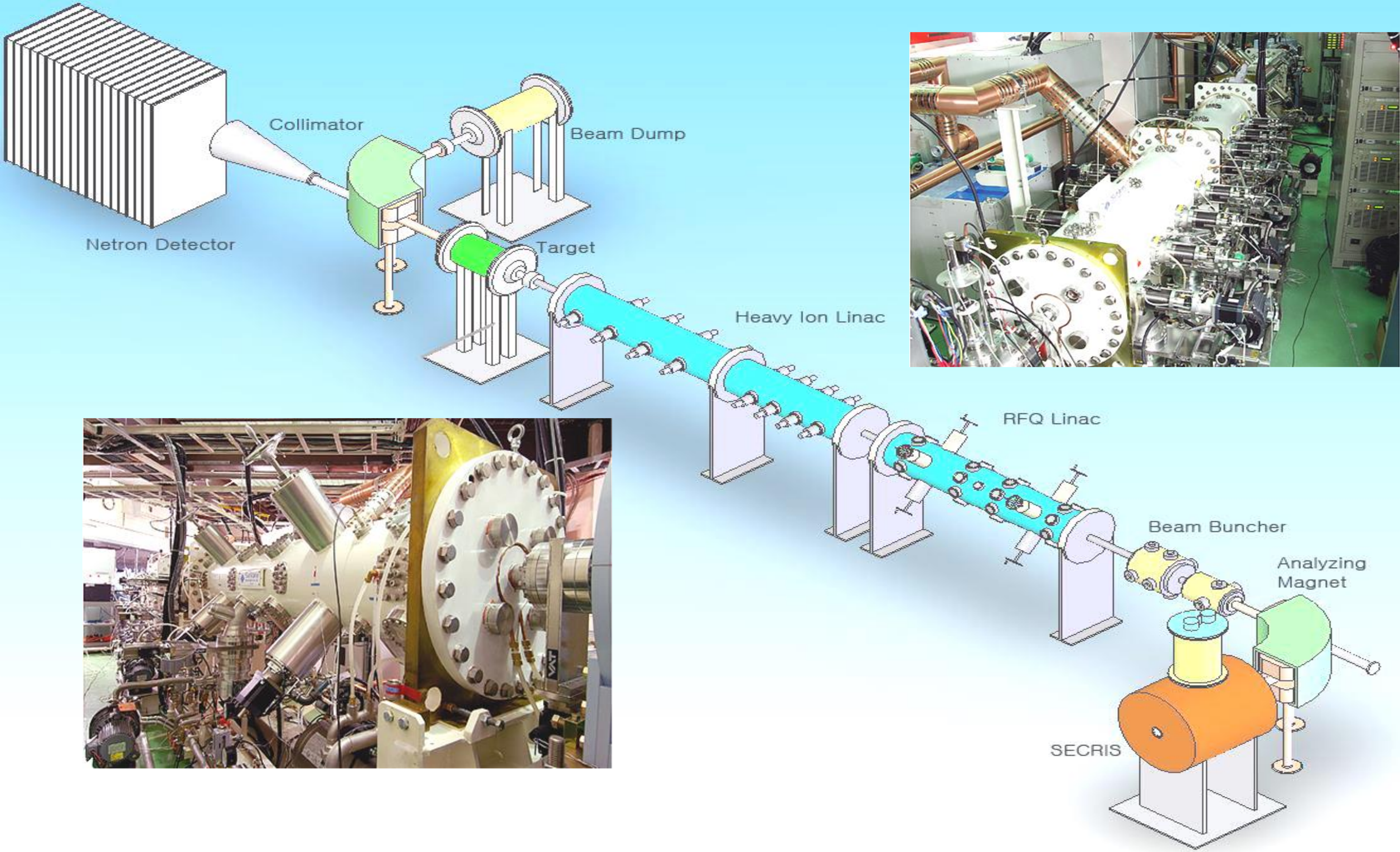
전자 맴돌이 공명(ECR) 이온원 개발 연구

Low Energy Heavy-Ion Beam Facility
at Korea Basic Science Institute

박진용, 안정근
이효상, 이병섭, 원미숙, 김종필, 윤장희
(Pusan National University
&
Korea Basic Science Institute)

1. Low Energy Heavy-Ion Beam Facility for fast neutron production
2. Fast Neutron Radiography & Applications
3. Superconducting ECR Ion Source and Prototype ECR Ion Source Project at KBSI
4. Current Status and Prospects

Schematic view of the Heavy-Ion Beam Facility



Featured Specifications

ECRIS	S-ECR : 10kW, 28GHz, 3W G-M cooler (4K) PM-ECR: 1kW, 2.45GHz
RFQ	8 keV/u → 0.6 MeV/u 200MHz, Q/M=1/2, Length ~2m, Diameter 35cm
HI-DTL	0.6 MeV/u →4 MeV/u 200MHz, Q/M=1/2, Length ~3.2m Diameter 35cm
Production Target	Hydrogen Gas Target at 500Torr
Beam Current	Li^{3+} 5mA / Ar^{8+} 2mA / Kr^{13+} 0.6 mA / Xe^{20+} 0.3 mA, Fast neutron 10^{12}/s with Li^{3+} 1mA

Fast Neutron Radiography

Neutron radiography

- Penetration thru high-Z material
- Sensitive to Low-Z material

Fast Neutron

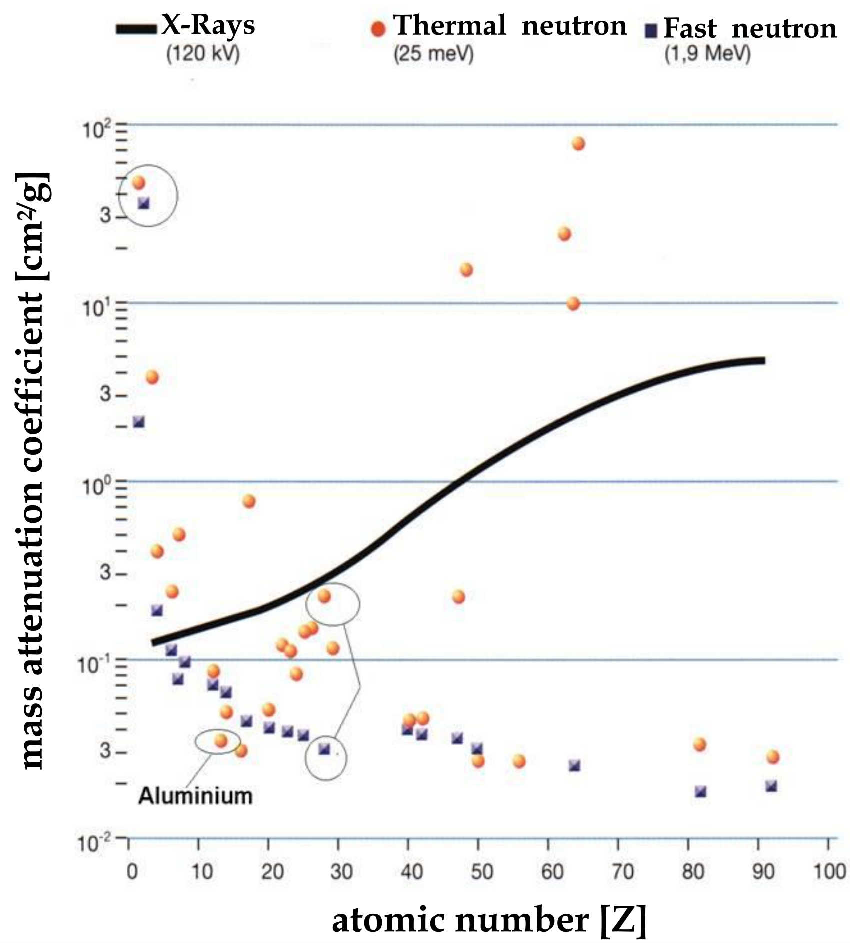
$$^{3}H(d,n)^{4}He$$

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

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

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

Neutron absorption



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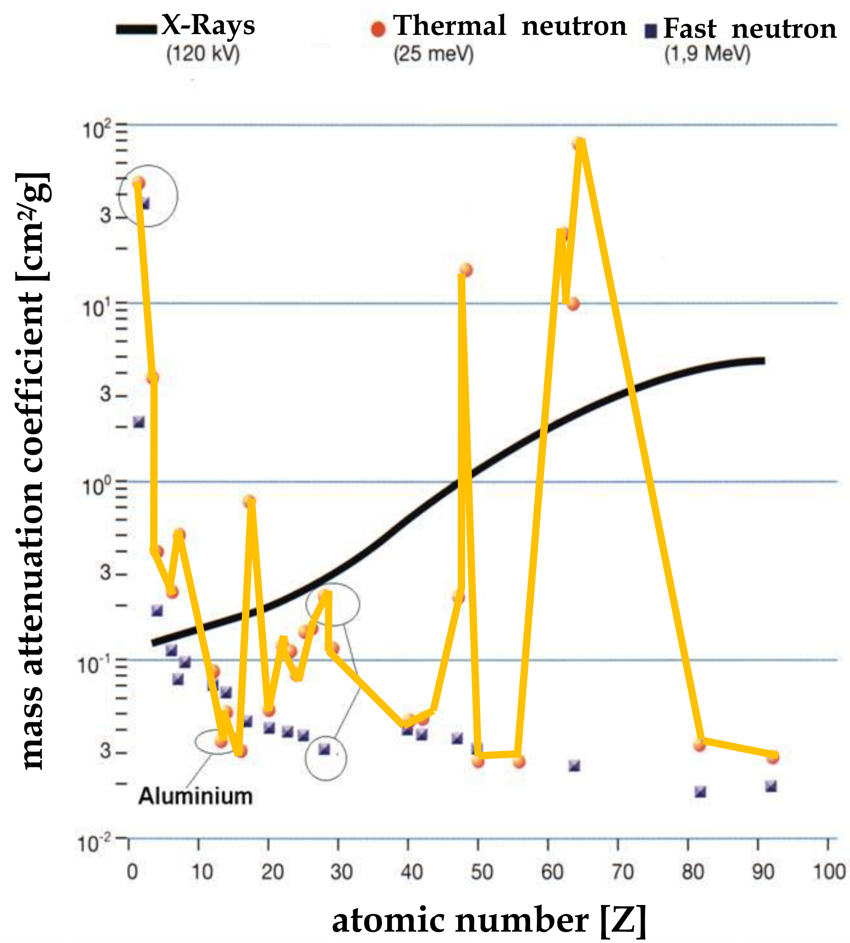

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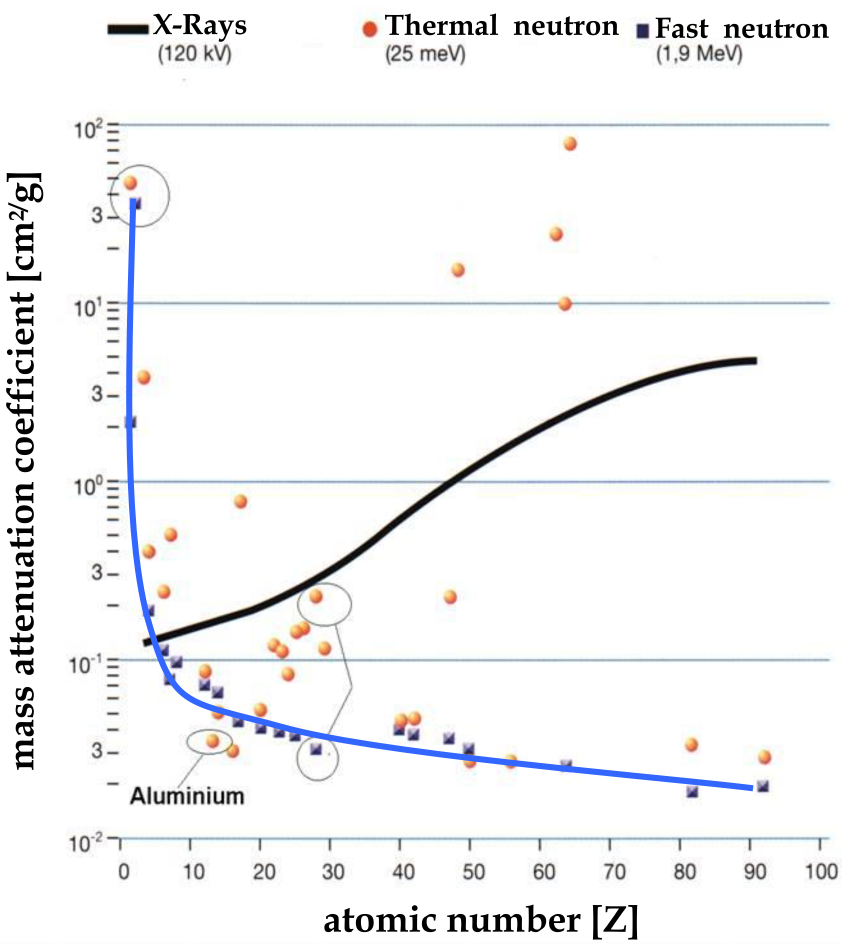
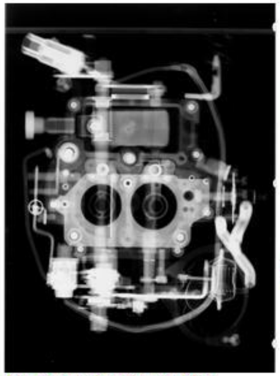
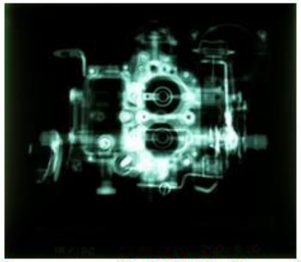


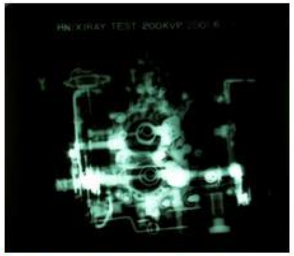
Fast Neutron Radiography



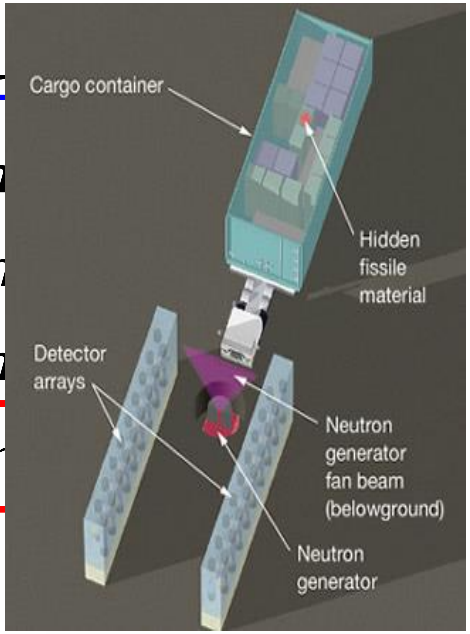
Neutron Radiography



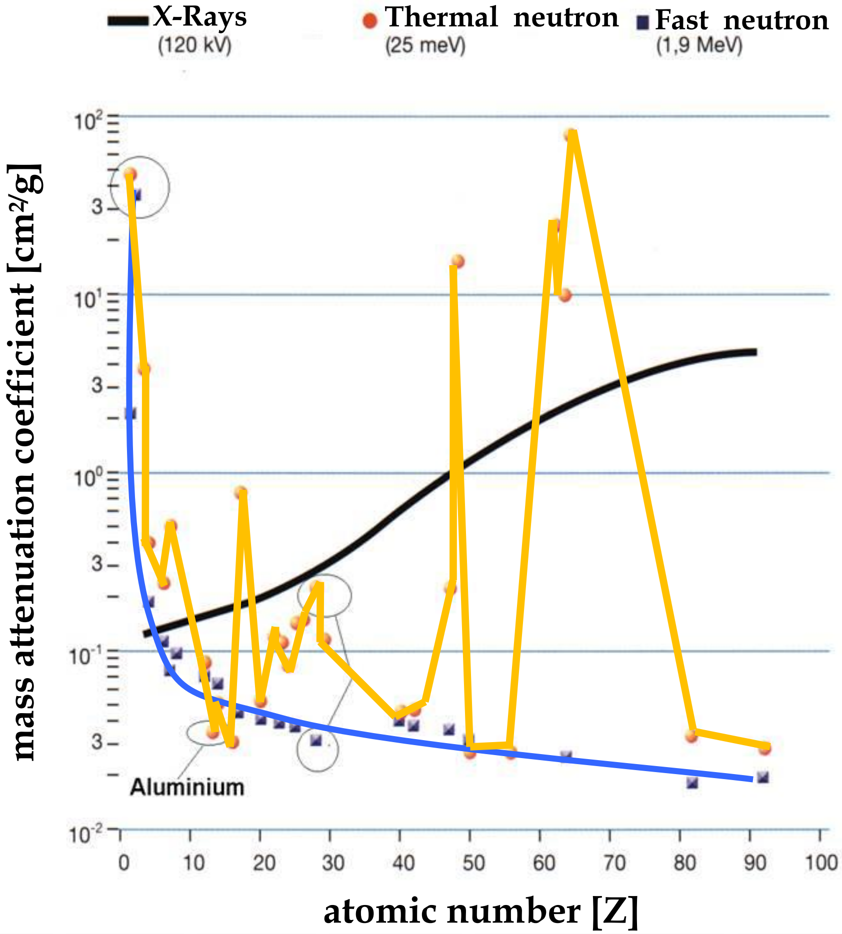
Gamma-ray(Ir-192) Radiography



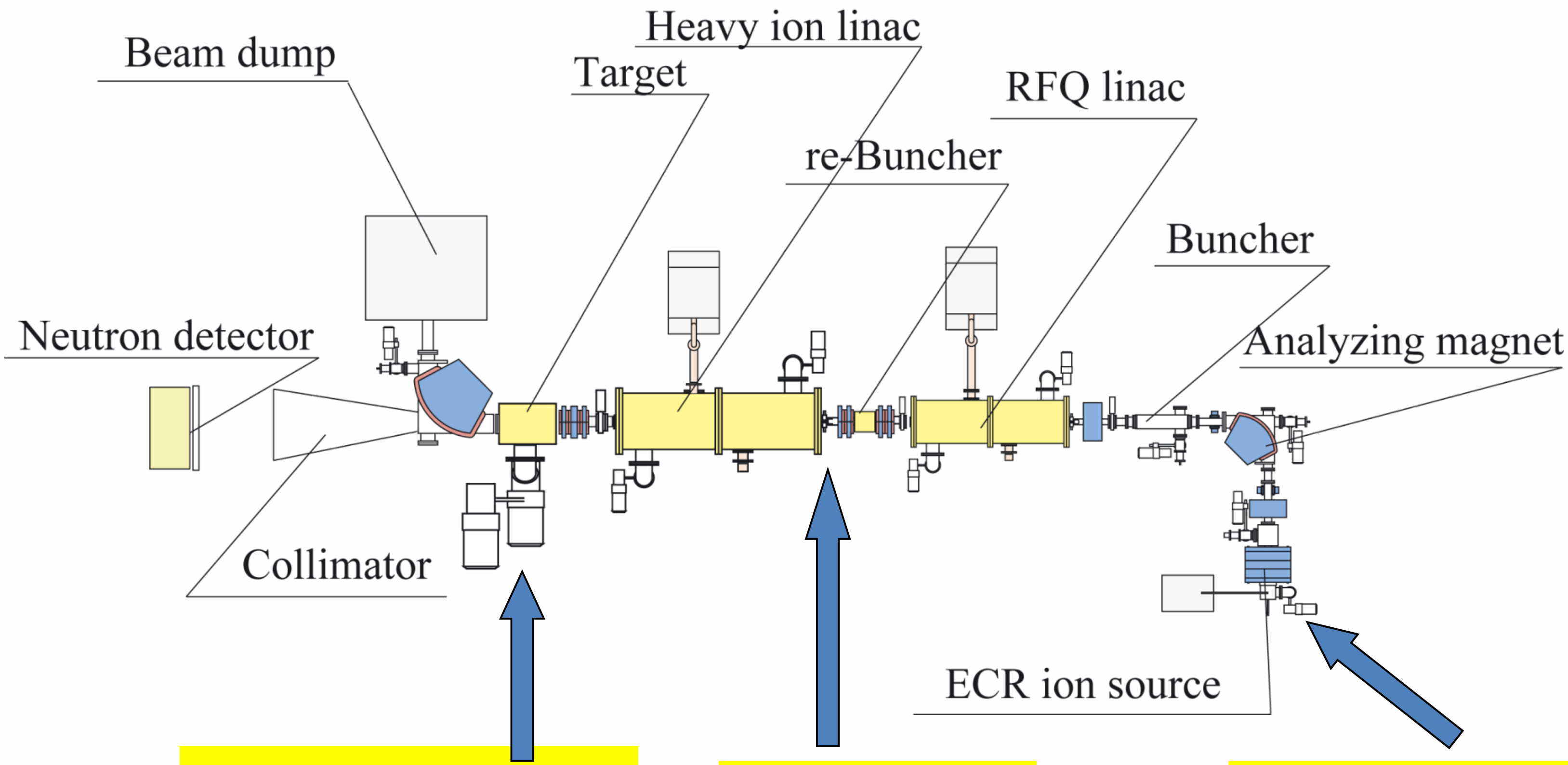
X-ray(200 KeV) Radiography



Neutron absorption



Fast Neutron Beam Facility



Neutron production
2.5MeV ~10^12/sec

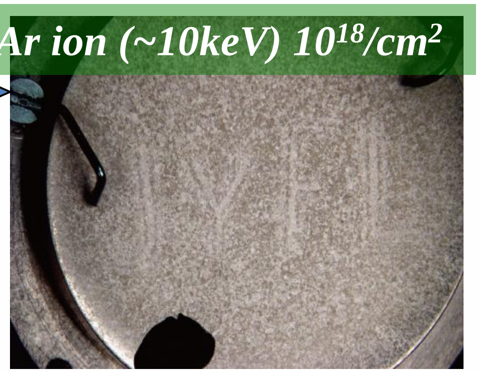
Acceleration
~2.5MeV/u

(Li^2~3+ production
>1pmA)

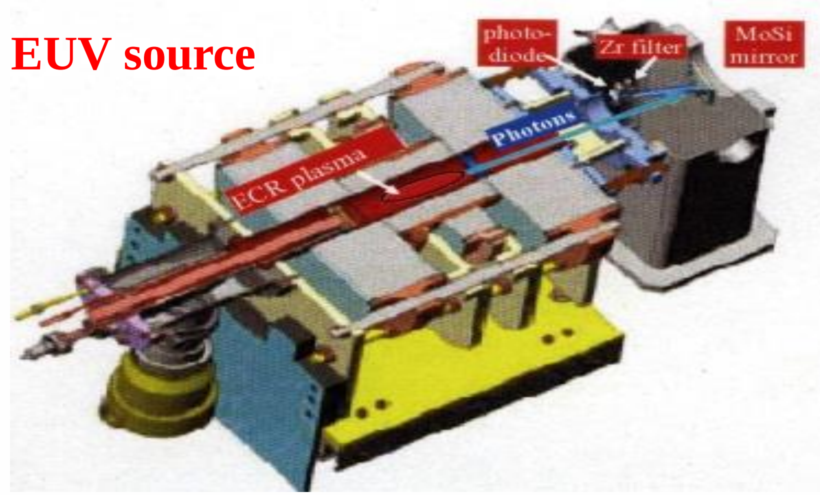
H(^{7}Li, n)^{7}Be Inverse kinematics

Application of the ECR Ion Source

Imaging of Deformed metal surfaces



EUV source



PECRIS
beam intensity Xe^{10+} 70μA
EUV power 100mW/2π sr

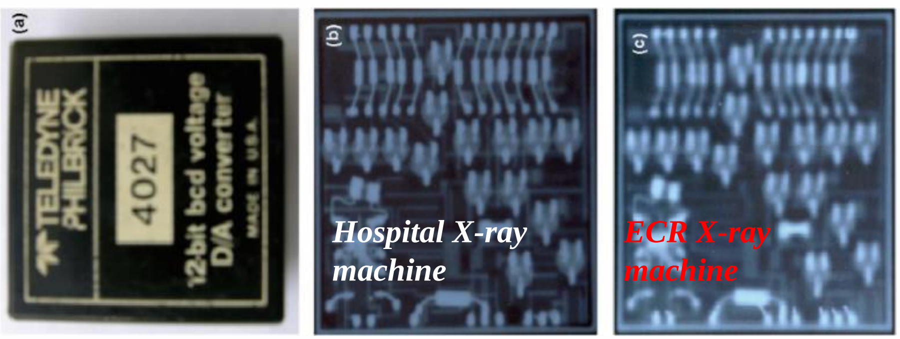
⇩

18 GHz ECRIS
beam intensity Xe^{20+} 300μA
Xe^{10+} ~3mA
EUV power 4W/2π sr

⇩

28GHz ECRIS ~ 100W/2π sr

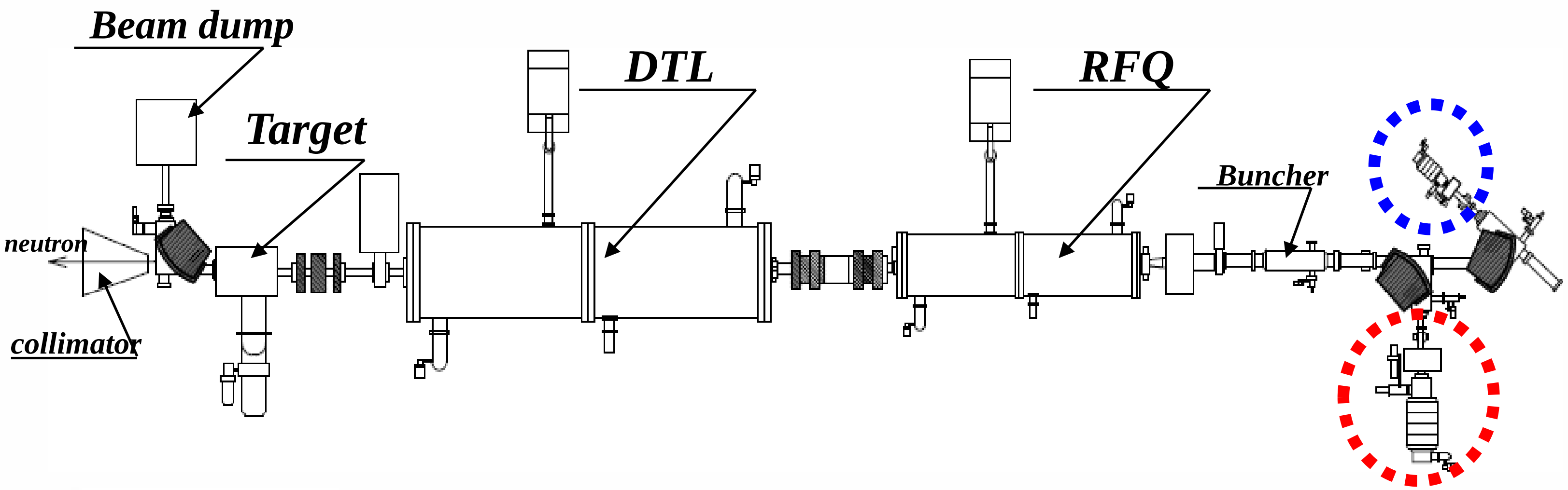
X-ray source



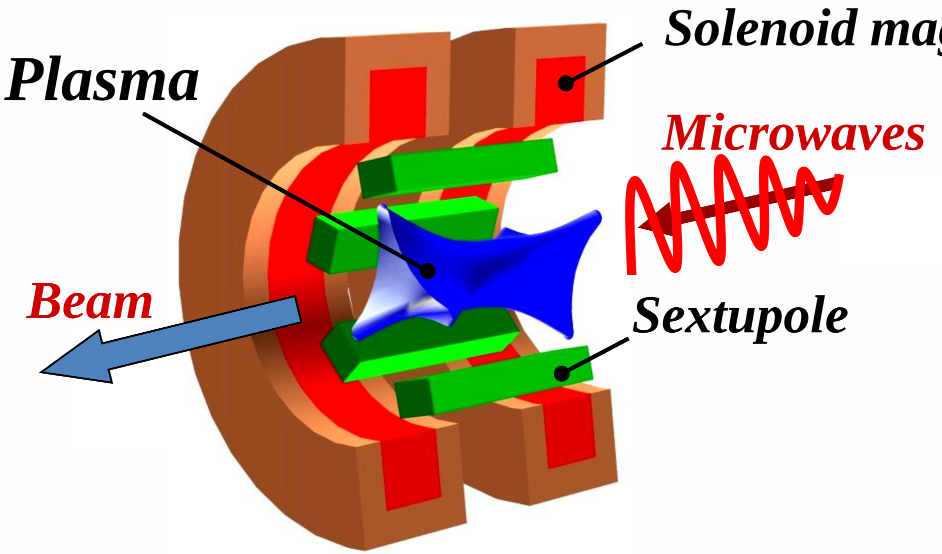
High energetic X-ray (~100 keV) without High voltage
Easily change the X-ray energy
High x-ray flux (~ 10R/h ~ 100msr/h)

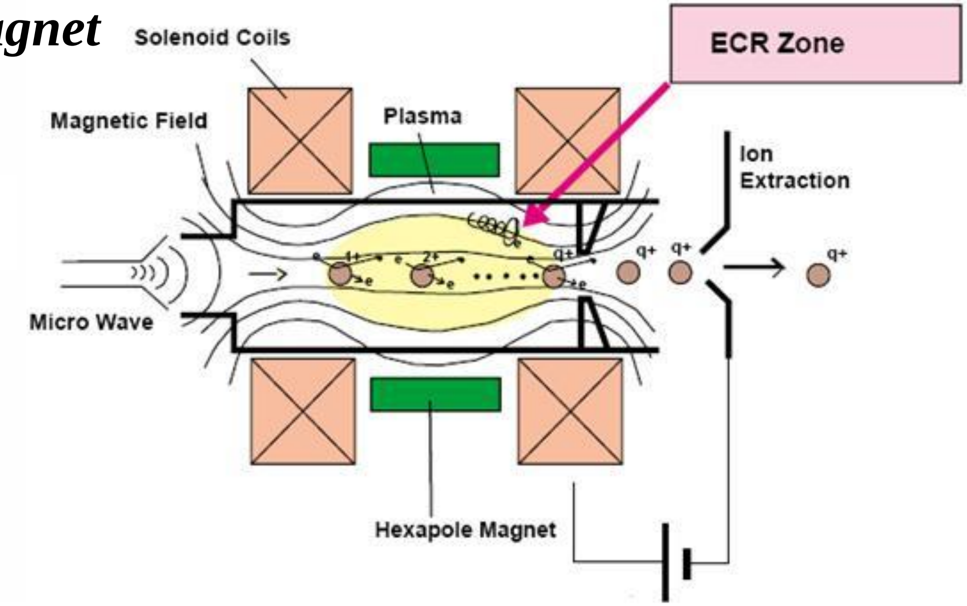
Current Trends in Development of the ECR Ion Source

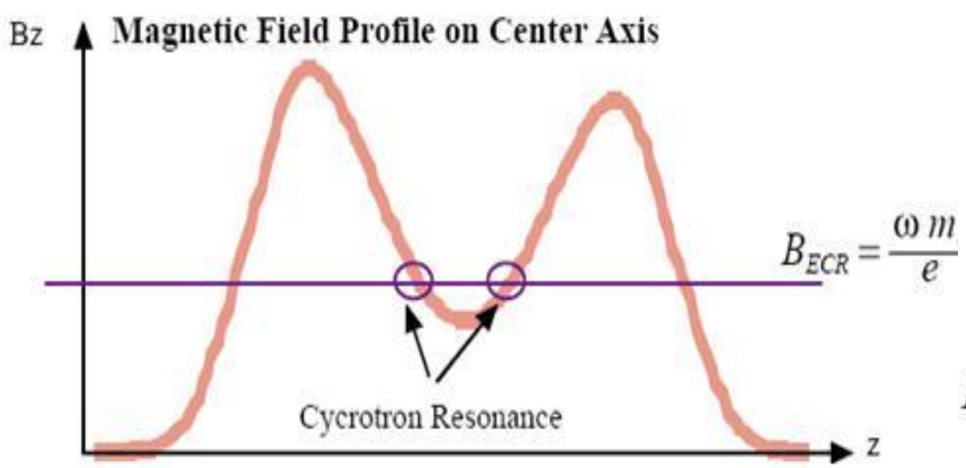
- Low cost and Compact ECRIS
  -> Permanent magnet ECRIS
- High current and multiply charged Ion Source
  -> Superconducting ECRIS

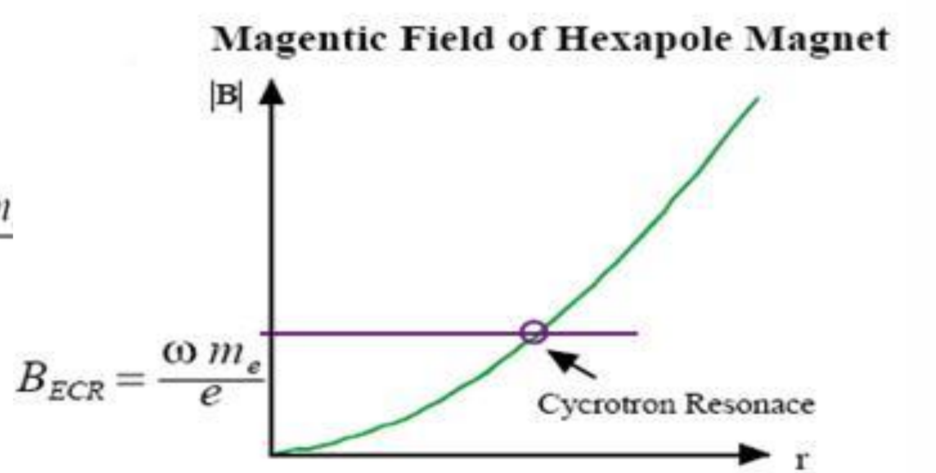


Principle of the ECR Ion Source

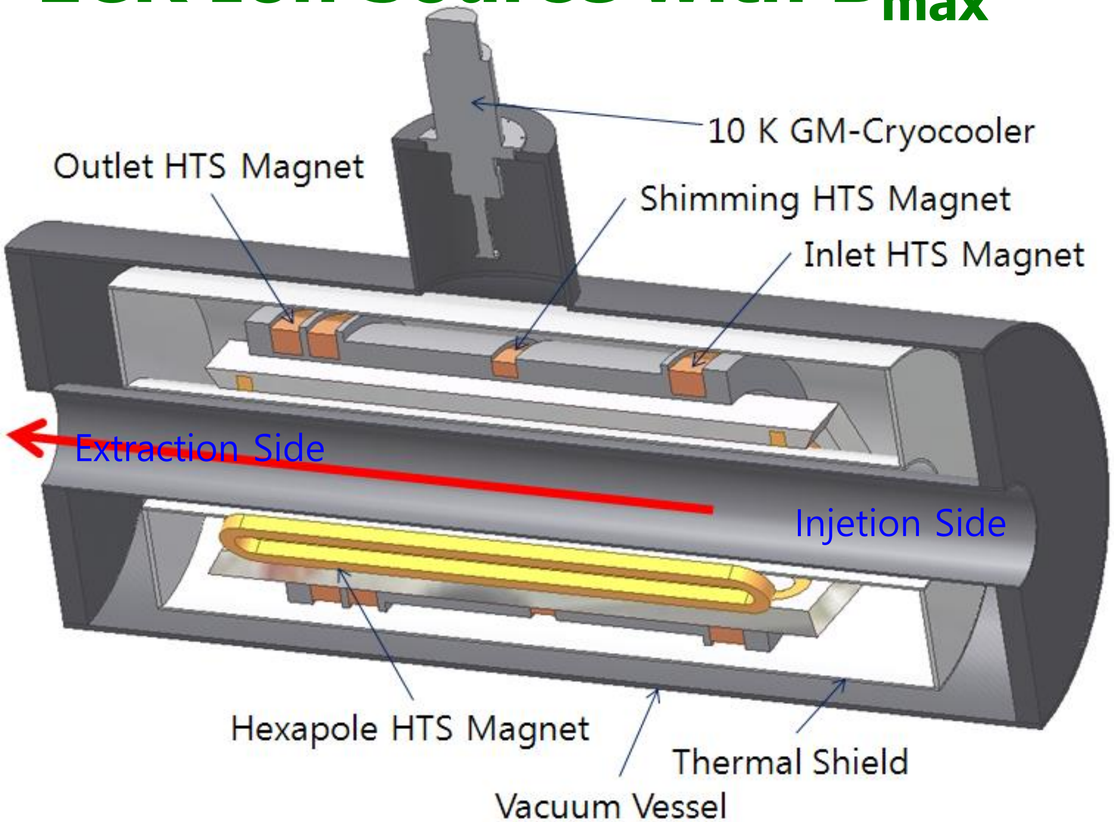








28GHz 10kW Superconducting ECR Ion Source with B_{max} = 4T

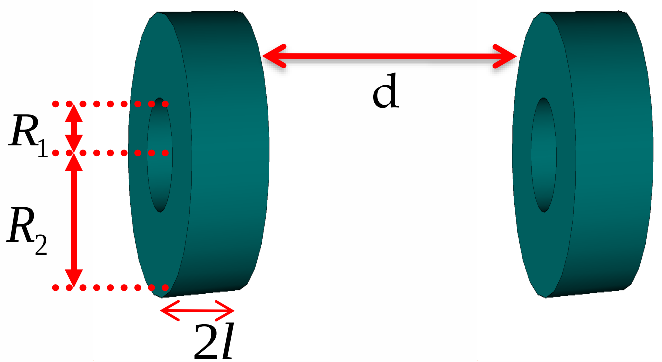


- 전도 냉각형 고온 초전도 자석
  (높은 안정성, 저렴한 유지 비용)
- Volume Type ECR Zone 설계
  (에너지 전달 효율 증대)
- Hexapole 자석을 위한
  고강도 구조 설계
- High-B mode 운영을 위해
  설계 수정 중
  (High intensity beam 산출)
- 28 GHz Gyrotron 설계 진행중

Target Ion
- Li $^{3+}$ 5mA / Ar $^{8+}$ 2mA
- Kr $^{13+}$ 0.6 mA / Xe $^{20+}$ 0.3 mA

Optimized configuration of permanent magnets

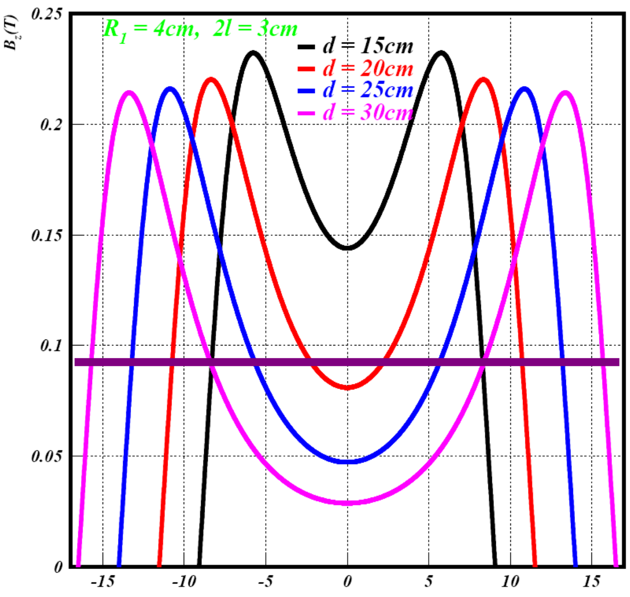
Annular Magnet

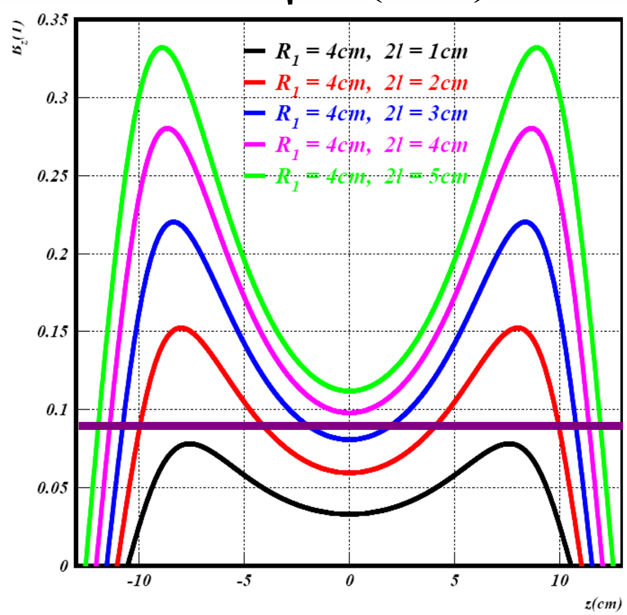


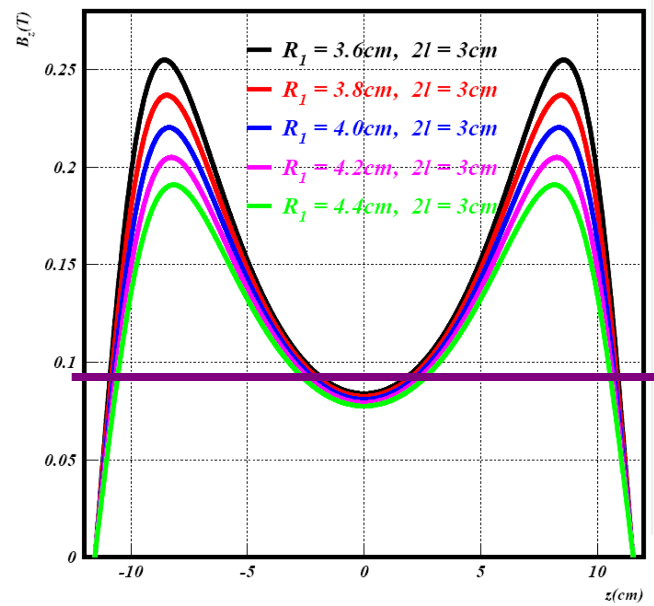
$$B_z(z)=\frac{B_r}{2}\left(\frac{1}{a_1}-\frac{1}{a_2}-\frac{1}{b_1}+\frac{1}{b_2}+\ln\left(\frac{(1+b_1)(1+a_2)}{(1+b_2)(1+a_1)}\right)\right)$$

$$a_1=\sqrt{1+\left(\frac{z+l}{R_2}\right)^2},\qquad a_2=\sqrt{1+\left(\frac{z-l}{R_2}\right)^2}$$

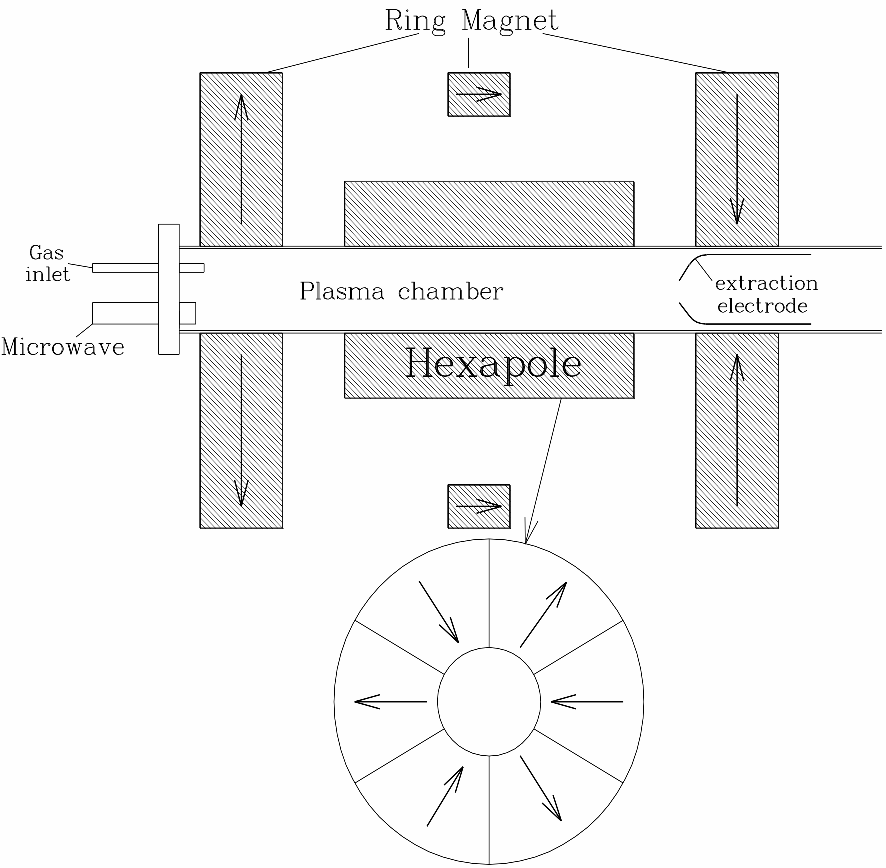
$$b_1=\sqrt{1+\left(\frac{z+l}{R_1}\right)^2},\qquad b_2=\sqrt{1+\left(\frac{z-l}{R_1}\right)^2}$$

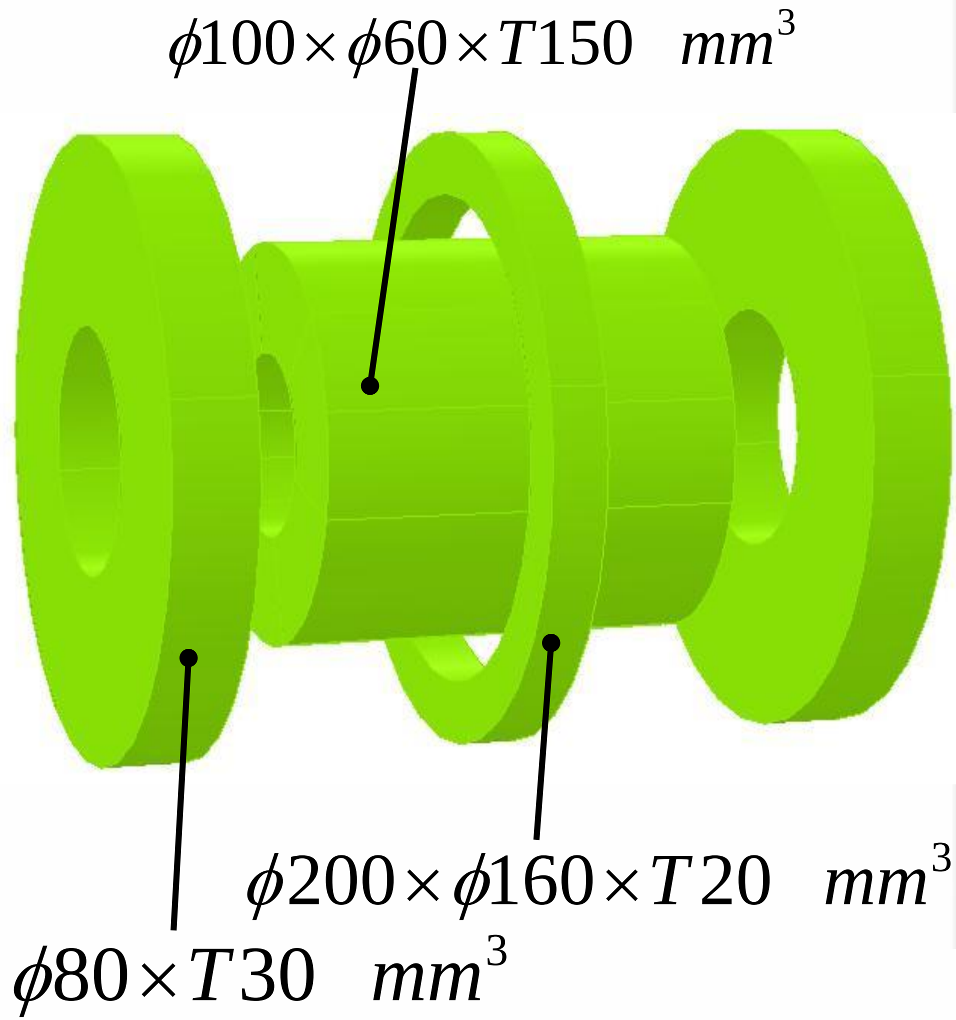




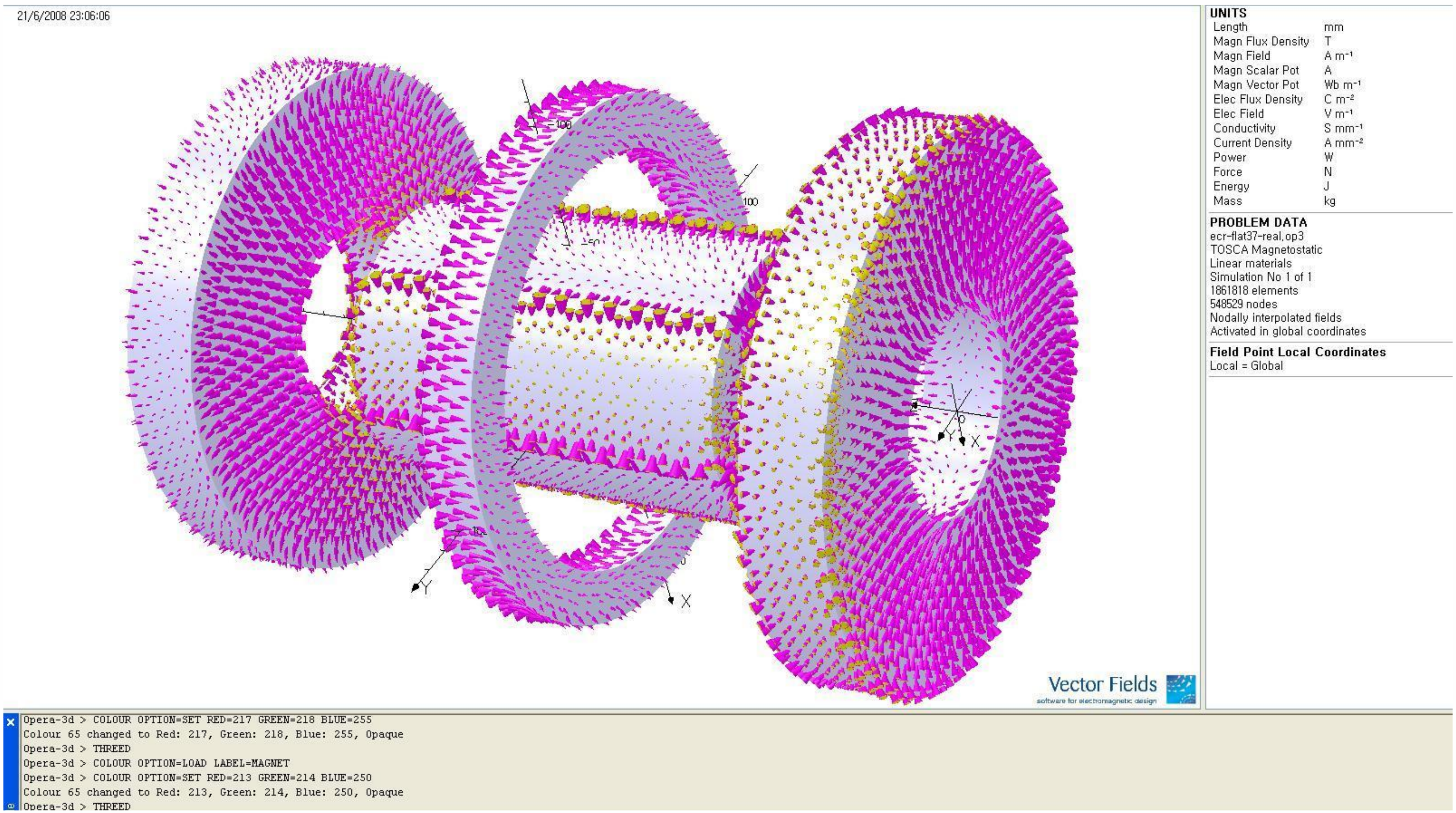


Geometry of Prototype ECRIS



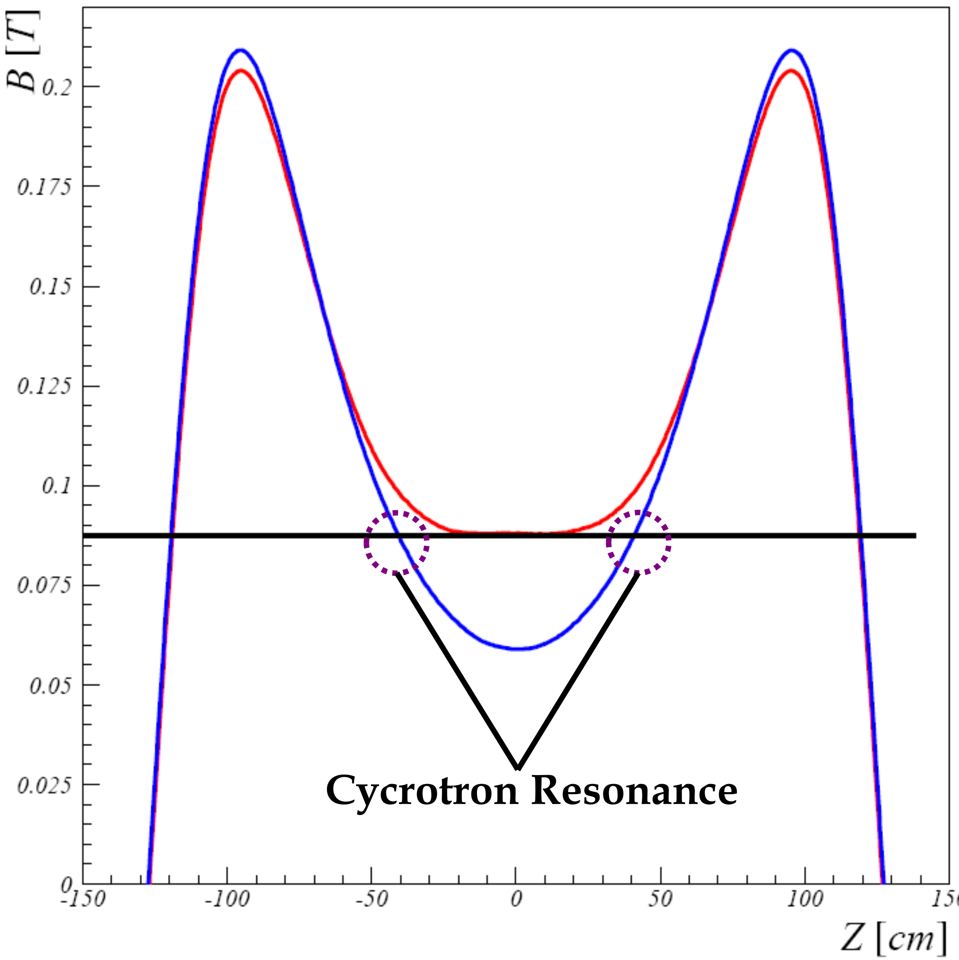


Opera-3D Simulation Results

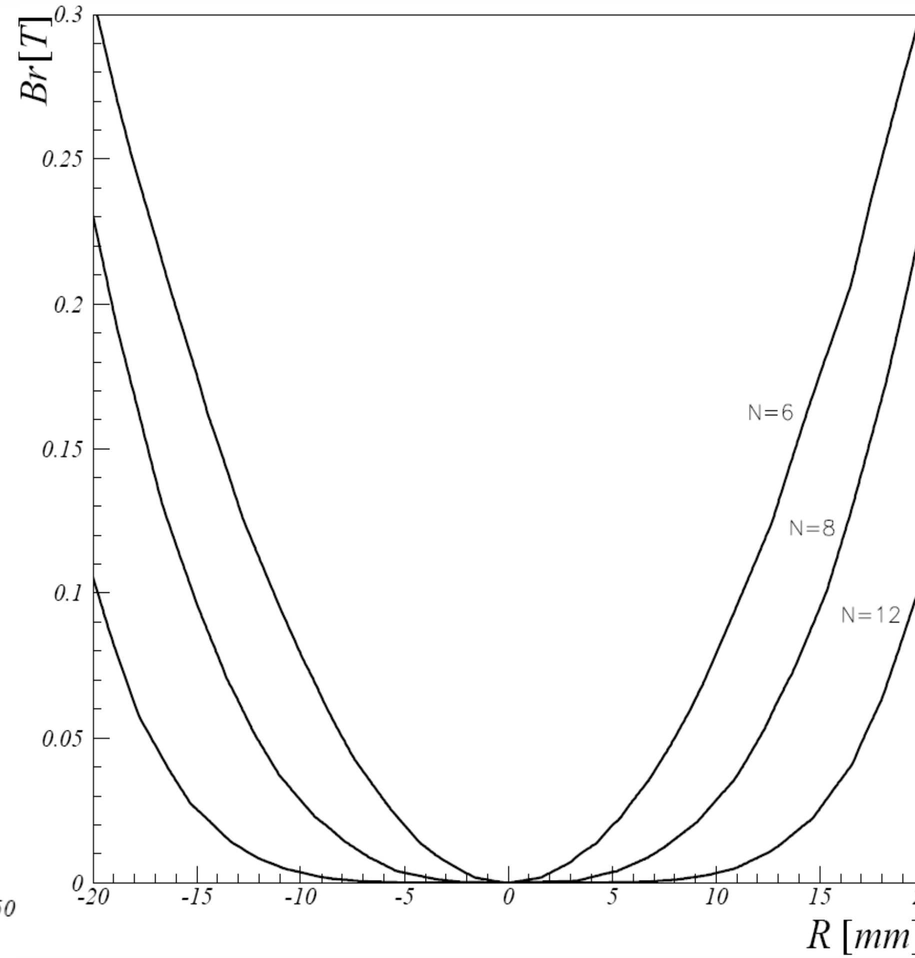


Opera-3D Simulation Results

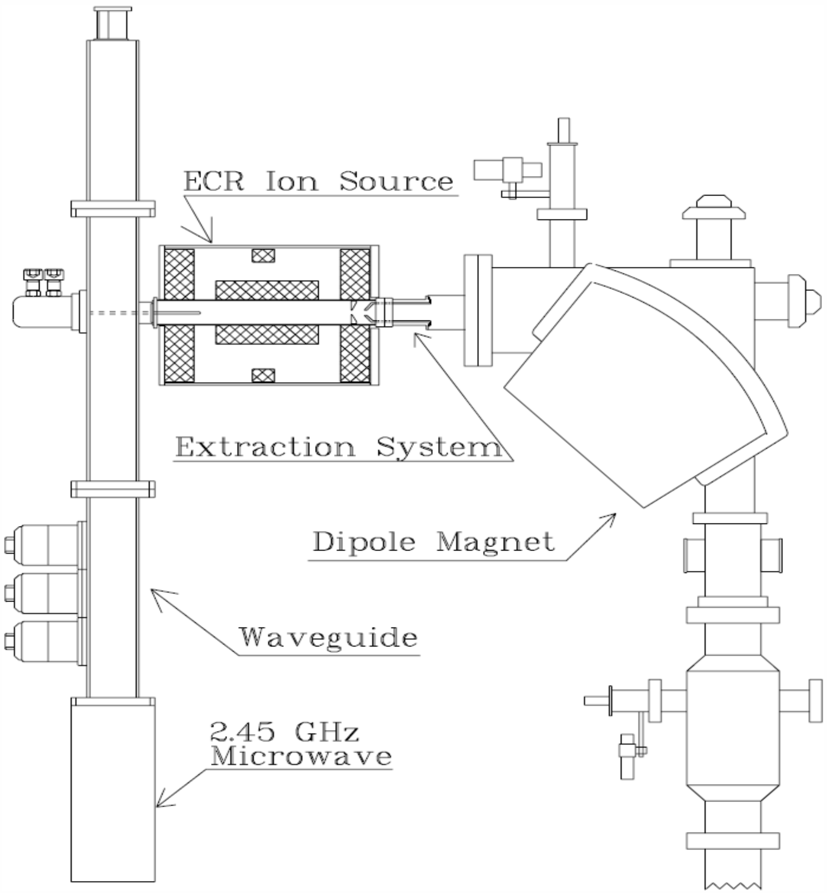
Magnet Field Profile on Center Axis

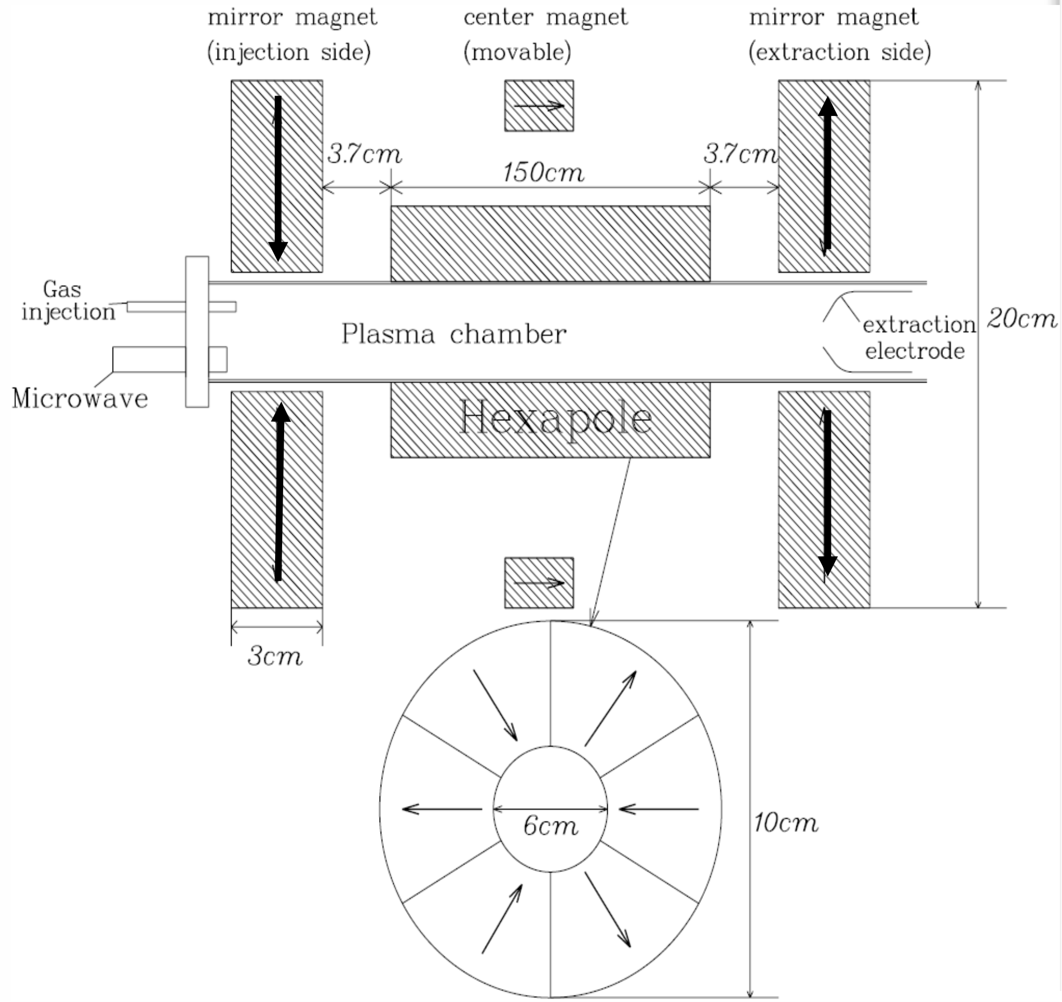


Magnet Field Hexapole Magnet



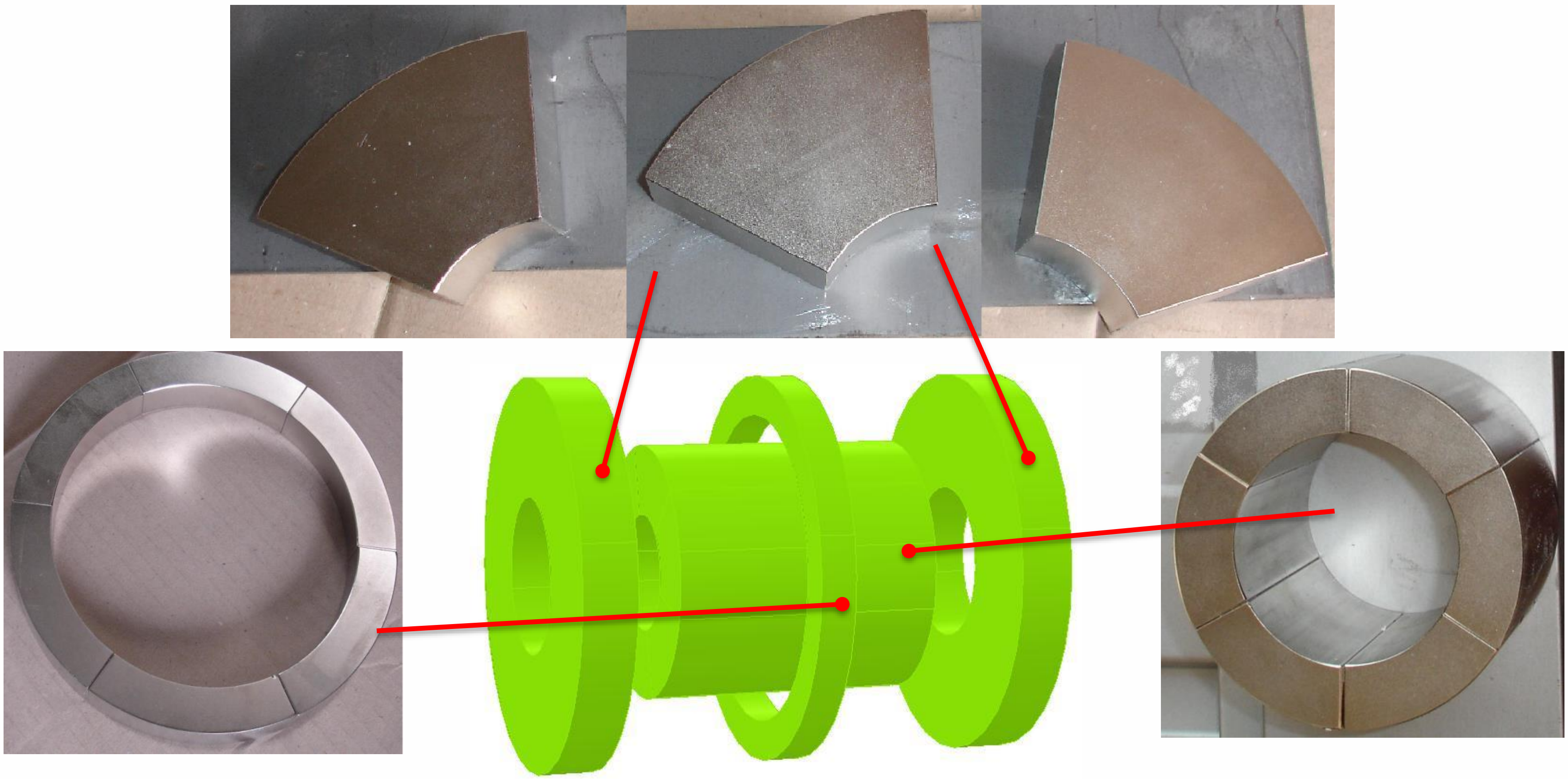
Schematic view of Prototype ECR ion source





Permanent Magnet

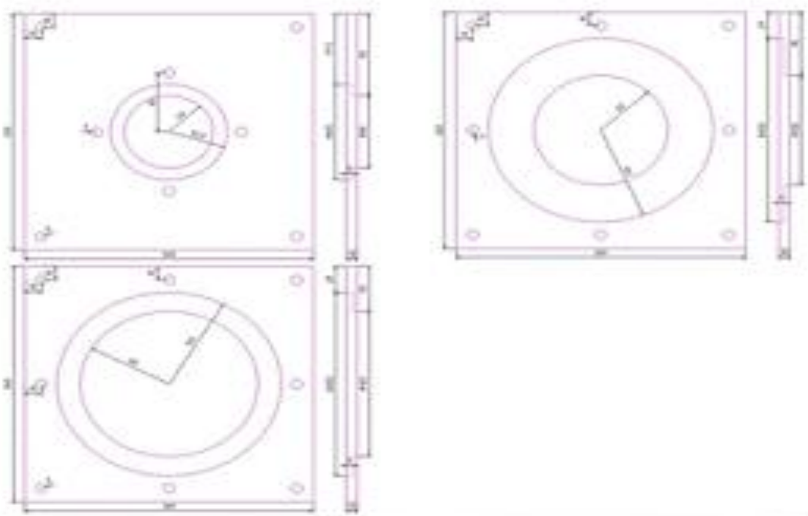
$\phi195\times\phi75\times T30\quad mm^3$

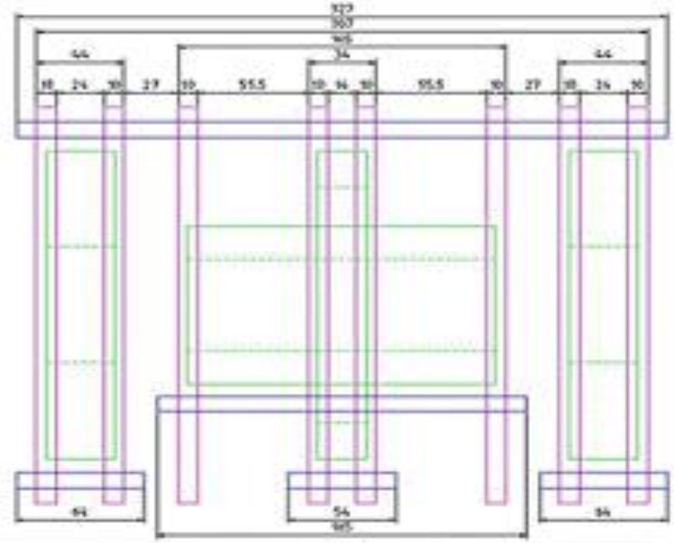


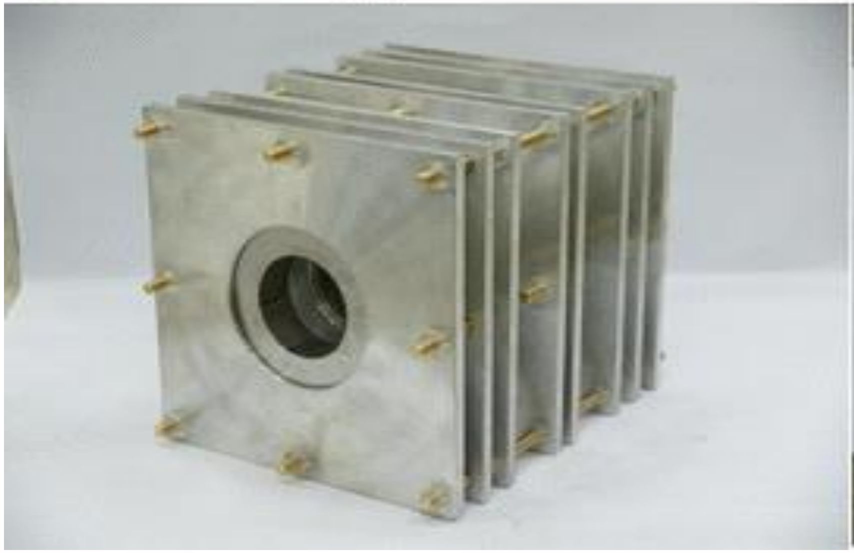
$\phi195\times\phi160\times T20\quad mm^3$

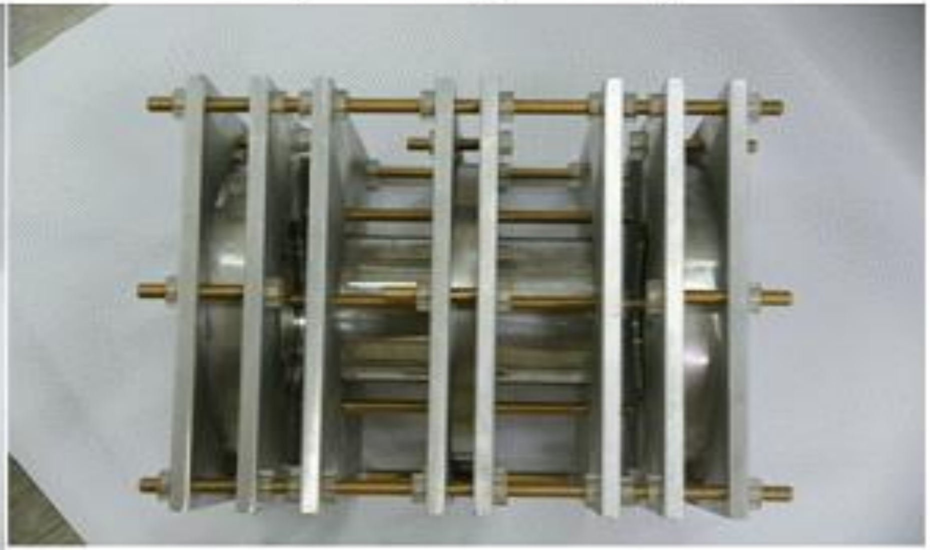
$\phi100\times\phi60\times T150\quad mm^3$

Permanent Magnet & Structure



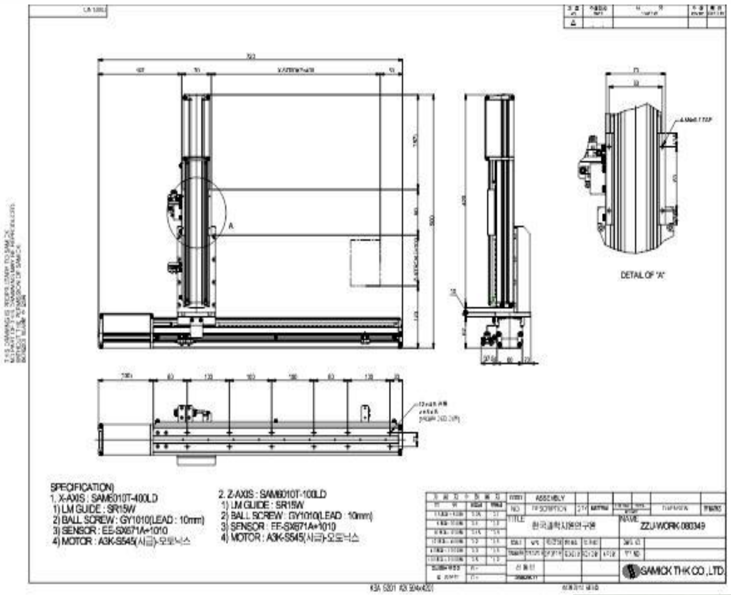


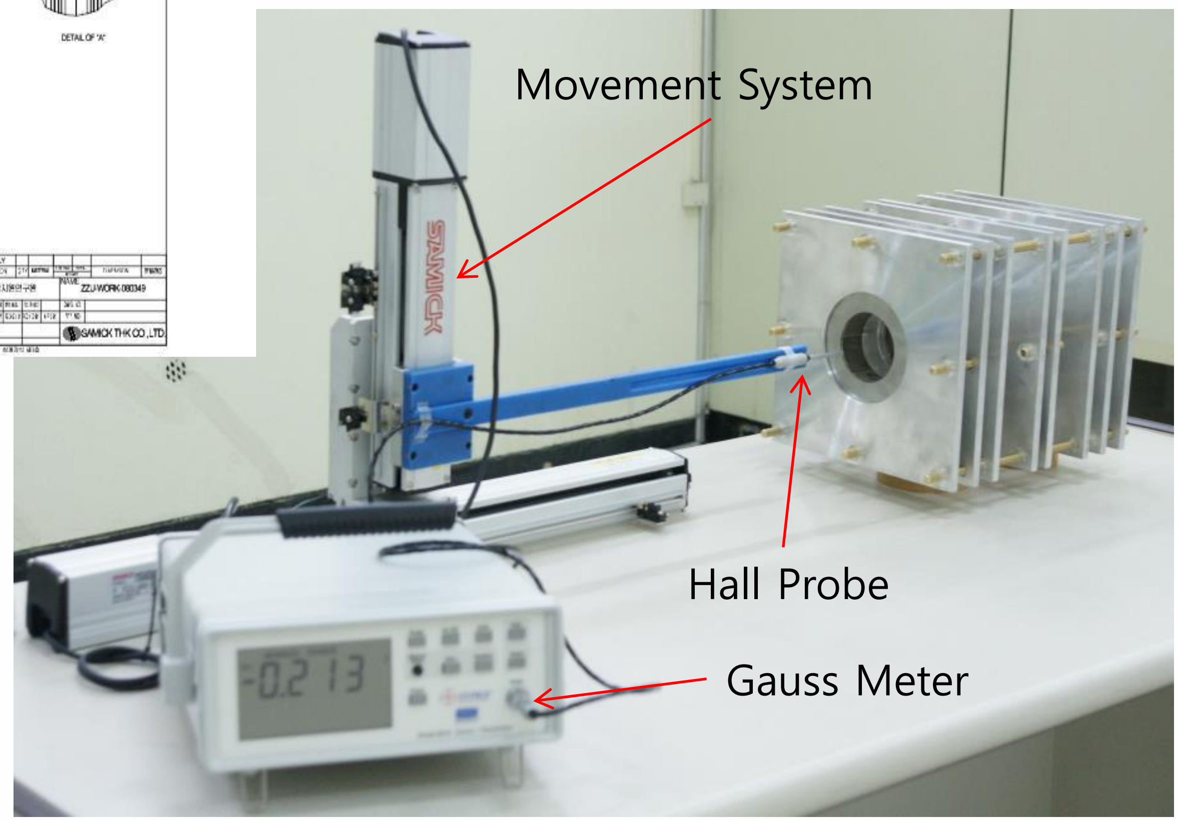




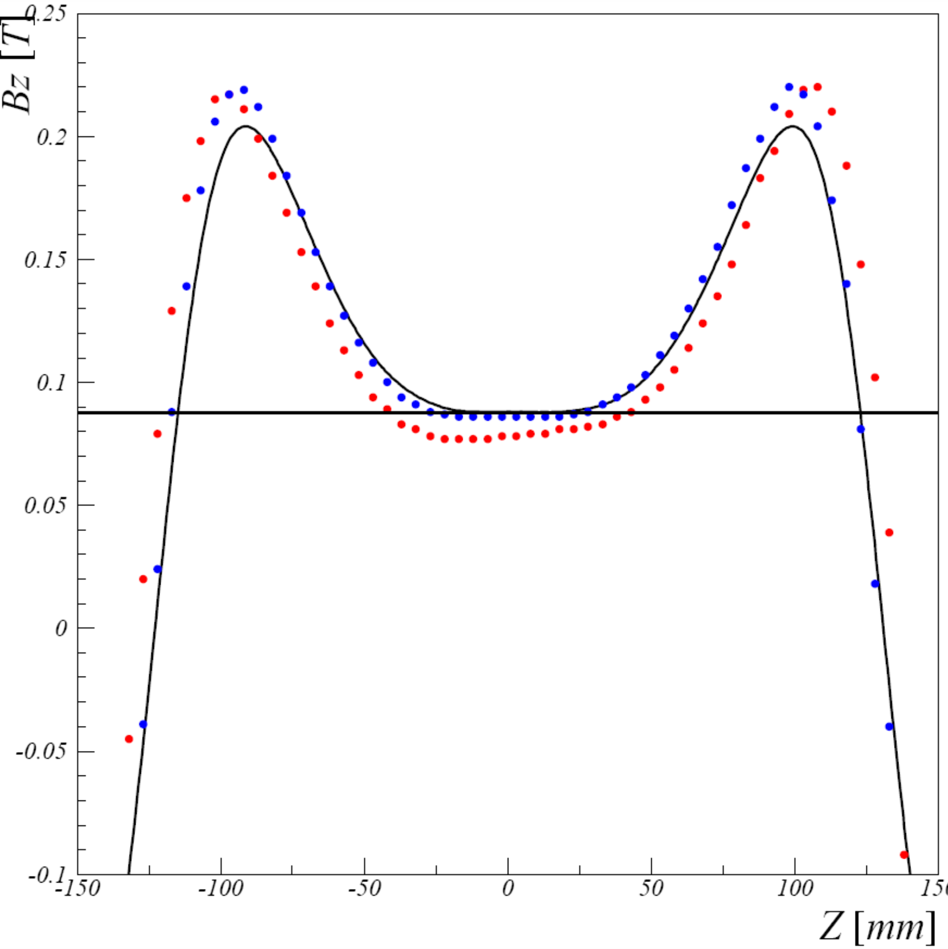
테스트 벤치 구축

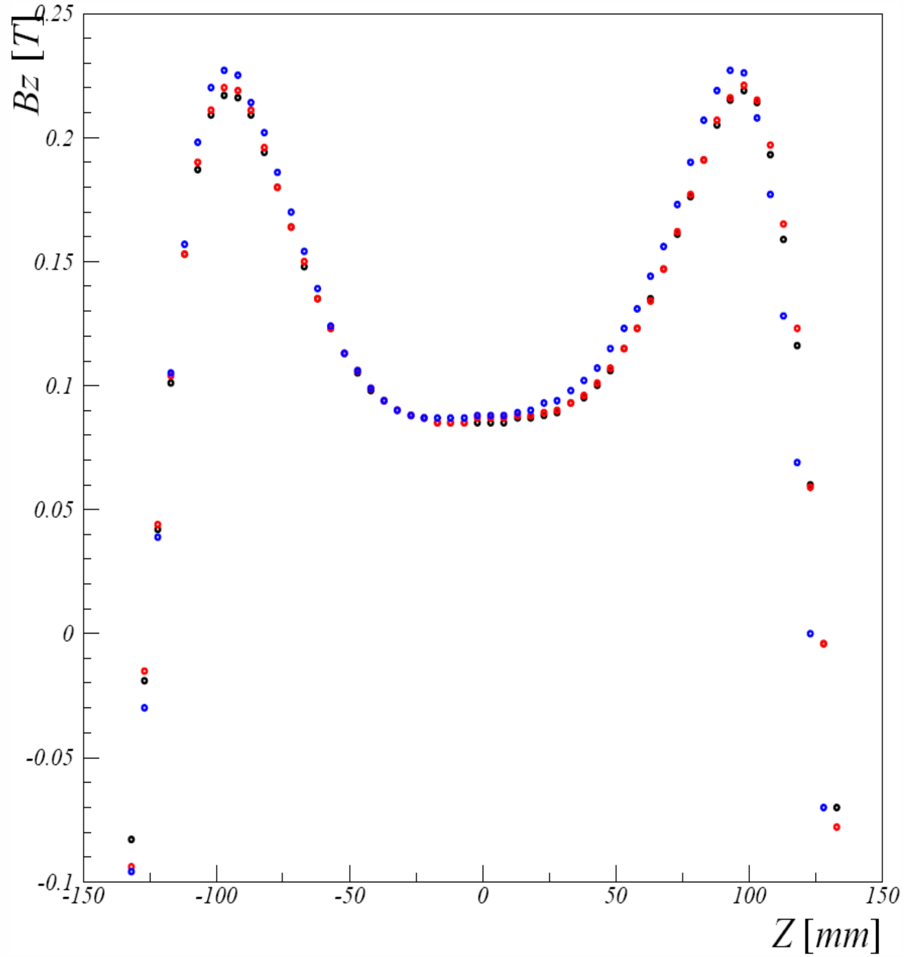
- 테스트 벤치 구축 완료
- 2.45 GHz Proteptype ECR 이온원 자기장 측정



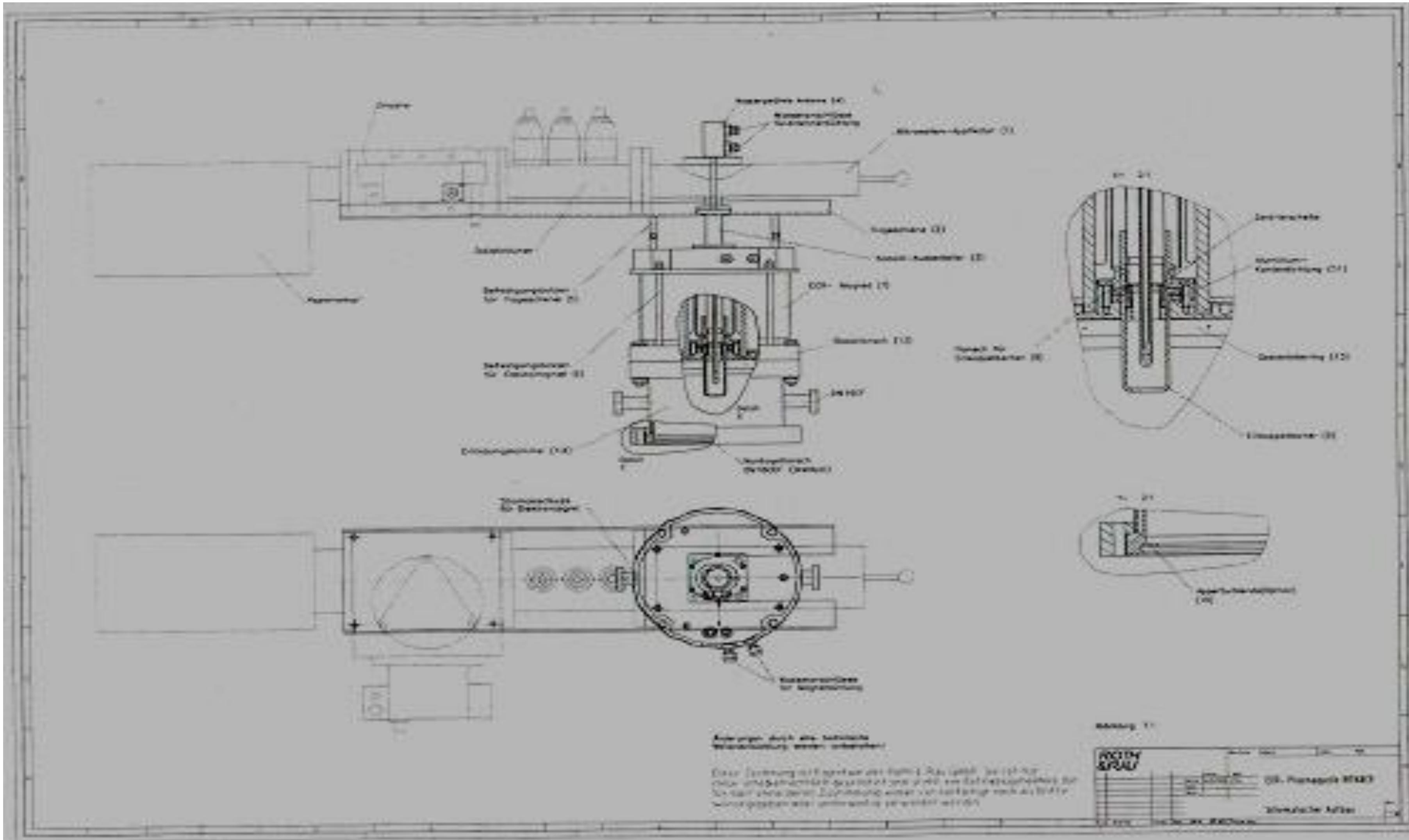


측정결과

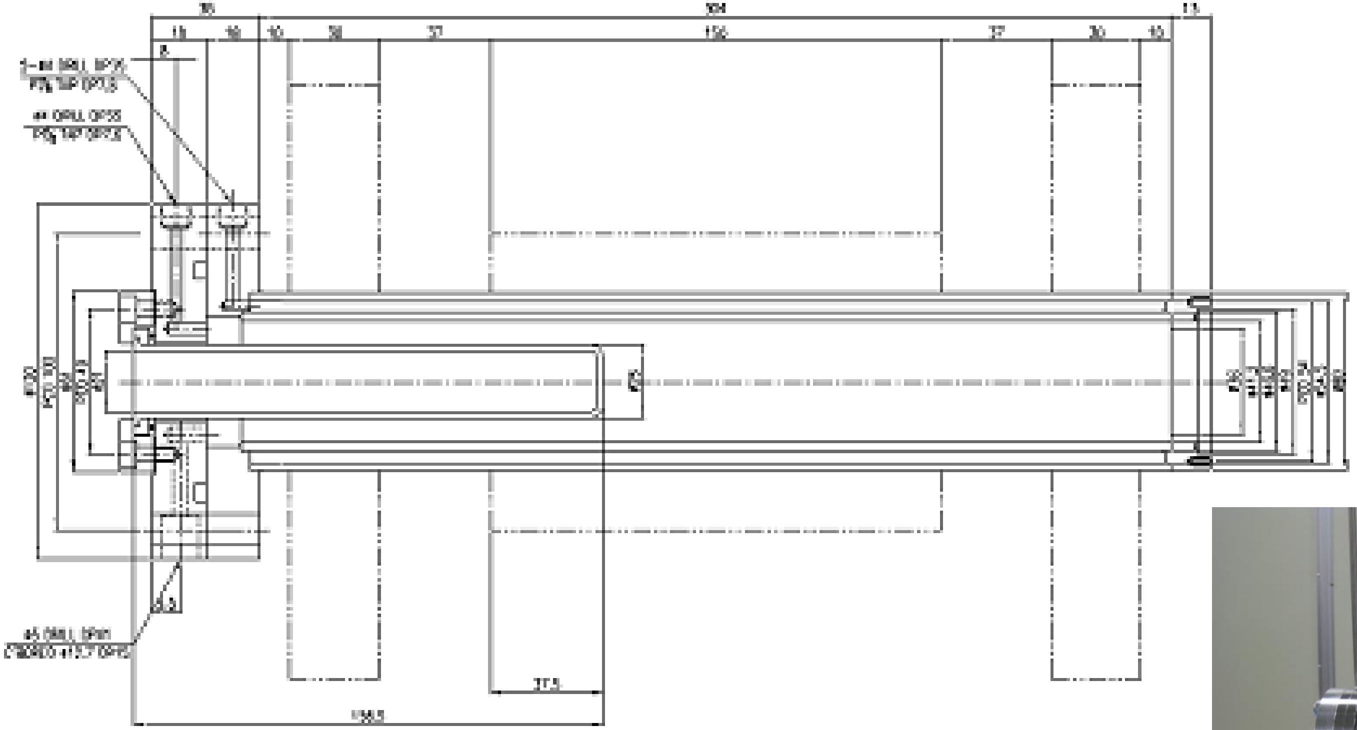

Bz [T]
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-150
-100
-50
0
50
100
150
Z [mm]

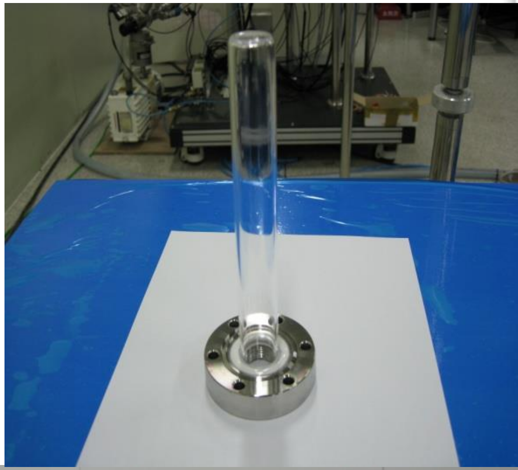

Bz [T]
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-150
-100
-50
0
50
100
150
Z [mm]

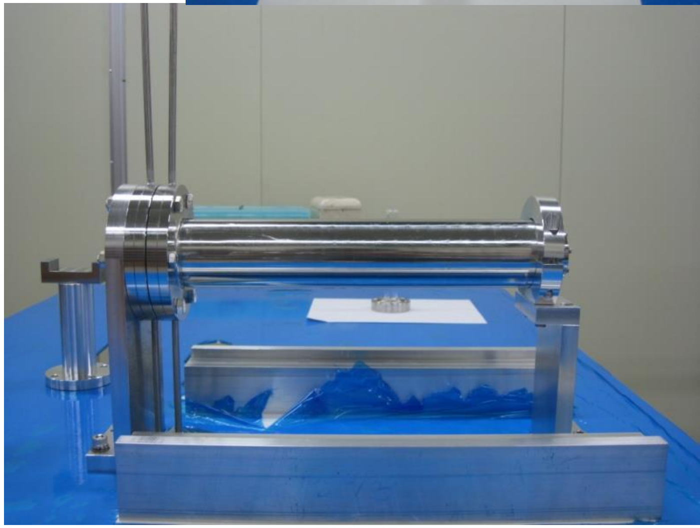
2.45GHz 안테나 마이크로웨이브



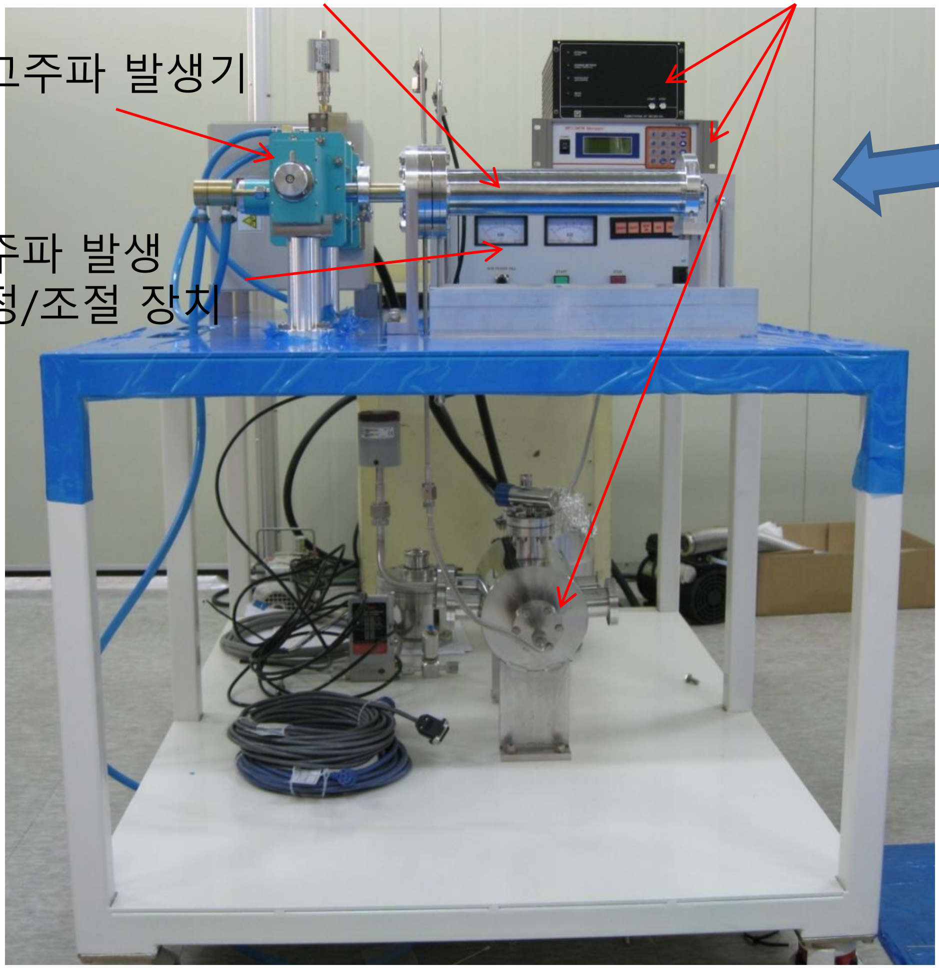
Chamber





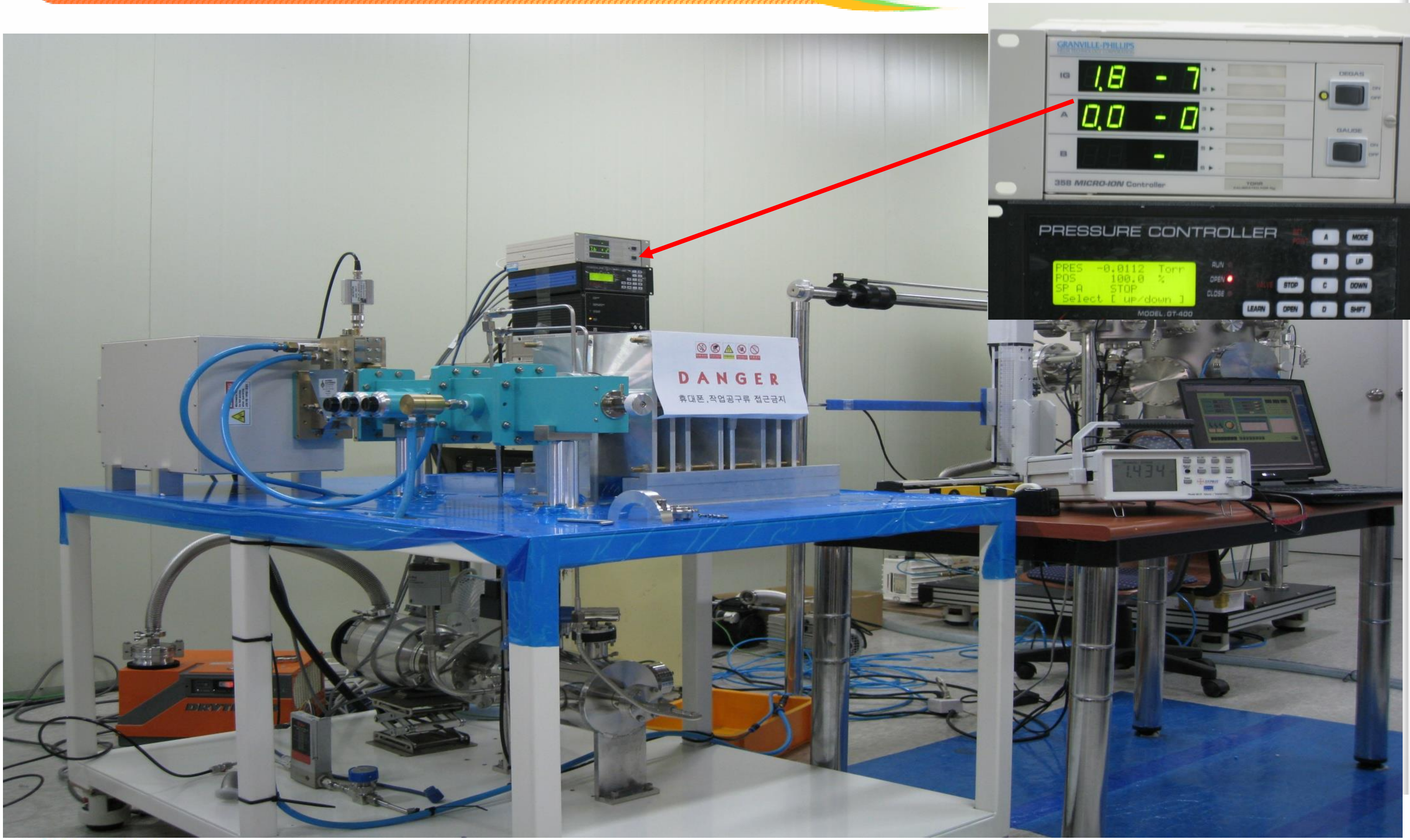


Prototype ECR 이온원

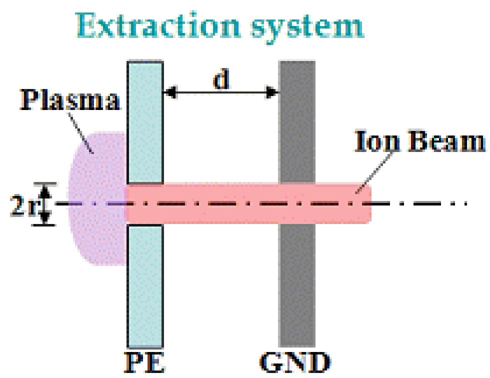


- Prototype ECR용 영구자석 제작
- 고주파 발생기 제작
- 이온화 챔버 하우징 제작
- 진공 및 가스 조절 장치 제작
- 플라즈마 실험 다음 주 진행

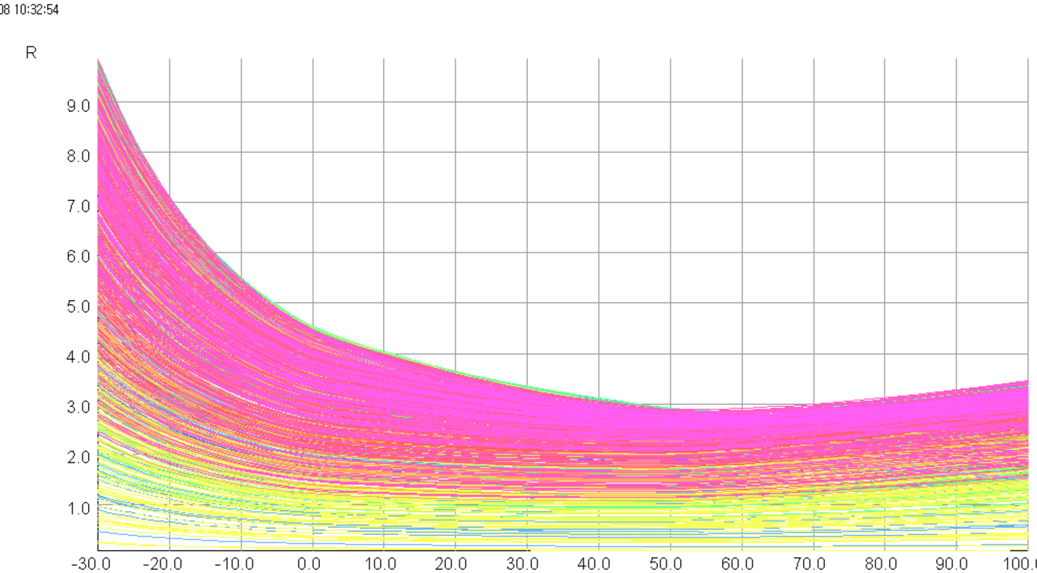
Prototype ECR 이온원 진공 테스트



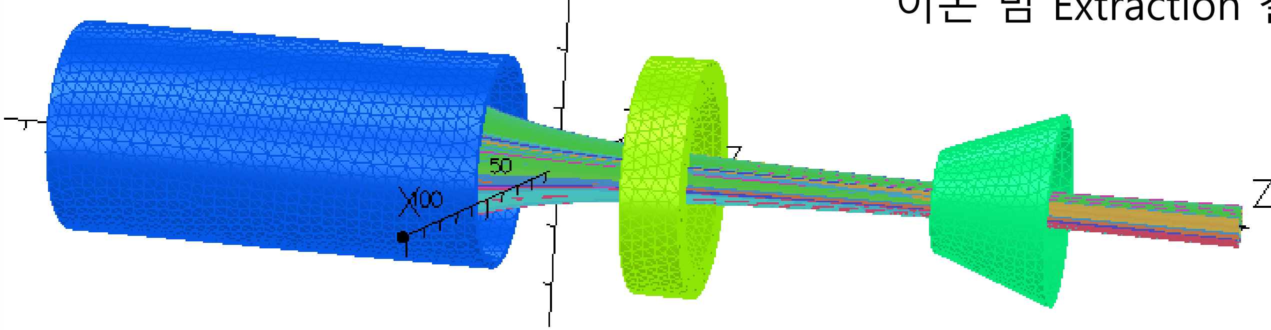
Ion Beam Extraction



$$J = \frac{4}{9}\varepsilon_0 \left(\frac{2q}{m}\right)^{1/2} \frac{V^{3/2}}{d^2}$$



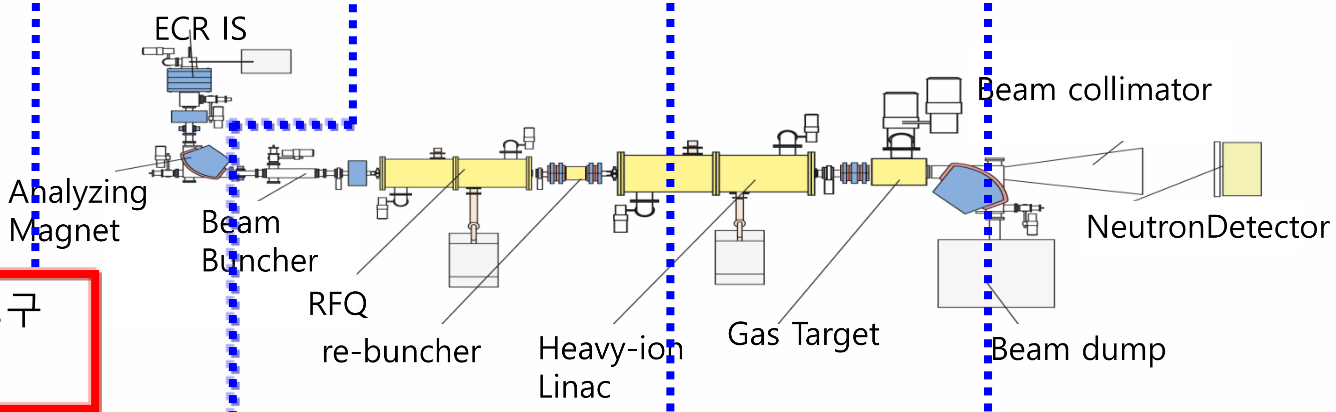
이온 빔 Extraction 결과 (인가 전압 10kV)



- 참조 가스로 Ar을 이용하여 2.45GHz ECR 이온원의 성능 평가
- Faradaycup을 이용하여 출력이온의 전하량 측정

Roadmap

2008 | 2009 | 2010 | 2011 | 2012



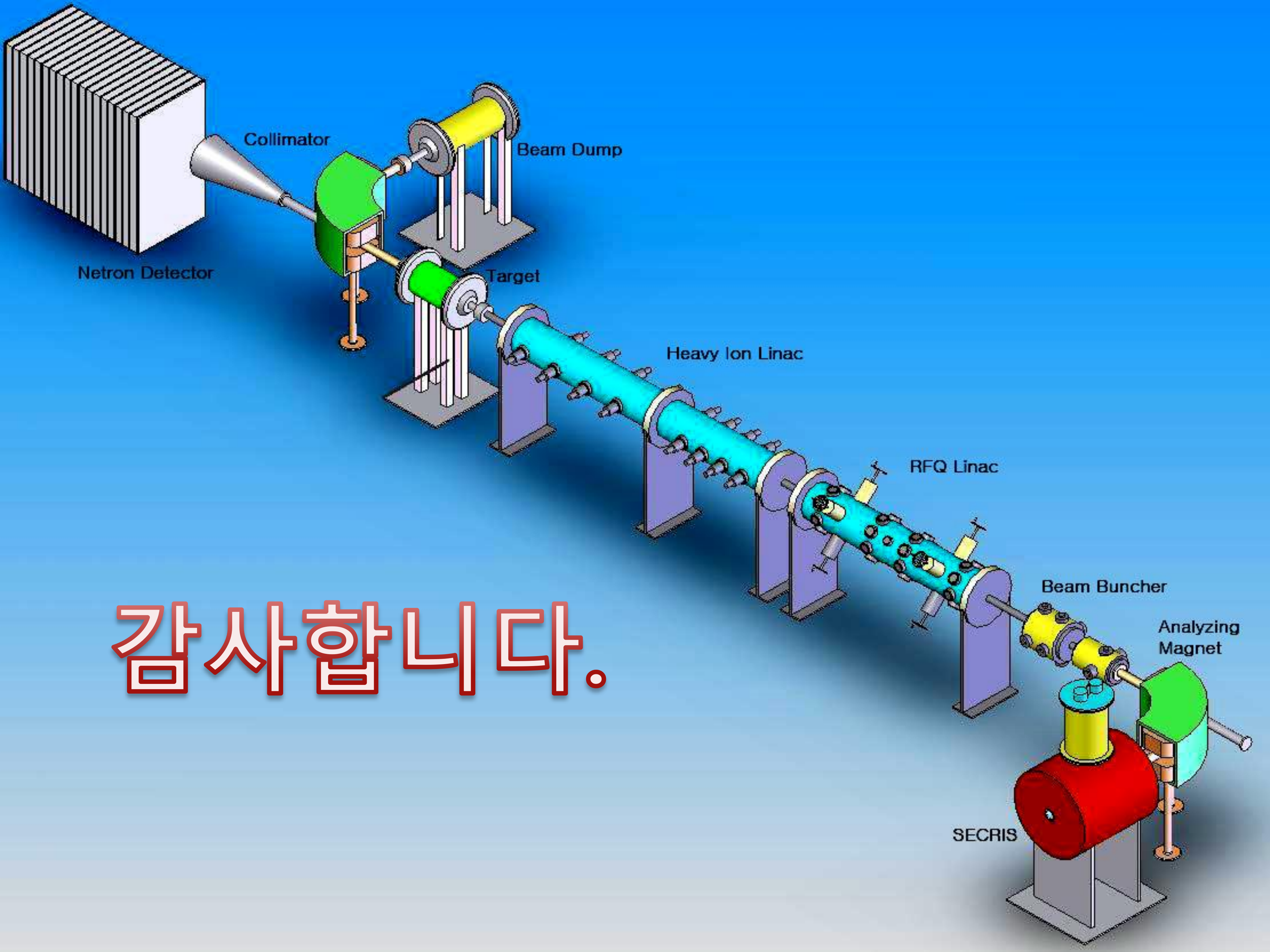
ECRIS 설계 및 영구
자석 ECRIS 제작

ECRIS의 초전도자석 제작 및 2kW RF 제작

10kW RF 제작
이온빔 인출 및 이용시설
빔번처제작
중이온선형가속기 도입

수소표적 개발
가속기 설치
차폐설계 및 설치

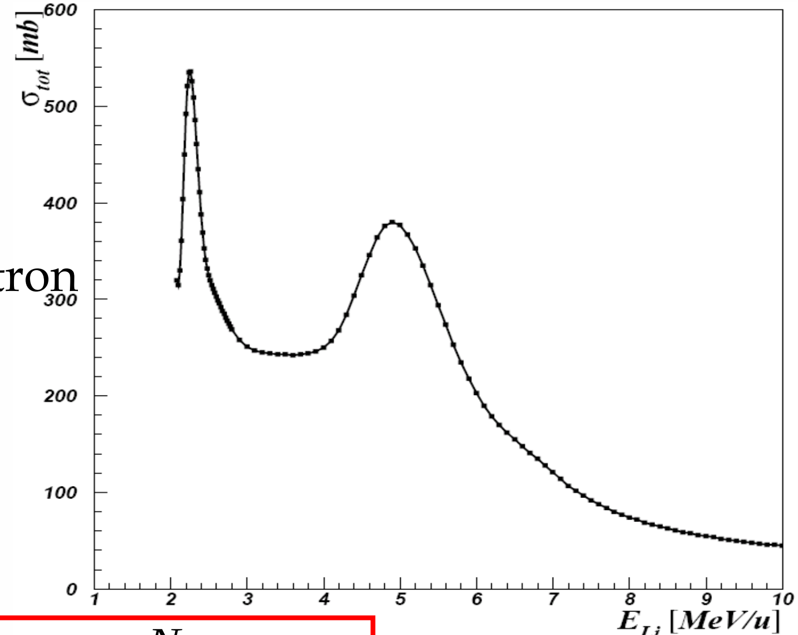
중성자 검출기 개발 및 설치
시험가동

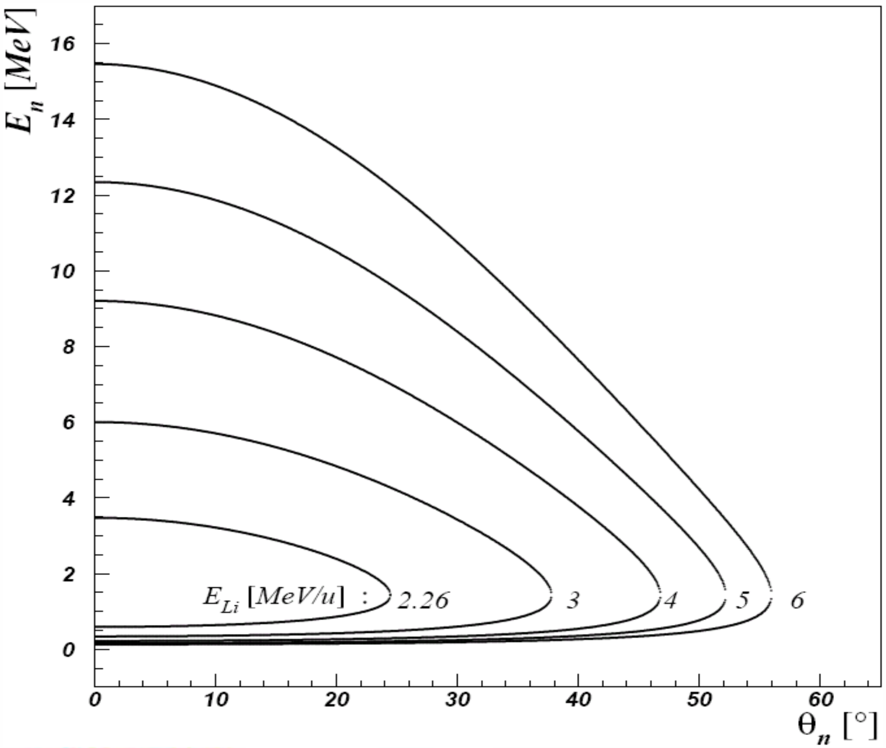

Collimator
Beam Dump
Netron Detector
Target
Heavy Ion Linac
RFQ Linac
Beam Buncher
Analyzing
Magnet
SECRIS

감사합니다.

Requirements for Neutron Radiography

- Beam flux: Production of 10^{12}/s (fast neutrons)
- beam intensity: $Li^{2\sim3+}$ higher than 2pmA
- Beam energy : ~2 MeV/u
- Gas target : >350 Torr
- Neutron detection : High efficiency for fast neutron





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

Y : neutron Yield
F_{Li} : Beam Flux
ρ : Density
N_A : Avogadro constant
A : Atomic Number
L : Target Length
σ : Cross section

Fast neutron flux is 5.3×10^{13} / *s* at a $^{7}Li^{+3}$ Beam current of 1mA