Beam Optics of the Linac for the Rare Isotope Science Project

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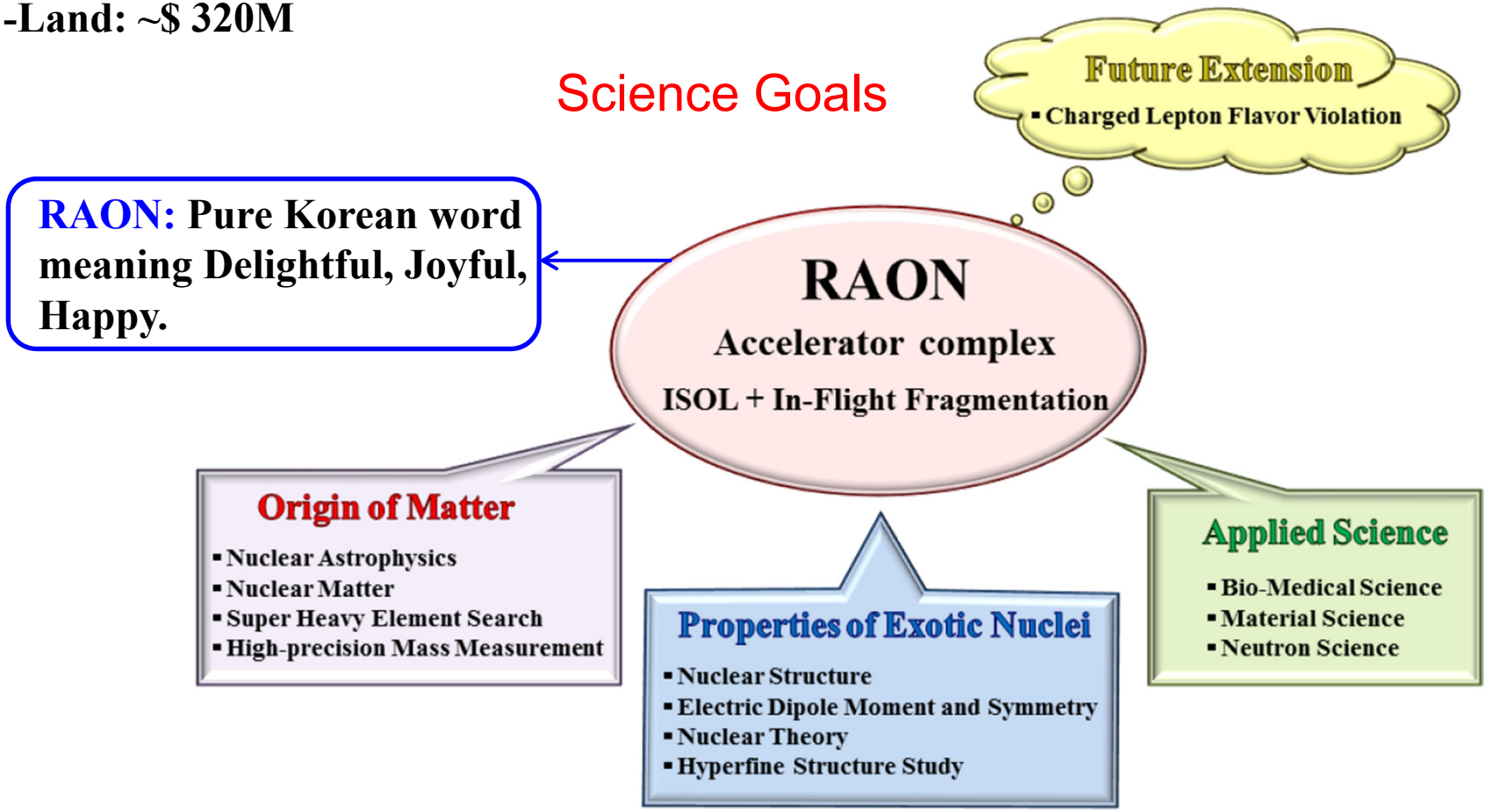
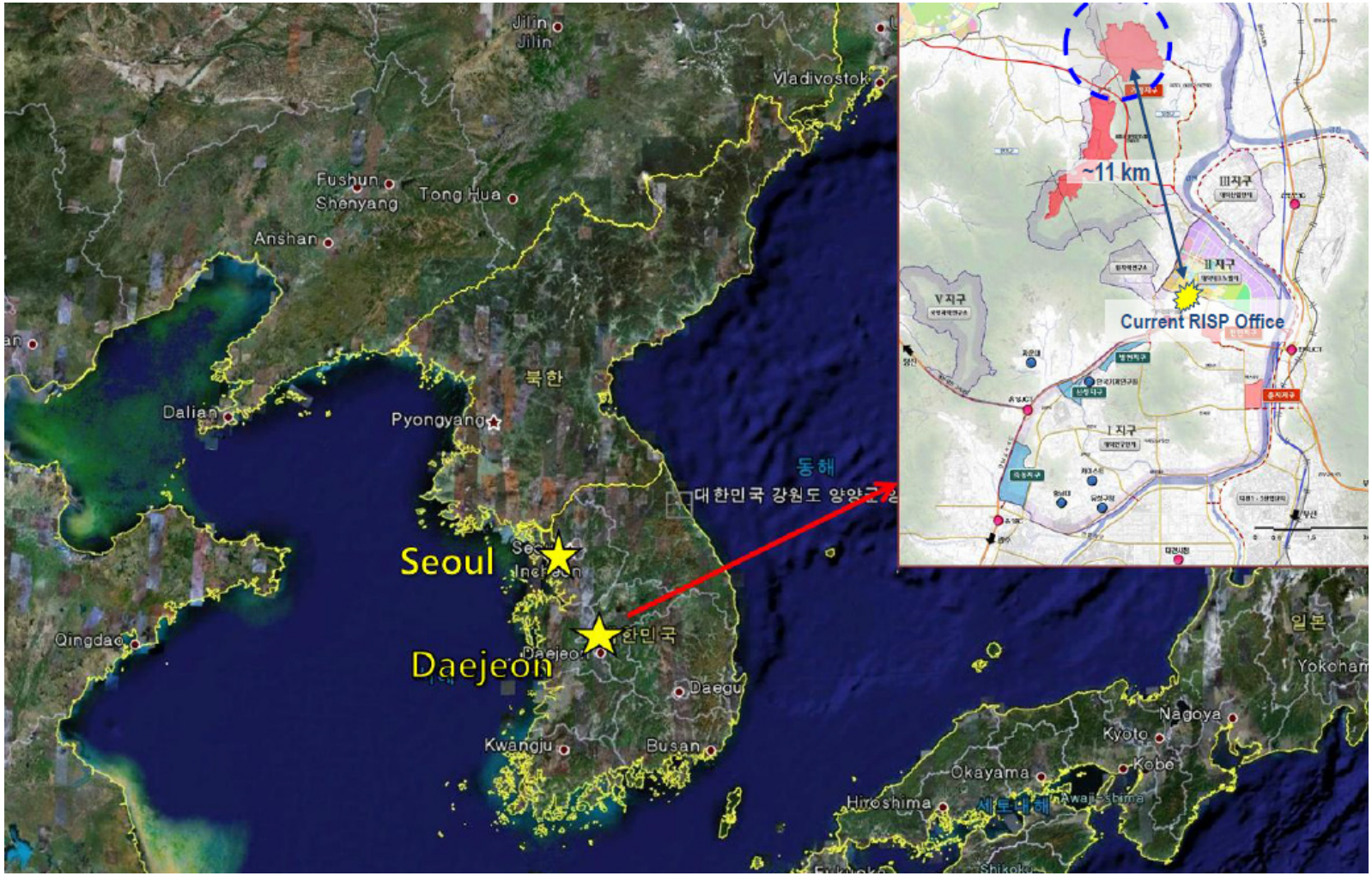
Rare Isotope Science Project (RISP)

- **Project period: 2012 12. – 2021 12. (10.1 years)**
- **Project cost: ~$1.3 B**
  - **-Accelerator and experimental systems: ~$ 420M**
  - **-Conventional facility: ~$560M**
  - **-Land: ~$ 320M**

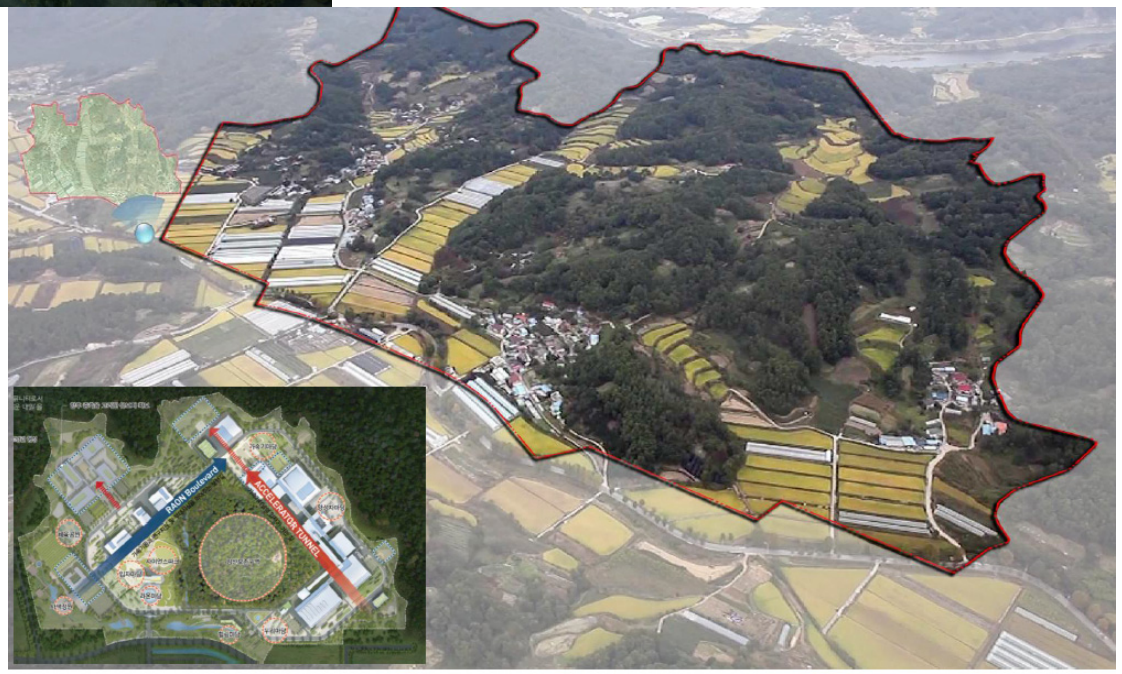


Location of RAON



Aerial views

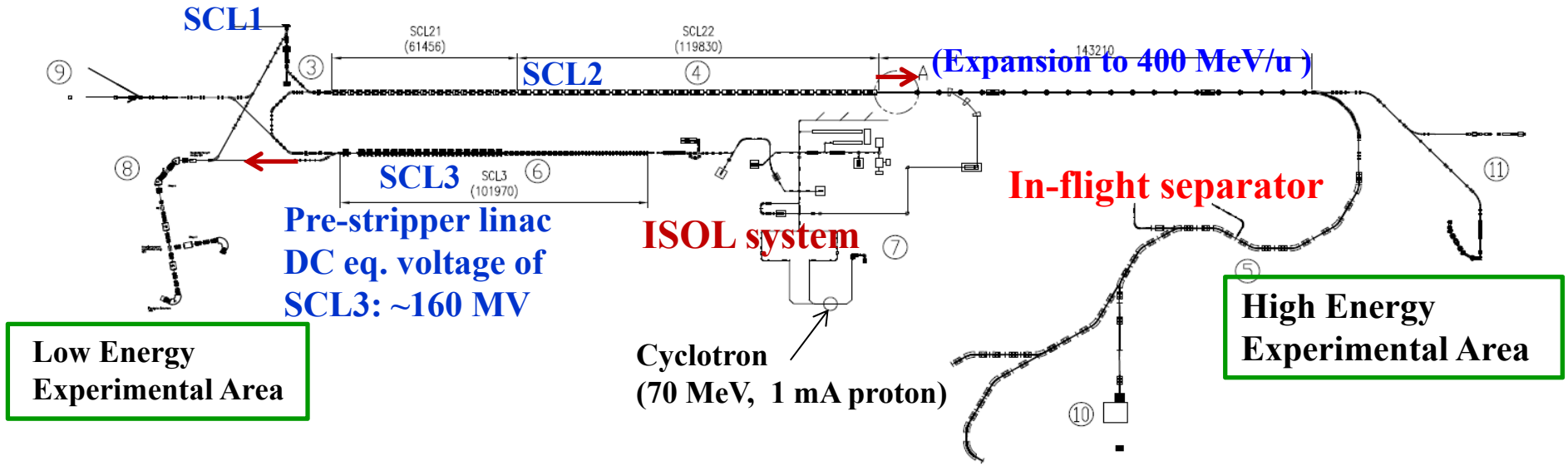
Land preparation, June 2016



A layout of accelerators and experimental systems

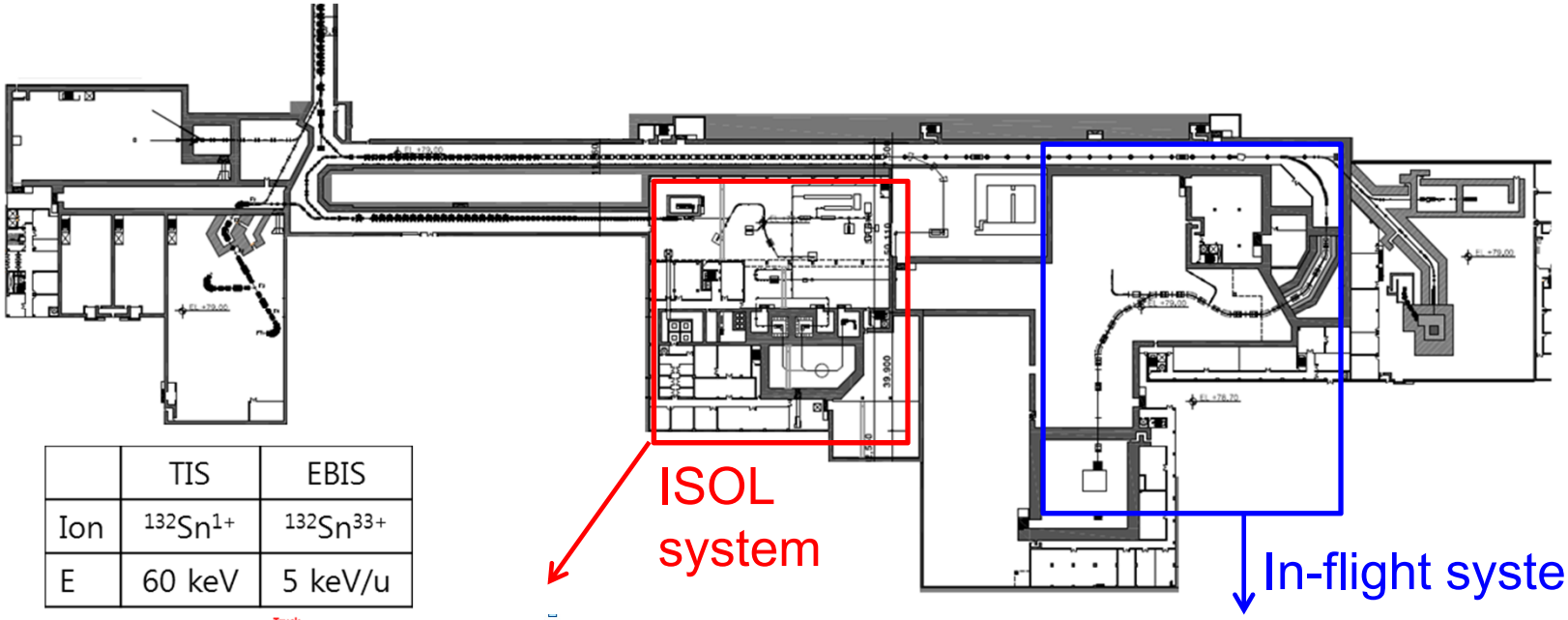
Total DC equivalent voltage: ~600 MV

	Driver Sc-Linac (SCL1+SCL2)				Post (SCL3)	Cyclotron
Particle	**H**	**O**	**Xe**	**U**	RI beam	proton
E (MeV/u)	**600**	**320**	**251**	**200**	18.5	70
I (pμA)	660	78	11	8.3	-	1000
Power (kW)	**> 400**	**400**	**400**	**400**	-	70

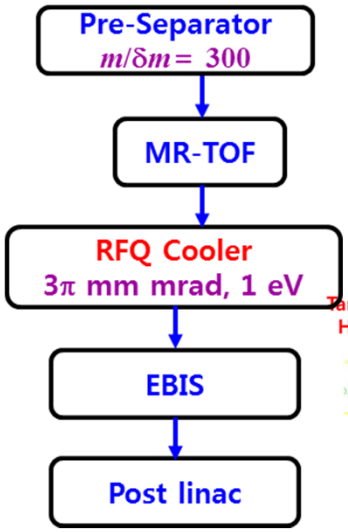


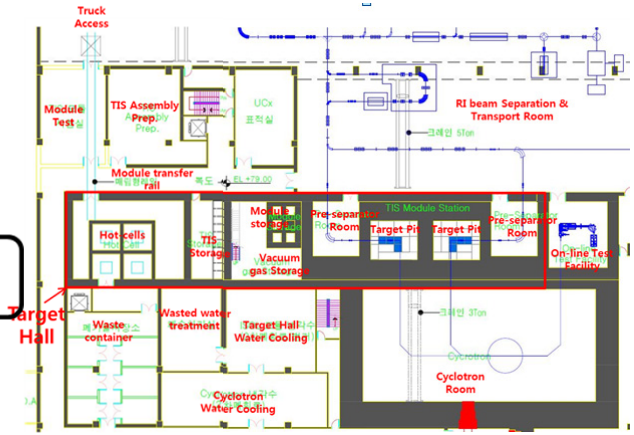
- **IF (In-flight) separation**
- **ISOL (ISotope On Line) separation**
- **ISOL+IF**

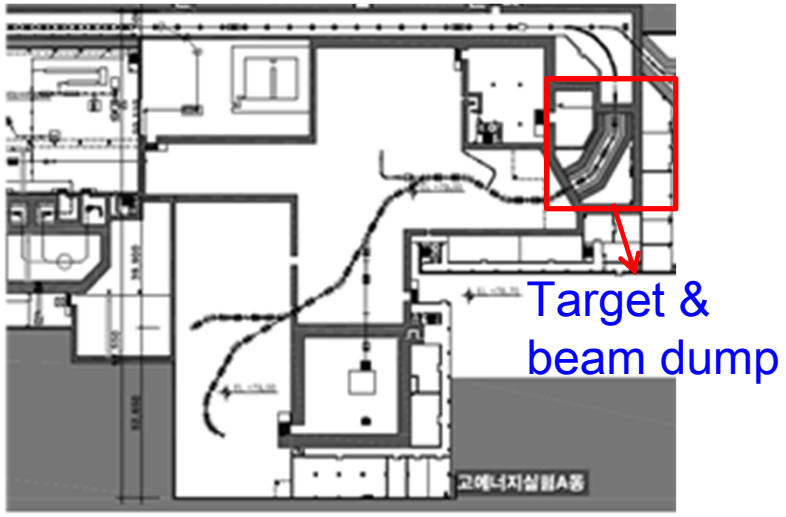
RI beam production systems: **ISOL** and **In-flight**



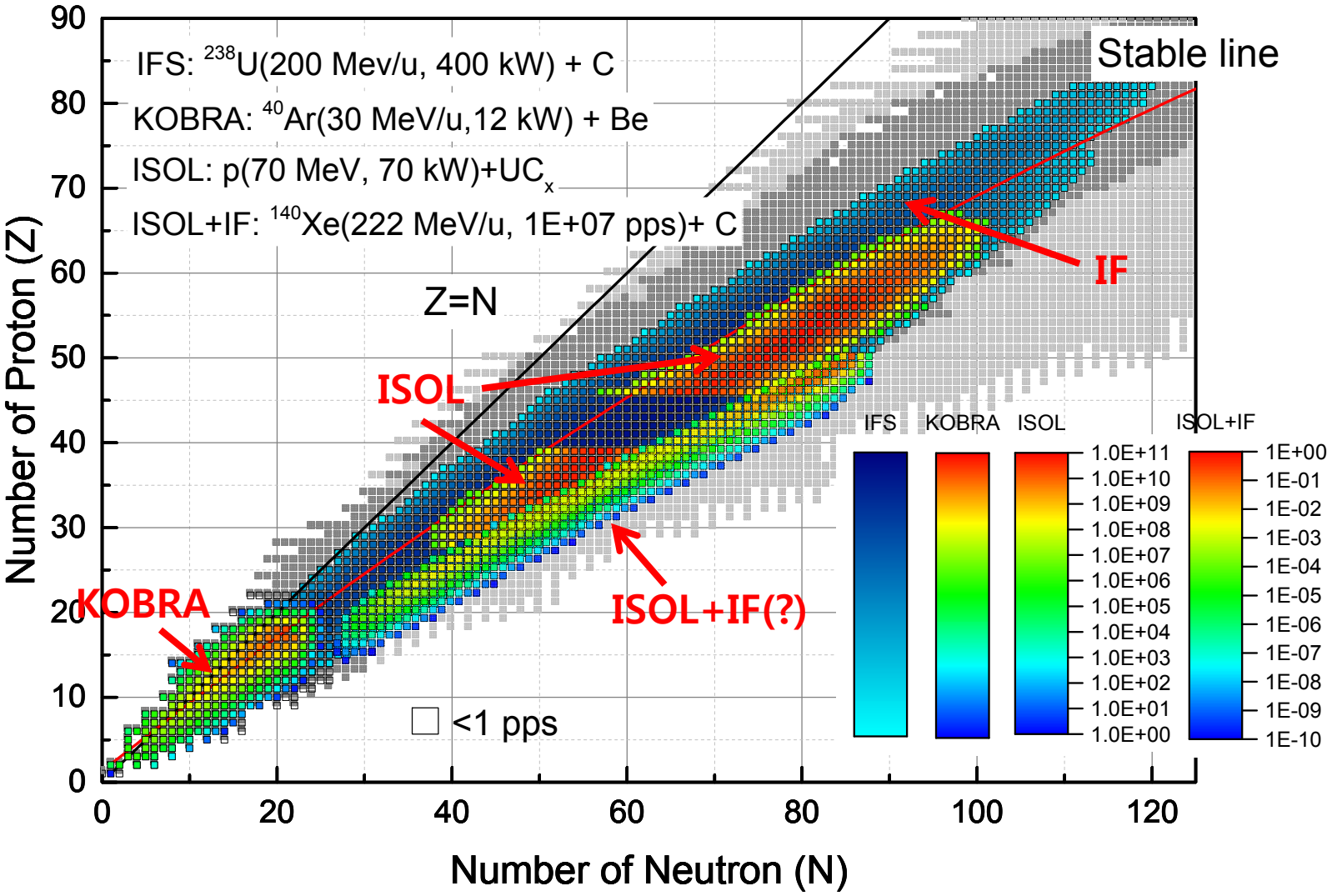
	TIS	EBIS
Ion	$^{132}Sn^{1+}$	$^{132}Sn^{33+}$
E	60 keV	5 keV/u







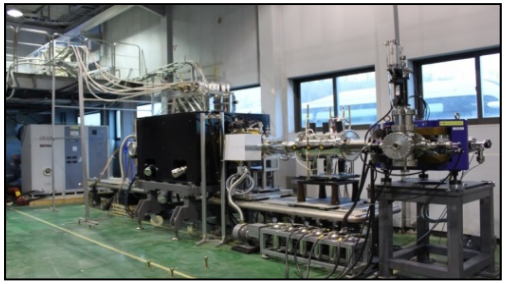
Rare isotope beams expected at RAON



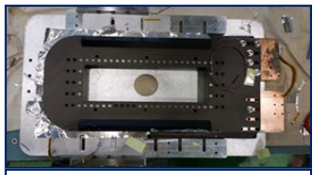
- **RAON will provide access to unexplored regions of the nuclear chart**

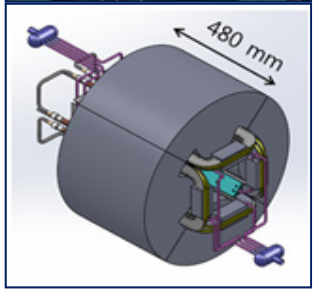
Development of major accelerator components

SSR SC Cavity and its Cryomodule

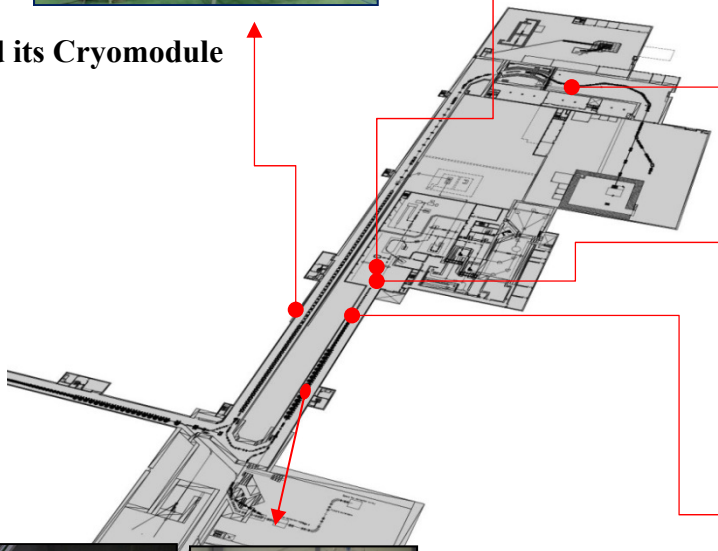


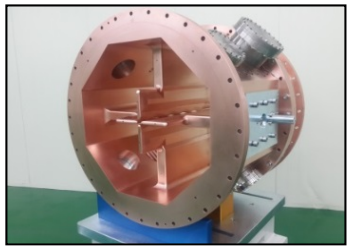
28 GHz ECR Ion Source





HTS-coil SC
quadupole -magnet





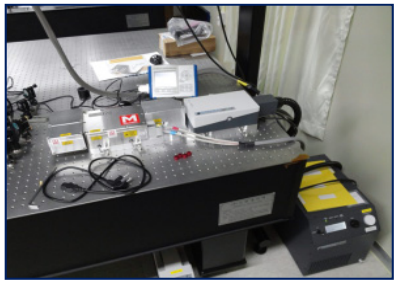
RFQ

HWR SC Cavity & its Cryomodule

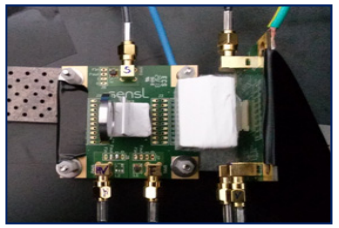
QWR SC Cavity & its Cryomodule

Development of the experimental systems

Gamma array



LASER for Collinear Laser Spectroscopy



β-detection System for μSR

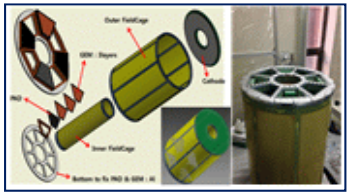
High energy

LAMPS

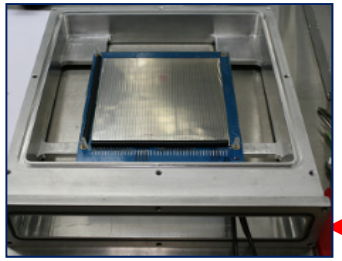
IF

ISOL

ISOL Test Facility



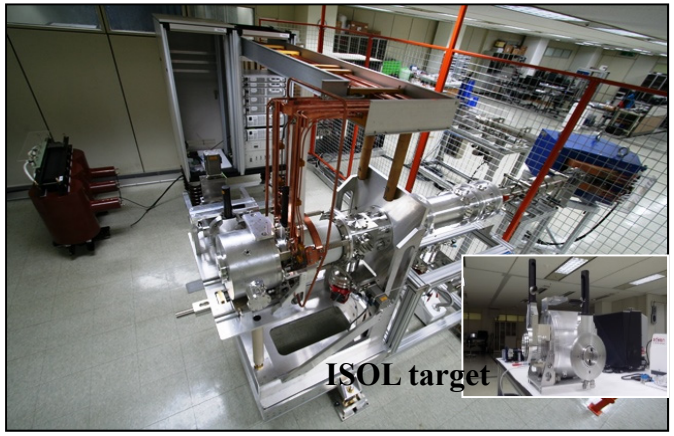
Time Projection Chamber

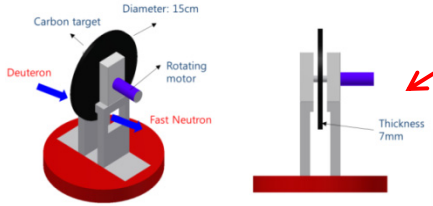


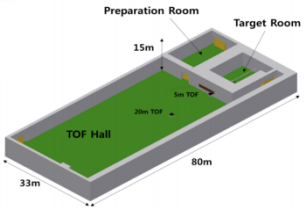
Beam Tracking Detector (PPAC)

KOBRA

Low energy
and neutrons





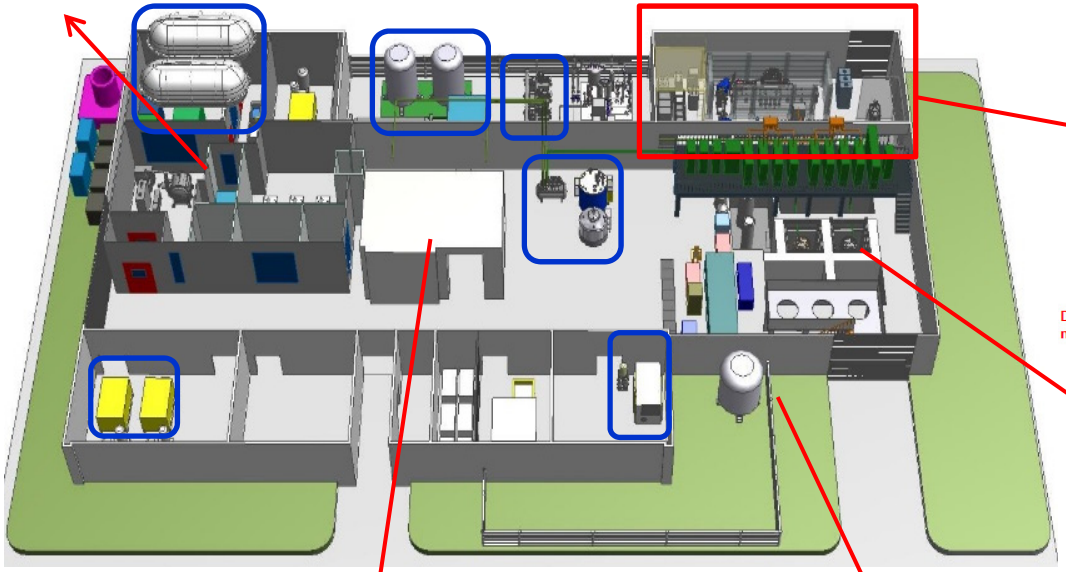


Neutron science facility

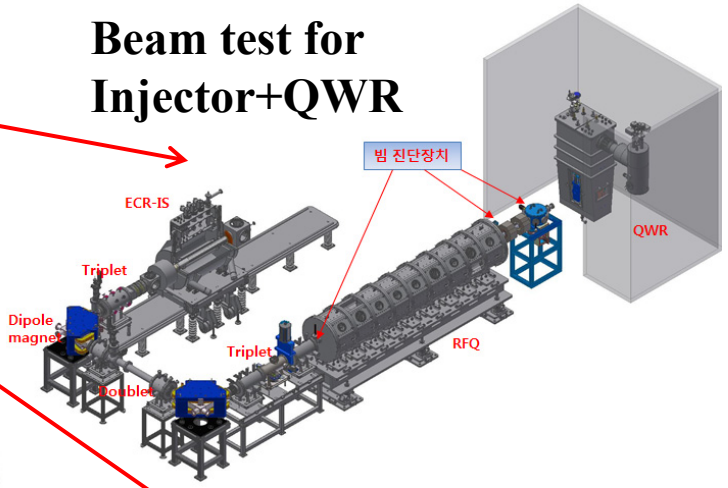
Construction of the SRF test facility

Clean room
up to class 10

Completion date: June 28, 2016

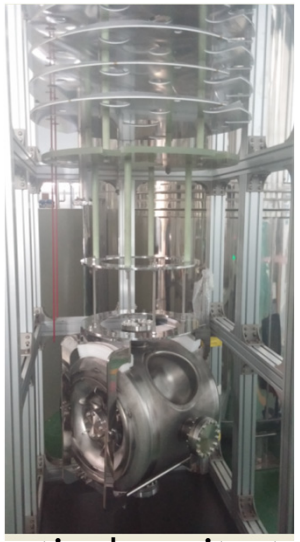


Beam test for Injector+QWR



Cryomodule test room

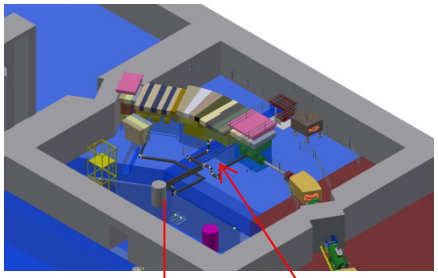
LHe system (330 W at 4.5 K)

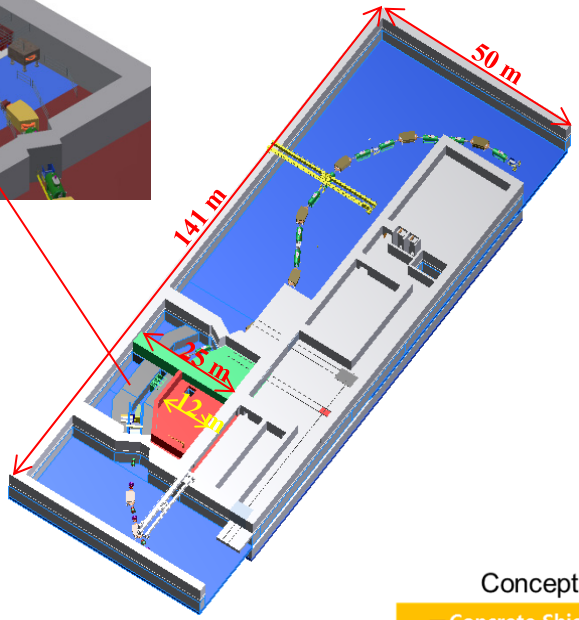


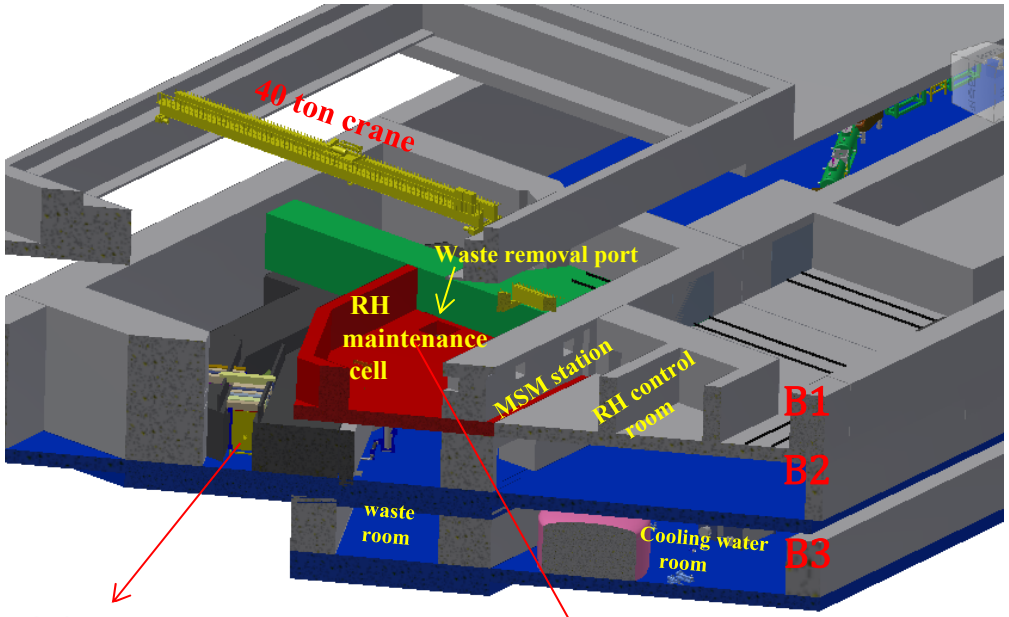
Vertical cavity test

Radiation shielding and RH design for in-flight separator

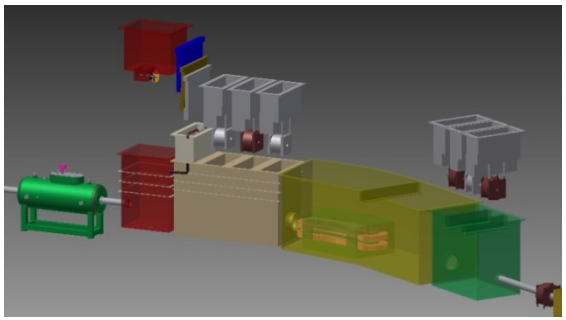
Compatible for remote handling (RH)



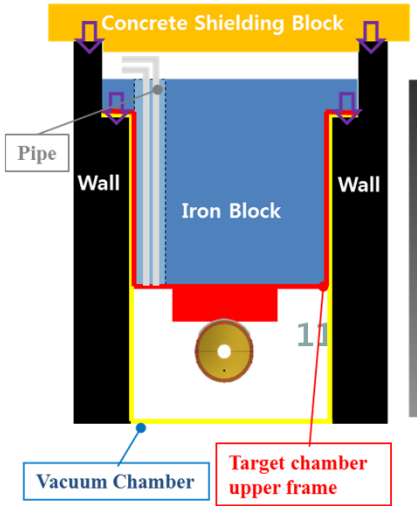




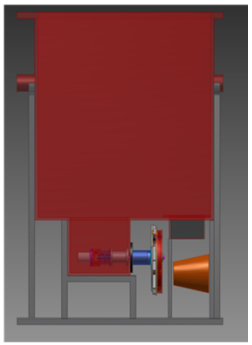
Vacuum chamber designed for RH

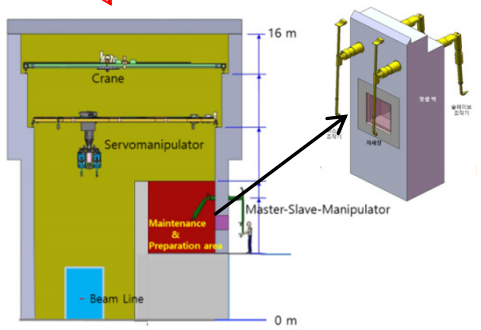


Conceptual view



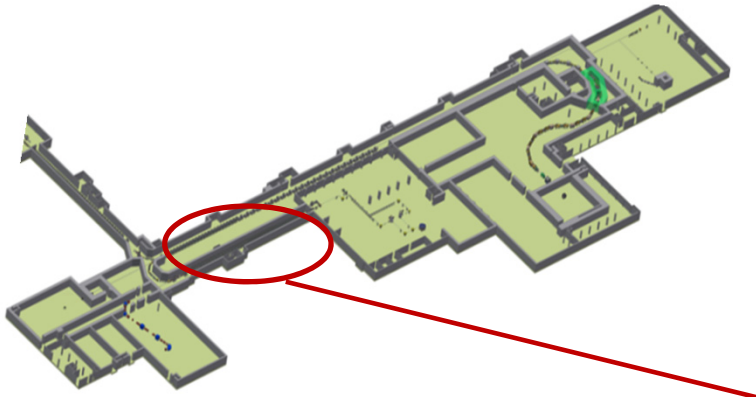
Side view





A work with a KAERI group

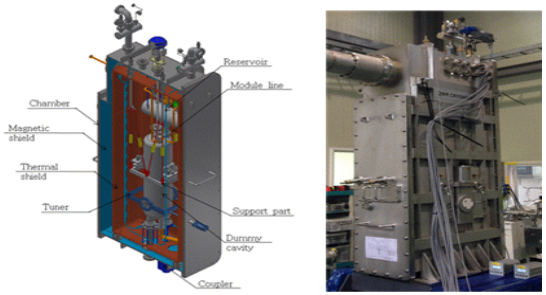
Tunnel for SCL3 (pre-stripper linac)



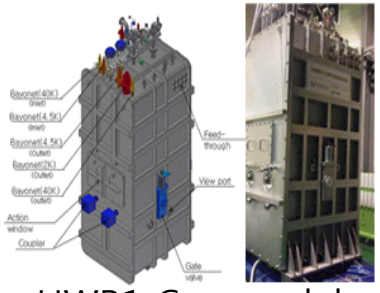
Magnified Views

LHe line

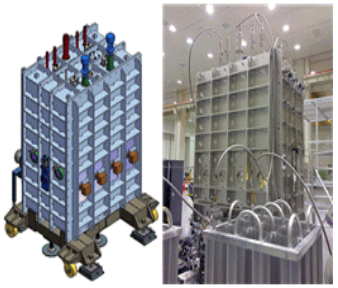
Three kinds of cryomodules for SCL3



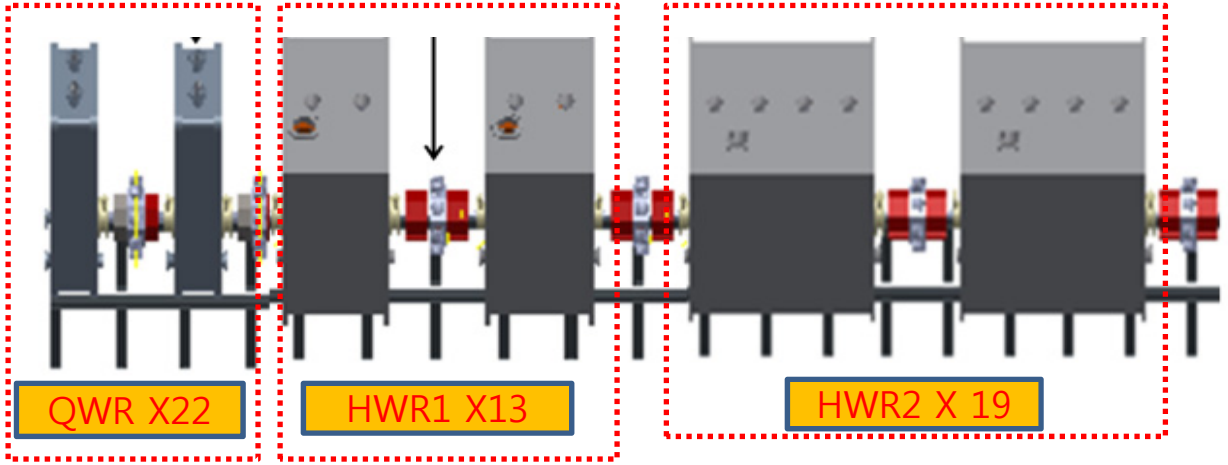
QWR Cryomodule



HWR1 Cryomodule



HWR2 Cryomodule

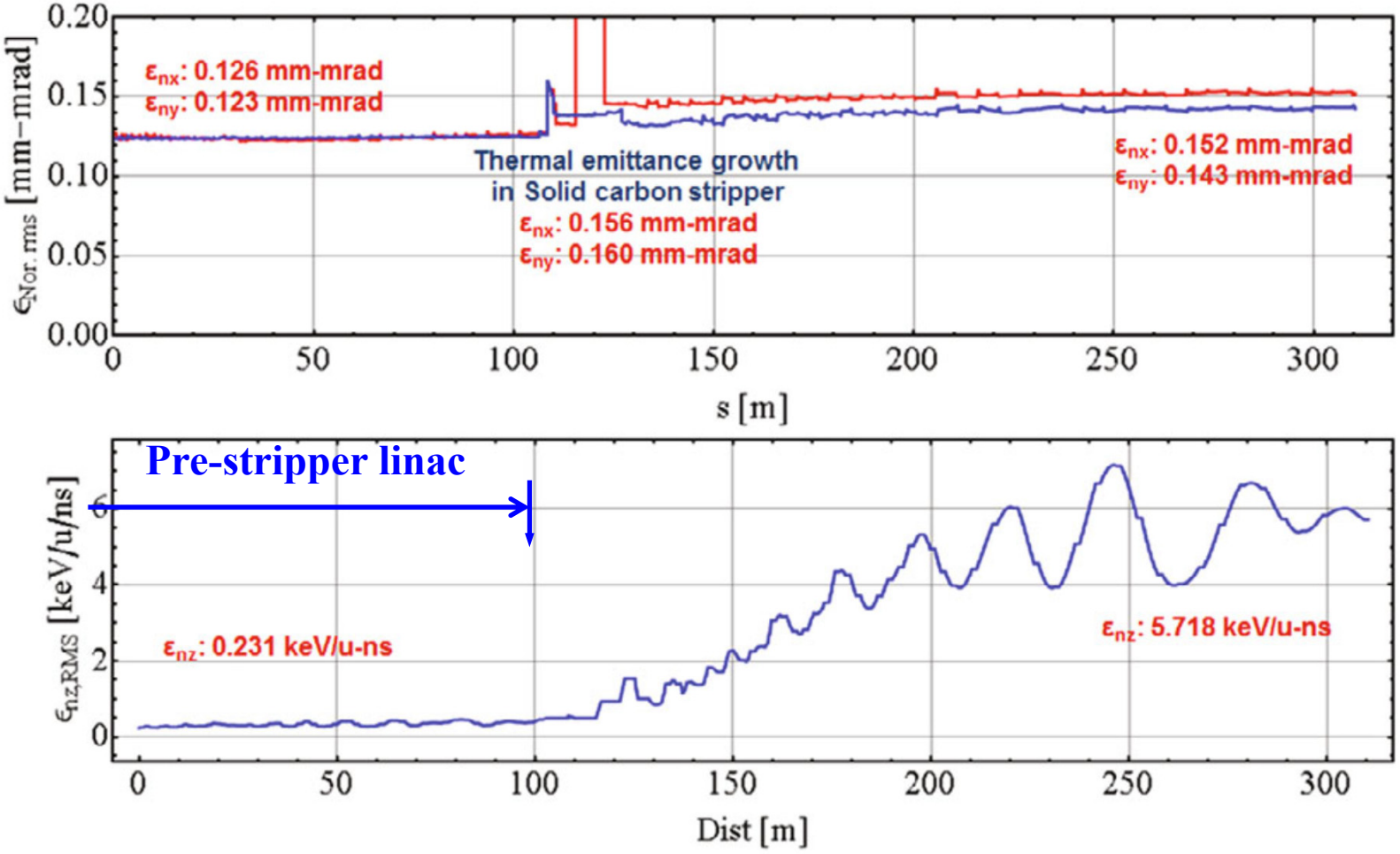


SCL31 (QWR)	
E_{in}, E_{out}	0.4 MeV/u, 2.4 MeV/u
Cavity type	beta=0.047 QWR
f	81.25 MHz
# of cavity	22
# of cryomodule	22

SCL32 (HWR1 + HWR2)	
E_{in}, E_{out}	2.4 MeV/u, 16.5 MeV/u
Cavity type	beta=0.12 HWR
f	162.5 MHz
# of cavity	102
# of cryomodule	32 (13+19)

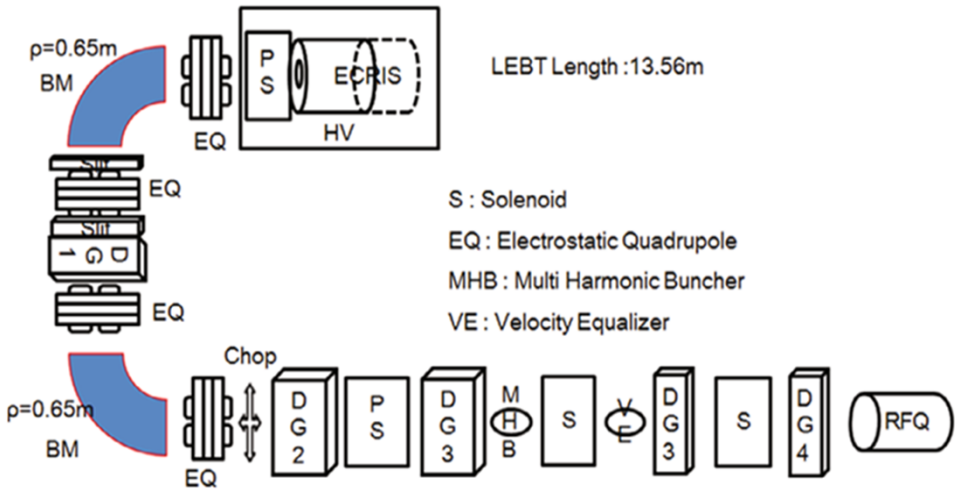
Beam dynamics simulation for SCL3

Transverse and longitudinal emittance variation along the linac



Start-to-end beam optics simulation for a U beam performed in 2013.

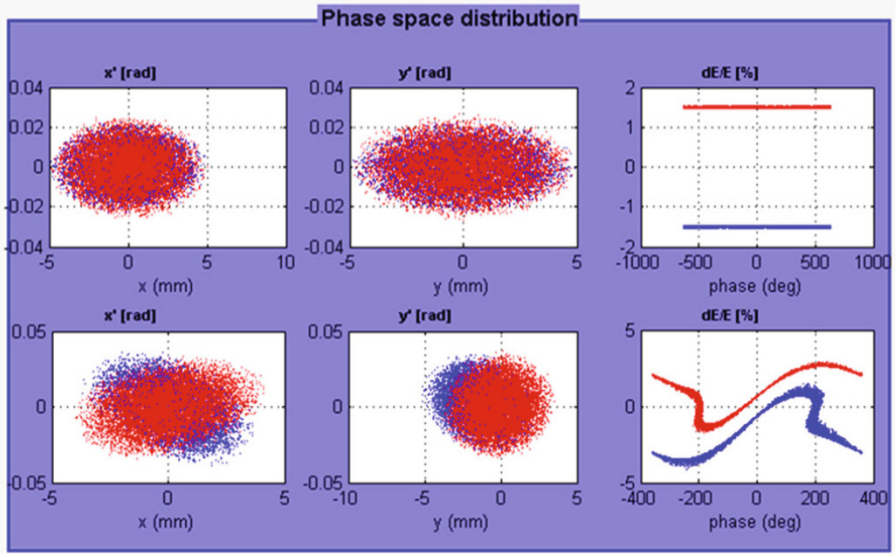
Beam optics of the injector

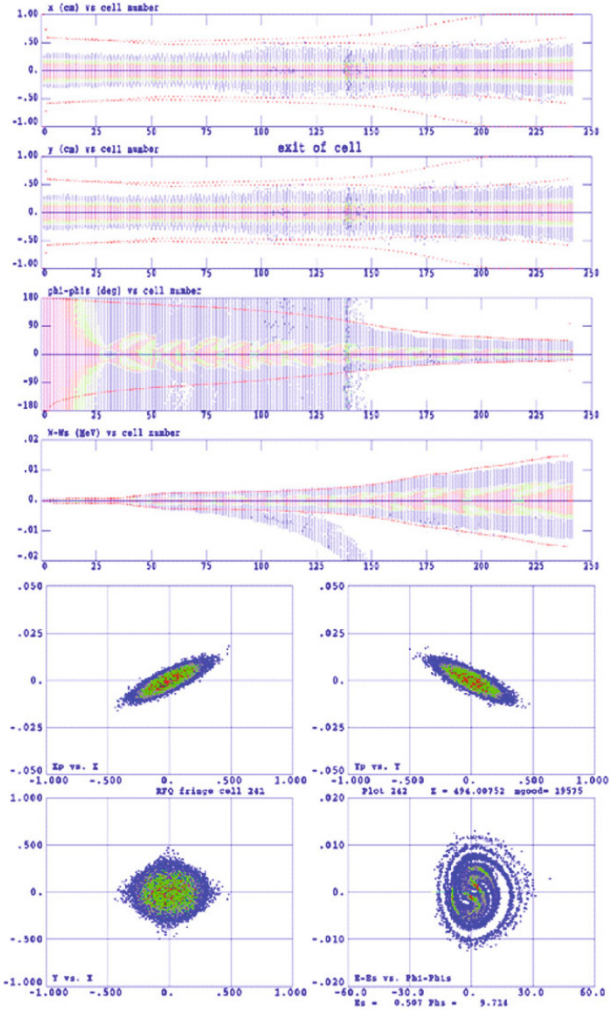


At LEBT entrance and exit

Blue: $^{238}U^{33+}$

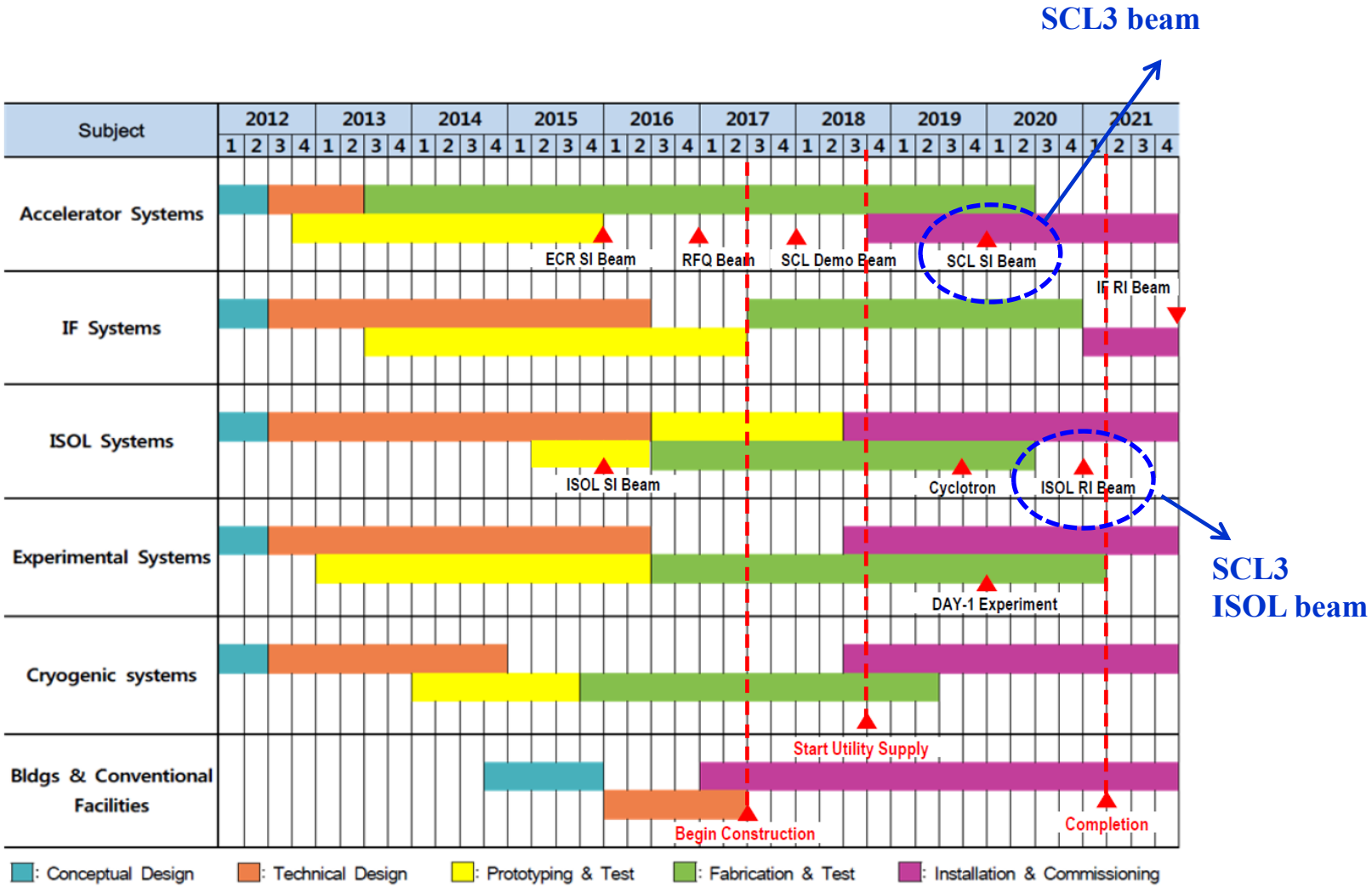
Red: $^{238}U^{34+}$



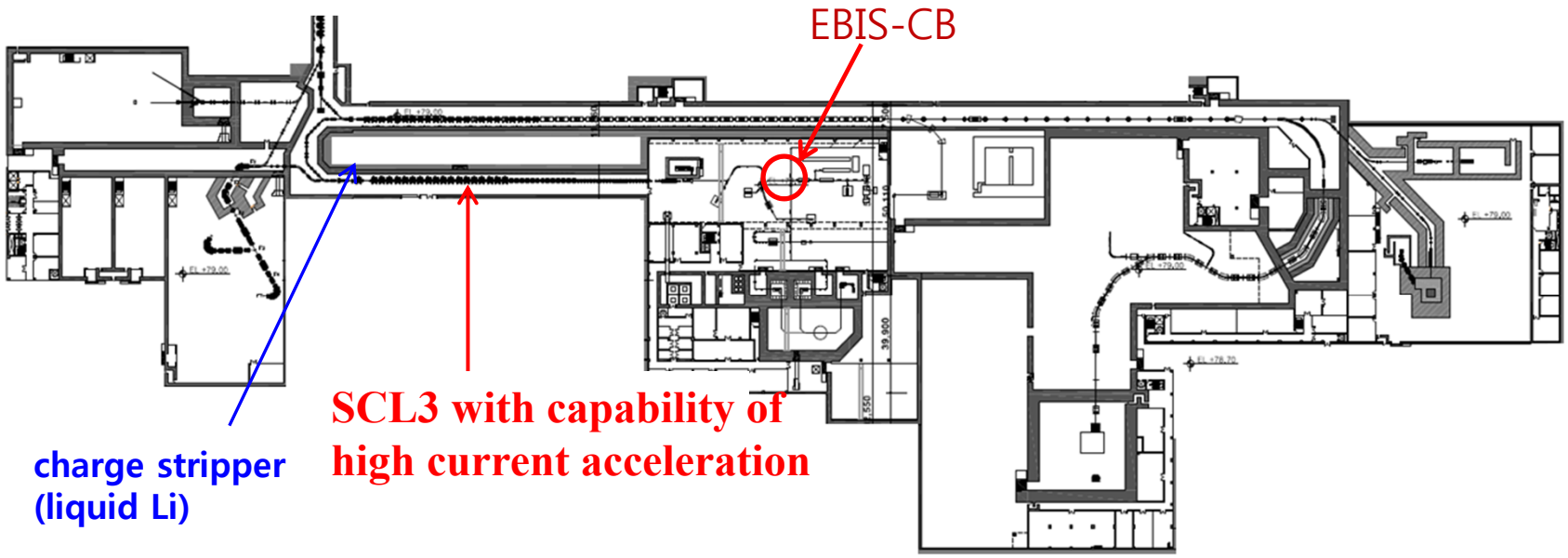


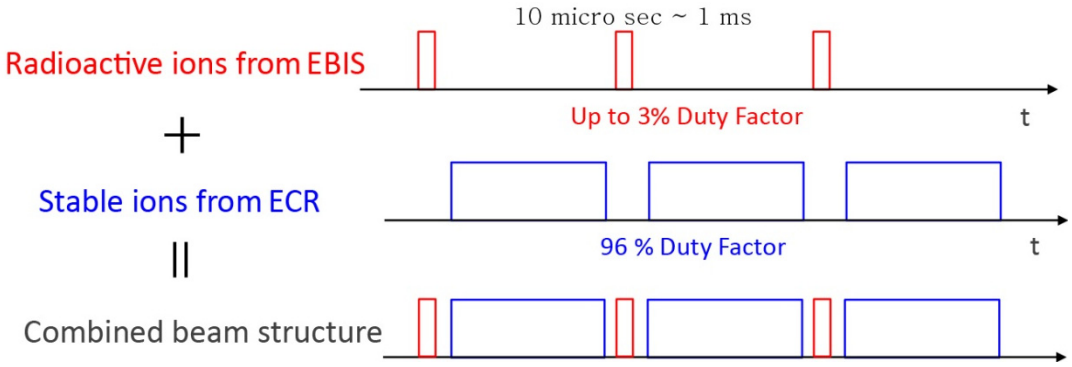
RFQ beam dynamics results using PARMTEQ

Time schedule of the RISP



A two-beam operation with pre-stripper linac





Simultaneous acceleration of stable and RI beams with similar q/A

IF beam: $^{238}U^{33+,34+}$ (q/A≅0.14); ECR
ISOL beam: $^{132}Sn^{19+}$ (q/A≅0.14); EBIS-CB

Discussion with P. Ostroumov in Nov. 2014, during ICABU workshop, Daejeon

Optics study with ANL group on pre-stripper linac

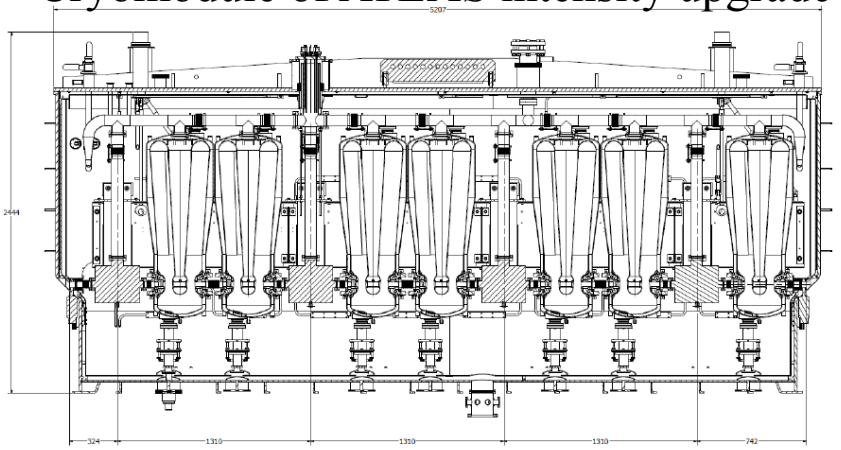
Pre-conceptual design on18.5 MeV/u pre-stripper linac for the RISP/IBS.

February 26, 2016

Argonne National Laboratory
Physics Division

B. Mustapha
P. N. Ostroumov, PI

Cryomodule of ATLAS intensity upgrade

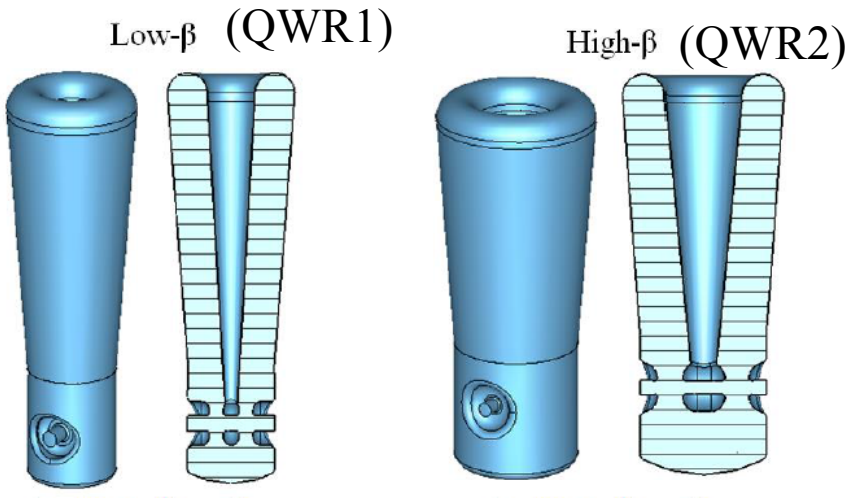


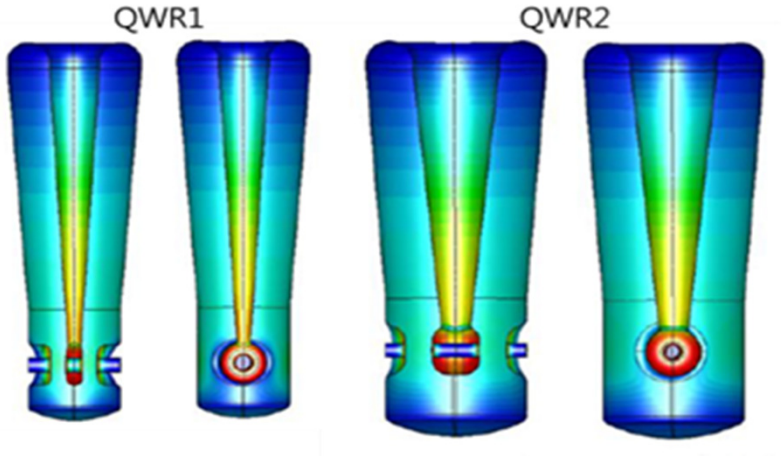
Comparison of SC Linac parameters.

Parameters	RISP baseline	ANL proposal
Number of QWR (or QWR1)	22	15
Number of HWR (or QWR2)	102	49
Number of cryomodule	54	9
Total length	100 m	53.3 m

*E_p assumed for RISP: 35 MeV/m,
E_p by ANL group: 40 MeV/m

Two kinds of QWR's for the design study



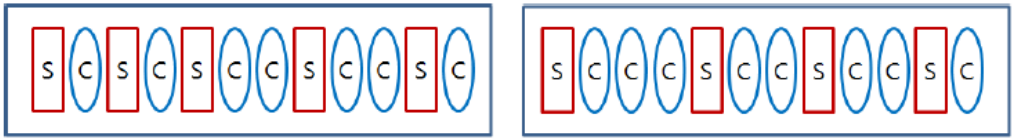


Electric field distributions

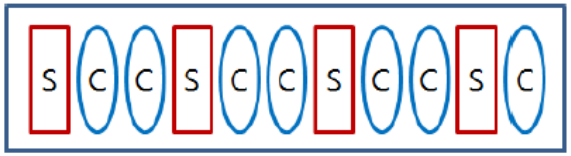
Parameters of the two cavities

Parameter	QWR1	QWR2
f (MHz)	81.25	81.25
β_{opt}	0.05	0.109
L_{eff} (cm)	18.5	40.2
E_{peak}/E_{acc}	5.6	5.6
B_{peak}/E_{acc} (mT/MeV/m)	7.7	7.3
R/Q (Ω)	493	552
G (Ω)	23	32
Aperture (mm)	40	40
Height (cm)	103	115
Top diameter (cm)	32	46

Cryomodule design for the linac study



First two cryomodules of QWR1

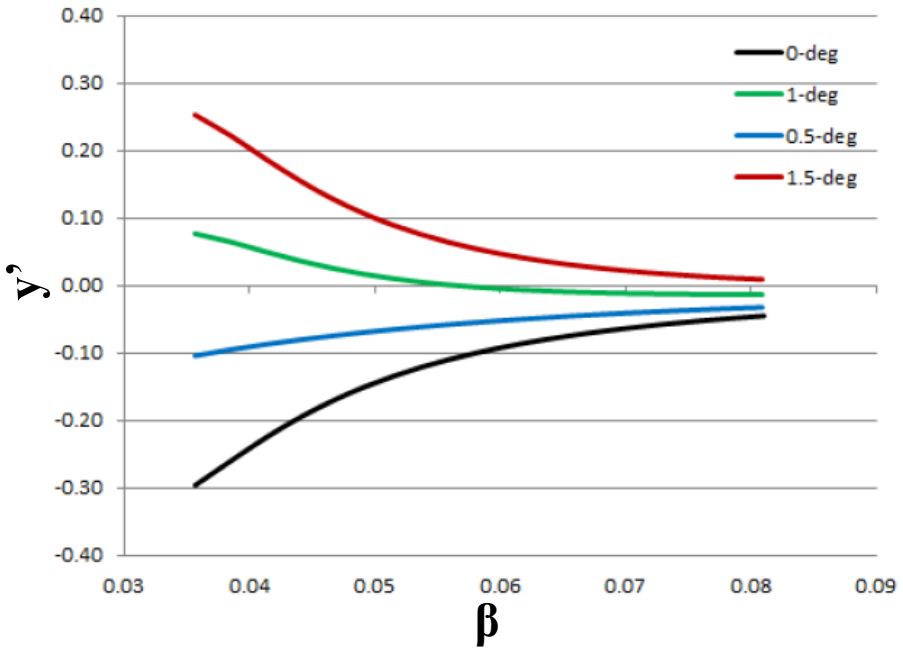


Cryomodule of QWR2

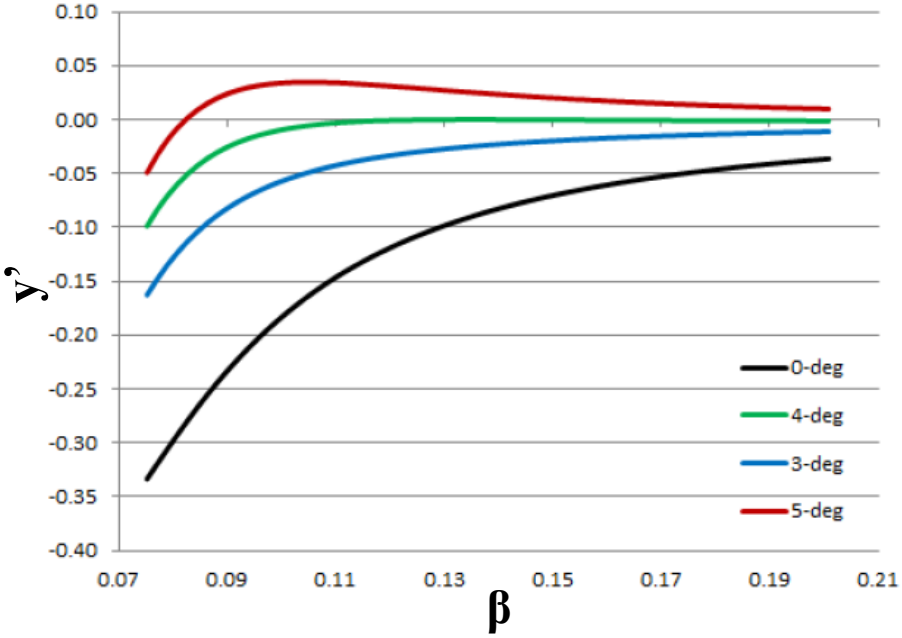
	QWR1	QWR2
Number of cryomodules	2	7
Number of cavities	15	49
Number of SC solenoids	9	28
Number of BPM	8	28
Cryomodule length	4678 mm	5941 mm
Inter-cryostat distance between flanges on beam line	436 mm	494 mm

Steering effect of QWR's

Tilt angles of drift-tube faces for steering-effect correction
QWR1: 1º tilt is the closest to the zero line for y'
QWR2: ~4º.

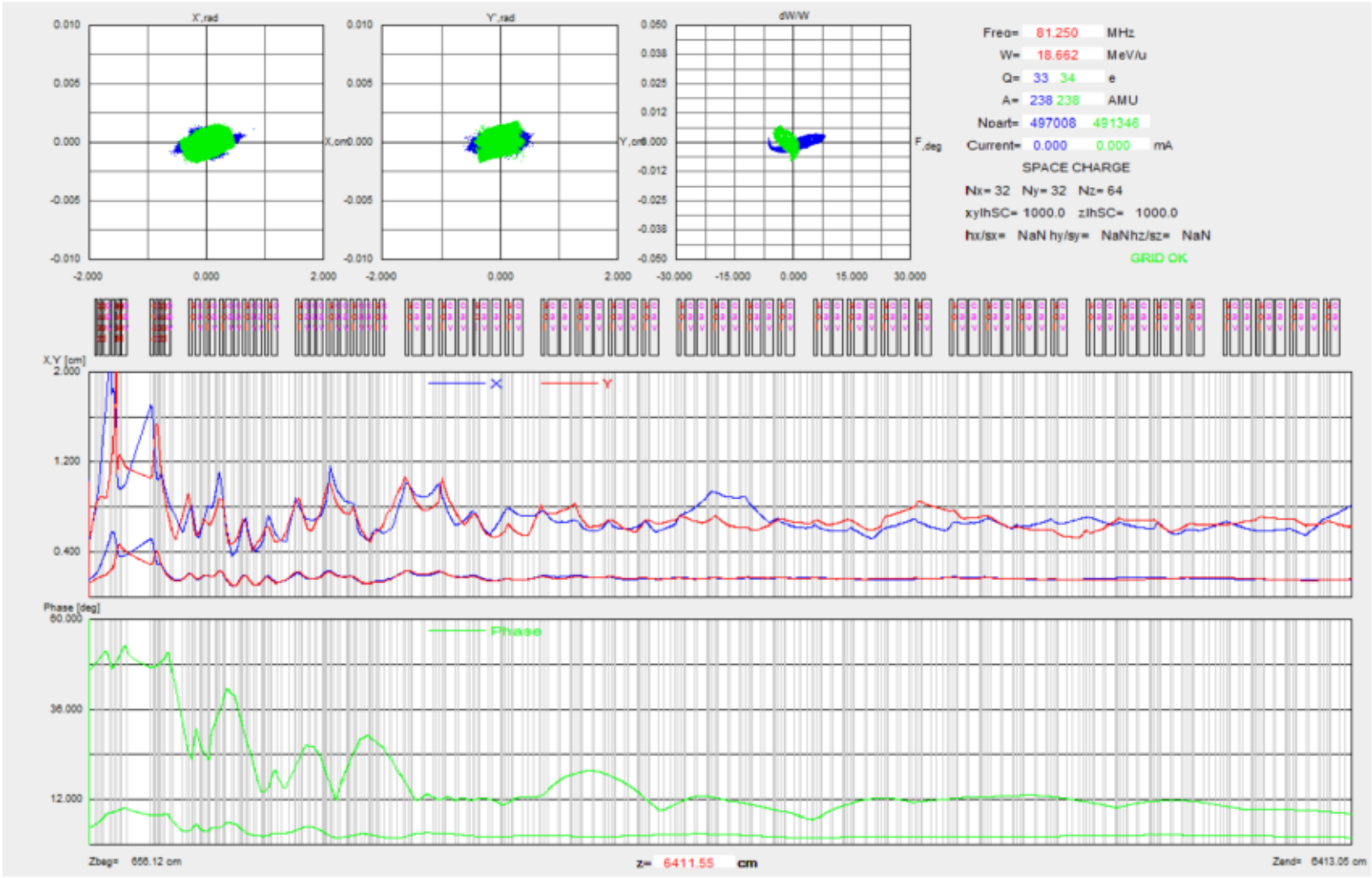


Steering effect of QWR1 versus β



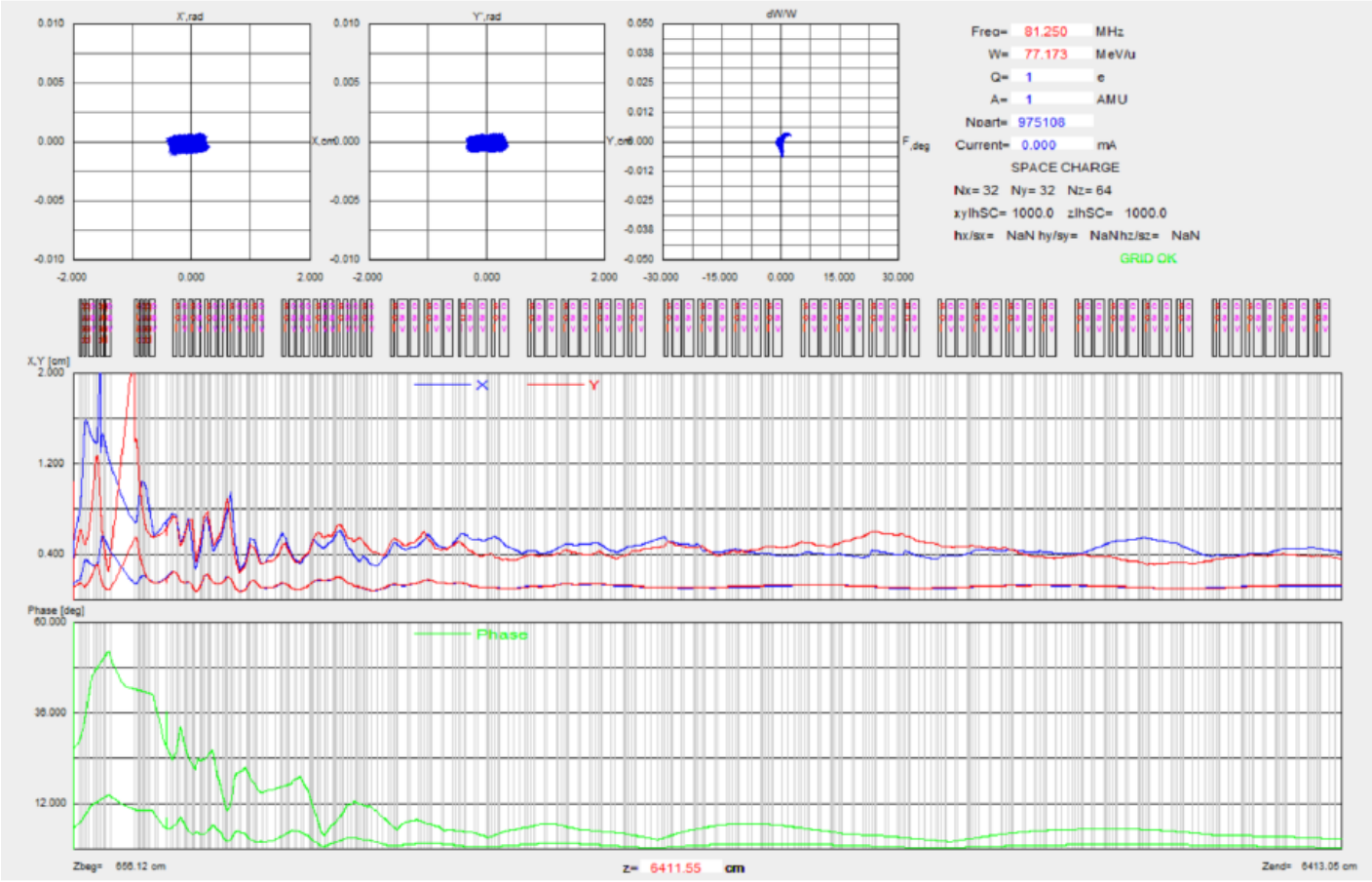
Steering effect of QWR2 versus β

Beam tracking of ^{238}U beam using TRACK



Evolution of **$U^{33+,34+}$ beam envelopes** (rms and full) along the MEBT and pre-stripper linac.

Beam tracking of proton beam



Evolution of **proton** beam envelopes (rms and full) along the MEBT and pre-stripper linac.

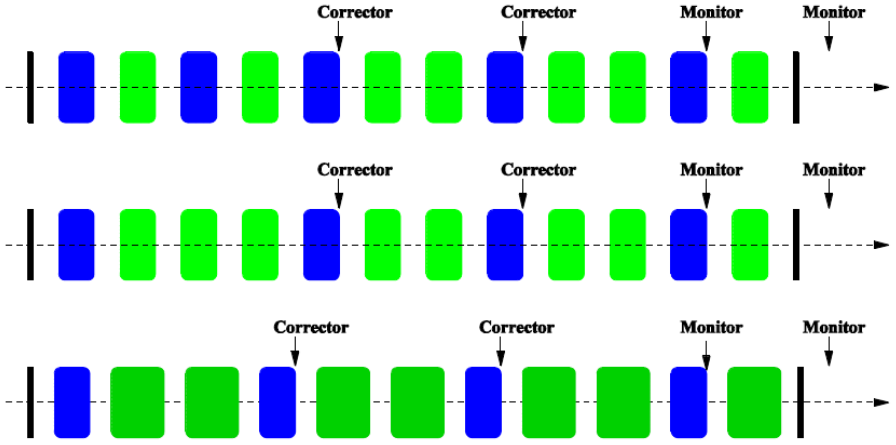
Machine error study

Error types and amplitudes for three sets of errors used in the simulations

Error set	Cavity & Solenoid misalignment (mm)	Cavity phase (deg)	Cavity amplitude (%)
1	0.25	0.5	0.5
2	0.25	1.0	1.0
3	0.5	0.5	0.5

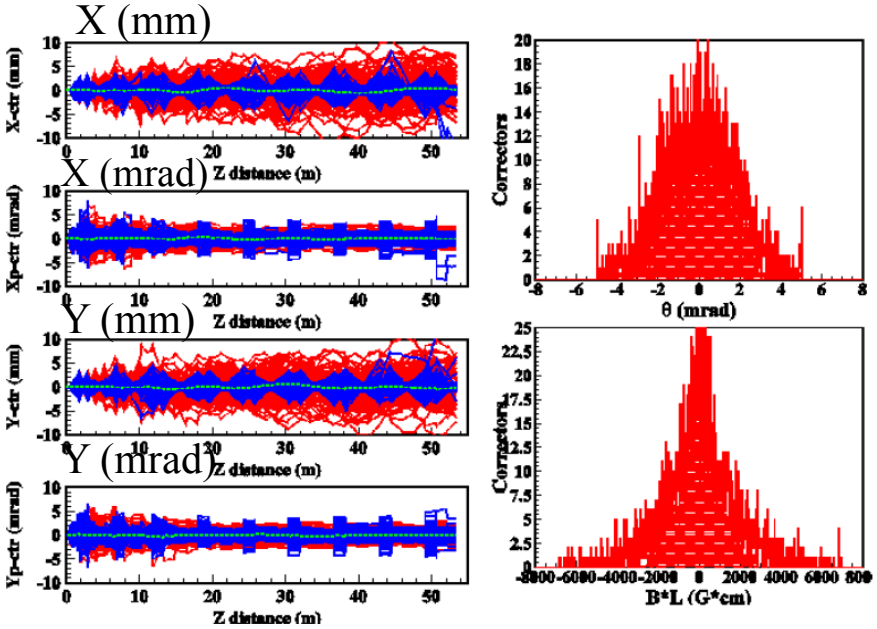
*Misalignment errors are uniformly generated within the given maximum value. RF errors are generated within a Gaussian truncated at 3σ.

Correction scheme used in error simulations with corrective steering for three kinds of cryomodule

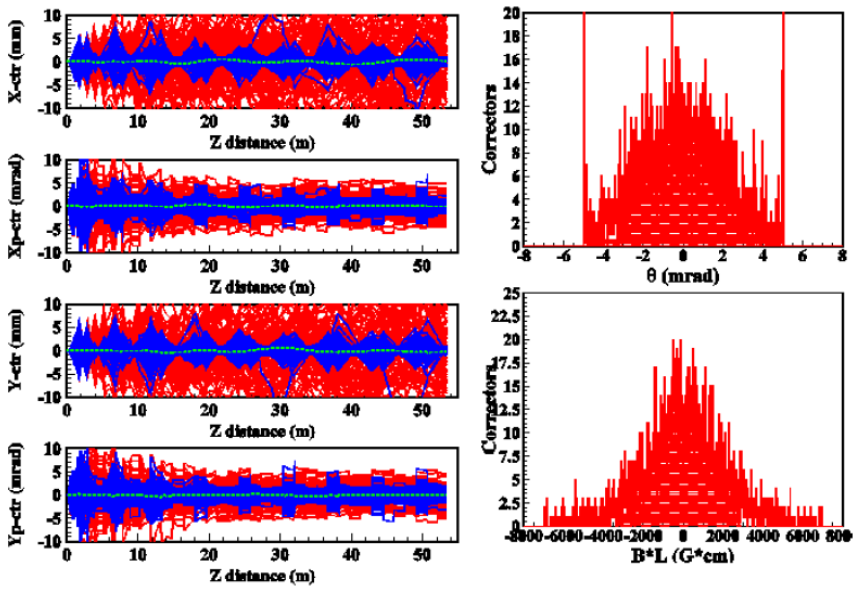


Error and correction simulation results for error sets 2 & 3.

For error set no.2



For error set no.3



Left: **Beam centroids** before (red) and after correction (blue).

Right: Corrector strength in mrad and the corresponding magnetic field integral in G*cm.

⟶ Max.: 8000 G•cm

A summary of error and correction simulation

Beam loss before and after correction

Error set	Fraction of lost beam before correction	Fraction of lost beam after correction
1	3×10^{-7}	0
2	5×10^{-7}	1×10^{-7}
3	5%	0

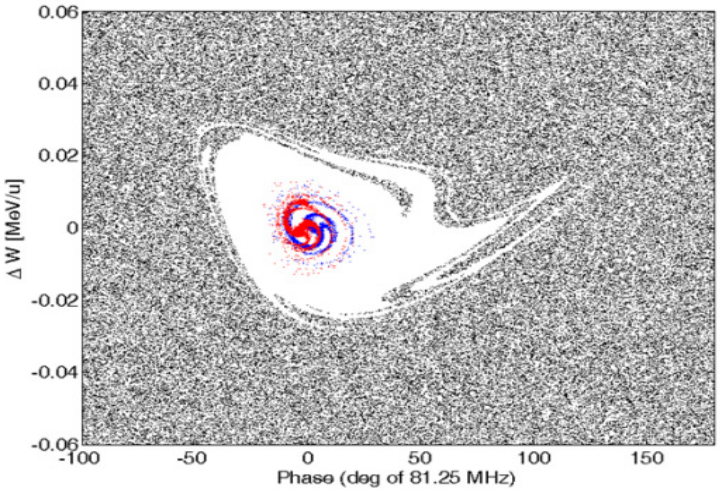
•**Error set 1 (nominal)**: after corrections, no failed seeds or beam loss.

•**Error set 2 (rf errors doubled):** A single macro-particle was lost longitudinally by leaving the linac acceptance before it is intercepted by an aperture. This single-particle loss measures the size of longitudinal acceptance.

•**Error set 3 (misalignment errors doubled)** : After adjusting the correction scheme for the lost seeds, no beam loss was observed.

Comparison of longitudinal acceptance

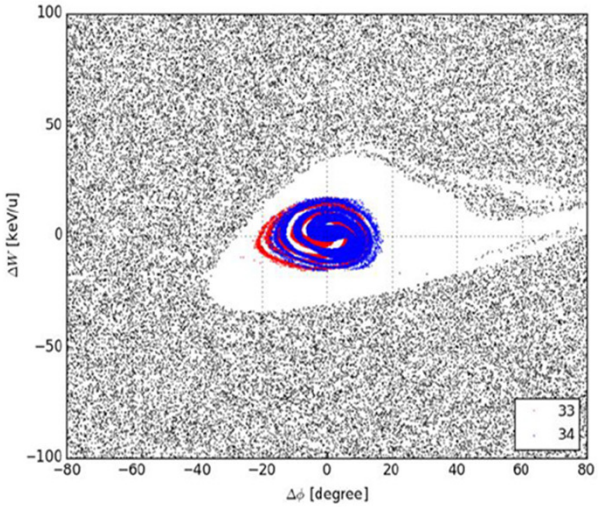
Baseline design



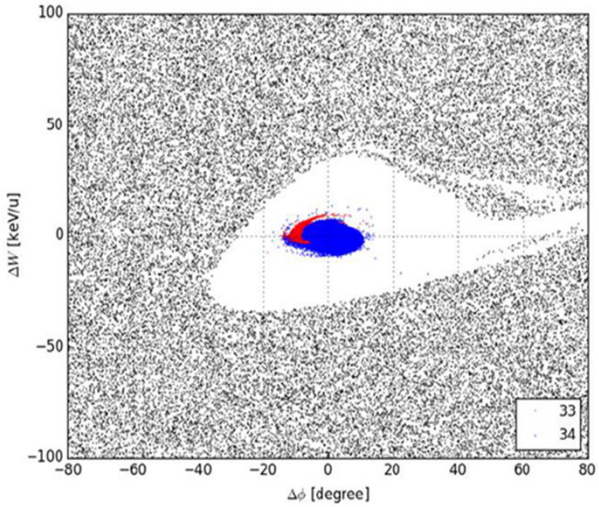
Modification of starting φ_s from -90º to -60º with modification of the first two or three sections of the current RFQ

→ The RFQ "filters" the longitudinal phase space formed by the MHB producing a significantly smaller emittance.

Alternative design



With RFQ of baseline design



With **modified** RFQ design

Cryogenic loads of an alternative design

Cryogenic heat loads for 2.0 K and 4.4 K operation for the new design

T_{op}	Cryomodules	Distribution	Total at 4.4 K
2.0 K	435 W	355 W	2.64 kW
4.4 K	985 W	355 W	1.34 kW

- The new design assumes to operate QWR1 & QWR2 at 4.4 K.
- The capacity of cryogenic plant considered is **2.5 kW at 4.4 K (4.2 kW for the current baseline design**.)

Concluding remarks

- RISP is fully funded and plans to be completed at the end of 2021.
- The beam optics for the current baseline design was accepted in 2013.
- The number of cavity and cryomodule in the current design of the pre-stripper linac is considerably larger than the that of ANL design performed in early 2016.
- The optics study for the ANL design showed both acceptance and tolerance of the linac lattice are acceptable.

Institute for Basic Science

DAEJEON Metropolitan City

Bid for the Organization of

58th ICFA Advanced Beam Dynamic Workshop on High Intensity and High Brightness Hadron Beam

HB 2018

Daejeon, KOREA

How to reach Daejeon

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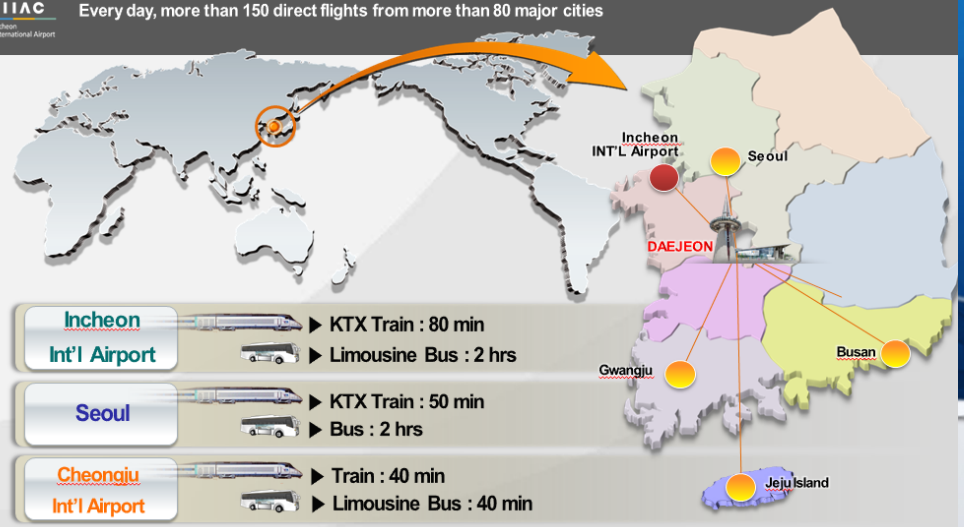

Incheon Int'l Airport	▶ KTX Train : 80 min	▶ Limousine Bus : 2 hrs
Seoul	▶ KTX Train : 50 min	▶ Bus : 2 hrs
Cheongju Int'l Airport	▶ Train : 40 min	▶ Limousine Bus : 40 min

DCC Daejeon Convention Center

Welcome to Daejeon, Korea in 2018!

- Location : SMART City, Doryongdong Yuseong-gu, Daejeon
- Area : Building 9,558m2, Total Space 29,512m2
- Levels : Different 5 levels
- Accommodation : 5-star hotel(300 rooms), youth hostels(100 rooms), guest house(80 rooms)
- Other facilities : KOTREX (KOTRA Exhibition Center, Daejeon), Expo Park, Daejeon Culture and Arts Center, Municipal Museum of Fine Arts , Hanbat Arboretum etc

Accommodations

Hanok(Korean Traditional House) Village

Tour of Ancient Baekje Dynasty (B.C.18~A.D.660)