Present Status and Future Plans for Linear Accelerators in Korea

2026. 08. 17.

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KAERI 한국원자력연구원 Korea Atomic Energy Research Institute
PAL 포항가속기연구소 POHANG ACCELERATOR LABORATORY
KBSI 한국기초과학지원연구원 KOREA BASIC SCIENCE INSTITUTE
ibs 기초과학연구원 Institute for Basic Science

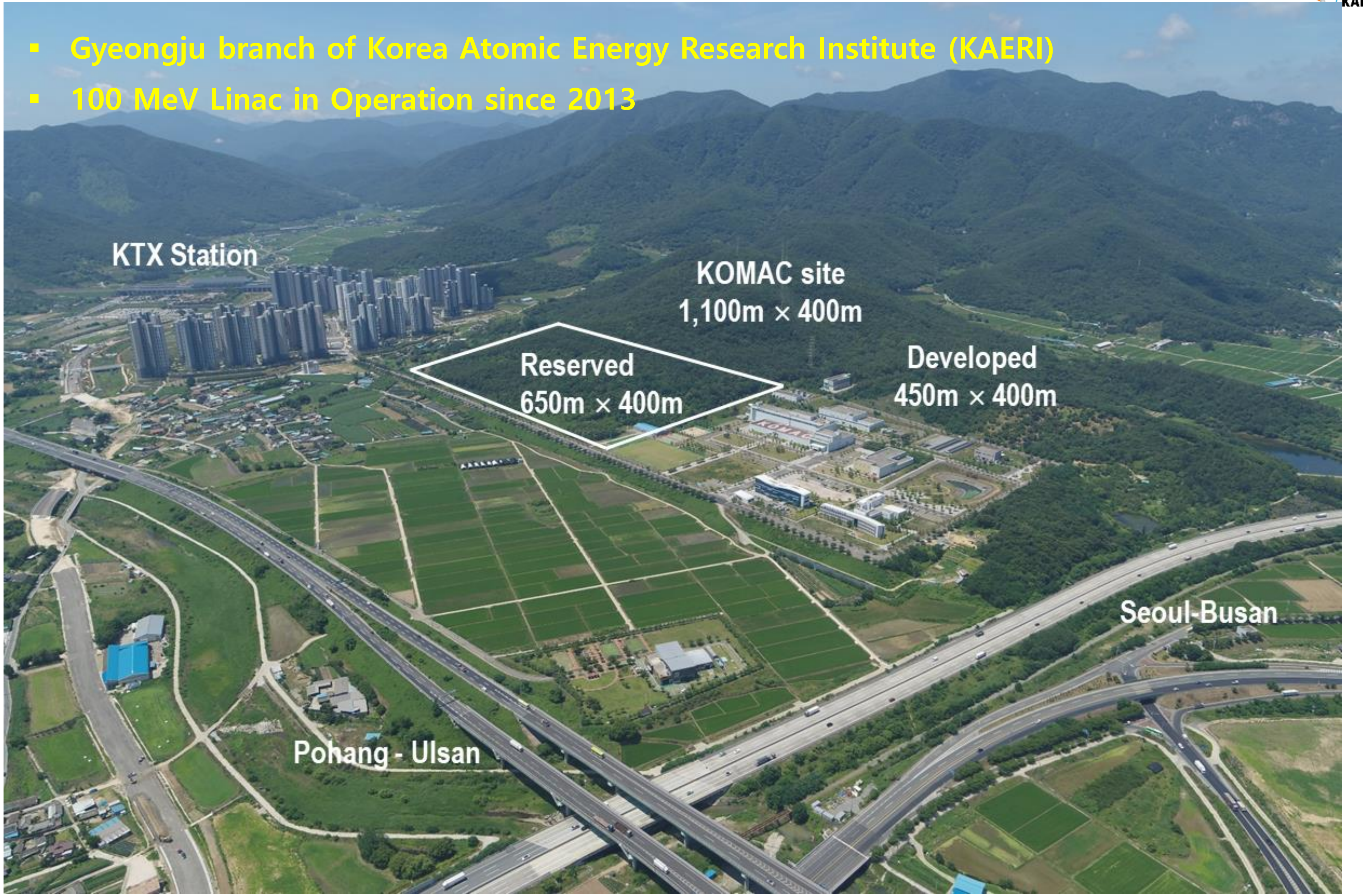
Major Accelerator Facilities in Korea

Contents

KOMAC at Gyeongju

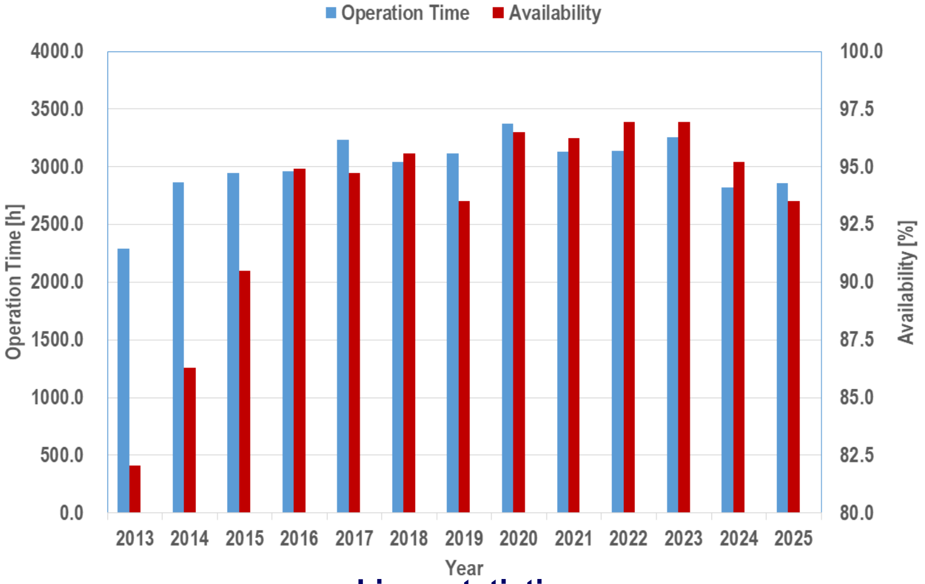
KOMAC (Korea Multipurpose Accelerator Complex)

- Gyeongju branch of Korea Atomic Energy Research Institute (KAERI)
- 100 MeV Linac in Operation since 2013

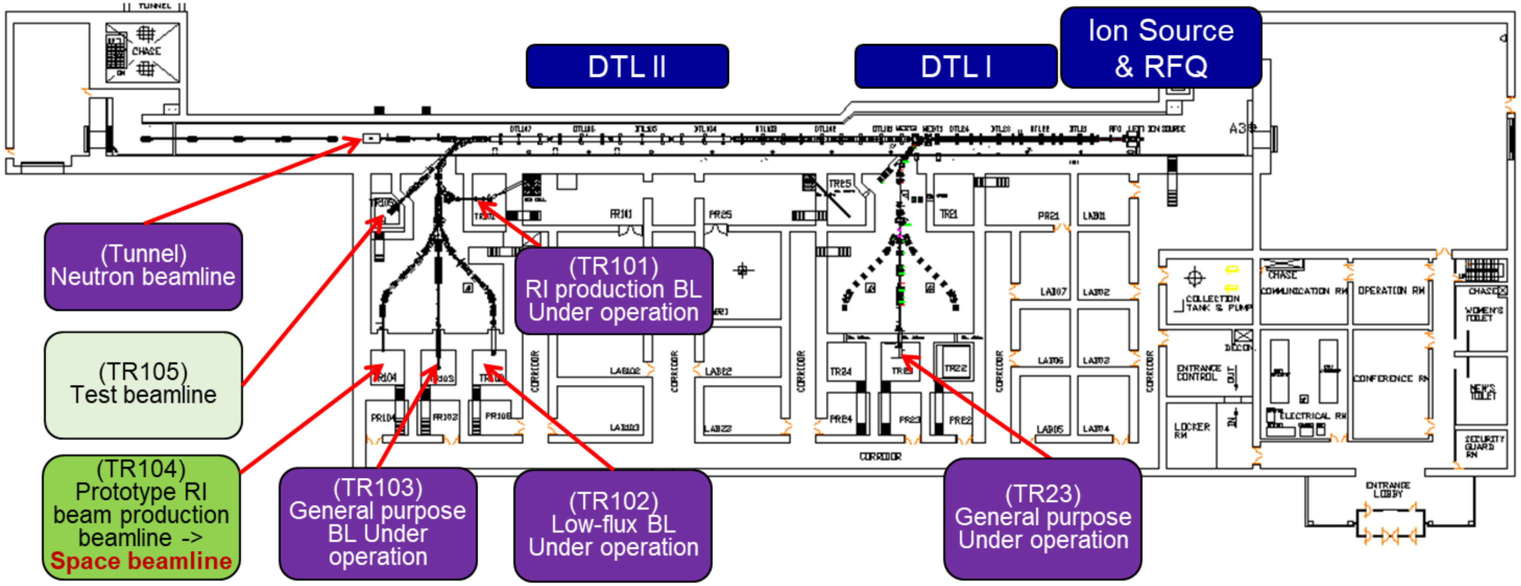


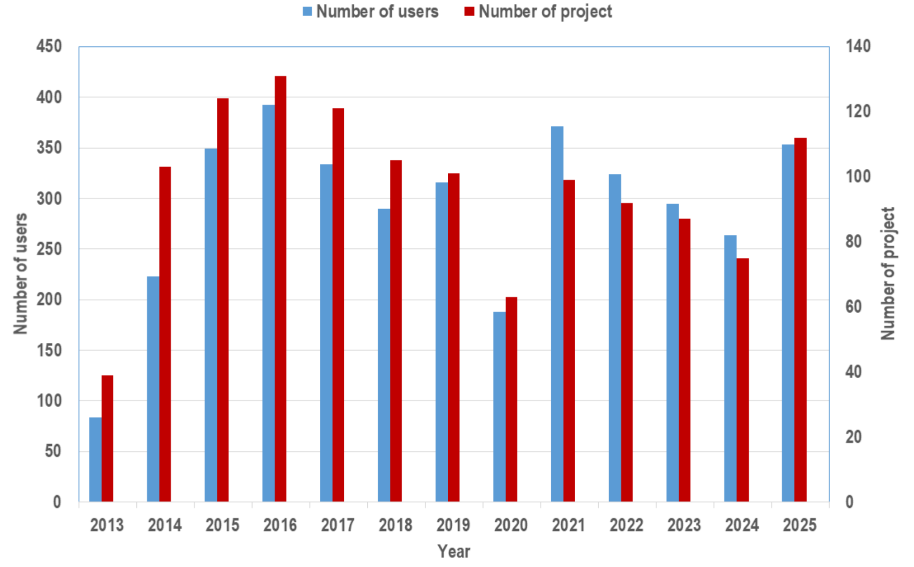
KOMAC 100 MeV LINAC and Beamlines Status

- Linac commissioned in 2013
- General purpose beamline and user service starts (2013~)
- RI production beamline (2016~)
- Low flux beamline (2017~)
- * Accelerator test beamline (2017~)
- * Prototype RI beam production beamline (2018~)
- * Pilot operation of neutron beam test (2018~)
- Official operation of neutron beam service (2024 ~)
- Total 4 proton beamlines and 1 neutron beamline are in user service as of 2025 (TR23, TR101, TR102, TR103, Tunnel)



Linac statistics



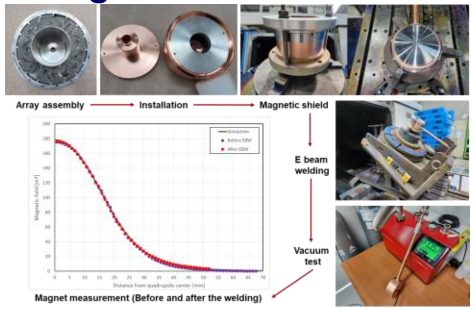


User statistics

Recent Activities

Machine Aging Control (Spare RFQ and DTL) : Spare RFQ under fabrication, Replacing EMQ with PMQ in DTL, New DTL tank

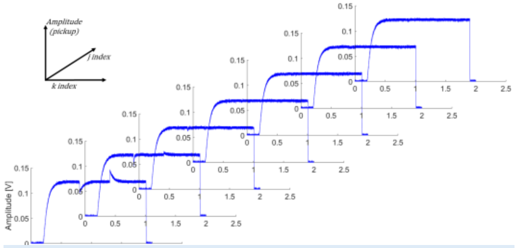
Spare RFQ development



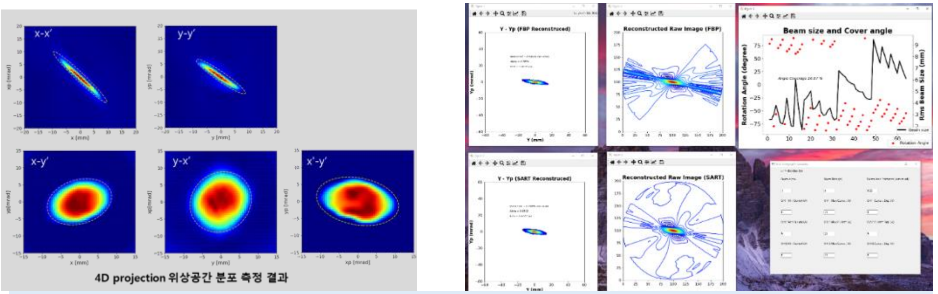
DTL with PMQ development

Beam Test Stand (BTS) : Ion source and LEBT study, LLRF control algorithm development, Beam diagnostics study

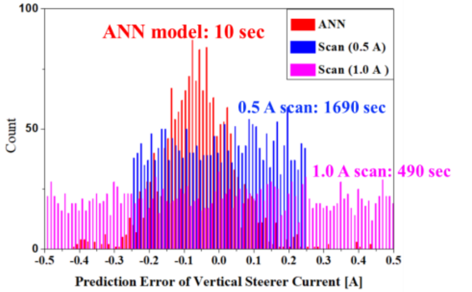
BTS (1 MeV RFQ)



LLRF control algorithm

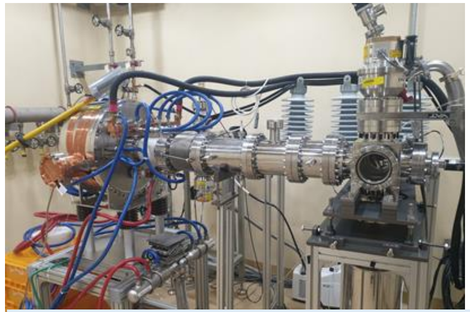


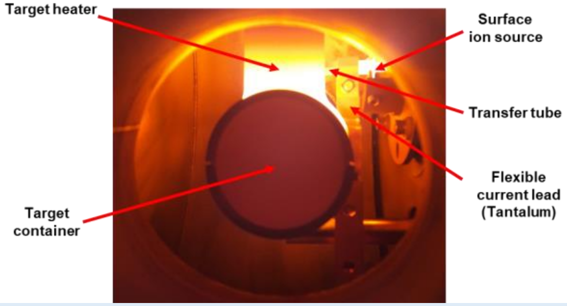
Beam diagnostics study

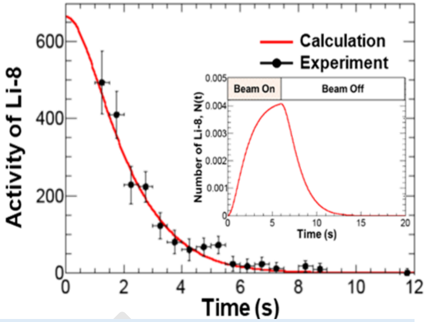


Machine learning

RI Beam Production and Neutron Beam Service







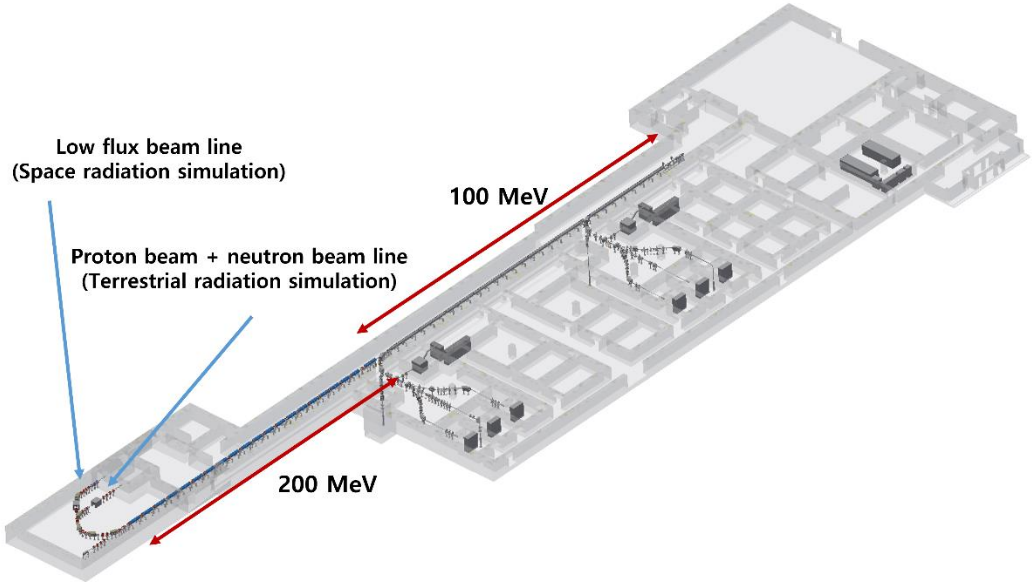
Target ion source and Li-8 beam production

Neutron production for user service

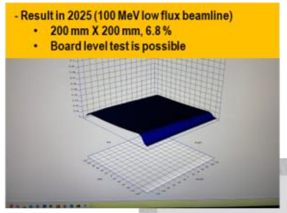
Upgrade and Future Plan

Operational Status of the KOMAC 100 MeV Proton Linac and Pilot R&D for the 200 MeV Upgrade (**TU1A001**)
By Dr. Han-Sung Kim

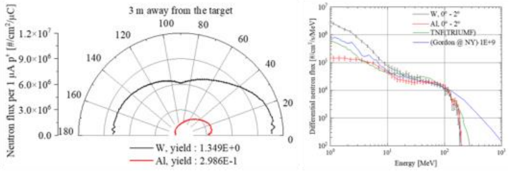
Short-term Plan : 200 MeV Energy Upgrade



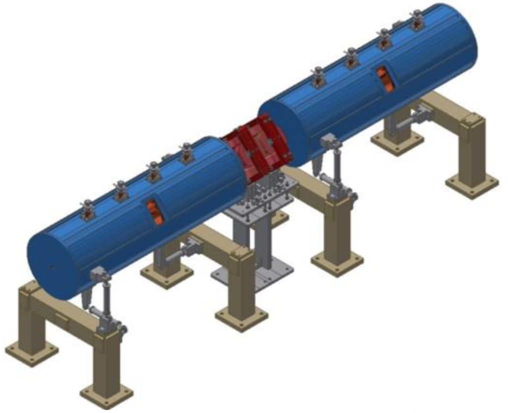
- Beam species: Proton
- Maximum energy: 200 MeV
- Beam size: 100 mm X 100 mm
- Uniformity: < 10%
- Flux range: 10^6 ~ 10^8 p/cm^2 s

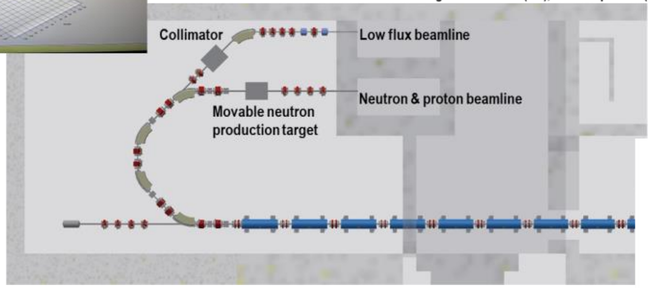


- Beam species: Neutron, proton
- Neutron maximum energy: 200 MeV
- Neutron flux: > 10^6 n/cm^2 s (> 10 MeV)
- Proton maximum energy: 200 MeV



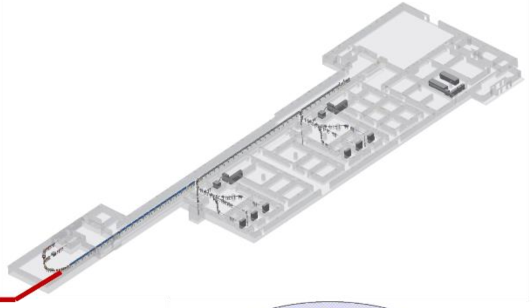
<Neutron angular distribution (left), Neutron spectrum (right)>

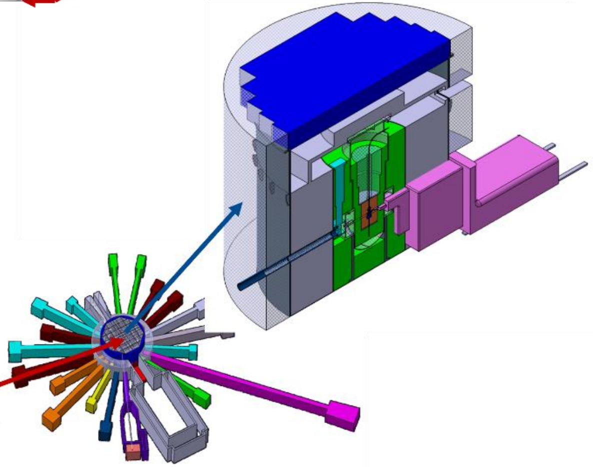




Long-term Plan : Spallation neutron source with Proton RCS

- 1 GeV RCS (2 GeV upgradable)
- Neutron target
- Instruments and Beam utilization facility

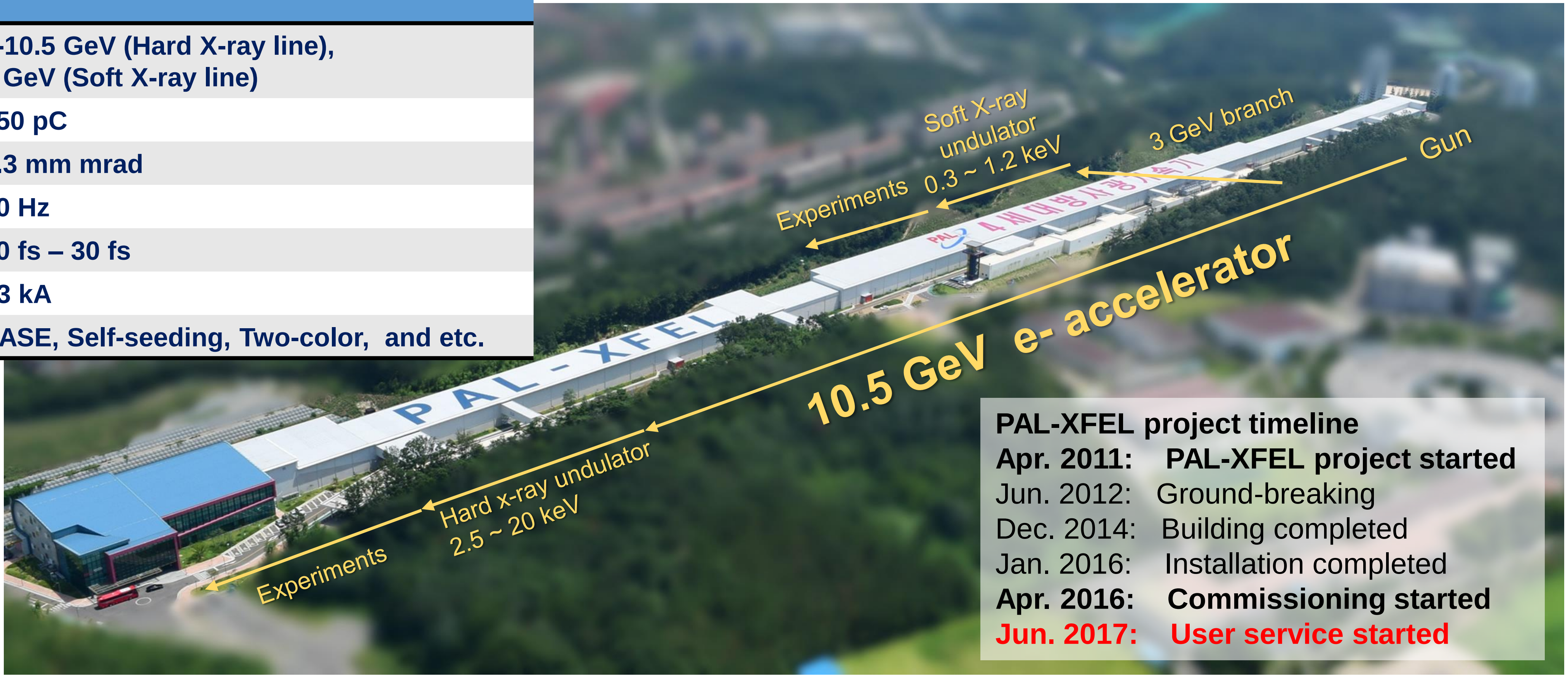




PAL-XFEL at Pohang

PAL-XFEL overview

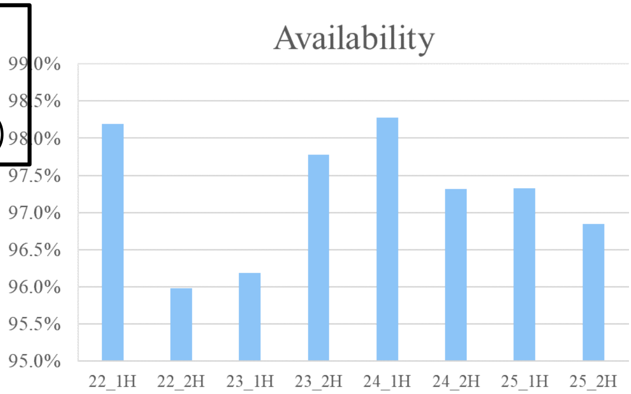
Main parameters	
e^- Energy	4-10.5 GeV (Hard X-ray line), 3 GeV (Soft X-ray line)
e^- Bunch charge	250 pC
Slice emittance	0.3 mm mrad
Repetition rate	60 Hz
Pulse duration	20 fs – 30 fs
Peak current	~3 kA
Operation mode	SASE, Self-seeding, Two-color, and etc.

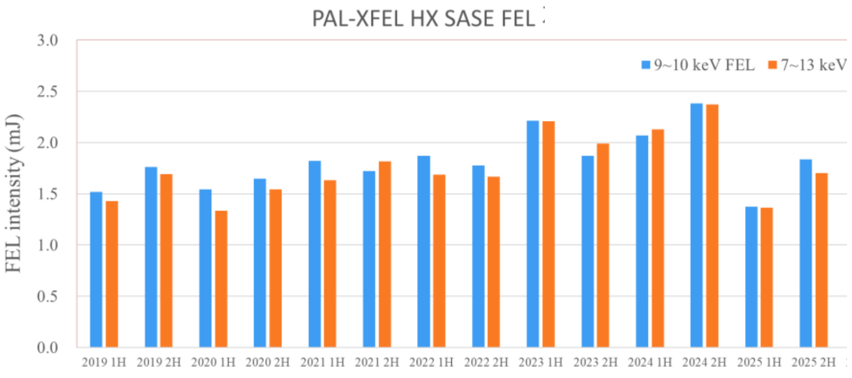


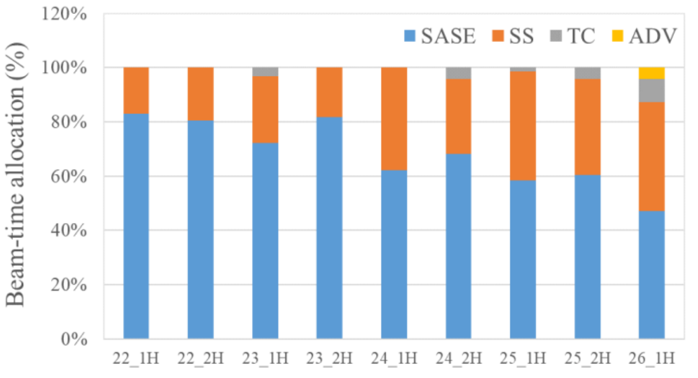
PAL-XFEL project timeline

Apr. 2011: PAL-XFEL project started
Jun. 2012: Ground-breaking
Dec. 2014: Building completed
Jan. 2016: Installation completed
Apr. 2016: Commissioning started
Jun. 2017: User service started

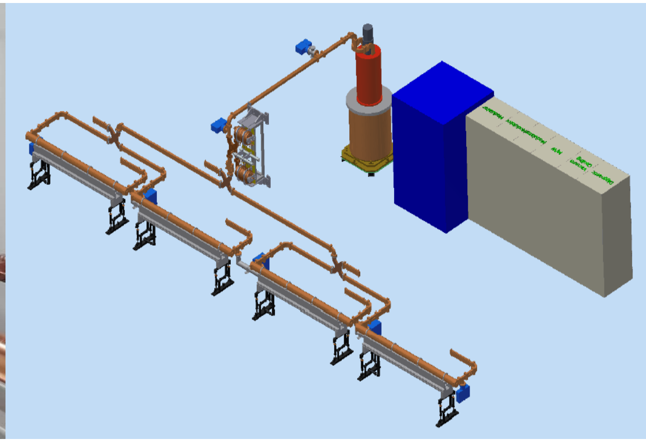
User Beamtime
: 190 Days
(24-hour Operation)







Sub - 20 femtosecond timing stability

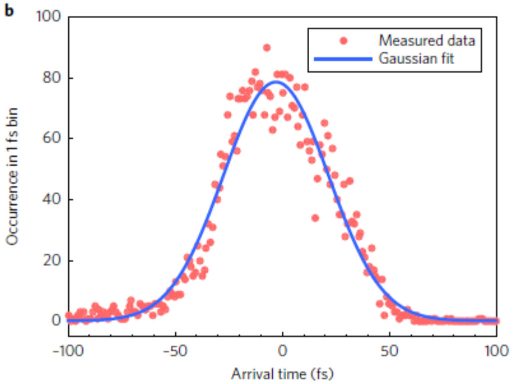


- ***S-band 4 hole photocathode gun, quasi-coupler acc. and SLED structures 0.01 deg temperature control.***
- ***20 ppm CCPS type modulator***
- ***Sub femtosecond jitter in reference timing distribution over 1 km distance***

ARTICLES
https://doi.org/10.1038/s41566-017-0029-8
nature photonics

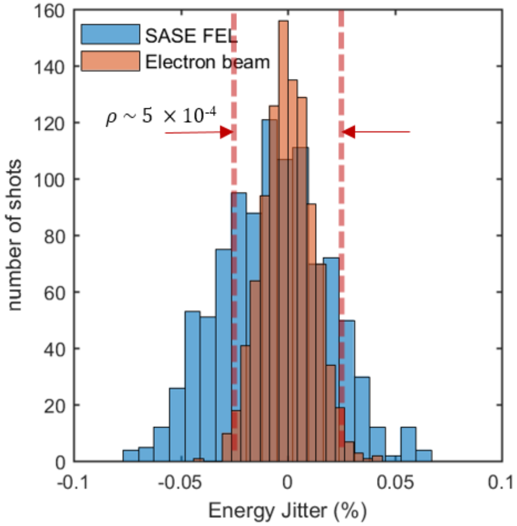
Hard X-ray free-electron laser with femtosecond-scale timing jitter

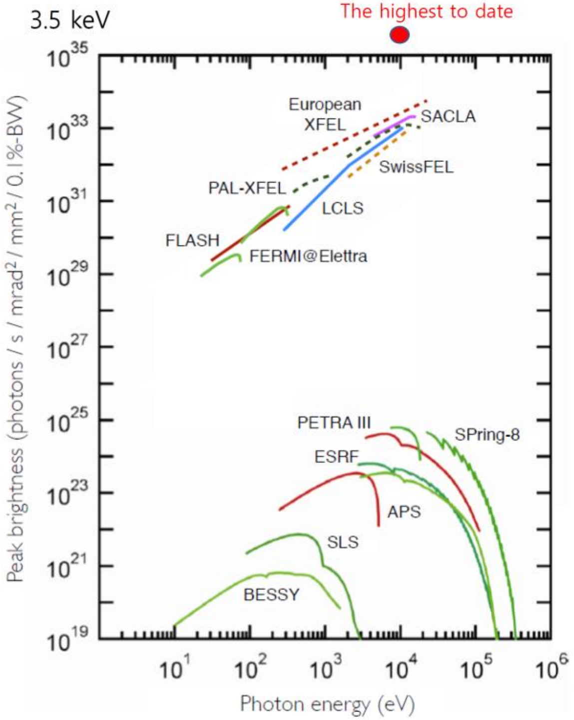
Heung-Sik Kang[1]*, Chang-Ki Min[1], Hoon Heo[1], Changbum Kim[1], Haeryong Yang[1], Gyujin Kim[1], Inhyuk Nam[1], Soung Youl Baek[1], Hyo-Jin Choi[1], Geonyeong Mun[1], Byoung Ryul Park[1], Young Jin Suh[1], Dong Cheol Shin[1], Jinyul Hu[1], Juho Hong[1], Seonghoon Jung[1], Sang-Hee Kim[1], KwangHoon Kim[1], Donghyun Na[1], Soung Soo Park[1], Yong Jung Park[1], Jang-Hui Han[1], Young Gyu Jung[1], Seong Hun Jeong[1], Hong Gi Lee[1], Sangbong Lee[1], Sojeong Lee[1], Woul-Woo Lee[1], Bonggi Oh[1], Hyung Suck Suh[1], Yong Woon Parc[1], Sung-Ju Park[1], Min Ho Kim[1], Nam-Suk Jung[1], Young-Chan Kim[1], Mong-Soo Lee[1], Bong-Ho Lee[1], Chi-Won Sung[1], Ik-Su Mok[1], Jung-Moo Yang[1], Chae-Soon Lee[1], Hocheol Shin[1], Ji Hwa Kim[1], Yongsam Kim[1], Jae Hyuk Lee[1], Sang-Youn Park[1], Jangwoo Kim[1], Jaeku Park[1], Intae Eom[1], Seungyu Rah[1], Sunam Kim[1], Ki Hyun Nam[1], Jaehyun Park[1], Jaehun Park[1], Sangsoo Kim[1], Soonam Kwon[1], Sang Han Park[1], Kyung Sook Kim[1], Hyojung Hyun[1], Seung Nam Kim[1], Seonghan Kim[1], Sun-min Hwang[1], Myong Jin Kim[1], Chae-yong Lim[1], Chung-Jong Yu[1], Bong-Soo Kim[1], Tai-Hee Kang[1], Kwang-Woo Kim[1], Seung-Hwan Kim[1], Hee-Seock Lee[1], Heung-Soo Lee[1], Ki-Hyeon Park[1], Tae-Yeong Koo[1], Dong-Eon Kim[1] and In Soo Ko[2]



High brightness self-seeding based on energy (phase space) stability

Electron energy jitter: 0.012% rms
Photon energy jitter: 0.025% rms





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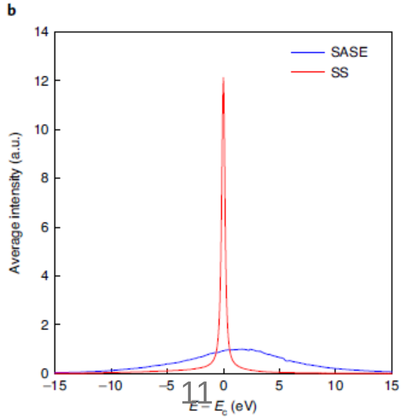
ARTICLES
https://doi.org/10.1038/s41566-021-00777-z
Check for updates

High-brightness self-seeded X-ray free-electron laser covering the 3.5 keV to 14.6 keV range

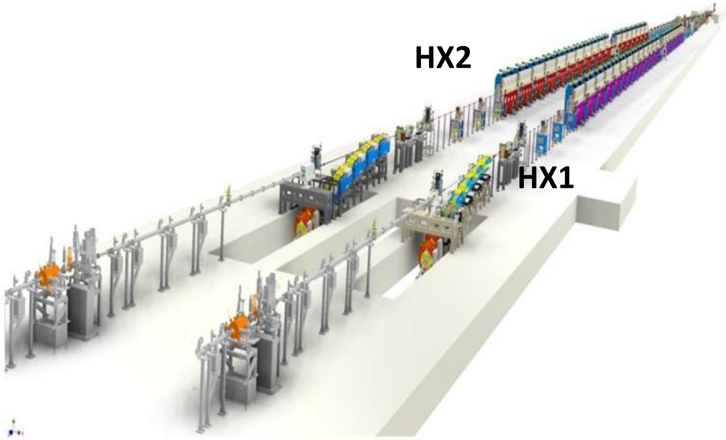
Inhyuk Nam[1,4], Chang-Ki Min[1,4], Bonggi Oh[1,4], Gyujin Kim[1], Donghyun Na[1], Young Jin Suh[1], Haeryong Yang[1], Myung Hoon Cho[1], Changbum Kim[1], Min-Jae Kim[1], Chi Hyun Shim[1], Jun Ho Ko[1], Hoon Heo[1], Jaehyun Park[1], Jangwoo Kim[1], Sehan Park[1], Gisu Park[1], Seonghan Kim[1], Sae Hwan Chun[1], HyoJung Hyun[1], Jae Hyuk Lee[1], Kyung Sook Kim[1], Intae Eom[1], Seungyu Rah[1], Deming Shu[2], Kwang-Je Kim[2], Sergey Terentyev[3], Vladimir Blank[3], Yuri Shvyd'ko[2]✉, Sang Jae Lee[1]✉ and Heung-Sik Kang[1]✉

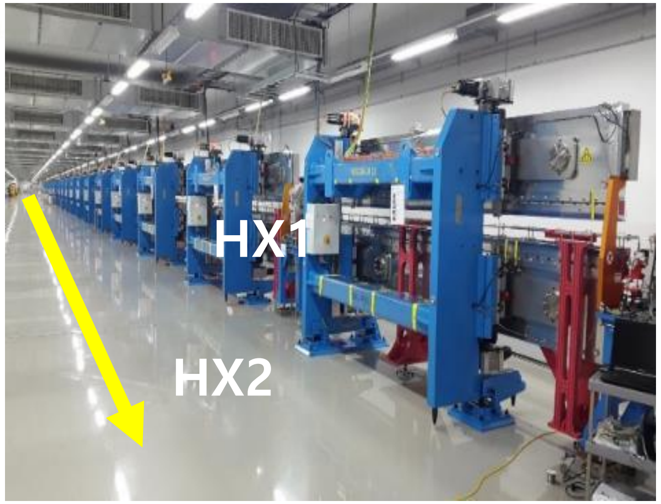


Ongoing Upgrade Project

2nd FEL line of PAL-XFEL (HX2) to meet the increasing demand for user beamtime

- ❖ Funding for the 2nd FEL Line of PAL-XFEL (HX2) starting in 2026
- ❖ Photon energy bandwidth: 1.5 ~ 10 keV
  - Over 3mJ FEL Pulse Energy from 1.5 to 8 keV (Over double HX1)
  - Best performance in stability (Timing jitter, Pointing jitter)
  - 20 undulators and self-seeding
- ❖ Simultaneous operation of 2 FEL lines
- ❖ Construction of 2 Experimental Stations





Resonant kicker for the simultaneous HX/SX operation

- ❖ Two bunches spaced by ~25 ns from the gun are split into the HX and SX lines; both beamlines provide FEL at 60 Hz.
- ❖ A resonant kicker system (~50 MHz, on-crest operation with a 180-degree phase difference), similar to that of SwissFEL, is under design.
- ❖ Preliminary tests for the laser system have been completed.
- ❖ A BPM electronics simulator for two electric pulses has been implemented. Various filters are currently being tested.

KLS at Ochang

한국기초과학지원연구원
KOREA BASIC SCIENCE INSTITUTE

KLS Construction Project Overview

KLS Beamlines

Priority support for Industries

① BioPharma-BioSAXS
② Material Structure Analysis
③ Soft X-ray NanoProbe

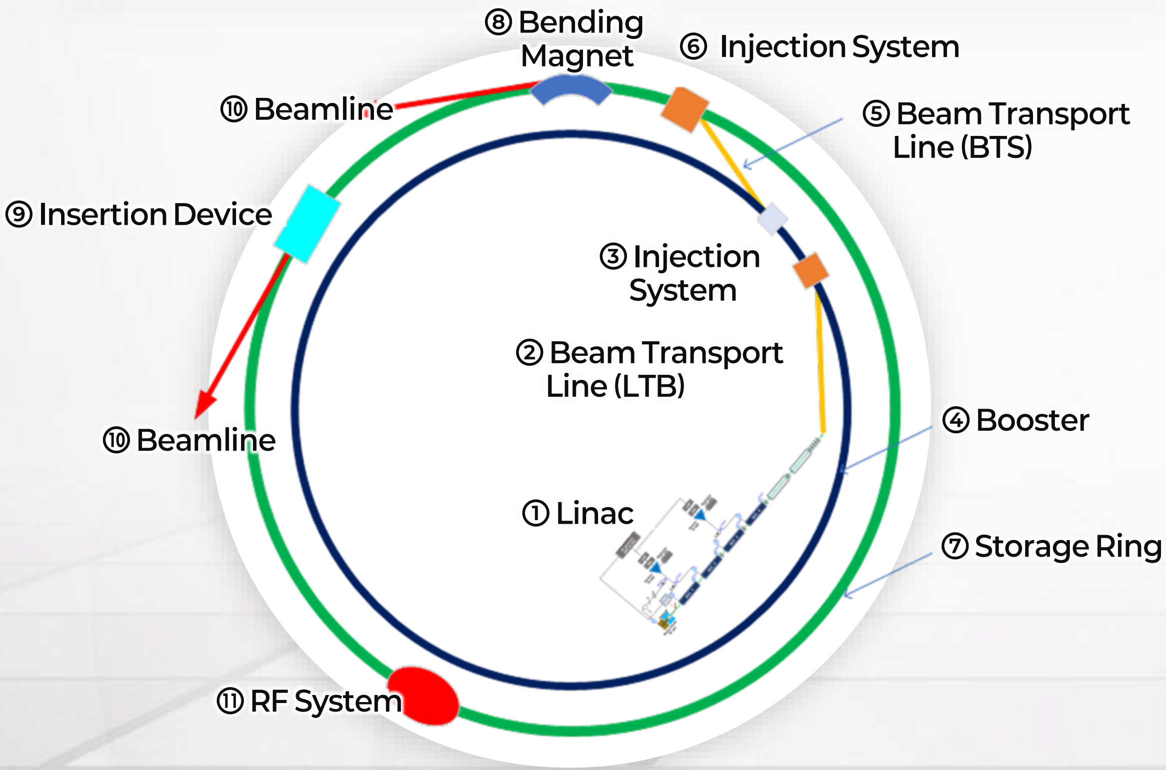
Support for Academic R&D

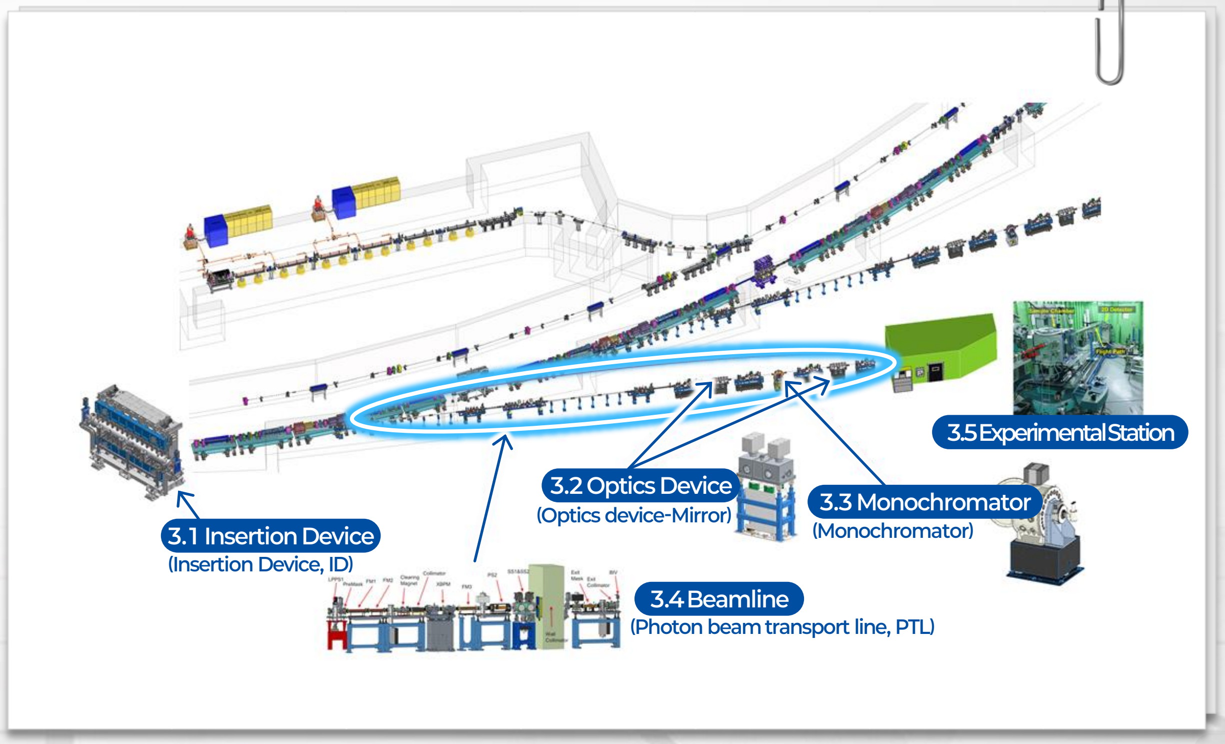
④ Nanoscale Angle-resolved Photoemission Spectroscopy
⑤ Coherent X-ray Diffraction
⑥ Coherent Small-angle X-ray Scattering
⑦ Real-time X-ray Absorption Fine Structure
⑧ Bio Nano crystallography
⑨ High Energy Microscopy
⑩ NanoProbe

Project Period	July 2021 – December 2029 (8.5 years)	**Facility Scale**	Site Area: 540,000 m^2 ※ Including base site of 310,000 m^2 Total Floor Area: 69,525 m^2
Lead Organizations	Ministry of Science and ICT / Chungcheongbuk-do / Cheongju City ※ (Government) Equipment & research facility construction, etc. (Local governments) Land, ancillary facilities, etc.		
Project Cost	Total: KRW 1,164.3 Billion (National) KRW 964.3B / (Local) KRW 200.0B (land acquisition, etc.) Total cost ▲ Managed scope: KRW 1,053.5B ▲ Outside managed scope: KRW 110.8B		
Location	Ochang-eup, Cheongju-si, Chungcheongbuk-do (within Ochang Techno-Polis Industrial Complex)		
Design Specifications	**Electron Beam Energy:** 4 GeV (Storage ring circumference: approx. 800 m) **Beam Emittance:** ≤ 100 pm·rad (Design target: 58 pm·rad) **Beamlines:** 40+ (Insertion device beamlines: 24) **Acceleration method:** Electron gun → Injector LINAC → 4 GeV Booster **Lattice:** MBA-based 7BA electron optics array		

System Configuration of KLS

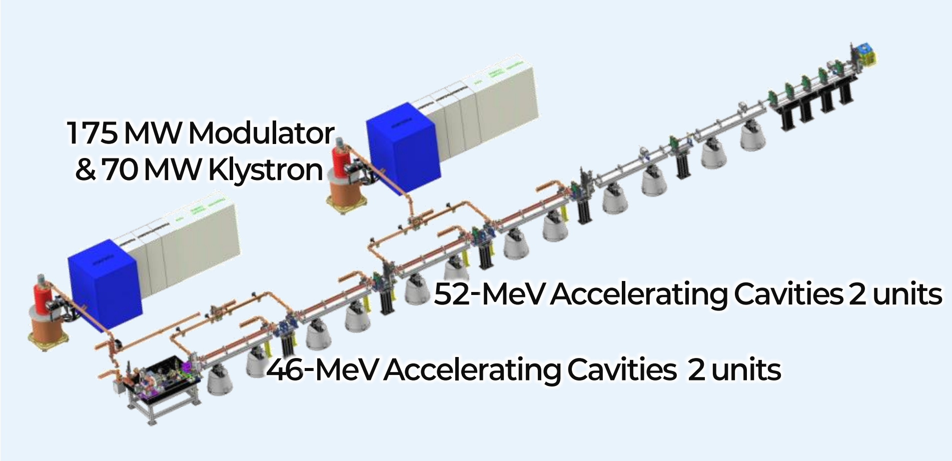
Linear Accelerator	Booster Ring	Storage Ring	Beamline
Electron beam generation & acceleration (4 MeV → 200 MeV)	Electron beam energy acceleration (200 MeV → 4 GeV)	Electron beam storage & photon beam generation	**Photon beam transport, focusing, selection & experiments**

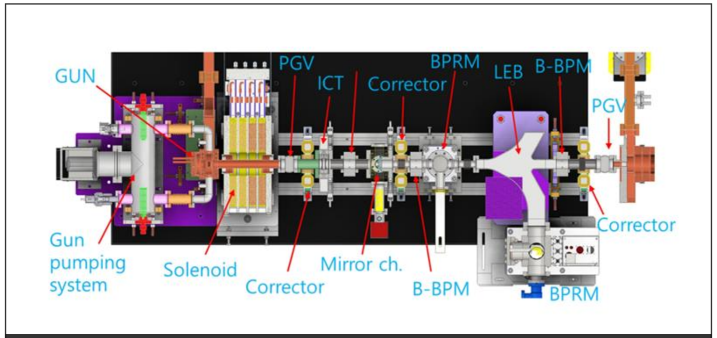




System Develop

Photocathode-driven injector linac design for Korea-4GSR (TU1A004)
By Dr. Chang-ki Min





Injector with Photocathode Electron Gun

70 MW Klystron

Electron Gun

Parameters	Multi-bunch	Single-bunch
Beam Energy	4 MeV	4 MeV
Charge	1～3 nC	0.01～1 nC
Pulse Length	128 ns (64 pulses)	≤20 ps
Repetition Rate	2 Hz	2 Hz

Linear Accelerator

Parameters	Multi-bunch	Single-bunch
Beam Energy	200 MeV	200 MeV
Frequency	2997.56 ± 0.1 MHz	2997.56 ± 0.1 MHz
Emittance (at 200 MeV)	≤ 10 nm	≤ 10 nm
Relative Energy Spread (rms)	≤ 0.3%	≤ 0.3%
Pulse-to-Pulse Energy Jitter (rms)	≤ 0.2%	≤ 0.2%
Bunch Charge (Charge Stability)	1 to 3 nC (5%)	0.01 to 1 nC (2%)
Pulse Duration	≈ 128 ns (64 bunches)	6–8 ps FWHM
Repetition Rate	2 Hz	2 Hz

Future Plan (Draft)

'24. Design Completion → '26. Start of Main Construction → '29. Project Completion

Accelerator System & Beamlines

'24.04.	Completion of Final Design
'24.10.	Adjustment of Total Project Budget
'24.H2	Manufacturing of Equipment
'26.~'28.	Delivery and Test of Equipment
~'29.	Installation of Equipment
'29.~	Commissioning

Infrastructure

'22.09.	Selection of Design Company & Start of Design
'23.09.	Completion of Intermediate Design
'24.11.	Completion of Final Design
'26.05.	Groundbreaking
'29.	Completion of Facility Construction

Site Development

'24.H2	Site Preparation for Accelerator Bldg. Construction
'26.04.	Land Provision Agreement

※ Agreement Parties:
Chungcheongbuk-do & Cheongju City <-> KBSI

Power Supply Infrastructure (Power Grid Connection)

'24.H1	Detailed Design Service
'25.06.	Start of Construction
'27.	Completion of Construction

RAON at Daejeon

ibS 기초과학연구원 Institute for Basic Science

RAON Rare isotope Accelerator complex for On-line experiments

RAON

Accelerator complex
ISOL + In-Flight Fragmentation

Origin of Matter

- Nuclear Astrophysics
- Nuclear Matter
- Super Heavy Element Search
- High-precision Mass Measurement

Properties of Exotic Nuclei

- Nuclear Structure
- Electric Dipole Moment and Symmetry
- Hyperfine Structure Study

Applied Sciences

- Bio-Medical Sciences
- Material Sciences
- Neutron Science

Goal

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

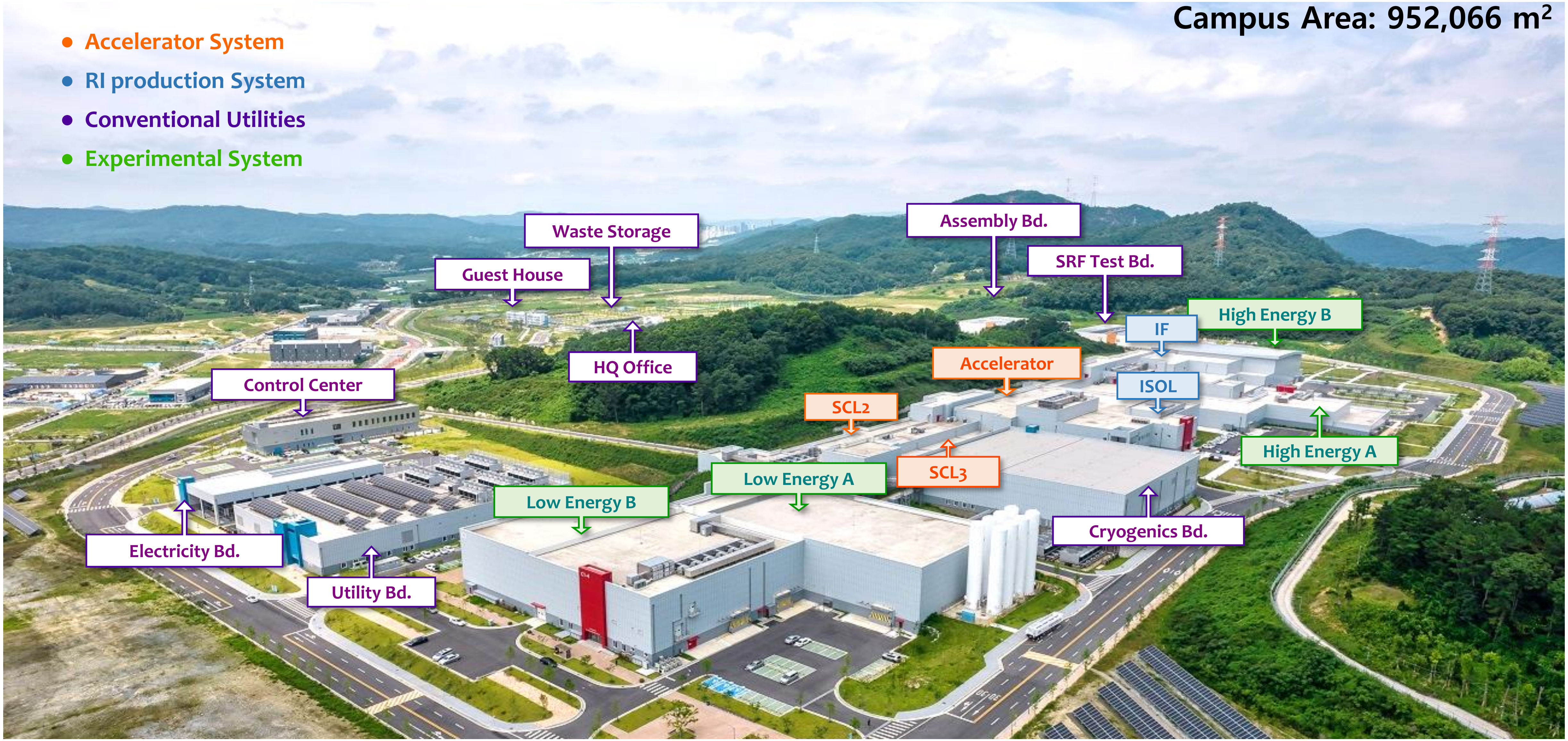
Status

Rare Isotope Science Project (RISP) : Dec. 2011 – Dec. 2022

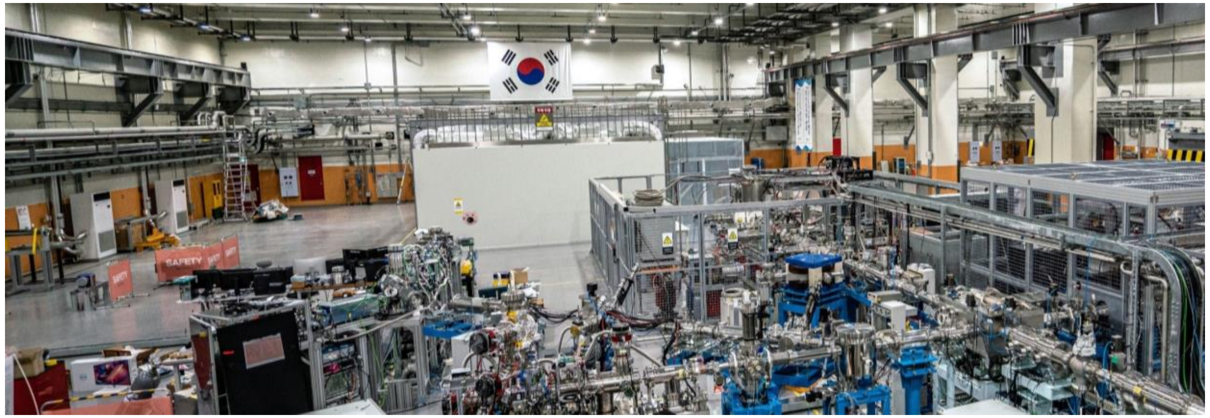
RISP is changed to "IRIS" as of July 1, 2022. (From project to operation)

R&D for high-energy linac (SCL2) : Dec. 2022 – Dec. 2027

RAON Rare Isotope Accelerator Complex

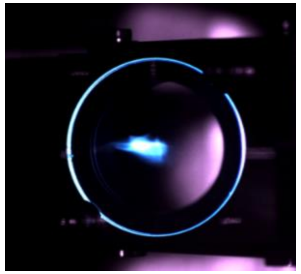


Brief History of RAON : RISP to IRIS









2011 2015 2019 2023 2026

- ‘10.02 Preliminary Design Study
- ‘11.02 Conceptual Design Study
- ‘11.11 IBS Established
- ‘11.12 Rare Isotope Science Project (RISP)
- ‘14.02 Purchasing the Land (RAON Site)
- ‘17.02 Civil Construction started

- ’19.04 RISP moved on RAON site
- ‘19.09 Installation Started
- ’20.09 QWR CM Installation
- ’21.12 HWR CM Installation
- ’22.07 Institute for Rare Isotope Science
- ’22.08 SCL3 Cryoplant commissioning
- ’22.12 1^{st} Phase Completed

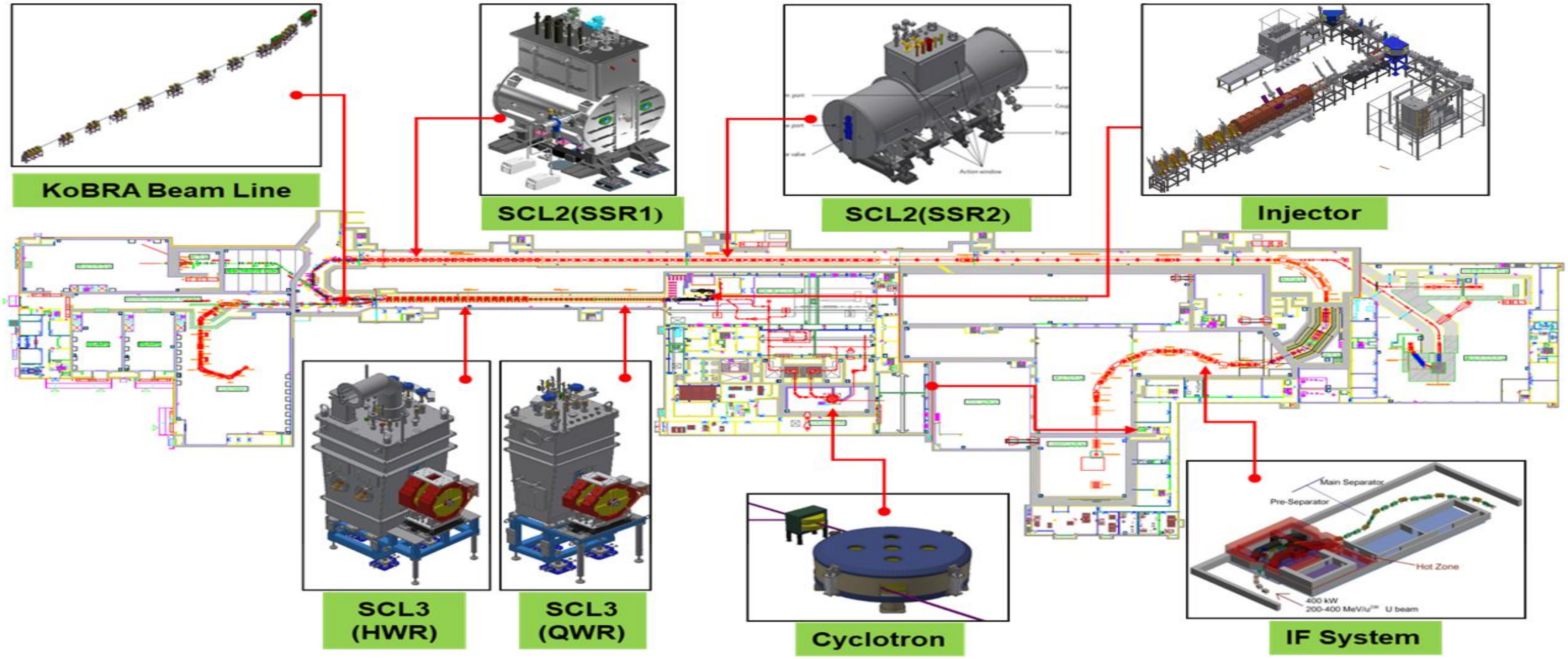
- ’23.03 1^{st} ISOL RIB Production
- ’23.05 SCL3 Beam commissioning
- ‘23.12 1^{st} Call for Proposals
- ‘24.03 1^{st} PAC meeting
- ‘24.07 User Beam Experiments started
- ‘25.01 2^{nd} Call for Proposals
- ‘25.05 2^{nd} PAC meeting
- ‘25.09 3^{rd} Call for Proposals
- ‘26.01 3^{rd} PAC meeting

RAON Accelerators

Injector | SC Linac | IF

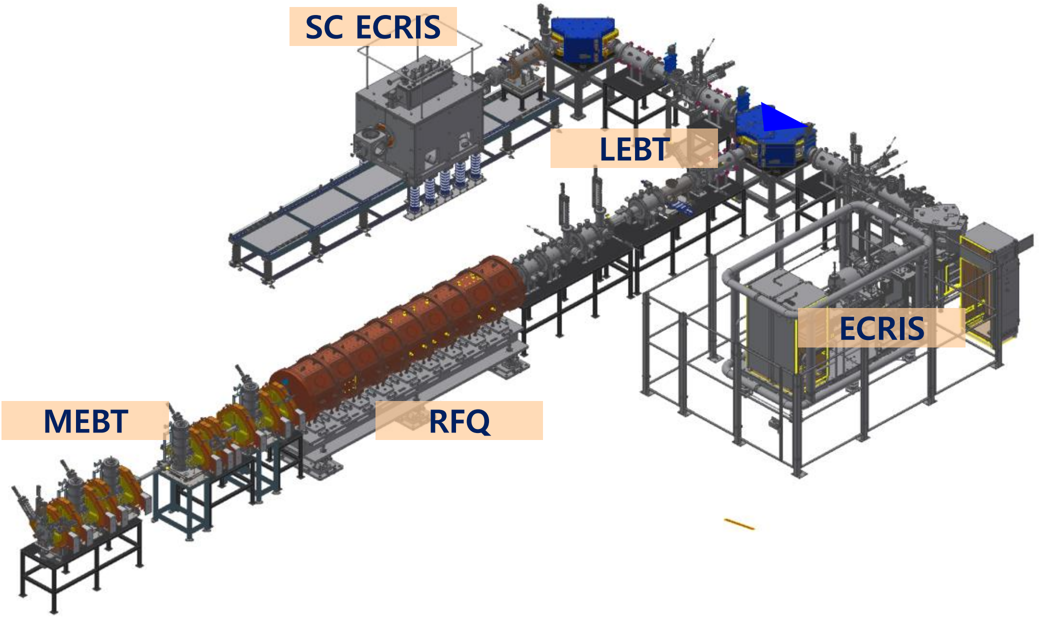
SCL3 | SCL2

0.5 MeV/u					18 MeV/u				200 MeV/u	
ISOL/ECR	LEBT	RFQ	MEBT	SCL3-1	SCL3-2	CSS	SCL2-1	SCL2-2	HEBT	IF
				β=0.047	β=0.12		β=0.32	β=0.51		



Injector System

- **Two ECR-IS on high voltage platforms**
  - 14.5 GHz ECR ion source
  - 28 GHz superconducting ECR ion source
- **LEBT (E = 10 keV/u)**
  - 10 keV/u, Dual bending magnet
  - Chopper & Electrostatic quads, Beam instrumentation
- **RFQ (E = 500 keV/u)**
  - 81.25 MHz, Transmission Eff. ~98%
  - CW RF Power 94 kW (SSPA: 150 kW)
- **MEBT (E = 500 keV/u)**
  - Four RF bunchers (SSPA: 20, 15, 2×4 kW)
  - Eleven quadrupole magnets, Beam instrumentation



- Installation completed and beam commissioning from October, 2020

Superconducting Linear Accelerator

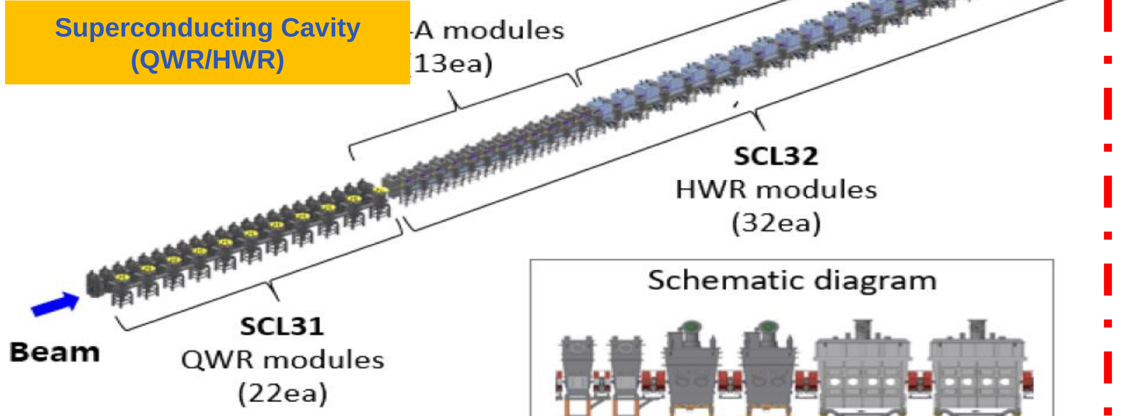
Injector				SC Linac					IF	
				SCL3		SCL2				
			0.5 MeV/u			18 MeV/u			200 MeV/u	
ECR	LEBT	RFQ	MEBT	SCL31	SCL32	CSS	SCL21	SCL22	HEBT	IF

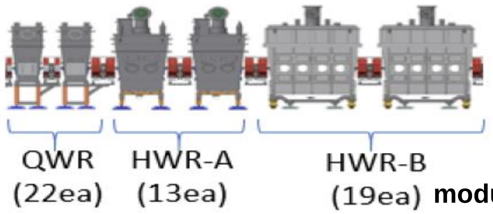
ISOL → LEBT

2nd Phase

Superconducting Linac 3(Low-energy section)

Superconducting Cavity (QWR/HWR)





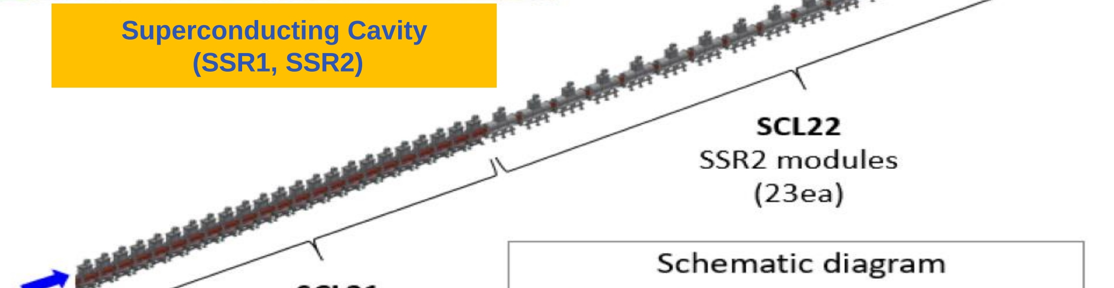
modules

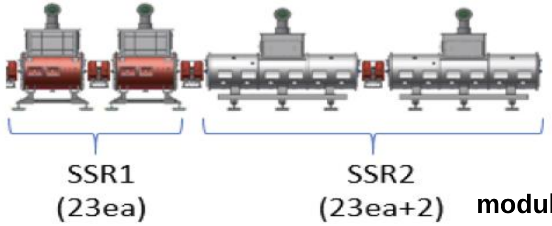
22 26 76

Total (124 cavities)

Superconducting Linac 2(High-energy section)

Superconducting Cavity (SSR1, SSR2)



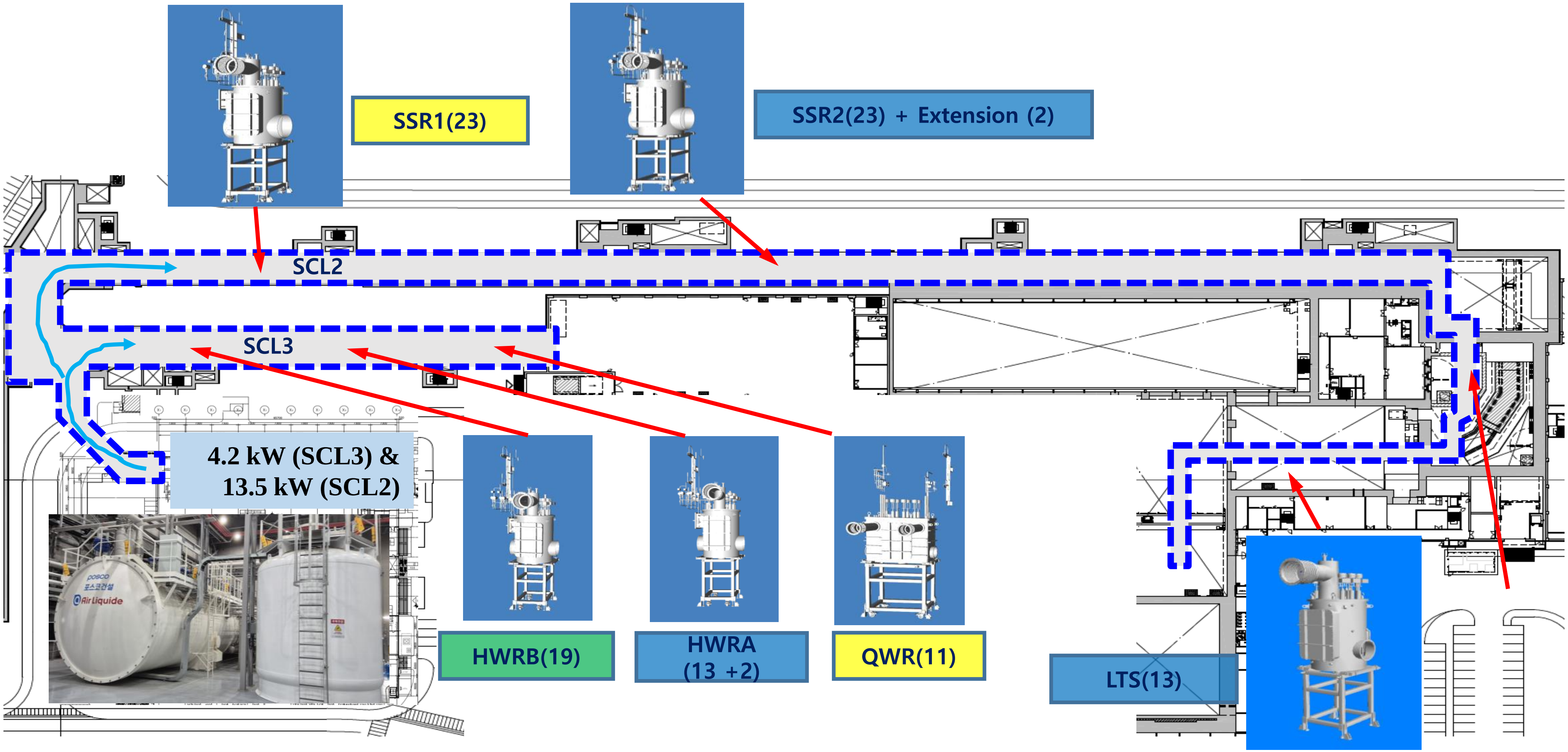


modules

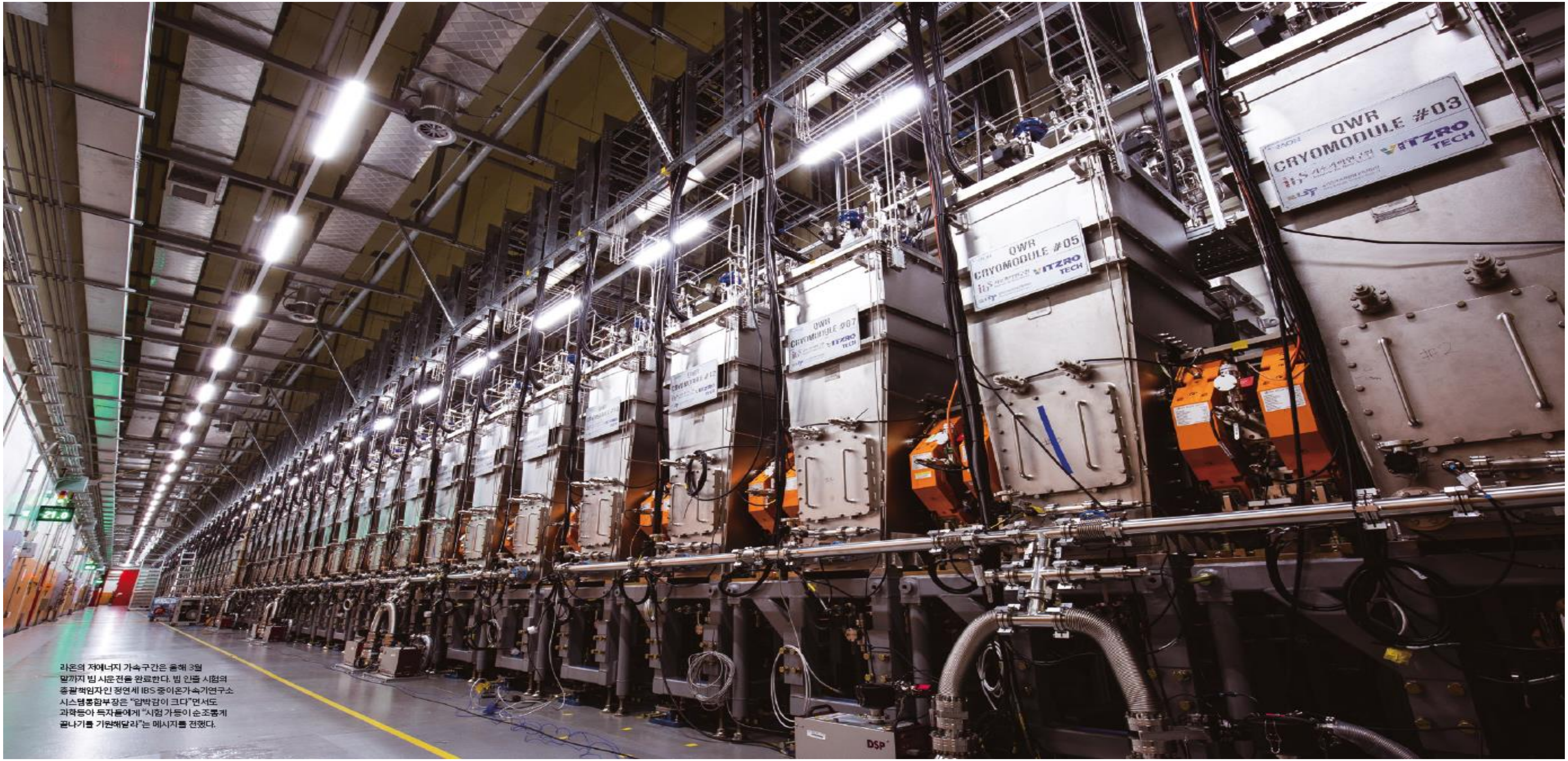
69 138+12

Total (219 cavities)

Layout of Cryogenic Distribution Systems



Superconducting linear accelerator (SCL3) in the tunnel

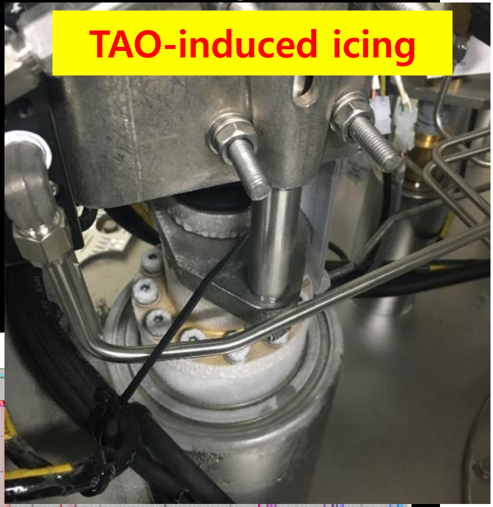


1st Cool-down of SCL3 in 2022.9-2023

2022 2023

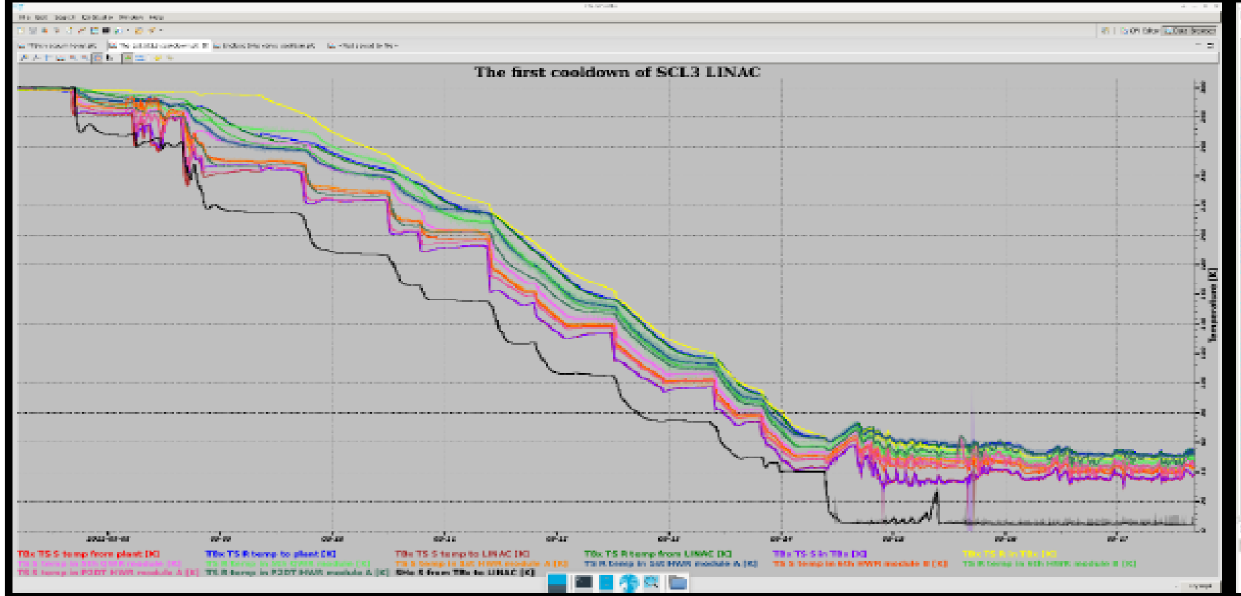
- Sep. 7th – Oct. 26th
  Cooldown under 4.5 K
- Sep. 21th – Oct. 7th
  Beam commissioning (6 QWR)
- Nov. 24th – Jan. 11th
  1st cooldown under 2 K
- Nov. 4th – Dec. 16th
  Beam commissioning (22 QWR)
- Feb. 21st – 24th
  2nd Cooldown under 2 K
- Feb. 27th – Jun. 7th
  Beam commissioning (SCL3)
- Apr. 21st
  3rd Cooldown under 2 K
- Jun. 8th – 31st
  Warmup

TAO-induced icing



◈ Cooling strategies

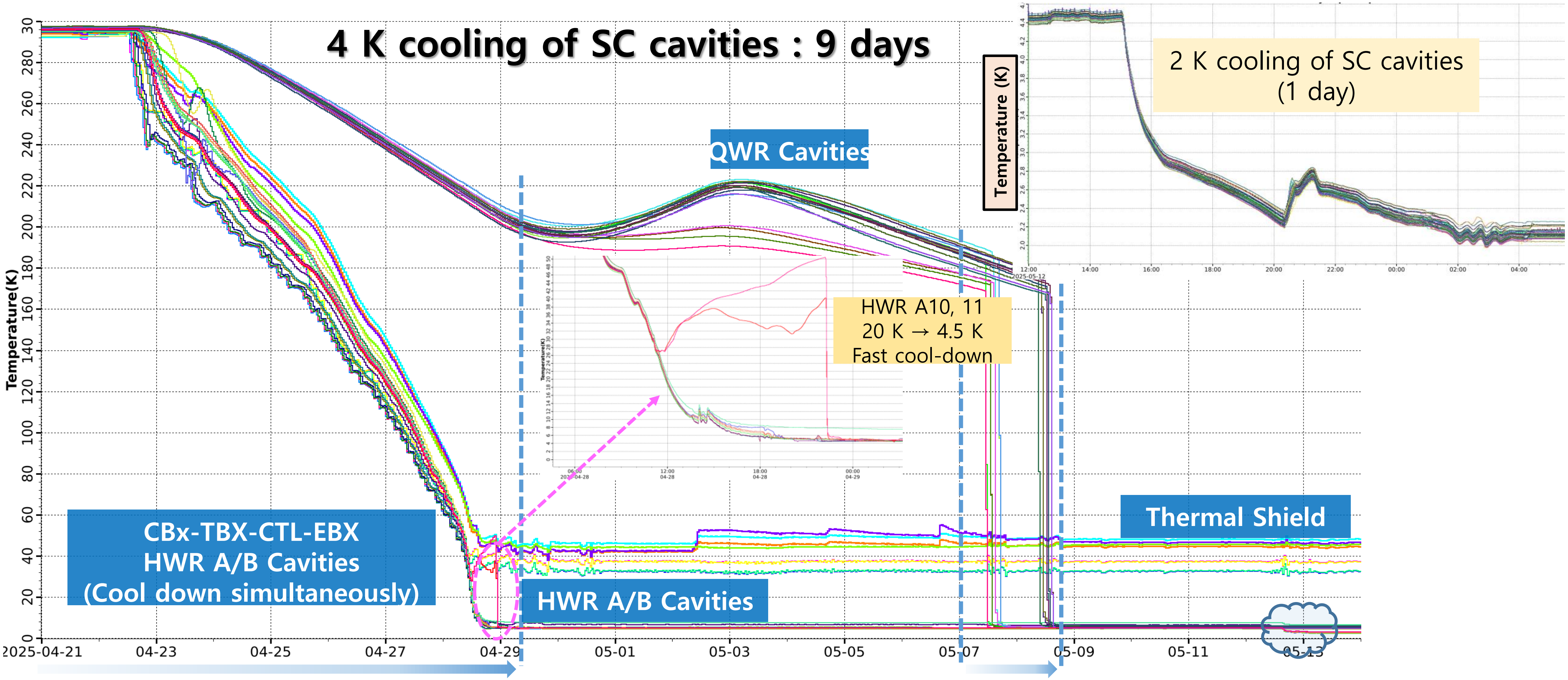
- **Step 1 : Step Cool-down(20K~50K) controlled by Turbine 1 → "SCL3 CBx + HDS(TBX / CTL / EBx)+THS(HDS/CM)"**
- **Step 2 : QWR/HWR fast cool-down(150K ~ 50K / one by one)**



Cooldown from 300 K to 4.5 K

Cooldown from 4.5 K to 2.05 K

Cool-down (3rd) of SCL3 in 2025

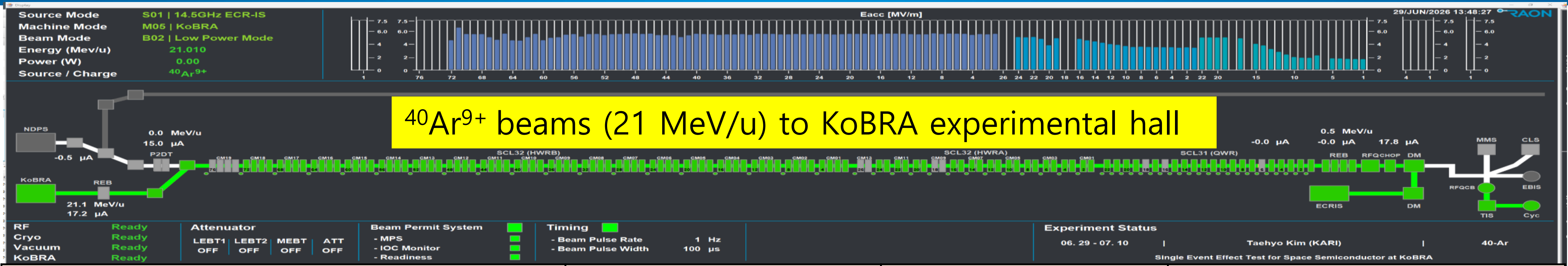


CBx-TBx-CTL-EBx and HWR A/B 4.5K Cool-down
Thermal Shield 40 K Cool-down(7 days)

QWR 4.5K
Cool-down(2 days)

HWR A/B 2K
Cool-down(1 day)

SCL3 SI Beam Commissioning (2024~2026)



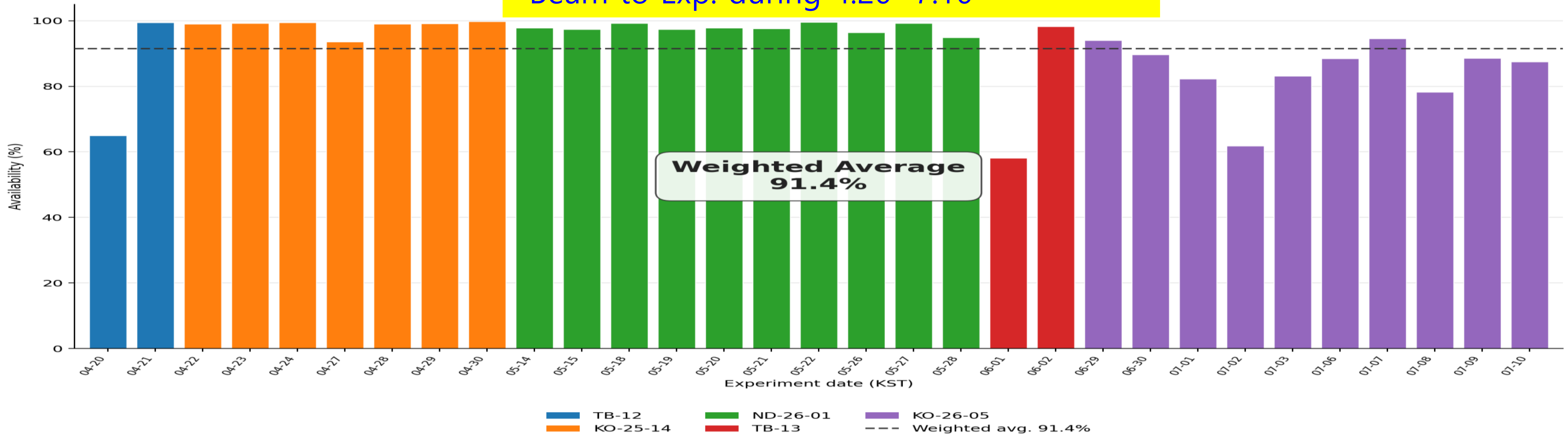
	2024	2025	2026
Particle	$^{40}Ar^{8+}$	$^{40}Ar^{8+}$	$^{22}Ne^{6+}$, $^{40}Ar^{8+\ \&\ 9+}$
Current (MEBT, μA)	42.4	46	3, 46, 20
QWR Field(MV/m)	5.0	5.0	5.0
HWR-A Field (MV/m)	5.0	5.0	5.0
HWR-B Field (MV/m)	(<±1%, <±1°)	5.5	5.5
QWR (Unused cavities)	19 (3, 12, 21)	19 (6, 16, 18)	19 (6, 16, 18)*
HWRA (Unused cavities)	24 (6, 8)	21 (6, 17&18, 25&26)	22 (17&18, 25&26)**
HWRB (Unused cavities)	71 (24, 28, 61)	72 (2, 37)	68
SCL3 energy (MeV/u)	16.4	~19.2	~24.5 MeV/u(22Ne6+, A/q=3.7), ~21 MeV/u(40Ar9+, A/q=4.4)
Transmission(SCL3)	91~93%	~91%	~93%

* Unable to tune cavity to resonance frequency(81.25 MHz) due to tuner failure

** 2 HWR CMs with the upgraded couplers and tuners are under evaluation at the SRF test facility.

SCL3 Beam Operation in 2026

Total beam delivery time = 226 hours
*Beam to Exp. during 4.20~7.10



- ❖ Total available beam time in 2026: ~ 1,000 hours planned
- ❖ Accelerator Beam Availability: ~98 % during regular experiments (KO-. ND-)
- ➢ No major downtime in key accelerator components (Injector, SCL3)
- ➢ Lower Beam Availability due to users requested beam stops
- ❖ Cryogenic system recovery took ~3 days after a brief power glitch (0.2s, June 8)
- ❖ Demonstrated 24Na5+, 22Na6+ (RI) beam acceleration/delivery based on the Ar, Ne (SI) beam commissioning

SCL2 R&D project (2022.12~2027.12)

- **Purpose:** Develop and validate key enabling technologies for SCL2 prior to mass production.
- **Scope:**

1) Fabrication of prototype CM for both SSR1 and SSR2 of SCL2 (one unit each)
2) Demonstration of Phase-1 prototype CM's performance
3) SRF technology development and operation
4) Project management and coordination

Cavity Type	Manufacturer	Vertical Test(VT)	Horizontal Test(HT)
β=0.32 SSR1	VitzroNextech	**Ongoing**	**By 2027**
β=0.51 SSR2	IHEP(China)	**Old) under surface treatment** **New) kick-off fabrication**	**Old) by 2026** **New) by 2027**

◆ **(SSR1 Balloon-type)** Design and engineering are led by IRIS, while the manufacturing process development is carried out by a domestic company ('24.1, VITZRO Tech)

- Jacket material of SSR1 cavity has been changed from STS (prototype #1) to Titanium (prototype #2)

➢ **β = 0.29 HWR considered as an alternative due to SSR1 fabrication complexity.**

◆ **(SSR2 Cylinder-type)** Considering the high technical complexity, we maximally utilize the use of external resources (KAT & IHEP) from engineering design to manufacturing

Summary and Outlook

- **KOMAC** - Reliable 100 MeV proton linac operation; **200 MeV upgrade** under consideration
- **PAL-XFEL** - Stable 10.5 GeV XFEL operation; **HX2 and multi-FEL operation** in progress
- **KLS** - New 4 GeV light source under construction; **commissioning planned from 2029**
- **RAON** - SCL3 in user operation with high availability; **SCL2 technology R&D ongoing**

Korea continues to advance through reliable user operation, facility upgrades, new construction, and next-generation accelerator technologies.

Acknowledgment: Special thanks to KOMAC, PAL-XFEL, and KLS for providing materials for this presentation.