RAON Rare isotope Accelerator complex for ON-line experiments

LINAC2022 LIVERPOOL

Status and Beam Commissioning of the RAON Superconducting Linac

M. KWON on behalf of RISP
IBS, Daejeon, Korea

August 30, 2022
Liverpool, UK

ibs 기초과학연구원 Institute for Basic Science

RISP 중이온가속기건설구축사업단 Rare Isotope Science Project

Contents

Part 1.

RAON Overview

RAON Layout

- Accelerator System
- RI producing System
- Conventional Utilities
- Experimental System

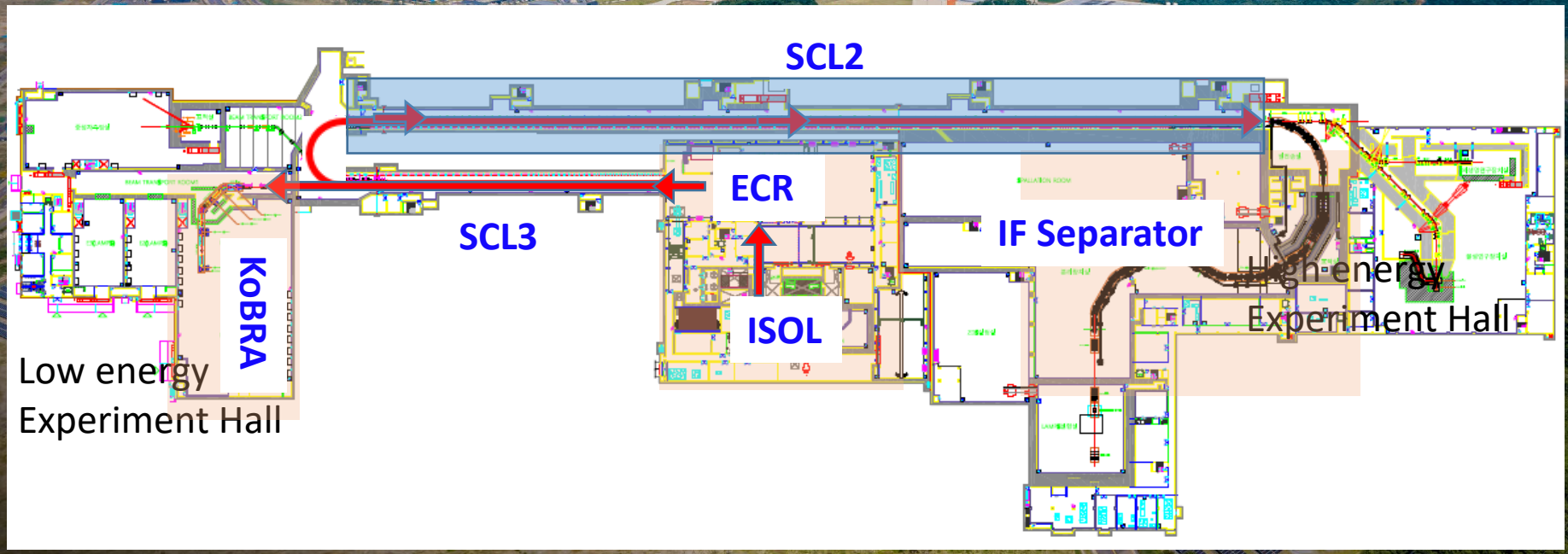
Waste Storage
Guest House
Assembly Bd.
SRF Test Bd.
High Energy B
IF
HQ Office
Accelerator
ISOL
Control Center
SCL2
SCL3
High Energy A
Low Energy B
Low Energy A
Cryogenics Bd.
Utility Bd.
Electricity Bd.

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

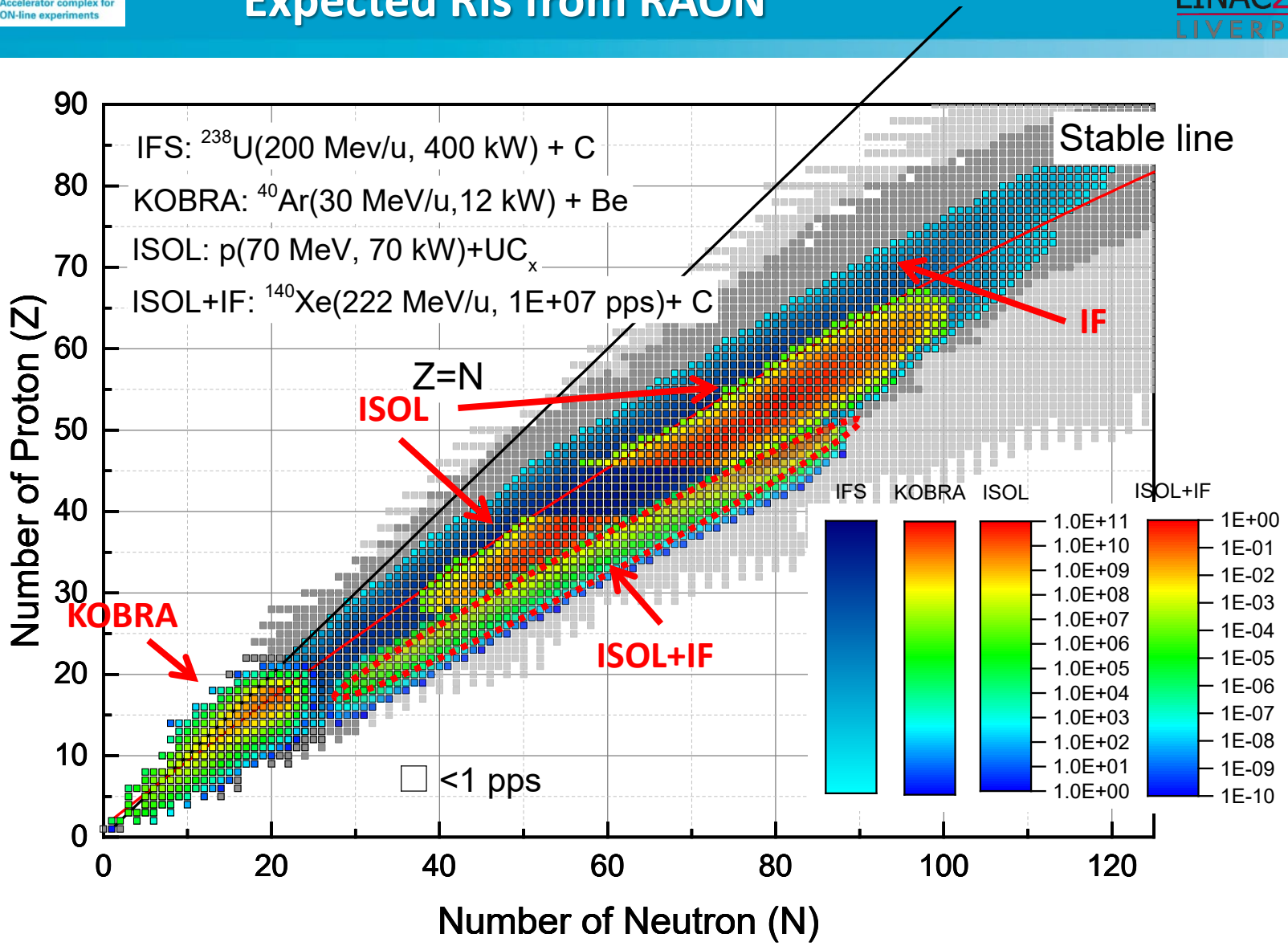
Science Goal of RAON

RIB production at RAON

	KoBRA	ISOL	IF Separator
Driver	SCL3(ECR/ISOL)	Cyclotron	SCL3(ECR/ISOL)->SCL2
(Post) Acceleration		SCL3 or SCL3->SCL2	
Production Mechanism	Direct reactions Multi Nucleon Transfer	P induced U fission	PF, U fission
RIB Energy	< a few tens of MeV/u	> a few of keV/u	< a hundreds of MeV/u



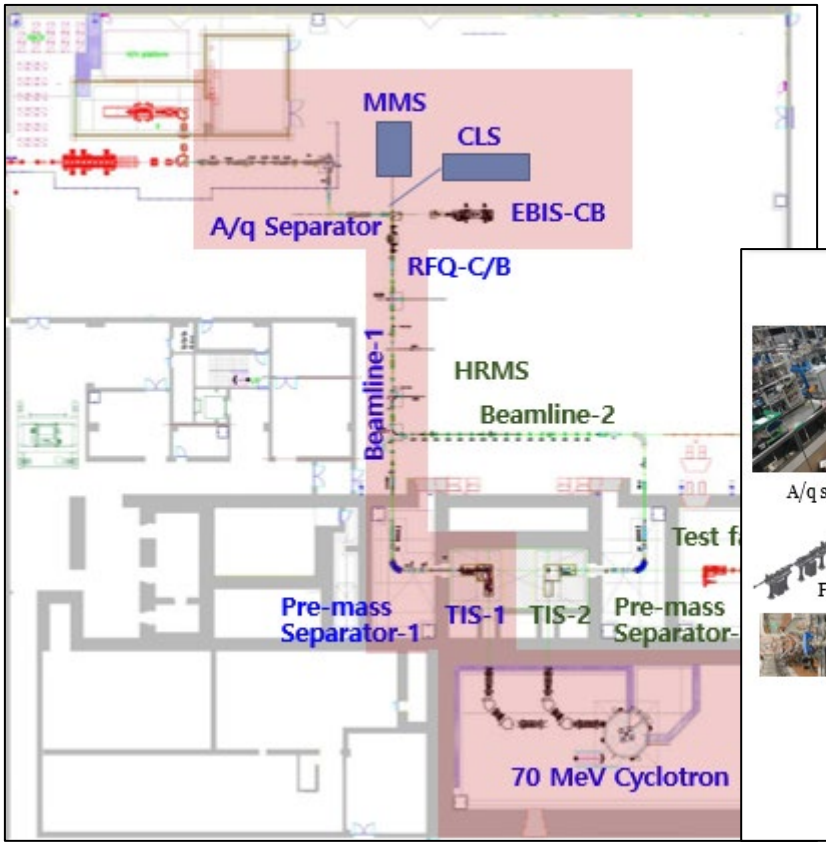
Expected RIs from RAON

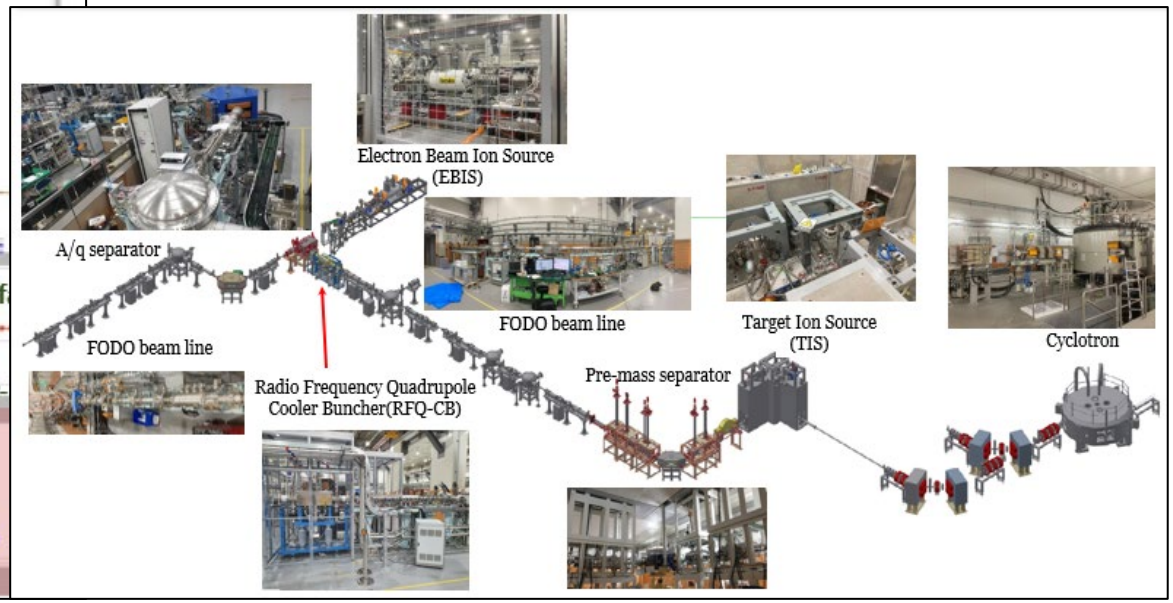


- **RAON will provide access to unexplored regions of the nuclear chart**

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+)



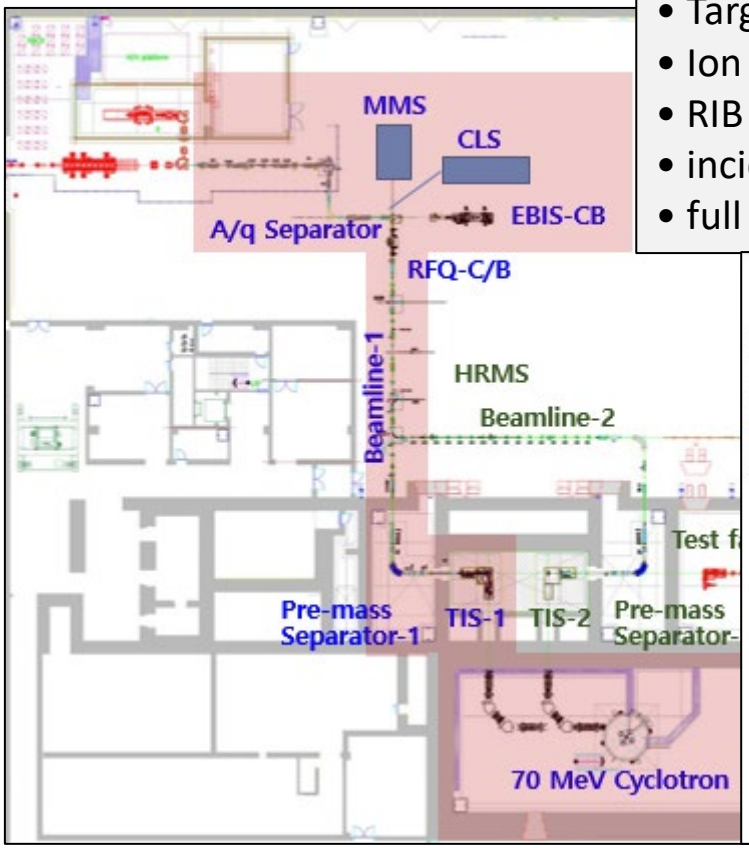


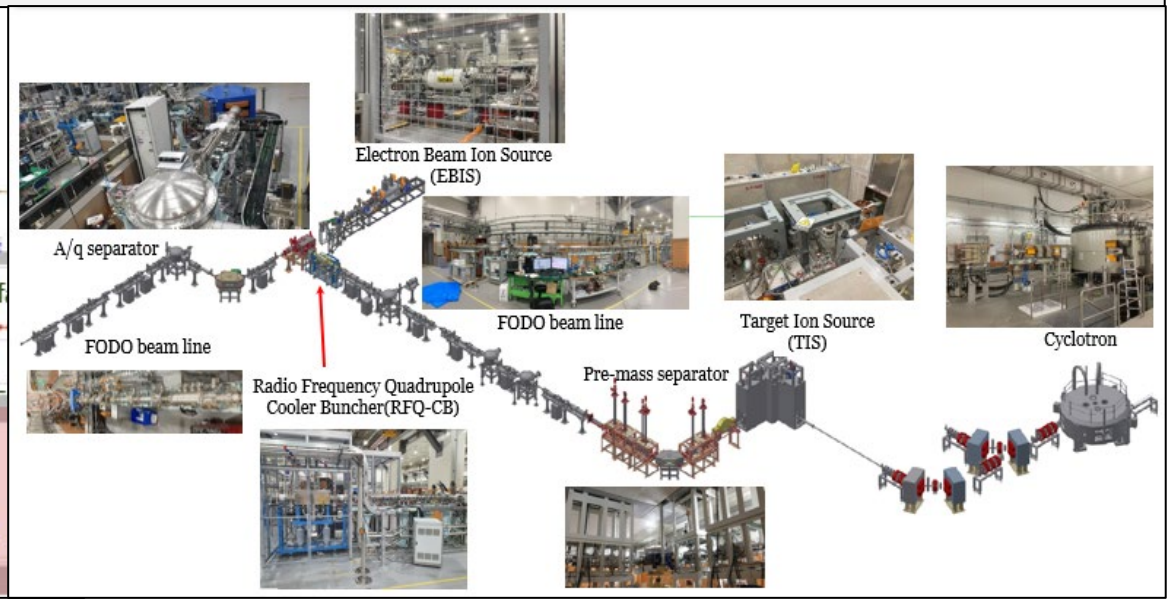
- ISOL beam lines including sub-systems are machine commissioned in 2021
- RI beam commissioning using SiC target (Dec 2022)

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

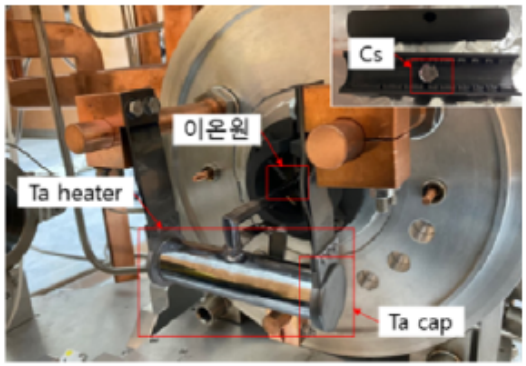




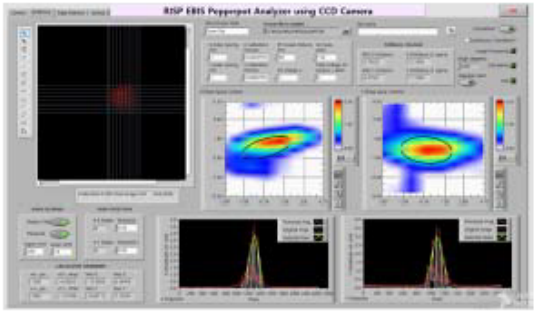
- ISOL beam lines including sub-systems are machine commissioned in 2021
- RI beam commissioning using SiC target (Dec 2022)

ISOL SIB commissioning

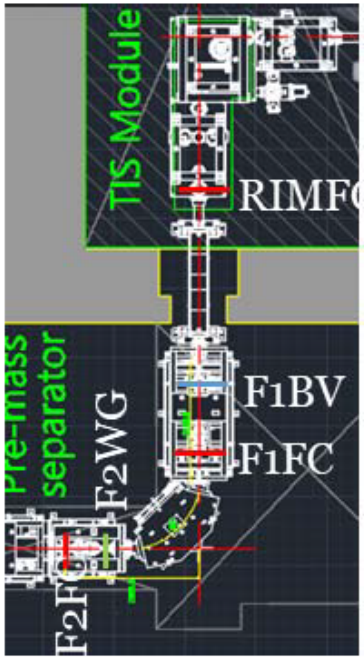
Target IS (20 keV, $^{133}Cs^{1+}$) → Pre-Separator (m/δm ~ 300) → RFQ Cooler (> 1x10^{8} ions/bunch) → EBIS (>15% Cs^{27+} A/q<6) → A/q Separator (m/δm ~ 250) → Post linac (10 keV/u, $^{133}Cs^{27+}$)

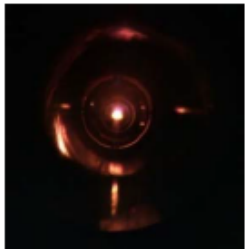


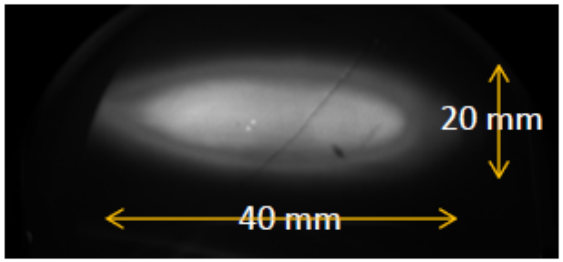
Cs sample preparation in TIS chamber



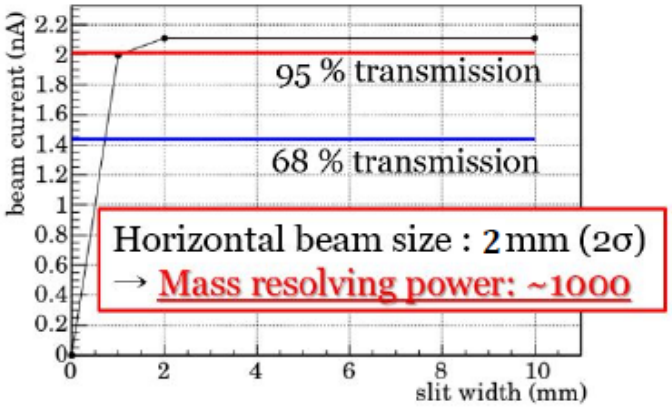
Beam emittance of TIS extracted Cs beam
X(2σ) : 15 pi mm mrad
Y(2σ) : 17 pi mm mrad





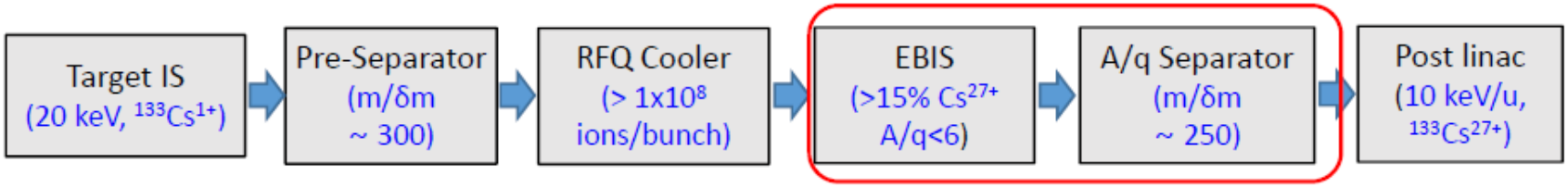


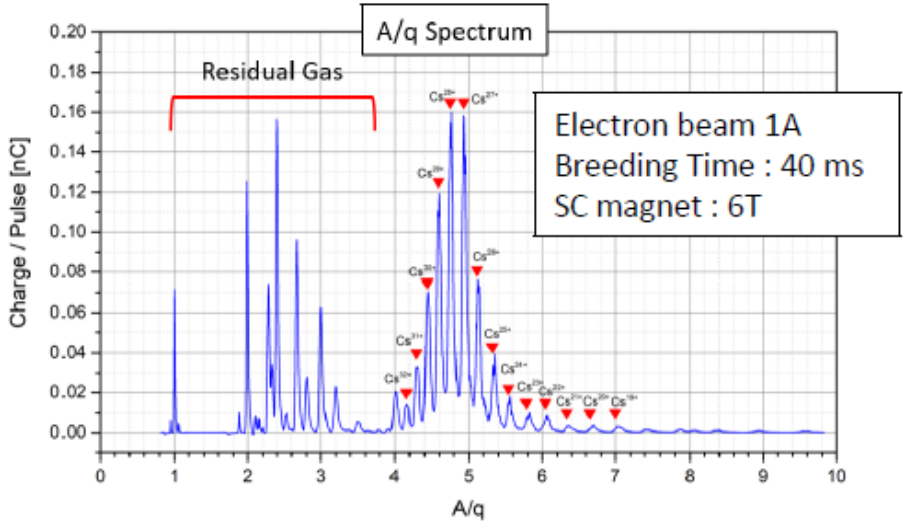
F1 beam viewer

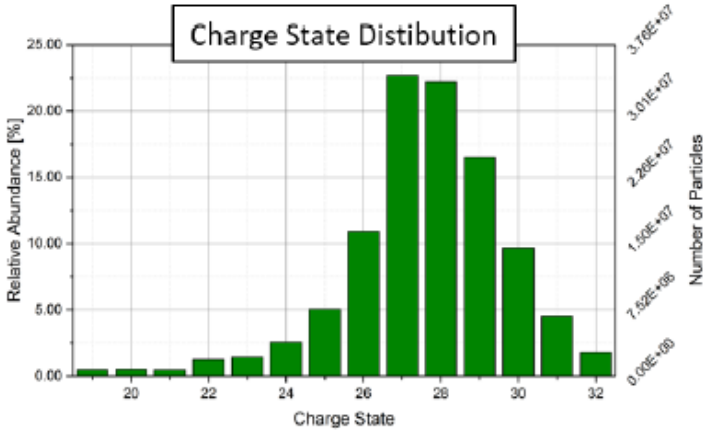


Beam size measurement by using F2 slit

ISOL SIB commissioning

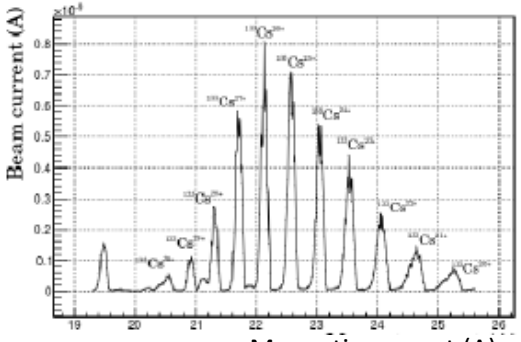






Cs Total Number	Cs^{27+} Number (A/q=4.92)
1.50E+8	3.41E+7 (22.67%)

A/q spectrum and the present resolving power(preliminary)



Momentum dispersion of the A/q magnet: 1.244 m

Beam size in 2σ ~ ±5 mm (from the slit width dependence of beam current)

→ Resolving power ~ 250 (2σ)

Our tuning is not finalized.

We may be able to obtain much higher resolving power (~400 in (2σ)) with careful tuning.

ISOL RI Beam

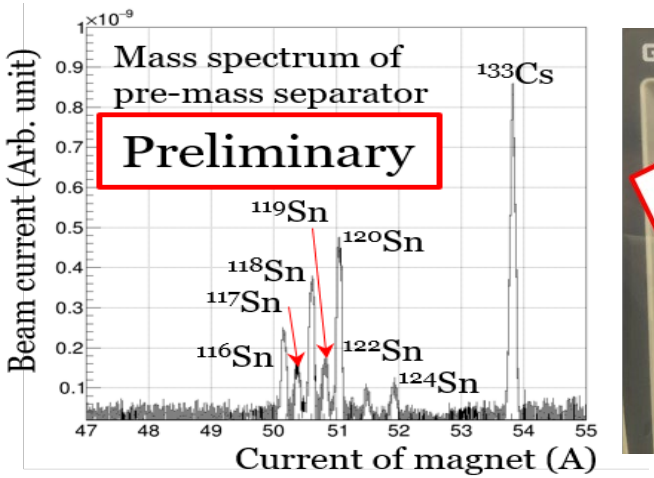
Cyclotron (35~70MeV, proton) → Target IS (20 keV, $^{133}Cs^{1+}$) Efficiency~30% → Pre-Separator (m/δm ~ 1,000) → RFQ Cooler (> 1x10^8 ions/bunch) → EBIS (>15% Cs^{27+} A/q<6) → A/q Separator (m/δm ~ 250) → Post linac (10 keV/u, $^{133}Cs^{27+}$)

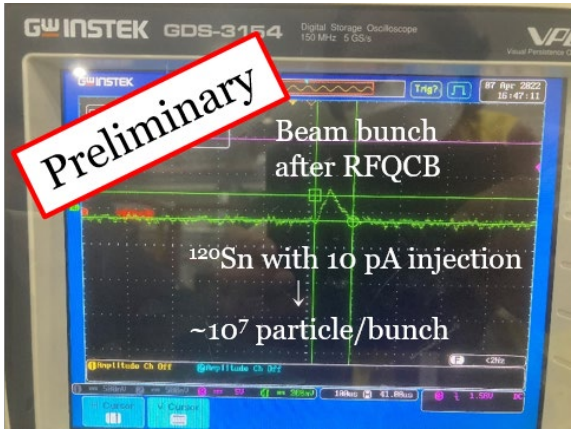
Target Ion Source(22.4)

- Sn beam extraction using RILIS and transports to A/q separator

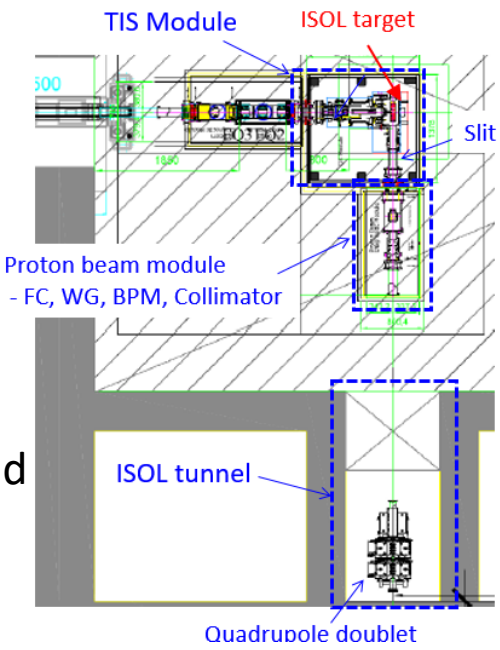
Cyclotron ready (22.8) then

- needs to finalized interface between Cyclotron and ISOL
- SiC to be used for Na isotopes(e.g. ^{24}Na~10$^{6-8}$pps/1kW@70MeV) on Dec 2022





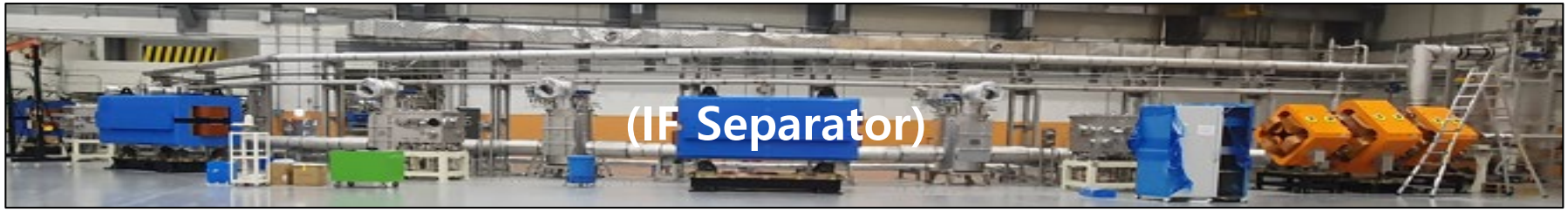
Connection to ISOL target

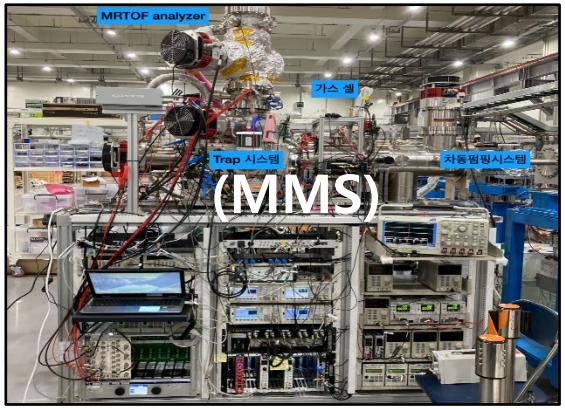


- **SiC for Al isotopes on 2023 :** $^{24-26m}$Al beam extraction using RILIS and transports to **MMS** and **CLS(e.g. $^{20-24}$Na, $^{22-23}$Mg, $^{24-26}$Al and $^{8-9}$Li)**
- **UCx begin to employ on 2025**

Preparation for user facility by 2024

Exp. Systems



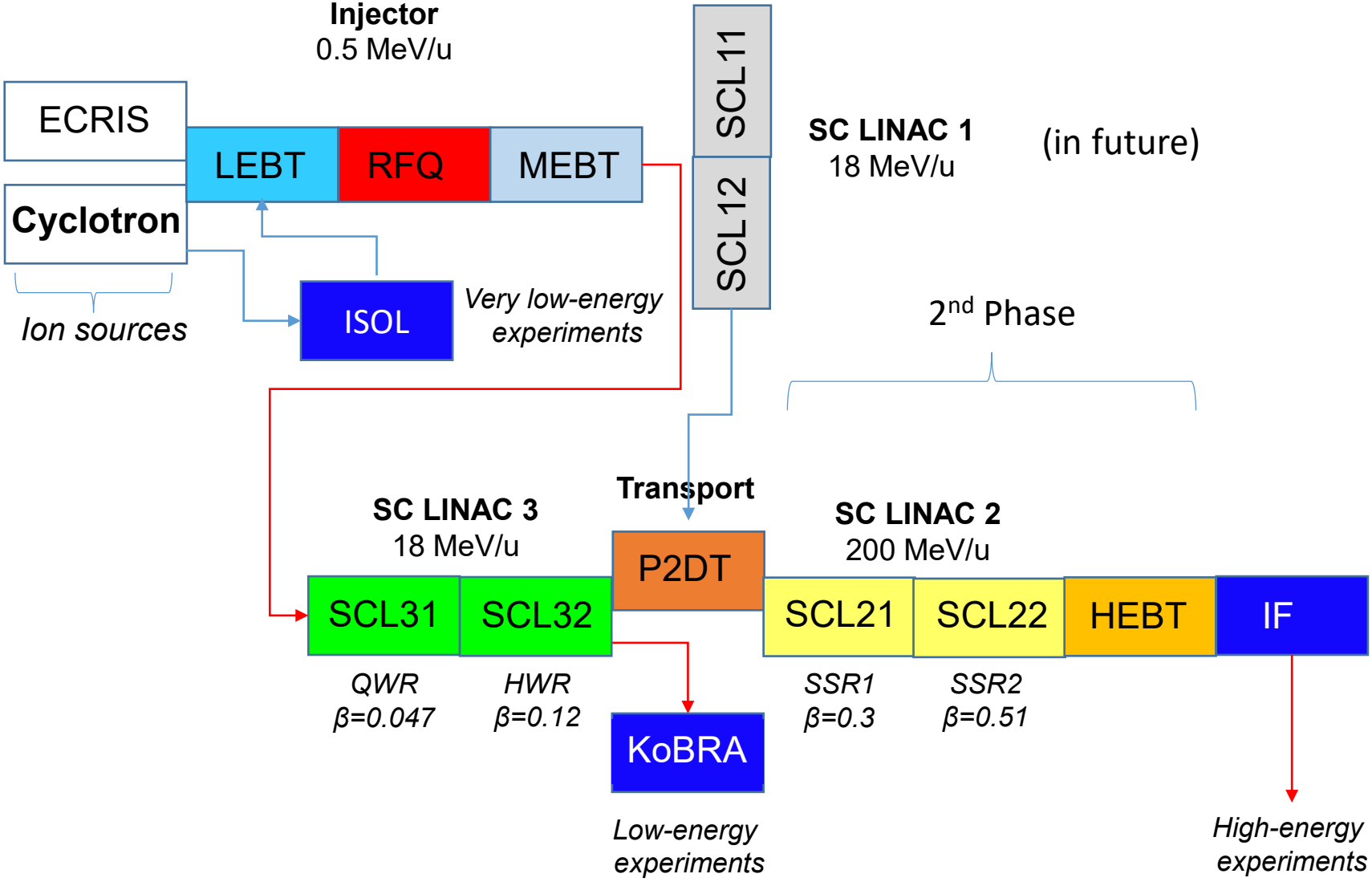


ISOL system installed in 2021 and RI beam test on 2022 & All Exp. Systems are to be installed by 2022 and machine commissioned

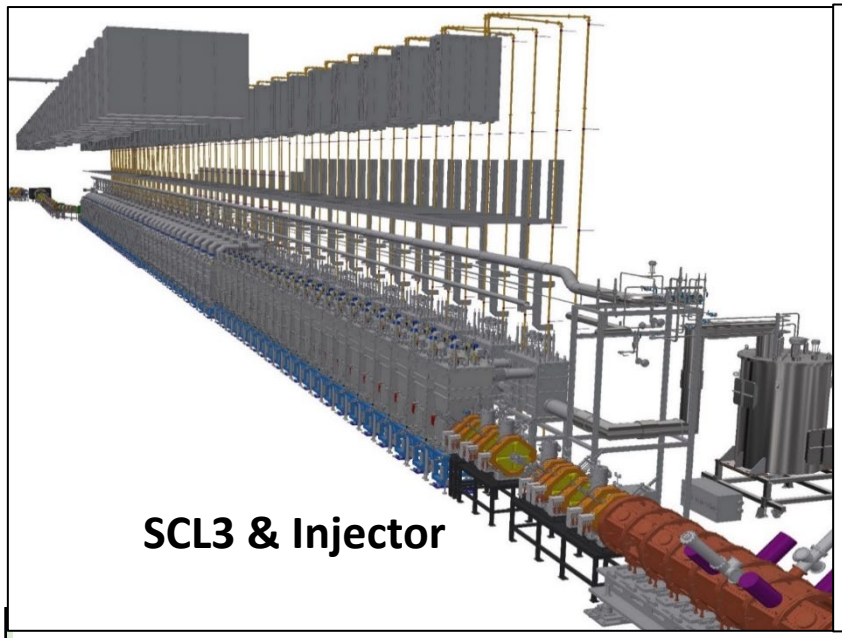
Part 2.

Accelerator Systems

Simple Diagram of RAON SRF Accelerator



Phased Installation



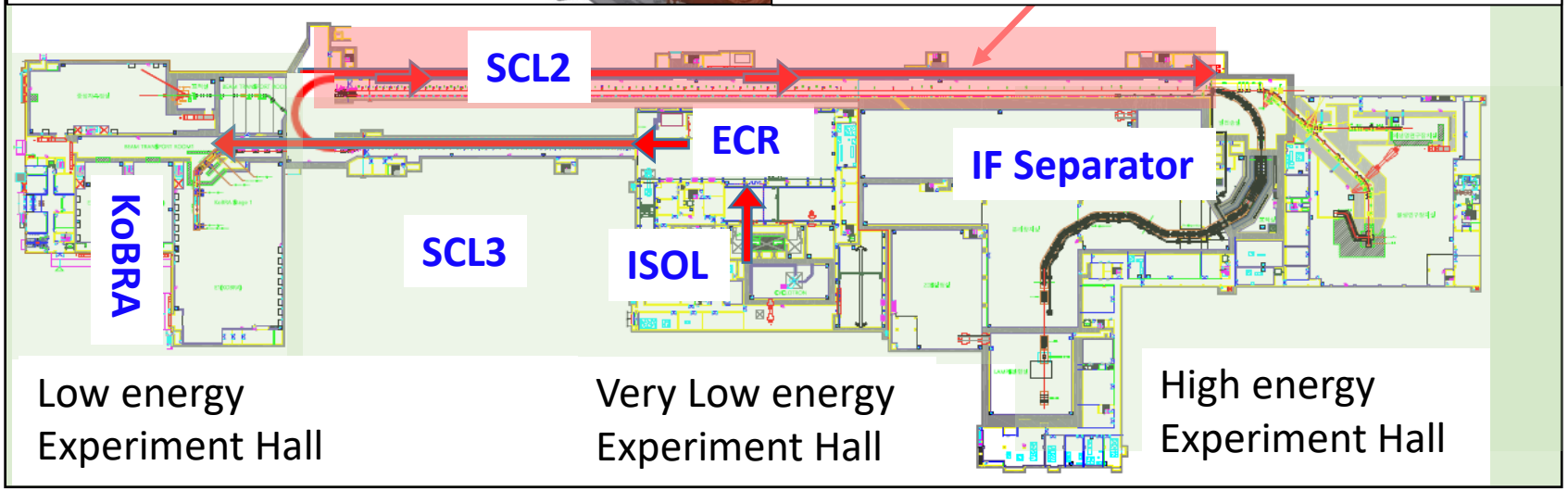
SCL3 & Injector

❖ Phase 1(~2022)

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

❖ Phase 2(~2029)

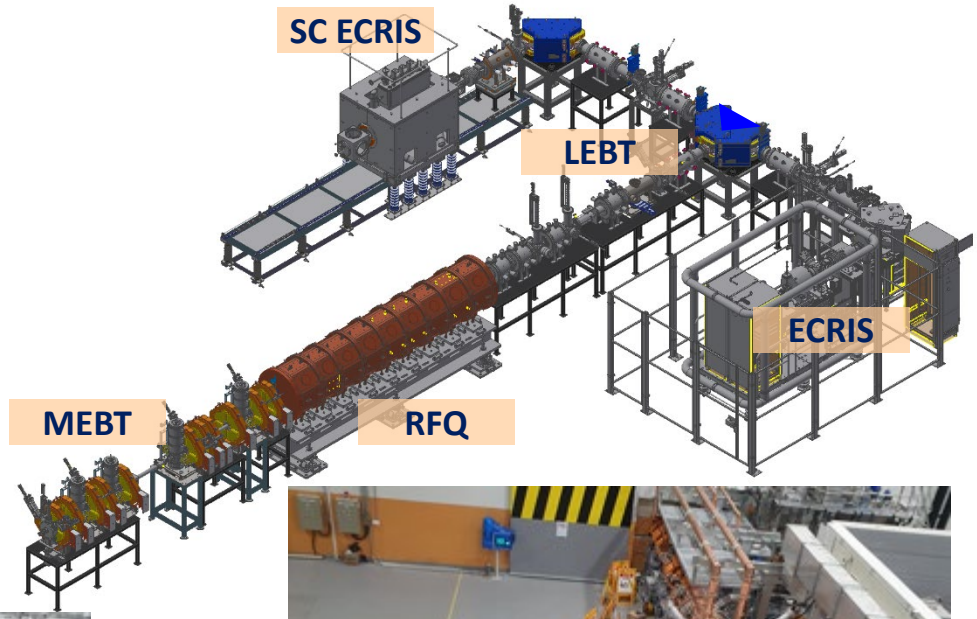
- ➢ High energy Linac, SCL2

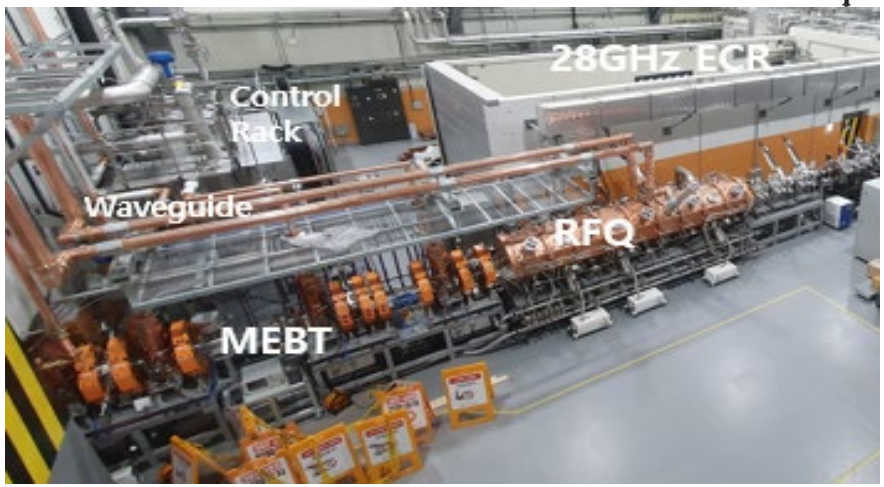


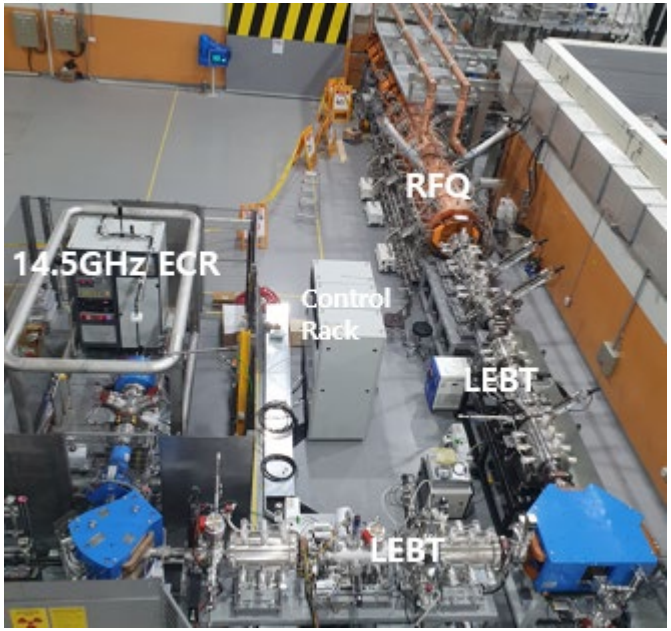
SCL3 → installation done on 2021 & commissioning on Oct 2022

RAON 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, 4×2 kW)
  - Simple quadrupole magnets, Instrumentation

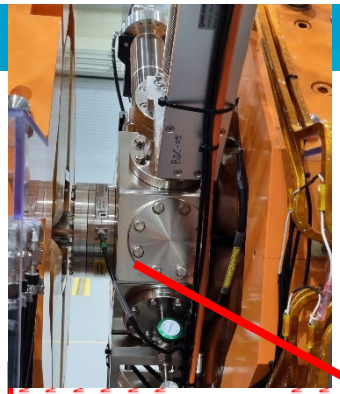


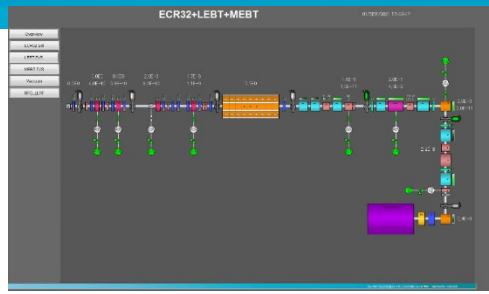


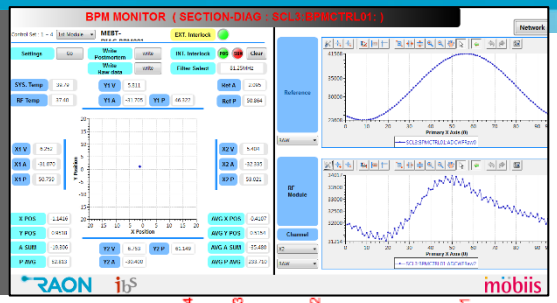


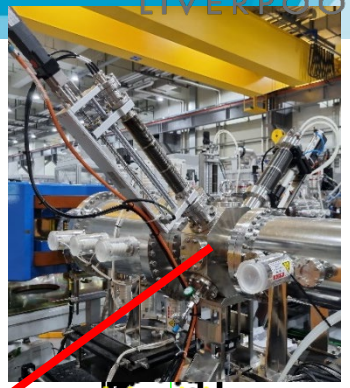
Installation completed and beam commissioning from October, 2020

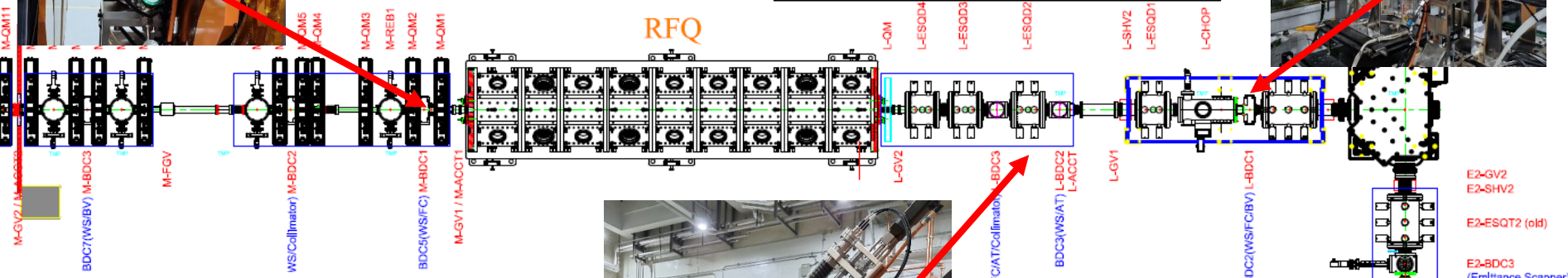
Beam Diagnostic System

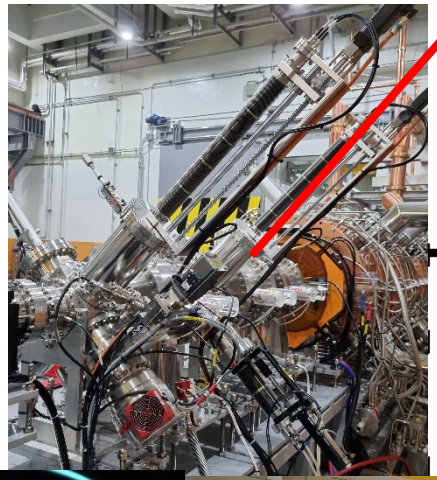


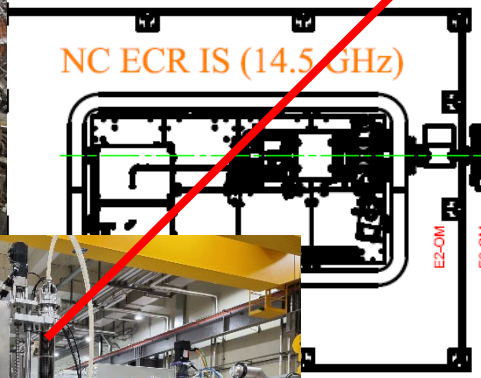










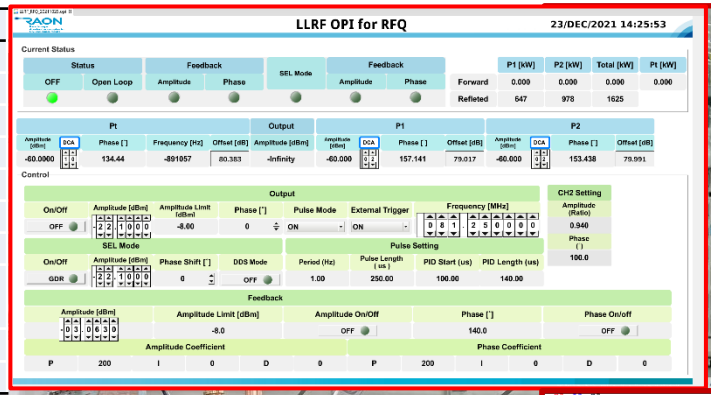


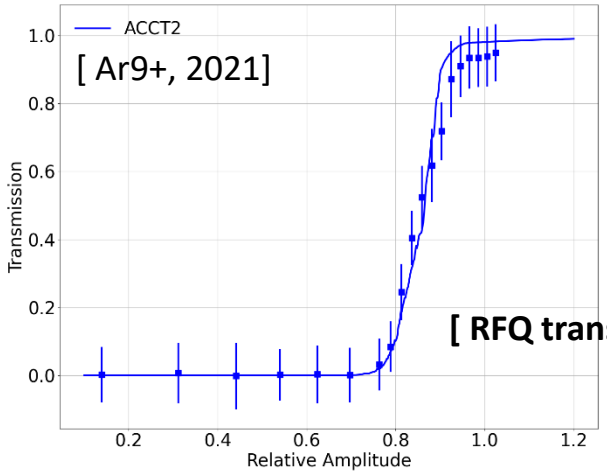
- **LEBT**
  - Wire scanner - 5 sets (4 installed)
  - Beam Viewer – 3 sets (2 installed)
  - Bergoz ACCT – 1 set
  - Faraday Cup – 5 sets (4 installed)
  - beam Attenuator – 2 sets
  - 2-D Allison Scanner – 2sets (1 installed)
- **MEBT (Installed)**
  - Wire scanner - 4 sets
  - Beam Viewer – 1 set
  - Bergoz ACCT – 2 sets
  - Faraday Cup – 2 sets
  - Stripline FFC – 1 set
  - BPM – 6 sets

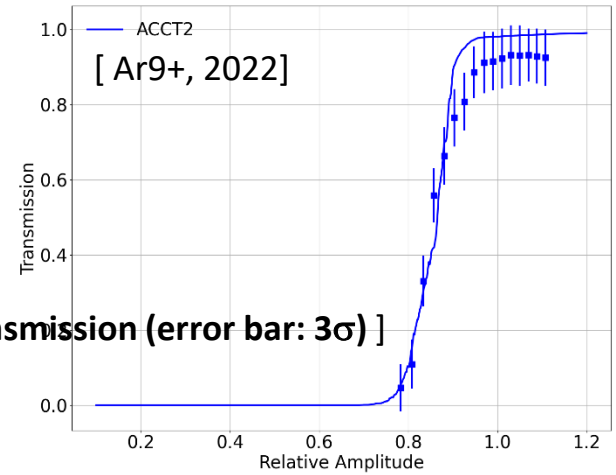
Ar^{8+} 10uA @ Beam Viewer('21)

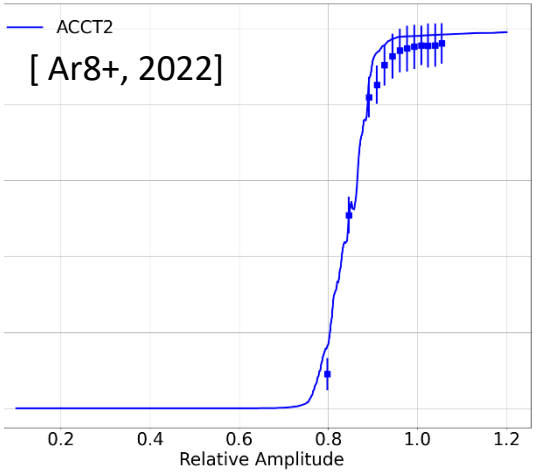
RFQ and MEBT

PARAMETER	VALUE
Beam Properties:	
Frequency	81.250 MHz
Particle	H^{+1} 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%





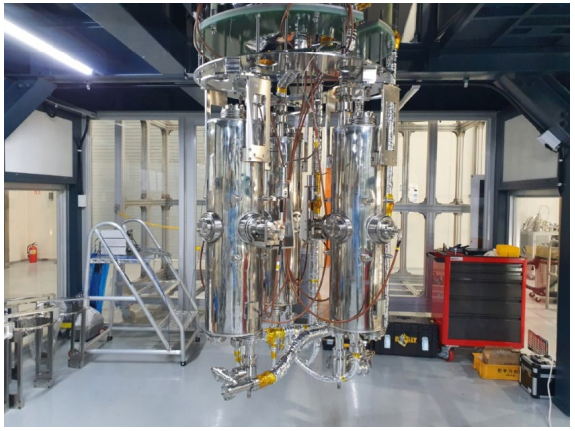




[RFQ transmission (error bar: 3σ)]

SRF Cavity Development

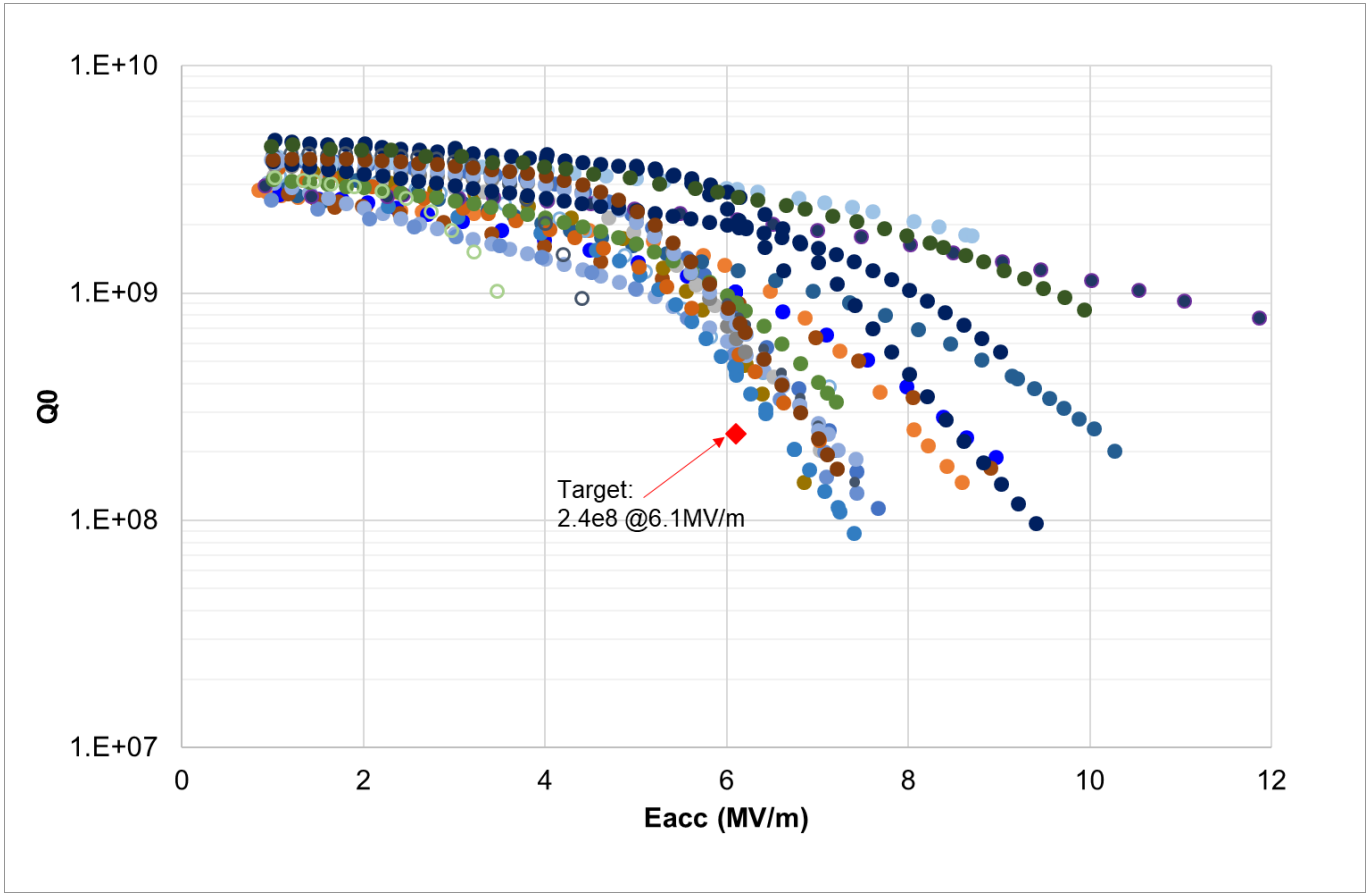
On-site (Shin-Dong) test facility



- 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)

SRF Cavity Development-QWR

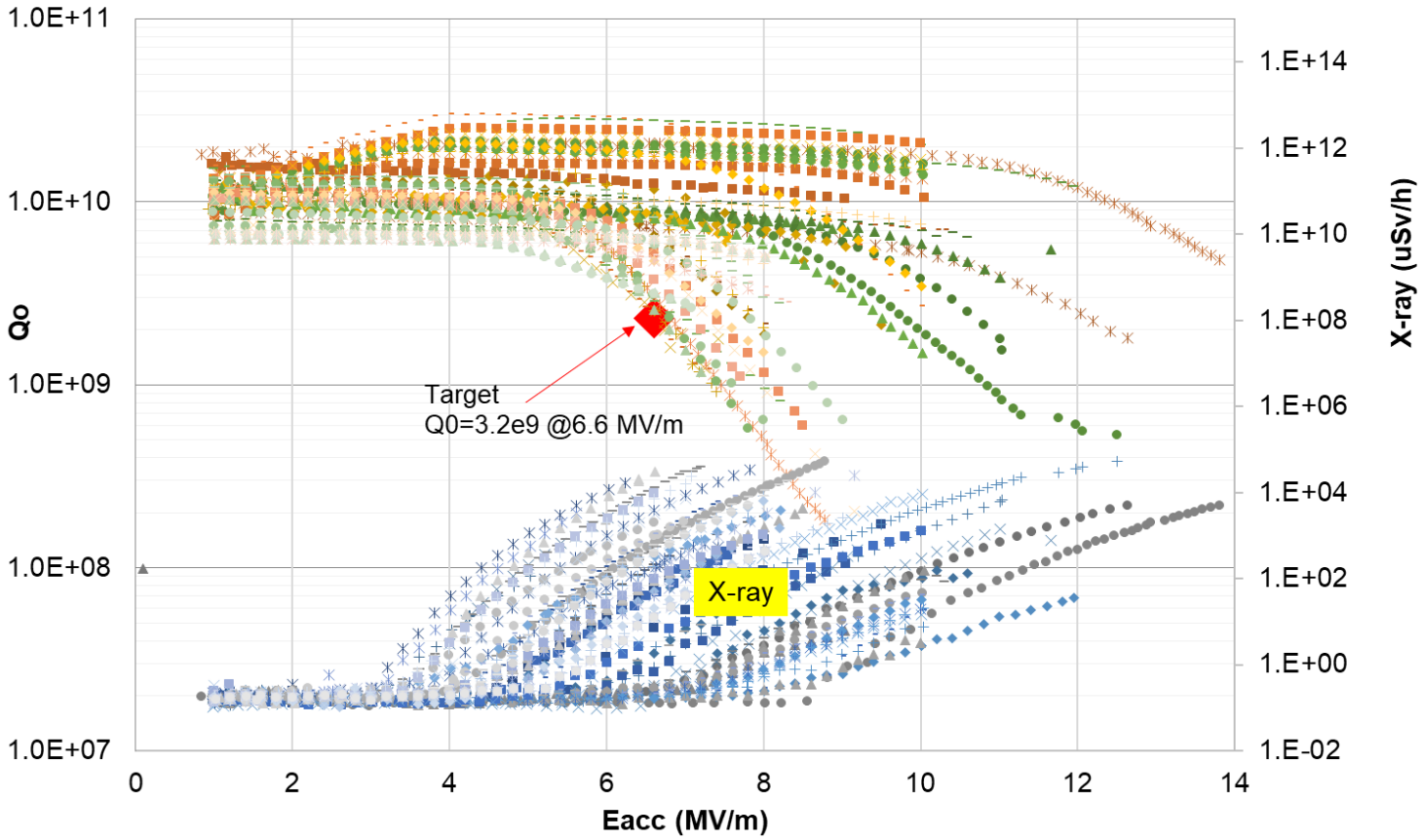
Frequency (MHz)	Optimum β	Eacc (MV/m)	Q0	# of cavity	# of module
81.25	0.047	6.1	2.4 e+8	22	22



MOPOPA20 by Yoochul Jung
MOPOGE24 by Heetae Kim

SRF Cavity Development-HWR

Frequency (MHz)	Optimum β	Eacc (MV/m)	Vacc (MV)	Q0	# of cavity	# of modules	Op. temp (K)
162.5	0.12	6.6	1.46	2.3e+9	106	35	2



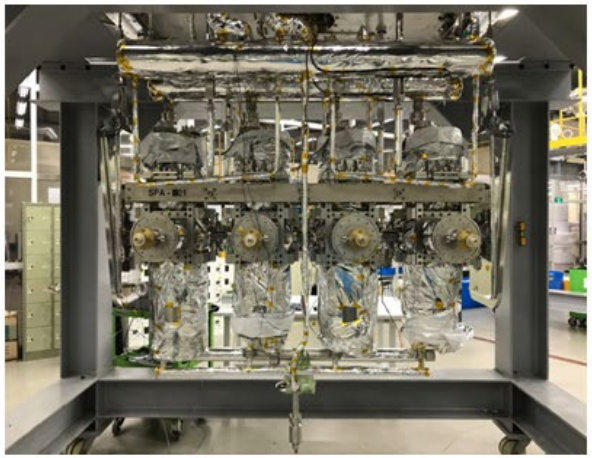
MOPOPA20 by Yoochul Jung
MOPOGE24 by Heetae Kim

SRF Cavity Development

Assembly of the HWR Cryo-module

Cavity String

Particle count inside cavity "0"



With cryogenic piping

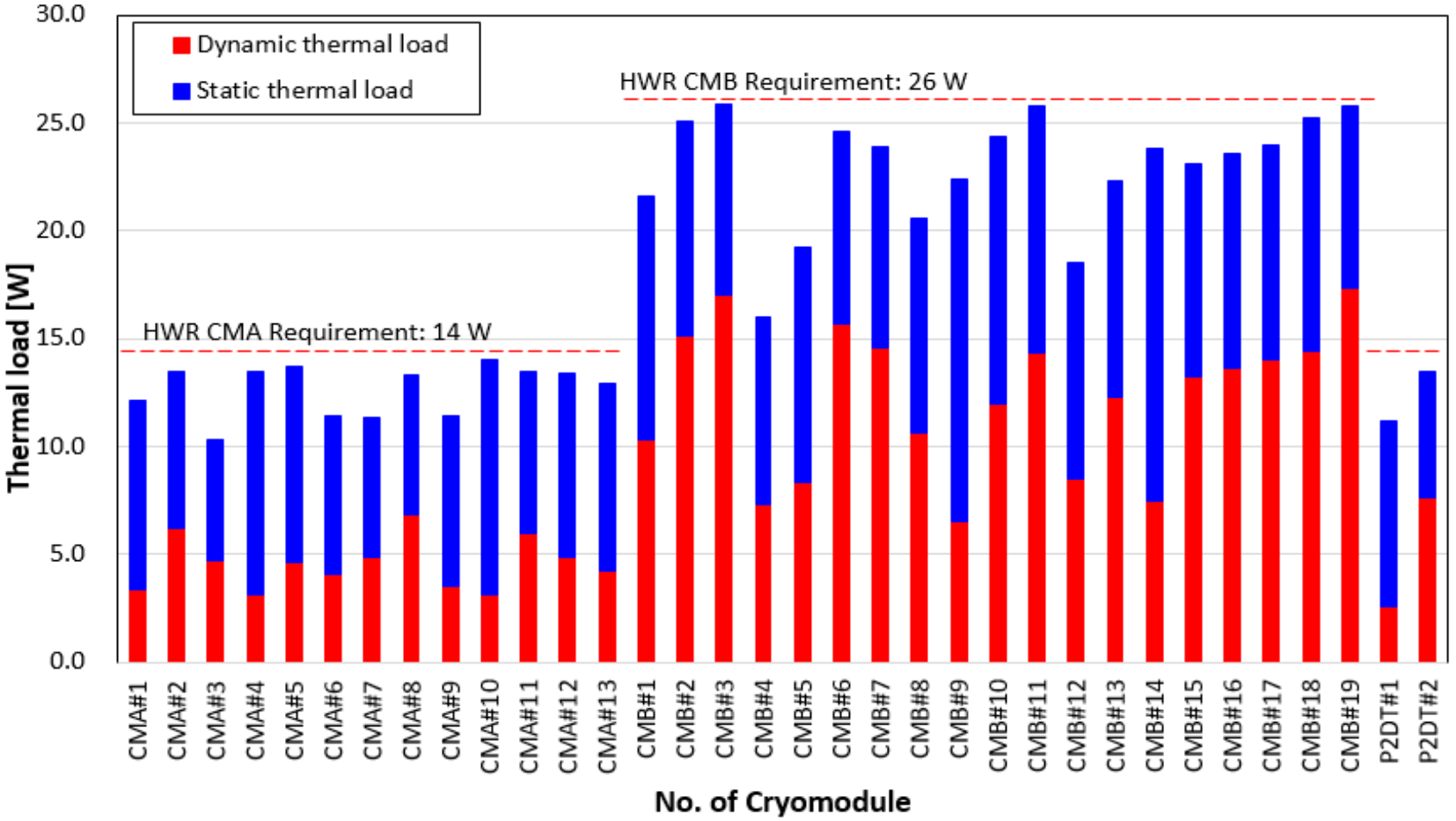
Top loading to cryostat

Vacuum leak rate

HWR B type

SRF Cavity Development

Thermal load of the HWR Cryo-module



TUPOGE06 by Youngkwon Kim

THPOPA18 by Hyunik Kim

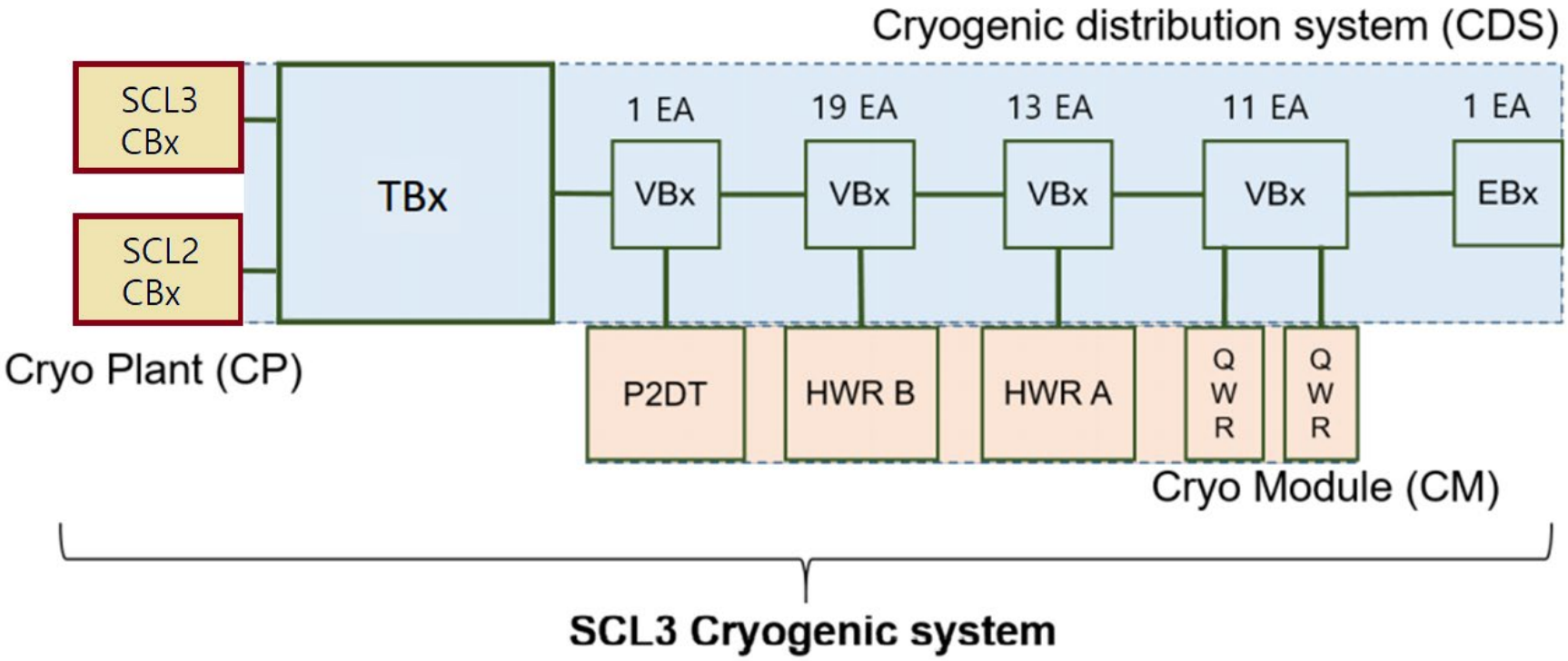
THPOPA17 by H. Jang

SRF Linac Assembled and Installed

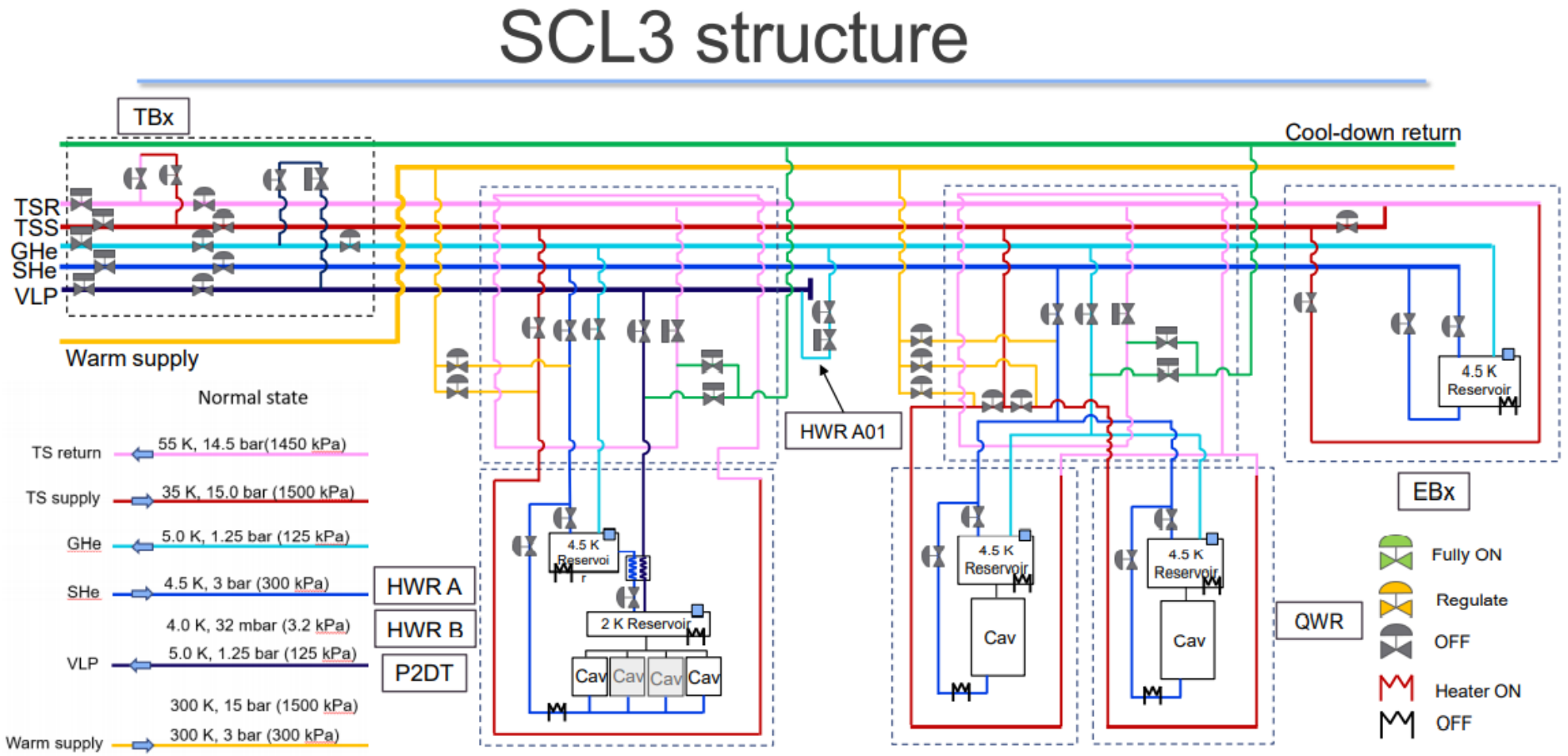
SCL3 and Cryo-plant Installation completed 2021 & Beam commissioning starts from Oct, 2022

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

Cryogenic system for SCL3



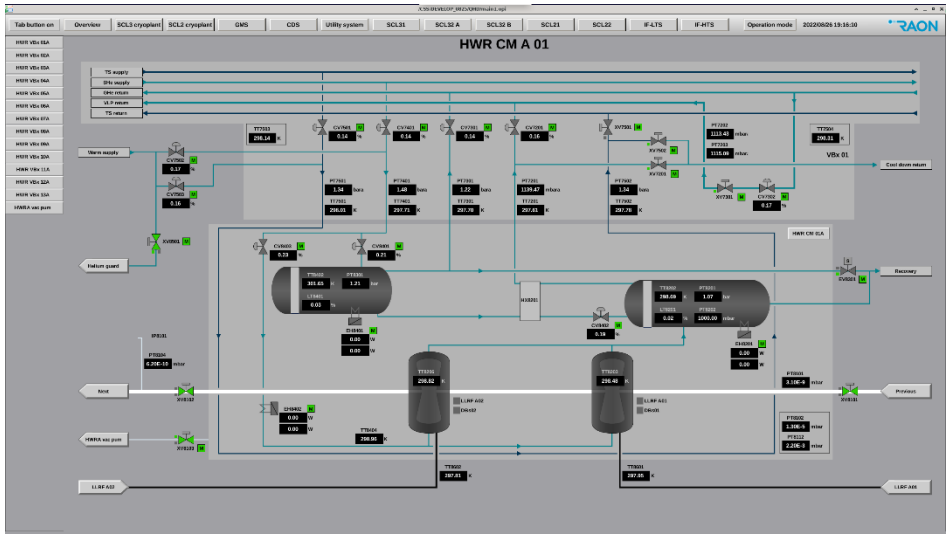
Simple Diagram of the SCL3 Cryo-system

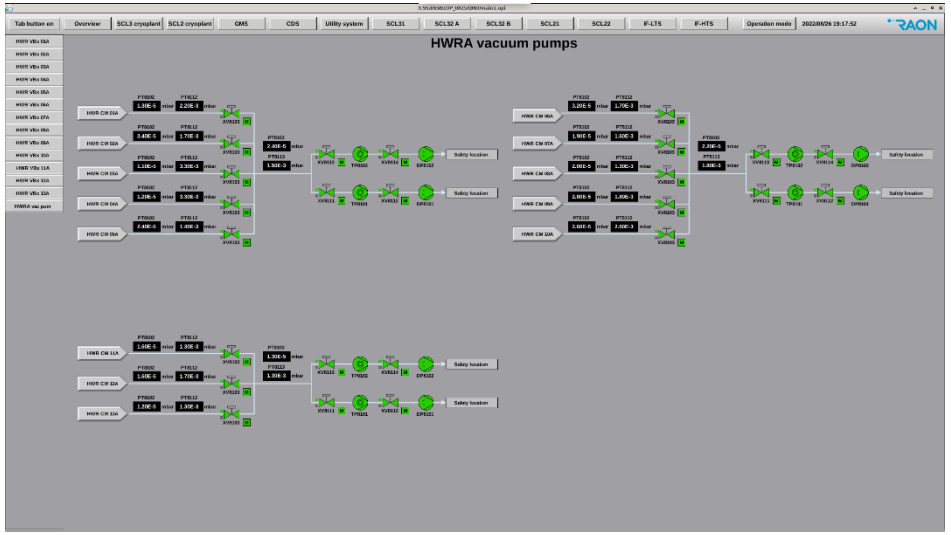


Cryo-system controls are ready

CMs and Valve boxes @ tunnel

CMs and Valve boxes Control GUI





Cryo-plants are ready

Plant configuration

- SCL3 cryoplant (4.2 kW @4.5K) for SCL3
- SCL2 cryoplant (13.5 kW @ 4.5 K) for SCL2
- Two plants connected to the same distribution box. If one plant down, the other can maintain cold condition for SCL 2&3 together or only one.

Cold box

Warm compressors

LHe distribution box

Plant status

- Mechanical installation and commissioning was done in July, 2022
- Cold box was connected to the Main distribution box
- First cool down begins shortly

Part 3.

Beam Commissioning Status

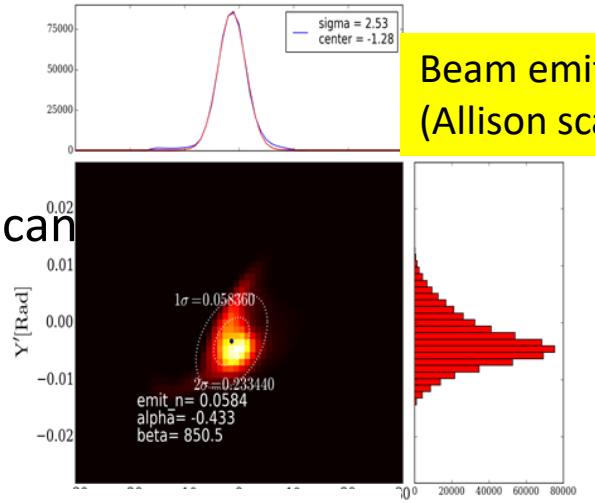
Injector Beam Commissioning

- **Measurements for commissioning**
  - MEBT Bunchers RF set-point (phase scan, BPM)
  - Beam energy (phase scan, TOF with BPMs)
  - Beam current, transmission (ACCT, FC)
  - Orbit correction (BPM / Wirescanner & dipole steerer)
  - Beam transverse profile (wirescanner)
  - Transverse matching (wirescanner)
  - Beam emittance (X and Y) : Allison scanners, Beam size fitting, quad scan methods

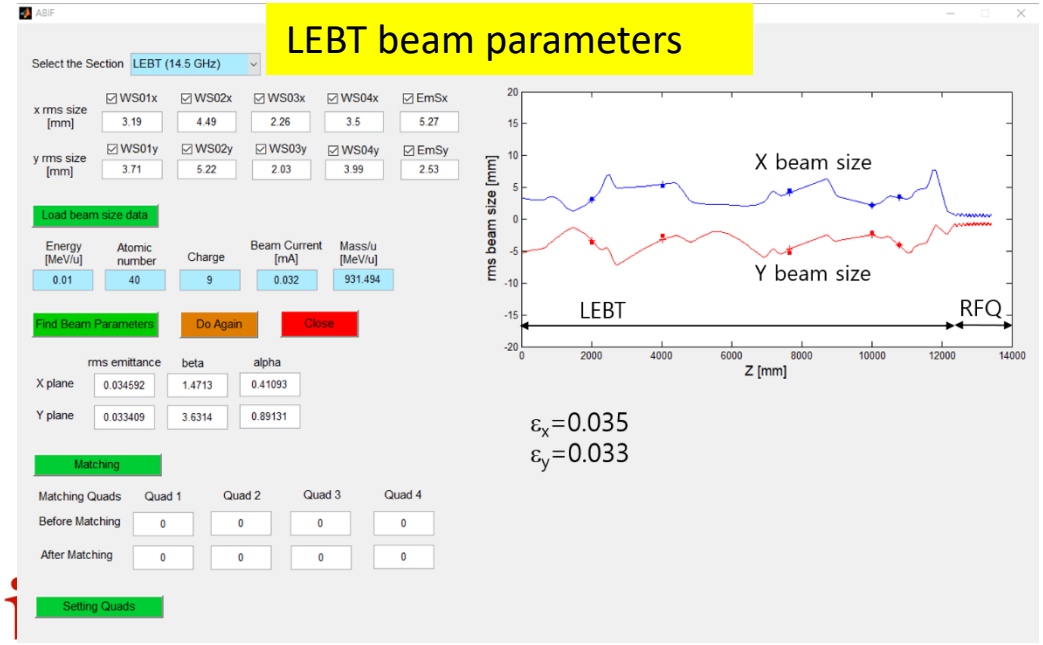
- **Physics applications for commissioning**
  - BIPAM (Beam Input Parameters And Matching)
  - CAPS (Cavity Amplitude and Phase Scan)
  - Orbit correction application
  - Emittance data analysis & wirescanner data analysis

Low Energy Beam Transport (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)

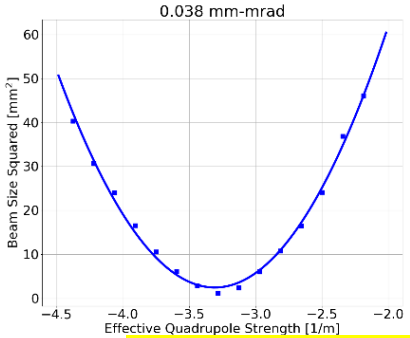


Beam emittance (Allison scanner)



LEBT beam parameters

ε_x=0.035
ε_y=0.033



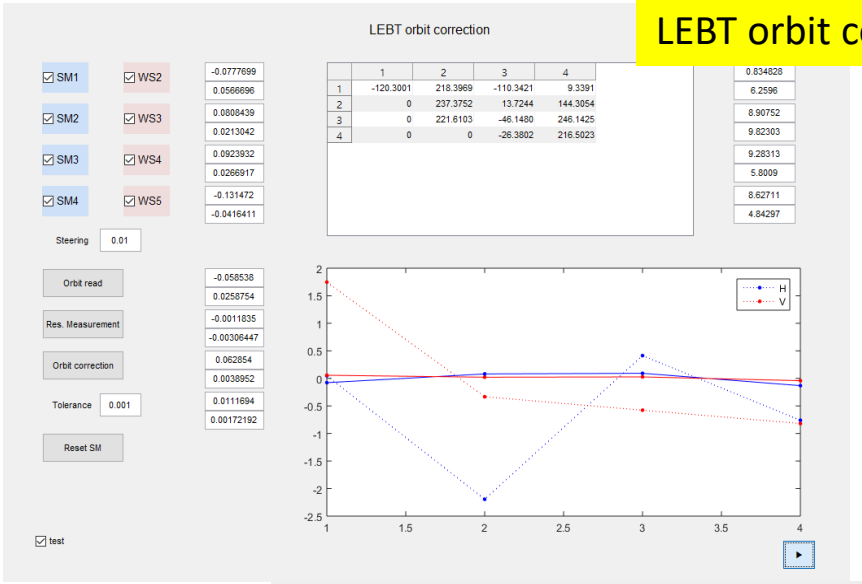
Beam emittance (quad scan)

emittance comparison

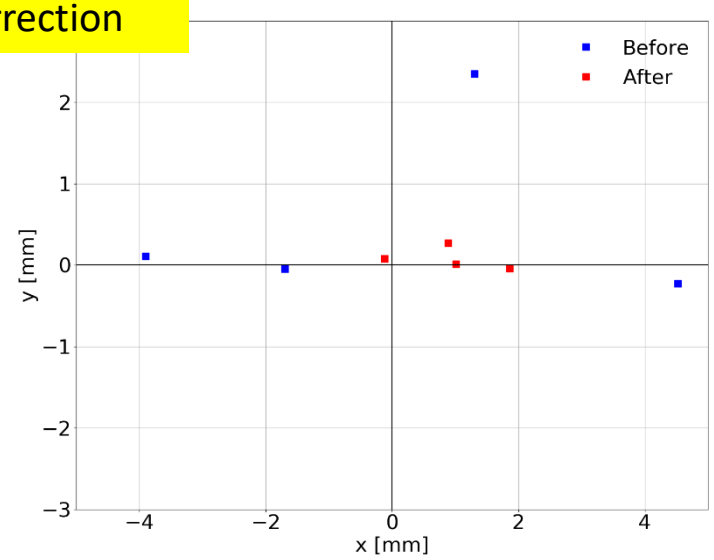
	X	Y
Allison	0.048	0.067
Quad Scan	0.041	0.038

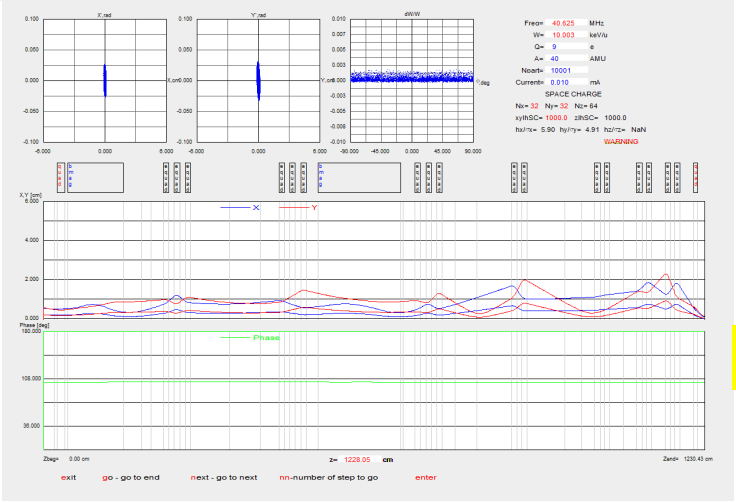
LEBT Orbit Correction

- orbit correction
- beam tracking (TRACK, DYNAC codes)



LEBT orbit correction



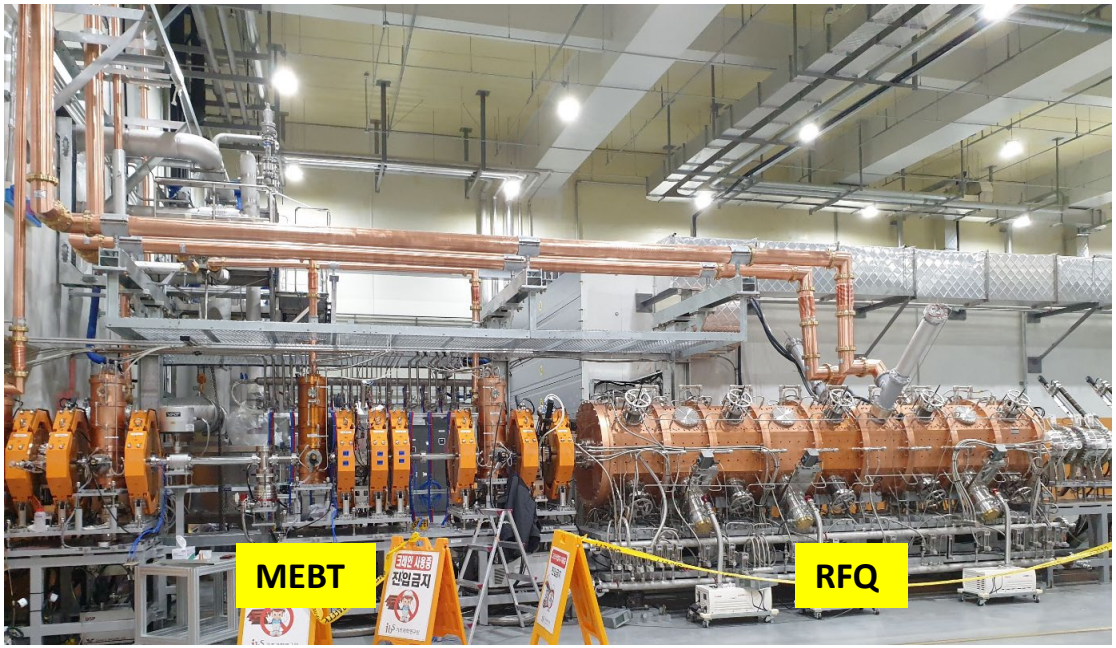


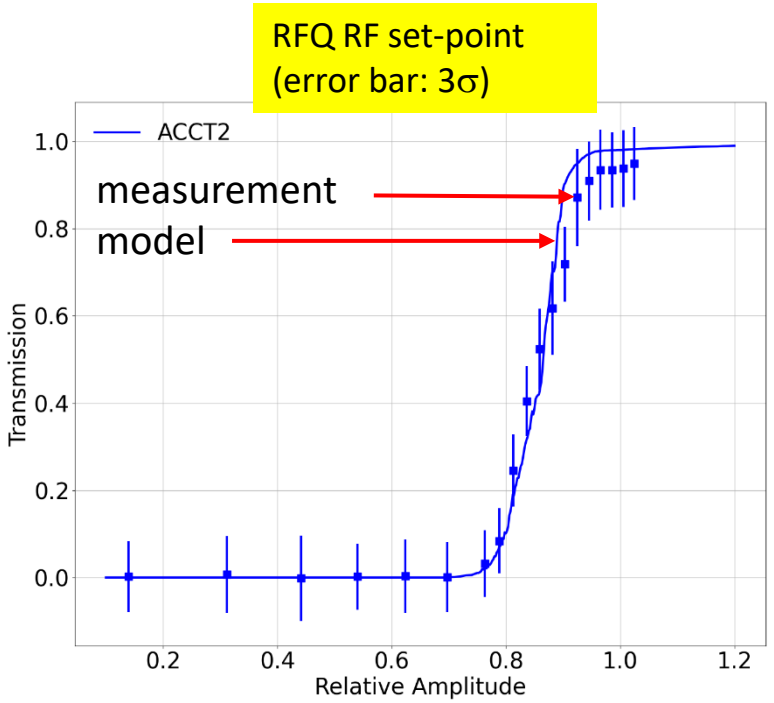
TRACK (beam dynamics code)

RFQ Beam Transmission

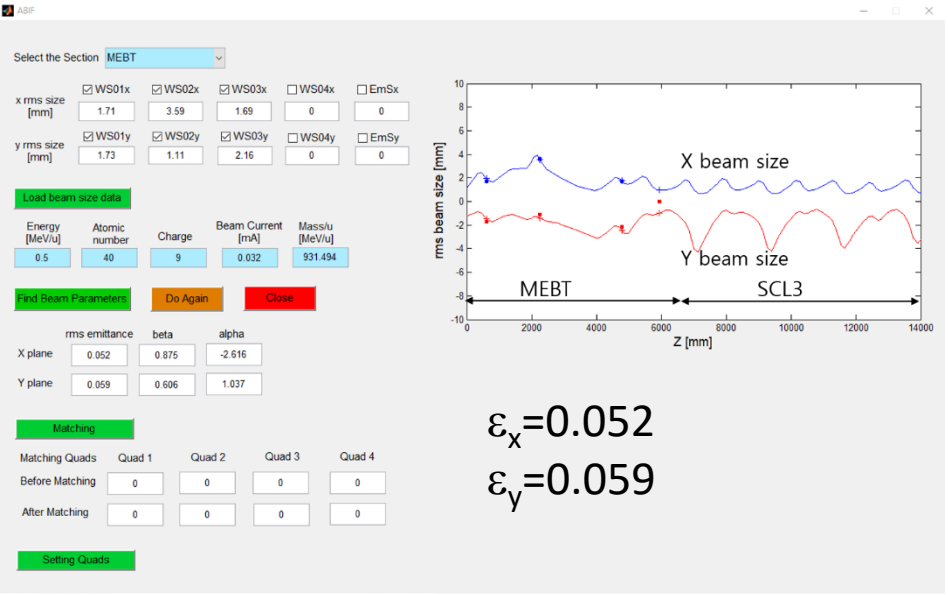
- RFQ RF set-point (Ar9+, Ar8+):
  - beam transmission measured using MEBT ACCT2
  - Fitting against model

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





Medium Energy Beam Transport (MEBT)

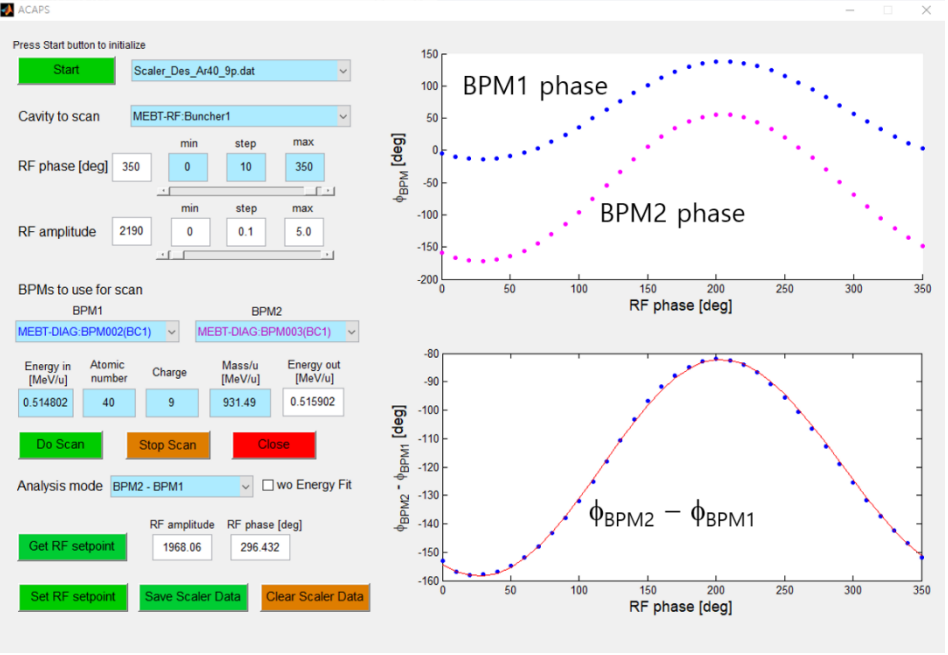


ε_x=0.052

ε_y=0.059

MEBT beam parameter measurements

- using beam sizes from wirescanners
- measure initial beam emittances & parameters
- can do matching to SCL3

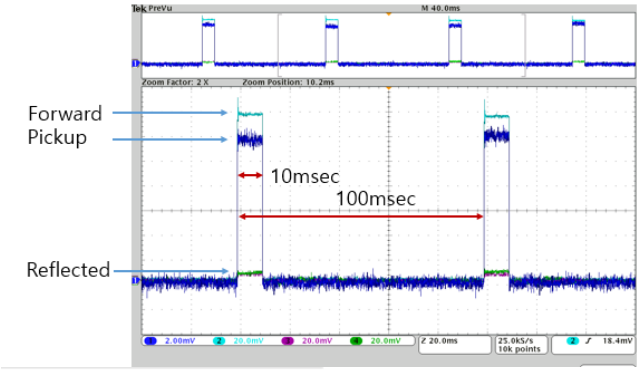


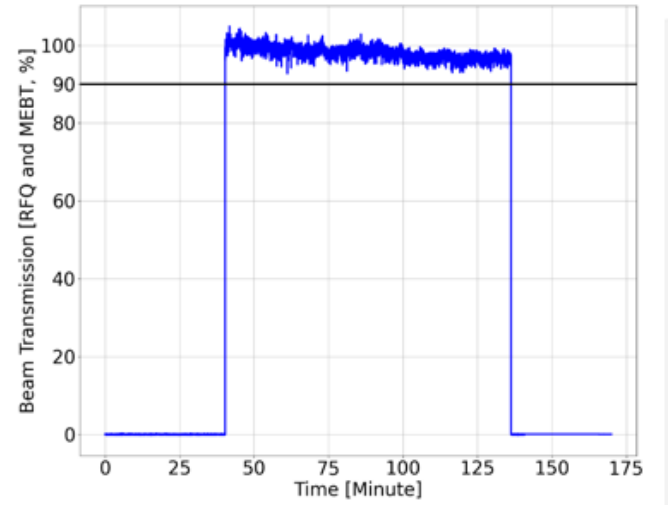
MEBT buncher RF set-point

- using phase scan technique
- determines RF amplitude & phase
- RF set-points of 4 bunchers obtained
- Beam energy is 514 keV/u (design 507 keV/u)

Injector Transmission

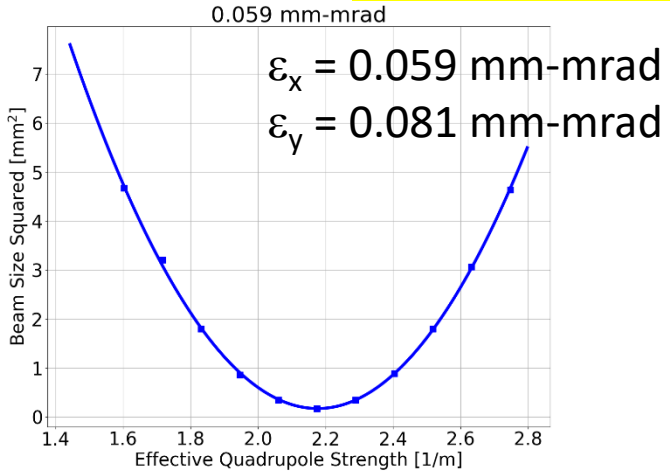
- 10% beam duty operation: 96 minutes, 10Hz, 10msec
  * Injector transmission > 94%
- MEBT beam emittance measurement based on quad scan

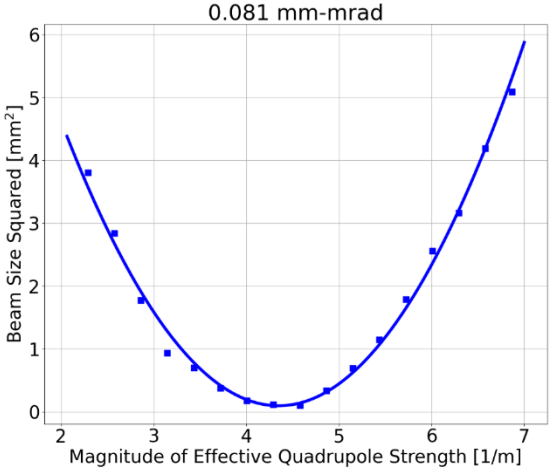




Injector beam transmission

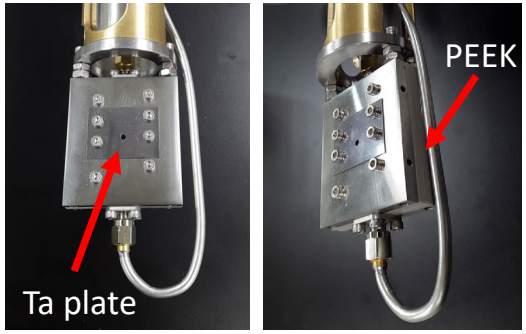
MEBT quad scan
emittance measurement

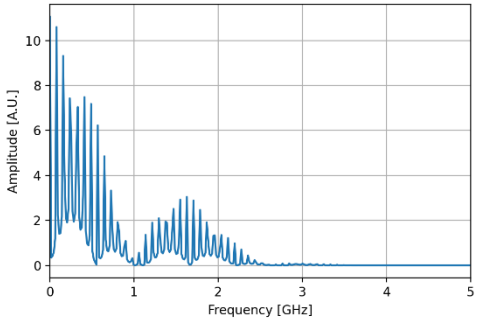




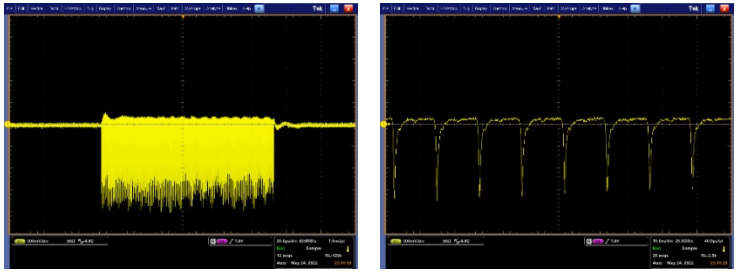
Bunch Length Measurement

- Fabrication of Stripline type Fast Faraday Cup



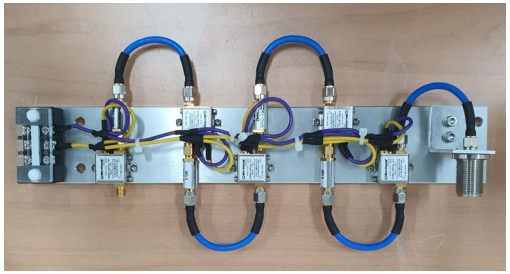


Frequency component < 3 GHz
With 0.13 ns bunch length



Oscilloscope (4 GHz, 25 GSPS)

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



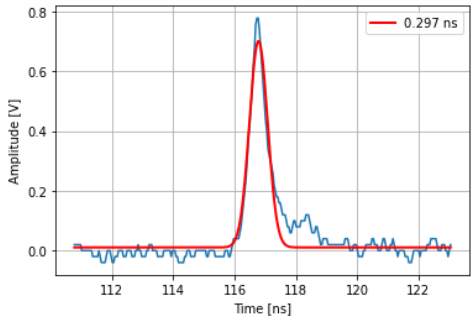
Amplifier (43 dB Gain)
Bandwidth 300 kHz ~ 14 GHz

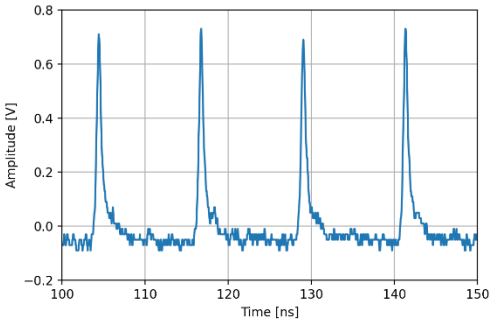
- Ar 8+, 50 uA, at the end of MEBT (4 bunchers)
- 100 μs macro pulse commissioning beam

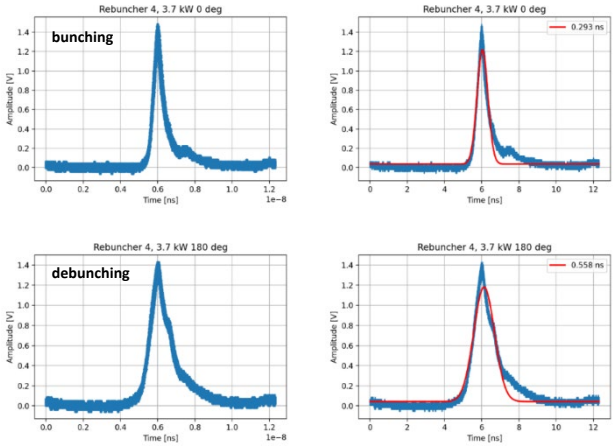
- Expected peak amplitude was ~ 4 mV
- RF amplifier and oscilloscope prepared, considering frequency component

Bunch Length Measurement

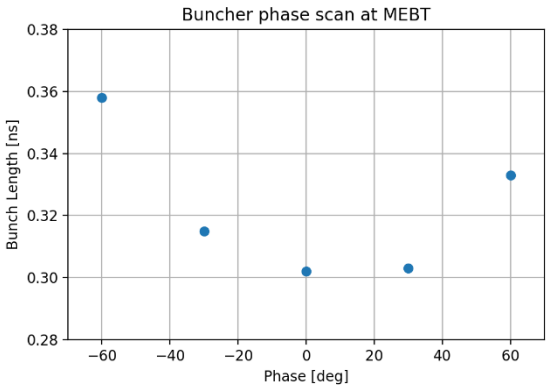
- Measured bunch Length at MEBT







Phase scan of Buncher 4



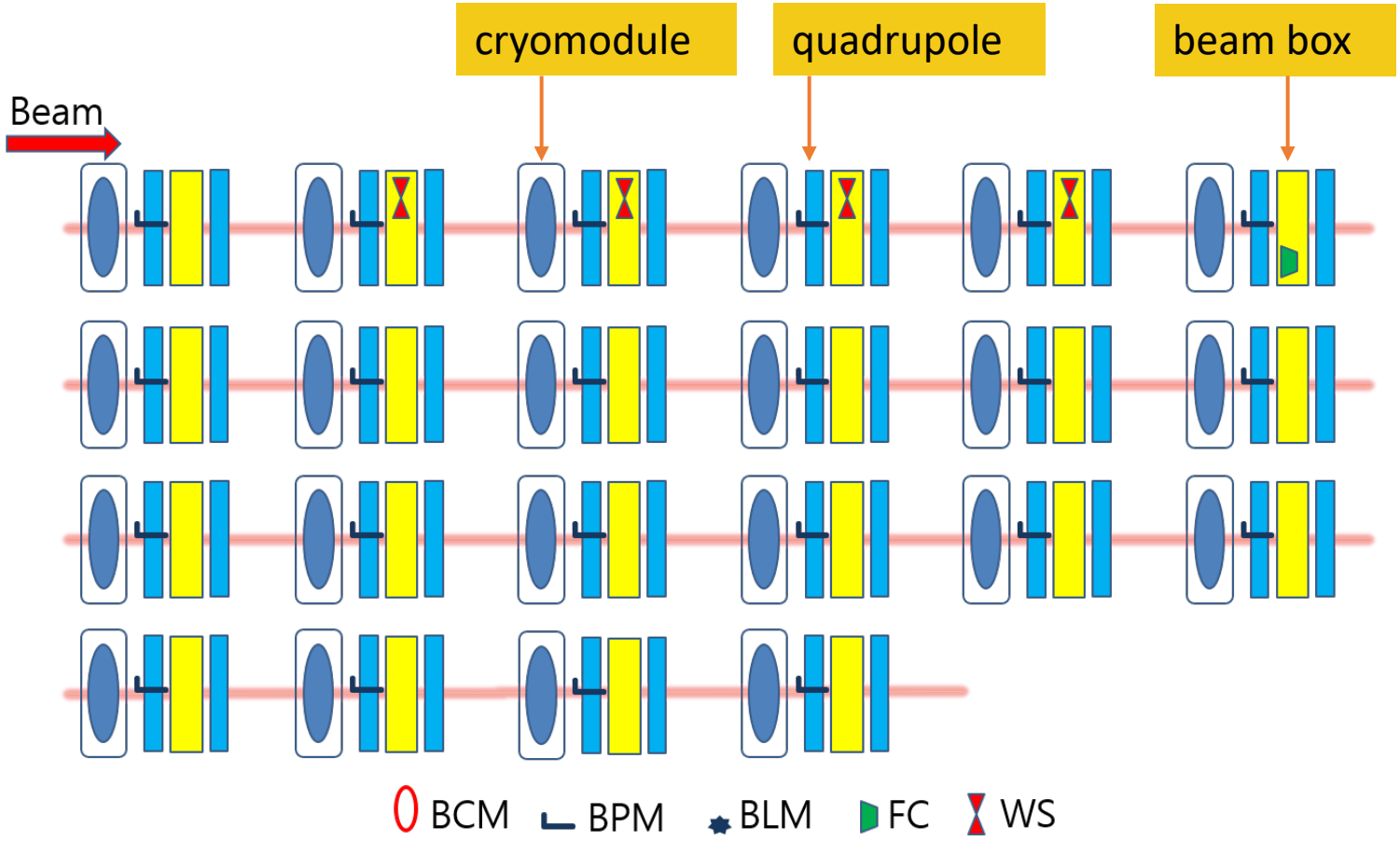
- Measured single bunch length was $0.297\ ns\ (1\sigma)$ with Gaussian fit.
- Shows good signal repeatability for measuring bunch trains.
- Overlapped signal of 325 bunches in 4 us is shown.
- Bunching and debunching was observed by rebuncher in MEBT.

SRF Linac Commissioning Plan

- **Measurements to perform**
  - QWR/HWR RF set-point (phase scan, BPM)
  - Beam energy (phase scan, TOF with BPMs)
  - Beam current, transmission (ACCT, FC)
  - Orbit correction (BPM & dipole steerer)
  - Beam transverse profile (wirescanner)
  - Transverse matching (wirescanner)
  - Beam emittance (X and Y) : beam size fitting, quad scan

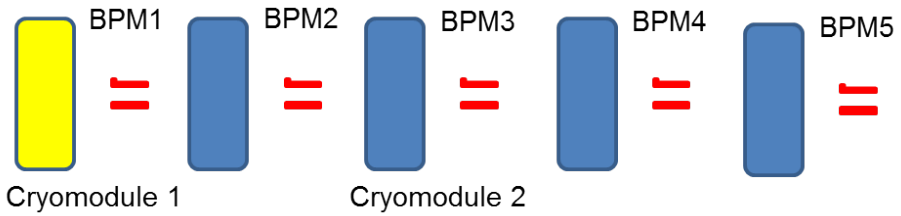
- **Physics applications for commissioning**
  - BIPAM (Beam Input Parameters And Matching)
  - CAPS (Cavity Amplitude and Phase Scan)
  - Orbit correction application
  - Emittance data analysis & wirescanner data analysis

Available Diagnostics in QWR Section

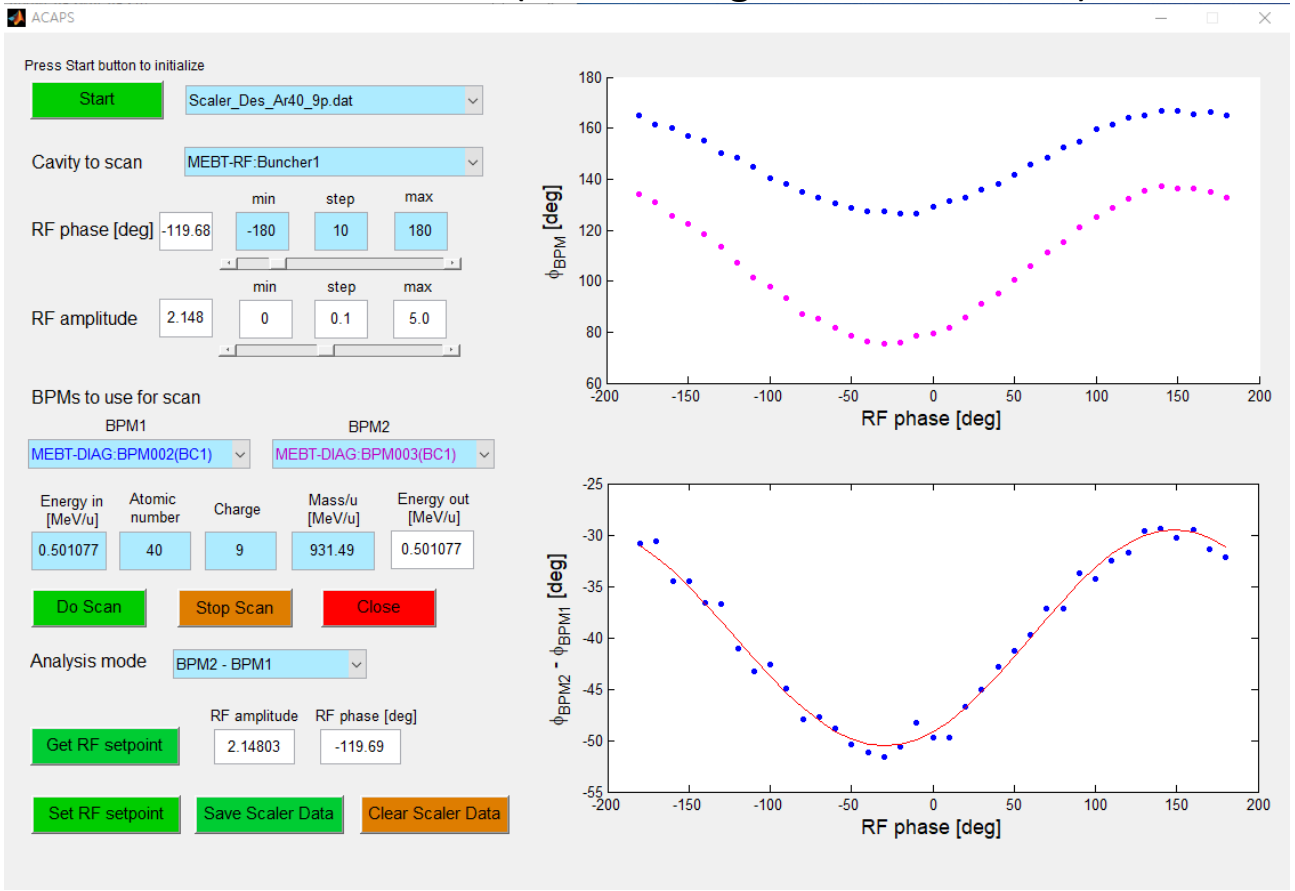


- Halo Collimators(aperture 36 mm) installed at beam boxes

CAPS (Phase Scan Tool, Cavity RF Setpoint)

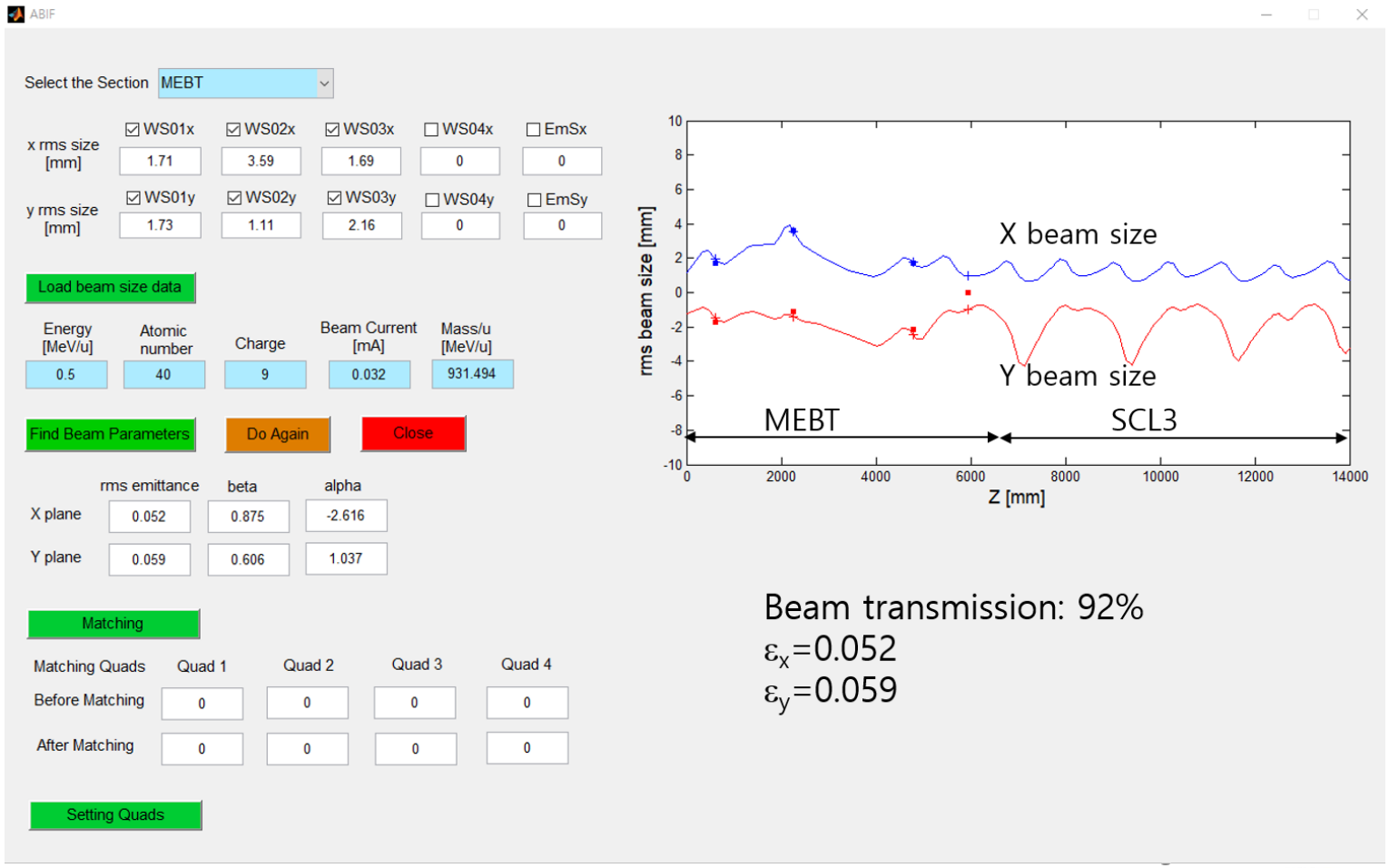


Phase scan with BPMs (Time of Flight measurement)



BIPAM (Beam Parameter & Matching)

- 4 wirescanners are installed in MEBT and in the SCL3.
- With 4 wirescanners, beam parameters are measured and used to match to the following section.



Beam transmission: 92%

ε_x=0.052

ε_y=0.059

Part 4.

Summary & Outlook

Summary & Outlook

- **RAON installation and system integration was successfully done :**
  - Progress rate is more than 95% for Phase 1

- **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

- **Commissioning team is ready for the superconducting linac beam commissioning this fall :**
  - physics applications are ready and tested

Summary & Outlook

- September : Cool-down of QWR/RF conditioning
  First Beam injection to first five modules
- October : Cool-down of HWR/RF conditioning
  Beam commissioning for QWR
- November : 2 K pumping for HWR section/RF conditioning
- December : 2 K stabilization for HWR section/RF conditioning
- January-March : Beam commissioning for whole SCL3


Thank You for Your Attention!