Superconducting Linac for the RISP (Rare Isotope Science Project)

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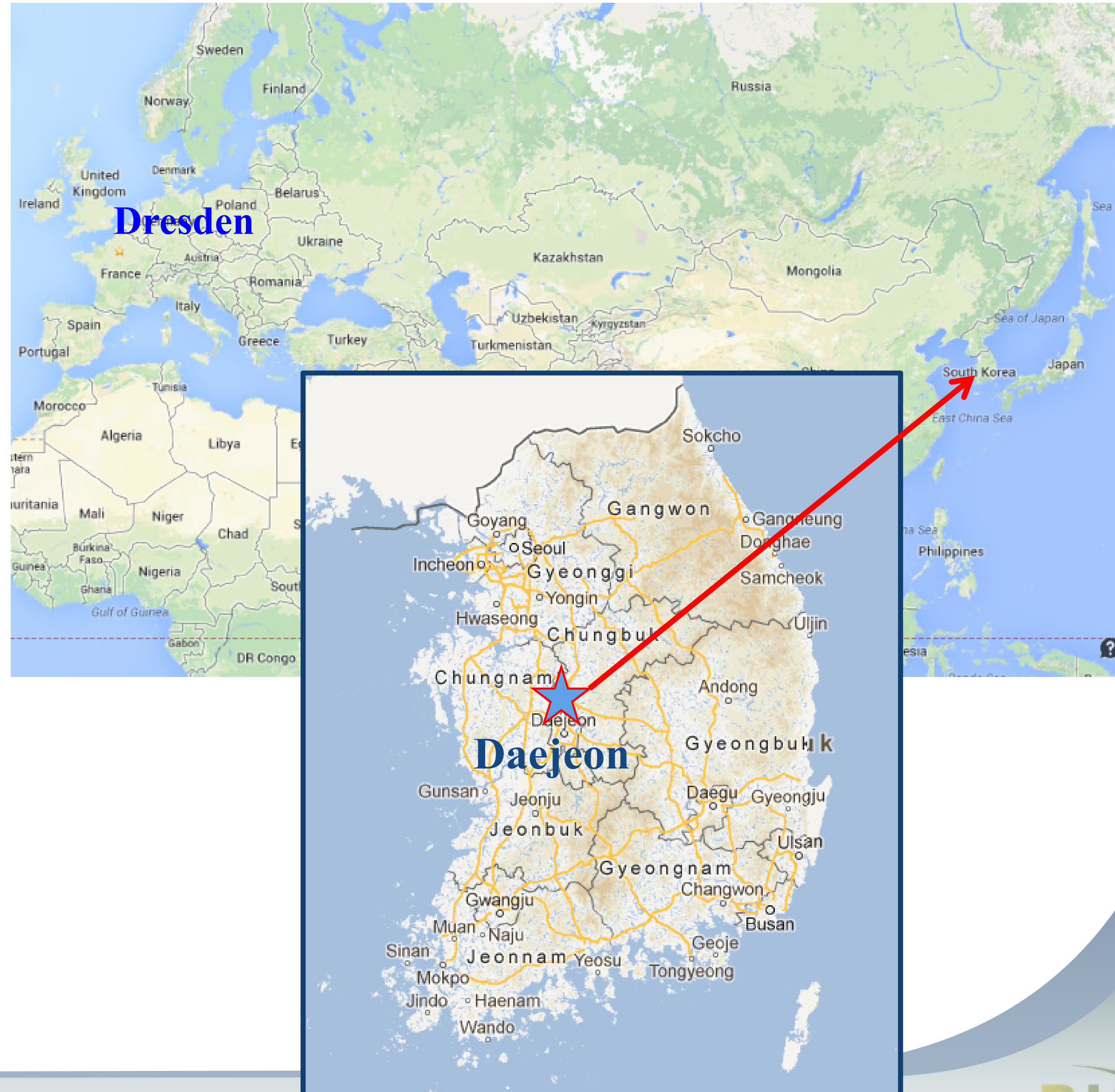
Collaboration with KNU, POSTECH, SNU, NFRI, Vitzrotech, SFA, TRIUMF, IHEP

Rare Isotope Science Project (RISP)

RAON

- **Conceptual Design Study (2009.3 - 2011.2)**
- **Rare Isotope Science Project(RISP) launched (2011.12)**

- **Construction period: 2012-2021**
- **46B KW (~443M USD) from central government for heavy ion accelerator itself**
- **62B KW (~597M USD) from central government for buildings and tunnel construction**
- **39BKW(~375M USD) from central government for land purchase**



RISP – Bird Eye View

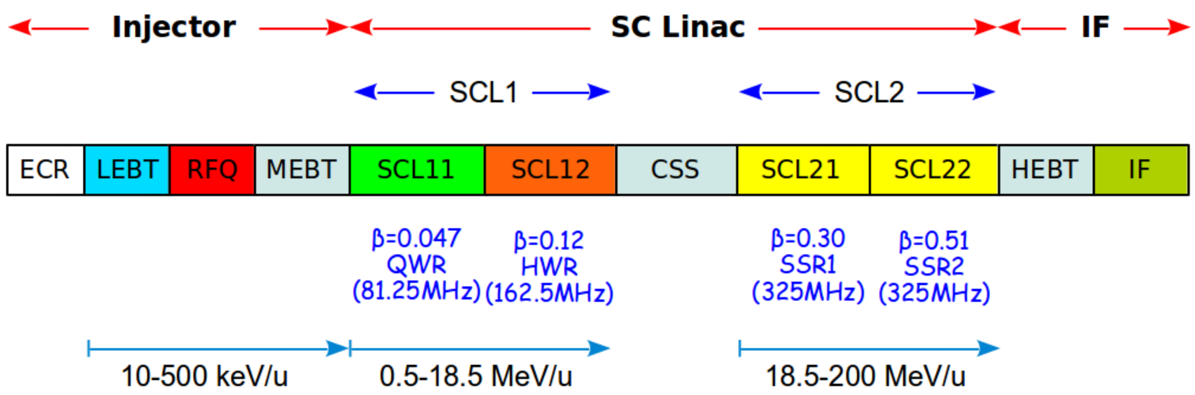
RAON

RISP – Bird Eye View

Accelerator	Driver Linac (SCL1-SCL2)		Post Acc. (SCL3-SCL2)
Particle	Proton	Uranium	RI beam (Sn-132)
A/q	1	7(+33.5)→3(+79)	7(+20)→3(+47)
Beam energy	600 MeV	200 MeV/u	180 MeV/u
Beam current	660 μA	8.3 pμA	-
Power on target	> 400 kW	400 kW	-

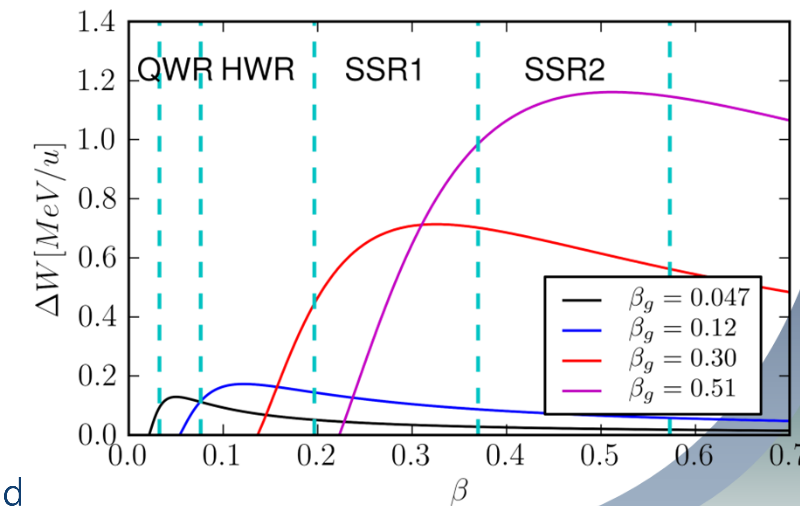
Superconducting Linac

- RISP consists of Injector, SC Linac and IF systems.
- SC Linac comprises low energy linac (SCL1), charge stripper section (CSS) and high energy linac (SCL2).



SCL Characteristics

- Linac baseline frequency is 81.25MHz
- Niobium Cavities operating at 2K and 4.5K
- Focusing by normal conducting quad doublets
- Optimized geometric beta of SC cavities (0.047, 0.12, 0.30, 0.51)
- Employs larger aperture to reduce beam loss (4cm and 5 cm aperture)



Layout of Driver Linac

RAON

ECR	LEBT	RFQ	MEBT	SCL11	SCL12	STRIP	SCL21	SCL22
				QWR (81.25MHz)	HWR (162.5MHz)		SSR1 (325MHz)	SSR2 (325MHz)

CAV QF QD — 22 cryomodules → Output 2.7 MeV/u

22 β=0.047 QWRs, 44 quadrupoles

CAV CAV QF QD — 13 cryomodules → Output 6.0 MeV/u

CAV CAV CAV CAV CAV QF QD — 19 cryomodules → Output 18.5 MeV/u

98 β=0.12 HWRs, 64 quadrupoles

Stripper: charge state 33, 34 → 77,78,79,80,81 for Uranium

C C C QF QD — 23 cryomodules → Output 56.5 MeV/u

69 β=0.30 SSR1, 46 quadrupoles

C C C C C C QF QD — 23 cryomodules → Output 200 MeV/u

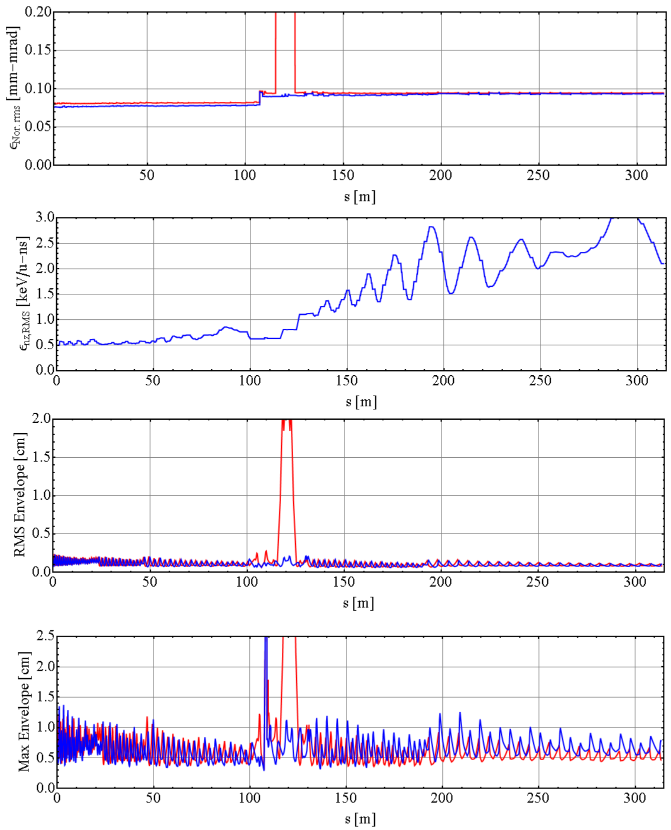
138 β=0.51 SSR2, 46 quadrupoles

Total 331 cavities, 100 cryomodules, 196 quadrupoles, 122m (LEL,CSS), 181m (HEL)

Beam Physics

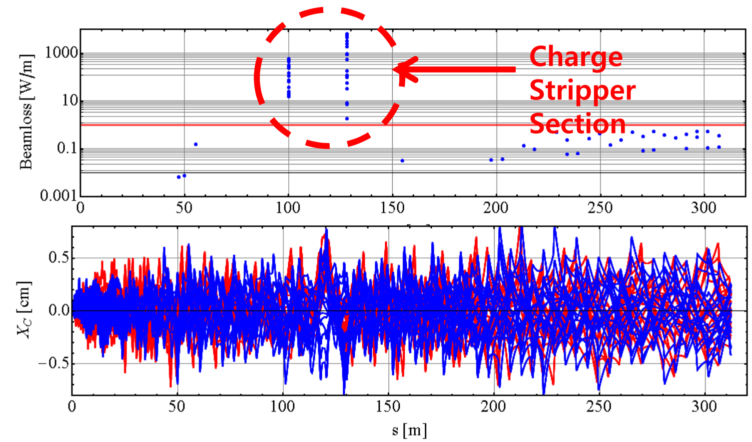
Lattice Design

- 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

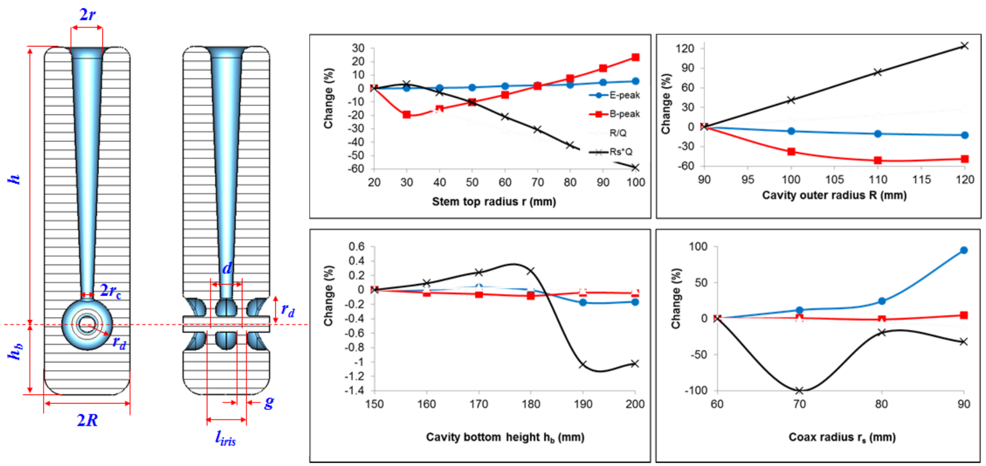
What is considered in RISP design

- Linac operation cost
  - The long-term operating costs of the accelerating linac are significant
    - Superconducting linac operating costs are dominated by the cryoplant and operating temperature.
    - RISP is focused on a superconducting linac design.
    - Components design is focused on optimization for reducing the cryogenic equipment and their operating costs.

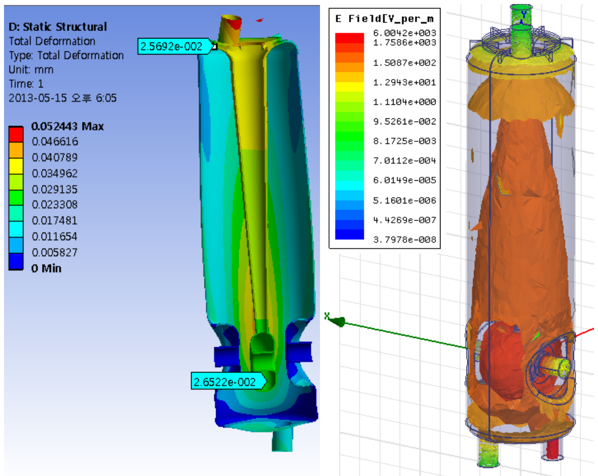
- Linac hardware cost
  - Superconducting cavity, cryomodule and cryoplant are complicated and costly.

Design of SC Cavity

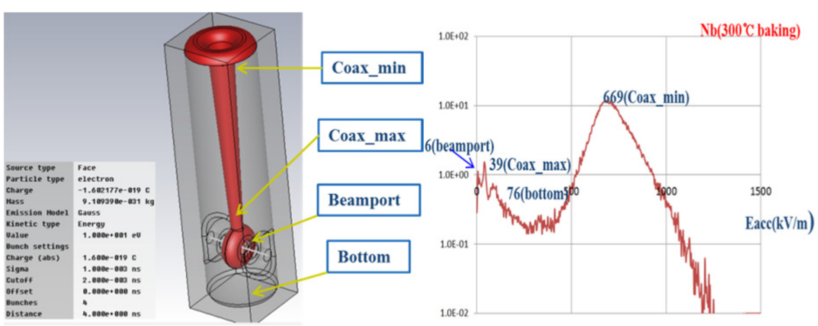
Optimization of Cavity Parameters



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

Superconducting cavity

QWR

HWR

SSR1

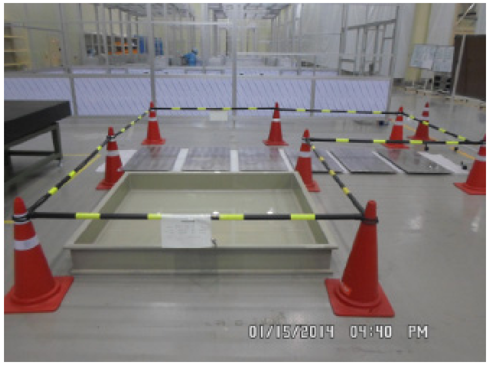
SSR2

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

EM design optimization: Parameters sweeping

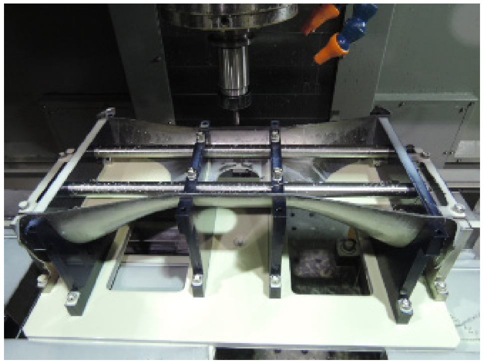
SC Cavity Prototyping

➢CAVITY Manufacturing Process



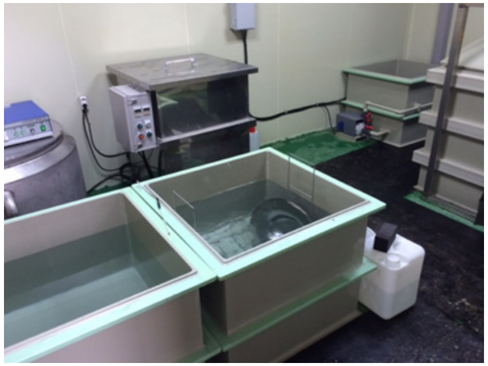
MATERIAL INSPECTION

DEEP DRAWING



MACHINING

3D SCAN (CMM)



BCP

EBW

➤ CAVITY PARTS – Material: Nb

SPOKE

END COVER

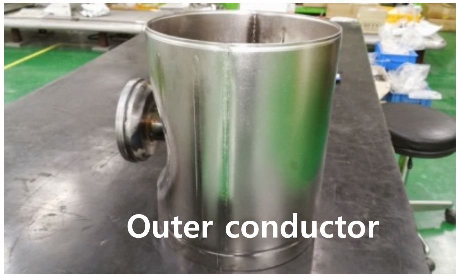
OUTER CYLINDER

BEAM TUBE 1

BEAM TUBE 2

VACUUM TUBE

Cavity Prototyping - EBW Test

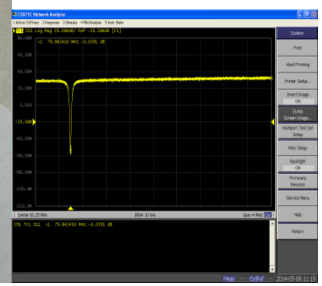


Prototyping SC Cavity

RAON

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 Clamp-up Test

SSR1 Clamp-up Test

SSR2 Clamp-up Test

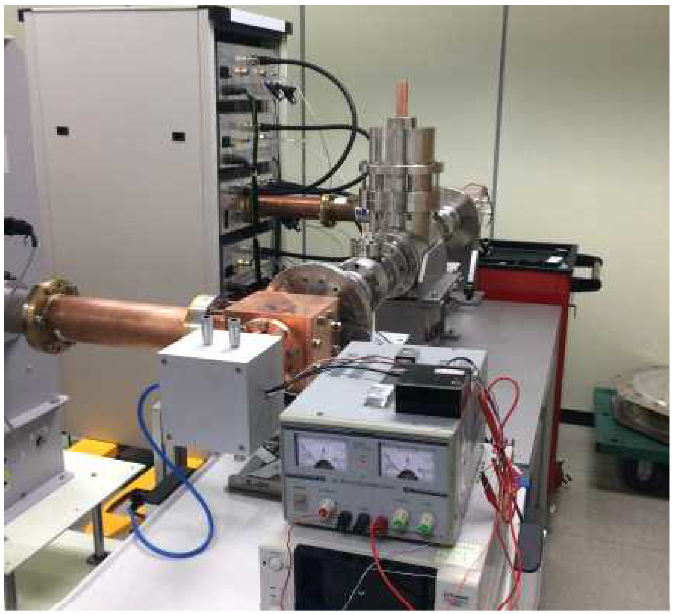
Final welding will be done in June by Vitzrotech and SFA.

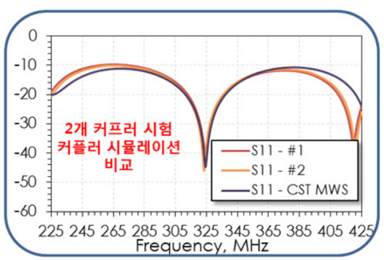
Vertical tests will be performed in 2014.

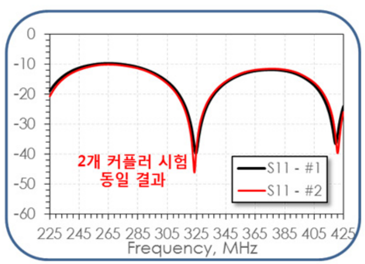
WEPRI035 (IPAC2014)

RF Coupler

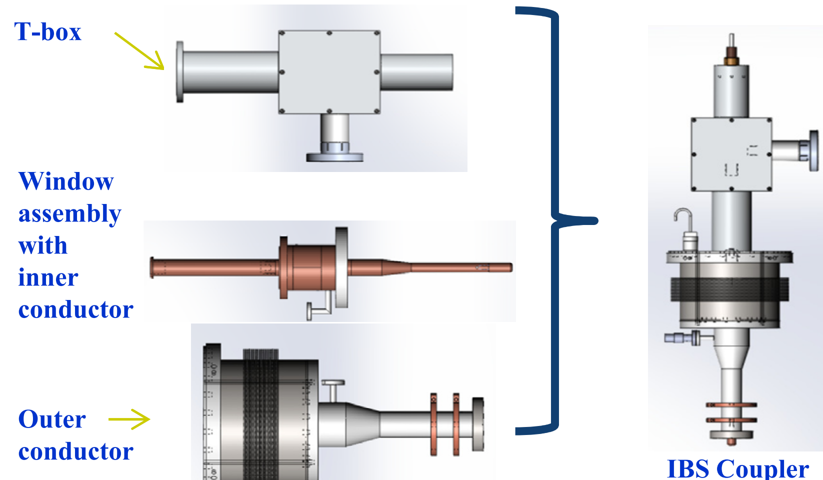
- Prototyping: SNU (Aug. 2013~Feb. 2014)
  - Performance test in progress
- Frequency: 325 MHz
- Nominal Power: 14.5 kW



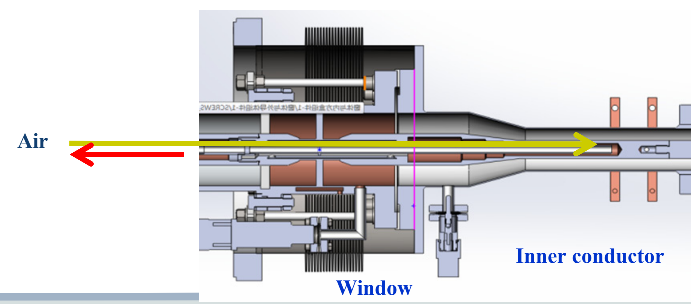




- Prototyping: IHEP (Mar. 2014~Dec. 2014)
- Frequency: 162.5 MHz
- Nominal Power: 3.7 kW

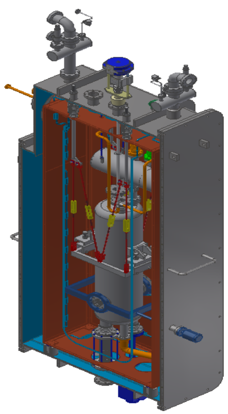


RF power :4kW → Window and Inner conductor with air cooling is available.

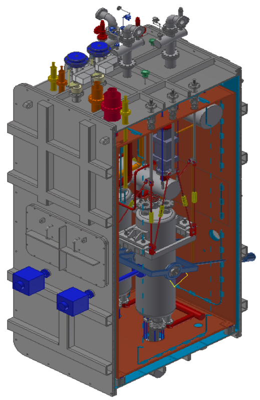


Cryomodule

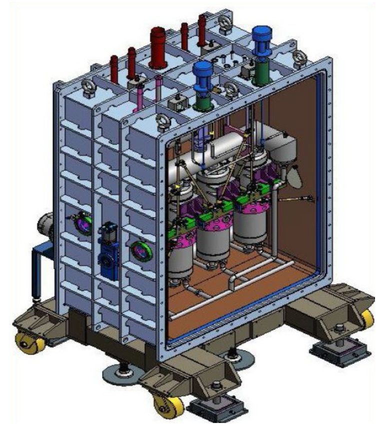
QWR Cryomodule



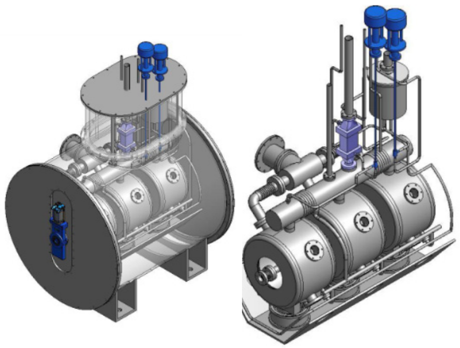
HWR#1 Cryomodule



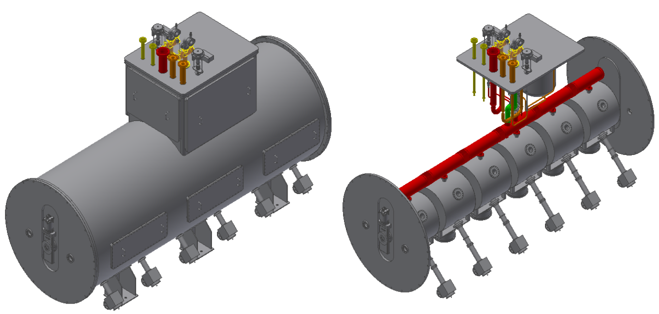
HWR#2 Cryomodule



SSR#1 Cryomodule



SSR#2 Cryomodule

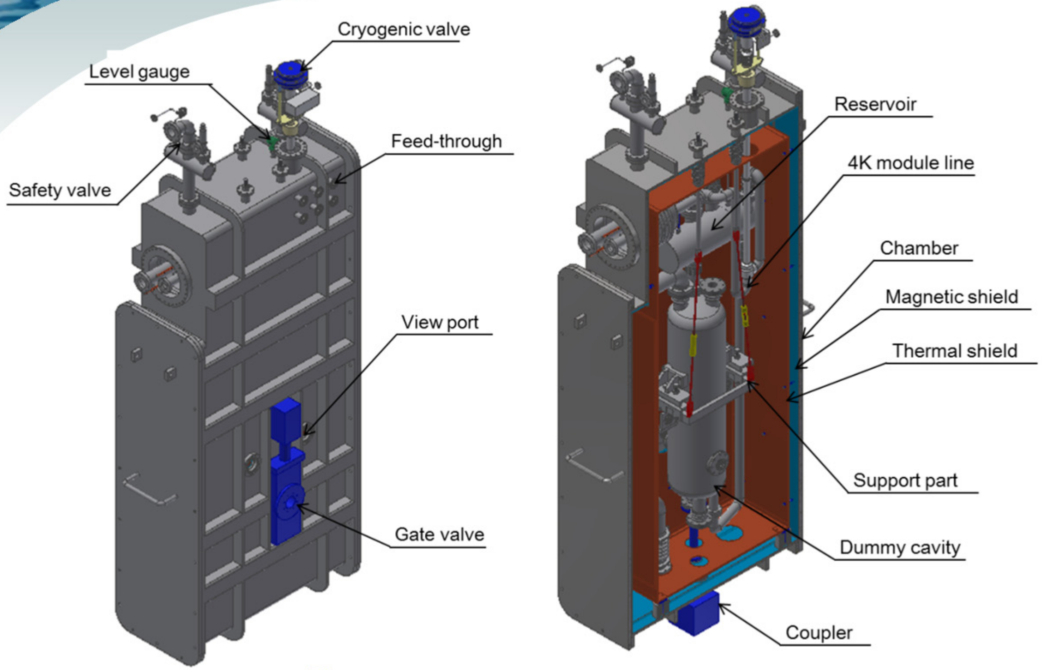


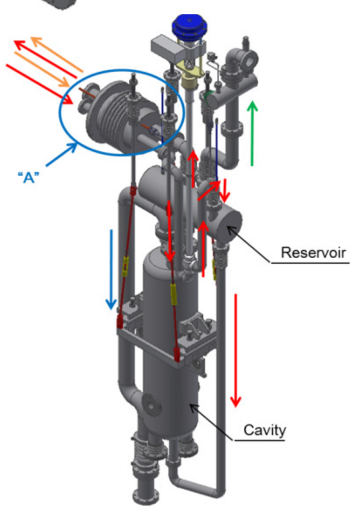
WEPRI035, WEPRI036 (IPAC14)

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˚

QWR Cryomodule





4K He line

Material : STS316L
Pipe inlet Size : 32A Sch5S
Pipe outlet Size : 50A Sch5S
Gasket : Helicoflex

40K He line

Material : Cu
Pipe inlet Size : 3/8" Tube
Gasket : VCR fitting

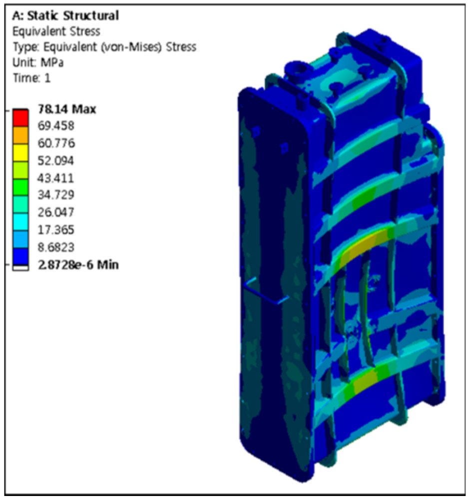
Vacuum line

Material : STS316L
Pipe inlet Size : 65A Sch5S
Gasket : Helicoflex

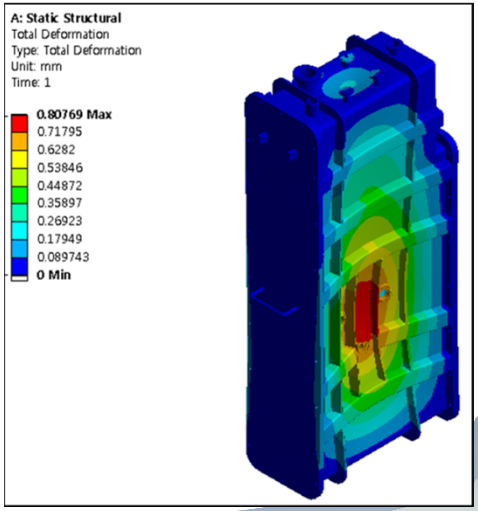
Safety line

Material : STS316L
Pipe inlet Size : 65A Sch5S
Gasket : Helicoflex

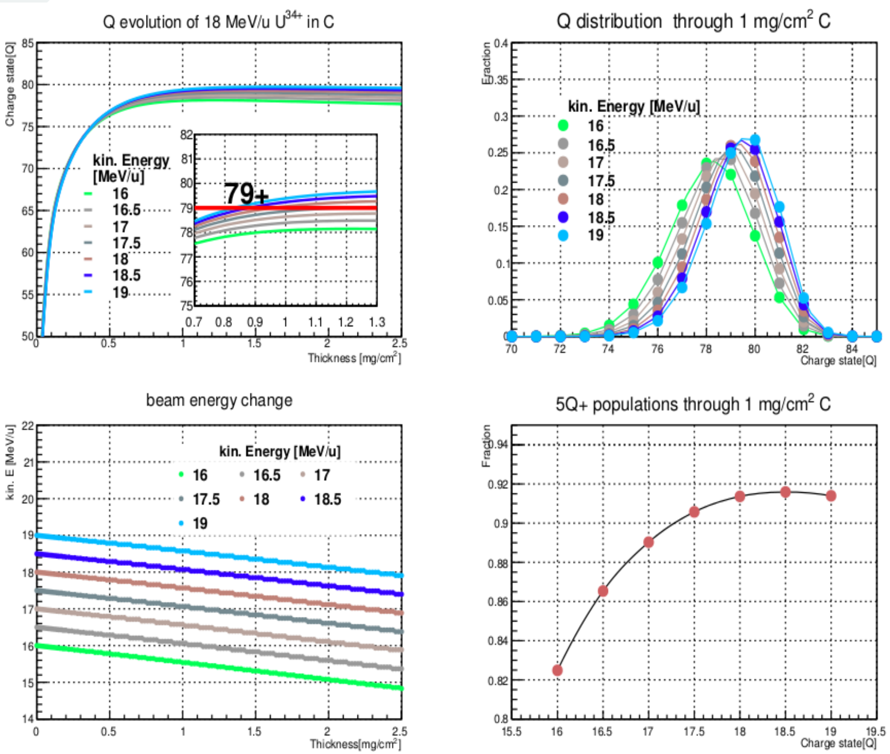
Stress (Condition : Vacuum)



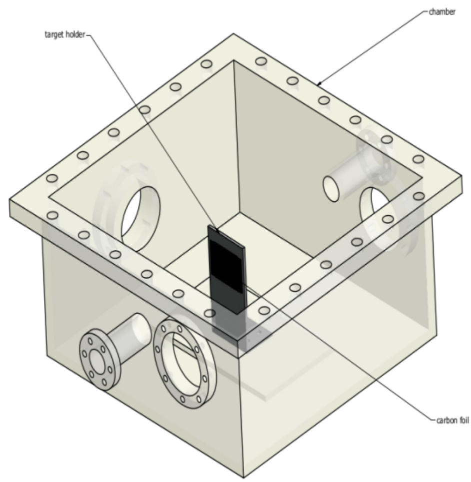
Displacement (Condition : Vacuum)



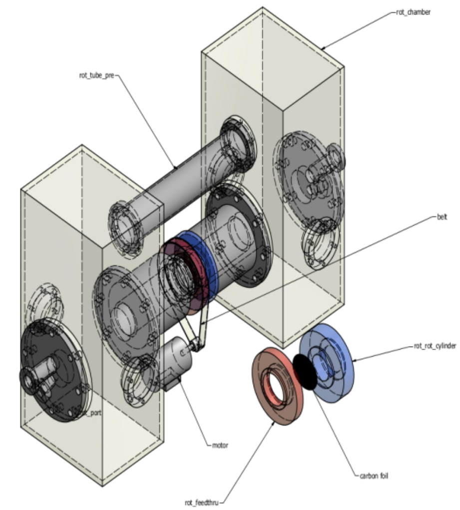
Design of Charge Stripper



Charge state evolution(top left), charge state distribution(top right), energy loss(bottom left) and 5Q+ populations for Uranium with C foil



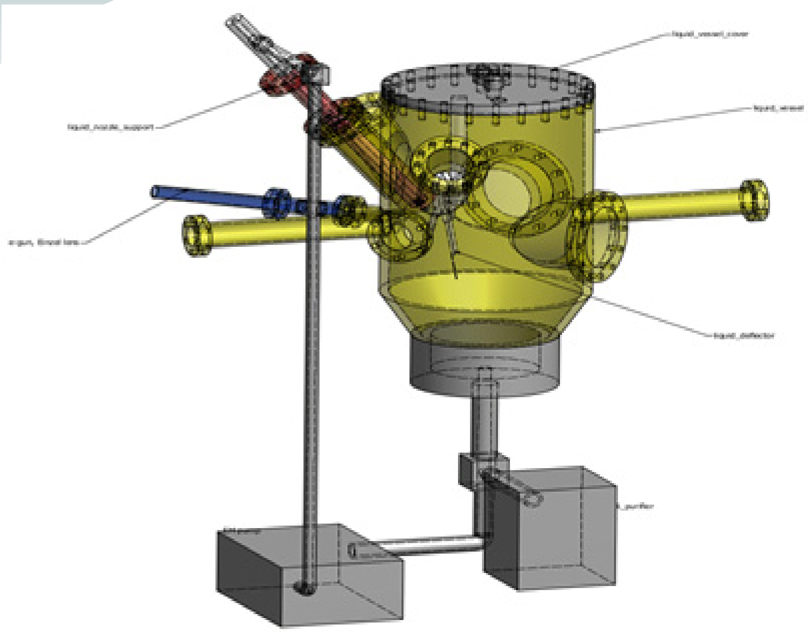
(a) Fixed C stripper



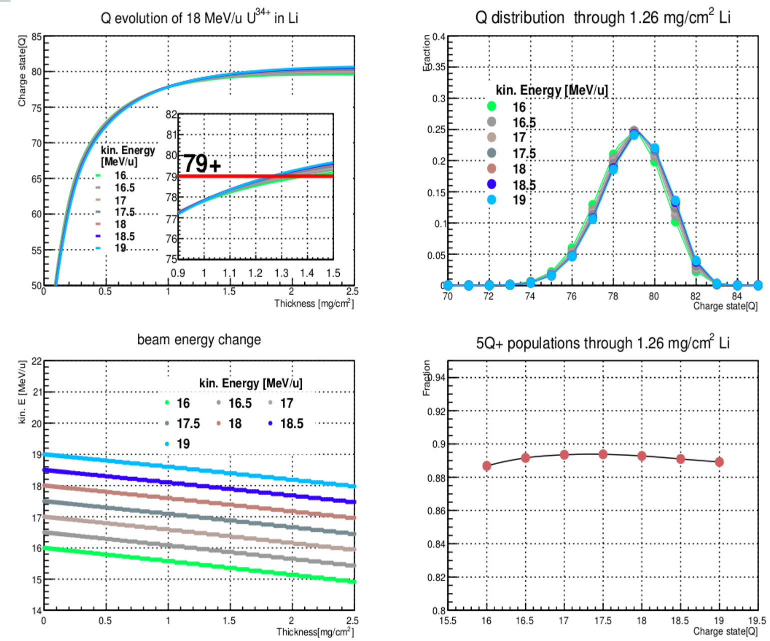
(b) Rotating C stripper

Schematic drawing of C stripper

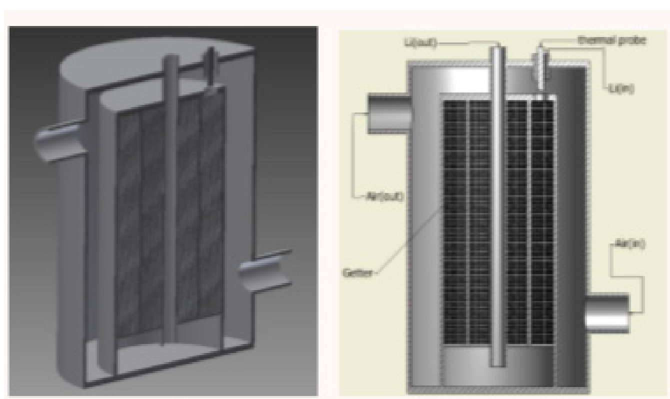
Design of Li Charge Stripper



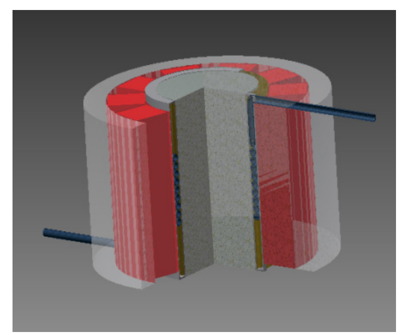
Schematic drawing of Li stripper



Charge state evolution(top left), charge state distribution(top right), energy loss(bottom left) and 5Q+ populations for Uranium with Li



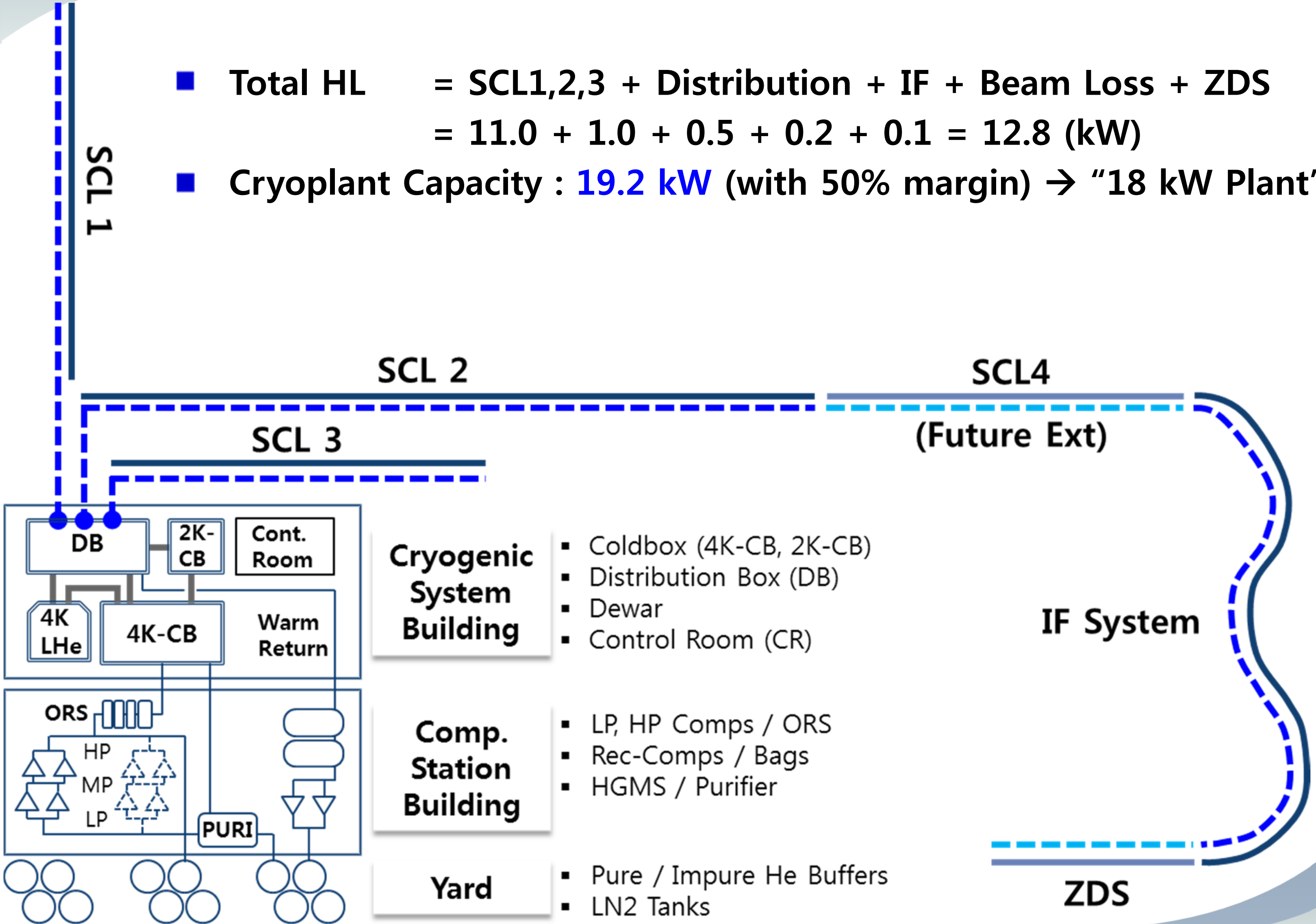
Cold trap of Li purifier



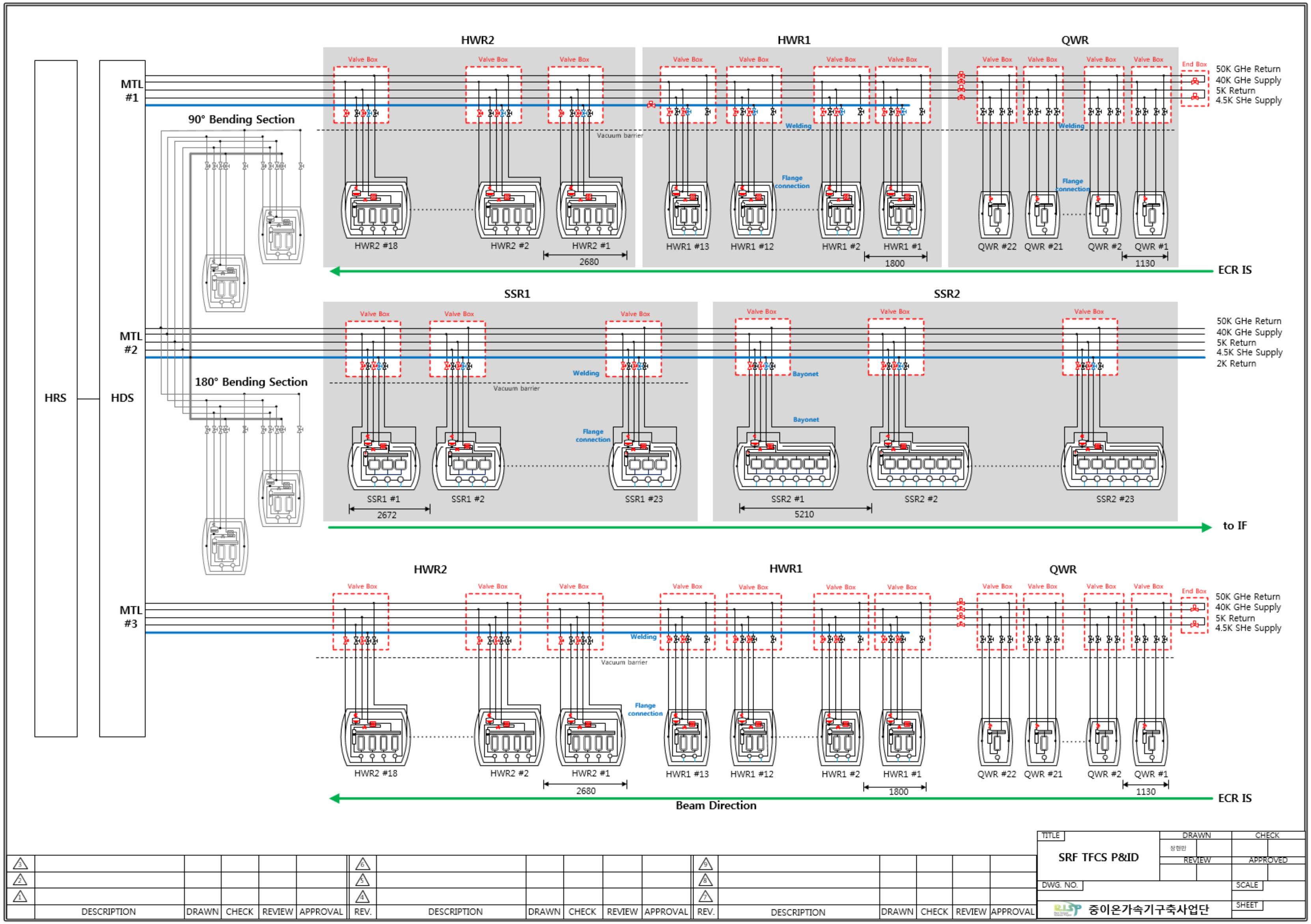
Design of EM pump

Cryogenic System

- **Total HL = SCL1,2,3 + Distribution + IF + Beam Loss + ZDS**
  = 11.0 + 1.0 + 0.5 + 0.2 + 0.1 = 12.8 (kW)
- **Cryoplant Capacity : 19.2 kW (with 50% margin) → "18 kW Plant"**

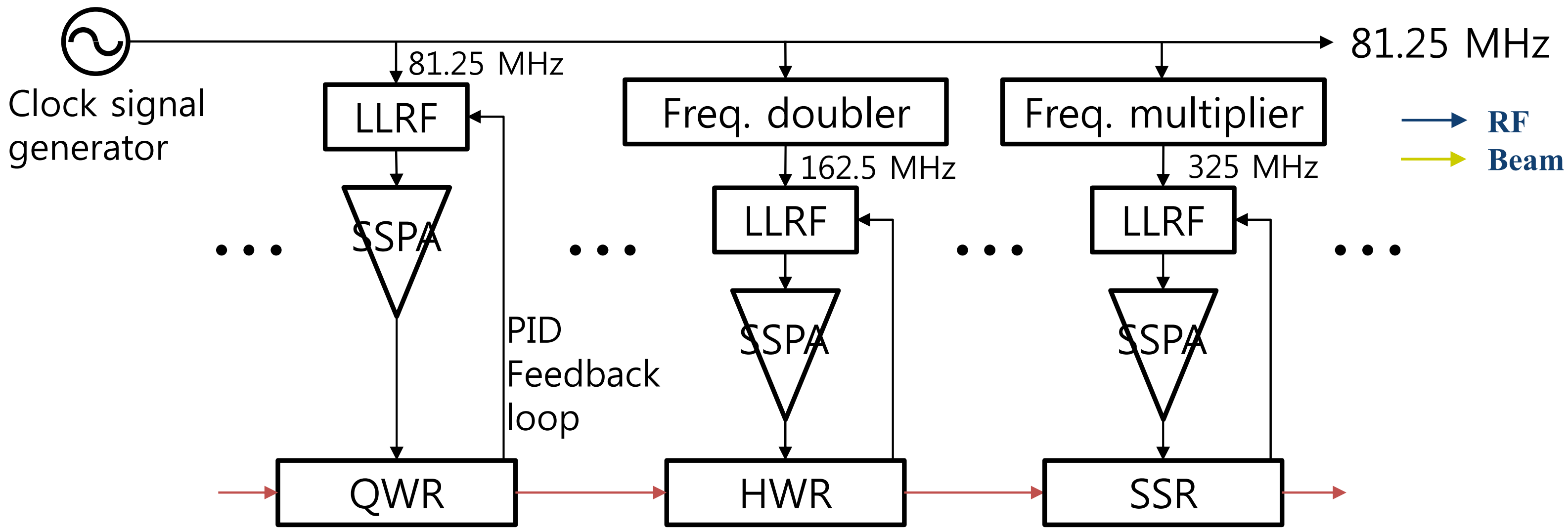


Helium Distribution System P&ID

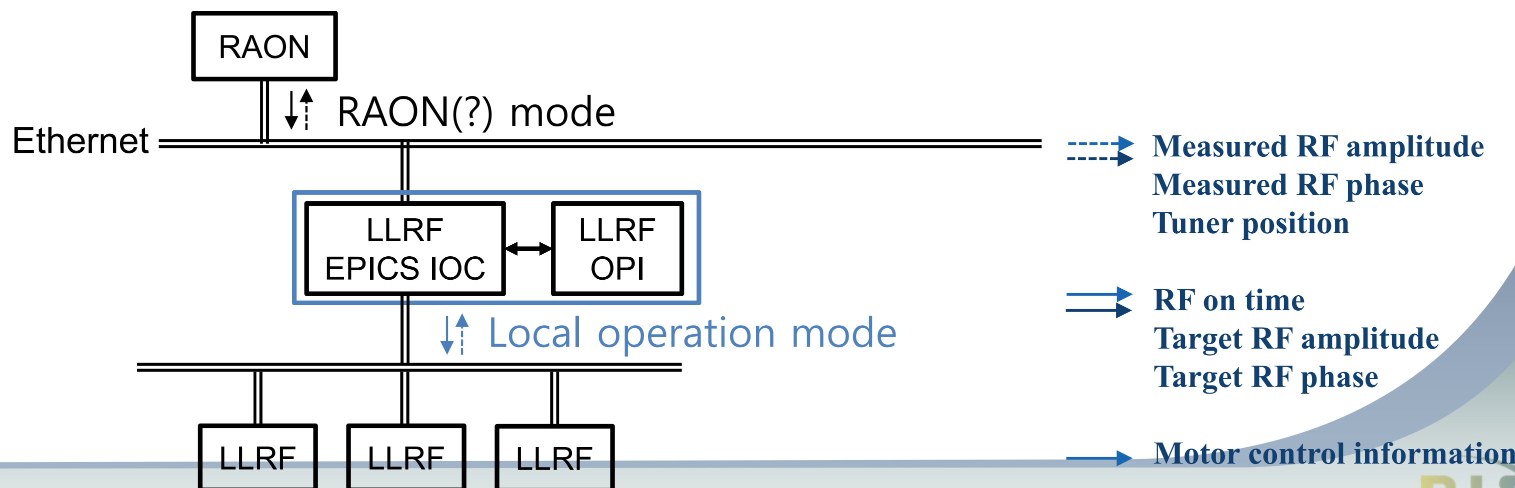


RF System

RF system

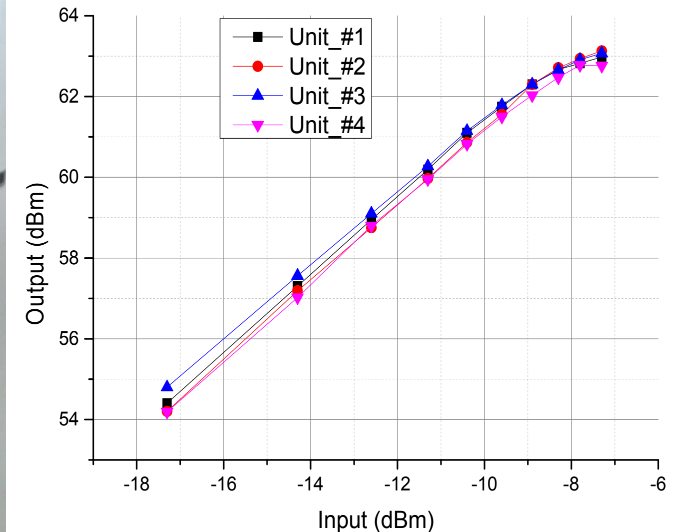


Control system

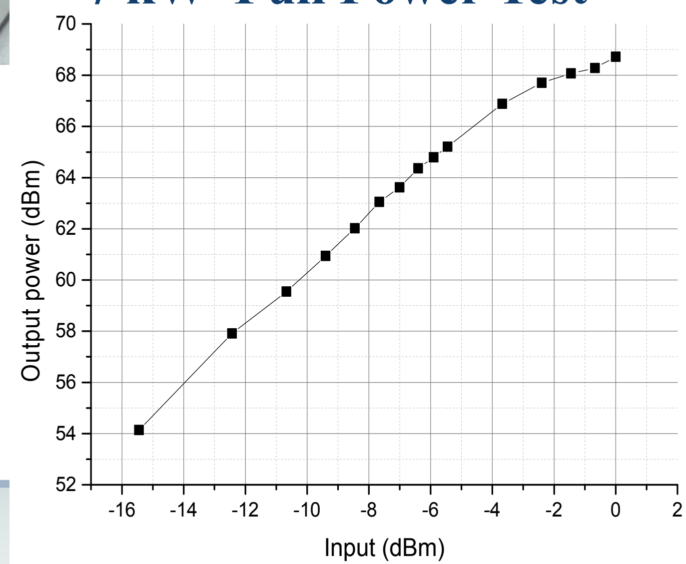


SSPA Test

2 kW SSPA Unit Test

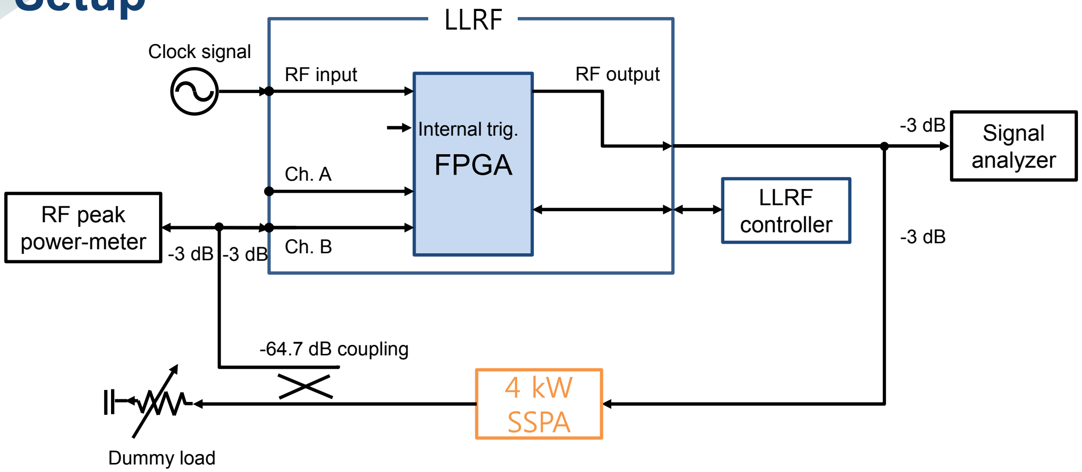


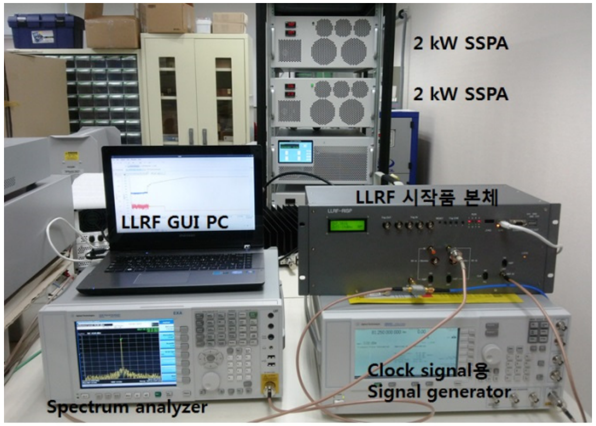
7 kW Full Power Test



LLRF+SSPA integration test

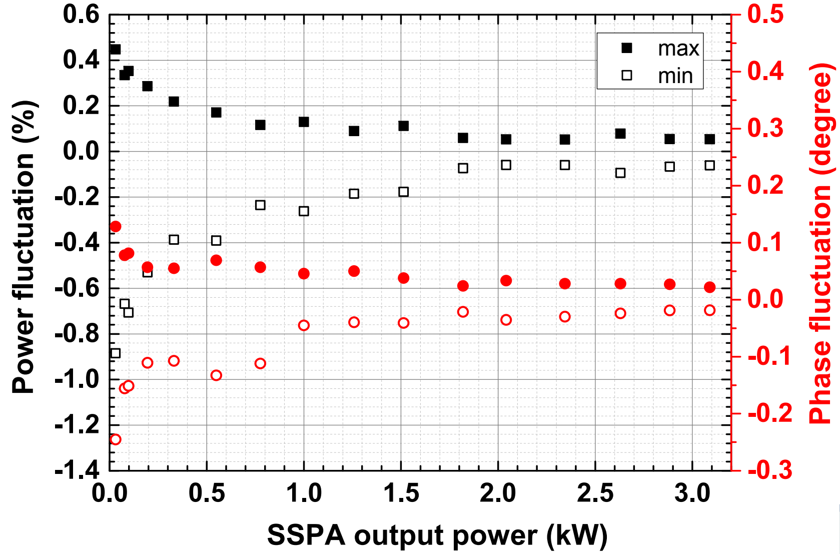
- **Setup**





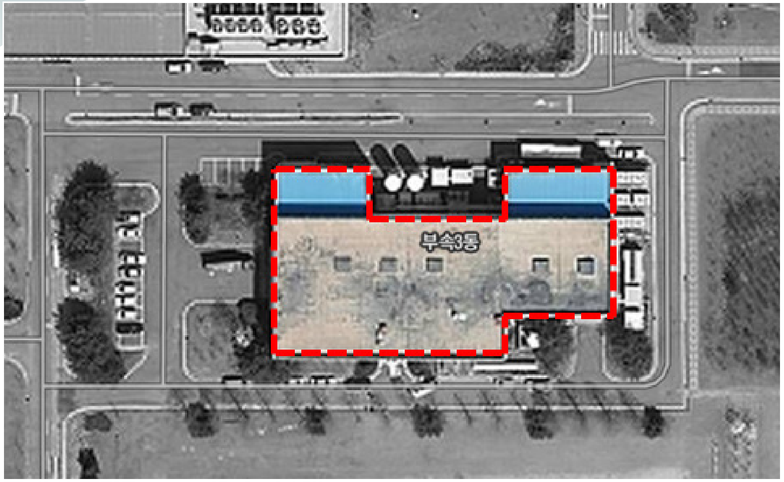
- ✓ With feedback control
- ✓ LLRF+SSPA
- ✓ 3 h CW operation

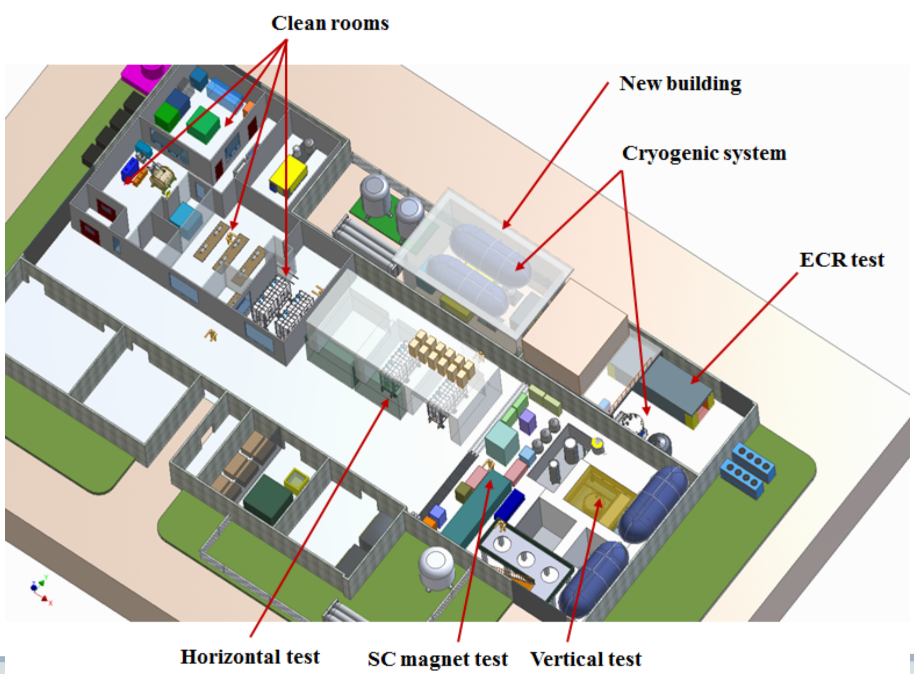
- **Long Term Test Result**



@ 3 kW	Max
Power	0.06%
Phase	0.02°

SRF Test Facility





- It will be ready for operation in 2015.

- 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

Summary

- Superconducting linac has been designed to meet the requirement of science goals and various users.
- Superconducting cavities have been designed for four different types, and their prototyping is done and under cold test.
- Cryomodules have been designed, and their prototyping is under way.
- Budget of thermal load and requirement of cryogenic system are documented.
- RF power sources (SSPA) are prototyped and being tested.
- SRF test facility will be completed in mid 2015.

Thank you !

감사합니다 !