Performance test of prototype cryomodule for RAON

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On behalf of Acceleration Systems Team

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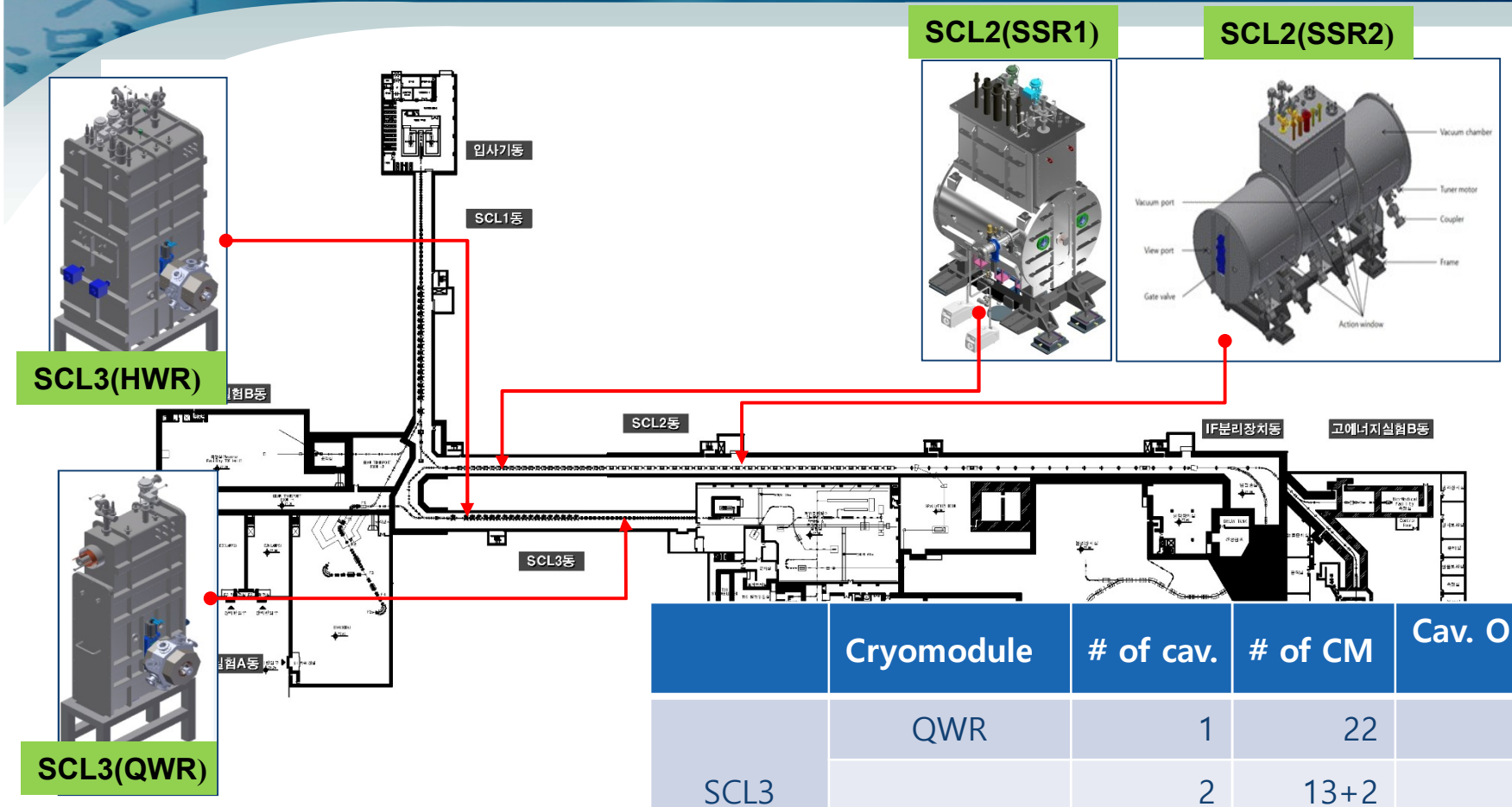
Outline

- Introduction
- Cryomodule and RF system
- Test results: QWR and HWR
- Summary

Introduction



	Cryomodule	# of cav.	# of CM	Cav. Op. T (K)
SCL3	QWR	1	22	4.5
	HWR	2	13+2	2.05
		4	19	2.05
SCL2	SSR1	3	23	2.05
	SSR2	6	23+2	2.05

Bending section(P2DT): 2 HWR1 cryomodule

SC cavity specifications

▪ SC cavity specification

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	1.4	2.5	4.1
E_{peak}	MV/m	35	35	35	35
B_{peak}	mT	57	55	55	67
$Q_{calc}/10^9$	-	0.24	1.45	>5	>5
Temp.	K	4.5	2.05	2.05	2.05

▪ Coupler for SC cavity specification

Parameters	Unit	QWR	HWR	SSR1	SSR2
Cav. β_g	-	0.047	0.12	0.30	0.51
f	MHz	81.25	162.5	325	325
Interface	inch	3.375	3.375	6	6
Qext/10^6		2	2	5.2	TBD
Pin	kW	<2	<4	<15	<20
Trans.	inch	$1\frac{5}{8}$	$1\frac{5}{8}$	$3\frac{1}{8}$	$4\frac{1}{16}$
Imped.	Ohm	50	90	100	100

Specifications of RF system

- **HPRF : RF Source (Solid State Power Amplifier)**
  RF Transmission Line (Coaxial type rigid transmission line)

	Cavity	Quantity (EA)	Frequency (MHz)	RF Power (kW)	RF Transmission Line
SCL1	RFQ	2	81.25	80	6 1/8 inch EIA
	Rebuncher	4	81.25	20,15,4	3 1/8 inch EIA
	QWR	22	81.25	4	1 5/8 inch EIA
	HWR	102	162.5	4	1 5/8 inch EIA
SCL2	SSR1	69	325	8	3 1/8 inch EIA
	SSR2	144	325	20	4 1/16 inch EIA
SCL3	RFQ	2	81.25	80	6 1/8 inch EIA
	Rebuncher	4	81.25	20,15,4	3 1/8 inch EIA
	QWR	22	81.25	4	1 5/8 inch EIA
	HWR	102	162.5	4	1 5/8 inch EIA
P2DT & CSS	HWR	6	162.5	4	1 5/8 inch EIA

- **LLRF: RF Controller (LLRF), RF Reference Line**

RF Dynamic Phase Error Requirement	**±1 degree (Peak-to-Peak)**
RF Dynamic Amplitude Error Requirement	**±1 % (Peak-to-Peak)**

Cryomodules for SCL3

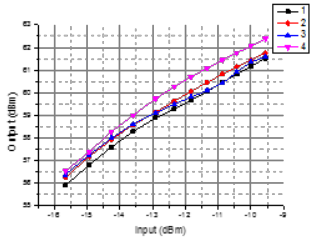
QWR cryomodule

HWR cryomodule A

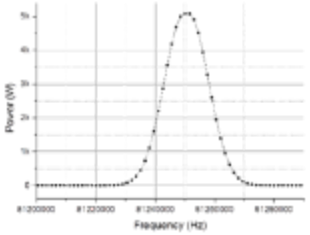
HWR cryomodule B

Prototyping of High Power RF Amplifier

- **QWR RF System**



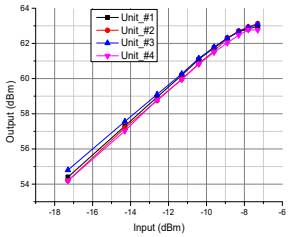
- SSPA 1 Unit Test



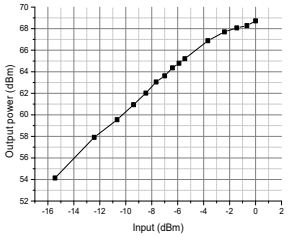
- Combined Mode Test

Specification	Value
Frequency	81.25 MHz
Output Power	5 kW

- **SSR1 RF SSPA**



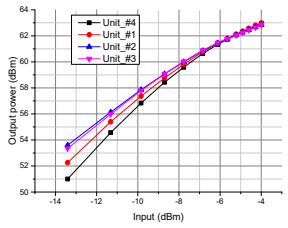
- SSPA 1 Unit Test



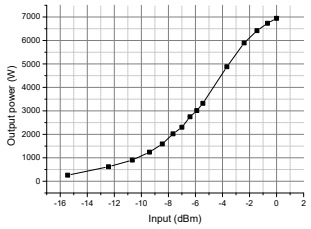
- Combined Mode Test

Specification	Value
Frequency	325 MHz
Output Power	7 kW

- **HWR RF SSPA**



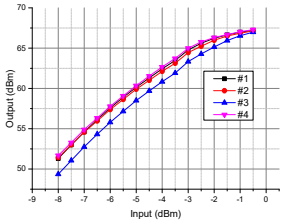
- SSPA 1 Unit Test



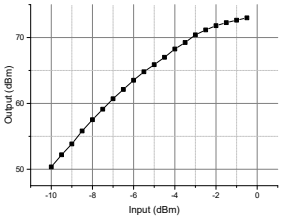
- Combined Mode Test

Specification	Value
Frequency	162.5 MHz
Output Power	7 kW

- **SSR2 RF SSPA**



- SSPA 1 Unit Test



- Combined Mode Test

Specification	Value
Frequency	325 MHz
Output Power	20 kW

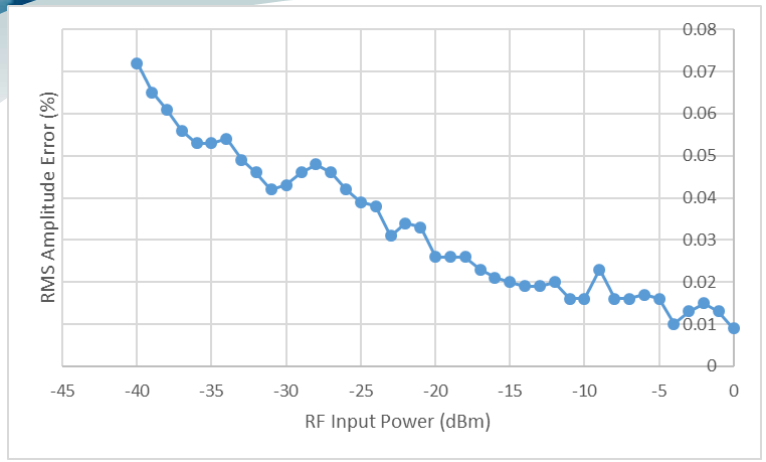
- Prototyping of high power RF amplifier was conducted.
- All amplifiers are based on solid-state amplification technology.
- Every amplifier is equipped with the circulators for protection from reflected RF.

Digital LLRF Development

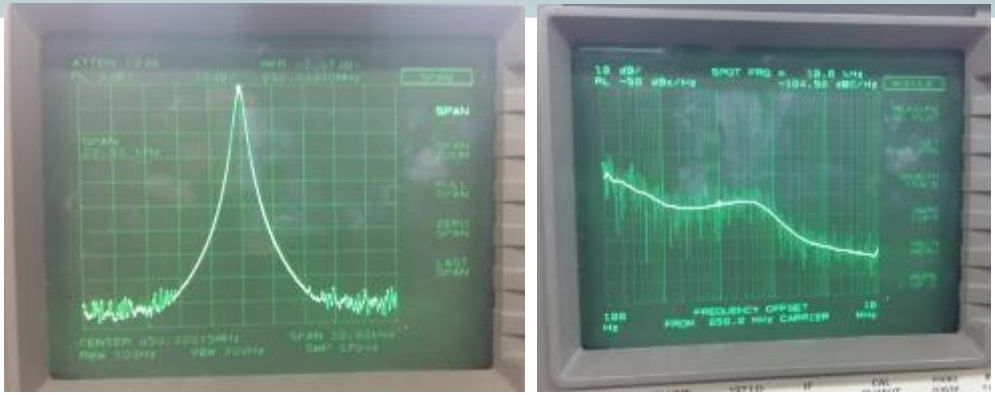
- Upgrade of analog LLRF system to digital LLRF is ongoing.
- 4 channel serial high speed ADC is adopted.
- Xilinx zynq SoC is used.
- With PLL circuit, the sampling of ADC, DAC/clocking of FPGA can be changed easily.
- One hardware can support any cavity in SCL3 and SCL2
- Generator-Driven mode and Self-Excited Loop algorithm have been implemented and being tested.

Item	Spec
RF Input	4
RF Output	1
RF ADC	AD9656 (16 bit, 4 ch, serial)
SoC	Xilinx Zynq Ultrascale ZU9EG
EPICS IOC	In Arm core of Zynq
Clock Gen	HMC7044 PLL

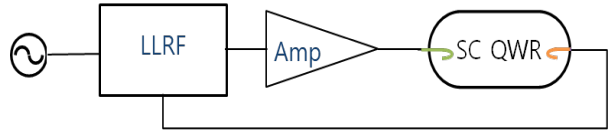
Test Result with Digital LLRF

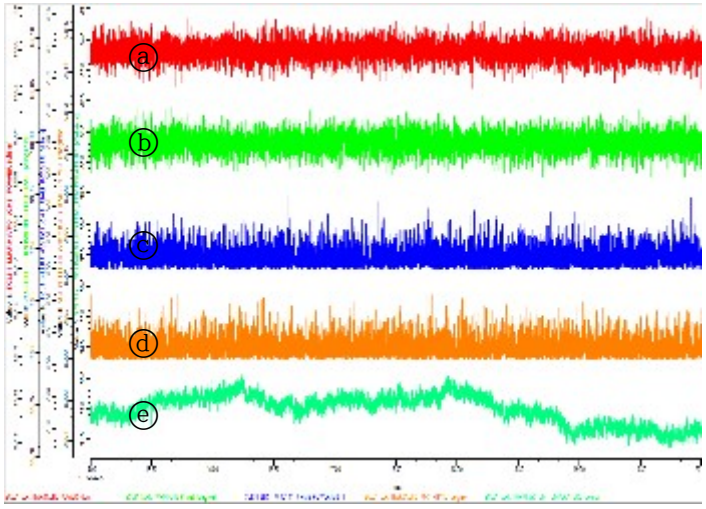


• RF measurement test (ADC test)



• PLL circuit test (up to 650 Mhz)





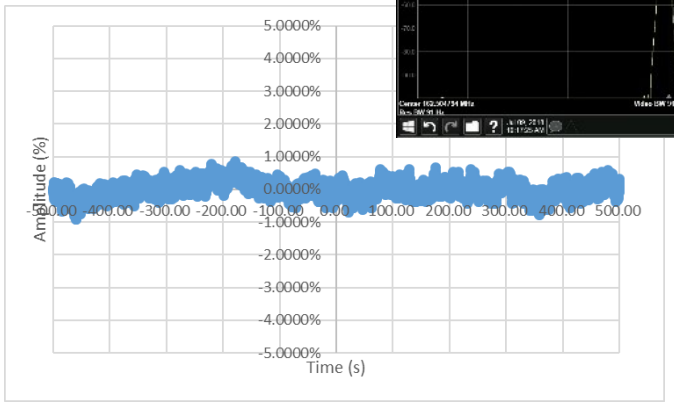
ⓐ Amplitude

ⓑ Phase

ⓒ Amplitude Stability

ⓓ Phase Stability

ⓔ Temperature

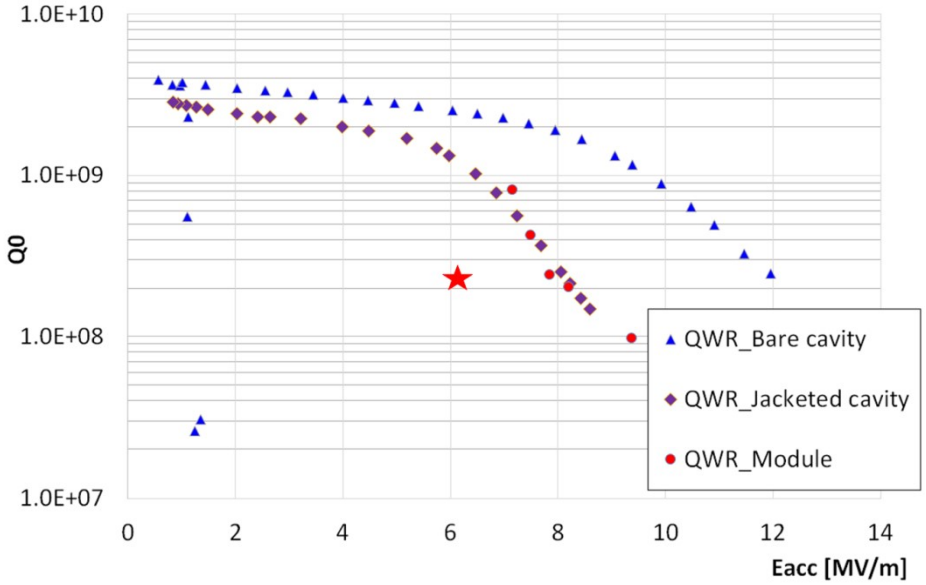


• LLRF self-stability test result

• Amplitude control and frequency tracking test in SEL mode (HWR cavity vertical Test @ Munji SRF)

Cryomodule performance test

- **QWR cryomodule**



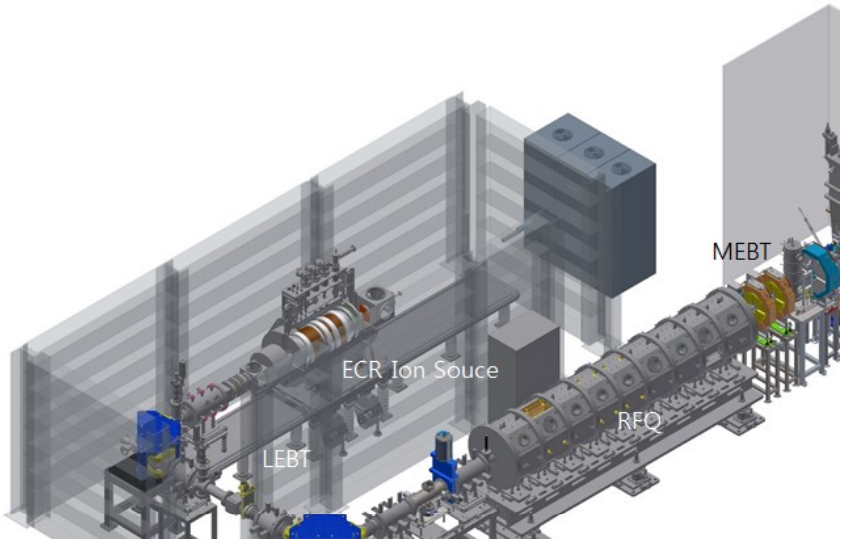
E_{acc}(MV/m)	**6.1**	6.4	7
Q (W)	**9.9**	13	23.7

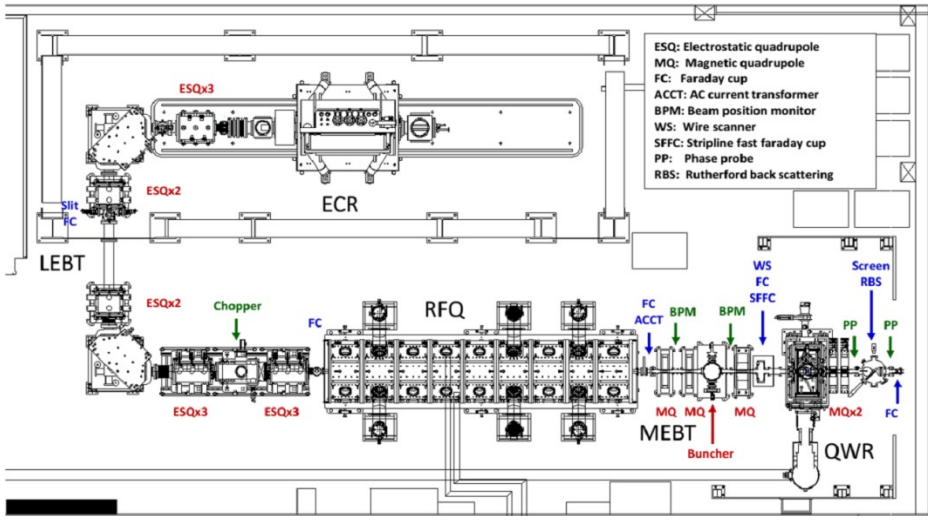
Total thermal load at various E_{acc}

Cavity: 2nd prototype(RI)
Tuner: 2nd prototype (Mirho)
Coupler: 1st prototype (Toshiba)
Cryomodule: 2nd prototype (Vitzro tech.)

Target total thermal load @ 6.1 MV/m: 25 W

QWR cryomodule in SCL demo



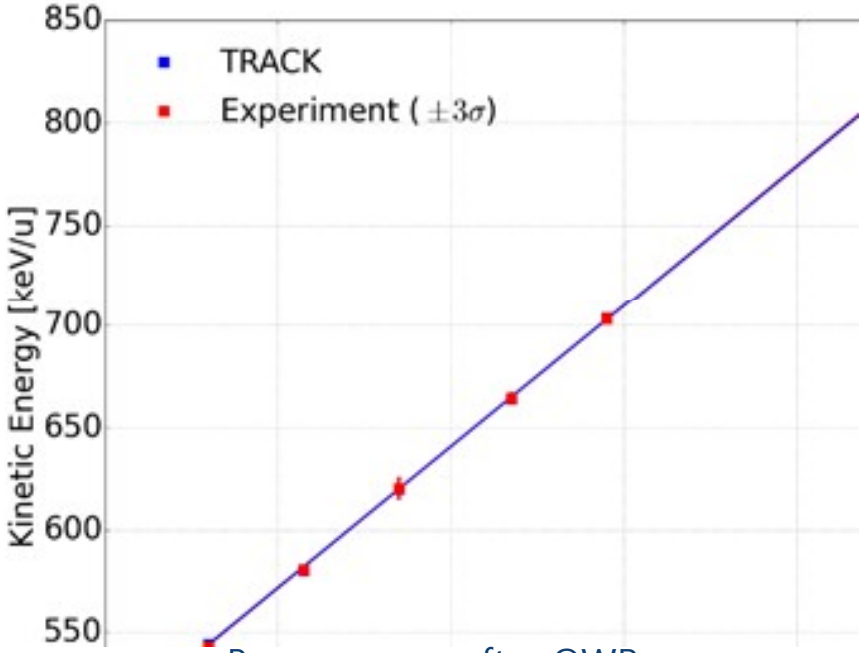


ECR-IS
LEBT(low energy beam transport)
RFQ
MEBT(medium energy beam transport)
QWR cryomodule

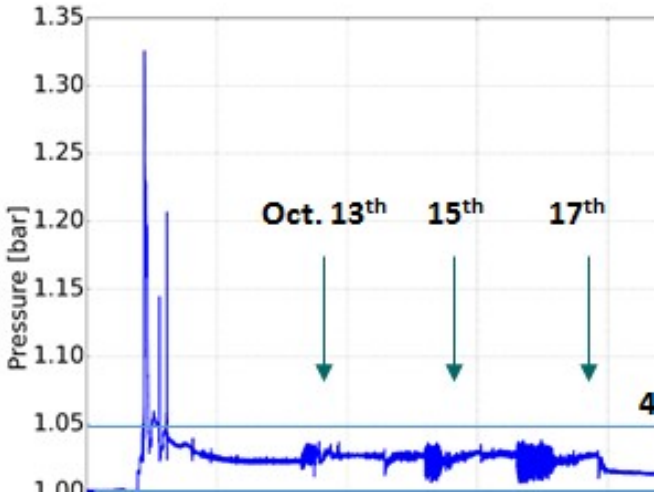
Beam parameter	Value
Particle	Oxyzen 7+
Energy	10 keV/u @ ECR
Beam current (peak)	>5uA after RFQ
Beam pulse width	100 usec.
RF pulse width (RFQ)	250 usec.
RF for QWR	CW
Repetation rate	0.1 ~ 1 Hz

Beam energy

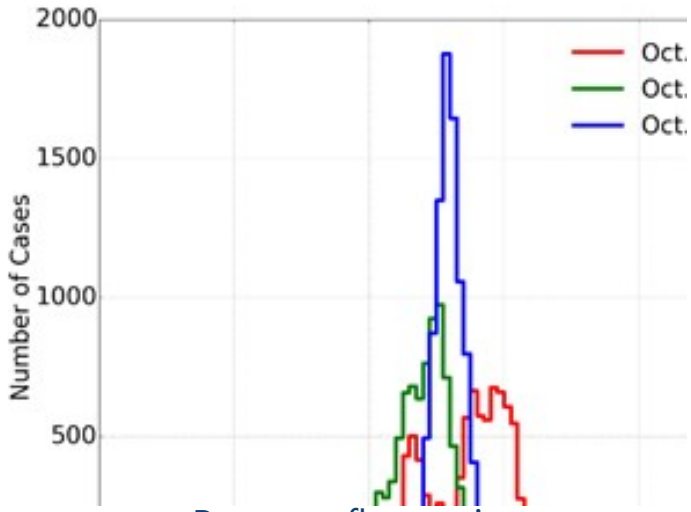
Beam energy after RFQ
(Est.: 508.5±4.0 keV/u)



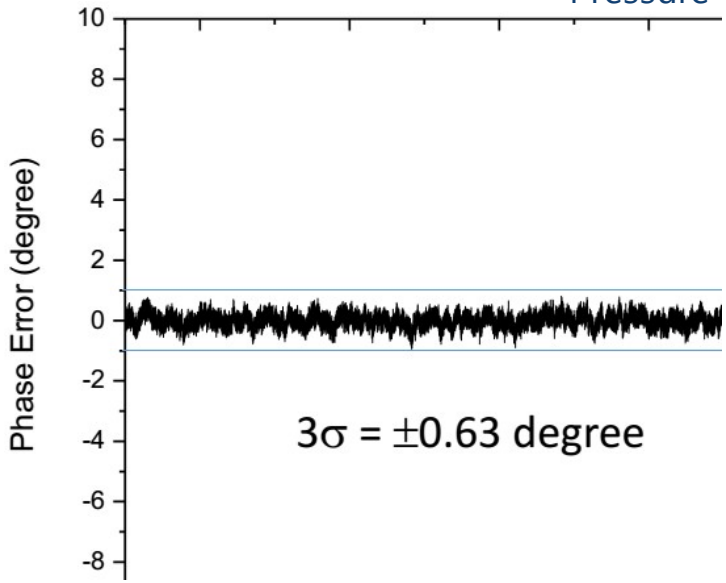
Beam energy after QWR
(703.6±2.8 keV/u)



Cool-down history

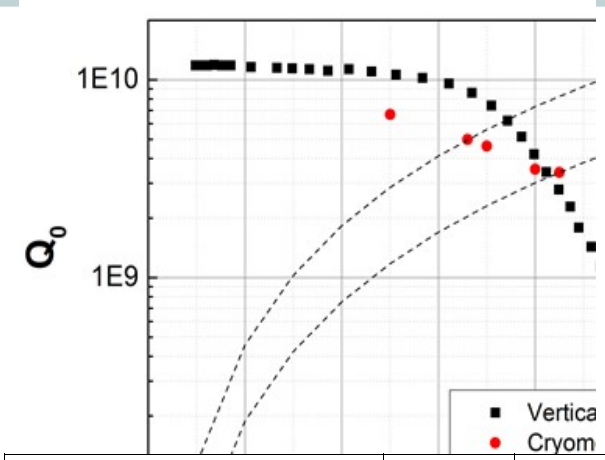


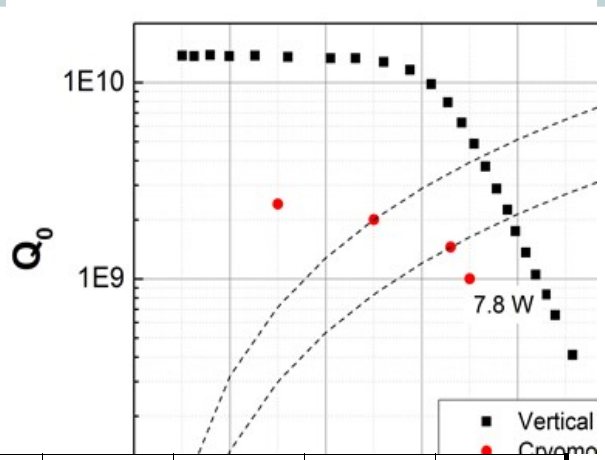
Pressure fluctuation



Phase stability during 1,000 sec.

▪ HWR cryomodule A





E_{acc}(MV/m)		3	5	6.6	7	8	8.5
Cavity #1	Q_d (W)	-	0.6	1.4	1.7	2.9	3.4
	Q_0 (10^9)	-	6.67	4.98	4.62	3.53	3.40
Cavity #2	Q_d (W)	0.6	2	4.8	7.8	-	-
	Q_0 (10^9)	2.4	2.0	1.45	1.0	-	-

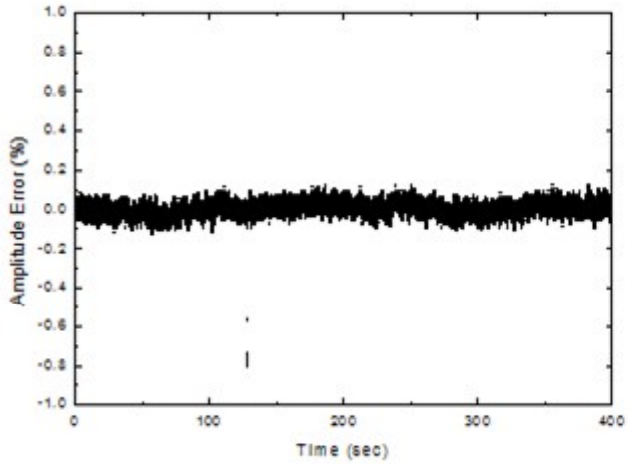
Cavity: 3rd prototype(Viztro tech.)
Tuner: 2nd prototype (Montrol)
Coupler: 2nd prototype (Toshiba, Viztro tech.)
Cryomodule: 2nd prototype (Vitzro tech.)

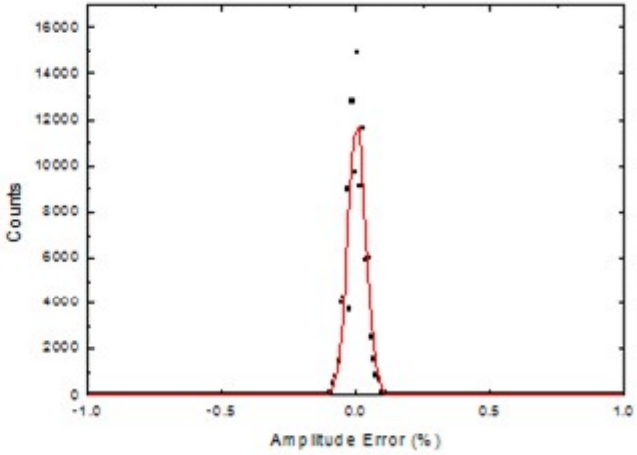
Static thermal load	Dynamic thermal load	Total thermal load
6.6 W	1.4 W (cavity#1)	12.8 W
	4.8 W (cavity#2)	

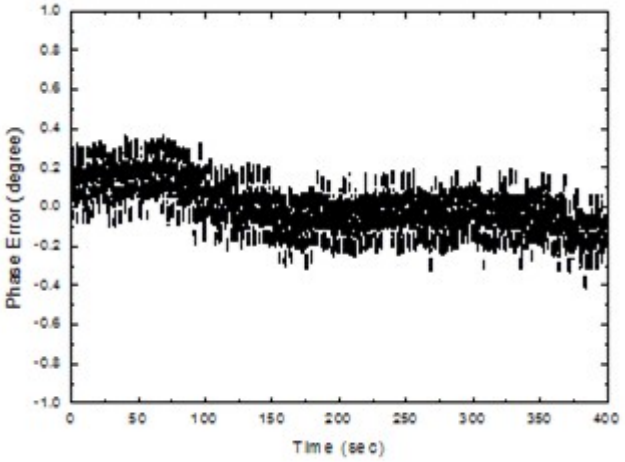
Target total thermal load @ 2.92 MV: 14.1 W

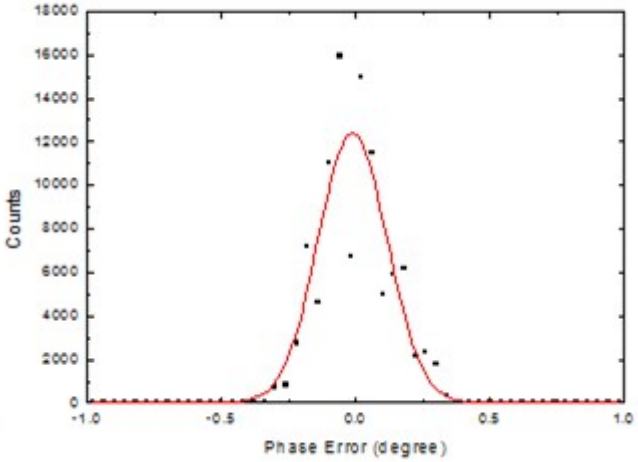
RF stability test

- Amplitude stability: 0.93% (requirement: ±1%, peak-to-peak)
- Phase stability: 0.784° (requirement: ±1°, peak-to-peak)









Summary

- **What we done:**
  - **Performance test of prototype cyromodules for SCL3 was conducted.**
  - **HPRF and LLRF system was developed.**
  - **Primitive control of cavity was started.**

- **What we will do:**
  - **Integration test of cryomodule and LLRF will be conducted.**
    - QWR cryomodule (10.29 ~)
    - HWR cryomodule type B
  - **Measurement of Δp (CM, cryo. system, warm pump system), Δf, source of microphonics**