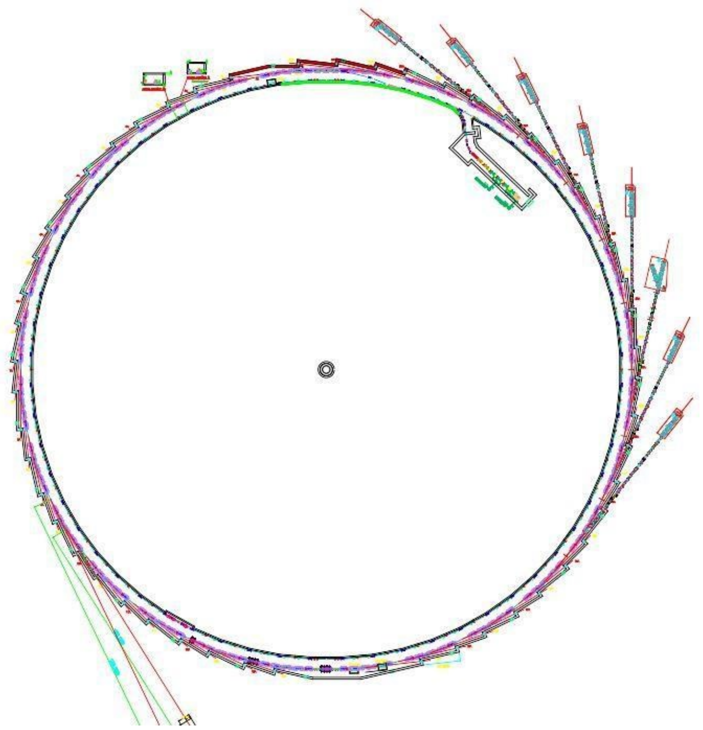
Chapter 1. TDR Summary

1.1 Korea-4GSR parameters

We have organized the target parameters and the overall outline. <Figure 1.1.1.1> shows the overall layout of the 4GSR. It consists of a 200 MeV injector linear accelerator, a 4 GeV booster, and a 4 GeV, 800 m storage ring, with the booster and storage ring installed in the same tunnel.

A total of 52 beamlines can be installed, and up to 60 beamlines are possible using canted insertion devices (IDs) if necessary. Out of 28 cells, one is designated for the injection area, and three are for RF installation. Excluding these four straight sections, 24 straight sections are available for the installation of insertion devices. The main parameters are presented in <Table 1.1.1.1>

An emittance of 62 pm has been achieved, and in round beam mode, the emittance can be reduced to 40 pm. The target beam current is 400 mA operation. For the injection method, we will use the conventional four-kicker system. However, to prepare for future upgrades, we will also consider the nonlinear injection kicker, which has proven its advantages at SIRIUS, through R&D. Details are described in Chapter 2.



<Figure 1.1.1.1> Layout of 4GSR, which consists of 200 MeV injector linac, 4 GeV booster and 800 m storage ring.

<Table 1.1.1.1> 4GSR general parameters

Parameters	Values
Energy / GeV	4
Number of cells	28
Straight sections: Number & length / m (ID straight sections, high-beta straight sections)	26 / 6.06, 2 / 5.40
Ring circumference / m	799.297
Natural emittance / pm rad	62
Regular hor/ver @ coupling	58 / 6 @ 10%
IBS (400 mA) hor/ver @ coupling	80 / 8 @ 10%
Energy spread / %	0.126
Bunch length mm	3.6 (without HC) / 14.4 (with HC)

<Table 1.1.1.2> Parameters on RF cavity, injection scheme, vacuum, and magents

Parameters	Values
RF frequency / MHz	499.593
# cavities / total voltage	10 / 3.5 MV
# buckets: total / gap	1,332 / 308
Harmonic RF system	3^{rd}, active, NC
Average current / mA	400
Lifetime / h (ideal lattice, w/o bunch lengthening)	7.30 (flat) / 29.22 (round)
Top up operation	Yes
Injection scheme	4 kicker bump
Beam pipe (in achrom.) / mm^2	D: 24(H)*18(V) @ ID straight section
Max. bending magnet field / T	2
Max. quadrupole grad. T/m	55
Max. sextupole strength T/m^2	1,737
Max. octupole strength T/m^3	120,083

<Table 1.1.1.3> Storage ring main parameters

Parameter	**Value (w/o IDs)**	**Value (w/ 9 IDs)**
Natural emittance	61.57 pm	52.55 pm
Circumference	799.297 m	
Beam energy	4 GeV	
Working point ν_x, ν_y	68.179 / 23.260	
Natural chromaticity ξ_x, ξ_y	-112.1 / -85.3	
Chromaticity ξ_x, ξ_y(corrected)	5.8, 3.5	
Horizontal damping partition $\mathcal{J}_x$	1.84	1.64
Momentum compaction α	7.8×10^{-5}	
Energy loss per turn U_0	1.098 MeV	1.449 MeV
Energy spread	0.126%	0.104%
Main RF voltage	3.080 MV	3.500 MV
Main RF frequency	499.593 MHz	499.593 MHz
Main RF synchronous phase (w/o harmonic cavity, w/ harmonic cavity)	159.13 deg, 156.36 deg	155.55 deg, 152.24 deg
Harmonic number	1332	
Damping times (H / V / L)	10.55 ms/ 19.43 ms/ 16.79 ms	8.98 ms/ 14.72 ms/ 10.81 ms
Harmonic cavity voltage	0.950 MV	1.048 MV
Harmonic cavity frequency	1,498.78041 MHz	1,498.78041 MHz
Harmonic cavity phase	351.70 deg	350.49 deg
Bunch length (w/o harmonic cavity, w/ harmonic cavity)	3.6 mm, 14.4 mm	2.8 mm, 11.4 mm
Beta function at center of ID straight β_x, β_y	6.33 m / 2.84 m	
Beta function at center of high-beta straight β_x, β_y	15.90 m / 4.45 m	

1.2 Initial 10 Beamlines parameters

The initial ten beamlines to be constructed at 4GSR are listed in <Table 1.2.1.2>. Among them, three beamlines, ① BioPharma-BioSAXS (Bio-Pharmaceutical and Bio Small-Angle X-ray Scattering), ② Material Structure Analysis, ③ Soft X-ray NanoProbe, are designated as industry-priority beamlines, focusing on high-throughput technologies required by industrial users.

The remaining seven beamlines, ④ Nanoscale Angle-Resolved Photoemission Spectroscopy (NanoARPES), ⑤ Coherent X-ray Diffraction (CoXRD), ⑥ Coherent Small-Angle X-ray Scattering (CoSAXS), ⑦ Real-Time X-ray Absorption Fine Structure (Real-Time XAFS), ⑧ Bio-Nano Crystallography (BioNC), ⑨ High Energy Microscopy (HEM), ⑩ Nano-Probe, are planned as leading-edge fundamental research beamlines. Details are described in Chapter 3.

<Table 1.2.1.1> Initial beamline plan of Korea-4GSR

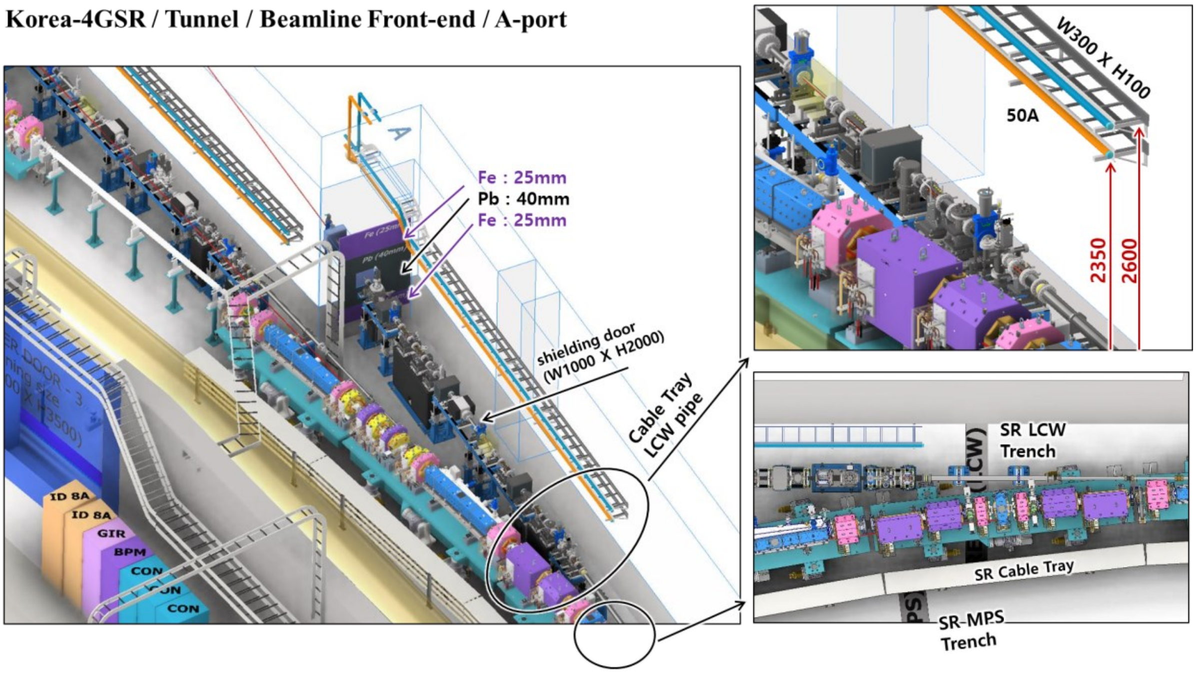
Beam port	Light source	Length [m]	Peak Field [T]	Period [mm]	Minimum gap [mm]
ID21	In-vacuum undulator	3.0000	1.2250	24.00	5.00
ID24	In-vacuum undulator	3.0000	0.7850	16.00	5.00
ID26-1	In-vacuum undulator	1.5000	1.2250	24.00	5.00
ID26-2	Elliptical polarized EPU78	2.0000	0.9540	78.00	15.00
	Circular polarized EPU78		0.6020		
	Max horizontal polarized EPU78		0.7760		
ID25	Elliptical polarized EPU98	3.6260	1.0100	98.00	15.00
	Circular polarized EPU98		0.6633		
	Max horizontal polarized EPU98		0.8799		
ID03	In-vacuum undulator	3.0000	1.2270	22.00	5.00
ID04	In-vacuum undulator	3.0000	1.0211	20.00	5.00
ID23	In-vacuum undulator	3.0000	1.2250	24.00	5.00
ID22	In-vacuum undulator	3.0000	1.0210	20.00	5.00
BM10	Center bend	Already considered			
ID10	In-vacuum undulator	3.0000	1.2253	20.00	5.00

<Table 1.2.1.2> Specifications of the Initial 10 Beamlines of 4GSR

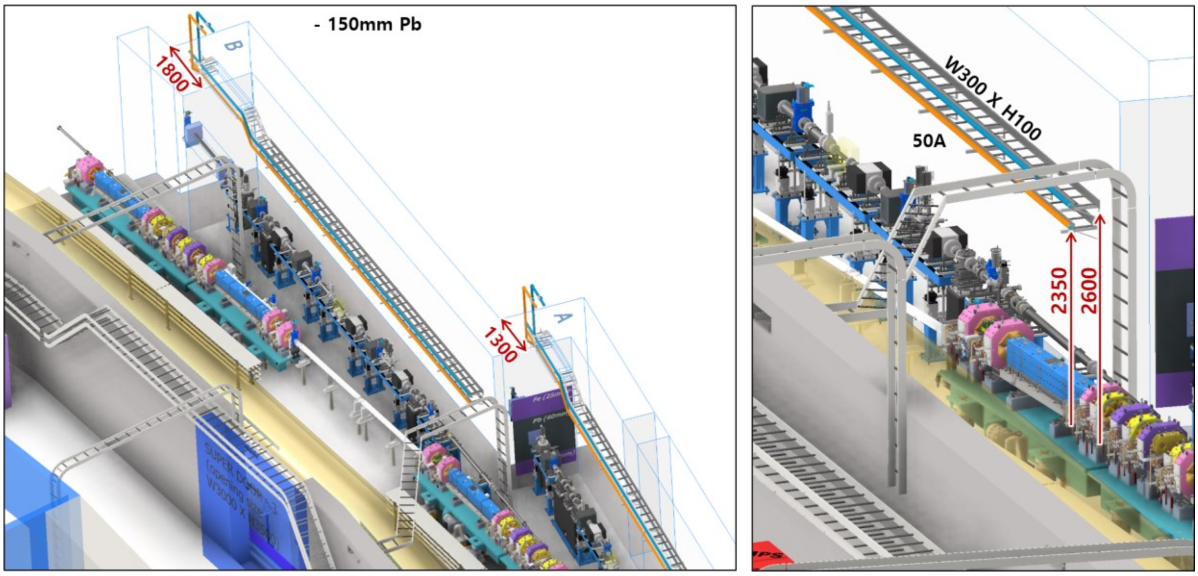
	Preliminary Feasibility Report Specifications	Detailed Design Specifications	Application	Remarks
1. BioPharma-BioSAXS (Industry-Priority)	• Beam Energy: from 5 to 20 keV • Experimental Method: Bio-SAXS	• Beam Energy: from 5 to 20 keV (Same) • Experimental Method: Solution SAXS • Resolution: from 8 to 4000 Å (SAXS) * $\triangle E/E < 2 \times 10^{-4}$ • Light Source: IVU24	Bio	• Optimized from 8 to 25 keV • SDD (Sample-to-Detector Distance) secured up to 6 m • Automation system implemented
2. Material Structure Analysis (Industry-Priority)	• Beam Energy: from 5 to 40 keV • Experimental Method: XRD (Powder XRD), XAFS	• Beam Energy: from 5 to 40 keV (Same) • Experimental Method: Powder XRD, XAFS • Resolution: $\triangle E/E < 2 \times 10^{-4}$ • Light Source: IVU24	Material, Energy	• Implementation of HRPD and XAFS Experimental Methods
3. Soft X-ray NanoProbe (Industry-Priority)	• Beam Energy: from 0.1 to 5 keV • Beam Size: Must be ≤1 ㎛ • Experimental Method: XPS, XAS	• Beam Energy: from 0.1 to 5 keV (Same) • Beam Size: from 100 nm to 10 ㎛ • Resolution: $\triangle E/E < 1.5 \times 10^{-4}$ @ 400 eV, 4 keV • Experimental Method: XPS, XAS • Light Source: EPU78 + IVU24	Semiconductor, Material	• EPU + IVU Tandem → from 0.1 to 5 keV • Designed with two branch beamlines • Beam Size: * ≤100 nm (Soft X-ray) * ≤10 ㎛ (Tender X-ray)
4. NanoARPES	• Beam Energy: from 0.1 to 2 keV • Beam Size: <100(H) × 100(V) nm² • Spatial Resolution: ≤30 nm • Experimental Method: Nano-ARPES	• Beam Energy: from 0.05 to 2 keV (Range Satisfied) • Beam Size: from 100 nm to 10 ㎛ • Spatial Resolution: ≤100 nm • Resolution: $\triangle E/E < 10^{-4}$ • Experimental Method: ARPES • Light Source: EPU98	Semiconductor, Material	• Optimized from 50 to 200 eV • Designed with two branch beamlines • Beam Size: * ≤100 nm (NanoARPES) * ≤10 ㎛ (MicroARPES)
5. CoXRD	• Beam Energy: from 3 to 30 keV • Beam Size: ≤1 ㎛ • Experimental Method: XRD, CDI	• Beam Energy: from 3 to 30 keV (Same) • Beam Size: 1.5 ㎛ • Experimental Method: XRD, CDI • Light Source: IVU22	Semiconductor, Material, Geology, Chemistry	• Micrometer beam Focusing

6. CoSAXS	• Beam Energy: from 4 to 40 keV • Experimental Method: SAXS/WAXS (Including GI Method), XPCS	• Beam Energy: from 8 to 30 keV (Satisfies Experimental Methods) • Beam Size: * <5 ㎛ (XPCS) * <50 ㎛ (SAXS/WAXS) • Resolution: △E/E < 1×10^{-4} • Experimental Method: SAXS/WAXS (Including GI Method), XPCS • Light Source: IVU20	Material, Chemistry	• Securing Coherent Beam. (Wave front preserve)
7. Real-Time XAFS	• Beam Energy: from 5 to 40 keV • Experimental Method: XAFS	• Beam Energy: from 4 to 40 keV (Range Satisfied) • Beam Size: <100 ㎛ • Resolution: ΔE/E < 2×10^{-4} • Experimental Method: XAFS • Light Source: IVU24	Energy, Environment, Material, Geology	• Consideration of XES-Based Real-Time X-ray Absorption Spectroscopy Experimental System
8. BioNC	• Beam Energy: from 5 to 20 keV • Resolution: ≤1 Å • Experimental Method: MX	• Beam Energy: from 5 to 20 keV (Same) • Beam Size: from 1 × 1 to 13 × 13 ㎛² • Resolution: from 0.7 to 3.5 Å • Experimental Method: MX • Light Source: IVU20	Bio	• Optimized from 8 to 25 keV • NanoMX • Supports Drug Development
9. HEM	• Beam Energy: from 5 to 100 keV • Resolution: 0.1 ㎛ (at 100 m reference) • Experimental Method: Projection Imaging	• Beam Energy: from 5 to 100 keV (Same) • Resolution: from 0.3 to 0.5 ㎛ • Experimental Method: Projection Imaging • Light Source: Centerbend • Sample Position: 100 m (Experimental Hutch: 120 m)	Material, Energy, Bio	• Bending Magnet • Excludes Near-Distance Hutch (Uses White Light)
10. Nano-Probe	• Beam Energy: from 5 to 25 keV • Experimental Method: Ptychography, XRS, XRF	• Beam Energy: from 5 to 25 keV (Same) • Beam Size: ≤50 nm @ 10 keV • Resolution: △E/E < 1.5×10^{-4} • Experimental Method: Ptychography, XRF • Light Source: IVU24	Semiconductor, Material, Energy, Environment, Chemistry	• Pursues Nano Beam Focusing • Designed for 5f-Block Elements and RI Materials → Experiments Possible After Radiation Safety Protocol Preparation

Korea-4GSR / Tunnel / Beamline Front-end / A-port

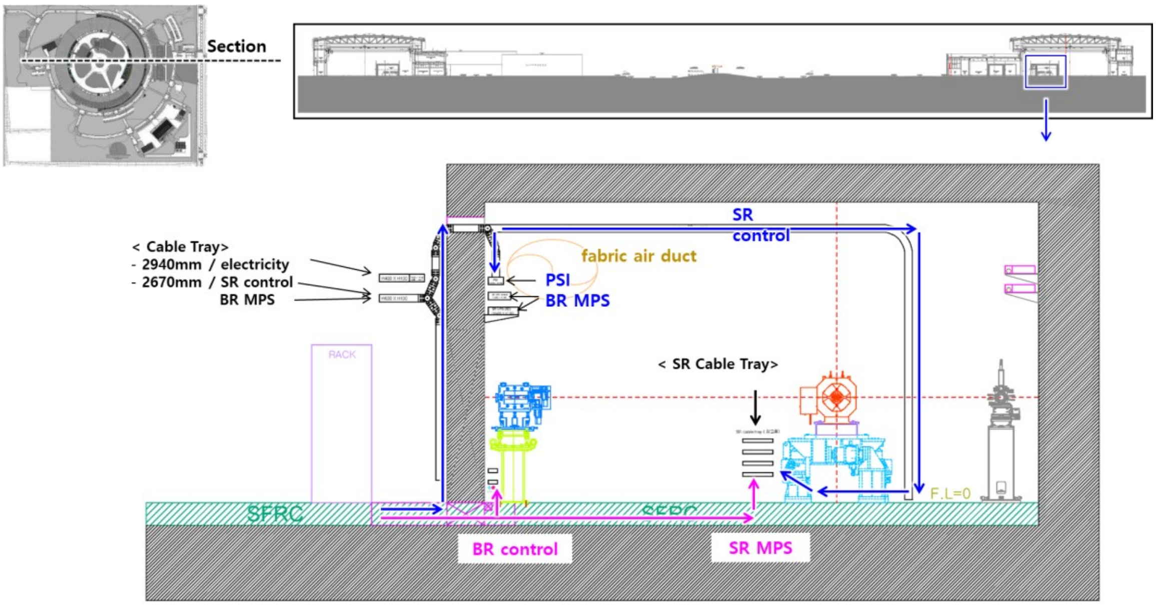


Korea-4GSR / Tunnel / Beamline Front-end / B-port

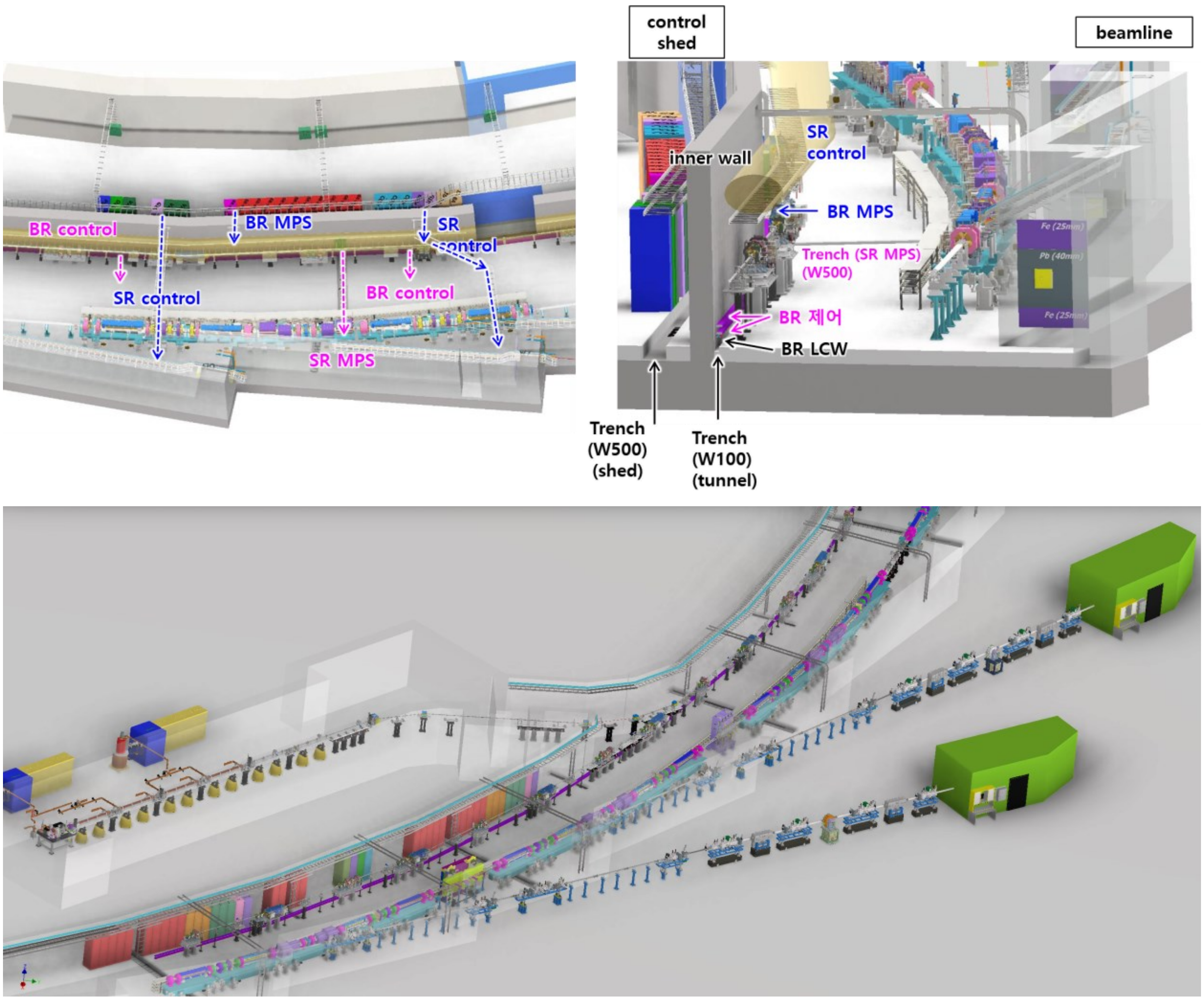


<Figure 1.2.1.1> Korea-4GSR/Tunnel/Beamline Front-end.

Korea-4GSR / Booster ring, Storage ring cable



<Figure 1.2.1.2> Korea-4GSR/Booster ring, Storage ring cable.



<Figure 1.2.1.3> Layout of the Beamline and Control System Trenches.