28GHz SC-ECRIS at RIBF

T. Nakagawa (RIKEN)

1.Introduction

RIKEN RIBF (requirements)

2.Structure of the ion source

Sc-coils, cryostat, plasma chamber, etc

3.Results of test experiments

ECR surface size, magnetic field gradient effect

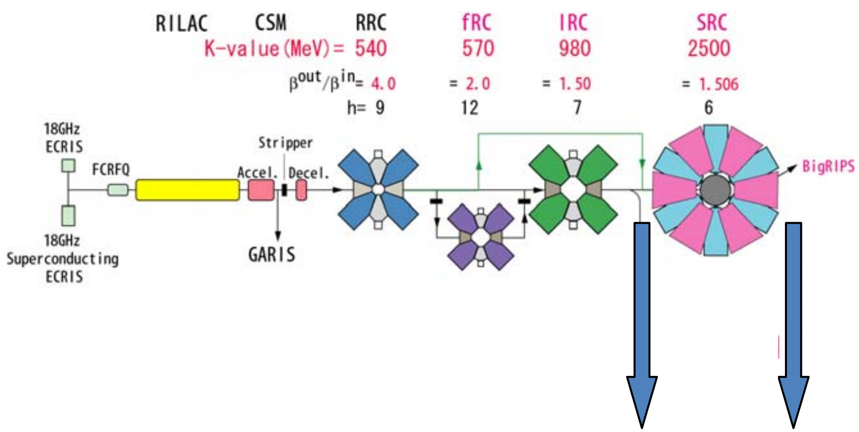
Effect of the magnetic field distribution (B_{min} region)

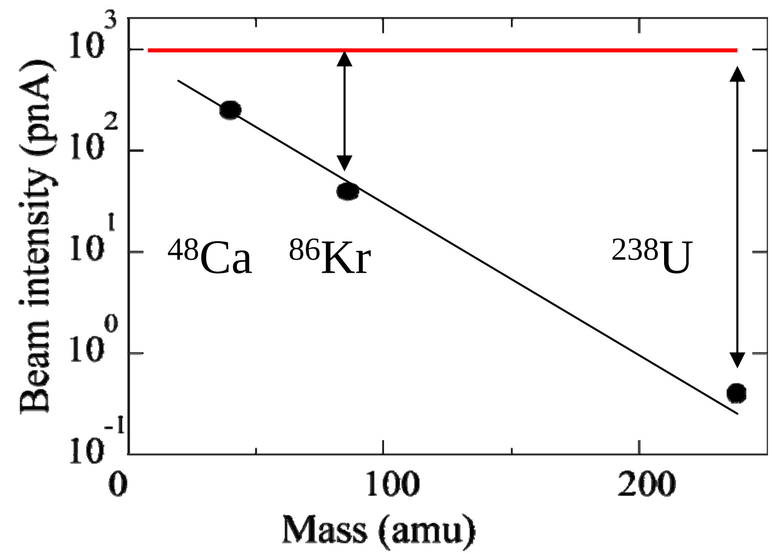
U beam production

4. Preparation for 28GHz operation

5. Schedule for improvement

From the IRC or SRC





Acceleration test (2007~2010)

From RIKEN 18 GHz ECRIS		on target
$^{48}Ca^{10+}$	50eμA(5pμA)	~250pnA
$^{86}Kr^{18+}$	100eμA(5.5pμA)	~30pnA
$^{238}U^{35+}$	2eμA(60pnA)	~0.4pnA

Increase the transmission efficiency of the accelerators

+

New ECRIS

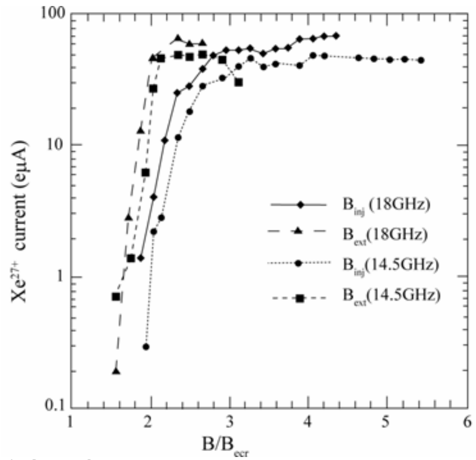
Optimization of ECRIS structure

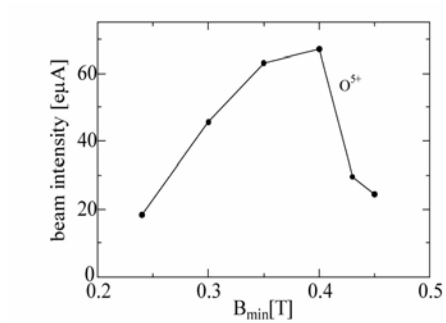
1.Magnetic field

B_{inj}~3.5B_{ecr} → Mirror ratio
B_{ext}<B_r → Plasma container
B_r~2B_{ecr}
B_{min}~0.8B_{ecr} → Microwave absorber

Questions?

(I)ECR zone size effect
(II)field gradient effect at ECR zone





$$W_{ecr} = \frac{\pi e^2 E_r^2}{m\omega\left(\frac{dB}{dz}\right)v_{//}}$$

Energy transfer from microwave to electron at ECR point

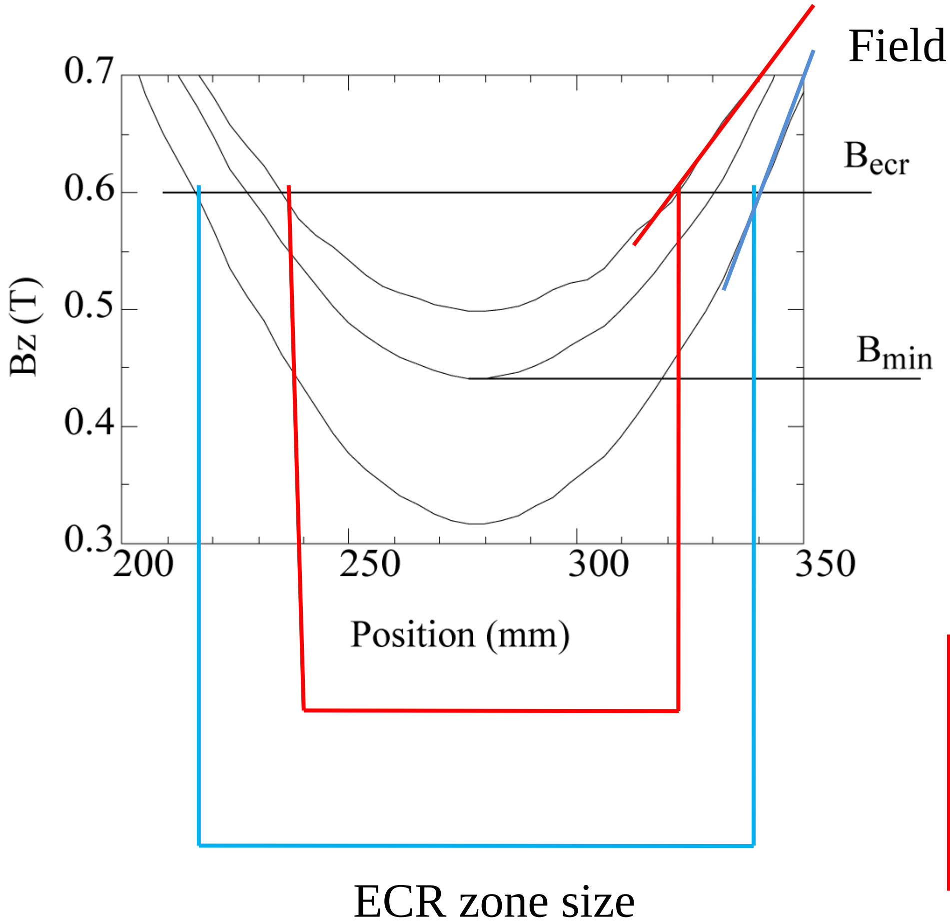
2.Chamber size

large chamber → longer confinement time → higher charge state

3.Microwave frequency

higher frequency → higher beam intensity

Magnetic field configuration I B_{min}



B_{min}	high	low
Zone size →	small	large
Field gradient →	gentle	steep

New RIKEN SC-ECRIS

The zone size and field gradient can be changed independently

Lager zone size and gentler field gradient

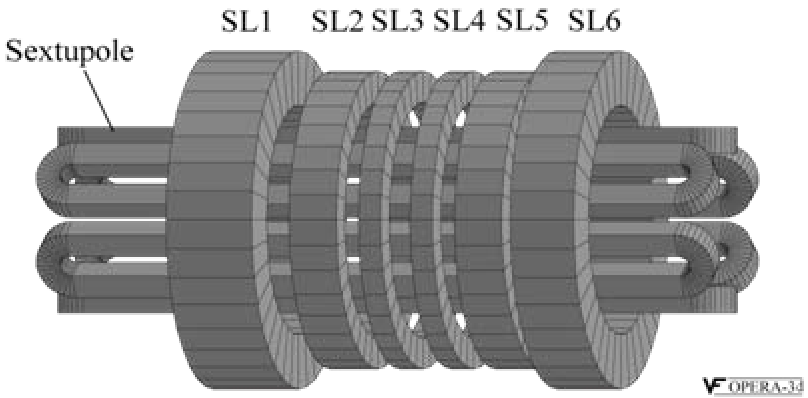
Possibility to increase the beam intensity

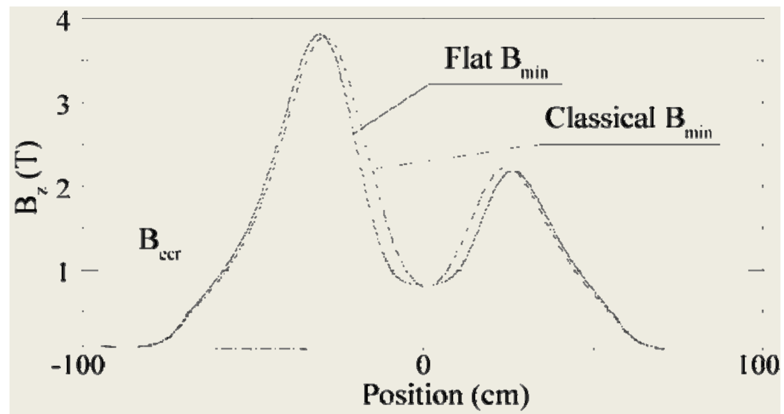
Key parameter for designing of Sc-ECRIS

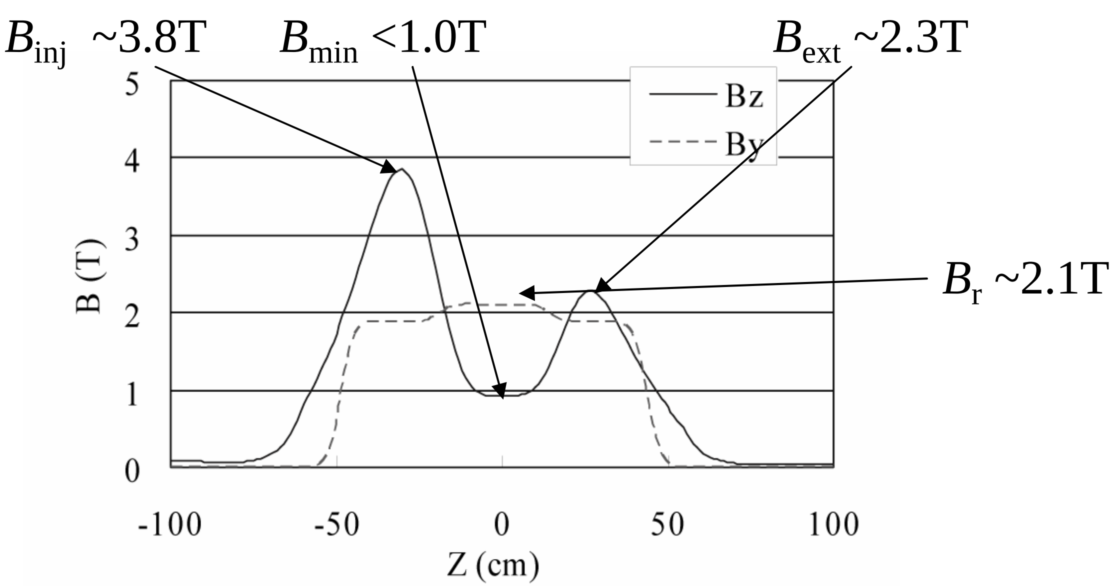
Magnetic field	B_{inj} ~4T B_{ext} ~2T B_r~2T (High B mode)(plasma confinement) B_{min} <1T (~0.8B_{ecr}) (field gradient) ECR zone size as large as possible
Chamber size	Diameter ~15cm (comparison between RIKEN 18 GHz and VENUS, SCRAL) Length ~50cm (Confinement time)
Microwave	28GHz Power ~10kW (1kW/L)(Power density)

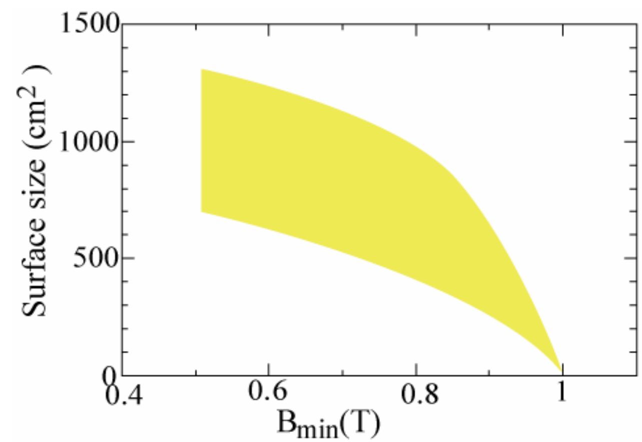
•Geometrical effect

Magnetic field strength

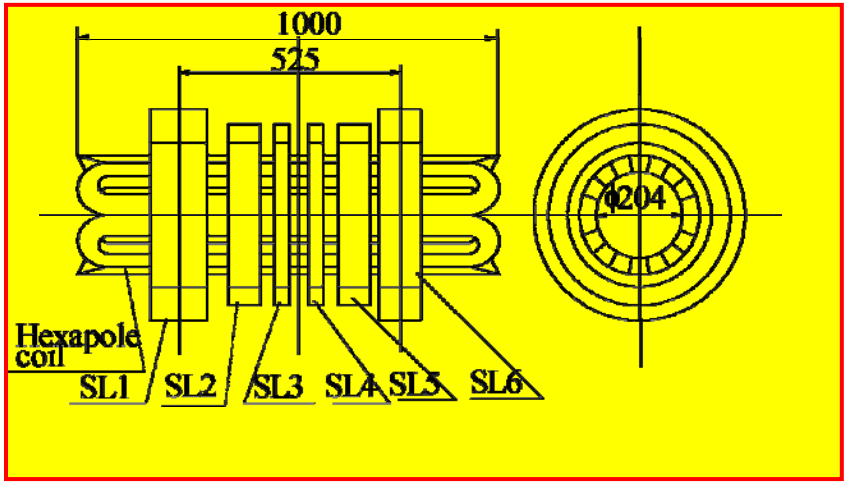








Main parameters of SC-Coils



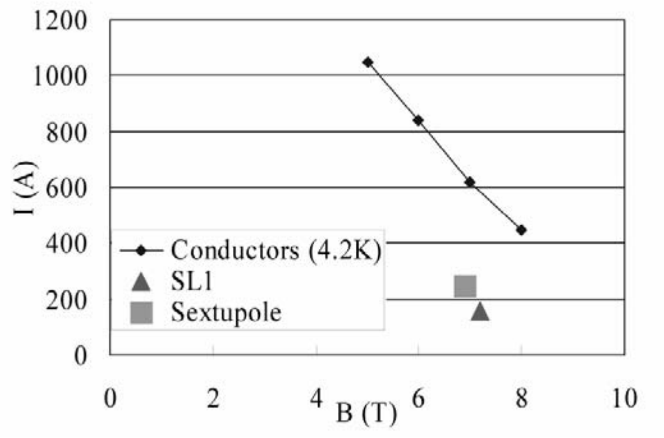
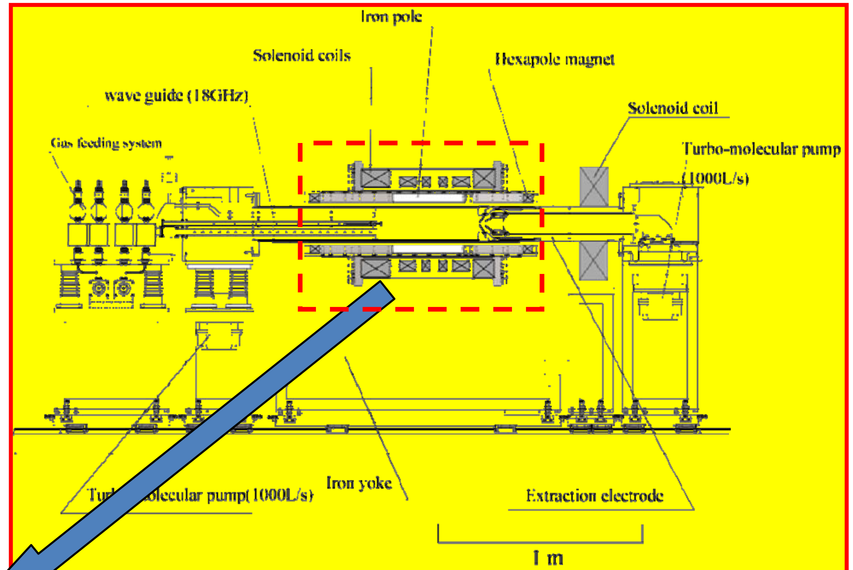


Table 1. Parameters of the supeconducting coils

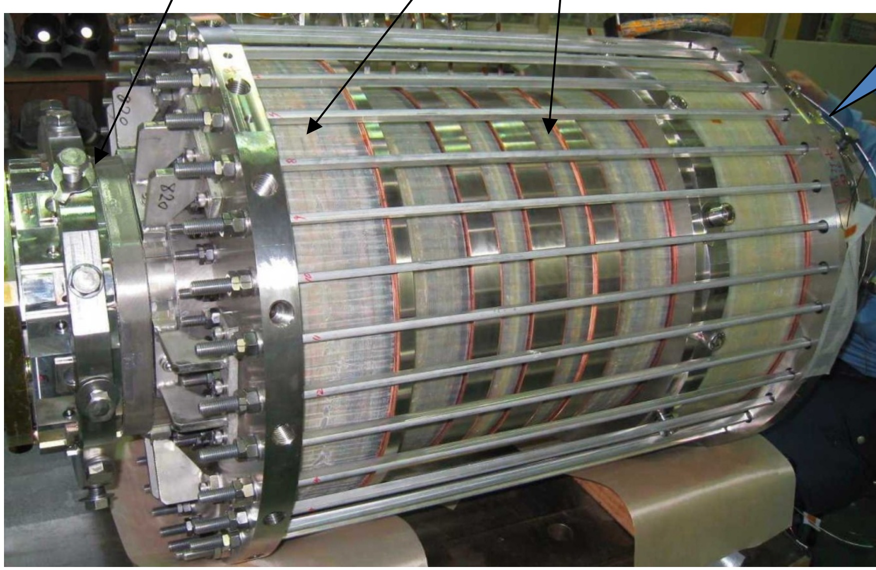
	SL 1	SL 2	SL 3	SL 4	SL 5	SL 6	Sextupole
Inner radius (mm)	170	175	175	175	175	170	102
Outer radius (mm)	250	220	220	220	220	250	142
Length (mm)	135	75	35	35	75	100	1073
Conductor size (mm)	0.82 x 1.15	0.82 x 1.15	φ1.09	φ1.09	0.82 x 1.15	0.82 x 1.15	0.82 x 1.15
Cu/NbTi ratio	1.3	1.3	6.5	6.5	1.3	1.3	1.3
No. turns	9124	2778	1305	1305	2778	6830	1216
Current (A)	162	182	109	109	155	132	271
Bmax (T)	7.2	5.2	3.1	3.0	4.8	5.4	7.4 (6.5)
Ic (A)	203	298	229	233	278	223	349
Iop/Ic	0.80	0.61	0.47	0.47	0.56	0.59	0.78
Inductance (H)	34.0	4.0	1.0	1.0	4.0	20.0	6.9

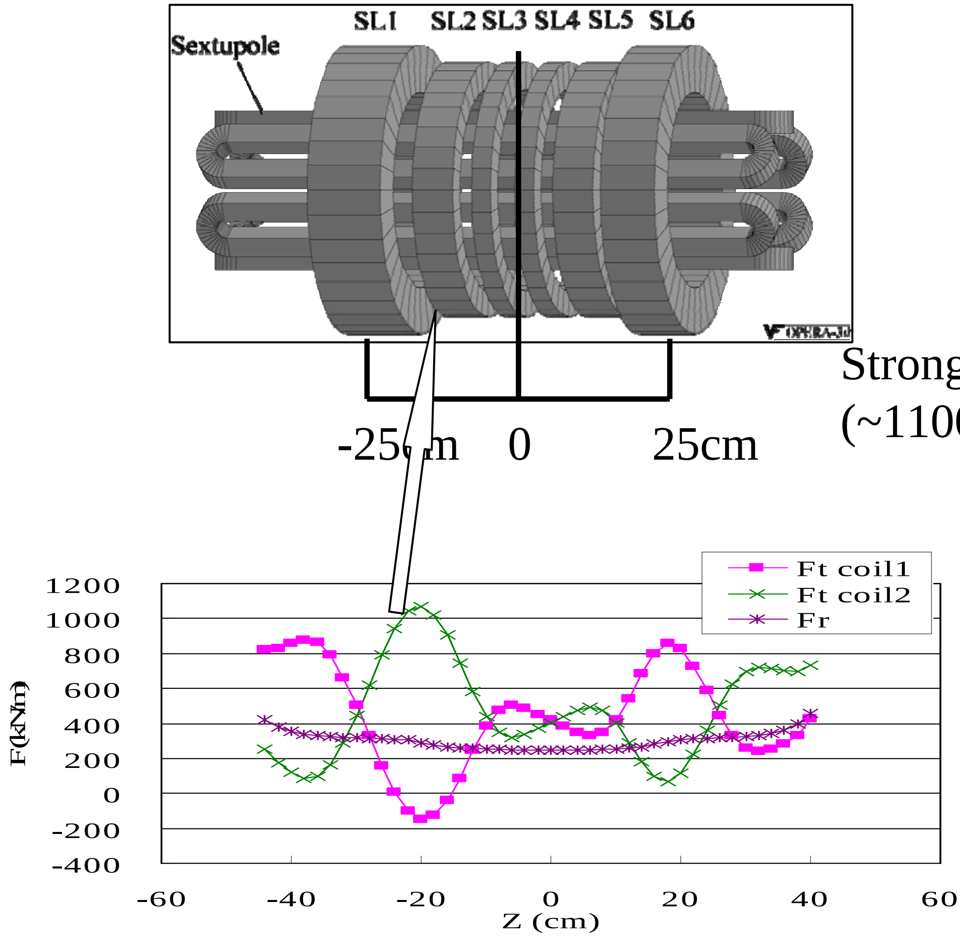
Superconducting coils



Solenoid coils

Hexapole magnet



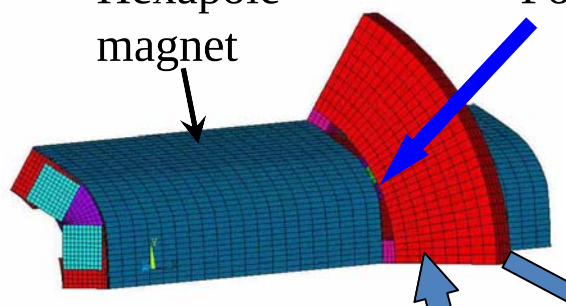


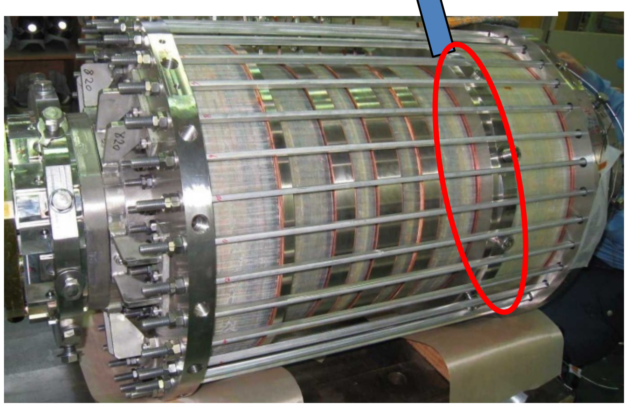
Strong force to hexapole magnet (~1100kNm max.)

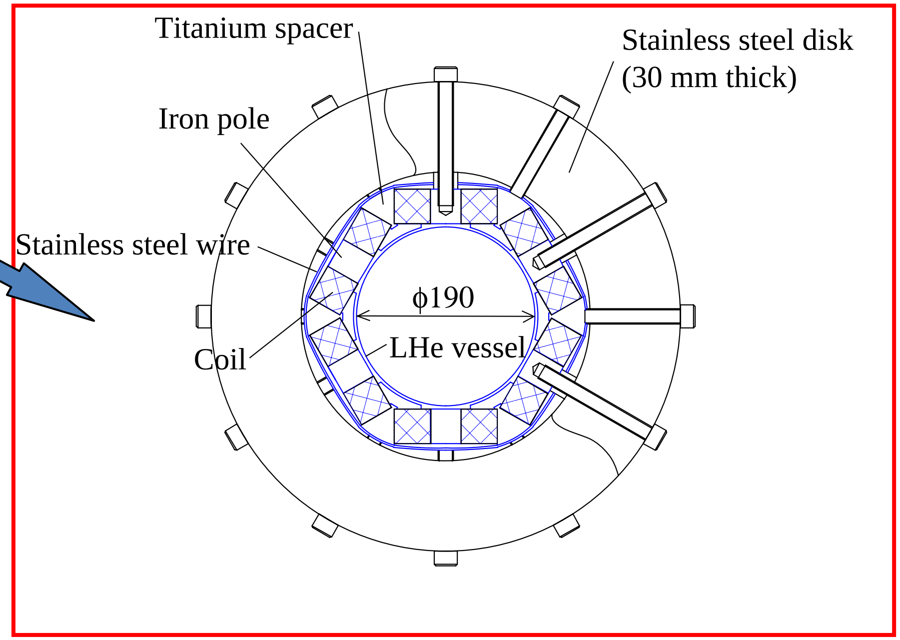
Support for hexapole magnet

Hexapole magnet

Force ~1100kNm max

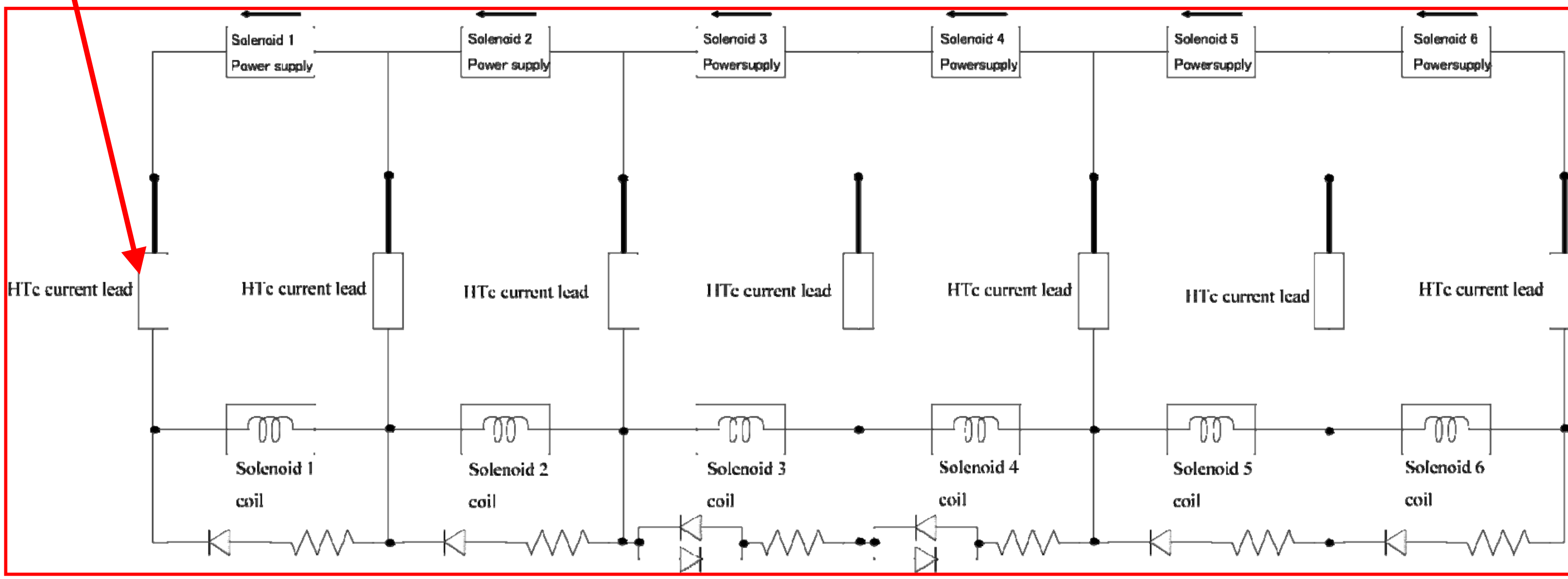






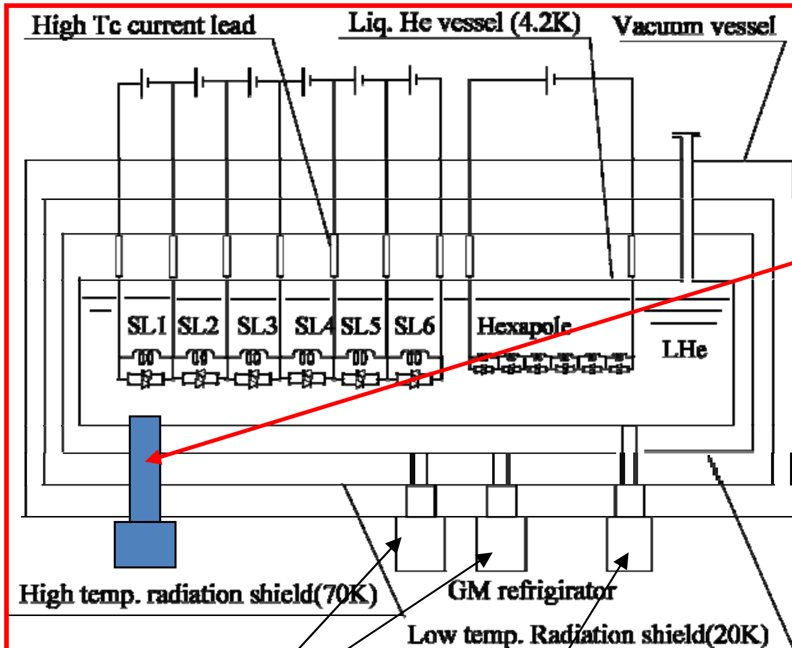
Circuit diagram for solenoid coil

HTc current lead



To minimize the heat inversion, 9 HTc current lead (7 for solenoid, 2for Hexapole) is used

Cryostat I



CG310SC(SUMITOMO)***(GM-JT refrig.)***

Cooling capacity
4.2W/5.0W@4.2K(50/60Hz)
Electric power consump. 5.1/6.1kW(50/60Hz)
Electric power AC200V 3 phase
Weight ~220kgr
Dimension 700Wx520Dx1095H

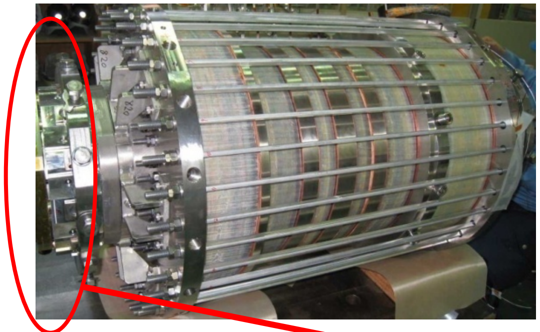
GM refrig. 35W(45K), 6.3W(10K)

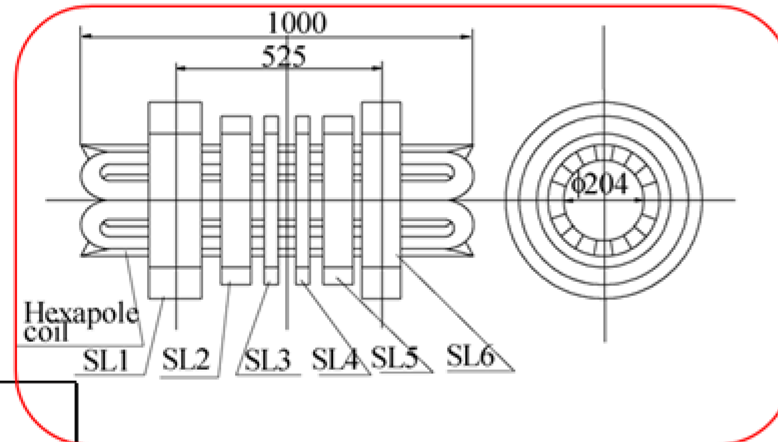
GM. Refrig. 50W(43K), 1.0W(4.2K)

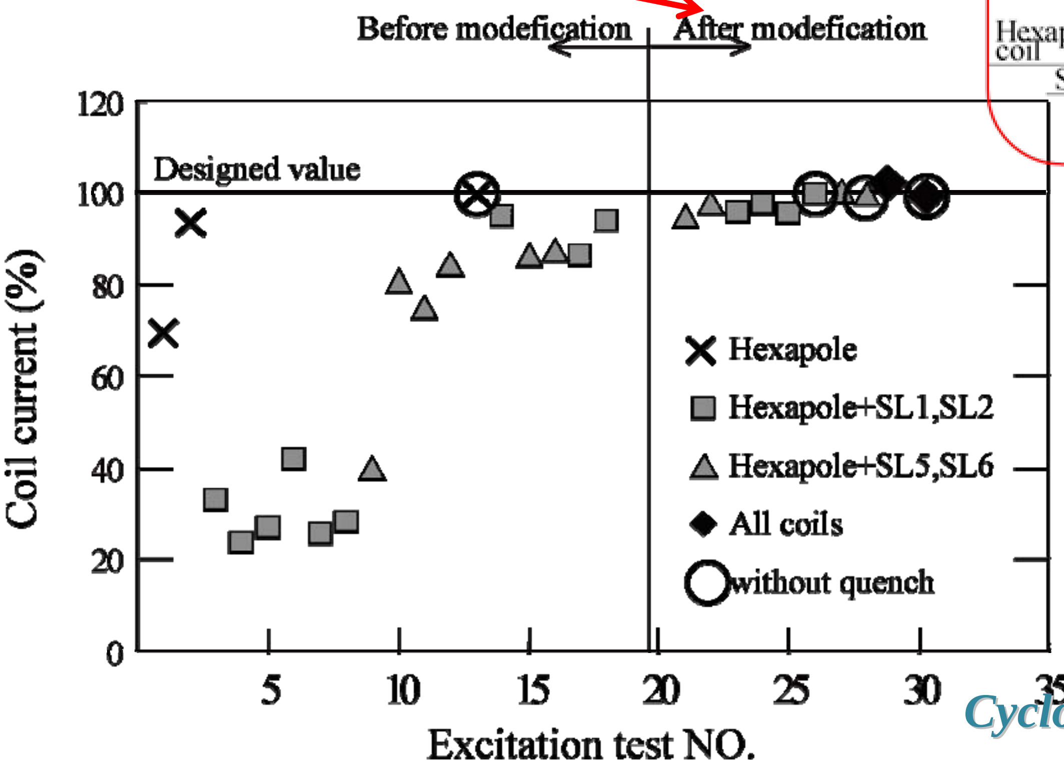
(W)

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

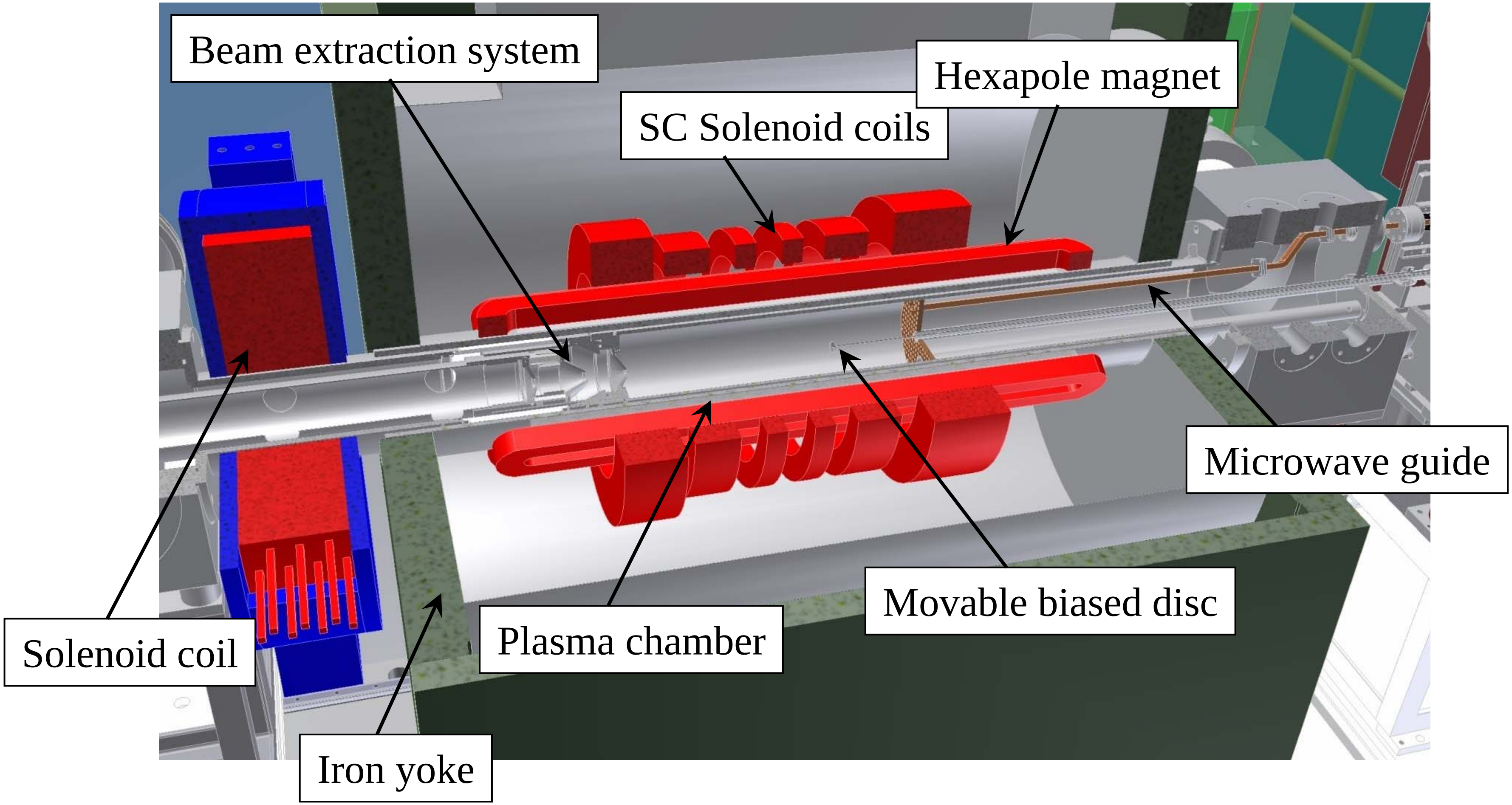
Excitation test



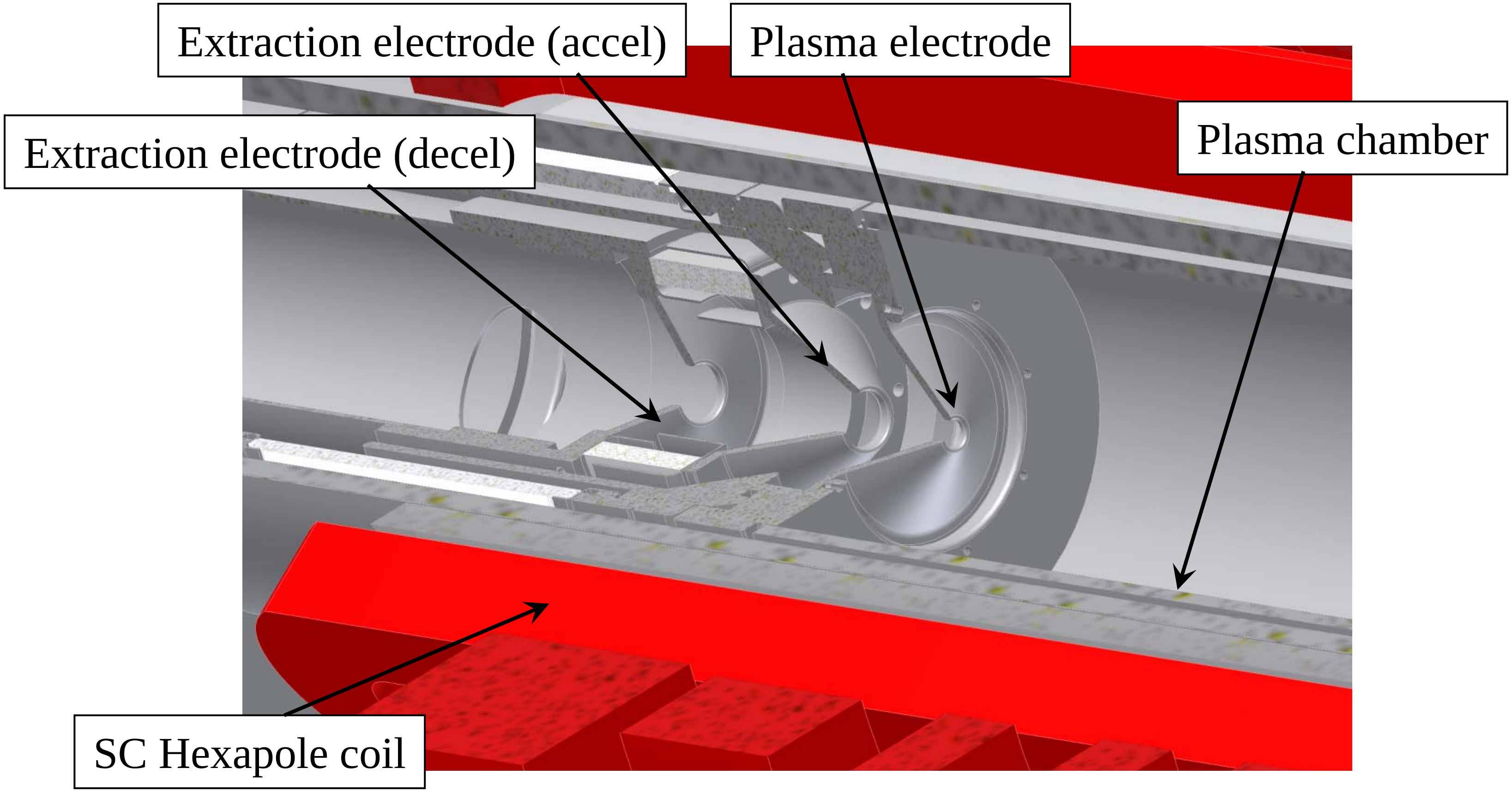




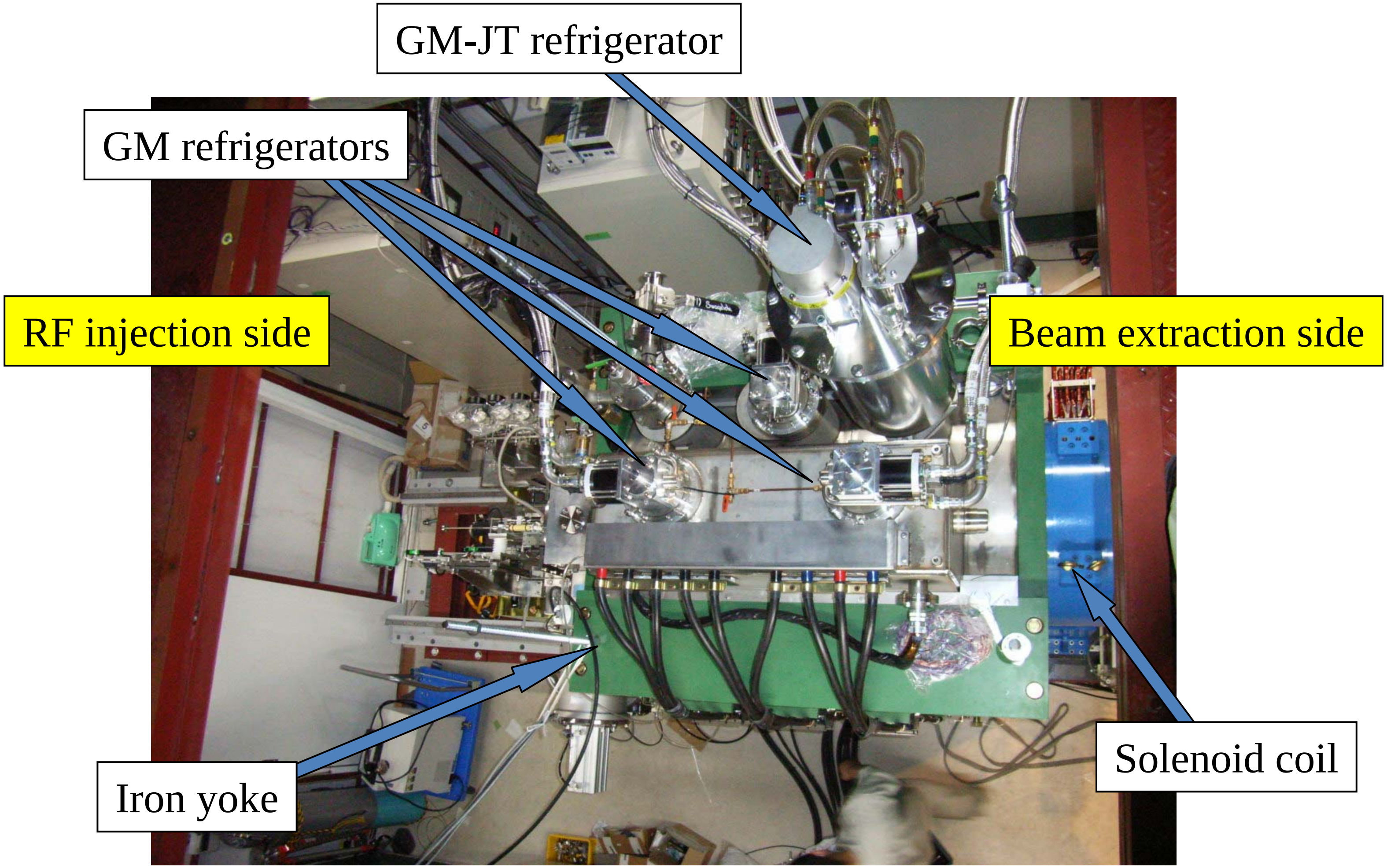
Plasma chamber



Beam extraction system



Picture (SC-ECRIS)



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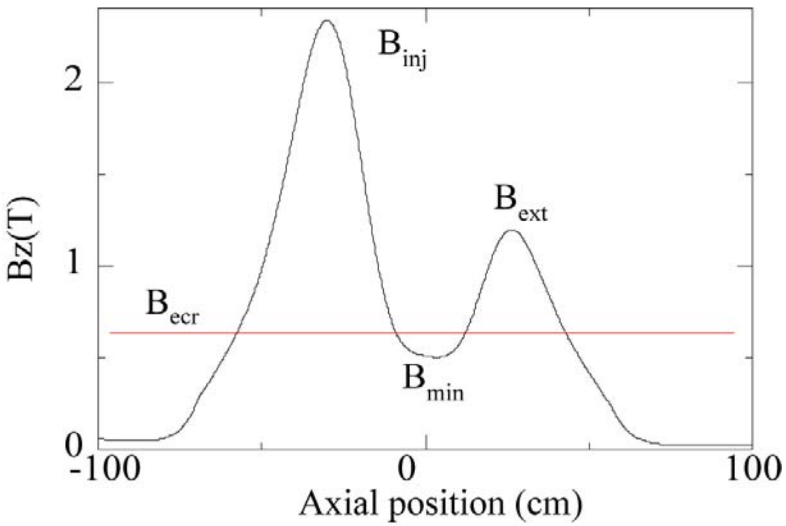
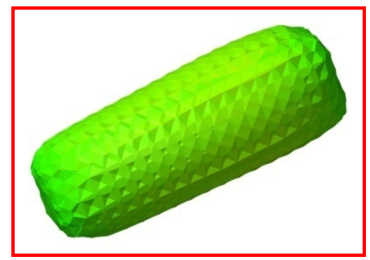
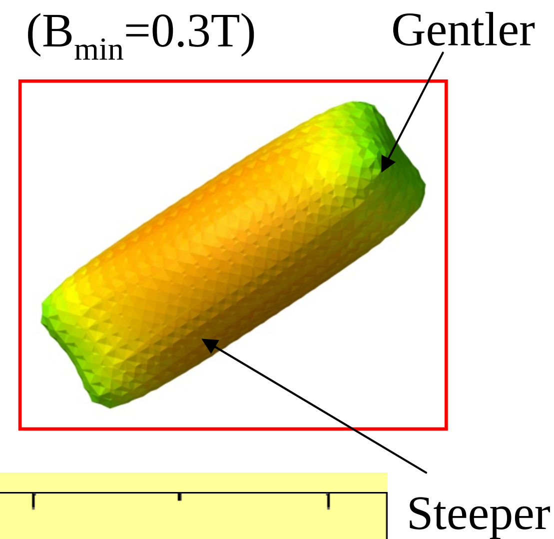
Magnetic field distribution

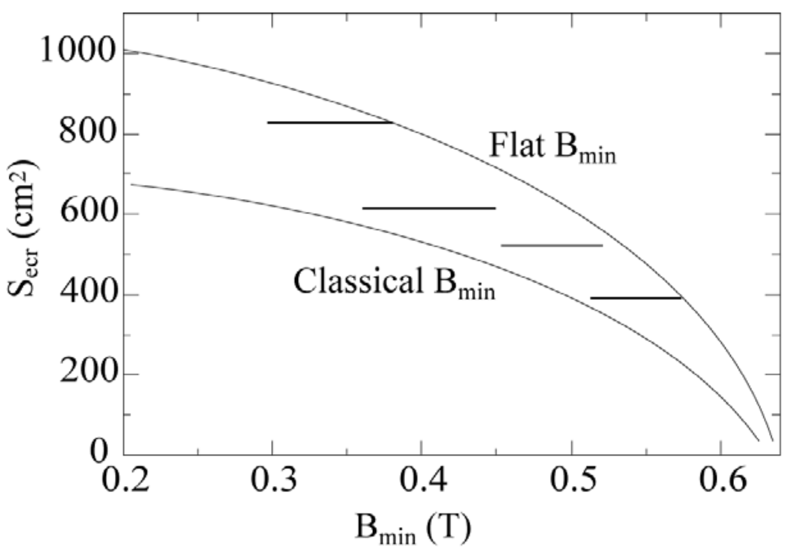


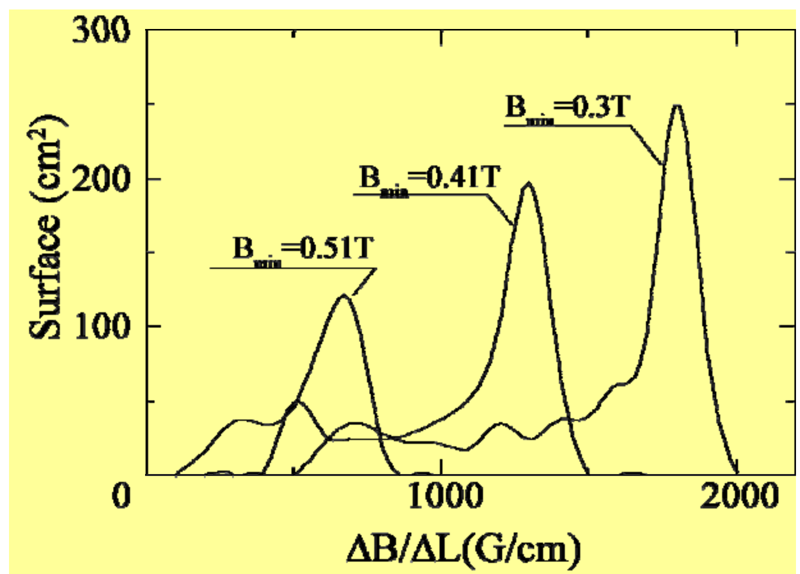
ECR zone shape (B_{min}=0.51T)



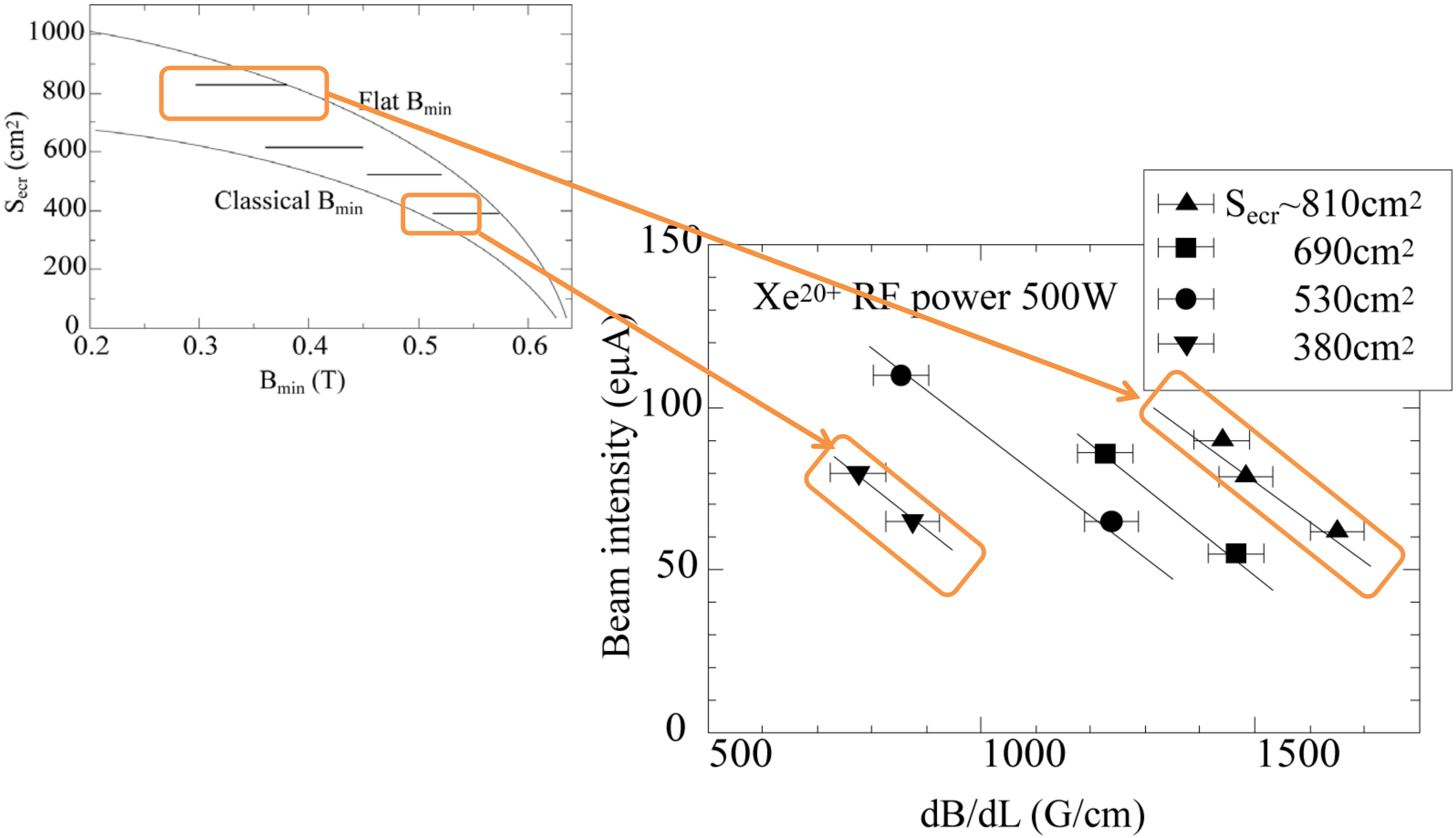
ECR zone shape (B_{min}=0.3T)



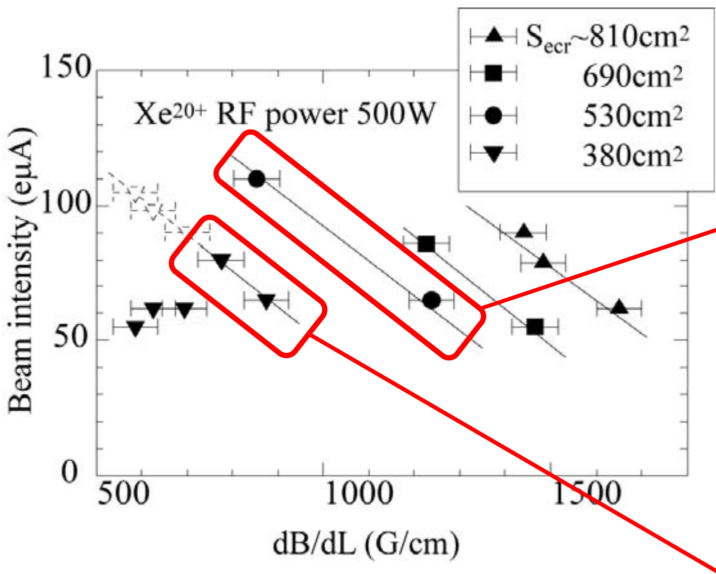


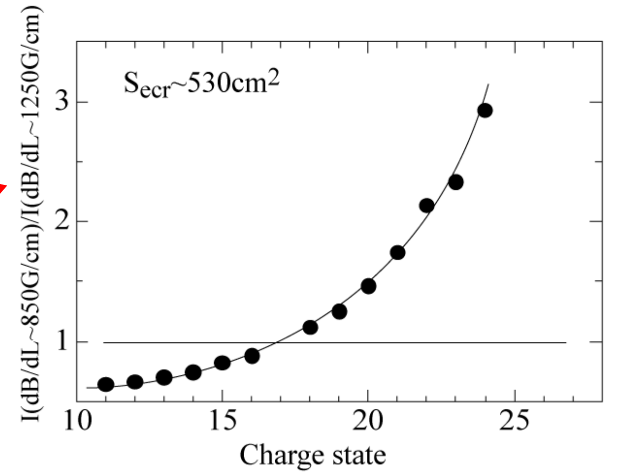


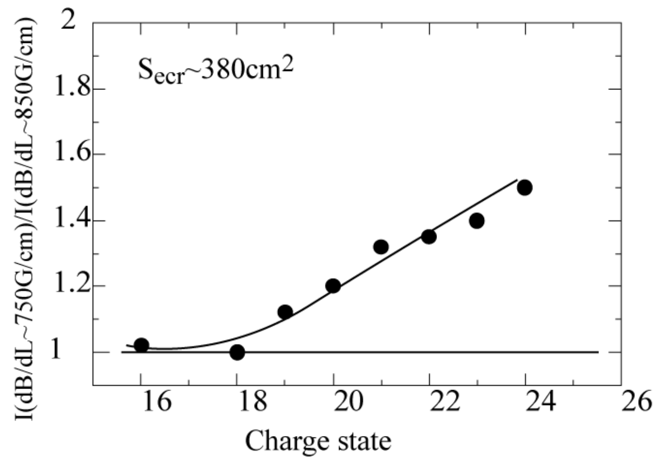
Field gradient, ECR zone size (I)



Field gradient effect



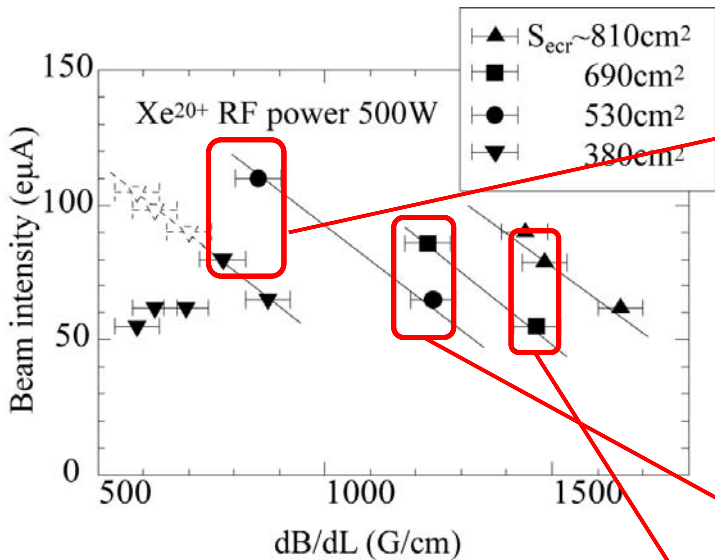


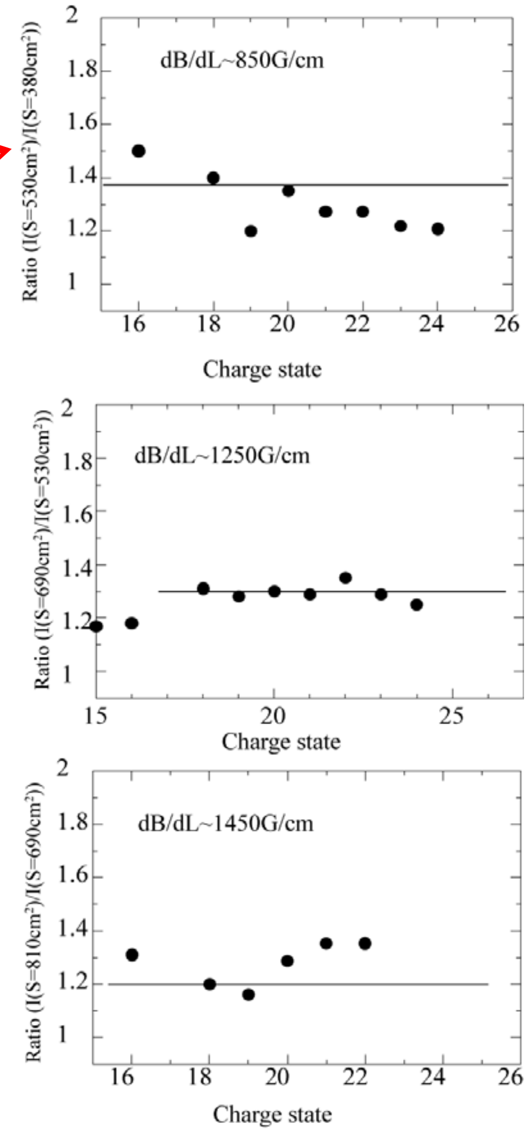


The ratio increases with increasing charge state

Electron temperature effect

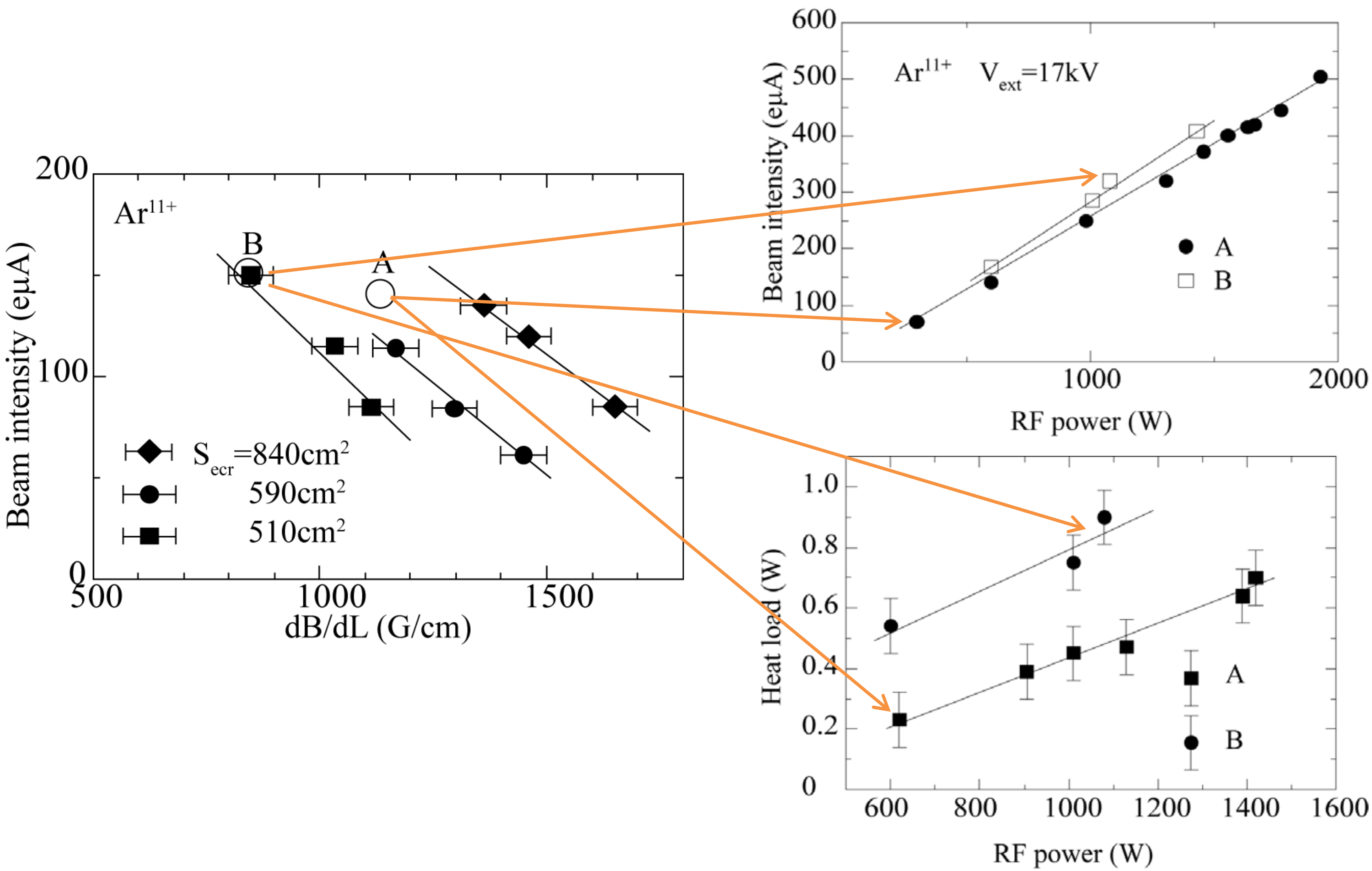
ECR zone size effect



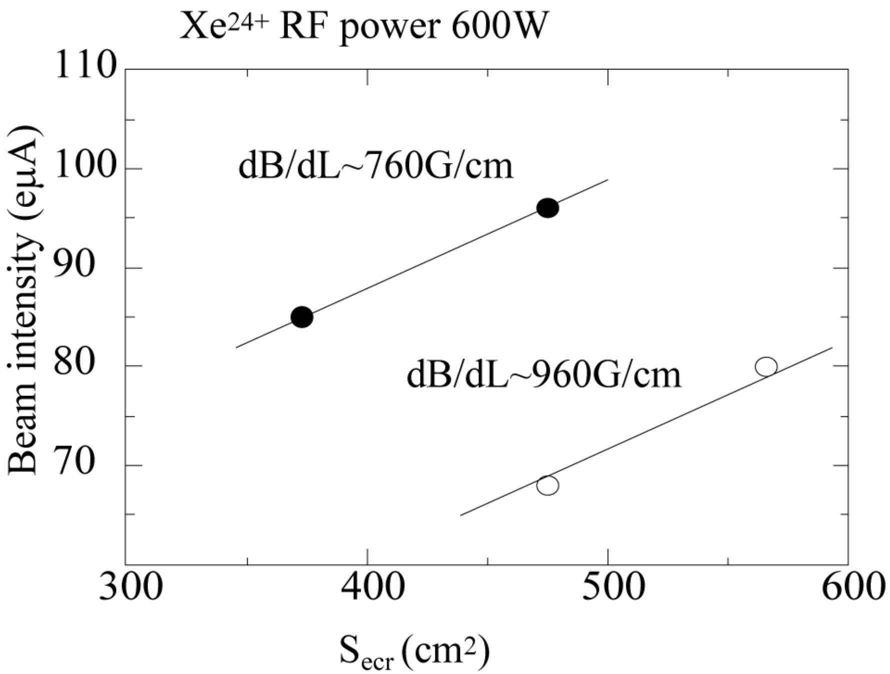


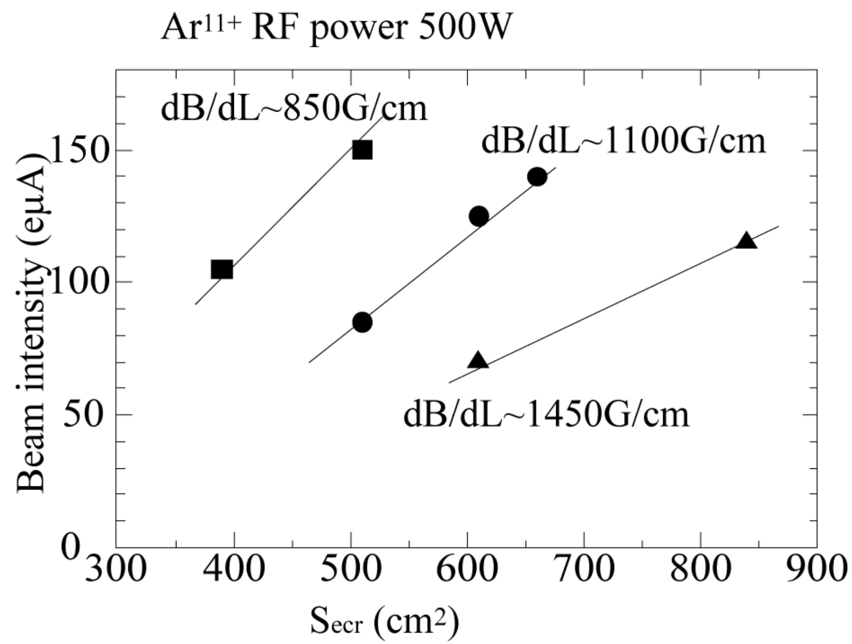
The ratio was almost constant
and independent on the charge state

RF power dependence (beam intensity, heat load)

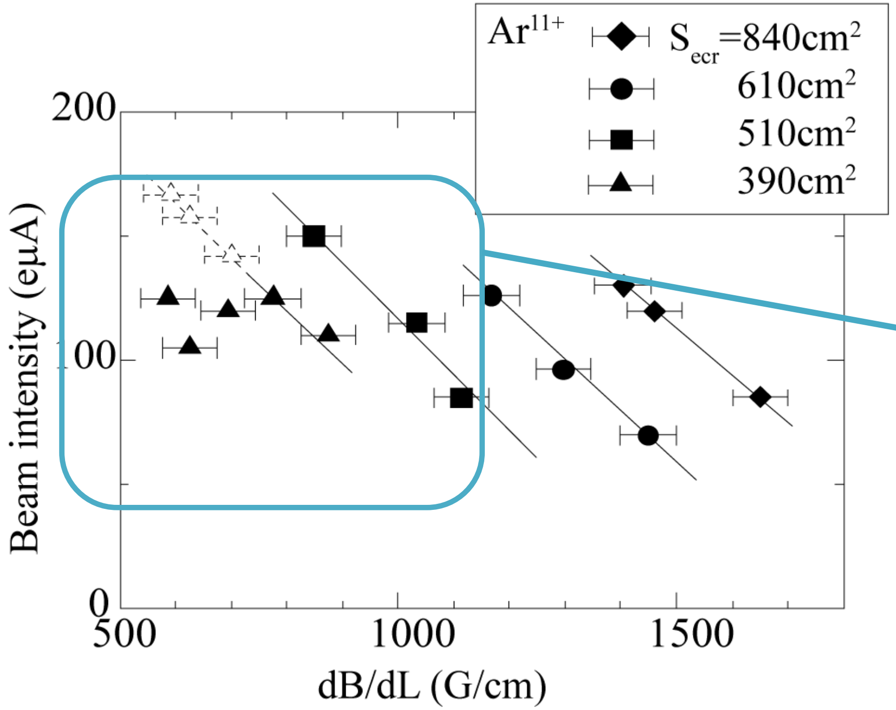


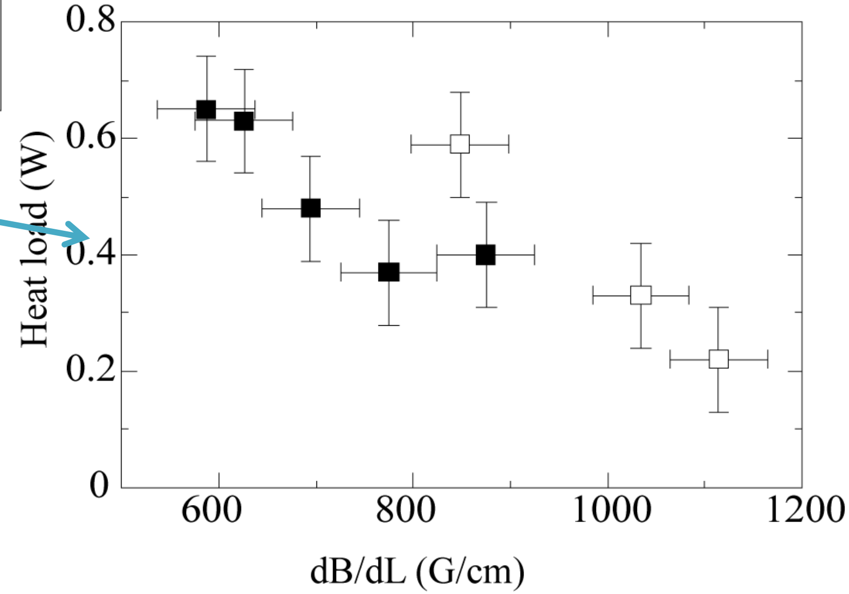
ECR zone size effect





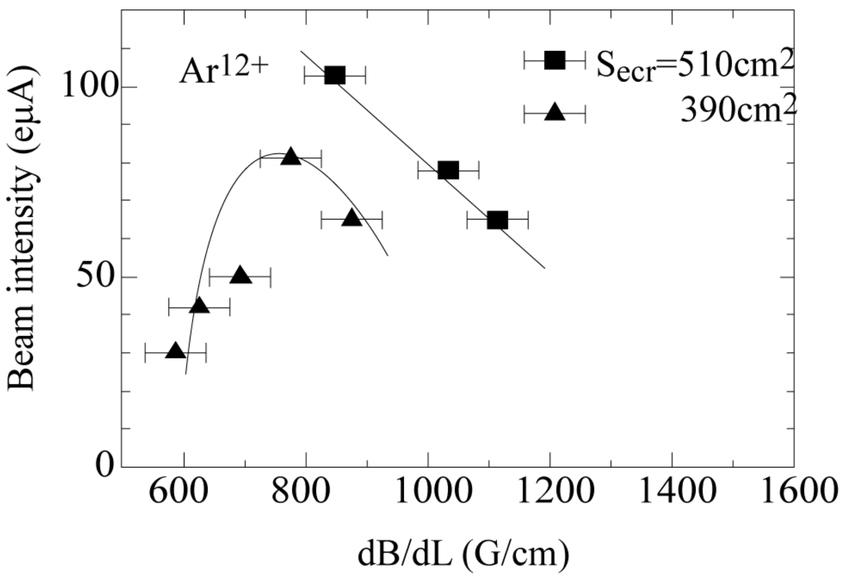
Field gradient limit ? (I)



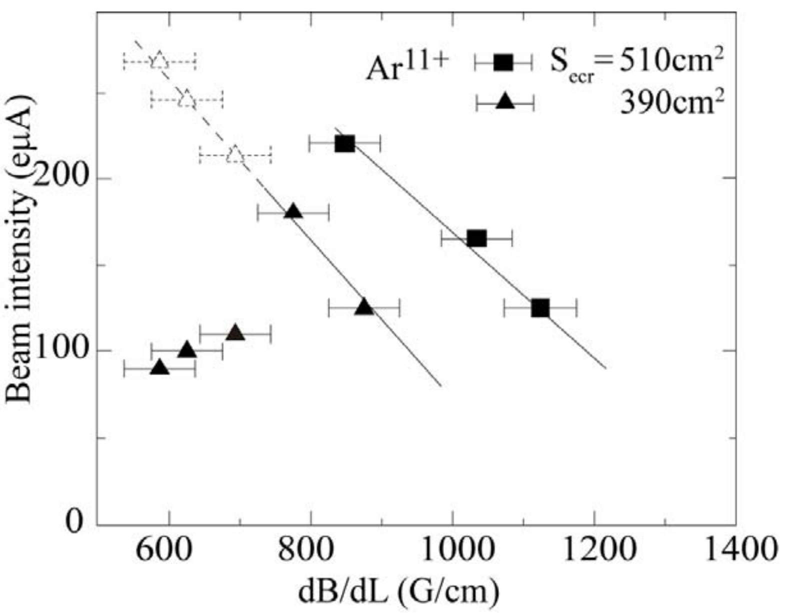


Field gradient limit ? (II)

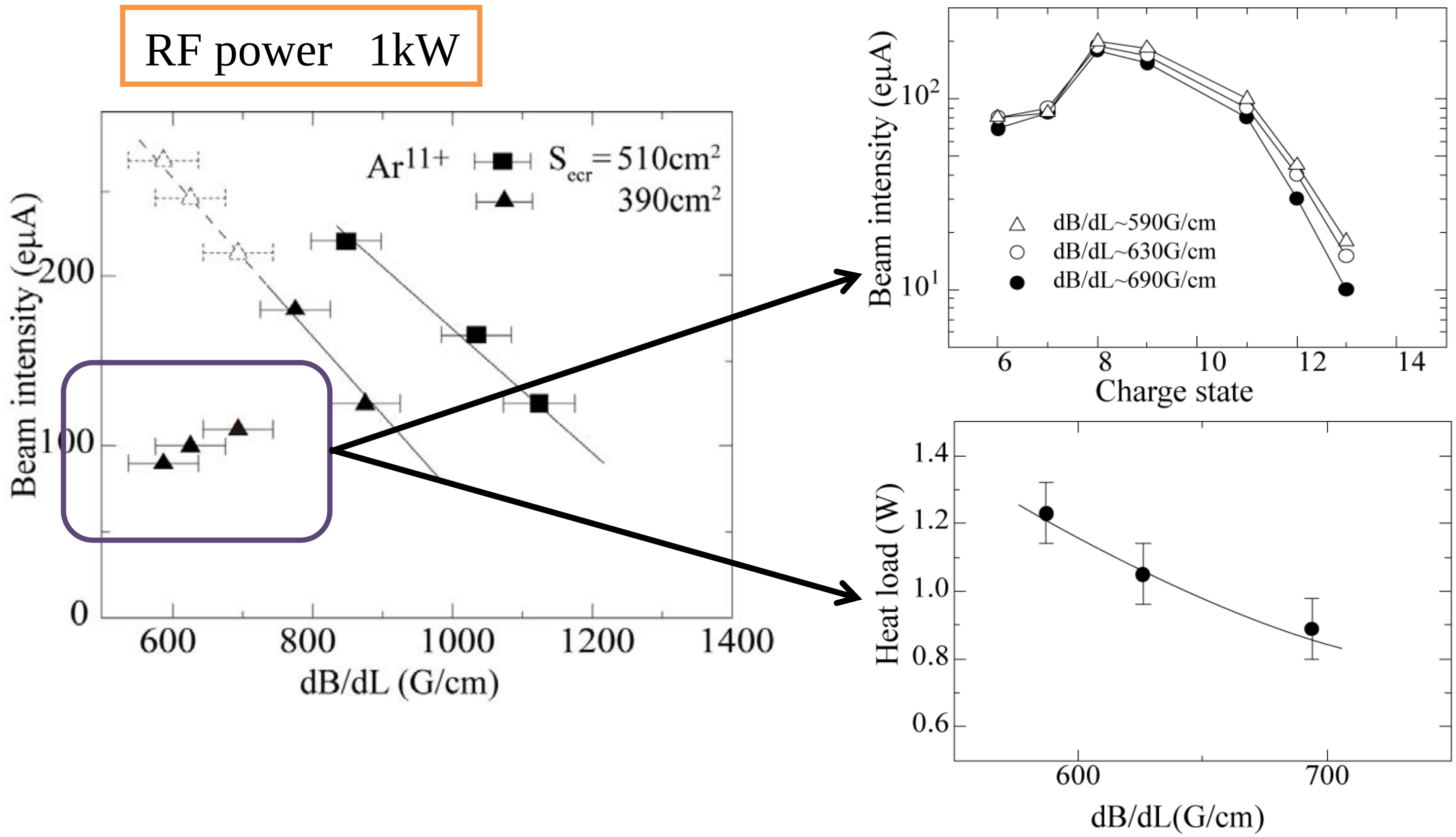
Ar^{12+}



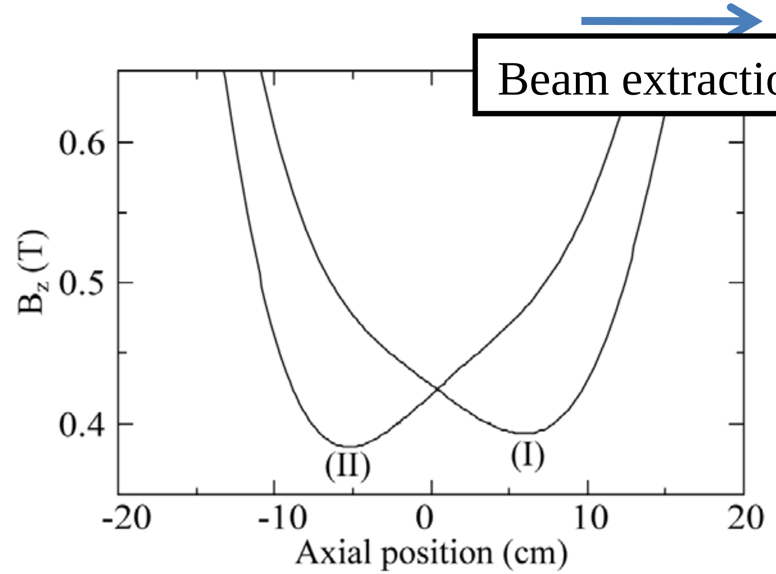
RF power =1kW

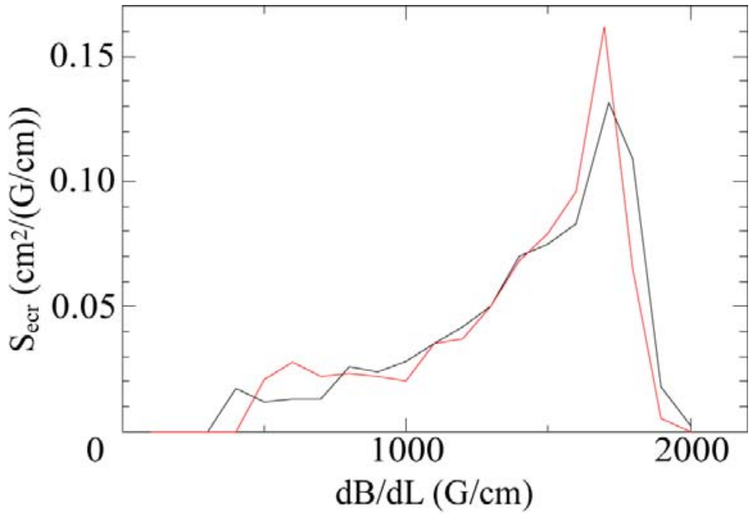


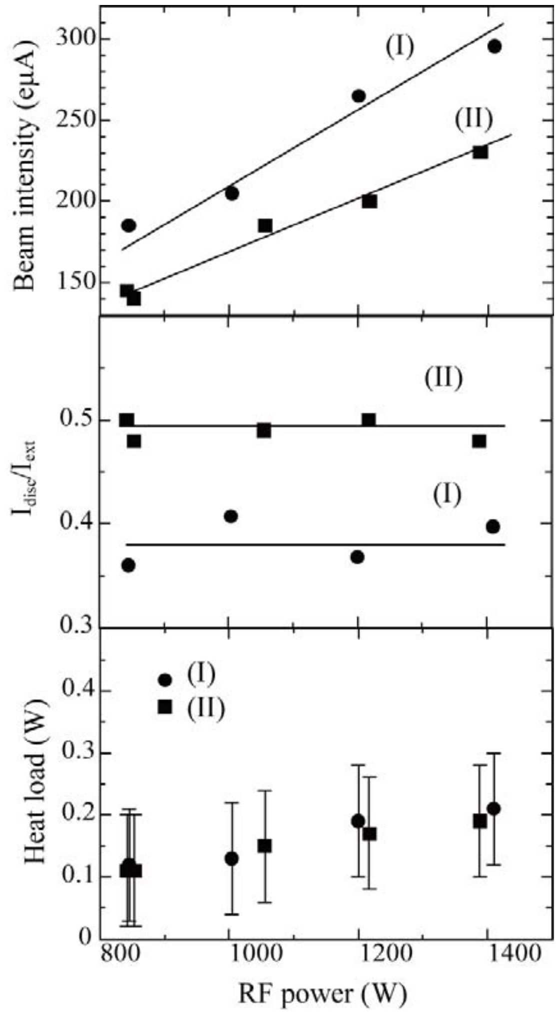
Field gradient limit ? (III)



Shape of B_{min}







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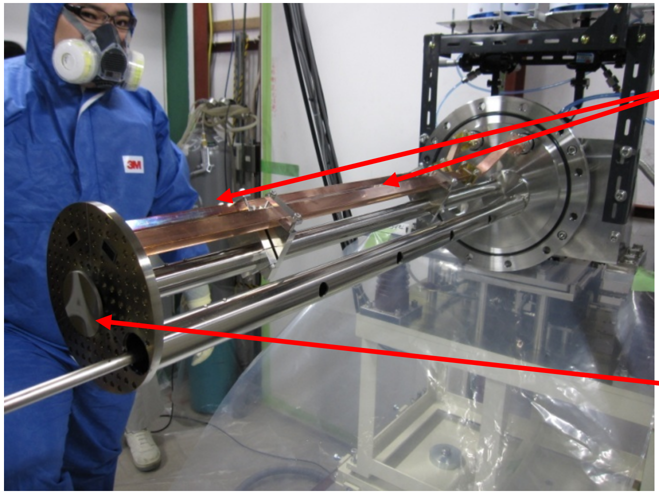
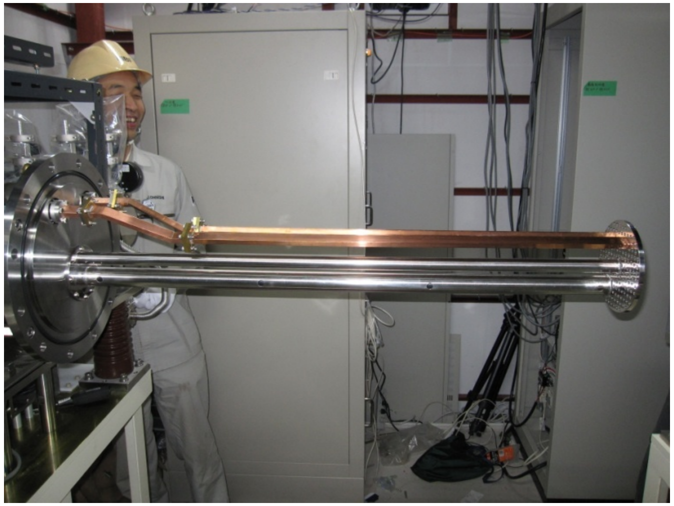
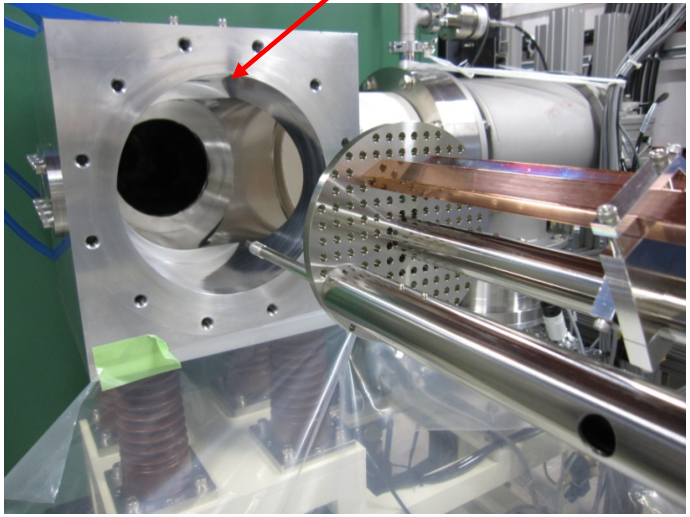


18GHz waveguides

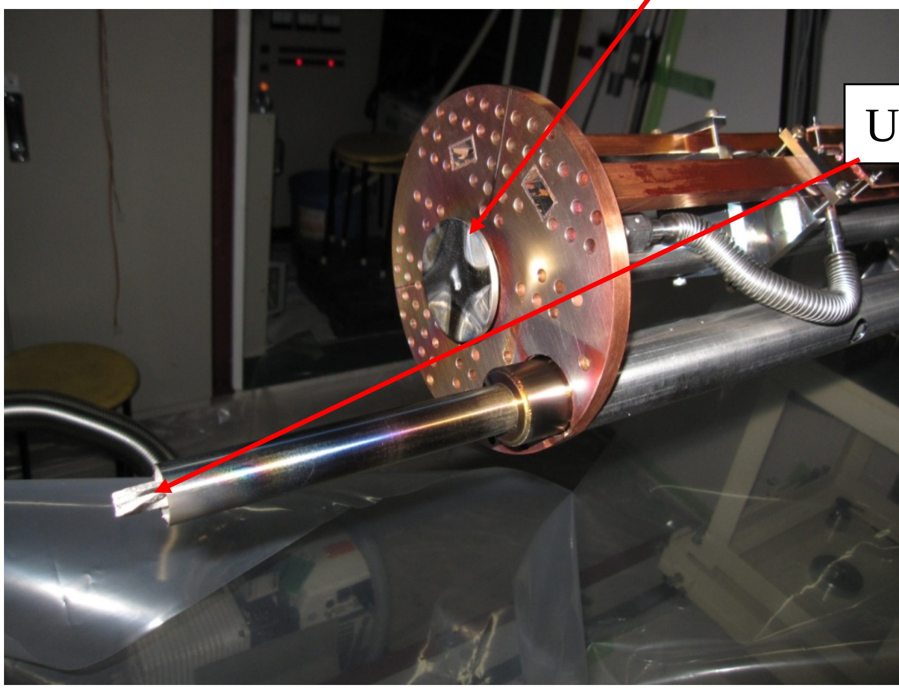
Biased disc

Chamber (RF injection side)

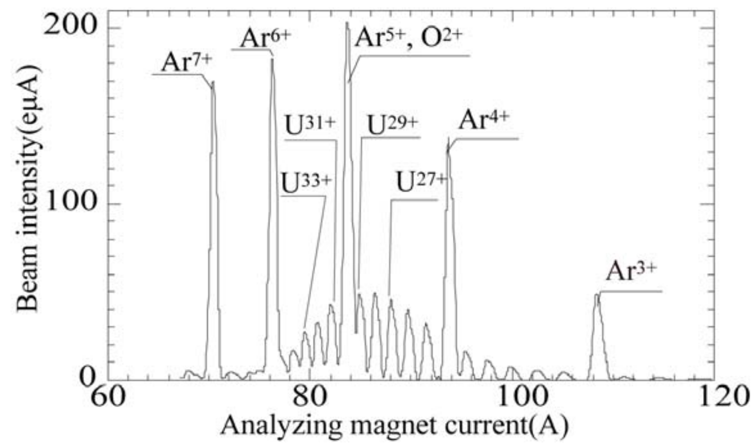




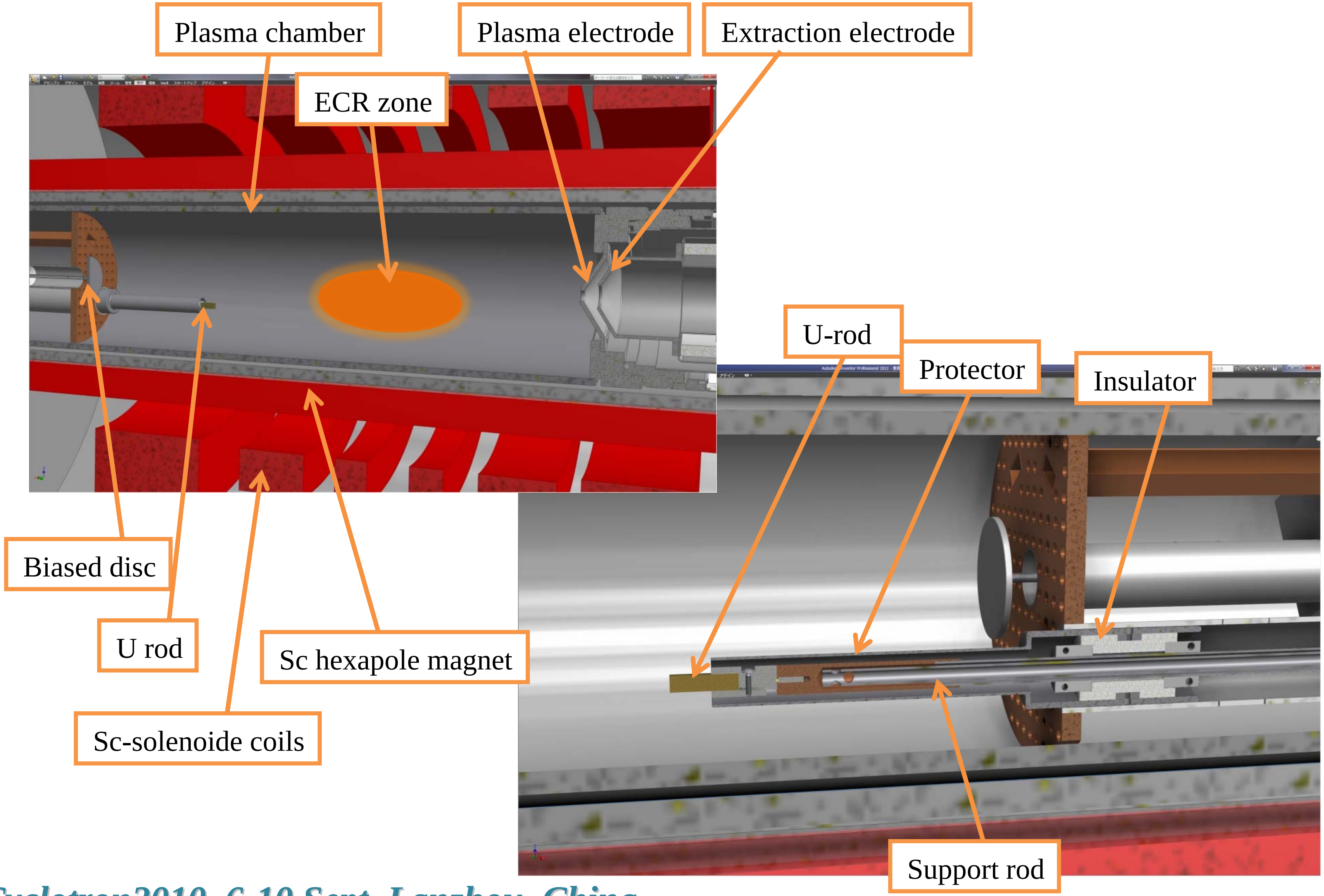
Production of metallic ions(sputtering method)



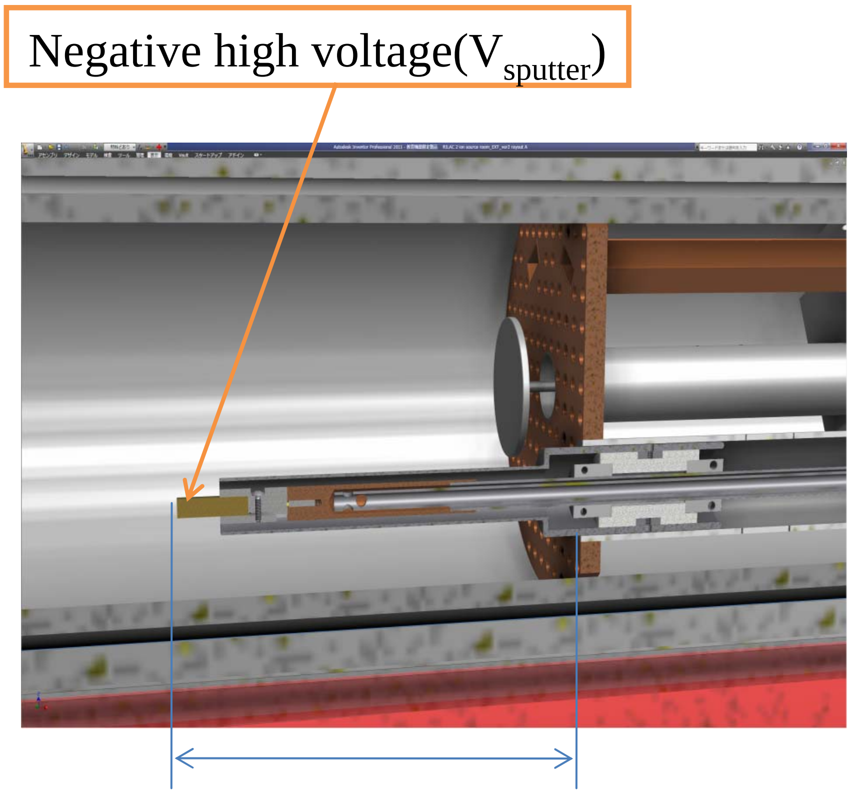
Charge distribution of U ions

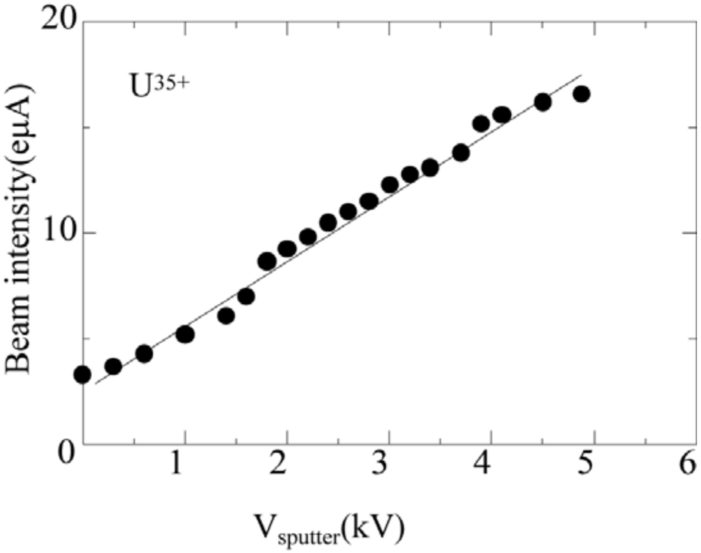


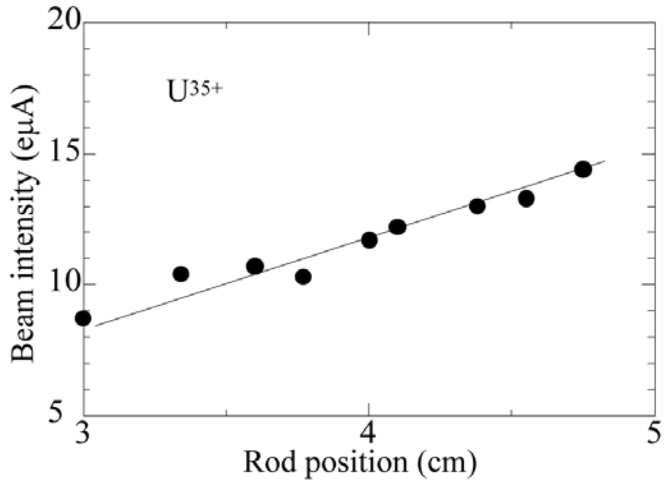
RF power ~900W
V_{ext}=15kV
O_2+Ar gas


Plasma chamber
Plasma electrode
Extraction electrode
ECR zone
Biased disc
U rod
Sc hexapole magnet
Sc-solenoide coils
U-rod
Protector
Insulator
Support rod

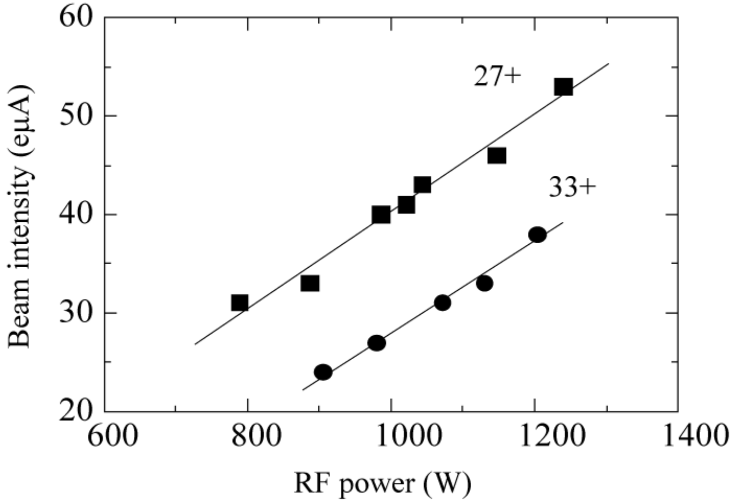
Sputtering method (U production)



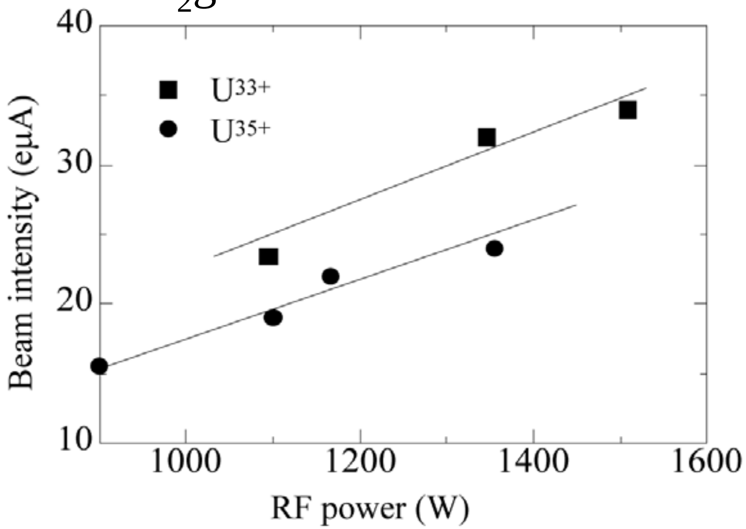




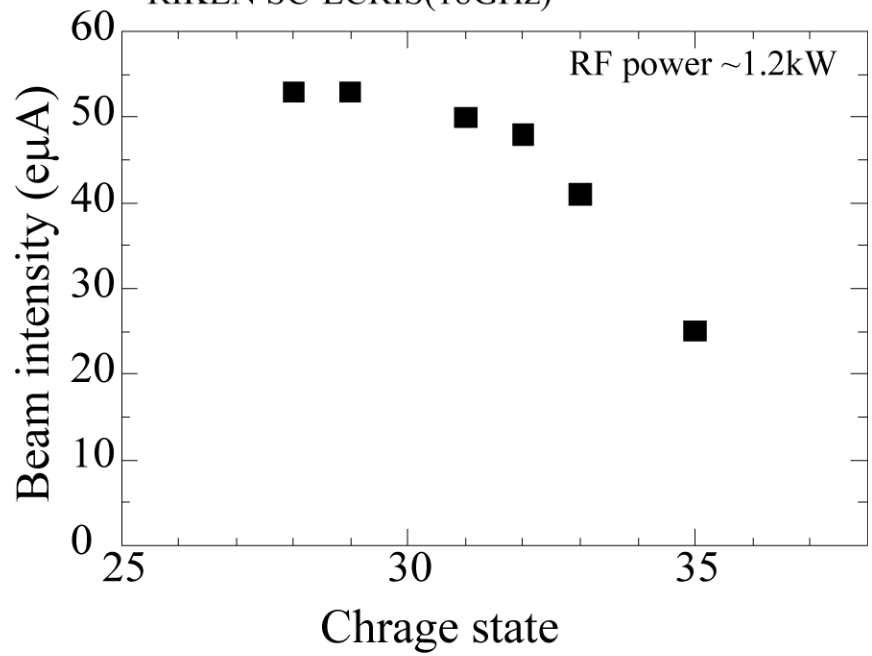
$Ar+O_2$ gas



O_2gas

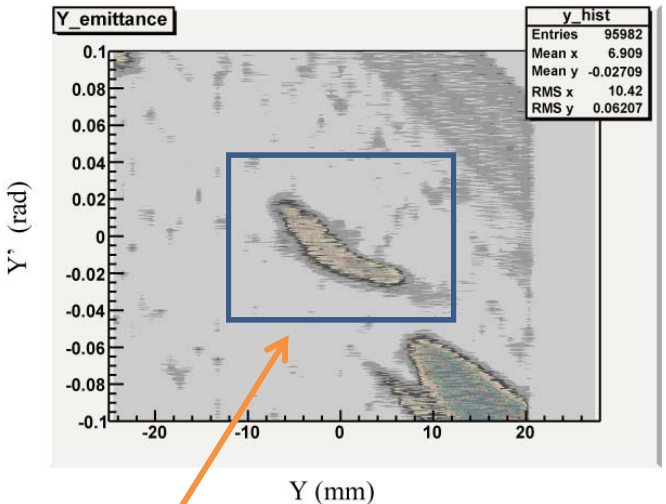


RIKEN SC-ECRIS(18GHz)



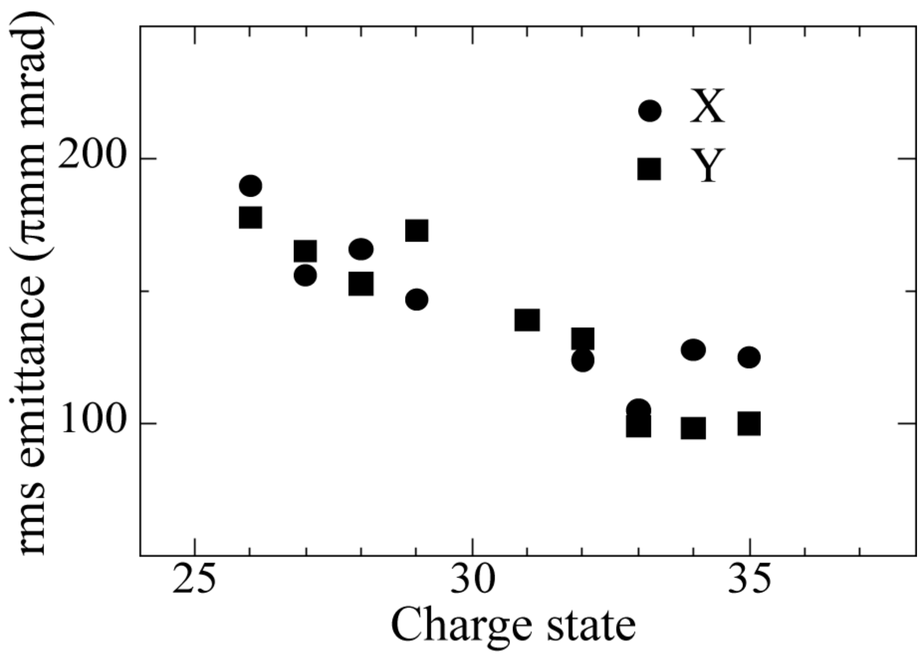
Emittance

$$\epsilon_x = \sqrt{<x^2><x'^2> - <x \cdot x'>^2}$$

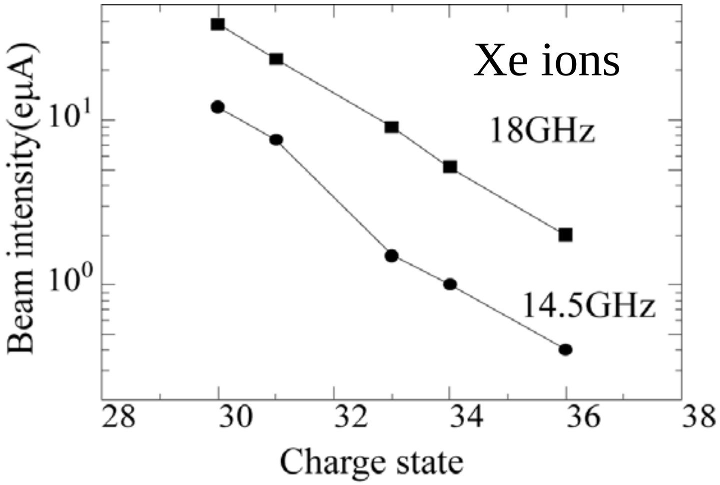


U^{35+} beam Y emittance

4 rms emittance



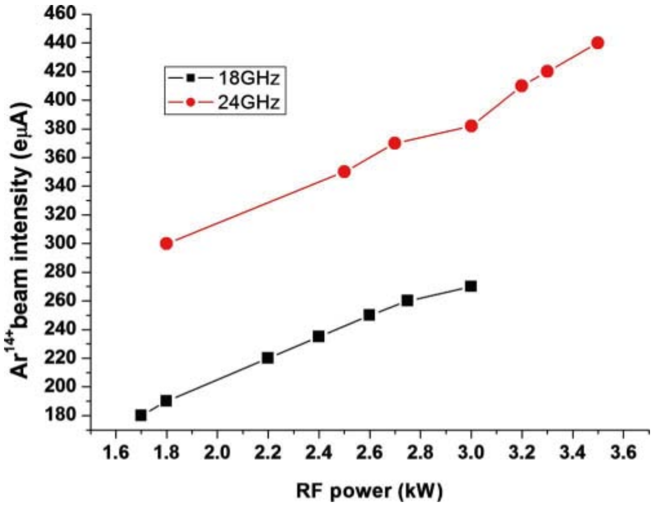
Microwave Frequency effect



SERSE
RF power 1.8kW

B_{inj}~3.5B_{ecr},B_{min}~0.8B_{ecr},B_{ext}~2B_{ecr}
B_r~2B_{ecr}

S. Gammino et al, RSI 70(1999)3577



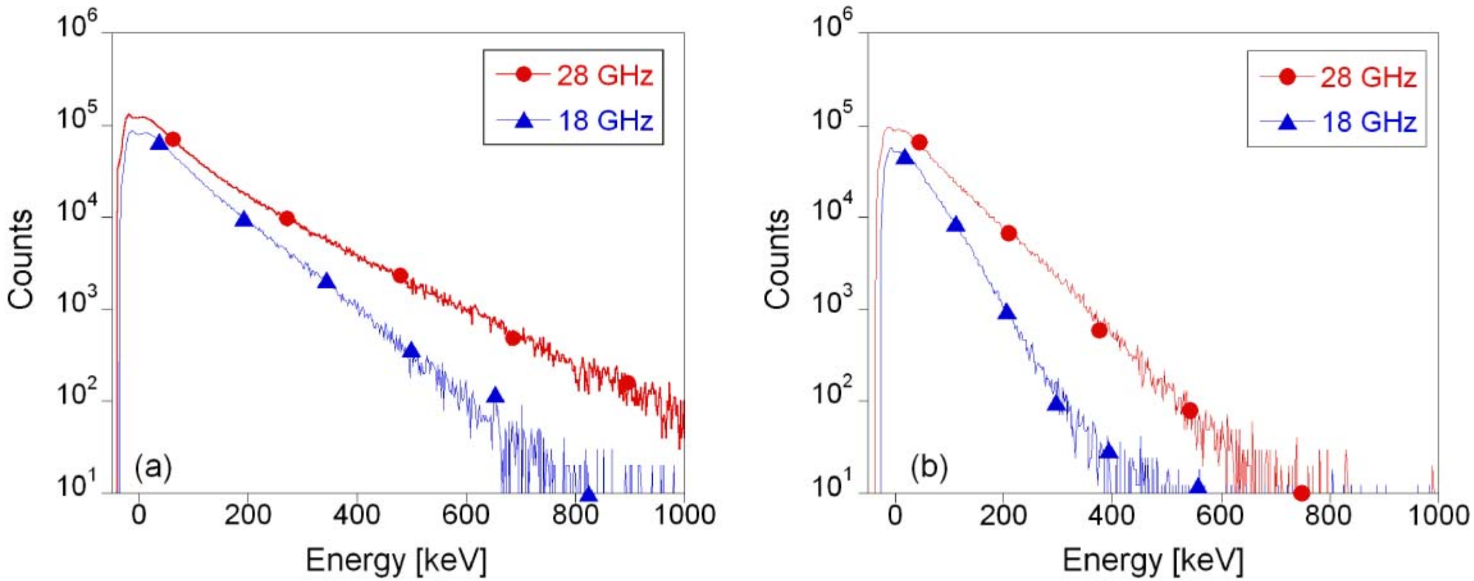
SECRAL

B_{inj}~3.5B_{ecr},B_{min}~0.8B_{ecr},B_{ext}~2B_{ecr}
B_r~2B_{ecr}

H. W. Zhao et al, RSI 81(2010)02A202

Microwave Frequency effect

X-ray energy spectra



B_{min}~$0.65B_{ecr}$

18GHz 0.41T
28GHz 0.65T

B_{min}~$0.45B_{ecr}$

18GHz 0.28T
28GHz 0.41T

D. Leitner et al, RSI 79(2008)033302

Microwave Frequency effect

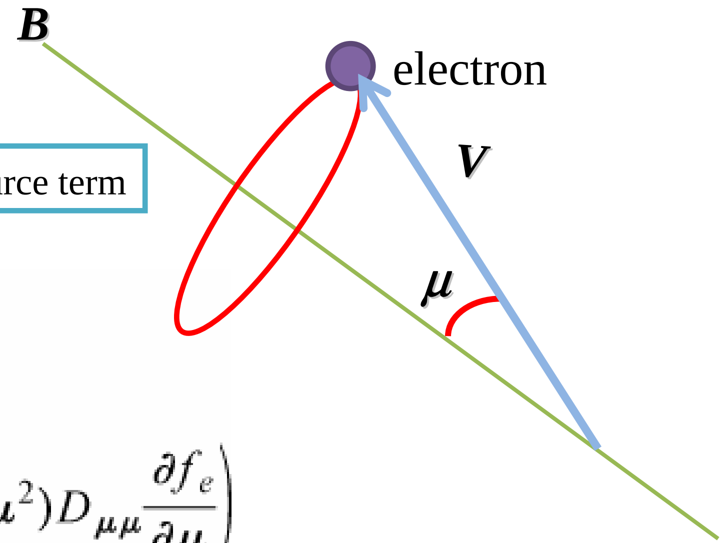
Fokker-planck equation

Collision term | HF term | Source term

$$\frac{\partial f_e}{\partial t} = C(f_e) + Q(f_e) + S(f_e)$$

$$Q = \frac{1}{v^2}\frac{\partial}{\partial v}\left(v^2 D_{vv}\frac{\partial f_e}{\partial v}\right) + \frac{1}{v^2}\frac{\partial}{\partial \mu}\left((1-\mu^2) D_{\mu\mu}\frac{\partial f_e}{\partial \mu}\right)$$

$$D_{vv} = D = \frac{4}{3}\pi\left(\frac{eE}{2m_e}\right)^2 \frac{d}{L\omega}, \quad D_{\mu\mu} = D\left(\frac{v}{v_{ph}}\right)^2.$$



$$\frac{k^2c^2}{\omega^2} \approx -\frac{\omega_p^2}{\omega k v_T}.$$

Taking the phase velocity $v_\phi = \omega/k$, we obtain

$$v_\phi^3 \approx \frac{\omega^2}{\omega_p^2} v_T c^2 = \frac{n_c}{n_e} v_T c^2,$$

$$n_c = \frac{\omega^2 m_e \epsilon_0}{e^2}$$

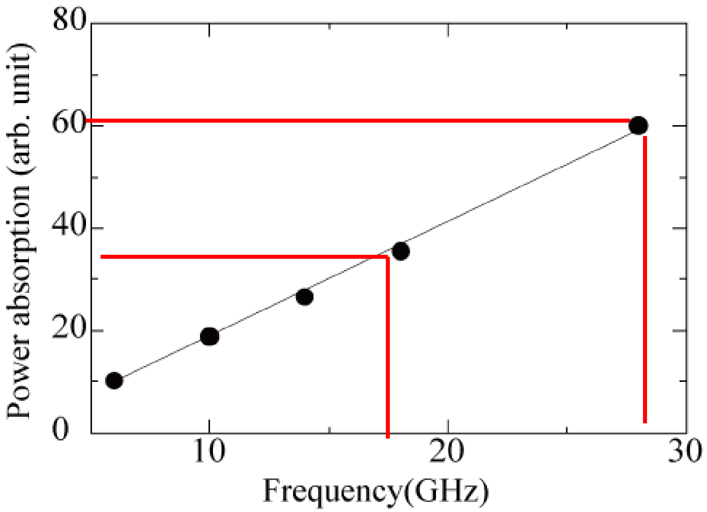
Strength of electric field (RF power)

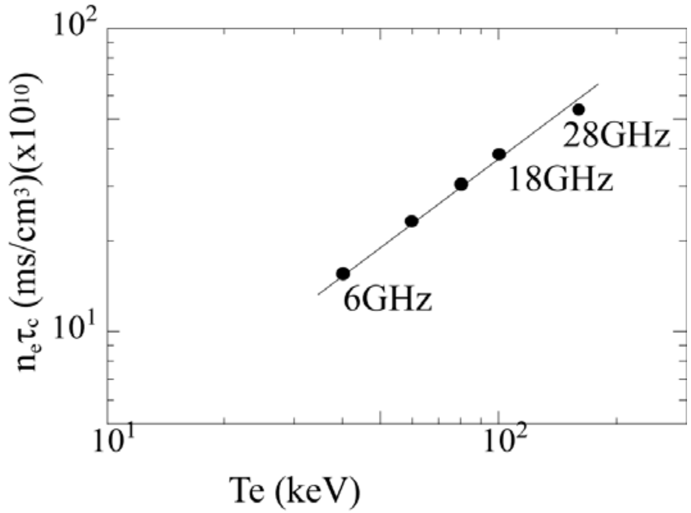
Magnetic field gradient (B_{min} effect)

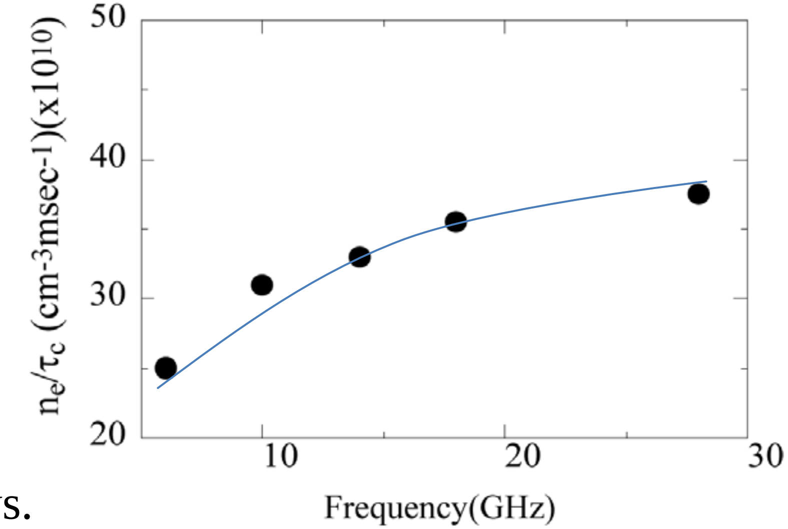
A. Girard et al, J. Computational Phys. 191(2003)228

Microwave Frequency effect

Fokker planck equation

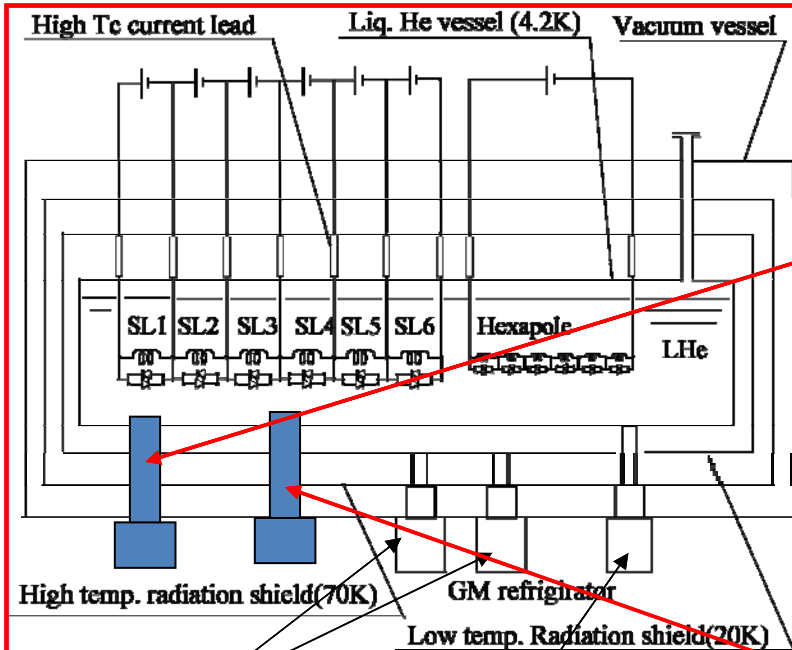






A. Girard et al, J. Computational Phys. 191(2003)228

Cryostat(2011) for 28GHz



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

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

2011. April
Total cooling power ~10W

2009. Oct.

CG310SC(SUMITOMO)**(GM-JT refrig.)**

Cooling capacity
4.2W/5.0W@4.2K(50/60Hz)

Electric power consump.	5.1/6.1kW(50/60Hz)
Electric power	AC200V 3 phase
Weight	~220kgr
Dimension	700Wx520Dx1095H

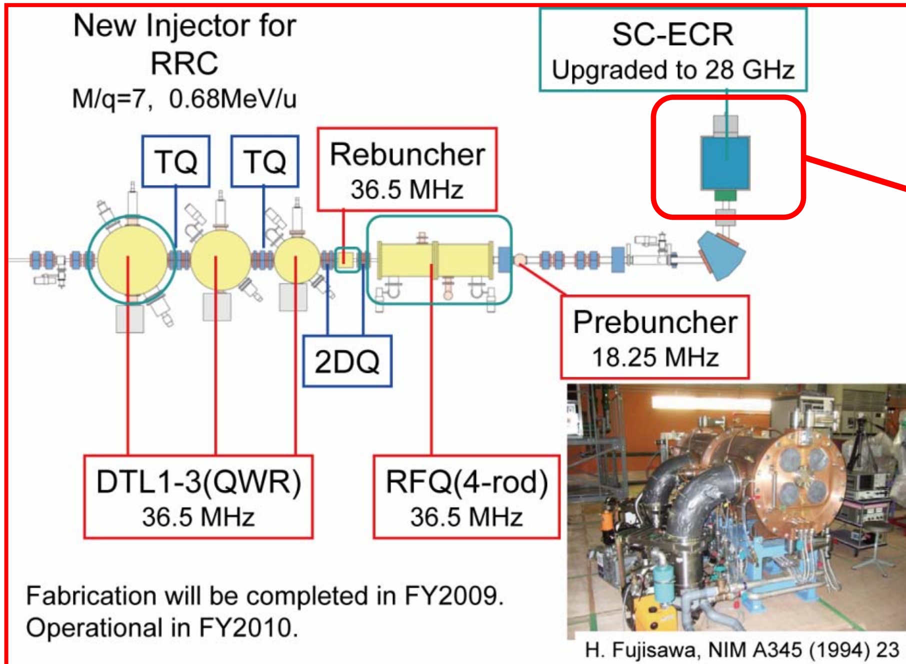
2011. March.

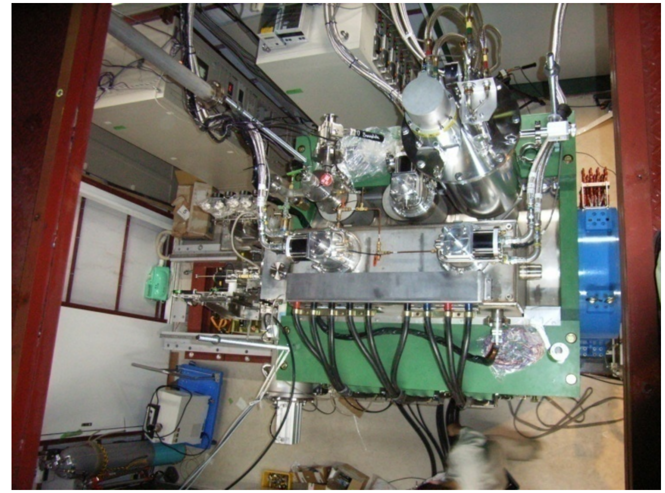
CG310SC(SUMITOMO)**(GM-JT refrig.)**

Cooling capacity
4.2W/5.0W@4.2K(50/60Hz)

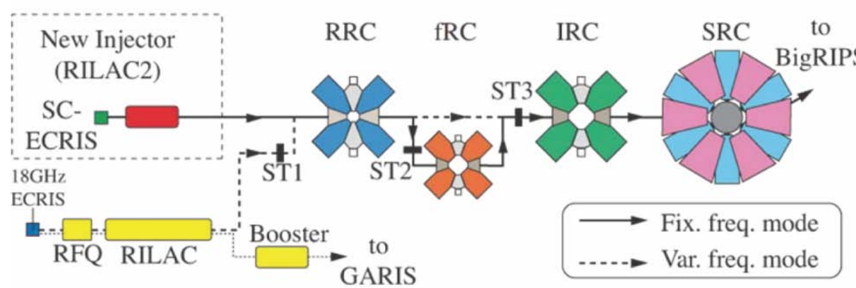
Electric power consump.	5.1/6.1kW(50/60Hz)
Electric power	AC200V 3 phase
Weight	~220kgr
Dimension	700Wx520Dx1095H

New injector (2011 March~)



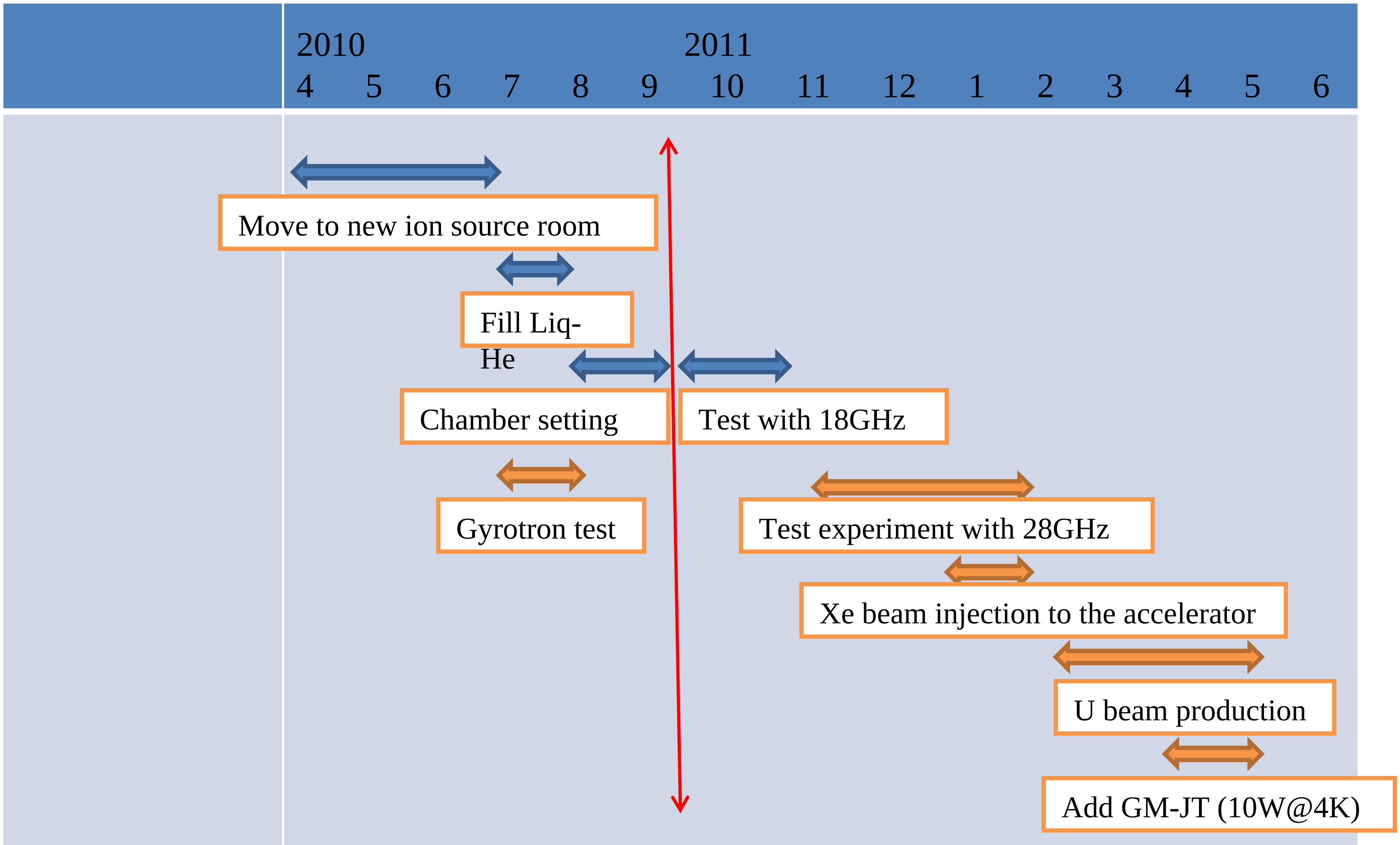


Mar. 2011



U: 50 - 100 pnA

Schedule



2010
2011
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6
Move to new ion source room
Fill Liq-He
Chamber setting
Test with 18GHz
Gyrotron test
Test experiment with 28GHz
Xe beam injection to the accelerator
U beam production
Add GM-JT (10W@4K)