Beam Dynamics for RAON Linac (Injector, SCL3, SCL2)

Fermilab workshop

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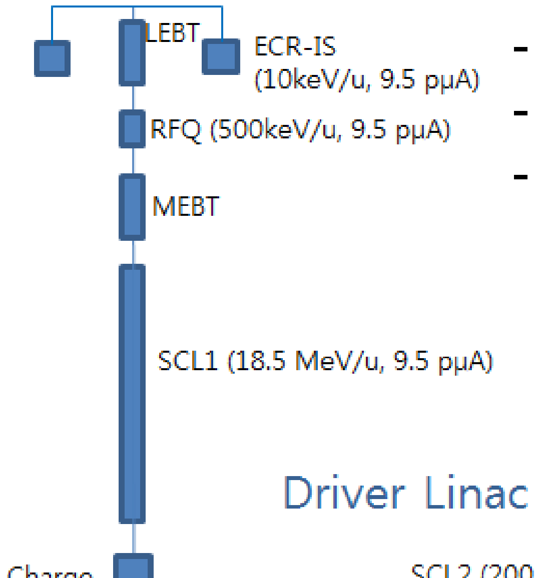
(IBS/RISP)

Contents

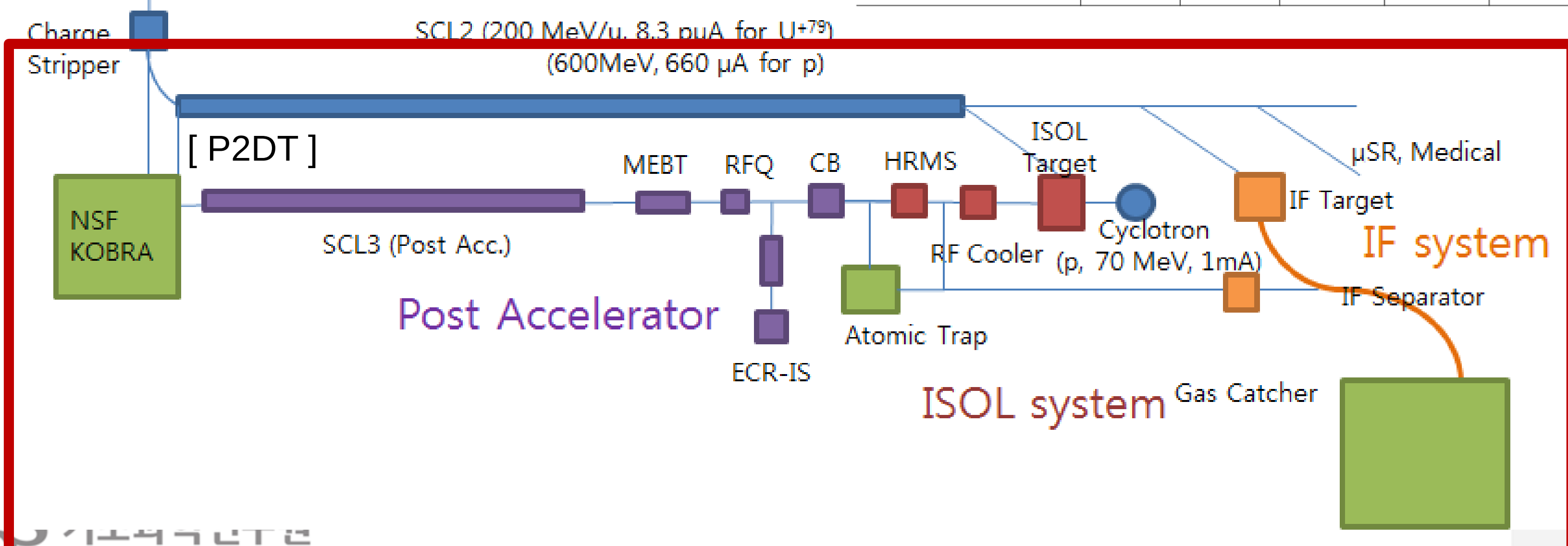
Introduction

RAON Layout

- ❑ RISP Linac:
  - Post injector: ECR-IS, LEBT, RFQ, MEBT
  - SCL: SCL3(QWR, HWR), P2DT, SCL2(SSR1,SSR2)
  - Beam Lines: KoBRA, NSF / BIS, μSR



	Driver Linac				Post Acc.	Cyclotron
Particle	H^{+}	O^{+8}	Xe^{+54}	U^{+79}	RI beam	proton
Beam energy (MeV/u)	**600**	**320**	**251**	**200**	**18.5**	**70**
Beam current (pμA)	660	78	11	8.3	-	1000
Power on target (kW)	**> 400**	**400**	**400**	**400**	-	70



RAON beam dynamics

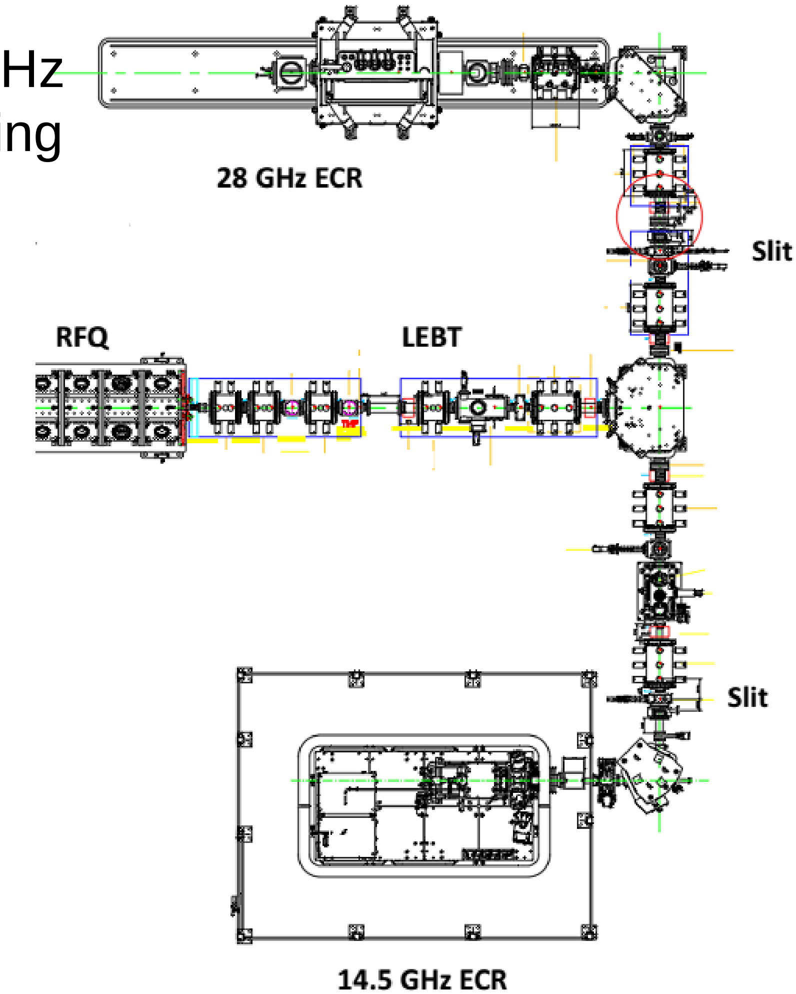
- ❑ Accelerating various ions with proton(A/q = 1) to uranium (A/Q=7.2)
  - Stable ion beams from two ECR IS
  - RI beams from ISOL
- ❑ Accelerating multiple charge states
  - Uranium beam of 400 kW (200MeV/u) on IF target.
    - ECR~SCL3: 2 charge states (33+, 34+)
    - SCL2: 5 charge states (77+ ~ 81+)
- ❑ Injector
  - 2 ECR ion source: 28GHz (uranium), 14.5GHz(beam commissioning)
  - RFQ: input energy of 10 keV/u, output energy of 500 keV/u
- ❑ SCL3
  - QWR, HWR: ~ 18.5 MeV/u for uranium beam
- ❑ P2DT: 180° bending section
  - 2nd order achromatic, isochronous design : 5 charge states for uranium beams
- ❑ SCL2
  - SSR1, SSR2: > 200MeV/u (400 kW) for uranium beam
  - Test of cavity and module is in progress

Injector Beam Dynamics
(LBET, RFQ, MEBT)

LEBT Layout

- LEBT
  - Two ECR ion sources: 28GHz, 14.5GHz
  - 14.5 GHz ECR for beam commissioning
    (Ar 9+, about 30 μA)

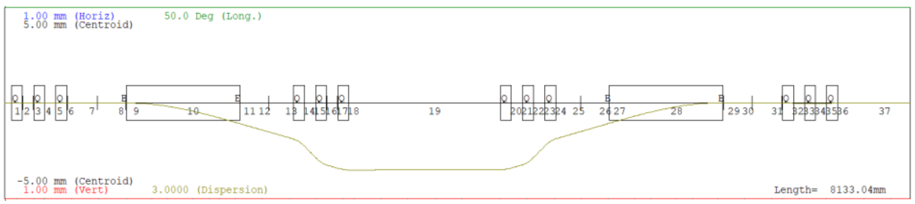
- LEBT Beam Dynamics
  - Charge selection at slits
  - 28 GHz: 1st order achromatic
    (33+, 34+ uranium)
  - 14.5 GHz: single charge state



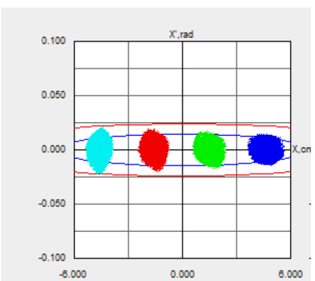
[LEBT layout]

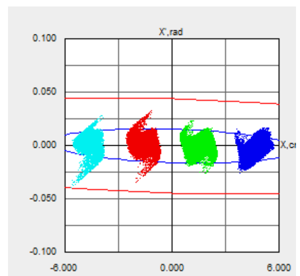
LEBT beam dynamics (design)

- Simulation: TRACK, TRAC3D
  - 28GHz: Uranium-238 (33+, 34+)
  - 14.5GHz: Argon-40 (9+)

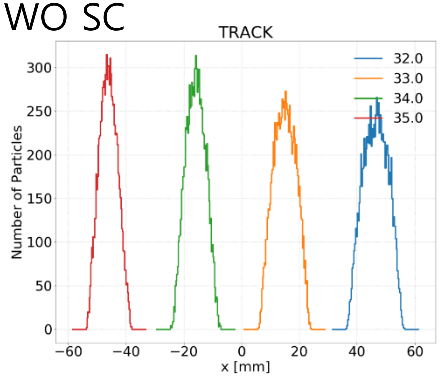


[Dispersion function]

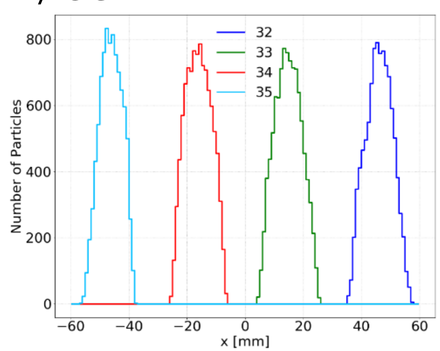




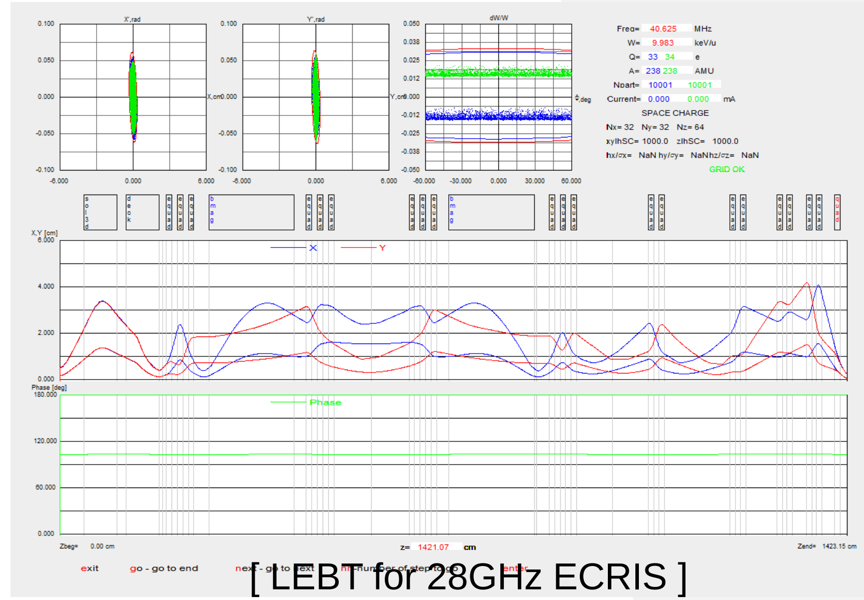
WO SC



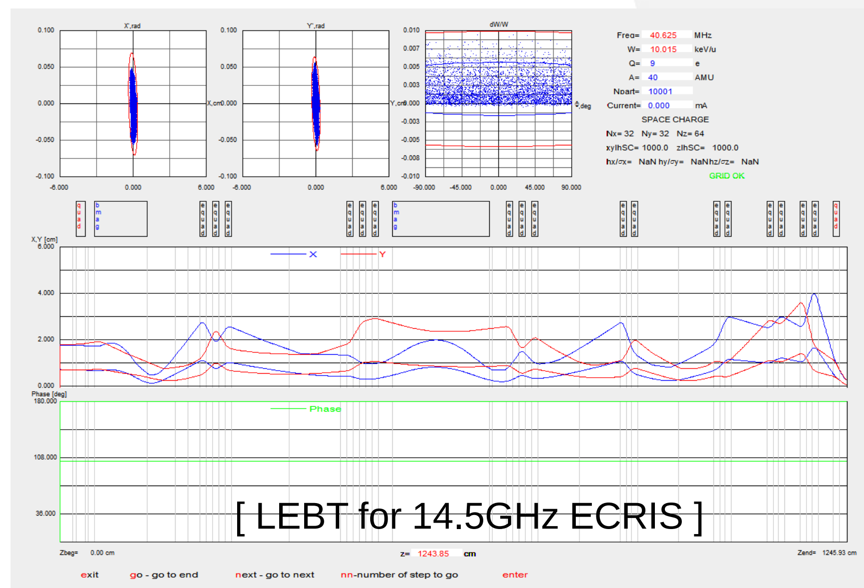
W/ SC



[Charge selection]



[LEBT for 28GHz ECRIS]



[LEBT for 14.5GHz ECRIS]

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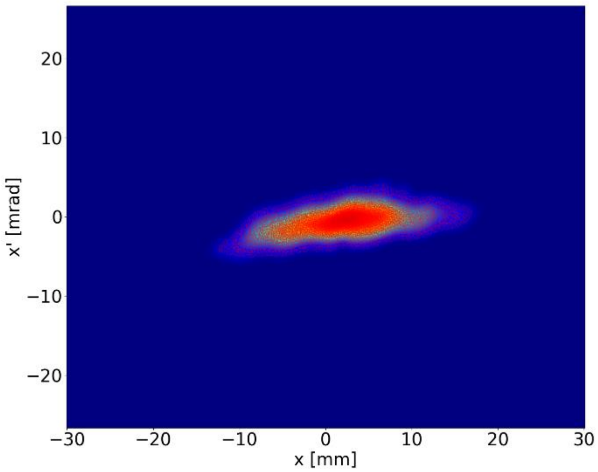
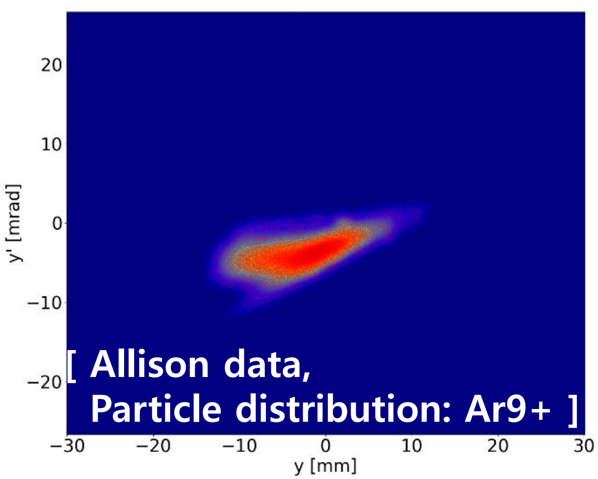
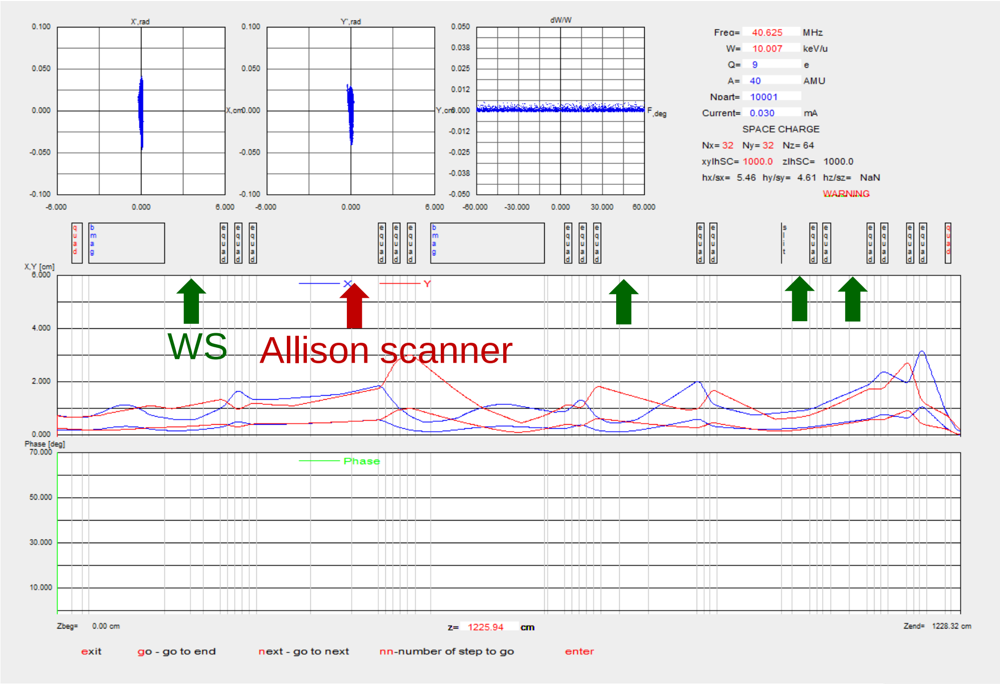
LEBT Beam Dynamics (modification)

- LEBT beam dynamics can be modified from beam commissioning (Ar beam)
  - Reconstruction of input beam by using Allison data





[Allison data,
Particle distribution: Ar9+]



[TRACK simulation (using Allison)]

mm-mrad	x	y
Design	0.12	0.12
Allison	0.039	0.041

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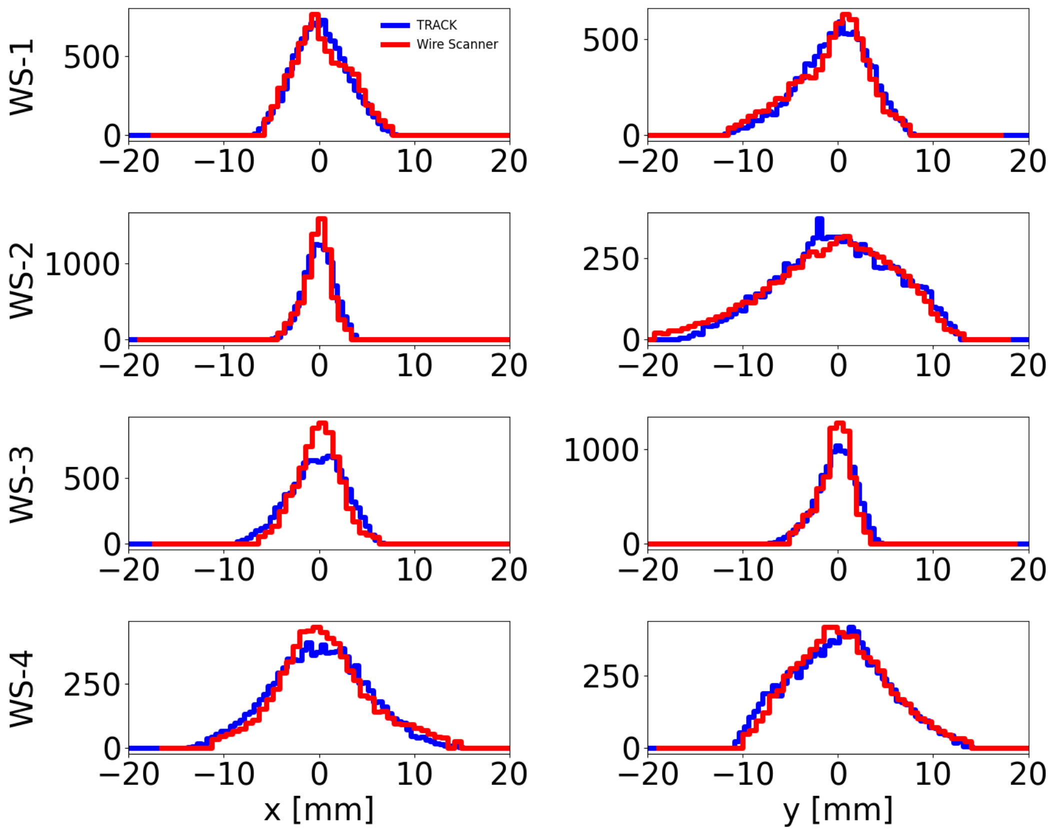
RISP

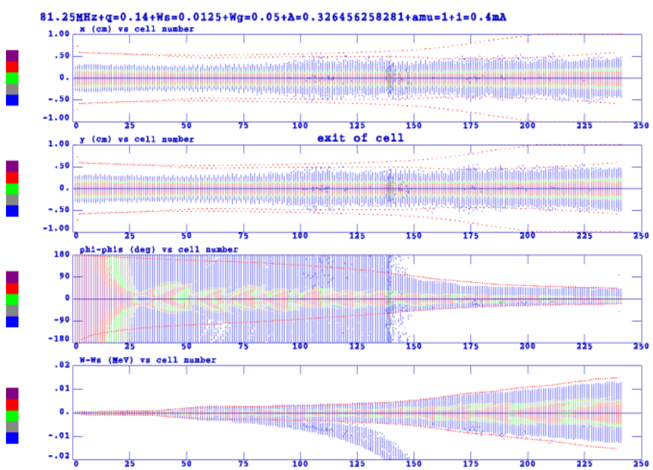
Particle distribution at WS in LEBT

❑ Particle distribution (Ar9+)
- 4 WS in LEBT
- Compare WS data and TRACK simulation to check input distribution (based on Allison data): well matched

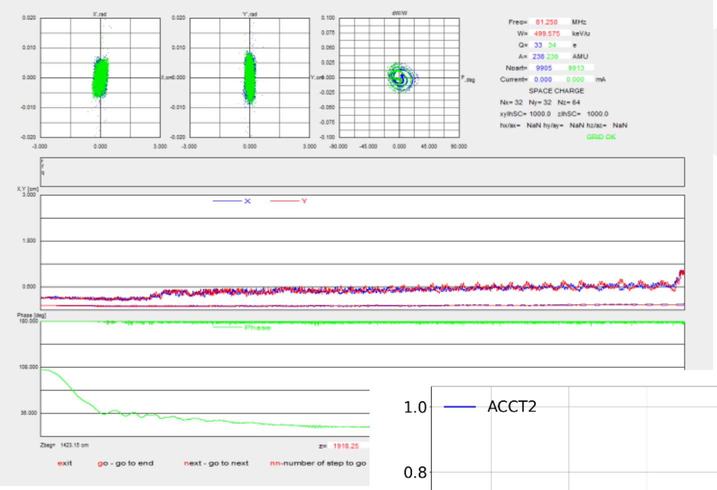


RFQ

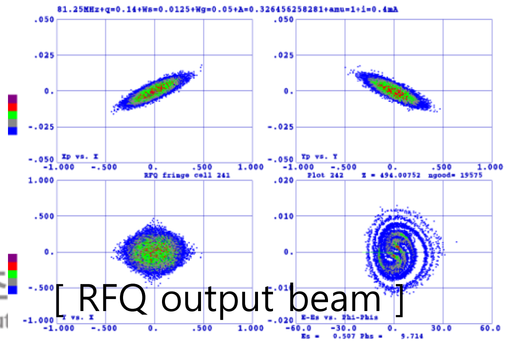
❑ RAON RFQ
- Designed by RI (Dr. L. Young), Manufactured by domestic company (Vitzro)
- Voltage ramping in order to reduce total length of RFQ
- 4-vane type, 1.7 kilpatrick, CW operation
- Transmission: ~ 98% (design) ~94% (commissioning, Ar)



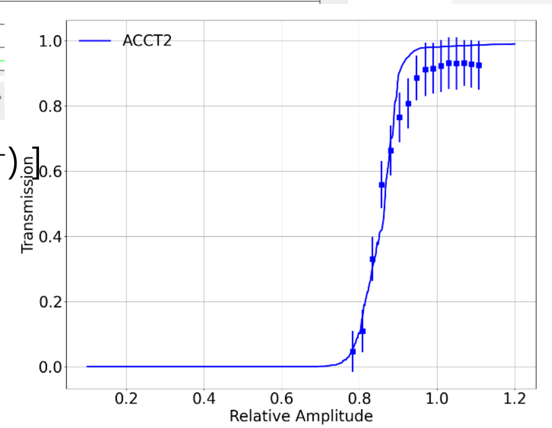
[PARMTEQ result ($U^{33+,34+}$)]



[TRACK result ($U^{33+,34+}$)]



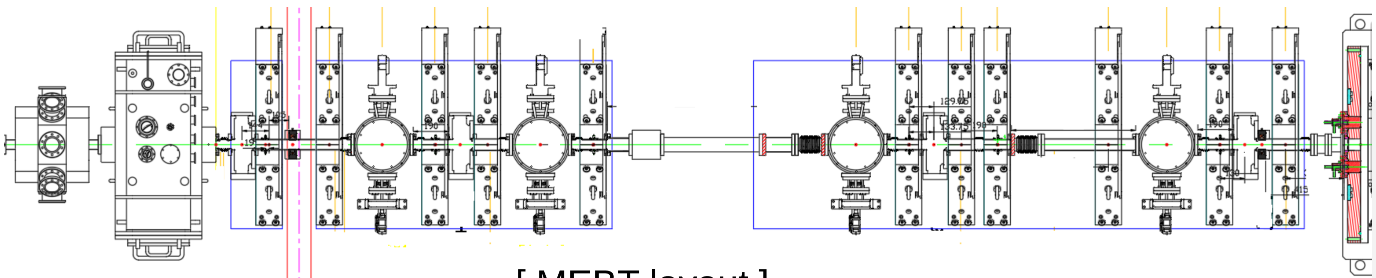
[RFQ output beam]



[RFQ set point (Ar beam, error bar: 3σ)]

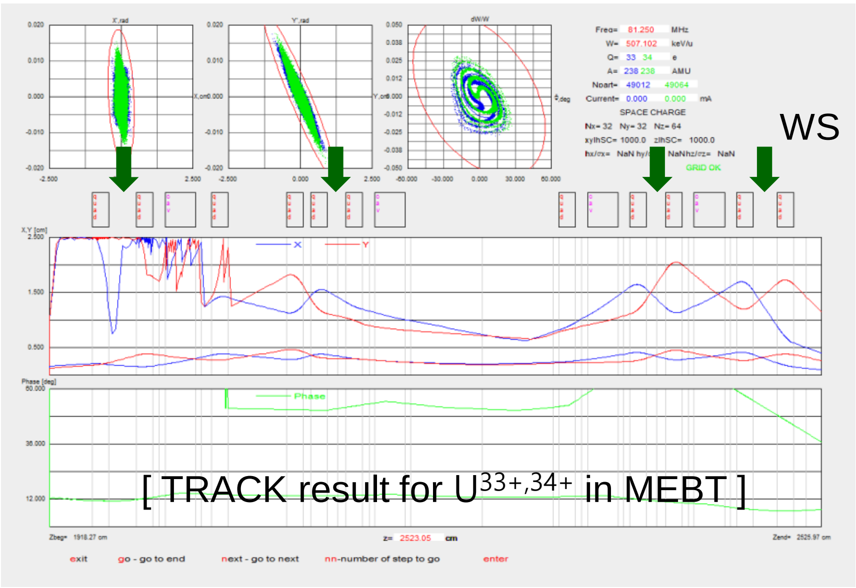
MEBT Beam Dynamics

- ❑ Layout
  - Long drift space: single bunch selector for neutron facility
  - 4 buncher cavity, 11 quadrupole



[MEBT layout]

- ❑ Beam dynamics: TRACK



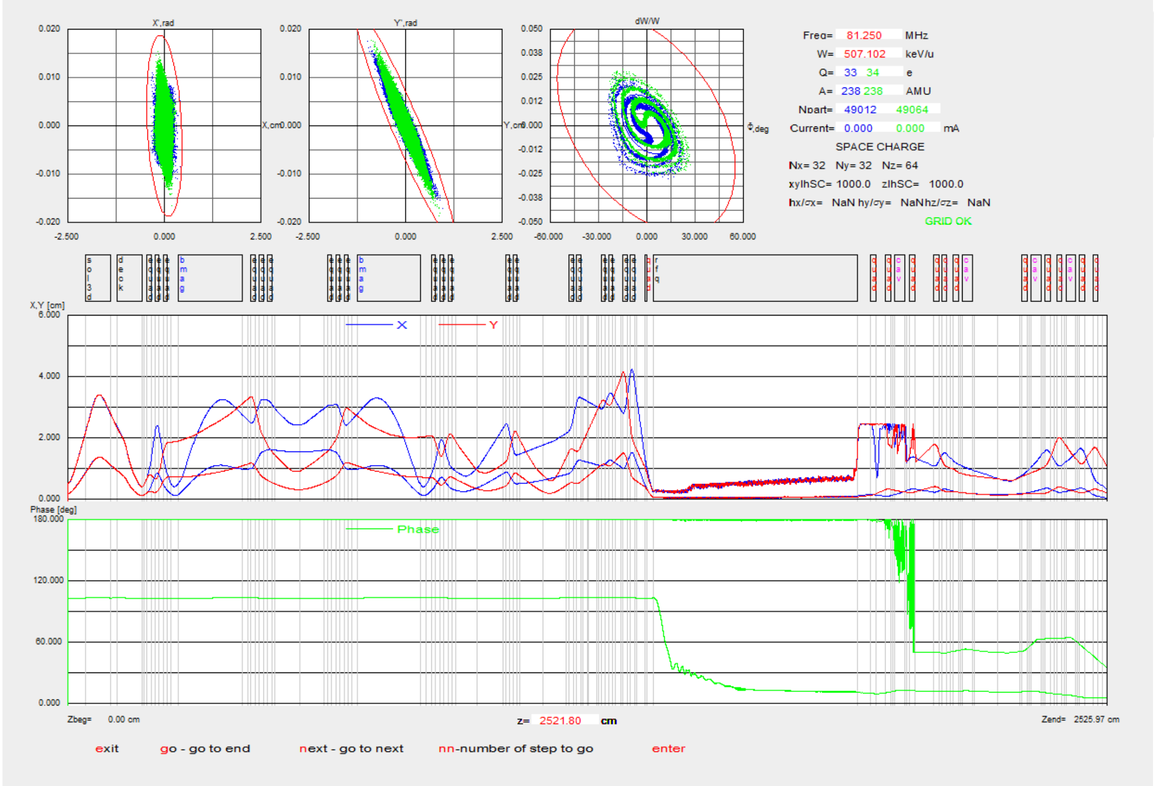
[TRACK result for $U^{33+,34+}$ in MEBT]

Injector beam dynamics

- TRACK simulation
  - Uranium : 33+, 34+
  - # of macro particles: 50,000 + 50,000
  - RFQ: Using RFQ routine in TRACK

[Transverse normalized rms emittance]

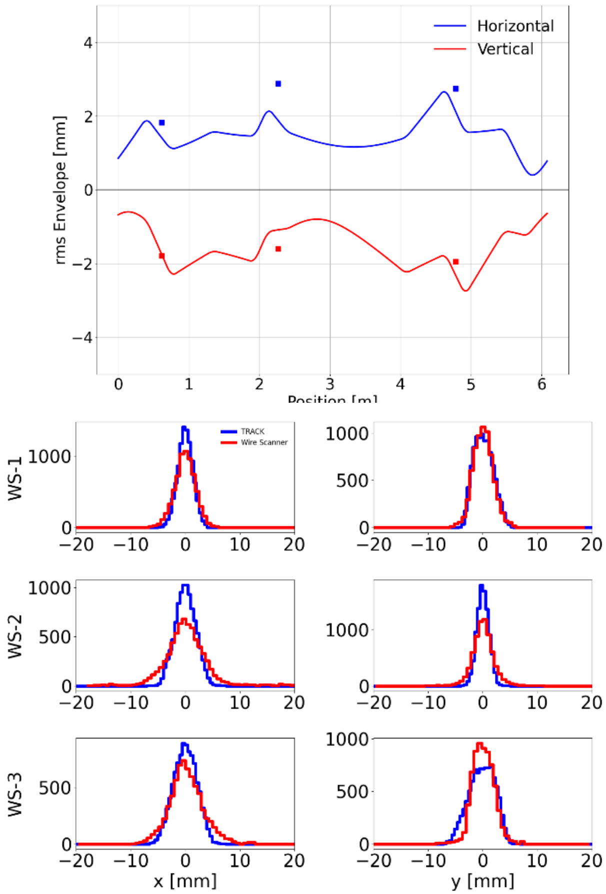
mm-mrad	input	output	Δ (%)
Horizontal	0.119	0.134	12.6
Vertical	0.120	0.132	10.0



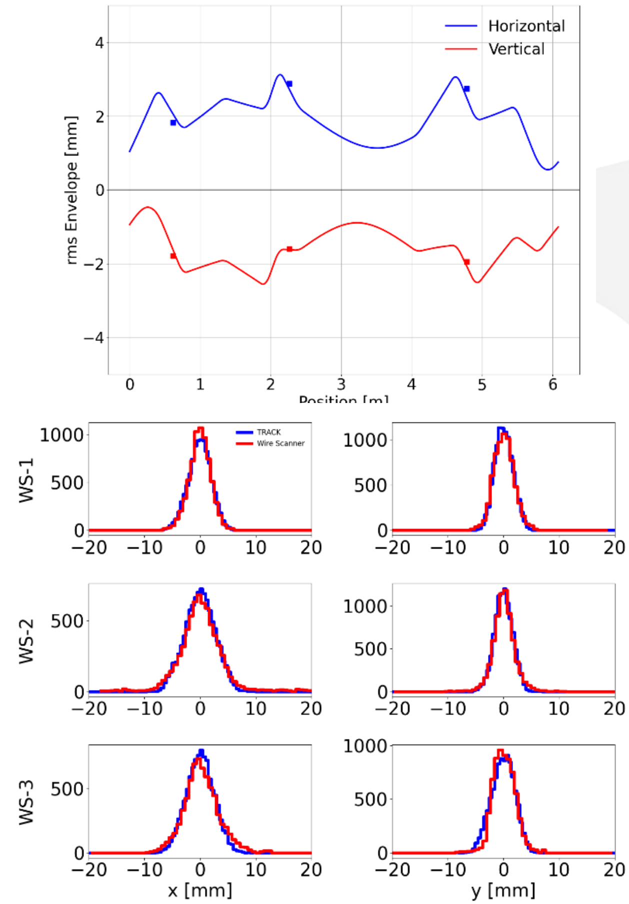
[TRACK result for injector]

Beam Profile at WS in MEBT

- Comparing rms beam envelop in MEBT and beam profiles at WS positions between TRACK and WS data (Ar beam)
- RFQ TRACK simulation and modified distribution for rms beam size



[using RFQ TRACK simulation]



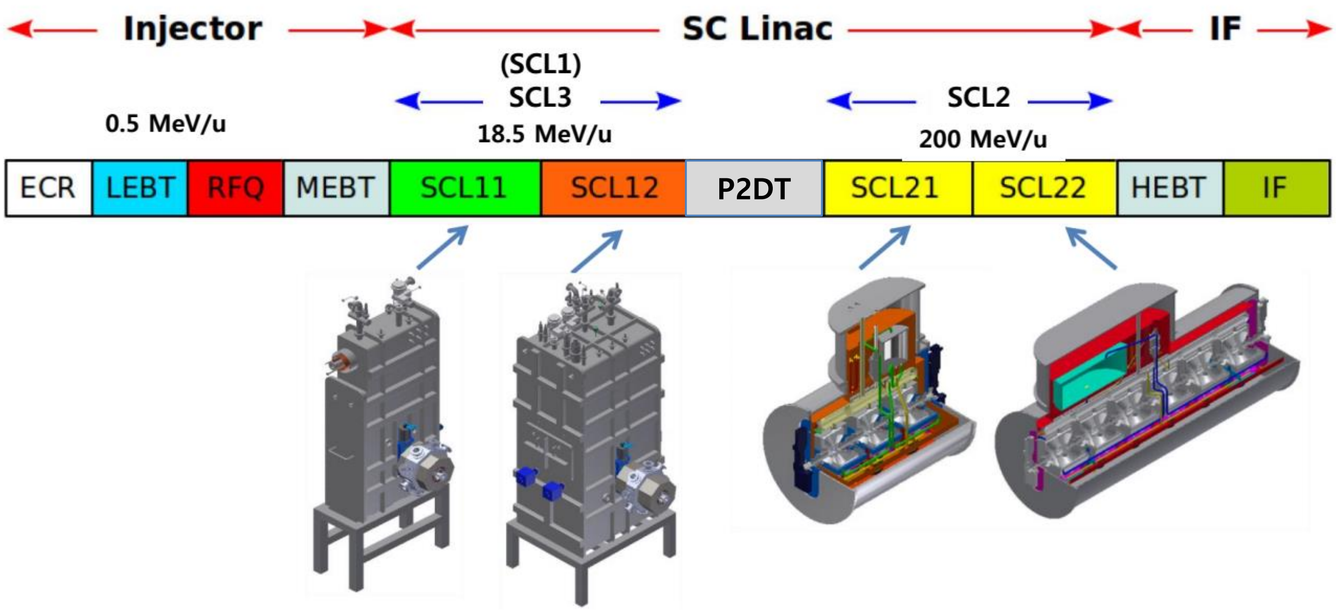
[using modified RFQ output beam]

[rms envelope and beam profile through MEBT]

SCL Beam Dynamics
(SCL3, P2DT, SCL2)

RAON SCL

❑ RAON SCL
- 4 types of cavities: QWR, HWR, SSR1, SSR2
- Normal conducting quadrupole doublet for transverse focusing
- Large aperture diameter for small beam loss: 40 / 50 mm
- Charge stripper in P2DT for changing charge state



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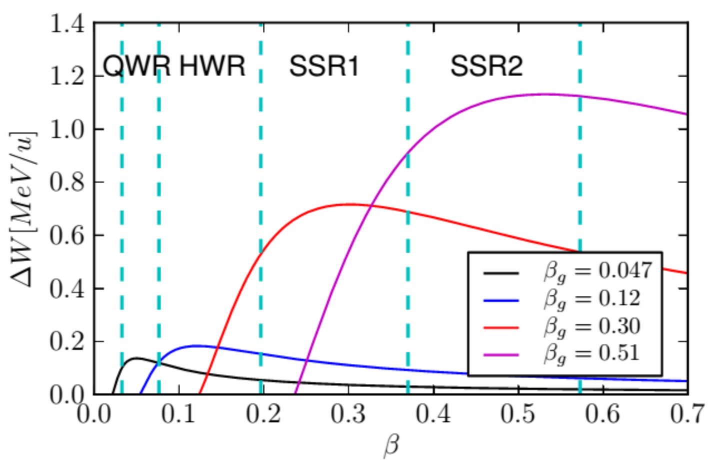
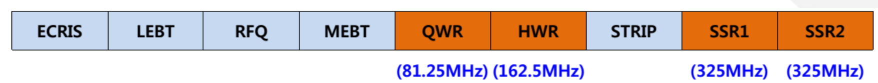
RISP

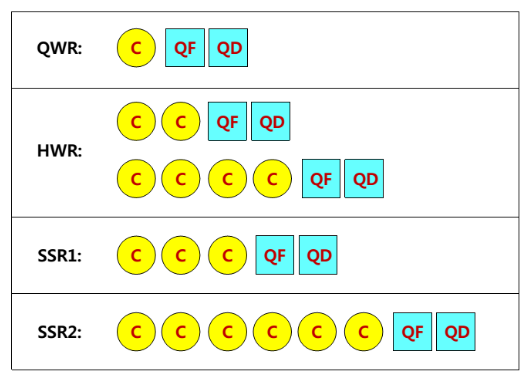
SCL lattice

❑ RAON SCL Lattice

- β_o (TDR) = 0.047 (QWR), 0.12 (HWR), 0.30 (SSR1), 0.51(SSR2)
- Reference particle: $^{238}U^{33.5+}$ (QWR, HWR), $^{238}U^{79+}$ (SSR1,SSR2)
- HWR/SSR output energy: 18.5 / 200 (MeV/u) for uranium
- Total number of CM / cavities in linac (SCL3+SCL2): 100 / 331
- CM/cavities for buncher: 2/4 (HWR) in bending section,
  2/6 (SSR2) in energy upgrade region



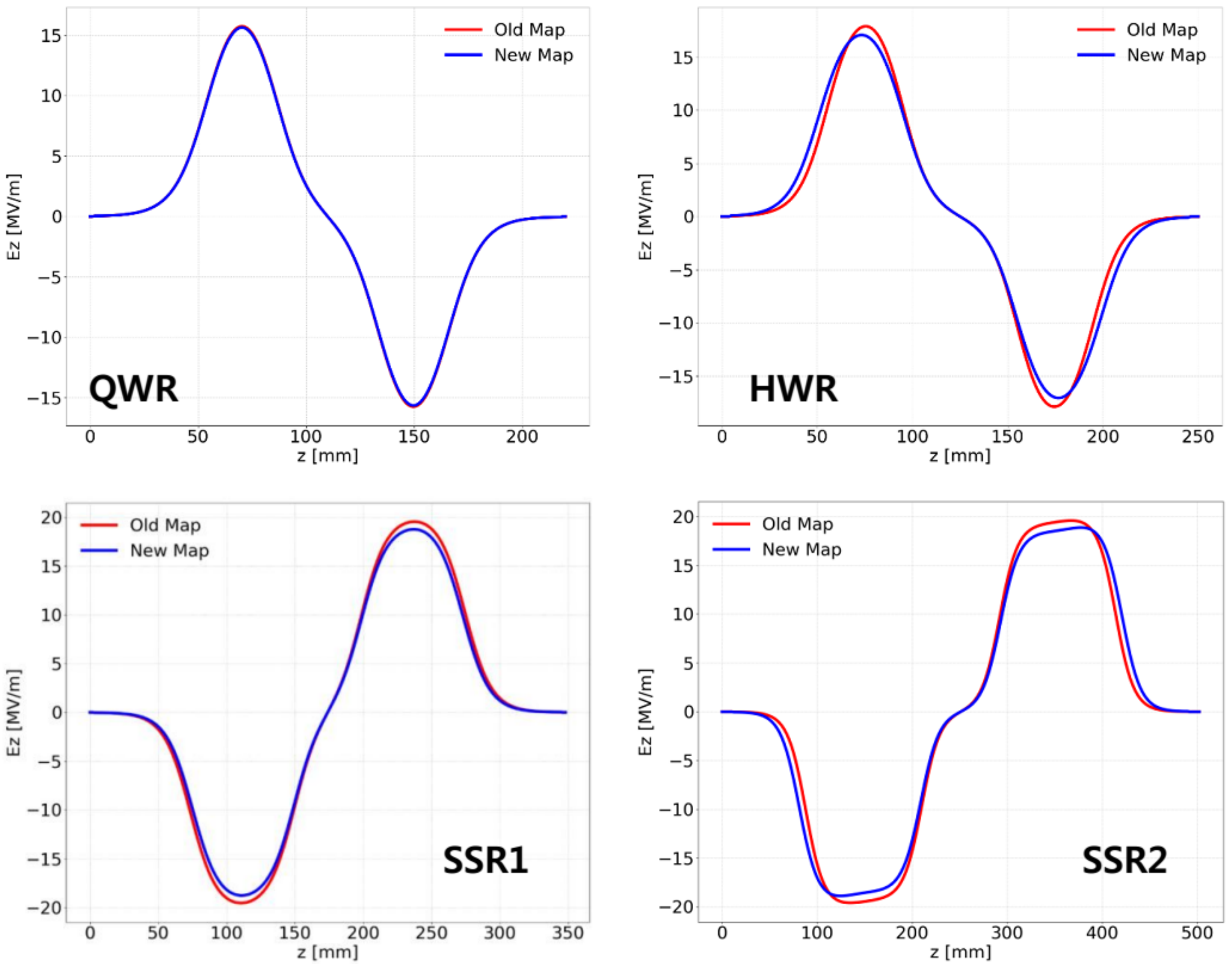




	QWR	HWR	SSR1	SSR2
β_o(TDR)	0.047	0.12	0.30	0.51
CM #	22	13/19	23	23
Cavity # / CM	1	2/4	3	6
Cavity #	22	102	69	138
(SCL3+SCL2) (SCL1+SCL3+SCL2)	331 cavities, 100 CM 455 cavities, 154 CM			
Charge stripper	33, 34 → 77~81 (Uranium)			
HWR energy SSR2 energy	18.5 MeV/u (Uranium) 200 MeV/u (Uranium)			

Field Map of SC Cavities

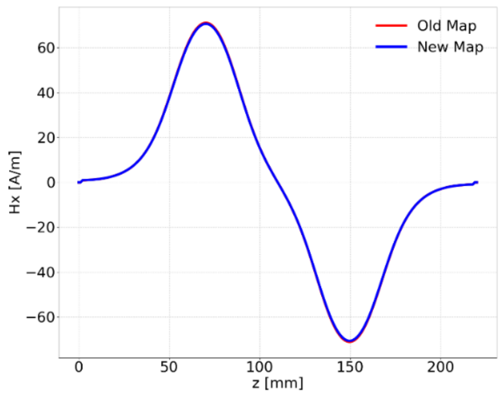
- Field maps of SC cavities are modified on 2019.



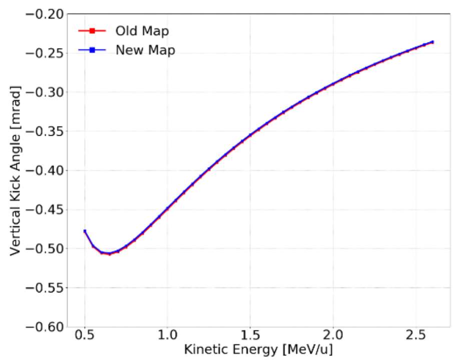
Steering Effect

❑ Steering effect in QWR cavity

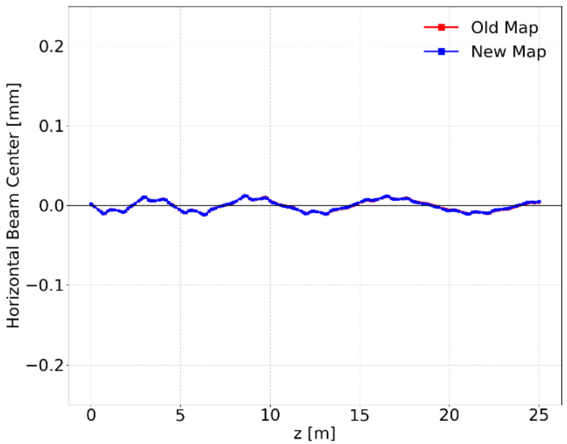
- Asymmetry in geometry of QWR cavity ⇒ kick beam from beam axis.
- Vertical beam center shift by the steering effect < 0.5 mm

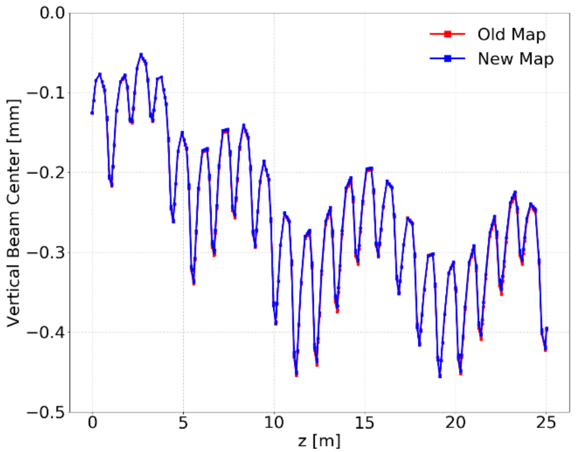


[Field giving steering effect]



[Vertical kick angle]

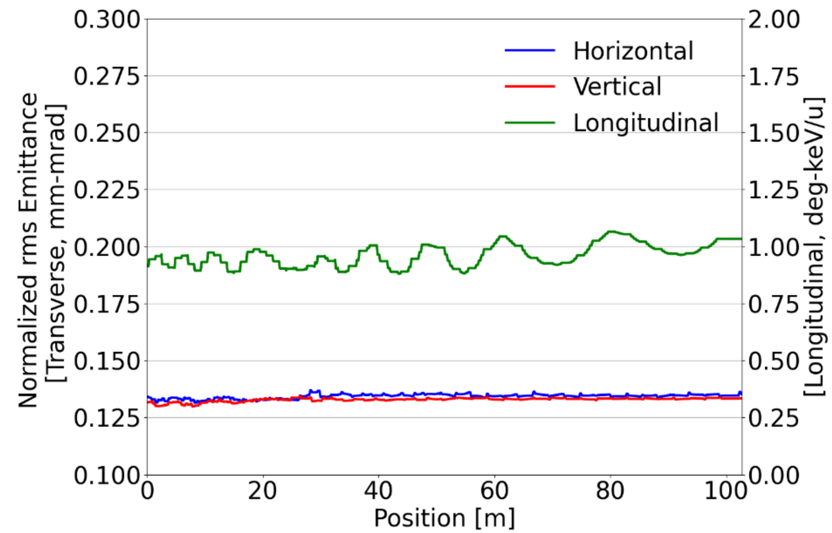




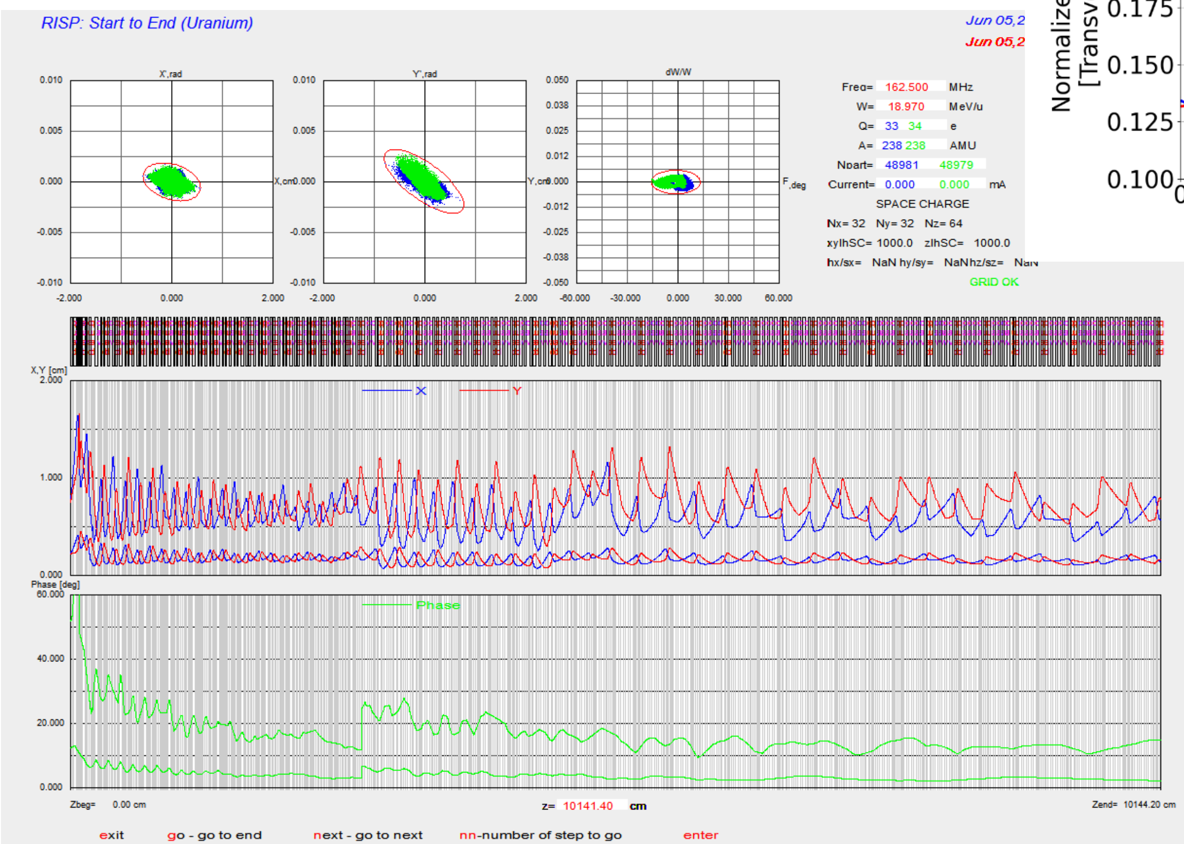
[Beam center shift in SCL3 by steering effect]

SCL3 beam dynamics

- ❑ Beam Dynamics
  - Matching: MEBT-QWR, QWR-HWR. HWRA-HWRB
  - TRACK, uranium 33+, 34+



[Normalized rms emttance]



[TRACK result]

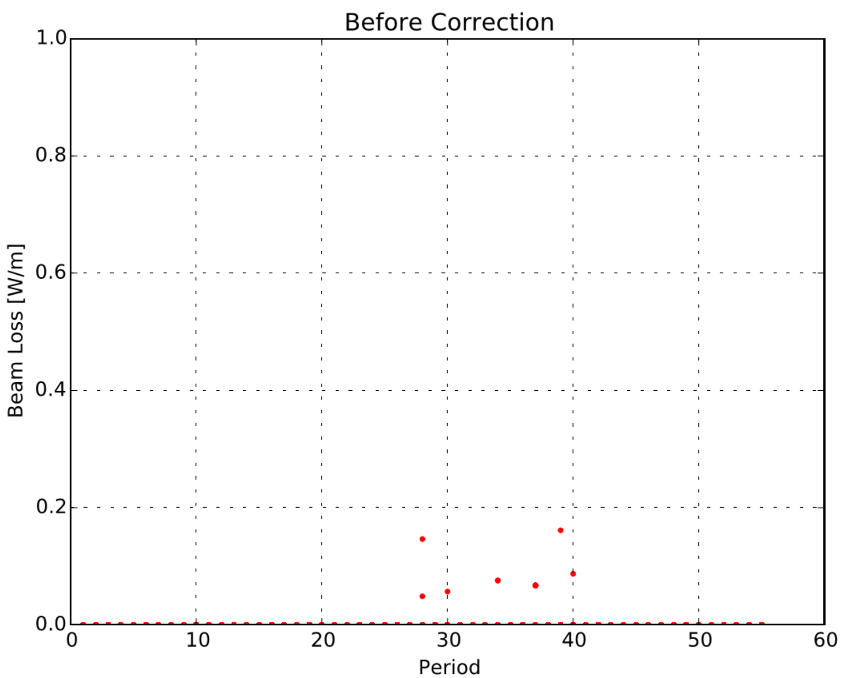
[rms emittance]

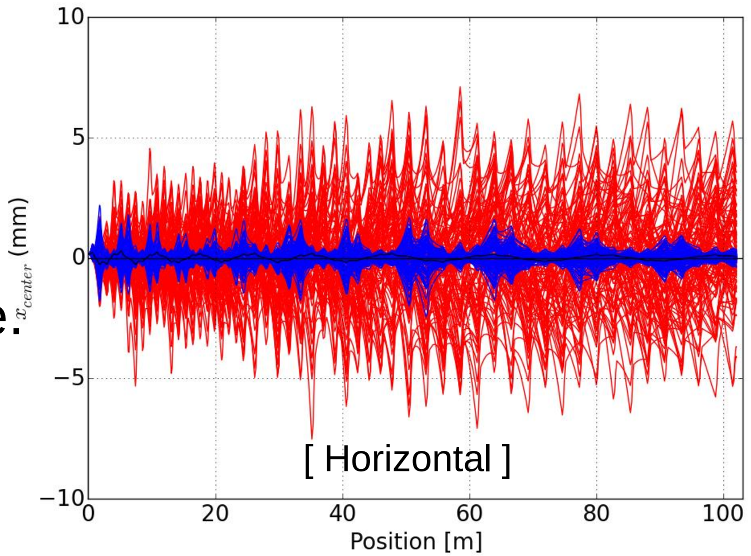
	input	output	Δ (%)
x	0.134	0.135	0.75
y	0.132	0.133	0.76
Long.	0.917	1.034	12.8

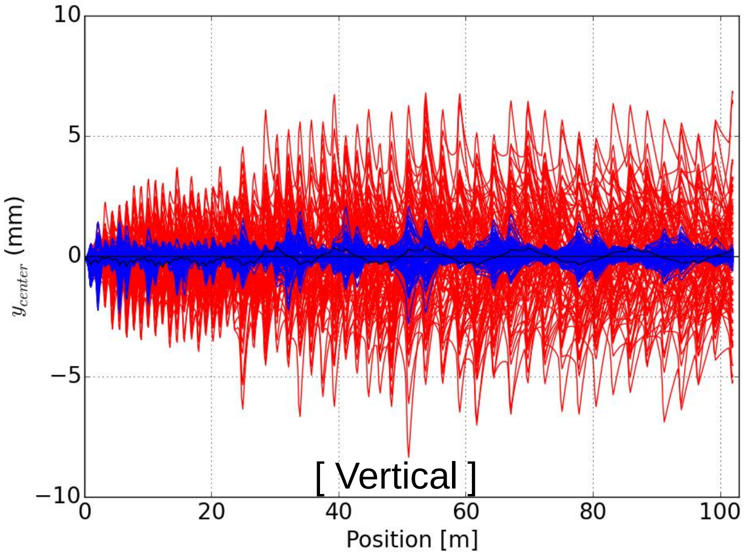
Transverse: mm-mrad
Longitudinal: keV/u-ns

SCL3 Orbit Correction

❑ Orbit correction
- Determine position and strength of steering magnets
- TRACK: uranium beam, 1000 seeds
- Steering effect is not serious in our case.
- less than 0.2W/m beam loss even without orbit correction

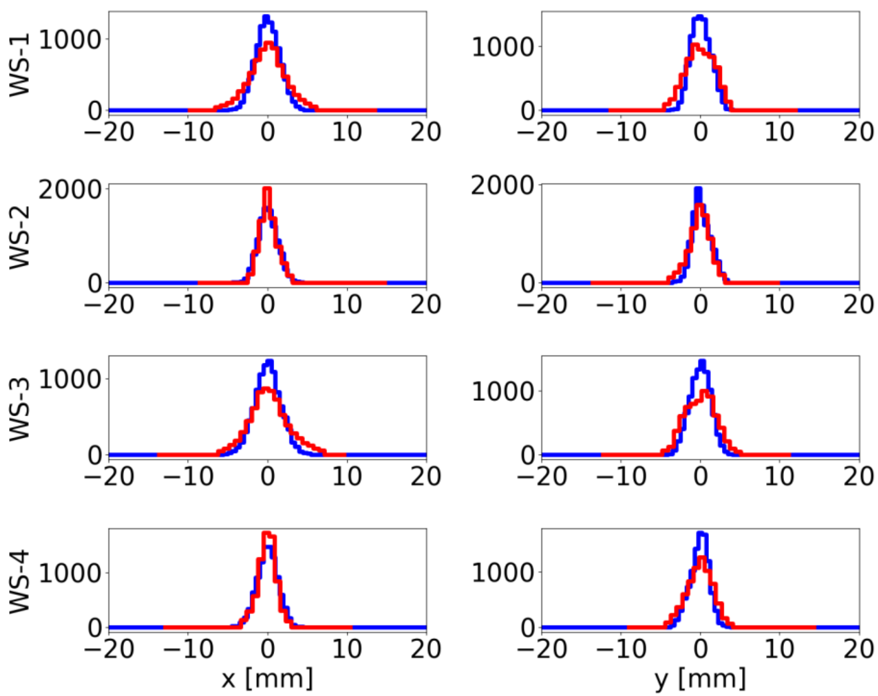




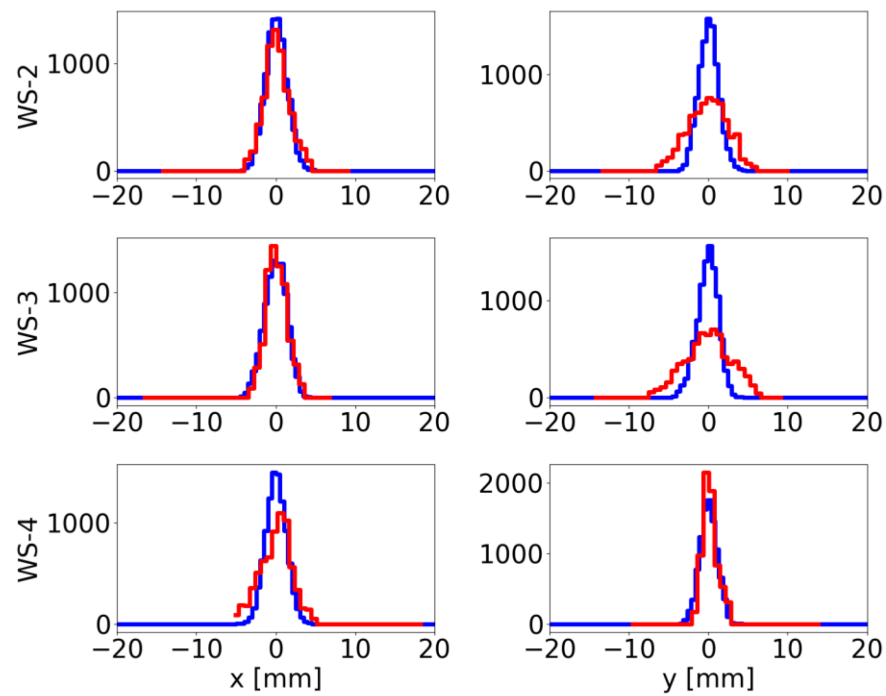


Beam Profile at WS in QWR and HWRA

❑ There are 4 wire scanners each in QWR and HWRA entrance regions
- We measured beam profiles in the QWR beam commissioning.
  (4 WS data in QWR, 3 WS ata in HWRA: TRACK(blue) WS(red))
- TRACK calculation: using modified RFQ output beam ⇒ Need more study



[Beam profile in QWR entrance]

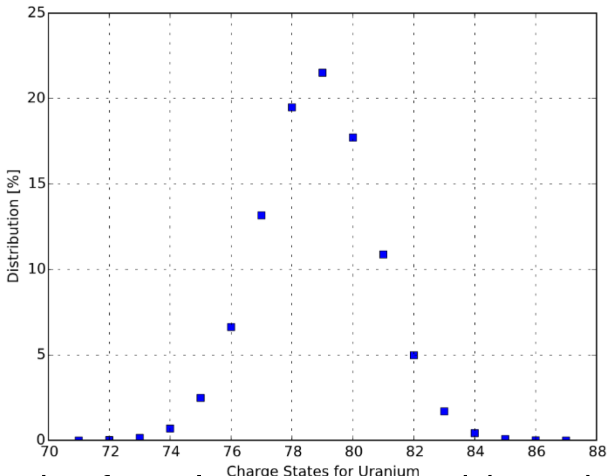


[Beam profile in HWRA entrance]

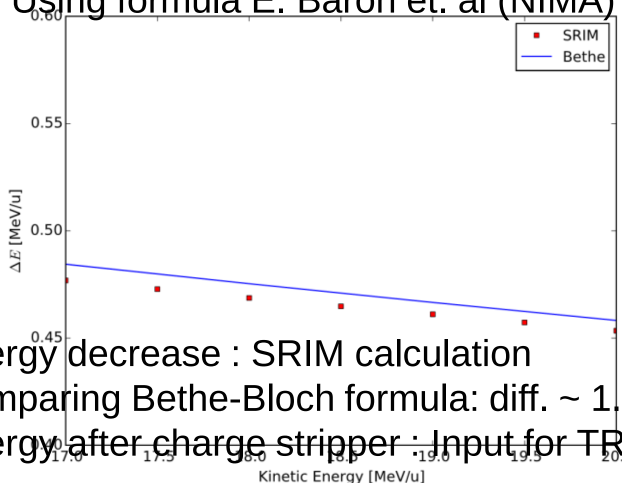
Charge stripper effects

❑ Charge stripping for efficient acceleration in SCL2

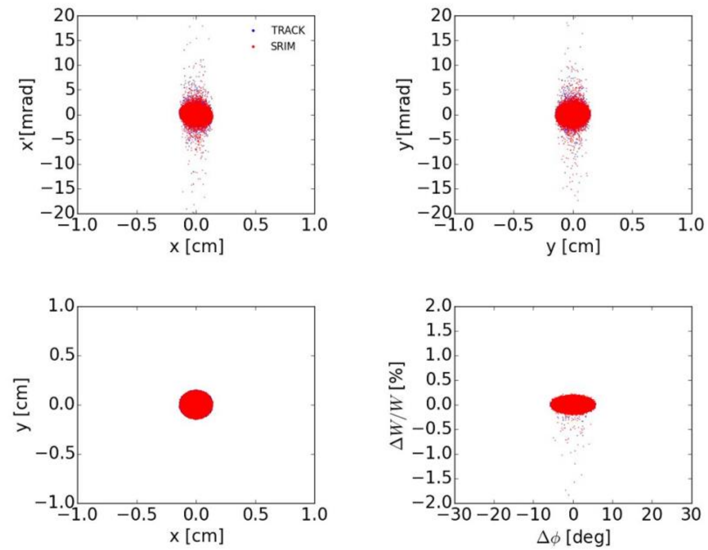
- Initial low intensity: Carbon ⇒ High intensity: Liquid Lithium
- Carbon thickness = 1 mg/cm^2
- Slit after charge stripper: removing halo particles

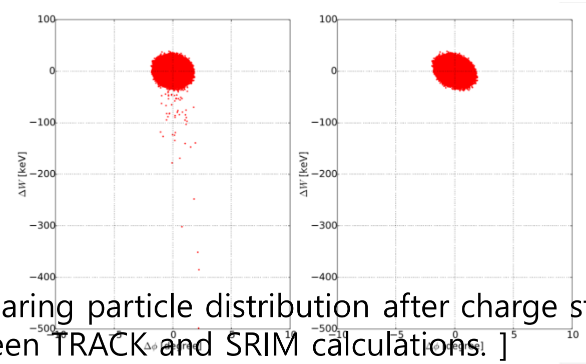


- Using formula E. Baron et. al (NIMA)



- Energy decrease : SRIM calculation
- Comparing Bethe-Bloch formula: diff. ~ 1.6%
- Energy after charge stripper : Input for TRACK

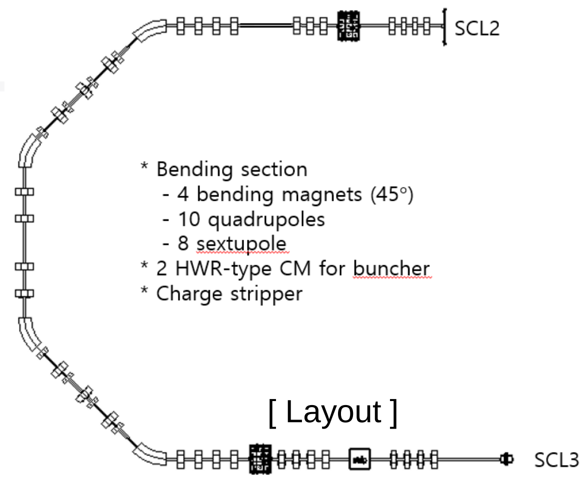




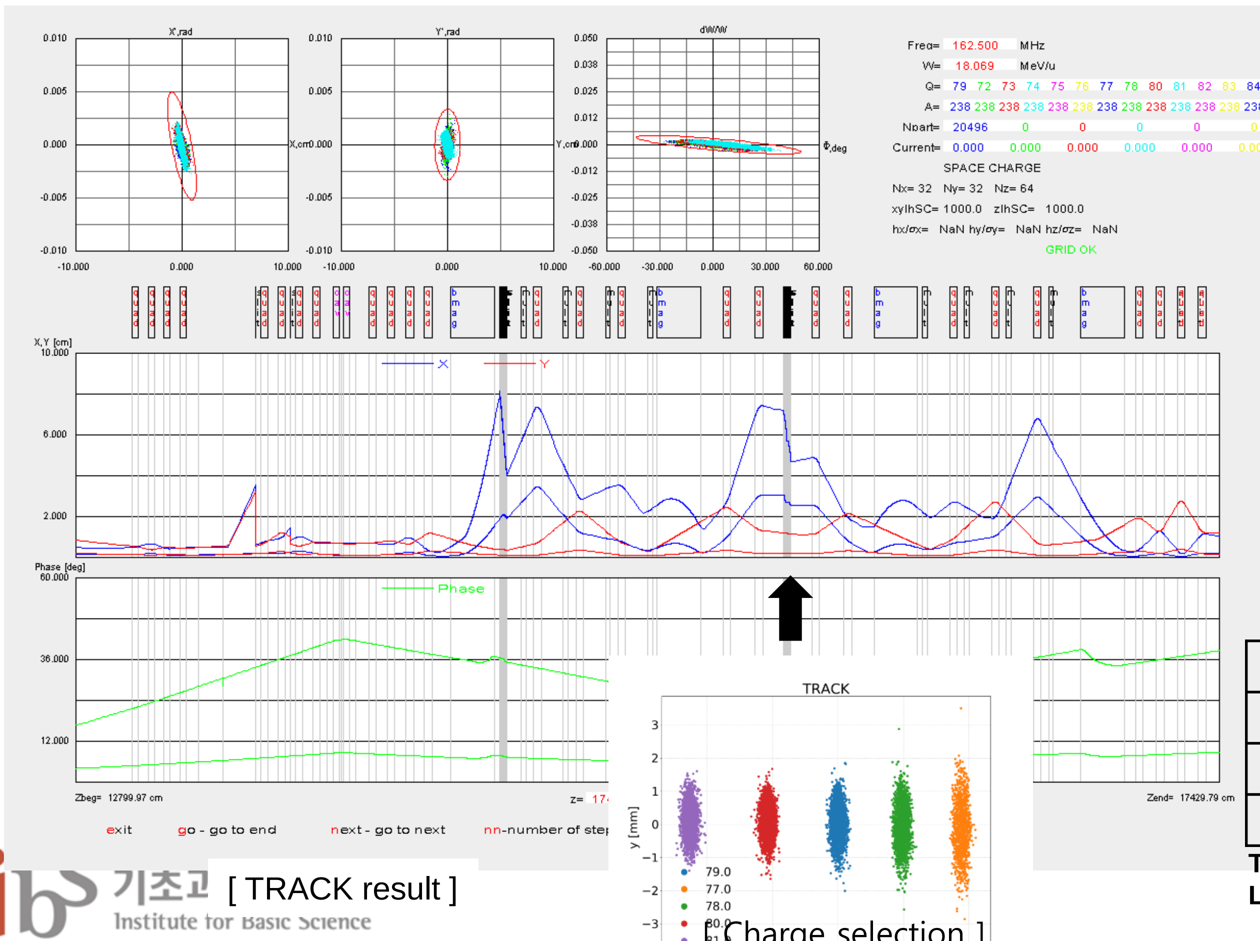
[Comparing particle distribution after charge stripper between TRACK and SRIM calculations.]

P2DT Beam Dynamics

- Beam dynamics: TRACK, GICOSY, TRACE3D
  - Mirror symmetric design
  - 2nd order achromatic, isochronous design
  - TRACK: 21 charge states after charge stripper

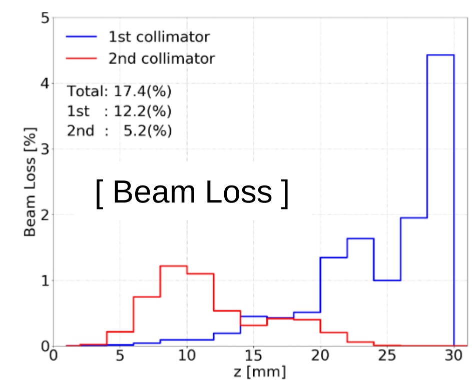


[Layout]



[TRACK result]

[Charge selection]



[Beam Loss]

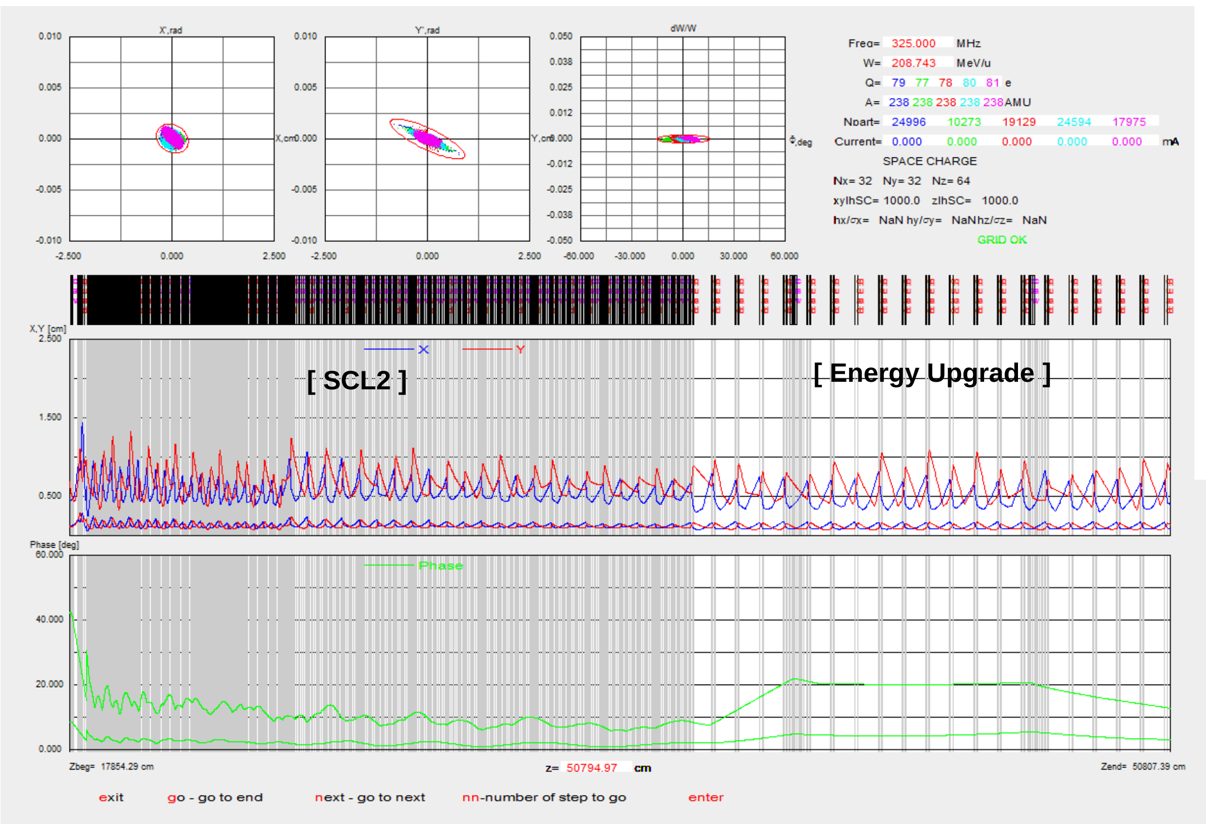
[rms emittance (before and after BM]

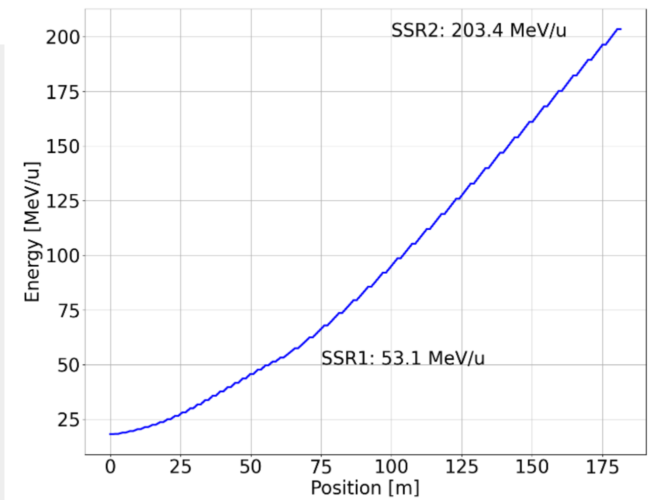
	input	output	Δ (%)
x	0.136	0.176	29.4
y	0.135	0.162	20.0
Long.	1.150	1.392	21.0

Transverse: mm-mrad
Longitudinal: keV/u-ns

SCL2 Beam Dynamics

- Beam dynamics: TRACK (Uranium, 77+ ~ 81+)
  - Matching P2DT-SSR1, SSR1-SSR2, SSR2-Energy upgrade region
  - Kinetic energy = 203.4 MeV/u





[Energy for Uranium beams]

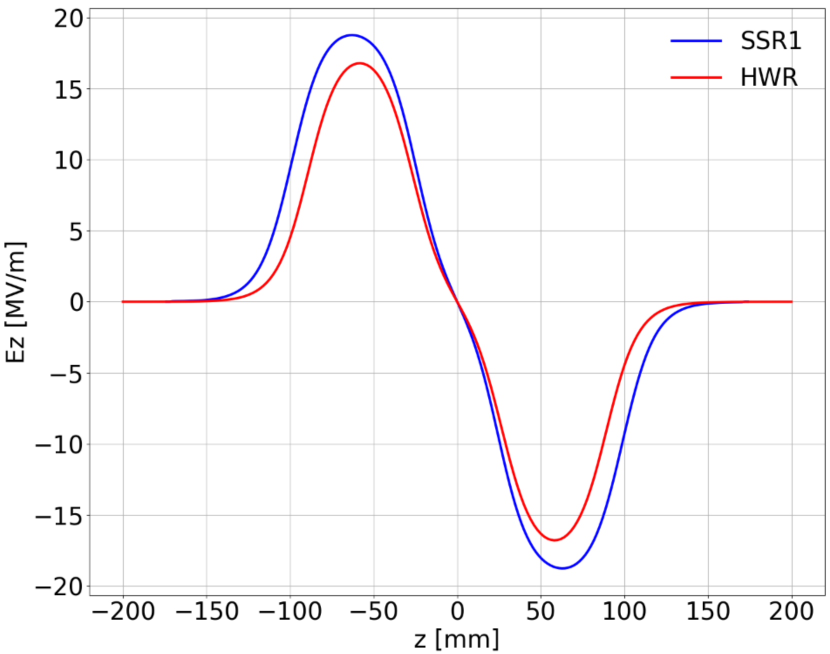
[rms emittance]

	SCL2 input	SCL2 output	Δ (%)
x	0.180	0.193	7.2
y	0.167	0.168	0.6
Long.	1.304	2.895	122

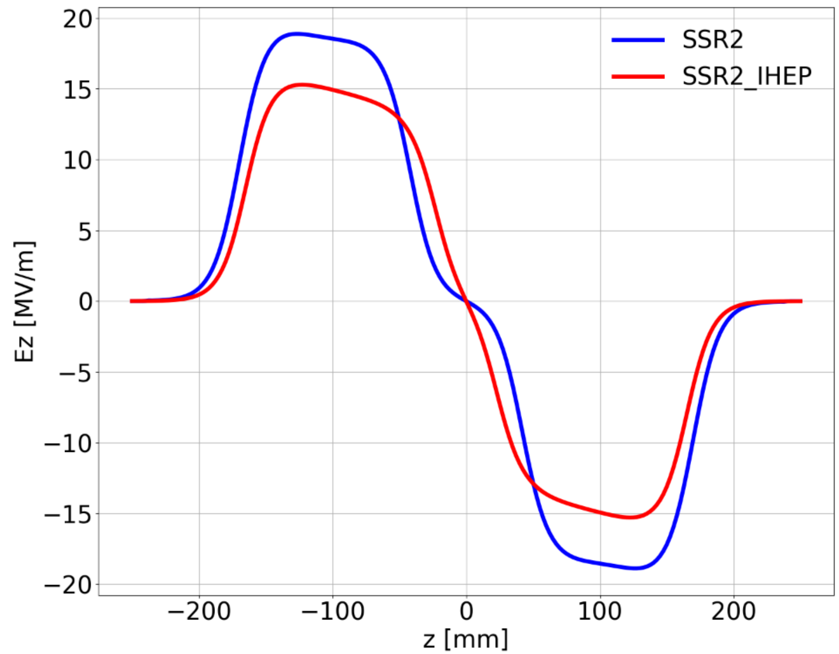
Transverse: mm-mrad
Longitudinal: keV/u-ns

SCL2 Cavity Types

- Different types of SCL21 and SCL22 cavities:
  SCL21: SSR1 or HWR
  SCL22: SSR2 or SSR2_IHEP



[Ez on beam axis (SSR1 and HWR)]



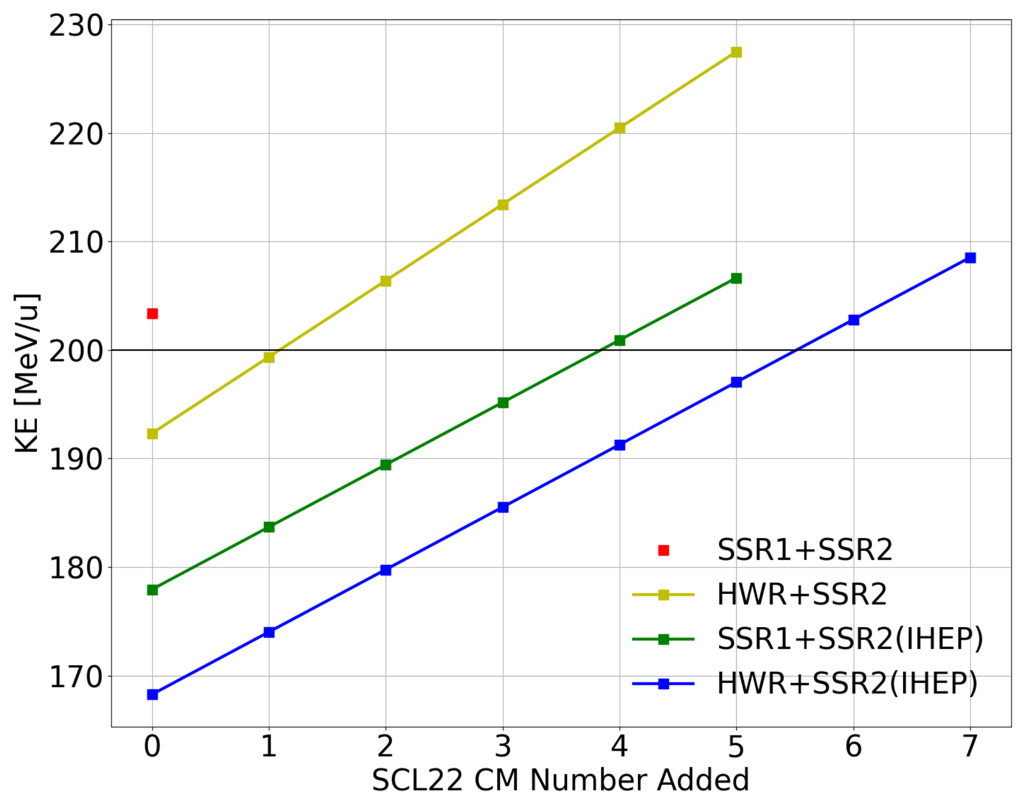
[Ez on beam axis (SSR2 and SSR2_IHEP)]

Number of additional CM for 200MeV/u

- Beam dynamics: TRACK simulation with same RF set-values
- Need more study: optimization on cavity design

[Number of CM and final Energy]

SCL21	SCL22	CM (Add)	KE [MeV/u]
SSR1	SSR2	-	203.4
	SSR2 (IHEP)	4	200.9
HWP	SSR2	2	206.4
	SSR2 (IHEP)	6	202.8



Summary

- ❑ SCL3 beam commissioning is in progress.
- ❑ Injector beam dynamics was modified for argon beam by using the beam commissioning results.
- ❑ P2DT/SCL2 lattice was fixed for SSR1, SSR2 types of SCL2 cavities.
- ❑ Beam dynamics study with new types (or modification) of SCL2 cavities is in progress.

Thank you very much.