RAON Rare isotope Accelerator complex for ON-line experiments

Status of RAON heavy-ion accelerator

Feb. 28, 2023

FNAL-IBS/RISP joint workshop

Yeonsei Chung on behalf of Rare Isotope Science Project

ibs 기초과학연구원 Institute for Basic Science

RISP 중이온가속기건설구축사업단 Rare Isotope Science Project

Contents

Part 1.

Project Overview

Rare Isotope Science Project (RISP)

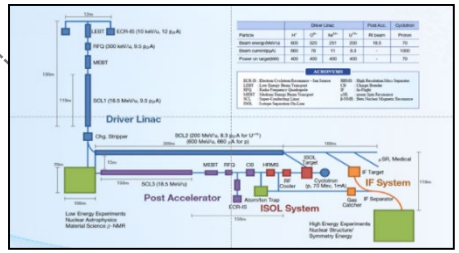
- **Goal:** To build **a heavy ion accelerator complex RAON,** for **rare isotope science** research in Korea.

  * 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 ~ 2022.12(1st Phase)**
  2023.01 ~ (2nd 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



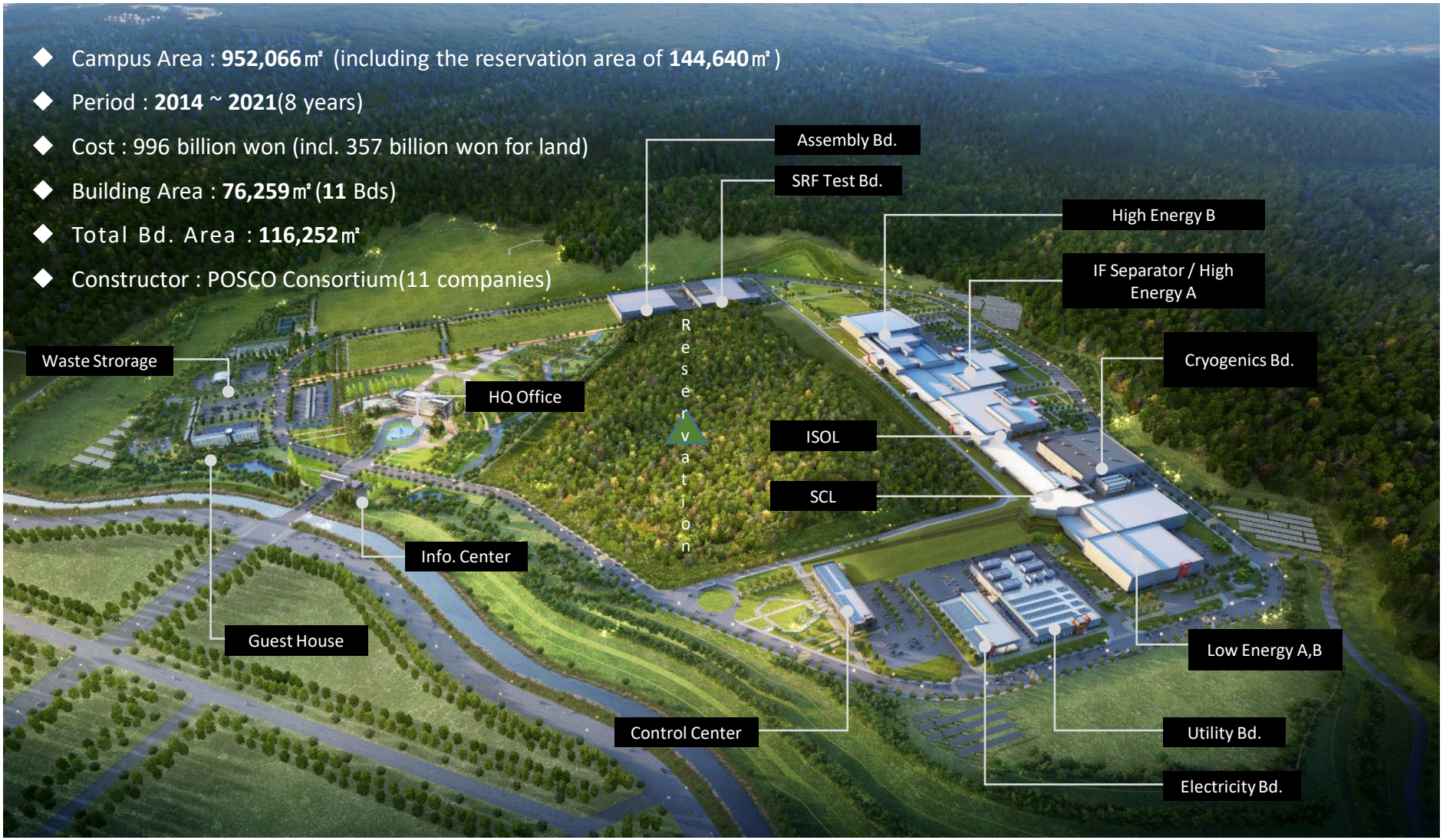
Facility Construction Project

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

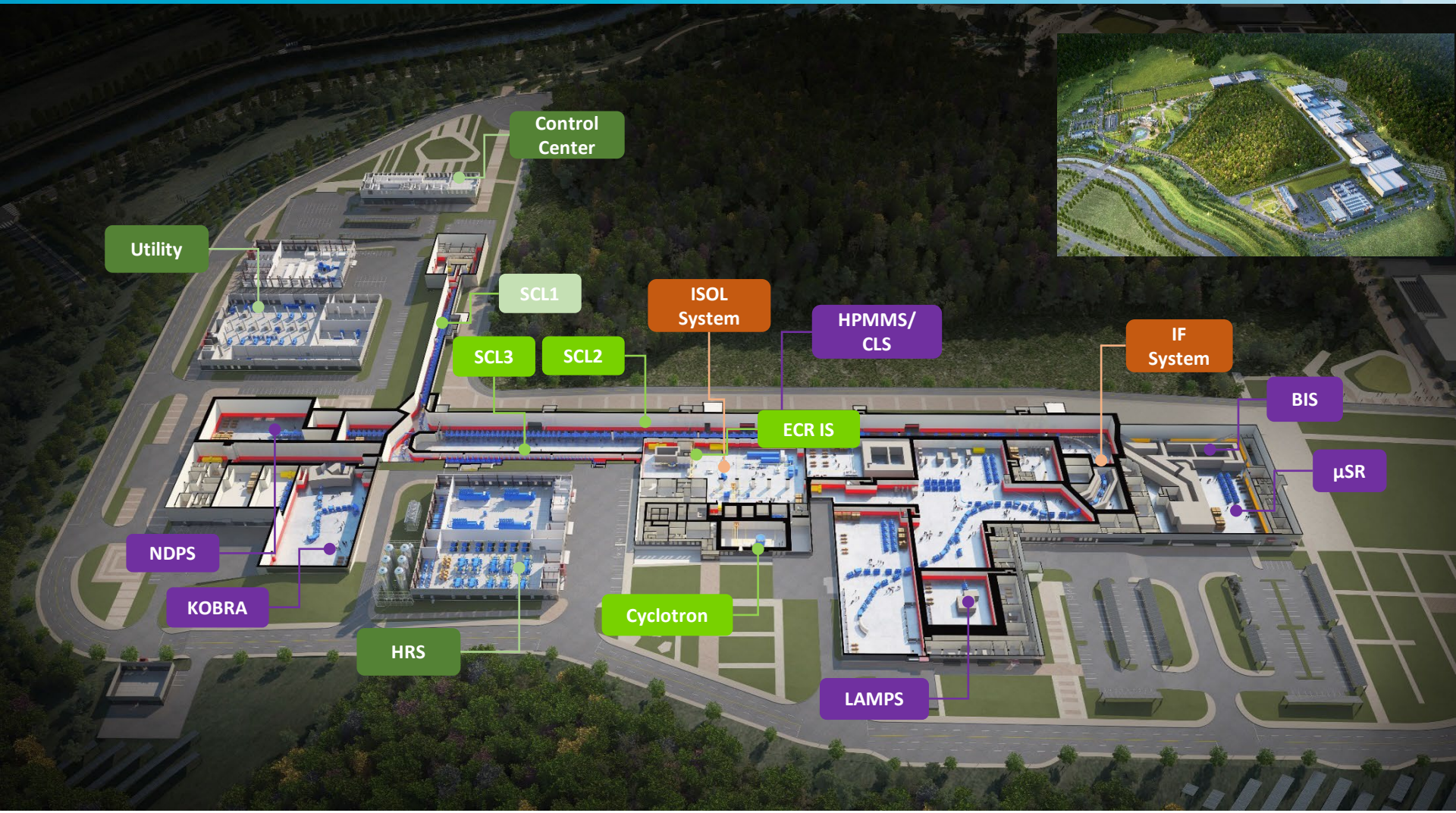
※ Accelerator and experiment buildings, support facility, administrative buildings, and guest house, etc.

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

Campus Layout



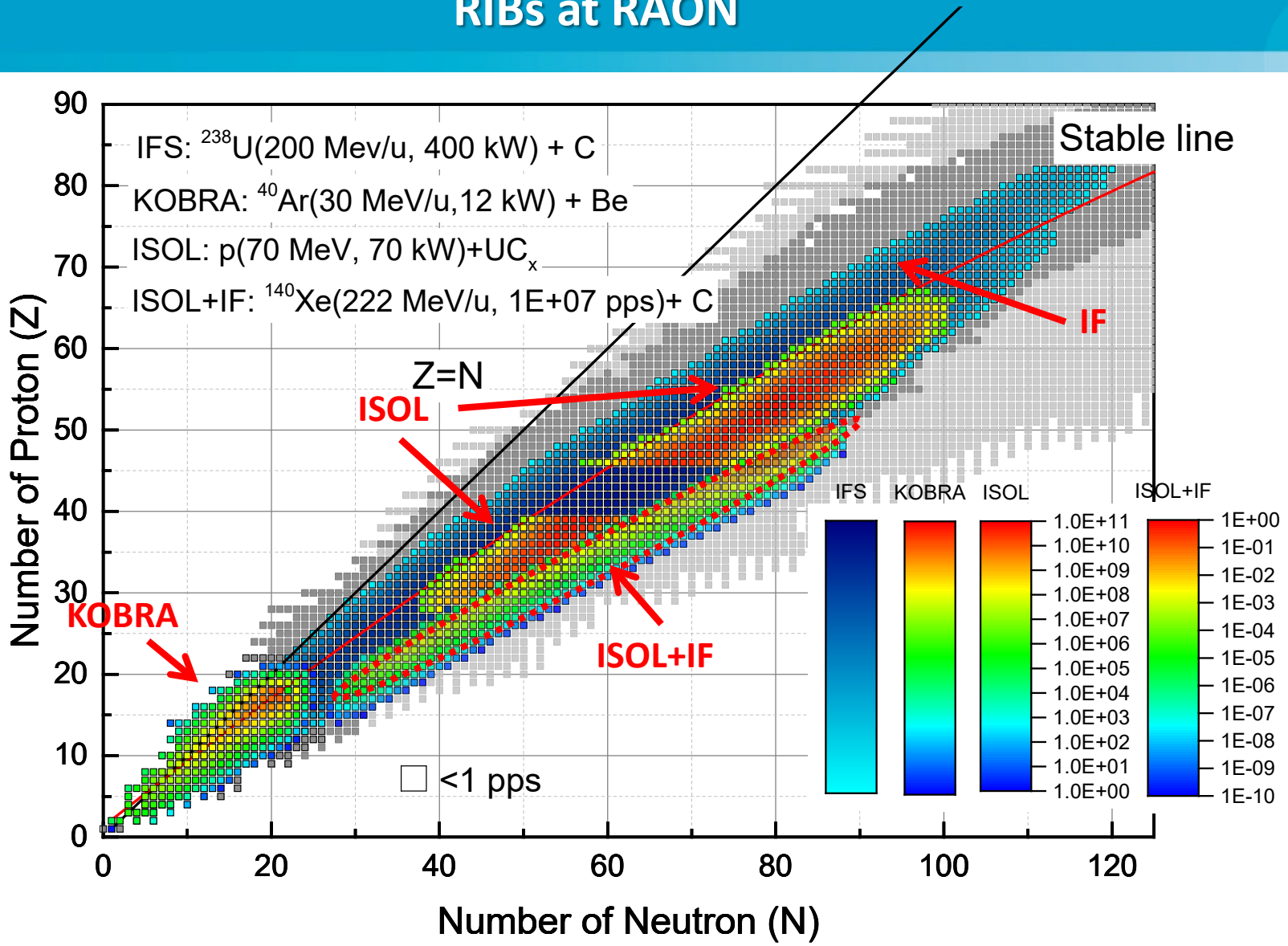
RAON Layout



● SCL1 has been decided to postpone

: SCL3 is going to be taking a role of SCL1 in the early operation

RIBs at RAON



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

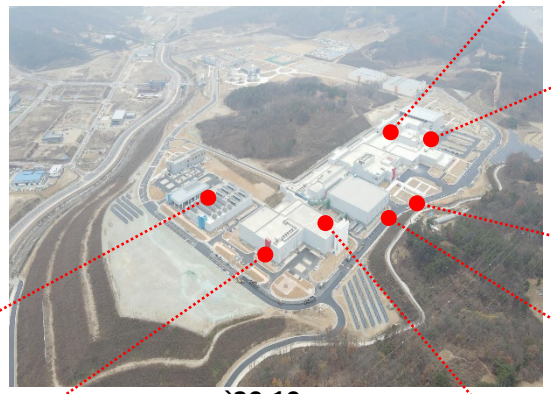
View of Construction Site

● View of Construction Place (`20.10)

<`17.01>

<`18.01>

<`19.01>



<`20.10>

Conventional Facilities

SRF Test Bd.

Assembly Bd.

Control Center

HQ Office Bd.

Utility Bd.

Electricity Bd.

Accelerator Building, Experimental Halls

SCL2

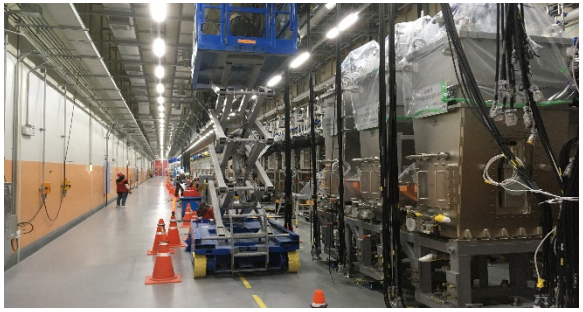
SCL3

Low Energy A/B

ISOL

IF/ High Energy A

High Energy B



SCL3

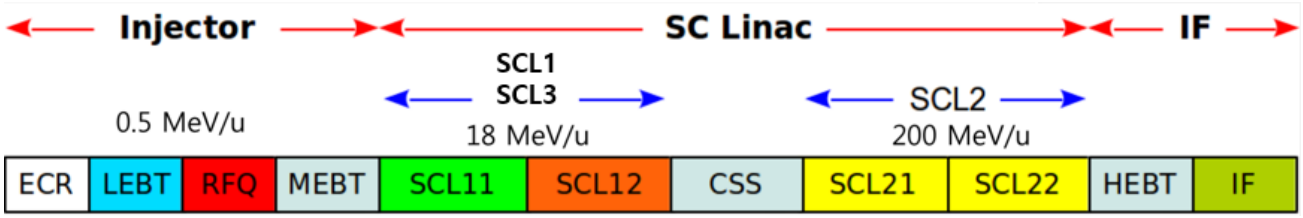
Bending Section

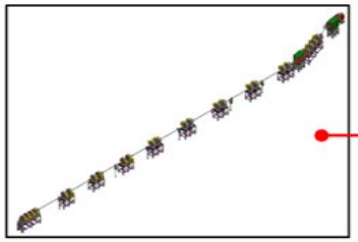
SCL3-gallery

Part 2.

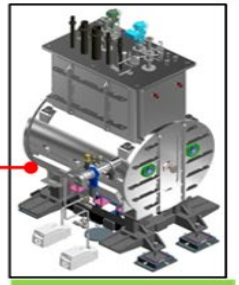
Accelerator Systems

Accelerator Systems

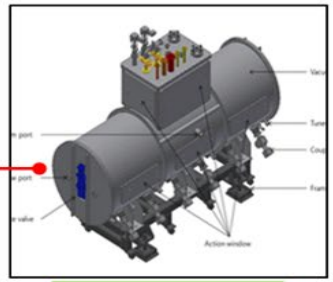




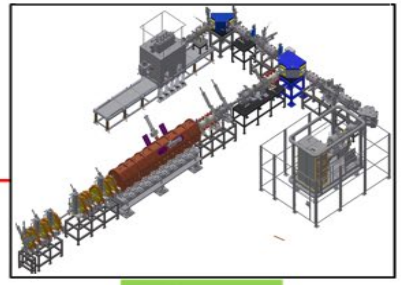
KoBRA Beam Line



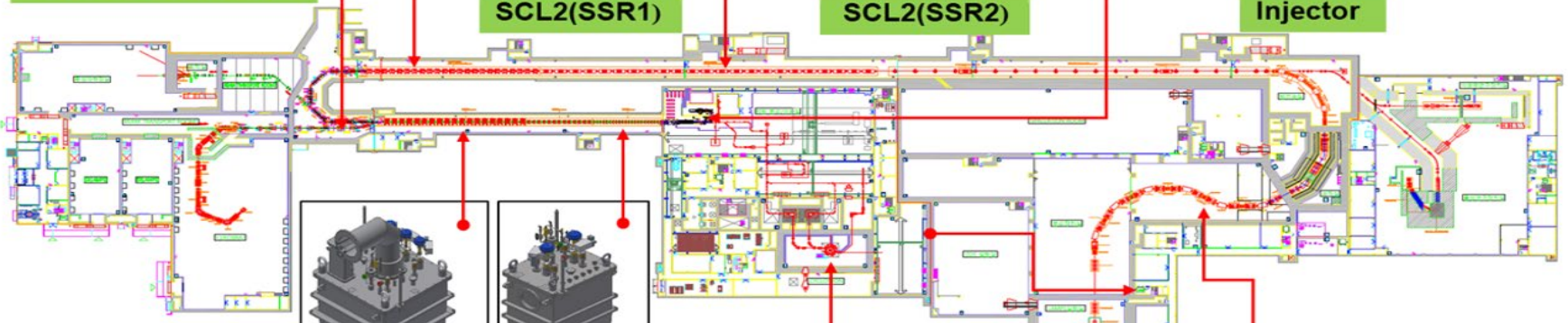
SCL2(SSR1)

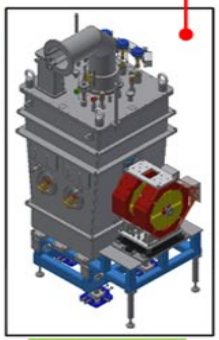


SCL2(SSR2)



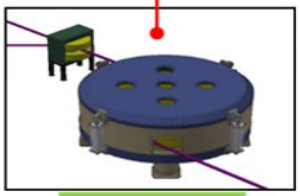
Injector



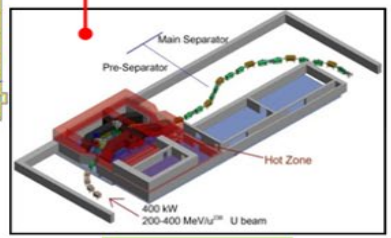


SCL3 (HWR)

SCL3 (QWR)



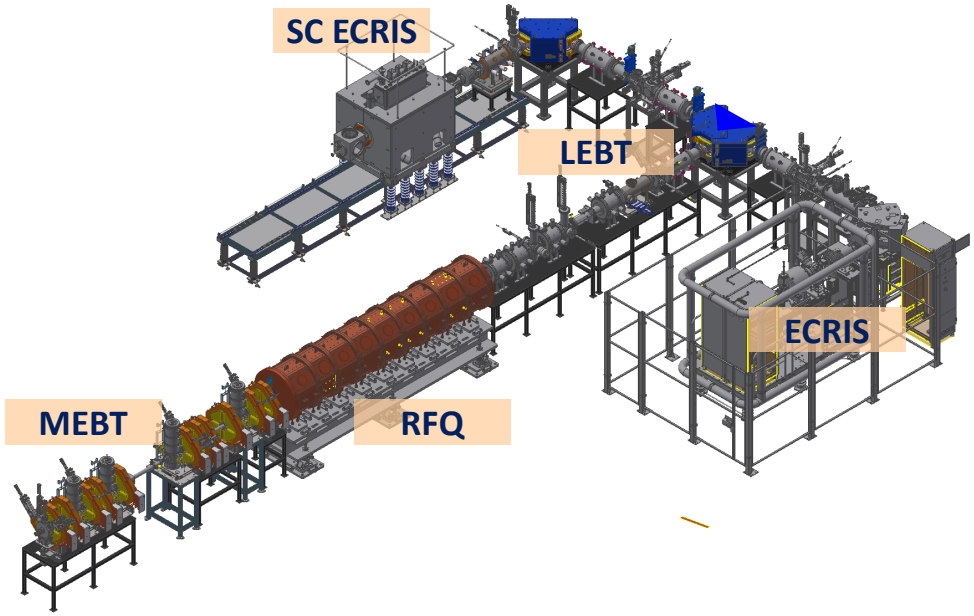
Cyclotron

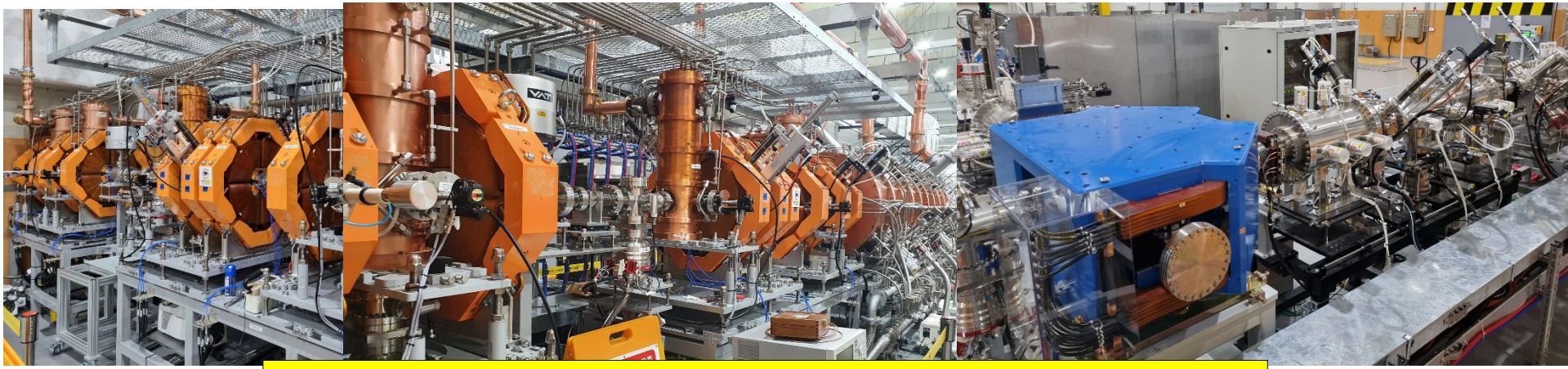


IF System

Injector System

- **Two ECR-IS on high voltage platforms**
  - 14.5 GHz ECR ion source
  - 28 GHz superconducting ECR ion source
- **LEBT (E = 10 keV/u)**
  - 10 keV/u, Dual bending magnet
  - Chopper & Electrostatic quads, Instrumentation
- **RFQ (E = 500 keV/u)**
  - 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, 2×4 kW)
  - Simple quadrupole magnets, Instrumentation

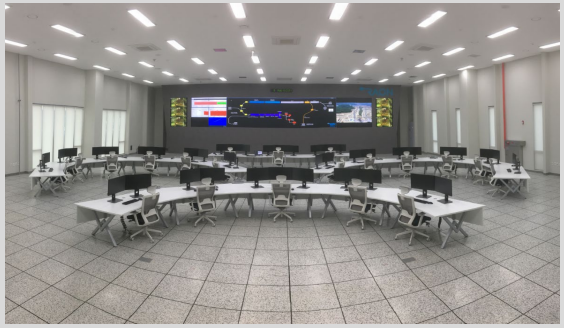




Installation completed and beam commissioning from October, 2020

Control System

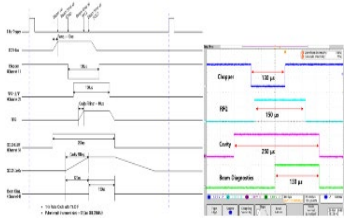
Control Center



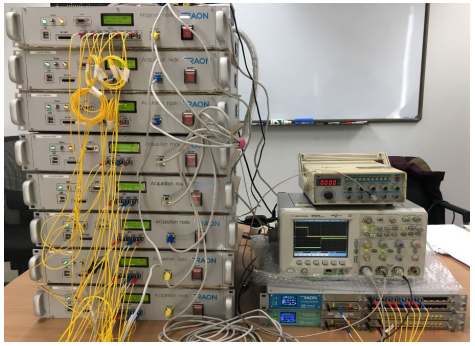
Main Control Room

Data Storage System

Integrated Control System



Timing System

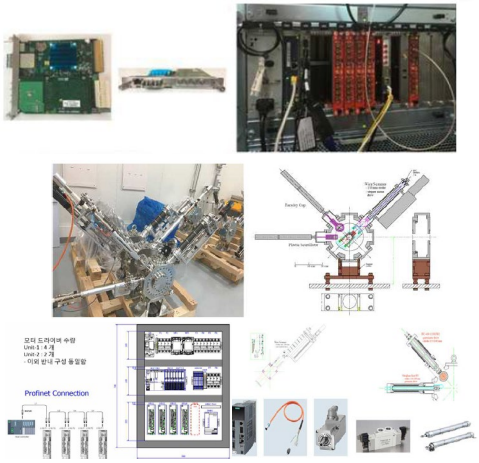


Fast Protection System

Local Control System

EPICS IOC Controllers

SCL3 Control System(43)

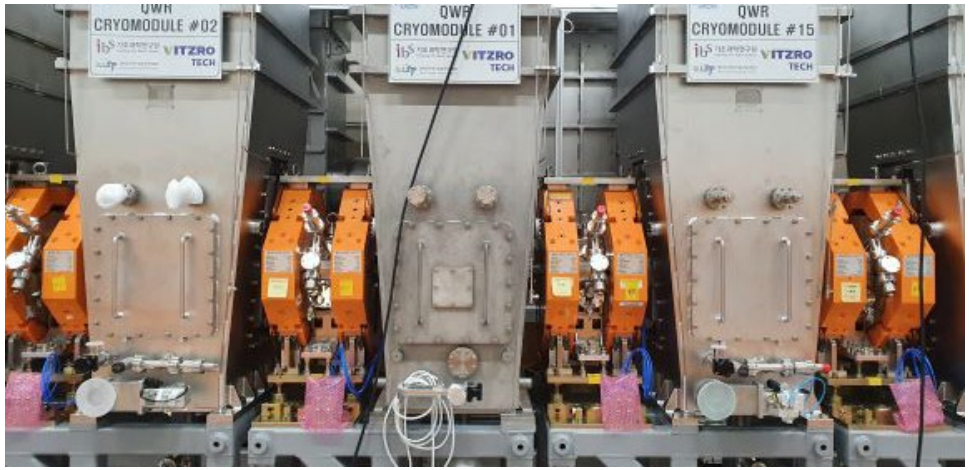


Beam Diagnostics Control System

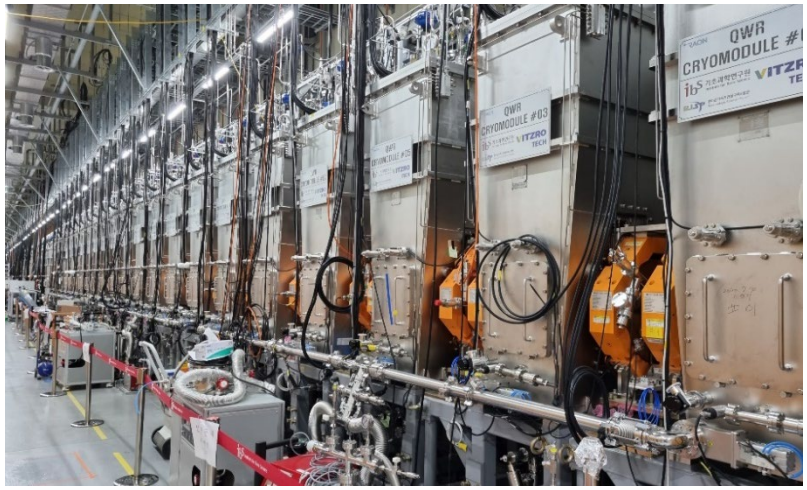
Clean Assembly @ Accelerator Tunnel

(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

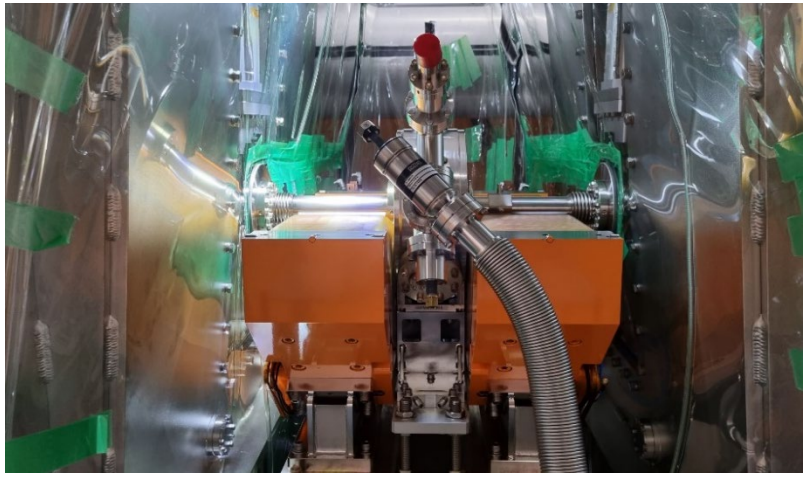


Superconducting Linac, SCL3 Tunnel and Gallery



QWR & HWR Cryomodule

Cryogenic Distribution to Cryomodule

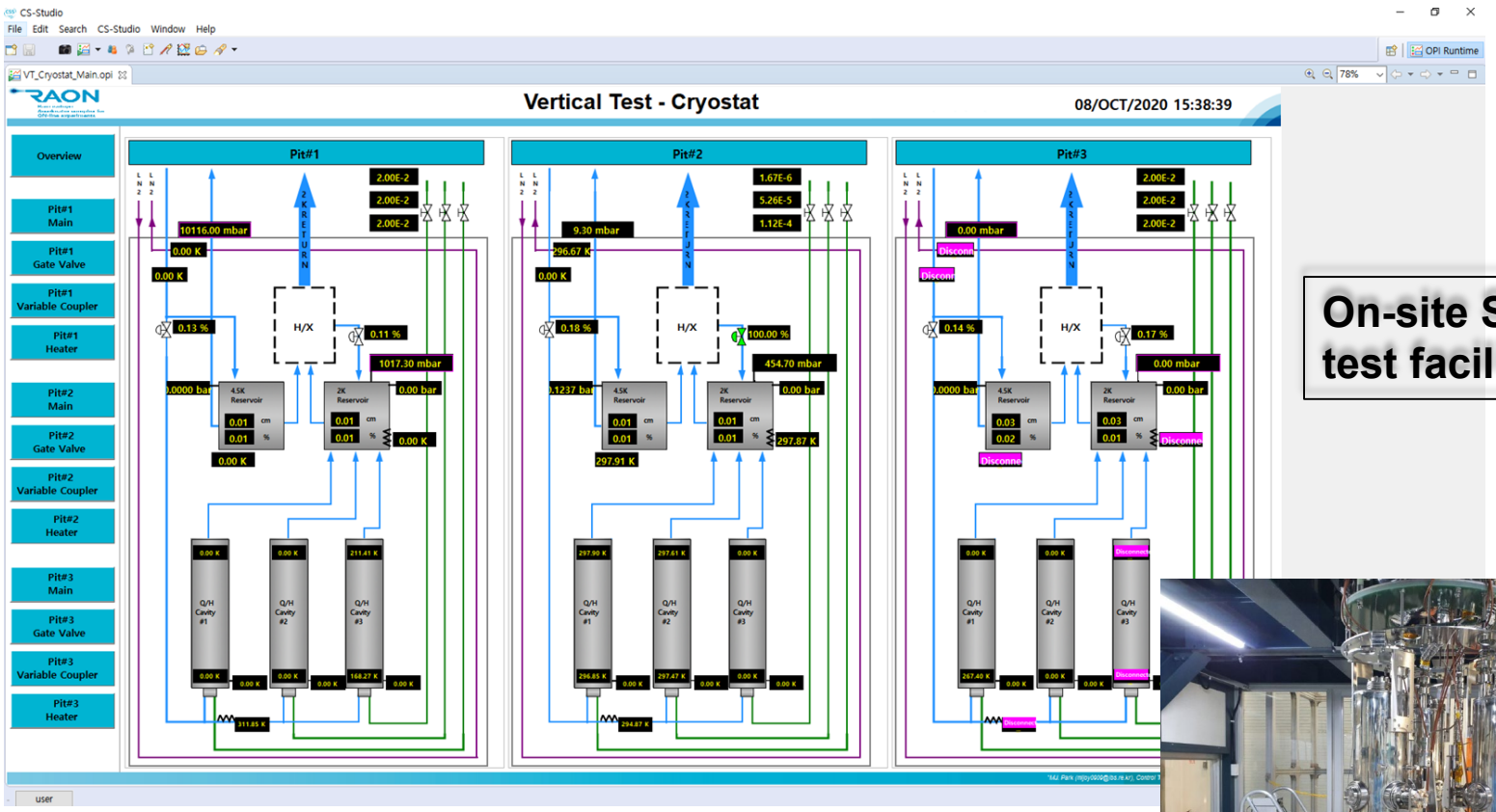


Clean beam line assembly

CM/Cryogenic Control Rack and SSPA

Installation completion and ready for beam commissioning in 2021

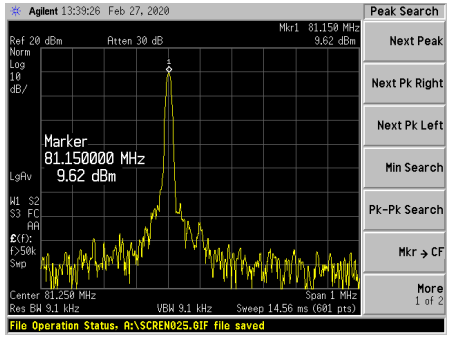
SRF Test facility



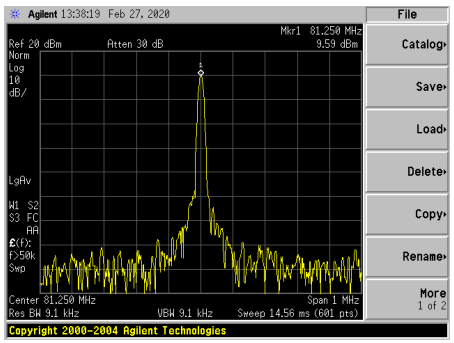
On-site SRF test facility

- 3 pits for VT; up to 3 cavities per pit
- 3 HT bunkers
- To cover all RAON cavities - QWR (82.125 MHz), HWR (162.5 MHz) and SSR1 & 2 (325 MHz)

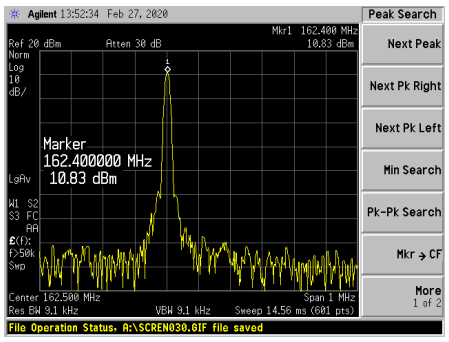
LLRF System



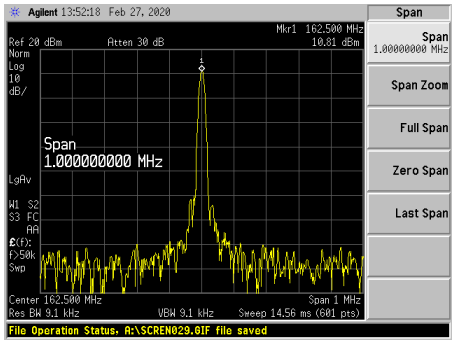
81.15 MHz (SEL)



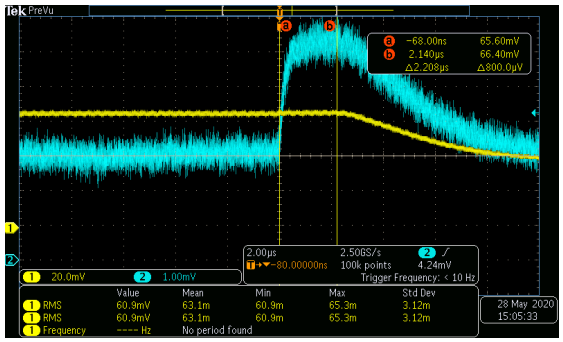
81.25 MHz (SEL)



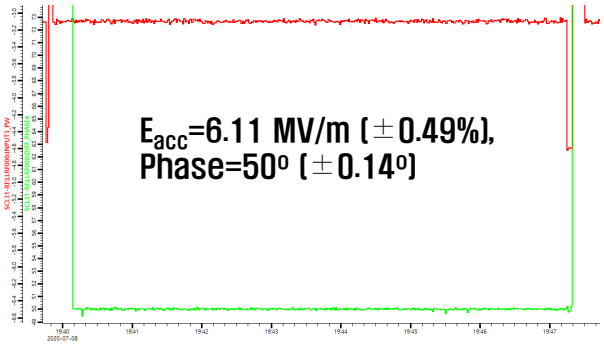
162.4 MHz (SEL)



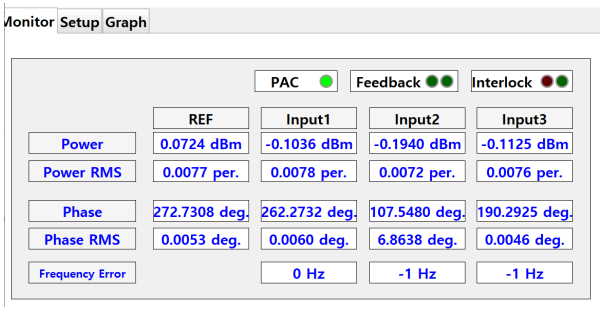
162.5 MHz (SEL)



LLRF Latency Test



QWR Cavity Control Test@SRF



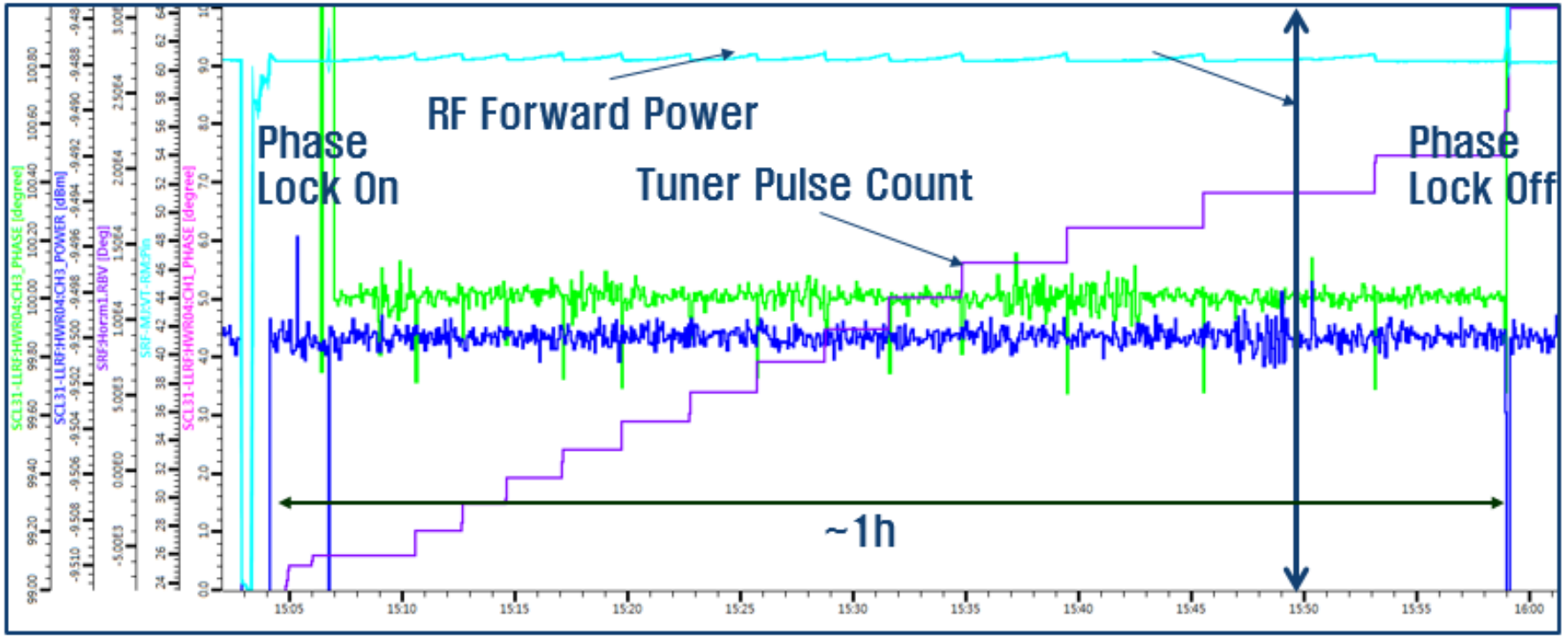
CSS OPI

- Test and confirmation with SEL(Self-Excited Loop) mode(±100 kHz) & GDR(Generator Driven Resonator) mode; GDR mode@nominal operation
- Realized, LLRF and control system via EPICS

RF Control Test of HWR#26

RF Control Test(Amplitude/Phase feedback with Tuner control)

RF Amplitude, Phase Control



- Target RF amplitude, 6.6 MV/m(±0.13%) < 1%, Phase=100º (±0.63º) < 1 deg
- Tuner operation threshold : +/- 5deg
- Control bandwidth: 90~160 Hz

Cryo-plant

- SCL3 cryoplant (4.2 kW @ 4.5 K)

Compressors and Oil Removal System (WCS)

Cold Box(CB)

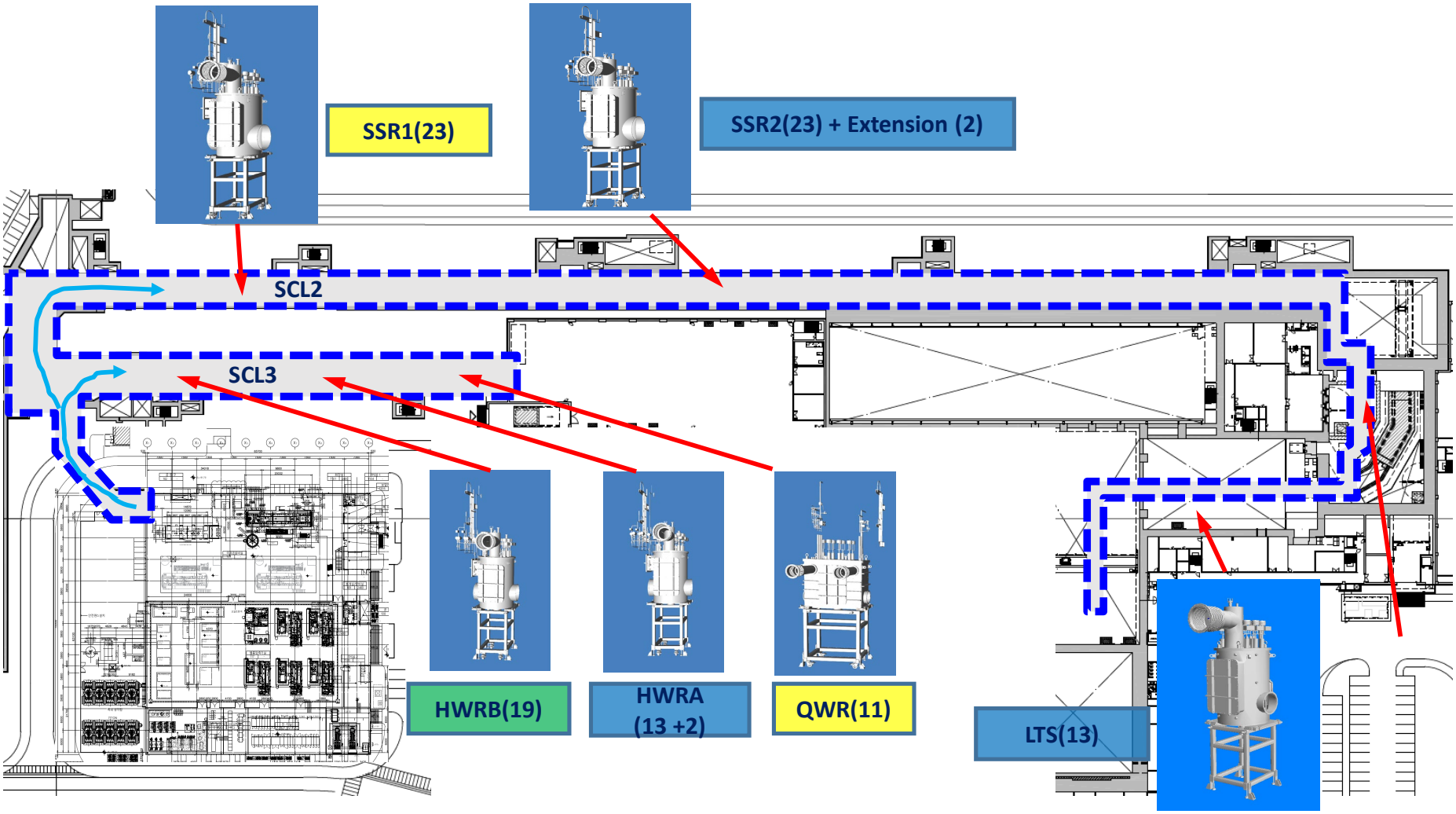
- SCL2 cryoplant (13.5 kW @ 4.5 K)

Compressors and Oil Removal System (WCS)

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

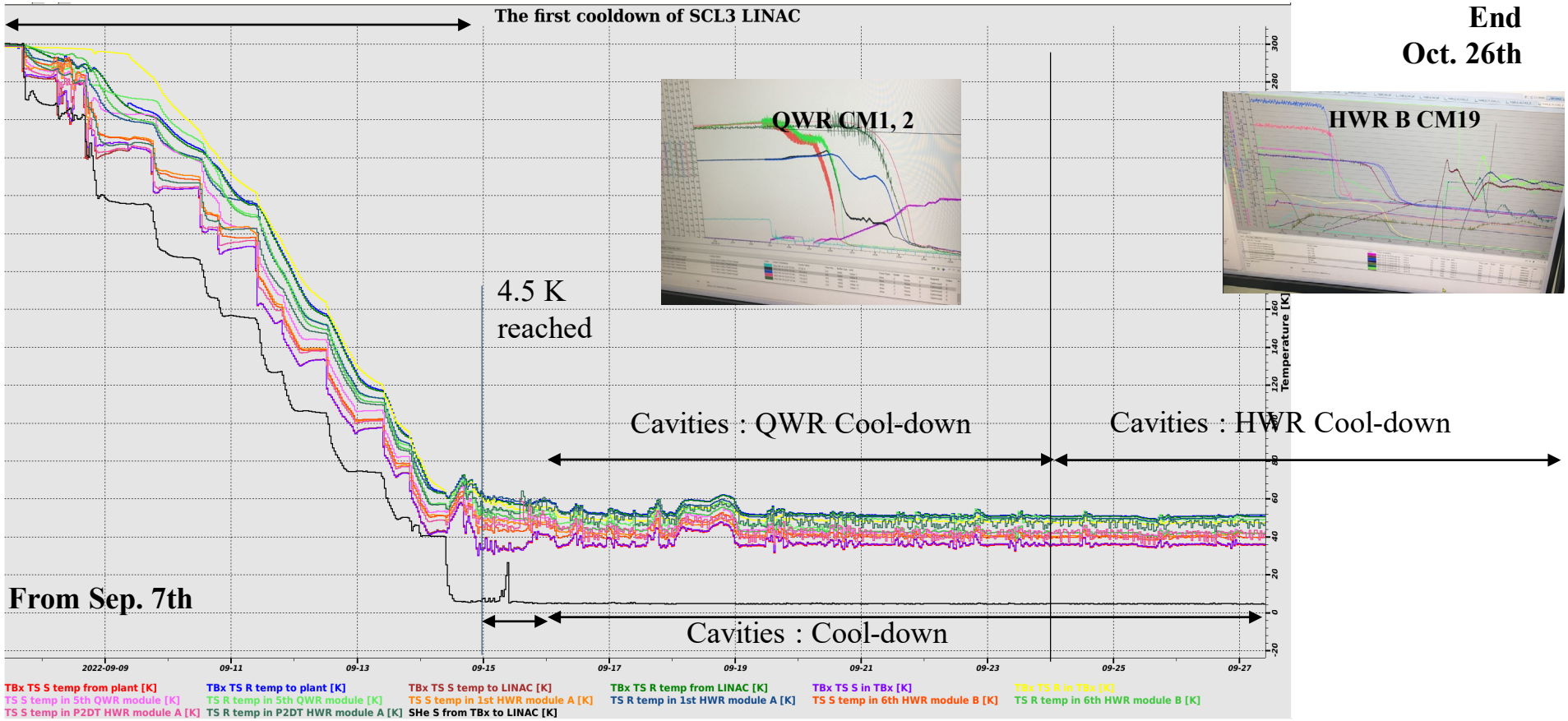
Cryogenic Distribution Systems

- Layout of cryogenic distribution system @ SCL3 and SCL2



The First Cool-Down Curve of SCL3

Cooling down cryogenic distribution system, thermal shields of all CM with SCL3 cryo-plant, simultaneously.



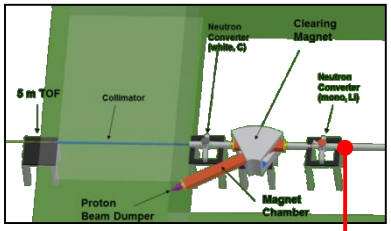
※ 1st cool-down of SCL3 : more conservative way – step cooling ! + manually checking dT @ cryogenic distribution system

Part 3.

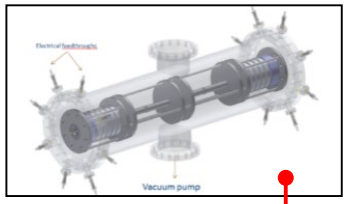
RI & Experimental Systems

RI & Experimental System

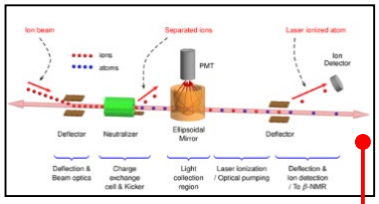
Neutron Facility



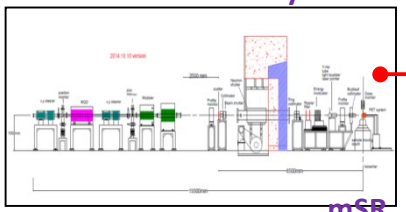
HPMMS



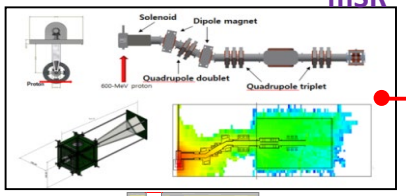
CLS



Bio-medical facility

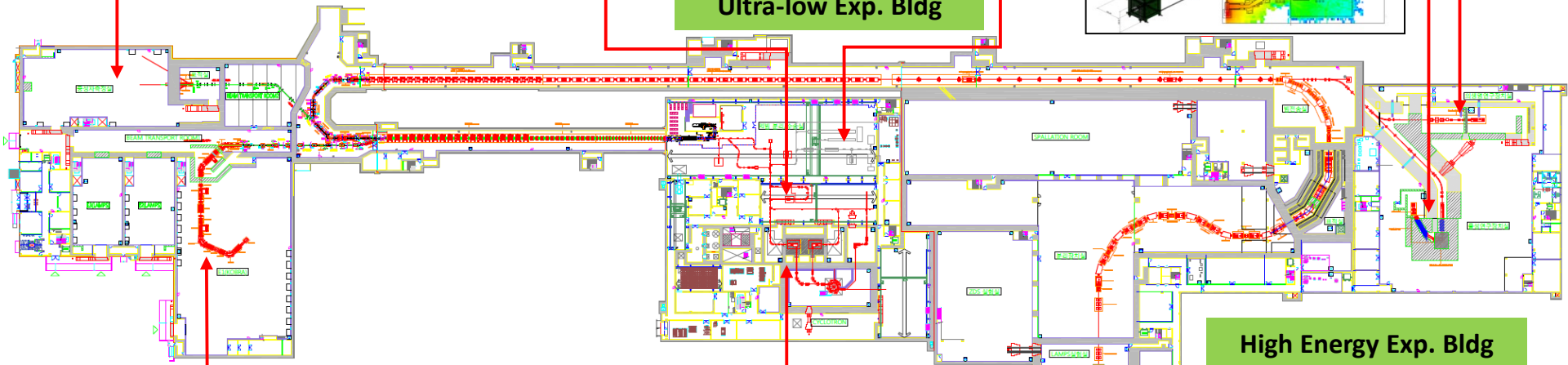


mSR



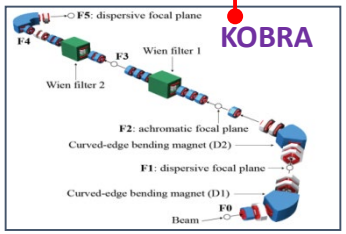
Low Energy Exp. Bldg

Ultra-low Exp. Bldg

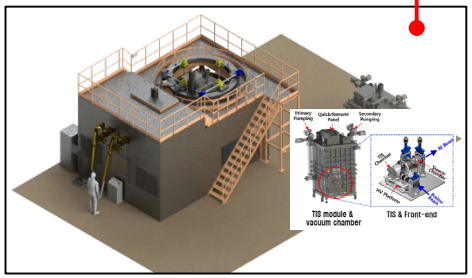


High Energy Exp. Bldg

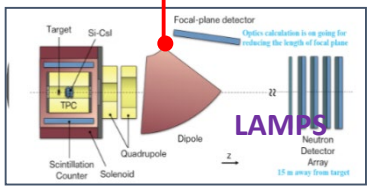
KOBRA



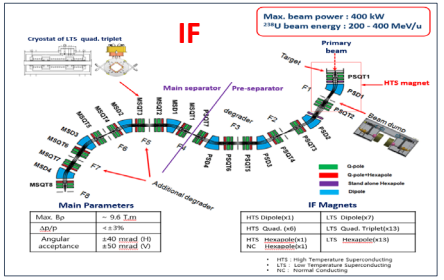
ISOL



LAMPS

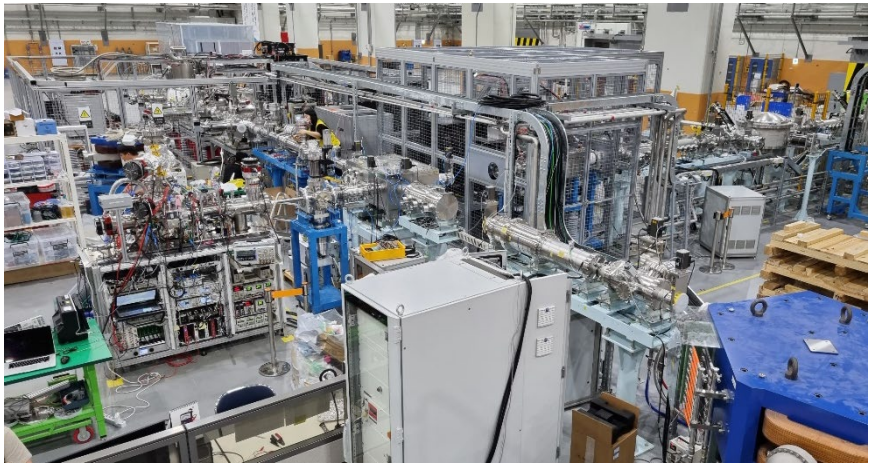


IF

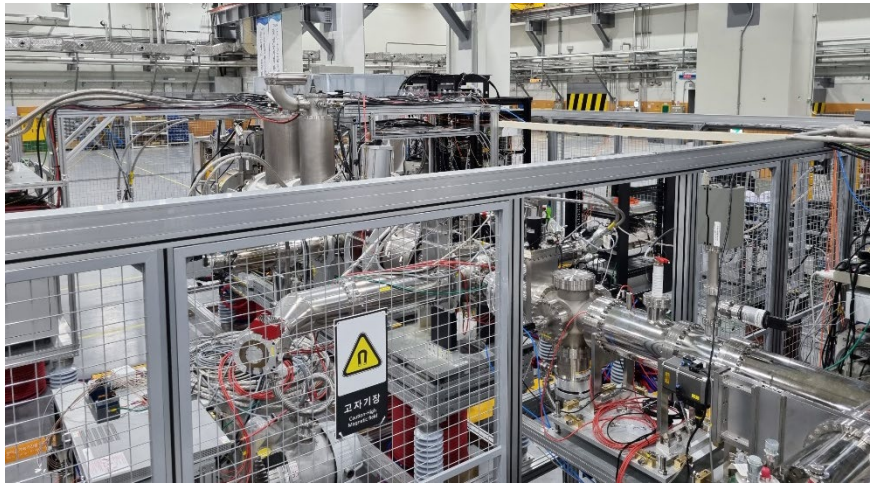


ISOL System

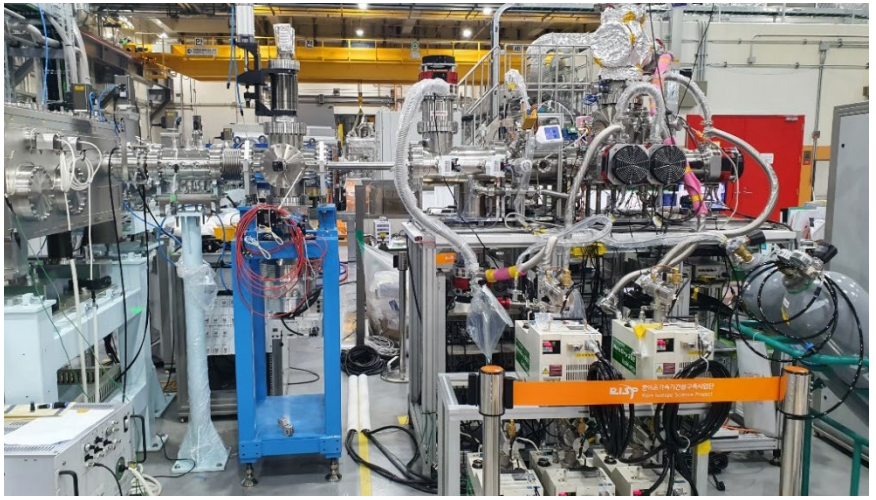
ISOL Target Room



ISOL Beam Line



EBIS Charge Breeder

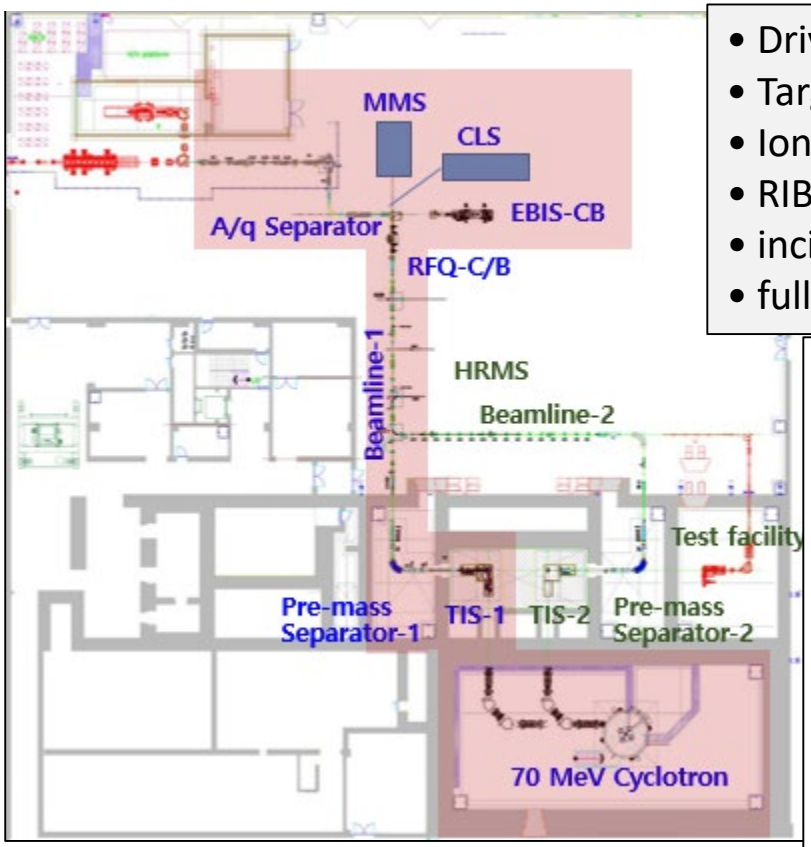


MMS/MR-TOF

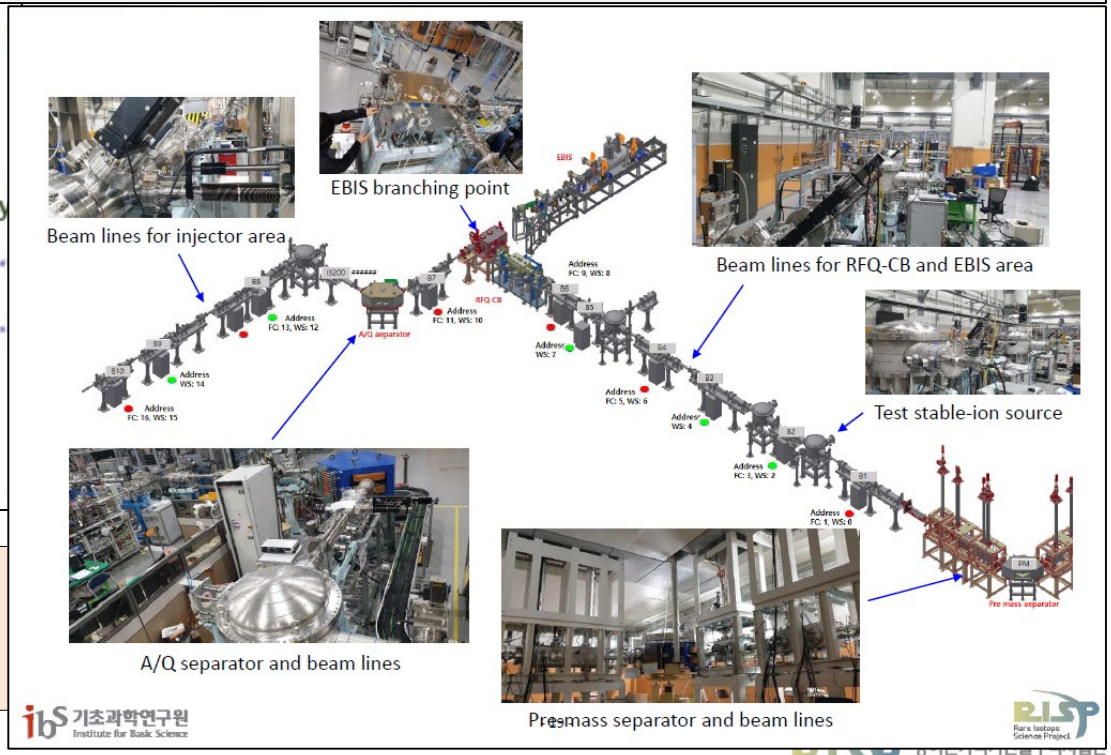
TIS, EBIS, RFQ-CB, beam line were tested with SI(Cs) beam, completed in 2021

ISOL System

Target ion Source (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+)

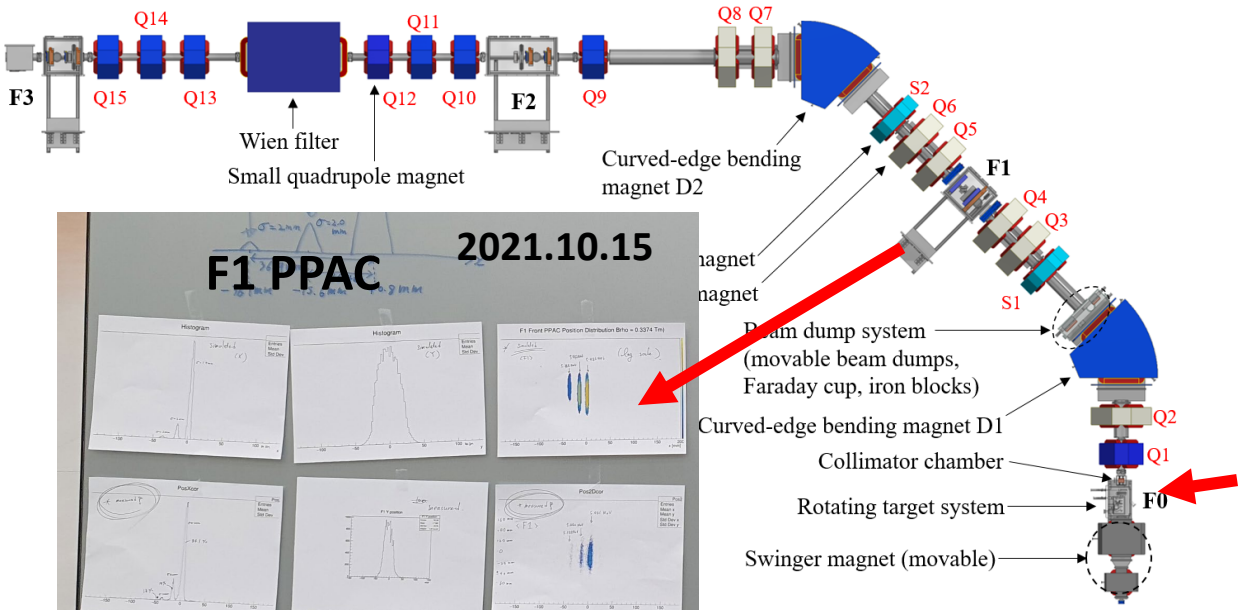


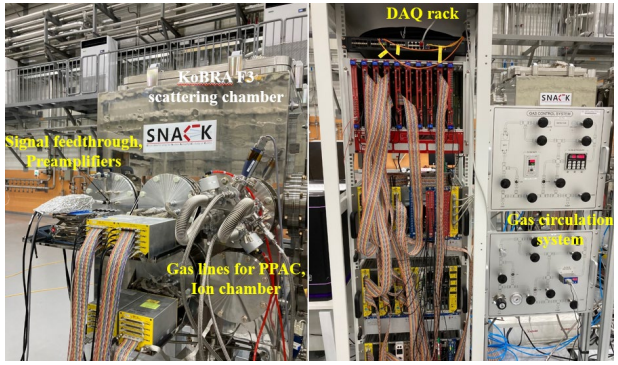
- Driver beam : proton 35<K<70 MeV, up to 70 kW
- Target : UCx, MgO, BN, CaO, BeO, SiC, etc
- Ion Source : Surface, RILIS, Plasma
- RIB : 6< A < 250, 10<K< 80 keV, 10^8 pps(Sn), >90% purity @Exp.
- incident to RFQ of Post accelerator 10 keV/u
- full remote maintenance system with TIS modularization

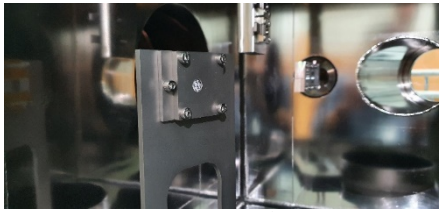


- ISOL beam lines including sub-systems are commissioned with Cs beam in 2021
- RI beam commissioning using SiC target (Q1 2023)

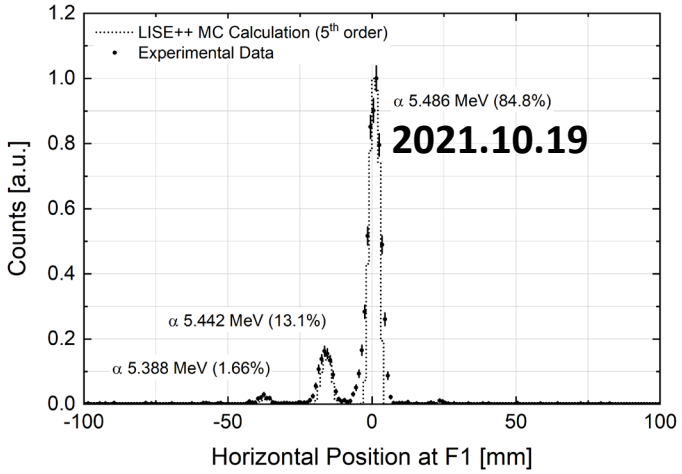
KoBRA Spectrometer commissioning in 2021



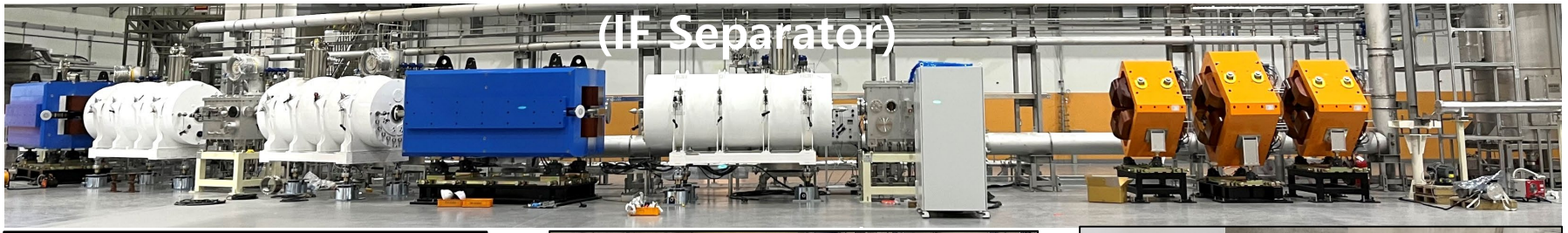


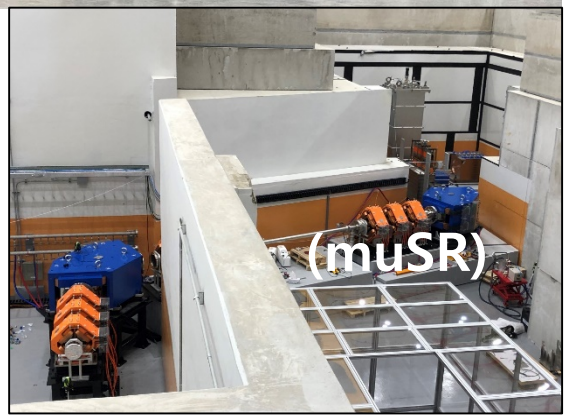


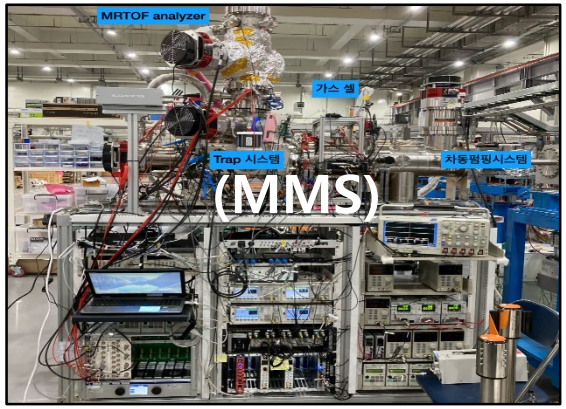
Alpha source (^{241}Am)

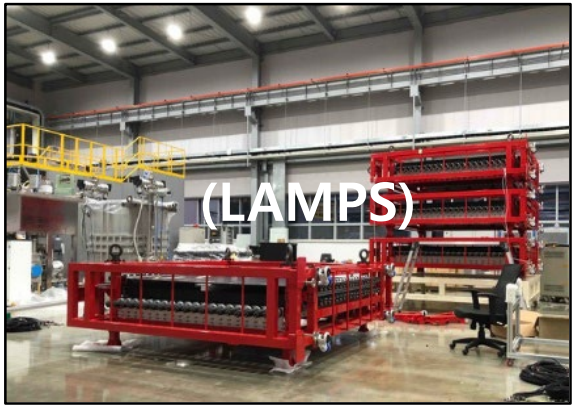


Other Experimental Systems









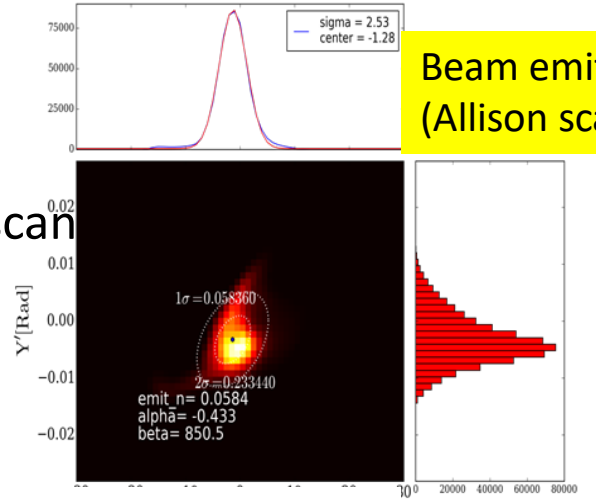
All exp. systems are installed and machine-commissioned by 2022

Part 4.

Beam Commissioning

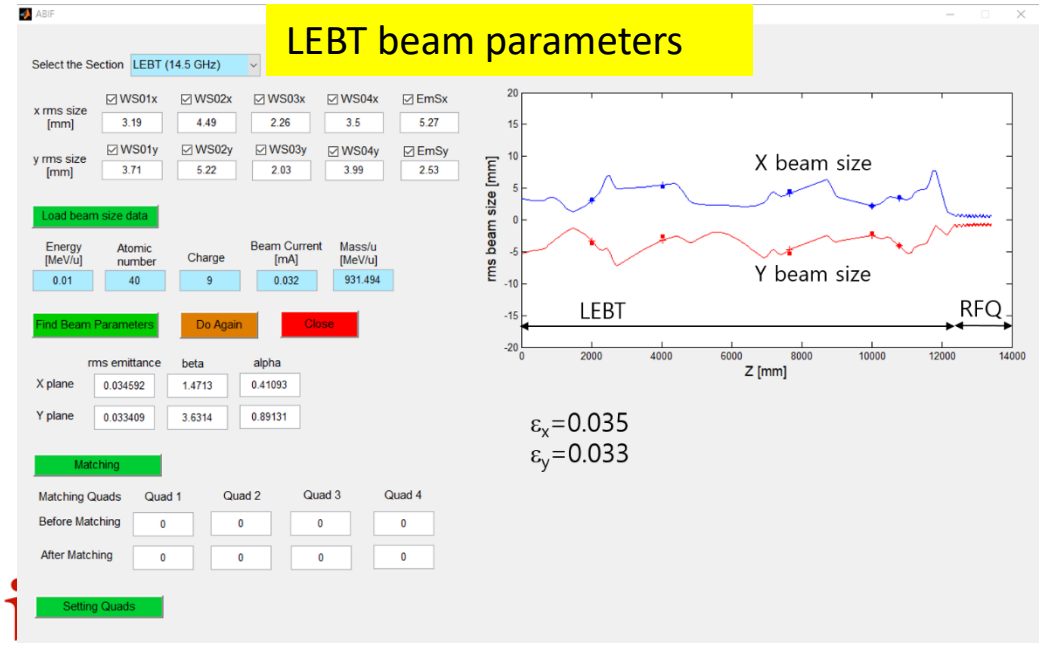
Beam commissioning (LEBT)

- Beam parameter measurements (Allison scanners, wirescanners)
  - measuring initial beam parameters (fitting beam sizes of wirescanners)
  - controlling optics when needed
  - do matching to RFQ
- Emittance measurement (Allison scanner, quad scan)
- Beams: Ar9+ (~30μA), Ar8+ (~47μA)

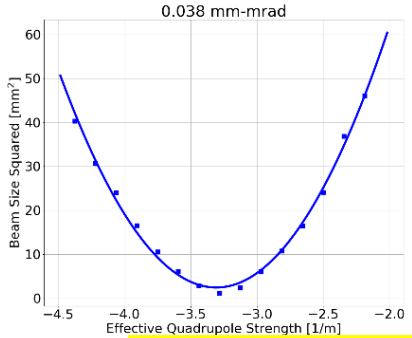


Beam emittance (Allison scanner)

LEBT beam parameters



ε_x=0.035
ε_y=0.033



Beam emittance (quad scan)

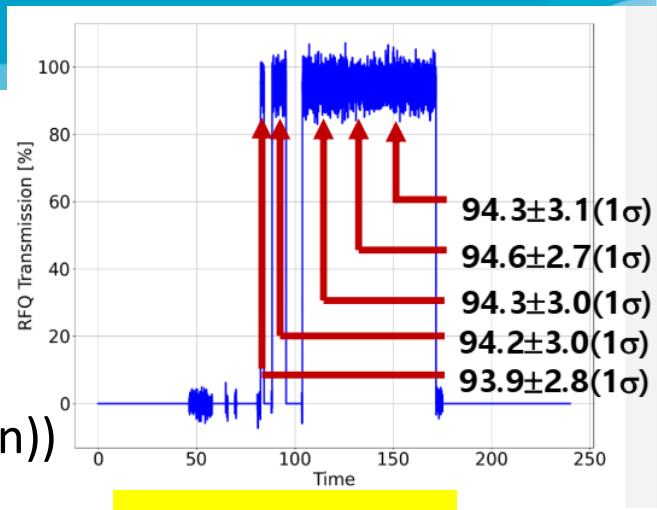
emittance comparison

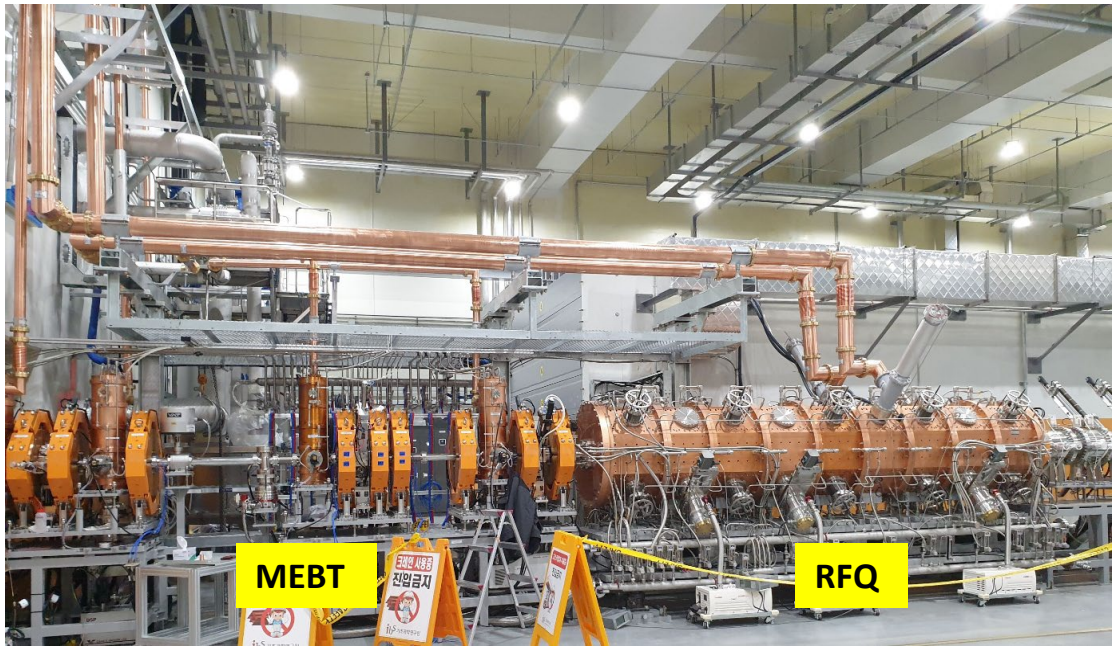
	X	Y
Allison	0.048	0.067
Quad Scan	0.041	0.038

RFQ Beam Transmission

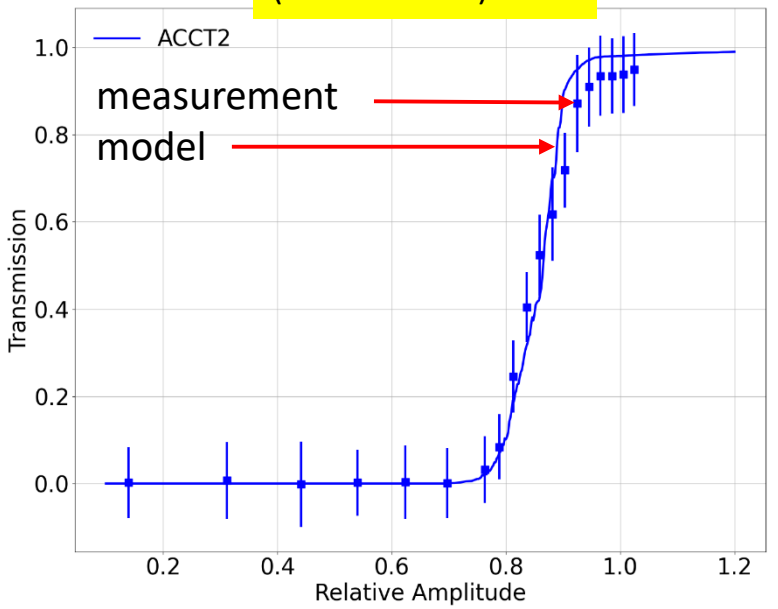
- RFQ RF set-point (Ar9+, Ar8+):
  - beam transmission measured using MEBT ACCT2
  - Fitting against model

  * Measured transmission = 94 % (simulation = 98%)
- Cavity RF power: 51.5 kW (Design ~39.1 kW (20% margin))



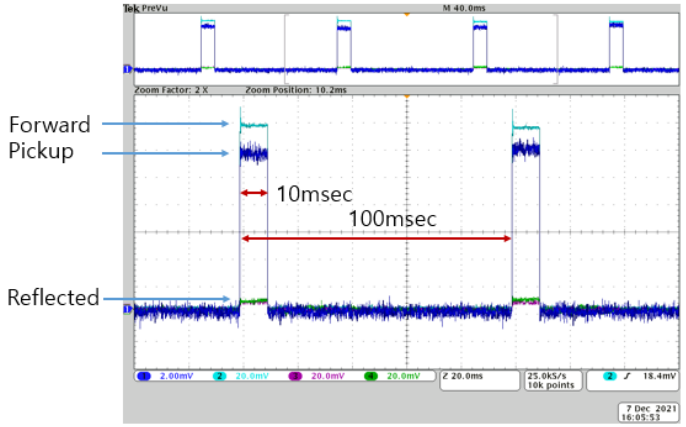


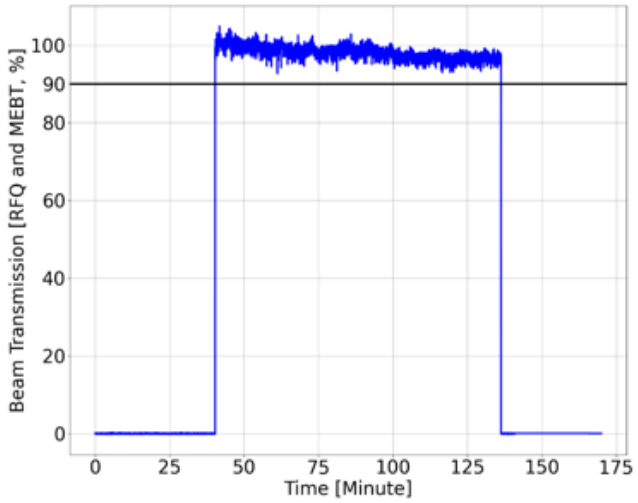
RFQ RF set-point
(error bar: 3σ)



Injector Transmission

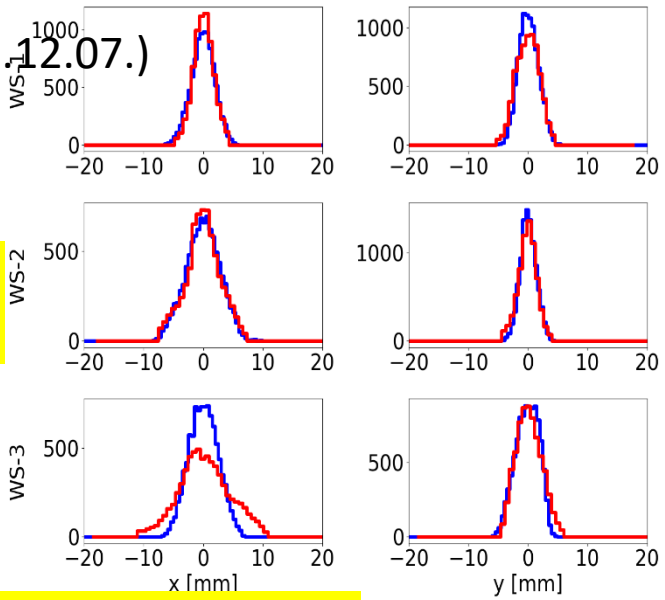
- 10% beam duty operation: 96 minutes, 10Hz, 10msec (2021.12.07.)
  * Injector transmission > 94%
- MEBT beam emittance measurement based on quad scan



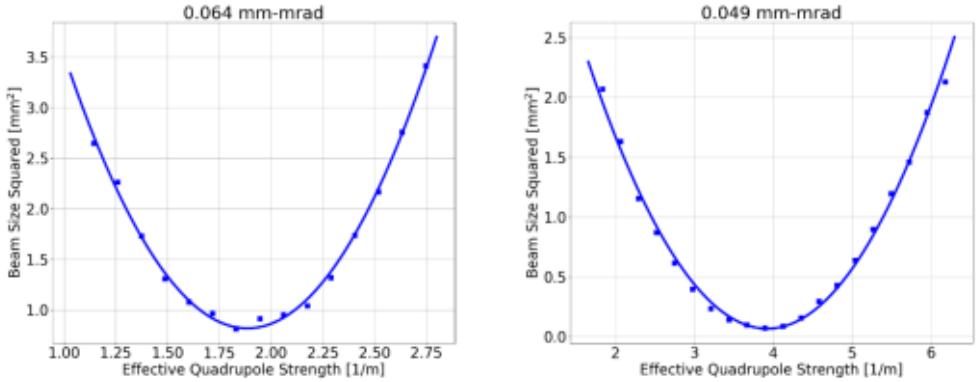


Injector beam transmission

TRACK (blue)
Measured(red)



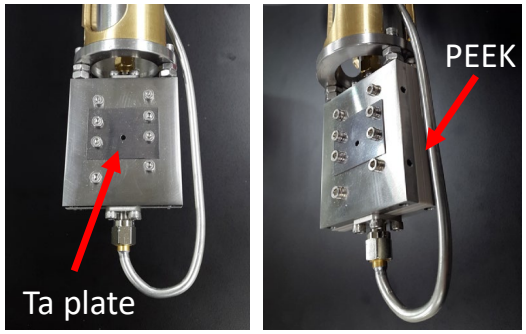
MEBT quad scan
emittance measurement



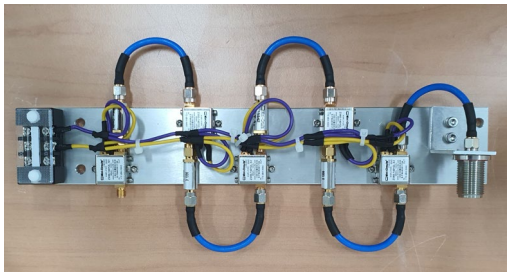
ε_x = 0.064 mm-mrad
ε_y = 0.049 mm-mrad

Bunch Length Measurement, Fast-FC

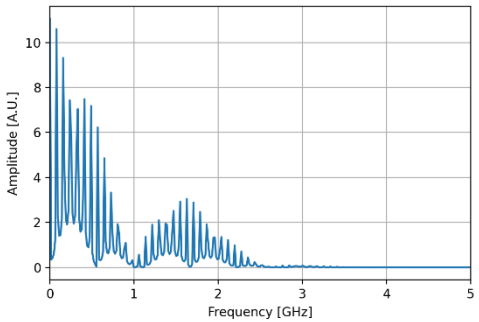
- Fabrication of Stripline type Fast Faraday Cup



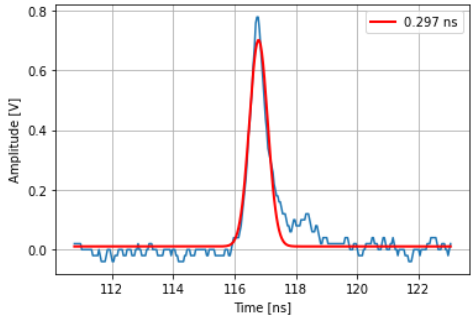
- Semi-rigid SMA cable in vacuum
- PEEK insulator
- Ta plate in front of FFC
- Bolting at irregular position

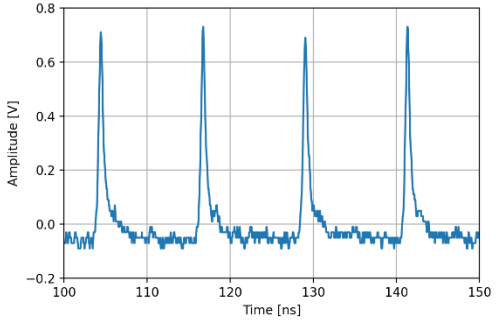


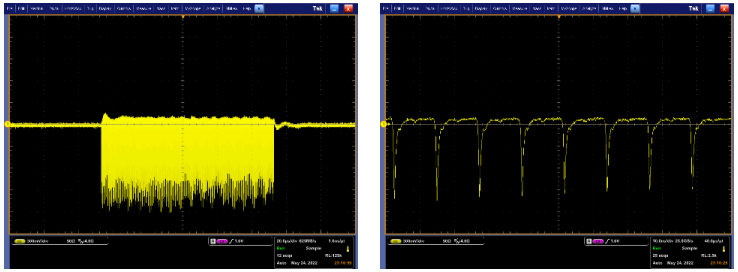
Amplifier (43 dB Gain)
Bandwidth 300 kHz ~ 14 GHz



Frequency component < 3 GHz
With 0.13 ns bunch length





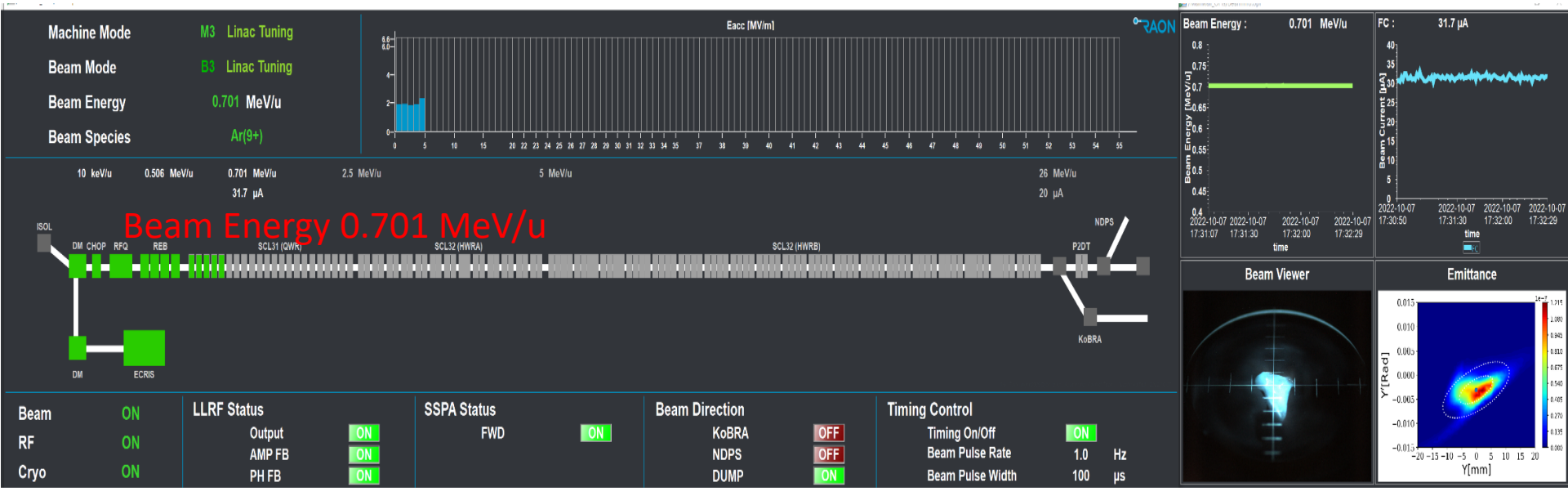


Oscilloscope (4 GHz, 25 GSPS)

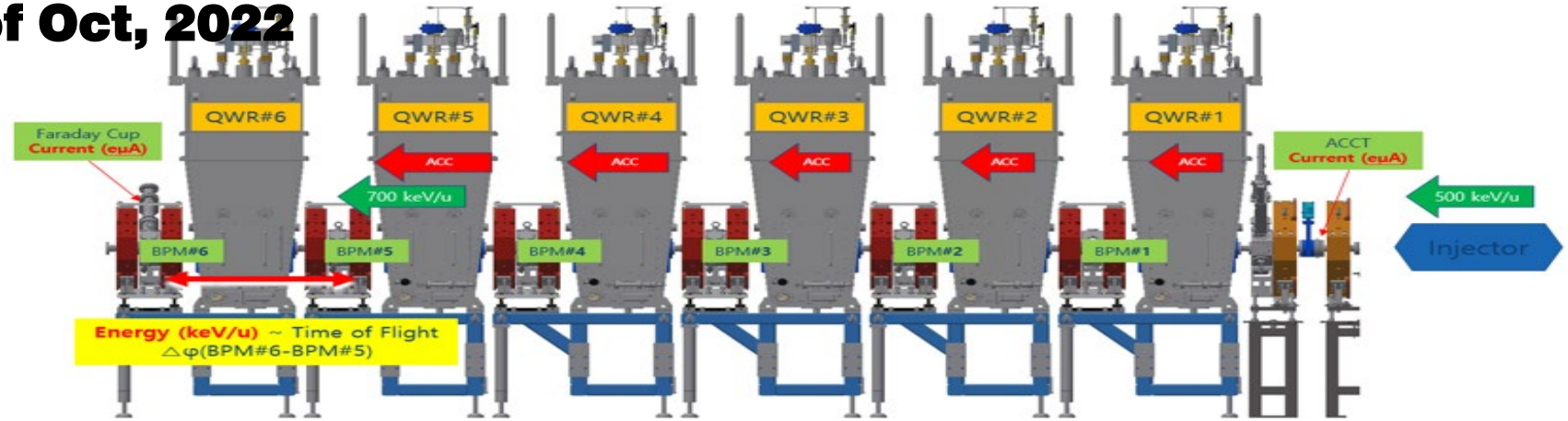
- Ar 8+, 50 uA, at the end of MEBT (4 bunchers)
- 100 μs macro pulse commissioning beam

- Expected peak amplitude was ~ 4 mV
- RF amplifier and oscilloscope prepared, considering frequency component

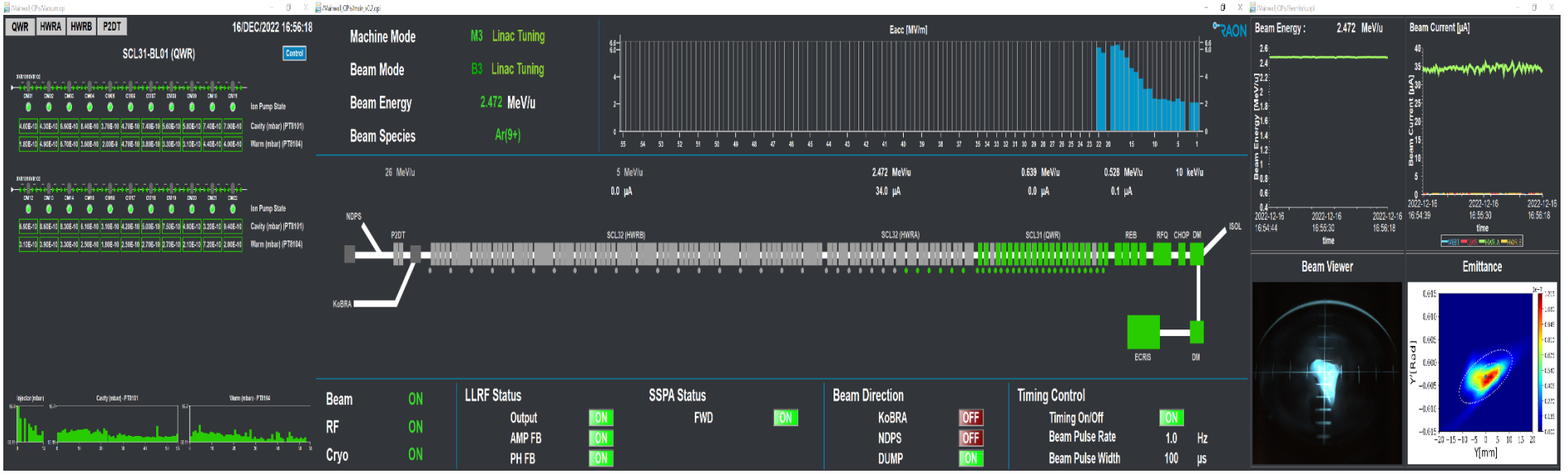
The 1st SCL3 Beam Commissioning (Oct. 7, 2022)



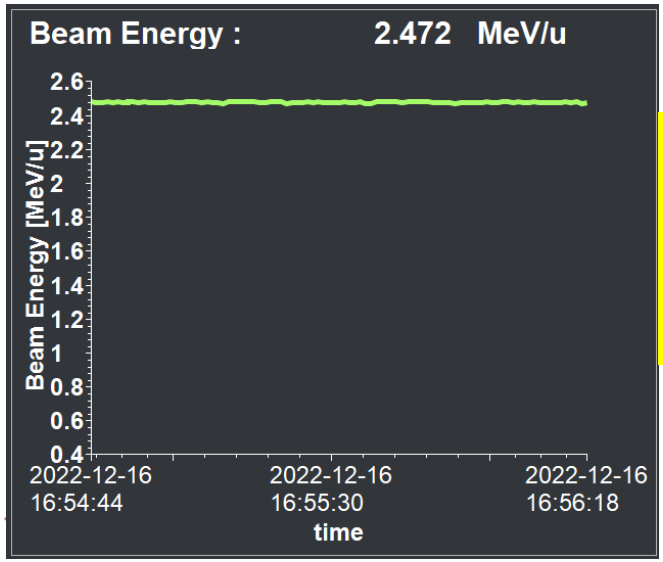
Ar^{9+} beams accelerated by QWR #1~#5 on the 7th of Oct, 2022



The 2nd SCL3 Beam Commissioning (Dec. 16, 2022)



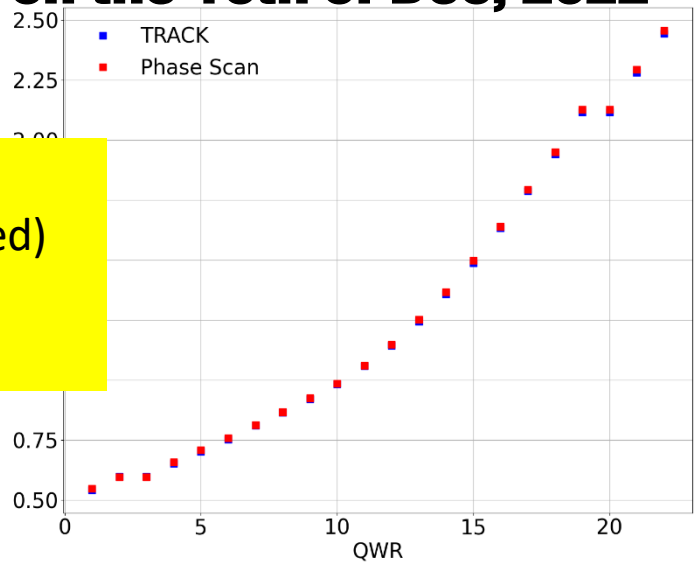
Ar^{9+} beams accelerated by QWR #1~#22 on the 16th of Dec, 2022



Final Results :

- 2.457 MeV/u (Measured)
- 2.444 MeV/u (TRACK)

QWR#3, #20 excluded

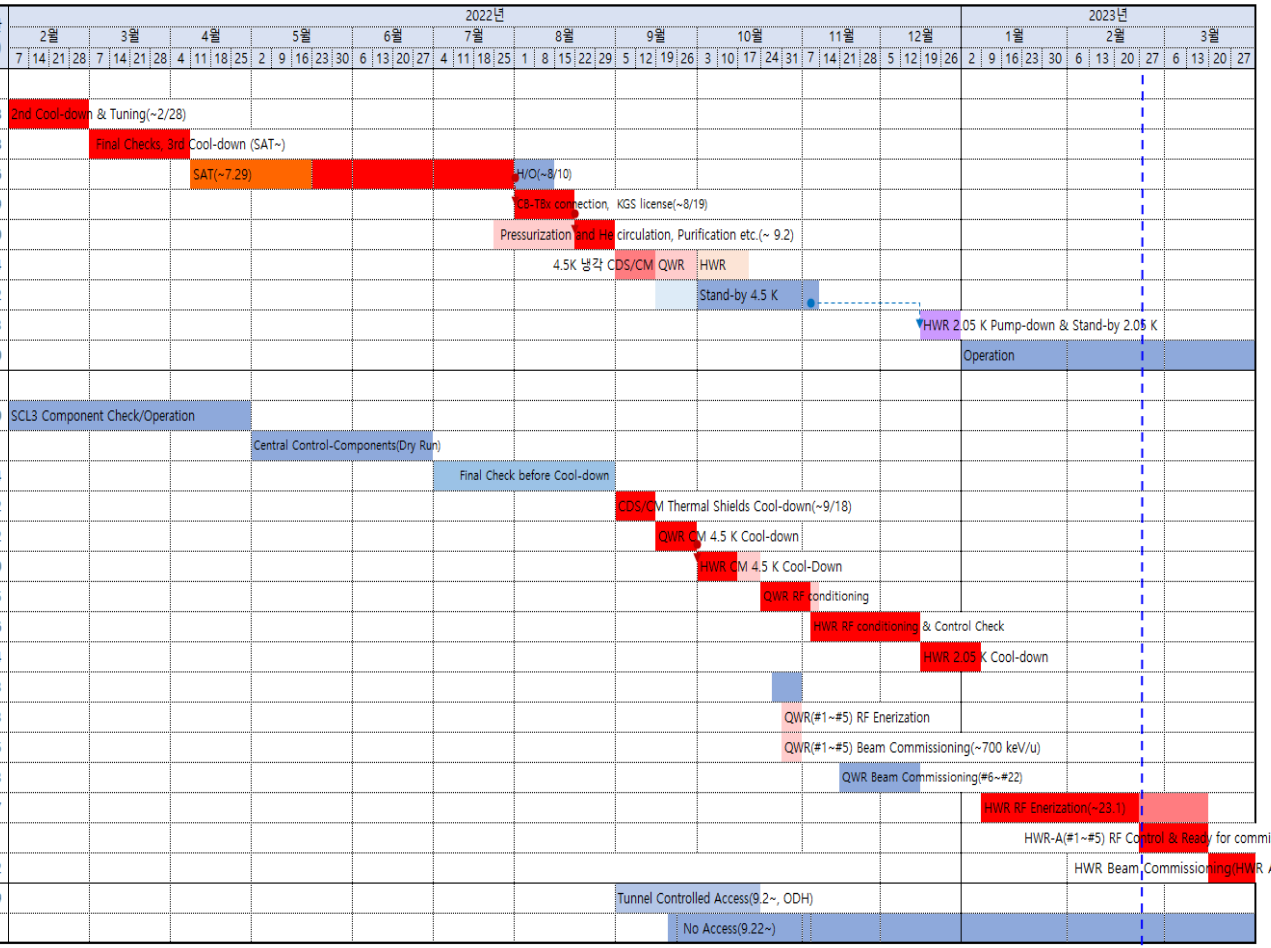


SCL3 Beam Commissioning Plan

● 작성일 : 2023. 02.07

● 작성자 : 중이온가속기연구소

구분 (System)	주요업무 (Activity)	시작 (Start)	완료 (Finish)	기간 (day)
Cryogenics System	★ SCL3 Cryoplant			
	• 2nd Cool-down & Tuning	22-02-01	22-02-28	28
	• Final Checks, 3rd Cool-down (SAT~)	22-03-01	22-04-07	38
	• SAT(~7.29) & Handover	22-04-07	22-08-10	126
	• CB-TBx connection, KGS license	22-08-01	22-08-19	19
	• Pressurization and He circulation, Purification	22-07-29	22-09-06	40
	• SCL3 4.5 K Cool-down	22-09-07	22-10-20	44
	• Stand-by @4.5 K	22-10-01	22-11-11	42
	• HWR 2.05 K Pump-down & Stand-by@2.05	22-12-19	22-12-31	13
	• Operation	23-01-01	23-03-31	90
SCL3 QWR/HWR	★ SCL3 QWR/HWR CM & RF			
	• SCL3 Component Check/Operation	22-01-01	22-04-30	120
	• Central Control-Components(Dry Run)	22-05-01	22-06-30	61
	• Final Check before Cool-down	22-07-01	22-09-02	64
	• CDS/CM Thermal Shields Cool-down	22-09-07	22-09-18	12
	• QWR CM 4.5 K Cool-down(22EA)	22-09-19	22-09-30	12
	• HWR CM 4.5 K Cool-down(33EA)	22-10-01	22-10-20	20
	• QWR RF conditioning & Control Check	22-10-21	22-11-04	15
	• HWR RF conditioning & Control Check	22-11-01	22-12-16	46
	• HWR 2.05 K Cool-down & Stand-by	22-12-19	23-01-11	24
	• Preparation for Beam commissioning	22-10-24	22-10-26	3
	• QWR(#1~#5) RF Enerization	22-10-24	22-10-26	3
	• QWR(#1~#5) Beam Commissioning(~700 ke	22-10-27	22-10-31	5
	• QWR Beam Commissioning(#6~#22)	22-11-14	22-12-16	33
	• HWR RF Enerization@2.05K	23-01-12	23-03-19	67
	- HWR RF Control & Ready for commissioning	23-02-27	23-03-19	21
	• HWR Beam Commissioning(HWR A/B)	23-03-20	23-03-31	12
SCL3 Tunnel	• Controlled Access	22-09-02	22-10-20	49
	• No Access	22-09-22	23-03-31	191



- Finished 2 K cool-down of SCL3 on Jan. 11, 2023.
- Commissioning of SCL3 to be finished until March 2023
- From March 2023, beams on KoBRA spectrometer

Part 5.

Summary & Outlook

Summary & Outlook

- **Injector beam commissioning was carried out, achieving machine setting and key measurements :**
  - measured beam parameters (energy, emittance, Twiss parameters, beam sizes etc)
  - capable of controlling LEBT and MEBT beam optics freely as needed
  - achieved beam transmission of 95% max (routinely > 90%)
  - machine verification including diagnostics devices
- **RAON is preparing for Linac(SCL3) beam commissioning**
  - 1st/2nd beam commissioning using 22 QWR CMs in SCL3 were successfully done
  - ECR → SCL3 → KoBRA using Ar-40(9+) in Q1/Q2 of 2023
  - Cyclotron → ISOL for RI beam extraction is expected in Q1 of 2023
- **Plan for SIB/RIB experiments**
  - RIBs from ISOL to be injected into SCL3 in Q4 of 2023
  - SIB experiments(ECR→SCL3 → KoBRA/NDPS) will be carried out in Q4 of 2023
  - RIB experiments in ISOL beamline using Al isotope beams
- **Plan for SCL2 linac construction**
  - CM(SSR1, SSR2) R&D project : 2022.12~2025.12
  - SCL2 construction is expected to begin in 2026


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.
감사합니다.
Thank you