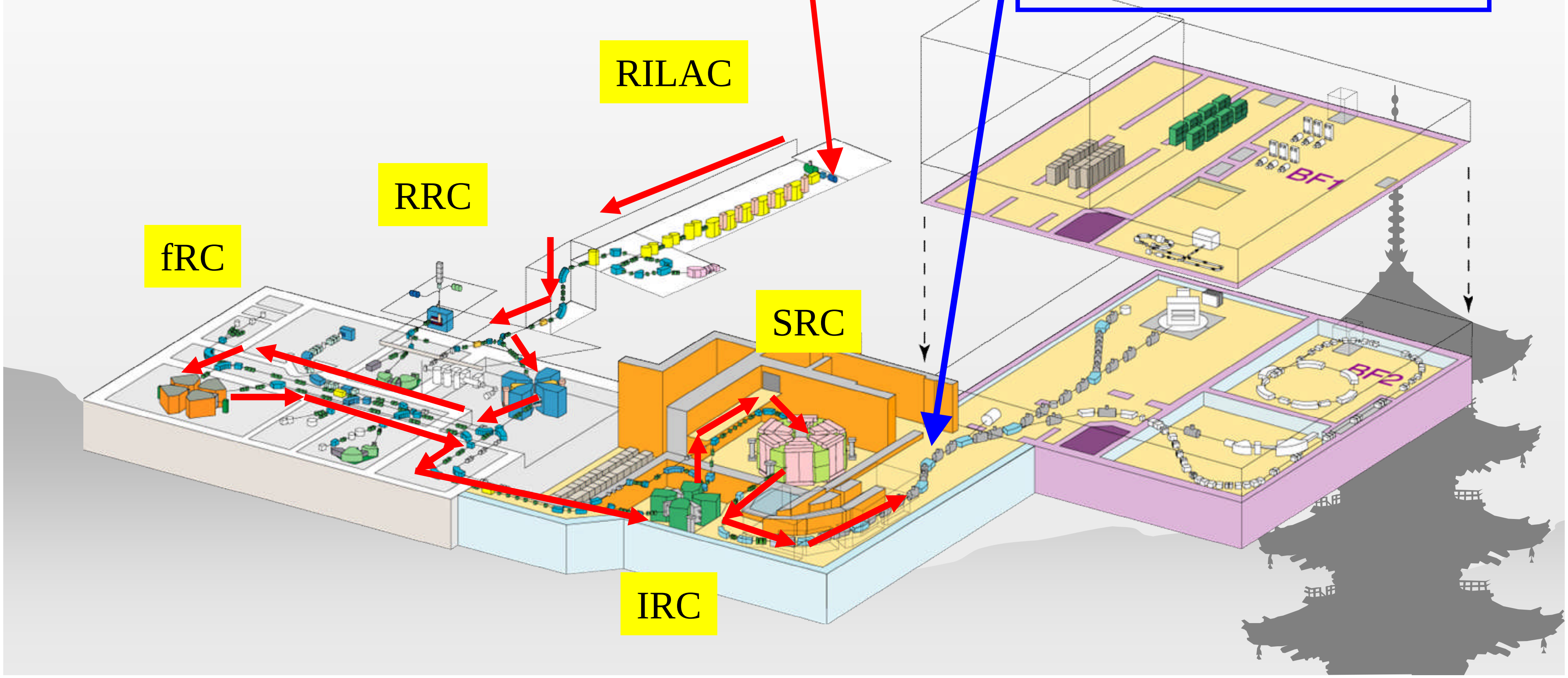
Accelerator complex for RIKEN RIBF

U^{35+} beam 2~3eμA for 1 month
without vacuum break
Sputtering method

ECRIS

345MeV/u U beam
3~4enA(~0.05pnA)
One day experiment
^{125}Pd ^{126}Pd (new isotope)
Journal of Physical Society of Japan 77(2008)083201



New 28GHz SC-ECRIS for RIKEN RI beam factory project

1. Status of RIBF

2. ***Physics of ECR plasma***

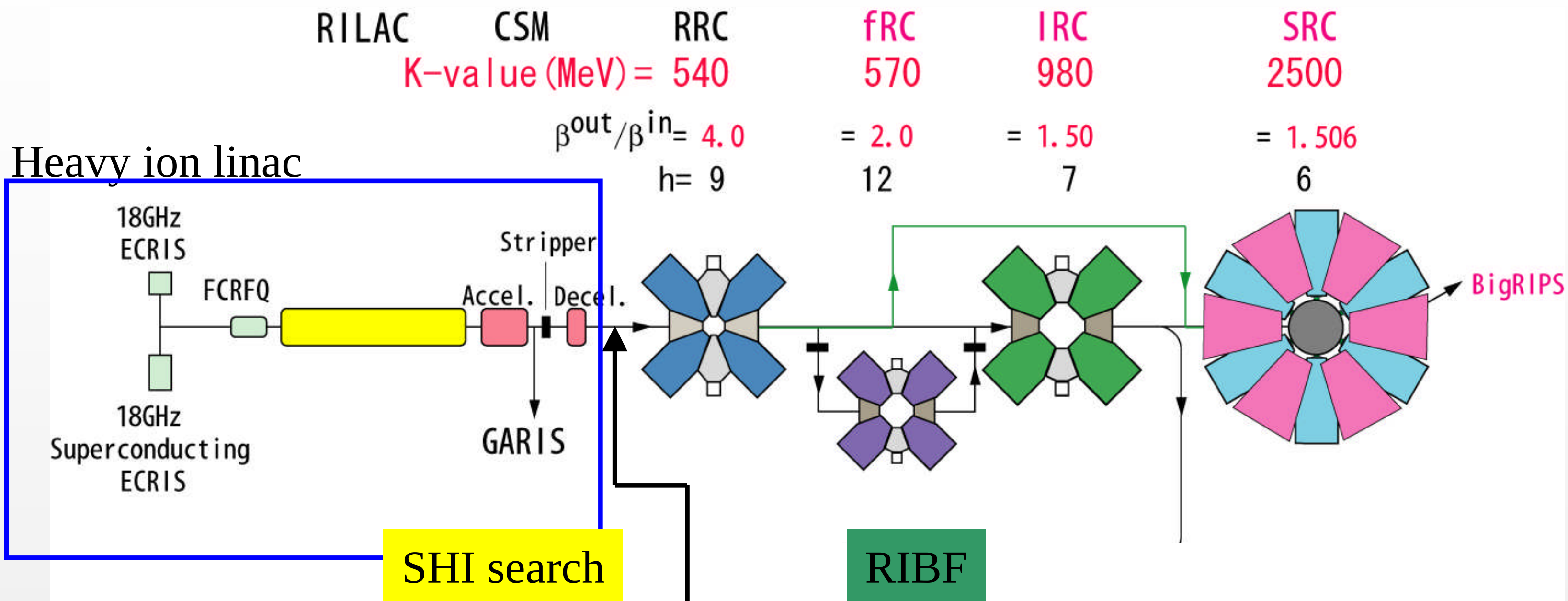
Magnetic field
Geometrical effect Biased disc
measurement of plasma potential

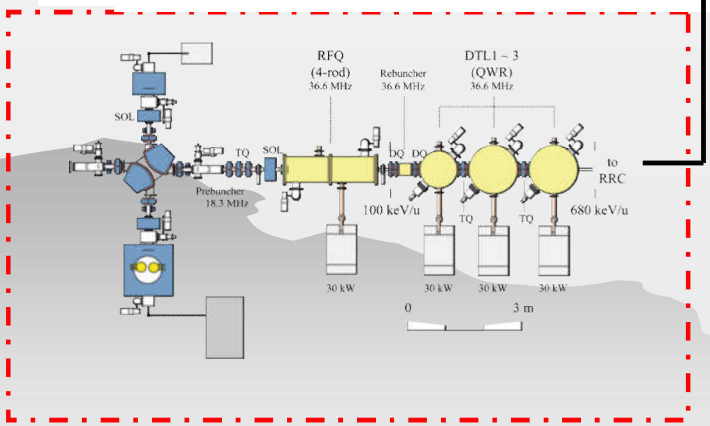
3. Structure of new SC-ECRIS

Sc-Coils
Cryostat
Plasma chamber

Schedule

New Injector System

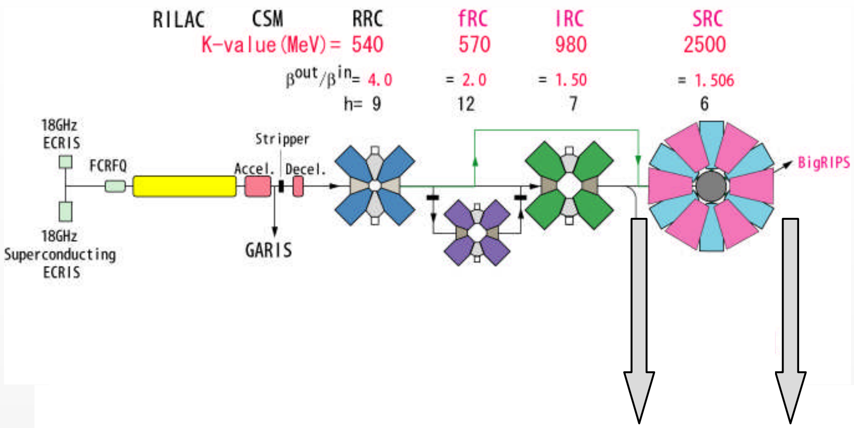




Planed schedule (2009~ construction)

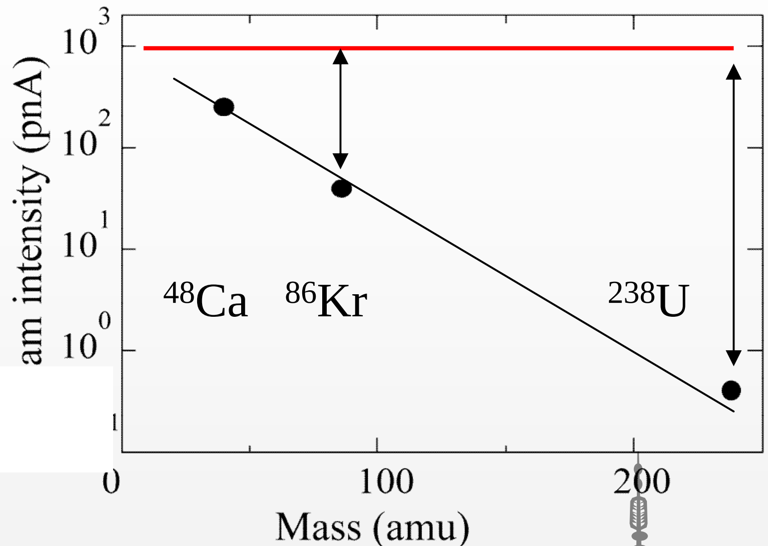
New Injector system

Ion source U^{35+} 15pμA



Acceleration test (2007~2008)

From the IRC or SRC



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

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Key parameters 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	Movable disc

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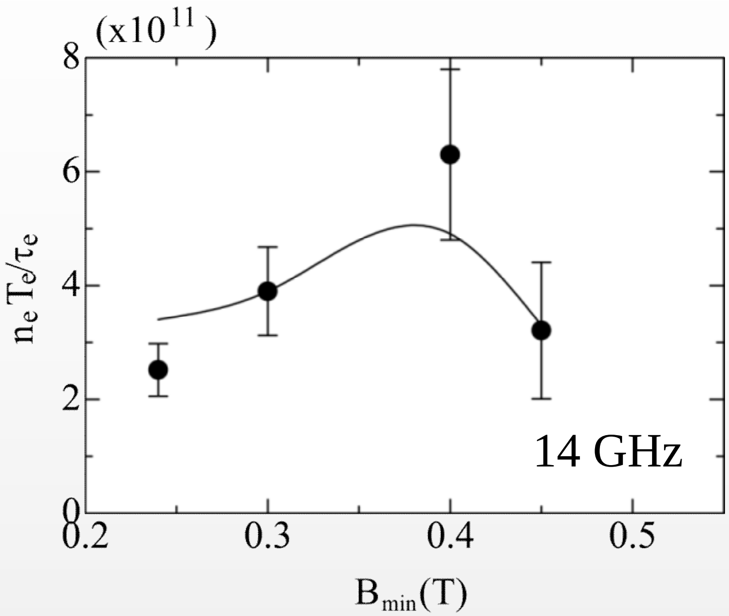
Energy absorption as a function of B_{min}



Field gradient + Size of resonance zone

B_{min} ——— Plasma generator

Absorption power

$$\frac{S_{abs}}{S_{inc}} = 1 - e^{-\pi\eta}$$

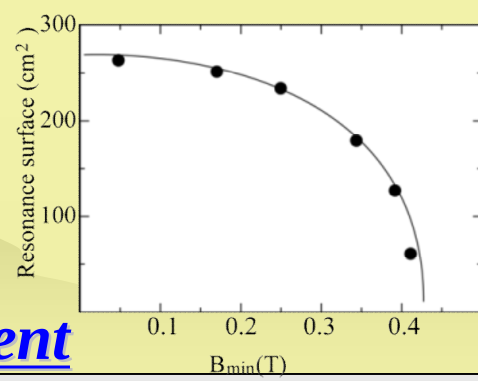
$$\eta = \omega_{pe}^2/(\omega c|\alpha|),$$

$$\boxed{\alpha = (d\omega_{ce}/dz)/\omega_{ce}}$$

Field gradient

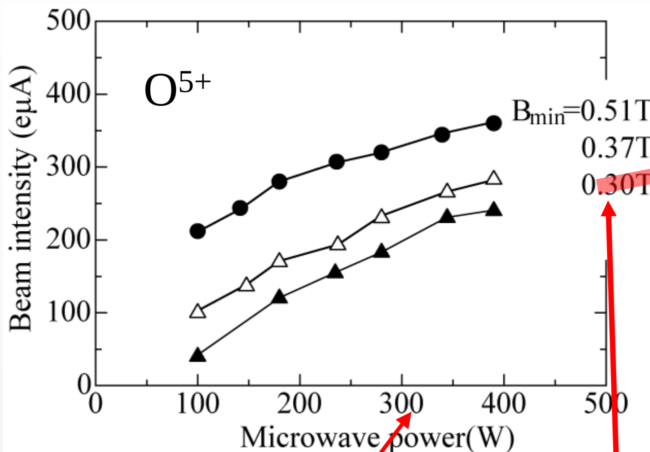
X

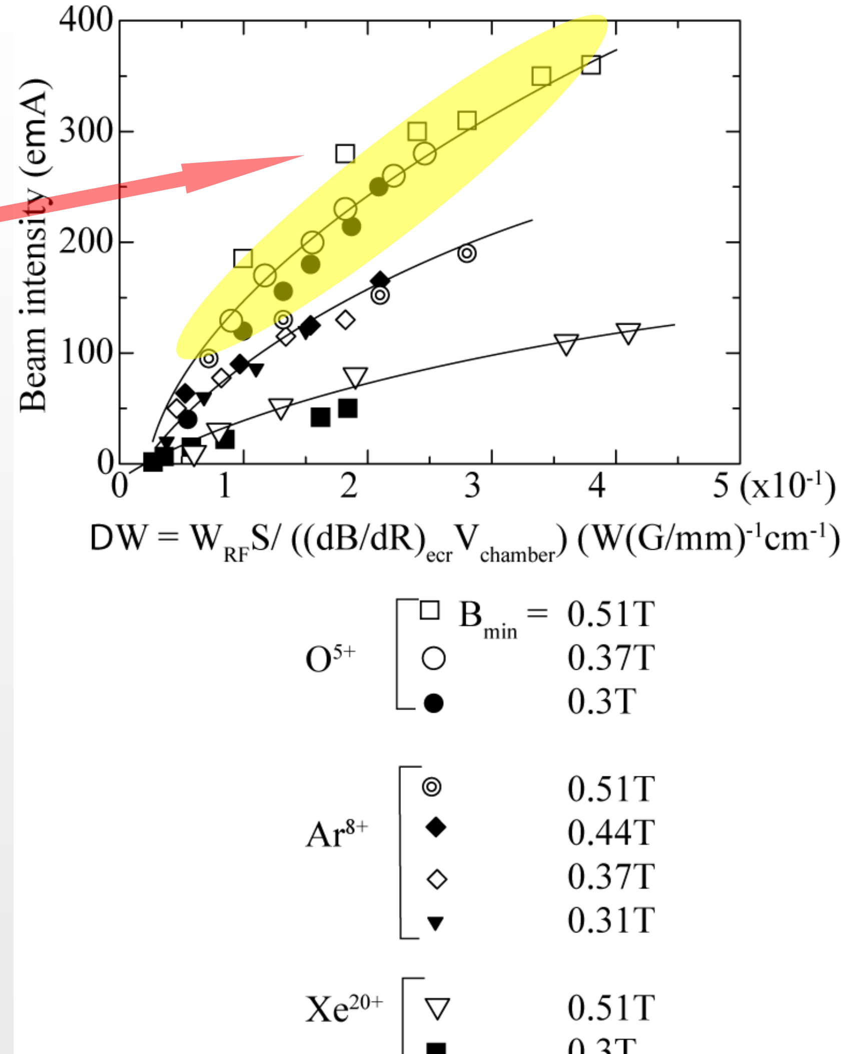
Resonance surface



Total absorption power

B_{min} effcet





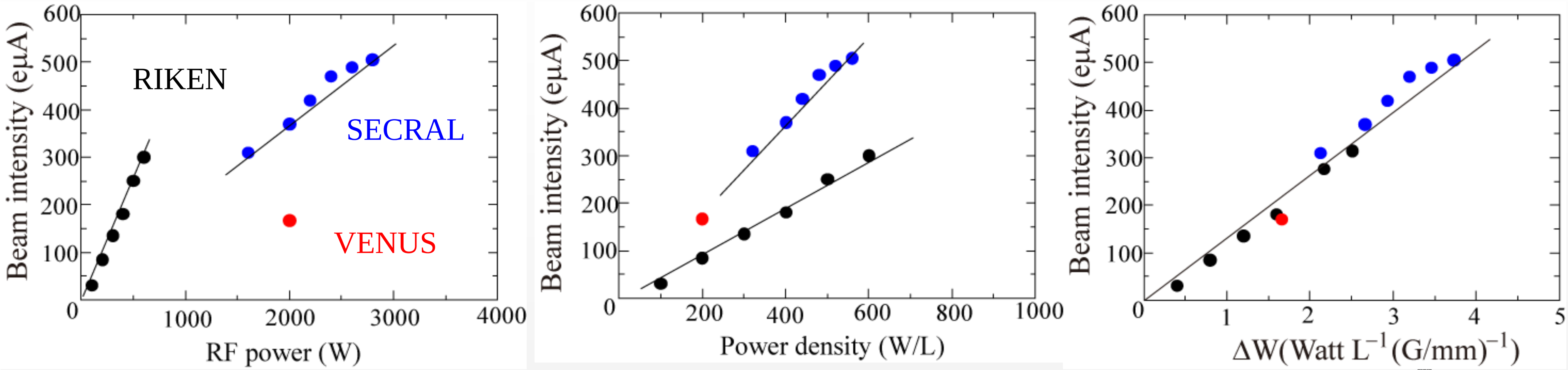
$$\Delta W \sim \frac{\pi e^2 \left|\vec{E}\right|^2}{m_e \nu \omega \frac{1}{B_{res}} \left(\frac{dB}{dZ}\right)_{res}}$$

B_{min} = 0.3T

(dB/dZ) gentler

0.5T

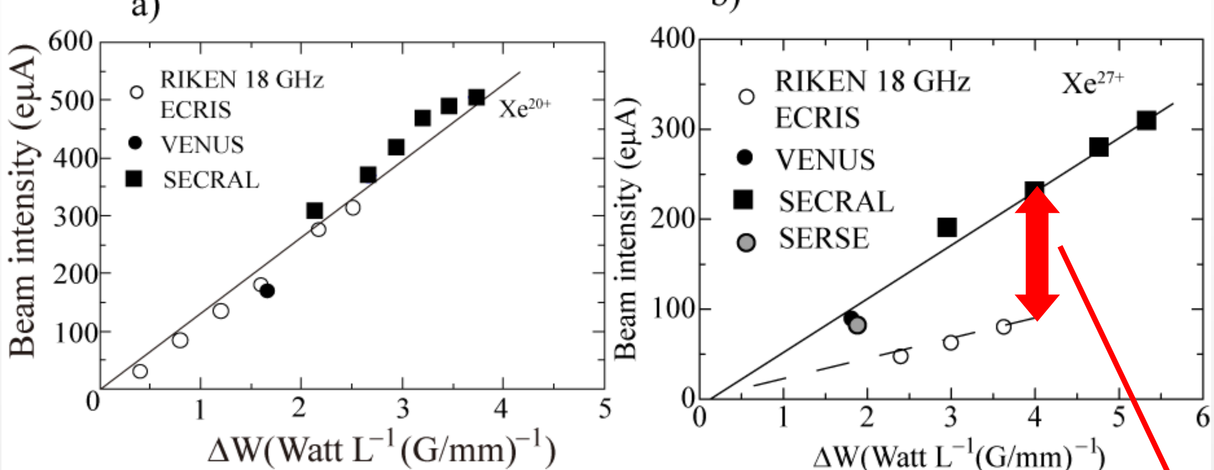
Power density effect

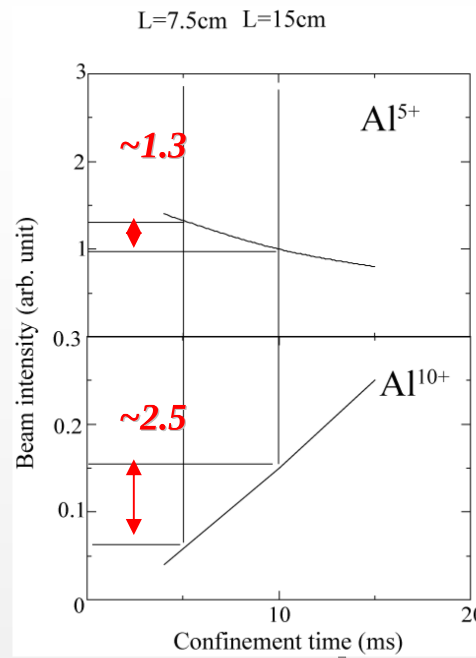


$$\Delta W \sim \frac{\pi e^2 \left|\vec{E}\right|^2}{m_e v \omega \dfrac{1}{B_{res}} \left(\dfrac{dB}{dZ}\right)_{res}}$$

	Xe^{20+} (eμA)	RF power	Chamber Vol	Magnetic Field Gradient (G/mm)	Energy transefer at res.
VENUS	167	2kW	~10L	110	1.8
RIKEN	300	0.6kW	~1L	250	2.4
SECRAL	470	2.4kW	~5L	130	3.7

$n_e\tau_i(Xe^{27+}) \sim n_e\tau_i(U^{35+})$





1)Confinement time

$$\tau_q = 7.1\times 10^{-20} Lq \,\mathrm{Ln}\,\Lambda \sqrt{A}\frac{n_e q_{\mathrm{eff}}}{T_i^{3/2} E}$$

2)ECR zone size

Additional effect

chamber size

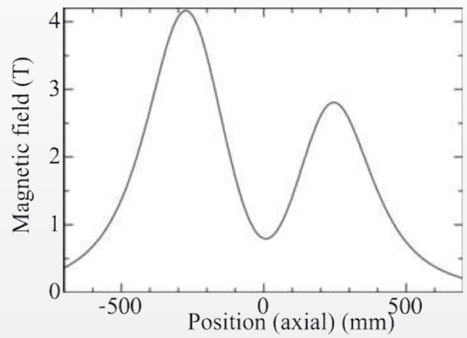
RIKEN ~1L

SECRAL ~5L

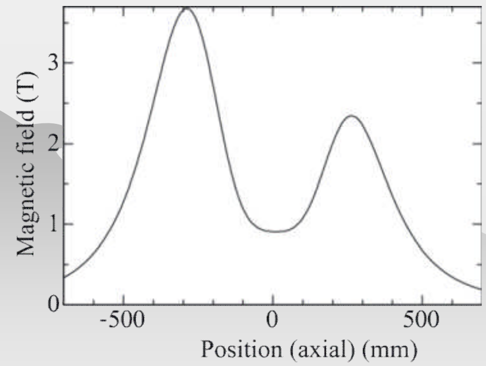
VENUS ~10L

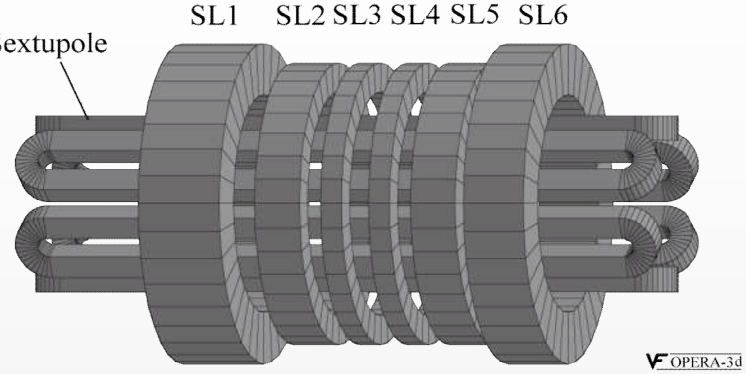
ECR zone size (I)

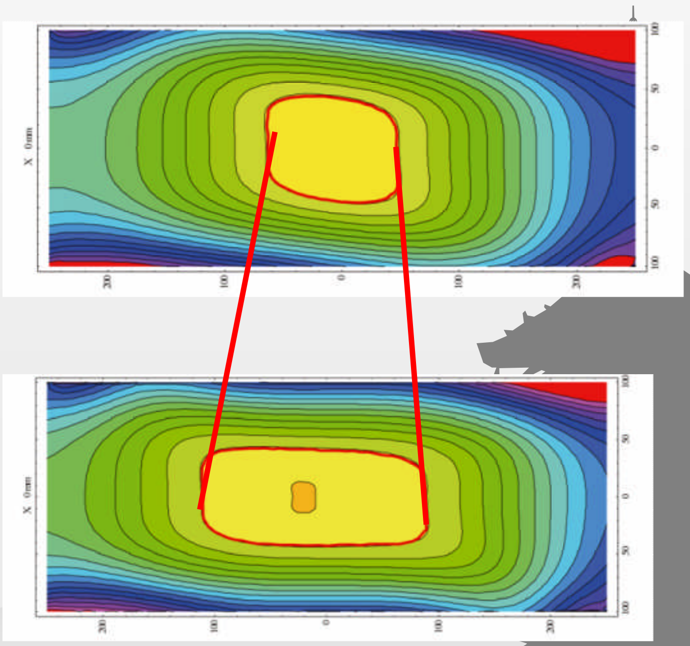
Classical Bmin



Flat Bmin







ECR zone size(II)

Field gradient effect

$$\Delta W \sim \frac{\pi e^2 \left|\vec{E}\right|^2}{m_e v \omega \frac{1}{B_{res}} \boxed{\left(\frac{dB}{dZ}\right)_{res}}}$$

Surface size effect

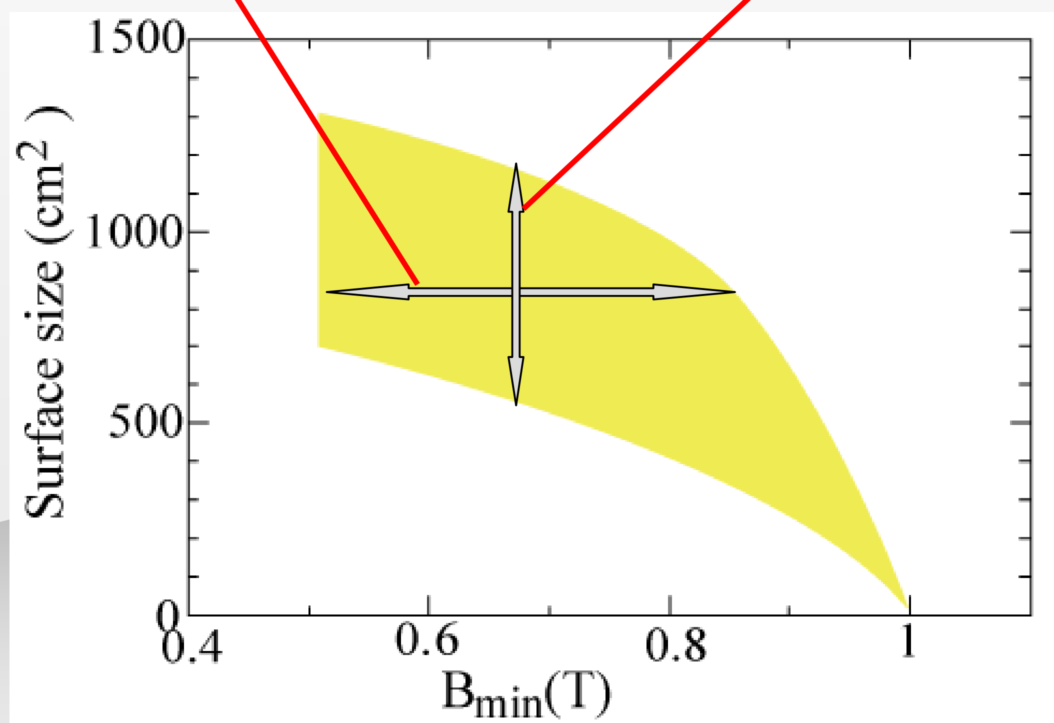
$$I_q = \frac{n_q\, q\, \boxed{V}}{\tau_c}$$

n_q : ion density

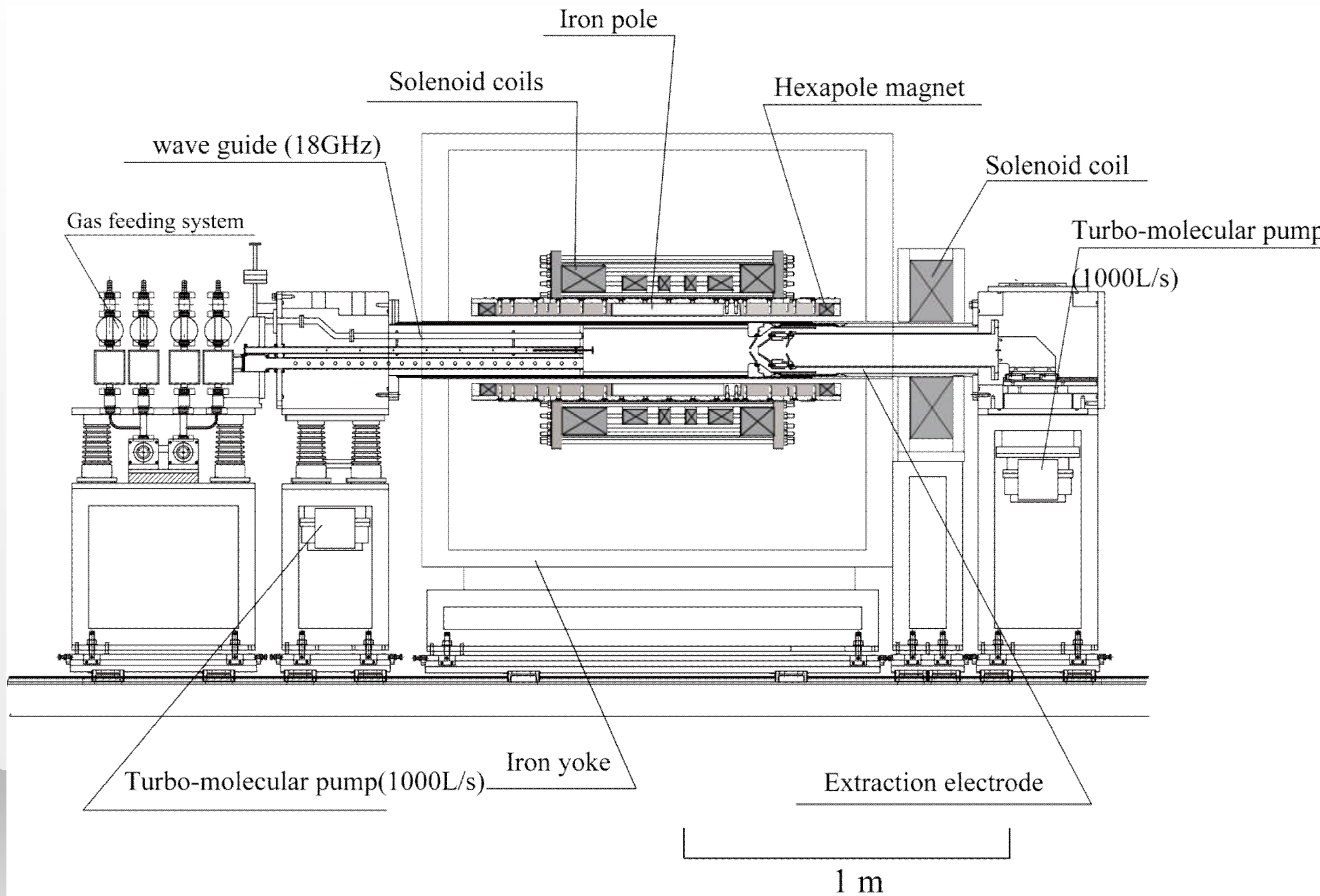
q : charge state

V : plasma volume

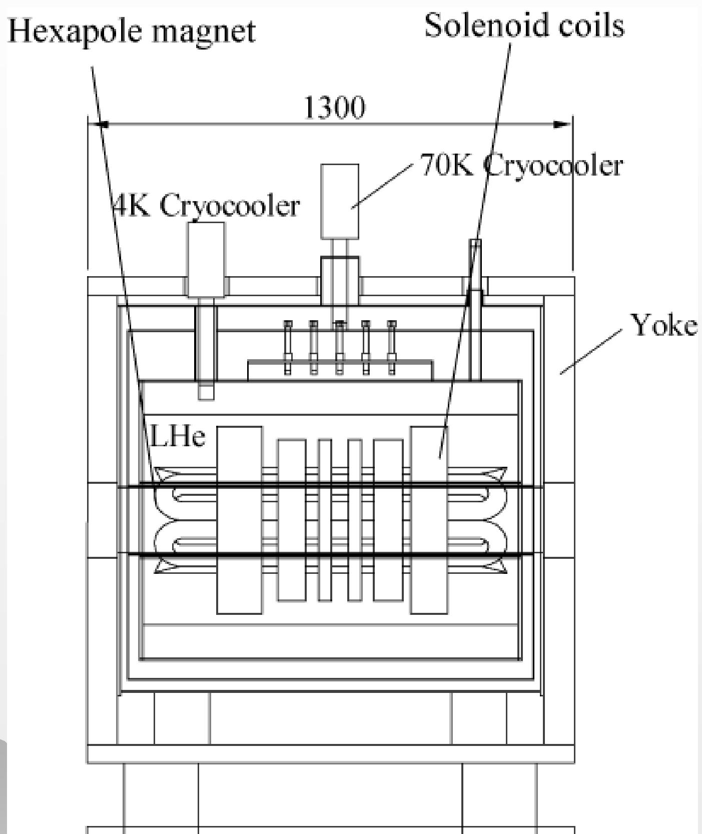
τ_c : ion confinement time



Schematic drawing of the RIKEN SC-ECRIS



Cryostat



Heat (4K)

Radiation	***~0.18W***
Support	***~0.5W***
Current lead	***~1W***
X-ray	***>3W***

70K(GM)	***160W***
4K(GM)	***1W***
4K(JT+GM)	***10W***

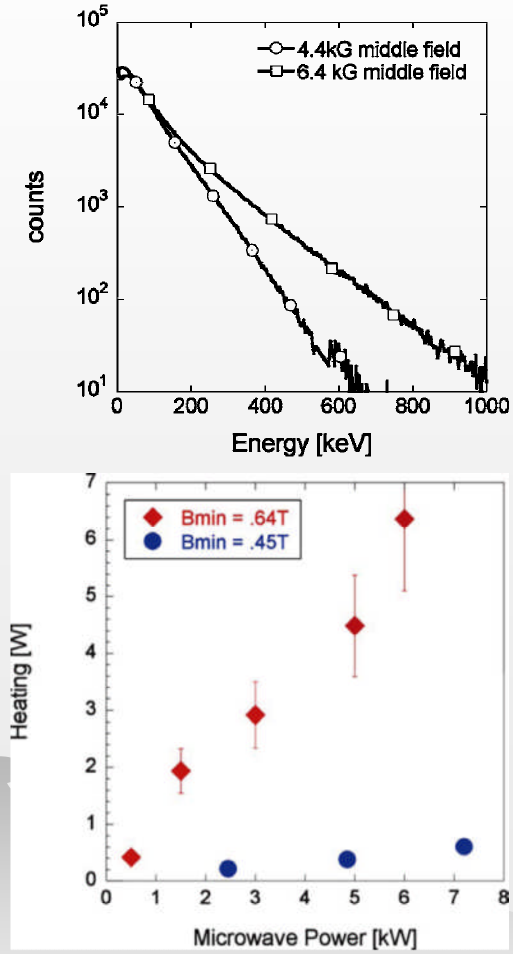
Amount of the LHe is about 500 L.

Total nine current leads made of high Tc material are used to reduce the heat load to 4 K.

The electromagnetic force between the magnetic shields and the cold mass is estimated to be 8 tons in maximum in axial direction

X-ray effect

Rev. Sci. Instrum. 79(2008)033302 D. Leitner et al,



Ta sheet (2mm) X-ray shield

10W@4K (2 GM-JT refrigerators)

GM-JT Cryo-cooler

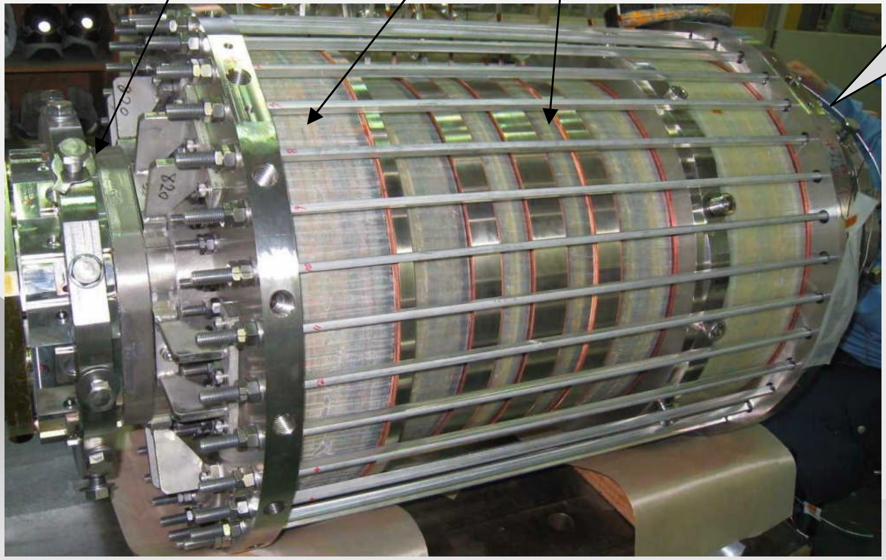
CG310SC(SUMITOMO)

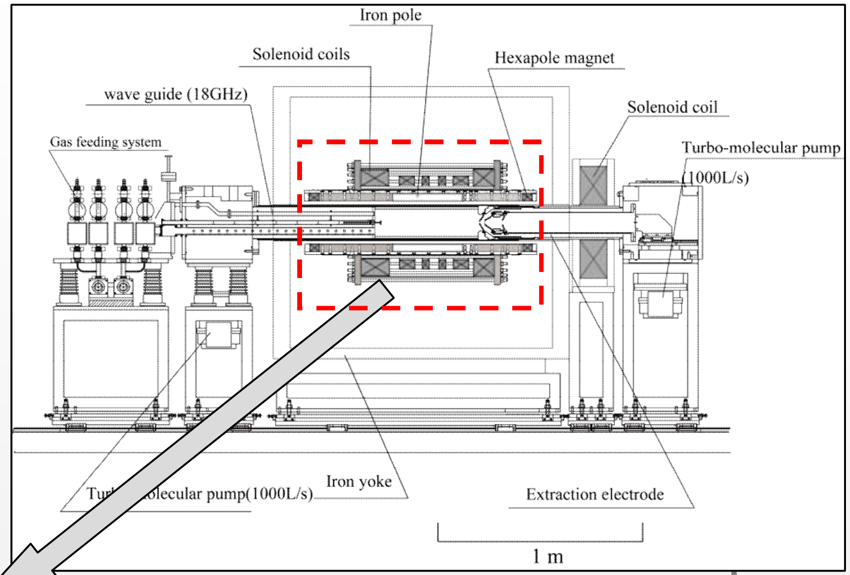
Cooling capacity		4.2W/5.0W @4.2K(50/60Hz)	
Ambient temp. range		4 to 38 deg.	
Dimension		ϕ360x789L	
Weight		~50kgr	
Compressor	cooling	water	
	ambient temp. range		5to 35deg.
	Electric power consump.		5.1/6.1kW(50/60Hz)
	Electric power		AC200V 3 phase
	Weight		~220kgr
	Dimension		700Wx520Dx1095H

Superconducting coils

Solenoid coils

Hexapole magnet





Main parameters of SC-Coils

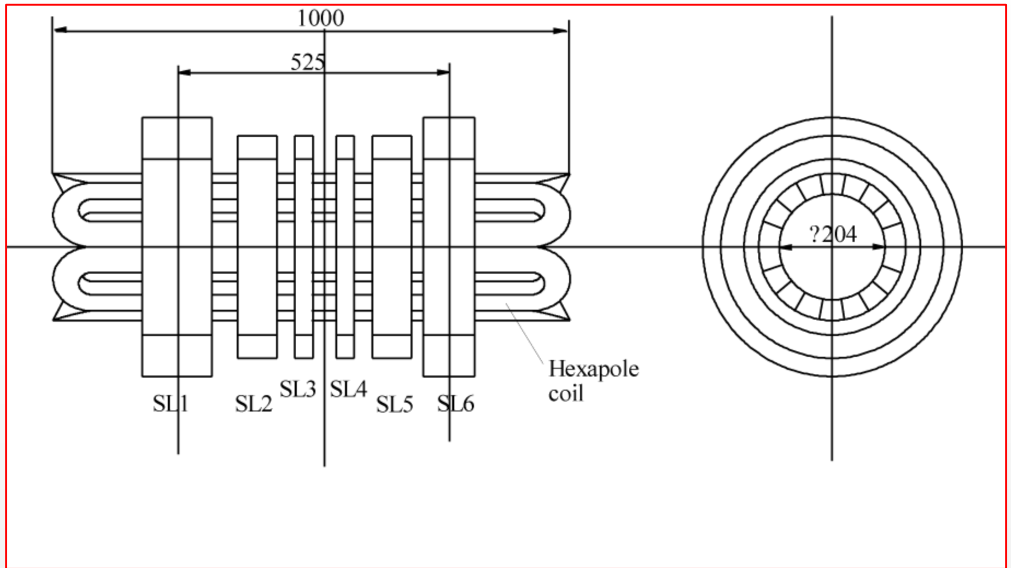
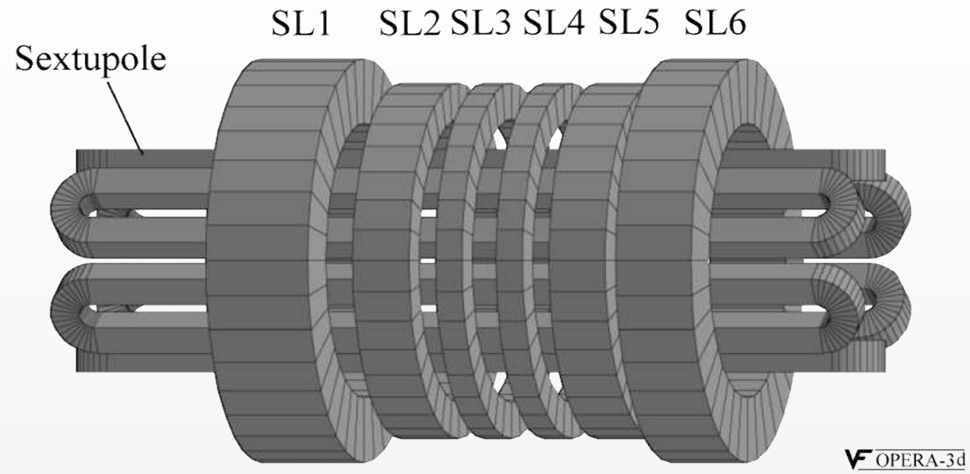
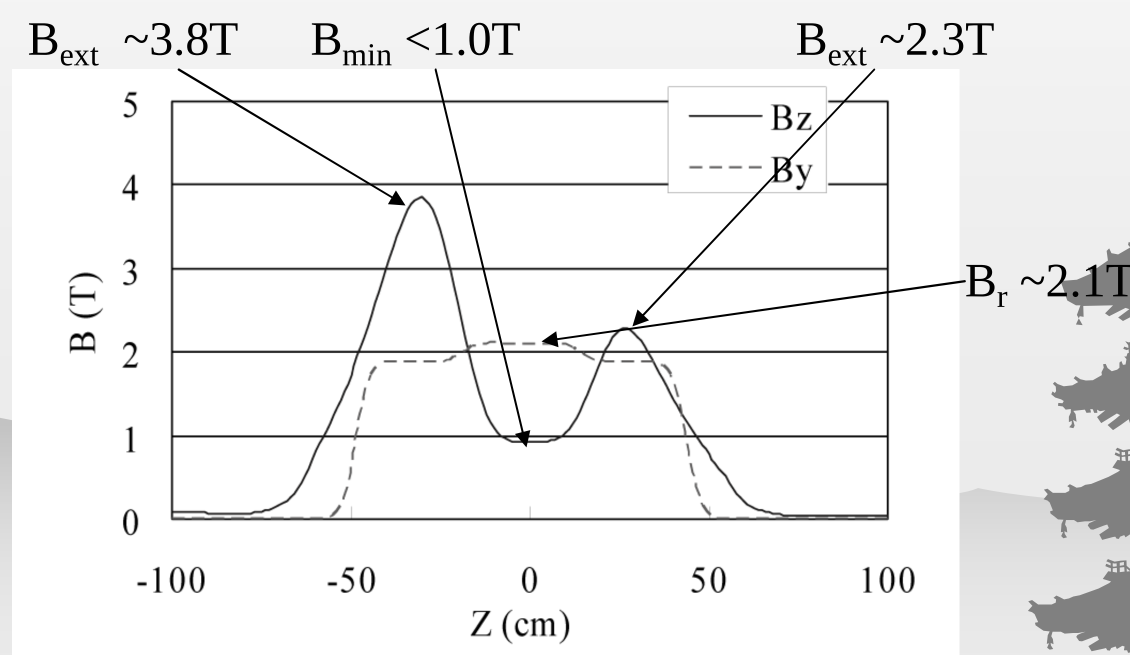


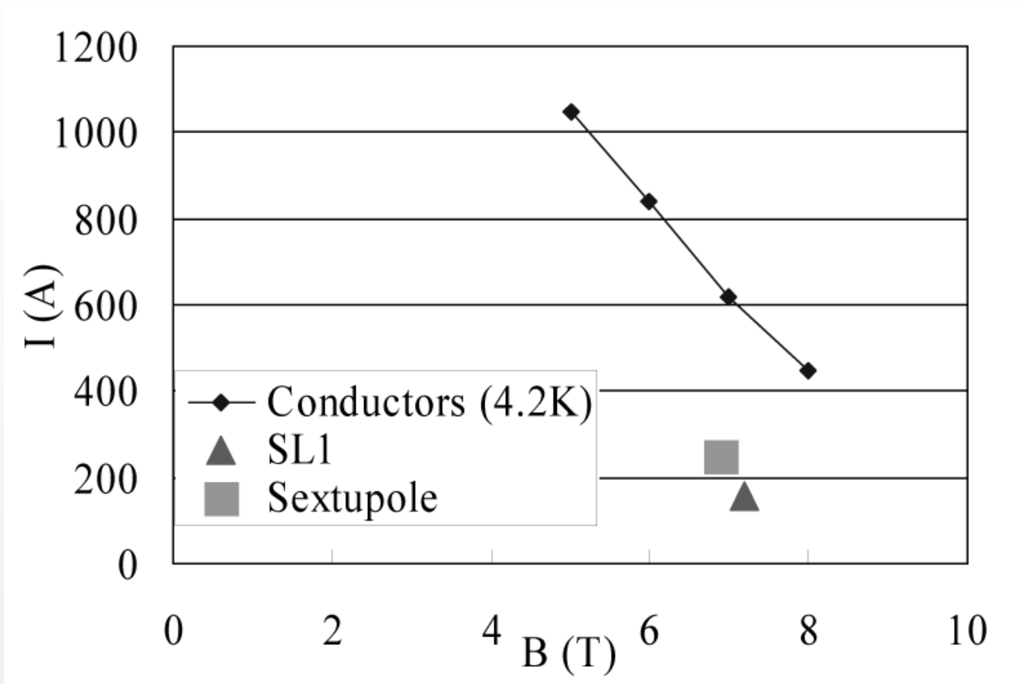
Table 1. Parameters of the supeconducting coils

	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

Magnetic field strength

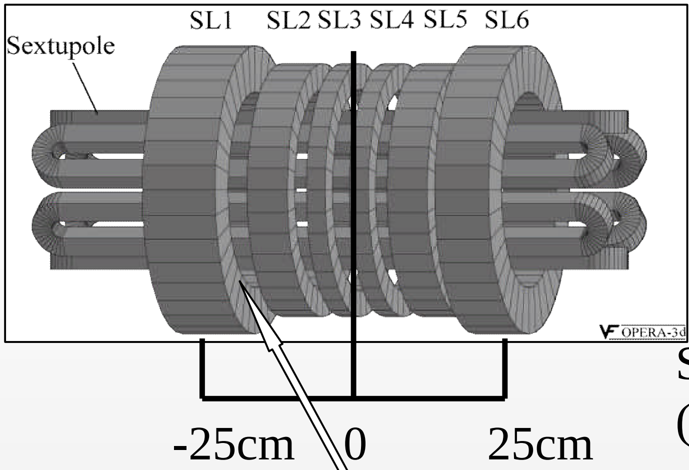




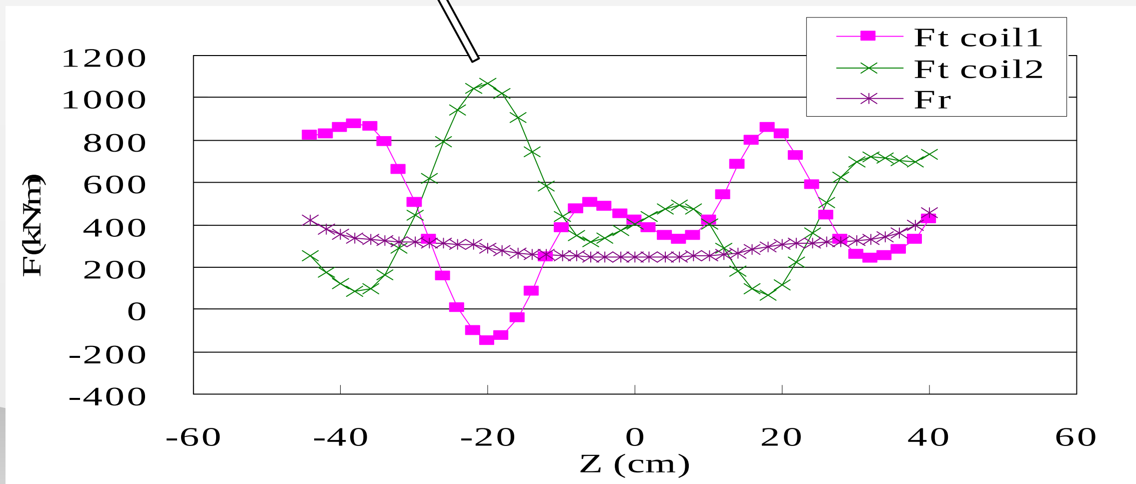


I_c performance of the conductor with a rectangular shape and the load points for the solenoid SL1 and the sextupole magnet.

Although the maximum field on the sextupole coil windings is 7.4 T, the component perpendicular to the current direction is 6.5 T.



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



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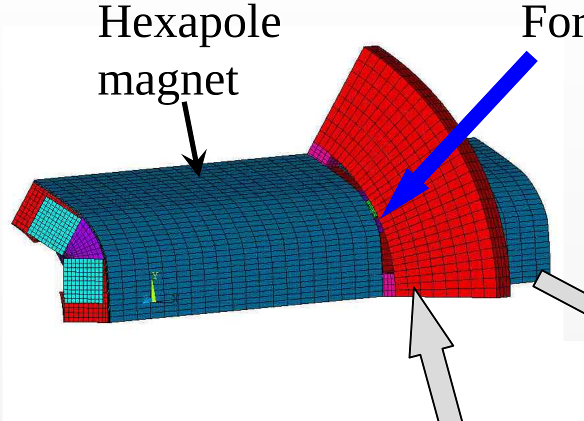
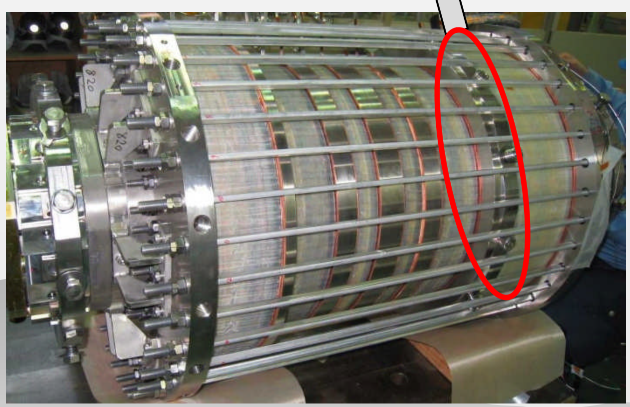
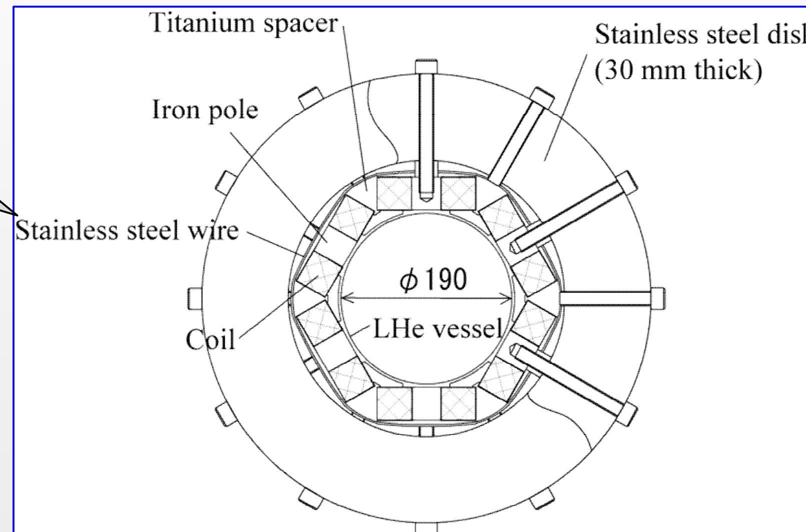
Support for hexapole magnet

Hexapole magnet

Force ~1100kNm max

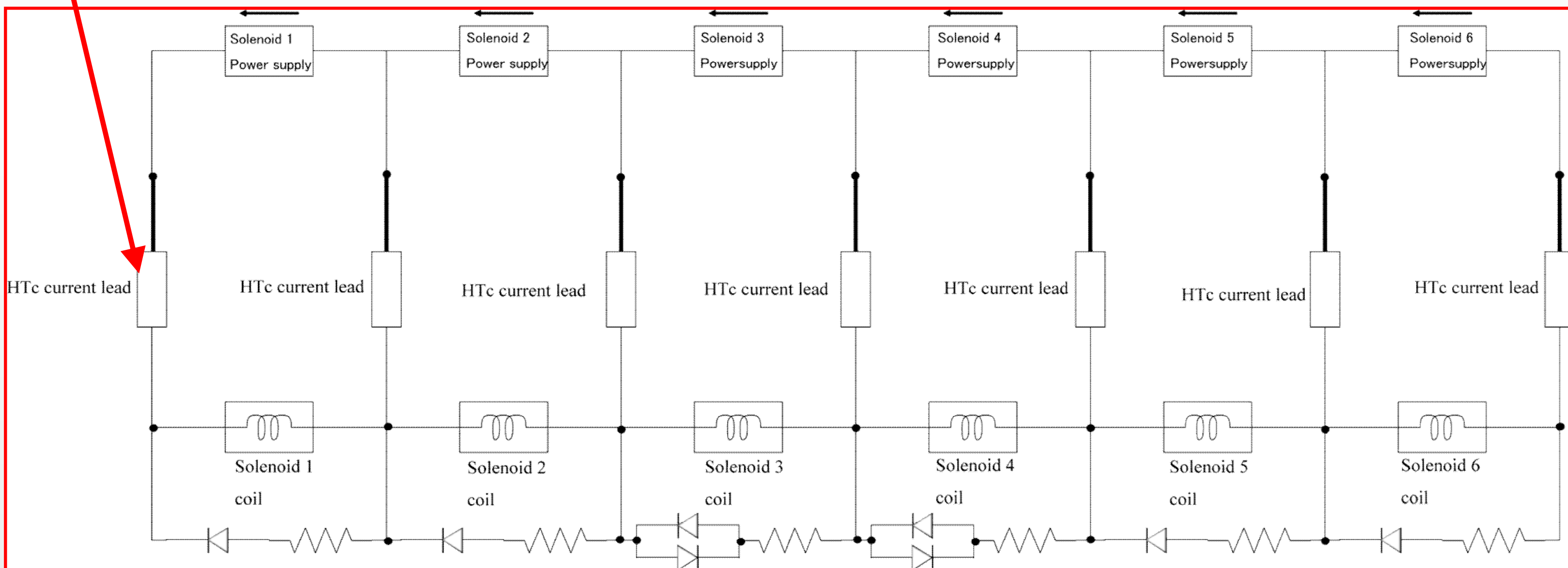






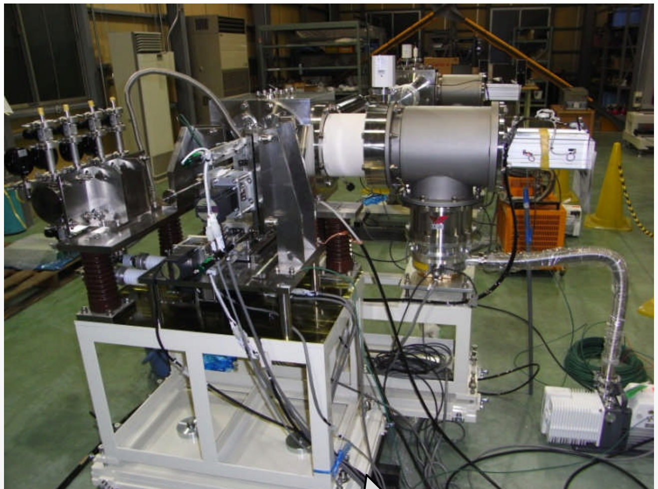
Circuit diagram for solenoid coil

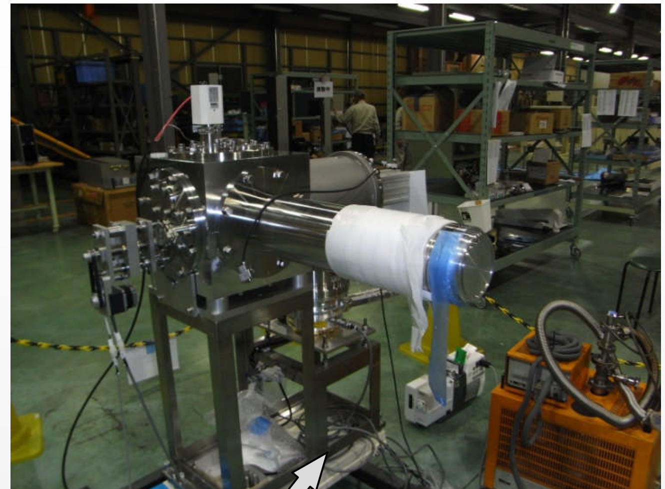
HTc current lead

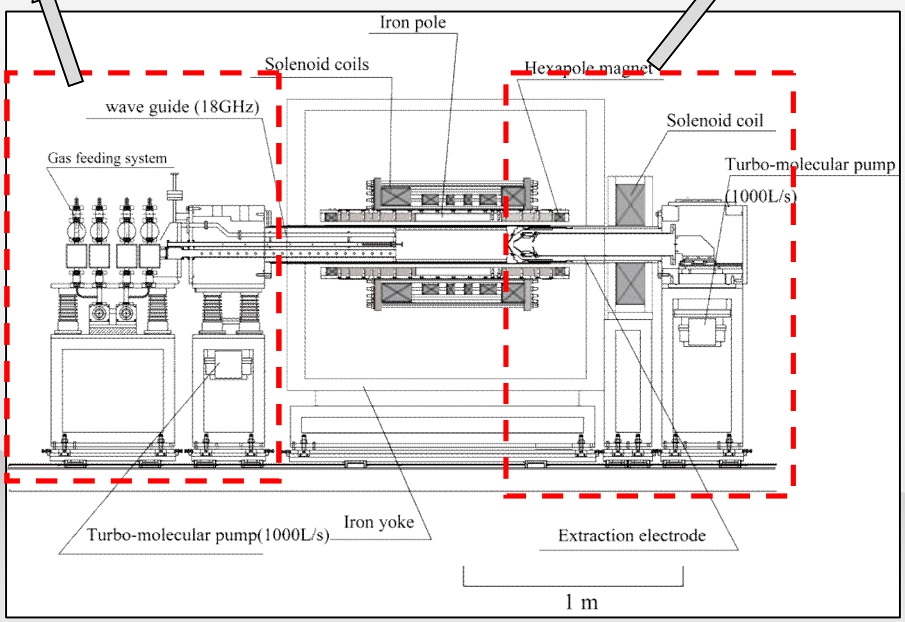


To minimize the heat inversion, 9 HTc current lead (7 for solenoid, 2for Hexapole) is used

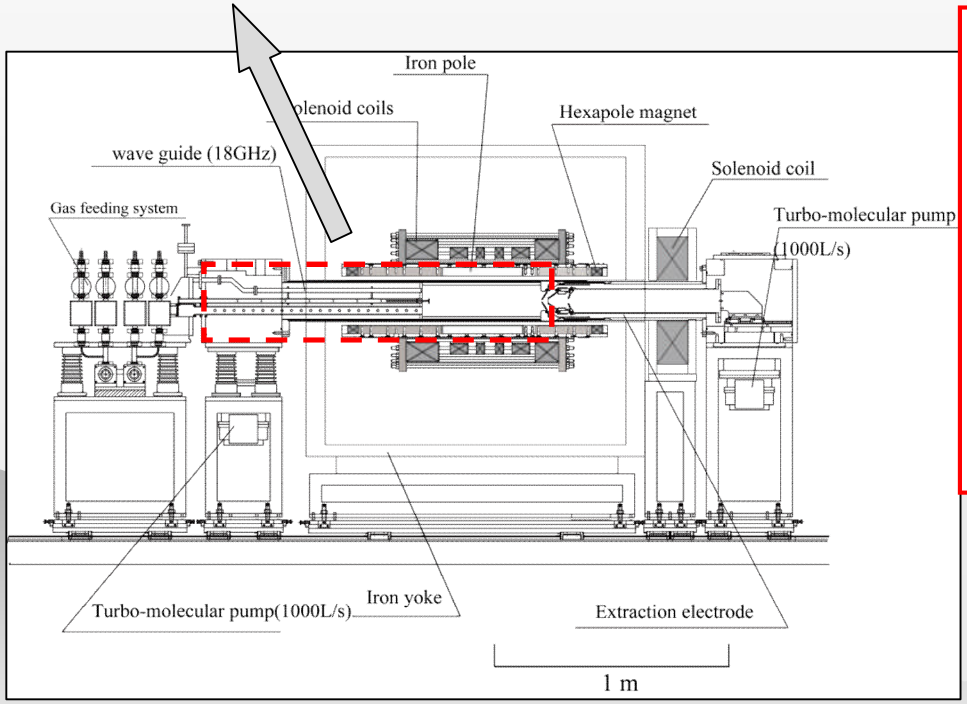
Plasma chamber, gas feeding system etc







Plasma chamber

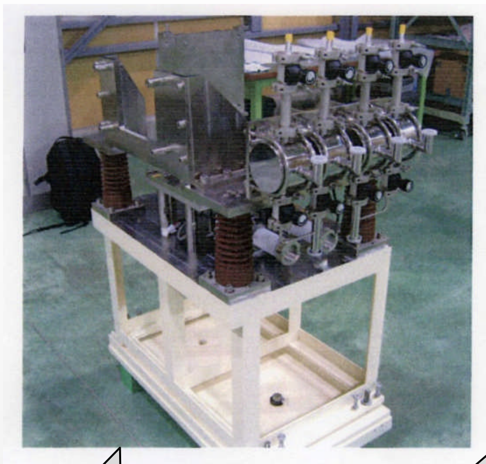


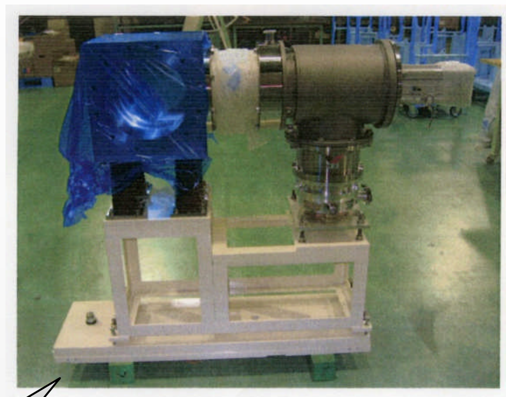
(I) Plasma chamber
- inner diameter 150mm
- outer diameter 164mm
- (double wall chamber)

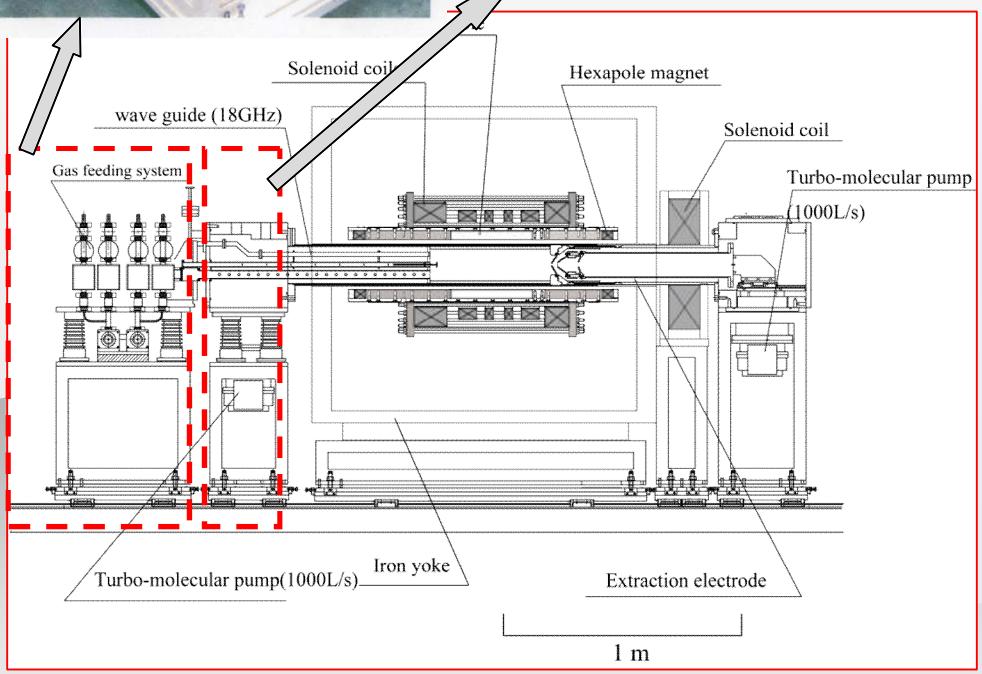
(II) Insulator Kapton sheet (~2mm)
(40kV max)

(III) X-ray shield 2mm Ta

Gas feeding system, Biased disc etc







Gas feed
  2 systems (main gas, support gas)
  gas flow rate

Biased disc 0~100 mm

High temp oven 0~100mm

Insulator 40kV max

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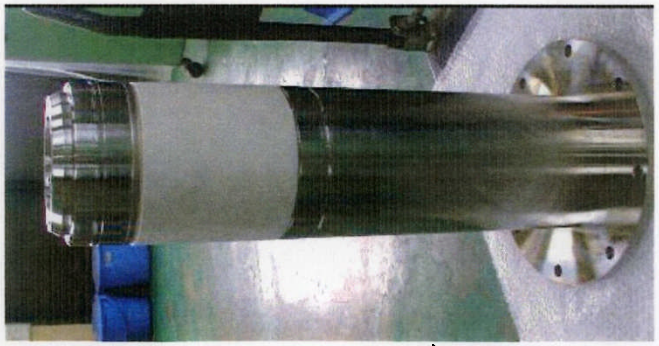
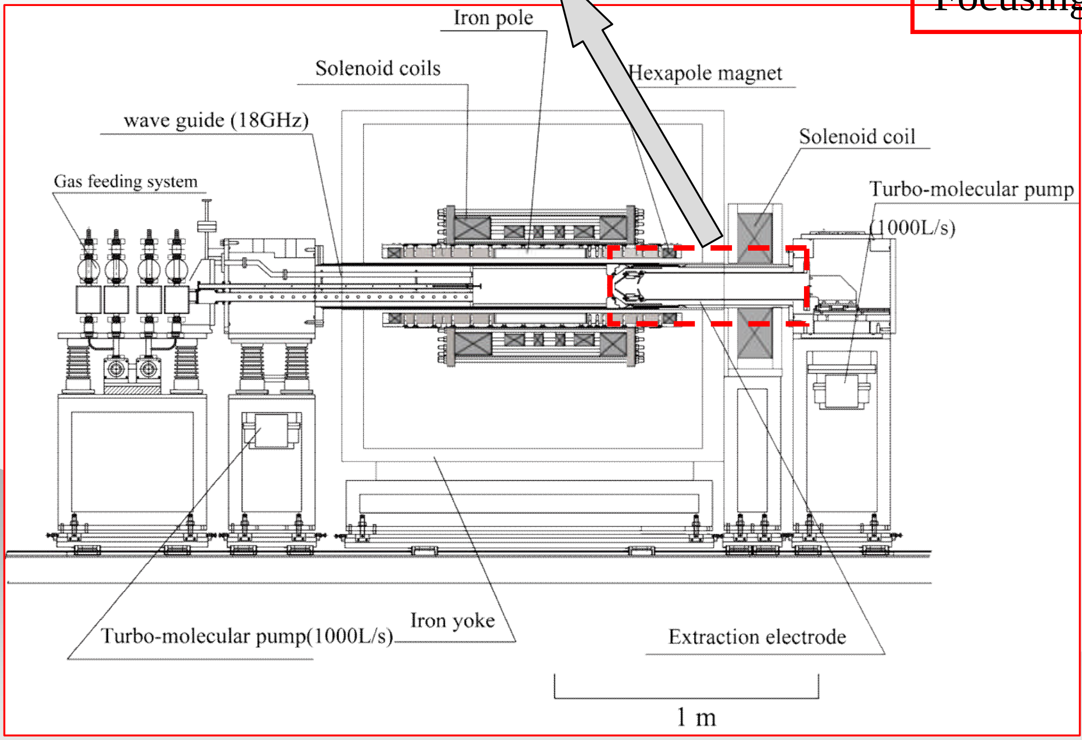
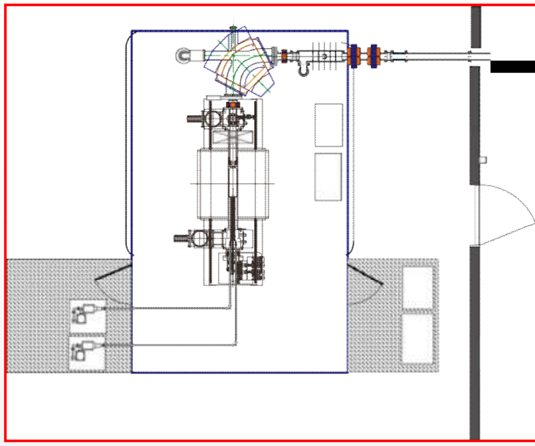
Beam extraction

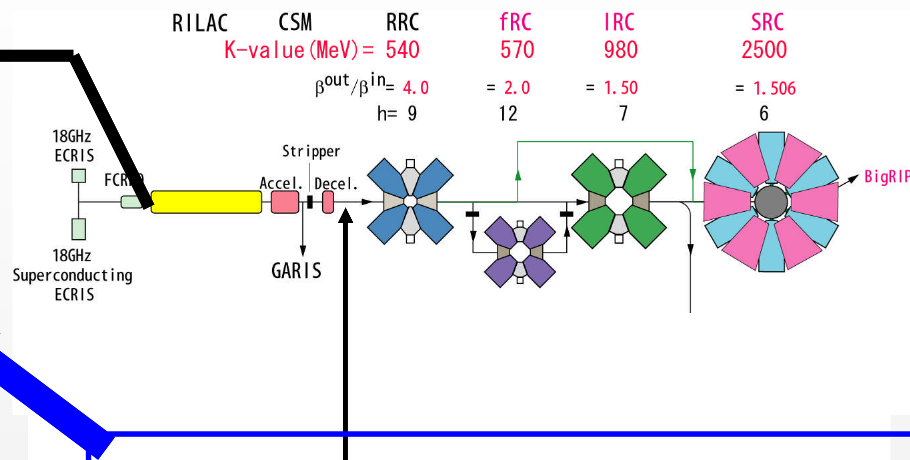


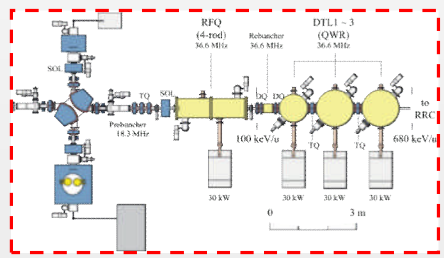
Extraction voltage	40kV max
Accel-decel system	
accel system	-30kV max
Electrode position	0~100mm (remotely controlled)
Focusing element	solenoid coil



New Injector System(II)





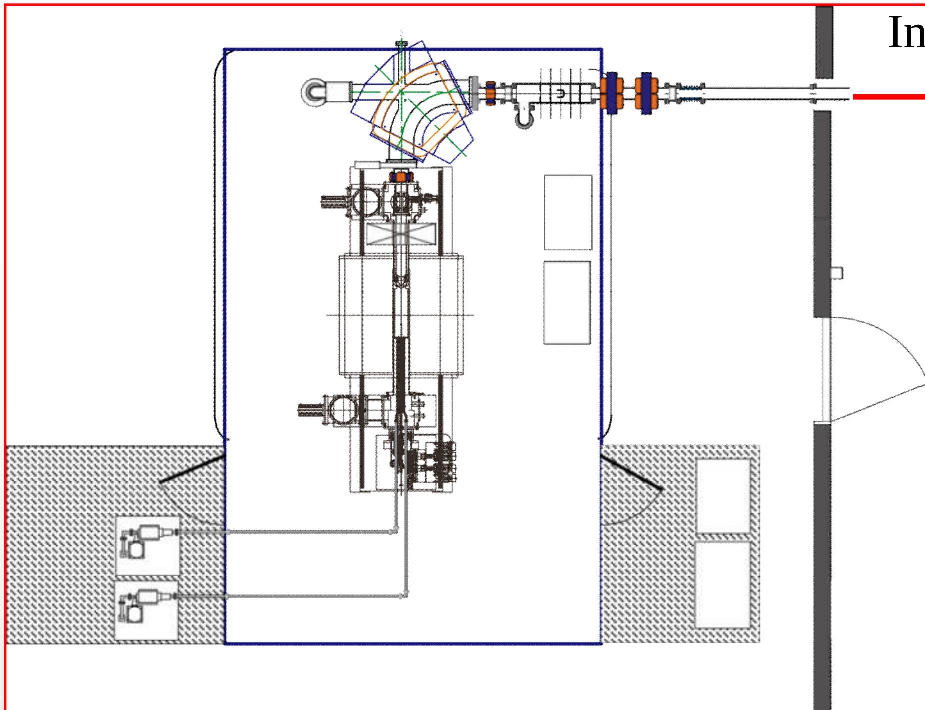


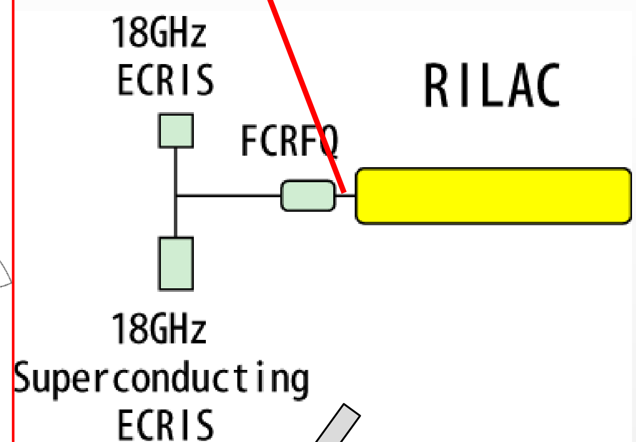
High voltage plat home
(under construction)
Beam injection
Summer 2009~

Beam intensity
several 10μA of U^{35+}
from ECRIS

Planed schedule (2009~ construction (Several years))
New Injector system
Ion source U^{35+} 15pμA

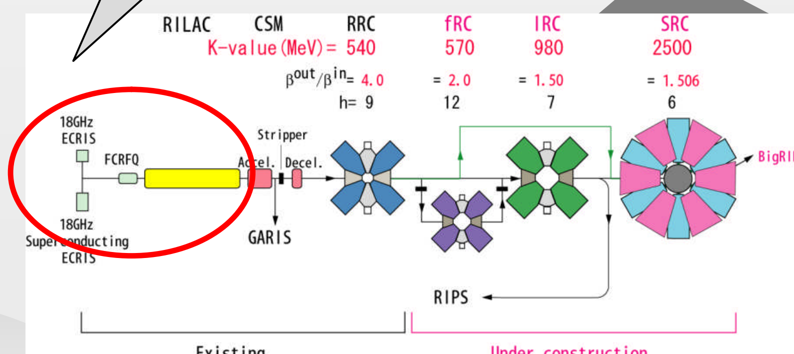
Injection energy of $^{238}U^{35+}$ ~19keV/A

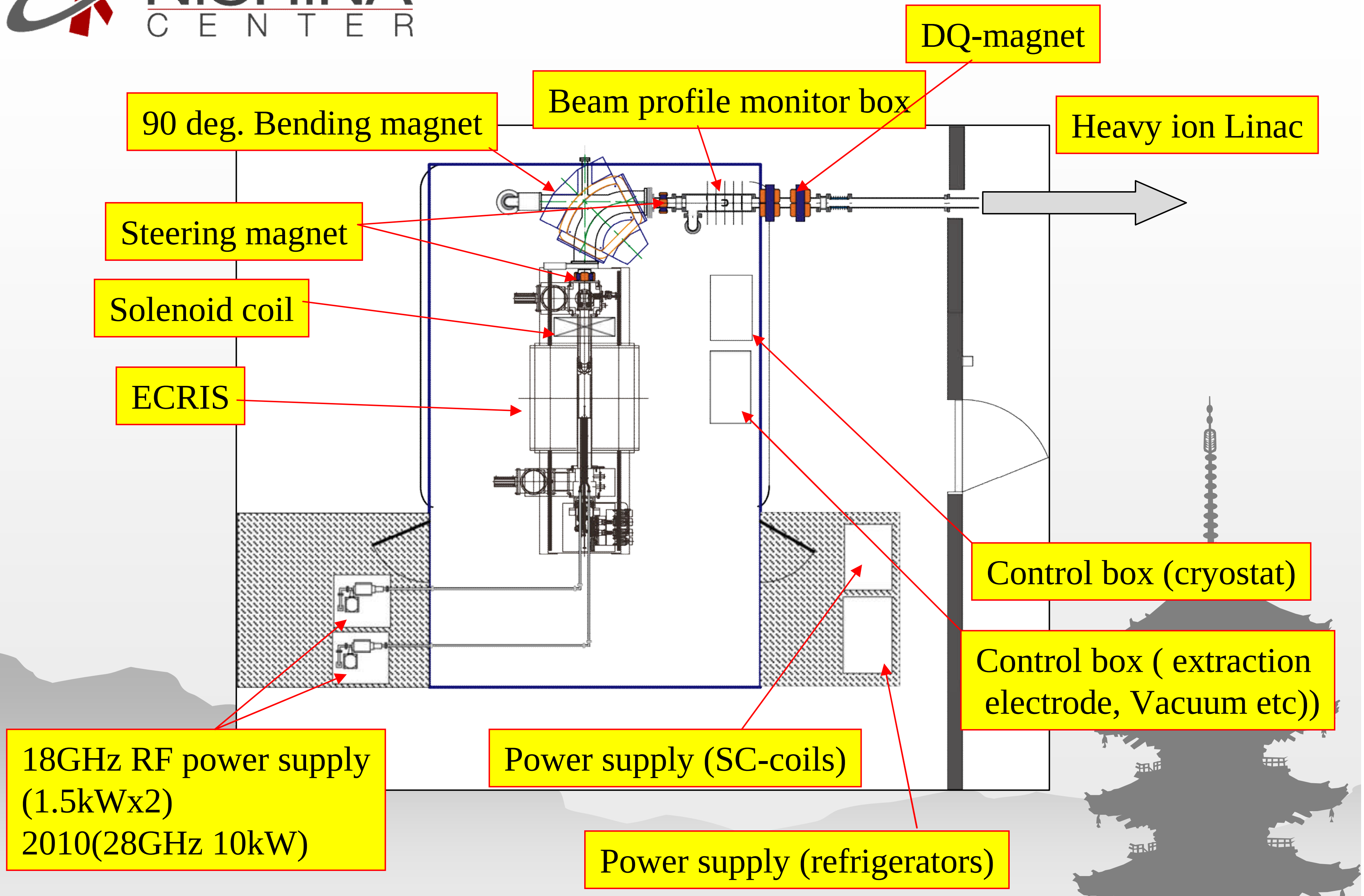




High voltage plat-home
(terminal voltage 100kV)

Extraction voltage ~30kV





DQ-magnet
Beam profile monitor box
90 deg. Bending magnet
Heavy ion Linac
Steering magnet
Solenoid coil
ECRIS
Control box (cryostat)
Control box (extraction electrode, Vacuum etc))
18GHz RF power supply
(1.5kWx2)
2010(28GHz 10kW)
Power supply (SC-coils)
Power supply (refrigerators)

EXCITATION TEST

Table 2. Coil currents (A) when the sextupole quenched.

run #	sextupole	SL1	SL2	SL5	SL6
design	272	162	182	155	132
1	189				
2	255				
3	90	136	183		
4	65	136	183		
5	73	136	183		
6	114	136	183		
7	70	136	183		
8	77	136			
9	109				132
10	220				92
11	204			155	132
12	230			132	112
13(NQ)	272				
14	258	146	164		
15	234			135	114
16	238			136	116
17	235	127	143		
18	256	137	154		

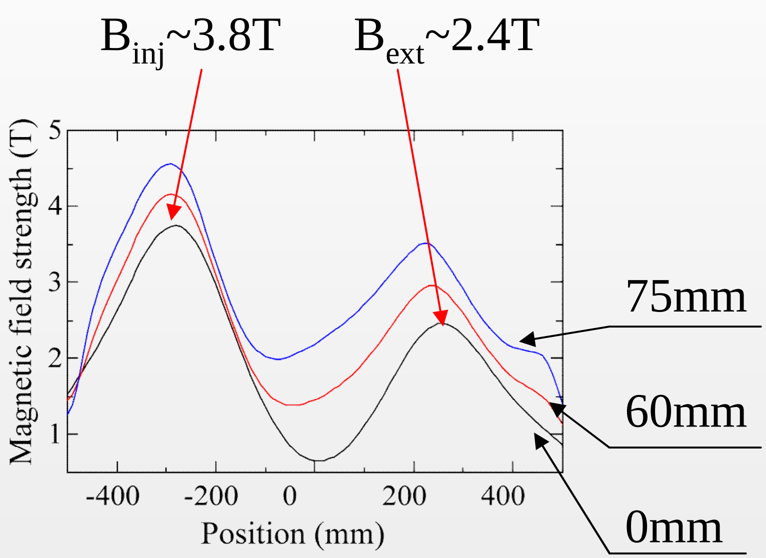
2 quenches

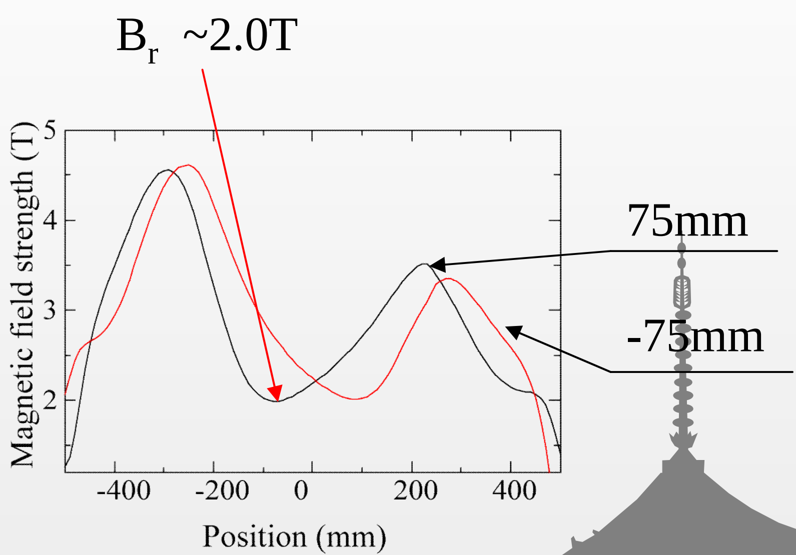
100% of designed value

85~90% of designed value

For 28GHz   Conventional magnetic field configuration

Estimated magnetic field configuration (85% of designed value)

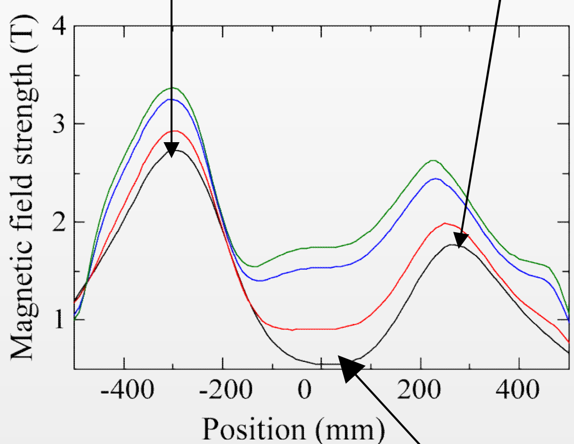




For 18GHz Flat B_{min} field

Estimated magnetic field configuration (85% of designed value)

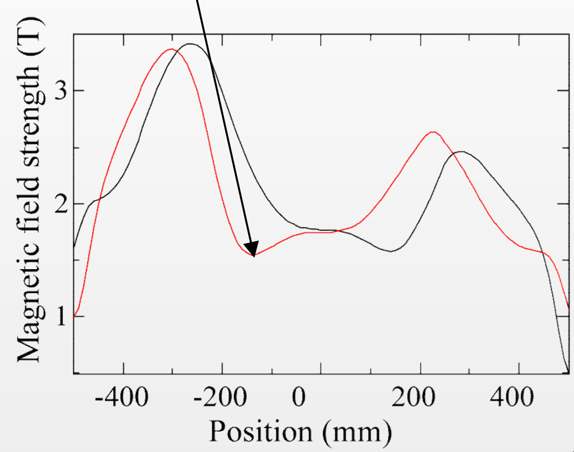
B_{inj}~2.7T B_{ext}~1.6T



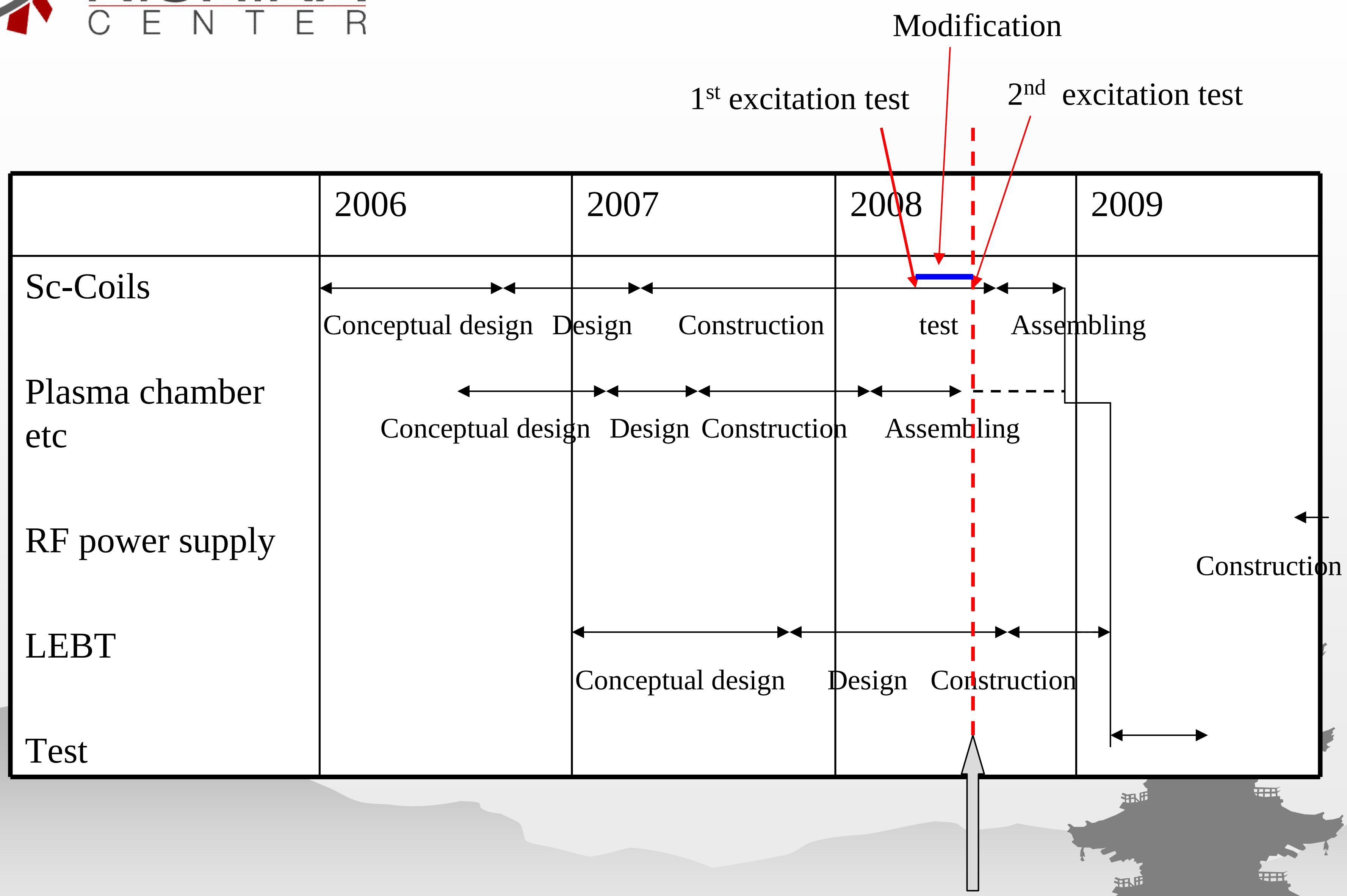
75mm
70mm
30mm
0mm

Flat field

B_r ~1.5T



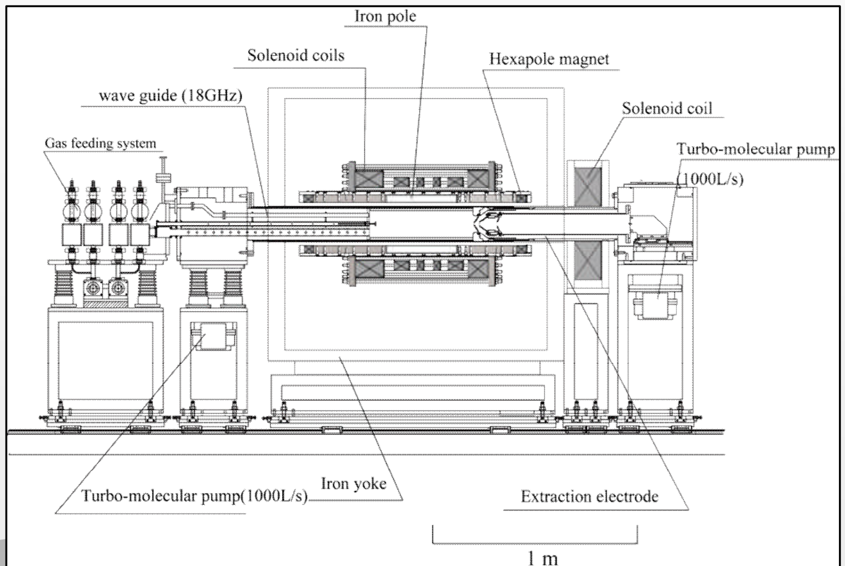
Planed schedule

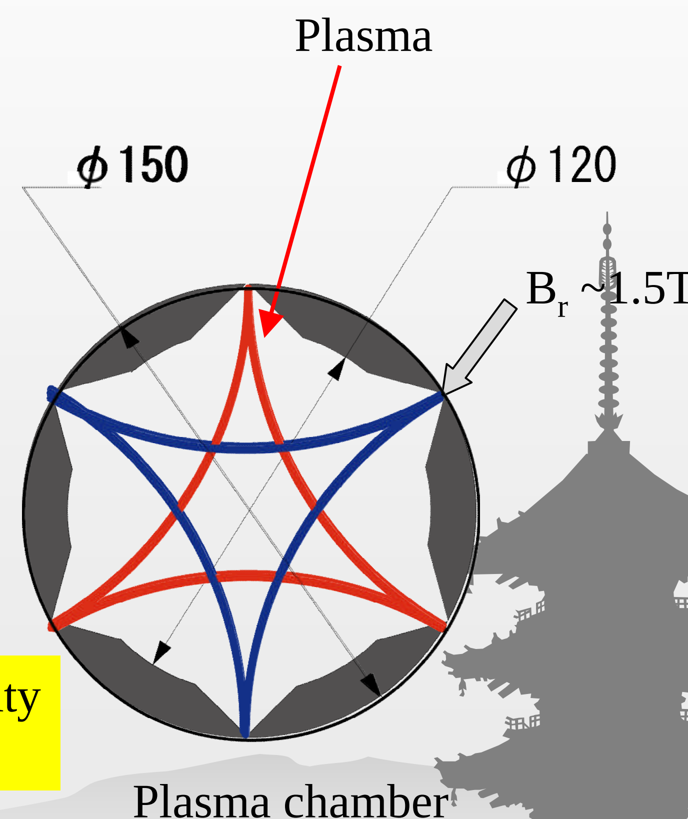


First plasma(2009 spring)   18GHz RF (3kW max)

Required beam form SC-ECRIS

several 10 μA of U^{35+}





Increase the power density of microwave