Rare isotope Accelerator complex for ON-line experiments

과학기술정보통신부 가속기인력사업

2022 가속기여름학교

중이온가속기 EBIS 시스템

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중이온가속기건설구축사업단 Rare Isotope Science Project

Outline

1. Overview

RAON Heavy Ion Accelerator in Daejeon, Korea

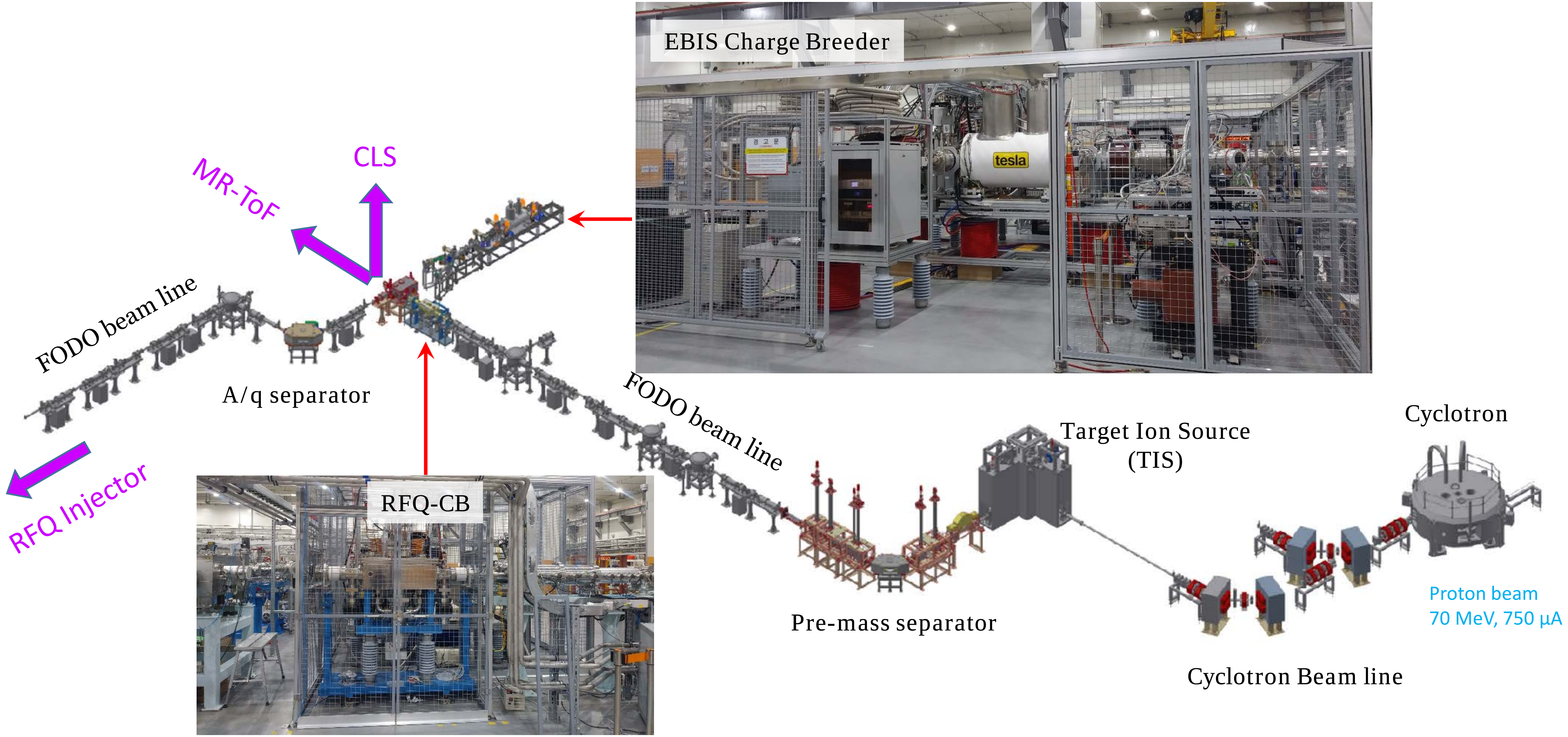
- Campus Area : **952,066**㎡ (including the reservation area of **144,640**㎡)
- Building Area : **76,259**㎡ (**11** bldgs) with total bldgs. Area of **116,252**㎡

1. Overview

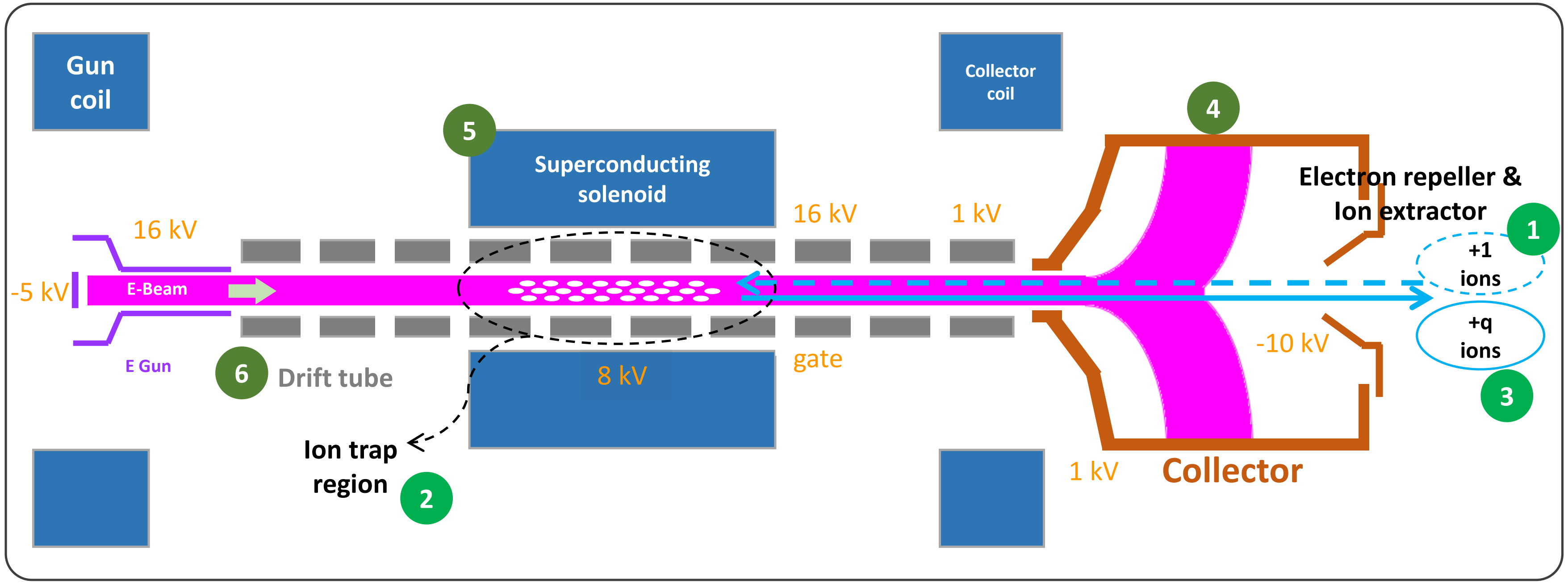
RAON Heavy Ion Accelerator in Daejeon, Korea

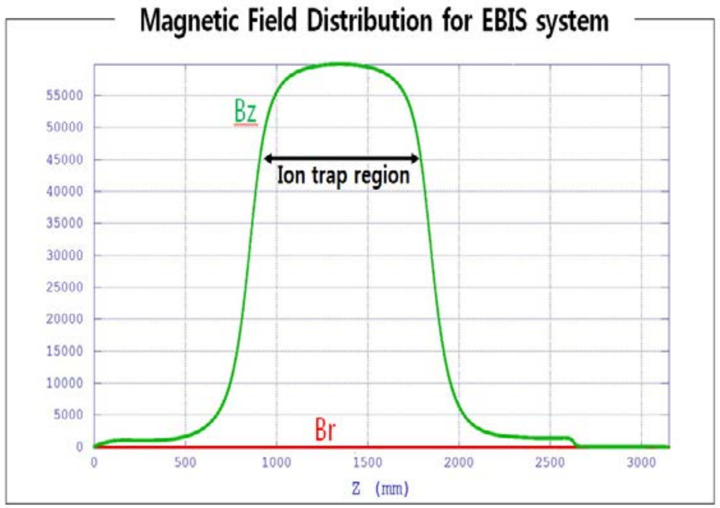
1. Overview

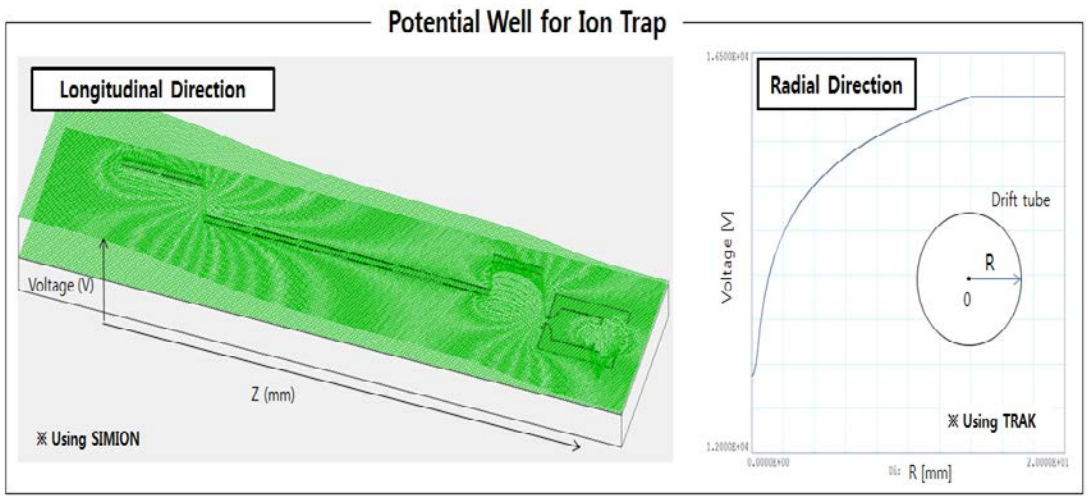
ISOL Beamline for Post-Acceleration of Rare Isotope Beams



2. Basic Principles Charge Breeding Process







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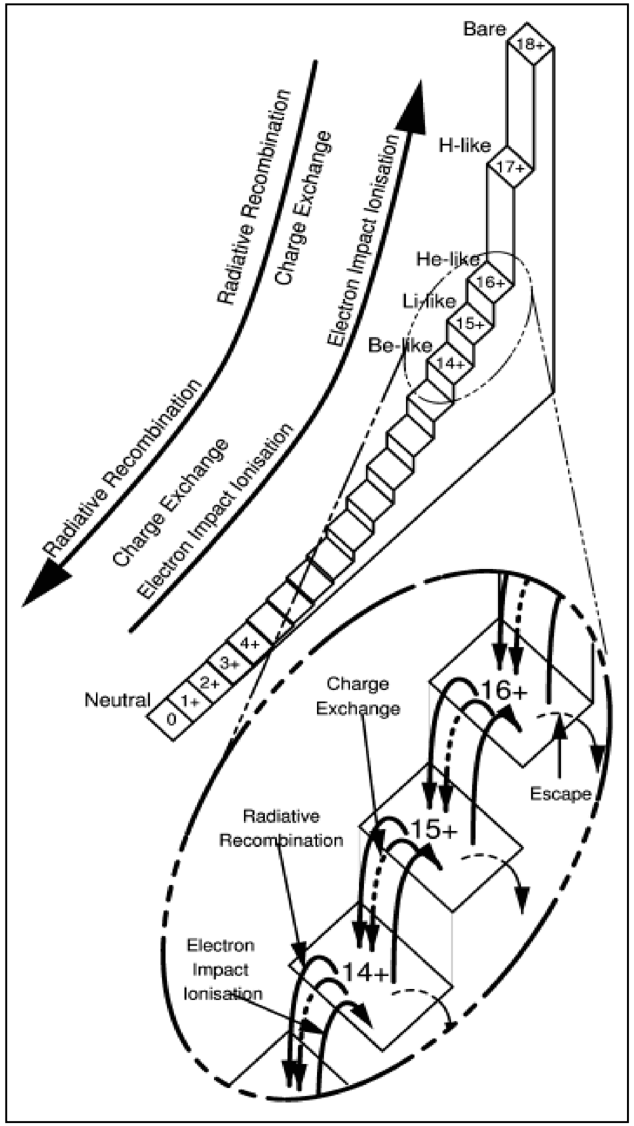


Overlap Factor: 0~1

$$\frac{dN_i}{dt} = \frac{J_e}{e}\left(N_{i-1}{\sigma_{i-1}}^{EI} f_{e,i-1} - N_i {\sigma_i}^{EI} f_{e,i}\right)$$ Electron Impact ionization

$$+\frac{J_e}{e}\left(N_{i+1}{\sigma_{i+1}}^{RR} f_{e,i+1} - N_i {\sigma_i}^{RR} f_{e,i}\right)$$ Radiative Recombination

$$+n_0\left(N_{i+1}\langle v{\sigma_{i+1}}^{CX}\rangle - N_i\langle v{\sigma_i}^{CX}\rangle\right)$$ Charge Exchange

$$-N_i {R_i}^{Esc}$$ Escape

Main parameters for charge evolution

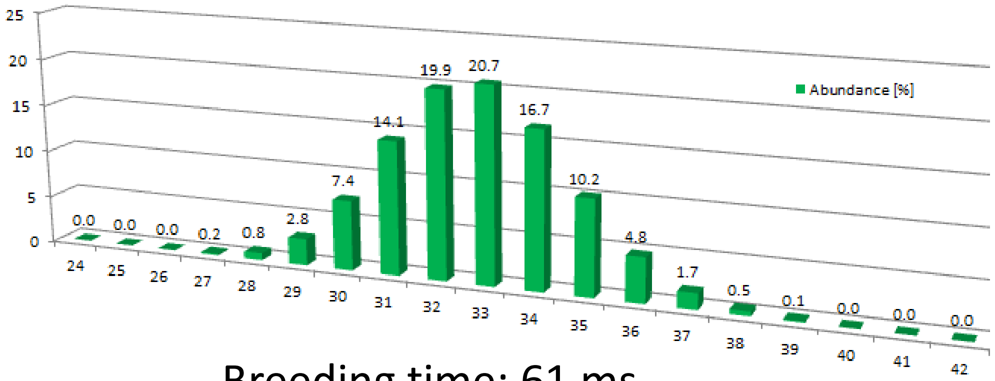
- Electron beam **energy**
- Electron beam **current density**

2. Basic Principles   Charge Breeding Simulation

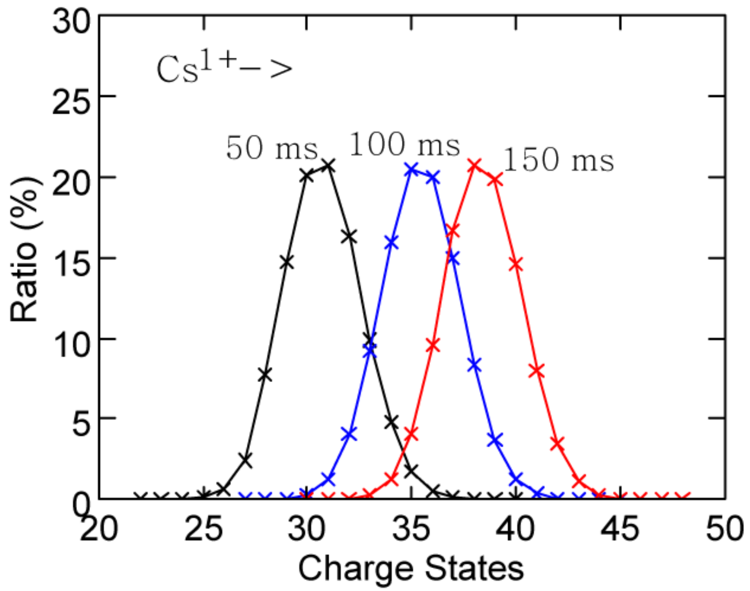
Electron Beam Energy : 20 KeV
E-Beam Current : 3 A
E-beam Current Density : 493.5 A/cm²

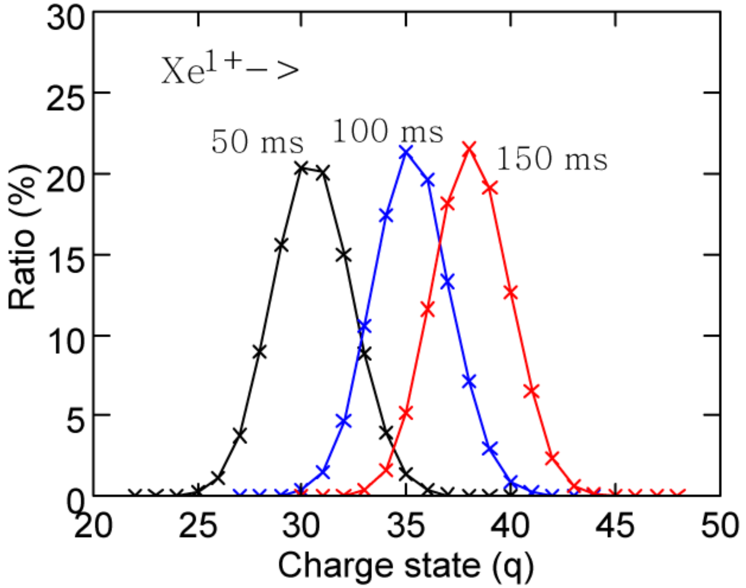
Isotopes of interest	Emittance	
	with rfq cooler	without rfq cooler
^{132}Sn, ^{142}Xe, ^{95}Sr, ^{15}O, ^{126}Al	3 π mm mrad	30 π mm mrad

Sn^{1+} ➔



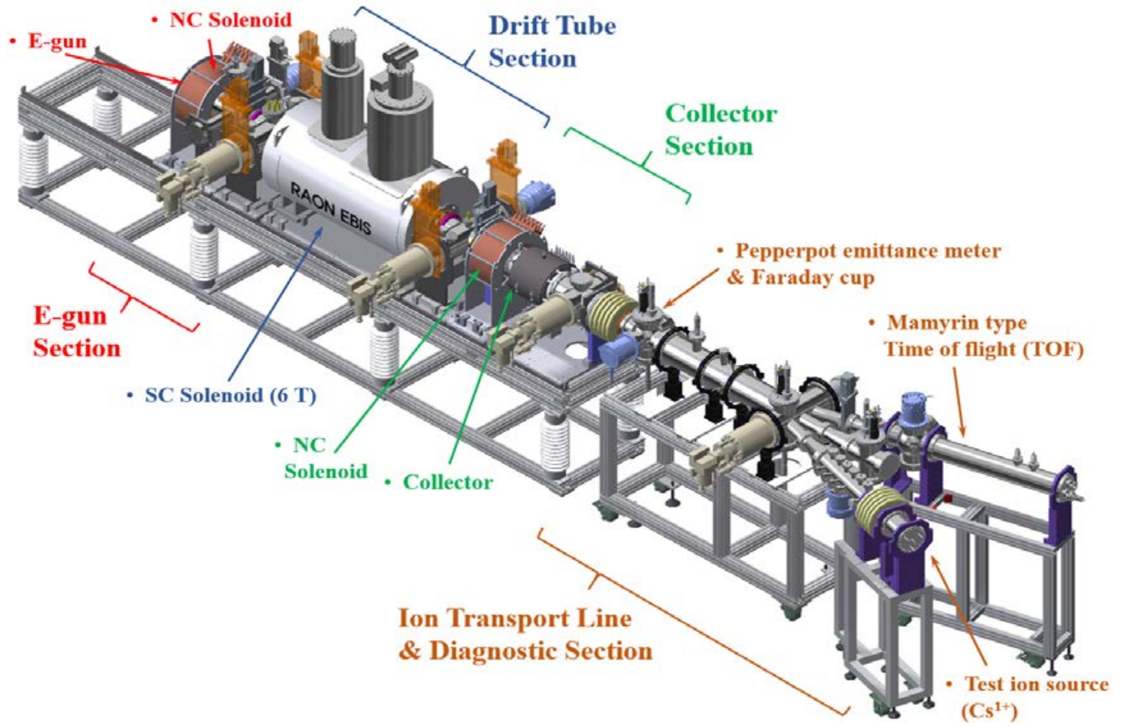
Breeding time: 61 ms



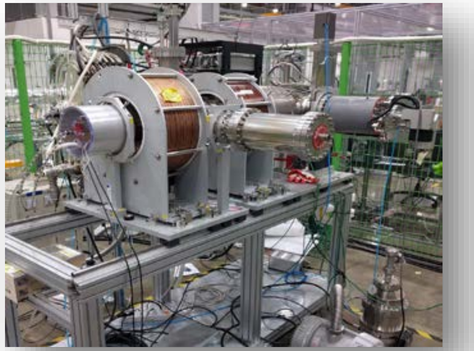


System Requirement of RAON EBIS Charge Breeder

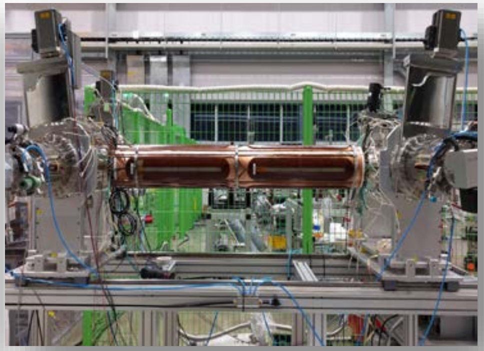
Requirements of EBIS Charge Breeder	
Extraction beam energy	10 keV/u
A/q	< 6
Breeding time	50 ~ 100 ms
Efficiency	15 % (for $^{133}Cs^{27+}$)
Capacity	up to 10^8/bunch
Electron beam current	Up to 3 A
Magnetic field at trap	6 T



E-gun/Collector



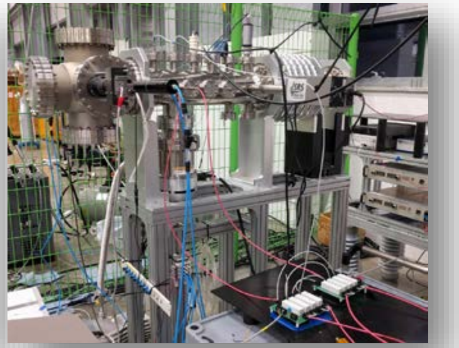
Ion trap region



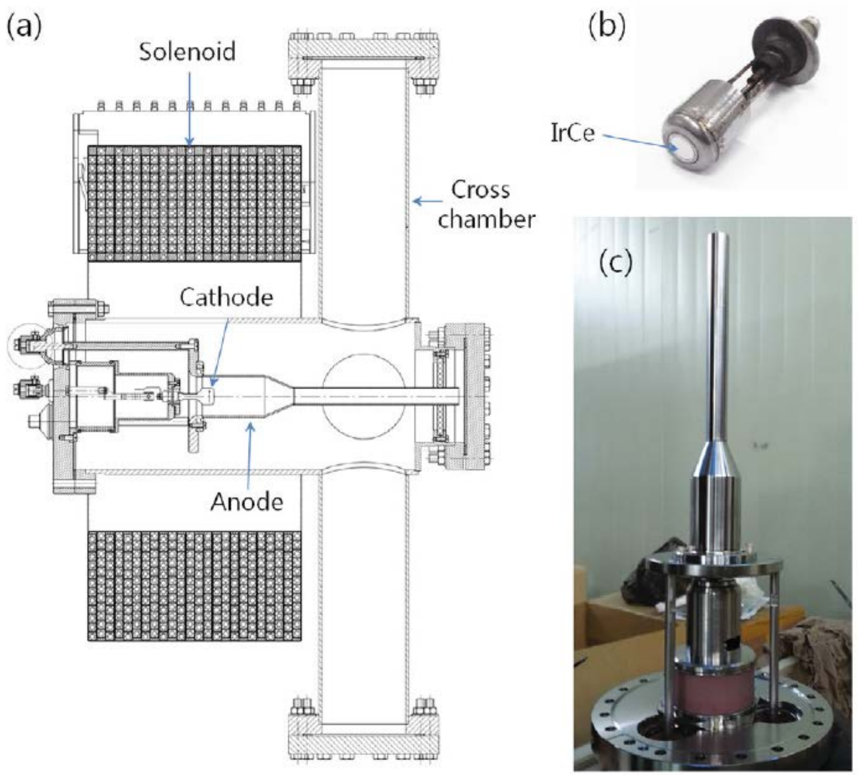
SC solenoid (6T)

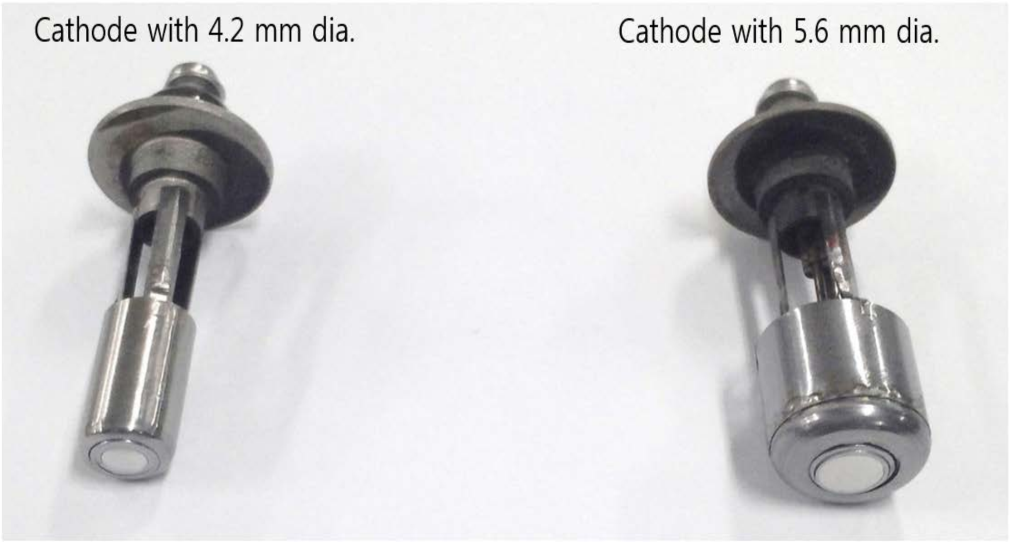
Ion transport line

Test ion source (Cs^{1+})



3. Components Tests   Electron Gun Assembly





- The e-gun assembly is manufactured by BINP in Russia

Parameters	Diameter	
	4.2 mm	5.6 mm
Cathode material	IrCe	
Cathode current density	10 ~ 15 A/cm^2	
Beam current	~ 2 A	~ 3 A
Beam energy	~ 12 keV	~ 20 keV
Magnetic field at cathode	~0.2 T	

3. Components Tests   Perveance Measurement

Simulation for the cathode test

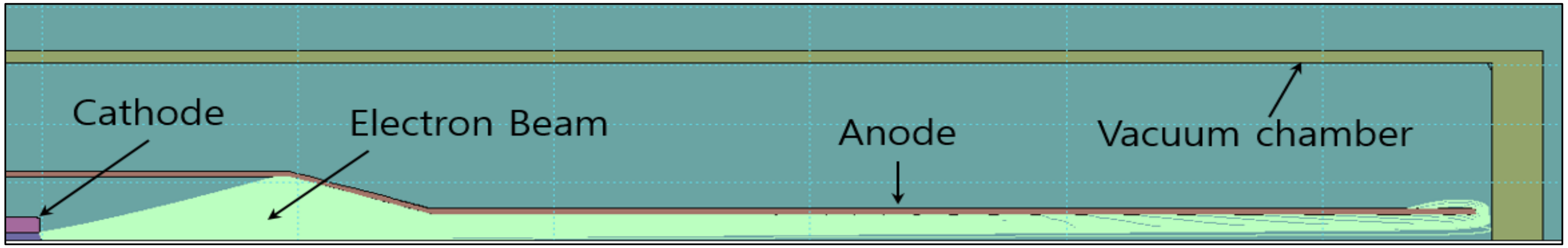
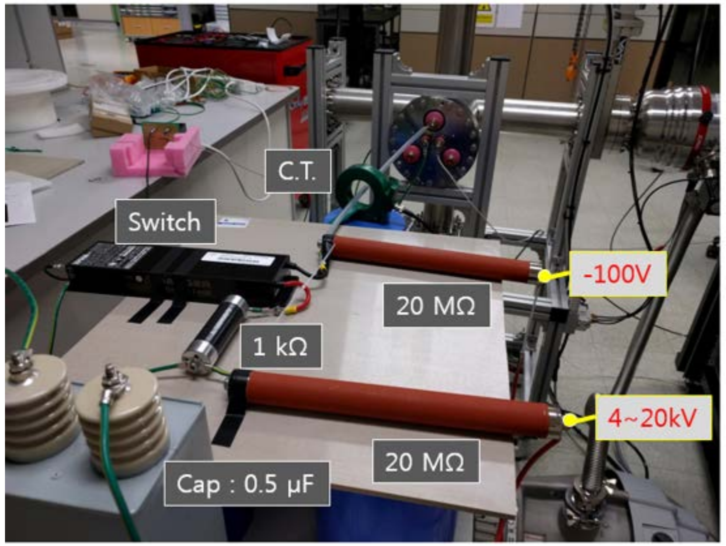
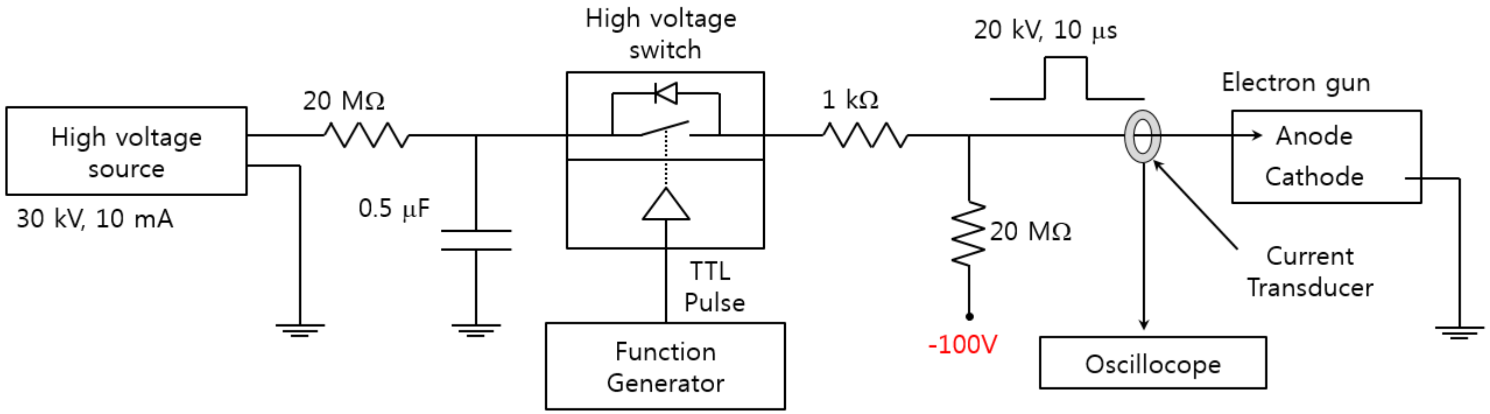


Figure II.11. Trajectory of the electron beam simulated by using the TRAK code for the electron cathode test without the e-gun solenoid.

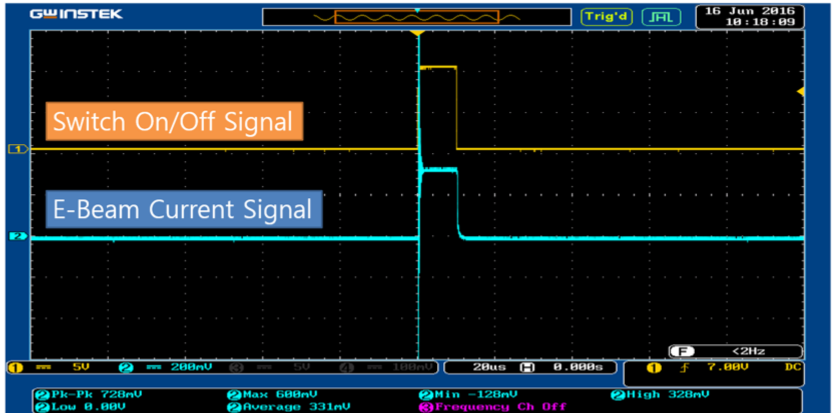
Experimental setting



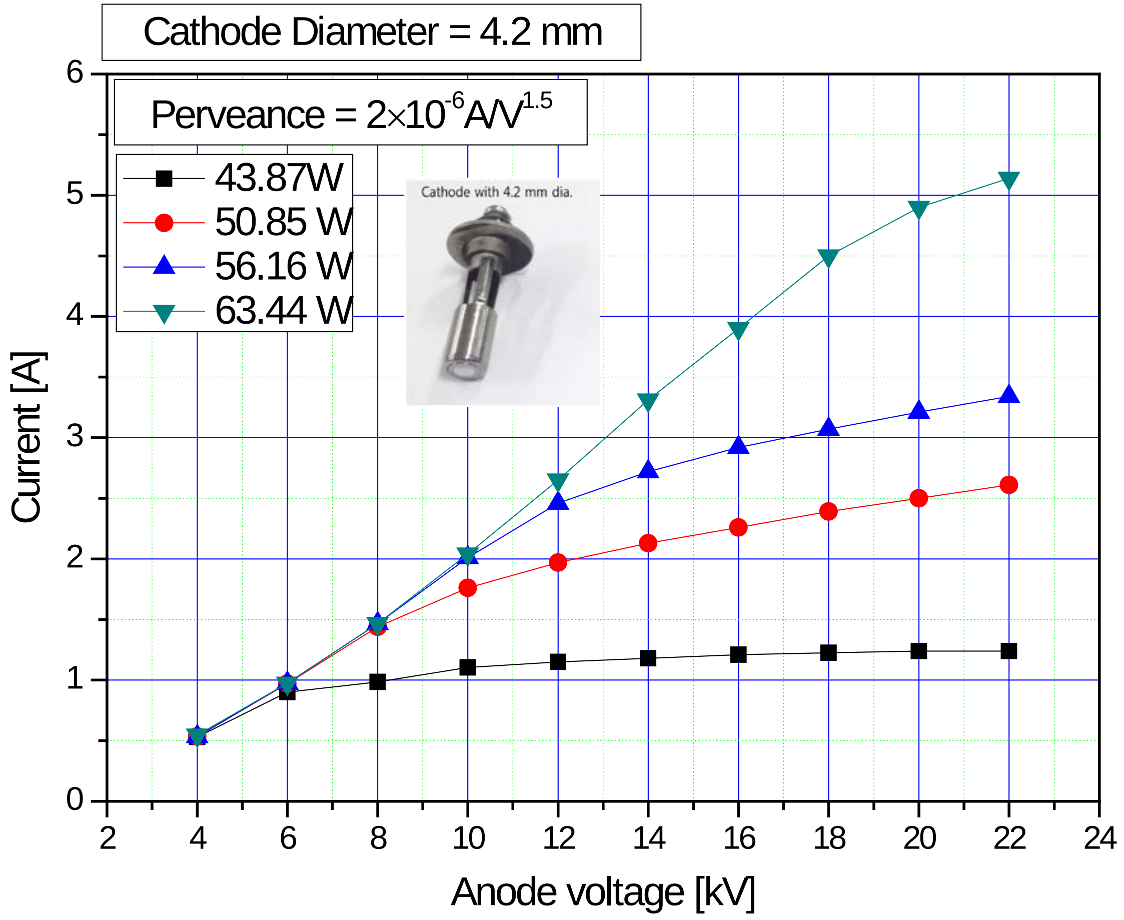
Pulsing circuit : Circuit diagram for the high-voltage pulsing

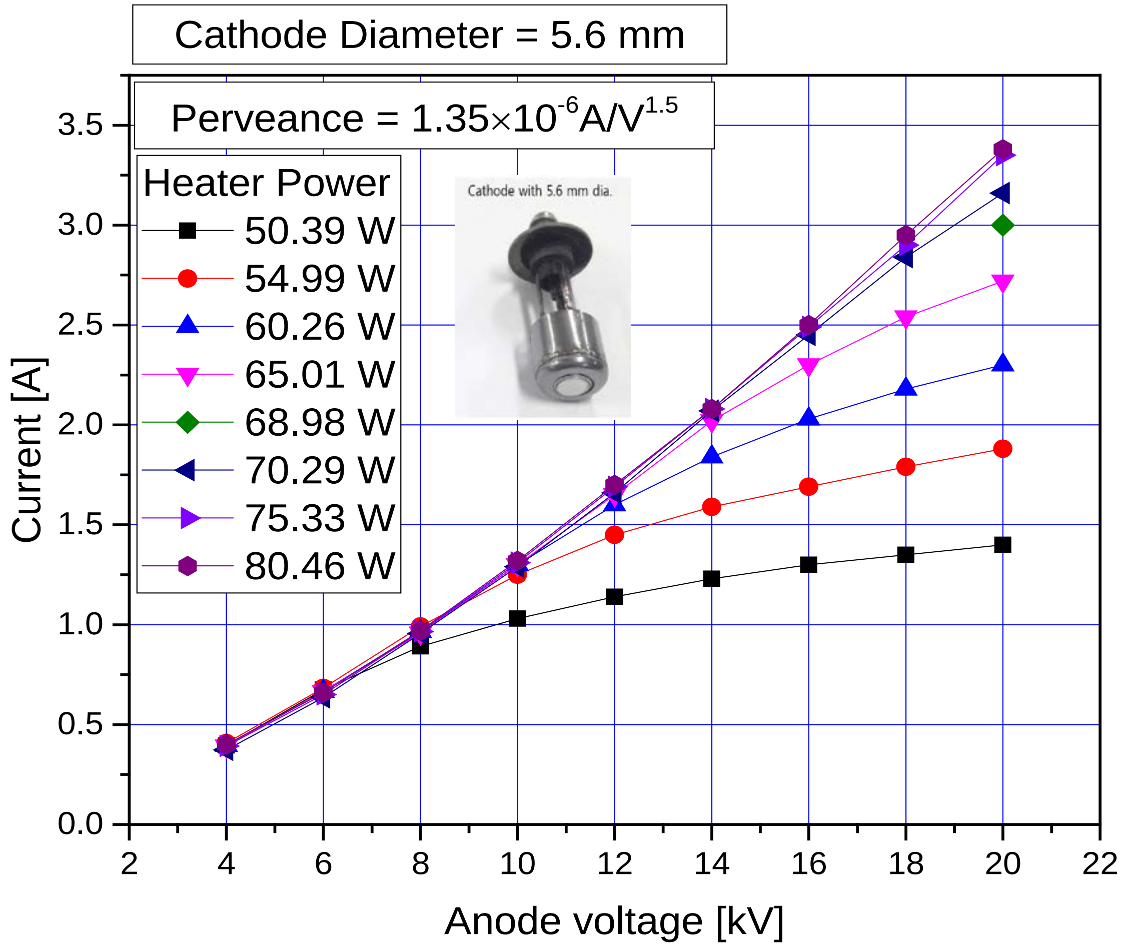


Pulsing signals on osc.



3. Components Tests   Perveance Measurement





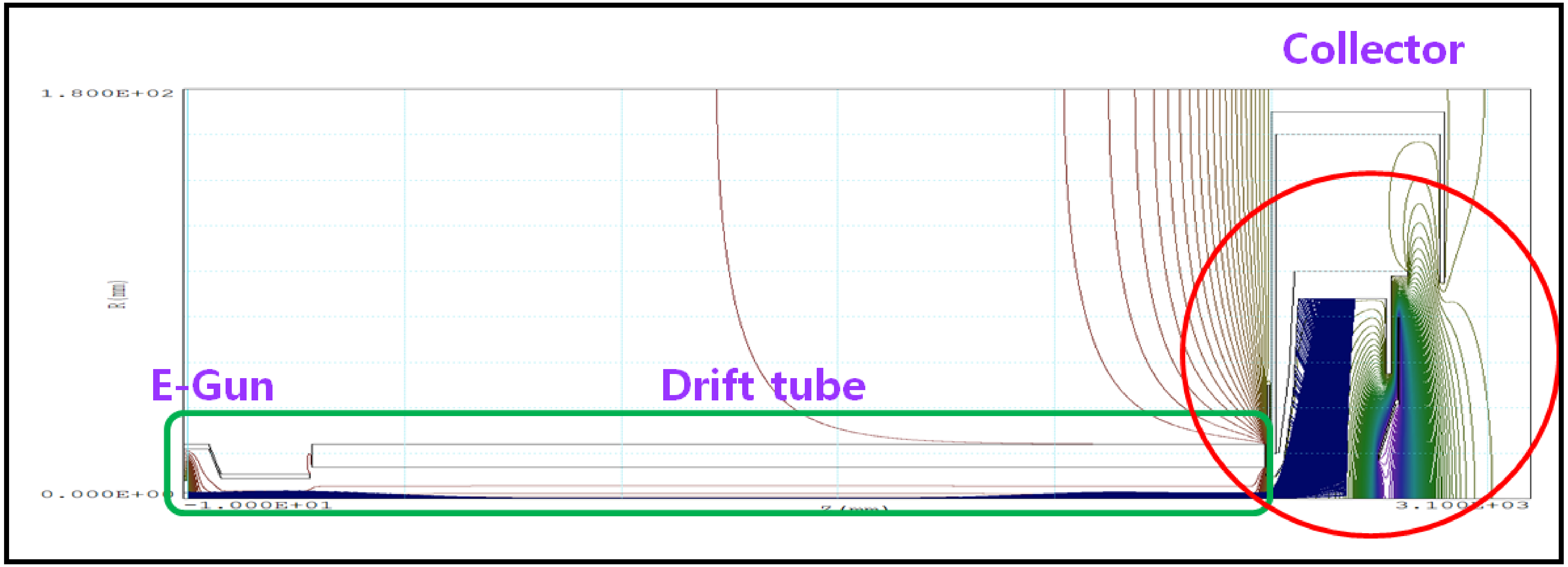
Child–Langmuir law : $I_{max} = P^* V^{1.5}$

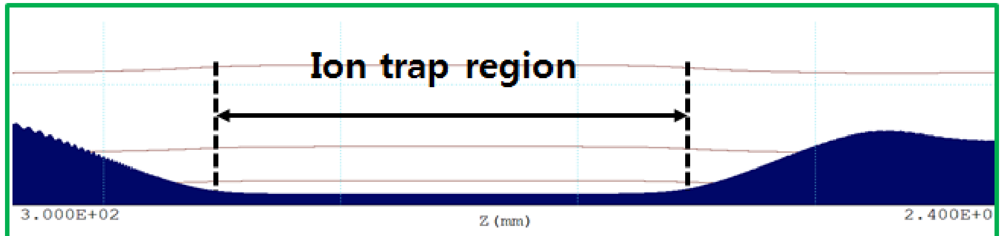
$$\text{Perveance} : P = 1.129 \times 10^{-6}\, A/V^{\frac{3}{2}}$$

(Simulation value)

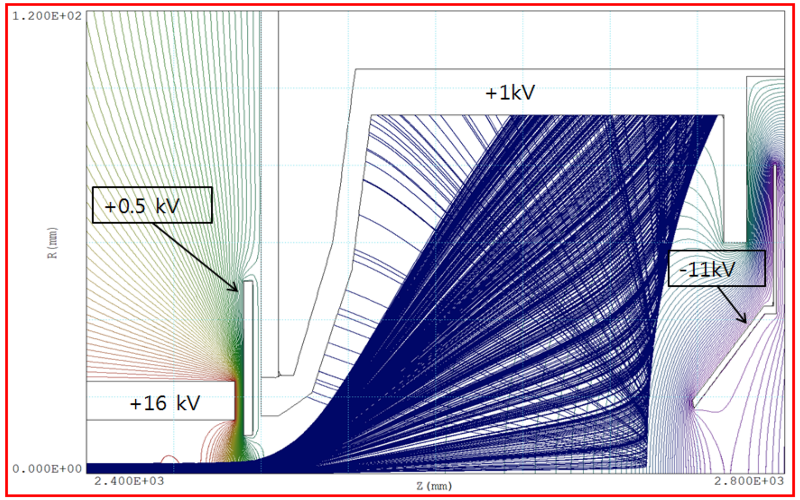
3. Components Tests

Electron Beam Simulation (TRAK)



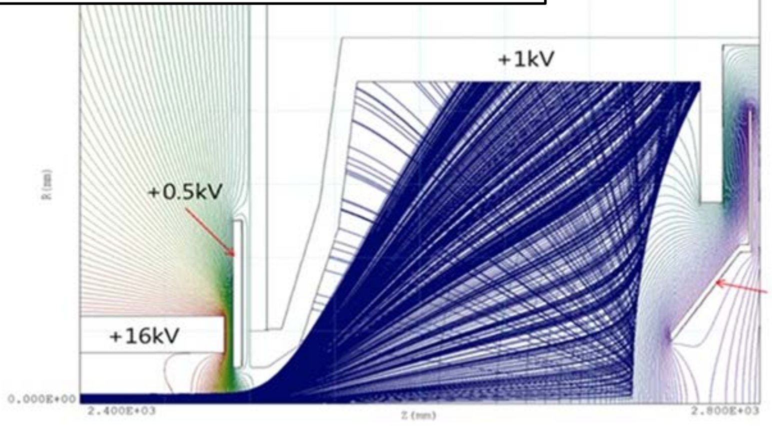


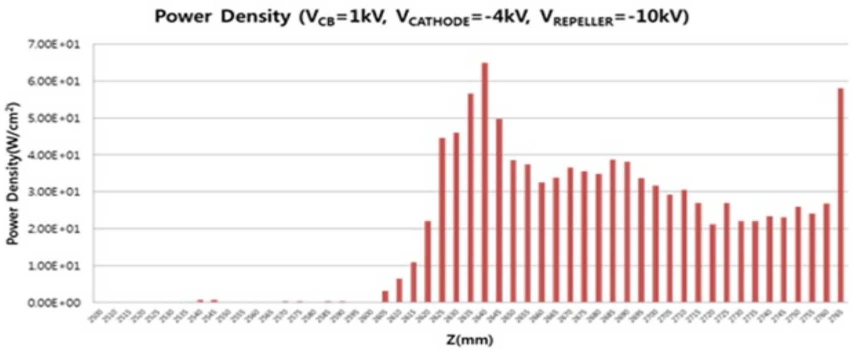
Within ion trap region
- Electron beam radius : 0.45 mm
- Electron beam current density : 500 A/cm^2
- Longitudinal B-field : 6T



3. Components Tests Electron Collector Design

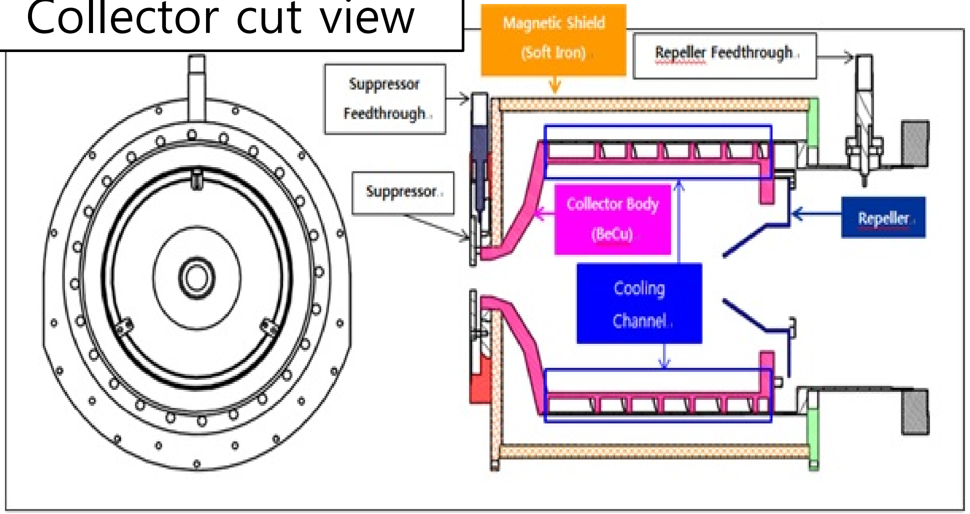
Electron dump simulation





Dissipated Power	Flow Rate (kg/s)	Flow Rate (liter/min)	Temperature Rise (℃)
15 kW	1.0	60	3.6
	0.8	48	4.5
	0.6	36	6.0
	0.4	24	9.0

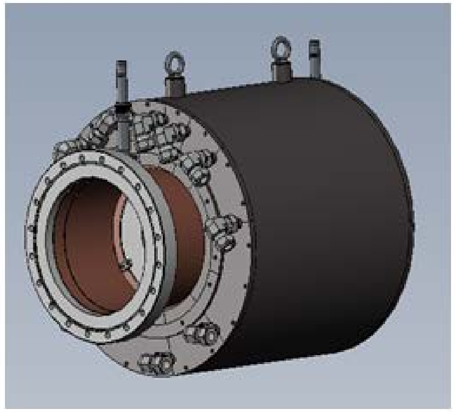
Collector cut view

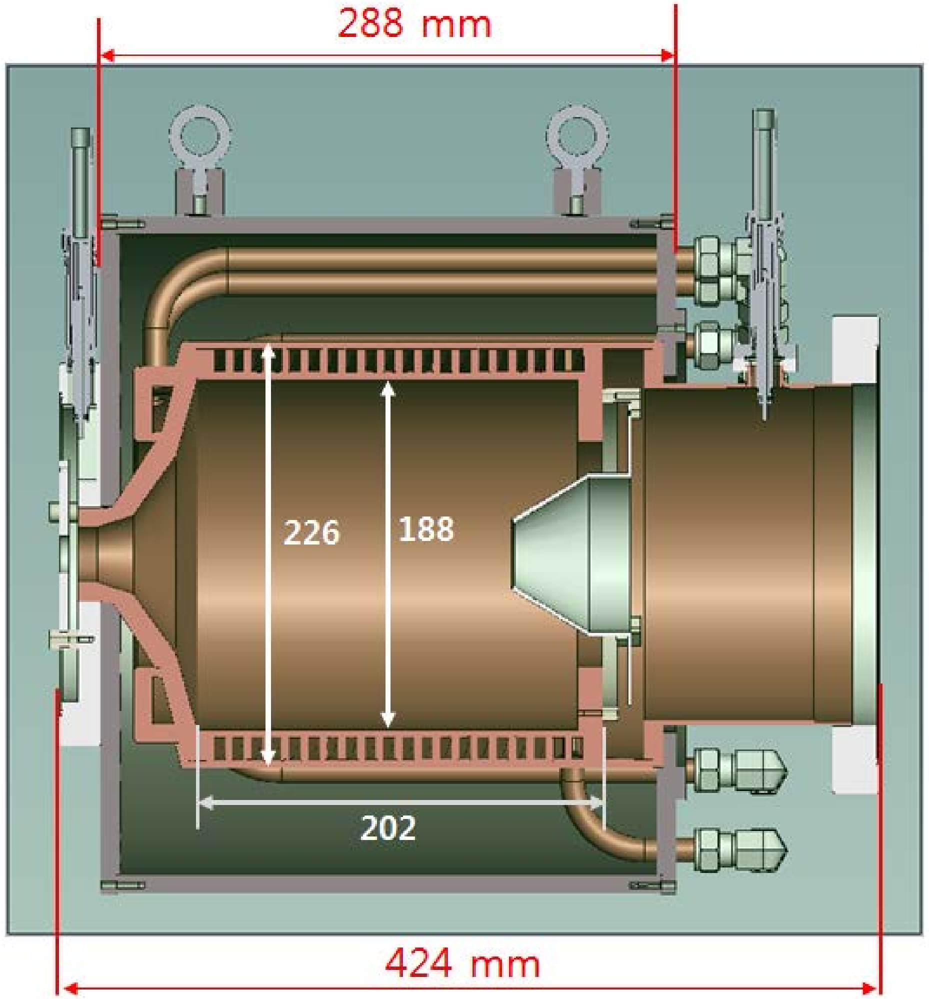


- ✓ E-beam simulation was performed with TRAK code.
- ✓ Colletor design was verified based on the simulation.
- ✓ Distribution of the power deposit on the inner surface of collector was calculated.
- ✓ Collector dimension, the repeller position, and the repeller voltage were tuned to achieve as small power density on the surface as possible.

3. Components Tests

Electron Collector Design





3. Components Tests Collector Design Simulation

Water flow analysis

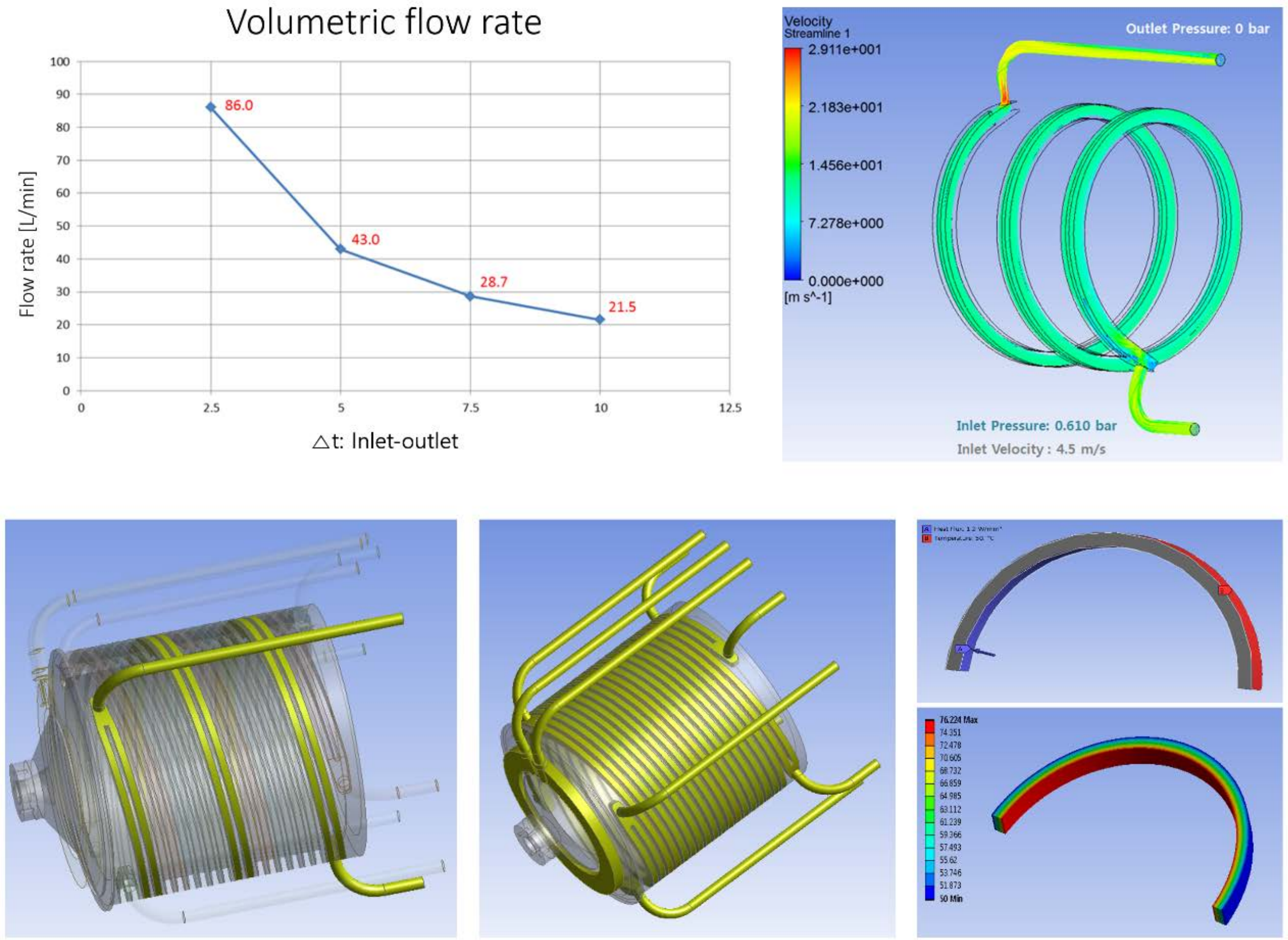


Figure II.17. Flow rate against water temperature growth (left) and water line structure at the side wall of the collector body (right).

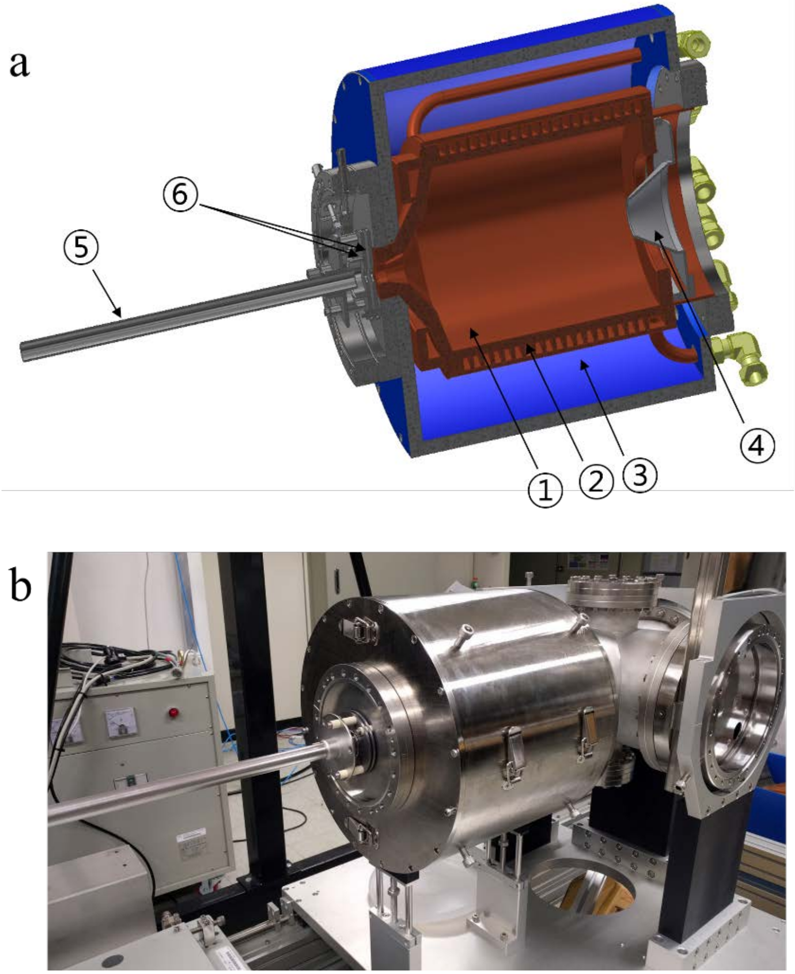


Figure II.16. a) Design of the EBIS collector: ① collector body, ② cooling water groove, ③ magnetic shield, ④ repeller, ⑤ drift tube #11, ⑥ apertures, b) Photograph of the manufactured collector.

3. Components Tests

E-Gun and Collector Test Bench

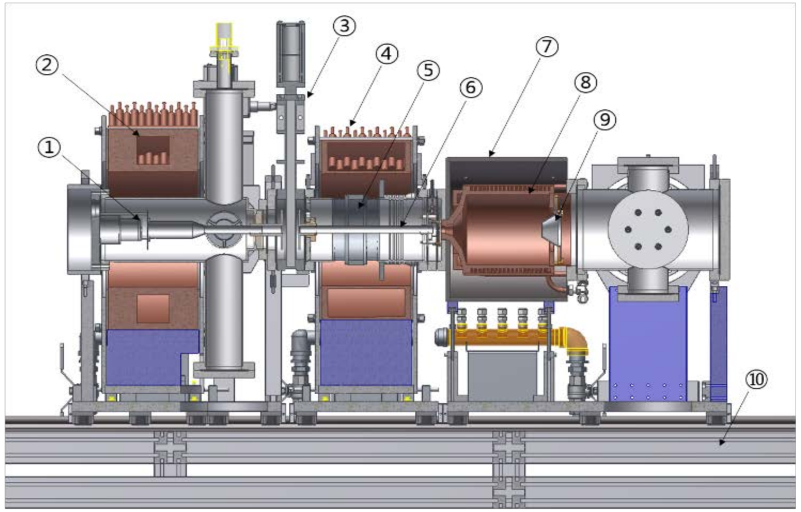
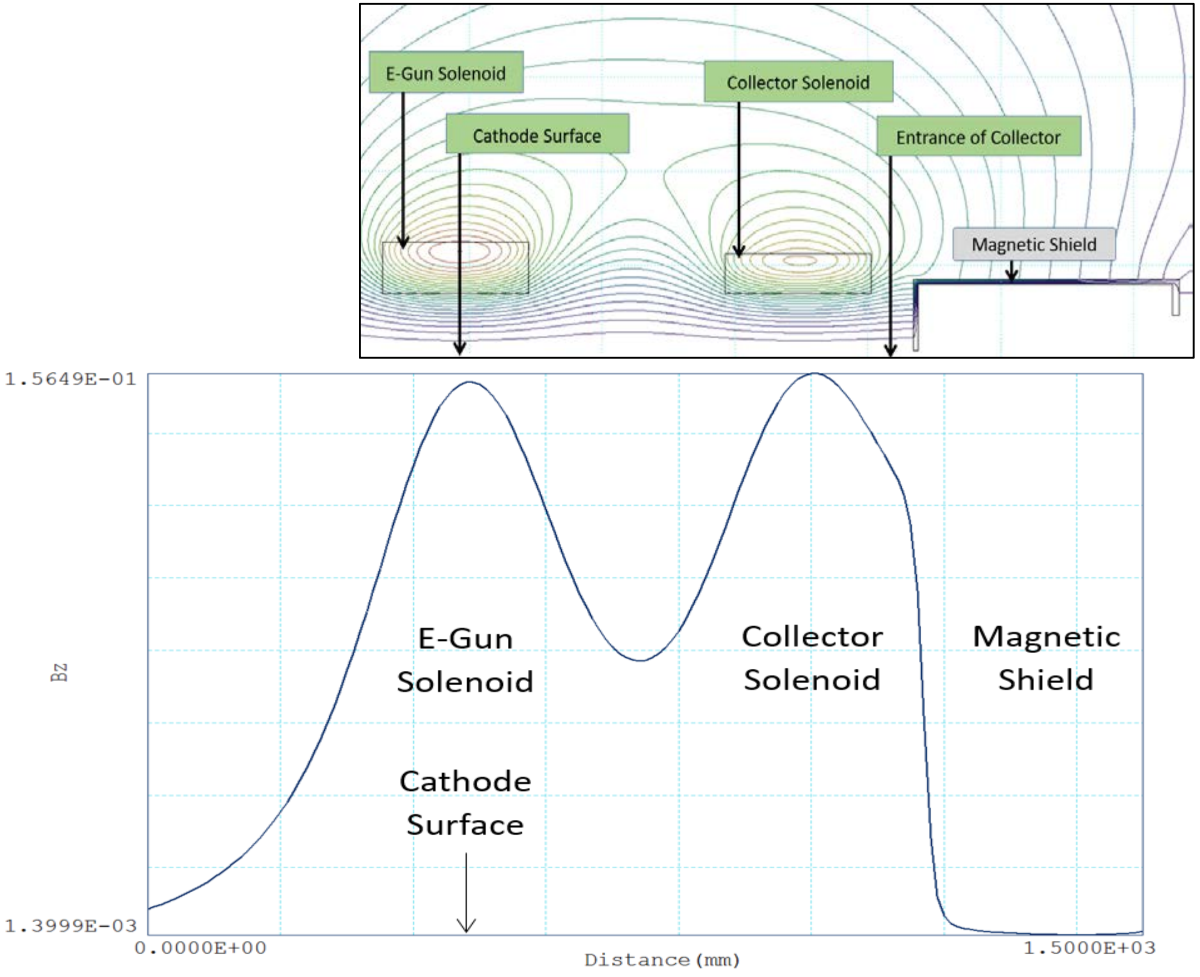


Figure II.18. (Upper) Cross-section view of e-gun/collector test bench: ① e-gun, ② gun coil, ③ gate valve, ④ collector coil, ⑤ vacuum breaker, ⑥ drift tube #11, ⑦ magnetic shield, ⑧ collector body, ⑨ repeller, ⑩EBIS stand, (Bottom) Photograph of the installed e-gun/collector test bench.

Magnetic field profile along the beam axis



3. Components Tests

E-Gun and Collector Test Bench

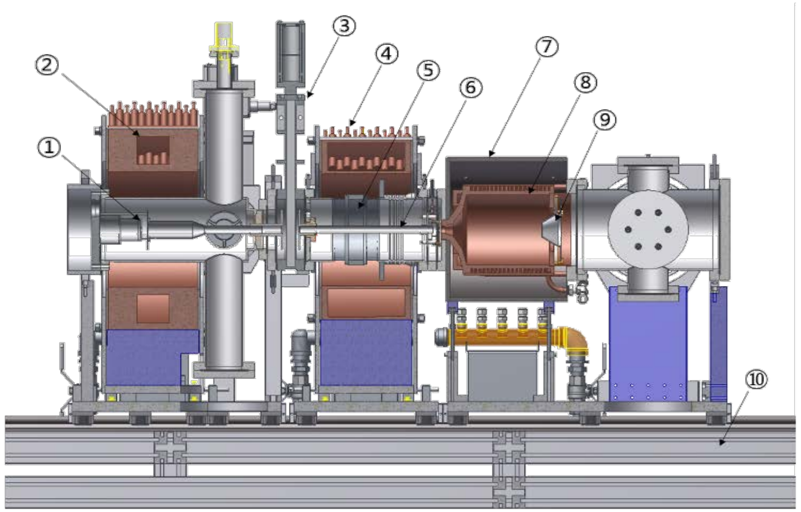
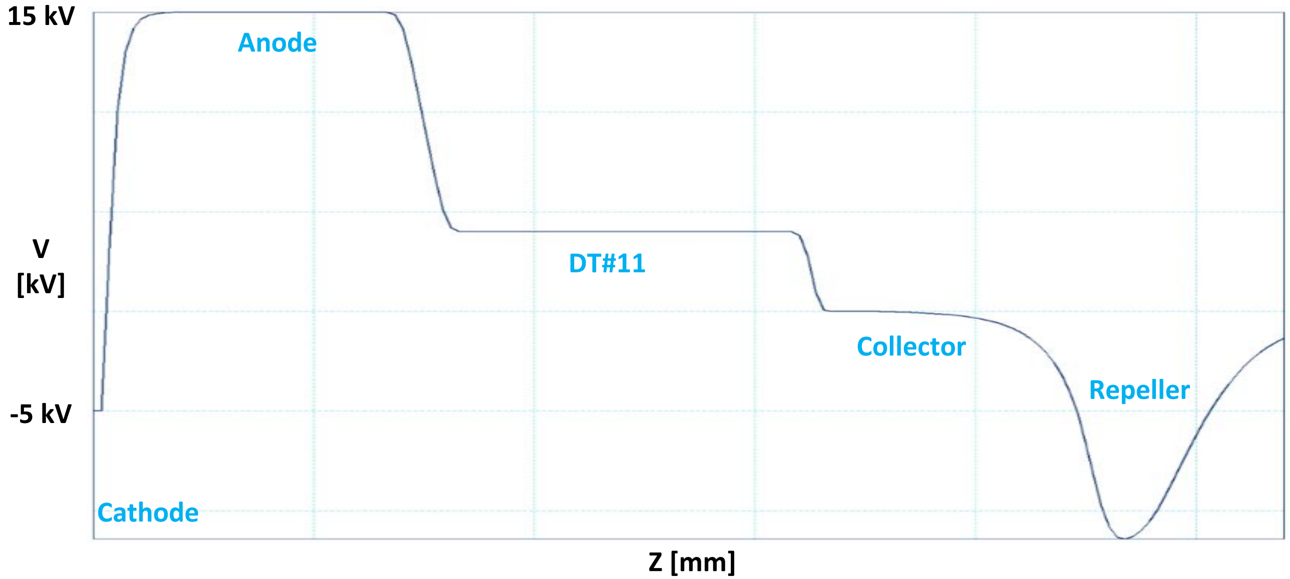


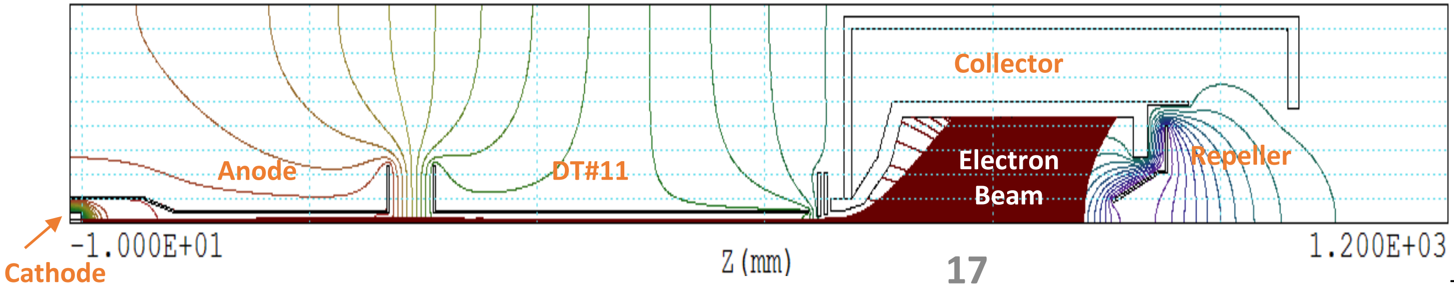
Figure II.18. (Upper) Cross-section view of e-gun/collector test bench: ① e-gun, ② gun coil, ③ gate valve, ④ collector coil, ⑤ vacuum breaker, ⑥ drift tube #11, ⑦ magnetic shield, ⑧ collector body, ⑨ repeller, ⑩EBIS stand, (Bottom) Photograph of the installed e-gun/collector test bench.

Voltage profile along the beam axis

Electrode	Cathode	Anode	DT #11	Aperture #1	Aperture #2	Collector	Repeller
Voltage	-5 kV	15 kV	4 kV	0 V	0 V	0 V	-11 kV

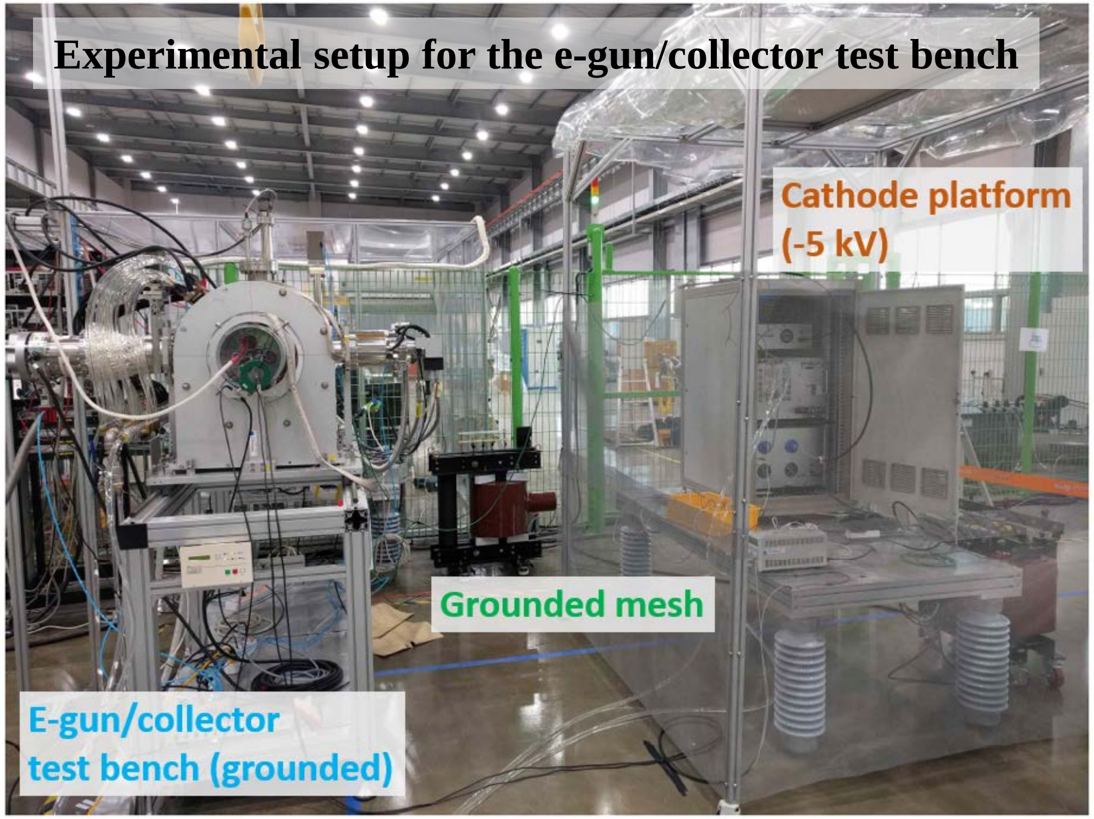


Electron beam trajectories



3. Components Tests

E-Gun and Collector Test Bench



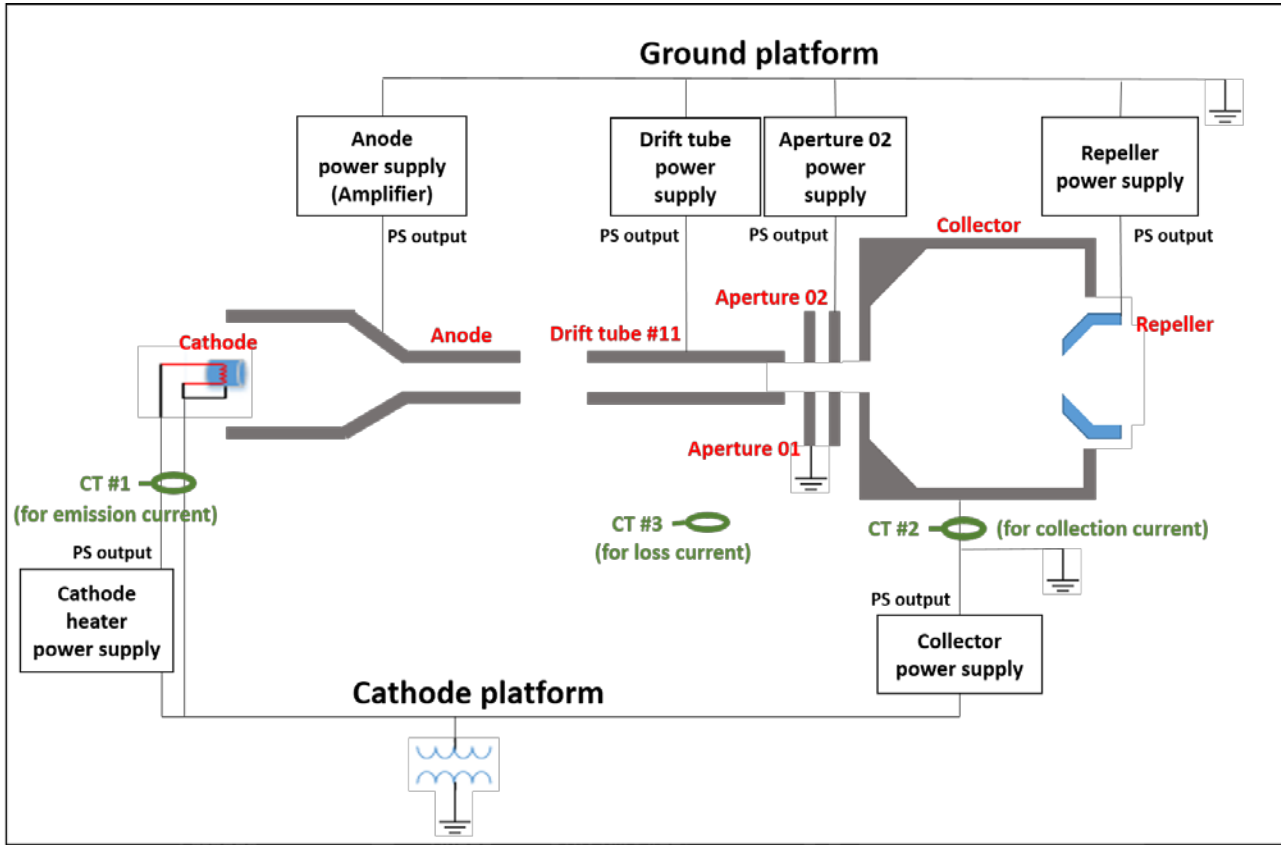
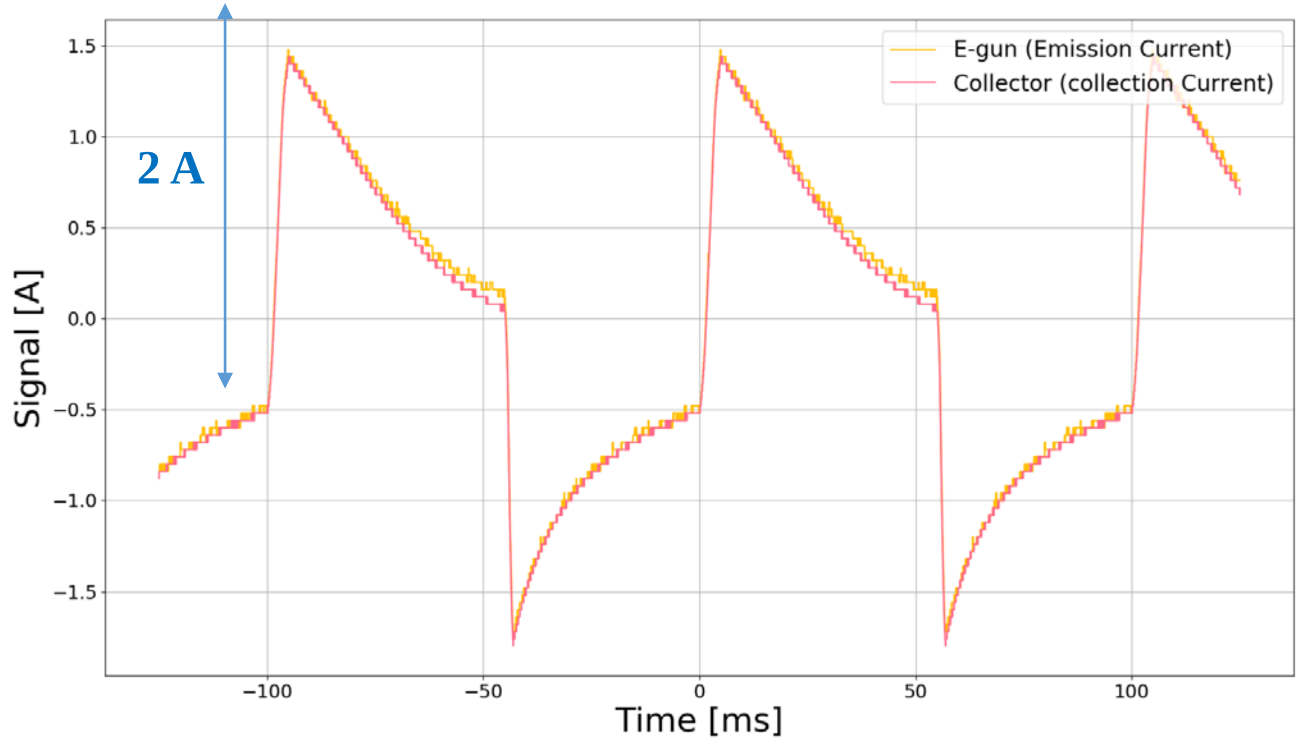


Table II.4 Setting voltage and potential profile of e-gun/collector test bench

Output of PS [kV]		Anode PS	DT PS		Aperture PS	Collector PS	Repeller PS
		15	14		-500V ~ ground	5	-12 ~ -10
Potential [kV]	Cathode	Anode	Drift tube	Aperture 1	Aperture 2	Collector	Repeller
	- 5	15	14	Ground	-500V ~ ground	Ground	-12 ~ -10

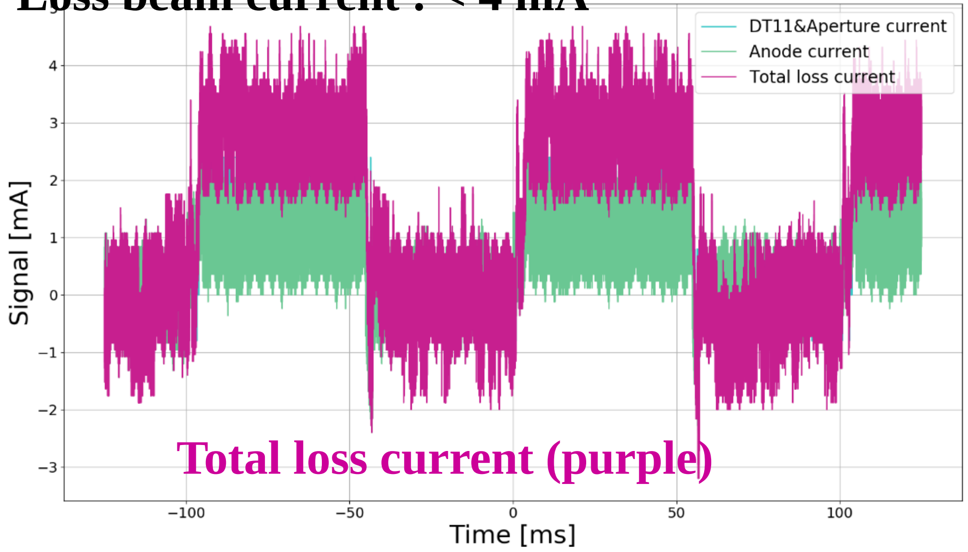
3. Components Tests E-Gun and Collector Test Bench

Emission/collection beam current : ~ 2 A

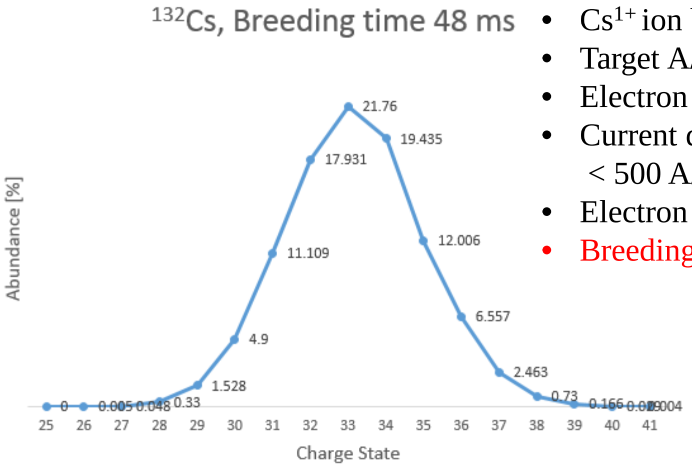


Emission Current [A]	Pulse Width [ms]	Duty cycle [%]	Frequency [Hz]
2	50	57	10

Loss beam current : < 4 mA



Off-line test : 1^{st} target breeding time



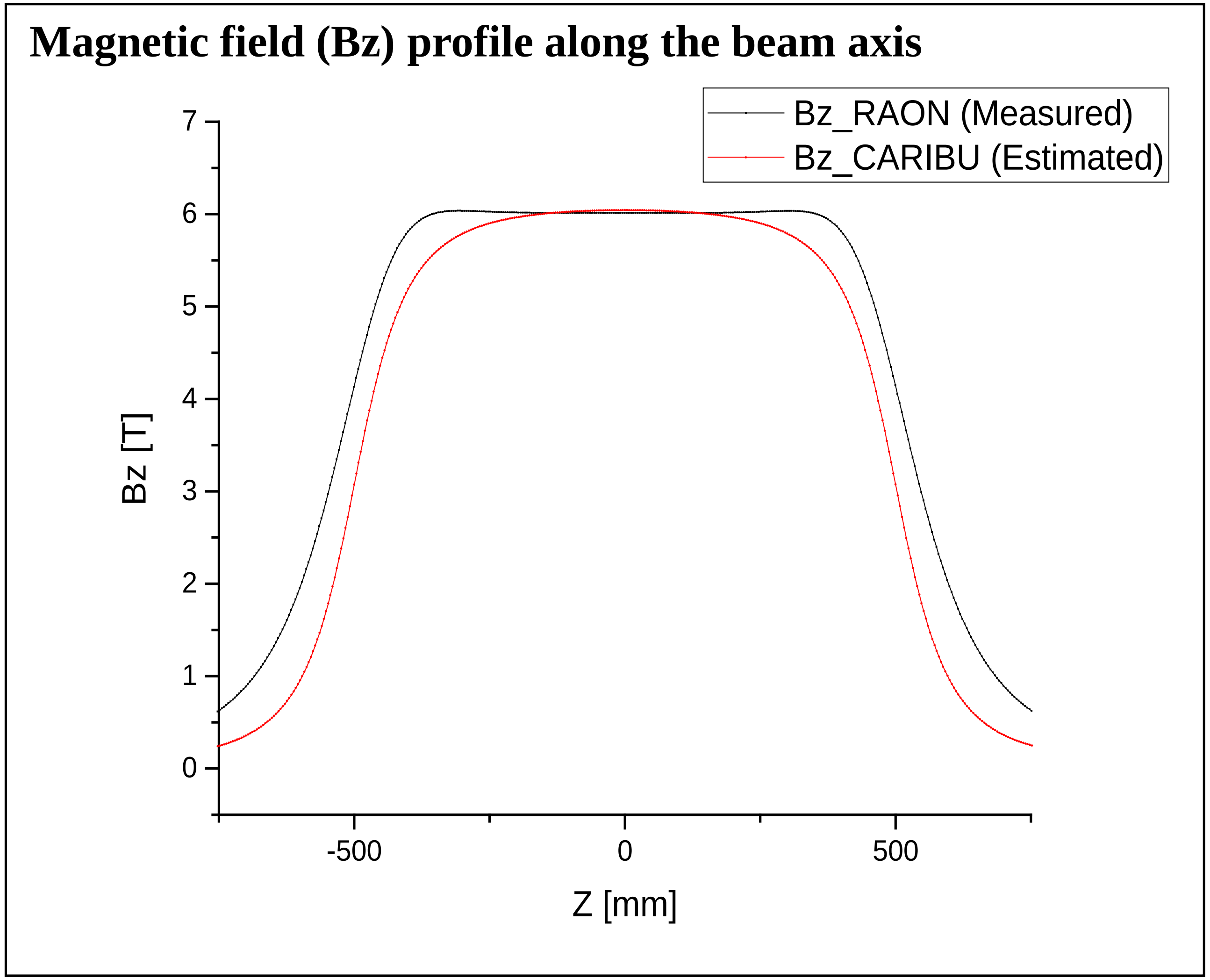
- Cs^{1+} ion beam
- Target A/q : ~4 ($^{132}Cs^{33+}$)
- Electron beam current : 2 A
- Current density at trap region : < 500 A/cm^2
- Electron beam energy : 12 keV
- Breeding tim : 48 ms

3. Components Tests Superconducting Magnet

@2017.07.08

3. Components Tests Superconducting Magnet

- Maximum magnetic field : 6 T
- The required field homogeneity along the axis
  ① +/- 0.4% over 0 to +/-350mm
  ② +/- 4% over 0 to +/- 400mm
- Bore size : 206 mm
- Cooling capacity of cryocooler : 1.5 W



★ Trap length increased compared with CARIBU EBIS

3. Components Tests　Importance of Field Alignment

(1) Argonne lab의 경우, 전자총에서 초전도 마그넷을 거쳐 컬렉터까지 전자빔을 전송하는 실험에서 전자빔 손실을 최소화 하기 위해 총 4조의 steering 코일(Helmholtz type)을 설치하여 운용: E-gun cross chamber - 1조, DT 챔버 – 2조, Collector cross chamber -1조 (RISP EBIS의 경우도 동일한 수량의 steering 코일 설치 예정)

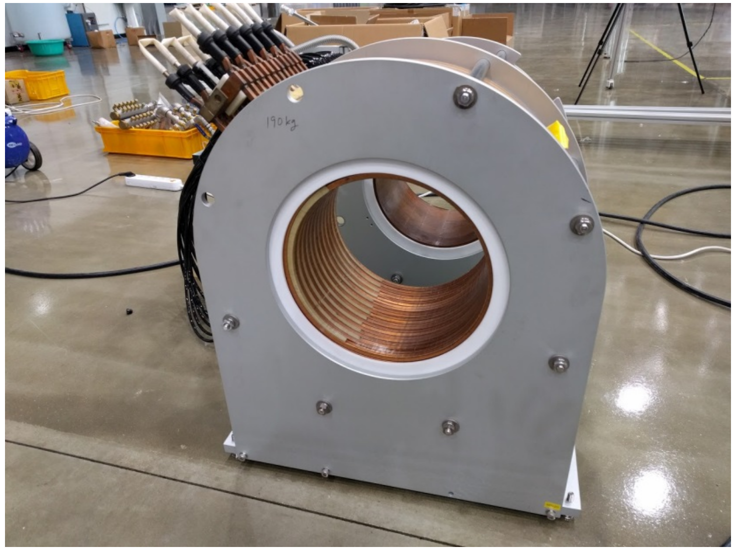
(2) Steering 코일의 조절 범위에 한계가 있기 때문에 처음 설치시 가능한 범위 내에서 최대한 자장 정렬을 할 필요가 있음

(3) 전자빔 손실을 최소화 하지 못할 경우, EBIS 동작시 전자총을 꺼야 하는 time slot을 길게 가져가야 하며 이는 e-beam pulse의 duty 감소(repeatition rate 감소)에 따른 처리 용량 저하로 이어짐, Argonne의 경우 최초 테스트시 반복율 3 Hz로밖에 운용을 못했으며 최적화를 통해 10 Hz까지 끌어 올림

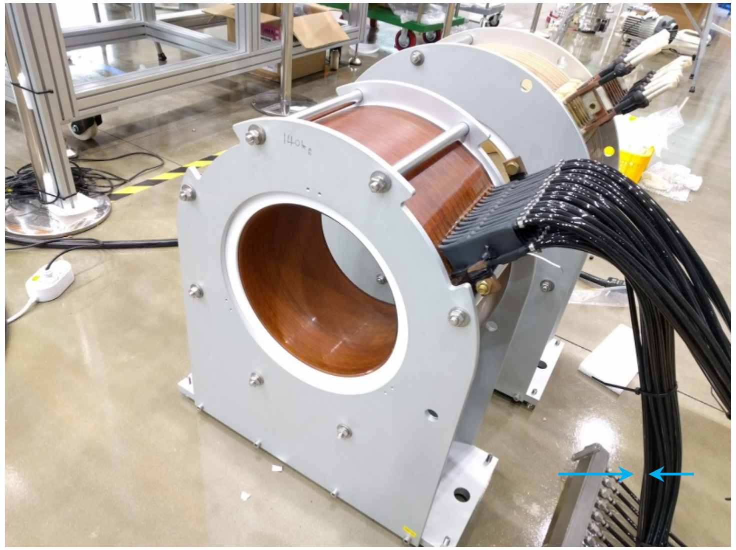
(4) 가장 우려되는 부분은 컬렉터 구멍 입구에 설치된 suppressor 전극으로 차동 펌핑을 위해 apperture 구조로 이루어져 있으며 전자빔에 의해 스퍼터링이 발생할 가능성이 있으며 이로 인해 주위 절연체 구조물에 전도성 피막이 형성되어 breakdown 및 구조물 기능 손상 야기

(5) Breeding 영역의 진공 조건 악화, Contaminant HCI 증가, 증식 효율/처리 용량 저하

3. Components Tests   Importance of Field Alignment



E-gun 코일



Collector 코일

좌측 에폭시 두께: ~5mm

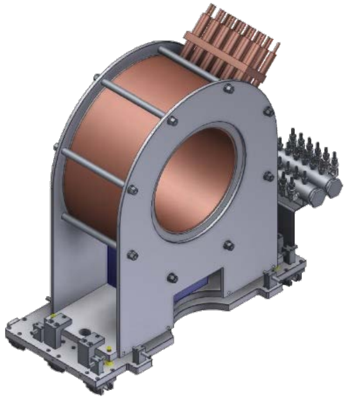
우측 에폭시 두께: ~1mm

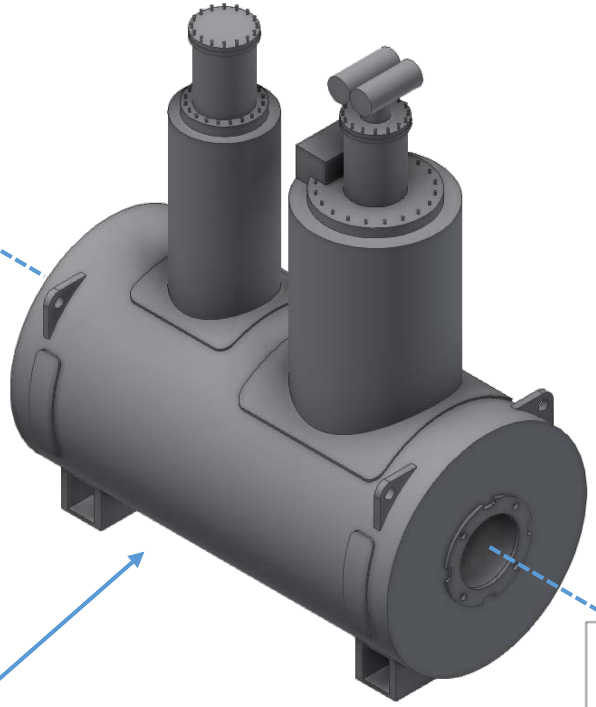
- 최조 코일 제작시 자기장 중심이 구조물에 표시되도록 요구하지 않음
- 에폭시 몰딩 형상의 중심과 코일의 중심이 일치하지 않음 (Collector solenoid의 경우 약 2mm 정도 어긋남)

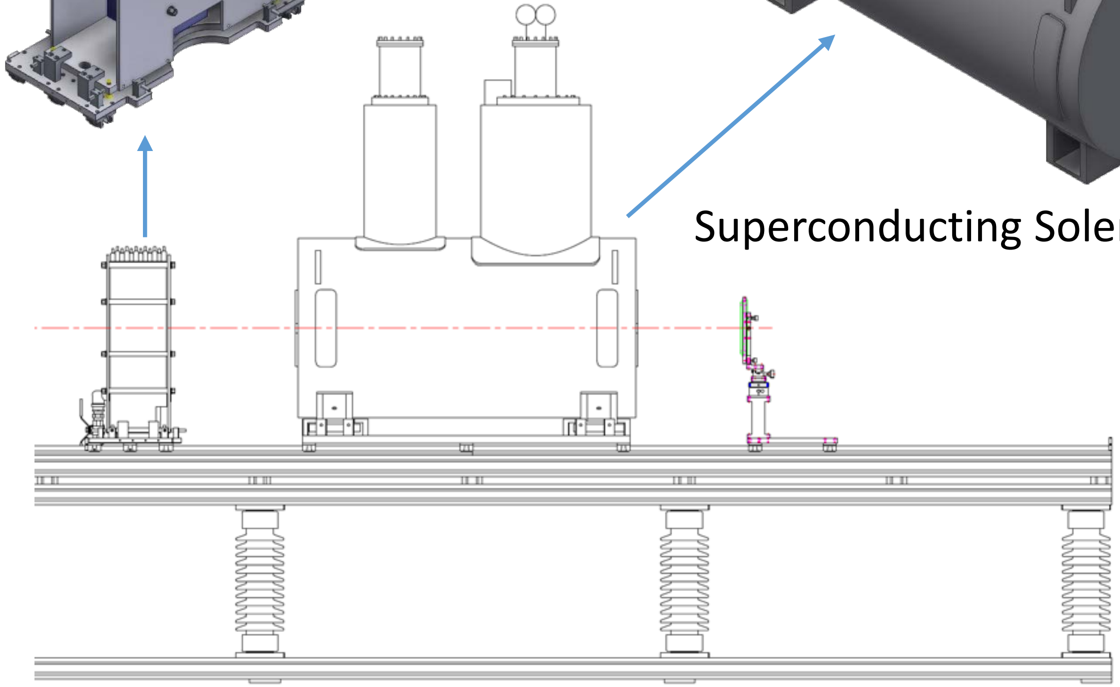
3. Components Tests

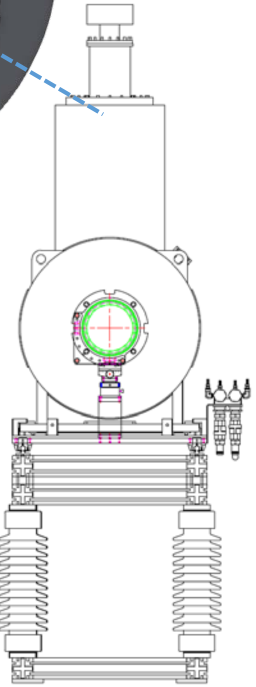
Finding Magnetic Field Centers

- Gun Solenoid
- Collector Solenoid

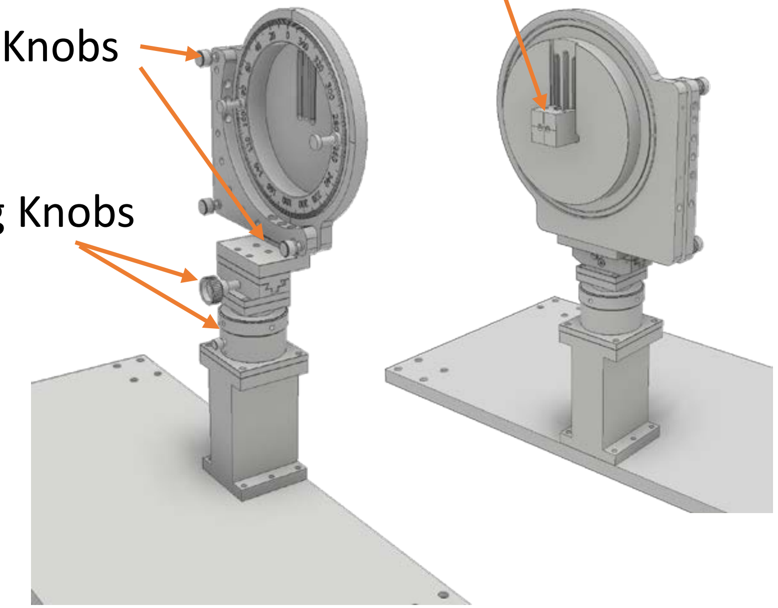






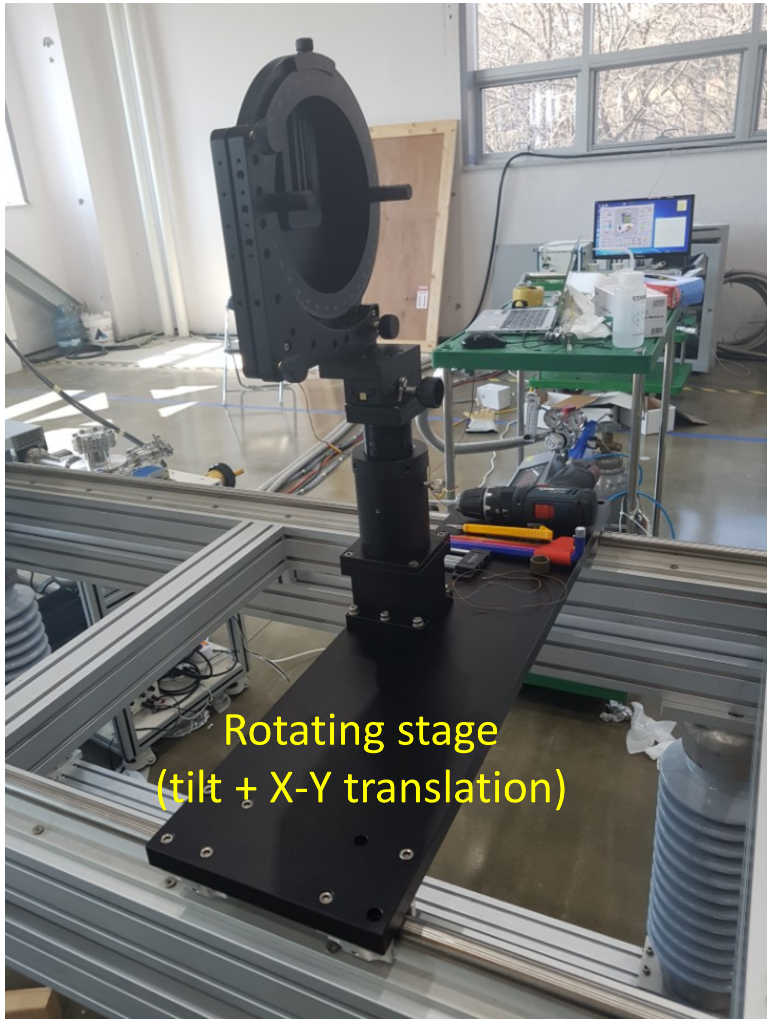


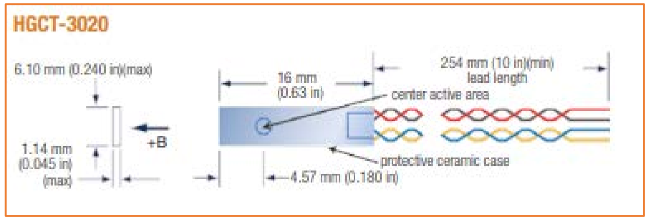
Superconducting Solenoid



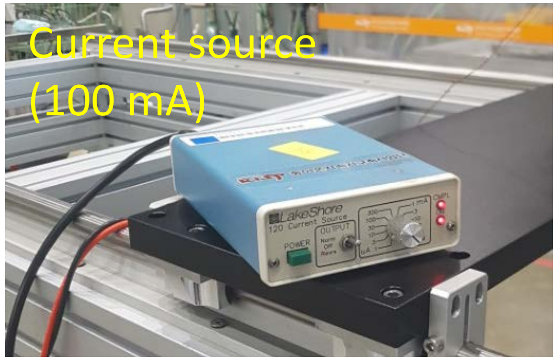
Gimbal Mount for
Field Measurement

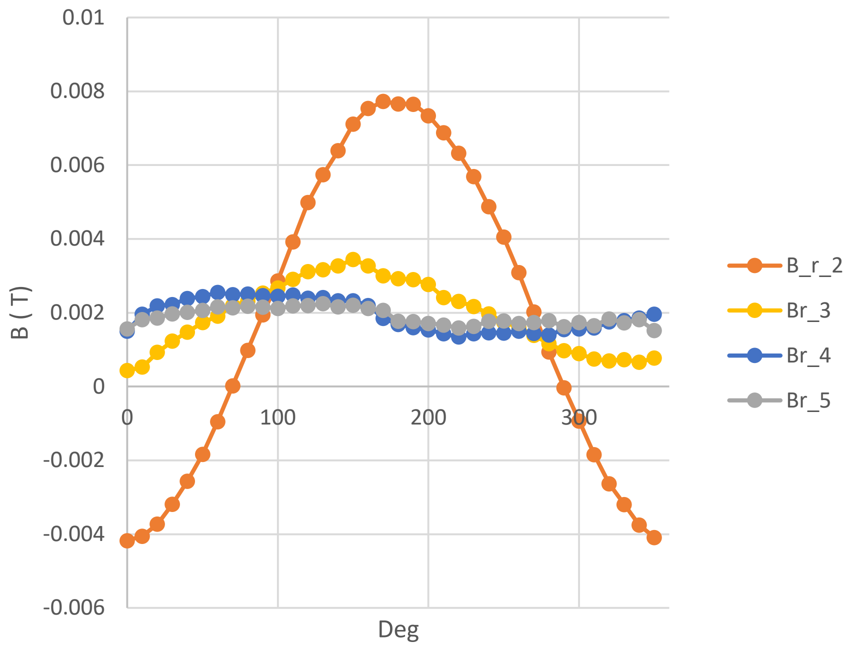
3. Components Tests   Alignment of the Solenoids

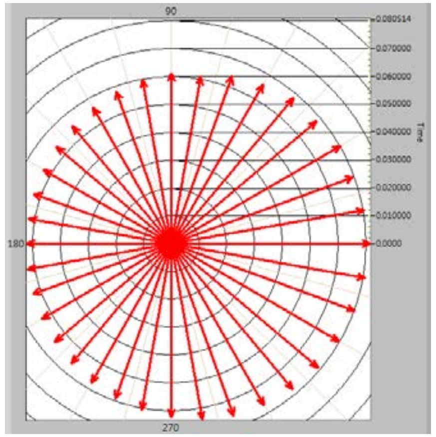


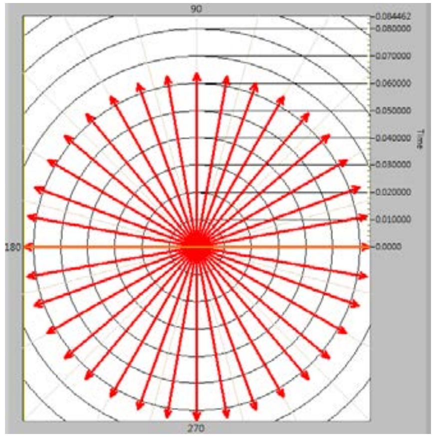


Voltmeter
(~µV)



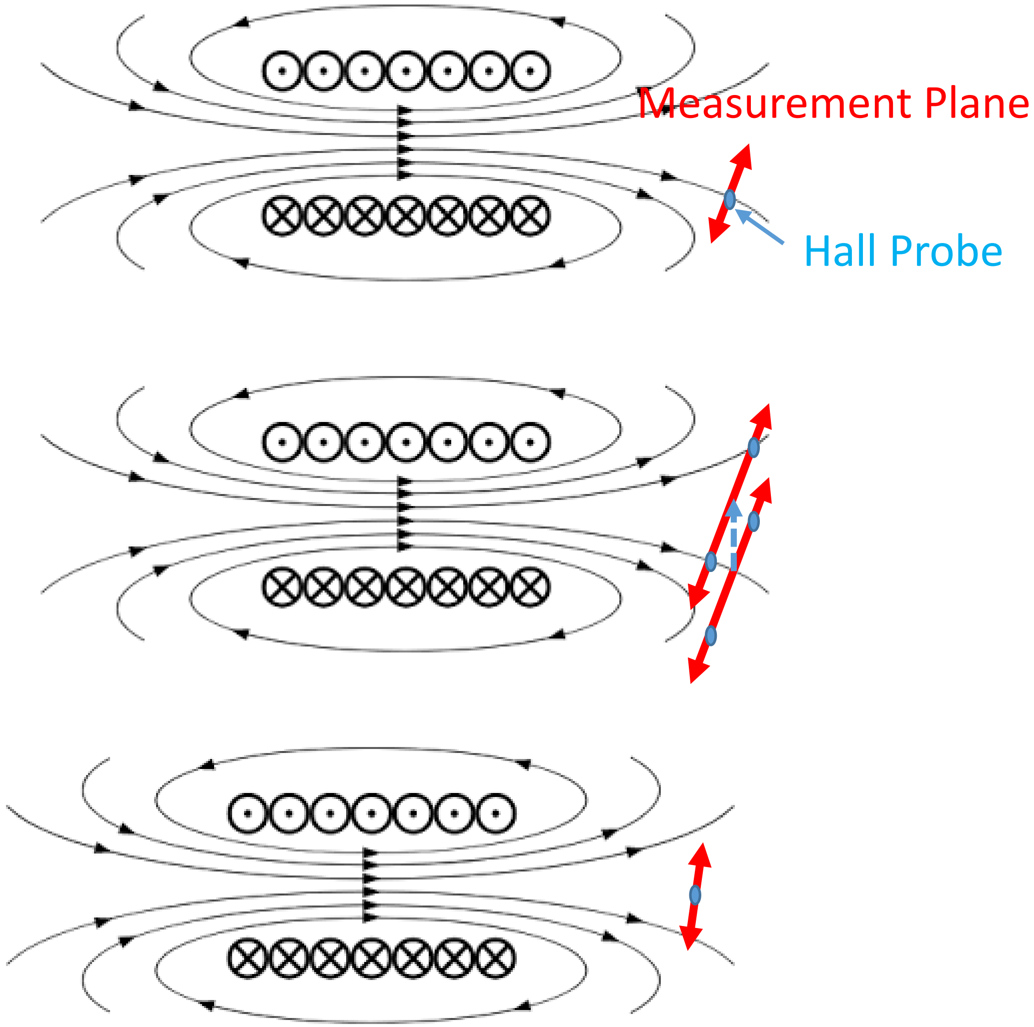






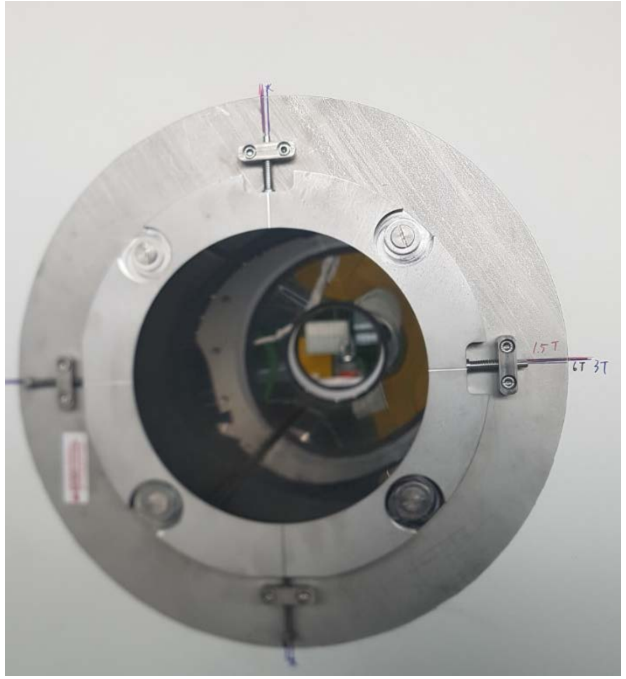
3. Components Tests

Finding Magnetic Field Centers



1) Radial components of the magnetic field against the rotation angles of the disk using a Hall probe at the center usually shows sinusoidal waveform giving information about whether the field direction is perpendicular to the disk plane or not.
2) By adjusting the tilting knobs while minimizing the amplitude of the sinusoidal waveform, we can make the disk plane perpendicular to the magnetic field at the disk center.
3) Then we move the Hall probe to the radially offset position and measure the radial components of the magnetic field against the rotation angles again. Another sinusoidal waveform can be obtained and used to search for the field center by adjusting the shifting knobs.
4) By iterating above procedures, we were able to mark the field center at both sides of the SC magnet.

3. Components Tests Marking Field Center Using Laser Leveler



Gun side offset : ~3 mm

Collector side offset : negligible

3. Components Tests

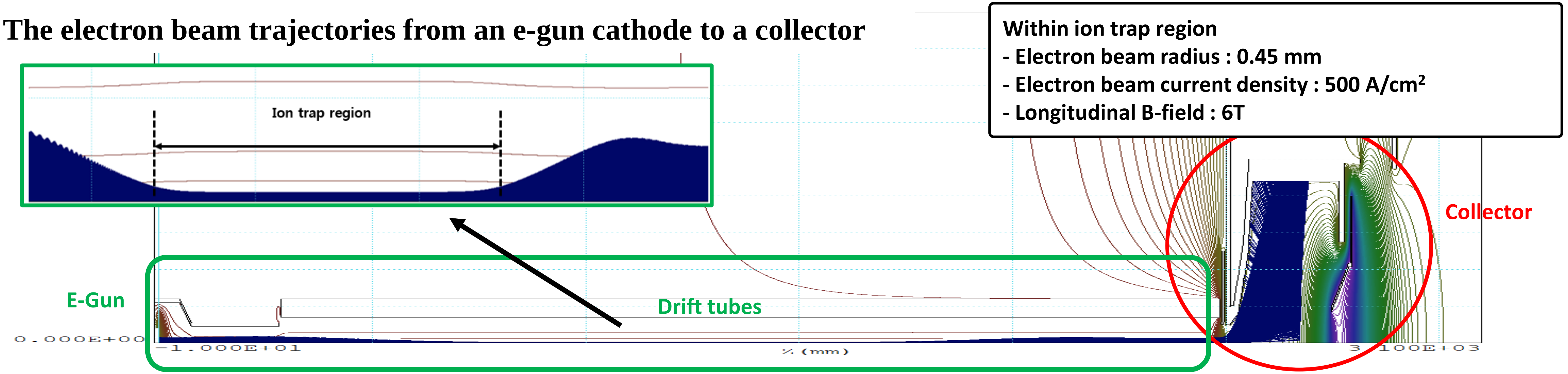
Marking Field Centers of Normal Conducting Coils

Collector side solenoid field center line

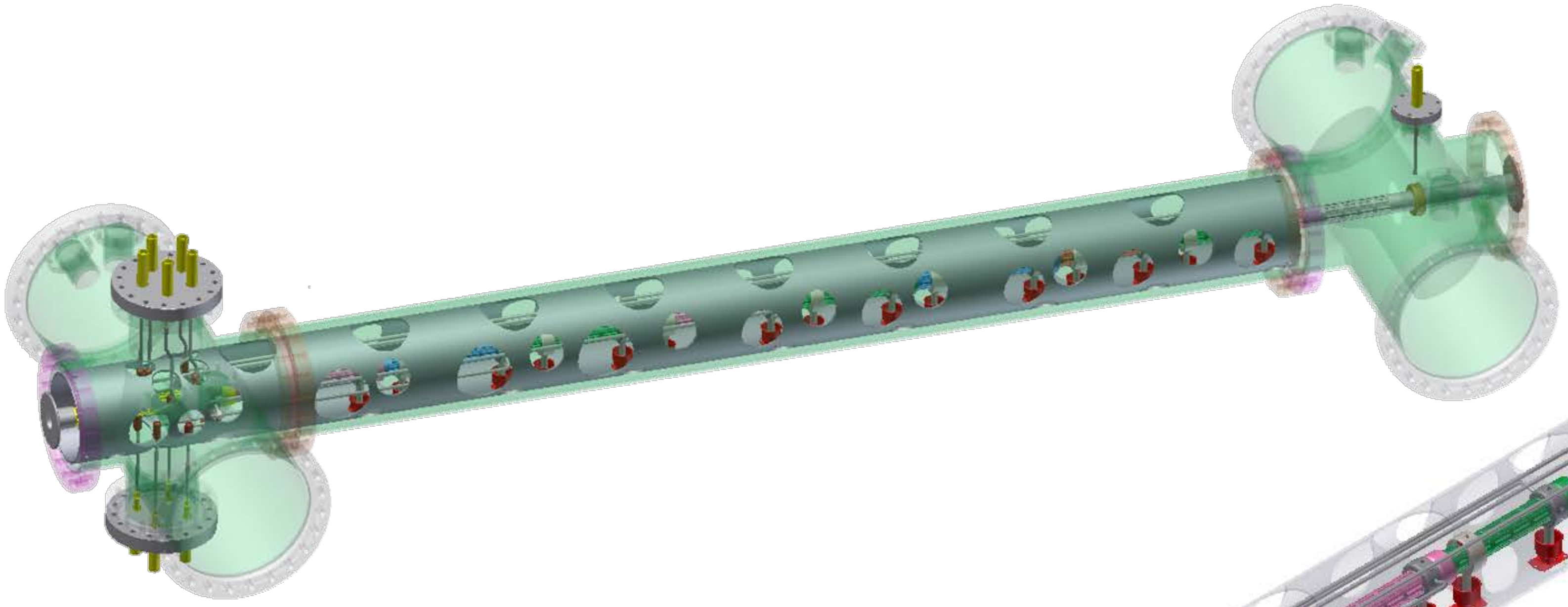
E-gun side solenoid field center line

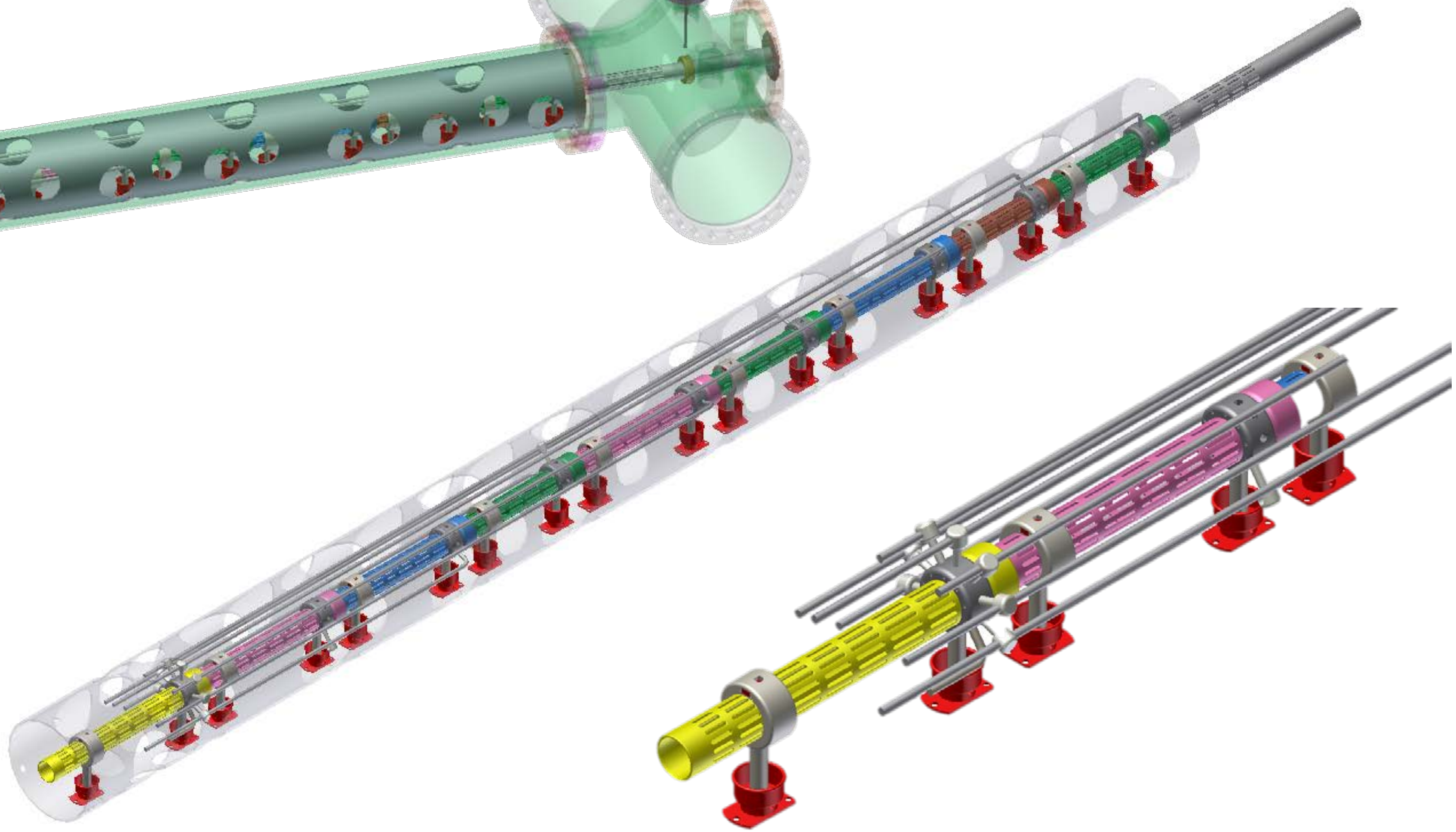
3. Components Tests Design of the Drift Tubes Chamber

The electron beam trajectories from an e-gun cathode to a collector



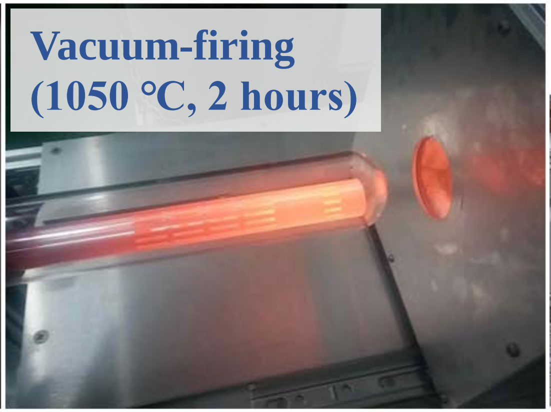
3. Components Tests Design of Drift Tubes

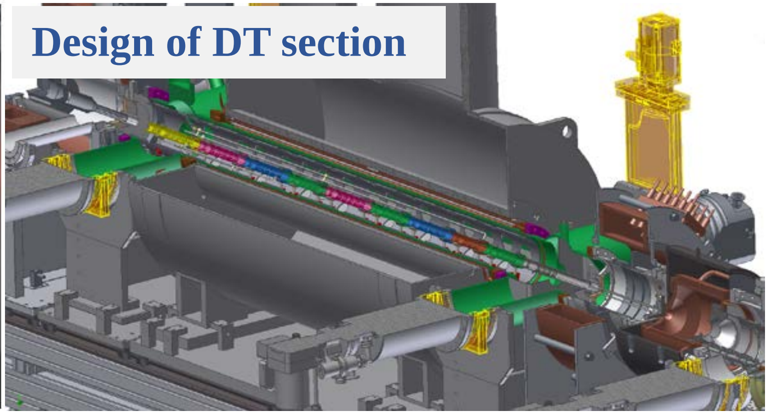


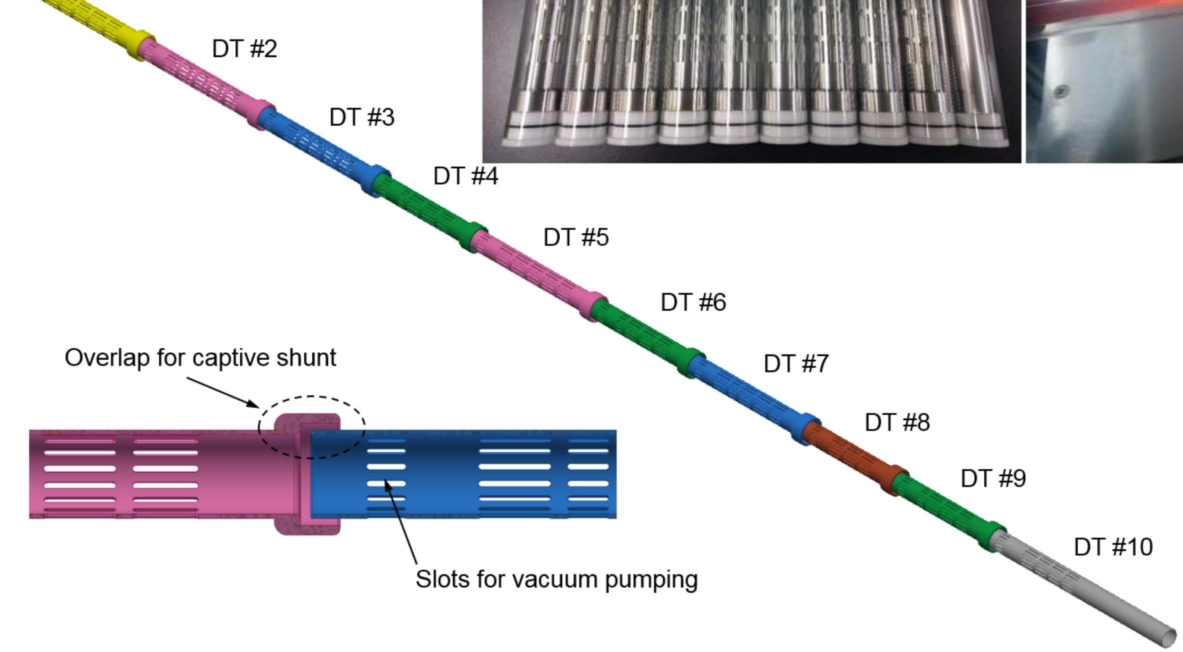


3. Components Tests   Design of Drift Tubes

- 10 drift tubes inside of vacuum chamber to generate axial potential well for ion trap
- Capacitive shunts on drift tube ends to short out RF signal
- To avoid unwanted RF coupling, the drift tubes should be aperiodic structure
- All drift tubes are vacuum-fired to remove the hydrogen in the material
- Trap length is 760 mm, and estimated trap capacity is $2 \cdot 10^{11}$ charges







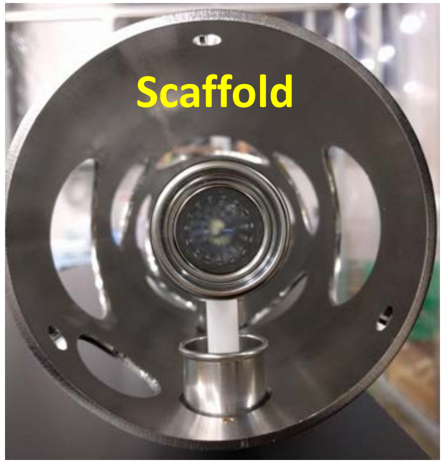
The electrical trap capacity is around $2 \cdot 10^{11}$ [charges]

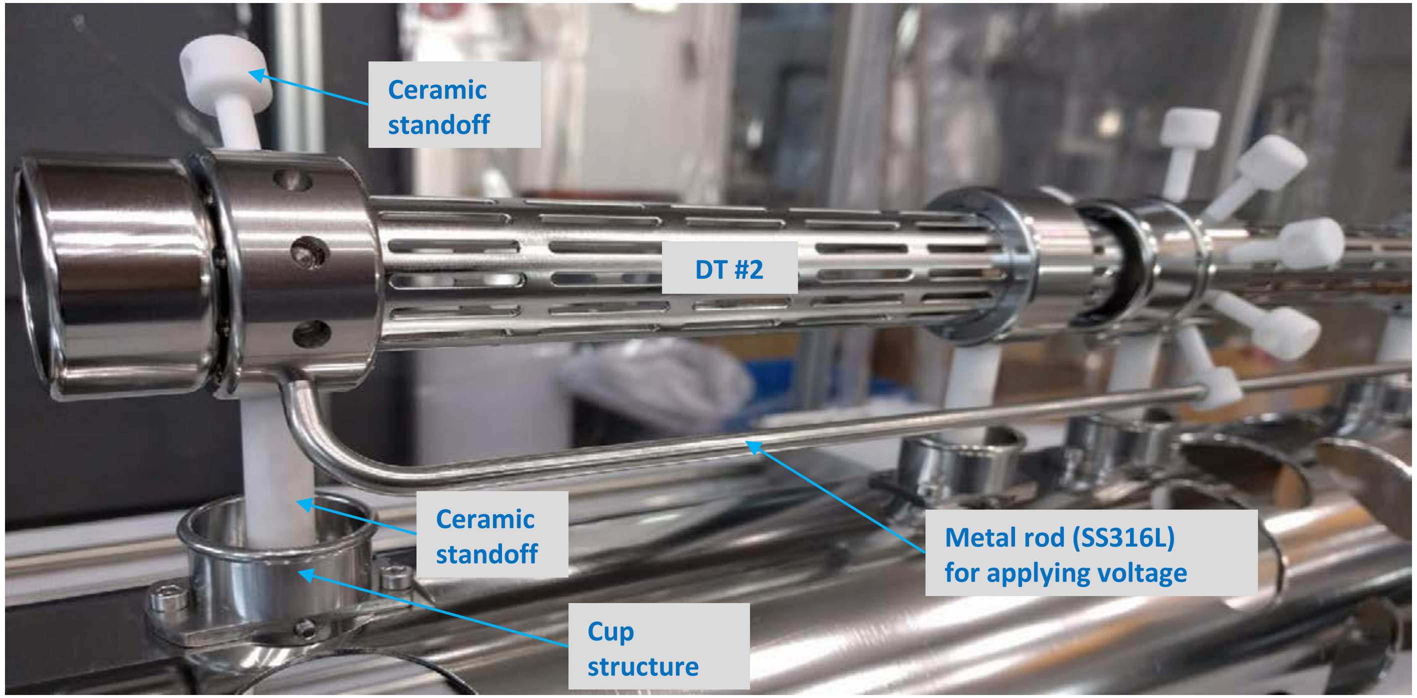
$$Capacity = 1.05 \times 10^{13} \times \frac{I_e \cdot L}{\sqrt{E_e}}\ [charges]$$

$$I_e = 3\ [A], \qquad L = 0.76\ [m], \qquad E_e = 12keV$$

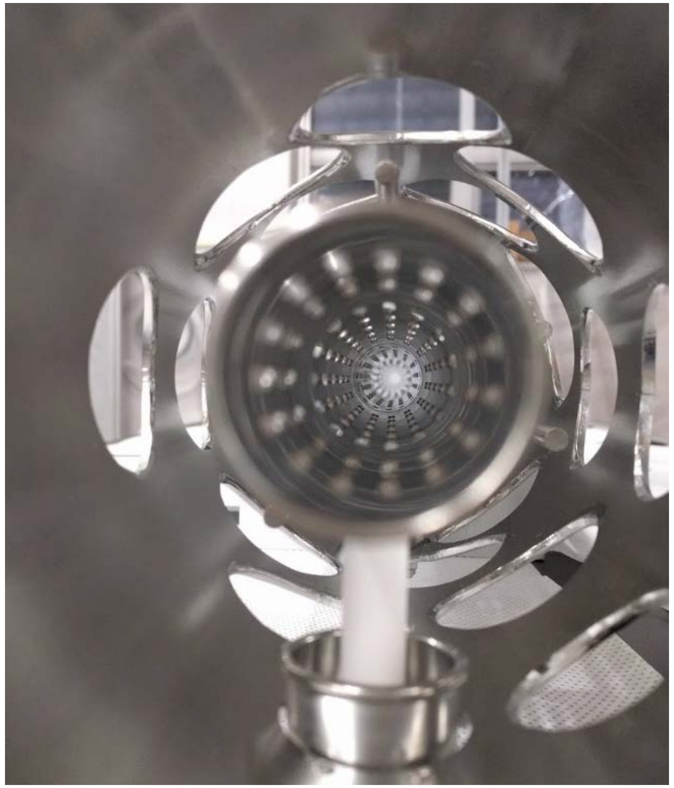
3. Components Tests

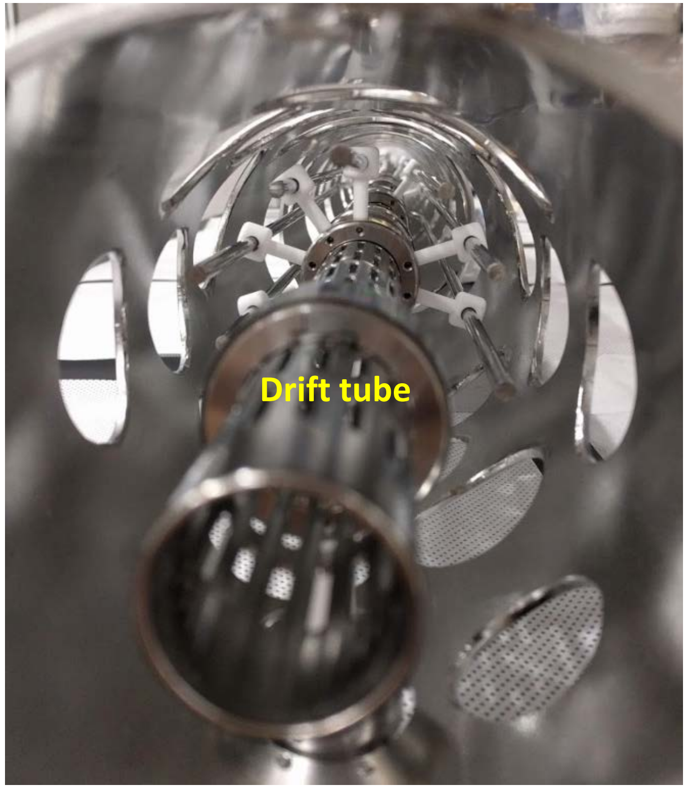
Design of Drift Tubes





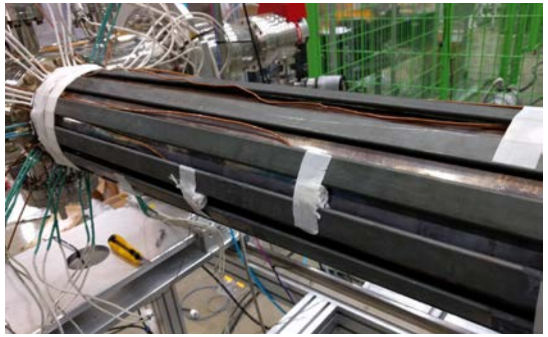
3. Components Tests   Assembling Drift Tubes inside the Scaffold



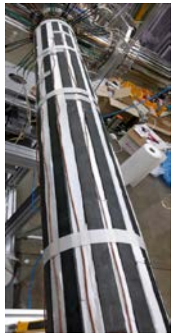


3. Components Tests

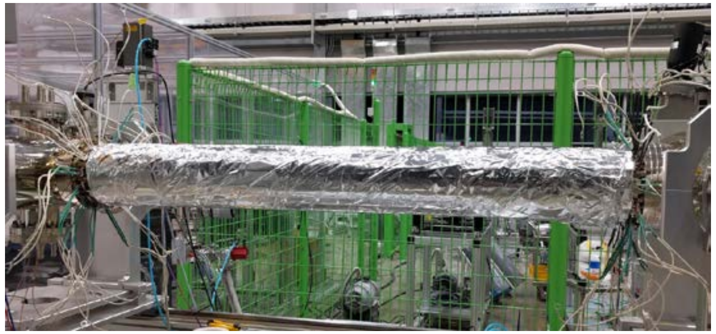
Drift Tubes Chamber Wrapping with Water Jacket



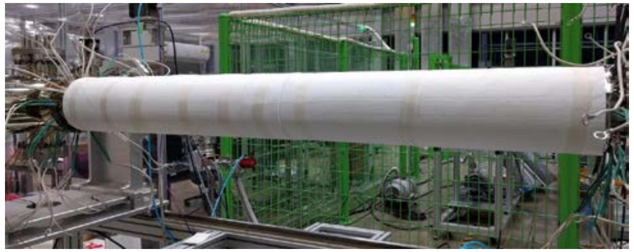
Installation of
Heating bars (12 units) and TC (9 positions)



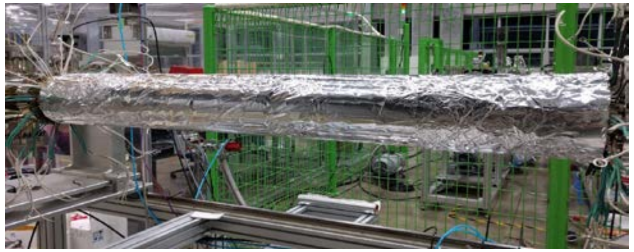
Inserting thermal
Isolations
(1st layer, cerac paper)



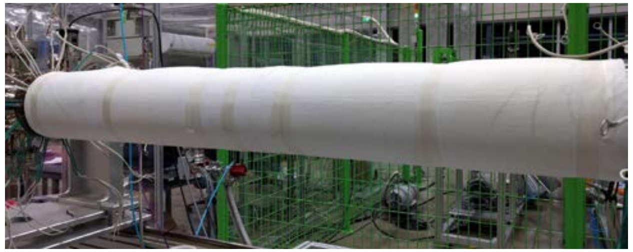
Covering Al foil (2nd layer)



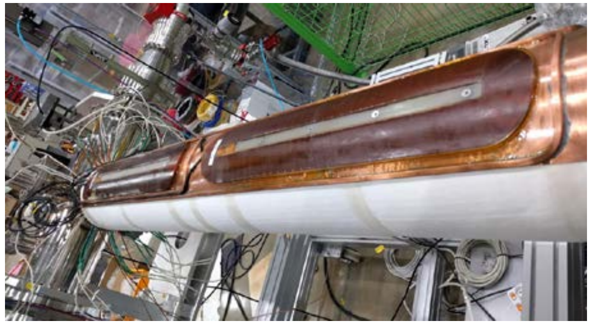
Covering thermal isolation
(cerac paper, 5 mm, 3rd layer)



Covering Al foil (4th layer)

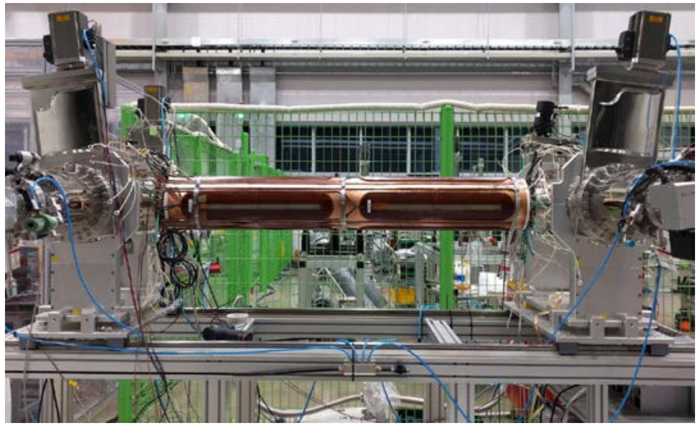


Covering thermal isolation
(cerac paper, 5 mm, 5th layer)



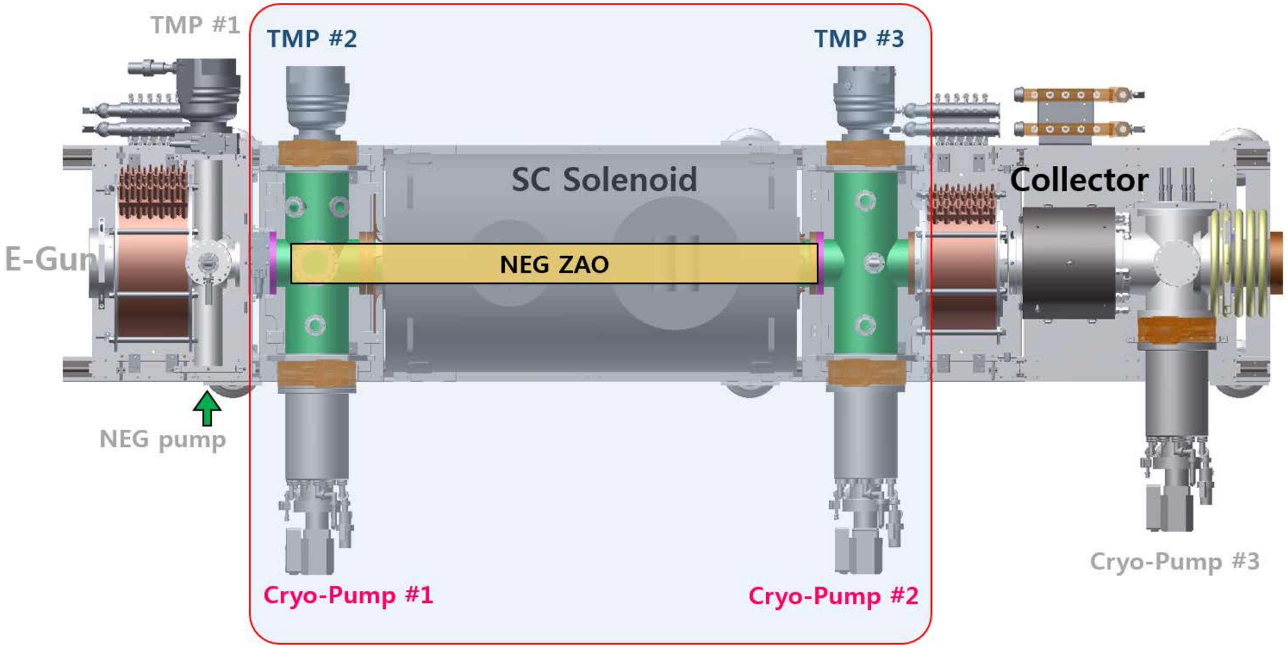
Installation of water jacket (upper side)

Installation of water jacket (bottom side)

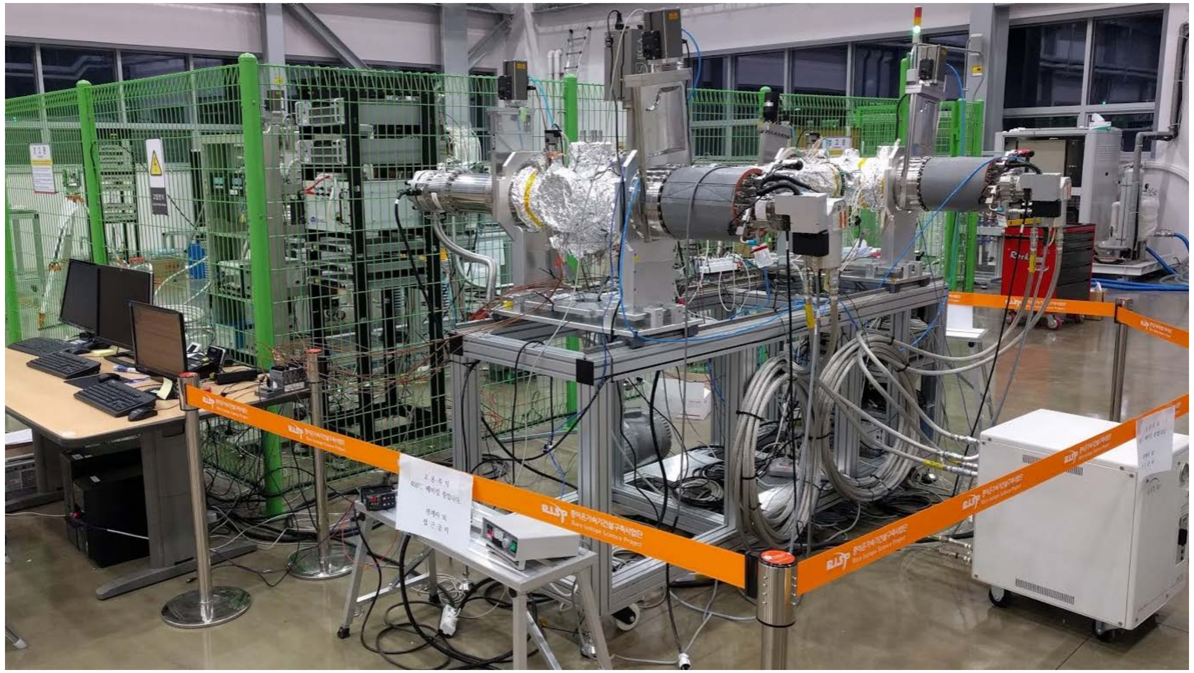


3. Components Tests

Vacuum Pumping System



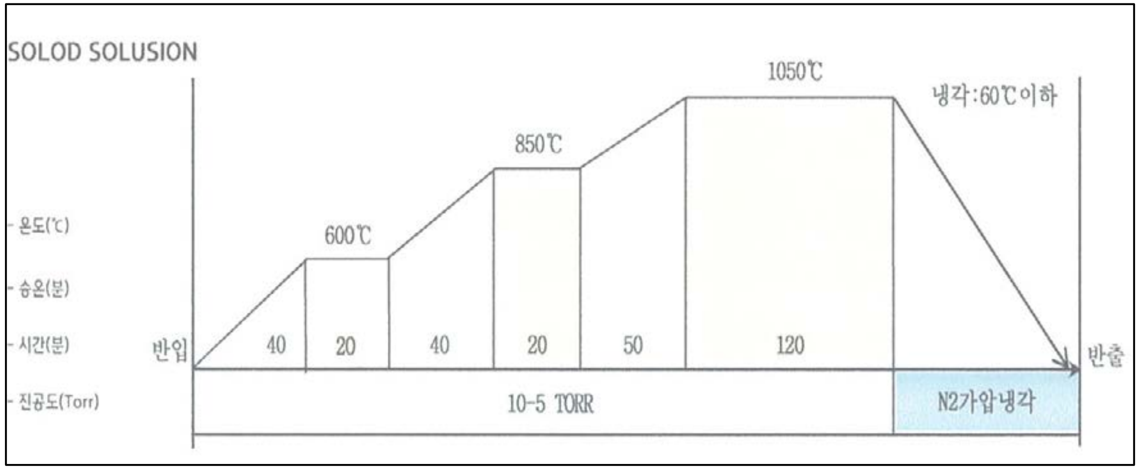
- **Vacuum test stand for DT section**



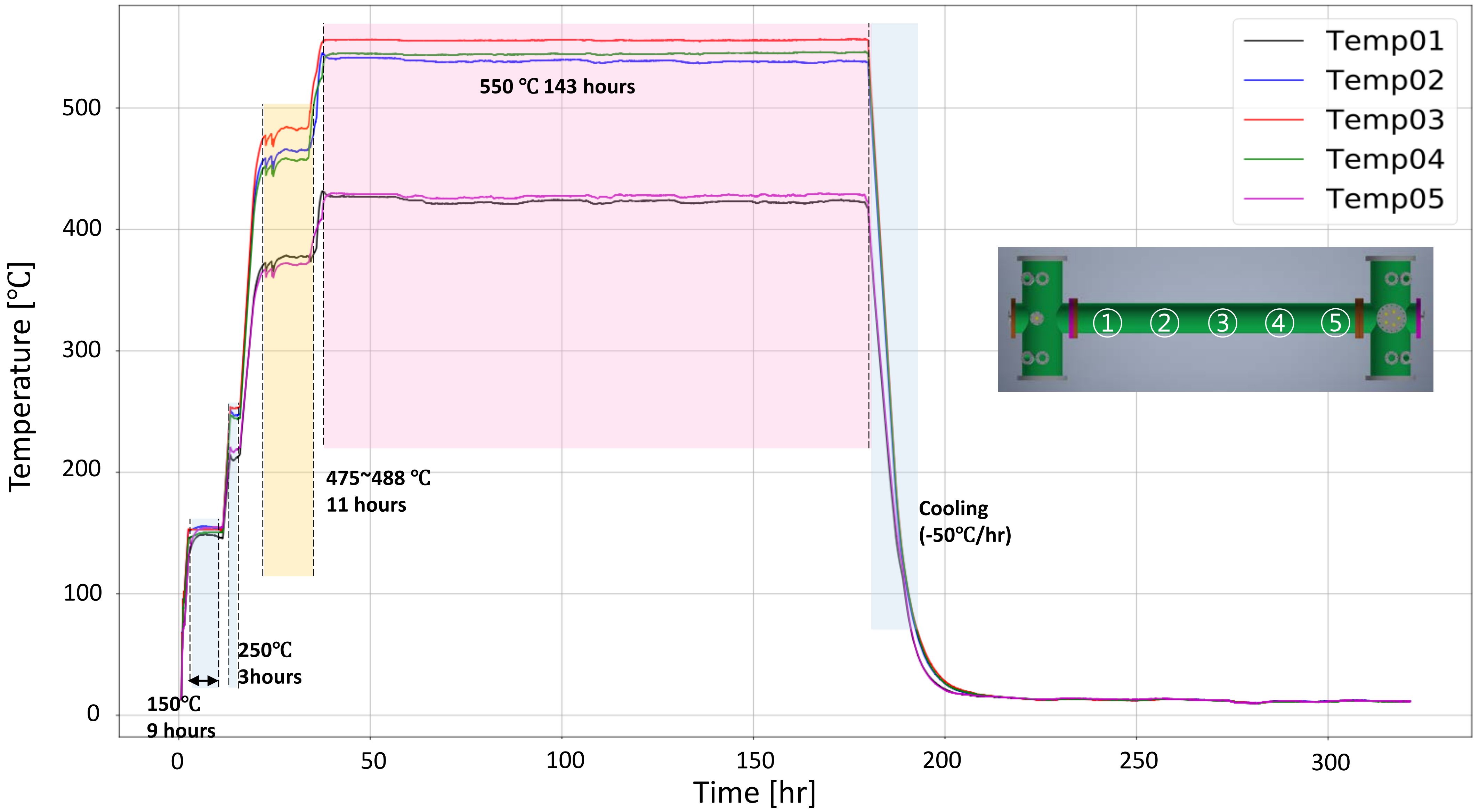
- Ultra-high vacuum in ion trap (~ 10^{-11} torr)
  - Vacuum firing (1050 °C for 2 hours) of all SS parts to remove hydrogen from bulk material (SS316L, 316LN – non-magnetic)
  - XHV compatible materials - 99.8% pure alumina for all isolators

3. Components Tests Vacuum Pumping System

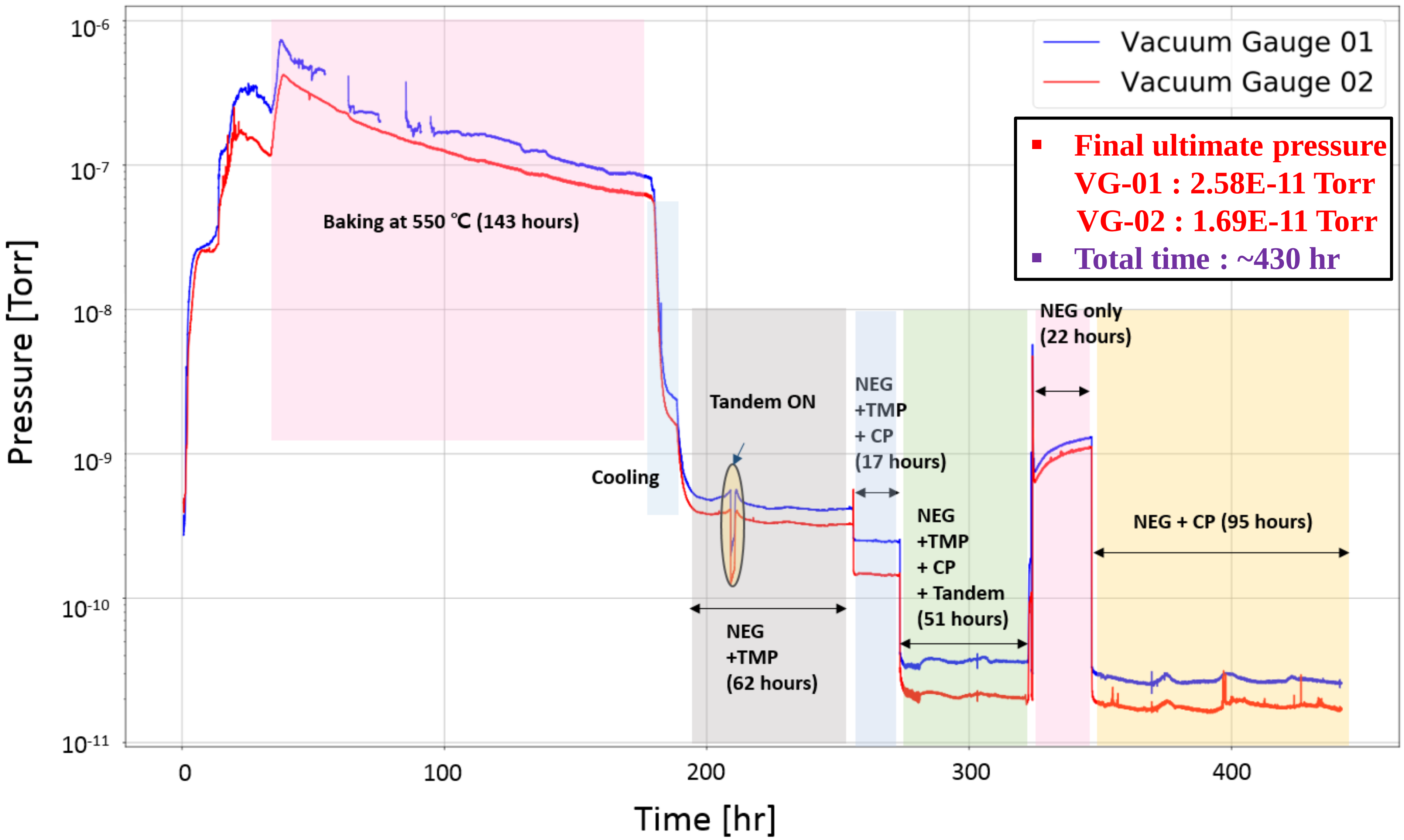
Vacuum firing (1050 °C for 2 hours)



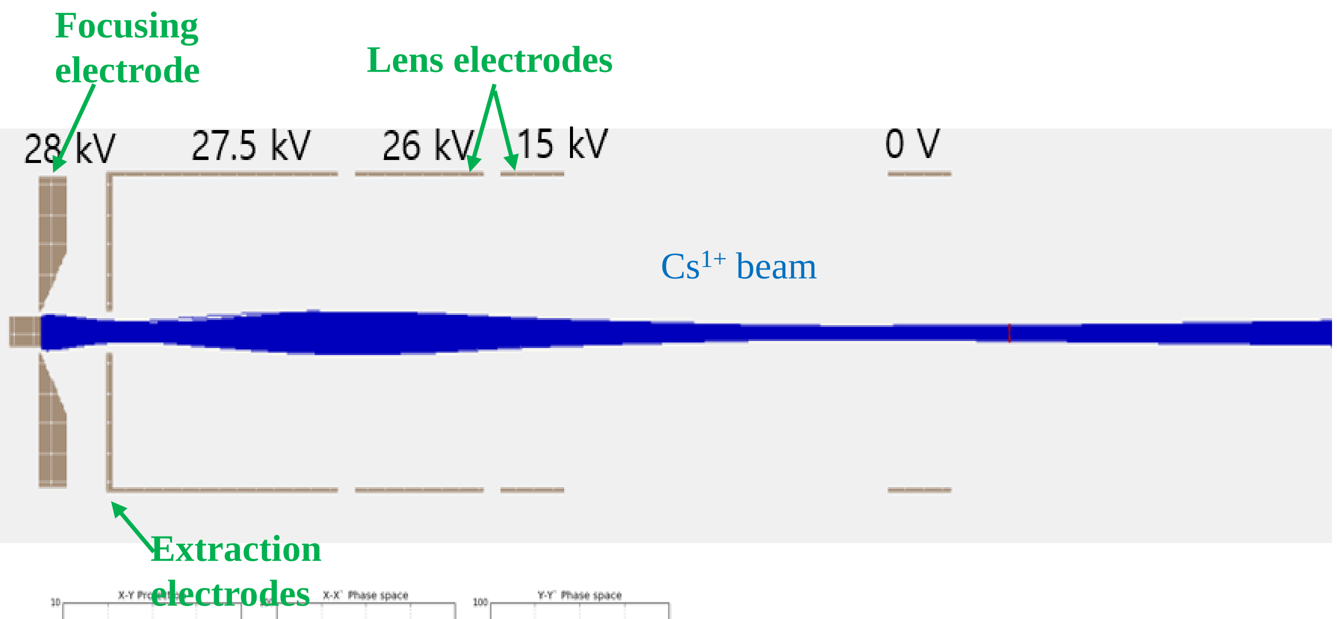
3. Components Tests Baking Drift Tube Chamber

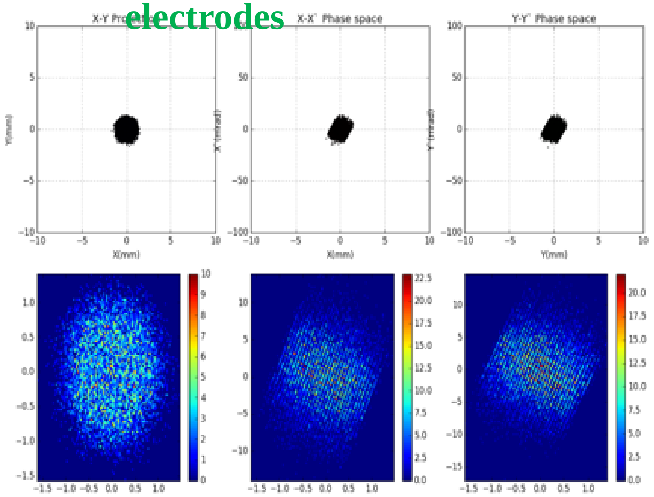


3. Components Tests Baking Drift Tube Chamber



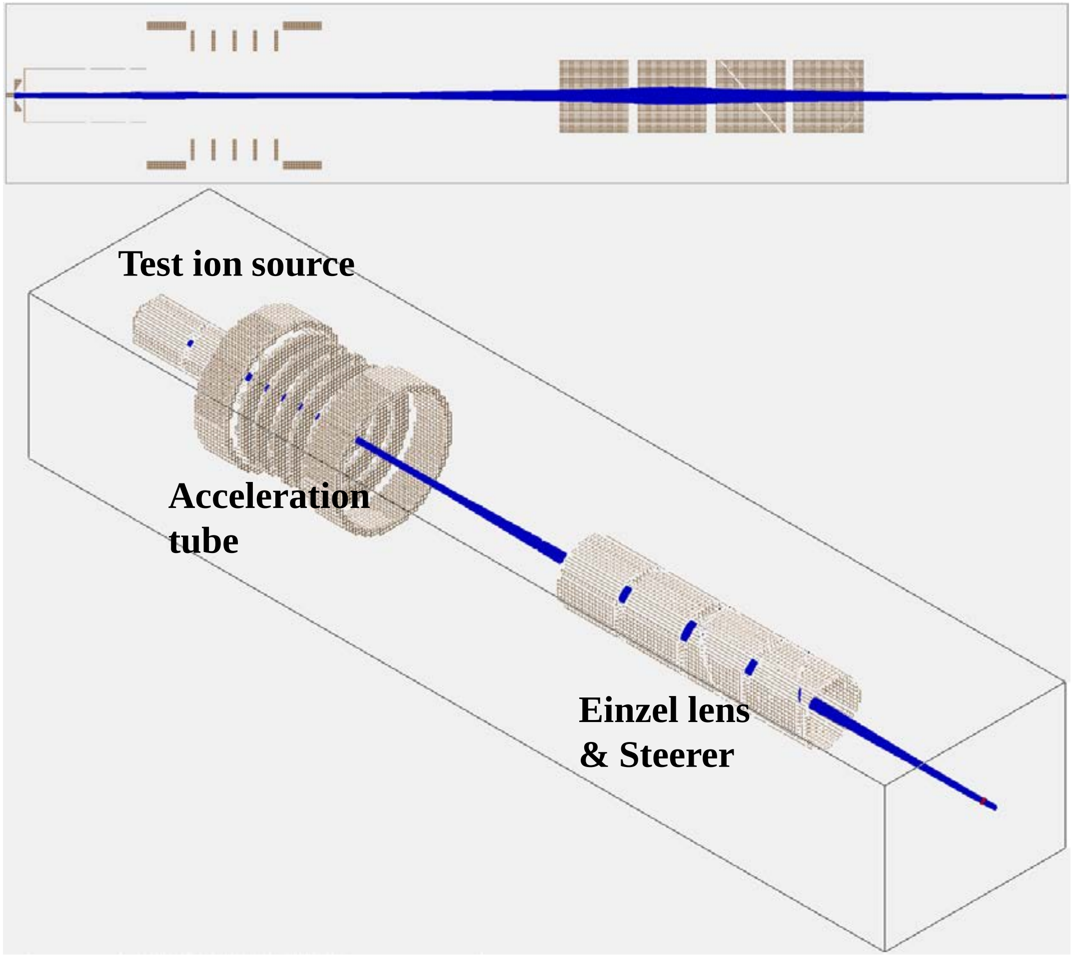
3. Components Tests   Test Ion Source Design Simulation





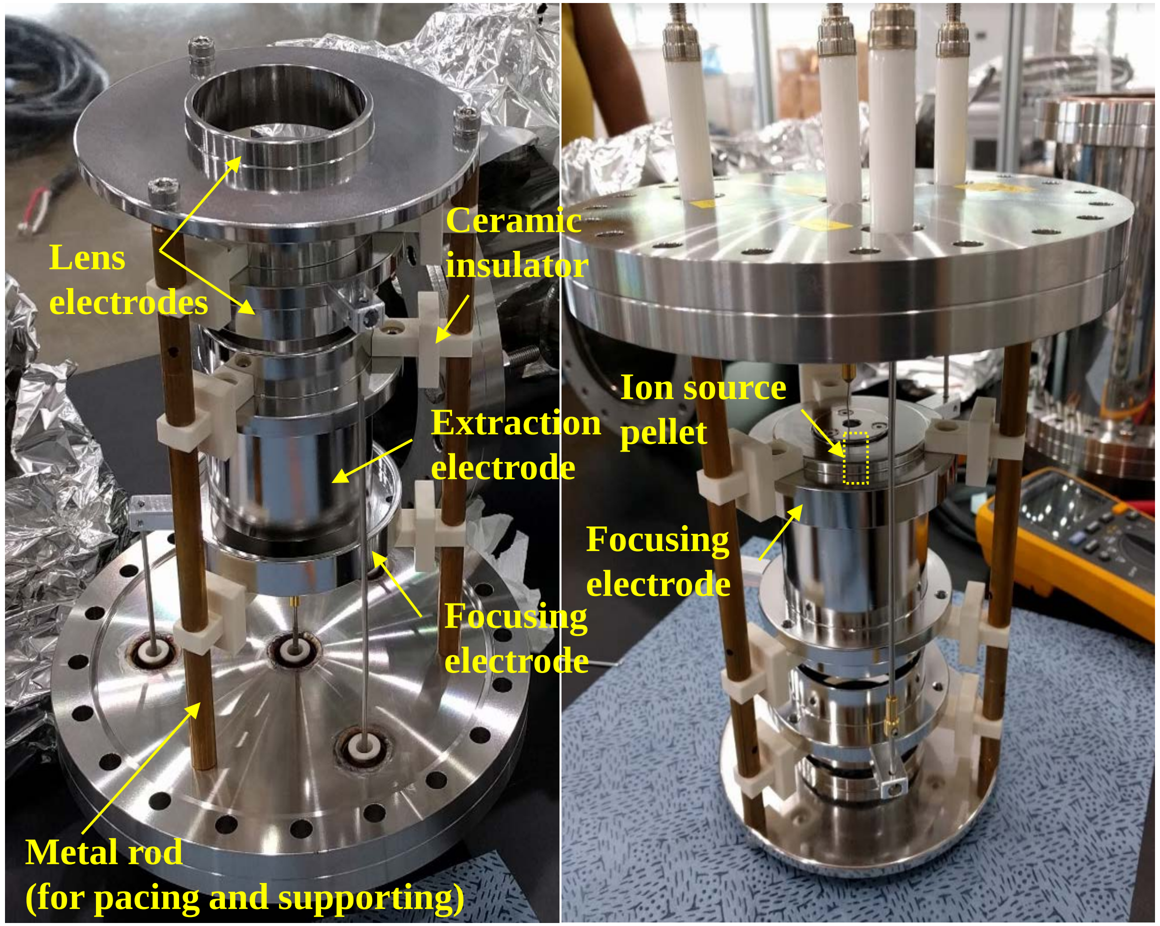
- Emittance (RMS)
  $8.5\,\pi\, mrad \cdot mm$
- Emittance (Normalized)
  XX' : $0.00876\,\pi\, mrad \cdot mm$

- **Test ion source with ion optical components**



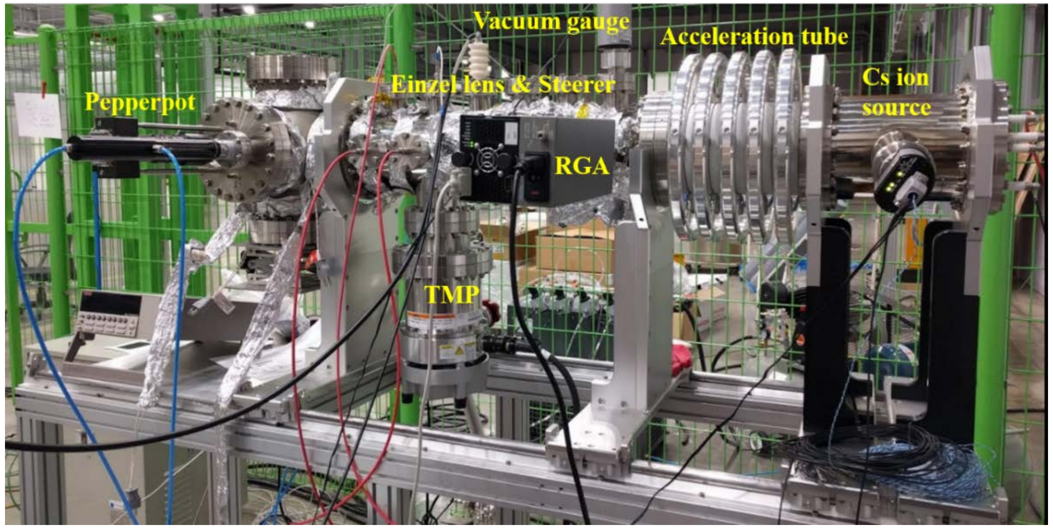
3. Components Tests

Test Ion Source



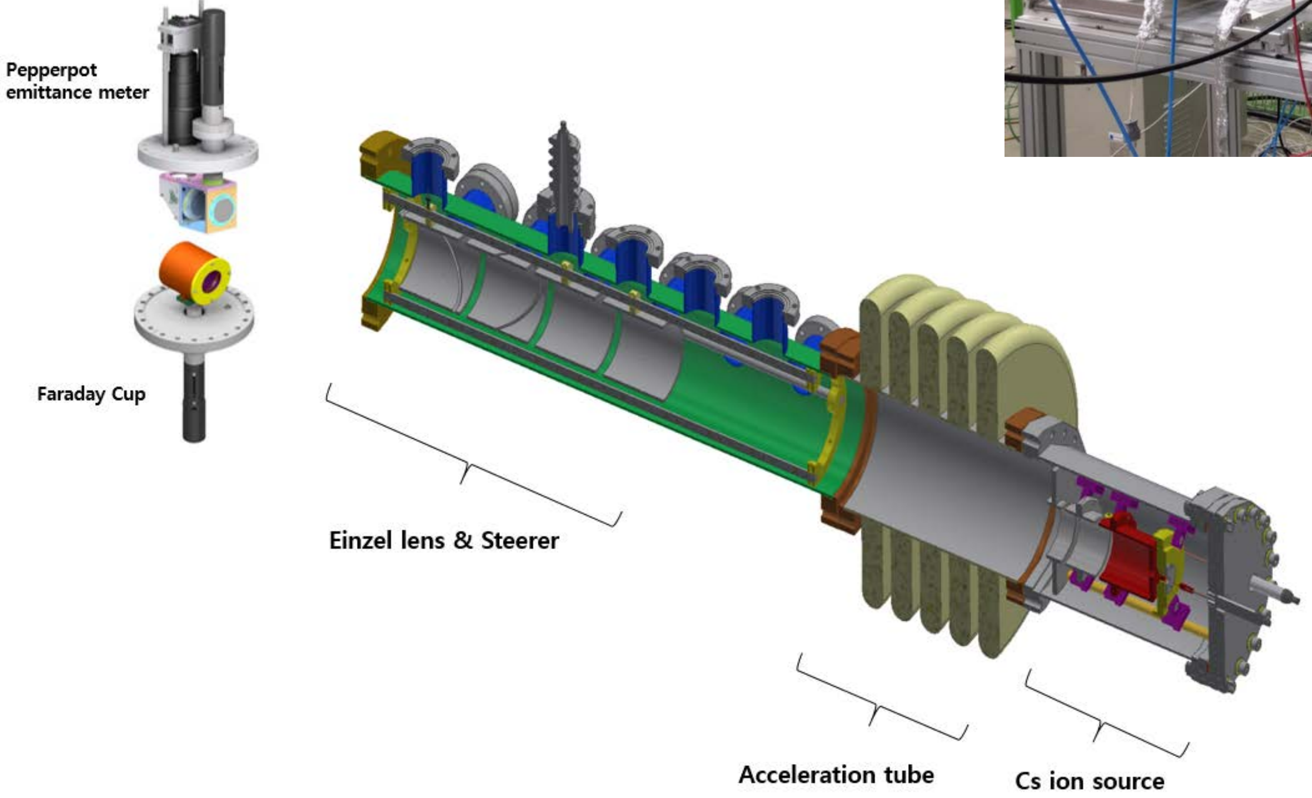
HeatWave Labs

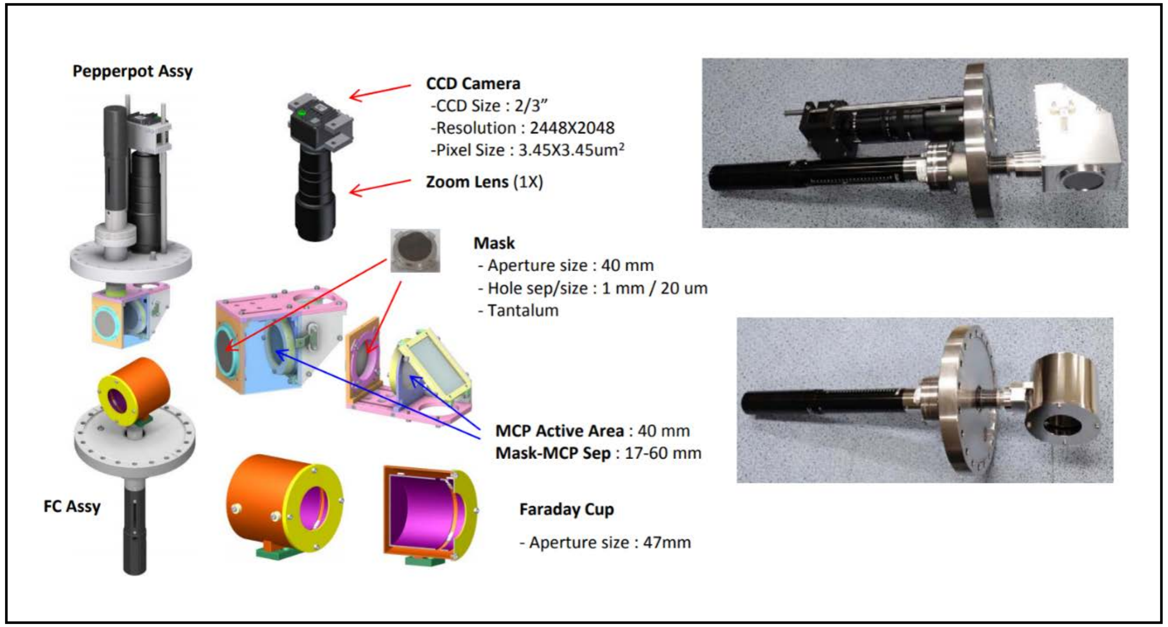
3. Components Tests   Test Ion Source



Cs ion source test

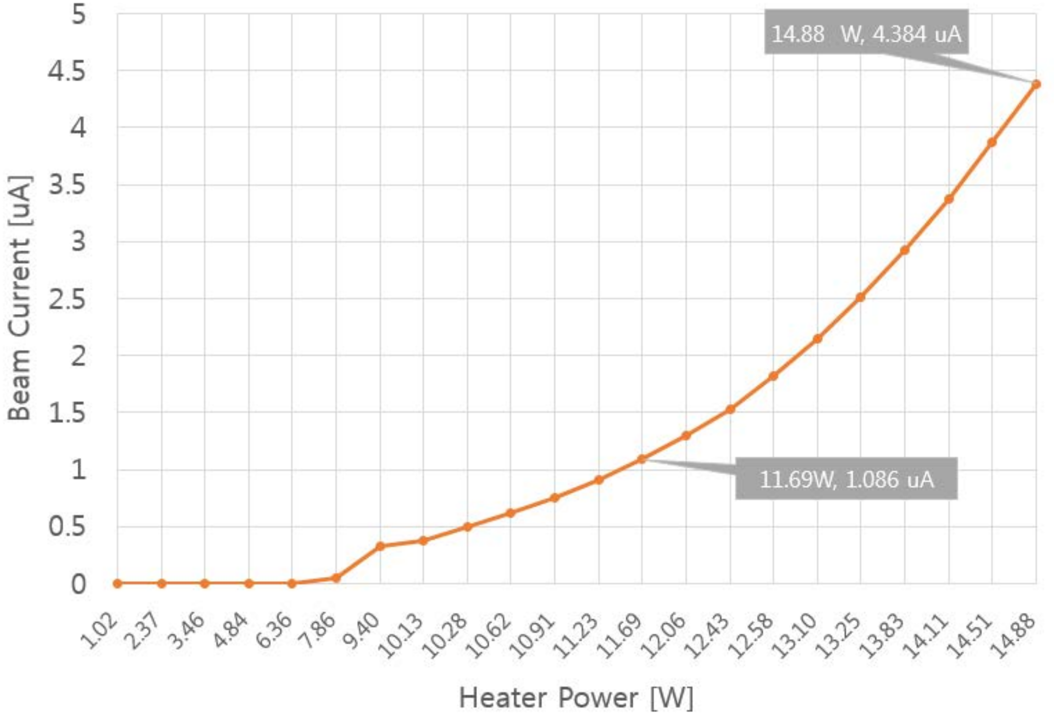
- 4.9 keV (4.9kV ion source platform)
- Einzel lens & steerer test
- Beam dianogstic (Pepperpot, FC)

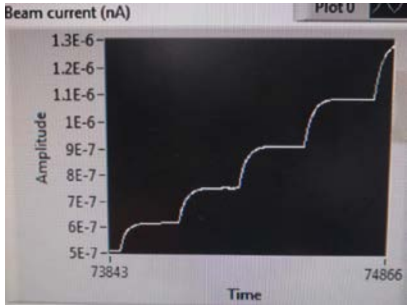




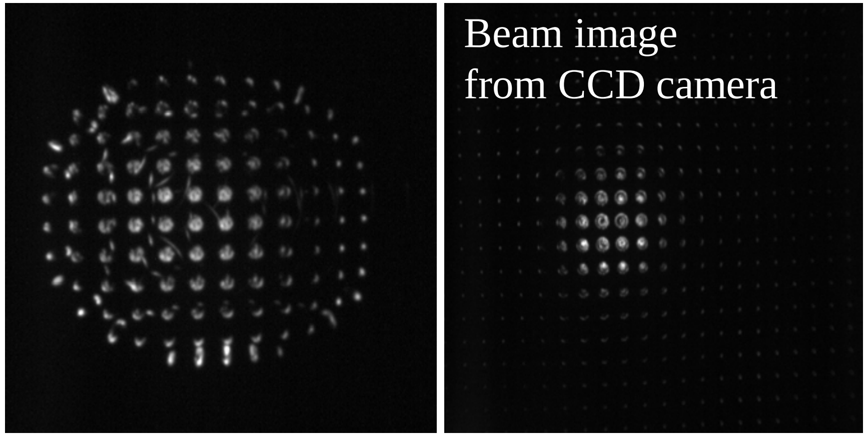
3. Components Tests Test Ion Source

Beam current (Faraday cup)

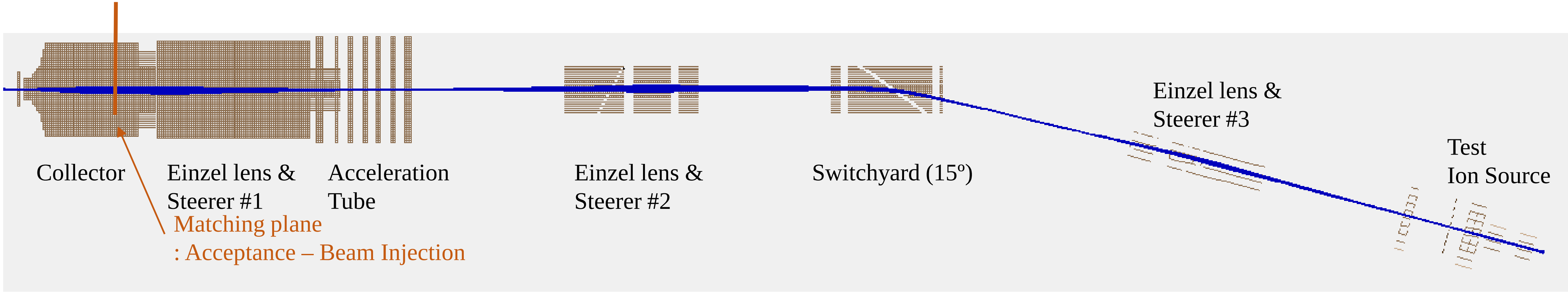




Pepperpot Image



3. Components Tests Injection / Extraction Beam Line



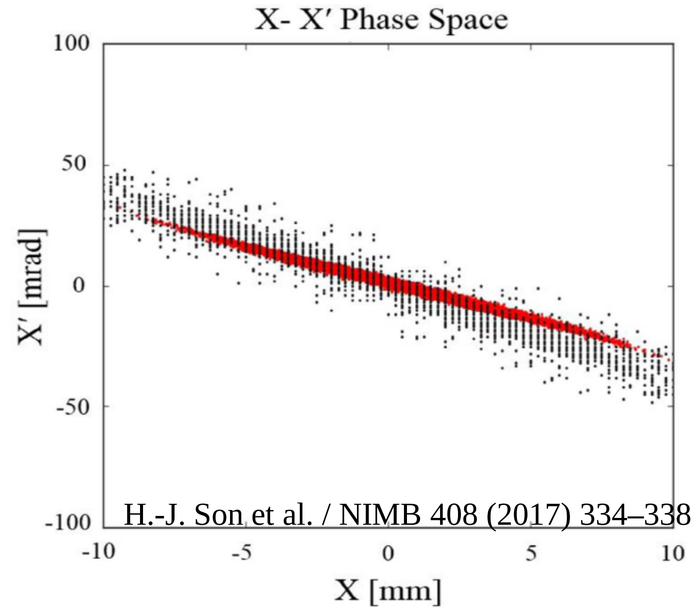
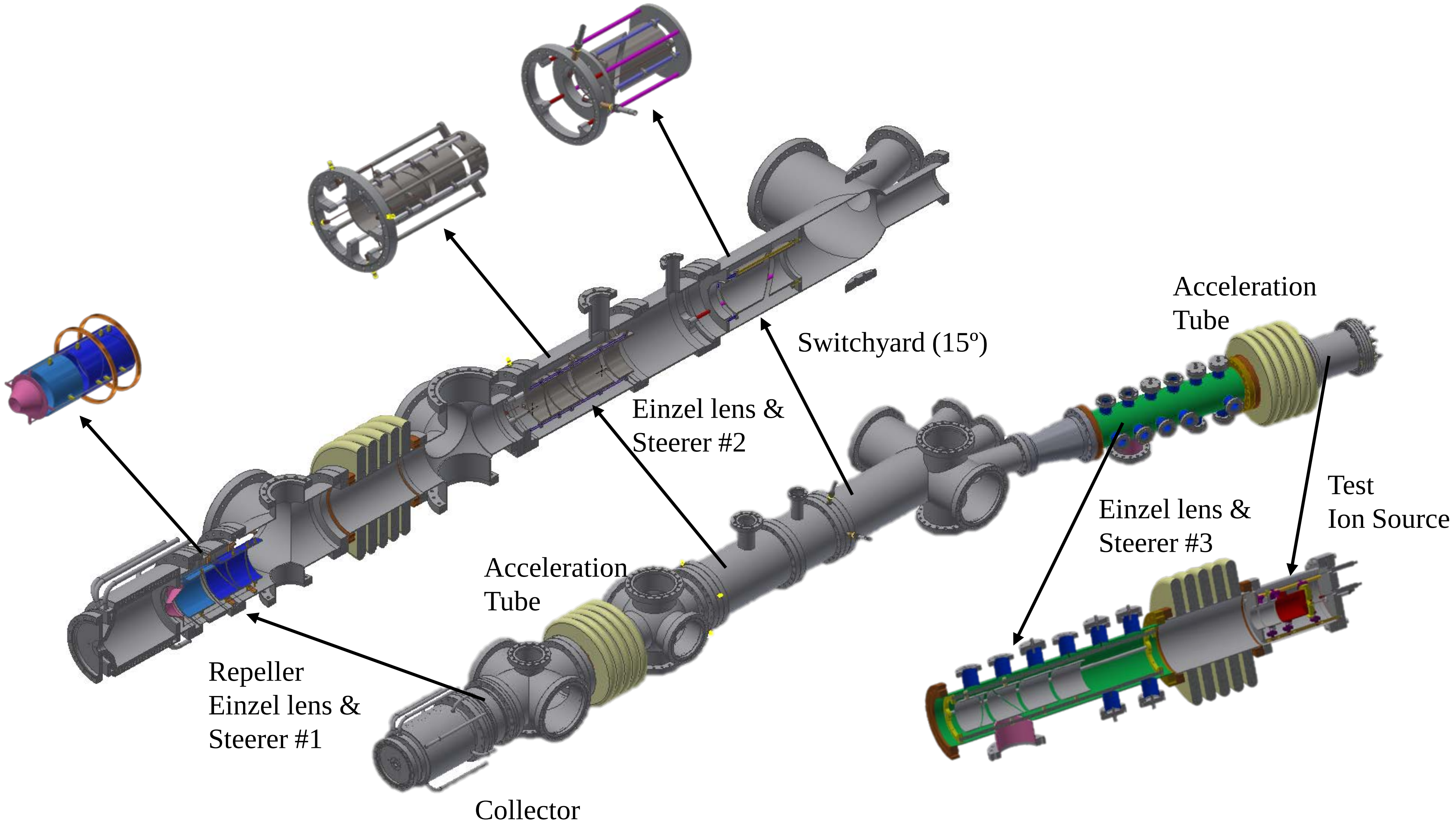


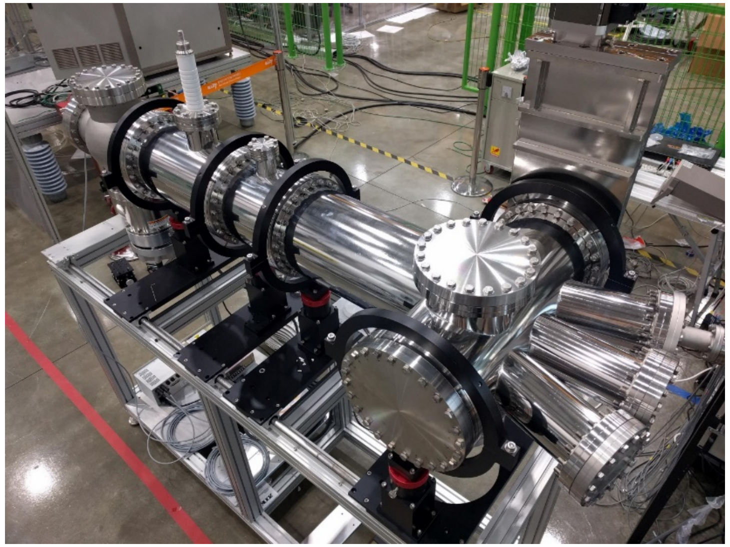
Fig. 10. Phase-space of acceptance and emittance of the injected beams: acceptance (black dots), and injected beam emittance (red dots).

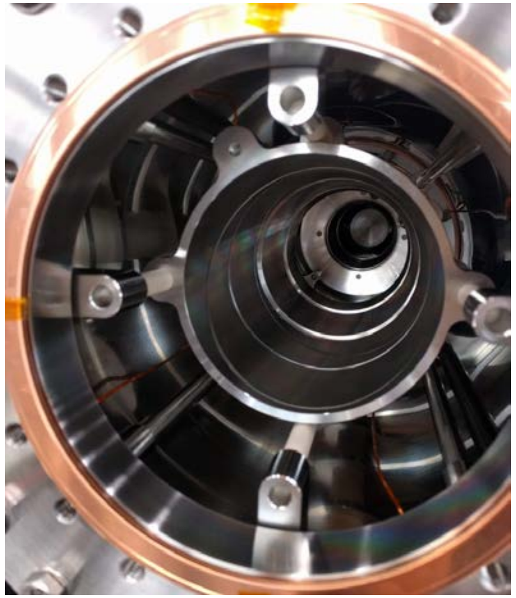
- Acceptance of EBIS (black-dot)
  - 160.9 π·mm·mrad
- Emittance of injection beam (red-dot)
  - 22 π·mm·mrad

3. Components Tests Injection / Extraction Beam Line

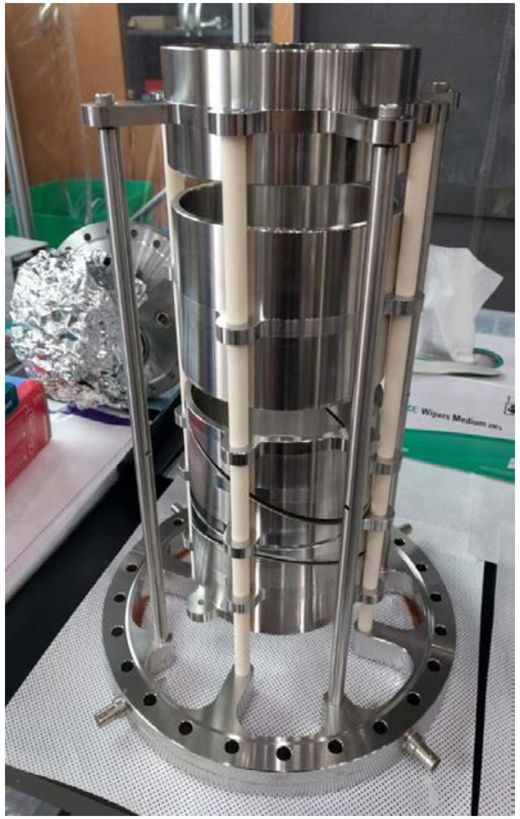


3. Components Tests   Injection / Extraction Beam Line





Repeller,
Einzel lens & Steerer #1



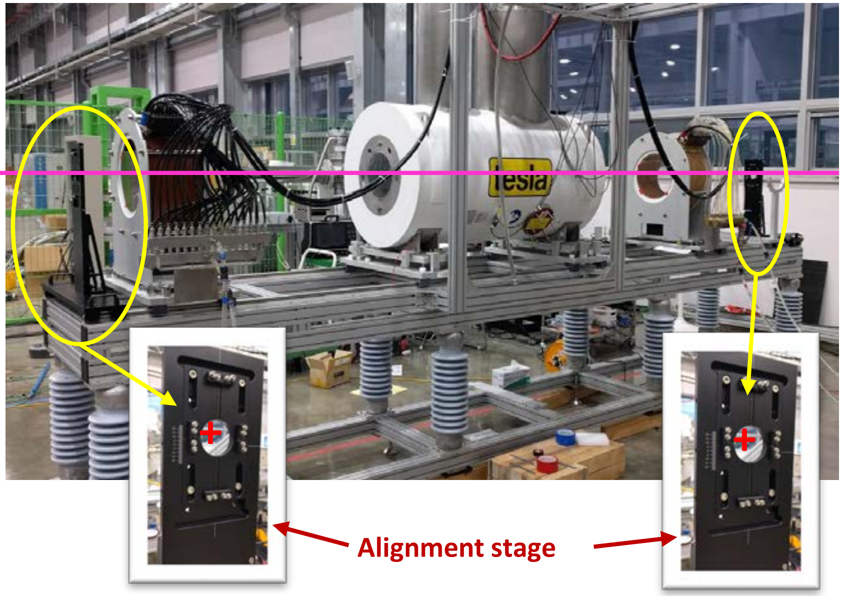
Einzel lens & Steerer #2

Switchyard (15º)

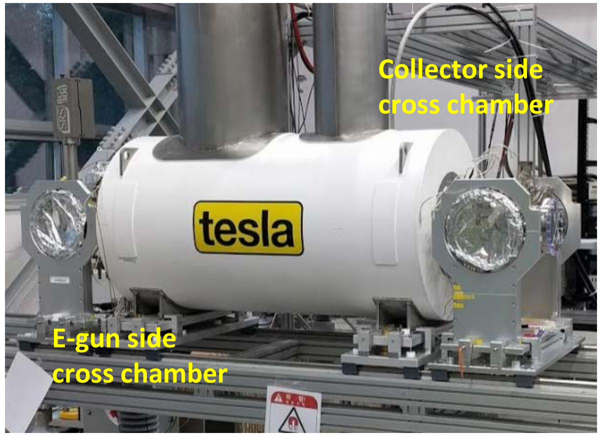
3. Components Tests   Assembly of the RAON EBIS at Off-Line Site

1. Set the virtual beam axis and alignment magnets

Telescope (Theodolite)

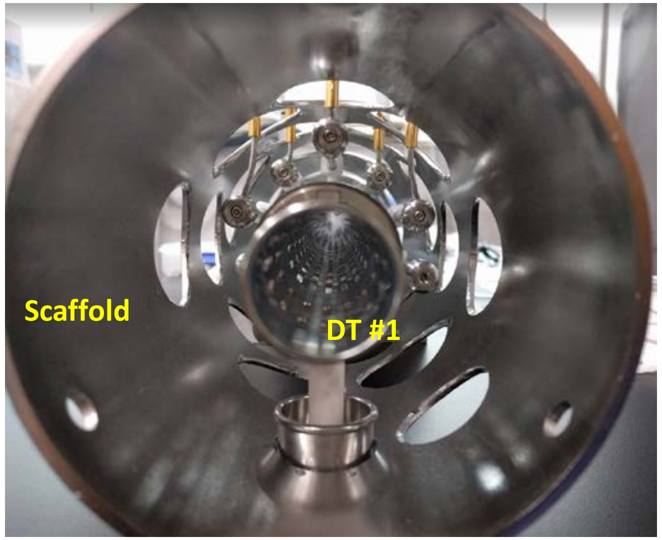


2. Installaion and alignment DT section chamber

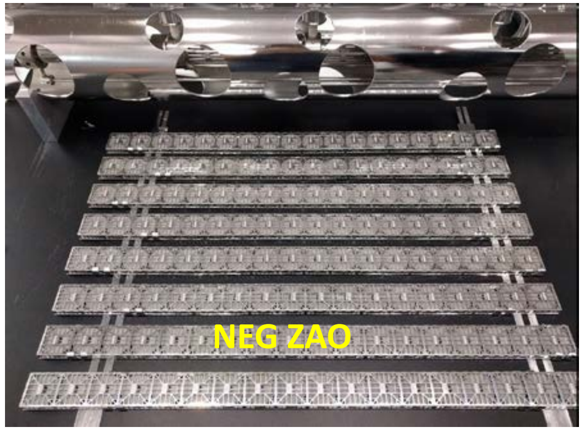


3. Preparation and assembly of inner DT structure

- Drift tubes (#1~#9) and scaffold



- Attachment of NEG ZAO on outside of scaffold

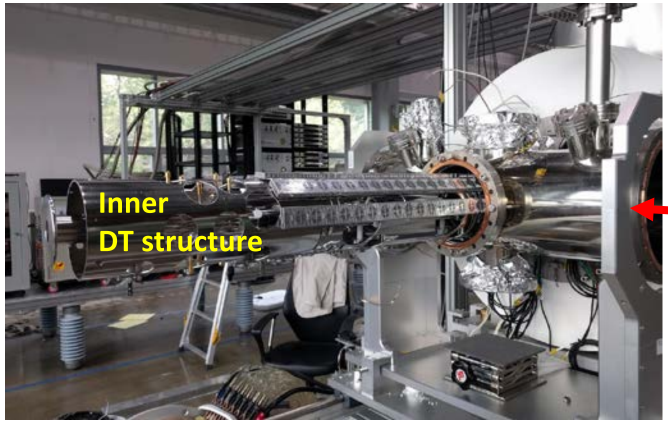


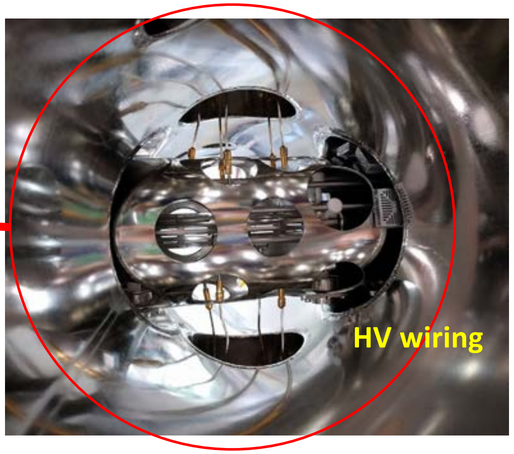
Assembled inner DT structure

3. Components Tests Assembly of the RAON EBIS at Off-Line Site

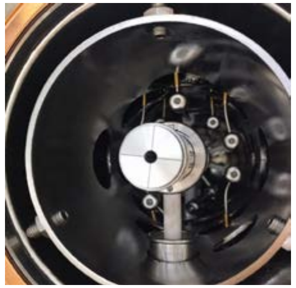
4. Installation and alignment of inner DT structure

- Inserting and HV wiring

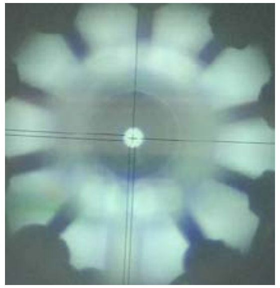




- Alingment of DT structure

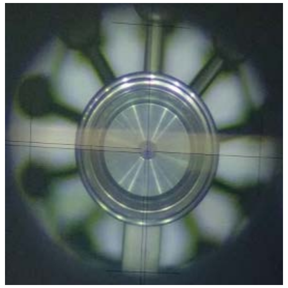


Alignment Block at DT #1



Alignment mark of telescope

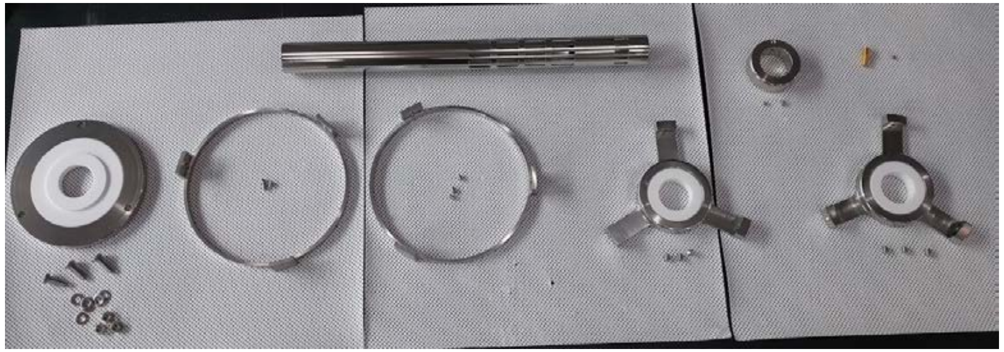
Alignment Block at DT #9



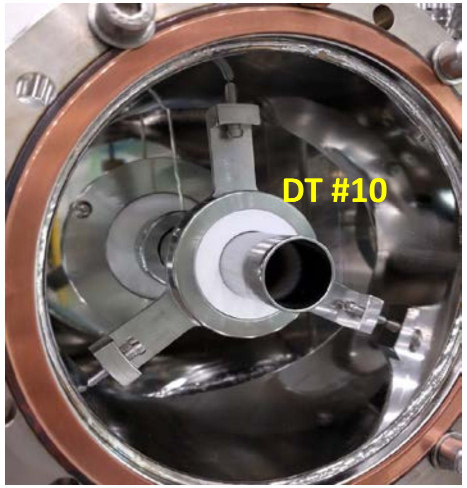
Alignment mark of telescope

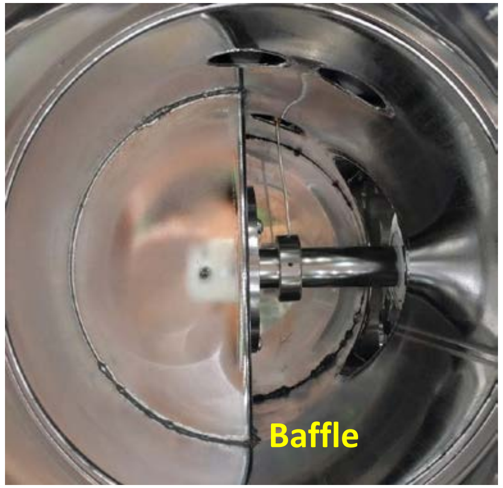
5. Installation and alignment DT #10

- Components for DT #10



- Installing DT #10 with alignment

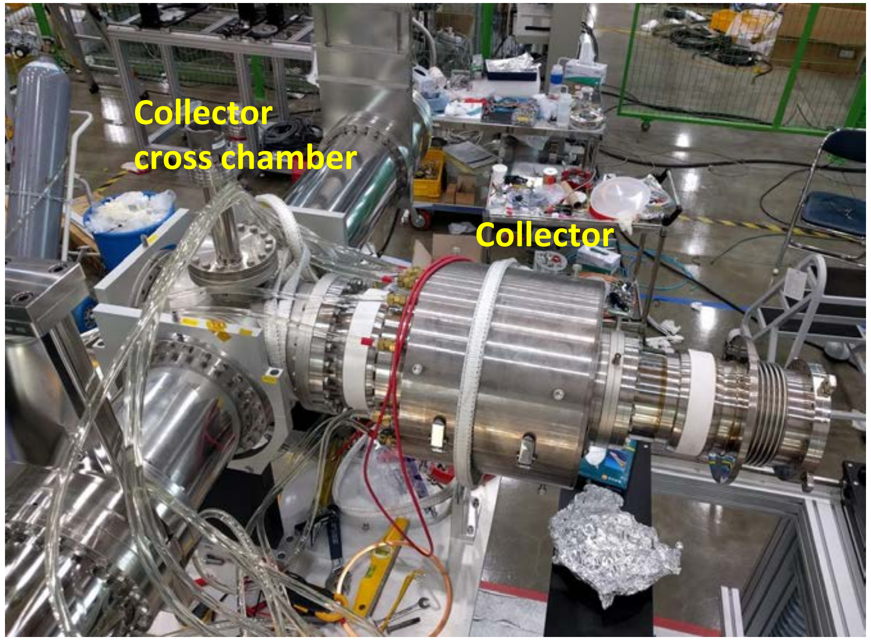




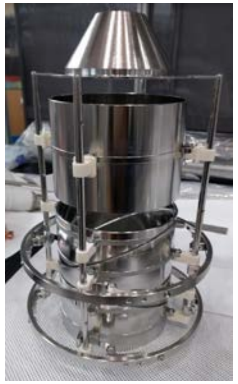
3. Components Tests   Assembly of the RAON EBIS at Off-Line Site

6. Installation and alignment of collector section

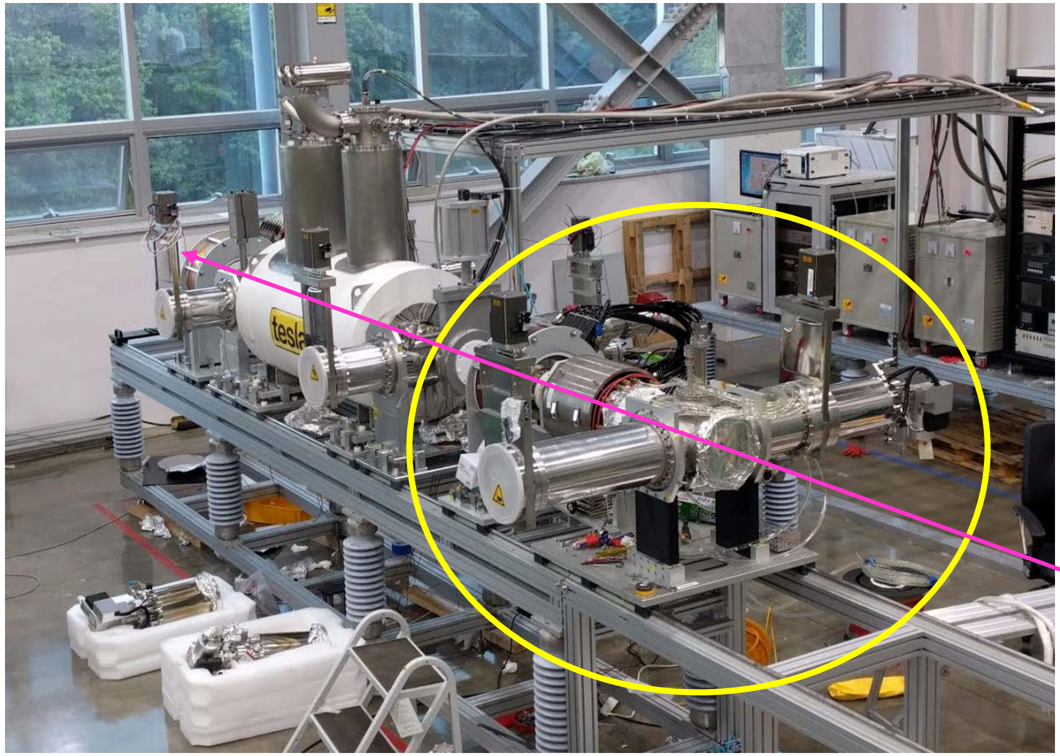
- Positioning collector section



- Installation repeller and ion optics in the collector cross chamber



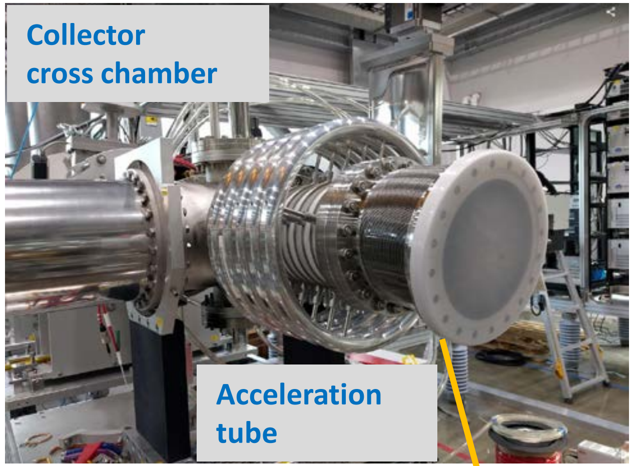
- Alingment and assembly collector section



3. Components Tests Assembly of the RAON EBIS at Off-Line Site

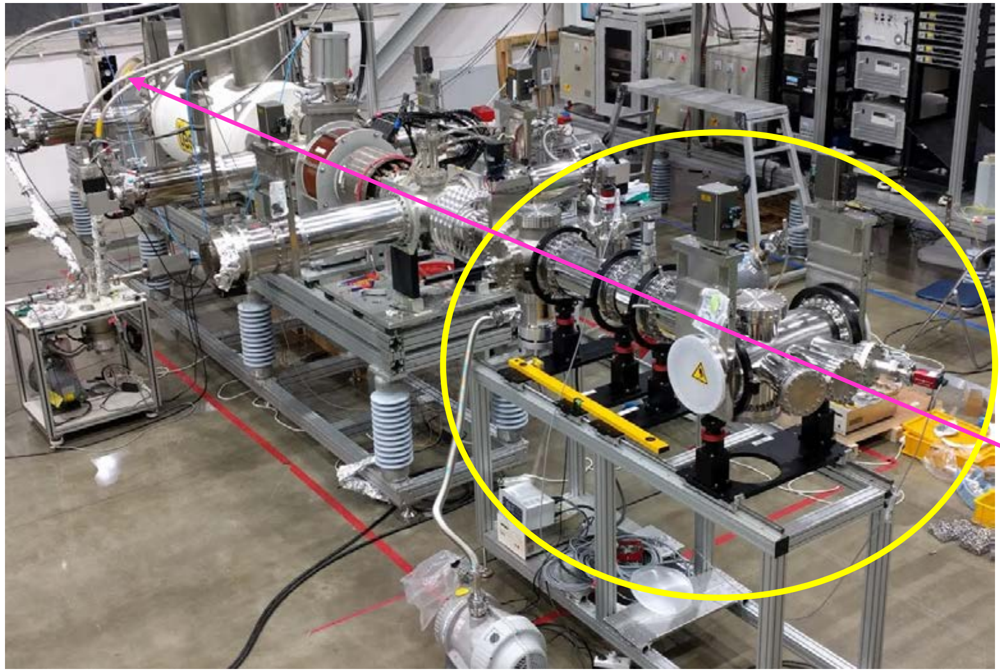
7. Installation and alignment of ion transport line

- Installing acceleration tube behind collector cross chamber



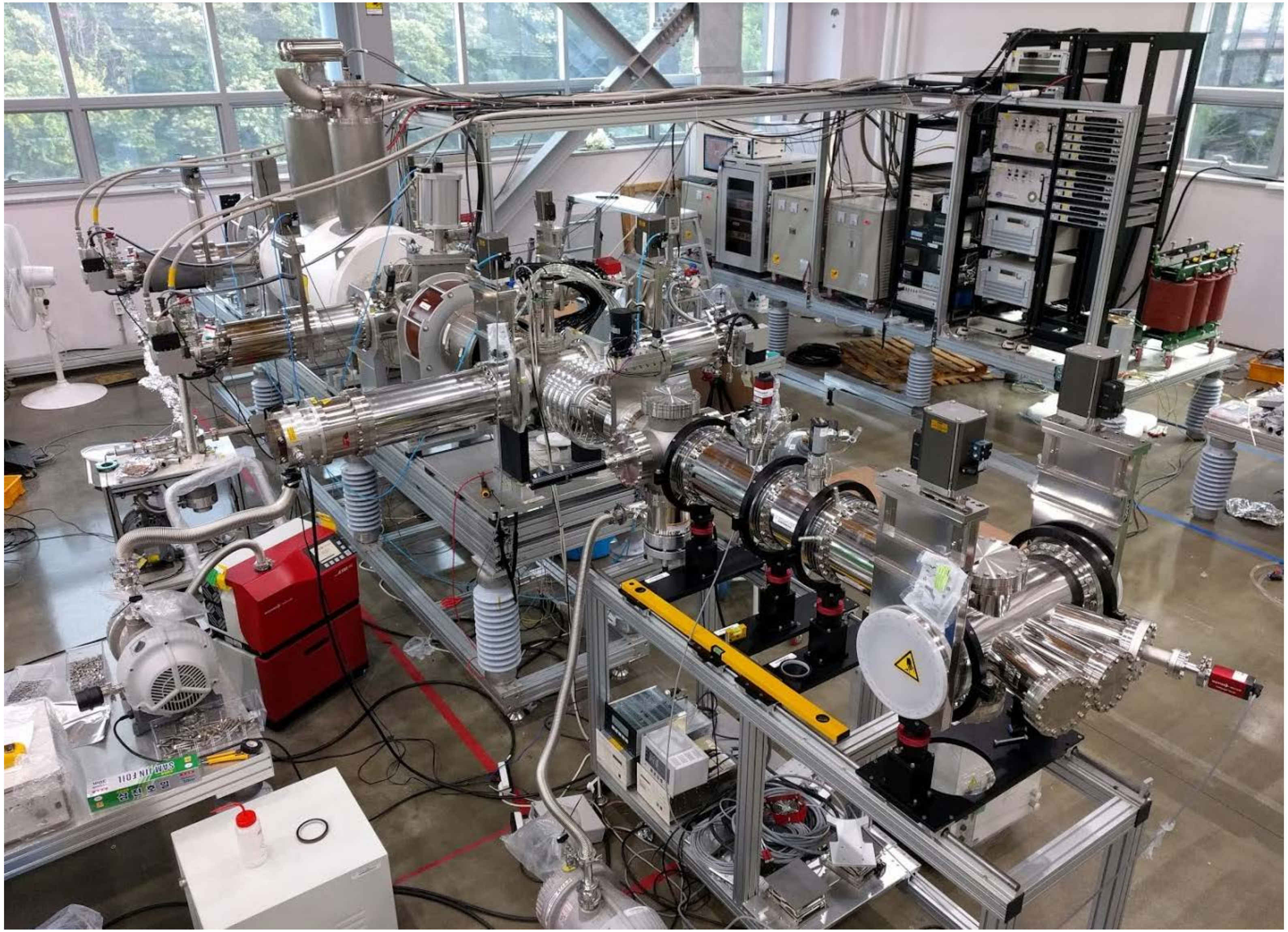
- Positioning ion transport line

- Alingment and assembly ion transport line



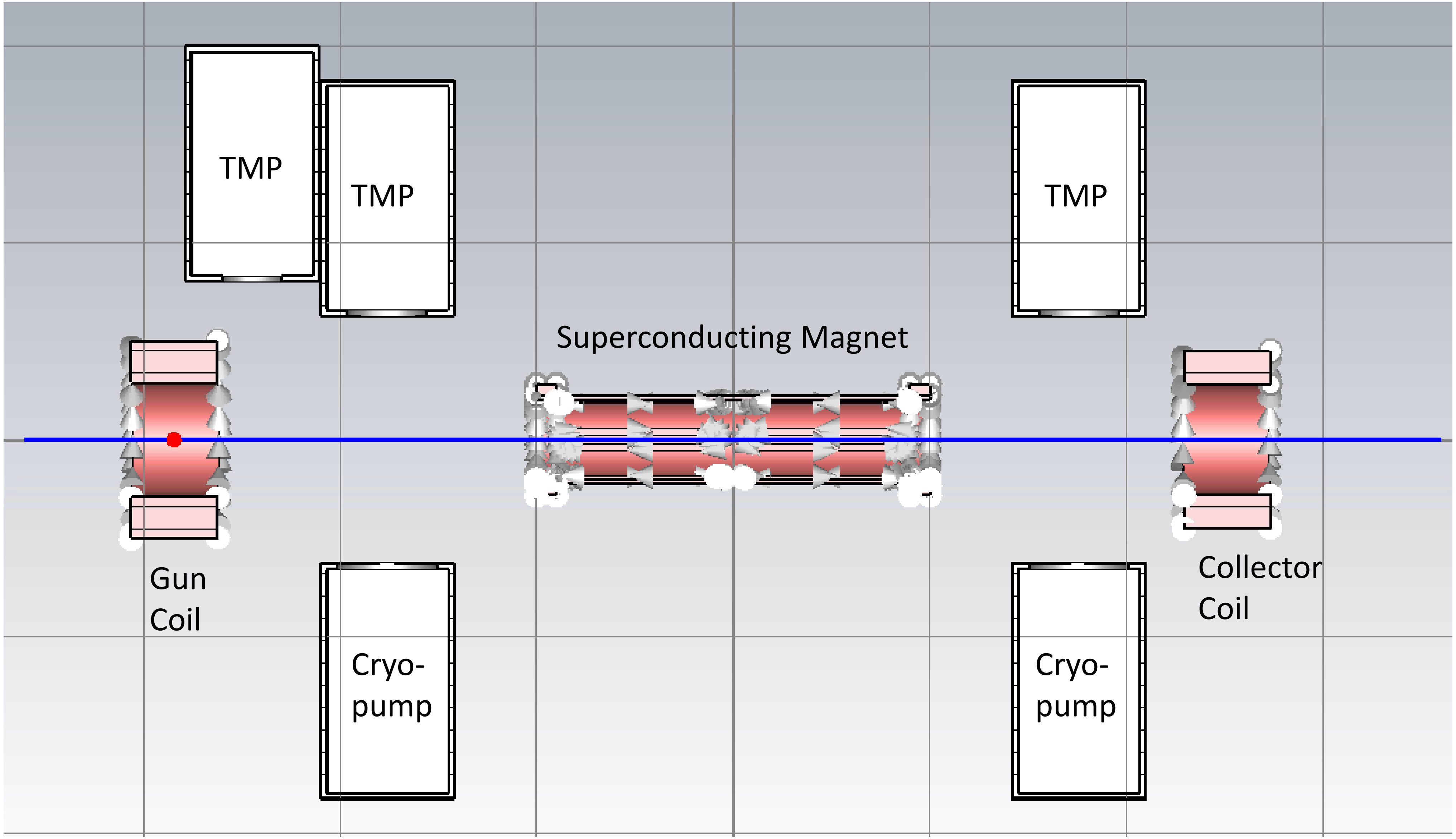
3. Components Tests

Assembly of the RAON EBIS at Off-Line Site



4. Magnet Issues

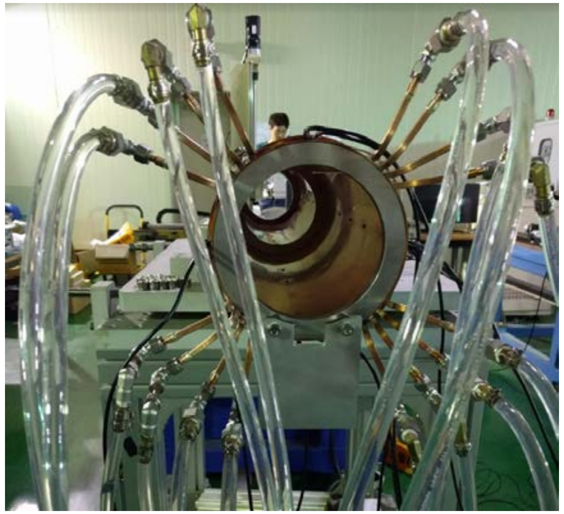
Calculation of Magnetic Field under Iron Shields

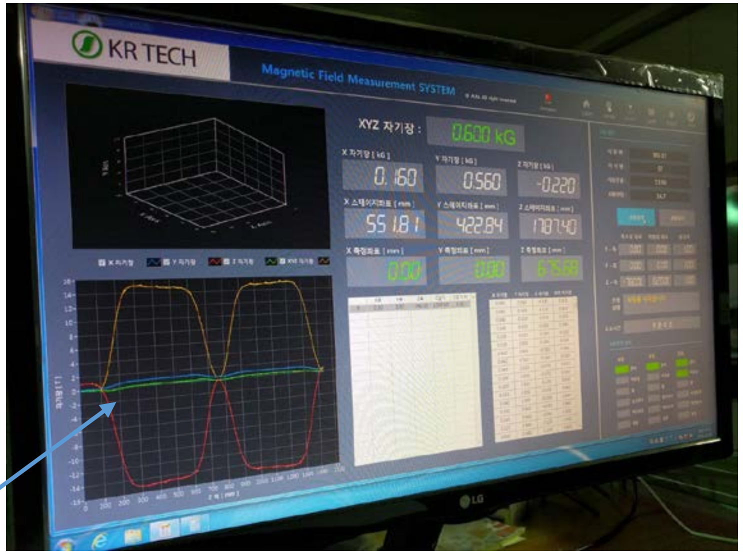


4. Magnet Issues

Water Jacket and Steering Coil

Four sets of Helmholtz-type steering coils on water jacket

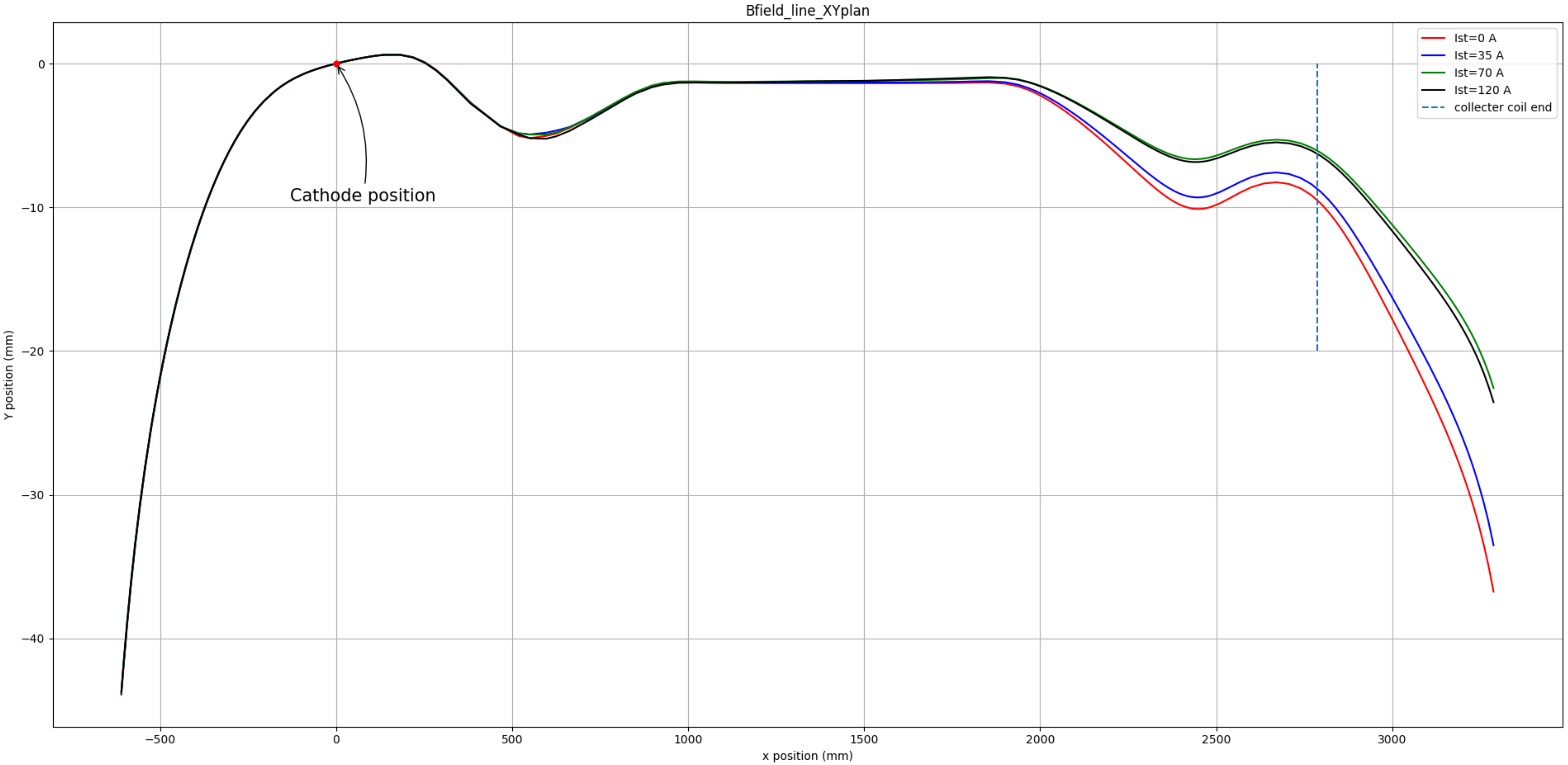




Field to current ratio of a coil set : 1.1 Gs/A

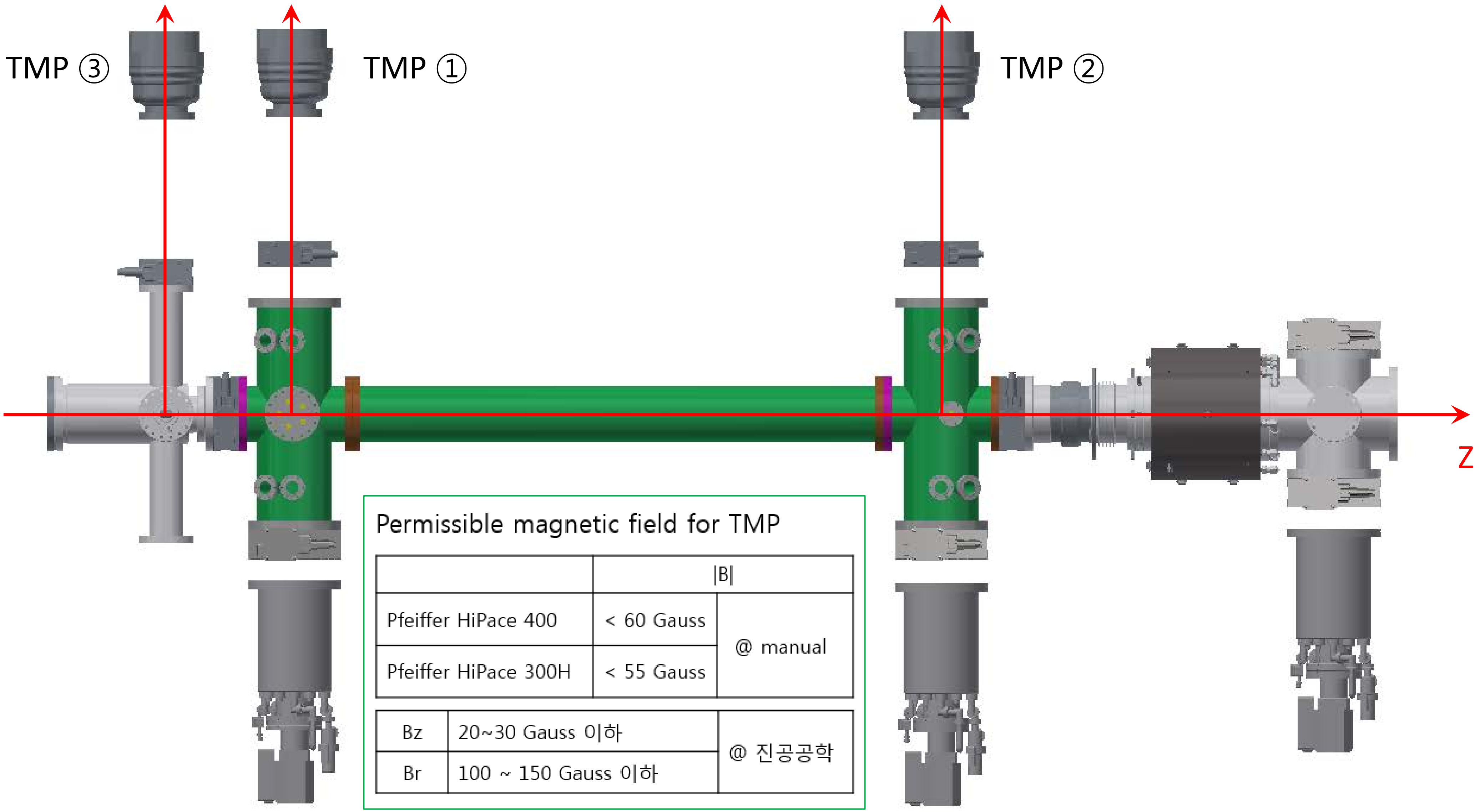
B_{Max} = 50 Gs

Calculation of Magnetic Field under Iron Shields



4. Magnet Issues

Repositioning TMPs and Gauges



Permissible magnetic field for TMP

	|B|	
Pfeiffer HiPace 400	< 60 Gauss	@ manual
Pfeiffer HiPace 300H	< 55 Gauss	

Bz	20~30 Gauss 이하	@ 진공공학
Br	100 ~ 150 Gauss 이하	

4. TMPs and Gauges under Strong Magnetic Field: @ OVC of SC Magnet

TMP1 (Br=35G, B=52G)
- Maintains 1,500 Hz
- Current increased by a factor of 1.4 (0.18 → 0.25 A)
- Power consumption increased by a factor of 2
- Angle btwn field line and TMP's rot. axis: 36°

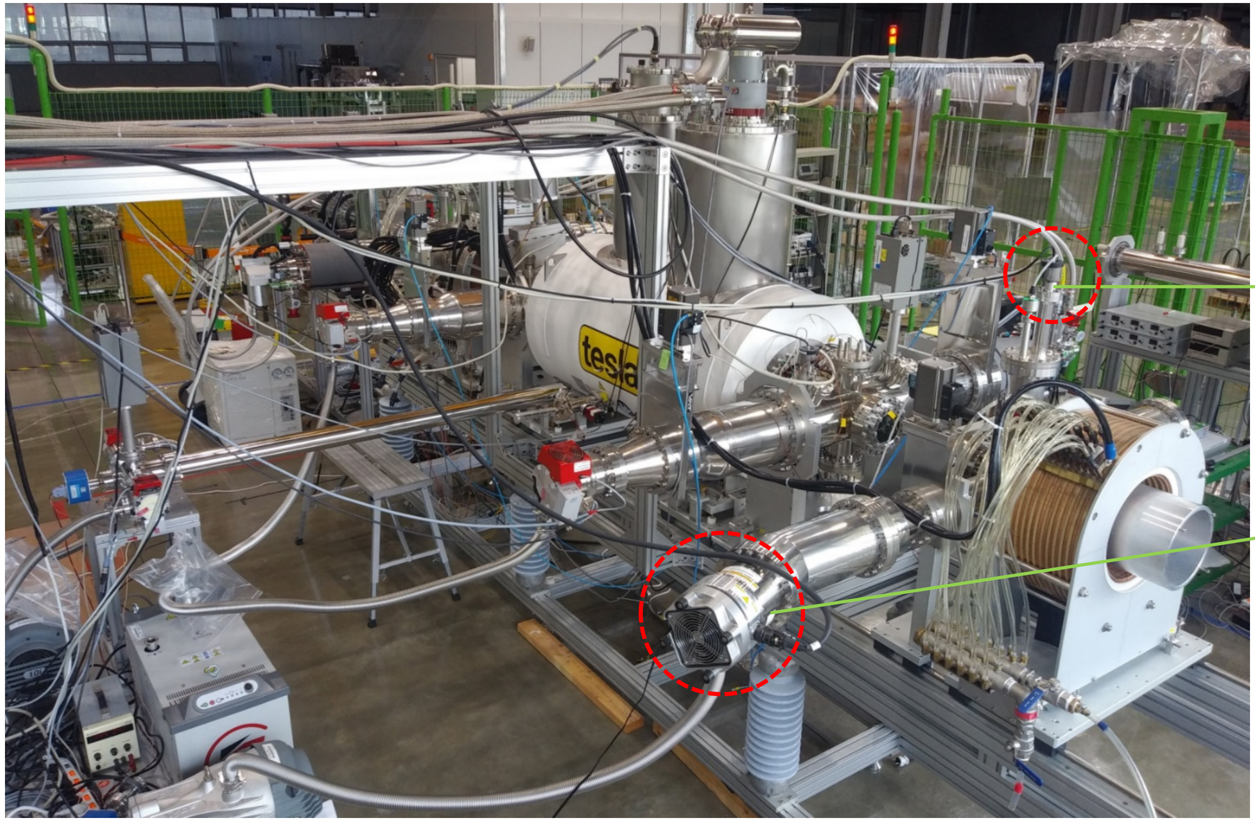
TMP2 (Br=3.3G, B=54G)
- Maintains 1,500 Hz
- No current increased (0.21 → 0.21 A)
- Angle btwn field line and TMP's rot. axis: 3°

Ion Gauge @ Pumping Station
- Pressure reading decreased by a factor of 2 ($4.1\times10^{-8} \rightarrow 2.3\times10^{-8}$ torr)
- Gauge is almost perpendicular to the magnetic line

Ion Gauge @ OVC Port
- Pressure reading decreases by a factor of 12 ($2.4\times10^{-7} \rightarrow 2.0\times10^{-8}$ torr)
- Gauge is parallel to the magnetic line

∗ There was no problem with TMPs and gauges during the superconducting magnet is energized.
∗ Cooling margin doesn't change.
∗ The gauge reading can be used after properly scaled

4. TMPs and Gauges under Strong Magnetic Field: @ E-Gun Chamber

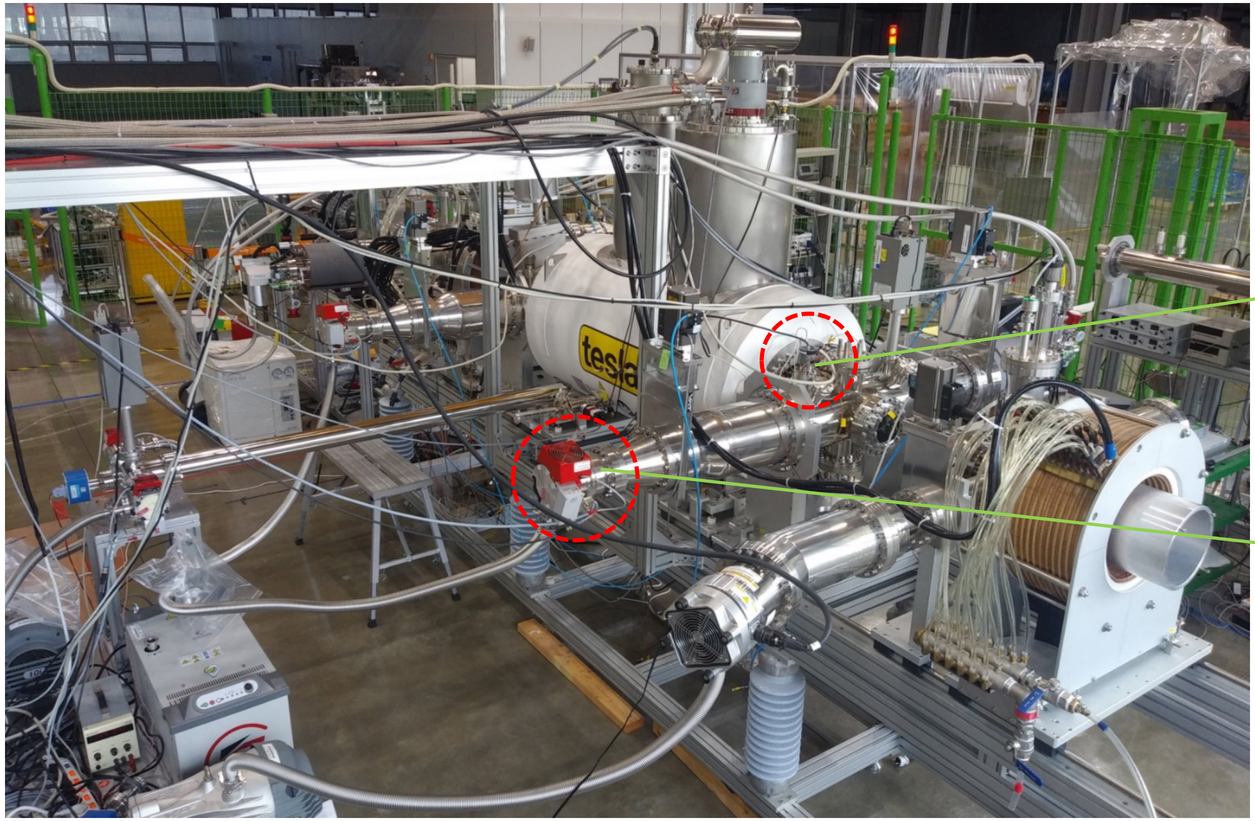


Ion Gauge @ EGun Chamber
- Gauge reading reduced by a factor of 2 ($1.26\times10^{-8} \rightarrow 5.46\times10^{-9}$ torr)

Egun-TMP (Br=27G, B=131G)
- Maintains 48,000 RPM
- Temperature increased by 2 °C (34 →36 °C)

* By using elbowed nipple, we made the e-gun TMP's rotation axis almost parallel to the magnetic line
* This Edwards TMP with magnetic bearing stopped with roar when the SC magnet was ramping down.
* A Pfeiffer TMP with hybrid bearing took the place of Edward TMP and has been working without any problems
* The gauge reading can be used after properly scaled

4. TMPs and Gauges under Strong Magnetic Field: @ Gun-side Cross Chamber



Ion Gauge @ EGun-side Cross Chamber

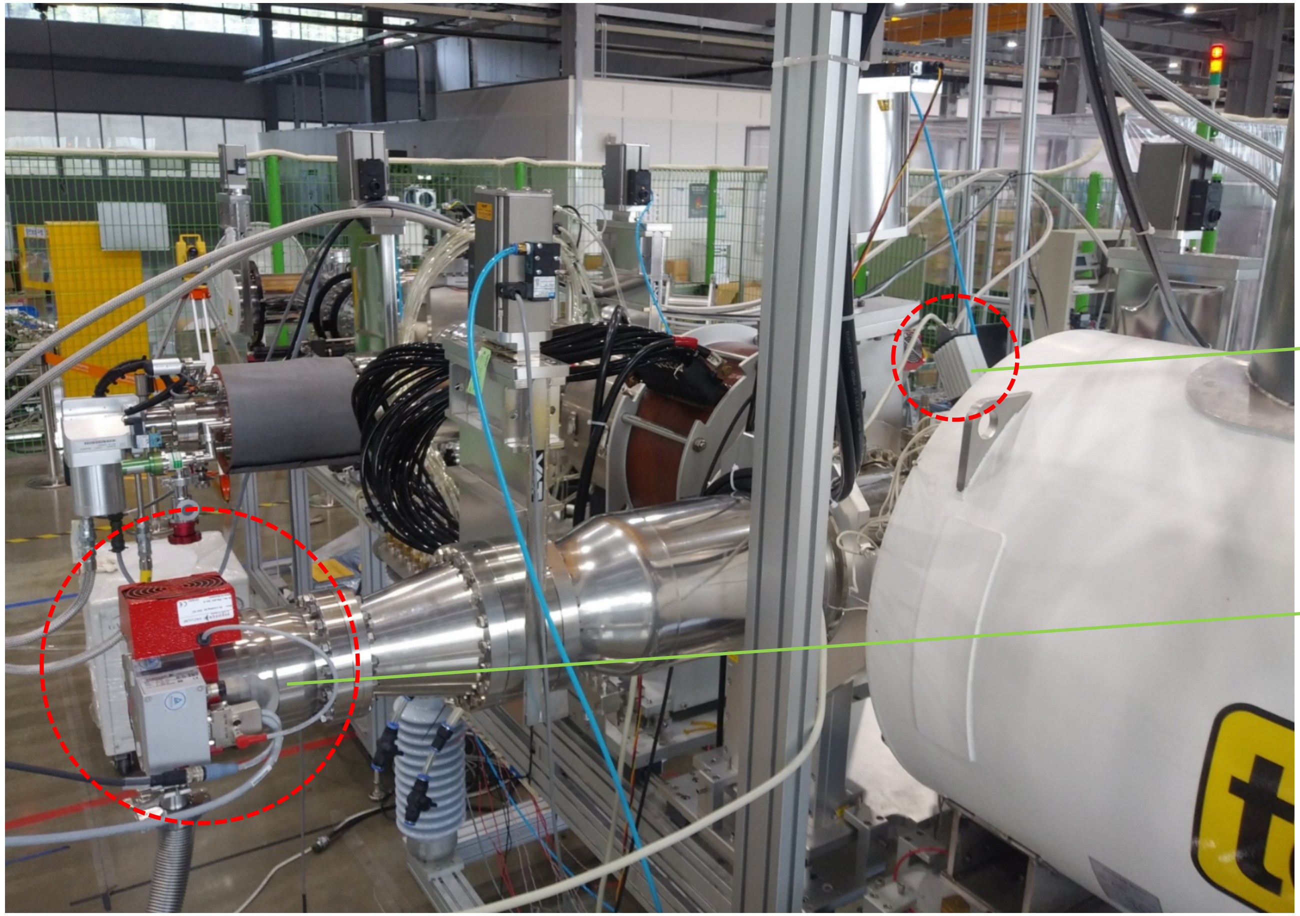
- Pressure reading reduced by a factor of 20 ($3.35\times10^{-9} \rightarrow 1.69\times10^{-10}$ torr)

DT(EGun)-TMP (Br=6G, B=332G)

- Maintains 1,000 Hz
- Current increased by a factor of 1.36 (0.11 → 0.15 A)
- Power consumption increased by a factor of 1.86

∗ By using elbowed nipple, we made the DT(EGun) TMP's rotation axis almost parallel to the magnetic line.
∗ There was no problem with this TMP when the SC magnet was fully energized.
∗ Ion Gauge needed to be aligned with the magnetic line.

4. TMPs and Gauges under Strong Magnetic Field: @ Coll.-side Cross Chamber

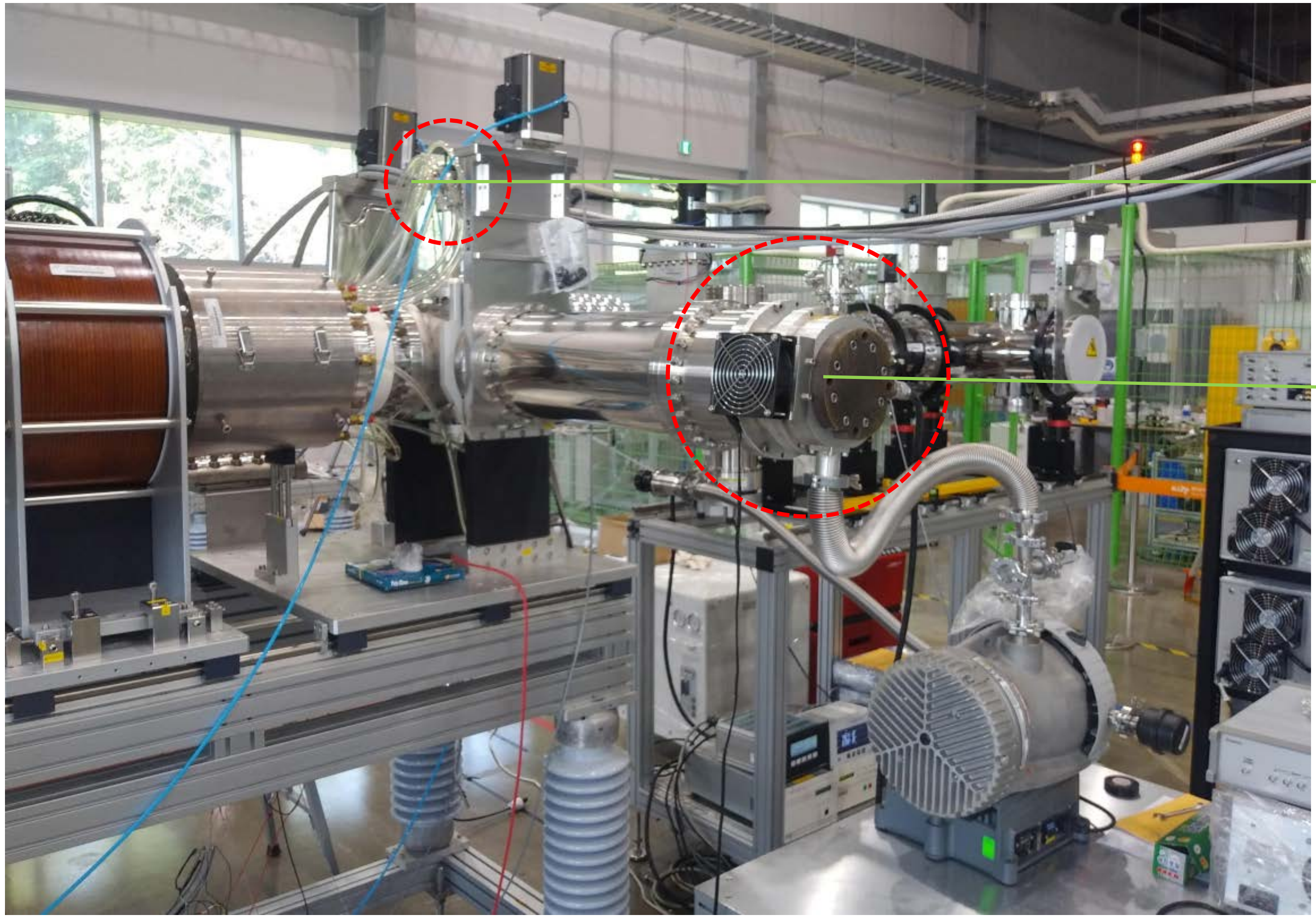


Ion Gauge @ Collector-side Cross Chamber
- It showed a tendency of increase with magnetic field
- Not operational over 2T

DT(Collector-side)-TMP (Br=1.6G, B=347G)
- maintains 1,000 Hz
- Current increased by a factor of 1.33 (0.12 → 0.16 A)
- Power consumption incrased by a factor of 1.8

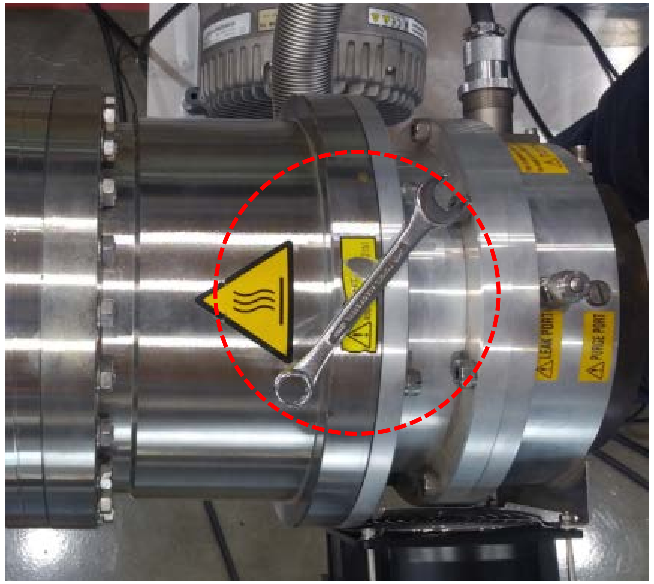
∗ Using I-Nipple, we moved DT(Collector-side)-TMP to the location where the TMP's rot. axis was almost parallel to the magnetic line.
∗ There was no problem with this TMP when the SC magnet was fully energized.
∗ Ion Gauge needed to be aligned with the magnetic line.

4. TMPs and Gauges under Strong Magnetic Field: @ Collector Cross Chamber



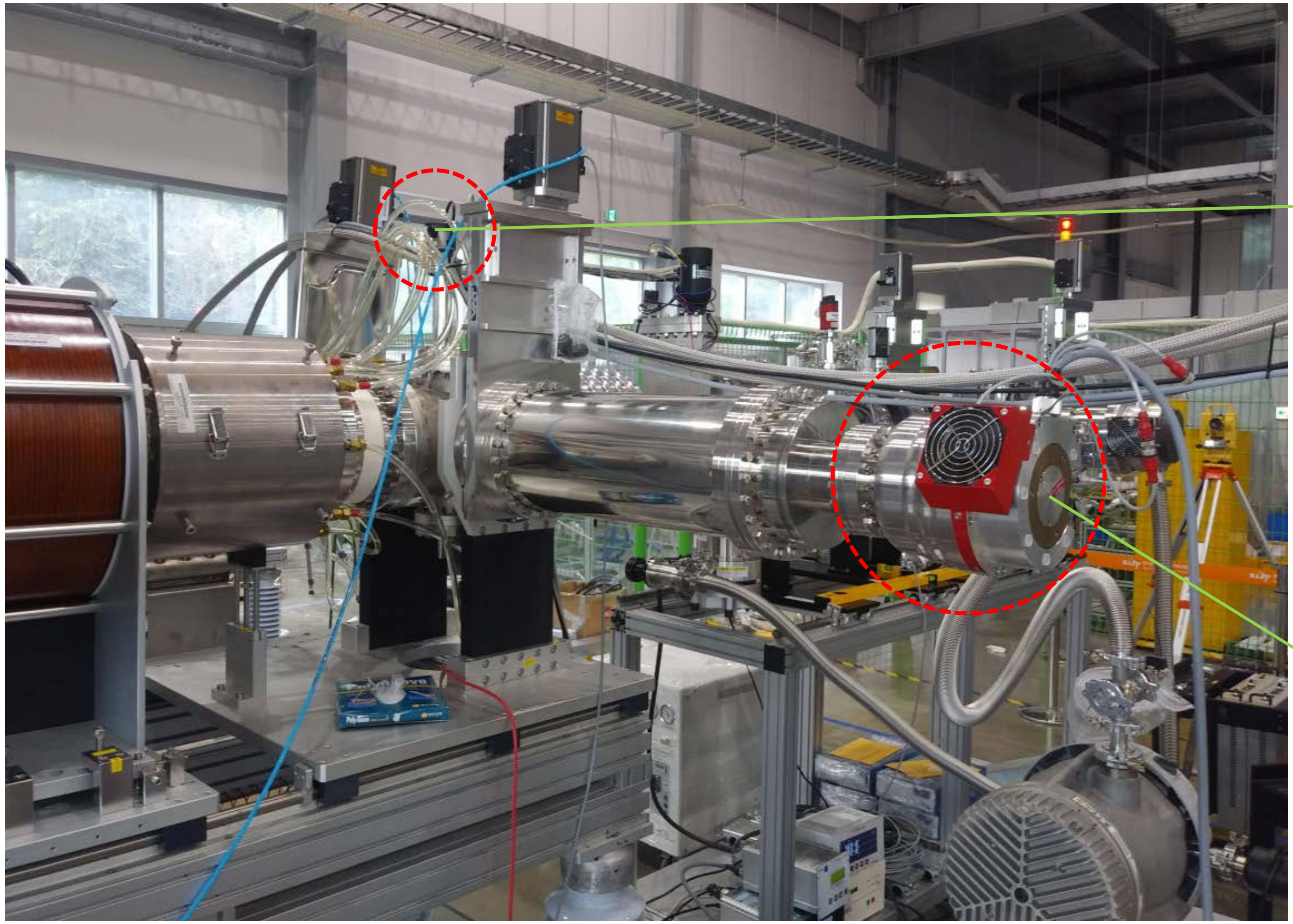
Ion Gauge @ Collector
- Pressure reading was reduced by a factor of 2.6 ($2.24\times10^{-8} \rightarrow < 8.4\times10^{-9}$ torr)

Collector-TMP (OSAKA) (Br=53.7G, B=80.5G)
- Maintains 33,600 RPM
- TMP's surface became hot and it made scratching noise at 6T



∗ Angle between the field line and the TMP's rotation axis was around 45°
∗ It didn't seem to work properly at a full strength of magnetic field.
∗ The gauge reading can be used after properly scaled

4. TMPs and Gauges under Strong Magnetic Field: @ Collector Cross Chamber



Ion Gauge @ Collector

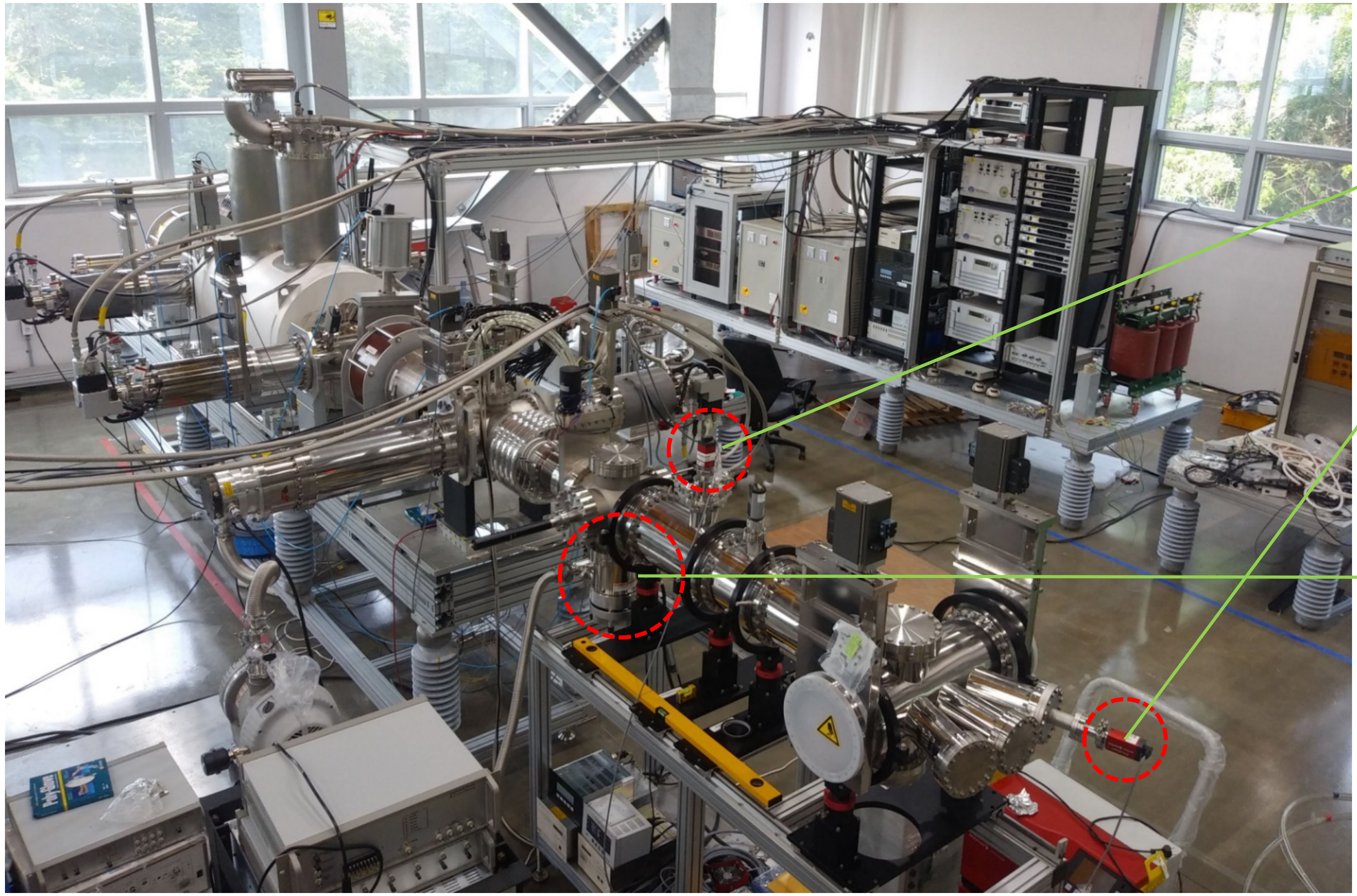
- Pressure reading was reduced by a factor of 2.6 ($2.24\times10^{-8} \rightarrow < 8.4\times10^{-9}$ torr)

Collector-TMP (Pfieffer, HiPACE-400)
(Br=53.7G, B=80.5G)

- Maintains 820 Hz
- Current increased by a factor of 1.95 (0.42 → 0.82 A)
- Power consumption increased by a factor of 3.8
- Temperature increased by 2 °C (37 →39.2 °C)

∗ We tested after replacing OSAKA pump with Pfeiffer pump
∗ We made a bent nipple to align the TMP's rotation axis with the magnetic line

4. TMPs and Gauges under Strong Magnetic Field: @ Transport Line



Ion Gauge @ Einzel lens #2

- Pressure reading increased by 7%
  ($4.69\times10^{-8} \rightarrow 5.01\times10^{-8}$ torr)

Ion Gauge @ Switchyard

- Pressure reading increased by 11%
  ($7.12\times10^{-8} \rightarrow 7.93\times10^{-8}$ torr)

Transpoerline-TMP (< 10G)

- Maintains 48,000 RPM
- Temperature increased by 1 °C (34 →35 °C)

∗ There was no problem with the TMP and the gauges because they are located relatively far from the SC magnet.

∗ Gauges can be used after properly scaled

4. Cryo-Pumps under Strong Magnetic Field

Cryopump @ DT(EGUN)
- 1^{st} Stage : No temperature changes (48 K)
- 2^{nd} Stage : No temperature changes (10 K)

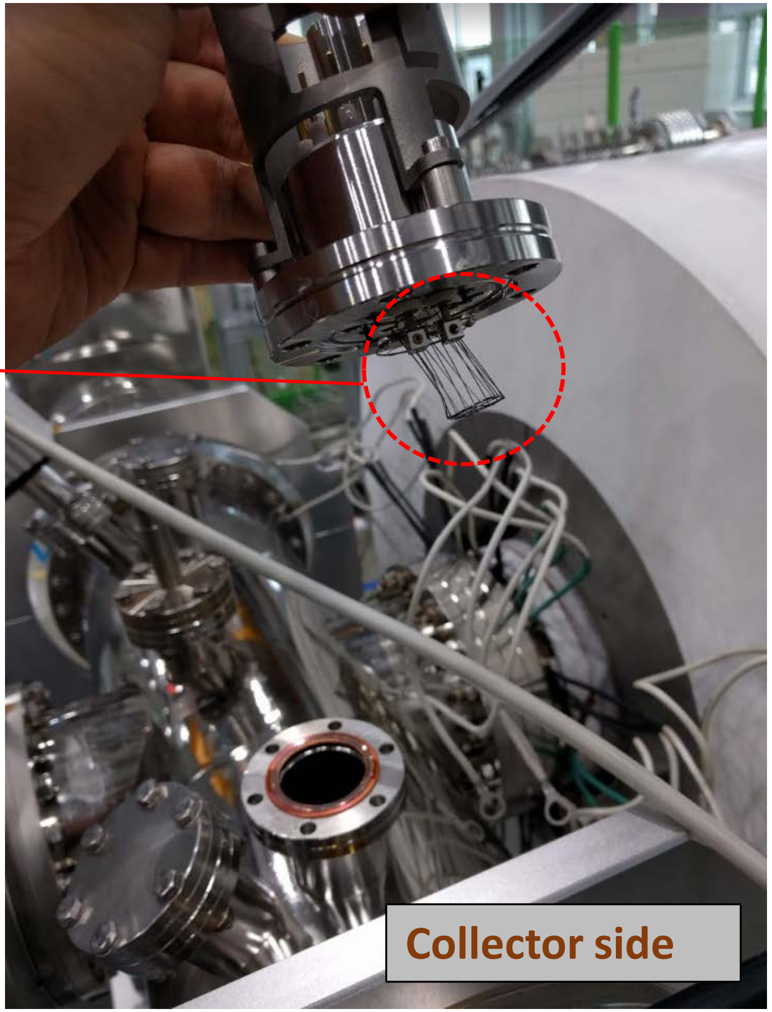
Cryopump @ DT(Collector-side)
- 1^{st} Stage : No temperature changes (55 K)
- 2^{nd} Stage : No temperature changes (10 K)

Cryopump @ Collector
- 1^{st} Stage : No temperature changes (55 K)
- 2^{nd} Stage : No temperature changes (10 K)

∗ There was no noticeable temperature changes in the cryopumps
∗ The performance of the cryopumps didn't degrade at the full strength of magnetic field

4. Gauges under Strong Magnetic Field: Near to SC Magnet

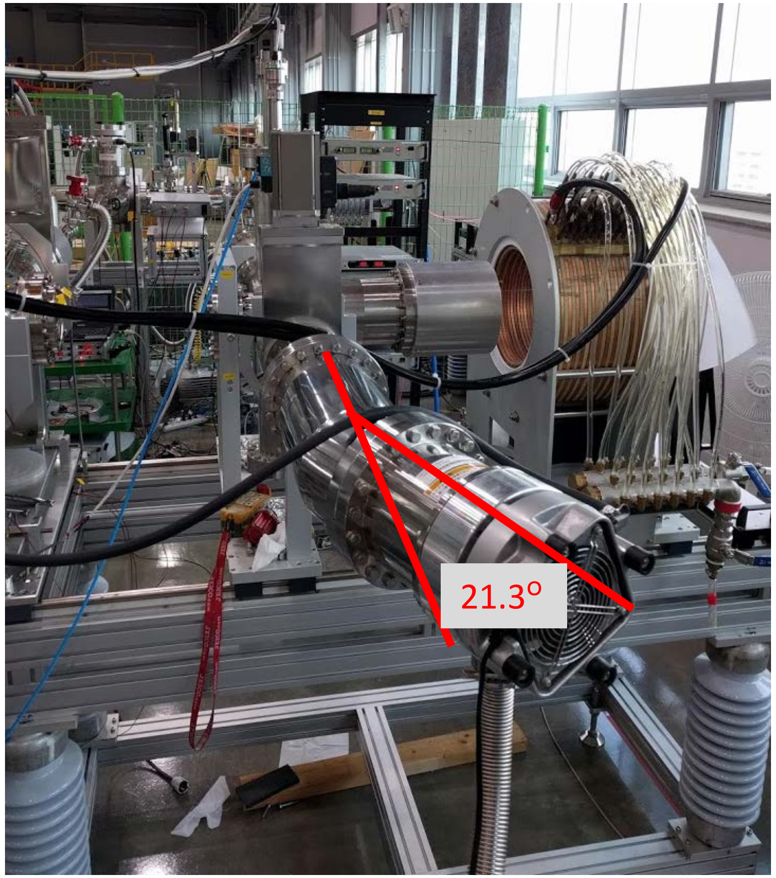
Gauge anode was bent

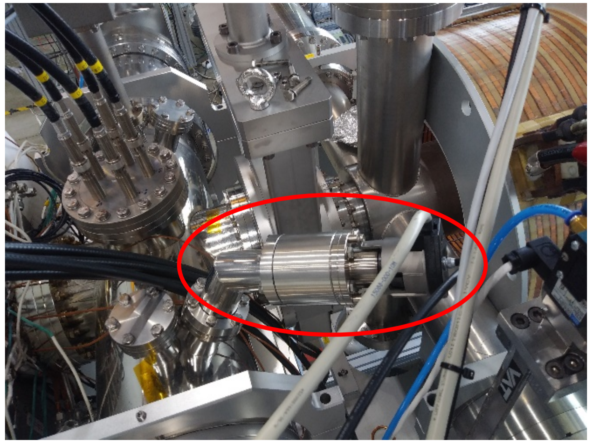


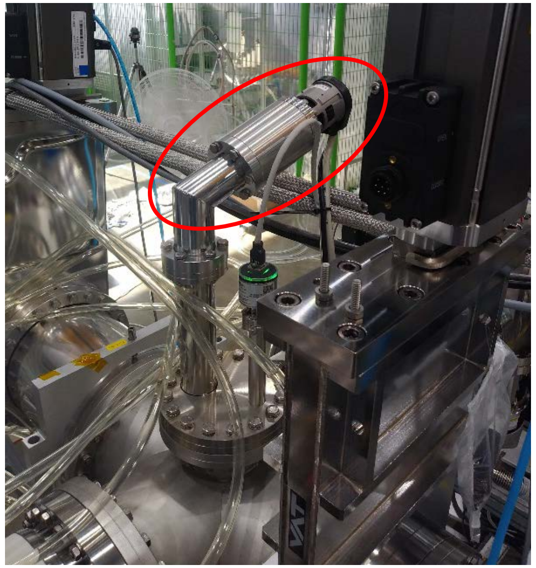
Gauge cathode was distorted

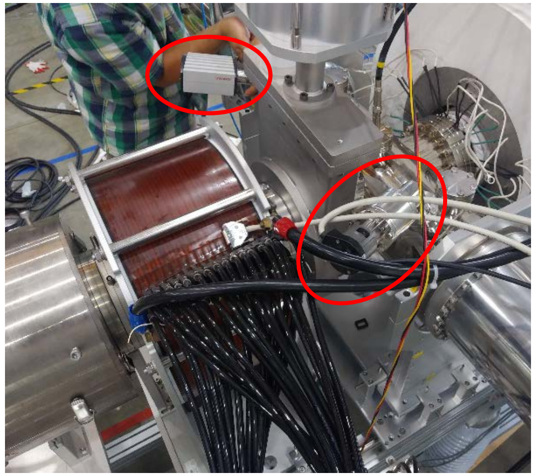
* Deformation of gauge cathode/anode by strong magnetic field

4. Aligning TMPs and Ion Gauges along the Magnetic Line

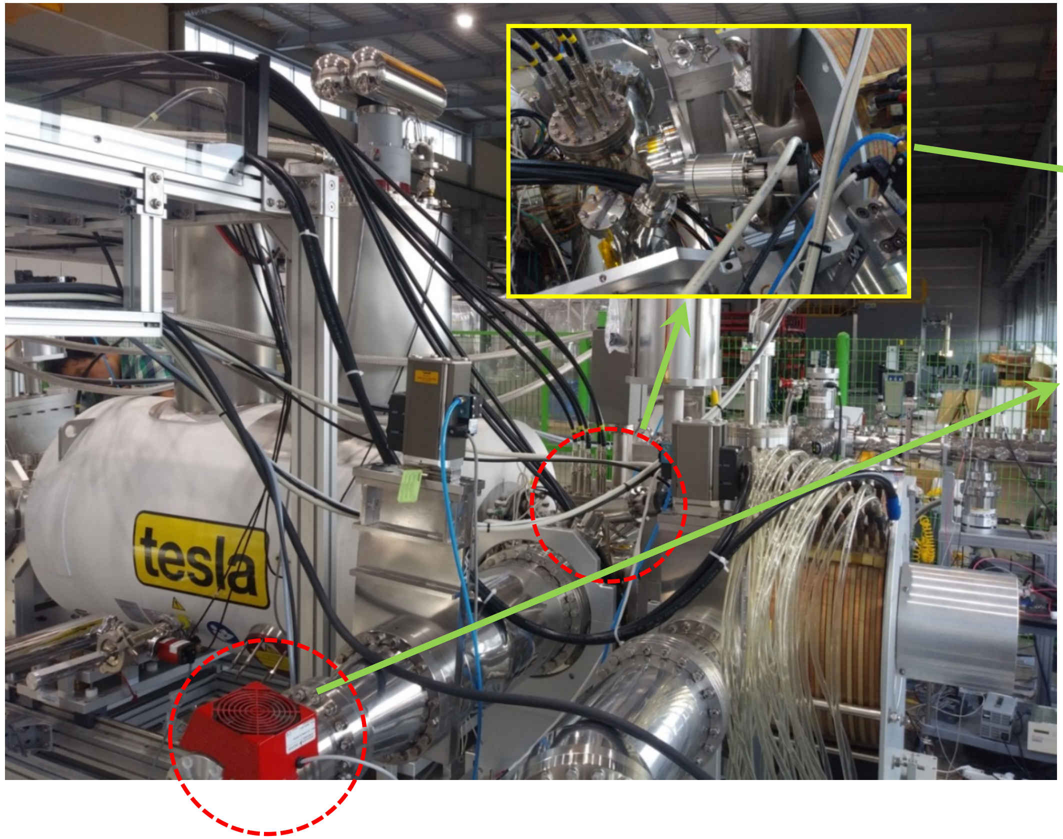






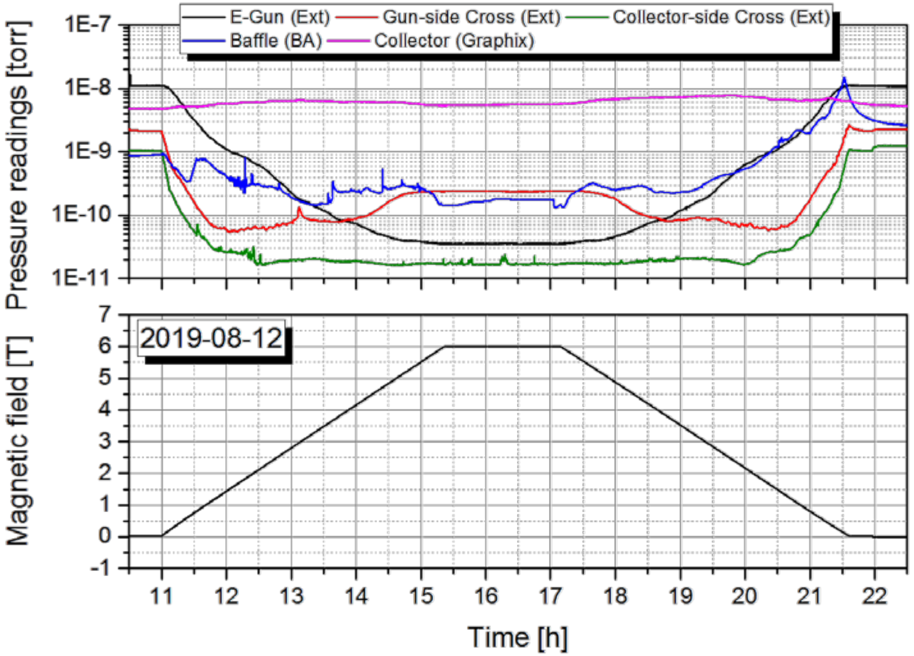


4. Confirming Operation of TMPs and Ion Gauges under Strong Magnetic Field



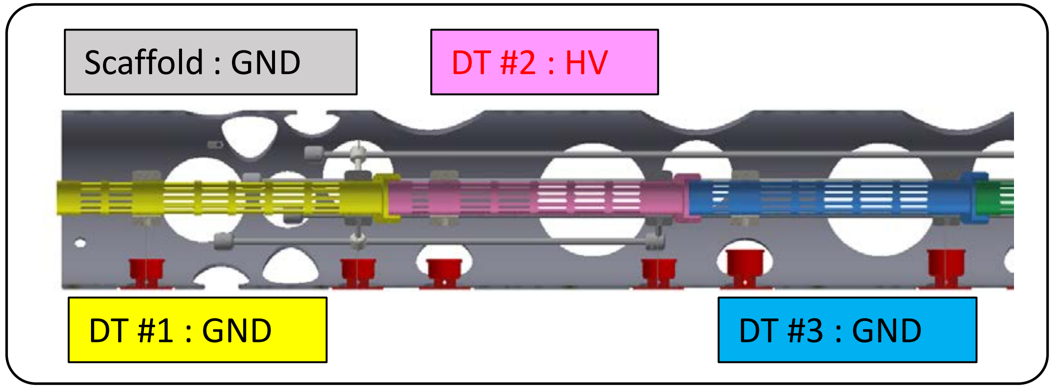
Ion Gauge @ EGun-side Cross Chamber
- Type: **Extractor**
- Bent Angle: **51°**
- Gauge reading was reduced by a factor of 9 ($3.5\times10^{-9} \rightarrow 3.8\times10^{-10}$ torr)

TMP @ Gun side DT (Br=6G, B=332G, ∠1°)
- Maintains its rotation at 1,000 Hz
- Current was increased by a factor of 1.36 (0.11 A → 0.15 A)

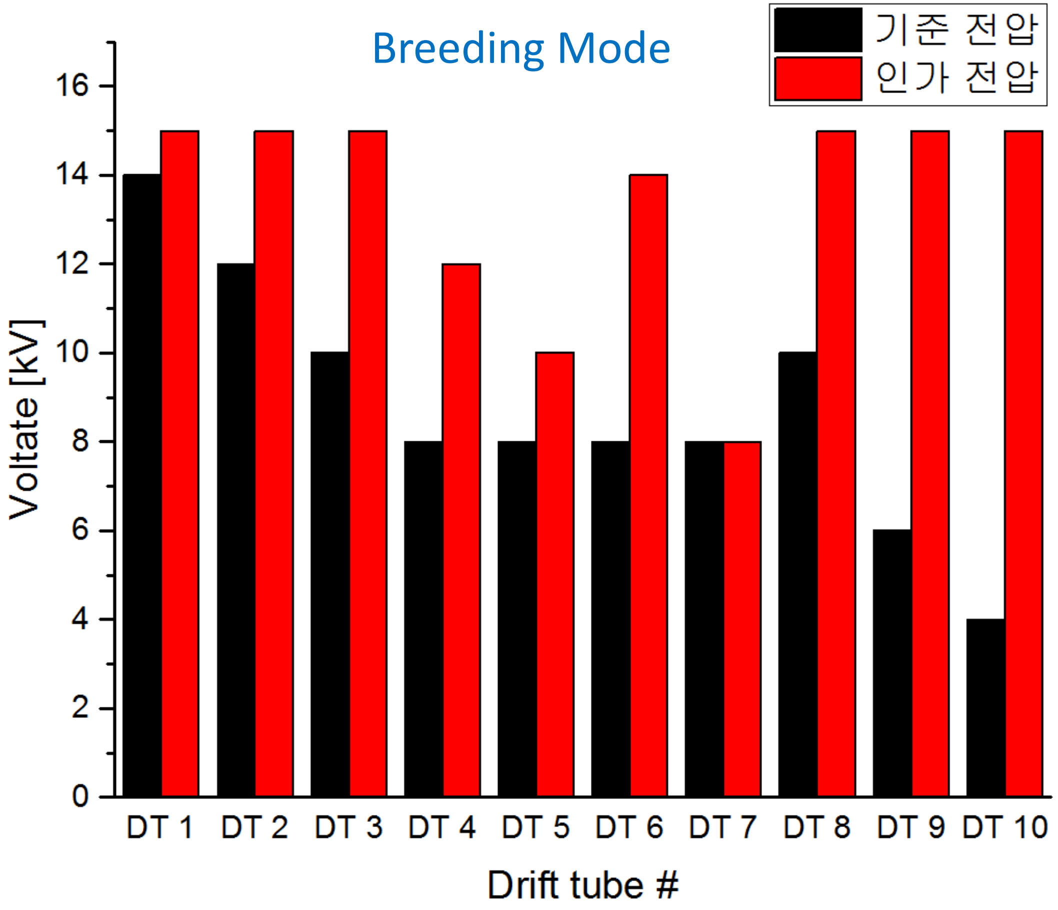


- TMPs are positioned such that the magnetic lines are parallel to the TMPs' rotation axis.
- TMPs and cryopumps without magnetic shields worked fine around the strong magnetic field of 6 T.
- Ion gauges are attached to the chamber using bent nipples to align the IG structure to the magnetic line.

4. High Voltage Training

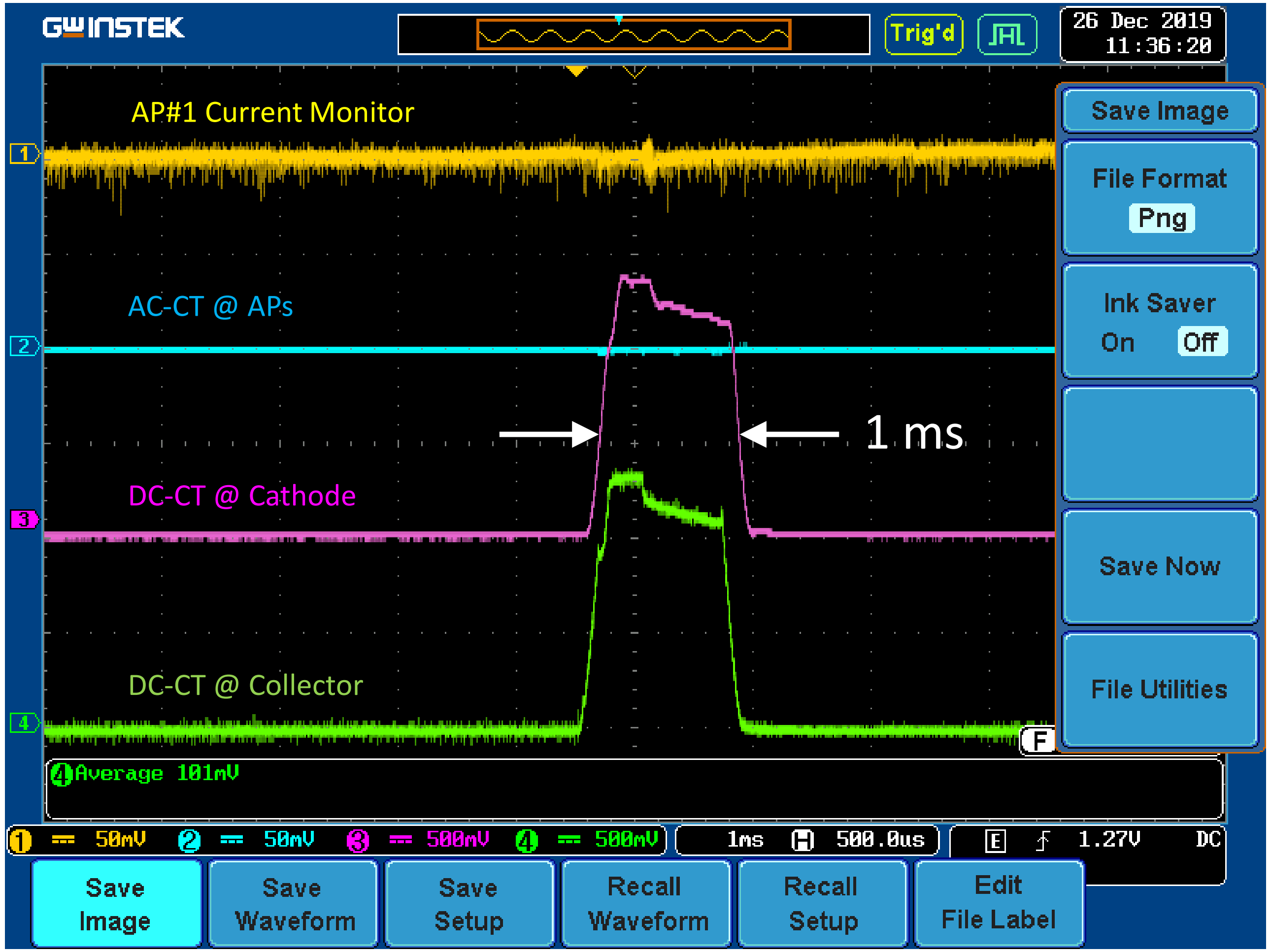


- Drift tube #1 ~ #10 고전압 인가 테스트 수행
- #1에서 #10 까지 순차적으로 고전압 인가
- 고전압을 인가하는 drift tube 기준으로 인접한 전극을 GND 처리
- Base pressure : 2.72 X 10^{-8} torr
- 자기장을 가한 상태에서 HV test 추가 수행



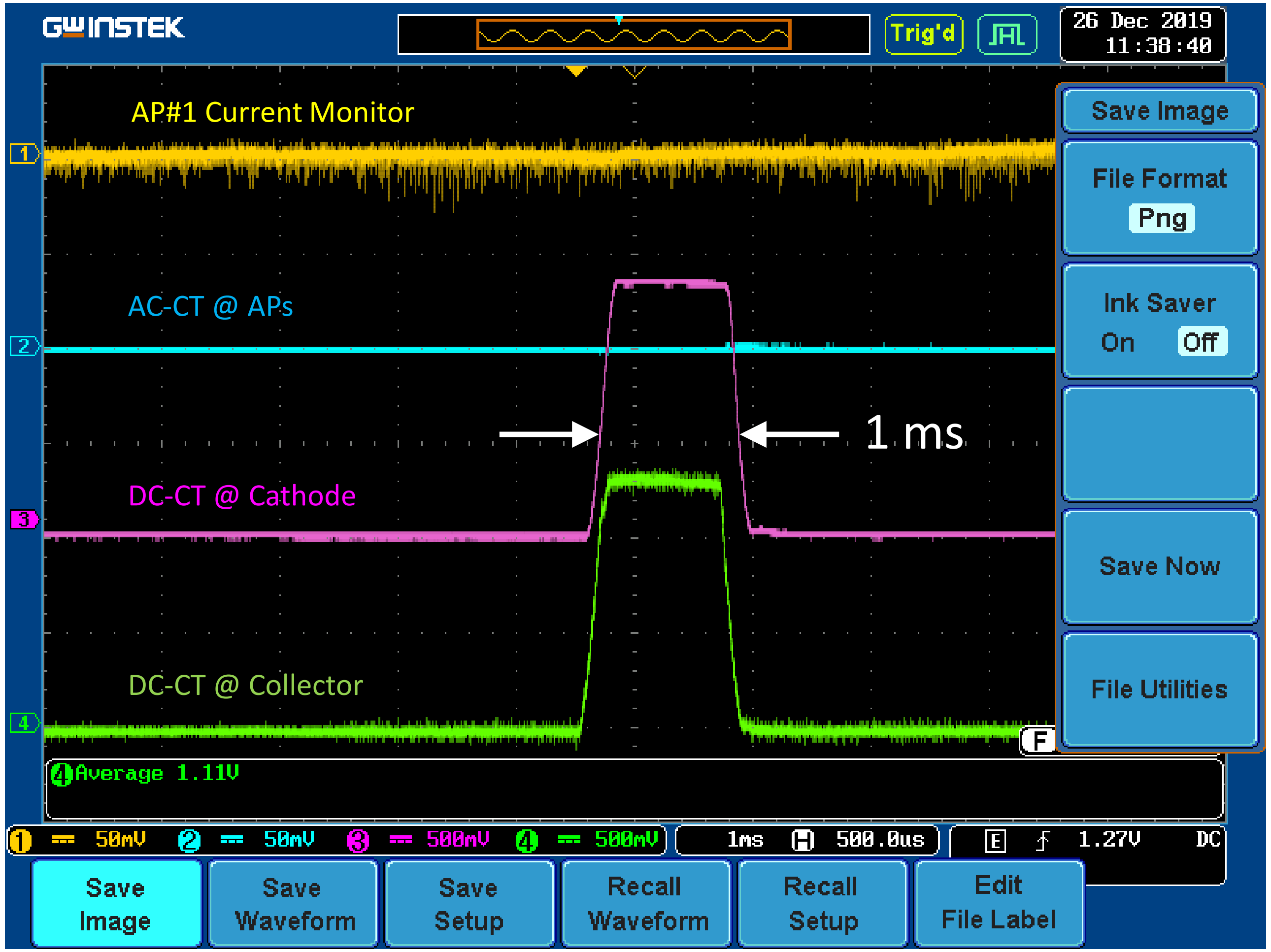
	특이사항	안정적 인가 전압	기준 전압
DT #1	11 kV에서 1회 trip 후, 15 kV 이상 없음	15 kV	14 kV
DT #2	15 kV까지 trip 없음	15 kV	12 kV
DT #3	15 kV까지 trip 없음	15 kV	10 kV
DT #4	12.8 kv에서 ≤10μA discharge 진공도 3.0 X 10^{-8} torr 로 상승	12 kV	8 kV
DT #5	11 kv에서 10μA discharge 진공도 3.03 X 10-8 torr 로 상승	10 kV	8 kV
DT #6	14.7 kV에서 trip	14 kV	8 kV
DT #7	9.2 kv에서 ≤10μA discharge 진공도 3.9 X 10-8 torr 로 상승	8 kV	8 kV
DT #8	15 kV까지 trip 없음	15 kV	10 kV
DT #9	13.7 kV에서 1회 trip 후, 15 kV 이상 없음	15 kV	6 kV
DT #10	15 kV까지 trip 없음	15 kV	4 kV

5. Commissioning : Single Pulse E-Beam Extraction @ 6T w/o Steering



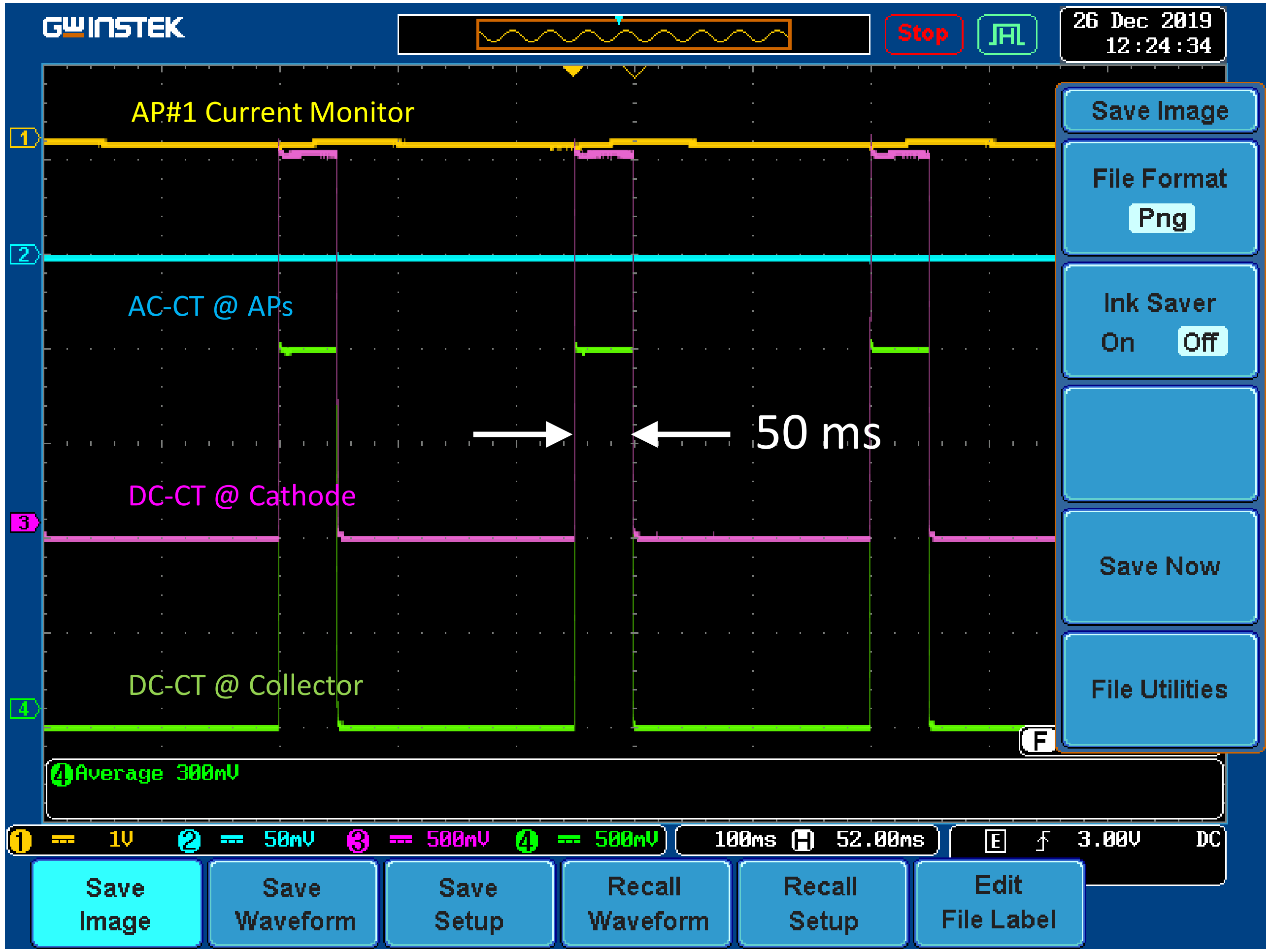
- SC Magnet : 6T
- Gun Coil : 250 A
- Collector Coil : 90 A
- Cathode Heater : 86.7 W (11.2 A)
- Cathode potential : 6 kV
- Vpp (extraction voltage) : **9 kV**
- Rising-Dwell-Falling : 0.2 ms – 1 ms – 0.2 ms
- Cathode Current (DC-CT): 1.22 A
- Collector Current (DC-CT): 1.18 A
- Transmission : 96.7 %
- Vertical Steering Coils: 0 A

5. Commissioning : Single Pulse E-Beam Extraction @ 6T with Steering



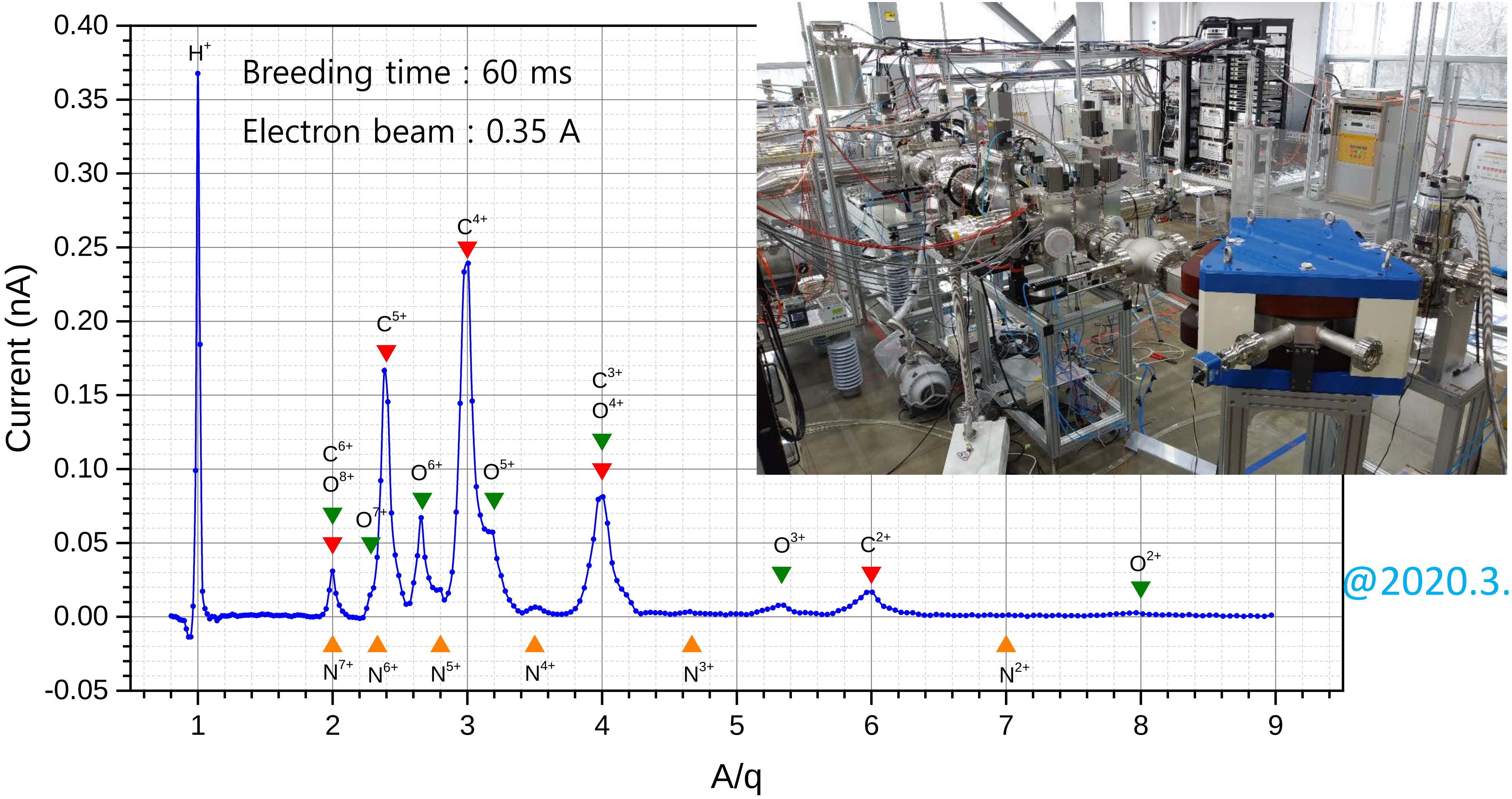
- SC Magnet : 6T
- Gun Coil : 250 A
- Collector Coil : 90 A
- Cathode Heater : 86.7 W (11.2 A)
- Cathode potential : 6 kV
- Vpp (extraction voltage) : 9 kV
- Rising-Dwell-Falling : 0.2 ms – 1 ms – 0.2 ms
- Cathode Current (DC-CT): 1.34 A
- Collector Current (DC-CT): 1.33 A
- Transmission : 99.3 %
- Vertical Steering Coils: 1 A

5. Commissioning : Multi-Pulse E-Beam Extraction @ 6T with Steering



- SC Magnet : 6T
- Gun Coil : 250 A
- Collector Coil : 90 A
- Cathode Heater : 96.2 W (11.6 A)
- Cathode potential : 6 kV
- Vpp (extraction voltage) : **12.2 kV**
- Rising-Dwell-Falling : 0.2 ms – 50 ms – 0.2 ms
- Cathode Current (DC-CT): 2.03 A
- Collector Current (DC-CT): 2.00 A
- Transmission : 98.5 %
- Vertical Steering Coils: 1 A
- Repetition Rate : 4 Hz (Duty 20 %)

5. Commissioning : Charge Breeding of Residual Gas



@2020.3.10

Moving EBIS and RFQ Cooler Buncher from Korea Univ. to RAON site

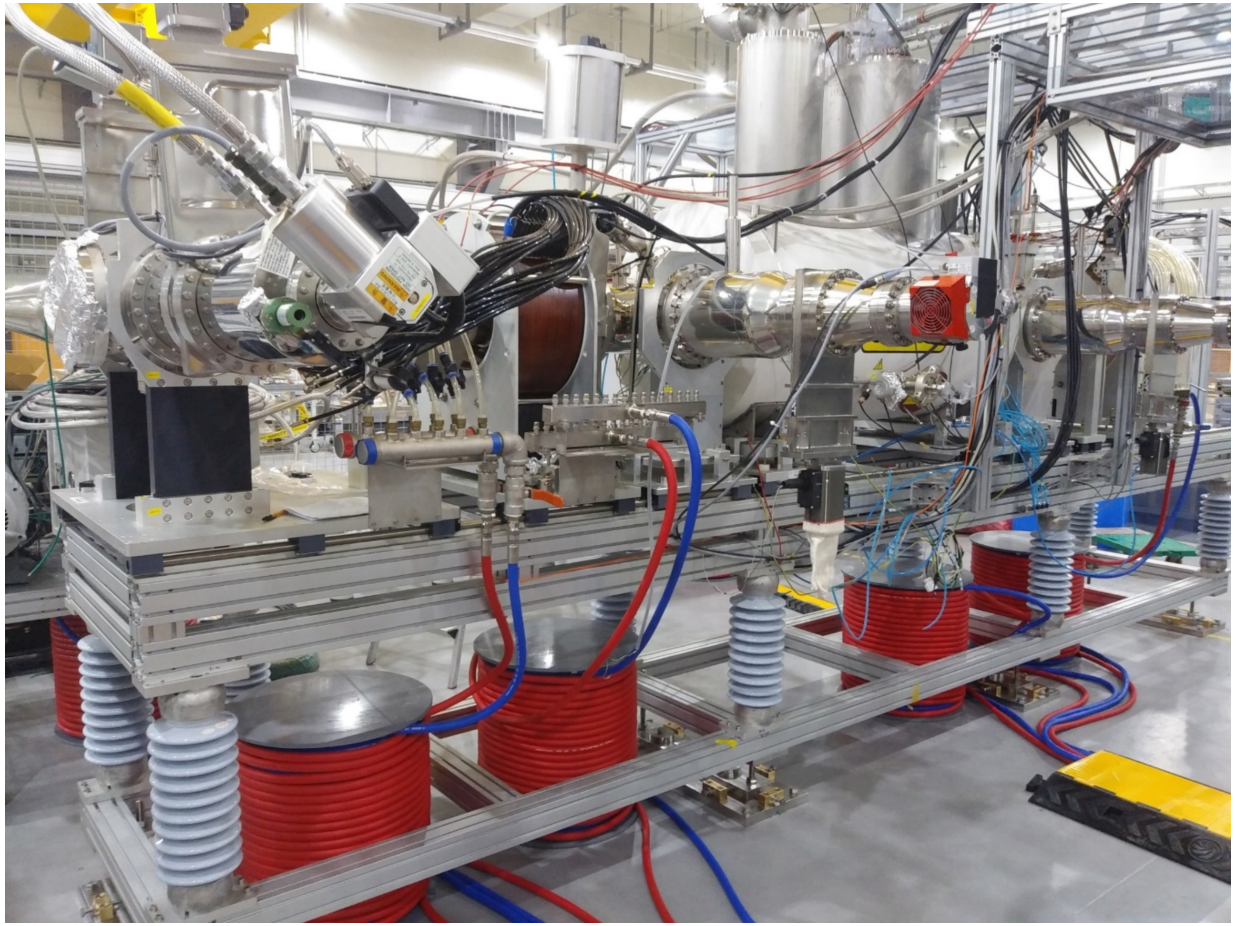






* Packing EBIS Charge Breeder and RFQ Cooler Buncher at Korea University Sejong in Oct. 2020

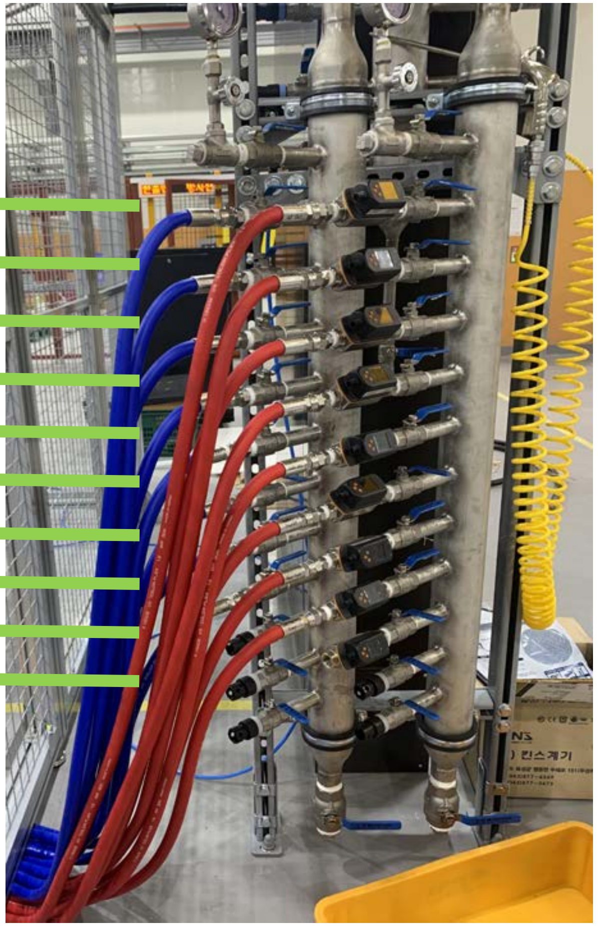
Online Installation of EBIS Charge Breeder



* Reinstalling EBIS Charge at ISOL beamline of RAON heavy ion accelerator at Shindong, Daejeon in 2021

Online Installation of EBIS Charge Breeder   Water Lines

Collector coil
Collector
Repeller Platform Cryopump He Compressor
EBIS Platform Cryopump He Compressor
Collector Power Supply
Water Jacket
Gun Coil
SC Magnet He Compressor
Switchyard Cryopump He Compressor
Dipole Magnet



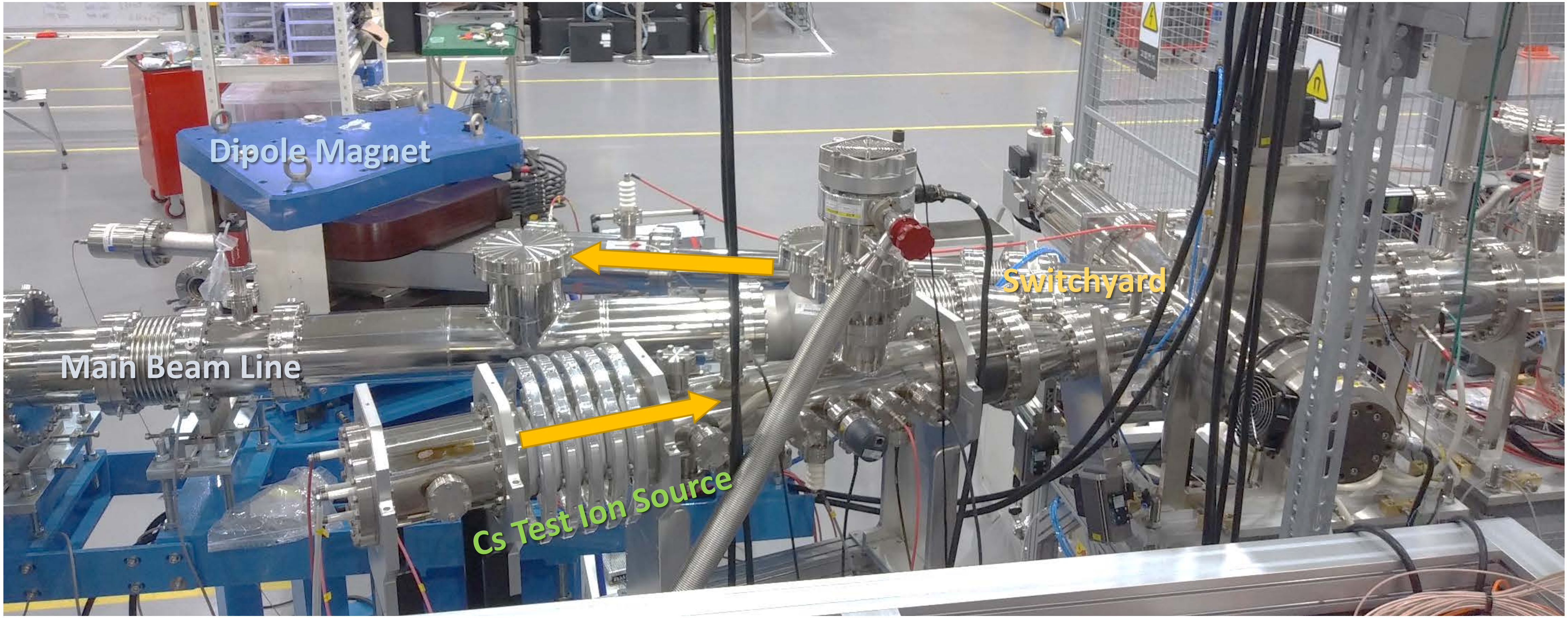
Resistance between EBIS and ground platforms is around 400 MΩ

Online Installation of EBIS Charge Breeder

* Reinstalling EBIS Charge at ISOL beamline of RAON heavy ion accelerator at Shindong, Daejeon in 2021

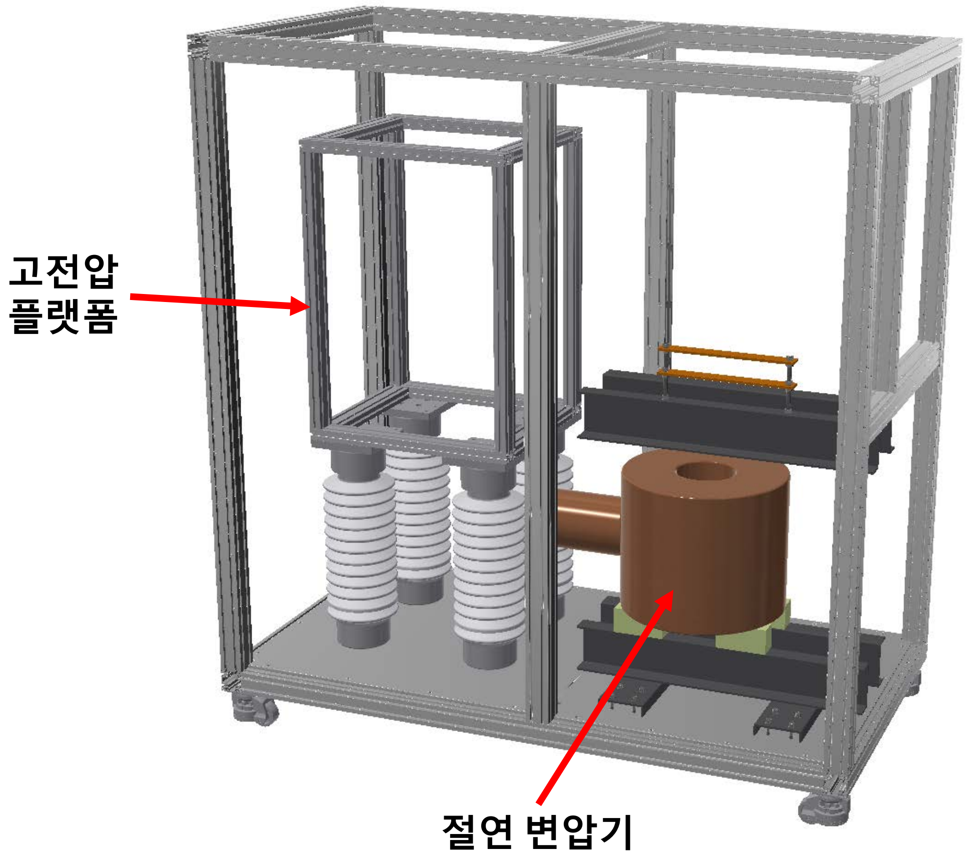
Online Installation of EBIS Charge Breeder

Test Ion Source

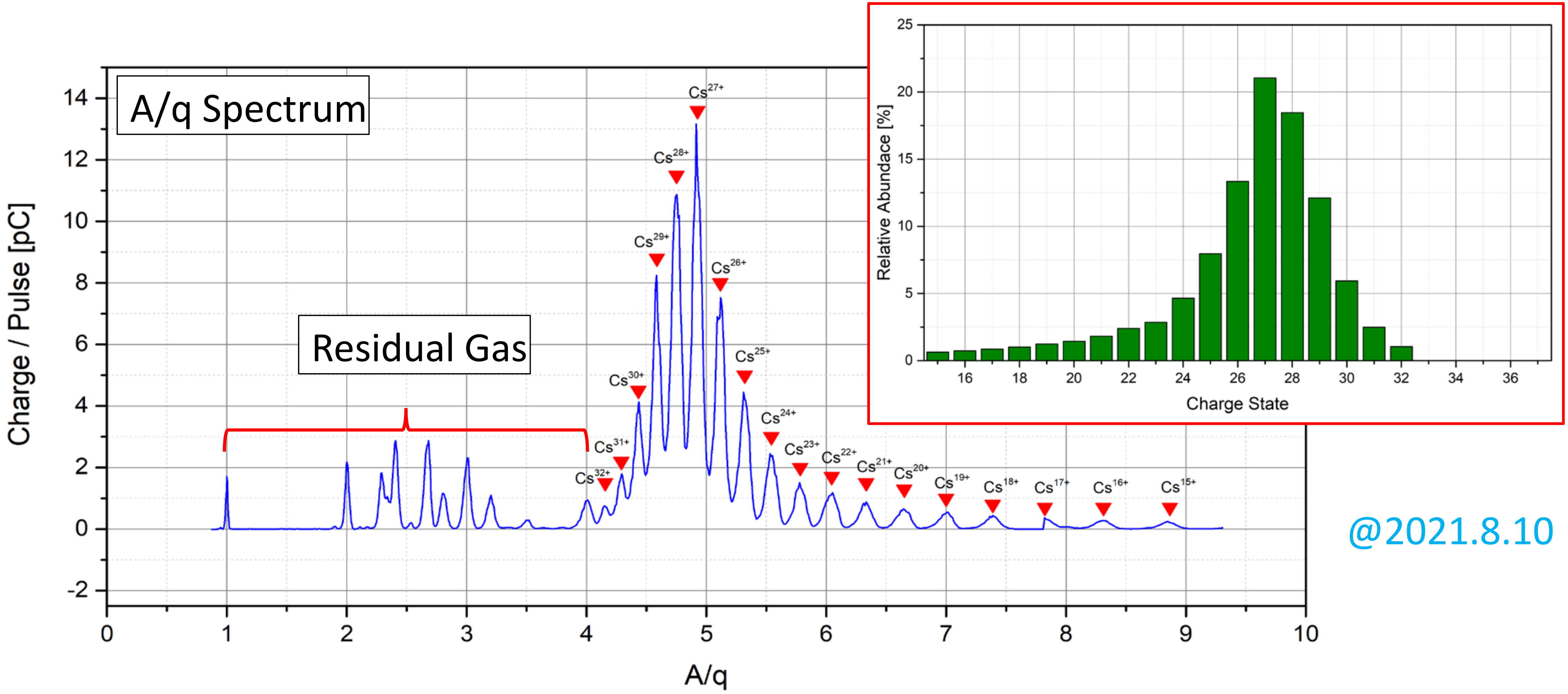


Online Installation of EBIS Charge Breeder

Cage Rack for Test Ion Source



5. Commissioning with Cs Test Ion Beam

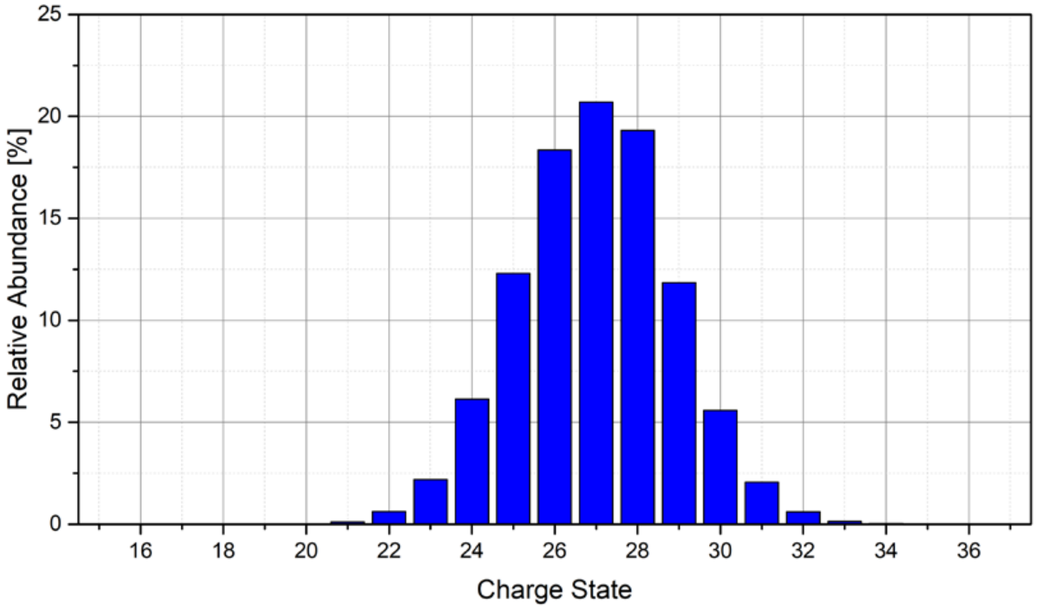


@2021.8.10

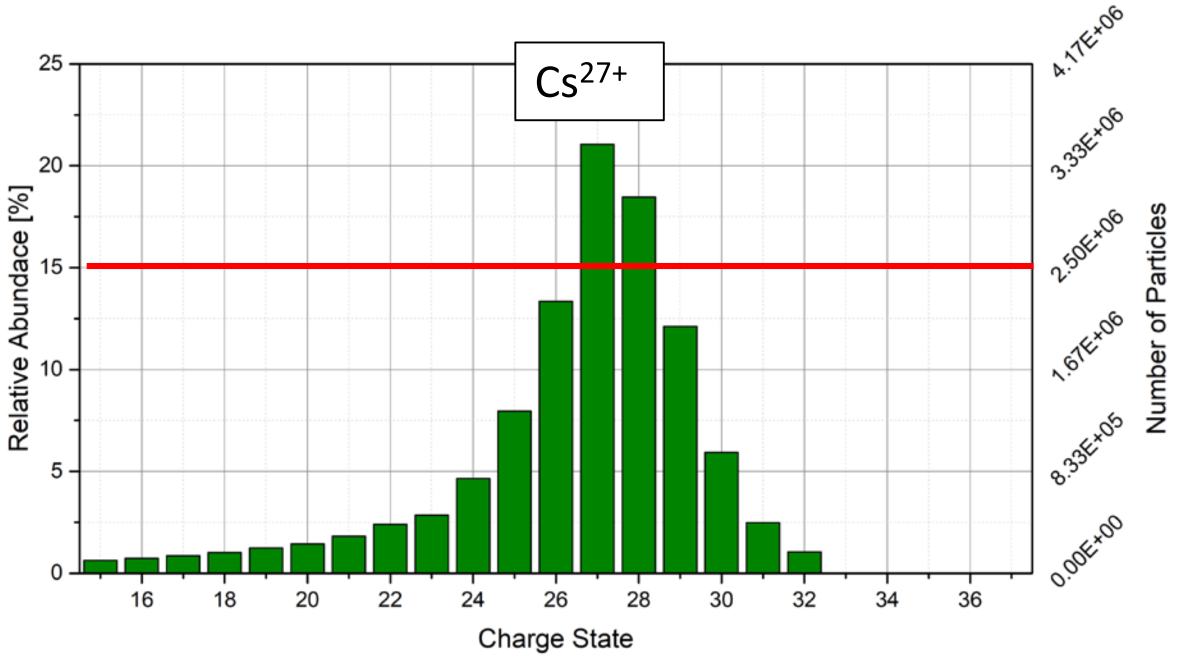
E-Beam Current 1A, Breeding Time 40 ms

5. Commissioning with Cs Test Ion Beam

Charge-State Distribution (CBSIM)



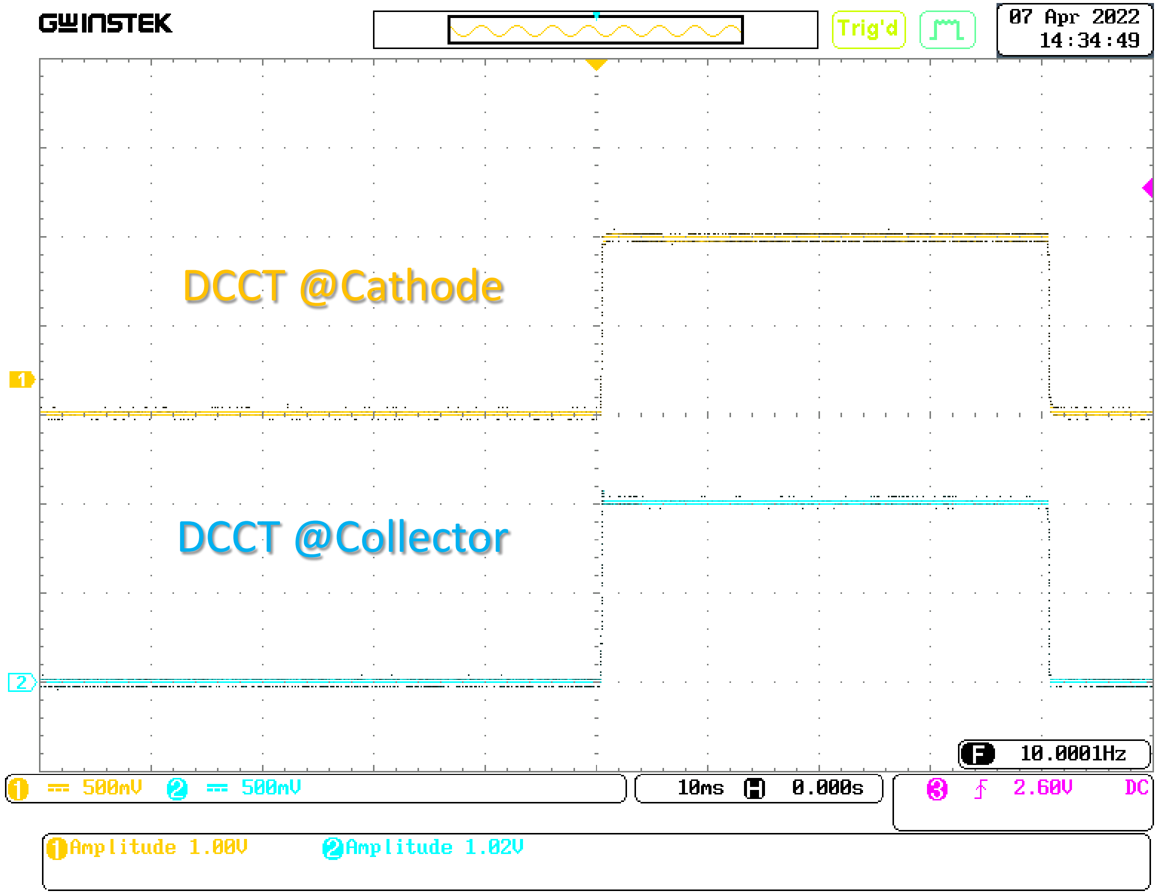
Charge-State Distribution (Experiment)



EBIS 성능 목표: Relative Abundance of Cs^{27+} ≥ 15% ⇒ 목표 달성

E-Beam Current 1A, Breeding Time 40 ms

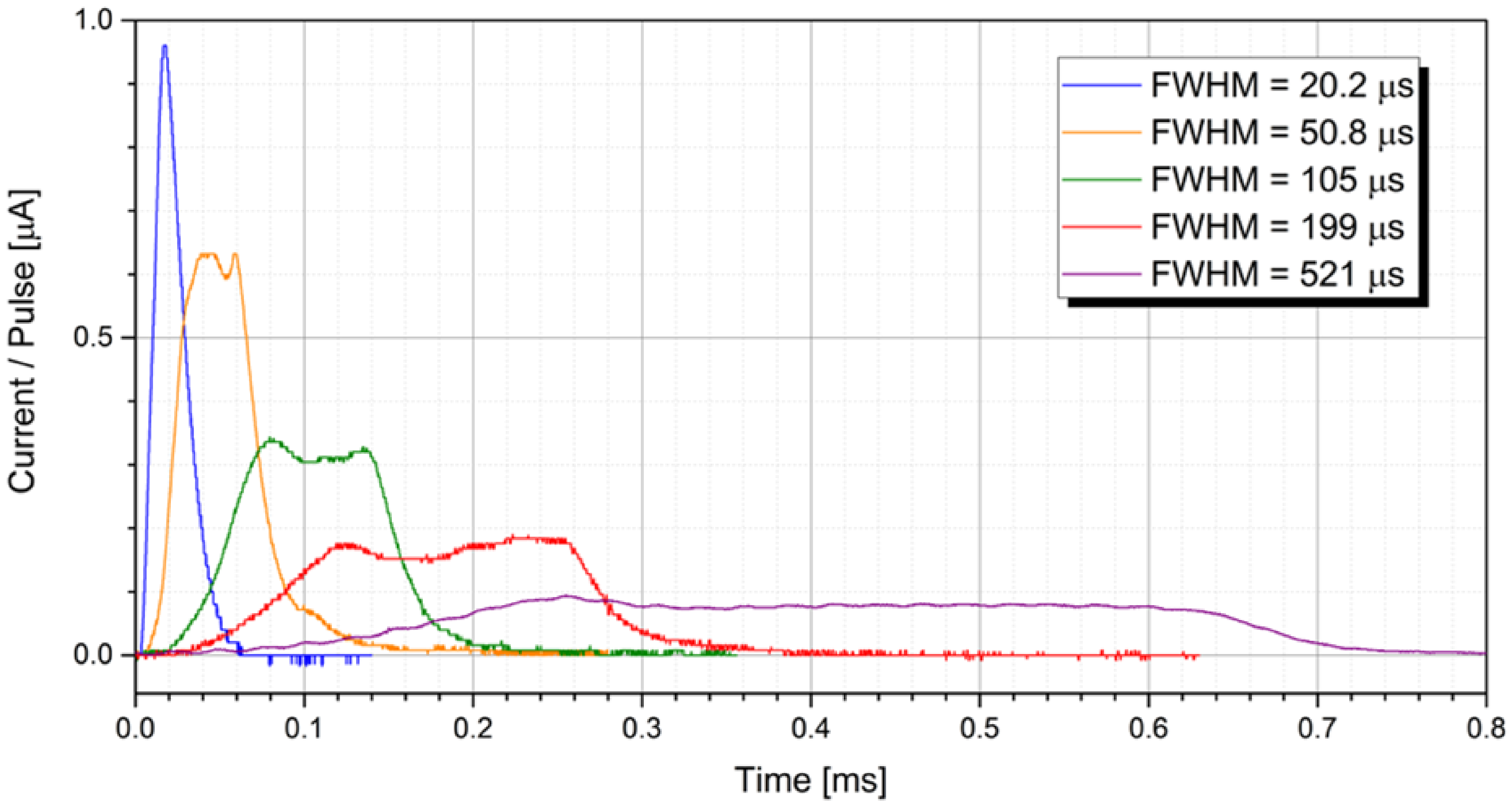
5. Recent Result for Electron Beam Transportation



- SC Magnet : 6T
- Gun Coil : 250 A
- Collector Coil : 175 A
- Vertical Steering Coil :
  - Gunside = -11 gauss (10.5 A) (bottomside)
  - Collectorside = -12 gauss (10.5 A) (bottomside)
- Horizontal Steering Coil :
  - Gunside =10.8 gauss 10 A (cryopumpside)
  - Collectorside =11.5 gauss 10 A (cryopumpside)
- Cathode Heater : 94.4 W (11.4 A)
- Cathode potential : -5 kV
- Vpp (extraction voltage) : **8.6 kV**
- Gate Voltage : 10 kV → 5 kV
- Gate Open Time : -0.22 ms (End of E-Beam Pulse)
- Rising-Dwell-Falling : 0.2 ms – 40 ms – 0.2 ms
- Cathode Current (DC-CT) : 1.00 A
- Collector Current (DC-CT) : 1.00 A
- Transmission : **100 %**
- Repeller : -5 kV (+ -10 kV from EBIS Platform)
- EBIS Platform : 13 kV
- Beam Energy : 20 keV

* By optimally tuning the steering coils, we were able to diminish the loss current of the electron beam.

5. Recent Result for Pulse Stretching



* Elongation of output beam by applying slowly varying voltage on the gate electrode (DT#8).

6. Summary and Outlook

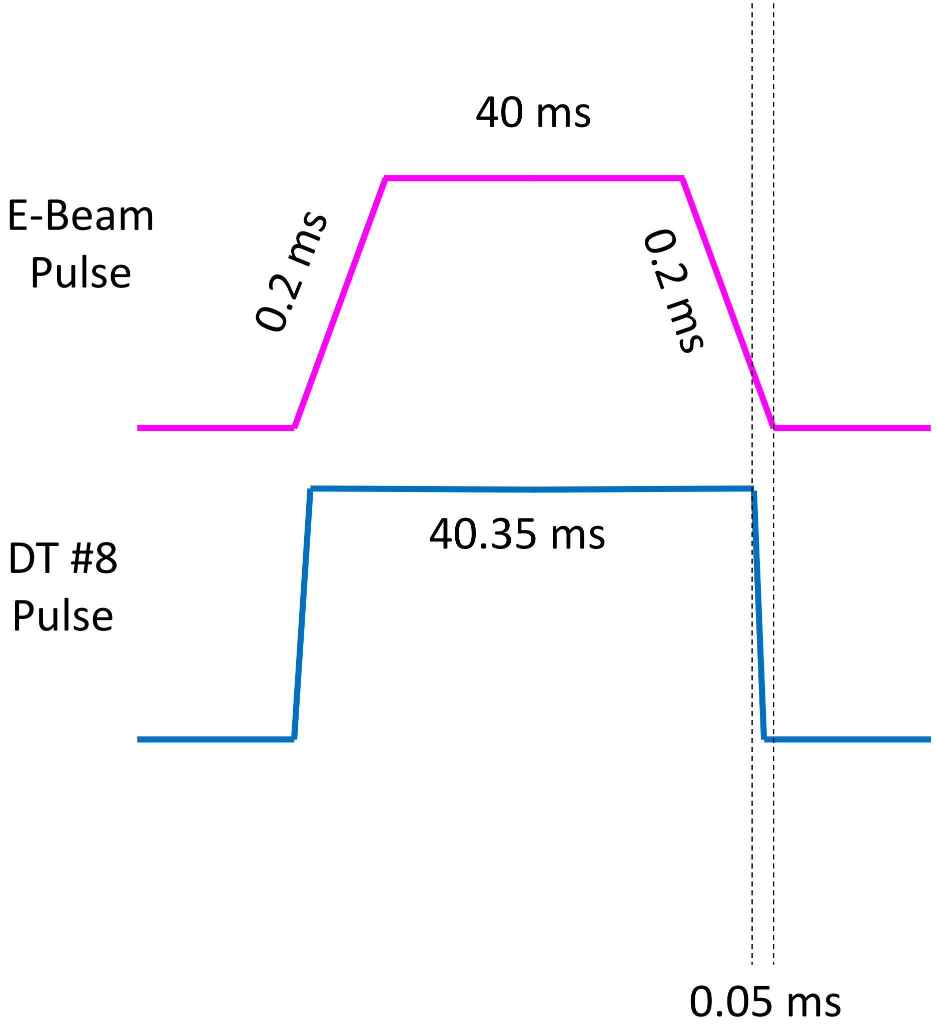
- Off-line installation RAON EBIS starting from 2017 finished successfully in 2020 with the charge breeding of the residual gas.
- After around one year of on-line installation, RAON EBIS showed its design performances with Cs, Sn, and Na ions.
- Pulse stretching experiment is in progress and preliminary results showed an elongated pulse width of 10 ms.
- RAON EBIS charge breeder will play a key role in reaccelerating rare isotope beams from ISOL target system.

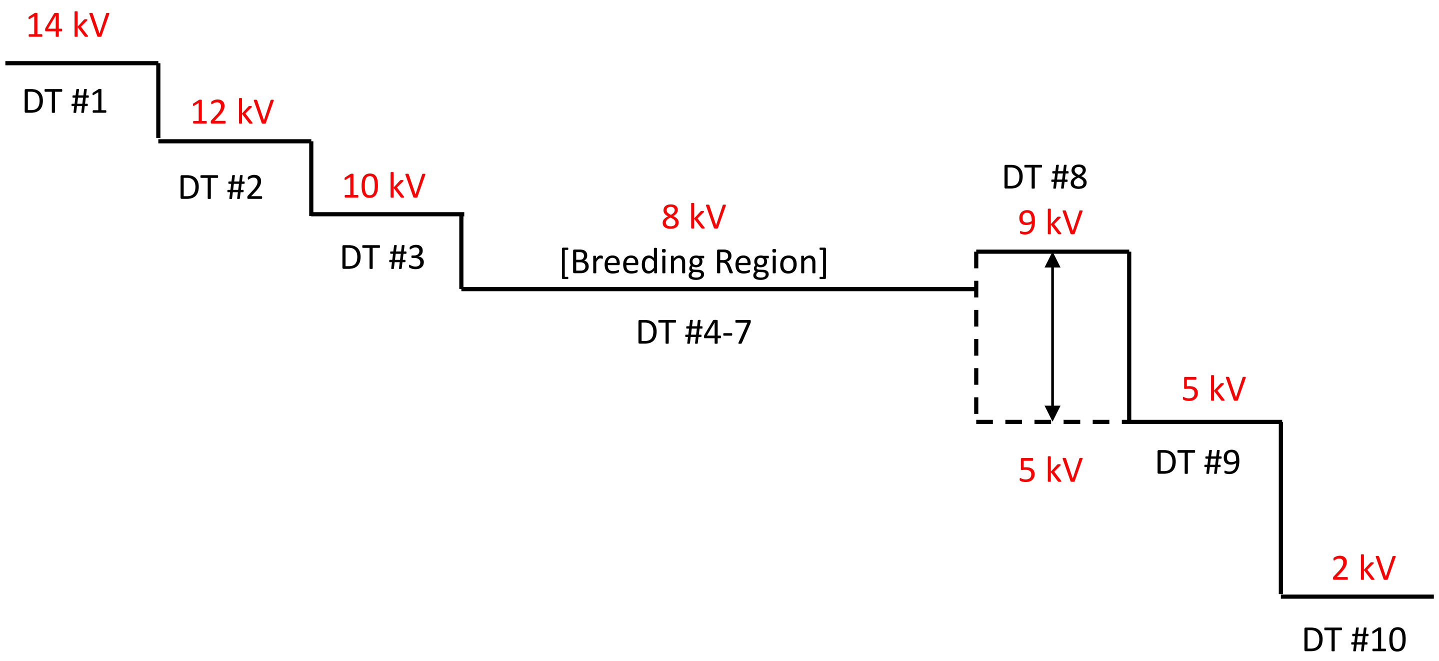
THANK YOU !

Vacuum Pressure (unit: torr)

E-Gun	DT Gun side	DT Collector side	Baffle	Collector	Switchyard	Dipole Magnet
1.1×10^{-9}	3.7×10^{-10}	3.8×10^{-10}	9.1×10^{-9}	3.8×10^{-9}	1.7×10^{-8}	2.1×10^{-8}

Timing and Voltages arrangement in Drift Tubes

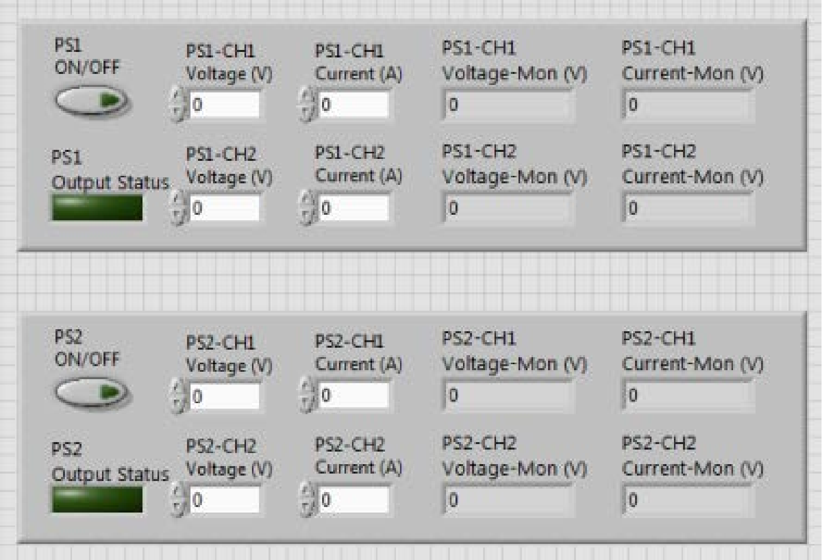


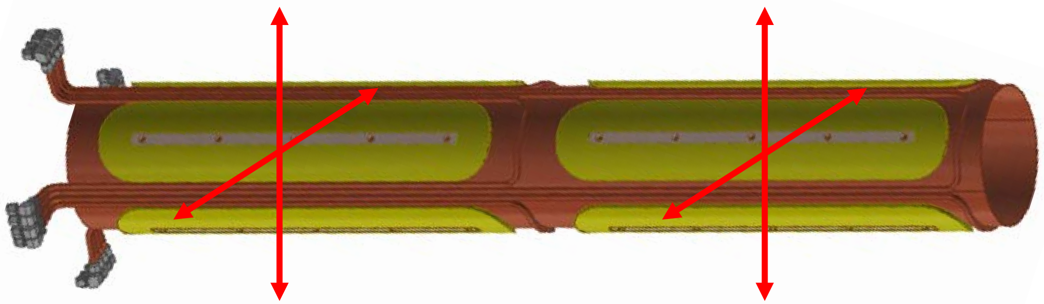


Steering Coil 준비

◦ Steering coil용 파워서플라이(2ch x 2ea)와 PXI간 통신 연결 (RS-485)

◦ PXI에서 제어코드 준비





1.1 G/A

18 V / 50 A

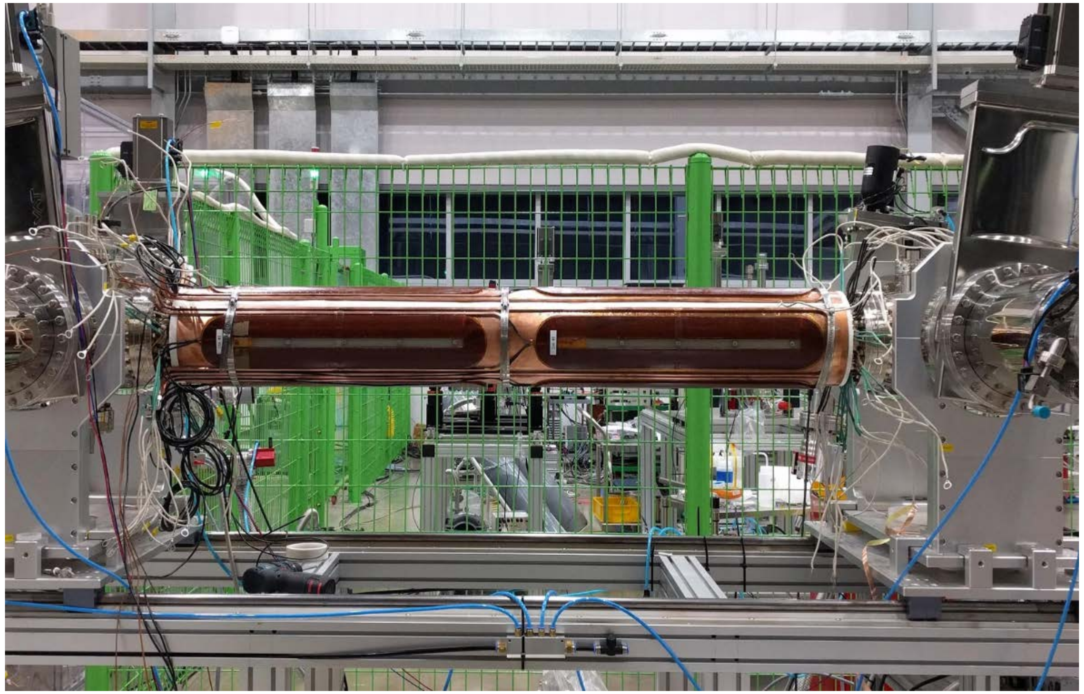
EBIS Super Conducting Magnet Ramp-up Test (Pumps' parameters)

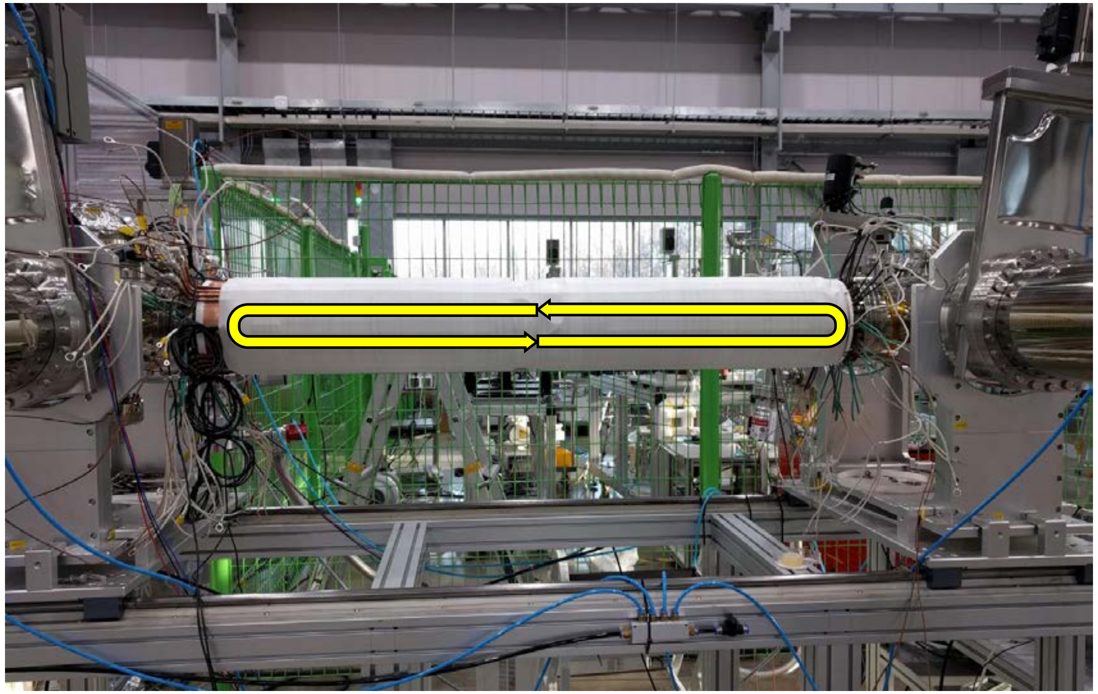
Magnetic Field Strength	0 T	1 T	2 T	3 T	4 T	5 T	6 T
OVC-TMP1 (1,500Hz)	0.18 A	0.18 A	0.18 A	0.18 A	0.21 A	0.21 A	0.25 A
OVC-TMP2 (1,500Hz)	0.21 A	0.21 A	0.21 A	0.21 A	0.21 A	0.21 A	0.21 A
Pressure @ Pumping Station	4.1e-8 torr	3.8e-8 torr	5.1e-8 torr	3.8e-8 torr	2.5e-8 torr	2.3e-8 torr	2.3e-8 torr
Pressure @ OVC Port	2.4 e-7 torr	2.6 e-7 torr	2.8 e-7 torr	1.1 e-7 torr	4.2 e-8 torr	2.6 e-8 torr	2.02 e-8 torr
Egun-TMP (48,000 RPM)	34 ℃	35 ℃	35 ℃	35 ℃	35 ℃	35 ℃	36 ℃
Pressure @ Egun Chamber	1.26e-8 torr	6.6e-9 torr	4.8e-9 torr	5.7e-9 torr	5.34e-9 torr	5.47e-9 torr	5.46e-9 torr
DT(Egun)-TMP (1,000Hz)	0.11 A	0.11 A	0.12 A	0.13 A	0.14 A	0.14 A	0.15 A
Pressure @ DT(Egun)	3.35e-9 torr	8.6e-10 torr	4.83e-10 torr	3.75e-10 torr	3.39e-10 torr	3.0e-10 torr	1.69e-10 torr
DT(Collector)-TMP (1,000Hz)	0.12 A	0.12 A	0.13 A	0.14 A	0.14 A	0.15 A	0.16 A
Pressure @ DT(Collector)	2.7e-9 torr	5.2e-9 torr	1.1e-1 torr	1.1e-1 torr	1.1e-1 torr	1.1e-1 torr	1.1e-1 torr
Collector-TMP (33,600 RPM, OSAKA)						Overheat, Scratching Noise	
Collector-TMP (820 Hz, HiPACE-400, Pfeiffer)	0.42 A	0.29 ~ 0.53 A	0.57 ~ 0.61 A	0.59 ~ 0.67 A	0.62 ~ 0.71 A	0.71 ~ 0.84 A	0.76 ~ 0.87 A (Overheat)
Pressure @ Collector	2.24e-8 torr	2.09e-8 torr	1.46e-8 torr	1.05e-8 torr	< 8.5e-9 torr	< 8.4e-9 torr	< 8.4e-9 torr
Transport Line - TMP (48,000 RPM)	34 ℃	34 ℃	34 ℃	34 ℃	34 ℃	35 ℃	35 ℃
Pressure @ Einzel Lens	4.69e-8 torr	4.71e-8 torr	4.75e-8 torr	4.76e-8 torr	4.8e-8 torr	4.88e-8 torr	5.01e-8 torr
Pressure @ Switchyard	7.12e-8 torr	7.24e-8 torr	7.35e-8 torr	7.33e-8 torr	7.5e-8 torr	7.63e-8 torr	7.93e-8 torr
DT(Egun)-Cryopump	48 K, 10 K	48 K, 10 K	48 K, 10 K	48 K, 10 K	48 K, 10 K	48 K, 10 K	48 K, 10 K
DT(Collector side)-Cryopump	55 K, 10 K	55 K, 10 K	55 K, 10 K	55 K, 10 K	56 K, 10 K	56 K, 10 K	55 K, 10 K
Collector-Cryopump	55 K, 10 K	55 K, 10 K	55 K, 10 K	55 K, 10 K	55 K, 10 K	55 K, 10 K	54 K, 10 K

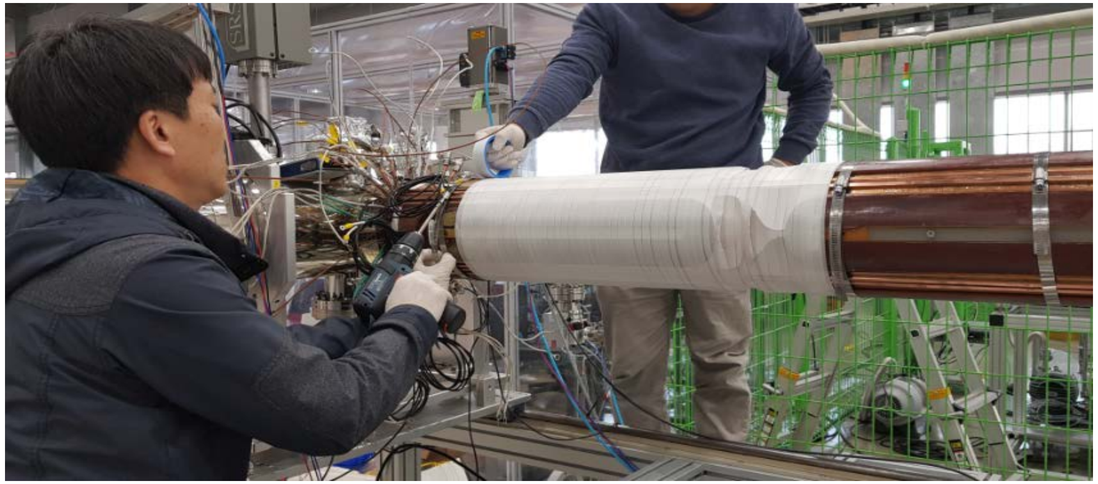
EBIS Super Conducting Magnet Ramp-up Test (Temperatures of pumps)

Magnetic Field Strength	0 T	1 T	2 T	3 T	4 T	5 T	6 T	B_r @ 6T	B_z @ 6T	B @ 6T	Angle
OVC-TMP1 - Power Box	33.6 °C	33.3 °C	33.4 °C	33.8 °C	33.8 °C	34.5 °C	34.1 °C	35.0 G	38.4 G	52.0 G	42.3°
OVC-TMP1 - Cylinder Side	31.5 °C	31.8 °C	31.8 °C	31.9 °C	32.1 °C	32.3 °C	32.5 °C				
OVC-TMP2 - Power Box	33.5 °C	33.1 °C	33.3 °C	33.7 °C	33.6 °C	33.7 °C	34.0 °C	3.3 G	53.5 G	53.6 G	3.5°
OVC-TMP2 - Cylinder Side	31.5 °C	31.6 °C	31.9 °C	31.8 °C	32.5 °C	31.9 °C	32.6 °C				
Scroll pump for OVC TMPs	42.8 °C	43.3 °C	43.5 °C	42.6 °C	42.9 °C	43.0 °C	42.0 °C				
Egun-TMP	28.4 °C	29.6 °C	30.1 °C	30.2 °C	30.5 °C	30.4 °C	30.8 °C	27.2 G	128.0 G	130.9 G	12.0°
Scroll pump for Egun TMP	41.4 °C	44.8 °C	41.9 °C	41.5 °C	42.1 °C	41.9 °C	41.2 °C				
DT(Egun)-TMP - Power Box	33.5 °C	33.4 °C	33.8 °C	33.8 °C	34.0 °C	34.6 °C	34.1 °C	5.9 G	331.5 G	331.6 G	1.0°
DT(Egun)-TMP - Cylinder Side	31.0 °C	31.0 °C	31.3 °C	31.6 °C	31.8 °C	31.7 °C	32.0 °C				
DT(Collector)-TMP - Power Box	33.9 °C	34.4 °C	34.0 °C	34.4 °C	35.1 °C	35.6 °C	35.6 °C	1.6 G	347.0 G	347.0 G	0.3°
DT(Collector)-TMP - Cylinder Side	31.1 °C	30.6 °C	31.3 °C	32.0 °C	31.7 °C	31.9 °C	32.0 °C				
Scroll pump for DT TMPs	30.1 °C	30.2 °C	30.1 °C	29.9 °C	30.6 °C	30.2 °C	30.0 °C				
Collector-TMP (HiPACE-400, Pfeiffer)	37.0 °C	37.2 °C	37.5 °C	37.7 °C	38.2 °C	38.8 °C	39.2 °C	53.7 G	60.0 G	80.5 G	41.8°
Scroll pump for Collector-TMP	43.0 °C	43.5 °C	44.4 °C	44.4 °C	44.7 °C	44.4 °C	44.5 °C				
Transport Line - TMP - Bottom	31.8 °C	31.6 °C	32.0 °C	31.8 °C	32.0 °C	32.2 °C	32.6 °C	< 10 G	< 10 G		
Transport Line - TMP -Cylinder Side	29.4 °C	29.5 °C	29.8 °C	29.8 °C	29.9 °C	30.3 °C	30.7 °C				
Scroll pump for TL-TMP	40.8 °C	40.2 °C	41.2 °C	41.8 °C	40.8 °C	41.6 °C	41.4 °C				
DT(Egun)-Cryopump	28.1 °C	28.3 °C	28.3 °C	28.4 °C	28.5 °C	28.7 °C	28.5 °C	18.3 G	285.0 G	285.6 G	3.7°
DT(Collector side)-Cryopump	27.0 °C	27.3 °C	27.1 °C	27.6 °C	27.3 °C	27.5 °C	27.6 °C	60.5 G	340.0 G	345.3 G	10.1°
Collector-Cryopump	31.0 °C	31.2 °C	31.2 °C	31.0 °C	31.0 °C	31.7 °C	31.6 °C	69.0 G	66.5 G	95.8 G	46.1°

1. Water jacket & steering coil 고정

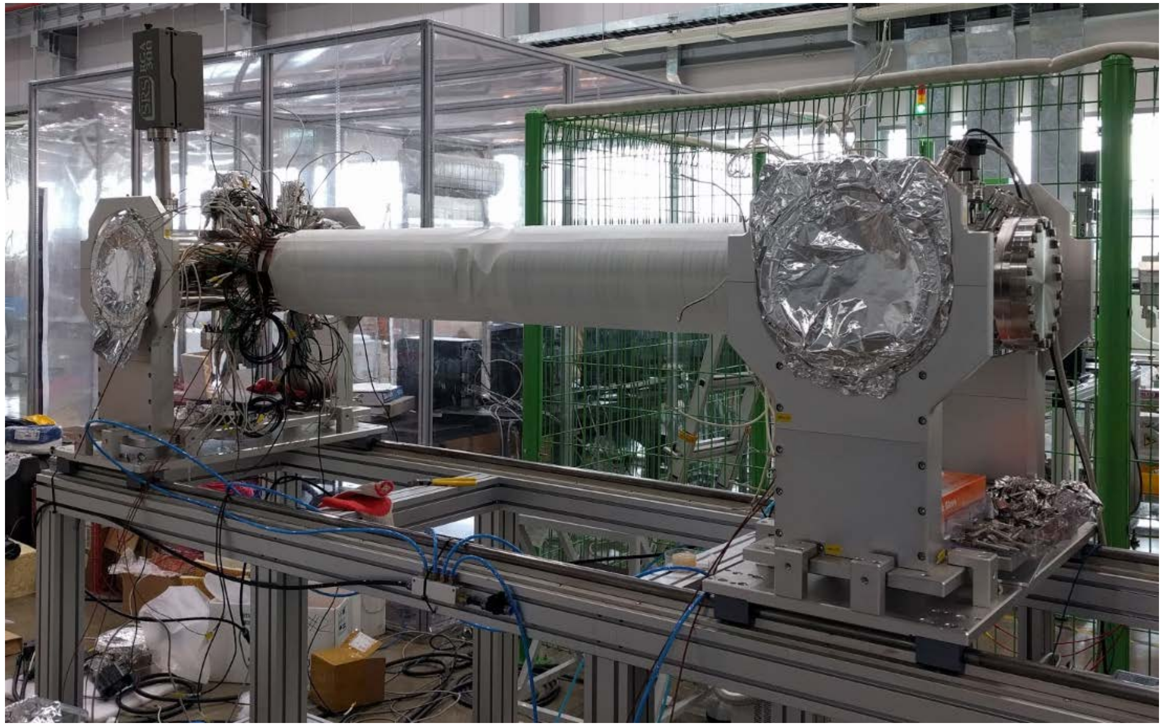






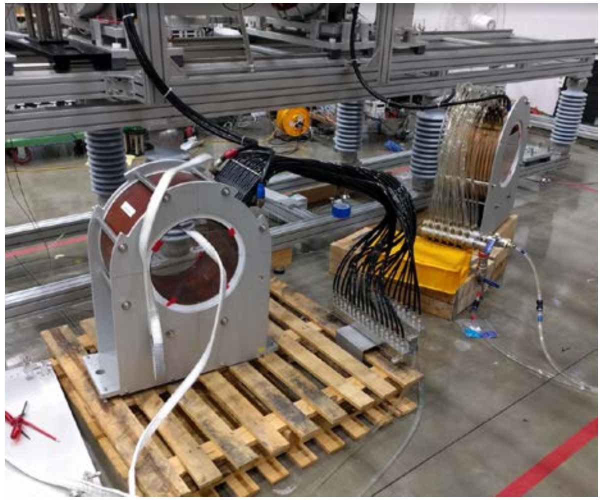
- 유리 섬유 테이프 (Glass fiber tape) 이용 water jaket 고정
  - SWACO AGT-3W0-180F : 내열 온도 155 ℃
  - 150 m (5롤) 사용
- Water jacket 온도 모니터용 TC 설치 (5 points)

2. DT section 해체 및 EBIS platform 위 DT chamber 설치



- DT section 해체
  - TMP, Cryopump, Gate valve, 공압 시스템 해체

2. DT section 해체 및 EBIS platform 위 DT chamber 설치



① EBIS platform 위 NC solenoid 분리

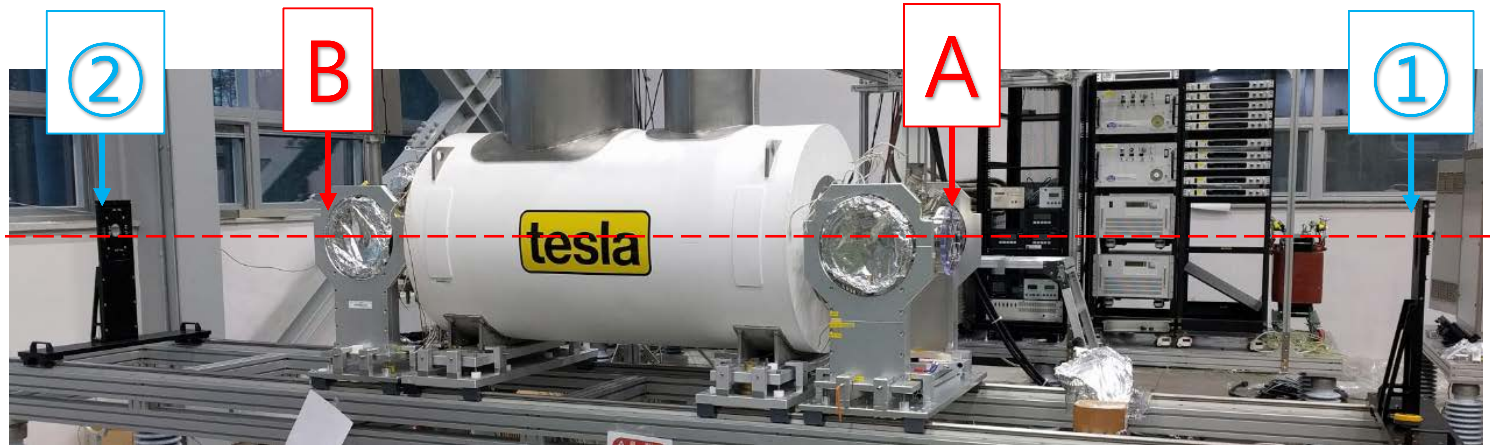
② DT chamber 이동

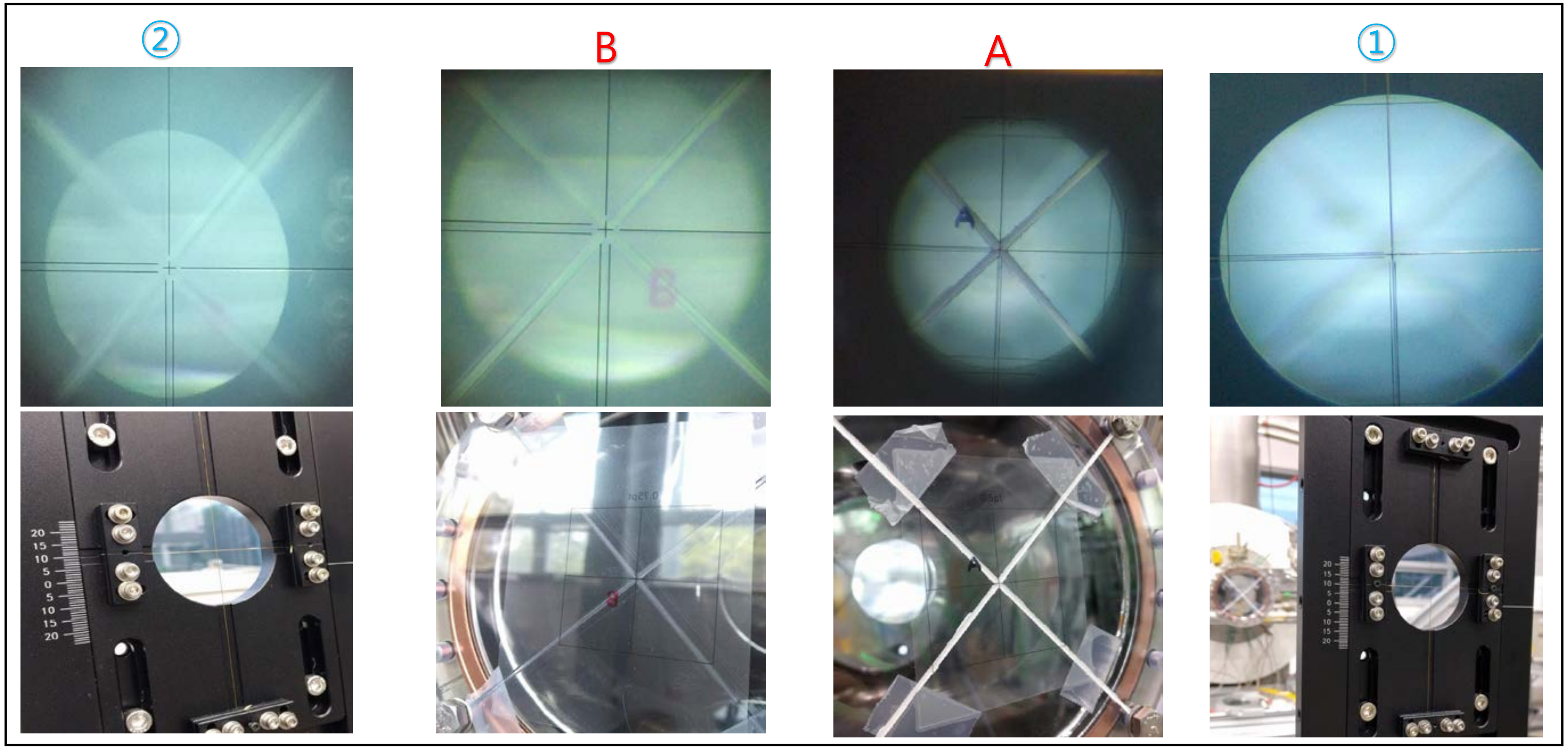
③ 초기 위치 설정 및 전선, TC 정리

④ SC magnet bore 내 DT chamber 설치 작업

⑤ 설치 완료

3. DT chamber 정렬

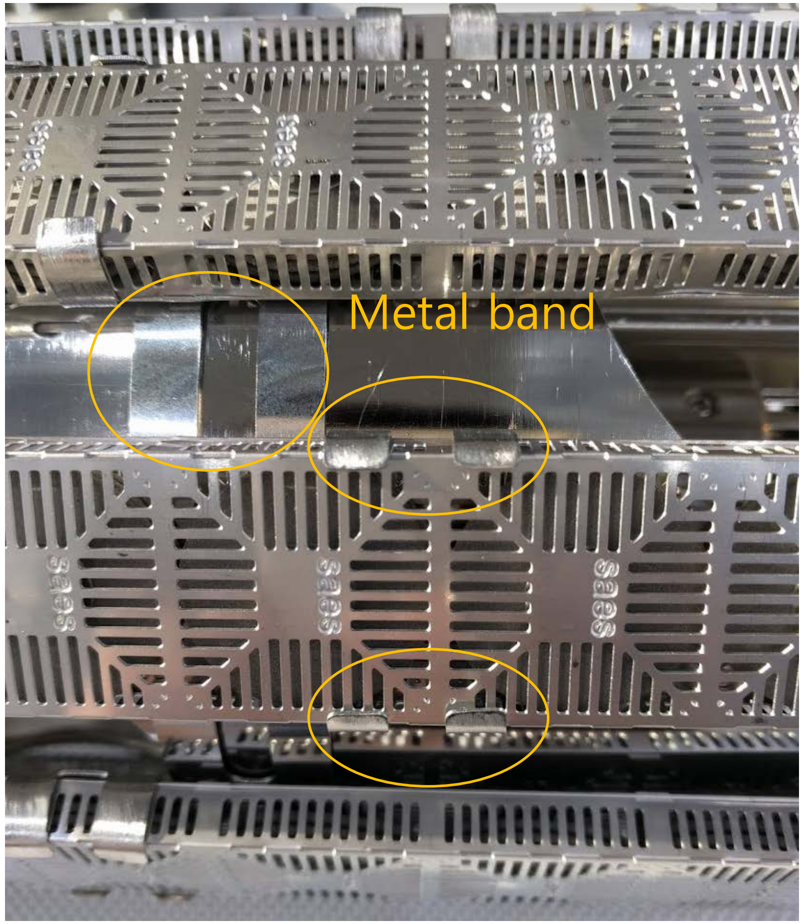




- DT chamber 가상 축상 정렬 완료
- A,B 위치의 flange 위에 아크릴 마스크 (flange 형상)을 장착하여 정렬 포인트를 설정
- 데오도라이트와 chamber supporter 하단에 위치한 정렬 블록(볼트 이용 X,Y,Z 위치 조절)을 이용하여 정렬 수행

1. DT 전압 인가용 rod, connector 재설계, 제작 (완료)

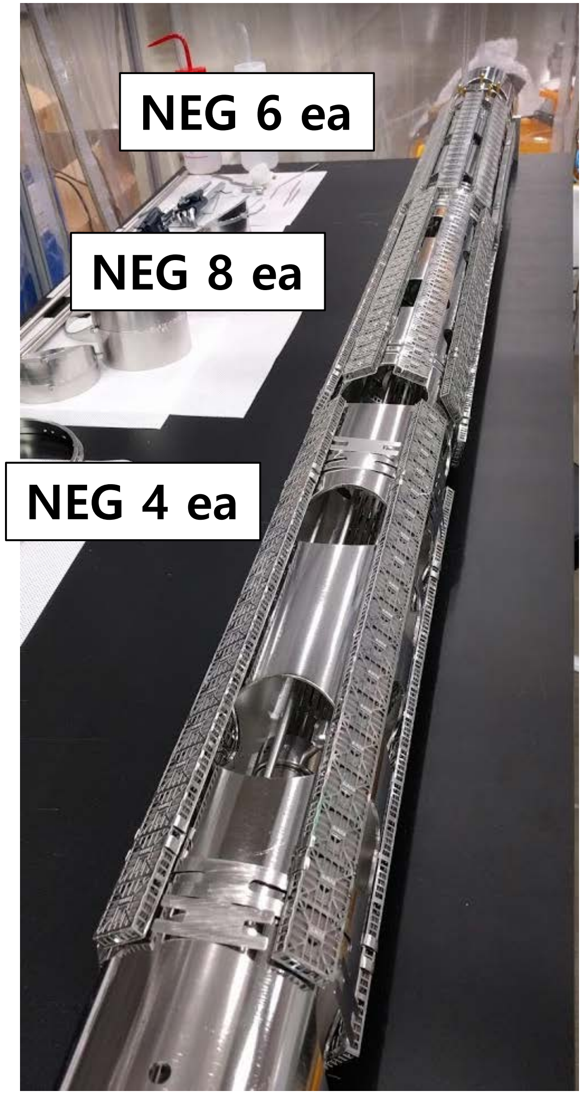
- DT 조립 완료후, scaffold 외벽에 NEG ZAO 설치
- SS316L metal band를 이용하여 NEG ZAO (6 ea) 설치
- NEG ZAO 12개 추가 설치 예정 (5월 9일)



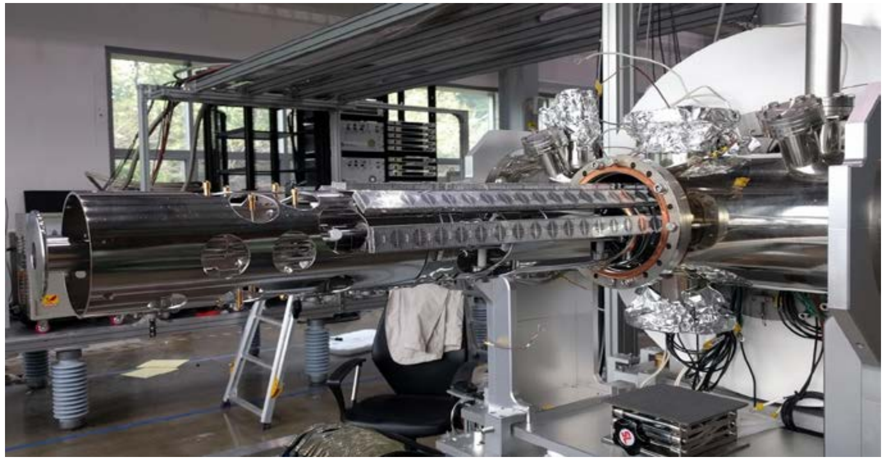
Metal band

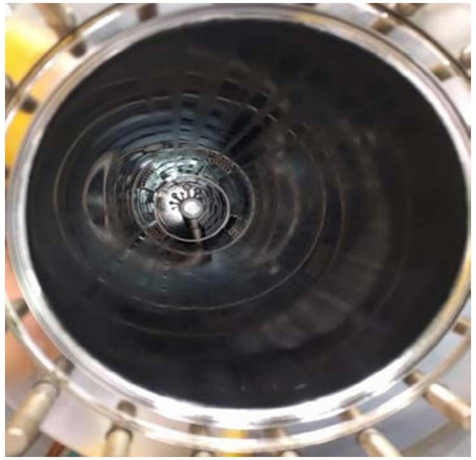
1. DT structure 조립 및 설치

- NEG ZAO 12개 설치 완료

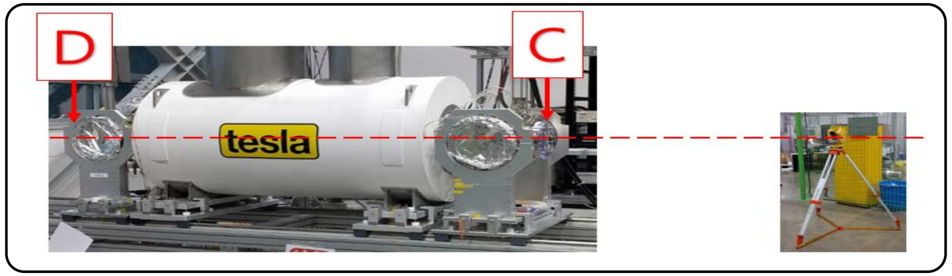


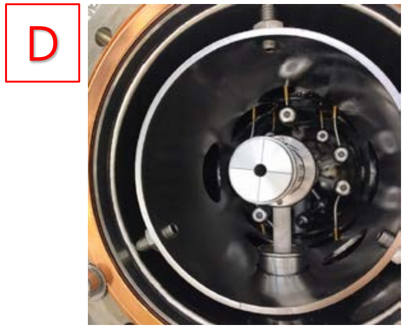
- DT structure 설치



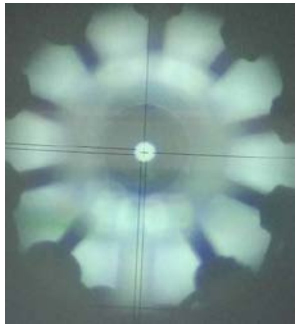


- DT structure 정렬 및 고정

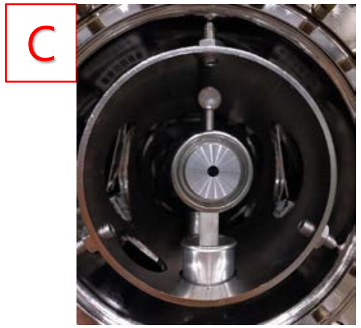




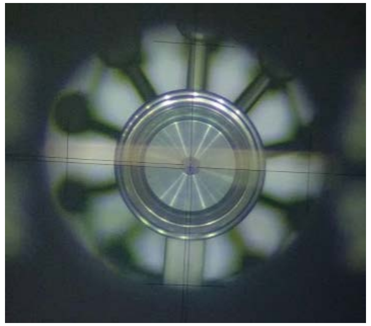
정렬 용
Block 장착



정렬 후
telescope mark



정렬 용
Block 장착

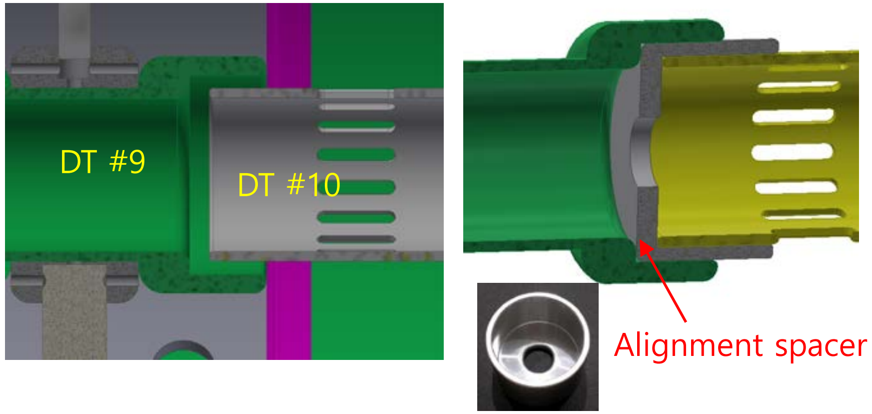


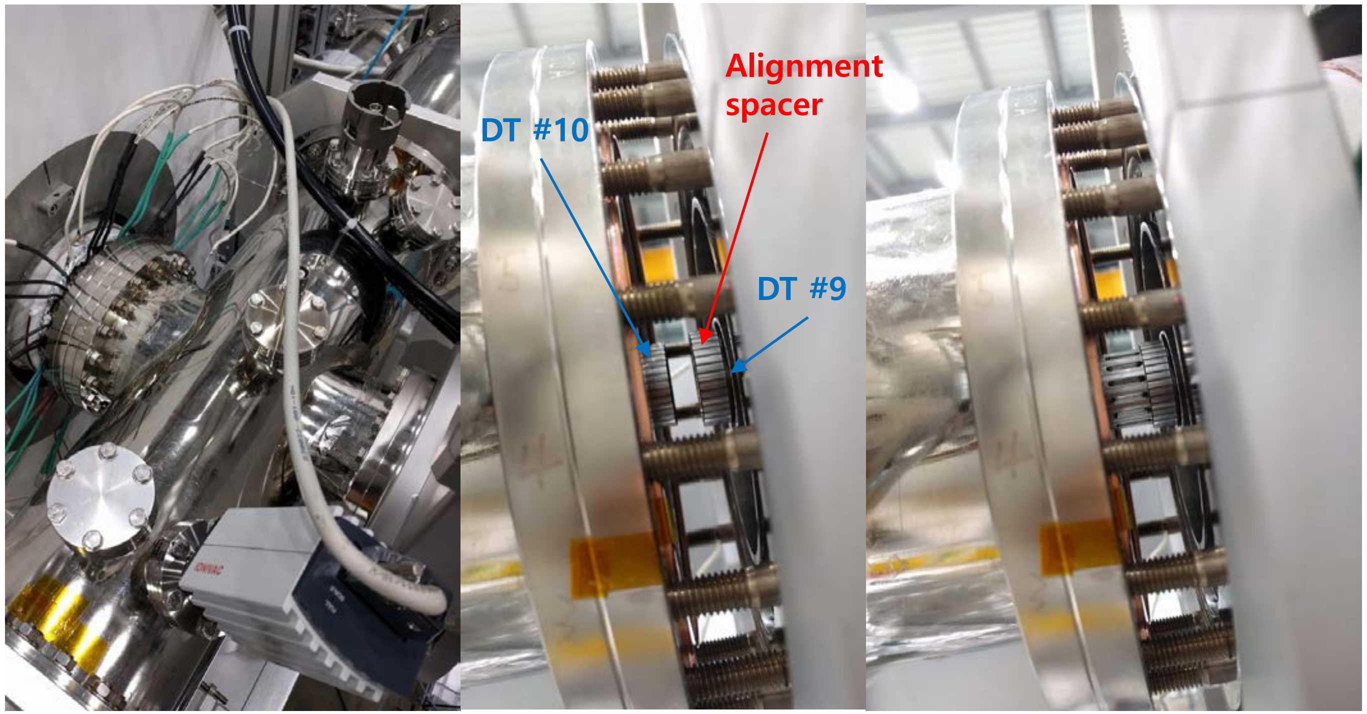
정렬 후
telescope mark

1. Installation of DT structure

- DT #10 설치

Alignment of DT #10





Alignment (DT #9 side)

Alignment (collector side)