Overview of 4GSR
Multipurpose Synchrotron Radiation Construction Project

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Project Director

Oct. 13, 2022

PAL POHANG ACCELERATOR LABORATORY

KBSI 한국기초과학지원연구원 KOREA BASIC SCIENCE INSTITUTE

4GSR Outline

❖ **Multipurpose Synchrotron Radiation Construction Project**

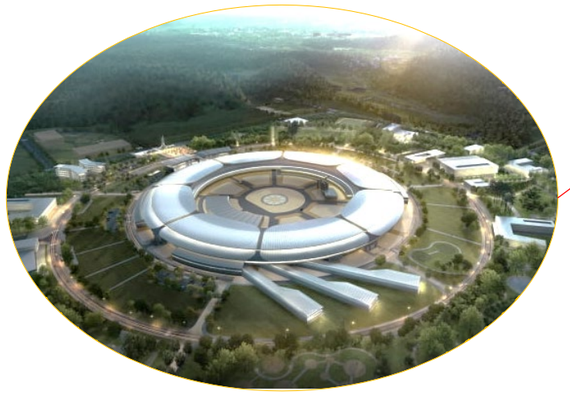
- Period: 2021 July to 2027 June (6yrs)
- Budget: 1.0454 Trillion KRW (≈ USD 750M)
- Land: 540,000㎡ / Building: 69,400㎡
- Location: Ochang, Chungcheongbuk-do

<4GSR Project Budget Plan> (Million USD)

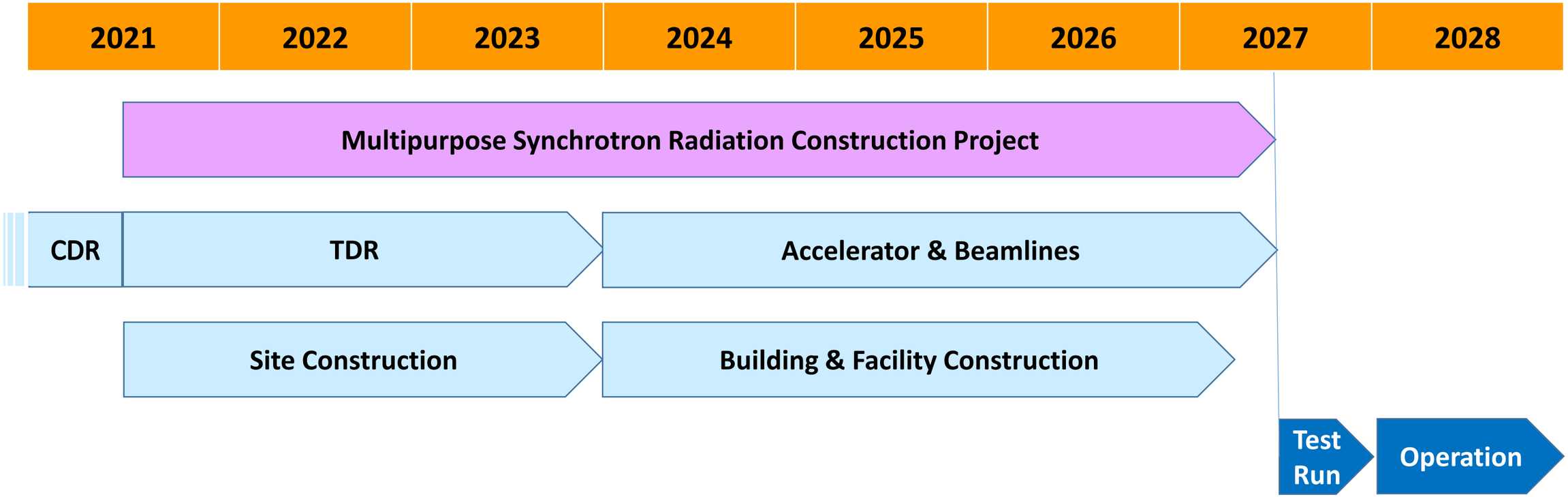
Years	2021	2022	2023	2024	2025	2026	2027	Sum
Machine	8	44	77	172	180	97	28	**606**
Site	72	72	-	-	-	-	-	**144**
Sum	80	116	77	172	180	97	28	**750**

Specifications

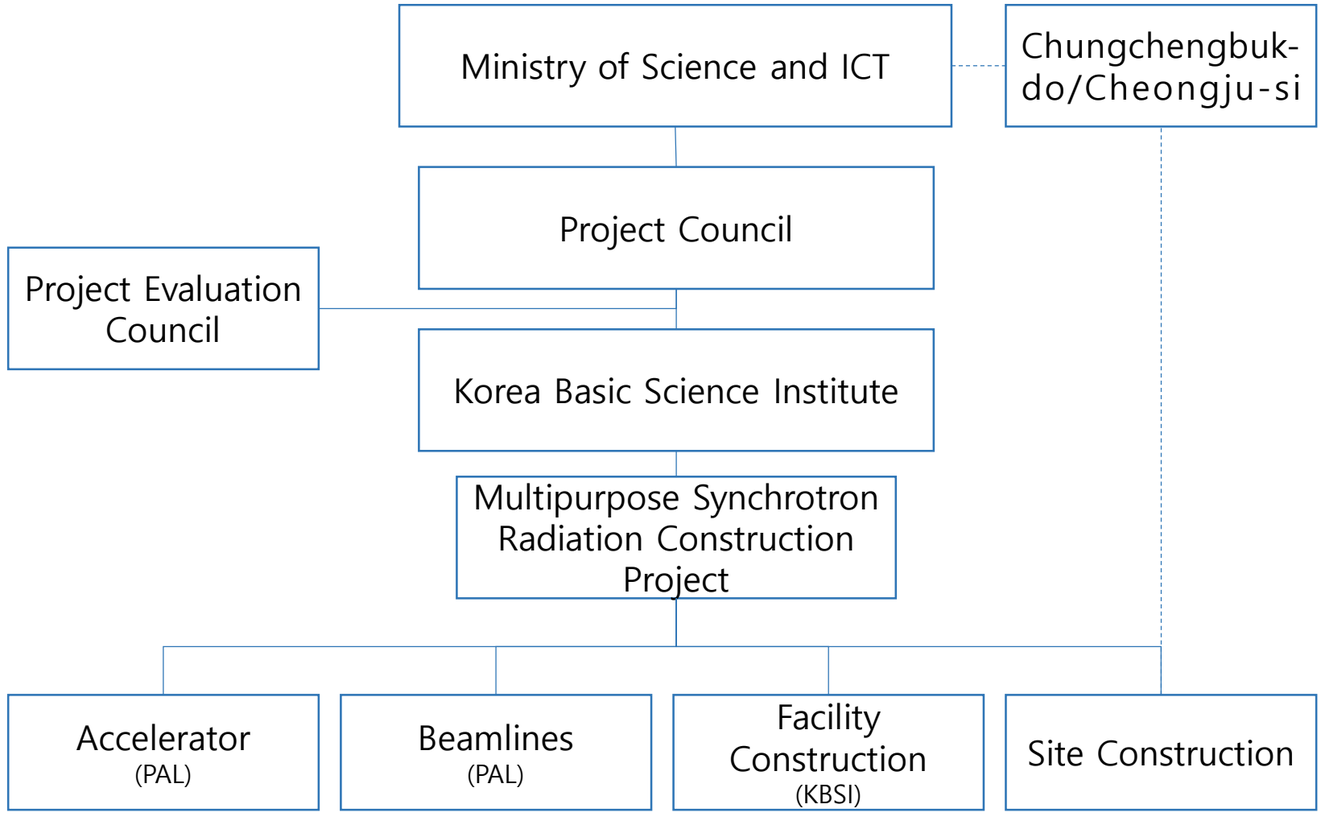
- Beam Energy: 4 GeV
- Beam Emittance: less than 100 pm·rad (CDR: 58 pm·rad)
- Circumference: 800m
- Beamlines : more than 40
- Accelerator: Gun, Injector LINAC, 4 GeV Booster
- Lattice: MBA-7 Bend Achromat



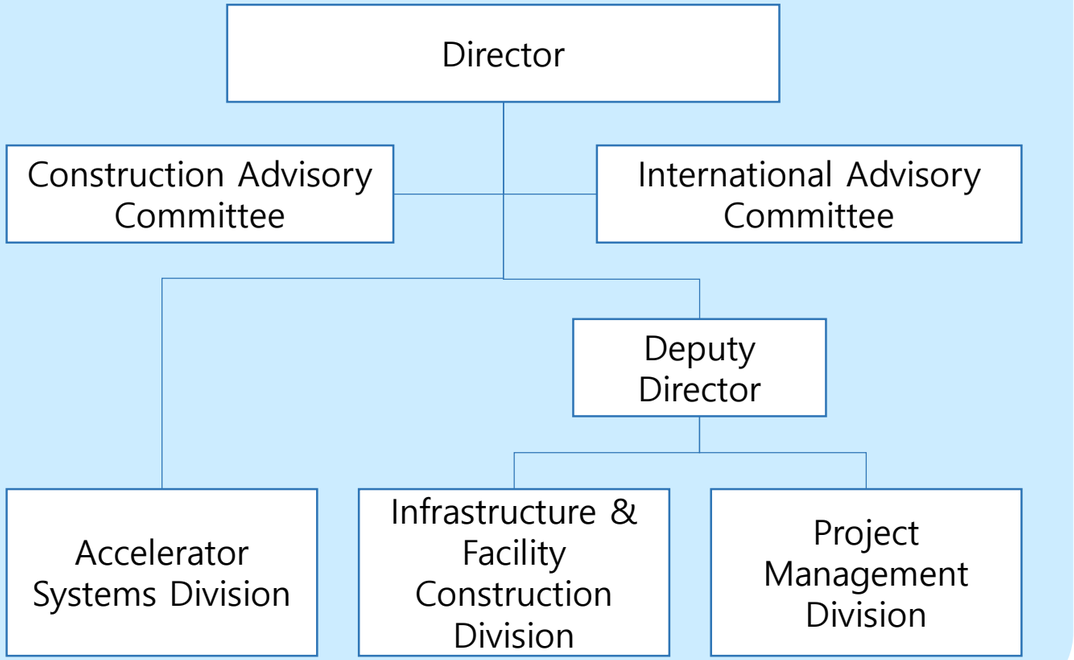
Project Timeline



Project Governance



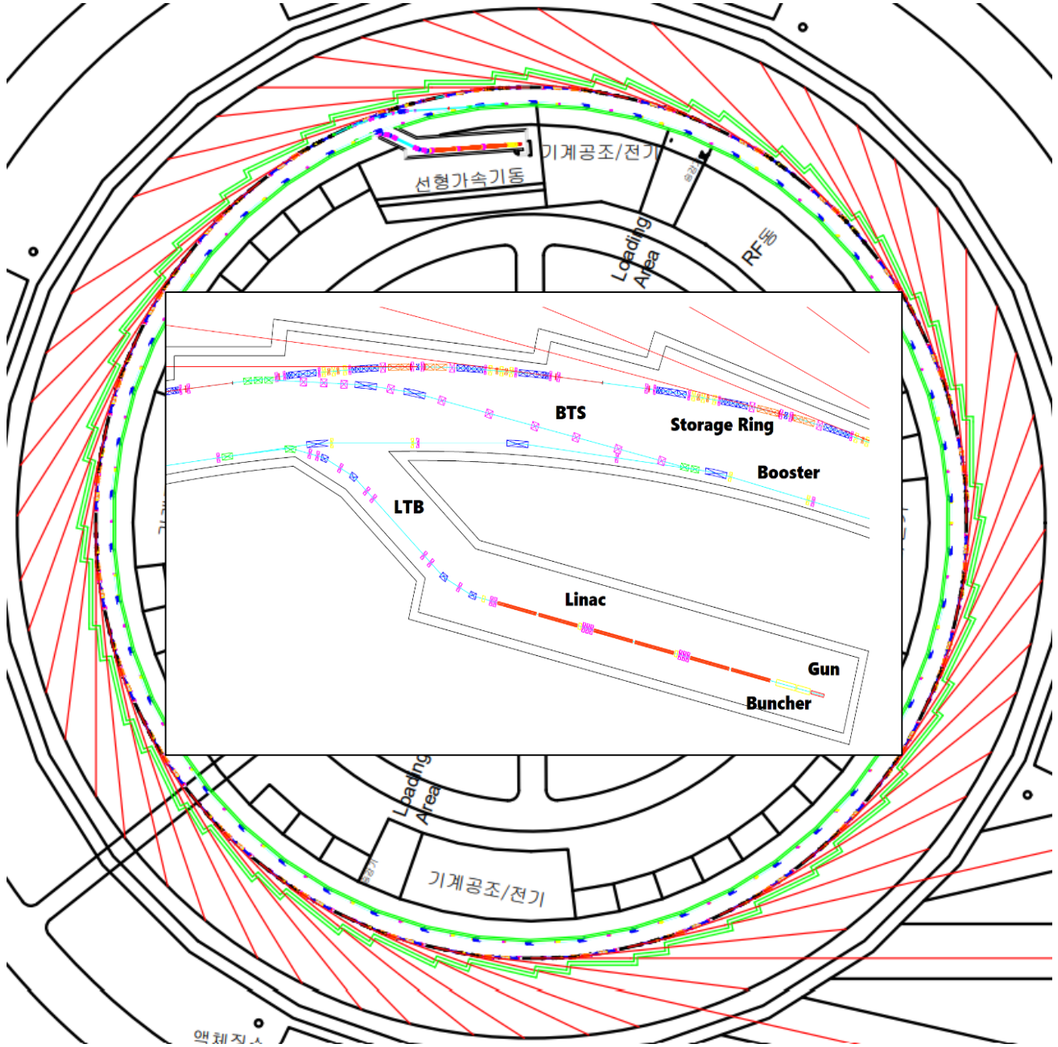
Project Structure



Manpower

		2022	2023	2024	2025	2026	2027
Director		1	1	1	1	1	1
KBSI	Vice Director	1	1	1	1	1	1
	Accelerator System	4	6	11	14	26	37
	Infrastructure & Facility	9	15	15	15	15	15
	Project Management	10	18	19	19	19	19
		24	40	46	49	61	72
PAL	Accelerator	85	92	105	109	117	117
	Beamlines	67	72	79	85	87	87
	Project Management	23	25	26	26	25	23
		175	189	210	220	229	227
Total		200	230	257	270	291	300

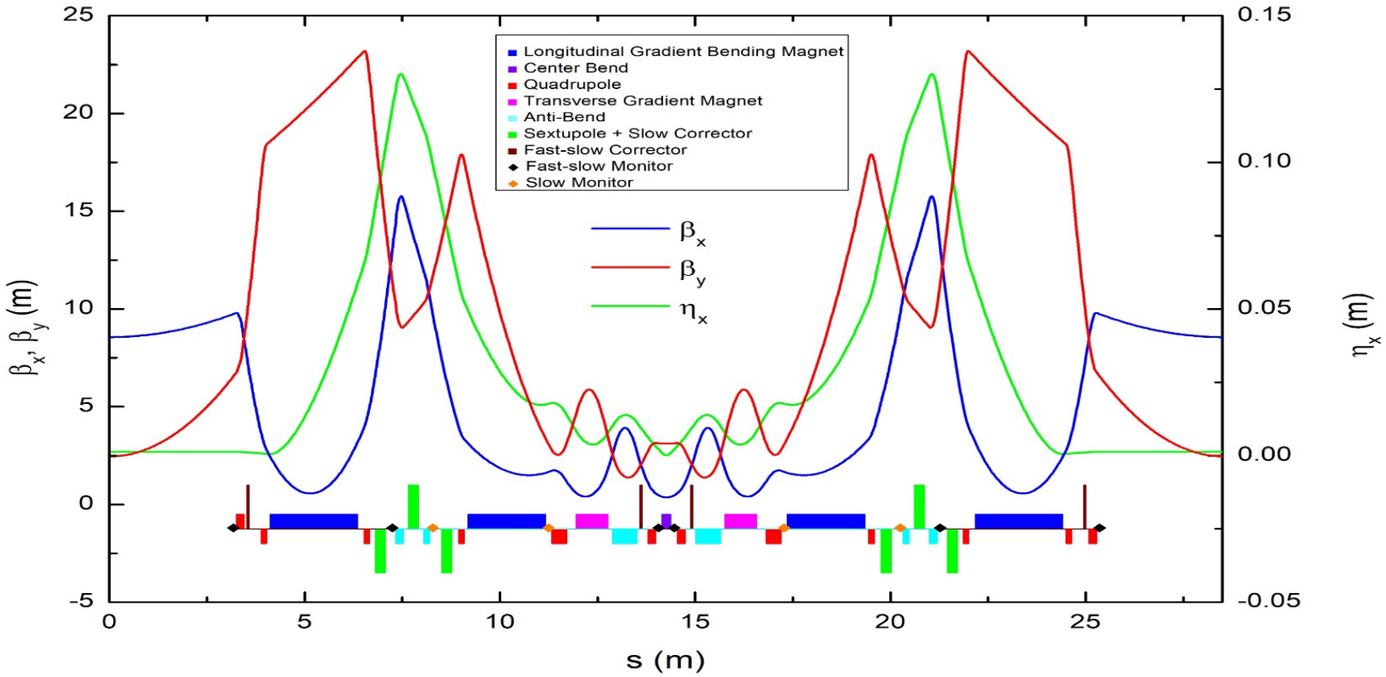
Main Parameter



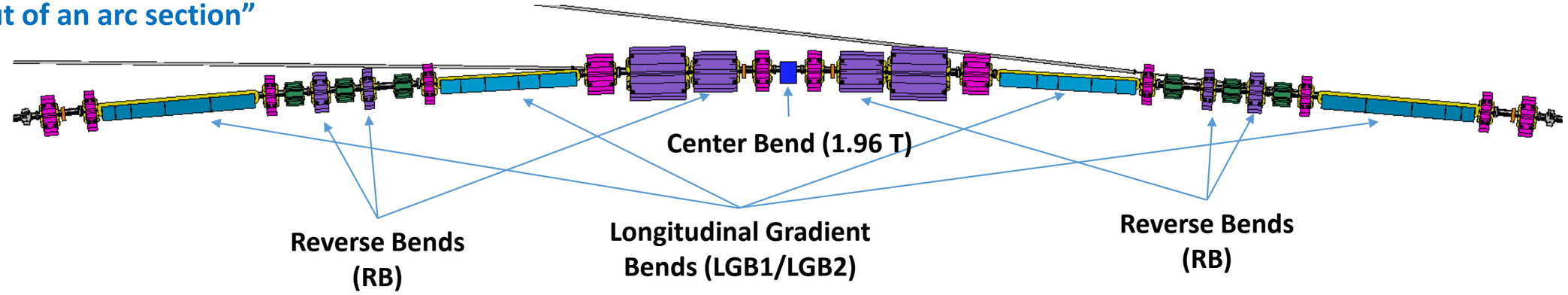
General Parameter	
Energy / GeV	4.0
Symmetry / Sub-Symmetry	28
Straight Sections: No & Length / m	28 / 6.5
Ring Circumference / m	798.8
# Dipole Magnets	28 * 7 = 196
Nat. Emittance / prad m	58
regular hor/ver @ coupling	55 / 6 @ 10 %
Diffraction limited source for	l > 1.7 / 0.365 nm
Energy spread	1.20E-3
Bunch Length s_t / ps	10.68 (without HC) / 53.40 (with HC)
RF Parameter & Others	
RF frequency / MHz	499.877
# cavities / total Voltage	3 x nc / 3.5 MV (1.8 MV max)
# buckets: total / gap	1332 / 267
Harmonic RF system	3rd, passive,sc, 800 kV
Average current / mA	400
Lifetime / h	4.54 (flat) / 8.81 (round)
Top up operation	yes
Injection scheme	4 Kicker bump
Beam pipe (in achrom.) / mm^2	D: 24(H)*20(V) @ Straight Section
Magnets:	
max. bending magnet field / T	1.7
max. quadrupole grad. T/m	56
max. sextupole strength T/m^2	1844

Hybrid multi-bend achromat

"Linear lattice design"



"Layout of an arc section"



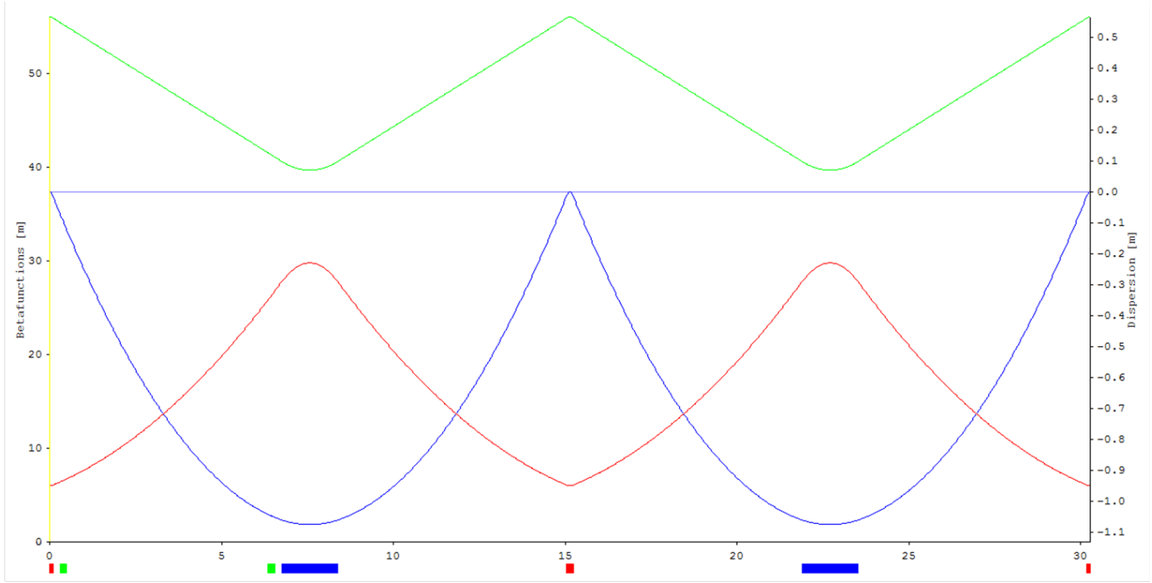
Injector

Booster

1. Same tunnel with SR.
2. Enough dynamic aperture: (Ax: -27 ~ 27 mm, Ay: ~ 14 mm).
3. Two normal cavities in one straight section.

Linac

1. Thermionic DC gun (Y-845).
2. 500 MHz sub-harmonic pre-buncher for multi-bunch.
3. 2.997 GHz (Pre) buncher and 6 accelerator tanks

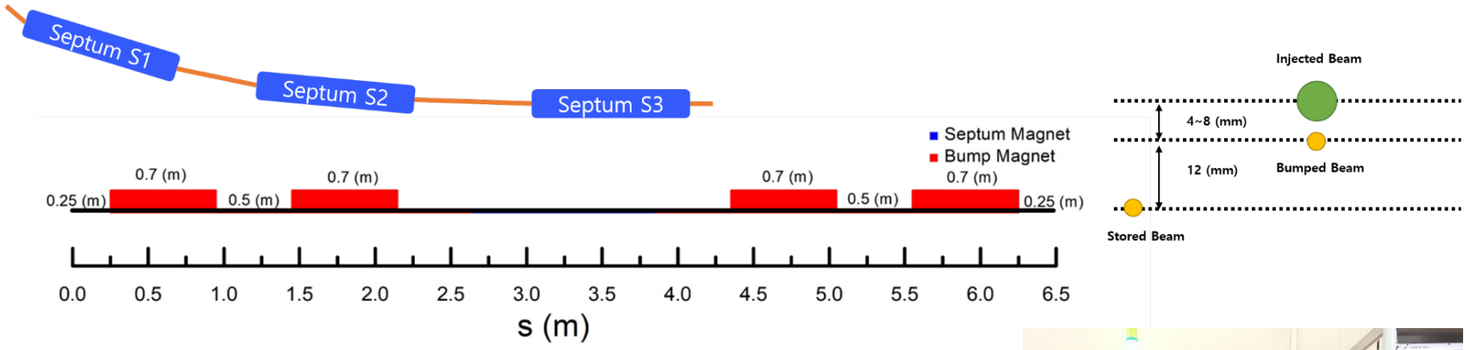


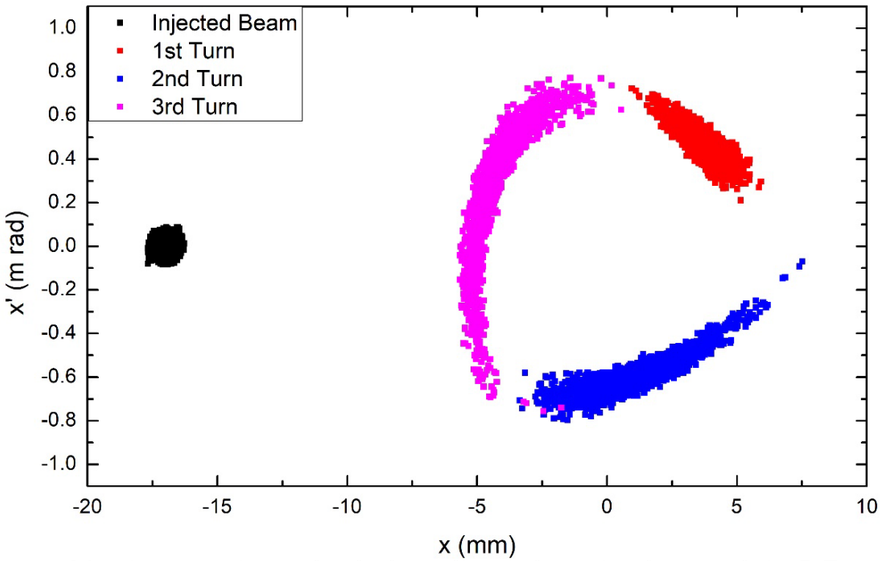
4GSR Linac	Multi-bunch	Single-bunch	
Energy	200	200	MeV
Frequency (e-gun and SHB)	499.546	499.546	MHz
Frequency (Accelerator)	2997.28	2997.28	MHz
Emittance (at 200 MeV)	≤ 200	≤ 200	nm
Relative energy spread (rms)	≤ 1	≤ 0.5	%
Pulse to pulse energy variation	≤ 0.25	≤ 0.25	%
Pulse to pulse beam position	≤ 0.20	≤ 0.20	mm
Pulse to pulse jitter	≤ 100	≤ 100	ps
Pulse charge	3 to 10	0.01 to 2.5	nC
Pulse duration	100 to 400	≤ 1	ns
Repetition rate	2	2	Hz

4GSR Booster		Value	Unit
Design Parameters	Cell Number	50	-
	Length	756.86	[m]
	Electron Energy	0.2 - 4	[GeV]
	Natural Emittance	6906	[pm rad]
Tune and Chromaticiy	Horizontal Tune	19.208	-
	Vertical Tune	9.268	-
	Natural Horizontal Chromaticity	-35.146	-
	Natural Vertical Chromaticity	-14.617	-
	Horizontal Chromaticity	-2	(target)
	Vertical Chromaticity	-2	(target)

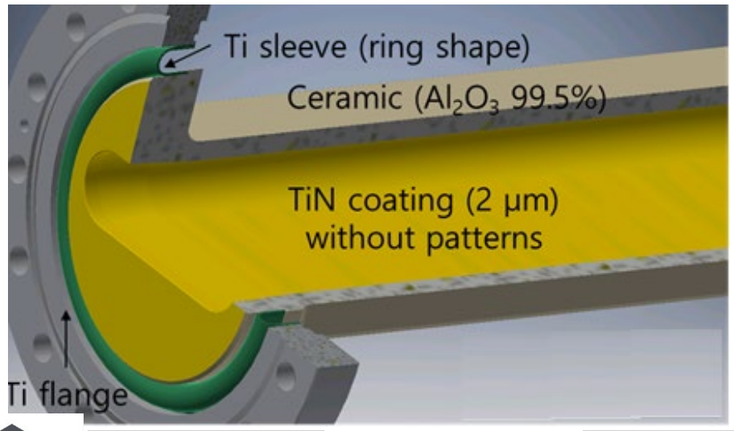
Beam Injection

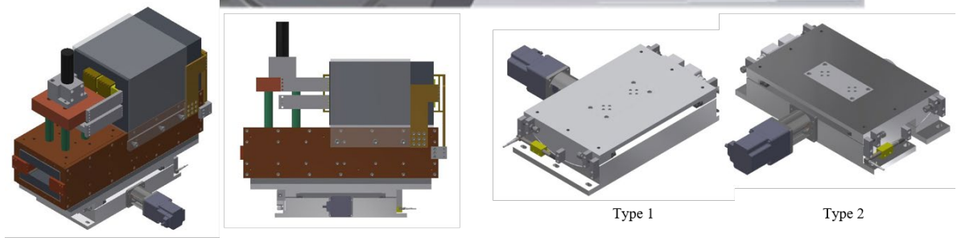
1. Well demonstrated scheme will be used.
2. Baseline: conventional four kickers injection.
   - Dynamic aperture: (Ax: -10 ~ 10 mm).
3. Including advanced scheme: NLK.





No beam loss in injection simulation with RF





3D Modeling with Kicker magnet

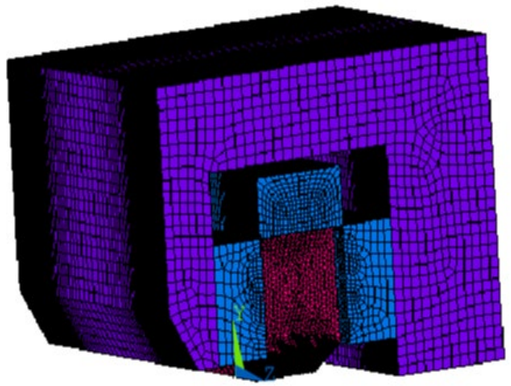
3D Modeling of Tilting Stage

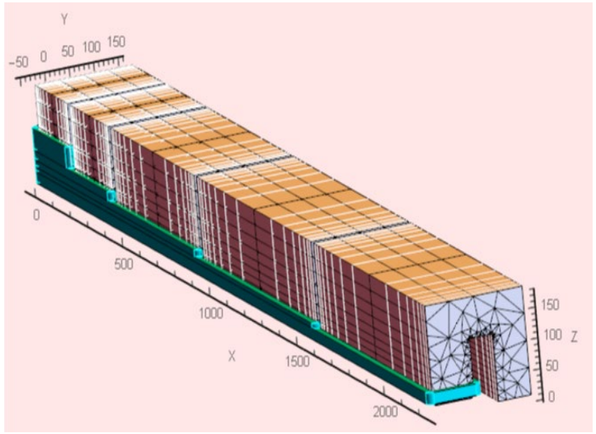
Solid-state switch test in PLS-II

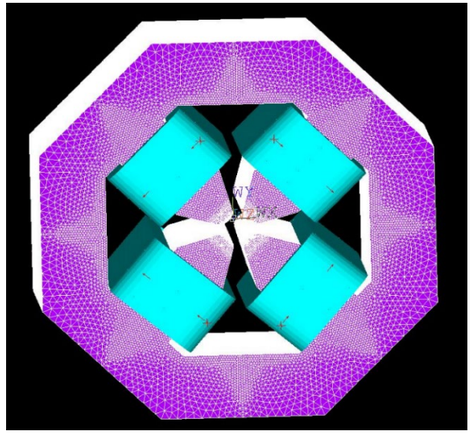
Magnet System

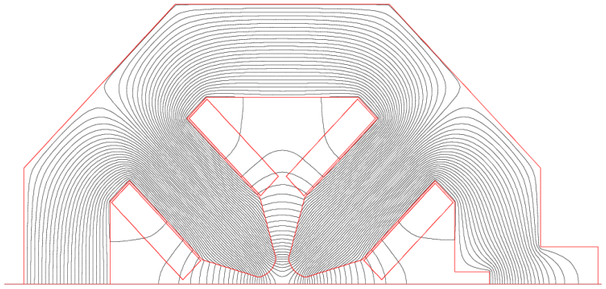
1. Korea-4GSR needs 980 demanding magnets.
2. Center bend features 2T field, and Permendur is adopted for the pole.
3. Longitudinal Dipole used staggered independent coils, and reluctance gap in the return yoke to follow the design field.
4. Quadrupole, Dipole Quad magnet achieved 60 T/m gradient using tapered pole, without using expensive Permendur.
5. Sextupole is not so demanding but requires non-interfering H/V/SQ windings.

Magnet	Required Number	Remark
Central BM	28	1*28
Long. BM	112	4*28
Reverse Bend	336	2*3*28 (should have B, B’)
Quad Bend	56	2*28 (should have B, B’)
Quadrupoles	336	6*2*28
Sextupoles	168	6*28 (should have B”, H/V Corr, Skew Quad)
Fast Corr.	112	4*28 (H/V combined corrector)
Magnets/Sec	35	31+4 (fast Corr.)
Total	980	Total number of magnets



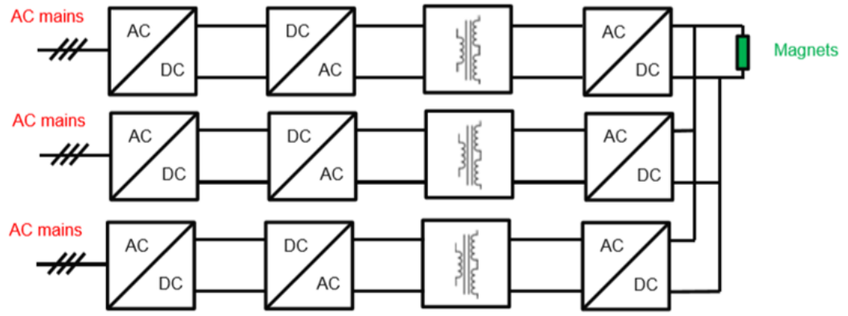






Magnet Power Supply

1. PS configuration with modular structure for easy and fast recovery from fault.
2. PS connection option: Individual or grouping (series) for high power unipolar PS.



Modular structure

Quantity	1,228
MPS Type	Unipolar
Input Voltage	380VAC 3phase
Max. Current	120 A
Max. Voltage	40 V
Max. Power	4.8 kW
Accuracy	TBD
Repeatability	10 ppm
Reproducibility	100 ppm
Ripple and Noise	10 ppm
Long-term Stability (8h)	10 ppm
Temperature Stability	5ppm / K
Line Regulation	±10 ppm
Load Regulation	±10 ppm
Setting Resolution	>18 bit
Readback Resolution	>18 bit
Parallel Operation up to	4

Specification of Power Module for High Power MPS

Quantity	840
MPS Type	Bipolar
Input Voltage	220VAC 1phase
Max. Current	15 A
Max. Voltage	5 V
Max. Power	75 W
Accuracy	TBD
Repeatability	10 ppm
Reproducibility	100 ppm
Ripple and Noise	50 ppm
Long-term Stability (8h)	100 ppm
Temperature Stability	5ppm / K
Line Regulation	±10 ppm
Load Regulation	±10 ppm
Setting Resolution	18 bit
Readback Resolution	18 bit

Specification of Slow MPS

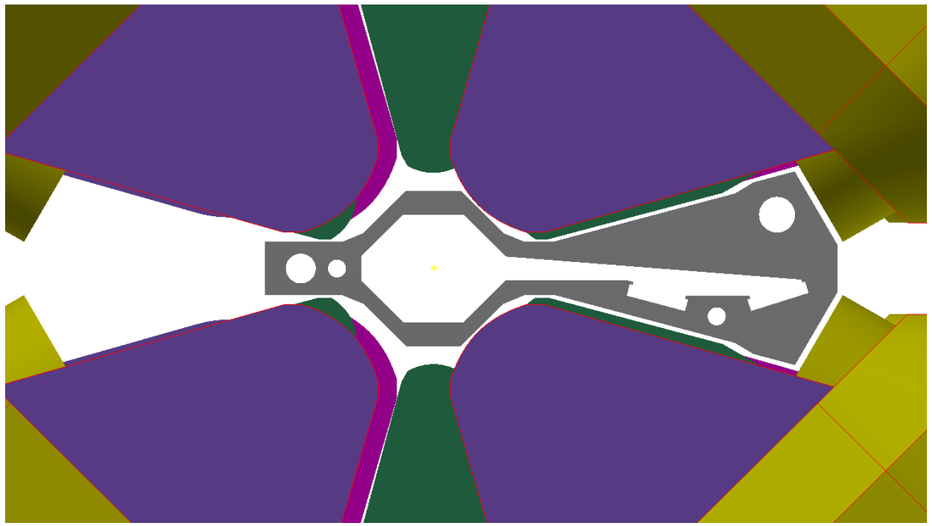
Quantity	112
MPS Type	Bipolar
Input Voltage	220VAC 1phase
Max. Current	5 A
Max. Voltage	20 V
Max. Power	100 W
Accuracy	TBD
Repeatability	10 ppm
Reproducibility	100 ppm
Ripple and Noise	50 ppm
Short-term Stability (30min)	10 ppm
Temperature Stability	5ppm / K
Line Regulation	±10 ppm
Load Regulation	±10 ppm
Setting Resolution	20 bit
Readback Resolution	24 bit
Small Signal Bandwidth	10 kHz

Specification of Fast MPS

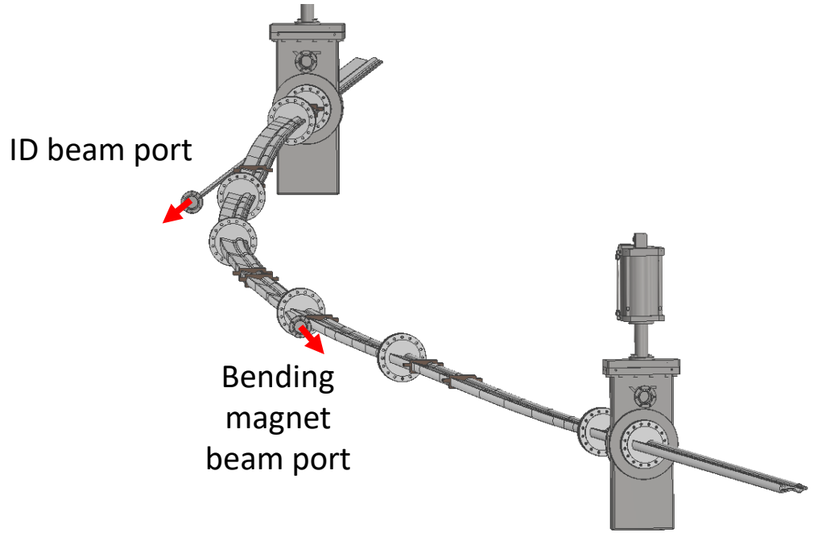
SR Vacuum Chamber

- Beam chamber cross section is octagon shape (24 mm (H) x 18 mm (V)) except for center bend.
- Vertical aperture of the center bend chamber is 10 mm.
- Eight RF-bellows are used for installation and to reduce stress.
- Two gate valves are located at the end of the arc section.
- Seven sputter ion pumps are installed for noble gas pumping.
- The clearance between the vacuum chamber and the magnets is larger than 0.6 mm.

✓ **Clearance**



✓ **Vacuum chambers of an arc-section**



Two Major Changes from CDR

❖ Electron Gun at Linac

>> Thermionic DC Gun

Subject	Single bunch mode	Multi-bunch mode
Beam energy	100 kV	100 kV
Charge	0.01~2.5 nC	3~5 nC
Pulse length	≤1 ns	100~400 ns
Repetition rate	2 Hz	2 Hz

>> Photocathode RF Gun

Subject	Single bunch mode	Multi-bunch mode
Beam energy	4 MeV	4 MeV
Charge	0.01~1 nC	1~3 nC
Pulse length	<20 ps	200 ns (100 pulses)
Repetition rate	2 Hz	2 Hz

* PAL-XFEL has sufficient experience with Photocathode RF Gun

❖ RF System for SR

>> SRF Cavity

>> NRF Cavity from RI

Two Major Changes from CDR

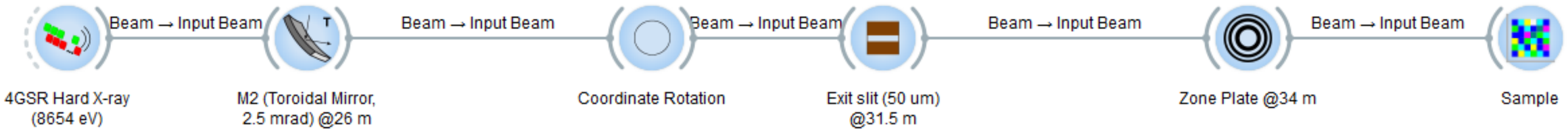
❖ Comparison

Cavity Type	SRF (CDR)	Normal RF* (Euro Design)	Remarks
Required RF voltage [MV]	3.5	3.5	
Required beam power [kW]	720	720	
Shunt impedance [M-Ω]	89,000.0	3.4	
Required power / coupler[kW]	240.0	90	
Wall loss power / cavity [kW]	0.008	18	
Beam Loading Power / cavity	240	72	
Required gap voltage/cavity [kV]	1,166.7	350	
# of cavity	3	10	
# of Klystron	3	10	
Total klystron output power [kW]	864.0	1,080.2	Applied 20% operational margin
AC power for klystron [kW]	1,885.2	2,700.4	RF conversion rate: 40%
Unit Klystron power (kW)	288.0	108	
Total cavity cooling load	700 W @4.5K	180 kW	SRF: He Refrigerator / NRF: LCW
Compressor cooling load, SC [kW]	300.0	-	
HPRF cooling power [kW]	754.1	3,240.5	Total loss + 20% operational margin

Beamlines

【 Industry oriented 】	① BioPharma BioSAXS
	② Material Structure Analysis
	③ Soft X-ray Nano probe
【 Research oriented 】	④ Nanoscale Angle resolved Photoemission
	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 Nano-probe

Beamlines


Beam → Input Beam
Beam → Input Beam
Beam → Input Beam
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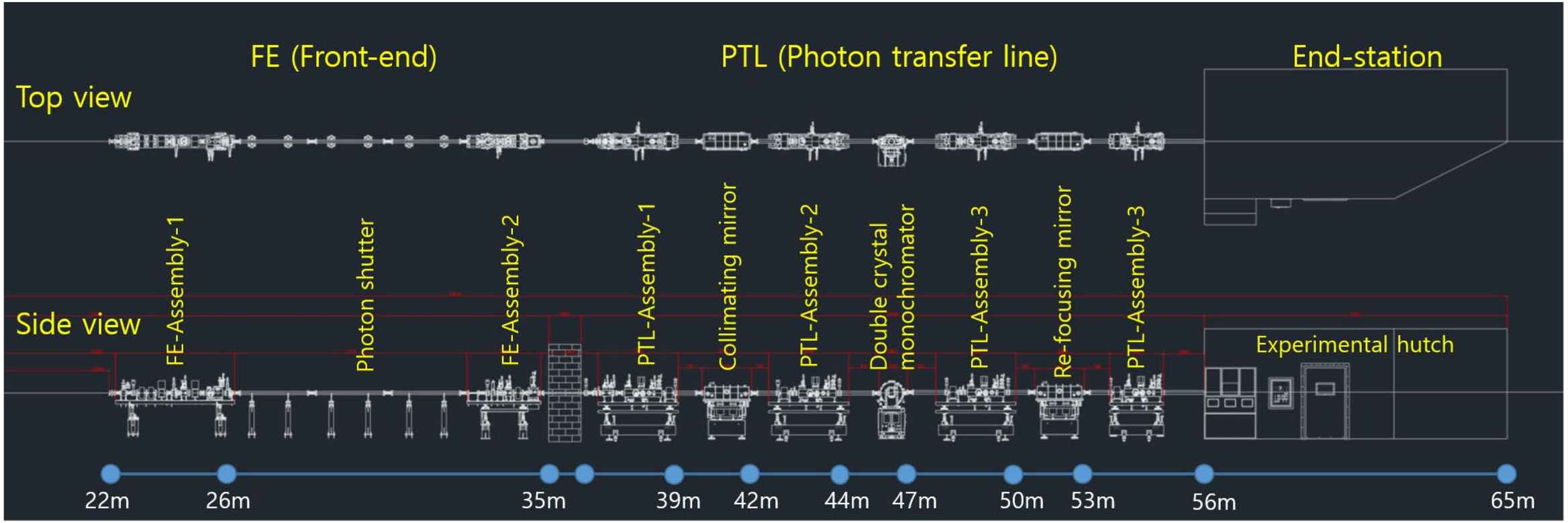
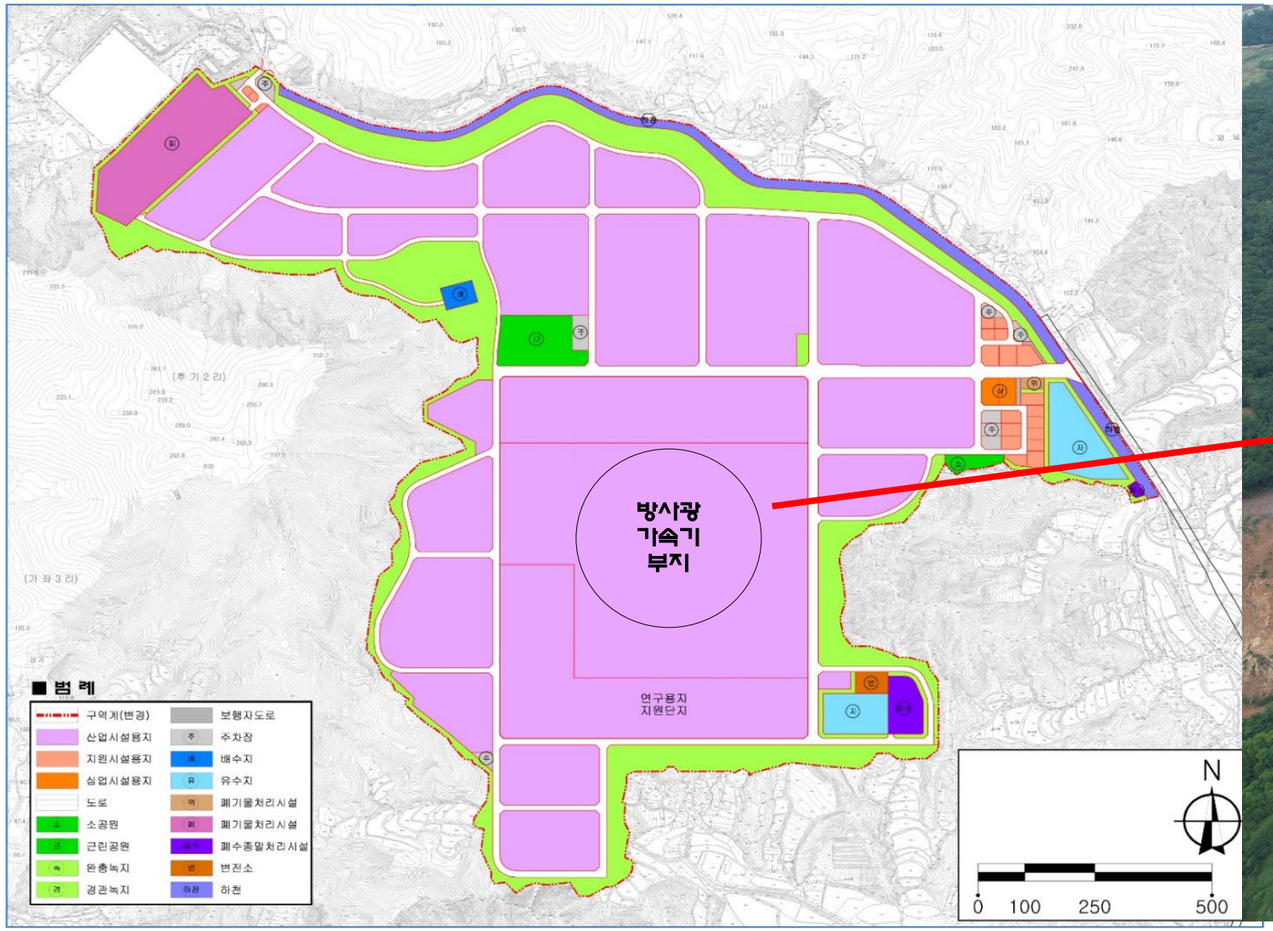
Beam → Input Beam
4GSR Hard X-ray (8654 eV)
M2 (Toroidal Mirror, 2.5 mrad) @26 m
Coordinate Rotation
Exit slit (50 um) @31.5 m
Zone Plate @34 m
Sample


FE (Front-end)
PTL (Photon transfer line)
End-station
Top view
Side view
FE-Assembly-1
Photon shutter
FE-Assembly-2
PTL-Assembly-1
Collimating mirror
PTL-Assembly-2
Double crystal monochromator
PTL-Assembly-3
Re-focusing mirror
PTL-Assembly-3
Experimental hutch
22m
26m
35m
39m
42m
44m
47m
50m
53m
56m
65m

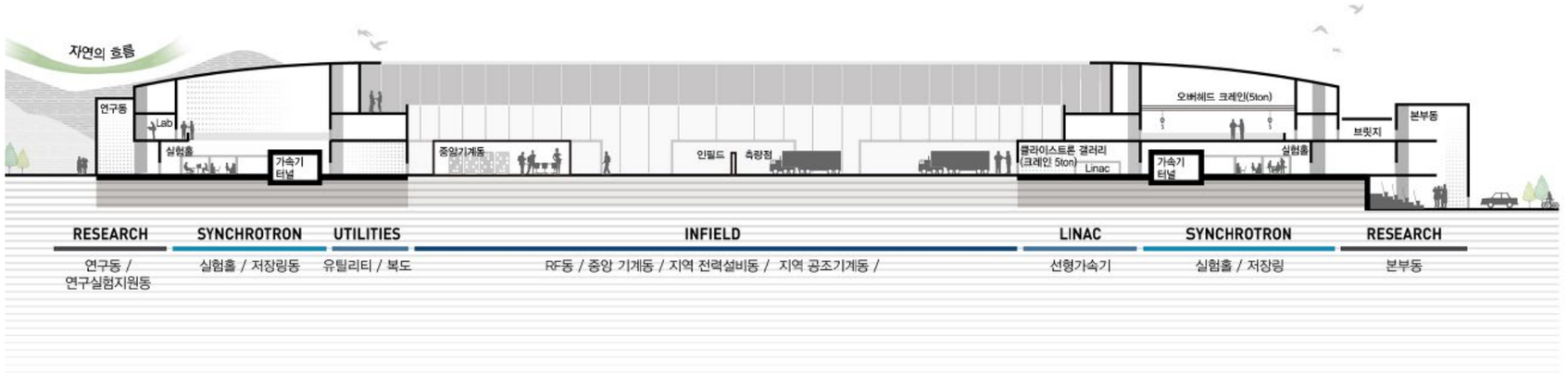
Construction Site



4GSR Design – Building Design Company (Haenglim*)

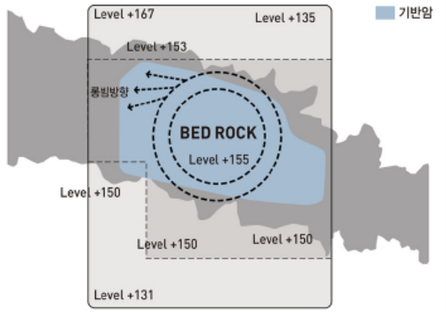
* Designed PAL-XFEL

4GSR Design – Building Cross-session



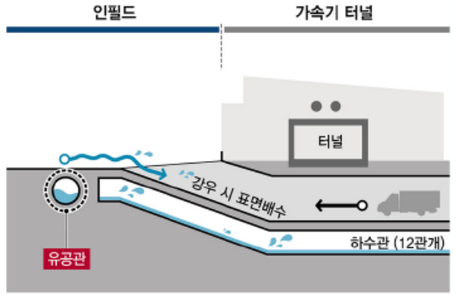
기초 지반 안정성 강화

가속기동 기초지반 100% 암반화



단계별 인필드 배수 계획 수립

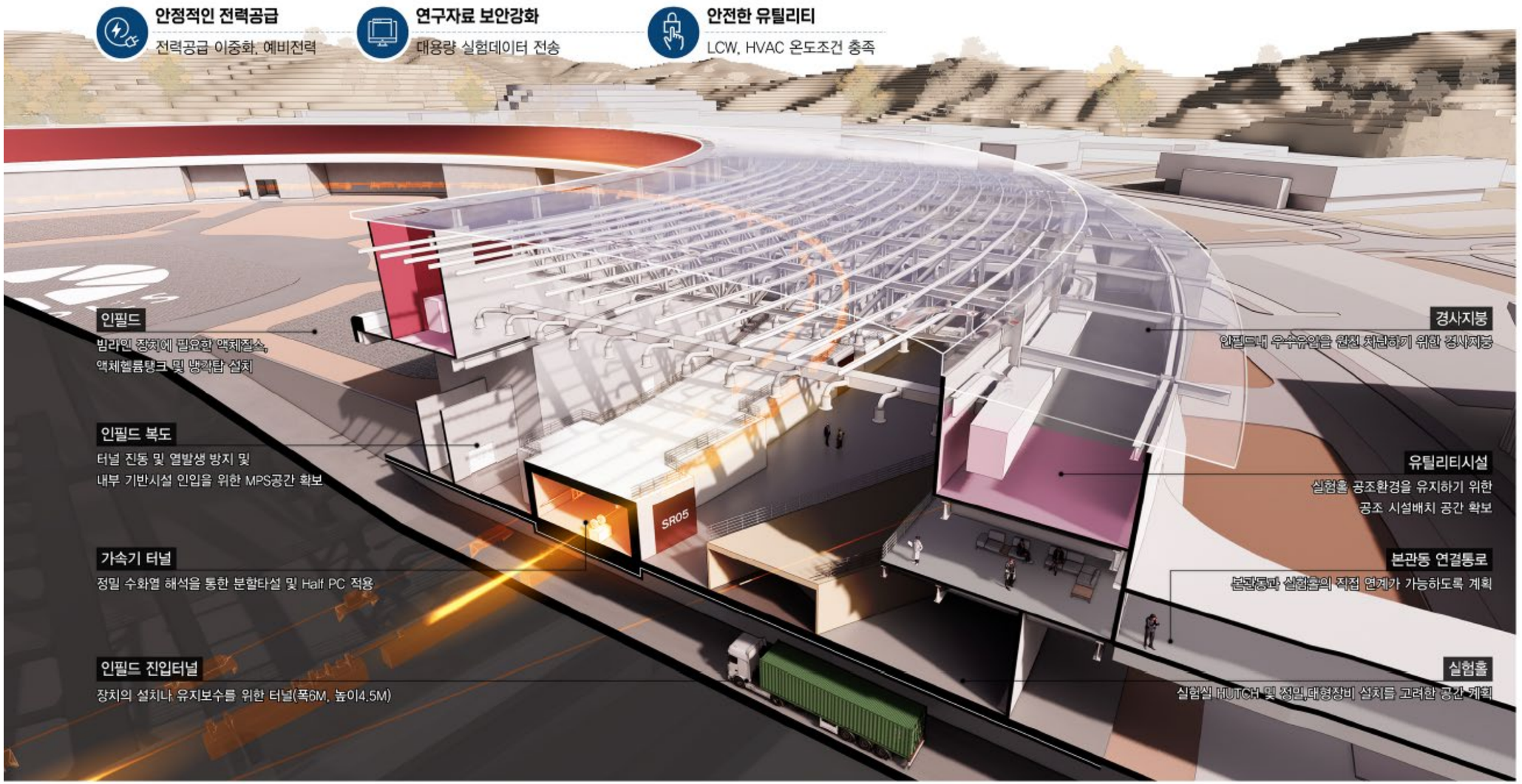
가속기 터널 우수유입 원천차단으로 침수 안전성 확보



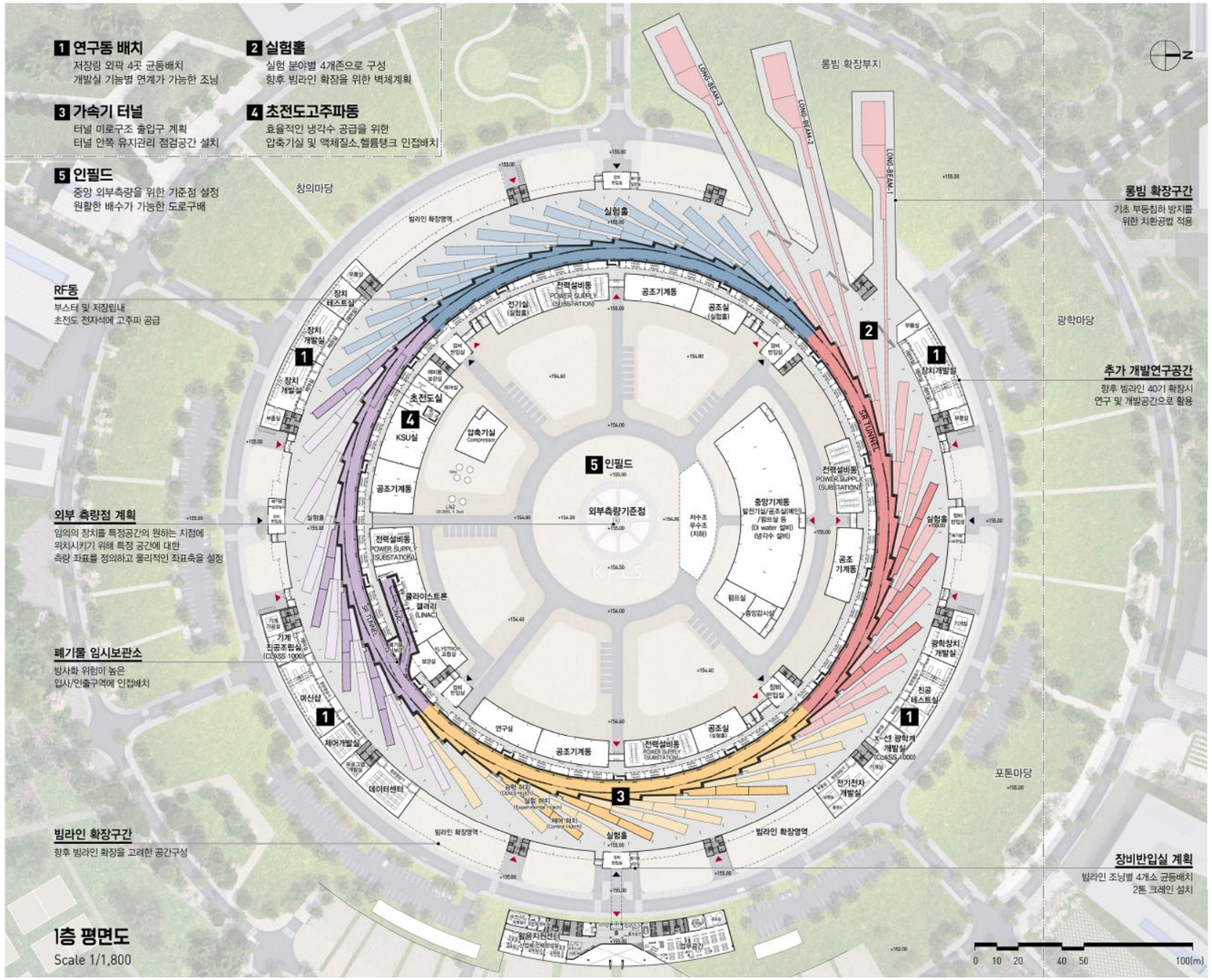
Mass con'c 품질관리

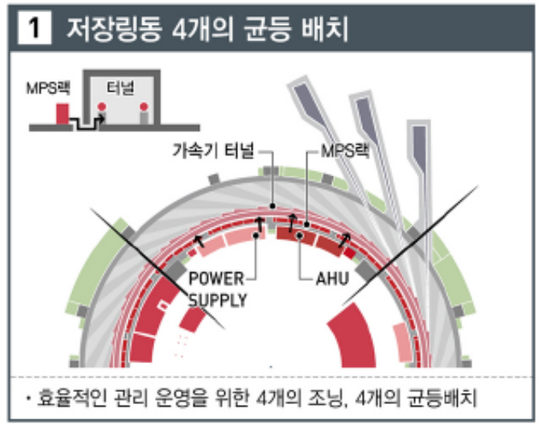
장스팬 구조물의 변형을 고려한 분리타설

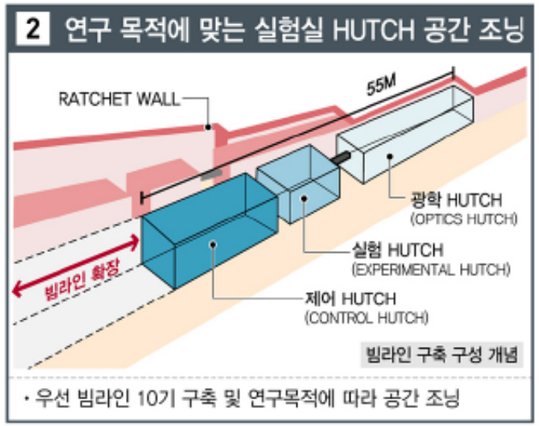
4GSR Design – Special Facilities & Utilities

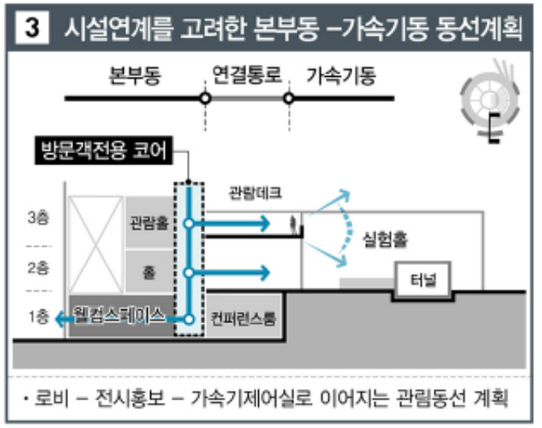


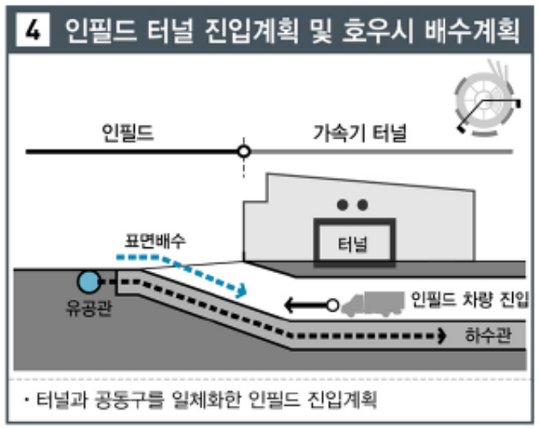
4GSR Design – Floor Plan











Summary

❖ **Multipurpose Synchrotron Radiation Project**

- The project aims to build 4 GeV storage ring with an emittance less than 100 pm
- Its circumference will be 800m
- It can host more than 40 beamlines. Initially, 10 beamlines will be ready.

❖ **2 Institutions working together**

- KBSI: Leading institution in charge of Building and Facility
- PAL: Partner institution in charge of Accelerator and Beamlines

❖ **Construction will be completed by 2027**

- Building design began in September, 2022 and will be completed by 2023
- TDR will be finished by 2023
- Construction will be started in spring, 2024

Thank You