Accelerator Design Overview



KBSI KOREA BASIC SCIENCE INSTITUTE

PAL POHANG ACCELERATOR LABORATORY

Design Features of KLS

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

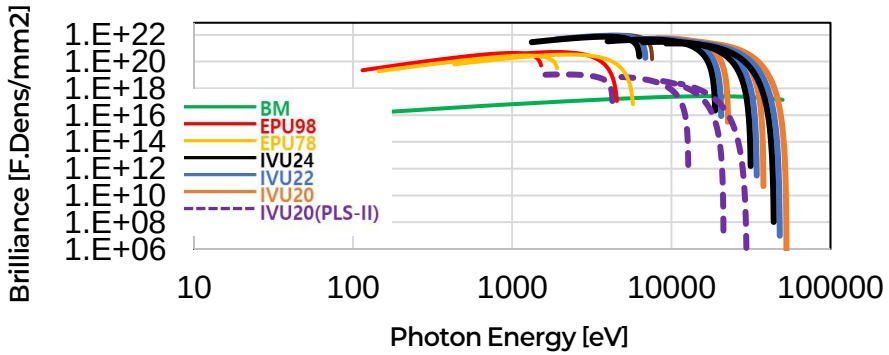
Considering well demonstrated technologies for the design

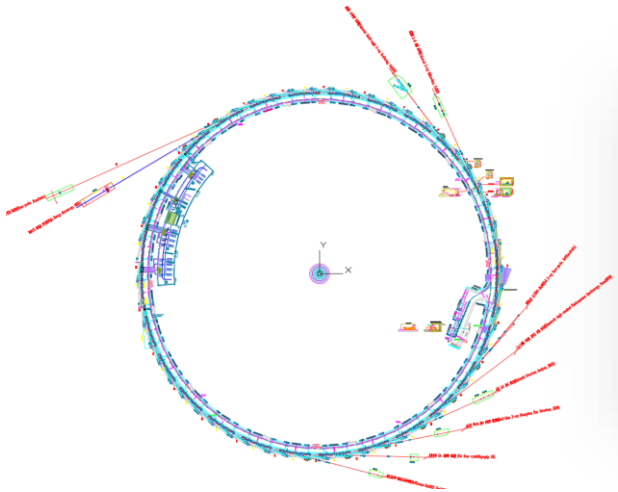
- Off-axis injection with conventional injection schemeCapability to generate photon beam up to 100 keV
- General technologies for magnet and vacuum systems
- On schedule user service and full performance

Synergy with PLS-II and PAL-XFEL

- Supporting full range of synchrotron radiation application

Brilliance vs photon Energy

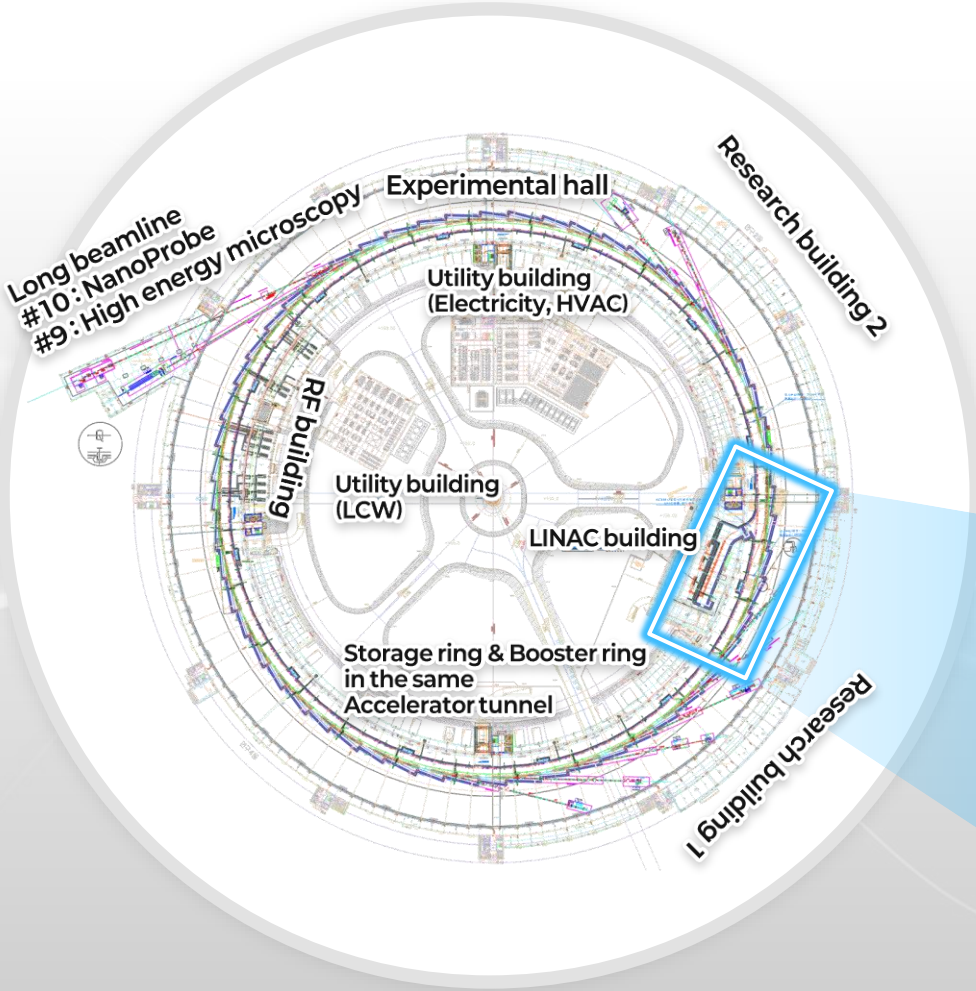


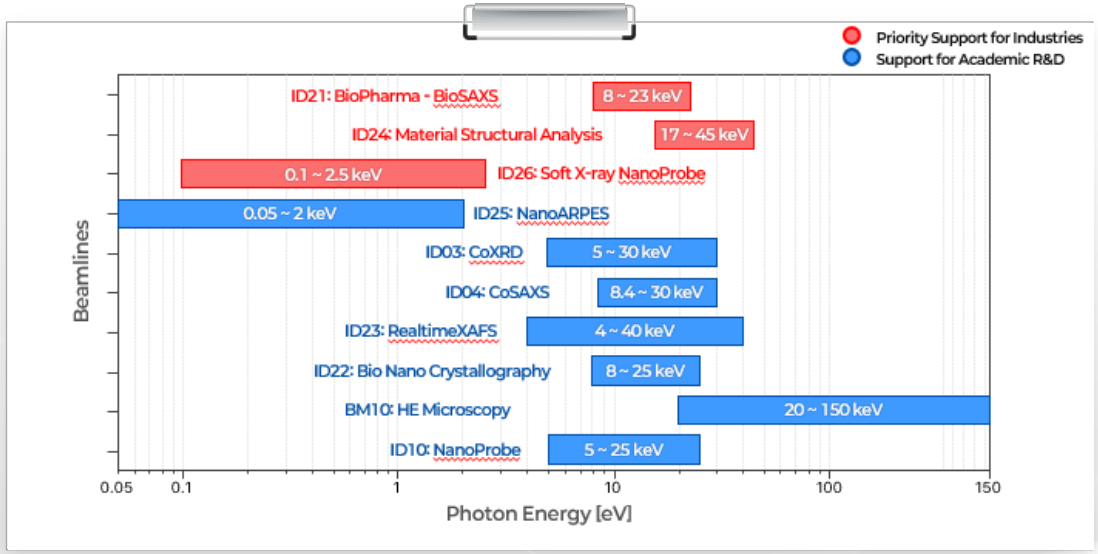


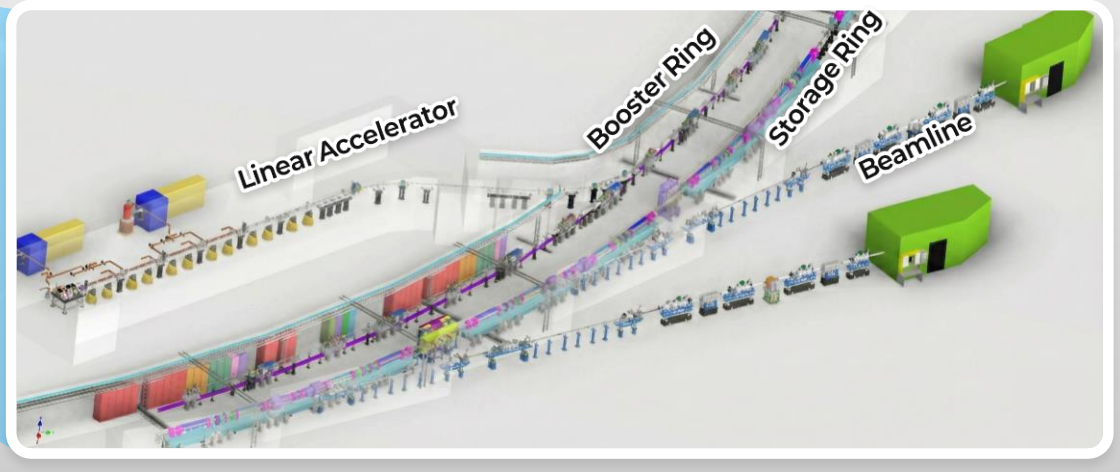
28 straight sections

- 200 MeV, photocathode linac
- 773 m, booster ring (200 MeV to 4 GeV)
- 800 m - 4 GeV, storage ring

Overall View of Accelerator Facility



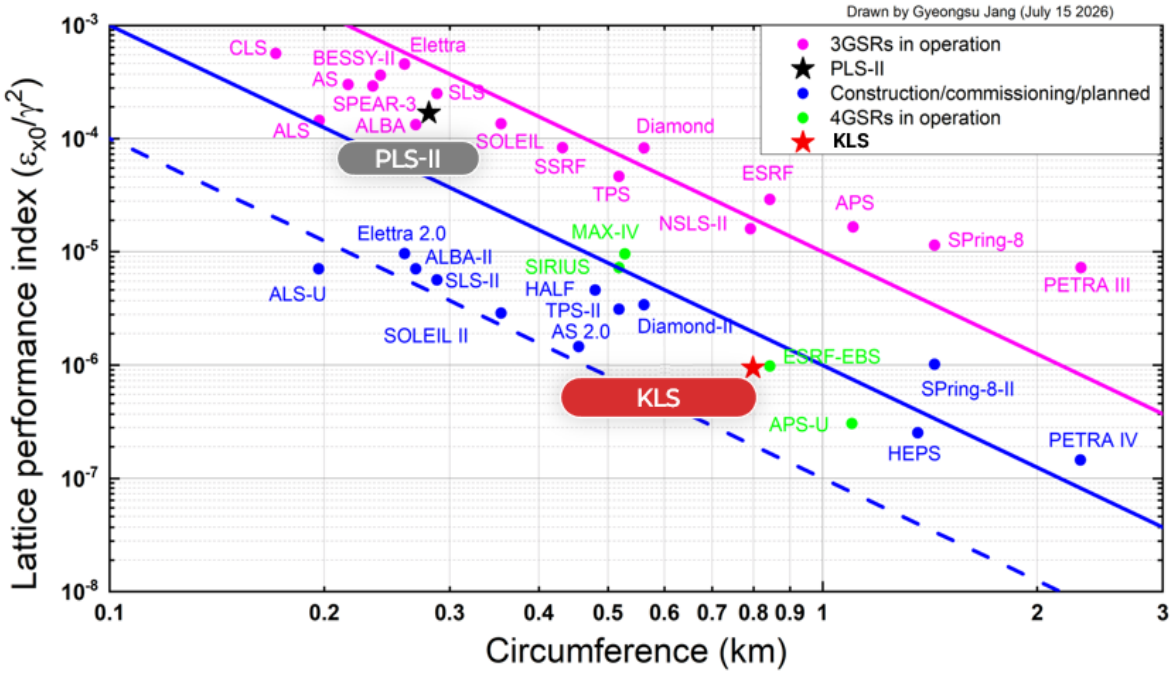




Parameters of KLS Storage Ring

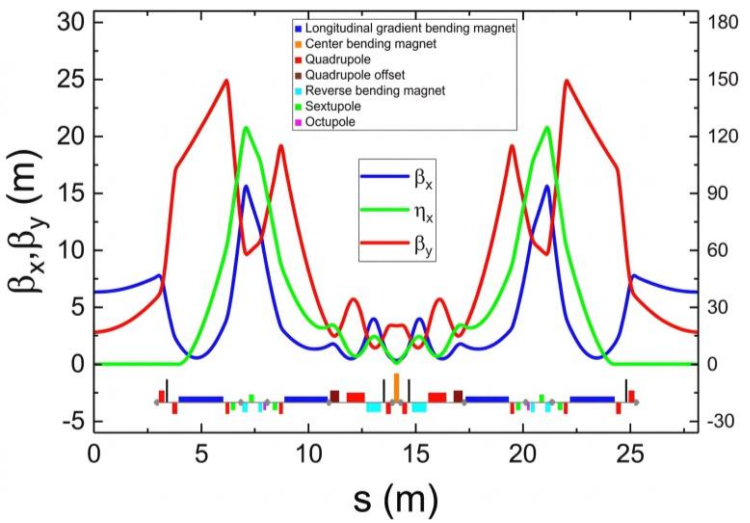
Ring/RF Parameter	Value
Energy [GeV]	4
Beam current [mA]	400
Nat. Emittance [pm·rad]	61.57(w/o IDs) / 52.55(w/ IDs)
Emittance coupling [%]	10
Energy spread	1.26E-03
Bunch Length(rms) [mm]	3.6(w/o HC) / 14.4(w/ HC)
Lattice	Hybrid 7 Bend Achromat
Ring Circumference [m]	799.297
Length of Straight Sections [m]	6.06
Tune (H/V)	68.179 / 23.260
(corrected) Chromaticity (H/V)	5.8 / 3.5
Momentum compaction factor	7.80E-05
Number of buckets	1332
Injection scheme	4 kicker bumps, off-axis, 2Hz
RF frequency [MHz]	499.593
RF Voltage [MV]	3.080(w/o IDs) / 3.5(w/ IDs)
Energy loss per turn [KeV]	1098(w/o IDs) / 1449(w/ IDs)

Lattice performance index vs. Circumference for world-wide storage rings

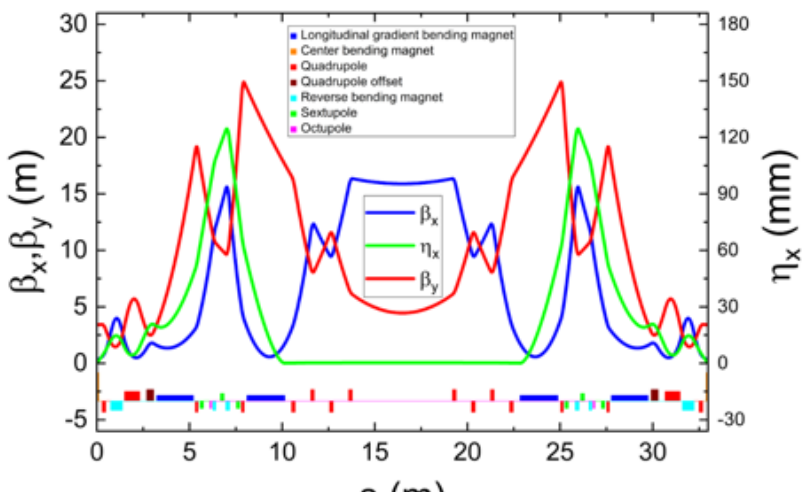


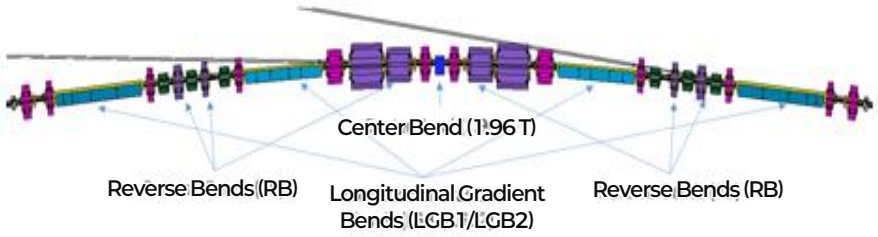
Beam Dynamics – SR Lattice (Hybrid 7-Bend Achromat, H7BA)

Arc + ID straight section



Arc + High-beta straight section





Features

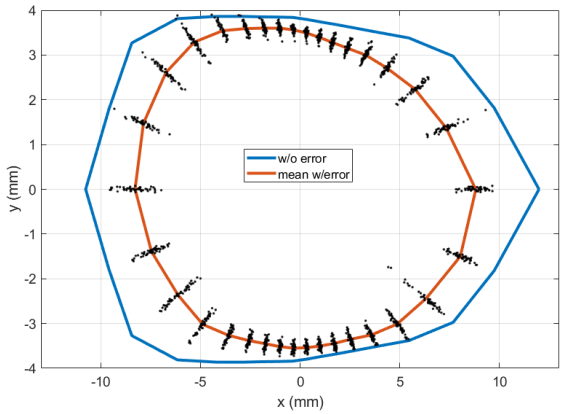
- The storage ring is a **800 m – 4 GeV – 28-cell** ring with natural emittance of 62 pm
- The unit cell is a H7BA with 2-T center bend
- It exploits longitudinal gradient bends (LGBMs) and reverse bend (RBs) to suppress emittance
- The storage ring design has been evolved from a circular ring to a race-track ring to achieve best compromise between dynamic aperture, Touschek lifetime and matching between photon beam and electron beam

Beam Dynamics – SR Dynamic Aperture and Touschek lifetime

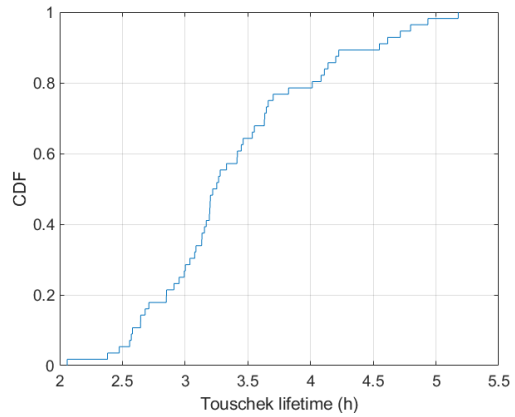
Magnet	Misalignment (μm) (X/Y/Z)	Rotation (μrad) (Roll/Pitch/Yaw)	Strength error (%)
LGBM	30 / 30 / 250	400 / 100 / 100	0.05
Combined-function magnet	30 / 30 / 250	400 / 100 / 100	0.05
Quadrupole	30 / 30 / 250	400 / 700 / 700	0.05
Center bend	30 / 30 / 250	400 / 100 / 100	0.05
Sextupole	30 / 30 / 250	400 / 700 / 700	0.05
Octupole	30 / 30 / 250	400 / 700 / 700	0.05
Girder	100 / 100 / 100	400 / - / -	-

Error tolerance used for SR commissioning simulations (rms value)

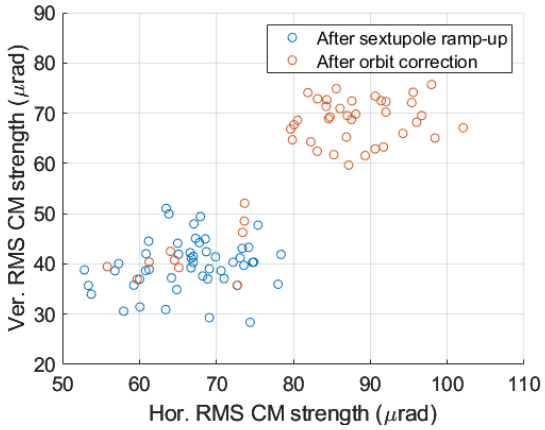
Results of SR commissioning simulations with 50 random error seeds



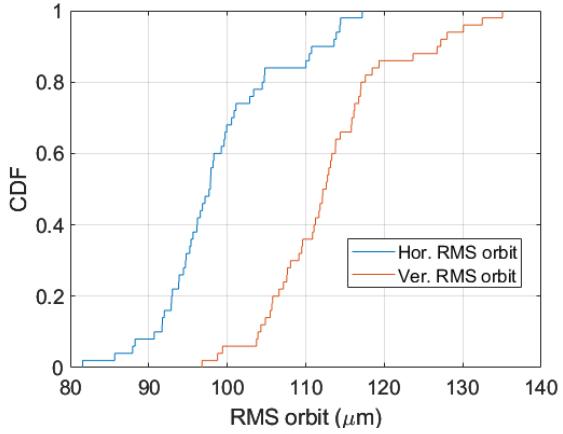
Dynamic aperture



Touschek lifetime (w/o 3HC)



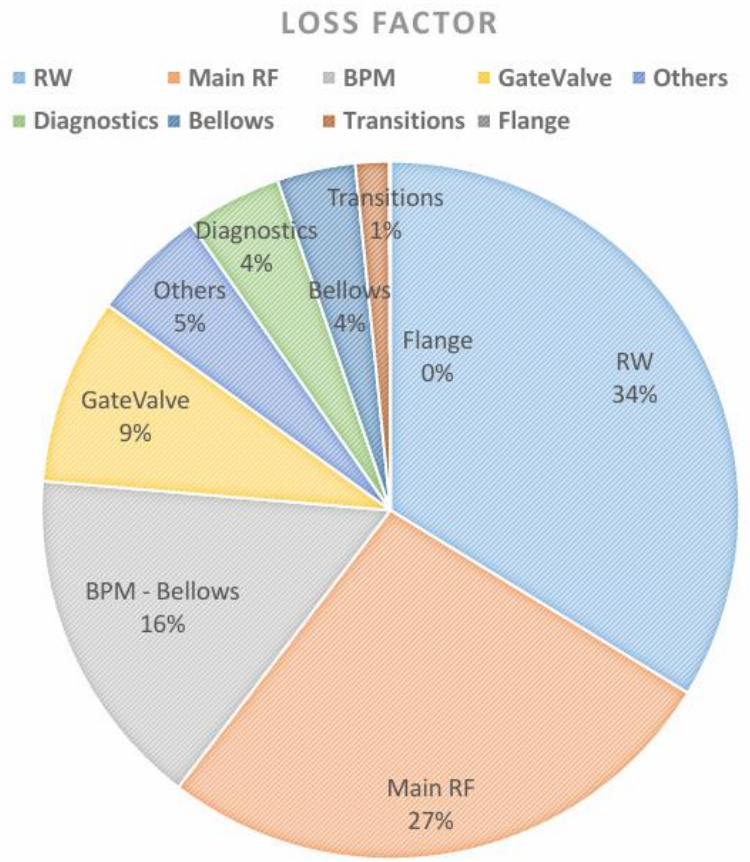
Corrector strength



RMS orbit

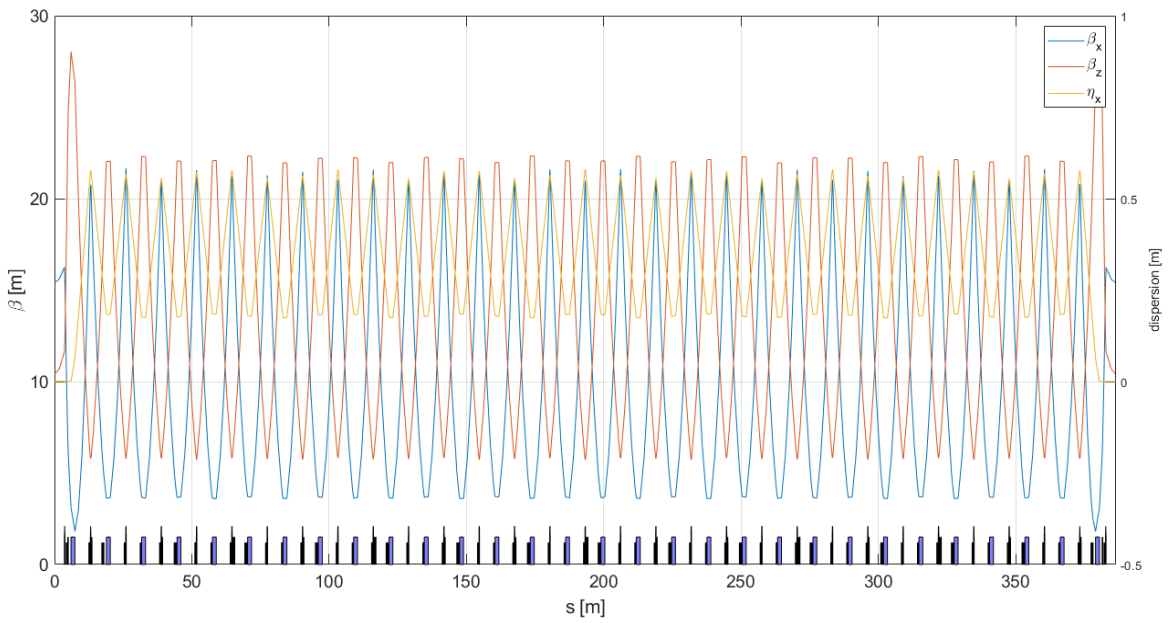
Beam Dynamics – SR Impedance Budget

Components	Number	Single Component k_z [V/pC]	Single Component Zn_z [mOhm]	Sum k_zT [V/pC]	Sum Zn_zT [mOhm]
Resistive Wall	1	14.78	158.20	14.78	158.2
Main RF cavity	10	1.17	5.98	11.65	59.80
LGBM1U chamber	28	2.34E-02	0.16	0.65	4.37
LGBM2D chamber	28	3.42E-02	0.34	0.96	9.39
BPM	176	2.30E-02	0.17	4.05	30.62
Gate valve	112	3.38E-02	0.30	3.79	33.82
ID taper	26	2.56E-03	0.89	0.07	23.17
Bellows	224	7.09E-03	0.07	1.59	15.19
BPM-Bellows 1	56	2.72E-02	0.23	1.52	12.94
BPM-Bellows 2	56	2.50E-02	0.23	1.40	12.94
Flange	840	3.00E-05	0.02	0.03	15.96
RF taper	6	7.70E-02	1.89	0.46	11.32
LFS	1	1.58E+00	6.30	1.58	6.30
RF transition chamber	5	8.50E-02	0.75	0.43	3.76
Pump tee	56	5.16E-03	0.13	0.29	7.45
TFS (vert-)	1	1.82E-01	0.67	0.18	0.67
TFS (hori-)	1	1.82E-01	0.67	0.18	0.67
Center bend chamber	28	3.52E-03	0.21	0.10	5.88
CH08 entrance	56	7.90E-04	0.03	0.04	1.68
CH08 exit	56	1.82E-04	0.01	0.01	0.73
Collimator	4	TBD		TBD	
Total				44	415
				Loss factor	Effective impedance



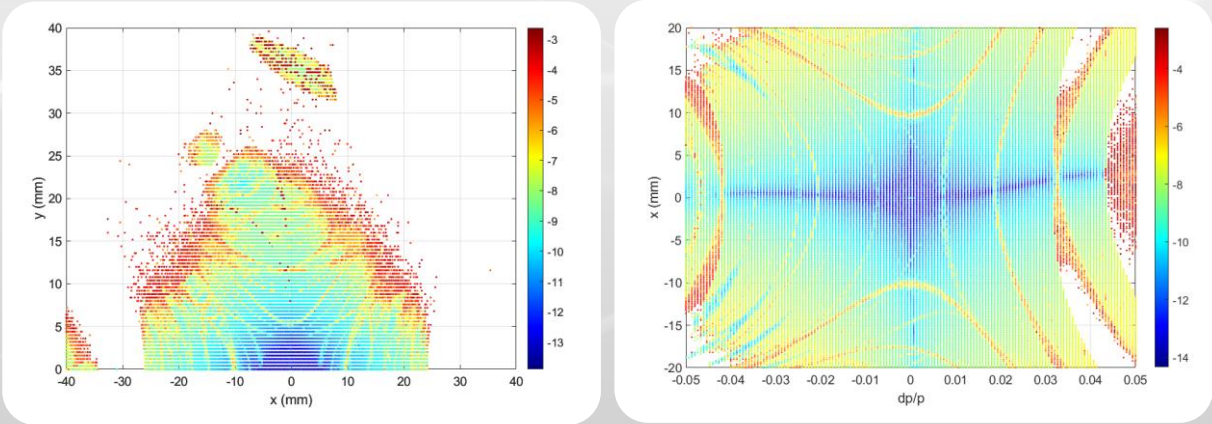
Beam Dynamics – Booster

- Booster shares the same tunnel with the storage ring
- FODO optics
- Race-track shape with two dispersion-free straights



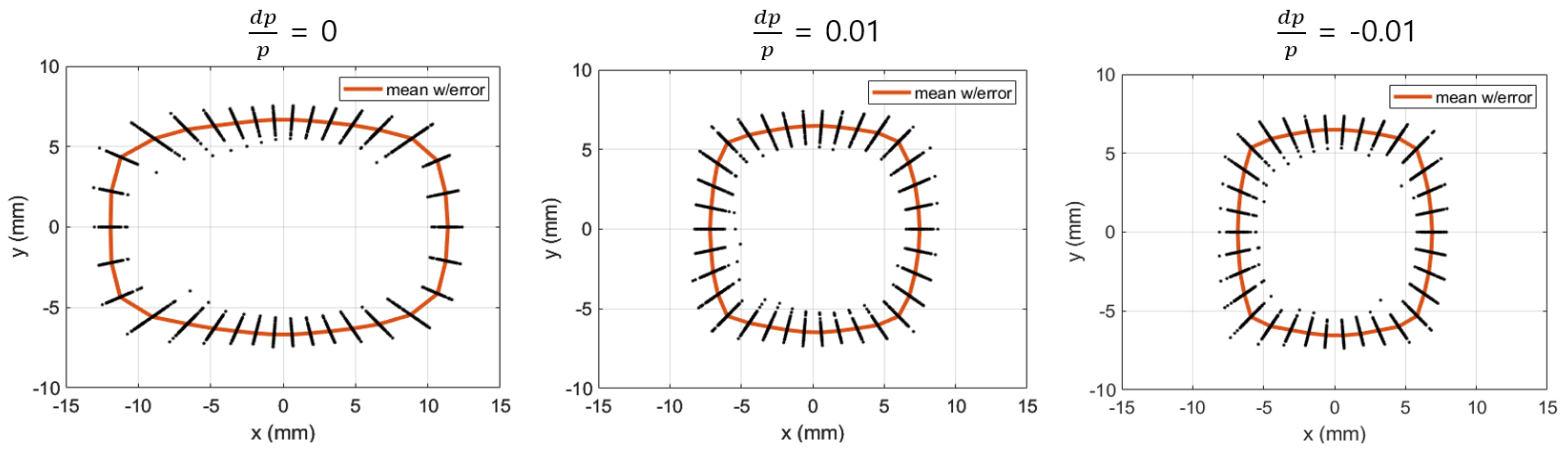
Half- cell optics

Booster Parameters		Value	Unit
Design Parameters	Number of Cells	30	-
	Circumference	772.9	[m]
	Beam Energy	0.2 - 4	[GeV]
	Natural Emittance (4 Gev)	10.9	[nm rad]
	Max. Beam Current	2	mA
Tune and Chromaticiy	Tune (H/V)	17.77 / 10.70	-
	Natural Chromaticity (H/V)	-22.3 / -15.1	-

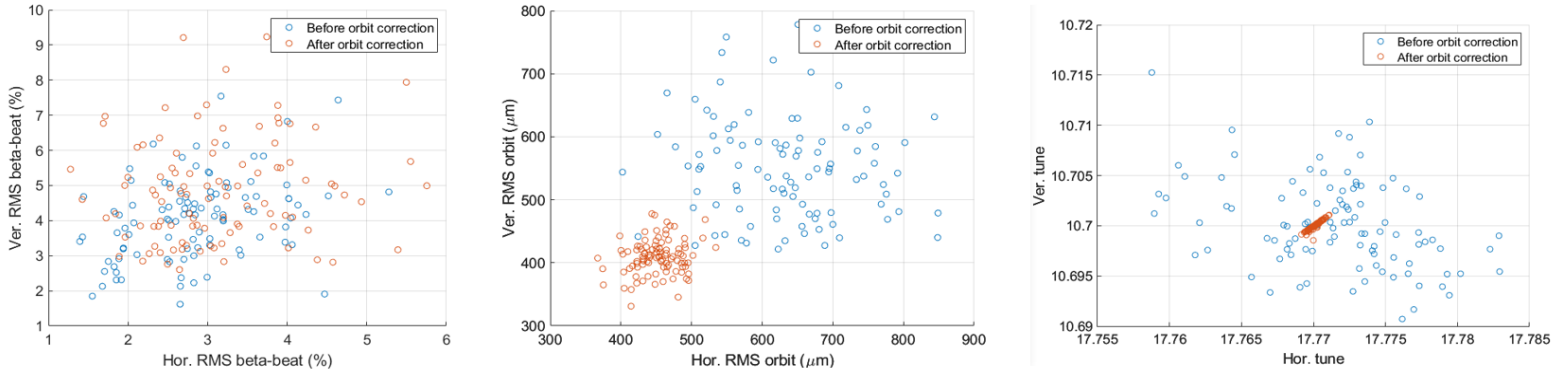


Frequency map analysis (w/o physical aperture)

Beam Dynamics – Booster Error Study



DA with errors



Beta-beat, rms orbit, and tune

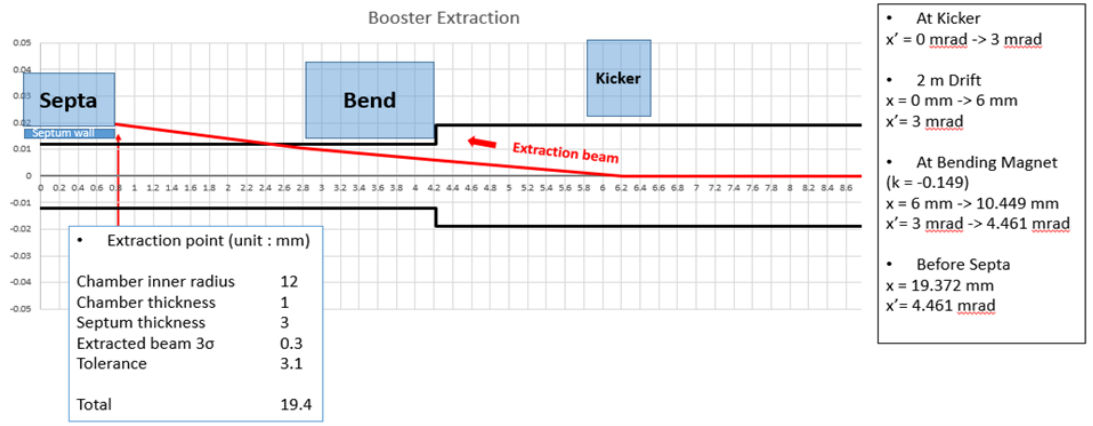
Magnet	Misalignment (μm) (X/Y/Z)	Rotation (μrad) (Roll/Pitch/Yaw)	Strength error (%)
Dipole	100 / 100 / 200	400 / 100 / 100	0.10
Quadrupole	100 / 100 / 200	400 / 700 / 700	0.10
Sextupole	100 / 100 / 200	400 / 700 / 700	0.10

Booster correction chain

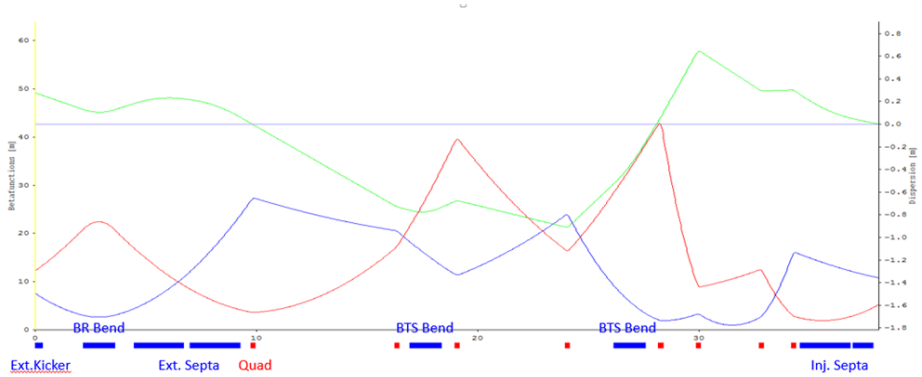
- trajectory correction
- RF correction
- orbit correction
- no BBA and no LOCO assumed

Beam Dynamics – Injection to Storage Ring

Booster extraction

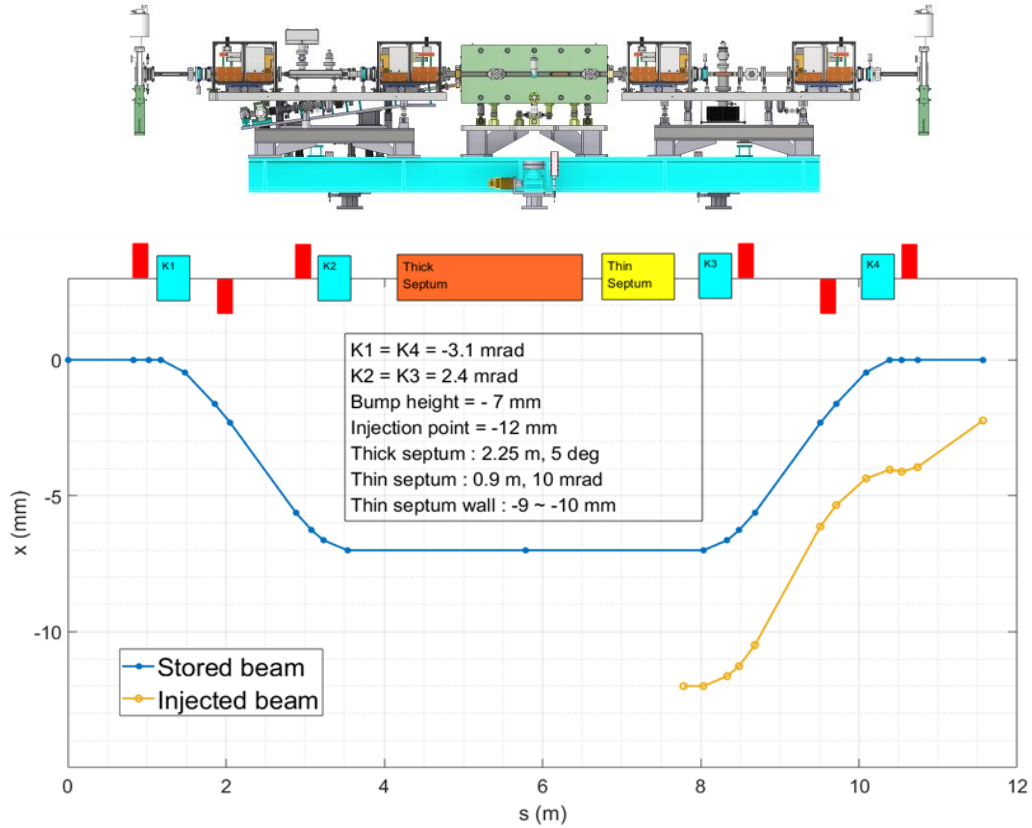


Booster-to-Storage ring beam transport line(BTS)

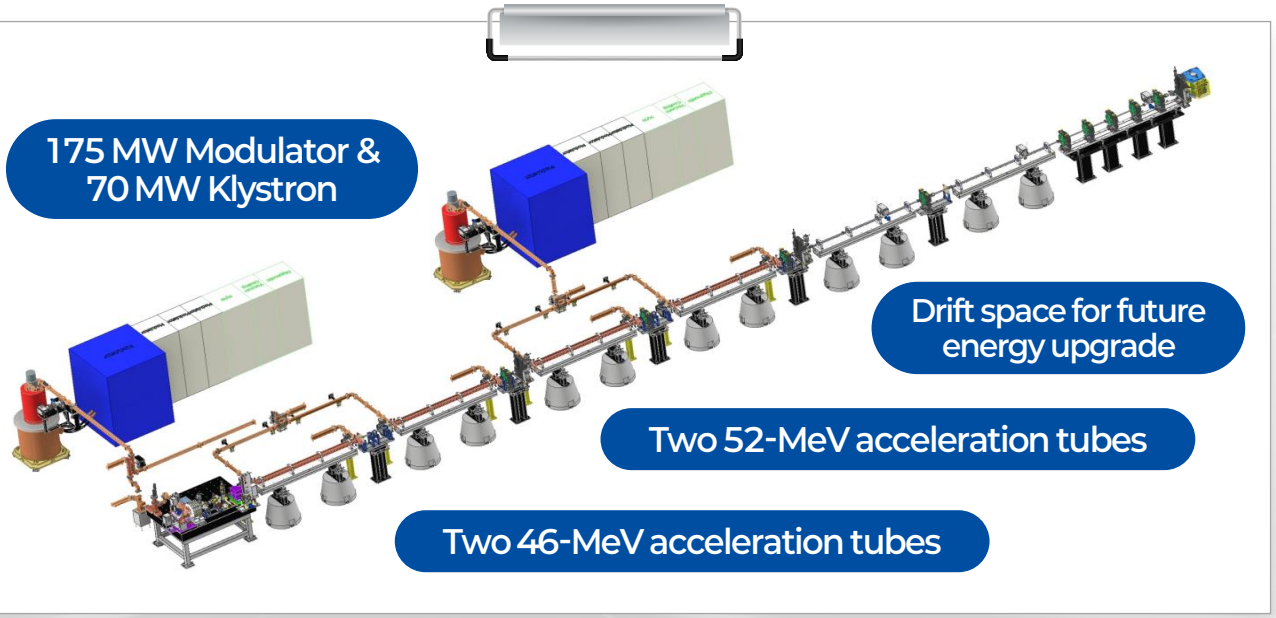


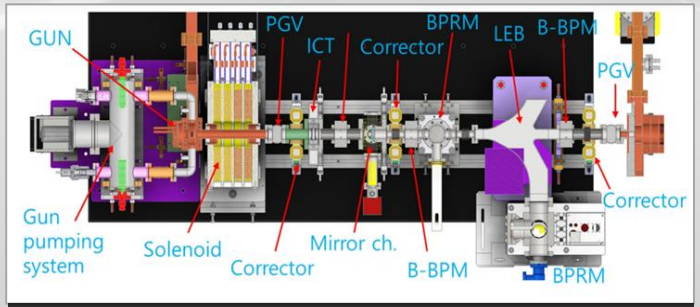
Baseline design: SR 4-kicker bump, off-axis injection

Alternative design: Non-linear kickers



200 MeV Injector Linac





Pre-Injector, including photo-cathode electron gun (Alternative design: thermionic DC electron gun)



Prototype of 3GHz Acceleration tube

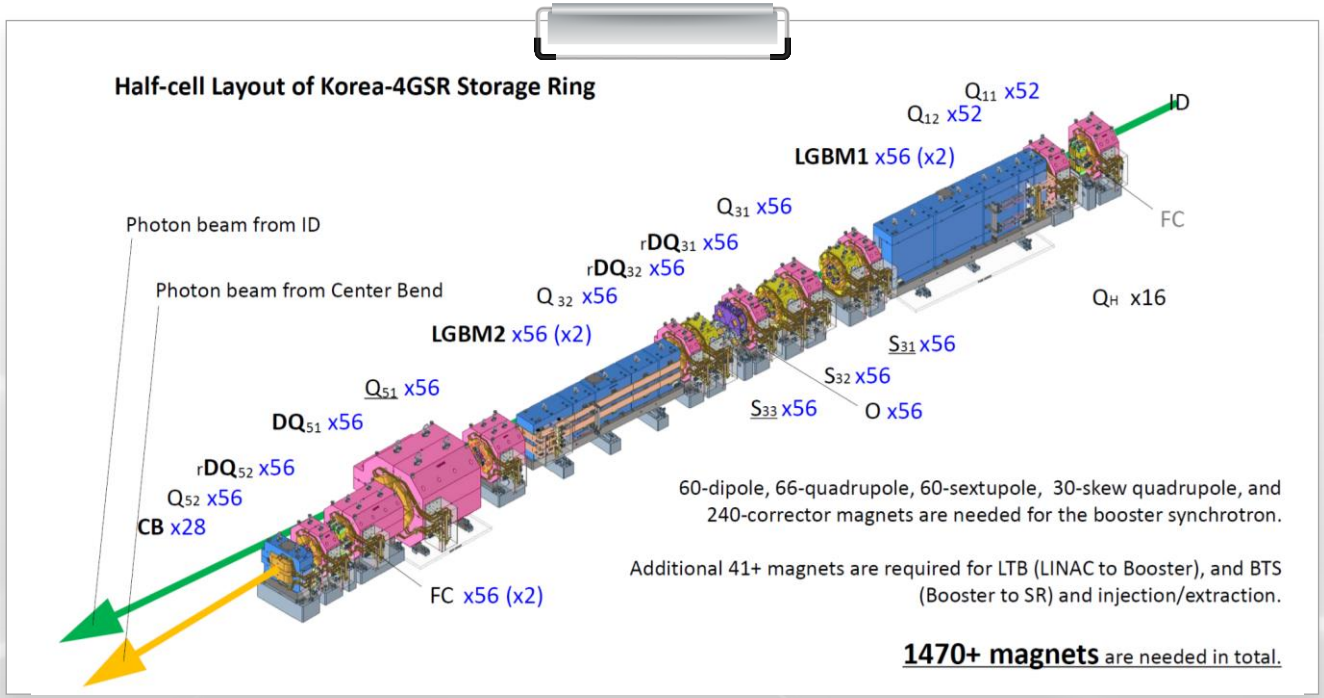
LINAC parameters

Parameters	Multi-bunch	Single-bunch
Energy	200 MeV	200 MeV
Frequency	2997.56 ± 0.1 MHz	2997.56 ± 0.1 MHz
Emittance (at 200 MeV)	≤ 10 nm	≤ 10 nm
Relative energy spread (rms)	≤ 0.3%	≤ 0.3%
Pulse to pulse energy jitter (rms)	≤ 0.2%	≤ 0.2%
Bunch charge (charge stability)	1 to 3 nC (5%)	0.01 to 1 nC (2%)
Pulse duration	≈ 128 ns (64 bunches)	6-8 ps FWHM
Repetition rate	2 Hz	2 Hz

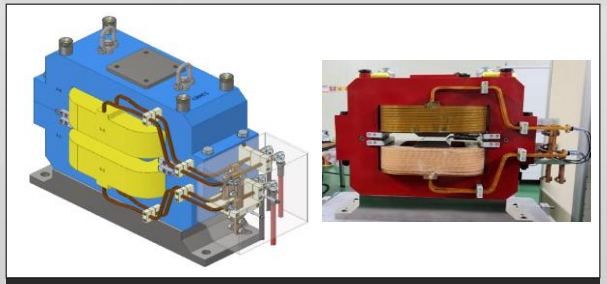
Electron gun parameters

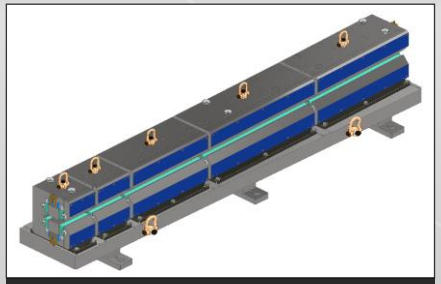
Parameters	Multi-bunch	Single-bunch
Beam energy	4 MeV	4 MeV
Charge	1~3 nC	0.01~1 nC
Pulse length	128 ns (64 pulses)	≤20 ps
Repetition rate	2 Hz	2 Hz

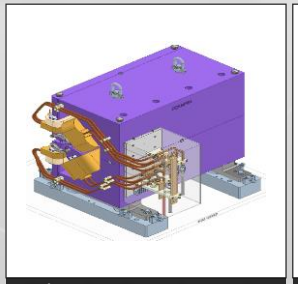
Magnet System – Storage Ring

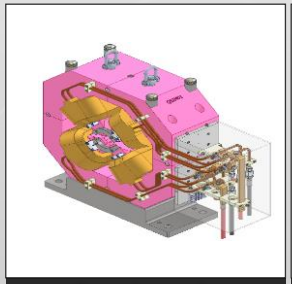


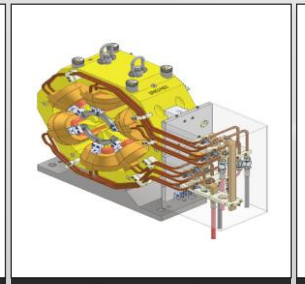
Magnet	Required Number	Remark
Center BM (2T)	28	1*28
Long. BM	112	4*28
Reverse Bend	168	2*3*28 (should have B, B')
Quad Bend	56	2*28 (should have B, B')
Quadrupoles	344	6*2*28+8(QH)
Sextupoles	168	6*28 (should have B", H/V Corr, Skew Quad)
Fast Corr.	112	4*28 (H/V combined corrector)
Octupole	56	2*28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

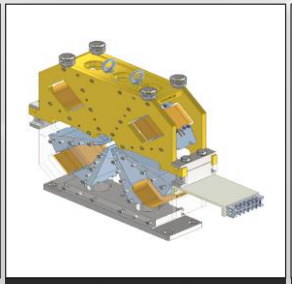

CB

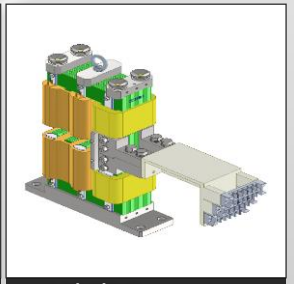

LGBM


Dipole-Quadrupole (DQxx, 56ea)


Quadrupole (Qxx, 344ea)


Sextupole (Sxx, 168ea)


Octupole (Oxx, 56ea)


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

Magnet System – SR LGBM (Permanent Magnet version)

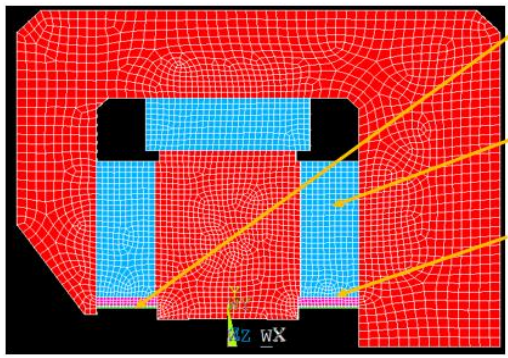
- LGBM has longitudinal field profile ranging from 0.15 T – 0.75 T to minimize beam emittances..
- Old design used electric excitation following APS-U for concerns on the long term radiation damage.
- But ESRF-EBS operating experience shows no radiation damage after 2 year operation.
- 2023 MAC (Machine Advisory Committee) recommended to consider PM version also.
- PM Version can save energy costs, Assuming, 1 kwh=200 Won, the design change can save 300 MW/year, 6,000 MWon for 20 year operation. (about 420kUSD/20 years)
- Also costs for MPS can be saved.

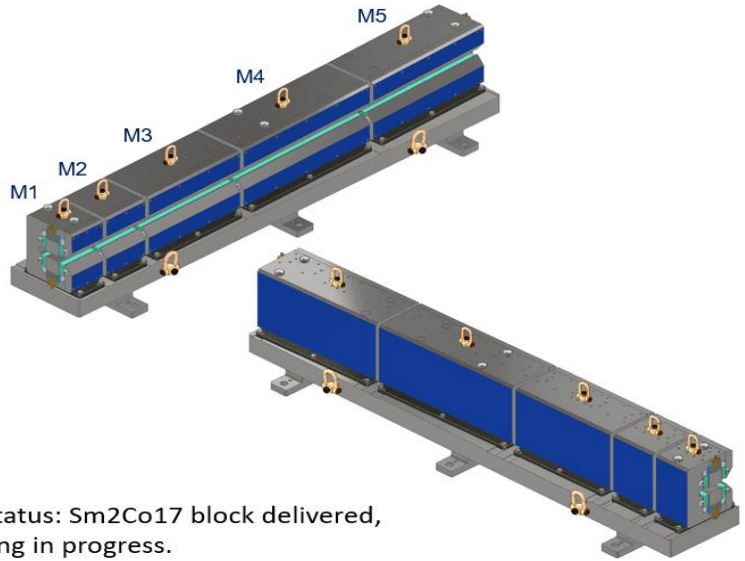
Technical Challenges

- No tunability like EM excitation, The final field profile should be met during measurement/tuning stage.
- Sm2Co17 PM has a temperature dependence $\Delta B/B / \Delta T = -3.3E-4/K$.
- There is cross talk between the modules.

Engineering Solution

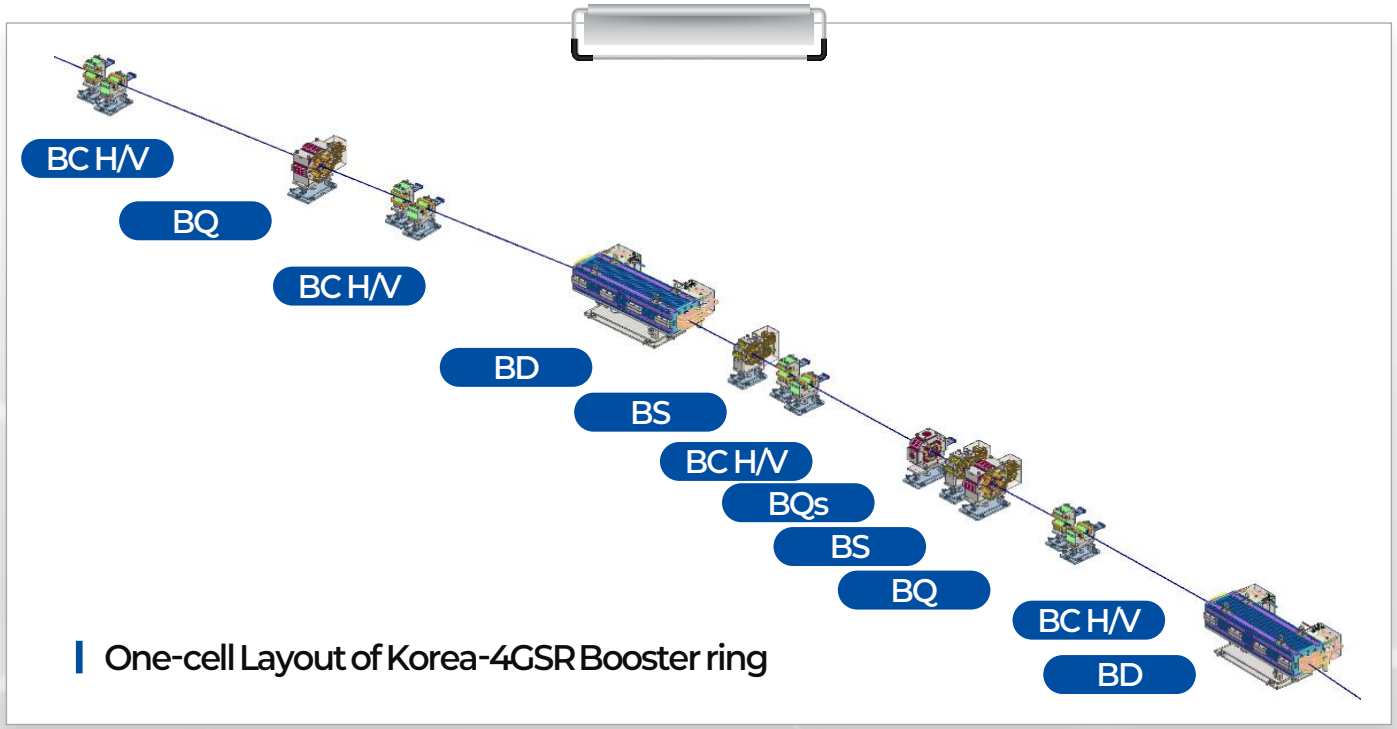
- Tunability using FeSi (Silicon Steel) shunts. (always in decreasing direction).
- Weakening of Temperature dependence using FeNi (Ni steel) plate.
- Magnetic design taking into account the Cross-talk between the modules.





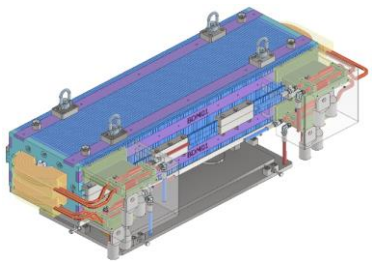
Current status: Sm2Co17 block delivered, prototyping in progress.

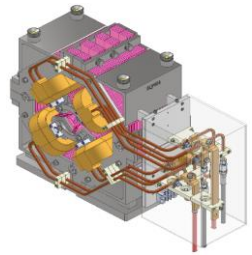
Magnet System – Booster Ring

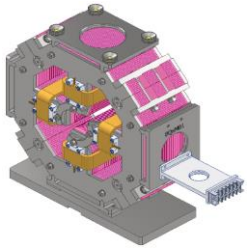


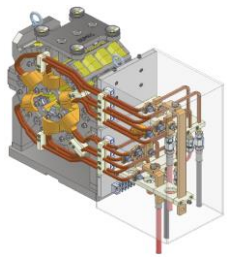
One-cell Layout of Korea-4GSR Booster ring

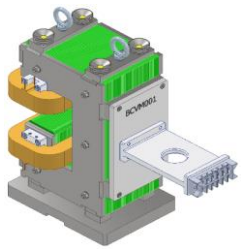
Magnet	Required Number	Remark
Combined Dipole	60	56 (6.07deg)+4(5.02deg)
Quadrupole	76	Normal 66, Skew 10
Sextupoles	60	
Corr.	240	H120, V120
Sum	436+	Total number of magnets

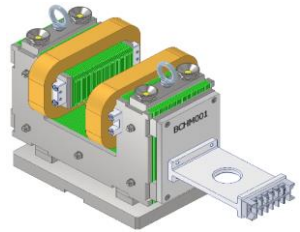

Combined Bending Magnet (BD, 60ea)


Quadrupole (BQ, 66ea)


Quadrupole Skew (BQs, 10ea)


Sextupole (BS, 60ea)

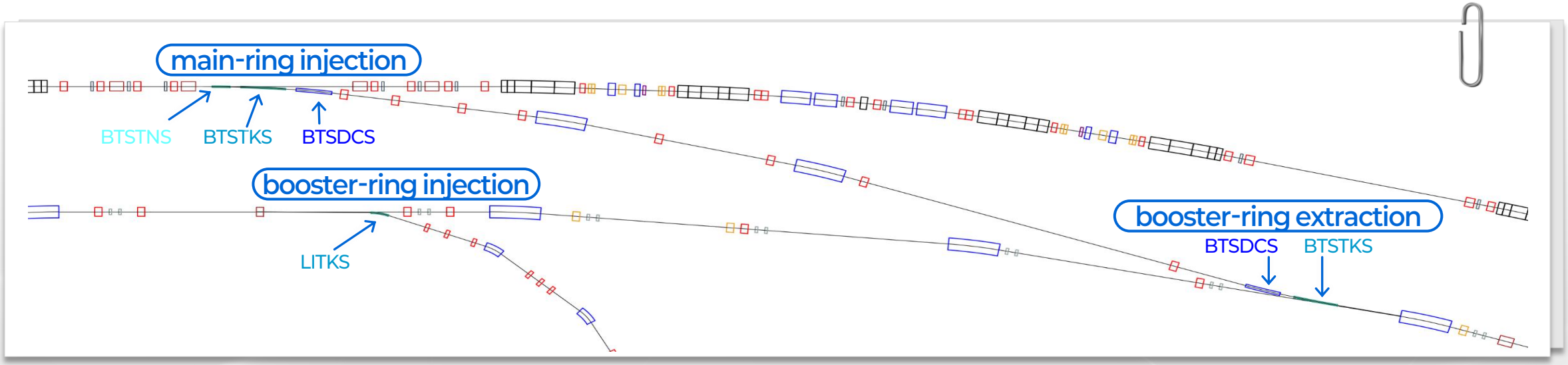

Corrector (BCH, 120ea)


Corrector (BCV, 120ea)

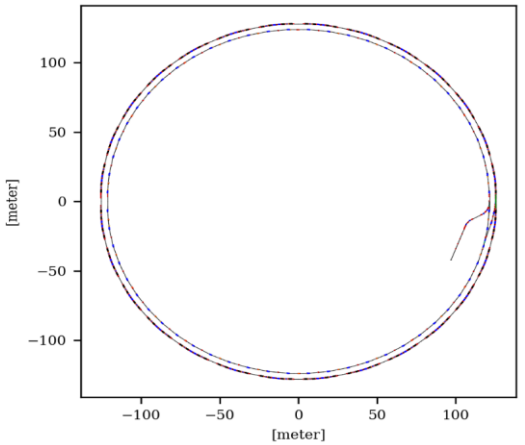
KOREA BASIC SCIENCE INSTITUTE

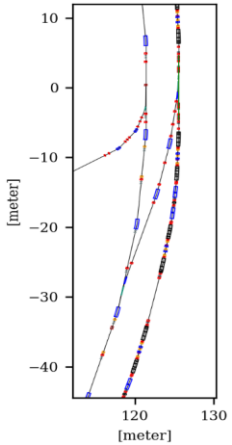
POHANG ACCELERATOR LABORATORY

Magnet System – SR Extraction/Injection Layout, Septum Parameters



4GSR Septums & Kickers	20241029			
	LITKS	BTSTKS	BTSTNS	BTSDCS
Type	pulsed	pulsed	pulsed	DC
Number of Used	1	2	1	2
Bending angle [deg]	20.0	3.0	1.432	3.5
[rad]	0.349	0.052	0.025	0.061
S mag length [mm]	500	1250	500	1000
V gap [mm]	15	15	13	22
H width [mm]	30	26	16	26
rho0 [m]	1.4	23.9	20.0	16.4
Peak B0 [T]	0.47	0.56	0.67	0.82
Peak Current [kA]	5.6	6.7	7.0	14.4
Inductance [uH]	1.23	2.67	0.76	1.46
Half-sine Pulse Width [us]	100.00	100.00	16.70	-
Hor. Displacement [mm]	90.1	32.7	6.3	30.6

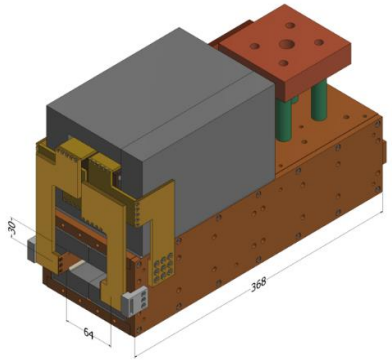


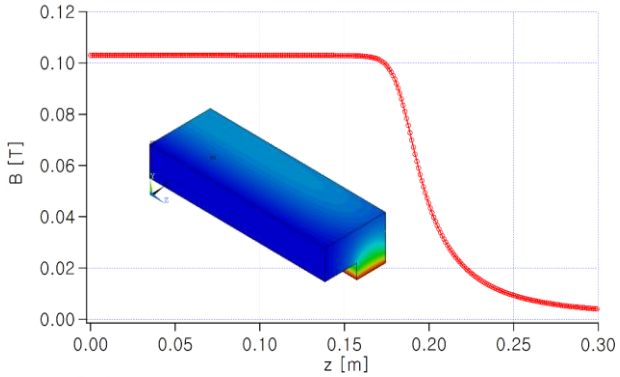


KOREA BASIC SCIENCE INSTITUTE

POHANG ACCELERATOR LABORATORY

Magnet System – Conventional Ferrite Kicker Magnets & Power System





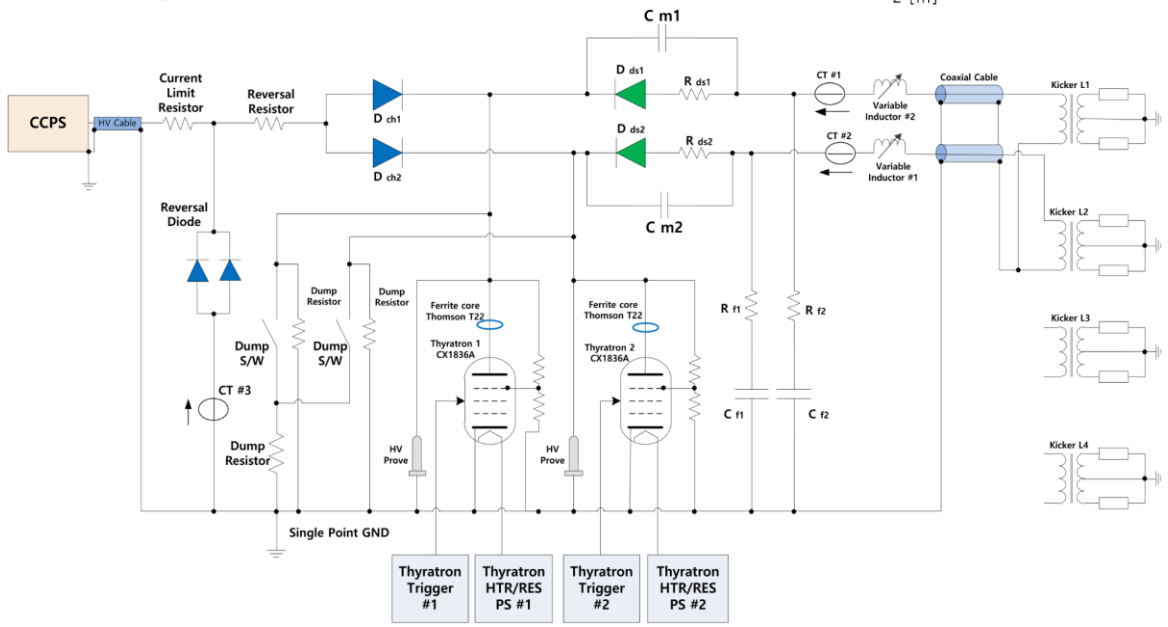


Table 1 : Major Parameters of SR Kicker1, 4

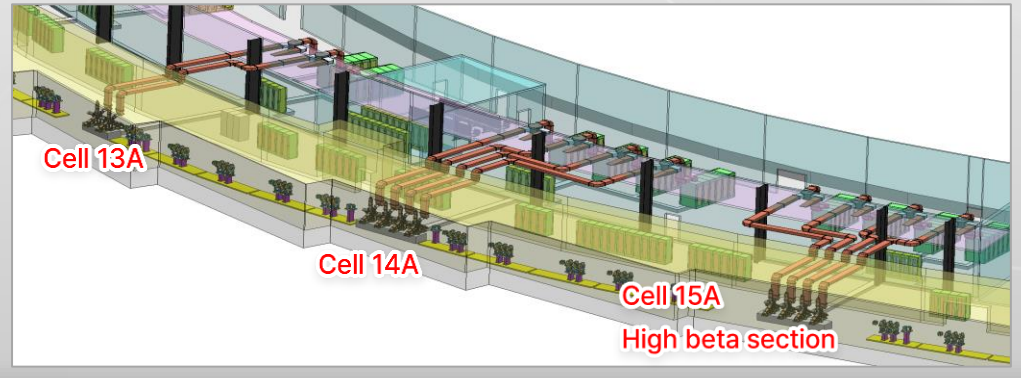
Parameters	Values
Max kick angle@4GeV	3.179 mrad
Field integral	4.24×10^{-2} Tm
Vertical Gap	30.0 mm
Horizontal Clearance	64.0 mm
Core Length	368.0 mm
Effective Lengthy	412.0 mm
Conductor Current	2.5 kA
Central field @ Imax	0.1030 T
Inductance before transformer	0.55 μH

Table 2 : Major Parameters of SR Kicker Power Supply

Parameters	Values
Pulse Current (Max)	7 kA
Pulse-width	< 5.0 μs
DC voltage at thyratron anode	14 kV
Flat-top width	200 ns
Repetition Rate	2 Hz
Energy per Pulse	70 J
Magnet Inductance	0.54 μH
Power Supply System Inductance (coaxial cable, variable inductance, line inductance, and others)	< 2.3 μH
Pulse Current Difference	± 0.2 %
Maximum Operable Beam Energy	4 GeV

RF System – Storage Ring

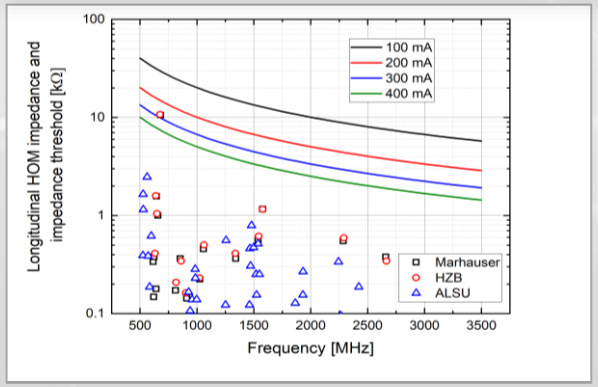
Parameters	Values	Unit
Energy [GeV]	4.0	GeV
Current [mA]	400	mA
Circumference [m]	799.297	m
Revolution time [sec]	2.67E-6	sec
Harmonic number	1332	-
Electron energy loss/turn (keV) with IDs	1877.65	keV
Beam loss power by synchrotron radiation [kW]	751.06	kW
RF frequency [MHz]	499.593	MHz
Accelerating Voltage [MV]	3.5	MV
Number of RF cavities	10	ea



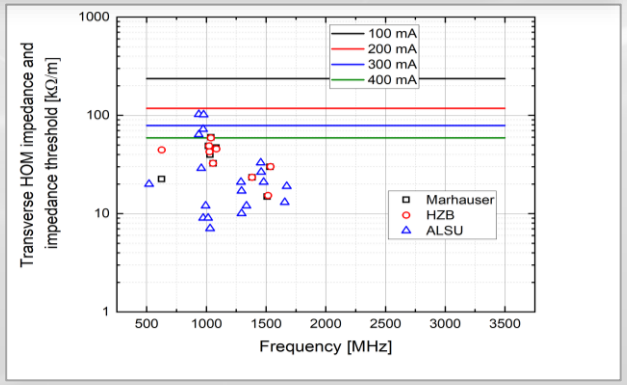
Characteristics of SR RF System

- Cavity : HOM-damped normal conducting cavity
- HPRF : 150 kW solid state amplifier per unit
- LLRF : digital type
- RF Transmission : WR1800 Waveguide
- Independent 10 RF circuit, occupying 2.5 straights





Longitudinal HOM impedance

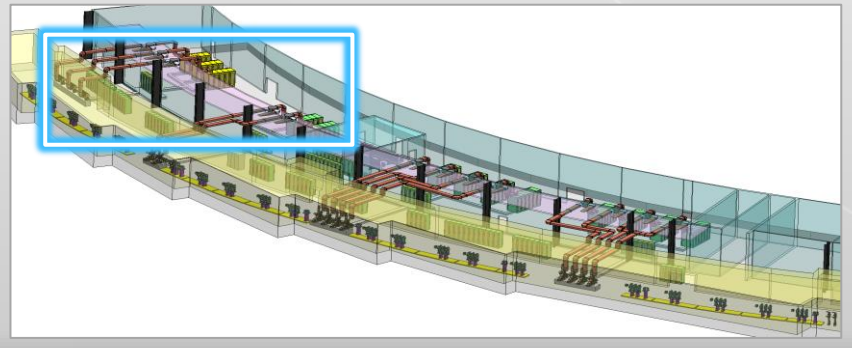


Transverse HOM impedance

The auxiliary system such as TFS/LFS and/or harmonic cavity to suppress coupled-bunch instability (CBI) is necessary for storing >300 mA.

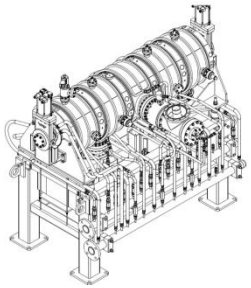
RF System – Booster Ring

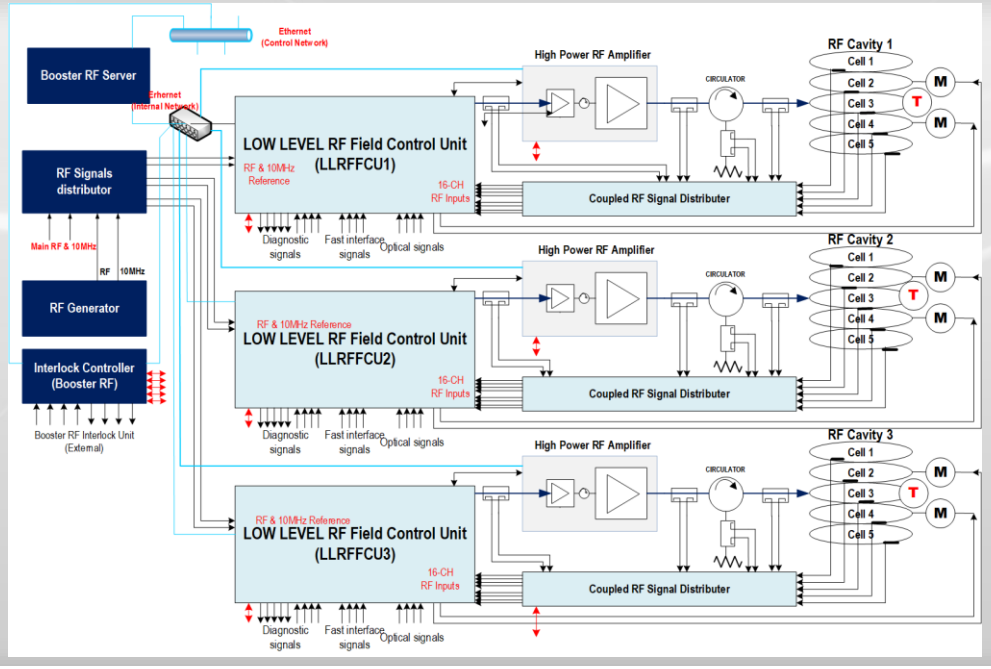
Parameters	Values	Unit
Beam energy	0.2 – 4.0	GeV
Beam Current with single / multi bunch	1 / 3	mA
Circumference	772.9	m
Harmonic number	1288	-
Revolution frequency	387.9	kHz
Synchrotron Frequency	4.24	KHz
repetition rate	2	Hz
Accelerating Voltage @ 0.2 GeV	0.3	MV
Accelerating Voltage @ 4.0 GeV	3.0	MV
RF Frequency	499.594	MHz
Energy loss per turn @ 4.0 GeV	1.671	MeV



Characteristics of booster RF system

- Cavity : 5-cell PETRA normal conducting cavity
- HPRF : 80 kW SSPA per unit
- LLRF : digital type
- RF Transmission : WR1800 Waveguide
- Independent 3 RF circuits, occupying 2 straights





Beam Diagnostics – Summary

Types, Numbers & Locations (2024-Nov-13)

CODE	Type	Meas. Target	Numbers / Section				
			LINAC	LTB	BR	BTS	SR
1	BPM	Beam Position	10	8	120	6	288
2	BPRM (YAG/OTR)	2D Profile, Emittance	7	6		3	
3	X-ray Diagnostic Hutch*	Beam Size, Emittance, Energy Spread					1
4	Visible light Diagnostic Hutch	Beam Size, Emittance, Bunch Length & Purity			1		2
5	Slow BLM	Beam Loss (Slow)	1	1	4	1	14
6	Fast BLM	Beam Loss (Fast)			5		30
7	ICT	Pulse Beam Current	2	1		2	
8	DCCT	DC Beam Current			1		2
9	PBPM	Photon Beam Position					20
10	Tune Monitor	Tune			1		1
11	TFS/LFS	Multi-bunch Feedback					3
Numbers in total			20	16	132	12	361

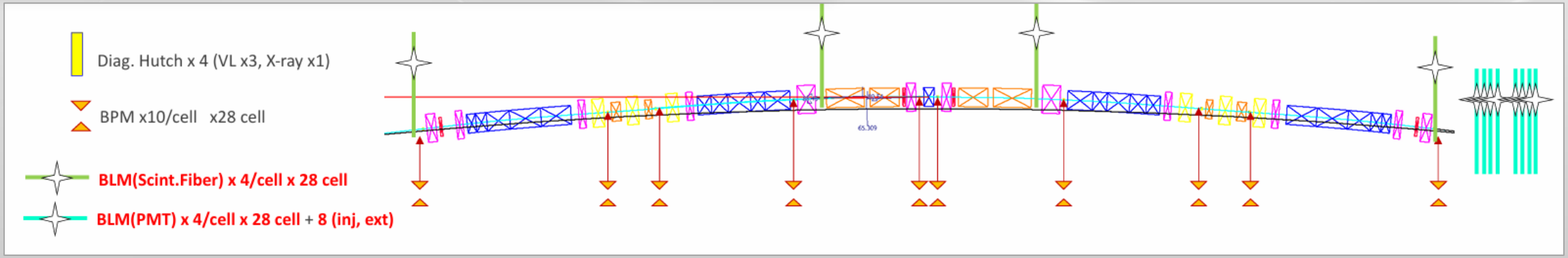
※ X-ray diagnostic hutch: location & budget assigned, installation pending.

Beam Diagnostics – SR

Storage Ring DIAG Update list

- BPM body design has been modified and finalized.
- Prototypes of BPM pick-ups were tested in the PLS-II storage ring.
- The second prototype of BPM electronics will be tested next year.
- Specifications for SOFB & FOFB have been determined.
  (1um for TbT & ~300 Hz suppression bandwidth)
- The #1 cell Beam Diagnostic Hutch was removed.
- A commercial BbB FB processor for 4GSR was tested in PLS-II.
- A gas chamber type PBPM was developed and will be tested in PLS-II.
- The Slow BLM design was modified to achieve greater sensitivity.

Property	Devices
Beam Position	SR BPM
Current	DCCT for BR
Beam Size & Emittance	Diag. Hutch with Interferometer
Fill pattern & bunch length	Diag. Hutch with streak camera & Online Bunch Length monitor
Beam Loss	Fast & Slow BLM
TFS/LFS	BbB FB system
Tune	BPM+S/A and BbB FB processor
Energy	BM MPS current or Spin polarization

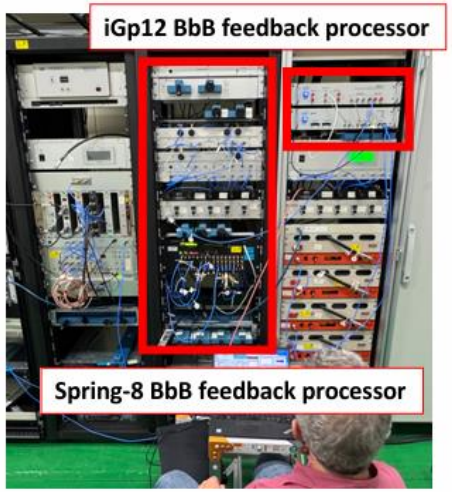


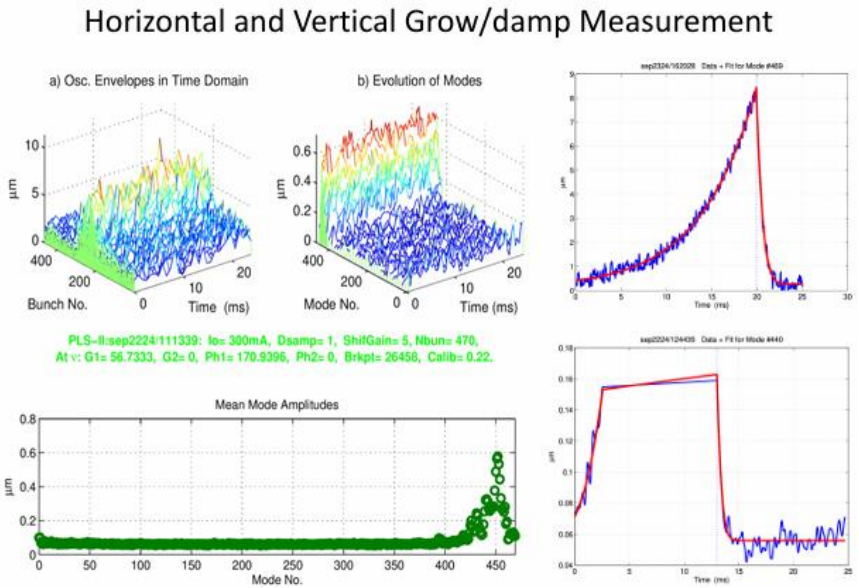
KOREA BASIC SCIENCE INSTITUTE

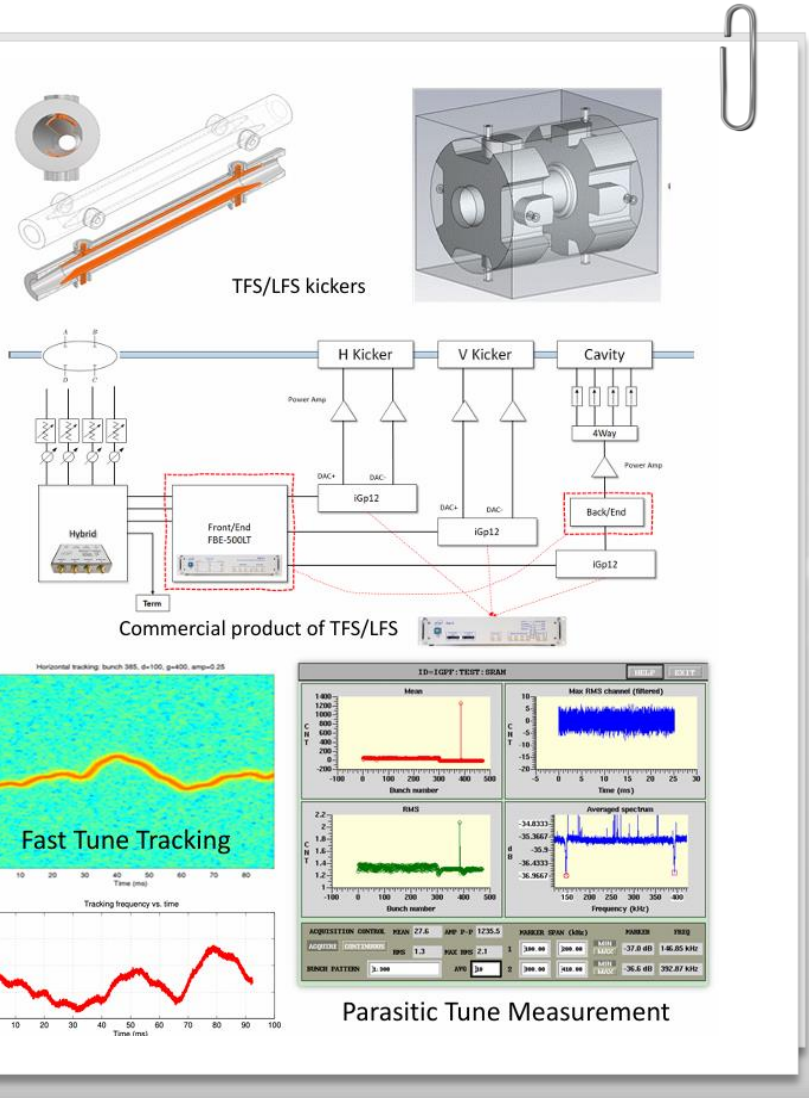
POHANG ACCELERATOR LABORATORY

Beam Diagnostics – TFS/LFS for BbB FB system

- TFS/LFS strip-line kicker and cavity kicker EM design was done
- TFS electronics by Dimtel was tested at PLS-II in Sep. 2024
- BbB feedback system can be measure storage ring Tune in H/V
- For high current operation mode as 400mA, BbB FB is essential
- Bunch cleaning can be make good purity of multi-bunch train.
- Most of system will be used commercial product.







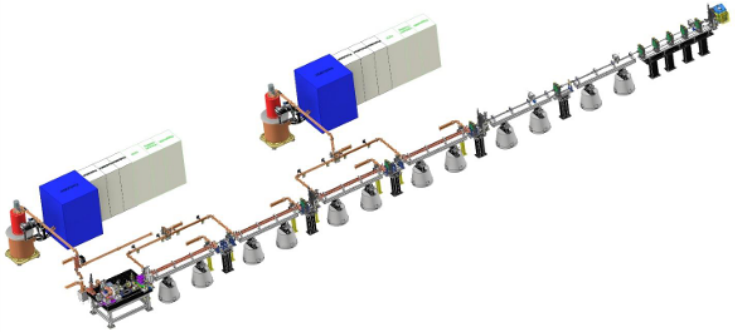
Vacuum System – Summary

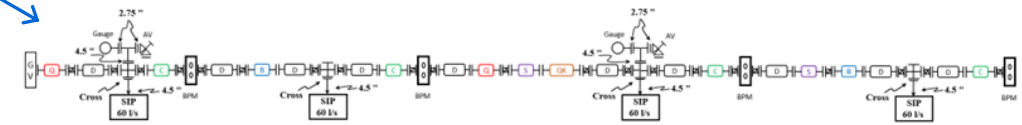
1 Linac vacuum
- Electron beam energy 0 → 200 MeV
- Four S-band accelerating columns with two modulator-klystron stations
- Photo-cathode E-gun (~10^{-11} mbar), AC and wave guide (~10^{-8} mbar)

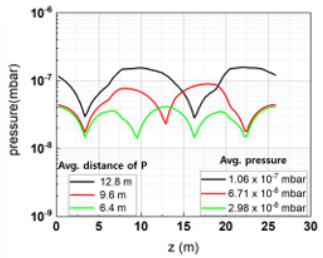
2 Booster vacuum
- Electron beam energy 200 MeV → 4 GeV
- Circumference ~770 m with 30 cells
- Beam duct OD Ø24~32 mm, thickness 0.7 mm (low eddy current)
- Chamber materials: SS316L (0.7 mm-thick) → Max. stress < 2.5 MPa
- Vacuum requirement ~10^{-8} mbar

3 Beam transfer system vacuum
- Transfer line length ~ 40 m
- Special chambers for the injection system
  (Ceramic kicker chamber, In-vacuum septum chamber, …)

4 Storage ring vacuum
- Electron beam energy 4 GeV & beam current 400 mA
- Circumference ~800 m with 28 cells
- Beam duct Inner diameter Ø18(V) x 24(H) mm
- Vacuum requirement during operation ~10^{-9} mbar





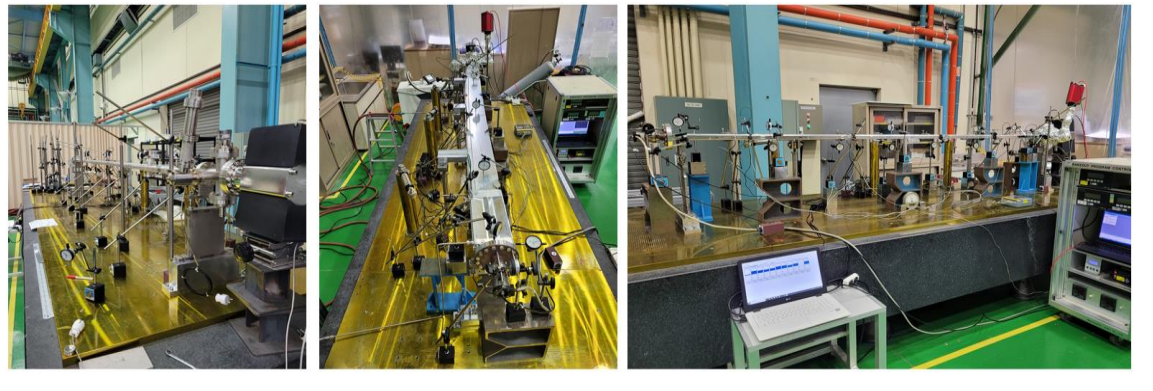


※ Pressure distribution w.r.t. pump distance

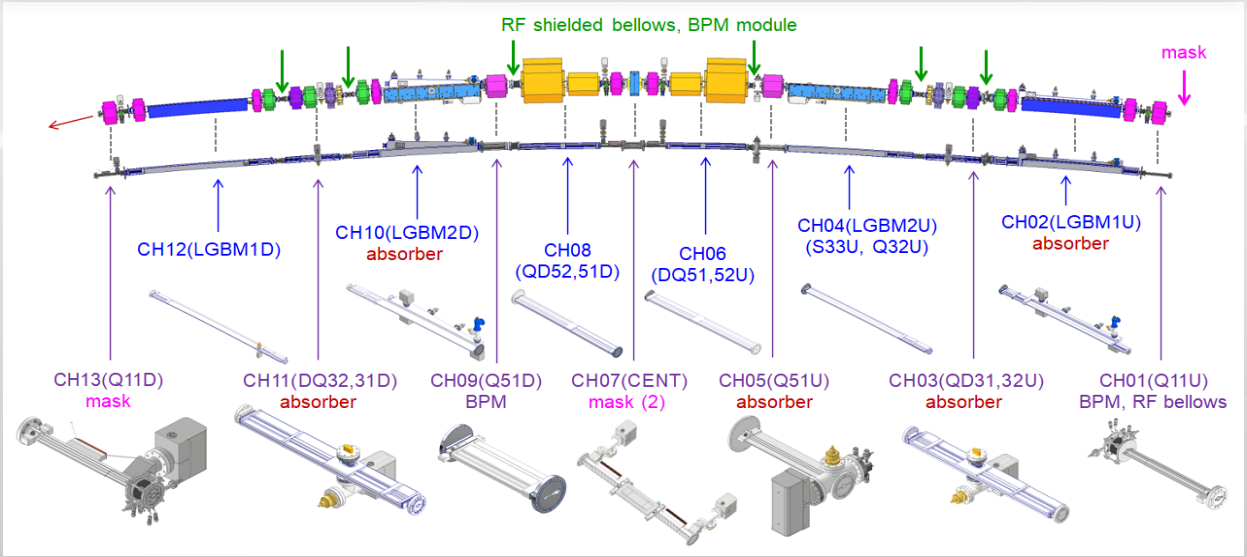
Vacuum System – SR Vacuum Chamber

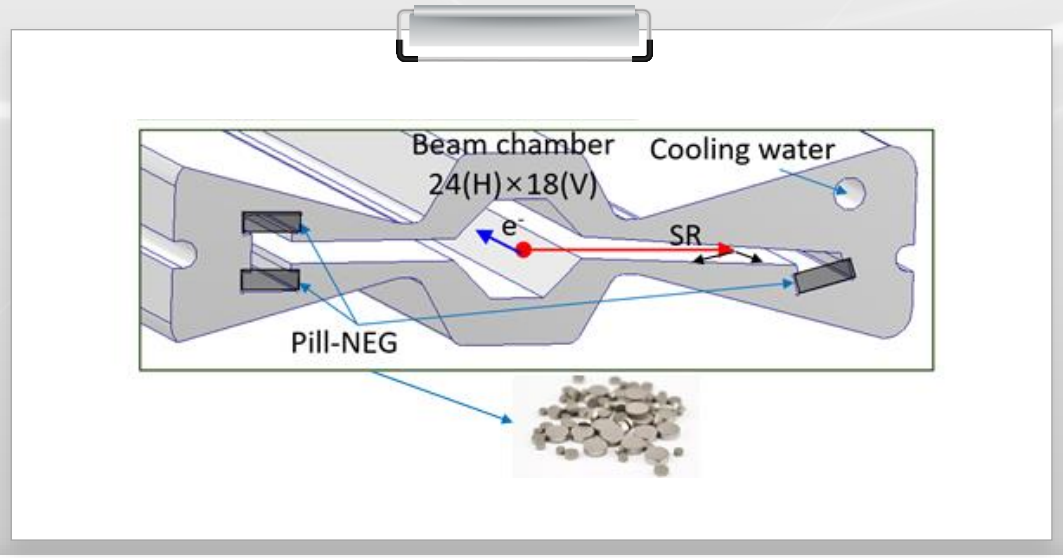
Characteristics of SR Vacuum System

- Octagon shape (24 mm,H) x (18 mm,V), except for center bend
- 10 mm vertical aperture at center bends
- 8 RF-bellows each sector for installation and stress reduction
- Gate valve at the both ends of each arc sector
- 7 sputter ion pumps for noble gas pumping.
- > 0.6 mm clearance between the vacuum chamber and the magnets



Prototype





Thank You



KBSI KOREA BASIC SCIENCE INSTITUTE

PAL POHANG ACCELERATOR LABORATORY