Commissioning of RAON Injector and Superconducting Linac

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on behalf of the project
2023.02.28.

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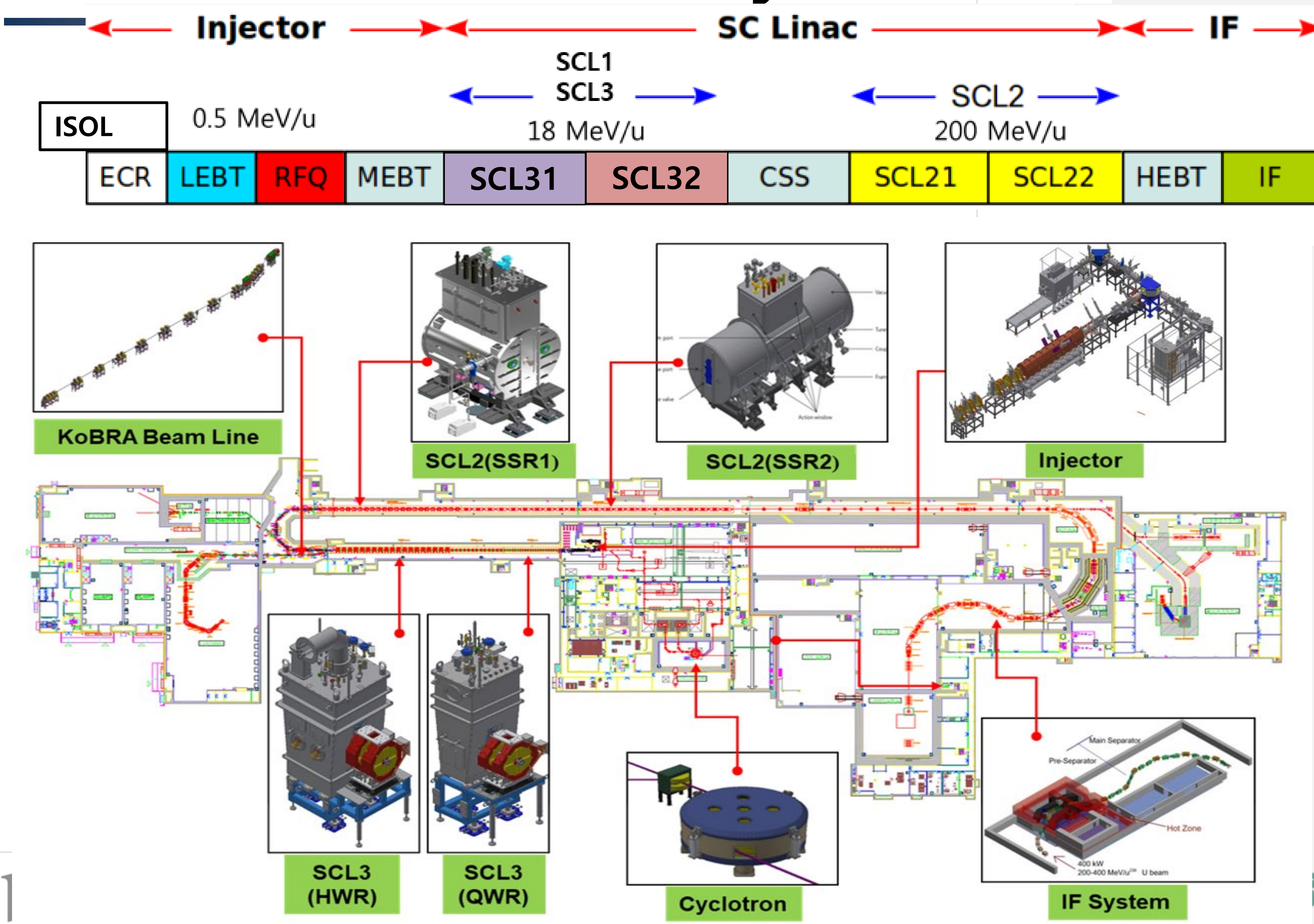
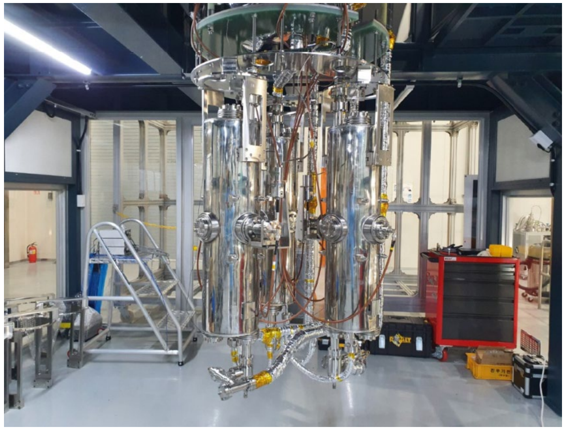
Accelerator Systems



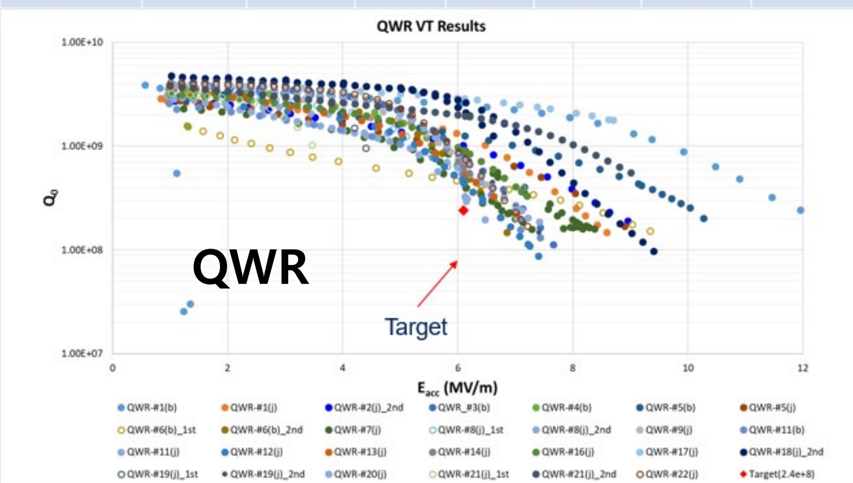
SRF Test Facility & Cavity Tests

SRF Test Facility

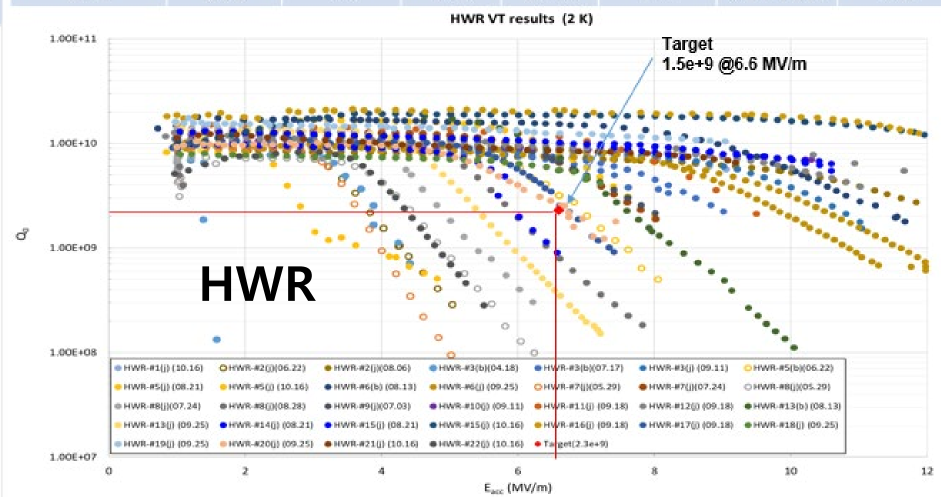


- 1 onsite - 3 VT pits and 3 cavities per pit, 3 HT bunkers
- 1 offsite (15 Km from site) - 2 VT pits and 2 cavities per pit
- Test all RAON cavities - QWR (82.25 MHz), HWR (162.5 MHz) and SSR1 & 2 (325 MHz)

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



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



SCL3 (Superconducting Linac)

SCL3 and Cryo-plant Installation completed 2022 & Beam commissioning started in Oct, 2022

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

- 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)

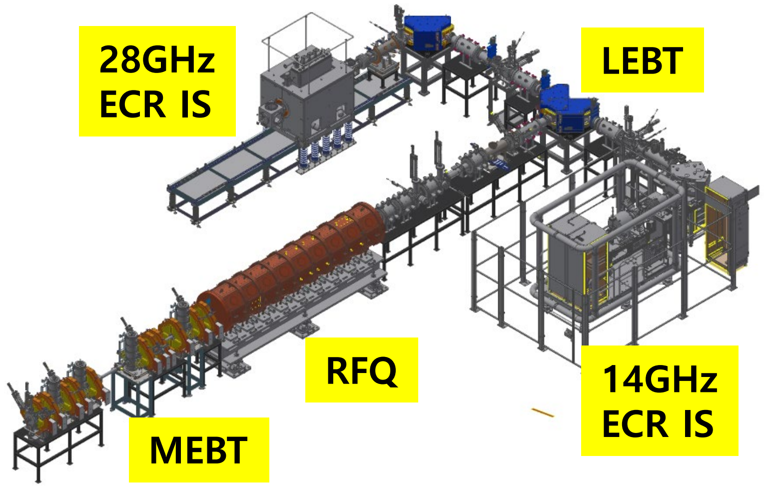
Cold Box (CB)
(Left warm side, right – cold side)

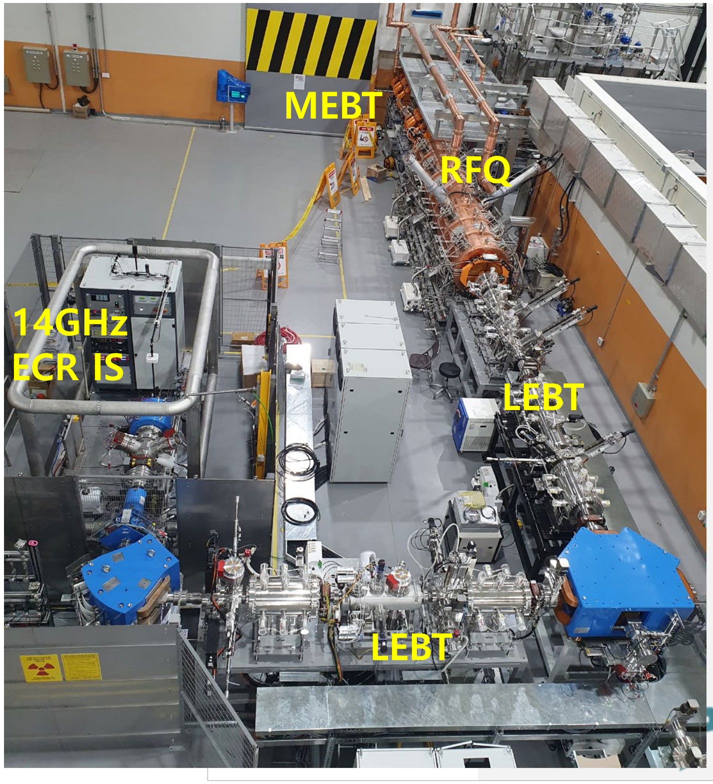
Injector Beam Commissioning

- **Injector**
  * Ion Source: 14.5 GHz ECR IS
  * LEBT: 10 keV/u
  * RFQ: 507 keV/u, 98% transmission
  * MEBT: 507 keV/u, 4 bunchers

- **Beams**: Ar^{9+}(A/q=4.4), Ar^{8+}(5.0), Ar^{11+}(3.6)
- **Beam Diagnostics**

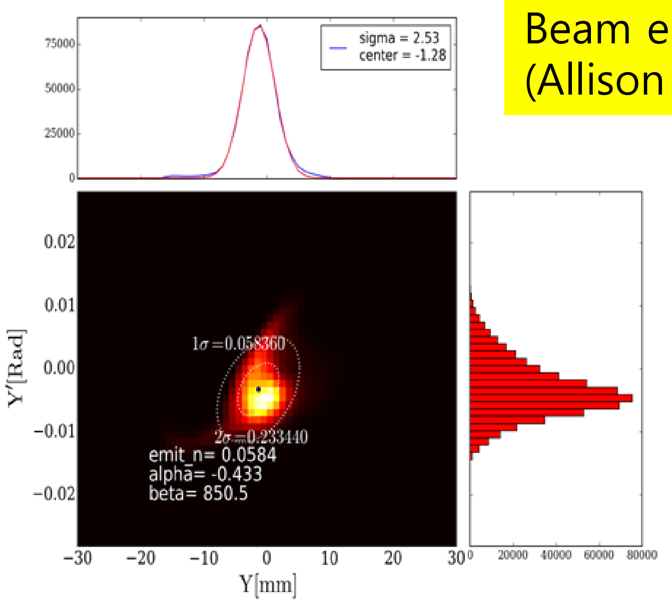
	LEBT	MEBT
Allison scanner	2 (X,Y)	-
Wire scanner	4	4
Faraday cup	4	2
ACCT	1	2
BPM	-	6
Beam viewer	2	1
Fast Faraday Cup	-	1



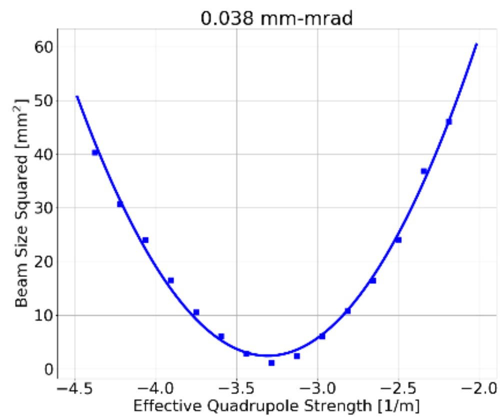


LEBT beam emittance & parameters

- Beams: Ar^{9+} (~30μA), Ar^{8+} (~47μA)
- Beam parameter measurements (Allison scanner, wirescanner)
  - BIPAM measures initial beam parameters (wirescanner)
  - controlling beam optics
  - matching to RFQ
- Emittance measurement (Allison scanner, BIPAM, quad scan)



Beam emittance (Allison scanner)



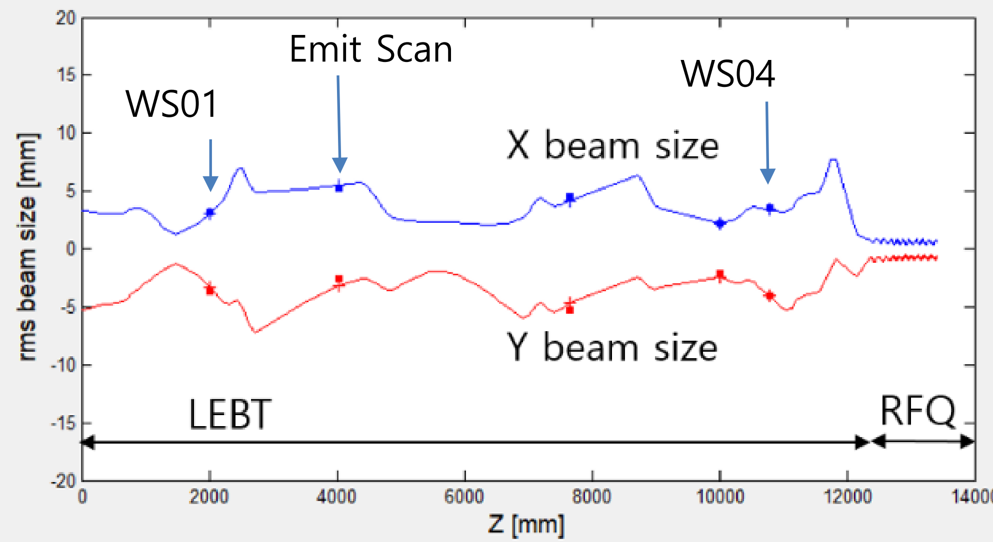
Beam emittance (quad scan) Ji-Ho Jang

emittance comparison

	ε_x (mm-mrad)	ε_y (mm-mrad)
Allison	0.048	0.067
Quad Scan	0.041	0.038

LEBT beam emittance & parameters

BIPAM measures initial beam parameters (emittance and Twiss parameters)

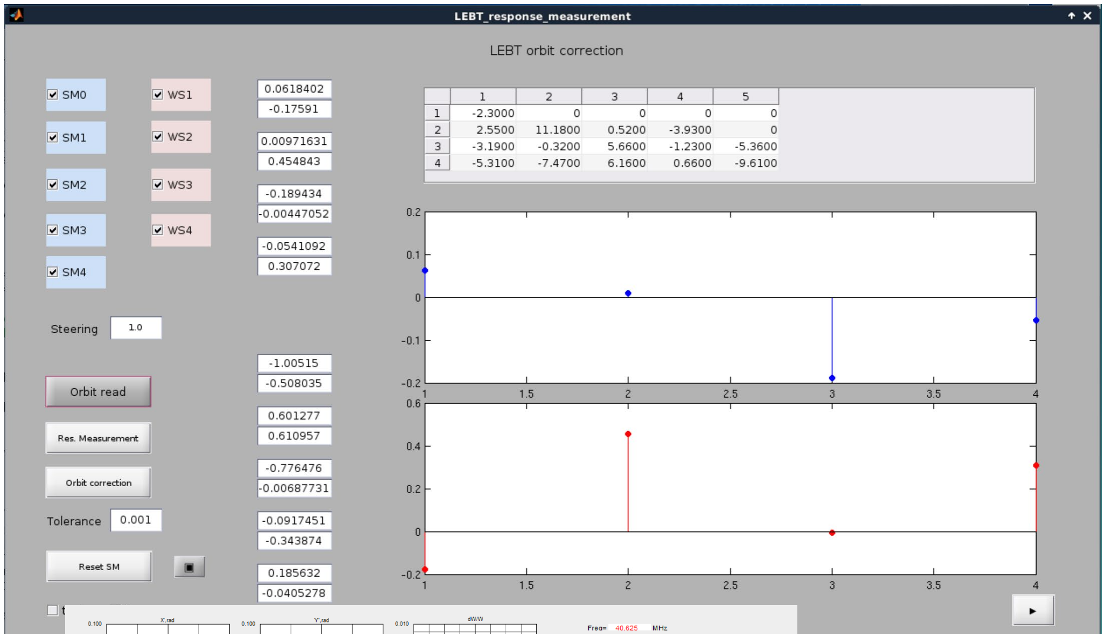


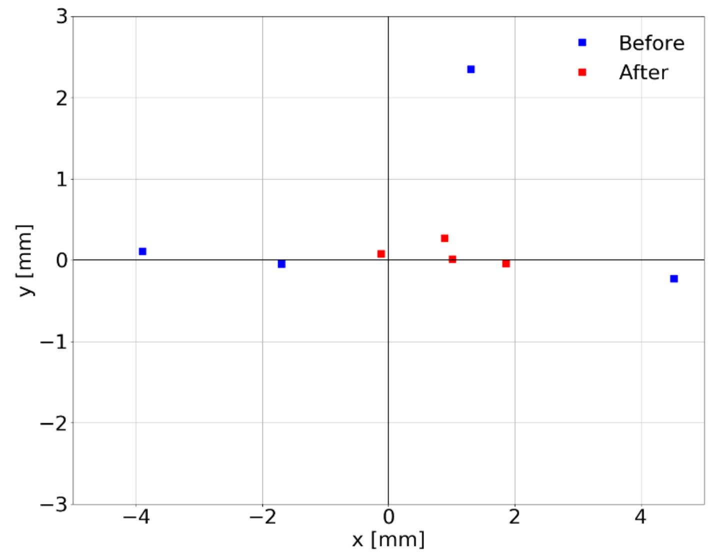
ε_x=0.035 mm-mrad (norm rms)
ε_y=0.033 mm-mrad (norm rms)

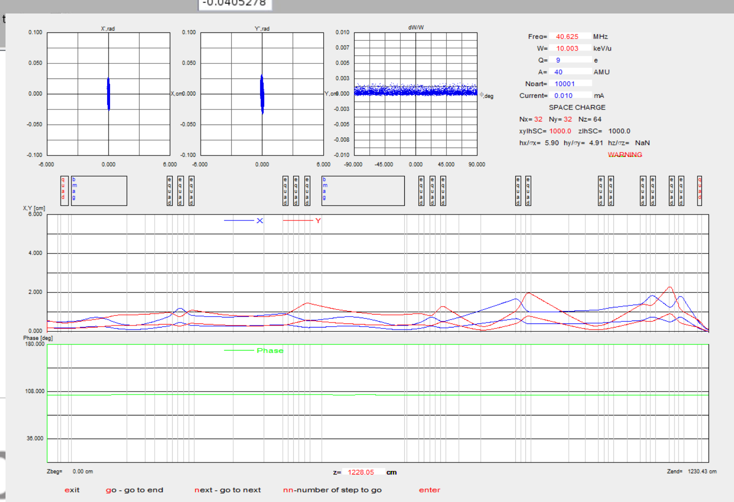
LEBT orbit correction

- orbit correction
- beam tracking (TRACK, DYNAC, Trace3D codes)

Hyunchang Jin







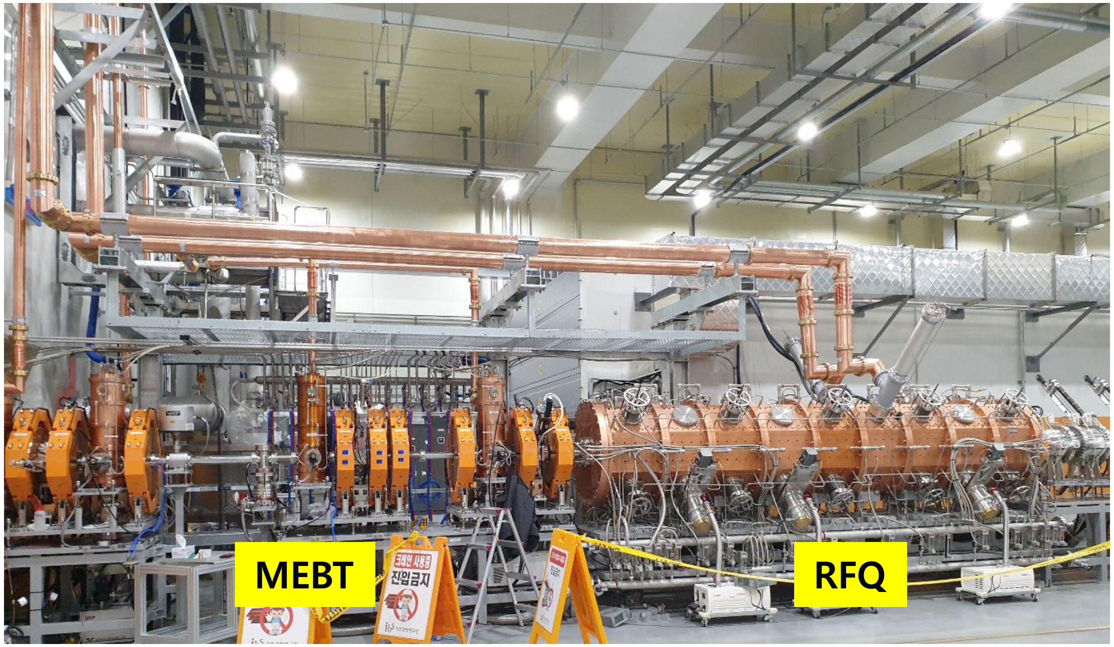
TRACK (beam dynamics code)

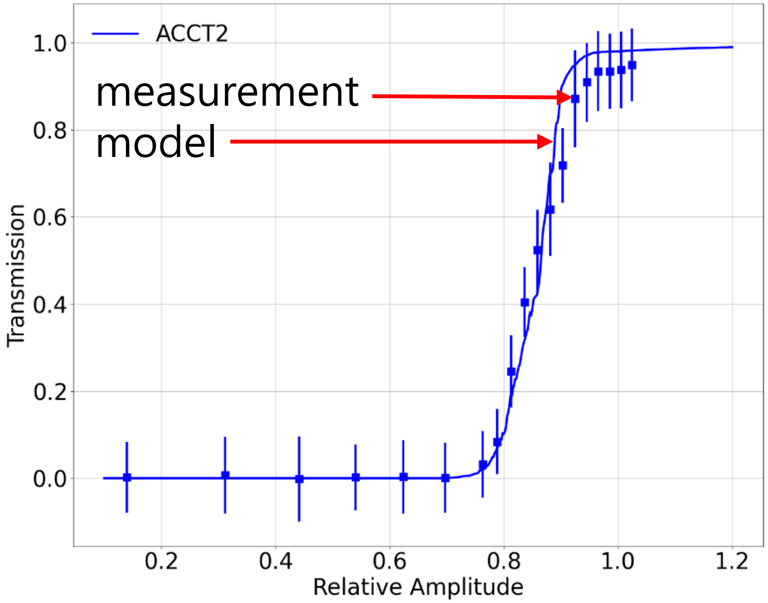
RFQ (Radio Frequency Quadrupole)

- RFQ RF set-point (Ar^{9+}, Ar^{8+}):
  - beam transmission measured using MEBT ACCT2
  - Fitting against model

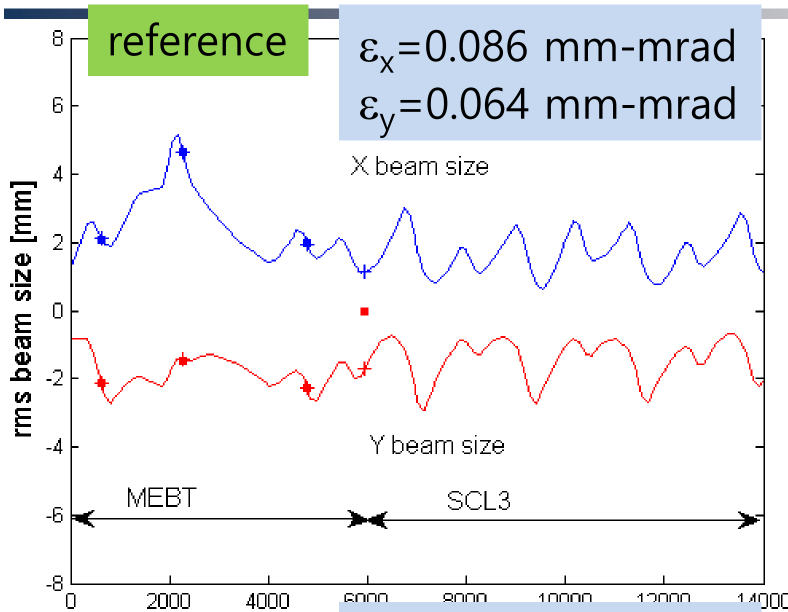
  * Measured transmission = 94 % (simulation = 98%)
- Cavity RF power: 51.5 kW (Design ~39.1 kW (20% margin))

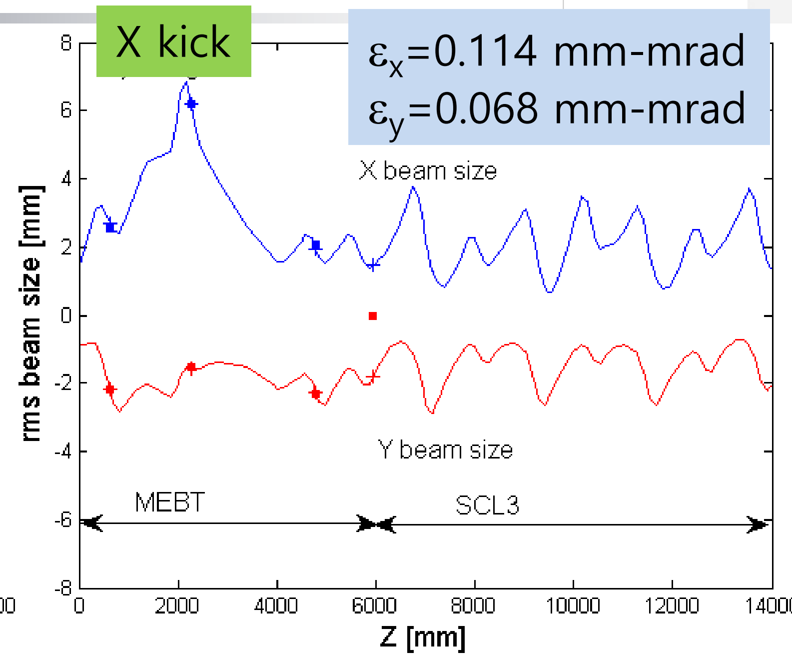
Ji-Ho Jang

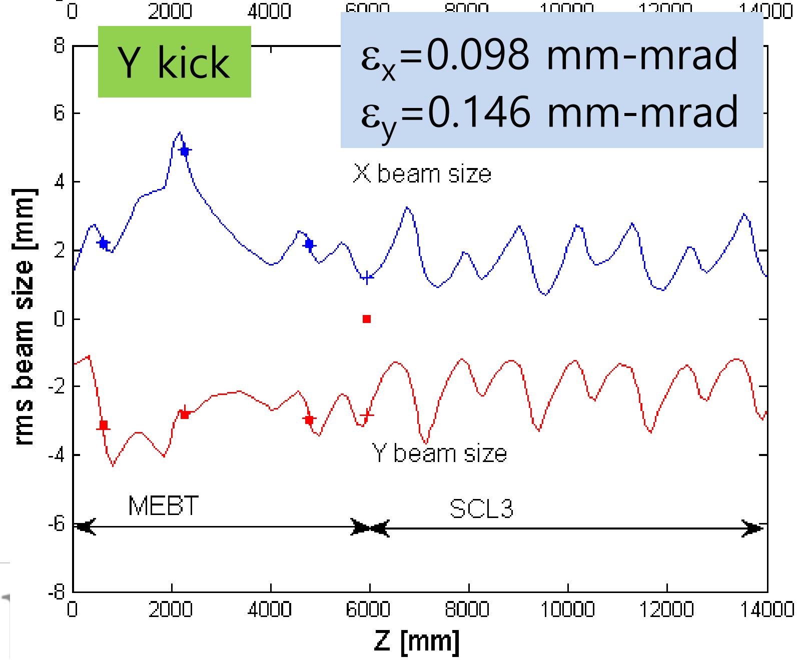




Off-axis beam injection to RFQ



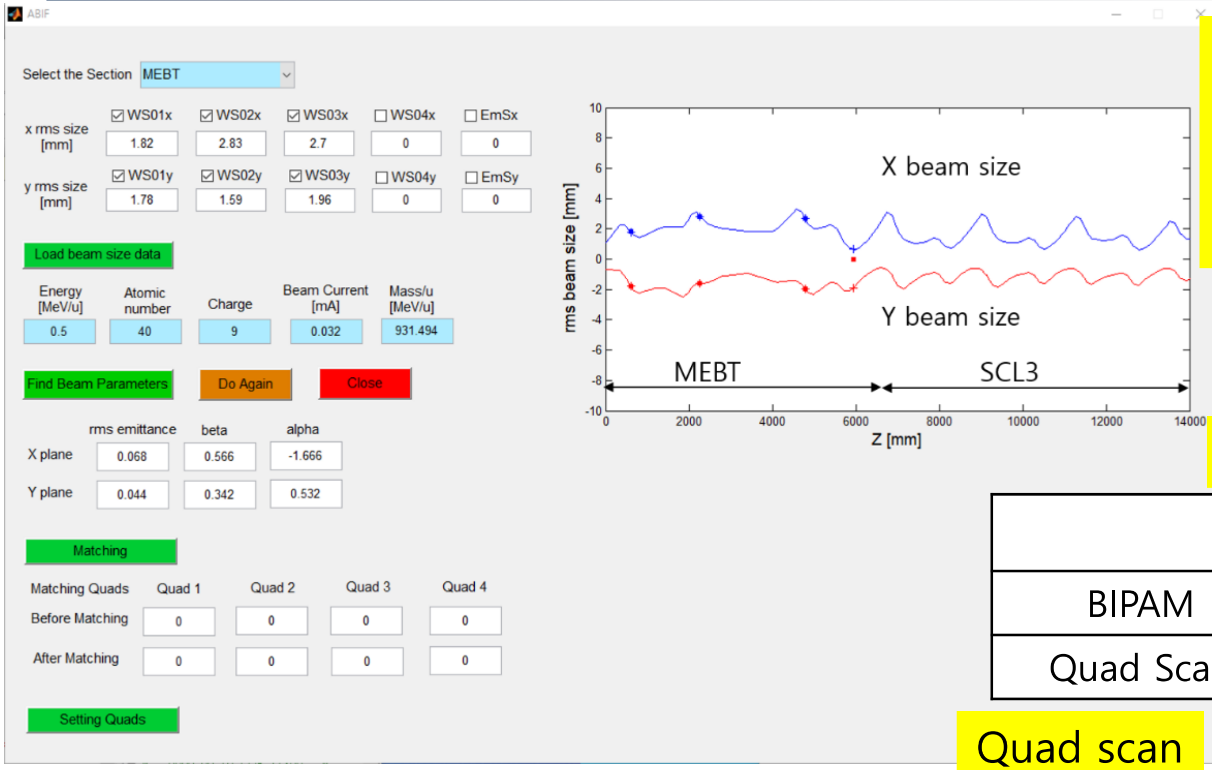




- Off-axis beam injection to RFQ can increase beam emittances and degrade beam transmission.

- LEBT orbit correction and on-axis injection matter.

MEBT beam emittance & parameters

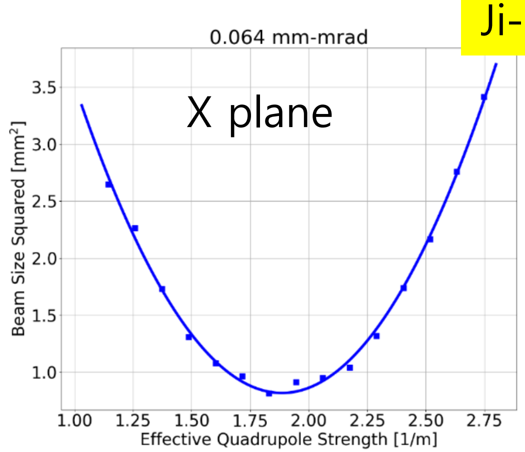


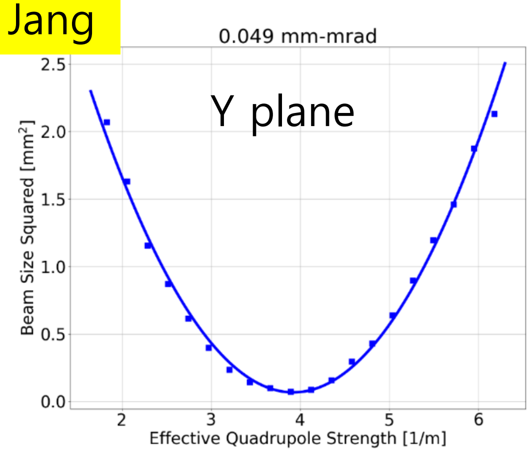
BIPAM
- measuring initial beam emittances & parameters
- matching to SCL3

emittance comparison

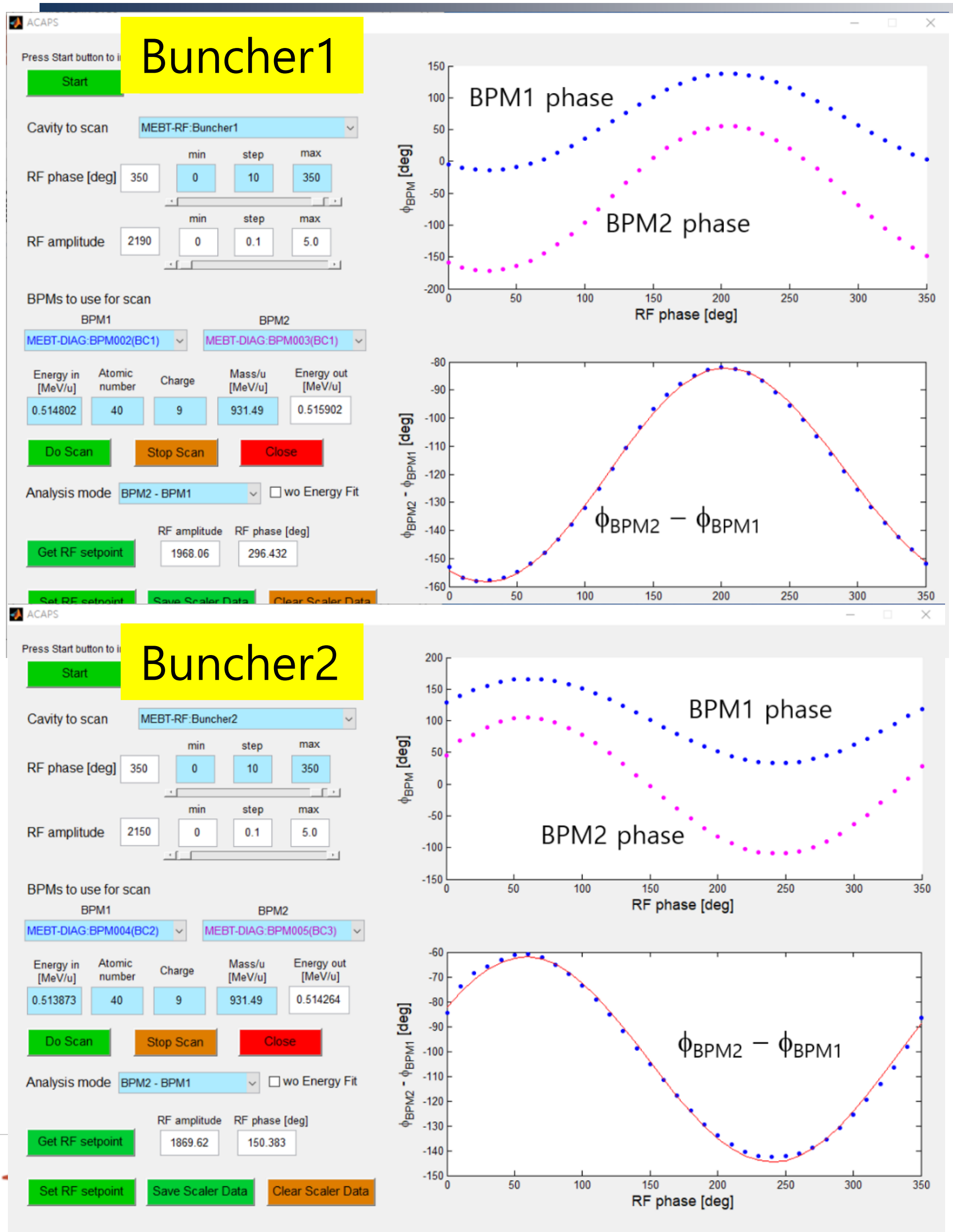
	ε_x (mm-mrad)	ε_y (mm-mrad)
BIPAM	0.068	0.044
Quad Scan	0.064	0.049

Quad scan
Ji-Ho Jang





MEBT buncher RF set-point

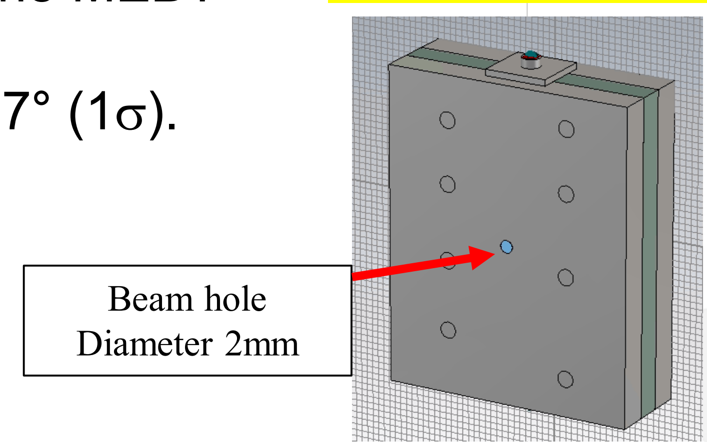


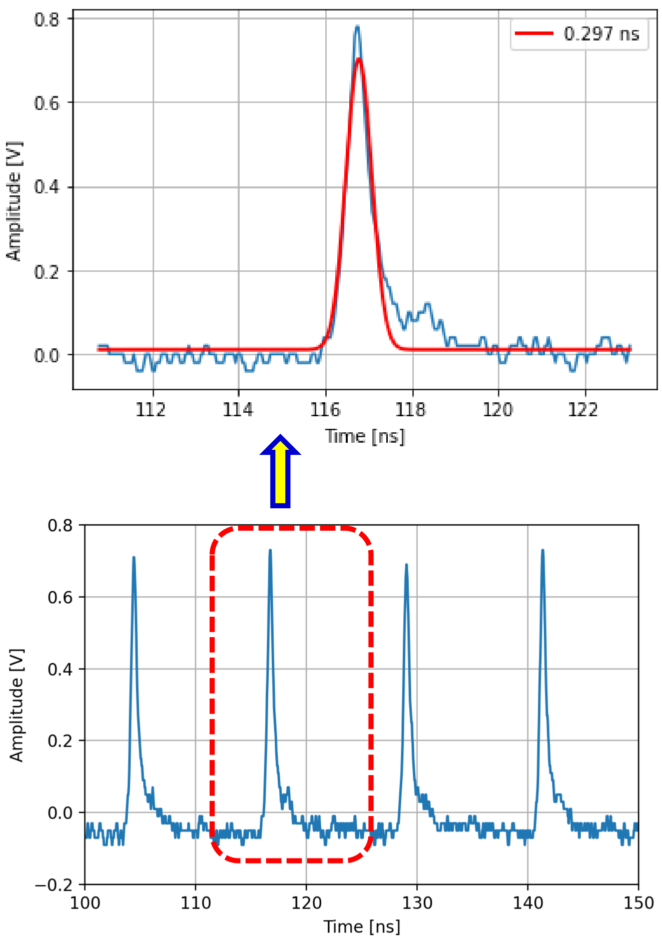
- MEBT bunchers RF set-points were set using phase scan technique:
  - obtained RF set-points of 4 bunchers
  - measured beam energy is 514 keV/u (design 507 keV/u)

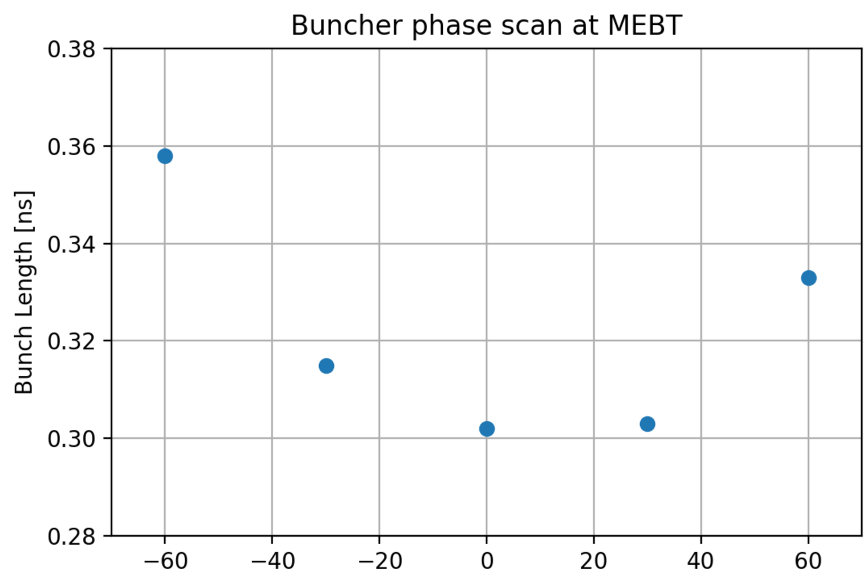
MEBT Bunch Length Measurement

- Bunch length measurement at the MEBT with Fast Faraday Cup (FFC).
- Bunch length was 0.297 ns = 8.7° (1σ).

Courtesy of Ki-Dong Kim et al







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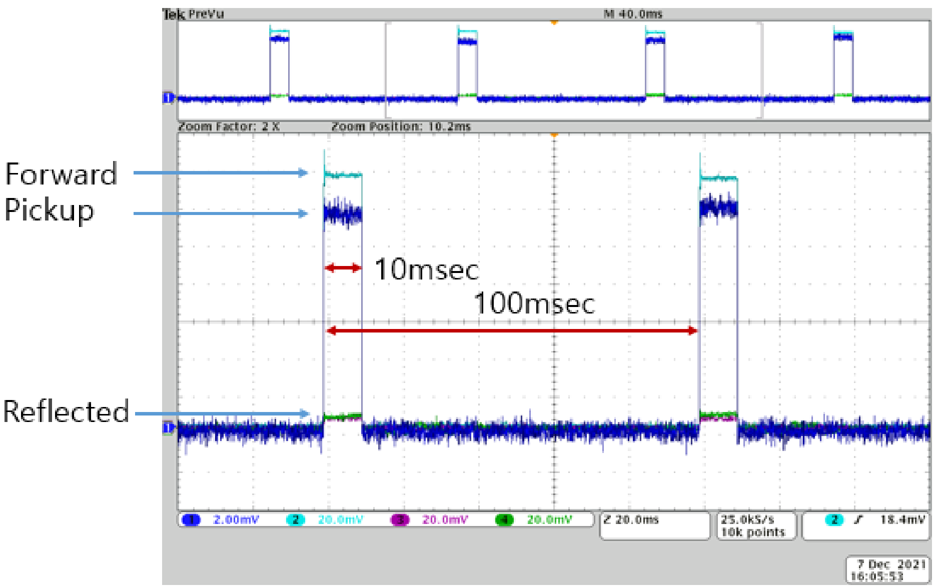
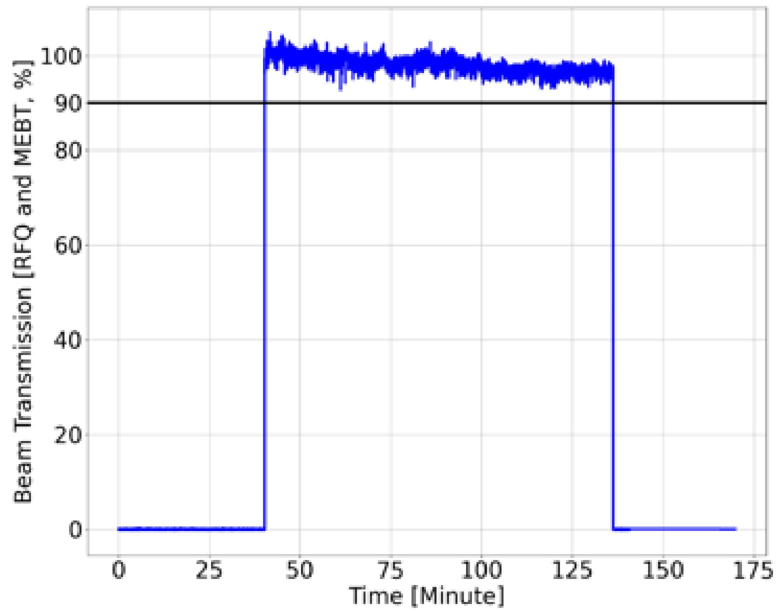
Injector transmission

- 10% beam duty operation: 96 minutes, 10Hz, 10msec (2021.12.07).
  * Injector transmission > 94% (determined by RFQ)

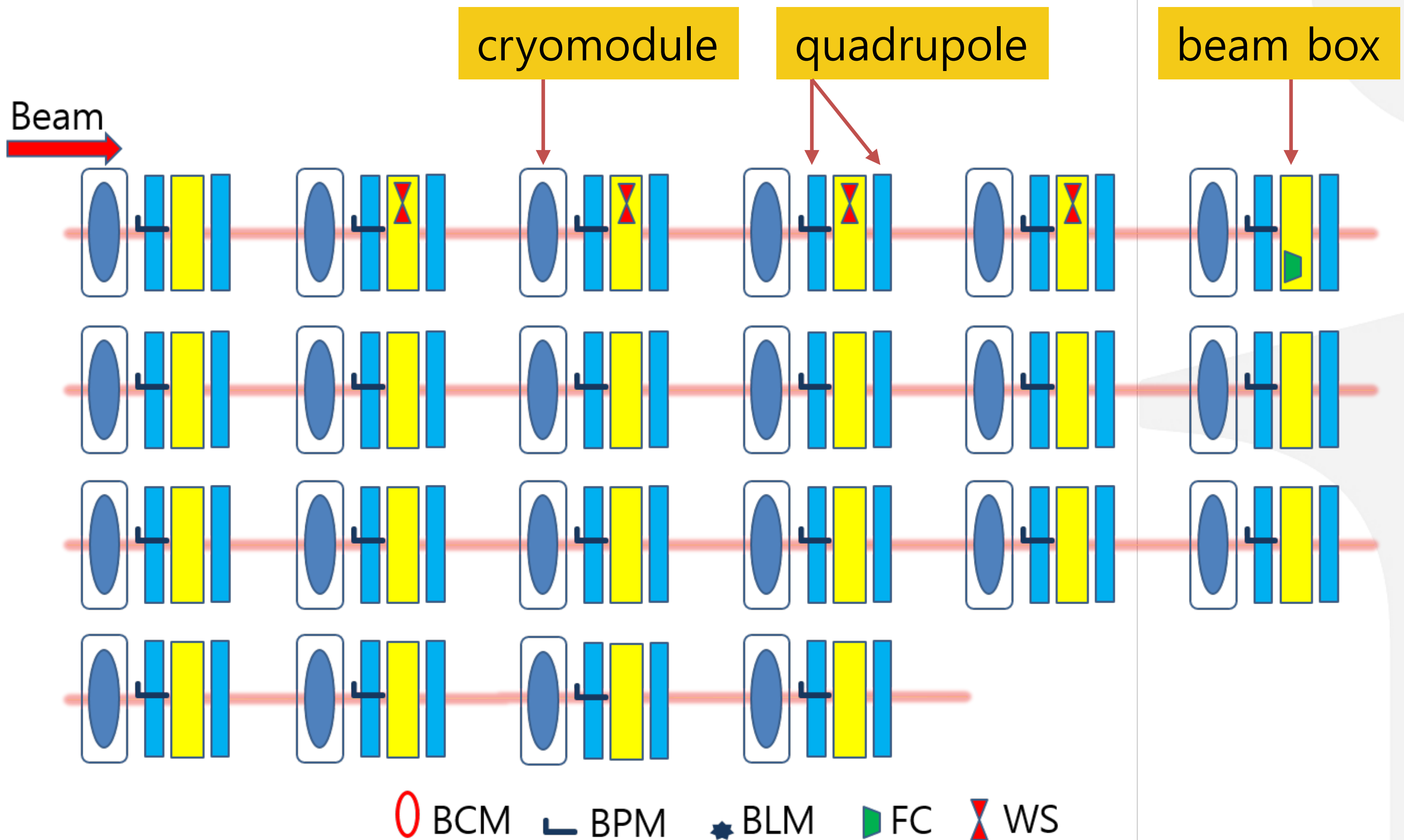
- orbit correction and matching help to increase the beam transmission.





Injector beam transmission

SCL3 Beam Commissioning

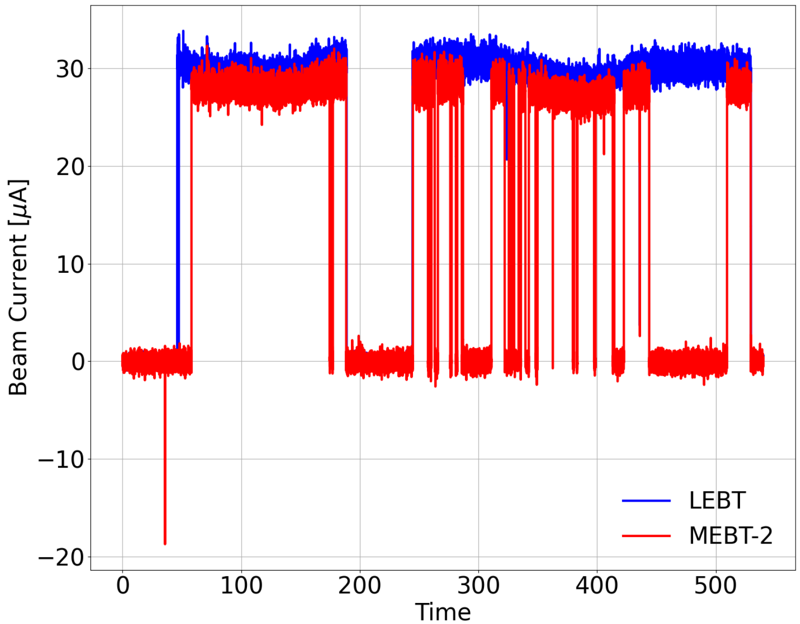


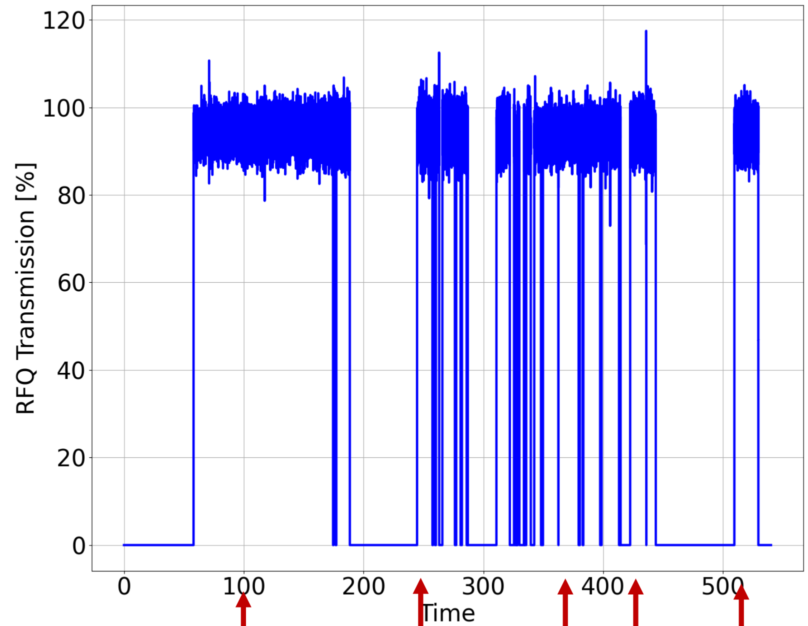
- One QWR cavity per cryomodule.
- Quad doublets are used for focusing.
- Beam diagnostics including Halo Collimators (aperture 36 mm) installed at beam boxes.

Beam Transmission

- Transmission ~94%, using ACCT(LEBT) and ACCT(MEBT)
- Transmission averaged over 5 minutes.

Ji-Ho Jang





94.1±2.4(1σ)

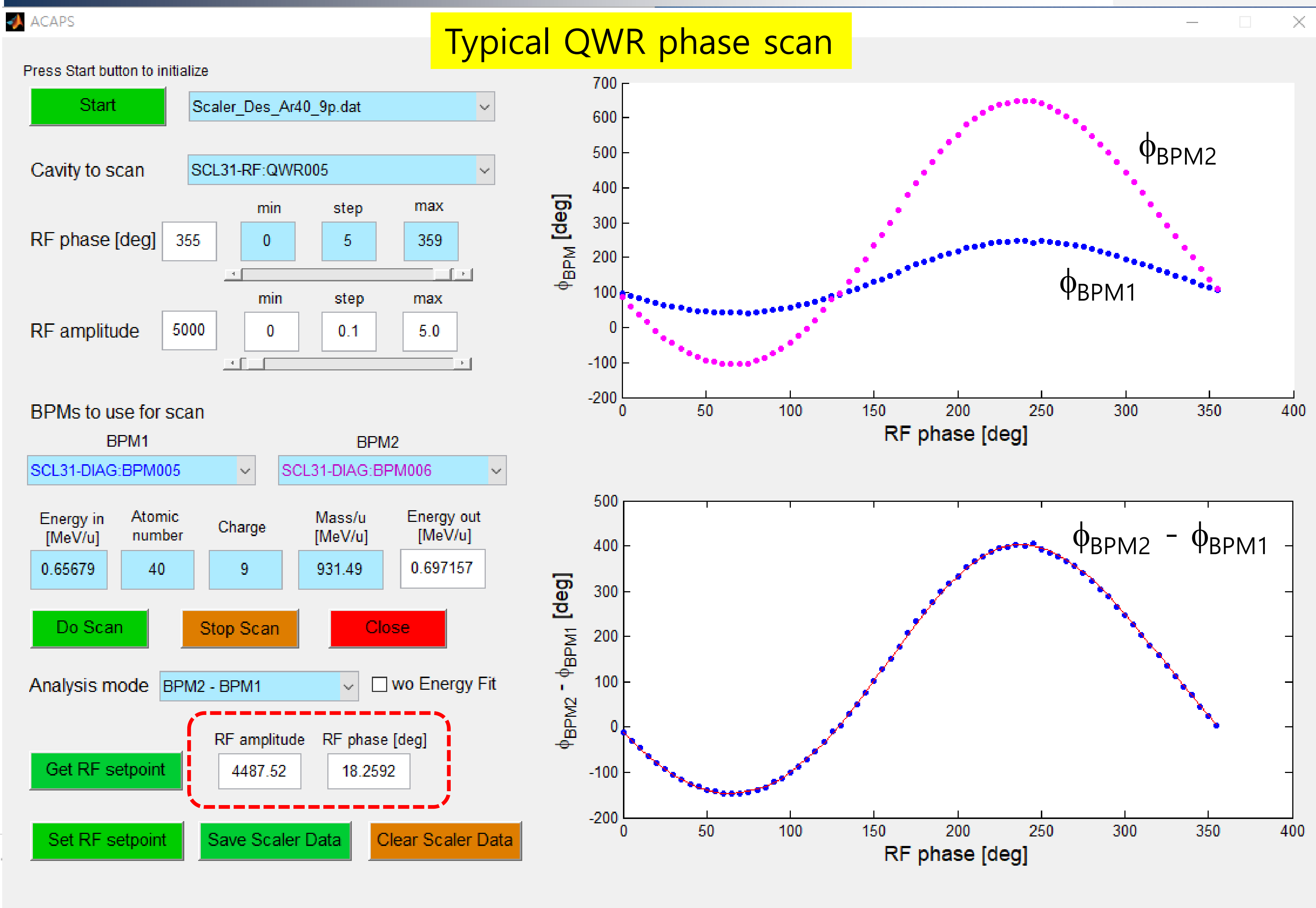
94.0±2.4(1σ)

93.7±2.3(1σ)

93.6±2.5(1σ)

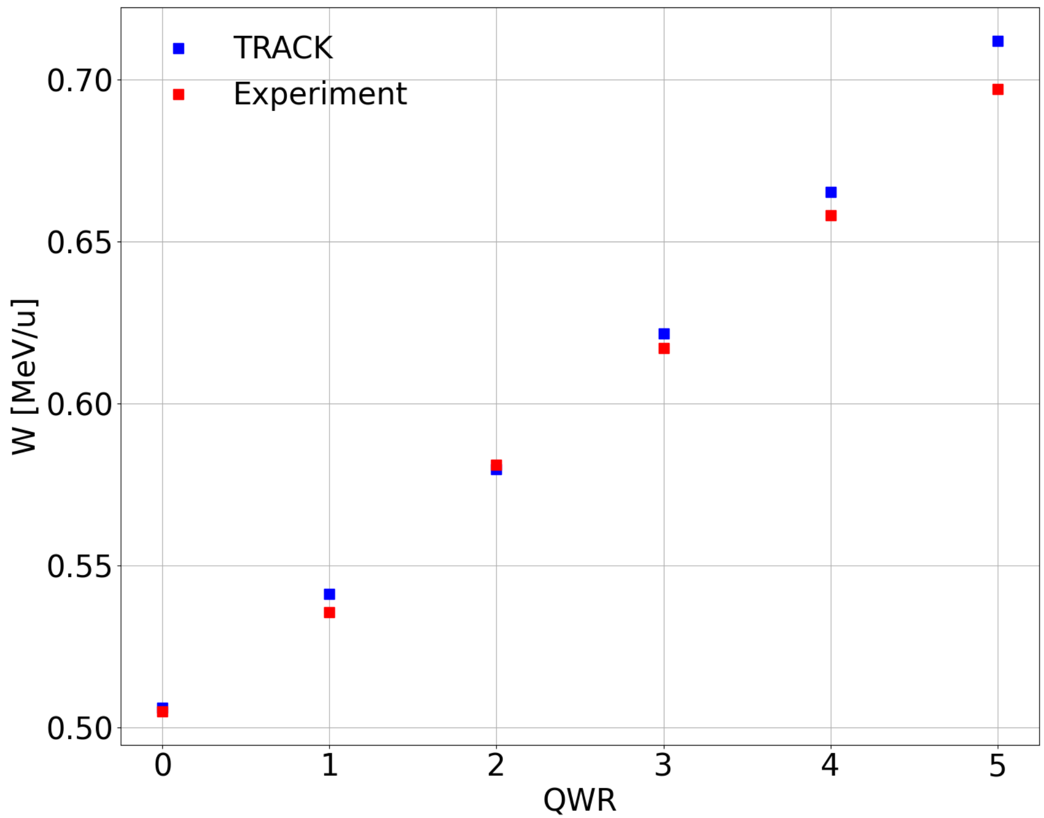
93.6±2.2(1σ)

QWR RF set-point by Phase Scan



QWR tuning (Oct/2022)

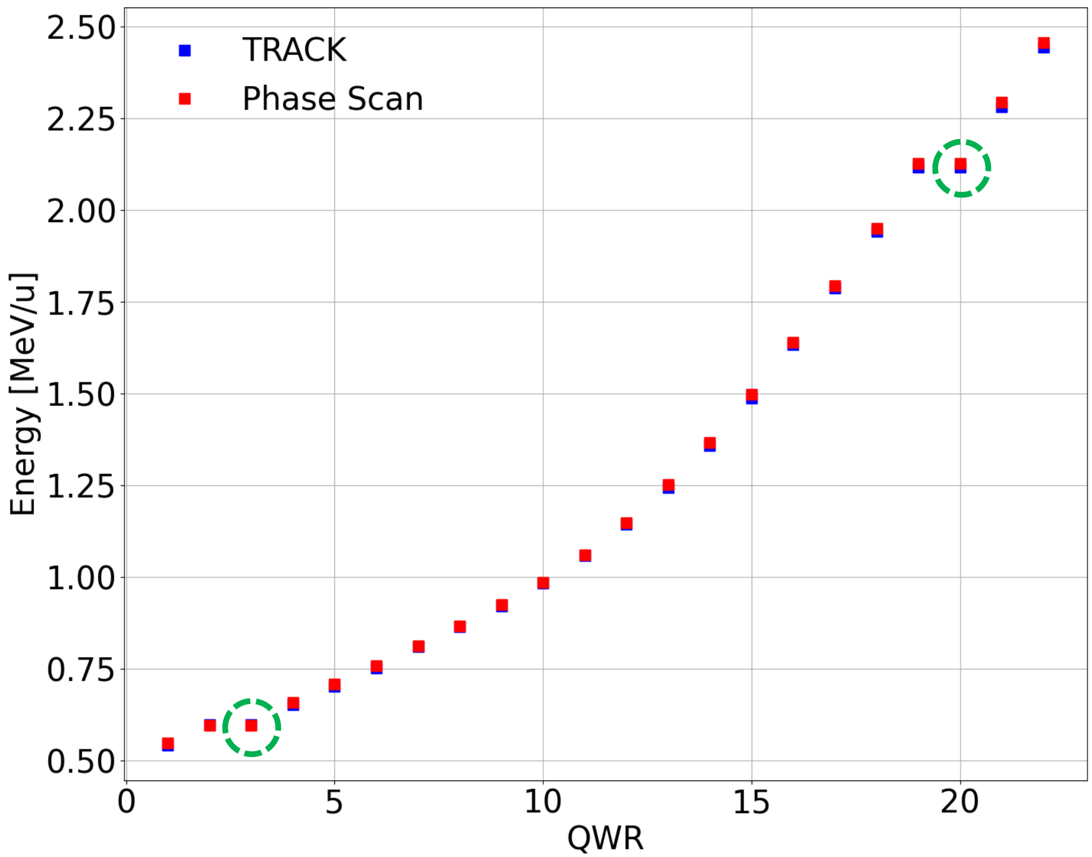
- Tuning 5 QWR cavities were done in Oct/2022 and achieved a beam energy of 0.697 MeV/u.
- Measured beam energy was slightly less than beam dynamics TRACK calculation.



Beam Energy of QWR cavities: Phase Scan vs TRACK code

QWR tuning (Dec/2022)

- **Beam tuning of the 22 QWR cavities achieved in 2 days:**
  - QWR beam energy : (phase scan) 2.457 MeV/u (TRACK) 2.444 MeV/u,
  - QWR3, QWR20 were off: RF control issue and detuned frequency,
  - Re-phasing of nearby cavities was done to compensate the off cavities.



SCL3 Profiles & Beam Parameters

ABIF

Emittances and beam parameters using wirescanner profile data

Select the Section: SCL31

	WS01x	WS02x	WS03x	WS04x	EmSx
x rms size [mm]	2.12	1.04	2.25	1.07	0

	WS01y	WS02y	WS03y	WS04y	EmSy
y rms size [mm]	1.96	1.26	2.08	1.65	0

Load beam size data

Energy [MeV/u]	Atomic number	Charge	Beam Current [mA]	Mass/u [MeV/u]
0.5	40	9	0.032	931.494

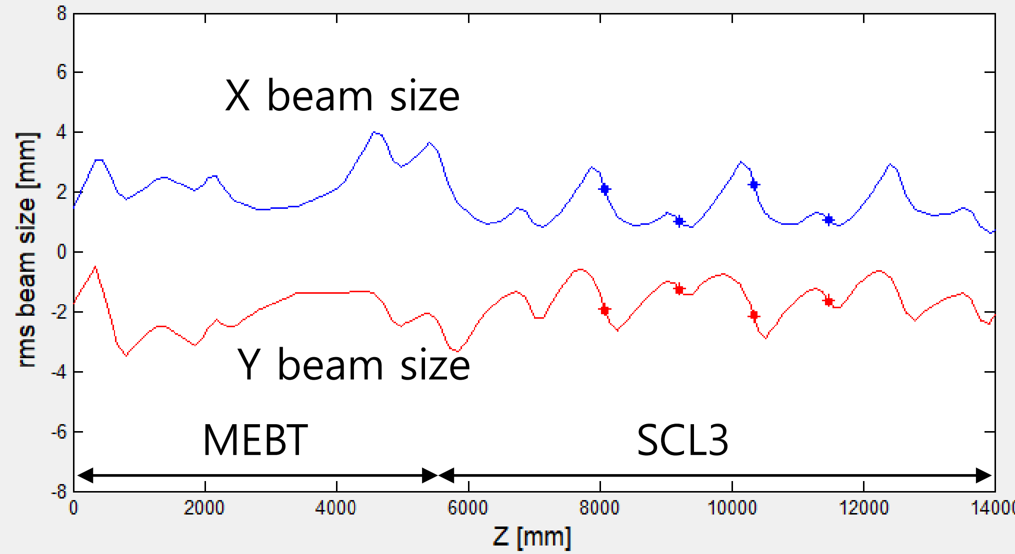
Find Beam Parameters | Do Again | Close

	rms emittance	beta	alpha
X plane	0.075	0.929	-3.174
Y plane	0.07	1.376	4.637

Matching

Matching Quads	Quad 1	Quad 2	Quad 3	Quad 4
Before Matching	0	0	0	0
After Matching	0	0	0	0

Setting Quads

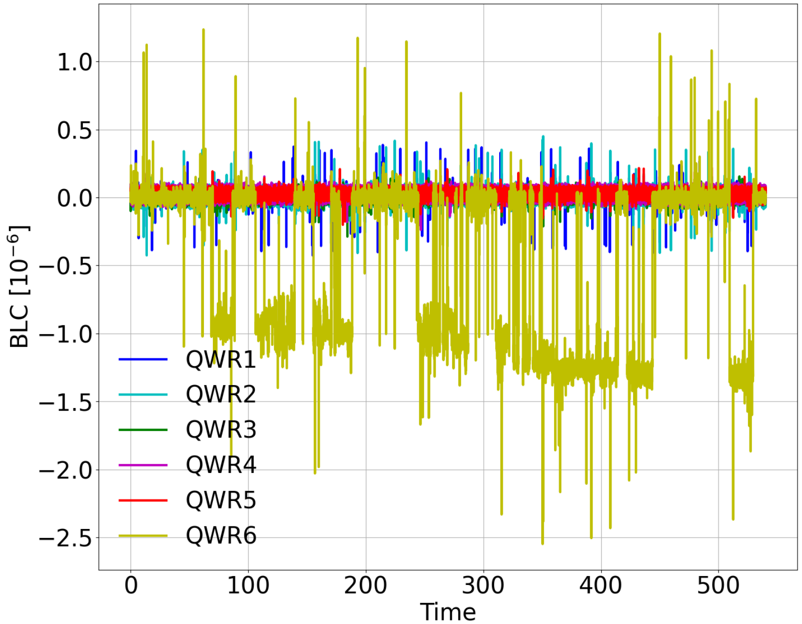


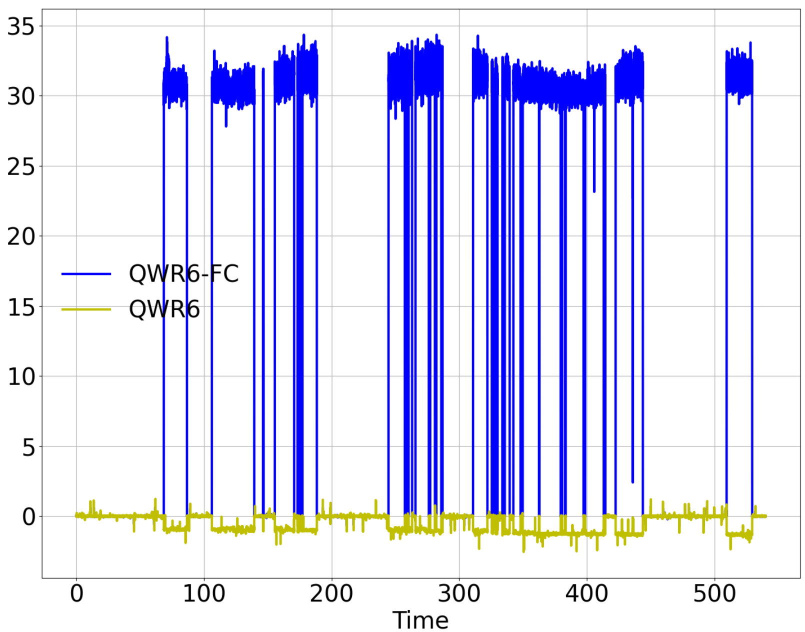
ε_x=0.075 mm-mrad (norm rms)
ε_y=0.070 mm-mrad (norm rms)

Halo monitors

- **Zero beam loss detected.**
  - Halo monitors for QWR1~QWR5 showing noise in background level.
  - Halo monitors for QWR6 showing back-streaming electron from the Faraday Cup (observed only when beam is on).
  - Signal increases, as the cavities are tuned.

Ji-Ho Jang





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RISP

Summary

- **Through the injector beam commissioning, beam tuning procedures and applications have matured.**
- **The SCL QWR section was commissioned, achieving 2.457 MeV/u for Ar^{9+} beam.**
- **Beam parameters were measured and ~100% transmission achieved for MEBT/SCL3.**

- **Identified some issues:**
  - Multipacting issue (couplers)
  - Stability issue: some QWR cavities have stability issues due to helium pressure fluctuation etc.

- **Planning to do the commissioning of the rest SCL3 in Mar/2023.**

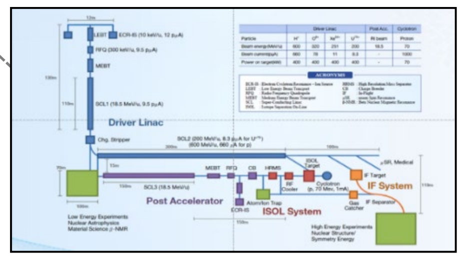
Rare Isotope Science Project

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

- **Budget: KRW 1,518 billion (US$ 1.32 billion, 1$=1,146krw)**
  - accelerators and experimental systems : 522.8 billion won
  - civil engineering & conventional facilities : 996 billion won (incl. site 357 billion won)
- **Period: 2011.12 ~ 2022.12 (1^{st} Phase)**

Accelerator & Experiment Systems

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



Conventional Facility

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

- **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 beams by combining ISOL and IF**

RAON Layout

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

RI Beam production

	KoBRA	ISOL	IF Separator
Driver	SCL3(ECR/ISOL)	Cyclotron	SCL3 + 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	< hundreds of MeV/u