The Installation of the 28GHz Superconducting ECR Ion Source At KBSI

Mi-Sook Won

on behalf of the ECR IS development team,

Busan Center, Korea Basic Science Institute

I Overview of KBSI Accelerator

II A goal of KBSI Accelerator

III Current status of ECR ion source

- 3.1 Plasma chamber and extraction system
- 3.2 28 GHz Microwave system
- 3.3 Superconducting magnet system
- 3.4 Remote control program

IV First plasma ignition

V Future plan

I. Overview of KBSI Accelerator

KBSI

Motivation

- Fast neutron radiography facility
- Achievement: High-yield neutron flux
- Implementation: Inverse kinematics
- Requirements: high beam current + windowless hydrogen target
- Pros.: compact size

28 GHz ECR IS

- 3solenoids+1 Hexapole SC magnet
- LHe re-condensing cryostat
- 28 GHz-10 kW gyrotron
- Large bore plasma chamber
- Output beam: 12 keV/u

Beam intensity: Li^{3+} higher than 1mA

LEBT System

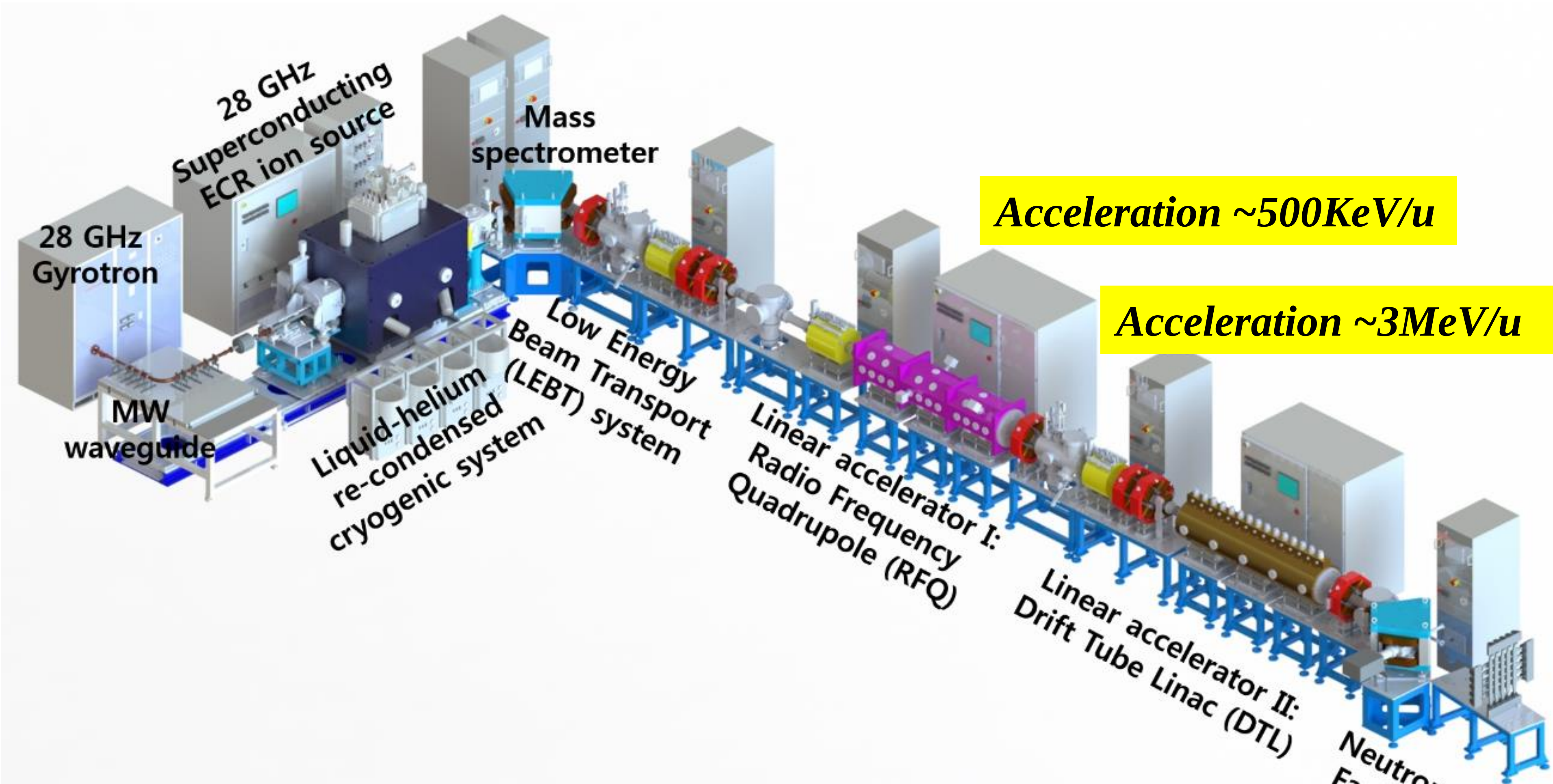
- to separate the ions from IS
- to satisfy the RFQ input condition: beam acceptance, current, size and etc.
- 1dipole+3solenoids+2quadrupoles
- 2 diagnostic chambers

Linear Accelerator

- Reference particle: Li^{3+}
- Freq.=165 MHz
- Output beam :
  ~ 500 keV/u@RFQ
  ~ 3 MeV/u@DTL

I. Overview of KBSI Accelerator

($Li^{2\sim3+}$ production >1pmA)



Acceleration ~500KeV/u

Acceleration ~3MeV/u

$p(^7Li, n)^7Be$ Inverse kinematics

Neutron production

II. A goal of KBSI accelerator: Neutron facility

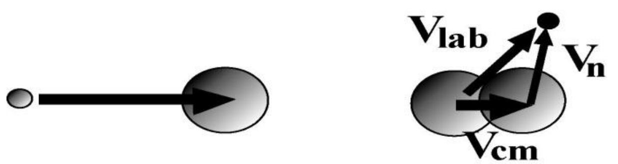
Concept of fast neutron production

$^{3}H(d,n)^{4}He$

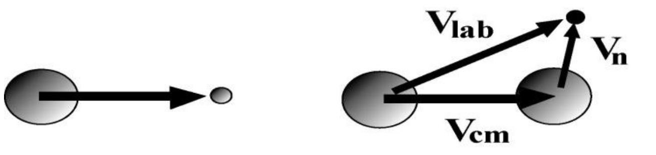
$^{2}H(d,n)^{3}He$

$^{7}Li(p,n)^{7}Be$

$\boxed{p(^{7}Li,n)^{7}Be}$



Normal kinematics: the produced neutron will be go to all direction.



Inverse kinematics: the produced neutron will be go forward.
Production angle is limited about 30 degree compared to forward direction.
High intensity neutron beam.

Concept of the heavy ion linear accele rator based neutron production.

II. A goal of KBSI accelerator: Neutron facility

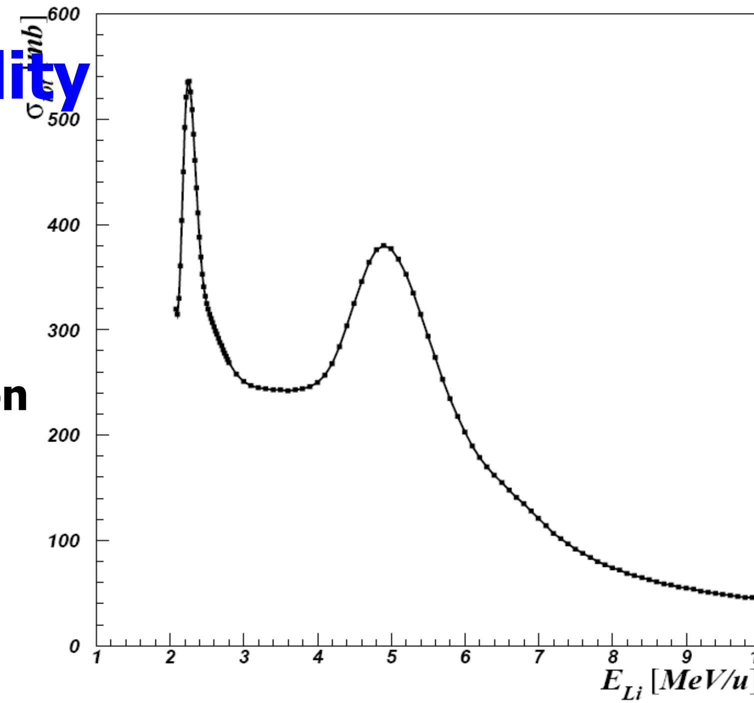
Requirement of KBSI Neutron Facility

→ Beam intensity: $Li^{2\sim3+}$ higher than 2pmA

→ Beam energy : ~2 MeV/u

→ Gas target : >350 Torr

→ Neutron detection : High efficiency for fast neutron



Fast Neutron Yield

$$\boxed{Y_n = F_{Li} \times \rho \frac{N_A}{A} \times L \times \sigma}$$

Y : Neutron yield

F_{Li} : Beam flux

ρ : Density

N_A : Avogadro constant

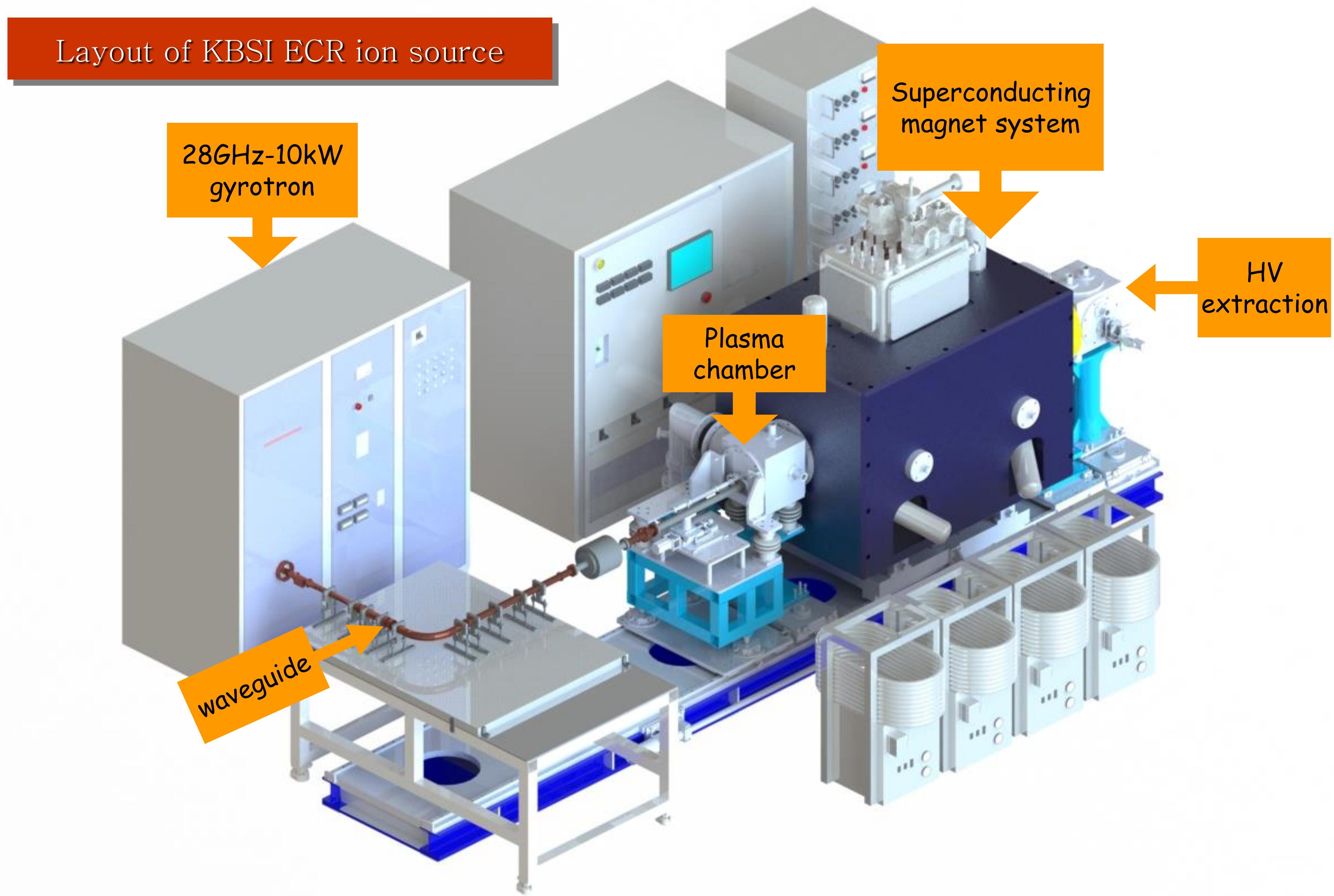
A : Atomic number

L : Target length

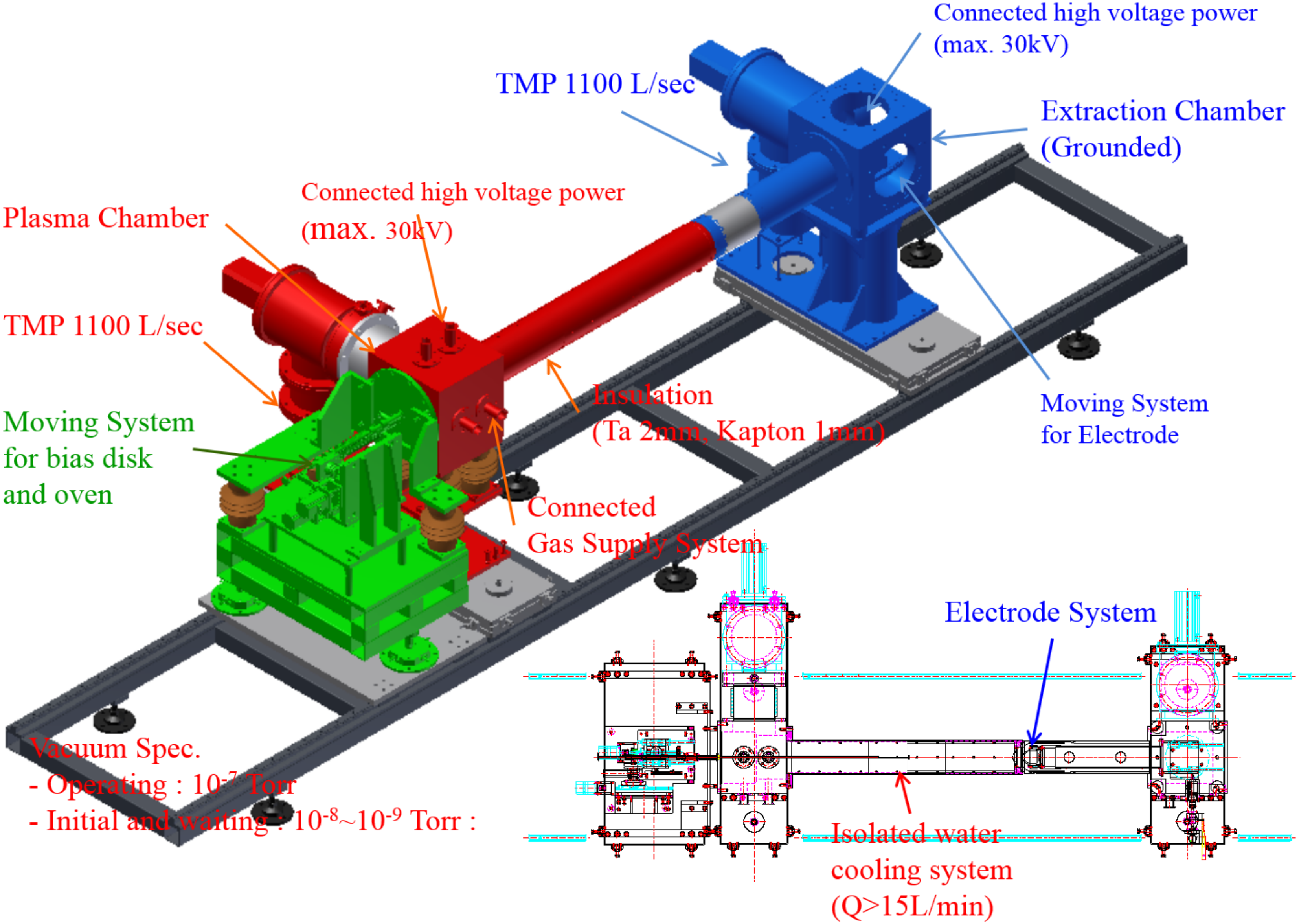
σ : Cross section

Li energy (MeV/u)	Neutron yield	Limit angle (deg)	Maximum neutron energy (MeV)
1.88	$8.5\text{x}10^{8}$	~few deg.	1.88
1.9	$1.7\text{x}10^{10}$	4	2.1
1.92	$3.6\text{x}10^{10}$	7	2.3
2.5	$1.0\text{x}10^{12}$	28	4.0

III. The current status of KBSI ECRIS



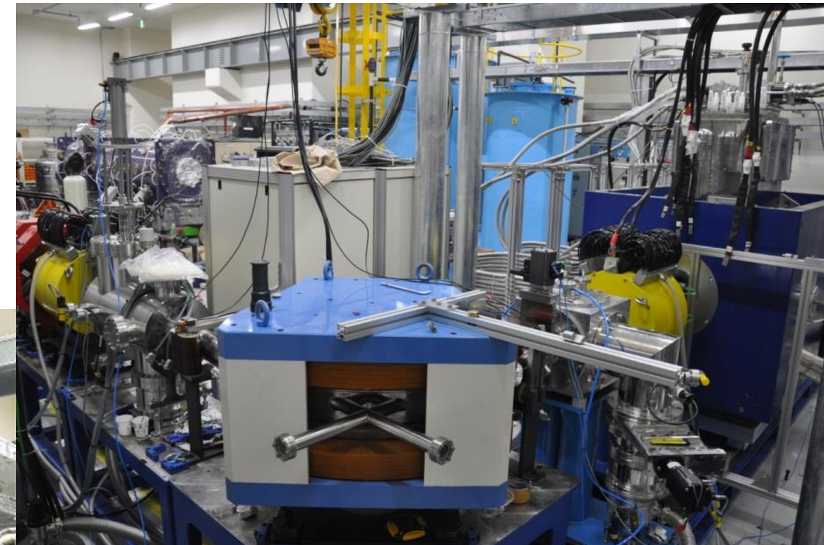
3.1 Plasma Chamber & Extraction System



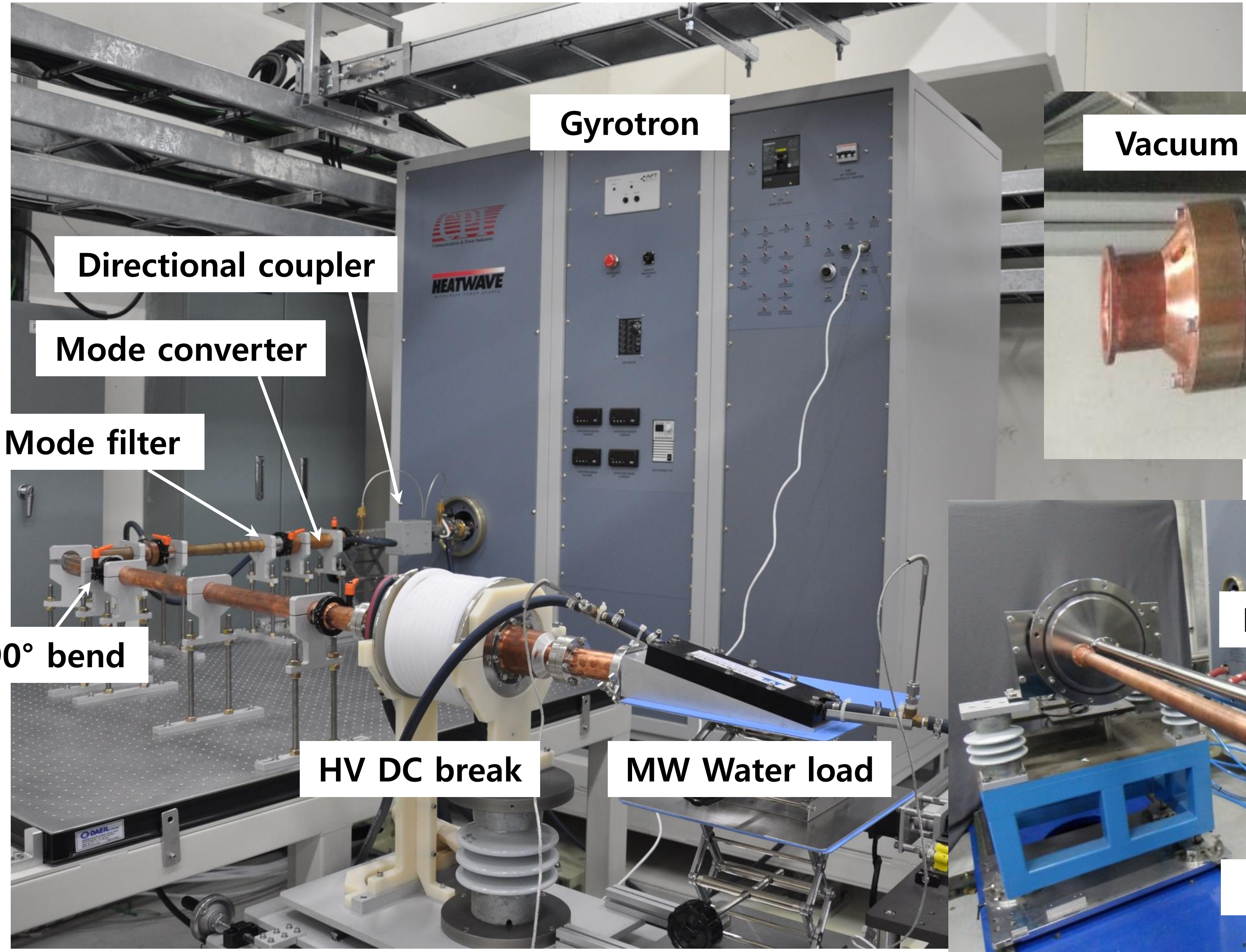
Vacuum Spec.

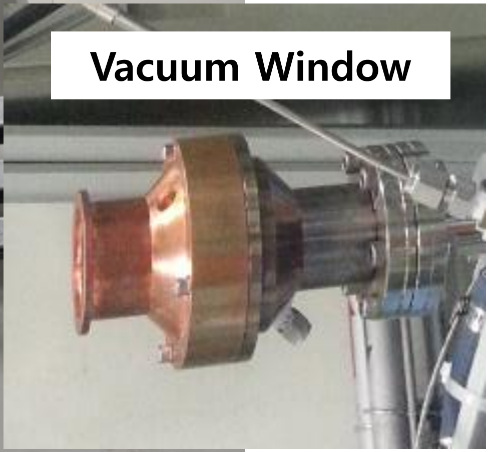
- Operating : 10^{-7} Torr
- Initial and waiting : 10^{-8}~10^{-9} Torr :

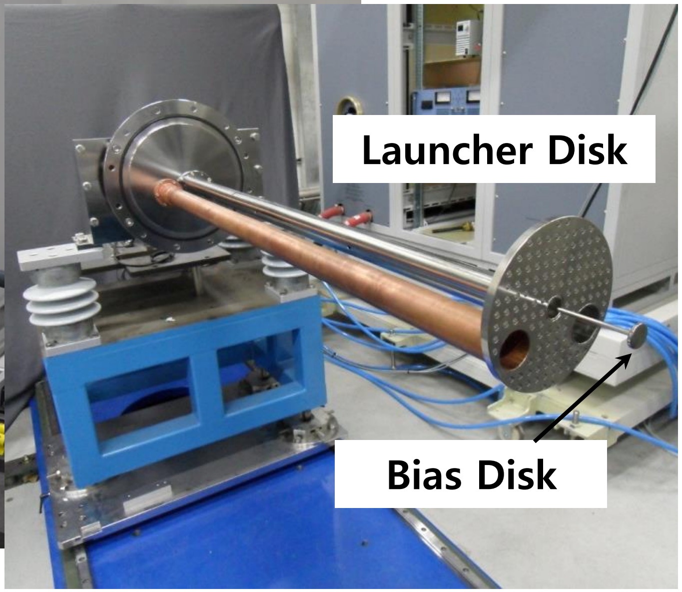
3.1 Plasma Chamber & Extraction System



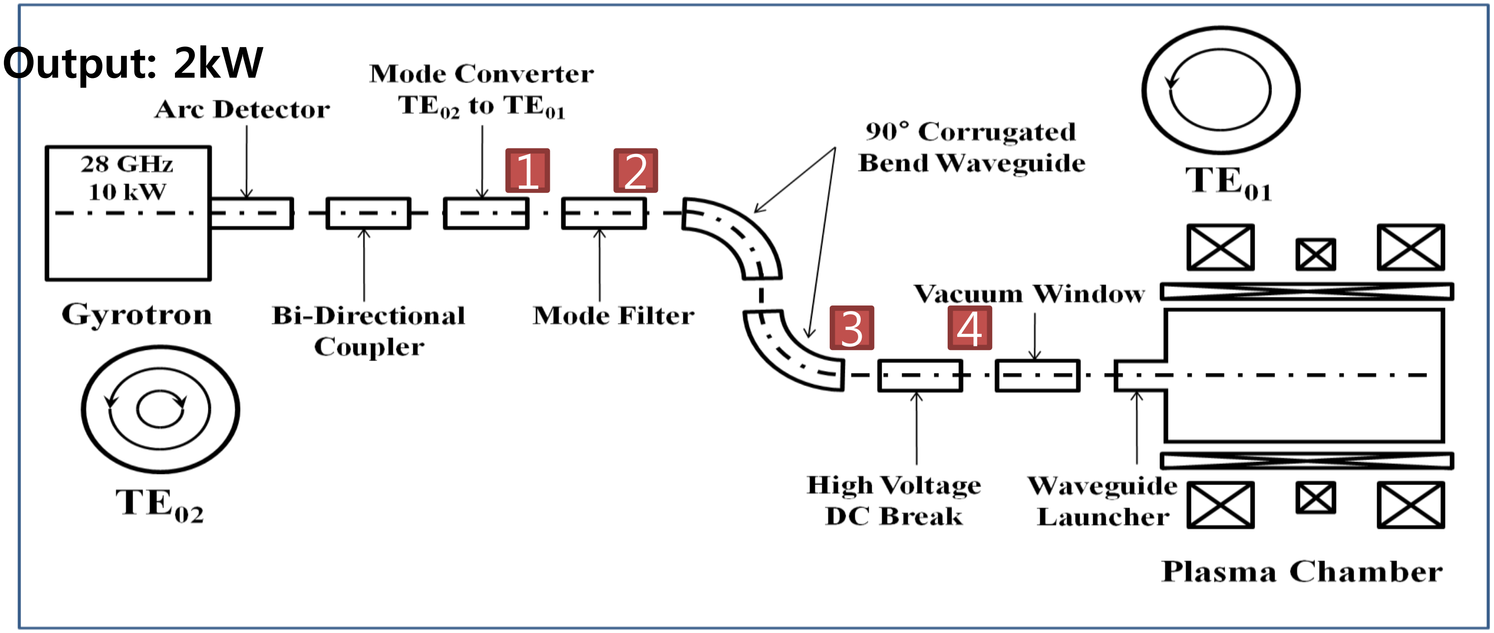
3.2 28 GHz microwave system







3.2 28 GHz microwave system:
MW transmission test at end of each component

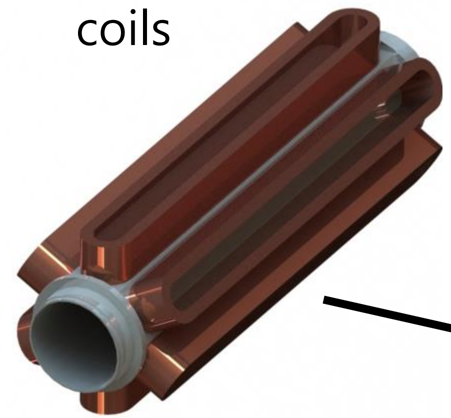


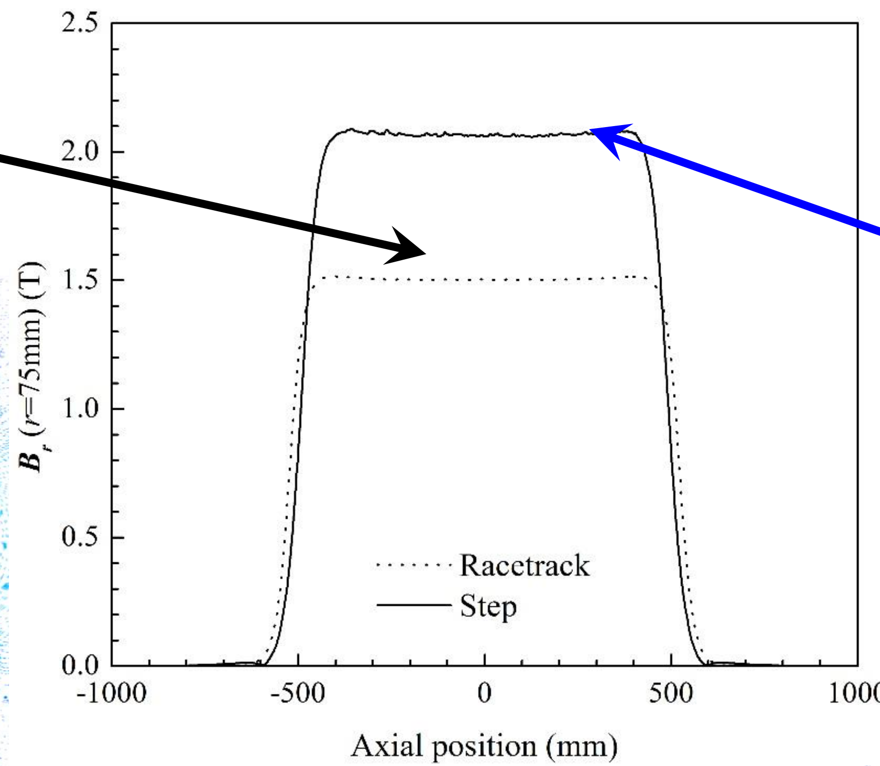
Location	Components	Transmitted power (kW)
Test condition: Gyrotron output = 28 GHz, 2 kW		
Default	Directional coupler	1.9
1	Default+mode converter	1.891
2	1+mode filter	1.886
3	2+ 90° bend	1.886
4	3+dc break	1.877

3.3 Superconducting magnet system: Design results

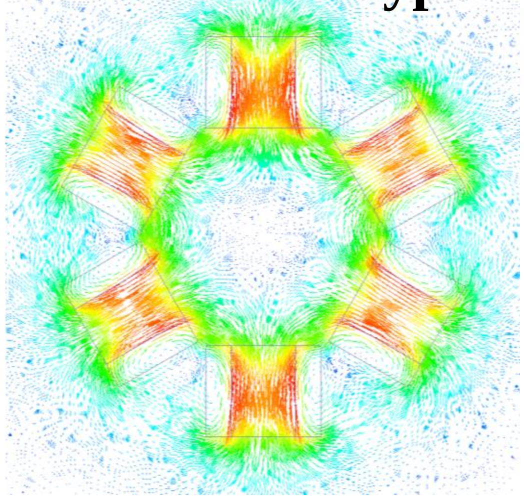
Two candidates considering domestic vendor technology

- Saddle type is the best but it difficult to make a winding by domestic supplier
- We've invented the **step-type hexapole** modified from racetrack and saddle coils

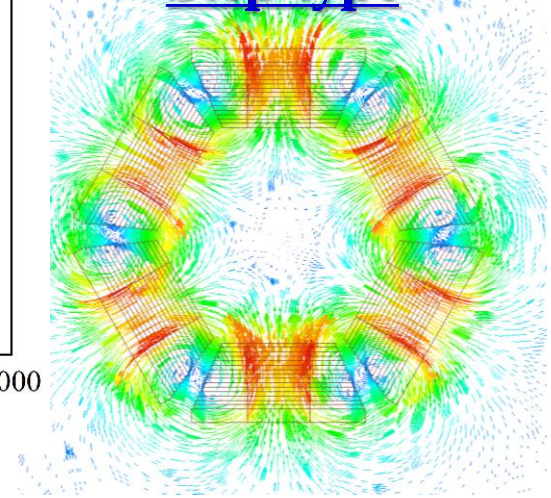




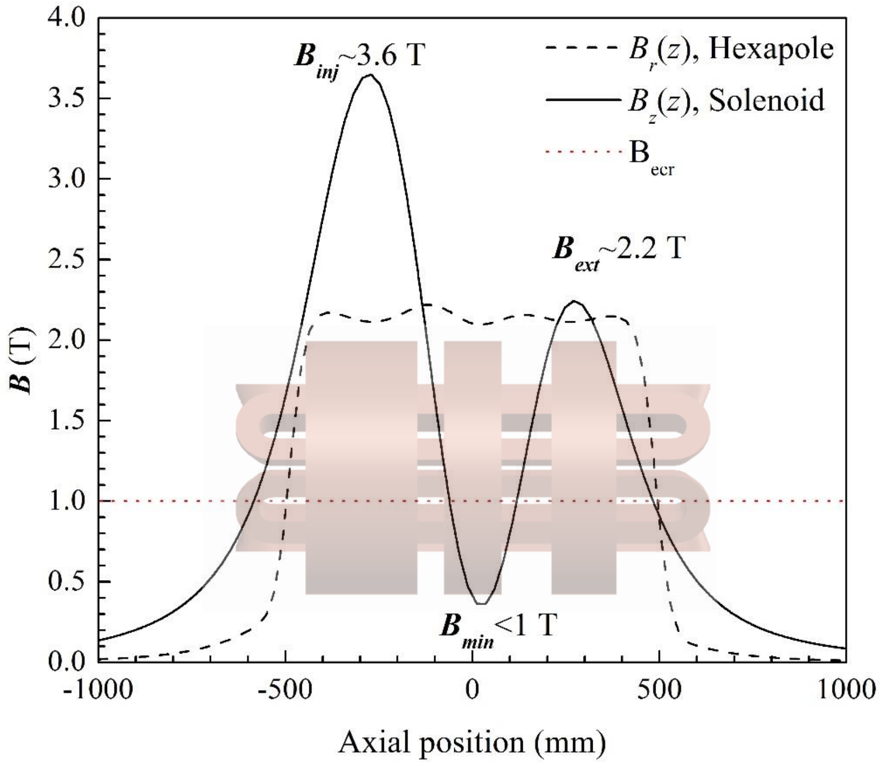
Racetrack type



Step type



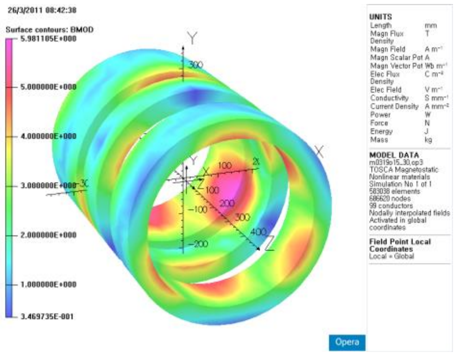
3.3 Superconducting magnet system: Design results

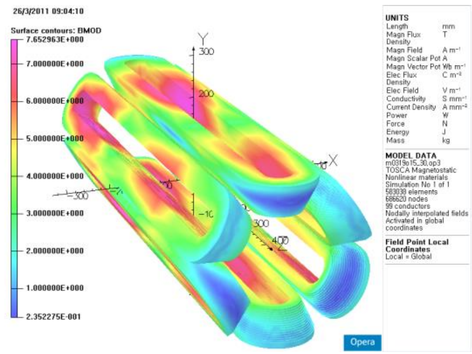


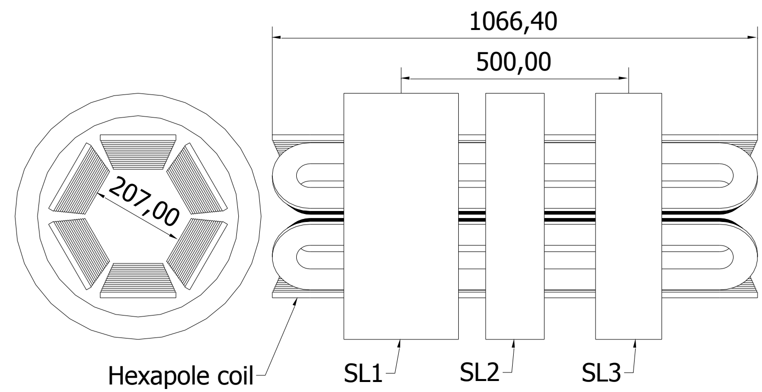
3 Solenoid + 1 hexapole magnet (6 step-type coils)

- The axial field: ~3.6 T at injection, ~2.2 T at extraction.
- The minimum axial field (variable): 0.4 ~ 0.8 T.
- The radial design field on the plasma chamber wall: 2.1 T

3.3 Superconducting magnet system: Design results

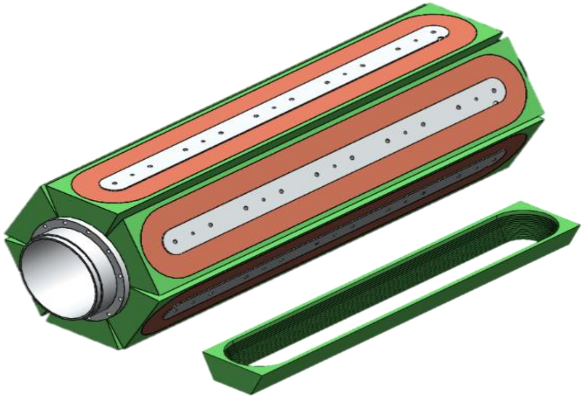




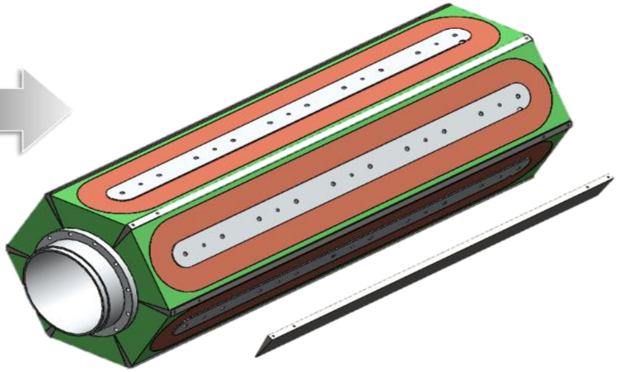


	SL1	SL2	SL3	Hexapole
Axial position of center (mm)	-250	+250	0	0
Inner diameter (mm)	442	442	442	207
Outer diameter (mm)	540.8	540.8	540.8	394.96
Depth (mm)	49.4	49.4	49.4	75.6
Width (mm)	252	128.8	145.6	53.2
Hexapole length (mm)	-	-	-	1066.4
Hexapole inner radius (mm)	-	-	-	30
Conductor size (mm)	0.95 x 1.4	0.95 x 1.4	0.95 x 1.4	0.95 x 1.4
Cu/NbTi ratio	4.9	4.9	4.9	2.32
Turns/coil	9360	4784	5408	2304
Wire lengths/coil (km)	14.5	7.4	8.4	4.9
Current (A)	197	198	197	263
B_{max} (T)	5.98	5.35	4.72	7.65
Inductance (H)	39	13.5	16.5	23

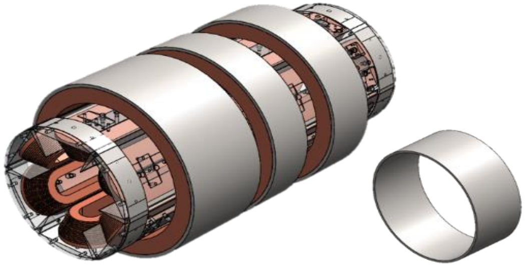
3.3 Superconducting magnet system: 4 step reinforcement for superconducting magnet



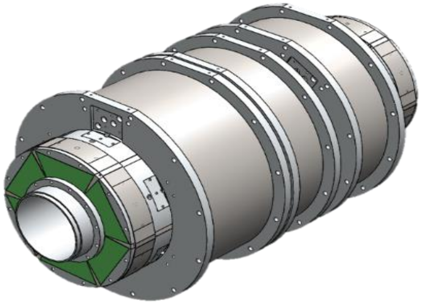
- 6 GFRP supports to guide the edge of step-type coils



- 6 Titanium wedges insertion between step-type coils in hexapole magnet



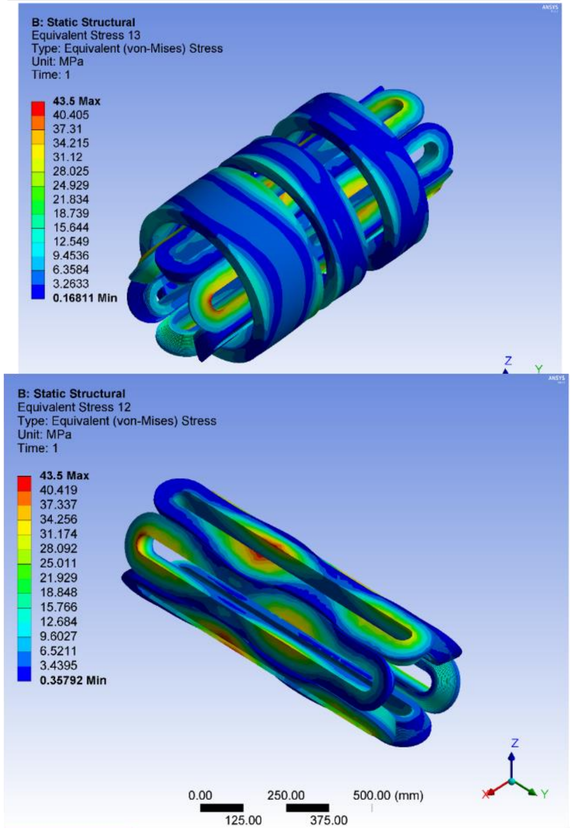
- 2 Metal (stainless-steel) clampings to squeeze the return-end section in hexapole magnet
- 3 Stainless-sttel tension wiring on the outer-most layers of solenoid magnet



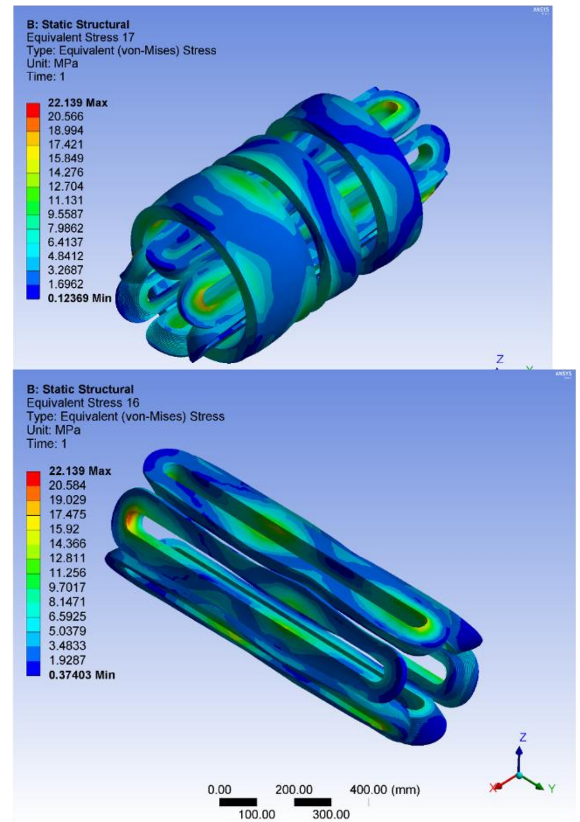
- Final assembly

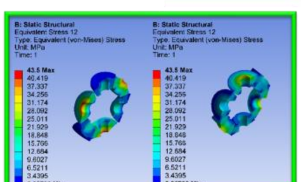
3.3 Superconducting magnet system: Structural improvement after reinforcement/support

Before reinforcement/support

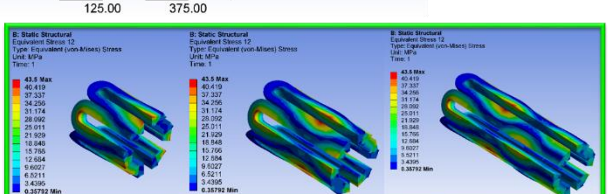


After reinforcement/support

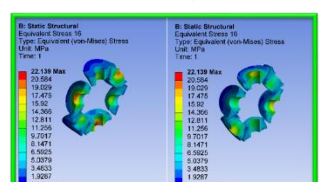




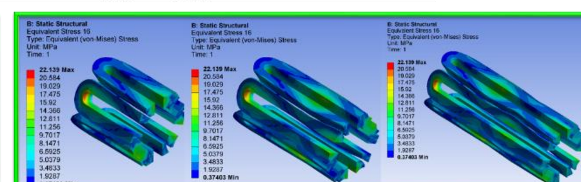
Return-end section



Straight section



Return-end section

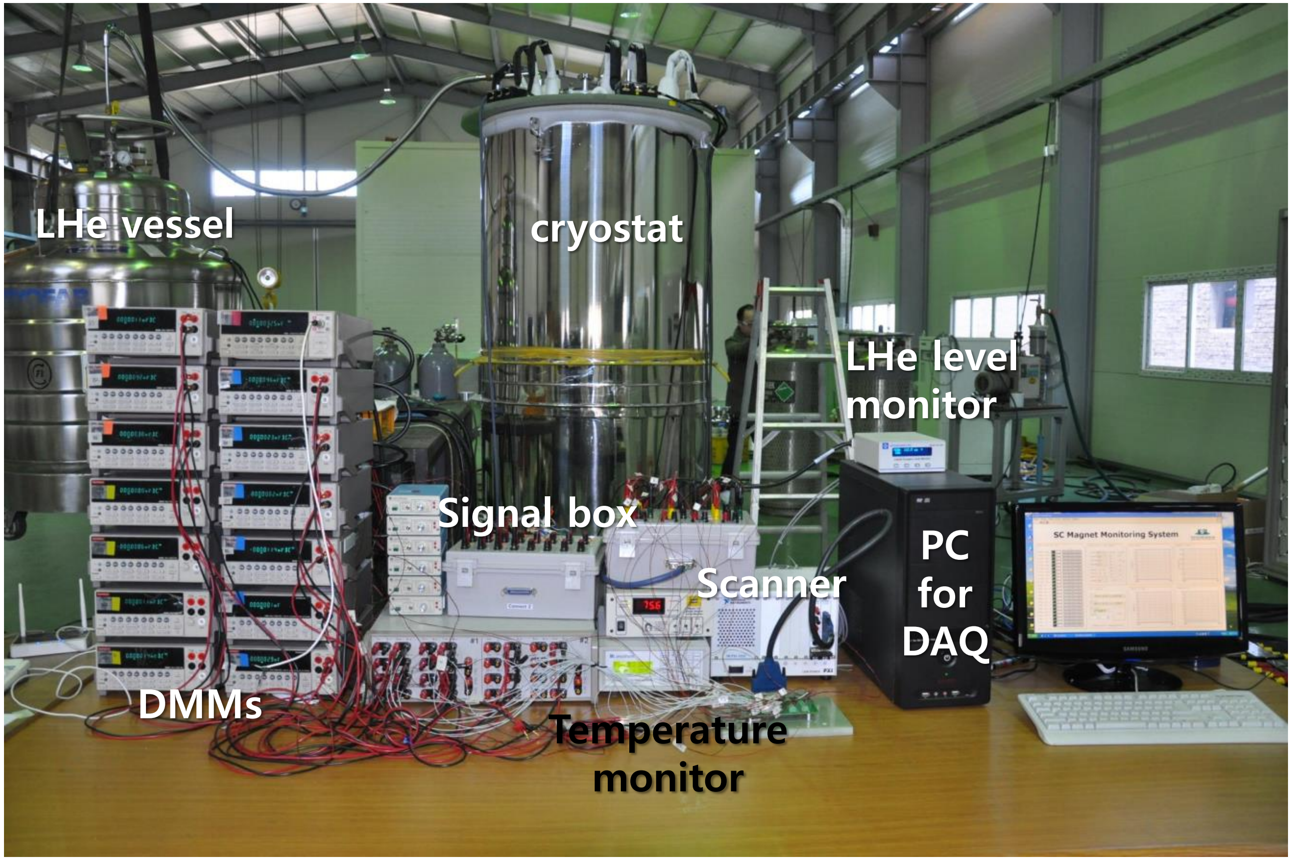


Straight section

3.3 Superconducting magnet system: Initial performance test of superconducting magnet

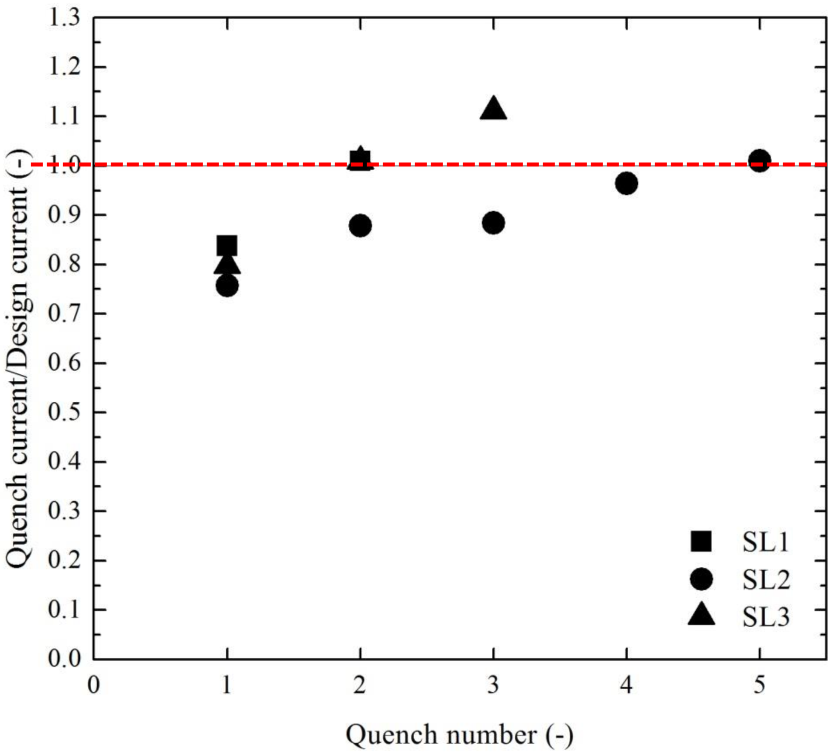
Magnet test at open-type cryostat

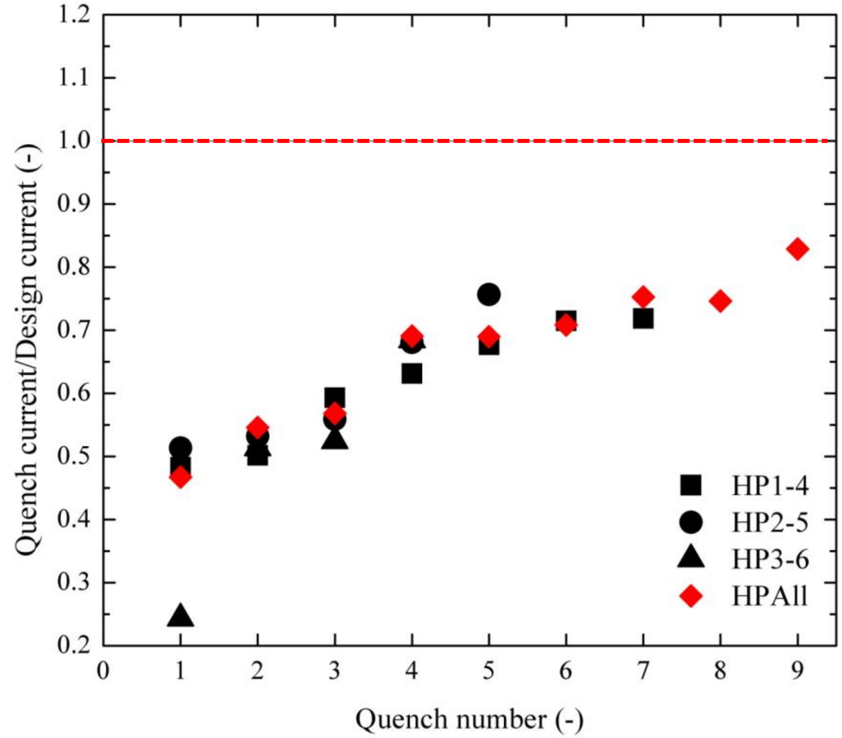
- Separate coil performance was checked before final assembly
- Vertical cryostat(open type) was prepared for convenient test
- Magnet status, temperature, magnetic field were observed



3.3 Superconducting magnet system:
Separate performance of superconducting magnet

The separate coil performance



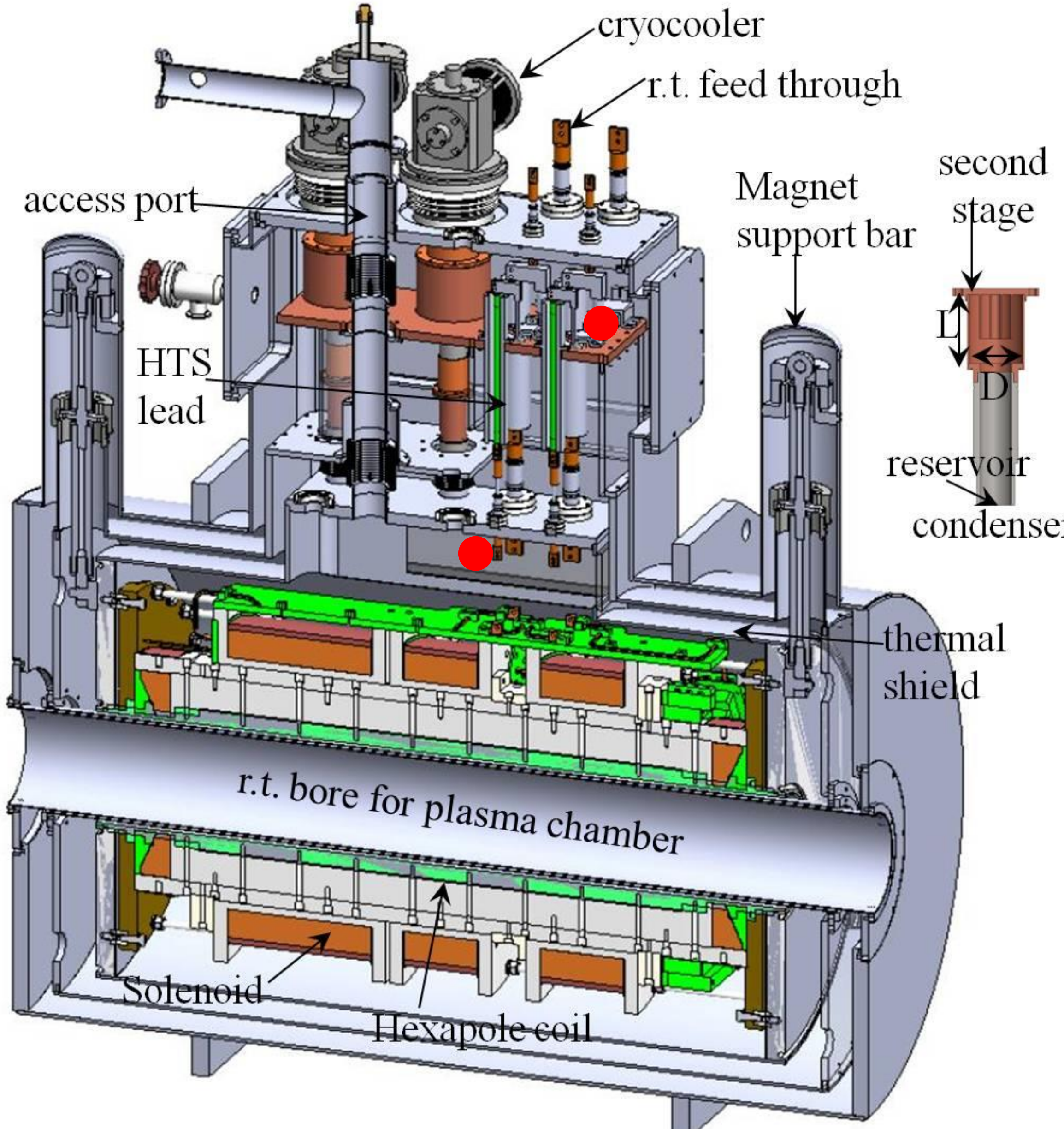


- **Solenoid coils satisfied the requirements of operating current.**
- **Hexapole have not reached the final values yet (83% of I_{op}).**
- **Further training has not carried out due to the shortage of LHe supply**

3.3 Superconducting magnet system: SC magnet assembly at LHe recondensed cryostat

Cryostat

- 4 GM cryocoolers
- 4 LHe recondenser
- HTS current lead: 300 A (6 ea), 500 A (2ea)
- temperature monitor: 7 cernox sensors
- level monitor: 2 LHe level sensors
- Several normal conducting joints (18ea @SC magnet)●



3.3 Superconducting magnet system: Cooling margin of LHe recondensed cryostat

Specification		Unit	Value
Weight of Cryostat (magnetic shield)		kg	<1500
Vacuum Rate of Cryostat		torr	$<\sim 9\times10^{-5}$
He Leak Rate of Cryostat		cc.atm/sec	$<\sim 9\times10^{-9}$
Volume of LHe Vessel		Litter	<950
Cooler Capacity (4ea)	First Stage (50K)	Watt	200
	Second Stage (4.2K)	Watt	6
Number of 4.2K Cooler Port		ea	4
Number of HTS 500A Current Lead		pairs	4

Heat estimation @ first stage	
Shield Radiation	35
Current Lead (4pair) Conduction	80
Access Port Conduction	5
Access Port Radiation	3
Support (8ea) Conduction	3
Total Heat Loss of Thermal Shield	**< 126 W**
Cooling capacity	200 W
Margin	**>74 W**

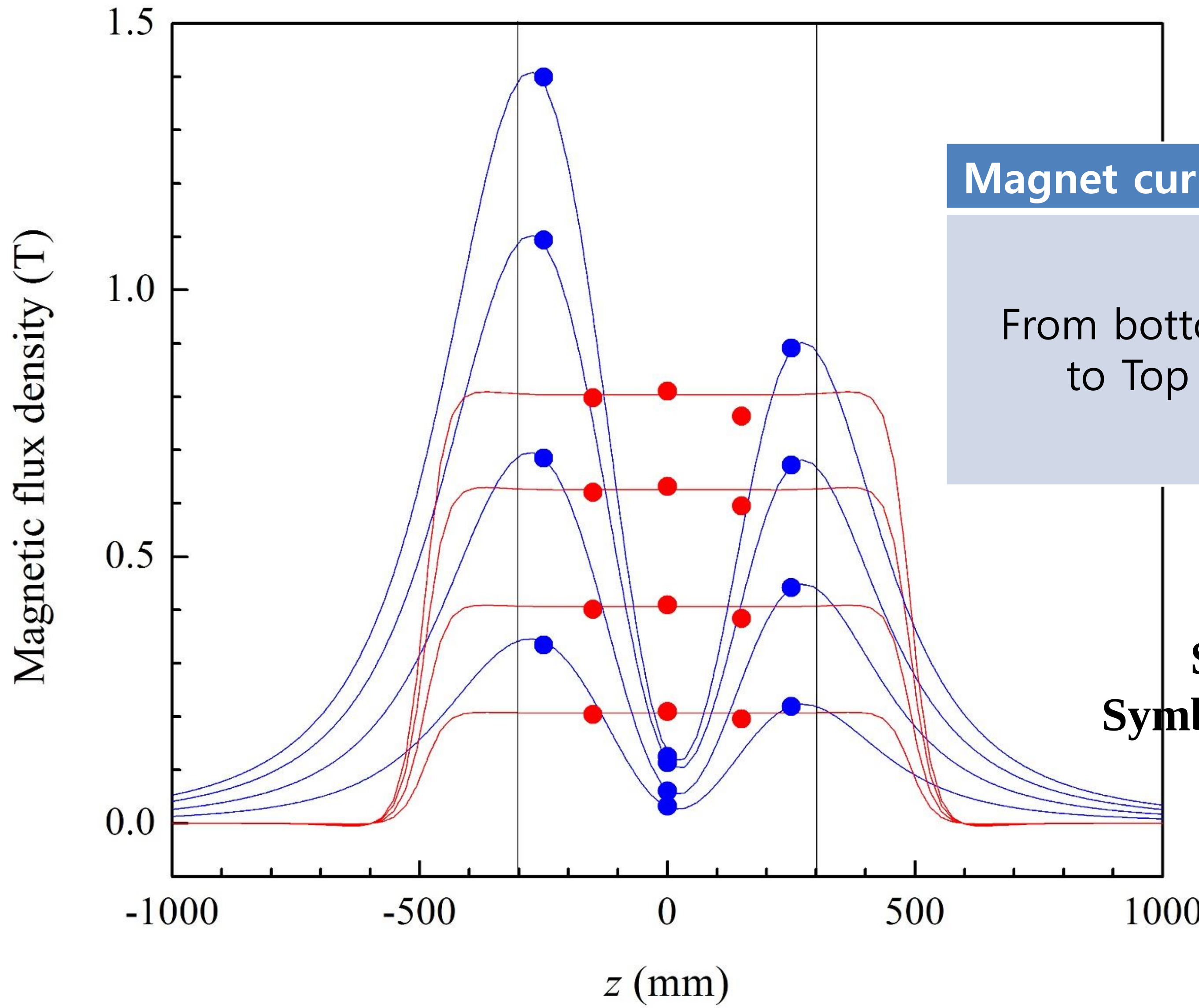
Heat estimation @ second stage	
LHe Vessel Radiation	0.3
HTS Current Lead (4pair) Conduction	0.5
Access Port Conduction	0.4
Access Port Radiation	0.2
Support (8ea) Conduction	0.2
X-ray Heating	3 (assuming)
Total Heat at Loss of LHe Vessel	**< 4.6 W**
Cooling capacity	6 W
Margin	**> 1.4 W**

- **Cooling margin at the first stage > 74 Watt**
- **Cooling margin at the second stage > 1.4 Watt (assuming 3 Watt x-ray heating)**

3.3 Superconducting magnet system:

KBSI

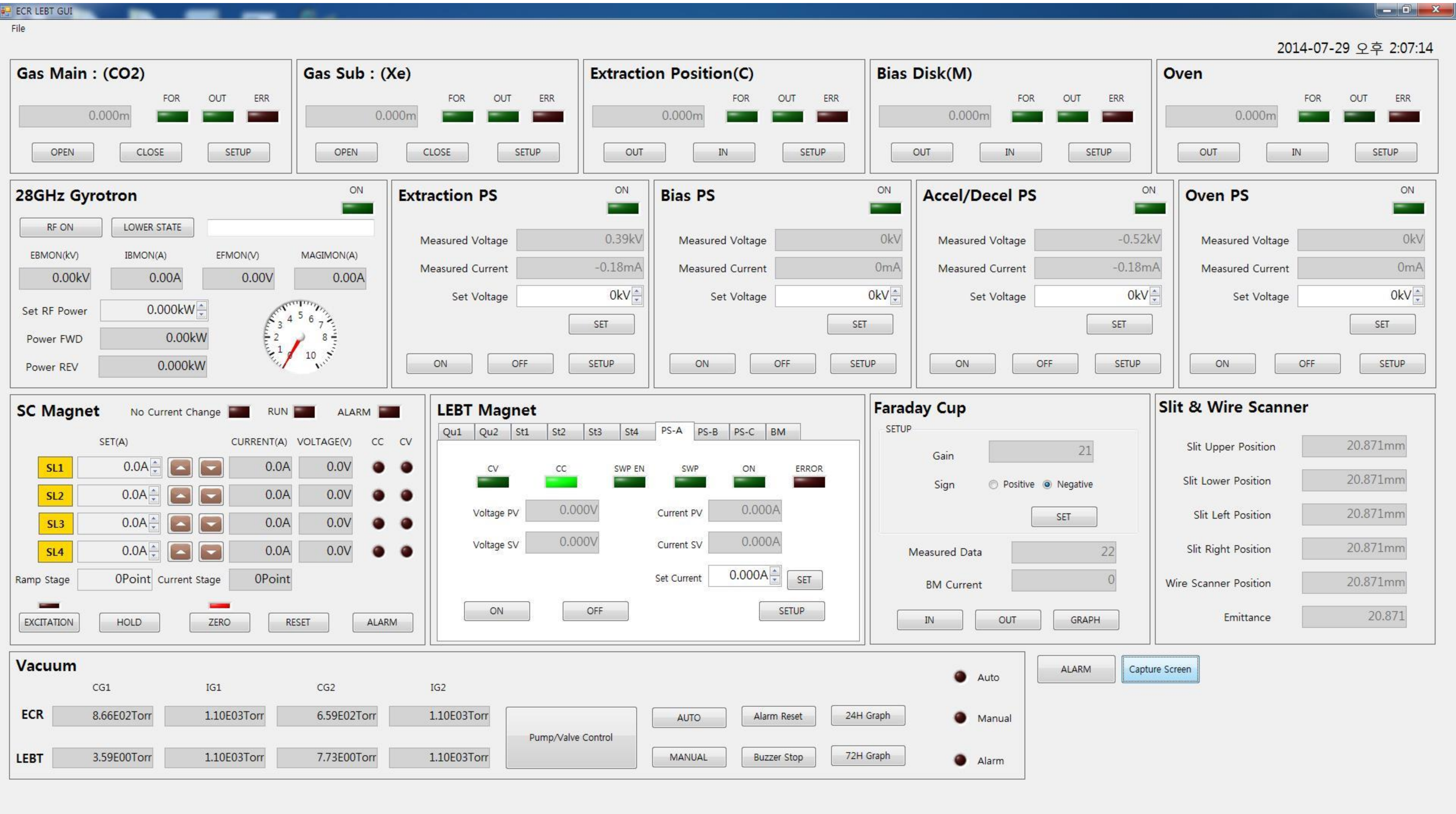
The comparison of magnet field between design and experimental values



Magnet current	HP	Sol
From bottom to Top	38A	20A
	51A	40A
	78A	60A
	100A	80A

Blue: HP,
Reds: Sol.
Solid lines: design,
Symbols: experimental

3.4 Remote control program



VI. The first plasma ignition

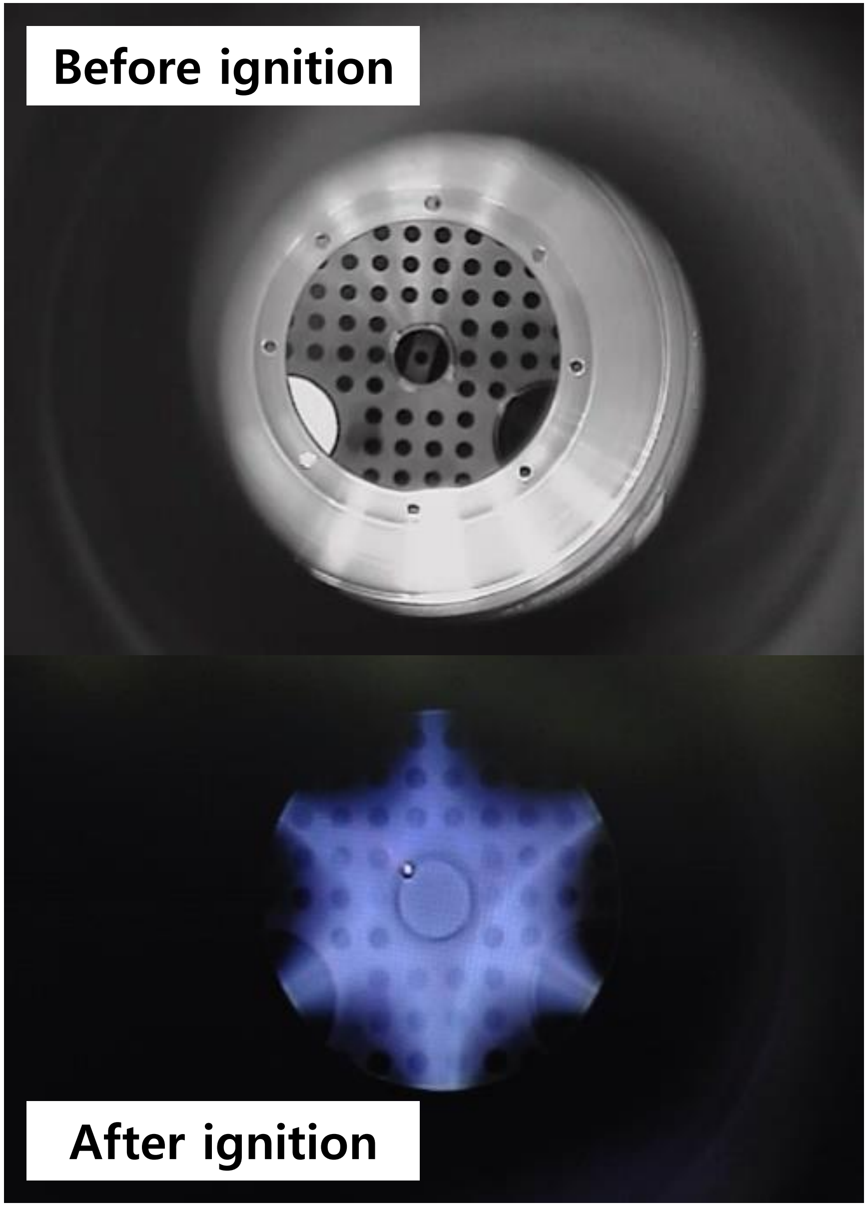
Setup for plasma ignition

VI. The first plasma ignition

Current status of ECRIS for first plasma ignition as of August 2014		
Gas type	Ready	Ar
SC magnet	Ready (limited)	Solenoid was qualified
		HP was limited yet (83% of design)
Plasma chamber	Ready	~ 10^{-8} Torr (Before gas injection)
		~ 10^{-7} Torr (After gas injection)
Microwave	Ready	28 GHz, below 1 kW

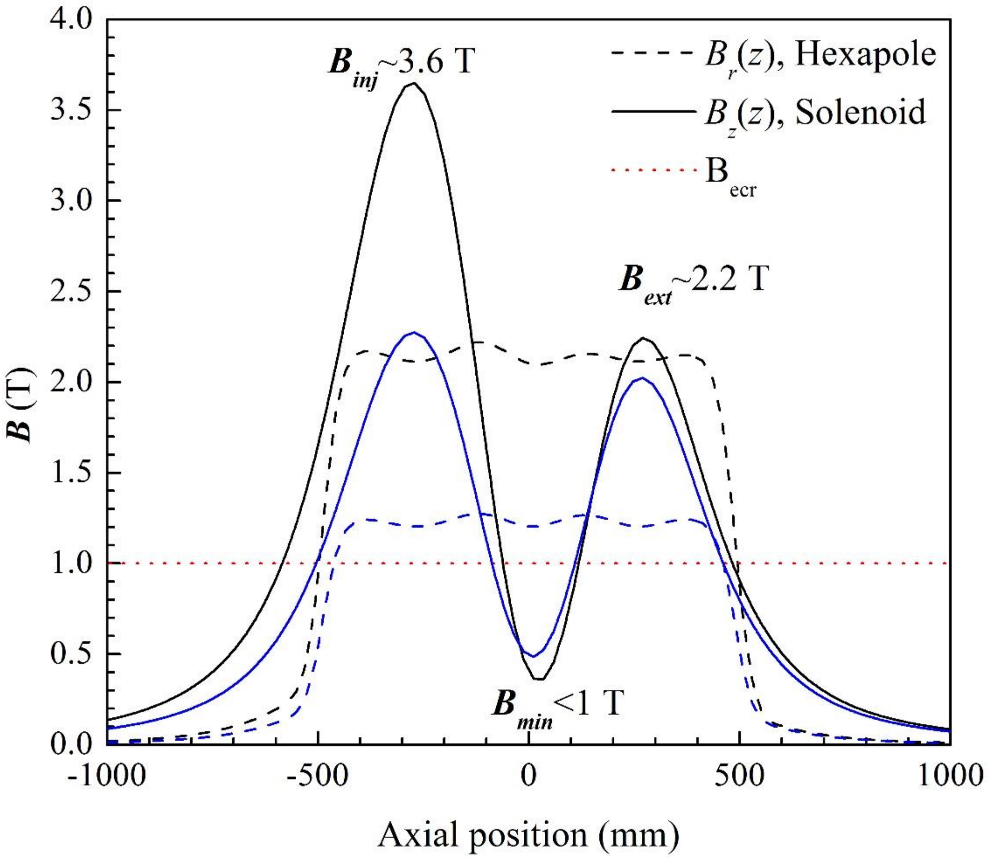
※ More training of superconducting magnet (HP magnet) will be required

VI. The first plasma ignition



- The first plasma ignition was performed on <u>14 August, 2014</u>
- 28 GHz ECR ion source developed at KBSI has been started to operate.

The magnet value of plasma ignition (preliminary)



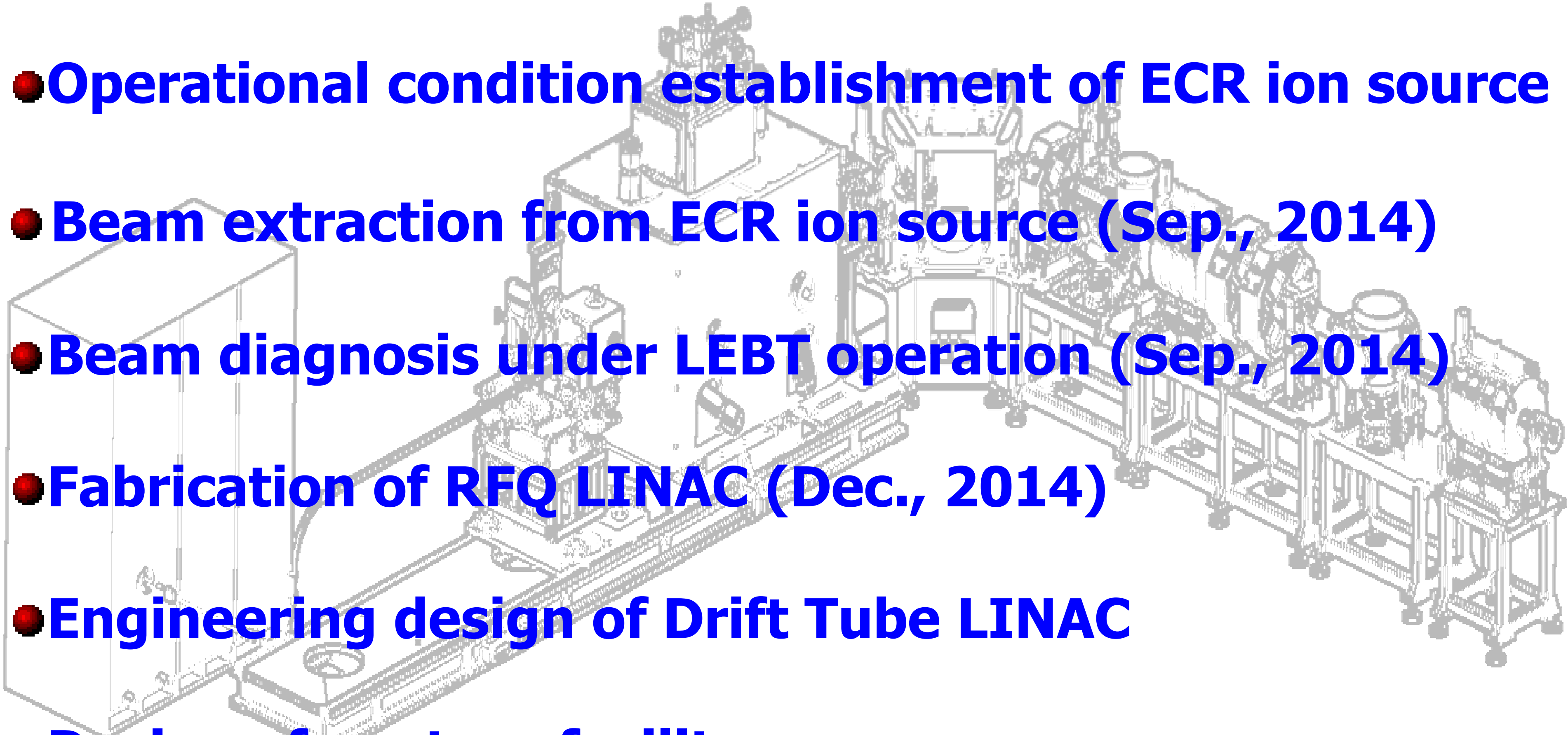
Location	Design values	Plasma ignition condition
B_{inj} (T)	3.65	2.3
B_{min}(T)	variable	0.48
B_{ext}(T)	2.24	2.02
B_r(T)	2.2	1.3

Black lines: Design values, **Blue lines: Plasma ignition condition**

※ Training of superconducting magnet has been much delayed due to LHe shock.
※ Solenoids performance is now limited by yet-trained Hexapole-magnet.
※ More training of superconducting magnet (HP-magnet) is planned.

V. Future plan

- More training of superconducting magnet (HP)
- Operational condition establishment of ECR ion source
- Beam extraction from ECR ion source (Sep., 2014)
- Beam diagnosis under LEBT operation (Sep., 2014)
- Fabrication of RFQ LINAC (Dec., 2014)
- Engineering design of Drift Tube LINAC
- Design of neutron facility



Thank you for your attention.