Overview of Accelerators in Korea

October 23, 2023

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Pohang Accelerator Laboratory

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- PAL-XFEL
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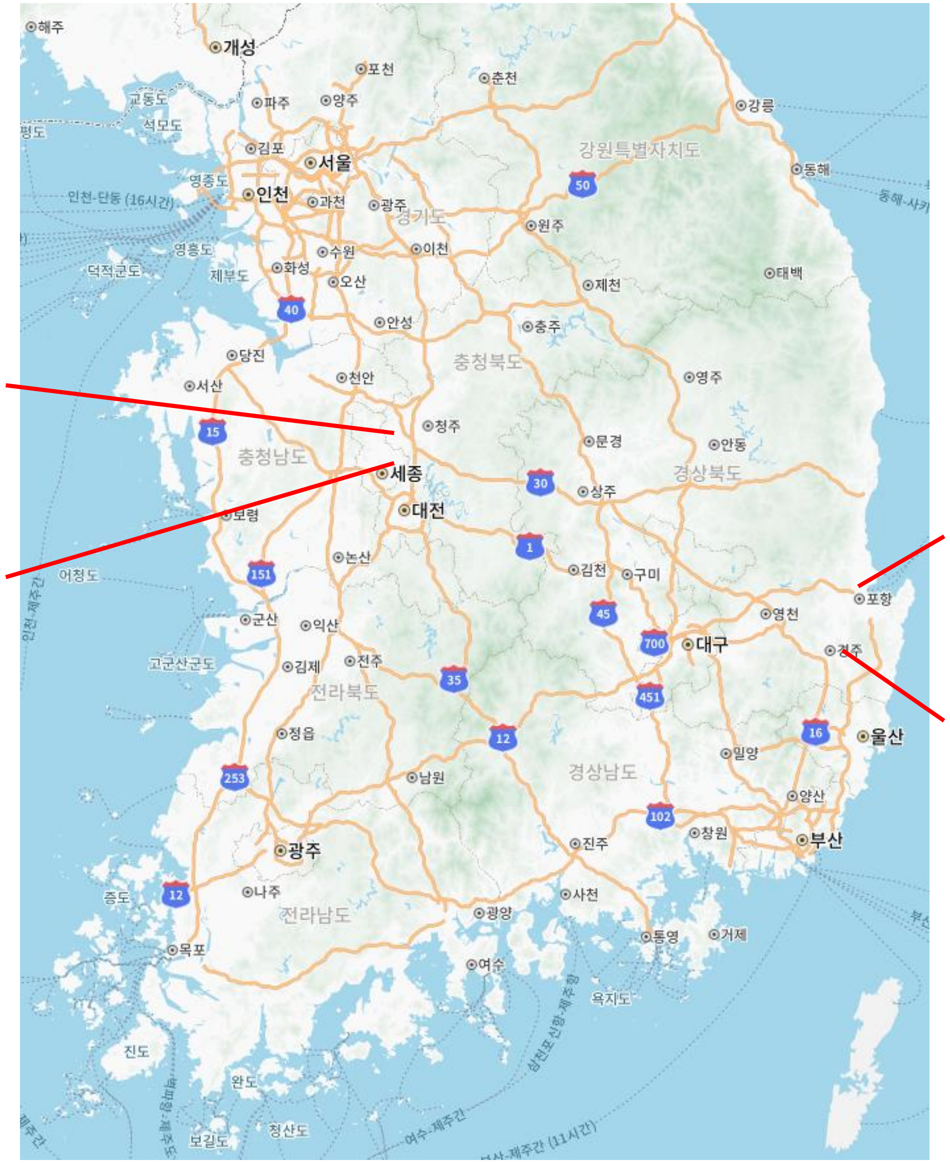
4GSR

RAON



PLS-II
PAL-XFEL

KOMAC

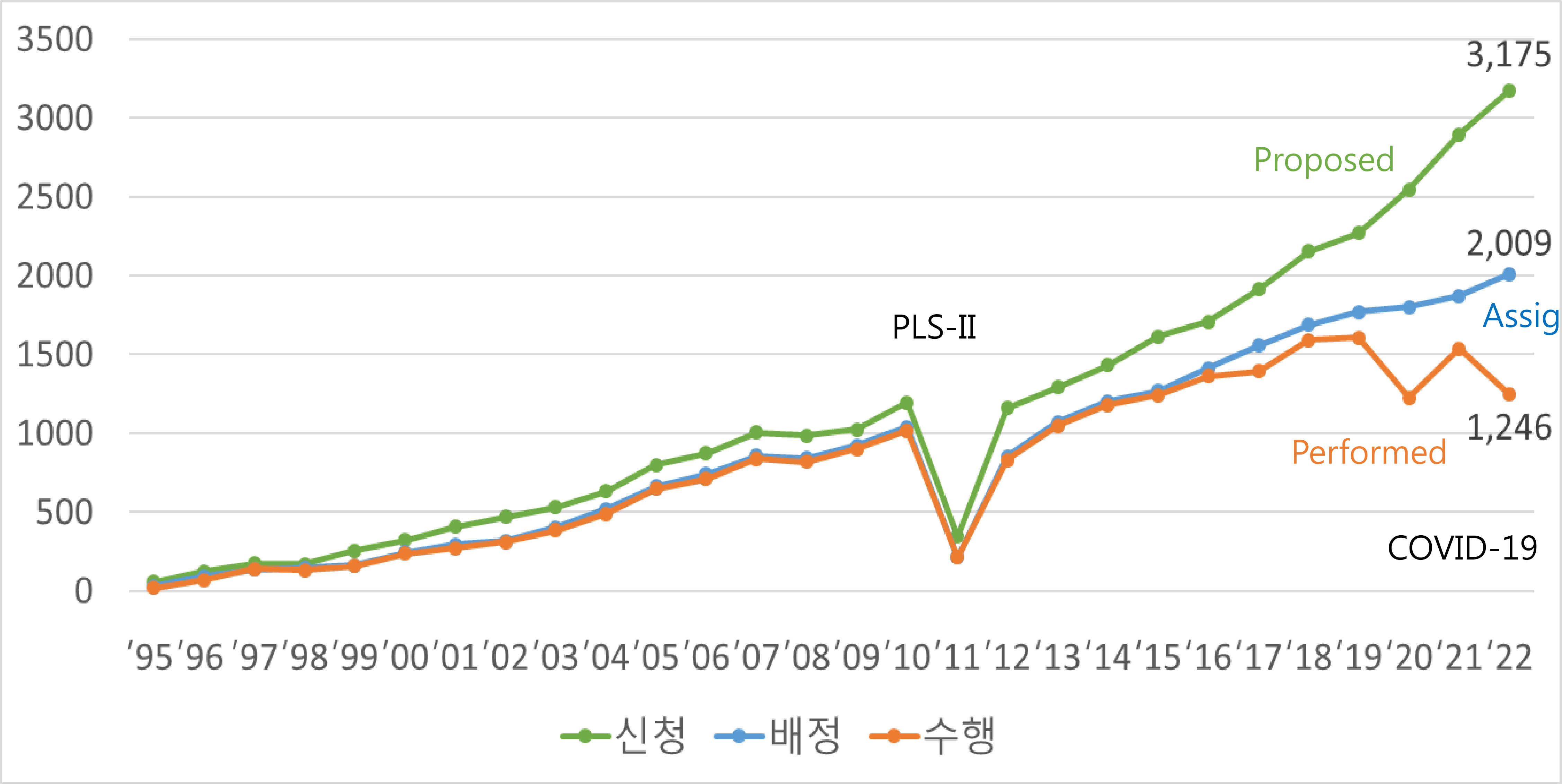
PLS-II & PAL-XFEL

Pohang Accelerator Laboratory

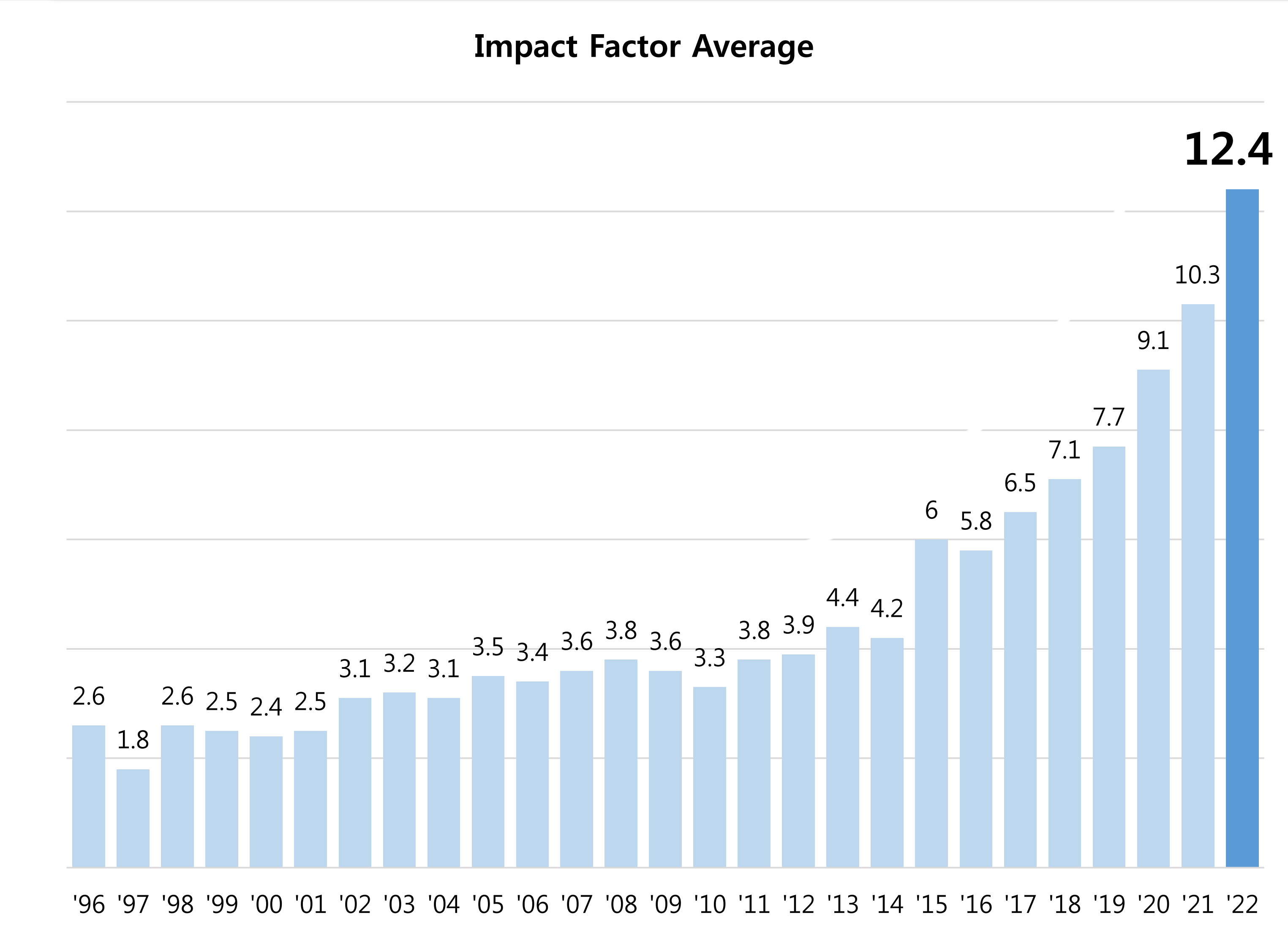
History of Pohang Accelerator Laboratory

- 1986: Pohang Light Source (PLS) project firstly proposed by Dr. Hogil Kim (the 1st president of POSTECH)
- 1988: Foundation of PAL (Supported by Mr. Taejoon Park) and initiation of PLS construction
- 1994: Completion of PLS construction
- 1995: Starting of user service operation with 2 Beamlines
- 2009: Upgrade of PLS (PLS-II) was started
- 2011: Construction of Hard X-ray Free Electron Laser (PAL-XFEL) was started

Quantity of Beamline Experiments



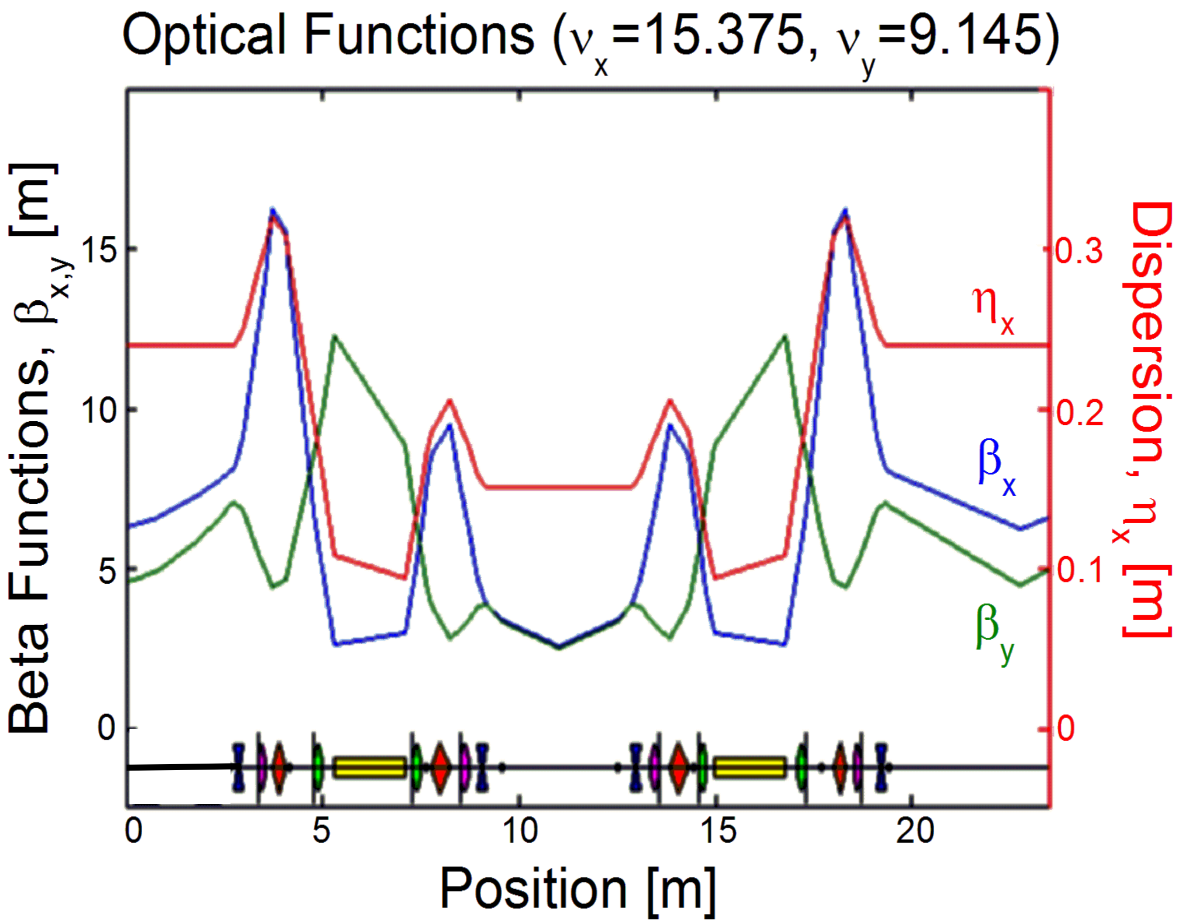
Quality of Beamline Experiments



Journal	Impact Factor
Nature	69.5
Nature Energy	67.4
Cell	66.9
Science	63.7
Nature Materials	47.7
Joule	46.0
Nature Nanotechnology	40.5
Nature Photonics	39.7
Energy & Environment Science	39.7
Advanced Materials	32.1
Applied Catalysis B – Environmental	24.3
Nature Physics	19.7
Nature Communications	17.7
Science Advances	15.0
Nano Letters	12.3

*** Average of SCIE journal Impact Factors for national R&D projects : 3.9**

Parameters of PLS-II



Parameter	Value
Circumference	281.82 m
Super-period	12
Energy	3 GeV
Beam current	250 ~ 400 mA
Emittance	5.8 nmrad
Emittance coupling	< 1 %
Energy spread	0.1 %
Momentum compaction	0.0013
Bunch length	16 ps
Tune (H/V)	15.375 / 9.145
Chromaticity (H/V)	3 / 3

36 Beamlines of PLS-II

8C_Nanoprobe X-ray Absorption Fine Structure (Nano XAFS)

8D_X-ray Scattering_POSCO (XRS_POSCO)

9A_Ultra-Small Angle X-ray Scattering (U-SAXS)

9B_High Resolution Powder Diffraction (HRPD)

9C_Coherent X-ray Scattering (CXS)

9D_X-ray Nano-Micro Machining (XNMM)

10A1_Soft X-ray Nanoscopy (SXN)

10A2_High-Resolution Photoemission Spectroscopy (HR-PES II)

10C_Wide Energy X-ray Absorption Fine Structure (Wide XAFS)

10D_High-Resolution Photoemission Spectroscopy I / X-ray Absorption Fine Structure_KIST (HR-PES I/XAS_KIST)

11C_Micro-Macromolecular Crystallography (μ-MX)

12D_Infrared Spectroscopy (IRS)

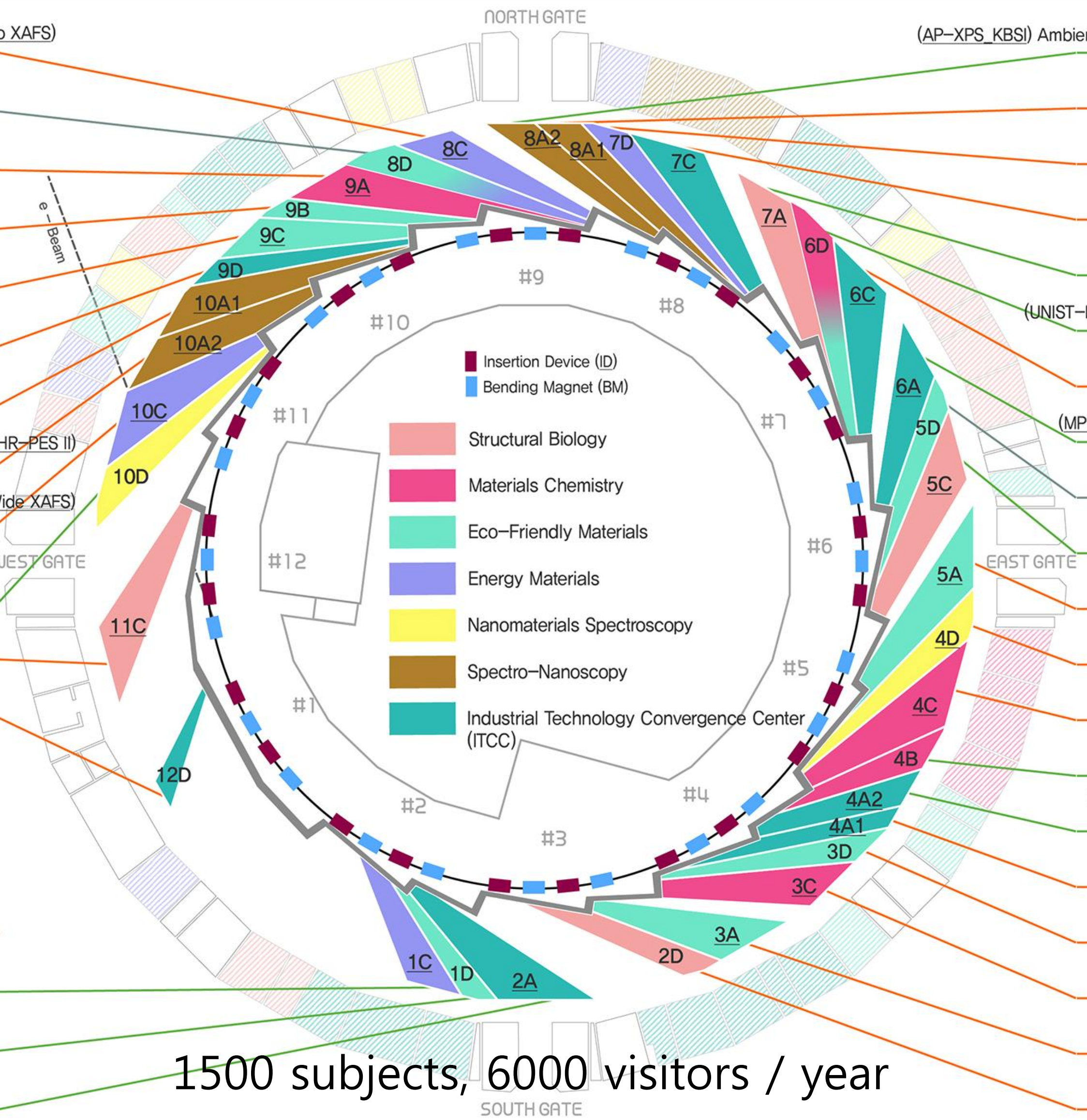
- Public Beamline
- Exclusive Beamline
- Agreement Beamline

fs-THz_Technical Building II (fs-THz)

1C_Time-resolved X-ray Scattering (TR-XRS)

1D_X-ray scattering KIST-PAL (XRS_KIST)

2A_Magnetic Spectroscopy (MS_MPK)



(AP-XPS_KBSI) Ambient Pressure X-ray Photoemission Spectroscopy_8A2

(SPEM) Scanning Photoelectron Microscopy_8A1

(XAFS) X-ray Absorption Fine Structure_7D

(XNI) X-ray Nano Imaging_7C

(SB I_KRIBB) Structural Biology I_7A

(UNIST-PAL C&S) Crystallography and Scattering_UNIST_6D

(BMI) BioMedical Imaging_6C

(MPK) Middle energy Soft X-ray Spectroscopy_MPK_6A

(XRS_GIST) X-ray Scattering_GIST_5D

(SB II_KRIBB) Structural Biology II_5C

(MS-XRS) Material Science XRS_5A

(PES) Photoemission Spectroscopy_4D

(SAXS II) Small Angle X-ray Scattering II_4C

(XMD_GIST) X-ray Microdiffraction_4B

Spin- and Angle-Resolved Photoemission_IBS_4A2 (SARPES_IBS)

(μ-ARPES) μ-Angle Resolved PES_4A1

(XRS) X-ray Scattering_3D

(SAXS I) Small Angle X-ray Scattering I_3C

(MP-XRS) Materials Physics X-ray Scattering_3A

(SMC) Supramolecular Crystallography_2D

1500 subjects, 6000 visitors / year

Operation Requirements

❖ **User Service of 190 days**

❖ **Beam Availability > 97%**

- Maintenance of linac and storage ring

❖ **3 GeV Top-Up Operation**

- Stable operation of linac klystrons

❖ **250 ~ 400 mA Beam Current**

- Stable operation of three cryomodules

❖ **Electron Beam Stability < 1 μm rms**

- Operation of slow orbit feedback

❖ **Photon Beam Stability < 2 μm rms**

- Operation of photon position feedback by using PBPM

❖ **Electron Beam Stability during ID gap change < 6 μm rms**

- Operation of fast orbit feedback

❖ **Single Bunch Current in Hybrid Mode: 5 mA**

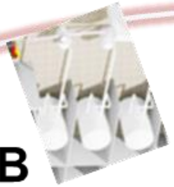
- Operation of transverse feedback system

Measures for Beam Stability of PLS-II

Electron beam

ID

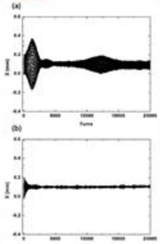
ID Cor.



RF FB
Corrector average measurements
RF freq control
0.05 Hz

IDFF
ID gap measurements
ID corrector control

Tune FB
Tune measurements
Main Quad 1,2 control
0.05 Hz



TFS
BPM 250 MS/s
Strip-line kicker control
500 MHz

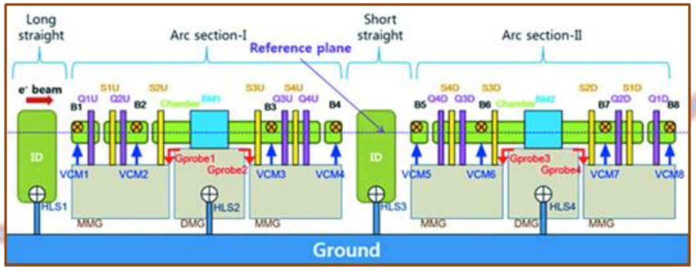
Fast Counter Kicker
Counteracts injection oscillation

BPM

ID or BM

BPM

1 Cell lattice



Mechanical alignments
- Few times per year

PBPM FB
PBPM SA (10Hz)
manipulate BPM offsets
~1 Hz

PBPM

SOFB
96 BPMs SA (10 Hz)
96 Correctors control
2 Hz

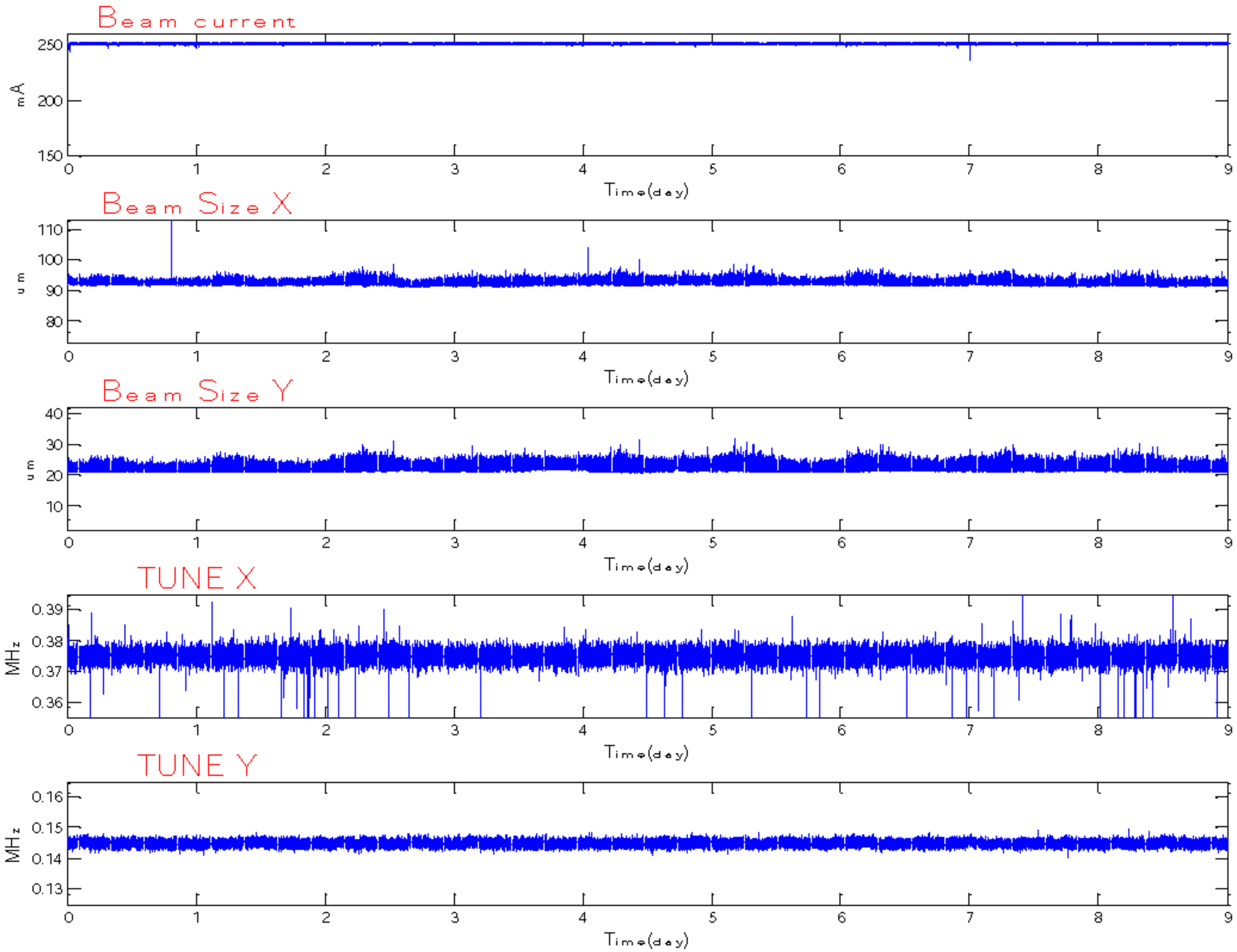
FOFB
96 BPMs FA (10 kHz)
48 Fast Correctors control
833 Hz

Photon beam

Operation Result

❖ Operation Parameter

- Beam current: 250 mA
- Top-up mode injection
- Injection period: 3 minutes
- Horizontal beam size: 90 μm
- Vertical beam size: 25 μm
- Vertical fractional tune: 0.375
- Vertical fractional tune: 0.145



10 days operation result (2023. 4. 26 ~ 2023. 5. 4)

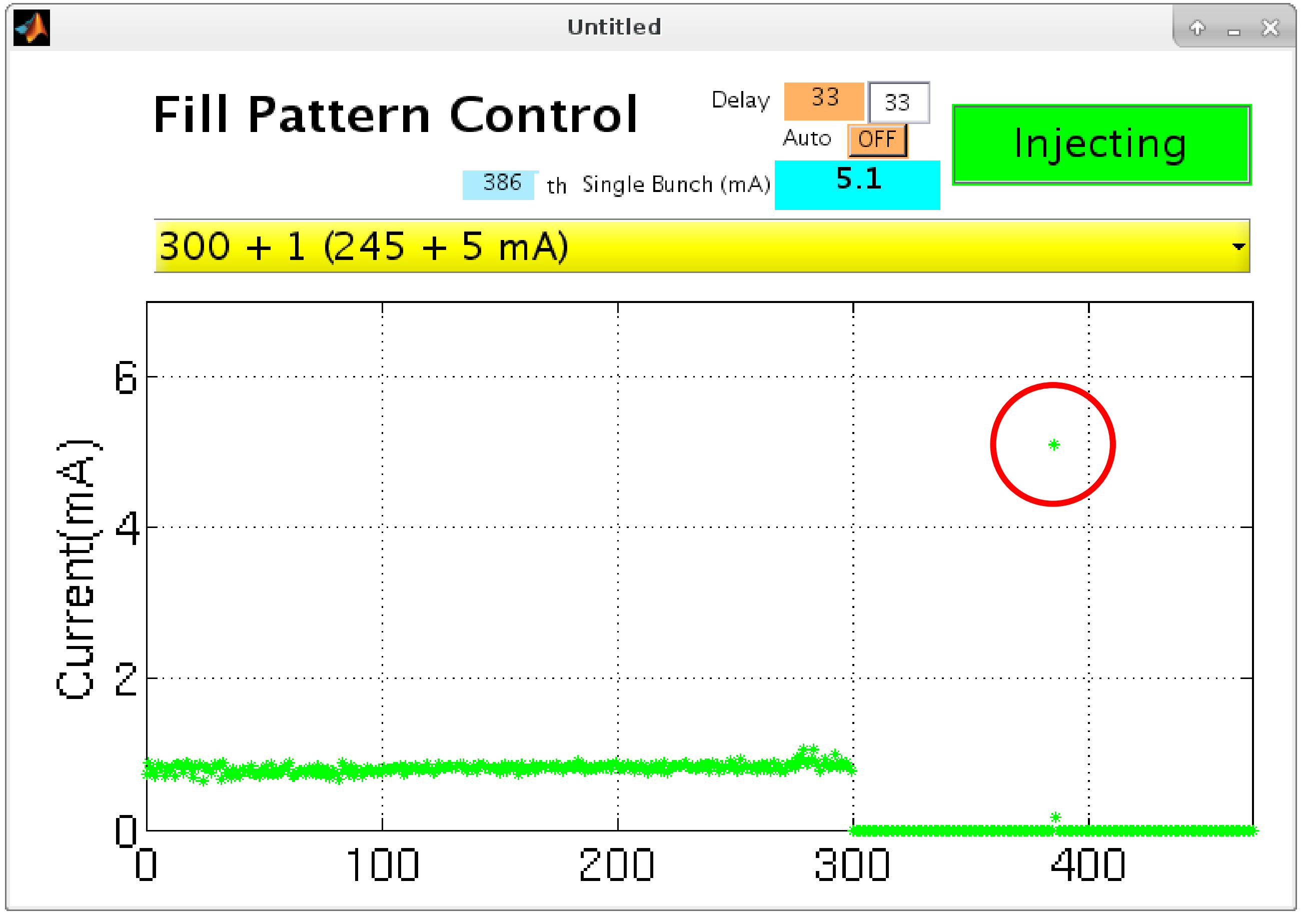
Fill Pattern & Hybrid Mode

❖ **Various fill pattern**

- Harmonic number: 470
- 400, 430, 430+1, 350+1, 340+3, 60x5, etc.

❖ **300 + 1 hybrid mode**

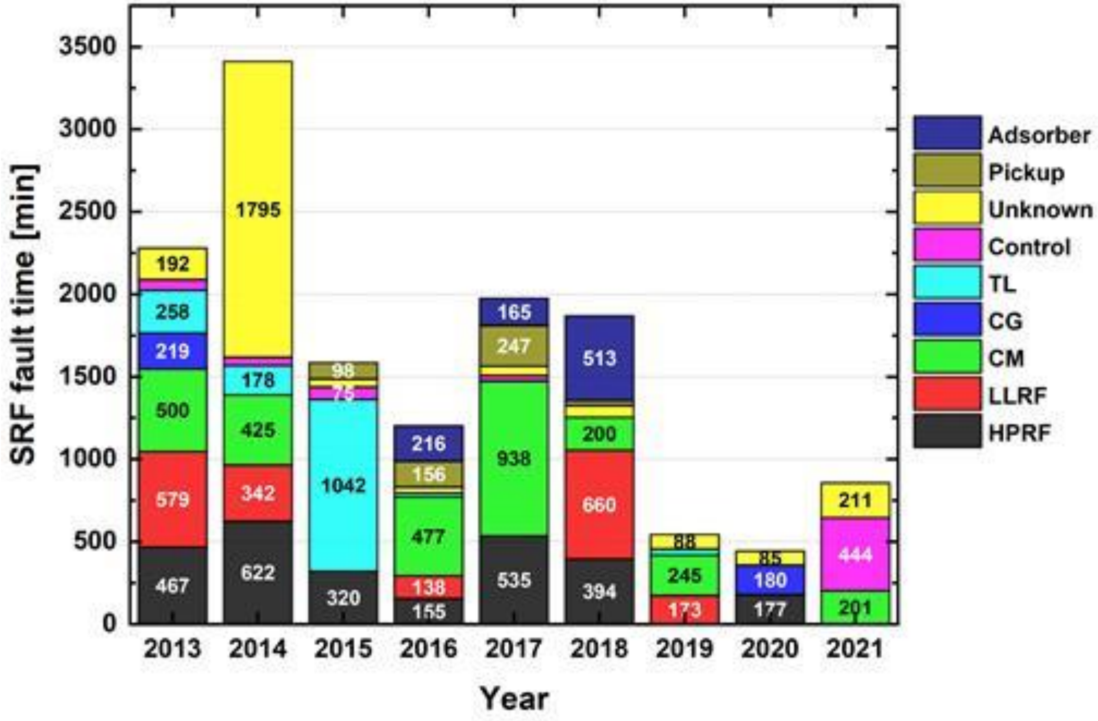
- 1st Transverse Feedback for equally filled bunches (up to 3mA)
- 2nd TFS for unequal bunch (5mA serviced in 2021)

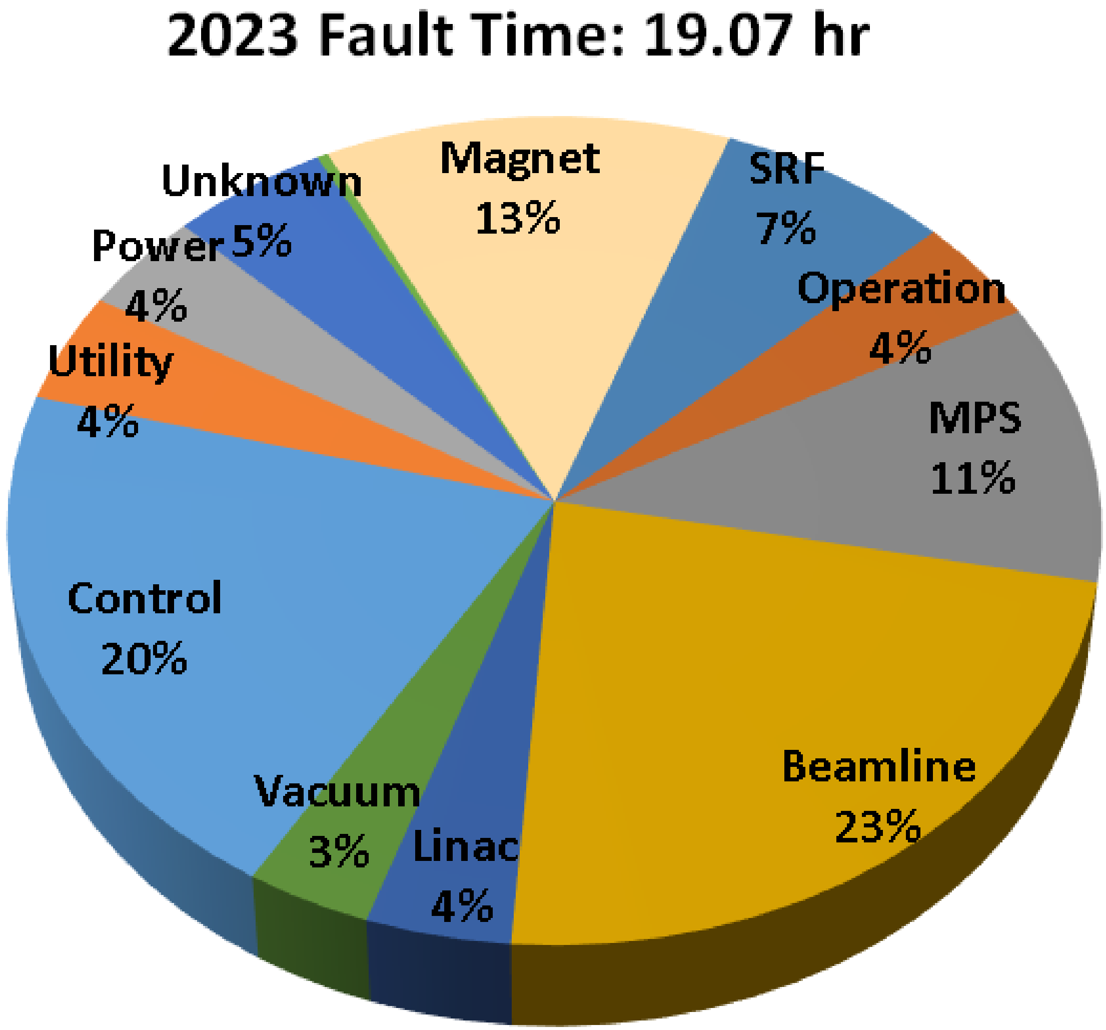


Beam Availability & Machine Faults (January 1, 2023 ~ August 1, 2023)

❖ Stability

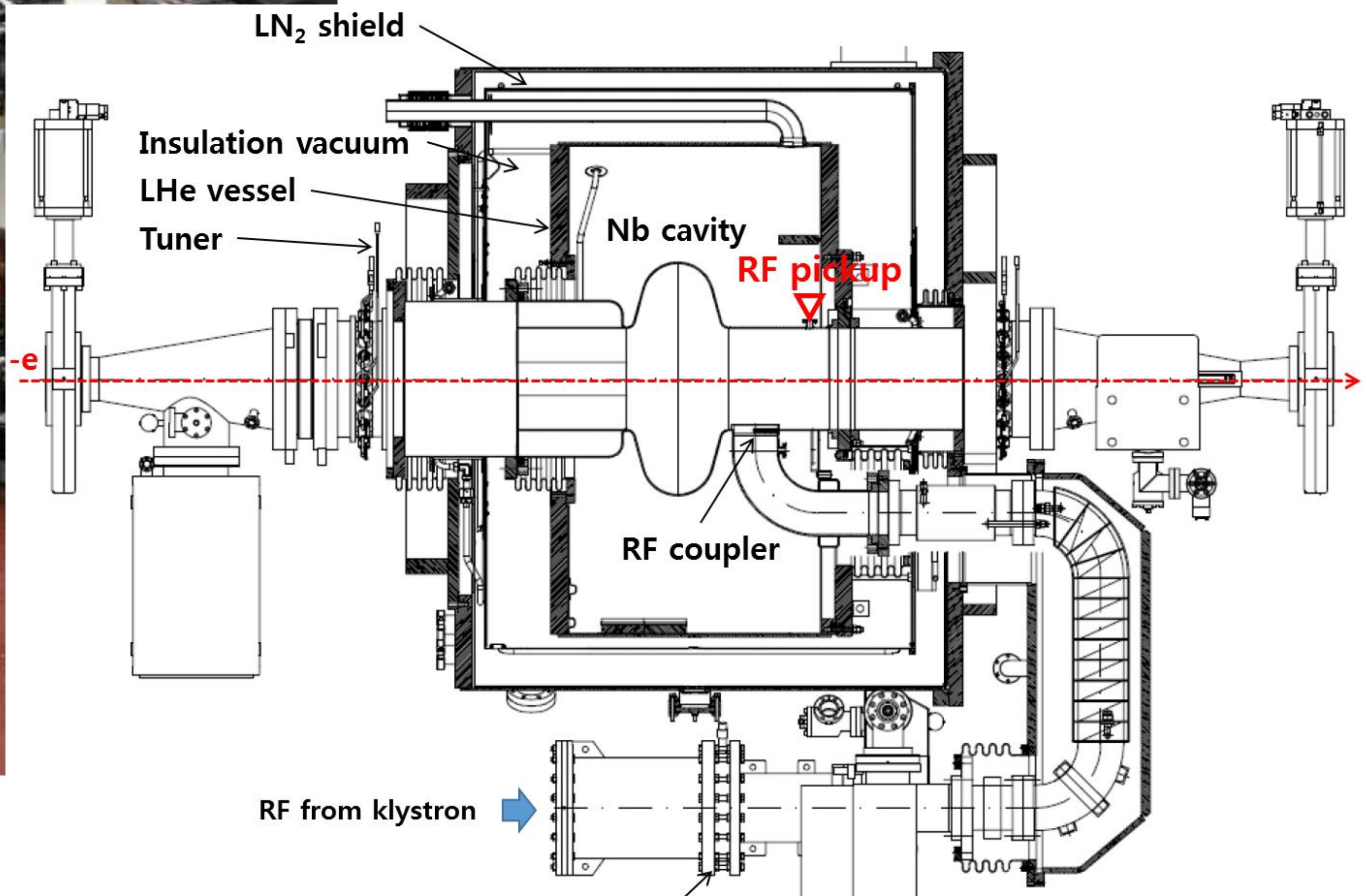
- Beam availability: 99.4% (3245.2 hr / 3264 hr)
- Mean time between faults: 120 hr
- Mean time trouble repair: 0.74 hr



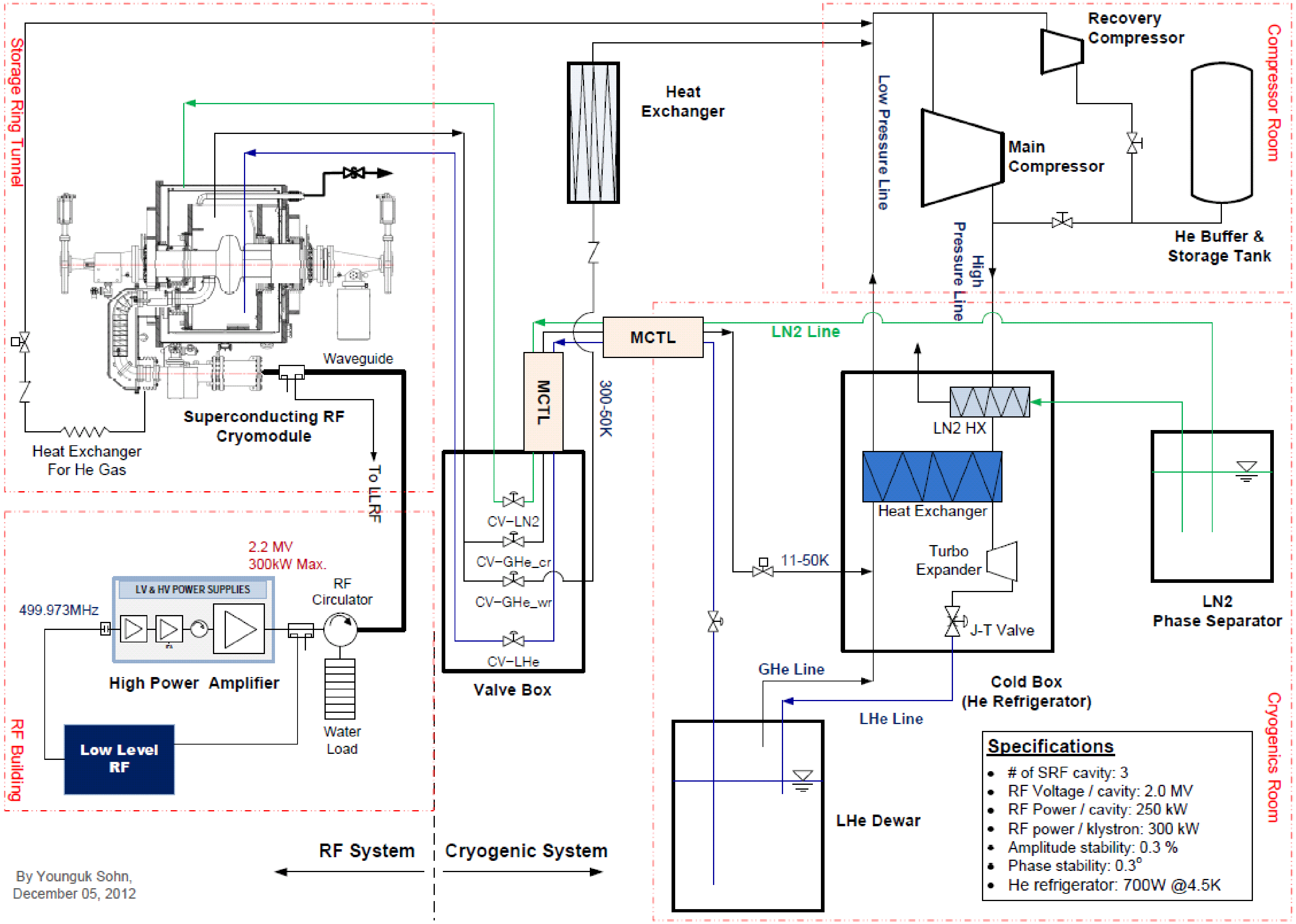


Supper-conducting RF Cavity

3 Cryomodules in Storage Ring

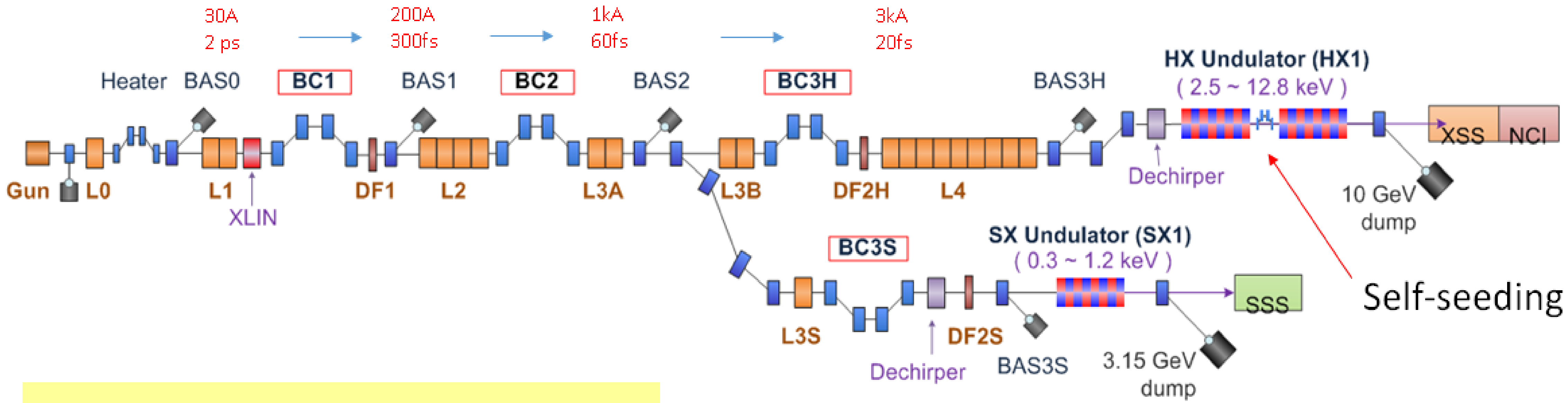


Cryogenic System & Major Faults



1. LN2 leak (2014/2/19~3/22)
2. Turbine trouble (2017/2/14~5/4)
3. Coldbox controller trouble by earthquake (2017/11/19~12/12)
4. Compressor control rack pan mal-function (2019/9/12~9/25)
5. Cavity #3 leak (2019/9/26~10/22)
6. Coldbox valve mal-function in 2020
7. Cryogenic emergency interlock by blackout in 2020
8. Cavity #1 leak (2022/8/22)

PAL-XFEL Layout & Parameters



Main parameters

e⁻ Energy	11 GeV
e⁻ Bunch charge	20-200 pC
Slice emittance	< 0.4 mm mrad
Repetition rate	60 Hz
Bunch length	5 fs – 50 fs
Peak current	3 kA
SX line switching	Kicker Magnet

Undulator Line	HX	SX
Photon energy [keV]	2.0 ~ 15.0	0.25 ~ 1.25
Beam Energy [GeV]	4 ~ 11	3.0
Wavelength Tuning	Energy	Gap
Undulator Type	Planar	Planar
Undulator Period / Gap [mm]	26 / 8.3	35 / 9.0

Operation History of PAL-XFEL

Apr. 2011: PAL-XFEL project started

Apr. 2016: Commissioning started

Jun. 2017: User-service started
- 120 days for user (95% of availability)

2018: 140 days for user (95% of availability)

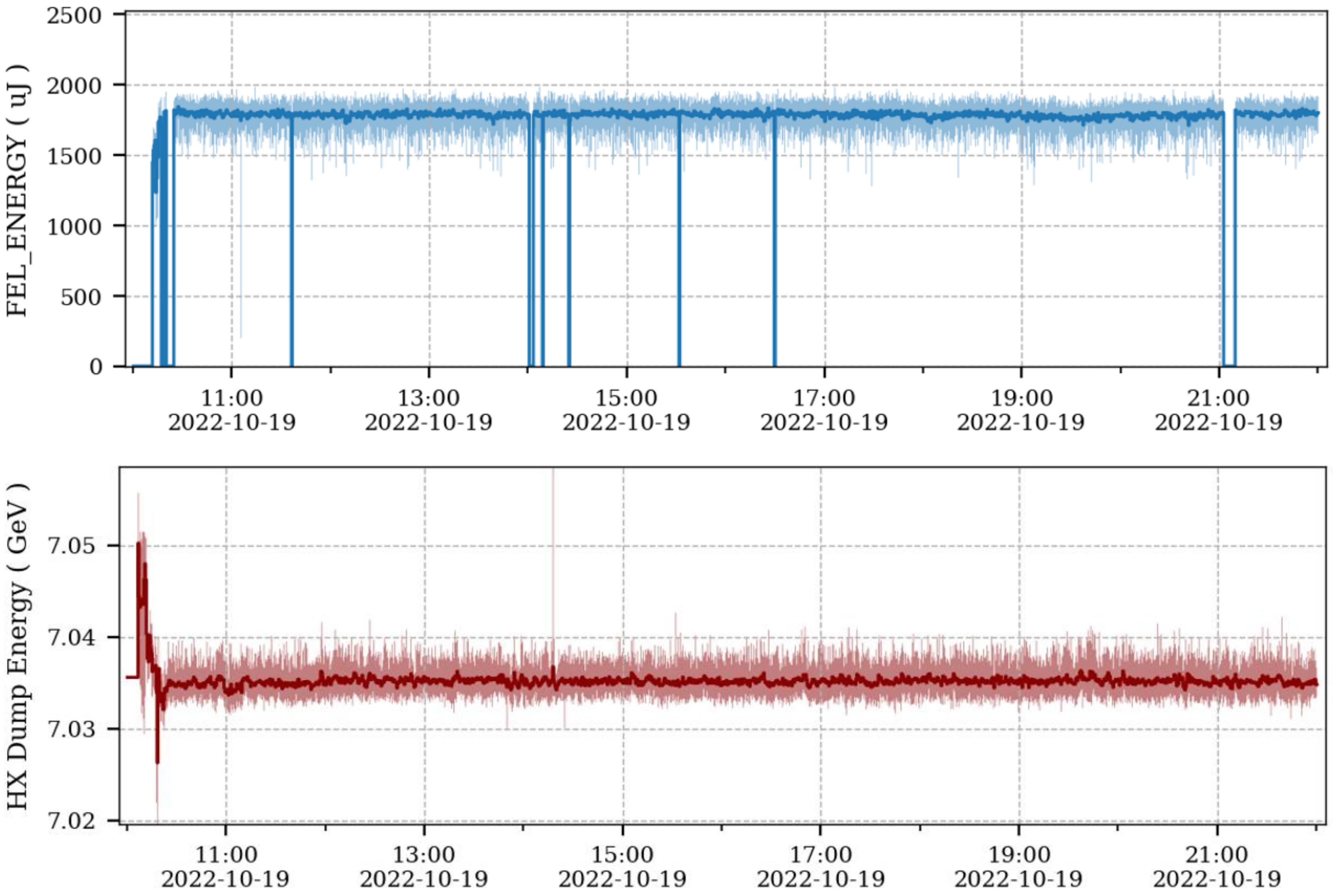
2019: 160 days for user (96.8% of availability)

2020: 170 days for user (96.9% of availability)

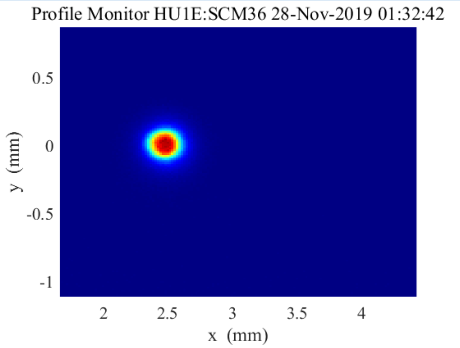
2021: 180 days for user (96.9% of availability)

2022: 190 days for user (97.0% of availability)

FEL Stability (12 hours, October 19, 2022)



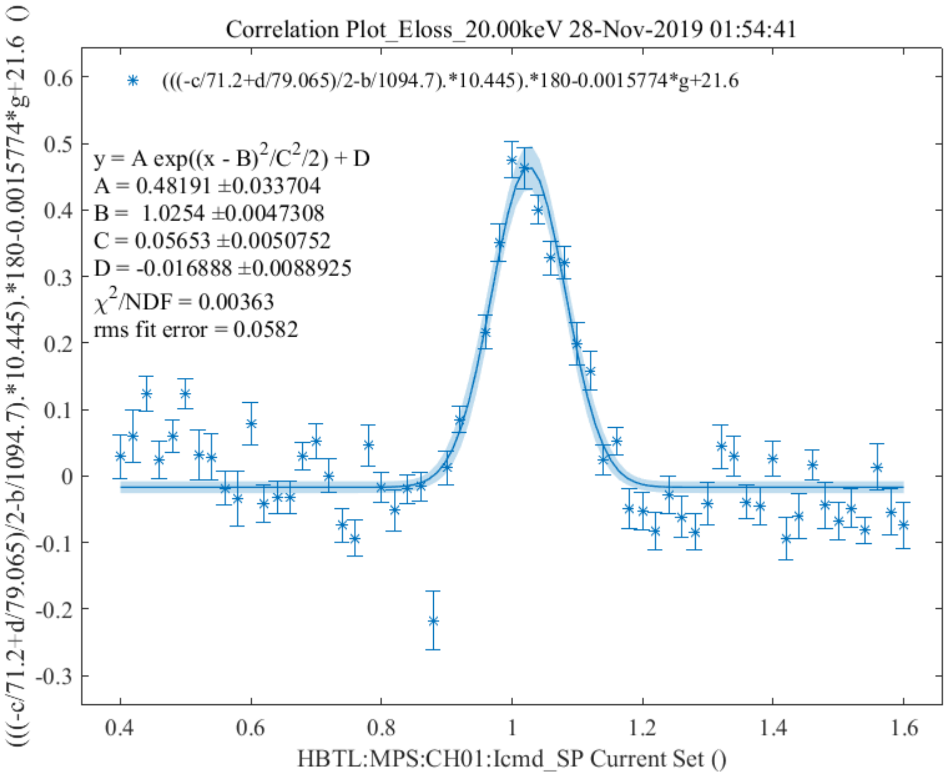
FEL Photon Energy up to 20 keV

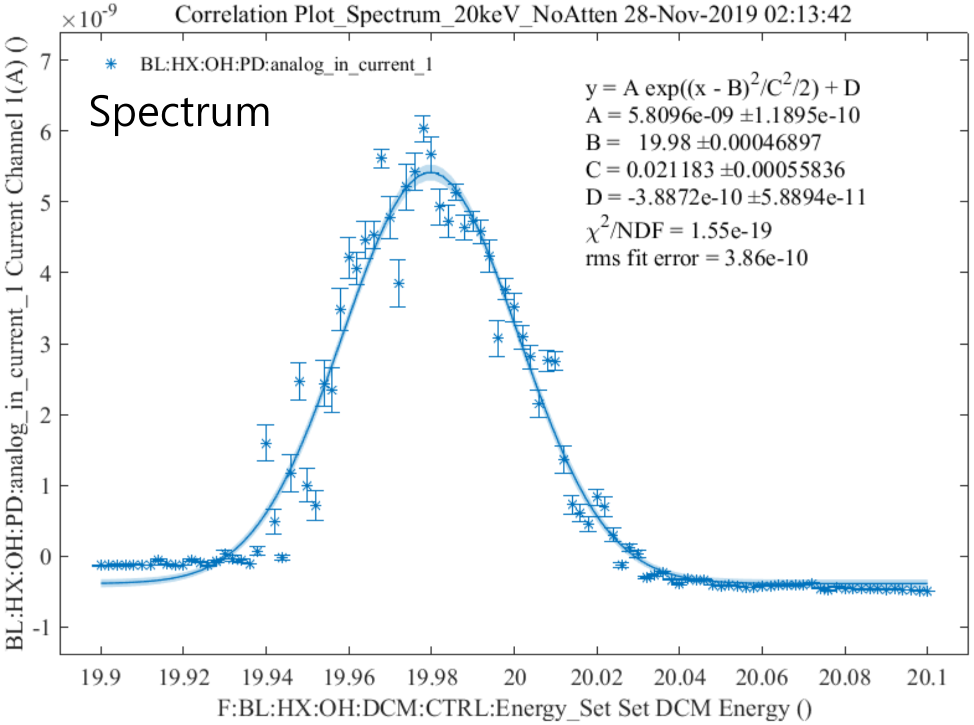


(YAG) screen monitor located 42m downstream from the last undulator

Energy loss measurement

$$\lambda_l = \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$



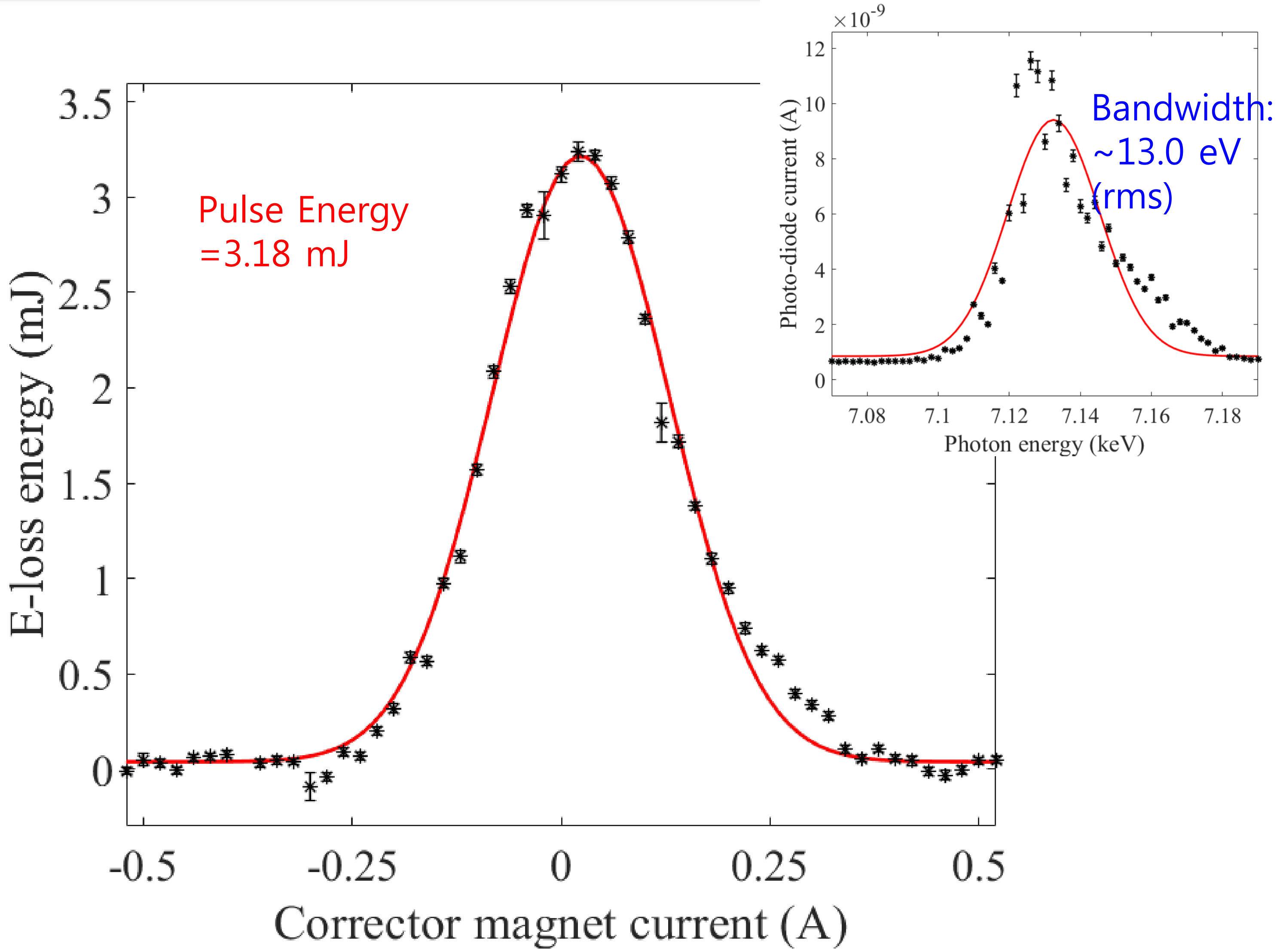


E-beam energy: 10.446 GeV (K=1.87 for 14.5 keV)
Undulator K = 1.409
FEL Pulse Energy: ~0.48 mJ

Bandwidth: ~ 21.2 eV (rms)

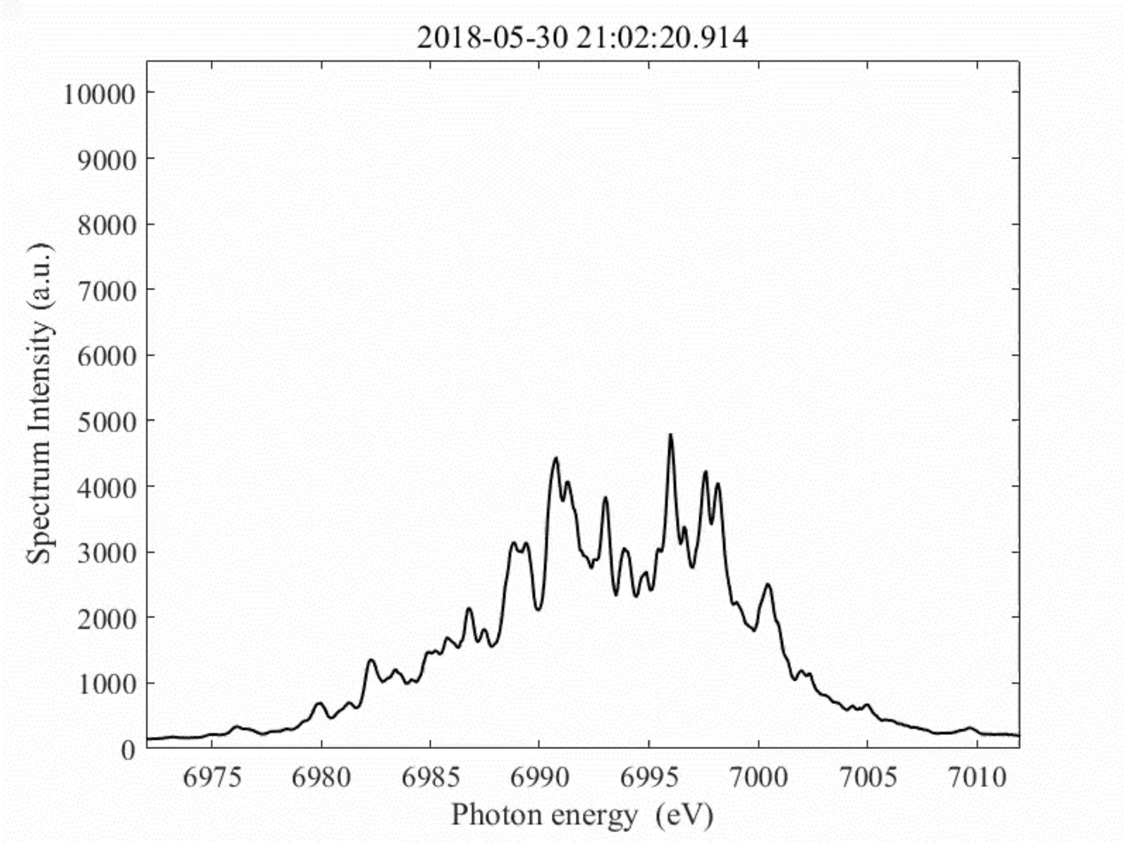
Highest FEL Pulse Energy

- E_{beam}: 7.325 GeV
- E_{photon}: 7.13 keV SASE FEL
- Norm. emittance at injector:
  0.35 mm (hor) / 0.31 mm (ver)
- Norm. emittance at Undulator:
  0.35 mm (hor) / 0.31 mm (ver)
- Peak current: 2.8 kA
- Used undulator number: 19
- XFEL pulse duration: 36.0 fs (FWHM)

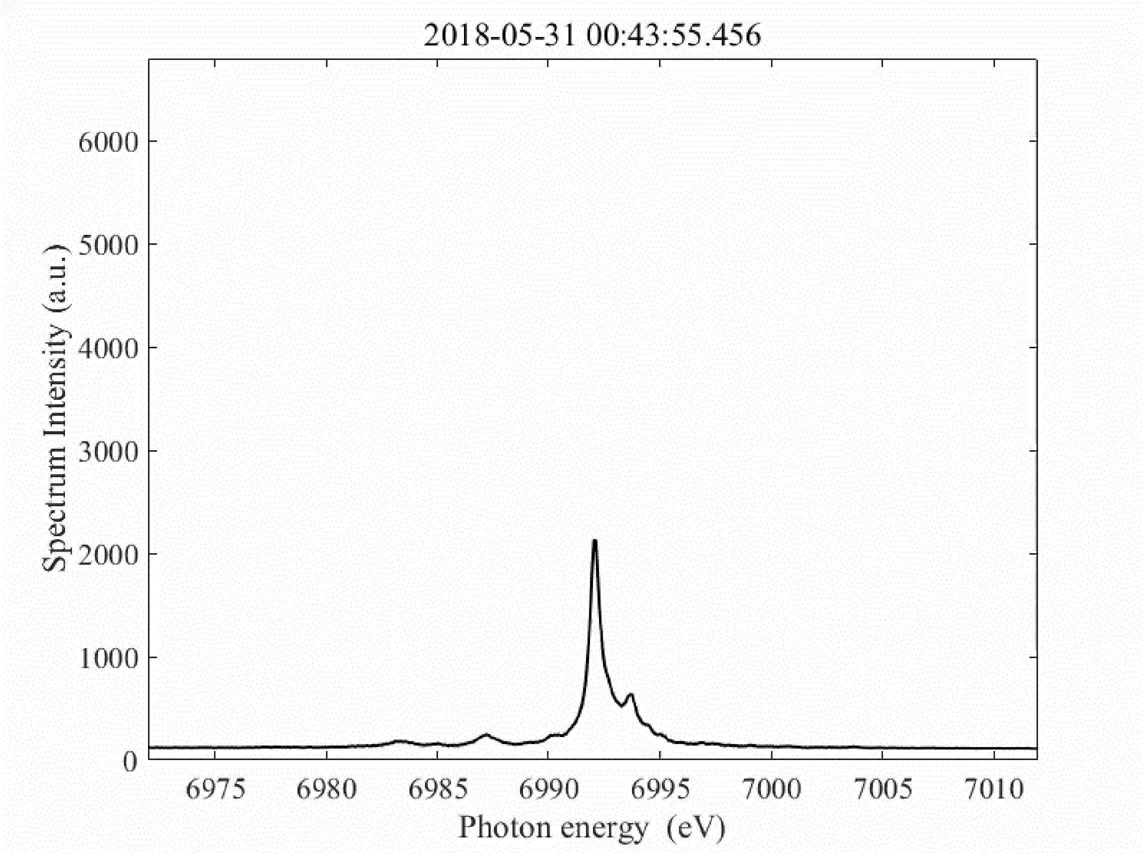


SASE FEL vs Self-Seeding FEL

SASE FEL at 6.99 keV

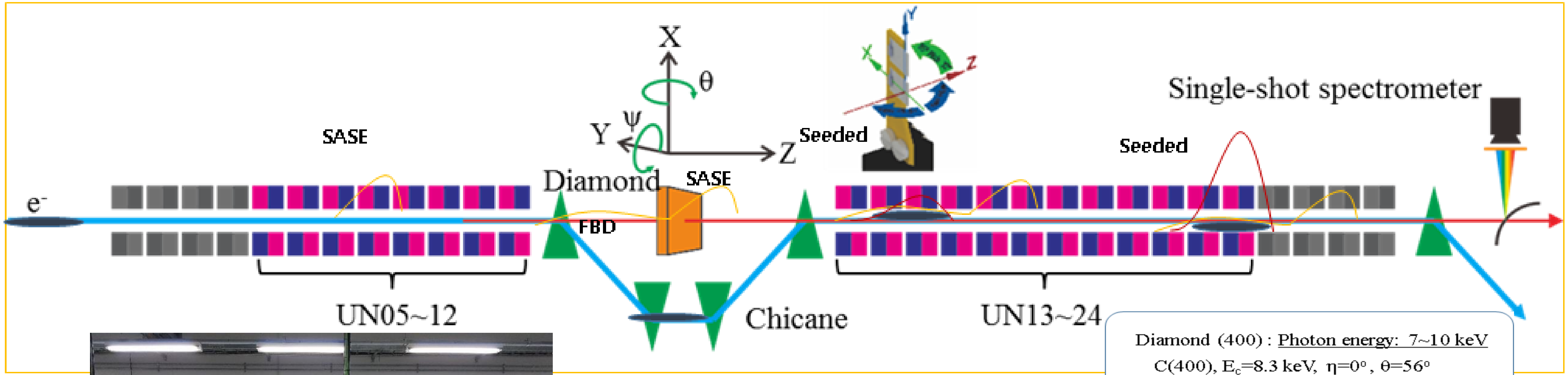


Self-Seeding FEL at 6.99 keV

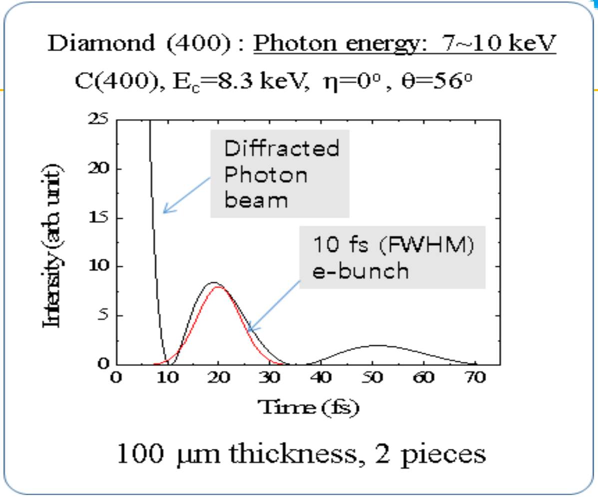


Self-Seeding FEL

- Self-Seeding was installed under collaboration with APS, LCLS and TISNCM (Russia) in 2018

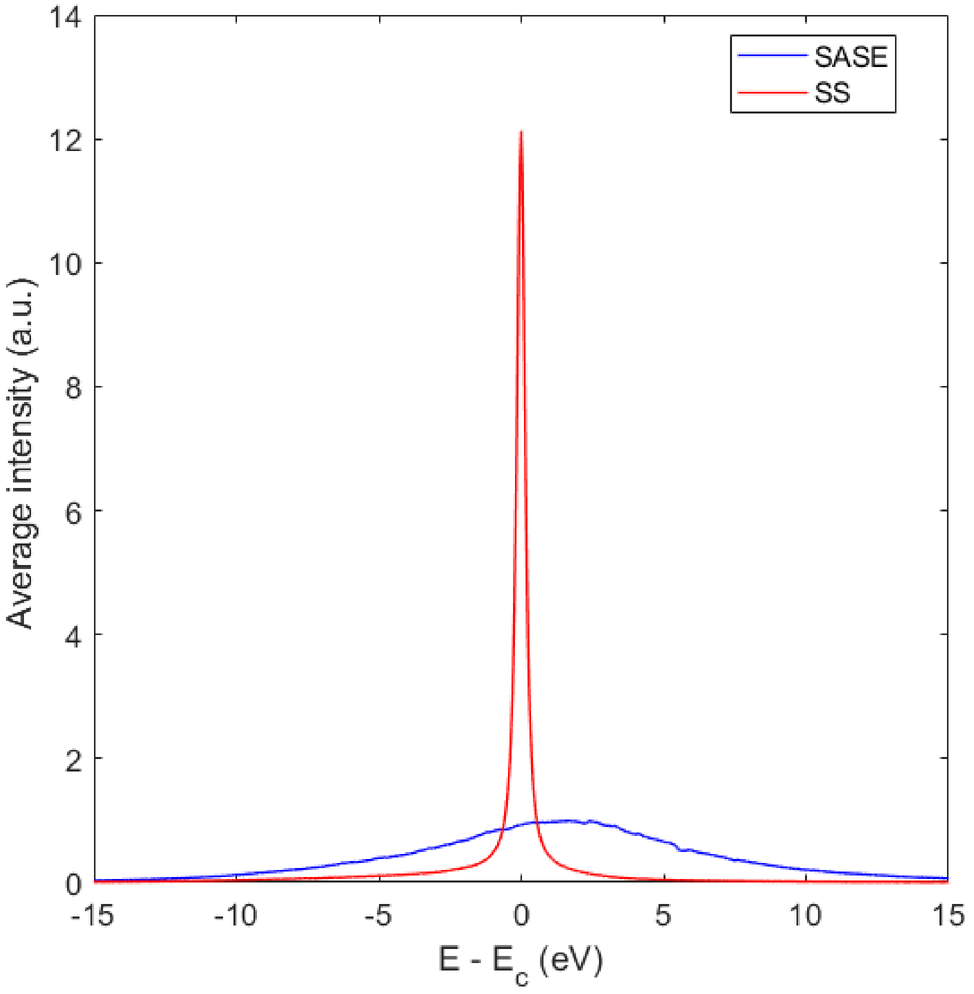



Picture of self-seeding section



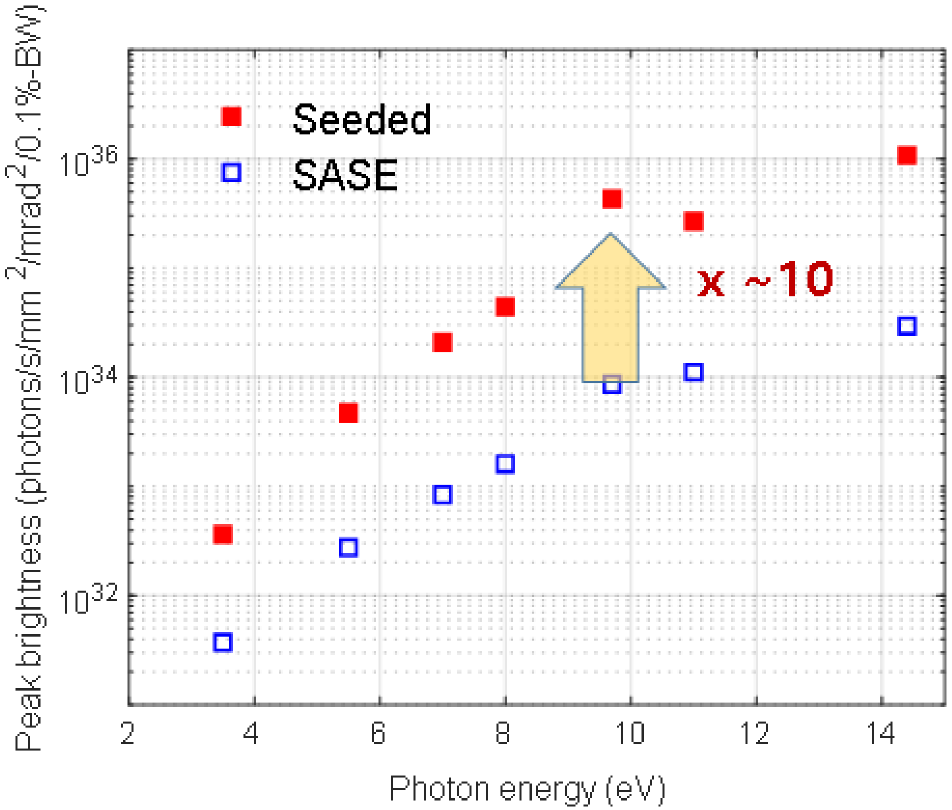
Progress in Self-seeding FEL

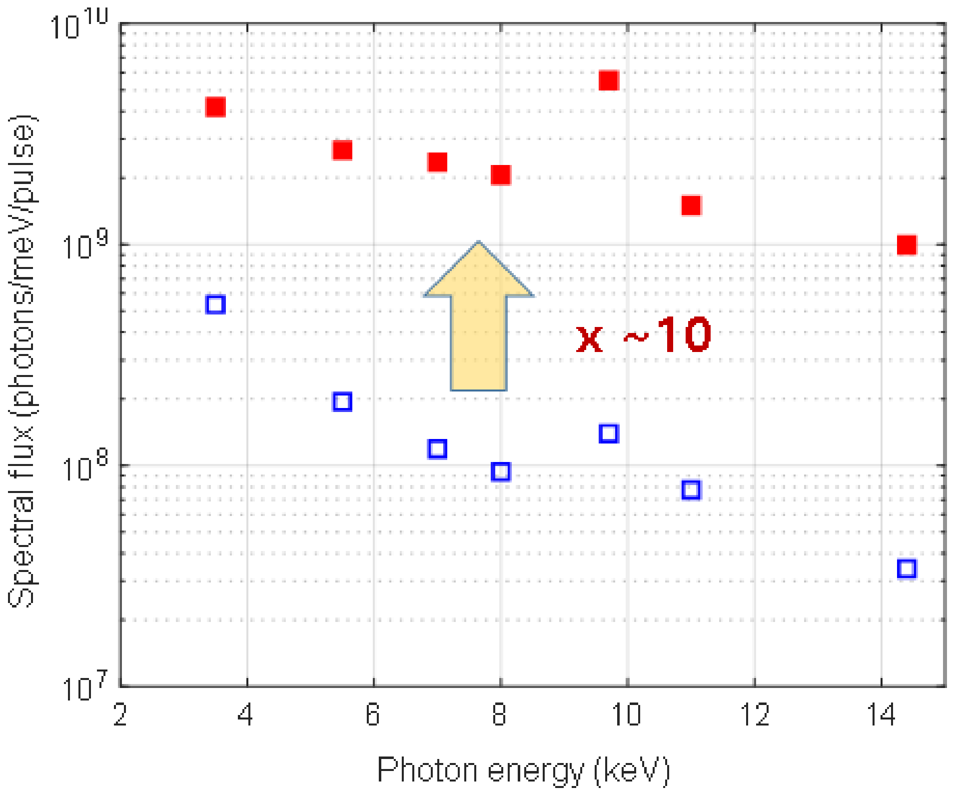
- Photon Energy Ec = 9.7 keV
- SASE FEL Energy: 2 mJ
- SASE FEL bandwidth (FWHM) = 27 eV
- Averaged Self-seeding FEL energy: **~850 μJ (~1.5 mJ for single shot)**
- Measured bandwidth = 0.35 eV (Resolution = 0.26 eV)
- De-convoluted bandwidth (FWHM) = **0.22 eV**
- FEL Pulse duration = ~ 20 fs



- **Peak brightness (photons/s/ mm^2 /mrad^2/0.1% BW): 5 x 10^{35}**

Peak Brightness and Spectral Flux

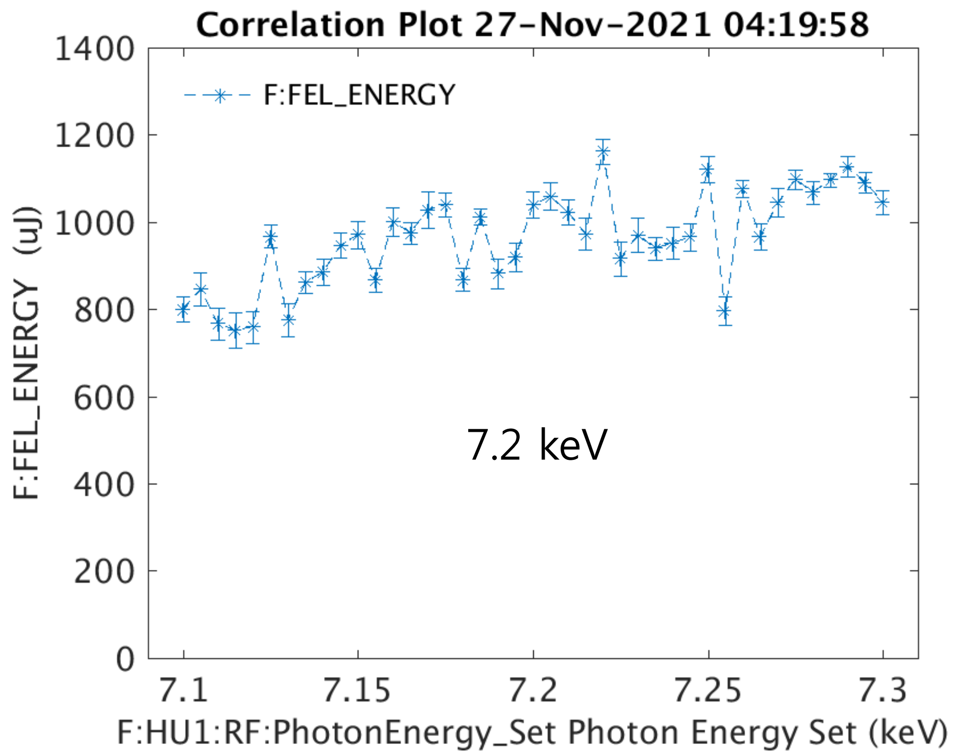




- **For self-seeded FEL, almost one order of magnitude enhancements of the peak brightness and spectral flux were obtained compared to that of the SASE mode**

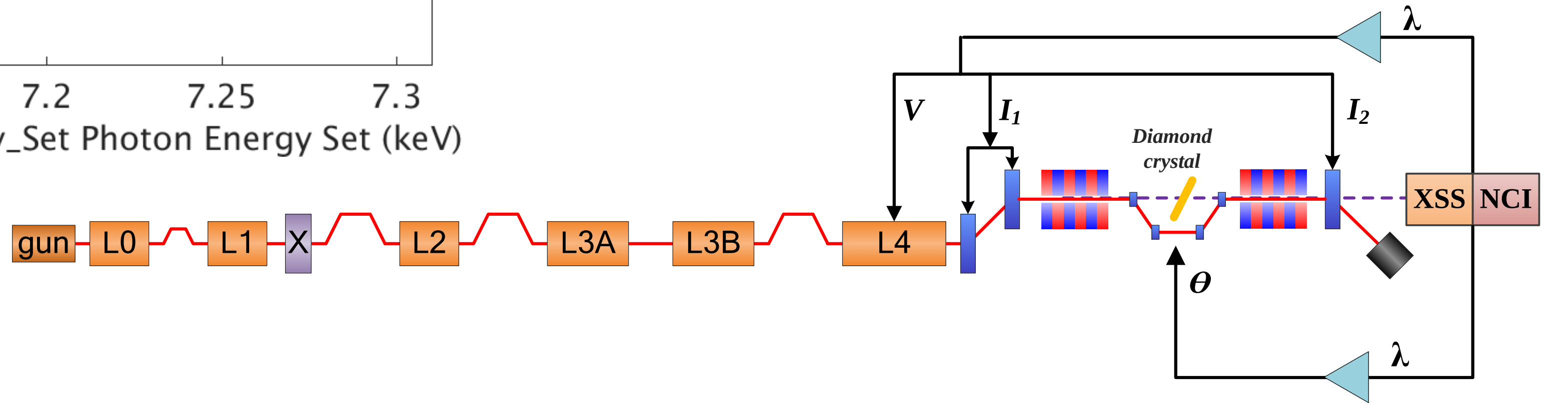
I. Nam *et al., Nature Photonics* (2021)

Energy Scan for Self-Seeding FEL

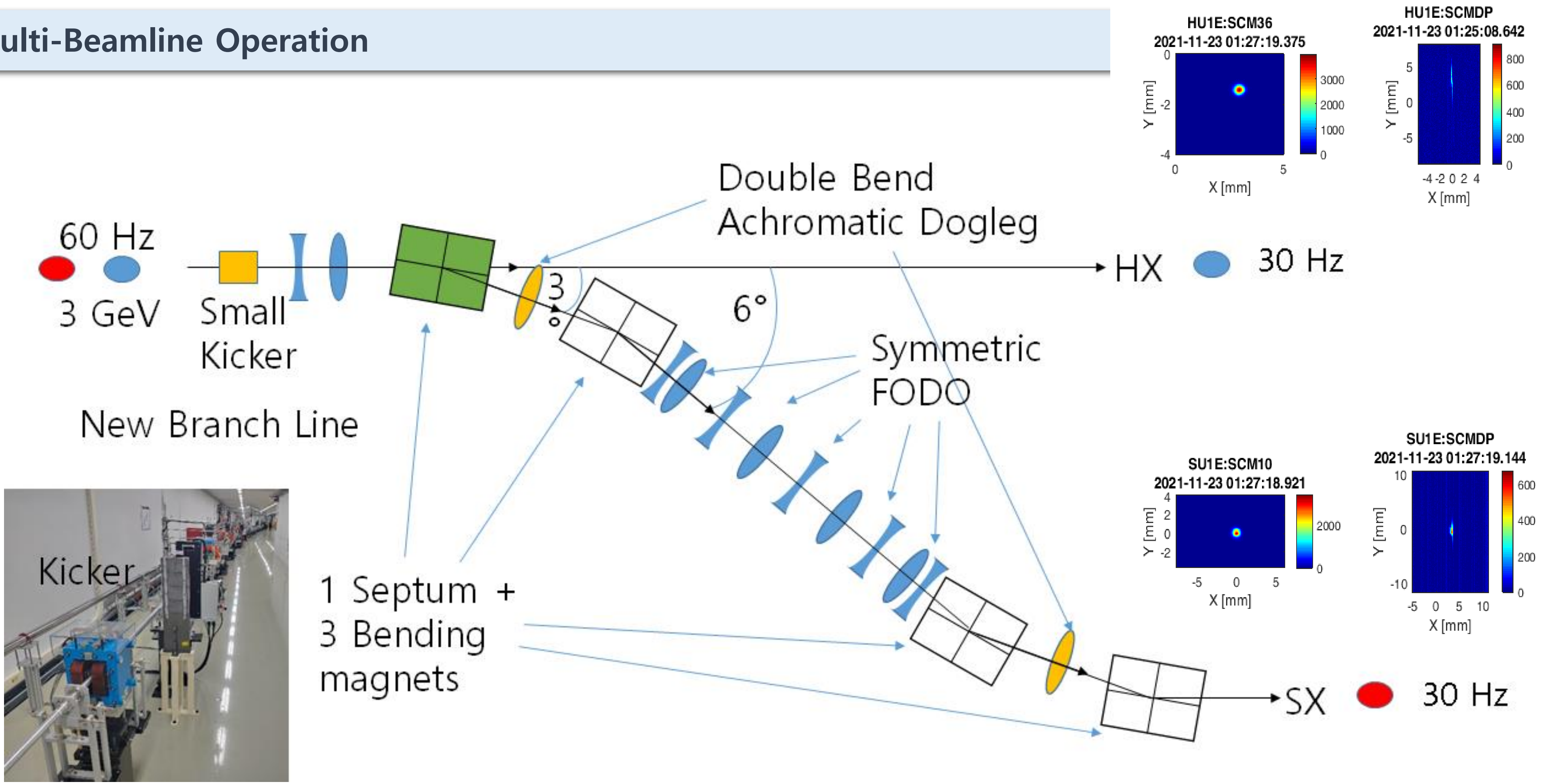


Energy control for Hard X-ray Self-Seeding

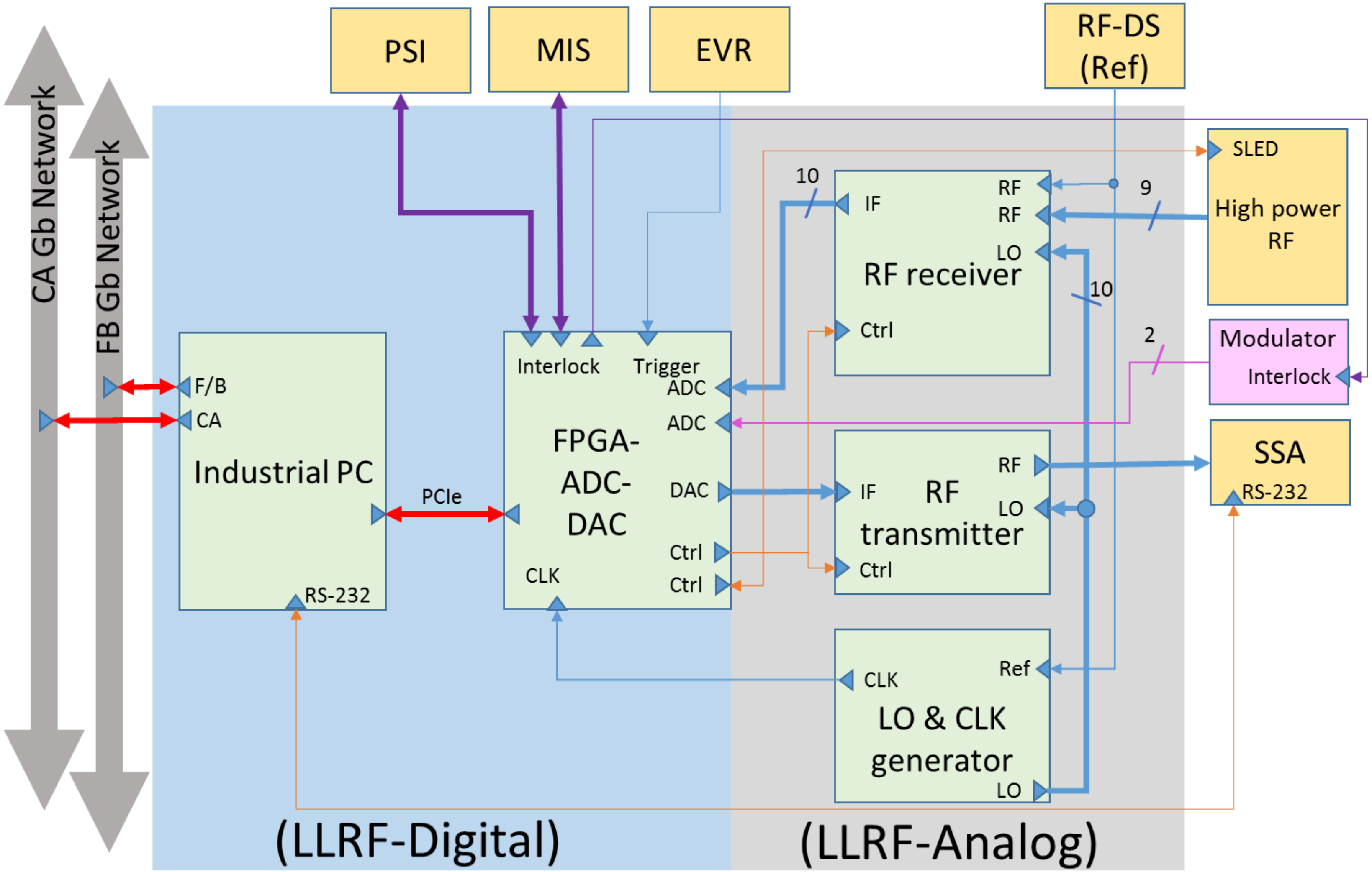
- Range : Photon energy ± 1 ~ 1.5 %
- e-Beam energy : Adjustable
- Diamond crystal angle : Adjustable



Multi-Beamline Operation



LLRF System for PAL-XFEL



Poster ID: 43, Jinyul Hu, New development of X-band LLRF for PAL-XFEL Linearizer

Status of 4GSR

Korea-4GSR Project

4GSR Outline

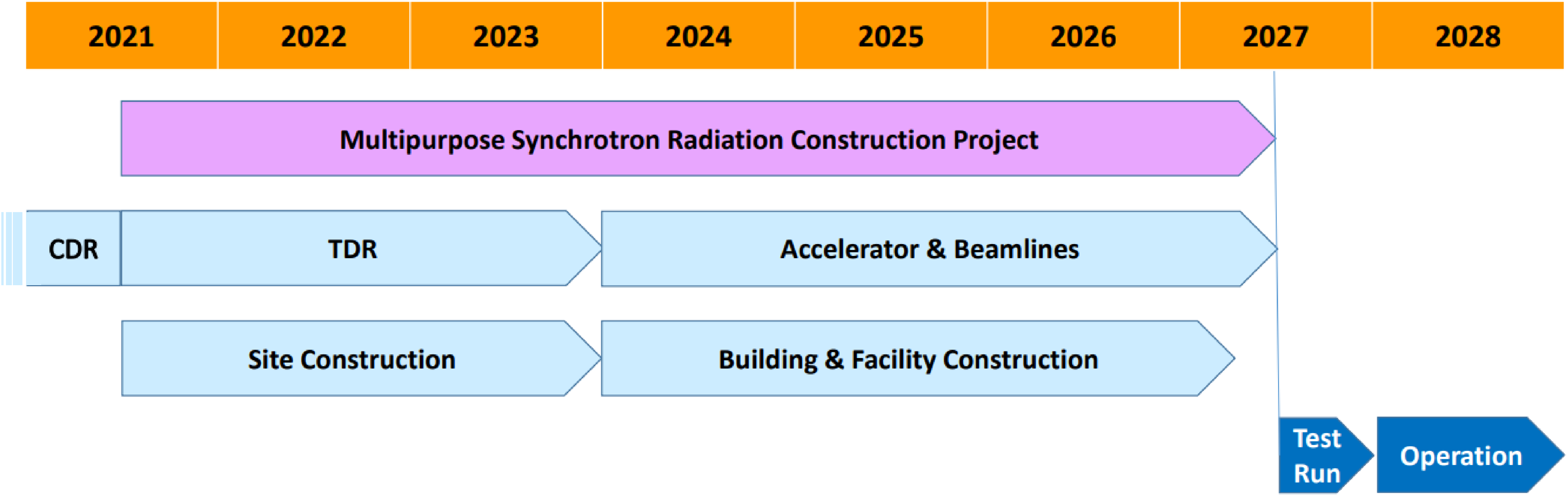
❖ **Multipurpose Synchrotron Radiation Construction Project**

- Period: 2021 July to 2027 June (6yrs)
- Budget: 1.0454 Trillion KRW (≈ USD 750M)
- Land: 540,000 ㎡ / Building: 69,400 ㎡
- Location: Ochang, Chungcheongbuk-do

Specifications

- Beam Energy: 4 GeV
- Beam Emittance: less than 100 pm·rad (CDR: 58 pm·rad)
- Circumference: 800m
- Beamlines : more than 40
- Accelerator: Gun, Injector LINAC, 4 GeV Booster
- Lattice: MBA-7 Bend Achromat

Project Timeline



Design features of Korean 4GSR

❖ High photon beam performance from storage ring.

- The best performance in the range of 10 ~ 30 keV.
- Capability to generate photon beam up to 100 keV.

❖ Considering well demonstrated technologies for the design.

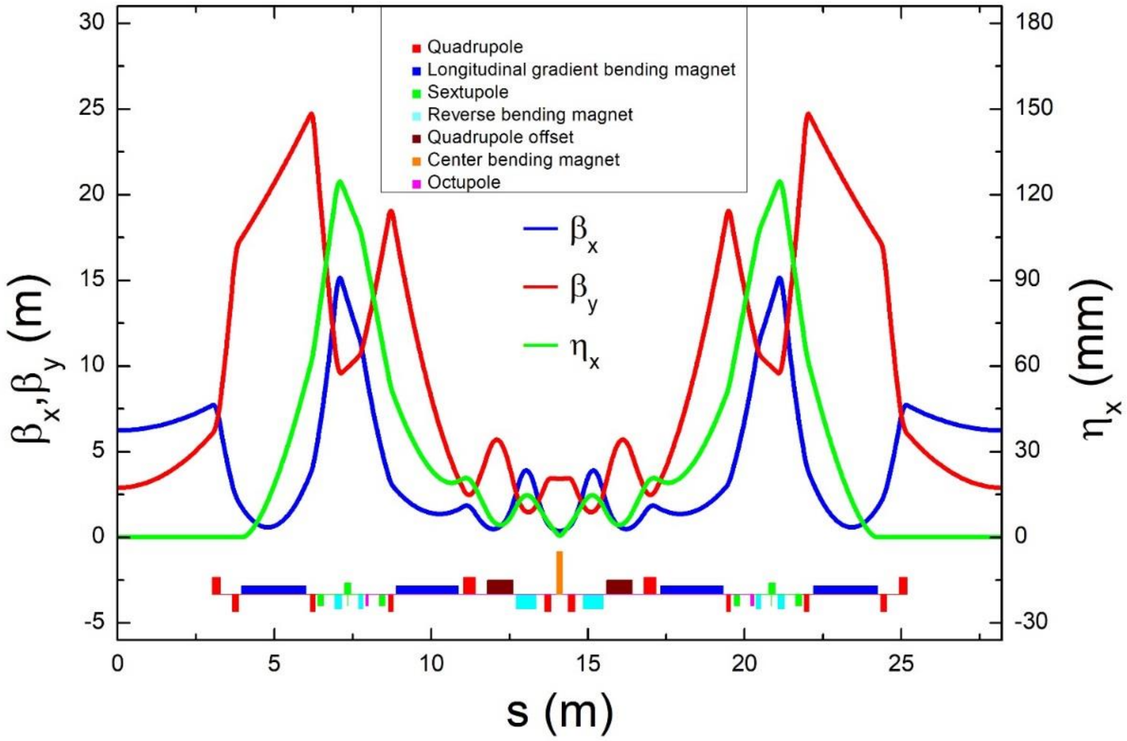
- Off axis injection with conventional injection scheme
- General technologies for magnet and vacuum systems.
- On schedule user service and full performance.

❖ Synergy with PLS-II and PAL-XFEL.

- Supporting full range of synchrotron radiation application.

Lattice Design of Storage Ring

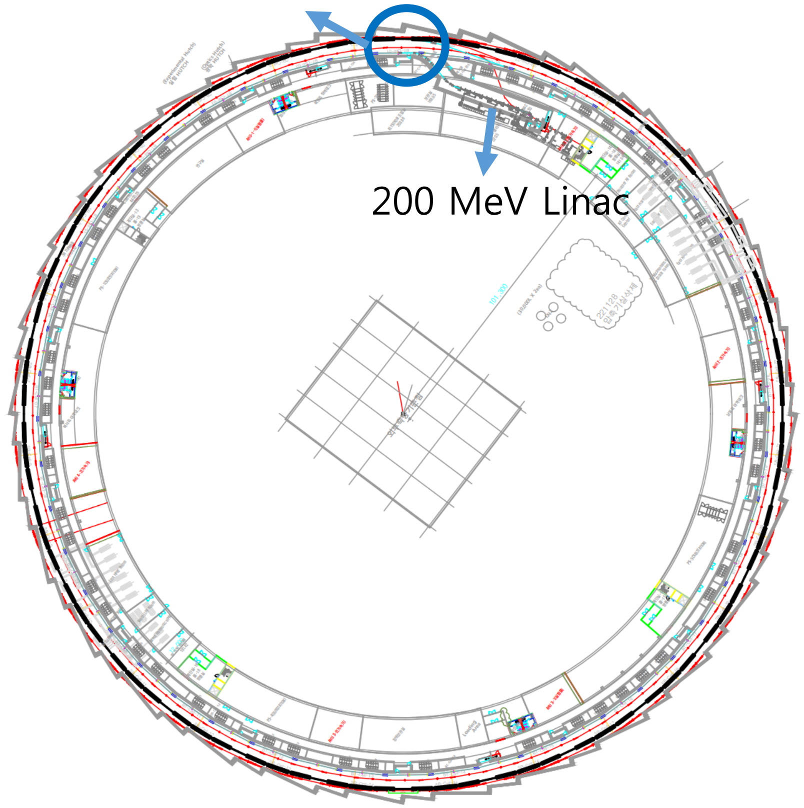
- ❖ **The storage ring is a 800 m, 4 GeV, 28-cell ring with natural emittance of 62 pm**
- ❖ **The unit cell is a H7BA with 2 T center bend**
- ❖ **It exploits longitudinal gradient bends (LGBMs) and reverse bends (RBs) to suppress emittance**



Parameters	**Value**
Energy (GeV)	**4**
Circumference (m)	**799.297**
Emittance (pm)	**62**
Tunes (H,V)	**68.10, 23.18**
Natural chromaticity (H,V)	**-109.6, -84.7**
Chromaticity (corrected) (H,V)	**4.5 , 3.5**
Hor. Damping partition	**1.84**
Momentum compaction	$\mathbf{0.78 \times 10^{-4}}$
Energy spread (σ_δ)	$\mathbf{1.26 \times 10^{-3}}$
Energy loss per turn (MeV)	**1.097**
Beam current (mA)	**400**
Bunch length (σ_z) (mm)	**4.058 / 16.232**
# of Beamline	**25 (ID)** **28 (2 T Bend)**

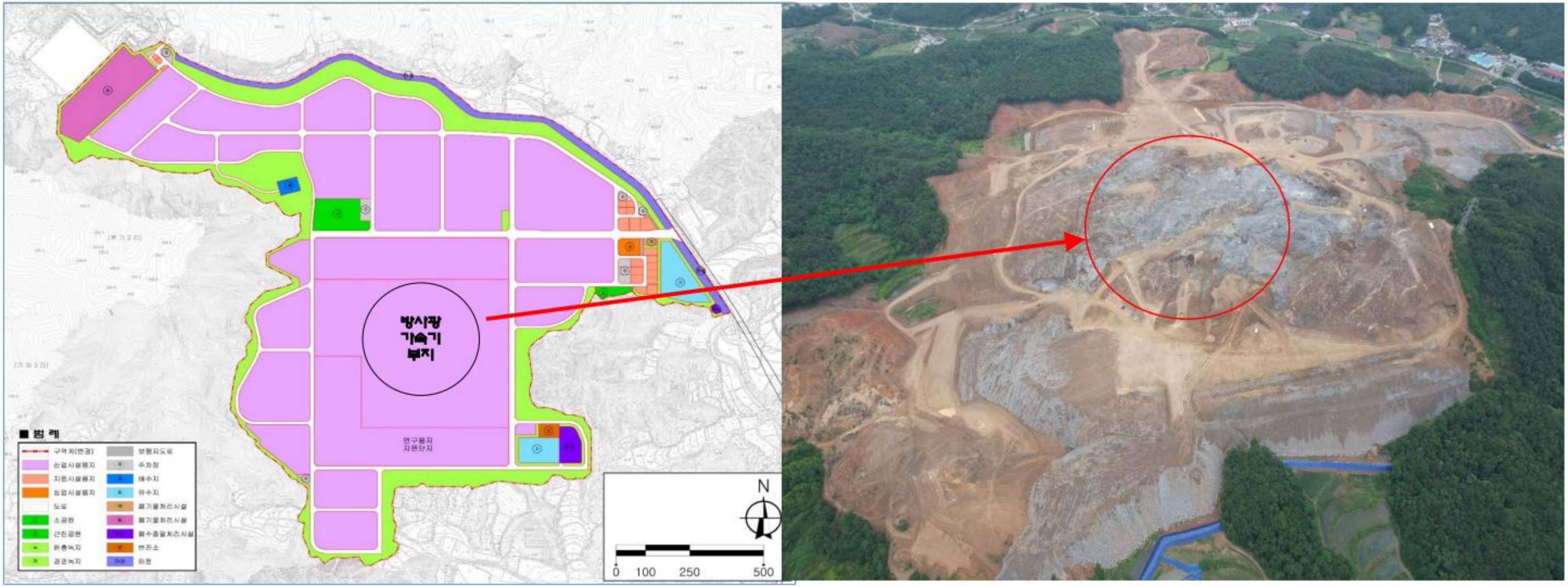
Injection system

- ❖ **Photocathod Gun & 200 MeV Linac**
- ❖ **Booster Ring : 2 Hz, 773 m, FODO**
- ❖ **Injection & Extraction**



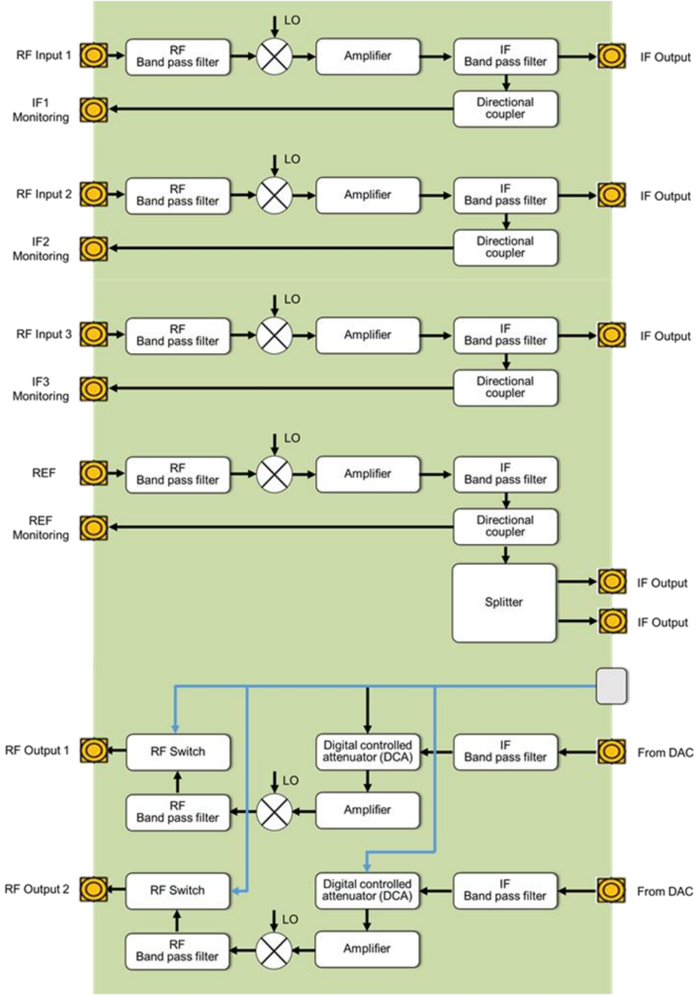
Booster Parameter	Value	Unit
Length	772.893	m
Electron Energy	0.2 - 4	GeV
Natural Emittance at 4 GeV	7717	pm rad
Natural Emittance at 200 MeV	19	pm rad
Momentum compaction	0.000925	
Horizontal Tune	19.195	-
Vertical Tune	14.19	-
Natural Horizontal Chromaticity	-27.7	-
Natural Vertical Chromaticity	-19.3	-
Energy Loss per Turn	1671.3	keV
Energy Spread	0.107	%
Horizontal Damping Time	8.4	ms
Vertical Damping Time	12.3	ms
Longitudinal Damping Time	8.1	ms
Synchrotron Frequency	4217	Hz
Synchrotron Tune	0.01087	
Bunch Length	11.17	mm

Construction Site

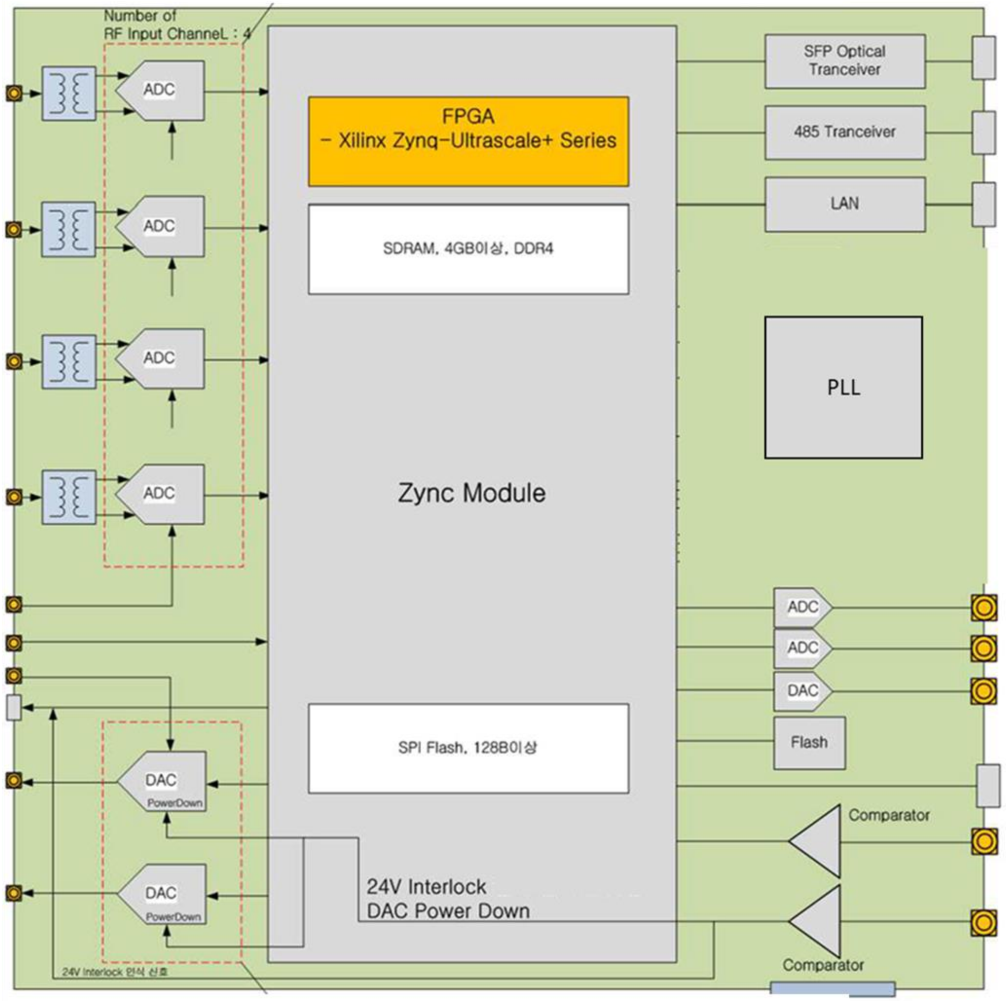


Proposed LLRF System for 4GSR

RF analog front board



Digital control board



Yong-Seok Lee, Progress in LLRF system development for Korea-4GSR

Korea Atomic Energy Research Institute

Status of KOMAC

Korea Multi-purpose Accelerator Complex

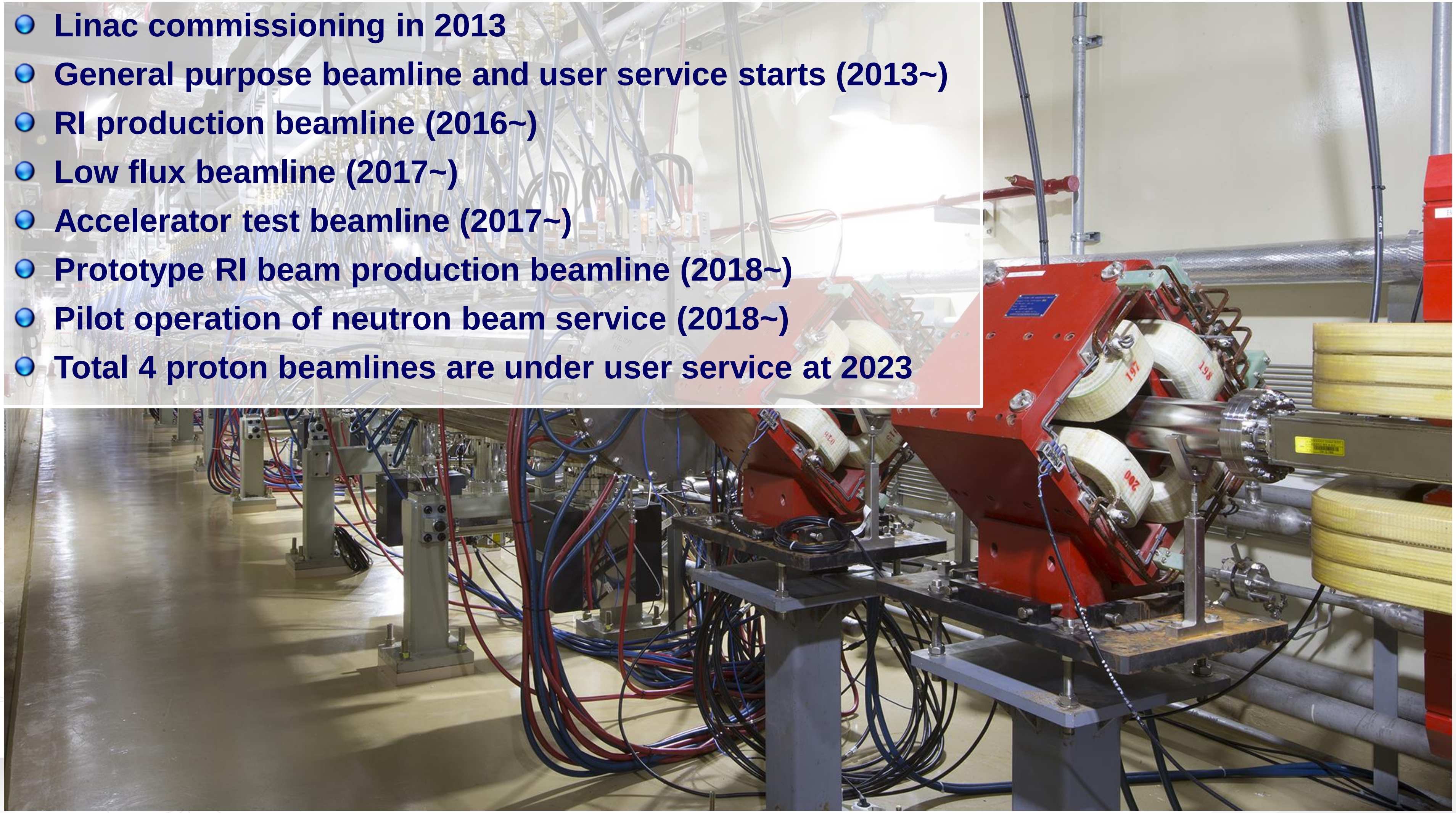
KAERI Korea Atomic Energy Research Institute

- One of branches of Korea Atomic Energy Research Institute (Gyeongju)
- Operation since 2013

100 MeV Linac and Beamline

Korea Atomic Energy Research Institute

- Linac commissioning 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 service (2018~)
- Total 4 proton beamlines are under user service at 2023



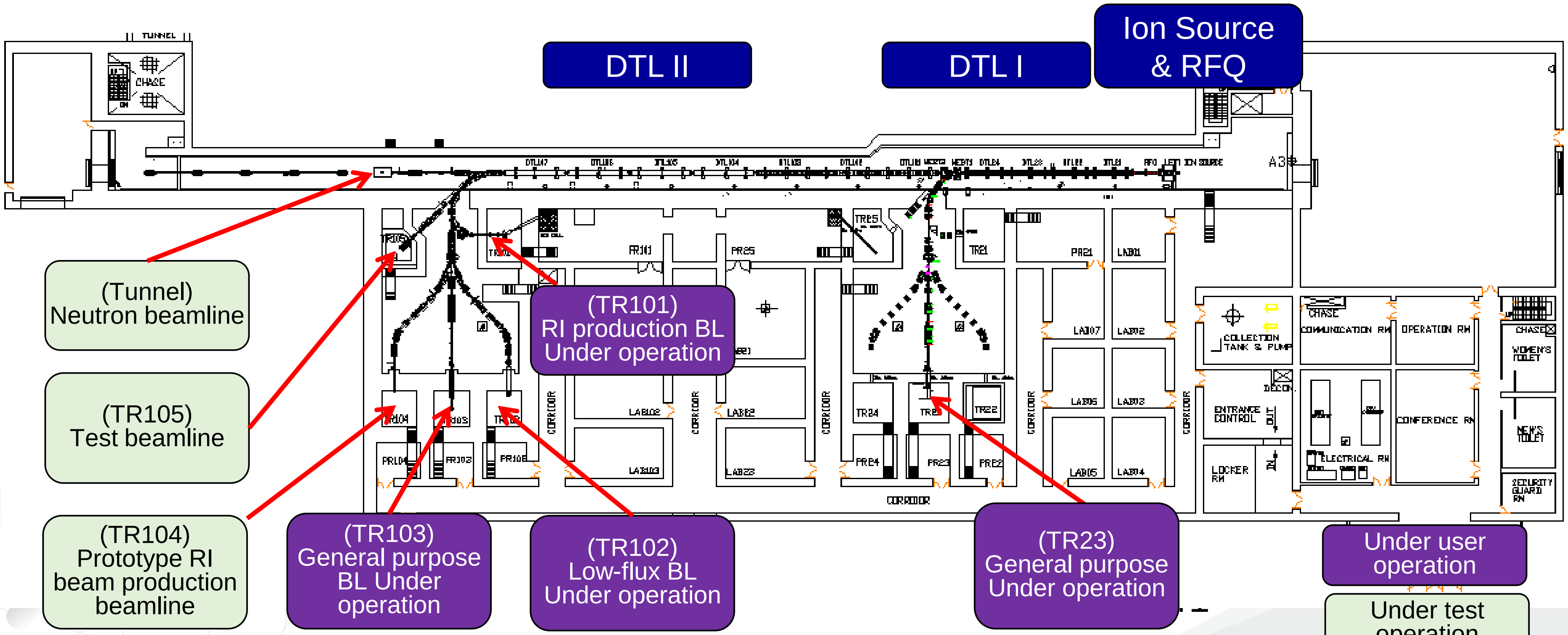
100 MeV Linac and Beamline

Korea Atomic Energy Research Institute

Features of KOMAC 100MeV linac

- 50-keV Injector (Ion source + LEBT)
- 3-MeV RFQ (4-vane type)
- 20 & 100-MeV DTL
- RF Frequency : 350 MHz
- Beam Extractions at 20 or 100 MeV
- 6 Beamlines for 20 MeV & 100 MeV

Output Energy (MeV)	20	100
Max. Peak Beam Current (mA)	1 ~ 20	1 ~ 20
Max. Beam Duty (%)	24	8
Avg. Beam Current (mA)	0.1 ~ 4.8	0.1 ~ 1.6
Pulse Length (ms)	0.1 ~ 2	0.1 ~ 1.33
Max. Repetition Rate (Hz)	120	60
Max. Avg. Beam Power (kW)	96	160

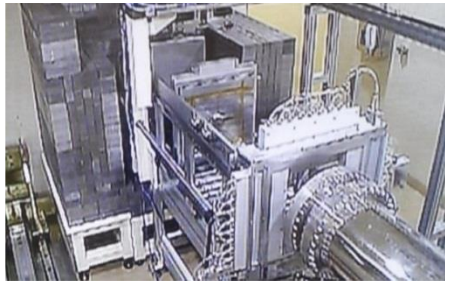


100 MeV Beamline Target Rooms

Korea Atomic Energy Research Institute

20MeV TR(TR23)

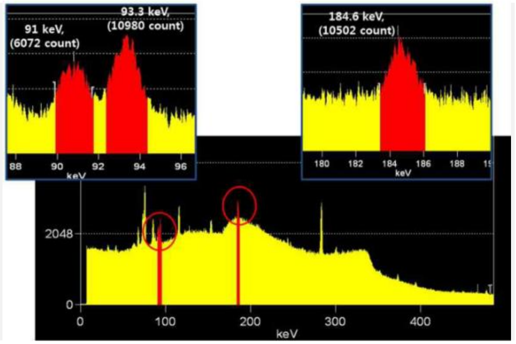
100MeV TR(TR103)



- **Application :** Proton beam irradiation for general purpose (material / nano-science, semiconductor etc.)
- **Proton beam**
  - Energy: 20 MeV / 33 ~ 100 MeV
  - Beam power: 10 kW @ 100 MeV
- **Status : in user service (2013~)**

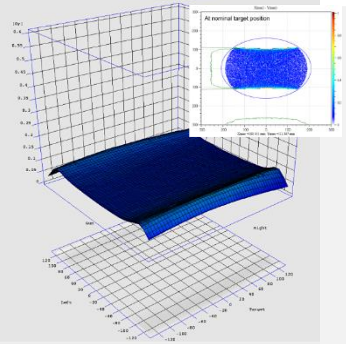
100MeV TR(TR101)

- **Application :** RI production: Cu-67, Sr-82, etc.
- **Proton beam**
  - Energy: 33 ~ 100 MeV
  - Beam power: 30 kW @ 100MeV
- **Status**
  - Installation: Dec. 2015
  - Started operation (2016~)



100MeV TR(TR102)

- **Application :** Space radiation, Detector R&D, etc.
- **Proton beam**
  - Avg. Current : max. 10 nA
  - Uniformity: < 10%, 100 mm X 100 mm
  - Flux: $1\times10^5 \sim 1\times10^8/cm^2$ / pulse
- **Status : in user service (2017~)**



100 MeV Linac Operation Statistics

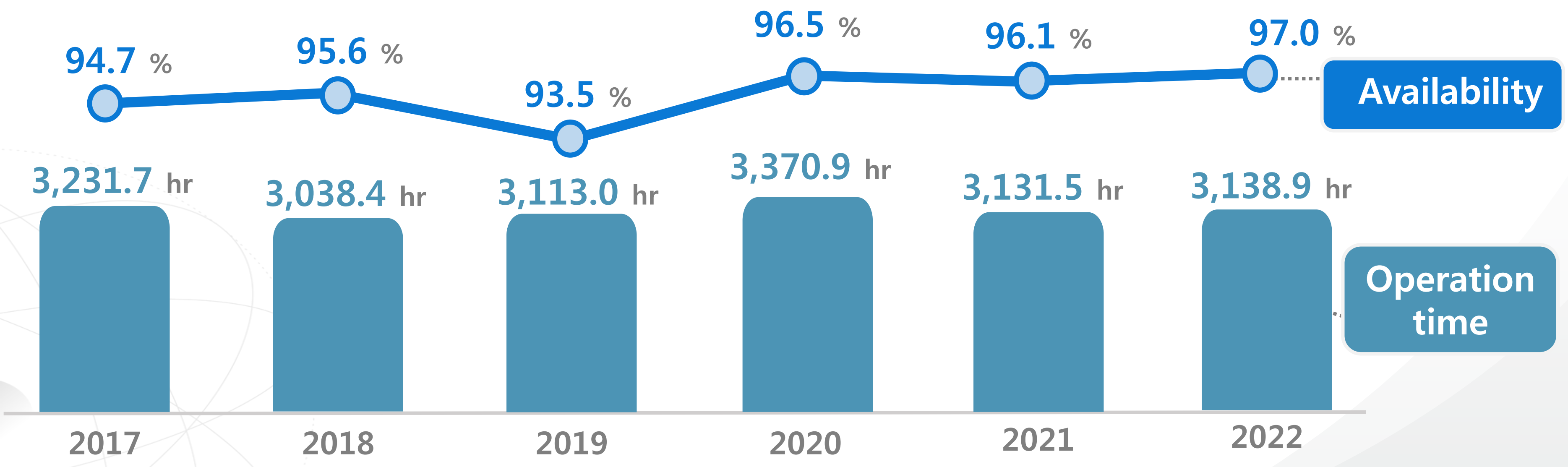
Korea Atomic Energy Research Institute

Accumulated statistics (2022)

Accumulated time	Avg. operation time / year	Avg. availability / year
30,087 hrs	3,158hr	94.7 %

Annual operation plan

User service 28 weeks + Machine study 7 weeks + Maintenance 17 weeks



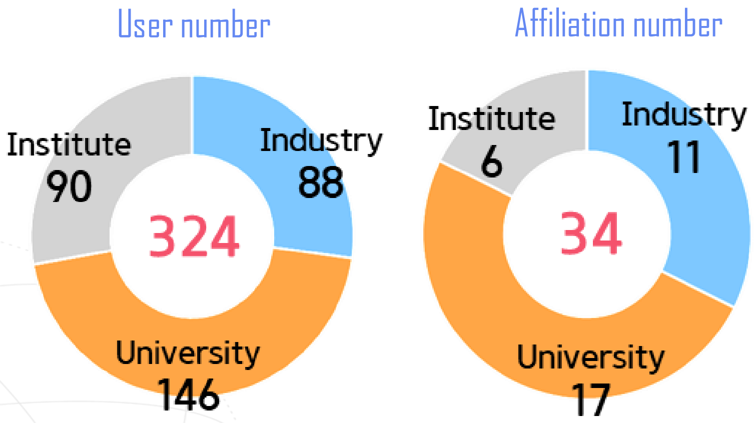
100 MeV Linac User Statistics

Korea Atomic Energy Research Institute
KAERI

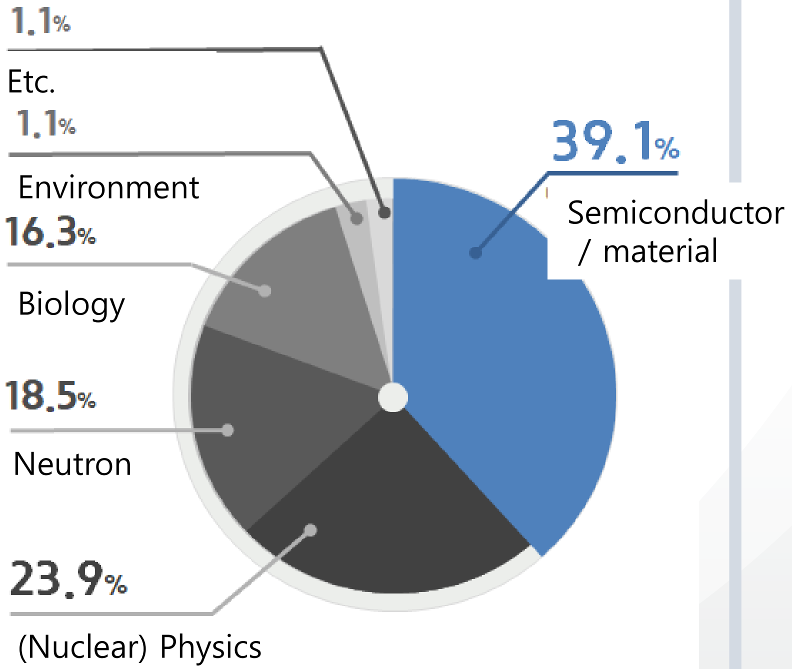
- Period: 2022.02.28. ~ 2022.12.30. (133 days / 28 weeks)
- Number of project: 95

20 MeV – 6 projects, 100 MeV – 89 projects

Affiliation

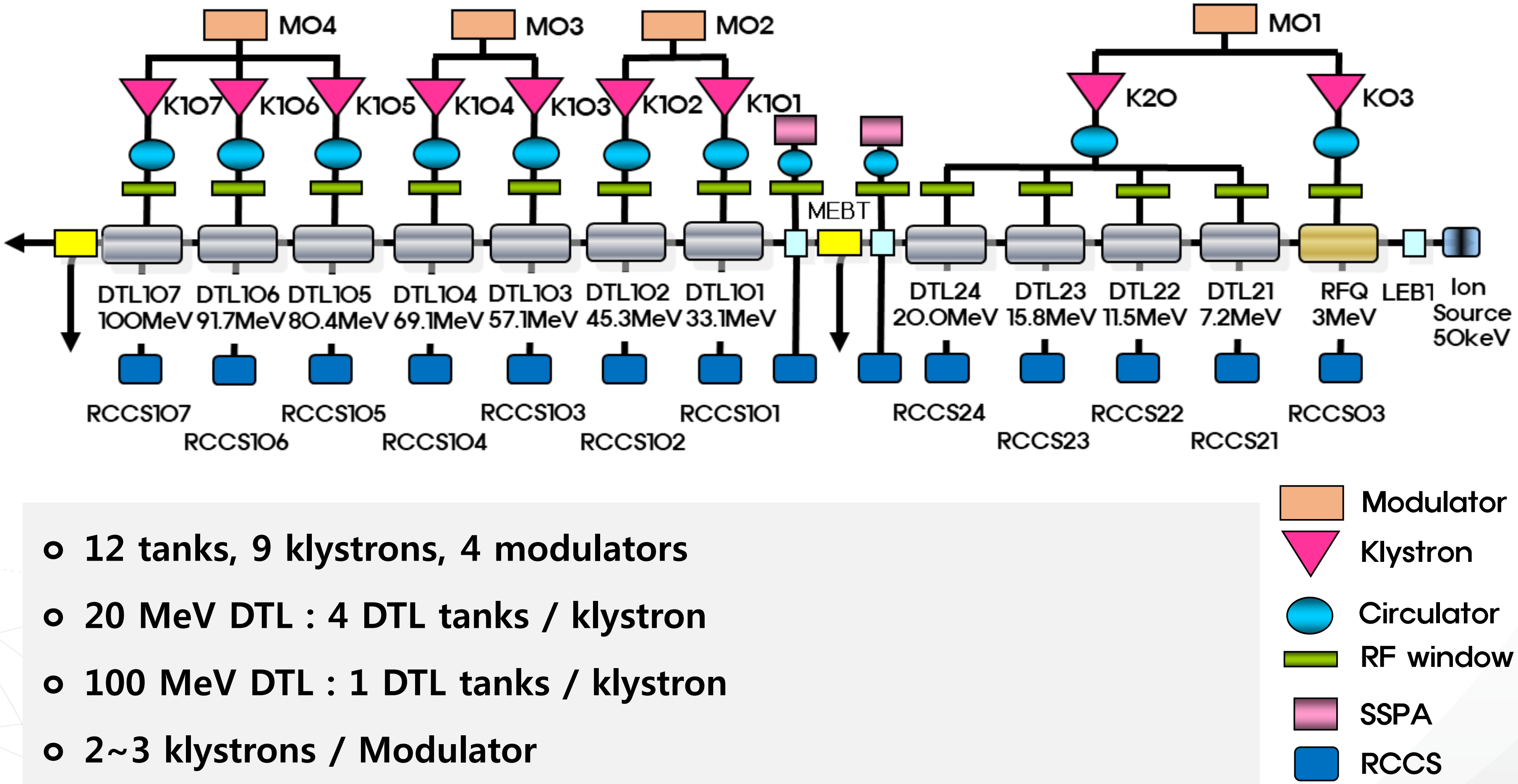


Field



100 MeV Linac RF System Layout

Korea Atomic Energy Research Institute



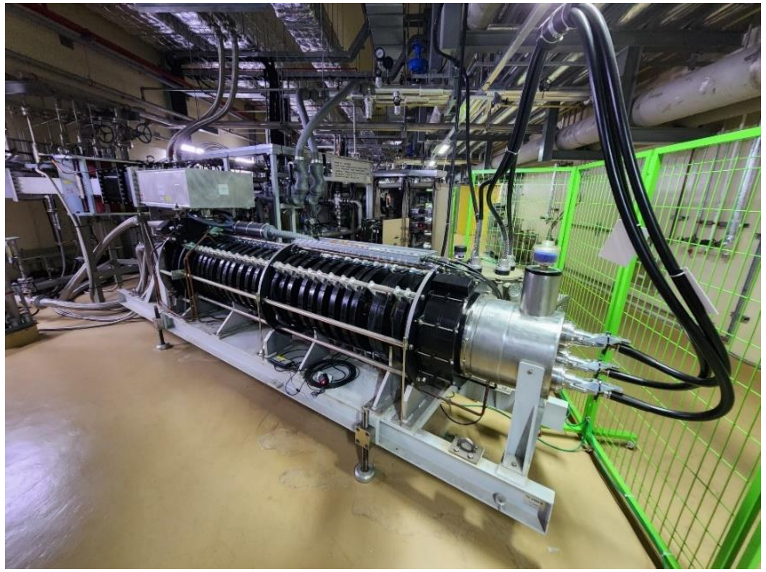
- 12 tanks, 9 klystrons, 4 modulators
- 20 MeV DTL : 4 DTL tanks / klystron
- 100 MeV DTL : 1 DTL tanks / klystron
- 2~3 klystrons / Modulator
- Resonant frequency control: Cooling water temperature by using RCCS (Resonant frequency control cooling system)

High Power RF System

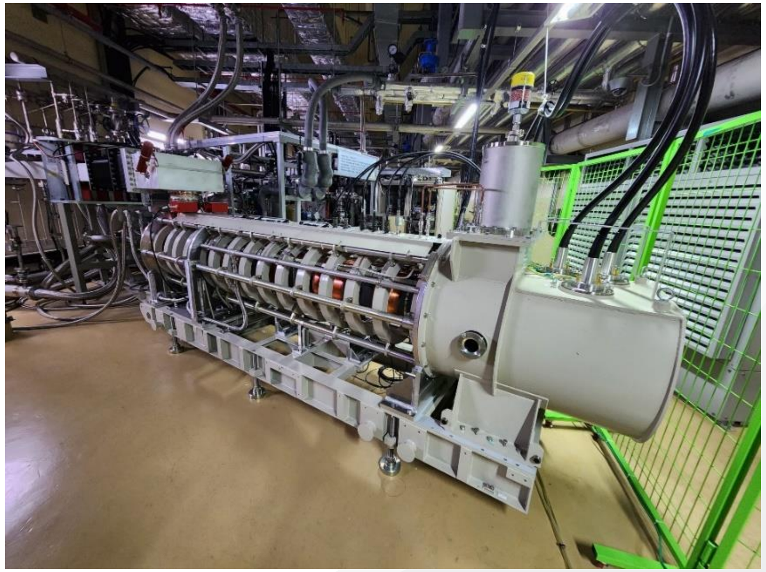
KAERI Korea Atomic Energy Research Institute

	Specifications	
Maker	THALES	Canon
Model	TH2089K	E37621
Frequency [MHz]	350	350
Peak RF output [MW]	1.6	1.6
Efficiency [%]	58	61
Gain [dB]	43	46.5
Pulse length [us]	1,500	1,500
Repetition rate [Hz]	60	60
Beam voltage [kV]	107	105
Anode voltage [kV]	54	88
Beam current [A]	26	25.9
Weight [kg]	2,500	2,790
Length [m]	4.9	5.3

- Two types of klystrons are used
  - TH2089K is modified version from CERN klystron
  - E37625 is modified version from J-PARC klystron
- Filament operation time > 60,000 hrs



THALES (TH2089K) klystron



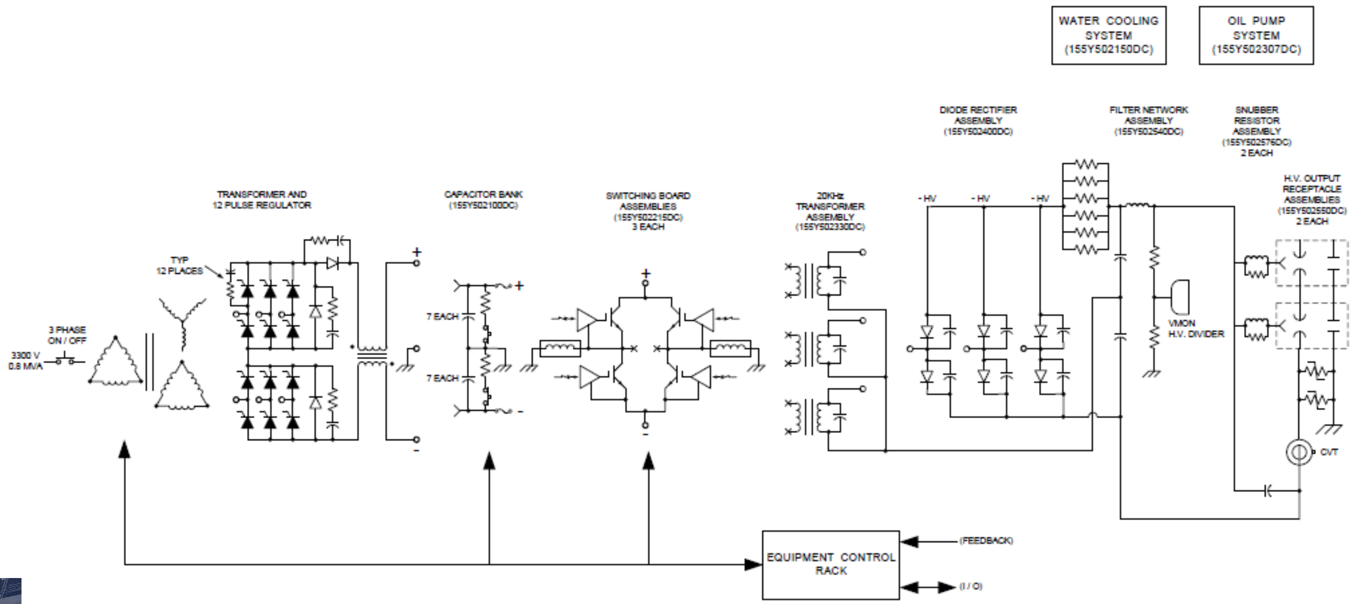
Canon (E37625) klystron

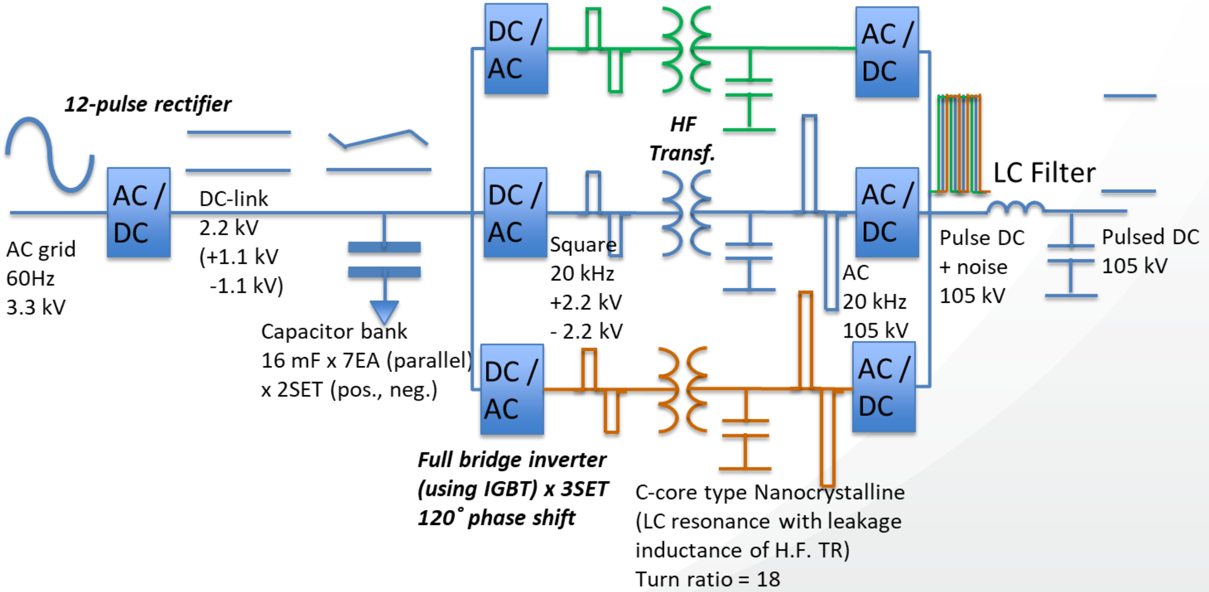
Klystron Modulator

KAERI Korea Atomic Energy Research Institute

Features of KOMAC Modulator

- Peak Voltage : -105 kV
- Peak Current : 53 A
- Pulse width : 1.5 ms
- Repetition rate : 60 Hz
- Duty cycle : 9% (1.5 ms, 60 Hz)
- Peak Power : 5.6 MW
- Average Power : 504 kW





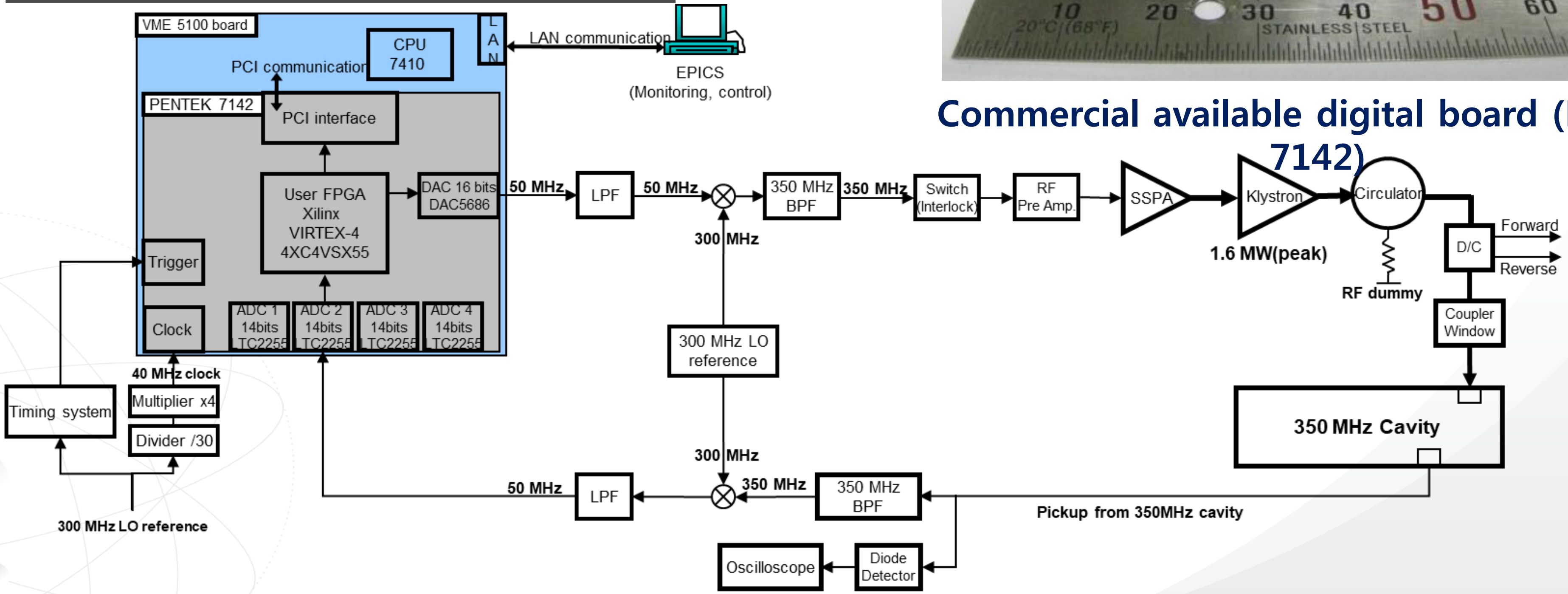
Low Level RF System

KAERI Korea Atomic Energy Research Institute

Features of KOMAC LLRF

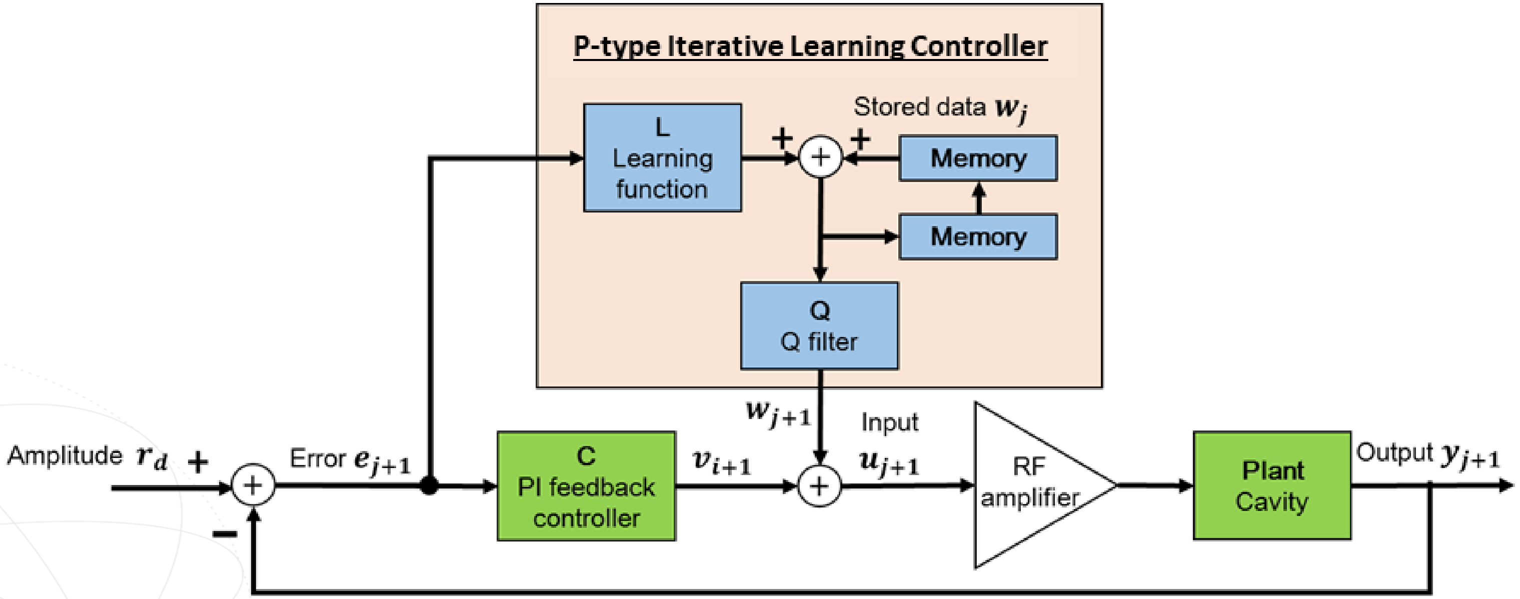
- FPGA : Xilinx Virtex-4
- ADC : LTC2255, 14 bit, 125 M/s max.
- DAC : DAC5686, 16 bit
- Manufacturer : Pentek (U.S.)
- Model : 7142-428
- IF Frequency : 50 MHz
- Lo Frequency : 300 MHz
- Sampling rate : 40 MHz (IQ sampling)

Commercial available digital board (PENTEK 7142)



Low Level RF System

- Iterative learning feed forward control was implemented to compensate beam loading effect
  - Feed-forward controller working parallel with feedback controller
  - Feed-forward table is updated based on the error iteratively

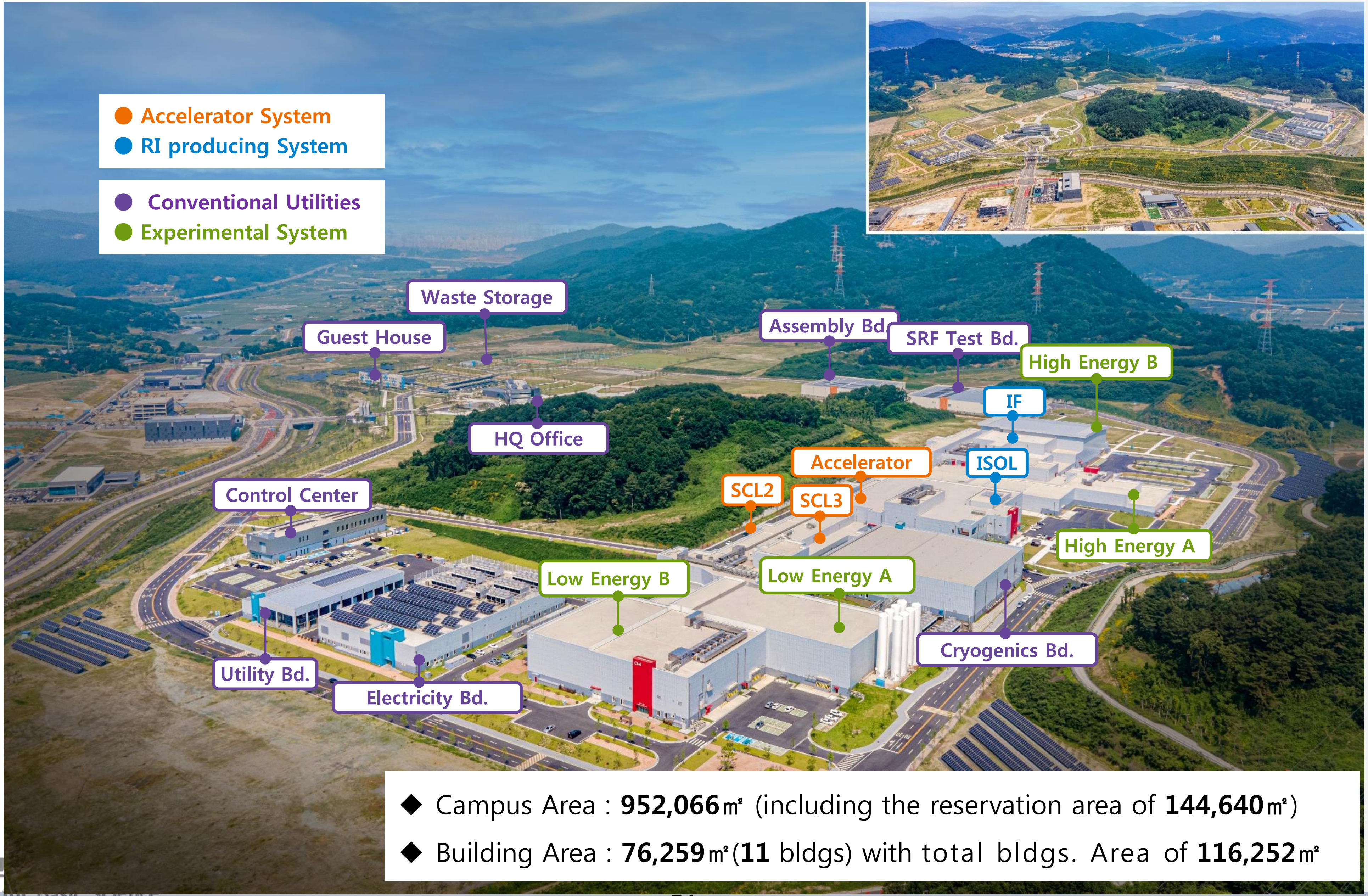


Poster ID : 102, Haeseong Jeong, et al., Development status of LLRF system for KOMAC

Status of RAON

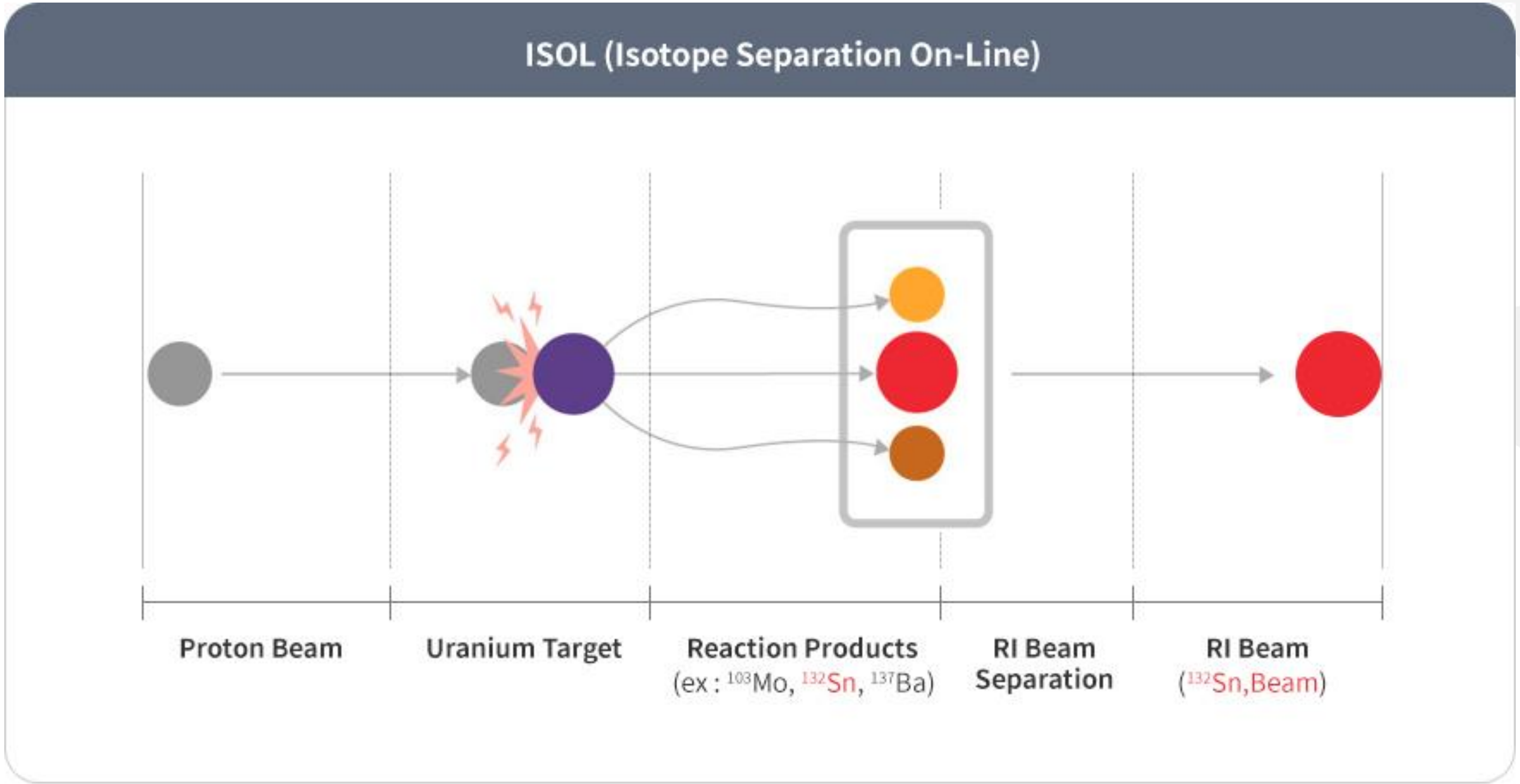
기초과학연구원
Institute for Basic Science

Rare isotope Accelerator complex for ON-line expreiements (RAON)



- Campus Area : **952,066**㎡ (including the reservation area of **144,640**㎡)
- Building Area : **76,259**㎡(**11** bldgs) with total bldgs. Area of **116,252**㎡

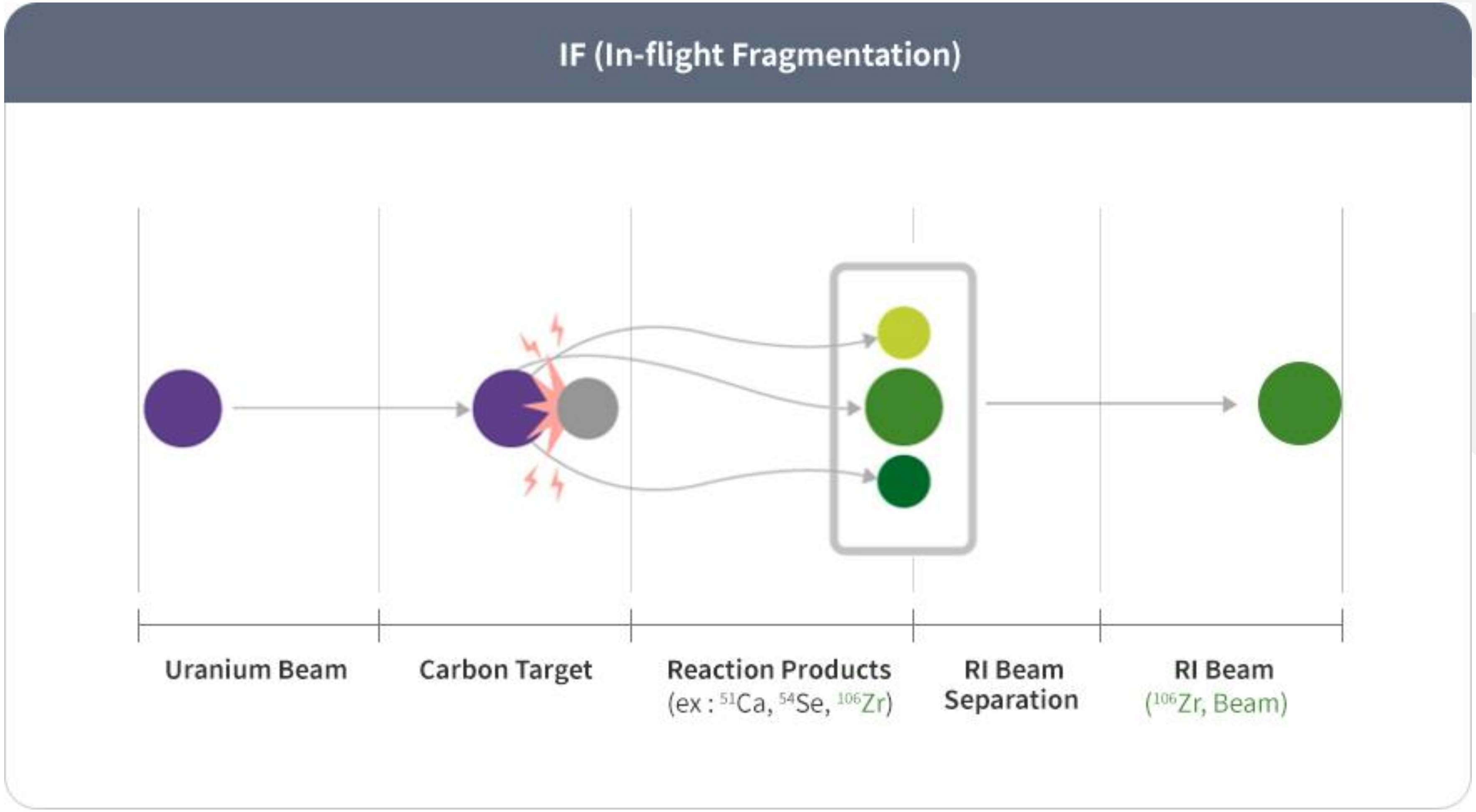
Isotope Separation On-Line (ISOL)



Acceleration of light atomic ions for collisions with heavy atomic targets

Production of large amounts of rare isotopes

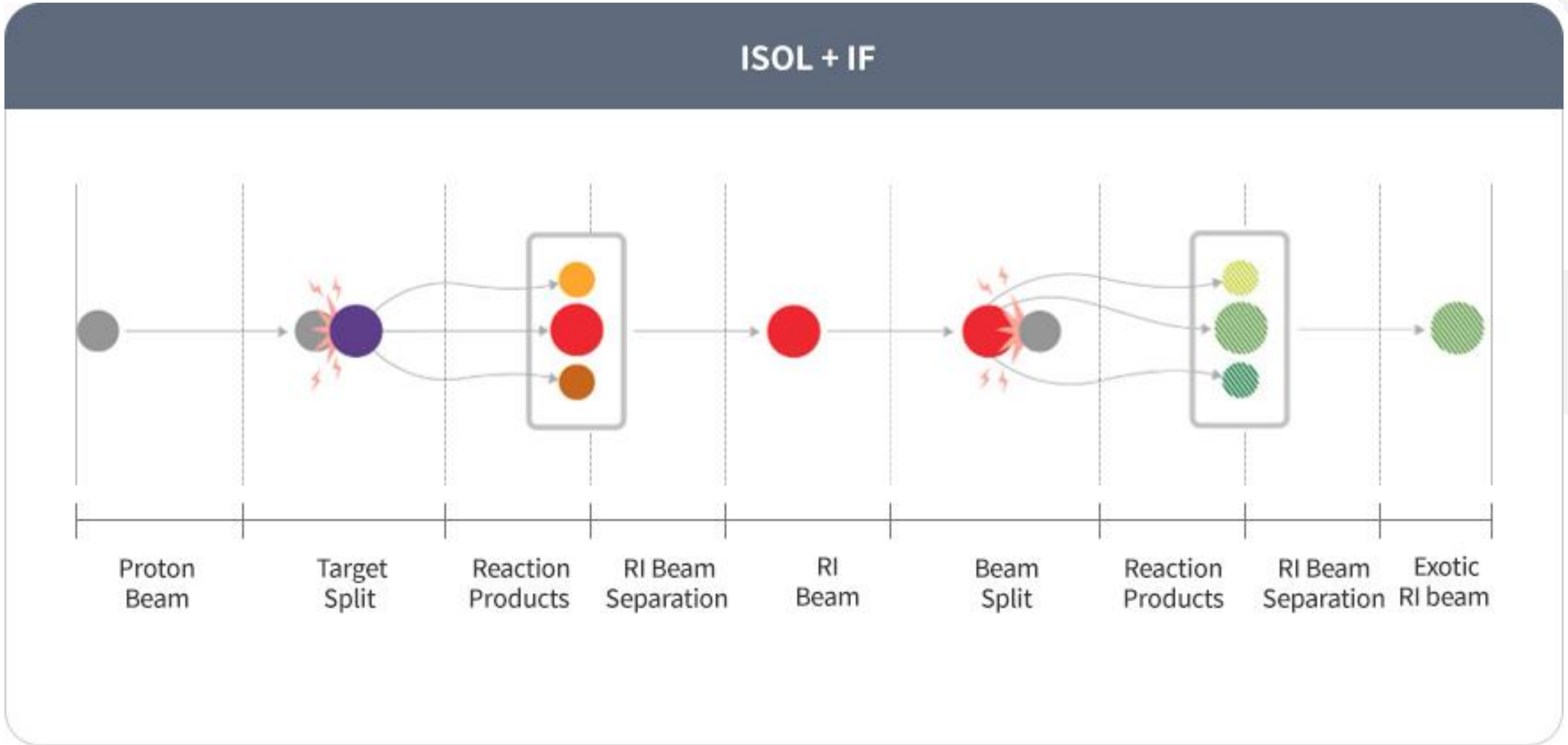
In-flight Fragmentation (IF)



Acceleration of heavy atomic ions for collisions with light atomic targets

Production of various rare isotopes

ISOL + IF

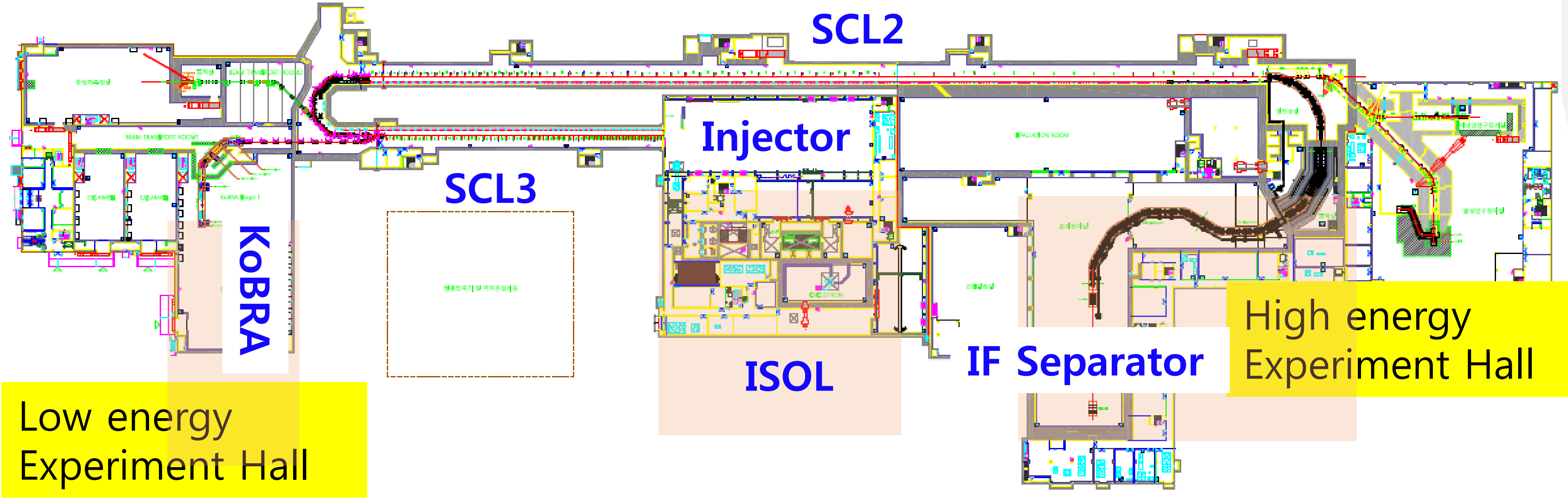


RAON will be the first kind of facility having ISOL and IF method combined

After producing rare isotopes with ISOL, RAON again accelerates them with IF

Rare Isotope Beam (RIB)

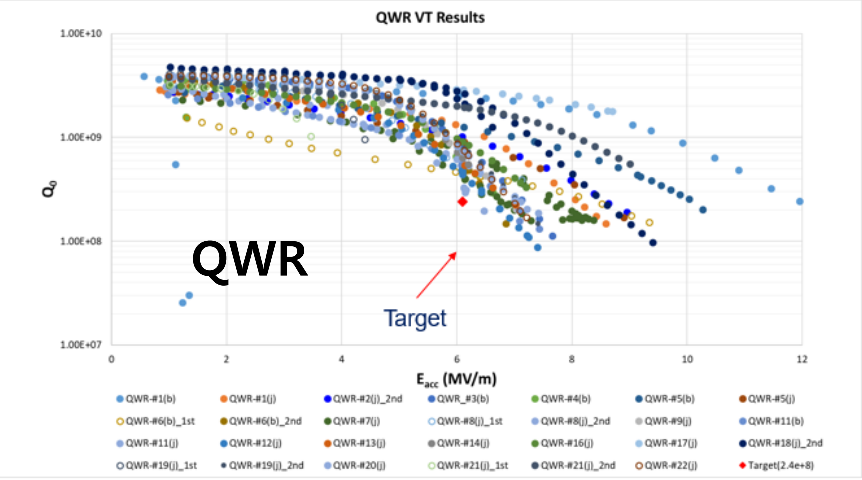
Driver Accelerator	SCL3 (ECR/ISOL)	SCL3 + SCL2	Cyclotron
Primary Beam Energy	80 MeV (p), 18 MeV/u (U)	600 MeV (p), 200 MeV/u (U)	< 70 MeV (p)
Experiment Facility	KoBRA, NDPS	In-flight Fragment Muon facility	ISOL



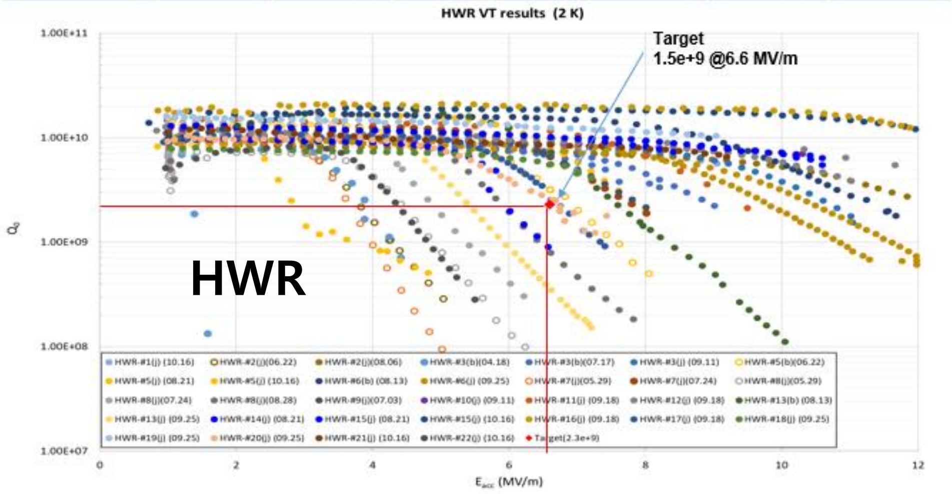
Accelerator Systems (Test Facility & Cavity Tests)

- SRF Test Facility: 3 Vertical Test Pits (3 cavities per pit), 3 Horizontal Test Bunkers
- Test all the RAON Cavities:
  22 QWR (82.25 MHz), 102 HWR (162.5 MHz) and SSR1,2 (325 MHz)

Frequency (MHz)	Optimum β	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



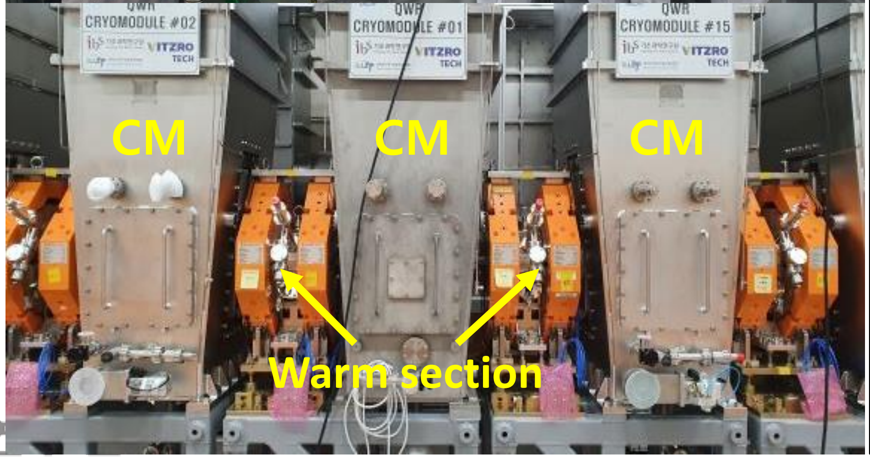
Frequency (MHz)	Optimum β	Eacc (MV/m)	Vacc (MV)	Q0	# of cavity	# of module	Op. temp (K)
162.5	0.12	6.6	1.46	1.5e+9	106	A/B = 14/19	2.05



Accelerator Systems (Low Energy Linac: SCL3)

Beam commissioning started in Oct, 2022

- Cryomodule(CM) & Warm section is assembled in the clean booth at tunnel
- Total Particle counts < 30 counts / 10 min (size > 0.5 um)



- SCL3 cryoplant (4.2 kW @ 4.5 K)

Compressors and Oil Removal System (WCS)

Cold Box(CB)

- SCL2 cryoplant (13.5 kW @ 4.5 K)

Compressors and Oil Removal System (WCS)

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

57

HPRF SSPA System

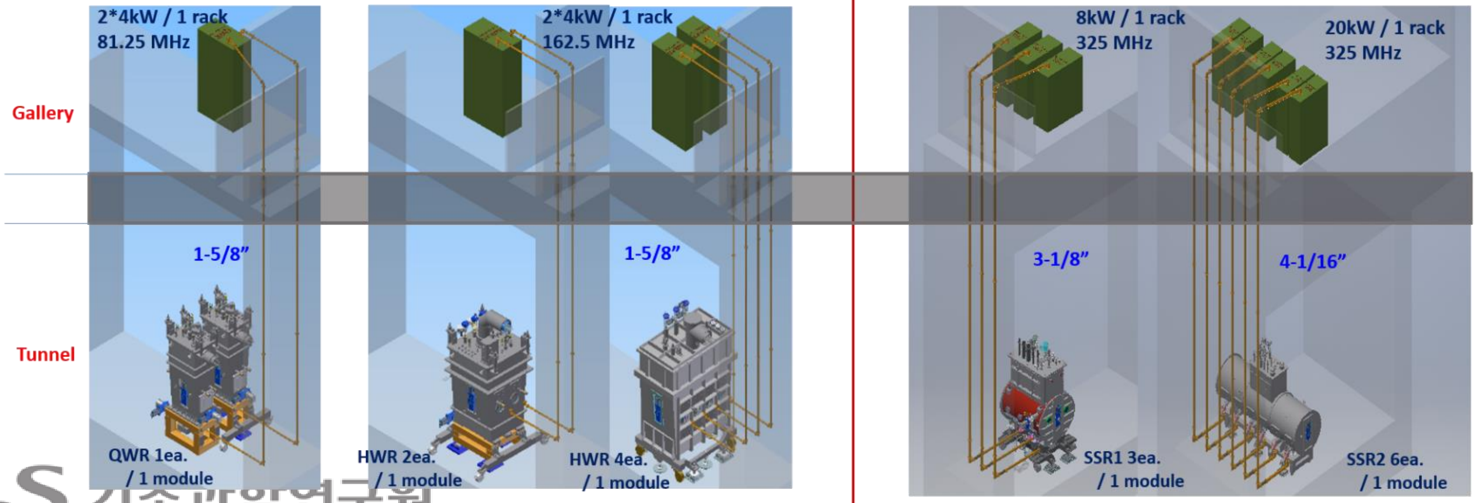
	Cavity	Quantity (EA)	Frequency (MHz)	RF Power (kW)	RF Transmission Line
SCL2	SSR1	69	325	8	3 1/8 inch EIA
	SSR2	144	325	20	4 1/16 inch EIA
SCL3	RFQ (NC)	1	81.25	160 (80*2)	6 1/8 inch EIA
	MEBT (NC)	4	81.25	20,15,4*2	3 1/8 inch EIA
	QWR	22	81.25	4	1 5/8 inch EIA
	HWR	102	162.5	4	1 5/8 inch EIA
P2DT & CSS	HWR	4 +2	162.5	4	1 5/8 inch EIA

Superconducting linac #3 (SCL3)

QWR (22 sets) **HWR-A** (26 sets) **HWR-B** (76 sets)

Superconducting linac #2 (SCL2)

SSR1 (69 sets) **SSR2** (144 sets)



SSPAs for Injector (RFQ, MEBT)
: 150kW, 81.25MHz

SSPAs for SCL3 :4kW, 124 sets

SSPAs for SSR1 :8kW, 69 sets

High Power RF System

□ System characteristics (Solid State Power Amplifier, SSPA)

Parameters	Unit	Value	Remark
Frequency range (QWR/HWR)	MHz	QWR: 81.25 ± 1 HWR: 162.5 ± 1	1dB compression
Power (CW and pulse)	kW	4 kW @ 0 dBm input	with any VSWR
I/O impedance	ohm	50	
Gain linearity	dB	< 6 (-20dB range) < 3 (-10dB range)	within specified range from m ax
Input return loss	dB	< -20	
Stability - Phase	degree	1	water temp. 25±1 ^{o}C
Stability - Power	%	1	water temp. 25±1 ^{o}C

HPRF & LLRF in Galley

□ Status

- Installation of all 22 QWR, 106 HWR SSPAs
- Test of each unit was finished
- Supported SCL beam commissioning

Low Level RF System

□ Characteristics

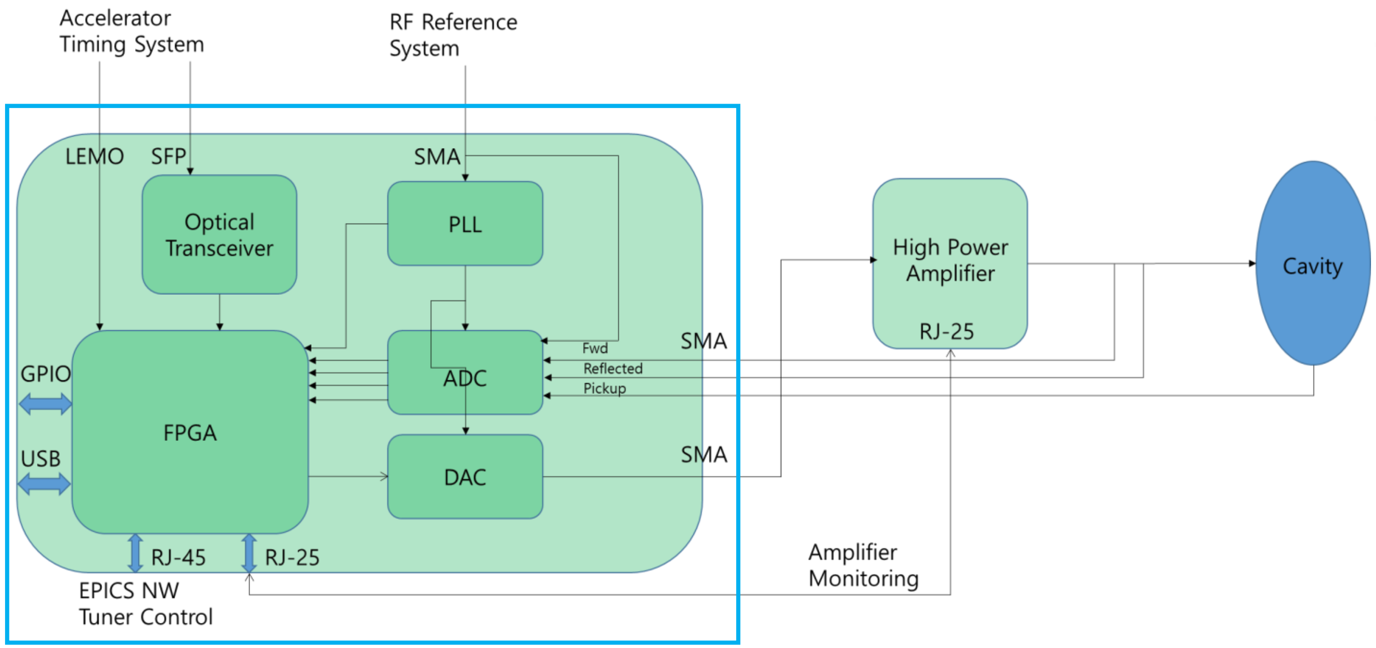
Digital LLRF based on FPGA

Each cavity owns its LLRF, one by one

Integrated SRF control & operation system including OPI with EPICS (RF feedback, interlock, protection, quench detection, monitoring, DAQ)

Pulse conditioning system for coupler and cavity

Specification	
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

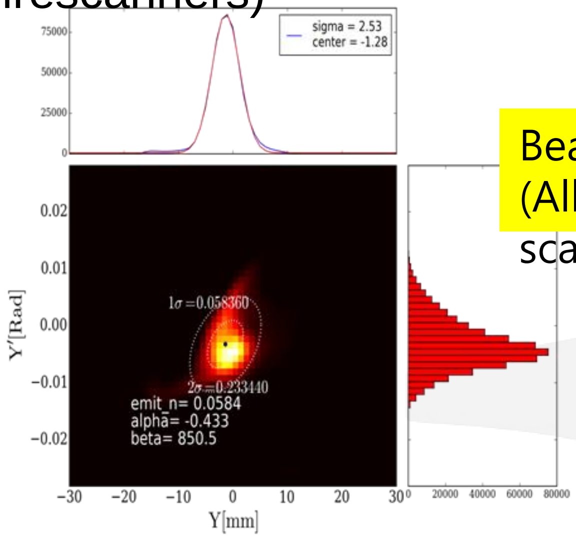


LLRF I/O Interface

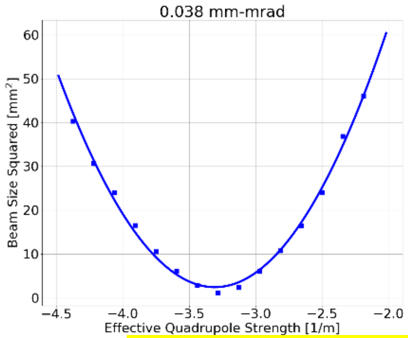
Production LLRF

Beam Commissioning (Injector)

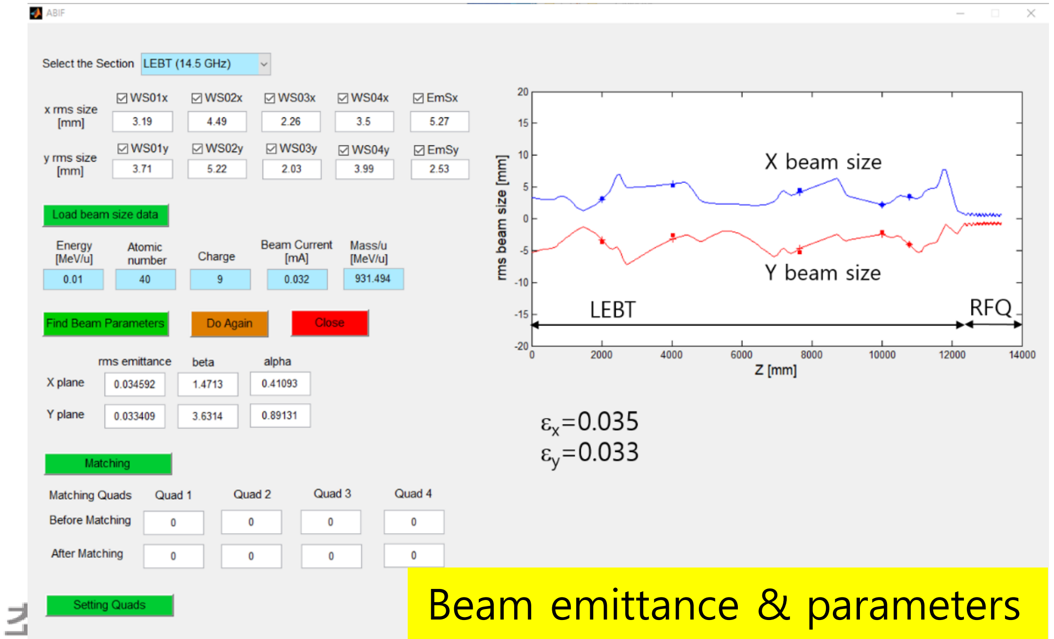
- Beam parameter measurements (Allison scanners, wirescanners)
  - measuring initial beam parameters (beam sizes)
  - controlling beam optics
- Emittance measurement (Allison scanner, quad scan)
- Beams: Ar^{9+} (~30μA), Ar^{8+} (~47μA)



Beam emittance (Allison scanner)



Quad scan (beam emittance)

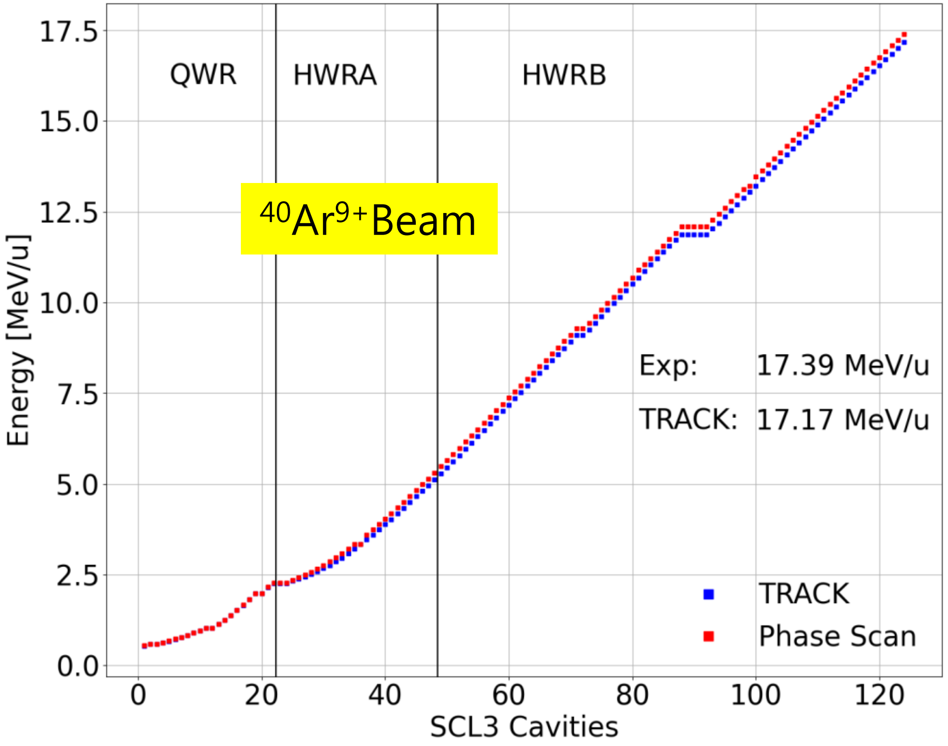


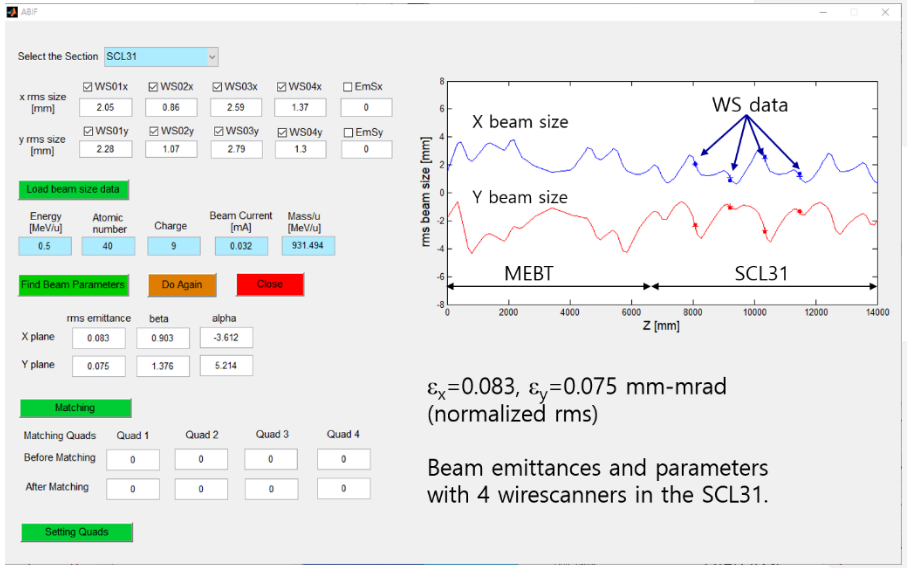
Beam emittance & parameters

Emittance comparison

	X	Y
Allison	0.048	0.067
Quad Scan	0.041	0.038

Beam Commissioning (Low Energy Linac: SCL3)





beam emittance & parameters using wirescanners

- Beam commissioning of the 1st superconducting linac in Korea.
- SCL3 commissioning was done in May 2023, achieving 17.4 MeV/u ($^{40}Ar^{9+}$).
- Achieved beam transmission was 64%.

High Energy Superconducting Linac (SCL2 R&D Project)

- ❖ SCL2 R&D Project : 2022. 12. 01. – 2025. 12. 31.
- ❖ Budget : ~$10 M USD (₩12,592 M KRW)
- ❖ Goal : Prototyping, preproduction and SRF Test Facility upgrade

SCL2 R&D Project
(2022.12~2025.12)
→
SCL2 construction
(2026~)

Preproduction/standardization

- 1 set of SSR1, 2 cryomodule
- Vertical / Horizontal Test
- Preproduction verification

Construction/commissioning

- SSR1 (23 sets), SSR2 (25 sets)
- Mass production
- Horizontal Test
- Installation / commissioning

Thanks to:

All members in PLS-II, PAL-XFEL, KOMAC and RAON