The 22nd International Workshop on ECR Ion Sources Busan, Korea
28 August - 1 September 2016

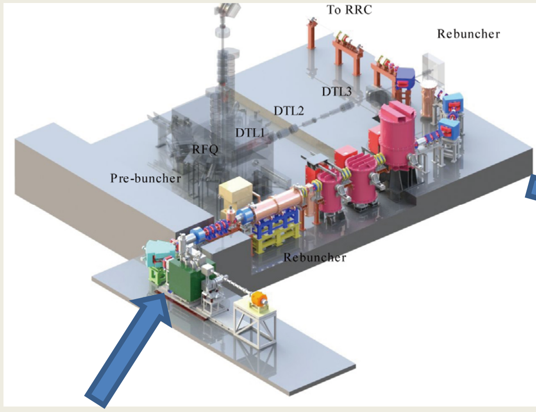
Recent development of RIKEN 28GHz SC-ECRIS

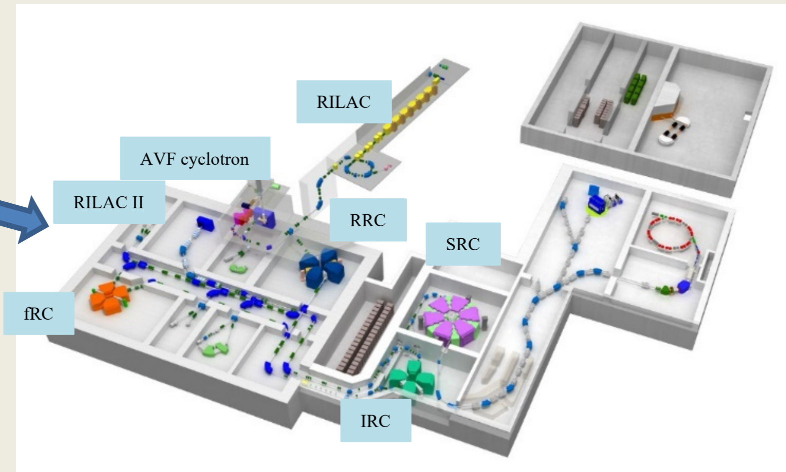
Y. Higurashi*, J. Ohnishi, H. Haba,
M. Kidera, K. Ozeki and T. Nakagawa
(RIKEN, Nishina center)

The outline of my talk

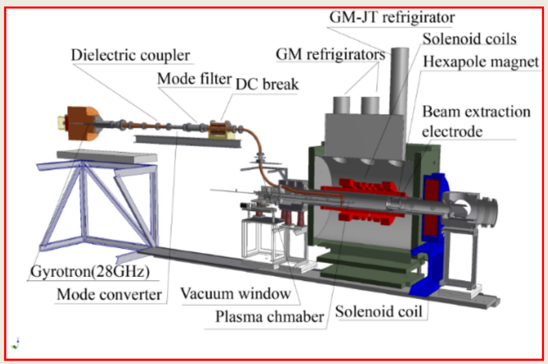
1. Introduction
2. U ion production (sputtering method)
3. U ion production (oven method)
4. Zn ion beam production (oven method)
5. Conclusion and next step

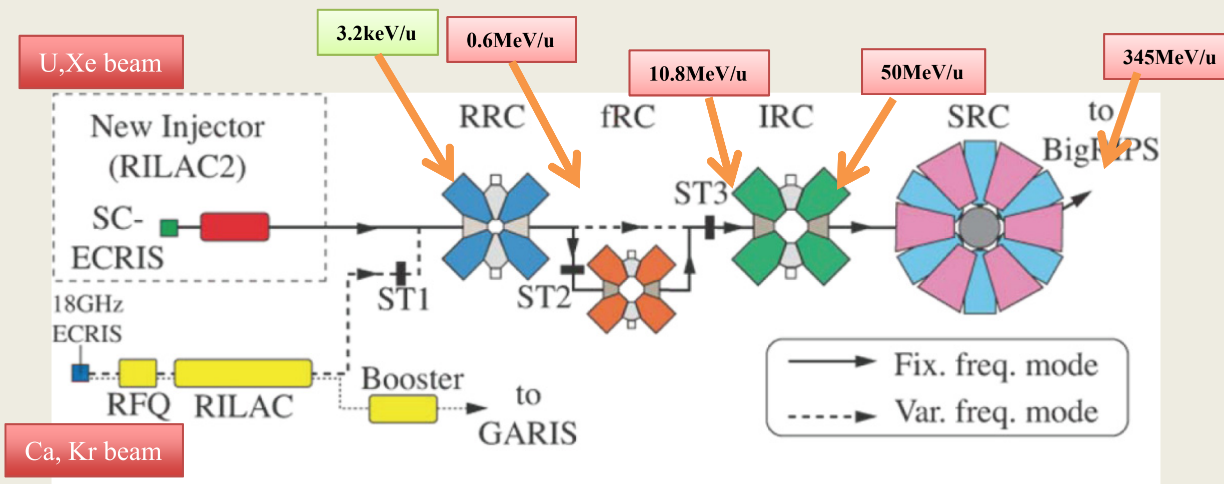
RIKEN RIBF





28GHz SC-ECRIS



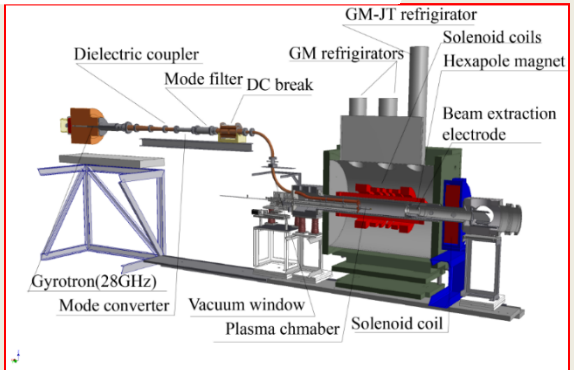


The transmission efficiency of U ion beam is only 5%, even we have 100% of transmission in the accelerators.

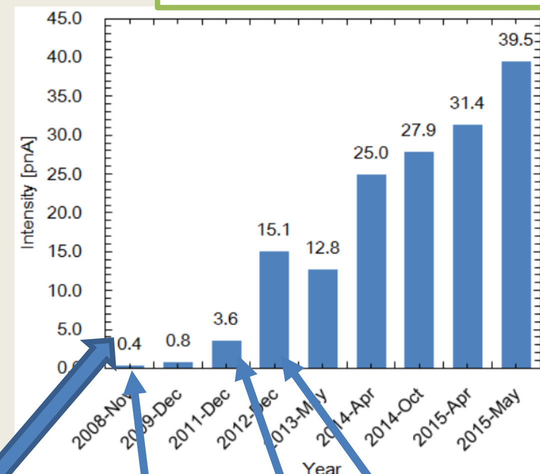
U beam production (~2015)

Sputtering method

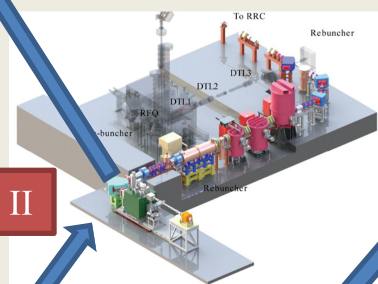
RIKEN 28GHz SC-ECRIS

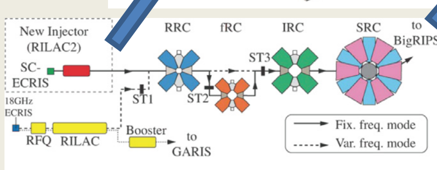


M. Nishida et al, PASJ 2015,FSP003



RILAC II





18GHz ECRIS

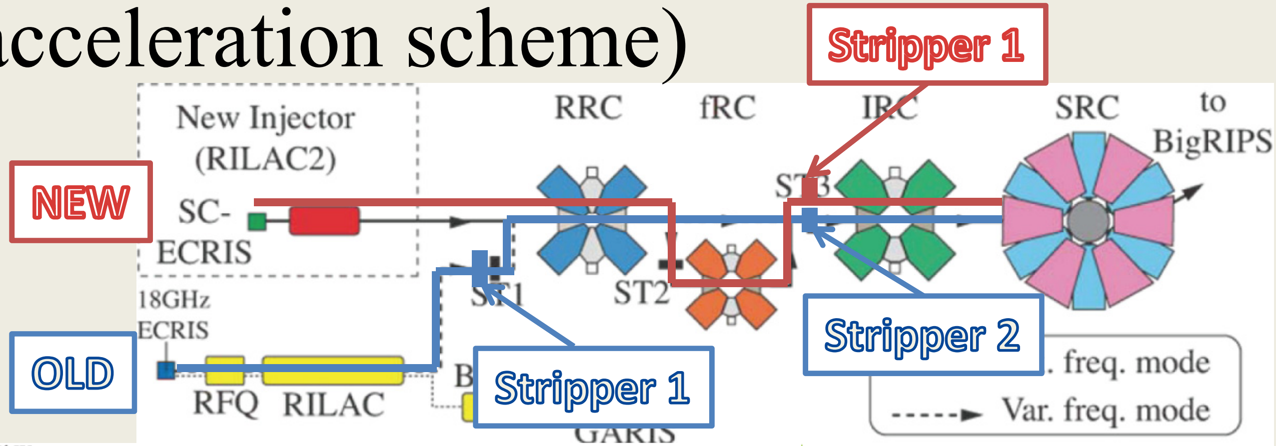
28GHz SC-ECRIS (Al chamber)

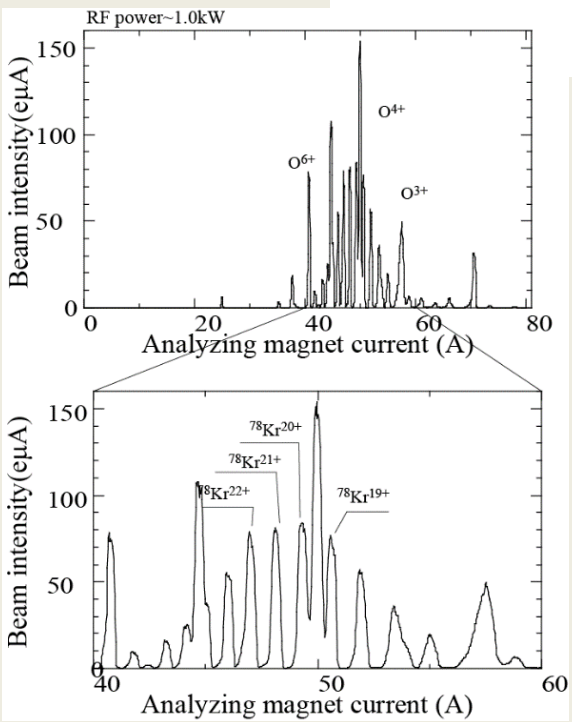
28GHz SC-ECRIS (SS chamber)

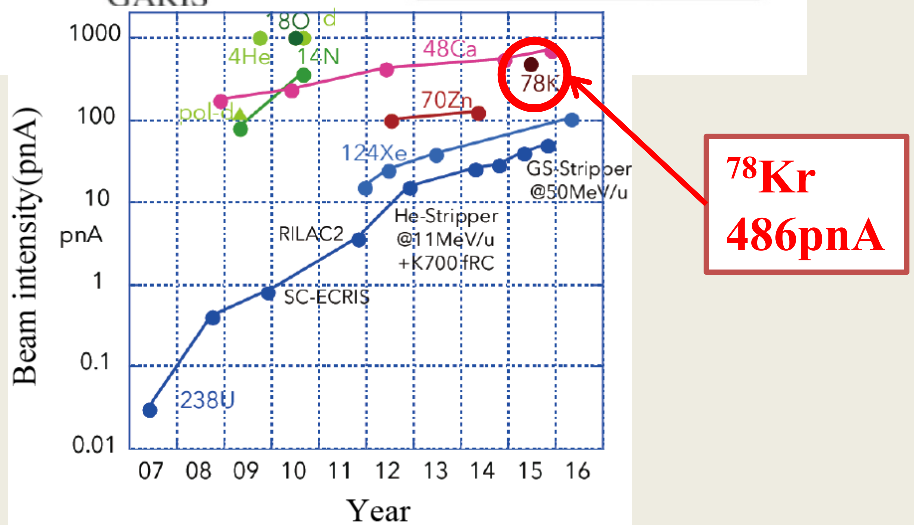
G. D. Alton and D. N. Smithe, Rev. Sci. Instrum. **65**, 775 (1994).

Need to increase the beam intensity and the stability

Kr beam acceleration (New acceleration scheme)







Plan to accelerate Zn ion beam

Requirement : Intense Zn^{19+} ion beam
longer than one month without break
(low consumption)

2015 ~2016

1. Increase the output beam intensity of U ion (RIBF ~345MeV/u)
   - Increase the beam intensity of U^{35+} ions from ion source
   - Stabilize the beam intensity

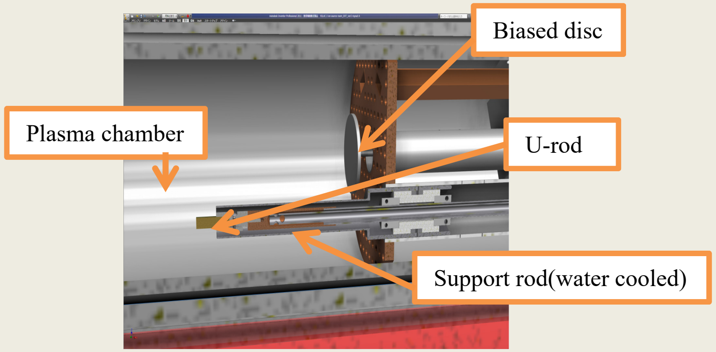
   - Improvement of sputtering method
   - Development of oven method

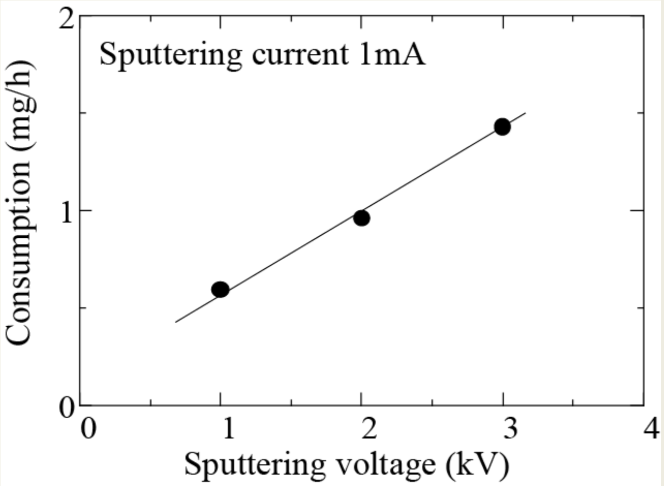
2. Production of Zn ion beam (The new acceleration scheme)

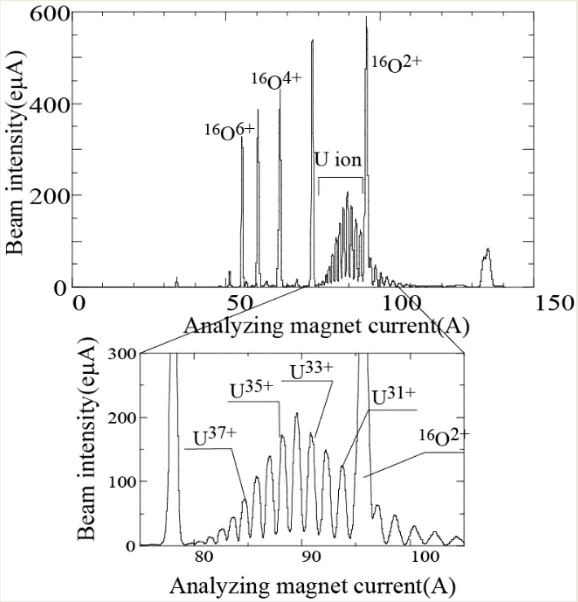
   - production of Zn^{19+} ion beam

   - We need to produce the beam longer than one month without break
     (low consumption rate)

U production (sputtering method)

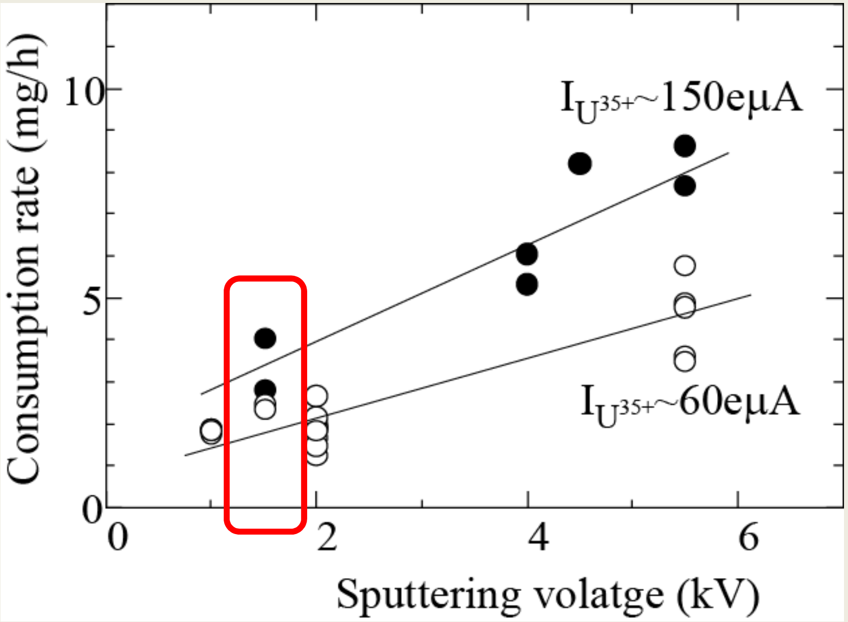






The metal U is supported by the support rod cooled by cooling water. the sputtering voltage was several kV to obtain enough neutral U atoms. This figure show the preliminary results of the consumption rate as a function of sputtering voltage. The consumption rate decreases linearly with decreasing the voltage. At 1kV, we obtained about 0.5mg/h at 1mA of sputtering current.

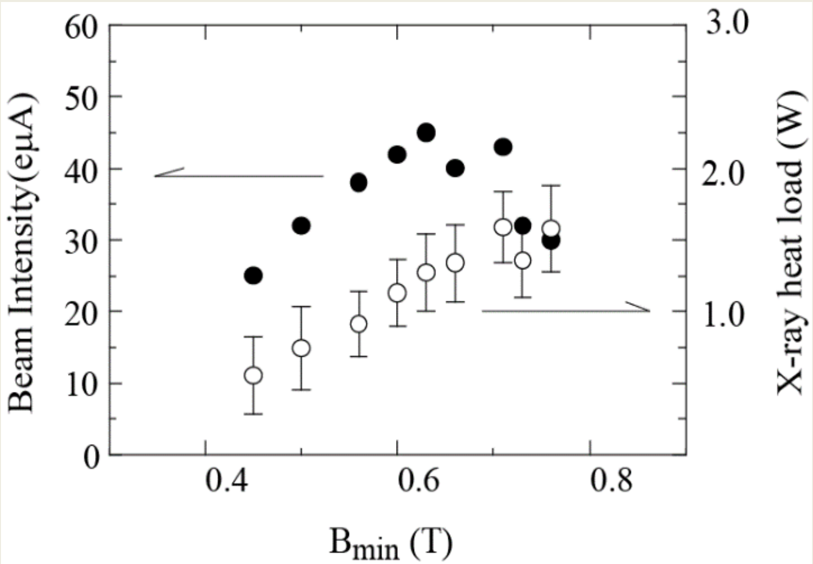
Consumption rate



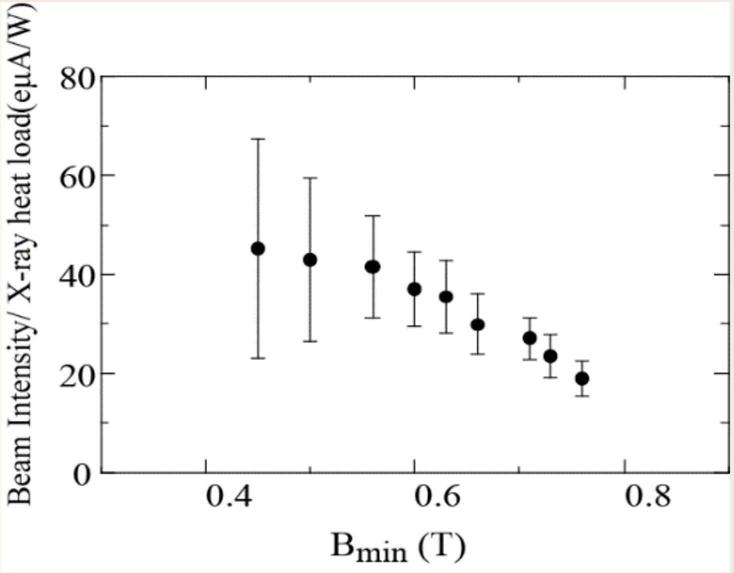
To obtain the consumption rate, we performed long-term measurements of the total amount of material consumption and total sputtering current, at fixed sputtering voltage. For example, we obtained the consumption rate of ~1 mg/h for 1 mA of sputtering current (ion current + current due to the secondary electron emission) at the sputtering voltage of -2 kV. Consumption rate strongly depended on the sputtering voltage and was proportional to the sputtering current at fixed sputtering voltage.

2~3mg/h for production of U^{35+} (100~150eμA)

Beam intensity and X-ray heat load (B_{min})

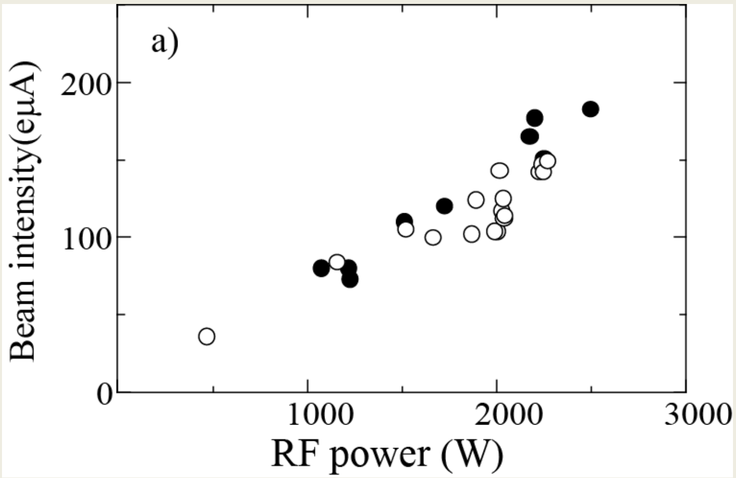


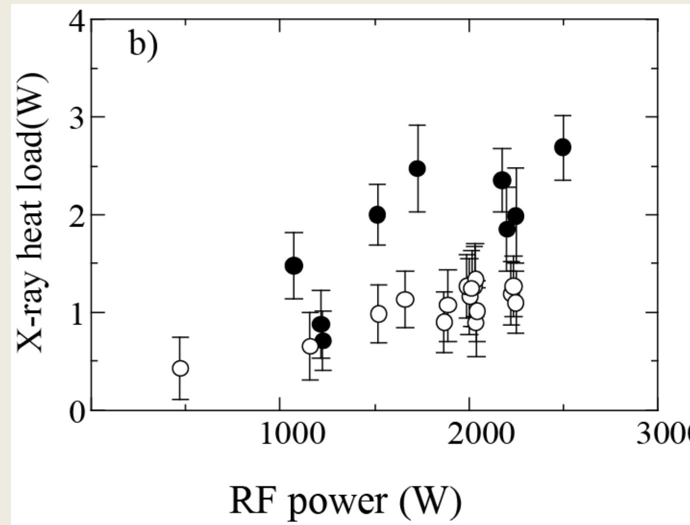
Beam intensity increases with increasing B_{min} up to ~0.65T and the gradually decreases. On the other hand, X-ray heat load increase with increasing B_{min}



Intensity/heat load increases with decreasing B_{min} . It seems that the value becomes almost constant at B_{min}~0.6T

RF power dependence
(beam intensity and X-ray heat load)



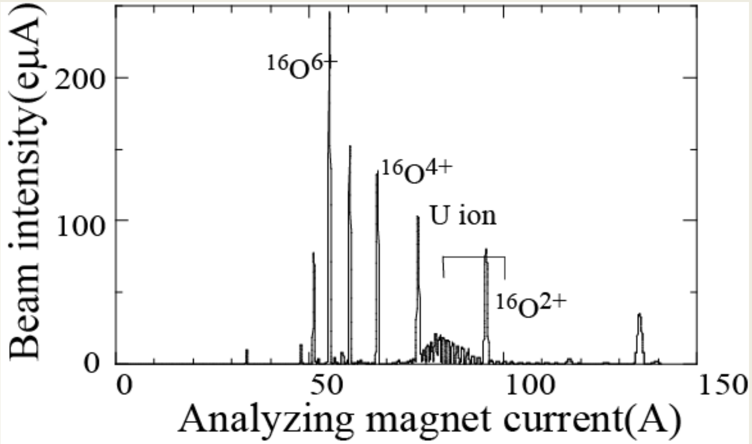


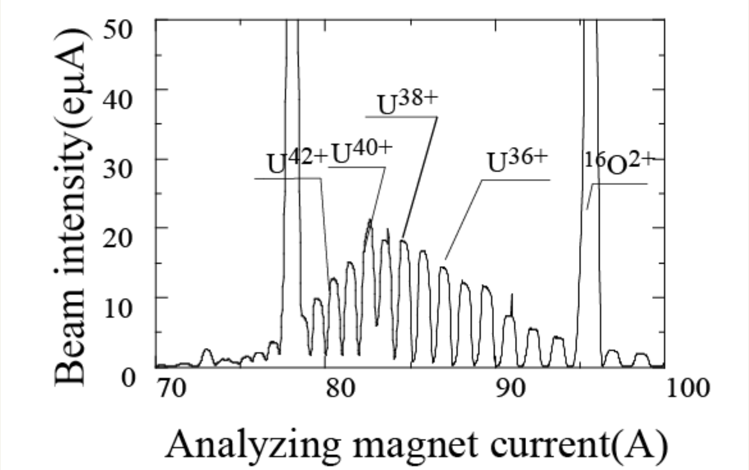
● B_{min}~0.66T
○ B_{min}~0.56T

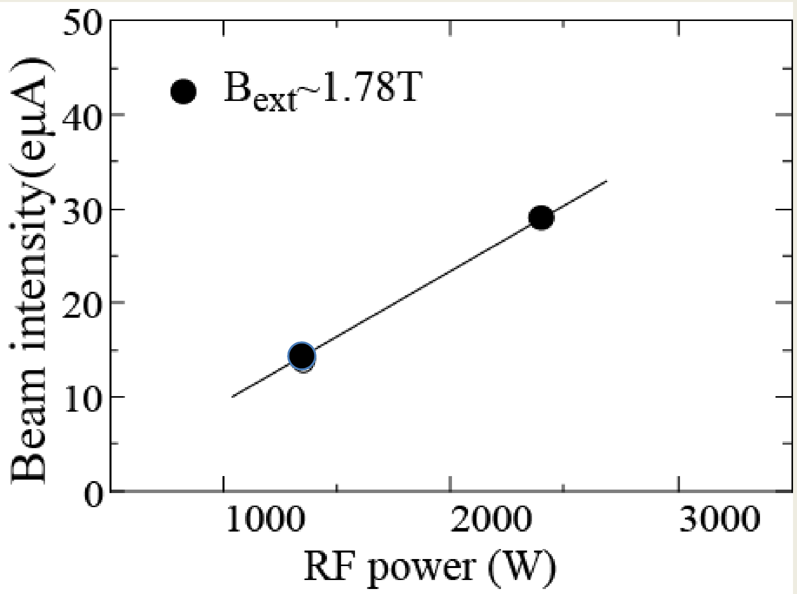
The heat load for B_{min}~0.56T is significantly lower than that for B_{min}~0.66T, which is mainly due to the magnetic field gradient at ECR zone.

The injected RF power was calculated using the increase of the cooling water temperature of the plasma chamber.
The extracted voltage was kept to 22kV
In case of Bmin~0.56T,we added the 18GHz microwaves .

Beam intensity for higher charge state (U^{42+})

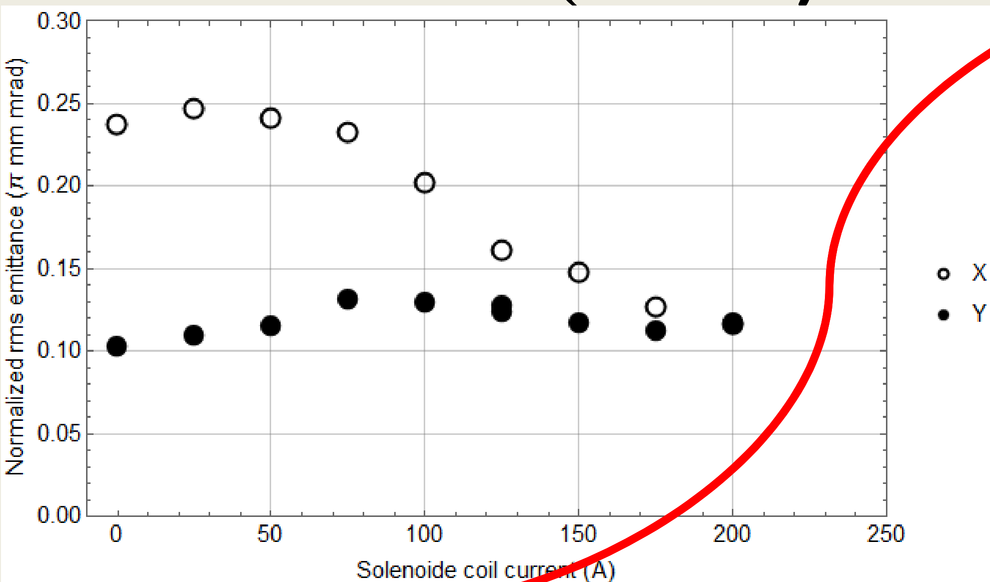




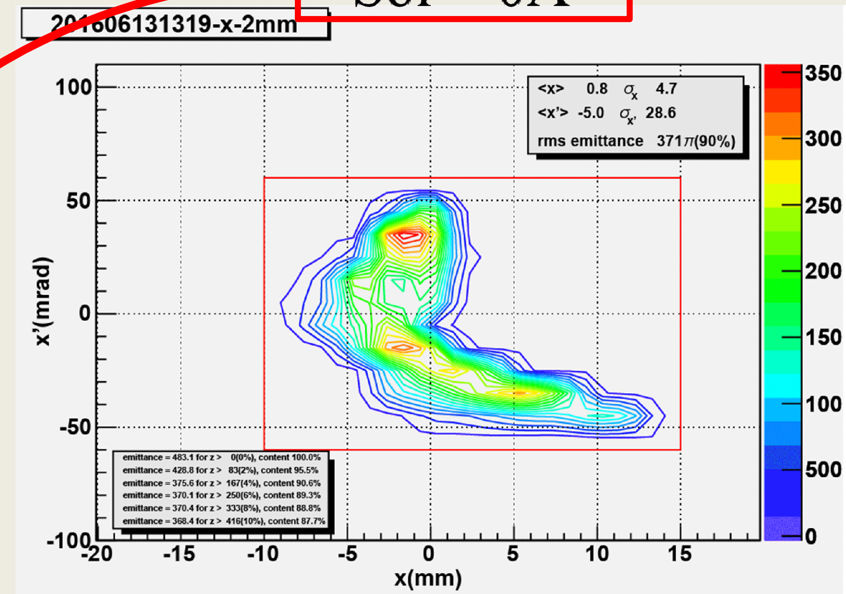


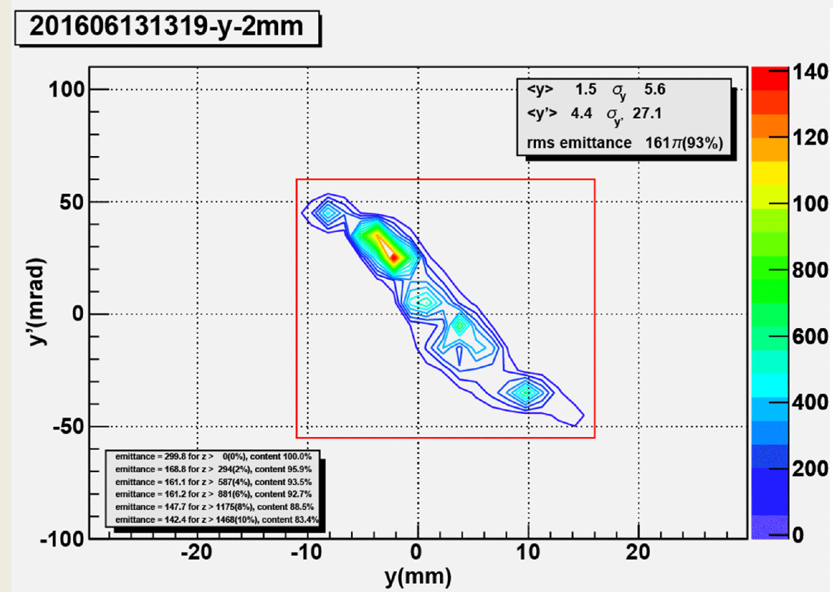
~29eμA at ~2.5kW power injection

Emittance (U^{35+})



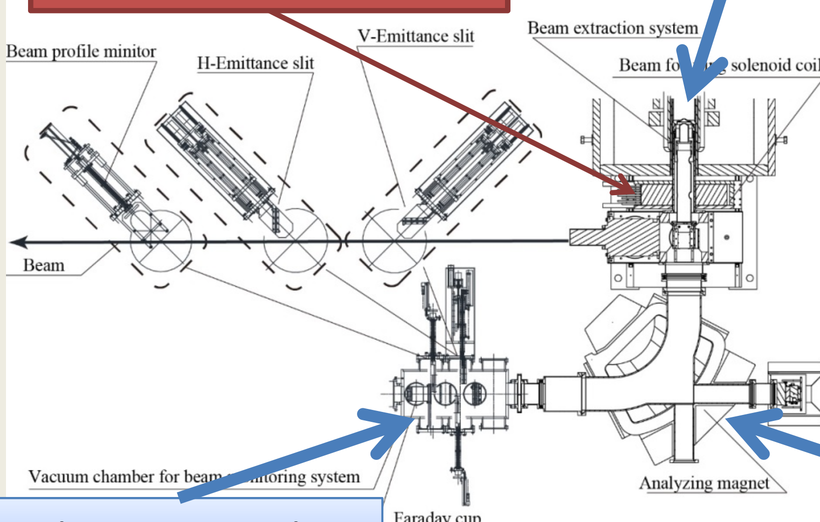
Sol= 0A





The Focusing Solenoid

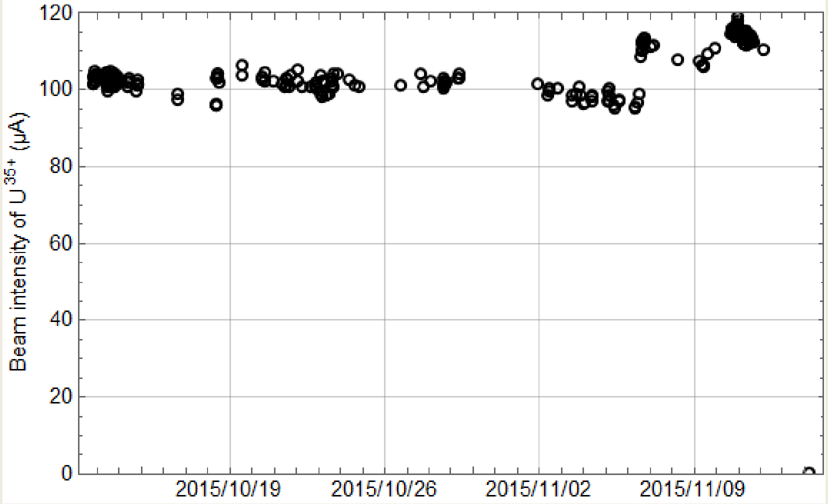
Beam extraction

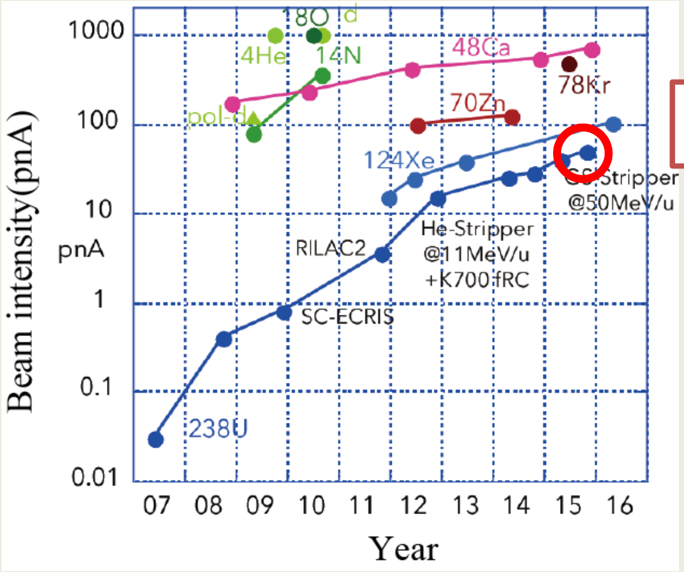


Emittance monitor

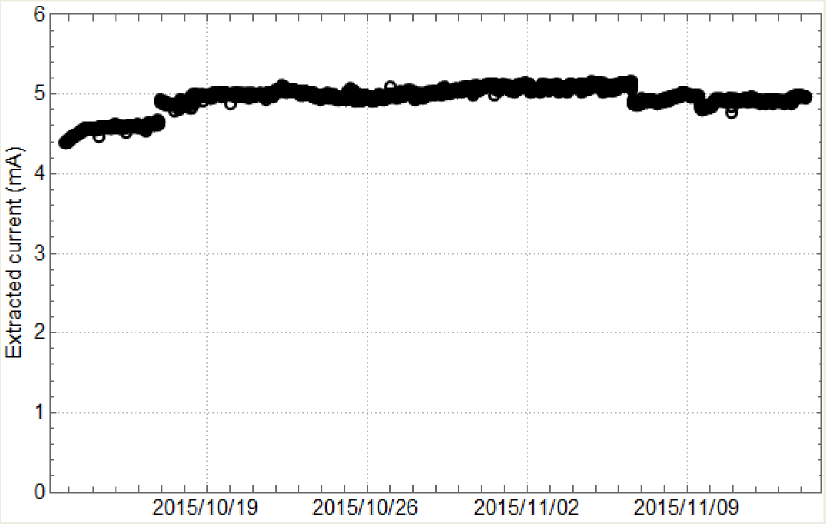
Analyzing magnet

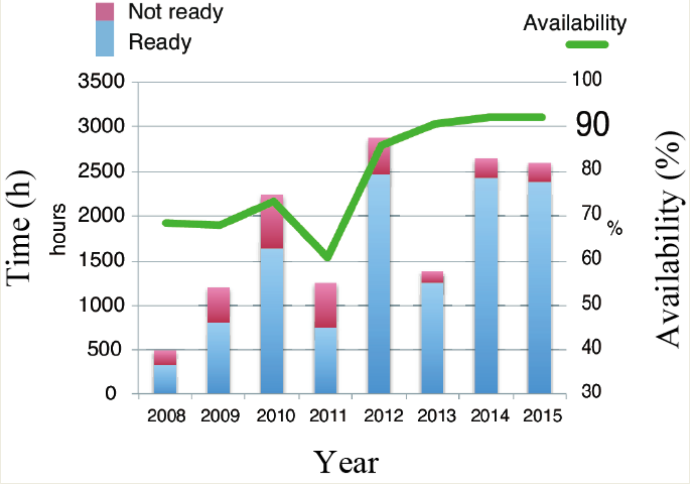
Stability (sputtering method)



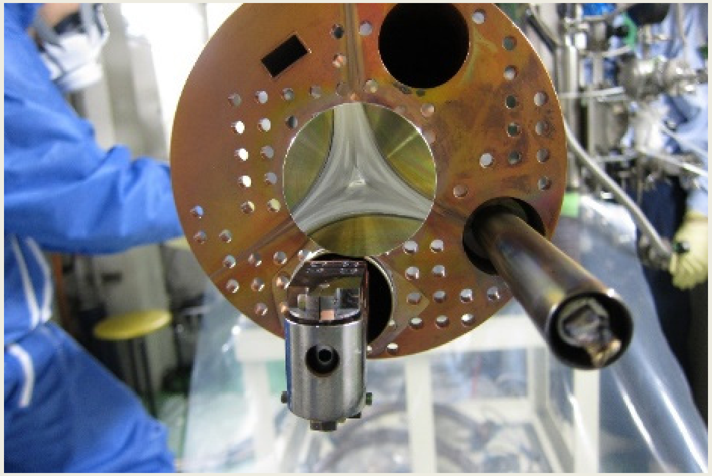


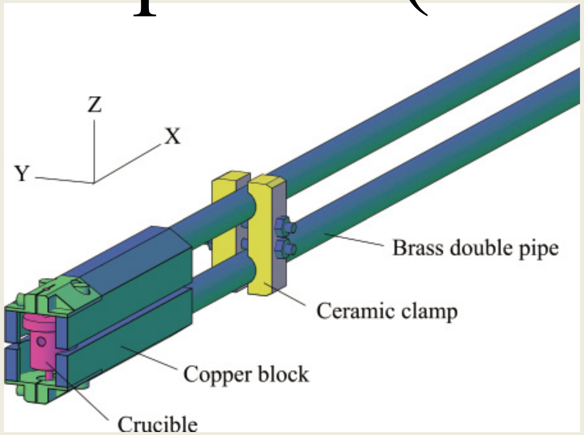
~49pnA

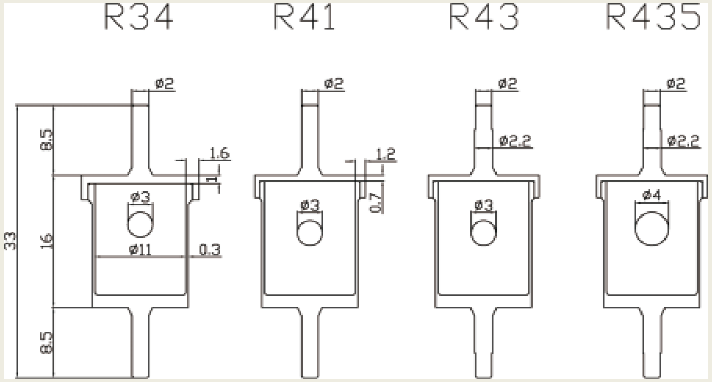


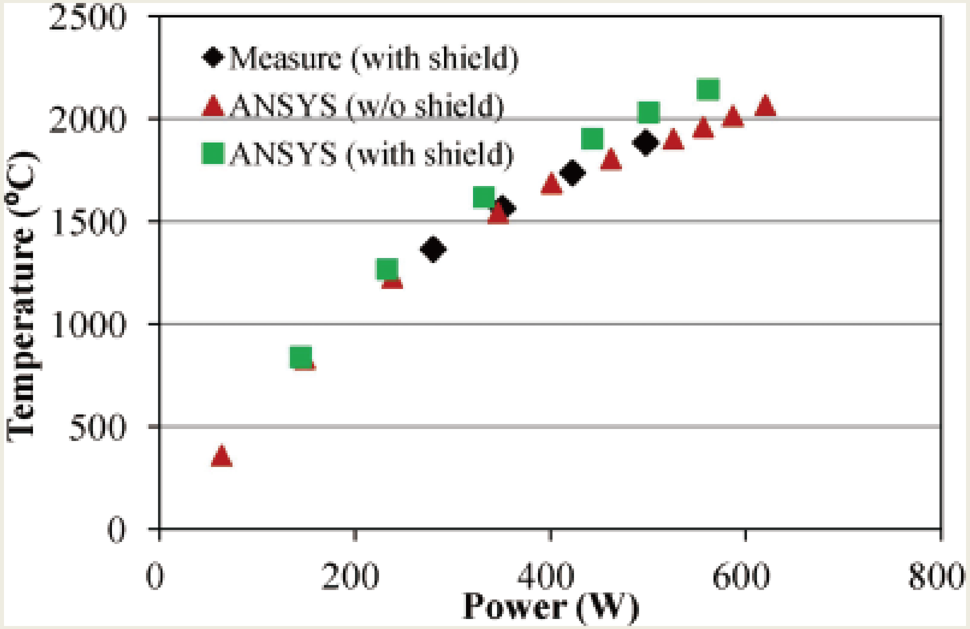


High temperature oven development (~2015)









J. Ohnishi et al, Rev. Sci. Instrum. **87**, 02A709 (2016)

Summary of the test experiments (~2015)

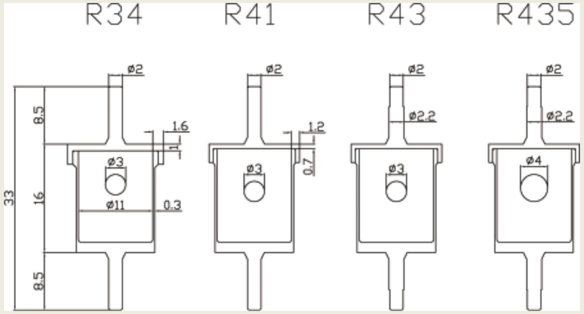


TABLE I. Summary of the oven operation results.

Run number	Operation period	Crucible type	Oven power (W)	U^{35+} current (μA)	Operation time (h)	UO_2 consumption rate (mg/h)	Comment
1	4/10-12/2013	R34	400-600	40-80	22	. . .	First test
2	7/816/2013, 7/22-27, 10/7/2011	R34	550-650	60 (typ.)	291	2.5	Blockage of the ejection hole was observed directly by opening the ion source (7/10, 19)
3	11/5-15/2013, 11/19-22	R34	550-600	70-90	294	2.4	Blockage
4	12/10-13/2013	R34	550-600	60-80	77	0.6 (?)	
5	1/14-22/2014	R41	560-580	55-65	188	2.6	New type. No blockage
6	1/23-29/2014, 2/13-15, 2/25-28,3/4-6	R41	480-510	55-70	283	1.7	Blockage removed by high power (640 W) operation
7	3/11-26/2014	R41	530-660	40-70	311	1	Blockage unstable on high power operation
8	6/24-7/6/2014	R43	570-660	70-100	257	4.7	Thick upper and lower rods. Oven current increased.
9	9/8-9/18/2014	R43	540-560	70-80	195	2.1	No blockage
10	2/5-3/11/2015	R43	560-630	80-100	326	2.6	Crucible moved forward by 25 mm U^{35+} current increased by 20%. Blockage observed.
11	6/30-8/5/2015	R435	450-500	80-100	411	2.4	Ejection hole φ3 ≥ φ4. Thermal shield added. Oven power decreased. No blockage.

Average : ~100eμA U^{35+} ~2.5mg/h

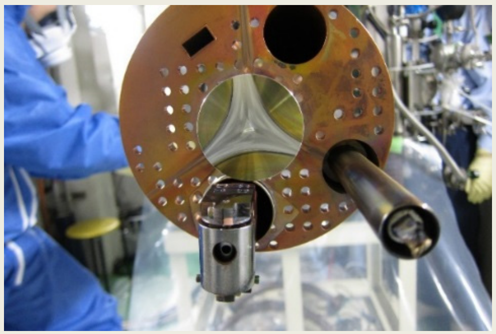
The amount of UO_2 is ~1gr in the crucible

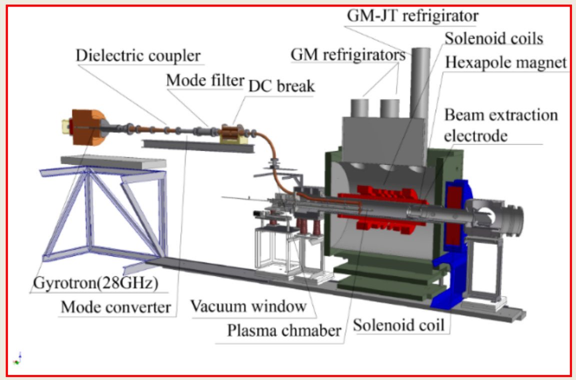
Total production time ~20days < one month

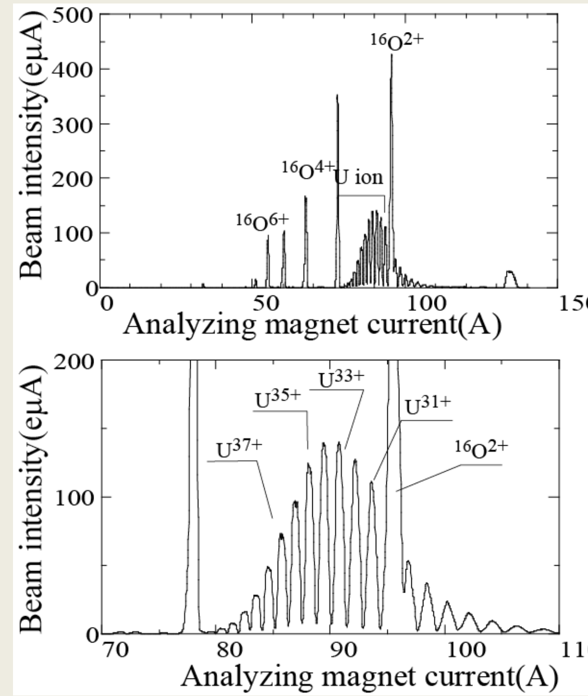
J. Ohnishi et al, Rev. Sci. Instrum. **87**, 02A709 (2016)

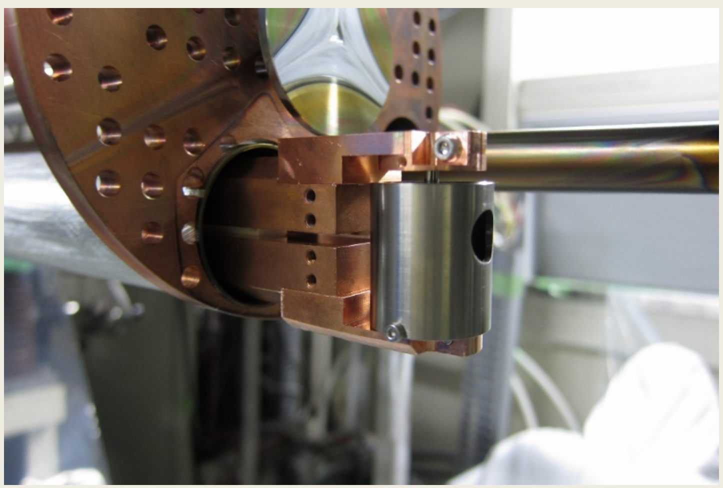
RIKEN NISHINA CENTER

Development of oven (2016) (larger size: ~3g in the crucible)





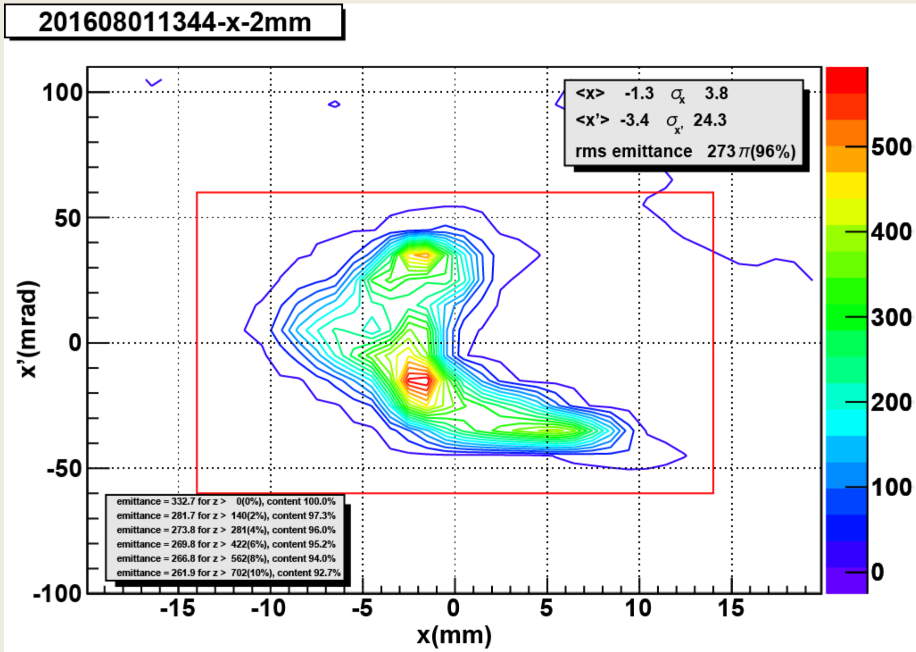


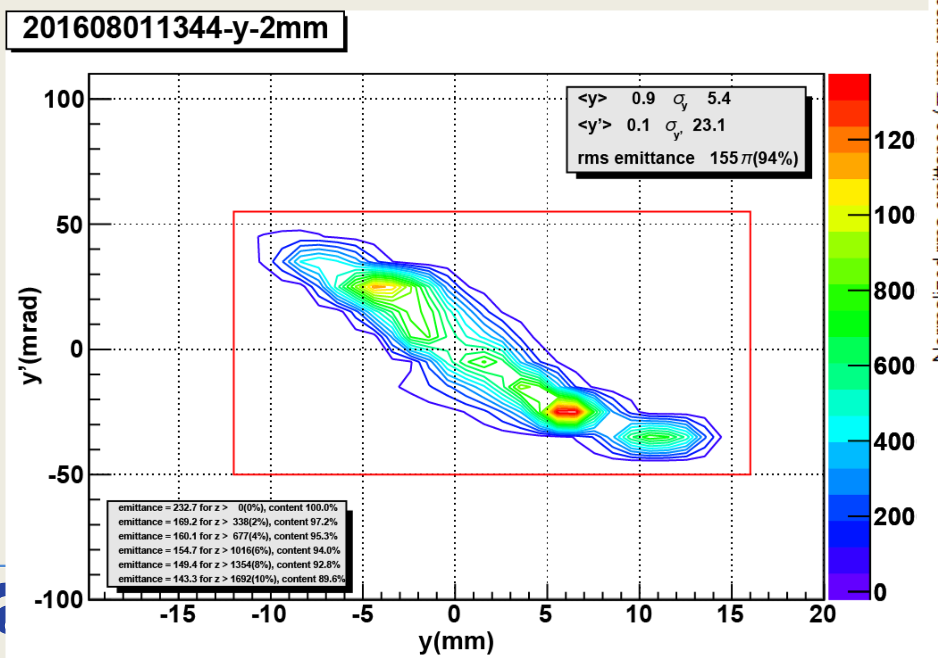


Intensity ~120 eμA (U^{35+})
Consumption rate : ~2.5mg/h
3g in the crucible

Production time ~1000h (41days)

Emittance





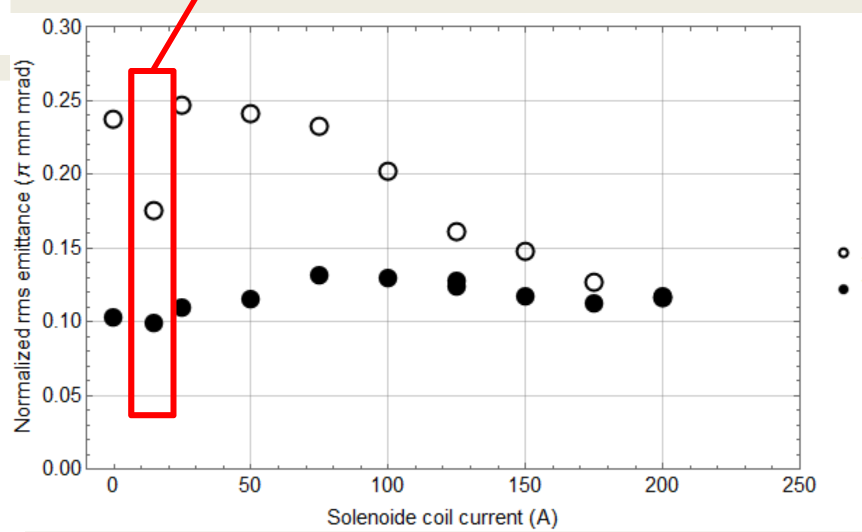
U^{35+} ion beam (H.T.O)

～128eμA

4 rms emittance

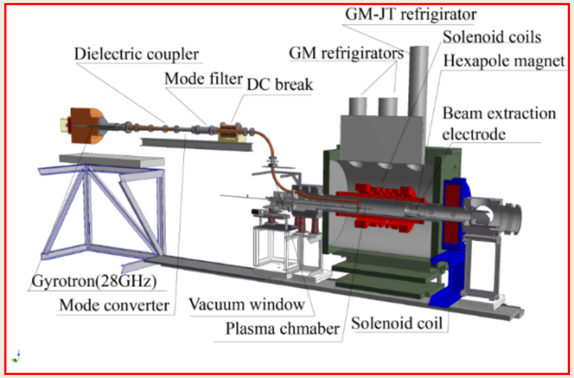
x- 273π mm mrad

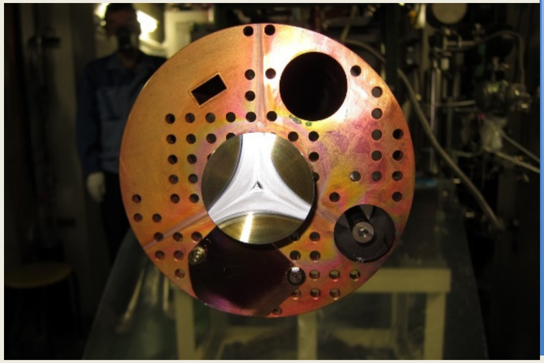
y- 155π mm mrad



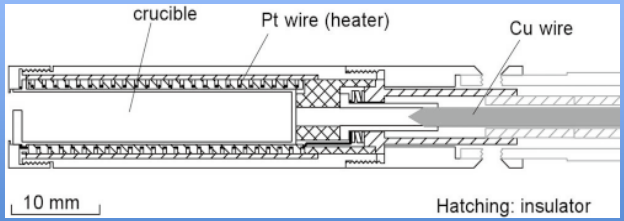
.The emittance was almost same as that with sputtering method

Zn ion beam production
Low temp oven (ZnO)

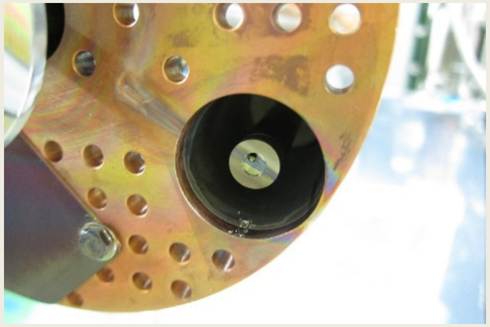


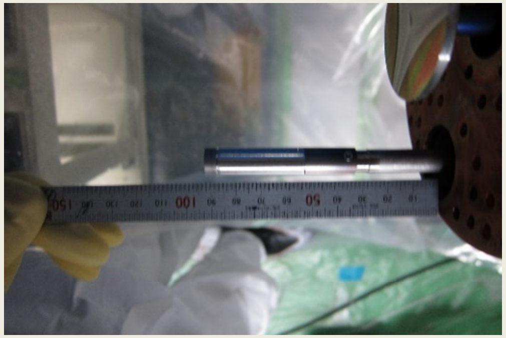


Low temp oven



K. Ozeki et al, HIAT2015, WEPB22





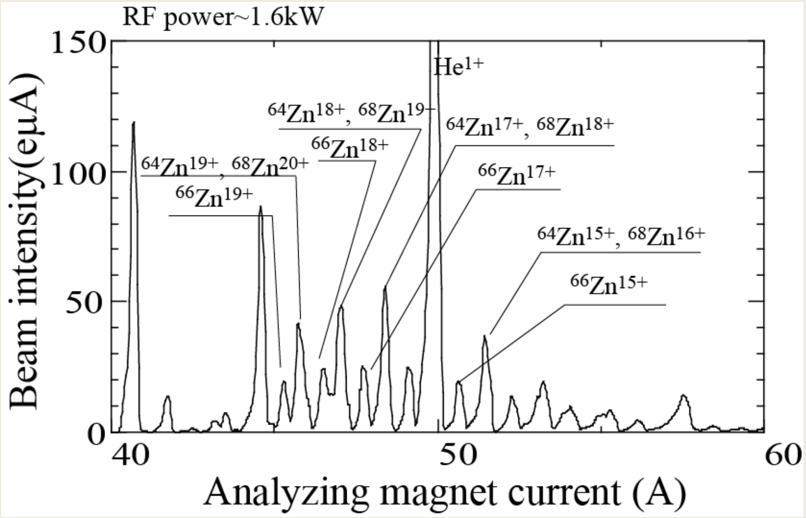
Same system as production of Ca beam

No water cooling

Typical power about 50 W

Zn ion beam

Ion source was tuned to produce Zn^{19+}



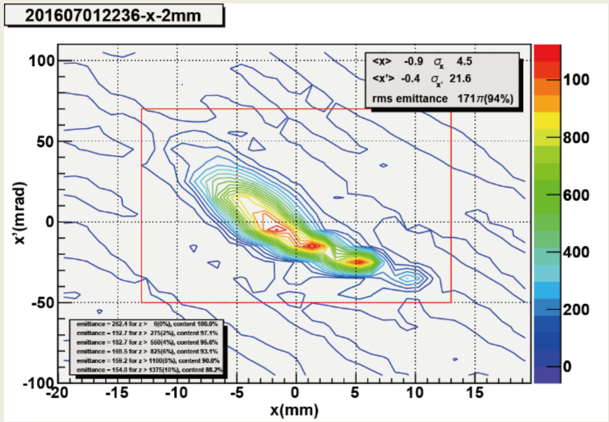
V_{ext}	12kV
RF (28GHz+18GHz)	~1.6kW
Binj	3.1 T
Bmin	0.62 T
Bext	1.78 T
Br	1.94 T
Support gas	He
	6.5~7.5x10-5 Pa

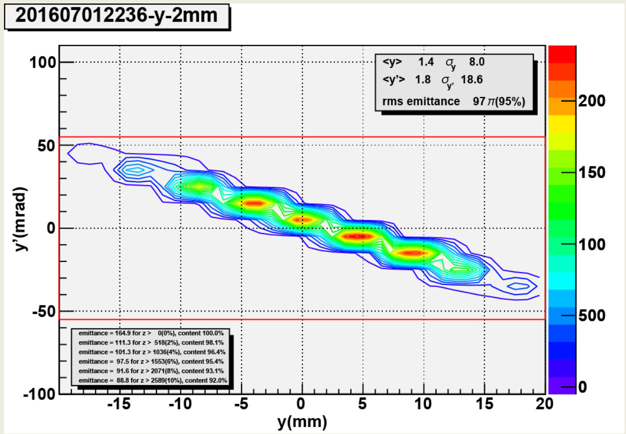
Consumption rate ~0.2mg/h
Total amount of material in crucible ~1000 mg (ZnO)
Estimated total production time ~1000 h (>one month)

Estimated $^{70}Zn^{19+}$ ion beam intensity (100% enrichment)
~60 μA (~3 pμA)
Estimated output beam intensity (RIBF 345MeV/u) ~500pnA

RIKEN
RIKEN NISHINA CENTER

Emittance





Zn^{19+} ion beam
4 rms emittance
x- 171π mm mrad
y- 97π mm mrad

Kr^{21+} ion beam
x- 225π mm mrad
y- 141π mm mrad

The emittance is almost same as those for Kr^{21+}
It is estimated that we can obtain same beam intensity as that for Kr ions

Estimated output beam intensity (present)
~500pnA

2016~
To increase the beam intensity
Optimization of the magnetic field distribution
Increase the RF power
Minimizing the consumption rate

Conclusion and next step

1. For long term operation (~one month), we successfully produced stable beam of ~100 eμA without break using sputtering method and did not observed the any serious damage of the components of the accelerator.
2. We produced ~30 eμA of $^{64}Zn^{19+}$ ion beam using ^{nat}ZnO in the first trial (estimated intensity ~60eμA of ^{70}Zn , consumption rate ~0.2mg/h)
3. We tested new (large) HT oven (~120eμA of U^{35+} for two weeks , consumption rate ~2.5 mg/h)
4. From this autumn, we try to produce the stable beam of U^{35+} higher than 100eμA for long term operation.
5. For production of ^{70}Zn beam, the optimization of the magnetic field, RF power, etc will be carried out to maximize the beam intensity with low consumption rate.

RIKEN

RIKEN NISHINA CENTER

Thank you
for your attention!!