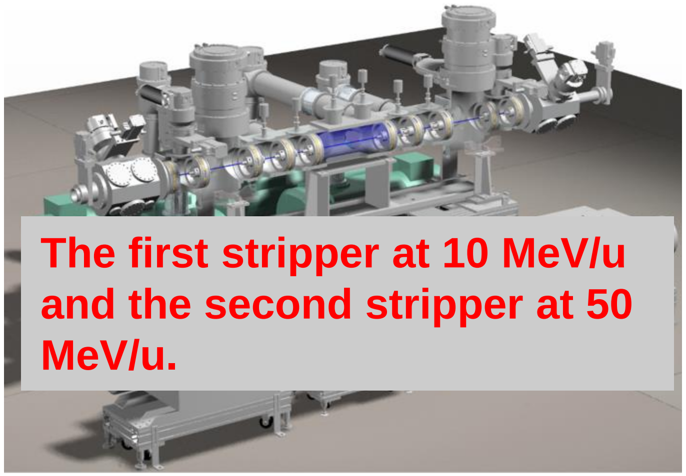
Preview

Introduction to RI beam factory



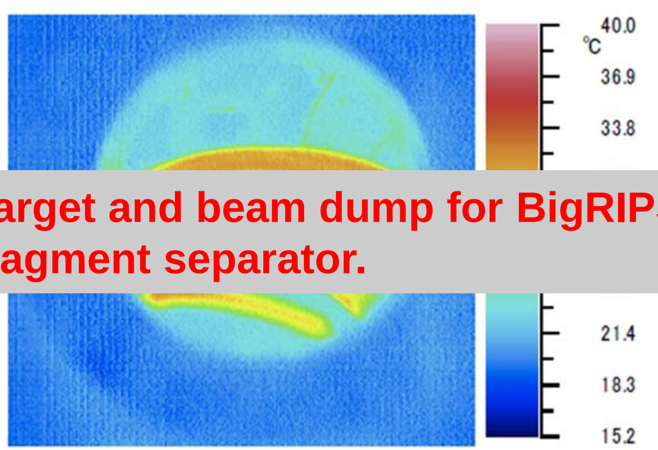
What is RIBF?
Successful operation for 12 years

Charge strippers for uranium ion



The first stripper at 10 MeV/u and the second stripper at 50 MeV/u.

Target & Beam Dump



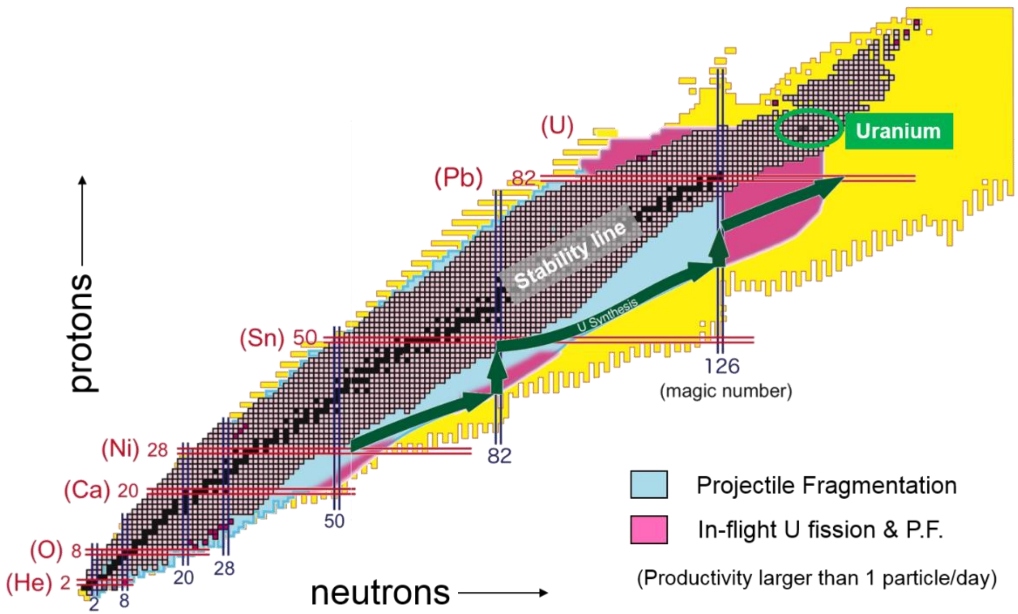
Target and beam dump for BigRIPS fragment separator.

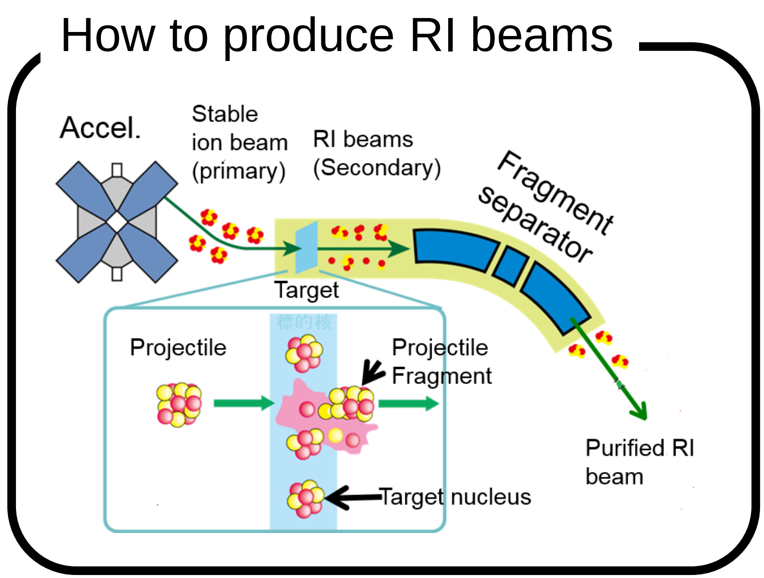
Possible Experiments at HiRADMat

Upgrade program of RIBF facility

Main Goals of RIBF

- Great expansion of the nuclear chart (1000 kinds of new isotopes, exotic nuclei)
- Challenge to solve the big puzzle of element genesis (r-prosess = U-synthesis)
- Promotion of industrial and biological applications

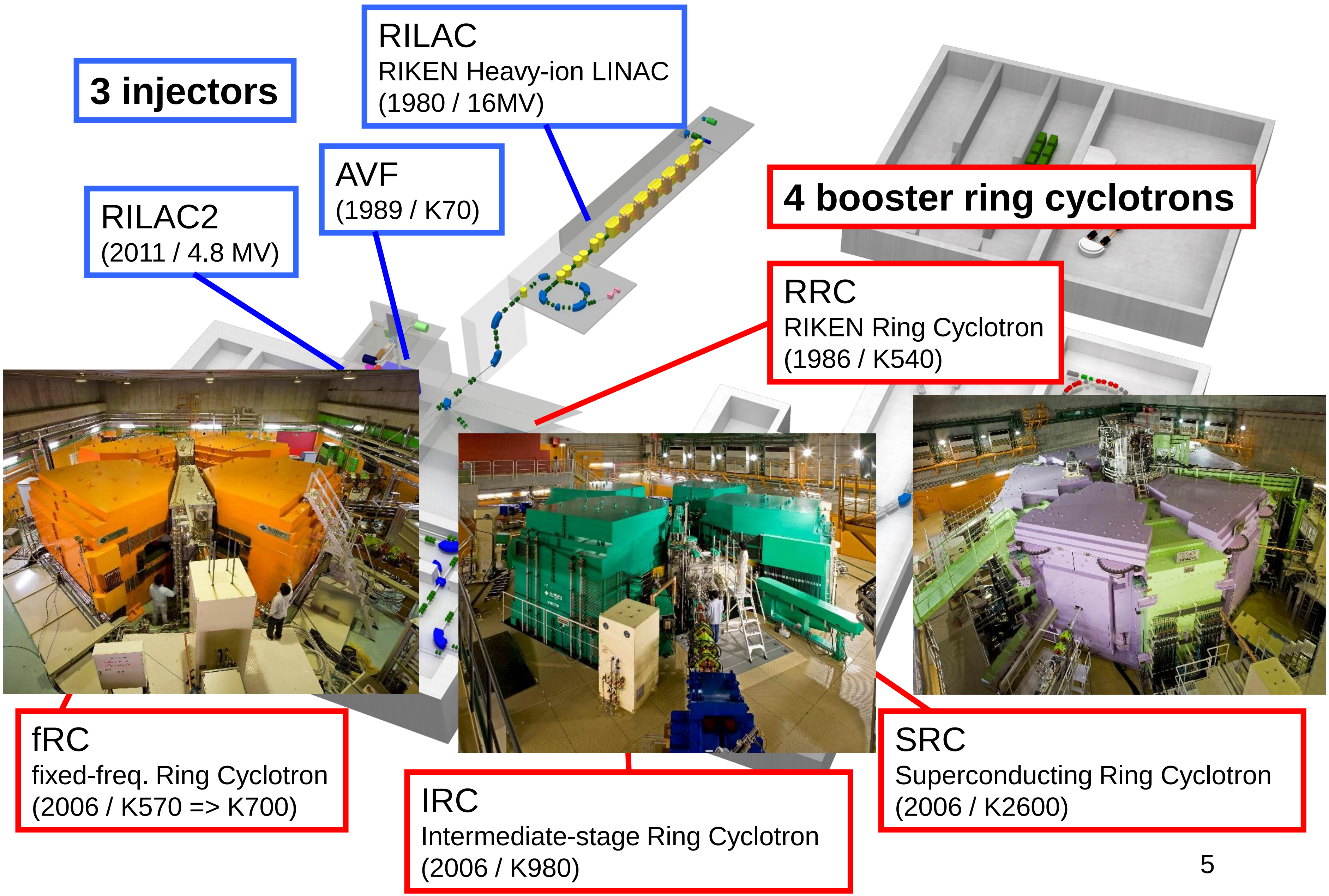




- RI beams are produced through fragmentation or fission of high speed heavy ion beams.
- This method requires accelerator complex to produce high speed heavy ion beams with high intensity.

RIBF accelerators

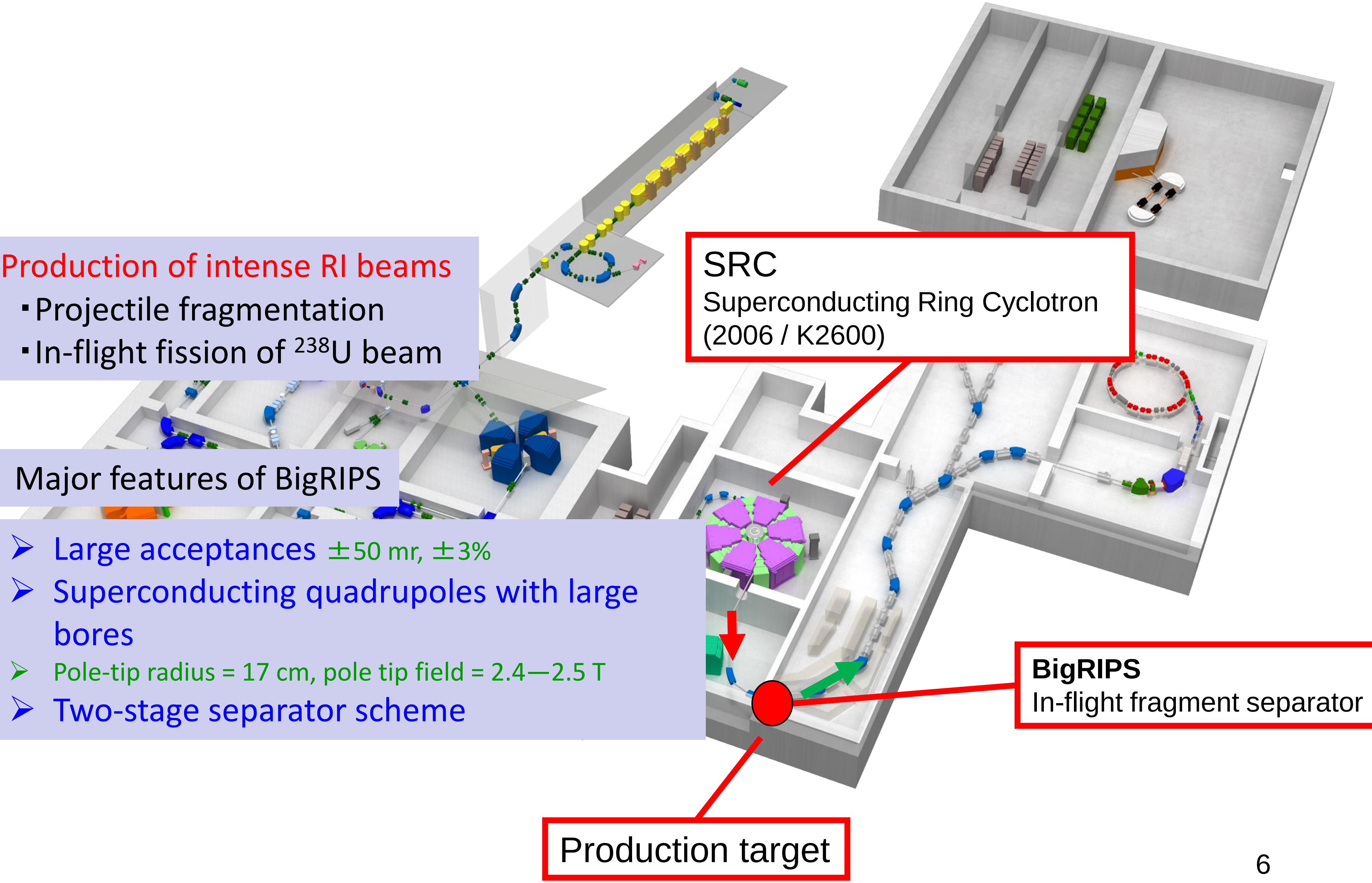
Y. Yano, NIM B261 (2007) 1009.



RIBF accelerators

Y. Yano, NIM B261 (2007) 1009.

Production of intense RI beams
- Projectile fragmentation
- In-flight fission of ^{238}U beam



Major features of BigRIPS

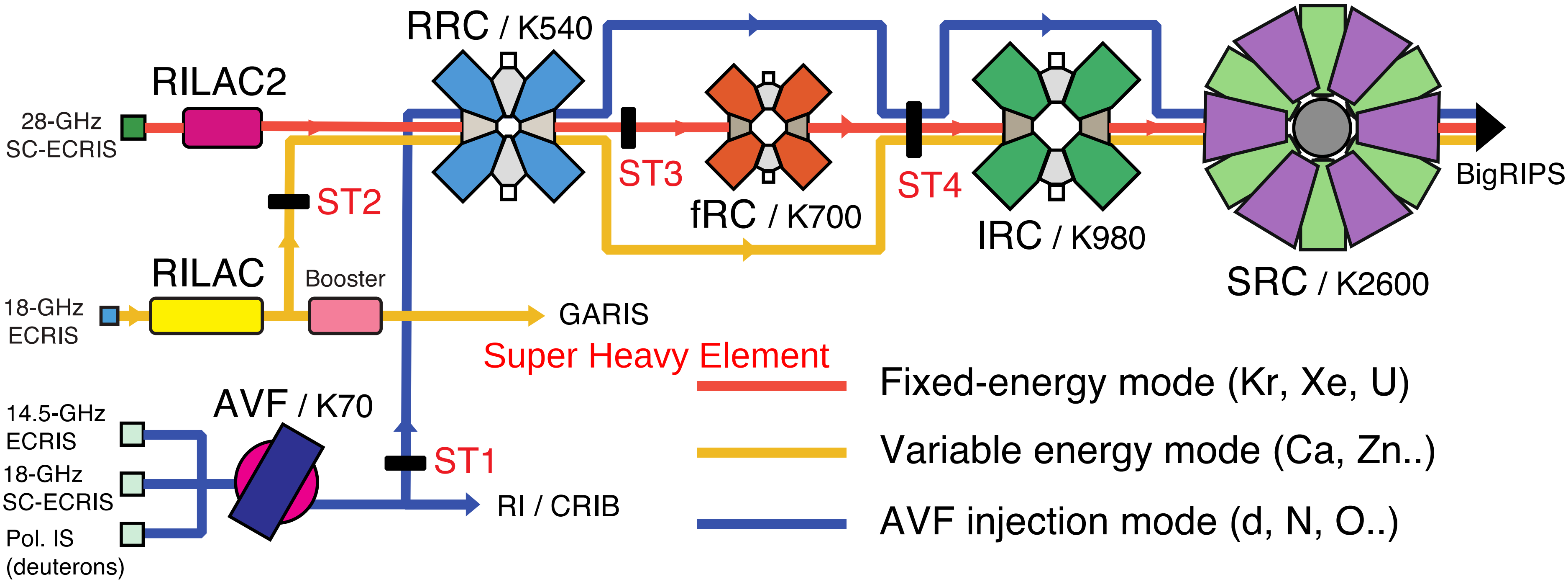
- Large acceptances ±50 mr, ±3%
- Superconducting quadrupoles with large bores
  - Pole-tip radius = 17 cm, pole tip field = 2.4—2.5 T
- Two-stage separator scheme

Acceleration modes

Accelerate ALL ions (from H_2^+ to U), up to 70% of the light speed, in CW mode

3 injectors + 4 booster ring cyclotrons

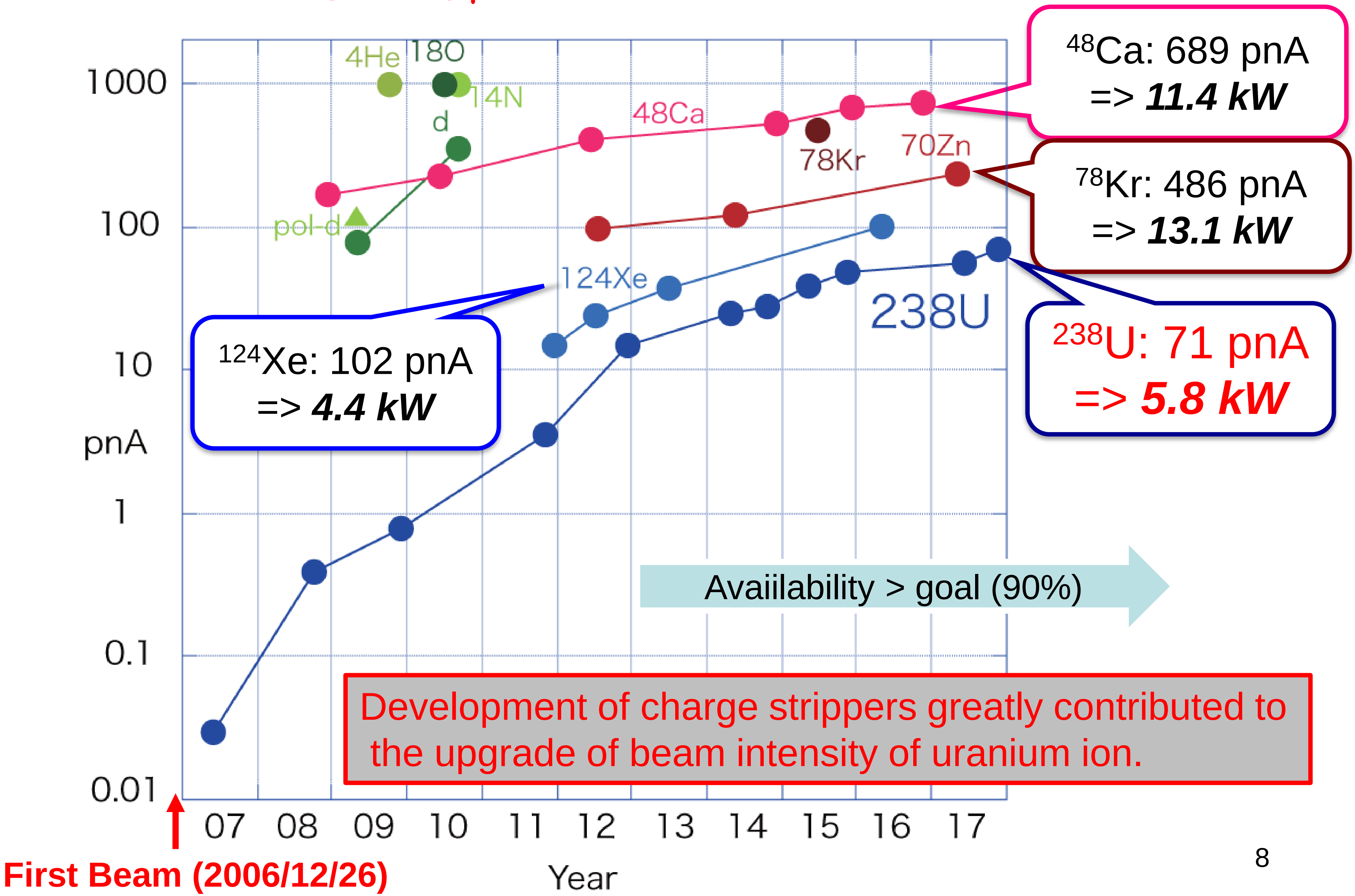
1) AVF-injection mode (< 440 MeV/u) : d, He, O, …
2) Variable-energy mode (< 400 MeV/u) : Ar, Ca, Zn, Kr, …
3) Fixed-energy mode (345 MeV/u) : Xe, U …



STn: charge stripper

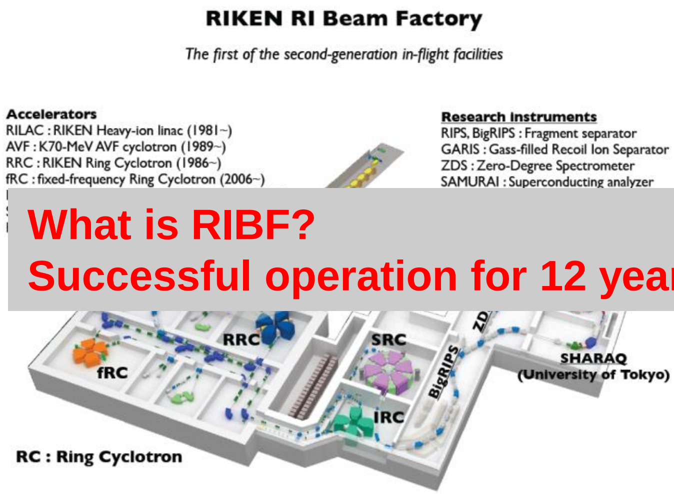
History of accelerator performance

Our goal:1 pμA (6 x 10^{12} #/s) for all elements



Preview

Introduction to RI beam factory



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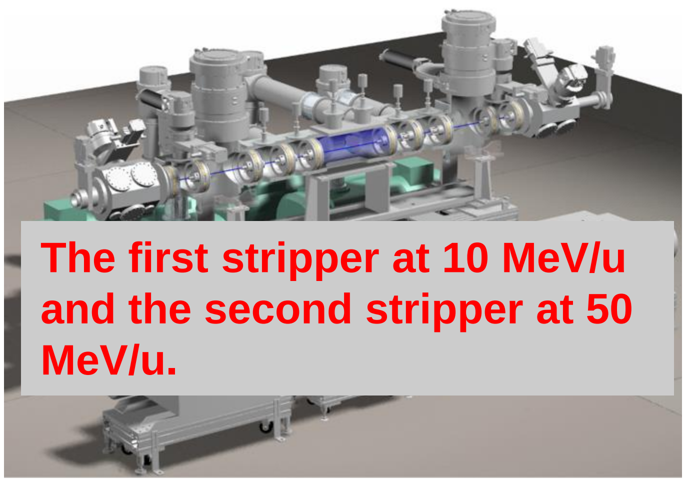
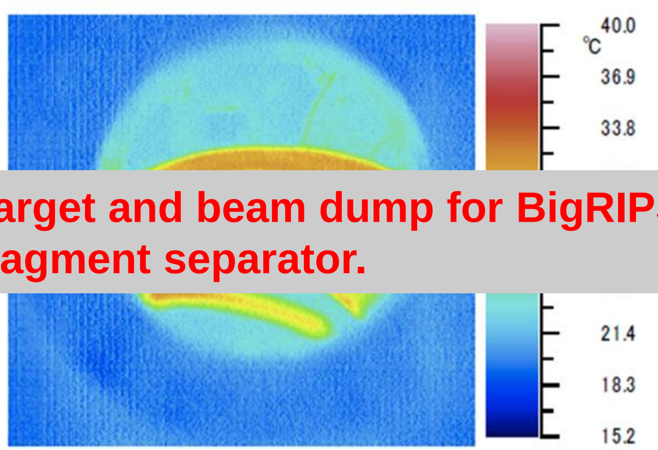


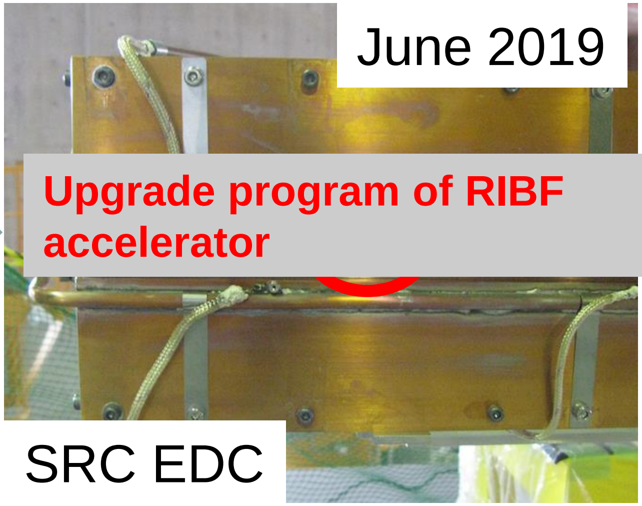
The first stripper at 10 MeV/u and the second stripper at 50 MeV/u.

Target & Beam Dump



Target and beam dump for BigRIPS fragment separator.

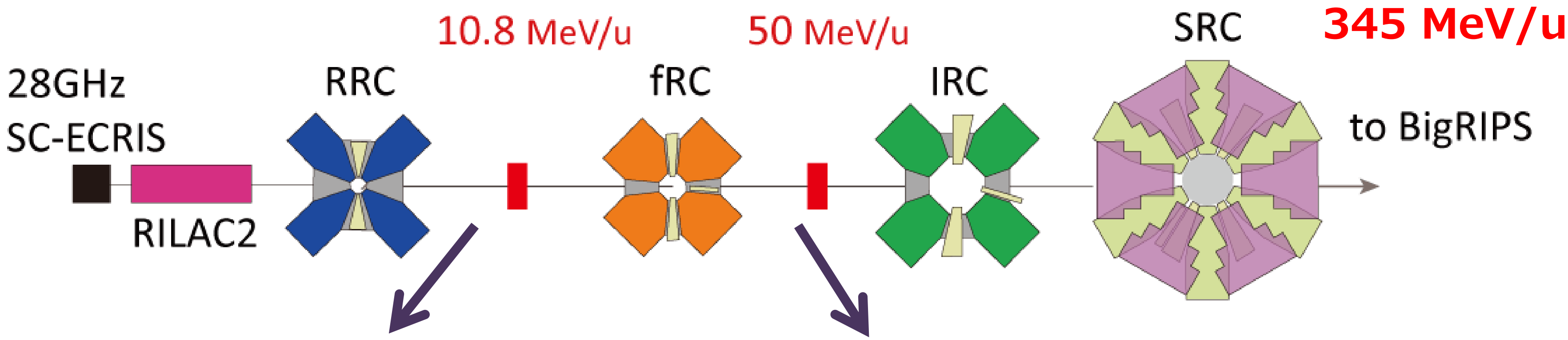
Possible Experiments at HiRADMat



Upgrade program of RIBF accelerator

Acceleration scheme of ^{238}U at RIBF

Conventional carbon foils for both strippers were used at the early stage of operation. (Lifetime and degradation of foil)

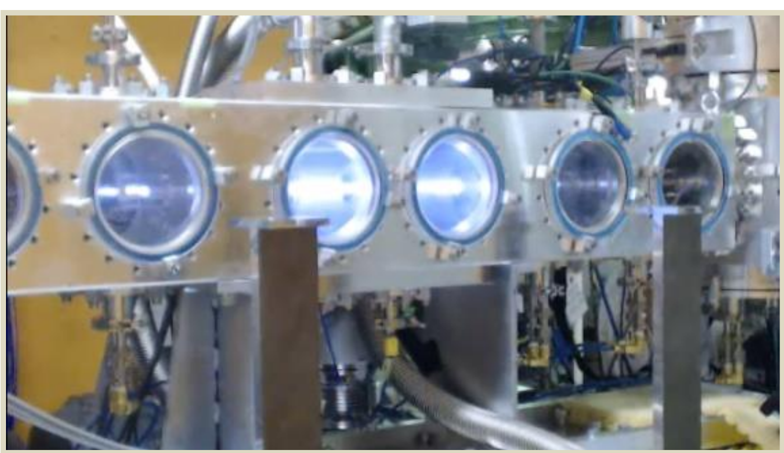


1． He gas stripper (since 2012)

2． Rotating disk stripper (since 2012)

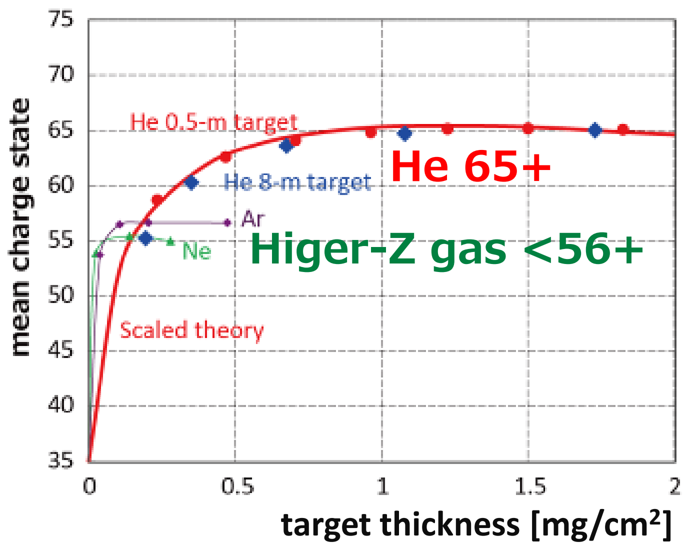
35+⇒64+ (20%)

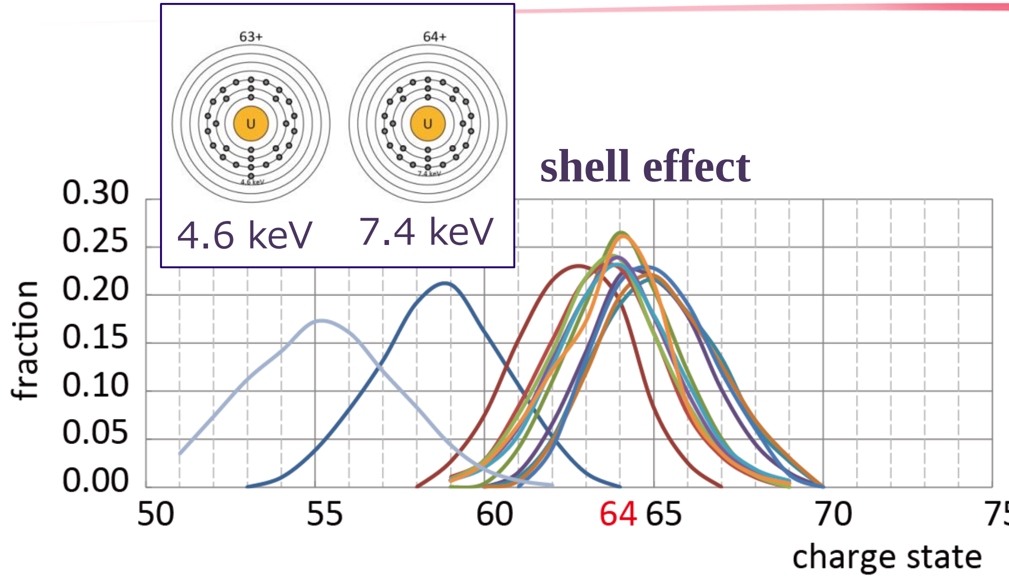
64+⇒86+ (30%)



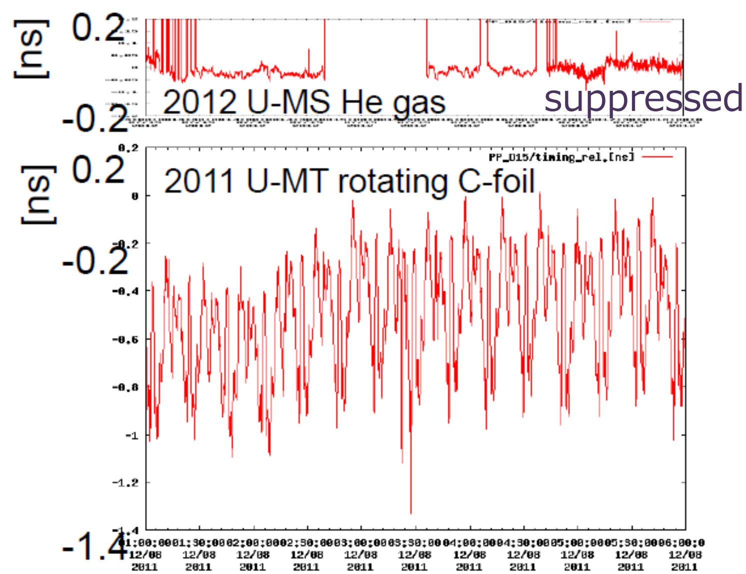
He gas stripper Fundamental data

•Charge evolution



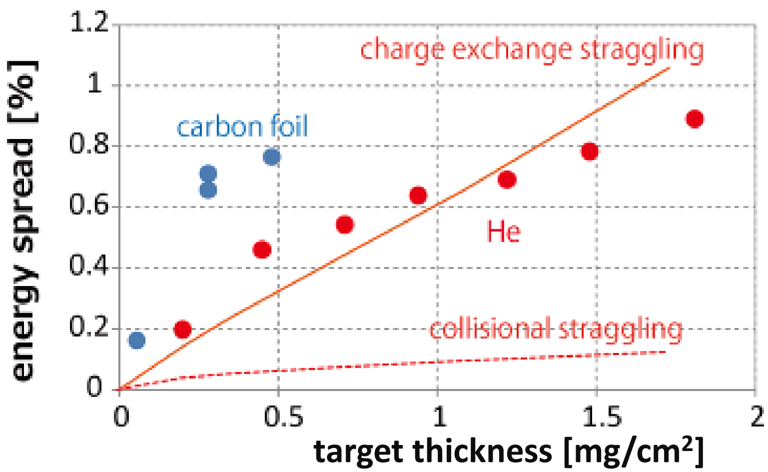


•Jitter of beam timing



•Energy spread

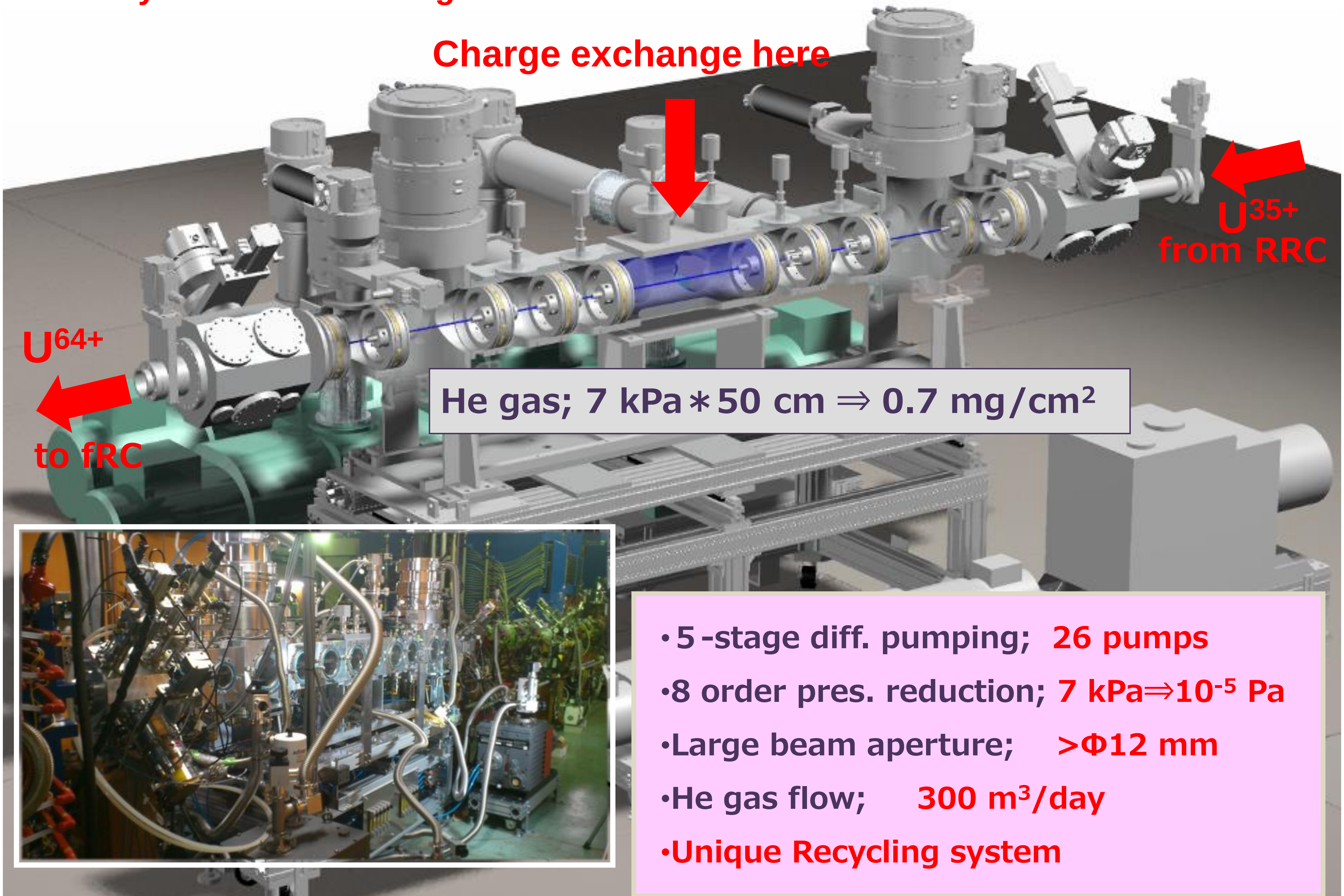
Half of spread (thickness uniformity)



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

Recirculating He stripper

Primary technical challenge ➡ windowless accumulation of He



Charge exchange here

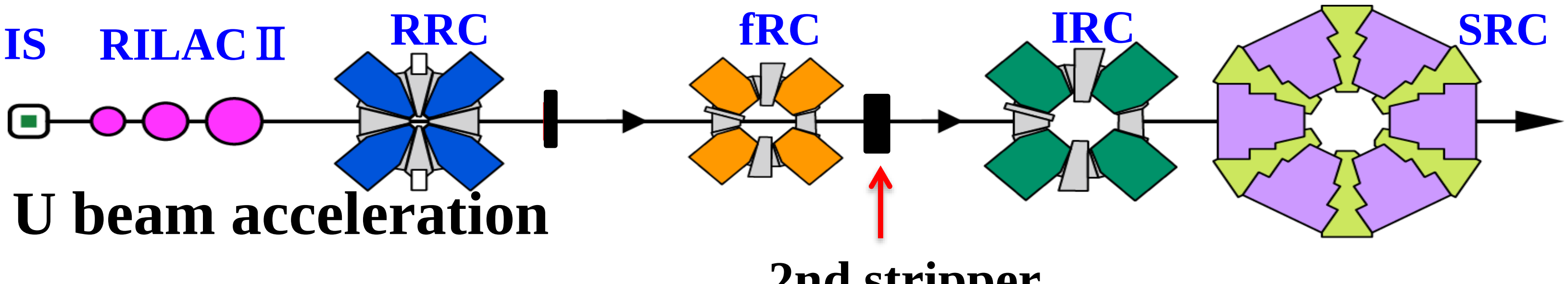
U^{35+} from RRC

U^{64+} to fRC

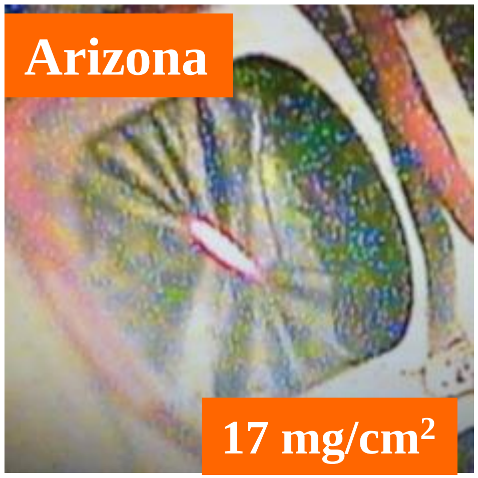
He gas; 7 kPa∗50 cm ⇒ 0.7 mg/cm²

- 5-stage diff. pumping; **26 pumps**
- 8 order pres. reduction; **7 kPa⇒10^{-5} Pa**
- Large beam aperture; **>Φ12 mm**
- He gas flow; **300 m³/day**
- **Unique Recycling system**

U beam acceleration



$U^{64+} \rightarrow U^{86+}$
50 MeV/u



Period	2007-2011	2012-2014	2015-Now
Maximum beam intensity	2-3 eμA	12 eμA	17.5 eμA
Irradiated particles	7.12×10^{15} (71+)	1×10^{18} (64+)	2.19×10^{18} (64+)
Lifetime	9 hours	20 days	40 days (2 × Beam Time)

28GHz ECR ion source

High Orientation Graphite Sheet (KANEKA)

Preparation of graphite sheet

Polyimide film
2 – 25 mm

1400 ºC →

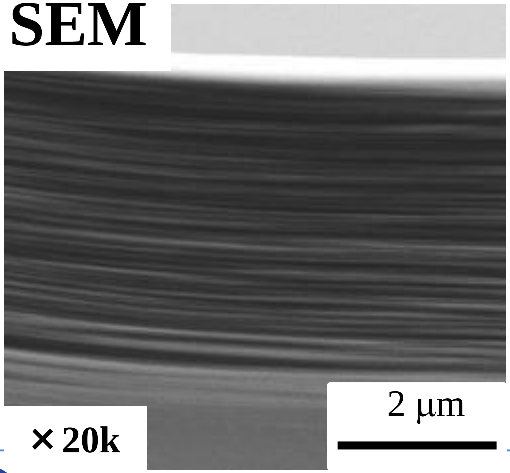
Carbonized film

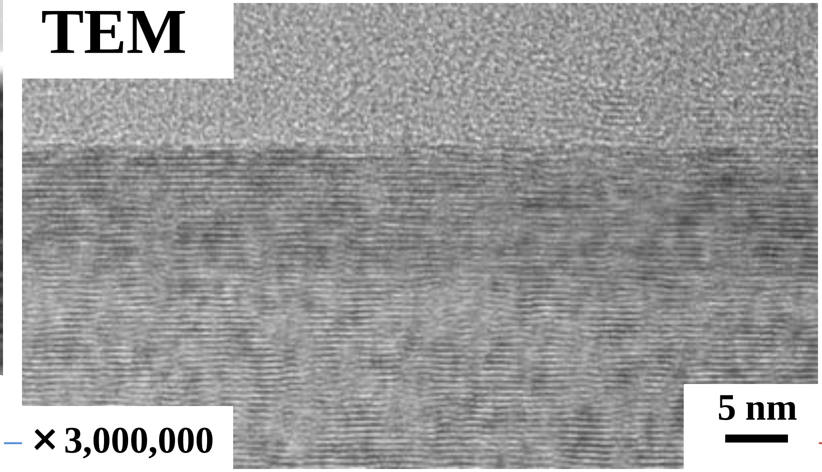
2900 ºC →

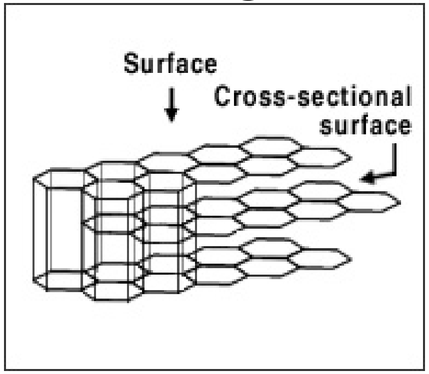
Graphite sheet
0.23 – 2.2 mg/cm^2

- Flexible
- Uniform
- Robust
- Large area

Cross section image of SEM and TEM





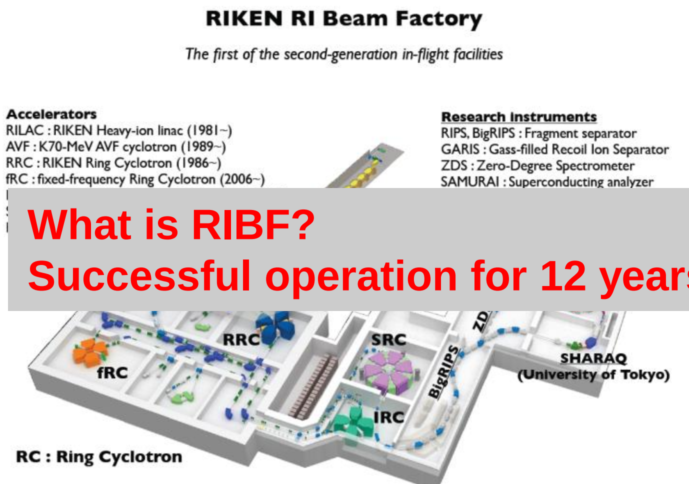


Crystal structure

Thermal conductivity is three times of that of Cu.

Preview

Introduction to RI beam factory



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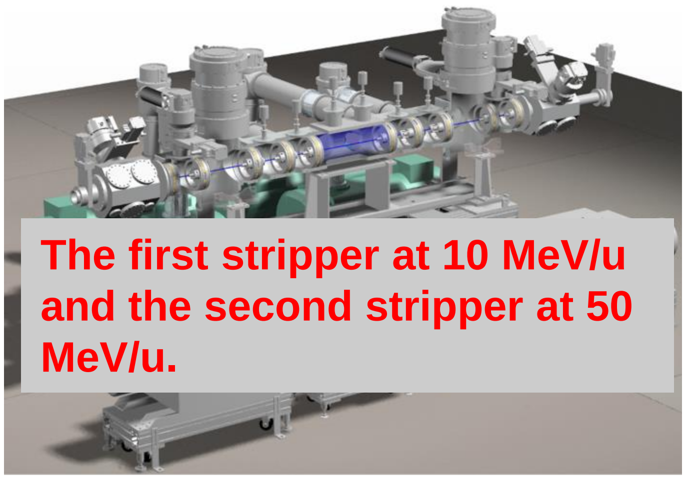
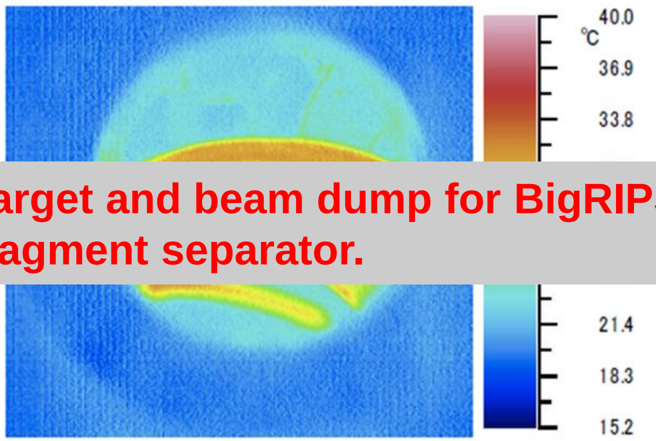


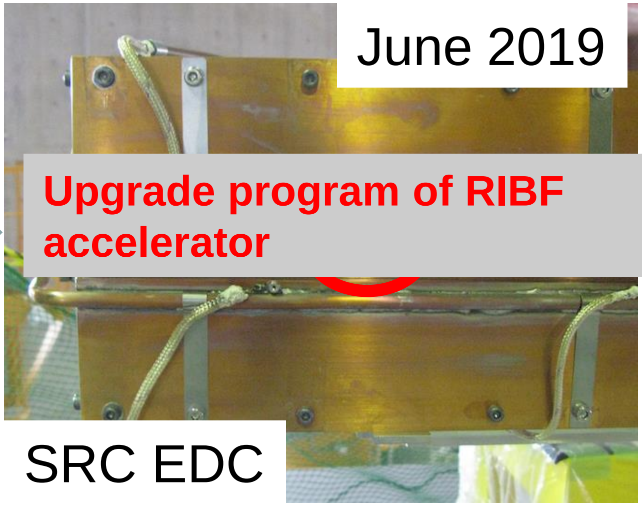
The first stripper at 10 MeV/u and the second stripper at 50 MeV/u.

Target & Beam Dump



Target and beam dump for BigRIPS fragment separator.

Possible Experiments at HiRADMat



Upgrade program of RIBF accelerator

Target and Beam Dump: Beam Spot and Power Density

Beam Power(^{238}U 345MeV/n,1pμA=82kW) is dissipated in a target and a beam dump.

▪Target

Beam Spot Size:

Small ϕ ~1mm (fwhm)

Target Thickness : various thicknesses necessary

Optimum thickness ~ 1/3 of the Range.

but depends on the experimental request.

Material:

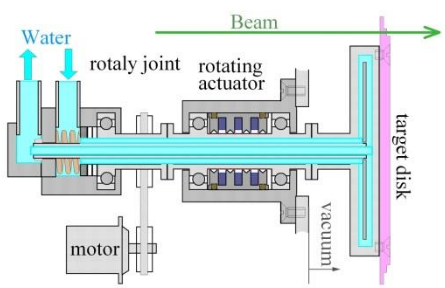
Be, C, W, Pb, etc.

Melt. Point 1284, 3600, 3382, 328 °C

Beam Power in Target (Be 1/3 Range)

Prim.Beam	^{238}U ~	^{48}Ca ~	^{12}C	1pμA
Trg.Thick	4.4 ~	17.2 ~	47.9	[mm] Be
Trg.ΔE	19.7 ~	3.2 ~	0.9	[kW/1pμA]
in ϕ1mm	25.1 ~	4.1 ~	1.1	[kW/mm^2]
in volume	5.7 ~	0.2 ~	0.02	[kW/mm^3]

→ Rotating wheel target with water cooling



▪Beam Dump (Beam stops inside the D1 magnet)

placed inside and exit portion of D1 magnet

Beam Spot Size, Power Density

varied as RI beam setting. R= $B\rho_{beam}$ / $B\rho_{separator}$

for the case of ^{238}U 345MeV/n with 4.4mm Be target,

R=0.5 10MW/m^2 →2.9MW/m^2

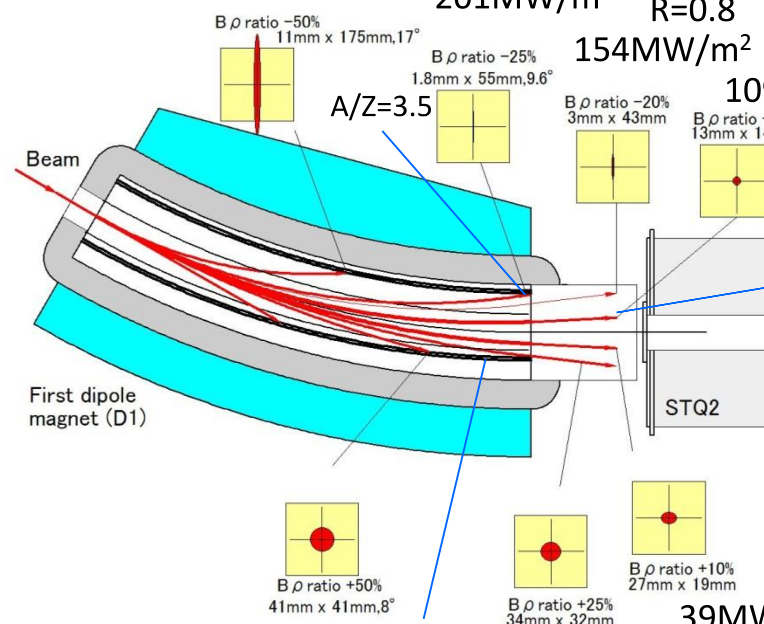
R=0.75 201MW/m^2 →156MW/m^2

R=0.8 154MW/m^2

R=0.9 109MW/m^2

A/Z=3.5

A/Z=3



R=1.5 12MW/m^2 →1.7MW/m^2

A/Z=2 ^{238}U→^{100}Sn

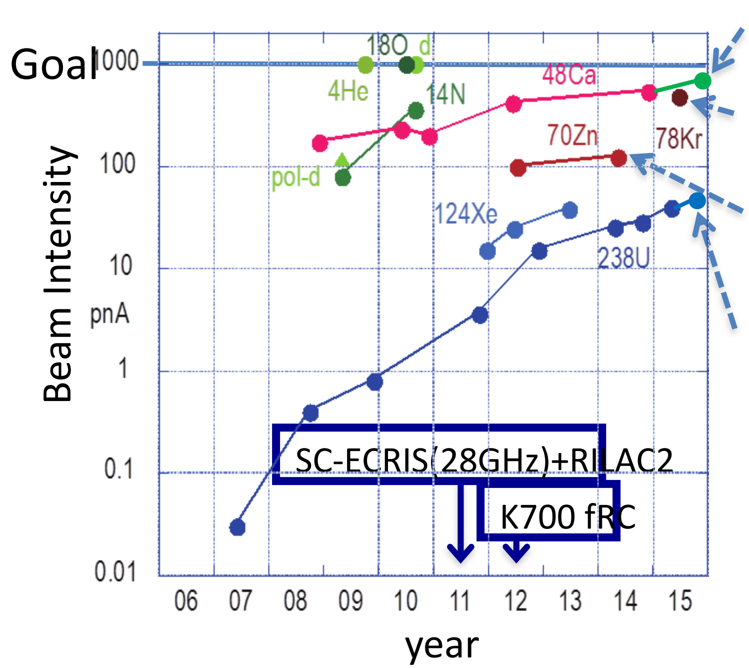
R=1.25 18MW/m^2

R=1.1 39MW/m^2

→ Stationary system with highly efficient water cooling

Current Status of the target and beam dump system

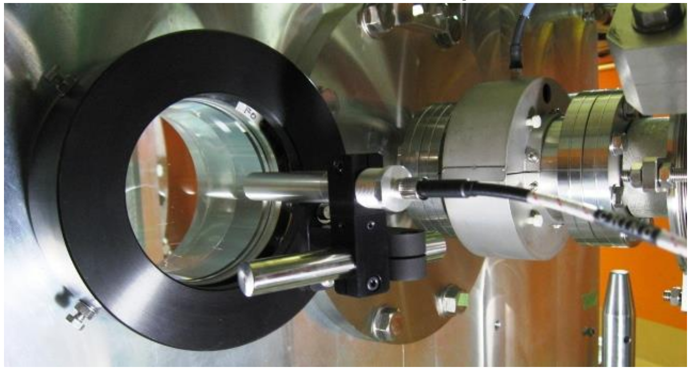
- Construction and Installation was finished at 2006, and operation was started at 2007. (beam intensity is low)
- Designs of target and beam dump system were based on thermal model simulation.
- Tests for the cooling power were performed by monitoring the beam spot temperature in parallel with operations.
- Up to 2014, fixed targets (ladder) were used for experiments.
- **In 2015, rotating targets started for using for experiments.**
- From 2014, effective tests of cooling power became possible. (beam intensity)



689 pnA
=> 11.4 kW, 2.2kW(rot Be 15mm)
486 pnA
=> 12.7 kW, 3.4kW(rot Be 10mm)
123 pnA
=> 3.1 kW, 1.4kW(Be 12mm)
49 pnA
=> 4.0 kW, 1.6kW(Be 7mm)

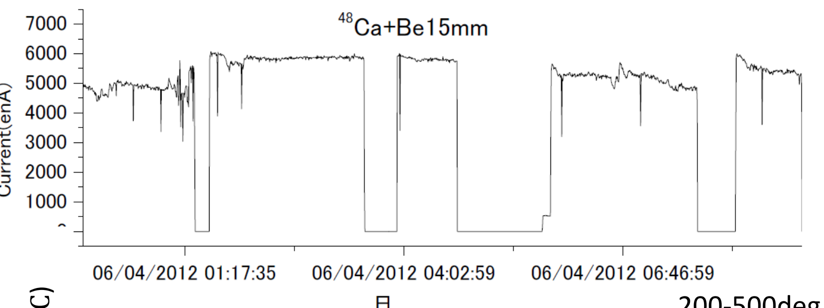
Beam-spot temperature measurement

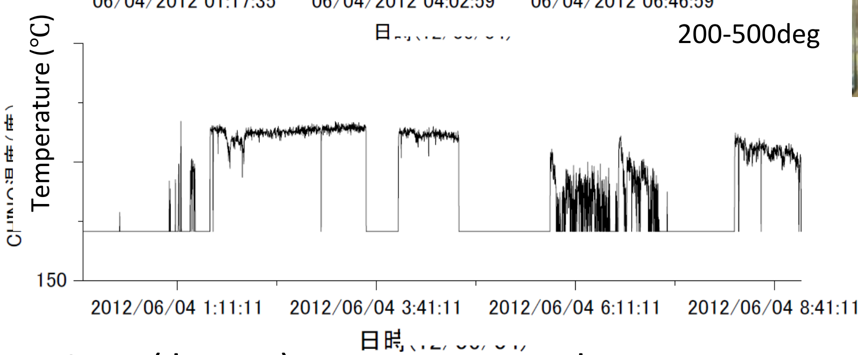
(1) Infrared Fiber Scope



Sapphire view port & Lenz unit mounted on the Target chamber

IR-FAIX43 200 ~ 500 ℃ InGaAs(1.55μm)

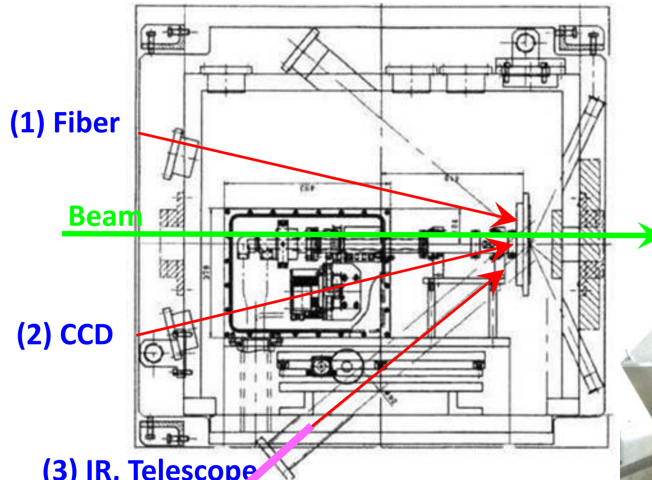




Spot (ϕ5mm) temperature only
Used as on-line monitor

(2) IR thermal image camera

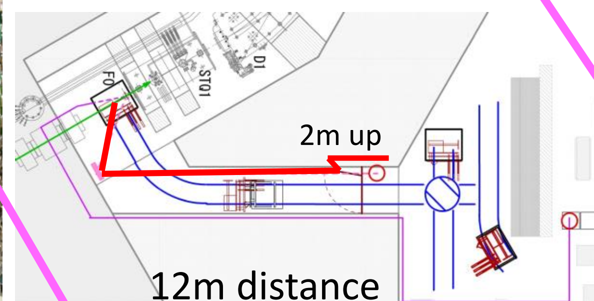
Target chamber (upper view)

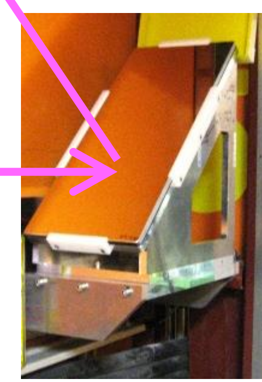


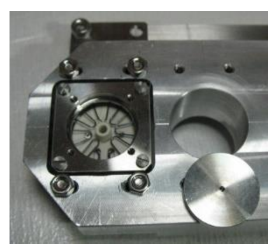
IR camera:

TVS-8500 AVIO (Japan)

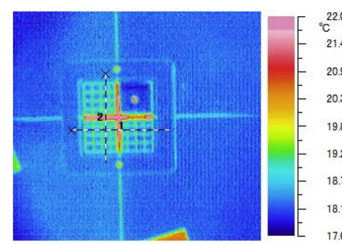
Very weak for radiation
Can be used only for a short time.







Temp. Calib.
Heater+Be plate, TC

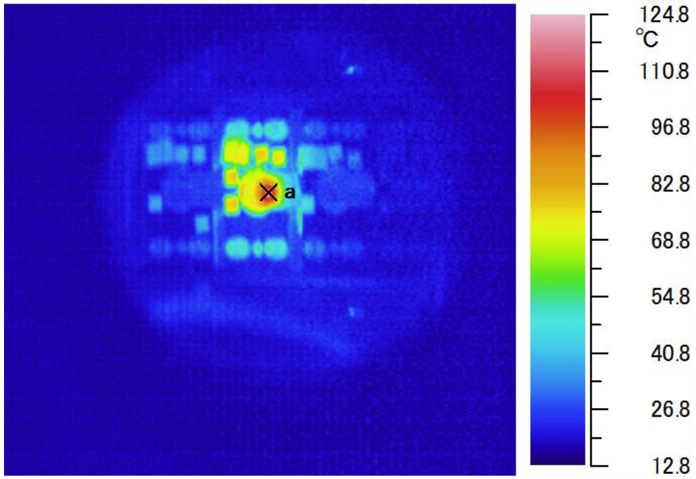


Spatial resolution (1px =0.5mm)
0.5mm slit -> 2mm(H), 3mm(V)

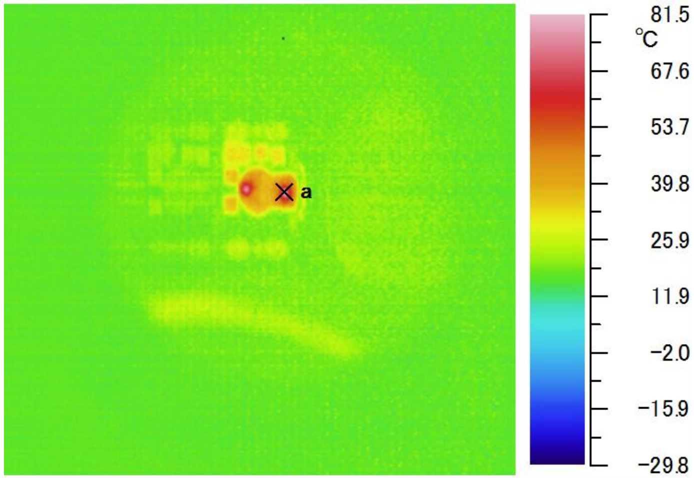
Beam spot temperatures for ^{48}Ca 345MeV/n Beam

Ladder target (fixed target)

Be 30mm、283pnA、 1.9kW 234℃



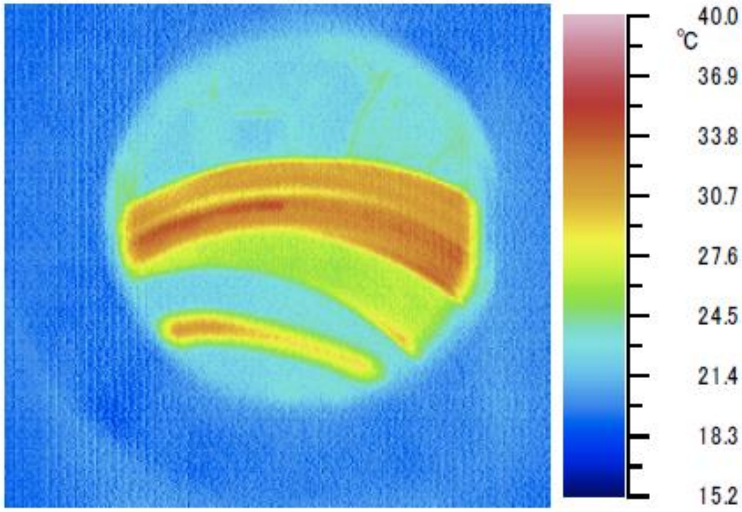
Be 15mm、280pnA、0.88kW 282℃



Rotating target

Be 15mm, 420pnA, 100rpm 1.3kW

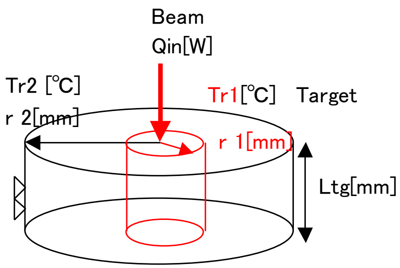
Beam spot 84℃



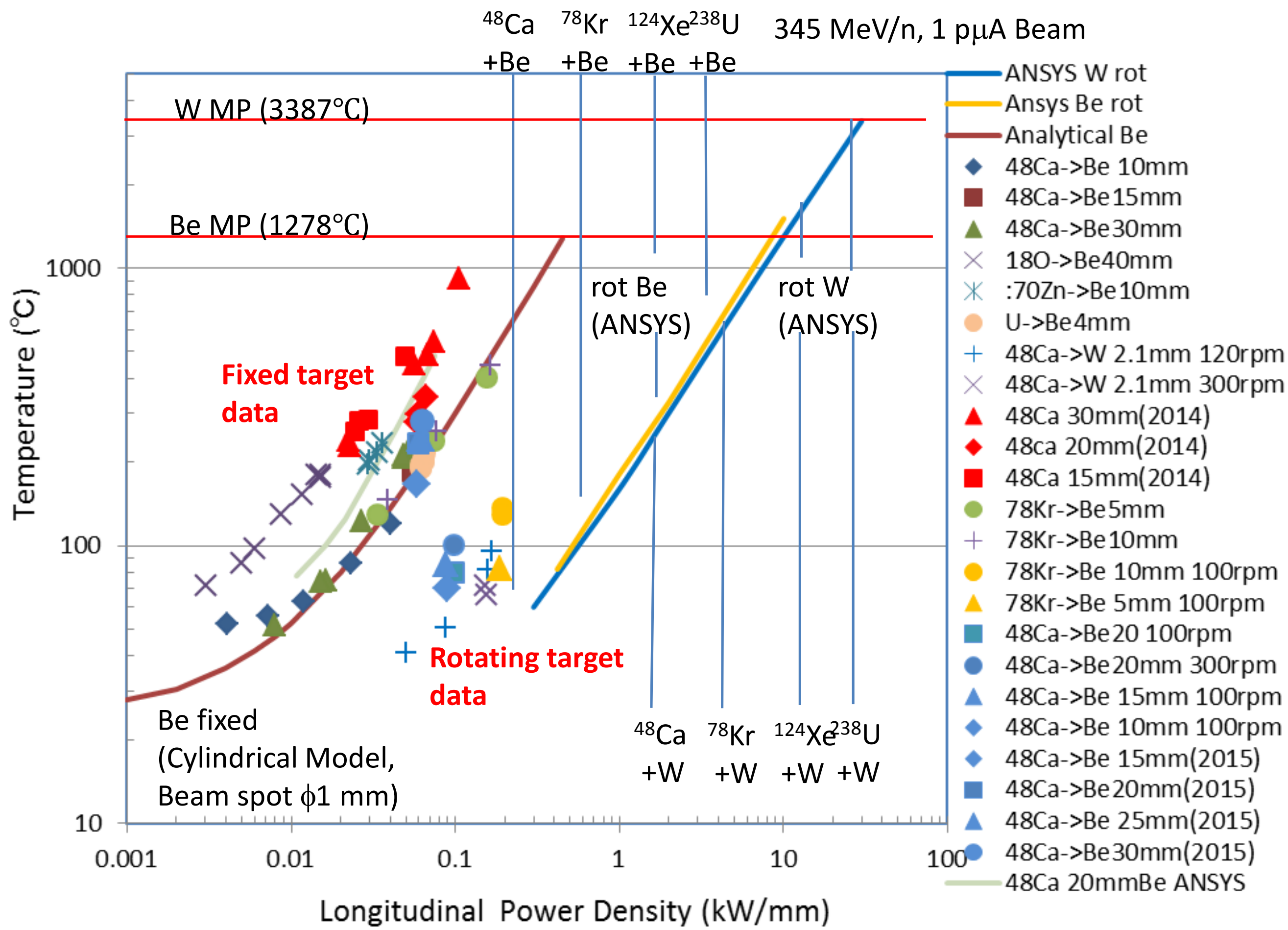
Beam spot temperatures for various beam

Various combination of beams and target thicknesses →
Deposited Power/target thickness is relatively well measure.

((Cylindrical model))
analytical model



Tr1 : Beam Spot Temp.
$= Tr2 + Qin*Ln(r2/r1) / (2\pi\kappa Ltg)$
$Qin = Ibeam * dE$
$\propto dE / Ltg$



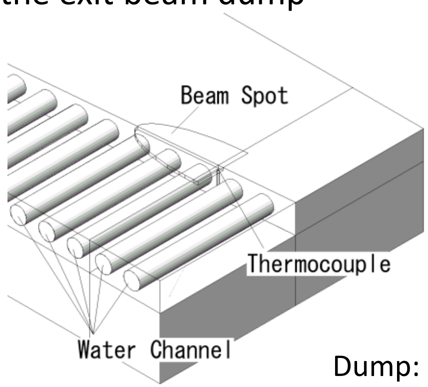
Fixed Target: agree with a simple cylindrical model -> heat transfer coeff. Is not important?
some data are higher -> thermal contact between target and ladder is bad?
ANSYS calc. -> Zeren Korkulu's talk

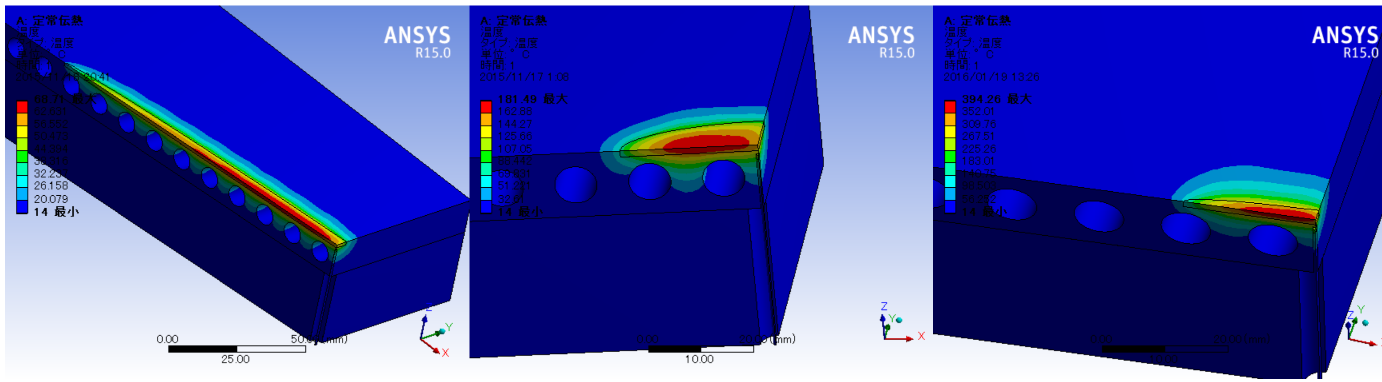
Rotating Target: higher temperature than the initial estimation -> need detailed simulations
Extensive simulations with ANSYS are now undergoing.

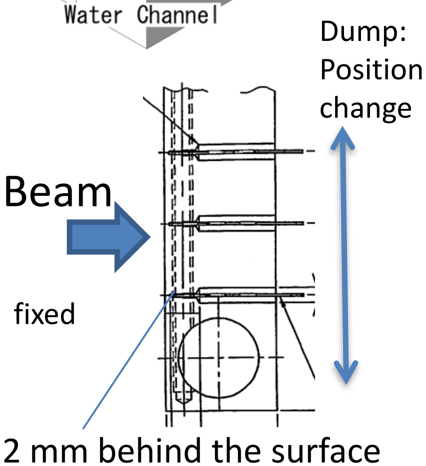
Temperature measurement with ^{48}Ca 345MeV/n 500pnA (8.3kW)

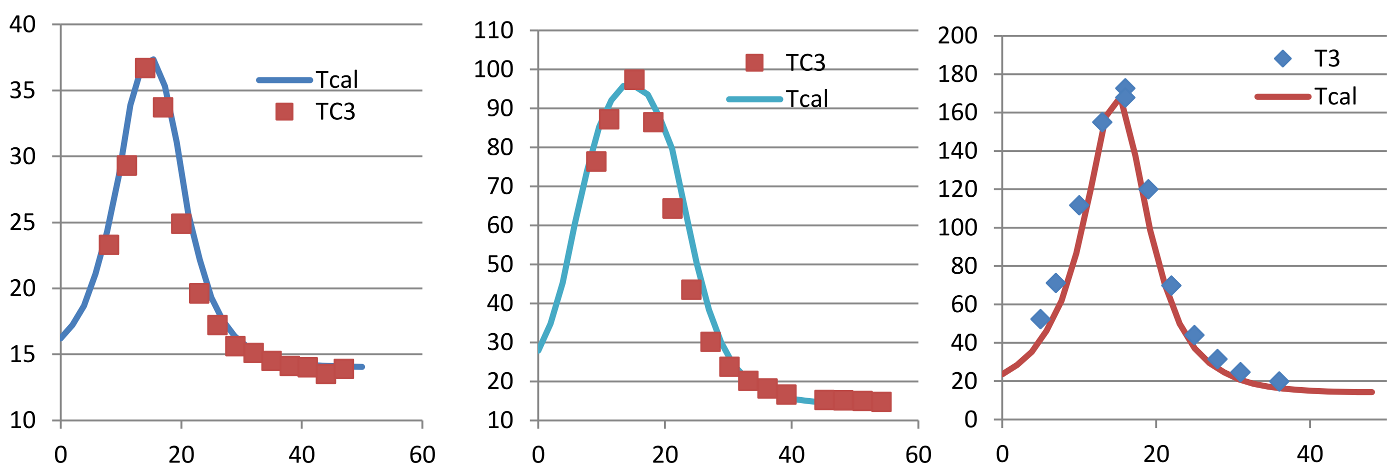
Beam spot size	4.5x141	8.8x28.1	1.9x23.6
Heat density (MW/m^2)	3.88	10.1	53.5
Cooling water speed (m/s)	10	10	10
Max. Temp (°C) :	68.7	182	394
Max. Temp at cooling channel(°C) :	44.2	129	179
Thermocouple Temp.(°C) :	37.43	96	168
Max heat flux at cooling channel(MW/m^2):	2.99	9.32	23.2

Thermo-couples mounted on the exit beam dump





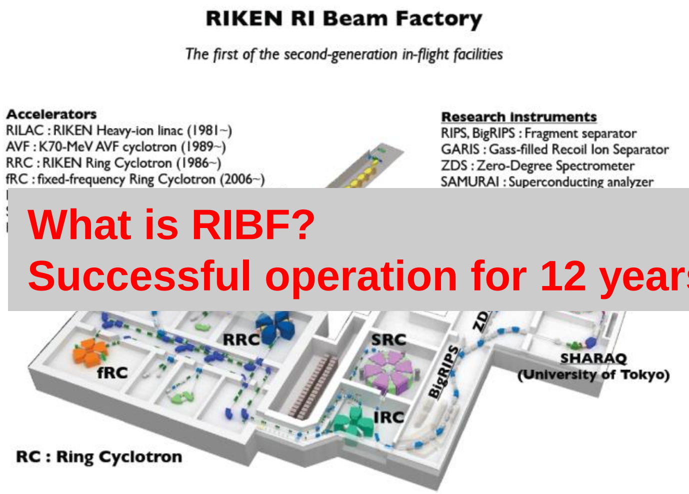




Change the beam optics -> various beam spots, Heat densities : good agreements (H.T.C.)

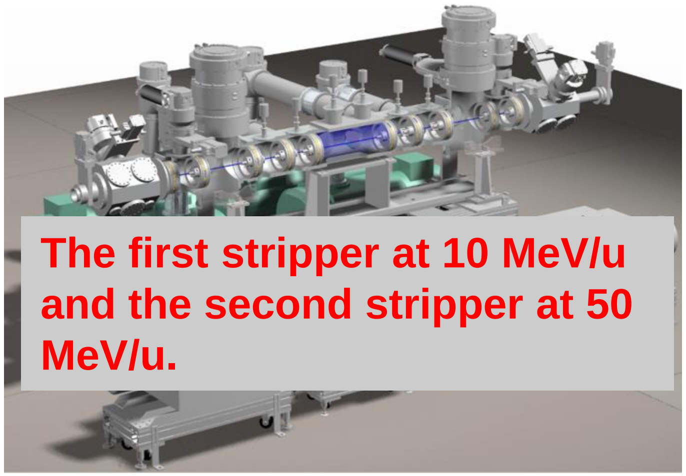
Preview

Introduction to RI beam factory



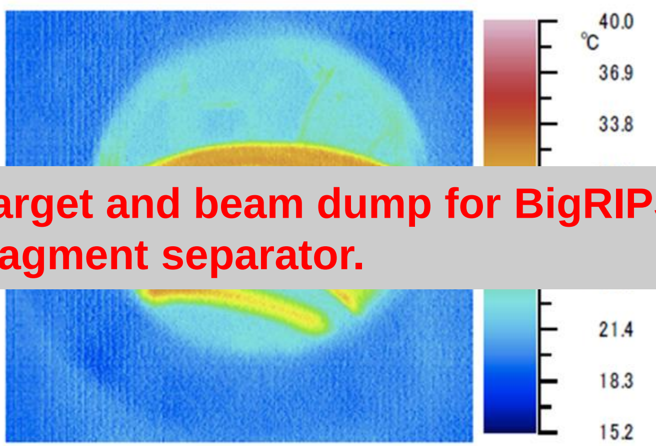
What is RIBF?
Successful operation for 12 years

Charge strippers for uranium ion



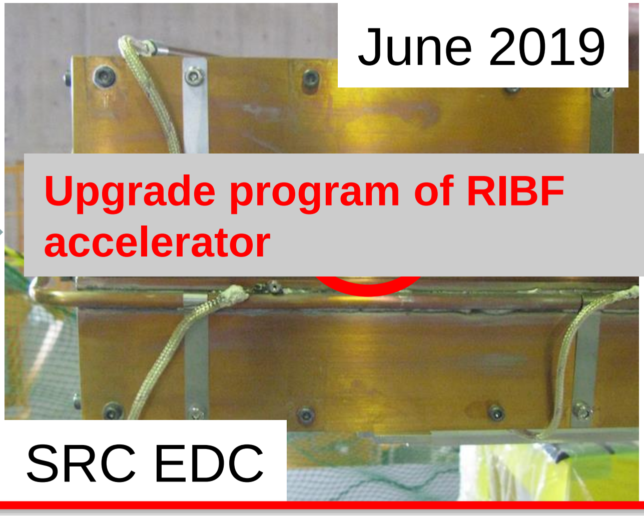
The first stripper at 10 MeV/u and the second stripper at 50 MeV/u.

Target & Beam Dump



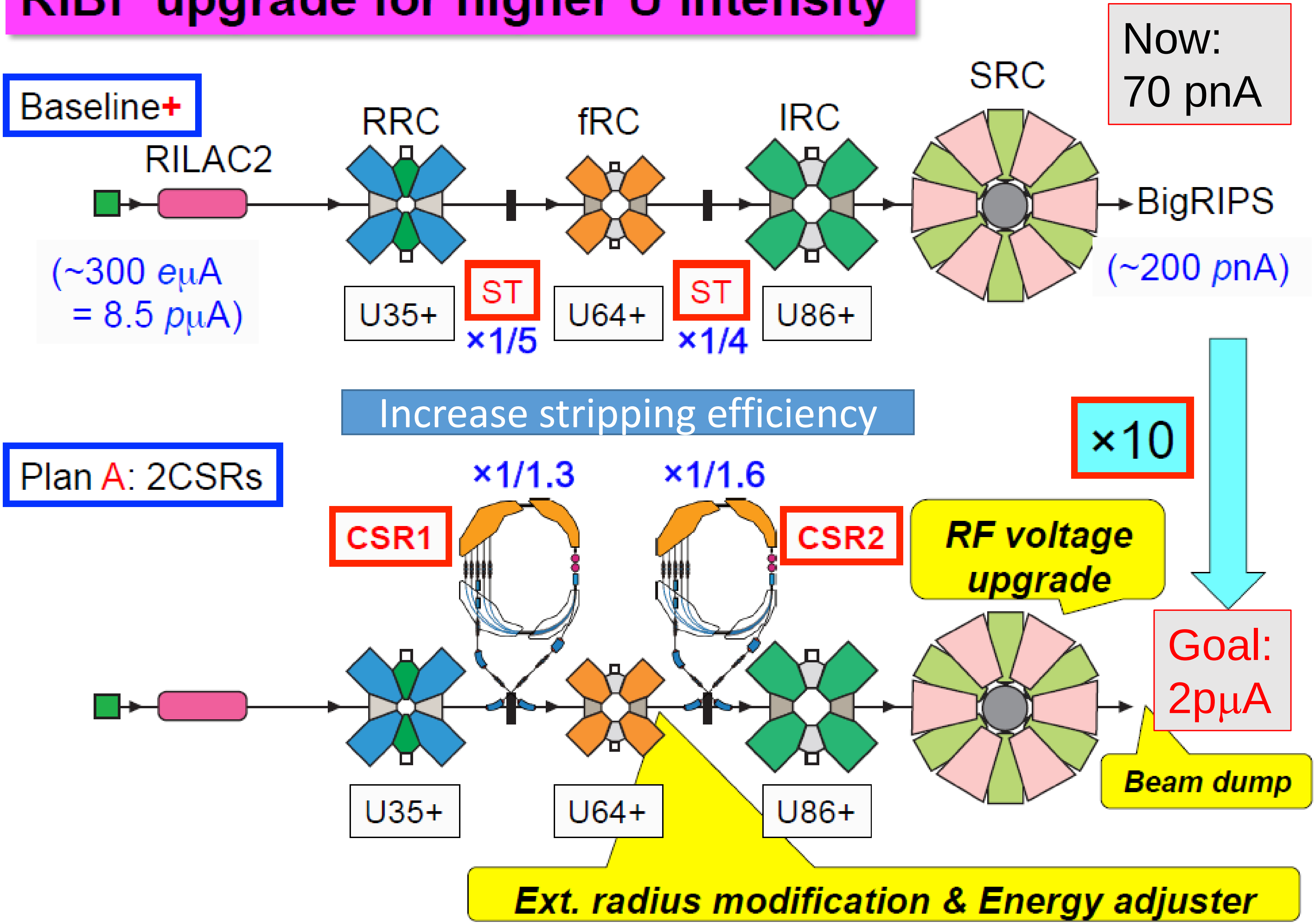
Target and beam dump for BigRIPS fragment separator.

Possible Experiments at HiRADMat



Upgrade program of RIBF accelerator

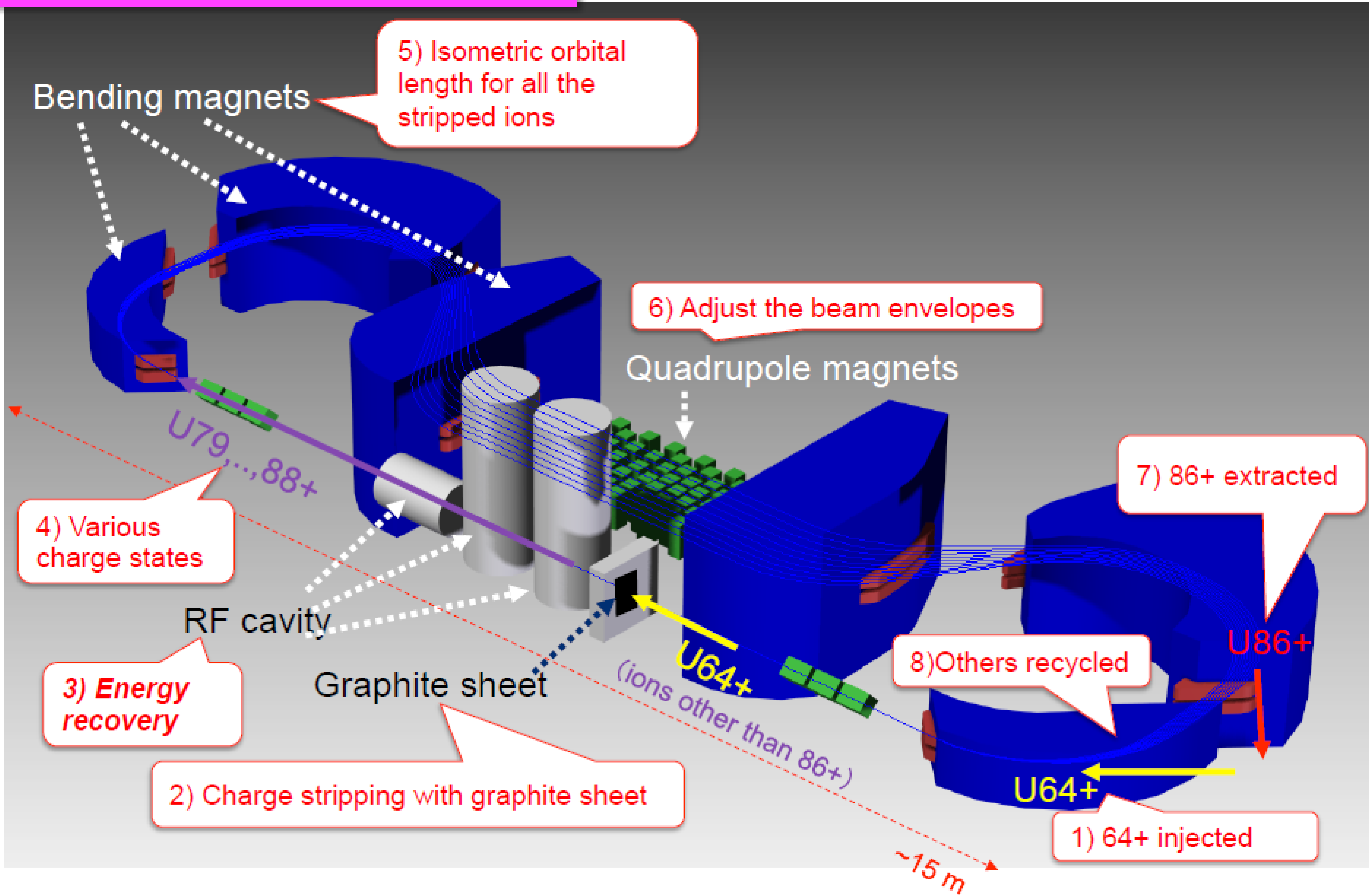
RIBF upgrade for higher U intensity



Imao

Charge Stripper Ring

Increase stripping efficiency



Experiments at Hiradmat for upgrade program in RIBF
- Comparison of the two beams

	> Pb	RIBF after upgraded (2puA)		
	Pb(Hiradmat)	U(SRC, BigRIPS)	U (1st Stripper)	U (2nd Stripper)
Type of Beam	Pulsed	CW	CW	CW
Beam Energy	173.5 GeV/u	345 MeV/u	10 MeV/u	51 MeV/u
Averages current (#/s)	2.8E+08	1.2E+13	2.52E+13	1.92E+13
Pulse Energy/52 bunches (J)	21000	0.4696692	0.02858856	0.111086976
Bunch intensity	7.00E+07	6.60E+05	1.39E+06	1.06E+06
No of Bunches	52	–	–	–
Bunch spacing (ns)	100	55	55	55
Cycle Length (s)	13.2	–	–	–
DDX (MeV/(mg/cm2))	14.8	25	125	65
DDX/pulse (MeV/(mg/cm2))	5.39E+10	8.58E+08	9.01E+09	3.57E+09
DDX/pulse (Relative)	1.00E+00	1.59E−02	1.67E−01	6.63E−02

DDX/pulse in HiRADMat is comparable to those in RIBF.

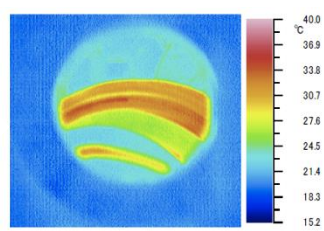
Sample

Beam → | → Transmission type experiments

Sample

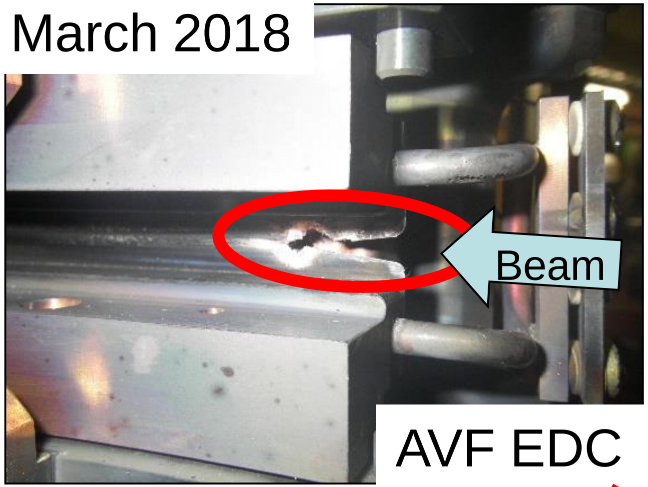
Kaneka foil

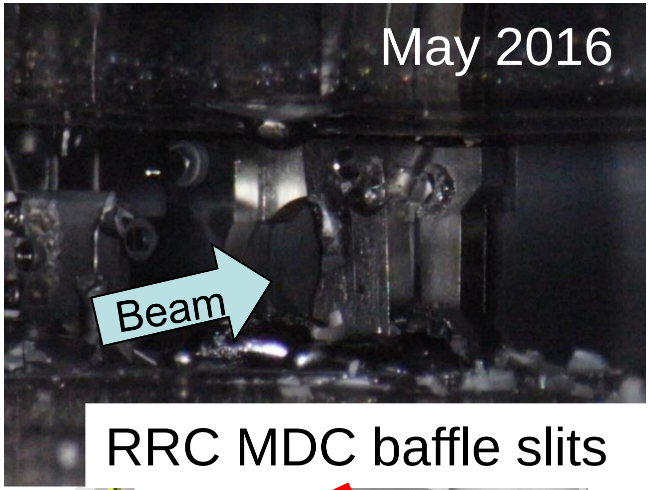
BigRIPS target



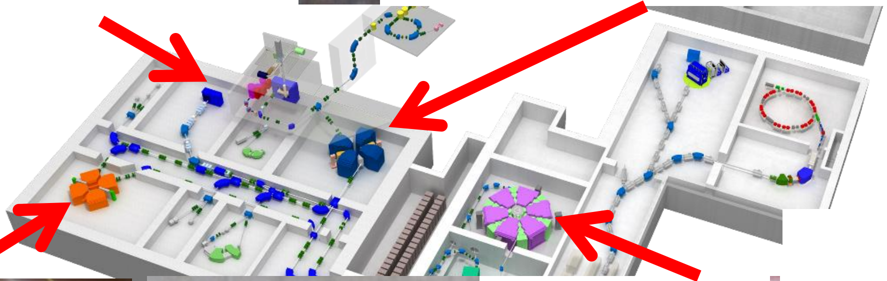
Accelerator components (EDC & Baffle slits)

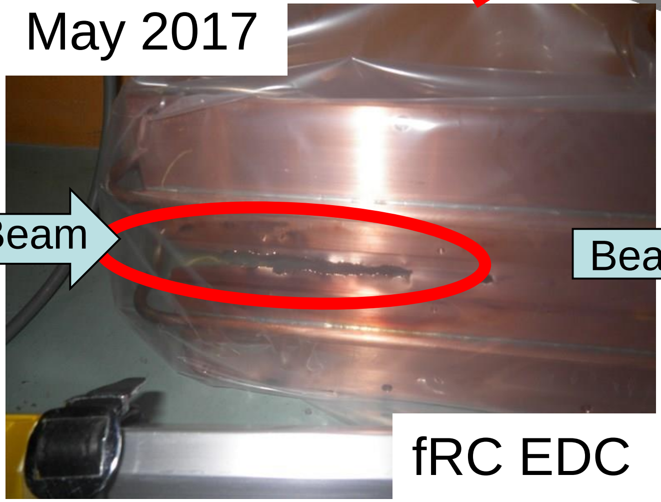
Devices damaged by ~kW beams (current situation)

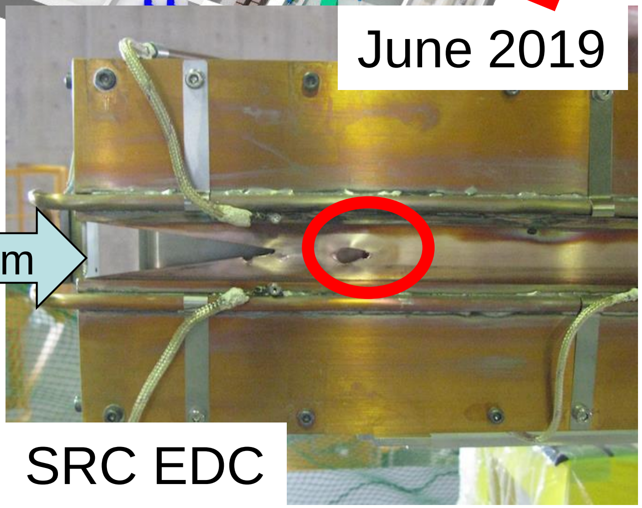


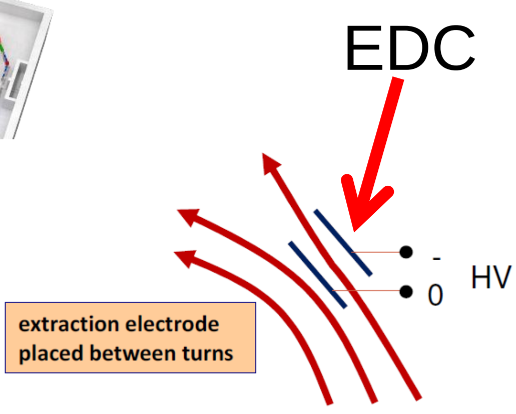


Damage will be 20 times!



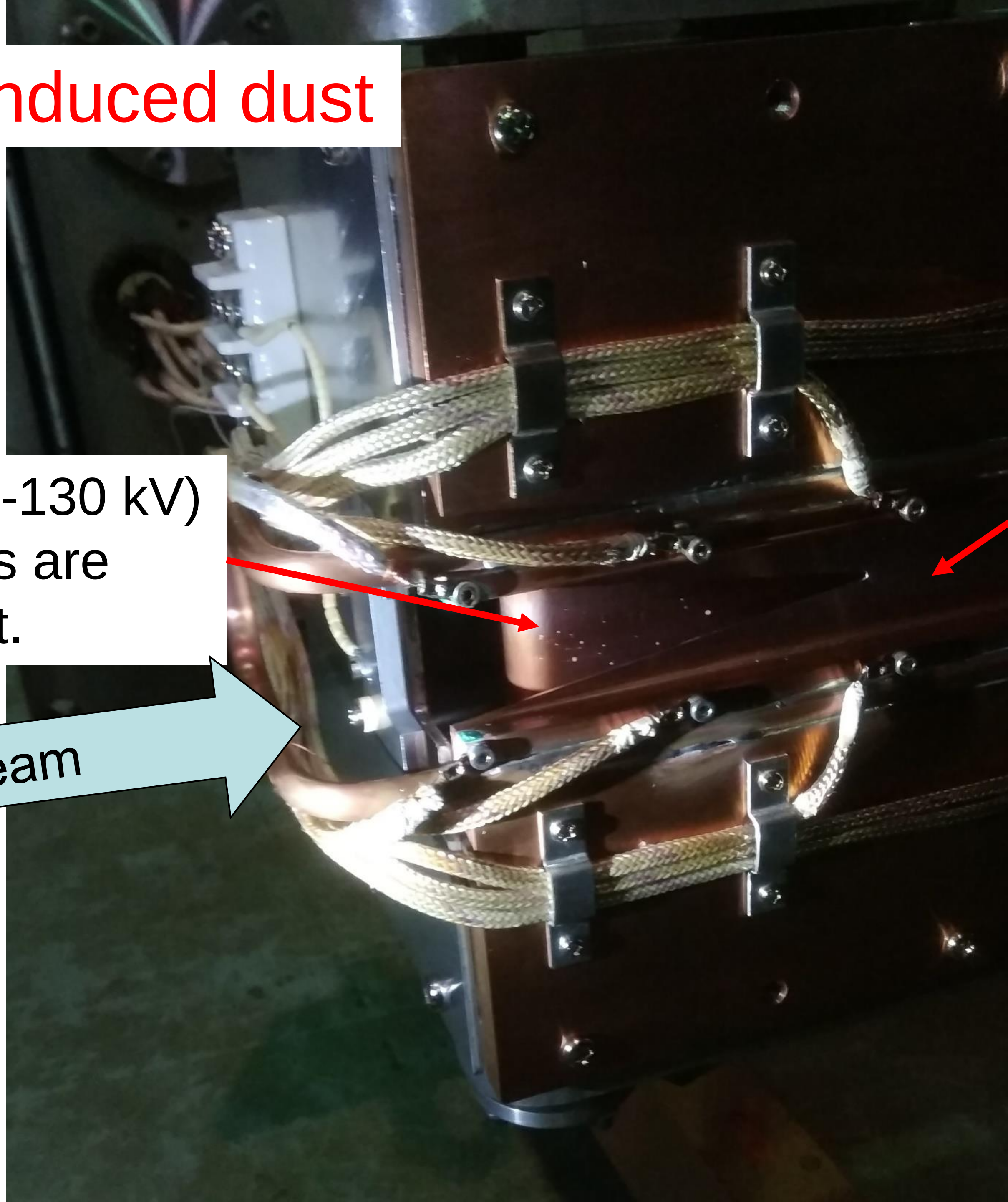






Beam extraction in the cyclotrons.

Beam induced dust



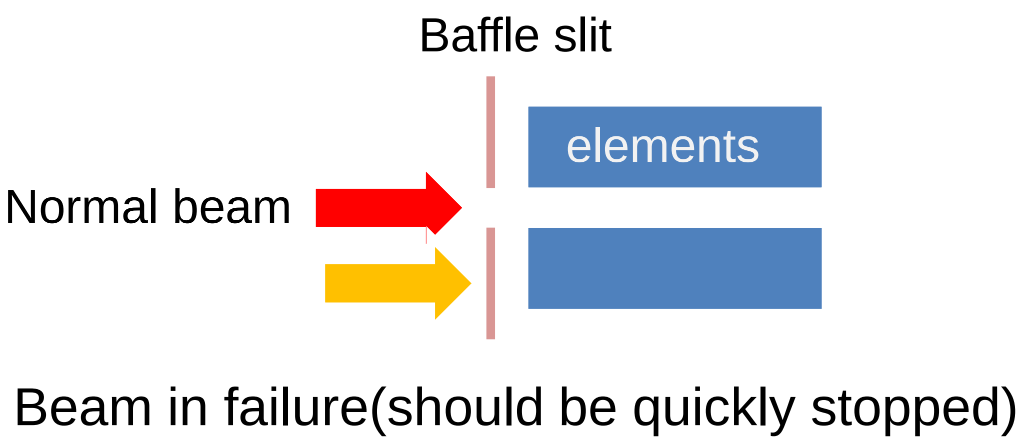
Electrode (-130 kV)
Small dusts are
sticked to it.

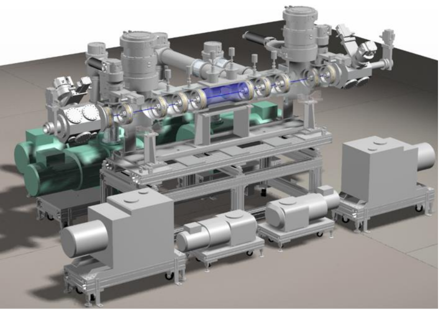
Septum
(0V)

Beam

We need fast interlock system.

- How fast does it stop the beams?
- How strong are the accelerator components such as the EDCs and the baffle slits against the short pulsed beam?
- The EDC and buffles are irradiated by pulsed beam in the case of failure of accelerators.
- HiRADmat experiments will give us the good severe tests of the EDC and buffles (sample test).

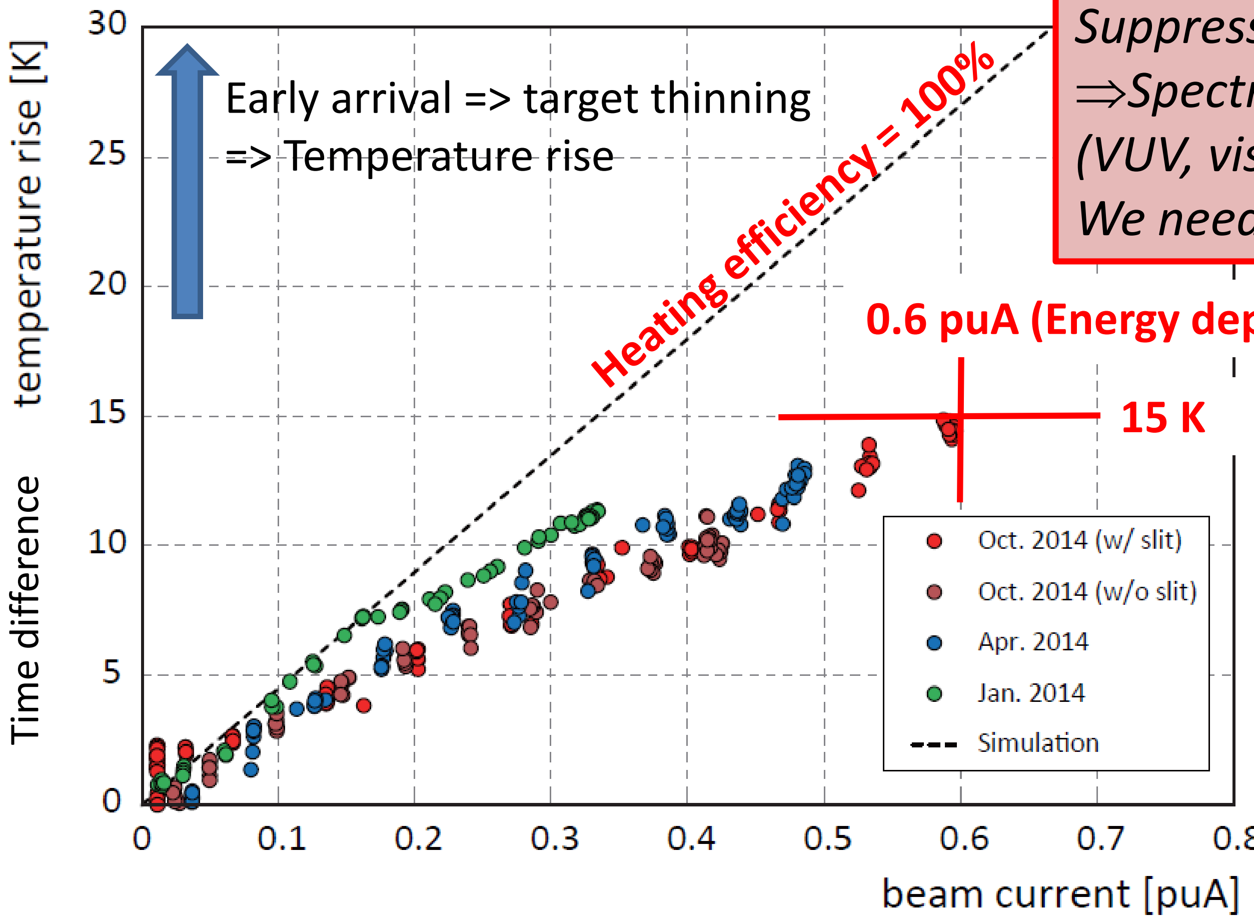




Target thinning of He stripper by heat load

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

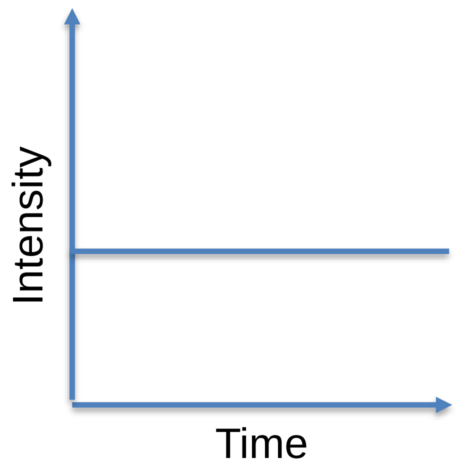
The TOF of U^{64+} beams as a function of the beam intensity using phase probes.

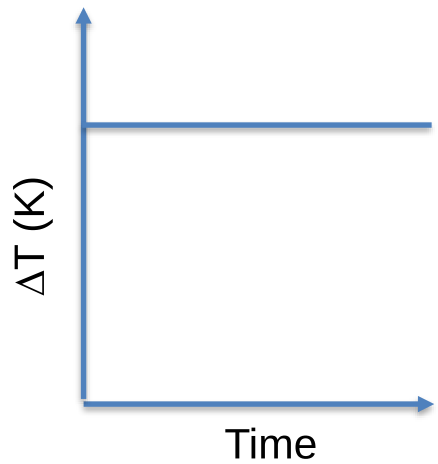


Suppression mechanism?
⇒Spectroscopic study
(VUV, visible light)
We need any hints.

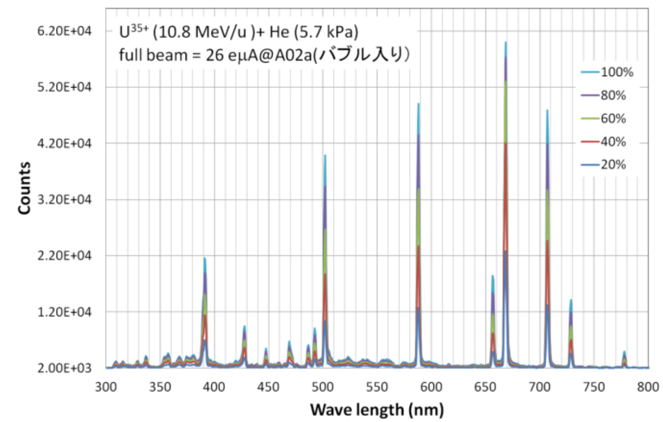
Possible experiments on He gas stripper

RIBF (Equilibrium)

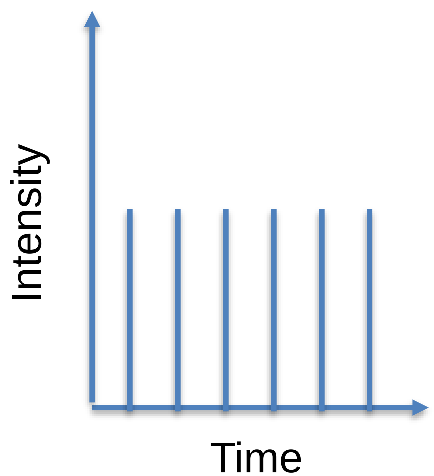


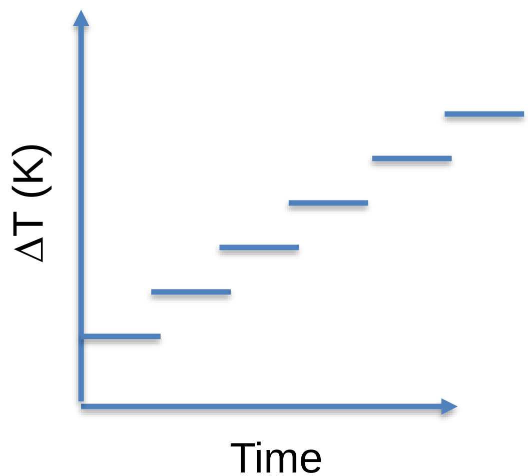


Spectroscopy (ex. Visible light)



HiRADMat (pre-Equilibrium)

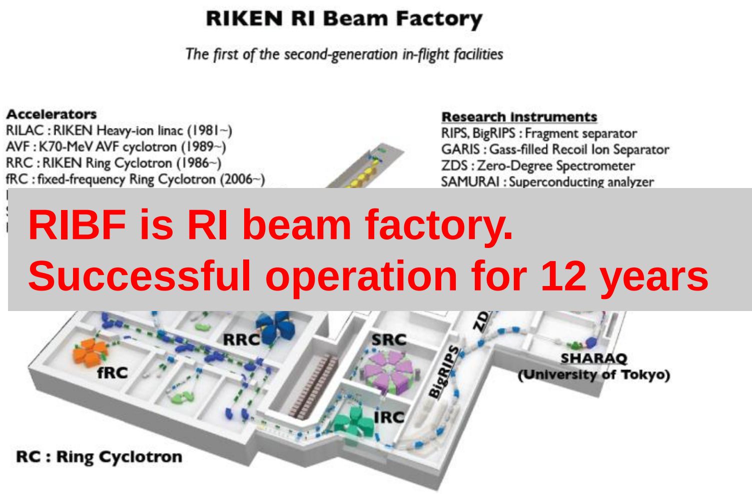




Spectroscopy

Review

Introduction to RI beam factory

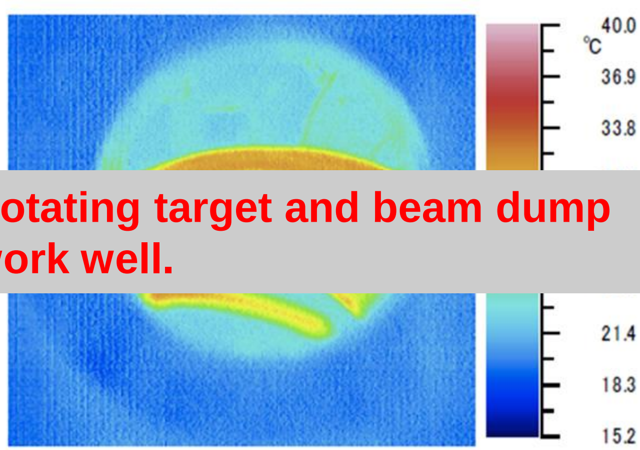


RIBF is RI beam factory.
Successful operation for 12 years

Charge strippers for uranium ion

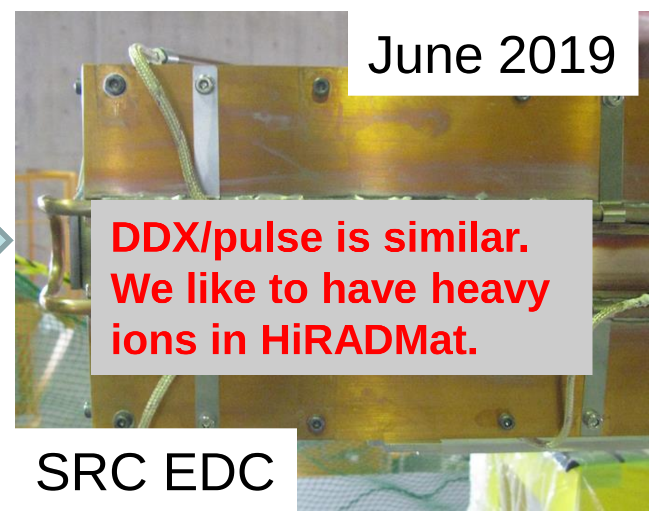
He gas stripper and Kaneka foils work well.

Target & Beam Dump



Rotating target and beam dump work well.

Possible Experiments at HiRADMat



June 2019

DDX/pulse is similar.
We like to have heavy ions in HiRADMat.

SRC EDC