New 4th Generation Synchrotron Radiation Source in Korea

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On behalf of 4GSR project team, KBSI and PAL

22 Nov. 2024

POHANG ACCELERATOR LABORATORY

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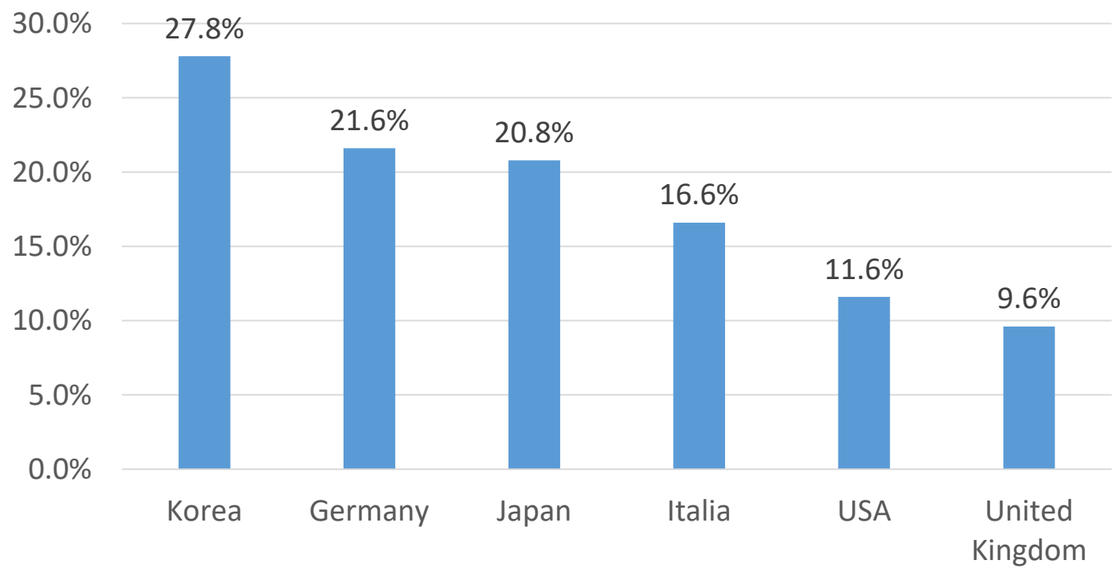
Talking about

- ❖ **Why another light sources in Korea ?**
- ❖ **Project Overview**
- ❖ **Site & Building**
- ❖ **Accelerator Characteristics**
- ❖ **Beamline Plan**

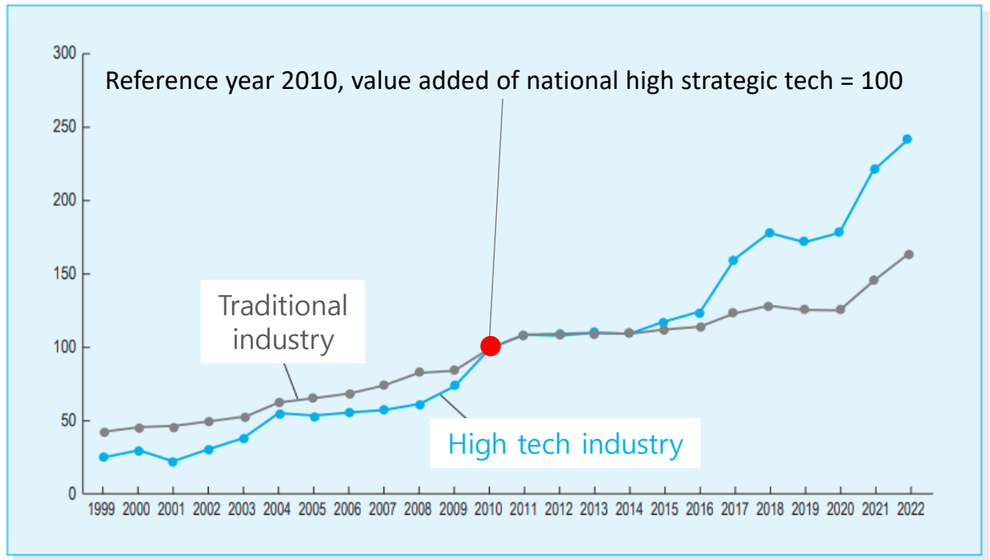
R&D in Korea, one of the driving force for national production

- Rare natural resources
- Less available land with respect to total area of country, less than 30%
- High population density, 516 peoples/km^2 and total 52M peoples only for south Korea.
- Big share ratio of Manufacturing to National Gross Production, 28.8 %.
- **Then, R&D is the key support for industrial production in Korea**

Ratio of Manufacture to National Gross Production



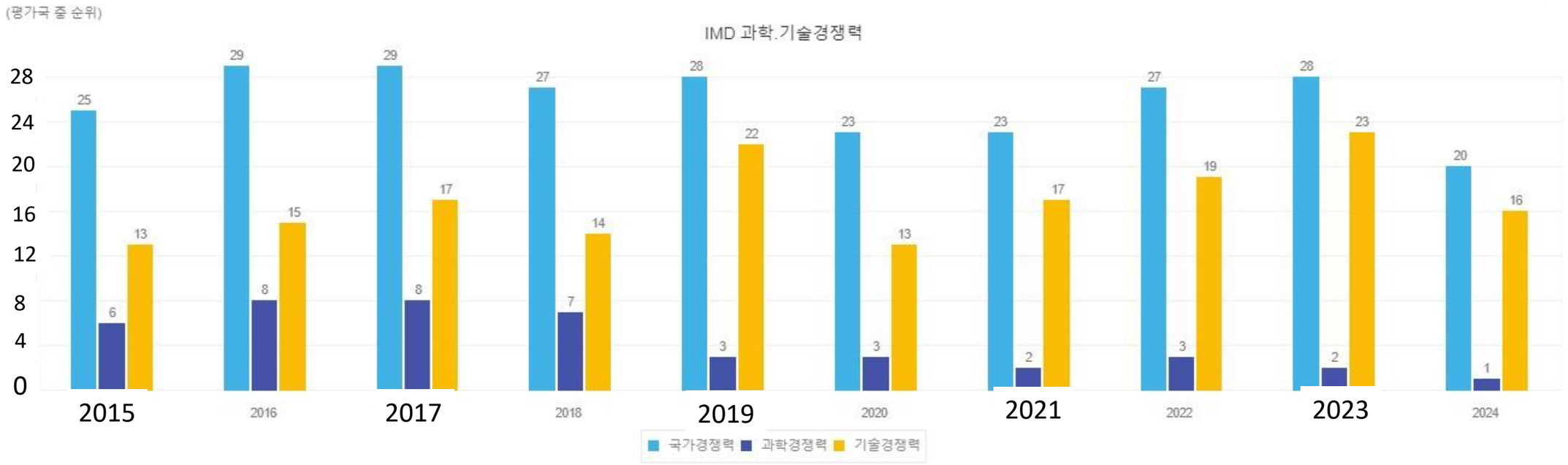
Comparison of added value in Korea between national high strategic tech(**Semiconductor, battery, Display, Bio**) . and traditional tech.



Importance of Science and Technology in Korea

The IMD World Competitiveness of Science and Technology

IMD : International Institute for Management Development



National gross Competitiveness

Science Competitiveness

Technology Competitiveness

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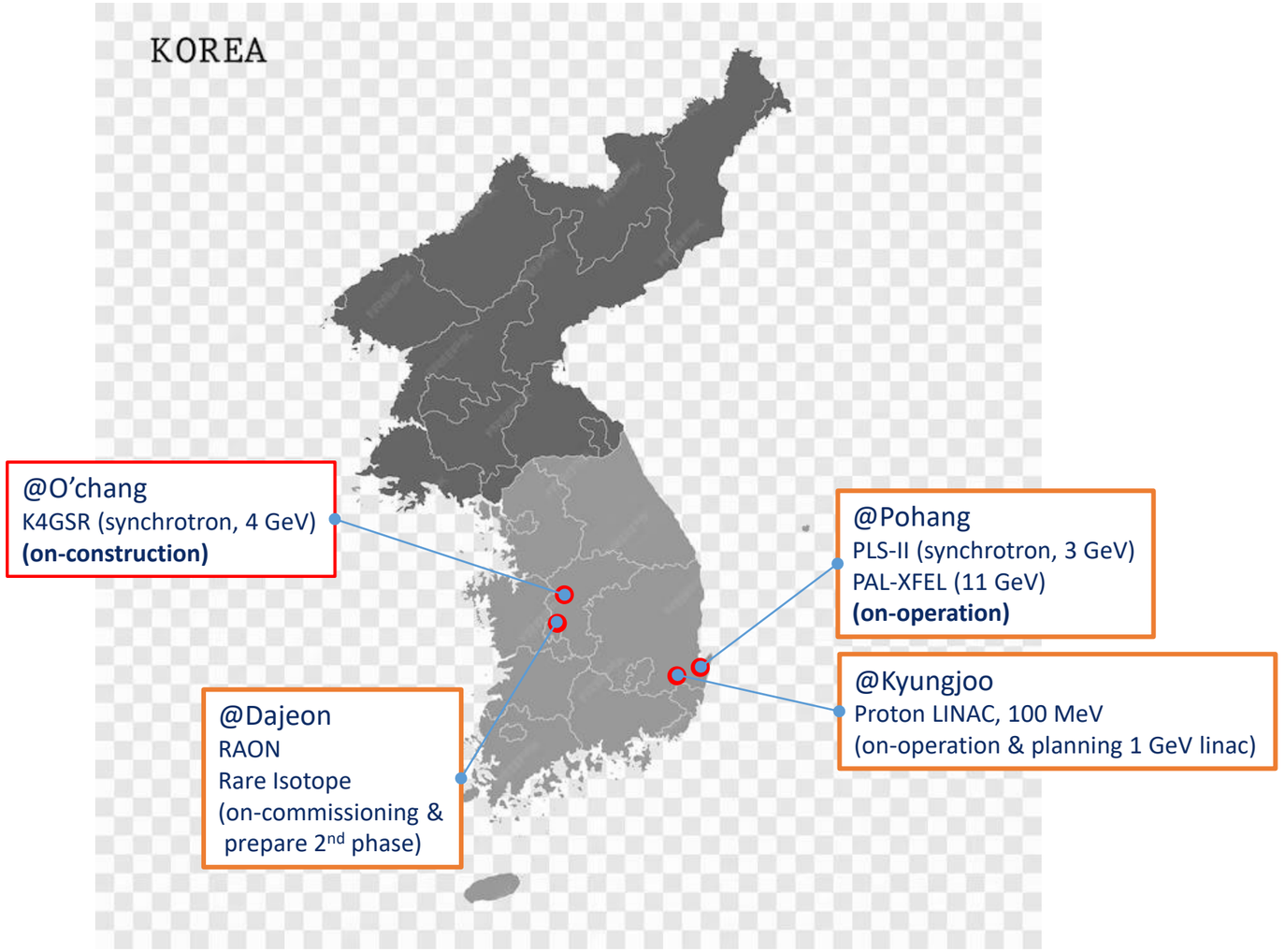
4 Large-scale Accelerators in Korea

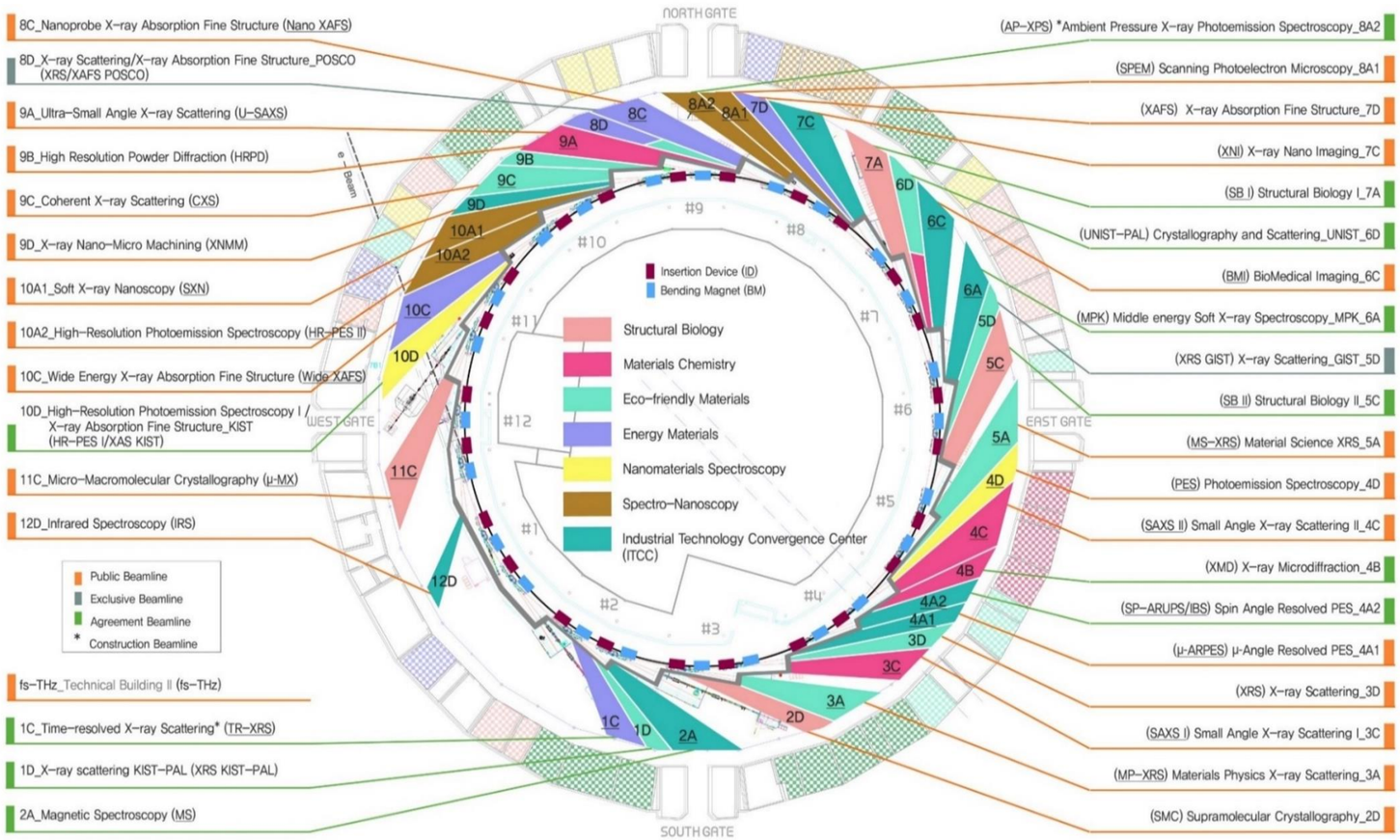
❖ **3 Large Scale Accelerators**
- **RAON(heavy ion)**
- **PLS-II**
- **PAL-XFEL(electron)**
- **KOMAC(proton)**

❖ **2 Large Scale Accelerators On-construction & plan**
- **4GSR O'Chang**
- **KOMAC upgrade(plan?)**



PLS-II, synchrotron

PLS-II, a 3rd Gen. Synchrotron Radiation



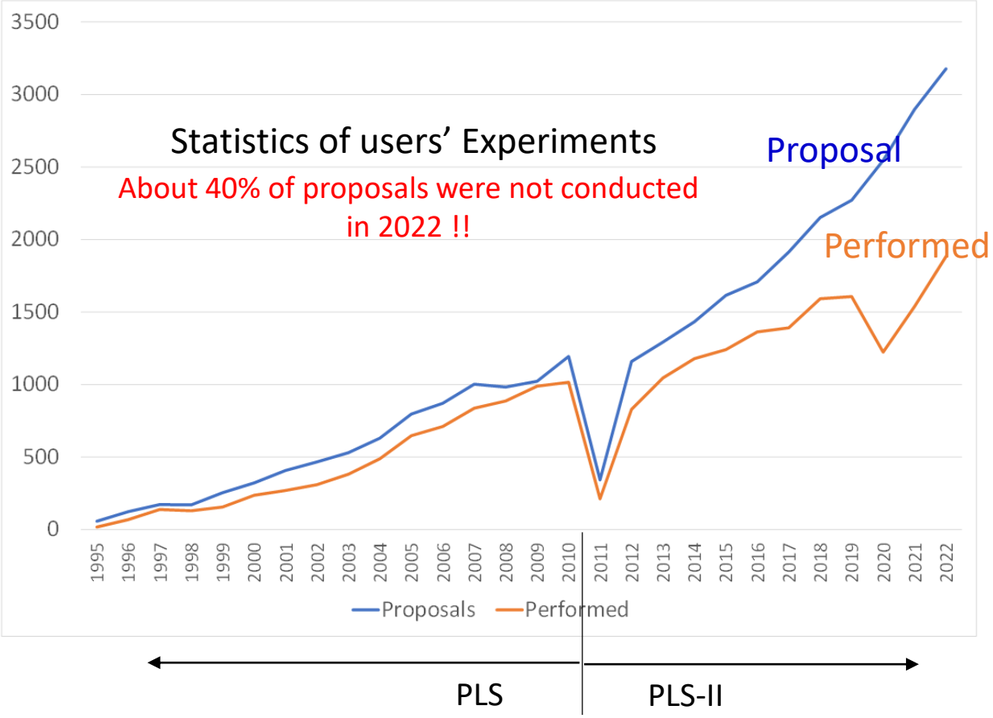
@Hyun-Whi Lee, 22nd International Advisory Committee Meeting (November 13-14, 2023)

Storage Ring

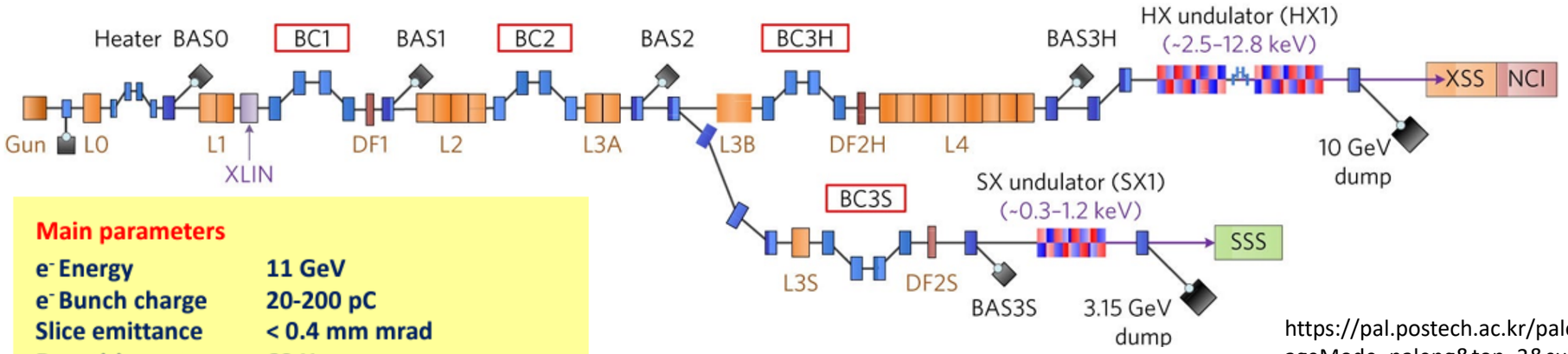
- Electron beam energy: **3 GeV**
- Ring current: **400 mA, Top-up mode**
- User beamtime: 190 days/year

Beamline Map (36 BLs)

1 renovation / 1 new



PAL-FEEL



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
Und. Period / Gap [mm]	26 / 8.3	35 / 9.0

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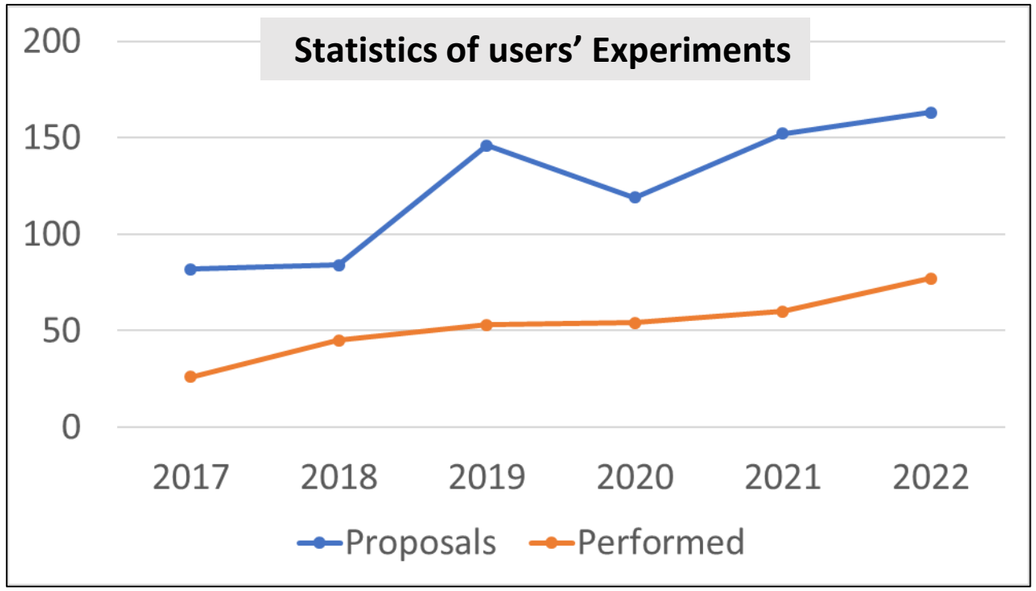


@Chi Hyun Shim, 2024 Spring EPICS Collaboration Meeting

Project Overview

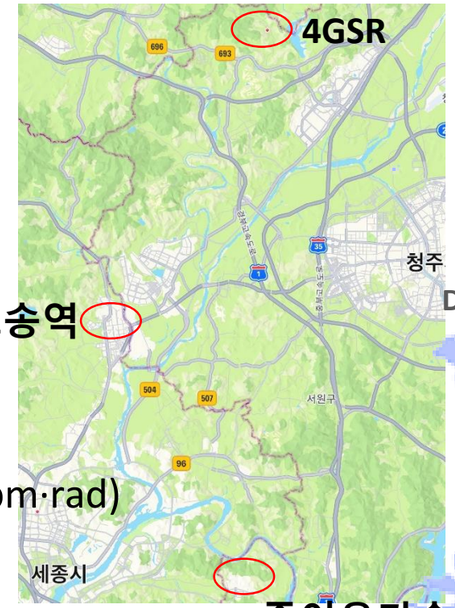
Korea 4th Generation Synchrotron Radiation Facility

❖ **Multipurpose Synchrotron Radiation Construction Project (다목적방사광가속기 구축사업)**

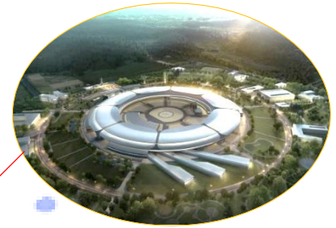
- Period: 2021 July to 2029 December
- Budget: 1.0454 Trillion KRW (≈ USD 750M)
- Land: 540,000 ㎡ / Building: 69,400 ㎡
- Location: Ochang, Chungcheongbuk-do

❖ **Characteristics**

- Beam Energy: 4 GeV
- Beam Emittance: less than 100 pm·rad (TDR: 62 pm·rad)
- Circumference: 800m
- Beamlines : more than 40
- Accelerator: Gun, Injector LINAC, 4 GeV Booster and Storage Ring
- Lattice: Hybrid 7 Bend Achromat (H7BA)
- Normal conducting RF cavity and 500 MHz

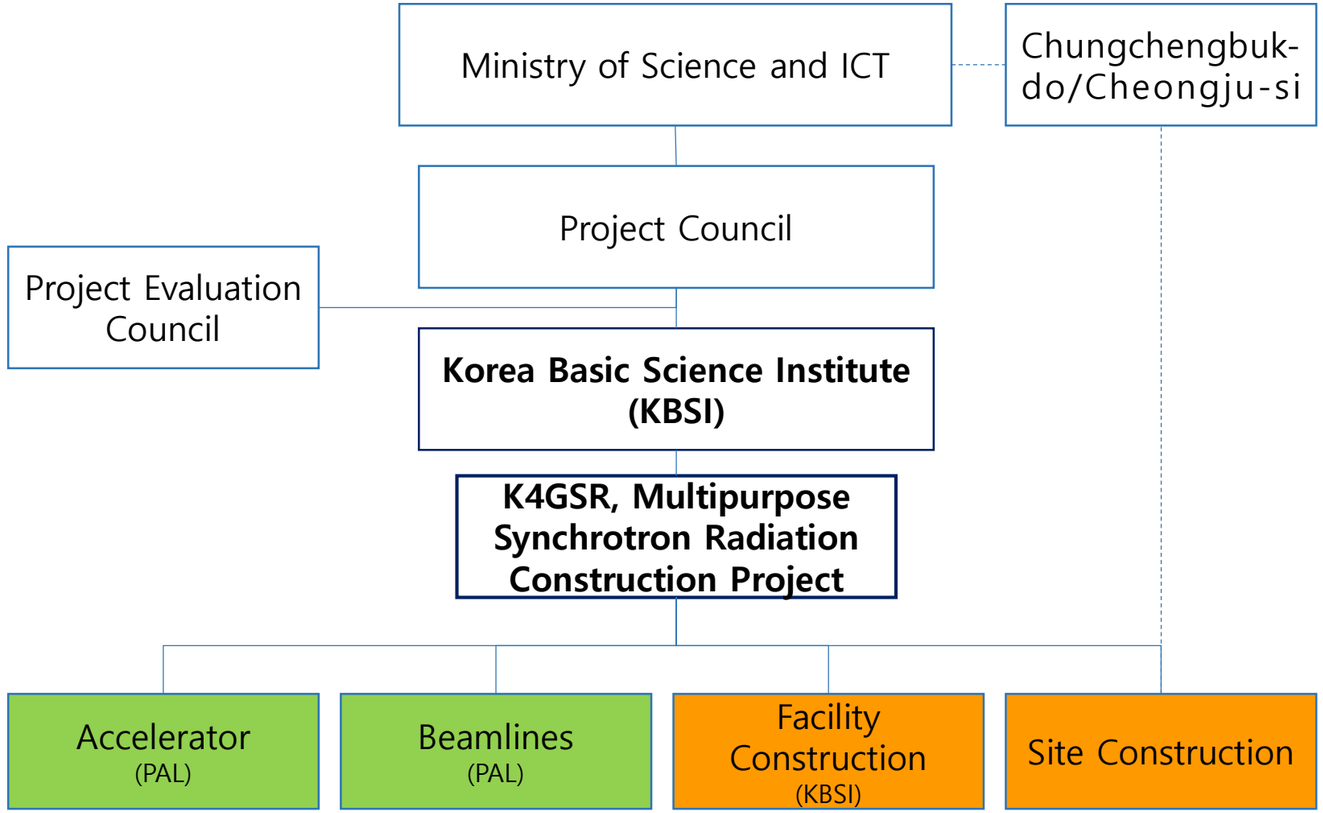


O'chang
(industrial city mainly for bio-pharmacy, semiconductor and battery)



Pohang
(industry-R&D city mainly for science, steel and battery)

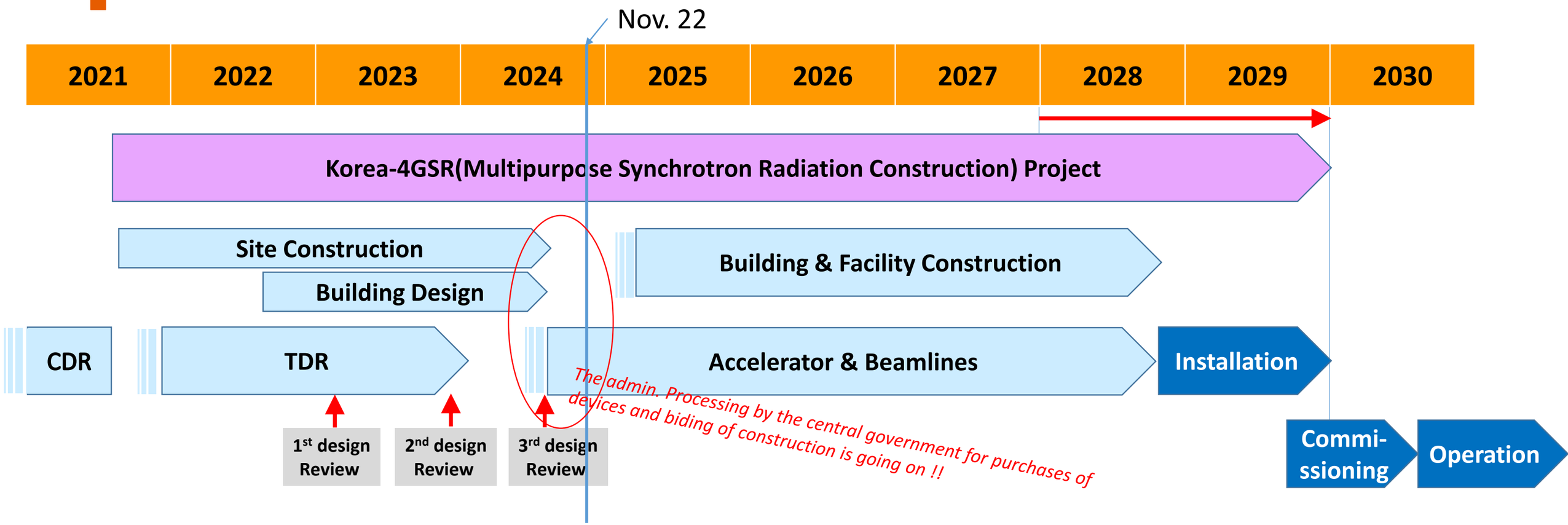
Project Governance



KBSI is the leading institute to carry out the project.
→ Responsible for **Facility Construction and Project Management**

PAL is joining as the collaborate partner.
→ Responsible for **Accelerator and Beamline construction**

Project Timeline



- As a total cost controlled project, this project requires official design reviews (with budget) by the Government in 3 stages.
- Among 3 stages, the 3rd design review was completed in July 2024. At the present, the finalizing the project budget and schedule is on processing.

Features of Korea 4GSR

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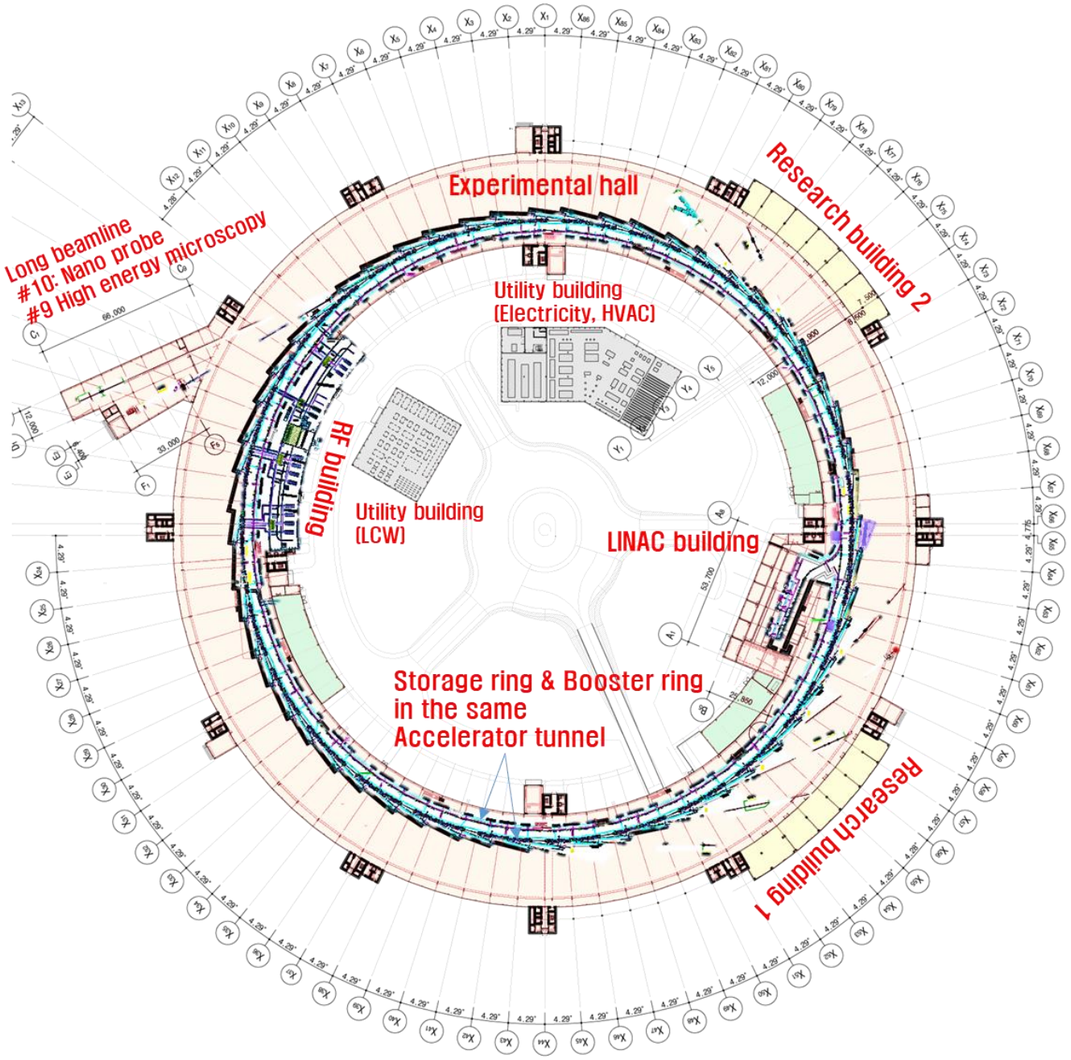
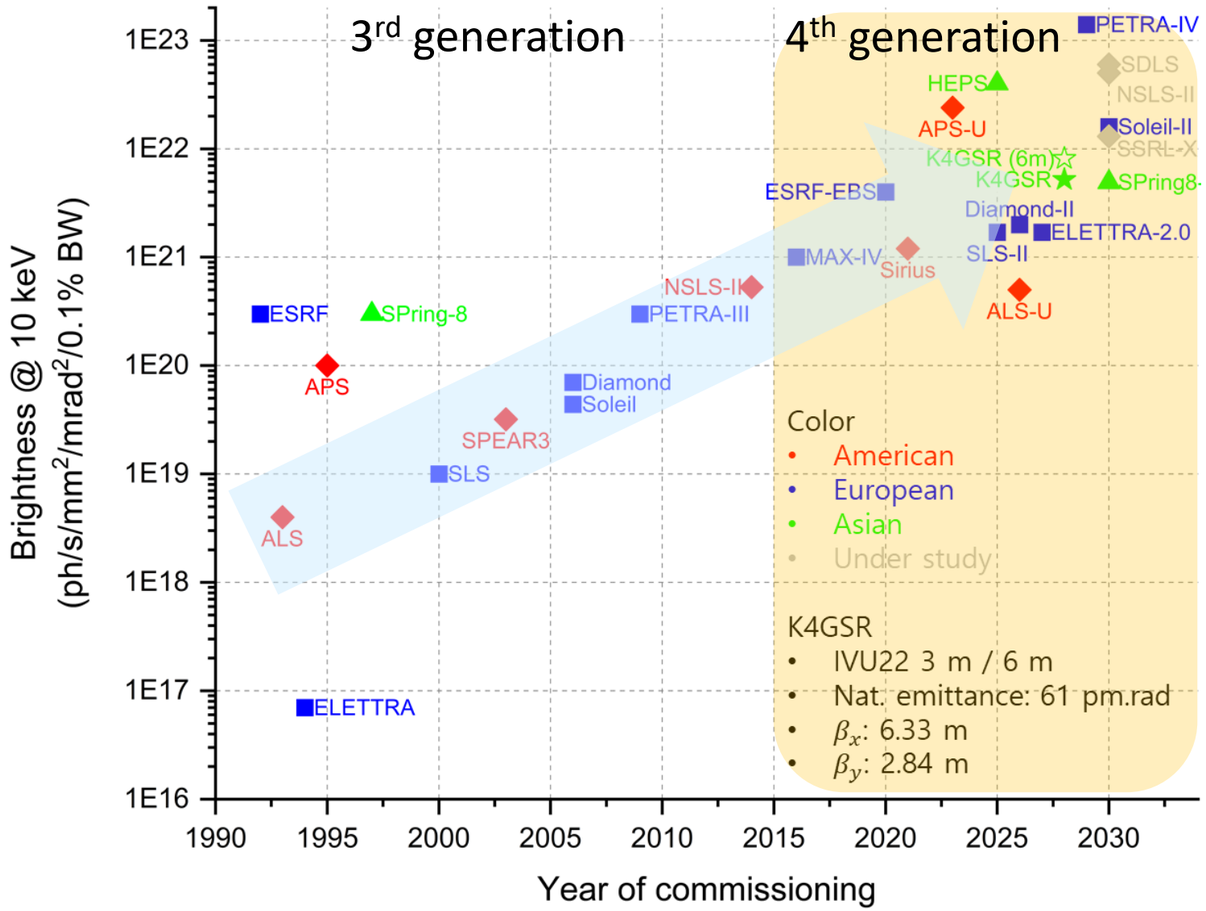
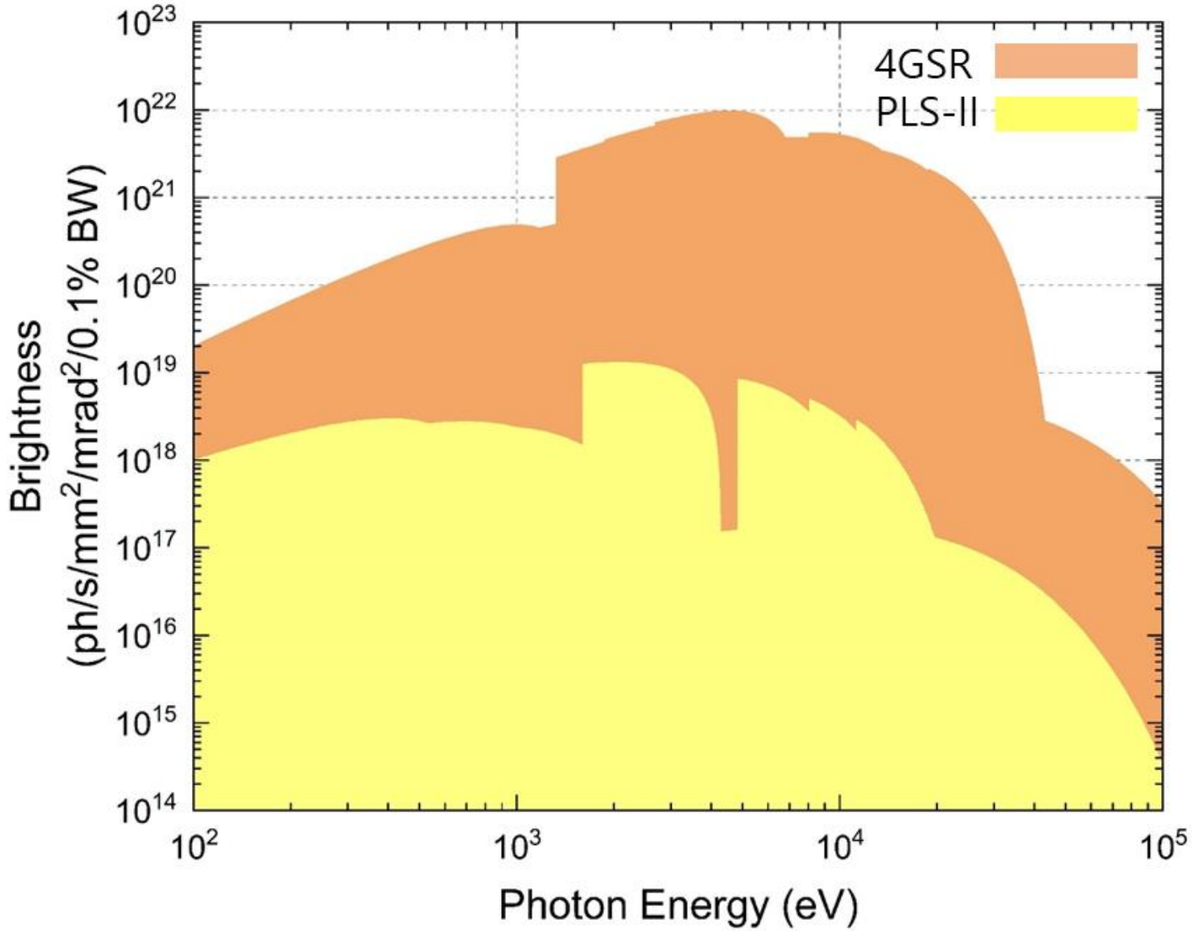
- **Characteristics of photon beam**
  - Optimal performance in the range of 10 – 30 keV
  - Photon energy up to 100 keV
- **Synergy with PLS-II and PAL-XFEL**
  - Wide coverage of energy spectrum for synchrotron radiation applications in Korea
- **Utilization of validated technologies for the accelerators and beamlines**
  - Inject 200 MeV LINAC and booster ring
  - Conventional injection scheme, off-axis injection with 4 kickers system in the storage ring as baseline design
  - General technologies for magnets, RF and vacuum systems, but new or advanced technologies for beam instrumentations, control, …
  - On schedule user service and full performance within 3 years from beam commissioning



Brilliance

Low emittance(small beam size) → High Brilliance
100 times smaller emittance than PLS-II





Site & Building

Site

23.01.13

23.05.31

23.06.07

23.06.27

23.08.08

23.09.07

23.10.04

23.11.02

23.12.12

24.06.30

Current Status of the Site

24.11.19

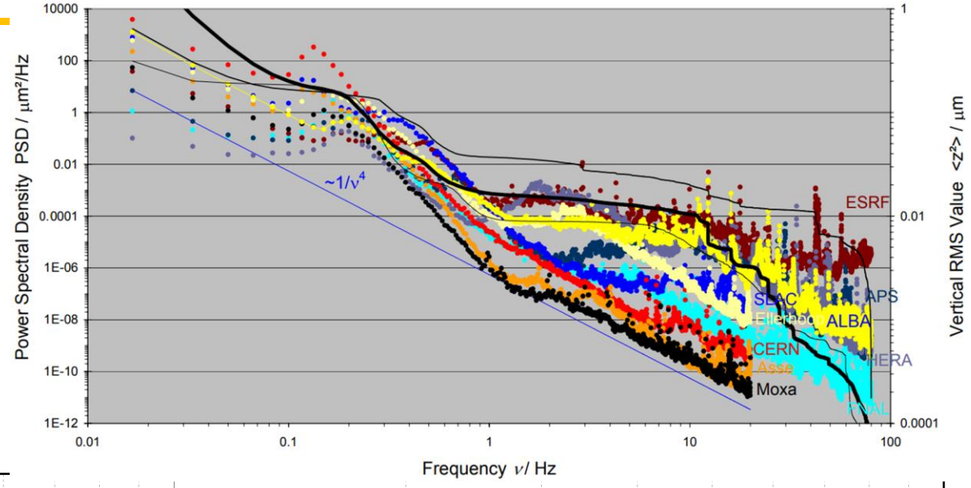
Complete Site Preparation, August 1st, 2024

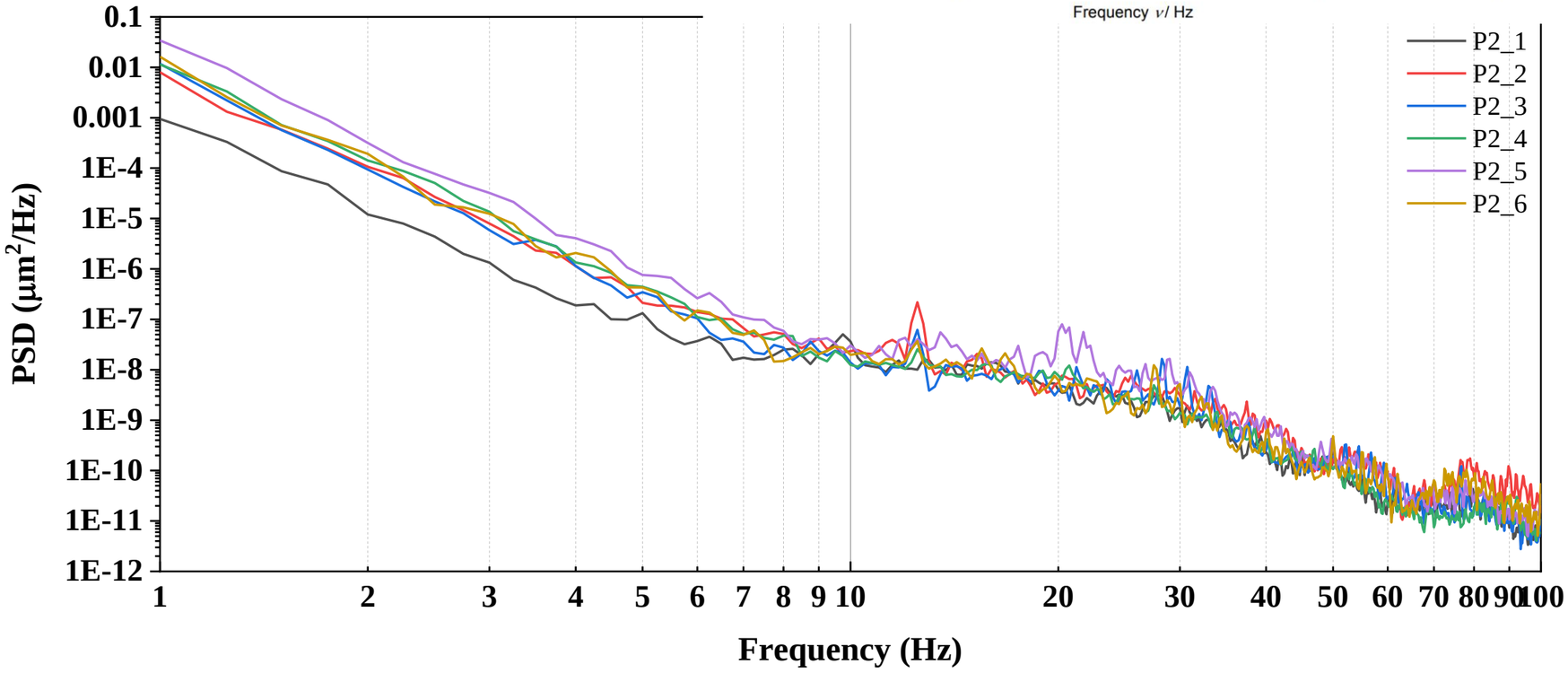
Vibration on Site

❖ **Vibration measurement**

- 6 times on same position
- Dump truck and excavator breaker in operation during measurement

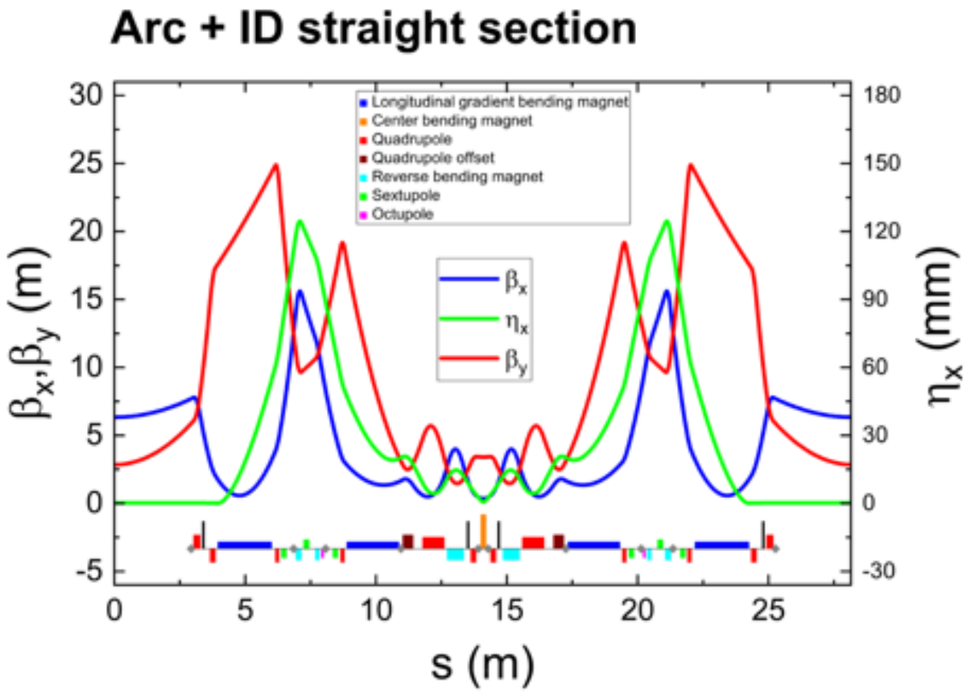
❖ **Smaller vibration, compared with other facilities**

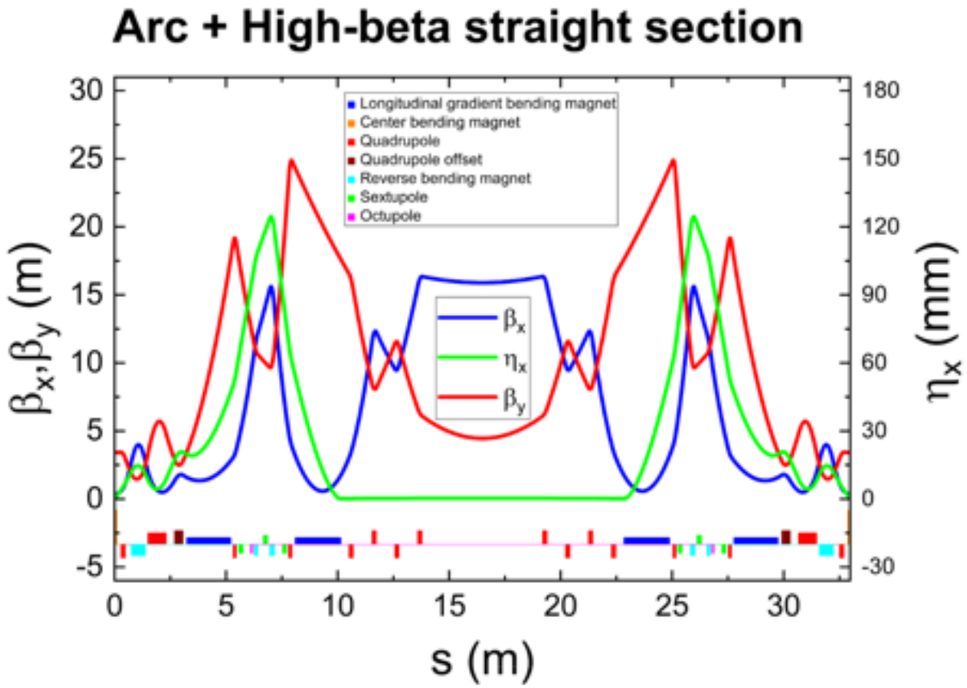




Accelerator

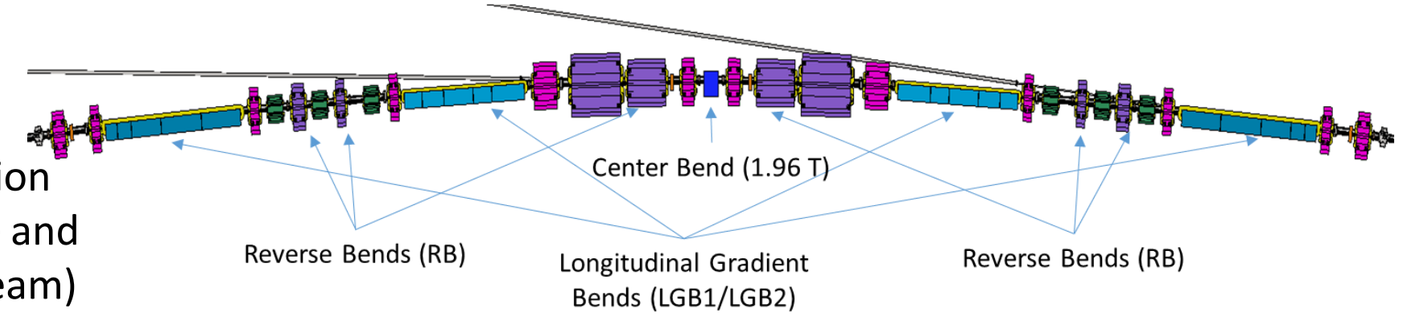
Lattice of Storage Ring



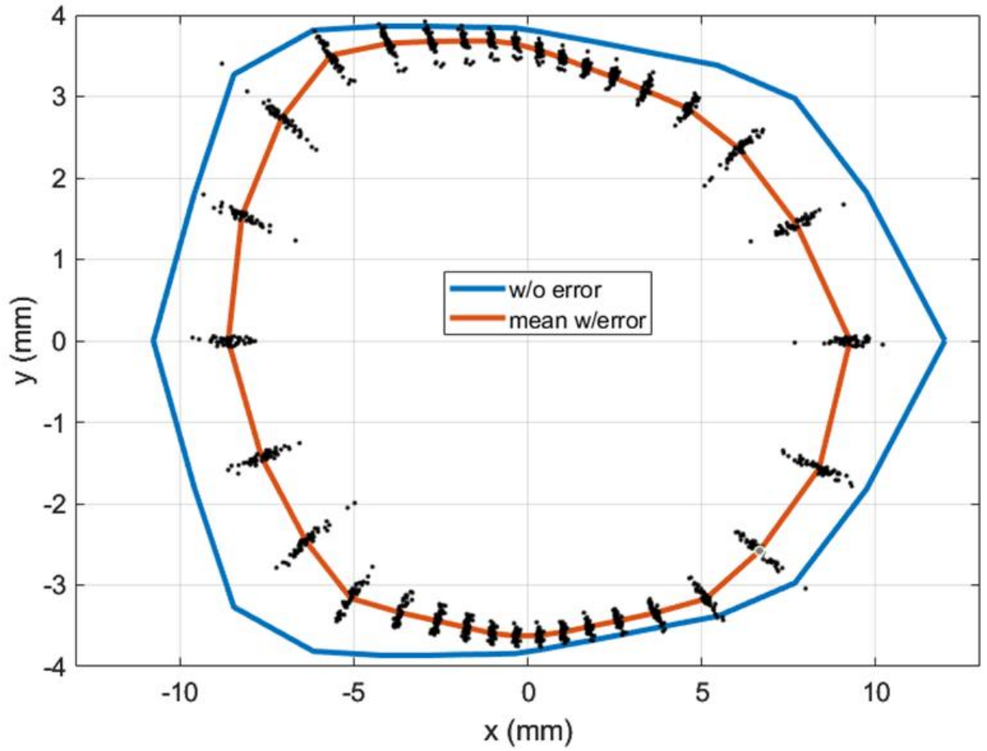


❖ **Features**

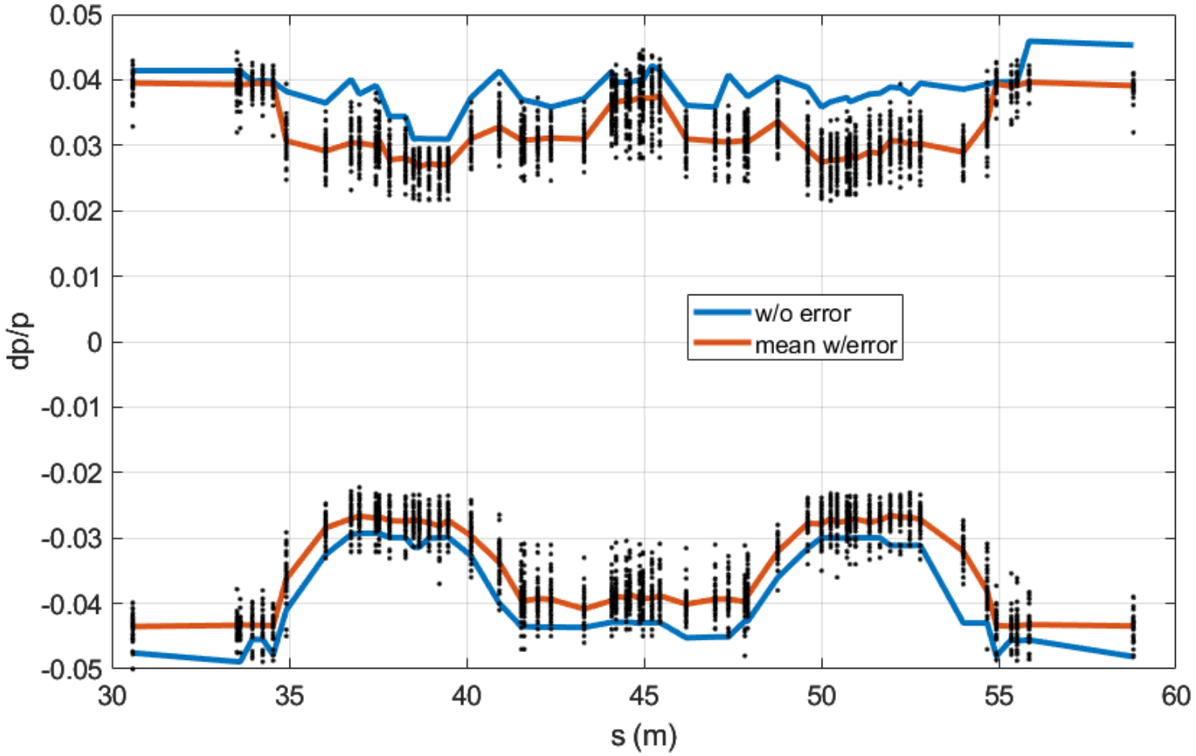
- The unit cell is a H7BA with 2-T center bend
- Longitudinal gradient bends and reverse bend
- 28 cells including two high beta long straight section for compromising between DA, Touschek lifetime and matching (between photon beam and electron beam)



Beam Dynamics: Nonlinear



Dynamic aperture



Momentum aperture

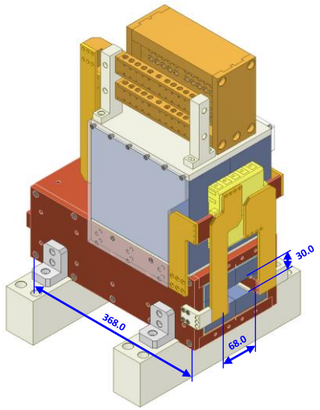
Dynamic aperture at injection side
x = -11 mm (w/o errors)
x = -8.3 ± 0.6 mm (w/ errors)

Touschek lifetime (w/o 3HC)
6.7 h (w/o errors)
3.36 ± 0.64 h (w/ errors)

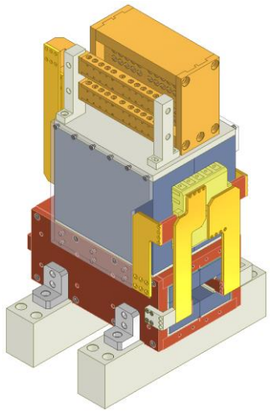
- Results with 50 random error seeds with 3rd generation SR tolerance level
- Realistic correction chain (orbit correction, rf correction, LOCO, coupling correction, etc.) is applied for each seed

Beam Dynamics: Injection

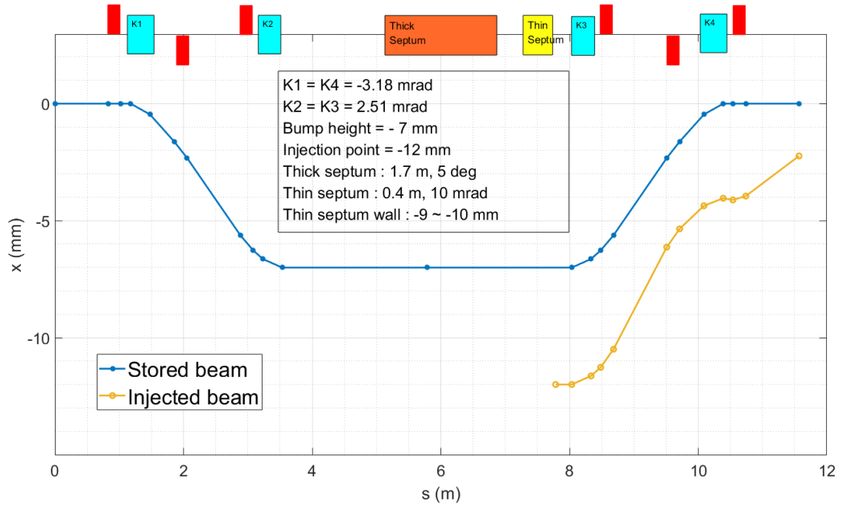
❖ **Baseline design: SR 4-kicker bump, off-axis injection**
Alternative design: Non-linear kicker

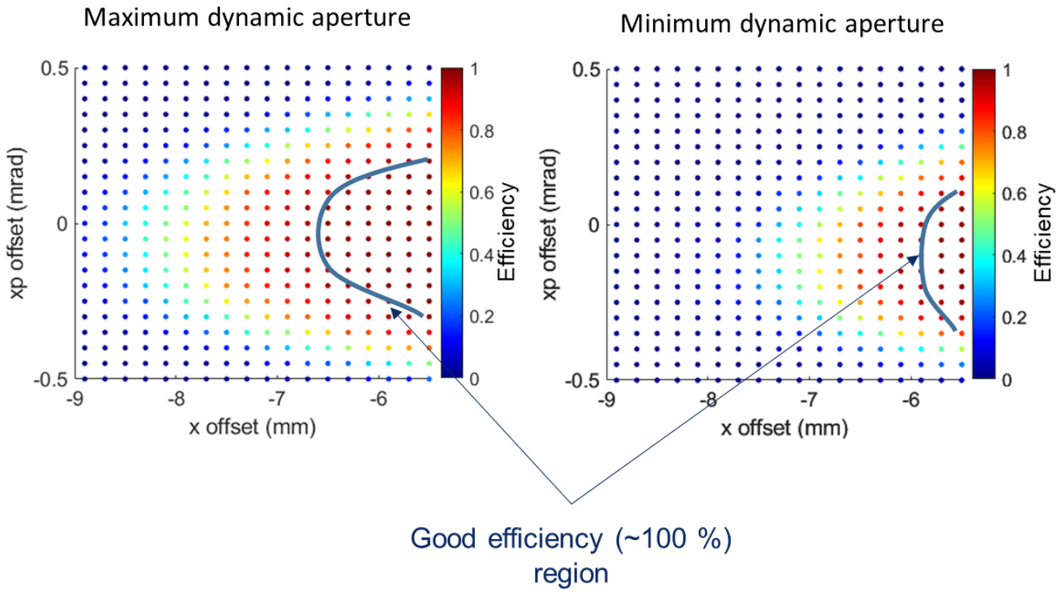


K1, K4

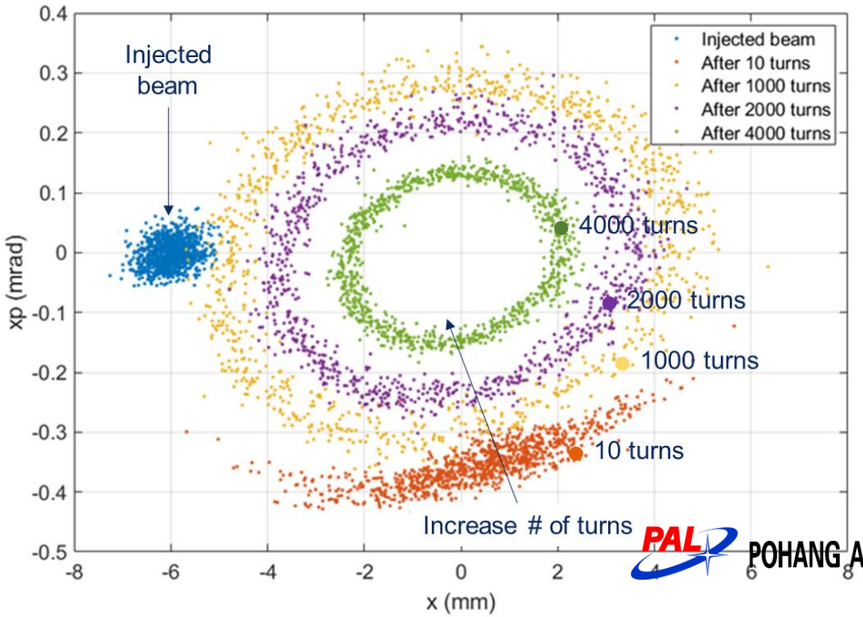


K2, K3

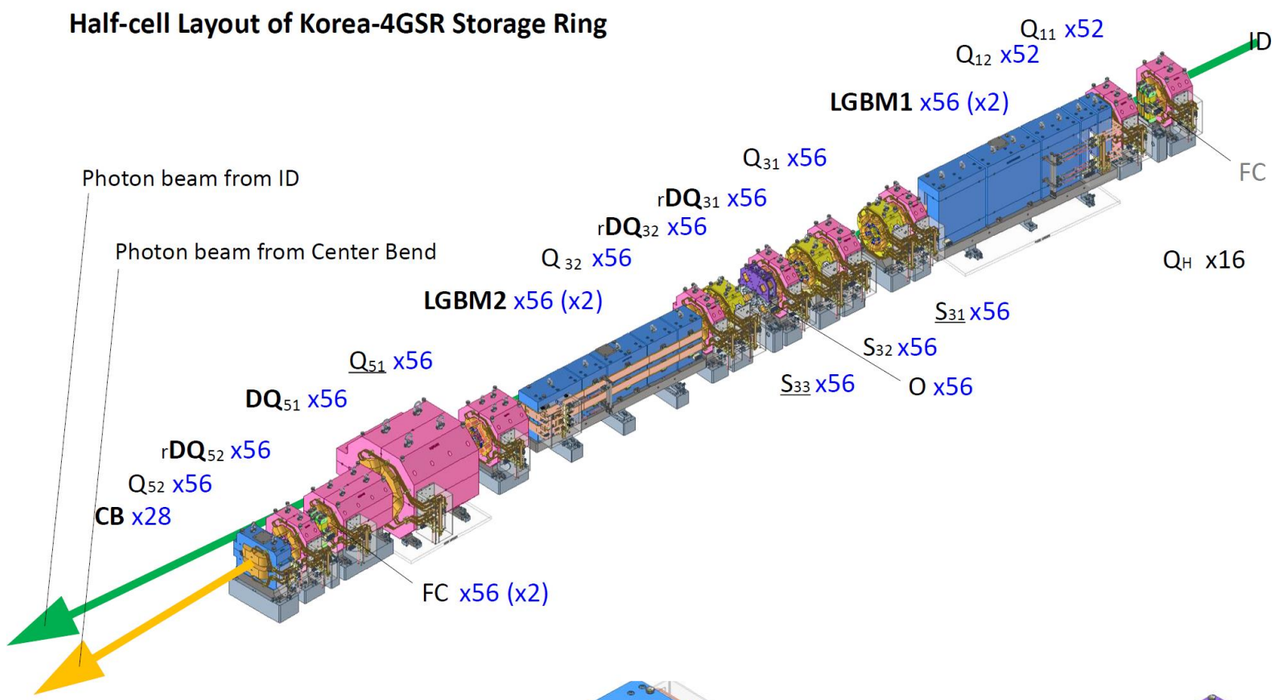




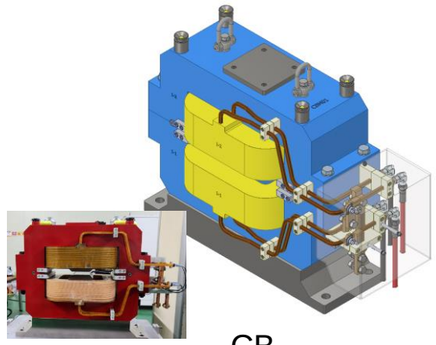
❖ Footprint of injected beam after injection



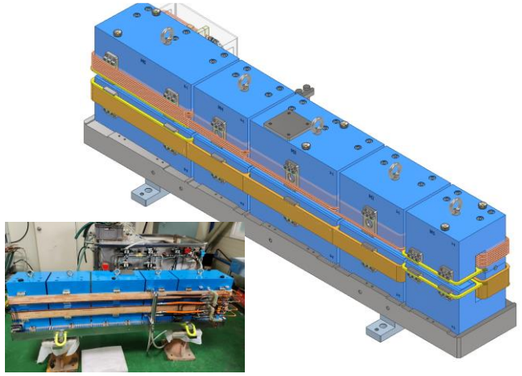
SR Magnet



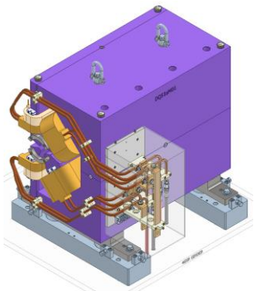
Magnets	Required Number	Remark
Center BM (2T)	28	1*28
Long. BM	112	4*28
Reverse Bend	168	2*3*28 (should have B, B')
Quad Bend	56	2*28 (should have B, B')
Quadrupoles	344	6*2*28+8(QH)
Sextupoles	168	6*28 (should have B", H/V Corr, Skew Quad)
Fast Corr.	112	4*28 (H/V combined corrector)
Octupole	56	2*28
SUM	1044	Total number of SR magnets



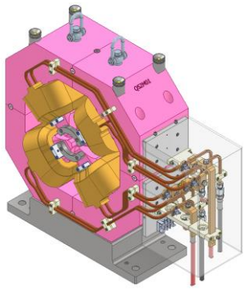
CB



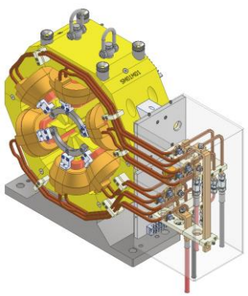
LGBM



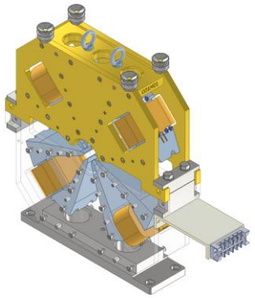
Dipole-Quadrupole (DQxx, 56ea)



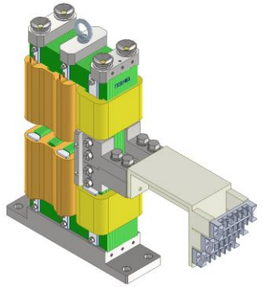
Quadrupole (Qxx, 344ea)



Sextupole Sxx, 168ea)



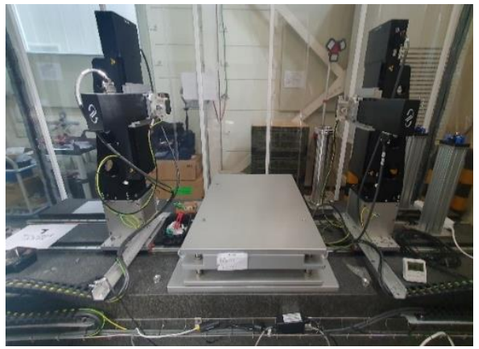
Octupole (Oxx, 56ea)



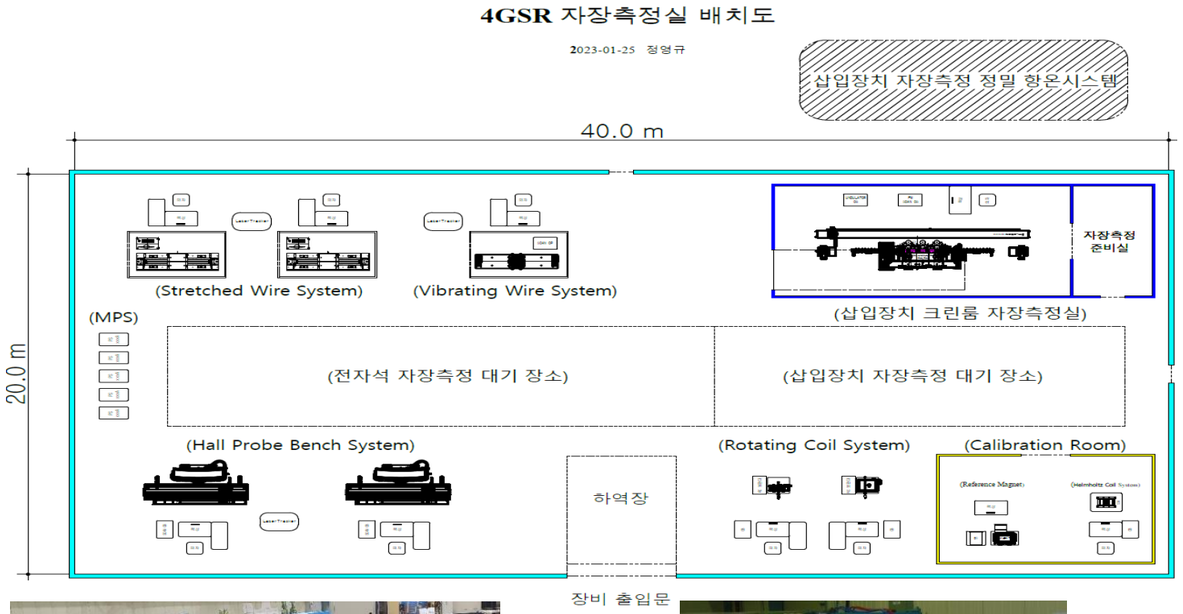
H/V/S Corrector (Cxx, 112ea)

Magnet: Measurement System (Plan)

- Hall probe 2 sets, Stretched wire 2 sets, Vibrating wire 1 set, Rotating coil 1 set.
- Clean room magnetic field measurement system for insertion device: Each 1 set for in and out vacuum ID
- Calibration room measurement system: Each 1 set for Reference magnet, NMR Probe, and Helmholtz coil



< Stretched wire system >



< Undulator measurement system >

< Hall probe system >

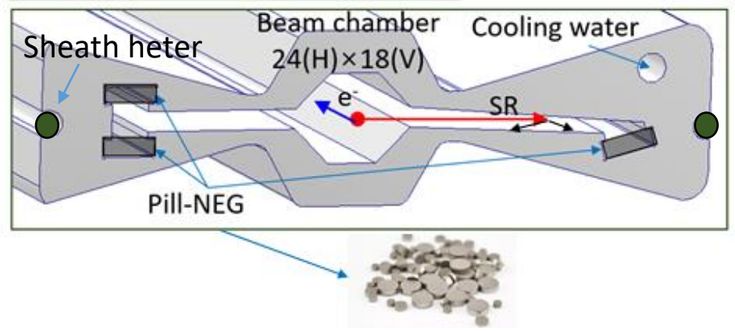
< Rotating coil system >

< Calibration system >

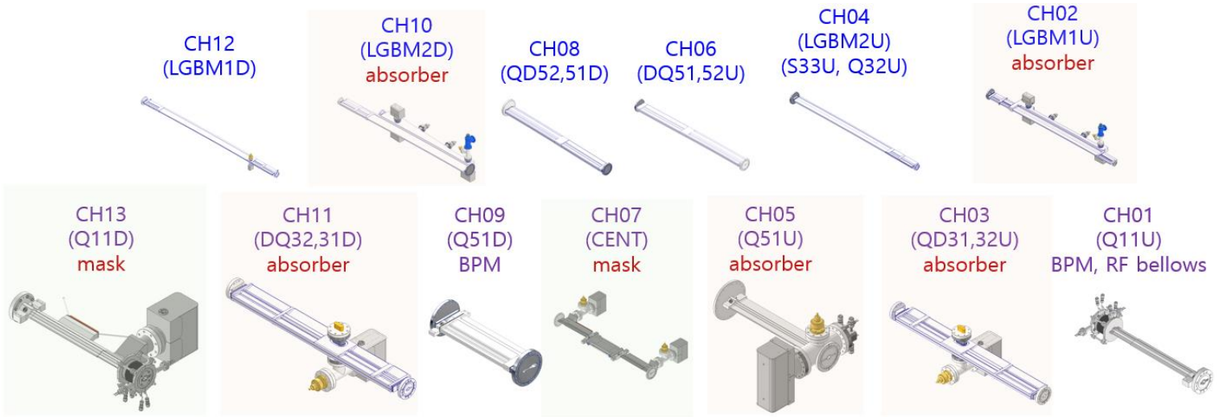
Vacuum

- ❖ Distributed pumping system using "**pill-type getters**"
- ❖ Bake-out & NEG activation in the tunnel ("**In-situ bake-out**")
- ❖ Maximize the exposure of the chamber wall to synchrotron radiation for **rapid beam cleaning**
- ❖ **Low impedance** design:
  - 24x18 octagon-shaped e-beam channel with 4 mm high winglet for synchrotron radiation handling
  - Transition angle (cross section) less than 1:10
  - Bellows and gate valve having RF-shielded finger which is made of thin copper plate with slots
  - No components penetrate into the beam channel (cross section change only in the winglet)

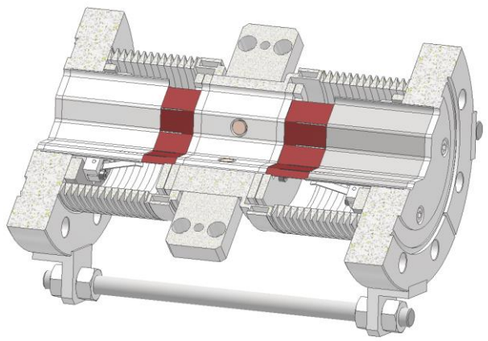
Vacuum chamber



SR vacuum chambers



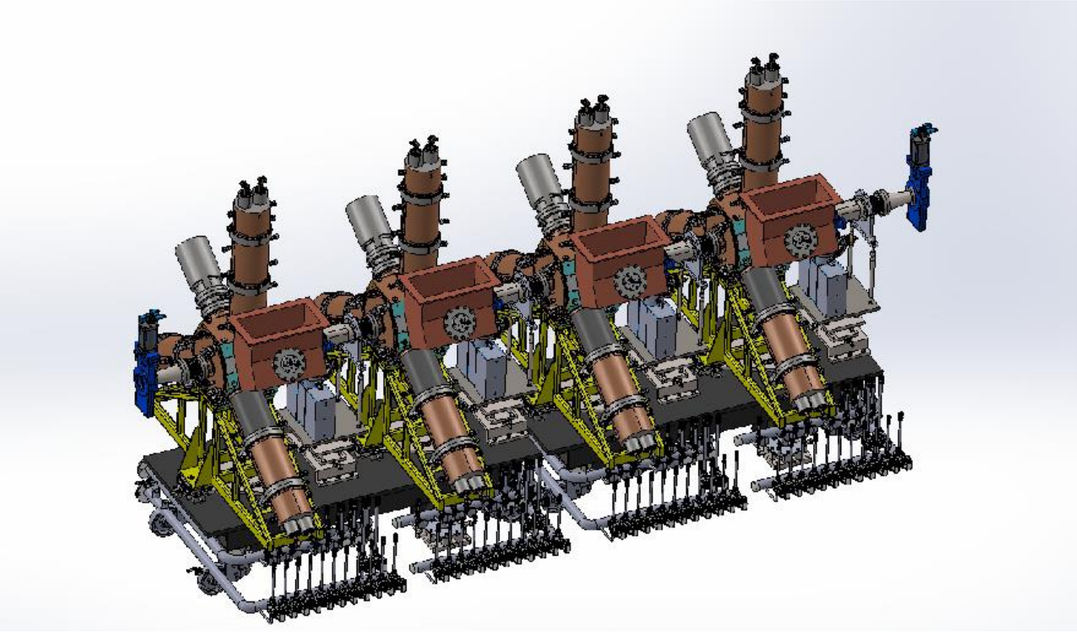
RF-shielded bellows

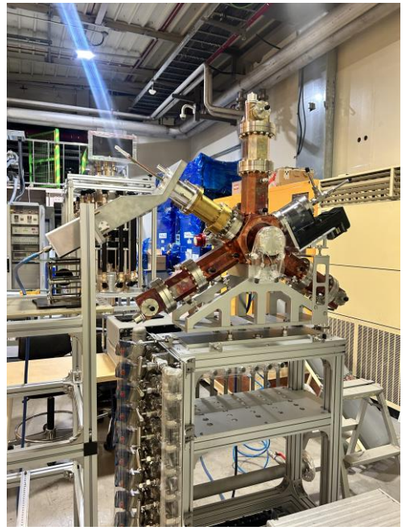


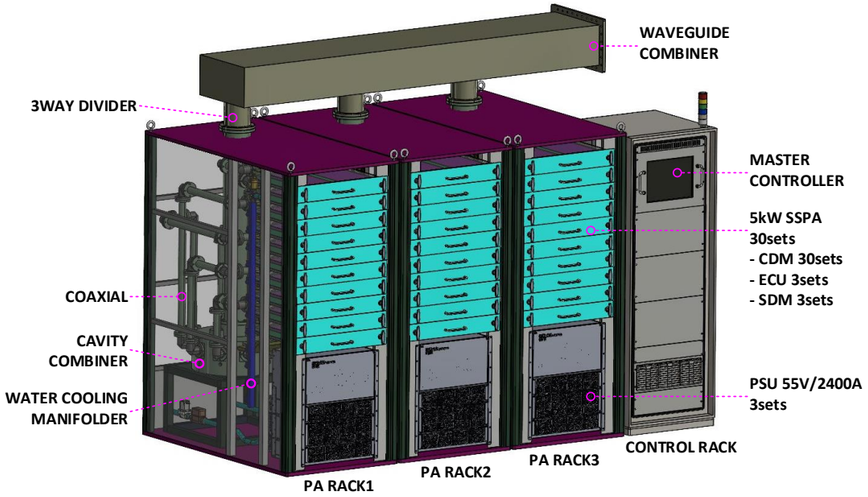
RF system

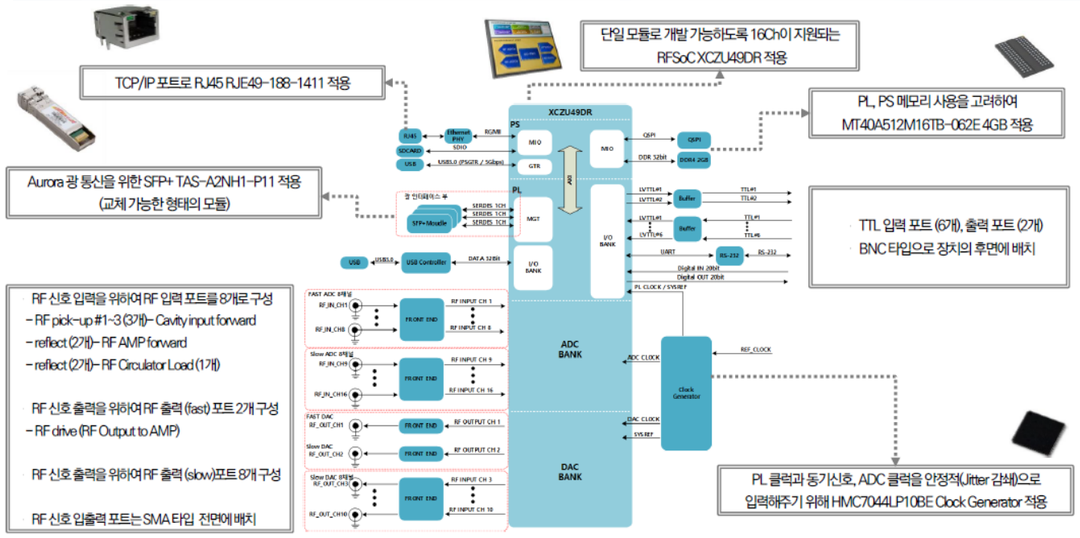
❖ **SR RF System**

- SC (CDR) => NC (TDR)
- Cavity: HOM-damped normal conducting cavity
- HPRF: 150 kW solid state amplifier per unit
- Independent 10 RF circuit, occupying 2.5 straight sections
- NC 3rd Harmonic Cavity for beam lifetime
- Solid State Power Amplifier
- EPICS based control system









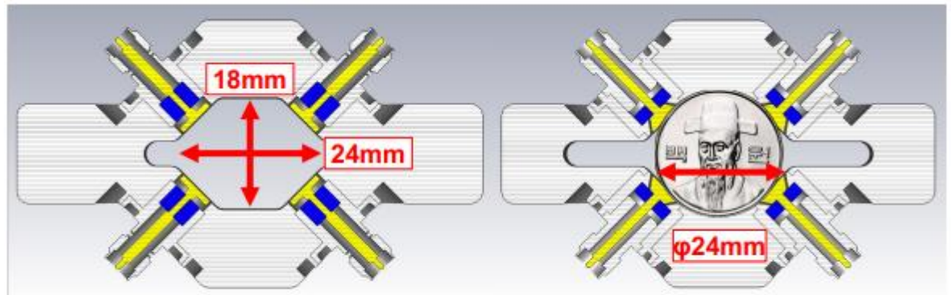
Other Hardware

❖ **E-gun**

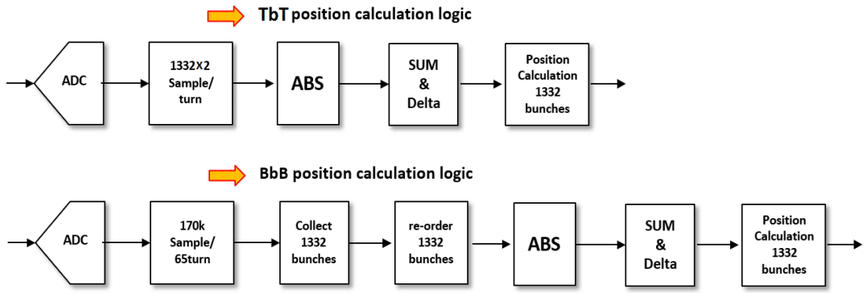
- Thermionic DC gun (CDR) => Photocathode RF gun (TDR)
- Sufficient experience in PAL-XFEL

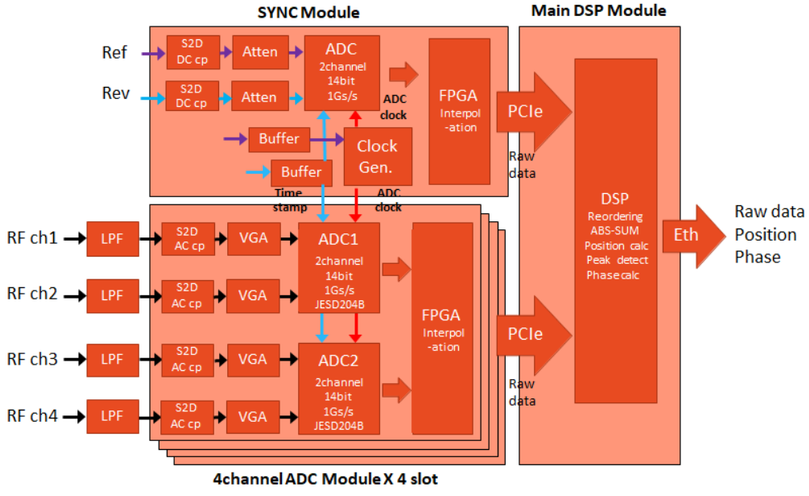
❖ **Instrumentations**

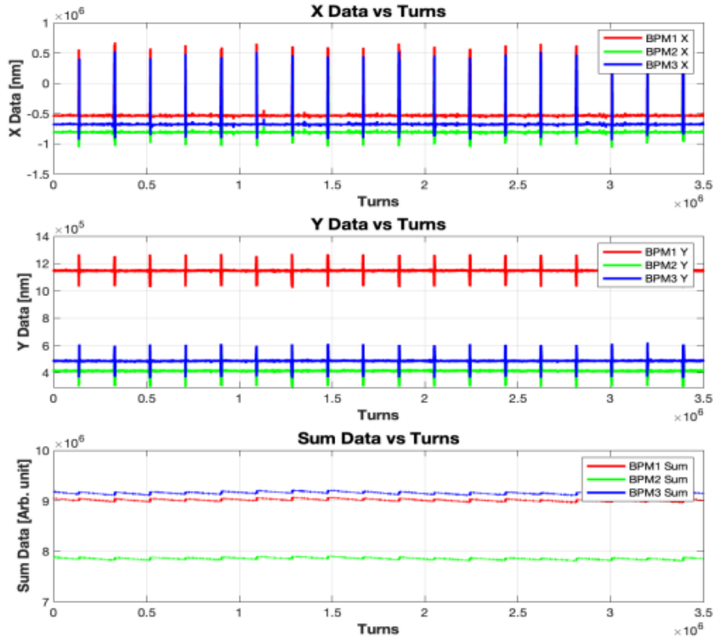
- Local manufacturing: BPM electronics, FOFB
- Proto-type electronics was (will be) tested @ existing machine (PLS-II)



SiO_2 Glass & Al2O3 Ceramic Feedthrough antenna BPM for 4GSR







BPM signal analysis @ PLS-II

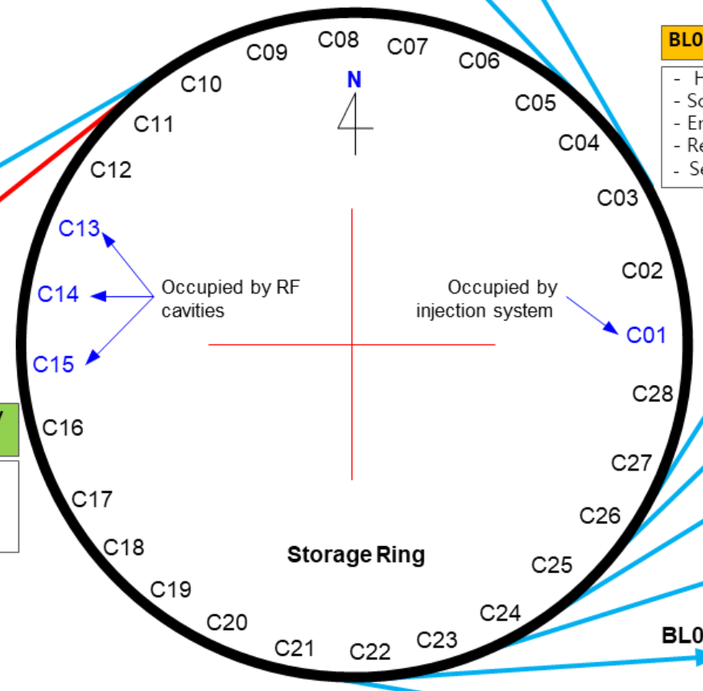
Beamline

Beamline Overview, at Phase 1

Beamline Plan	
Total straight section (SS)	28
Occupied SS by accel. devices	4
Available ID sections	24
Center band	28
Planed total beamline	52
Beamline of Phase 1	**10**

Industry Priority

General R&D



BL06, CoSAXS

BL06, Coherent Small-angle X-ray Scattering
- Source: IVU20
- Energy: 4~40 KeV
- Resolution: △E/E < 2 ×10⁴
  5 μm (XPCS), 50 μm (SAXS/WAXS)
- Organic chemistry Material science

BL05, CoXRD (CDI)

BL05, Coherent X-ray Diffraction
- Source: IVU22
- Energy: 3~30 KeV
- Resolution: 1.5μm (EH1), 500nm (EH2)
- Semiconductor, Material science, Chemistry, Geology

BL03, Soft X-ray Nano-probe
- High spatial resolution
- Source: EPU78 + IVU24
- Energy: 0.1~2 KeV
- Resolution: <100 nm△E/E < 1.5 ×10⁴
- Semiconductor, Material science

BL03, Soft X-ray NanoProbe

BL04, Nanoscale Angle-resolved Photoemission Spectroscopy
- Source: IVU24
- Energy: 0.1~2 KeV
- Resolution: 100 nm?? , △E/E < 10⁻⁴
- Semiconductor, Quantum material

BL04, NanoARPES

BL02, Material Structure Analysis
- Source: IVU24
- Energy: 5~40 KeV
- Resolution: △E/E < 2 ×10⁴
- Energy material (crystal structure)

BL02, Material Structure

BL07, Real-time X-ray Absorption Fine Structure
- Source: IVU24
- Energy: 5~40 KeV
- Resolution: < 10μm
- Catalyst reaction, Crystal transition

BL07, RealtimeXAFS

BL08, Bio Nano crystallography
- Source: IVU20
- Energy: 5~20 KeV
- Resolution: <0.7~3.5?
- Bio (Protein structure alalysis)

BL08, BioNX

BL01, BioSAXS

BL01, BioPharma-BioSAXS
- High resolution image
- Source IVU24
- Energy: 5~20 KeV
- Resolution: < 1?, △E/E < 2 ×10⁴
- Semiconductor, Material science, Chemistry (protein, polymer)

BL10, NanoProbe (150 m Long)
- Source: IVU24
- Energy: 5~25 KeV
- Resolution: ~50 nm NanoProbe
  1~10 μm MicroProbe
- Material science, Environment, Semiconductor, Display

BL10, NanoProbe

BL09

BL09, High Energy Microscopy (100 M Long)
- Source: Center bend
- Energy: 5~100 KeV
- Resolution: 0.1μm
- Material science, Biol

10 Beamlines (in the 1st phase)

Priority support for industries

Support for Academic R&D

Beamline	Photon Energy	Resolution	Photon Source	Exp.	Application
① **BioPharma-BioSAXS**	**5~25 keV**	SAXS: 1 Å 이하 $\Delta E/E < 10^{-4}$	**IVU24**	① Bio-SAXS	Bio.
② **Material Structure Analysis**	5~40 keV	$\Delta E/E < 10^{-4}$	**IVU24**	① HRPD, XRD ② XAFS	Material Science, Energy material
③ **Soft X-ray Nano-probe**	0.1~5.0 keV	sub-micro beam $\Delta E/E > 15\times10^{-4}$@1keV	**EPU78 +IVU24**	① XAS ② XPS	Semiconductor, Material Science * Tandem U., Two Branched Beamline
④ **Nanoscale Angle-resolved Photoemission Spectroscopy**	0.1~2 keV Optimize: 50 ~200 eV	100 nm < $\Delta E/E < 10^{-4}$	**EPU98**	① Nano-ARPES	Semiconductor, Material Science *Two Branched Beamline
⑤ **Coherent X-ray Diffraction**	3~30 keV	sub-micro beam	**IVU22**	① XRD ② CDI	Semiconductor, Material Science Geosciences, Chemistry
⑥ **Coherent Small-angle X-ray Scattering**	4~40 keV Optimize: 8-17 keV	~ a few nm ~ μm $\Delta E/E < 2\times10^{-4}$	**IVU20**	① SAXS/WAXS (GI 기법 포함) ② XPCS	Material Science, Chemistry
⑦ **Real-time X-ray Absorption Fine Structure**	5~40 keV	~ a few μm	**IVU24**	① XAFS	Material Science, Environments, Geosciences, Chemistry
⑧ **Bio Nano crystallography**	5~20 keV	1 Å <	**IVU20**	① MX	Bio.
⑨ **High Energy Microscopy**	5 ~ 100 keV	Spatial R. ~ 0.1μm	Centerbend	① Projection imaging	Material Science, Energy material, Bio * Spatial Resolution : 0.1 μm→0.3-0.5 μm
⑩ **Nano-probe**	5~25 keV	~50nm NanoProbe	**IVU24**	① Ptychography /XRF ② XRS	Semiconductor, Material Science, Geosciences, Chemistry, Environments

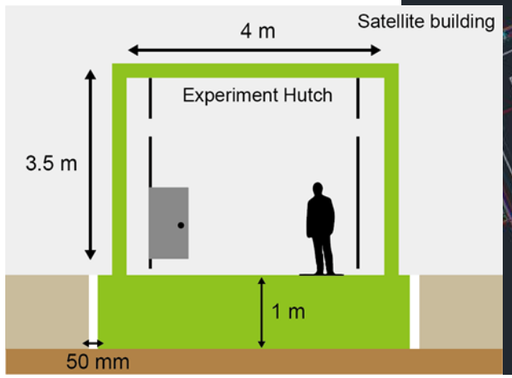
Long BeamLines

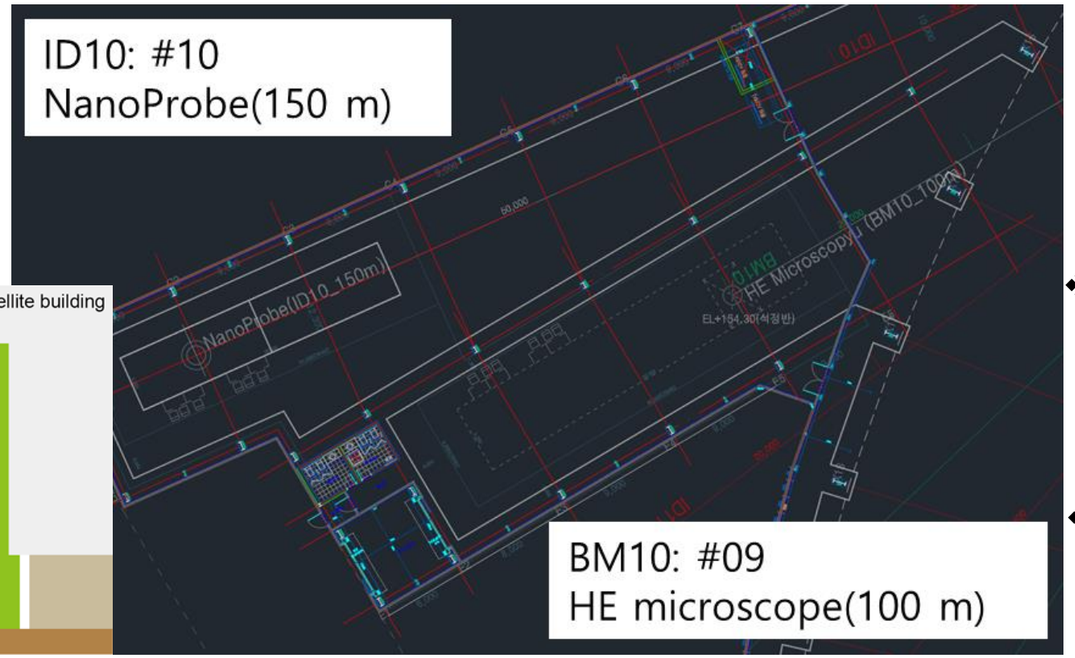
❖ **Long BL in Korea-4GSR**

- (09) HE Microscopy BL (L= 100 m)
- (10) Nano Probe BL (L=150 m)

❖ **Key point**

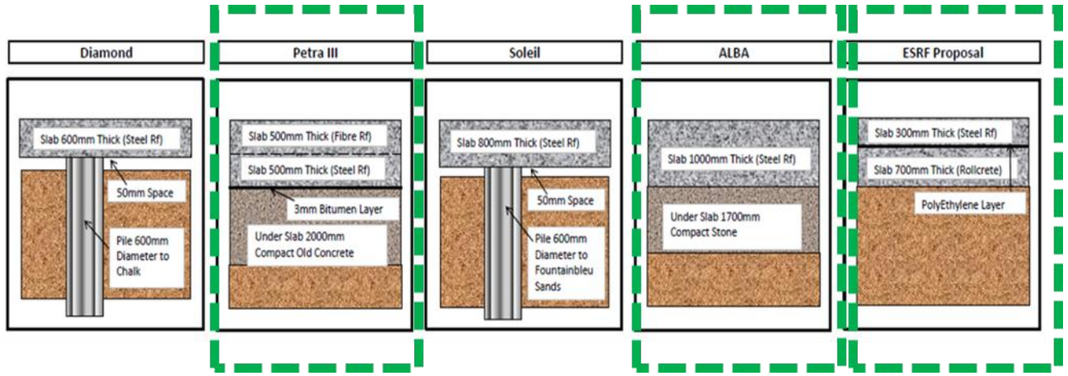
- Vibration / Radiation safety / Thermal stability





❖ **Slab for vibration damping**

- 1 m slab structure
- Similar to Petra-III, ALBA, ESRF-EBS



❖ **Radiation safety: PTL and Exp. Hutch concrete**

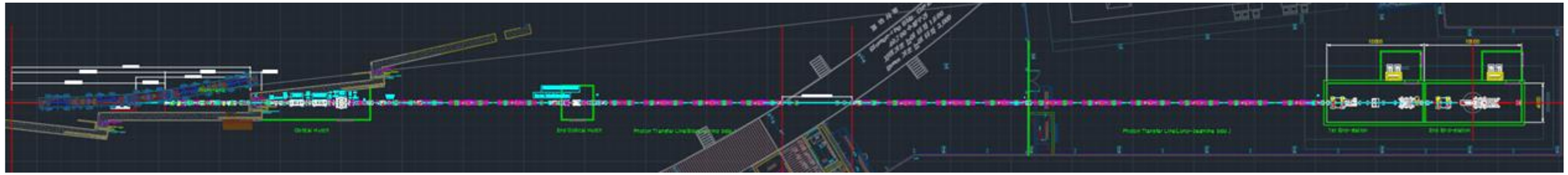
- HE Microscopy: 5 ~ 100 keV

❖ **House in house hutch structure**

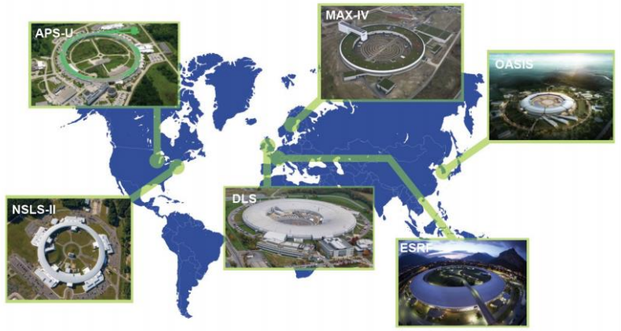
- Thermal stability

Hard X-ray Nano-probe

❖ BL Drawing



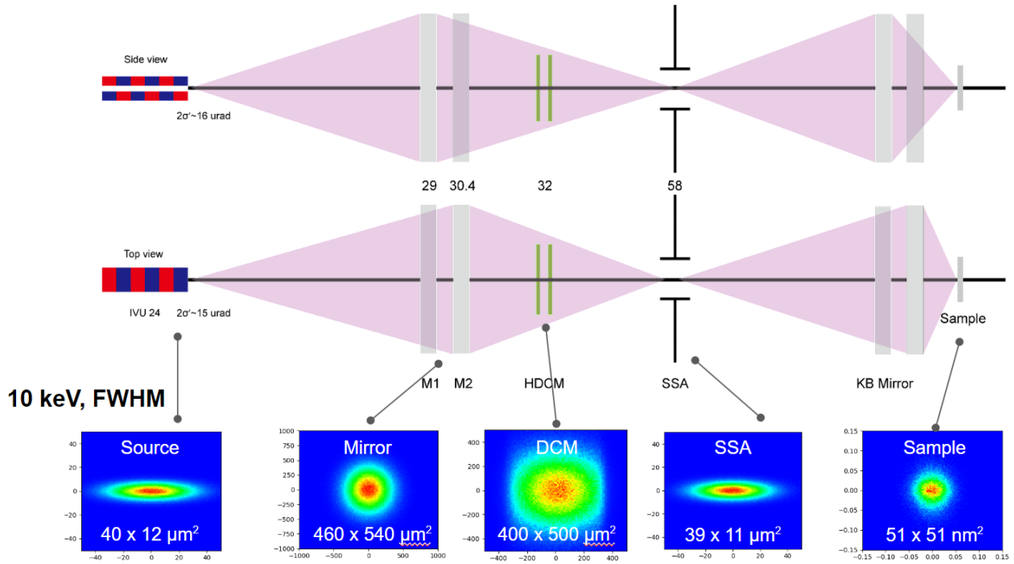
❖ Worldwide reference beamlines



Beamline	E (keV)	Focusing Optics	Beam size	WD (mm)
4GSR HXNP (150 m)	5 ~ 25	K-B mirrors	50 nm @ 10 keV	50
APS-U ISN (220m)	5 ~ 30	K-B mirrors	30 nm @ 25 keV	61
ESRF NI (180 m)	5 ~ 30	K-B mirrors	30 nm @ 20 keV	100
MAX-IV NanoMAX (150m)	6 ~ 28	K-B mirrors	50 nm @ 22 keV	130
DLS HXN (185m)	5 ~ 23	K-B mirrors	50 nm @ 12 keV	-
NSLS-II HXN* (120m)	6 ~ 25	Zoneplate/MLL	13 nm @ 12 keV	< 1

❖ BL layout & Ray tracing simulation

From the ray tracing done with the proposed mirror specification, we can see that a 50 nm beam can be generated.



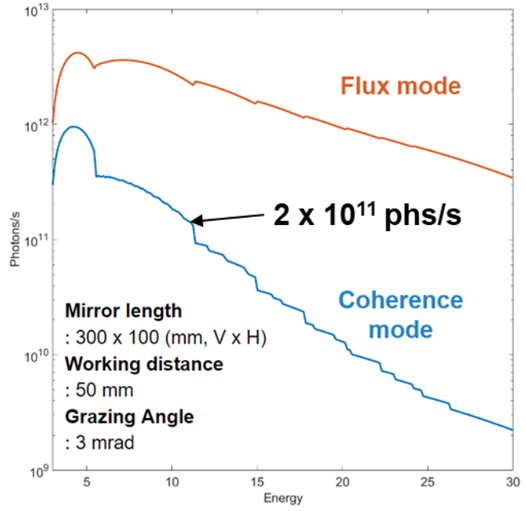
* Darwin width: 26.1 urad (Si 111) @ 10 keV

Hard X-ray Nano-probe

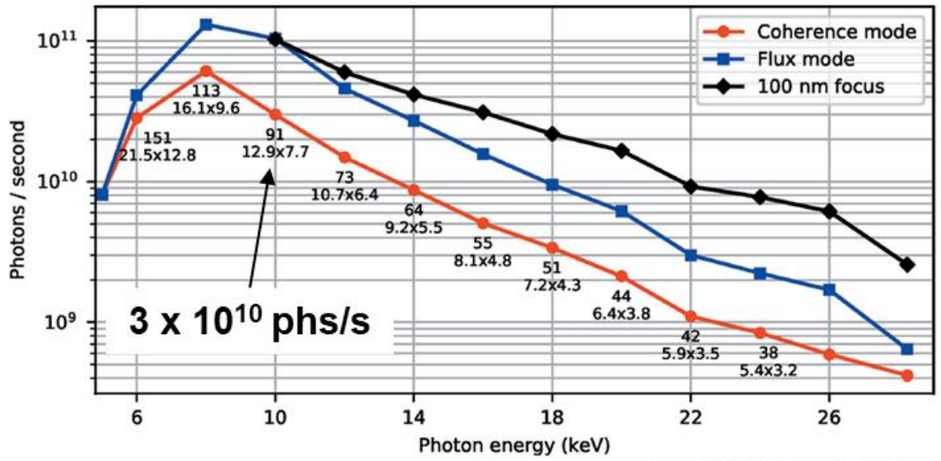
❖ BL Performance

Considering to
1. Mirror reflectivity $(0.9)^4$
2. BDA gap size for full coherence
3. KB mirror acceptance
4. Mono-beam
5. Polarization effect from HDCM

>10^{11} - 10^9 Photons/s @ 5 - 25 keV



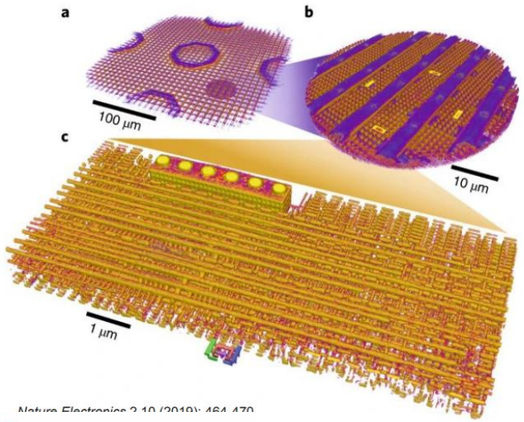
Beam flux of MAX-IV(4GSR) nanoprobe beamline



Journal of Synchrotron Radiation 28.6 (2021): 1935-1947.

❖ Estimation to imaging performance

100 um x 100 um x 4 um Computer chip
: 40 um x 40 um x 4 um → 53.5 hrs (Current)

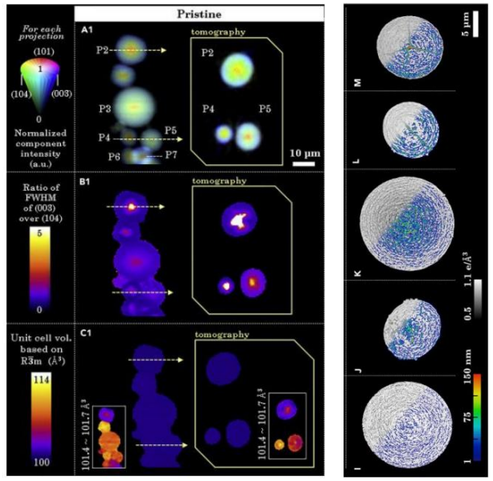


Nature Electronics 2.10 (2019): 464-470.

Parameter	SLS-CSAXS	Korea-4GSR HXNP	
Focus flux(ph/s)	7 x 10^8	1 x 10^{11}	
Num. projections	7180	7180	13642
Total exp. time	**834.2 hrs**	**5.8 hrs**	**11.0 hrs**
3D resolution	**19**	**19**	**10**

Scaled to experimental parameters of *Nature Electronics* 2.10 (2019): 464-470.

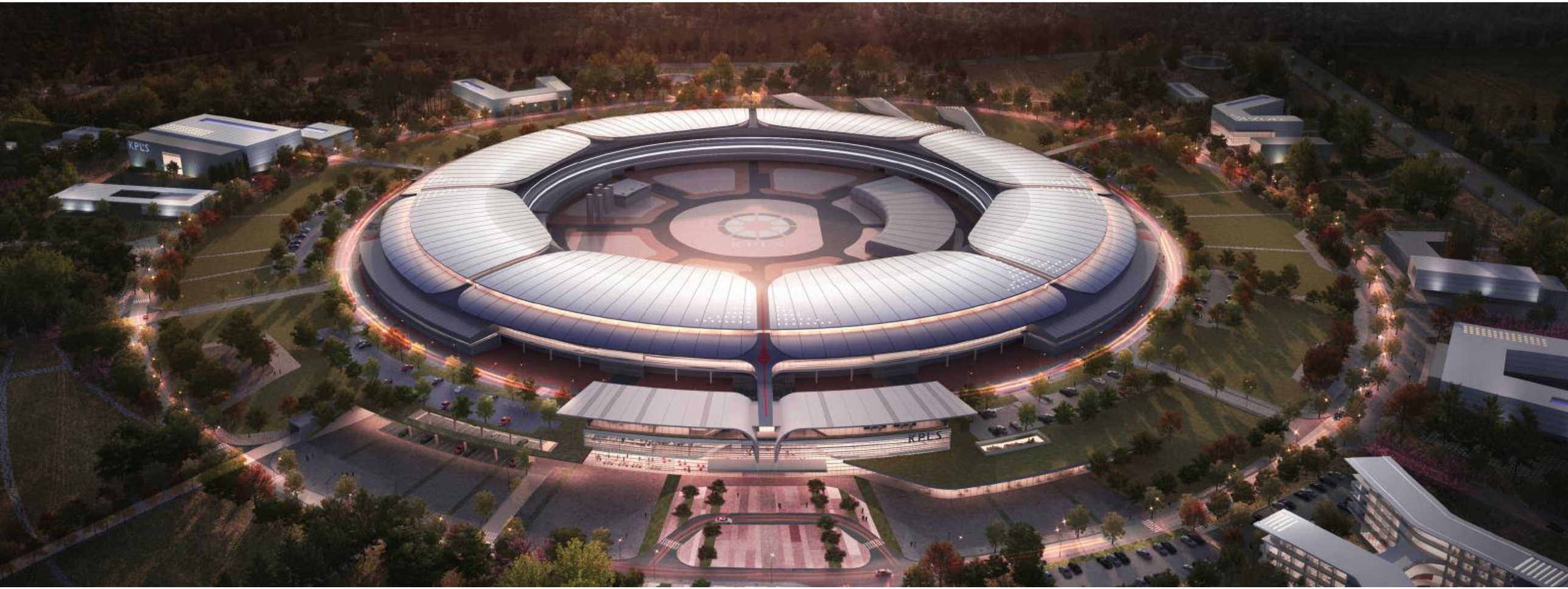
NMC 811 battery particle tomography:
~ 20 um x 20 um x 20 um



IScience 11 (2019): 356-365.

Parameter	SLS-CSAXS	Korea-4GSR HXNP	
Focus flux (ph/s)	7 x 10^8	1 x 10^{11}	
Total time	**12 hrs**	**1.2 hrs**	**12 hrs**
Resolution (nm)	**35**	**35**	**< 5**

Scaled to experimental parameters of *IScience* 11 (2019): 356-365.



Thank You

KOREA BASIC SCIENCE INSTITUTE

POHANG ACCELERATOR LABORATORY