Introduction and SCL3 Cryogenic Commissioning (First Run) of Cryogenic Systems for RAON Accelerator

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On behalf of Cryogenic System Team

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Accelerator Seminar
@ Jefferson Lab.

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Thanks

Jefferson Lab

Just, finished the FRIST RUN of SCL3

Outline

- RAON Superconducting Accelerator
- Requirements/fundamentals for SCL3 Cryogenic Systems
- Development of RAON Cryogenic Systems for SCL3
- SCL3 Cryogenic Commissioning
- Summary

RAON - Rare Isotope Science Project (RISP)

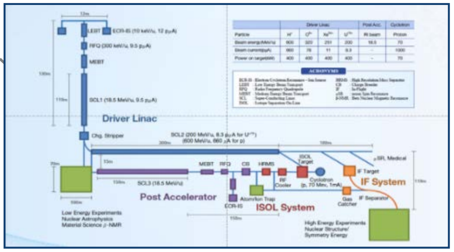
- **Goal:** To build **a heavy ion accelerator complex RAON,** for **rare isotope science research** in Korea.

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

- **Budget: Total 1.15 billion USD**
  - Accelerators and experimental apparatus : 0.4 billion USD
  - Civil engineering & conventional facilities : 0.75 billion USD
- **Period:** **<u>2011.12 ~ 2022.12</u> for SCL3 section (The first phase)**

System Installation <u>Project</u>

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



Facility Construction <u>Project</u>

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.

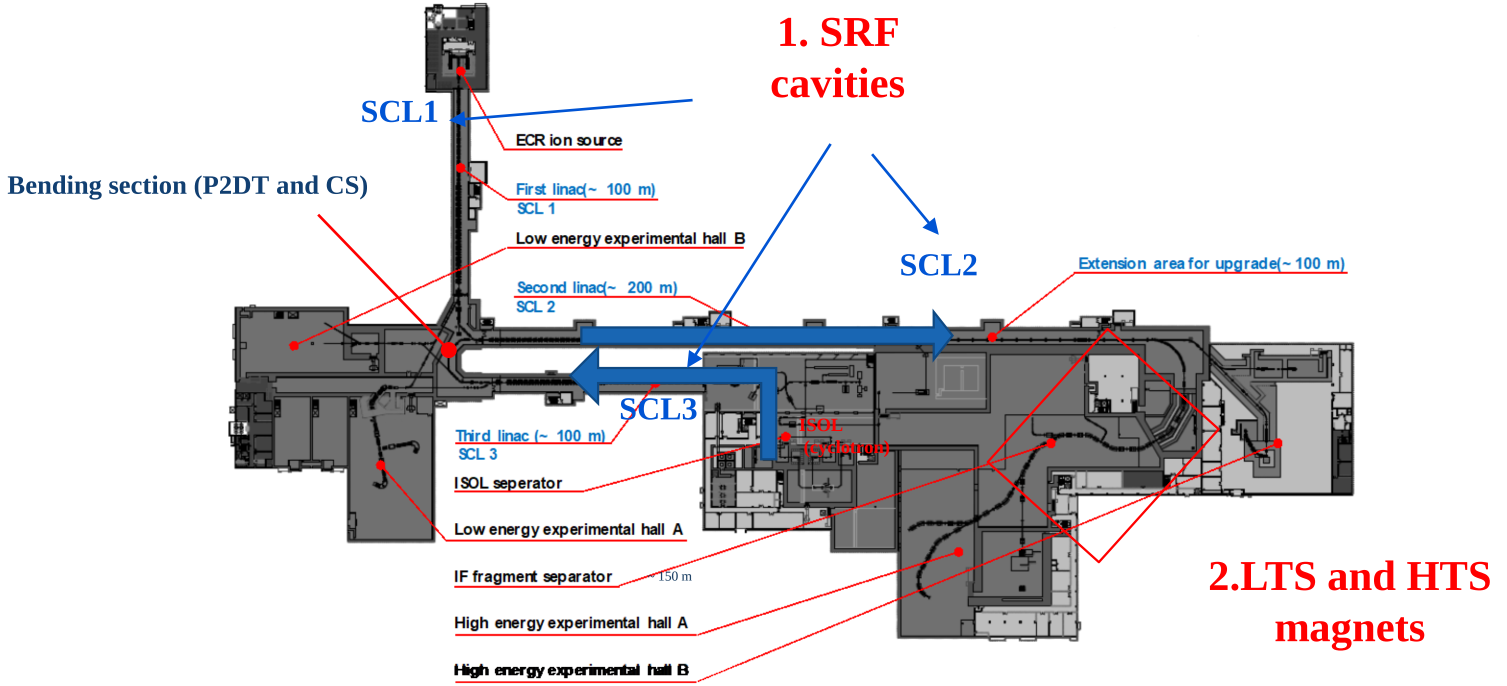
RAON accelerator with Superconducting systems

- Heavy ion linear accelerator (Final : 200MeV/u, 400kW)

(Isotope Separation On-Line + In-flight Fragment separator for Rare Isotope beams)

- Design : By **SuperConducting LINACs (SCL)**
- Third Linac (SCL3) : **Accelerate SI beams made by ECR** (2022)
- Second Linac (SCL2) : Reaccelerate SI and RI beams from SCL3 (The second phase – making the plan)

The first phase (2022)
+ 2023~2024 (ISOL)



ECR	LEBT	RFQ	MEBT	SCL31	SCL32	P2DT	SCL21	SCL22	HEBT	IF

QWR $\beta = 0.047$ HWR $\beta = 0.12$ SSR1 $\beta = 0.3$ SSR2 $\beta = 0.51$

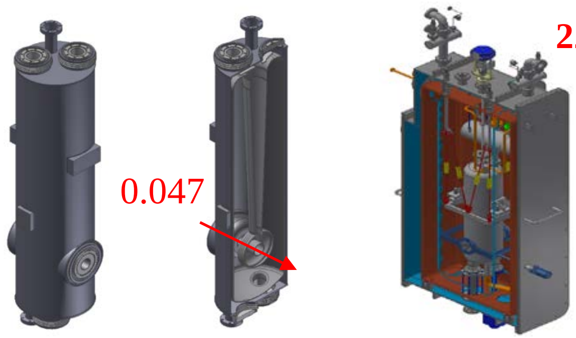
10-500 keV/u → 0.5-2.7-18.5 MeV/u → 18.5-200 MeV/u

RAON accelerator by Superconducting Cavities

▪ SRF Cavities in Cryomodules

SCL3

Quarter Wave Resonator (4.5 K) and cryomodule for SCL3



0.047

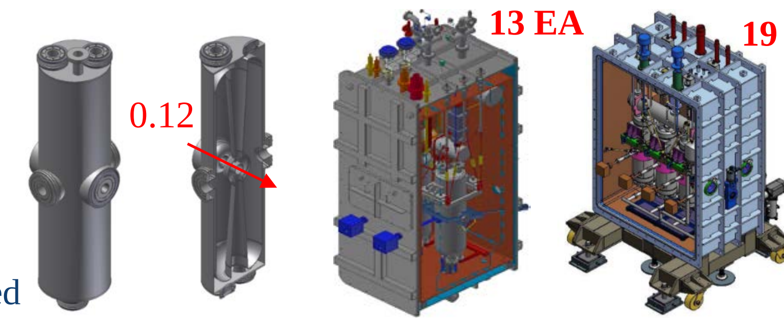
22 EA

Resonance frequency : 81.25 MHz

$2d\,\nu_0\uparrow \le \uparrow\beta c$

Freq. Speed

Half Wave Resonator (2.05 K) and cryomodules for SCL 3



0.12

13 EA

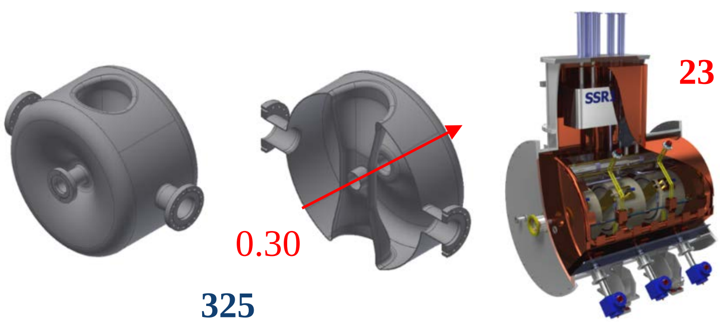
19 EA

162.5 MHz

HWR A (2 cavities)

HWR B (4 cavities)

Single Spoke Resonator 1 (2.05 K) and cryomodule for SCL 2



0.30

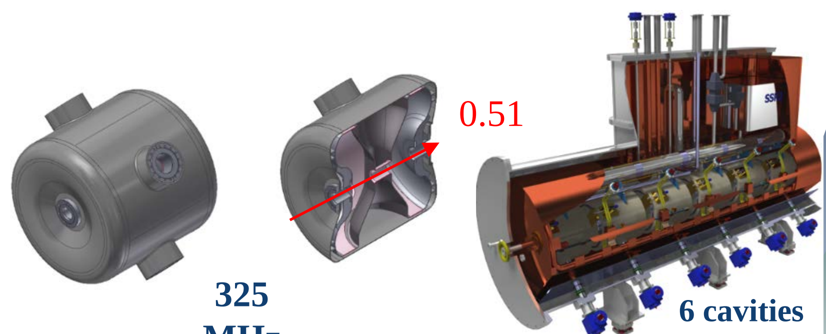
23 EA

325 MHz

3 cavities

Single Spoke Resonator 2 (2.05 K) and cryomodule for SCL 2

25 EA



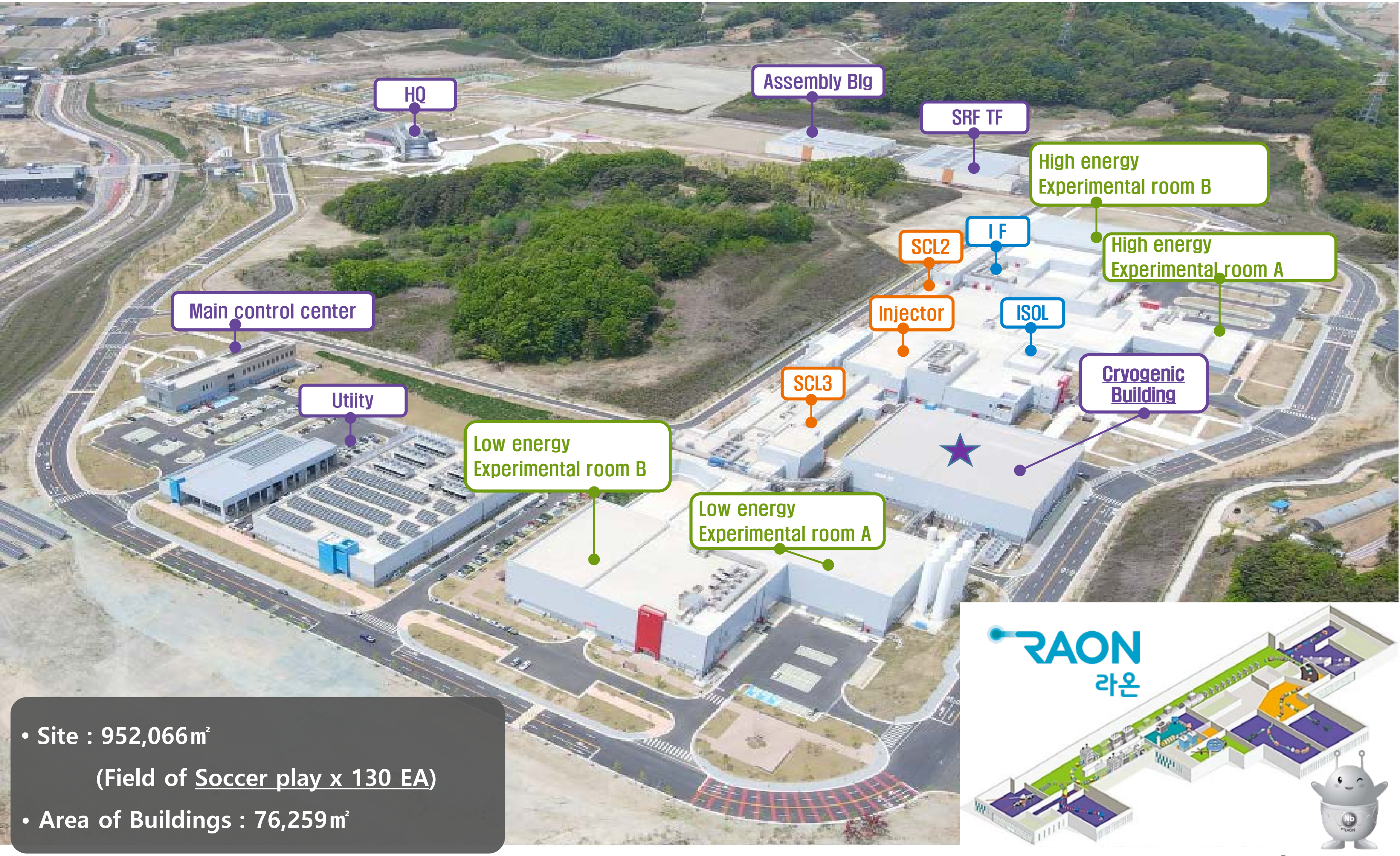
0.51

325 MHz

6 cavities

Bird’s-eye view

● 가속장치 ● 기반시설
● RI생성장치 ● 실험장치



- Site : 952,066㎡
  (Field of Soccer play x 130 EA)
- Area of Buildings : 76,259㎡

11 years

Concepts (Basic design) +
Development of Prototypes for cavities/cryomodules
SCL Demo (with 1 QWR cryomodule) @ temporary place: 5 years

Cryogenics

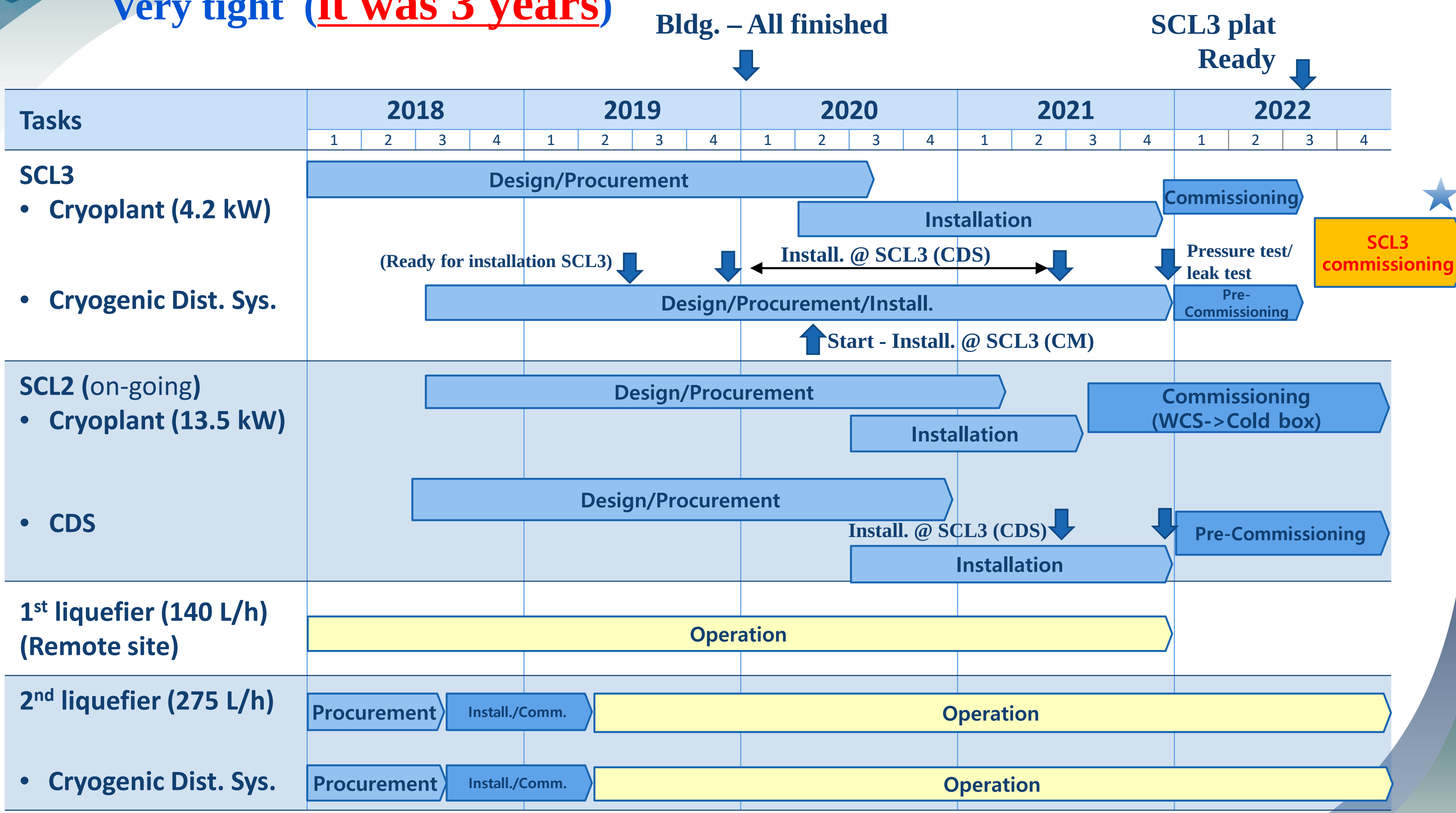
2017 : 1 years (Requirement + Contracts)
2018~2022 : 5 years (including : construction)
SCL3 cryogenic commissioning : Sep. 2022~

@ 2023,
+ 6 months for the first beam by all cavities of SCL3

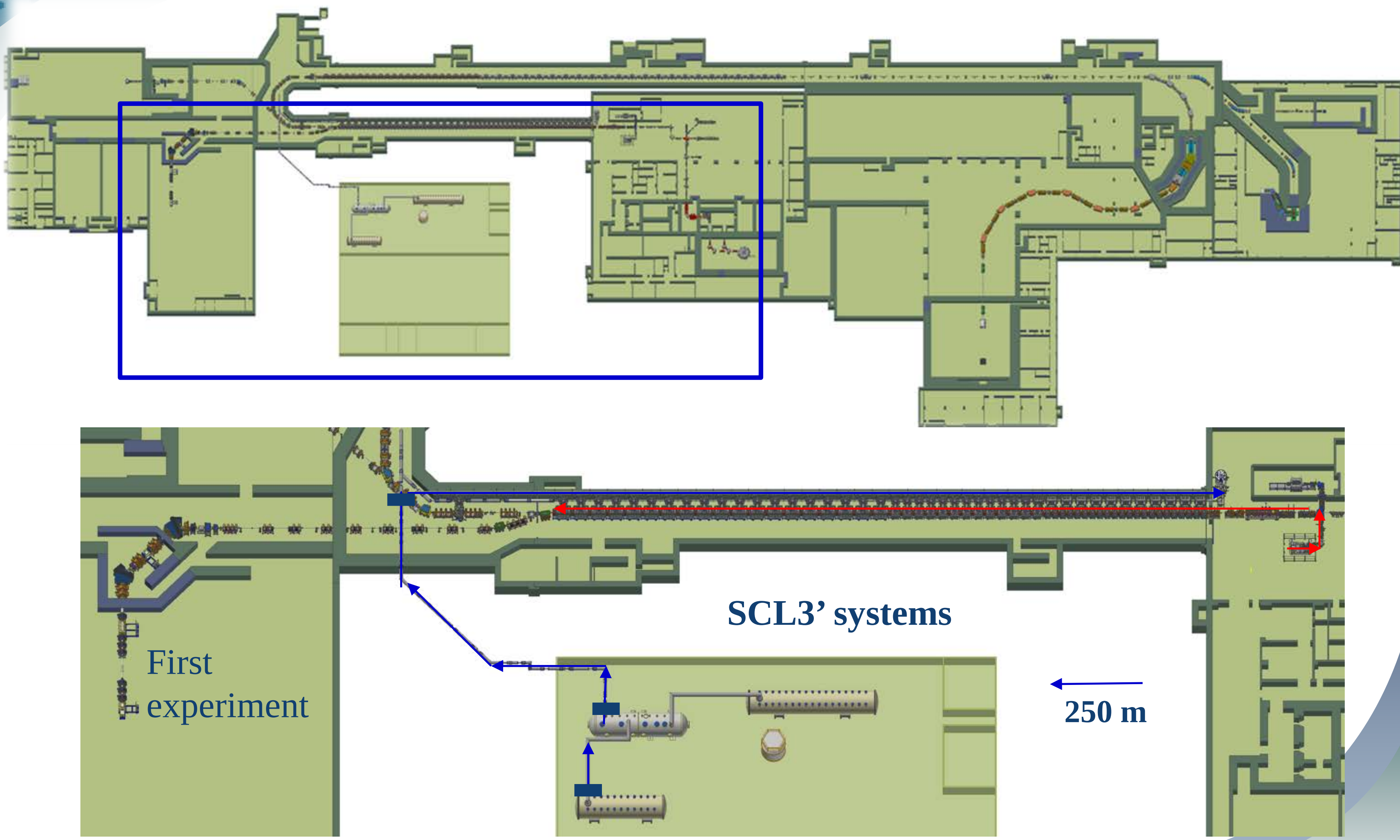
Schedule for cryogenic systems (SCL3/SCL2)&IF - Conclusion

RAON

Very tight (it was 3 years)

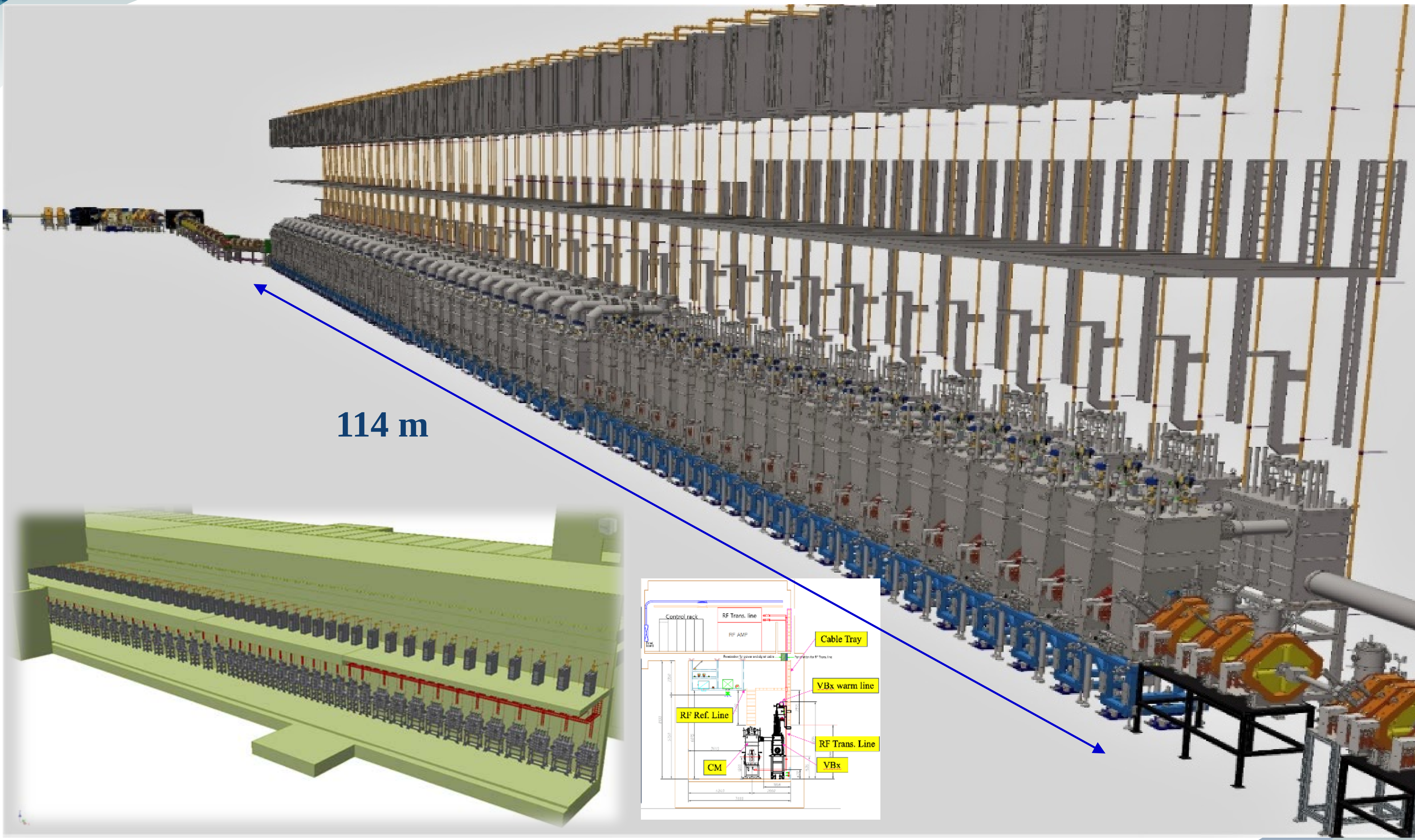


3D Layout



SCL3 of RAON Accelerator

RAON



Requirements for SCL3 cryogenic systems

- Superconducting systems in stable conditions (**T**)
  - **Cryomodules** with **Superconducting cavities (Nb, bath cooling)** @ LINACs
    - QWR (**22 EA**) @ **4.5 K**
    - HWRA and B (**13 EA, 19 EA**) **2.05 K**
- **Thermal insulation (for thermal radiation) with 35 K ~ 40 K**
- **Only Coolant** : **He** (He I, He II)

Requirements for cryogenic refrigeration systems (SCL3)

- **Heat loads**
  - 4.2 kW; equivalent total heat load @ 4.5 K
  - 894 W @ 2.05 K - 36 mbara (cavities)
  - 1,038 W @ 4.5 K @ 1.3 bara (cavities, thermal intercepts)
  - 10.2 kW @ 35 K (all thermal shields, thermal intercepts)

- **Very high stability/availability/many functionalities required**
  - Pressure for cavities (very stable boundary conditions)
    - Very high standard (peak to peak) : ±1 mbar (4.5 K), ± 0.3 mbar (2 K)
      - **<u>As Result from "Cryoplants + Cryogenic distribution system + Cryomodules</u>"**
  - Final Target: No stop for 3 years + 99 % availability (for user service – Third Run;2024)
  - **Fast cool-down required from 150 K to 50 K for cavities (duty : QWR + option : HWR)**
  - **Individual control for many cases (cool-down/warm-up/purging/others)**

- **Big roles for operation :**
  Cool-down, keeping the stability
  (including cryomodules' operation – except for couplers/tuners/LLRF/SSPA)
  warm-up

Scope of Work for Cryogenic Systems

Two SRF TFs
- Helium liquefiers
- Valve boxes
- Cryogenic transfer lines
- Test stands

<u>Control of all actives for cryogenic system</u>

Supports for all works and items

Interconnection between VB-CM

Control of CDS/Cryomodules
- Logic development
- Dynamic simulation
- Racks/PLC and EPICS

Cryogenic Commissioning/maintenance for SCL3&SCL2-IF&SRF TFs

SCL2 and 3 cryoplants
- Compressors
- Cold boxes
- ORS
- SCL3 helium tanks
- LHe dewars

Installation (HYE)
- SCL3 cryoplant

Helium recovery system
- Gas bag
- Heaters
- Recovery compressors
- Purifier

Commissioning (ALAT)
- SCL2 and 3 cryoplants

Support for LINAC Commissioning (ALAT)

Cryogenic distribution system
- Main distribution box
- Valve boxes with Sub-TL
- Cryogenic transfer lines
- End boxes

Warm pipes
- Warm supply
- Recovery/safety
- Cool-down

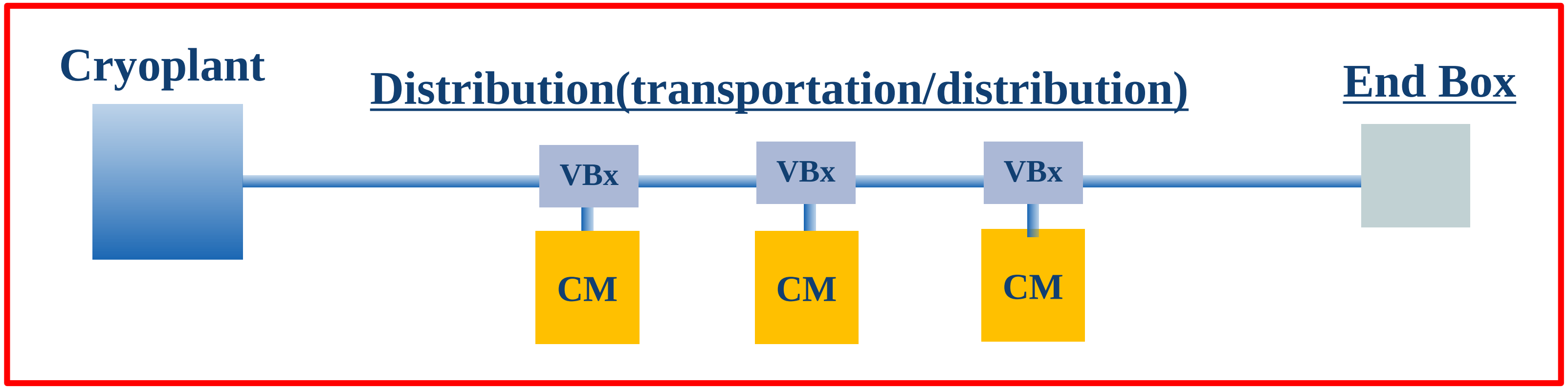
Installation and Pre-commissioning of CDS

Infrastructure
- All buildings/utilities
- SCL2 helium tanks

Development of Customized RAON Cryogenic Systems “fundamentals”

He path/phase in RAON

Our concept



"Refrigeration + Mix mode (due to the fast cool-down)"

+

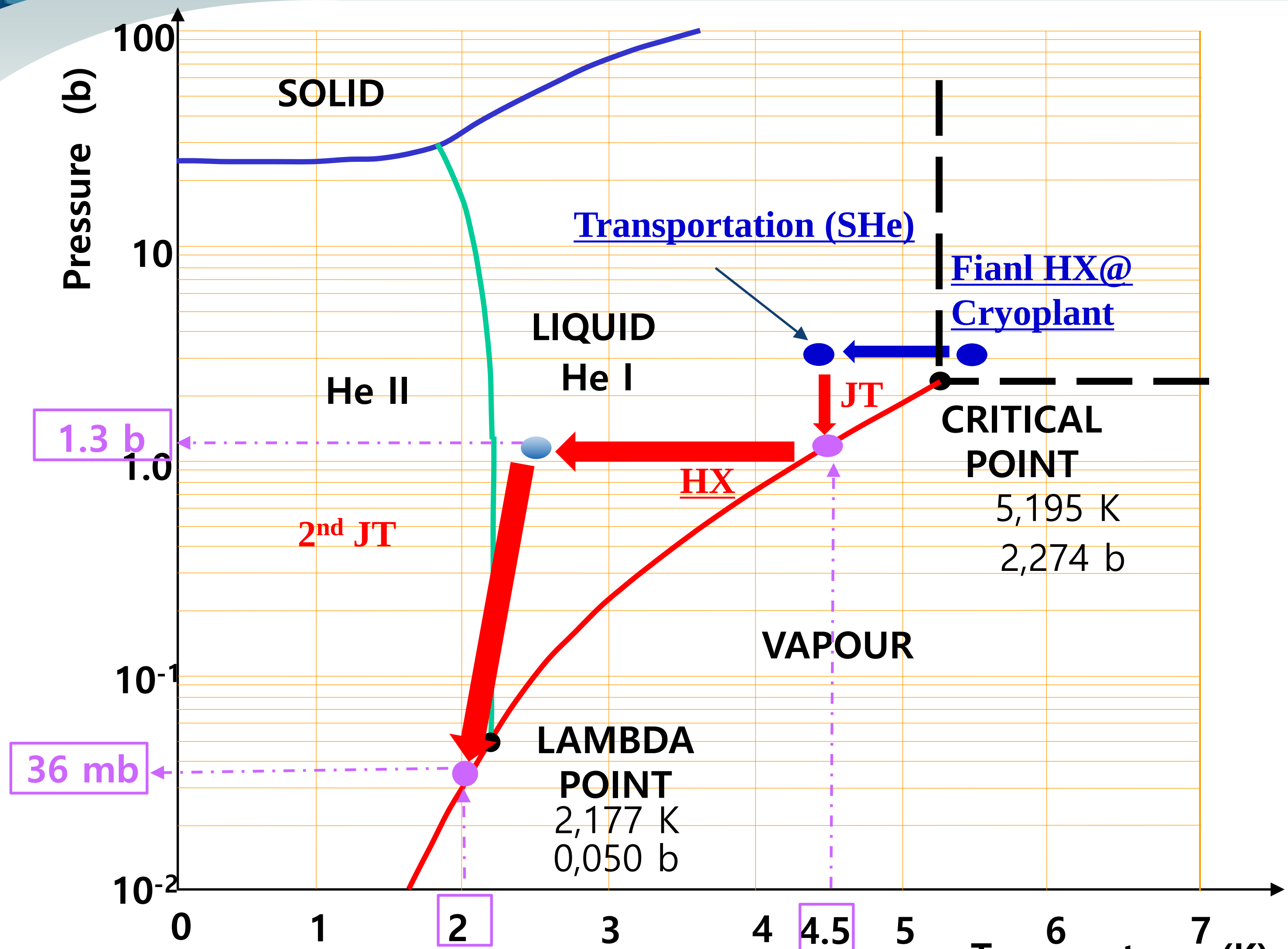
"Dedicated distribution (individual valve-box)

+

Cooling of targets

(Bath cooling - 4.5 K (thermosiphon) and 2 K reservoirs)"

He Path in RAON Cryogenic System



* CEC 2019 paper, thermodynamic and cost-effectiveness analyses of chosen cooling loops for local production and saturated superfluid helium in large cryogenic systems

Expected thermal loads

RAON

CDS	CTL (W/m)	QWR VBx (W/EA)	HWR VBx (W/EA)	End Box [W]	Main Distribution Box [W]
Thermal shield	2.69	36	24.3	21	440
4.5 K line (SHe+GHe)	0.13	2.68	1.14	3.1	24
2 K VLP return	0.12	-	2.63	-	43

CM	Full load of thermal shields (W)	4.5 K Static/dynamic (W)	2 K Static/ dynamic (W)
QWR	55.5	5/12.1 Total : 17.1	-
HWR A	78.6	Total : 3	3/6.4 Total : 9.4
HWR B	121	Total : 5	4.5/12.8 Total : 17.3

So, Boundary conditions for SCL3 Cryoplant

RAON

	Design (RF OFF)			Design (RF ON – Full loads)		
	T (K)	P (bara)	m (g/s)	T (K)	P (bara)	m (g/s)
Thermal shield Supply	**35**	**15**	**< 95.3**	**35**	**15**	**95.3**
Thermal shield Return	**55**	**14.5**	**< 95.3**	**55**	**14.5**	**95.3**
SHe Supply	**4.5**	**3**	**36.4**	**4.5**	**3**	**82.4**
GHe return	**5**	**1.25**	**27.1**	**4.8**	**1.25**	**48.7**
2 K return	**7.1**	**0.032**	**9.3**	**4.5**	**0.032**	**33.7**

Consideration for Specification

Consideration of current status and technologies in the field + Test results for Performance (thermal, others)

Consideration of piping routes (bellows, fixed/sliding points)/taps/cryogenic valve – Thermal acoustic oscillation

Dedicated : Structure/thermal analysis

Sensors – locations/installation method

Interconnection (Cryoplant-CTL, Valve box-Cryomodules)

Cool-down process due to the fast cool-down

Process control; Cooling strategies

※ 1st cool-down of SCL3 : more conservative way – step cooling ! + manually checking dT @ cryogenic distribution system

- Step 1: The FIRST cool-down : **Should be very conservative**

SCL3 CB+ CDS – **Step cool-down (50 K) controlled by Turbines**: within 16 days

(300 K – 250 K + 1 day stay – 200 K + 1 day stay– 150 K + 1 day stay – 100 K + 1 day stay– 50 K + 1 day stay – 4.5 K + 1 day filling and stabilization)

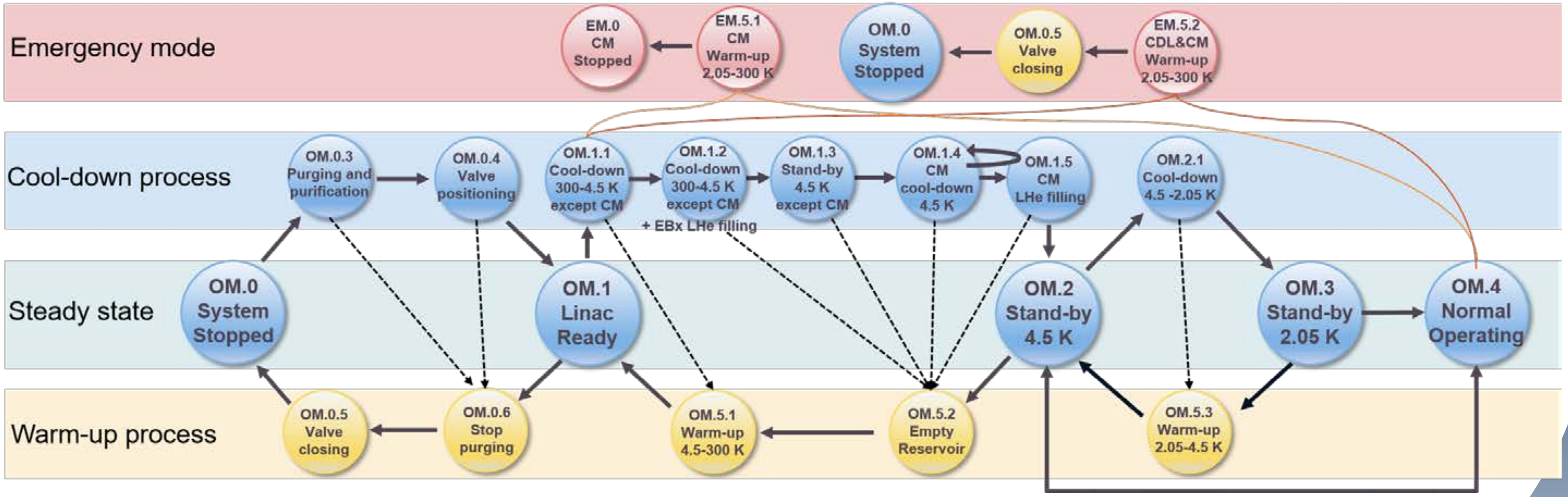
※ Calculation with energy balance + **conservative assumption**
= 291~330 hours (< 14 days) ; 18 tons (AL), 9 tons (SUS) for CDS+TS

- Step 2: CM – **QWR fast cool-down** : within 12 days
HWR : within 20 days

Need to be checked @ cryoplant and SRF TS, simulation

Process control; Operation mode

Defined and designed
- Definition
- Start and End
- Internal process



Safety

- Safety (Cryogenic components)

  - **FMEA (Failure Mode Effect Analysis) for checking effect on control**
  - **HAZOP (Hazard and Operability) for checking equipment and human’ safety**
  - **Safety Alarm/Interlock System**
  - **Dedicated international reviews**
  - **Others (Korea Gas Standard – Inspection)**
    - All cryogenic piping and pressure vessels should be checked by KGS (from design to commissioning)

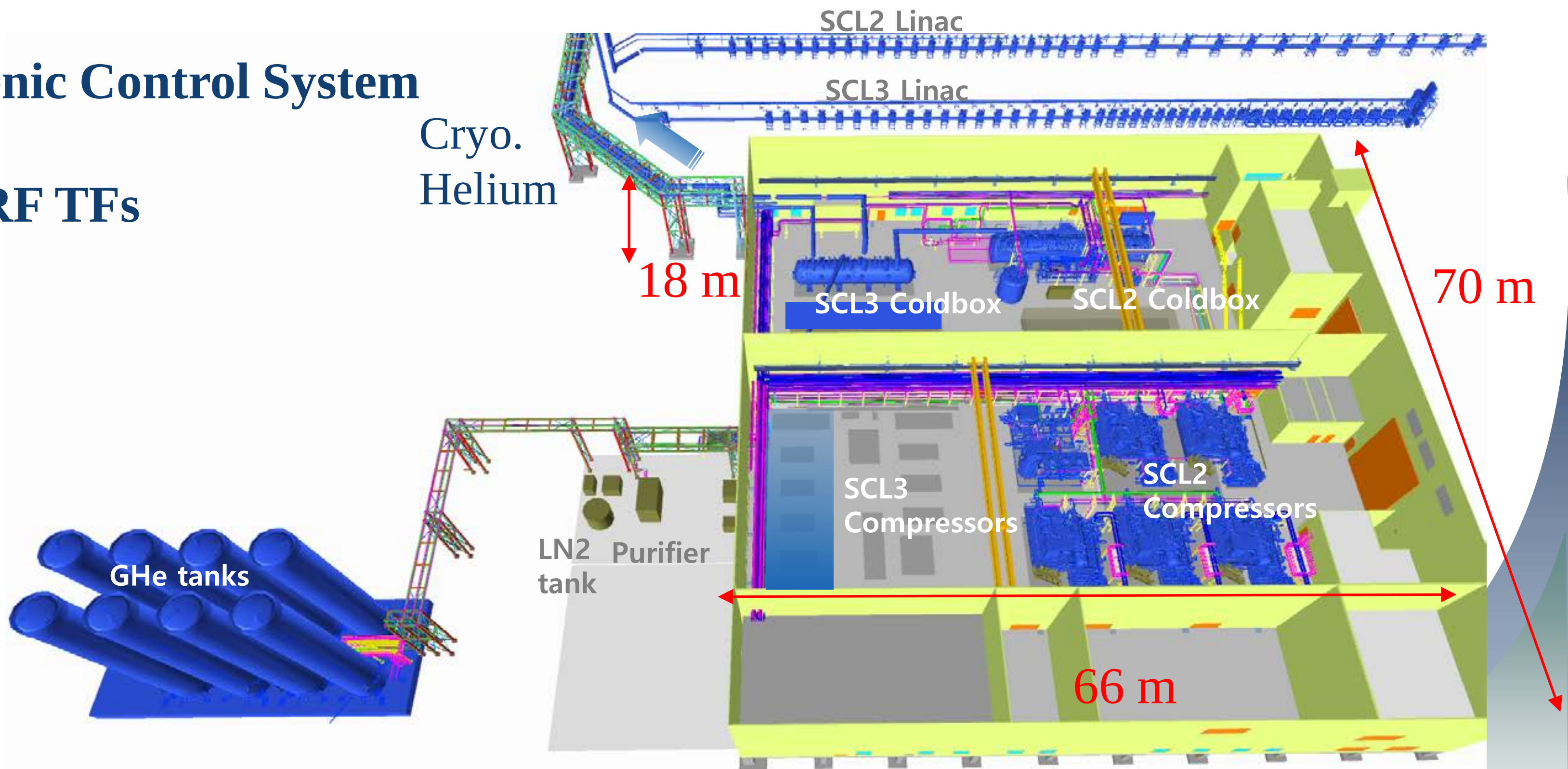
Development of
Customized
RAON
Cryogenic Systems

- Real System

Real application
What you have to do

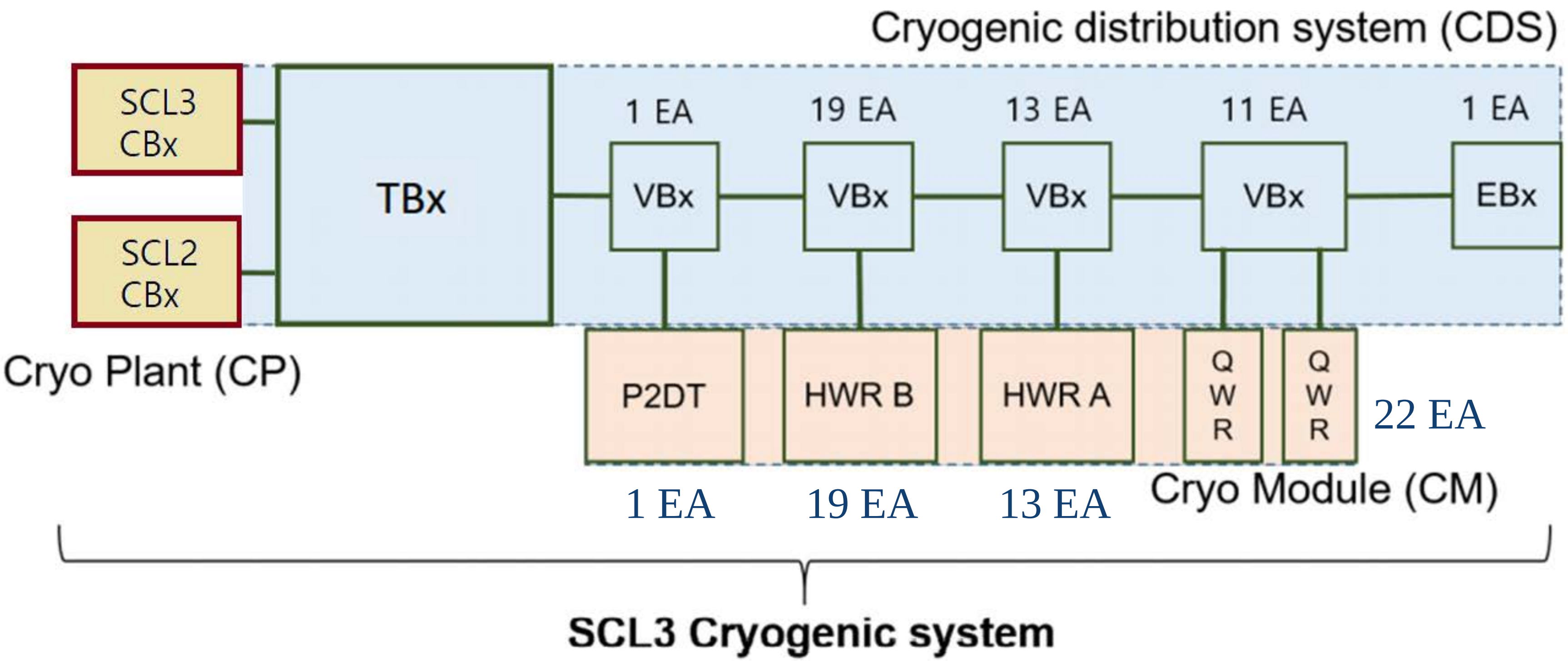
Final Layout

- **Two Cryoplants and Recovery System**
- **Cryogenic Distribution System/Cryomodules**
- **Cryogenic Control System**
- **Two SRF TFs**

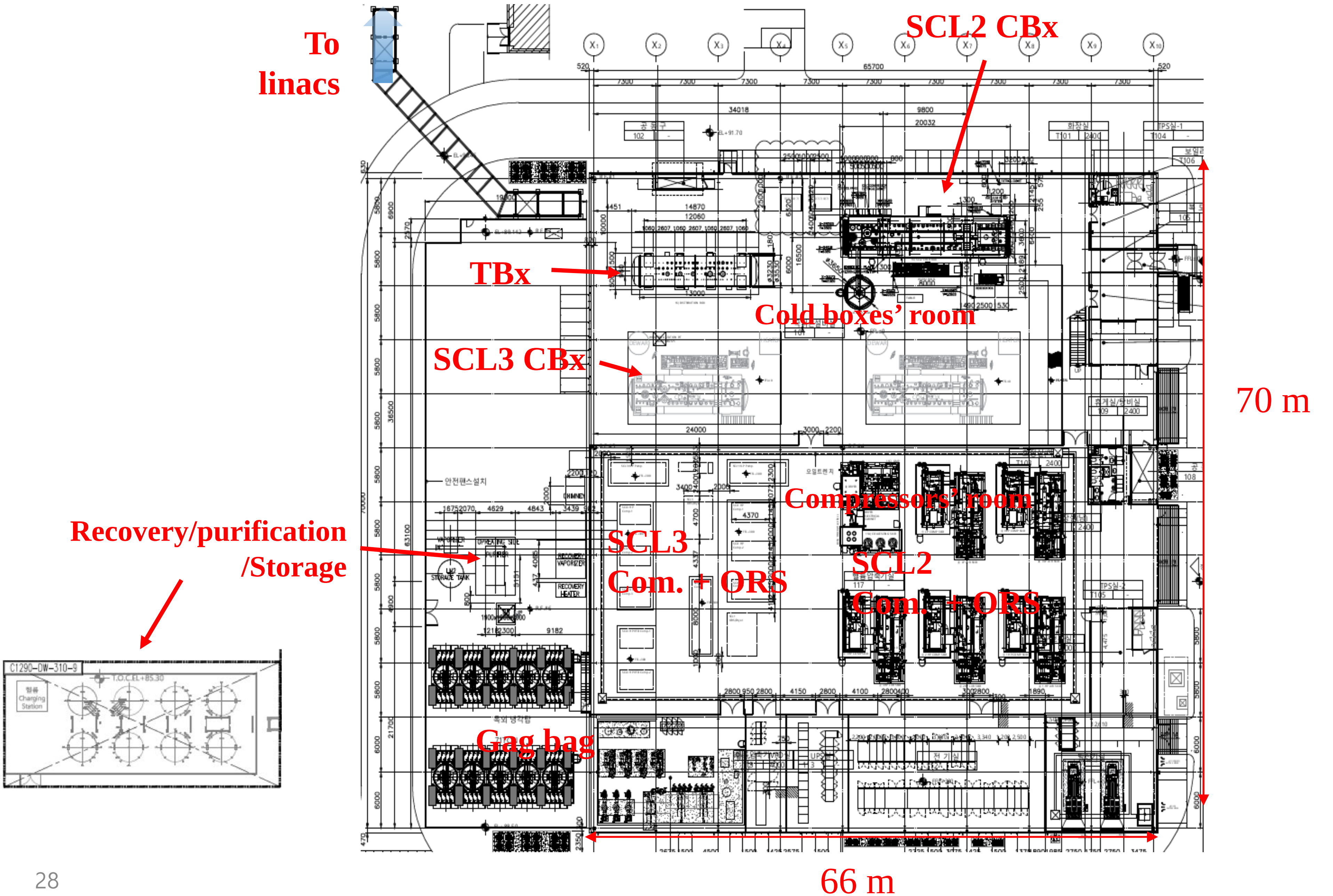


SCL3 Cryogenic systems

Cryogenic System for SCL3



Cryoplants– Layout



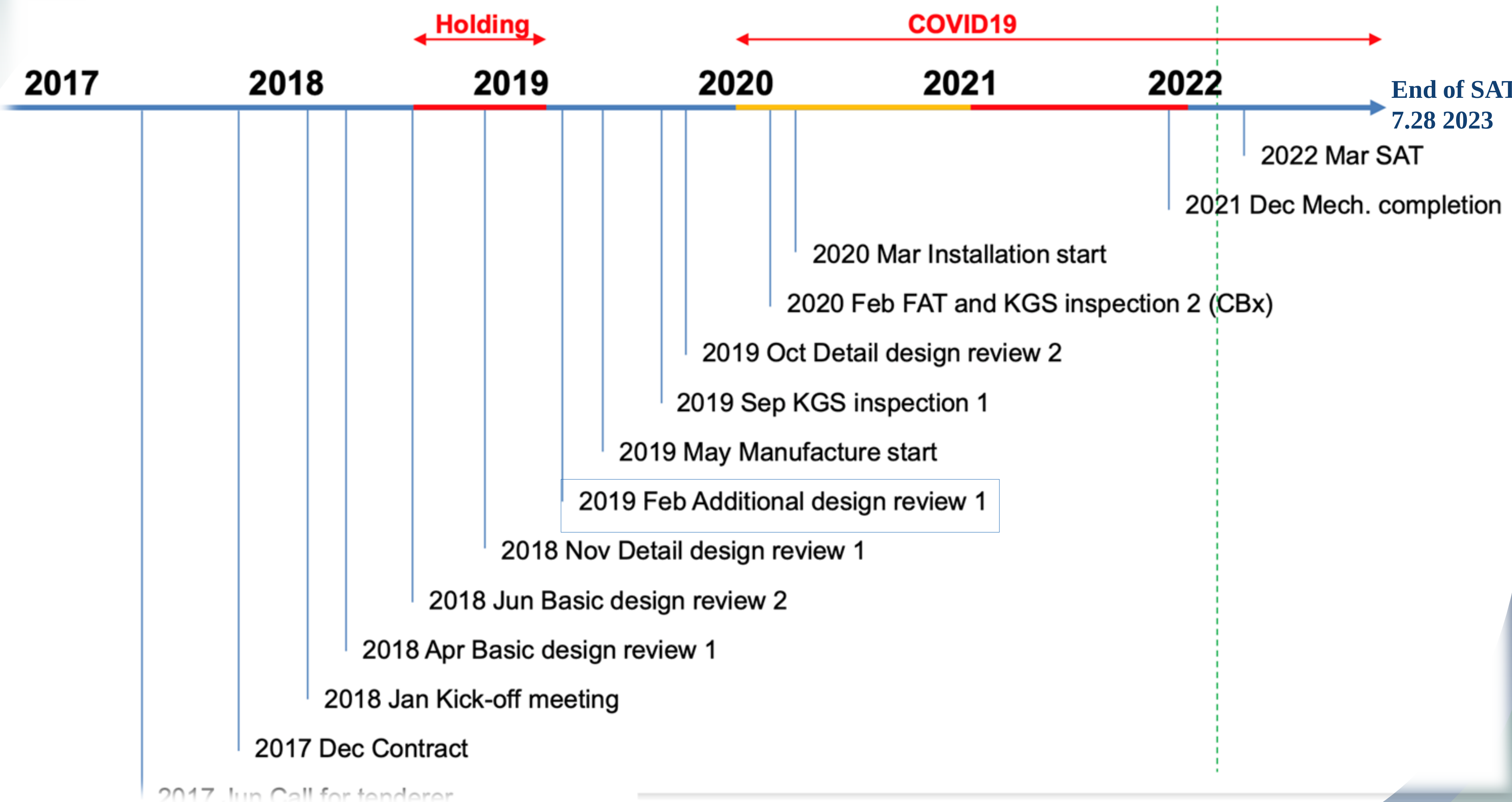
SCL3 Cryoplant

- SCL3 cryoplant (Contracted with ALAT&HY ENG) including several operation modes

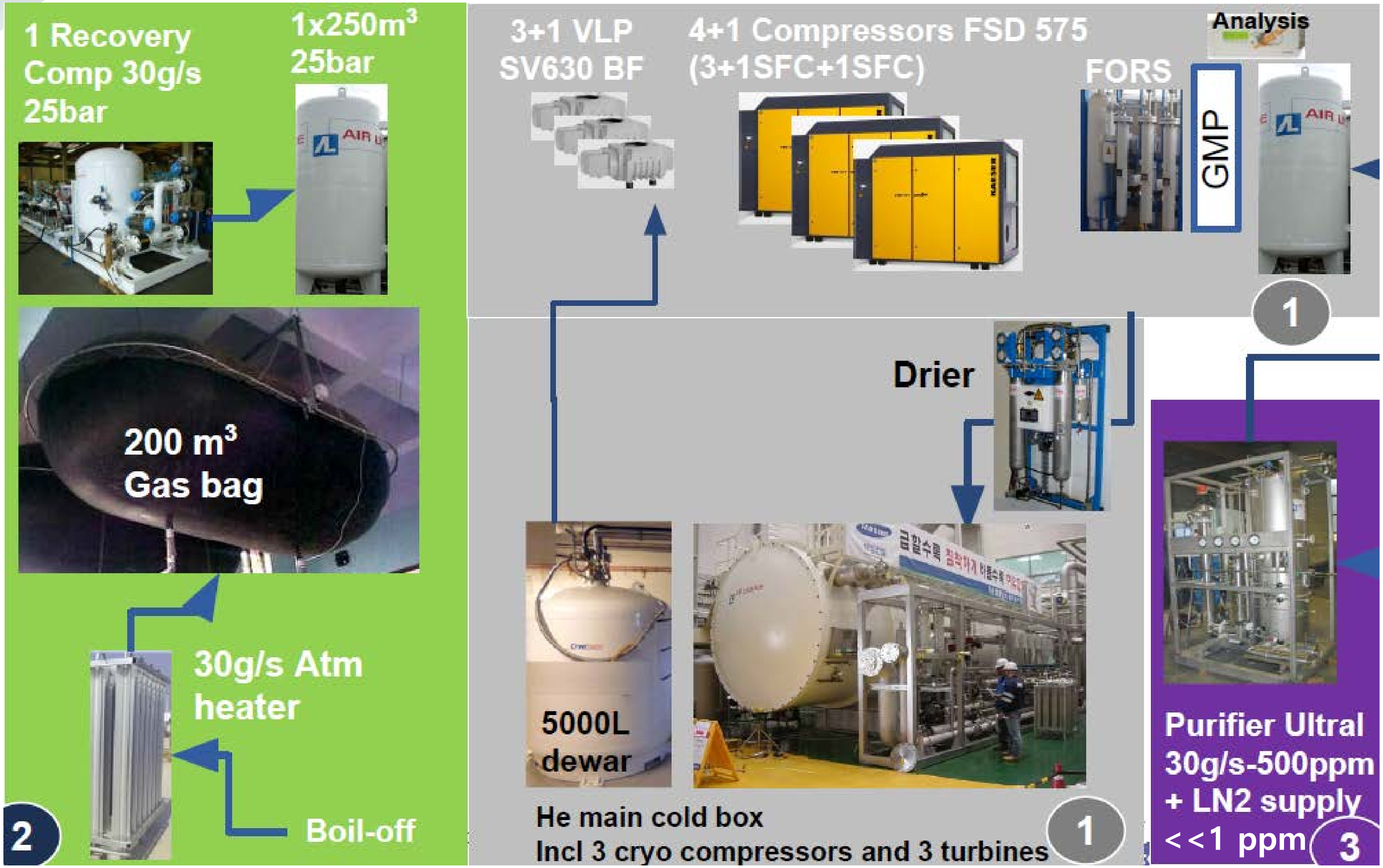
SCL3 Cryo. Modes	2.05 K [W]				4.5 K [W]					35 – 55 K [W]
	Isothermal		Non-isothermal	Sum	Isothermal		Non-isothermal		Sum	Sum
	Static	Dynamic			Static	Dynamic	Supply	Return		
Nominal	199	519	176	894	378	401	128	131	1038	10,172
Beam commissioning	199	191	176	566	378	113	128	131	750	10,172
2.05 K Turndown	199	-	176	375	378	-	128	131	637	10,172
4.5 K standby	-	-	-		577	-	128	307	1012	10,172
TS standby	-	-	-			-	-	-		10,172

Based on the boundary conditions : Nominal mode
894 W @ 2.05 K circuit, 1,038 W @ 4.5 K circuit, 10.2 kW @ 35 K circuit

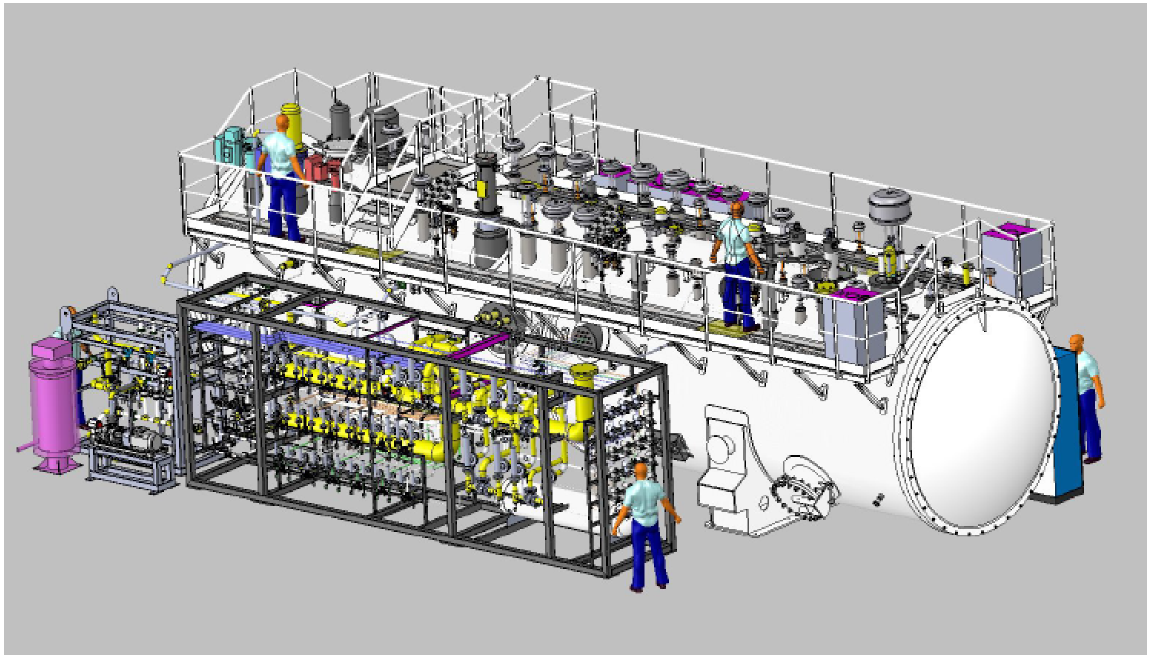
Long journey for development (4 years and 7 months)



SCL3 Cryoplant – Concept/Basic design



- HP : 15 bara (LP -> HP : 4 compressors, 1 back-up with VFD, Kaeser compressors)
- 3 turbines (Isentropic eff. ~ 78 %)
- 3 cold compressors with VFD in series + VLP pumps for 32 mbara
- 4.2 kW @ 4.5 K equivalent, ~ 25 % Carnot efficiency
- Including recovery and external purifier (25 bara, 30 g/s) for all linacs
- Availability : > 99 %



L x W x H : 15 x 5.4 x 4.7 m
95 ton (cold box only)

SCL3 cryoplant - Process (cycle) design

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Nominal mode
980 W @ 2.05 K circuit, 930 W @ 4.5 K circuit, 11.8 kW @ 35 K circuit

Compressors

1 dryer

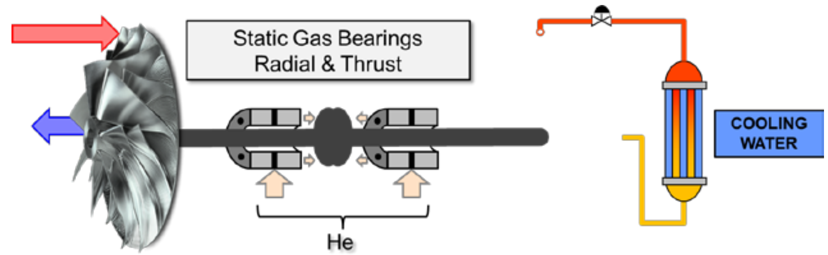
Cycle compressors

3 Coalescers

1 Charcoal adsorber

Cold Box

Turbine 1



Dewar

Turbine 3

Turbine 2

80 K
adsorbers

20 K
adsorber

Phase
Separator
(4.5 K)

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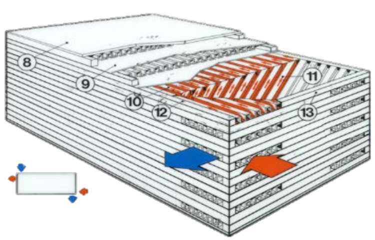
Cold
compressors

Phase
Separator
(2 K)



Cold compressors for 2 K

Manufacturing with mechanical technicians

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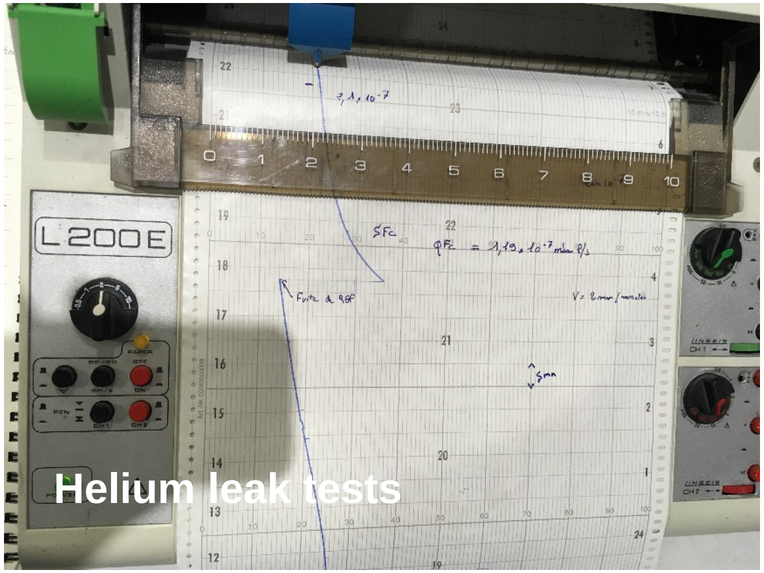
Manufacturing – Qality/KGS inspection @ ALAT Site

Fully assembled and FAT

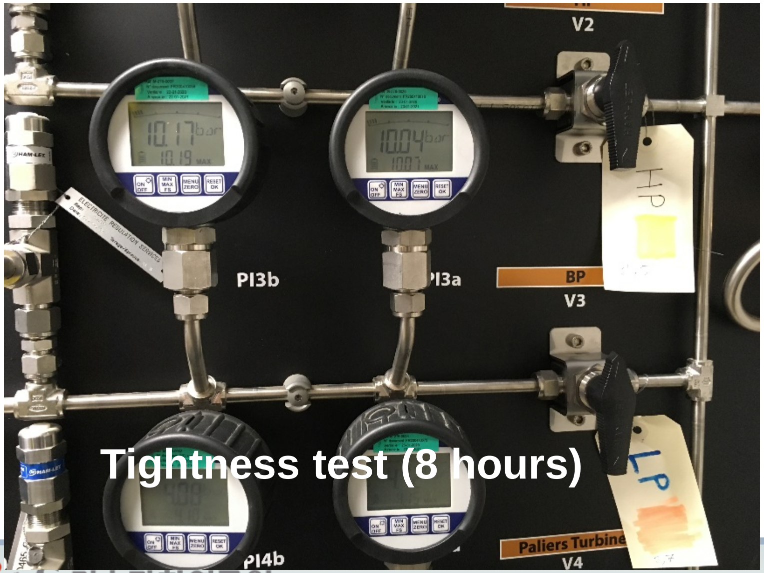
Last section of cold box

FAT @ ALAT


EPICS communication check



Helium leak tests

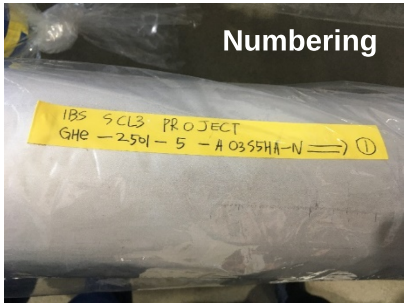


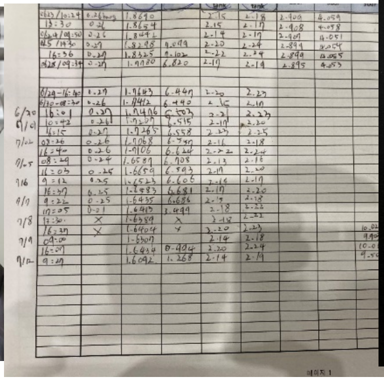
Tightness test (8 hours)

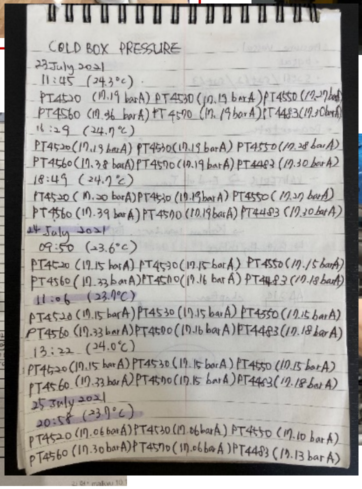
8 hours tightness tests with KGS inspector

Re- performed the tests @ RAON site, again

Installation



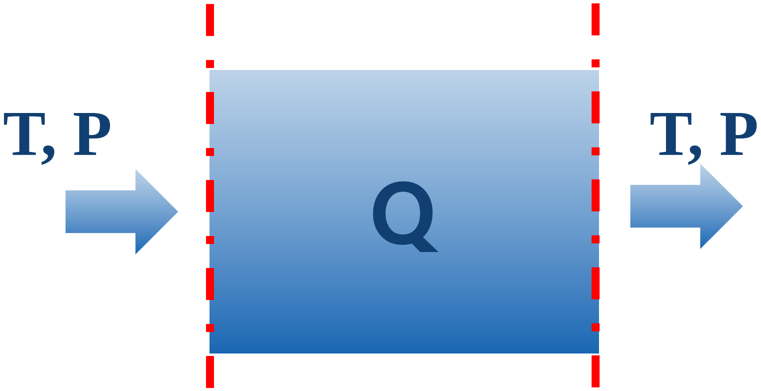



COLD BOX PRESSURE
23 July 2021
11:45 (24.3°C)
PT4520 (19.19 barA) PT4530 (19.19 barA) PT4550 (19.27 barA)
PT4560 (19.36 barA) PT4570 (19.19 barA) PT4483 (19.30 barA)
16:29 (24.7°C)
PT4520 (19.19 barA) PT4530 (19.19 barA) PT4550 (19.28 barA)
PT4560 (19.38 barA) PT4570 (19.19 barA) PT4483 (19.30 barA)
18:49 (24.7°C)
PT4520 (19.20 barA) PT4530 (19.19 barA) PT4550 (19.27 barA)
PT4560 (19.39 barA) PT4570 (19.19 barA) PT4483 (19.30 barA)
24 July 2021
09:50 (23.6°C)
PT4520 (19.15 barA) PT4530 (19.15 barA) PT4550 (19.15 barA)
PT4560 (19.33 barA) PT4570 (19.16 barA) PT4483 (19.18 barA)
11:06 (23.9°C)
PT4520 (19.15 barA) PT4530 (19.15 barA) PT4550 (19.15 barA)
PT4560 (19.33 barA) PT4570 (19.16 barA) PT4483 (19.18 barA)
13:22 (24.0°C)
PT4520 (19.15 barA) PT4530 (19.15 barA) PT4550 (19.15 barA)
PT4560 (19.33 barA) PT4570 (19.15 barA) PT4483 (19.18 barA)
25 July 2021
20:58 (23.9°C)
PT4520 (19.06 barA) PT4530 (19.06 barA) PT4550 (19.10 barA)
PT4560 (19.30 barA) PT4570 (19.06 barA) PT4483 (19.13 barA)

2021. Dec : Completion of Mech. Installation (up to gas conditioning/loop checks)

1st cool-down of CB : Jan. 4th 2022

SAT Test method for SCL3 Cryoplant



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By energy balance (in open system)

T, P in
Q
T. P out

Flow rate

In the Steady/Transient conditions

1. Cold power tests (**steady @ 4.5 K and 2 K modes**)
2. Cold power tests (Modes/Loads' changes-**transient**)
3. Failures/trips
4. Cool-down + Optional tests
5. Warm-up

Finally, SAT result of SCL3 cryoplant

- Ready for SAT from ALAT (March 31st 2022)
- But, need **3 Months (mitigation of problems) more**
- **Completion of SAT (July 15th ~ July 28th 2022)**

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- Results

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Additional tests in order to check the possibility +

- Maximum possibility +
  - Max. 4.5 K refrigeration mode (important) for all cavities (4.5 K)
    - Need to check it for 4.5 K Cryo. + RF commissioning (If it will be needed)
    - Can be possible over > **2,154 W**
  - Max. liquefaction rate @ 4.5 K stand-by mode
    - 378 L/h -> **12 g/s**
  - Min. Pressure @ 2 K section of Cold Box (with full load)
    - < **28.5 mbara**
  - Test of step cool-down (**checked @ cool-down test**)

Ready for SCL3 Cryogenic Commissioning

Cryogenic Distribution System

Thermal Packing
Distribution/Transportation (He)

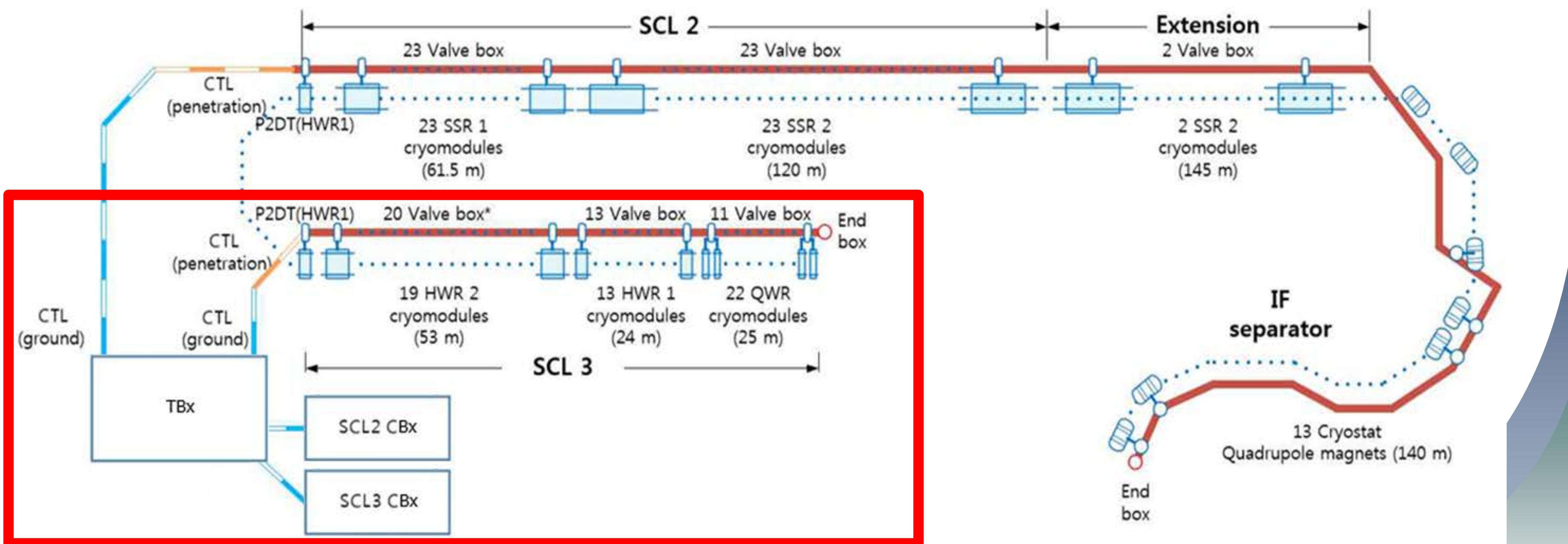
with thermal & dynamic/structure stability

Cryogenic Distribution System (SCL3)

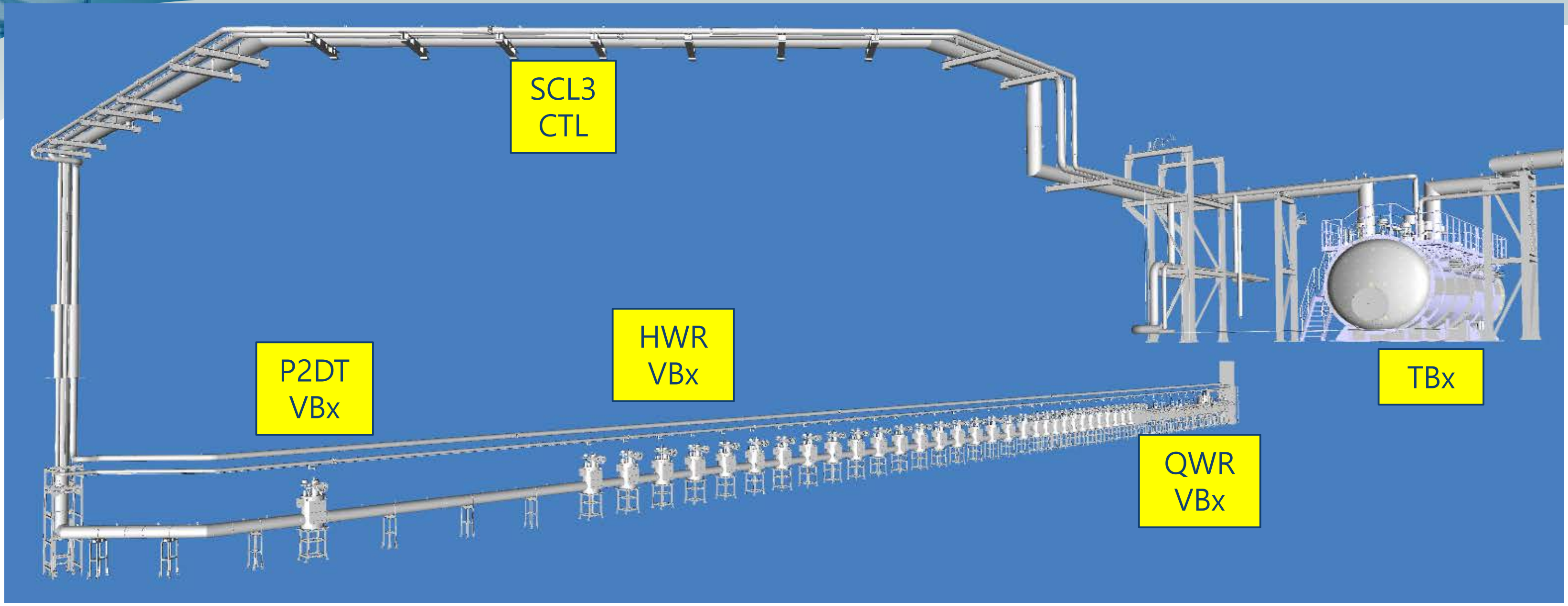
- Cryomodules(CMs) **<u>cooled by cryo. helium, stably</u>**
- Valve box (VBx) – distributes SHe helium to each CM
- Cooling target
  - ➢ **SCL3: QWR (4. 5 K, 35~55 K), HWRA QWR (2.05 K, 4. 5 K, 35~55 K), HWRB (2.05 K, 4. 5 K, 35~55 K), Cryogenic Distribution System (CDS)**
- Helium flow direction: CBx – TBx – CTL – VBx – CM – Ebx

250 m @ SCL3 (today' talk)

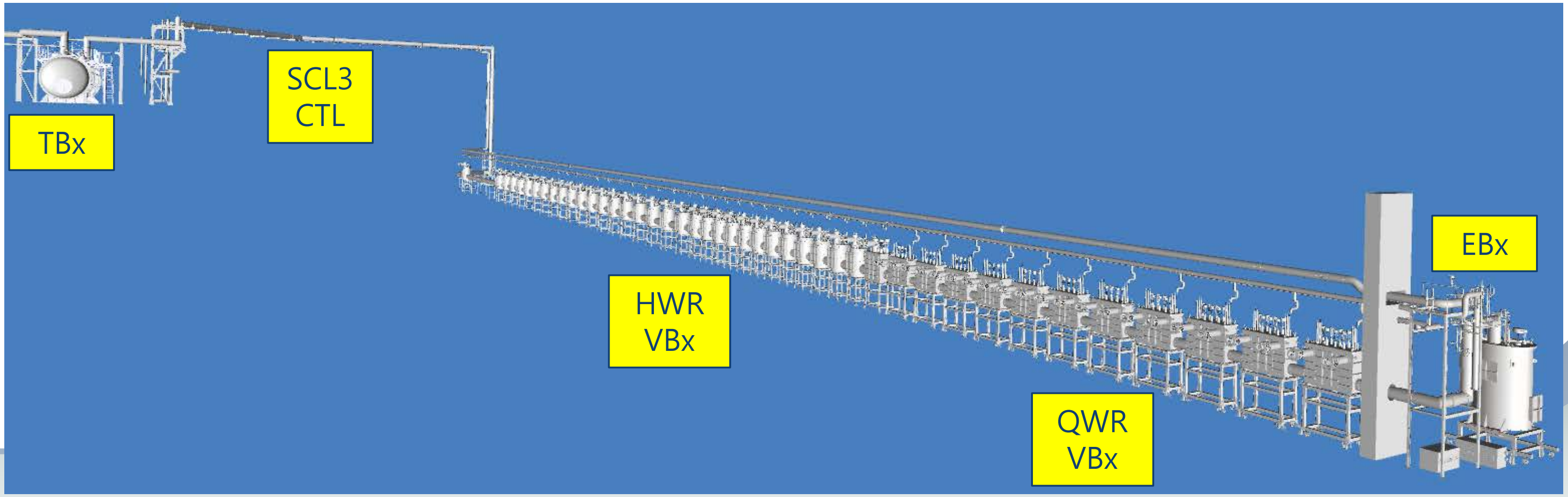
700 m @ SCL2-IF



3D view of SCL3 CDS



- 3D view of SCL3 CDS adjacent to SCL3 EBx



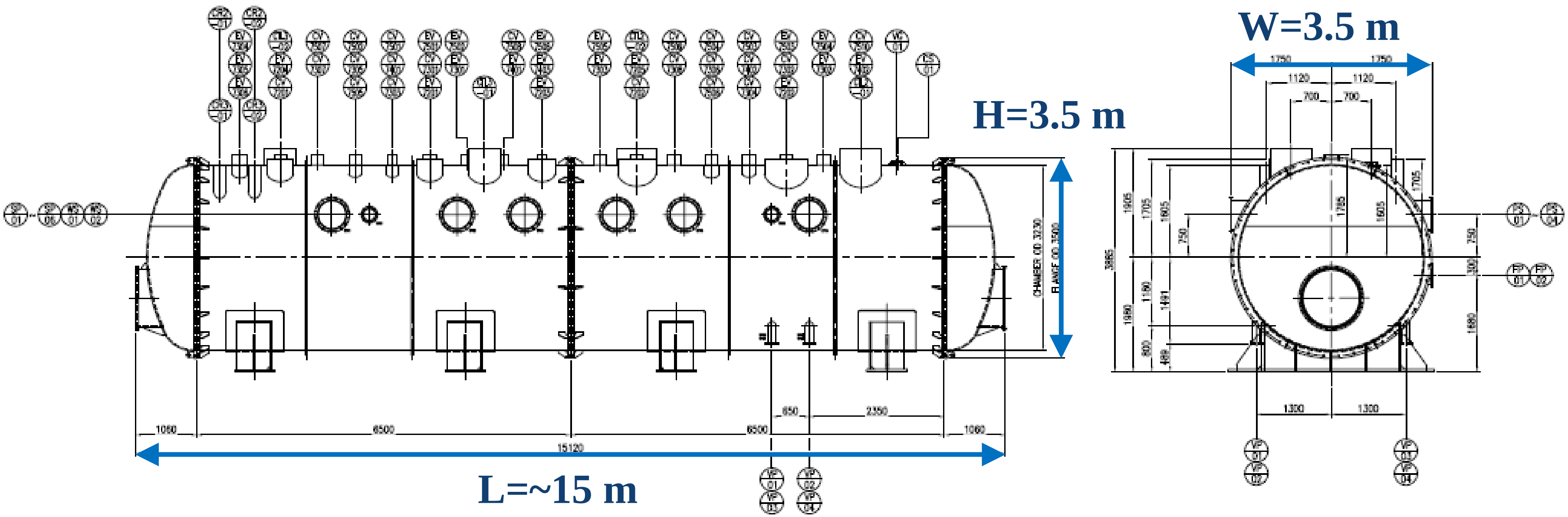
CDS-Main Distribution Box (TBx)

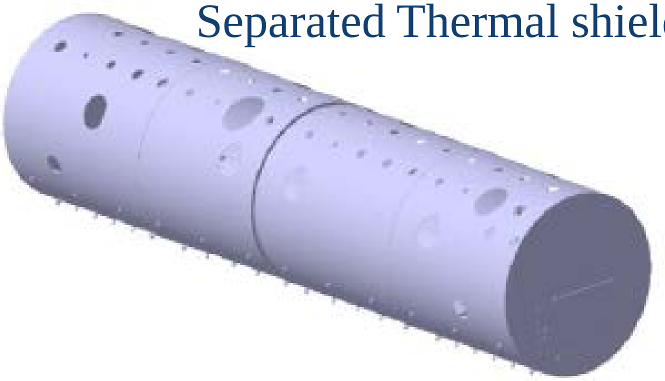
*** Material for all lines: STS316L**

Confidential
– cannot be copied

Part Name	Spec.	Remark
SHe /GHe	- Size: 32A~50A - Design Temp.: 4.5 ~ 5 K - Design Press.: 9 barG (GHe) 19 barG (SHe)	- MLI (20 layer) - Bellows (due to cryogenic valves/thermal effect) - T : inside of pipes - P taps (locations) - Thermal anchoring - Sizing : Cv/pressure drop
TSS /TSR	- Size: 40A~65A - Design Temp.: 35 ~ 55 K - Design Press.: 25 barG	
VLP	- Size: 150A~250A - Design Temp.: 2.1 K - Design Press.: 3 barG	
CDR	- Size: 80A~100A - Design Temp.: 4.5~300 K - Design Press.: 9 barG	
Safety /Warm	- Size: Depends on the usage - Design Temp.: Cyo. T/300 K - Design Press.: 3~25 barG	- Cryo-check valves @ P taps and Safety lines for main lines

* **Weight: ~44 ton (including stair and deck)**

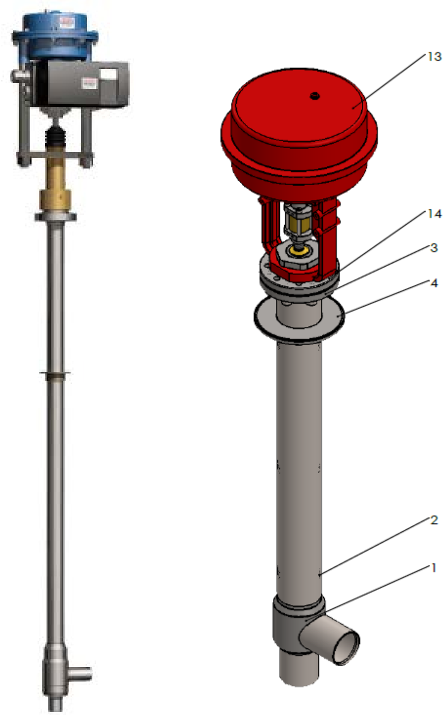




Separated Thermal shields

Part Name	Spec.
Cylinder	- 2 pcs. (SCL3/SCL2) - Material: AL6061
Cooling pipe	- Size: 10A_Seamless - Material: STS316L
MLI	- 30 layer

Cryogenic valves



(a) (b)

Cryogenic valve

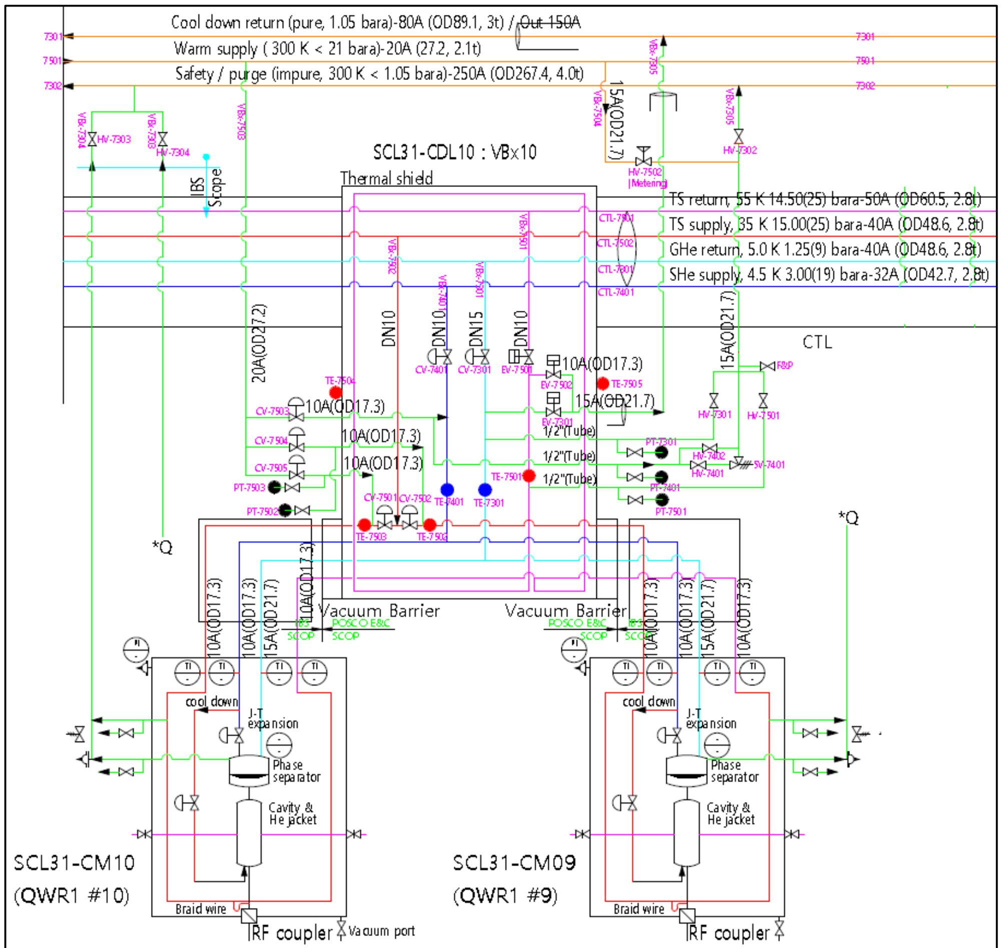
Size	Manufacturer (Country)	Qt.	Remark
DN10	WEKA (Switzerland)	4	TS
DN32	WEKA (Switzerland)	3	SHe
DN40	WEKA (Switzerland)	12	TS/SHe/GHe/VLP
DN50	WEKA (Switzerland)	12	TS/GHe/VLP
DN65	WEKA (Switzerland)	3	TS/GHe
DN150	WEKA (Switzerland)	3	VLP
DN250	WEKA (Switzerland)	2	VLP
DN80	Surim tech. (Korea)	2	CDR
DN100	Surim tech. (Korea)	3	CDR
Total		44	

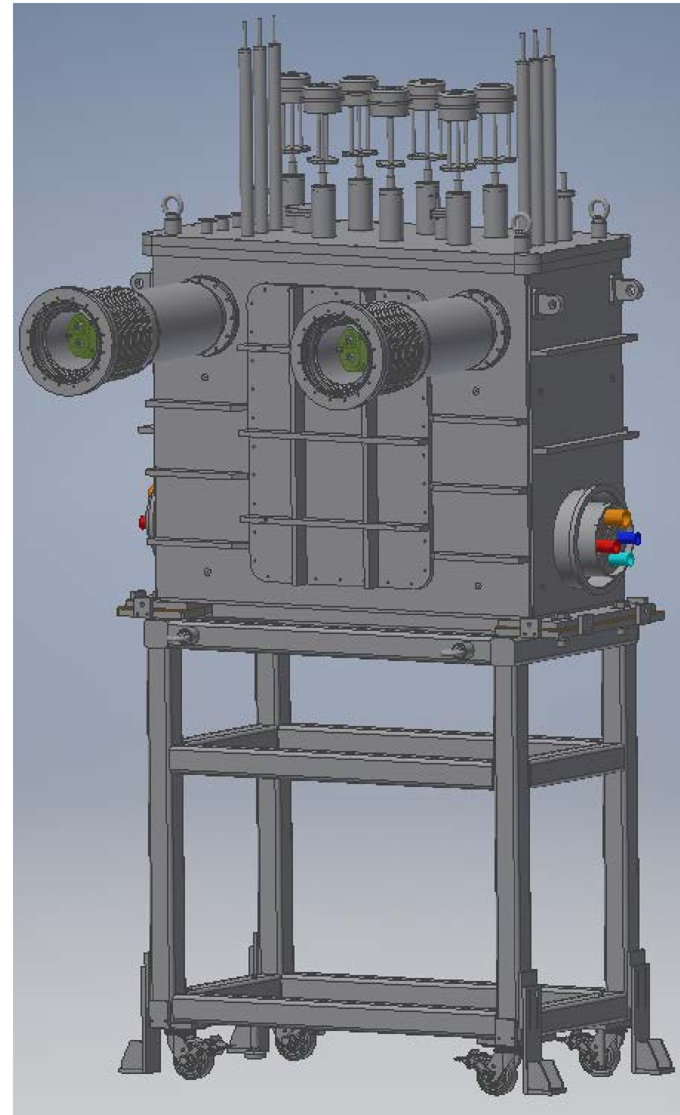
(a) WEKA, (b) Surim tech. (demostic)

CDS – Valve Box (VBx)

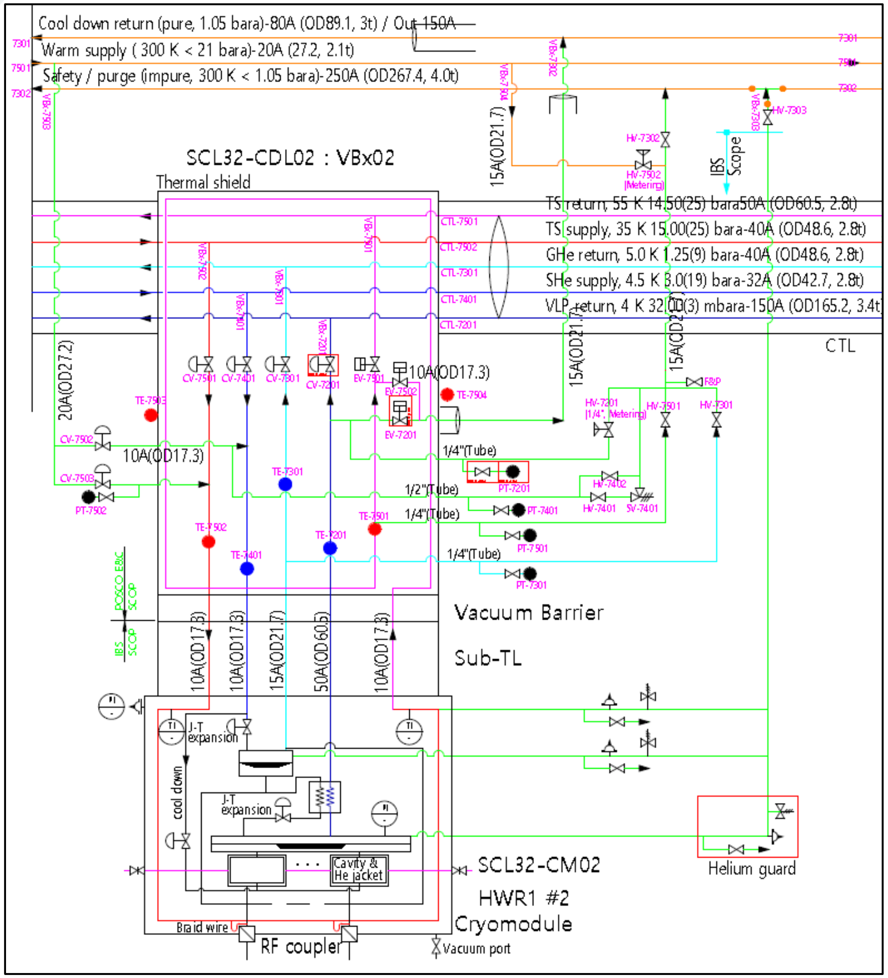
Main Role : distribute He to dedicated section

QWR Valve Box – 2 cryomodules



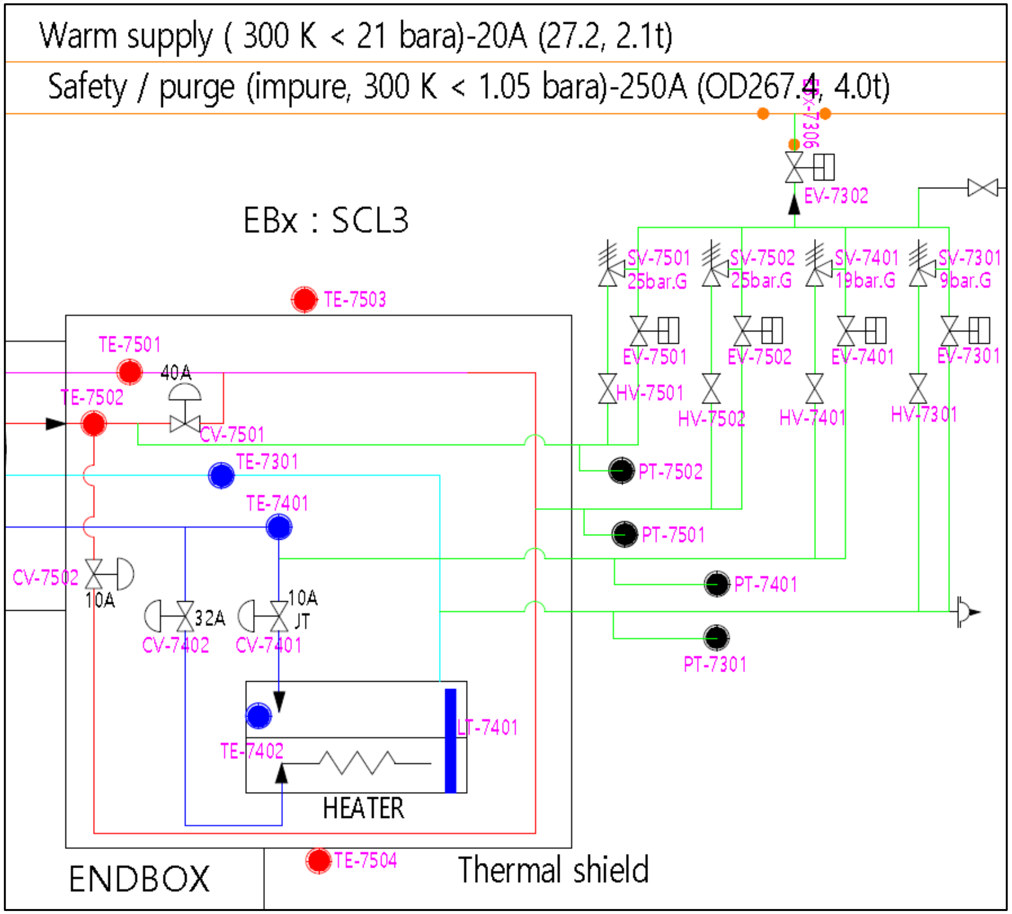


HWR Valve Box – 1 cryomodule



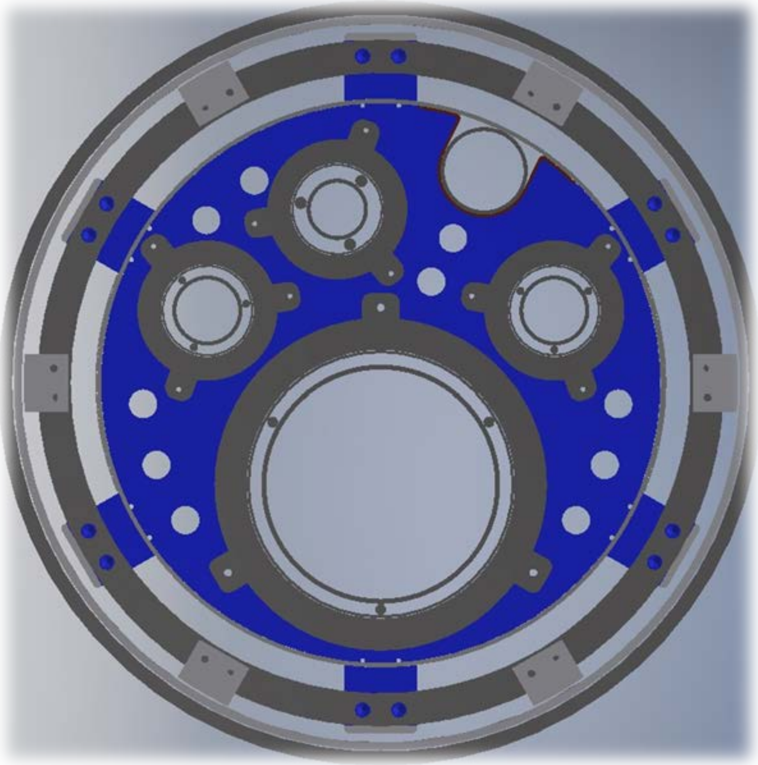
End Box

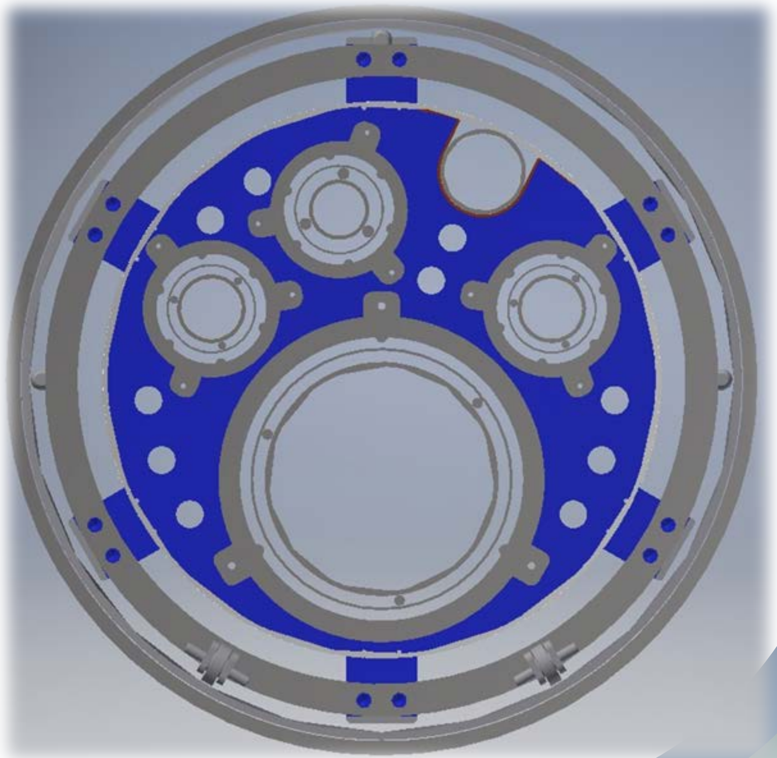
End Box (with 4.5 K reservoir, heater)



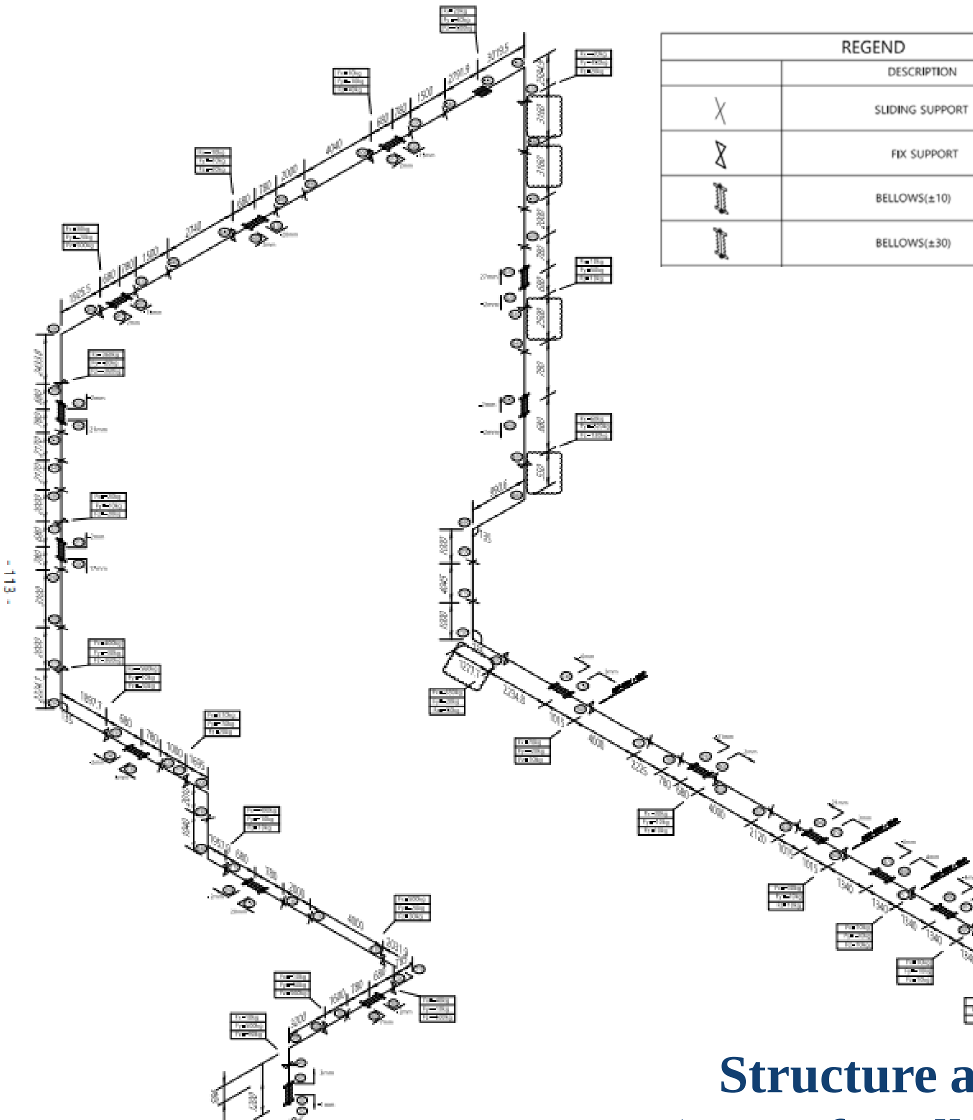
Cryogenic Transfer Lines (CTL)

– Fixed points/sliding points (structure –stress/deformation) + thermal insulation + delta P

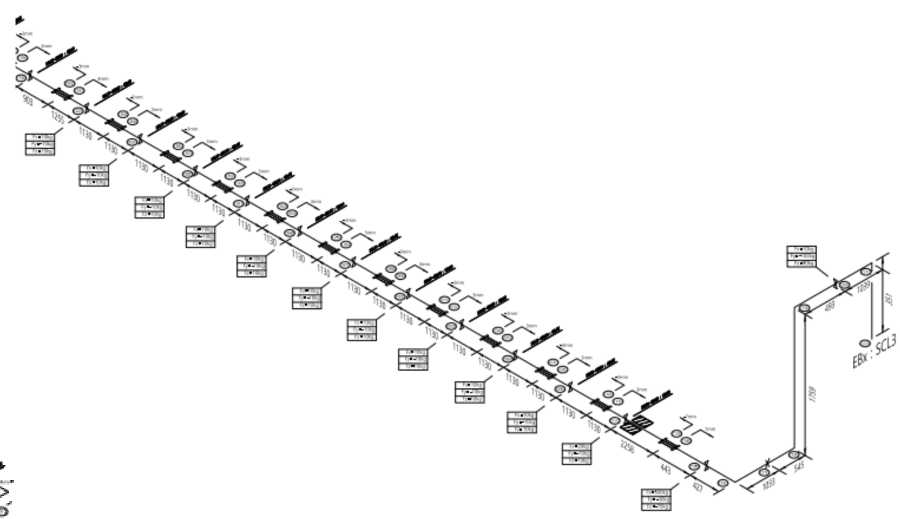




Layout (boundary conditions) of CTL (one pipe) of SCL3

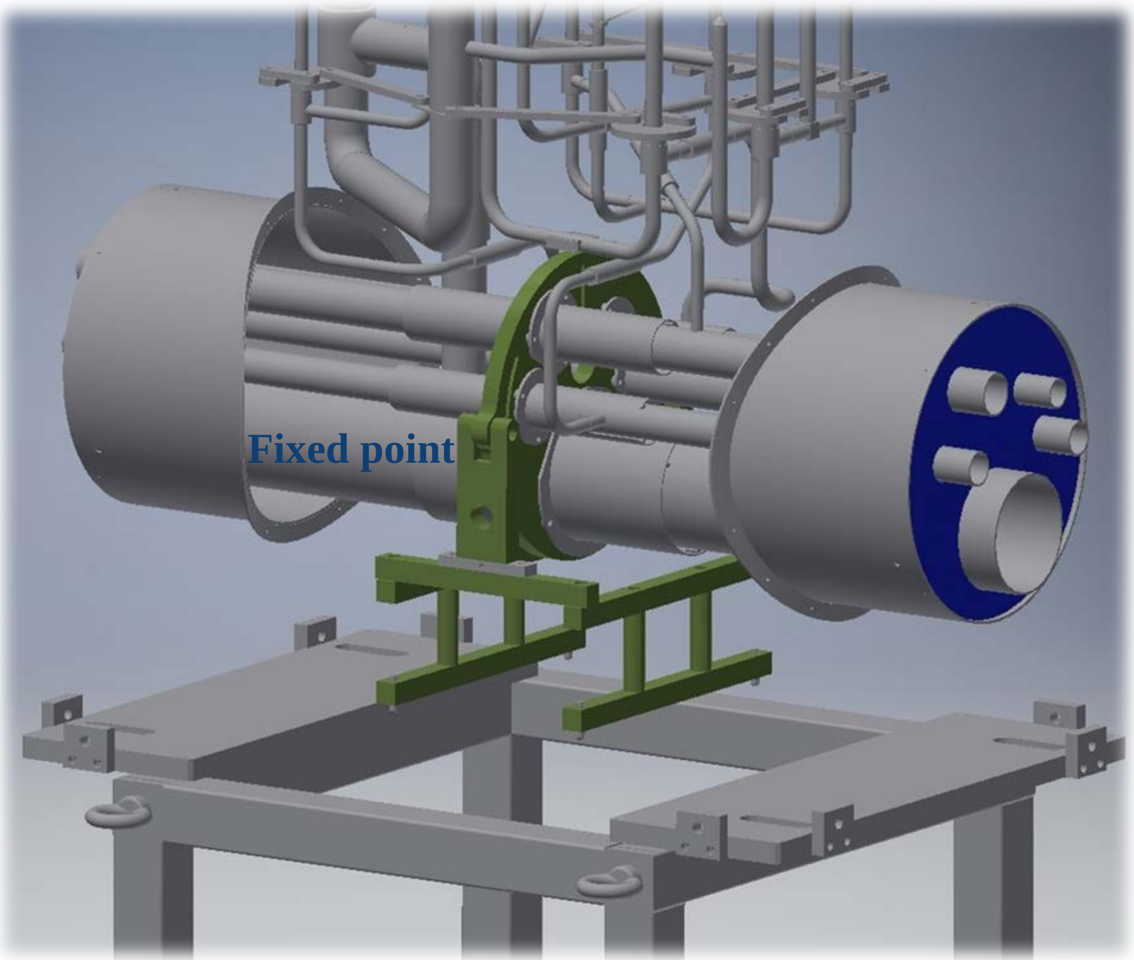


REGEND	
	DESCRIPTION
	SLIDING SUPPORT
	FIX SUPPORT
	BELLOWS(±10)
	BELLOWS(±30)



Structure analysis with CAESAR II
(B31.3 for allowable stress, deformation)

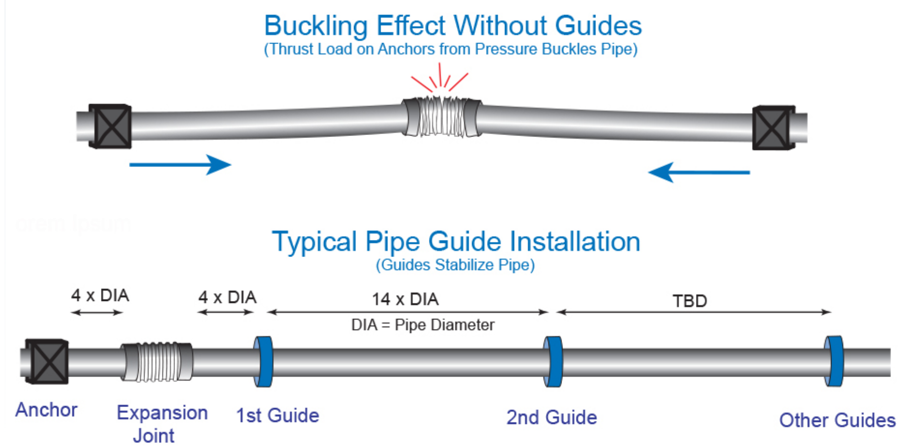
Valve box



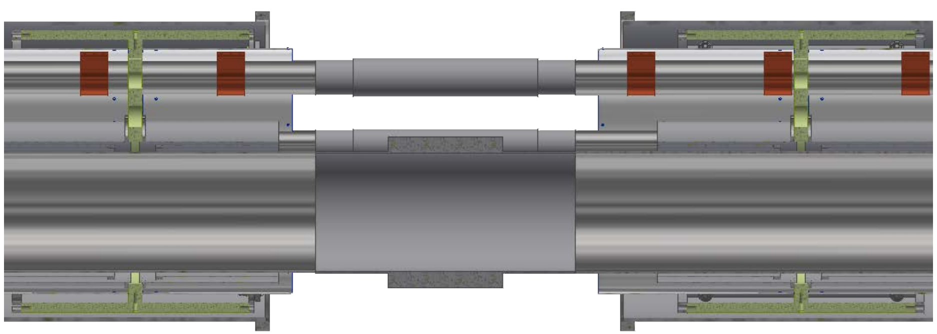
Stress for all pipes and spacers (allowable stress)

Deformation for cryogenic valves/bellows (within the specification/limits)

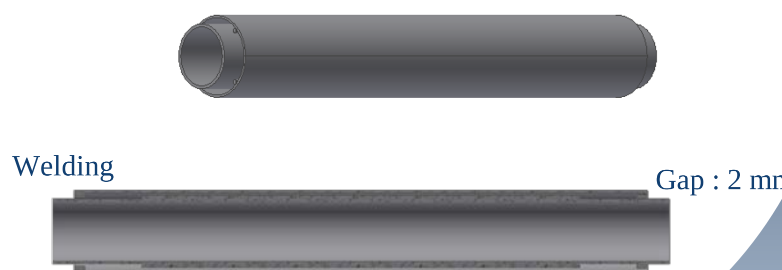
+ Guide of bellows; checked @ pressure tests



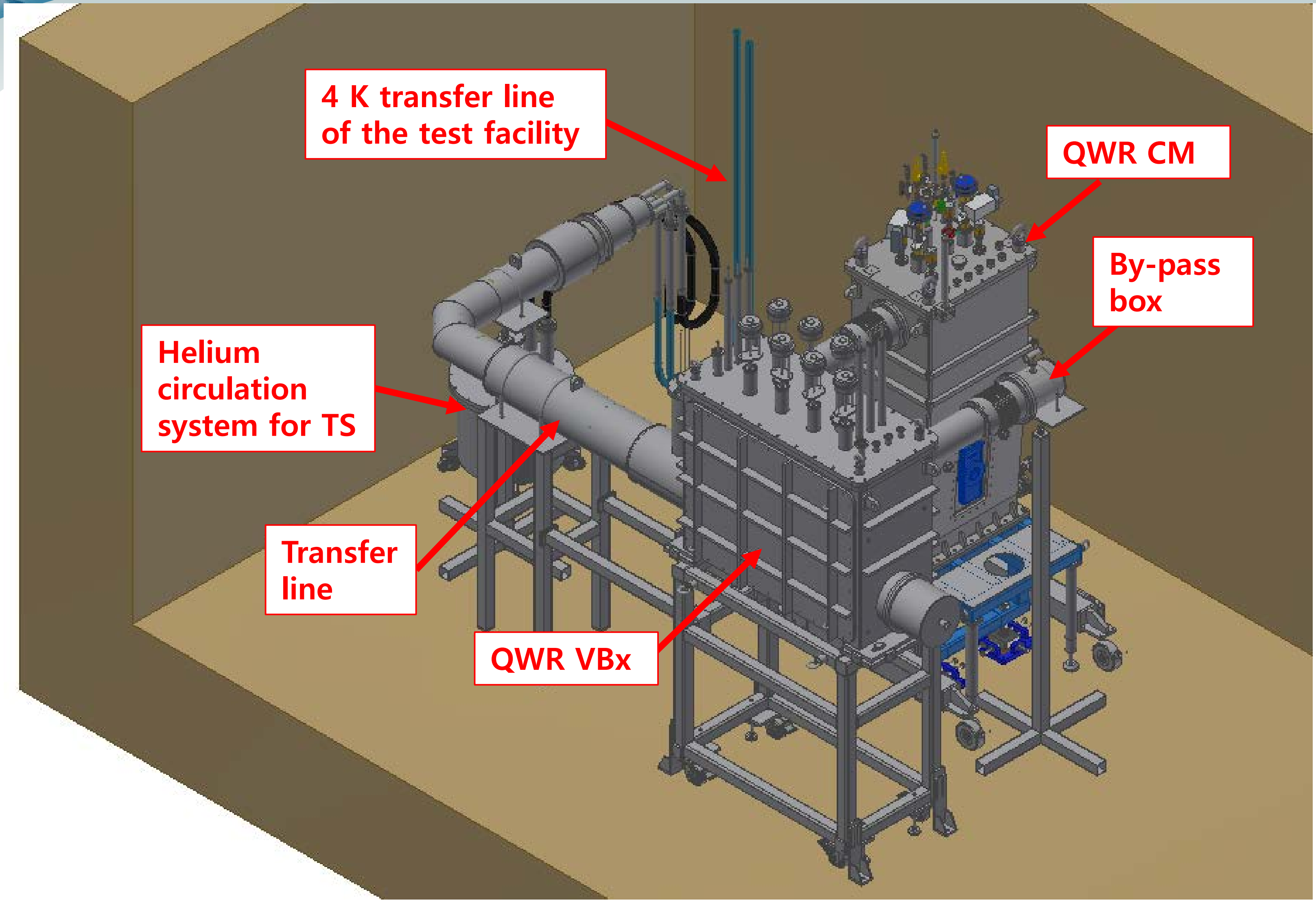
Fixed/sliding



Guide

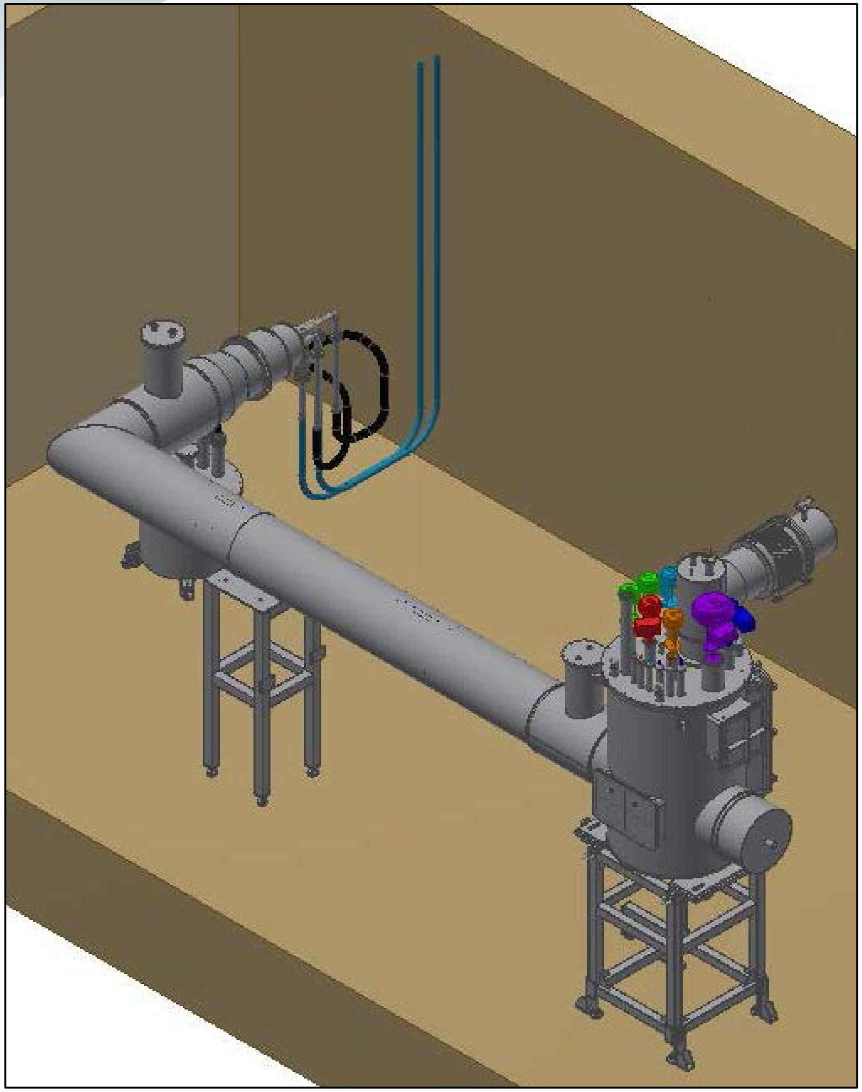


Cryogenic test of QWR VBx with CM



❖ **Thermal performance + components' test with cryomodule**

Cryogenic test of HWR VBx



Cryogenic Tests' results (Total : 8 tests)

QWR VBx Heat load

- 1st test results:
  - Thermal shield line ~ 60 W @ 50 K
  - 4.5 K line ~ 7 W
- Last test results:
  - Thermal shield line ~ 33 W @ 50 K
  - 4.5 K line ~ 1.3 W

HWR VBx Heat load

- 1st test results:
  - Thermal shield line ~ 60 W @ 50 K
  - 4.5 K line(SHe, GHe line) ~ 1-5 W
  - VLP return line ~ 6-19 W
- Last test results:
  - Thermal shield line ~ 30 W @ 50 K
  - 4.5 K line(SHe, GHe line) ~ 1 W
  - VLP return line ~ 5.2 W

Many issues

1. Design/procedure :
Design change for vacuum breaker
2. Installation : cryogenic valves/MLI/spaces
3. TAO : convection brake, dampers
4. Conditioning : drying (control of dew point)

Solved
(without convection brake/dampers)

Only one section applied to SCL3 (convection brake)
Dampers : not installed, but ready for installation

Preparation of Installation

Anchor point marking

Anchor drilling for Valve Boxes' positioning

Valve Boxes' transportation

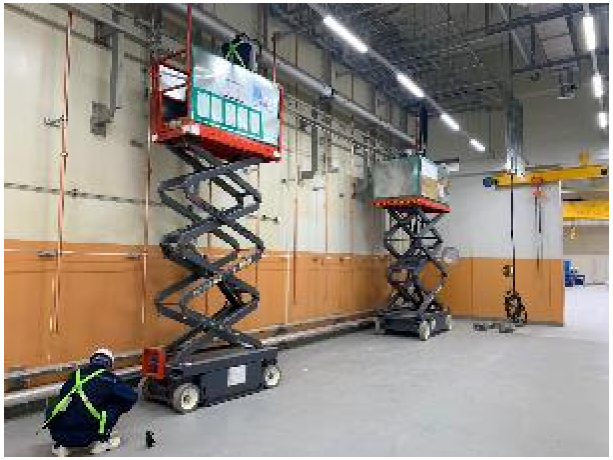
Installation (after passing FAT of VBx/CTL)

QWR VBx positioning

VBx bracket anchoring – initial positioning



VBx 3 D measurement and alignment



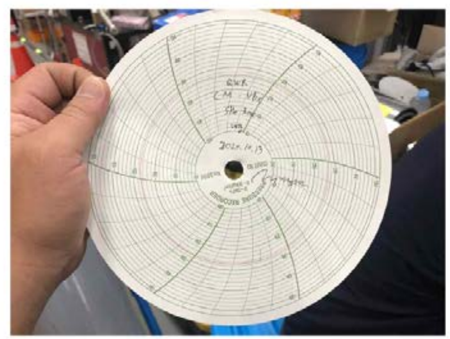
SCL3 warm service line installation

HWR VBx/CTL installation and Helium Leak Test

Pressure test (KGS inspection)

- QWR, HWR sections – performed (after each section @ factory)
- Pressurize each process line (based on KGS regulation, DP X 1.25)
  - Pressure/tightness
- Record pressure and check pressure stability (tightness)

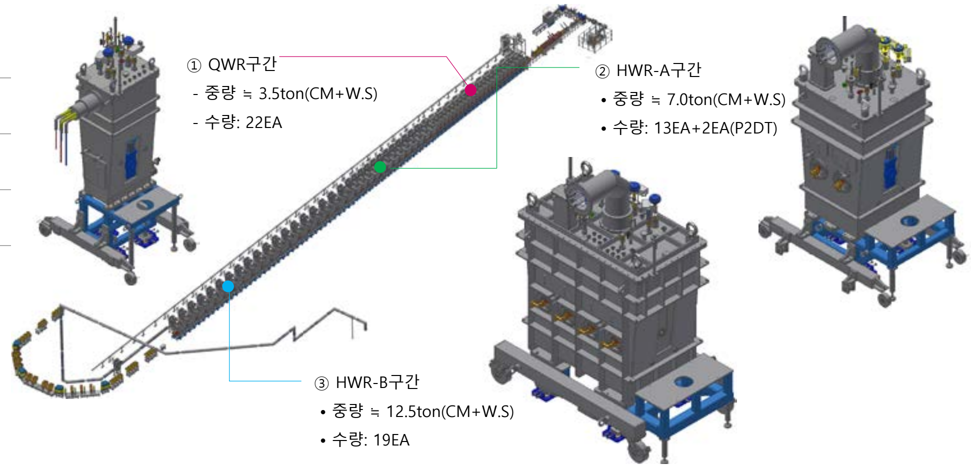




- And then, **final helium leak tests**

Cryomodules

Period	2020. 4. 2 ~ 2021.12. 27 (21 months)
#CM	56 EA(QCM 22, HACM 15, HBCM 19)
Duration	7-day cycle(1EA/week)



Process of Cryomodules' Installation designed by RAON

① SRF실험동→ISOL구역 장비반입구반입

② 전자석 포장분해/상하분리/높이조절

③ 전자석+진공챔버(빔진단챔버)조립

④ 상온구간(Warm Section) 모듈 안착

⑤ CM+상온구간(Warm Section) 정렬

⑥ 터널 이동 및 Base 안착

⑦ 빔라인 정렬(터널)

⑧ Clean booth 이동설치(해체)

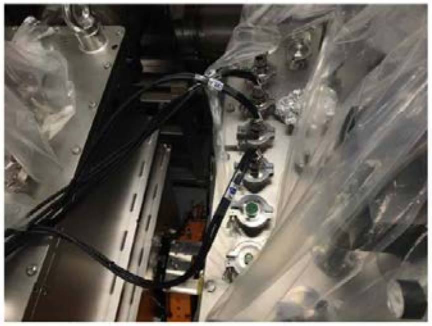
⑨ 빔라인 청정조립(터널)

⑩ Chamber 진공배기

QWR-CM interconnection - preparation

RAON

[T sensor signal check before welding]

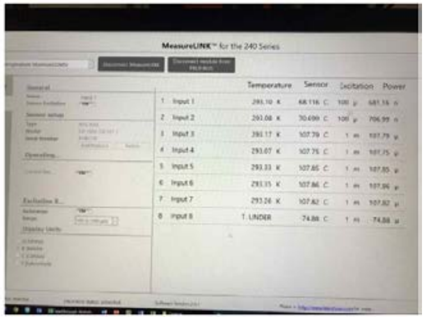


[Temperature feedthrough connecting cable]

[cutting/cleaning preparation]

[burr removal]

[Temperature sensor values of CM]



[Temperature sensor values of VBx]

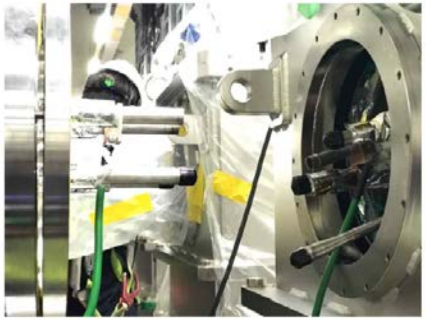
[vacuum cleaning of inner pipe]

[sealing of connection point]

[Short 4-wire temperature sensors to protect current leak]

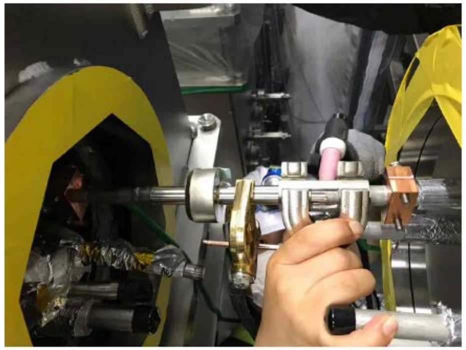
Welding of VBx-CM process pipes

[G-10 spacer, O-ring installation]



[Ground cable installation on the pipe]

[Extention pipe welding]

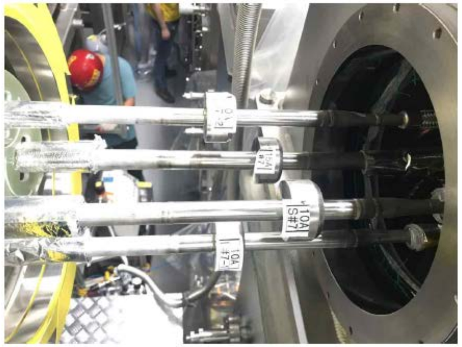


[Lip-seal alignment and tack welding]

[Ground cable installation on the copper ground]

[Welding condition check]

[Auto welding of the pipe]

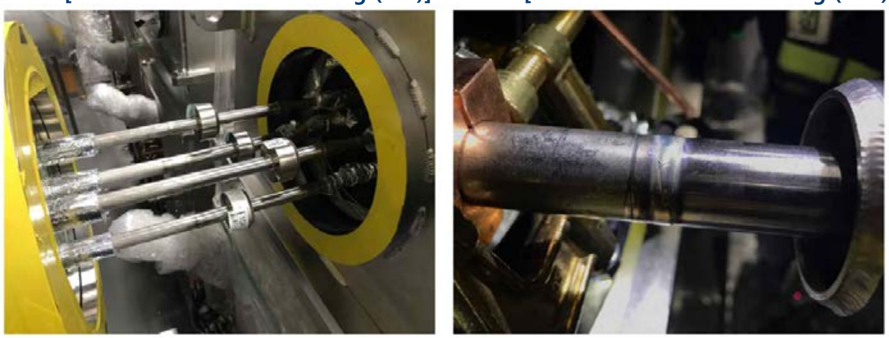


[The welding process is complete]

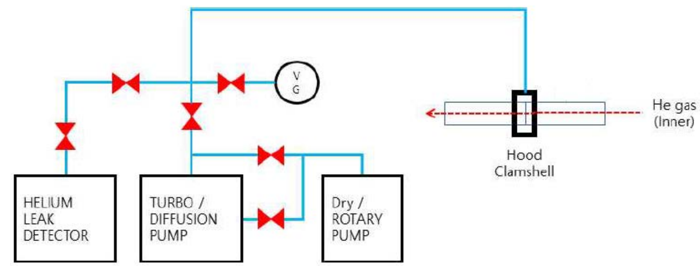
Inspection after welding

[T sensor check after welding (CM)]

[T sensor check after welding (VBx)]



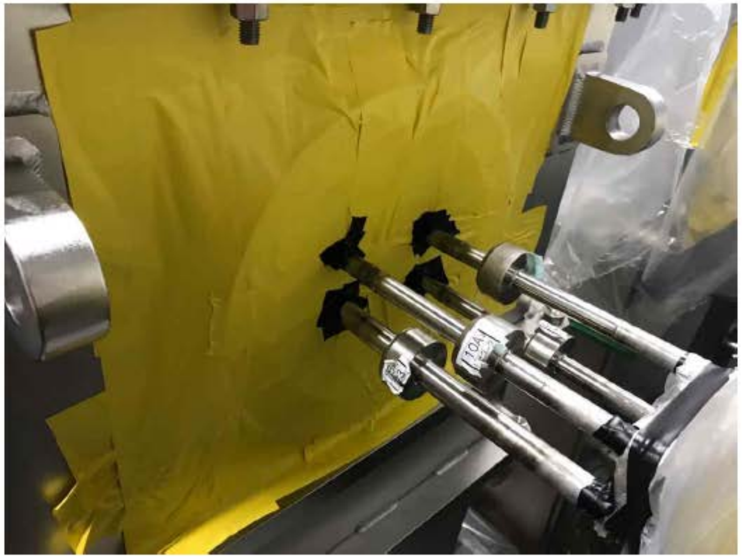
[Visual check of welding point]



[Visual check of welding point]

-Make vacuum state near welding point by hood clamshell
-Measure helium leak rate (<1.0 x 10^{-9} mbar.l/s)

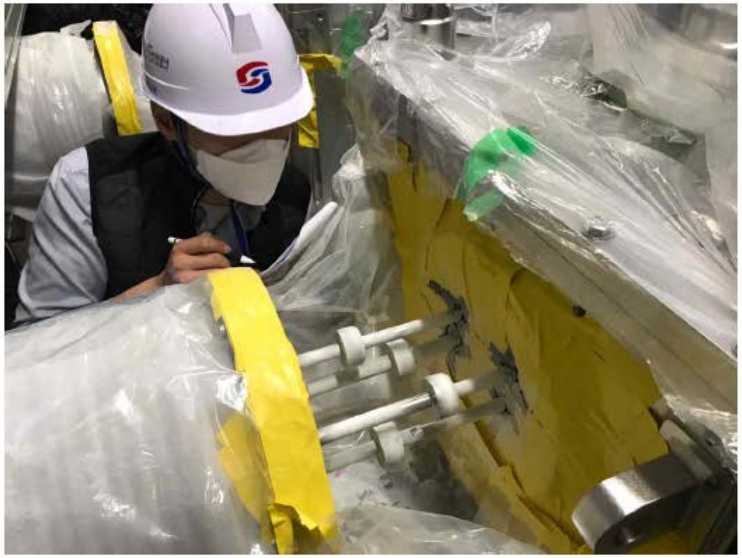
Liquid penetrant test



[Preparation of PT inspection]

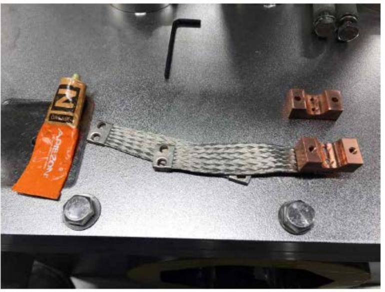
[Application of penetrant]

[Excess penetrant removal]



[Application of developer and inspection]

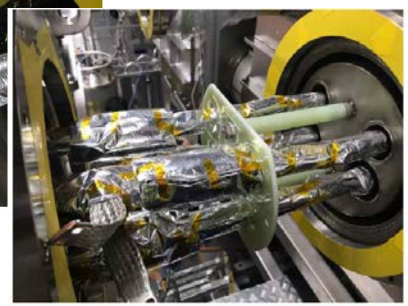
Installation of TS/MLI



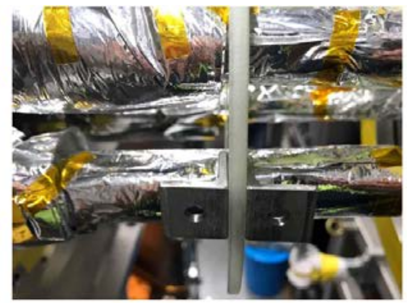
[Copper thermal braids]

[Connect copper thermal braids to the pipe]

[MLI winding on the pipes]



[G-10 Spacer installation]



[Fix guide for TS]

[Connect thermal braids with lower TS]

[Connect thermal braids with upper TS]

[Install TS]

[MLI winding of TS]

Final helium leak test

- He pressurization of process pipe
- Spray He adjacent to the vacuum jacket
- Measure helium leak rate (<1.0 x 10^{-9} mbar.l/s)

[Evacuation of CM including connection point]

[He pressurization]

[Helium leak measurement]

By our Engineers/Technicians @ RAON

- Step-by-Step Installation/Inspection

QWR 2020. July ~ 2020. October : 4 months (22 sections)

HWR 2021. June ~ 2021. December : 7 months (32 sections)

Cryogenic Control

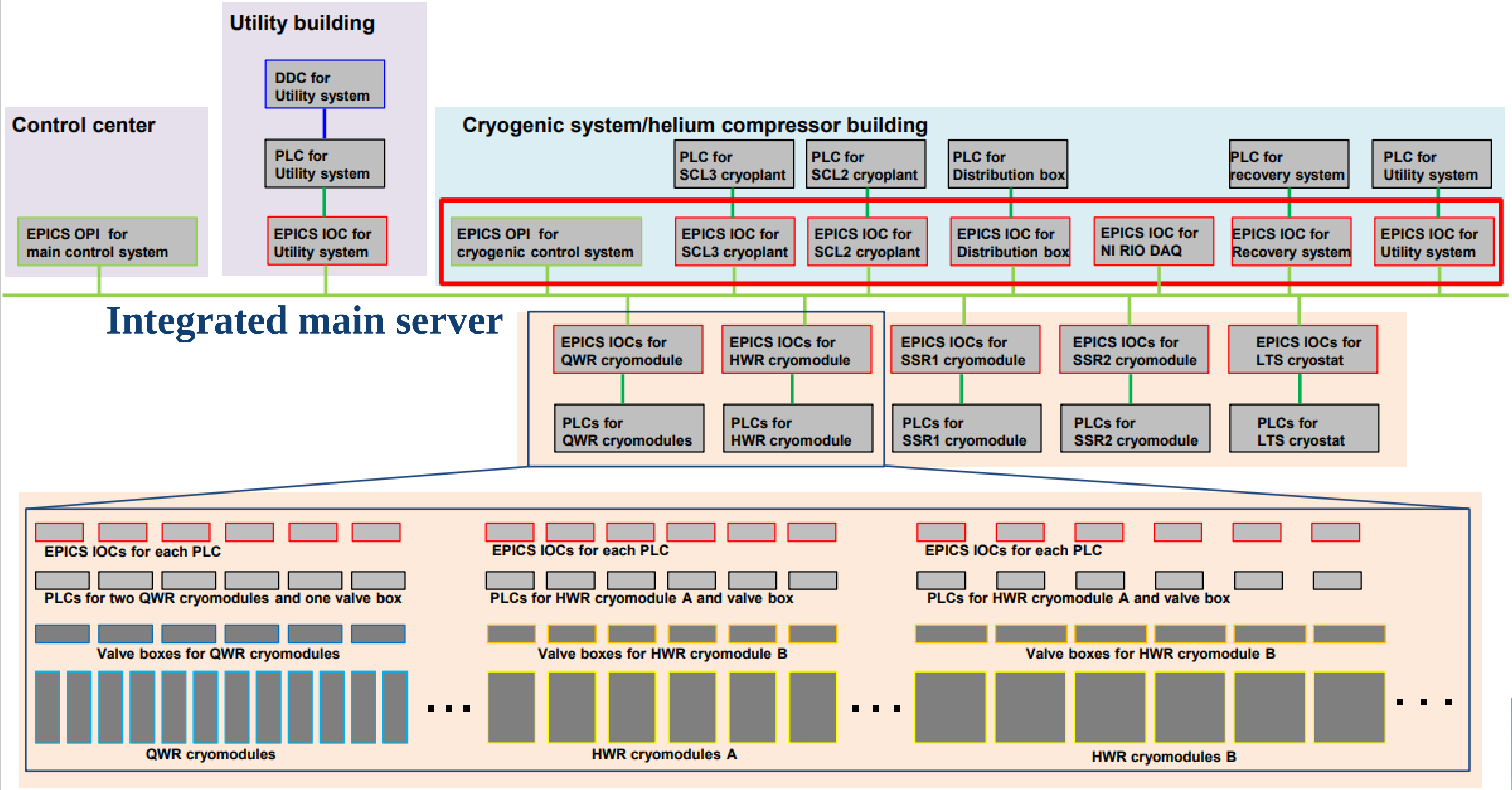
Cryogenic systems – Control

- **Control**
  - Control logic : **Developed by IBS (RAON) Engineers**
  - Cryoplants+CDS (VBx 44 EA, EBx, TBx)+Cryomoudules (55 EA)
  - **Many users/high stability + safety (warning/alarms/interlocks) ; total number of cryo. valves - 485 EA + other warm valves**
  - As simply as possible

- **Dynamic simulation** to check/update control logic
  - Cool-down (especially, for fast cool down) logic
  - Checking safety logic @ emergency cases

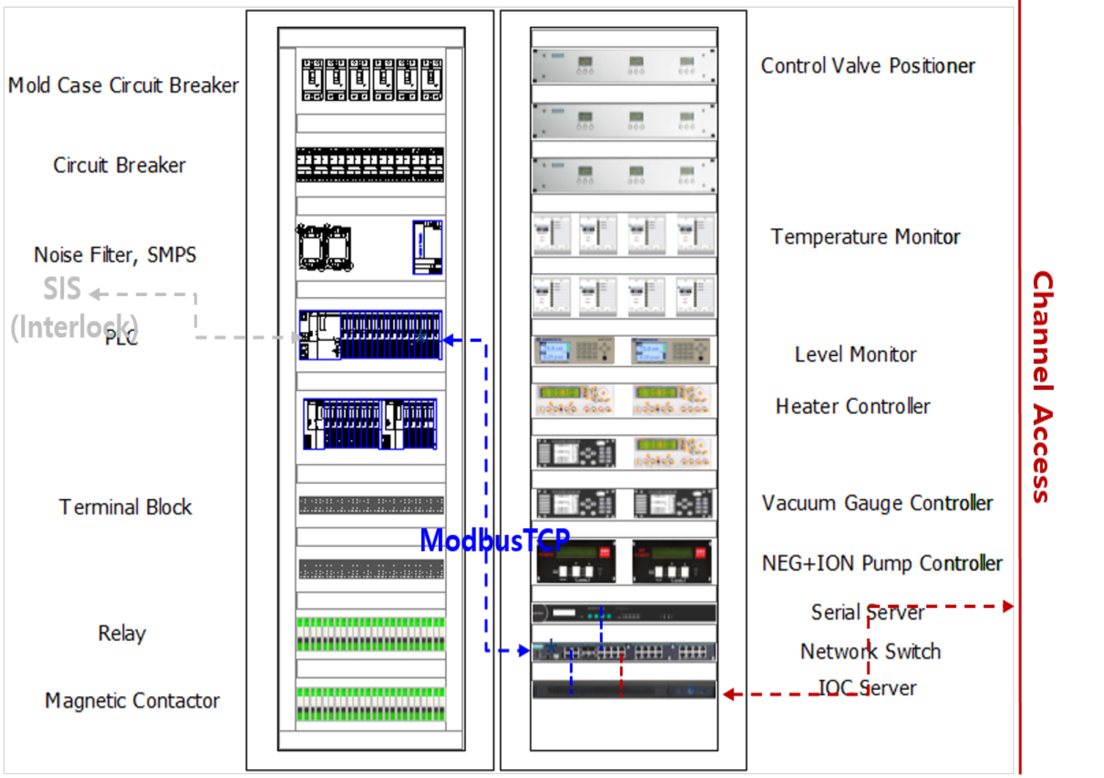
Control – structure (EPICS + PLC)

Experimental physics and industrial control system (EPICS)

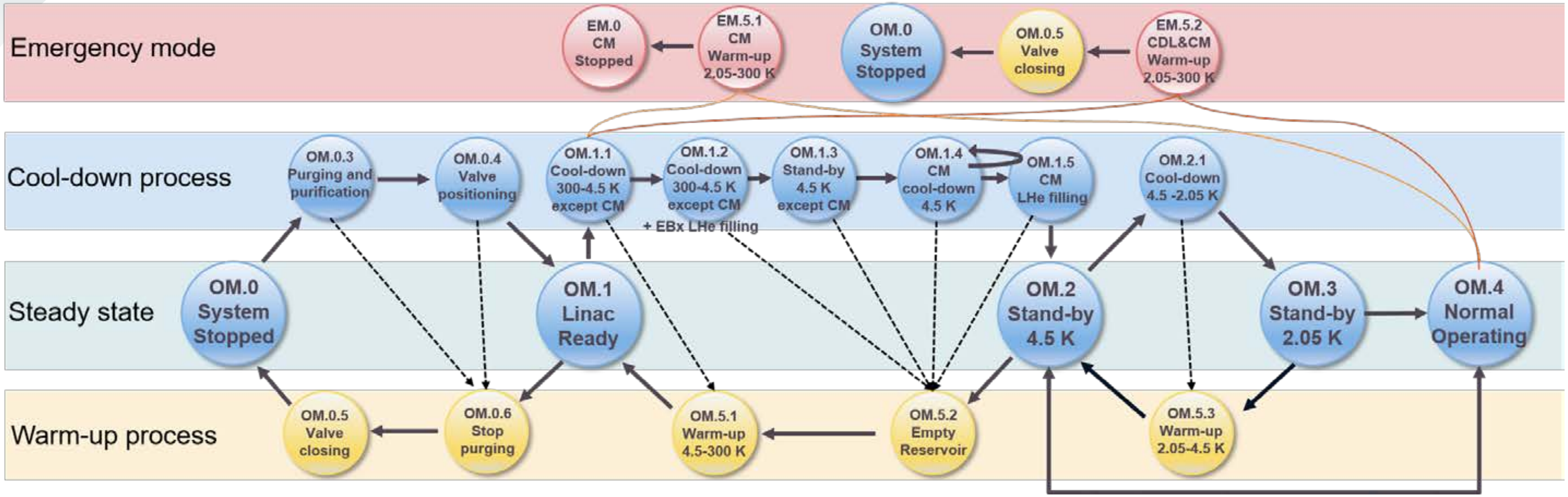


PLC (Local control racks)

➤ **Control racks (PLC, instruments, EPICS IOC) – local control (PID), interlocks**
- Helium distribution system
- Cryomodules
- Vacuum
- QWR(11), HWR-A(13), HWR-B(19) P2DT (HWR A 1) total 44
- Network interface (EPICS control network)



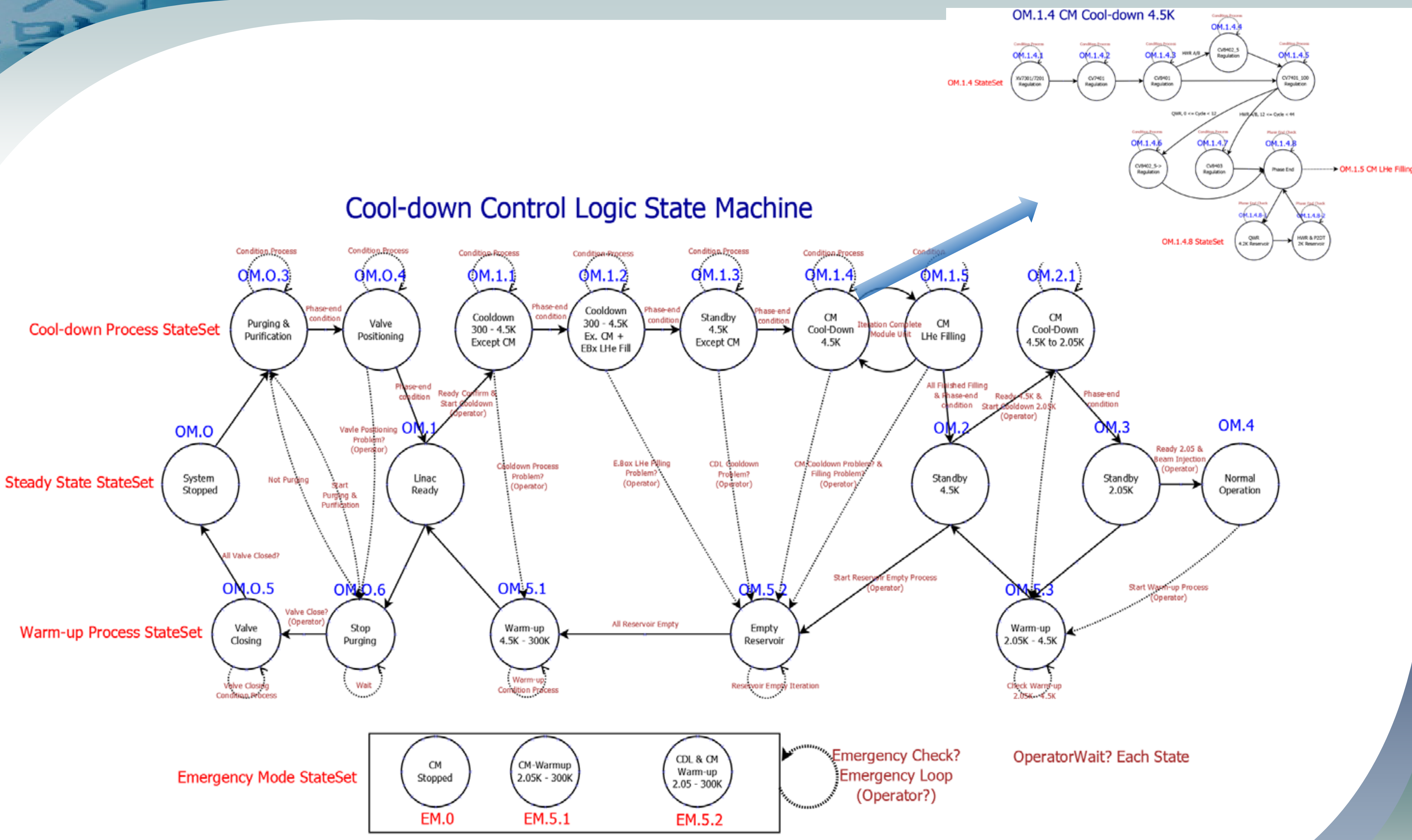
Operation modes for RAON cryo. systems



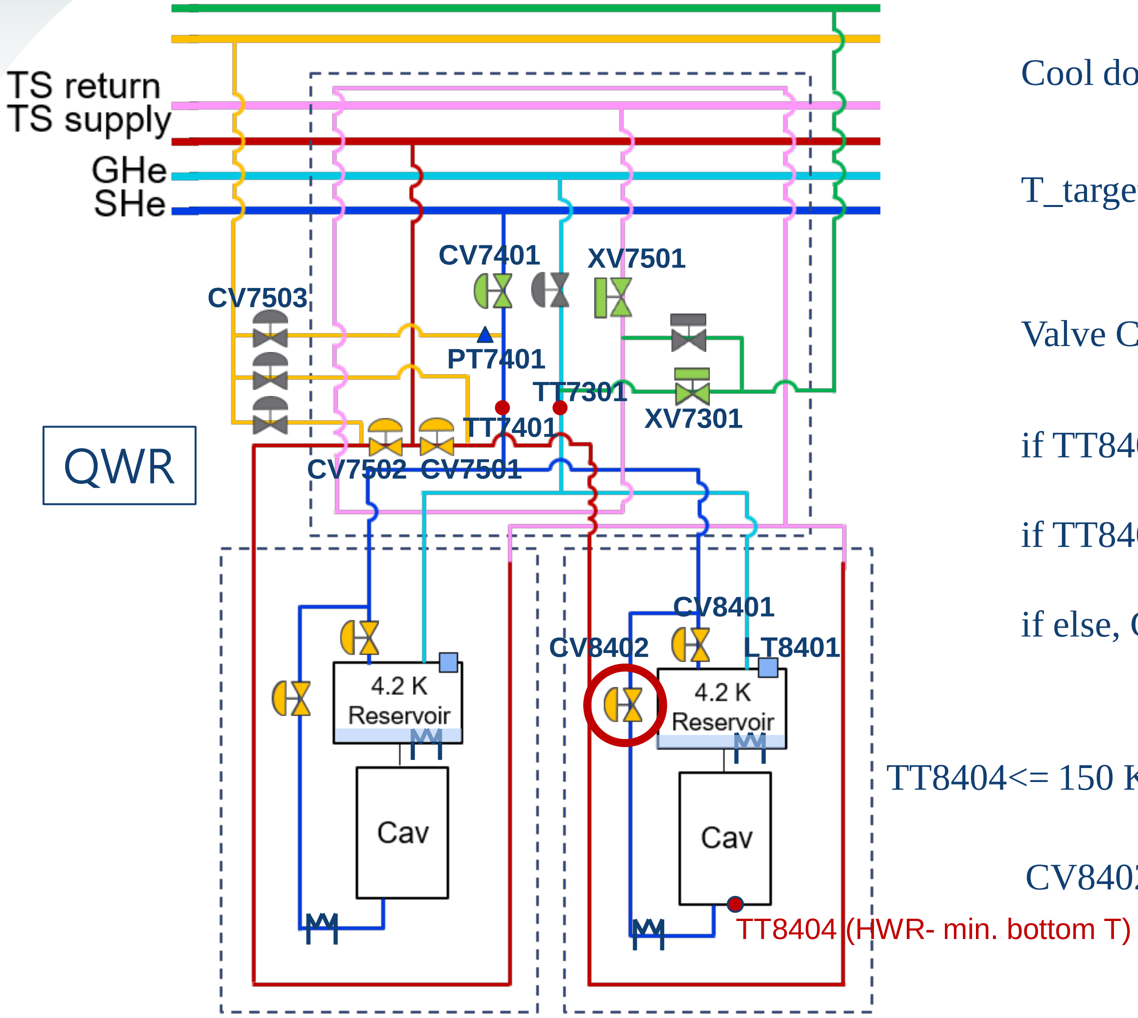
* Steady state based by PLC + EPICS (Thermal shield)

* Transient state based EPICS

Development Logic @ each operation mode



For test of OM. 1.4 in simulation (fast cool-down)



Logic

TT8404> 150 K

Cool down speed : 10 K/hour

T_target [K] = 280 -10/3600× $t(s)$

Valve Control (CV8402):

if TT8404> T_target + 10 K, CV8402 open (0.01%/s)

if TT8404< T_target - 10 K, CV8402 close

if else, CV8402 keep the state (open/close)

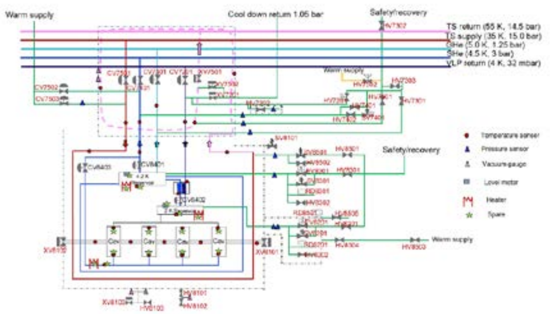
TT8404<= 150 K

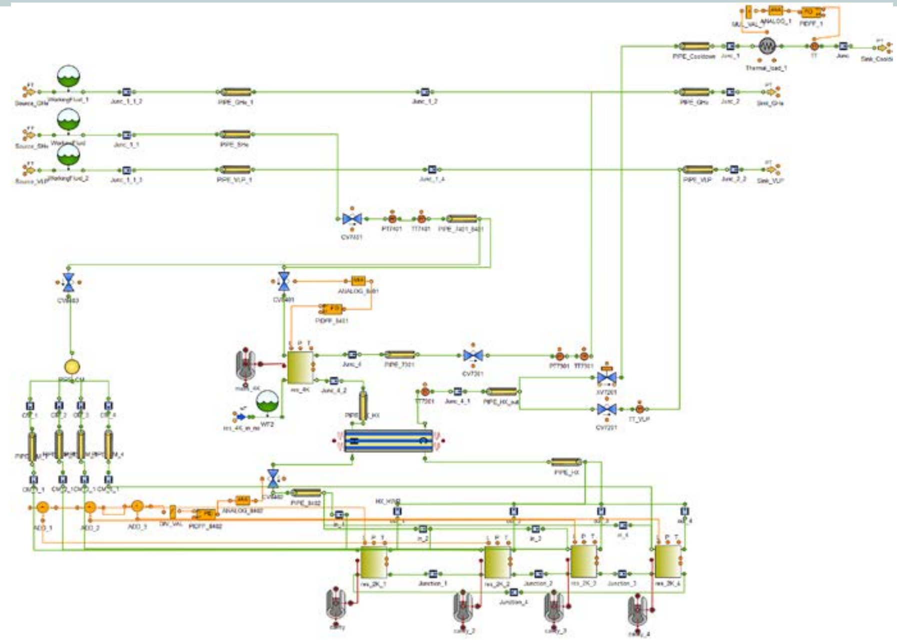
CV8402 keep opening (0.01%/s)

Tests in simulation (work with KAIST graduate student)

RAON

[HWRB EcosimPro model in SCL3]



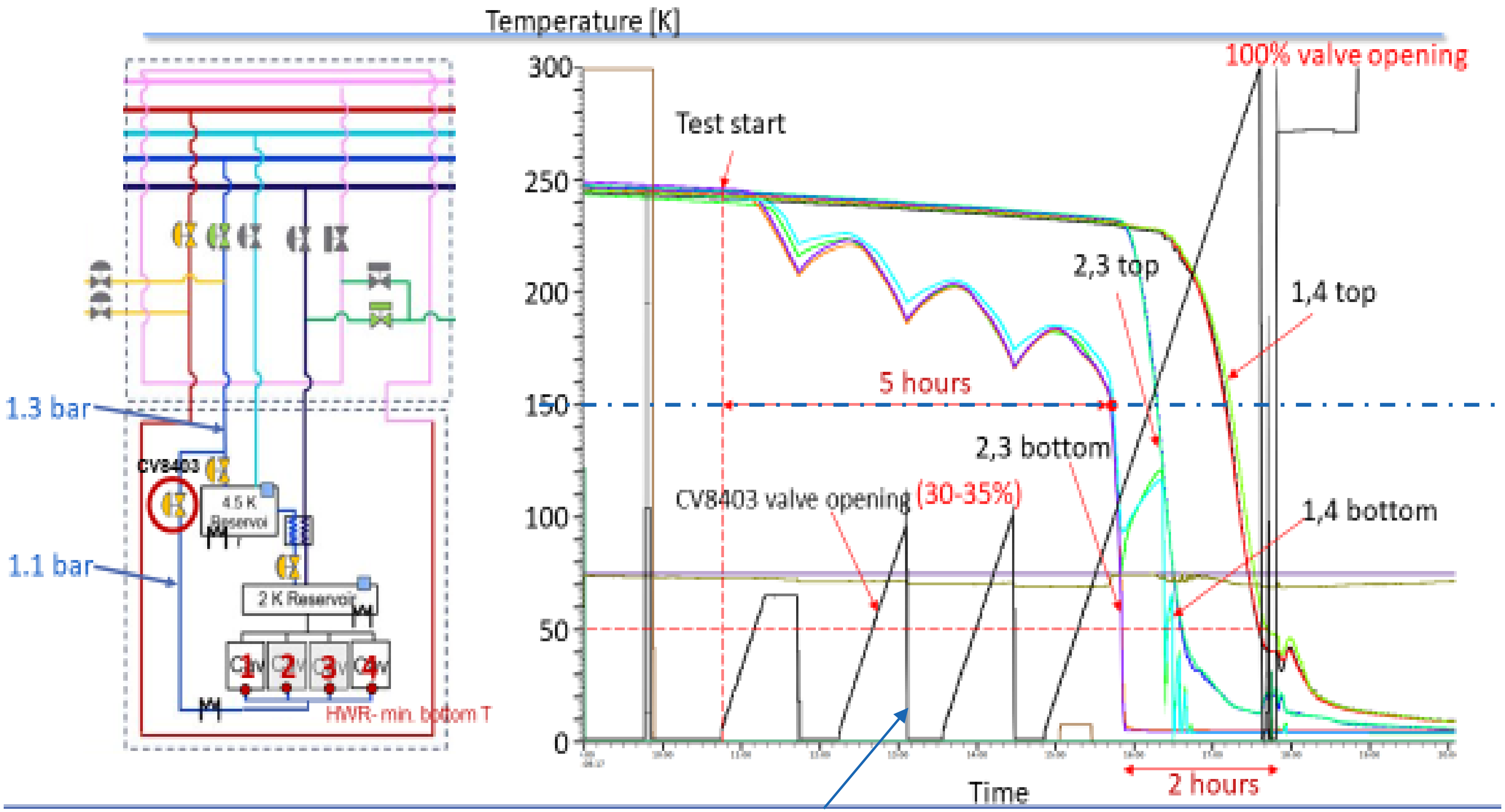


Cryomodule	Strategy (with fast cool-down; 150 K - 50 K)				
	Total Cool-down Time (s)	Pressure (bar)		Max. Mass flow rate for fast cool-down (g/s)	
HWRB	~ About 45,000 (Depends on cooling slope)	4K res	**1.25**	4K res	**<u>0.8</u>**
		2K res	**1.24**	2K res	**<u>3.9</u>**
HWRA		4K res	**1.25**	4K res	**<u>0.8</u>**
		2K res	**1.24**	2K res	**<u>3.8</u>**
QWR		4K res	**1.27**	4K res	**<u>2.9</u>**

<u>Required: 3~4 g/s (estimation)</u>

Test of logic @ SRF TF

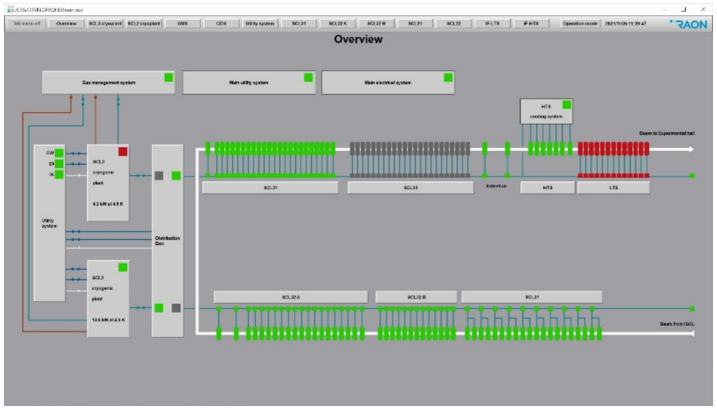
Working @ Real system

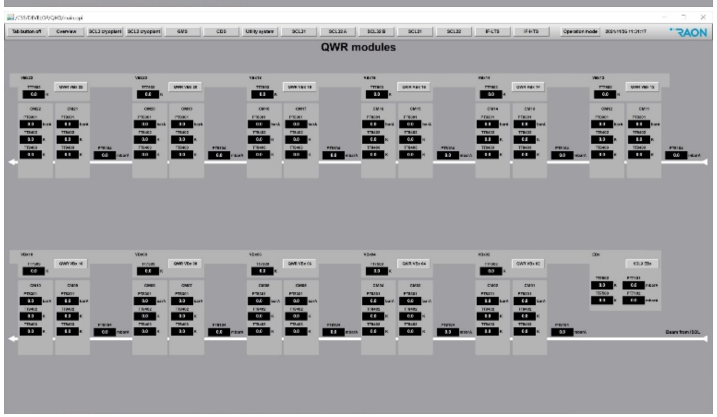


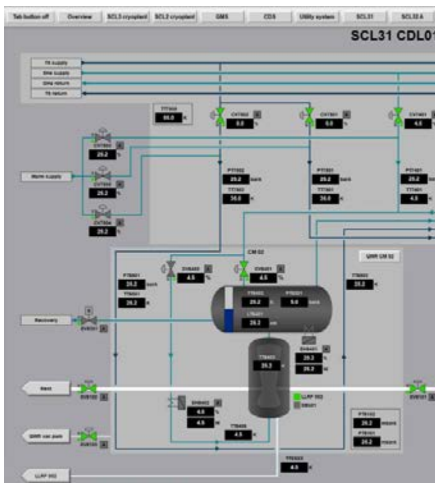
Valve controlled by logic
(CV8403)

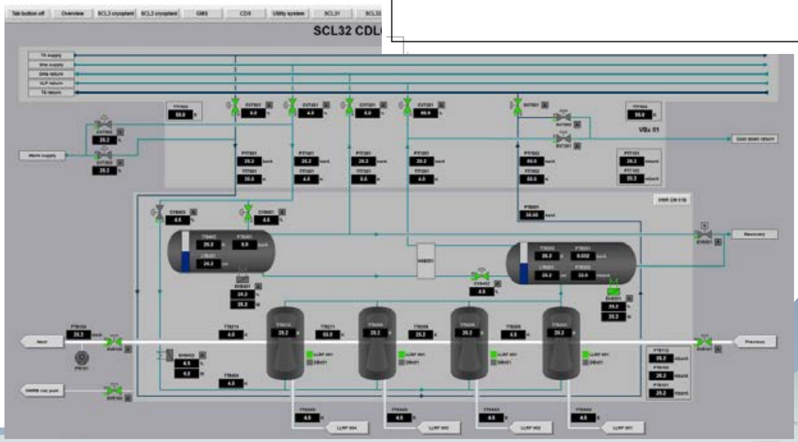
OPI (GUI)

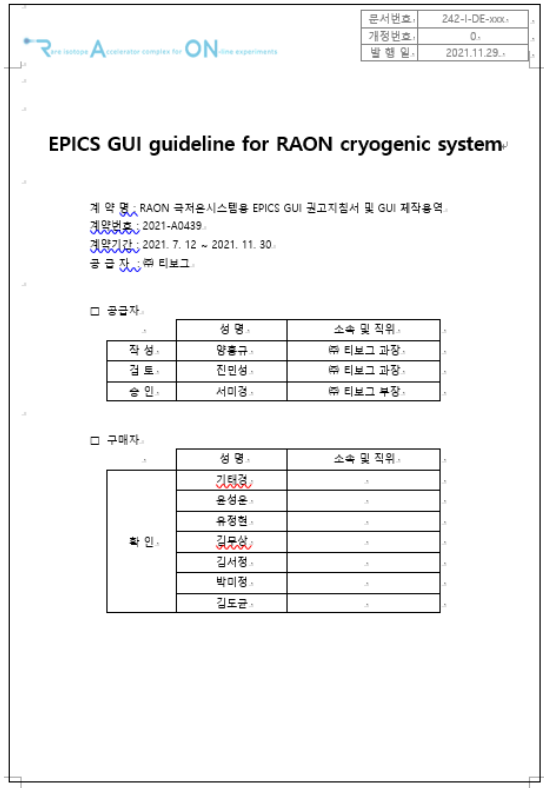
- To reduce human errors based on the NUREG-0700
- To reduce programing scripts in GUI
- To simplify screen navigation
- To standardize GUI based on guideline











문서번호	242-I-DE-xxx
개정번호	0
발 행 일	2021.11.29.

Rare isotope Accelerator complex for ON-line experiments

EPICS GUI guideline for RAON cryogenic system

계 약 명 : RAON 극저온시스템용 EPICS GUI 권고지침서 및 GUI 제작용역
계약번호 : 2021-A0439
계약기간 : 2021. 7. 12 ~ 2021. 11. 30
공 급 자 : ㈜ 티보그

□ 공급자

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검 토	진민성	㈜ 티보그 과장
승 인	서미정	㈜ 티보그 부장

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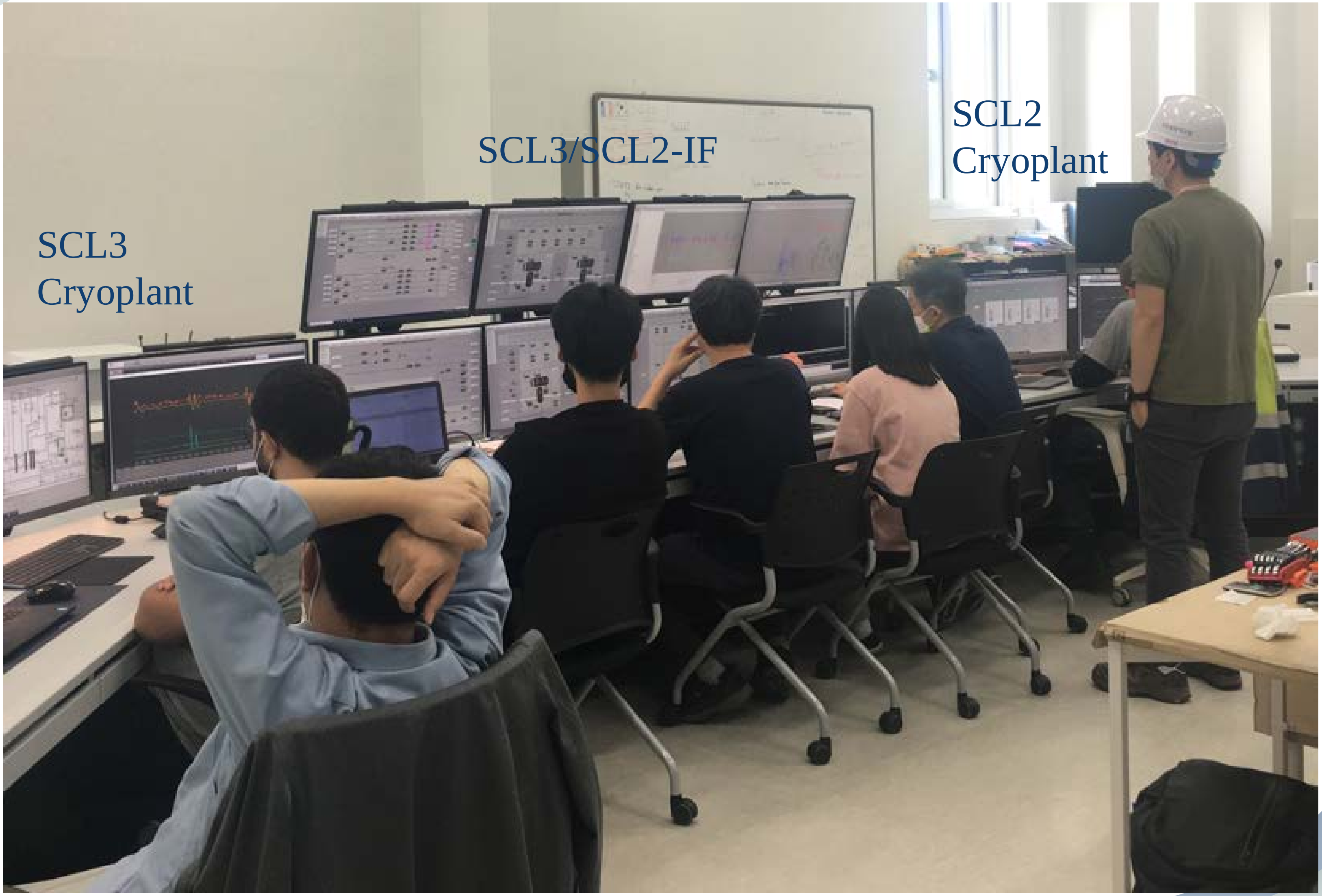
	윤성은	
	유정현	
	김무상	
	김서정	
	박미정	
	김도균	

Our control room



Safety

- Safety (Cryogenic components)
  - **FMEA (<u>Failure Mode Effect Analysis</u>) for checking effect on control**
  - **HAZOP (<u>Hazard and Operability</u>) for checking equipment and human' safety**
  - **Interlock System**
  - **<u>Dedicated international reviews</u>**
  - Others (Korea Gas Standard – Inspection)
    - All cryogenic piping and pressure vessels should be checked by KGS (from design to commissioning)

SCL3
Cryogenic Commissioning

Plan for SCL3 Cryogenic Commissioning

Very tight schedule

SCL3 Beam Commissioning Master Schedule (Rev. 1)

RF/Beam commissioning

- 작성일 : 2022. 05. 23
- 작성자 : 중이온가속기건설구축사업단

구분 (System)	주요업무 (Activity)	시작 (Start)	완료 (Finish)	기간 (day)	2022년 – 2023년 (2월 – 2월)
	Milestone				터널설치업무완료(22.4.30); 제어연동시험1차(6.30); 극저온플랜트 H/O(22.8.10); 4.5K 냉각착수(22.9.3~); QWR 빔시운전 착수(22.10~); 방사선출입통제(22.10.21~); SCL3 빔인출완료(22.10); HWR 빔시운전 착수(23.2.1~)
Injector	★ 14.5GHz ECR-LEBT-RFQ-MEBT				★ SCL3 빔시운전을 위하여 시운전 빔을 SCL3로 안정적 전송 준비 완료(~5월); < 빔시운전 준비 >; SCL3 빔시운전(22.10.24~23.03.31)
Cryogenics System	★ SCL3 Cryoplant				
	• 2차 냉각 및 튜닝	22-02-01	22-02-28	28	2차 냉각 및 튜닝(~2/28)
	• 기능시험 및 3차 냉각(SAT 착수)	22-03-01	22-04-07	38	기능시험 및 3차 냉각(~4/7)
	• 성능검증(SAT, ~7/29) 및 인수인계	22-04-07	22-08-10	126	성능검증 및 인수인계 (SAT, ~5/20 → 7/29로 연장); H/O(~8/10)
	• TBx와 연결 및 KGS 인허가	22-08-01	22-08-19	19	TBx와 연결 및 KGS 인허가(~8/19)
	- 연결(선진행) 및 KGS 인허가(완성)	22-08-04	22-08-12	9	연결 및 KGS 인허가(완성)
	- 사업개시 신고(유성구청)	22-08-15	22-08-19	5	사업개시 신고(유성구청)
	• 가압/헬륨 순환, 정화 등	22-08-22	22-09-02	12	가압/헬륨 순환, 정화 등(~ 9.2)
	• SCL3 4.5 K 냉각	22-09-03	22-10-21	49	4.5K 냉각 CDS/CM QWR HWR
	• 열적안정화 및 성능평가	22-10-01	22-11-11	42	열적안정화 및 성능평가
	• SCL3 2.05 K 냉각 및 안정화	22-12-19	22-12-31	13	SCL3 2.05 K 냉각 및 안정화(~12.31)
	• 장치운전	23-01-01	23-03-31	90	냉각장치운전(23.1.2~)

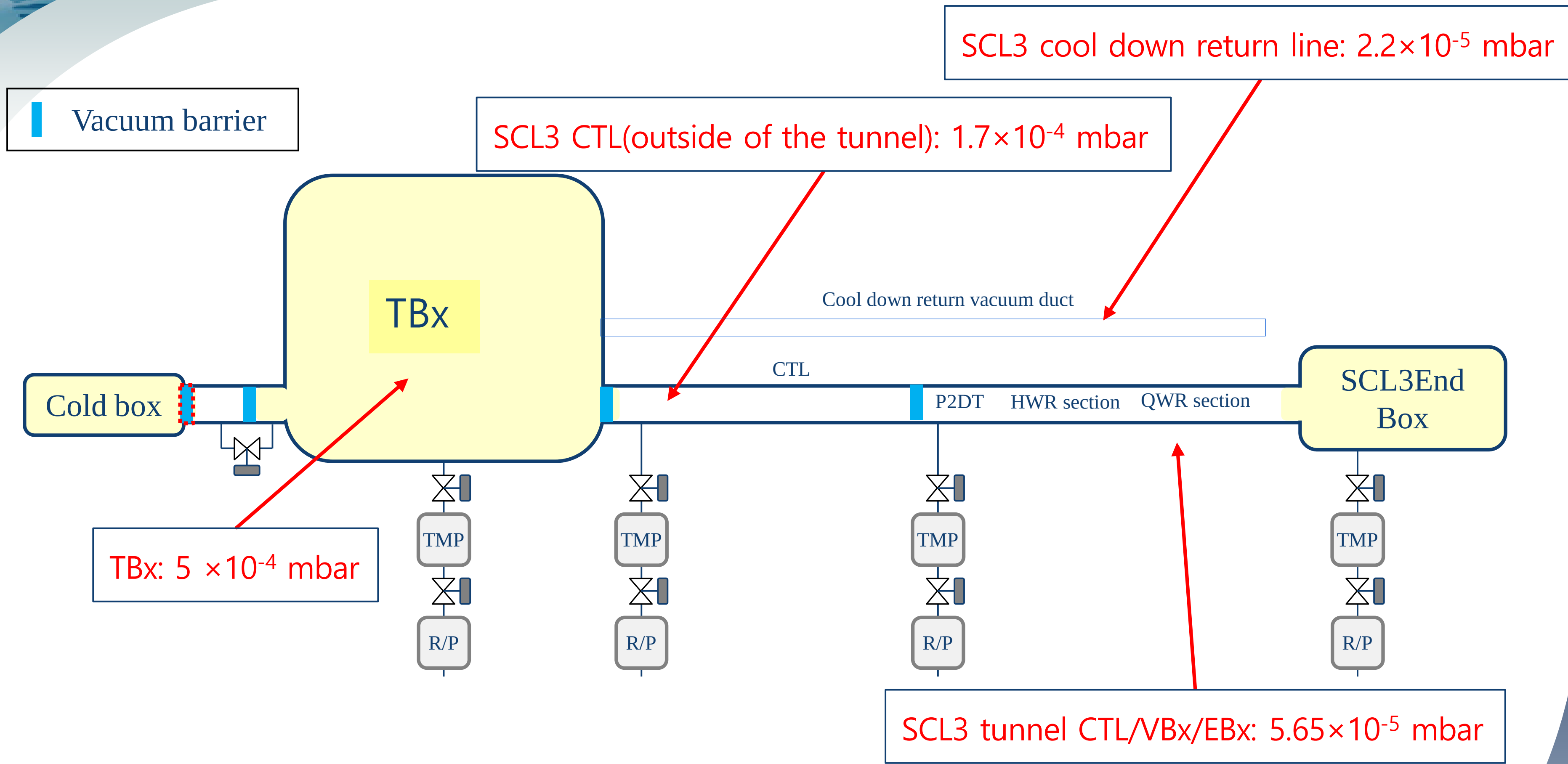
3 months' plan only

From connection between SCL3 cyroplant and SCL3
To the completion of SCL3 4.5 K cool-down

3 parts (Cryoplants/CDS-CM/Cryogenic Control) :
Overall operation – Cryogenic System Team

From Aug.2020 to TBD for the First Run

First, vacuum/tightness with He pressure



Insulation vacuum for CM :
QWR~HWR 10^{-5} mbar

Final tests of Control/instruments

- SCL3 Controls with our control team' members
  - Loop tests : Final – done (Local-GUI)
  - Final Modification – done (a few, almost improved)

HWR VBx 13A

Pressure (TAG) @HWR A/B/P2DT VBx-CM No	가압 압력 @ 터널 가압 (Command)			TEST TRANSDUCER READING End Switch (@ SCL3)			TEST TRANSDUCER READING (@ HMI, 갤러리)			TEST TRANSDUCER READING (@ GUI)		
1. PT7501	1.43 bara	1.63 bara	2.99 bara	1.4	1.6	3.0				1.43	1.64	3.01
2. PT7502	"	"	"	1.4	1.6	3.0				1.44	1.65	3.02
3. PT8501	"	"	"	—	—	—				1.41	1.62	3.00
4. PT7401	"	"	"	1.4	1.6	3.0				1.46	1.67	3.04
5. PT8301	"	"										
6. PT7301	"	"										
7. PT8201	"	"										
8. PT7201	"	"										
9. PT8112												
10. PT8102												
11. PT8101												
12. PT8104												
13.												
14. CV8402			Close 시									

HWR VBx 13B

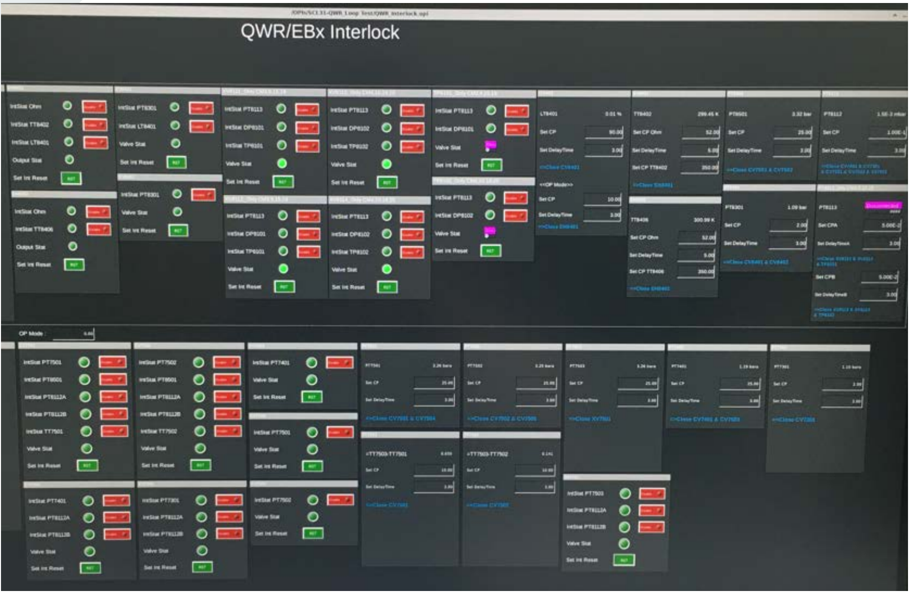
VALVE and HEATER (TAG) @HWR B/P2DT VBx-CM No	"0/50%/100%", "ON/… ON/OFF limit", 1W			
1. CV7501	50%	100%	0%	
2. XV7502	open	close		
3. XV7501	open	close		
4. CV7401	50%	100%	0%	
5. CV7301	제어반 조작 불가.			
6. XV7201	open	close		
7. CV7201	50%	100%	0%	
8. CV7503	50%	100%	0%	
9. CV7502	50%	100%	0%	
10. CV8401	50%	100%	0%	
11. CV8403	50%	100%	0%	
12. CV8402	50%	100%	0%	
13. EV8301	open	close		
14. EH8401	1W	0W		
15. EH8201	1W	0W		
16. EH8402	1W	0W		
17.				
18.				
19.				
20.				

HWR

Pressure (TA… @HWR A/B/P2DT V…				
1. PT7501				
2. PT7502				
3. PT8501				
4. PT7401				
5. PT8301				
6. PT7301				
7. PT8201				
8. PT7201				
9. PT8112				
10. PT8102				
11. PT8101				
12. PT8104				
13. PT7102				
14.				
15.				
16.				
17.				
18.				
19.				
20.				

	VALVE and HEATER (TAG) @ QWR VBx22/ CM21 and 22	"0/50%/100%" "ON/OFF ON/OFF limit", 1W (Command)			TEST TRANSDUCER VISUAL POSITION/ End Switch (@ SCL3)			TEST TRANSDUCER READING (@ HMI, 갤러리)			TEST TRANSDUCER READING / End Switch(@ GUI)			
1	XV7501	100%	0%	ON	OK	OK	OK	OK	OK	—	OK	OK		OK
2	XV7502	100%	0%	OFF	OK	OK	OK	OK	OK	—	OK	OK		OK
3	CV7501	50%	100%	0%	OK	OK	OK	—	49.65	98.64	0.24	49.65	98.64	0.28
4	CV7502	50%	100%	0%	OK	OK	OK	—	50.04	98.82	0.12	50.04	98.82	0.12
5	CV7301	50%	100%	0%	OK	OK	OK	—	50.59	99.12	6.79	50.59	99.12	0.79
6	CV7401	50%	100%	0%	OK	OK	OK	—	50.75	99.87	0.19	50.75	99.87	0.19
7	XV7301	100%	0%	OFF	OK	OK	X	OK	OK	—	OK	OK		X limit switch 교체
8	CV7504	50%	100%	0%	OK	OK	OK	—	50.2	100	0.17	50.2	100	0.17
9	CV7505	90%	100%	0%	OK	OK	OK	—	50.29	100	0.25	50.29	100	0.22
10	CV7503	50%	100%	0%	OK	OK	OK	—	50.01	100	0.24	50.01	100	0.24
11	CV8401	50%	100%	0%	OK	OK	OK	—	50.7	99.92	0.32	50.75	99.92	0.24
12	CV8402	50%	100%	0%	OK	OK	OK	—	50.5	99.78	0.2	49.91	99.78	0.2
13	EV8301	100%	0%		OK	OK		—	OK	OK		OK	OK	
14	EH8401	1W	0W		—			—	1.06W	0W		1.06W	0W	
15	EH8402	1W	0W		—			—	0.99W	0W		0.99W	0W	
16	CV8401	50%	100%	0%	OK	OK	OK	—	51.08	98.73	0.52	51.08	97.72	0.55
17	CV8402	50%	100%	0%	OK	OK	OK	—	50.34	99.7	0.2	50.34	99.72	0.2
18	EV4301	100%	0%		OK	OK		—	OK	OK		OK	OK	
19	EH8401	1W	0W		—			—	0.96W	0W		0.96W	0W	
20	EH8402	1W	0W		—			—	0.98W	0W		0.98W	0W	

Tests of interlocks (final chain for our safety) @ RT



Interlock monitoring UI

Working or Not

- Interlock tests

HWR Local interlock test

HWR-VBx (HWRA01, HWRB03)

Sensor	Actuator	Override	SetCP	Timer	Interlock	Reset
PT7501	CV7501	O	O	O	O	O
PT7501	CV7503					
PT7502	XV7501	O	O	O	O	O
PT7401	CV7401	O	O	O	O	O
PT7401	CV7502					
PT7301	CV7301	O	O	O	O	O
PT7201	CV7201	O	O	O	O	O
TT7502-TT7501	CV7501	O	O	O	O	O
PT7202 (HWRA01)	XV7301	O	O	O	O	O

HWR-Helium guard (HWRA03, HWRB03 진행)

Sensor	Actuator	Override	SetCP	Timer	Interlock	Reset
PT8203	XV8201	O	O	O	O	O
PT8201(ON/OFF 조건)	XV8501	O	O	O	O	-
PT8203(ON/OFF 조건)	XV8201	O	O	O	O	-

HWR-Mode interlock (HWRA01, HWRB03)

Sensor	Actuator	Override	SetCP	Timer	Interlock	Reset
LT8201	EH8201	O	O	O	O	O
LT8401	EH8401	O	O	O	O	O

HWR-CM (HWRA01, HWRB03)

Sensor	Actuator	Override	SetCP	Timer	Interlock	Reset
LT8401	CV8401	O	O	O	O	O
LT8201	CV8402	O	O	O	O	O
Resistance	EH8401	-	O	O	O	O
TT8402	EH8401	O	O	-	O	O
Resistance	EH8402	-	O	O	O	O
TT8404	EH8402	O	O	-	O	O
Resistance	EH8201	-	O	O	O	O
TT8202	EH8201	O	O	-	O	O
PT8501	CV7501	O	O	O	O	O
PT8301	CV8401	O	O	O	O	O
PT8201	CV8402	O	O	O	O	O
PT8201	CV8403	O	O	O	O	O
PT8112	CV7401	O	O	O	O	O
	CV7301					
	CV7501					
	CV7201					
	XV7501					

Estimation in advance

- Cool-down time @ 4.5 K (< 2 months)

※ 1st cool-down of SCL3 : more conservative way – step cooling ! + manually checking dT @ cryogenic distribution system

- Step 1: The FIRST cool-down : **Should be very conservative**
SCL3 CB+ CDS – **Step cool-down (50 K) controlled by Turbines**: within 16 days

(300 K – 250 K + 1 day stay – 200 K + 1 day stay– 150 K + 1 day stay – 100 K + 1 day stay– 50 K + 1 day stay – 4.5 K + 1 day filling and stabilization)

※ Calculation with energy balance + **conservative assumption**
= 291~330 hours (< 14 days) ; 18 tons (AL), 9 tons (SUS) @ CDS + thermal shields of CM

- Step 2: CM – **QWR fast cool-down** : within 12 days
HWR : within 20 days

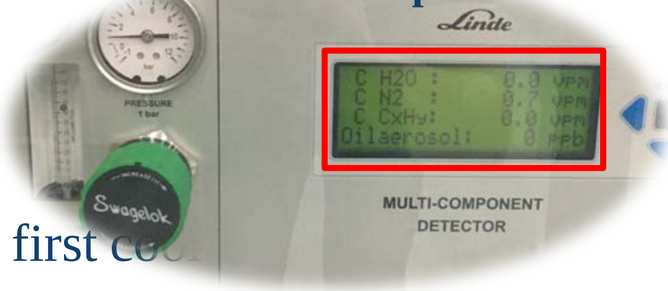
SCL3 ready

Visual checks/Parameters satisfied (Sep. 7th 2022)

▪ What we did for Readiness of SCL3 Cryogenic commissioning

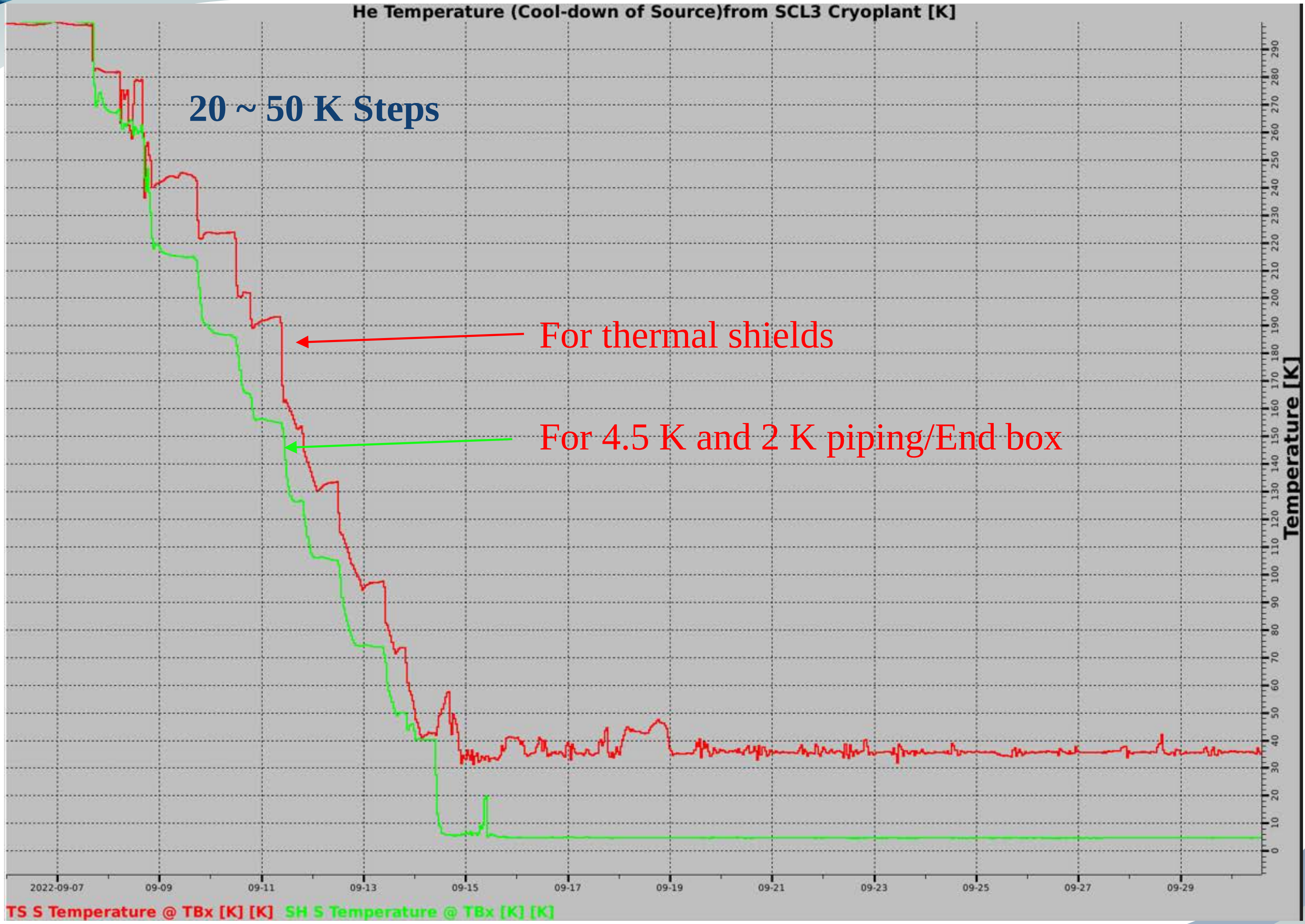
- SCL3 Cryoplant – Confirmation of performance
- Final Loop tests from equip. to GUI (QWR, HWR, TBx, Vacuum systems)
- Interlocks' tests (designed by IBS)
- Helium conditioning on all cryogenic pipes
- Final checking (visual) and positioning for the first coo

2022. Sep. 3rd 15:50

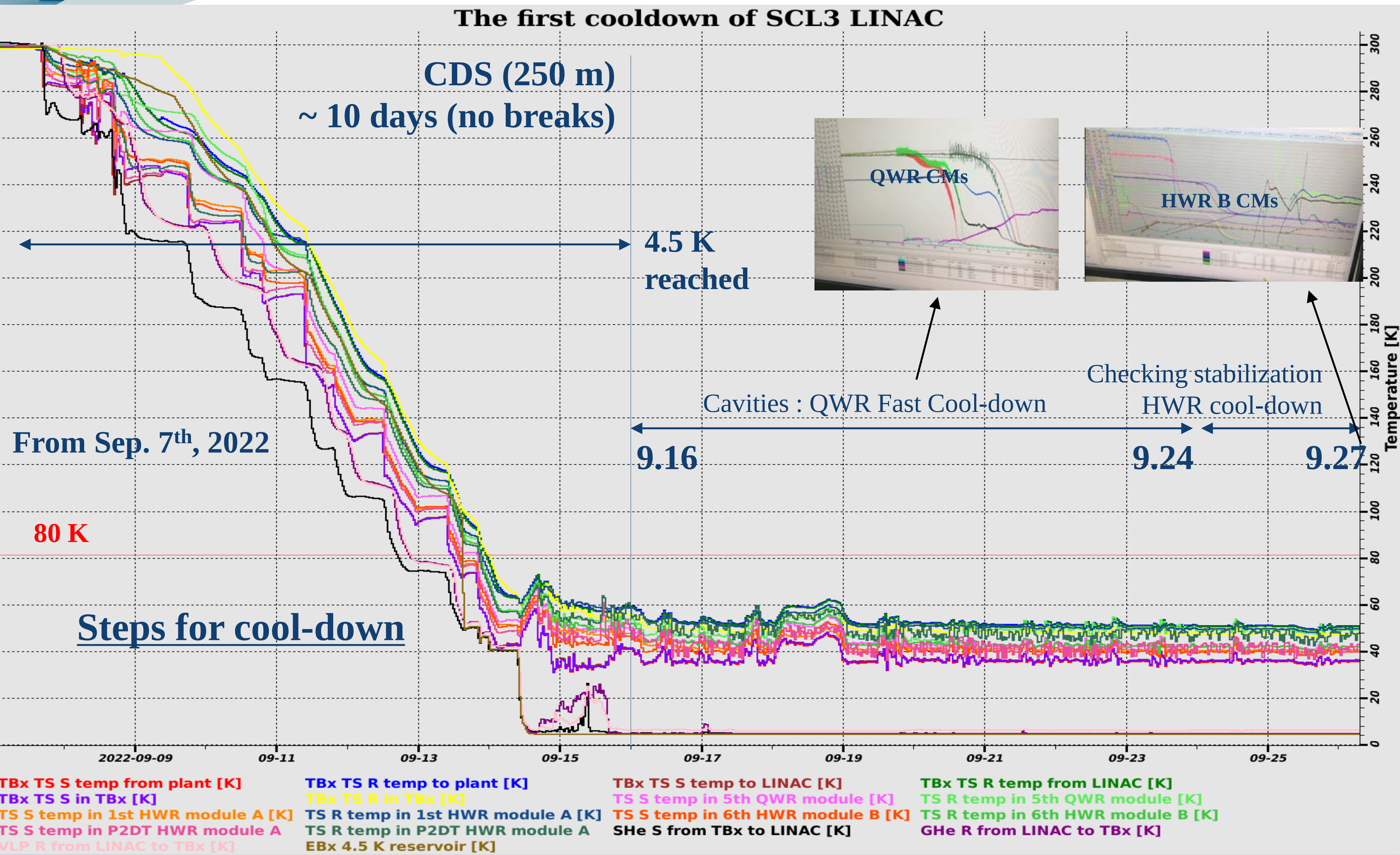


- Insulation Vacuum
  - Cryogenic Distribution System : 5 x 10^{-4} mbar~10^{-5} mbar
  - Cryomodules : 1~8 x 10^{-5} mbar

T steps for 1st cool-down of SCL3 to 4.5 K (T1 – controlled)

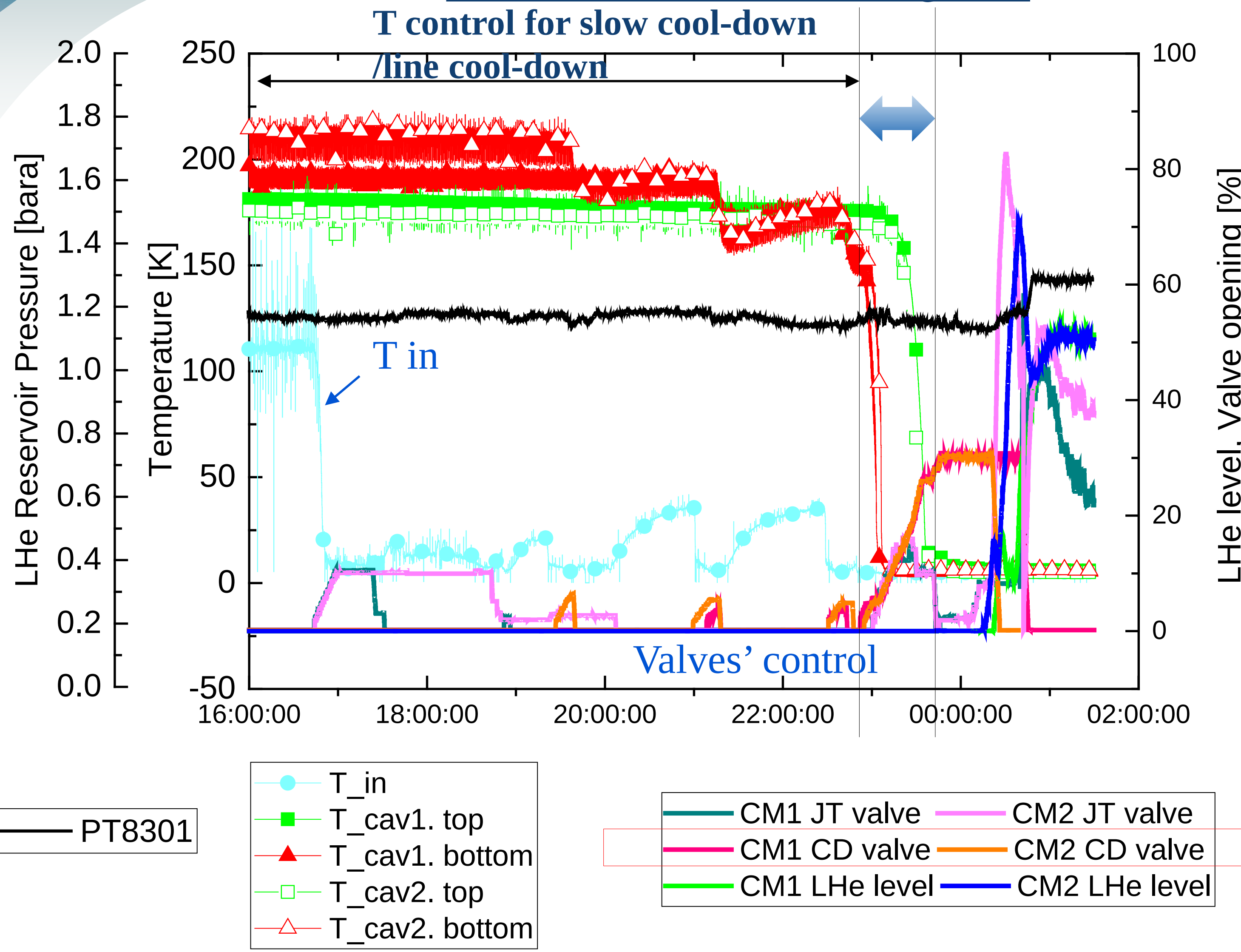


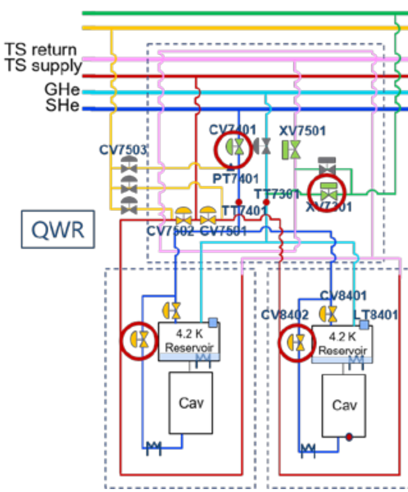
1st cool-down of SCL3 to 4.5 K



QWR CMs : 9 days (no breaks)

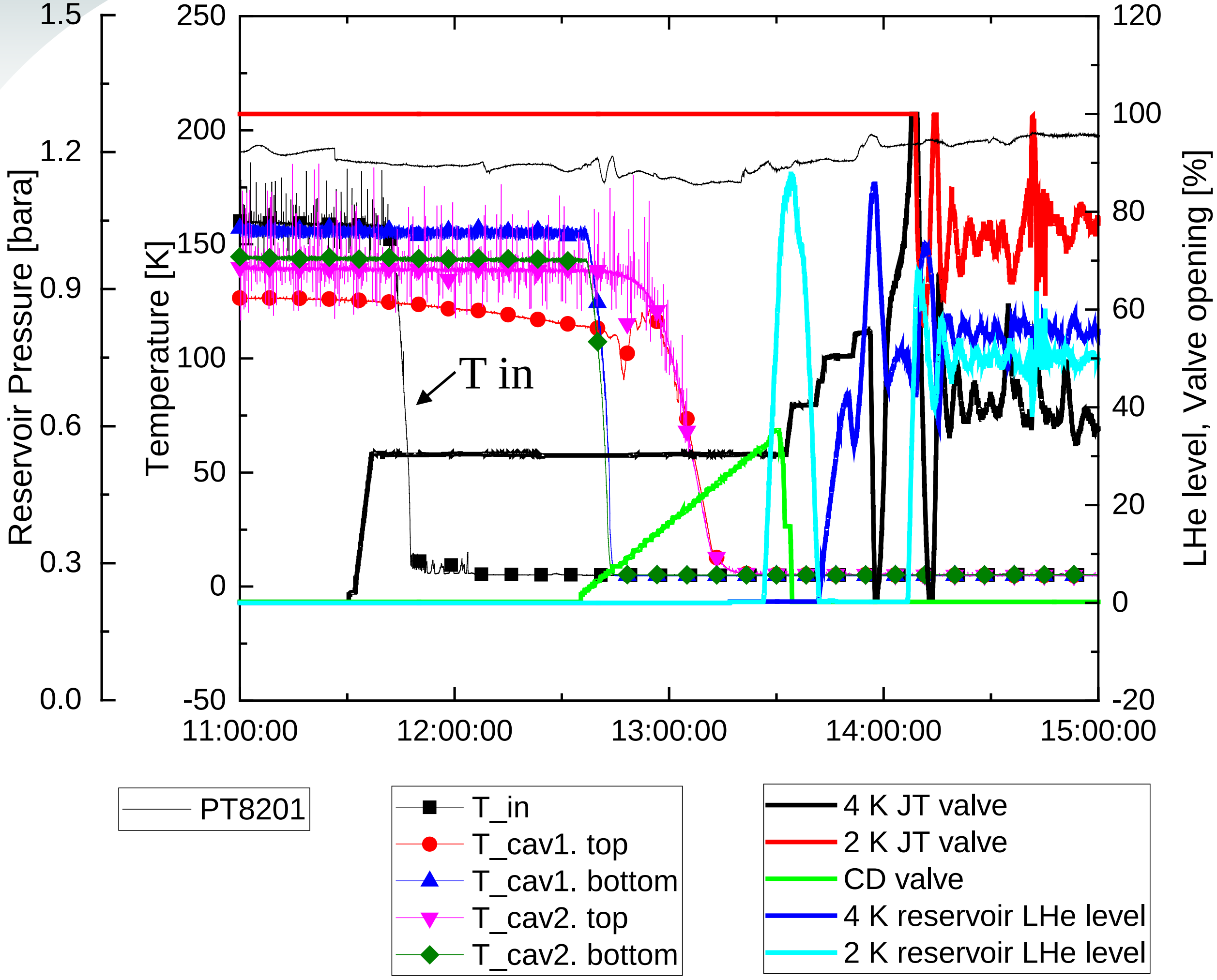
Fast cool-down for QWR

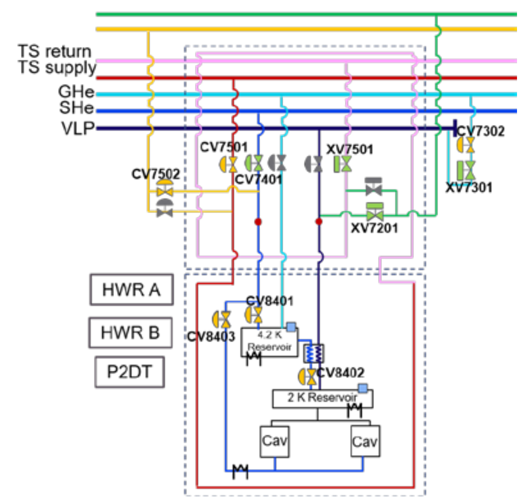




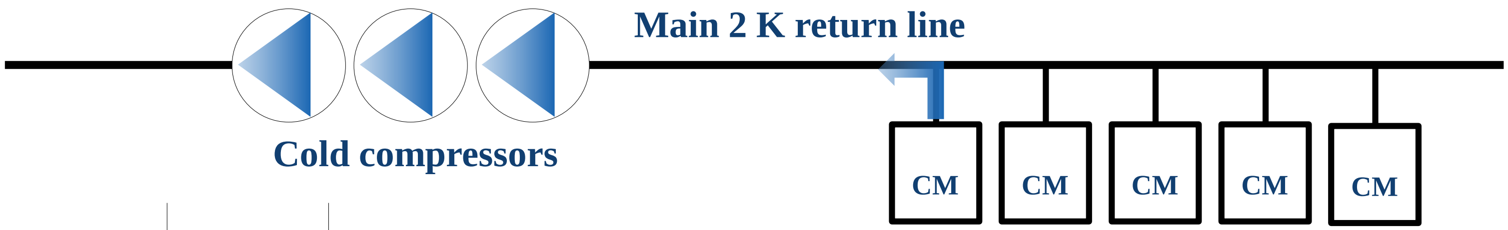
Cool-down of HWR A Cryomodule (4.5 K)

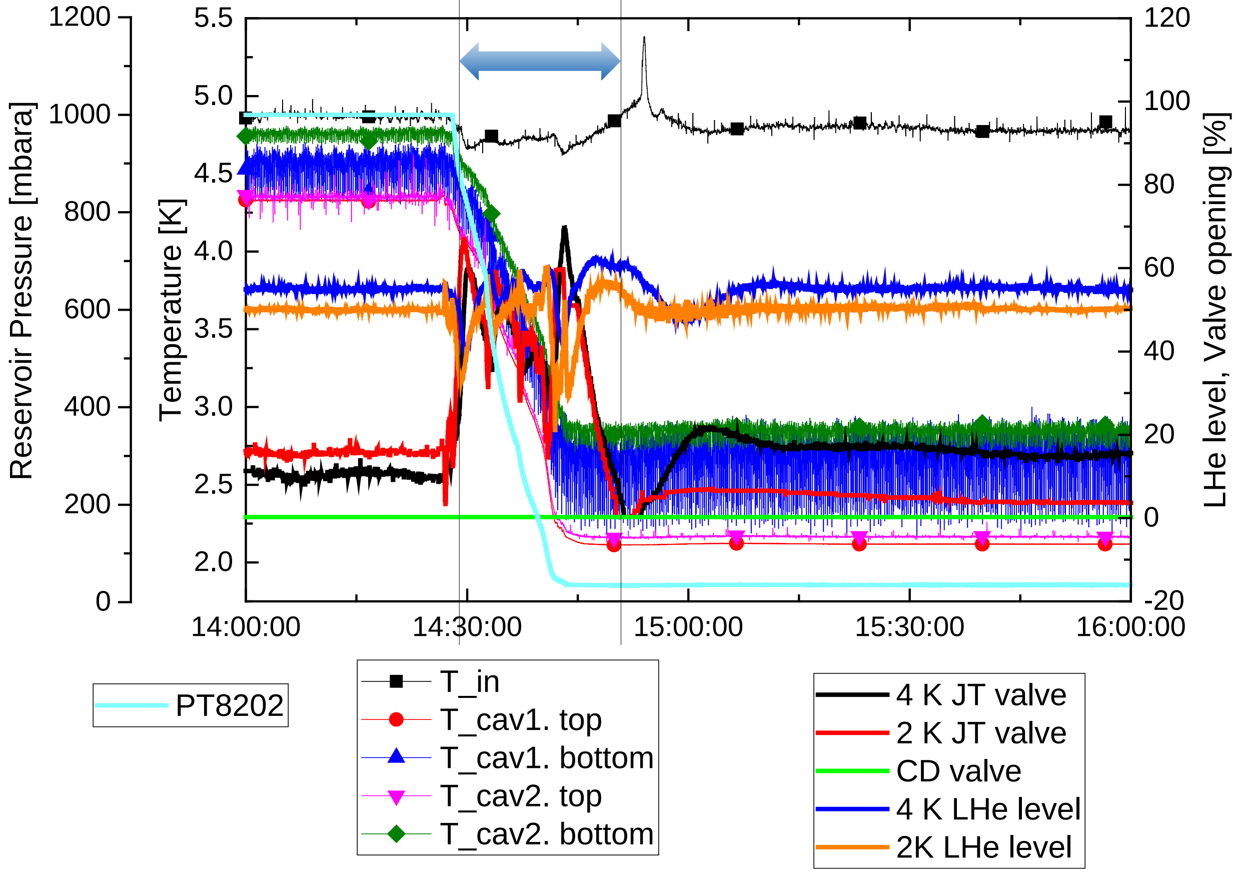
HWR CMs: 8 days + 17 days = 25 days (including holidays)





Cool-down of HWR A Cryomodule (2 K) – one by one (~ 3 CMs/day)





First pump-down : One-by-One (for all - 13 days)

Due to : Concern of TAO @ 2 K Cryogenic valve @ 4.5 K

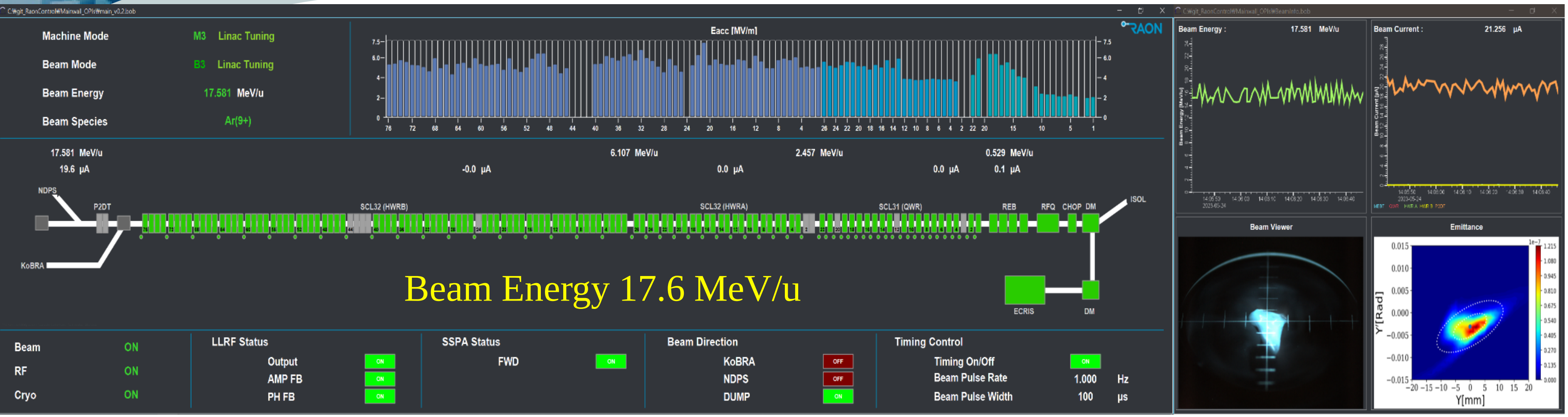
End of Cool-down (4.5 K)

Acknowledgement : RAON SCL3 @ 4.5 K and 2.05 K

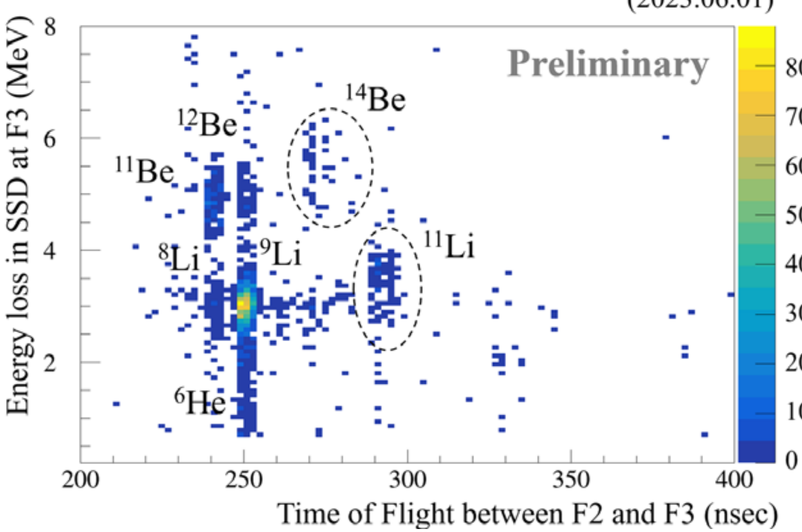
Date: Oct. 26th, 2022
Jan. 11th, 2023

First Cool-down

SCL3 Beam Commissioning – 1st Phase and first experiment



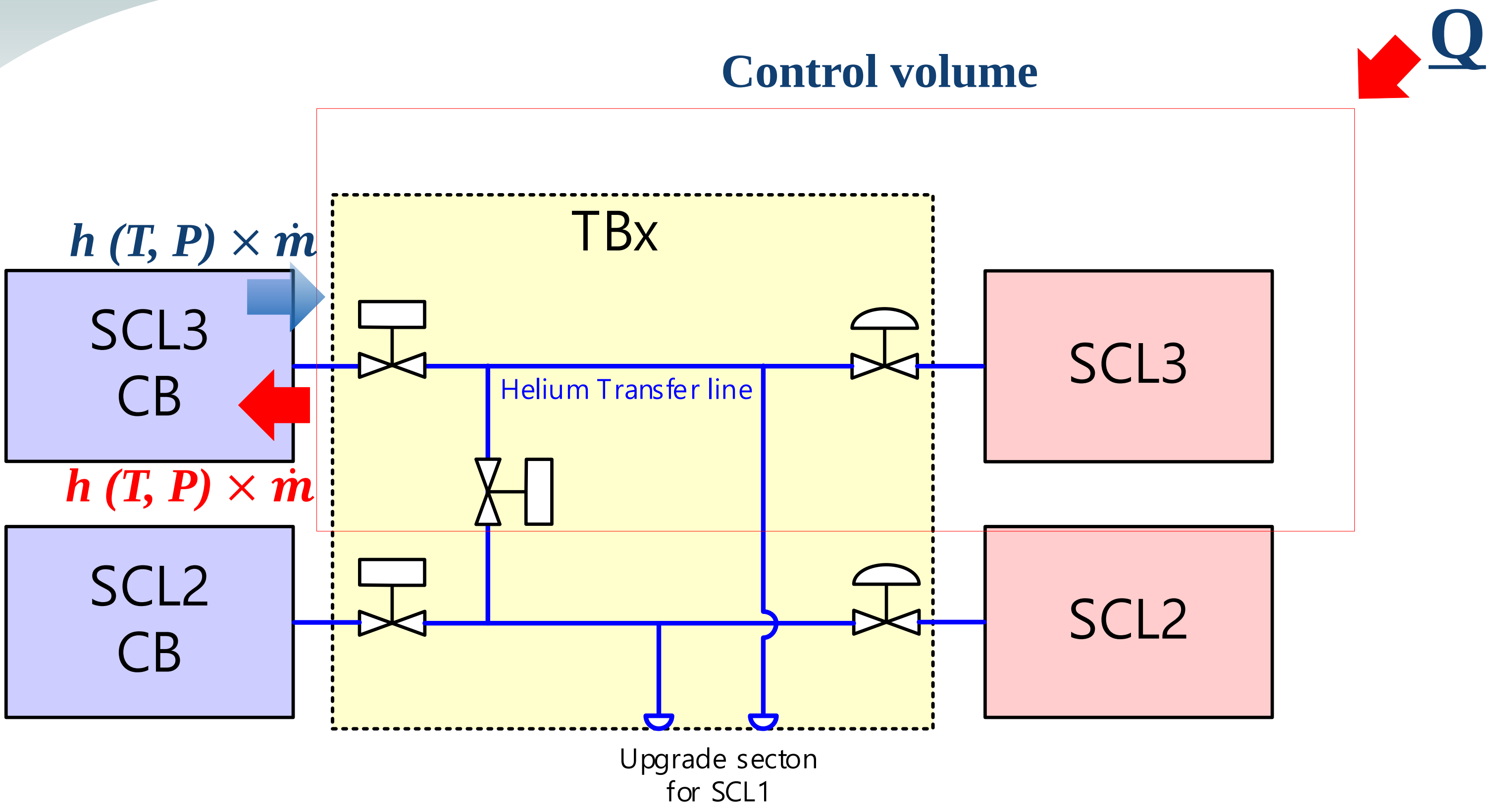
Particle identification with the first KoBRA beam commissioning (2023.06.01)



Acceleration to the end of SCL3 : May 23rd 2023

First experiment : May 31st ~ June 2nd, 2023

Overall thermal performance of SCL3



@ RAON, every 9:00 AM – regular checked/reported
Overall thermal loads (T, P, mass flow rate)
Vacuum conditions

Thermal performance

Total Static Heat Loads @ SCL3	Design (RF OFF)	Results (RF OFF)	Margin
	Total (W)	**Total (W)**	
Thermal shield (35~55 K)	**≪ 10,172**	**<u>7,270</u>**	
4.5 K +2 K	**1,012**	**<u>785</u>**	**<u>1.29</u>**

	Design (RF OFF)			Results (RF OFF + Heater ON)		
	T (K)	P (bara)	m (g/s)	T (K)	P (bara)	m (g/s)
Thermal shield Supply	35	15	**95.3**	35.6	14.76	**97.4**
Thermal shield Return	55	14.5	**95.3**	49.6	14.62	**97.4**
SHe Supply	4.5	3	**36.4**	4.5	3	**33.5**
GHe return	5	1.25	**27.1**	5.6	1.2	**19.7**
2 K return	7.1	**0.032**	**9.3**	5.6	**0.030**	**13.8**
Insulation Vacuum	$< 6 \times 10^{-7}$ mbar					

Total Heat Loads (Static+Dynamic) @ SCL3	**Design (RF ON) <u>Beam commissioning mode</u>**	**Results (RF ON)**	**Margin**
	Total (W)	**Total (W)**	
Thermal shield (35~55 K)	**10,172**	**<u>7,491</u>**	**<u>1.35</u>**
4.5 K +2 K	**1,316**	**<u>850</u>**	**<u>1.5</u>**

Full Heat Loads @ Cryomodules

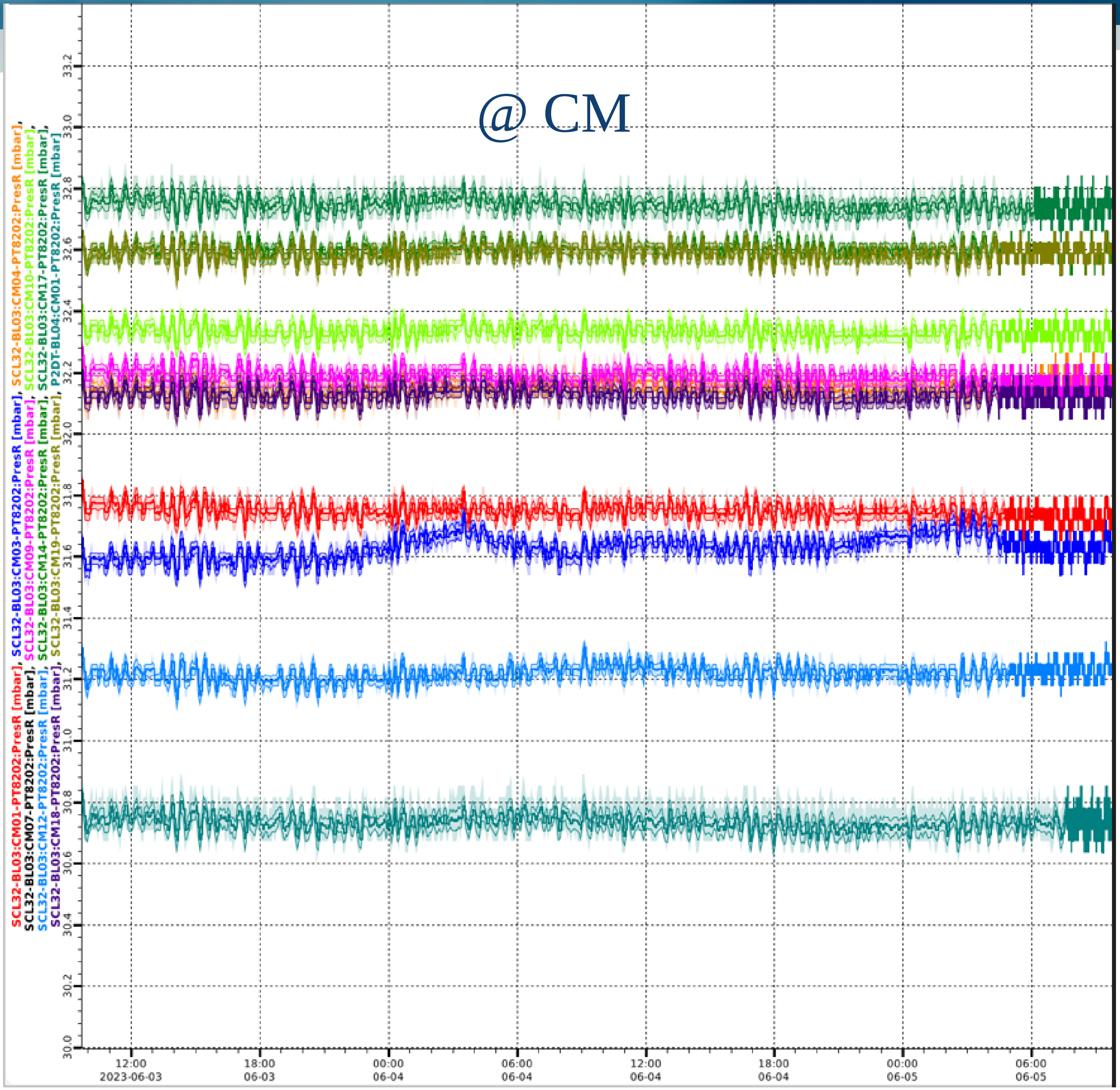
Total Heat Loads (Static+Dynamic) @ SCL3 (4.5 K + 2 K)	Design (Target/with margin)	Results (Min.~Max.)	Results (Average)
	Total (W)	Total (W)	Total (W)
QWR Cryomodules @ 6.1 MV/m	17.1/25.7	7.4~44	13.6
HWR A Cryomodules @ 6.6 MV/m	12.4/18.6	9.5~33.7	14.4
HWR B Cryomodules @ 6.6 MV/m	22.3/33.5	16~21	18.5

- Measuring full dynamic load @ each Cryomodules
  - Results of total heat load : **less than our expectation**
  - SCL3 :

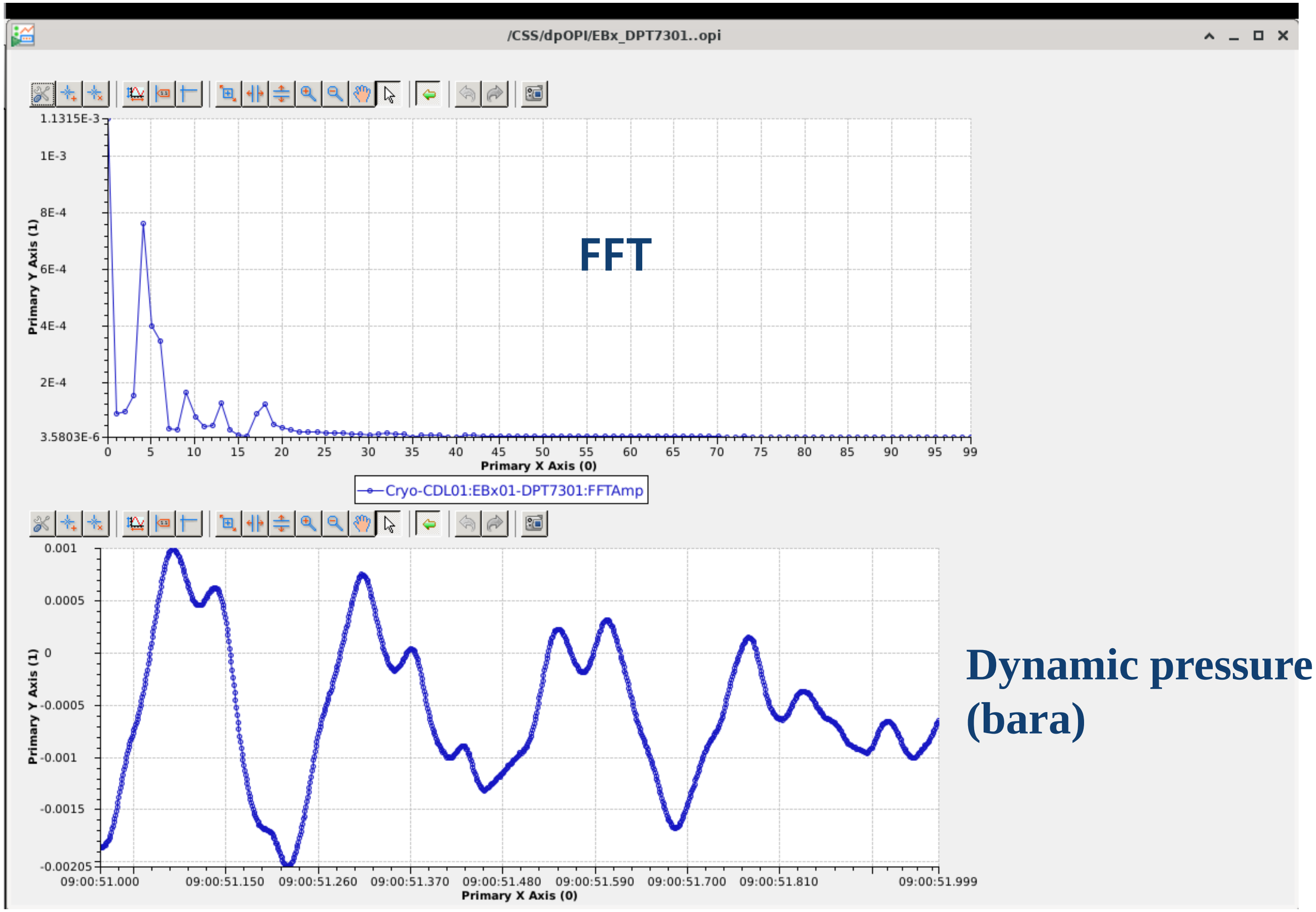
We may run to SCL3 with full RF powers – need to be confirmed by beam dynamics/diagnostics

Dynamic Stability

- Target (Peak to Peak) by Cryogenic System Team
  - GHe pressure : $\pm 1\ mbara$
  - VLP pressure : $\pm 0.3\ mbara$


@ CM
SCL32-BL03:CM01-PT8202:PresR [mbar], SCL32-BL03:CM03-PT8202:PresR [mbar], SCL32-BL03:CM04-PT8202:PresR [mbar],
SCL32-BL03:CM07-PT8202:PresR [mbar], SCL32-BL03:CM09-PT8202:PresR [mbar], SCL32-BL03:CM10-PT8202:PresR [mbar],
SCL32-BL03:CM12-PT8202:PresR [mbar], SCL32-BL03:CM14-PT8202:PresR [mbar], SCL32-BL03:CM17-PT8202:PresR [mbar],
SCL32-BL03:CM18-PT8202:PresR [mbar], SCL32-BL03:CM19-PT8202:PresR [mbar], P2DT-BL04:CM01-PT8202:PresR [mbar]
30.0
30.2
30.4
30.6
30.8
31.0
31.2
31.4
31.6
31.8
32.0
32.2
32.4
32.6
32.8
33.0
33.2
12:00 2023-06-03
18:00 06-03
00:00 06-04
06:00 06-04
12:00 06-04
18:00 06-04
00:00 06-05
06:00 06-05

GHe main line
With dynamic pressure sensor



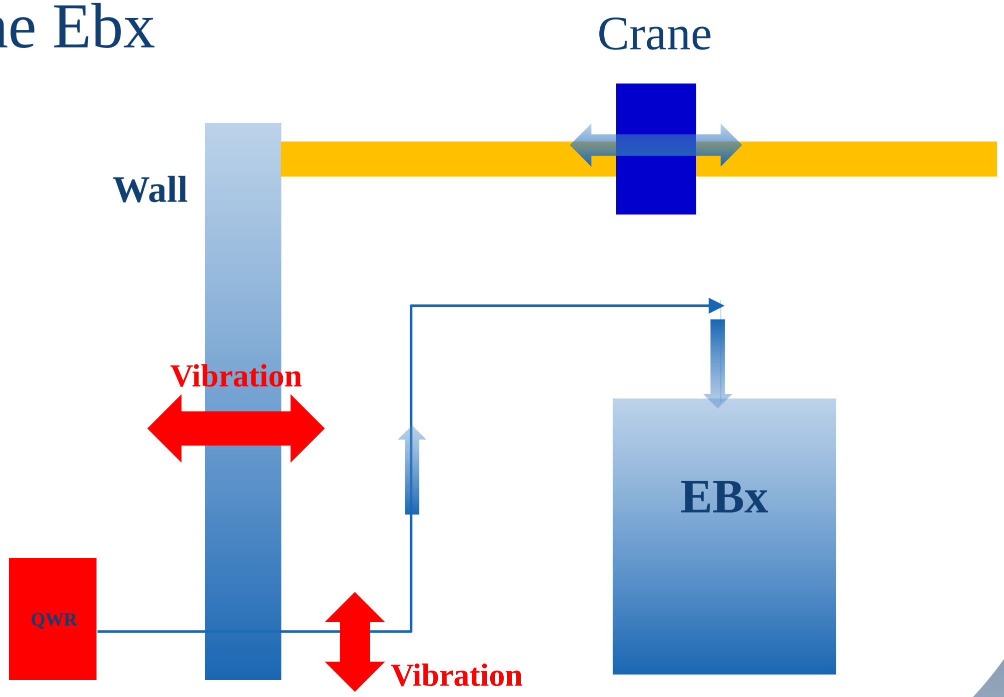
Dynamic pressure (bara)

For Stability of SCL3

- SHe flow to End Box
  - Unstable flow by SHe flow @ the end of SCL3
  - Vibration observed
  - Disappeared when stopping the SHe flow
  - For cool-down : Used the Ebx

<u>Othermodes - not used</u>

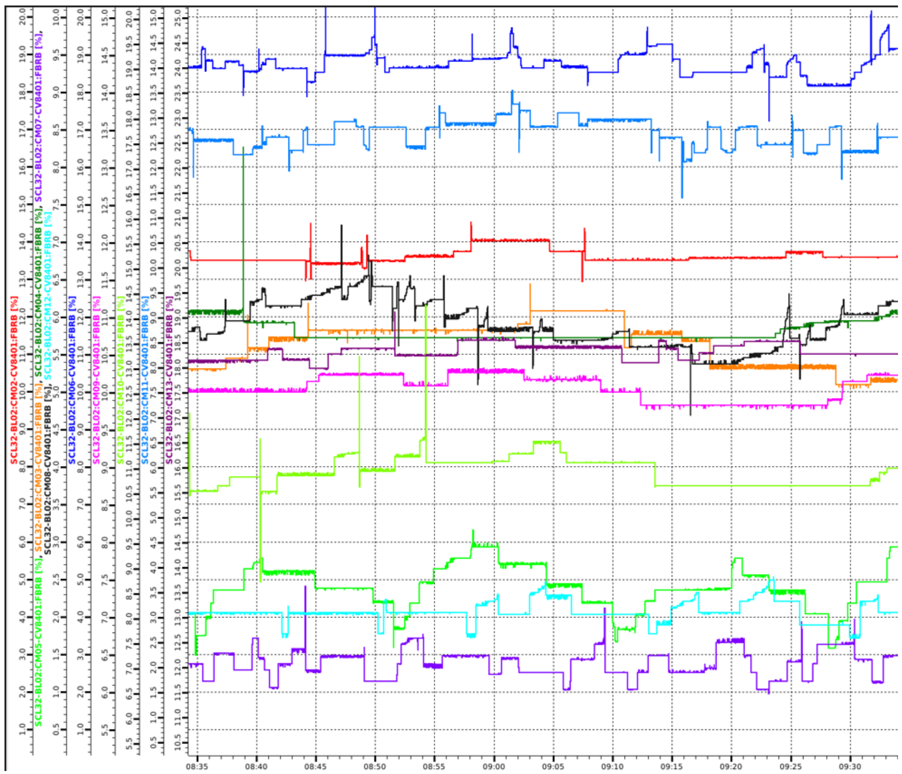
- Vibration by crane



- Dampers
    - “Valve and reservoir” system in order to minimize TAO
    - Dampers @ GHe installed
    - Thermal performance improved
      (Total decreased heat load : ~100 W)

Icing @ GHe port

- Motion of cryogenic valves (especially for pressure control)
  - Minimize the motion with slow speed (PI values @ PID control)
    - ✓ Critical effect on df
  - Solving the hunting by positioners’ issue (IA leak)



- GHe Pressure Control
  - Not for each CM
  - Controlled @ the main GHE line only
  - with valve installed @ main distribution box
  - Each CM – return valve : fully open

- Control of heaters @ CM
  - For making good position of cryogenic valves
  - In order to minimize the effect from RF on/off (on-going)

- VLP return valve without convection brake
  - We could not use this valve without 2 K operation.
  - Due to TAO @ DN50 Weka cryogenic vale
  - @ 2 K pressure – TAO disappeared – used for 2 K operation

TAO analysis

Confidential – cannot be copied

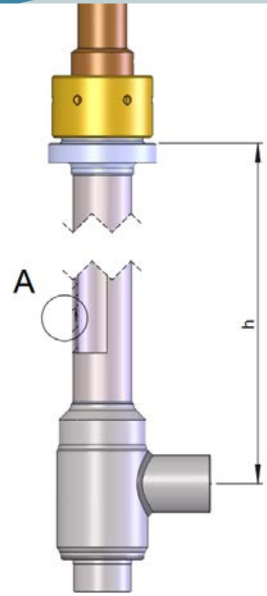
@ Commissioning

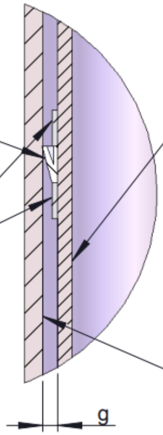
4.5 K operation : Unstable

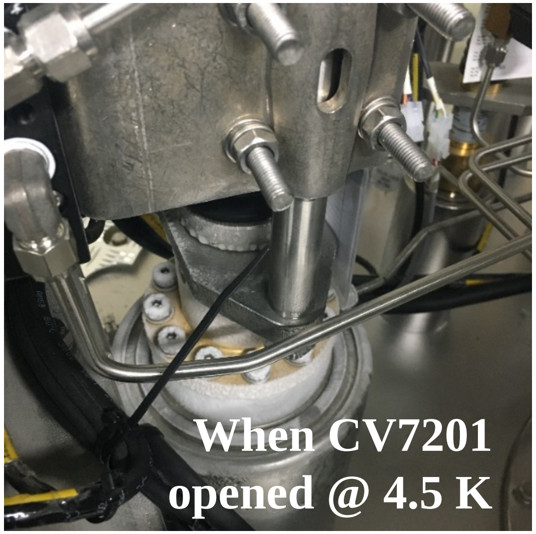
2 K operation :
Stable

-> need to be investigated

We already knew the necessity.





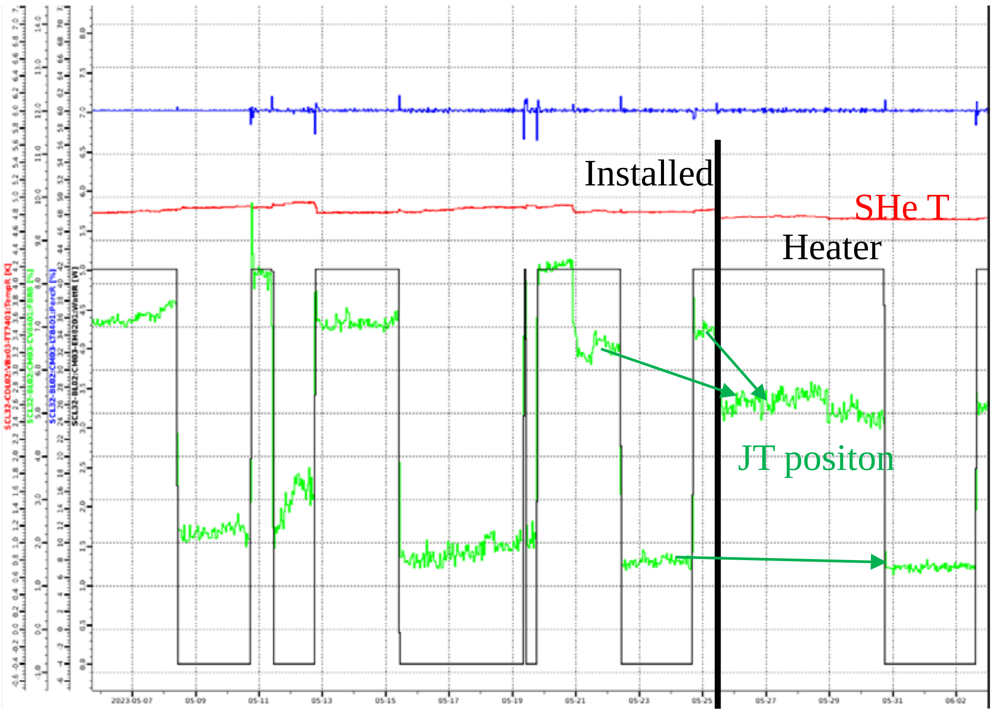


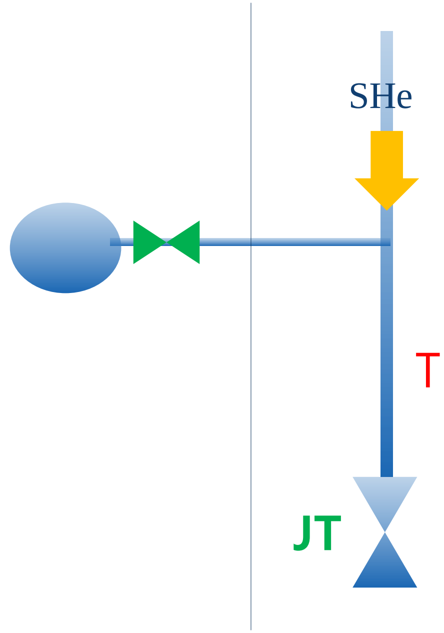
Confidential – cannot be copied

Our convection brake,
Installed @ 1 CM and no problem –
confirmed @ the FIRST RUN

Before the Second Run,
All valves will be modified.

- Our system is very sensitive
  - Especially by GHe dynamics
  - Relation between GHe and VLP (flow - > vibration)
  - Dampers @ SHe: Checked the necessity - by temperature/JT Position

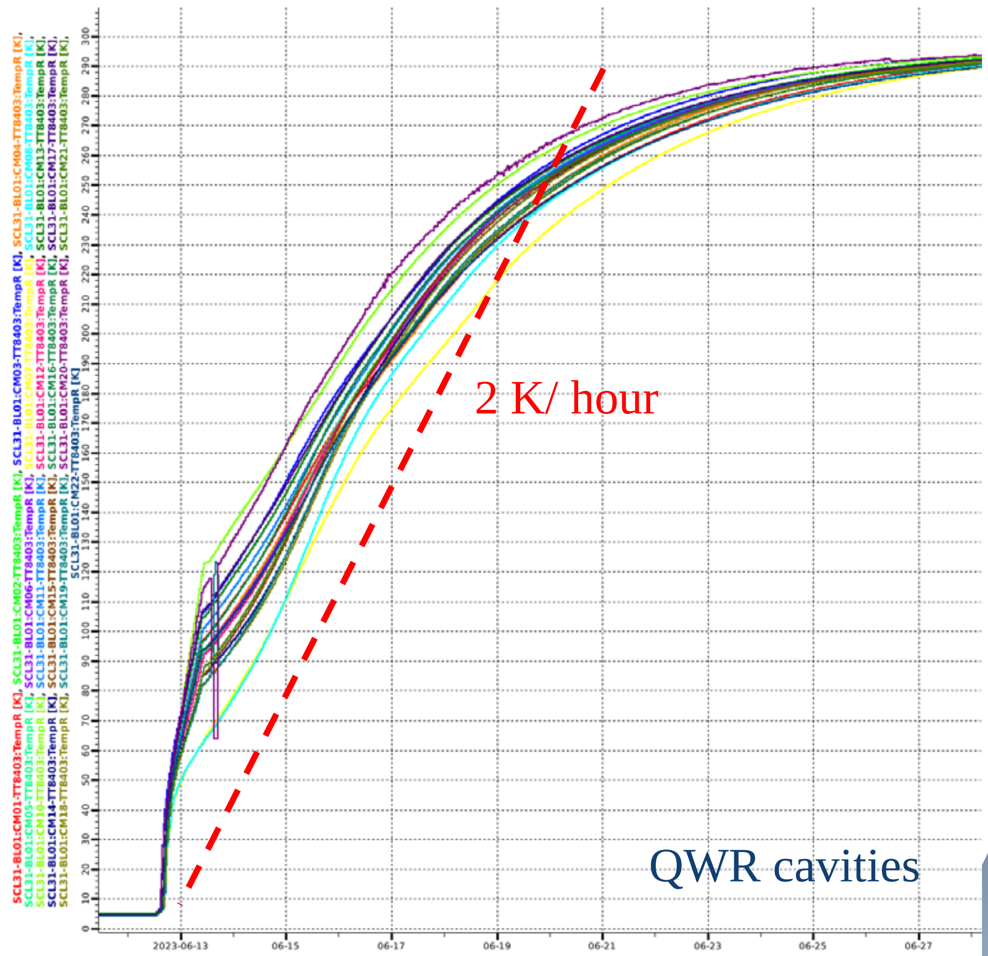


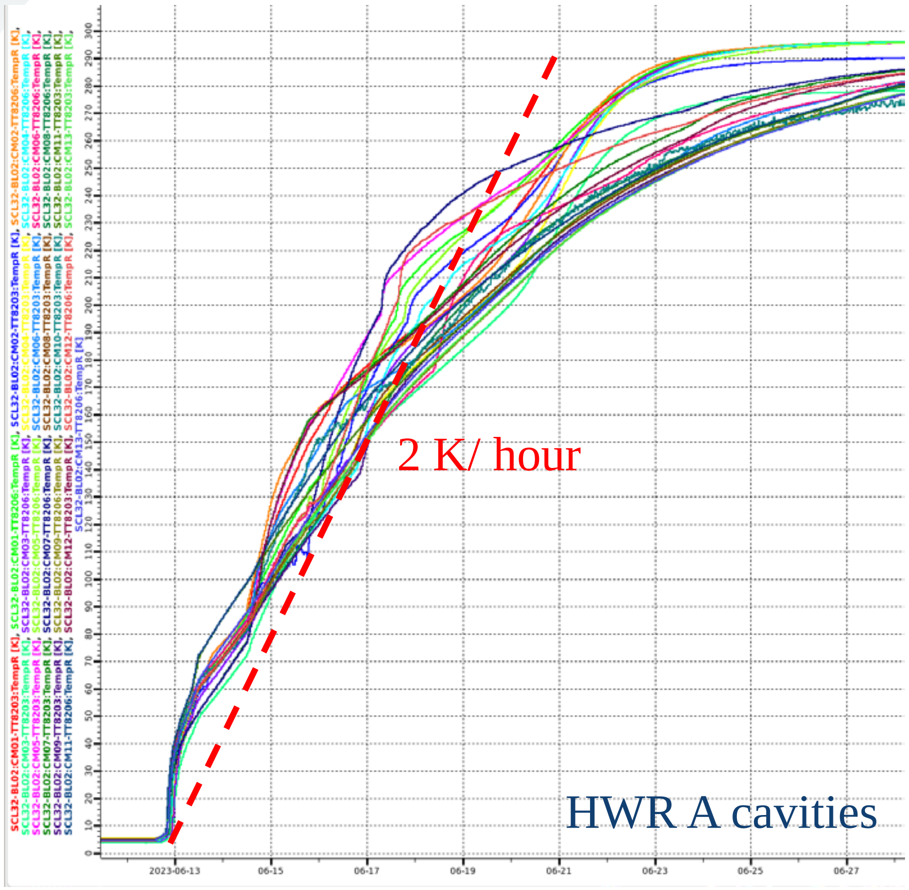


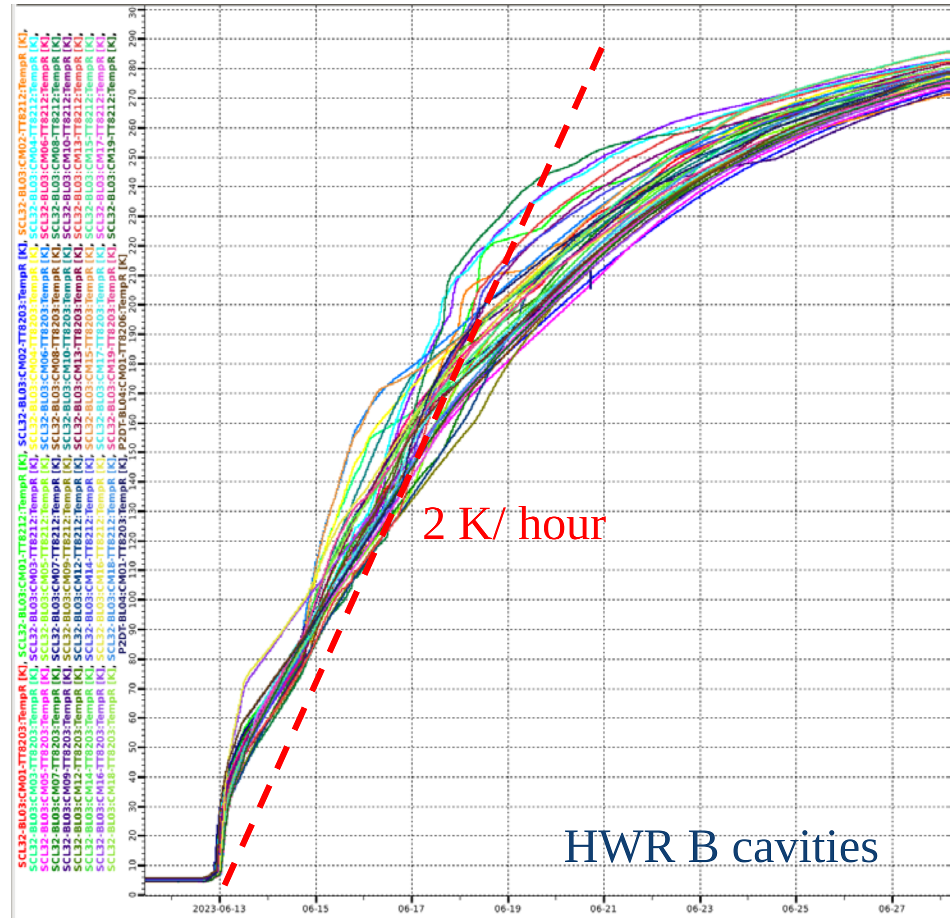
- Current Stability @ CM : **2~3 mbar @ GHe pressure (1.2 bara)**
  0.1~ 0.5 mbar @ VLP pressure (30~34 mbara)

Warm-up : for 3 weeks

- By manual mode
  - Source
    - **Warm flows from cryo. plant**
    - **Temperature of TS (thermal radiation/conduction)**
  - Temperature
    - < 3 K/hour
    - < Max. 50 K difference
  - Pressure : < 1.3 bara




2 K/ hour
HWR A cavities


2 K/ hour
HWR B cavities

Availability and Reliability

- Sep. 7th 2022, 3:00 PM ~ up to now.

#	Failure' Cases	Down-time
1	Small capacity of a circuit breaker @ TBx	6 hours
2	SHe flow instability of Main SHe @ End of cool-down (End box – filling)	24 hours
3	Frozen nitrogen, oxygen, and water to block the inlet filter of 1st cold compressor	385 hours
4	VLP pumps' oil filling (not expected)	16 hours
5	Failure of PI control (HWR B CM18)	6 hours
6	Disconnected with EPICS IOC (just before warm-up, made by human error)	2 hours
	Total	439 hours

- 87 % for 2 K operation

- Issues' tracking
  - 2 K return cryogenic valves @ valve boxes : convection brake
  - Cold leak of HWR B CM#11
  - SCL3 cryoplant : VLP pumps and safety line @ SHe line
- Punch lists + regular maintenance
  - Cryoplant : 3 items
  - CDS/CM : 48 items
  - Control (including updates) : 32 items

From 3rd of July ~ to end of Oct. 2023 : our maintenance period

No accident in SCL3 !

Long Journey, but very incredible

"6 Years and 6 months"

Acknowledgement : RAON SCL3 @ 4.5 K

Date: Oct. 26th, 2022

First Cool-down

Moving the next step,
Just turns on the light @ RAON

We made the achievement,

But, need to be improved more

We just start and make a background <u>for other challenges (Second run, Third run – open for users).</u>

Our RAON of IRIS @ IBS,
Just accelerated the first beam as an superconducting accelerator.

<u>With your interest and collaboration, want to go to the next stages.</u>

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