Status of RIKEN 28GHz SC-ECRIS

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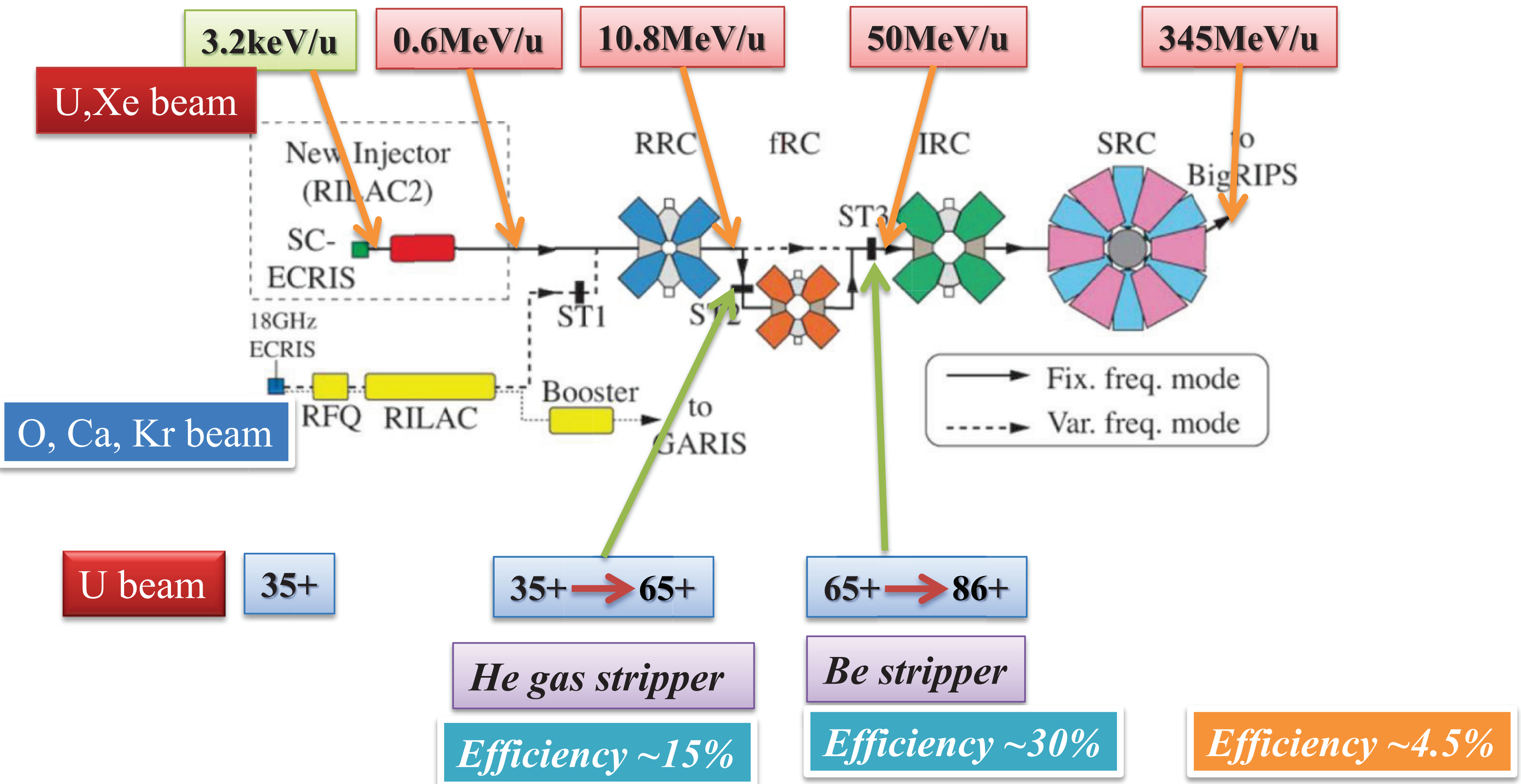
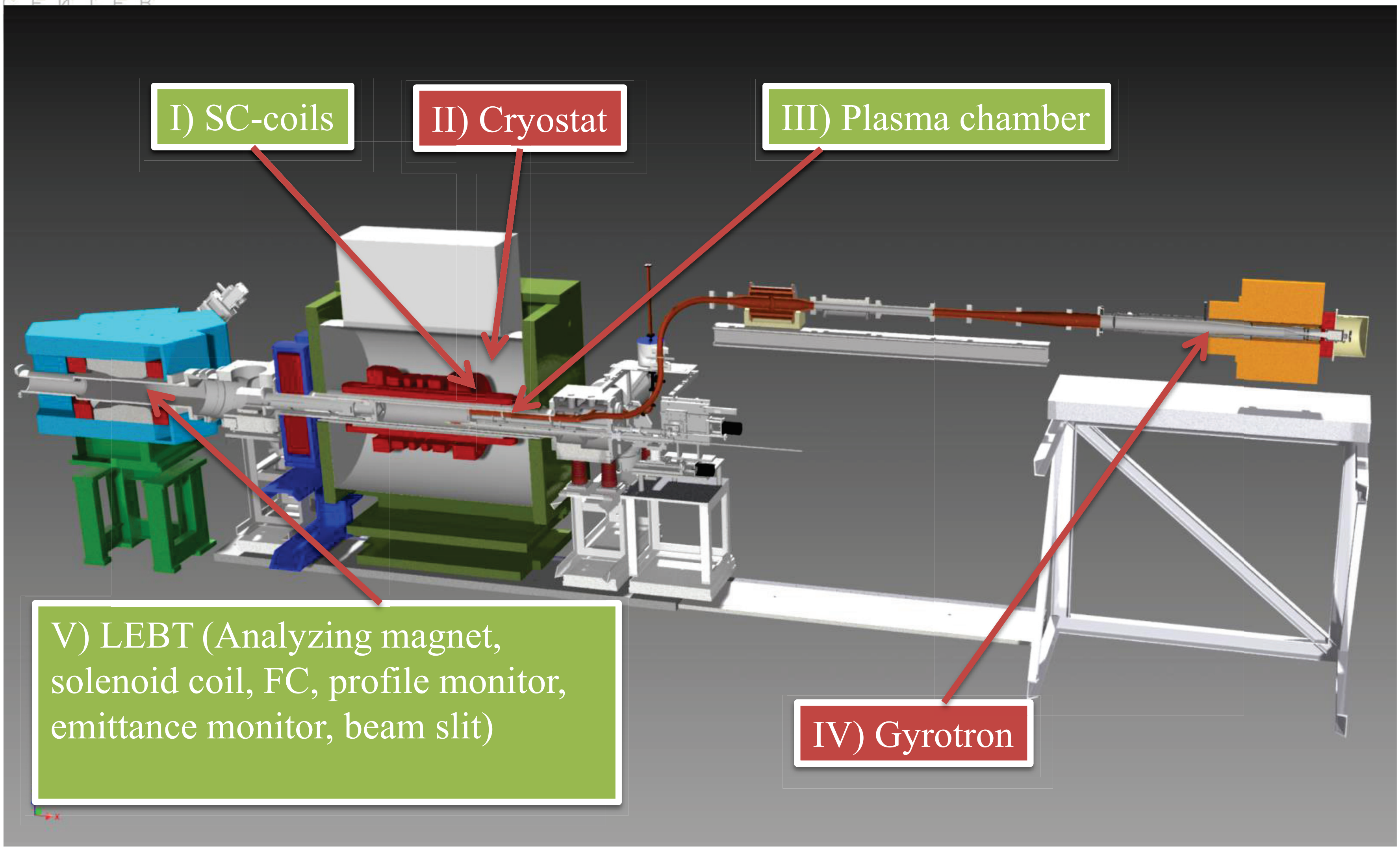
1. Introduction
   RIKEN RIBF project
2. RIKEN 28GHz SC-ECRIS
   Cooling power of the cryostat
   stability of Gyrotron output
3. Experimental results
   Al-chamber effect (highly charged uranium ion production)
   beam intensity of highly charged U ions with sputtering method
   High temperature oven
4. Summary and future plan

RIKEN RIBF

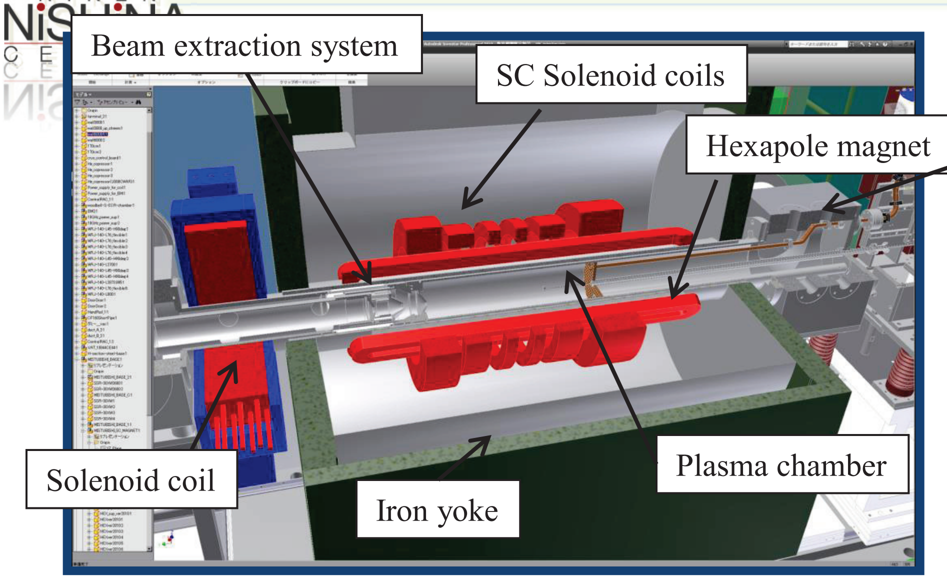


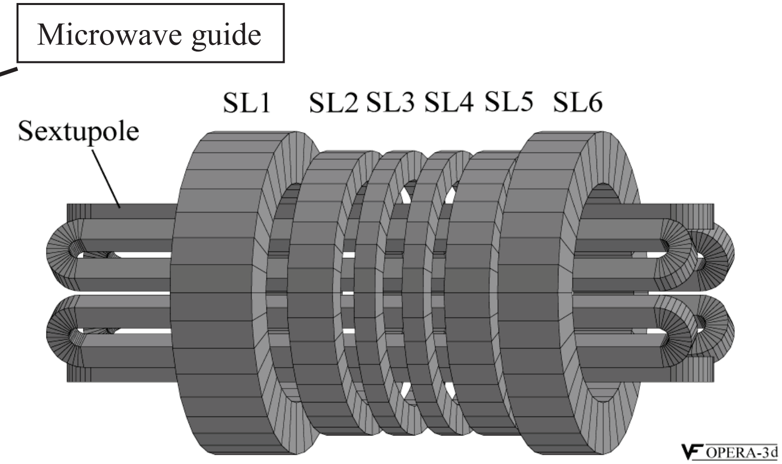
3.2keV/u
0.6MeV/u
10.8MeV/u
50MeV/u
345MeV/u
U,Xe beam
New Injector (RILAC2)
SC-ECRIS
RRC
fRC
IRC
SRC
to BigRIPS
ST1
ST2
ST3
18GHz ECRIS
RFQ
RILAC
Booster
to GARIS
Fix. freq. mode
Var. freq. mode
O, Ca, Kr beam
U beam
35+
35+ → 65+
65+ → 86+
He gas stripper
Be stripper
Efficiency ~15%
Efficiency ~30%
Efficiency ~4.5%

RIKEN 28GHz SC-ECRIS



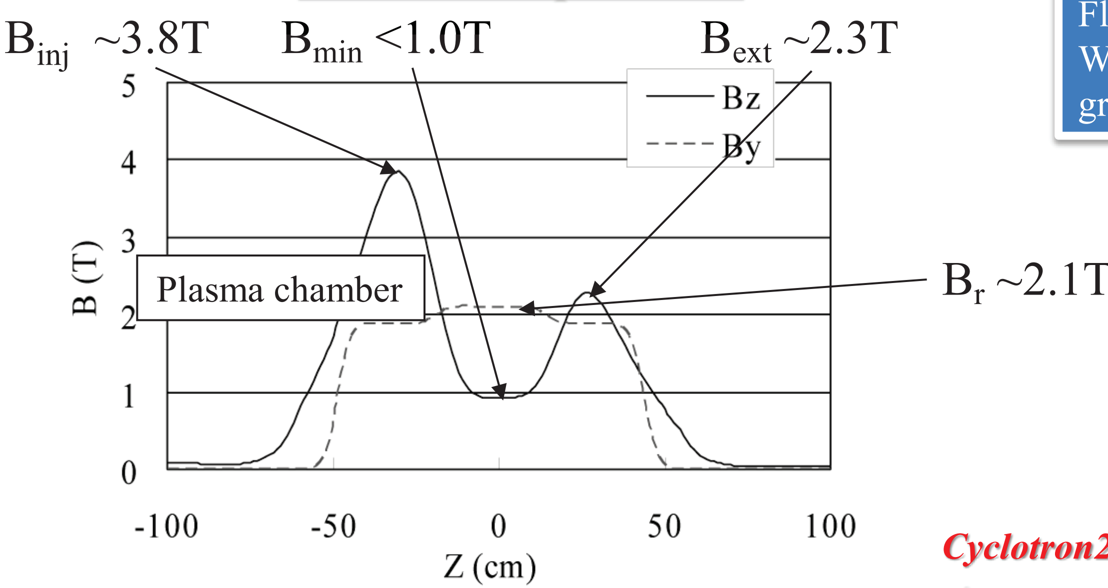
RIKEN 28GHz SC-ECRIS





6 solenoid coils
Flexible magnetic distribution
We can change the magnetic field gradient and ECR zone size independently

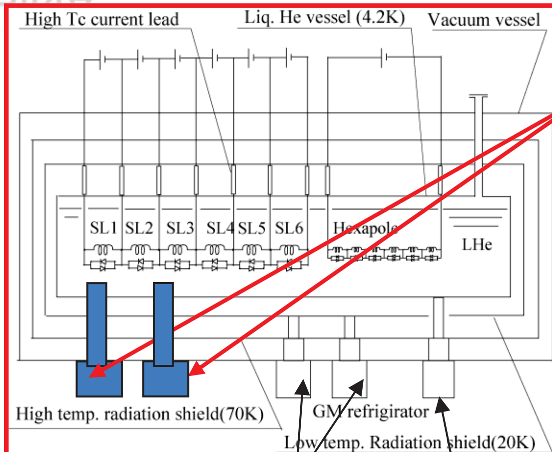
For 28GHz operations



High energy Physics and Nuclear Physics 31(2007)37
J. Ohnishi et al,

"Flat B_{min}" structure
G. D. Alton and D. N. Smithe, Rev. Sci. Instrum. 65 (1994) 775

Cooling power (cryostat)



2 GM-JT

GM refrig. 35W(45K), 6.3W(10K)

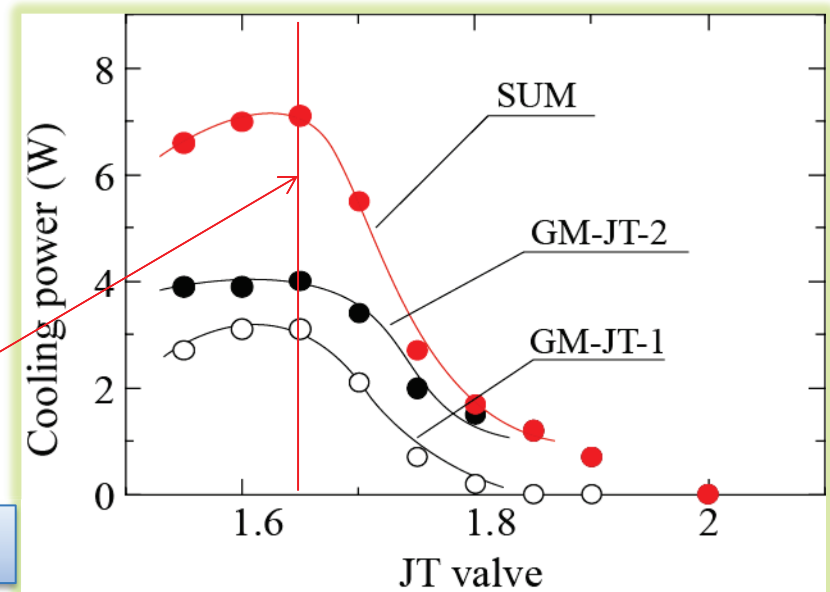
GM. Refrig. 50W(43K), 1.0W(4.2K)

Heat load

(W)

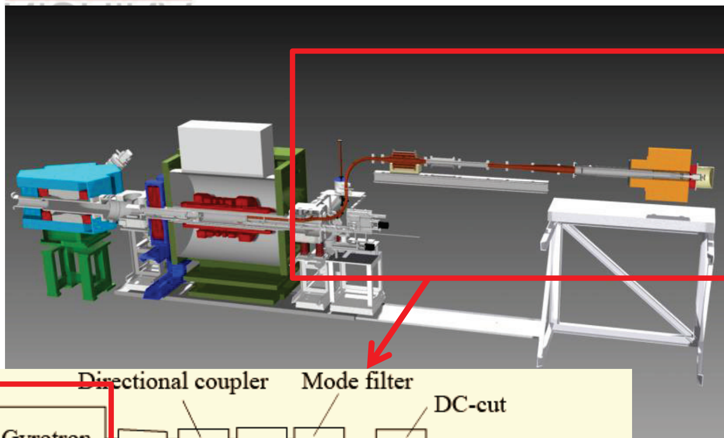
Item	Helium vessel	Low temp. radiation shield	High temp. radiation shield
Design temp.	4.2 K	20 K	70K
Radiation	0.005	5.5	40
Conduction			
Support	0.005	0.3	4
Port	0.06	1.5	20
Current lead	0.07	10	64
Total heat load	0.14	17.3	128

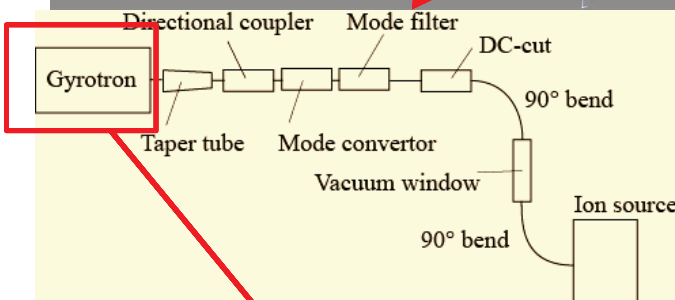
Cooling power (4.2K)	**2GM-JT**	**~7.3W**
	1GM	**~1.0W**
	Total	**~8.3W**

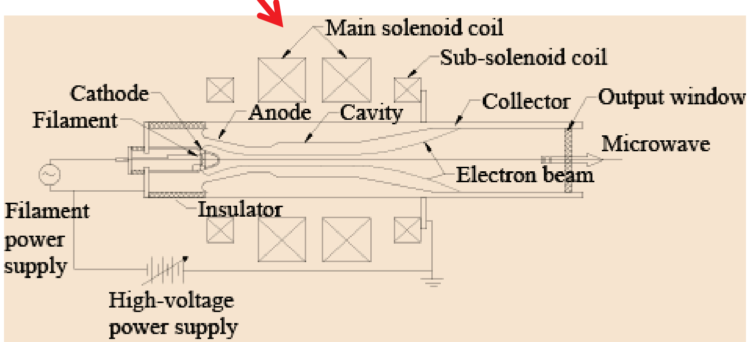


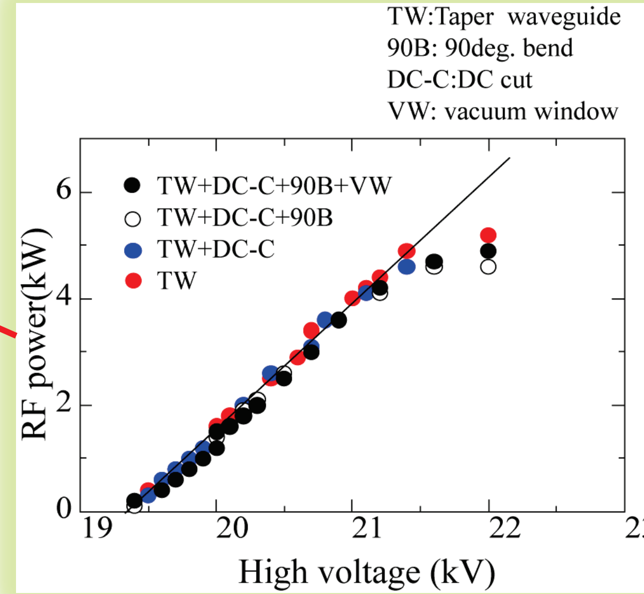
Without plasma cooling power ~8W

Output power stability I (gyrotron)



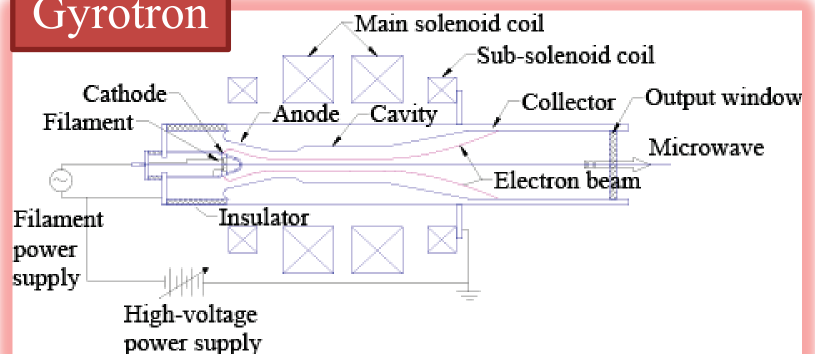


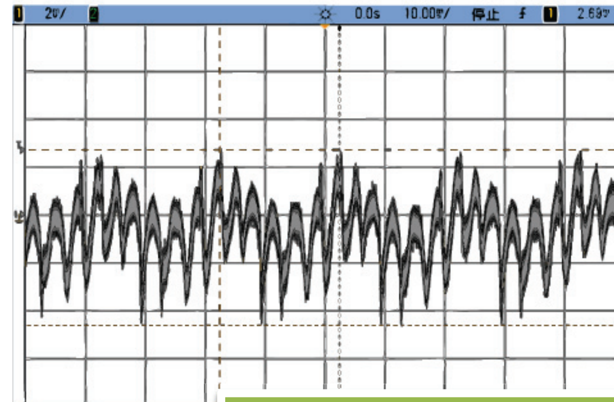




Output power stability II (gyrotron)

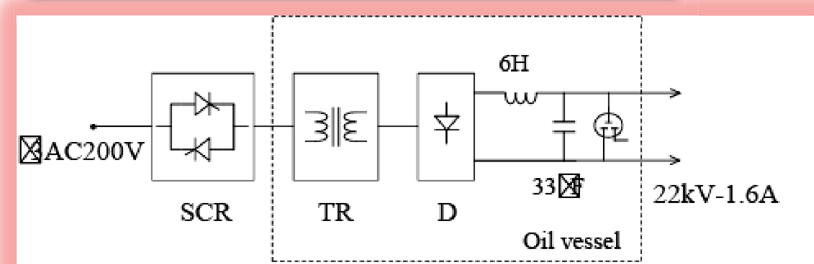
Gyrotron





~300Hz ripple (~400W)

HV power supply for Gyrotron

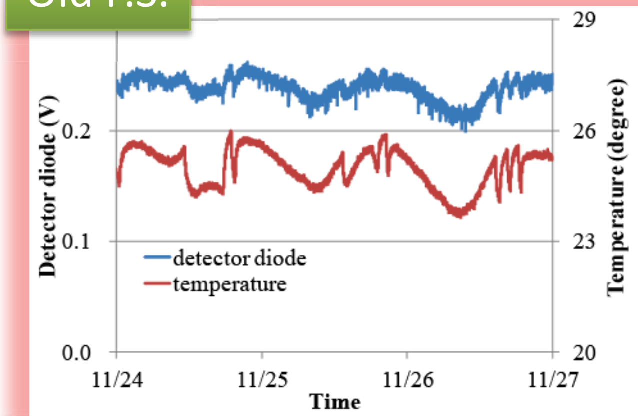


Initially, the rectification circuit shown in Figure for the cathode power supply consisted of a 6 H inductor and a 3 μF capacitor. To reduce the voltage ripples, we increased the capacitance tenfold by adding four 7.5 μF paper capacitors with a maximum rated voltage of 37.5 kV. As a result, the ripples in the cathode voltage and RF power were reduced to approximately 15 V and 100-150 W, respectively, and operation below 500 W became possible.

Output power stability III (gyrotron)

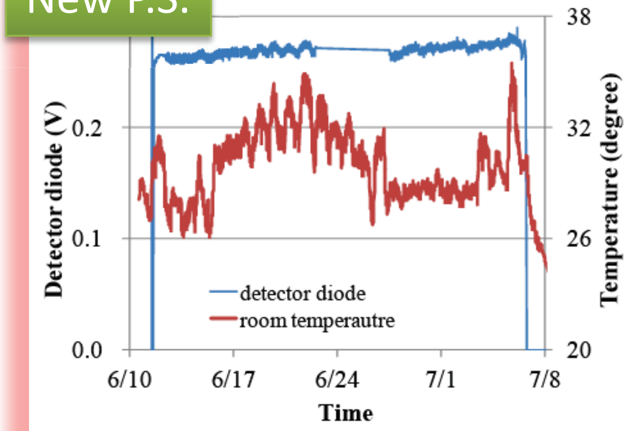
The fluctuation in the diode voltage corresponds to a fluctuation in the RF power of approximately 300 W. This fluctuation seems to be correlated with the temperature of the room in which the power supplies are housed, We investigated this phenomenon intensively because any fluctuation in the microwave power would influence the beam currents. As a consequence, we found that the RF power is very sensitive to the current in the main solenoid coil and that the current changes slightly, on the order of $1 \times 10^{-4}/°C$ with the temperature of the room. In order to reduce this power fluctuation, we replaced the main solenoid power supply with another with a current stability of less than 1×10^{-5} per day. As a result, the RF power could be stabilized to within 7-8% of the total power in one month

Old P.S.

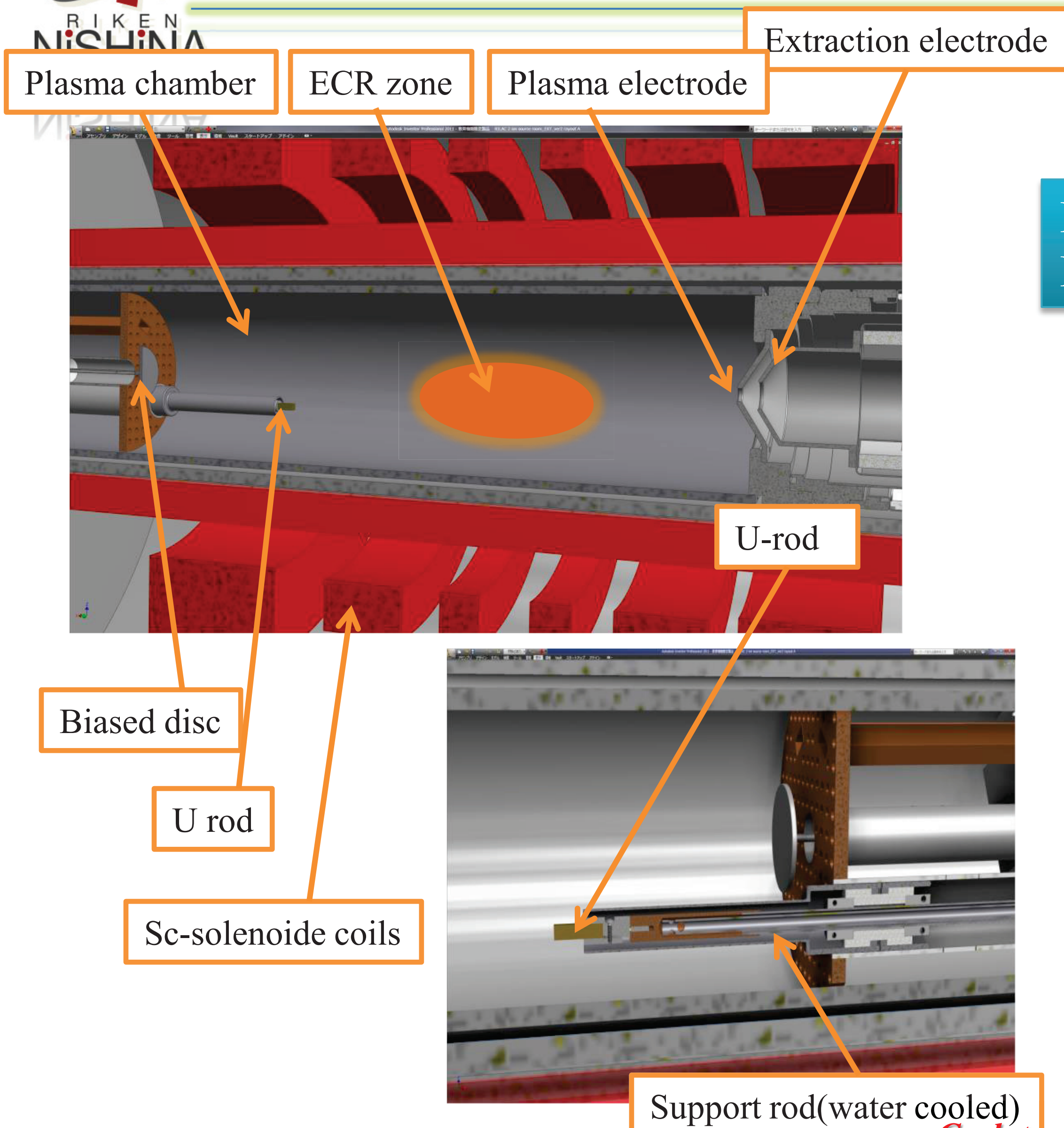


(a)

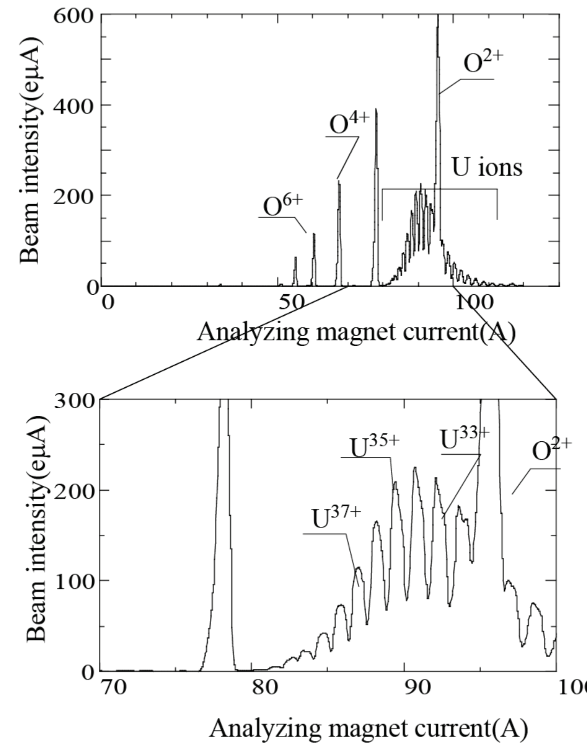
New P.S.



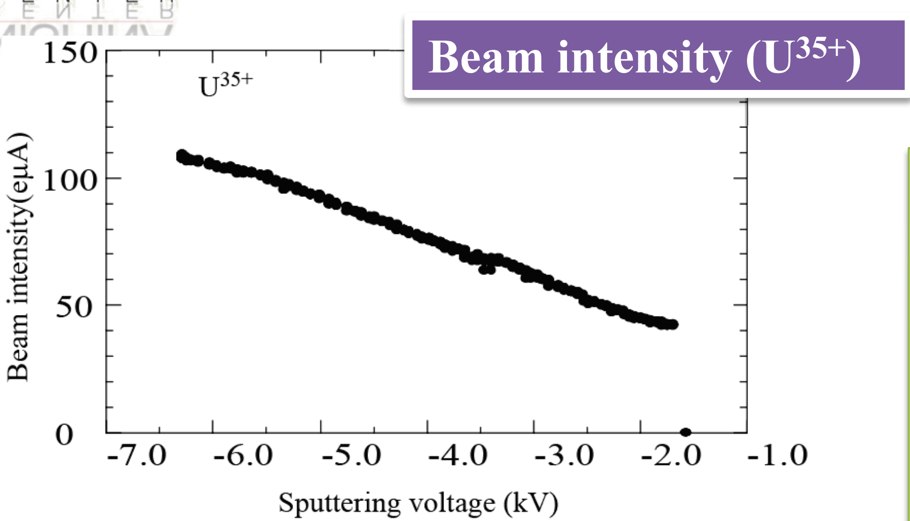
Sputtering method I

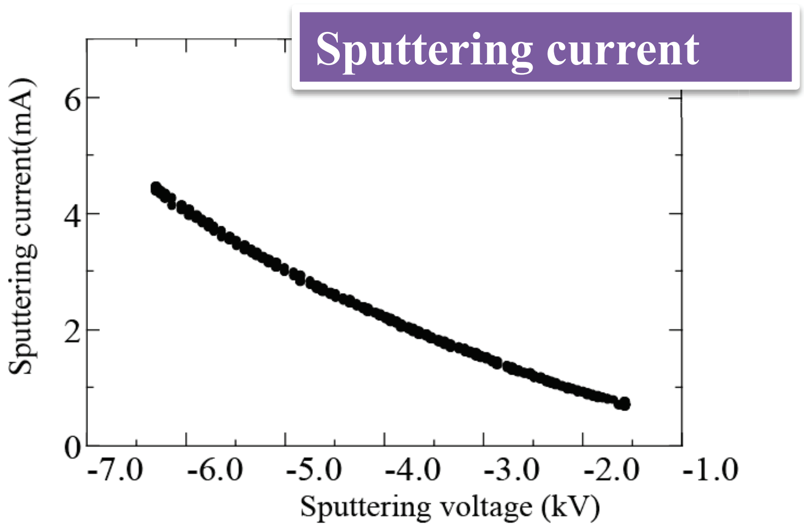


B_{inj}~3.2T, B_{min}~0.6T, B_{ext}~1.8T
B_r~1.85T



Sputtering method II



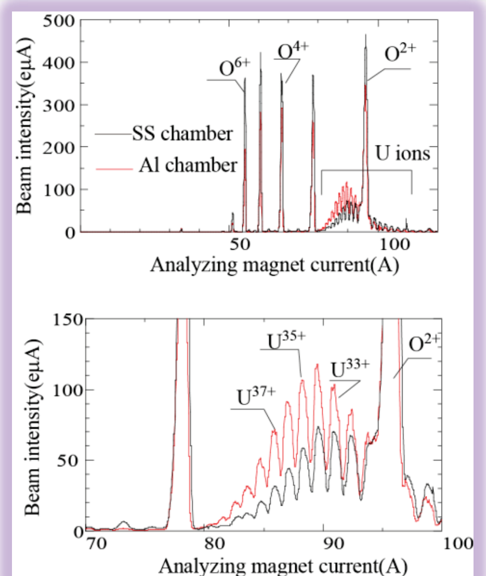


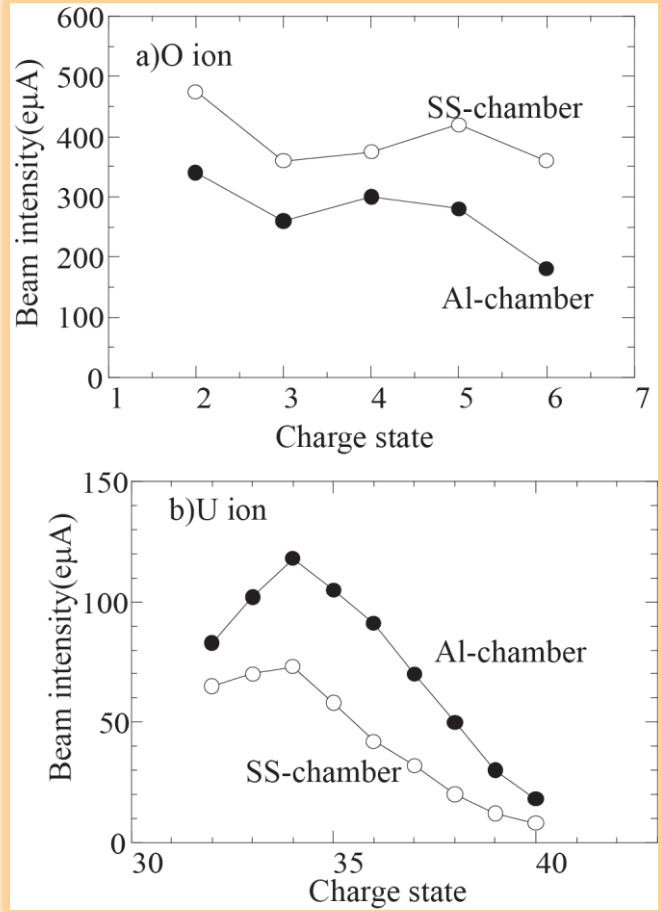
The beam intensity linearly increased with increasing the sputtering voltage.

The beam intensity was not saturated at highest sputtering voltage (-6,5kV)
It may possible to increase the beam intensity at higher voltage

Due to the risk of spark at the high sputtering voltage and instability of the beam, we did not supply the sputtering voltage higher than 6.5kV

Aluminum chamber effect

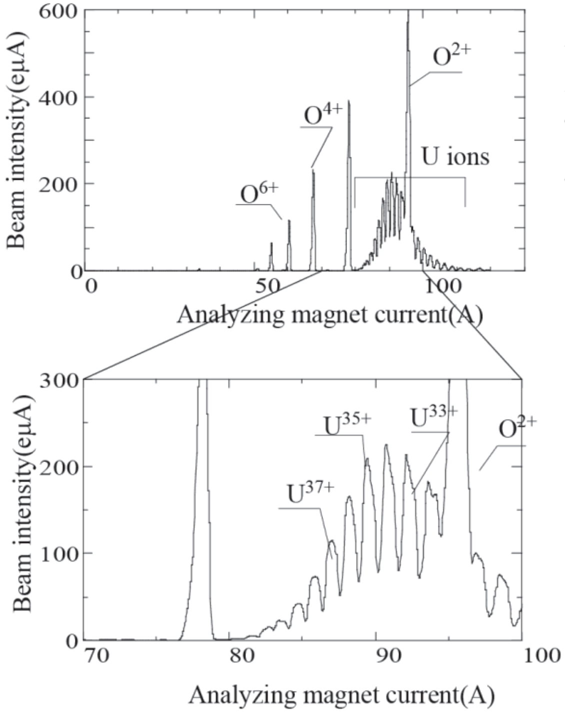




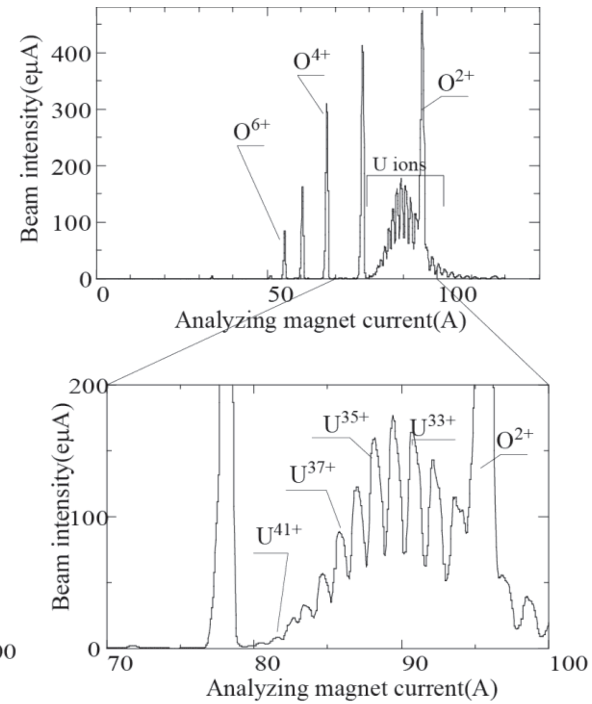
The injected RF power was 2 kW for both cases. The ion source was tuned to produce U^{35+}. As shown in fig. 1, the intensity of the highly charged U ion beam with the Al chamber was higher than those with the SS chamber. For example, the intensity of the U^{35+} ion beam with the Al chamber was 110 eμA, which was almost twice the value (60 eμA) with the SS chamber. It should be stressed that the intensity of an oxygen ion beam with the Al chamber was lower than that with the SS chamber

U beam production

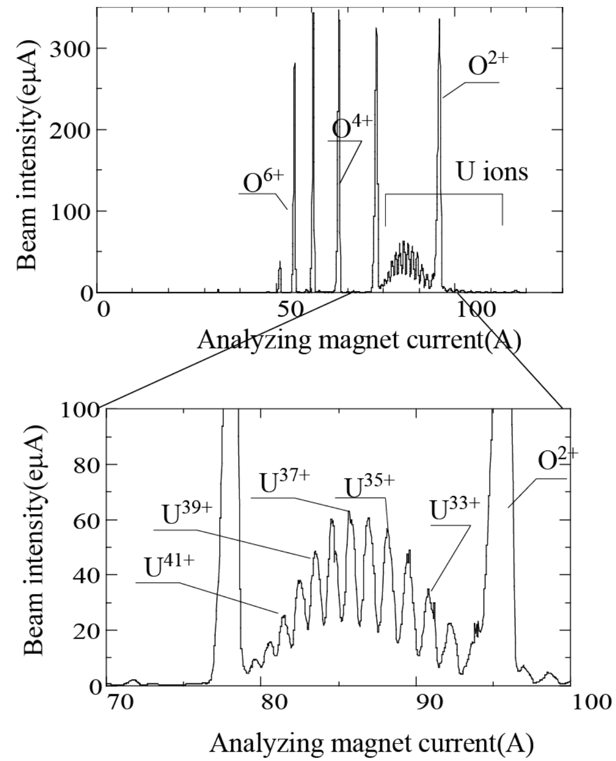
Tuned for 33+ production



Tuned for 35+ production



Tuned for 41+ production



U beam production

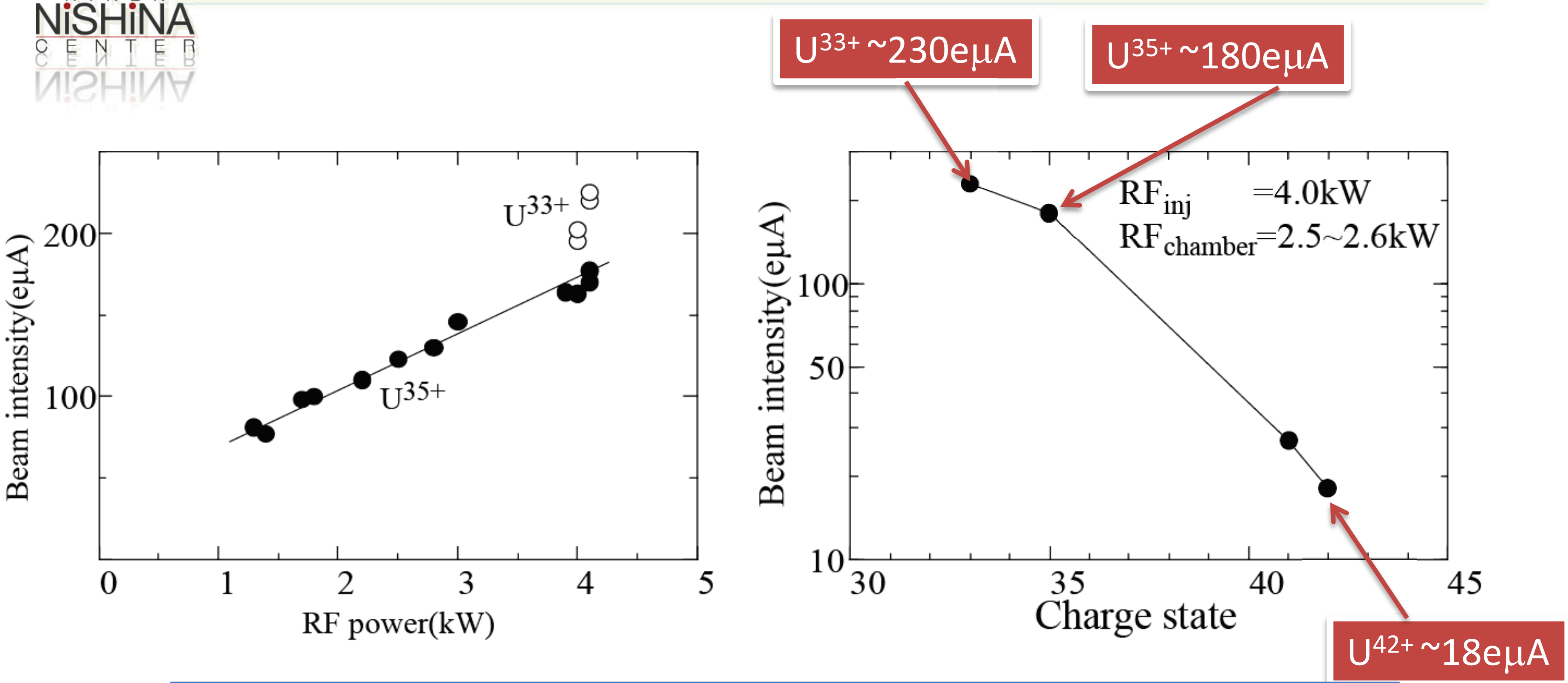
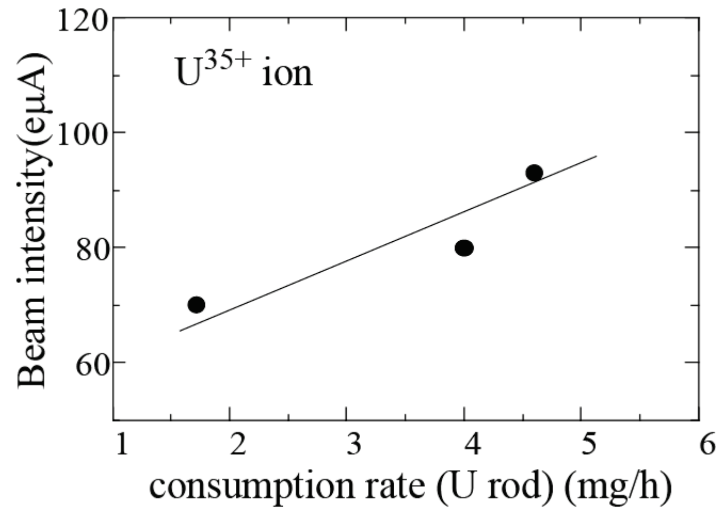


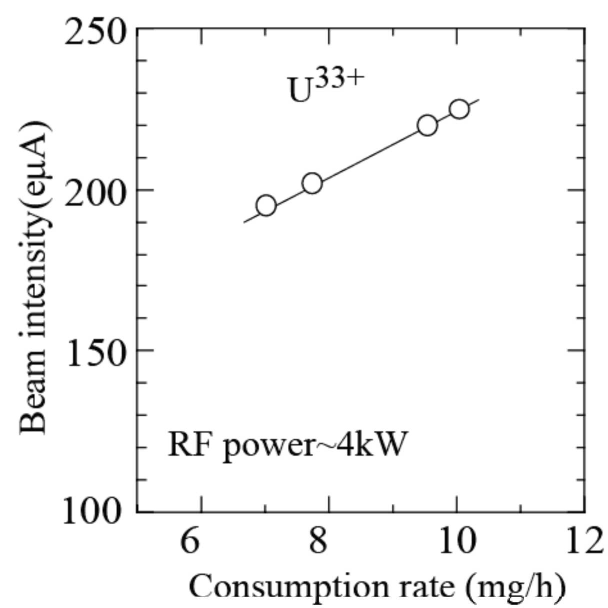
Figure shows the beam intensity of $U^{33+,35+}$ ions as a function of RF power up to 4kW. The beam intensity increased linearly with increasing the RF power. It should be stressed that the beam intensity of $U^{33+,35+}$ ion beams was not saturated at highest RF power (~4kW). We may obtain higher beam intensity with higher RF power. The beam intensity of U^{33+} was strongly dependent on the sputtering current at 4kW. In this experiment, the extraction current was ~5mA at 4kW.

Consumption rate

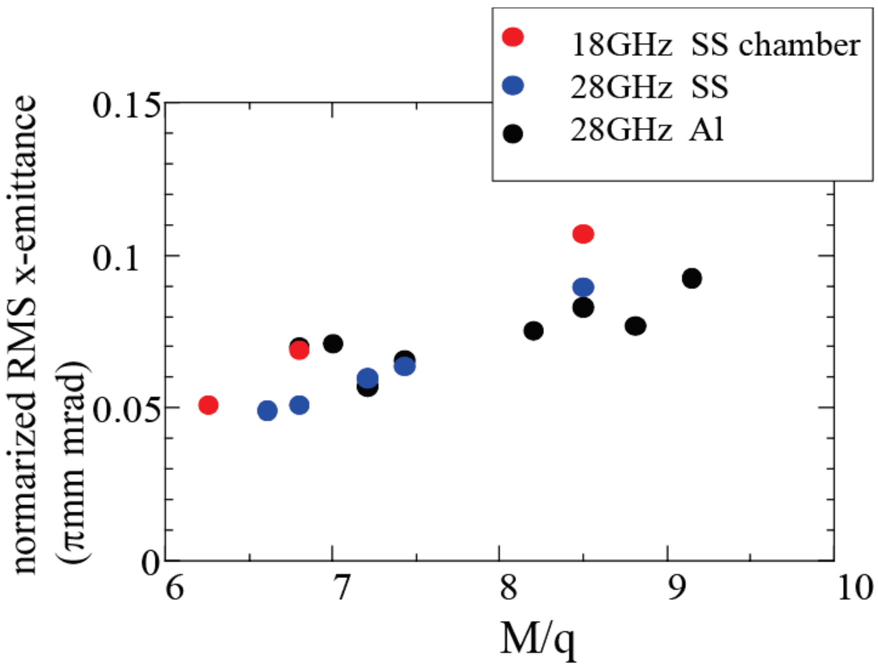
For long term operation without break, the low consumption rate of the material is essential. One of the requirements of RIKEN RIBF project is to produce intense U^{35+} ion beam longer than one month without break. The consumption rate of the U rod was ~5mg/h at the sputtering voltage of -5.5kV and sputtering current of 2.9 mA. **To produce ~180eμA of U^{35+} ion beam, the consumption rate was ~6mg/h.**

To produce U^{33+} ion beam, the beam intensity (190~225eμA) increased with increasing the consumption rate (7~10mg/h) at the RF power of 4kW and it was not saturated at highest consumption rate in this experiment. For this reason, we may produce higher beam intensity of U^{33+} ion with higher consumption rate at same RF power (~4kW) with sputtering method.

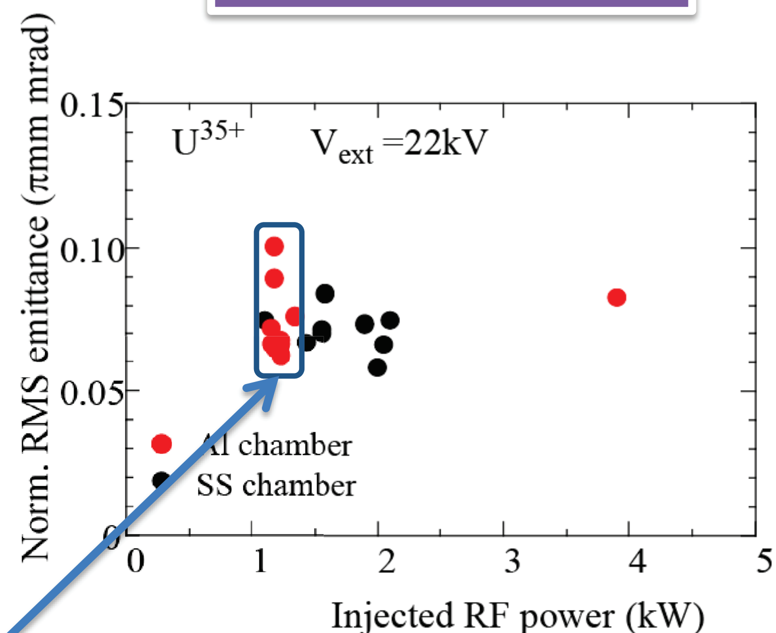




Emittance II



RF power dependence



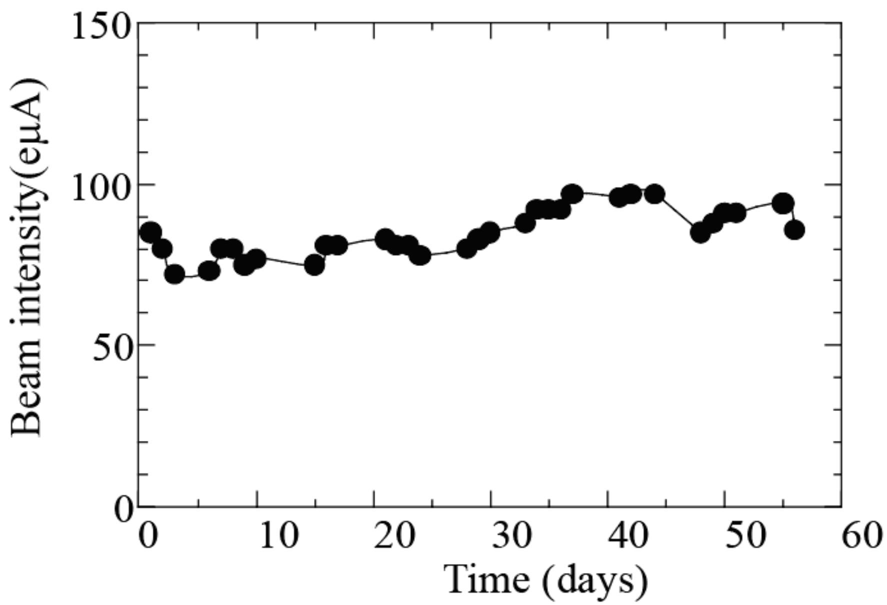
Emittance during the beam time (for two months)

Emittance was strongly dependent on the ion source condition (0.06 ~0.1πmm mrad)

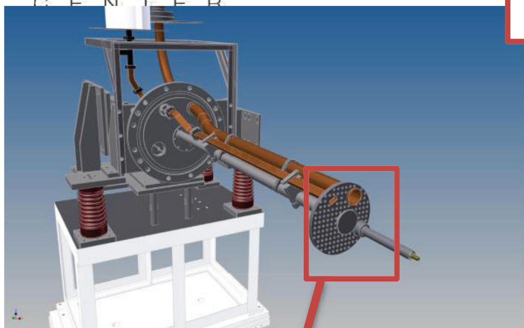
Long term operation (U beam)

U35+ beam production with sputtering method

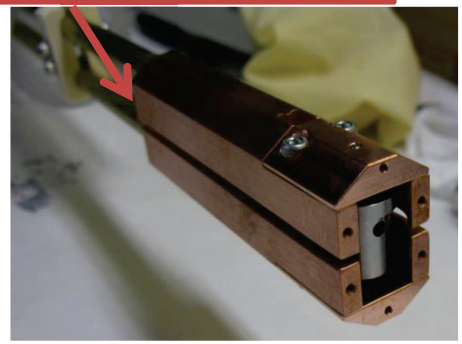
RF power	~ 1.3kW
average beam intensity	~86 eμA
U rod	~15gr
consumption rate	~4 mg/h



High temperature oven I



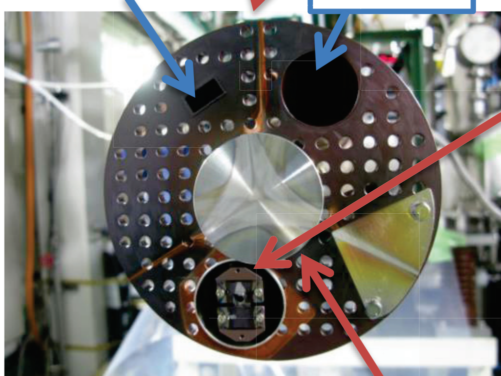
Cooling water channel

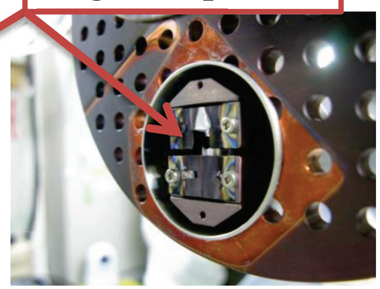


18GHz

28GHz

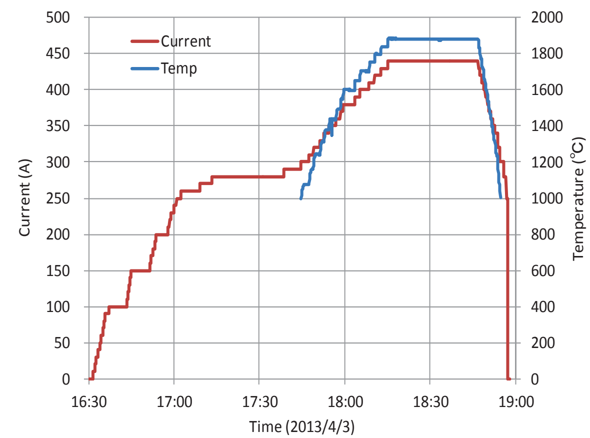
High temp oven





Movable biased disc

Current and temperature of the oven



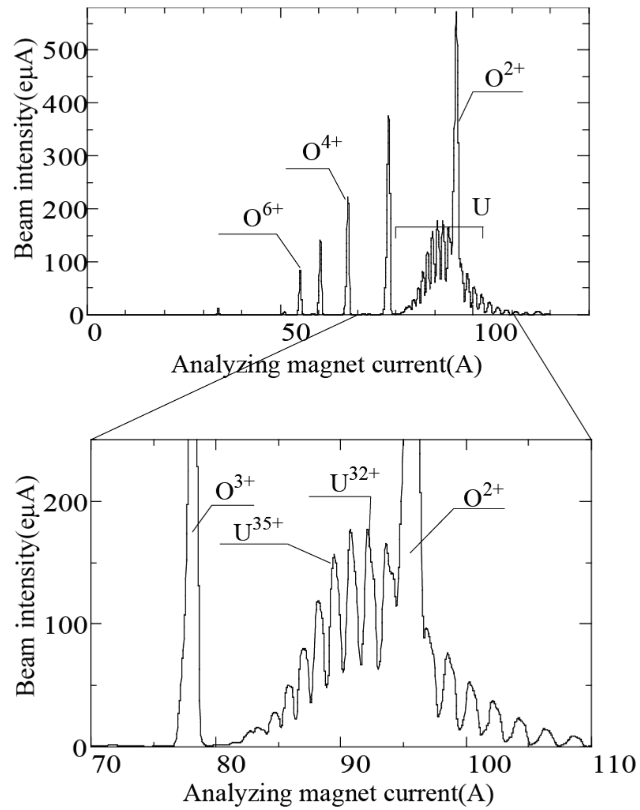
High temperature oven II

1. beam intensity of U^{35+}~170eμA@4kW
Oven current 445A(~1900deg.)

2. We need 2days for production of the beam (1day for evacuation of the chamber, 1day for ion production)

3. Check the life time of the oven and consumption rate of the material(UO_2)

Tuned for production of U^{33+} ion



Conclusions

1.Beam intensity of highly charged U ion beams (Al chamber)

Sputtering method +single RF (28GHz) at 3~4kW injection

U^{35+} ~180eμA

U^{33+} ~230eμA (**U^{33+}+U^{34+} ~450eμA**)

U^{42+} ~18eμA

2. The intense beam of U^{35+} ion was produced for RIBF experiment **longer than one month without break**

3. The emittance of the U^{35+} ion beam

~0.06πmm mrad (normalized 1 rms)(it is strongly dependent on the ion source condition 0.06~0.1πmm mrad)

4. **High temperature oven**

successfully started to produce U^{35+} ion beam with high temperature oven

Future plan

1. Optimizing the magnetic field distribution

2. Two frequency heating (28GHz+18GHz)

3. Minimizing the consumption rate of the material
   sputtering method 4mg/h
   Total consumption ~6g/2months

   consumption rate for oven method?
4. Stabilizing the beam intensity (minimizing the damage of the accelerator)
   (emittance slit?)

5. Minimalizing the X-ray heat load

Thanks for your attention!!