Status of the RISP Superconducting Heavy Ion Accelerator

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SRF2015
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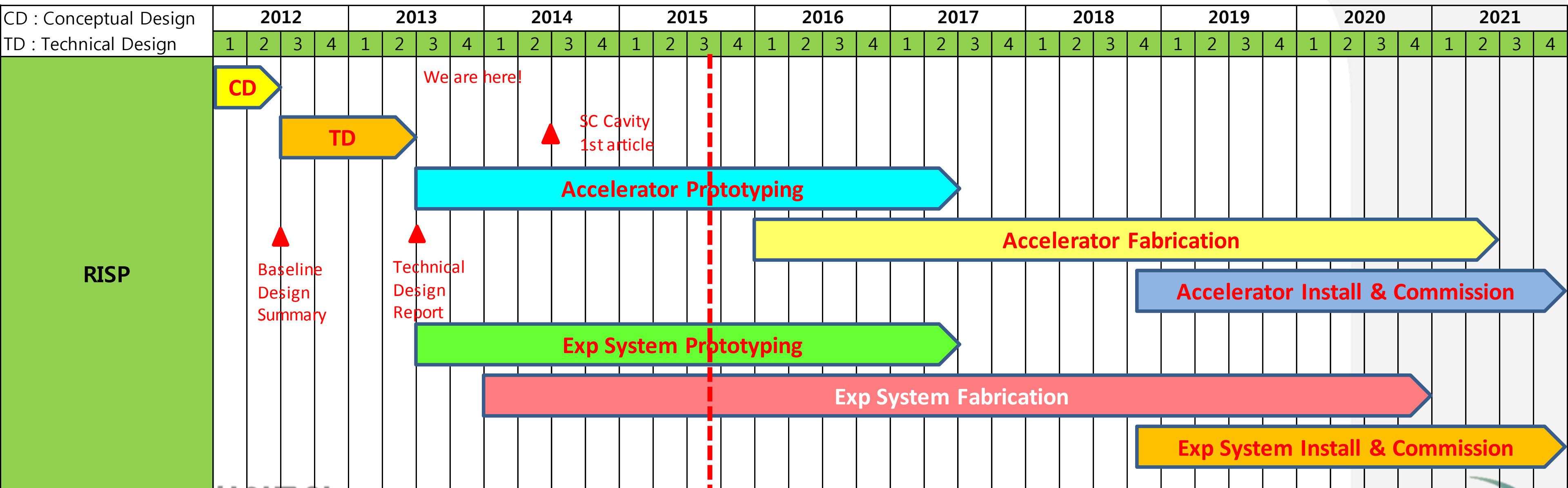
기초과학연구원
Institute for Basic Science

Cost and Schedule

- **Project Cost**
  Accelerator and Experimental Systems : $420M (4602억원)
  Conventional Facility : $568M (6243 억원)
  Site Cost (부지매입비) : $327M (3600 억원)

- Conventional facility budget was finalized 2014.05.
- Construction to be completed by 2021.12.

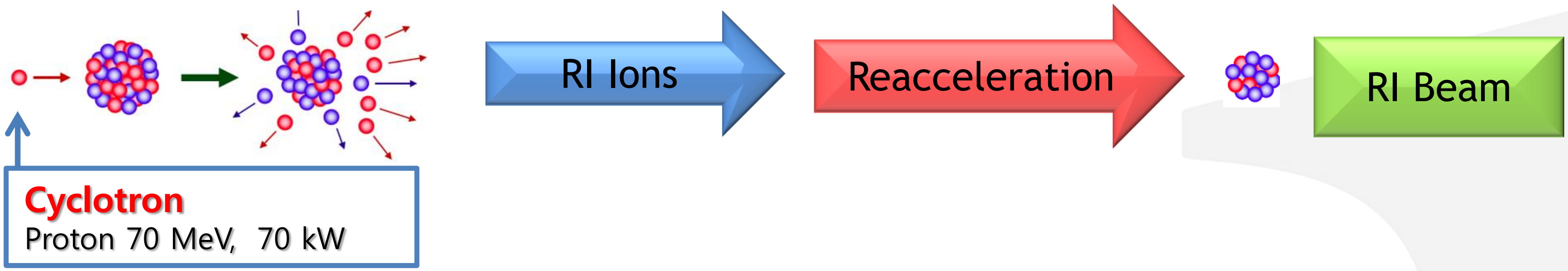
- **Project Schedule** (2011.12 – 2021.12)



Bird's-eye View

RISP has both ISOL and IF systems

ISOL (Isotope Separator On-Line)
proton → thick target (eg. Uranium) → target spallation or fission (low energy)



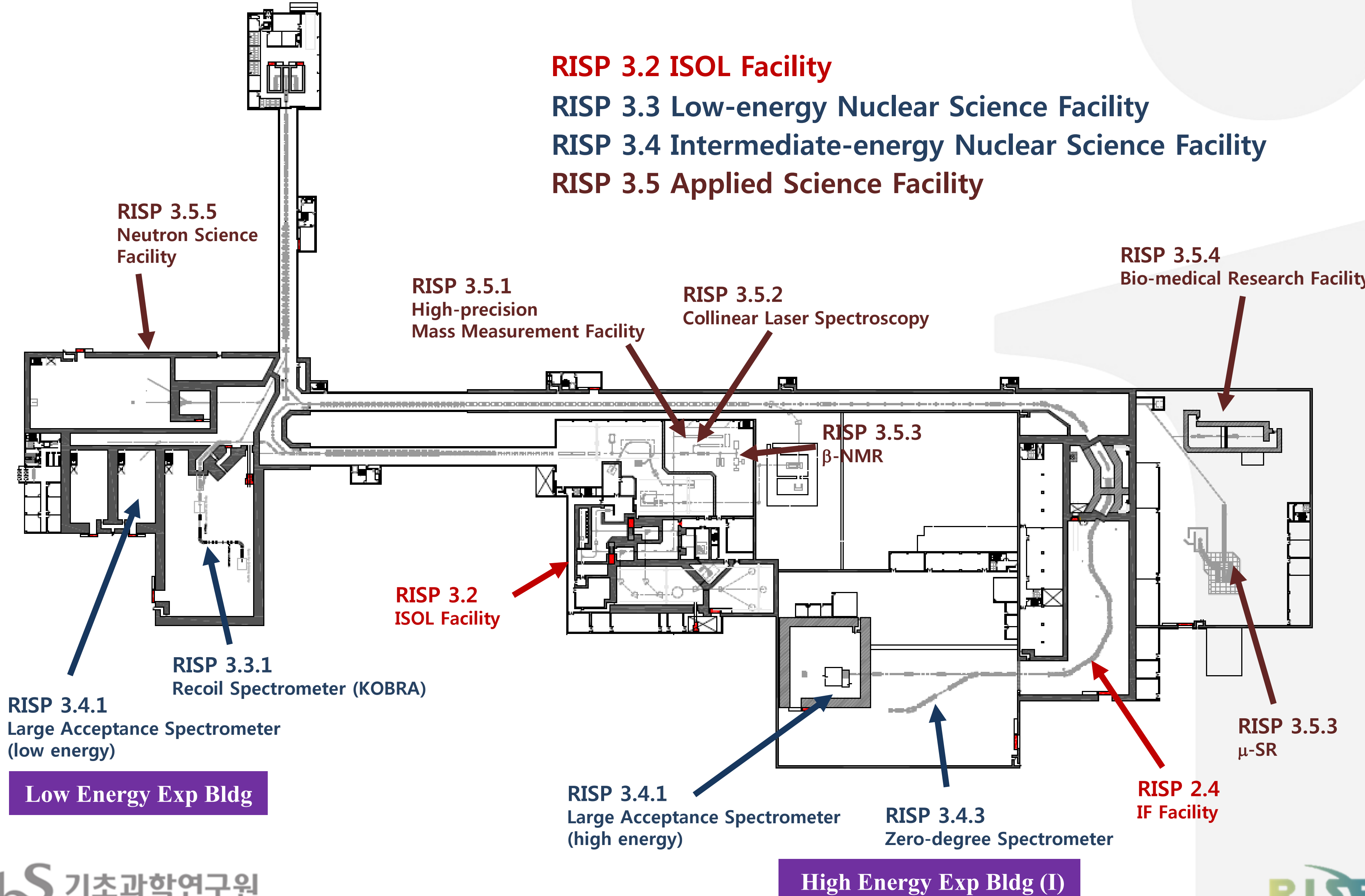
RISP has both ISOL and IF systems

Driver LINAC
Heavy ion
e.g. U : 200MeV/u, 400 kW

IF (In-flight Fragmentation)
Heavy ion beam → thin target (eg. Carbon) → projectile fragmentation (high energy)

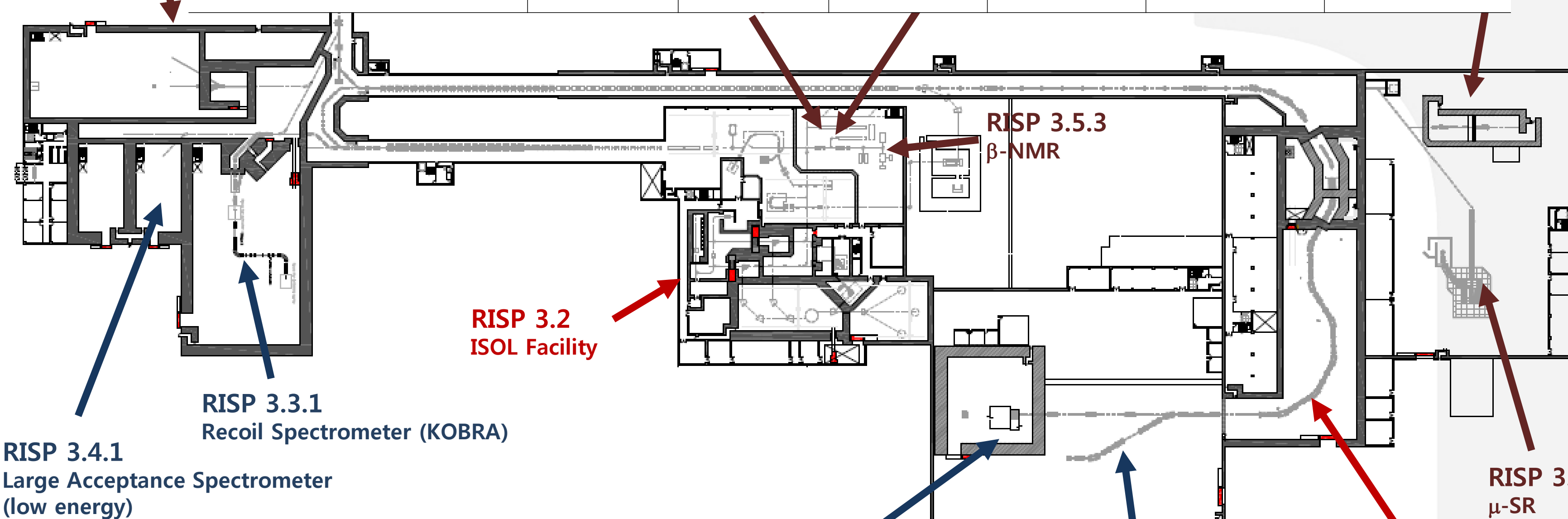
Layout and Beam Parameters

RISP 3.2 ISOL Facility
RISP 3.3 Low-energy Nuclear Science Facility
RISP 3.4 Intermediate-energy Nuclear Science Facility
RISP 3.5 Applied Science Facility

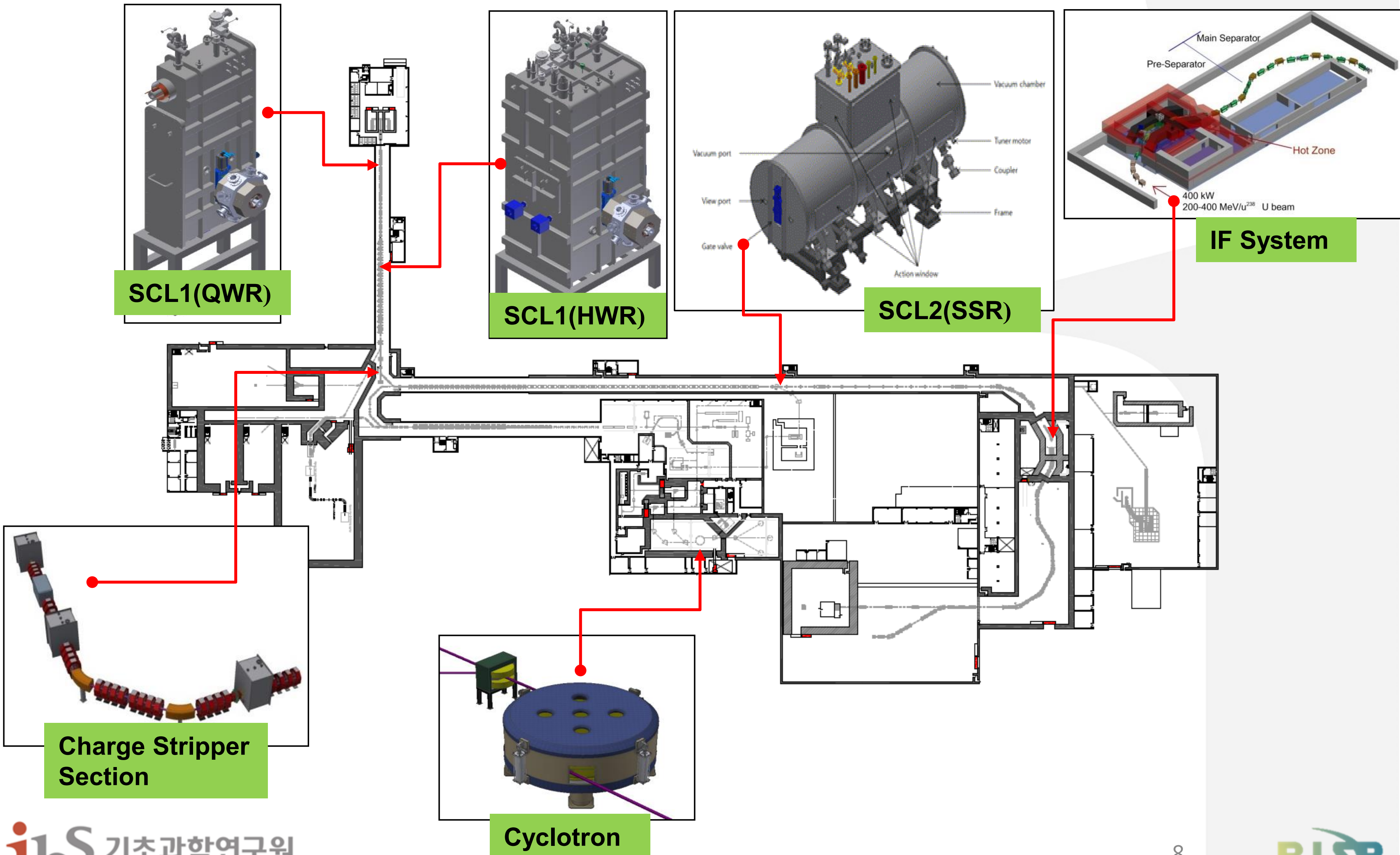


Layout and Beam Parameters

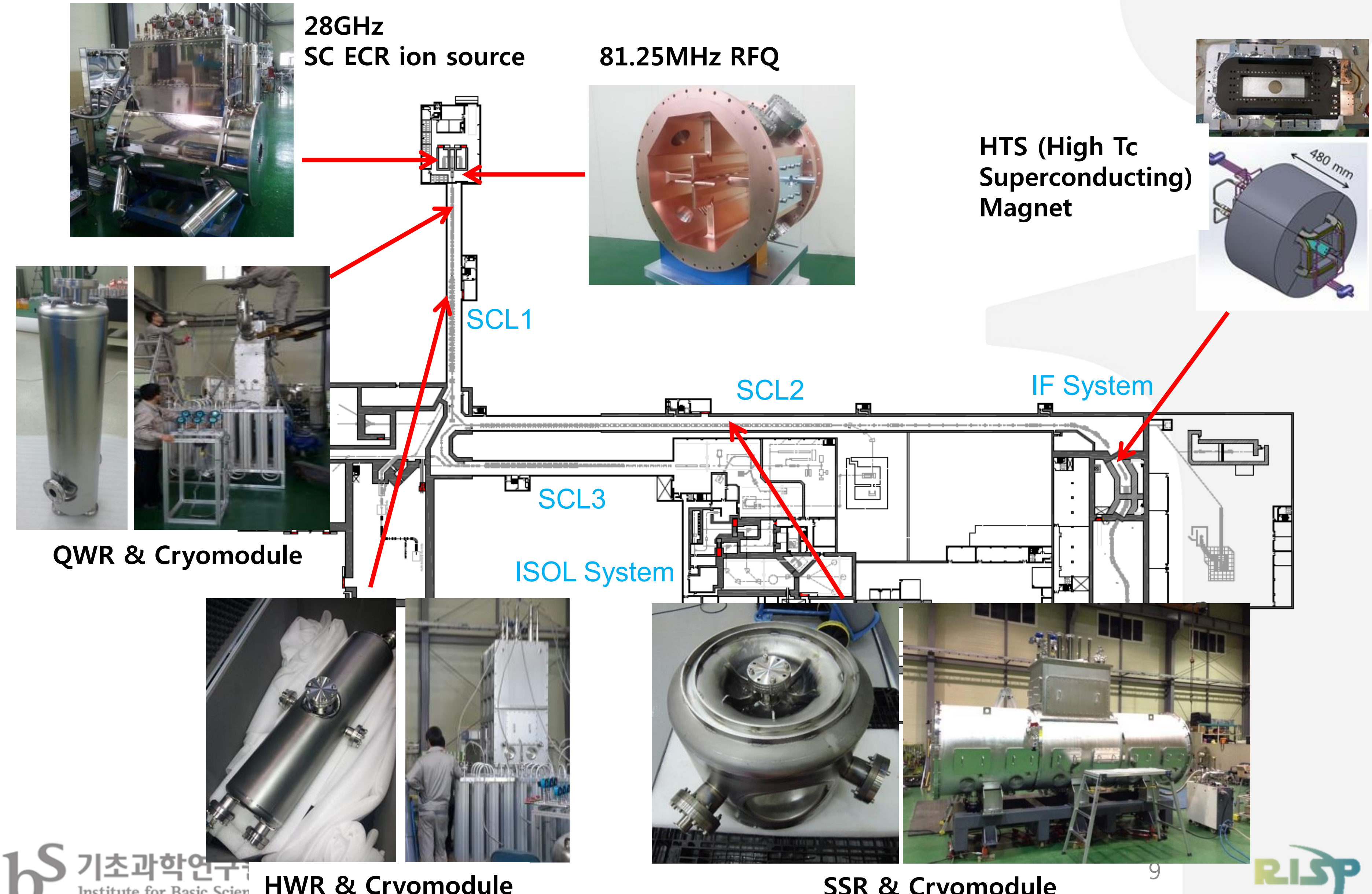
	Driver Linac				Post Acc.	Cyclotron
Particle	H^{+}	O^{+8}	Xe^{+54}	U^{+79}	RI beam	proton
Beam energy (MeV/u)	**600**	**320**	**251**	**200**	**18.5**	**70**
Beam current (pμA)	660	78	11	8.3	-	1000
Power on target (kW)	**> 400**	**400**	**400**	**400**	-	70



Accelerator Layout



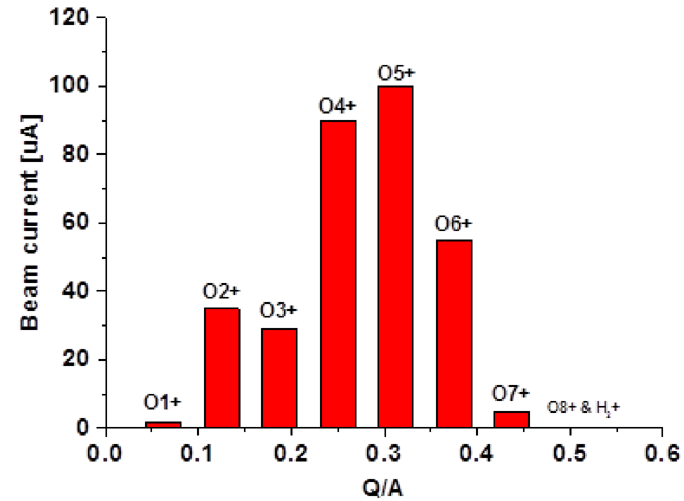
Status of Prototyping

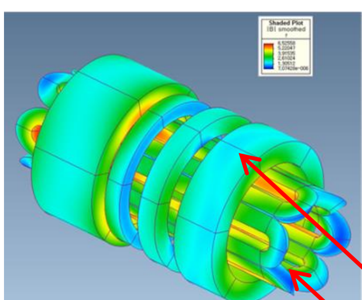


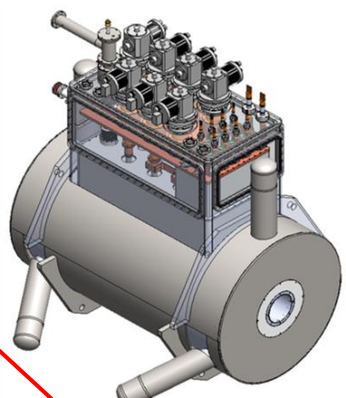
28-GHz ECR Ion Source test stand

Preliminary

Oxygen beam experiment result







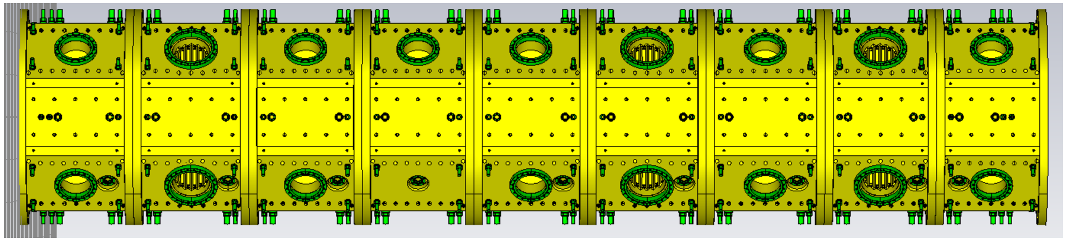
- Superconducting sextupole and solenoid prototypes were tested individually.
- Superconducting magnet assembly (sextupole + 4 solenoids) was completed.
- Test is under way at 4K in liquid He.
- Achieved sextupole 95%, solenoids 80% so far
- Beam test is on-going

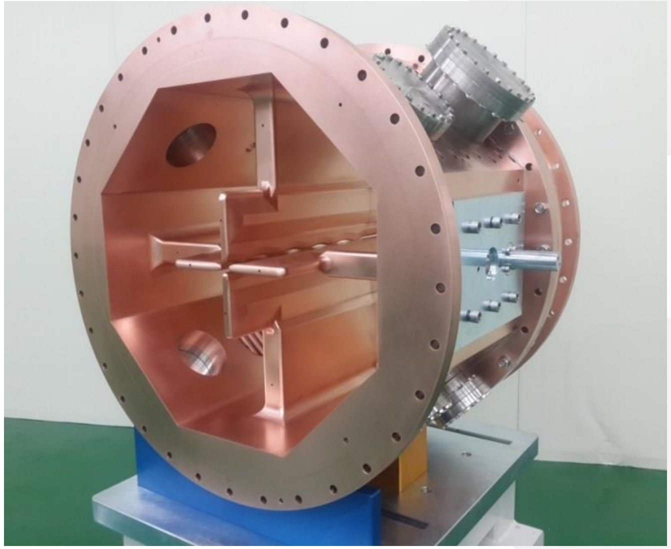
RFQ Prototyping

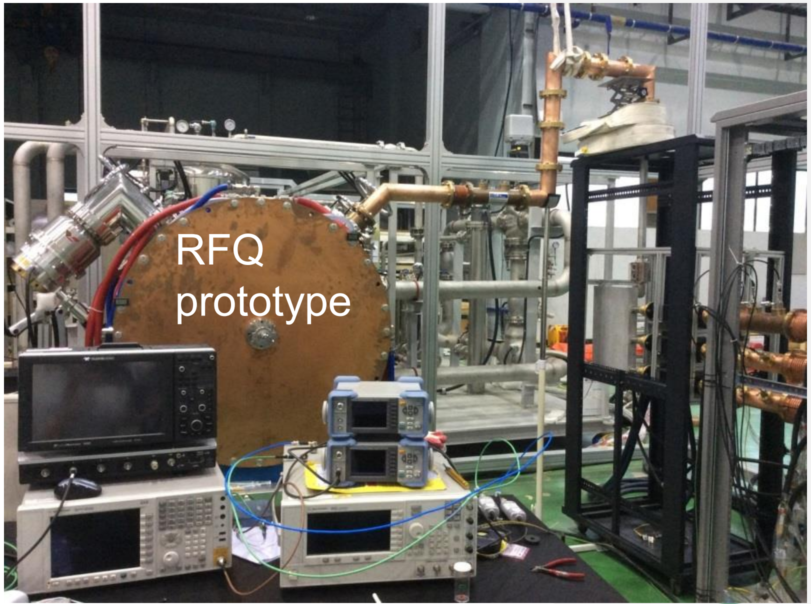
- RFQ Design (2013.08)
- Design review (2013.11)
- RFQ Prototype (High Energy End)

- RFQ prototype completed successfully through domestic vendor (2014.10)
- RFQ prototype test is in progress and reached so far 15kW@10% duty, 11kW@CW

- Contract awarded for RFQ fabrication to be delivered by Aug/2016.

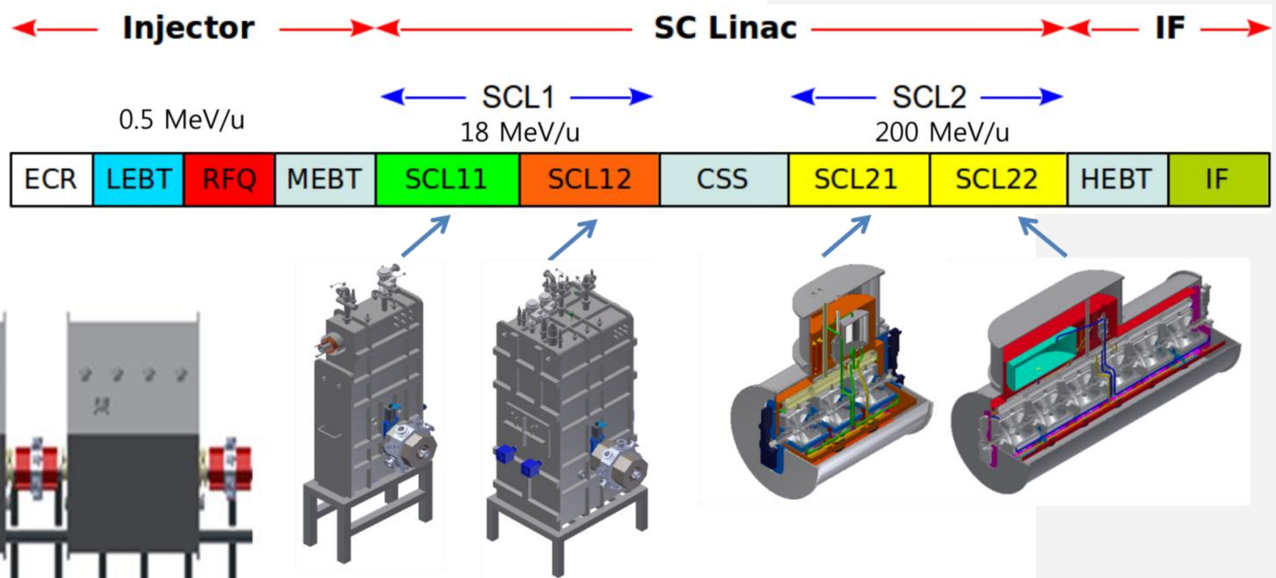


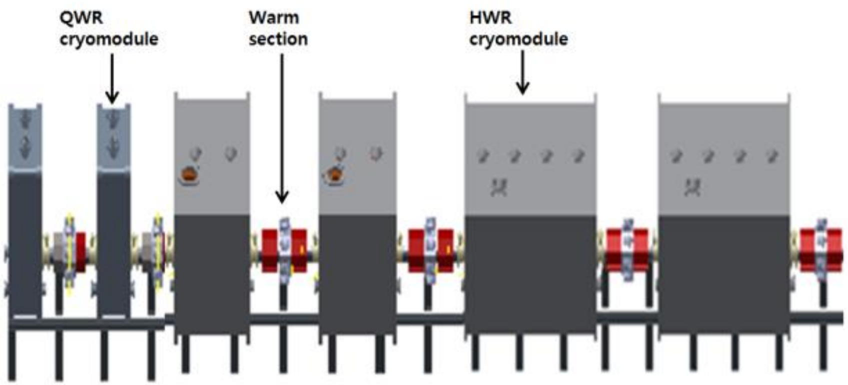




RISP Superconducting Linac (SCL)

- RISP SCL is designed to accelerate high intensity beams.
- Lattice consists of units of (cryomodule + quad doublet).
- Optimized geometric β of SC cavities (0.047, 0.12, 0.30, 0.51).
- Employs larger aperture SC cavities to reduce beam loss (40 mm and 50 mm aperture).



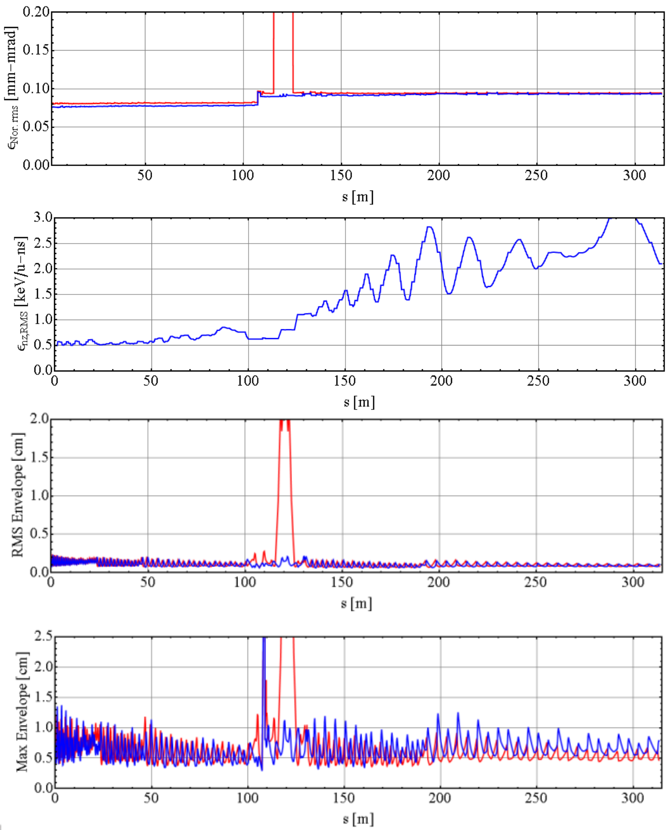


Beam Dynamics

Beam Loss is a concern for a high-power accelerator

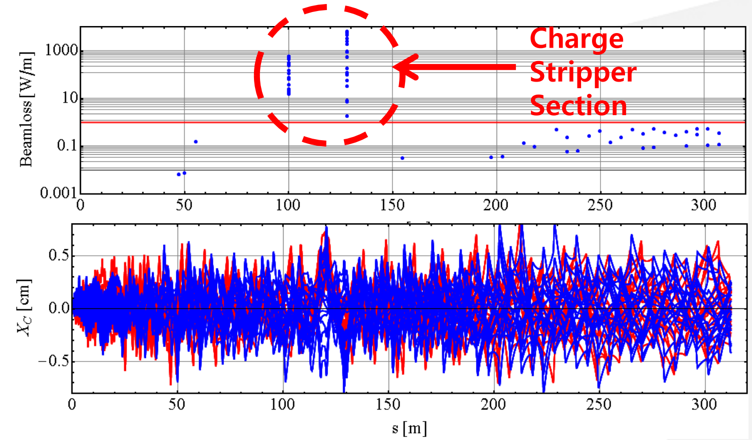
Lattice Design

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



Machine Imperfection Effects

- Beam loss requirement is met even without orbit correction.
- 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

Error budget

Superconducting Cavity

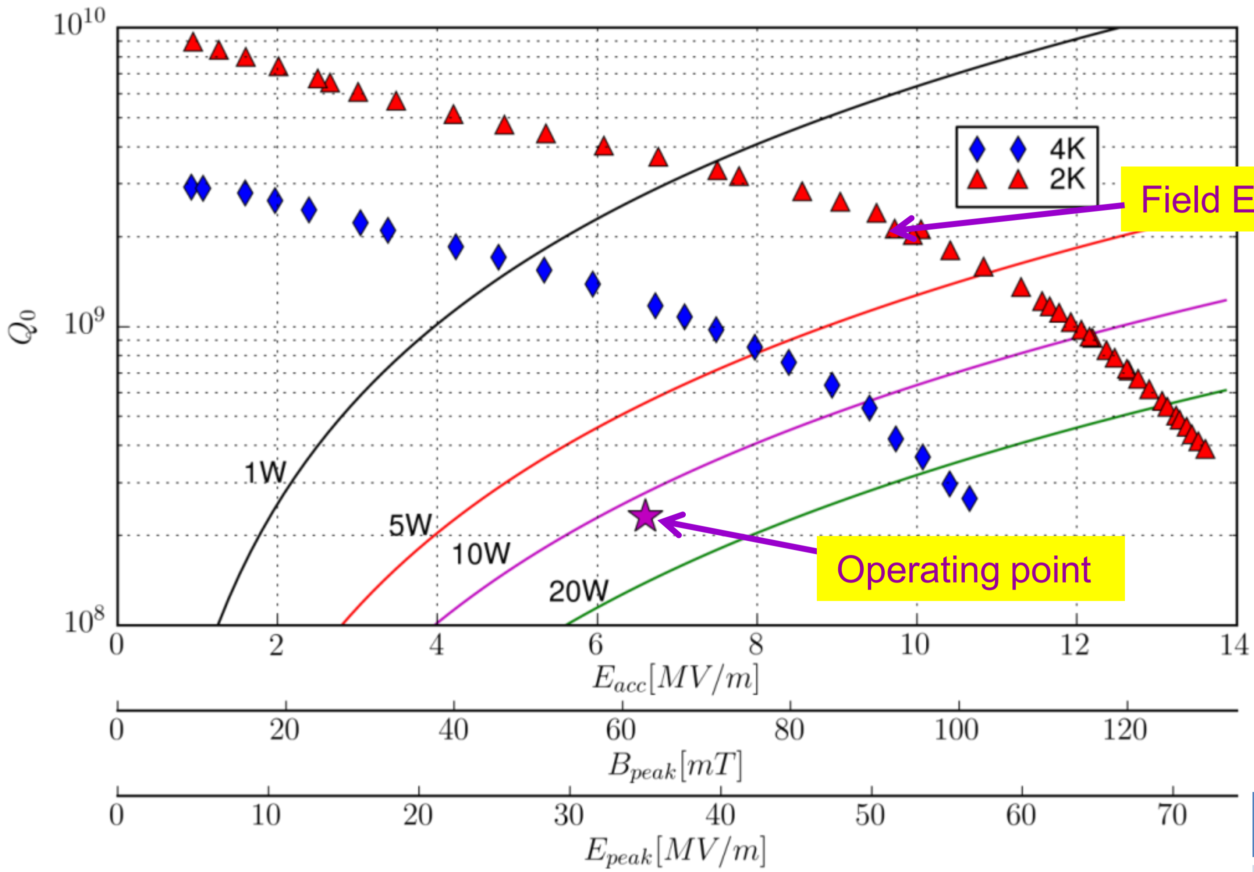
Prototype cavities fabricated through domestic vendors

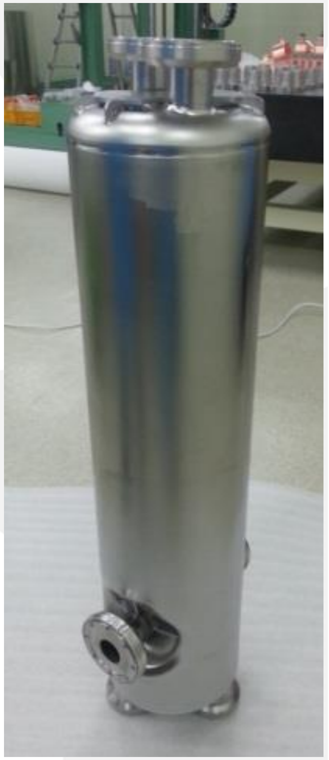
Parameters	Unit	QWR	HWR	SSR1	SSR2
β_g	-	0.047	0.12	0.30	0.51
F	MHz	81.25	162.5	325	325
Aperture	mm	40	40	50	50
QR_s	Ohm	22	42	94	112
R/Q	Ohm	468	310	246	296
V_{acc}	MV	1.1	1.5	2.4	4.1
E_{peak}	MV/m	35	35	35	35
B_{peak}	mT	57	55	58	64
$Q_{calc}/10^9$	-	2.1	4.2	9.0	10.5
Temp.	K	4.5	2	2	2

(E_{peak} = 35MV/m)

QWR prototype test

Tested in collaboration with TRIUMF





- QWR designed by the IBS, fabricated by domestic vendors met the specification, tested at the TRIUMF.
- QWR achieved 160% of design at 4K test.
- QWR achieved 210% of design at 2K test.

LFD	-19.8 Hz/(Mv/m)^2
df/dp	-42.9 Hz/Torr
BCS	0.14 nΩ (2K) 4.7 nΩ (4K)
Residual	2.5 nΩ

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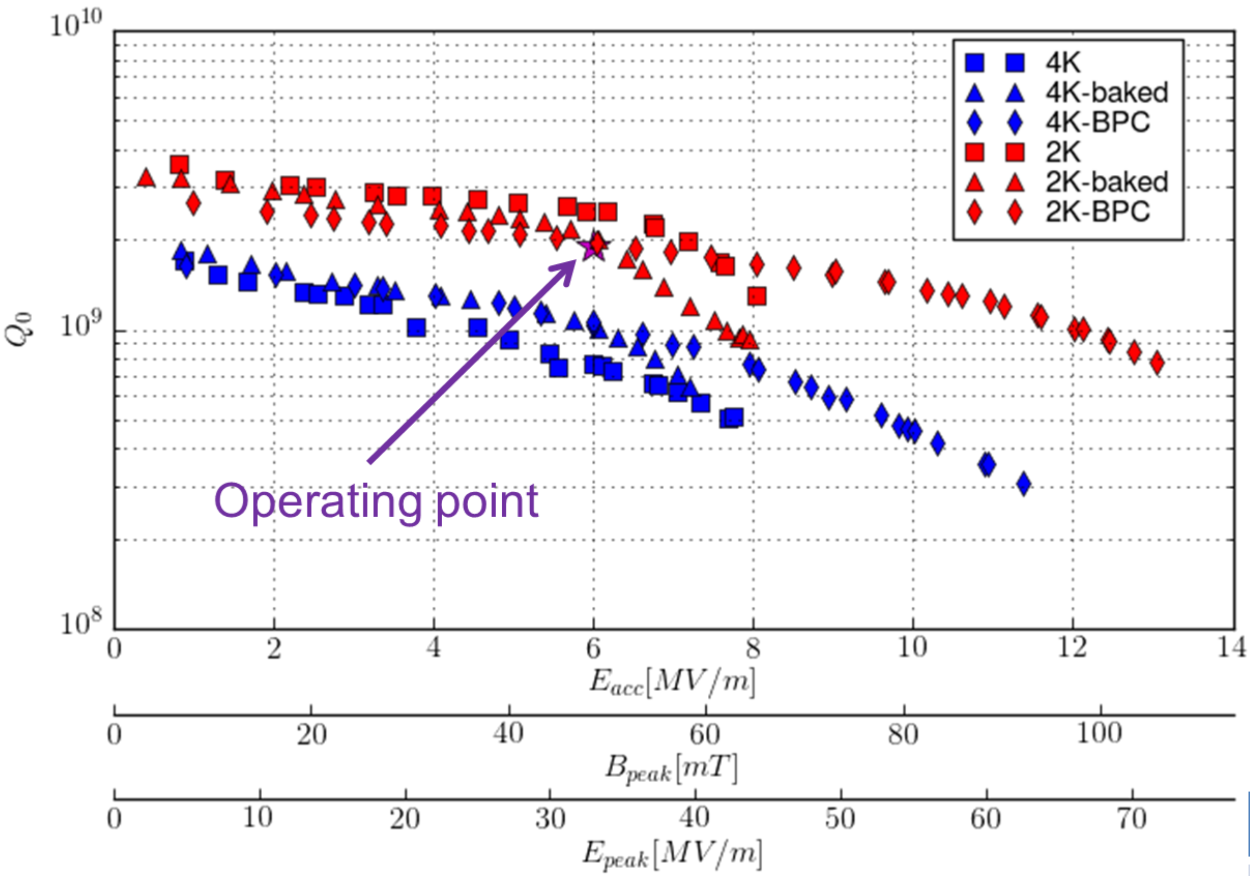
HWR prototype test

Tested in collaboration with TRIUMF

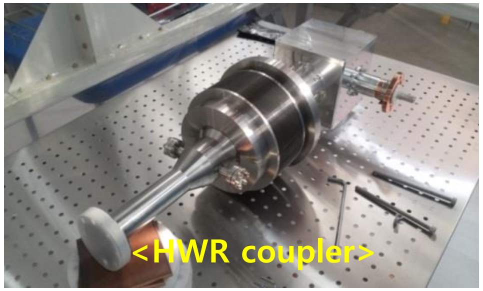


- The prototype met the specification and achieved more than 200% of design field at 2K,
- But need to improve the Q factor at 2K
- Design change to remedy the multipacting band near the operating point.

LFD	-8.8 Hz/(Mv/m)^2
df/dp	-10.8 Hz/Torr
BCS	0.11 nΩ (2K) 9.8 nΩ (4K)
Residual	16.8 nΩ

RF Couplers

In collaboration with IHEP, KEK

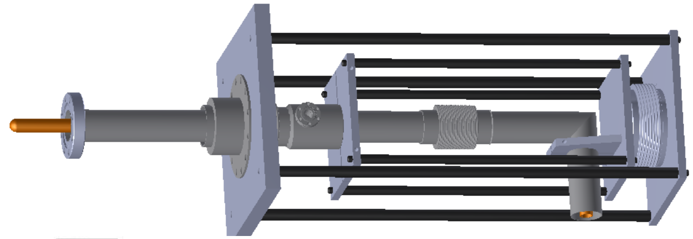

<HWR coupler>


<Power meter, vacuum gauge>

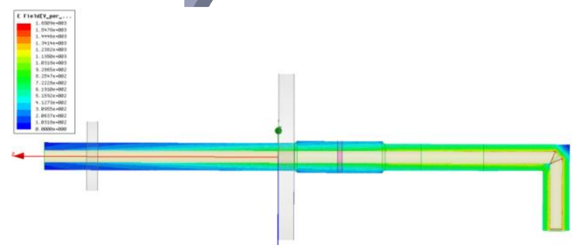

<High power test>

HWR Coupler

High power test: TW 16kW, SW 5kW
Frequency: 162.5 MHz
Nominal RF power: 5kW
In collaboration with IHEP



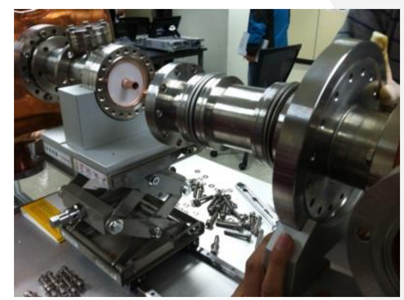
QWR Coupler
Frequency: 81.25 MHz
Nominal RF power: 4 kW
In collaboration with KEK



SSR Coupler

Frequency: 325 MHz

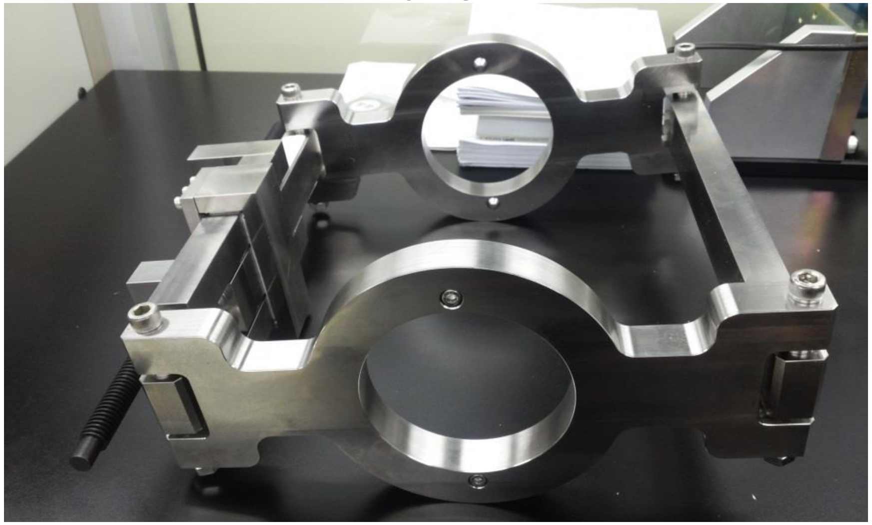
Nominal RF power: 20 kW

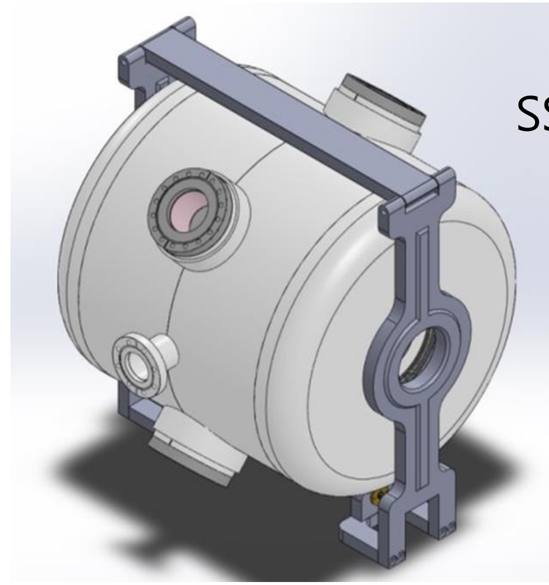



High power test in progress

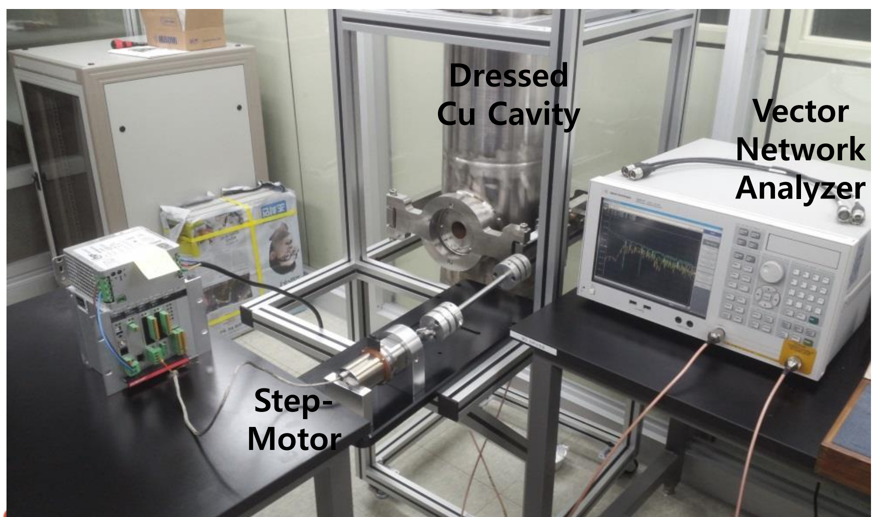
Tuners

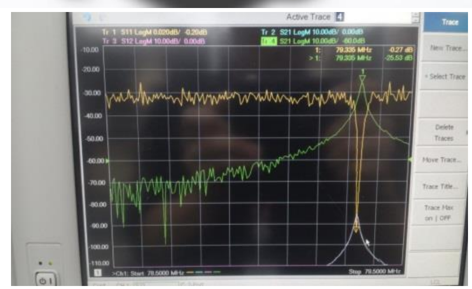
Tuner



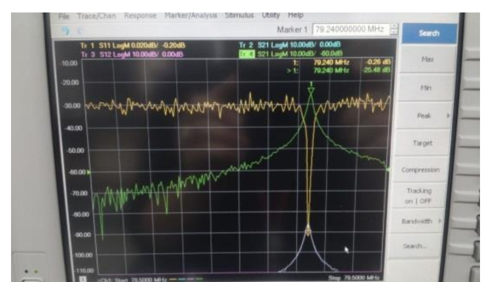


SSR with tuner





81.1MHz



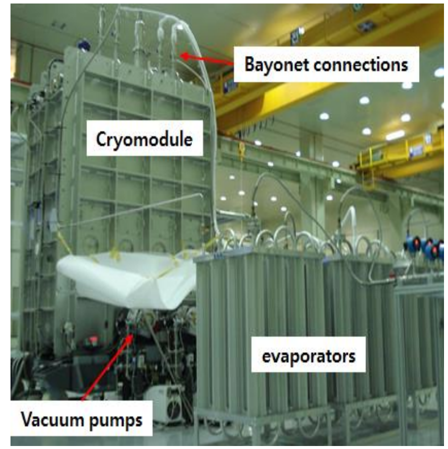
80.99MHz

Prototype Cryomodules

QWR Cryomodule

HWR1 Cryomodule

HWR2 Cryomodule



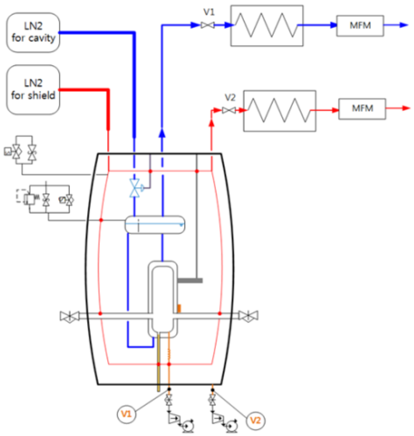
SSR1 Cryomodule

SSR2 Cryomodule

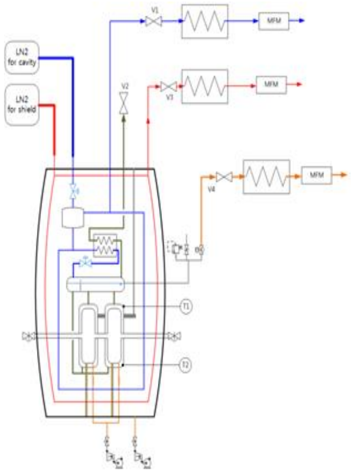
Module	Thermal load (4.5K equivalent, W) Without margin		
	Static	Dynamic	Total
QWR	227	532	760
HWR1	389	557	945
HWR2	682	1,459	2,141
SSR1	475	1,014	1,489
SSR2	790	5,009	5,800
Total	**2,563**	**8,572**	**11,135**

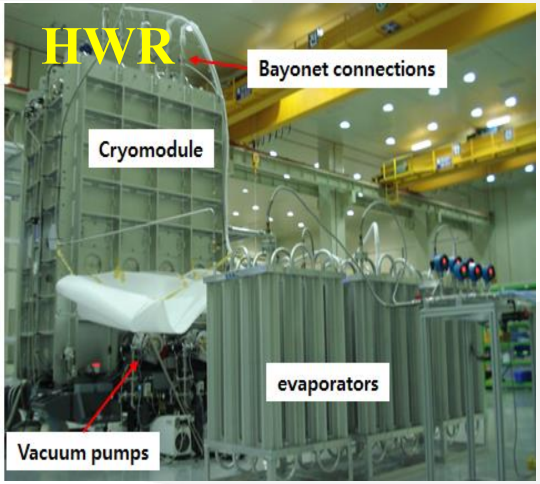
	Type	No of Cavities per Cryomodule	No of Cryomodules
SCL1	QWR	1	22
	HWR1	2	13
	HWR2	4	19
CSS	HWR1	2	2
SCL2	SSR1	3	23
	SSR2	6	23
SCL3	QWR	1	22
	HWR1	2	13
	HWR2	4	18
P2DT	HWR1	2	1

QWR/HWR Cryomodule Prototyping



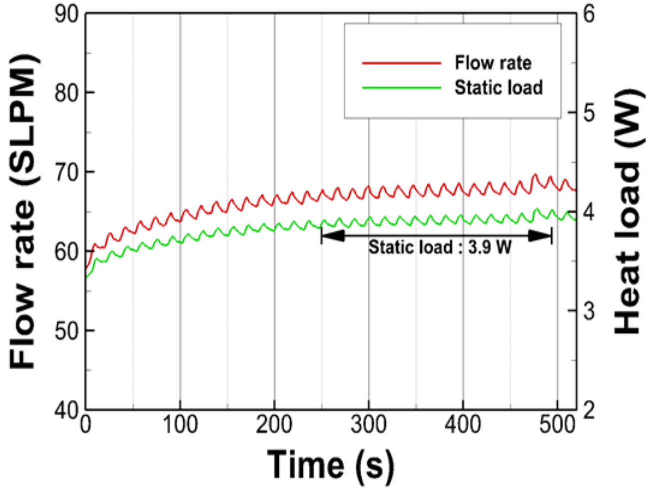
P&ID and photo for QWR cryomodule test apparatus





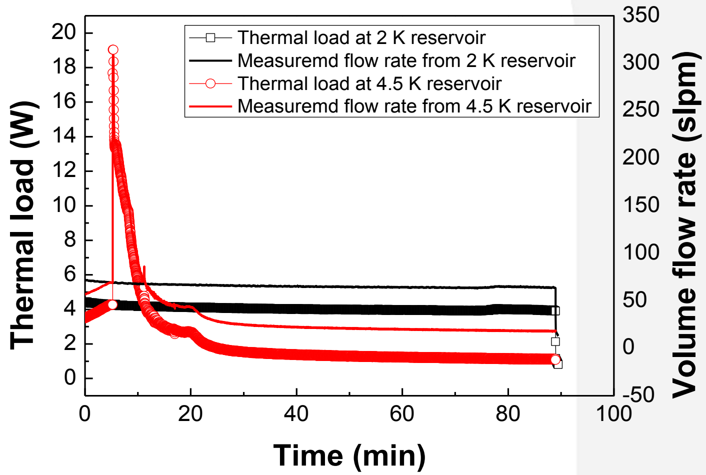
P&ID and photo for HWR cryomodule test apparatus

*Design :   Static Heat Load(3.2 W)
*Measm'nt : Static Heat Load(3.9 W)



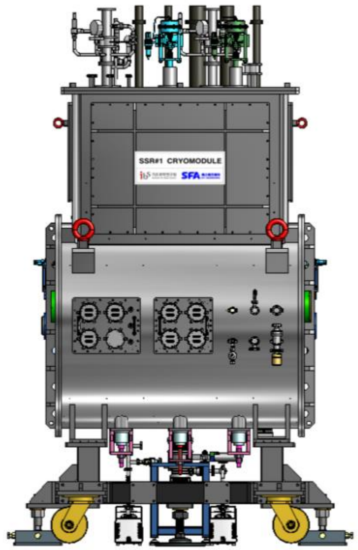
Static load by evaporated mass flow rate

* Design : Static Heat Load (14.7 W)
* Measm't: Static Heat Load (13.5 W)



Static load by evaporated mass flow rate

SSR1/SSR2 Cryomodule Prototyping



SSR1 cryomodule

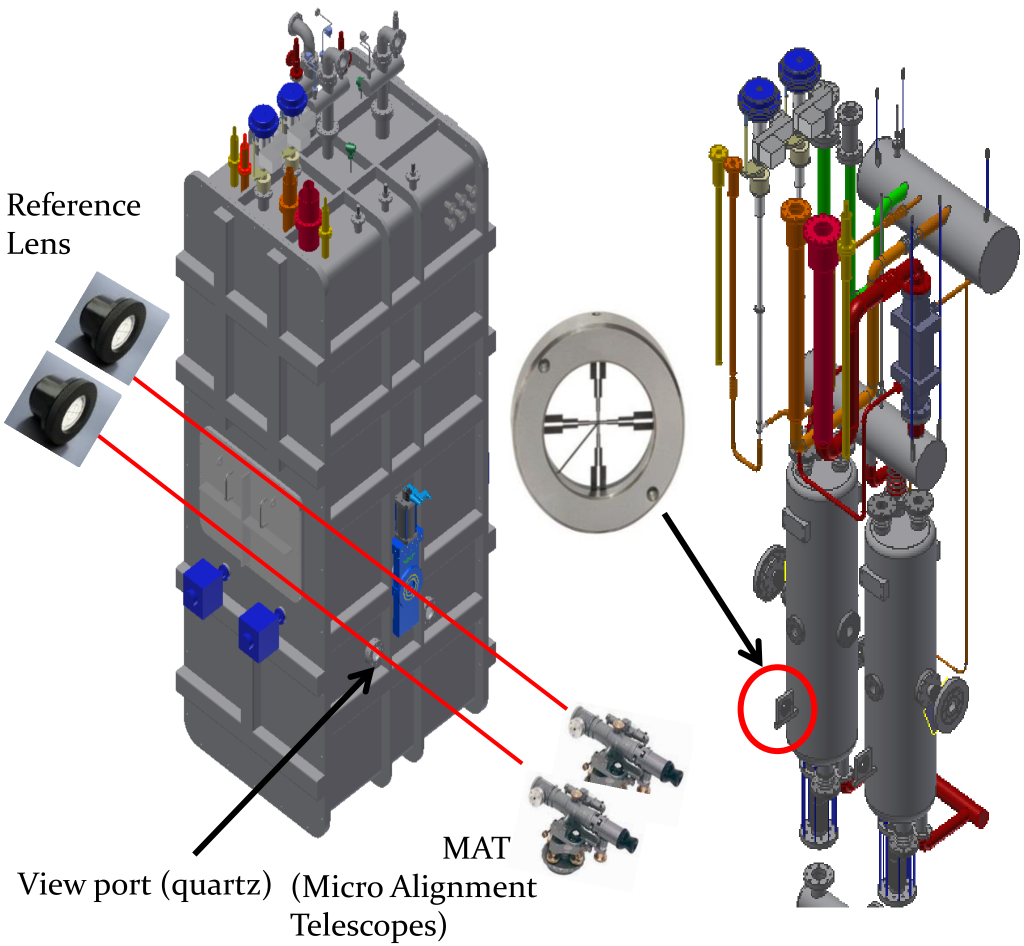
Vacuum beamline	TBM
Vacuum insulation	TBM
Cav stat load	TBM
LN_2 cooldown	done

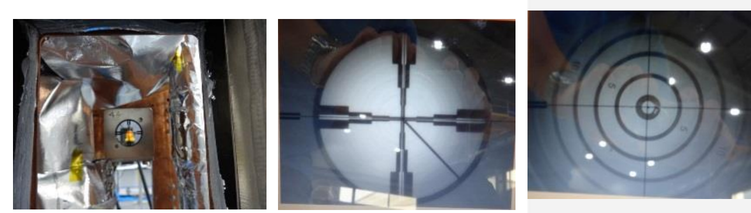
SSR2 cryomodule

Vacuum beamline	1.1e-7
Vacuum insulation	1.1e-6
Cav stat load	TBM
LN_2 cooldown	done

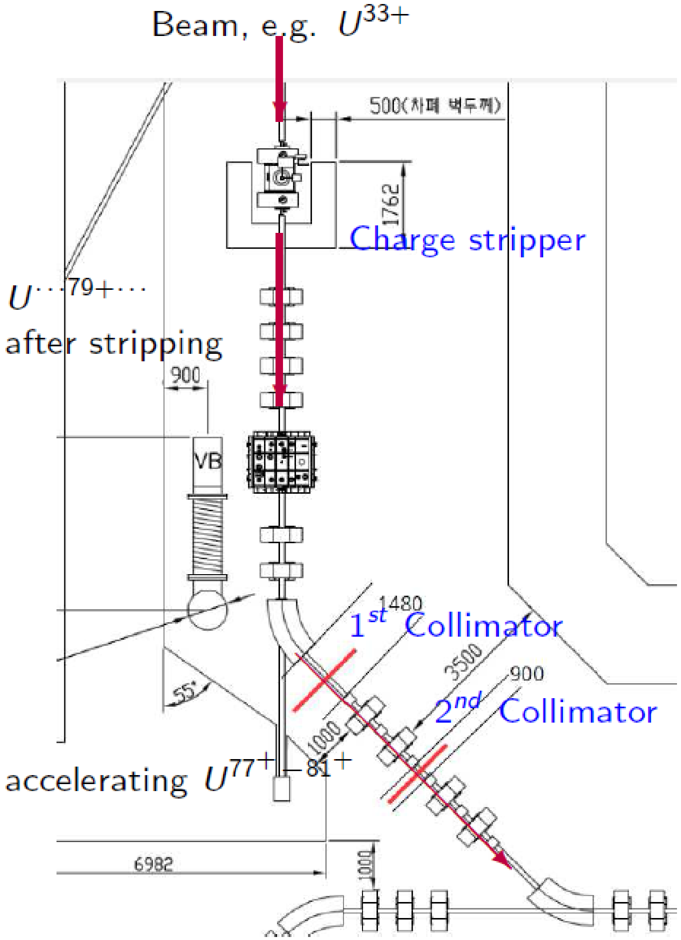
Cryomodule alignment

Cryomodule alignment test is underway.

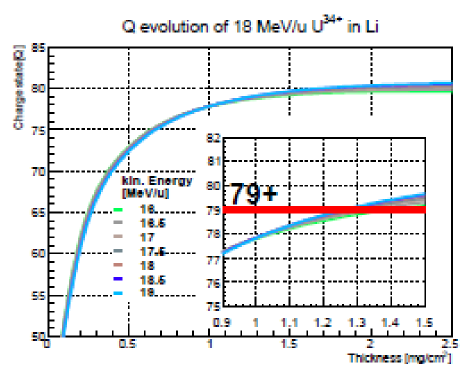


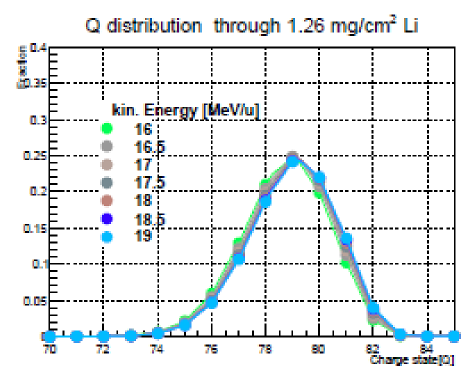


Lithium Charge Stripper



- ❖ 90° bending section
  - Charge stripping to achieve high charge state
  - Collimation of unwanted charge state beams
- ❖ Charge stripper
  - Li charge stripper is the baseline design.
  - Carbon stripper can be used for low power op.
  - Design of the stripper and prototyping are underway.

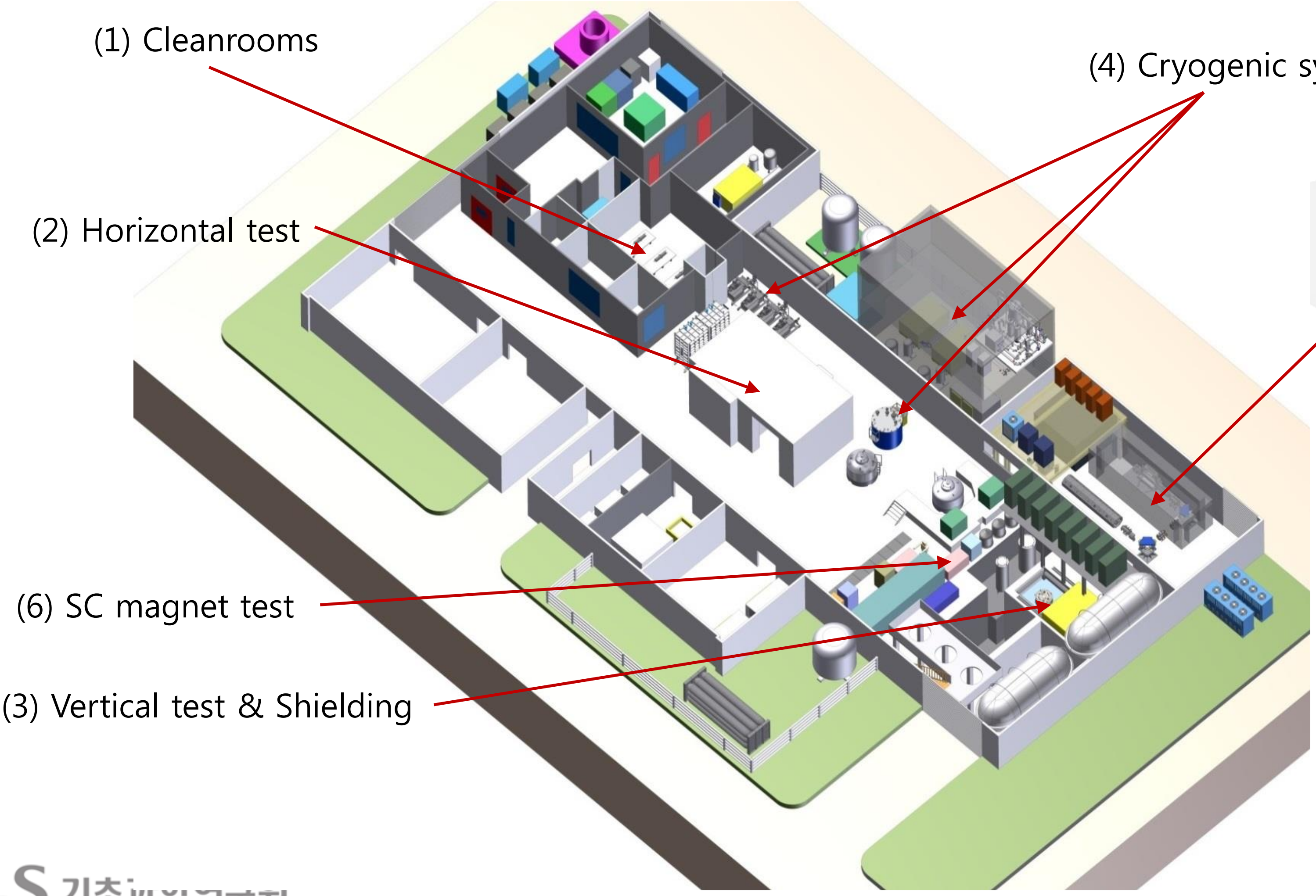




	Optimized thickness [mg/cm^2]	Optimized thickness [μm]	Incident energy [MeV/u]	Final Energy [MeV/u]	Amounts of high 5 charge state [%]
Carbon	1	$\sim$ 5	18	17.6	91
Lithium	1.26	$\sim$ 25	17	16.5	89

SRF Test Facility

Remodeling of the facility underway.
To be completed by April 2016.



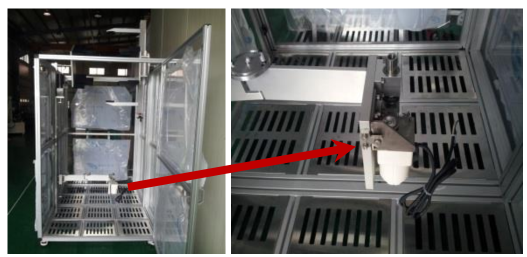
Equipment for SRF Test Facility

DI water system (completed)

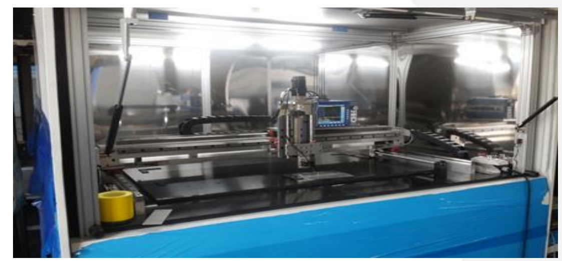
Vacuum Furnace (completed)

Cryostat (completed)

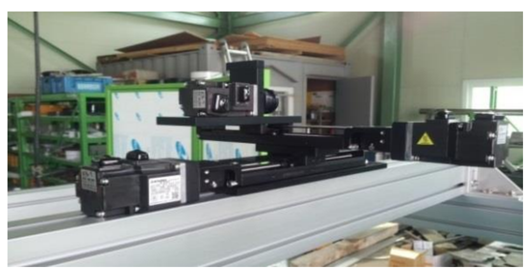
HPR (completed)



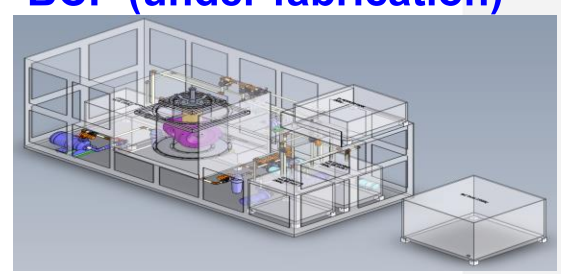
ECT (completed)



Field profiler (completed)

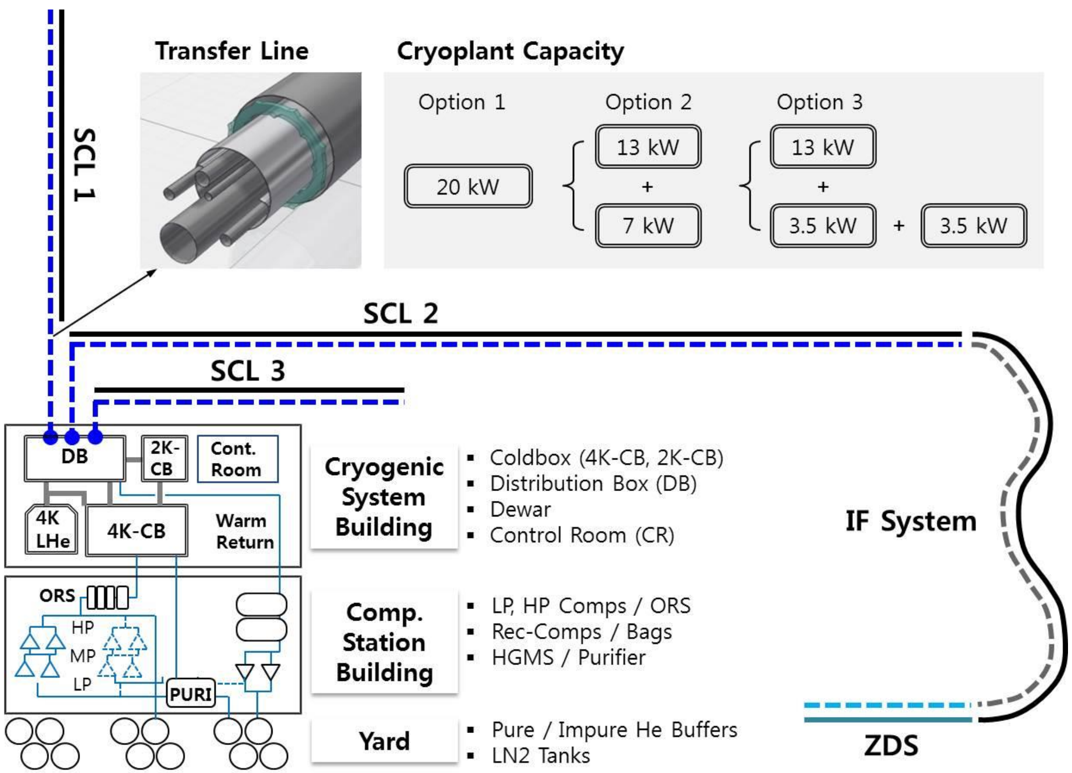


BCP (under fabrication)



Cryogenic System

- **Required Cryo-Plant Capacity : 20 kW @ 4K with 50% margin**



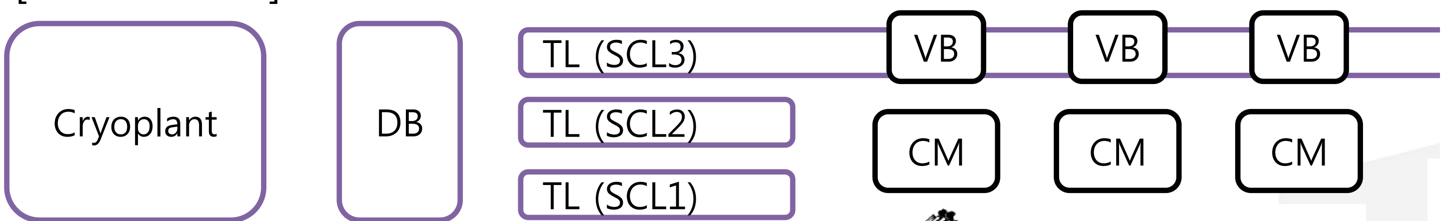
Load	SCL 1	SCL 2	SCL 3
Static	1.5 kW	3.9 kW	1.5 kW
Dynamic	1.95 kW	9.0 kW	1.95 kW
Total	19.8 kW @ 4.5 K		

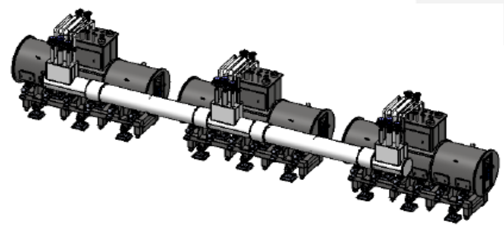
	2K Load	4K Load	Shield
Temperature	2.1 K	4.5 K	40K
Pressure	41 mbar	3 bar	20 bar
Static load	248 W	2,182 W	13,123 W
Dynamic load	2,853 W	338 W	64 W
Total load @ 4.5 K	9.3 kW	2.5 kW	1.3 kW
Plant capacity	19.8 kW @ 4.5 K (w/ 50% margin)		

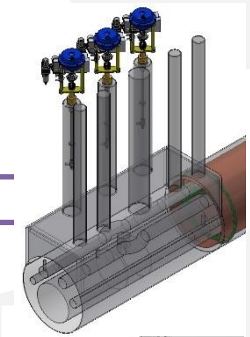
Helium Distribution System

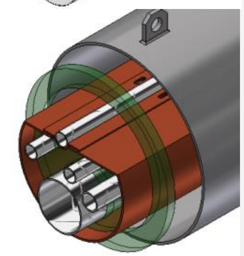
- Cryoplant : cools down He to 4K
- DB (Distribution Box): Distributing liquid He to superconducting linacs
- TL (Transfer Line) → VB (Valve Box) → CM (Cryomodule)

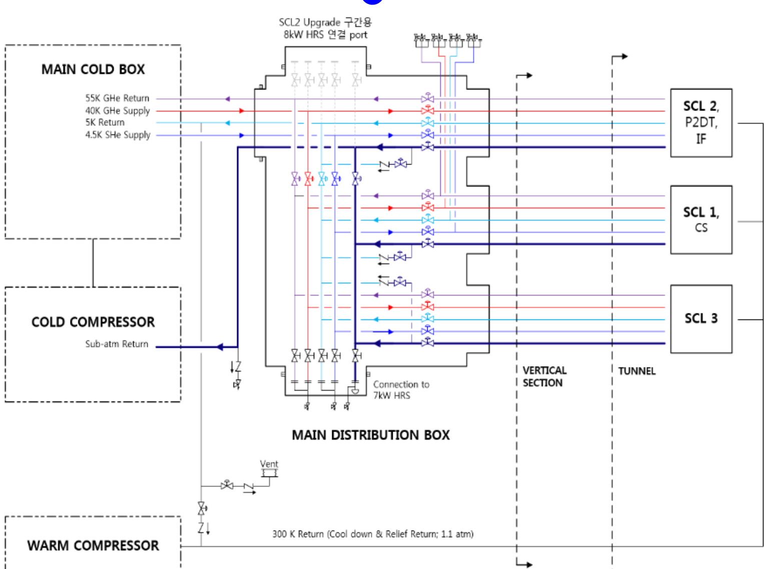
[Helium Flow]



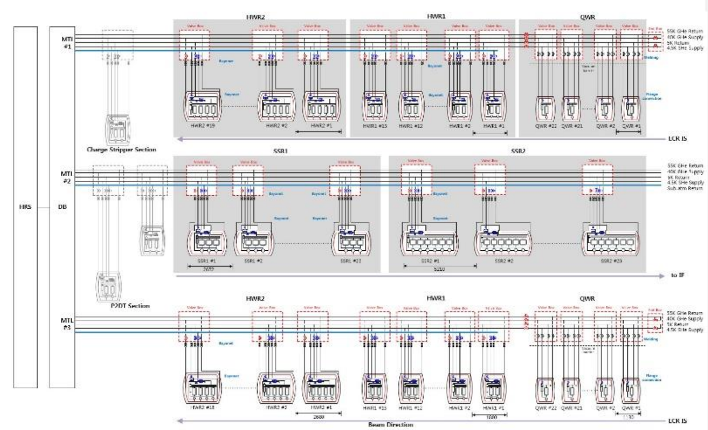








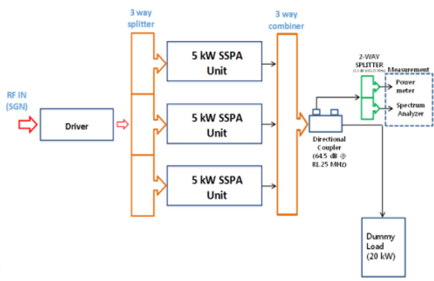
[DB P&ID]



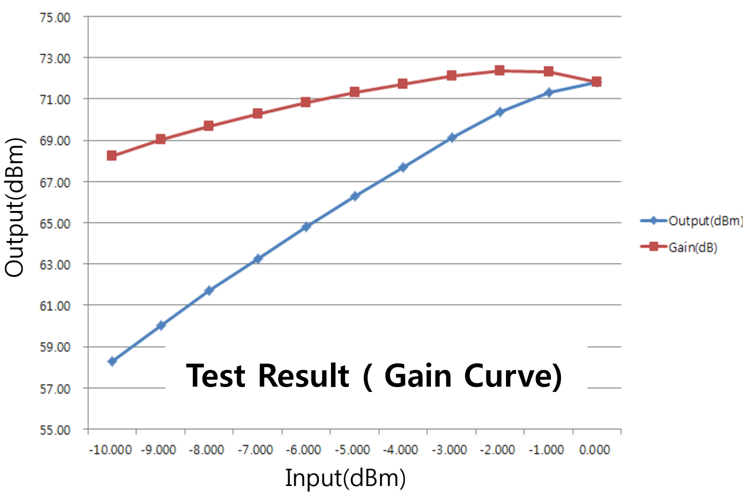
[Helium Distribution System P&ID]

RF System
based on solid-state technology

- 81.25 MHz, 15 kW Solid State Power Amplifier (for Prototype RFQ)
  → test

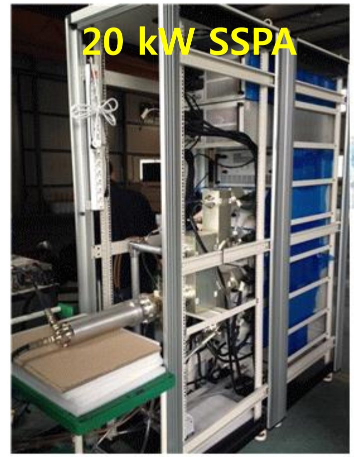


Test Block diagram



Test Result (Gain Curve)

- 325 MHz, 20 kW SSPA (for SSR2)

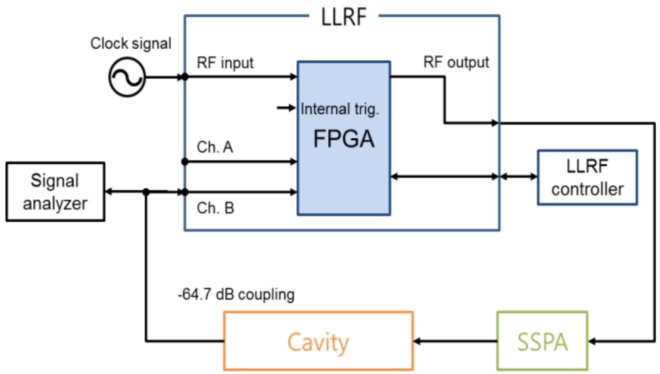


Input (dBm)	Power (dBm)	Current (A)	Gain (dB)	Efficiency (%)
-10	50.35	54.1	60.35	4.01
-9.5	52.19	67.8	61.69	4.88
-9	53.84	80.2	62.84	6.04
-8.5	55.81	99.5	64.31	7.66
-8	57.52	120.4	65.52	9.38
-7.5	59.12	145.0	66.62	11.26
-7	60.70	174.2	67.7	13.49
-6.5	62.12	206.0	68.62	15.82
-6	63.52	242.4	69.52	18.56
-5.5	64.80	280.8	70.3	21.51
-5	65.88	318.0	70.88	24.36
-4.5	67.00	360.8	71.5	27.78
-4	68.26	408.9	72.26	32.77
-3.5	69.25	456.8	72.75	36.84
-3	70.41	526.8	73.41	41.72
-2.5	71.16	575.2	73.66	45.42
-2	71.80	621.6	73.8	48.70
-1.5	72.26	657.0	73.76	51.22
-1	72.64	693.7	73.64	52.95
-0.5	72.99	722.4	73.49	55.11

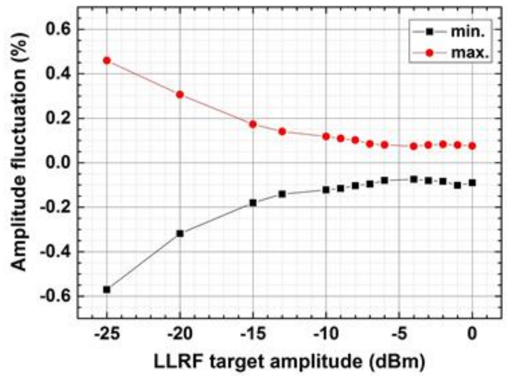
Gain Curve

RF System Test

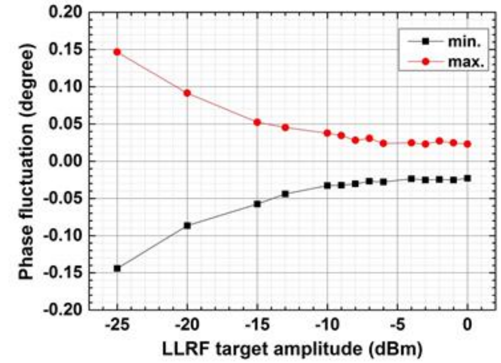
- With Superconducting Cavity (for QWR)
- With Normal Conducting Cavity (for QWR, RFQ, SSR1, SSR2)



- RF System Test Block Diagram

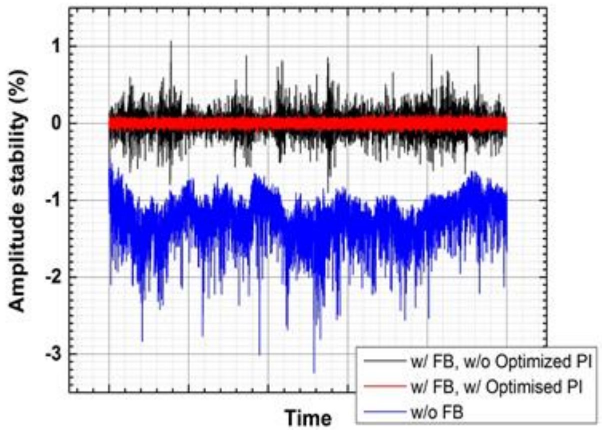


- Amplitude Stability



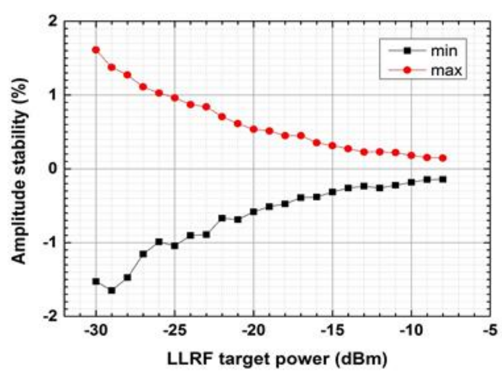
- Phase Stability

- 81.25 MHz LLRF Test

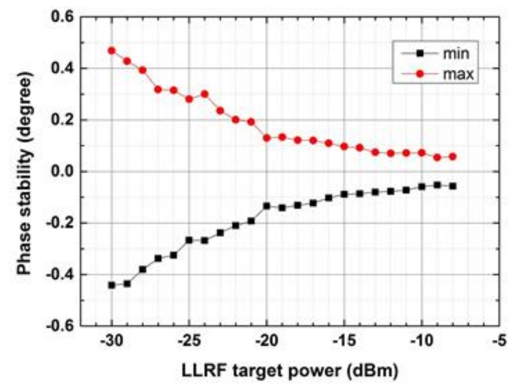


- Amplitude Stability

- RF System Test with SC Cavity



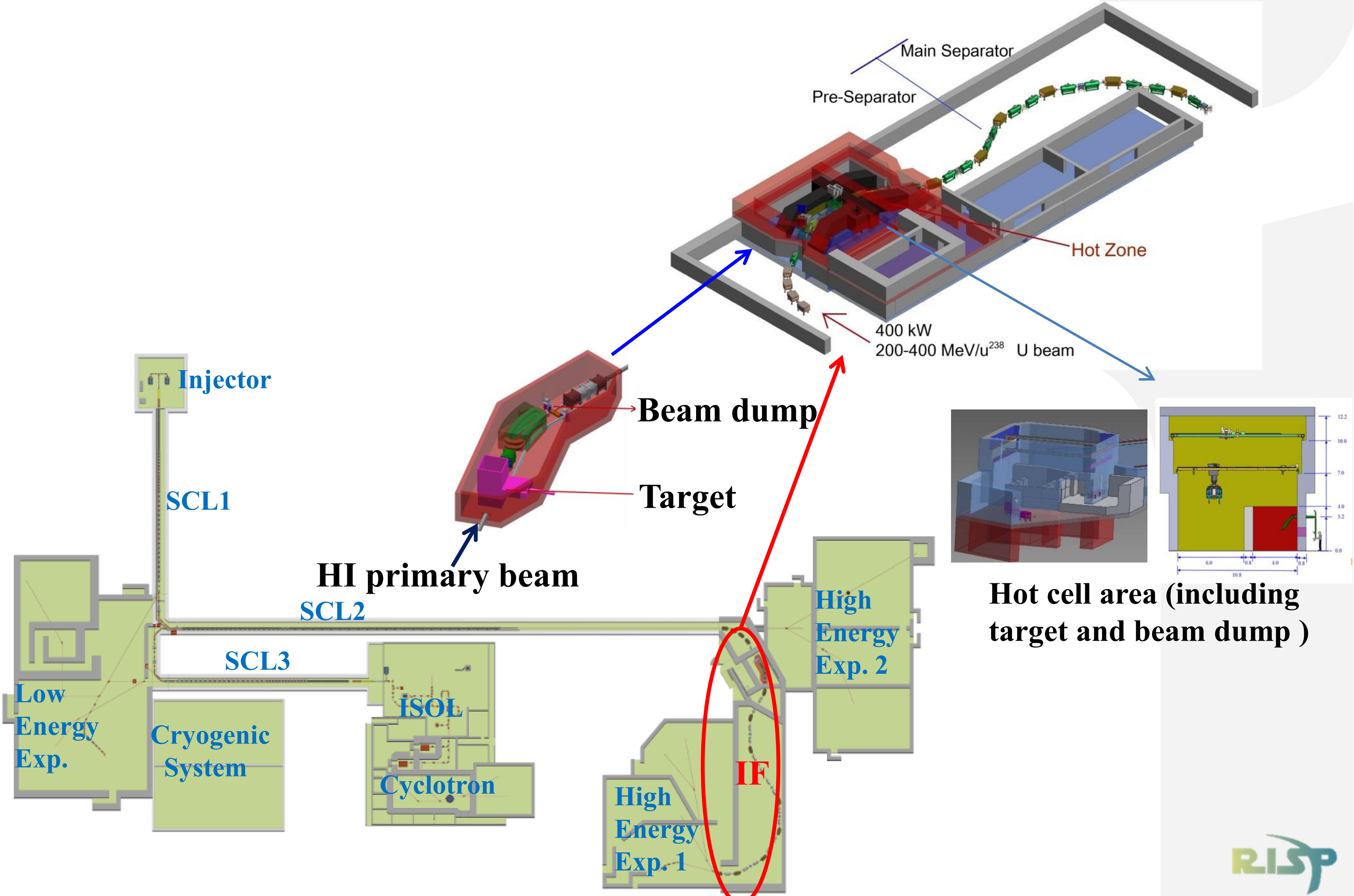
- Amplitude Stability



- Phase Stability

- 162.5 MHz LLRF Test

IF (In-flight Fragment) System



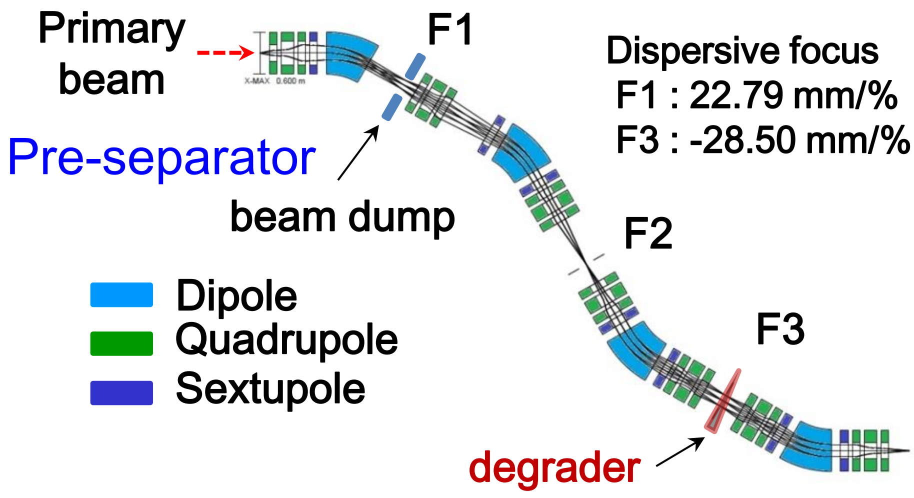
Hot cell area (including target and beam dump)

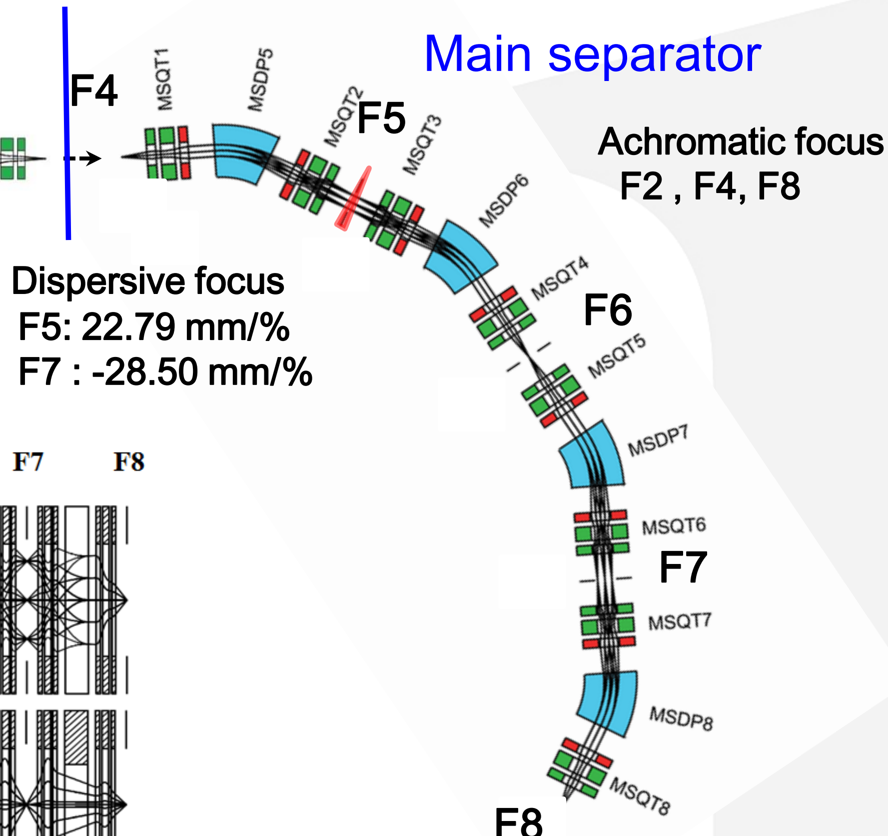
Design of the IF Separator

In-flight separator (max. $B\rho = 9.6\ Tm$)

Momentum acceptance
± 3 %

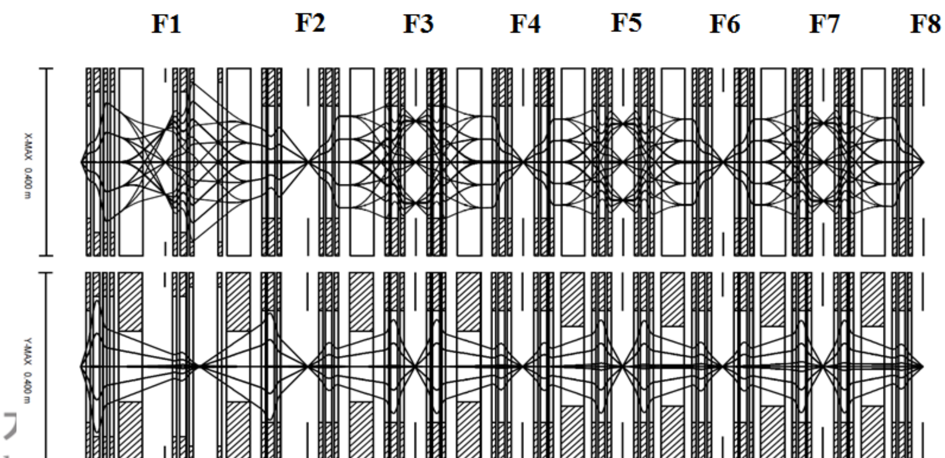
Angular acceptance
± 40 mrad in horizontal
± 50 mrad in vertical





Max. beam power: 400 kW

^{238}U beam energy: 200- 400 MeV/u

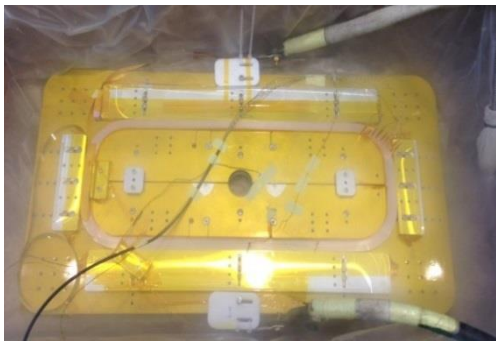


High Tc Superconducting Magnet Development

- **Coolant: 20-40 K cold He gas→ > x5 times higher Carnot efficiency compared to LHe**
- **Domestic HTS manufacturer exist (SuNam Inc.)**

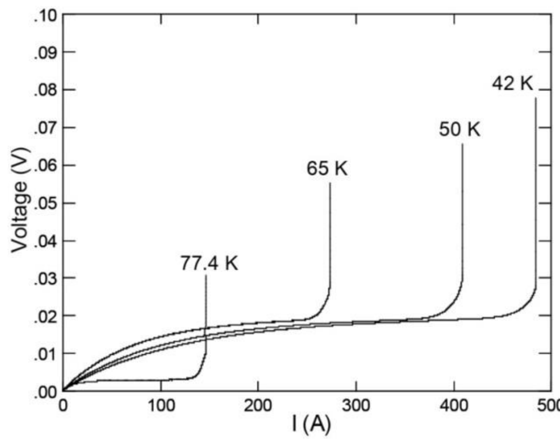
Working with Korea Electric Research Institute (KERI)

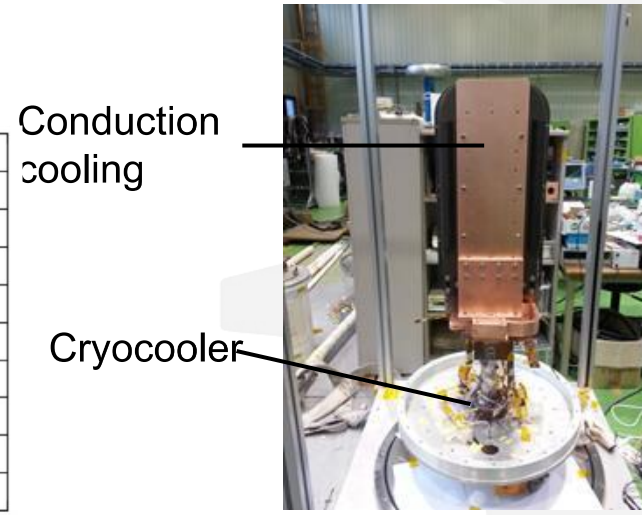
Test at 77K (LN_2)



HTS prototype coil test (LN2)

Voltage vs. current

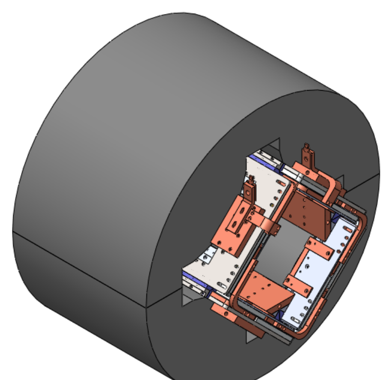


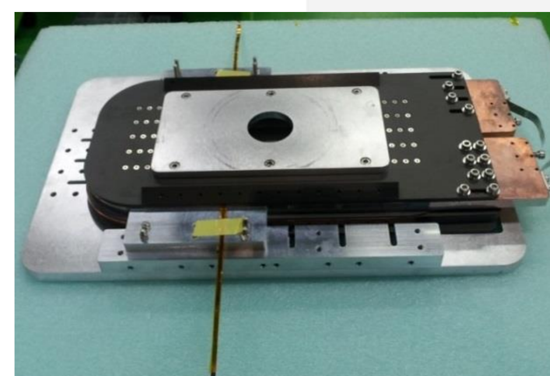


Main parameters of HTS quadrupole

Aperture radius	120 mm
Effective length	558 mm
Yoke length	480 mm
Field gradient	15 T/m
Pole tip field	1.95 T
Current density	140 A/mm^2
Turn number of turns	164 turns
Max operating current	370 A
B //c	2.1 T
Max stored energy	70 kJ

Working with Changwon Univ for design of forced-flow GHe cooling





Summary

- The RISP is the only accelerator facility in the world that has both the ISOL and IF systems.
- Technical Design Report was completed in Sep/2013 meeting the project milestone.
- Prototyping of major accelerator parts has been in progress since 2013 through domestic vendors :
  - 28 GHz SC ECR ion source was fabricated (Sep/2014)
  - RFQ prototype fabricated successfully (Oct/2014)
  - SC cavity prototypes were delivered for test (Jun/2014)
  - Cryomodule prototypes delivered (Dec/2014)
  - HTS (High Tc Superconductor) quad and dipole prototyping in collaboration with domestic institutes (Aug/2016)
- Some prototypes are in testing stage.
  - ECR ion source, RFQ prototype, MEBT buncher
  - QWR vertical test (Feb/2015), HWR vertical test (Apr/2015) with successful results
  - Prototype cryomodules

Collaboration

The RISP appreciates the collaboration with

- ANL
- CEA
- FNAL
- IHEP
- KEK
- SPIRAL2
- TRIUMF


Thank you for your attention!
감사합니다