RAON Rare isotope Accelerator complex for ON-line experiments

Recent Progress of The Korean Heavy Ion Accelerator : RAON

Myeun Kwon on behalf of RISP staff

ibs 기초과학연구원 Institute for Basic Science

RISP 중이온가속기건설구축사업단 Rare Isotope Science Project

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Part 1.

Project Overview

1. Overview Rare Isotope Science Project (RISP)

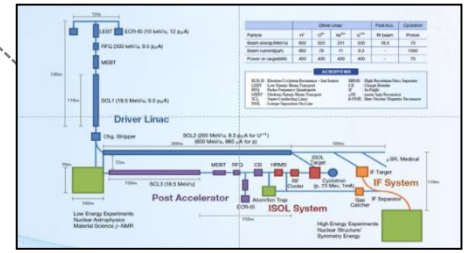
- **Goal:** To build **a heavy ion accelerator complex RAON,** for **rare isotope science** research in Korea.

  * RAON - Rare isotope Accelerator complex for ON-line experiments

- **Budget: KRW 1,518 billion (US$ 1.32 billion, 1$=1,146krw)**
  - accelerators and experimental apparatus : 522.8 billion won
  - civil engineering & conventional facilities : 996 billion won (incl. site 357 billion won)
- **Period: 2011.12 ~ 2021.12 (1st Phase)**

System Installation Project

Development, installation, and commissioning of the accelerator systems that provides high-energy (200MeV/u) and high-power (400kW) heavy-ion beam



- **Providing high intensity RI beams by ISOL and IF**
  ISOL: direct fission of ^{238}U by 70 MeV proton
  IF: 200 MeV/u ^{238}U (intensity: 8.3 pμA)
- **Providing high quality neutron-rich beams**
  e.g., ^{132}Sn with up to 250 MeV/u,
  up to 10^9 particles per second

Facility Construction Project

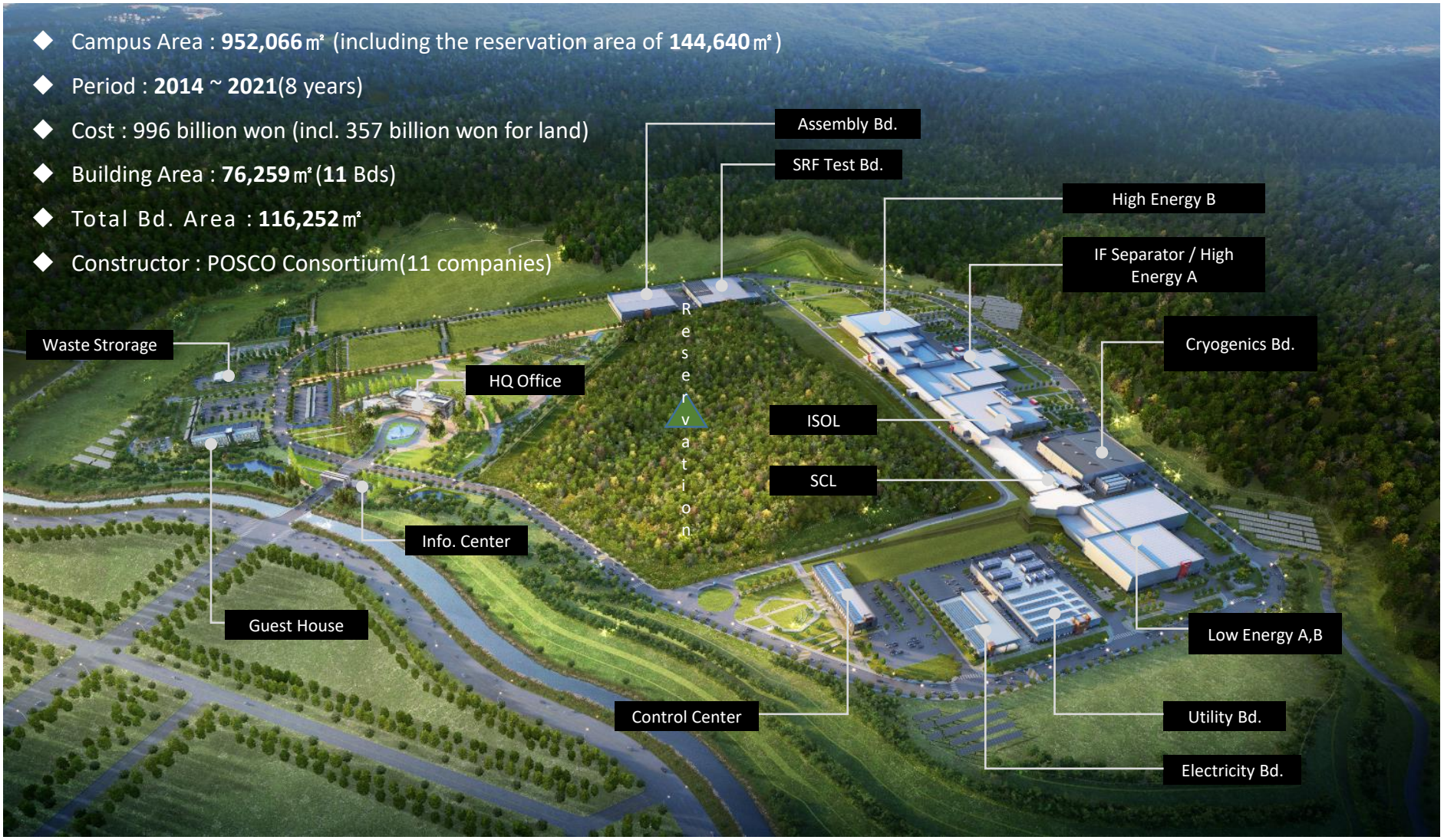
Construction of research and support facility to ensure the stable operation of the heavy-ion accelerator, experiment systems, and to establish a comfortable research environment

※ Accelerator and experiment buildings, support facility, administrative buildings, and guest house, etc.

- **Providing More exotic RI beam production by combination of ISOL and IF**

● Building Layout

- Campus Area : **952,066㎡** (including the reservation area of **144,640㎡**)
- Period : **2014** ~ **2021**(8 years)
- Cost : 996 billion won (incl. 357 billion won for land)
- Building Area : **76,259㎡**(**11** Bds)
- Total Bd. Area : **116,252㎡**
- Constructor : POSCO Consortium(11 companies)

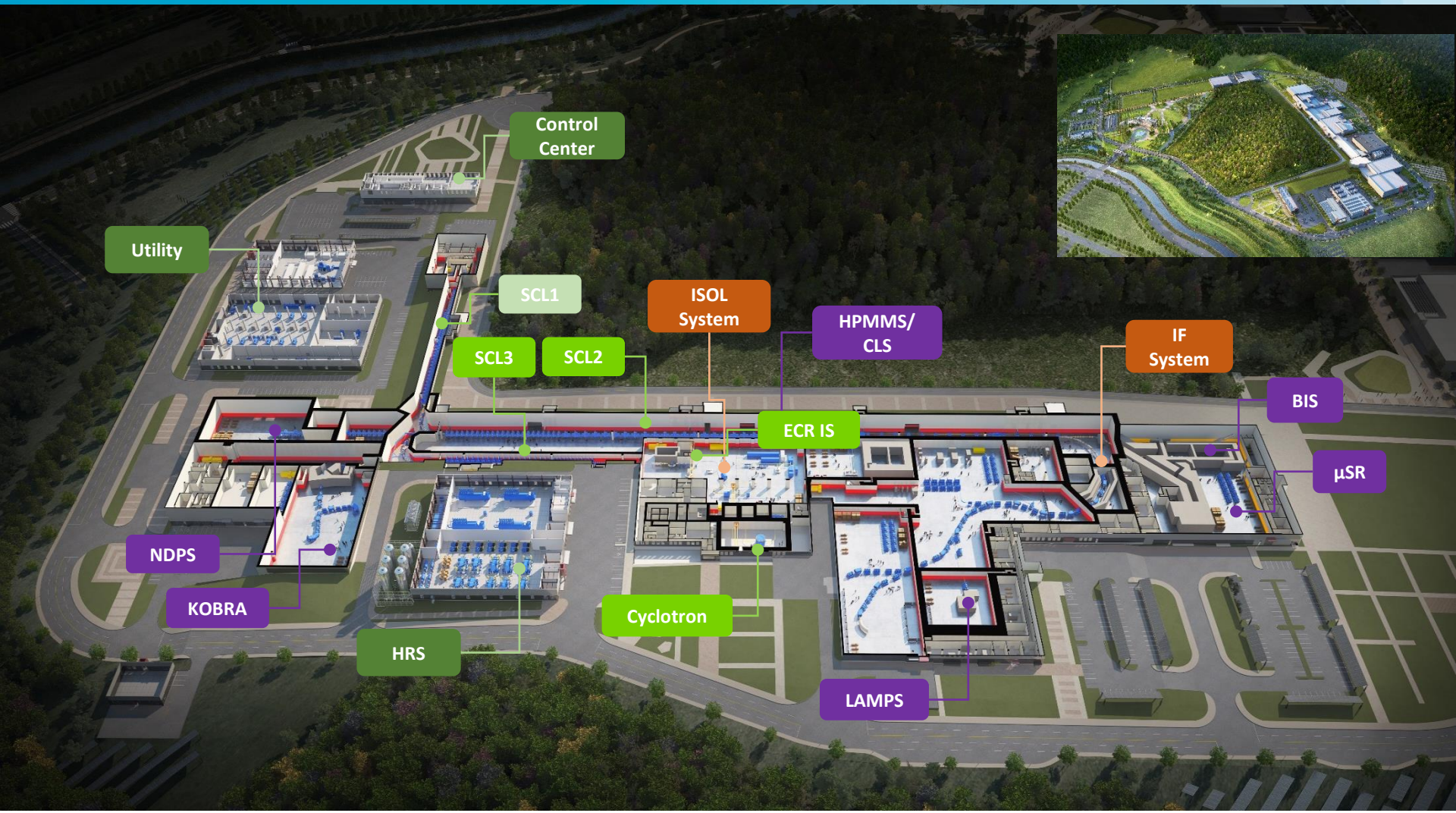


Building Layout

RAON Layout

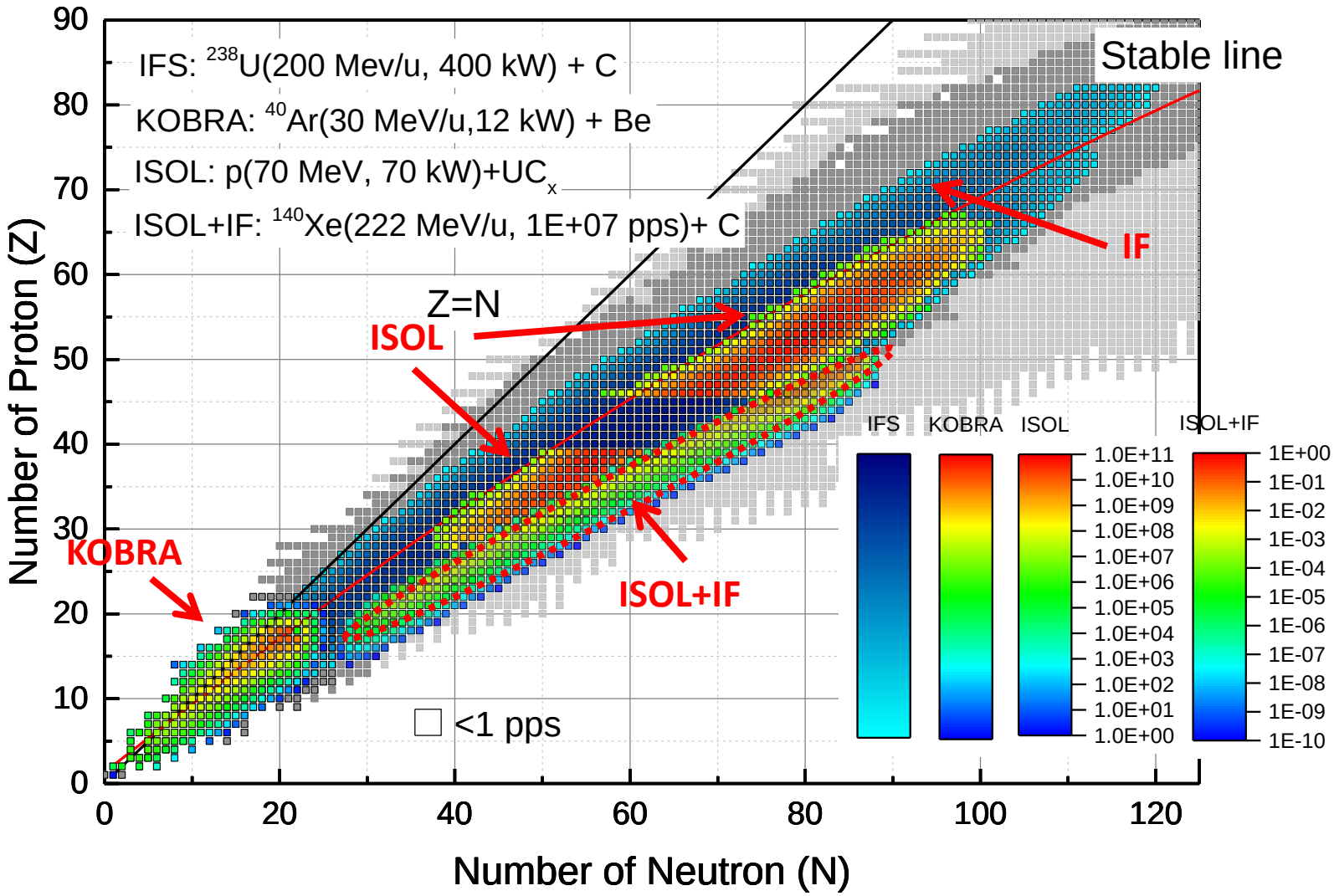
Accelerator System
Conventional Utilities
RI producing System
Experimental System

1. Overview RAON Layout



- SCL1 has been decided to postpone
  : SCL3 is going to be taking a role of SCL1 in the early operation

1. Overview RIBs at RAON



- **RAON will provide access to unexplored regions of the nuclear chart**

1. Overview Project Milestone

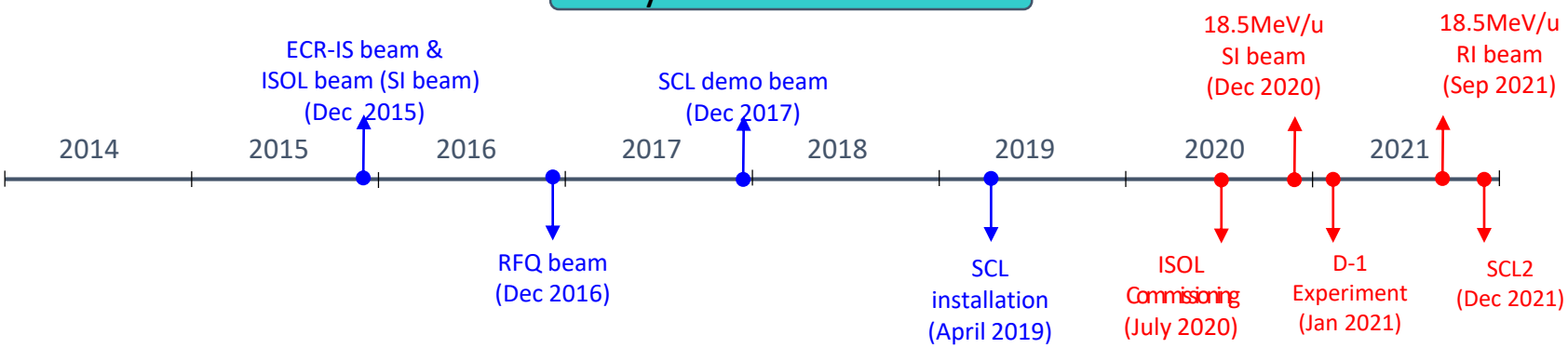
(2018)
SCL3 manufacturing
SCL2 Prototype

(2019)
SCL3 Installation
SCL2 manufacturing

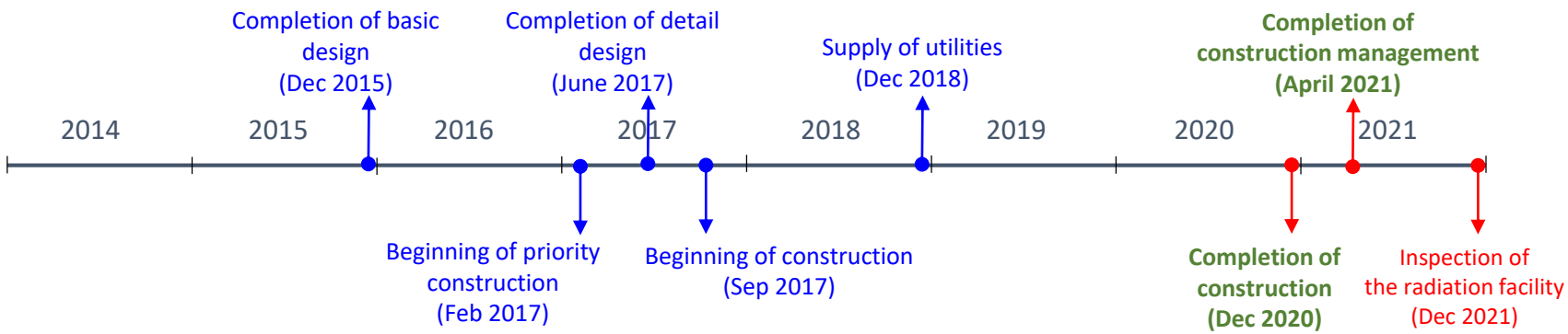
(2020)
SCL3 Beam Commissioning/
Const. Completion

(2021)
KOBRA operation/
Project Completion

System Installation



Facility Construction



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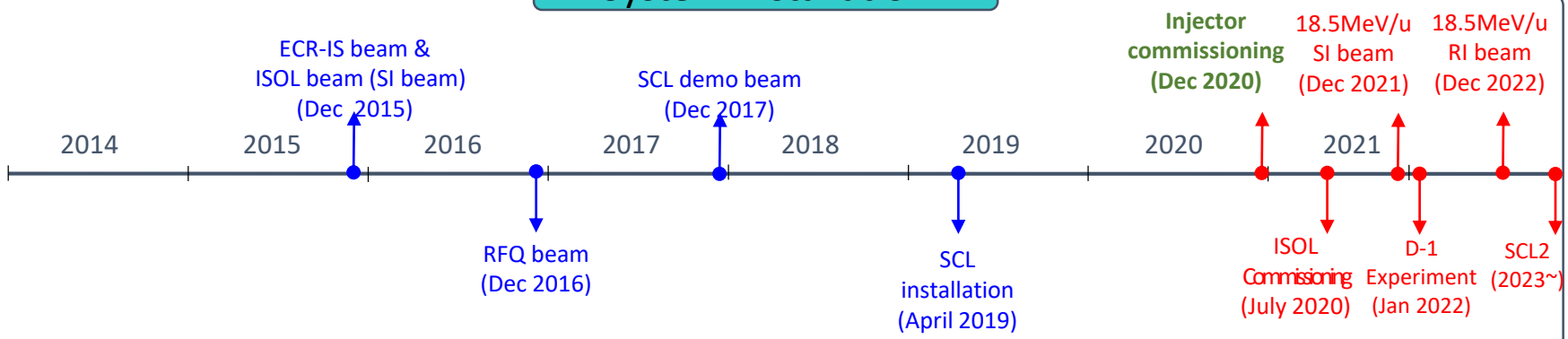
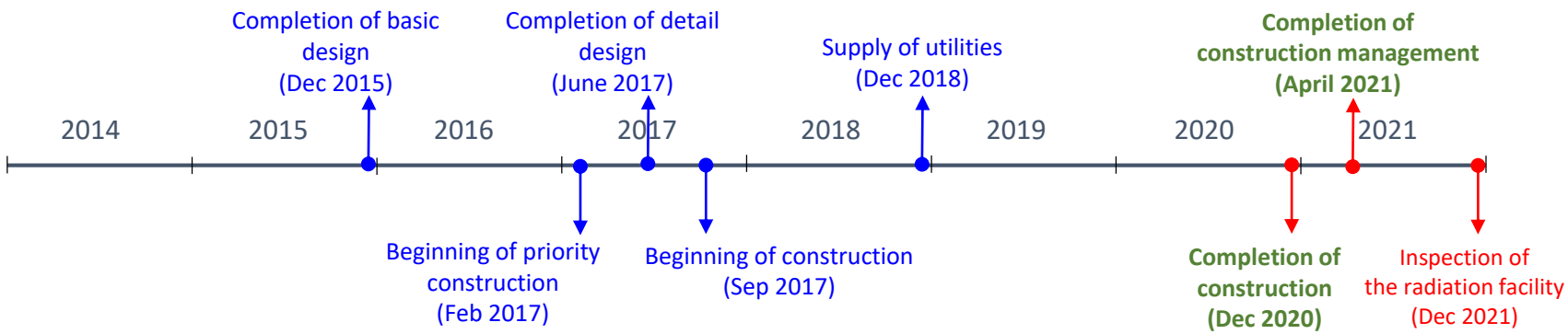


Facility Construction



2. Construction View of Construction Place

● View of Construction Place (`20.10)

<`17.01>

<`18.01>

<`19.01>

<`20.10>

<Assembly Bd.>

<SRF Test Bd.>

<High Energy Exps.>

<Control Center>

<Low Energy Exps.>

<SCL3>

<ISOL>

2. Construction Conventional Facilities

SCL2

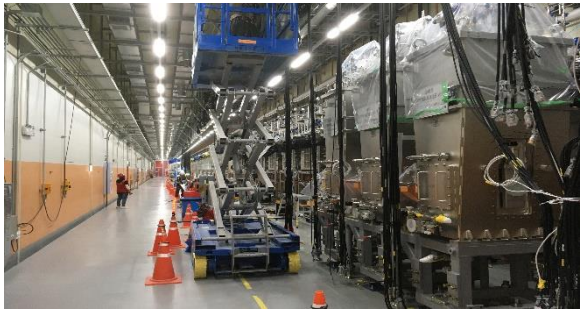
SCL3

Low Energy A/B

ISOL

IF/ High Energy A

High Energy B



SCL3

Bending Section

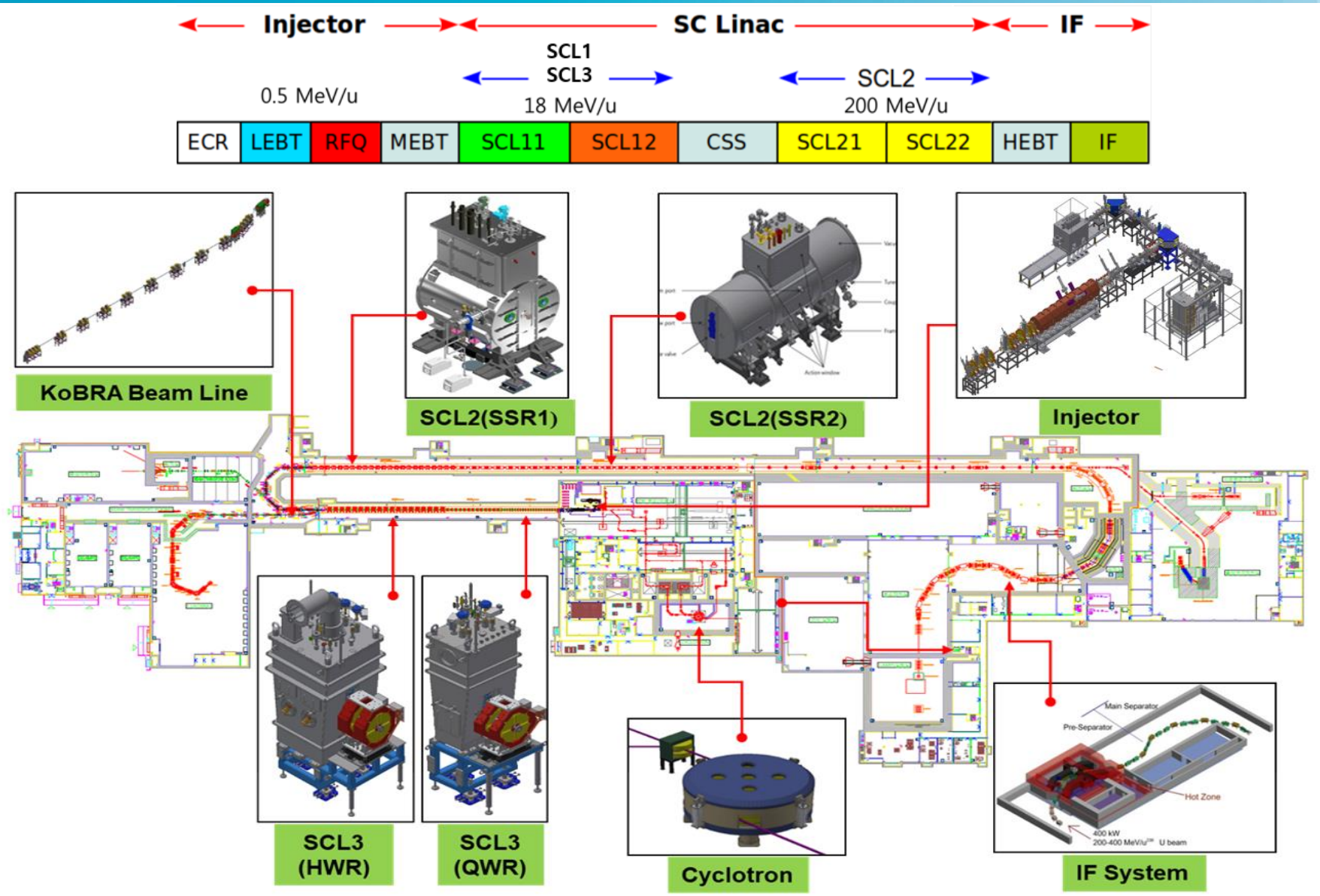
SCL3-gallery

Accelerator Bd.

Part 2.

Accelerator Systems

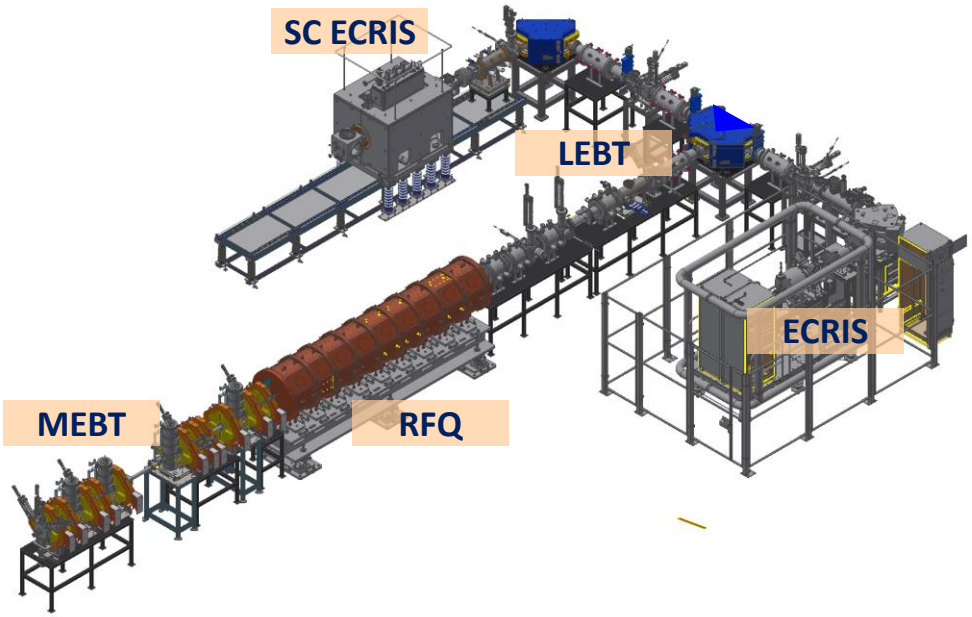
2. Sys. Install. Accelerator System



Accelerator System - Injector

Injector

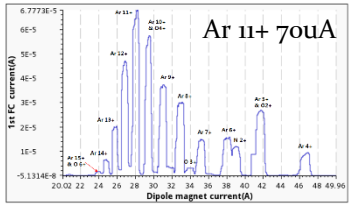
- **Two ECR ion sources on high voltage platforms**
  14.5 GHz ECR ion source
  28 GHz superconducting ECR ion source
- **LEBT (E = 10 keV/u)**
  Beam energy – 10 keV/u, Dual bending magnet
  Chopper & Electrostatic quads, Instrumentation
- **RFQ (E = 500 keV/u)**
  Frequency 81.25 MHz, Transmission Eff. ~98%
  CW RF Power 94 kW (SSPA: 150 kW)
- **MEBT (E = 500 keV/u)**
  Four RF bunchers (SSPA: 20, 15, 4×2 kW)
  Simple quadrupole magnets, Instrumentation



SC ECRIS commissioning

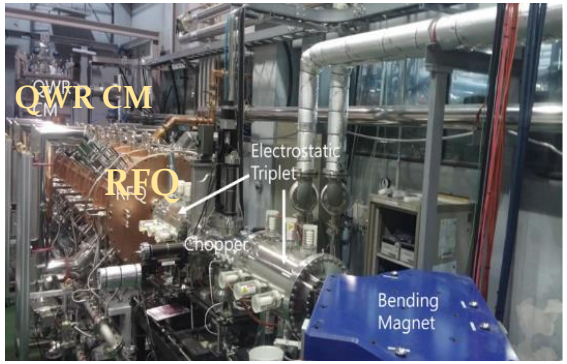
- **Beam experiment for the performance enhancement**
- **Basic metal beam experiment**

Ar beam experiment
Charge distribution

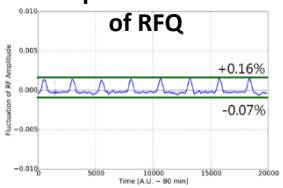


RFQ commissioning

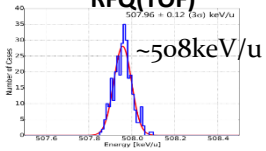
- **RFQ has been conditioned to 40kW, sufficient to accelerate A/q=4.5 beams**



Amplitude control of RFQ

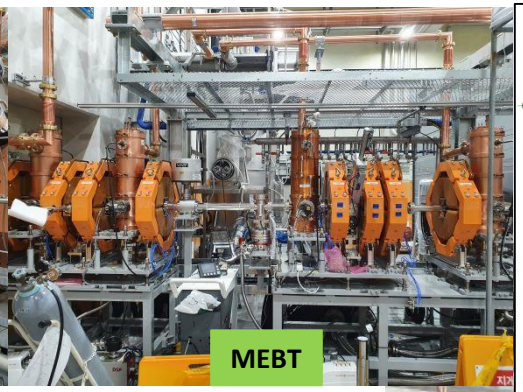


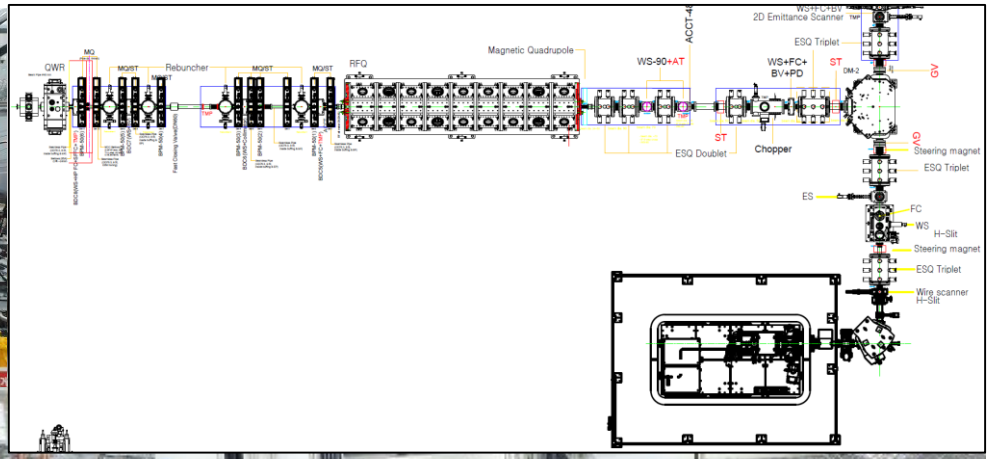
Output Energy of RFQ(TOF)



◈ Injector beam commissioning

- ✓ Period: 2020. 10 ~ 2020. 12
- ✓ Section: 14.5 GHz ECR-IS → LEBT → RFQ → MEBT
- ✓ Reference beam: $^{40}Ar^{9+}$ or O (50 μs pulse beam, ≤1Hz repetition rate)

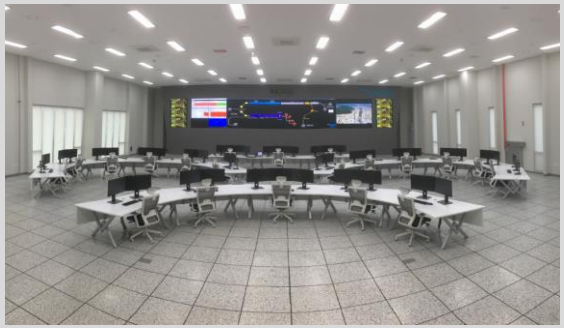




- LEBT
  - Charge selection
  - Emittance measurement → beam distribution regeneration
  - Transverse beam size measurement
  - Orbit correction
  - Pencil beam test, etc.
- RFQ
  - Beam transmission
  - Beam energy measurement, etc.
- MEBT
  - Rebuncher amplitude & phase scan
  - Transverse beam matching
  - Longitudinal beam matching
  - Orbit correction, etc.

2. Sys. Install. Control System

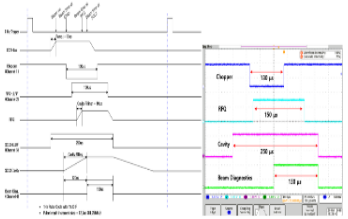
Control Center



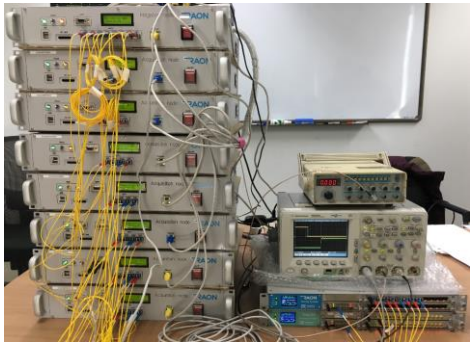
Main Control Room

Data Storage System

Integrated Control System



Timing System

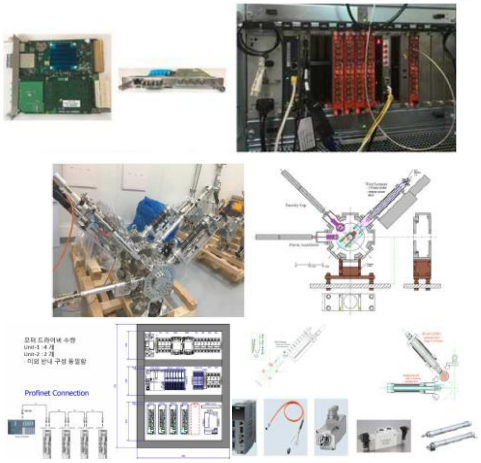


Fast Protection System

Local Control System

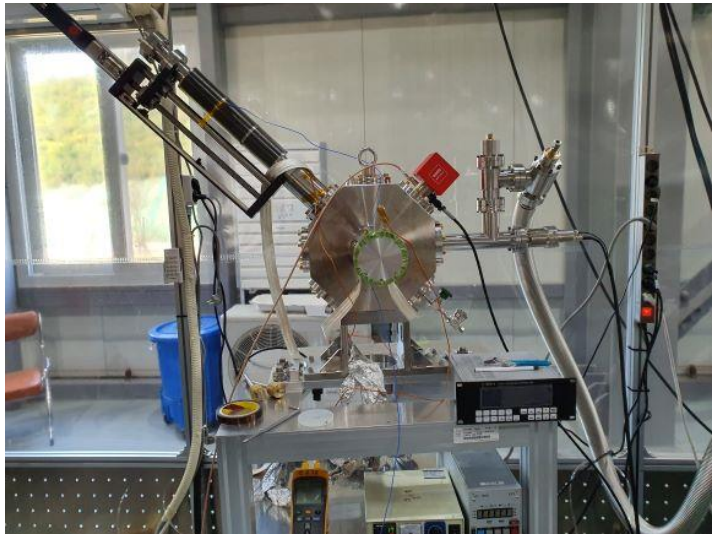
EPICS IOC Controllers

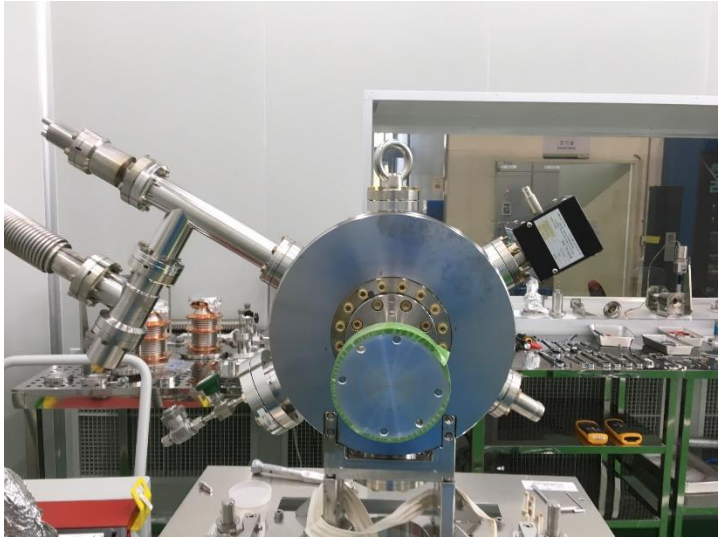
SCL3 Control System(43)



Beam Diagnostics Control System

2. Sys. Install. SCL3 Warm Section – Chamber and magnets





Diagnostic chamber

· 15 sets were fabricated.
  - BPM, BLC, Wire scanner or Faraday cup, NEXTorr, etc
· Assembled in the clean room(Class 10)
· 5 sets were installed in the QWR section

Vacuum chamber

· 39 sets were fabricated.
  - BPM, BLC, NEG, SIP pumps, gauges, etc
· Assembled in the clean room(Class 10)
· 16 sets were installed in the QWR section

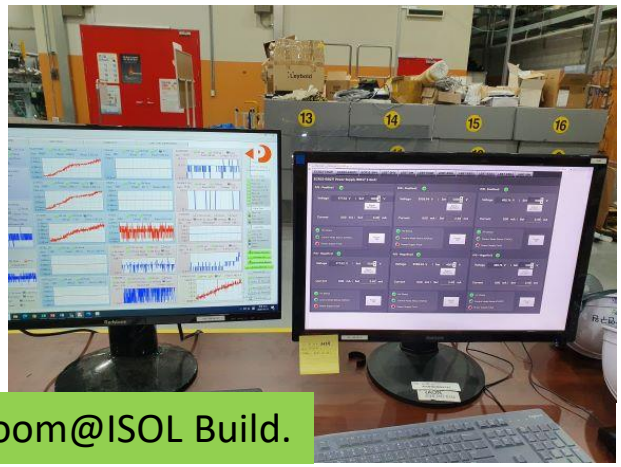
Magnets

· 53 sets were fabricated.
  - Quadruple doublet, Steering
· 21 sets were installed in the QWR

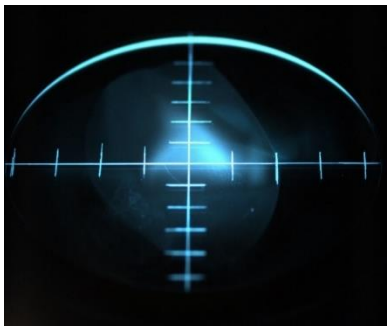
◈ Injector beam commissioning

- ✓ Starts on 10.19, and 2~3 times/week
- ✓ Section: 14.5 GHz ECR-IS(Supernanogan) → LEBT → RFQ → MEBT(10.19~12.30)
- ✓ Achieved more than 95% of transmission with good emittance and energy

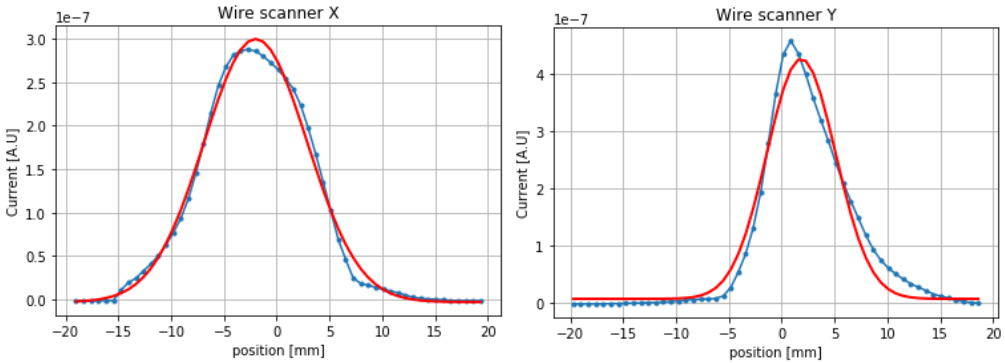
Reference beam: $^{40}Ar^{8+}$, $^{16}O^{6+}$



Local Control Room@ISOL Build.

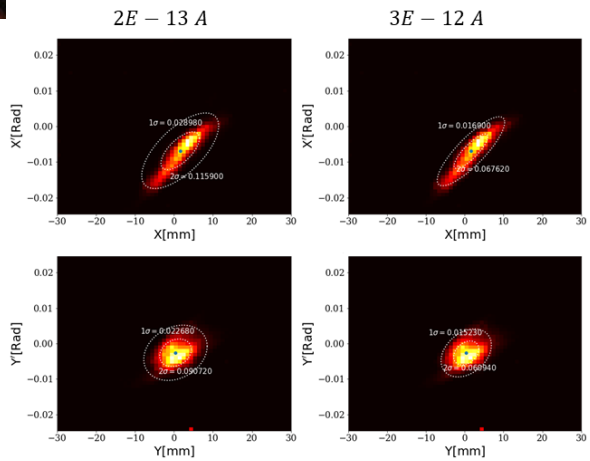


Ar^{8+} 10uA @ Beam Viewer



Beam size [mm] @ Wire Scanner

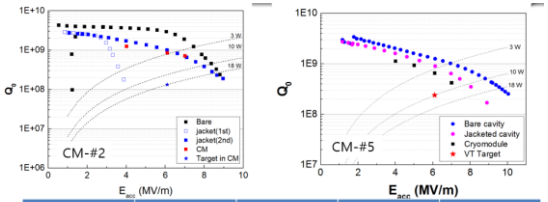
Background 설정



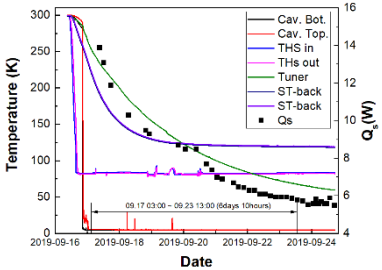
2. Sys. Install. Accelerator System – SCL3

SCL31(QWR)

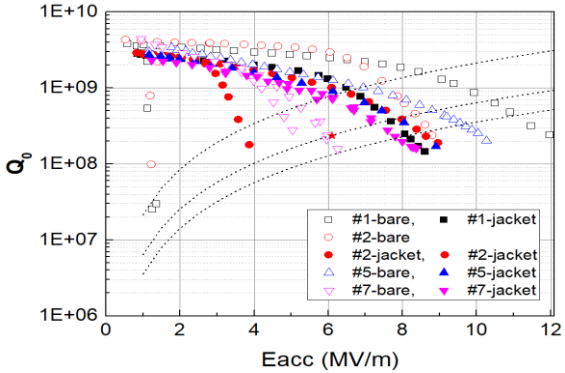
- **Design performance was achieved with prototypes(2017.5)**
- **Oxygen beam was accelerated with injector and one QWR module(2017.10)**
  500 keV/u → ~700 keV/u, Successful long-tem operation of cryomdoule
- **Mass production was contracted with domestic vendor(2017.12)**
  Pre-production cavities and cryomodules passed qualification, mass production is on-going
  Total thermal load <20W@6.1MV/m, 4.2 K



	Total (W)	Static (W)	Dynamic (W)	Q_0 of cavity
QWR-CM-#1	11.7	7.7	4.0	6.0e+8
QWR-CM-#2	10.8	8.0	2.8	8.5e+8
QWR-CM-#3	13.1	8.4	4.7	5.1e+8
QWR-CM-#5	14.4	9.5	3.5	6.6e+8



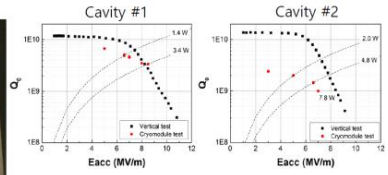
Static thermal load: 5.8 W
(Target: max. 7.5 W)



VT target: 2.4e+8@6.1MV/m

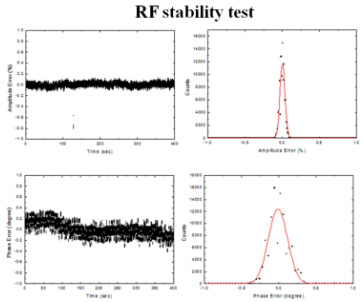
SCL32(HWR)

- **Design performance was achieved with prototypes(2017.10)**
  Thermal load <14.1W@6.6MV/m, 2.1 K (HWR type A)
- **Mass production was contracted with domestic vendor(2018.5)**



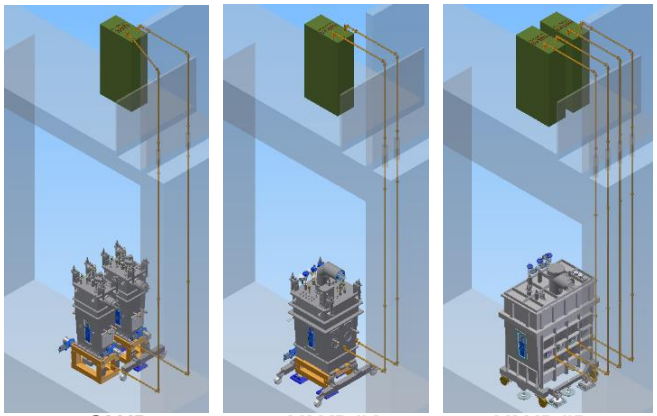
Static thermal load	Dynamic thermal load	Total thermal load
6.6 W	1.4 W (cavity#1)	12.8 W
	4.8 W (cavity#2)	

Target total thermal load @ 2.92 MV, 2K: <14.1 W



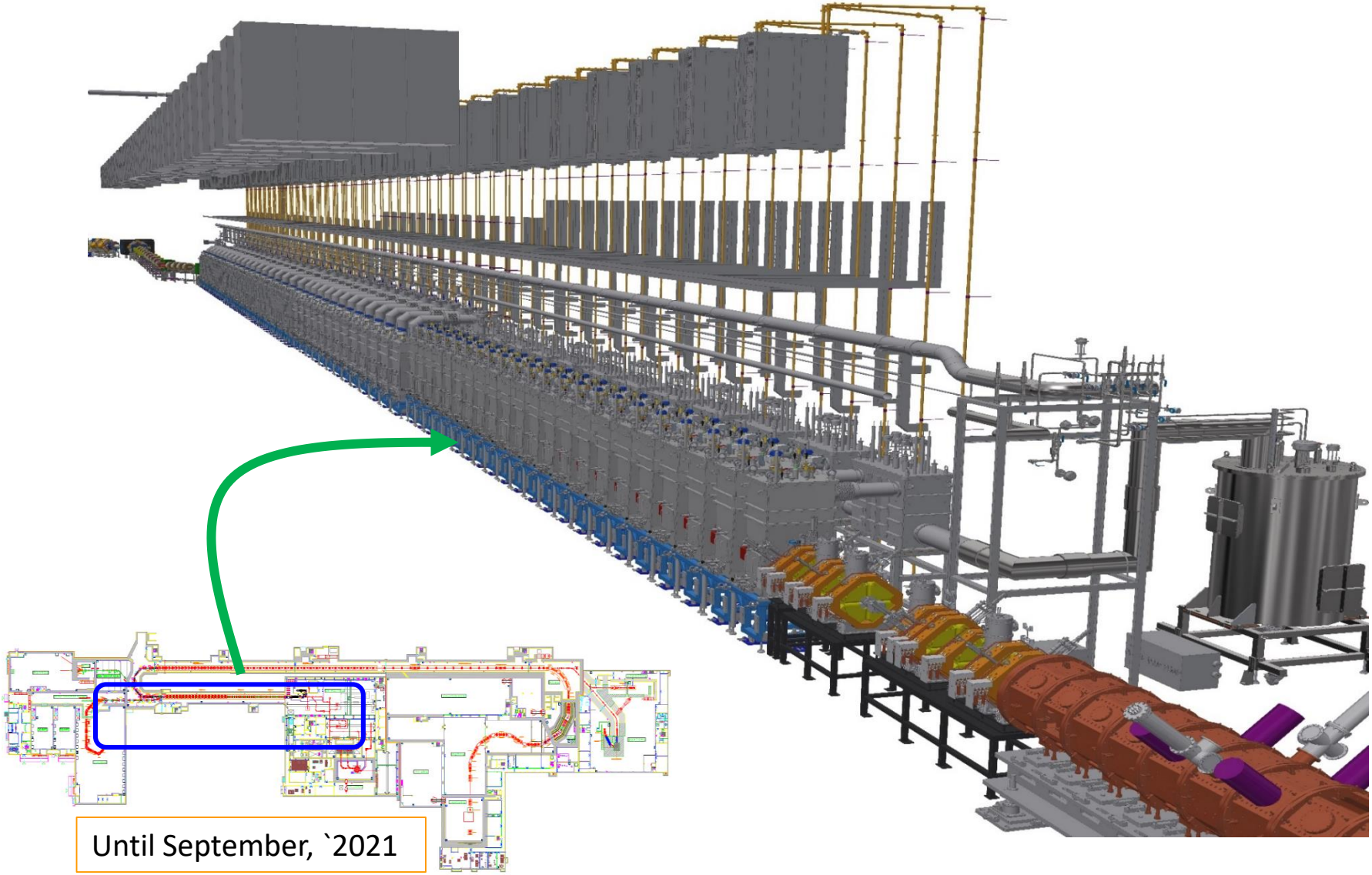
RF System

- **SSPA (4kW) : 2018.07~2020.05**
  Pre-production performance test(2019.11)
- **HPRF transmission line (1-5/8")**
  Installation vertical parts (2019.10)
- **LLRF control system (2019.07~2020.06)**
- **RF reference line (81.25MHz) : ~2019.12**



QWR HWR#A HWR#B

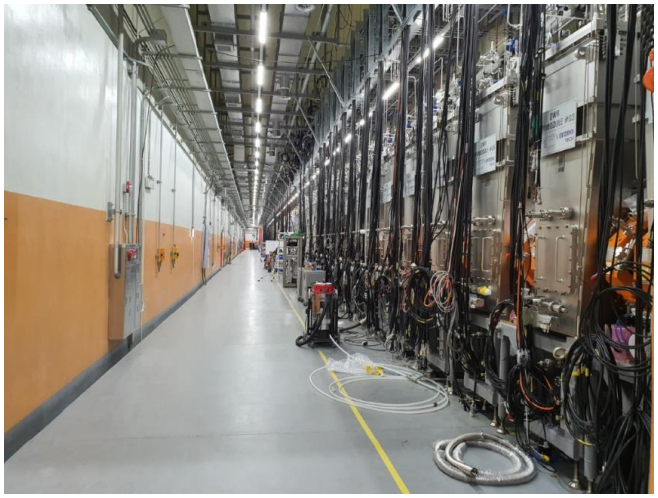
2. Sys. Install. Accelerator System



2. Sys. Install. SCL Tunnel and Gallery for QWR

Cryogenic Valve Boxes

Combination of Cold & Warm Section



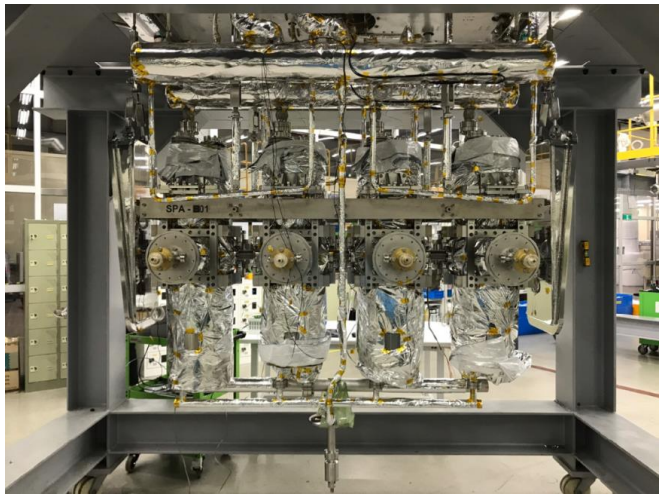
QWR Installation

CM Cryogenic Control Rack and HPRF

2. Sys. Install. Accelerator System – HWR Assembly

Cavity String

Particle count inside cavity “0”



With cryogenic piping

Top loading to cryostat

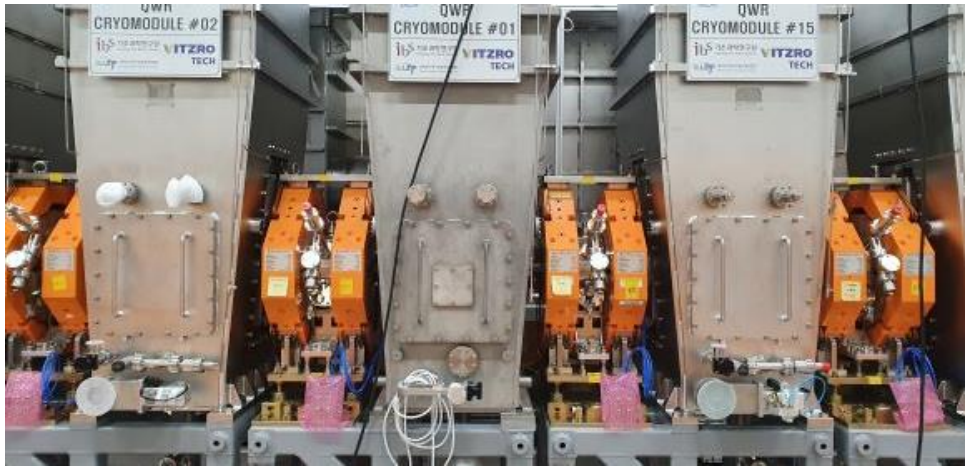
Vacuum leak rate

HWR B type

Installation Procedure

(Cryomodule + Warm section) + (Cryomodule + Warm section)

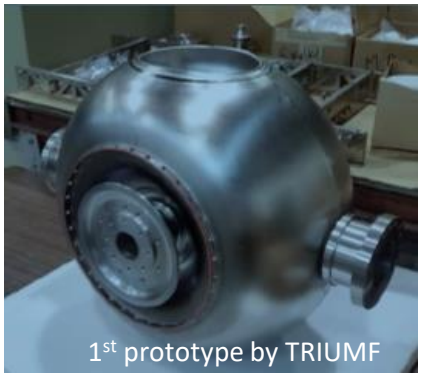
- Cryomodule & Warm section is clean assembled in the clean booth@tunnel
- Total Particle counts(size=0.5um above/10 mins) were less than 30 counts

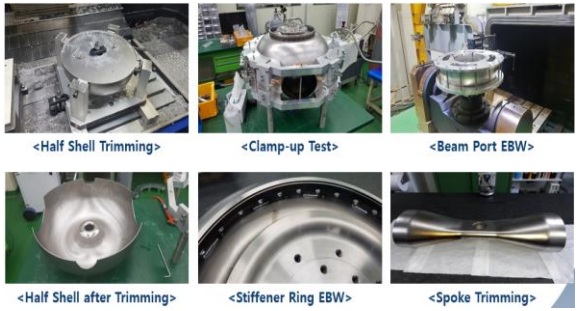


2. Sys. Install. Accelerator System – SCL2

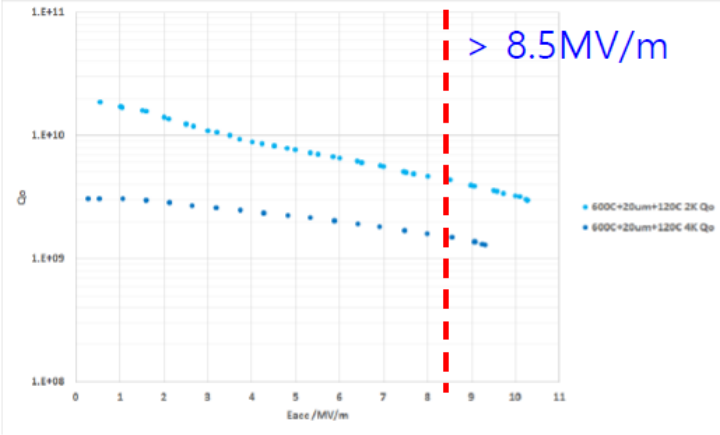
SCL21(SSR1)

- **1st prototype was performed by TRIUMF(2019.6)**
  Balloon type(less multipacting, better mechanical characteristics)
  Accelerating gradient over 8.7MV/m, Multipacting below 2MV/m
- **2nd prototype with domestic vendor is on-going**


1st prototype by TRIUMF

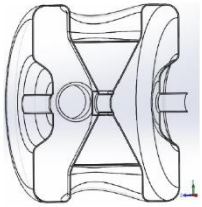


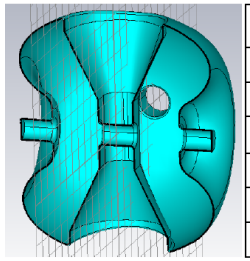
2nd prototype by domestic vendor



SCL22(SSR2)

- **1st prototype of cavity is on-going**
  Designed by RISP, fabricated by domestic vendor
  Balloon type, Deep drawing (depth ~280mm)
- **2nd prototype with IHEP is on-going**
  Cylindrical type



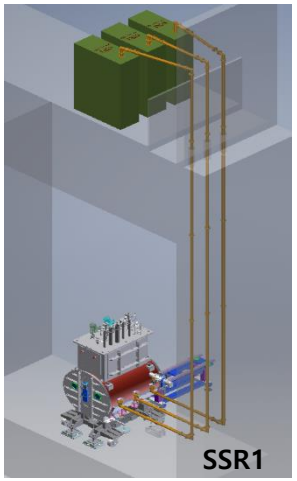


Parameters	Value
β	0.51
$f\ [MHz]$	325
$L_{eff}(=\beta_o\lambda)[mm]$	~470
Beam tube diameter [mm]	50
$E_{acc}\ [MV/m]$	8.7
$V_{acc}\ [MV]$	4.1

RISP design(balloon type)

RF System

- **SSPA (8, 20 kW): 2020.01~2021.06**
  Requirement for RF power rating
- **HPRF transmission line**
  3-1/8", 4-1/16" rigid coaxial
- **LLRF control system (2020.04~2021.06)**
- **RF reference line (81.25MHz) : ~2020.12**


SSR1

SSPA Prototype

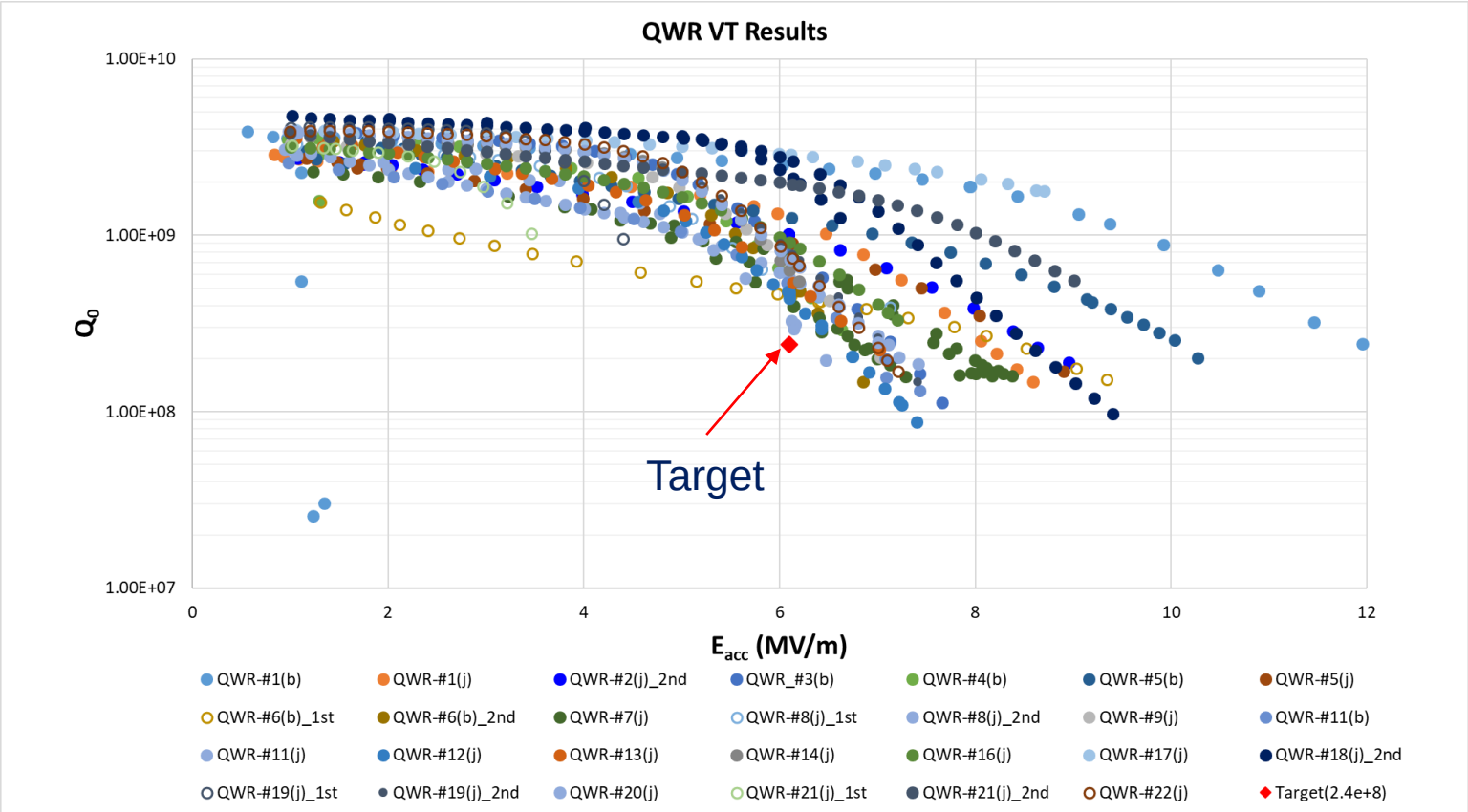
Accelerator System – Test facility

On-site (Shin-Dong) test facility

- 1 onsite - 3 VT pits and 3 cavities per pit, 3 HT bunkers
- 1 offsite (15 Km from site) - 2 VT pits and 2 cavities per pit
- Cover all RAON cavities - QWR (82.125 MHz), HWR (162.5 MHz) and SSR1 & 2 (325 MHz)

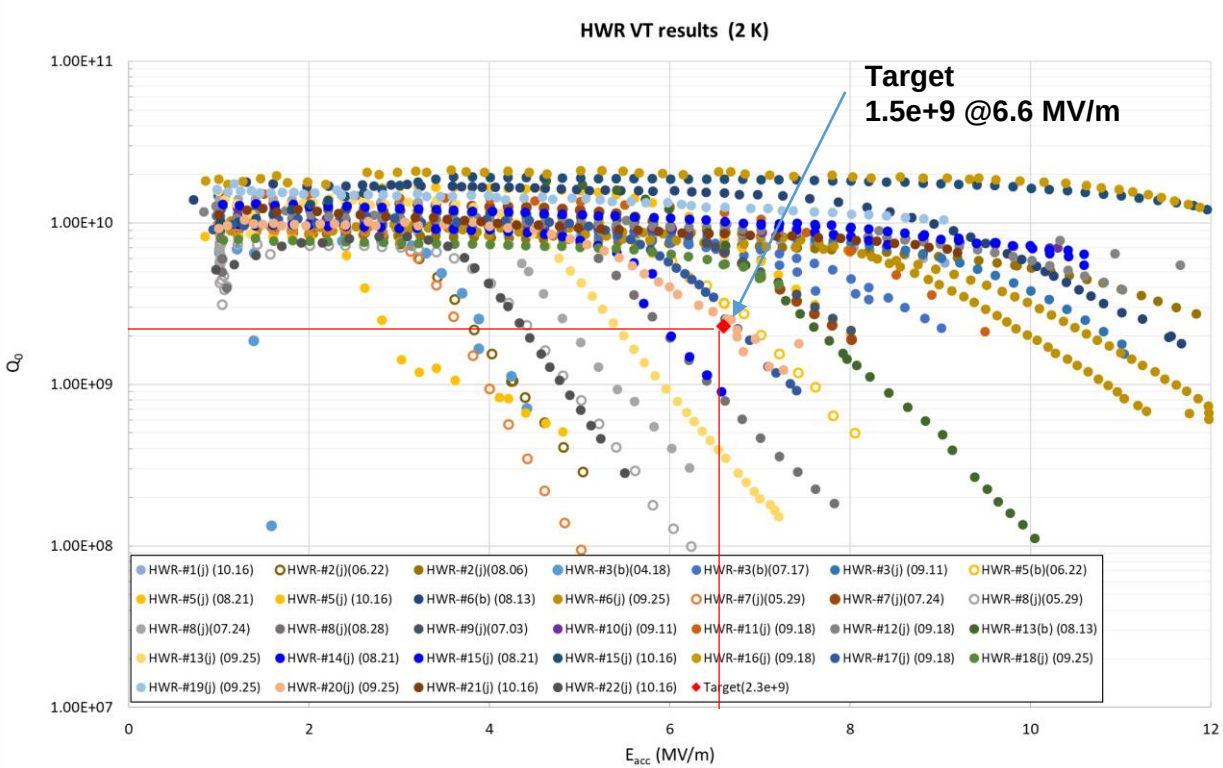
2. Sys. Install. Accelerator System – QWR test results

Frequency (MHz)	Optimum β	Eacc (MV/m)	Vacc (MV)	Q0	# of cavity	# of module	Op. temp (K)
81.25	0.047	6.1	1.06	1.3e+8	22	22	4.5



Accelerator System – HWR test results

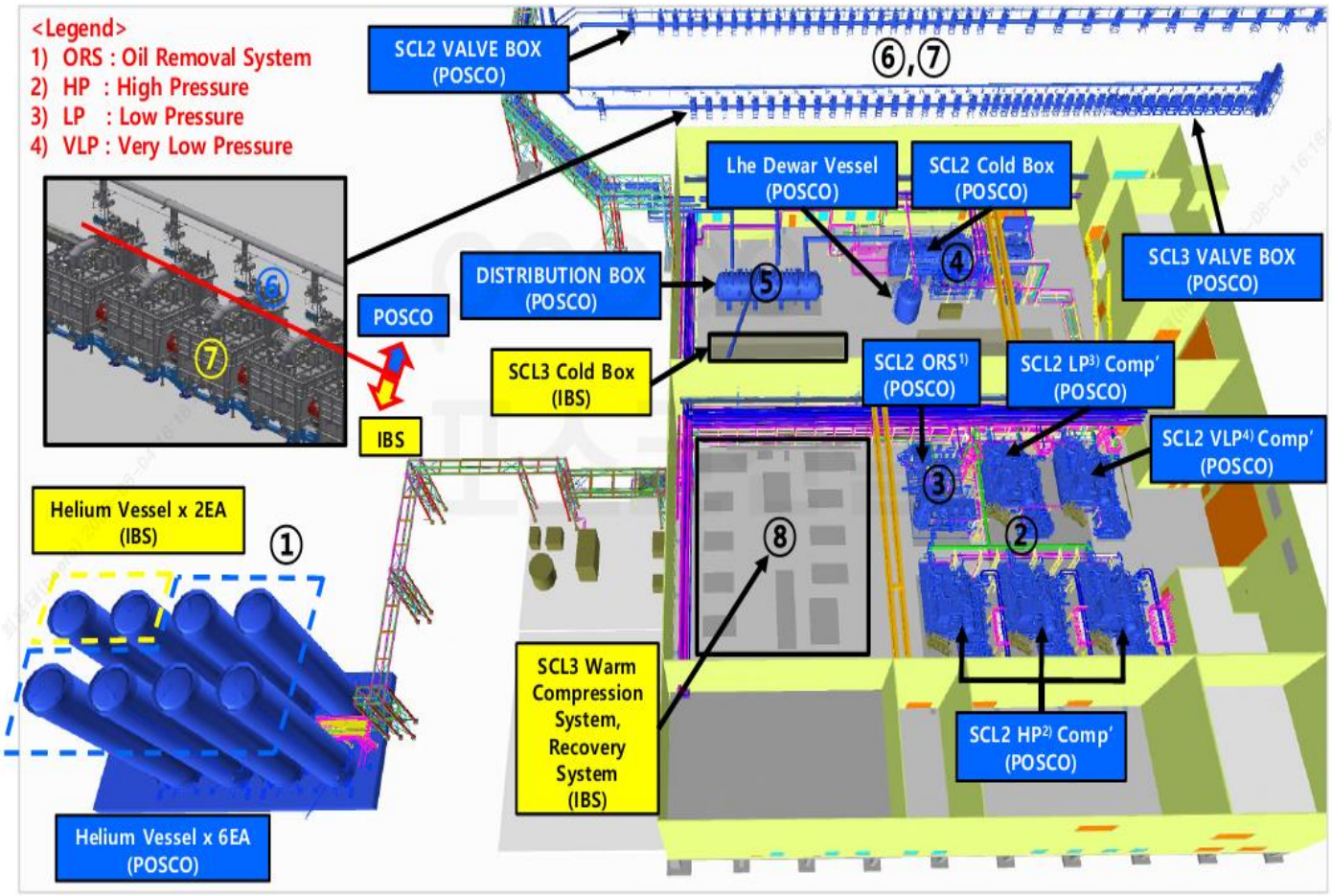
Frequency (MHz)	Optimum β	Eacc (MV/m)	Vacc (MV)	Q0	# of cavity	# of module	Op. temp (K)
162.5	0.12	6.6	1.46	1.5e+9	106	A/B = 14/19	2.05
# of fabrication (@10/03/2021)					80	A : 13, B : 2	



The cavities below the target include bare cavities as R&D phase and all were re-processed after 1st VT.

Accelerator System – Cryo-plant

- Layout of the cryogenic building



2. Sys. Install. Accelerator System – Cryo-plant

- SCL3 cryoplant (4.2 kW @ 4.5 K)

Compressors and Oil Removal System (WCS)

Cold Box System (CB)

- Installation progress : 100 %
- Pre-commissioning (Ready for start-up/load test) : Nov. (WCS) ~ Mar. (CB). 2021
- Commissioning : May. 2021
- Cool-down of SCL3 : From Sep. 2021
- Commissioning of SCL3 cryogenic system and performance tests : @ July 2021

Accelerator System – Cryo-plant

- SCL2 cryoplant (13.5 kW @ 4.5 K)

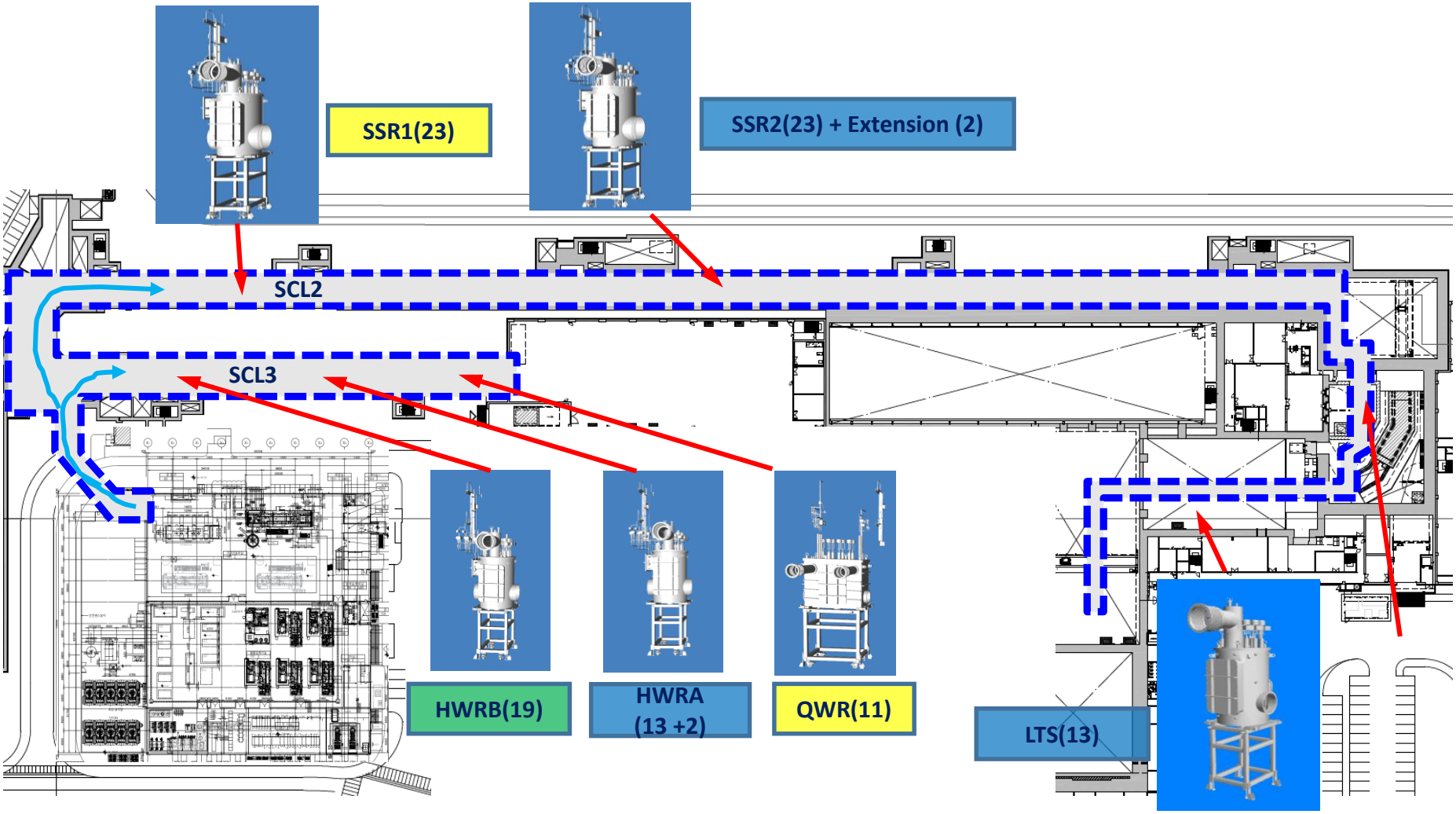
Compressors and Oil Removal System (WCS)

Cold Box (CB)
(Left warm side, right – cold side)

- Cold box integration @ ALAT, FAT of CB : Nov. 2020
- Warm Compression Station – being installed @ RISP (progress : 98 %)
- Mechanical completion of WCS : Nov. 2020
- Cold box delivery : Feb. 2021
- Commissioning : April 2021~

Current Statue of Cryogenic Systems

- Layout of cryogenic distribution system @ SCL3 and SCL2



- Cryogenic Distribution System
  - Cryogenic performance tests of QWR/HWR Valve boxes (VBx) for each type
  - 11 QWR VBx are installed and assembled (VBx-VBx, VBx-CM).
  - 33 HWR VBx were delivered and being installed @ SCL3.
  - Cryogenic Transfer Lines are being installed from building to SCL3

  (Progress of installation - outside : 98 %, SCL3 : 100 %).
  - Pre-commissioning of SCL3 : ~ May 2021
  - SSR1 VBx : 23 ea, SSR2 VBx : 25 ea being installed.

QWR VBx-CM

HWR VBs @ tunnel

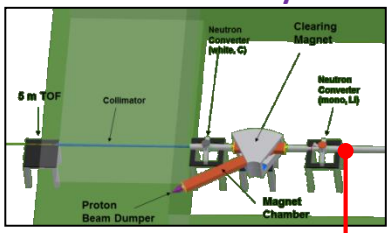
SSR 1 VBx @ tunnel

Part 3.

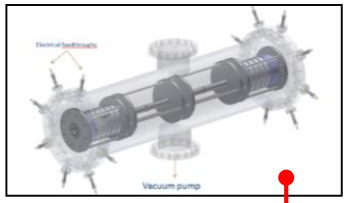
RI & Experimental Systems

3. Sys. Install. RI & Experimental System

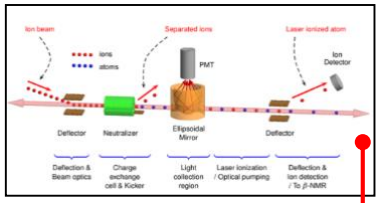
Neutron Facility



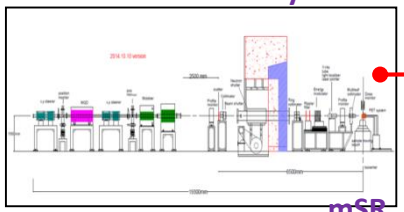
HPMMS



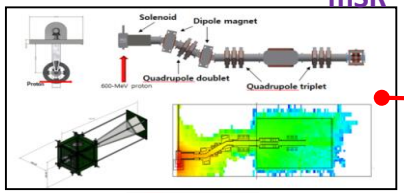
CLS



Bio-medical facility

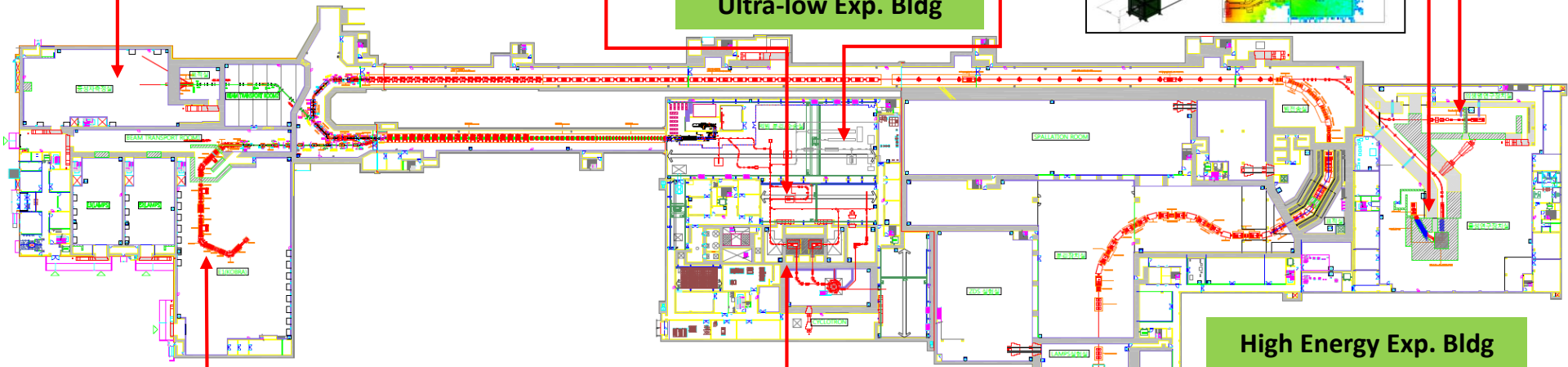


mSR



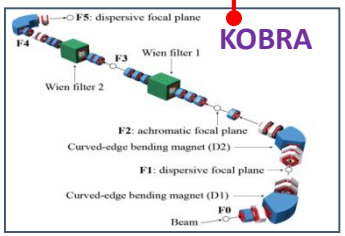
Low Energy Exp. Bldg

Ultra-low Exp. Bldg

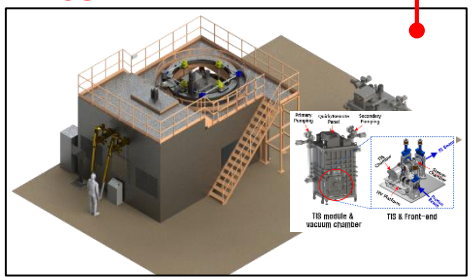


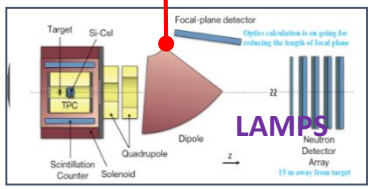
High Energy Exp. Bldg

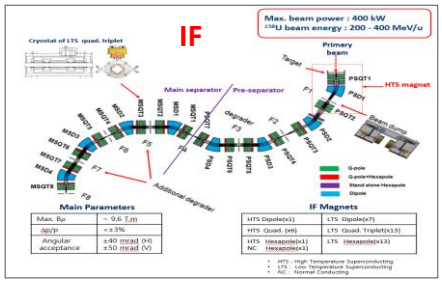
KOBRA



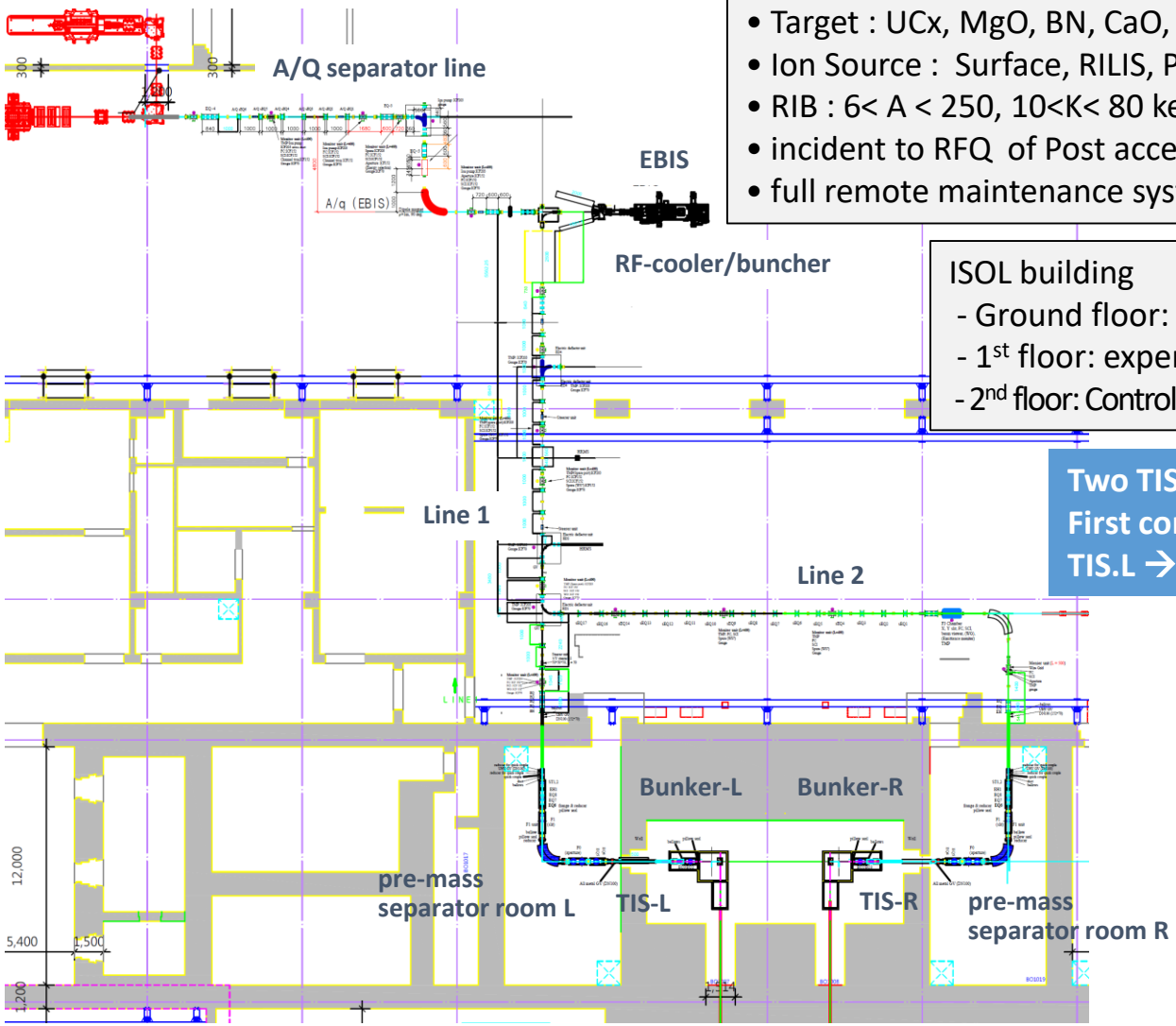
ISOL







3. Sys. Install. ISOL System Layout

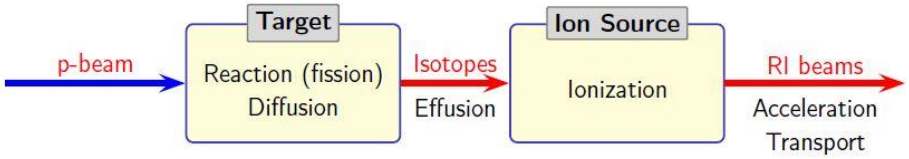


- Driver beam : proton 35<K<70 MeV, up to 70 kW
- Target : UCx, MgO, BN, CaO, BeO, SiC, etc
- Ion Source : Surface, RILIS, Plasma
- RIB : 6< A < 250, 10<K< 80 keV, 10^8 pps(Sn), >90% purity @Exp.
- incident to RFQ of Post accelerator 10 keV/u
- full remote maintenance system with TIS modularization

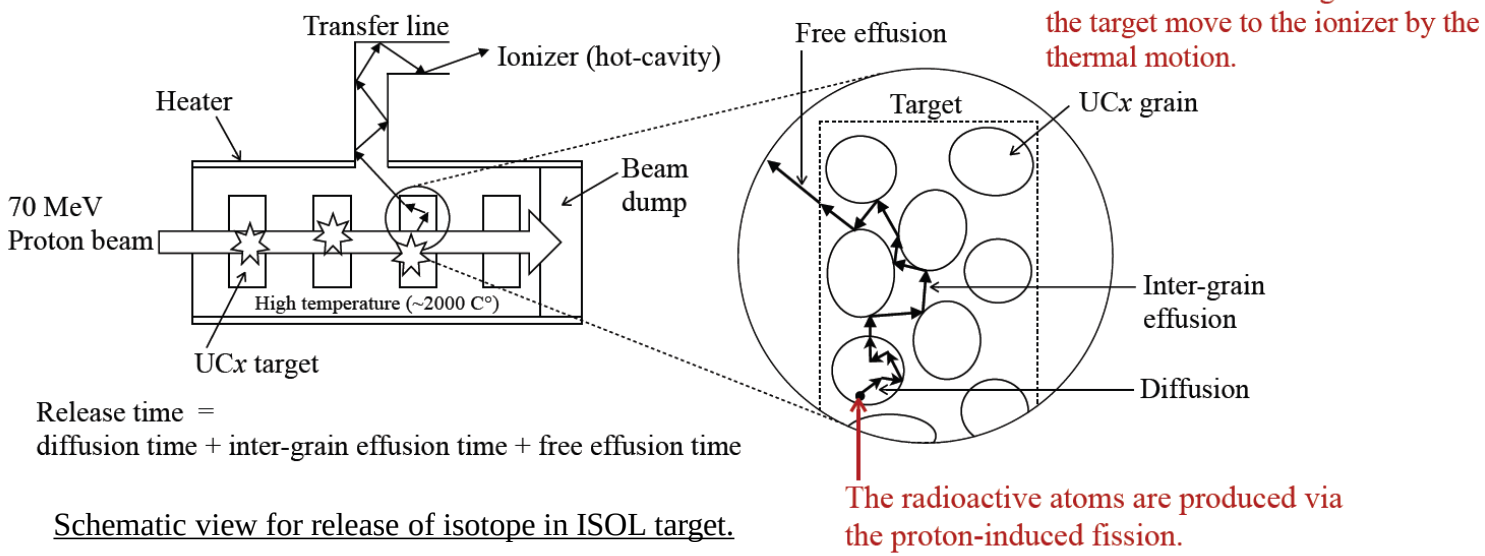
ISOL building
- Ground floor: TIS, beamline, experimental hall
- 1st floor: experimental hall, Laboratory, utilities
- 2nd floor: Control room, Analysis room

Two TIS bunker,
First concentrating on the shortest line
TIS.L → Pre.sep → EBIS → A/q → Post.acc

ISOL Target Concept



$Y_{\text{Target}} = \Phi_p \times \sigma \times N_T \times \varepsilon_R$ $\varepsilon_{\text{ionization}}$



Release time =
diffusion time + inter-grain effusion time + free effusion time

Schematic view for release of isotope in ISOL target.

Requirements of the ISOL target

- Fissile material : for production of n-rich rare isotope
- High temperature operation under vacuum condition - Low vapor pressure / Efficient release (short diffusion and effusion times)
- High thermal conductivity and emissivity - Low thermal stress and efficient radiation cooling
- Small grain size(particle size) and high porosity - For high release efficiency

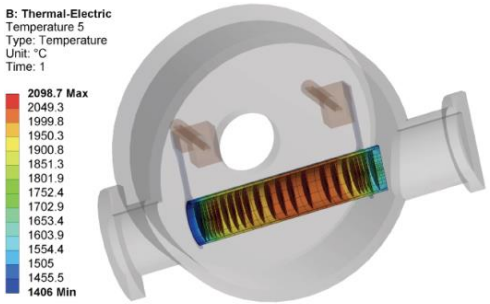
➔ the best candidate is Uranium carbide dispersed in an excess carbon

10 kW UCx Target System Design

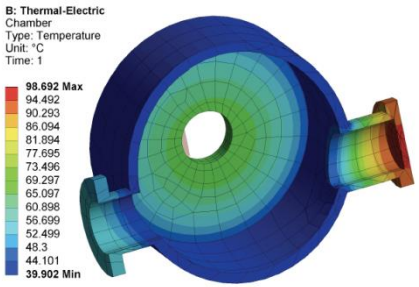
Proton Beam	
Energy	70 MeV
Power	10 kW
Beam size	45 mm

Target	
Material	UCx
Density	2.5 g/cm^3
U weight	101 g
# of disk	19
Disk thickness	1.3 mm
Disk diameter	50 mm
Total length	22 cm

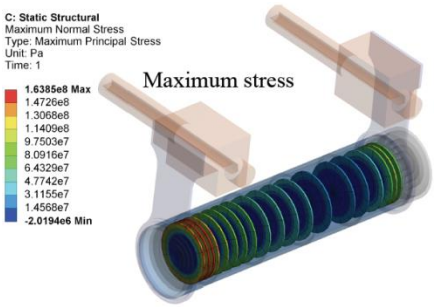
Temperature of the target



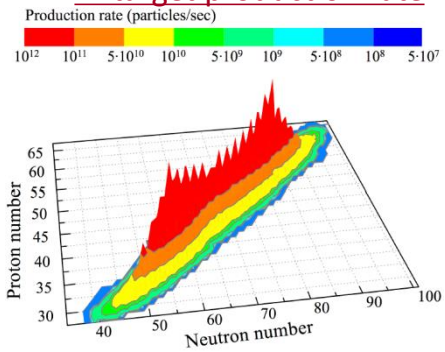
Temperature of the chamber



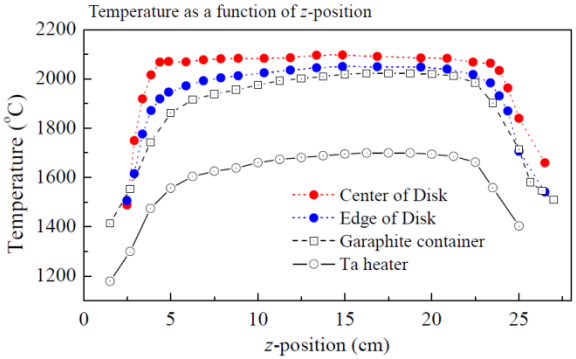
Thermal stress of the target



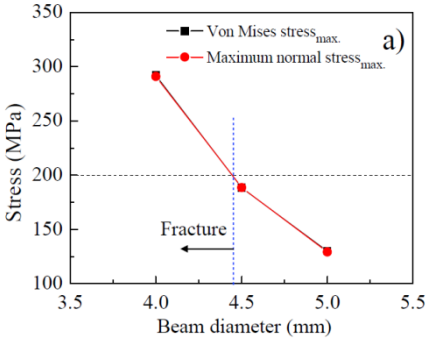
In-target production rate



Temperature distribution



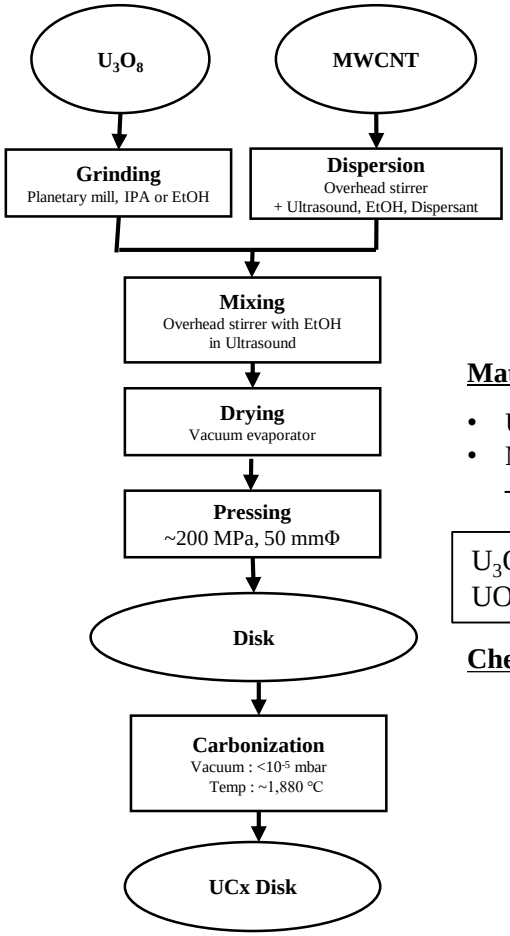
Maximum thermal stress



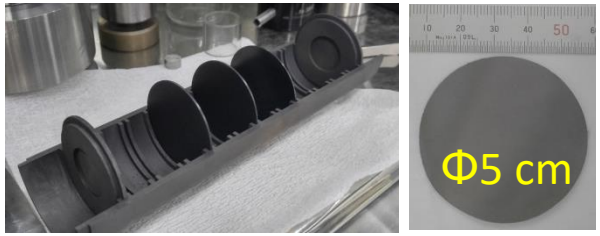
Expected In-target fission rate
= 1.6×10^{13}/s

※ benchmarking SPES 8 kW target system

3. Sys. Install. UCx Target fabrication



Procedure of UCx fabrication based on Nano-UCx (CERN-ISOLDE)



UCx target using MWCNTs disk before (L) and after (R) thermal treatment (~1650 ℃).

원소	라인 유형	무게 %	무게 % 시그마	원자 %
U	M 시리즈	79.97	1.94	17.69
C	K 시리즈	15.00	1.02	65.75
O	K 시리즈	5.03	1.09	16.56
총		100.00		100.00

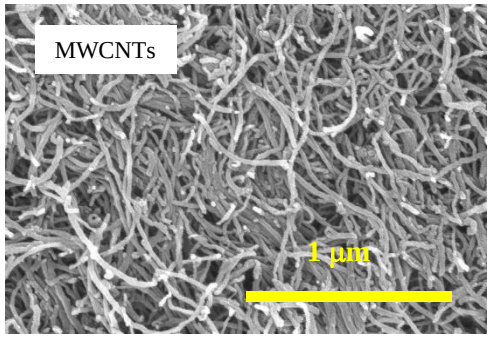
Result of component analysis

Materials

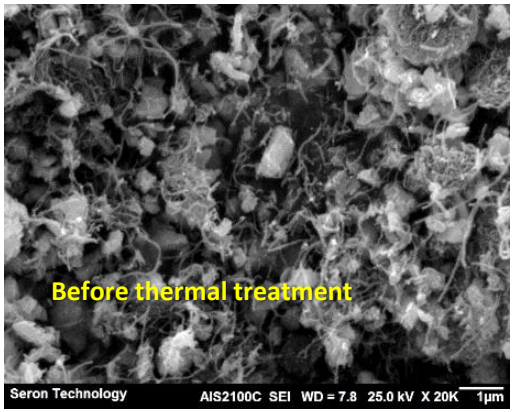
- U_3O_8 (depleted ~0.3% ^{235}U)
- MWCNTs
  - 95%. 0.015 x 2 μm, Avention

$$U_3O_8 + C \rightarrow 3UO_2 + CO_2\uparrow$$
$$UO_2 + 5C \rightarrow xUC_2 + (1-x)UC + (2-x)C + (1+x)CO\uparrow$$

Chemical reaction

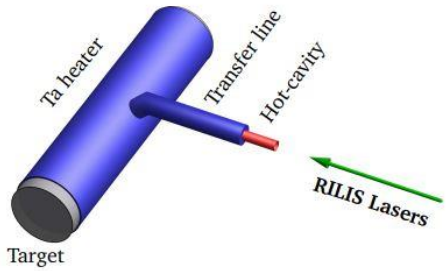


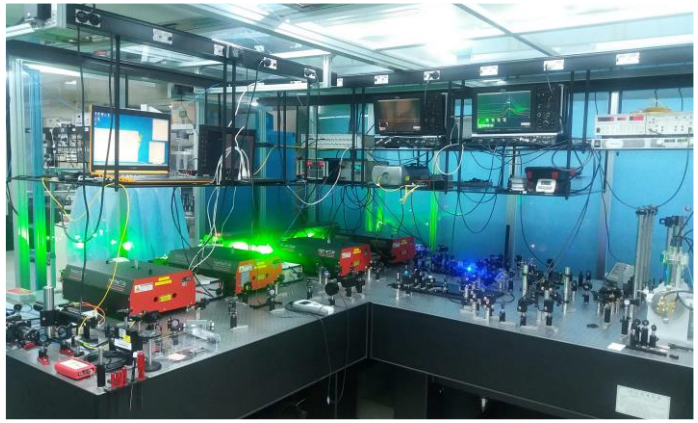
MWCNTs raw powder

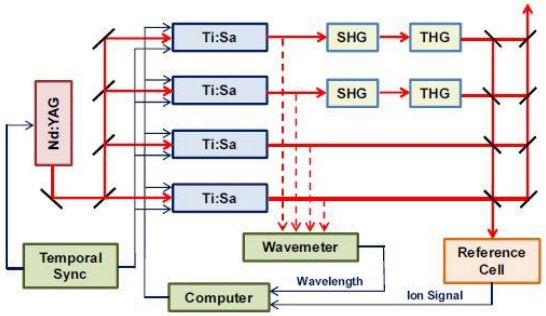


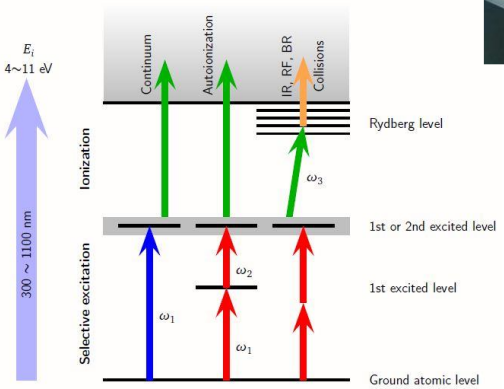
Manufactured @KNF

Resonant ionization laser ion source (RILIS)









Laser System installed at RISP

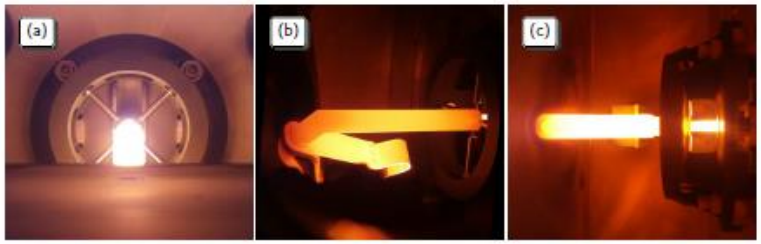
Laser	Ti:Sa Laser (4 ea)	• Radiant Dyes Laser (Germany) • 5 W (20 W pump), 40 ns • 690 ~ 950 nm (fundamental)
	Nd:YAG (1 ea)	• Lee Laser (USA) • 100 W, 10 kHz, 100 ns • 532 nm

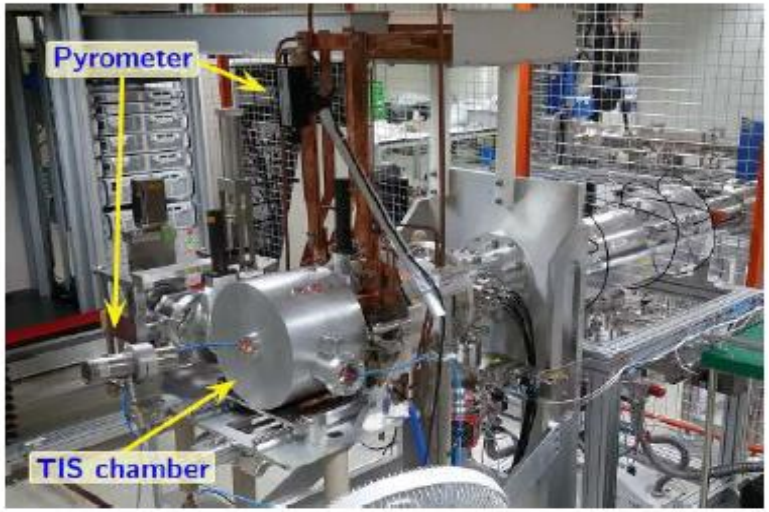
LASER ion source for on-line application

- Resonant ionization laser ion source (RILIS) is the most useful method to obtain pure ion beam, since atoms can be selectively ionized by laser lights
- Each element has its unique energy level structure
- If lasers are tuned to the atomic transition line, specific element can be ionized selectively
- In the last step of excitation, transition to the ionization continuum or to an autoionizing state can be used

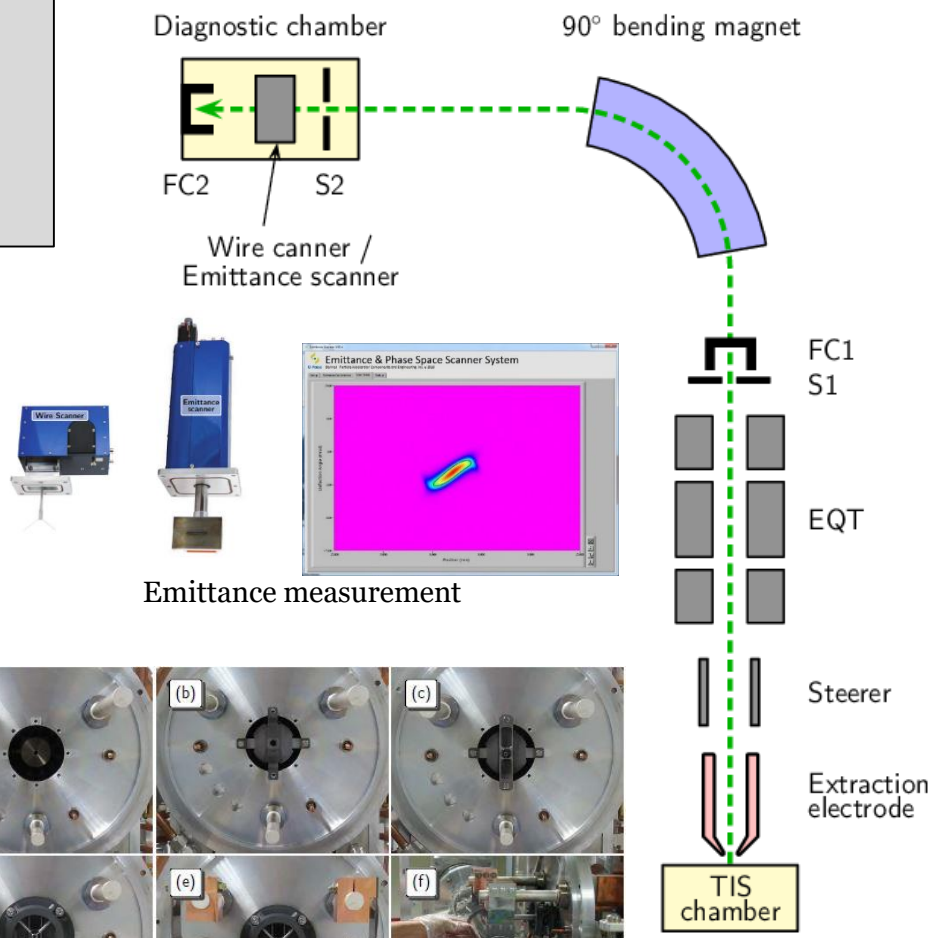
3. Sys. Install. Off-line Test facility

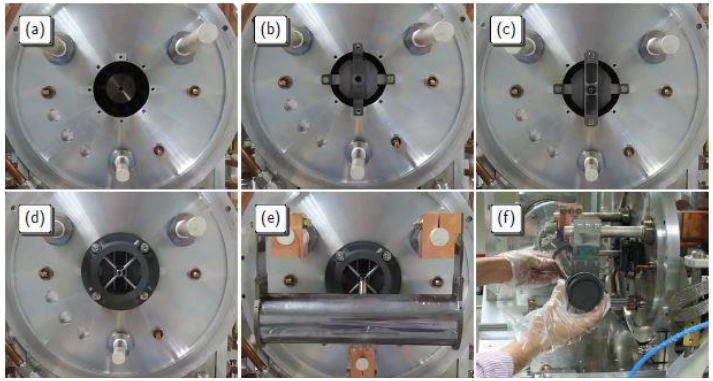
- **Ion beam extraction experiment**
  - SIS: Cs and Rb ion beam extraction
  - RILIS: Sn ion beam extraction
  - Ionization efficiency measurement
  - Mass resolving power M/ΔM > 400
  - Control system (EPICS based)





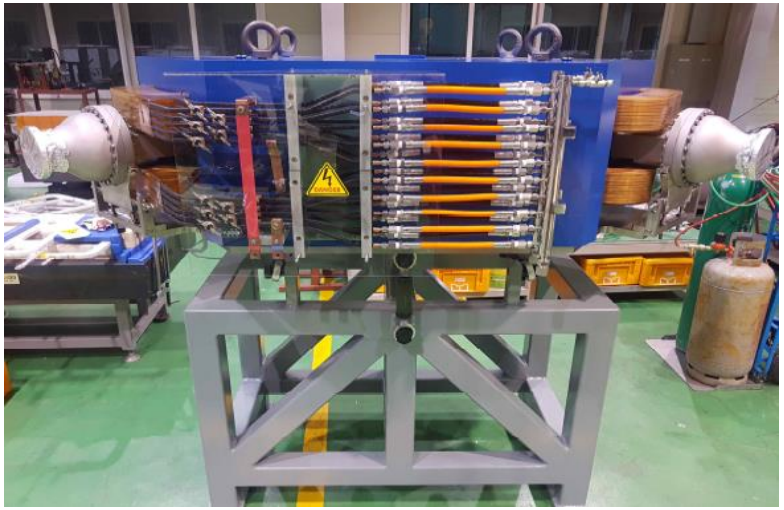
High temperature applied to TIS





3. Sys. Install. Beamline Installation

< Low energy beamline installation >



< Pre-mass separator >

< A/q separator >

Beamline Installation

ISOL System to be installed by 2021

Beam Transport System to SCL3

Beam Transport System

Pre-mass separator module

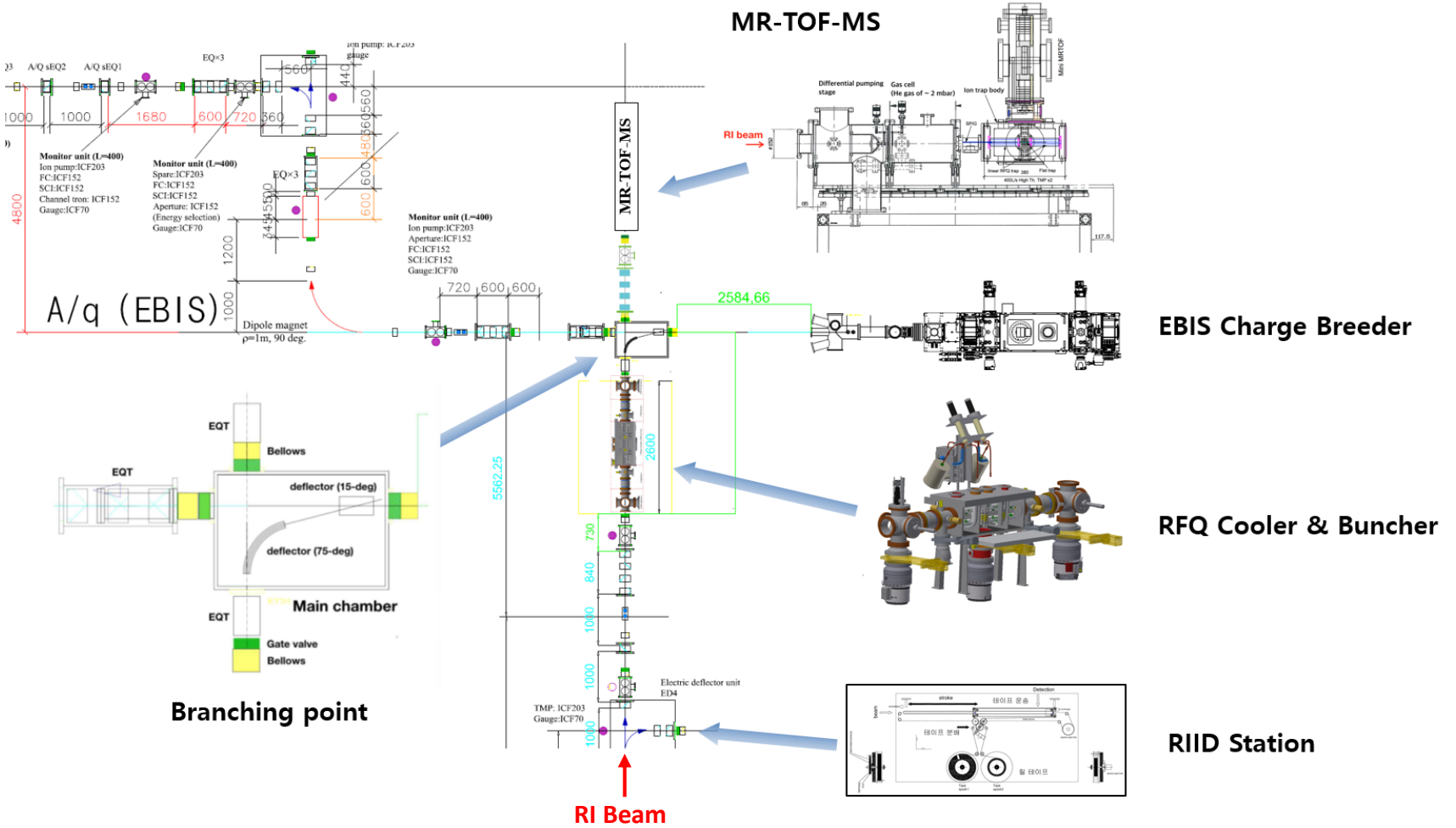
Beam Transport System to RFQ-CB

Target Ion Source Module

Cyclotron @IBA

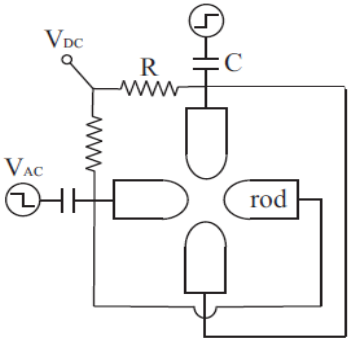
3. Sys. Install. Integrated coupling beamline

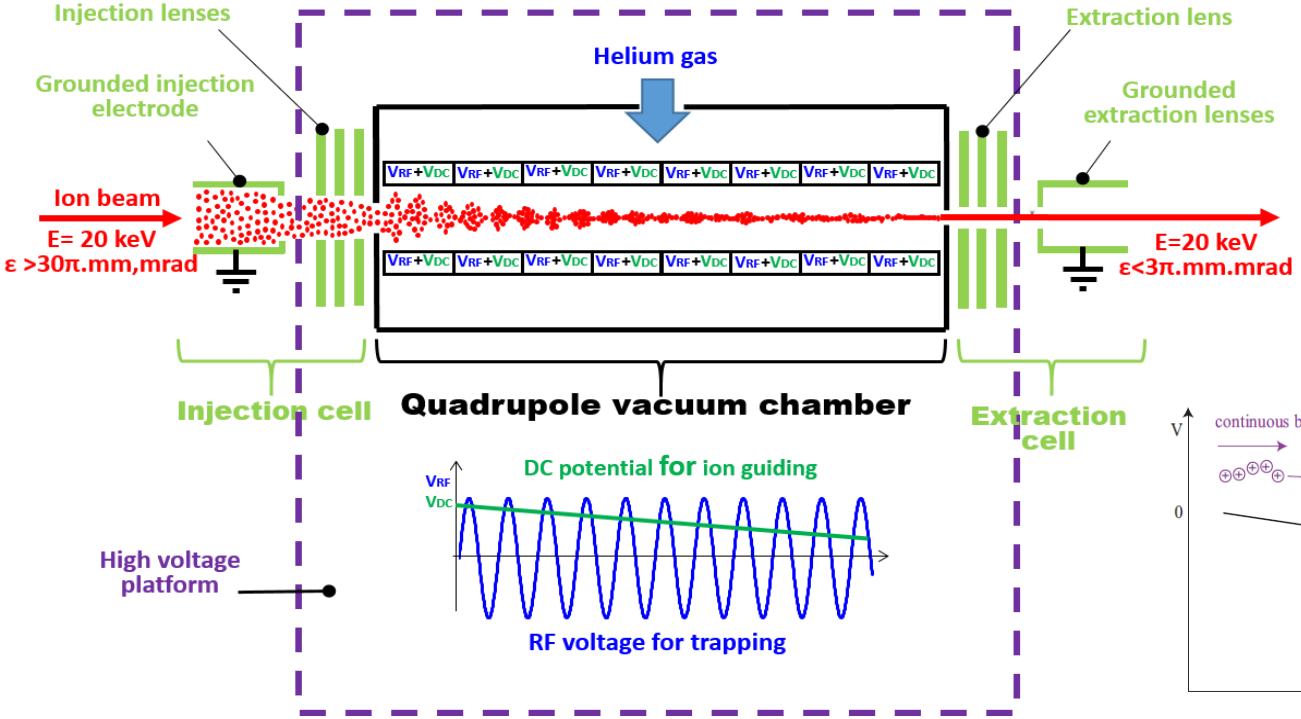
TIS (20 keV, $^{132}Sn^{1+}$) → Pre-Separator (m/δm = 400) → RFQ Cooler (3πmm mrad, < 5ev) → EBIS (10 keV/u, $^{132}Sn^{33+}$) → Post linac (Charge state n+)

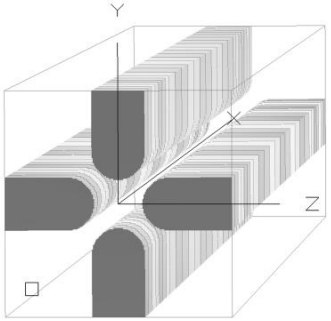


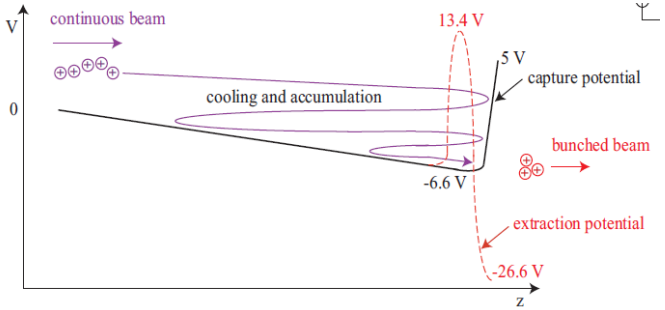
3. Sys. Install. RFQ-Cooler buncher

- **Purpose**
  - Improving ion beam quality (emittance, energy spread reduction and bunching)
  - Providing high quality ion beam for EBIS(Electron Beam Ion Source)
- **Design goal**
  - DC / Bunch dual mode operation
  - Emittance reduction: 30 → 3 [π mm mrad]
  - Efficiency: ≥ 80 % (DC mode)
  - Energy spread after RFQ-Cooler: <5eV



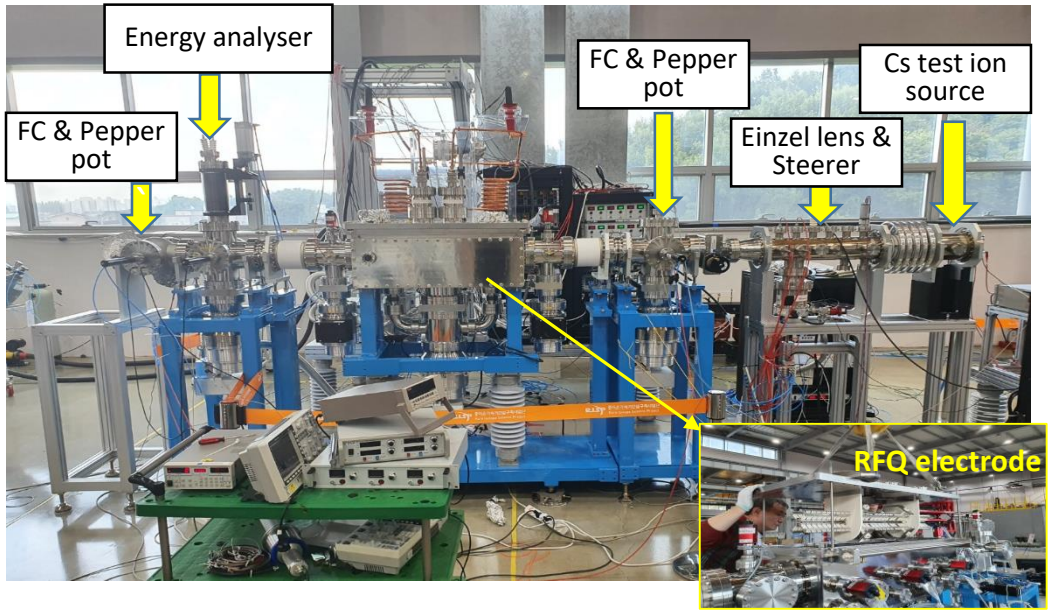




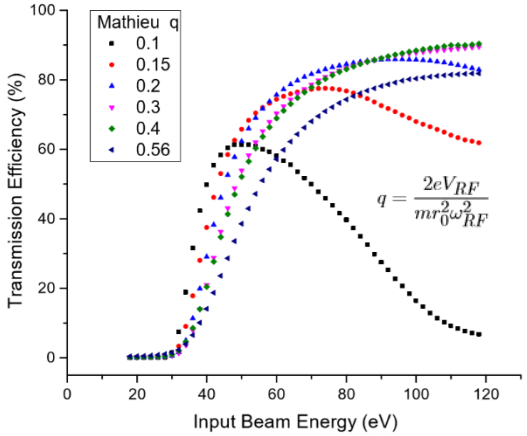


3. Sys. Install. RFQ Cooler buncher

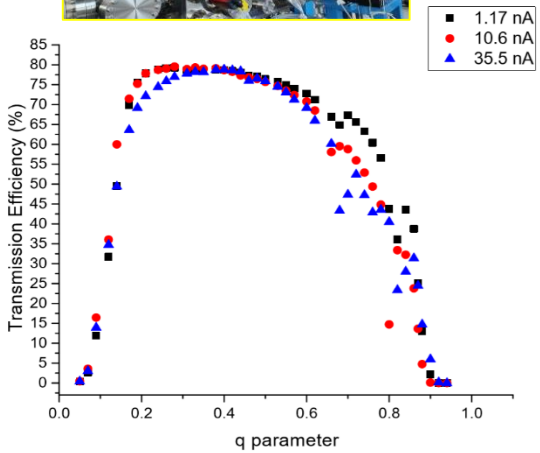
DC Beam Test



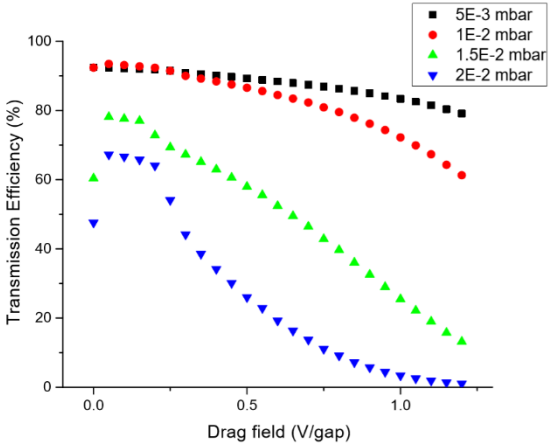
Parameter	(1)	(2)	(3)	unit
Beam energy	5 k	5 k	5 k	eV
RFQ Input Energy	20 ~ 120	90	90	eV
RF frequency	2	2	2	MHz
RF voltage	500 ~ 3000	500 ~ 4725	500 ~ 4725	Vp-p
Mathu q parameter	0.1 ~ 0.56	0.1 ~ 0.9	0.1 ~ 0.9	
RFQ He pressure	0.5	0.5	0.5	Pa
Beam current	1	1.17 ~ 35.5	1.17 ~ 35.5	nA
DC gradient	0.1	0.1	0 ~ 1.2	V/gap



(1) Input Energy VS Transmission Efficiency



(2) RF voltage VS Transmission Efficiency

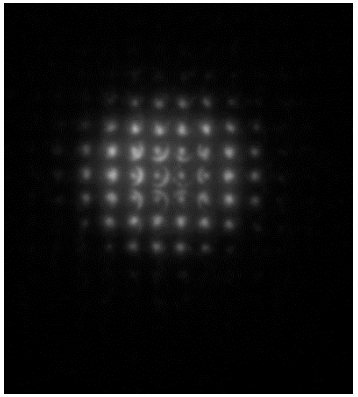


(3) DC voltage VS Transmission Efficiency

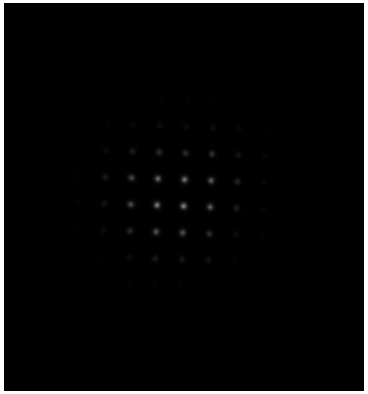
DC Beam emittance measurement

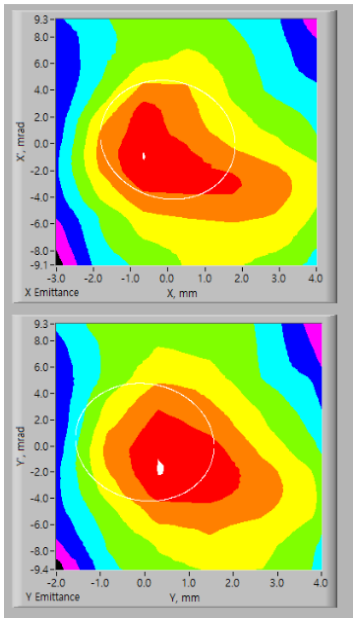
Parameter	Value	unit
Beam energy	5 k	eV
RFQ Input Energy	90	eV
RF frequency	2	MHz
RF voltage	2100	Vp-p
Mathu q parameter	0.4	
He pressure	0.5~2	Pa
Beam current	1	nA
DC gradient	0.1	V/gap
Hole size	20	um
Hole gap	1	mm

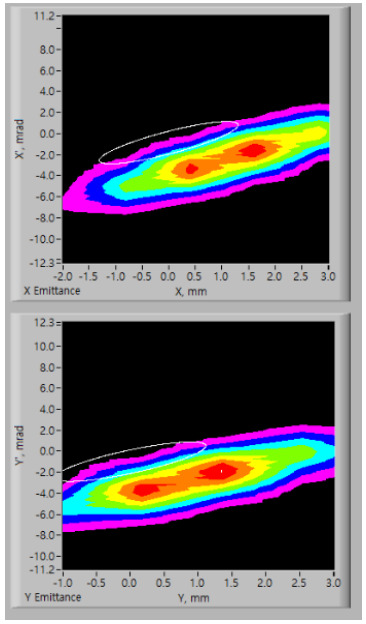
Initial Beam



After RFQ CB (2 Pa)







Initial beam emittance

- X Emittance (upper) : 8 mm*mrad
- Y Emittance (lower) : 7 mm*mrad

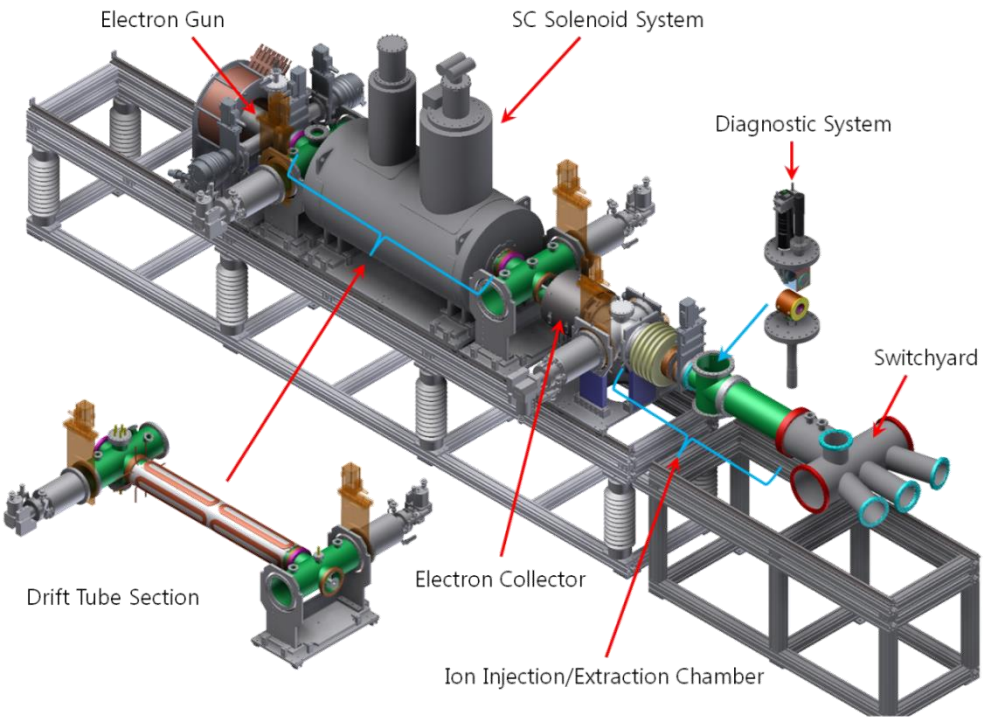
Cooling beam emittance

- X Emittance (upper) : 1.4 mm*mrad
- Y Emittance (lower) : 1.4 mm*mrad

3. Sys. Install. EBIS charge breeder

Design parameters

Electron beam current	Electron beam current density	Extraction beam energy	B-field in Trap region
0 ~ 3 A	500 A/cm^2	10 keV/u	6 T
A/q	Capacity	Breeding time	Breeding efficiency
< 6	~ 10^8 ions/bunch	50 ~ 100 ms	15 % for $^{133}Cs^{27+}$
Repetition rate	Pulse width		
~ 10 Hz	10 ~ 20 μs		



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

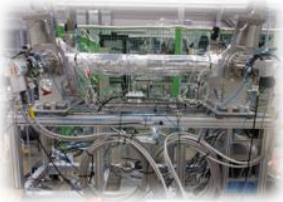
Main parameters for charge evolution

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

3. Sys. Install. EBIS charge breeder

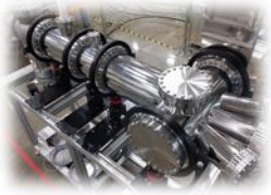
SC solenoid (6T)

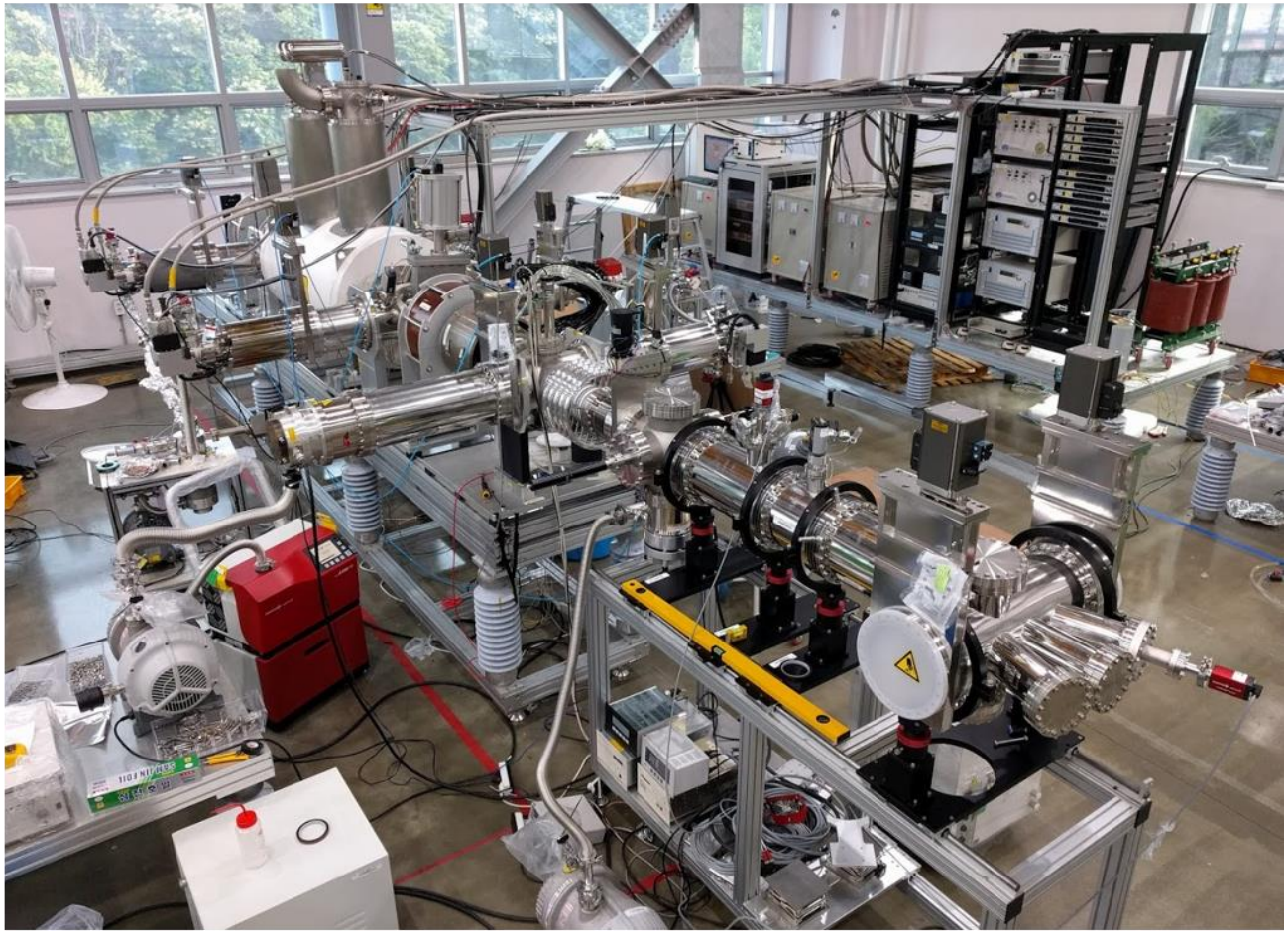
Ion trap region



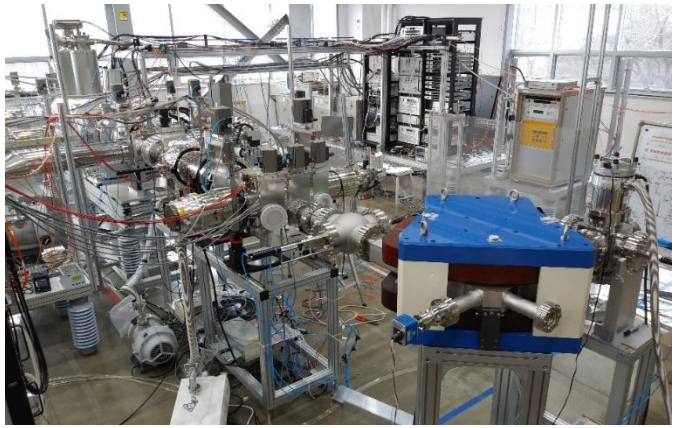
E-gun/Collector

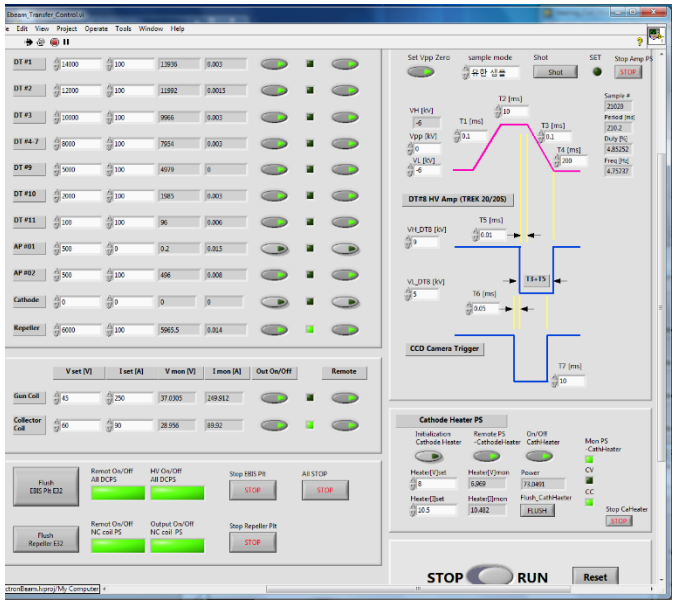
Ion transport line



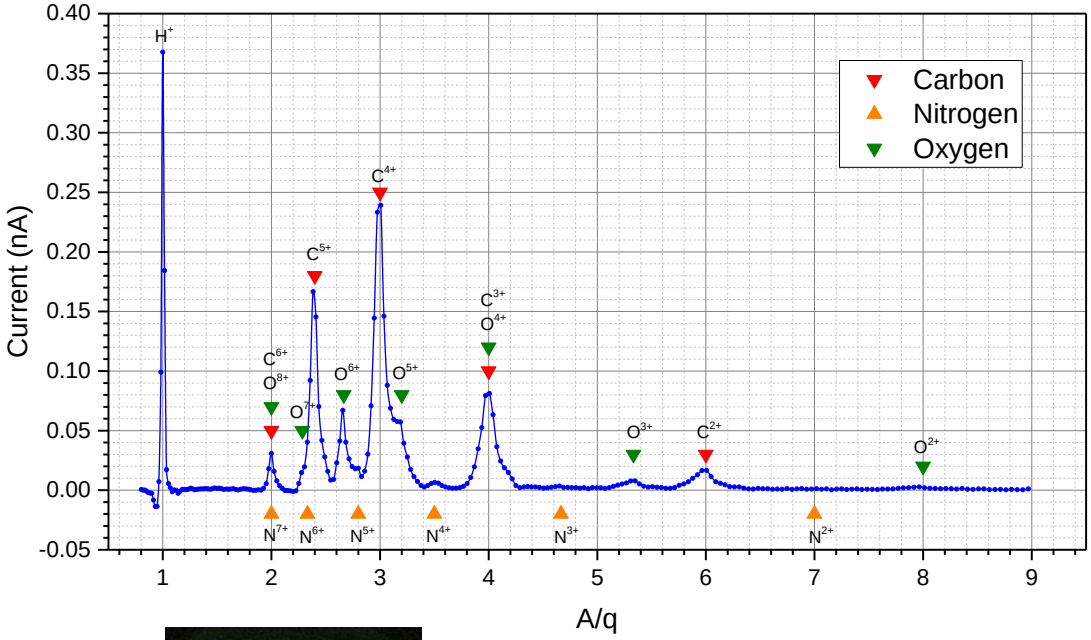


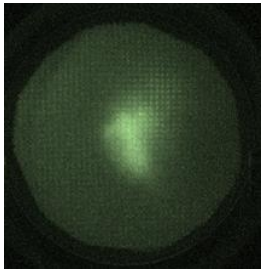
Charge-bred residual gas





SC magnet : 6T
Electron beam : 0.35 A
Breeding time : 60 ms





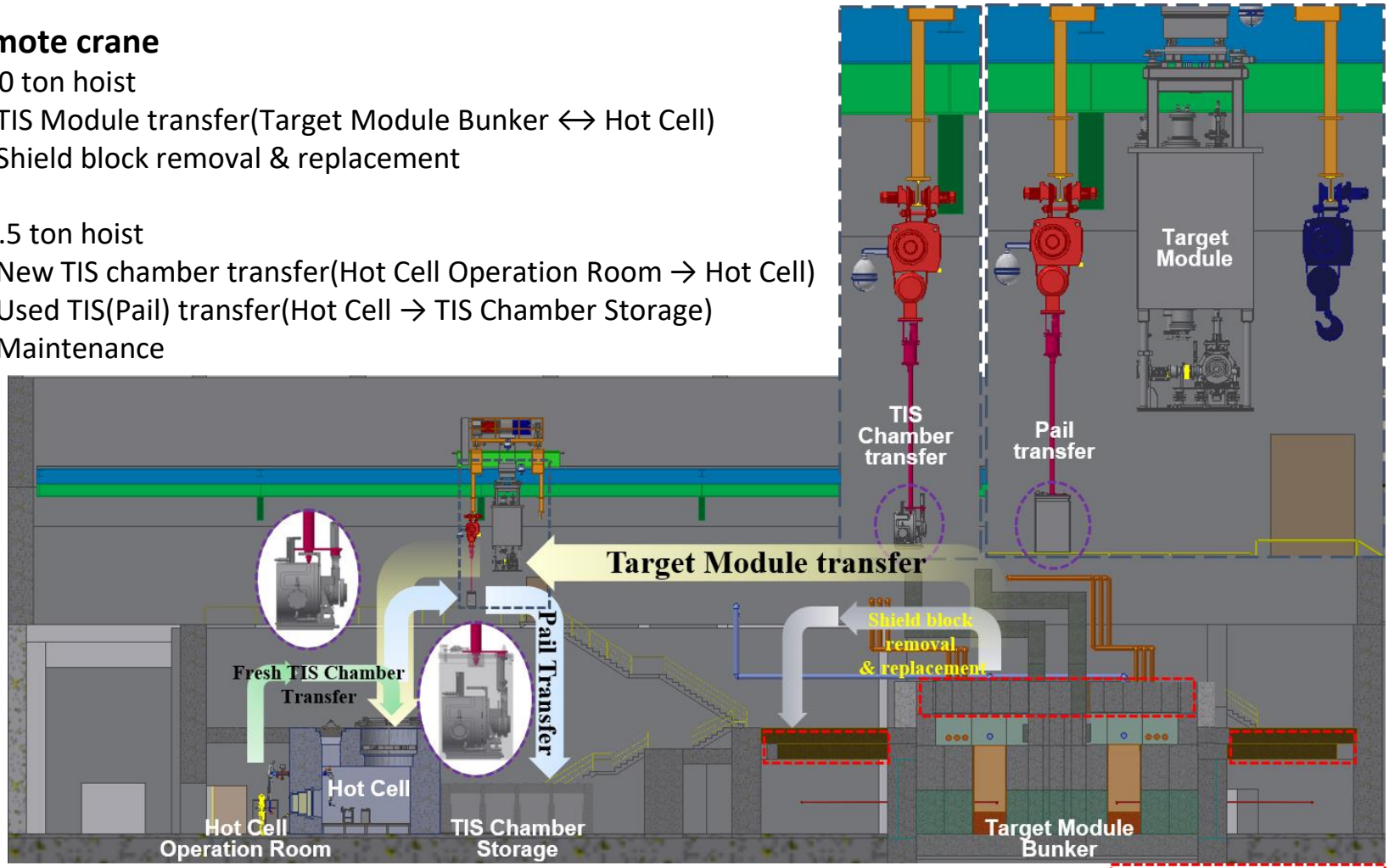
Pepperpot image of charge-bred residual gas

Remote crane, Hot-cell, TIS Storage

Remote crane

- 20 ton hoist
  - TIS Module transfer(Target Module Bunker ↔ Hot Cell)
  - Shield block removal & replacement

- 7.5 ton hoist
  - New TIS chamber transfer(Hot Cell Operation Room → Hot Cell)
  - Used TIS(Pail) transfer(Hot Cell → TIS Chamber Storage)
  - Maintenance

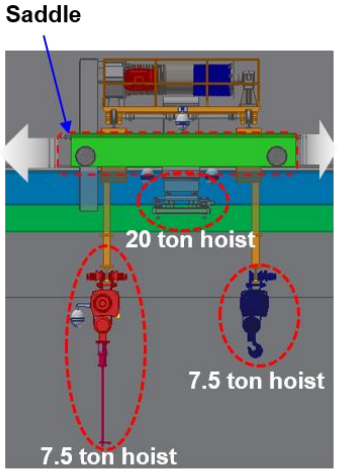


Target Hall (Section View)

Shield block

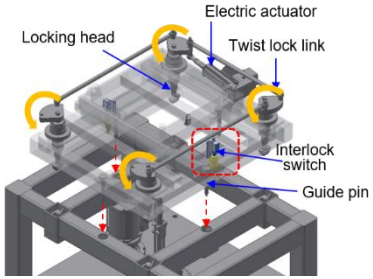
3. Sys. Install. TIS Remote handling system

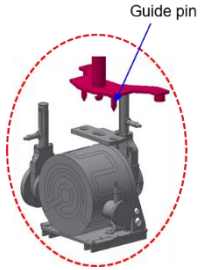
Remote crane and interface device

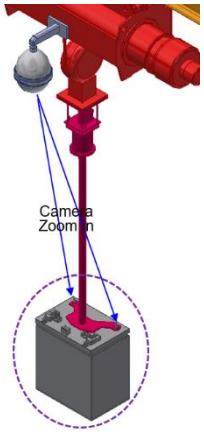


Crane(View F)

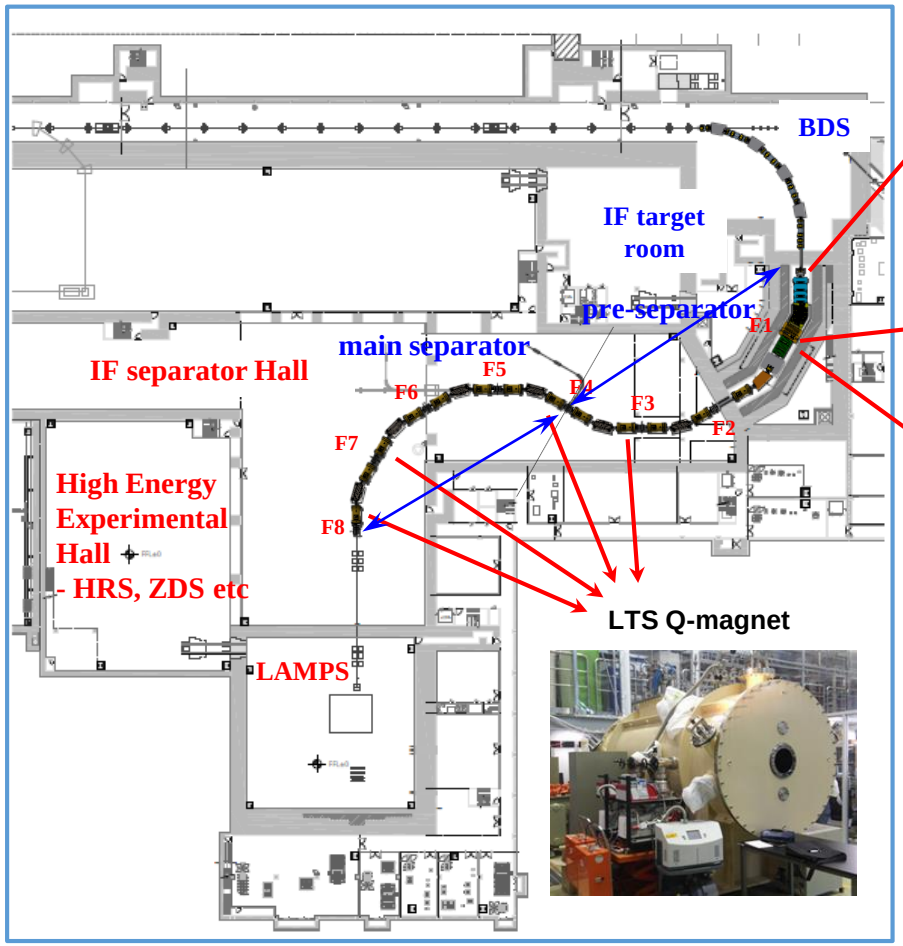
ITEM	SPECIFICATION	REMARK
Lifting capacity	20 ton / 7.5 ton / 7.5 ton	
Actual Lift	15.9m / 13m / 13 m	
Lifting speed	0.45m/min to 4.5m/min	Speed variable
Operation Mode	Normal / Emergency	
Rotation	270°	20 ton hoist
Rotation speed	1.2 rpm	
Camera	Rotation / Tilt / Zoom	5 Set
Position accuracy	< 5mm	Dual Encoder





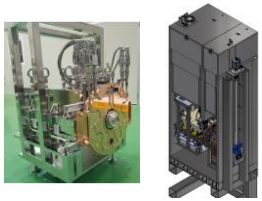


In-Flight separator layout

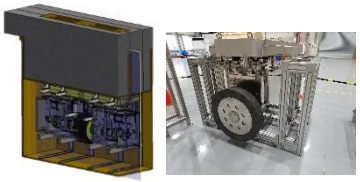


LTS Q-magnet

target system



beam dump system



HTS Q-magnet

Focal plane chamber

Total length~ 120 m

Current status

- Target system
  : Completed manufacturing
  Under performance test

- Beam dump system
  : Manufactured 1 out of 2
  : Under manufacturing

- HTS Q-pole magnet (6 ea)
  : Completed manufacturing and performance test for prototype
  Under manufacturing
  Manufactured 3 out of 6

- LTS Q-pole triplet (13 ea)
  : Completed manufacturing and performance test for prototype
  Under manufacturing
  Manufactured 4 out of 13

- NC Dipole (8 ea)
  : Under manufacturing

- Focal plane chamber (8 ea)
  : Under manufacturing
  Manufactured 1 out of 7

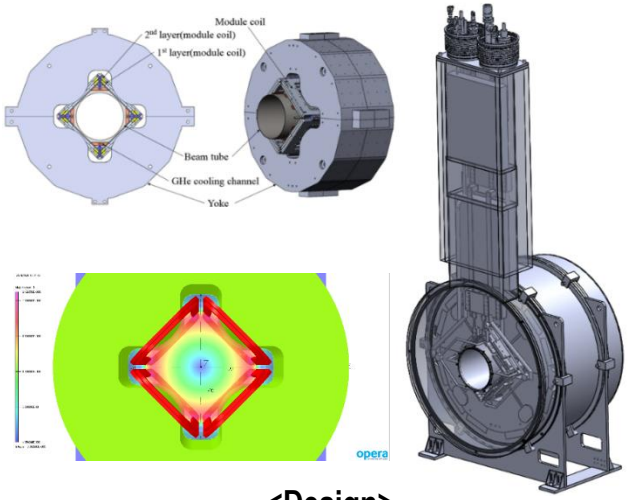
3. Sys. Install. IF HTS Magnet

IF HTS Quadrupole/Sextupole magnets

- Quantity: 4-pole 6 sets, 6-pole 1 set
- Operating temperature: 40 K (GHe)
- Field gradient: Max. 10.5 T/m
- Field uniformity: ≤ ±0.5%
- Effective length: ~550mm
- HTS wire
  - REBCO tape (12mm x ~0.14 mm)
  - Critical current : 600 A↑ @77K

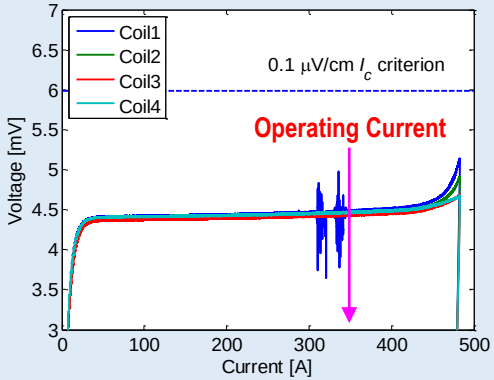
Coil assembly | Cryostat assembly | test

<HTS Quadrupole #5 (HQ5) assembly & test>



<Design>

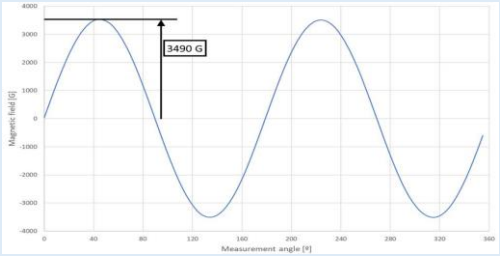
① Critical current measurement



► Operating current margin : 30%↑

② Temperature margin @ I_{op} (350 A): 18.7 K

③ Field gradient: 2.91 T/m (Spec. : 2.9 T/m)



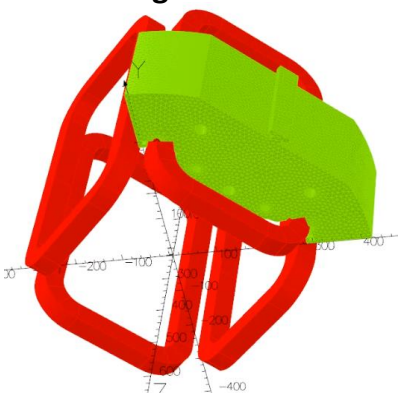
<HTS Quadrupole #5 (HQ5) test analysis>

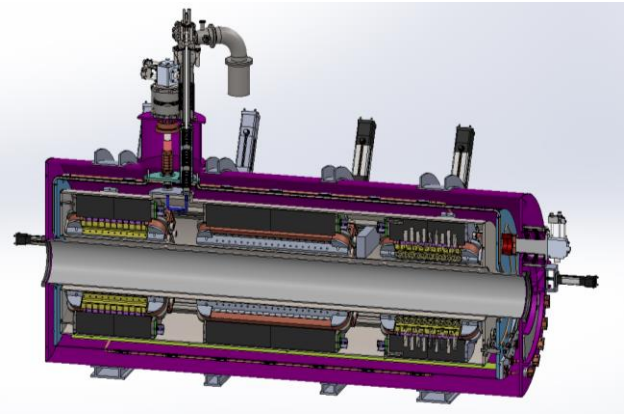
3. Sys. Install. IF LTS (Low Temperature Superconducting) Magnet

LTS Quadrupole magnet Triplet Specifications

- Configuration of Triplet
  : Quadrupole(LQ) 3 ea,
  Sextupole & Octupole 1 ea @LQ1
- Quantity : Triplet 13 sets
- Operating temperature : 4.2 K
- Field gradient : 11.0 T/m
- Field uniformity : ≤ ±0.5%
- Cryostat length : ≤ 3.4 m
- LTS wire
  - Nb-Ti/Cu 1.02 mm wire (Cu ratio : 4.3)
  - Critical current : 470 A @ 4.2K 5 Tesla

<Design>

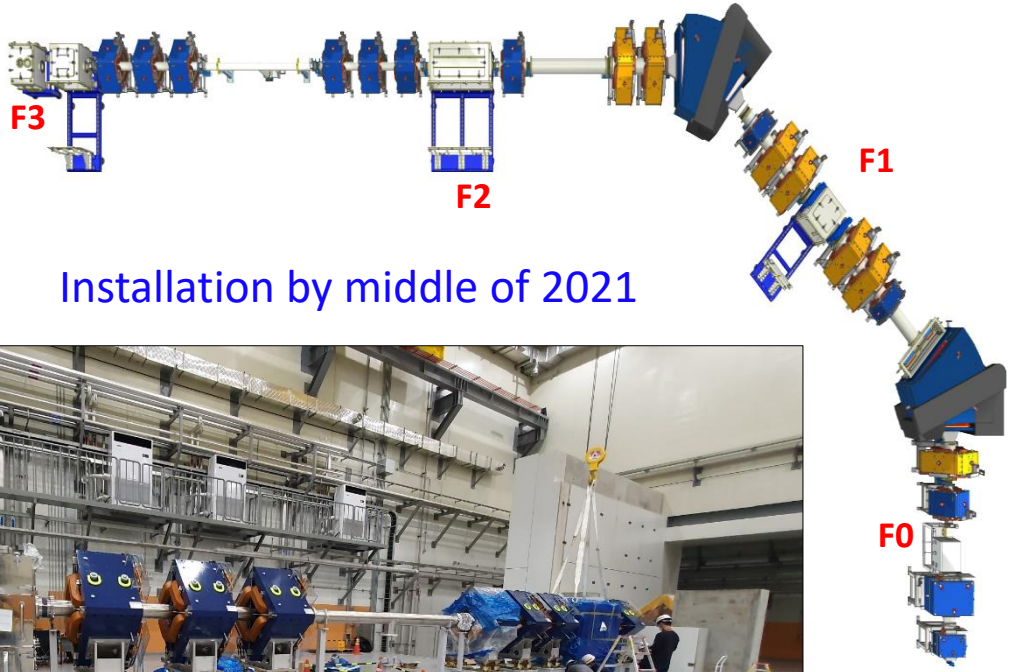




<Initial product manufacture & test completed>

<Mass production>

3. Sys. Install. KOBRA



Installation by middle of 2021

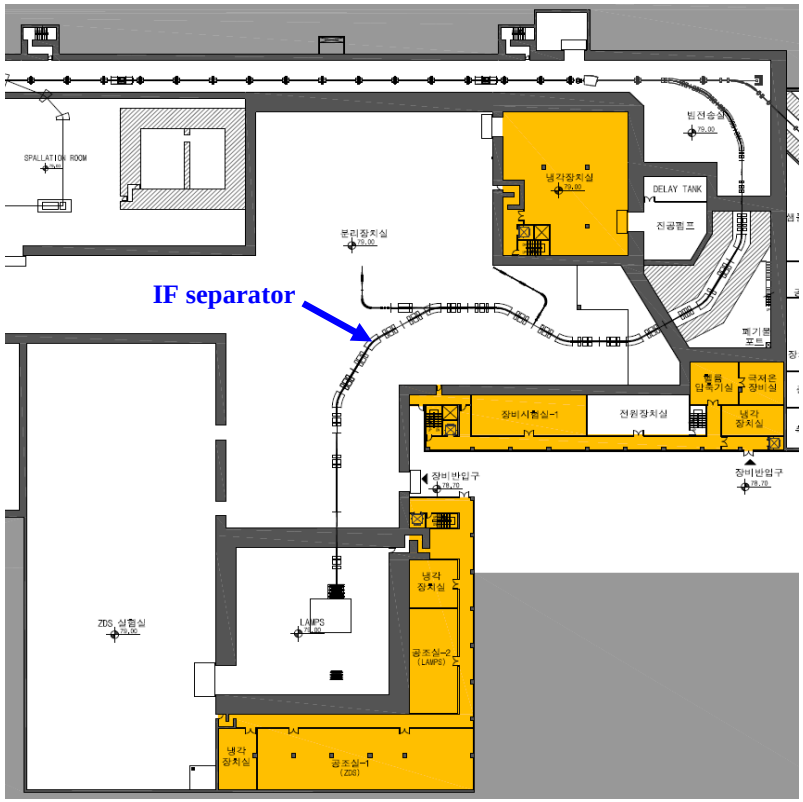
3. Sys. Install. LAMPS

Main facility for nuclear matter and nuclear reaction studies with stable and rare isotope beams at intermediate energy

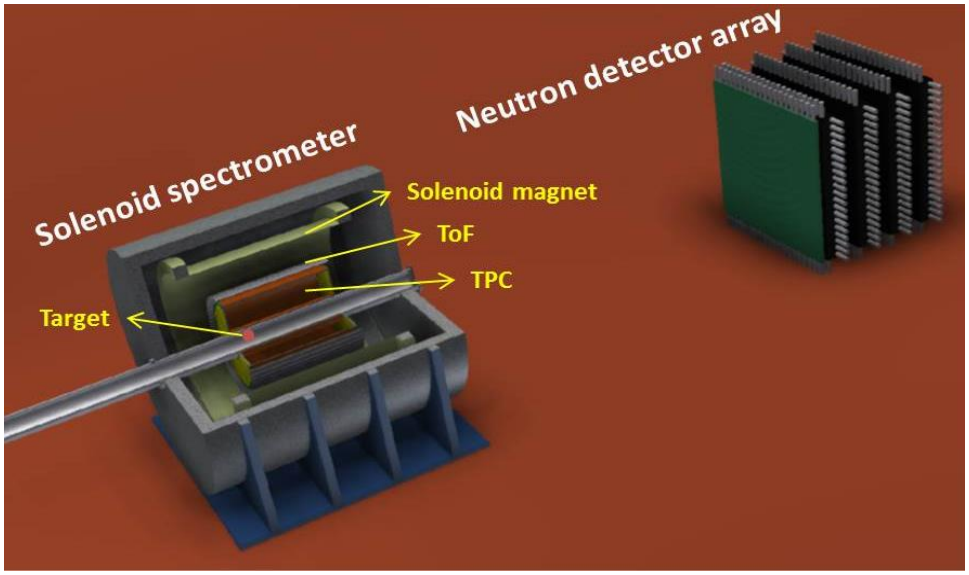
- **Main Research Subject**

Study of nuclear symmetry energy at supra-saturation density via heavy-ion collision experiment using rare isotope beam with varying beam energies and collision systems

(e.g. measure *n/p* ratio & collective flow at the same time in the combination of $^{50,54}Ca+^{40}Ca$, $^{68,70,72}Ni + ^{58}Ni$, $^{106,112,124,130,132}Sn + ^{112,118,124}Sn$)

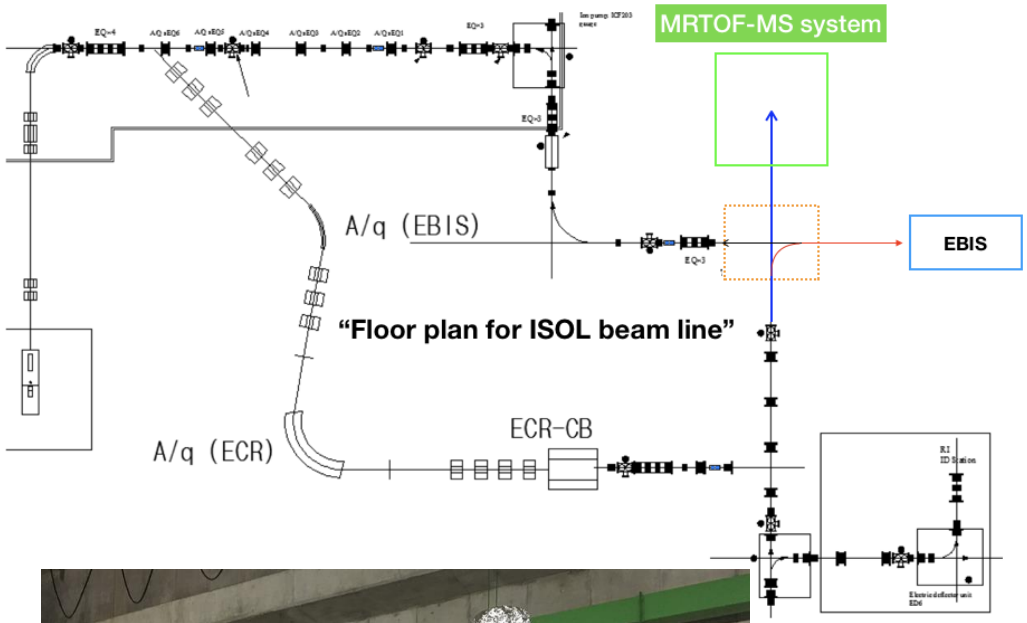


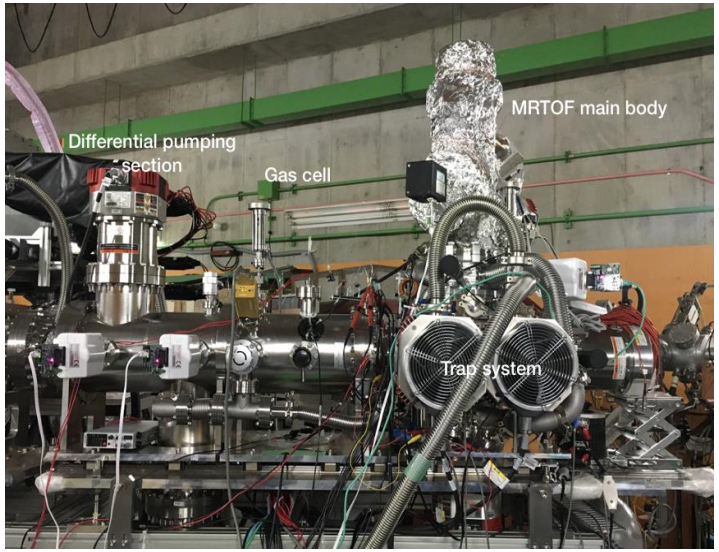
- **Beam Energy: up to 250 MeV/u for ^{132}Sn (≤ 10^8 pps)**
- **Solenoid Spectrometer**
  - Max. 1T solenoid magnet
  - TPC (~ 3π sr acceptance, charged particle tracking)
  - Scintillation counter (trigger & ToF)
- **Neutron Wall (neutron tracking)**



3. Sys. Install. MR-TOF

RI beam of A < 150 and E = 40 ~ 60 keV requires windowless Gas catcher/Differential pumping system (similar beam condition to KISS).





- Low energy beam of < 60 keV
- Differential pumping stage
- Windowless helium gas catcher
- Trap and bunching system
- MRTOF reflection chamber

3. Sys. Install. Scientific program at early phase operation(candidate)

Facility	Subject for early phase operation
KOBRA	· **Transfer reaction measurements in inverse kinematics** ($^{29}P(d,p)^{30}P$, $^{26}Al(a,p)^{24}Si$) · **Radiative capture reactions using batch mode RI beams** ($^{26g}Al(p,g)^{27}Si$) · **RI beam production via quasi-projectile-like fragmentation** for ^{16}O or ^{40}Ar
LAMPS	· **Ar+KCl or Xe+CsI** in case of IF separator commissioning not completed
MMS	· **Isomer separation** with using $^{26g.s.}$**Al** and ^{26m}**Al** beams
CLS	· **Laser ionization** and **measurement of isomeric property** for ^{26}**Al**
NDPS	· **Activation experiments with a quasi mono energy neutrons** for light and heavy nuclei · **Surrogate reactions** for fission
mSR	· One of research areas of **superconductivity** and **quantum magnetism** with their scientific significance at the time of the μSR instrument completion
BIS	· **Physical dose distribution** and **linear energy transfer** measurements with a $^{12}C^{+6}$ **beam (310 MeV/u)**

3. Sys. Install. International Cooperation (MOUs with 18 Intl Institutes)

Part 4.

Summary & Outlook

Summary & Outlook

- **Accelerator**
  - Mass production for SCL3 is under way and SCL2 is under pre-production stage.
  - Beam commissioning for the injector is continued to the end of 2021.
  - Installation for SCL3 will be completed by Aug. of 2021, followed by cool down and beam commissioning.

- **By the end of 2022, we will achieve**
  - **SI beams:** Stable ion beams (^{16}O, ^{40}Ar) from ECRIS → SCL3 → low E exp hall
  - **RI beams:** RIBs extraction from ISOL → re-acceleration through SLC3 → low E exp hall
  - Stable / RI beams will be delivered to low-E experimental hall
  - **Early phase experiments are going to be performed using KOBRA**
    → RIBs production at KOBRA (A<~50, beam energy < 20 MeV/u) using SI beams from SCL3
  - Preparation for the 2nd stage of construction begins for SCL2
  - Installation and independent commissioning for IF, LAMPS, Neutron, bio-medical and μSR
    → Collaborative works with RUA (RAON Users Association) via RULC (RAON Users Liason Center)

- **Beyond 2022,**
  - Beam commissioning for ISOL → SCL3 → SCL2 → IF
  - Stable operation with 200MeV/u beams up to 80kW
  - Science program starts with both ISOL and IF systems
  - UCx target and U-beam operation

Summary & Outlook

- Phased Assembly and Operation Plan

	~2020	2021	2022	2023~
Accelerator System	Injector	SCL3	-	SCL2
Infrastructure		Cryogenic System	-	-
RI Production System		ISOL System (Beam line)	ISOL (Cyclotron), IF system	-
Experimental System		KoBRA, LAMPS, μSR, MMS, BIS	CLS, NDPS	-

노벨상 향한 대장정 스타트
중이온가속기 라온
가속기는 '노벨상의 산실'로 불린다. 기초과학 연구에는 필수 실험시설이자, 산업계에는 새로운 기술 개발의 터전이다. 머리카락 한 올 두께보다 작은 나노미터(nm·1nm는 10억 분의 1m)와, 이보다 100만 배 더 작은 펨토미터(fm·1fm는 1000조 분의 1m)의 세계를 보여주는 최첨단 '현미경'이기도 하다. 한국형 중이온가속기 '라온(RAON)'이 2021년 완공을 목표로 구축에 들어갔다. 빅뱅 3분 뒤의 우주를 재현하고, 한국의 이름을 붙인 새로운 원소 '코리아늄'을 발견해 주기율표에 등재하겠다는 포부도 세웠다.

Thank you