Beam Dynamics simulations for Korea-4GSR

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Outline of the Korea-4GSR project

4GSR Outline

❖ **Multipurpose Synchrotron Radiation Construction Project**

- Period: 2021 July to 2027 June (6yrs)
- Budget: 1.0454 Trillion KRW (≈ USD 750M)
- Land: 540,000 m^2 / Building: 69,400 m^2
- 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

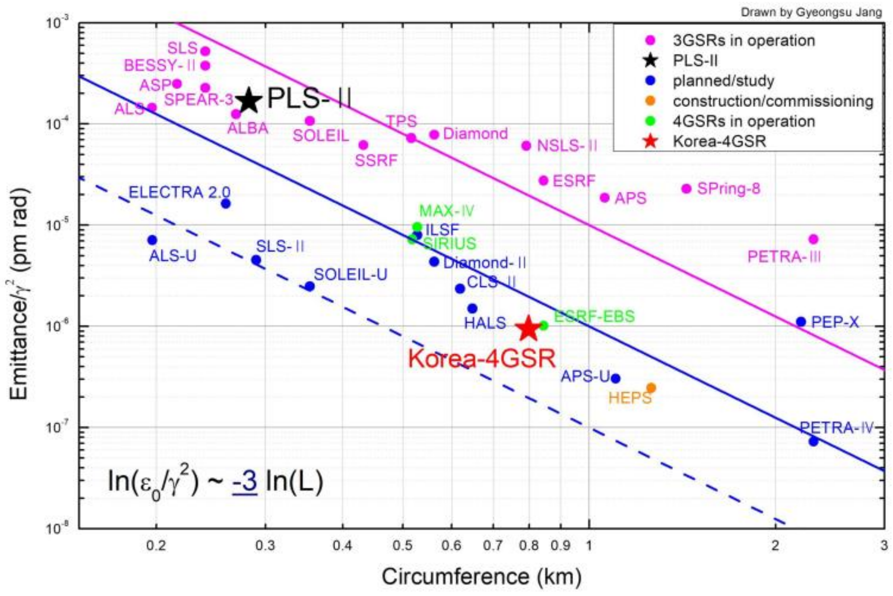
Specifications

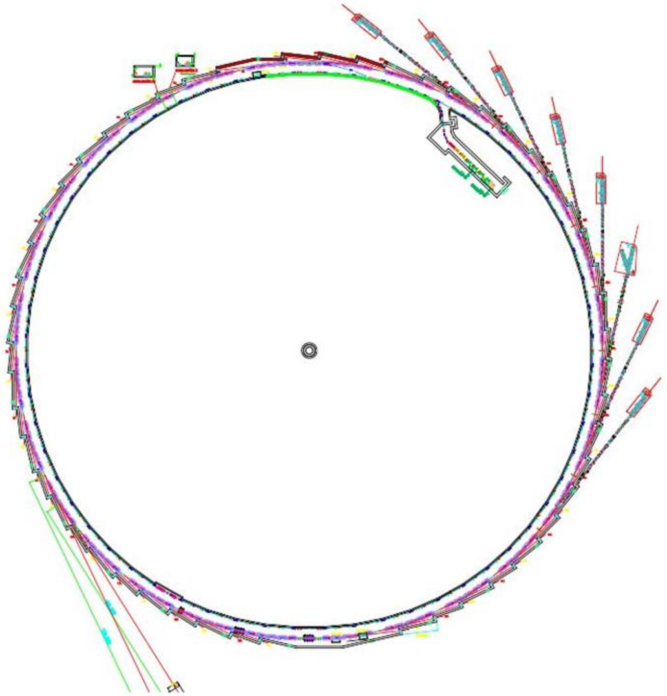
- Beam Energy: 4 GeV
- Beam Emittance: less than 100 pm·rad (CDR: 58 pm·rad)
- Circumference: 800m
- Beamlines : more than 40
- Accelerator: Gun, Injector LINAC, 4 GeV Booster
- Lattice: MBA-7 Bend Achromat

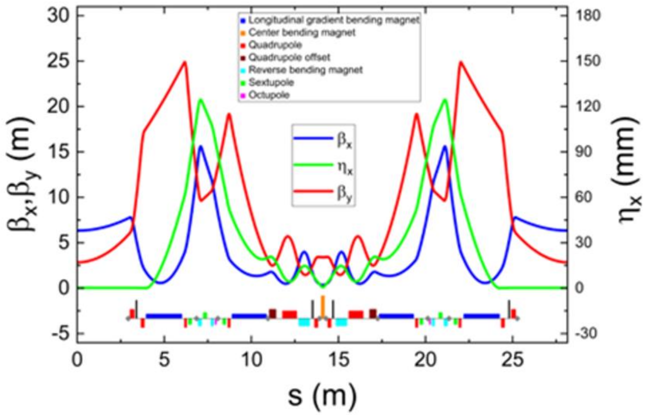
❖ **2 Institutions working together**

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

Storage ring lattice parameters



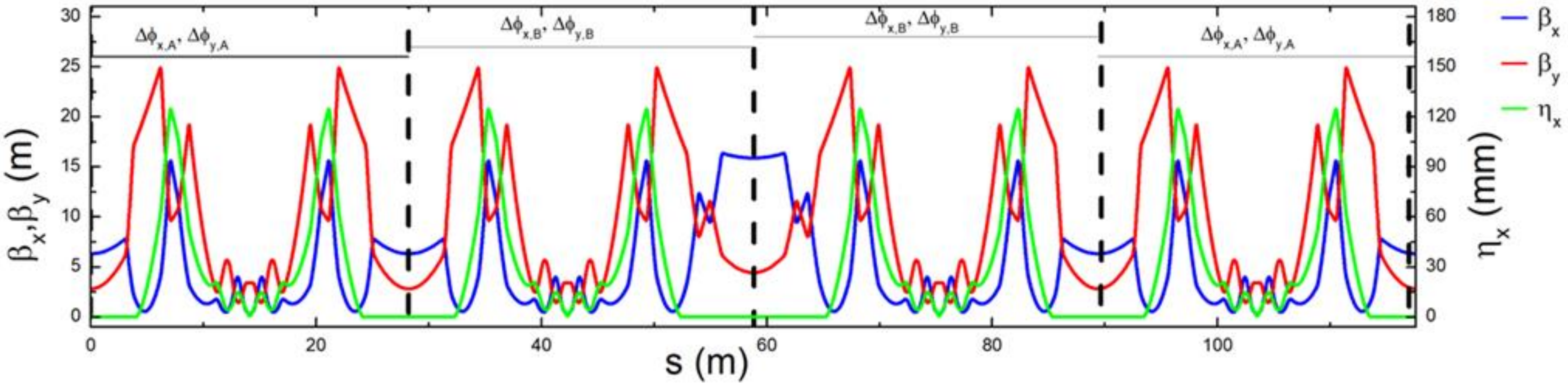




- The ring is composed of 28 cells
(28 identical arcs, 26 ID SS + 2 high-beta SS)
- It has 2-fold geometric symmetry

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**
Beam current (mA)	**400**
Bunch length (σ_z) (mm) (w/o HC, w/ HC)	**3.66 / 14.66**

Linear optics



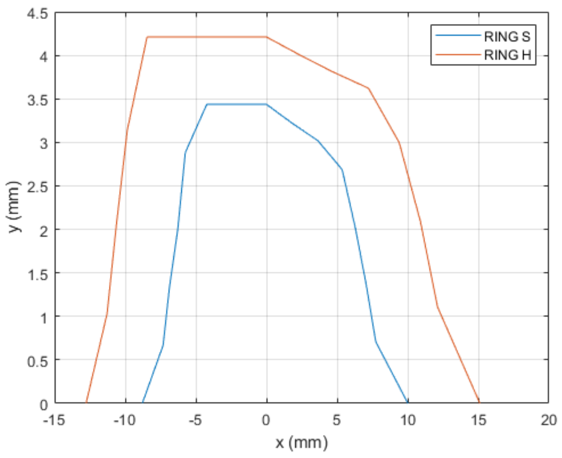
Beta functions at the center of ID SS:
(β_x, β_y) = (6.33 m, 2.84 m)

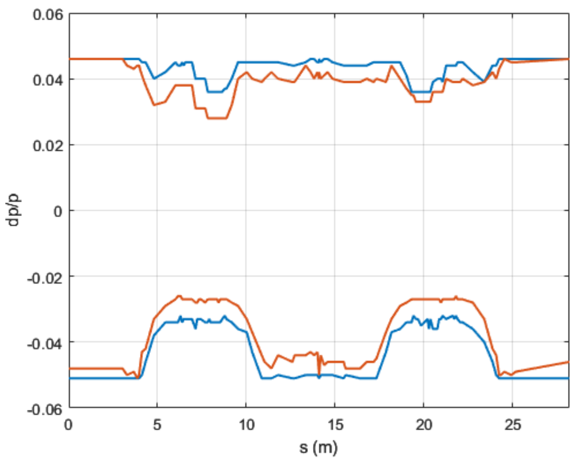
Beta functions at the center of High-beta SS:
(β_x, β_y) = (15.90 m, 4.45 m)

- The ring is composed of 28 H7BA cells (28 identical arcs, 26 ID SS + 2 high-beta SS)
- Phase advance is matched ($\Delta\phi_{x,A}$ = $\Delta\phi_{x,B}$ and $\Delta\phi_{y,A}$ = $\Delta\phi_{y,B}$)
- Though the ring has 2-fold geometric symmetry, it has 28-cell symmetry in terms of on-momentum phase advance
- One high-beta straight is dedicated for off-axis injection

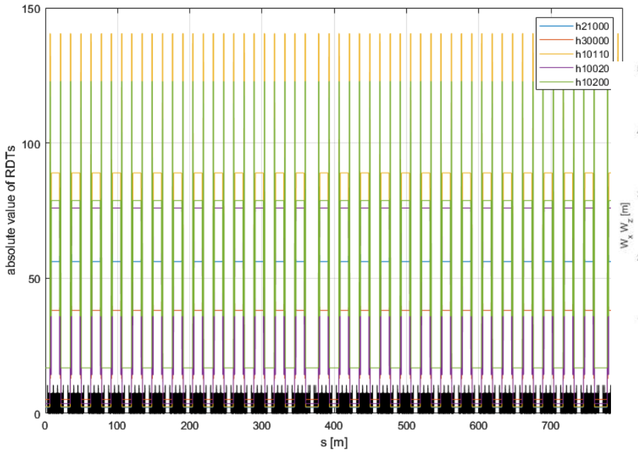
Impact of high-beta straights

RING_S : Ring with full periodic 28-cell (no high-beta straight)
RING_H : Ring with 26 ID straights + 2 high-beta straights
(28 identical arcs)

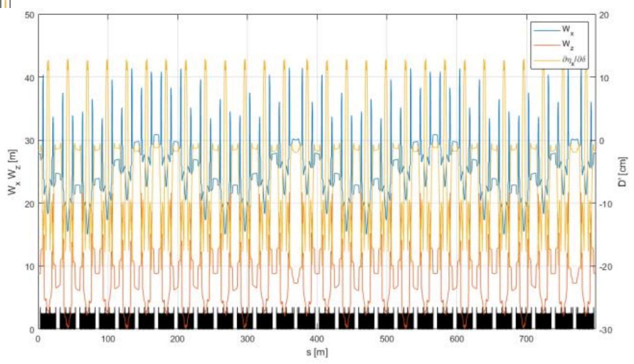




atplot(THERING,@plotRDT)



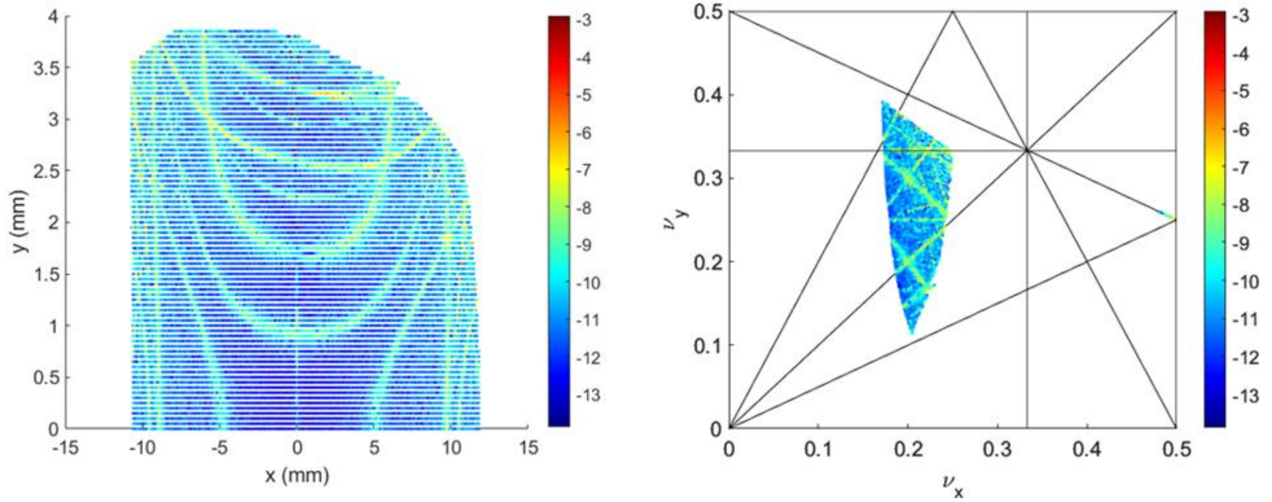
atplot(THERING,@plotWdispP)



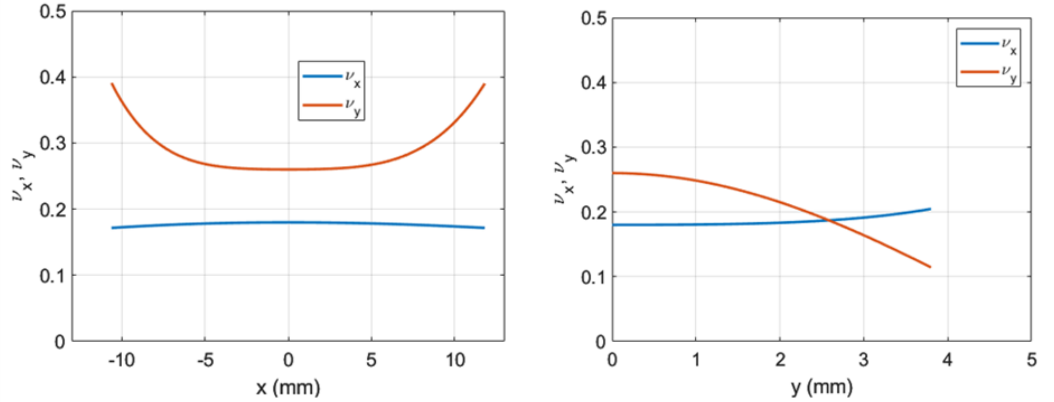
- RING_H has larger DA as much as ~ 1.45
- RING_H has smaller MA which result in 27% decrease of Touschek lifetime

- The psedo-symmetry keeps symmetry of RDTs over the ring
- W-function is not fully periodic since chromaticities of high-beta cells are not exactly matched

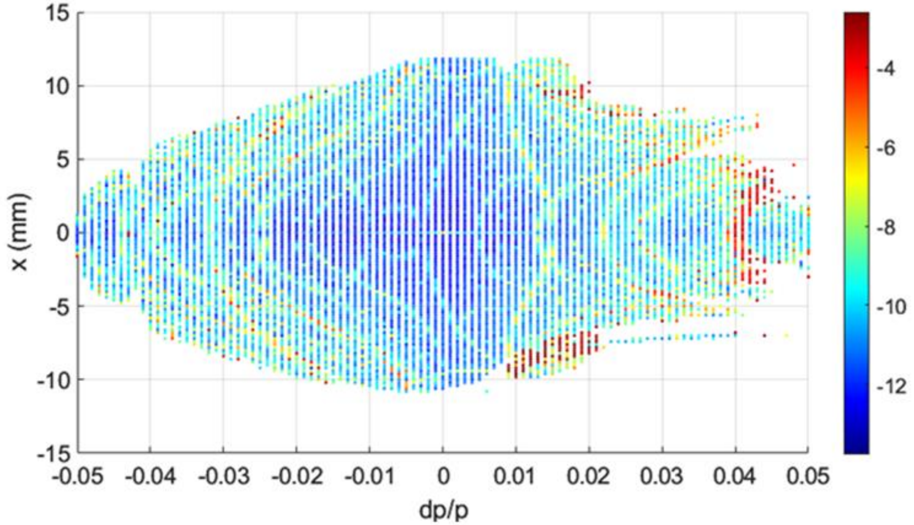
Frequency map and detunings



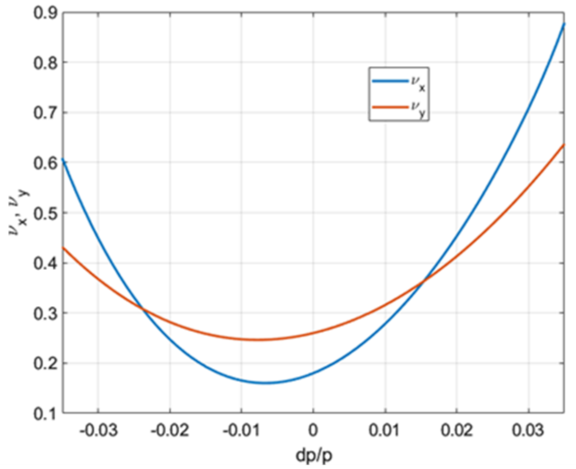
FMA with x-y offset



Amplitude dependent tune shifts (ADTS)



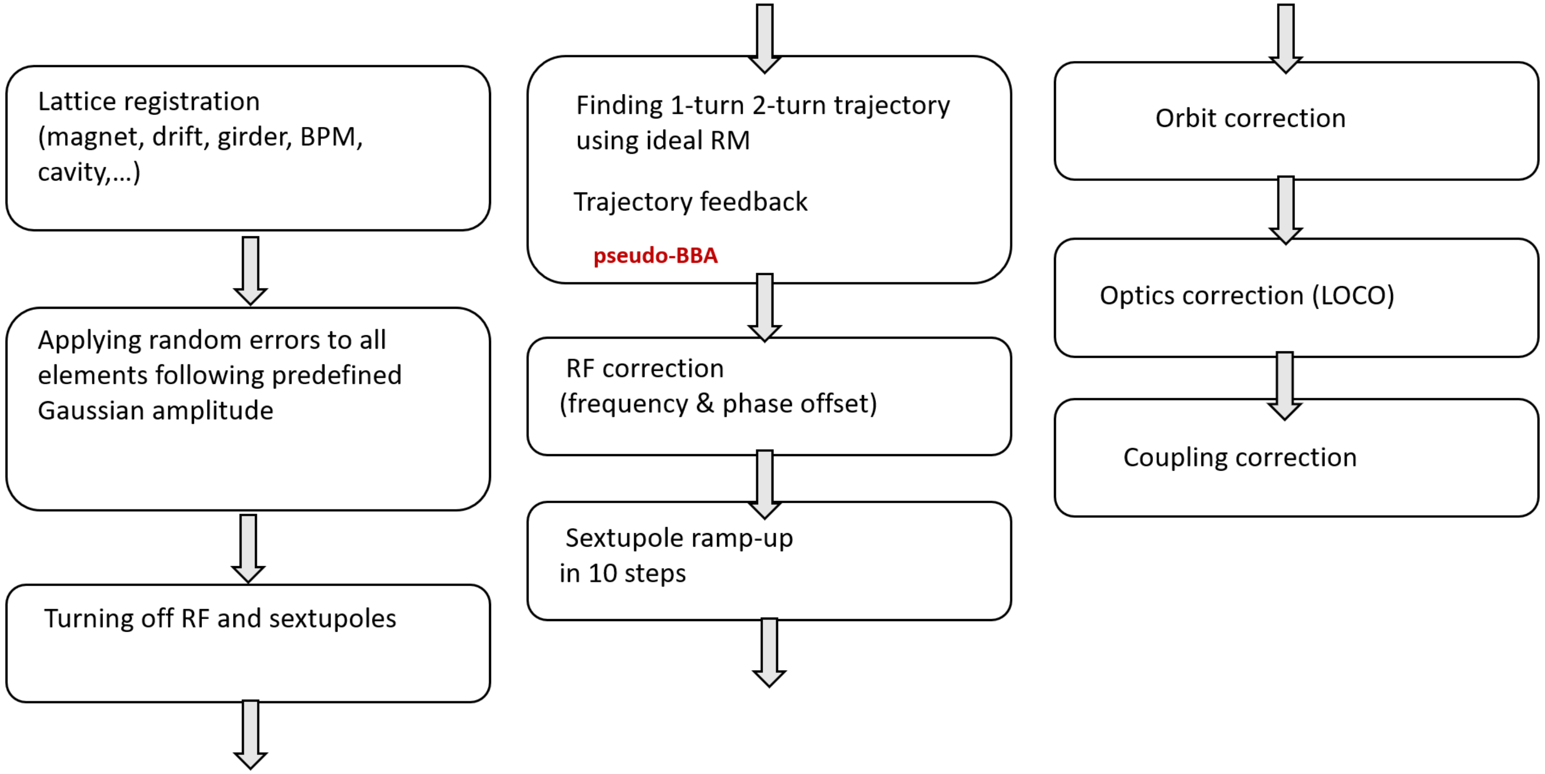
FMA with x-dp/p offset



Momentum dependent tune shifts (MDTS)

Commissioning simulation

Correction chain



- Existence of closed orbit and beam transmission need to be checked at each step

In the simulation,

-Existence of 1-turn trajectory means that 1 turn transmission is achieved

-Existence of closed orbit means that a fixed point x exists such that $x = Mx$ *where* M *is one turn map*
(AT function 'findorbit6' is used)

Toolkit for Simulated Commissioning (SC)

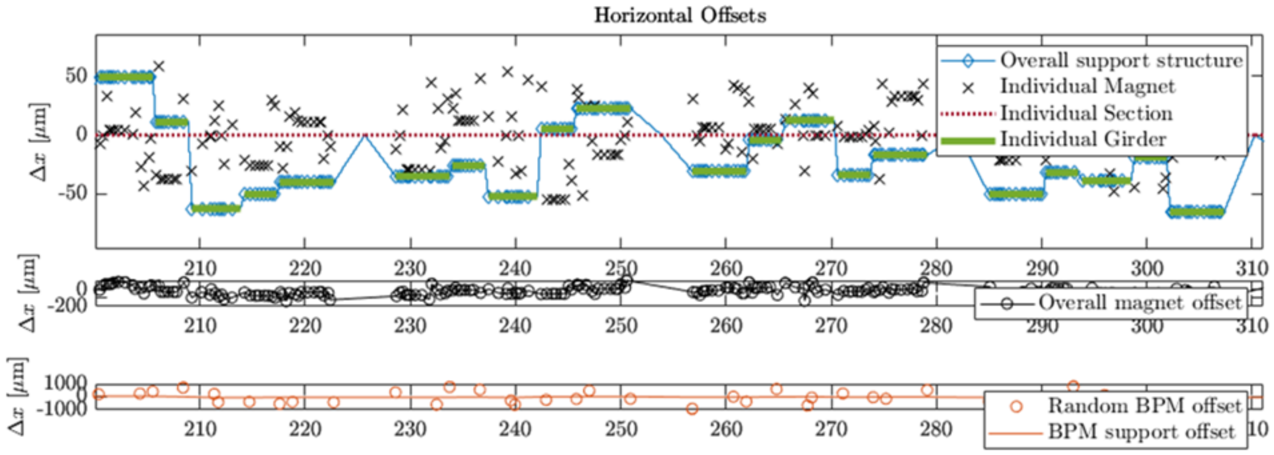
https://sc.lbl.gov/

Lattice ensemble of 50 random error seeds is generated after applying the correction chain to each error seed

Error tolerances for commissioning simulation

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	50 / 50 / 100	400 / - / -	

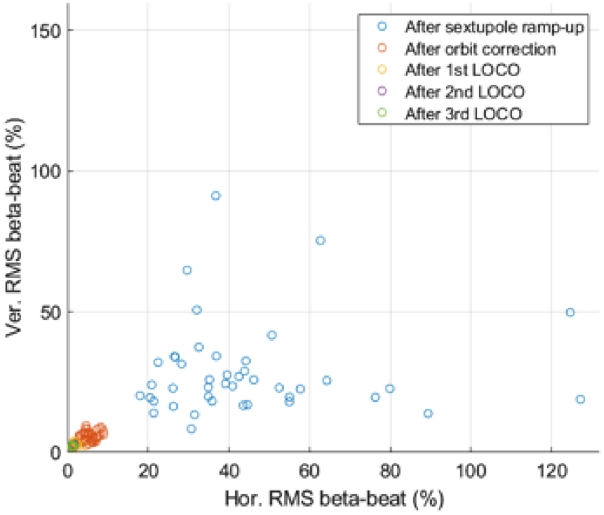
Error tolerance of Korea-4GSR magnet elements (rms value, 2-sigma cutoff is used for commissioning simulations)



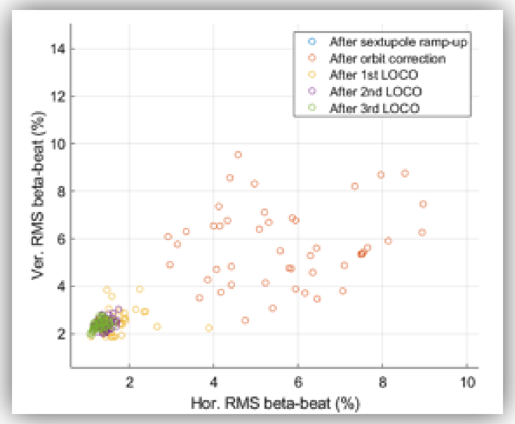
Example of horizontal offset distribution over reference orbit

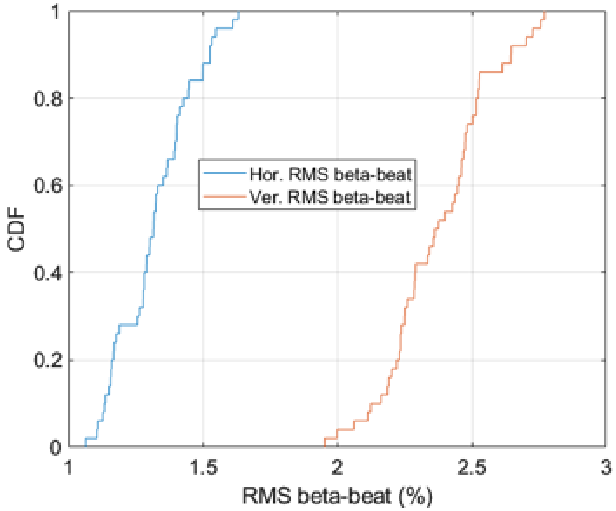
* Overall magnet offset is sum of girder offset and individual magnets mounted on the girder

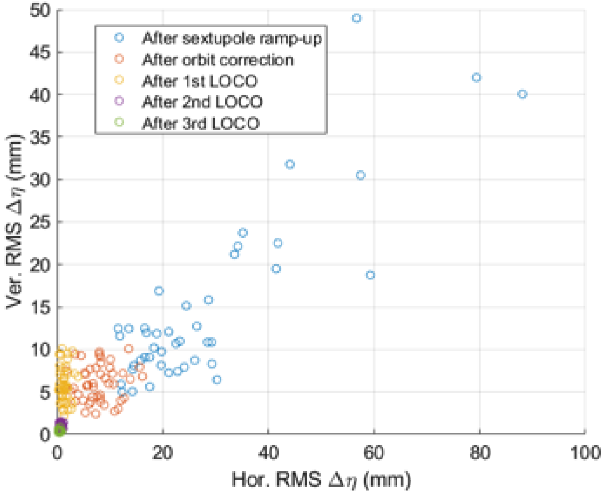
Result of commissioning simulation: beta-beat



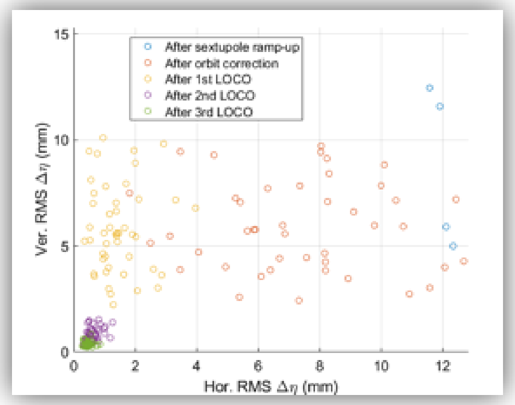
zoomed in

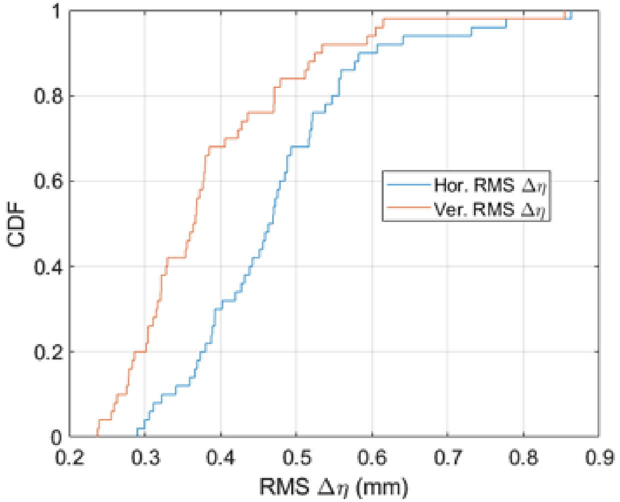






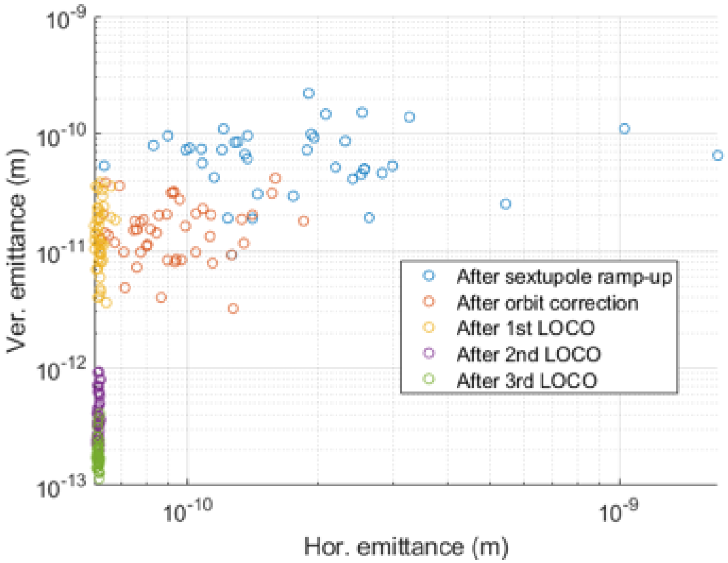
zoomed in



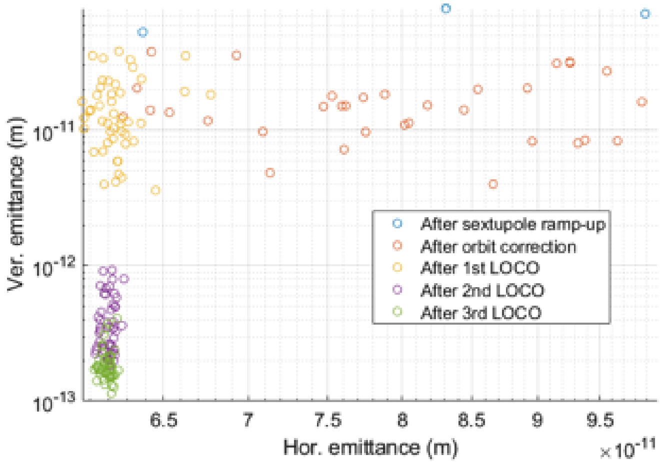


Improvement of beta-beat and dispersion-beat over each correction step

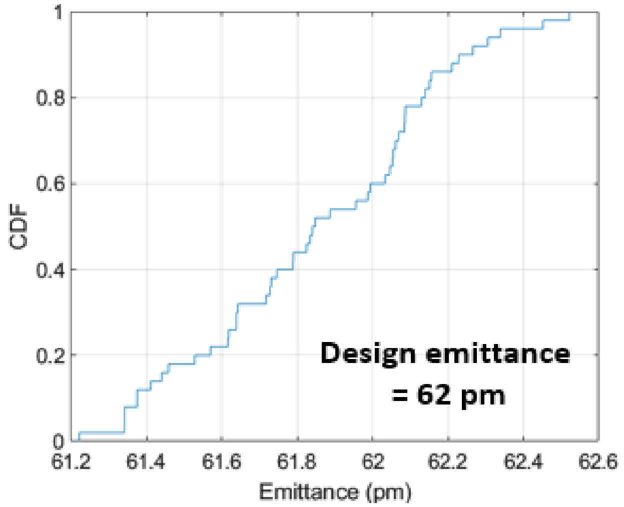
Result of commissioning simulation: equilibrium emittance



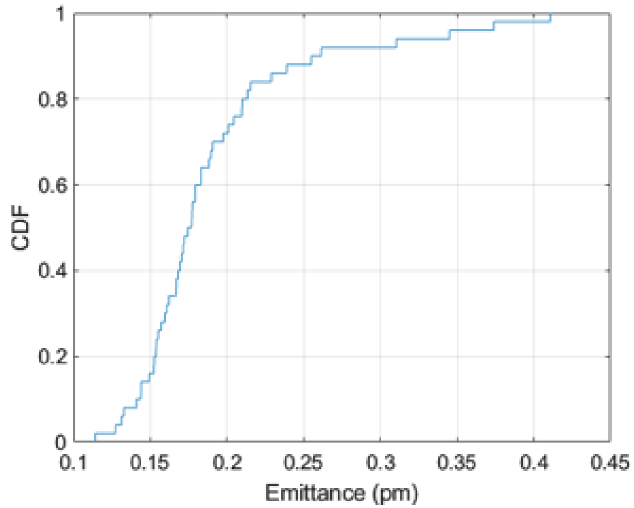
zoomed in



Improvement of hor/ver emittance over each correction step



CDF of horizontal emittance after 3rd LOCO

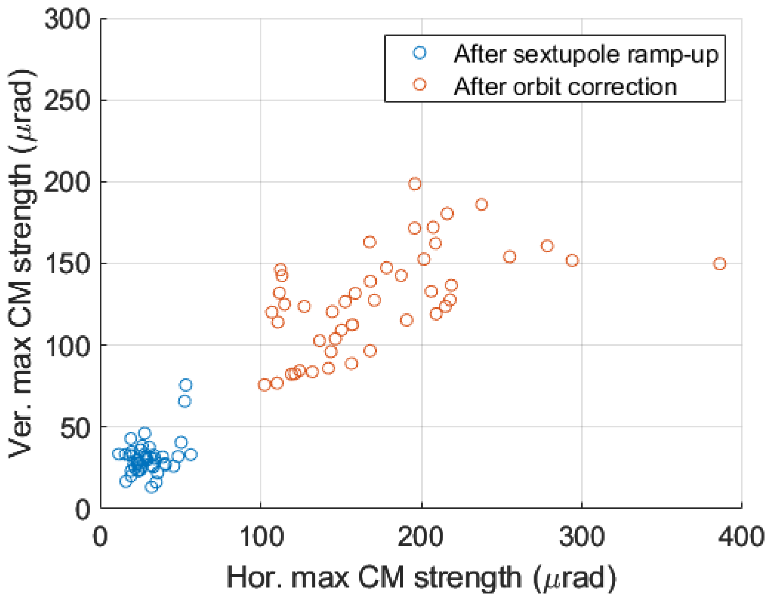


CDF of vertical emittance after 3rd LOCO

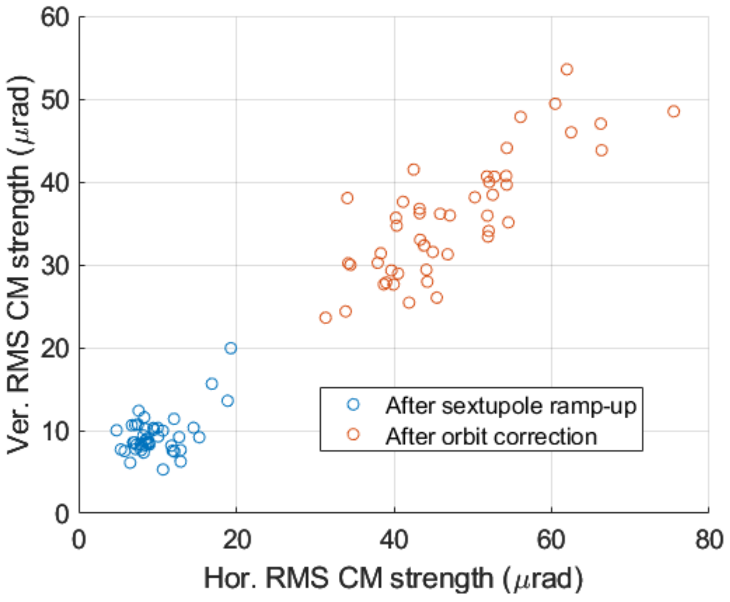
Design emittance is achieved after the end of correction chain

Result of commissioning simulation: corrector strength

- In AT, there are two ways to apply horizontal kick; 'Kick angle' or 'PolynomA'.
- Kick angle is simply kick angle in rad, but PolynomA is kick angle per unit length.
  'PolynomA'*(corrector length) = -'Kick angle'



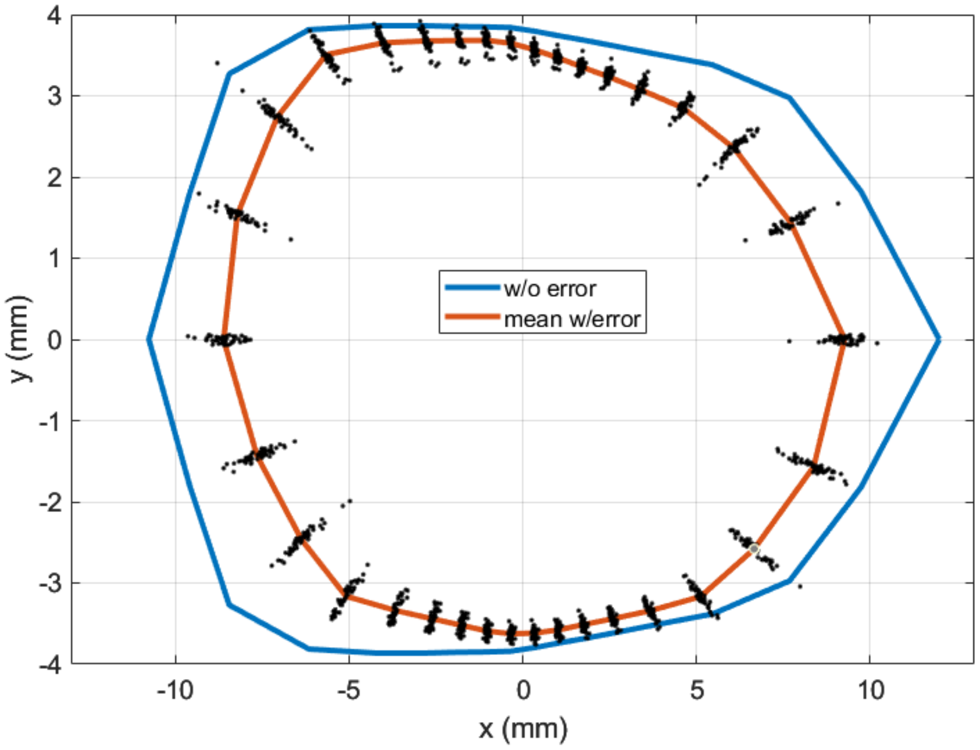
Max corrector strength



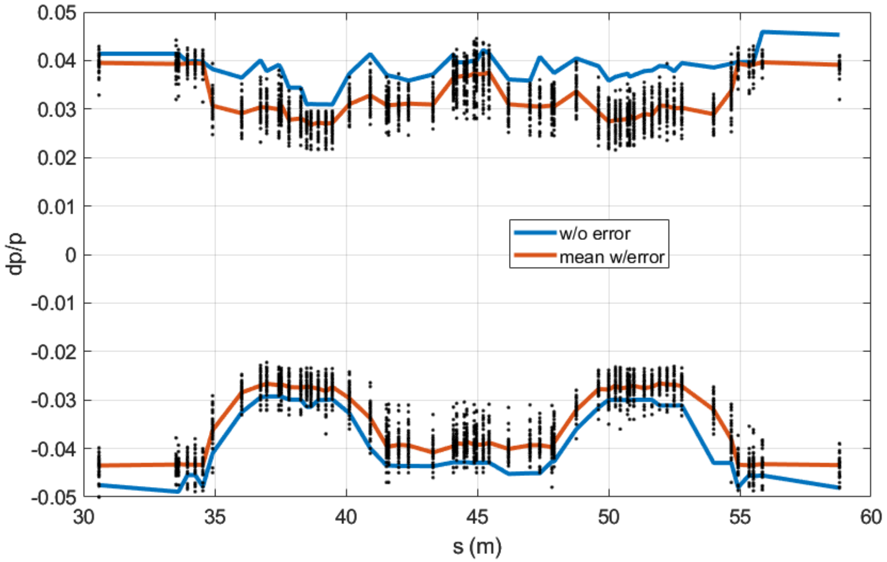
RMS corrector strength

Corrector strengths after orbit correction are below mechanical limit (600 μrad)

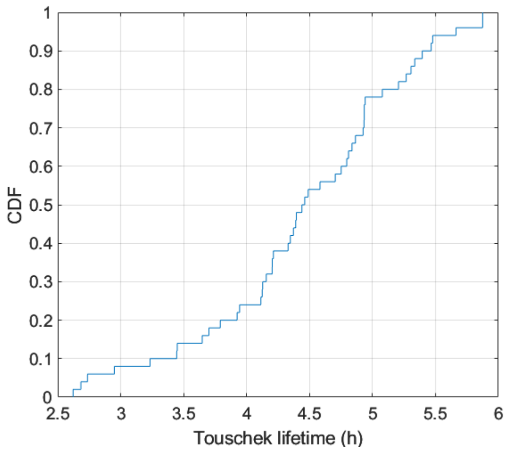
Result of commissioning simulation : dynamic aperture and momentum aperture



Dynamic aperture



Momentum aperture



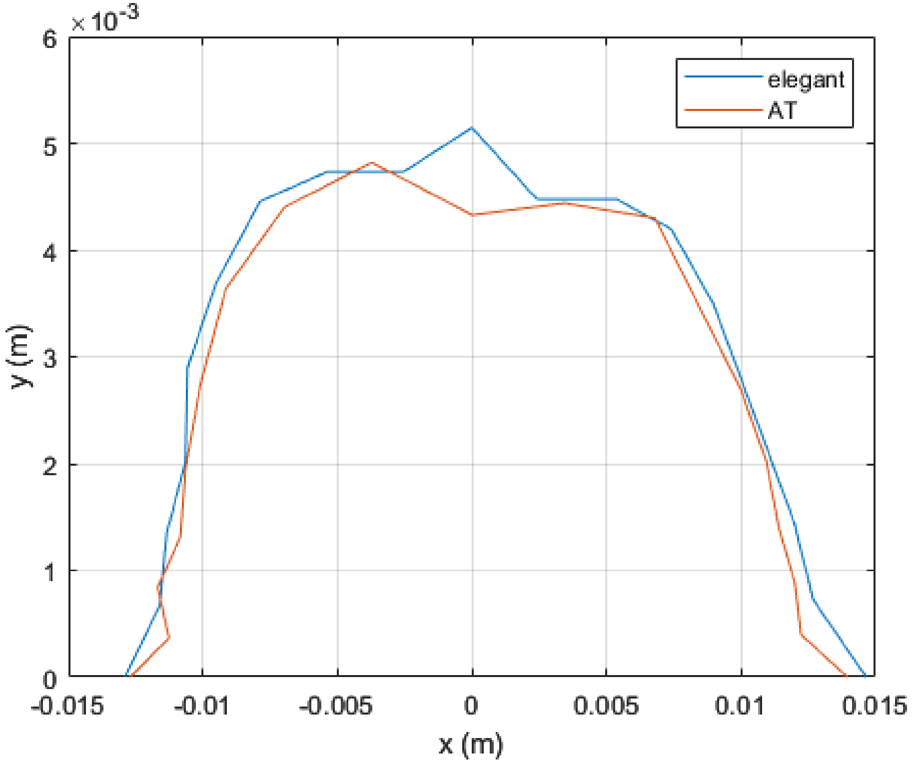
Touschek lifetime w/o error : 7.18 h

Physical aperture limit for all elements (m) (EAper):
x = [-0.012 0.012]
y = [-0.009 0.009]

Charge set:
- a single bunch of 1 nC (or 0.375 mA)
- 400 mA = 1067×0.375 mA

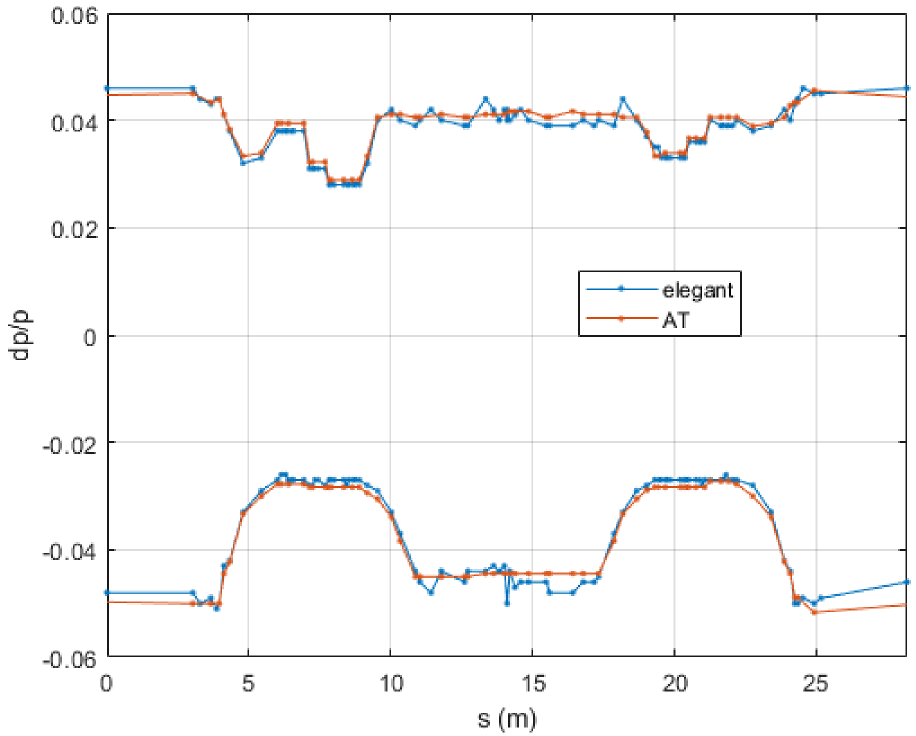
Coupling ratio (emity/emitx) = 0.10

Comparison of elegant and AT



Dynamic aperture

- -Tracking for 2048 turns
- -RF-on/RAD-on/QE-off
- -Physical aperture not included



x0 = 1e-5 m
y0 = 1e-5 m

Momentum aperture

- -Tracking for 2048 turns
- -RF-on/RAD-on/QE-off
- -Physical aperture not included

Summary

- Korea-4GSR is a greenfield storage ring of 4 GeV – 800 m – 62 pm emittance
- The H7BA ring has 2 high-beta straights for off-axis injection
- Pseudo-symmetry is met between a normal cell and a high-beta cell
- The design study and error study has been conducting mainly using AT and SC
- Realistic correction chain including orbit correction, LOCO and coupling correction is simulated and error lattice ensemble is obtained
- Ring performances based on the error lattice ensemble looks promising (beta-beat, natural emittance, dynamic aperture, Touschek lifetime)