Status of
the RAON Heavy Ion Accelerator Project

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RAON Site

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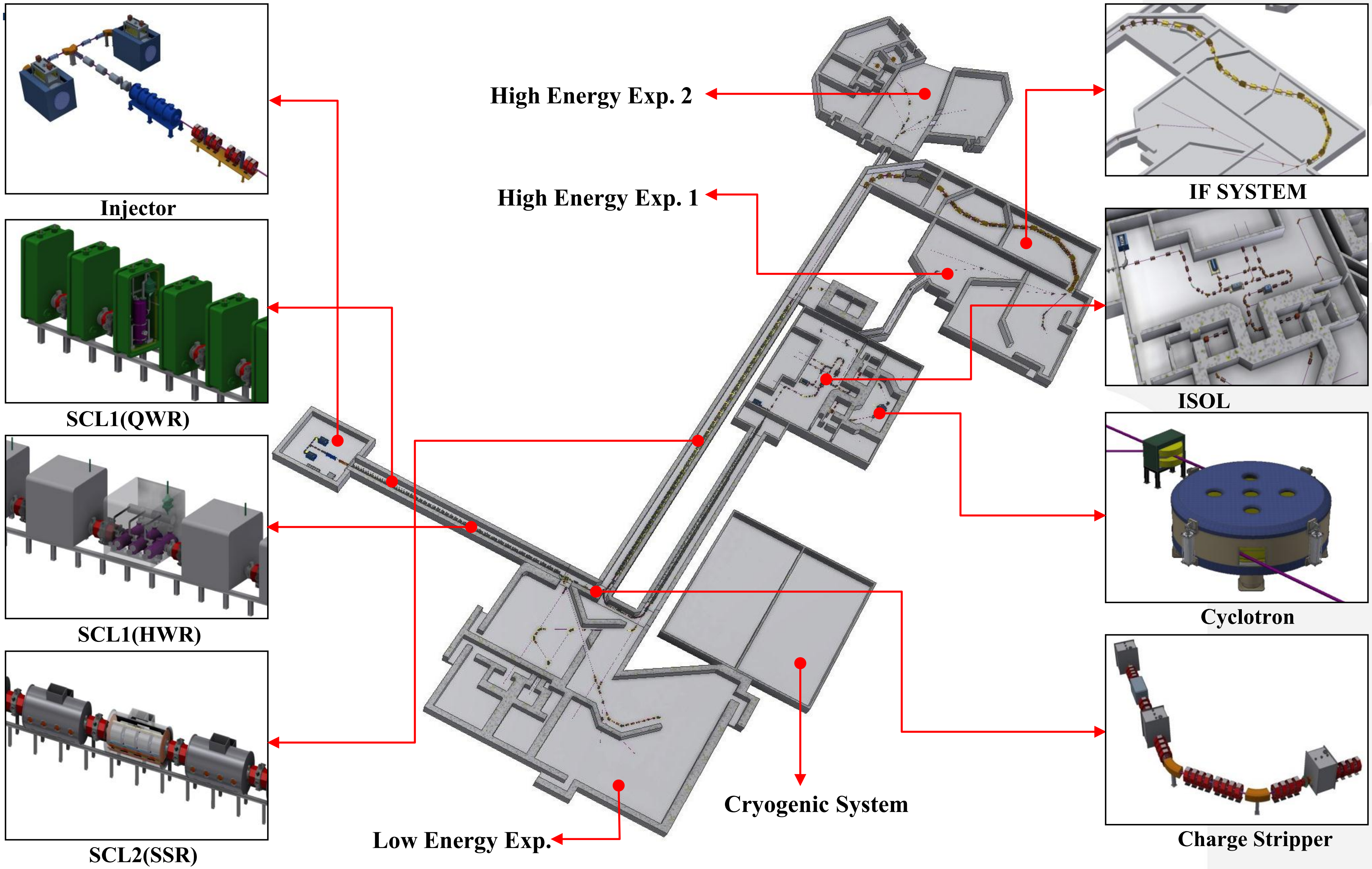
Institute for Basic Science

RAON Layout and Beam Parameters



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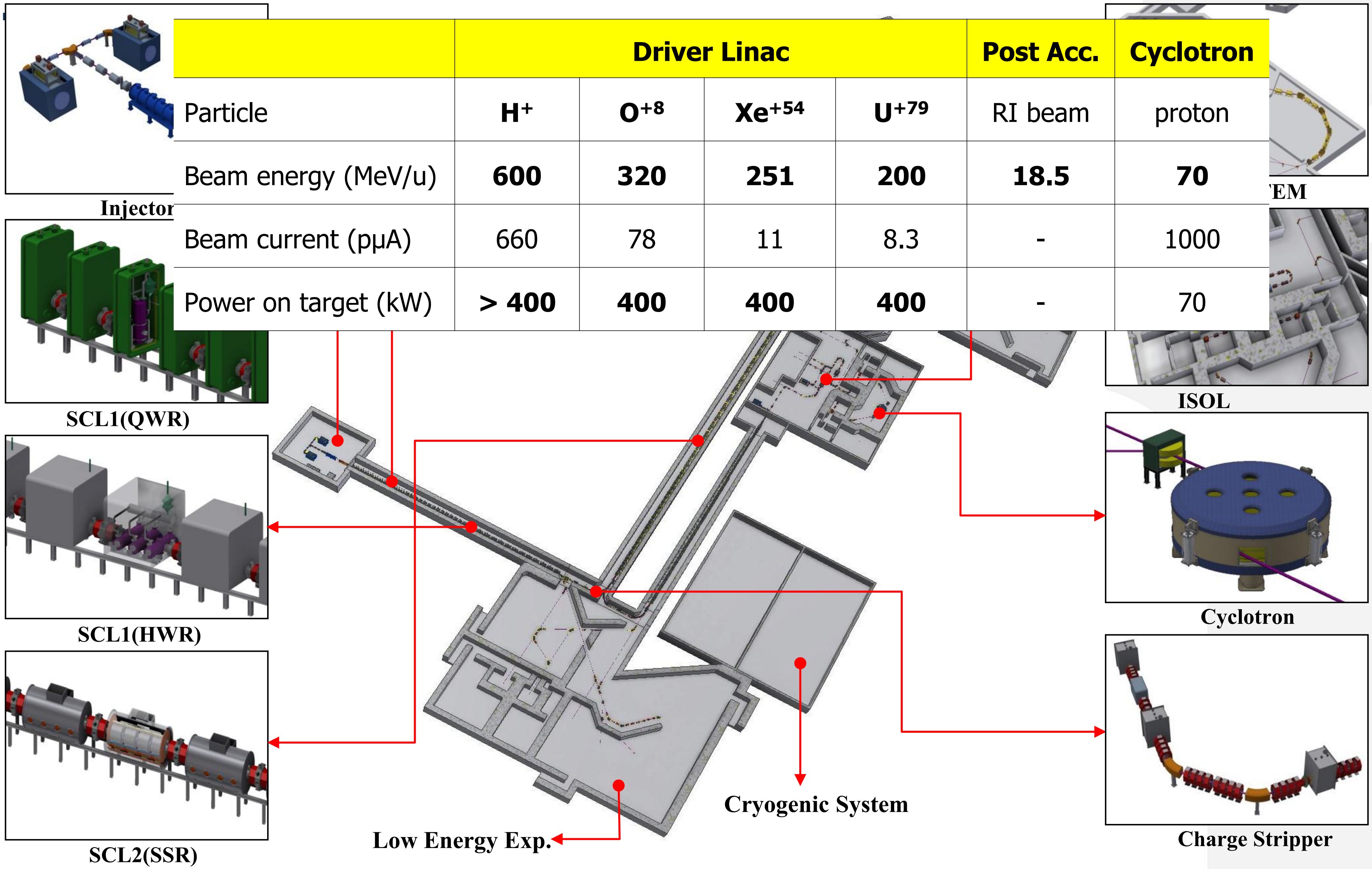
RAON Layout and Beam Parameters

	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

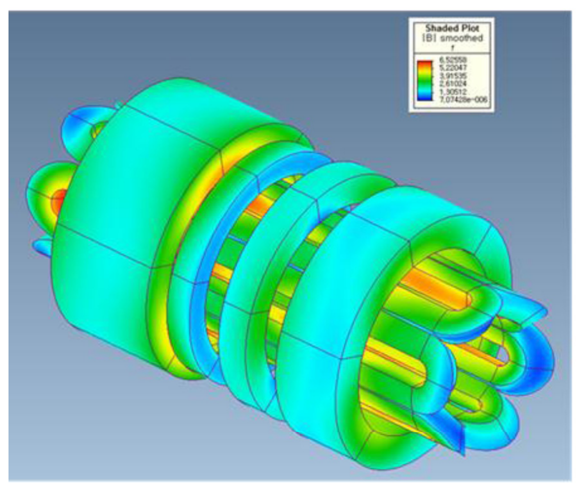


Progress of Accelerator Systems

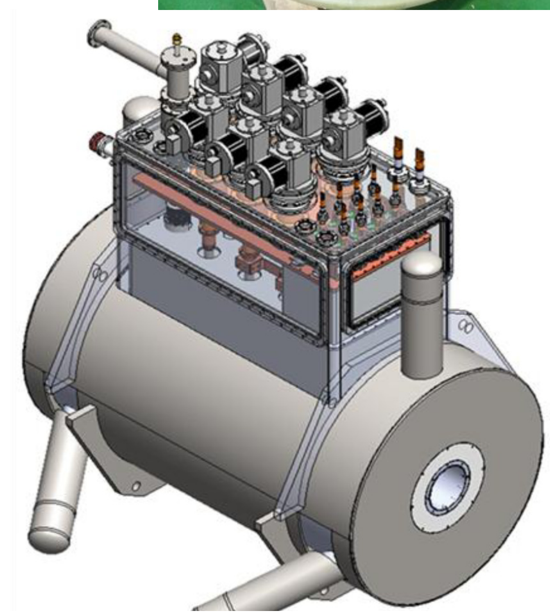
28 GHz ECR Ion Source

- Superconducting sextupole and solenoid prototypes were tested and achieved > 30% margin.
- Superconducting magnet assembly (sextupole + 4 solenoids) was completed.
- Cryostat fabrication is in progress and test will be performed.
- Preparing for beam test in late 2014.

Cryostat fabrication



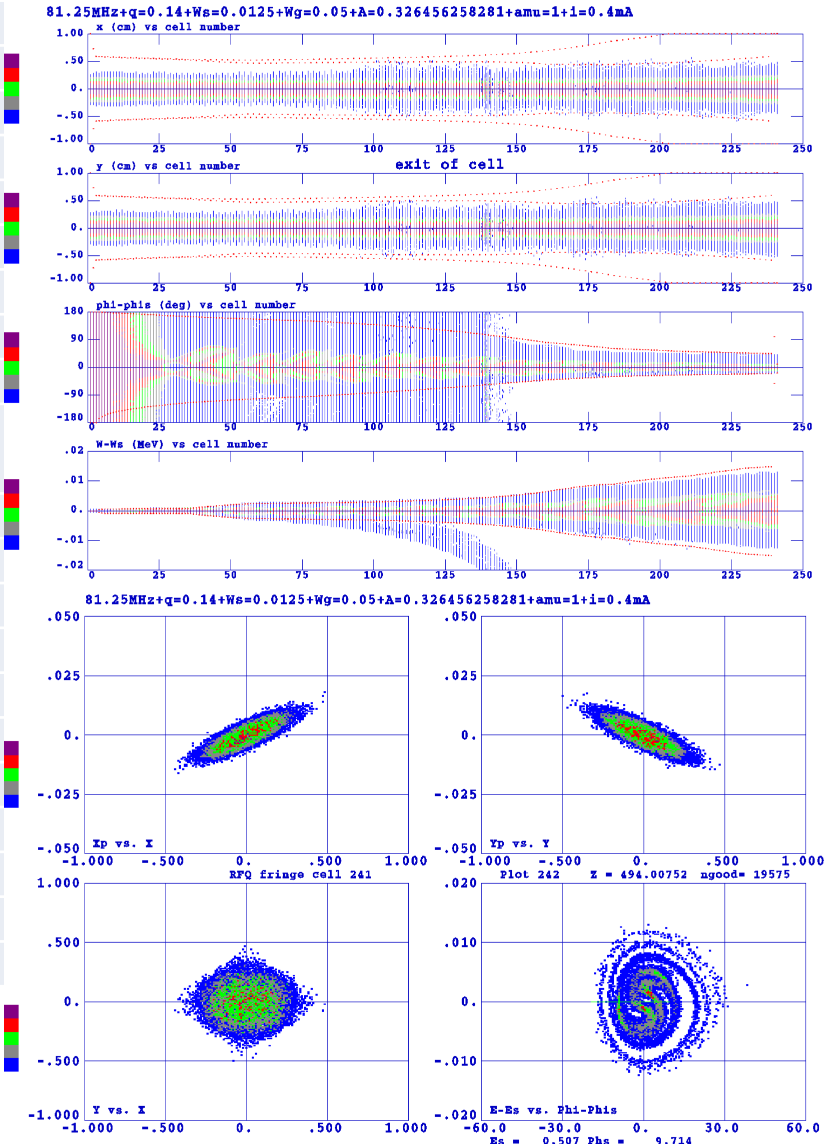
B_{inj}= 3.5 T, B_{ext}= 2.2 T,
B_r= 2 B_{ecr}, B_{min}= 0.7 T



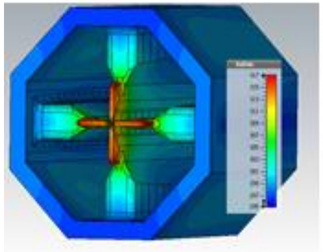
Six 4K cryocoolers,
One single stage cryocooler

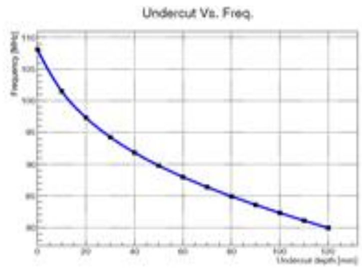
RFQ design parameters

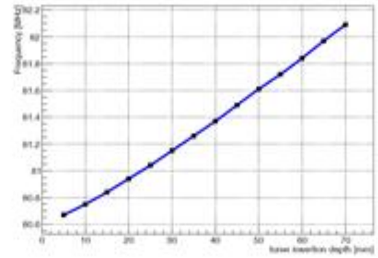
PARAMETER	VALUE
Beam Properties:	
Frequency	81.250 MHz
Particle	H^{+1} to U_{238}^{+33}
Input Energy	10 keV/u
Input Current	0.4 mA
Input Emittance: transverse (rms, norm)	0.012 .cm. mrad
Output Energy	0.507 MeV/u
Output Current for 0.4mA in.	~0.39 mA
Output Emittance: transverse (rms, norm) longitudinal (rms)	0.0125 .cm. mrad ~26 keV/u-Degree
Transmission	~98 %
Structures and RF:	
Peak surface Field	1.70 Kilpatrick
Structure Power (for U_{238}^{+33})	92.4 kW
Beam Power (for 0.2mA each $U_{238}^{+33\&+34}$)	1.44 kW
Total Power	94 kW
Duty Factor	100%
RF Feed	1 Drive loops
Mechanical:	
Length	4.94 meter
Operating Temperature	TBD Degree C

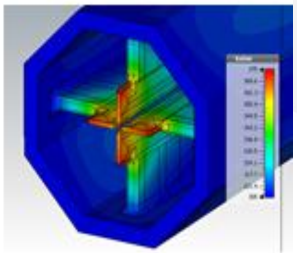


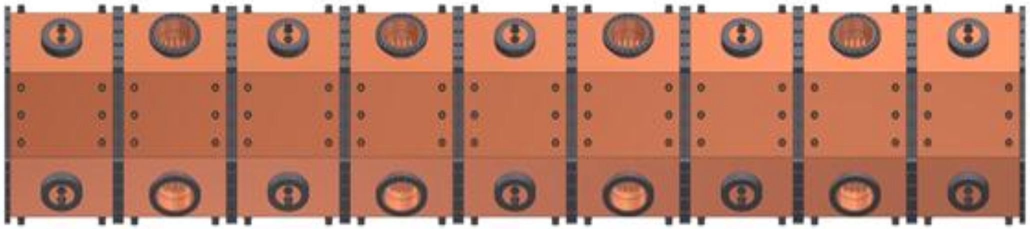
RFQ Engineering Design



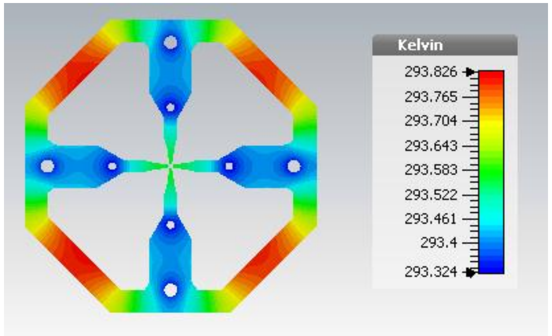




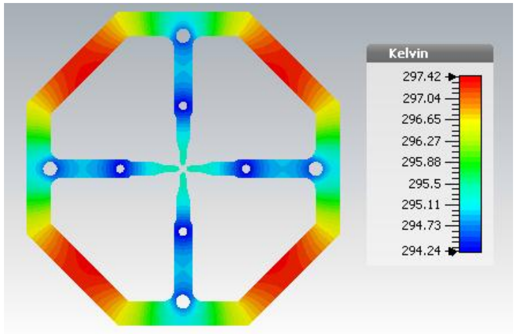




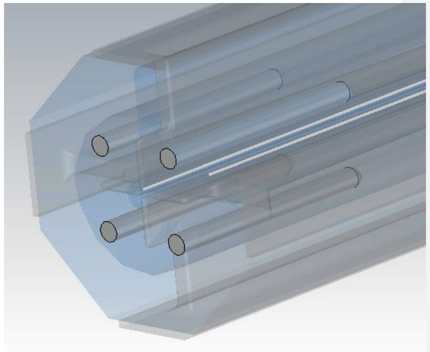
LE End



HE End



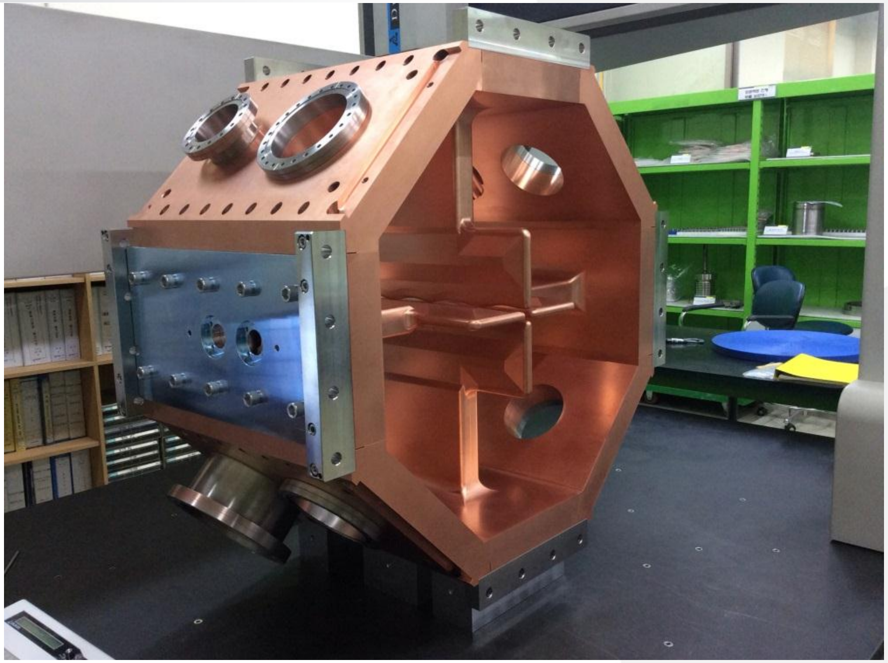
Mode separation 1.84 MHz

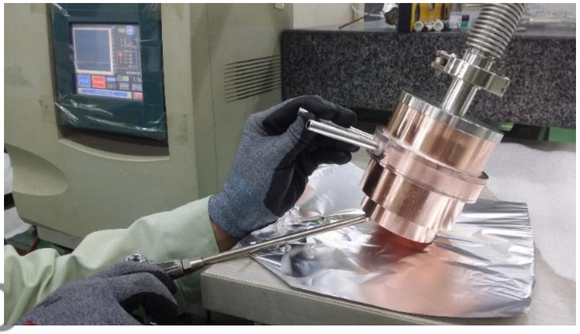


Technical design was completed (August 2013) and reviewed November 2013.

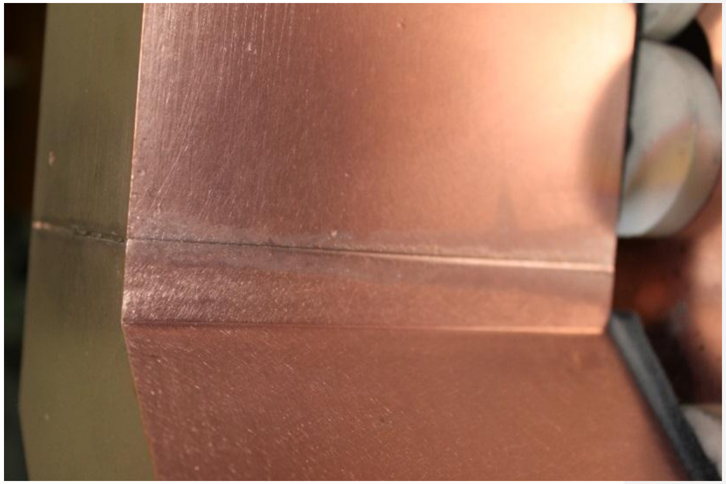
RFQ Prototype

- RFQ Design (2013.08)
- Design review (2013.11)
- RFQ Prototype
  - vane machining and 3D measurement
  - The 1st brazing failed (2014.04)
  - Assessed the related issues
  - Brazing procedure modified (2014.05)
  - Confirmed brazing procedure (2014.06)
  - RFQ prototype to be completed (2014.09)
- RFQ Prototype test
  - 15kW SSA, coupler, RCCS are ready





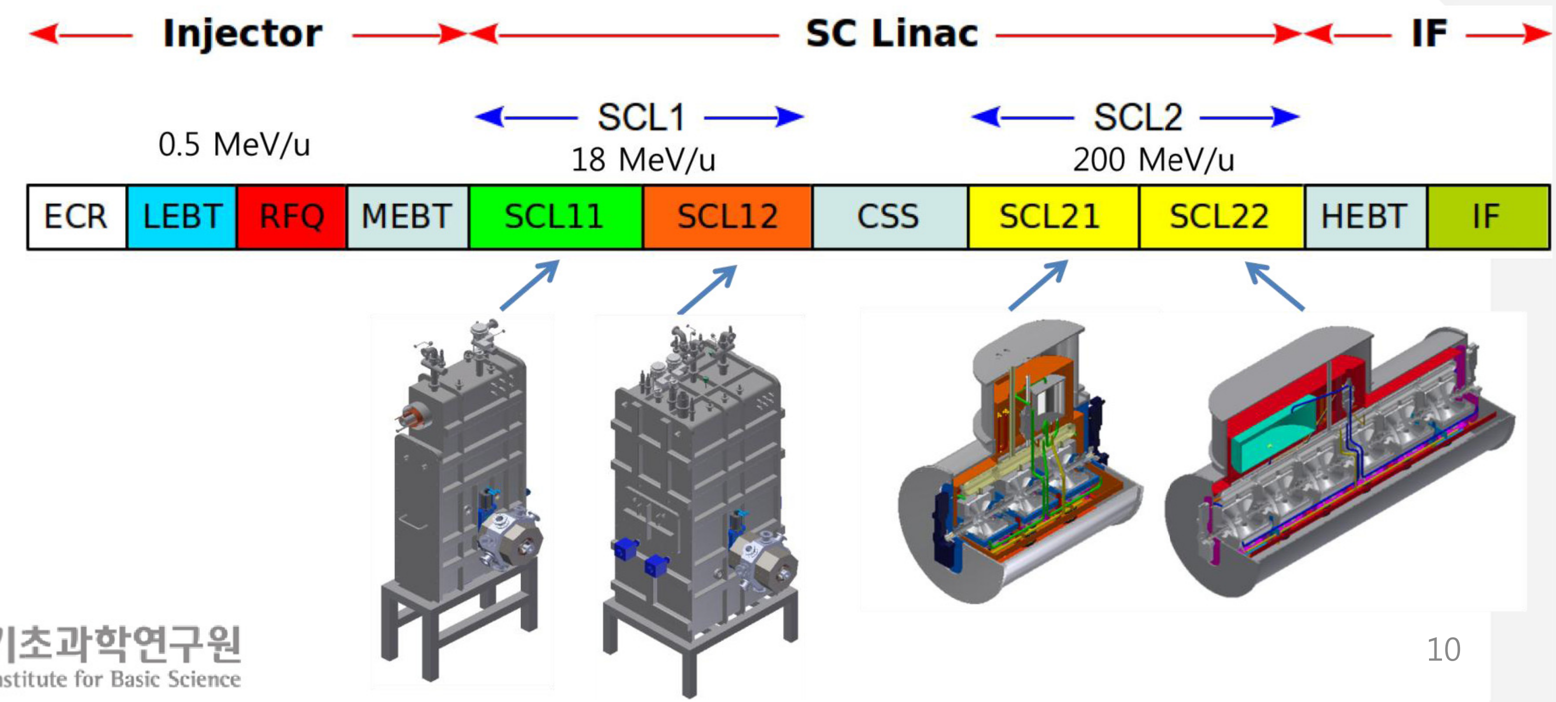
RFQ coupler
Leak test



Sample brazing test

RAON Superconducting Linac

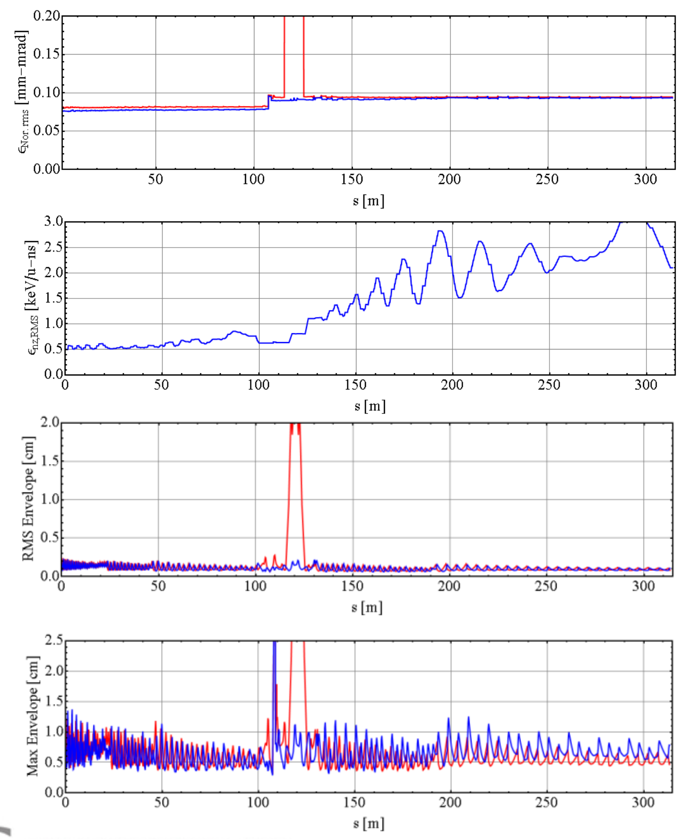
- RAON SCL is designed to accelerate high intensity beams.
- Focusing by NC quad doublets rather than SC solenoids.
- Optimized geometric beta of SC cavities (0.047, 0.12, 0.30, 0.51).
- Employs larger aperture to reduce beam loss (40 mm and 50 mm aperture).
- Prototyping of SC cavities and cryomodules is under way at present.



Beam Dynamics

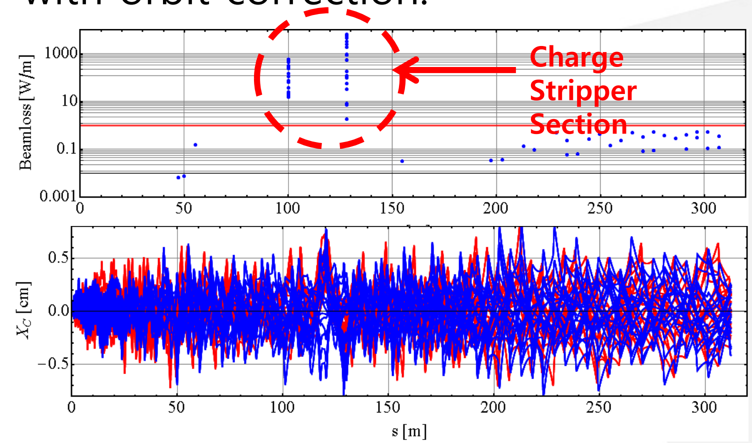
Lattice Design

- Transverse emittance increase is less than 20%.
- Longitudinal emittance is improved.



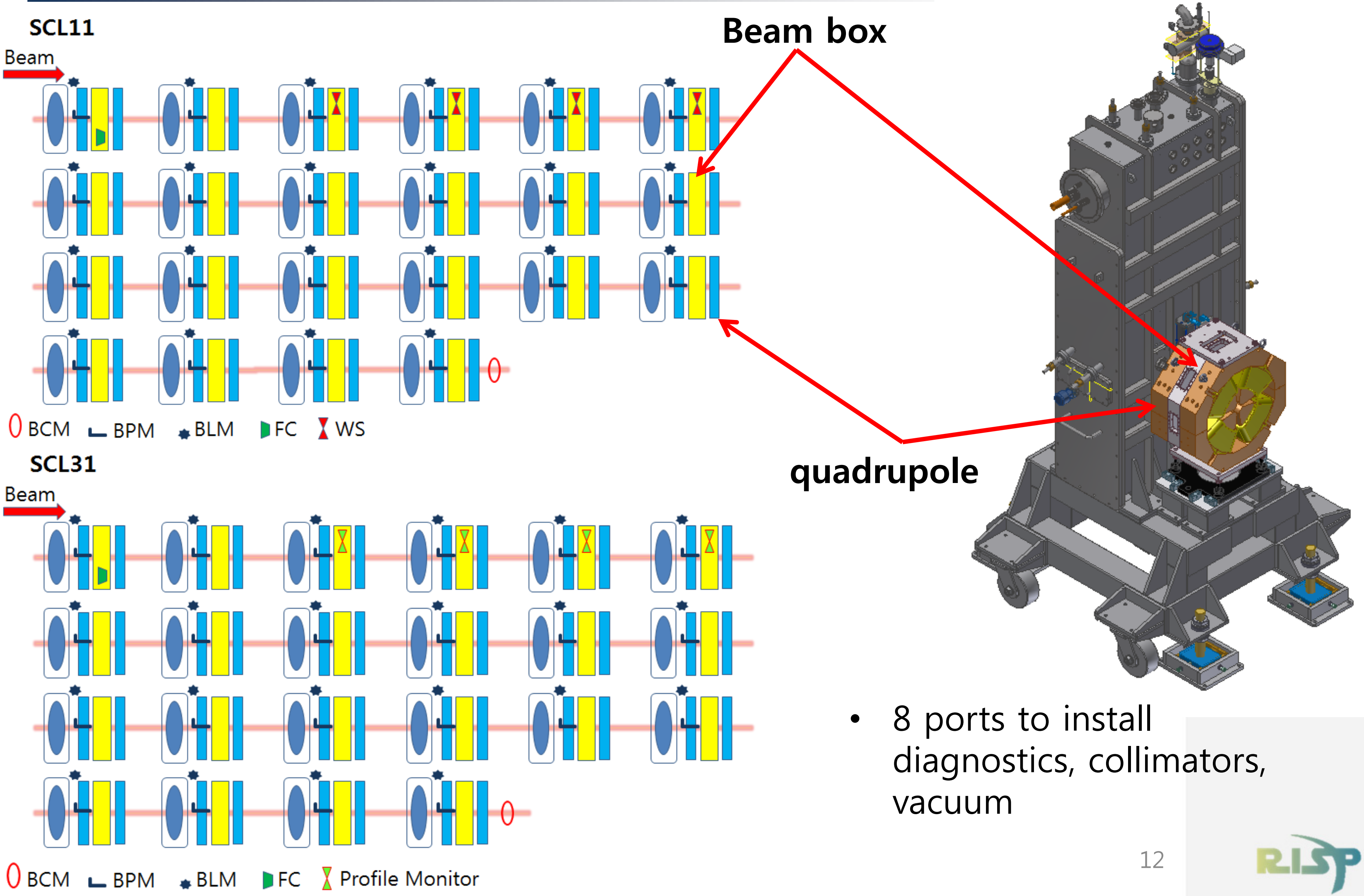
Machine Imperfection Effects

- Beam centroid exhibits max orbit deviation of 8 mm.
- It is expected that beam loss will reduce with orbit correction.



Item	Quantity	Error	Distribution
Cavity	Misalignment	1mm	Uniform
	Tilt	5 mrad	Uniform
	Voltage, phase	1%, 1°	Gaussian
Quadrupole	Misalignment	0.15mm	Uniform
	Tilt	5 mrad	Uniform
	Magnetic field	1%	Gaussian

Beam Diagnostics Configuration



- 8 ports to install diagnostics, collimators, vacuum

Superconducting cavity

RAON

QWR

HWR

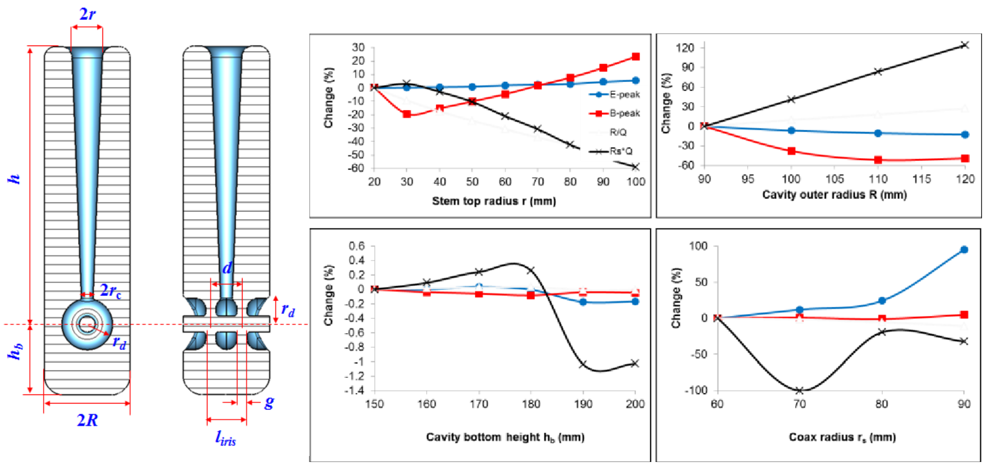
SSR1

SSR2

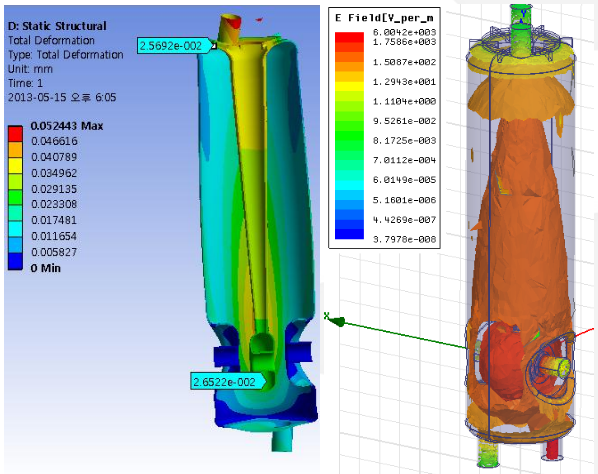
Parameters	Unit	QWR	HWR	SSR1	SSR2
β_g	-	0.047	0.12	0.30	0.51
F	MHz	81.25	162.5	325	325
Aperture	mm	40	40	50	50
QR_s	Ohm	21	42	98	112
R/Q	Ohm	468	310	246	296
V_{acc}	MV	0.9	1.3	1.9	3.6
E_{peak}/E_{acc}		5.6	5.0	4.4	3.9
B_{peak}/E_{acc}		9.3	8.2	6.3	7.2
$Q_{calc}/10^9$	-	1.7	4.1	9.2	10.5
Temp.	K	4.5	2	2	2

Design of SC Cavity

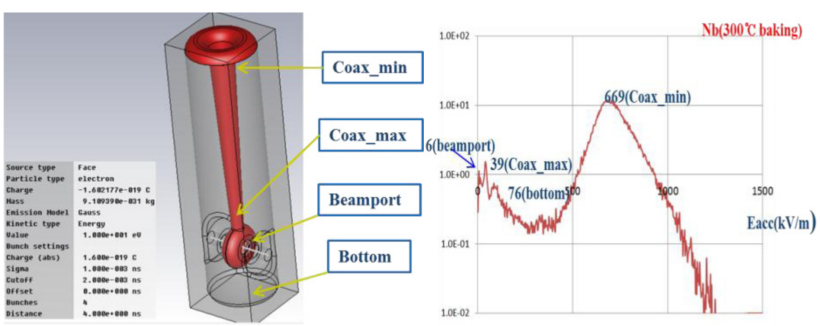
Optimization of Cavity Parameters



Mechanical analysis



Multipacting analysis



Frequency shift

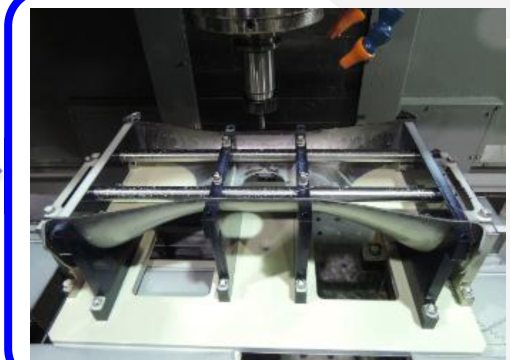
Frequency shift	QWR
Resonant Frequency	81.25MHz
Cavity length(upper)	-67.1kHz/mm
Cavity length(lower)	+1.3kHz/mm
Welding (0.58mm shrink)	+38.2kHz
EP/BCP (125um)	+267kHz
External pressure(Vacuum, L-He)	-4.6Hz/mbar
Cool down(293K→2K)	+203kHz
Lorentz Detuning	$-1.7Hz/(MV/m)^2$

SC Cavity Prototyping

➢CAVITY Manufacturing Process

MATERIAL INSPECTION

DEEP DRAWING



MACHINING

3D SCAN (CMM)

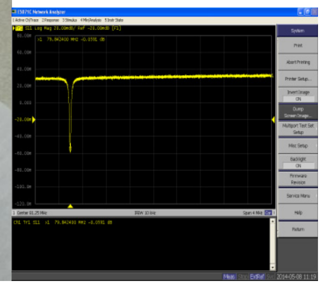
BCP

EBW

SC Cavity Prototyping

QWR Final EBW

Date	Cutting length	Resonant Frequency
5.20	-2mm	80.85MHz(-67kHz/mm)
5.23	-0.2mm(사선 가공)	80.83MHz
5.23	Upper end +center +outer 용접	80.92MHz(+90kHz)
5.27	Lower end 용접	80.933MHz(+10kHz)



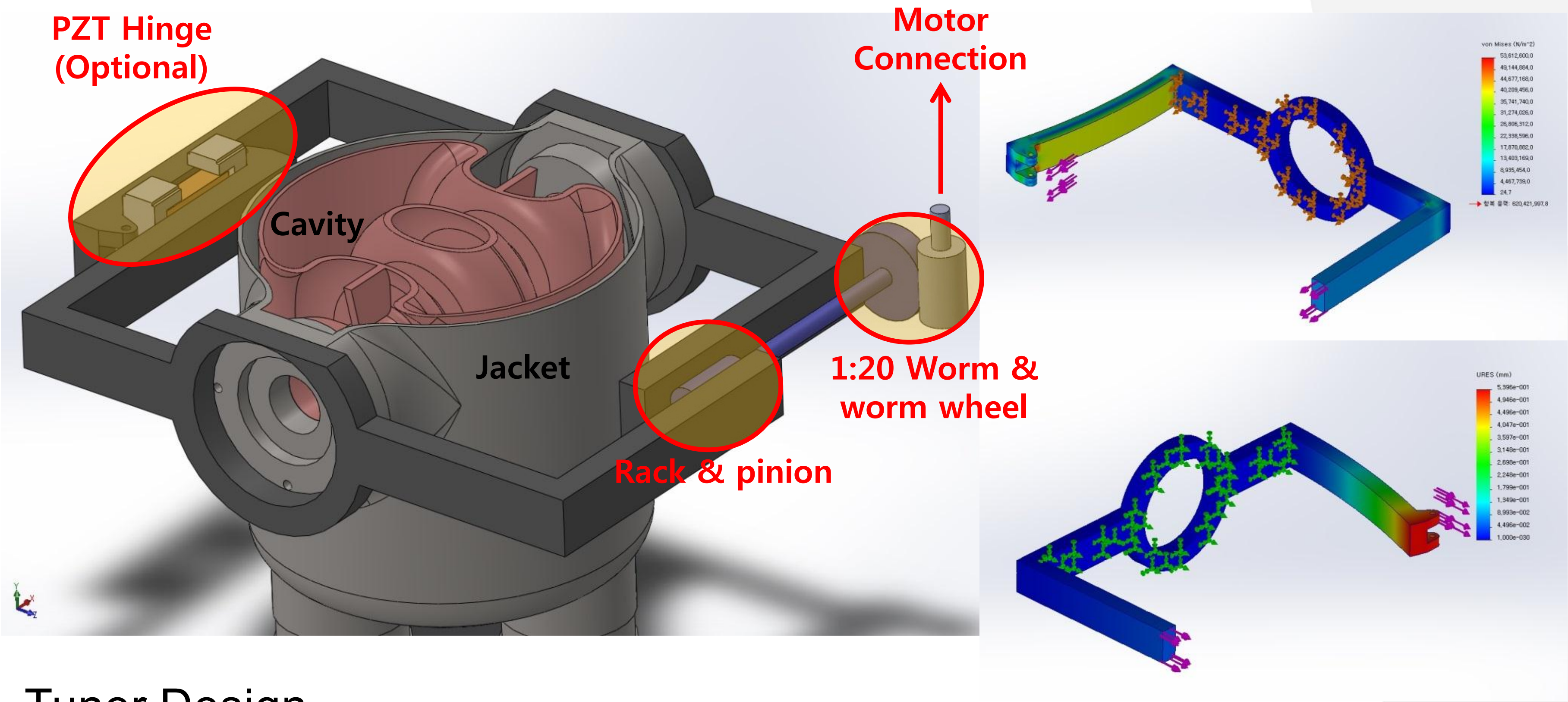
HWR Final EBW

SSR1 Clamp-up Test

SSR2 Clamp-up Test

Prototype superconducting cavities are fabricated through domestic vendors.

Tuner Prototyping

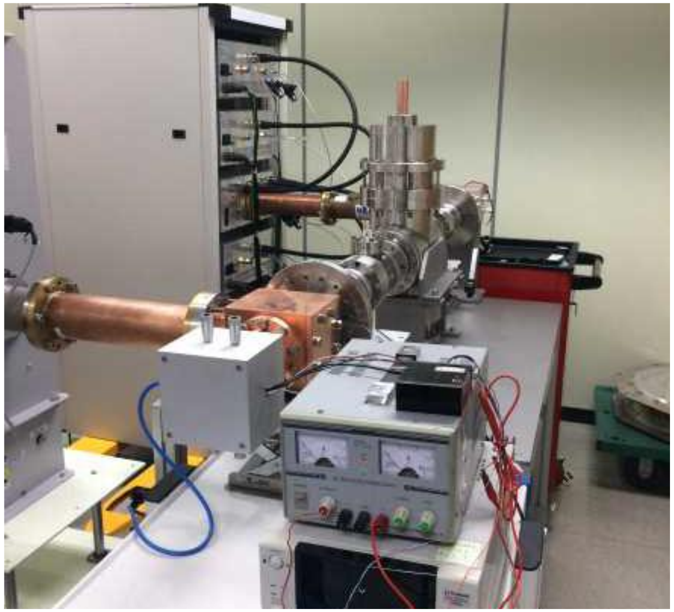


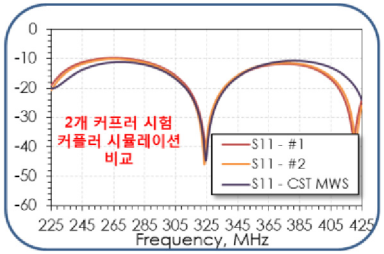
Tuner Design

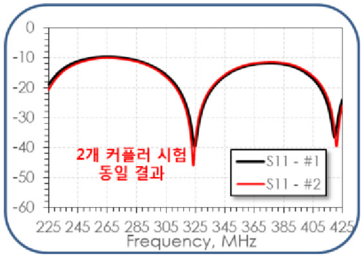
- Lever (1:2~2.5) & Worm-worm wheel (1:20) mechanism – MAX 1:50
- Vacuum Interface : Rotary Feedthrough
- Actuator : Step Motor & PZT

Coupler Prototyping

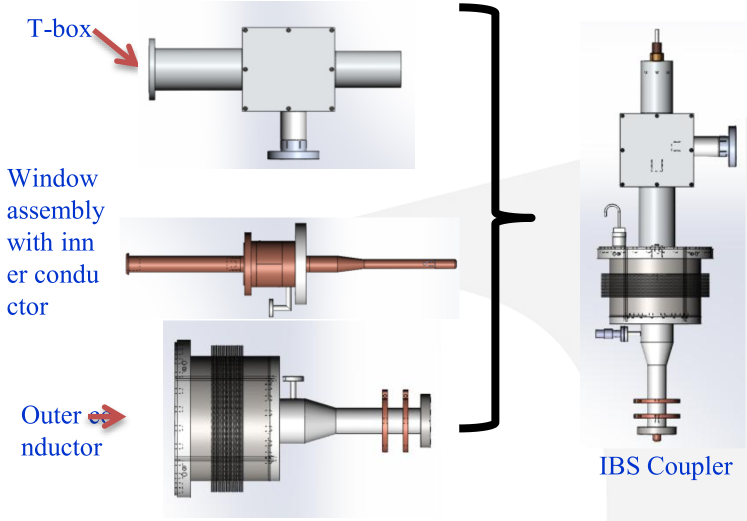
- Prototyping: SNU (Aug. 2013~Feb. 2014)
  - Performance test in progress
- Frequency: 325 MHz
- Nominal Power: 14.5 kW



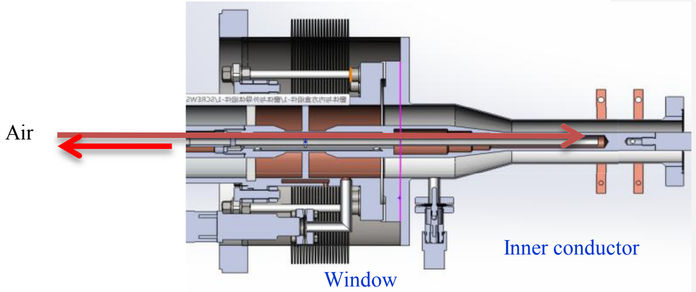




- Prototyping: IHEP (Mar. 2014~Dec. 2014)
- Frequency: 162.5 MHz
- Nominal Power: 3.7 kW

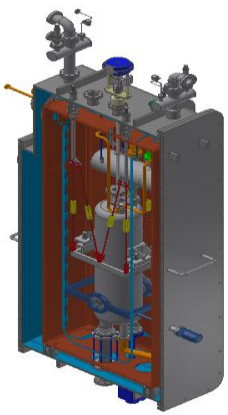


RF power :4kW → Window and Inner conductor with air cooling is available.

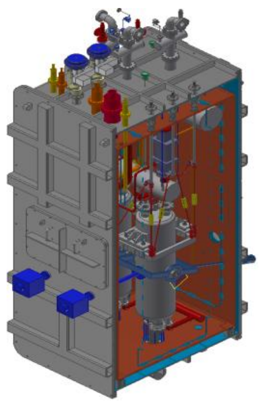


Cryomodule Prototyping

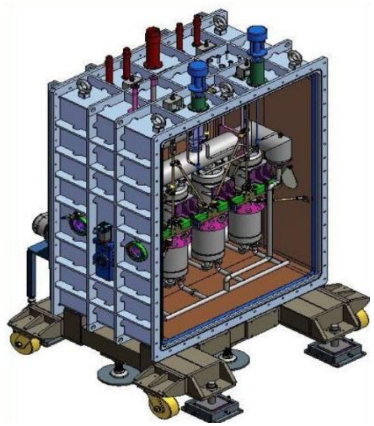
QWR Cryomodule



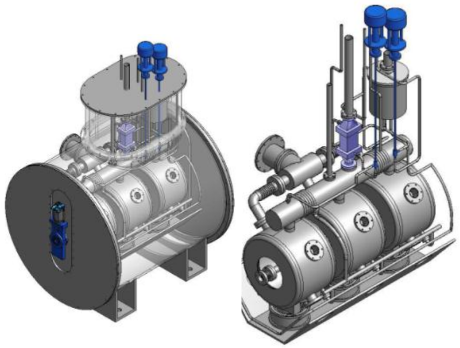
HWR#1 Cryomodule



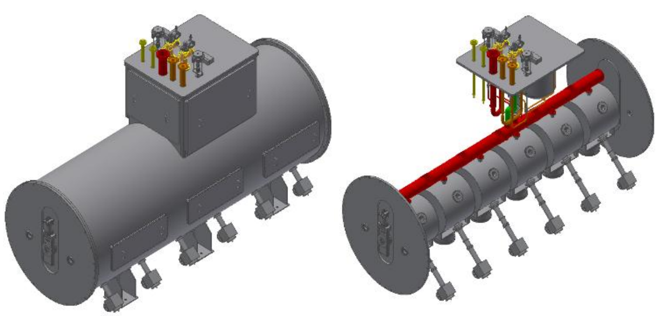
HWR#2 Cryomodule



SSR#1 Cryomodule



SSR#2 Cryomodule



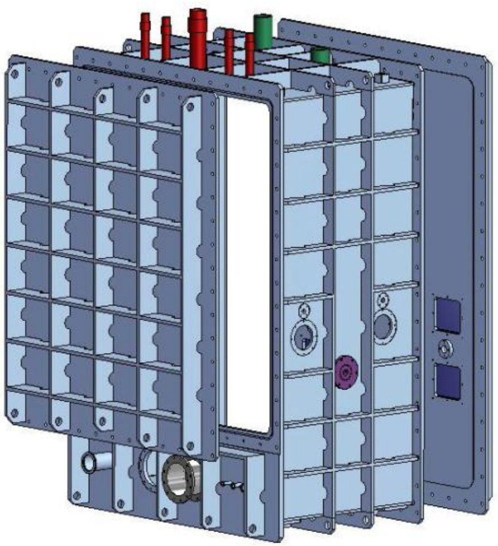
Module	Thermal load (4.5K equivalent, W) Without margin		
	Static	Dynamic	Total
QWR	227	532	760
HWR1	389	557	945
HWR2	682	1,459	2,141
SSR1	475	1,014	1,489
SSR2	790	5,009	5,800
Total	**2,563**	**8,572**	**11,135**

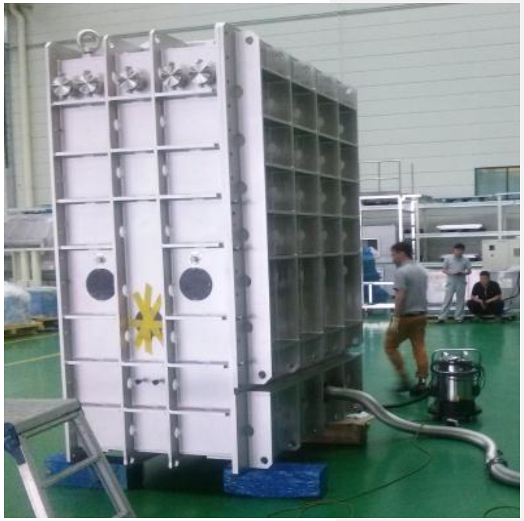
tolerance	unit
X	±0.25mm
Y	±0.25mm
Z	±0.5mm
Pitch	±0.1˚
Yaw	±0.1˚
Roll	±0.1˚

Cryomodule prototyping in progess

HWR#2 Cryomodule
Vac. chamber Ass'y

Vacuum chamber

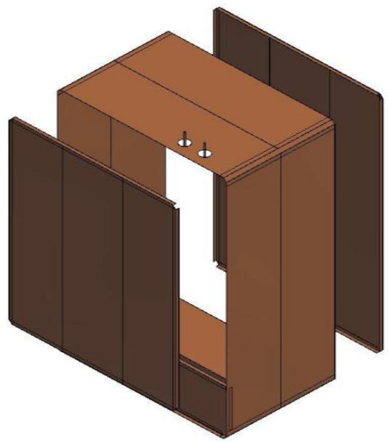




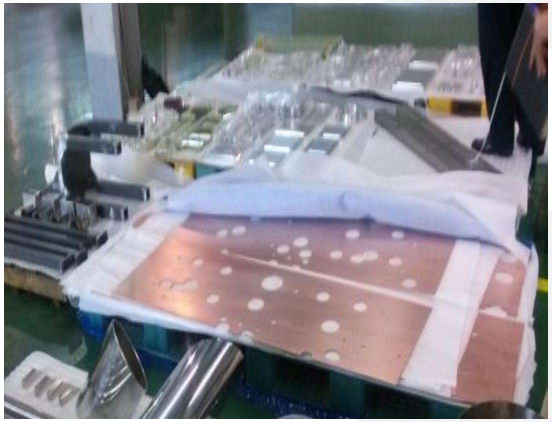
Cryomodule prototyping in progess

Cryomodule components fabrication

Thermal shield

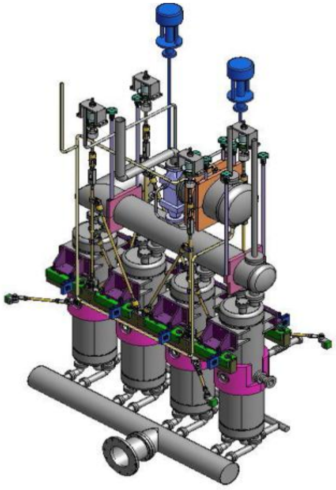


Cryomodule components



Thermal shield parts

Cryogenic pipe line



Cryogenic pipes

Dummy cavity and pipe parts

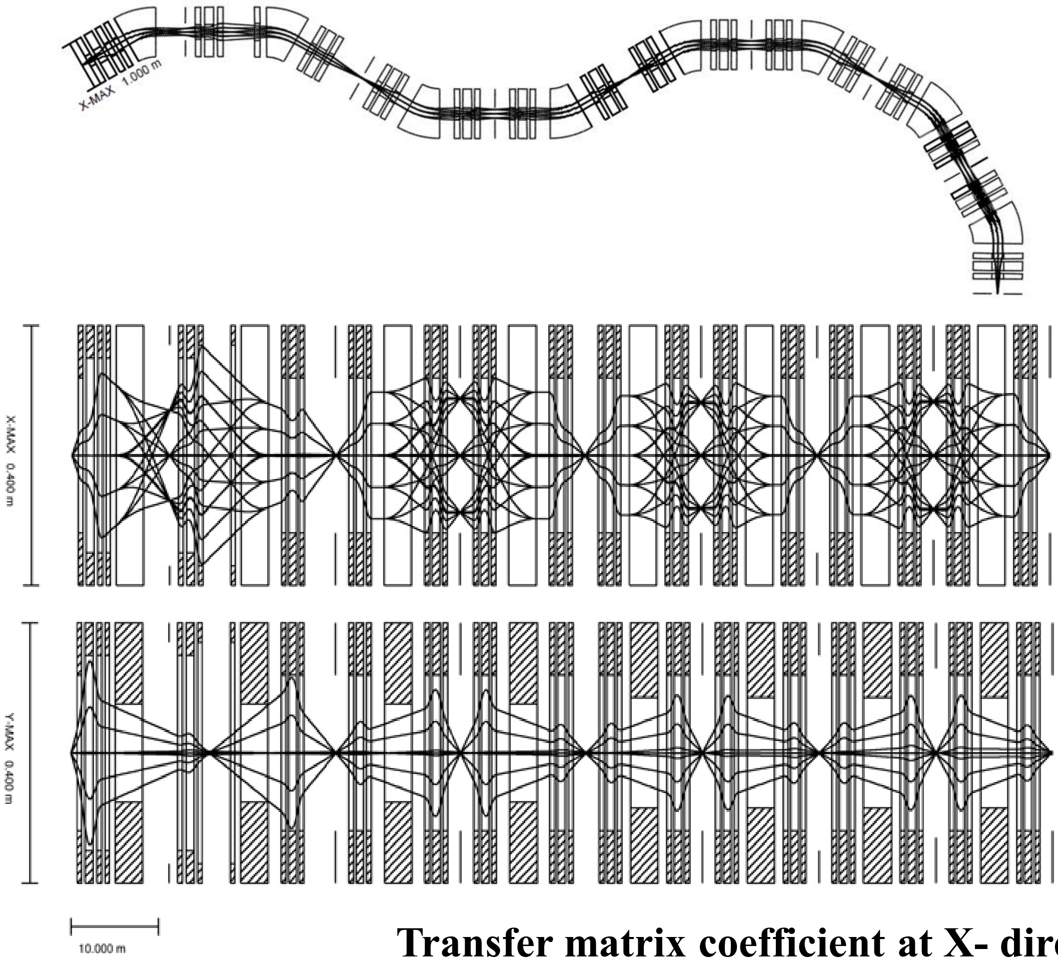
In-flight Fragment (IF) System

- U beam to C target generates various rare isotope beams.

- Separator's function is to separate rare isotope beam of interest.
- Nonlinear term correction of IF Separator is undertaken.
- Technical design of Beam Dump is proceeding.

- HTS(High Tc Superconductor) quadrupole coil prototyping is in progress (in collaboration with KERI).
- LTS(Low Tc Superconductor) quadrupole prototyping is in progress.

IF System
First order optics of In-flight separator



Characteristics of In-flight separator

- Maximum magnetic rigidity: ~10 Tm
- Momentum acceptance: ± 3%
- Angular acceptance : ±40 mrad (H)
  ± 50 mrad (V)
- Focal plane
  Achromatic: F2, F4, F5, F7
  Momentum dispersive: F1, F3, F6, F8
  Doubly achromatic: F9
- Momentum resolving power
  pre-separator: 1140 at F1
  2280 at F3
  Main separator: 2600 at F6
  2600 at F8

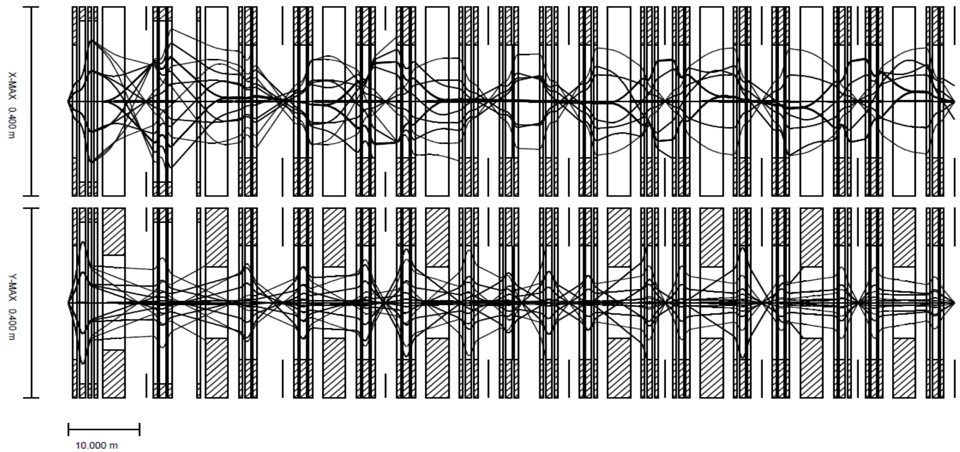
Transfer matrix coefficient at X- direction

	F1	F2	F3	F4	F5	F6	F7	F8
[X,X]	-2.08	2.18	-2.39	2.00	-2.37	2.00	-2.38	2.02
[X,D]	2.30	0.00	-2.92	0.00	2.71	0.00	2.77	0.00

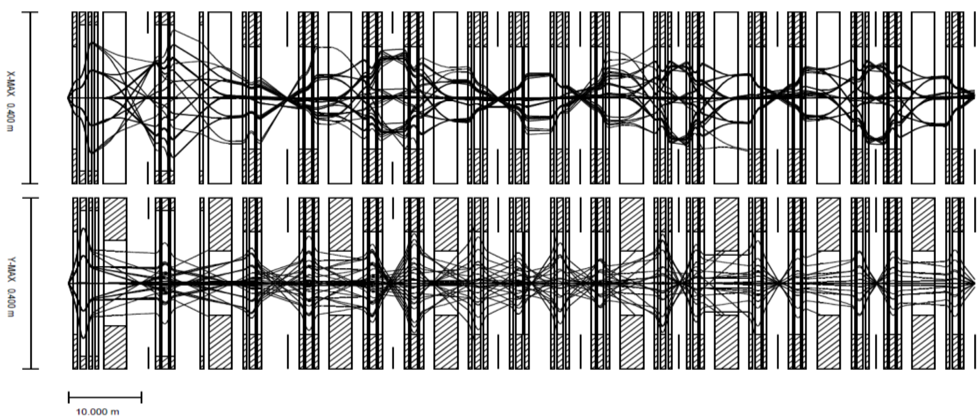
Second order optics of In-flight separator

High order correction

Before 2nd order correction

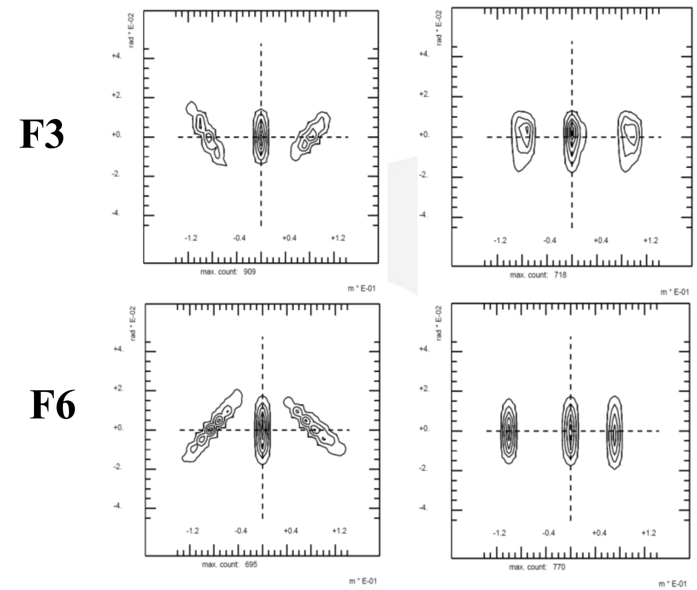


After 2nd order correction



Beam distribution in X–A phase space

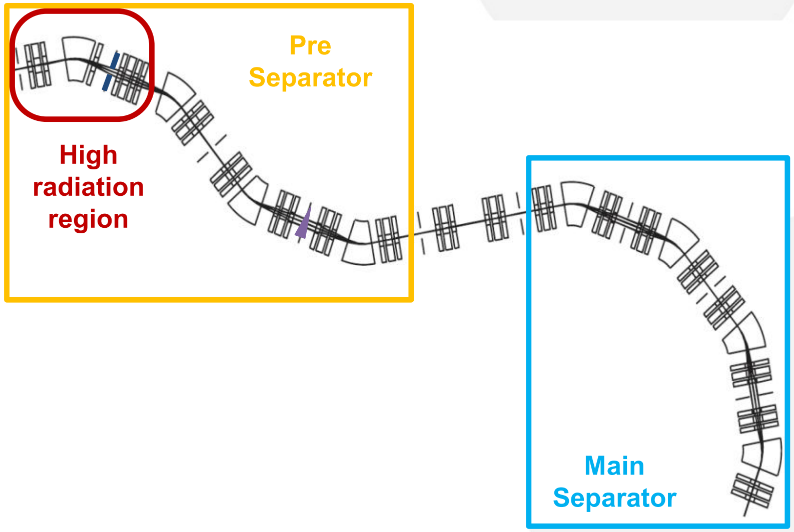
Before 2nd order correction | **After 2nd order correction**



	Tilt angle (degree)		
	F3	F6	F8
Before 2nd order correction	-87.7	88.2	88.8
After 2nd order correction	0	0.02	0.01

HTS Q-magnet

- In the target region, magnets are under the influence of high radiation.
- Magnets are subjected to high radiation heat loads, and it should be resistant to the radiation damage.



- Benefits of HTS magnets in Fragment Separator
  - Technical Benefits

    HTS provides large temperature margin – HTS can tolerate a large local and global increase in temperature caused by beam-induced heating.
  - Economic Benefits

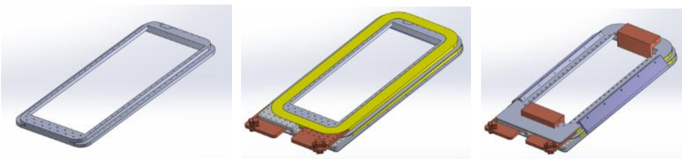
    Removing large heat load at higher temperature (~50 K) rather than at ~4 K (LTS) is more efficient.
  - Operational Benefits

    The temperature need not be controlled precisely. → more robust magnet operation.

HTS Q-magnet

• HTS Q-magnet prototype

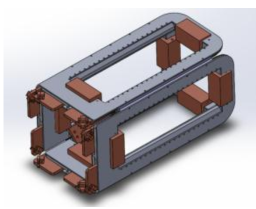
◆ An HTS coil for HTS Q-magnet



- bobbin, current terminal, cooling channel..
- Winding

◆ Full scale HTS coil for HTS Q-magnet

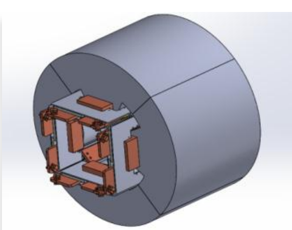
Design modification



- Manufacture of 4 HTS coils
- Full coil assembly
- Series connected coil

◆ HTS Q-magnet

Final design

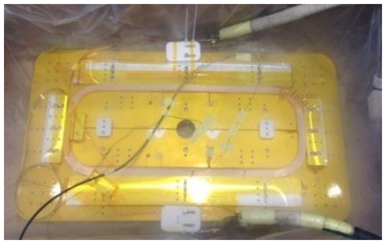


- Machining of iron yoke
- Coil-yoke-cooling channel interface (Thermal and Mechanical)
- Full system assembly

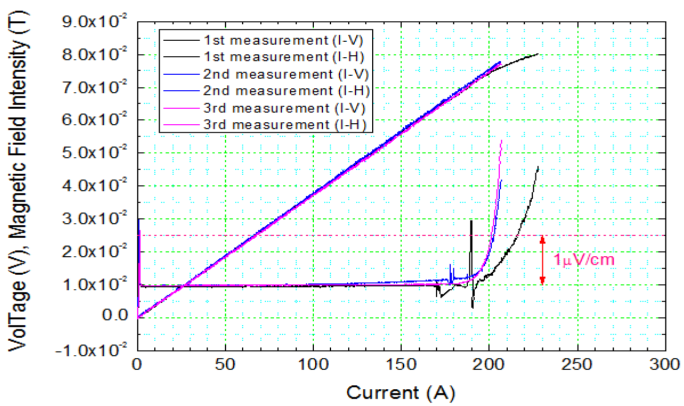
Design Parameters (HQs_R12)	
Aperture radius (mm)	120
Pole tip radius (mm)	130
Effective length (mm)	579
Yoke length (mm)	480
Field gradient (T/m)	15
Pole tip field (T)	1.95
Total current (kA)	121
Coil size (mm^2)	864 (36 mm x 12 mm x 2)
Current density (A/mm^2)	140
Turn number (N)	164
Operating current (A)	370
Critical current	640 A (SuperPower)
One turn length (m)	1.57/1.63
Total length of HTS tape (km)	2.25 (562 m / 1 coil)
Volume of coil (cm^3)	4028
B //c (T)	2.1
Field uniformity (%) (for 12^{th} harmonic order)	0.6%

HTS Q-magnet

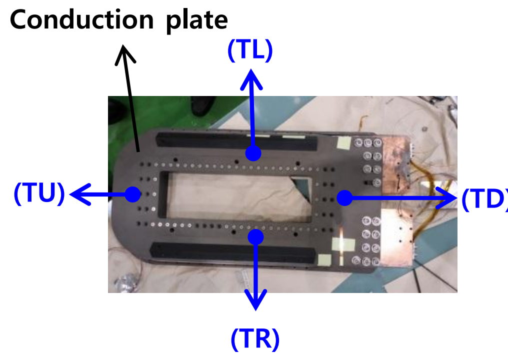
- **Test results of HTS coil prototype**



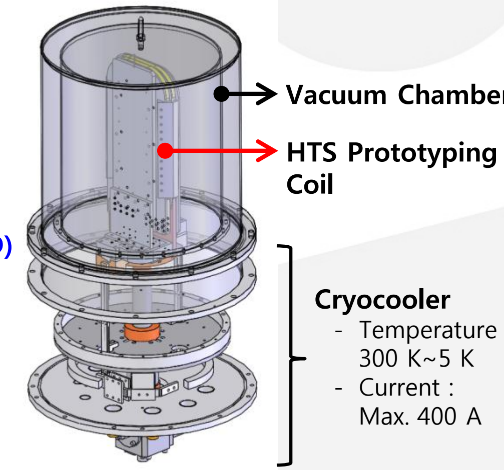
[HTS coil in liquid nitrogen for experiment]



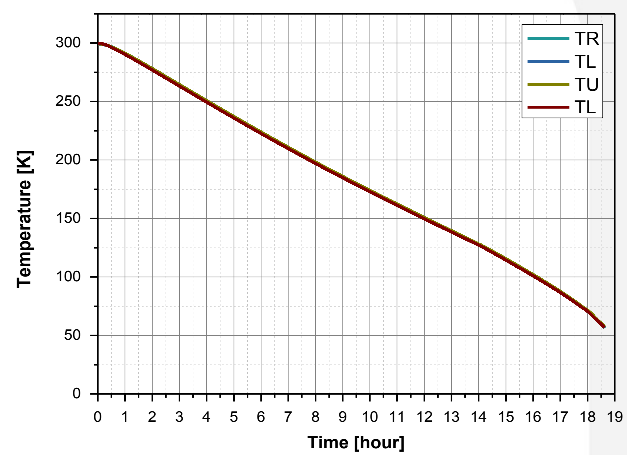
[Voltage and magnetic field during ramp-up]



[HTS coil for conduction cooling test and the position of temperature sensors]



[Conducting cooling system]

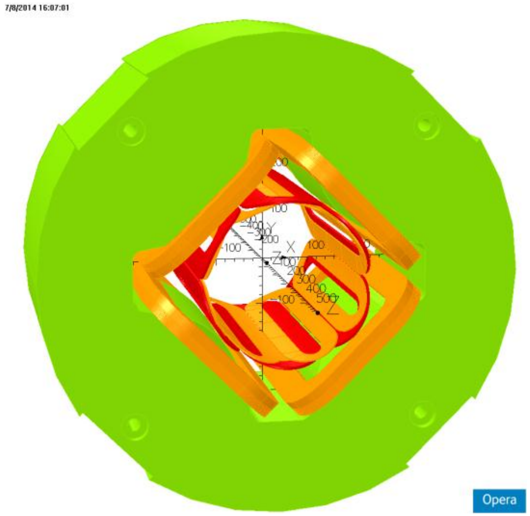


[Temperature traces at cool down]

- Measured critical current = 202 A (expectation = 207 A)
- No Ic degradation observed after several times of cool-down and warm-up.
- Metal (stainless steel) insulator has enough resistance to prevent the current flowing across the insulator in normal state.

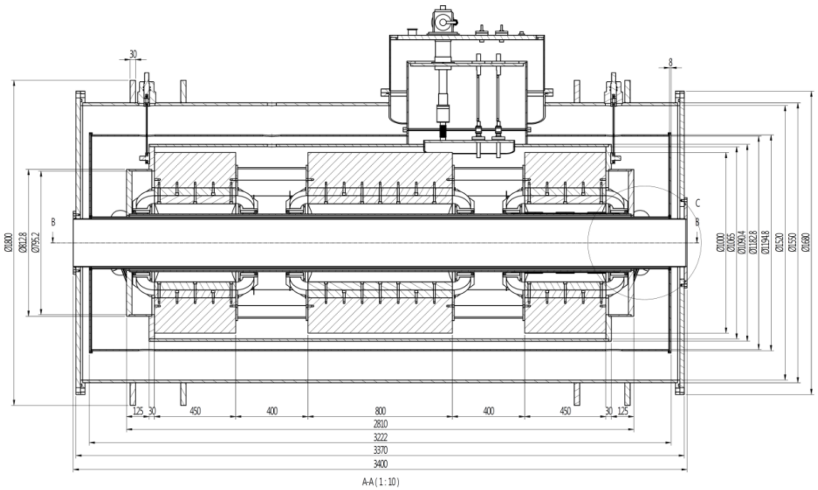
- Cool down time : about 18 hours (300 K → 50 K)
- Critical current tests at conduction cooling are in progress.

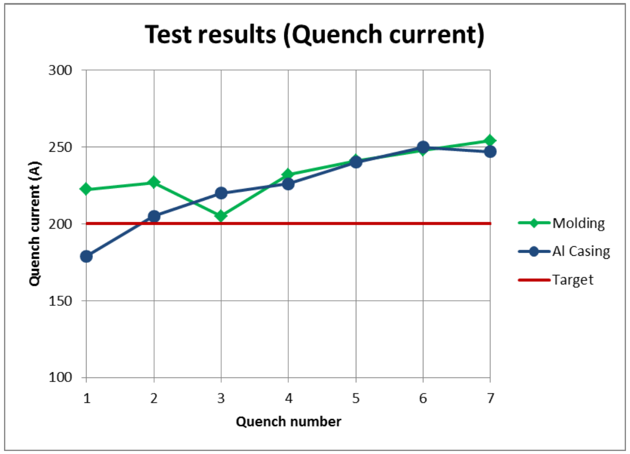
LTS Q-magnet



LTS Q-magnet with multi-pole coil

Parameters	LQ1 (2)
Pole tip radius	180 mm
Nominal length	550 (900) mm
Yoke length	450 (800) mm
Yoke diameter	1000 mm
Field gradient	15 T/m
Total current	~ 300 kA
Bmax in the coil	~ 4.1 T


LTS Q-magnet triplet cryostat design

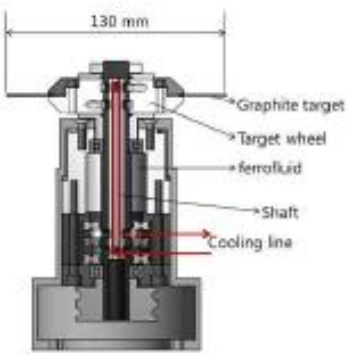


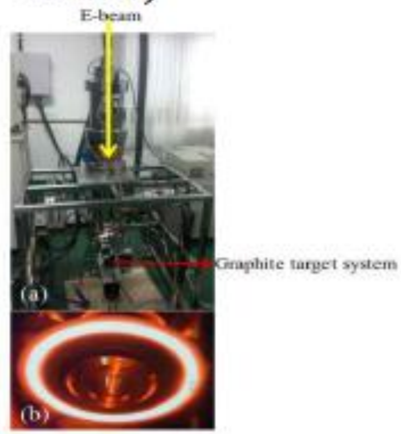
Quadrupole coil test result


Heat treatment & Ultrasonic examination

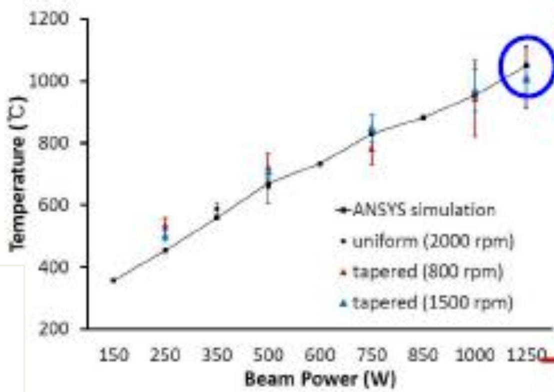
Graphite target for high-intensity beam

A single layer graphite target test (Max. power deposit: ~10 kW)





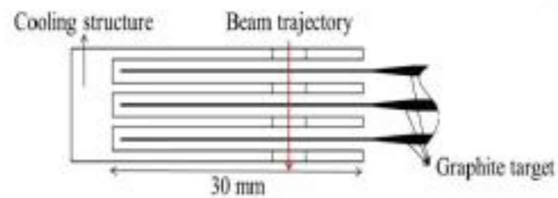
Use an electron beam at EB Tech Inc. (50 keV)

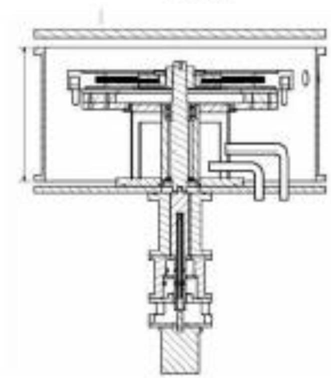


Beam power density: >

Measure with IR camera

Multi-lay target (~100 kW)



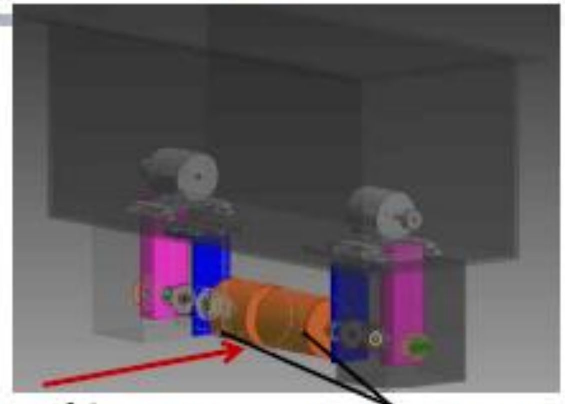


A test target (3 layer) → To be tested at BINP, Russia

Thermo-mechanical analysis with ANSYS: S. Hong et al., "Design and test of a graphite target system for in-flight fragment separator", NIM A752 (2014)

Beam Dump

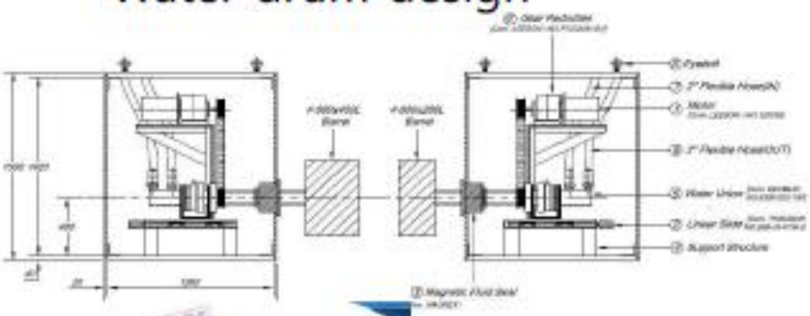
Max. power dissipation for design: 400 kW

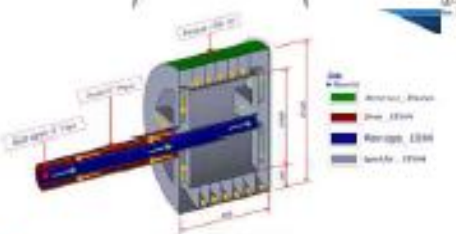


Pathway of isotope beam of interest

Rotating water drum

Water drum design

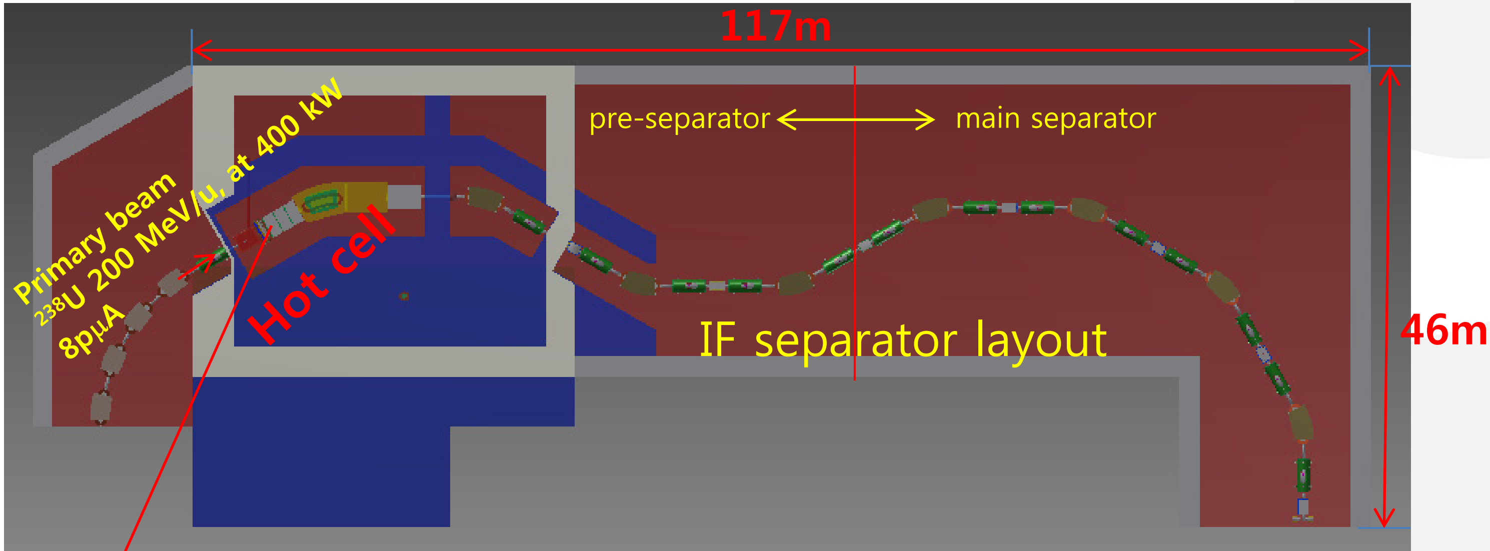


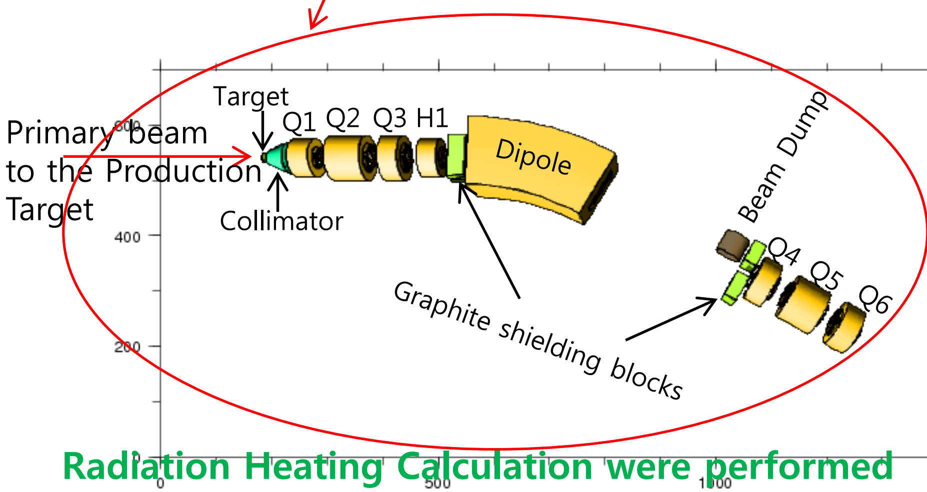


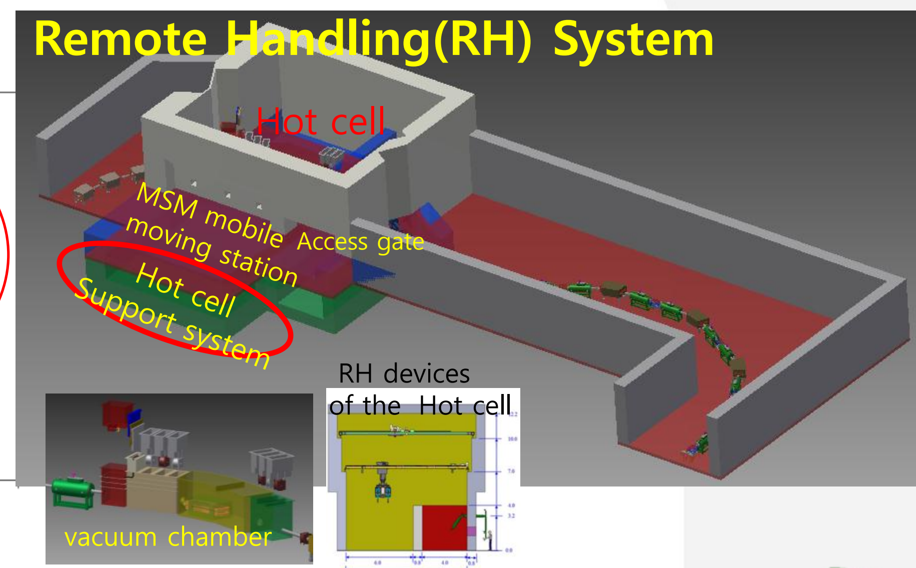
Beam dump design underway for FRIB (Thermal and radiation damage analysis on Ti drum)

May, 2014

Radiation Heating Calculation & Remote Handling System



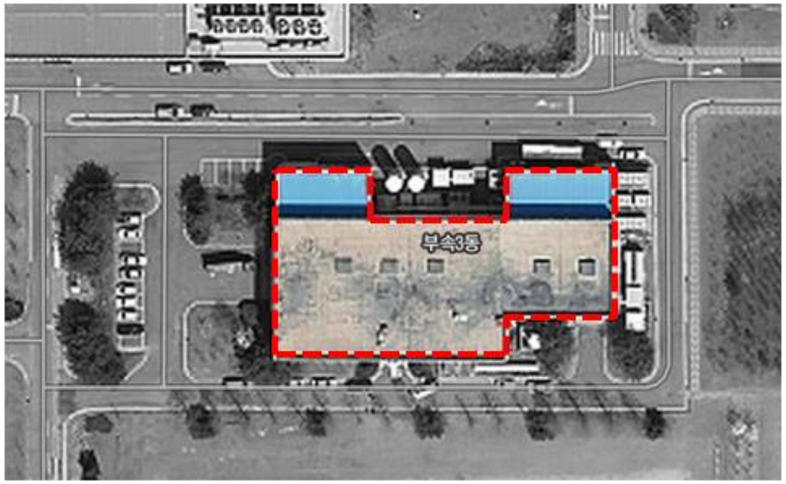


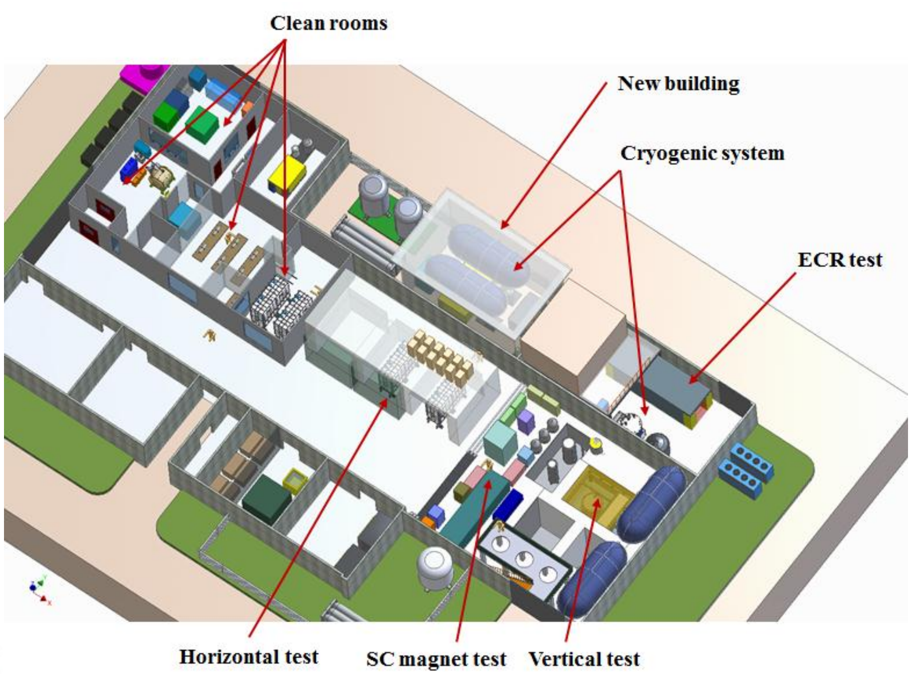


Radiation Heating Calculation were performed for the Hot cell components using PHITS

*MSM: master-slave manipulators

SRF Test Facility





- SRF TF is constructed at KAIST Munji campus.
- It will be ready for operation in 2015.

SRF TF includes :

- 2 vertical test stands
- 3 cryomodule test benches
- 1 buffered chemical processing
- 2 high pressure rinsing
- 1 high temperature furnace
- 1 ultrasonic clean
- Cryogenic system

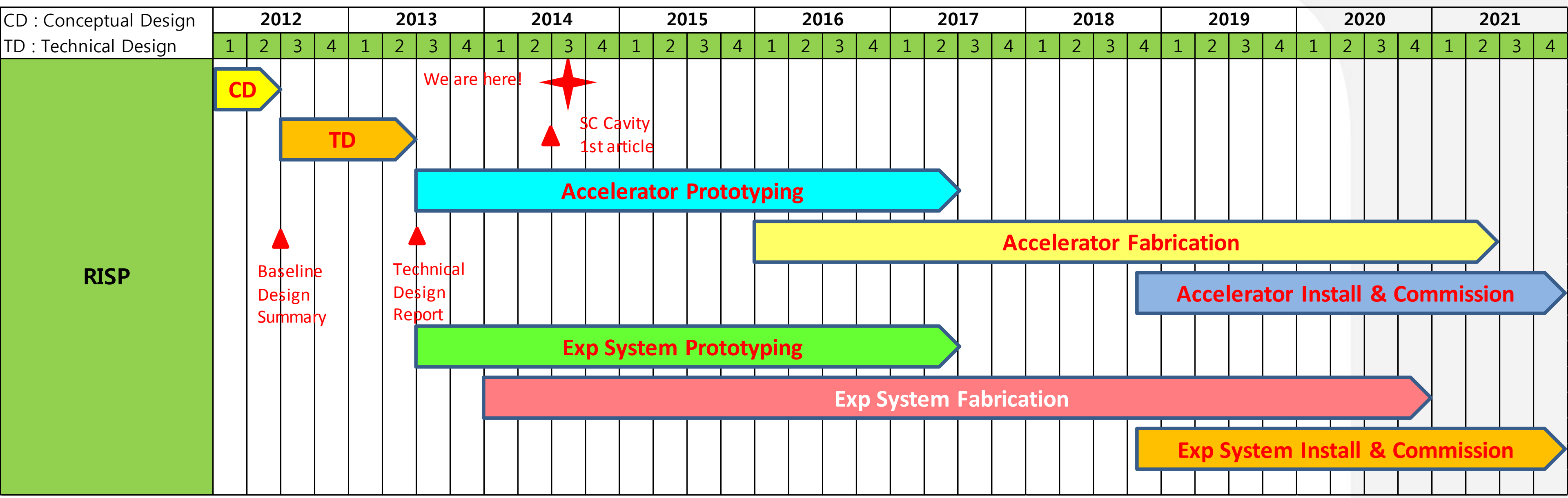
Budget and Schedule

- RISP budget

  Accelerator and Experimental Systems : $420M (460.2T KRW)

  Conventional Facility : $568M (624.3T KRW)

- Conventional facility budget was finalized May 2014.
- Construction to be completed by 2021.



Summary

- The RAON has phased into prototyping stage.
- Fabrication of ECR Ion Source is in progress and beam test in late 2014.
  - Superconducting magnet assembly is fabricated and being tested.
- RAON is undertaking prototyping efforts:
  - RFQ
  - Superconducting cavities through domestic vendors and international vendors
  - Cryomodules through domestic vendors
  - HTS(High Tc Superconductor) quadrupole coil in collaboration with domestic research institutes
  - LTS(Low Tc Superconductor) quadrupole
- The conventional facility budget for the RAON was finalized May 2014.

- **MOPP080**, H. Jang, Beam Dynamics Study for RAON Superconducting Linac
- **MOPP081**, M.J. Joung, The ECT System for RAON's Cavities
- **MOPP082**, H.J. Kim, Superconducting Linac for RISP
- **TUPP085**, W.K. Kim, RAON Cryomodule Design for QWR, HWR, SSR1 and SSR2
- **TUPP086**, H. Kim, RAON Superconducting Radio Frequency Test Facility Construction
- **TUPP088**, M. Lee, QWR/HWR type cryomodule prototype design for the RAON
- **TUPP083**, M.O. Hyun, Design and Analysis of Slow Tuner in the Superconducting Cavity
- **TUPP084**, J.D. Joo, Surface Treatment Facilities for SCRF cavities at RISP
- **THPP079**, H,J. Cha, Prototyping Progress of SSR1 Single Spoke Resonator for RAON


Thank you for your attention!
감사합니다