

Commissioning Status of the Injector of RAON Superconducting Accelerator

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IPAC22, Bangkok, Thailand

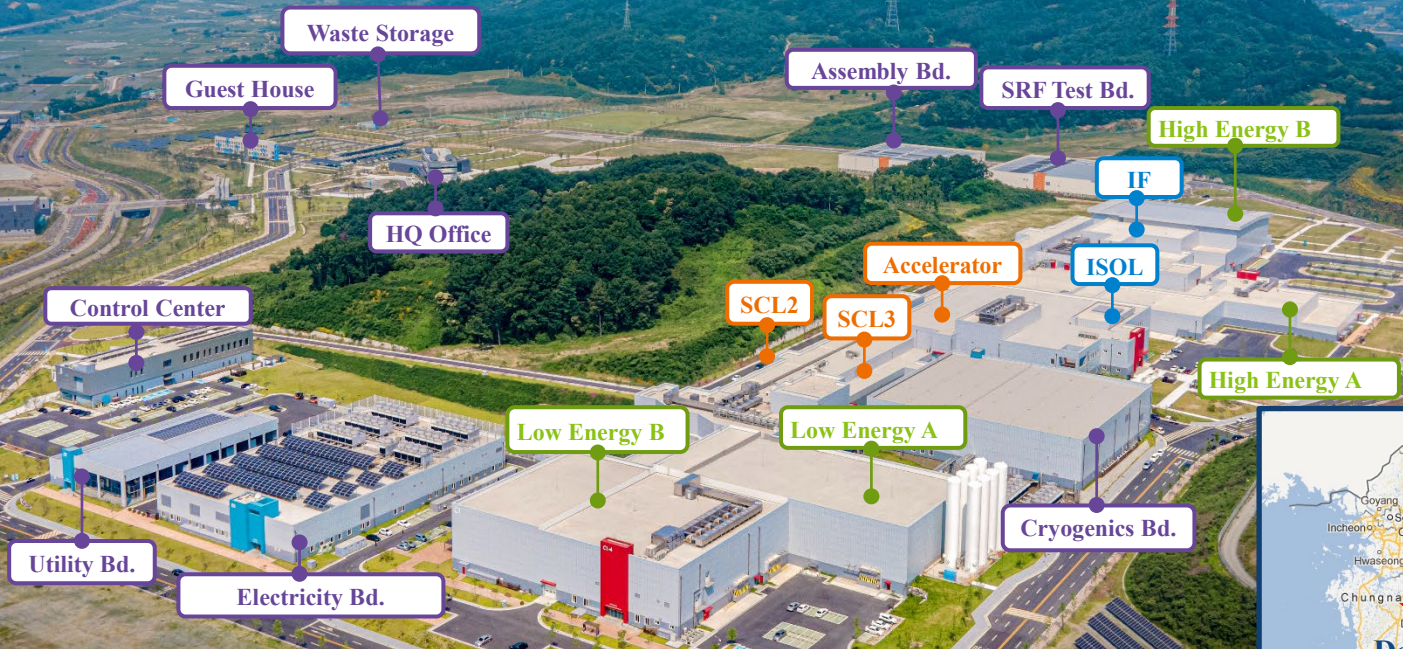


- RAON status
- Injector beam commissioning
- Summary

Bird-eye view of RAON site

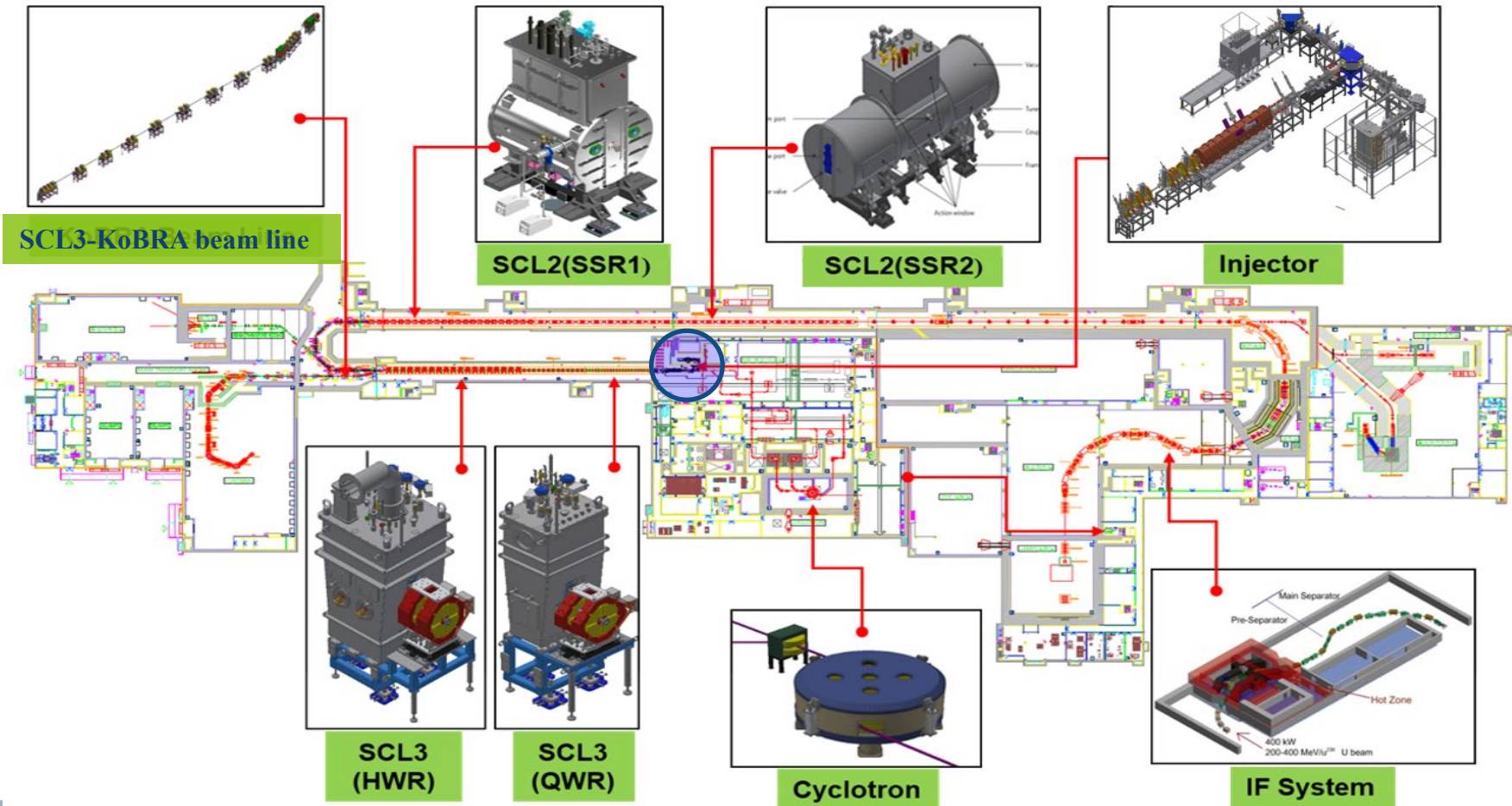
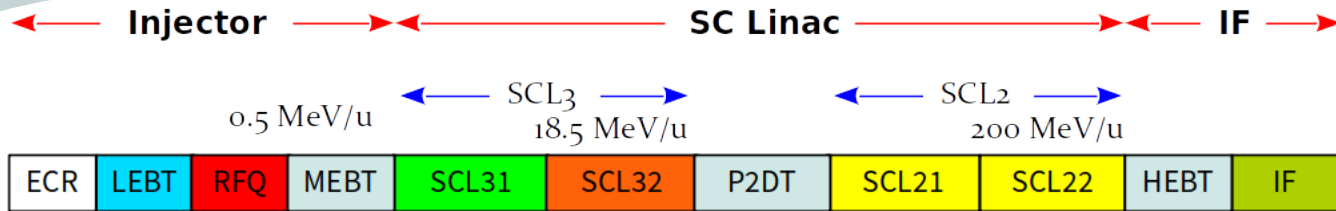
I Accelerator System
IRI producing System

I Conventional Utilities
I Experimental System



- ◆ RAON project started in Dec. 2011, and TDR in 2013.
- ◆ Site excavation and construction from Feb. 2017 to Aug. 2020.
- ◆ Beneficial occupancy of accelerator building for installing accelerator equipment (mid 2019)

RAON Accelerator Systems

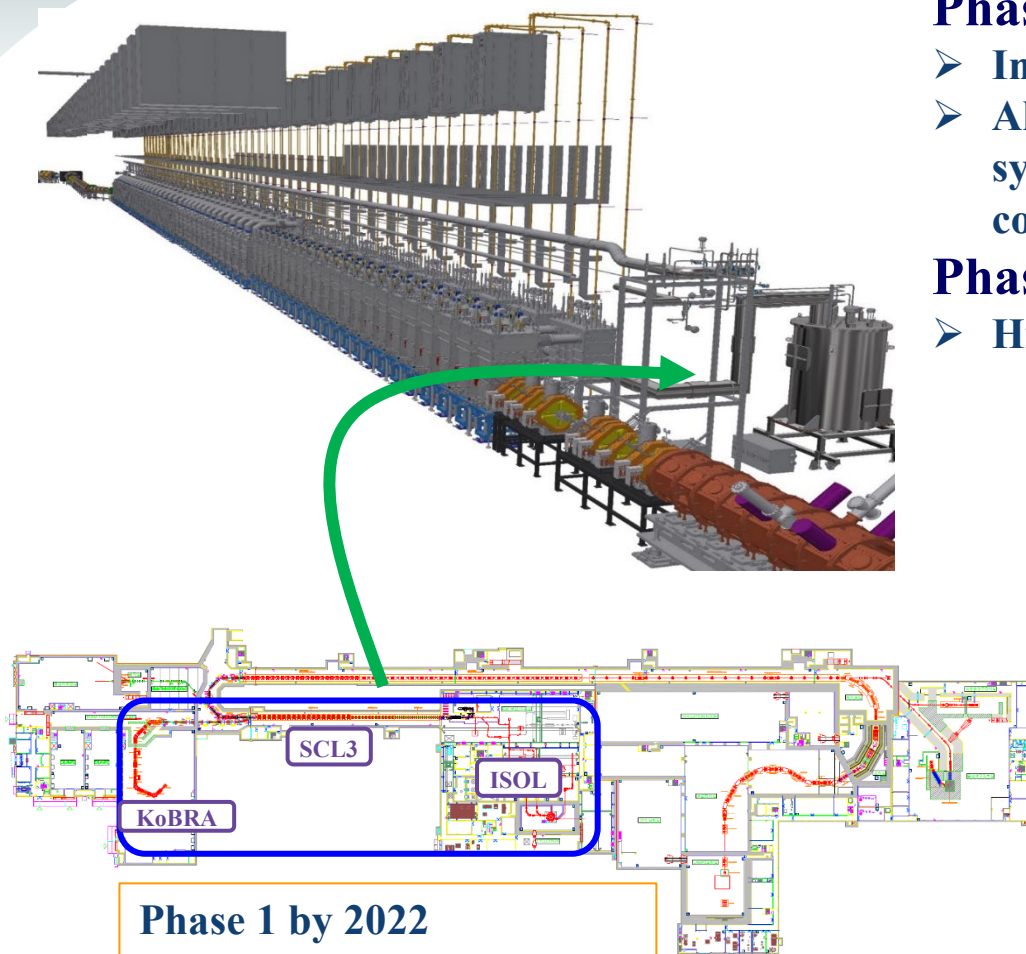


Phase 1(~2022)

- Injector, SCL3, ISOL beam commissioned
- All the experimental systems including IF system to be installed and machine commissioned

Phase 2(~2030)

- High energy Linac, SCL2



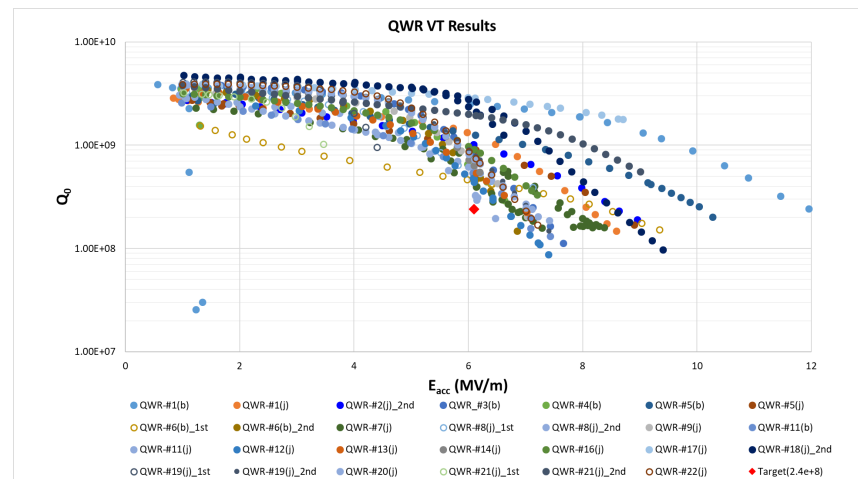
SCL3 installation done on 2021 & commissioning on Oct. 2022.

SCL3 Installation

- Cryomodule(CM) & warm section is clean assembled in the clean booth@tunnel
- Focusing by normal conducting quad doublets
- Niobium cavities operating at 2K and 4.5K
- Waiting for cool-down



Warm section



Installation completed 2021

22 of QWR & 33 of HWR CMs

Cryoplant & distribution system

Commissioning of SCL3 cryogenic system is underway (July 2022)

■ 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)

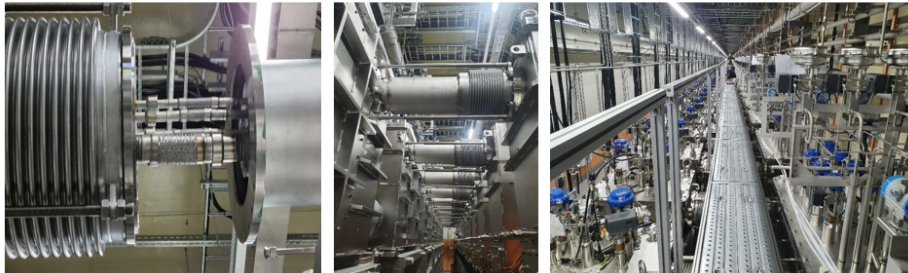


Cold Box (CB)

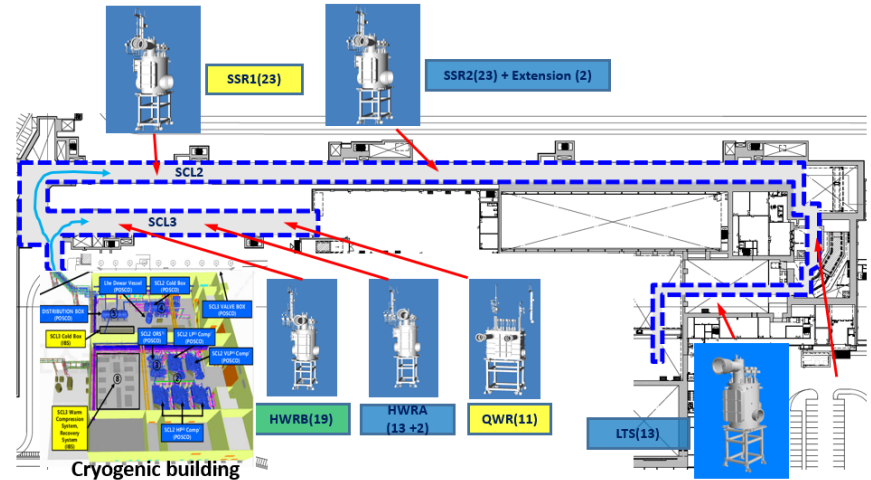
(Left warm side, right – cold side)

■ Cryogenic Distribution System

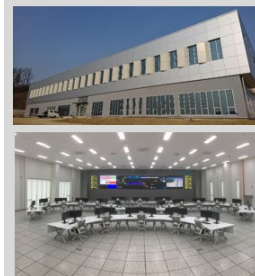
- All QWR VBx are installed and assembled (VBx-VBx, VBx-CM).
- 44 HWR VBx are installed and assembled @ SCL3.
- Cryogenic transfer Lines are being installed and preparing for commissioning
- SSR1 VBx : 23 ea, SSR2 VBx : being installed and preparation for pre-commissioning



■ Layout of cryogenic distribution system @ SCL3 and SCL2



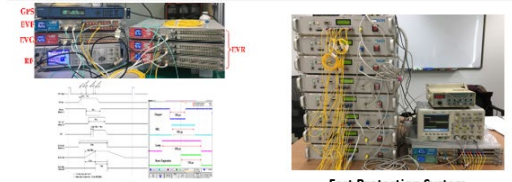
Control Center



Main Control Room

Data Storage System

Integrated Control System



Timing System

Fast Protection System

Local Control System

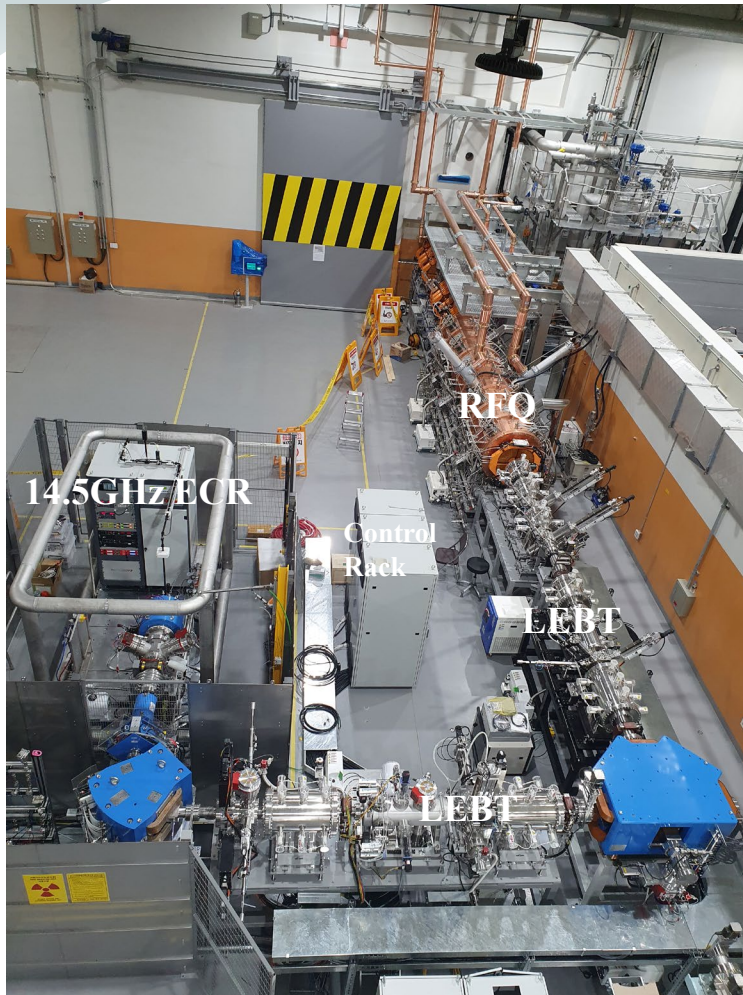


EPICS IOC Controllers

SCL3 Control System(43)

Beam Diagnostics Control System

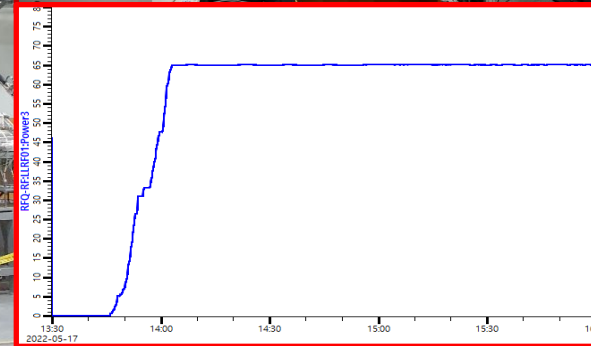
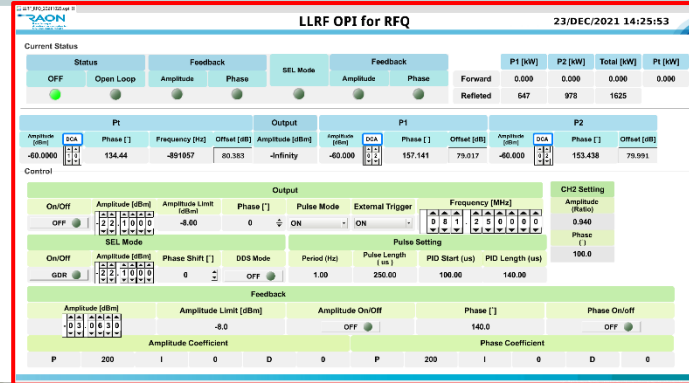
Injector Layout



- Two ECR-IS on high voltage platforms
 - 14.5 GHz ECR ion source
 - 28 GHz superconducting ECR ion source
- LEBT ($E = 10 \text{ keV/u}$)
 - 10 keV/u, dual bending magnet
 - Chopper & Electrostatic quads, Instrumentation

Radiofrequency Quadrupole

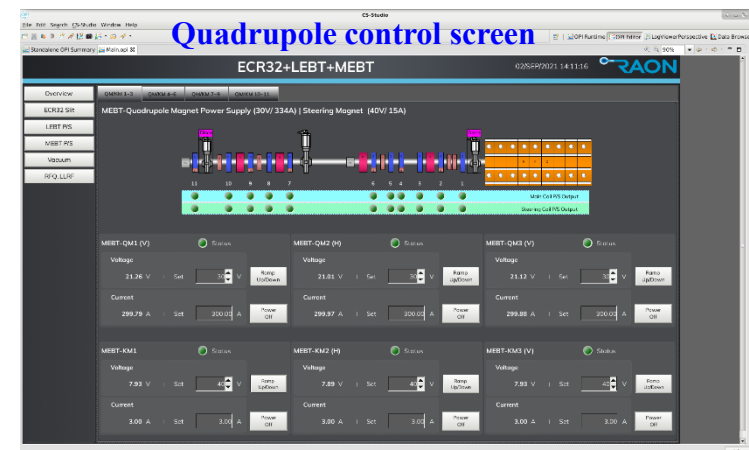
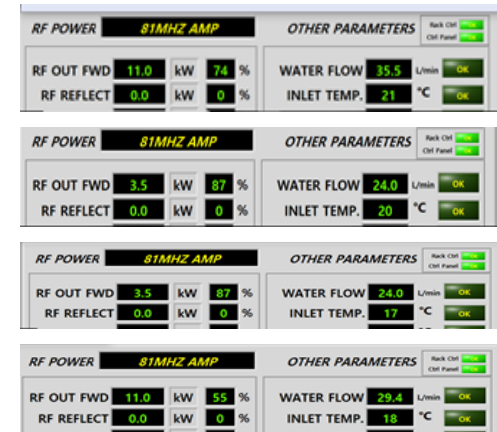
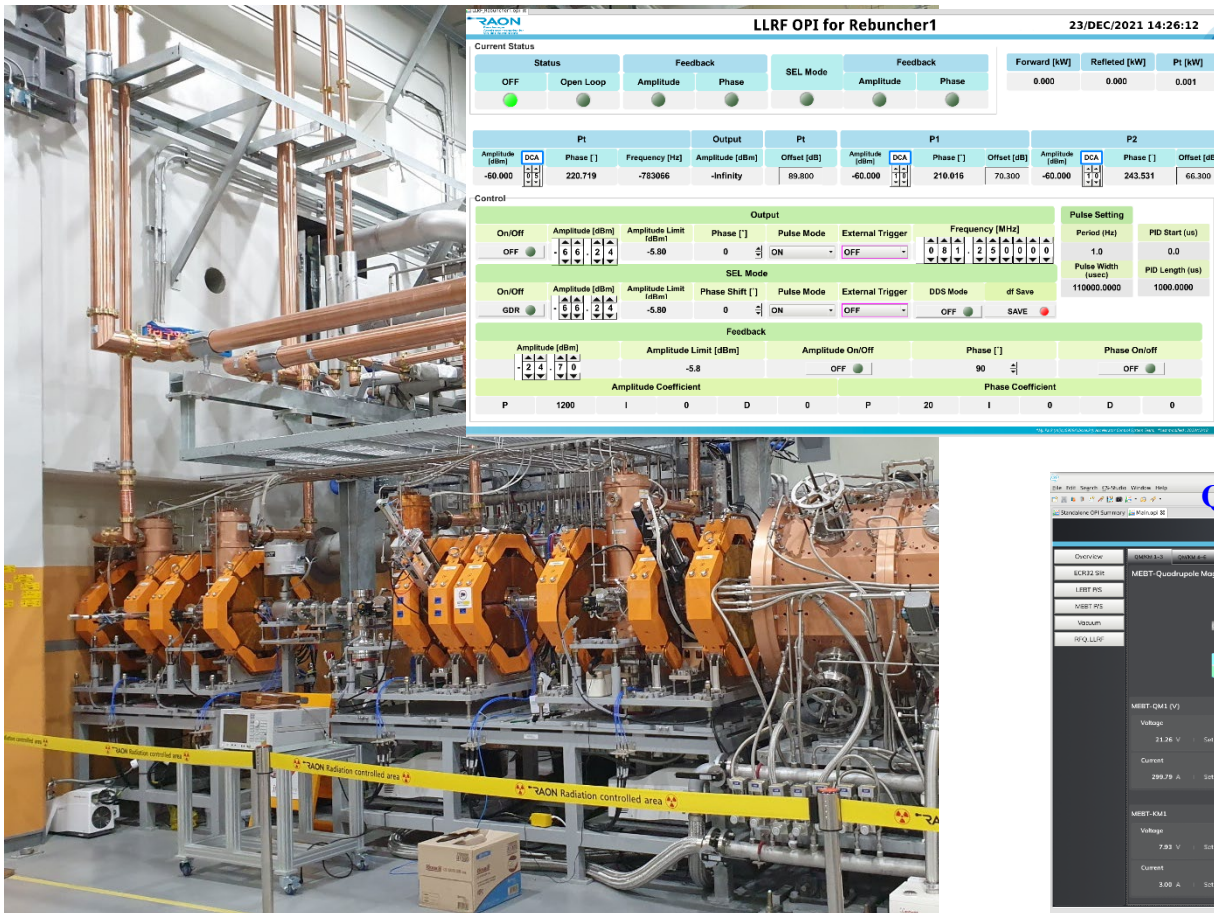
PARAMETER	VALUE
Beam Properties:	
Frequency	81.250 MHz
Particle	H ⁺ to U ₂₃₈ ⁺³³
Input Energy	10 keV/u
Input Current	0.4 mA
Input Emittance	0.012 .cm. mrad
Output Energy	0.507 MeV/u
Output Emittance	0.0125 .cm. mrad
	~26 keV/u-Degree
Transmission	~98 %
Duty Factor	100%



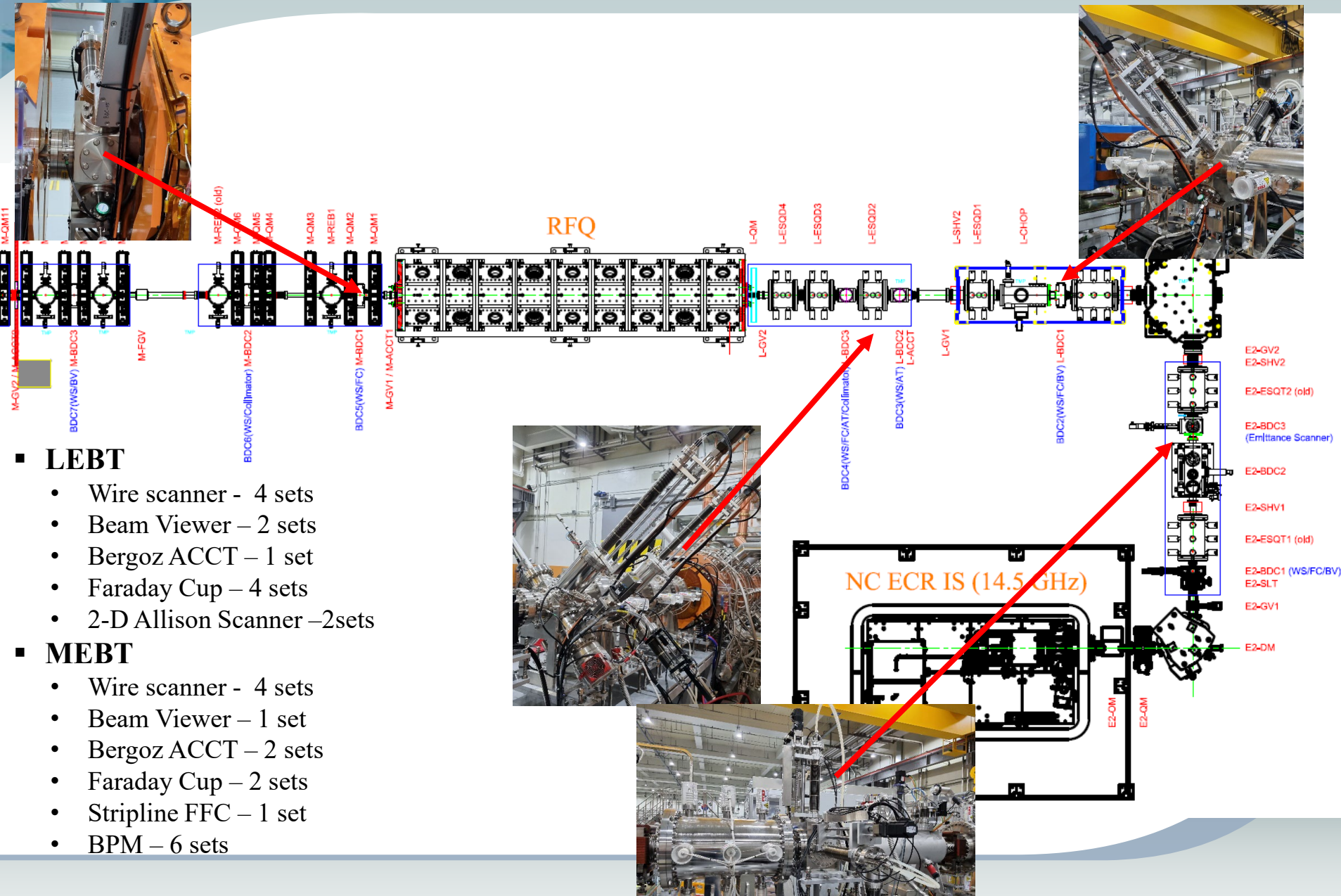
- The RFQ is designed to accelerate beams from proton to uranium from 10 to 500 keV/u. One feature is that this RFQ can accelerate two different charge states of uranium beams (for an example, $^{238}\text{U}^{+33}$ and $^{238}\text{U}^{+34}$ of 12 pμA) simultaneously.

- Quadrupole 11EA (Leff 130 mm, 27 T/m), Steering magnet(300 gauss)
- Rebuncher 4EA
- Instrumentation

Rebuncher: #1:11kW, #2: 3.5kW,
#3: 3.5kW, #4:11kW



Injector Instrumentation

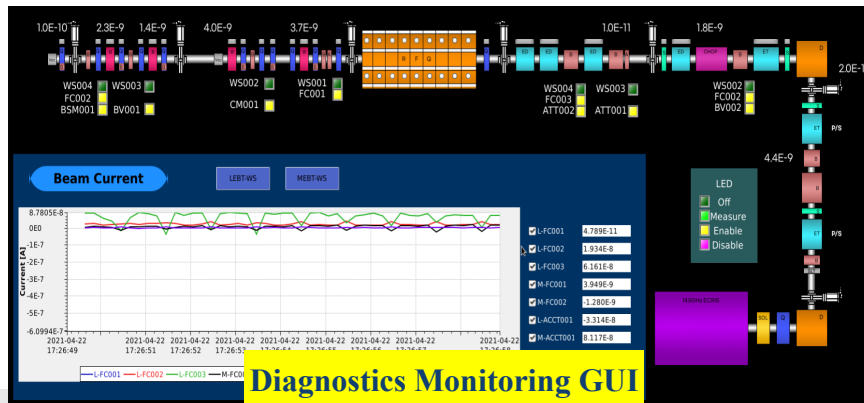


- **LEBT**
 - Wire scanner - 4 sets
 - Beam Viewer – 2 sets
 - Bergoz ACCT – 1 set
 - Faraday Cup – 4 sets
 - 2-D Allison Scanner – 2 sets
- **MEBT**
 - Wire scanner - 4 sets
 - Beam Viewer – 1 set
 - Bergoz ACCT – 2 sets
 - Faraday Cup – 2 sets
 - Stripline FFC – 1 set
 - BPM – 6 sets

Injector beam commissioning

- Injector beam commissioning

- * stated in August 2021
- * 14.5 GHz ECR-IS → LEBT → RFQ → MEBT
- * Ion used: Ar⁹⁺ ($A/q=4.4$), Ar⁸⁺(5.0) (1Hz, 100 μ sec)
- * EPICS based control system



Diagnostics Monitoring GUI

■ LEBT

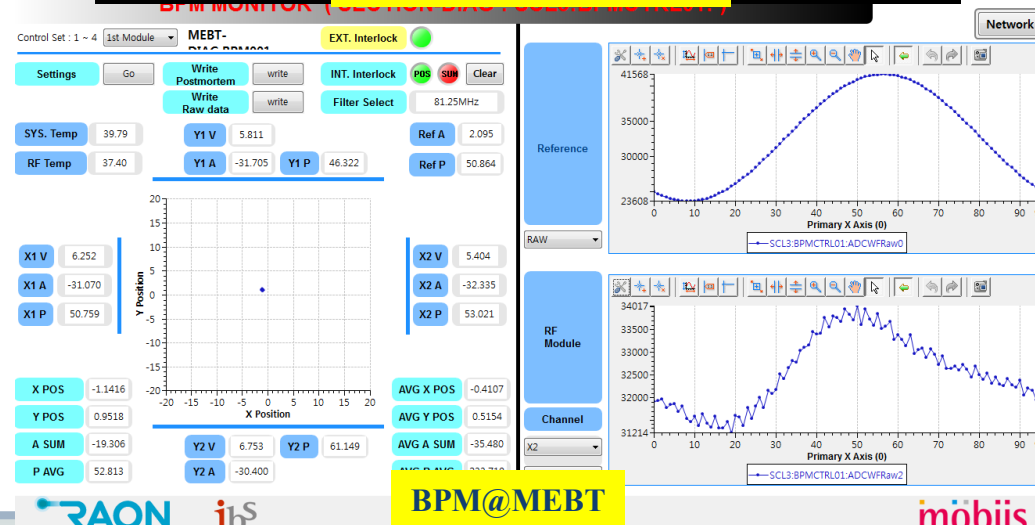
- Charge selection
- Emittance measurement
- Transverse beam size measurement
- Orbit correction, etc

■ RFQ

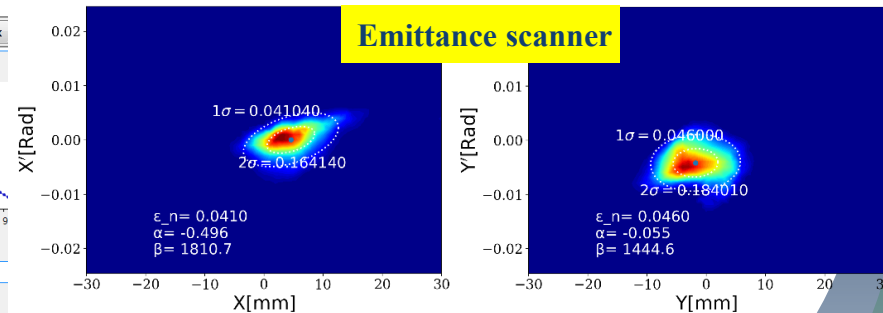
- Beam transmission
- Beam energy measurement, etc.

■ MEBT

- Rebuncher amplitude & phase scan
- Transverse beam matching
- Longitudinal beam matching
- Orbit correction, etc.



BPM@MEBT



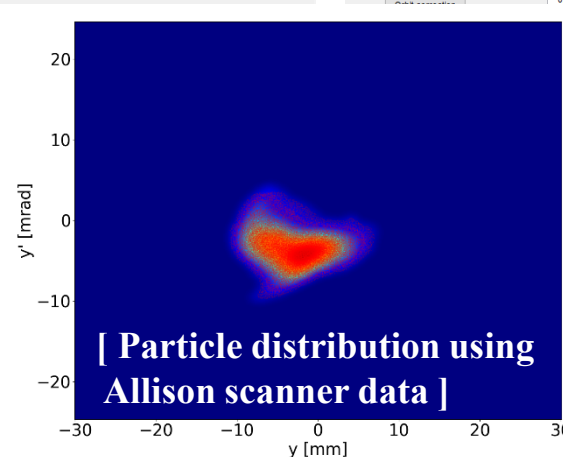
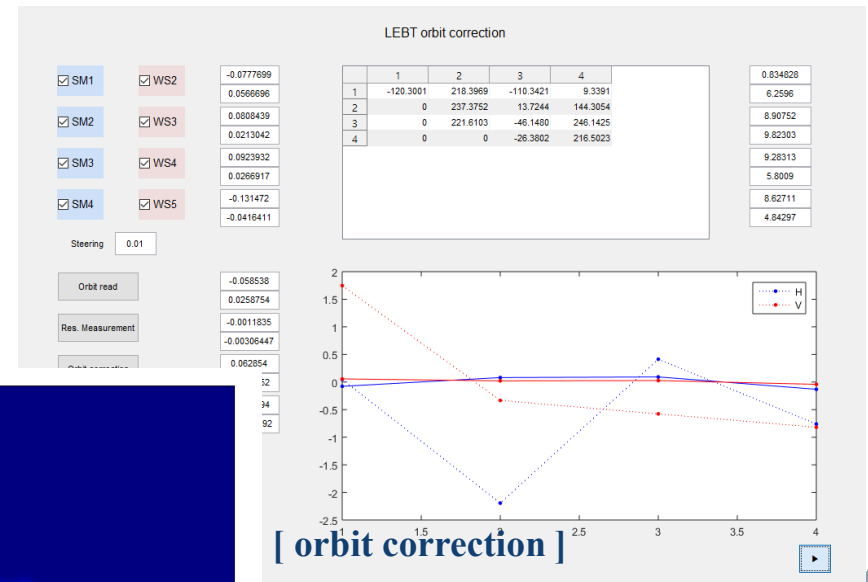
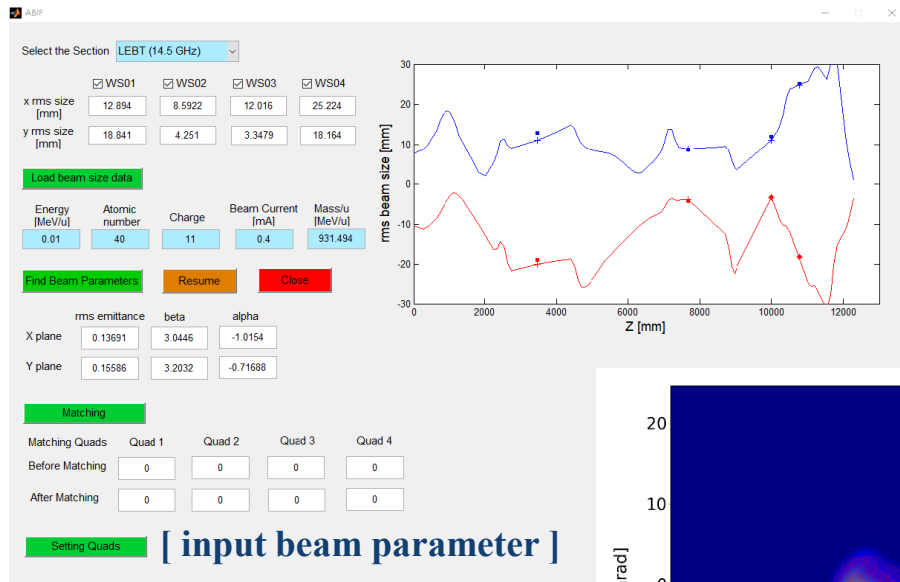
Emittance scanner



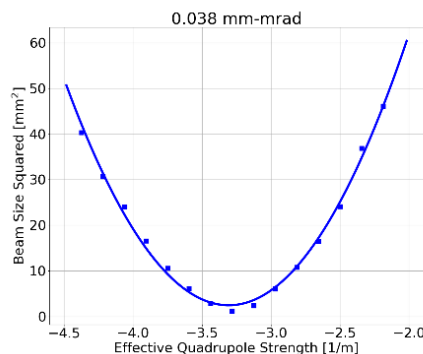
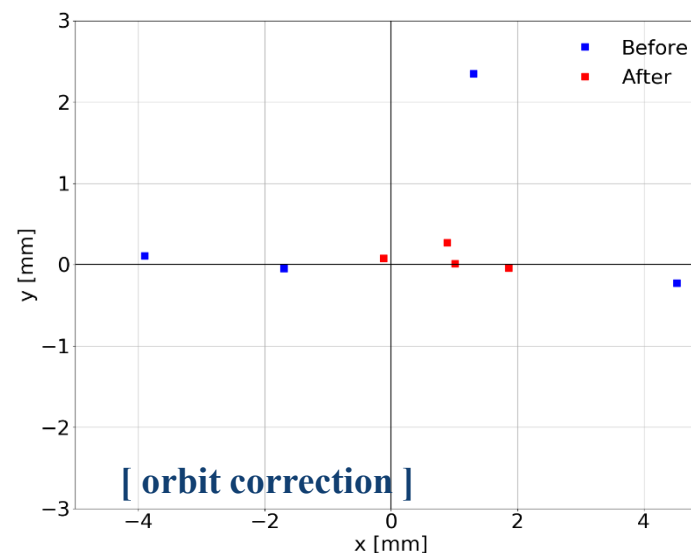
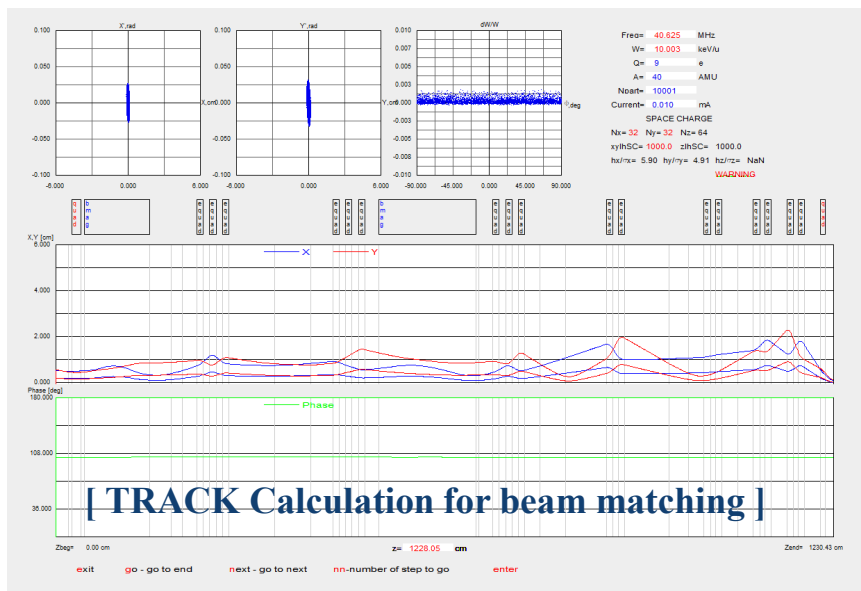
Beam viewer

LEBT Beam Commissioning (1/3)

- Main purposes of LEBT beam commissioning:
 - * Characterization of input beam parameters (Allison, Wire scanner)
 - * Orbit correction (Wire scanner)
 - * Beam matching into RFQ
- Beam dynamics group developed some physics application tools.
- Beam current (FC): Ar⁹⁺ (~30μA), Ar⁸⁺ (~47μA)



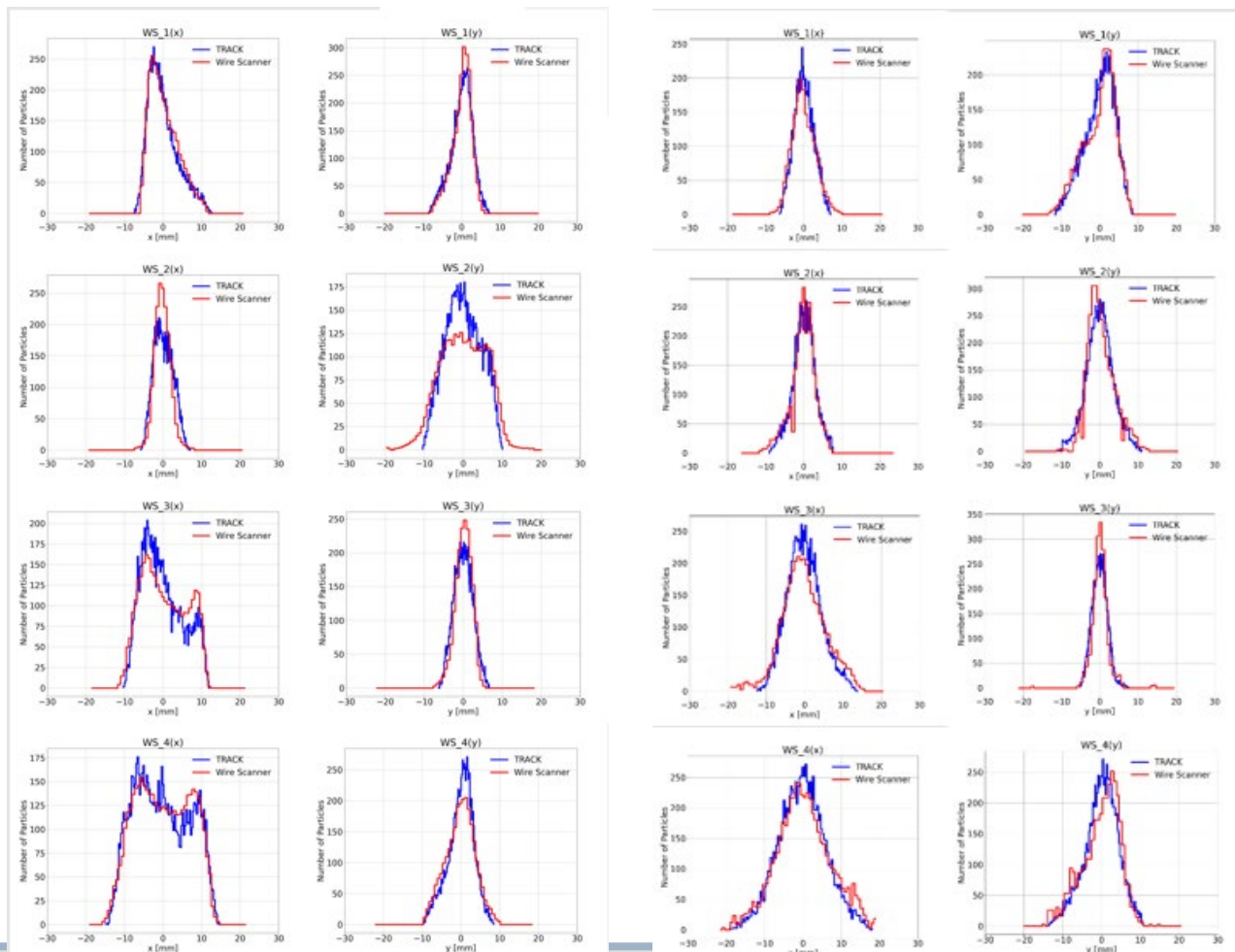
- Input beam parameter -> beam matching calculation into RFQ (TRACK code)
- Orbit correction using wire scanner data (November 2021)
- Emittance measurement using Quad scan (November 2021)



[Results on November 2021]

	x	y
Quad Scan	0.041	0.038

- modelling of initial beam using wire scanner and Allison data
- * Comparing WS data with TRACK simulation
- * First wire scanner is located before Allison scanner



- RFQ set point: beam transmission by using ACCTs in LEBT and MEBT

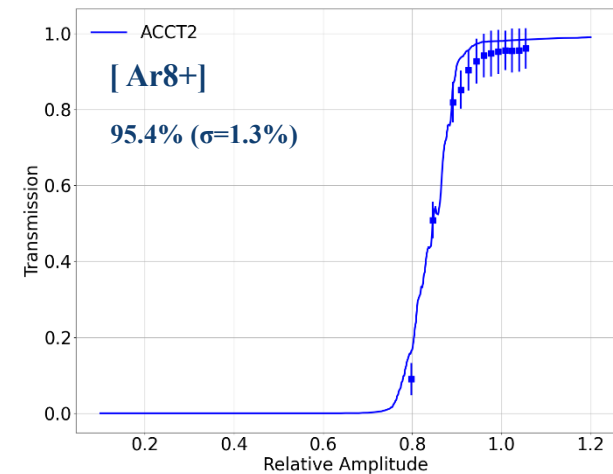
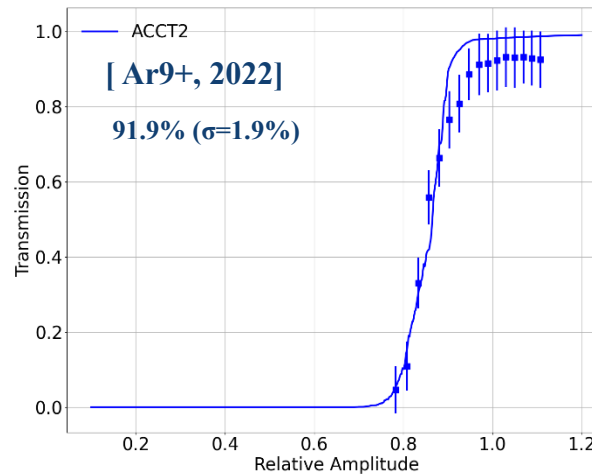
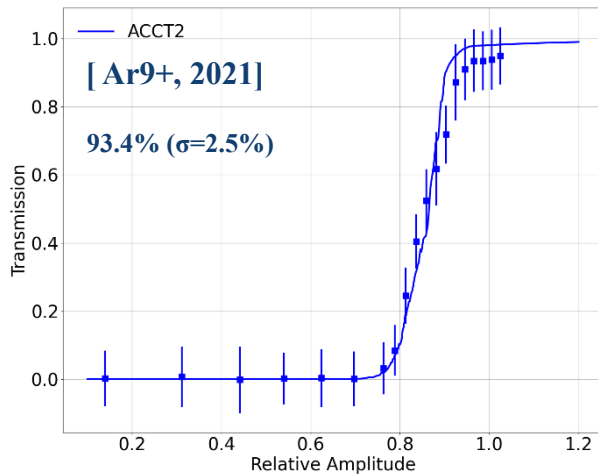
* each data: obtained in about 2 minute measurement

* beam current: Ar9+ ($\sim 30\mu\text{A}$), Ar8+ ($\sim 47\mu\text{A}$)

* Transmission:

9+	93.4% ($\sigma=2.5\%$)	December 2021
9+	91.9% ($\sigma=1.9\%$)	April, 2022
8+	95.4% ($\sigma=1.3\%$)	April, 2022

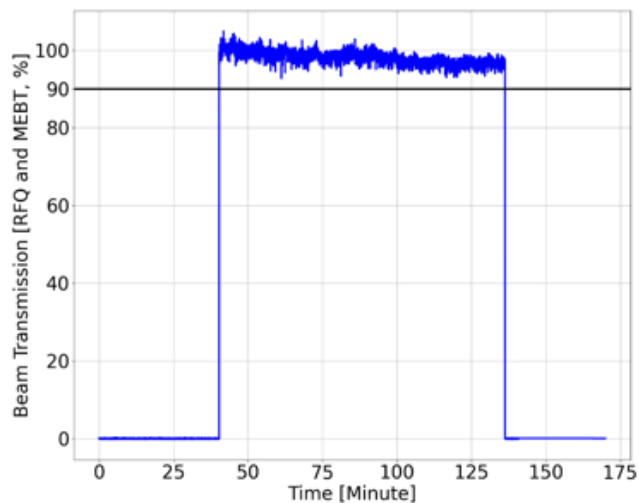
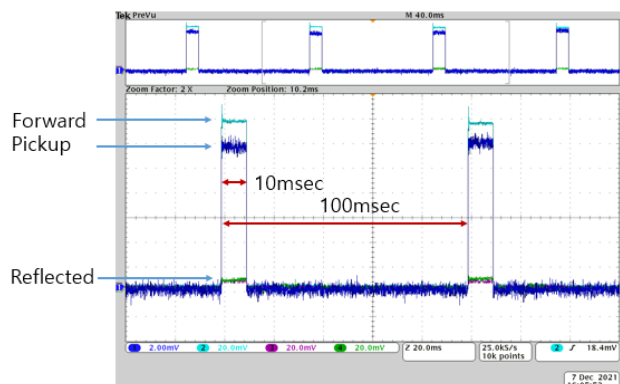
* Energy: ~ 507 keV/u (TOF, 1st and 2nd BPMs in MEBT)



[RFQ transmission (error bar: 3σ)]

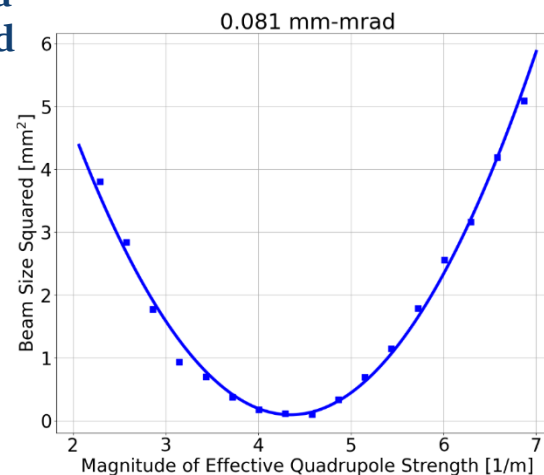
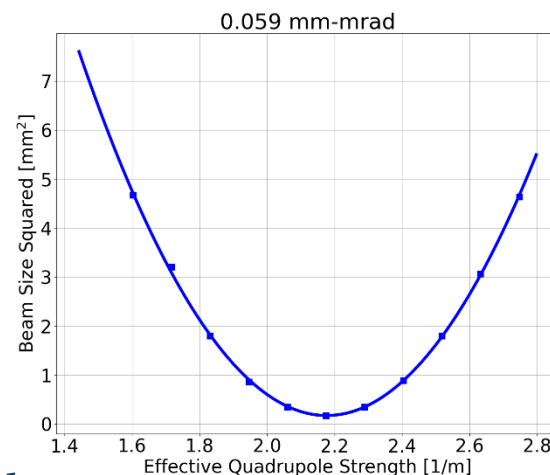
10% duty Operation and MEBT

- 10% beam duty: about 100 minutes, 10Hz, 10msec
 - * beam transmission through injector > 92.7%
- MEBT quad scan for beam emittance
 - * MEBT beam commissioning: from May 2022



$$\epsilon_x = 0.059 \text{ mm-mrad}$$

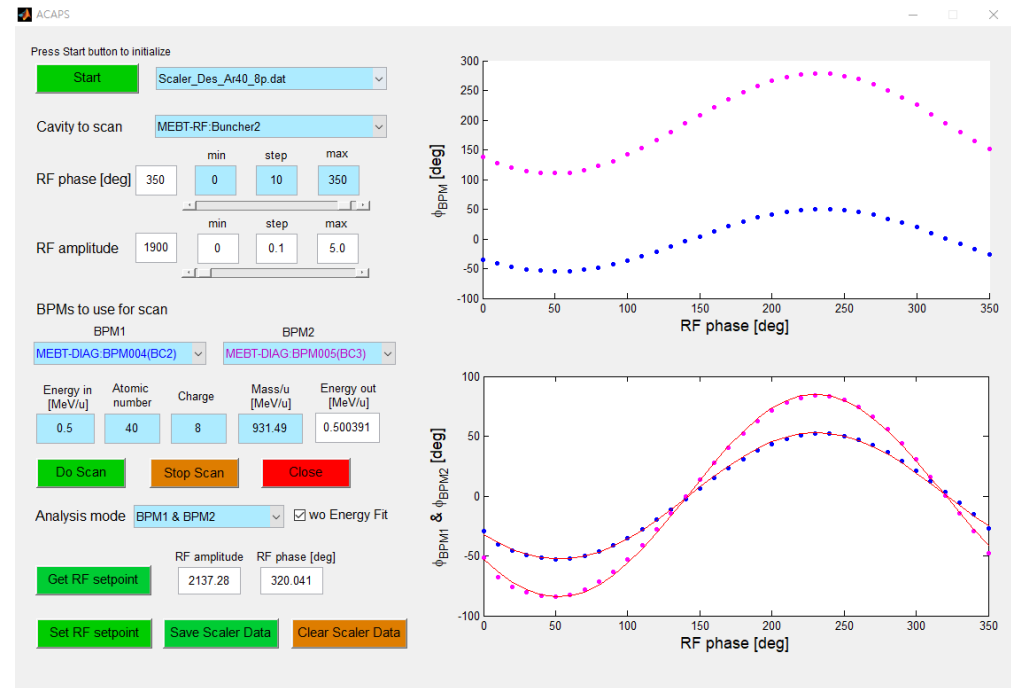
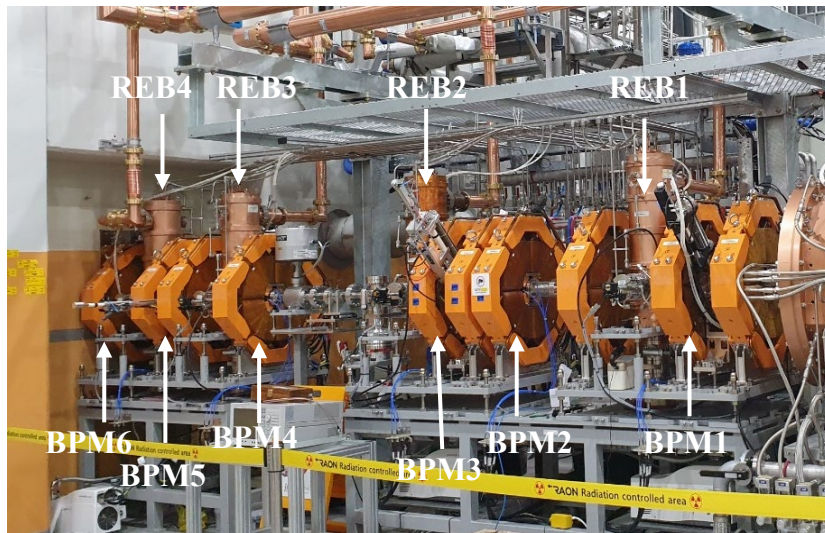
$$\epsilon_y = 0.081 \text{ mm-mrad}$$



[beam transmission (FC)]

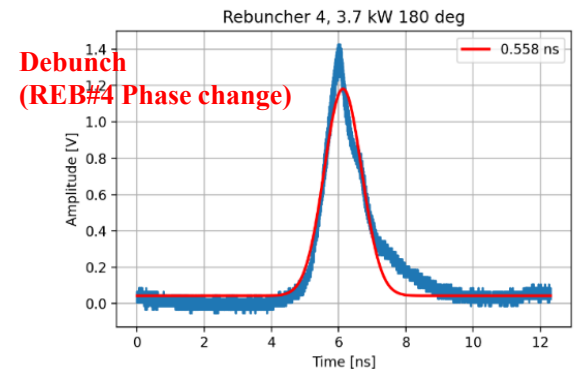
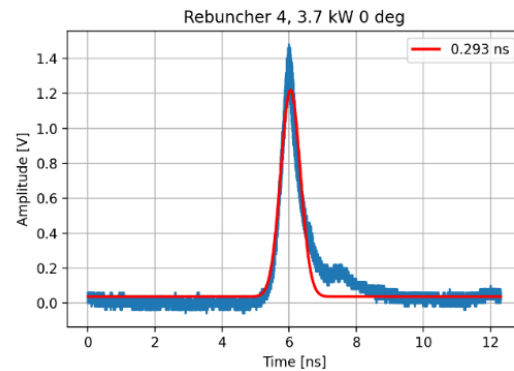
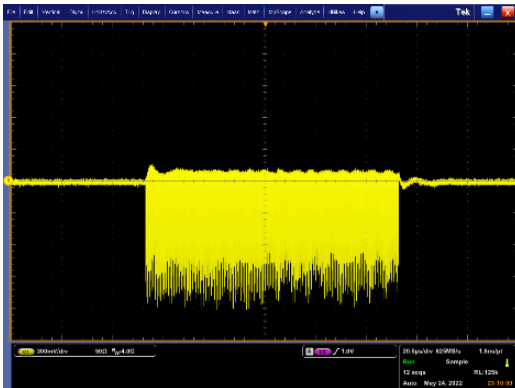
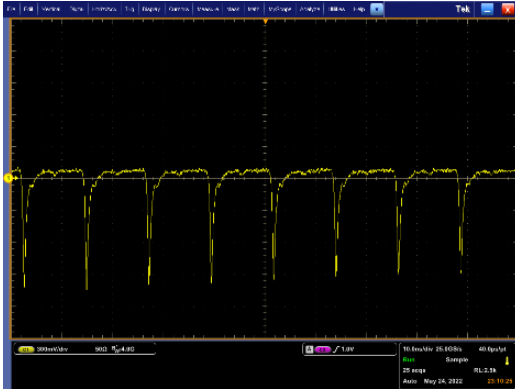
Phase scan with BPM (MEBT)

- Set phase and amplitude of four rebunchers in MEBT
- Phase scan with BPMs (Time of Flight measurement)



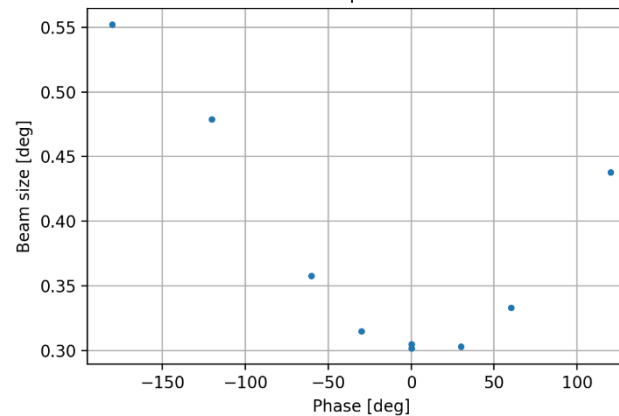
Preliminary result of fast Faraday cup

Screenshot of Oscilloscope



Debunch
(REB#4 Phase change)

Bunch length vs. buncher phase



- **RAON low-energy superconducting linac(SCL3) has been installed and its beam commissioning will be started in October 2022.**
- **Beam commissioning of injector system of RAON was started from August 2021. During commissioning period, we tested performance of RF system, diagnostics, control system and so on for linac operation. Input beam parameters are characterized by Allison scanner and wire scanner data. TRACK simulation results are compared with measurements. RFQ accelerates beam to 507MeV/u. Overall beam transmission of RAON injector is above 92.7%.**
- **Beam parameters are well controlled, and the beam is ready to inject to the superconducting linac.**

Thank you !

