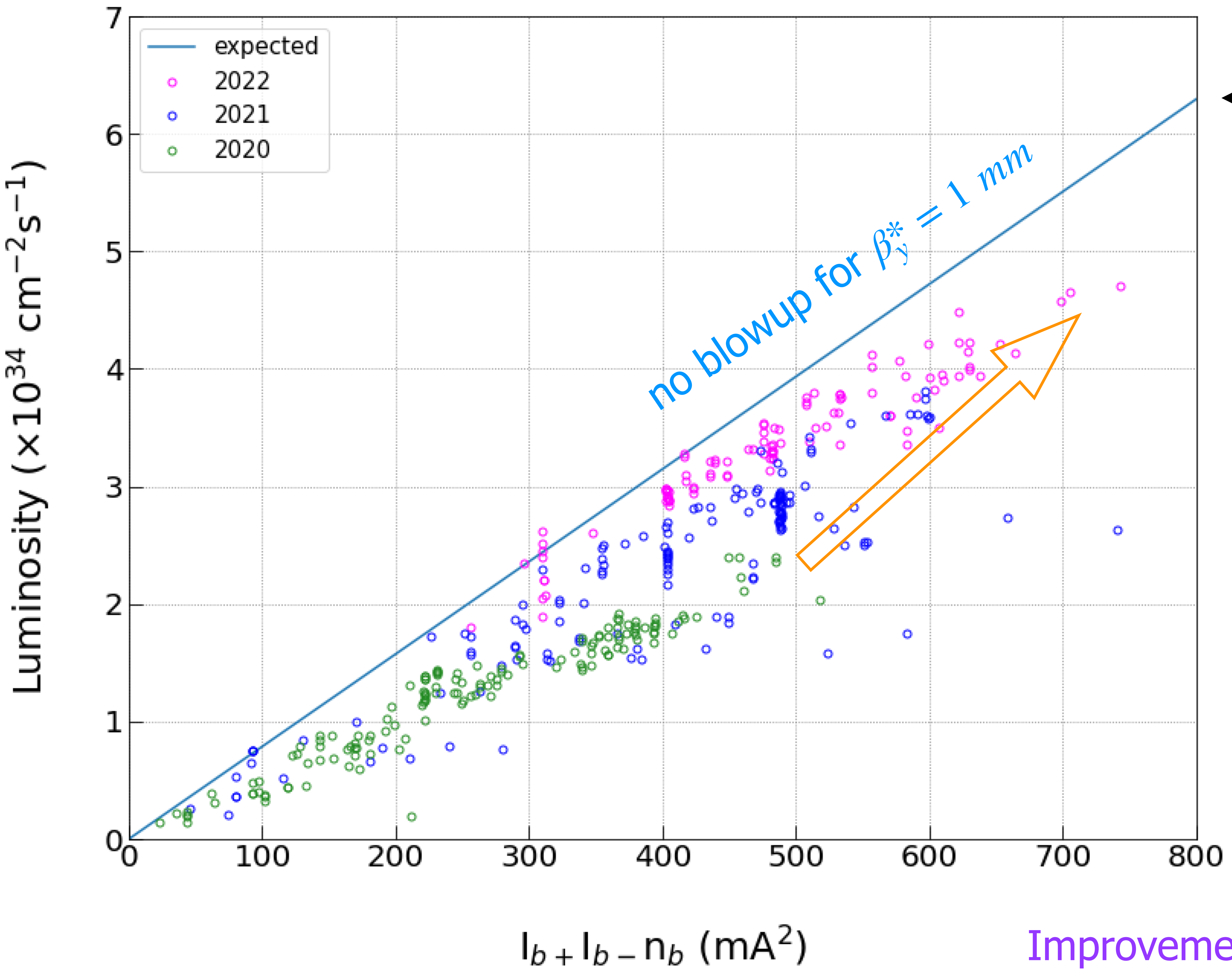
Commissioning Plan in Run 2

Y. Ohnishi

BPAC Focused Review



$$L = \frac{N_+ N_- n_b f_0}{4\pi\sigma_x^*\sigma_y^*} R_L = \frac{n_b I_{b+} I_{b-}}{2\pi(e^2 f_0)\phi_x \Sigma_z \Sigma_y^*}$$

half crossing-angle: $\phi_x = 41.5\ mrad$

expected: $\Sigma_z = 7.8\ mm$

bunch length: $\Sigma_z = \sqrt{(\sigma_{z+})^2 + (\sigma_{z-})^2}$

$\beta_y^* = 1\ mm$

$\varepsilon_{y+} = 35\ pm$

$\varepsilon_{y-} = 25\ pm$

$\Sigma_y^* = \sqrt{(\varepsilon_{y+} + \varepsilon_{y-})\beta_y^*}$

The luminosity improves with each passing year: 2020, 2021, and 2022. Especially, it is significant for higher $n_b I_{b+} I_{b-}$.

Improvements:
from 2020 to 2021: manage of HER BxB FB gain, impedance (collimator)
from 2021 to 2022: chromatic X-Y coupling correction, unexpected β_y^* squeezing ?

In order to achieve 10^{35} cm^{-2}s^{-1}, blowup should be considered. $n_b I_{b+} I_{b-}$ = 1295 mA^2 is necessary with $\beta_y^* = 0.8\ mm$.

I_{b+} / I_{b-} / nb = 0.89 mA / 0.62 mA /2346

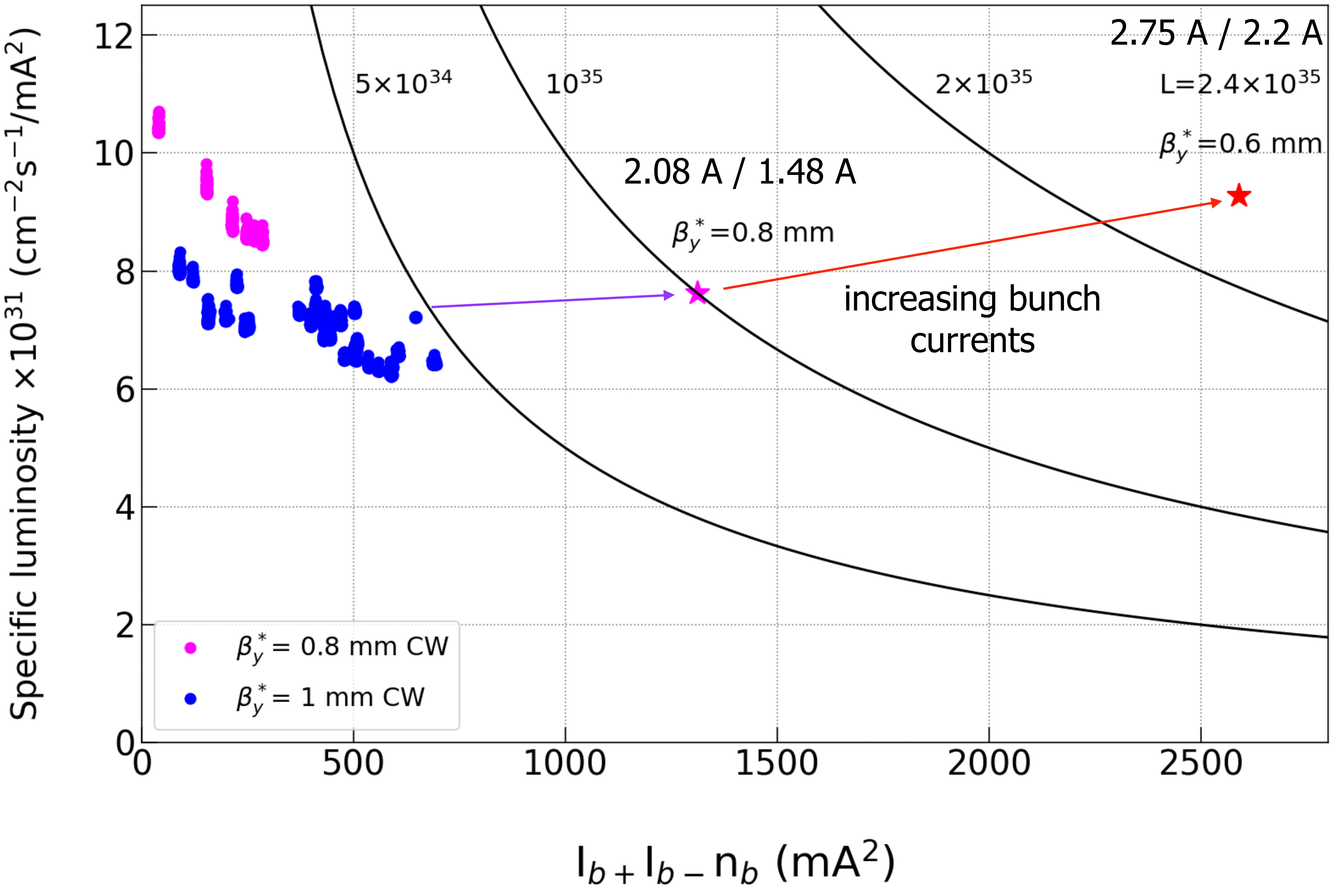
Machine Parameters

	June 8, 2022		Target at post-LS1 (1)		Target at post-LS1 (2)		Unit
Ring	LER	HER	LER	HER	LER	HER	
Emittance	4.0	4.6	4.0	4.6	4.0	4.6	nm
Beam Current	1321	1099	2080	1480	2750	2200	mA
Number of bunches	2249		2346		2346		
Bunch current	0.587	0.489	0.89	0.63	1.17	0.94	mA
Horizontal size σ_x*	17.9	16.6	17.9	16.6	17.9	16.6	μm
Vertical cap sigma Σ_y*	0.303		0.217		0.178		μm
Vertical size σ_y*	0.215		0.154		0.126		μm
Betatron tunes ν_x / ν_y	44.525 / 46.589	45.532 / 43.573	44.525 / 46.589	45.532 / 43.573	44.525 / 46.589	45.532 / 43.573	
β_x* / β_y*	80 / 1.0	60 / 1.0	80 / 0.8	60 / 0.8	80 / 0.6	60 / 0.6	mm
σ_z	4.6	5.1	6.5	6.4	6.5	6.4	mm
Piwinski angle	10.7	12.7	10.7	12.7	10.7	12.7	
Crab waist ratio	80	40	80	80	80	80	%
Beam-Beam ξ_y	0.0407	0.0279	0.0444	0.0356	0.0604	0.0431	
Specific luminosity	7.21×10^{31}		7.62×10^{31}		9.31×10^{31}		$cm^{-2}s^{-1}/mA^2$
Luminosity	4.65×10^{34}		1×10^{35}		2.4×10^{35}		$cm^{-2}s^{-1}$

10^{35} and 2.4×10^{35} are tentative and considered by Y. Funakoshi.

Strategy toward 2.4 x 10^{35} $cm^{-2}s^{-1}$

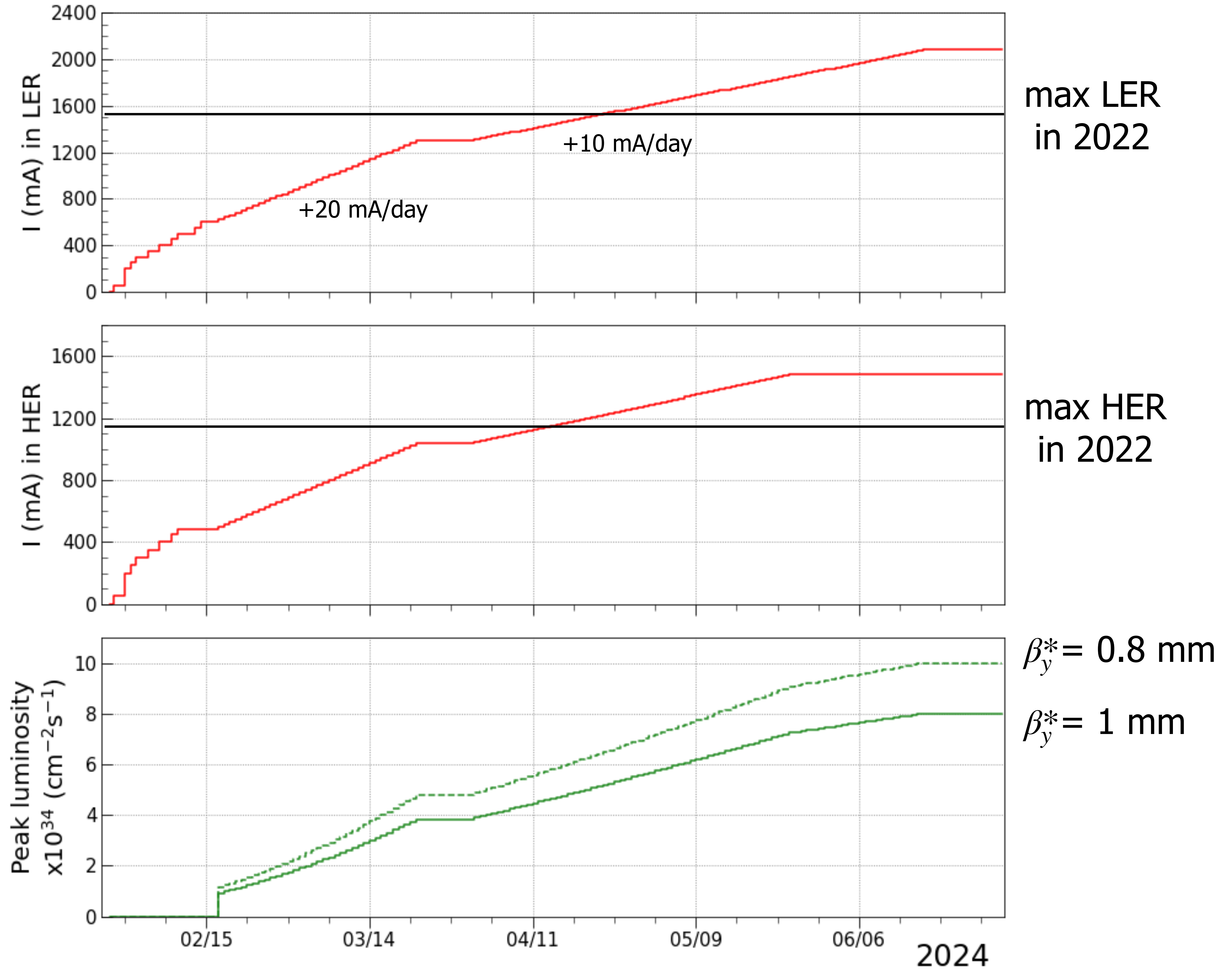
$$L_{sp} = \frac{L}{I_{b+} I_{b-} n_b}$$



Target Luminosity in 2024ab

Preliminary

8×10^{34} - 10^{35} $cm^{-2}s^{-1}$



Total bunch number is assumed to be 2346.
Increase total currents with bunch currents.

Sudden beam loss has to be suppressed.

Injection efficiency has to be kept at high currents
(Beam lifetime should be improved.)

Beam background has to be manageable level.
Number of beam aborts/day should be reasonable.

Single beam size blowup should be suppressed by reduction of the impedance and
BxB FB optimization (noise reduction)

Beam optics should be stable at high currents
by reducing beam orbit deviation between low and high currents.

Dynamic aperture for β_y^* = 0.8 mm might be problem
when we try to achieve 10^{35} $cm^{-2}s^{-1}$.

Seven Major Issues

1. Sudden beam loss
2. Beam-size blowup due to Beam-Beam interactions
3. Beam-related background
4. Injection efficiency and emittance blowup in the beam transport line
5. Difficulties to keep beam orbit stable and large vertical emittance for single beam
6. Short lifetime and narrow dynamic aperture
7. Beam-size blowup due to -1 mode instability in the LER (almost fixed the problem)

Schedule after LS1 at SuperKEKB

Beam tuning and machine study at Linac/e+DR/BT will be 6 weeks before MR start.
Vacuum scrubbing and machine study will be 3 weeks for the MR.
Machine study will be a higher priority even though during physics run.

	2023c				2024a												2024b											
	December				January				February				March				April				May				June			
Linac	Oct. 2 start			Dec. 28 end			Jan. 15 start																					
e^+DR	Nov. 27 start			Dec. 28 end			Jan. 15 start																					
BT	Nov. 30 start			Dec. 28 end			Jan. 15 start																					
LER								Jan. 29 start																				Jun. 30 end
HER								Jan. 29 start																				Jun. 30 end
Physics																												Jun. 30 end

Vacuum scrubbing and Machine study

Physics run will be available from end of February.

Shopping List for 2024a

- Vacuum scrubbing
  - 80 - 100 Ah (owl shift on weekday, 3 shifts for holiday)
- Adjustment and check of hardware devices (need time because it is after 1 year and half shutdown)
  - beam monitors, magnet polarity, magnet power supplies, timing system, injection system, cooling system, etc.
  - Mis-wiring of magnet cable and BPM cable should be considered.
- Commissioning of nonlinear collimator (including OHO wiggler optics tuning) in LER
- Correction of beam obit and optics (including BPM gain mapping, beam based alignment)
- Measurements of optics parameters, orbit fluctuations, tune scan, tune shift, TBT BPM analysis, etc.
  - chromatic X-Y coupling($r_1^{*\prime}$ and $r_2^{*\prime}$) adjustment by using rotatable sextupoles in LER
- Measurement and optimization of dynamic aperture (beam lifetime)
  - change sextupole setting, change crab-waist ratio, use QCS octupoles, etc.
- Study for single beam blowup and optimization of BxB feedback system
- Study of beam background with movable collimators

- Sudden Beam Loss
  - We replaced the damaged collimator heads during LS1.
  - Copper coating of collimator heads (D06H3, D06V1, D05V1, D02V1); It is effective if SBL is fire-ball event.
  - Install more loss monitors to find timing and acoustic sensors to detect sounds of fire-ball events.
  - Add another BOR to observe beam orbit changes at SBL source; Two BORs will be available to detect.
- Impedance
  - Nonlinear collimator in LER leads wider physical aperture in vertical. It helps to reduce impedance.
- Beam Orbit and Optics Changes between Low and High Currents
  - Beam pipe deformation caused by SR heating (magnets move as the result, orbit offset at sextupoles might induce beta-beat and X-Y couplings, etc.). → isolation of BPM from quadrupole magnet and install gap sensor between the BPM and quadrupole magnet.
  - Cooling water temperature effects → improve control system

Measures Against (cont'd)

- Beam Injection and Emittance Blowup in the Beam Transport Line (BT)
  - Modification of injection point in HER; enlargement of horizontal aperture of beam pipe to reduce coherent orbit oscillation, then injection efficiency is expected to be improved.
  - Additional pulse dipole/quadrupole magnets in linac can control beam optics well and contribute better injection efficiency. (commissioning before MR)
  - Since the influence of CSR is suspected, we will test shielding effects to suppress CSR in the positron BT.
- Machine Error
  - Vertical angle at IP in HER is optimized by using temperature balance between upper and lower side of beam pipe due to SR heating at downstream of IP. Then, the vertical angle at IP in LER is optimized by luminosity scan.
  - Horizontal angle at IP in HER is optimized by minimizing error of horizontal dispersions. We expect SR on PXD will decrease at the new IP chamber.

Summary

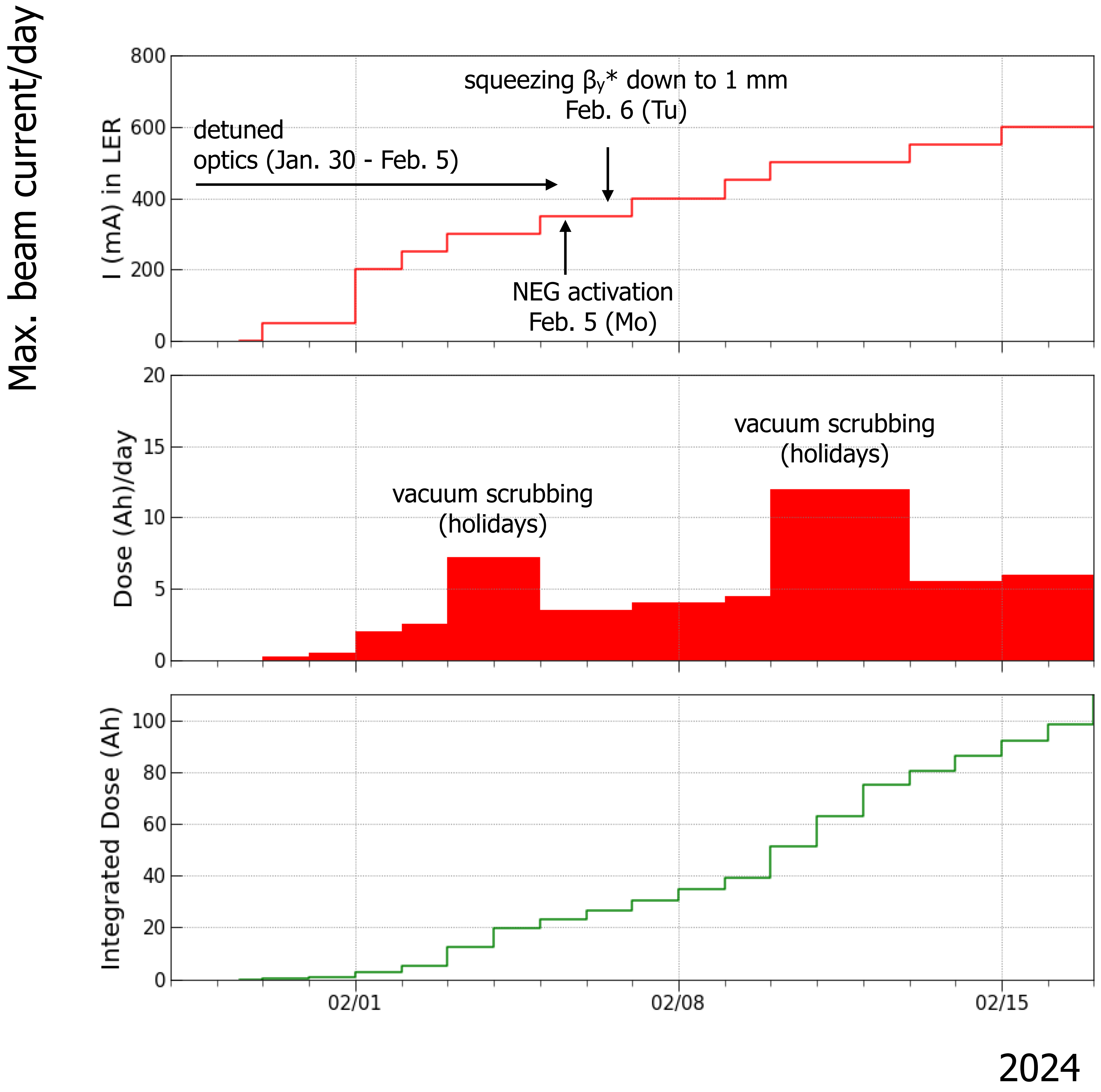
Strategy for 10^{35} $cm^{-2}s^{-1}$ luminosity

- We will increase bunch currents. Max. number of bunches is 2346 (design value).
  - SBL problem has to be fixed.
  - Larger dynamic aperture and physical aperture (collimators) should be realized by sextupole setting and better detector background controls.
- Beam injection
  - Emittance blowup in the beam transport line (BT) has to be fixed.
- Luminosity performance at high beam currents
  - Single beam blowup has to be suppressed enough.
  - Beam-beam blowup should be suppressed as much as possible by reducing machine error.
- How to squeeze beta function at IP ? (still under discussion)
  - Tentative target is 0.8 mm. We have to decide at some point. We 'd like to check SBL occurs or not first.
  - Machine study is needed to make larger dynamic aperture (longer lifetime). It takes a lot of time.

Appendix

Plan of Vacuum Scrubbing for LER in 2024a

Y. Ohnishi, Nov. 2 ver.



I_{max} = 600 mA for the first 2 weeks
Bunch number depends on situations.

Day and evening shift (weekday) : machine study

Owl shift (1 am - 9 am) and holiday: vacuum scrubbing

Target integrated dose is 100 Ah until Feb. 17.

Sudden Beam Loss (SBL)

Beam becomes unstable suddenly at high beam current.
Beam loss can lead to severe damage on collimators or final focus magnet (QCS) quench.

LER beam current : 1.4 A
number of bunches : 2249
luminosity : 4.58 x 10^{34} $cm^{-2}s^{-1}$

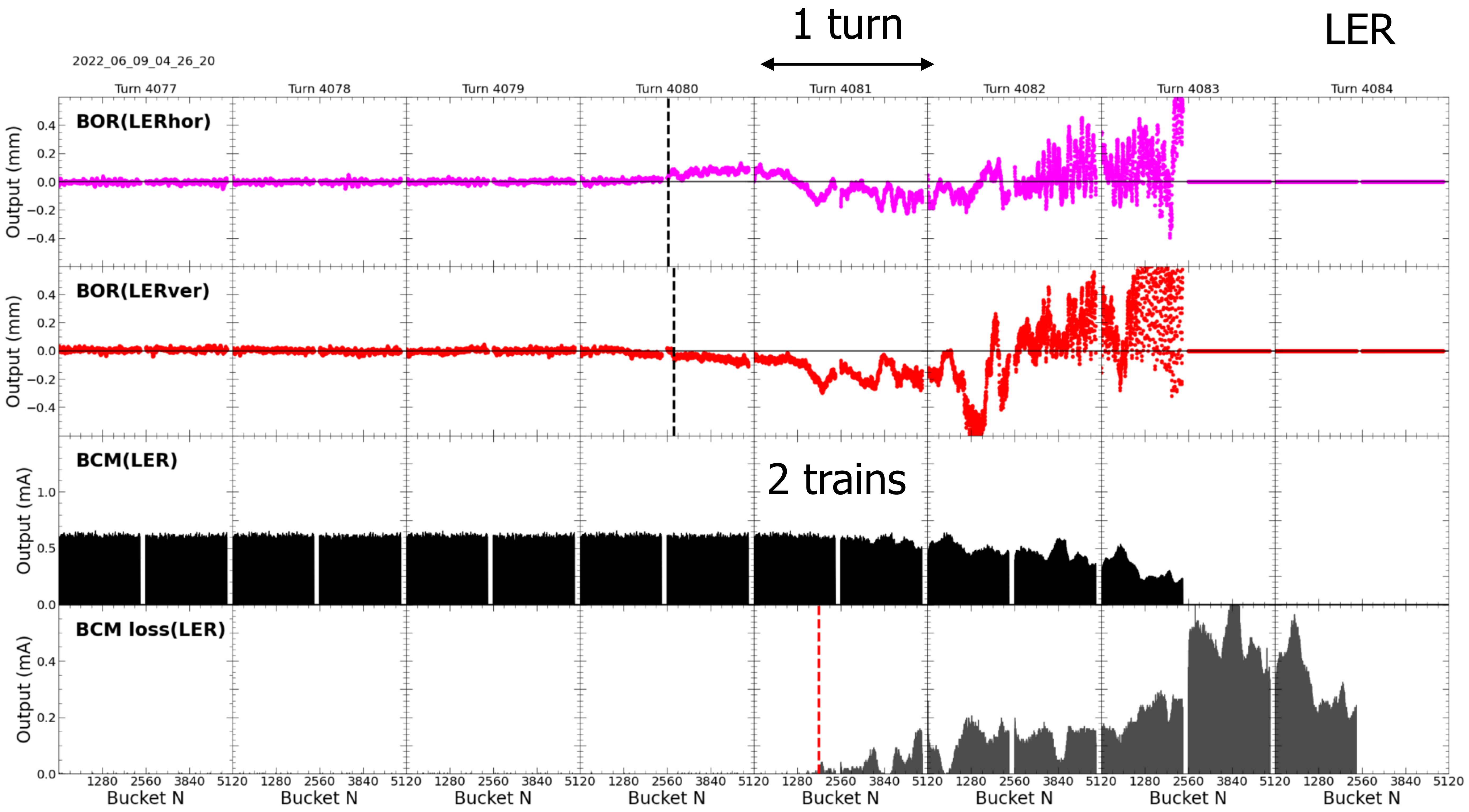
Beam loss within a few turns
without large oscillation before the loss.

Horizontal position

Vertical position

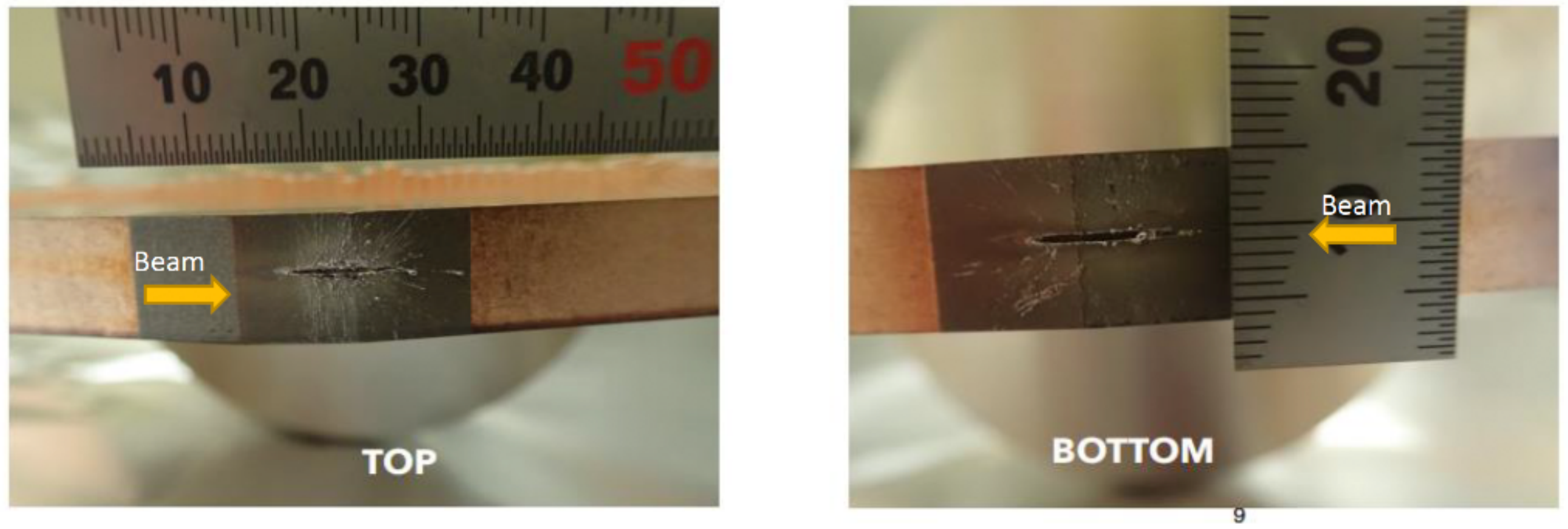
Bunch current

Amount of beam loss



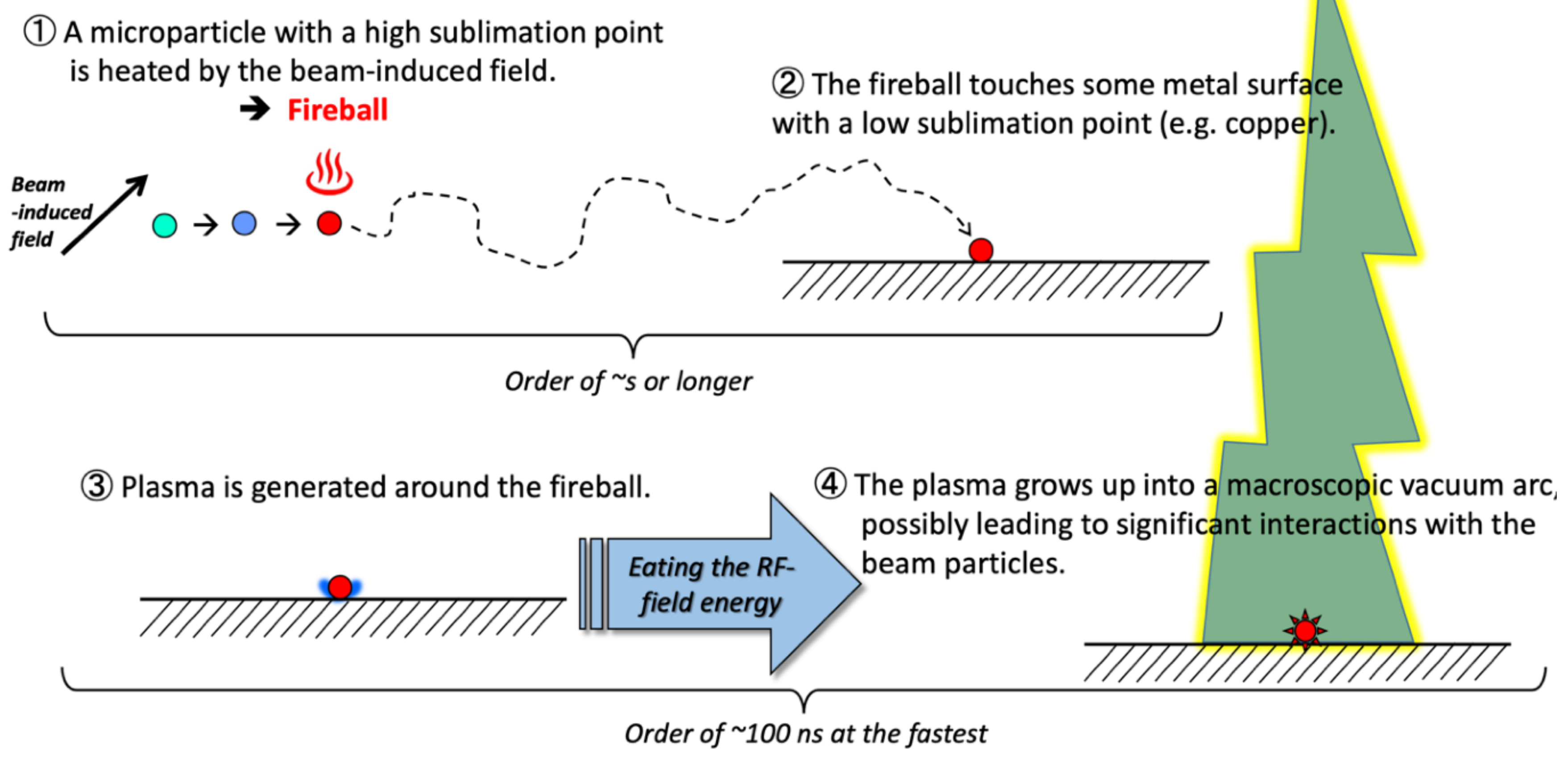
M. Aversano

Damage of collimator head



Fireball hypothesis

Physical process of the "Fireball" hypothesis, leading to fast beam loss



T. Abe at al., RF breakdown trigger, PR-AB 21, 122002, 2018.

Trigger source can be collimator head.

Copper coating of collimator head will be effective if different sublimation point is problem.

Commissioning of Nonlinear Collimator: D05V1 in LER

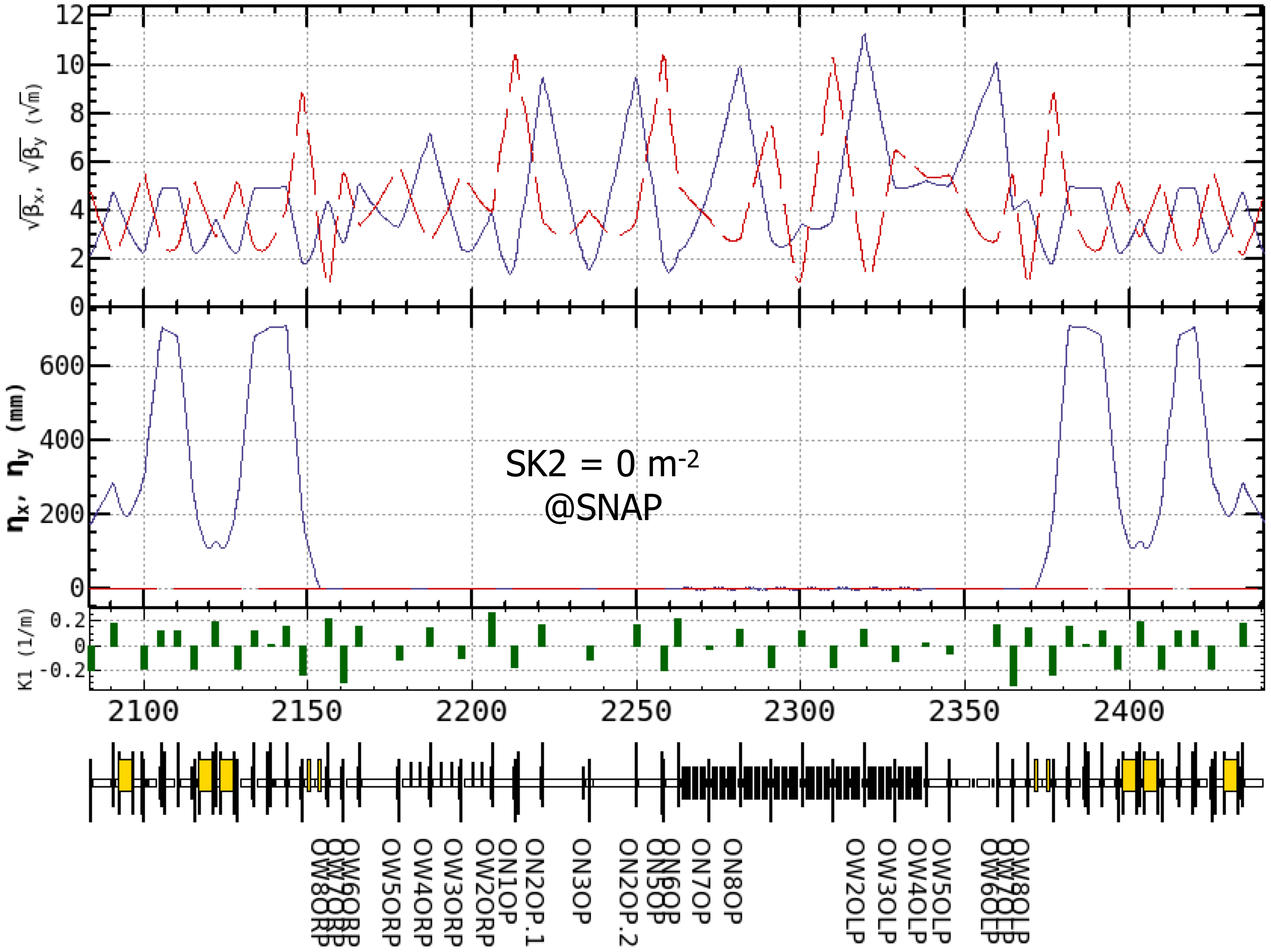
$\beta_x^* = 384$ mm / $\beta_y^* = 48.6$ mm

$\nu_x = 44.555$ / $\nu_y = 46.624$

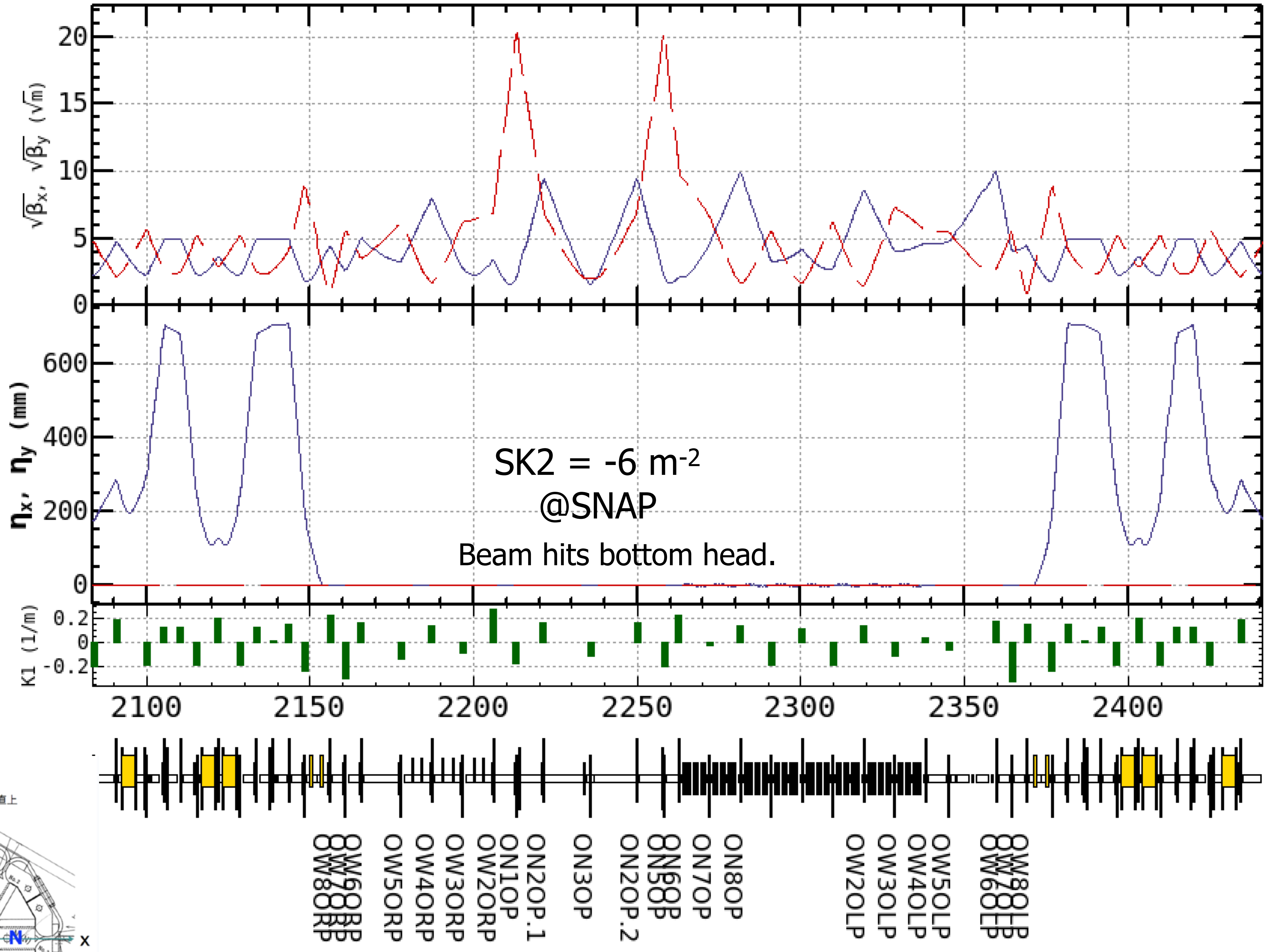
$$B_x = -\frac{B''}{2}(x^2 - y^2) \qquad \Delta p_y = \frac{B_x L}{B\rho} = \frac{K_2}{2}(y^2 - x^2)$$

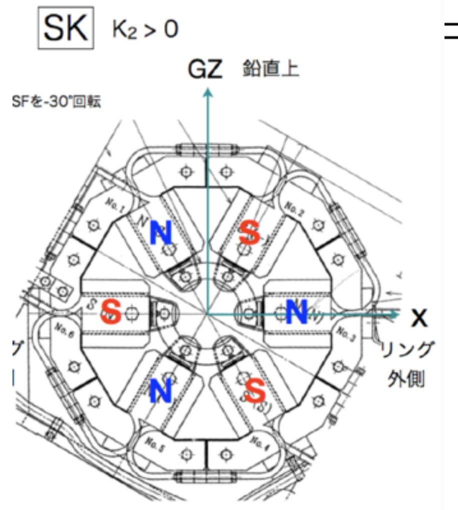
$$B_y = B'' xy \qquad M_{SNAP \to D05V1} \begin{pmatrix} 3.105 & 37.69 \\ -0.217 & -2.311 \end{pmatrix}$$

without D05V1 (day-1 optics)



with D05V1



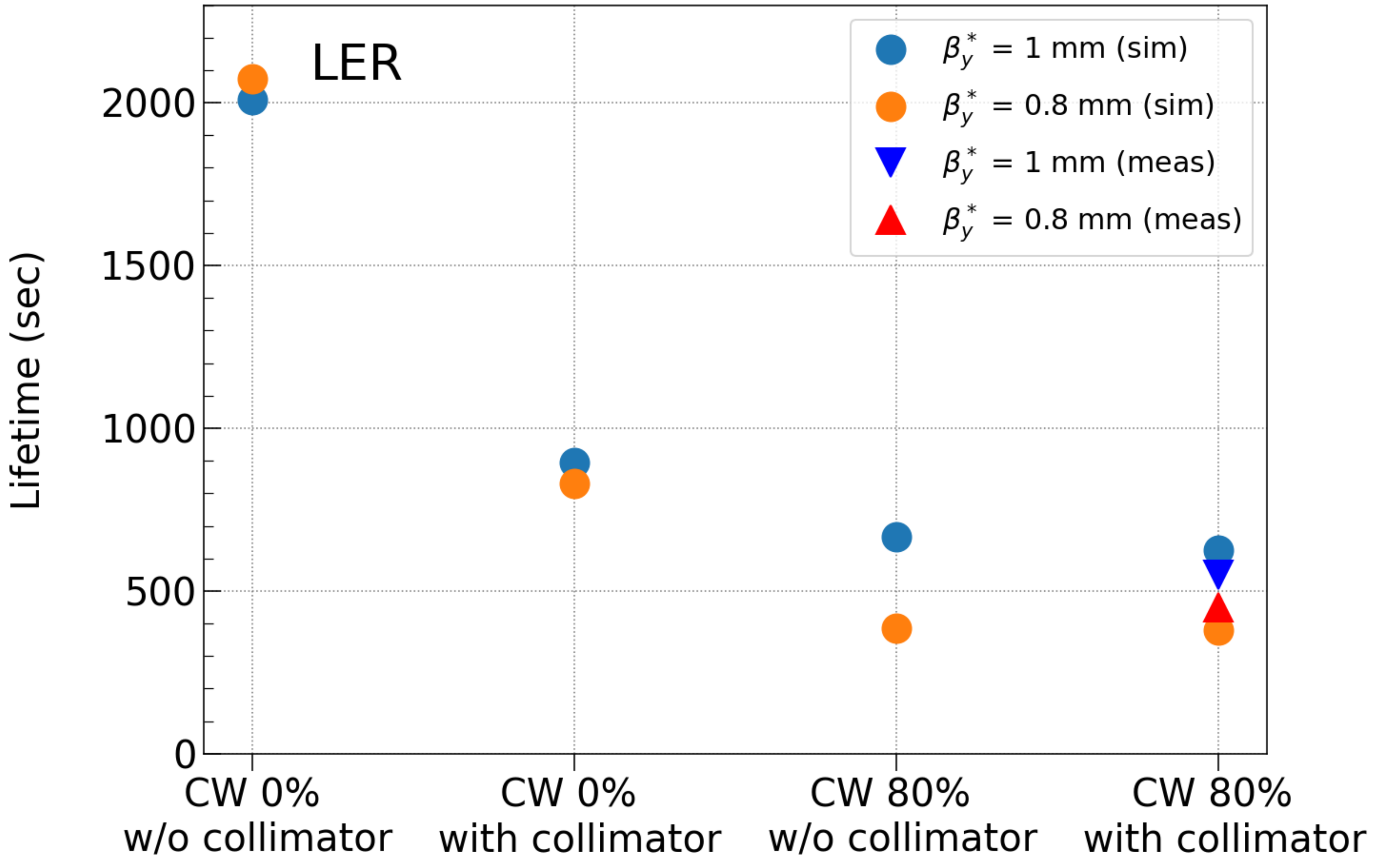


SNAP
(skew sextupole magnet)

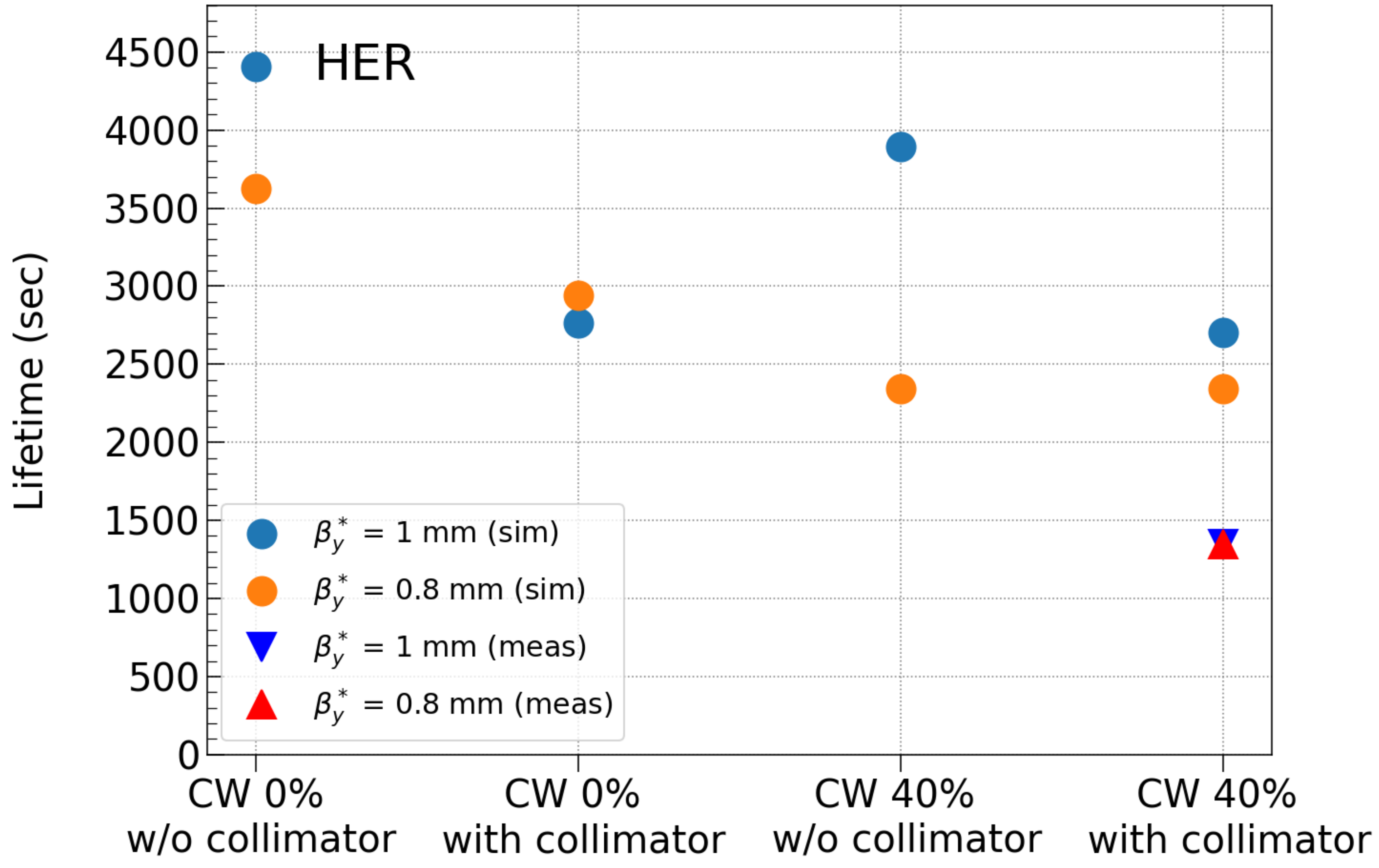
Touschek Lifetime: Simulation and Measurement

CW: Crab Waist

I_{b+} = 0.62 mA/bunch, ε_y = 40 pm



I_{b-} = 0.50 mA/bunch, ε_y = 35 pm



Simulation and measured lifetime is consistent with each other.
CW 80 % reduces lifetime significantly.
Dynamic aperture for CW 80 % restricts lifetime.

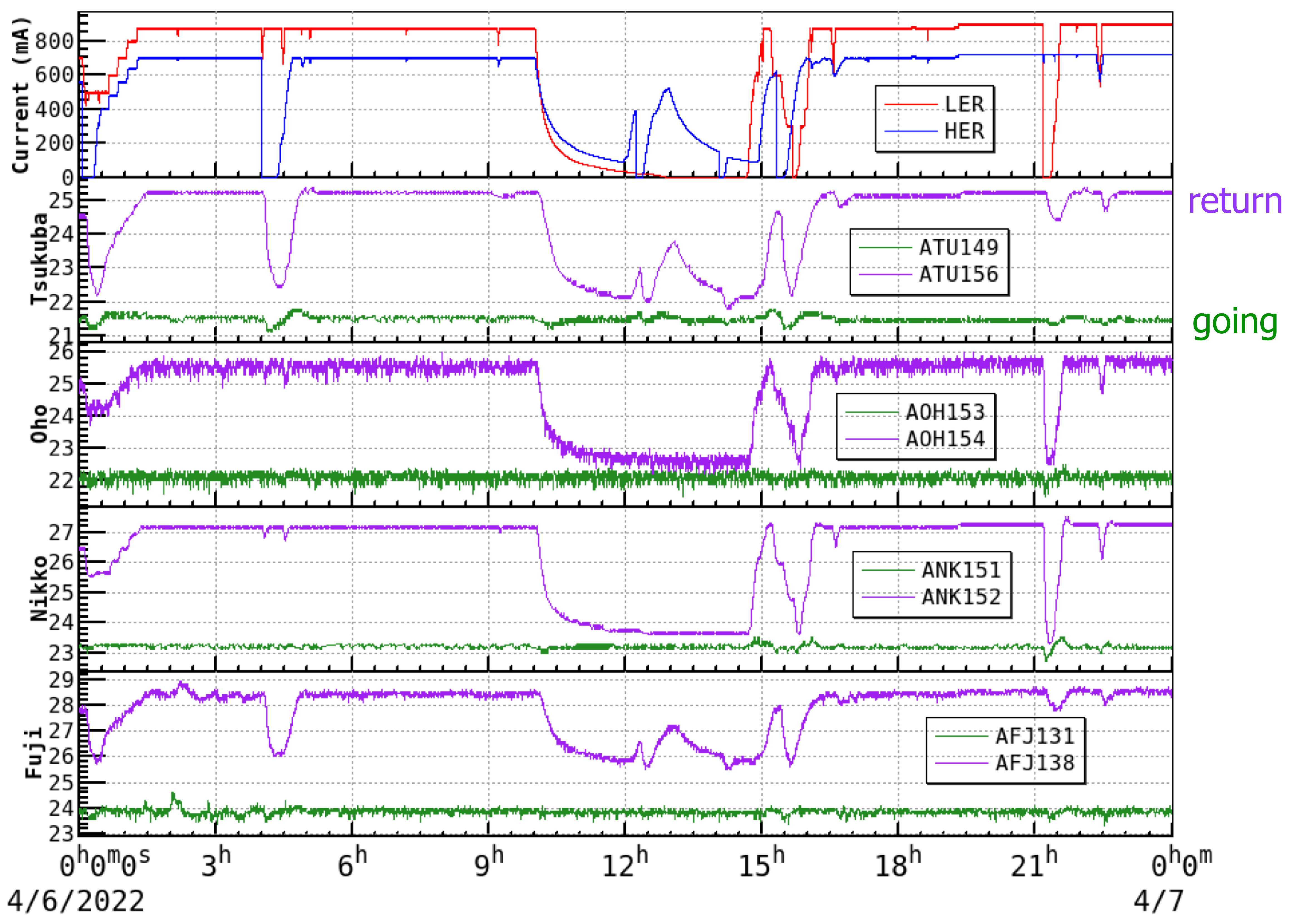
Machine error should be taken into account
such as skew sextupole and skew octupole magnet
gradient error in QCS, dispersion error at strong sextupoles.

Collimator aperture is narrower than dynamic aperture
for β_y^* = 1 mm. For β_y^* = 0.8 mm with CW 40 %,
dynamic aperture restricts lifetime.

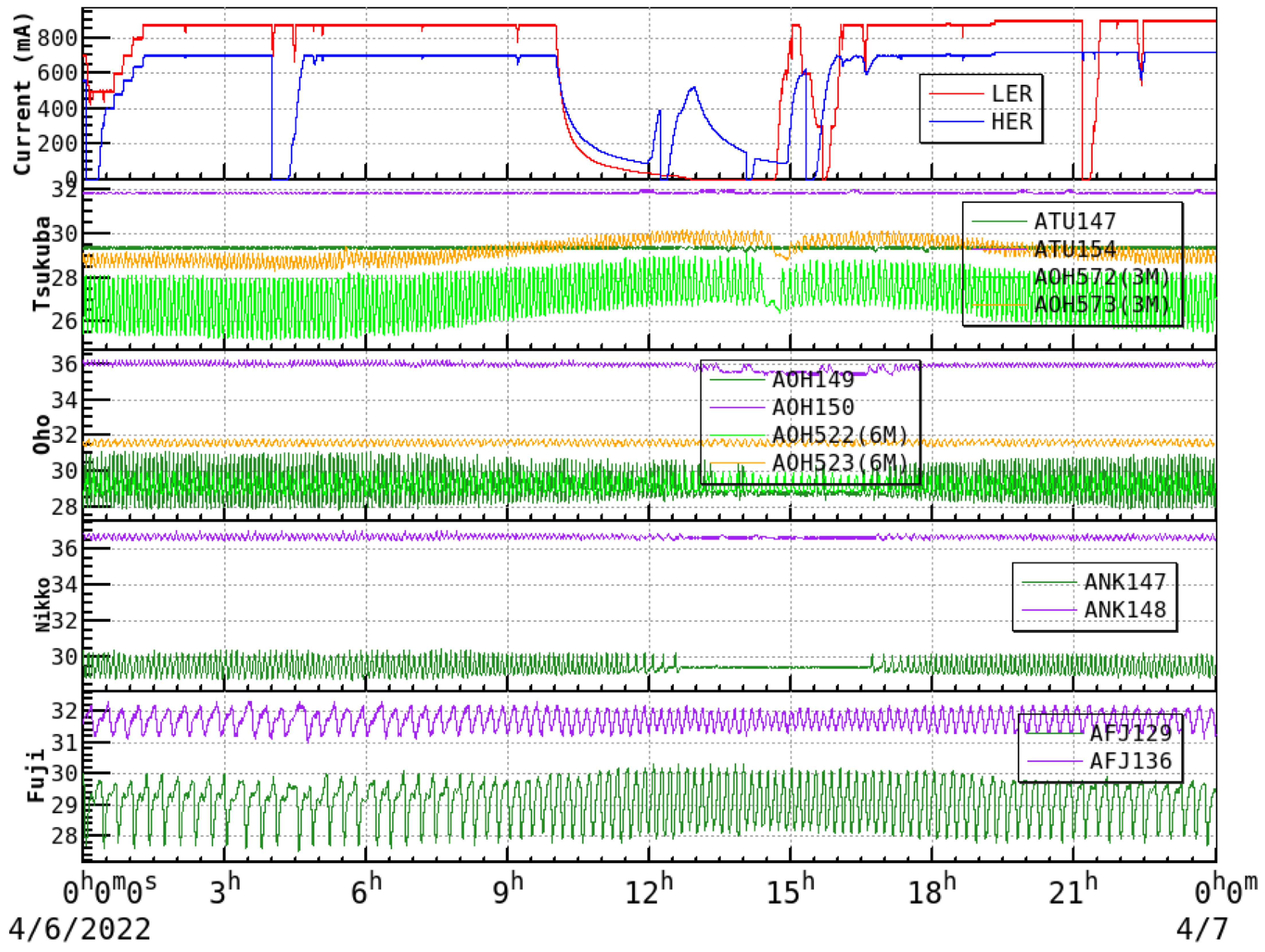
Cooling Water Temperature (Vacuum and Magnet System)

Vertical orbit fluctuation is affected by cooling water temperature of magnet system.

Vacuum system

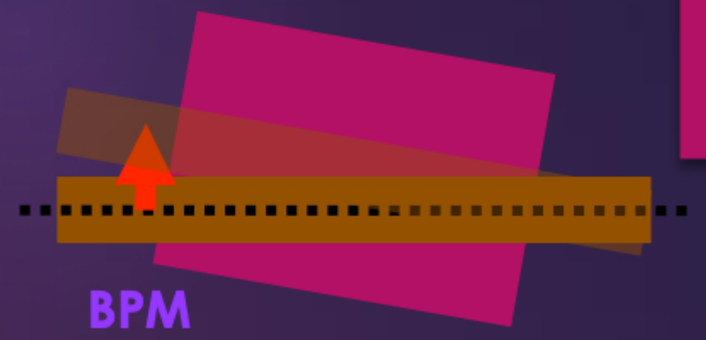


Magnet system



Cooling water system for vacuum system is very stable. If the heat load is lost due to abort, there is nothing that can be done.
Once the heat load is gone, the chiller will shut down for 30 minutes (for protection). This is the reason why it is recommended to slowly ramp up the beam current after abort.

Beam Optics & Orbit :Hypothesis of why orbit depend on beam current



Quad. moves like yaw
and horizontal shift
if BPM pushes quad.

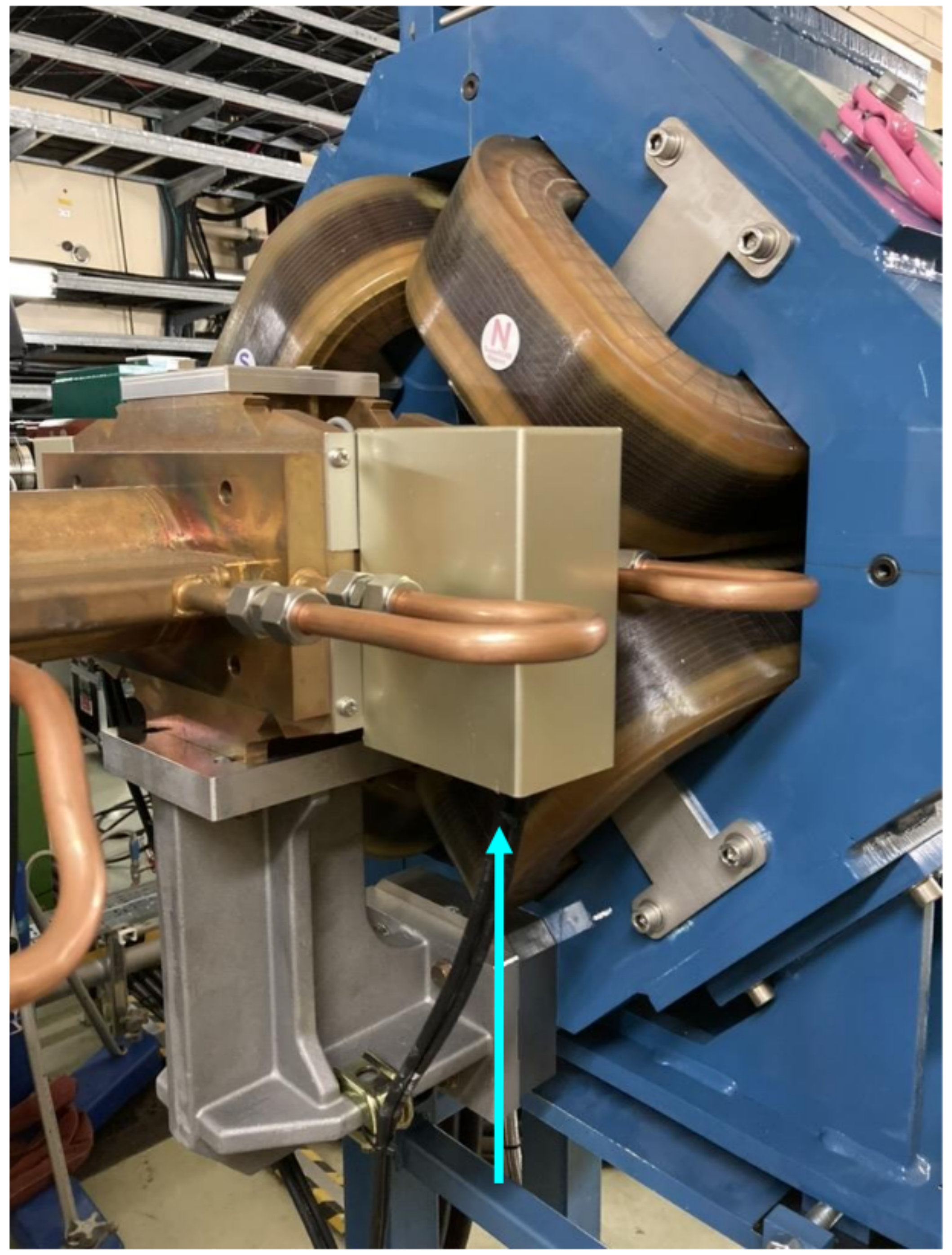
Radiation from the bending magnet thermally deforms the beam pipe.

- BPM and quadrupole magnet (Q) are connected by supports.
- When the beam pipe moves due to heat generation, BPM and Q move.
- Beam receives a dipole kick.

The fact that BPM is connected to Q complicates matters.

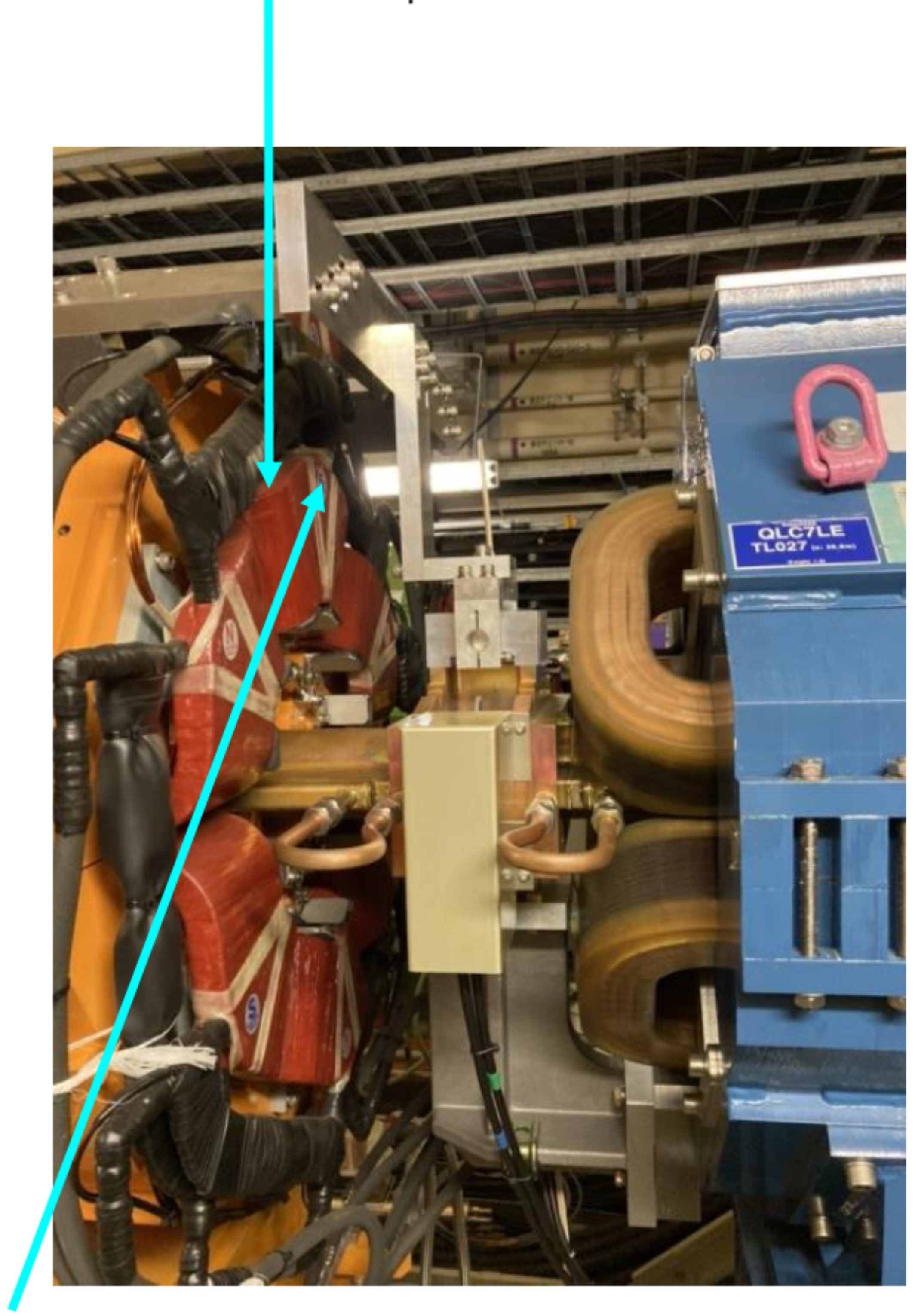
- If BPM and Q are disconnected, the problem becomes simpler.
- If the connection is severed, Q will not move even if the beam pipe is deformed and no orbit will be generated.
- Beam test scheduled for next operation

BPM and Quadrupole Magnet



The beam pipe (BPM) is fixed to the quadrupole magnet.

Crab Sextupole in the HER

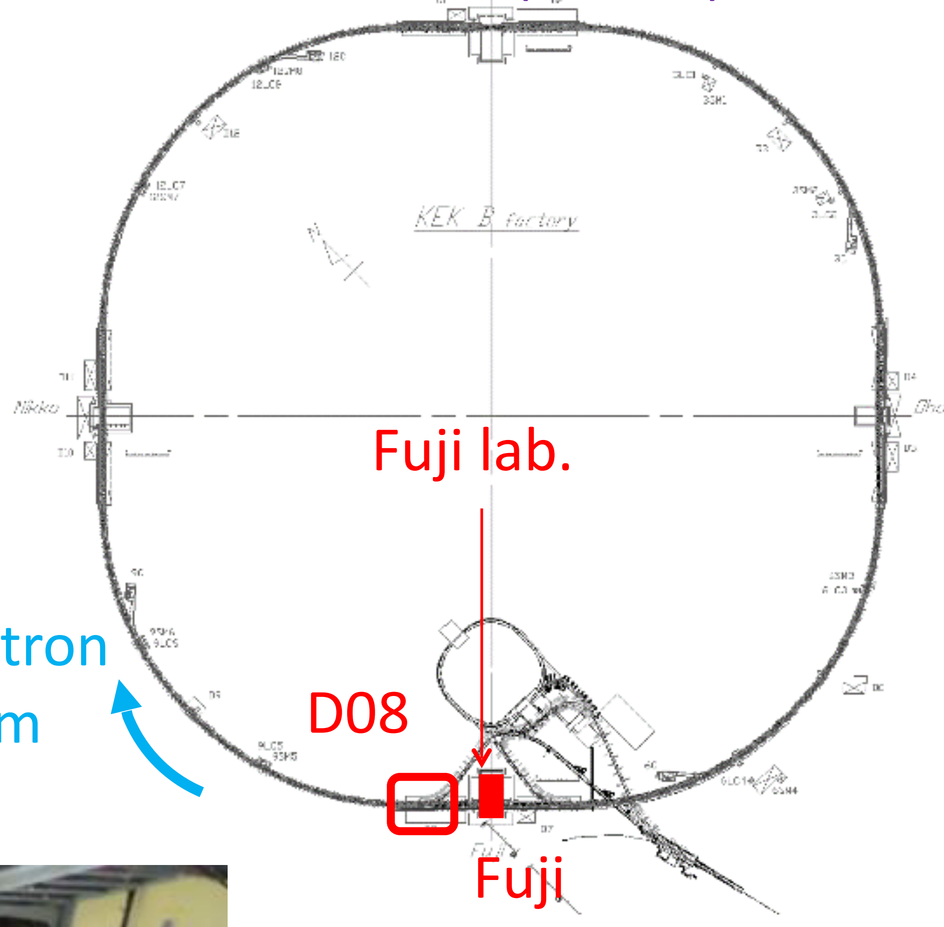


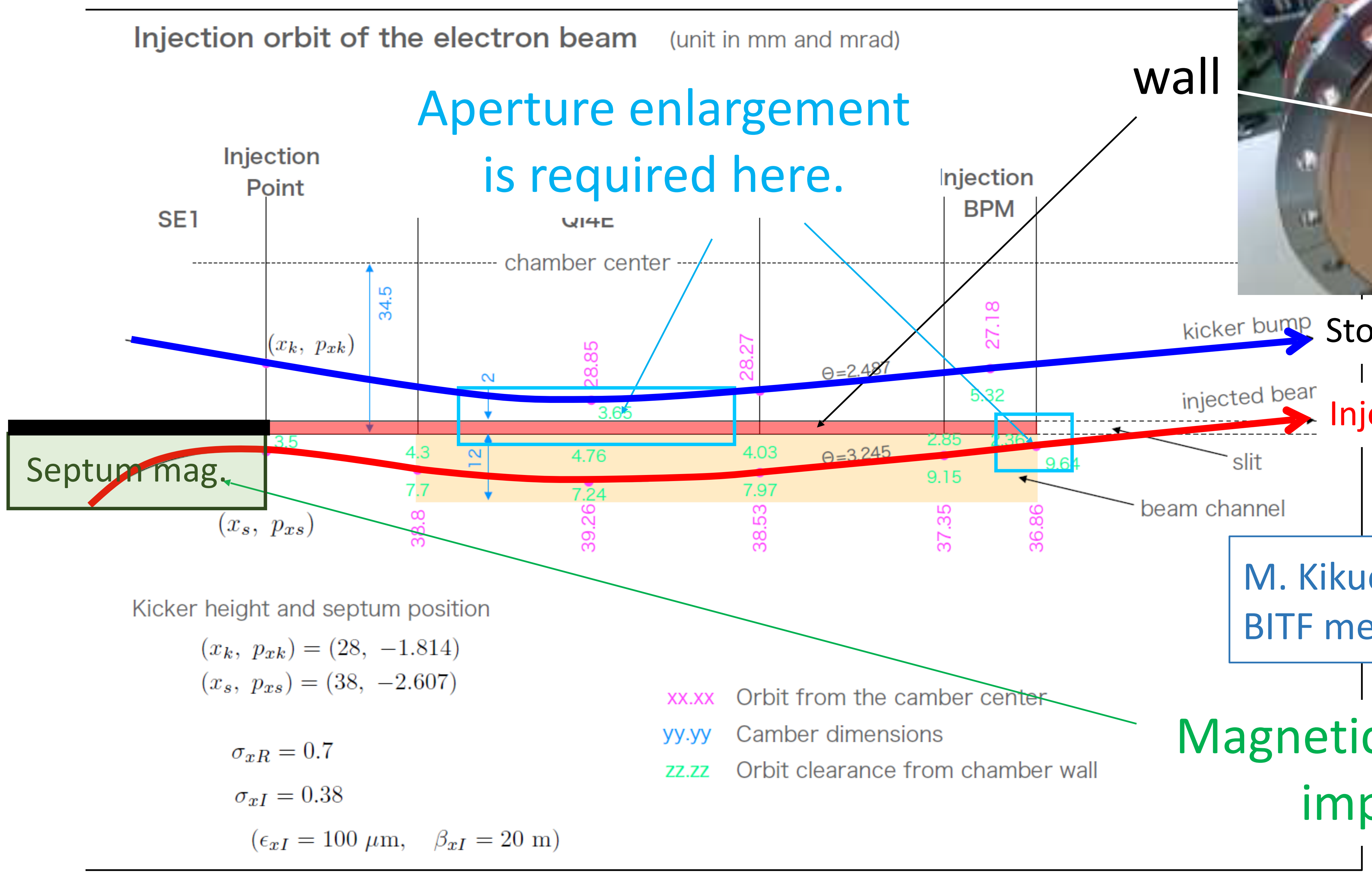
Gap sensor measures $(\Delta x, \Delta y)$ between BPM and sextupole.
Relation between BPM and quad. does not change. (see left fig.)

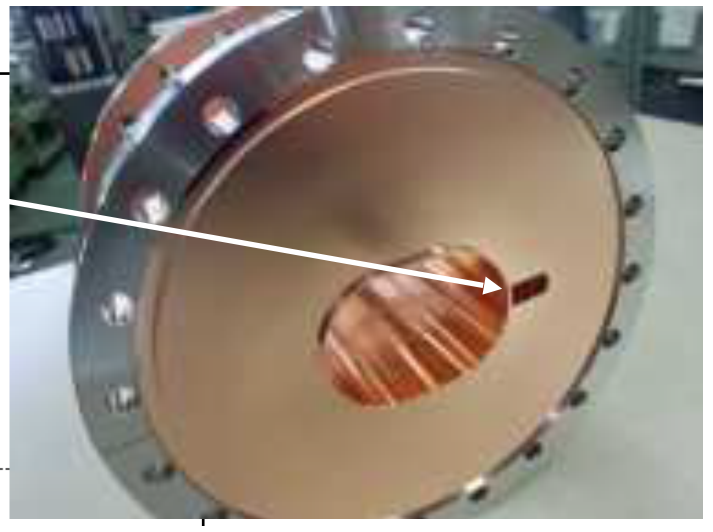
HER injection point

K. Shibata

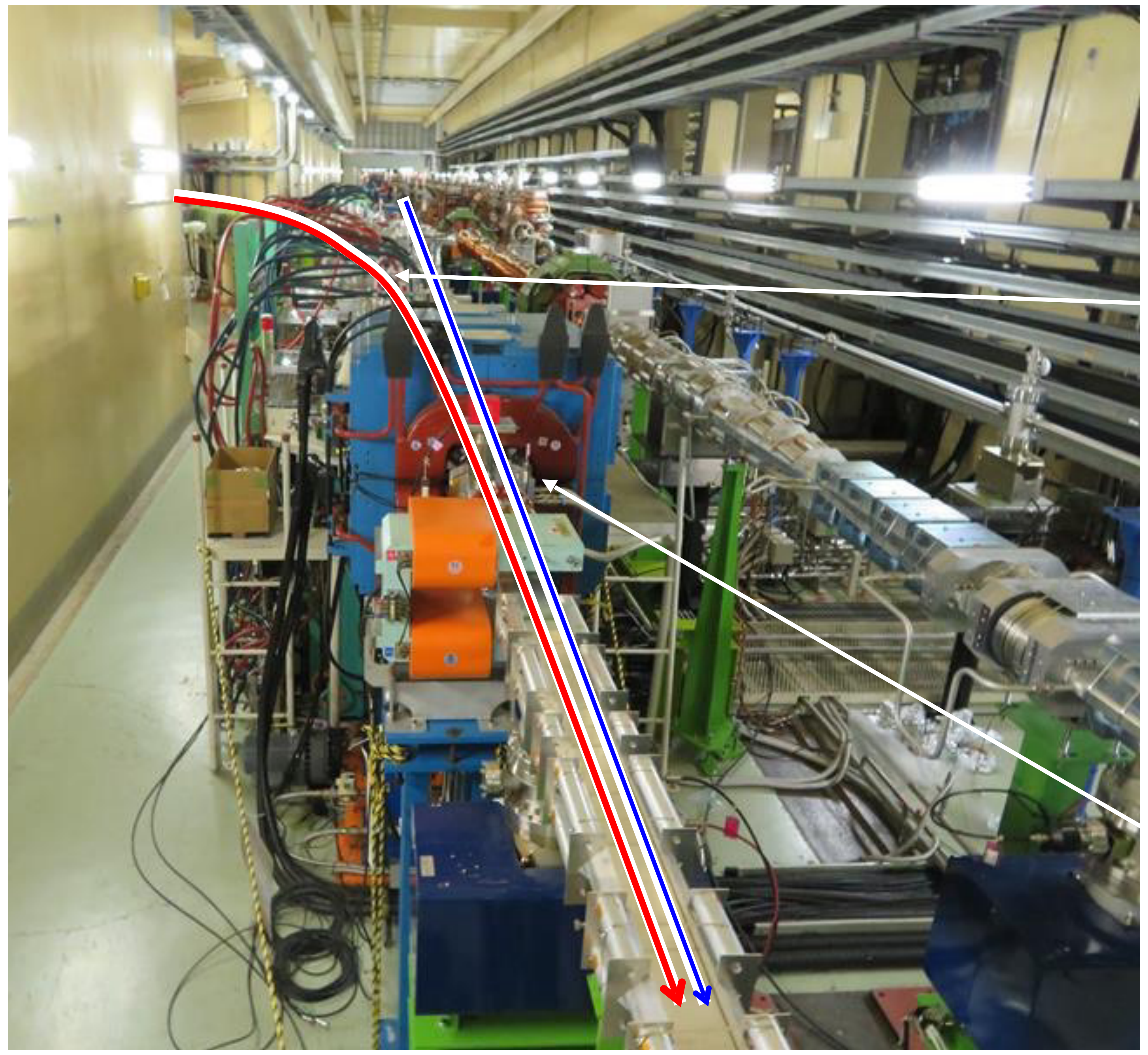
- Required upgrade to improve HER injection efficiency (what we have learned from beam operation until 2022b);
  - Enlargement of the horizontal aperture of beam pipe
  - ⇨ Replacement of beam pipes at injection point with new one with larger aperture (last week)
  - Reduction of amplitude of horizontal oscillation of injected beam
  - ⇨ Replacement of injection septum magnet with new one with improved magnetic field (Oct.)







M. Kikuchi (2021.12.03)
BITF meeting



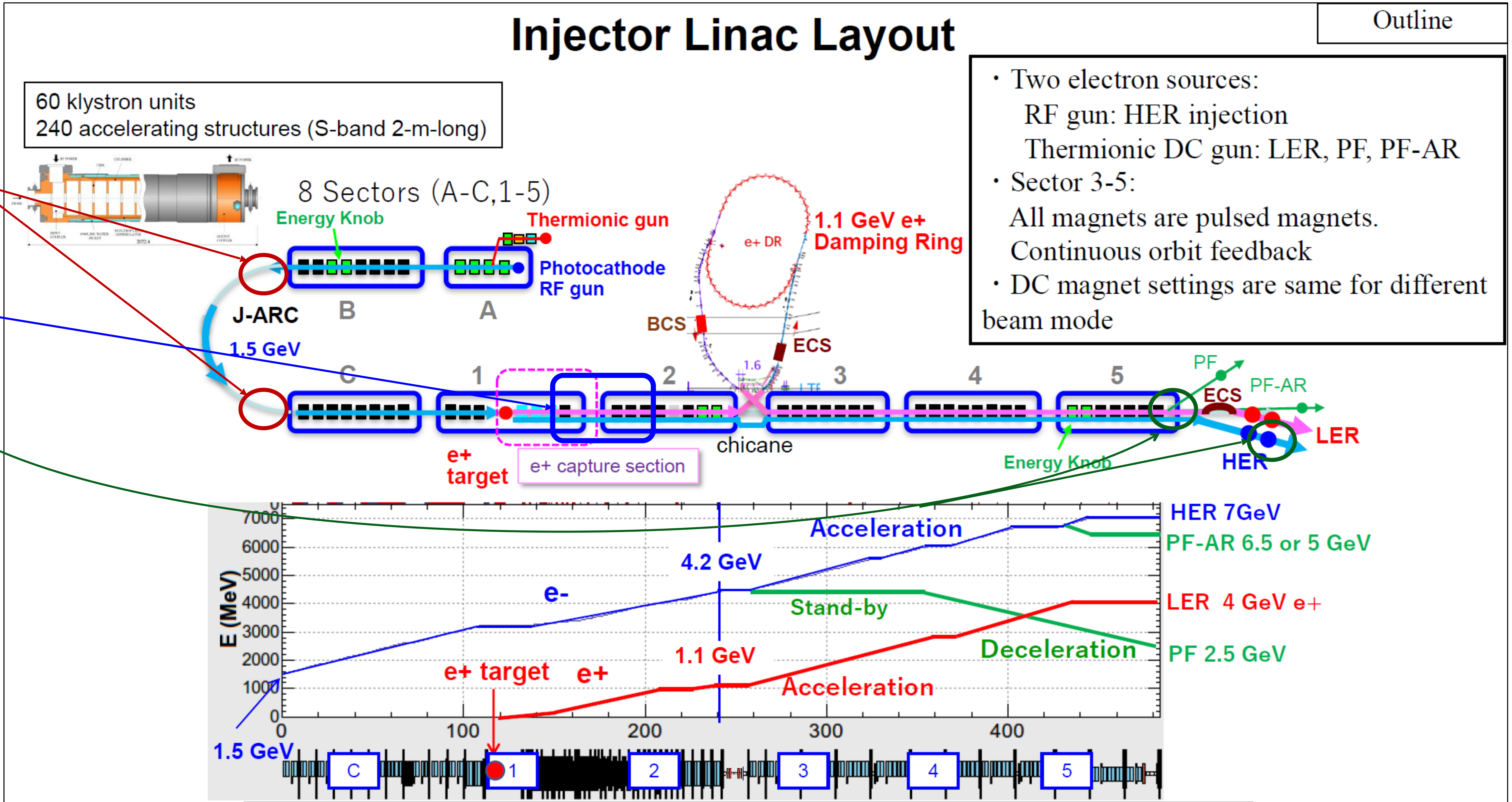
Injector Linac upgrade #1

For injection efficiency improvement;

- New pulsed Quads for the simultaneous dedicated matching of HER/LER injection beam
- New pulsed Quads for low beta optics of HER injection beam
- Fast kicker for 2nd bunch orbit correction

For stable operation;

- New accelerating structure
- Replacement of air conditioners in the tunnel



Beam energy variation for each beam mode along the beam line after J-ARC

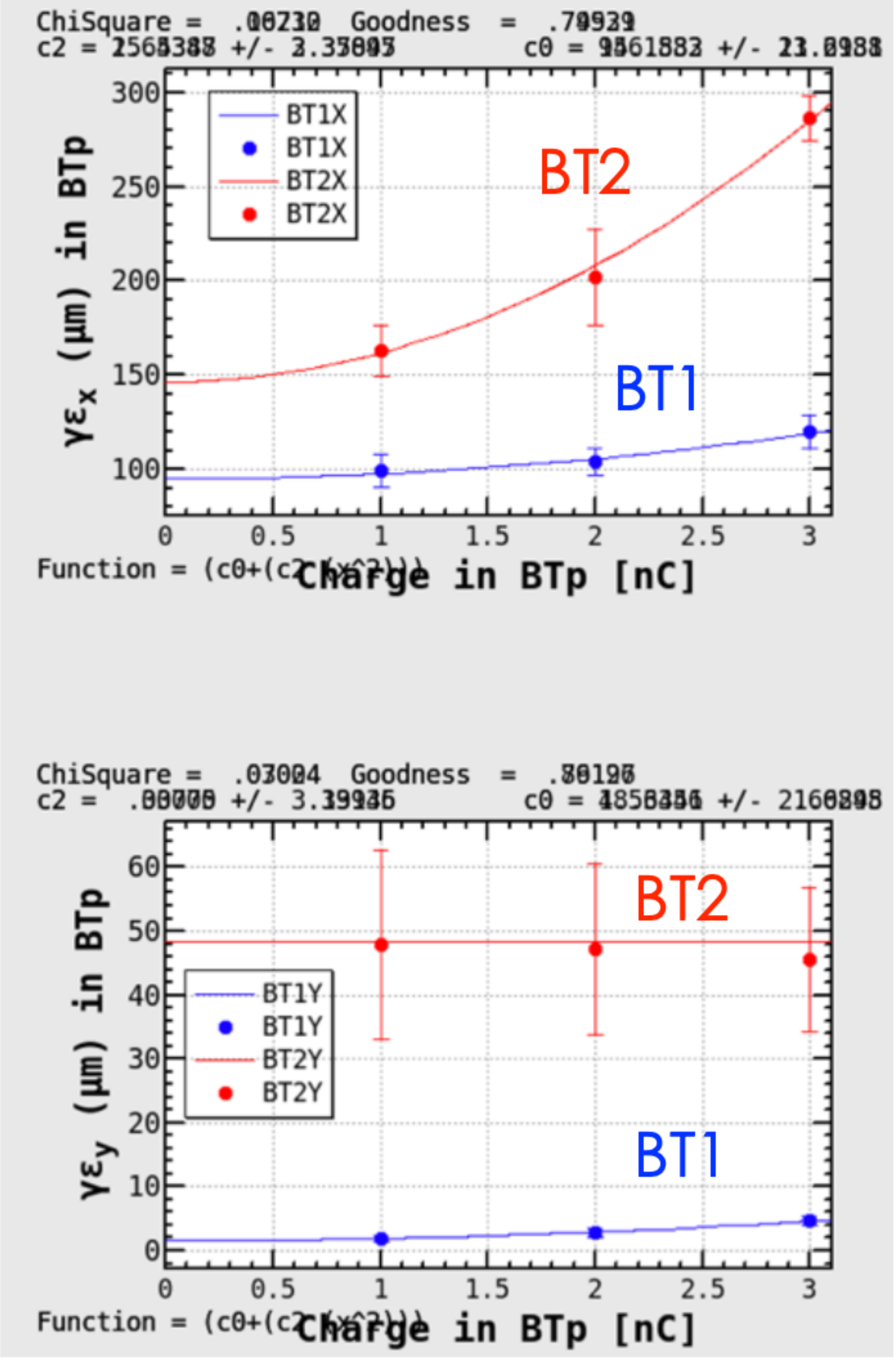
M. Satoh

Studies regarding the offset of the first arc in e+ BT

Measured emittance

Horizontal emittance

Vertical emittance

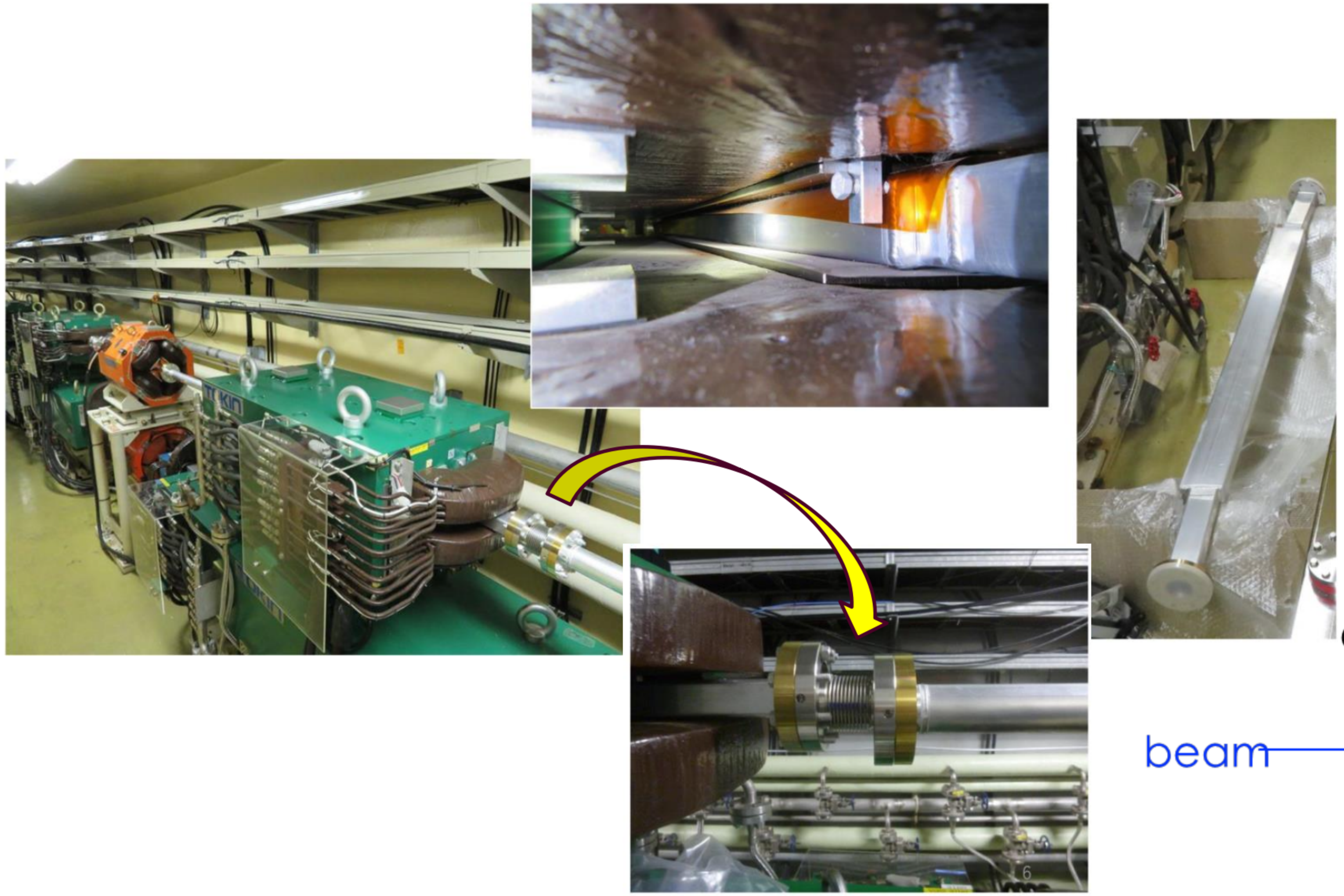


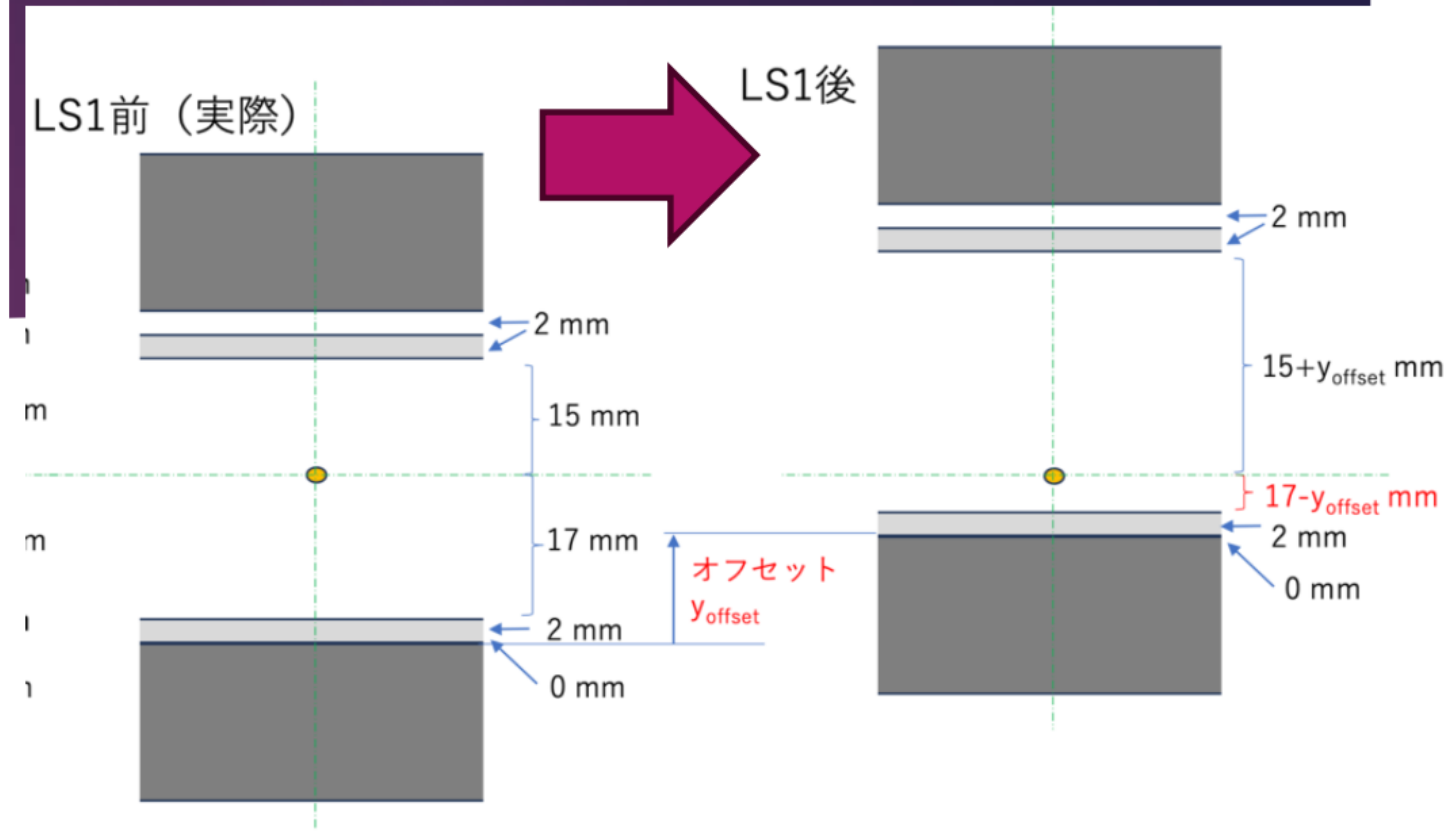
1. Since the horizontal emittance blowup seems to depend on the amount of charge, we suspected the influence of CSR and decided to move the e+ beam closer to the chamber inner wall of the first arc bend (BH1P) to see if the blowup would be reduced.
2. However, there was no large gap between the chamber and bend, so it was decided to offset the chamber and bend upwards.
3. In normal operation, the beam is designed to pass near the vertical center of the bend, but if the offset is set to 14 mm, there is a concern that the unexpected vertical dispersion generates due to the influence of the fringe magnetic field of the bend. We confirmed it using tracking simulation to find that the beam tuning will take a longer time than before.

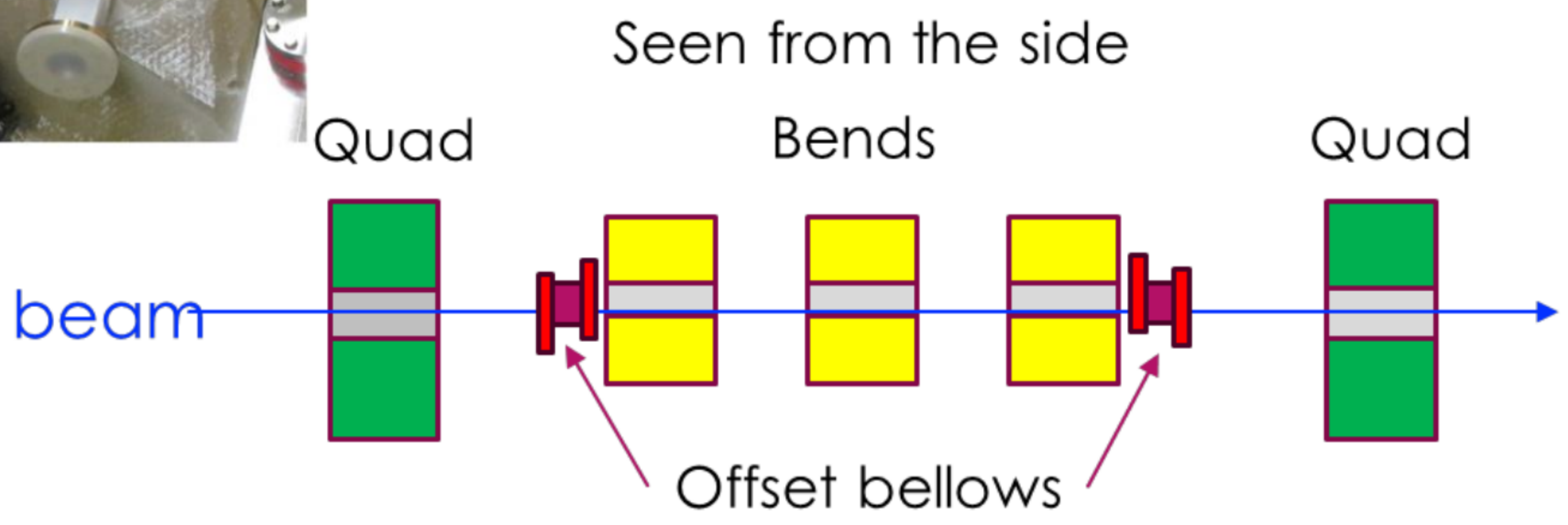
MDI, 19.Oct.2023, Injection, N. Iida

H. Ikeda

Bending magnet chamber







The bellows were replaced with ones with a 13mm offset on the left and right sides.

K. Shibata

H. Ikeda

Progress and outlook for emittance blowups of the injection beam

e- beam	Issue	Solution	LS1	Sometime after LS1
Horizontal emittance γεx growth (Charge dependent)	Cancellation of CSR	Exchanging to the narrower chambers	No	balance with budget
		Low dispersion optics	if good	under consideration
Horizontal emittance γεx growth (Charge independent)	ISR	New straight BT line	No	balance with budget
Vertical emittance γεy growth	**Still mystery**			
Longitudinal acceptance	Just barely in HER acceptance	ECS installation (already decided)	No	to be completed in BT1 by 2024

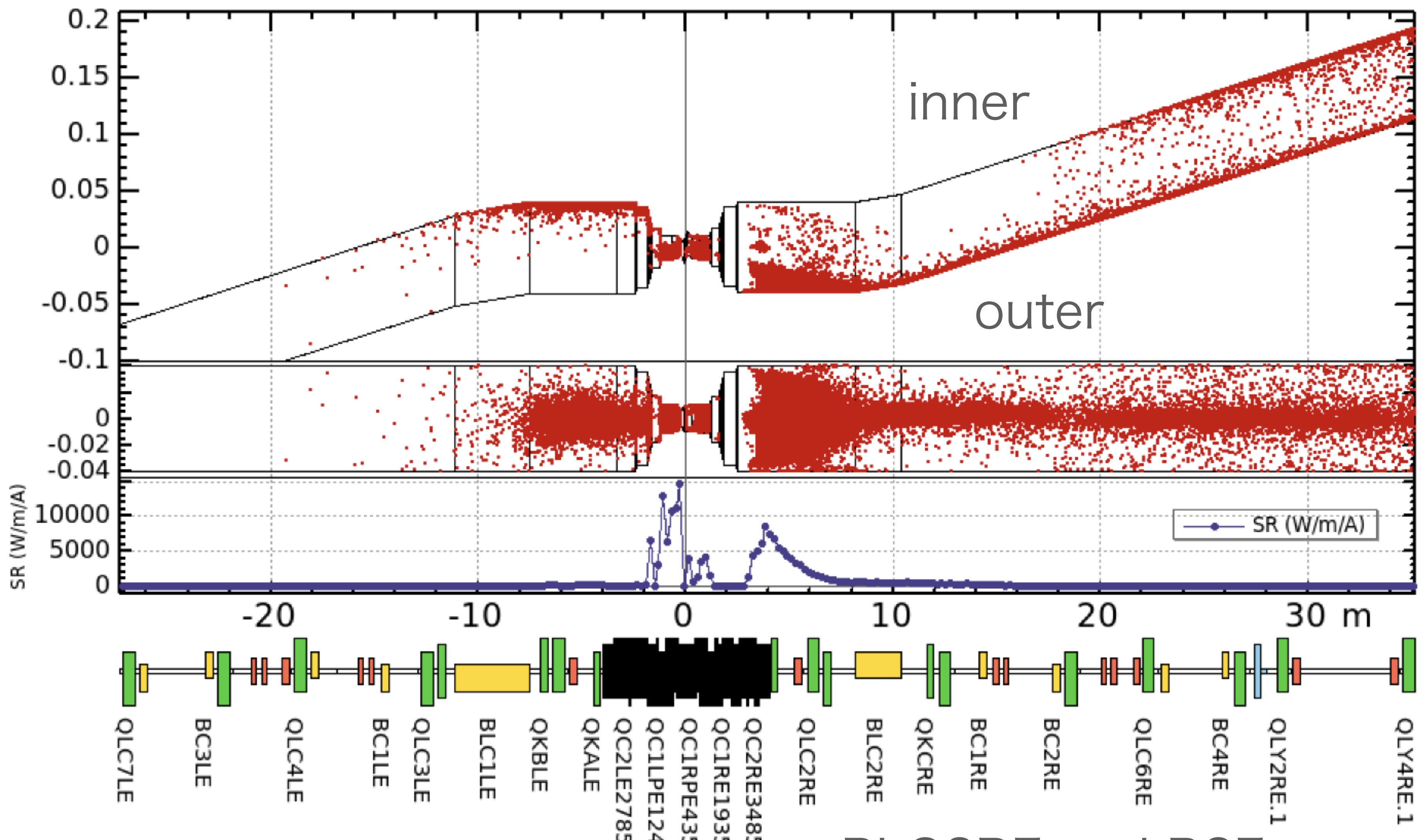
e+ beam	Issue	Solution	LS1	Sometime after LS1
Horizontal emittance γεx growth (Charge dependent)	CSR	**V. Offset of bending in e+BT Arc1**	Yes	**will be studied in December**
		Low dispersion optics	If good	under consideration
Horizontal emittance γεx growth (Charge independent)	Blowup somewhere from DR to BT1	Low emittance optics in the DR		under consideration
Vertical emittance γεy growth	**Still mystery**			
Longitudinal acceptance	no problem			

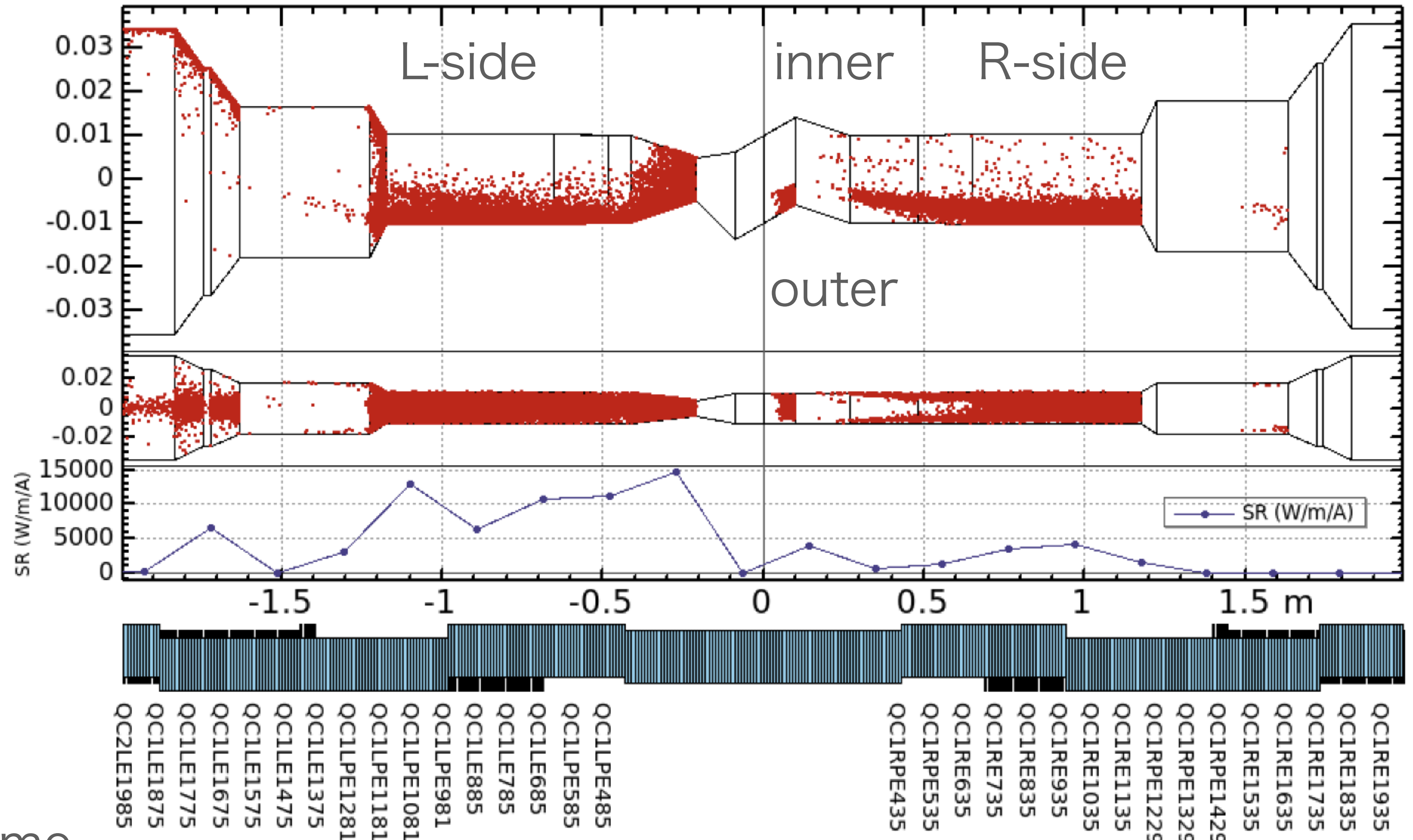
SR Simulation in HER

M. Kikuchi,
ITF Beam-Tuning
Sept. 19, 2023

Injected beam (First turn)

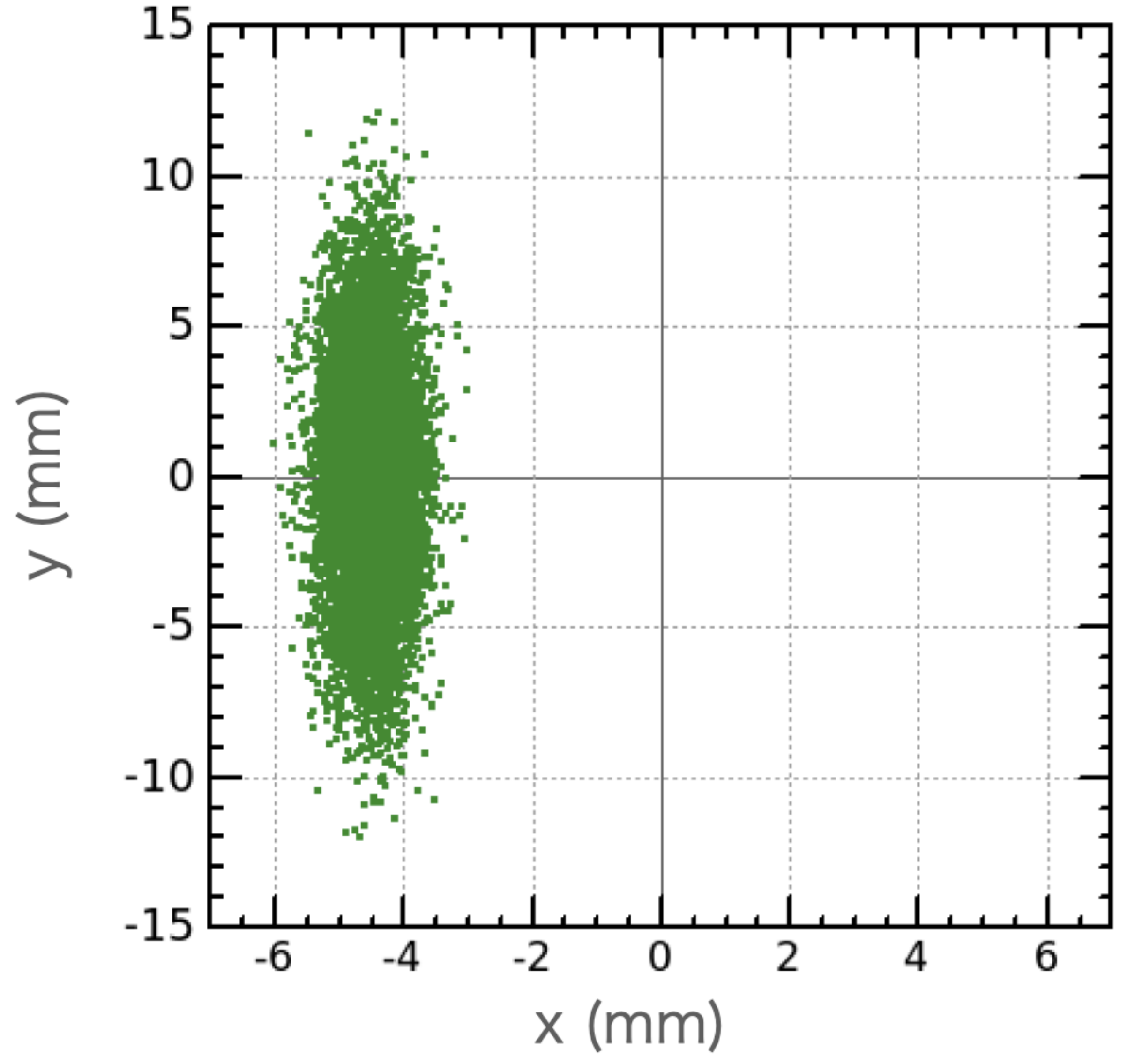
$\gamma\varepsilon_x = 160\ \mu m,\ \gamma\varepsilon_y = 100\ \mu m$



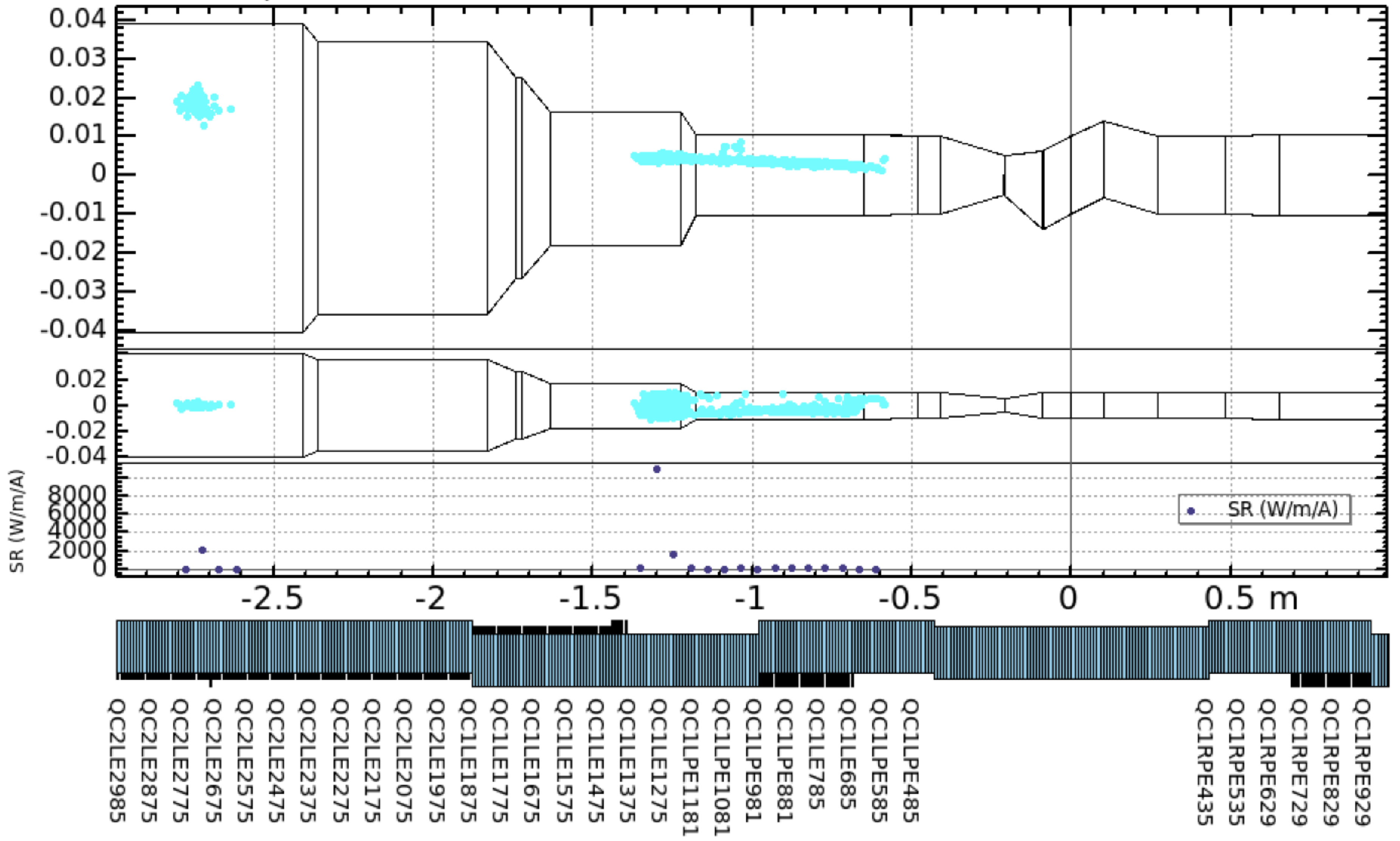


BLC2RE and B2E are same sign of bending angle.

s = -1.5



Source points for 0 < x < .15



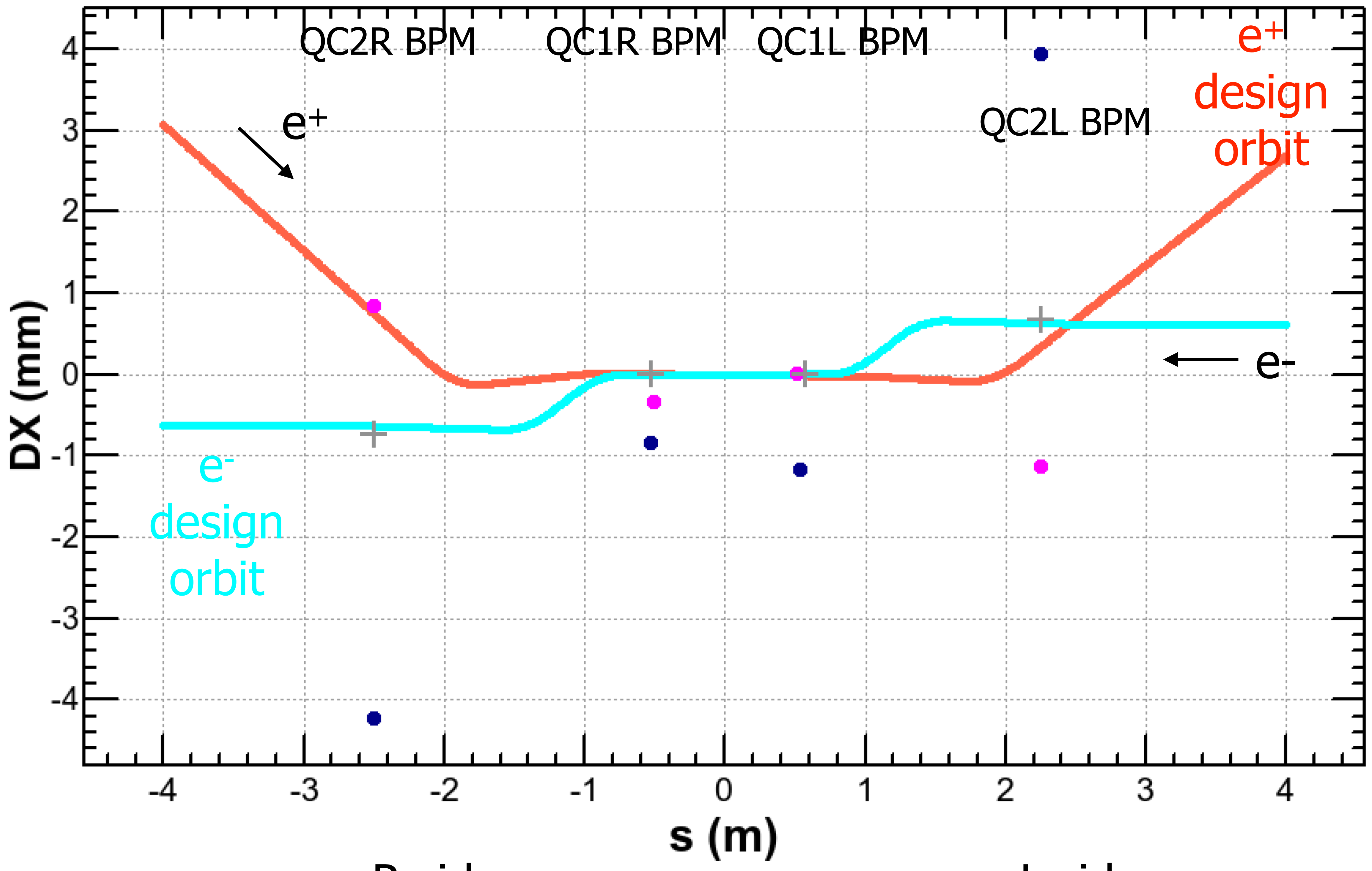
Horizontal Orbit in the vicinity of IP

LER: 2022/06/22 08:14:14
HER: 2022/06/22/08:13:03

Orbit at IP deviation from 41.5 mrad line

LER meas: Δx = -0.159 mm, Δp_x = +0.363 mrad
HER meas: Δx = -1.006 mm, Δp_x = -0.308 mrad

Estimated from QC1R and QC1L BPMs.

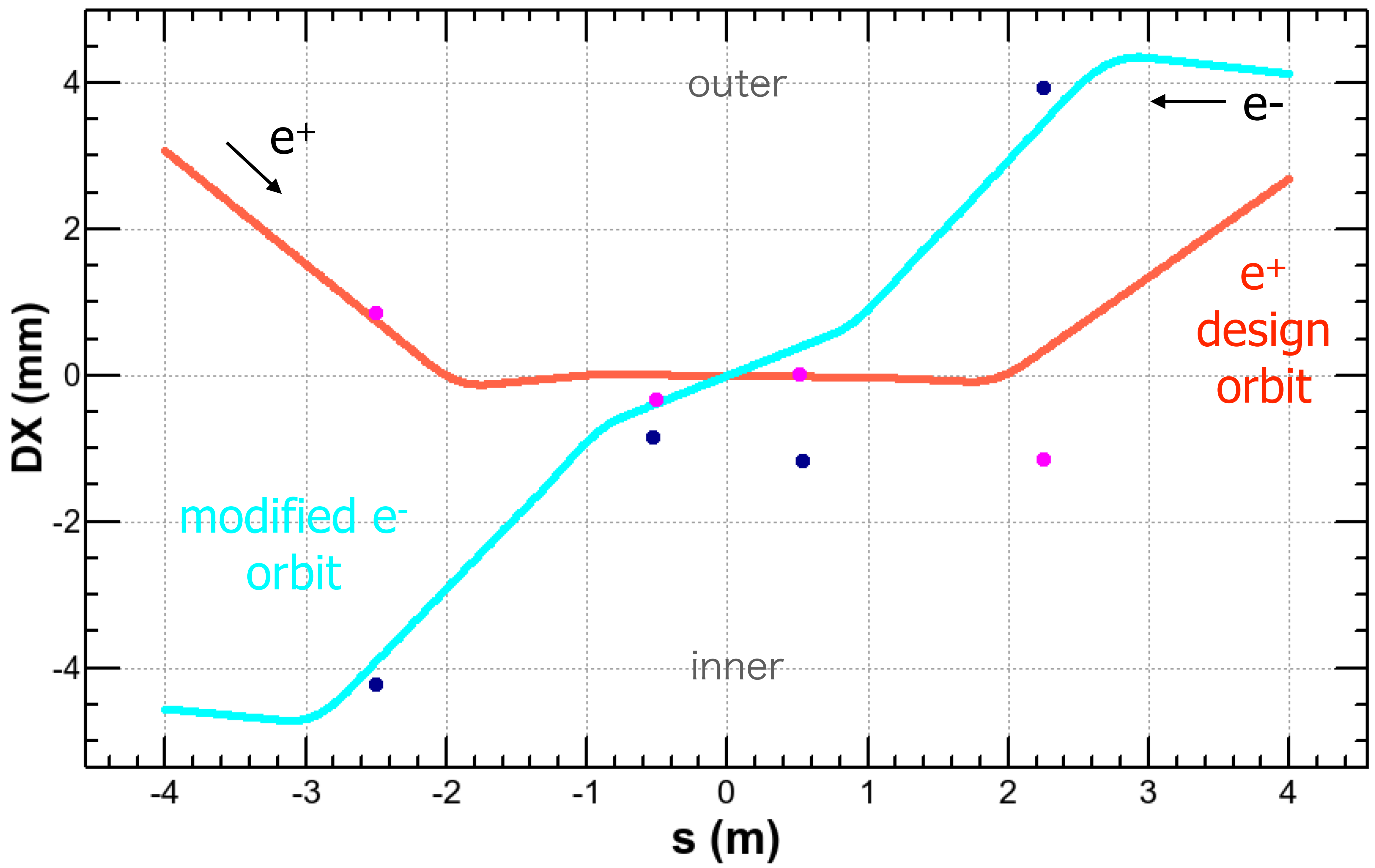


R-side L-side

HER: QC2RE: -0.7 mm HER: QC2LE: +0.7 mm

H-offset (LER -HER) : 0.847 mm
H-angle (LER -HER) : 0.671 mrad

HER: $\Delta\theta_x$ = +0.75 mrad (model)

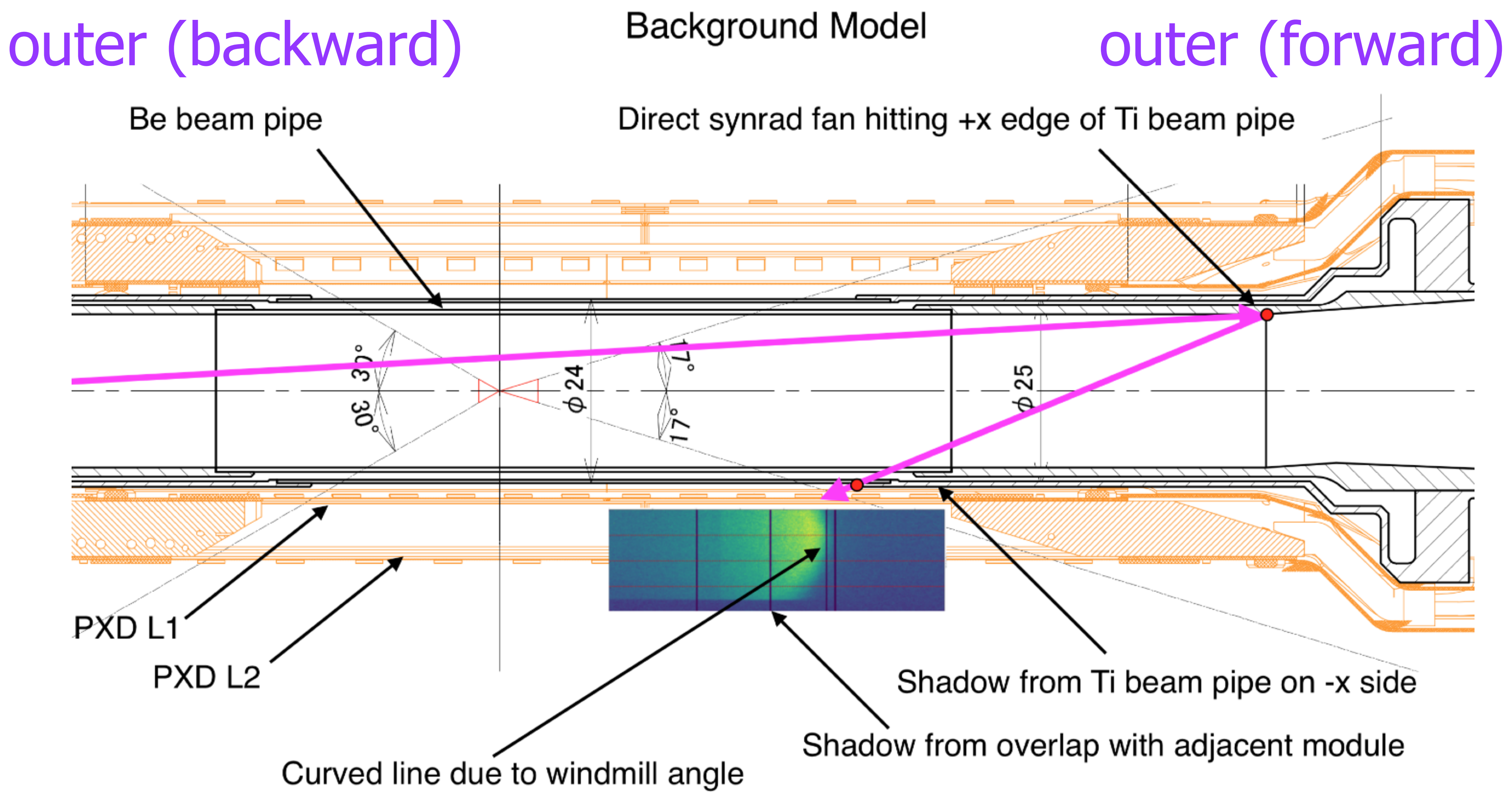


R-side L-side

H-angle at IP for HER can be made by steerings outside of QCS.

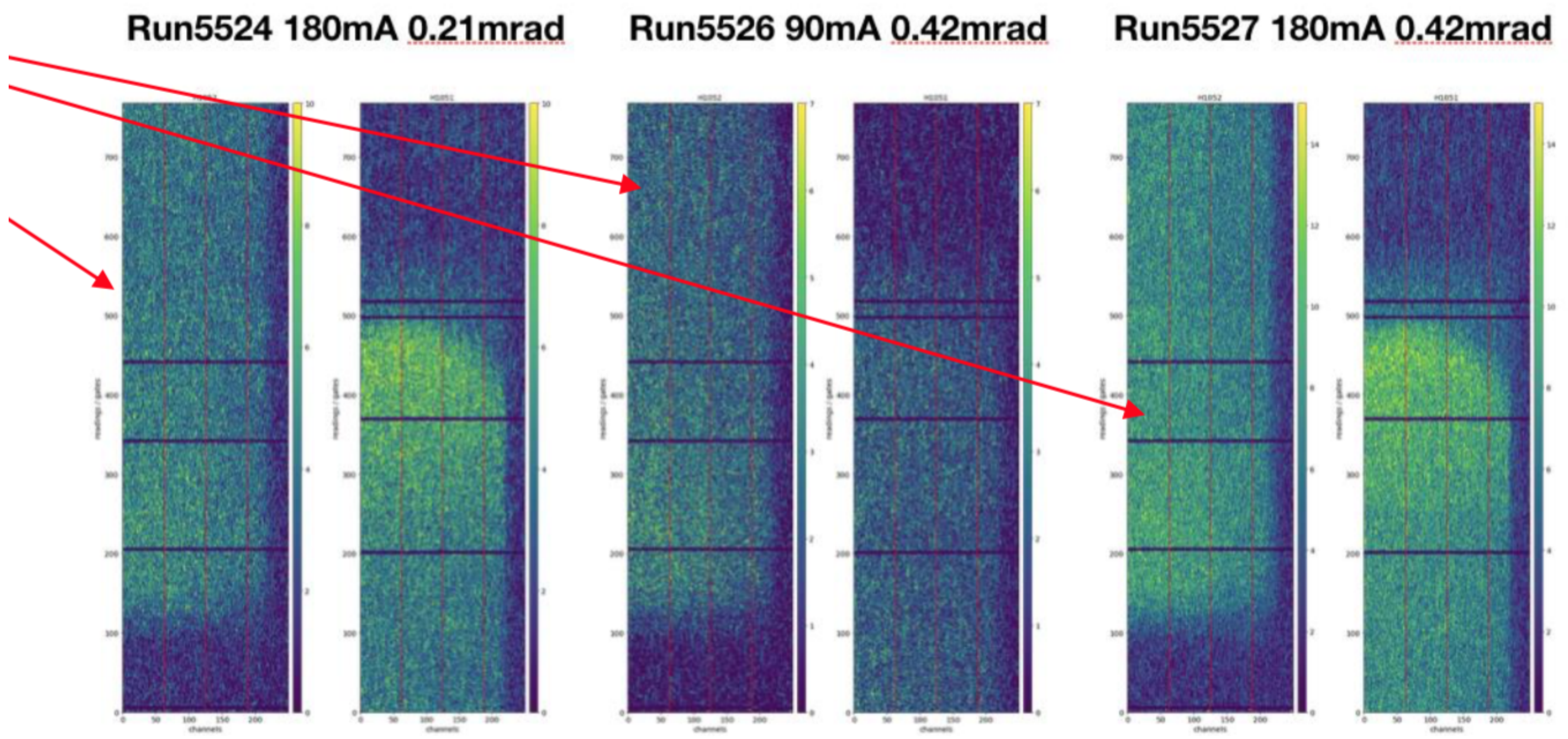
ZHQLC6RE, ZHQLC2RE, ZHQLC2LE, ZHQLC4LE

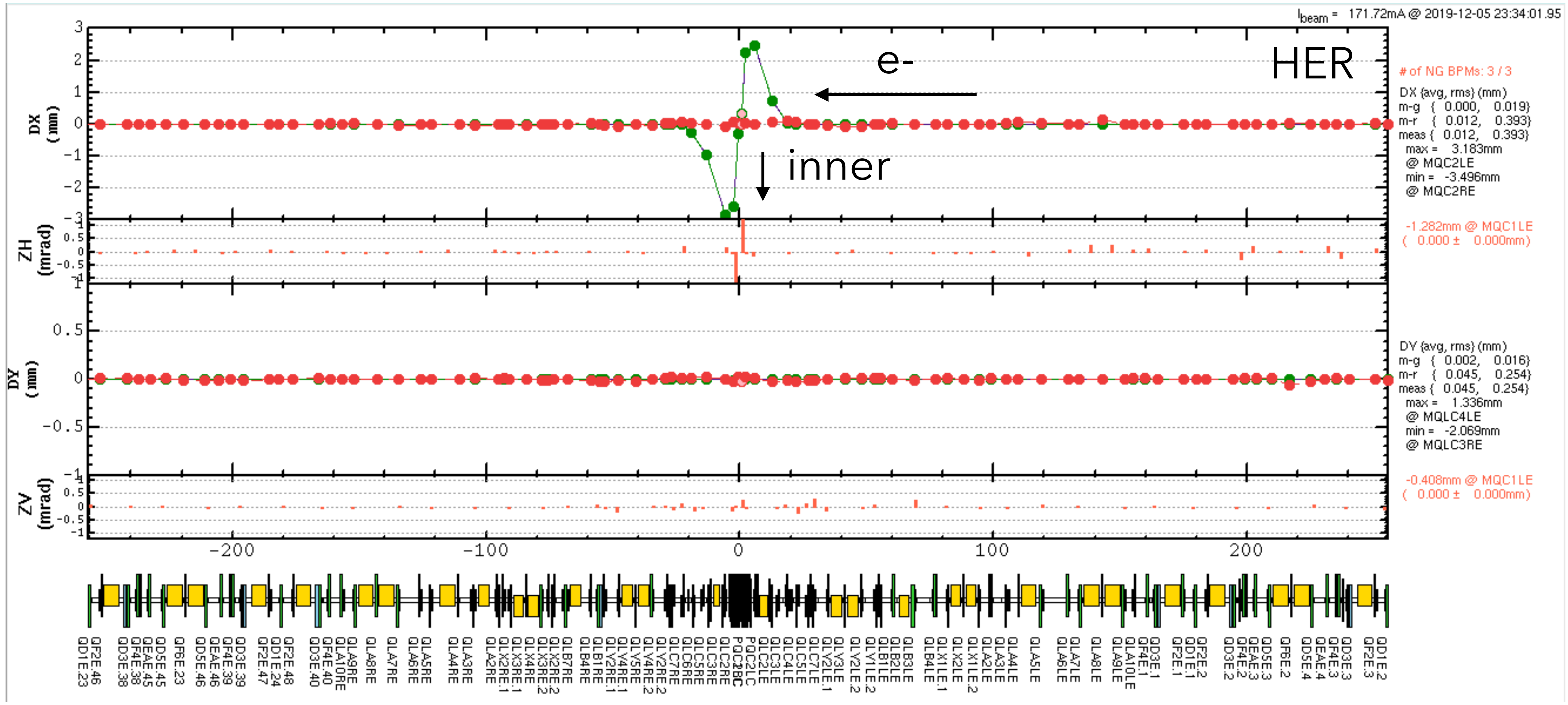
Synchrotron Radiation on PXD



After squeezing the horizontal beta at IP in HER from 80 mm to 60 mm

SR pattern on the modules





We scanned horizontal angle at IP in HER:

-0.14 mrad, +0.14 mrad, +0.28 mrad, **+0.42 mrad**

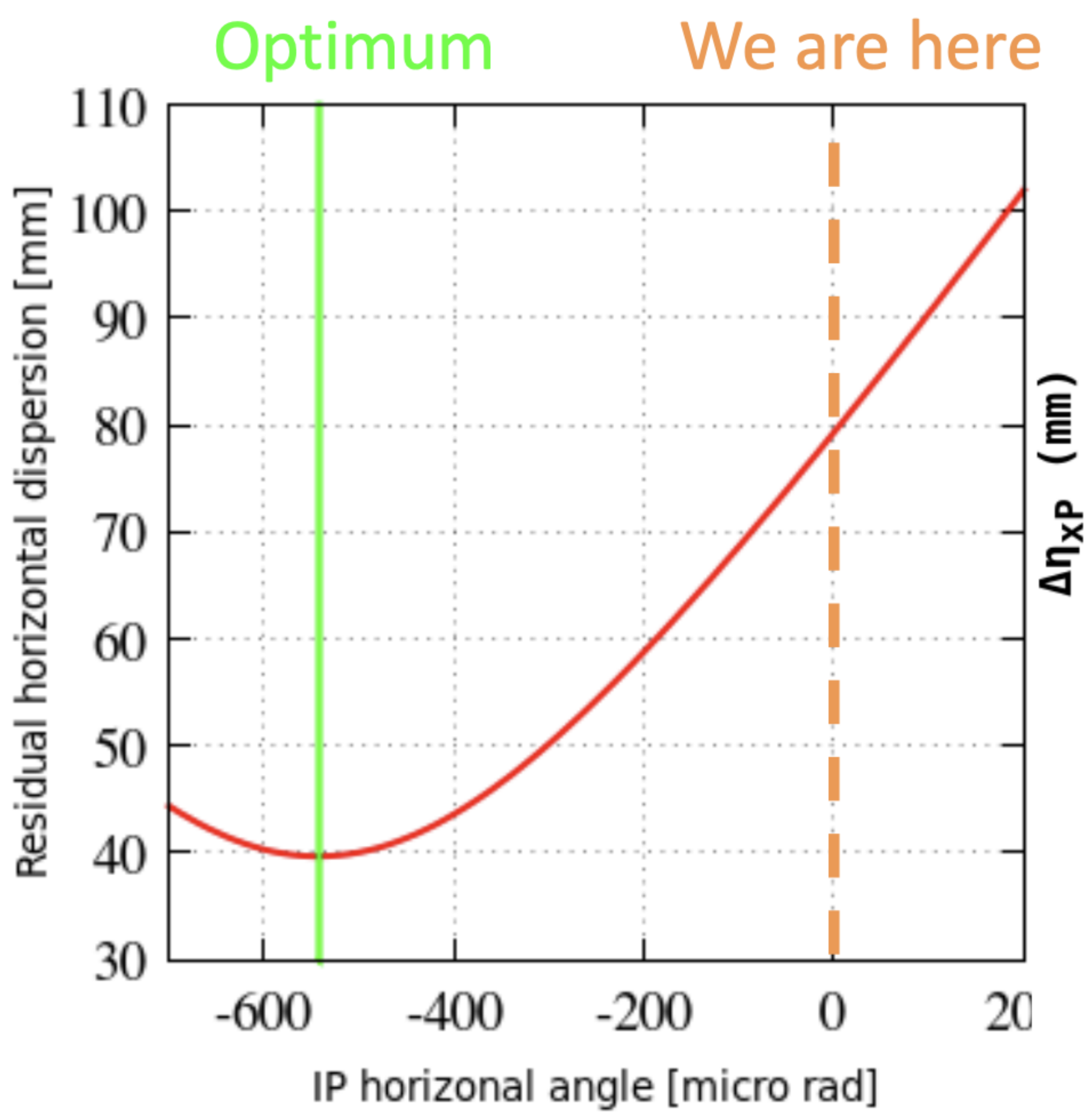
However, this angle adjustment affects horizontal dispersions in HER.

Deterioration of Horizontal Dispersion for Horizontal Angle at IP in HER

H. Sugimoto

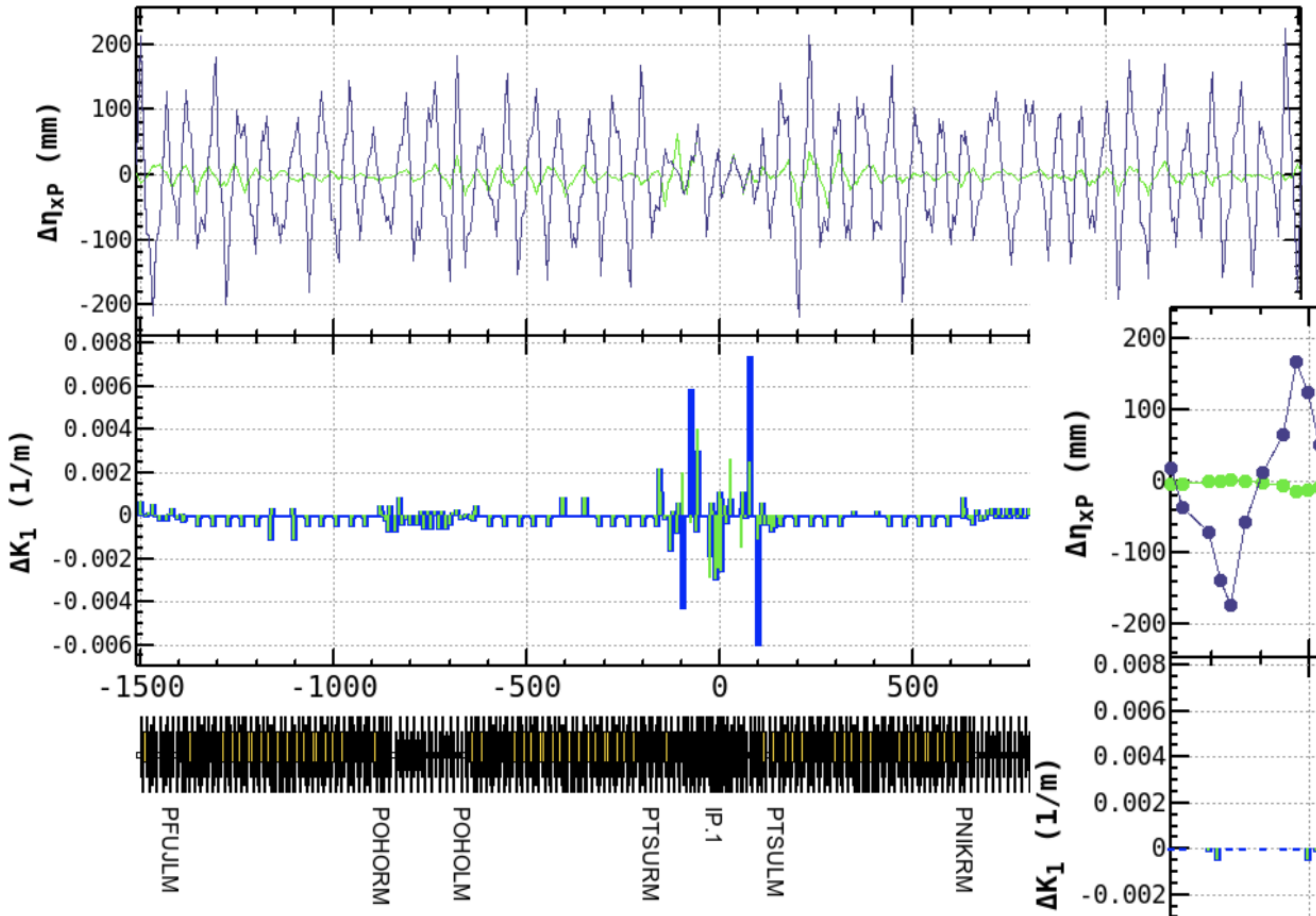
Model Calculation with the Optimized Angle

IP angle and expected residual dispersion
in the Tsukuba section



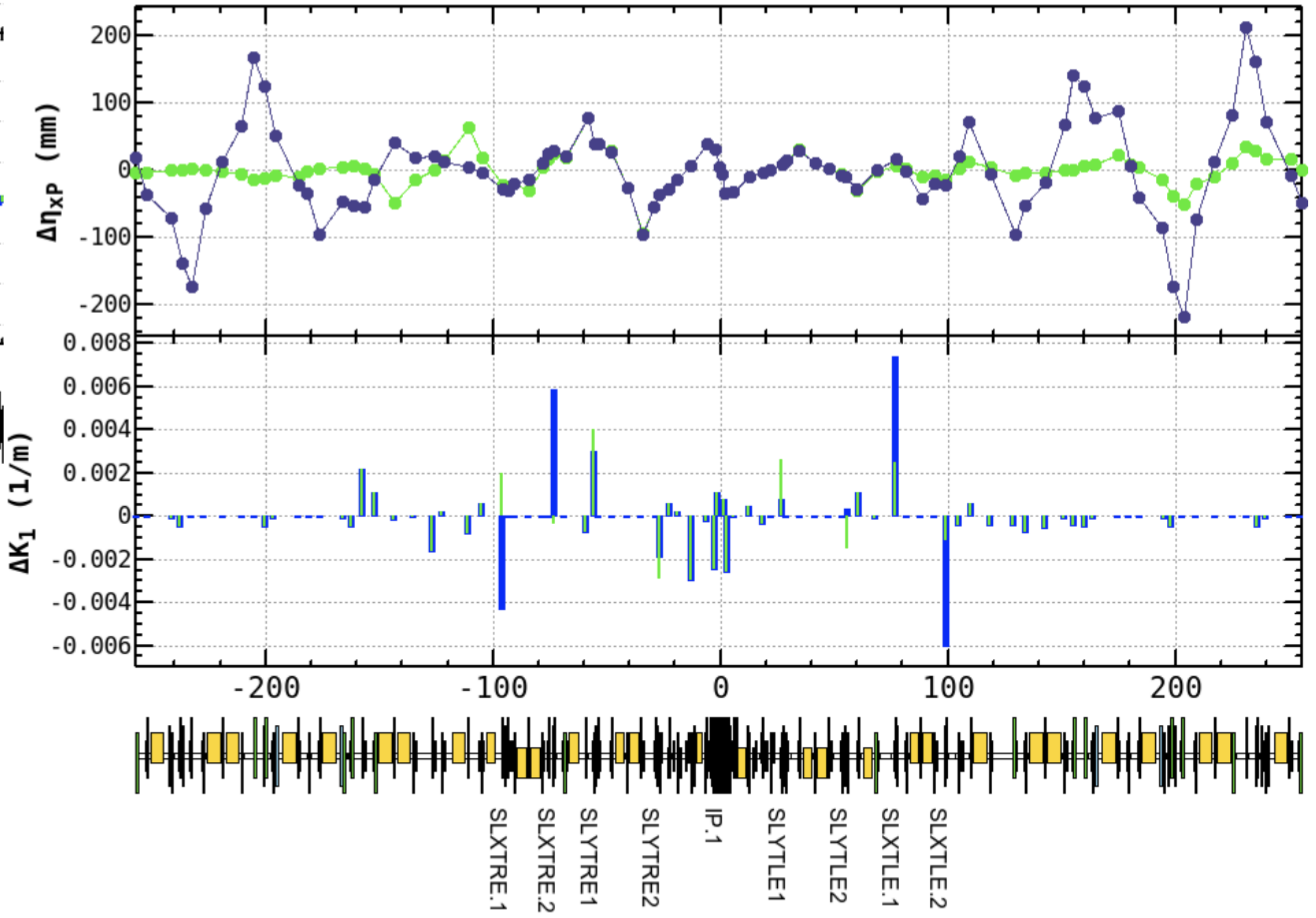
- Perform Hori. dispersion correction to the expected Hori. dispersion obtained in the previous page.

Whole ring



Blue: 2020/05/11
Green: Expected

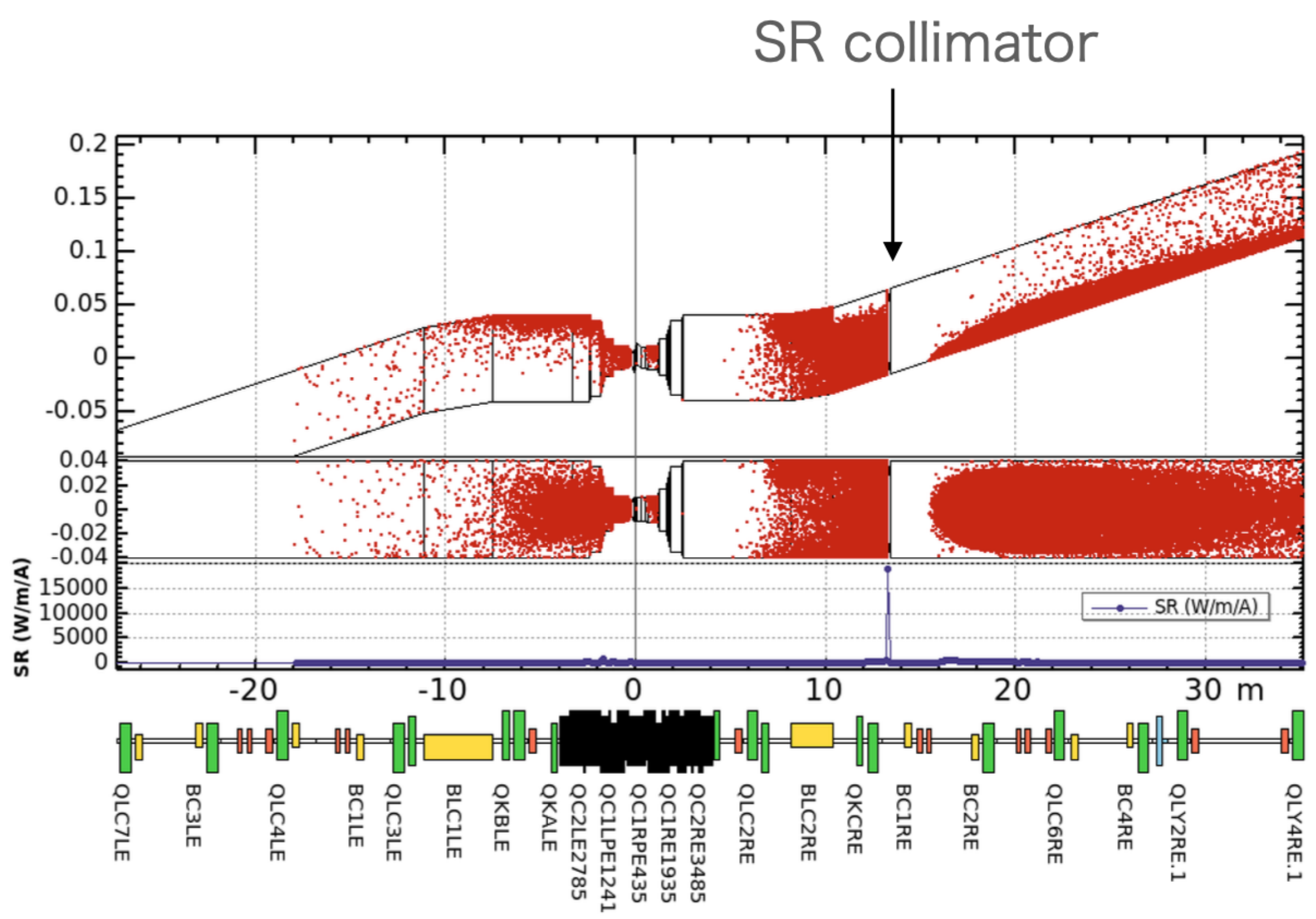
Tsukuba section

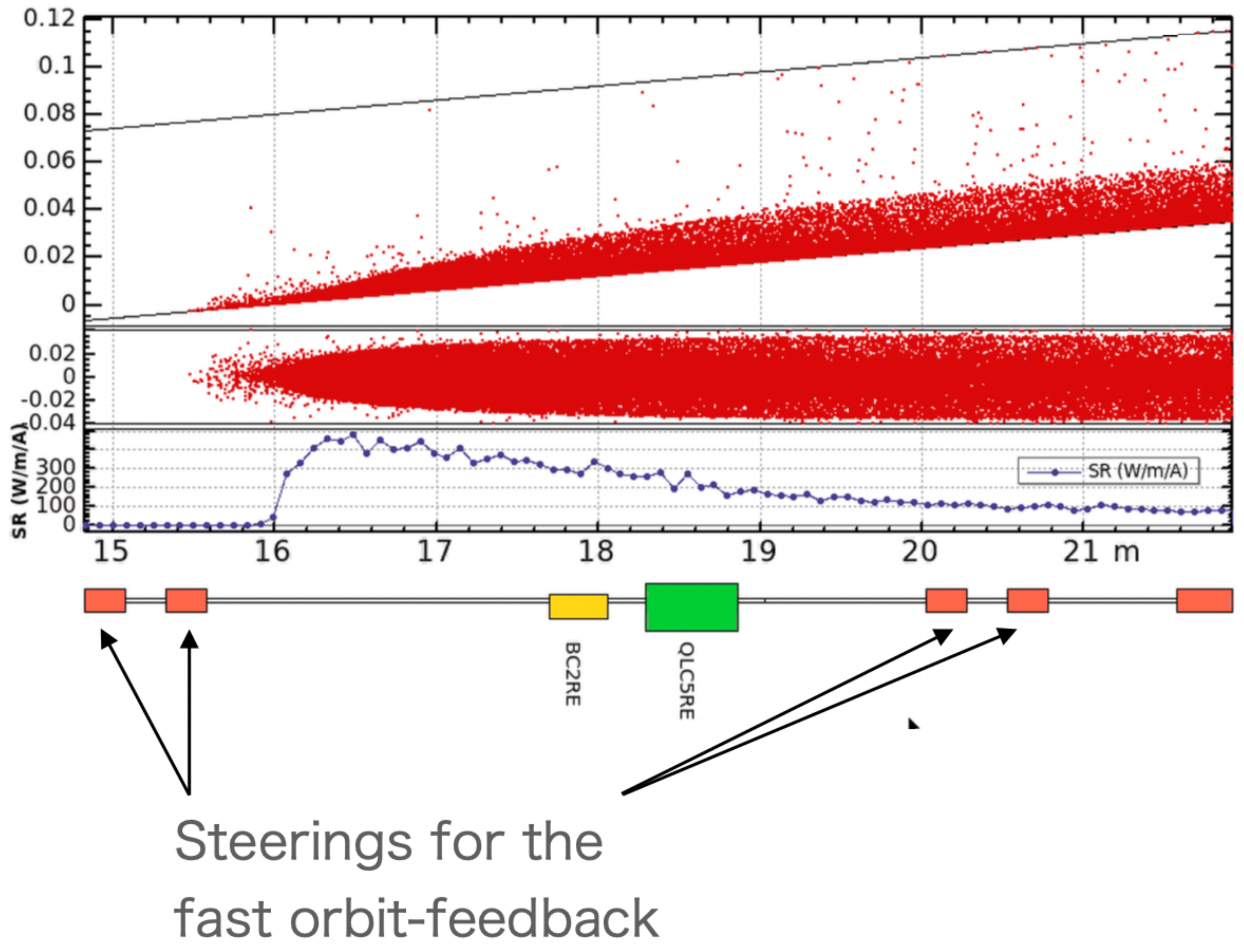


SR Simulation in HER

M. Kikuchi,
ITF Beam-Tuning
Sept. 19, 2023

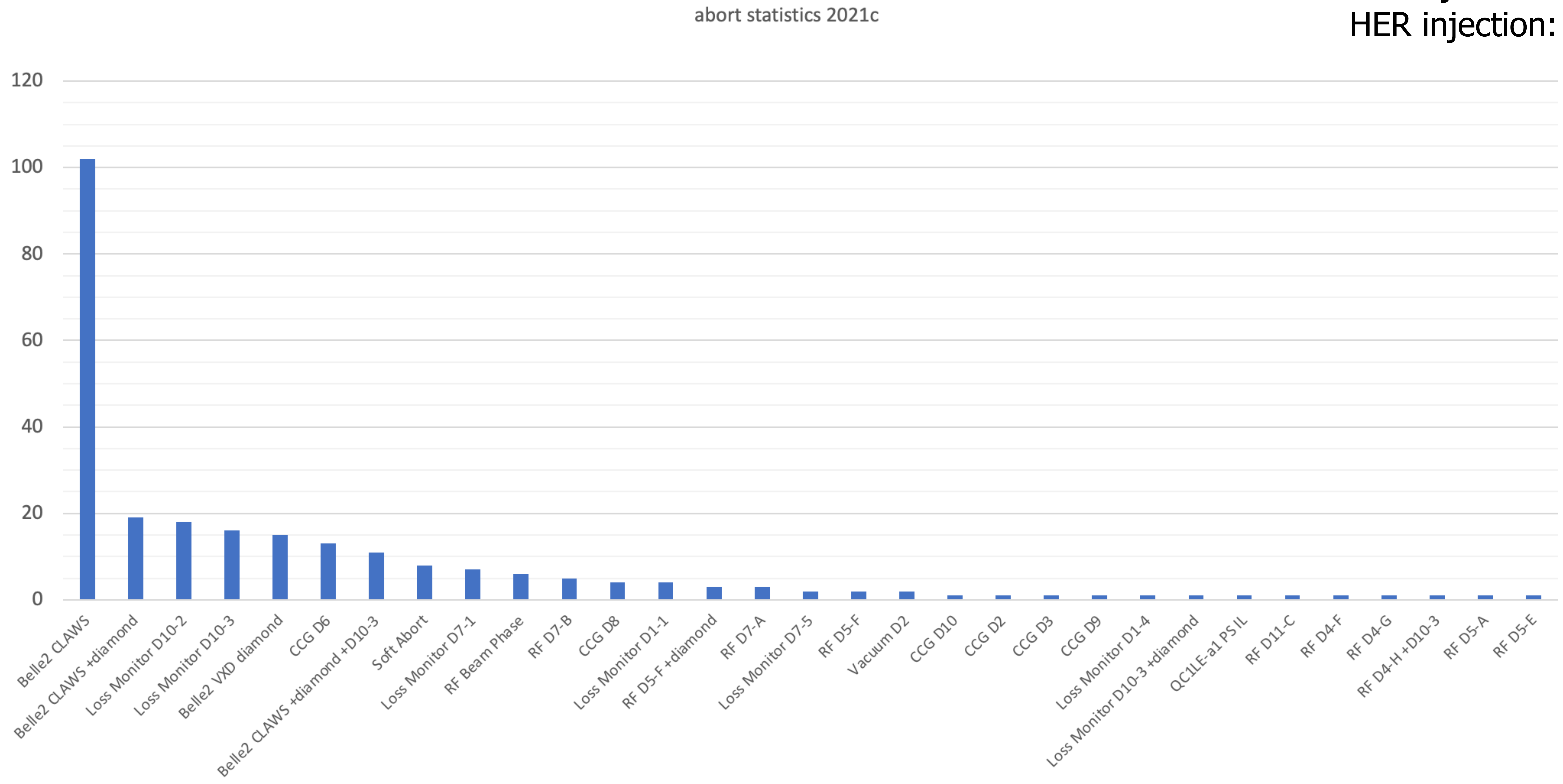
- Asymmetry of the vertical distribution of SR reflects the vertical angle at IP. From measurement of the vertical distribution we can get information on the vertical angle at IP.
- SR mask is necessary to protect the Cu-SUS flange junction, which is vulnerable to temperature change. But use of ordinal simple SR mask loses information of SR distribution at the downstream.
- Novel SR monitor using SR mask was proposed by Vac group (Terui-san)





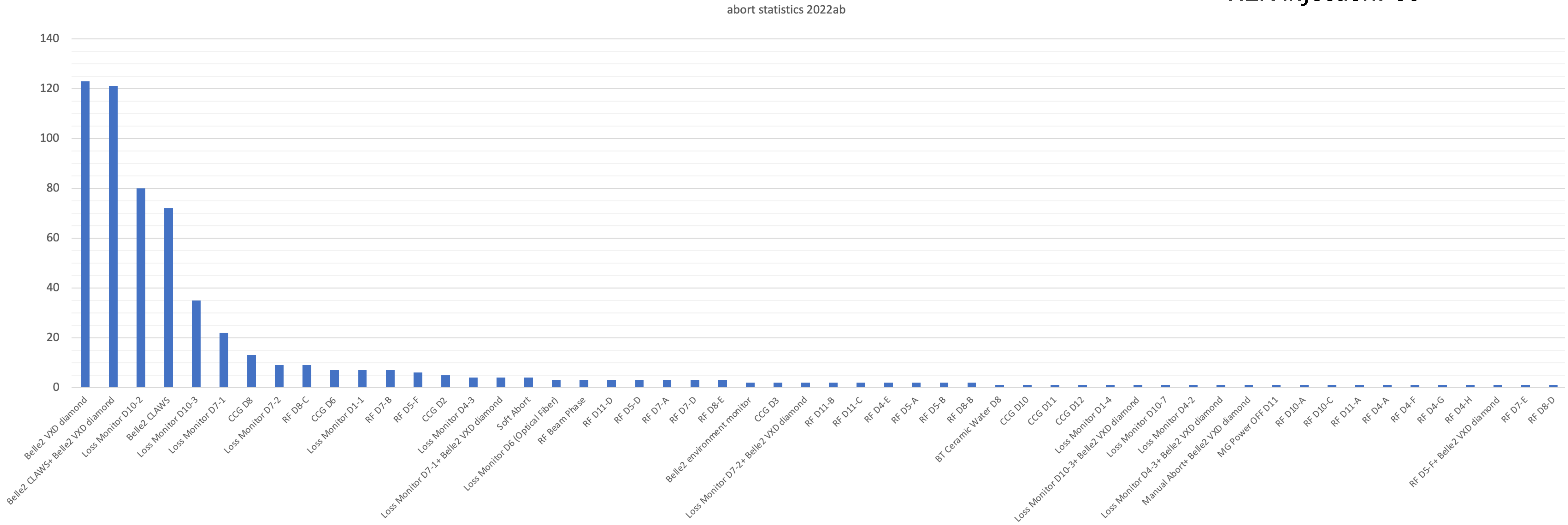
Abort Statistics in 2021c

total aborts: 253 for 64 days
ave. 4.0 aborts / day
Belle II aborts: 147 (58.1 %)
LER injection: 68
HER injection: 41

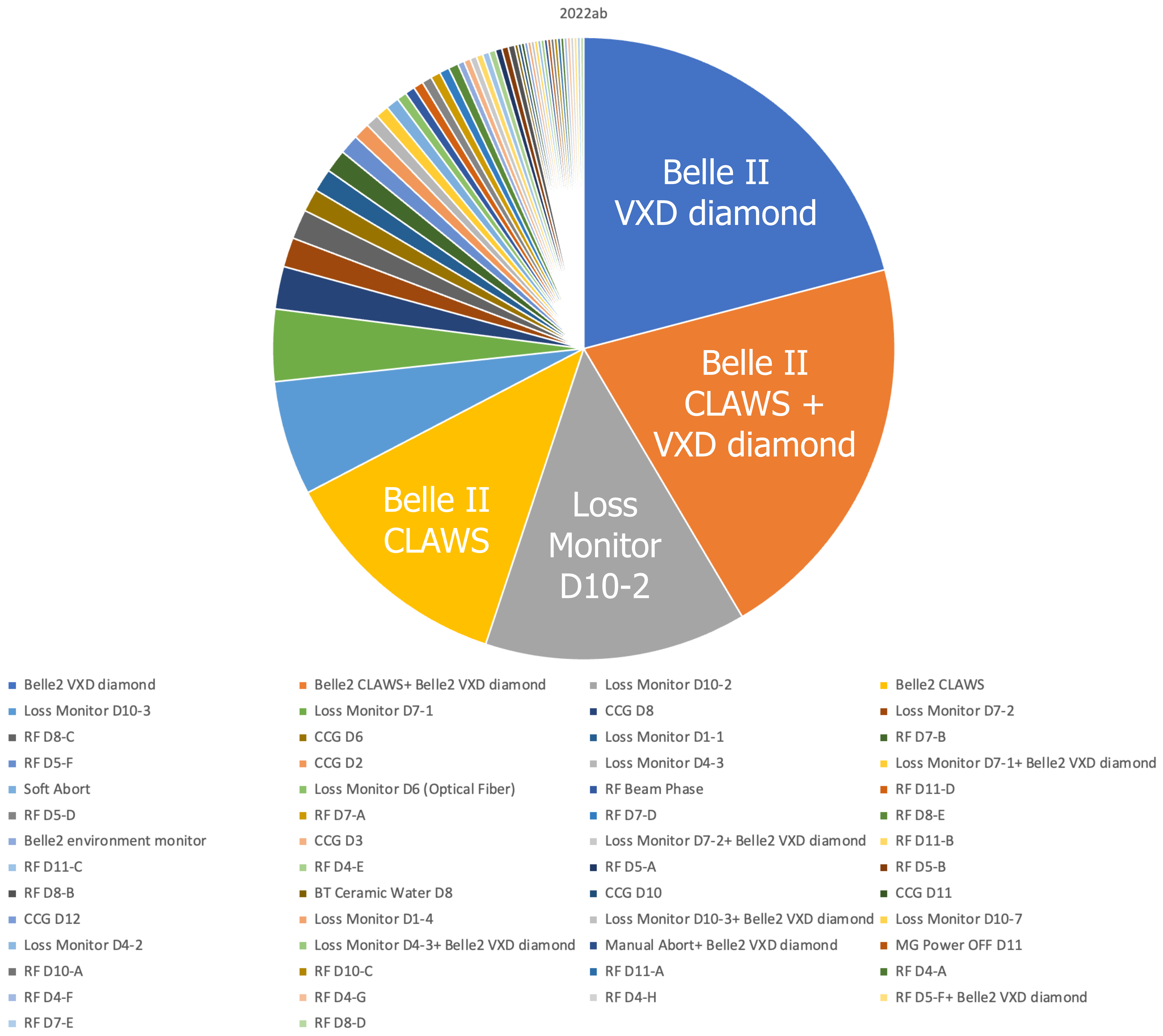


Abort Statistics in 2022ab

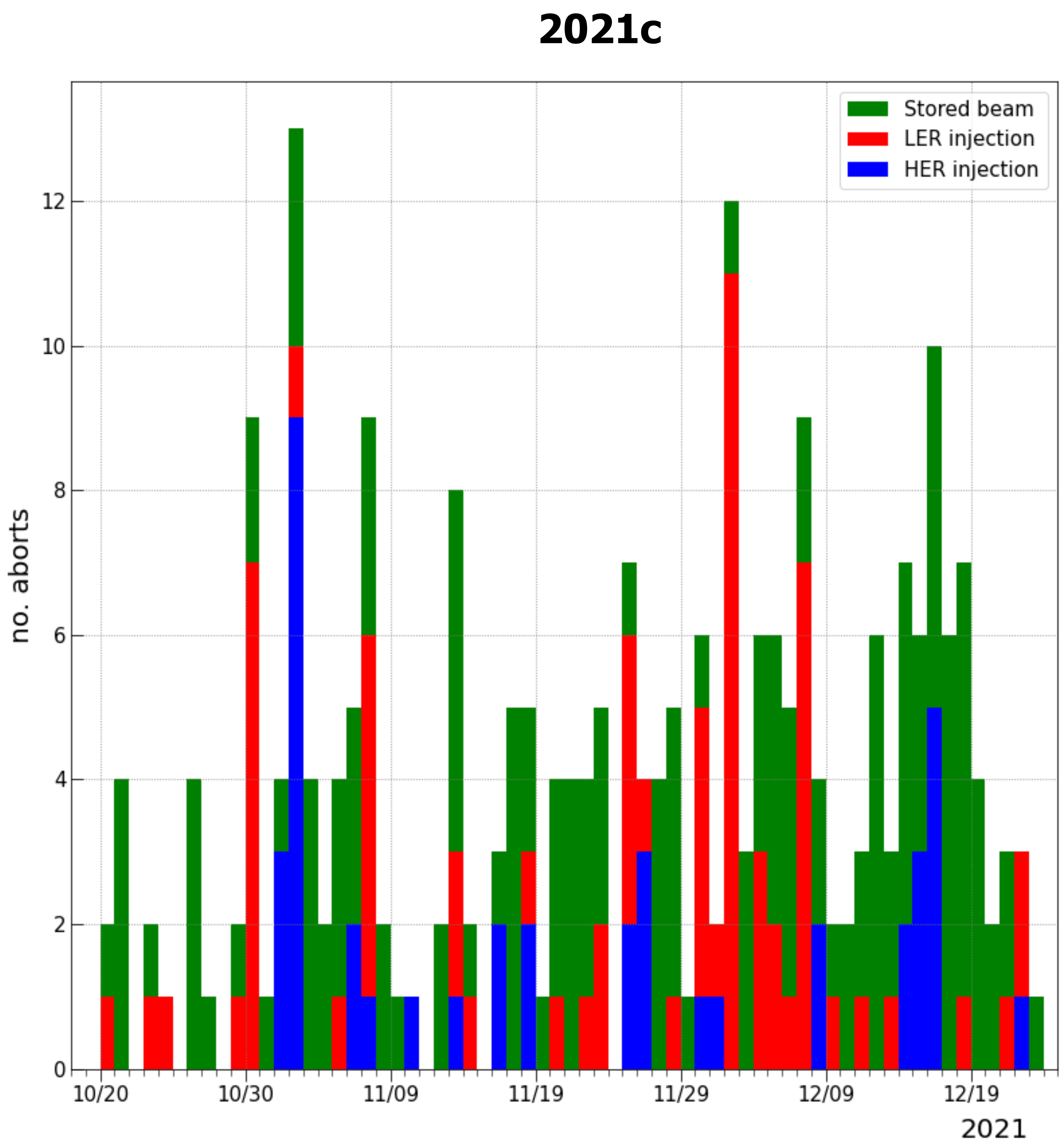
total aborts: 588 for 119 days
ave. 4.9 aborts / day
Belle II aborts: 316 (53.7 %)
LER injection: 83
HER injection: 60

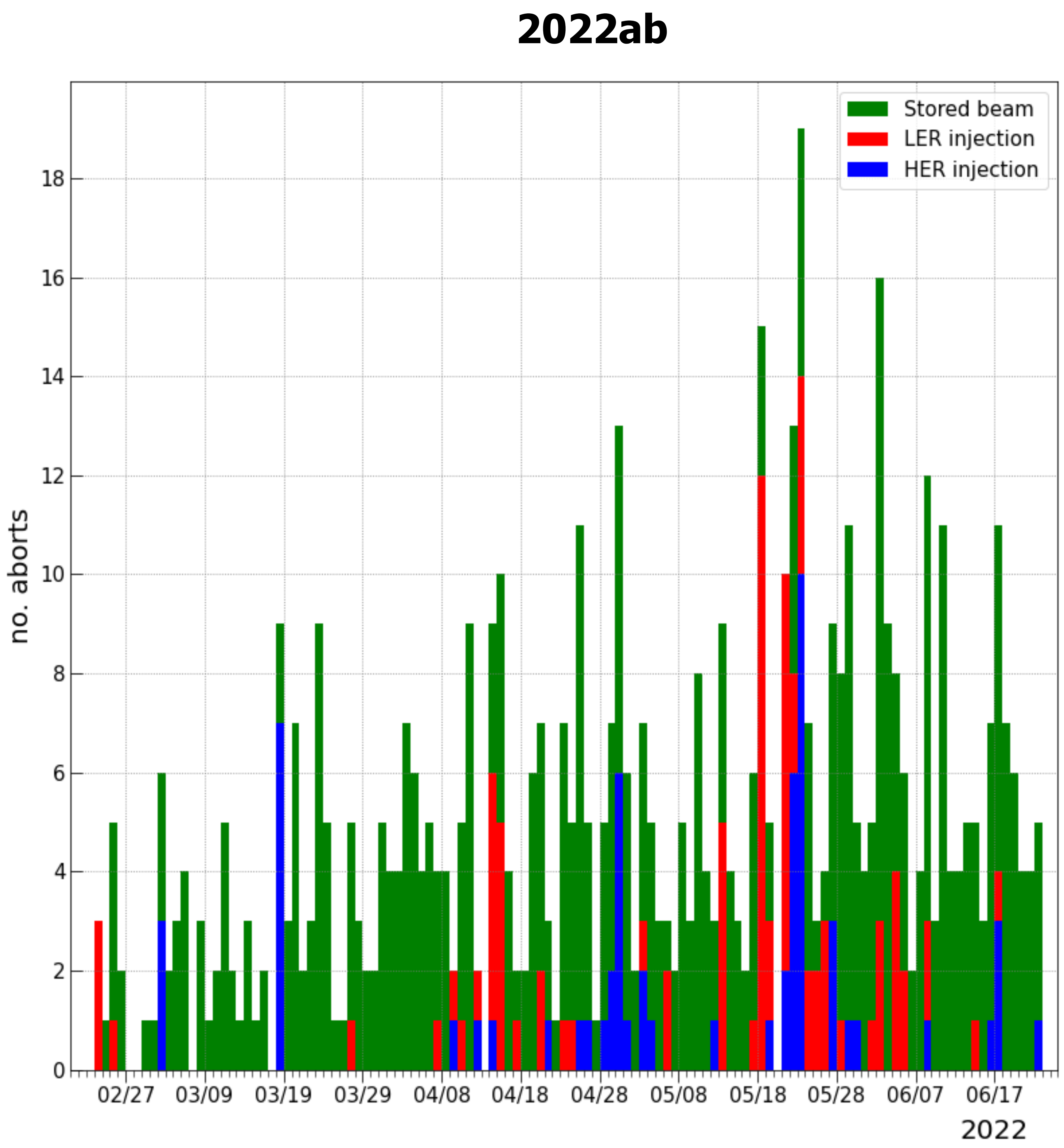


Aborts in 2022ab



Number of Aborts per Day





Machine Troubles

2021c

HER XRM trouble	HER	Monitor	2
HER optics dgradation due to earthquake	HER	Others	2
Linac RF-gun laser trouble	Linac	Gun	2
HER RF D10AB KPS 66kV OPEN PHASE deu to air fan motor trouble	HER	RF	1
LER Cooling water pump trouble for D07AB dummy load	LER	Infrastructure	1
LER thyratron replacement and conditioning	LER	Injection	1
LER XRM trouble	LER	Monitor	1
LER longitudinal FB cable trouble	LER	Monitor	1
LER D02 chiller trouble	LER	Vacuum	1
LC7 displacement monitor trouble	LER/HER	Monitor	1
QCS quench due to earthquake	LER/HER	Others	1
QCS quench due to cryogenic operation error	LER/HER	Others	1
IR cooling water trouble	LER/HER	Vacuum	1
M3 cooling water trouble	Linac	Infrastructure	1
M0A cooling water trouble	Linac	Infrastructure	1
Linac SXC81 PS and QF1656 PS trouble	Linac	Magnet	1
Linac KL 22 down	Linac	RF	1
Linac KL A1B trouble	Linac	RF	1

2022ab

BTe BH1E_11_15 PS trouble	BTe	Magnet	5
Linac RF-gun laser trouble	Linac	Gun	4
HER XRM trouble	HER	Monitor	3
HER optics degradation deu to earthquake	HER	Others	3
LER BWDNLP PS trouble	LER	Magnet	3
LER RF D07C KLY OC	LER	RF	3
Linac magnet trouble (control)	Linac	Magnet	3
BTp BPM FO trouble	BTp	Monitor	2
LER BLC2LP PS trouble	LER	Magnet	2
LER RF D08 window temp	LER	RF	2
Linac network trouble	Linac	Control	2
QCS oxygen alarm due to Belle II environment monitor trouble	Belle II	Control	1
Belle II -KEKB gateway abort trouble	Belle II	Control	1
BTe VT17E PS trouble	BTe	Magnet	1
BTe B1E magnet PS water stop	BTe	Magnet	1
BTp/RTL BPM trouble	BTp	Monitor	1
BTp BH1P PS down	BTp	Magnet	1
DR injection kicker E/O trouble	DR	Control	1
HER abort kicker cooling system sequencer trouble	HER	Infrastructure	1
HER septum trouble	HER	Injection	1
HER QD1E PS tracking error	HER	Magnet	1
HER RF D10C tuner trouble	HER	RF	1
HER D04G µTCA trouble	HER	RF	1
HER RF D11: He control NIM PS trouble	HER	RF	1
LER thyratron replacement and conditiong	LER	Injection	1
LER 2-bunch injection trouble	LER	Injection	1
LER D07E SQC abort trouble	LER	RF	1
LER D04 vacuum trouble	LER	Vacuum	1
QCS/ECS quench due to earthquake	LER/HER	Others	1
Linac EVENT system trouble	Linac	Control	1
Linac QDA23 PS trouble	Linac	Magnet	1
Linac KL A3 trouble	Linac	RF	1
Linac KL 45 trouble	Linac	RF	1