Injection

T. Yoshimoto

on behalf of
LINAC beam analysis group, Beam Injection Task Force (BITF), and Injection Commissioning Group (ICG)

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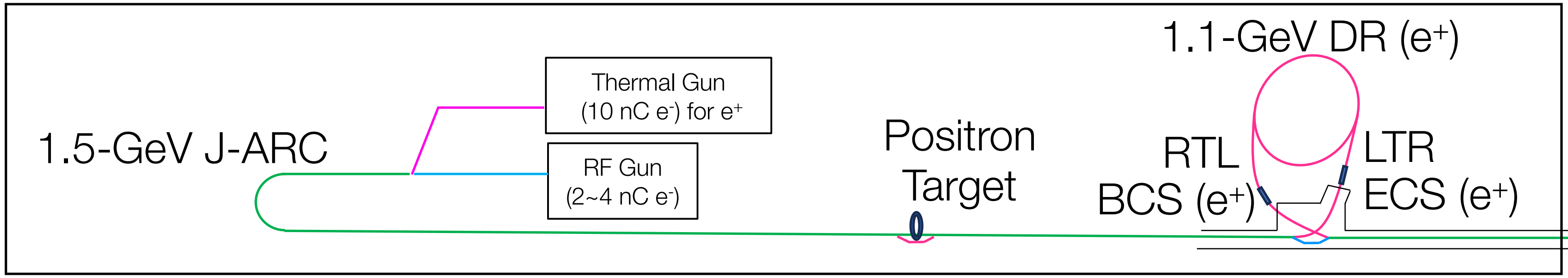
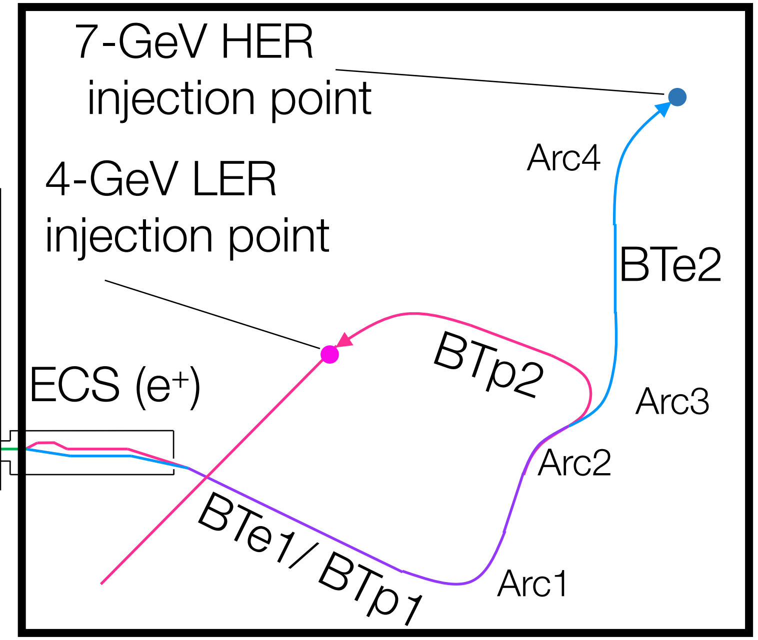
Injector Complex Overview



7-GeV e- & 4-GeV e+ Beam Transports (BT)



DR: positron Damping Ring
LTR: Linac-To-DR Beam Transport
RTL: DR-To-Linac Beam Transport
ECS/BCS: Energy/Bunch Compression System
BT: Beam Transport line
LER/HER: Low/High Energy Ring for e+/e-

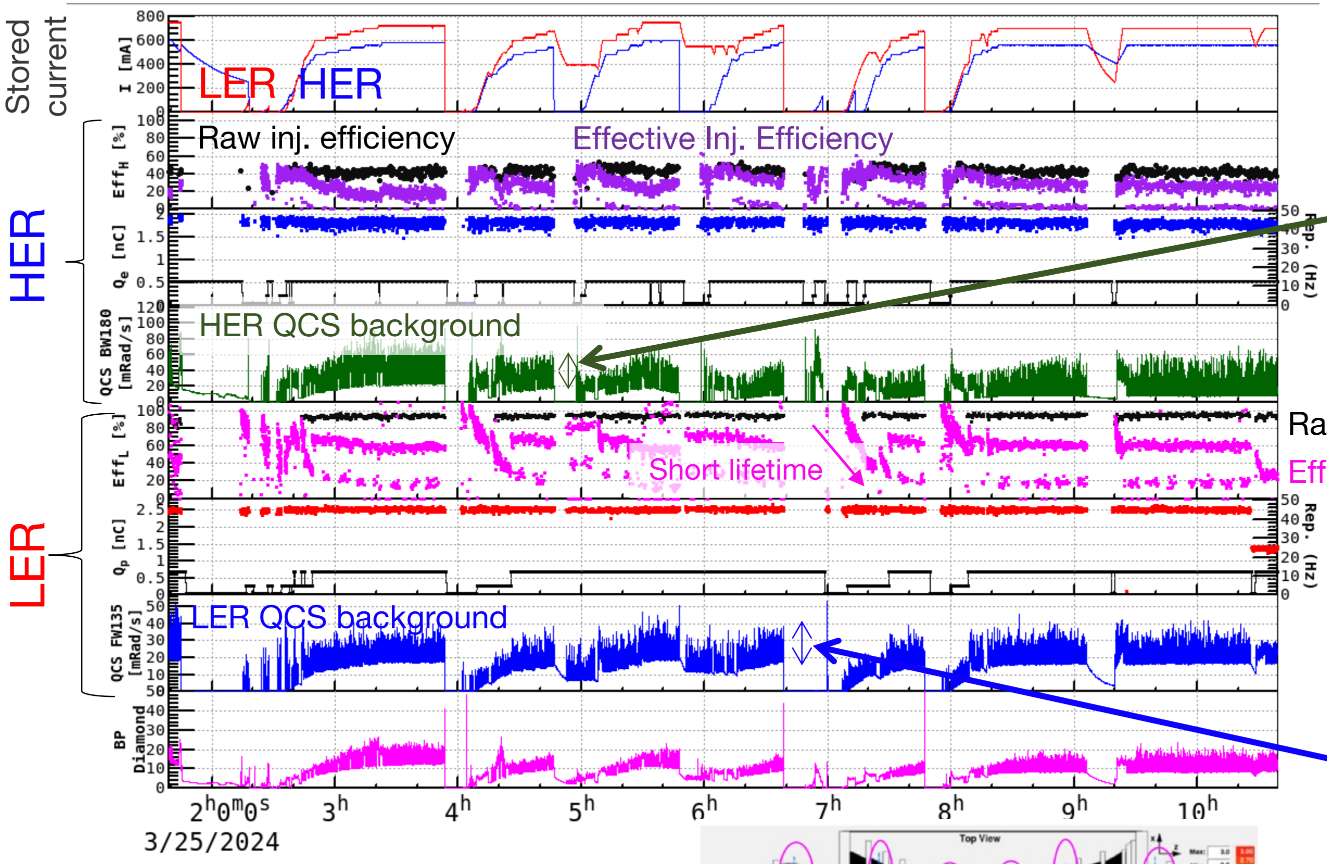
- **How to achieve these parameters toward higher luminosity?**
- **Emittance blowups in BTe/p are currently one of the bottlenecks.**

Injector beam parameters (design)*:

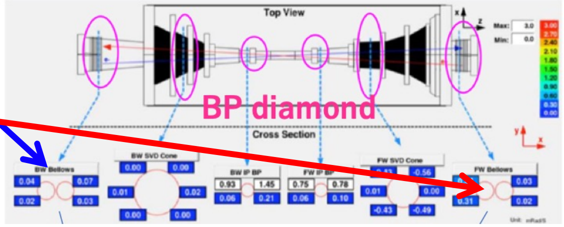
Beam	Positron	Electron	
Beam energy	4.0	7.007	GeV
Normalized emittance $\gamma\varepsilon_{x/y}$	100/15	40/20	μm
Energy spread	0.16	0.07	%
Bunch charge	4	4	nC
No. of bunches/pulse	2	2	
Repetition rate	50		Hz

* H. Akai, et al., https://arxiv.org/pdf/1809.01958.pdf

Short-term Injection Status (β_y^* = 1 mm)



HER: QCS (Diamond) BW135
LER: QCS (Diamond) FW135



Most sensitive to the Background (BG) on Belle2.

HER

- Raw injection efficiency : 20~40%
- Effective injection efficiency : ~20%.
- Large injection background

Measures:
1) two-bunch injection, 2) higher bunch charge, 3) higher rep. rate, 4) low-emittance injected beams, …

LER

- Raw injection efficiency : ~ 90%
- Effective injection efficiency : 10~90% (shorter lifetime at high currents)
- Large injection background

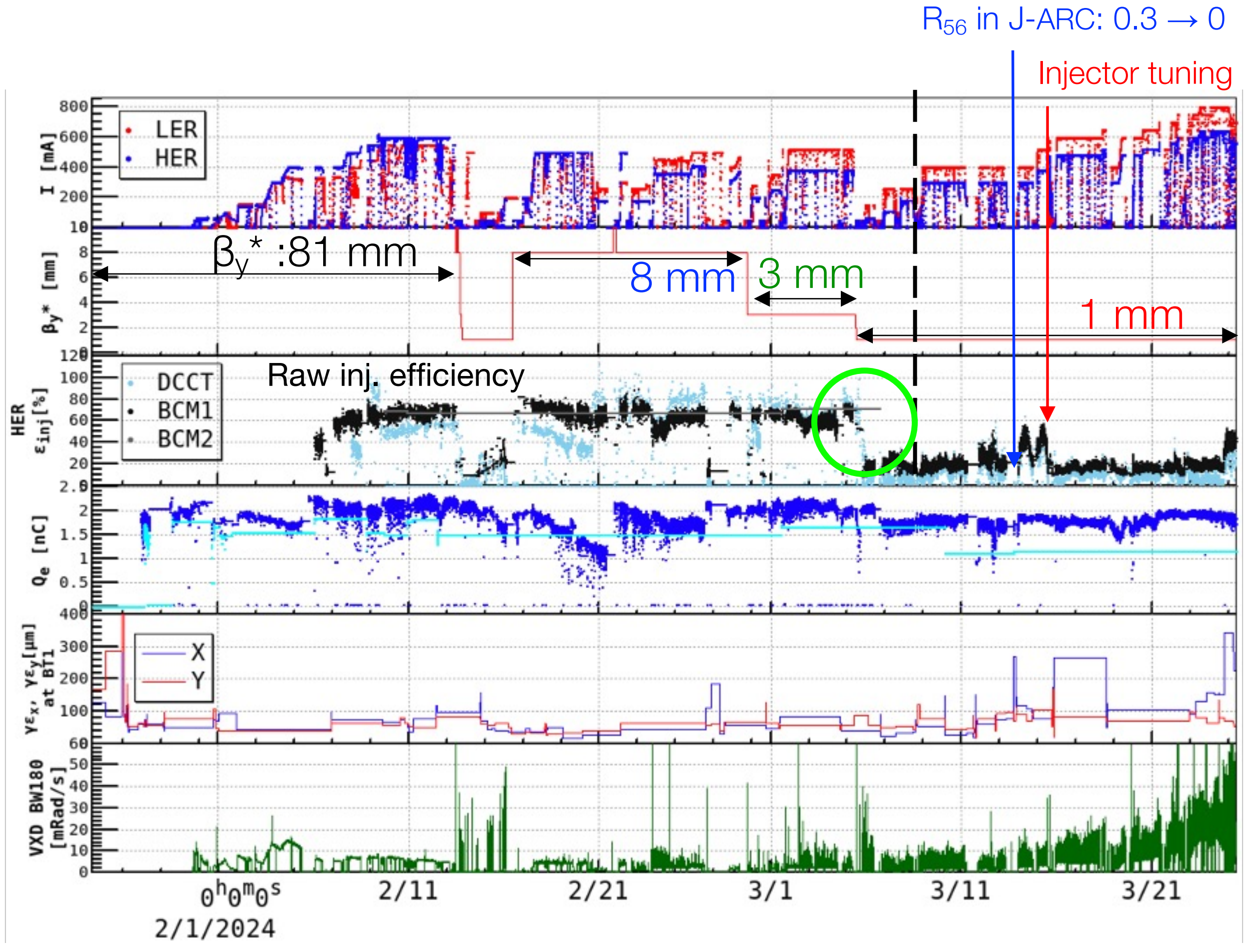
Measures:
1) two-bunch injection, 2) higher bunch charge, 3) higher rep. rate, 4) large dynamic aperture, …

Injected beam quality and stability are the key toward high current operation => 1) higher injection efficiency, 2) lower background, 3) fewer injection related aborts => relaxed collimator setting => lower impedance, …

Injection Stability (Feb. 1~ Mar. 21, 2024)

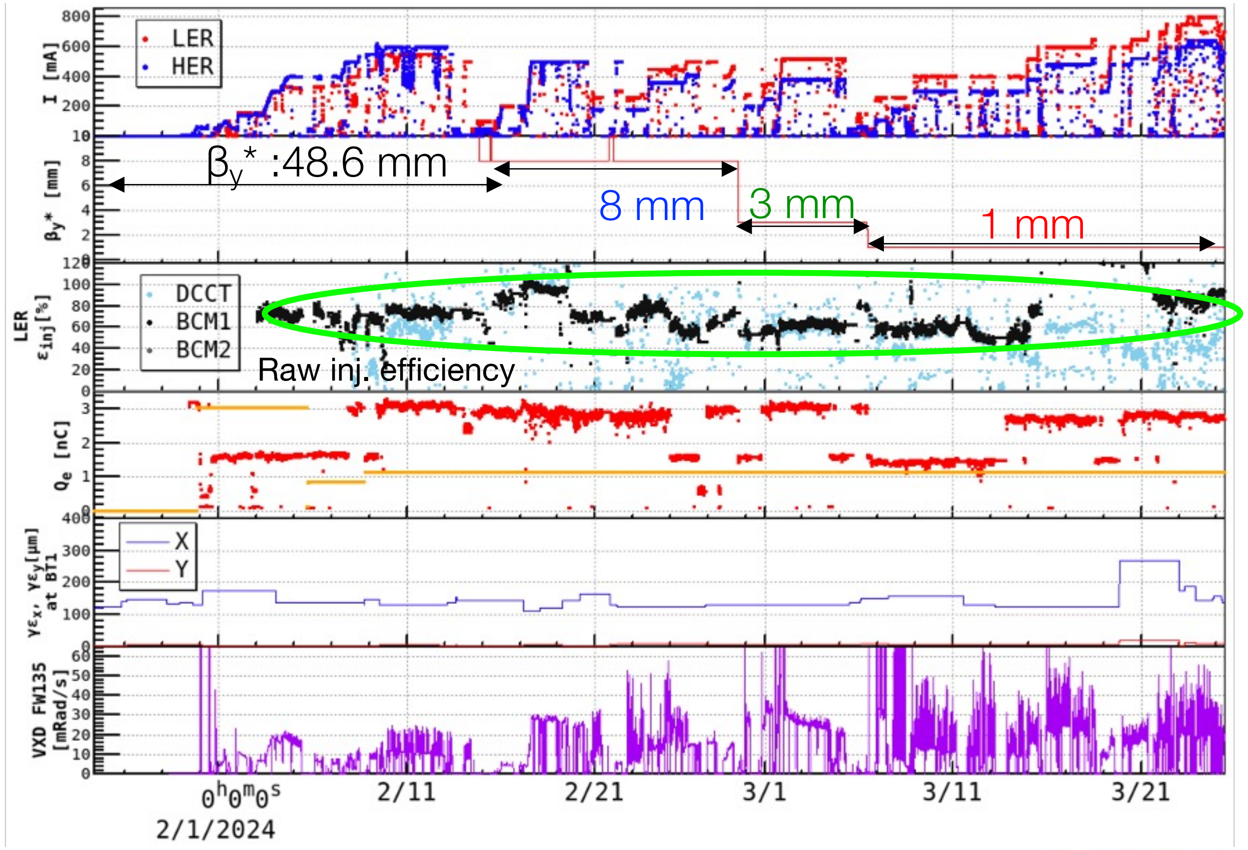
HER

- After β_y^* = 1 mm, poor raw beam injection efficiency: 60% → 20%
- Low stability of raw beam injection efficiency

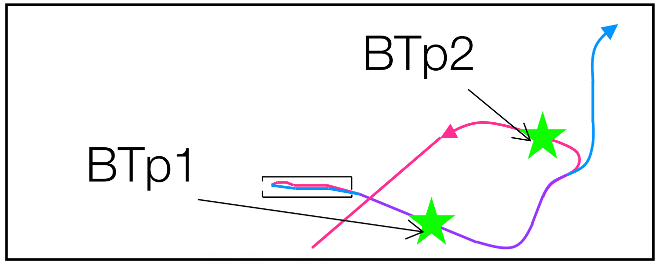


LER

- Low stability of raw beam injection efficiency: 60 ~ 90%.

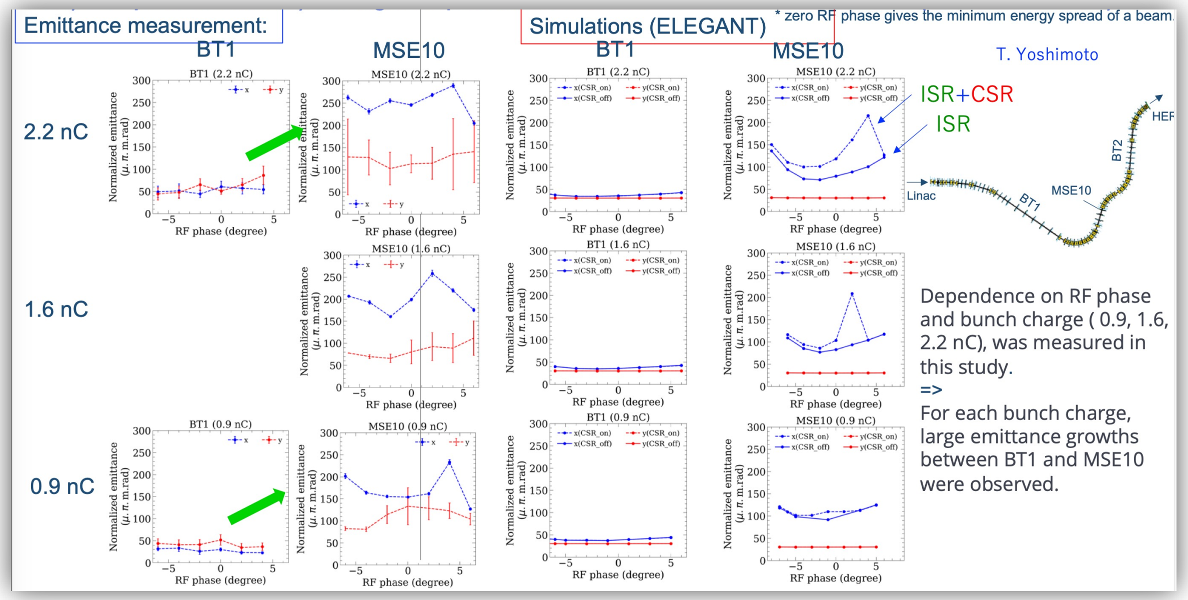


BT Beam Emittance Issues

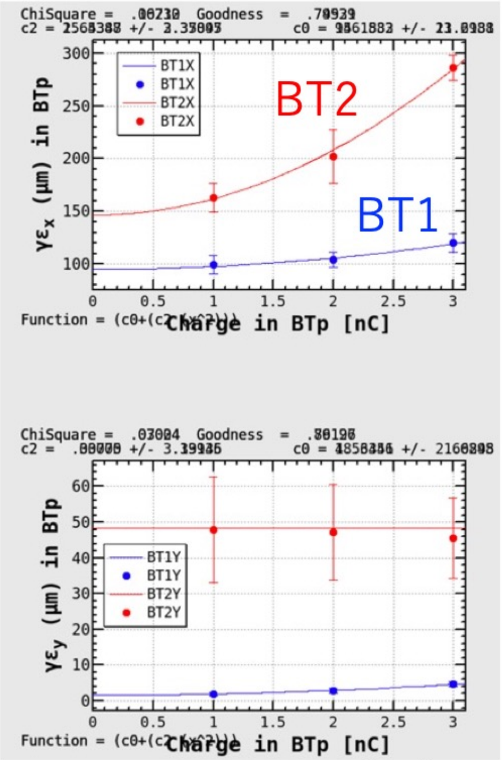


HER

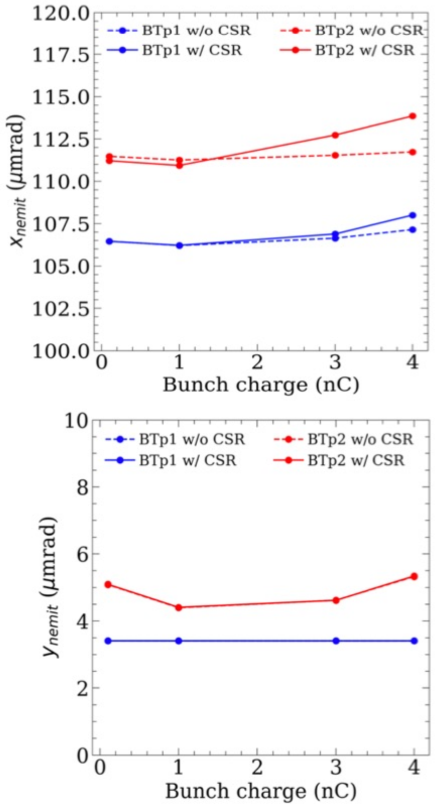
Previous MAC in 2022. 12



Measurement



T. Yoshimoto
Simulation[1,2]



- Primary sources of horizontal emittance blowup in BTe[1]:
  1) **ISR (incoherent synchrotron radiation): +~30 μm**
  2) **CSR (coherent synchrotron radiation): +~60 μm (2 nC)**
- Vertical emittance blowup remains unaddressed. (3D-CSR?)

1) https://www-kekb.kek.jp/MAC/2022/Report/Iida.pdf

LER **As of 2022, we did not know emittance blowup sources in LER-BT.**

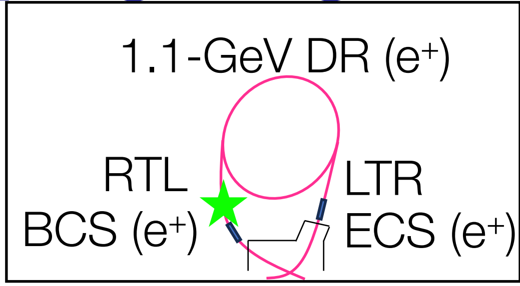
- Nominal particle tracking simulations (SAD, ELEGANT) after DR show negligible ISR and CSR effects.
- Measured results showed large bunch-charge dependent emittance growths.

Does a longitudinal spiky bunch profile cause unidentified CSR effect?

We should check it!

Positron Beam Studies

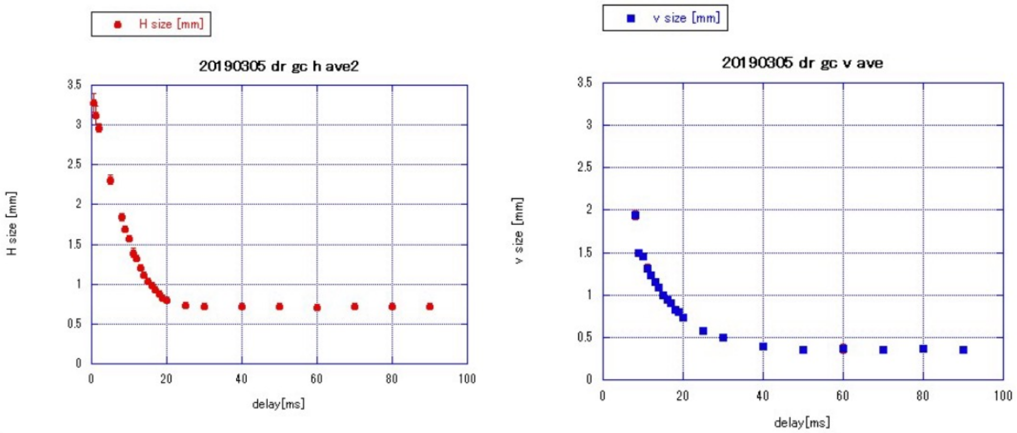
1.1-GeV Positron Beam Emittances in RTL After Damping Ring



Beam size measurement with a DR-SR monitor

measured by H. Ikeda

2019/3/5

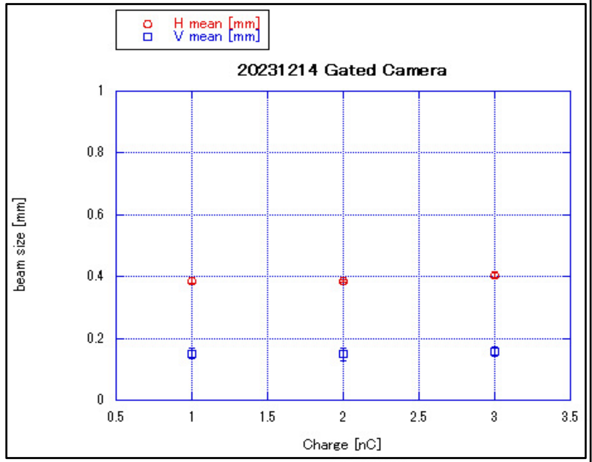


2023/12/14 測定

- 入射後90ms
- 電荷：3nC, 2nC, 1nC

σx~0.4mm

σy~0.15mm



$\beta_x = 3.4$ m

$\eta_x = -25$ mm

$\sigma_x \sim 0.4$ mm

$\sigma_\delta = 5.5^{-4}$

$$\varepsilon_x = \frac{\sigma_x^2 - (\eta_x \sigma_\delta)^2}{\beta_x} = 47.0 \text{ nm}$$

$$\gamma\varepsilon_x = 101.2\ \mu\text{m}$$

$\beta_y = 5.7$ m

$\sigma_y \sim 0.15$ mm

$$\varepsilon_y = \frac{\sigma_y^2}{\beta_y} = 3.95 \text{ nm}$$

$$\gamma\varepsilon_y = 8.50\ \mu\text{m}$$

	Design @ DR	SR monitor @ DR	Q-scan with OTR screen @ RTL
$\gamma\varepsilon_x$ [μm]	65	101.2	70~76.0
$\gamma\varepsilon_y$ [μm]	0.65	8.50	0.2~0.24

- **No large emittance blowup after DR**
- **No large bunch charge dependence of beam emittances**

How to Confirm Unidentified CSR Effect in BT

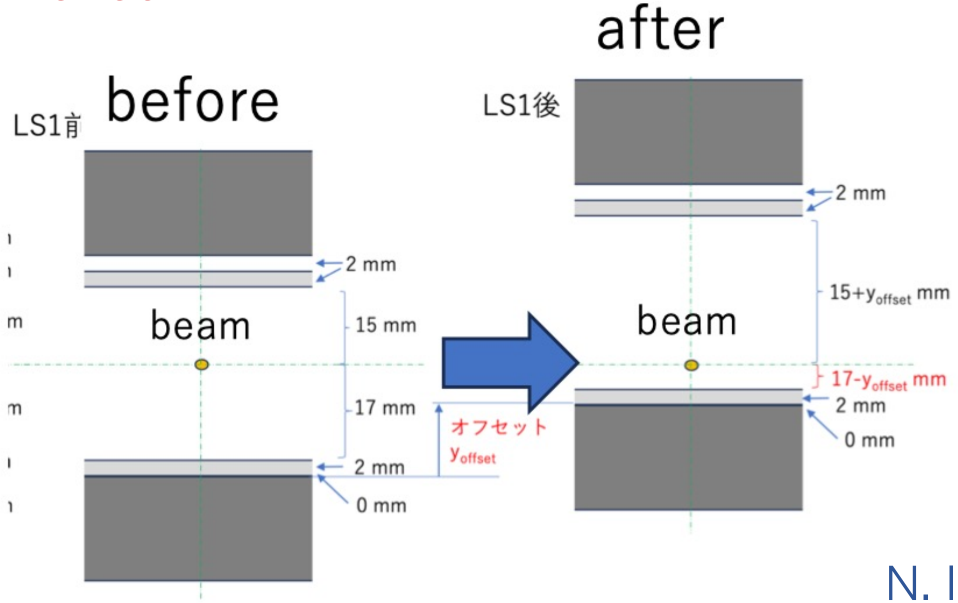
What is the source of emittance growth?:

Unidentified CSR effect can be caused by a longitudinal spiky bunch profile.

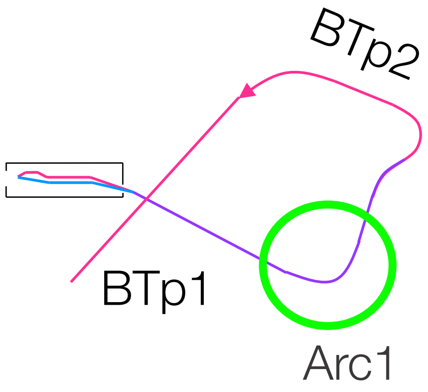
Countermeasure setup:

Most beam ducts of bending magnets in Arc1 were offset to suppress unidentified CSR effects. ➡ **Off-axis shielded CSR effect[1]**

See talk on “BT” for hardware in detail



[1] T. Mori, IPAC2023



N. Iida

Side effects:

1) Large resistive wall (RW) impedance

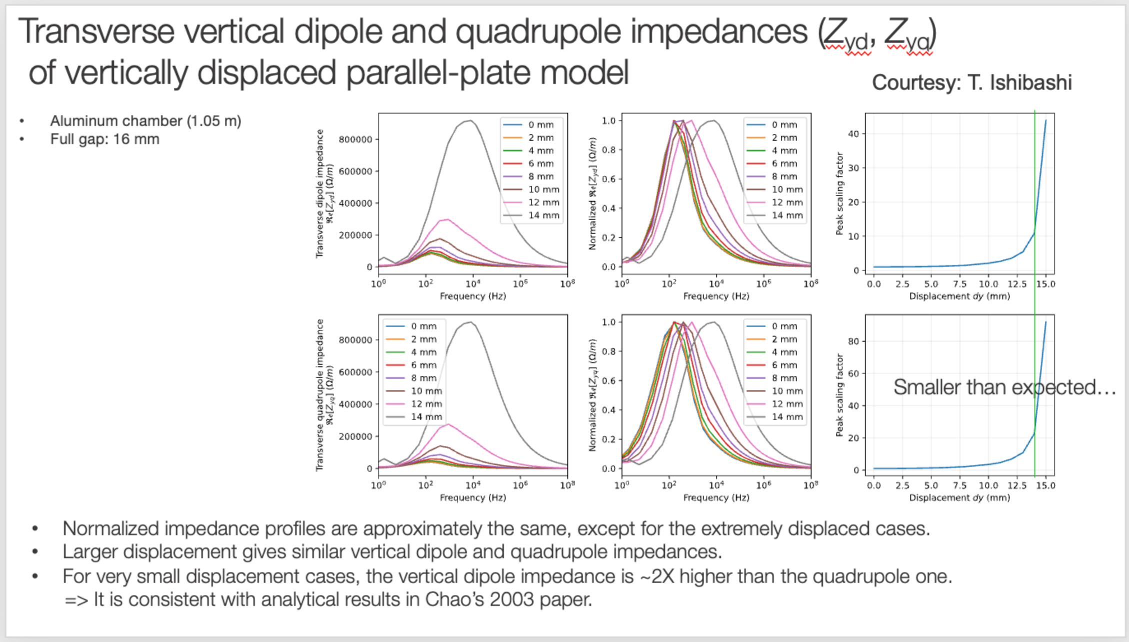
RW impedance can increase beam emittances due to the finite conductivity of beam ducts.

2) Vertical dispersion caused by vertically offset bending magnets

Countermeasures Against Side Effects

Off-axis RW impedance effect[1]:

T. Ishibashi , T. Yoshimoto



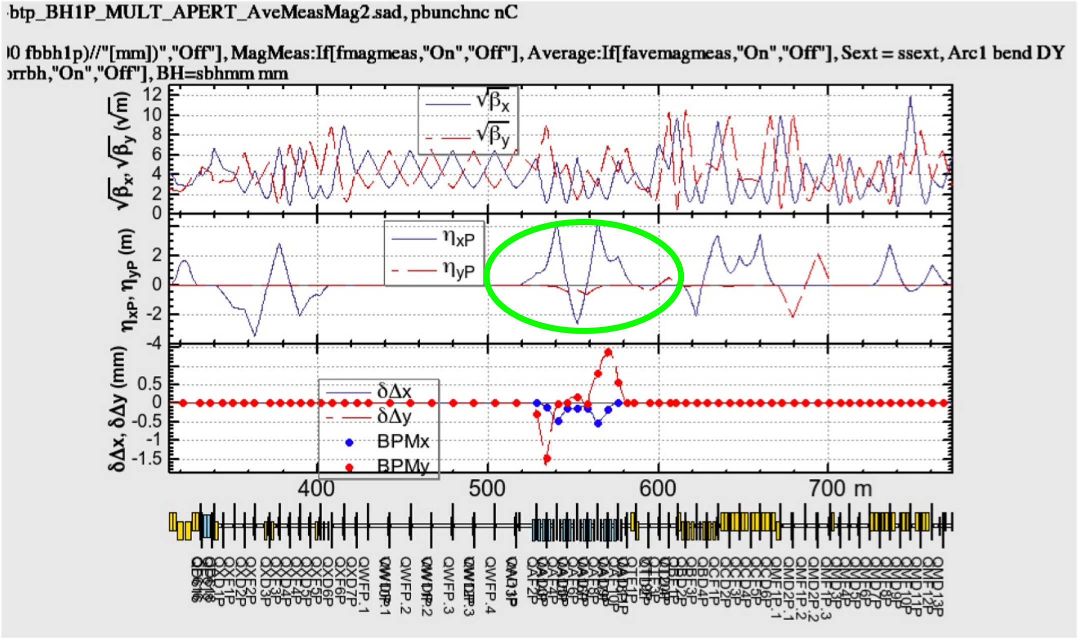
Simulation results:

- Significant vertical emittance growth was caused by duct displacement >= 14 mm in this simulation, whereas13 mm displacement was acceptable.

➡ **13 mm duct offset is not harmful and adapted.**

Optics with ver. dispersion suppression in Arc 1:

N. Iida



Simulation results:

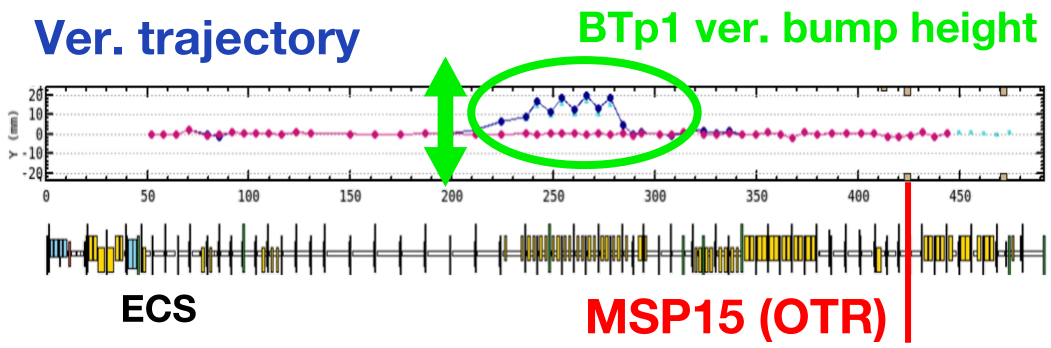
➡ **Optic can be cured with vertical correctors and quadrupoles**

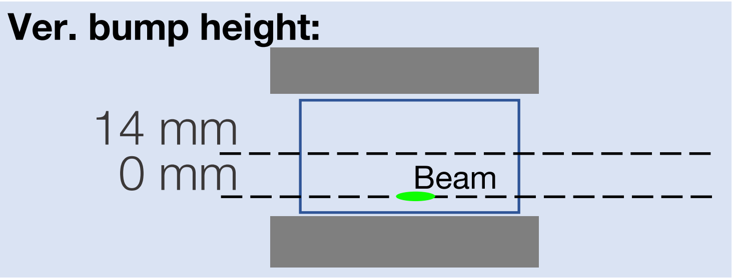
[1] T. Yoshimoto, BITF, Aug 25, 2023, https://kds.kek.jp/event/47643/

BTp-Arc1 Bump Height Dependence of Beam Emittances @ MSP15

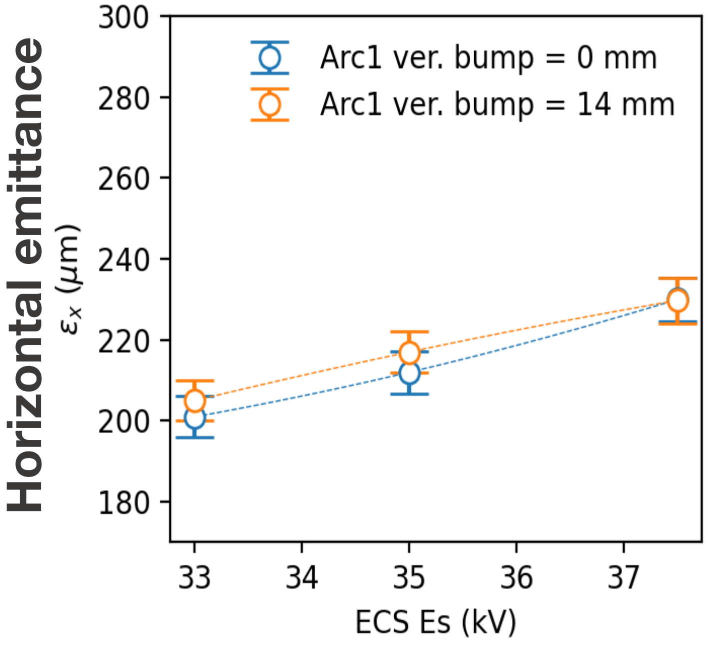
Scheme:

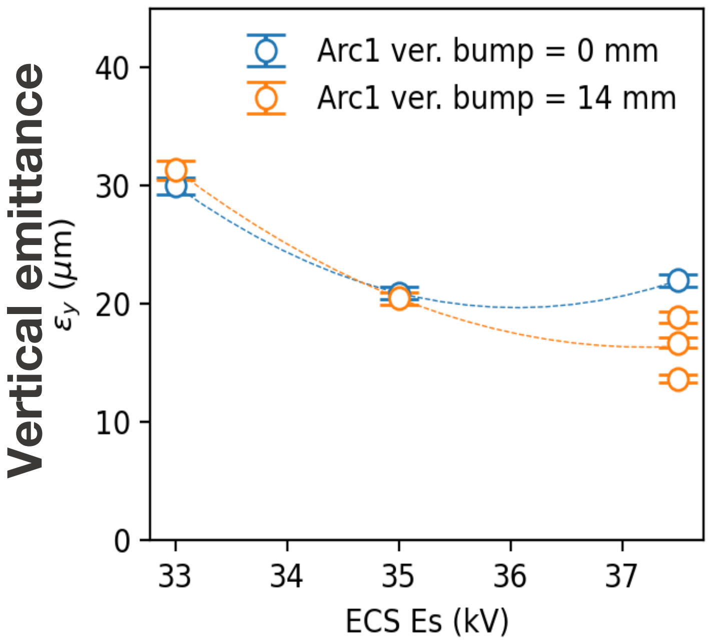
1. Change BTp Arc1 bump height:0, 14 mm
2. Measure vertical emittance with MSP15-OTR





Measurement: 20231228





Measurement results:

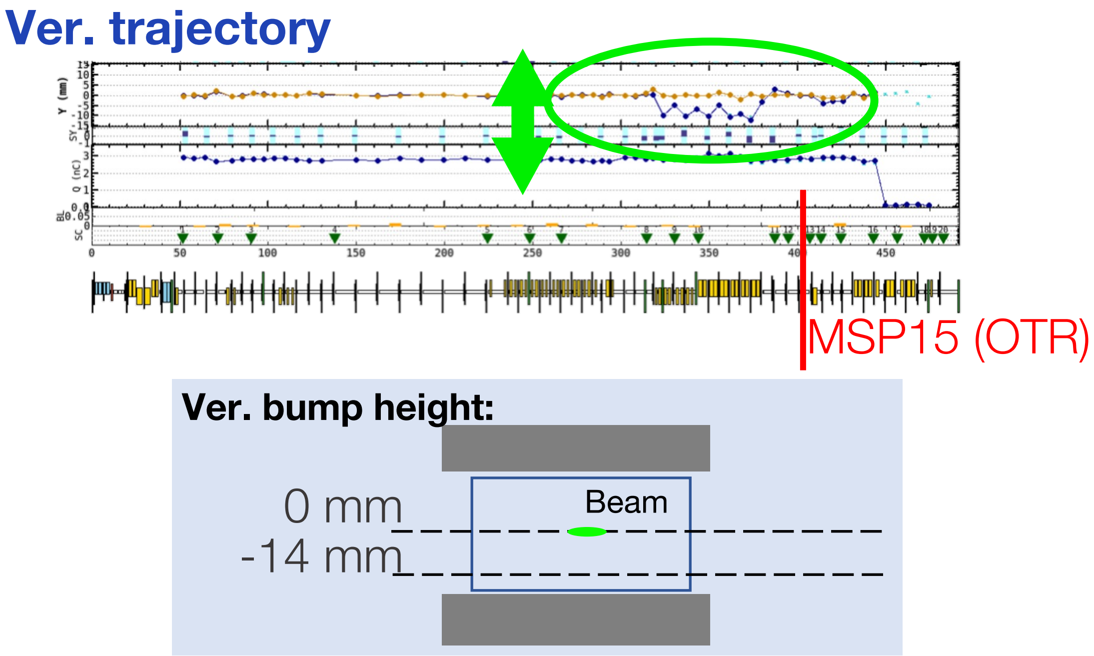
1) ECS setting slightly affects hor. and ver. beam emittances.
2) BTp Arc1 vertical bump height does not change hor. and ver. emittances at MSP15 in BTp2.

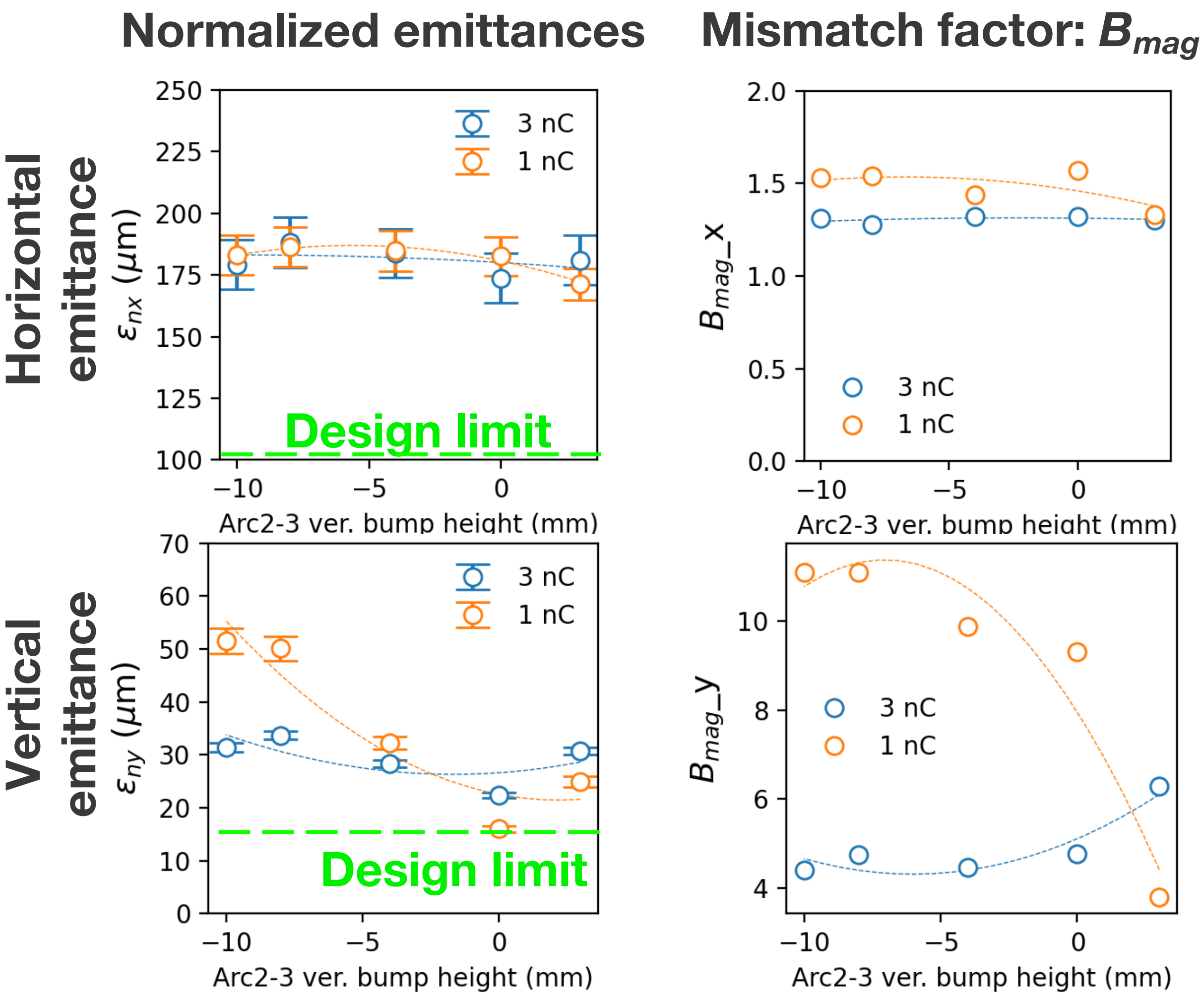
=> No symptom of CSR wake and RW wake effects

BTp-Arc2-3 Bump Height Dependence of Beam Emittances @ MSP15

Scheme:

1. Change BTp Arc2-3 bump height: -10 ~ 3 mm
2. Measure vertical emittance with MSP15-OTR





Measurement: 20231223

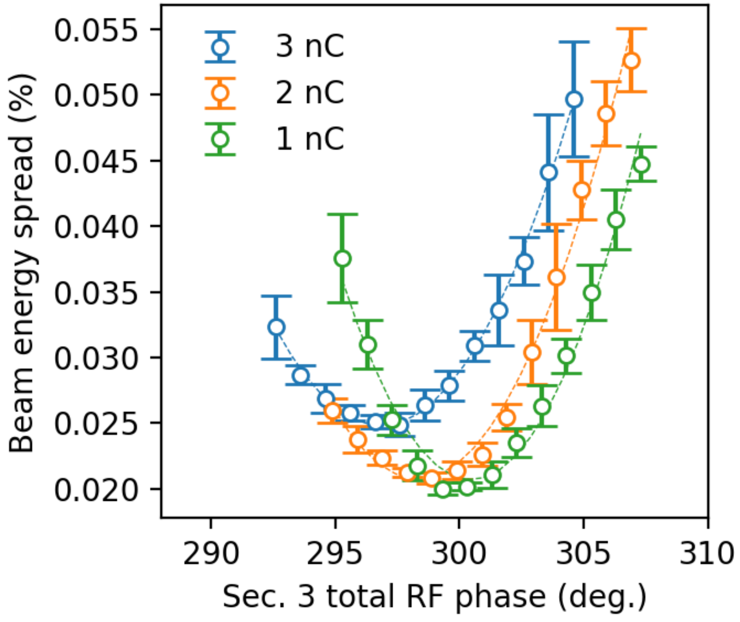
Measurement results:

- No large bunch-charge dependence of beam emittance was observed.
  => No wake field effect including CSR effect. It is consistent with nominal simulation results.
- Ver. bump height dependence of beam emittance and Twiss params were observed.
  => There would be unidentified (high-order?) magnetic errors in BTp-Arc 2-3.

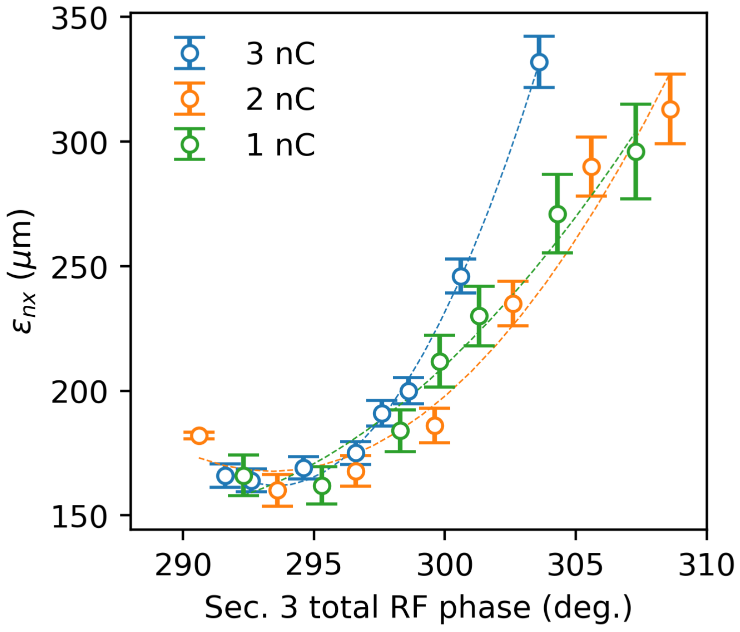
Energy Spread Dependence of Beam Emittance

ECS-E_S: 35 kV

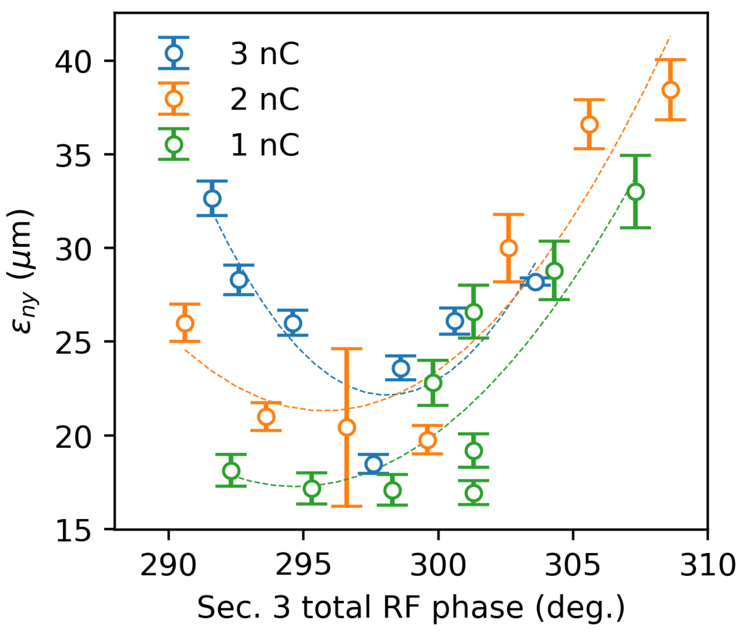
Energy spread @ MSP6



Hor. Emittance @ MSP15



Ver. Emittance @ MSP15



Measurement:
~202312240700 (3 nC), 202312242300~ (1, 2 nC)

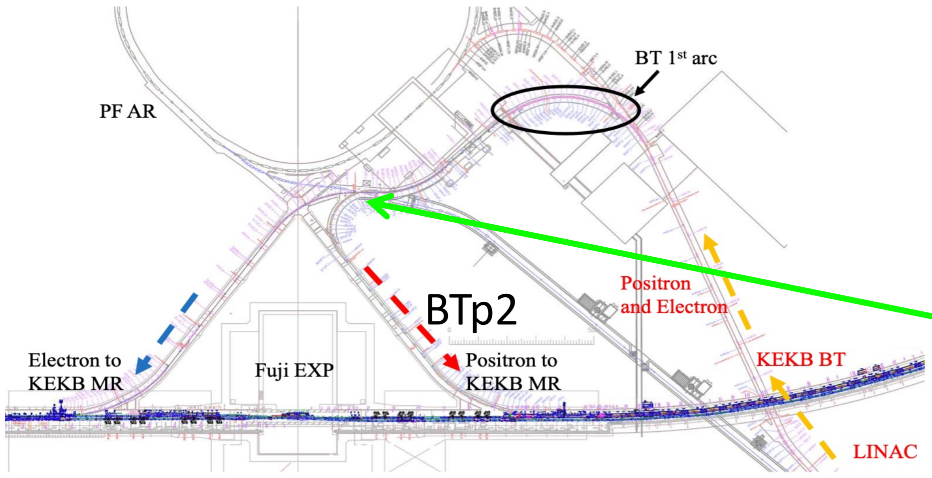
- **LINAC RF phase for minimum energy spread generally does not give minimum beam emittances in both hor. and ver. directions.**
- **In actual operation, the phase should be optimized to minimize 1) energy spread, 2) hor. emittance and 3) ver. emittance comprehensively.**

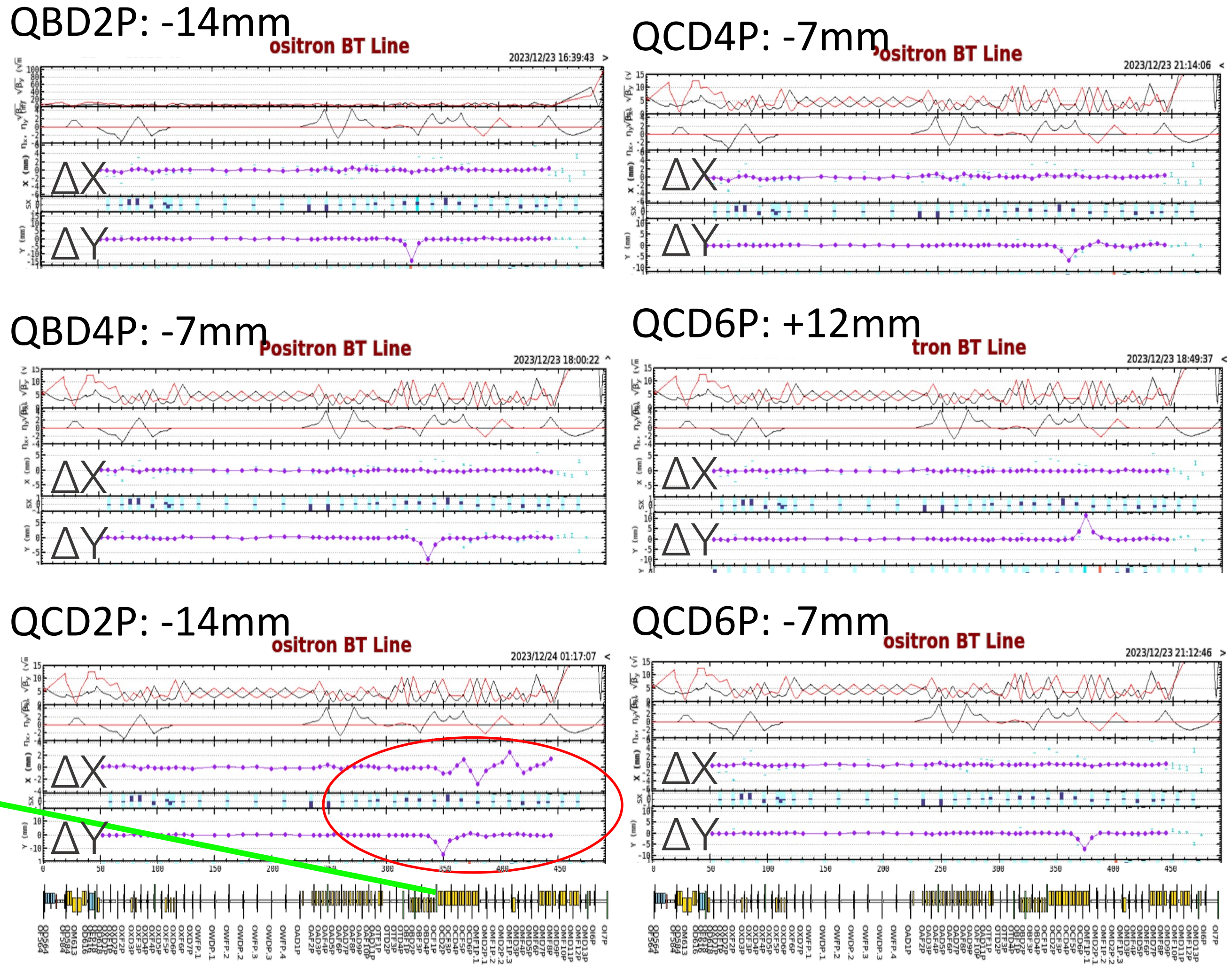
Local Vertical Bump Study in BTp Arc2-3

N. Iida

Where are unexpected magnetic errors?

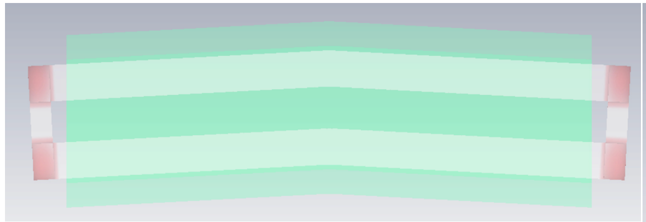
Scheme:
1. Change a local vertical bump position:
2. Observe X-Y coupling from BPM signals

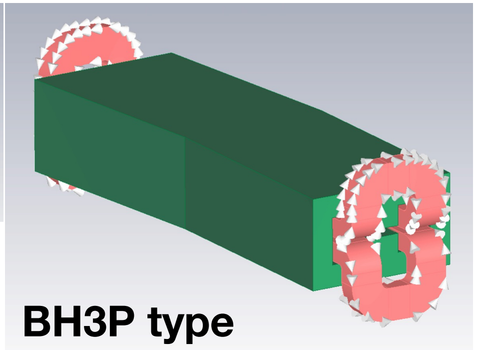




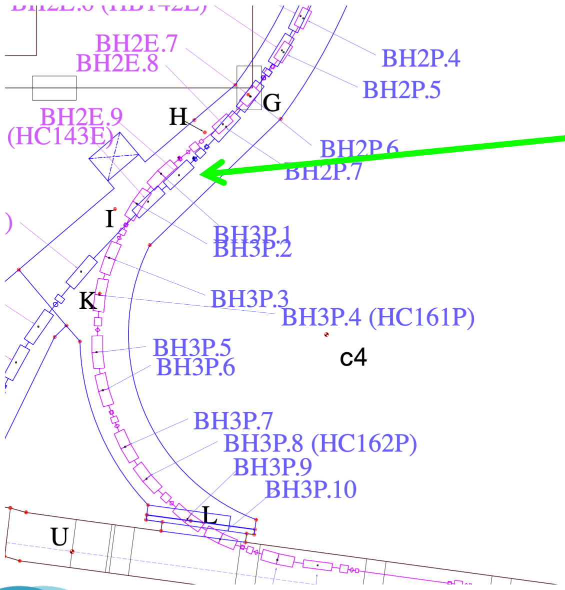
- **Unexpected X-Y coupling was observed near Arc3 entrance.**

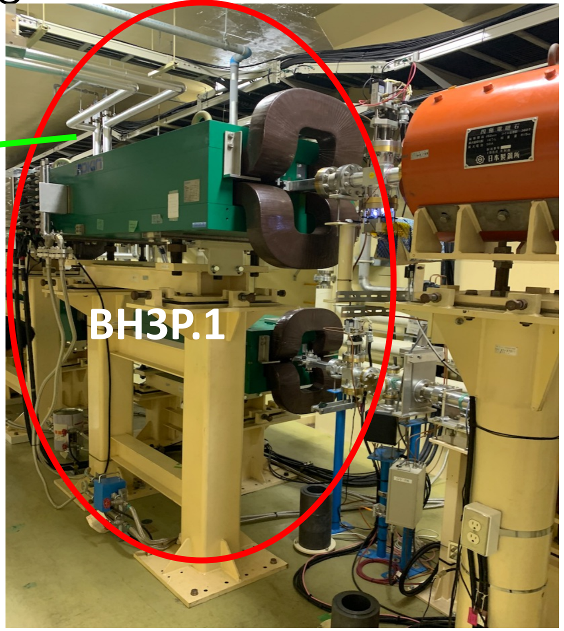
History of BTp Arc 2-3





- **Arc3 bending magnet (BH3P type)**:
  - Saddle-type coil
  - Non-conventional V-shaped yoke
  - Asymmetric insertion of 6-mm iron plate on upper pole surface (BH2P, BH3P) to increase dipole field
- **Permanent skew quads at the entrances of many Arc2-3 bending magnets**
  - In the past, they were placed to reduce unexpected vertical dispersion in this section.
  - It works well to reduce vertical emittance blowup significantly, although vertical residual emittance blowup remains (M. Kikuchi).





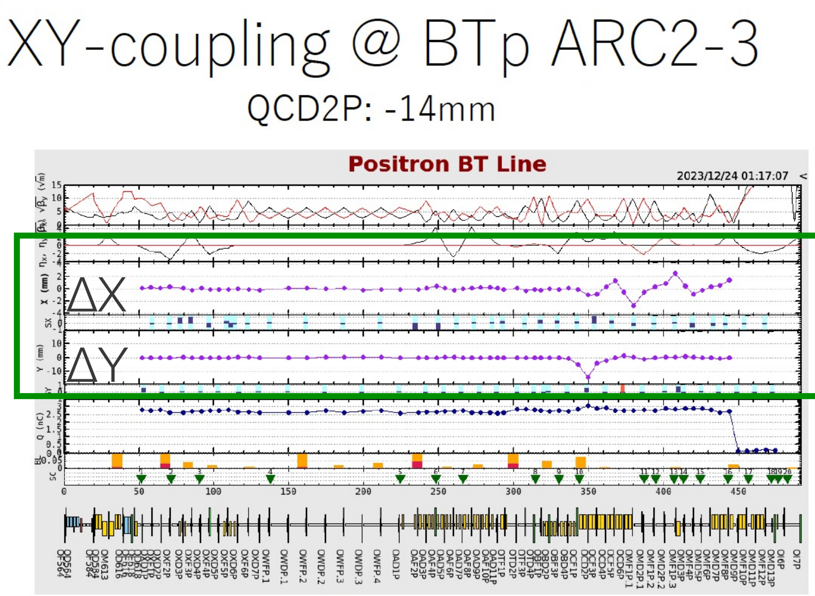
- **Physical sources of the XY coupling have not been identified.**

Arc2-3 XY-Coupling Analysis

- In simulations, some quadrupole rotation errors reproduce the XY coupling, although experts say such large rotational errors are unlikely.
- Each error case has solutions for XY-decoupling with a new skew quad around the first bending magnet of Arc-3
- Further study is ongoing.

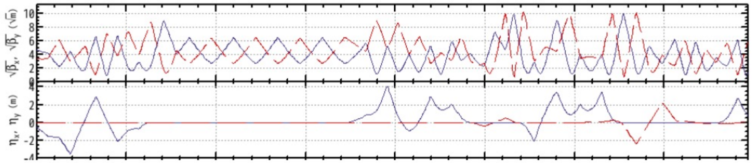
Y. Seimiya

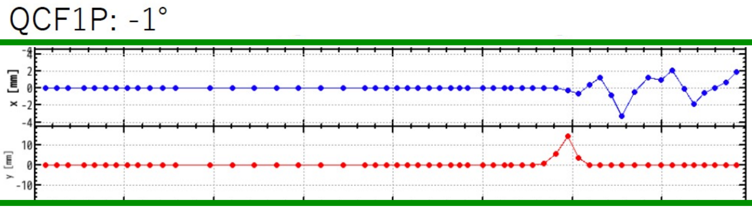
Measurement:



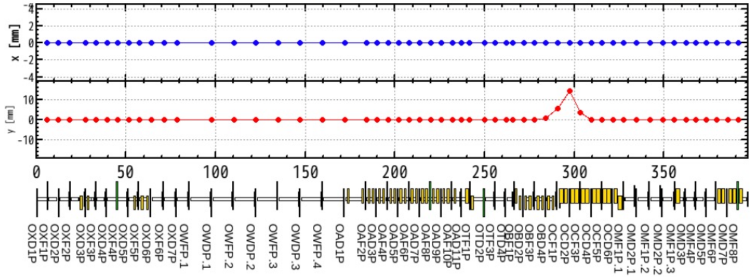
Simulations:

(1) QCF1P: -1 deg.

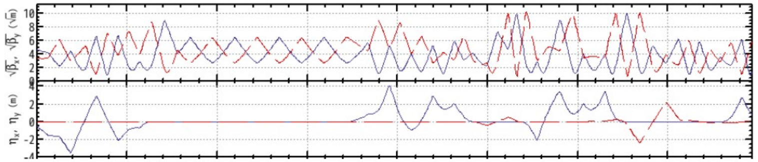


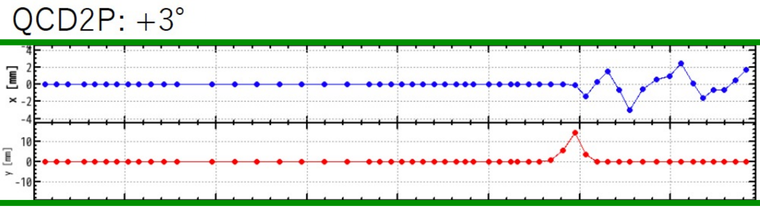


QCF1P: -1 deg
& Skew Q SK1@BH3P.1 = 0.0065

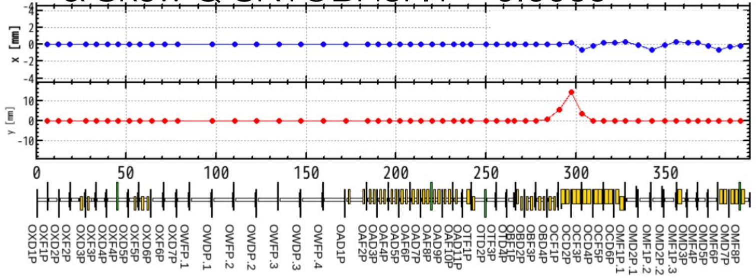


(2) QCD2P: +3 deg





QCD2P: +3 deg
& Skew Q SK1@BH3P.1 = 0.0065



Realistic SAD Simulations With Multipoles of Bending Magnets and Others

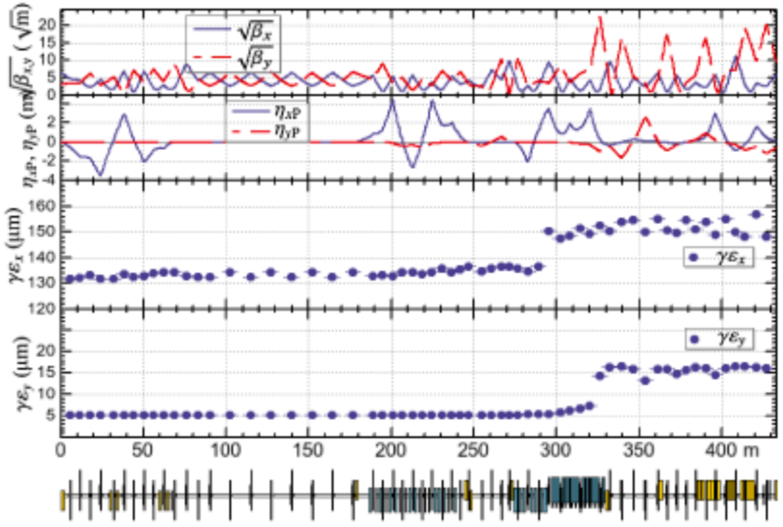
Multipoles on BH2P/BH3P (refined bend model)

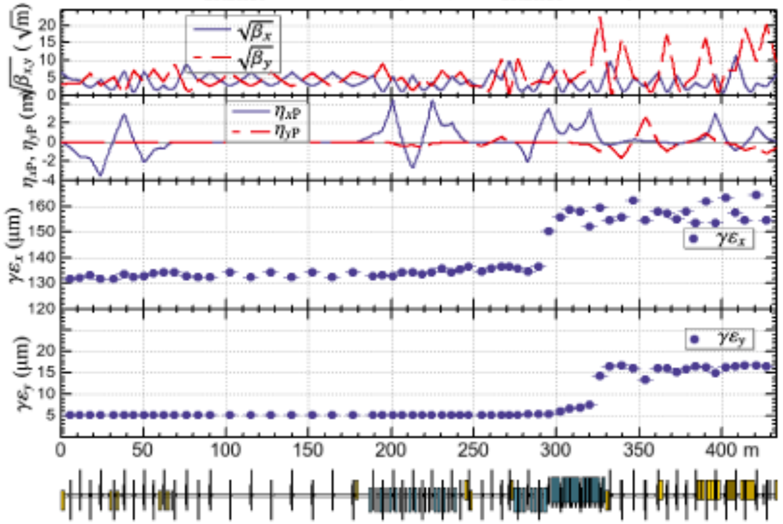
K. Oide, Feb. 14, 2024 @ICG
Multipole calculation, quad roll: M. Tawada
Perm. skew Q: M. Kikuchi
Emittance meas. @BT1 T. Yoshimoto
Sext. meas., Lattice, initial particles, etc.: N. Iida, Y. Seimiya, T. Yamaguchi

K. Oide

- Tracking by SAD includes:
  - multipoles in BH1P/2P/3P (Tawada)
  - vertical offset of BH1P (Iida)
  - measured rotation/pitch errors of quads in ARC3 (Tawada)
  - perm. skew quads for dispersion correction (Kikuchi)
  - measured emittances at BT1 (Yoshimoto) scaled on particles @ linac exit (Iida)
  - additional sextupole at BH3P.1 based on bump meas. (Yamaguchi, Iida)
  - refined bend model
  - synchrotron radiation in all elements

K2, 1/m²	0	0.65
$\gamma\varepsilon_x$ @BT2, μm	153	160
$\gamma\varepsilon_y$ @BT2, μm	16	17





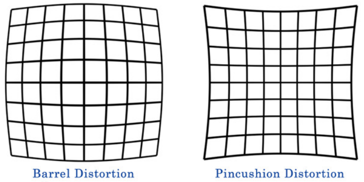
This simulations reveal that 1) multipoles of bending magnets and 2) sextupole component from the measured XY coupling can reproduce measured X/Y emittances in BT2.

Raster Scan to Observe “Magnetic Lens” Distortion

Preliminary

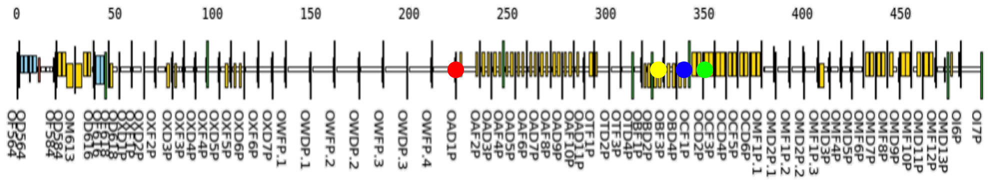
Basic idea:

In general, beam optics and light optics have a common theory
=> Beam optics distortion is visually observable!

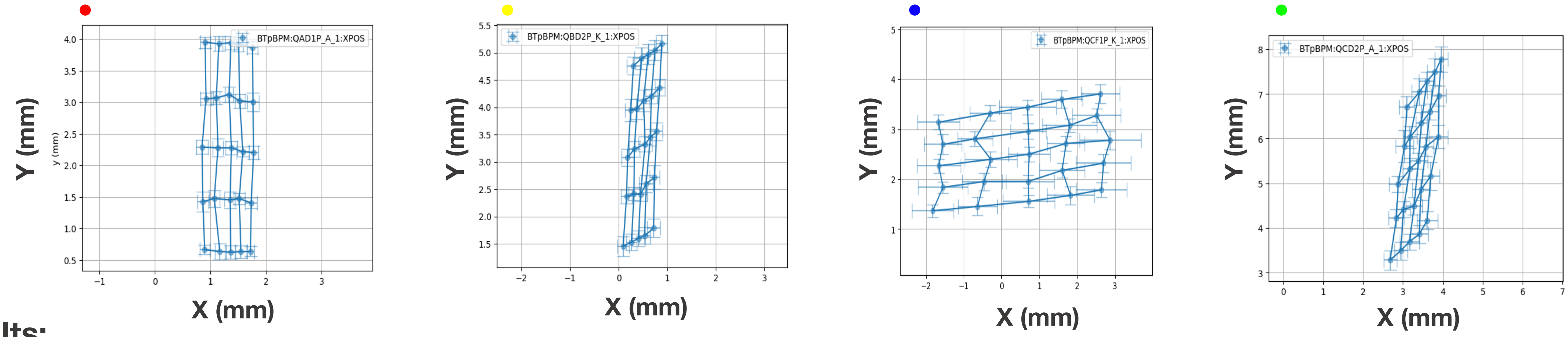


Scheme:

1. Change X and Y corrector kicks in BT1 in a grid pattern.
2. Measure downstream BPM response.



BPM response:



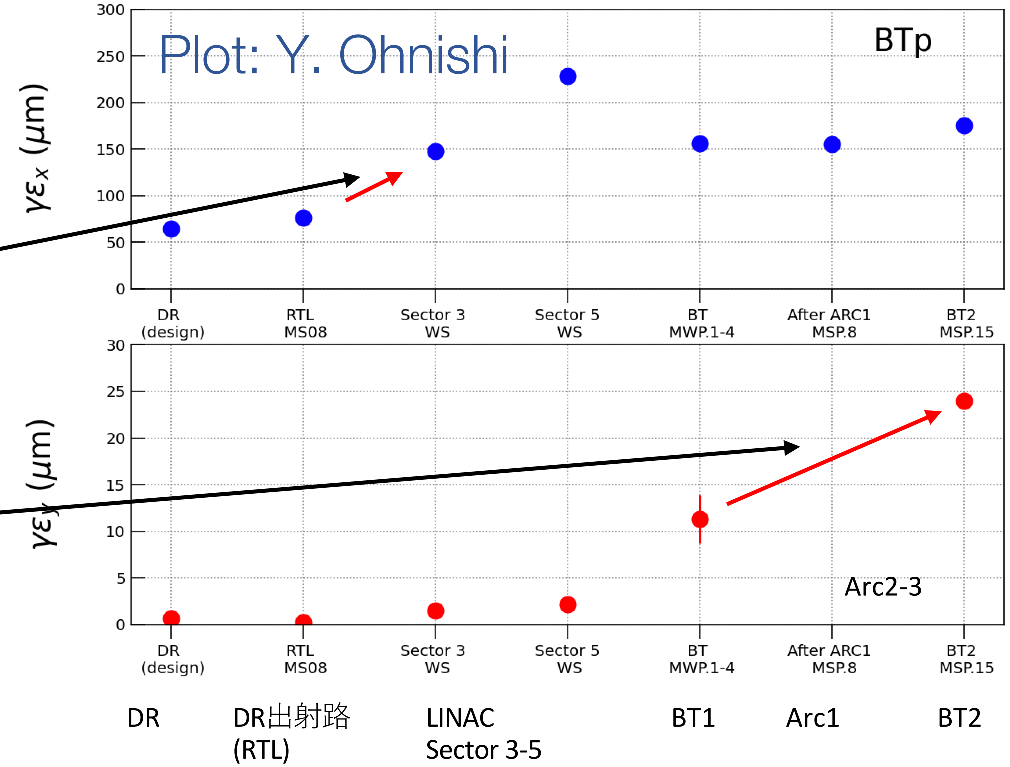
Results:

- Slight XY coupling is observed in Arc-2
- Strong XY correlation just after the first Arc-3 bending magnet
- It is useful to get better linearity region in a magnetic field.
- Further study is necessary.

[1] https://clickitupanotch.com/wp-content/uploads/2014/06/lens-distortion-graphic.jpg

Summary of Emittance Blowup

- The horizontal blowup here is suspected at an accelerator structure in the BCS.
- The vertical blowup here is being understood by the BT study in 2023.



3 nC	DR (design)	RTL (MSs08)	Sector 3 (WSs)	Sector 5 (WSs)	BT1 (MWP.1-4)	after Arc1 (MSP.8)	BT2 (MSP.15)
$\gamma\varepsilon_x$ [μm]	65	76.04	147.5	228 ± 53	156.5 ± 35.9	155	175
$\gamma\varepsilon_y$ [μm]	0.65(κ=1%)	0.24	1.5	2.2 ± 0.3	11.3 ± 2.6	---	24

3 [nC] e+ BT1→BT2	Measured	Simulation (K. Oide)
$\gamma\varepsilon_x$ [μm]	130→175 ± 10	130→160
$\gamma\varepsilon_y$ [μm]	5 →20 ± 1	5 →17

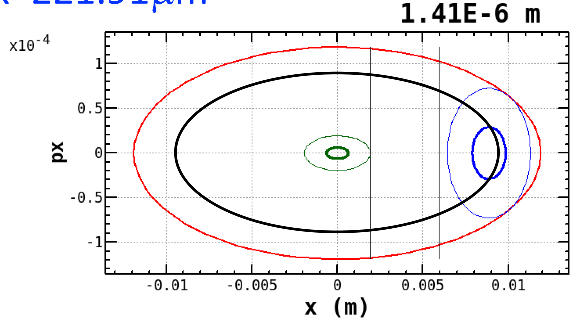
The simulations have good agreement with the measurements.

LER Dynamic Aperture (β_y^* = 3~1 mm)

Y. Ohnishi, N.Iida

1) Hor. aperture

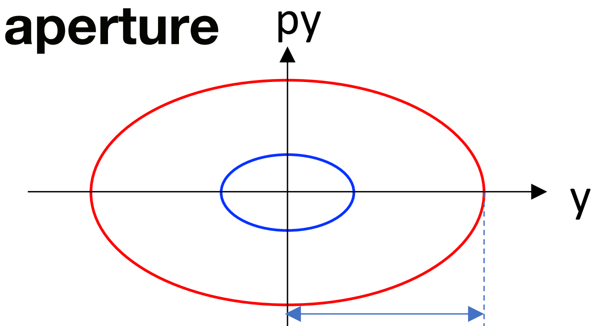
$\gamma\varepsilon x$=221.91μm



βy* LER	3 mm	1 mm CW off	1 mm CW 80%
Measured (Simulated) horizontal acceptance, $2J_x$ [μm]	2.24 (4.88)	1.13 (3.77)	0.90 (3.37)
Maximum action of injected beam ($6.25\varepsilon_{x\_rms}$), $2J_x$ [μm]		1.41	

~1.6 X

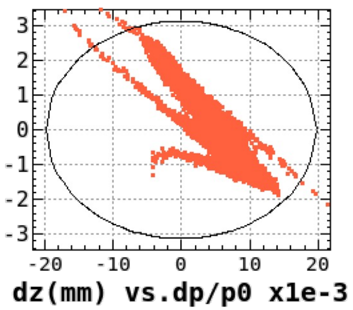
2) Ver. aperture



$$3\sigma_y = 3\sqrt{\varepsilon_y \beta_y} = \sqrt{2J_y \beta_y}$$

βy* LER	3 mm	1 mm CW off	1 mm CW 80%
Measured (Simulated) vertical acceptance, $\gamma 2J_y$ [μm]	No data	No data	No data
Maximum action of injected beam($9\varepsilon_{y\_rms}$) , $\gamma 2J_y$ [μm]		196.7	

3) Momentum aperture



βy* LER	3 mm	1 mm CW off	1 mm CW 80%
Measured (Simulated) momentum acceptance, p/p_0 [%]	0.38 (1.26)	0.53 (1.33)	0.61 (1.11)
Simulated injected beam momentum spread (99%) [%]		~0.32	

Raw LER injection efficiency: ~90%.

7-GeV Electron Beam Transport Status

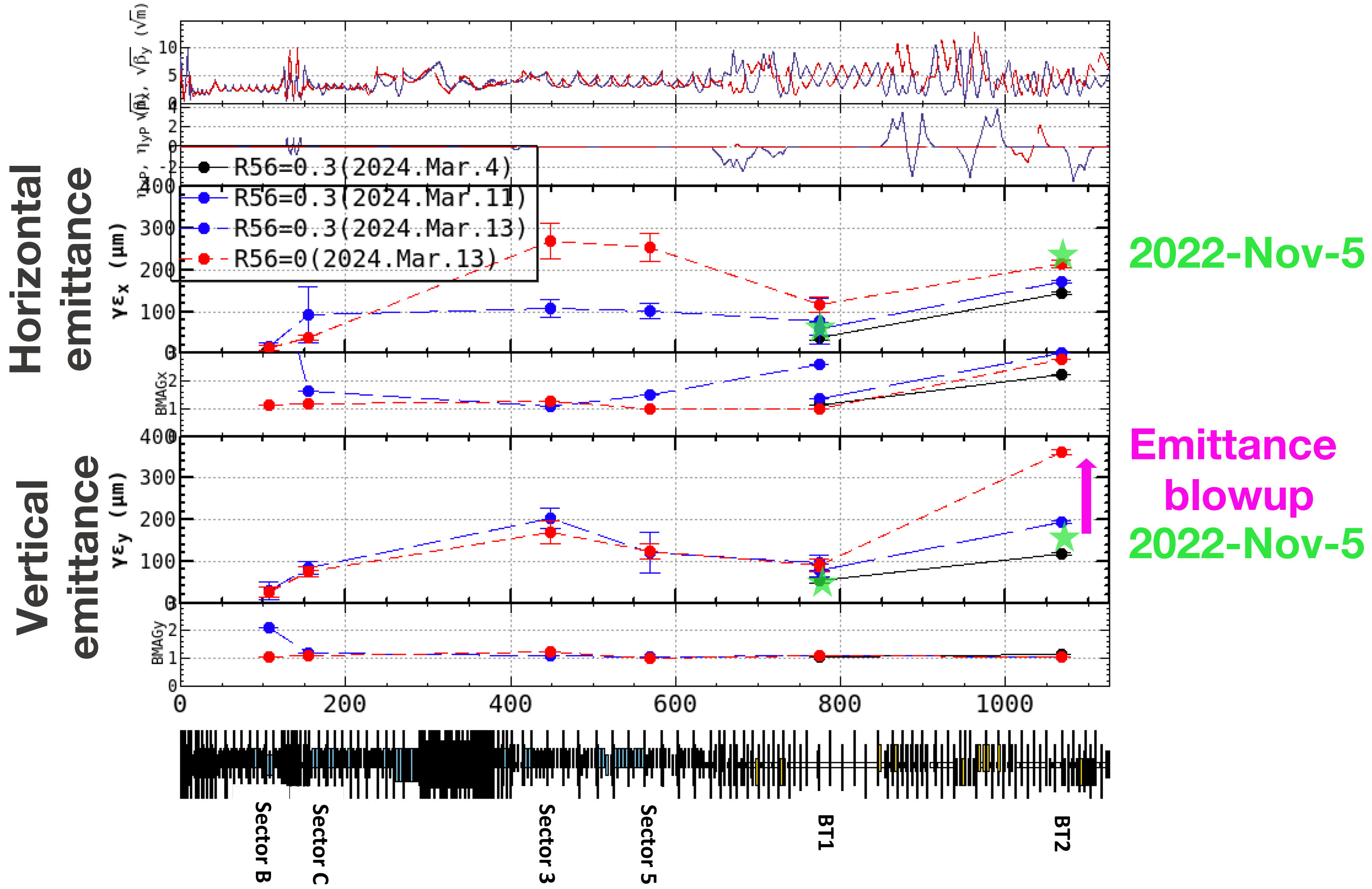
Known sources of hor. emittance blowup[1]:

1) Incoherent Synchrotron Radiation (ISR)
2) Coherent Synchrotron Radiation (CSR)

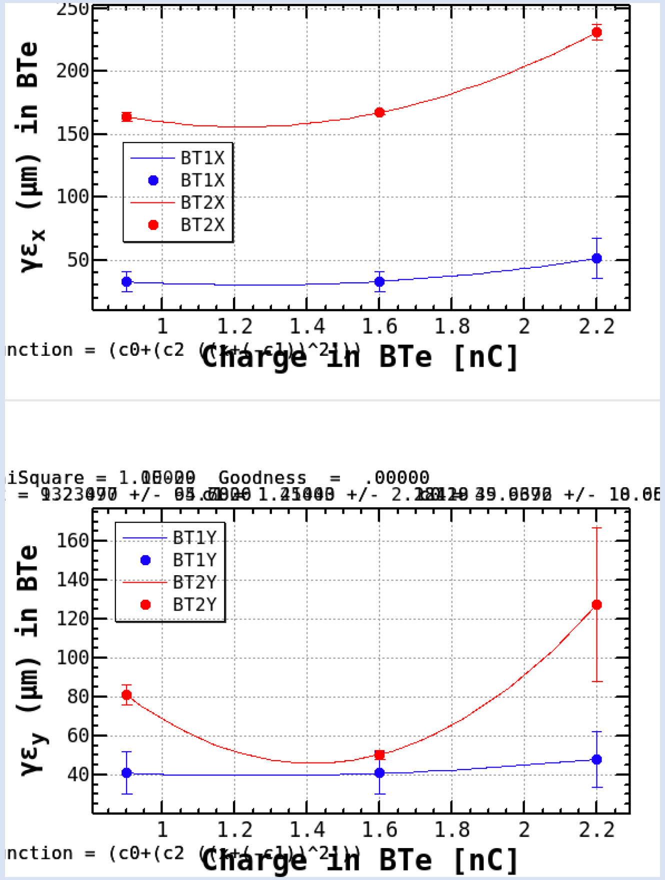
1) https://www-kekb.kek.jp/MAC/2022/Report/Iida.pdf

Electron Beam Emittance Status

Run 2024 (J-ARC R_{56}=0, 0.3)



Reference data:
Run 2022-Nov-5 (J-ARC R56=0)

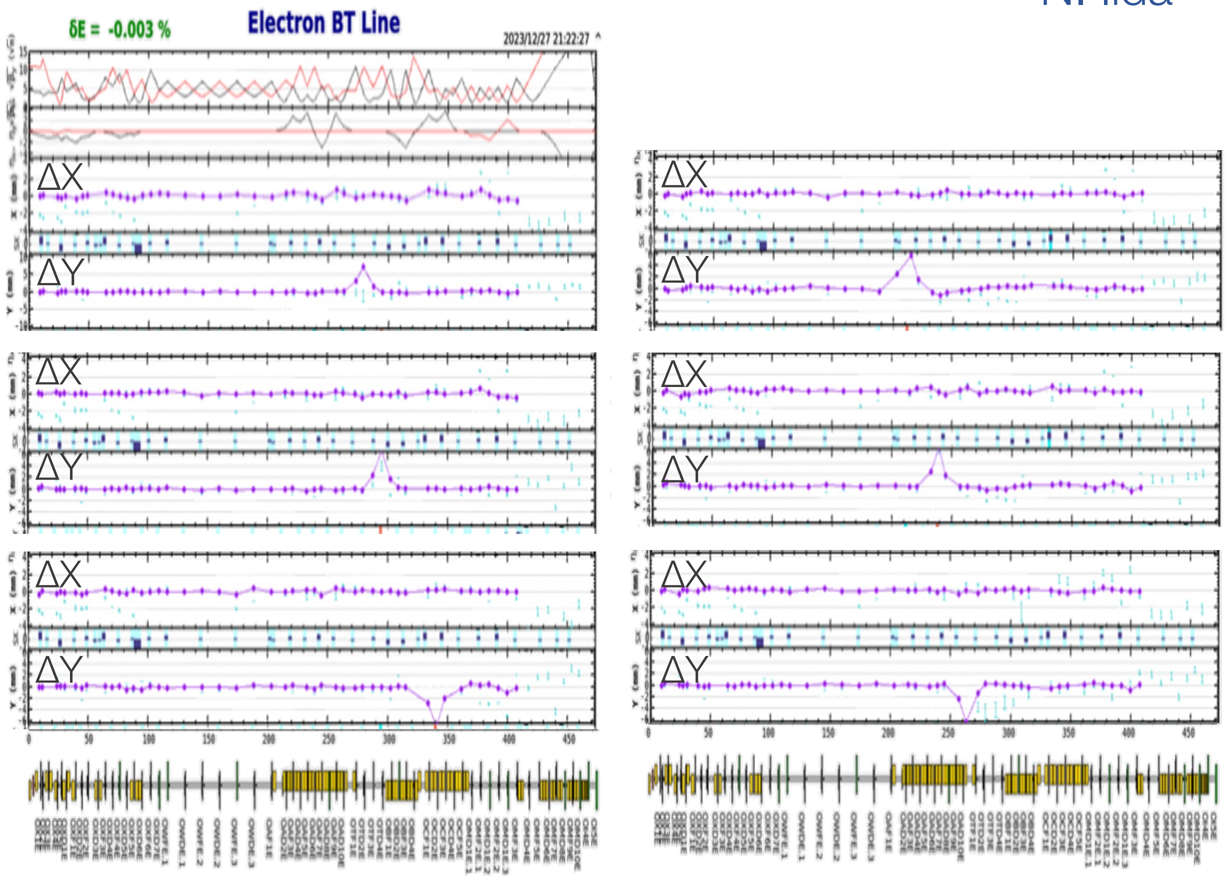


- Unexpected additional vertical emittance blowup was observed after BT1.
- The blowup is necessary to be mitigated, prior to high-current operation (>1 A).

Local Vertical Bump Study in BTe Arc1-3 & Dispersion Measurement

Local Vertical Bump Study

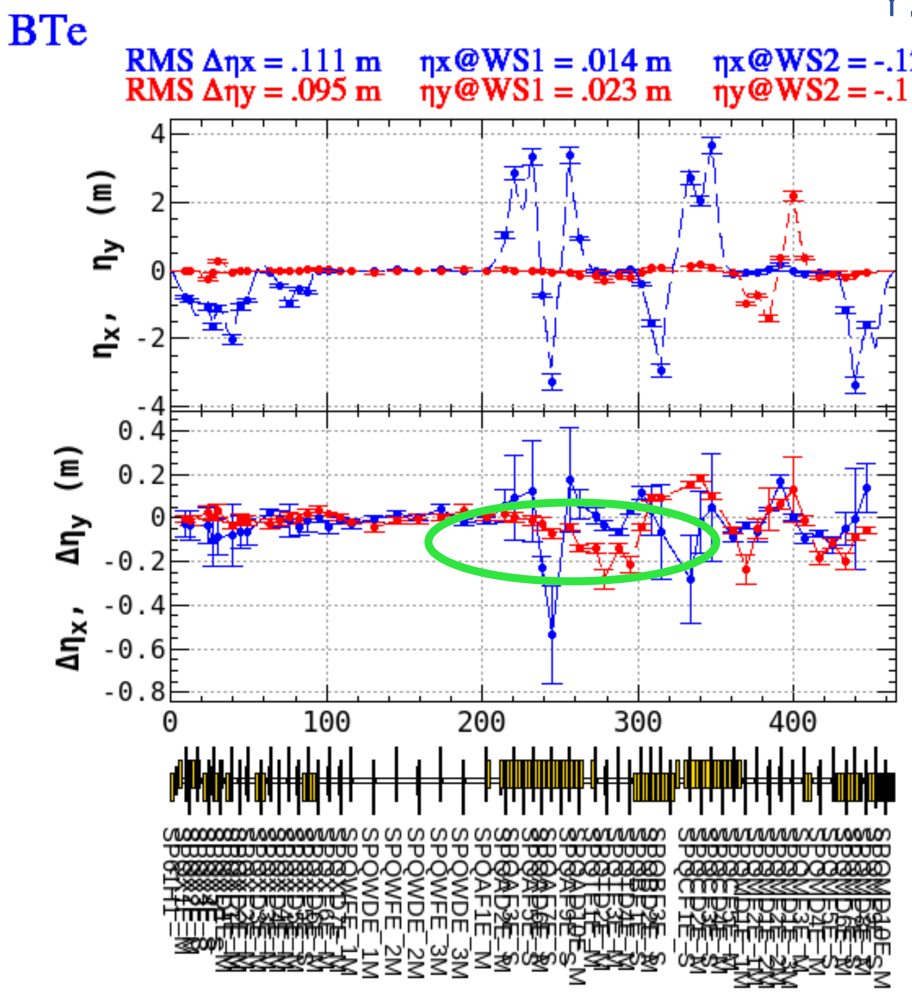
N. Iida



No obvious X-Y coupling was observed with horizontal and vertical local bumps (±7mm) in Arc 1 or 2-3.

Dispersion Measurement

Y. Seimiya

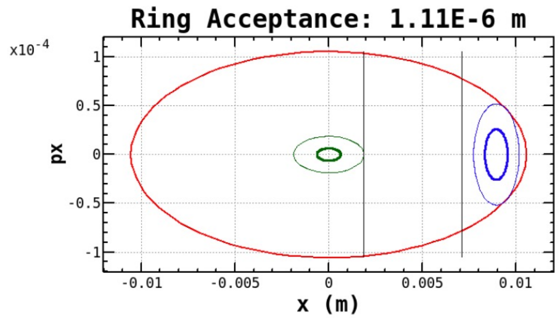


Undesigned vertical dispersion was observed in Arc1. It is still a mystery.

HER Dynamic Aperture (β_y^* = 3~1 mm)

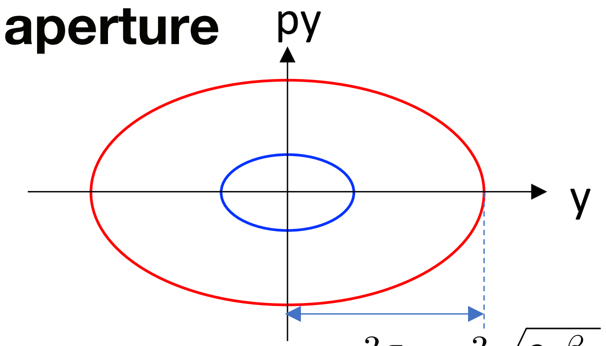
Y. Ohnishi, N.Iida

1) Hor. aperture



βy* HER	3 mm	1 mm CW off	1 mm CW 40%
Measured (Simulated) horizontal acceptance, $2J_x$ [μm]	3.89 (3.31)	1.34 (2.77)	1.13 (2.77)
Maximum action of injected beam ($9\varepsilon_{x\_rms}$), $2J_x$ [μm]		1.07~1.1	~1 X

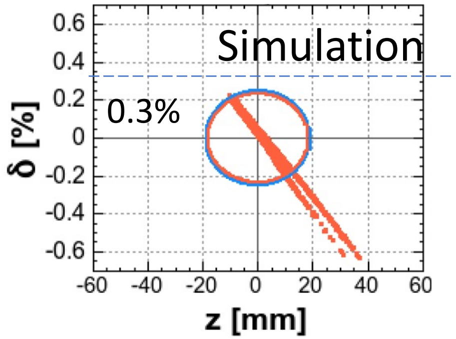
2) Ver. aperture



$$3\sigma_y = 3\sqrt{\varepsilon_y \beta_y} = \sqrt{2J_y \beta_y}$$

βy* HER	3 mm	1 mm CW off	1 mm CW 40%
Measured (Simulated) vertical acceptance, $\gamma 2J_y$ [μm]	1187 (3982)	649 (973)	712 (973)
Maximum action of injected beam($9\varepsilon_{y\_rms}$) , $\gamma 2J_y$ [μm]		1068~3263	1.5~4.5 X

3) Momentum aperture



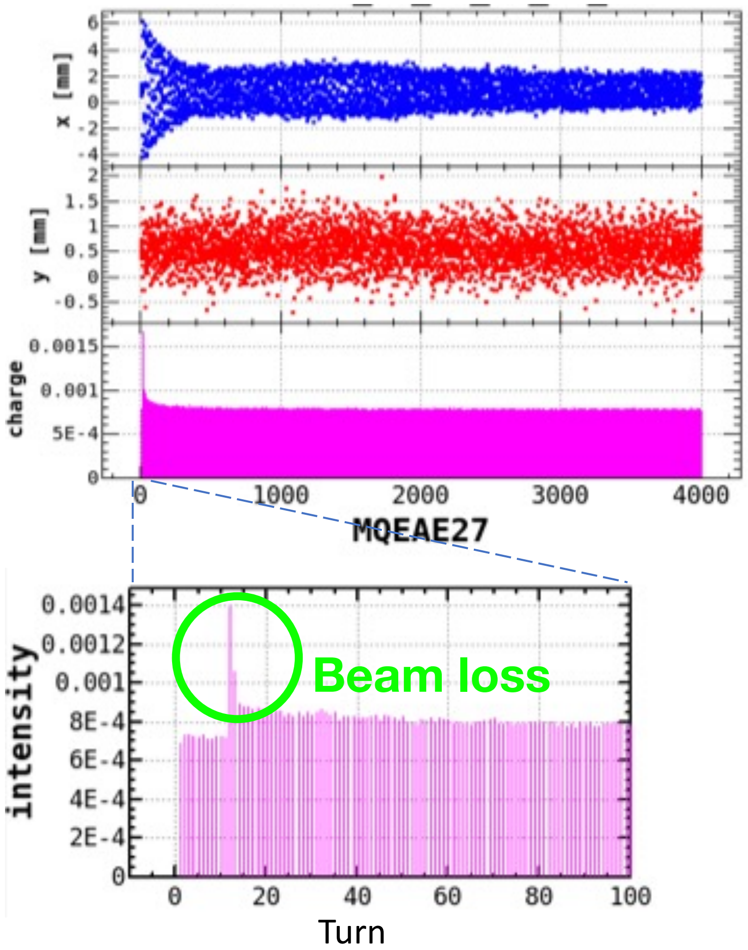
βy*	3 mm
Measured momentum acceptance, p/p_0 [%]	0.69
Simulated injected beam momentum spread (95%) [%]	~0.31

- Small ver. aperture and large ver. emittance reduce a raw HER injection efficiency: ~30%.

TbT[1)]-BPM Measurements in HER (β_y^* = 1 mm)

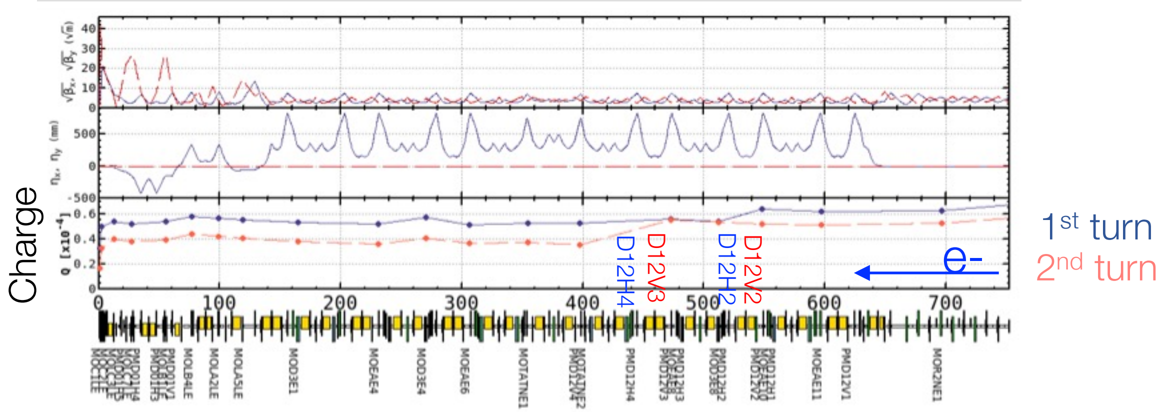
[1)]turn-by-turn

TbT beam survival at a BPM (MQEAE27)

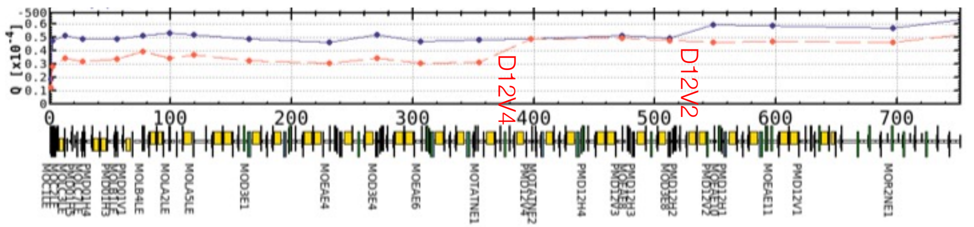


Local TbT beam survival

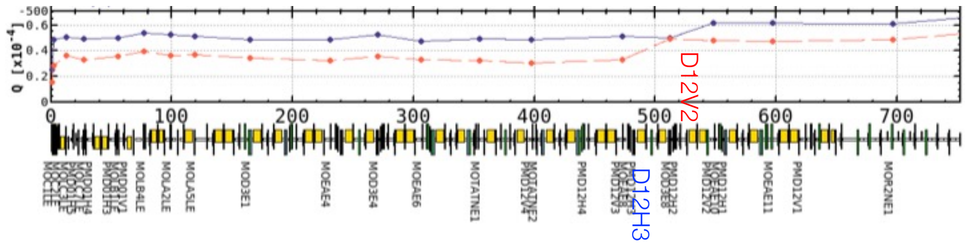
Shot #1



Shot #2



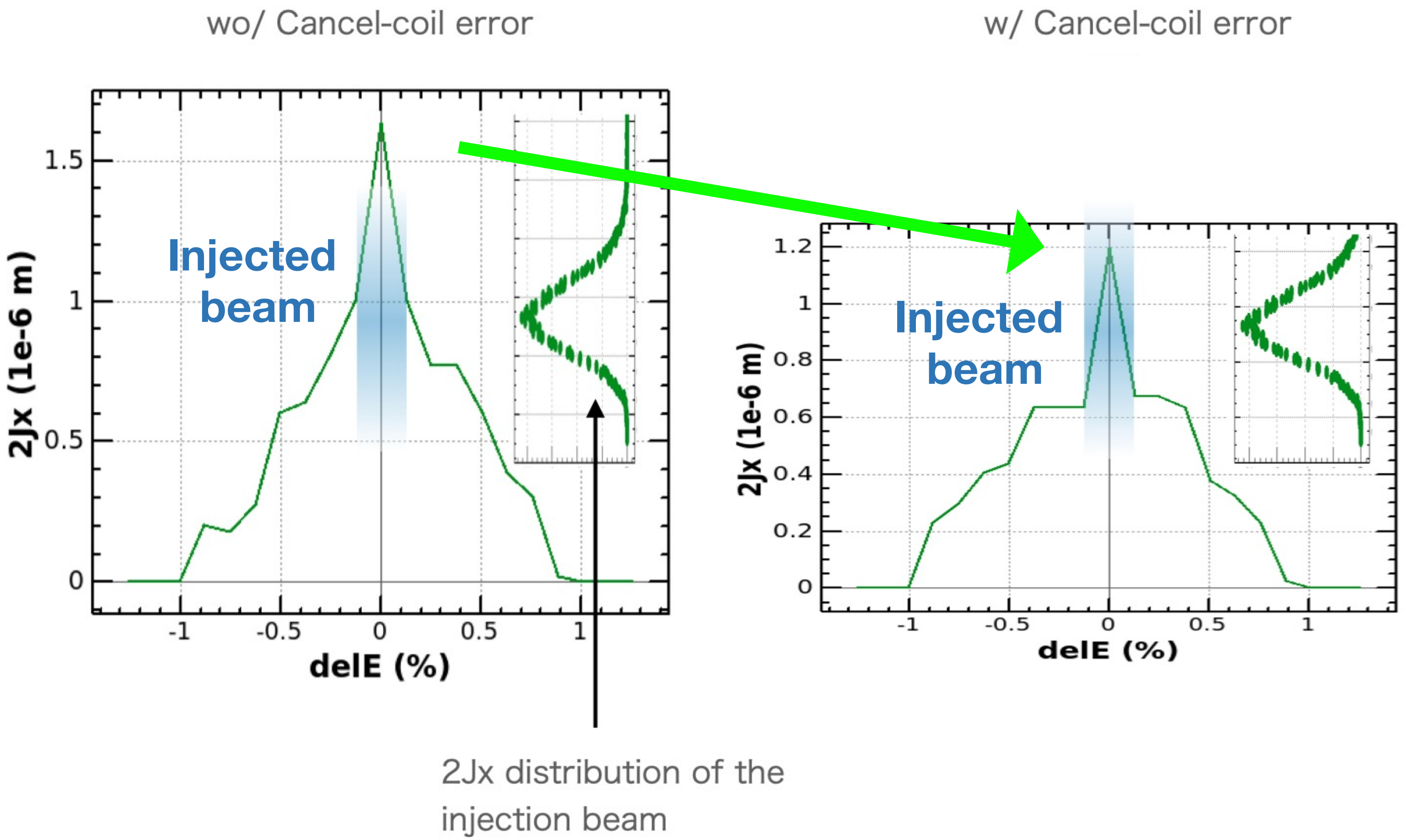
Shot #3



- Approximately 50 % of the injected beam is lost within the first two turns by D12 collimator.
- The beam loss location of the injected beam at the 2nd turn varies in each injection.
  => It is consistent with narrow horizontal and vertical dynamic aperture (βy^* = 1 mm) for present injected beam with large emittance blowup.

On-Momentum Dynamic Aperture Degradation due to QCS Cancel-coil Errors[1]

M. Kikuchi



- **QCS cancel-coil errors reduced on-momentum dynamic aperture (2Jx) by ~25%.**
- **It is crucial for HER beam injection.**

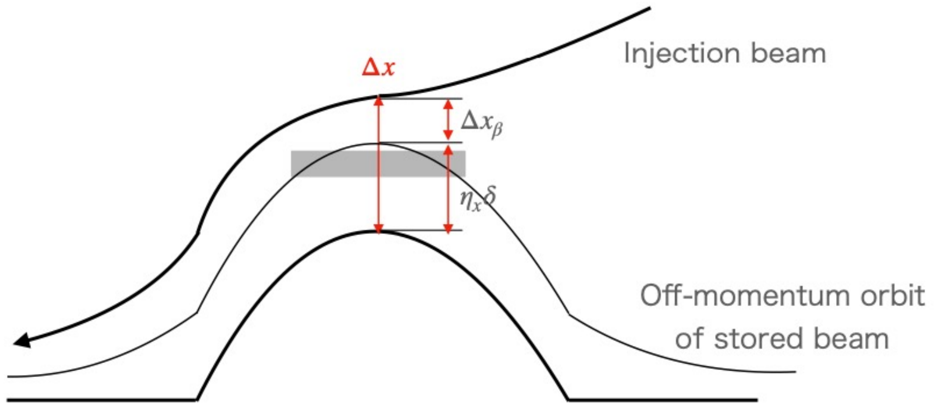
[1] M. Kikuchi, "Simulation of the injected beam in HER (2)", SKB Commissioning meeting, Dec. 22, 2023, https://kds.kek.jp/event/49259/

Synchro-beta Injection (1)

M. Kikuchi

Synchro-beta Injection

- Synchrotron injection was proposed to recover the aperture for the injected beam.
- But momentum aperture is not enough.
- Synchro-beta scheme may be a possible option.



- In the synchro-beta injection, energy offset and the betatron amplitude shares the distance between kicker-orbit and injection beam.

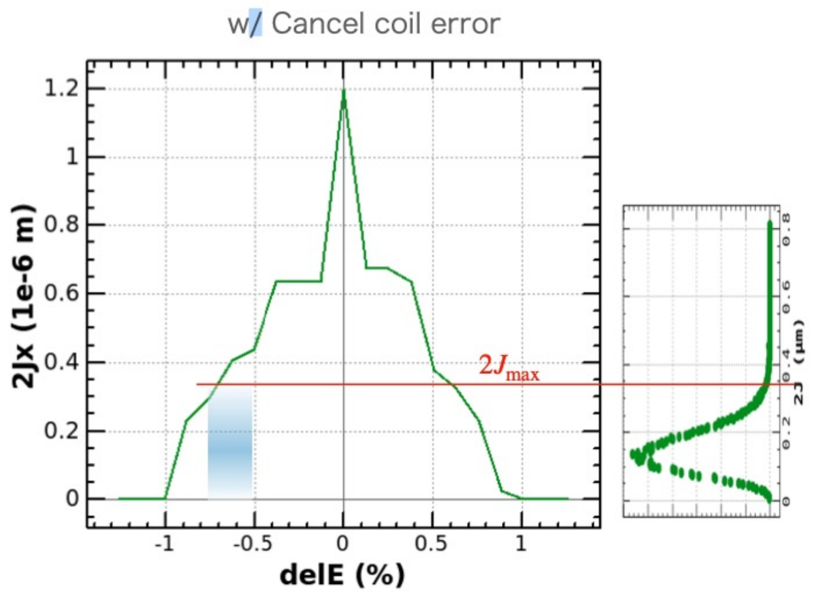
$$\Delta x = \eta_x \delta + \Delta x_\beta$$

Assumption

$$\Delta x = -10 \text{ mm},$$
$$\eta_x = 1 \text{ m}, \quad \beta_x = 100 \text{ m},$$

for example,

$$\Delta x_\beta = -3.65 \text{ mm} \rightarrow \delta = -0.635 \%,$$
$$2J_{max} = 0.375 \ \mu\text{m}.$$



[1] M. Kikuchi, "Simulation of the injected beam in HER (2)", SKB Commissioning meeting, Dec. 22, 2023, https://kds.kek.jp/event/49259/

Synchro-beta Injection (2)

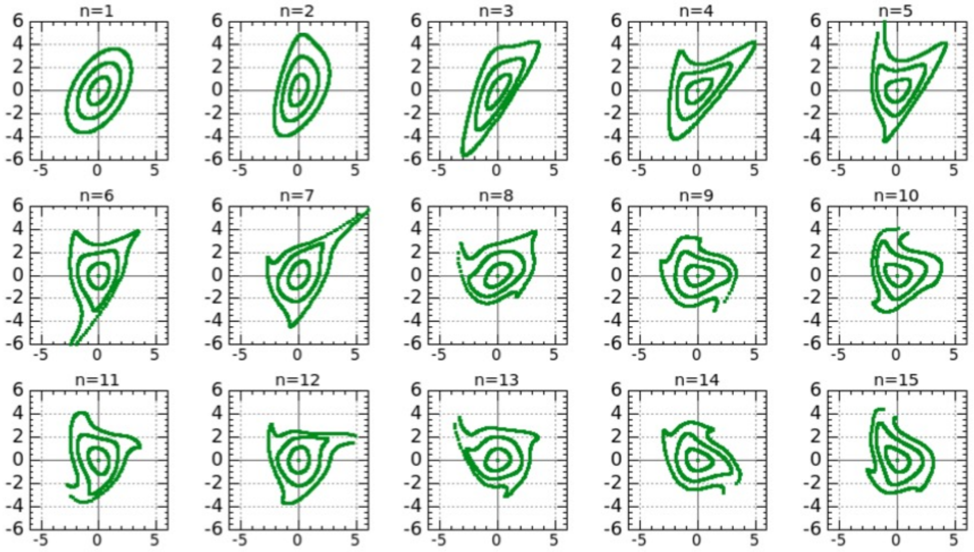
M. Kikuchi

- **Synchro-beta injection scheme**

$\delta = -0.635\ \%$

With Cancel-coil error

D01V1



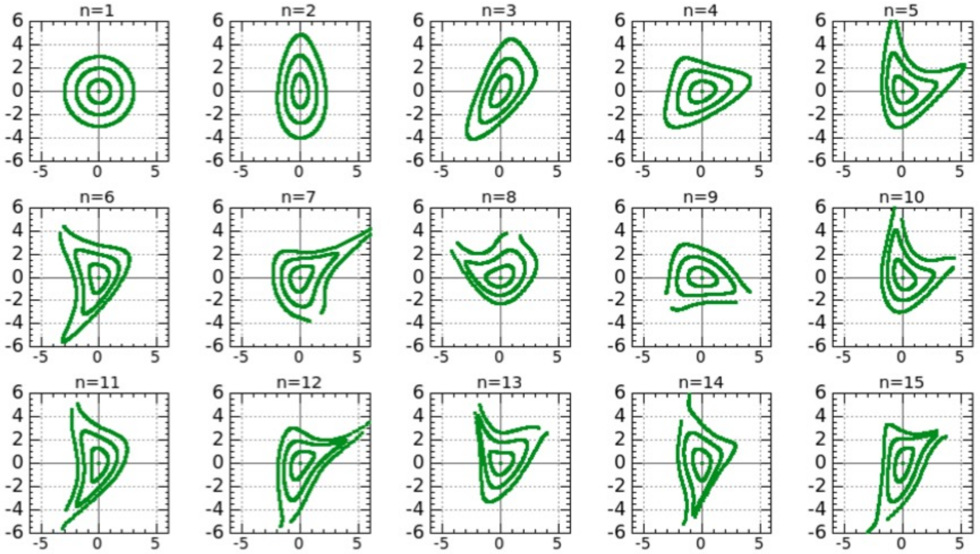
- Third-order resonance is seen.

- **Betatron injection scheme**

D01V1

$\delta = 0\ \%$

With Cancel-coil error



[1] M. Kikuchi, “Simulation of the injected beam in HER (2)”, SKB Commissioning meeting, Dec. 22, 2023, https://kds.kek.jp/event/49259/

Summary

Positron BT:

- No bunch charge dependence of beam emittances after DR.
- No bunch-charge dependence of beam emittances. **=> No wakes, No CSR wakes**
- **There are magnetic errors in Arc3** to explain the horizontal and vertical emittance blowups.
- BTp-Arc1 modification with 14-mm vertical offset does not degrade beam qualities.
- Raw injection efficiency is ~90%.

Electron BT:

- The vertical blowup is necessary to be mitigated, prior to high-current operation.
- Undesigned vertical dispersion was observed in Arc 1.
- QCS cancel-coil errors reduce on-momentum dynamic aperture by ~25%.
  => It reduces HER Injection efficiency.
- Raw injection efficiency is ~40% due to vertical emittance blowup in BT.
  => Synchro-beta injection is an option.

Thank you !

LER / HER Ring Acceptance Summary

Y. Ohnishi

LER

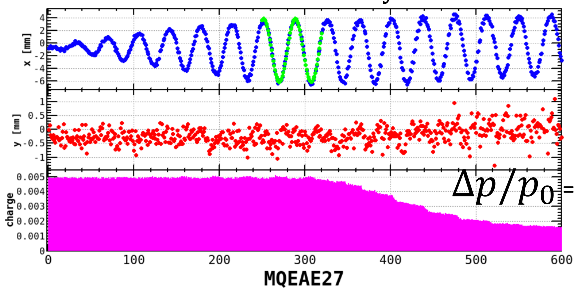
β_y^*	8 mm	3 mm	1 mm: CW OFF	1 mm: CW 80 %
	Feb. 19, 2024	March 4, 2024	March 6, 2024	March 18, 2024
$2J_x$ (m)	2.5×10^{-6} 25 σ_x 9.49×10^{-7} 15 σ_x	2.24×10^{-6} 23.6 σ_x 4.88×10^{-6} 35 σ_x	1.13×10^{-6} 16.8 σ_x 3.37×10^{-6} 29 σ_x	8.99×10^{-7} 15.0σ_x 3.37×10^{-6} 29 σ_x
$\gamma 2J_y$ (μm)	-	-	-	-
	Feb. 27, 2024	Feb. 29, 2024	March 6, 2024	March 18, 2024
$\Delta p/p_0$ (%)	0.58 1.03	0.38 1.26	0.53 1.33	0.61 1.11

HER

β_y^*	8 mm	3 mm	1 mm: CW OFF	1 mm: CW 40 %
	Feb. 20, 2024	March 4, 2024	March 5, 2024	March 18, 2024
$2J_x$ (m)	3.89×10^{-6} 28.9 σ_x 2.92×10^{-6} 25 σ_x	2.11×10^{-6} 21.8 σ_x 3.31×10^{-6} 27σ_x	1.34×10^{-6} 17.4 σ_x 2.77×10^{-6} 25σ_x	1.13×10^{-6} 16.0 σ_x 2.77×10^{-6} 25σ_x
	Feb. 26, 2024	Feb. 29, 2024	March 14, 2024	March 18, 2024
$\gamma 2J_y$ (μm)	1426 6413	1187 3982	649 973	712 973
	Feb. 20, 2024			
$\Delta p/p_0$ (%)	0.69 1.07	-	-	-

green: tracking simulation with collimator aperture

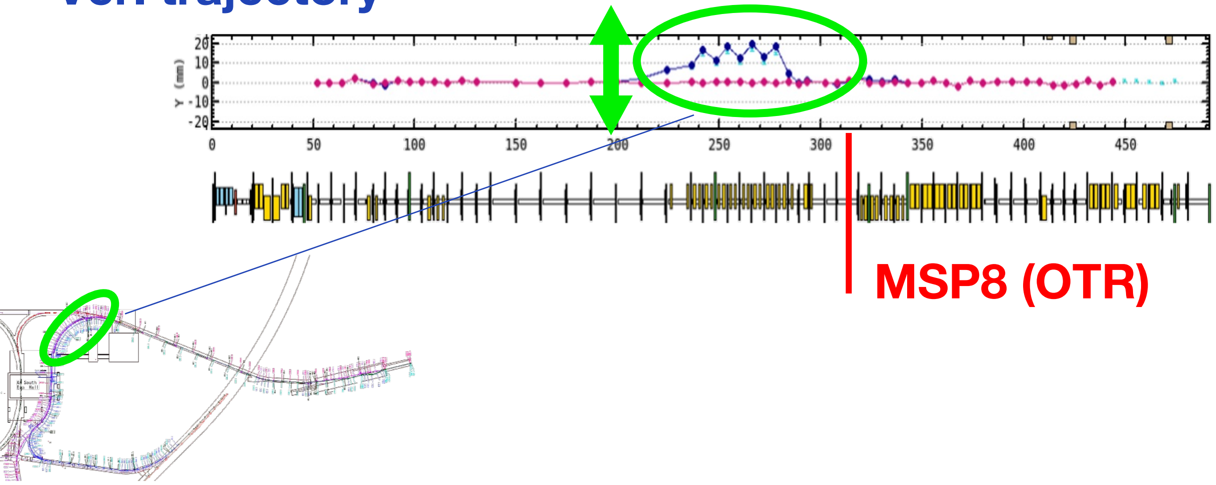
HER RF Kick example ($\beta_y^* = 8$ mm)



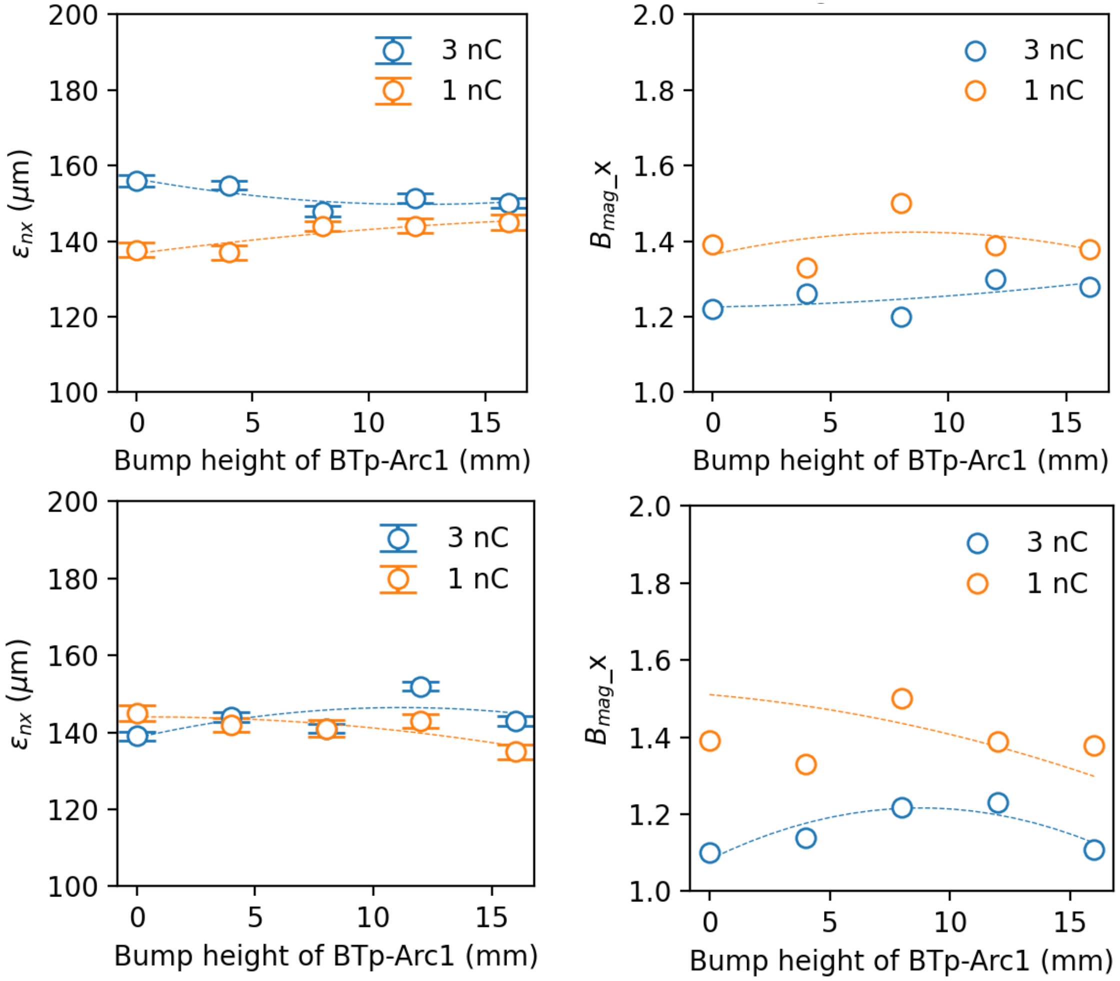
BTp-Arc1 Bump Height Study @ MSP 8

Scheme:
Change ver. bump height in BTp-Arc1 to confirm whether wake (bunch-charge dependence) effects including CSR ones are significant or not.

Ver. trajectory



ECS-Es (kV)	Normalized hor. emittance	Mismatch factor: B_{mag}
35		
37.5		



Results:
No large bump height dependence of hor. emittances, regardless of the ECS setting (ECS-Es).

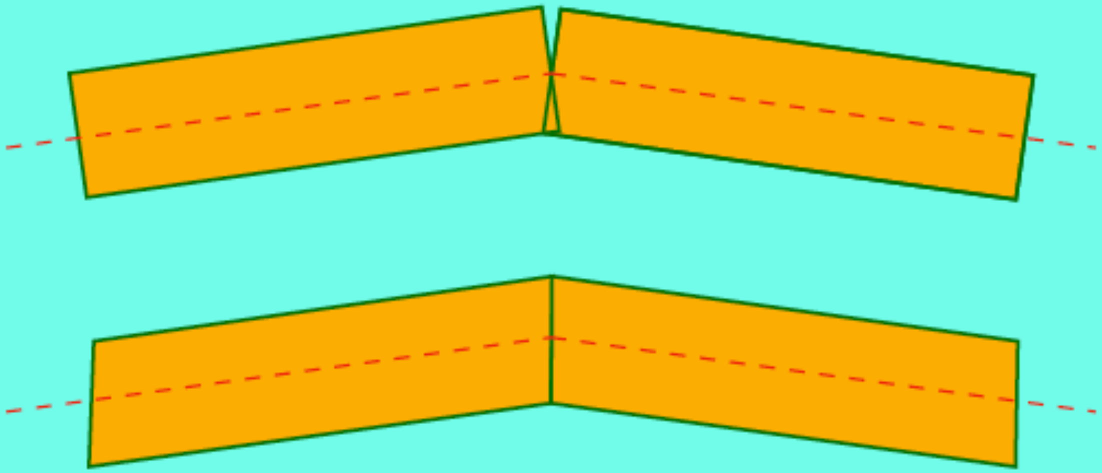
=> No significant wakes?

Measurement: 20231223

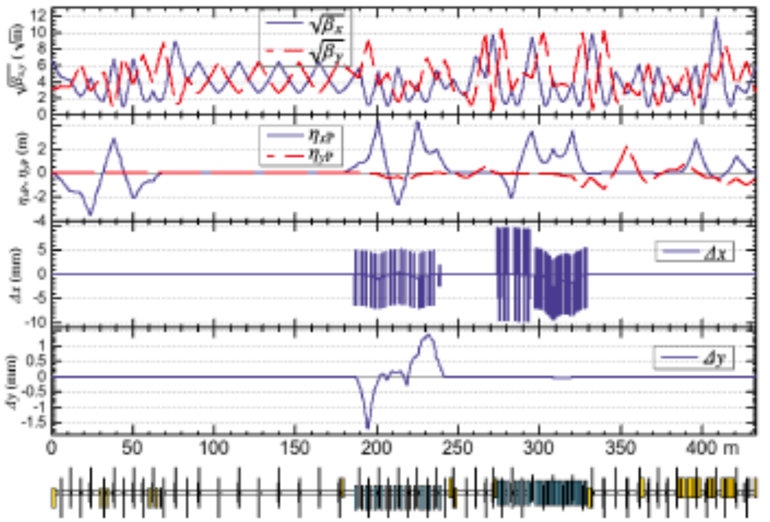
Multipoles on BH2P/BH3P (refined bend model)

K. Oide, Feb. 14, 2024 @ICG
Multipole calculation, quad roll: M. Tawada
Perm. skew Q: M. Kikuchi
Emittance meas. @BT1 T. Yoshimoto
Sext. meas., Lattice, initial particles, etc.: N. Iida, Y. Seimiya, T. Yamaguchi

- The model of BH3P is refined to represent the magnet and field measurement more correctly:
- previous
- now:



- A modification of SAD was necessary to put arbitrary edge angles in MULT.



	BH2P	BH3P
SK0	4.54E-18	-5.202E-07
SK1	2.787E-04	3.867E-04
SK2	2.465E-15	-3.130E-03
SK3	-1.903E-01	-4.740E+00
SK4	6.518E-11	1.172E+01
SK5	3.609E+02	2.436E+04
K0	-7.106E-02	-2.119E-01
K1	-5.427E-16	1.039E-03
K2	2.907E-01	1.843E+00
K3	-3.099E-12	-3.870E-01
K4	-2.771E+02	4.396E+01
K5	3.011E-09	1.333E+03

M. Tawada https://kds.kek.jp/event/32764/contributions/157768/attachments/126065/149470/EPTF-190927.pdf

Various BTe Emittance Data:

$\Delta\phi$(SB3-5) = -4°

J-Arc R_{56}: 0 m

BT1 (WS)	0.8 nC	1.1 nC	1.3 nC	1.5 nC	1.6 nC
$\gamma\varepsilon x$ [μm]	43.8±9.4	47.0±6.1	43.8±4.8	40.9±7.3	47.1±6.9
$\gamma\varepsilon y$ [μm]	40.1±7.2	48.3±12.7	53.5±6.3	45.3±6.1	49.0±5.1

BT2 (MSE.16)	0.8 nC	1.1 nC	1.3 nC	1.5 nC	1.6 nC
	2022/Jun/27				
$\gamma\varepsilon x$ [μm]	96.6±0.82	117±1.3	126±1.7	122.9±2.2	127.9±2.1
$\gamma\varepsilon y$ [μm]	104.8±4.2	78.9±1.9	57.3±1.7	50.8±1.0	68.5±2.3

J-Arc R_{56} : 0.3 m

		1.0 nC	0.9 nC	1.6 nC	2.2nC	2.0 nC	1.8 nC
		2021/3/26	2022/Nov/5			2024/Feb/12	2024/Feb/28
BT1 (WS)	$\gamma\varepsilon x$ [μm]	50	33.2± 8.0		51.5±15.7	95.2±15.3	78
	$\gamma\varepsilon y$ [μm]	30	40.8±11.1		48.0±14.3	81.9±13.4	
BT2 (MSE.16)	$\gamma\varepsilon x$ [μm]	100	164.0±3.8	167.3±1.8	231.3±6.0	230±58	143±3.2
	$\gamma\varepsilon y$ [μm]	50	81.0±5.2	50.5±2.3	127.7±39.3	182±14	218±3.5