RAON Rare isotope Accelerator complex for ON-line experiments

ibs 기초과학연구원 Institute for Basic Science

# Status of RAON Project

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# Topics

1. Overview
2. Cryomodules for SCL
3. RF System for SCL
4. Cryoplants and CDS
5. Summary

# Overview Rare Isotope Science Project (RISP)

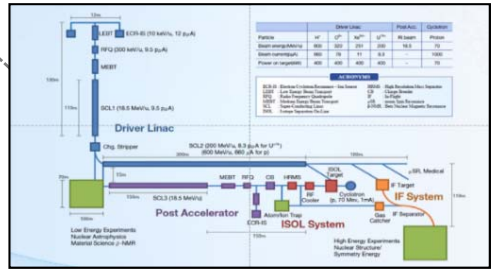
- **Goal:** To build **a heavy ion accelerator complex RAON,** for **rare isotope science** research in South Korea.

  * RAON - Rare isotope Accelerator complex for ON-line experiments

- **Budget: KRW 1,498 billion (US$ 1.23 billion, 1$=1,209krw)**
  - accelerators and experimental apparatus : 502.8 billion won
  - civil engineering & conventional facilities : 996 billion won (incl. site 357 billion won)
- **Period: 2011.12 ~ 2021.12**

## System Installation Project

**Development, installation, and commissioning of the accelerator systems that provides high-energy (200MeV/u) and high-power (400kW) heavy-ion beam**




## Facility Construction Project

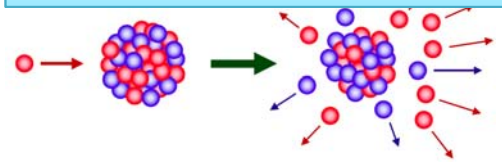
**Construction of research and support facility to ensure the stable operation of the heavy-ion accelerator, experiment systems, and to establish a comfortable research environment**

**※ Accelerator and experiment buildings, support facility, administrative buildings, and guest house, etc.**

- **Providing high intensity RI beams by ISOL and IF**
  ISOL: direct fission of $^{238}$U by 70 MeV proton
  IF: 200 MeV/u $^{238}$U (intensity: 8.3 pμA)
- **Providing high quality neutron-rich beams**
  e.g., $^{132}$Sn with up to 250 MeV/u,
  up to $10^9$ particles per second
- **Providing More exotic RI beam production by combination of ISOL and IF**

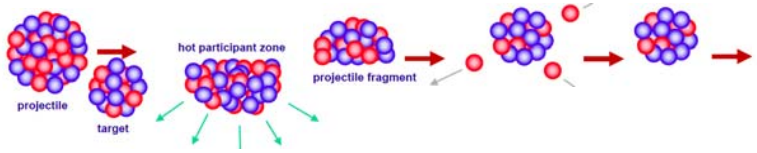
# Overview RAON RI Beam by ISOL and IF

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



RI Ions → Reacceleration → RI Beam

Stopping → Stopped Beam Experiment (Traps)




RI ion beam → Fast Beam Experiment

**IF(In-Flight methods)**
Stable Heavy ion beam → thin target → projectile fragmentation, fission, multi-nucleon transfer reaction, …

# Overview ISOL vs In-flight

❖ISOL

- Extraction time : ms-s
- High energy resolution
- Good beam quality

❖In-flight

- Very short flight time : *μs*
- High efficiency
- Good particle identification

# Overview

## Project Milestone

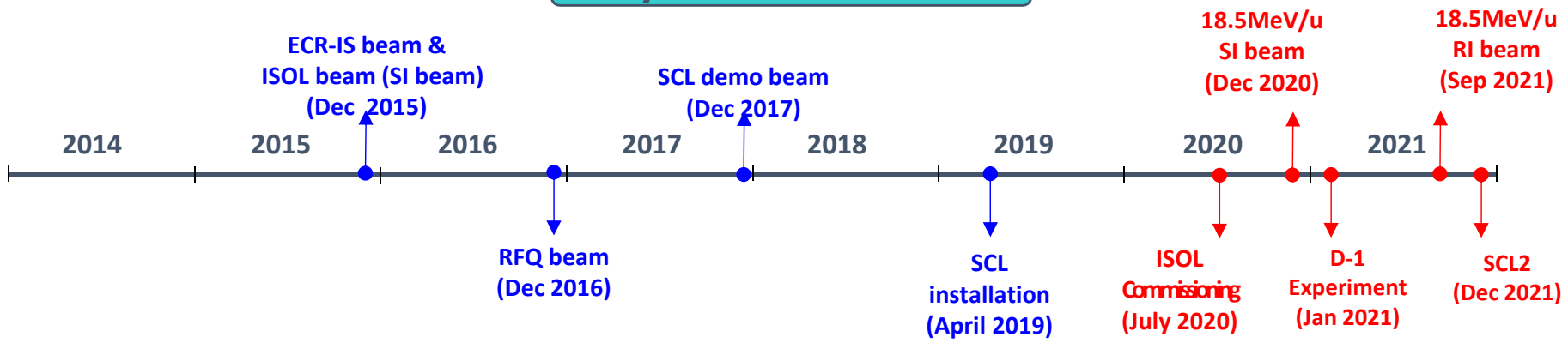
(2018)
SCL3 manufacturing
SCL2 Prototype

(2019)
SCL3 Installation
SCL2 manufacturing

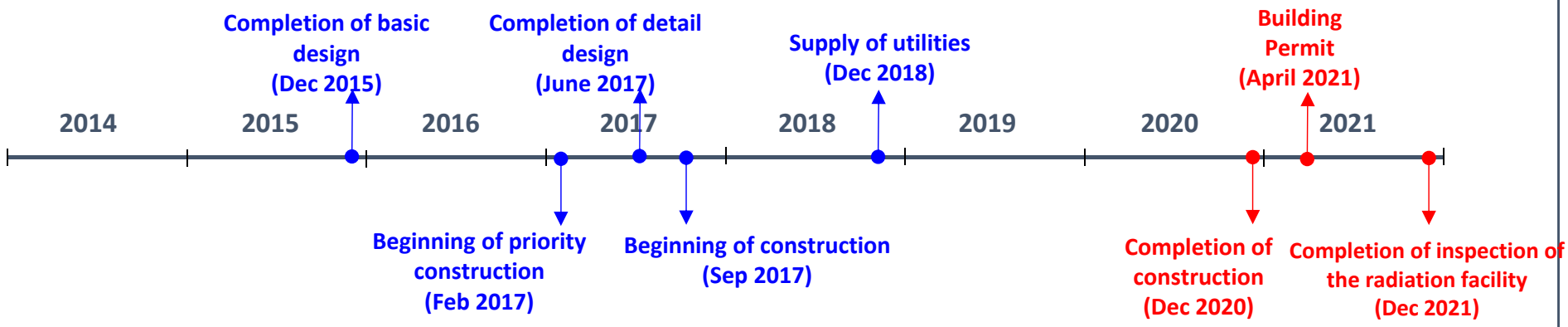
(2020)
SCL3 Beam Commissioning/
Const. Completion

(2021)
KOBRA operation/
Project Completion

### System Installation




### Facility Construction



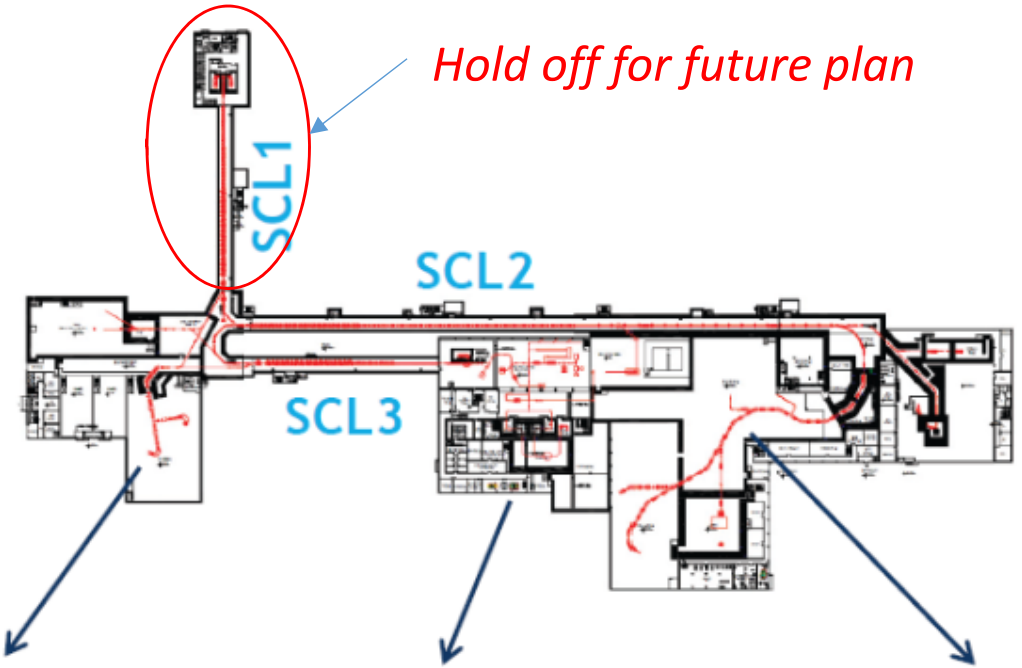
# Overview Lineup of RIB Production & Separation

**ISOL → IF**

- ISOL → SCL3 → SCL2 → IF
- ISOL → SCL3 → KOBRA

**IF → Re-Acc** (Future upgrade)

- IF → Stopped beam → SCL




| | KOBRA (low E IF) | ISOL | IF (high E) |
|---|---|---|---|
| Driver | SCL3 or SCL1 | Cyclotron | SCL3→2 or SCL1→2 |
| Post Acc | | SCL3 or SCL3→2 | |
| Production mechanism | Direct reactions - (p,d), ($^3$He,n) etc , MNT | p induced U fission | PF, U fission |
| Available RIB energy | < a tens of MeV/u | > a few of keV/u | < a hundreds of MeV/u |

# Overview RAON Layout


- SCL1 has been decided to postpone
  : SCL3 is going to be taking a role of SCL1 in the early operation

# Construction Accelerator Building

SCL2

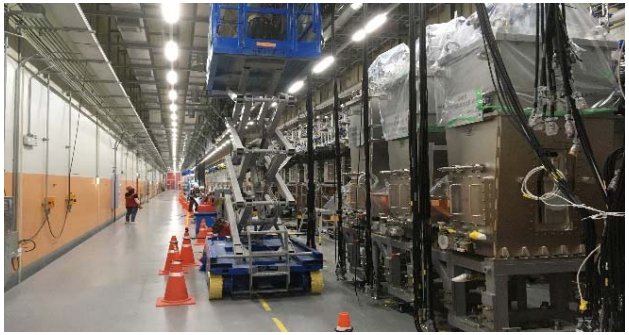
SCL3

Low Energy A/B

ISOL

IF/ High Energy A

High Energy B



SCL3

Bending Section

SCL3-gallery

# Construction Conventional Facilities

**SRF Test Bd.**

**Assembly Bd.**

**Control Center**

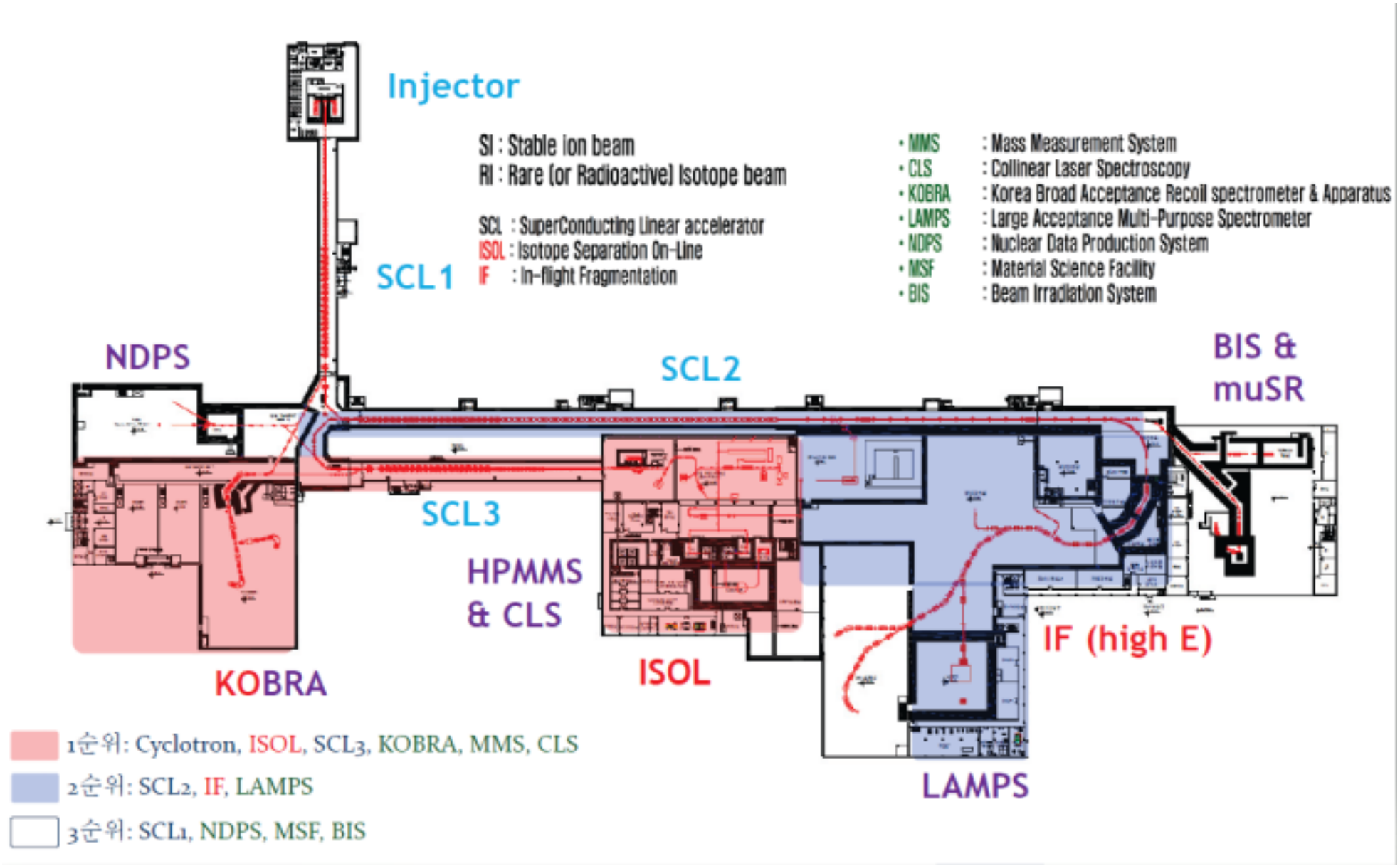
**HQ Office Bd.**

**Utility Bd.**

**Electricity Bd.**

# Cryomodules for SCL

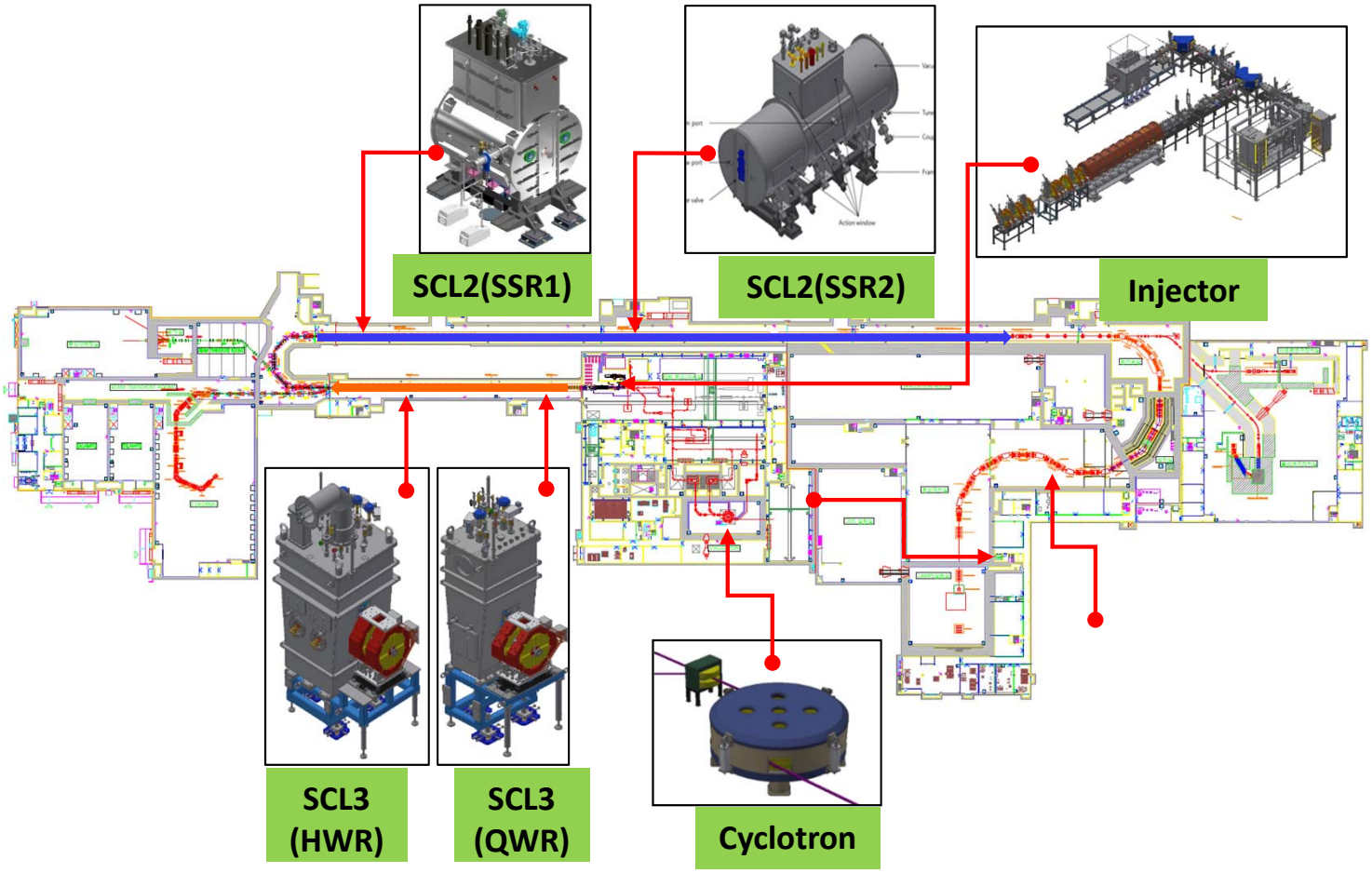
# Overview General Layout of RAON



# General Layout of RAON

Injector to SCL3

ECR | LEBT | RFQ | MEBT | SCL3 (QWR → HWR)



# Cavity & Cryomodule for SCL 2 & 3

| Parameters | Unit | QWR | HWR | SSR1 | SSR2 |
|---|---|---|---|---|---|
| **Beta** | - | 0.047 | 0.12 | 0.30 | 0.51 |
| **Frequency** | 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 |
| **$E_{acc}$** | MV/m | 6.1 | 6.5 | 8.5 | 8.7 |
| **$E_{peak}/E_{acc}$** | | 5.6 | 5.0 | 4.4 | 3.9 |
| **$B_{peak}/E_{acc}$** | | 9.3 | 8.2 | 6.3 | 7.2 |
| **$Q_{calc}/10^9$** | - | 0.23 | 1.5 | 3.2 | 3.2 |
| **Temp.** | K | 4 | 2 | 2 | 2 |
| **Accel. range** | | SCL 3 | SCL 3 | SCL 2 | SCL2 |
| **# of module** | - | 22 | 15 (A) /19 (B) | 23 | 25 |
| **# of cavity/module** | - | 1 | 2 (A) / 4 (B) | 3 | 6 |
| **Module production @ Oct. 2020** | | Completion & Installation | On mass production | prototyping | prototyping |

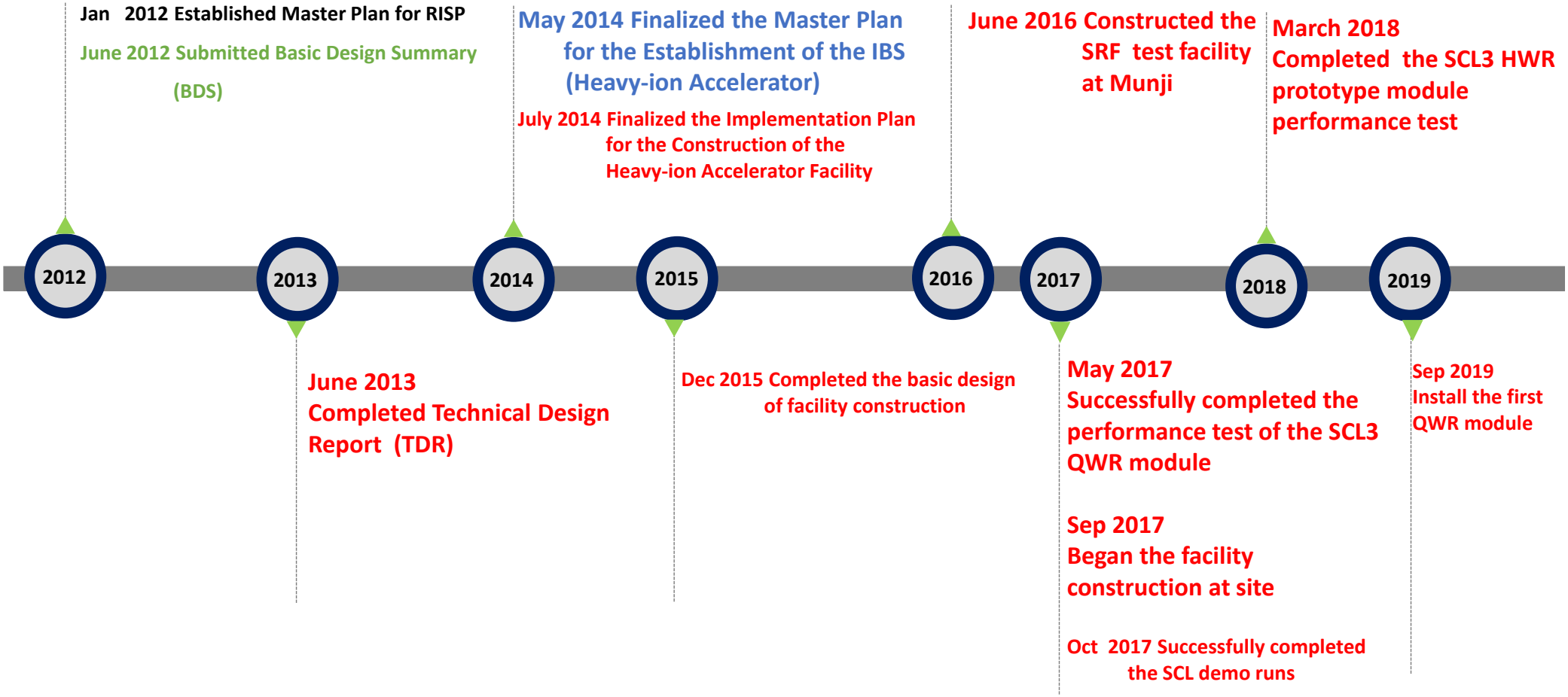
# Overview

## Project History

June 2010
Completed the research to establish the Heavy-ion Accelerator Construction Plan

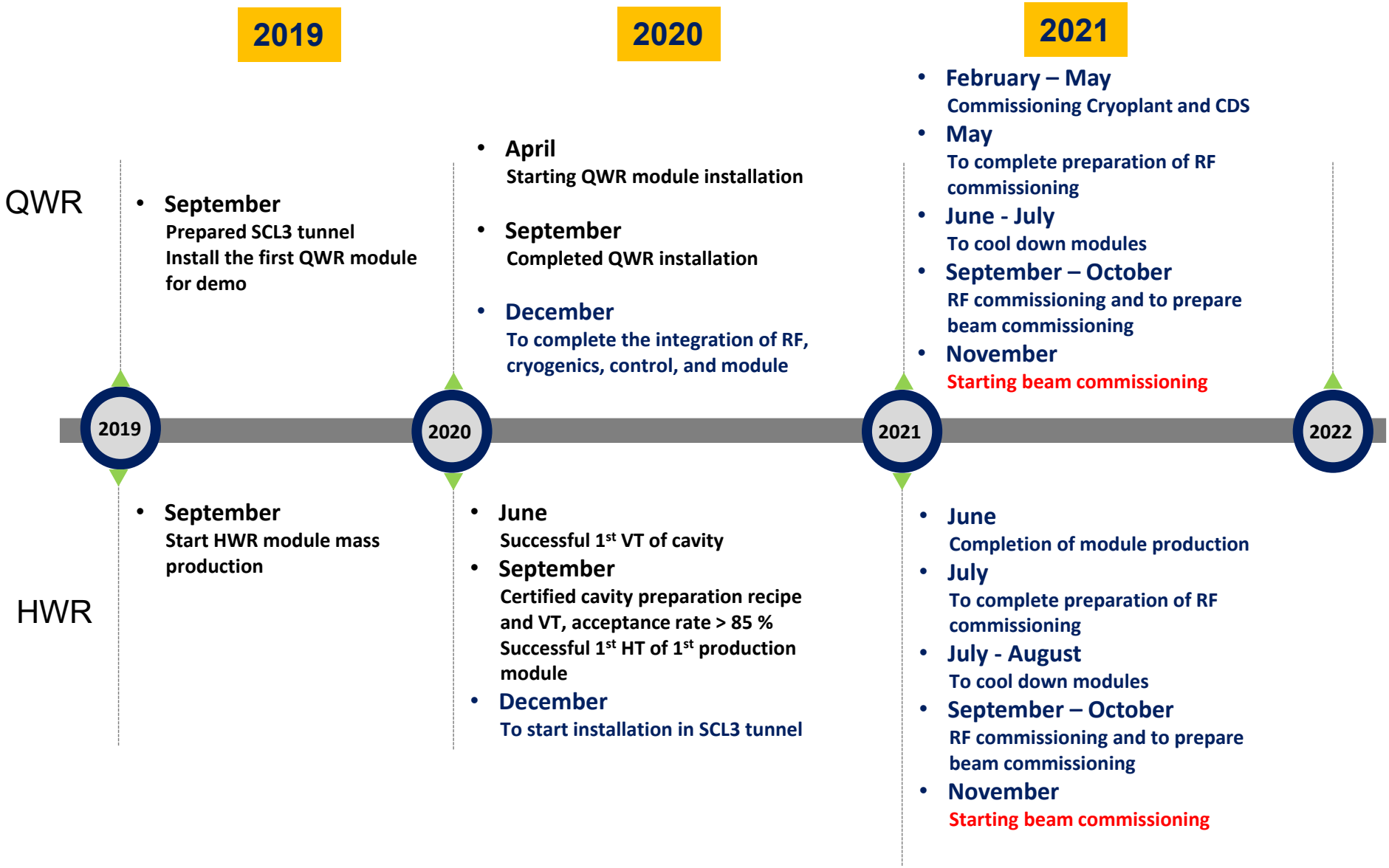
Feb 2011 Completed the Heavy-ion Accelerator Conceptual Design

Dec 2011 Launched the Heavy-in Accelerator Project



# Overview

# Status and Plan - SCL3 (QWR, HWR)



# Overview

## Status Summary - SCL3 (QWR, HWR)

❖ QWR

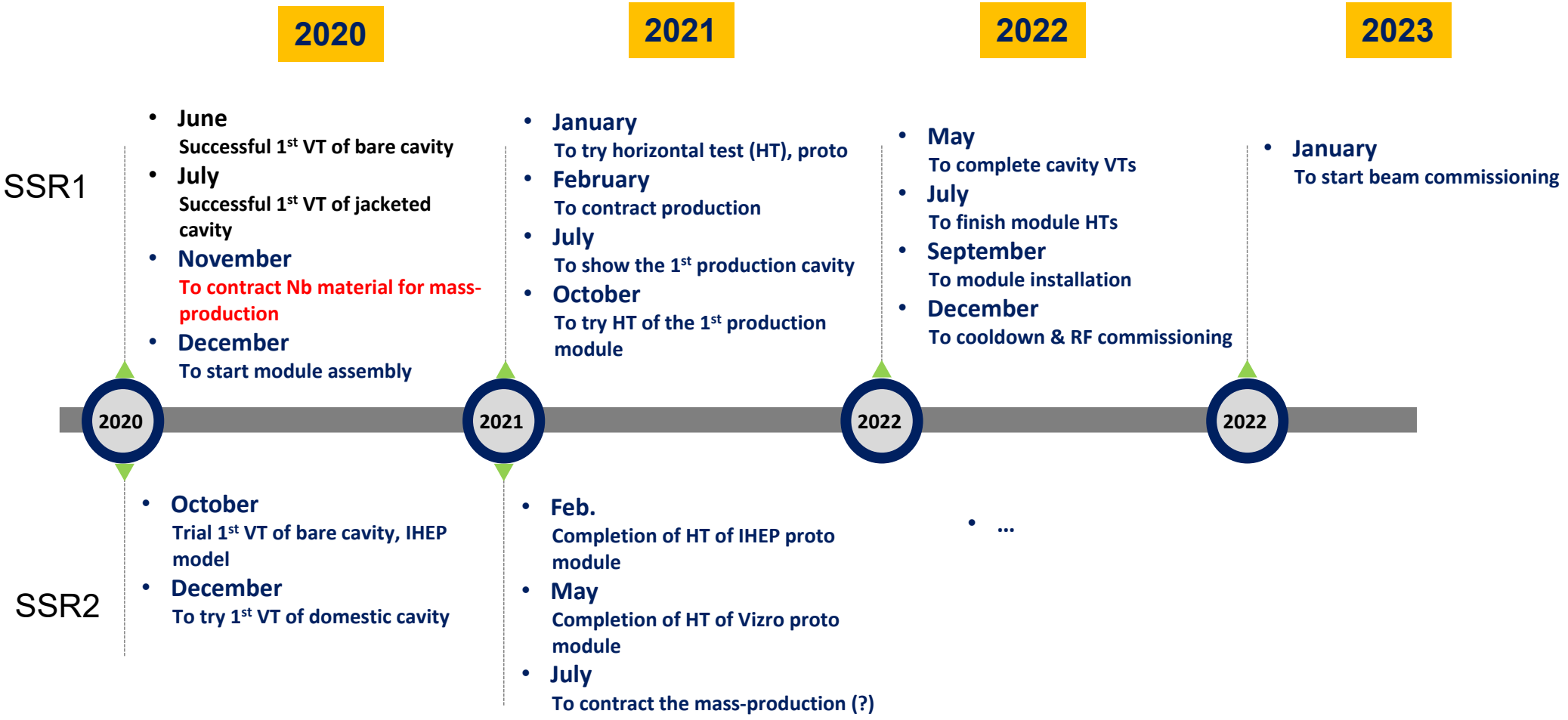
- Done production, performance test (HT) and installation in the tunnel.
- On-going integration connection with cryogenics, RF and control.
- Preparing RF commissioning is on going until May, 2021
- RF commissioning with cold cavities will be until October, 2021
- Beam commissioning start in November, 2021

❖ HWR

- Start mass production: 1$^{st}$ A module passed HT and 3 A types, 1 B types are ready for HT
- All cryomdules (34) will be prepared until June, 2021
- RF commissioning with cold cavities will be until October, 2021
- Beam commissioning start in November, 2021

# Overview

# Status and Plan – SCL2 (SSR1 & 2)



# Overview

## Status Summary – SCL2 (SSR1 & 2)

❖ SSR1

- On-going prototype R&D since 2018, but delayed progress due to several constraints such as jamming facility, human resource and lack of experience
- Prototyping is expected to be done until January 2021.
- To contract the mass production, February 2022.
- The 1st HT of module, October 2021 and finished in July 2022.
- To cool down cavities and RF commissioning , December 2022.
- Beam commissioning, January 2023

# Overview

## Status Summary – SCL2 (SSR1 & 2)

❖ SSR2

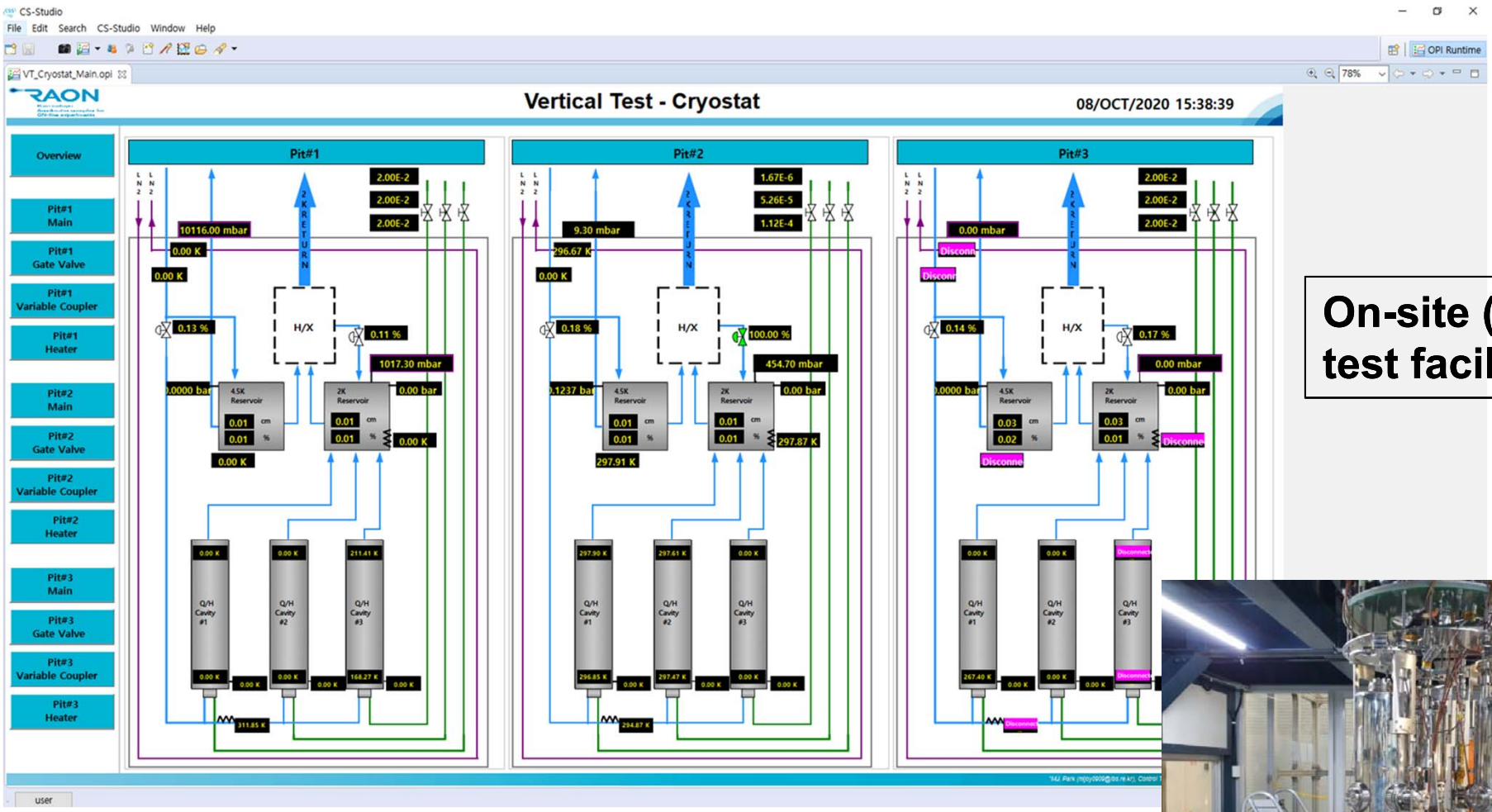
- Two proto. R&Ds, with domestic company (Bitzrotech), and with foreign institute (IHEP, China).
- On-going prototype R&D since 2018/2019, but delayed progress due to several constraints such as jamming facility, human resource and lack of experience
- IHEP prototyping is expected to be done until February 2021, while Bitzro proto until May 2021.
- *The plan of the mass production is expected to be floated until next March (?). The master plan of RISP is on the table of severe review by Korea science community and Minister of Science and ICT about milestone, budget, and scientific topics.*

SCL3 and part (SSR1) of SCL2 would look completion on-milestone (until December 2021).
All planned accelerators would take another two years with consideration of given constraints.

# SRF Facility

- When the project start 2013, we had nothing absolutely about a superconducting LINAC. No human resource, no technology and limited experience, no facility and no building.
- Before preparation of facility, the prototyping R&Ds were done with ANL and TRIUMF with collaborations.
- Two independent SRF facilities: each one onsite and offsite, respectively.
- Offsite (Munji campus of KAIST) working in 2016: for prototyping & production due to site preparation, 2 VT pits and 2 HT bunkers and a He liquefier
- Onsite (Shin-dong), working in 2018: for production, 3 VT pits and 3 HT bunkers and a He liquefier
- The availability of facilities is about 70 % at present, and still to enlarge test capacity.

# SCL SRF Facility for RAON Project




**On-site (Shin-Dong) test facility**

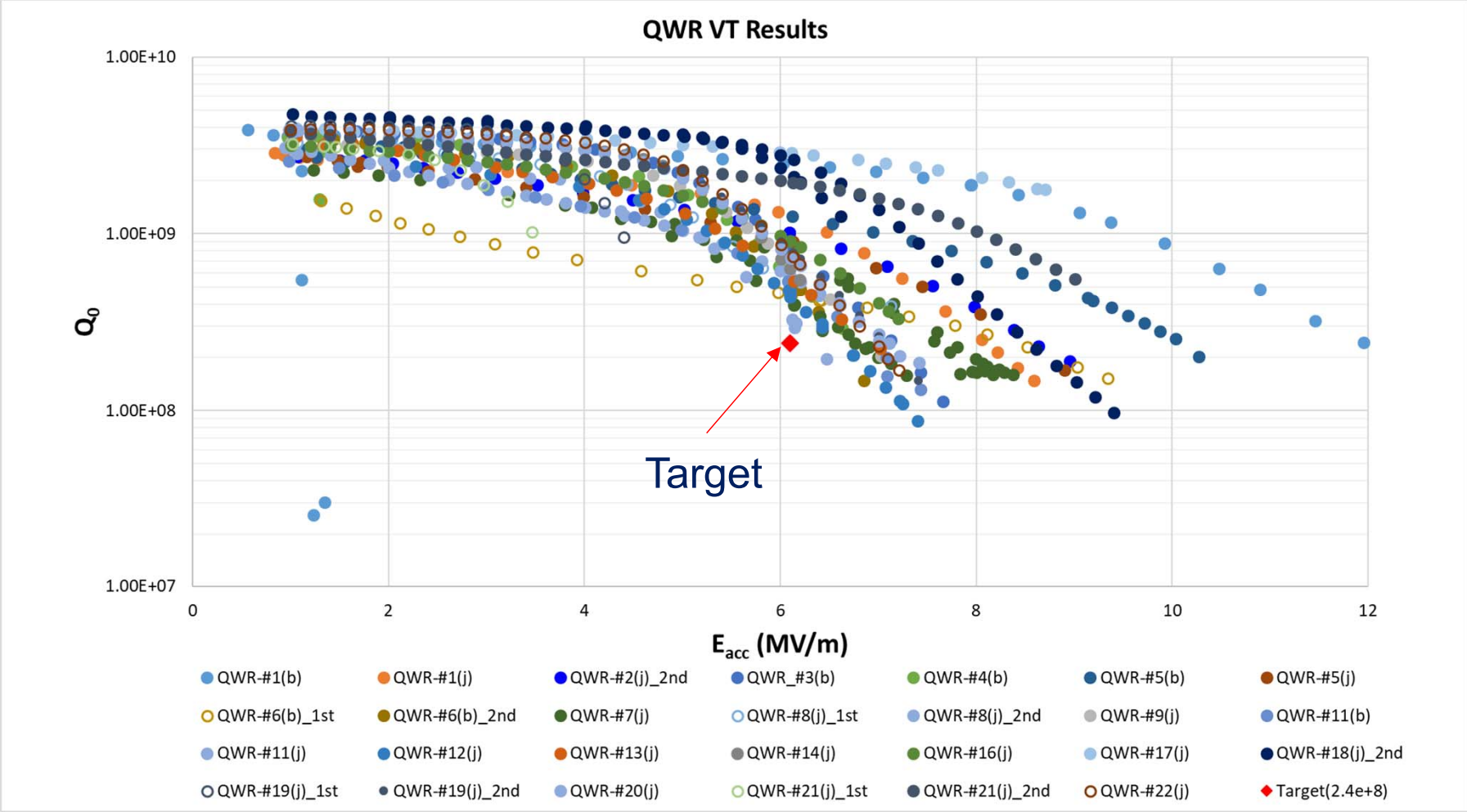
- 1 onsite - 3 pits and 3 cavities per pit
- 1 offsite (15 Km from site) - 2 pits and 2 cavities per pit
- To cover all RAON cavities - QWR (82.125 MHz), HWR (162.5 MHz) and SSR1 & 2 (325 MHz)

# SCL3 QWR Cryomodule

- Completion of fabrication, performance test (HT), installation in the SCL3 tunnel
- All connection with cryogenic valve boxes
- Cavities under vacuum
- On procedures of preparing integrated RF commissioning and cavity cool down
- Cavity cooldown: June in 2021
- Integrated RF commissioning: September in 2021
- Beam commissioning: November 2021 together HWR

# QWR Cavity - VT Results

| Frequency (MHz) | Optimum $\beta$ | Eacc (MV/m) | Vacc (MV) | Q0 | # of cavity | # of module | Op. temp (K) |
|---|---|---|---|---|---|---|---|
| 81.25 | 0.047 | 6.1 | 1.06 | 1.3e+8 | 22 | 22 | 4.5 |



# SCL3 QWR Cavity - VT Results

◆VT acceptance rate

| Accepted (%) | 1st Accepted | 2nd Accepted | 3rd Accepted | 4th Accepted | Total |
|---|---|---|---|---|---|
| # of VTs | 19 | 10 | 2 | 1 | 32 |
| Accepted | 9 | 7 | 1 | 1 | 32 |
| Acceptance (%) | **47%** | 70 | 50 | 100 | **56%** |

◆ Impact on cavity performance:

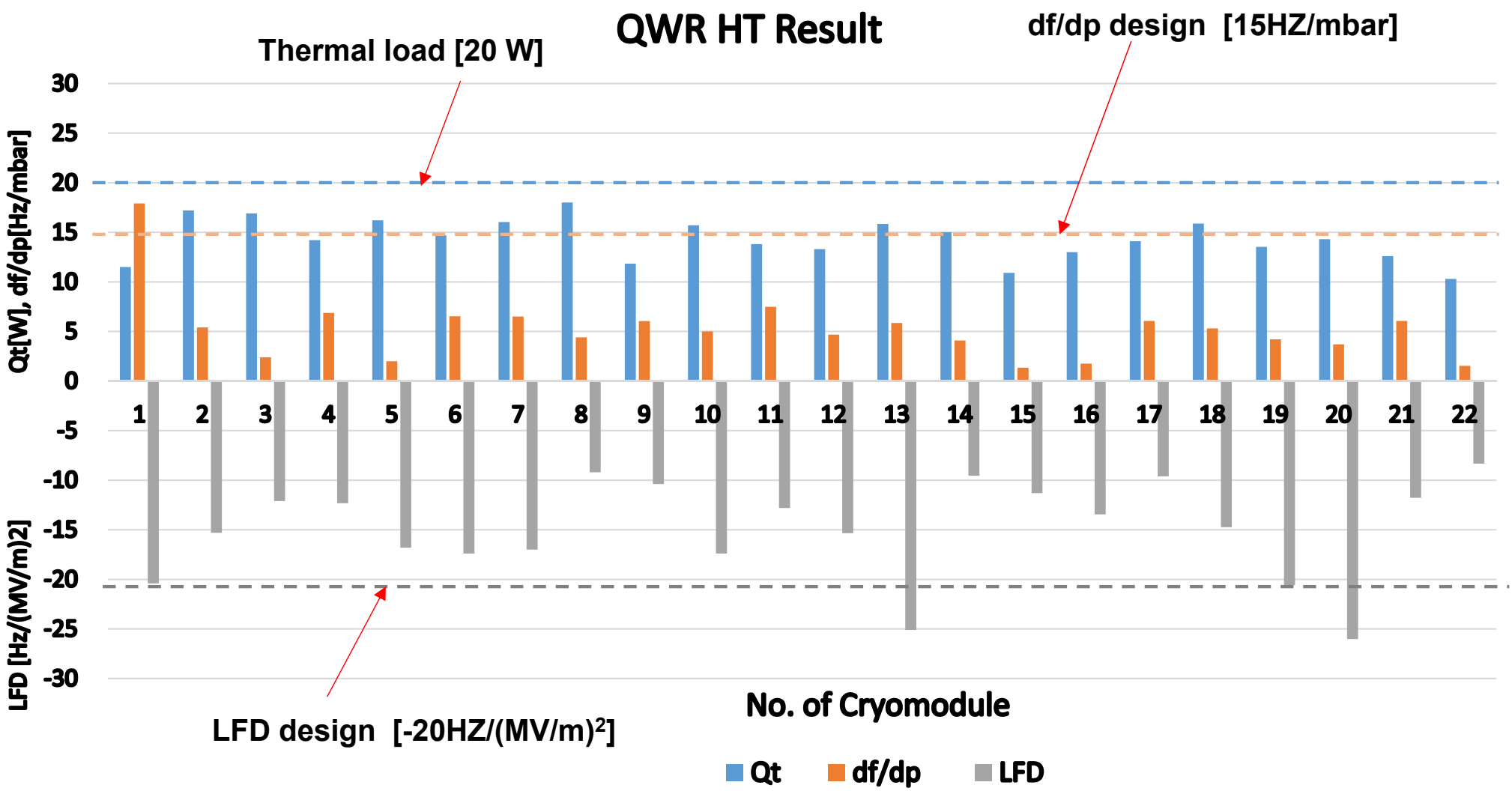
- At beginning, VT test facility such as a cryogenic system, RF circuit and VT hanging system was the major trouble.
- A multipaction (MP) in a coupler was the severe cause.
- A field emission (FE) in a cavity was common trouble in more and less.
- A vacuum leakage was another trouble.

So, VT of QWR cavities was delayed more than 1 year.

The production of QWR modules was the 1st SRF project for the real accelerator in Korea.

The time would be for setup SRF R&D facility and compiling knowledge and knowhow/experience of SRF system.

# SCL3 QWR Cryomodule – Horizontal Test



# SCL3 SCL Tunnel and Gallery for QWR

Cryogenic Valve Boxes


Combination of Cold & Warm Section

QWR Installation

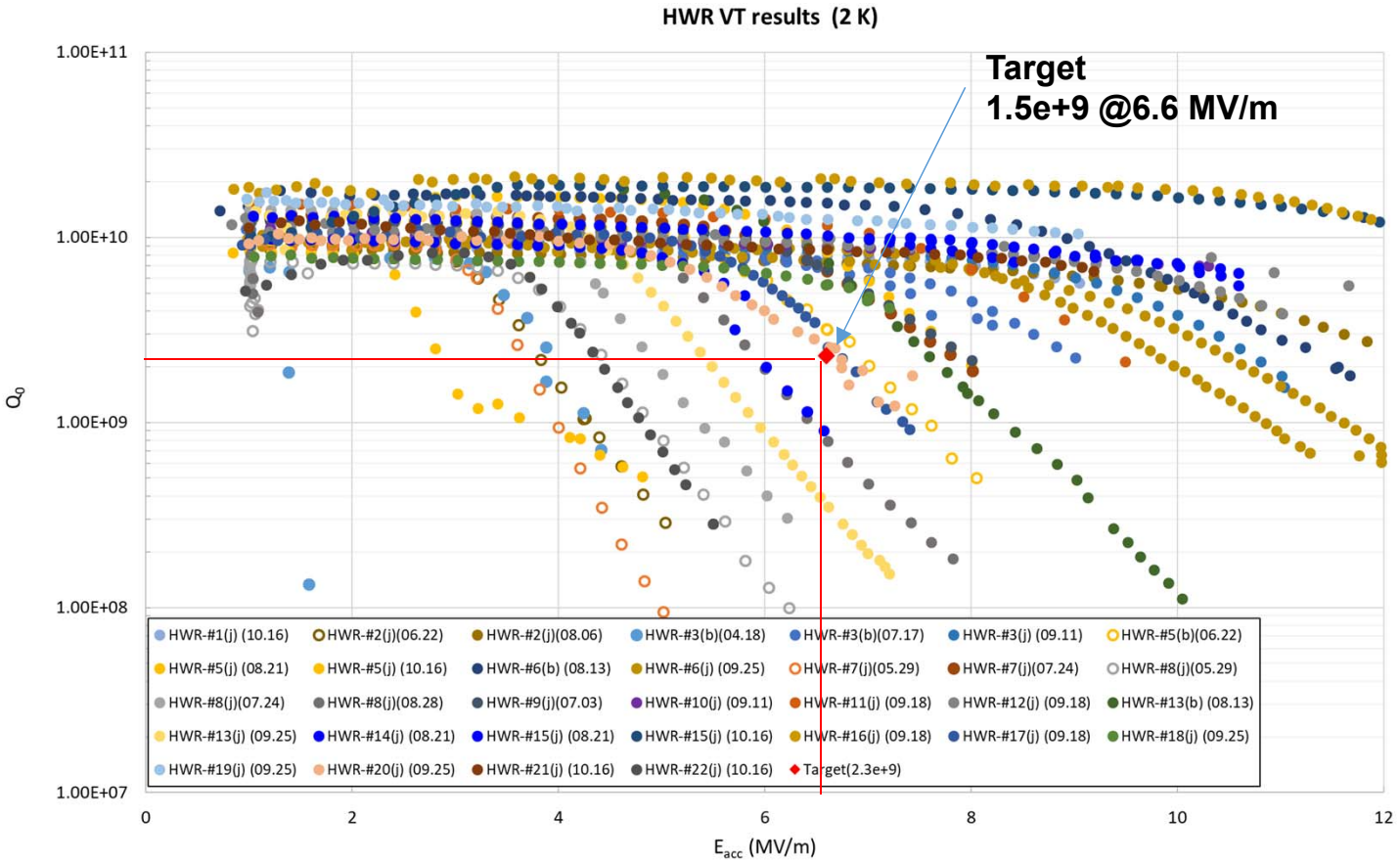
CM Cryogenic Control Rack and HPRF

# SCL3 HWR Cryomodules – A and B types

- On the way of mass production
  - Cavity: 29 produced, 21 VT passed
  - All couplers and tuners at standby to be installed to modules
  - Cryomodule: 3 produced (A-3, B-1), 1 on the test and analyzing as the 1st production unit for the deep investigation of its performance. The Eacc and thermal load are satisfied.
  - Cavities VTs are to be done until march 2021
  - All modules will be prepared, including HT until June 2021
  - Installation in SCL3 tunnel: 30/06/2021
  - Beam commissioning: November 2021 together QWR

# SCL3 HWR Production until June 2021

| Frequency (MHz) | Optimum $\beta$ | Eacc (MV/m) | Vacc (MV) | Q0 | # of cavity | # of module | Op. temp (K) |
|---|---|---|---|---|---|---|---|
| 162.5 | 0.12 | 6.6 | 1.46 | 1.5e+9 | 106 | A/B = 14/19 | 2.05 |
| # of fabrication (@20/10/2020) | | | | | 29 | A-3, B-1 | |




The cavities below the target include bare cavities as R&D phase and all were re-processed after 1st VT.

# SCL3 HWR Cavity - Vertical Test

◆VT acceptance rate

| Accepted (%) | Until August | September | October | Total |
|---|---|---|---|---|
| # of VTs | 11 | 11 | 8 | 30 |
| Accepted | 4 | 10 | 7 | 21 |
| Acceptance (%) | 36 | 91 | 88 | **70 %** |

◆ Impact on cavity performance:

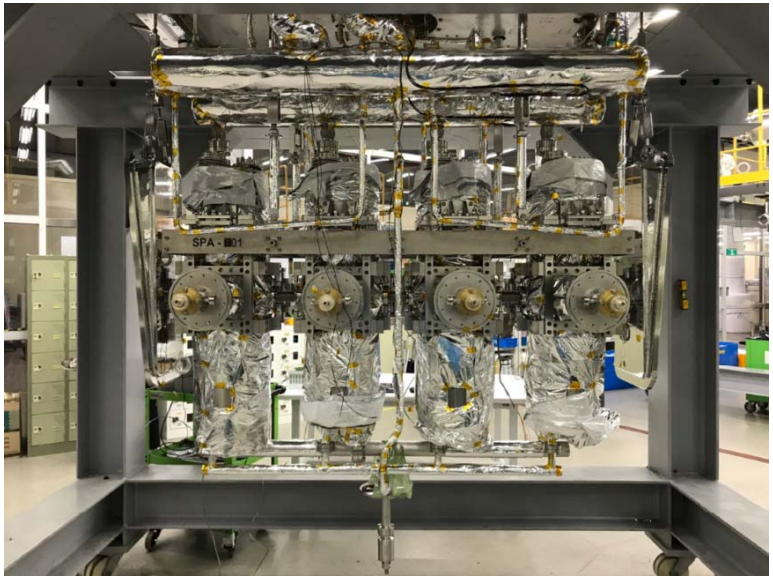
- Cavity production, VT preparation and VT are well-setup through the QWR production.
- MP in a coupler and FE in a cavity are major troubles, but acceptable rate.
- Now the bottle-neck factor of cavity production is the capacity limit of He liquefier.

The VT acceptance rate during Sept. – Oct. shows 89%. It seems the world level performance ever since.

# SCL3 Starting Mas-production of HWR


Cavity String


Particle count
inside cavity “0”




With cryogenic piping

Top loading to cryostat


Vacuum leak rate

HWR B type

# SSR Cryomodules for SCL2

- SSR1 Cryomodule on the prototyping phase
  - Cavity: 4 cavities produced, 1 jacked and 1 bare VT passed.
  - VT priority behind HWRs makes time delay, but VTs will be concentrated in November 2020.
  - All couplers and tuners at standby to be installed to modules
  - Cryomodule will be assembled until December 2020
  - HT of SSR1 module until January, 2021
  - Procurement will be completed February 2021.
- SSR2 Cryomodule on the prototyping phase
  - Cavity: fabrication phase
  - VT : Jan. – Mar. 2021.
  - Module assembly: Mar. – Apr. 2021
  - HT SSR2  until May 2021
  - Procurement will be completed until June 2021.

# RF System for SCL

- HPRF - SSPA, Solid State Power Amplifier
- LLRF - Digital

# Specification of SCL3 SSPA

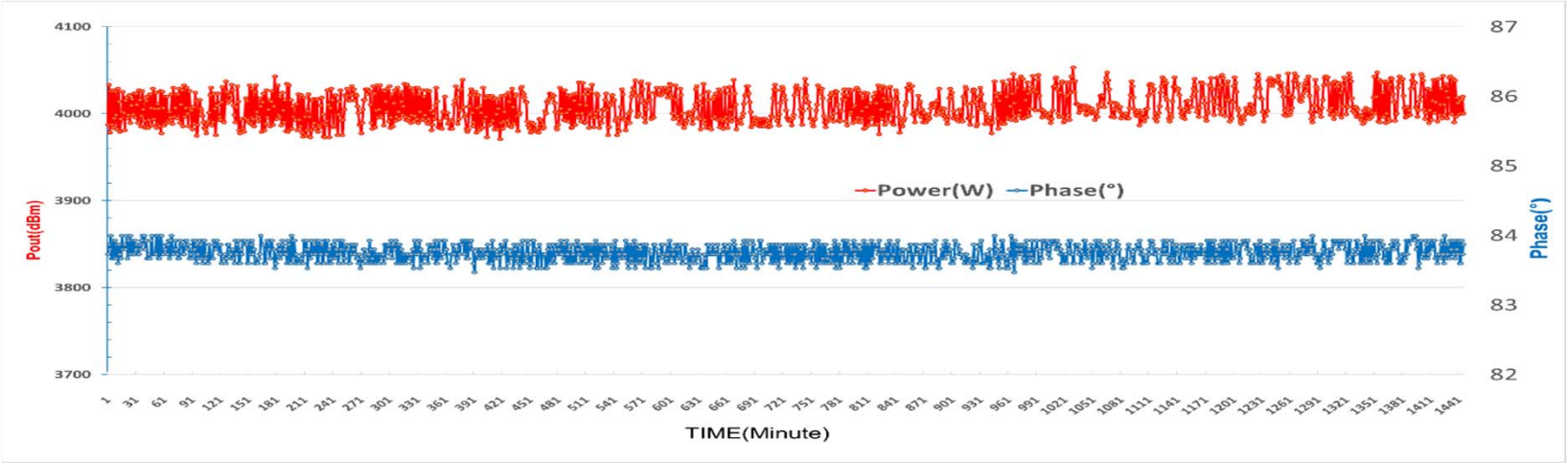
| Parameters | Unit | Value | Condition | Planned (Possibility) |
|---|---|---|---|---|
| **Frequency Range** | MHz | 81.25 ± 1, 162.5 ± 1 | 1dB Compression | **81.25 ± 1, 162.5 ± 1** |
| **Input Power** | dBm | ≦0 (0 dBm for rated output) | No damage up to 20 dBm input | **≦0 (0 dBm for rated output)** |
| **Output Power (CW and pulse)** | kW | 0~4 kW<br>4 kW @ 0 dBm input | With any VSWR | **0~4 kW**<br>**4 kW @ 0 dBm input** |
| **I/O Impedance** | ohm | 50 | | **50** |
| **Gain Linearity** | dB | < 6 (-20dB range)<br>< 3 (-10dB range) | Within specified range from max | **< 6 (-20dB range)**<br>**< 3 (-10dB range)** |
| **Input Return Loss** | dB | < -20 | | **< -21** |
| **Load VSWR** | | 1~∞ | Any phase, indefinitely | **1~∞** |
| **Harmonics** | **dBc** | **< -30** | | **< -33** |

# Installation in SCL3 Gallery

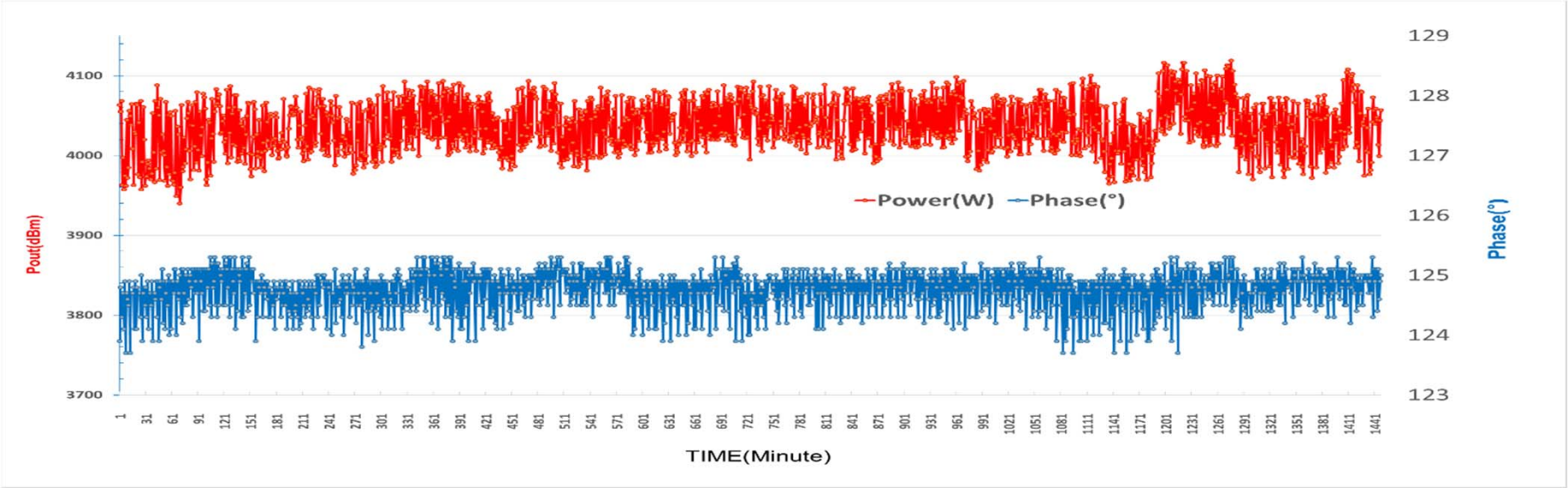
## Status

- Completion of installation :QWR(22set), HWR(106)
- Under connection transmission lines to cavities
- On-going connecting cooling lines, signal cables, network cables, …


# FAT – Long Term Stability

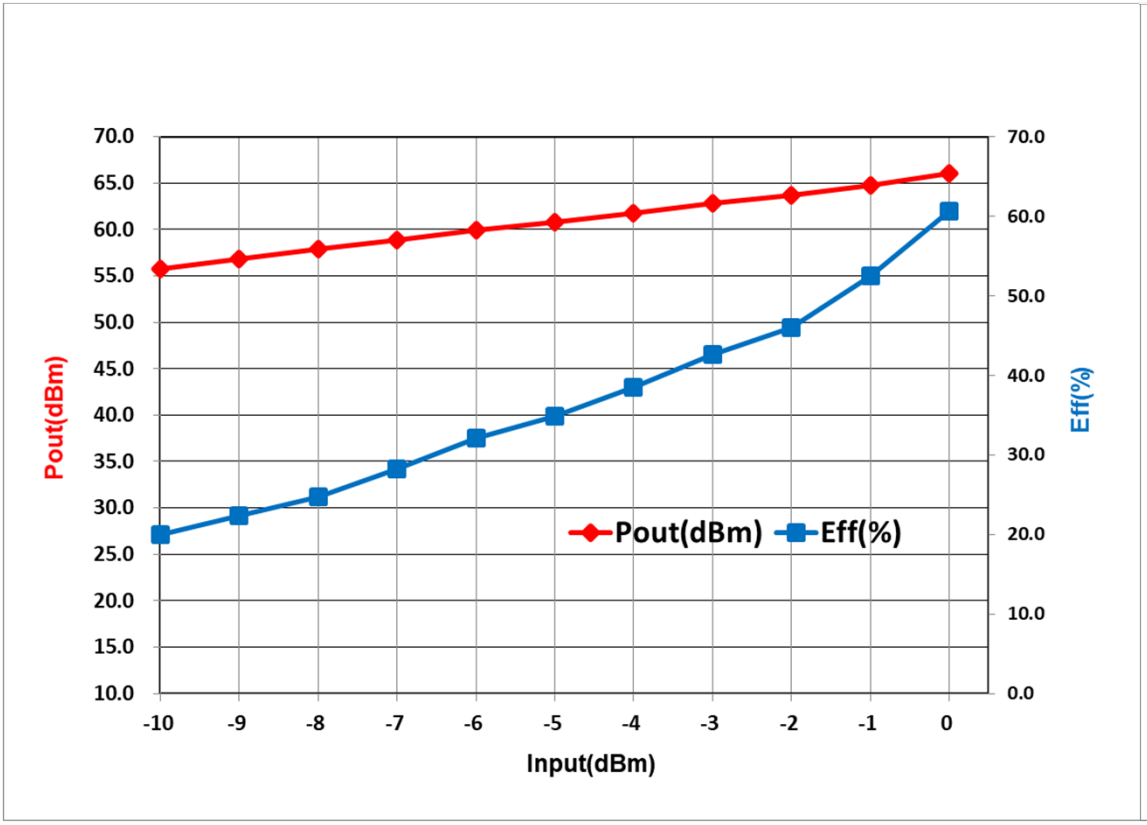



- QWR (81.25 MHz): 1% of amplitude, 0.25 degree

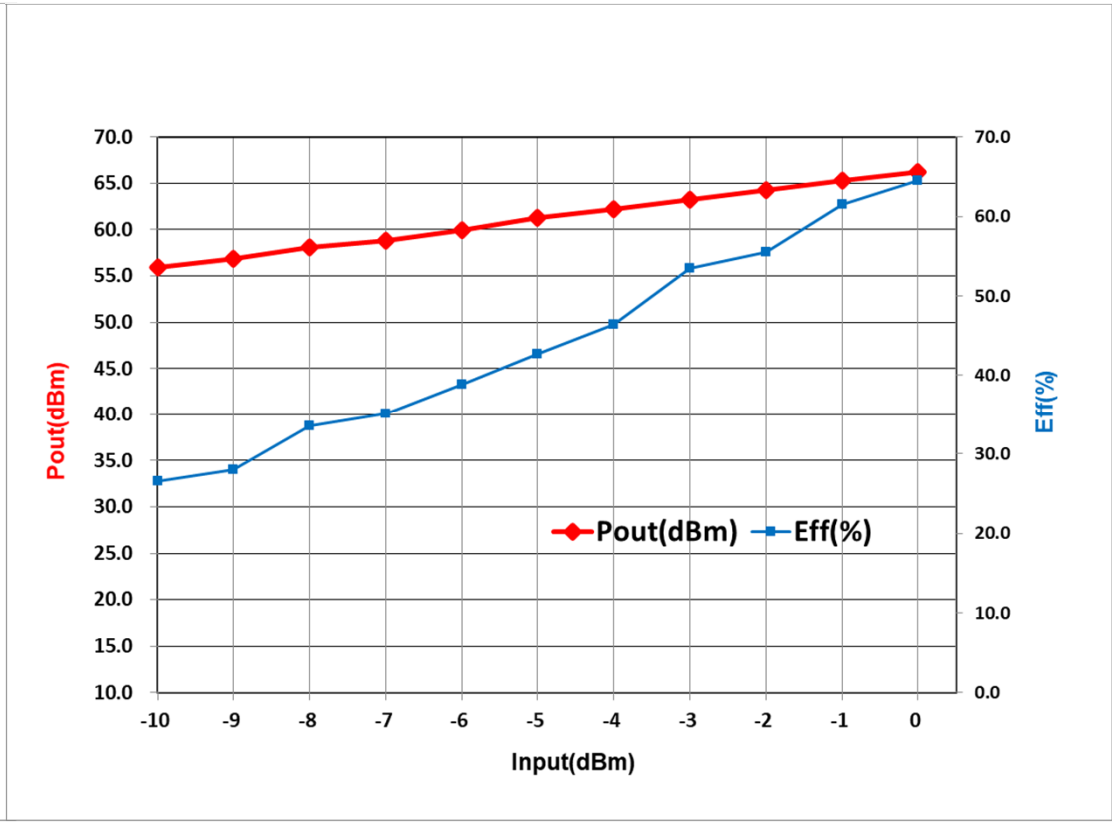



- HWR (162.5 MHz): 1.5% of amplitude, 0.7 degree

# SC - RF FAT – Output & Efficiency



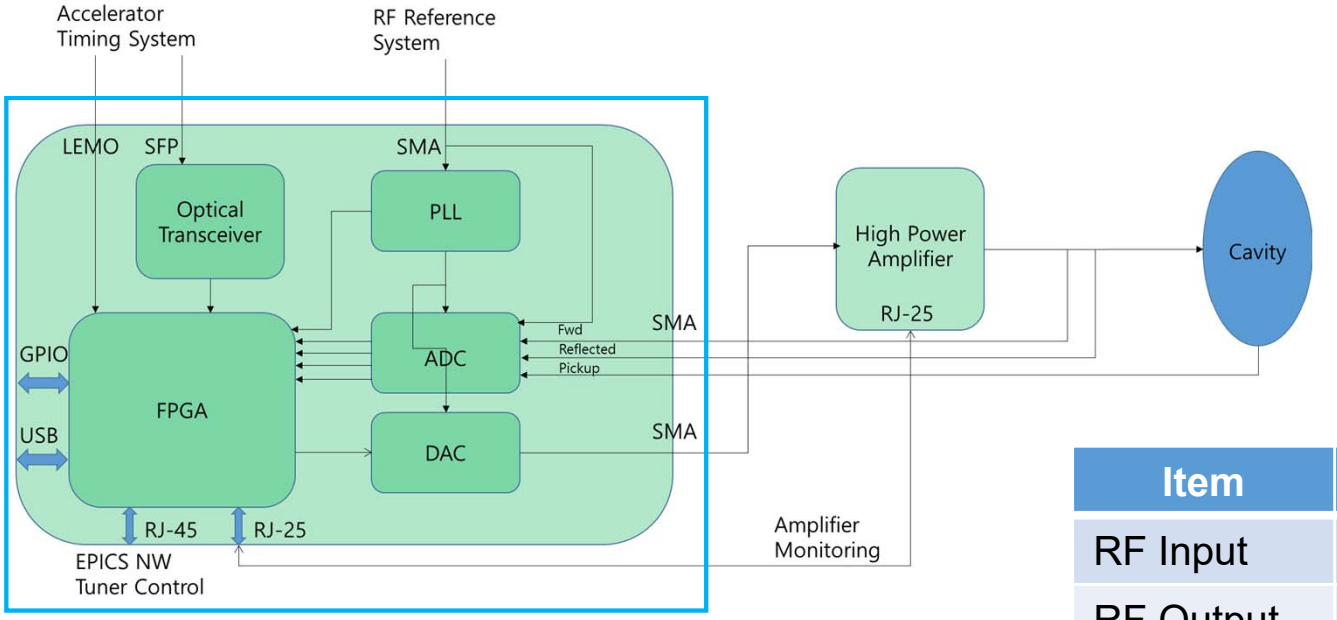

QWR – 81.25 MHz




HWR – 162. 5 MHz

# SC - RF LLRF for SCL3

- Digital LLRF based on FPGA
- Completion of installation with FAT: QWR(22set), HWR(106)
- On-going connecting signal cables, network cables, …
- To prepare HMI (Human & Machine Interface) for a expert and an operator

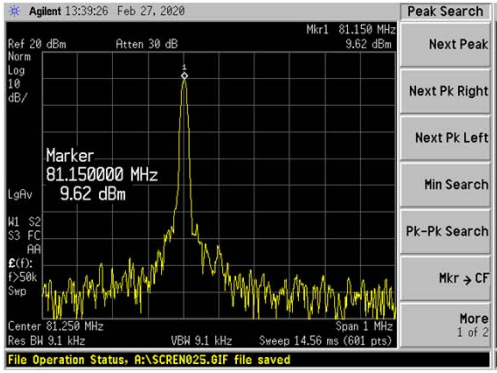



LLRF I/O Interface

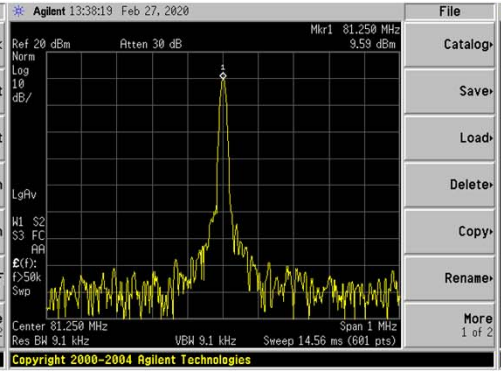
Production, LLRF

| Item | Spec |
|---|---|
| RF Input | 4 |
| RF Output | 1 |
| RF ADC | AD9653(16 bit, 4 ch, serial) |
| SoC | Xilinx Zynq Ultrascale ZU9EG |
| EPICS IOC | In Arm core of Zynq |
| Clock Gen | LMK04828 PLL |

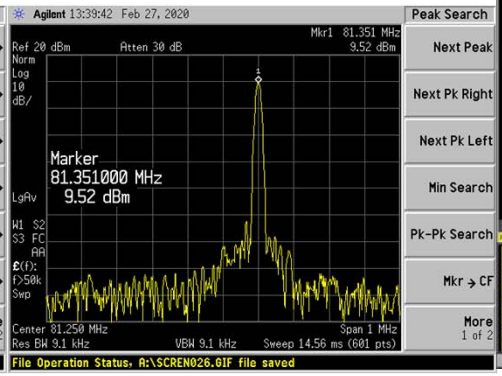
# LLRF - Integrated Test with QWR Modules



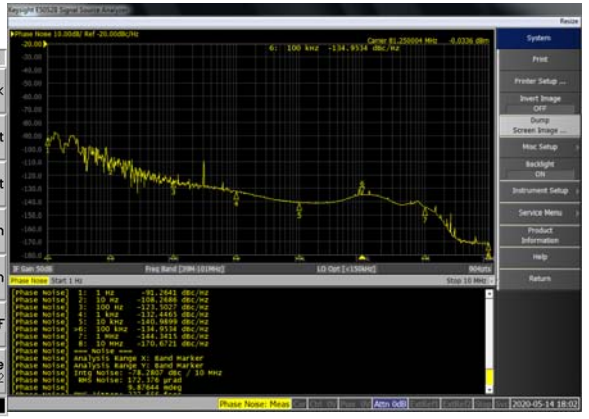

81.15 MHz (SEL)



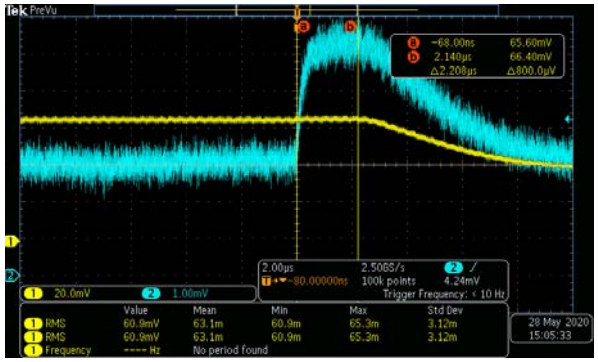

81.25 MHz (SEL)



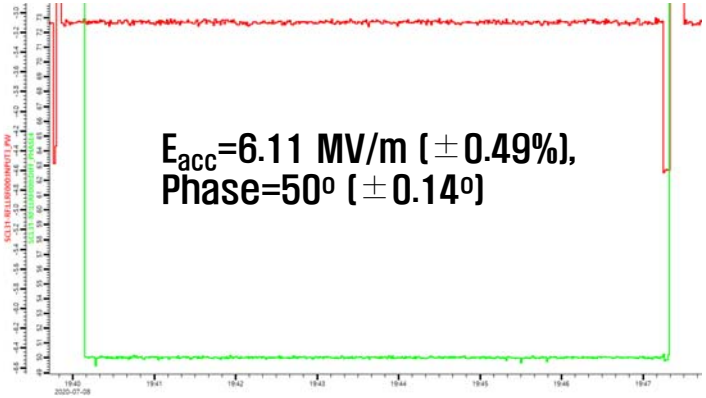

81.35 MHz (SEL)



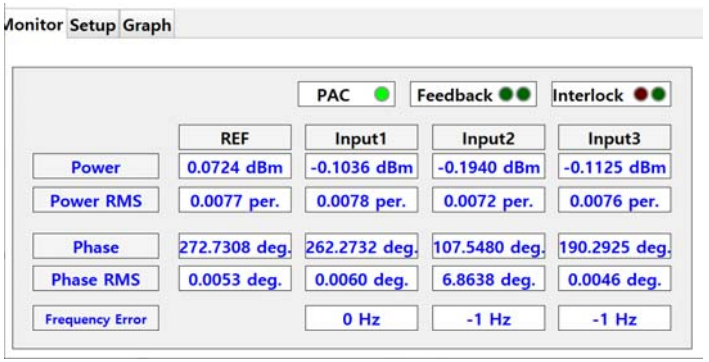
81.25 MHz RF Generation




LLRF Latency Test




QWR Cavity Control Test@SRF




CSS OPI

- Test and confirmation with SEL mode, GDL mode will be tested at nominal Eacc = 6.1 MV/m.
- Realized, LLRF and control system via EPICS

# Cryoplants and CDS

- 4.2 kW, for SCL3
- 13.5 kW, for SCL2

# Cryoplant Statue of Cryogenic Systems

- SCL3 cryoplant (4.2 kW @ 4.5 K)

Compressors and Oil Removal System (WCS)

Cold Box System (CB)

- Installation progress : 95 %
- Pre-commissioning (Ready for start-up/load test) : Nov. (WCS) ~ Dec (CB). 2020
- Commissioning : Feb. 2020
- Cool-down of SCL3 : From June 2020
- Commissioning of SCL3 cryogenic system and performance tests : @ July 2020

# Cryoplant — Statue of Cryogenic Systems

- SCL2 cryoplant (13.5 kW @ 4.5 K)

Compressors and Oil Removal System (WCS)

Cold Box (CB)
(Left warm side, right – cold side)

- Doing cold box integration @ ALAT (progress : 90 %), FAT of CB : Nov. 2020
- Warm Compression Station – being installed @ RISP (progress : 92 %)
- Mechanical completion of WCS : Nov. 2020
- Cold box delivery : ~ Feb. 2021
- Commissioning : April ~ 2021

END