Overview of the Korea-4GSR Accelerator Project

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2025/11/05

KOREA BASIC SCIENCE INSTITUTE

PAL

Overview of the Korea-4GSR Project

Design Features of Korea-4GSR

❖ **High photon beam performance from storage ring**

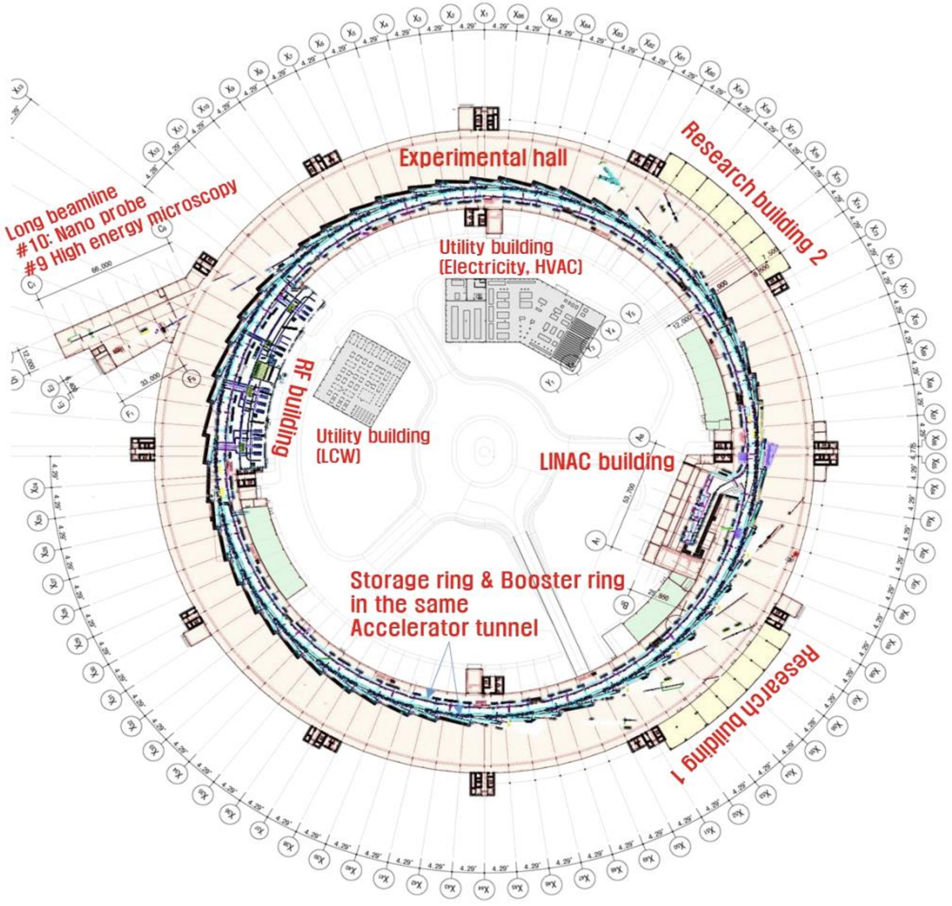
- The best performance in the range of 10 – 30 keV
- Capability to generate photon beam up to 100 keV

❖ **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**

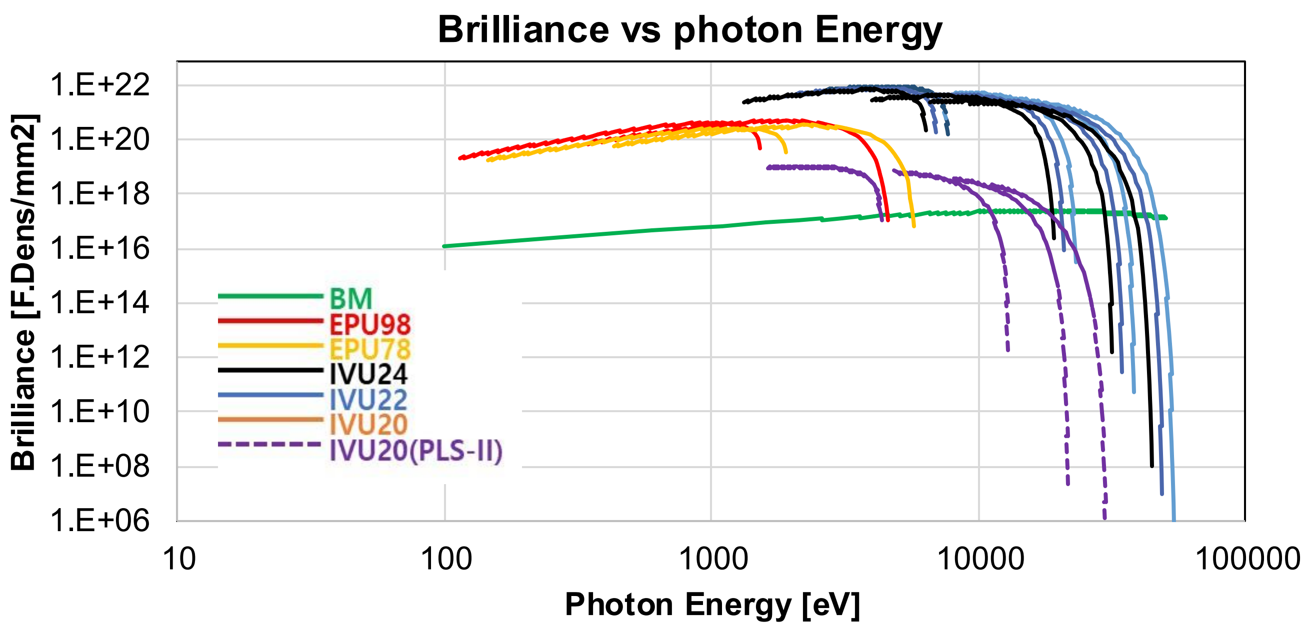
- Supporting full range of synchrotron radiation application



Overview of the Korea-4GSR Project

Design Features of Korea-4GSR

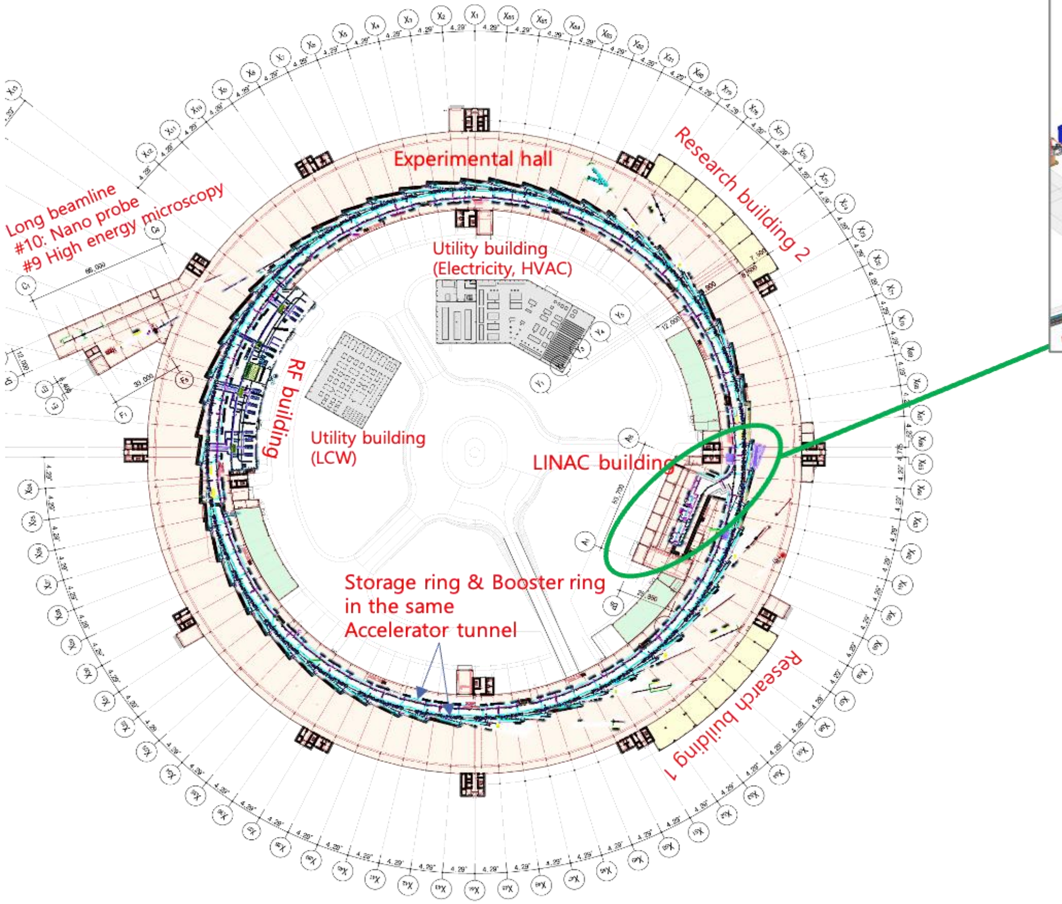
Parameters	Value
Energy (GeV)	**4.0**
Circumference (m)	**799.297**
Emittance (pm)	**62**
Tunes (H,V)	**68.18, 23.26**
Natural chromaticity (H,V)	**-112.1, -85.3**
Chromaticity (corrected) (H,V)	**5.8 , 3.5**
Hor. Damping partition	**1.84**
Momentum compaction	$\mathbf{0.78 \times 10^{-4}}$
Energy spread (σ_δ)	$\mathbf{1.26 \times 10^{-3}}$
Energy loss per turn (MeV)	**1.097**
Main RF voltage (MV)	**3.5**
Beam current (mA)	**400**
Bunch length (σ_z) (mm) (w/o HC, w/ HC)	**3.66 / 14.66**

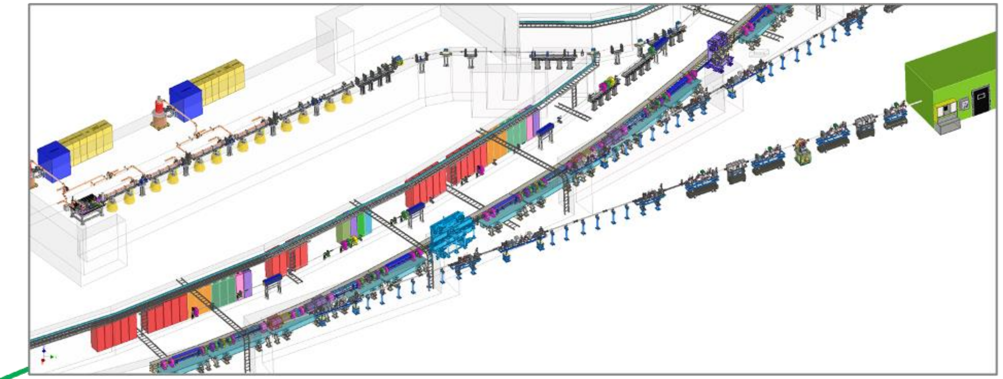


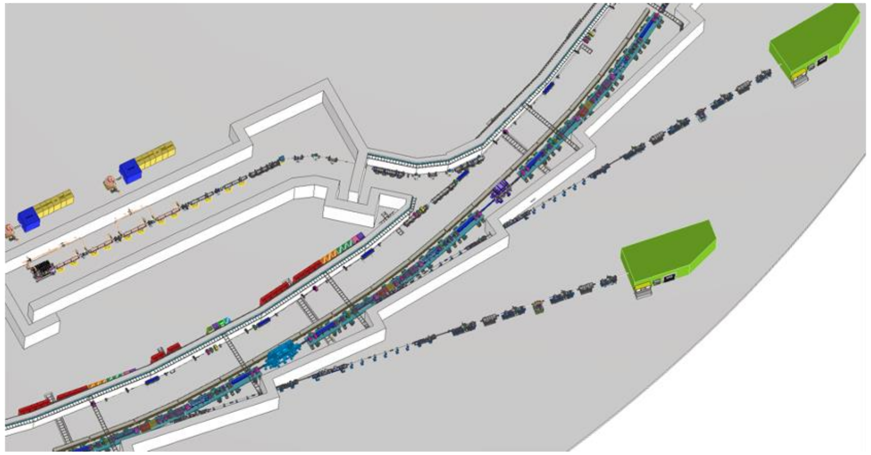
- 4 GeV electron beam energy is chosen for best performance of photon beam in the range of 10 – 30 keV
- Phase 1 construction plan includes 9 ID beamlines and 1 BM beamline.
- ~100 times brighter photon beam than that of PLS-II

Overview of the Korea-4GSR Project

Design Features of Korea-4GSR

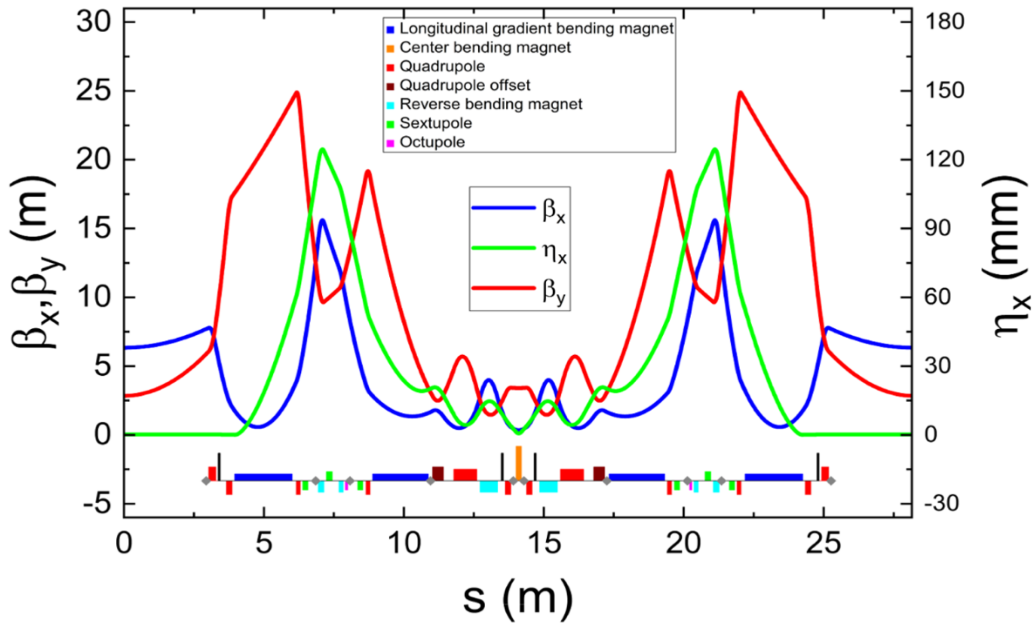






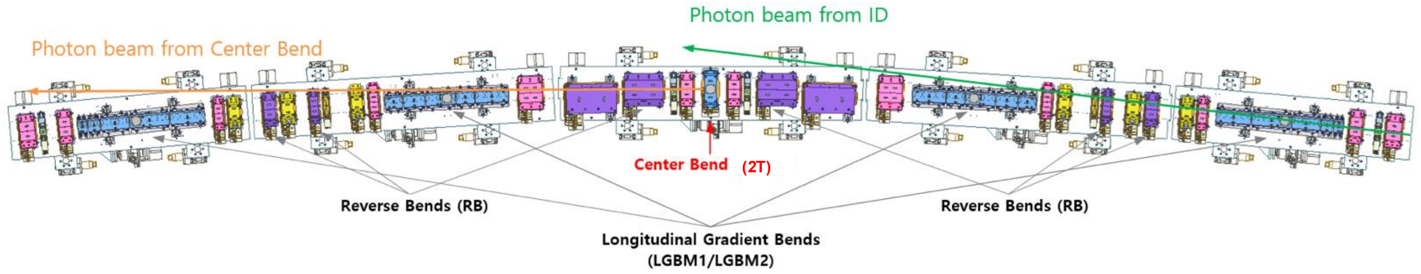
Storage Ring Lattice of Korea 4GSR

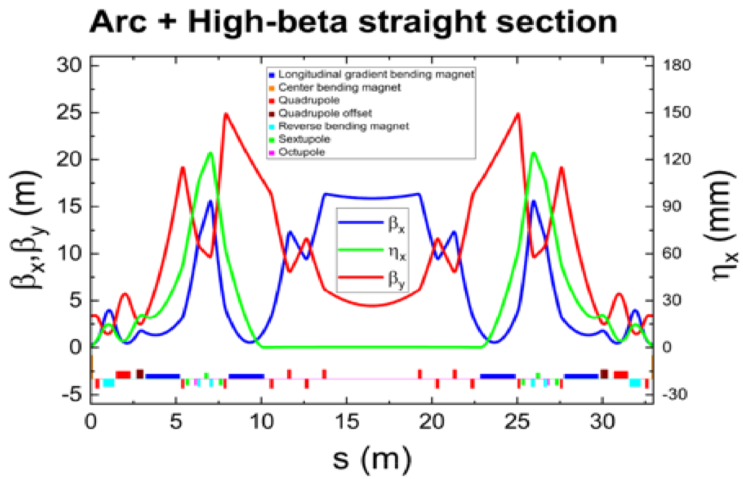
Hybrid 7-Bend Achromat, H7BA



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 2T 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





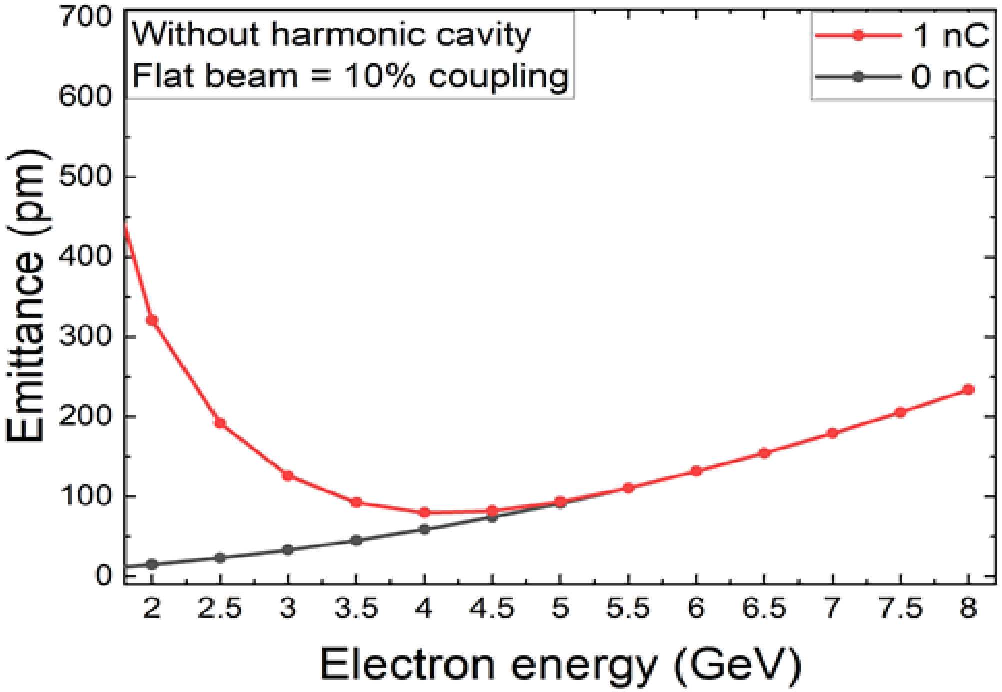
Storage Ring Lattice of Korea 4GSR

Design Parameters of the Bare Lattice

Touschek lifetime (ideal lattice)

Flat beam : coupling 10%		
Without HC	Without IBS	With IBS
Emittance (H/V)	58.40/5.84 pm	79.57/7.96 pm
Touschek lifetime	7.30 h	8.52 h
With HC	Without IBS	With IBS
Emittance (H/V)	58.40/5.84 pm	65.32/6.53 pm
Touschek lifetime	29.22 h	34.09 h

Intra Beam Scattering

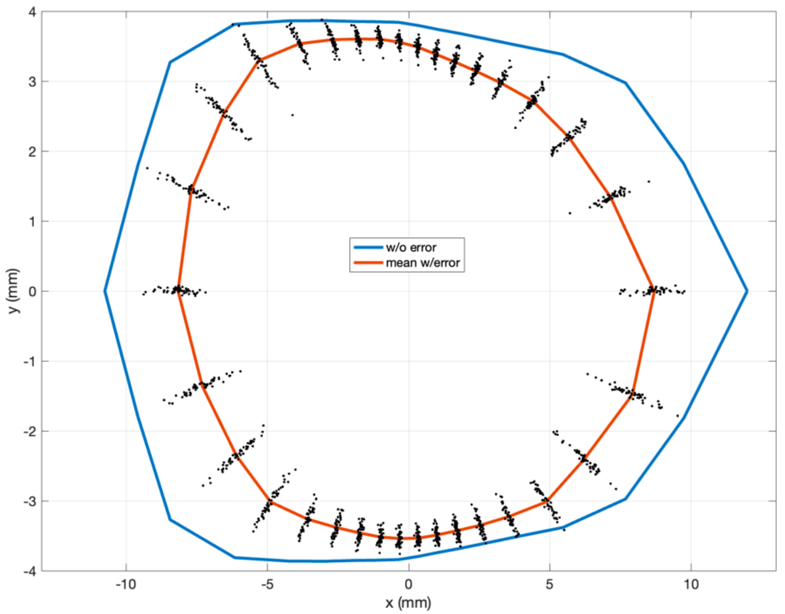


~36% emittance increase is expected due to IBS effect at E = 4 GeV

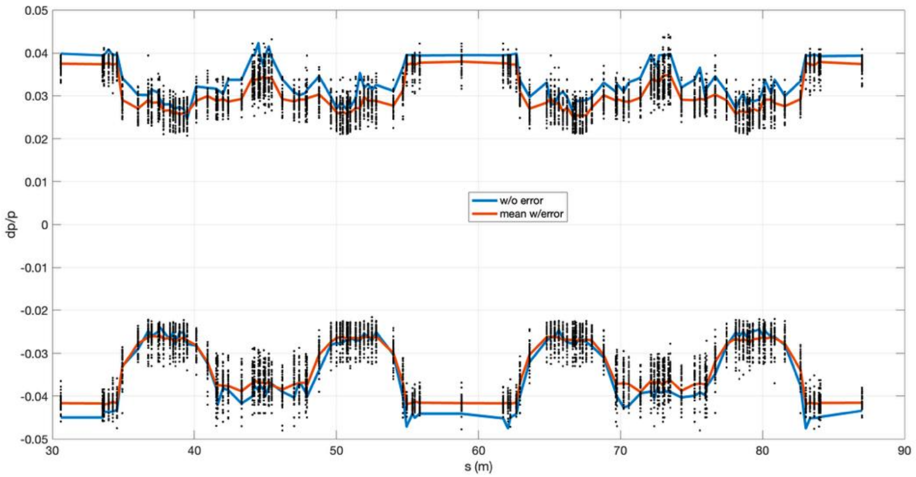
Storage Ring Lattice of Korea 4GSR

Dynamic Aperture and Momentum Aperture

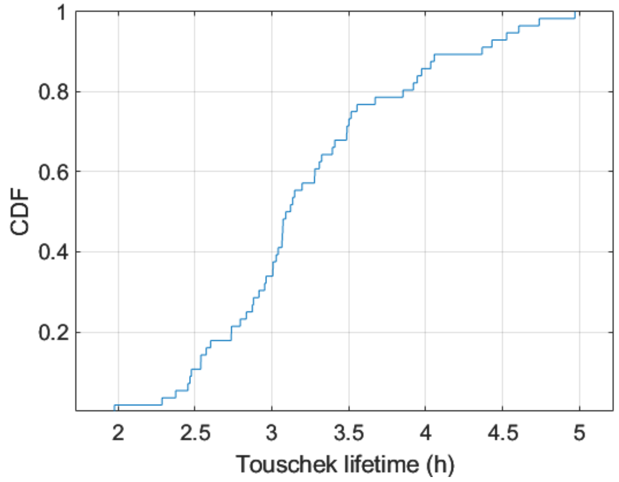
Dynamic aperture



Momentum aperture



Touschek lifetime w/o error : 7.18 h

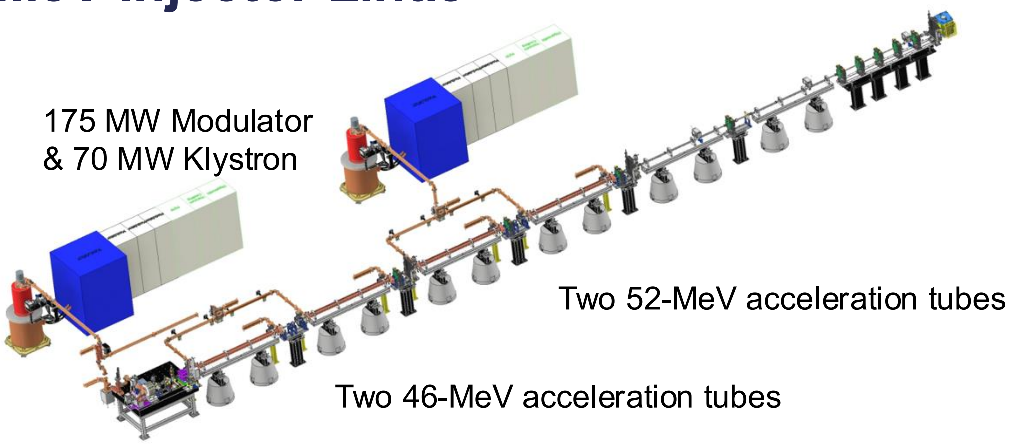


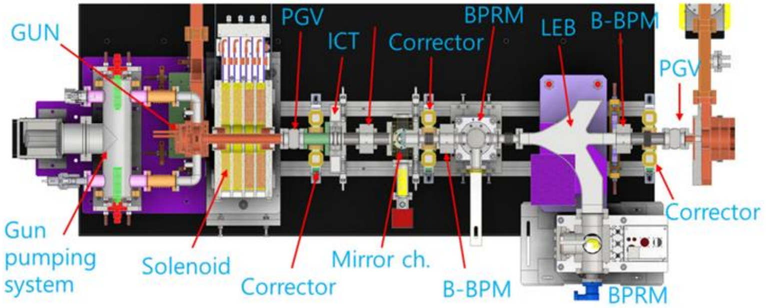
-Results with 50 random error seeds
-Realistic correction chain (orbit correction, LOCO, etc) is applied for each seed

Charge set:
-a single bunch of 1.04 nC (or 0.3906 mA)
-400 mA = 1024 x 0.3906 mA
-Coupling ratio (emity/emitx) = 0.10

Injector System

200 MeV Injector Linac





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

❖ 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**

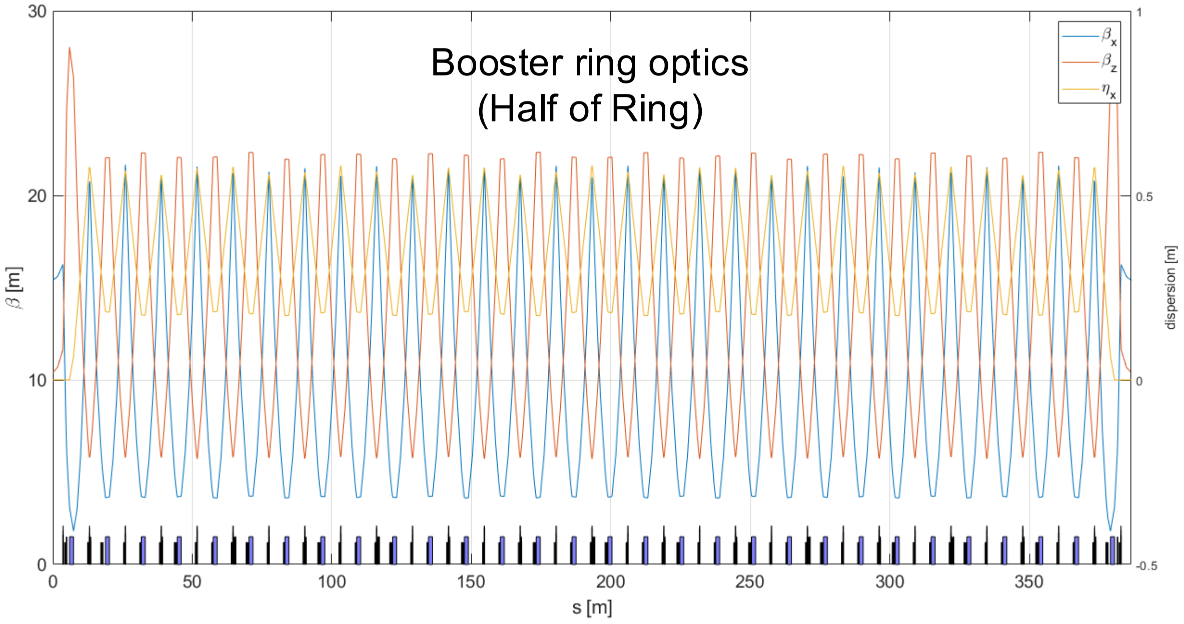
❖ Electron gun parameters

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

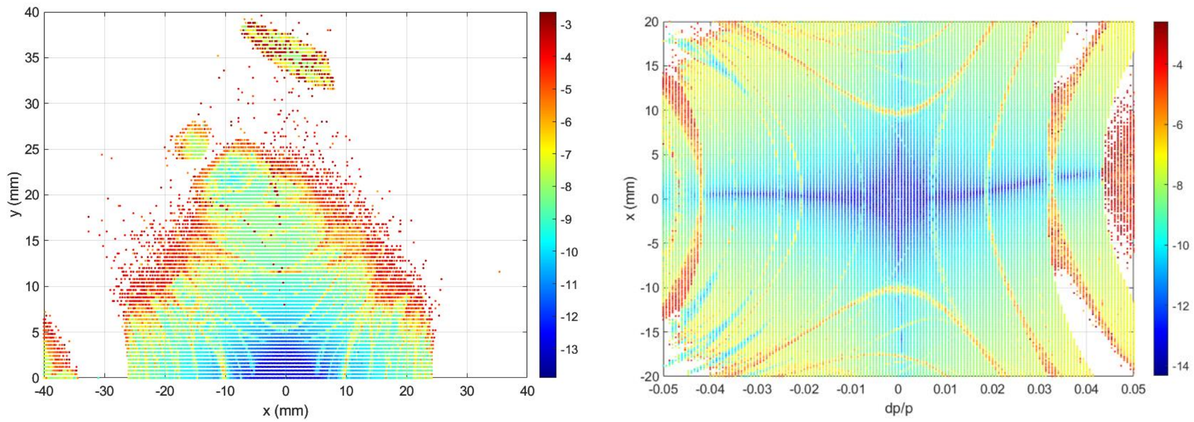
Booster Ring of Korea 4GSR

Beam dynamics of Booter ring

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



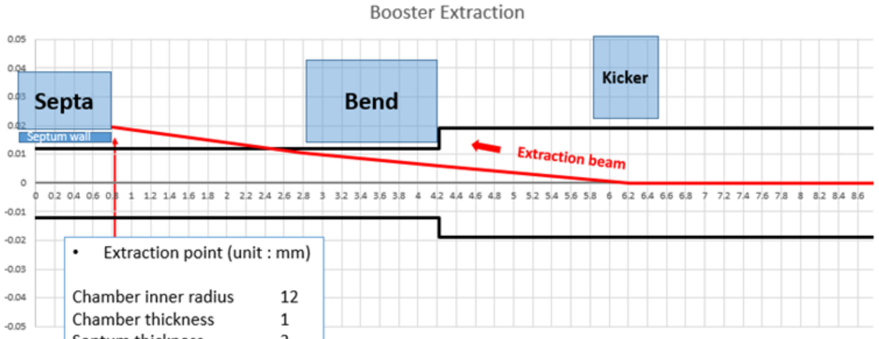
Booster Parameters		Value	Unit
Design Parameters	Number of Cells	30	-
	Circumference	772.9	[m]
	Beam Energy	0.2 - 4	[GeV]
	Natural Emittance (4 GeV)	10.9	[nm rad]
	Max. Beam Current	2	mA
Tune and Chromaticity	Tune (H/V)	17.77 / 10.70	-
	Natural Chromaticity (H/V)	-22.3 / -15.1	-



Frequency map analysis (w/o physical aperture)

Injection to Storage Ring

Booster extraction

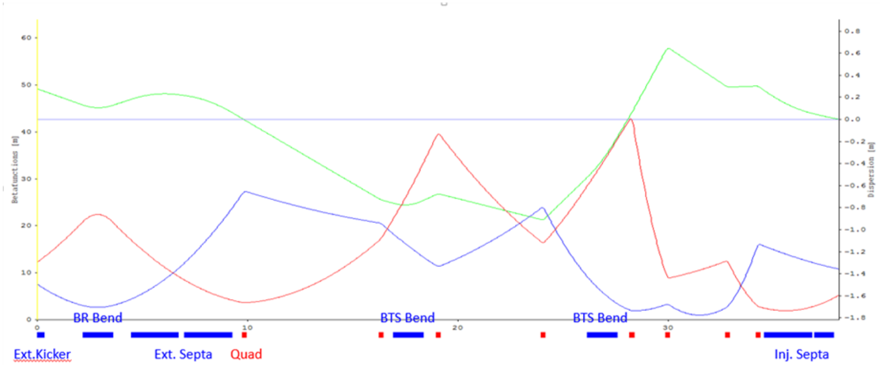


- At Kicker
x′ = 0 mrad -> 3 mrad
- 2 m Drift
x = 0 mm -> 6 mm
x′= 3 mrad
- At Bending Magnet
(k = -0.149)
x = 6 mm -> 10.449 mm
x′= 3 mrad -> 4.461 mrad
- Before Septa
x = 19.372 mm
x′= 4.461 mrad

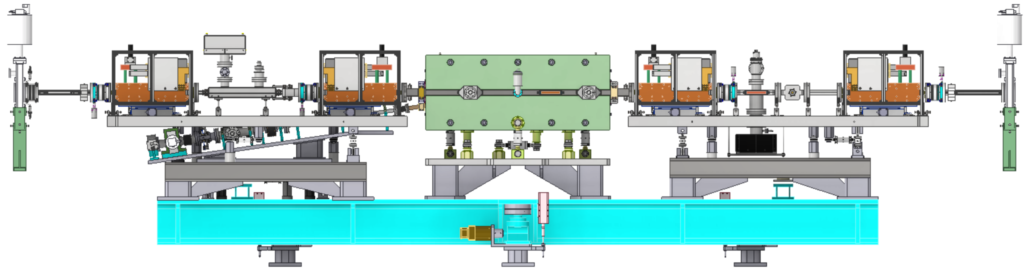
- Extraction point (unit : mm)

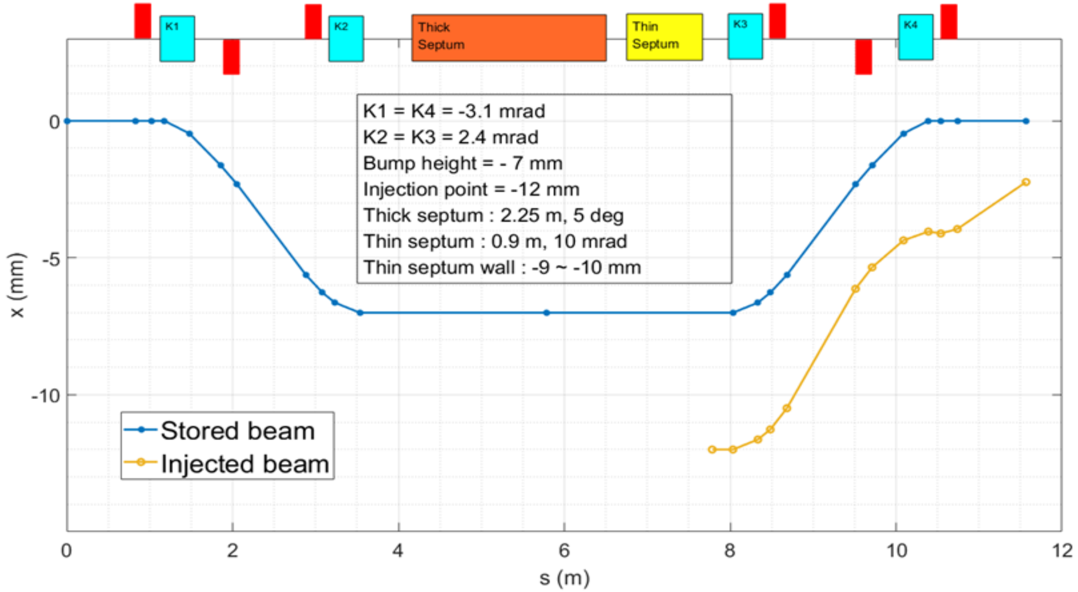
Chamber inner radius	12
Chamber thickness	1
Septum thickness	3
Extracted beam 3σ	0.3
Tolerance	3.1
Total	19.4

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

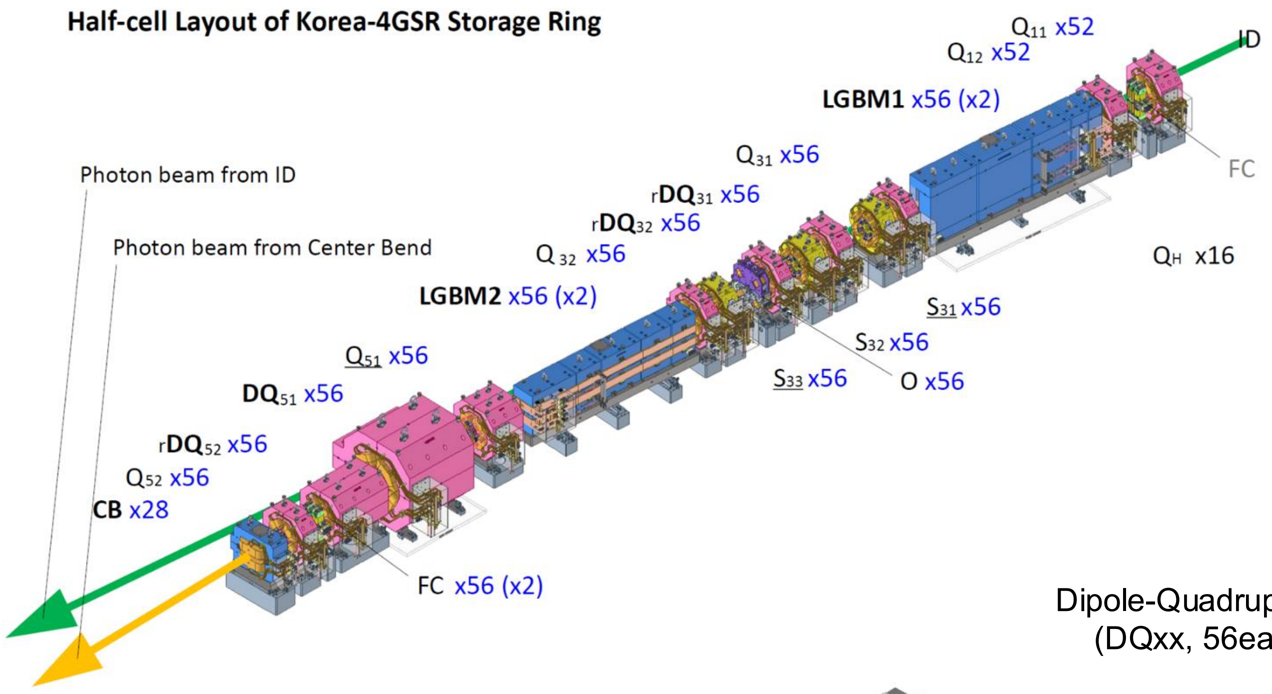


❖ Baseline design: SR 4-kicker bump, off-axis injection
Alternative design: Non-linear kickers

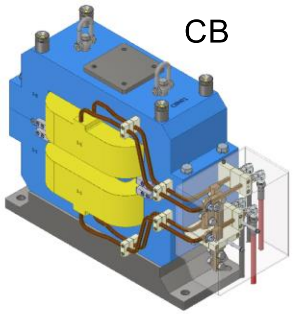




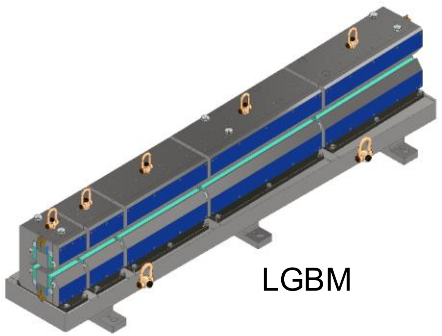
Magnet system of Storage Ring



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

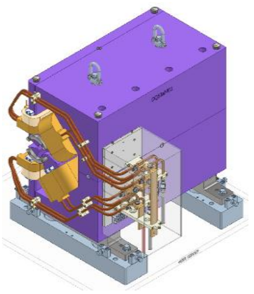



CB

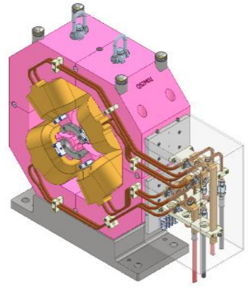


LGBM

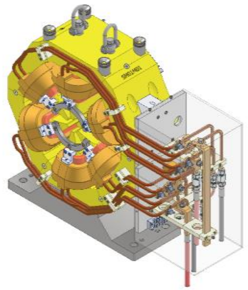
Dipole-Quadrupole (DQxx, 56ea)



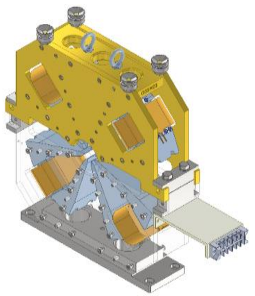
Quadrupole (Qxx, 344ea)



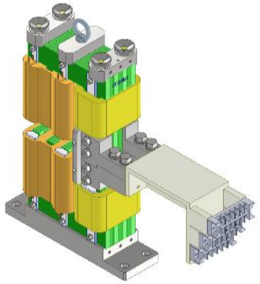
Sextupole Sxx, 168ea)



Octupole (Oxx, 56ea)

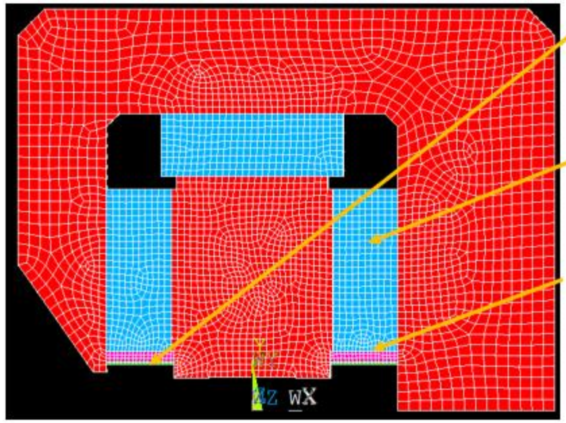


H/V/S Corrector (Cxx, 112ea)



Magnet system of Storage Ring

SR LGBM (Permanent Magnet version)



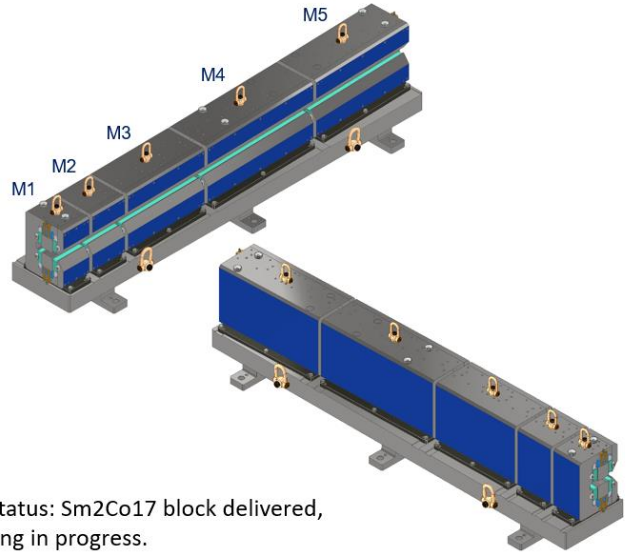
- LGBM has longitudinal field profile ranging from 0.15 T – 0.75 T to minimize beam emittances..
- Old design used electric excitation following APS-U for concerns on the long term radiation damage.
- But ESRF-EBS operating experience shows no radiation damage after 2 year operation.
- 2023 MAC (Machine Advisory Committee) recommended to consider PM version also.
- PM Version can save energy costs, Assuming, 1 kwh=200 Won, the design change can sove 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 ΔB/B/ Δ T= -3.3E-4/K.
- There is cross talk between the modules.

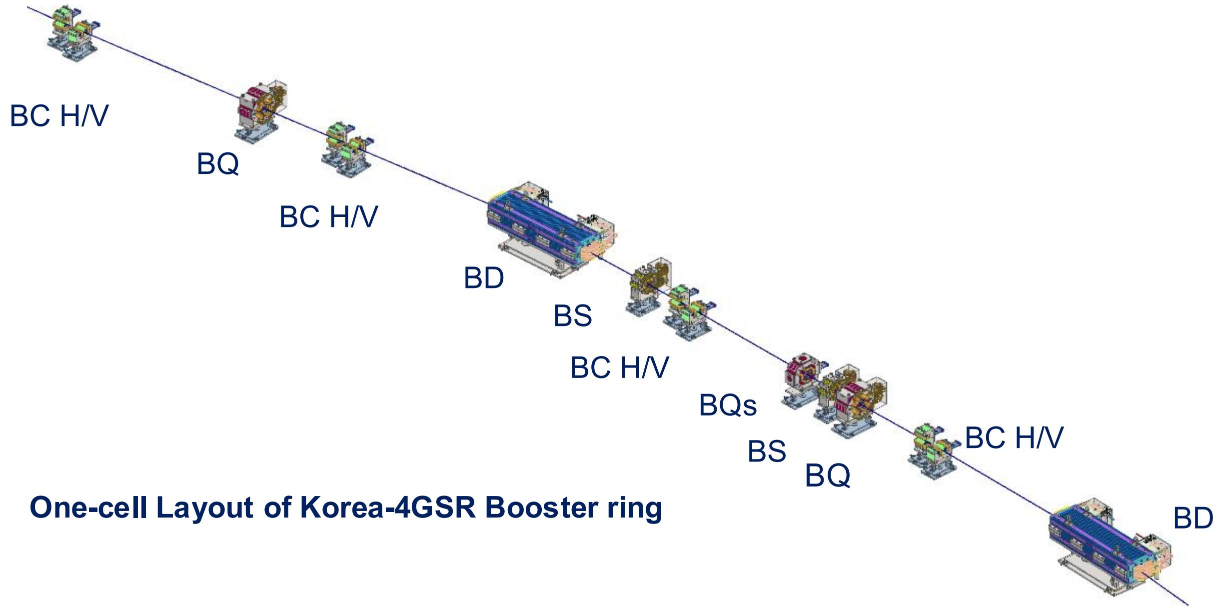
Engineering Solution

- 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.



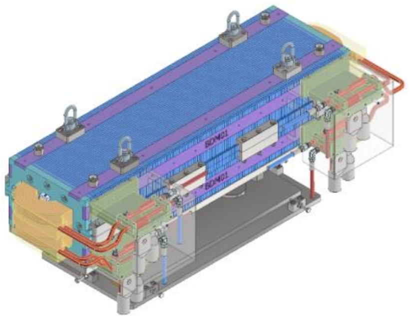
Current status: Sm2Co17 block delivered, prototyping in progress.

Magnet system of Booster Ring

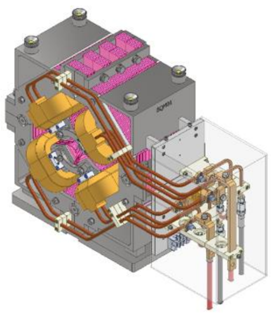


One-cell Layout of Korea-4GSR Booster ring

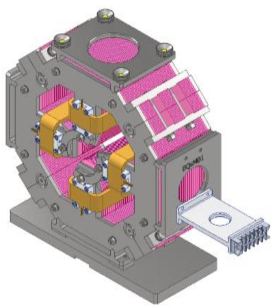
Magnets	Required Number	Remark
Combined Dipole	60	56 (6.07deg)+4(5.02deg)
Quadrupole	76	Normal 66, Skew 10
Sextupoles	60	
Corr.	240	H120, V120
Sum	436+	Total number of magnets



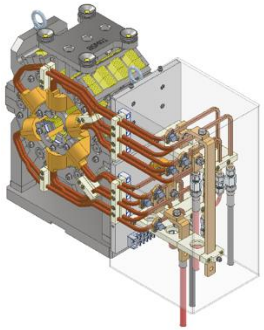
Combined Bending Magnet
(BD, 60ea)



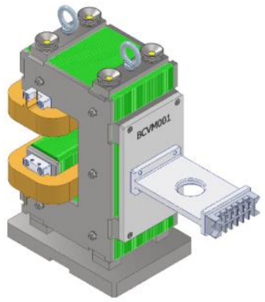
Quadrupole
(BQ, 66ea)



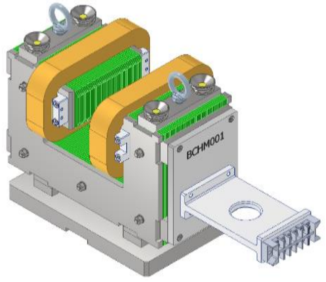
Quadrupole Skew
(BQs, 10ea)



Sextupole
(BS, 60ea)



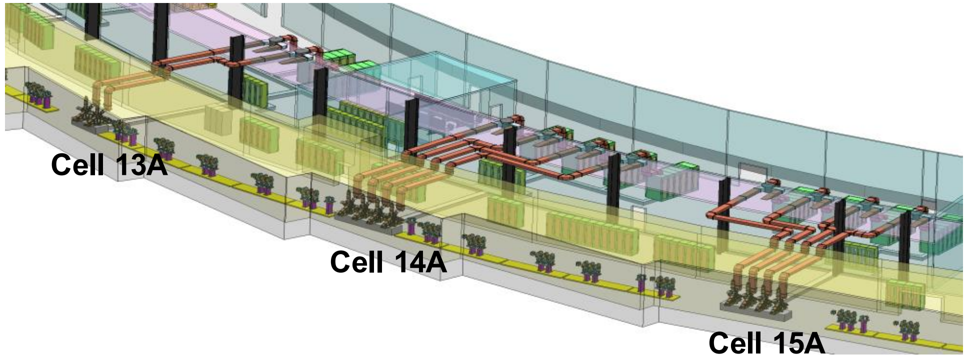
Corrector
(BCH, 120ea)



Corrector
(BCV, 120ea)

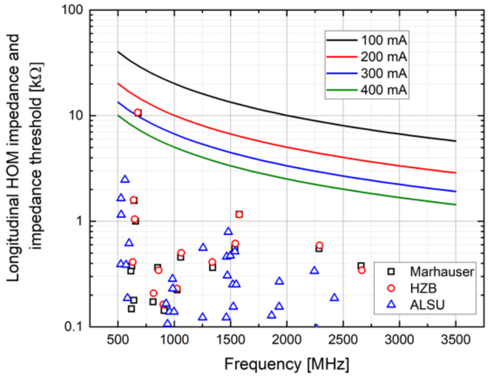
RF system of Storage Ring

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

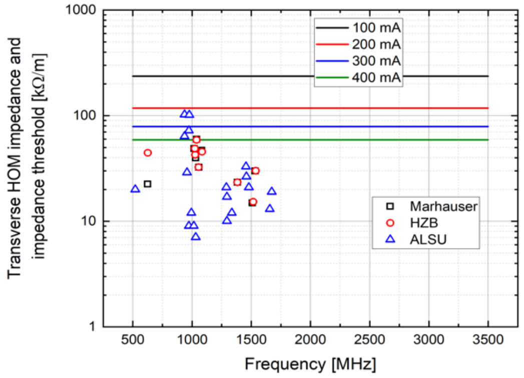


❖ Characteristics of SR RF System

- 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

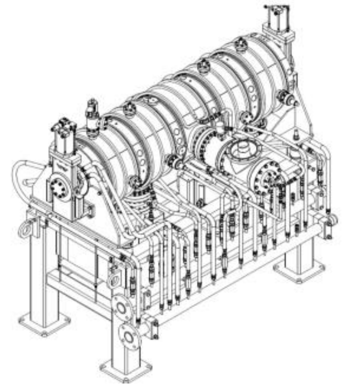
The auxiliary system such as TFS/LFS and/or harmonic cavity to suppress coupled-bunch instability (CBI) is necessary for storing >300 mA.

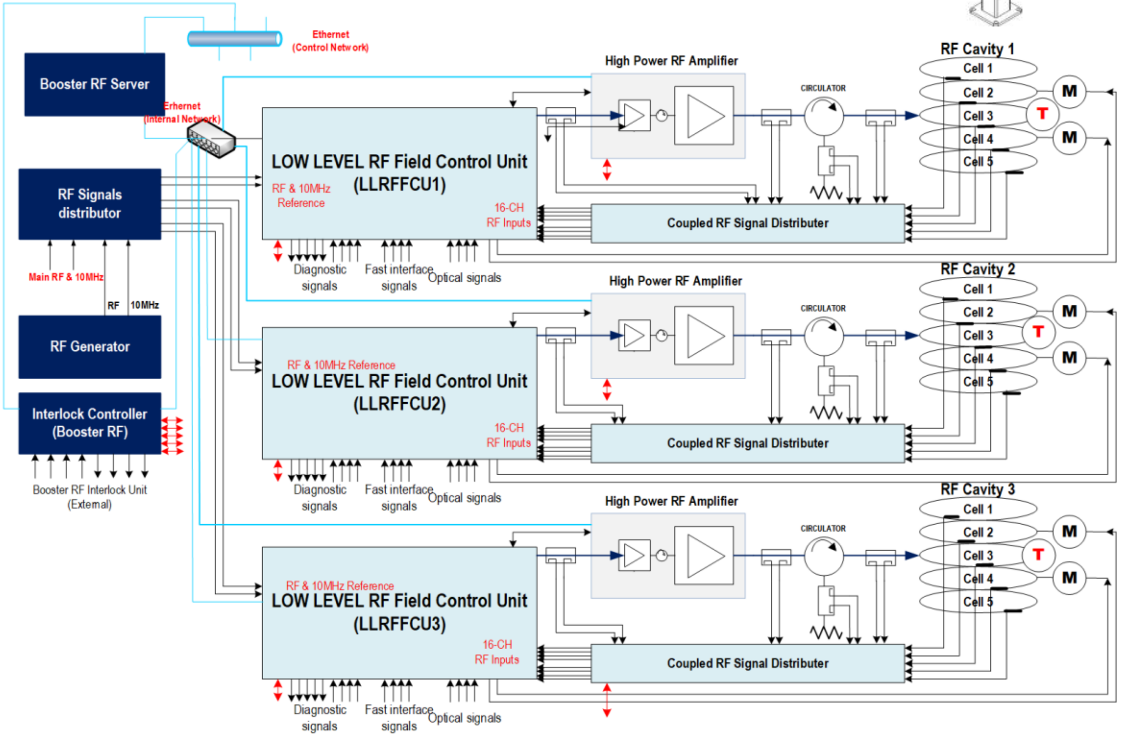
RF system of Storage Ring

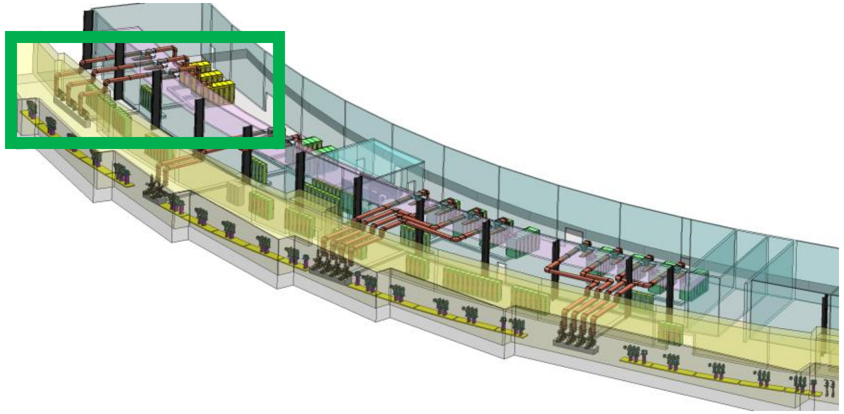
Parameters	Values	unit
Beam energy	0.2 – 4.0	GeV
Beam Current with single / multi bunch	1 / 3	mA
Circumference	772.9	m
Harmonic number	1288	-
Revolution frequency	387.9	kHz
Synchrotron Frequency	4.24	KHz
repetition rate	2	Hz
Accelerating Voltage @ 0.2 GeV	0.3	MV
Accelerating Voltage @ 4.0 GeV	3.0	MV
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



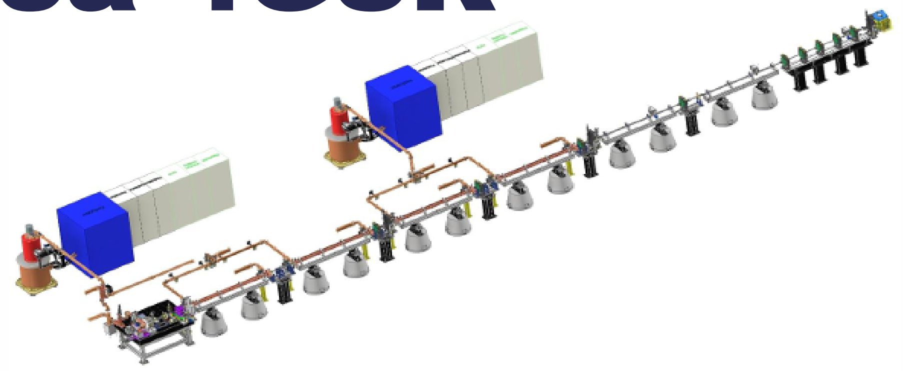


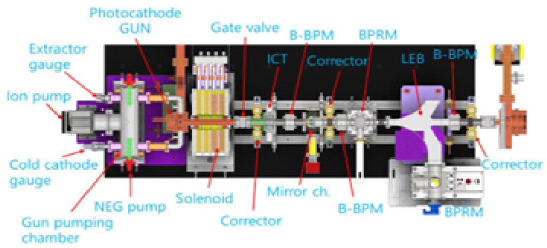


Vacuum system of Korea 4GSR

Accelerator Vacuum System

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





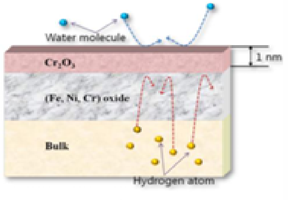
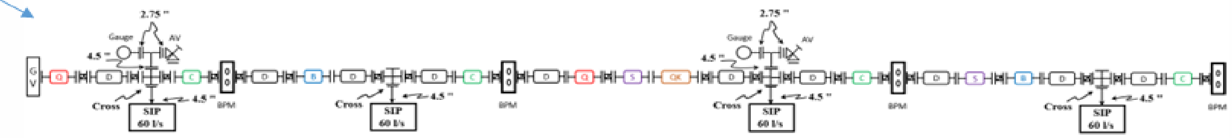
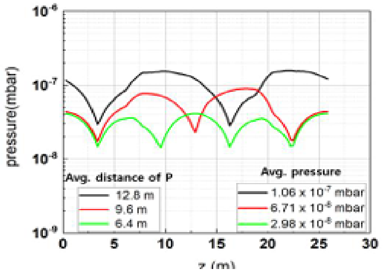


Photo cathode GUN
(Vacuum thermal oxidation treatment)





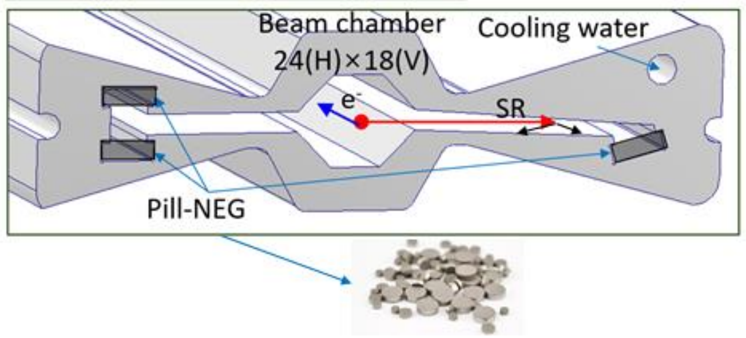
※ Pressure distribution w.r.t. pump distance

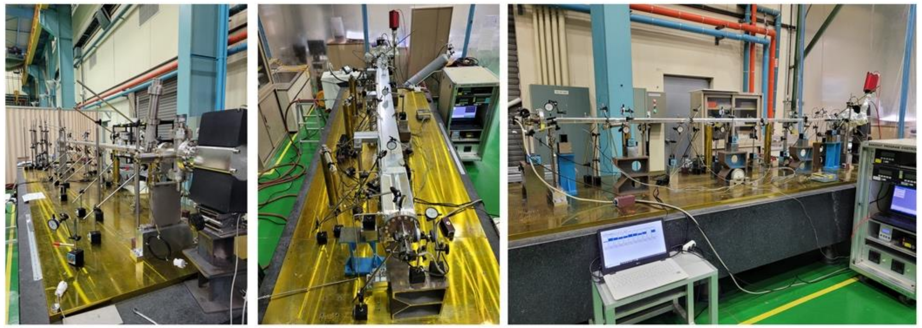
Vacuum system of Korea 4GSR

Vacuum System of Storage Ring

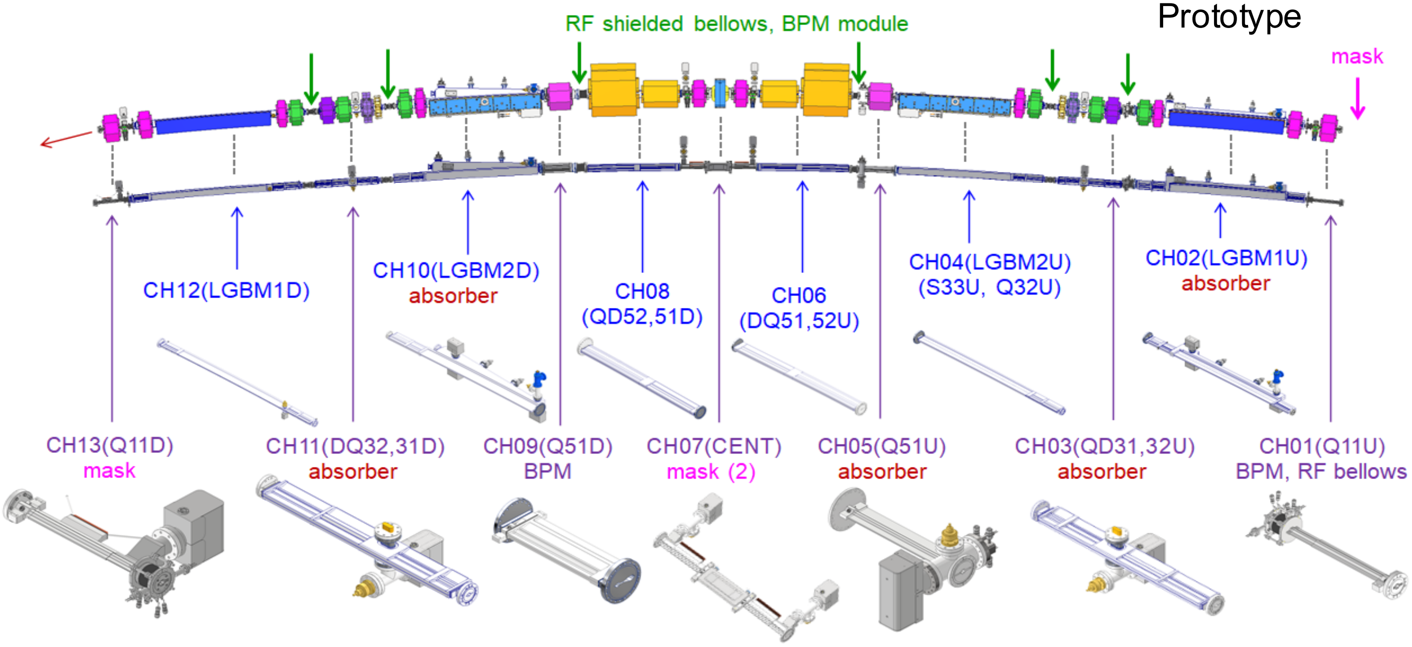
❖ Characteristics of SR Vacuum System

- 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



Summary of beam diagnostics

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

Types, Numbers & Locations (2025-Nov-05)

CODE	Type	Meas. Target	Numbers / Section				
			LINAC	LTB	BR	BTS	SR
1	BPM	Beam Position	10	8	120+2	6	288+5
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(H/V) / LFS	Multi-bunch Feedback					3
Numbers in total			20	16	134	12	366

4GSR Button BPM development

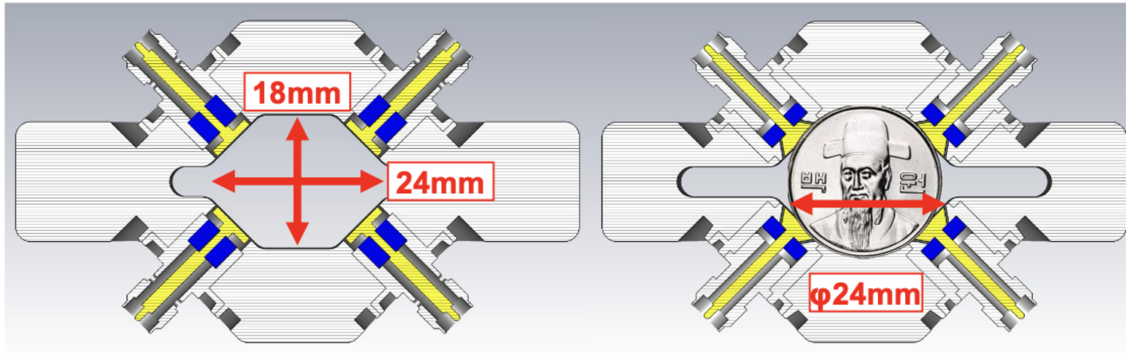
Development strategy of 4GSR Beam Position Monitor

Key Points of 4GSR BPM Pick-up Design:

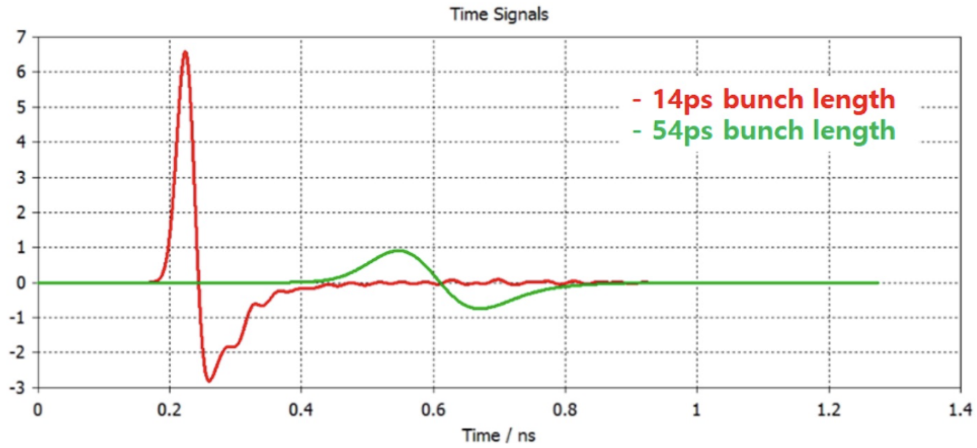
1. Minimize longitudinal wakefields.
2. Address challenges with insulator materials (e.g., SiO2).
3. Suppress ringing signals within 2 ns for BbB feedback.
4. Ensure impedance matching for signal efficiency.
5. Avoid trapped modes in button gaps.
6. Enhance signal sensitivity for higher resolution.
7. Optimize signal strength based on bunch length.

Design Considerations:

- **Small Button Head**: Reduces wakefields but lowers signal strength.
- **Fixed Chamber Design**: Set by the vacuum group, limiting modifications.
- **Geometry**:
  - **Storage Ring**: Octagonal shape
  - **Booster Ring**: Round shape
  - **LTB/BTS** : Round shape

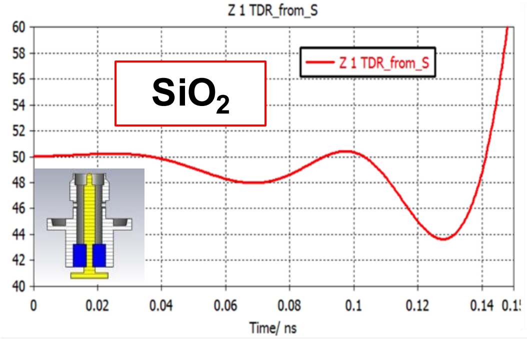


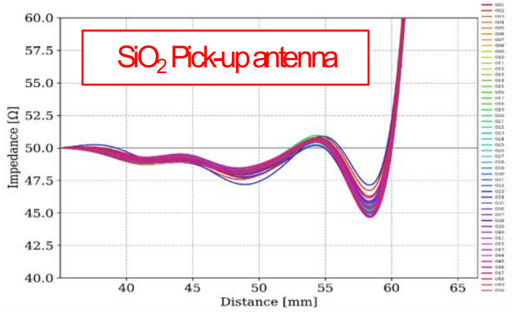
SiO_2 Glass & Al_2O_3 Ceramic Feedthrough antenna BPM for 4GSR

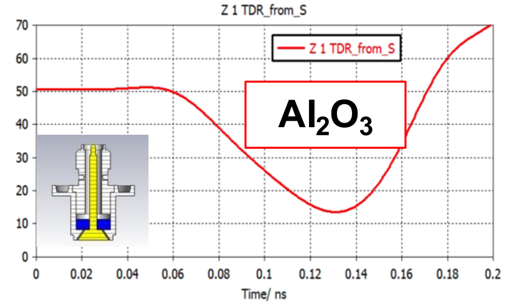


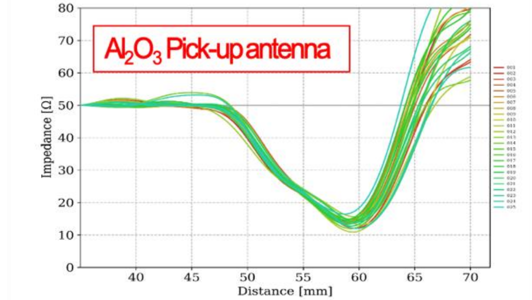
Button BPM pick-up

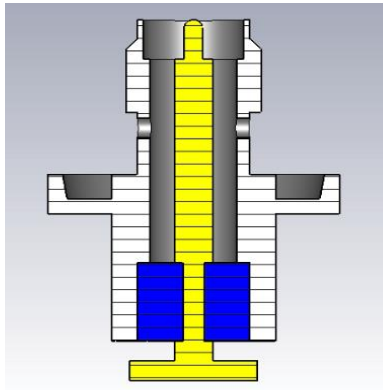
- RF Pick-up (Linac. to SR: All button type)
    - Two type of buttons were fabricated and test at PLS-II
    - SiO2 pick-up shows more good quality and easy for mass production
    - Reviewing production processes and quotations for mass production
    - TDR & tolerance measurements of pick-up have been complete.
    - Challenges include ceramic thickness constraints and maintaining Al2O3 pickup concentricity during brazing



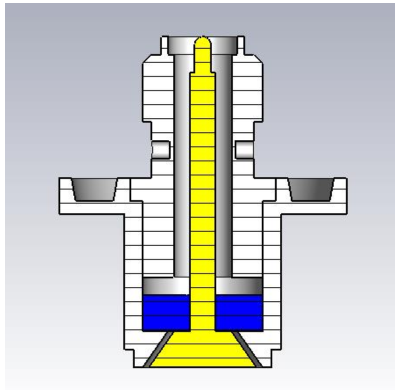




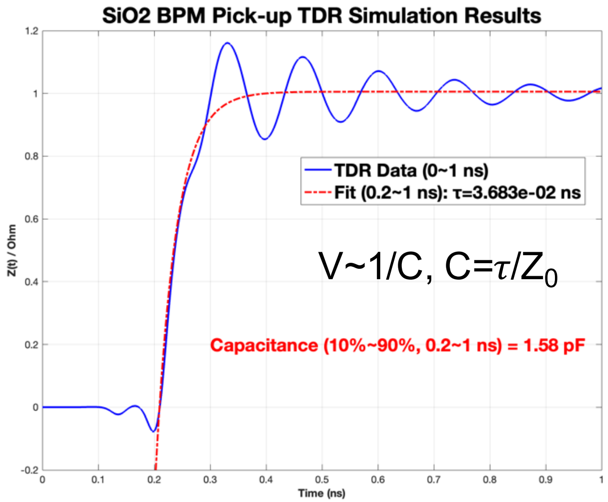


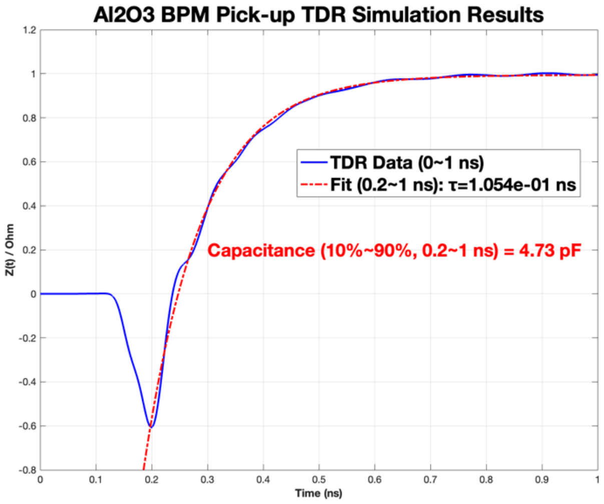


Type-A (SiO_2 Glass)



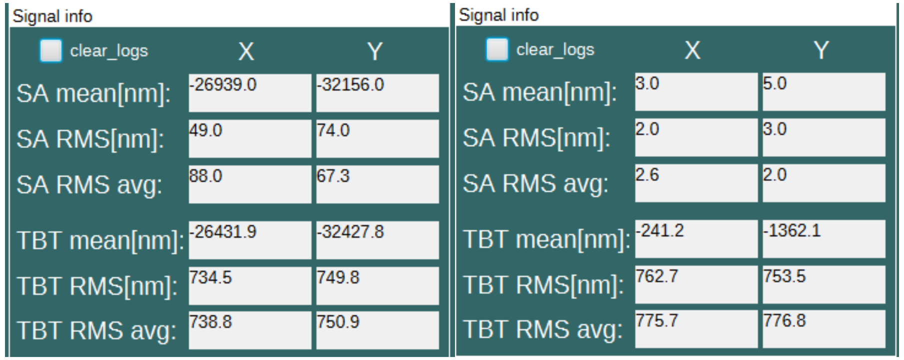
Type-B (Al_2O_3 Alumina)



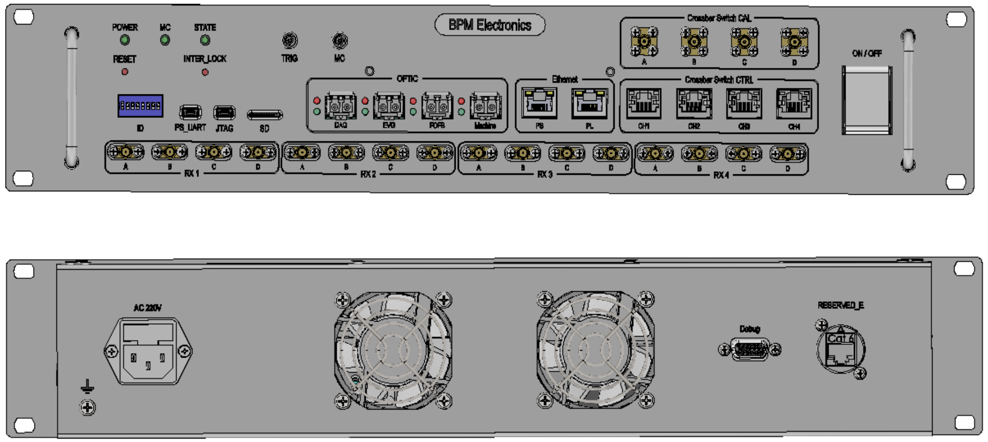


BPM electronics

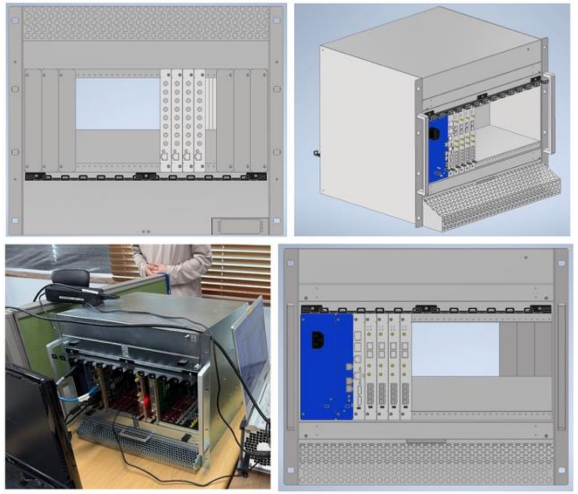
- Two type of 2nd prototype BPM electronics
  - Continued development of BPM (Beam Position Monitor) and BPM electronics.
  - Completed prototypes of both types of BPM pickups.
  - Conducted beam tests in the PLS-II storage ring.
  - Near final selection of the BPM pickup type after reviewing mass production processes.
  - Collaborating with two domestic companies on second prototypes of two different BPM electronics for mass production:
  - First model: Improved version of the existing prototype—based on RFSoC utilizing a 2.5 GS/s ADC with 14bit.
  - Second model: Uses commercial µTCA boards with a 125 MS/s & 16bit ADC to reduce budget and risk.
  - Both models aim to achieve 1 µm beam precision for turn-by-turn measurements, the goal of 4GSR.
  - Developing a crossbar switch module to compensate for phase changes in cables due to temperature variations.
  - Development scheduled for completion in the end of 2025.



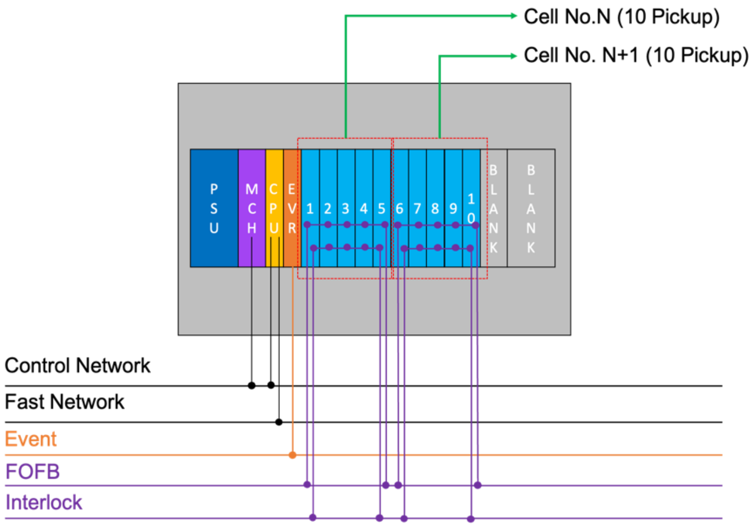
RFSoC BPM electronics: TbT/SA rms position with Crossbar Switch OFF and ON



RFSoC BPM electronics

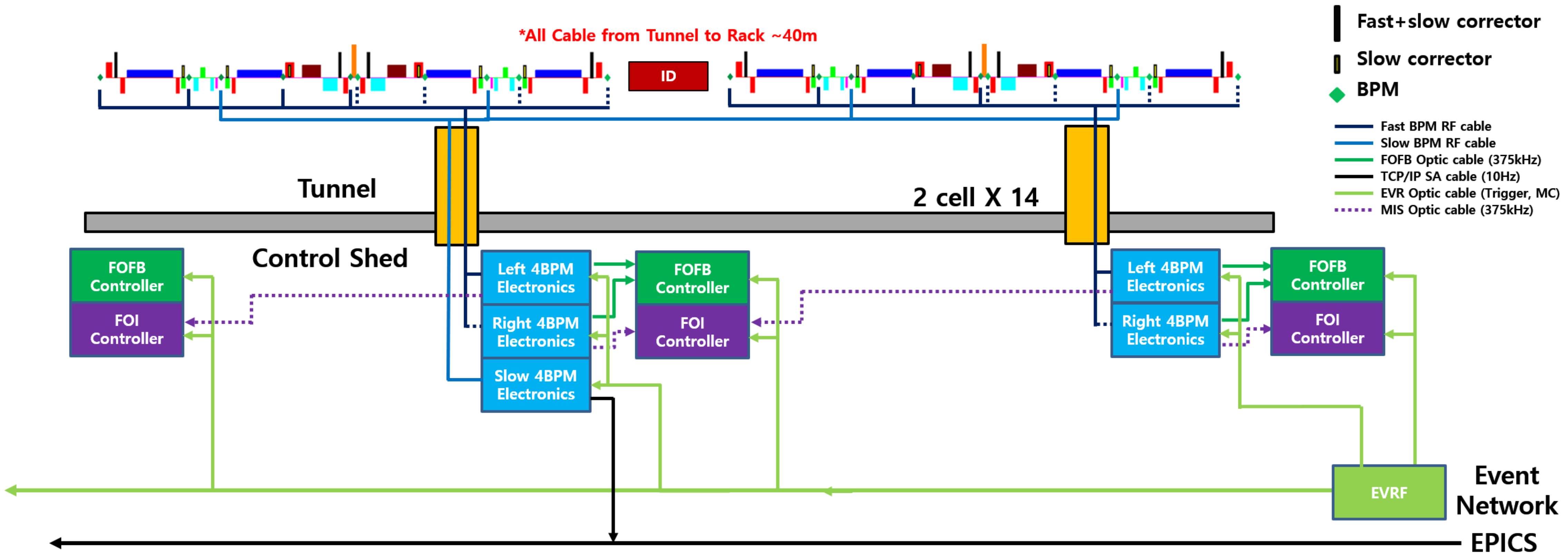


MTCA.4 BPM electronics



SR BPM RF cable & data cable configuration

FOFB, FOI, Timing with BPM electronics

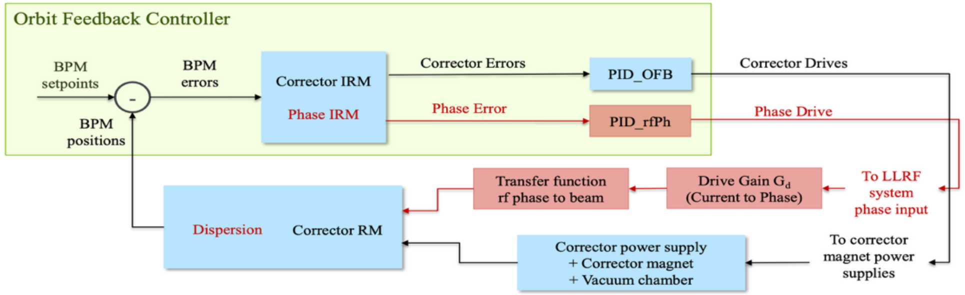


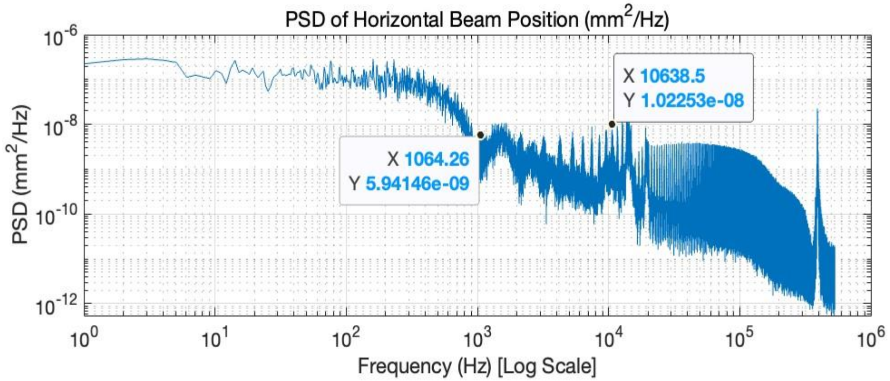
Strategy of FOFB

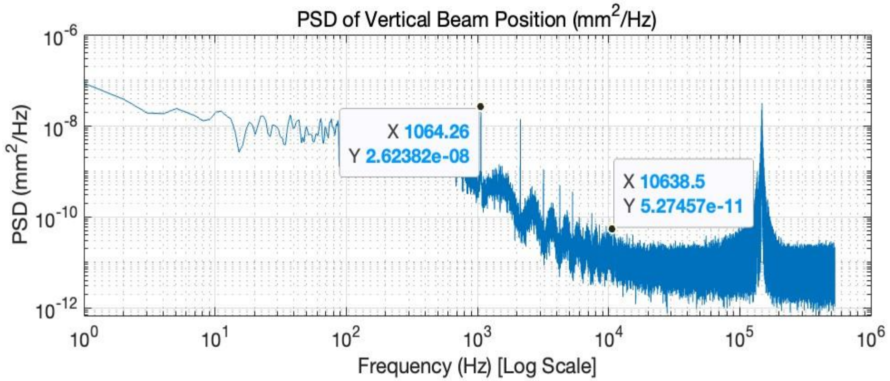
How determined close loop freq.? (FB freq. of FOFB)

- **Beam Test with SiO2 BPM and Libera Brilliance+ at PLS-II 7Cell on Sep 4, 2024**

Experimental setup – Orbit feedback controller with RF actuator







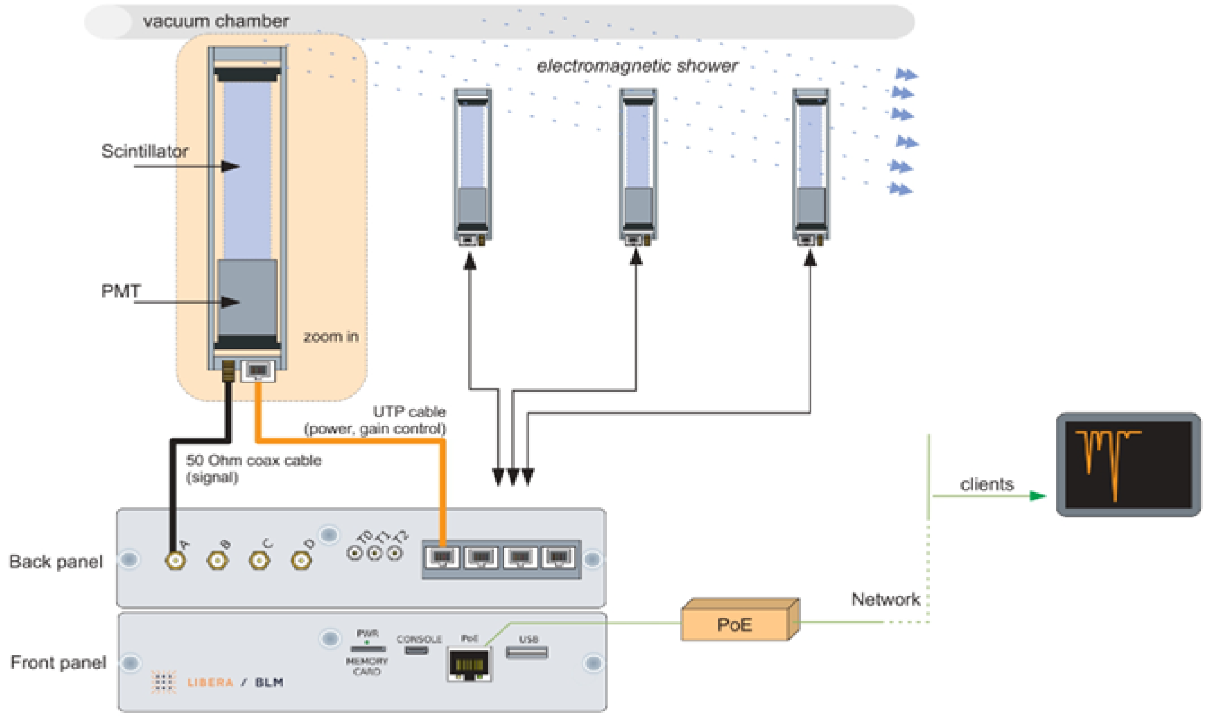
Summary of PLS-II TbT BPM PSD Measurements and Recommendations for 4GSR:

- **PLS-II Observations**:
- The PSD measurements with all feedback systems active showed a peak at the synchrotron frequency (~10.6 kHz). However, the vibration amplitude remained at the nanometer scale due to the feedback system's suppression.
- The peak at 10.6 kHz is likely attributed to the CBM0 mode vibrations.
- **4GSR Expectations**:
- It is anticipated that the CBM0 mode will also appear in the synchrotron frequency range for 4GSR. If the vibration amplitude is significant, it will need to be suppressed using feedback systems.
- **Recommendation**:
- Based on the APS-U example, it is recommended to implement a mixed feedback system combining FOFB (Fast Orbit Feedback) and LLRF (Low-Level RF) to mitigate CBM0 mode vibrations effectively.

Summary of Synchrotron Tune and Feedback System Analysis for CBM0 Suppression:

- **Without HC**: The synchrotron tune is 0.00341 @ 4 GeV, corresponding to a frequency of 1.28 kHz.
- **With HC**: The synchrotron frequency is expected to decrease below 1kHz.
- **Feedback System Analysis**: The FOFB system alone cannot suppress CBM0 in the absence of HC. However, with HC, integrating FOFB with LLRF feedback may enable effective suppression of CBM0 vibrations. If CBM0-coupled vibrations for 4GSR case do not appear below 1 kHz in the transverse plane or remain negligible, an FOFB suppression bandwidth of 500 Hz should be sufficient.

Beam Loss Monitor (fast)



Schematic of Libera-BLM

- Fast enough to measure turn by turn beam loss
- Use a commercial product that has proven performance by other labs

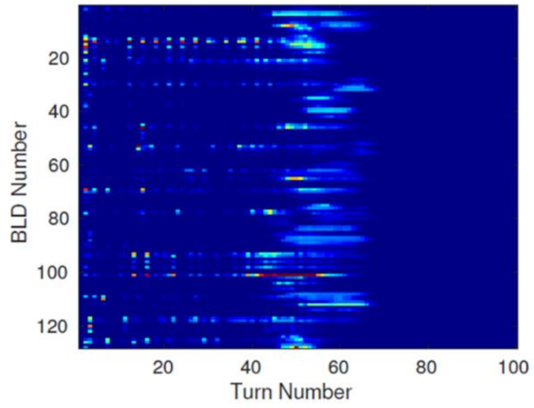
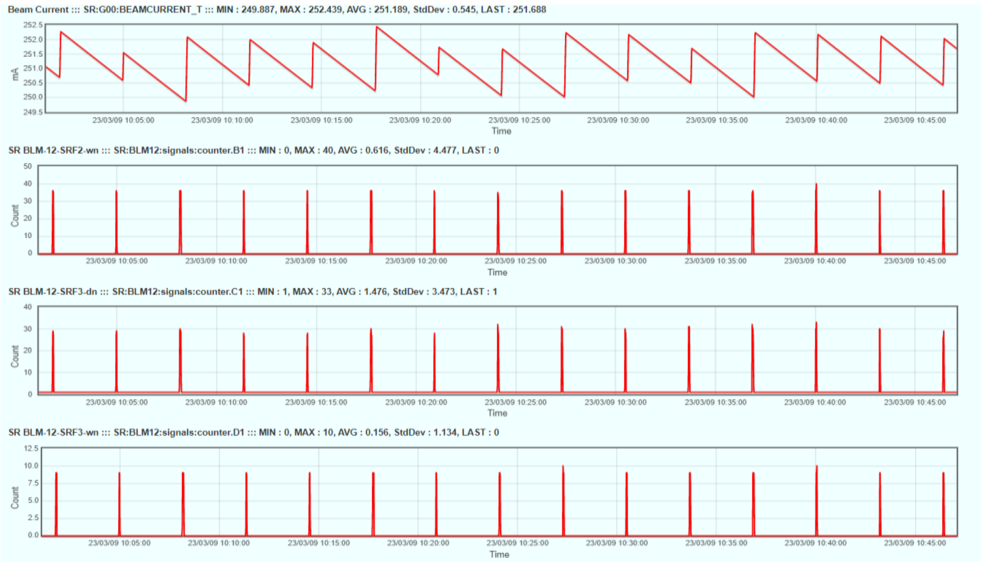


Figure 13: TbT losses with RF off. The beam preforms about 60 turns and is lost mainly close to BLD number 100 (Cell 26, position1).

Torino L. et. *al*., IBIC2018-WEOB01, ESRF



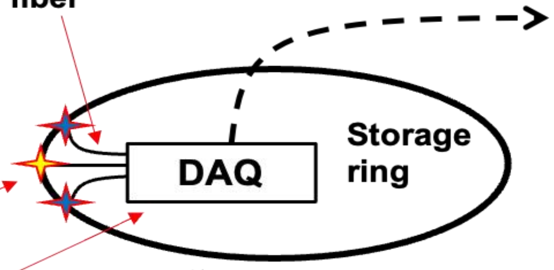
Beam current (first line) and
Beam loss counter @ PLS-II WEB IOC

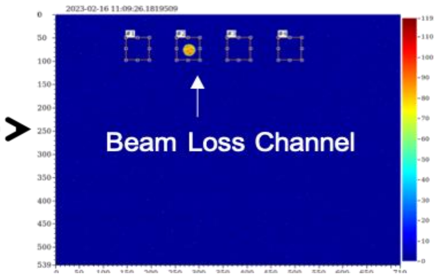
Beam Loss Monitor (slow)

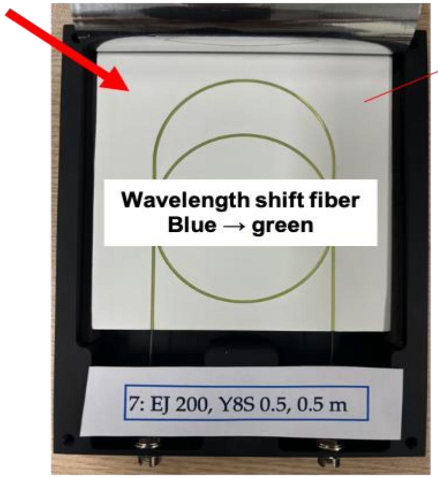
- 100 Sample/sec/ch x 25 ch of low-cost BLM was developed by using scintillation plate with fiber and CMOS camera
- Detector was modified from scintillation fiber to plate for higher sensitivity
- Beam loss location detection (mainly e- , photons, ions)
- Main idea was originated from PSI

IBIC2021, C. Ozkan Loch et *al*., "CMOS BASED BEAM LOSS MONITOR AT THE SLS"

Schematic of SBLM

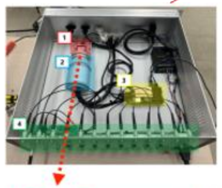




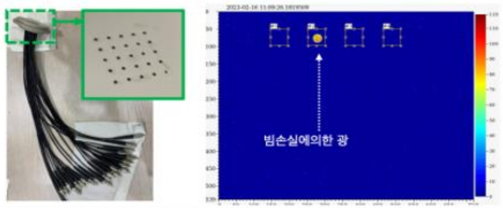


Detector

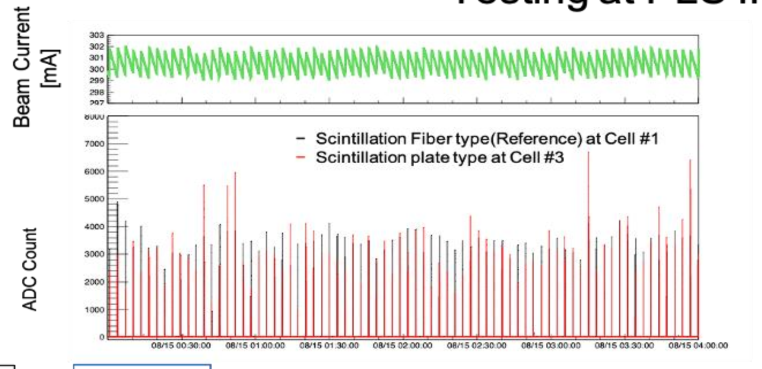
DAQ

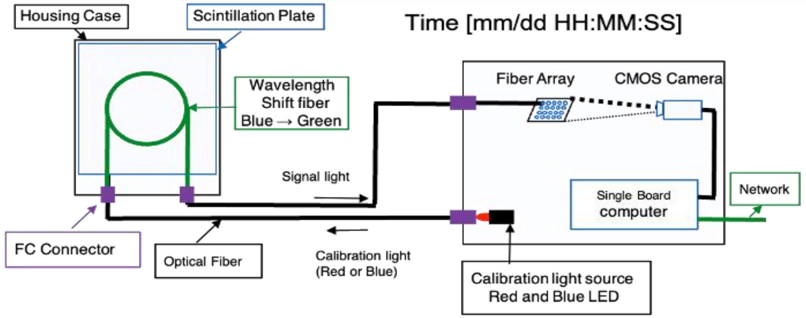


1. Camera
2. Fiber holder + lens
3. Raspberry Pi 4
4. Fiber/LED Connectors



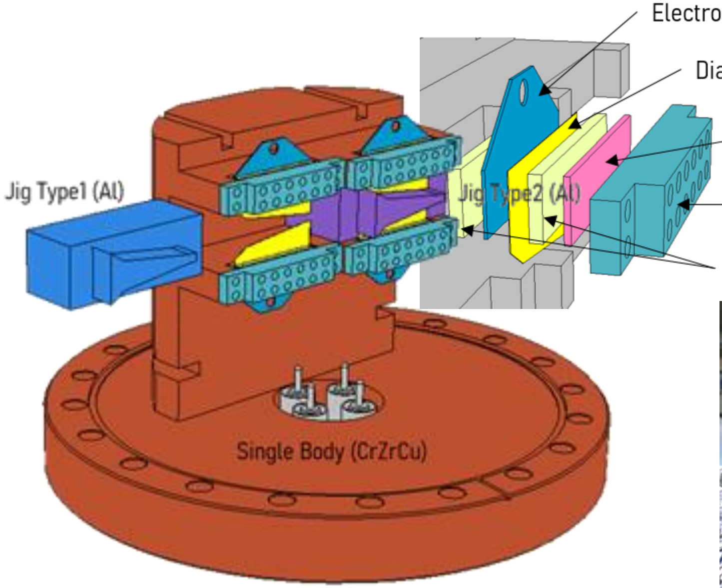
Testing at PLS II

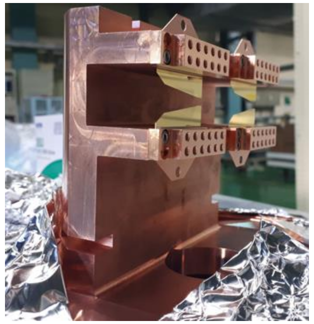




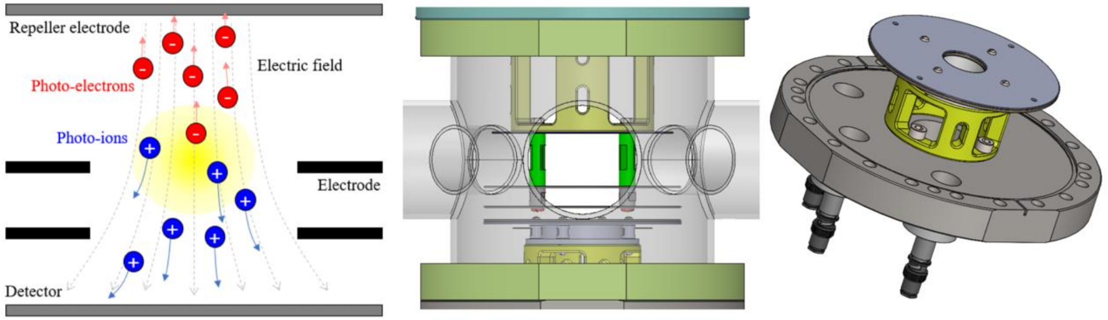
Photon Beam Position Monitor

- Diamond Blades PBPM (Hard X-ray)
  - Development completed (Installed in PLS-II, since 2020)
  - Available to scan full range photon beam (low heat depo.)
  - R/O module : Libera-photon current integrator
  - Impossible to remove a contamination photon generated by up/down-stream bending magnet, that is moving by SOFB

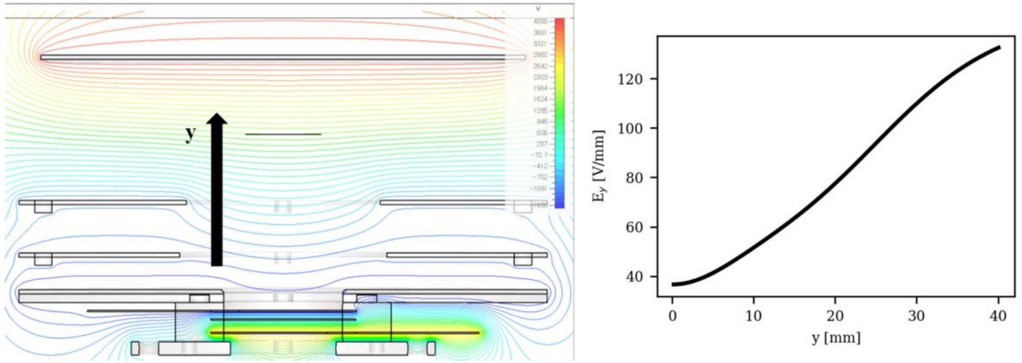




- Gas chamber PBPM (Soft X-ray)
  - No contamination effect
  - Both center of charge and profile can be measured



Basic principle of the GPBPM (left) and the external shape of GPBPM (right)



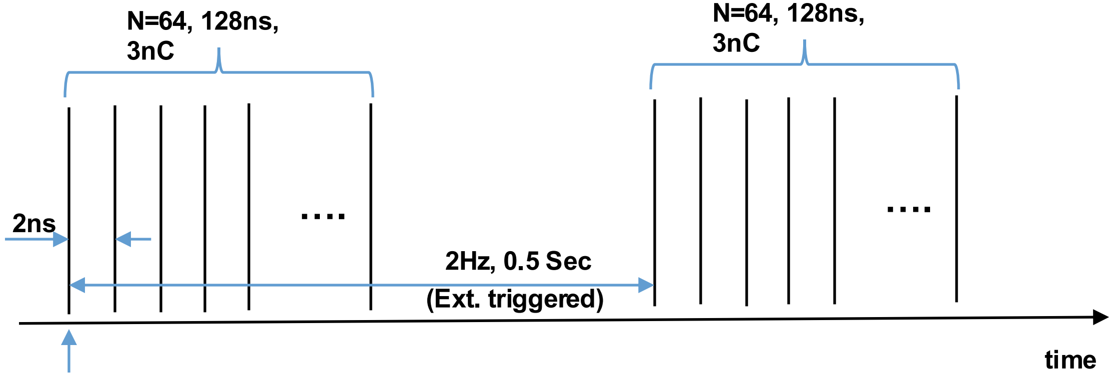
Equipotential line distribution of the GPBPM (left) and the electric field in the y-direction at the center (right)

Bunch Resolved Energy Measurement

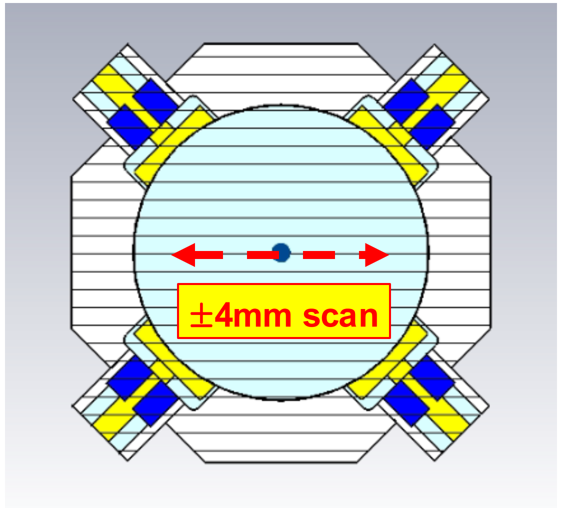
- Energy measurement of bunch by bunch at LTB
    - BbB analyzing module
- 4GSR BBB E-meas. System for beam injection energy stabilization
- E-meas. BPM offset calibration: -4mm to 4mm with 30pC

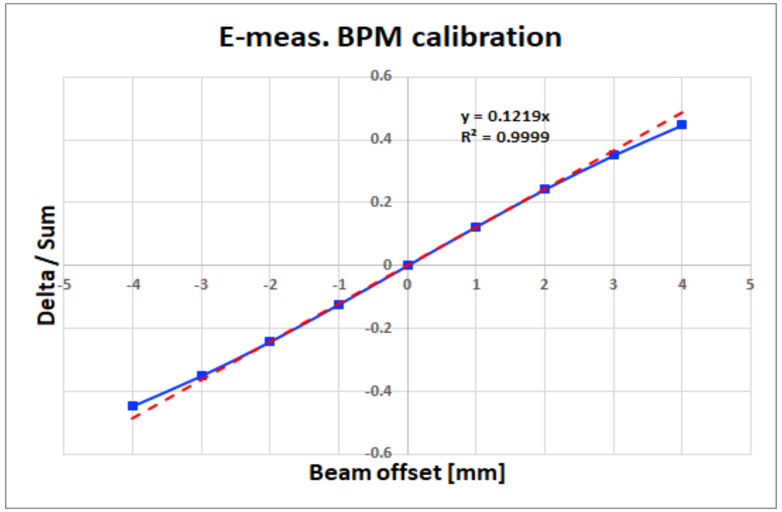
  -> BPM is 45deg rotated for beam axis, Horizontal axis beam offset was scanned

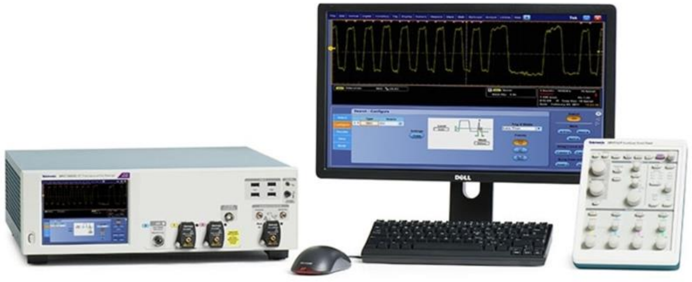
  -> Expected calibration factor K_x for E-meas. BPM is 8.203mm
- Final goal of E-meas. BPM system will provide bunch by bunch beam energy information.



Multi-bunch mode of 4GSR Linac.





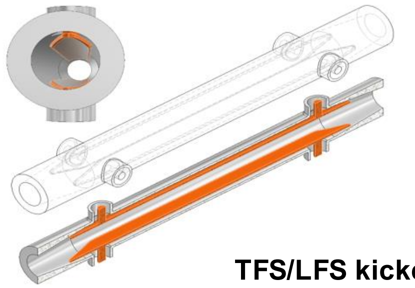
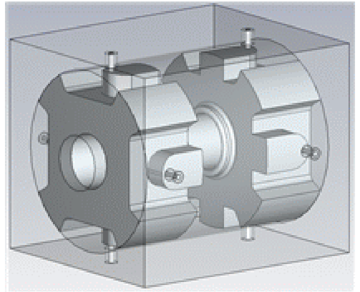


Commercial High-speed Digitizer
100GS/s

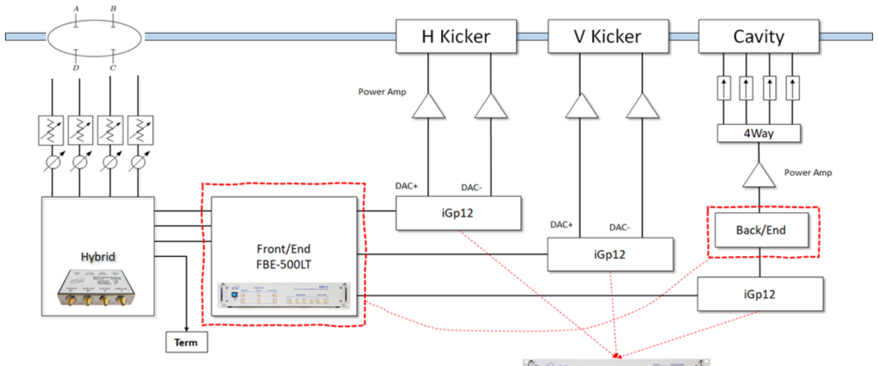
TFS/LFS

Bunch by Bunch Feedback System for Korea 4GSR

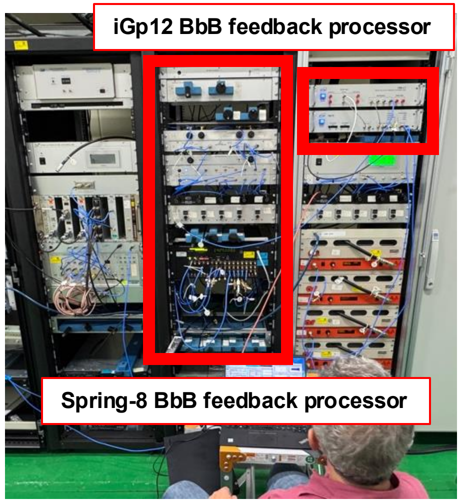
- The EM design of the TFS/LFS stripline kicker and the cavity kicker has been completed.
- The TFS electronics developed by Dimtel were tested at PLS-II in September 2024 and 2025.
- BbB feedback system can measure the horizontal, vertical and synchronous tunes of the storage ring.
- For high-current operation modes (up to 400 mA), the BbB feedback is essential for stable operation.
- Bunch cleaning is also required to maintain high purity in multi-bunch trains.
- Most components of the system will be implemented using commercial off-the-shelf products.

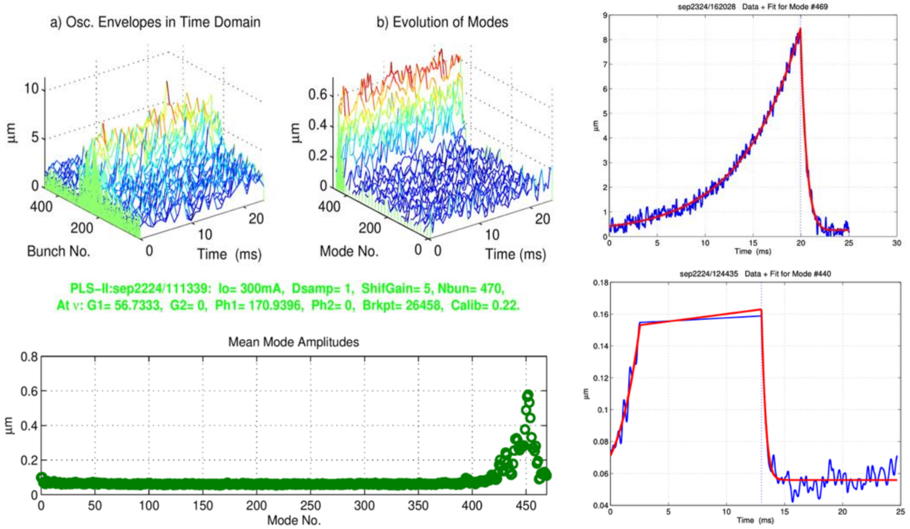
TFS/LFS kickers

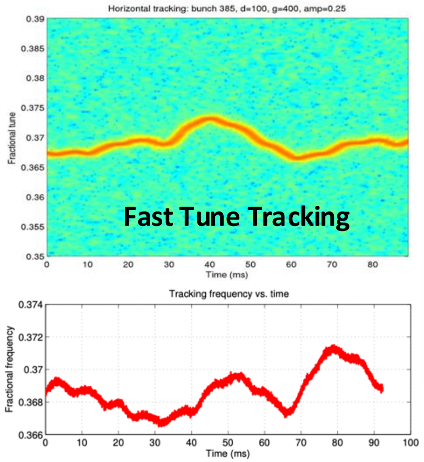


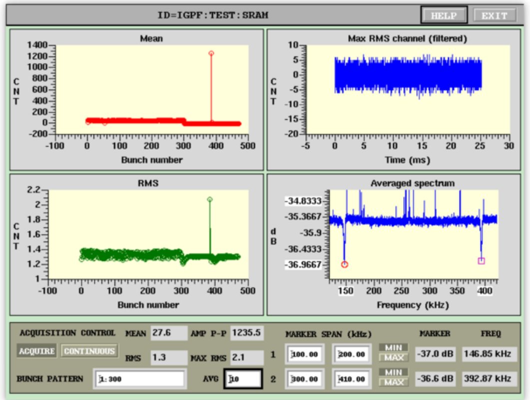
Commercial product of TFS/LFS



Horizontal and Vertical Grow/damp Measurement



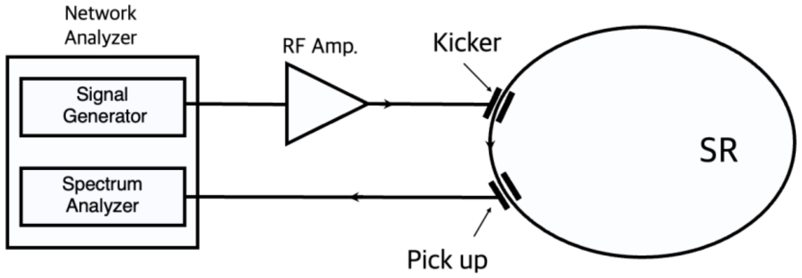




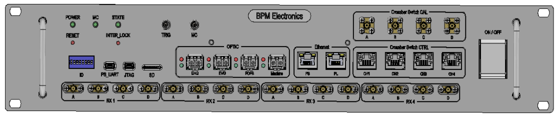
Parasitic Tune Measurement

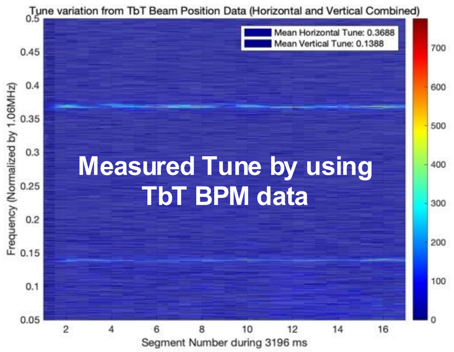
Tune Monitor

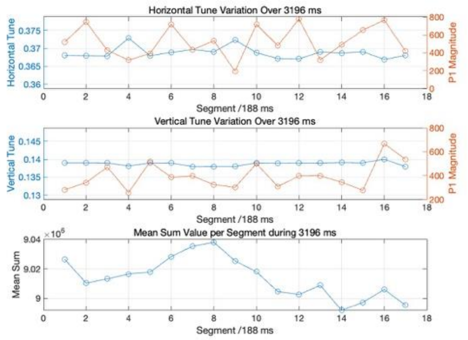
- Analog setup (c.f. PSL-II)
  - Spectrum analyzer with tracking generator
  - Kicker at small β, pickup at large β preferred

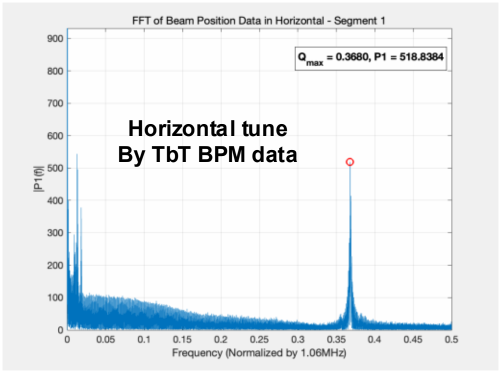


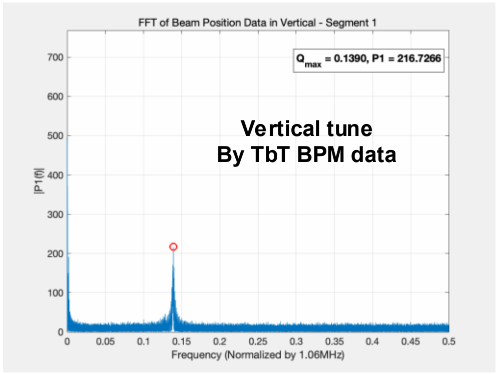
- Digital tune measurement (BR + SR)
  - Average Tune measurements by using BPM TbT data
  - Tune measurement of Individual bunches are also possible
  - use a BbB FB processor as Dimtel iGp12
  - wideband(0~1MHz on carrier) noise signal generation + FFT

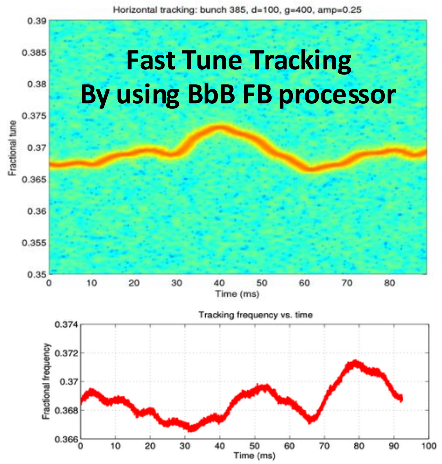


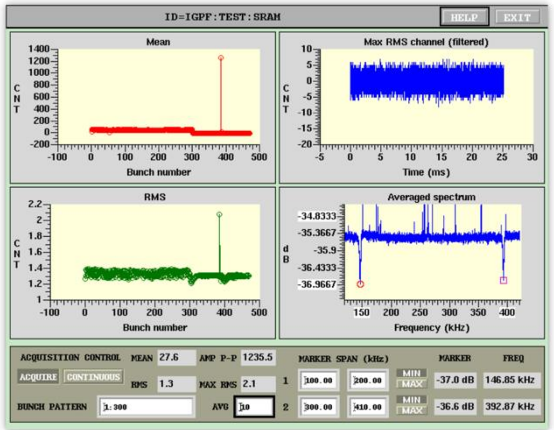












Summary

- 4 GeV storage ring with 800 m circumference, 28 cells, and natural emittance of 62 pm; full-energy booster (10.9 nm) shares the tunnel; injector is a 200 MeV photocathode linac.
- Facility can host >40 beamlines; Phase 1 includes 9 ID and 1 BM beamline (10 total).
- KBSI leads building and facility construction, while PAL is responsible for accelerator and beamlines.
- Building design began in Sep 2022, TDR finished in 2023, construction started Spring 2024, and completion is targeted for 2029.
- Accelerator requires ~1044 magnets in SR and 436 in booster, plus correctors, LTB/BTS, and injection/extraction devices; For LGBMs, a pure EM staggered coil design was initially studied, but the PM version was officially adopted in July 2025 following the MAC review.
- RF system: 10 HOM-damped normal-conducting cavities occupying 2.5 straights.
- Beam diagnostics: device types, numbers, and layout determined for budget planning.
- Vacuum system design optimized; expected average pressure < 1×10^{-9} mbar.

Thank you !

Beam diagnostics of Korea 4GSR (Back up slide)

KBSI KOREA BASIC SCIENCE INSTITUTE

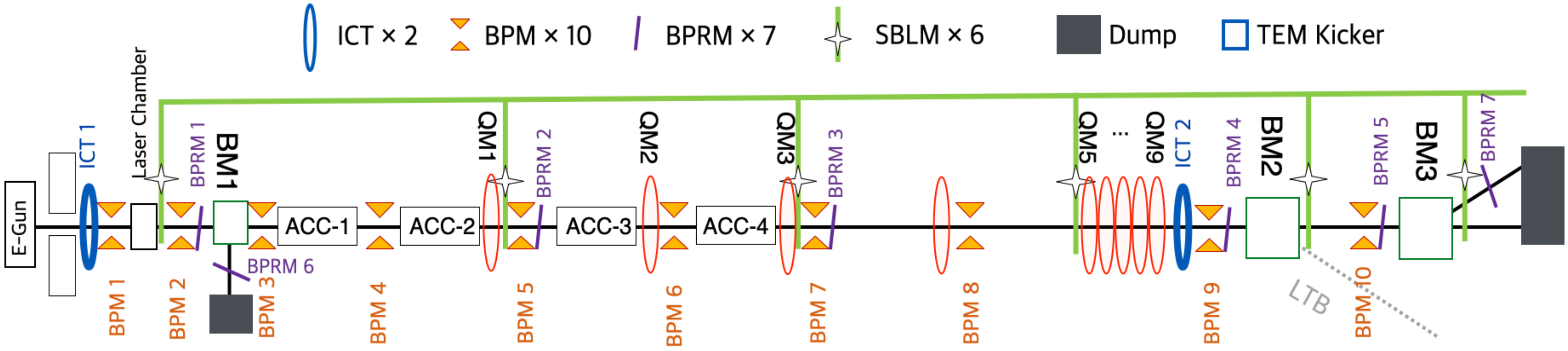
PAL

Beam Diagnostics of LINAC

LINAC DIAG Update list

- **Beam Analysis Section is Added**
  Energy & multi bunch energy trend measurement
- **Faraday cup is removed**
  ICT has enough accuracy.
- **Slit for Emittance and Twiss parameter is remove**
  Emit. and Twiss parameter is measured by Q-Scan

Beam Parameters	Devices	Section
Energy & Energy Spread	BM1 & BPRM 6 / BM3 & BPRM 7	Gun / Beam Analysis
Position & Profile	BPMs & BPRMs	All
Emittance & Twiss	QM3 & BPRM4	Acceleration
Energy & Energy Spread	BM3 & BPM7	Beam Analysis Section
Multi-bunch Energy Trend	TEM Kicker,BM3 & BPM7	Beam Analysis Section
Charge and Beam Transmission	ICT 1 / ICT2	Gun / Acceleration

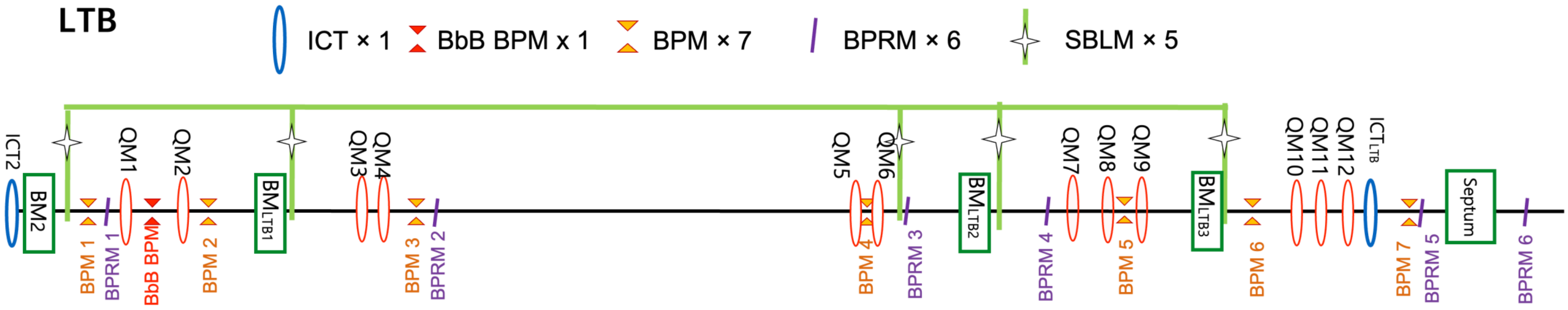


LTB: LINAC to Booster Ring

LTB DIAG Update list

- Beam dynamics lattice was updated
- Beam diagnostics are re-aligned to fit new lattice design
- One BPRM was removed
- Proto-type of BPRM will be tested in PLS-II BTL

Property	Devices
Bunch By Bunch Energy	BM_{LINAC_2} and BbB BPM
Energy & Energy spread	BM_{LINAC_2} and BPRM 1
Position & Profile	BPMs & BPRMs
Emittance & Twiss	QM4 & BPRM 3
Charge & Beam Transmission	$ICT_{\_LTB}$/ $ICT_{\_LINAC\_2}$

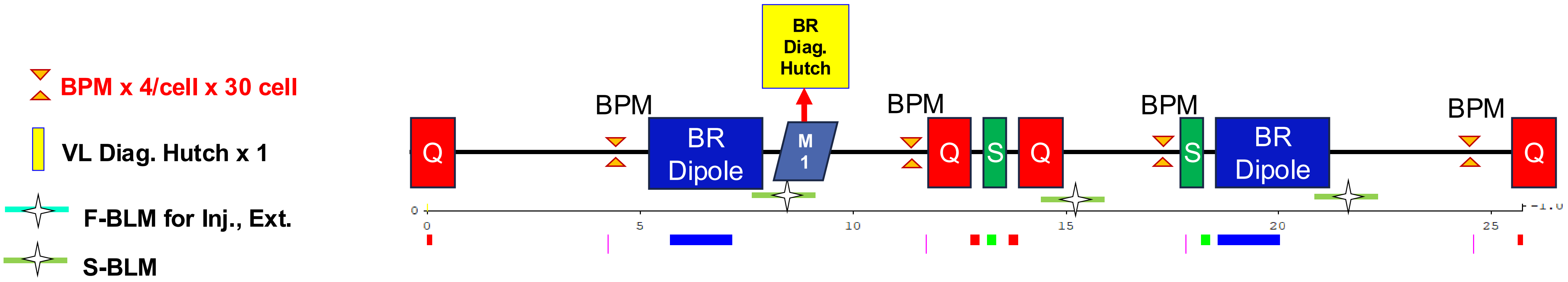


Beam Diagnostics of Booster Ring

Booster DIAG Update list

- Beam dynamics lattice was updated
- Beam diagnostics are re-aligned to fit new lattice design
- BPM body design was modified and fixed
- BPM number was increased from 60 to 120 for orbit feedback
- The location of Booster Beam diagnostic Hutch was readjusted from #1 cell to #16 cell
- The BPRM for the first turn has been removed, and measureme nts will now be taken at the BR Diagnostic Hutch.

Property	Devices
Beam Position	BR BPM
Current	DCCT for BR
Beam Size & Emittance	Diag. Hutch with Interferometer
Fill pattern & bunch length	Diag. Hutch with streak camera
Beam Loss	Fast & Slow BLM

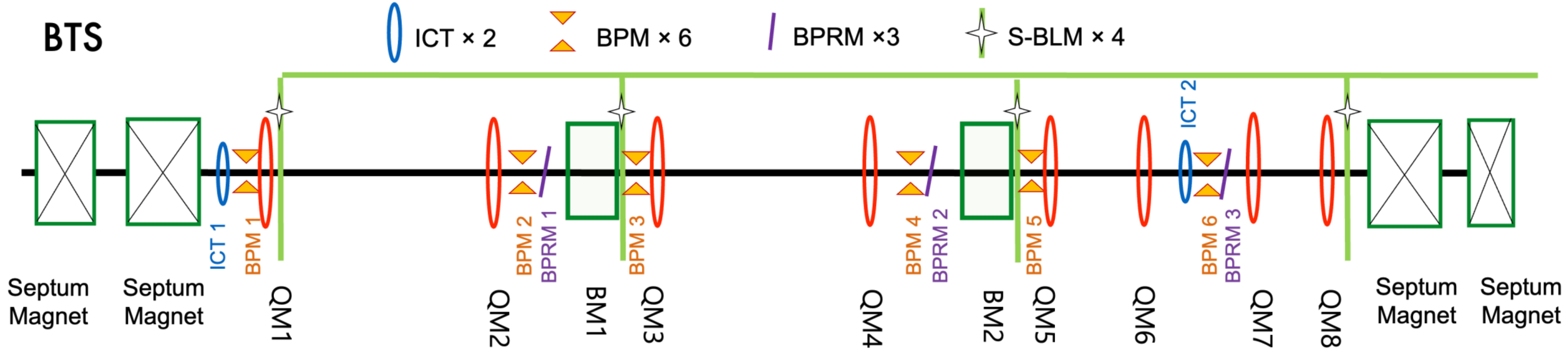


BTS: Booster Ring to Storage Ring

BTS DIAG Update list

- Beam dynamics lattice was updated
- Beam diagnostics are re-aligned to fit new lattice design

Property	Devices
Energy	BPM
Position & Profile	BPMs & BPRMs
Charge & Beam Transmission ICT_{BTS1}/ ICT_{BTS2}	ICT1/ ICT 2

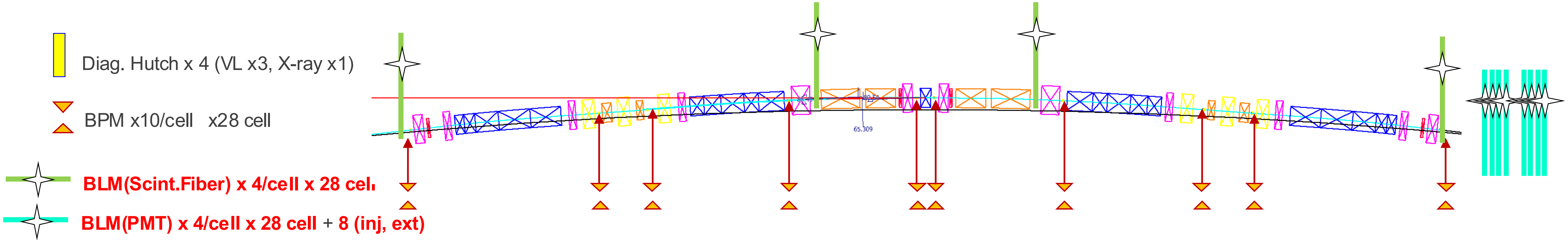


Beam Diagnostics of Storage Ring

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 & ~1 kHz FOFB 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.

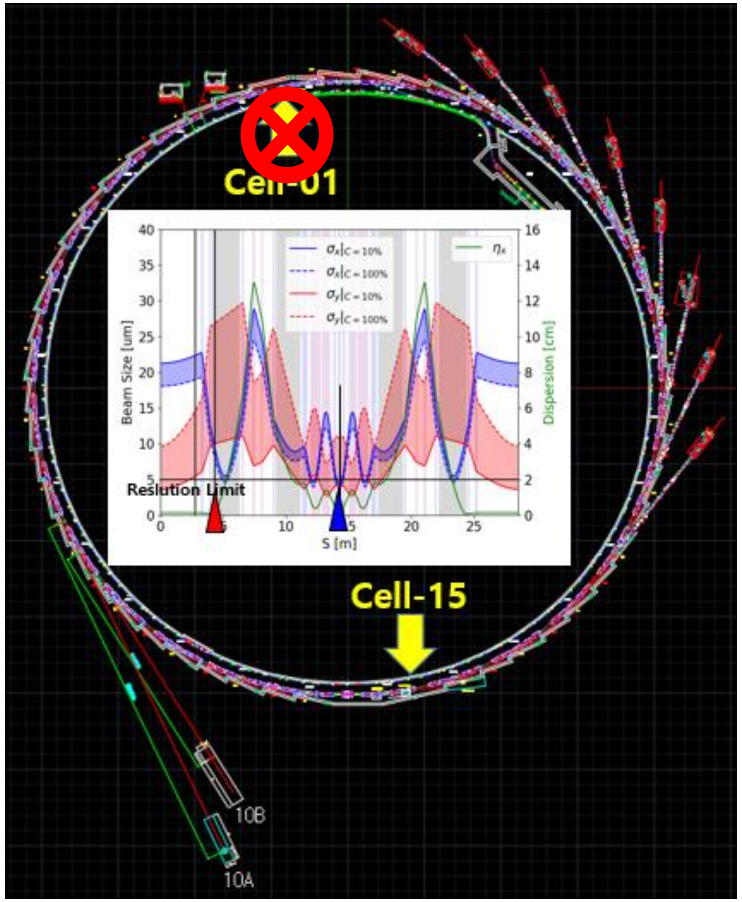
Property	Devices
Beam Position	SR BPM
Current	DCCT for SR
Beam Size & Emittance	Diag. Hutch with Interferometer
Fill pattern & bunch length	Diag. Hutch with streak camera & Online Bunch Length monitor
Beam Loss	Fast & Slow BLM
TFS/LFS	BbB FB system
Tune	BPM+S/A and BbB FB processor
Energy	BM MPS current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



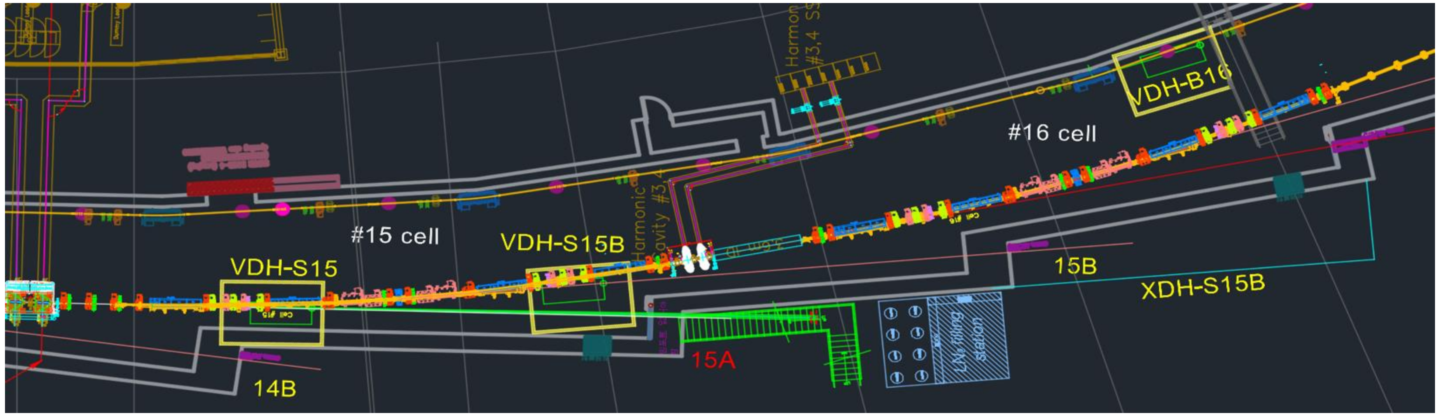
Diagnostic Beamlines

Beam Size, Emittance, Bunch Length, Fill-pattern

- **Beamlines and hutches**
  - Located on the rooftop of the tunnel
  - The number of mirrors will be minimized to reduce wavefront error
    → for accurate beam size & emittance measurement
  - Use of visible light for easy build and maintenance
  - VDH-S1 is removed due to budget of project
- **Light sources**
  - [VDH-S15, VDH-B1] Beam size, emittance, mechanical vibration by using a visible light Interferometer
    - VDH-S15 : Bending magnet (LGB, 0.7 T) : almost dispersion free, right after the long straight section
    - VDH-B1 : Bending magnet (booster synchrotron)
  - [VDH-S15B, VDH-B1] Online bunch length & fill-pattern, longitudinal beam instability by using a fast photo-diode
    - Beam instability by using Streak Camera
    - VDH-S15B : Center-bend (main synchrotron)
    - VDH-B1 : Bending magnet (booster synchrotron), if needed



VDH-S15: source to M1 = 6.5m
VDH-S15B: source to M1 = 9.3m
VDH-B16: source to M1 = 8m



Diagnostic Beamlines

Comparison of diagnostic beamlines

Table 1. Beam parameters at 15A-BEND diagnostic beam port.

	Horizontal	Vertical
Beta function (β) [m]	1.54	17.72
Dispersion (η) [m]	2.62e−4	0
E. Spread (δ) [%]	0.13	
Emittance (ϵ_{rms}) [pm]	59.0	5.90
B Field Strength [T]	0.734	
Beam Size (σ) [μm]	9.53	10.2

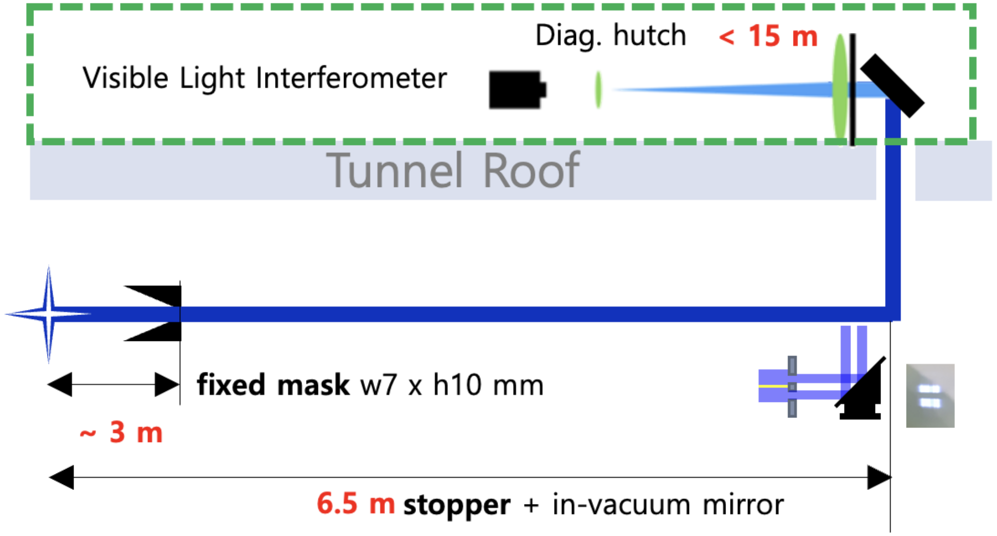
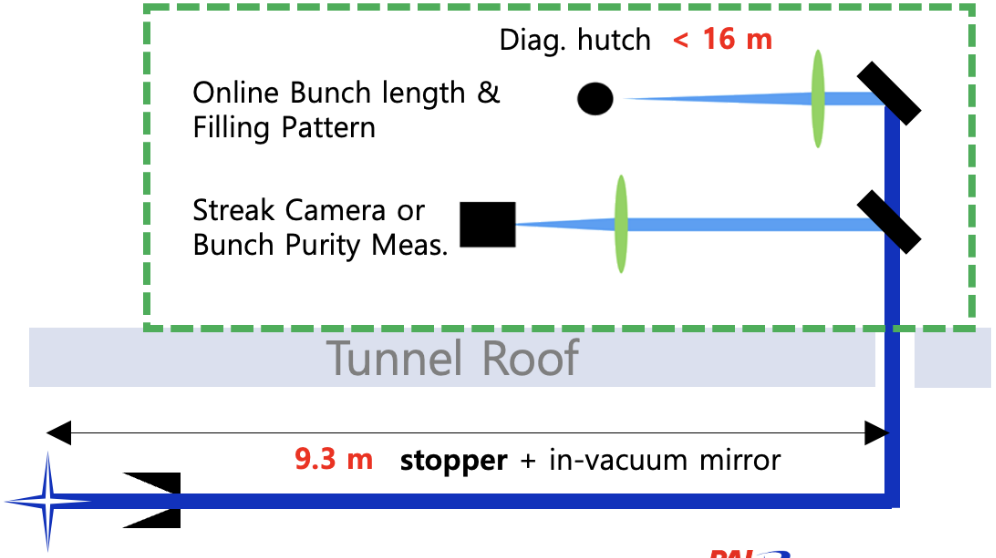


Table 2. Beam parameters at 15B diagnostic beam port.

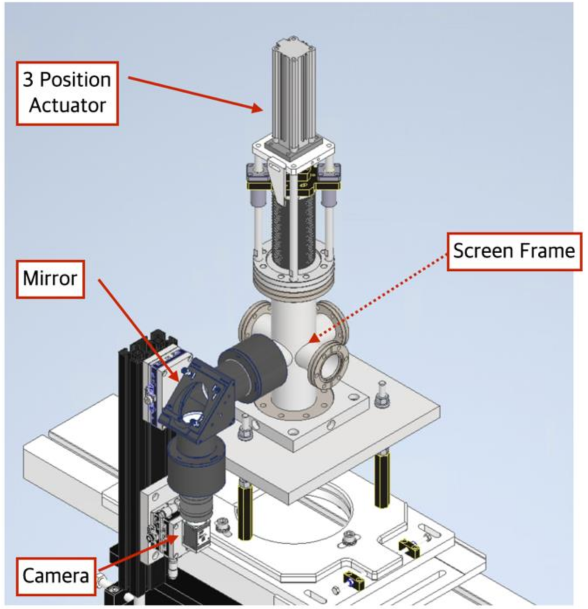
	Horizontal	Vertical
Beta function (β) [m]	0.366	3.435
Dispersion (η) [m]	6.54e−4	0
E. Spread (δ) [%]	0.13	
Emittance (ϵ_{rms}) [pm]	59.0	5.90
B Field Strength [T]	1.994 (0.186 m)	
Beam Size (σ) [μm]	4.7	4.5



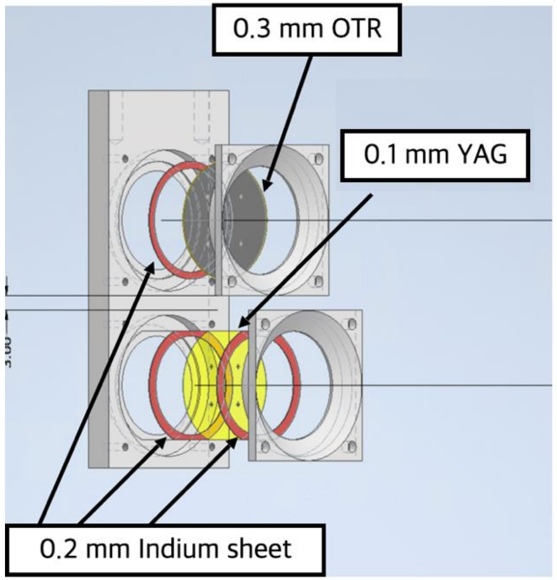
BPRM

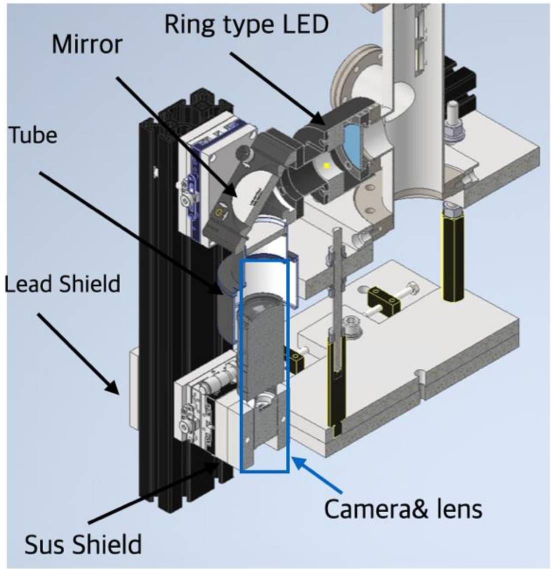
Beam Profile Monitor

- Chamber and mover system are modified
- Beam transverse profile and position
- Emittance, energy spread using Bending, Quadrupole Magnet
- Screen: 25 mm diameter YAG, OTR with 3 position actuator
    - YAG: Low Charge, camera position calibration with LED
    - OTR: High Charge and precise beam profile



	X	Y
Screen Size	21 mm 14.85 mm (Active)	21 mm
Camera # Pixels	1070	1430
Screen Pixel Size	19 µm	14.6 µm
YAG/GAGG size resolution	50 µm: Thickness 7 µm: Point Spread	7 µm: Point Spread
OTR size uncertainty	0~3 µm Flatness	0~3 µm Flatness

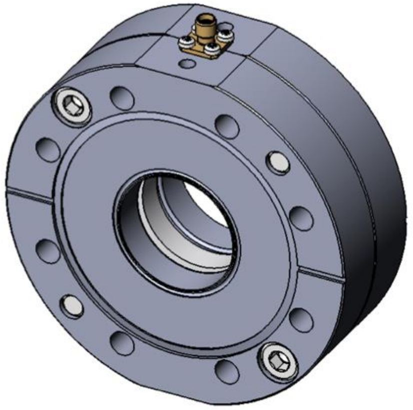




ICT(Pulse Charge), DCCT(Beam Current)

*VFCT in Storage ring is still under consideration.

ICT



Bergoz, ICT In-Flange model

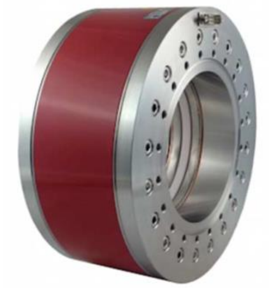
Total Pulse Charge measurement at LINAC, LTB, BTS

ICT, In Flange model, Bergoz, ICT-CF4"1/2-38-40-UHV-070-5.0-LD

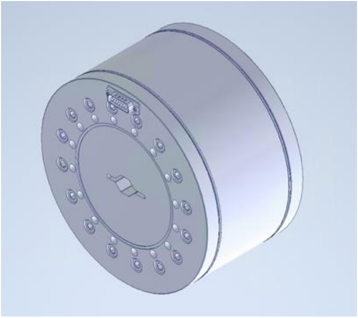
- Up to 40 nC, 2 pC resolution for 4nC range Operation
- Low Droop: ~ 4%/200 ns for Multi-bunch mode
  - Droop Calibration or Correction Required
  - Multi Bunch: 6~8 ps, 30 pC/Bunch, 102 bunches

DCCT (Bergoz, NPCT)

- Booster & Storage Ring
- **Wake impedance study to determine chamber type**
  - Bergoz, In-flange model
  - Own chamber Design with in-air model



Bergoz, NPCT



Customized DCCT for 4GSR

- Up to 20 A, Resolution ~ 3 μA
- 6 inches CF Flange, 120 mm length
- Customized ID, 0.3 mm Gap
- Baking temp. < 100 ℃

→ special care for baking