KBSI 한국기초과학지원연구원
KOREA BASIC SCIENCE INSTITUTE

# The current status of KBSI heavy ion accelerator project

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# Contents

# Overview of KBSI Accelerator Project

## 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: 84 keV

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

## LEBT System

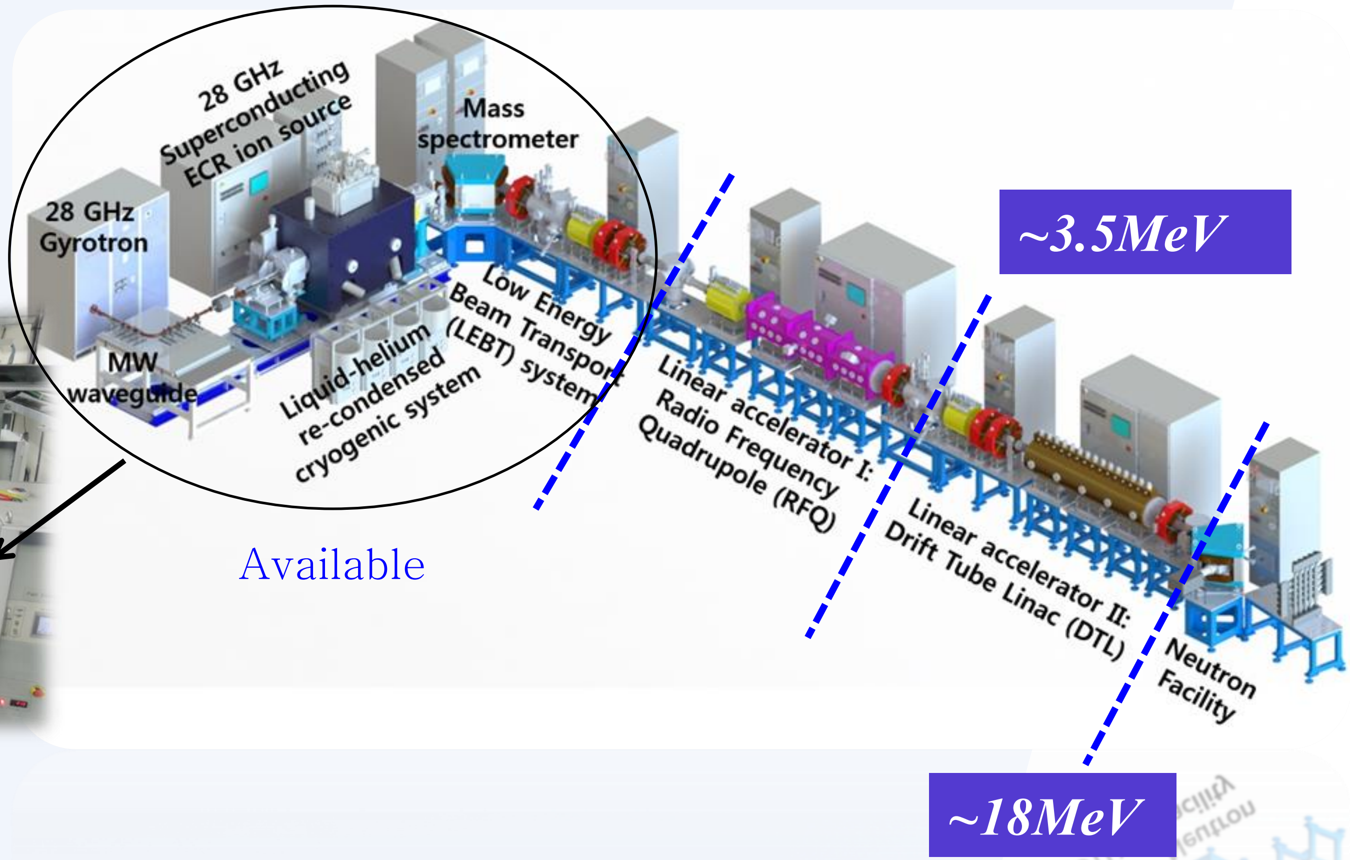
- enable to separate the ions from IS
- satisfy the RFQ input condition: beam acceptance, current, size and etc.
- 1dipole+3solenoids+2quadrupoles
- 2 diagnostic chambers

## Linear Accelerator

- Reference particle: $Li^{3+}$
- Freq.=165 MHz
- Output beam :
  ~ 3.5 MeV@RFQ
  ~ 18 MeV@DTL

# KBSI Accelerator System Layout

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




p($^7$Li, n)$^7$Be Inverse kinematics → *Neutron production*

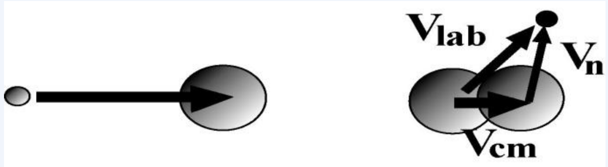
# Concept of neutron production

## Normal kinematics

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

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

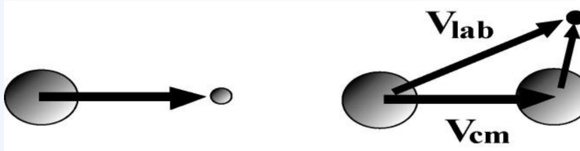
$$^{7}Li(p,n)^{7}Be$$




Normal kinematics: light particle interact with heavy element target. the produced neutron will be go to all direction.

## Inverse kinematics

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




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

Concept of the heavy ion linear accelerator based on compact sized neutron production.

# Neutron yield

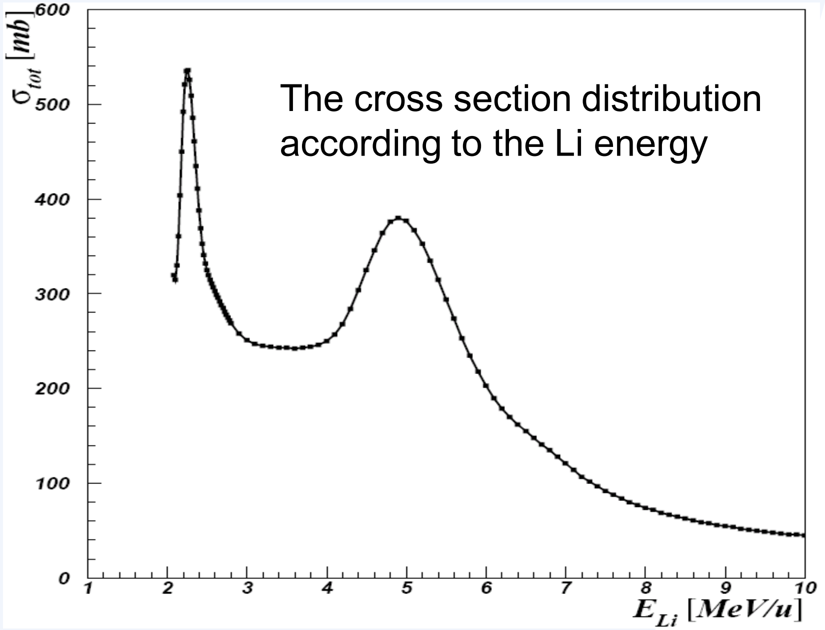
## Requirement of KBSI Neutron Facility

→ Higher than 1pmA of $Li^{2\sim3+}$ beam intensity

→ ~2.5 MeV/u (17.5 MeV) of beam energy

→ Gas target : >350 Torr

→ High efficiency detector for fast neutron detection




## Fast Neutron Yield

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

Y : Neutron yield

$F_{Li}$ : Beam flux

ρ : Density

$N_A$ : Avogadro constant

A : Atomic number

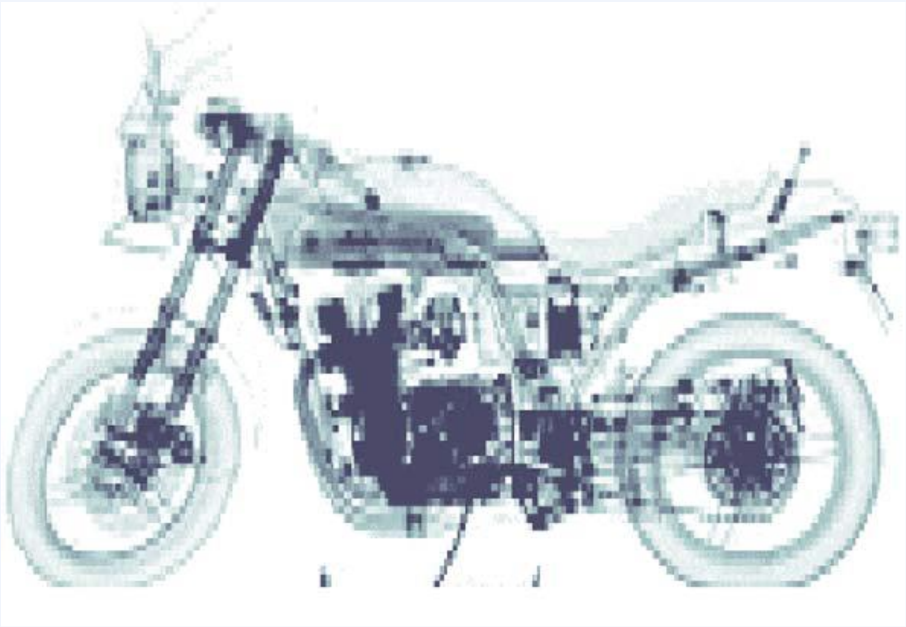
L : Target length

σ : Cross section

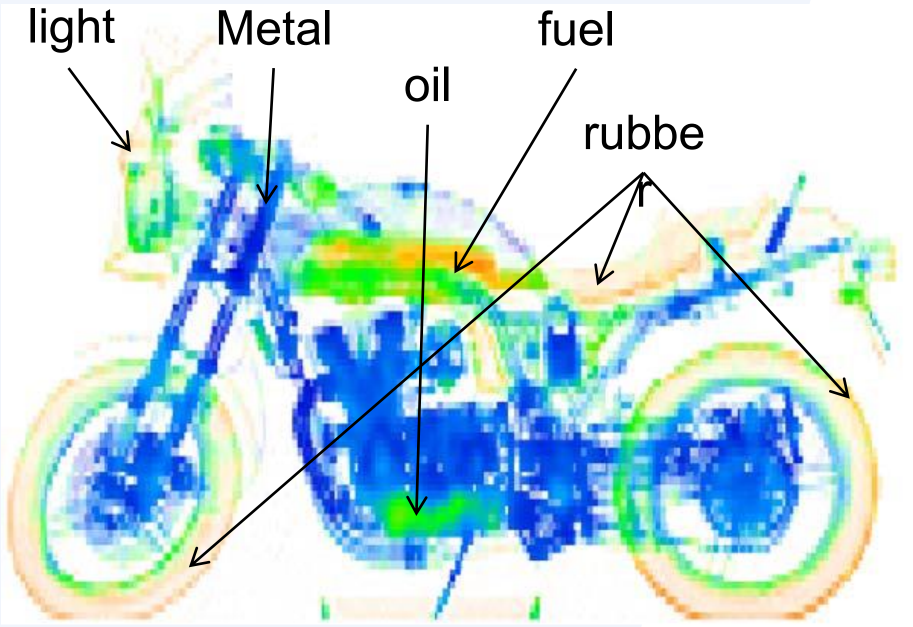
| Li energy (MeV/u) | Neutron yield (n/cm² ·s) | Limit angle (deg) | Maximum neutron energy (MeV) |
|---|---|---|---|
| 1.88 | $8.5 \times 10^{8}$ | ~few deg. | 1.88 |
| 1.9 | $1.7 \times 10^{10}$ | 4 | 2.1 |
| 1.92 | $3.6 \times 10^{10}$ | 7 | 2.3 |
| 2.5 | $1.0 \times 10^{12}$ | 28 | 4.0 |

# Application of neutron

Neutron Radiography



Scan image using gamma ray



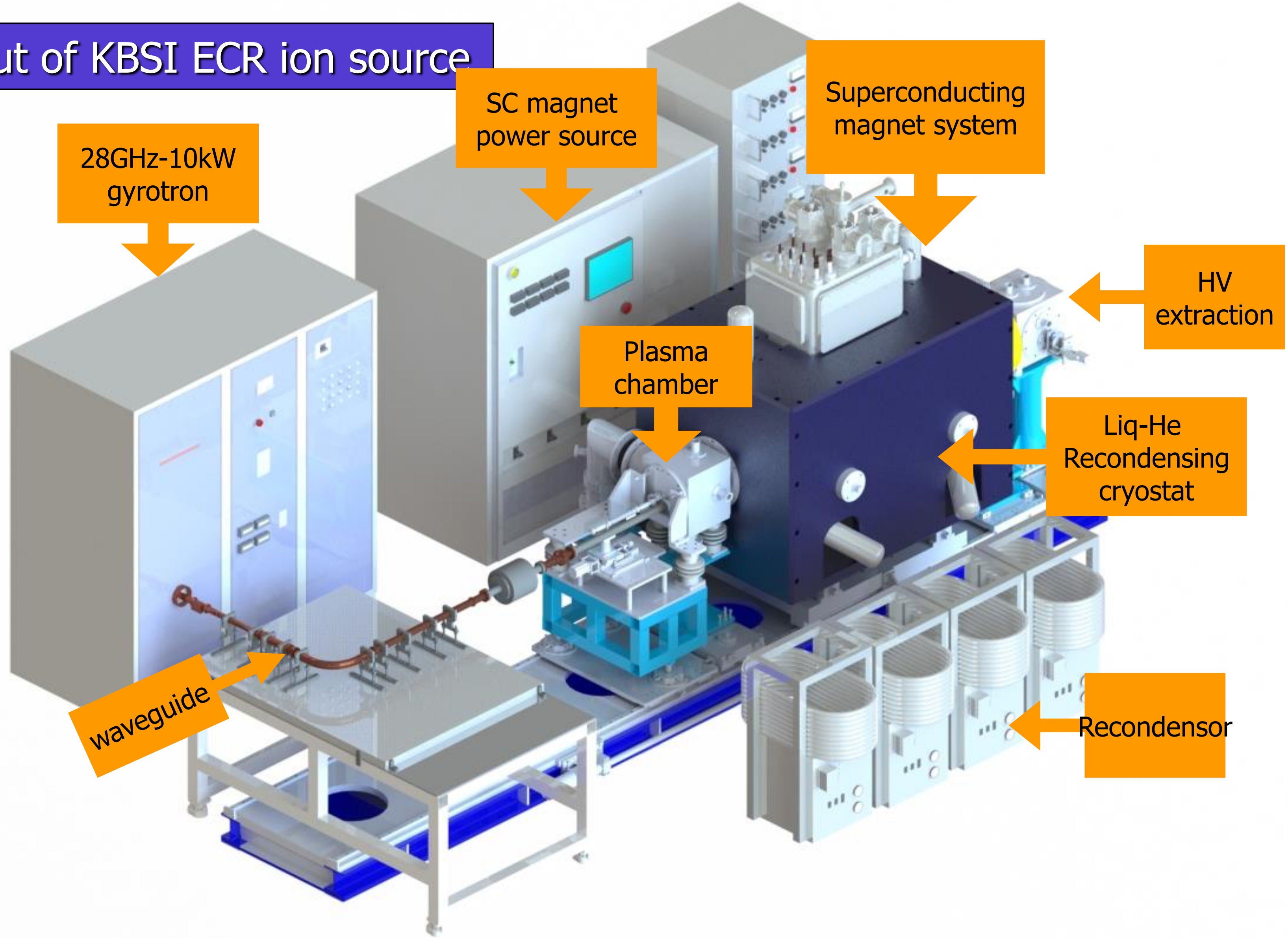

Scan image using neutron

*J.E. Eberhardt et al. / Applied Radiation and Isotopes 63 (2005)*

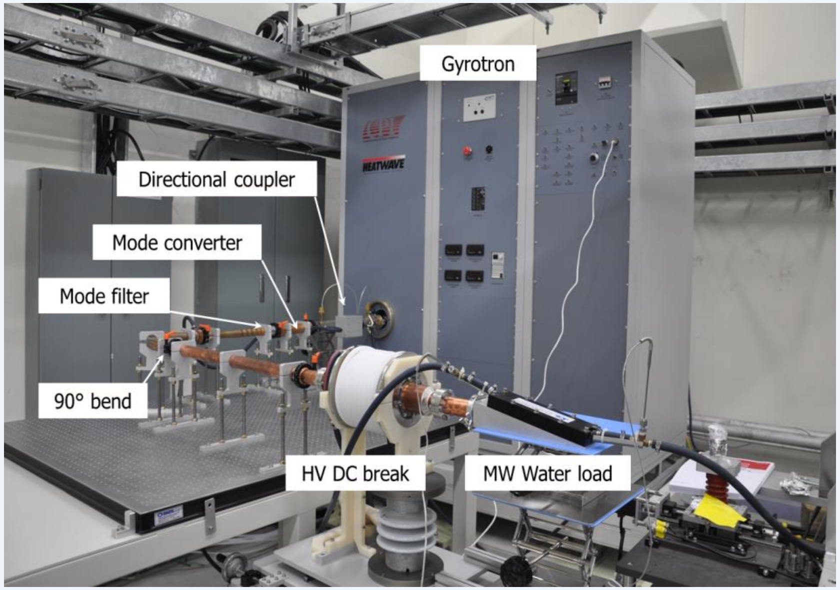
# 28GHz SC ECR ion source

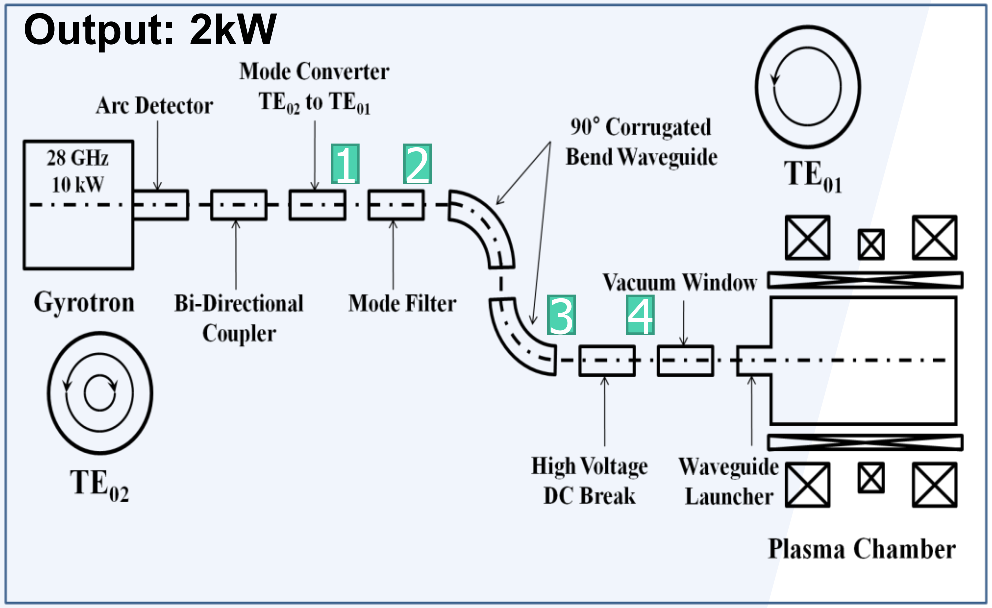
# 28GHz SC ECR ion source

## Layout of KBSI ECR ion source



# 28 GHz Microwave Power Source



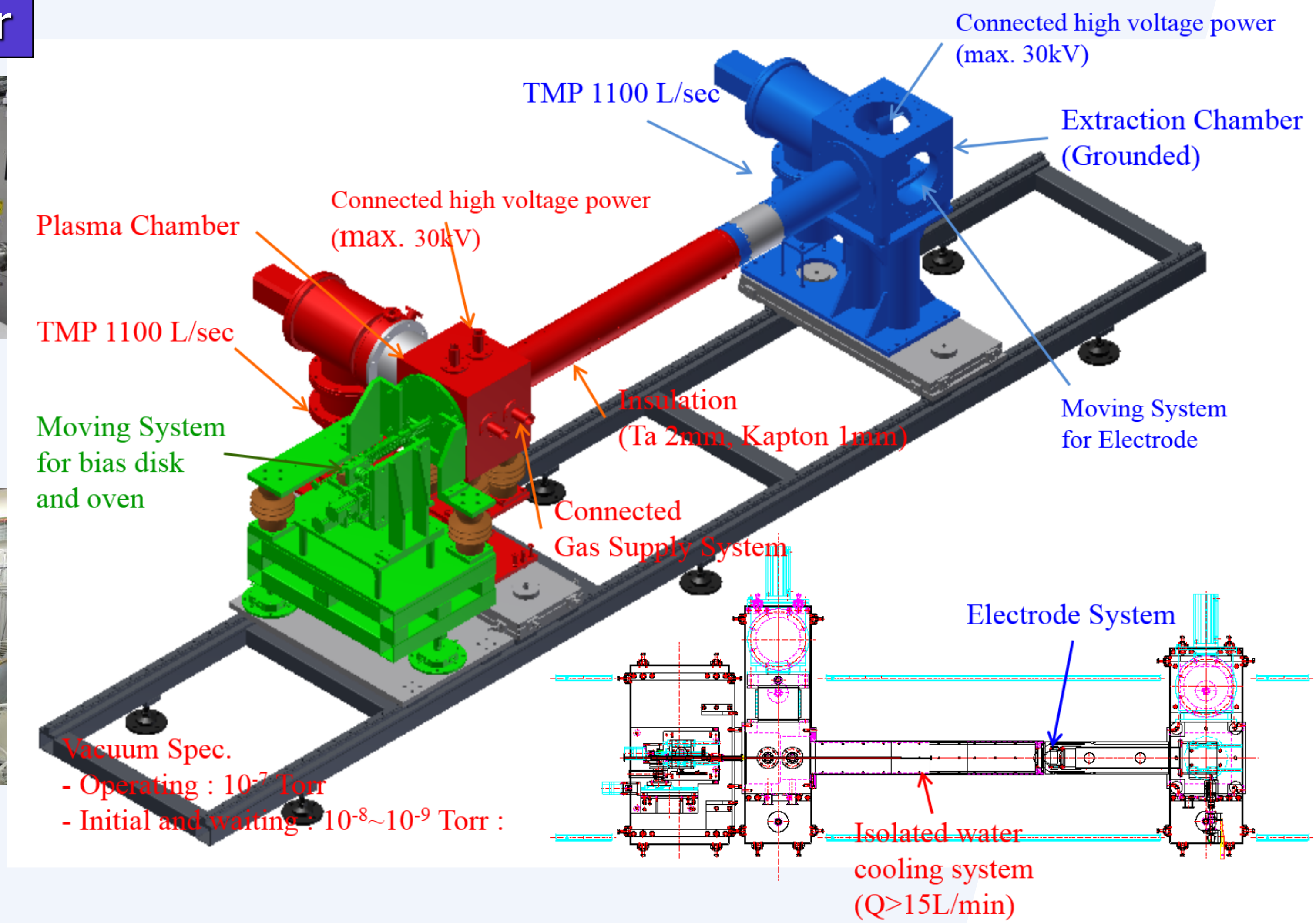




| Location | Components | MW Transmitted power (kW) |
|---|---|---|
| Test condition: Gyrotron output = 28 GHz, 2 kW | | |
| Default | Directional coupler | 1.9 |
| 1 | Default+mode converter | 1.891 |
| 2 | 1+mode filter | 1.886 |
| 3 | 2+ 90° bend | 1.886 |
| 4 | 3+dc break | 1.877 |

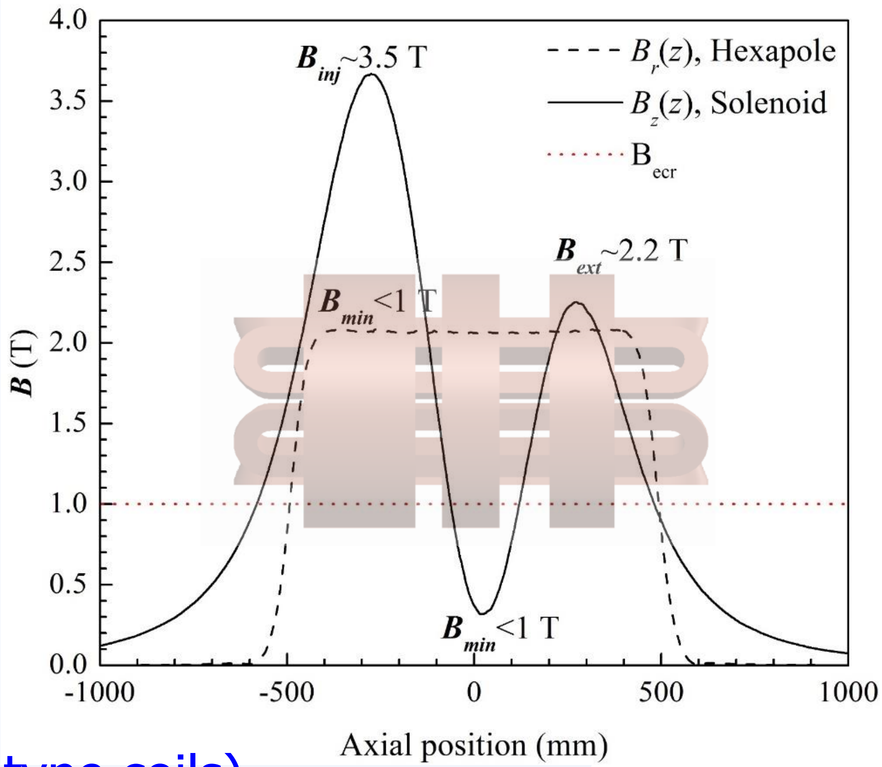
# Plasma Chamber & Extraction System

## Plasma chamber

## Assembly



# Superconducting magnet system




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

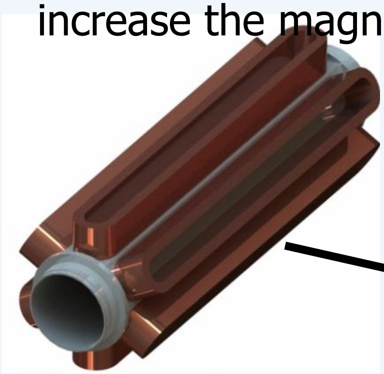
**The magnetic field distributions in the plasma chamber were obtained from Opera**

- The axial field: 3.5 T at injection, 2.2 T at extraction.
- The minimum axial field (modifiable): 0.4 ~ 0.8 T.
- The radial design field on the plasma chamber wall: 2.1 T

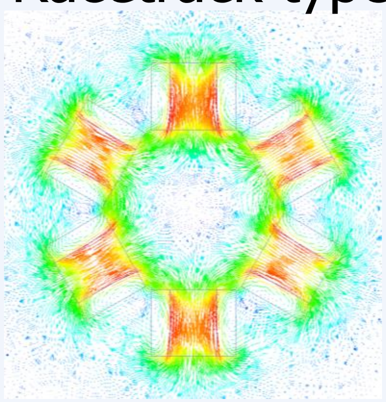
# Superconducting magnet system

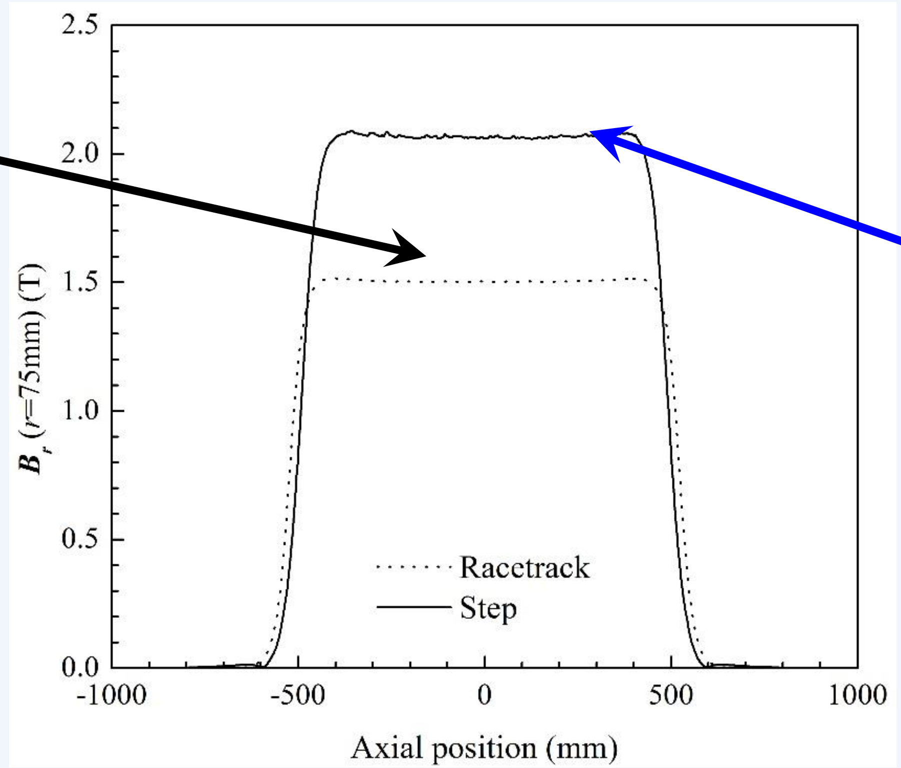
## Two candidates considering domestic vendor technology

- Saddle type is the best but it difficult to wind by domestic supplier
- By adopting, the **step-type hexapole** modified from racetrack and saddle coils, we could increase the magnetic field of radial field.

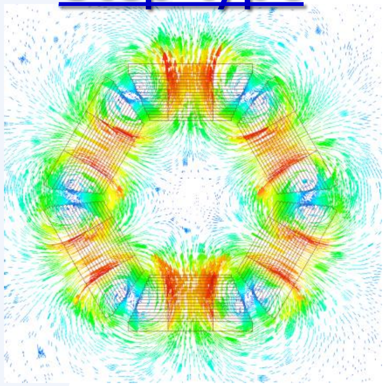


Racetrack type





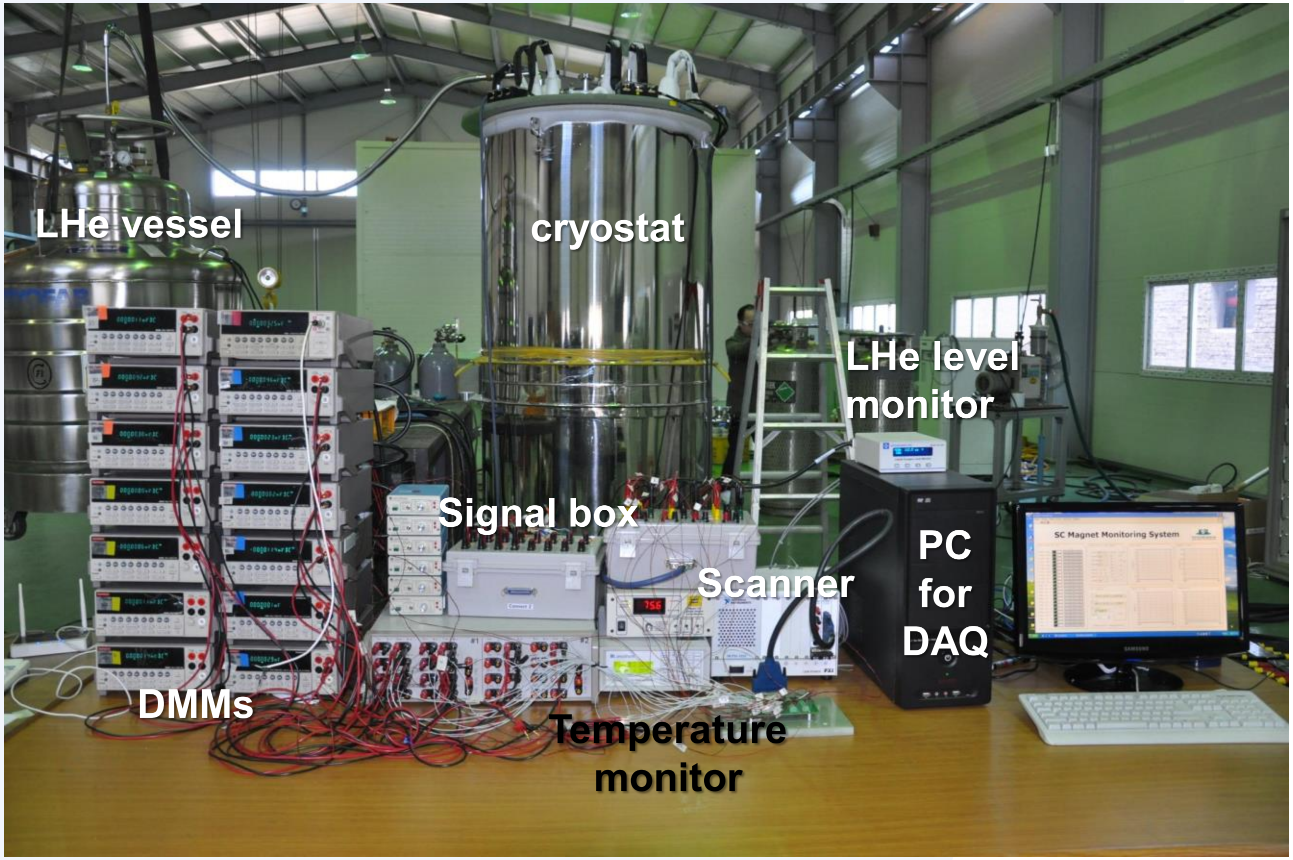

Step type



# Superconducting magnet system

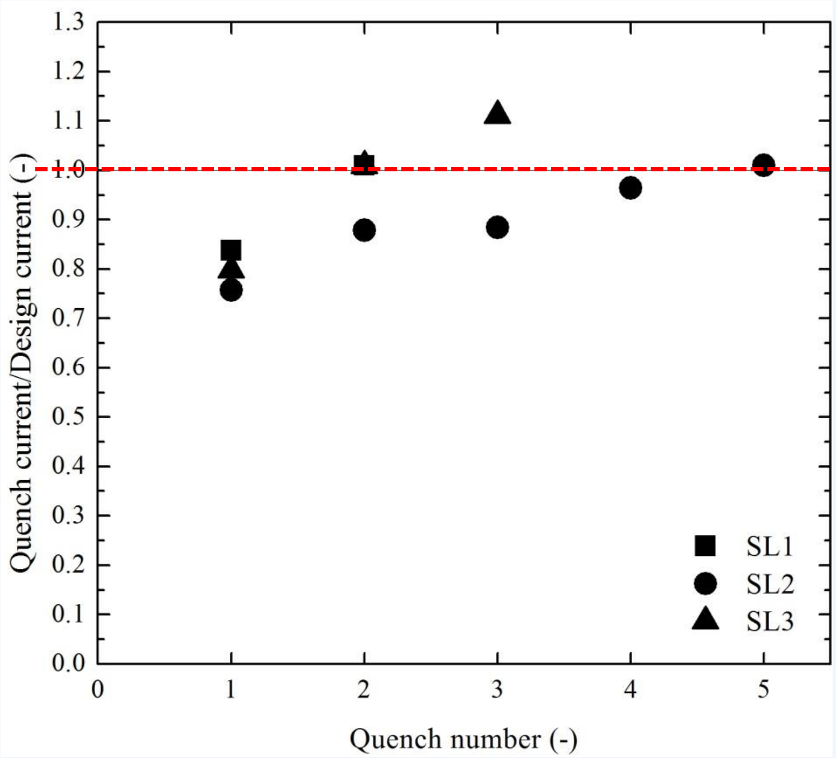
## Magnet test at open-type cryostat

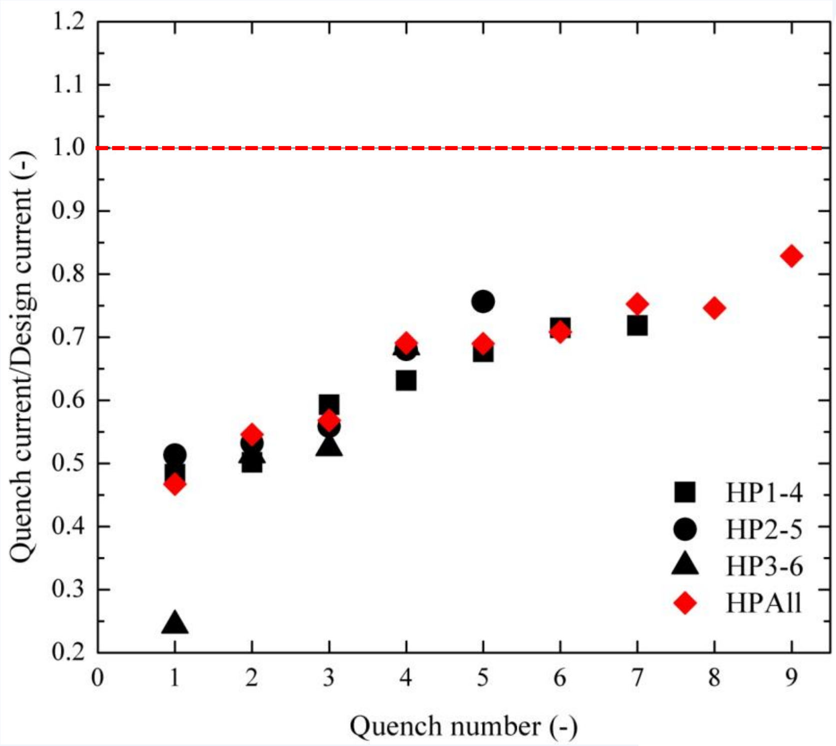
- Before final assembly, separate coil performance was checked
- Vertical cryostat(open type) was prepared for convenient test
- Magnet status, temperature, magnetic field were observed



# Superconducting magnet system

## The separate coil performance




- Solenoid coils satisfied the requirements of operating current.
- Hexapole have not reached the final values yet (83% of $I_{op}$).
- Needs reinforcement of hexapole magnets

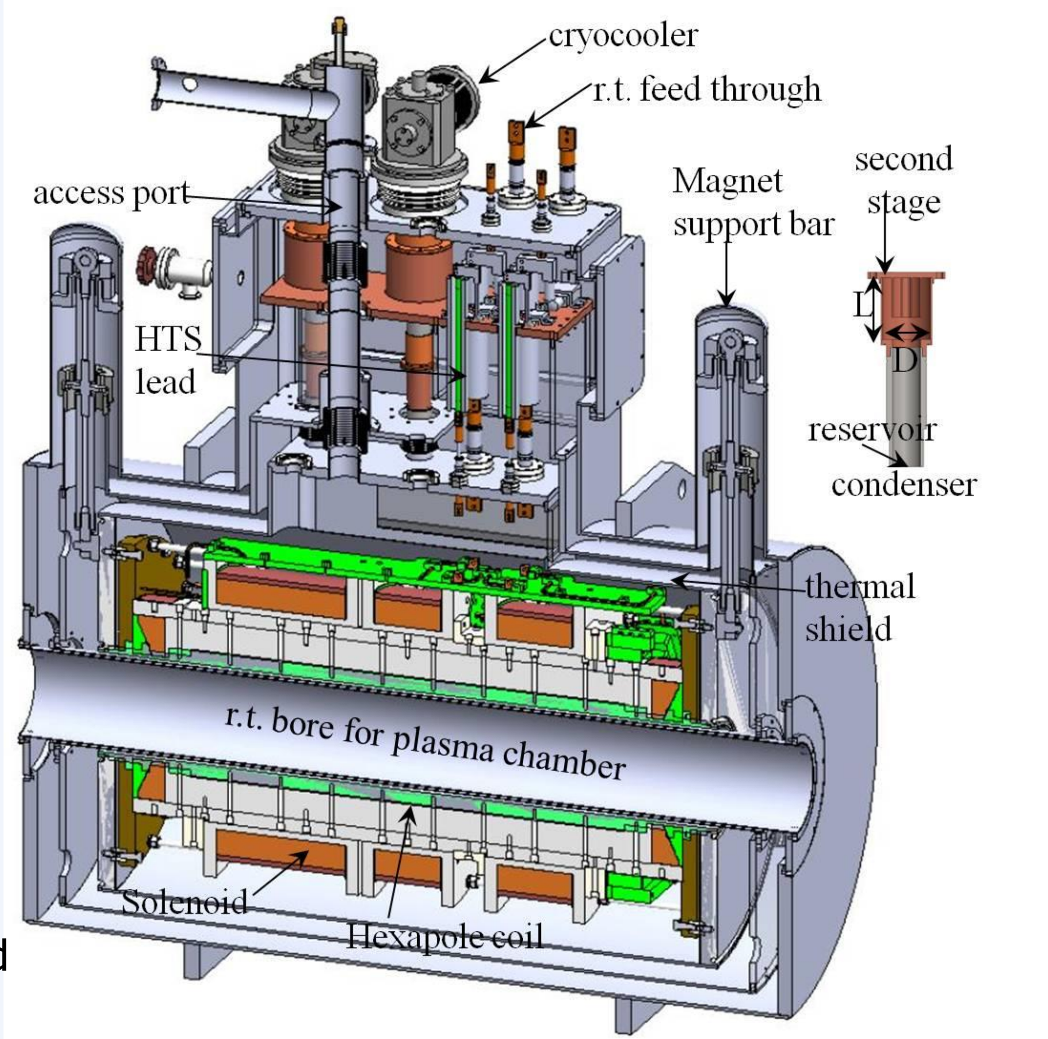
# Superconducting magnet system

## Cryostat

For the Lhe recondensing on the cryostat

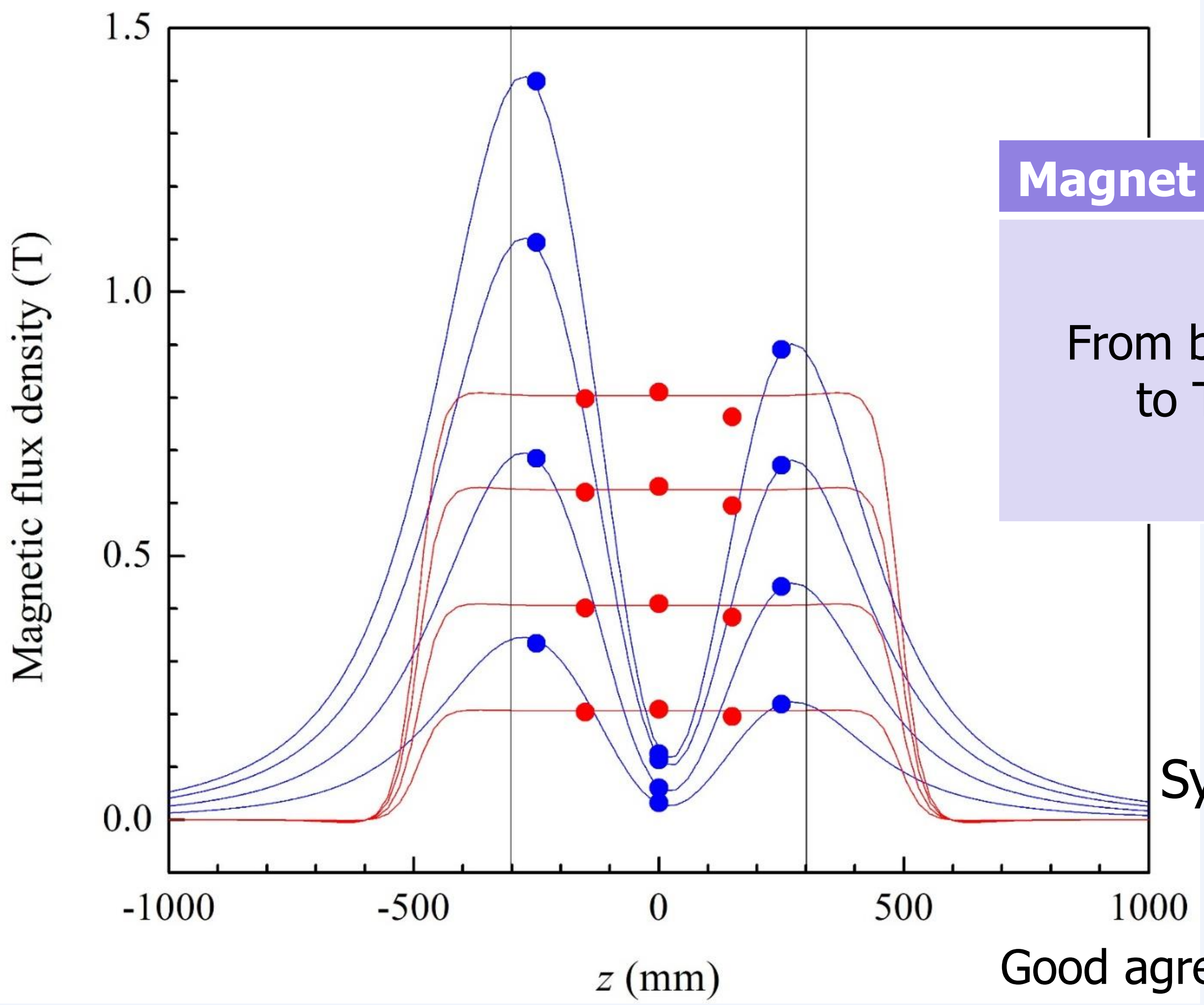
- 4 GM cryocoolers
- 4 LHe recondenser
- HTS current lead: 300 A (6 ea), 500 A (2ea)
- temperature monitor: 7 cernox sensors
- level monitor: 2 LHe level sensors

A cryocooler works the two stages operating at 4.2 K on the second stage and 50 K on the first stage. Cooling capacity of each stage is 1.5 W and 50 W, respectively.



# Superconducting magnet system

## 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 |

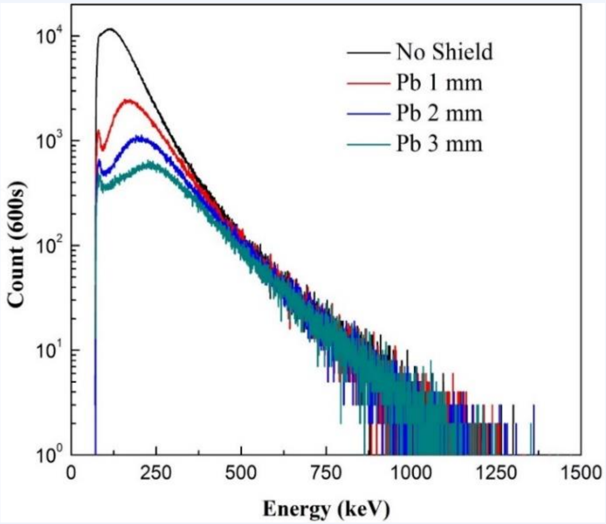
Blue: HP,
Reds: Sol.
Solid lines: design,
Symbols: experimental

Good agreement was observed

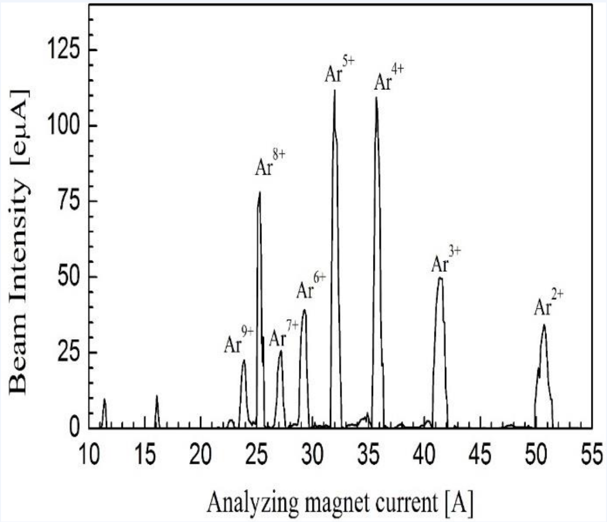
# Operation of 28 GHz SC ECR ion source

- The ECR plasma was generated in last year
- The first beam was extracted from 28 GHz ECR ion source this year
- Optimization of ECR ion source with various conditions is under way
- Beam spectrum as well as x-ray from ion source
- Further study about ECR ion source will be conducted

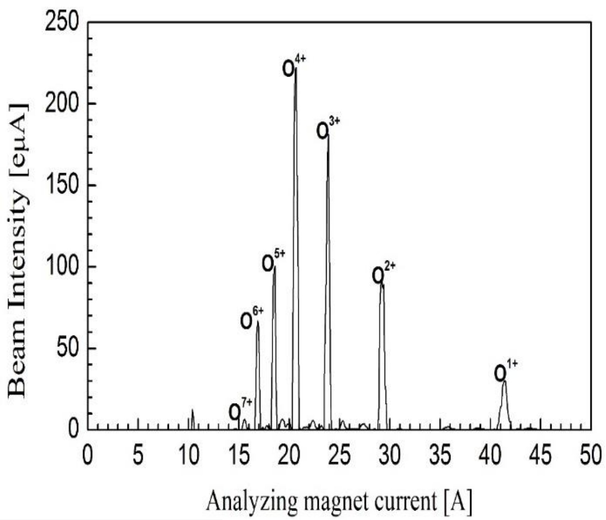
X-ray measurement



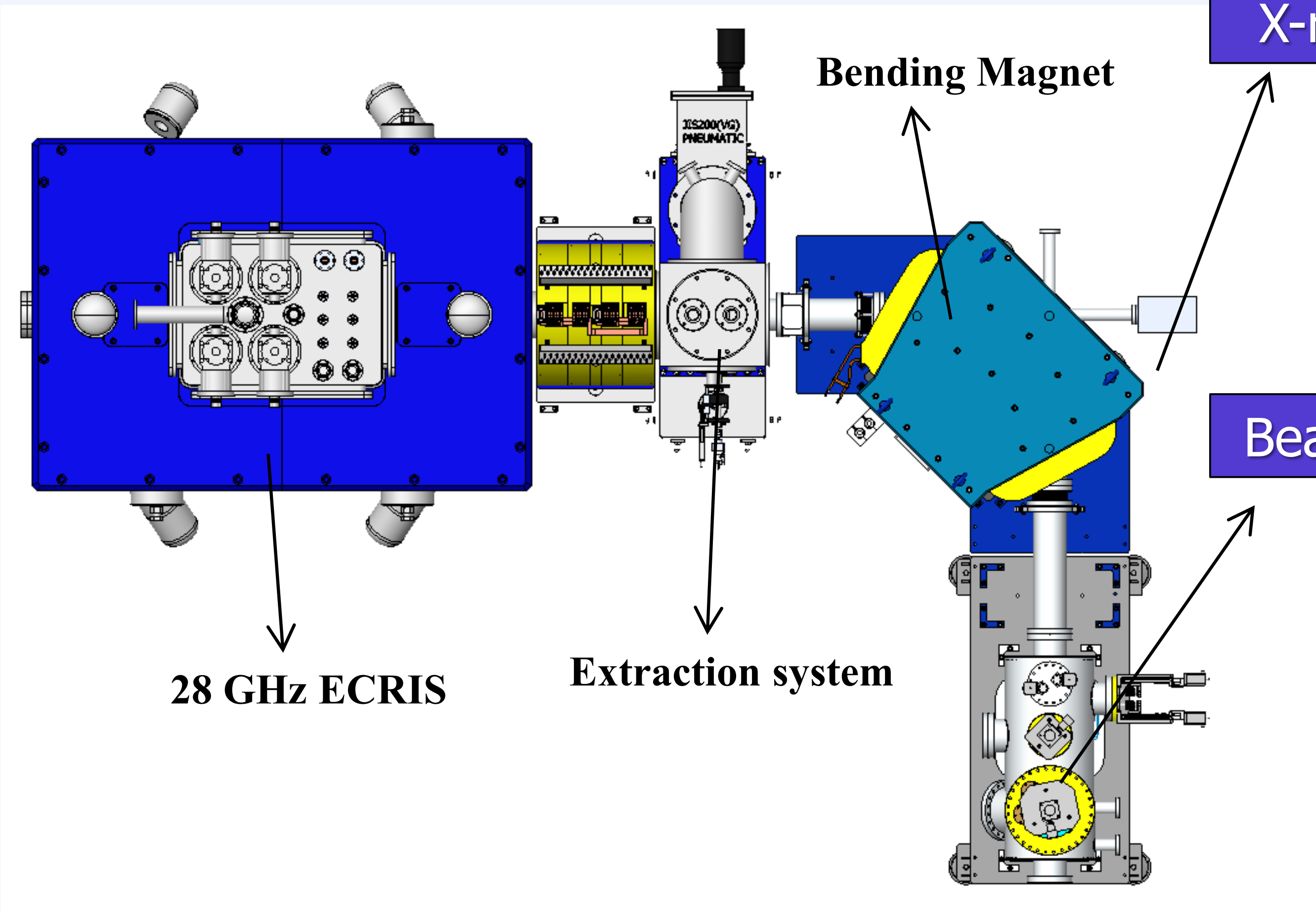

Ar beam spectrum



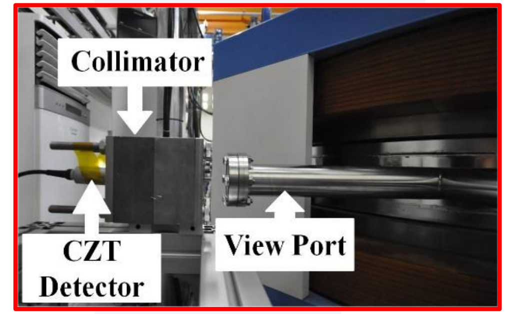

O beam spectrum



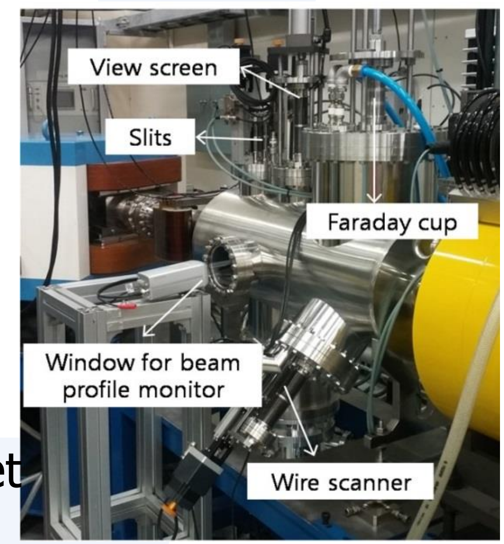
# Beam measurement system in LEBT




## X-ray detection system




## Beam diagnostic system




- Extracted beam spectrum was measured using dipole magnet
- Also, x-ray from plasma chamber was measured with x-ray detection system

# KBSI Accelerator System

# Progress of Accelerator Development

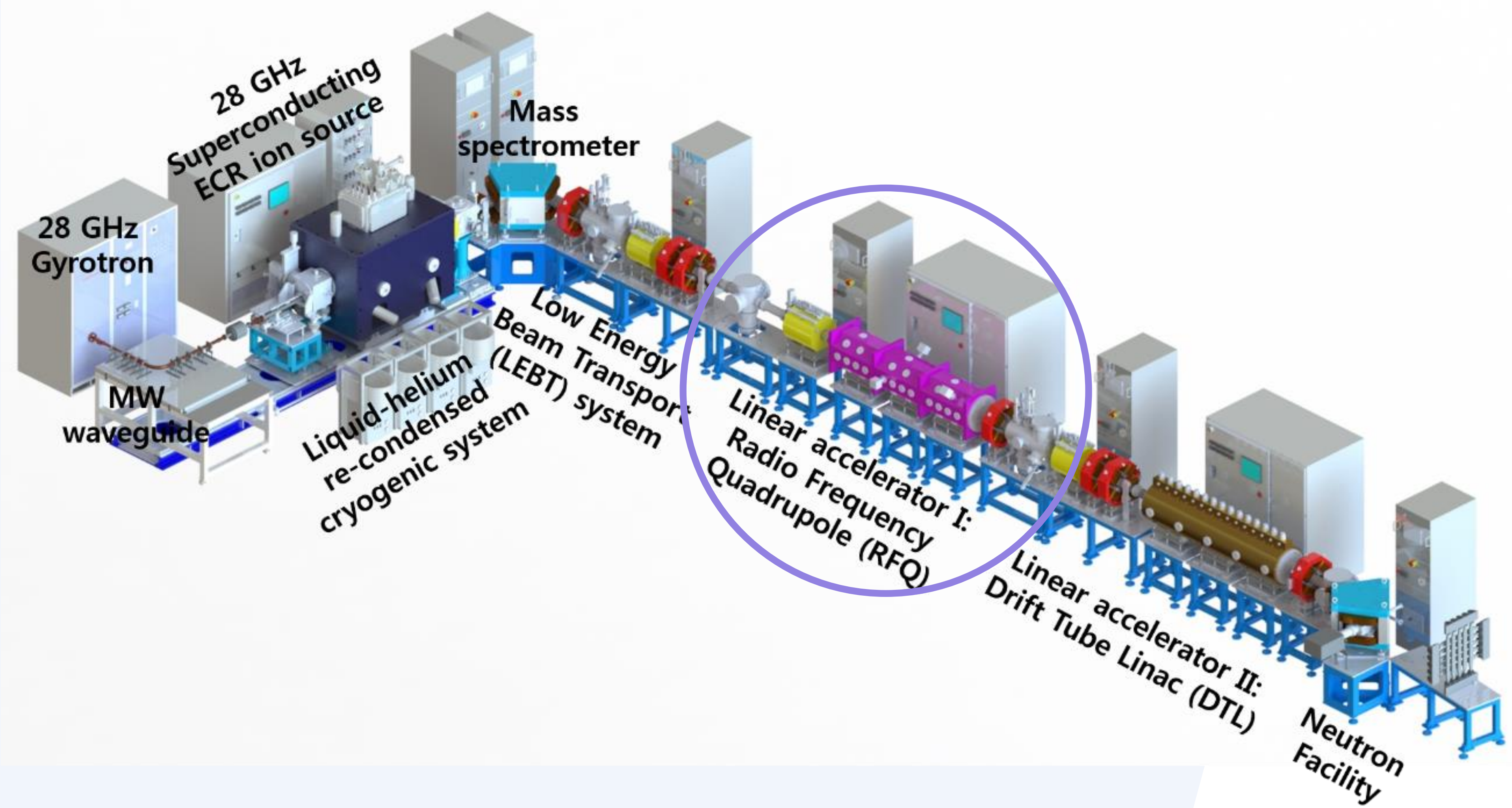
## Radio-Frequency Quadruple (RFQ)

- Design of RFQ is concluded (4-vane type)
- Total length of RFQ: < 2.4 m
- Particle transmission rate: > 98%
- Beam energy: 3.5 MeV
- The KBSI RFQ and 100 kW RF power source are scheduled to be completed in this year

## Drift Tube Linac (DTL)

- By the conceptual design of DTL , we will adopt IH type DTL for the high electric power efficieny.
- Beam energy: ~ 18 MeV

# Radio-Frequency Quadrupole (RFQ)



# Design specification of RFQ

- **Beam dynamics**

| **Particle** | **$Li^{3+}$** |
|---|---|
| Input Energy | 12 keV/u |
| Output Energy | 500 keV/u |
| Max. Beam Current | 1 pmA |
| Input Transverse Emittance | 0.2 pi.mm.mrad |
| Max. Emittance Increase | <10% |
| Min. Beam Transmission | >95 % |

- RF structure

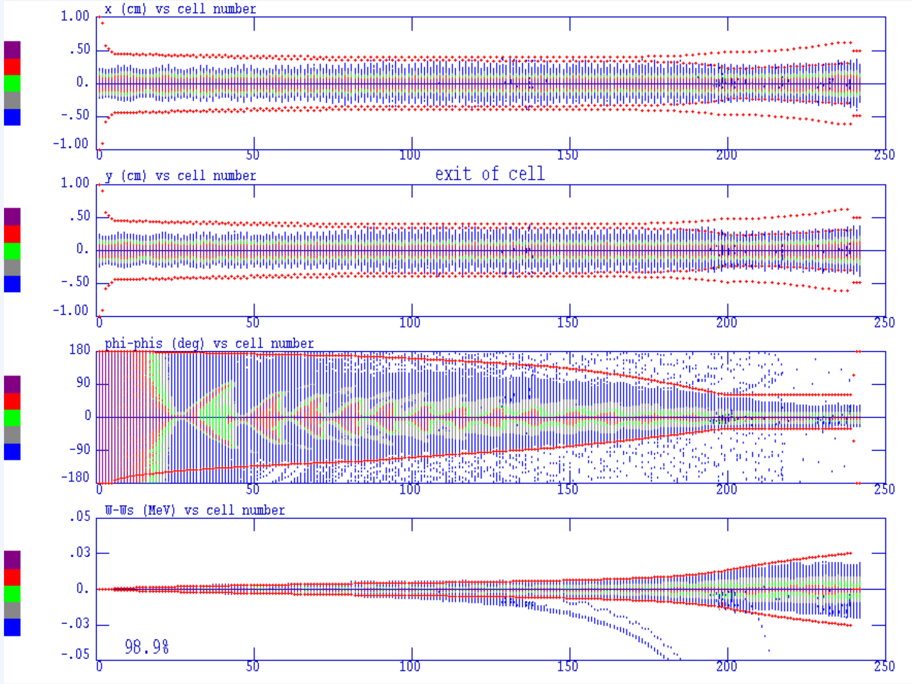
| **Cavity Structure** | **4 vane** |
|---|---|
| Mechanical Design | Brazed structure with Octagonal shape |
| Frequency Quadrupole mode | 165 MHz |
| Max. Duty Cycle | CW mode |
| Max. Surface Fields | <1.7 Kilp. |

# Design Parameters of the RFQ

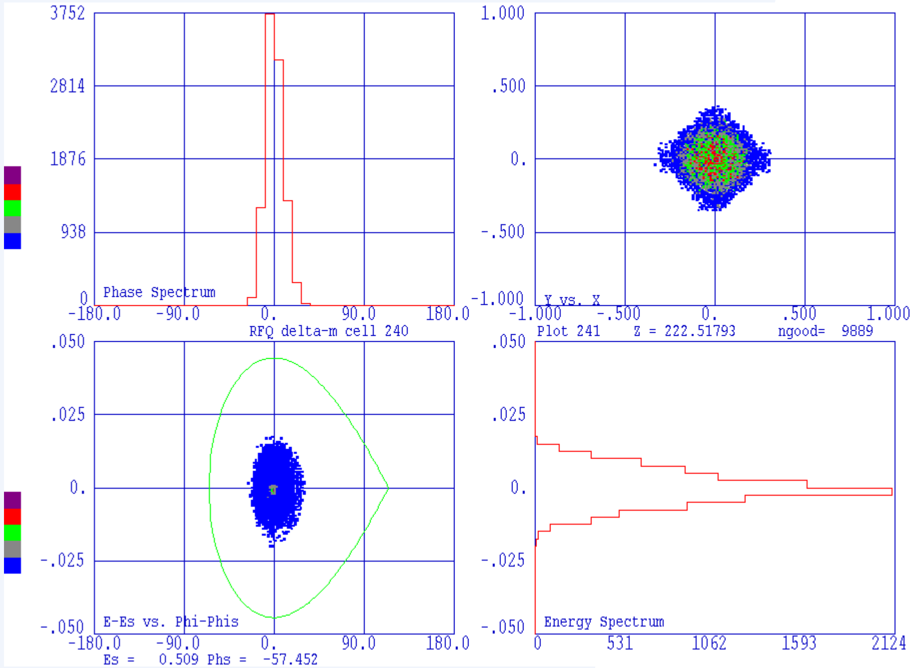
| Design parameters | value | unit |
|---|---|---|
| Vane voltage | 55 | kV |
| Beam current | 1 | pmA |
| Modulation parameter, m | 1 ~ 2.08 | |
| Transverse focusing parameter, B | <6 | |
| Synchronous phase, $\varphi_s$ | -90→-30 | Deg |
| Maximum surface electric field | <20.2 (1.5kilp.) | MV/m |
| Transmission efficiency | >97 | % |
| Total length | 2324.8 | mm |
| Input emittance, $\varepsilon_{x,y,rms,n}$ | 0.187 | mm.mrad |
| Output emittance, $\varepsilon_{x,rms,n}$<br>$\varepsilon_{y,rms,n}$<br>$\varepsilon_{z,rms,n}$ | 0.213<br>0.211<br>0.051 | mm.mrad<br>mm.mrad<br>MeV.deg/u |

# Beam dynamics simulation

Beam transmission

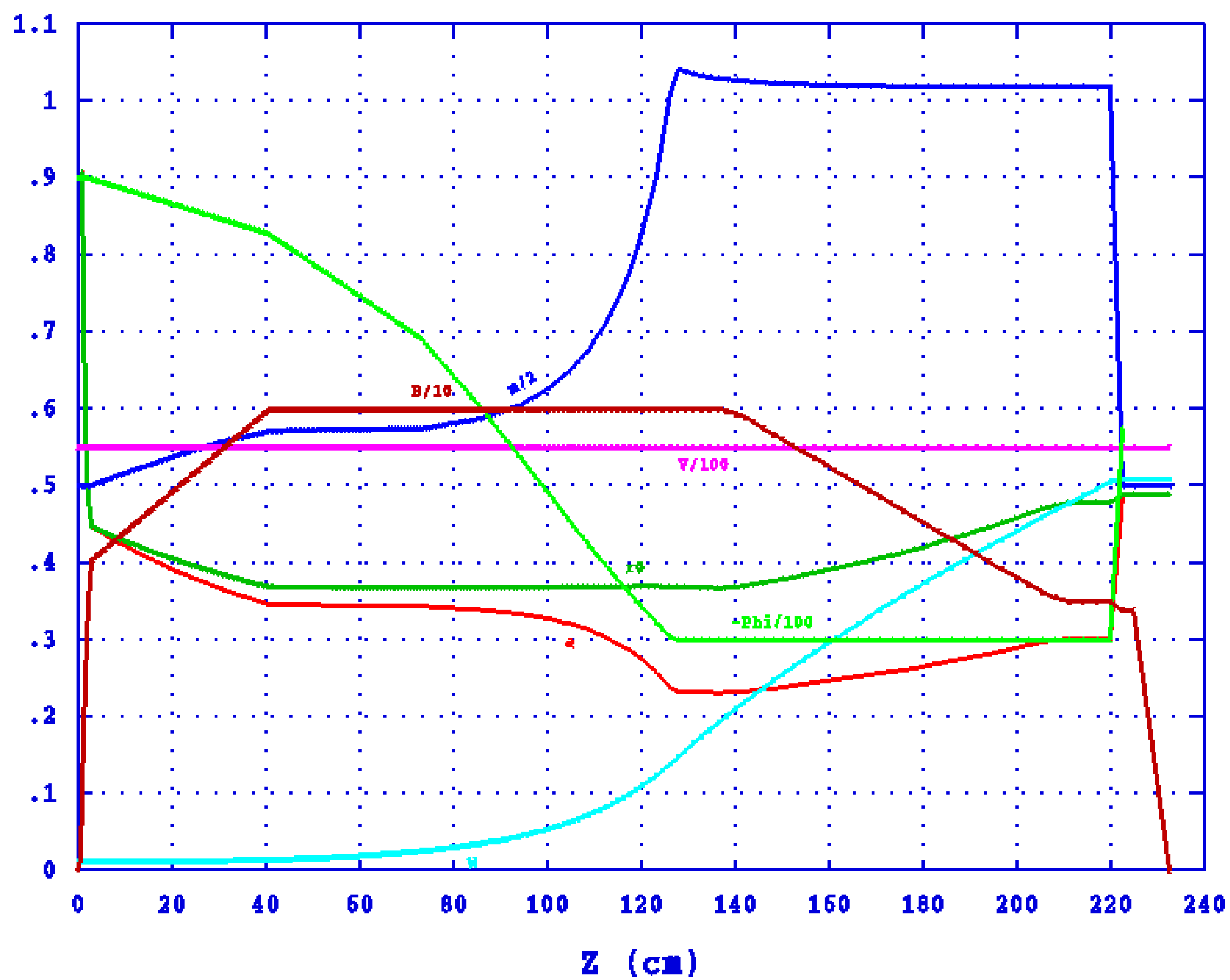



Beam profile




- Beam transmission rate : >98.9%
- Beam energy : >500 keV/u

# RFQ vane design parameters

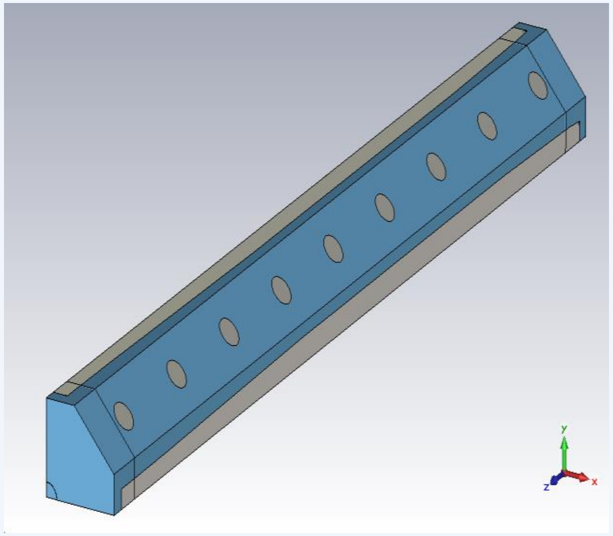


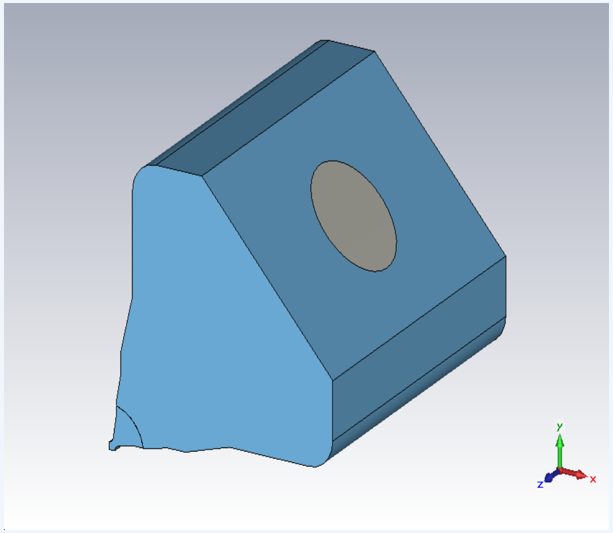
# Design of RFQ cavity

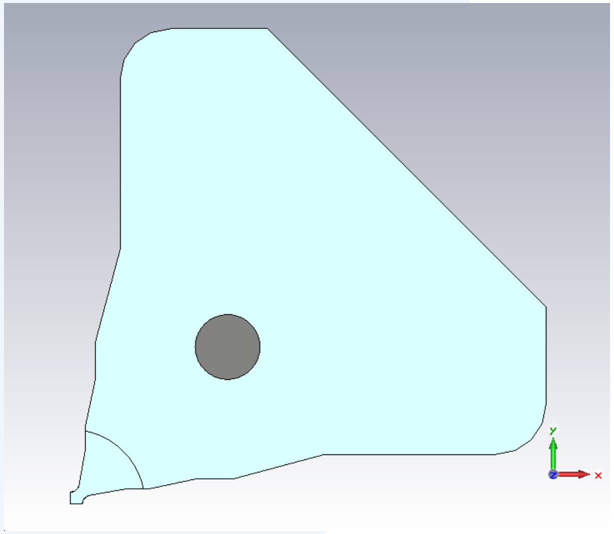
Quardrant model

Tuner effect

Mode stabilizer





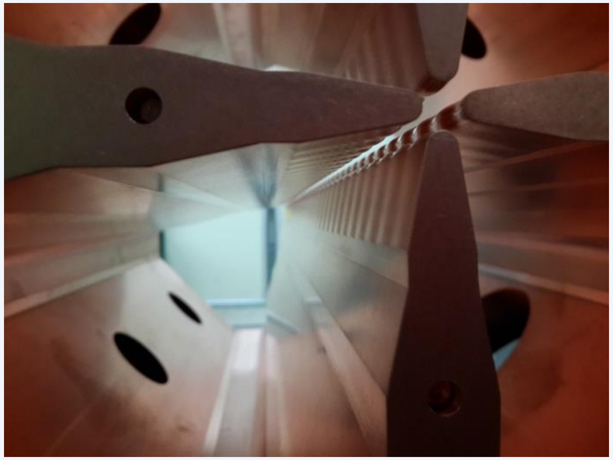


- Resonance frequency: 165 MHz
- Field flatness: <±2.5%
- Tuner sensitivity: 0.117 MHz/mm
- span between two mode(dipole & quadrupole): >4 MHz

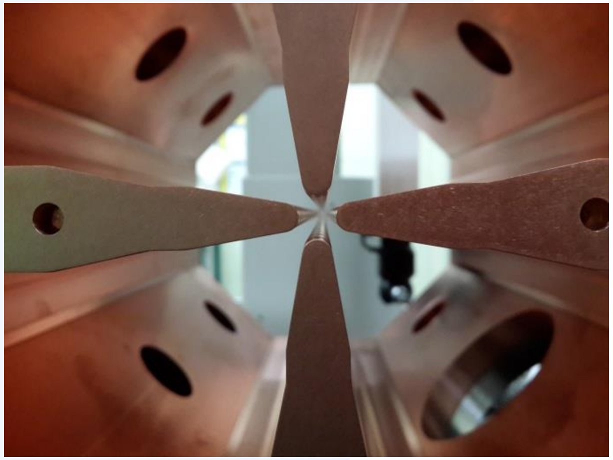
# Design & fabrication of RFQ cavity

1 Section (1/3)

Vane-tip modulation



3D measurement



- Resonance frequency: 165 MHz
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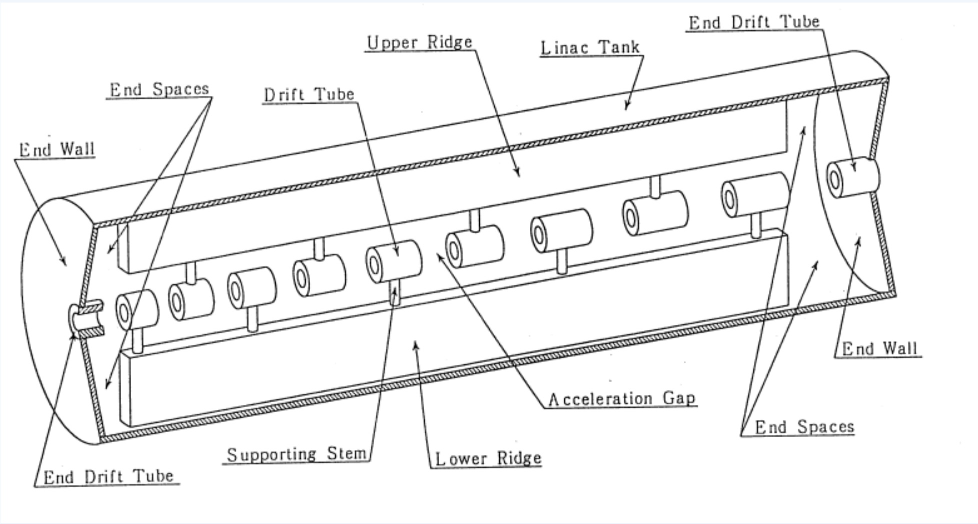
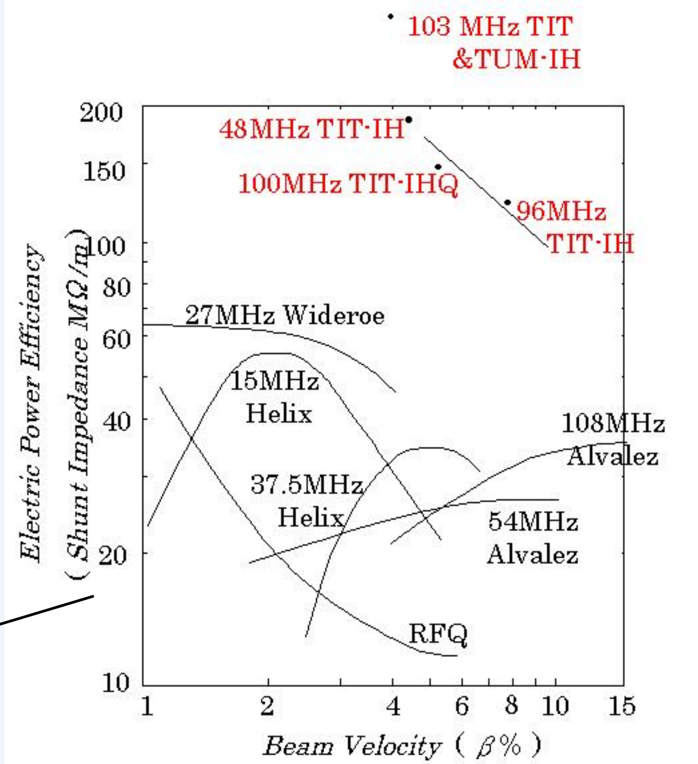
# Interdigital-H (IH) type DTL



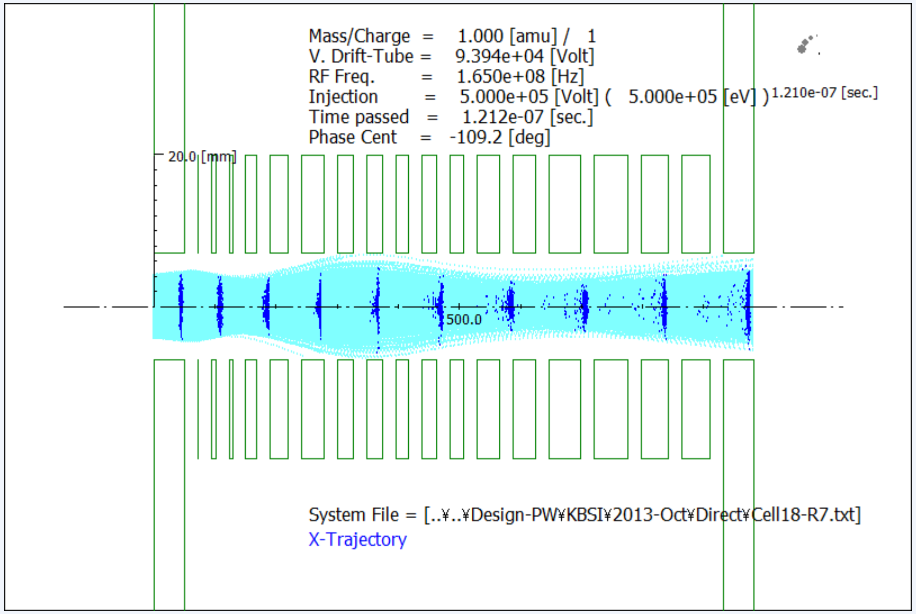

Shunt impedances vs. Beam velocities for different structures

- High Shunt impedance of Interdigital H (IH) Structure
- IH structures have high electric power efficiency in low energy region
- Best choice for the accelerator with compactness and low electric power

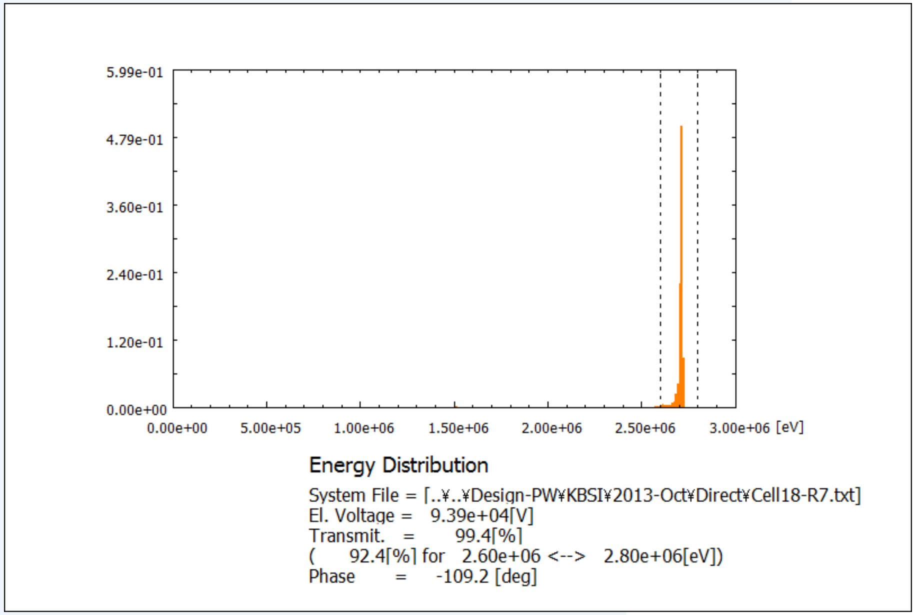
*Courtesy of Prof. T. Hatori @ NIRS*

# Beam dynamics simulation - preliminary study

## Particle trajectory




## Energy distribution




- Total length of DTL: < 2.3 m
- Particle transmission rate: > 92%
- Beam energy: 2.7 MeV/u
- More research for DTL is under way

*Courtesy of Dr. S. Ogata @ Atelier Modeling*

# Future plan

- Optimization of ECR ion source operational condition
- Beam diagnosis under LEBT operation
- Beam acceleration using RFQ LINAC
- Engineering design of Drift Tube LINAC
- Design of neutron application

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# Thank You For Your Attention !