Summary of 2024 Runs

Y. Ohnishi
KEK

28th KEKB Accelerator Review Committee

Preliminary Report

The 27th KEKB Accelerator Review Committee Report

2024a Run

The recommendation tells us "Test of Beta Squeezing is Very Important."

We tried β_y^* = 0.9 mm for the last two weeks in 2024b run.

Most of the period is β_y^* = 1 mm.

We decided Pan A
to achieve 5 - 8 x 10^{34} $cm^{-2}s^{-1}$ luminosity in 2024c.

We increased beam currents rather than beta squeezing.

We could not try β_y^* = 0.8 mm or smaller during 2024 runs.

Recommendations

R2.1: Push peak luminosity (using a combination of Plans A, B, and C) towards 10^{35} $cm^{-2}s^{-1}$ and beyond, e.g. by gradually increasing beam currents and/or by further squeezing the vertical beta* to 0.8 mm and correcting the IR optics errors, as fast as possible. This might imply accepting a large injection background or turning off the detector for the initial tuning period.

R2.2: Consider operating (perhaps briefly) early in the 2024a run at a betay* of 0.8 mm to observe what are the next technical steps needed to be done during the 2024 summer shutdown to run stably at this value in the fall.

R2.3: As progress allows (just before or after summer), perform accelerator studies related to potential LS2 projects that need early lead-time decisions, e.g. by pushing betay* down to 0.6 mm or to the nominal value, at low current.

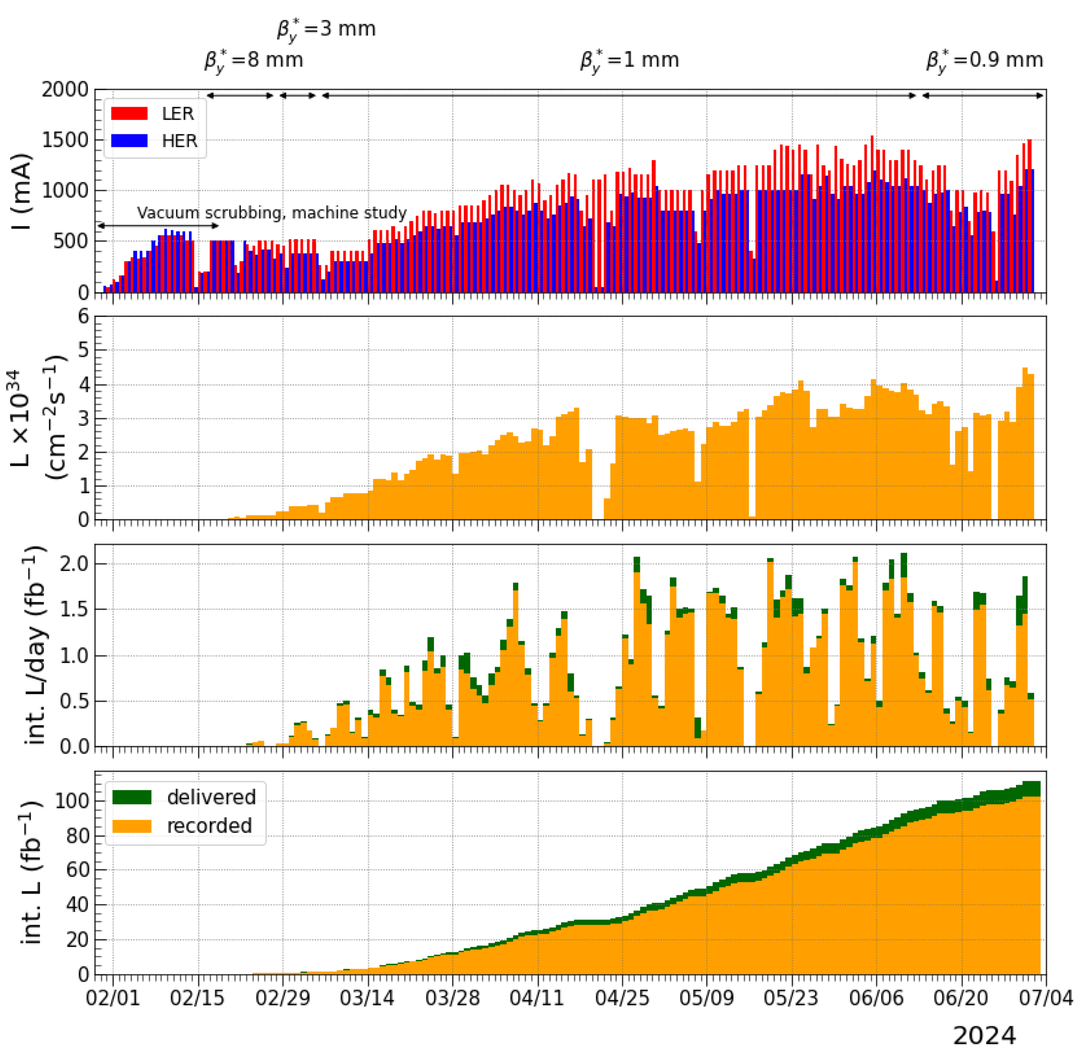
	Plan A	Plan B	Plan C
β_y^* (mm)	1	1	0.8
L_{sp} ($cm^{-2}s^{-1}/mA^2$)	6.1 x 10^{31}	6.1 x 10^{31}	7.6 x 10^{31}
$I_{b+}I_{b-}$ (mA^2)	0.56	0.66	0.56
I_{LER} / I_{HER} (A)	2.08 / 1.46	2.26 / 1.61	2.08 / 1.46
L ($cm^{-2}s^{-1}$)	8 x 10^{34}	9.4 x 10^{34}	10^{35}

Conclusions of 2024 Runs

- Peak Luminosity: 5.1 x 10^{34} $cm^{-2}s^{-1}$: $\beta_x^* = 60\ mm$, $\beta_y^* = 1\ mm$, I_{LER} = 1.63 A, I_{HER} = 1.26 A, n_b = 2346
- We Devoted to High Current Operation in 2024 Runs.
- Understanding and Avoiding of SBL Is Top Priority. One Candidate Is Vacuum Leak Sealant.
- Key Points for High Current Operation
  - Dynamic Aperture (Physical Aperture), Quality of Injection Beam, SR Heating and Orbit Control, Betatron Tune Shift and Synchro-Beta Resonances
- Nonlinear Collimator Helps Beam Background Mitigation.
  - Tolerance of Vertical Orbit at Skew Sextupole Is Very Tight.
- We observed Horizontal Tune Defference along Bunch Train in LER.
  - Variation Increases as Increasing Beam Current. Injection Becomes Difficult because Head or Tail Could Hit Resonance Line.
- Beam-Beam Blowup
  - Horizontal Beam Blowup in LER Could Be Mitigated by Squeezing β_x^*.
- Large Vertical Emittance in 2024c than 2024ab

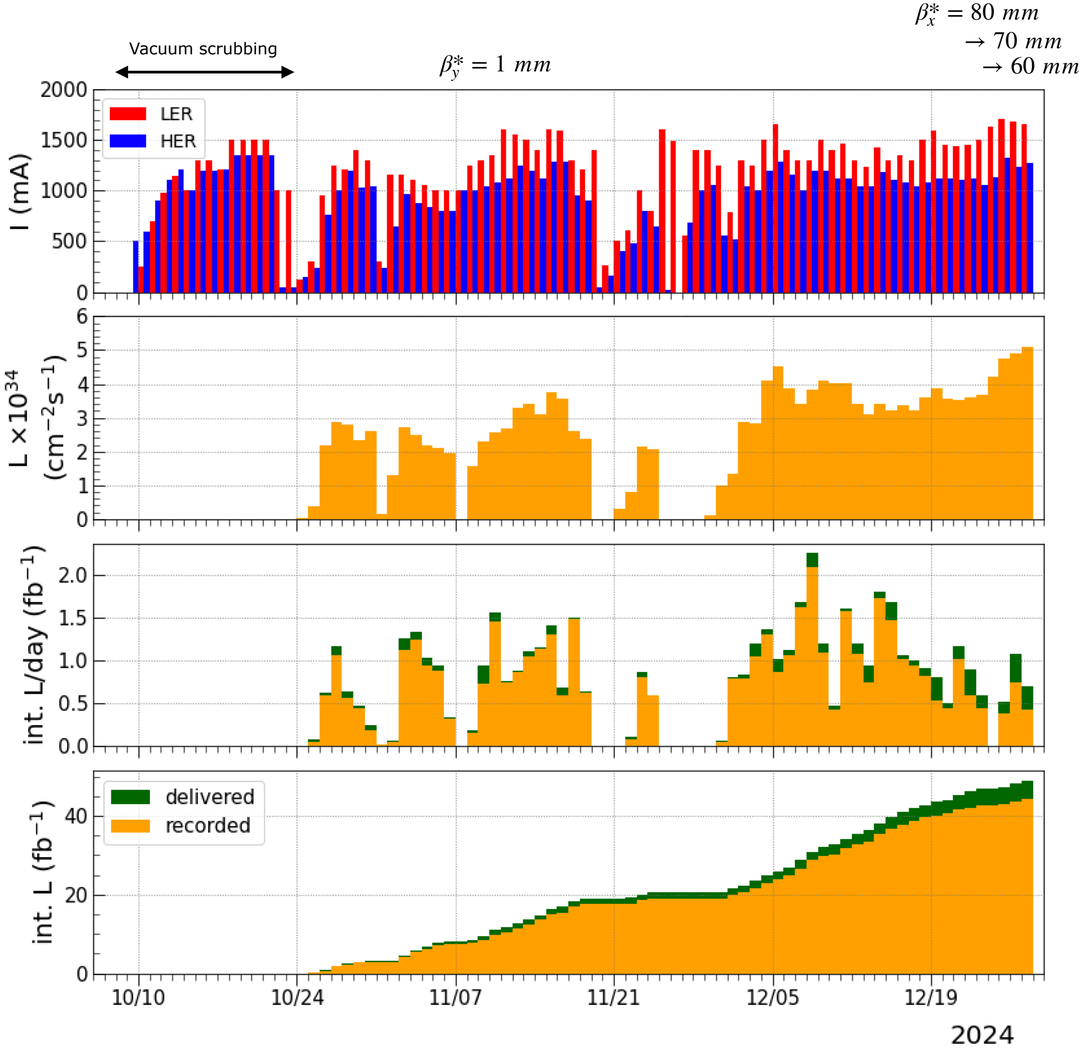
Histroy of 2024 Runs

2024a / 2024b



Jan. 29 - July 1 (155 Days)

2024c



Oct. 9 - Dec. 27 (80 Days)

Machine Parameters

	December 27, 2024		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	1632	1259	2080	1480	2750	2200	mA
Number of bunches	2346		2346		2346		
Bunch current	0.696	0.537	0.89	0.63	1.17	0.94	mA
Horizontal size σ_x*	15.5	16.6	17.9	16.6	17.9	16.6	μm
Vertical cap sigma Σ_y*	0.375		0.217		0.178		μm
Vertical size σ_y*	0.265		0.154		0.126		μm
Betatron tunes ν_x / ν_y	44.525 / 46.589	45.531 / 43.599	44.525 / 46.589	45.532 / 43.573	44.525 / 46.589	45.532 / 43.573	
β_x* / β_y*	**60** / **1.0**	60 / **1.0**	80 / **0.8**	60 / **0.8**	80 / **0.6**	60 / **0.6**	mm
σ_z	4.6 (6.0*)	5.1 (6.1*)	4.6 (6.5*)	5.1 (6.4*)	4.6 (6.5*)	5.1 (6.4*)	mm
Piwinski angle	**12.3**	**12.7**	10.7	12.7	10.7	12.7	
Crab waist ratio	80	60	80	80	80	80	%
Beam-Beam ξ_y	0.036	0.027	0.0444	0.0356	0.0604	0.0431	
Specific luminosity	5.8×10^{31}		7.62×10^{31}		9.31×10^{31}		$cm^{-2}s^{-1}/mA^2$
Luminosity	**5.1×10^{34}**		1×10^{35}		2.4×10^{35}		$cm^{-2}s^{-1}$

* Bunch lengthening is considered by using streak camera measurements.

Beam Aborts in 2024

S. Ogasawara et al.

All Aborts

2024ab

155 Days (3696 Hours)

Abort ring	SBL	BeamLoss	Injection	RF	Mag	VA	EQ	Others	Manual	Uncategorized	TOTAL
TOTAL	162	588	1800	134	17	19	37	65	-	2	2824
Both(LER)	128	86	156	2	7	-	-	16	-	-	395
Both(HER)	19	143	1135	2	-	-	-	3	-	-	1302
Both	-	-	-	-	8	-	7	1	-	2	18
LER	15	234	199	75	1	4	5	24	-	-	557
HER	-	125	310	55	1	15	25	21	-	-	552

Beam abort per 79 min

2024c

80 Days (1896 Hours)

ring	SBL	BeamLoss	Injection	RF	Mag	VA	EQ	Tuning	Others	Manual	Uncategorized	TOTAL
TOTAL	114	352	423	63	4	13	9	440	17	-	9	1444
Both(LER)	80	53	31	2	1	-	-	76	6	-	-	249
Both(HER)	18	69	354	-	1	1	-	233	1	-	1	678
Both	-	-	-	-	1	5	2	-	-	-	4	12
LER	15	161	13	32	1	3	1	27	9	-	-	262
HER	1	69	25	29	-	4	6	104	1	-	4	243

Beam abort per 79 min

I_{LER} > 60 mA, I_{HER} > 60 mA

Abort ring	SBL	BeamLoss	Injection	RF	Mag	VA	EQ	Others	Manual	Uncategorized	TOTAL
TOTAL	139	470	205	84	8	11	30	22	-	1	970
Both(LER)	114	73	63	2	3	-	-	13	-	-	268
Both(HER)	18	131	114	2	-	-	-	1	-	-	266
Both	-	-	-	-	4	-	7	-	-	1	12
LER	7	183	6	49	-	3	3	3	-	-	254
HER	-	83	22	31	1	8	20	5	-	-	170

HER Injection was too many.

LER: #SBL/Beam Dose = 0.064 (1/Ah)
HER: #SBL/Beam Dose = 0.012 (1/Ah)

ring	SBL	BeamLoss	Injection	RF	Mag	VA	EQ	Tuning	Others	Manual	Uncategorized	TOTAL
TOTAL	102	310	76	45	3	7	9	1	15	-	8	576
Both(LER)	72	46	19	2	1	-	-	1	5	-	-	146
Both(HER)	18	64	52	-	1	1	-	-	1	-	1	138
Both	-	-	-	-	1	1	2	-	-	-	3	7
LER	12	146	1	20	-	2	1	-	8	-	-	190
HER	-	54	4	23	-	3	6	-	1	-	4	95

Aborts due to injection was much Reduced.

LER: #SBL/Beam Dose = 0.074 (1/Ah)
HER: #SBL/Beam Dose = 0.020 (1/Ah)

Issues in 2024ab

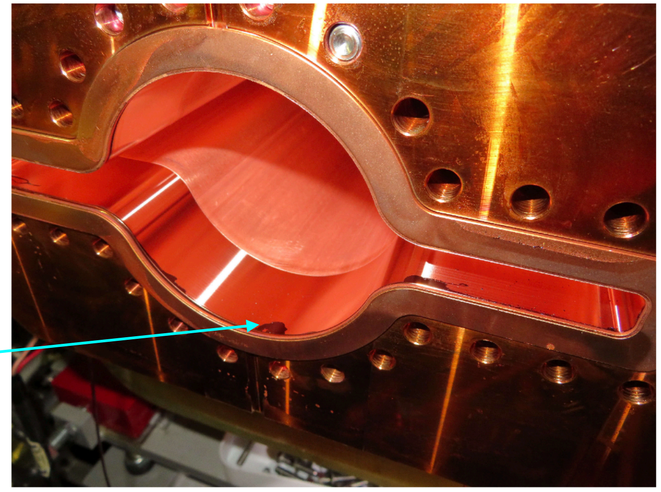
- What Limits Beam Current ?
  - Max in LER : 1.5 A
    - Lower Injection Efficiency due to Beam-Beam Interaction. Horizontal Beam Blowup
    - BxB FB Helps Injection Significantly. It Reduces as Increasing Stored Bunch Current. ($I_{b,stored} > I_{b,injection}$)
  - Max in HER : 1.21 A
    - Poor Injection Efficiency ~30 % → Improved Up to 80 % at the end of June (2024b)
    - Lower Injection Efficiency due to Beam-Beam Interaction. BxB FB Similar to LER.
  - Crab Waist in HER: 40 % up to 60 % → No Apertrue Defference
  - Stability of 2-Bunch Injection
  - Sudden Beam Loss (SBL)
    - Clearing Electrodes in Wigglers, Dust Drop?, Knocker Is Effective. What about HER ?

Issues in 2024ab (Cont'd)

- Too Many Aborts
  - SBL, Injection Related Aborts, Unidentified Beam Aborts (UBA)
- Orbit Stability
  - Beam Pipe Deformation due to SR Heating
    - SLYs(Loacl Chromaticity Correction) and Other Strong Sextupoles
    - Isolation between Quad and BPM (3 BPMs in Left Side of Y-LCC) Works Well in HER.
    - Vertical Orbit at Skew Sextupoles at Nonlinear Collimator Section; Needs $\Delta y < 10\ \mu m$
- Beam Blowup at Non-Collision and Collision
  - Significant, $I_b > 0.5$ mA ~ 0.6 mA. $I_{b+}I_{b-}$ Is Difficult Larger than 0.3 mA^2.
- Aging Effect
  - Many Machine Troubles

Issues in 2024c

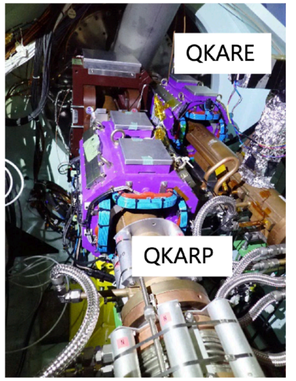
- What Limits Beam Current Again ?
  - Max in LER : 1.7 A
    - Similar to 2024ab
    - Touschek Lifetime and Vacuum Lifetime
    - Betatron Tune Depends on Bunch Location
      - Horizontal Tune at the Head of Train is lower than the Tail of Train. Head of Train Is Short Lifetime (Close to Synchro-Beta Resonance or Half Integer).
  - Max in HER : 1.35 A
    - Similar to 2024ab
    - Dynamic Apertrue and Physical Aperture for Injection
  - Sudden Beam Loss (SBL)
    - Swap Upside Down of Beam Pipe with Clearing Electrode
    - "VACSEAL", High Vacuum Leak Sealant ? Also Used in HER



Issues in 2024c (Cont'd)

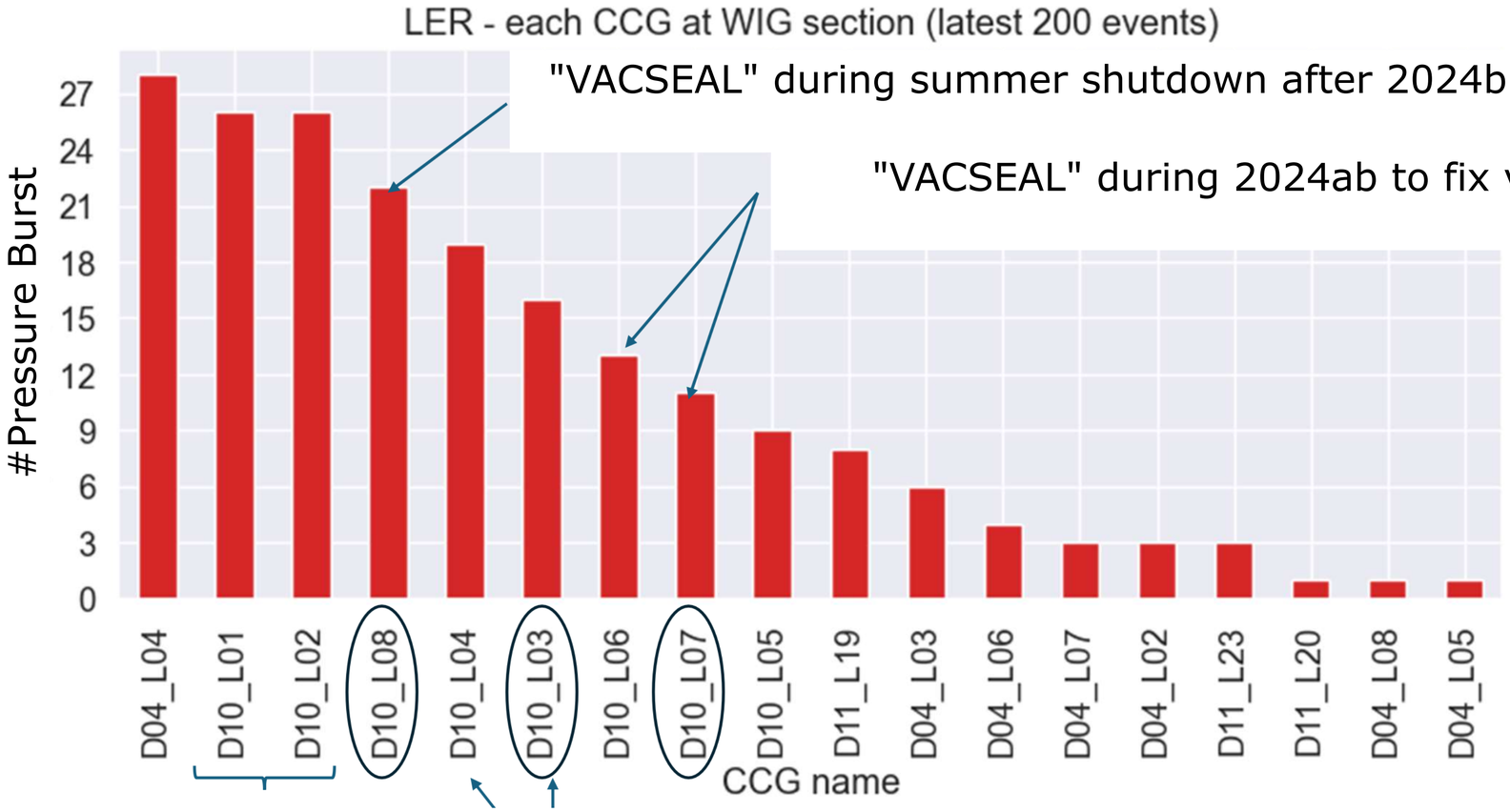
- Injection Error (Coherent Oscillation) in LER
  - β_x at Injection Point from 100 m to 160 m to Reduce Injection Error
  - Beam Background due to Injection Was Mitigated.
- Large Vertical Emittance in HER and LER
  - HER : 20 - 30 pm in 2024ab → 70 - 80 pm in 2024c
  - LER : 20 pm in 2024ab → 40 pm in 2024c
- β_x at Sqew Sextupoles in the Nonlinear Collimator : from 7 m to 3 m to Reduce Injection Background
- Apertrue Measurement (x, y, Momentum) Becomes Available for Both Rings.
- β_x^* in LER : from 80 mm to 60 mm to Mitigate Synchro-Beta or Betatron Resonance in Collision
- Many QC1RP Quenches at High Current Operation in LER (Radiation Dose Is Problem.)

Issues in 2024c (Cont'd)



- Aligment of QKARP (Sqew Quad near IP) during Summer Shutdown
  - Δy = -1.9 mm : Orbit Distortion due to Changing Magnetic Field Was Much Reduced.
  - Used for IP Knob and Optics Correction
- Orbit Stability
  - Isolation between Quad and BPM in LER (One BPM in Left Side of Y-LCC, during Summer Shutdown)
  - New Orbit Correction Algorithm Was Impremented. Constraint for Sextupole Orbit
- BxB FB Tuning (Gain and/or Phase) Affects Luminosity Performance Significantly.

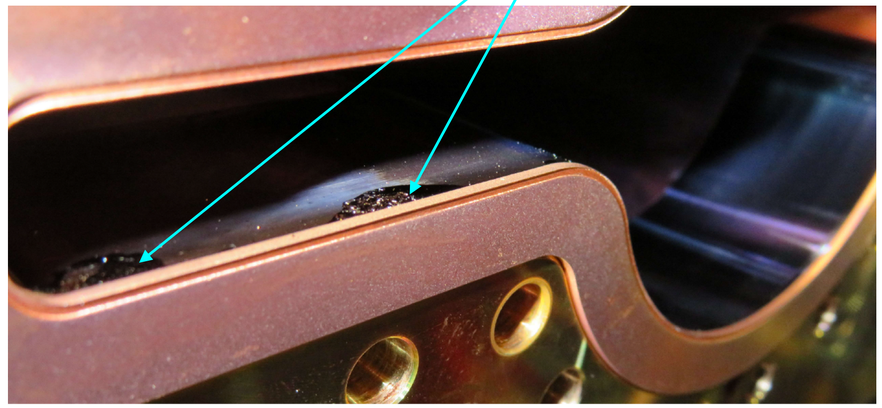
SBL and Vacuum Leak Sealant



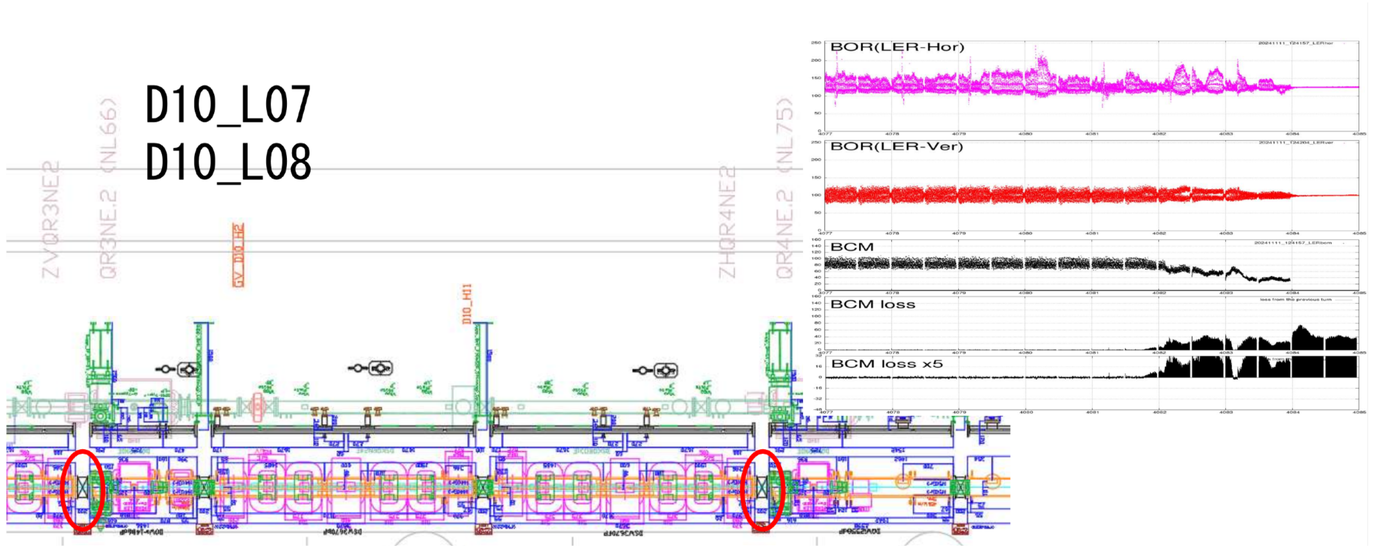
"VACSEAL" during summer shutdown after 2024b to check inside

"VACSEAL" during 2024ab to fix vacuum leak

"VACSEAL" ?

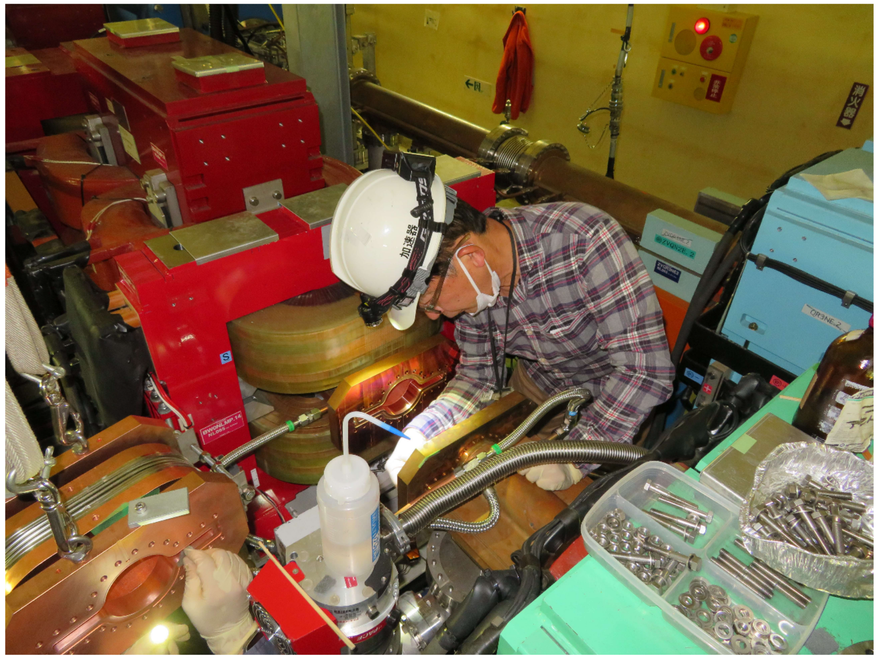


SBL Event



* Bellows Chamber at Nikko Wiggler Section Was Exchanged on November 6 2024

LER Wiggler Section

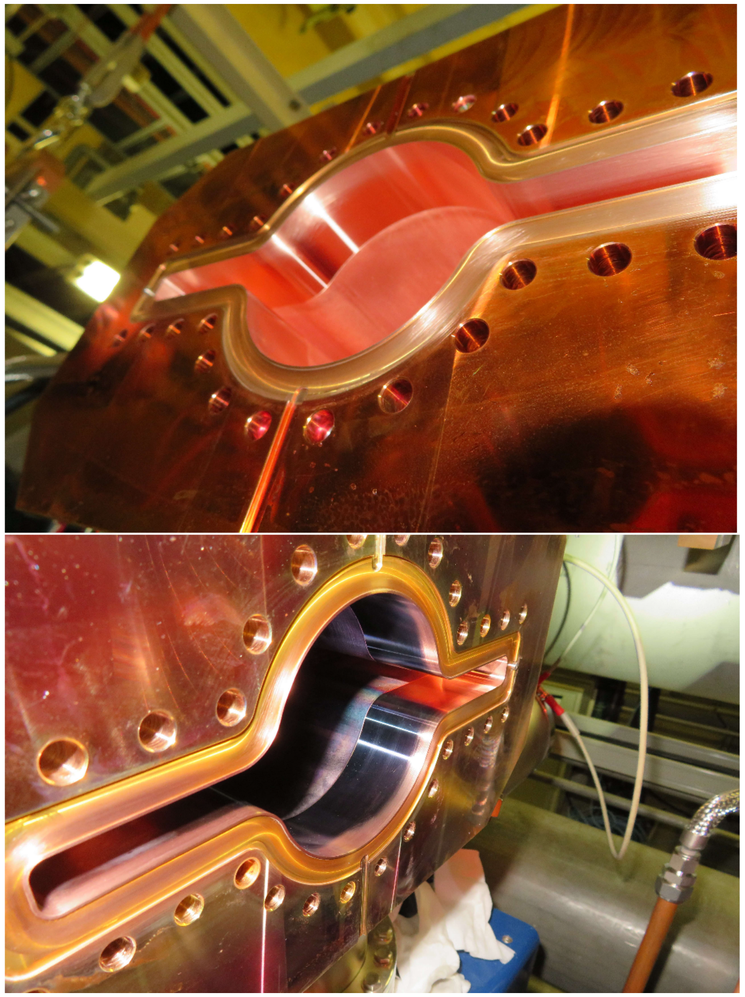


* Cleaning work at Nikko wiggler section on Nov. 26 2024

This reduces SBL related to the presssure burst at the pipe where VACSEAL removed.

Oct. 9 - Nov. 6 : #SBL/Beam Dose = 0.141 (1/Ah)
Nov. 6 - Dec. 27 : #SBL/Beam Dose = 0.043 (1/Ah)

After removing VACSEAL (black color)



Vertical Emittance, Tunes, and X-Y Coupling

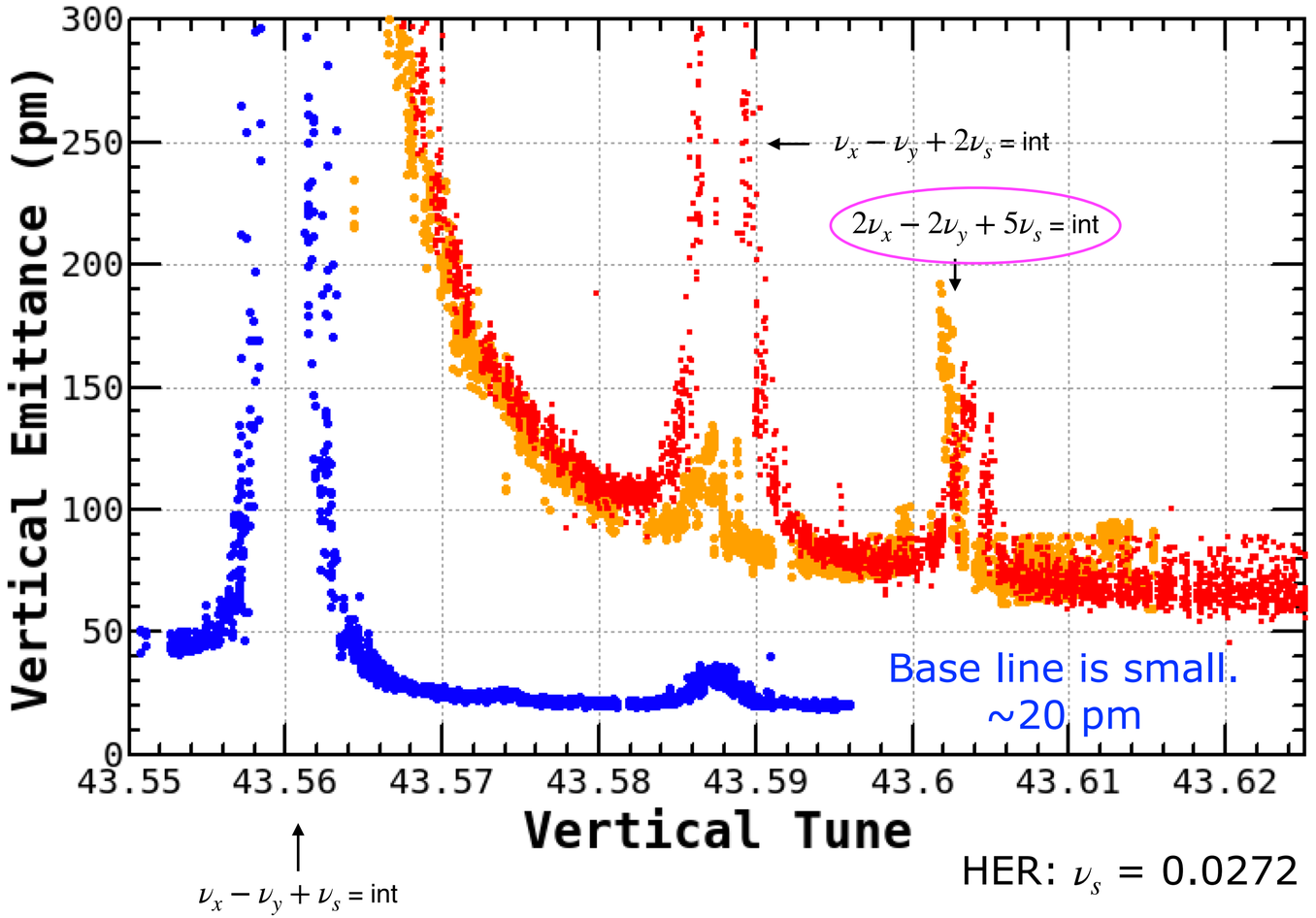
Vertical Tune Scan in HER

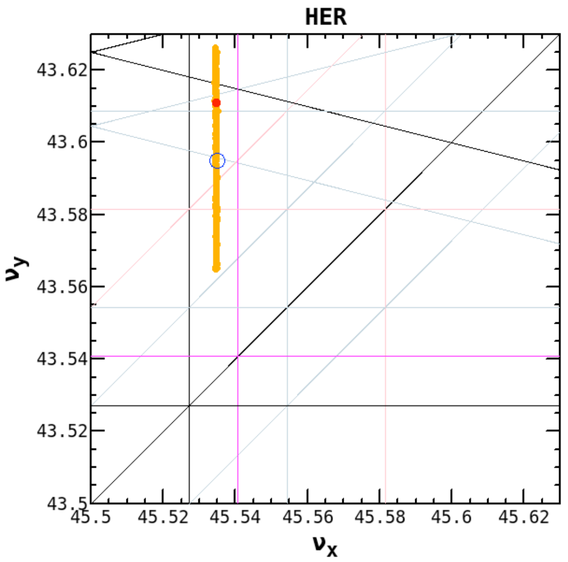
Vertical emittance in 2022ab and 2024ab is small, but large in 2024c.

2022 March 29 (2022a)

2024 Nov. 22 (2024c)

2024 Nov. 29 (2024c)
Another different optics correction





Base line is large.
~70 pm

HER: ν_s = 0.0272

Higher order synchro-beta X-Y coupling resonance (9th)

Horizontal kick (injection kicker) measured by TBT BPMs

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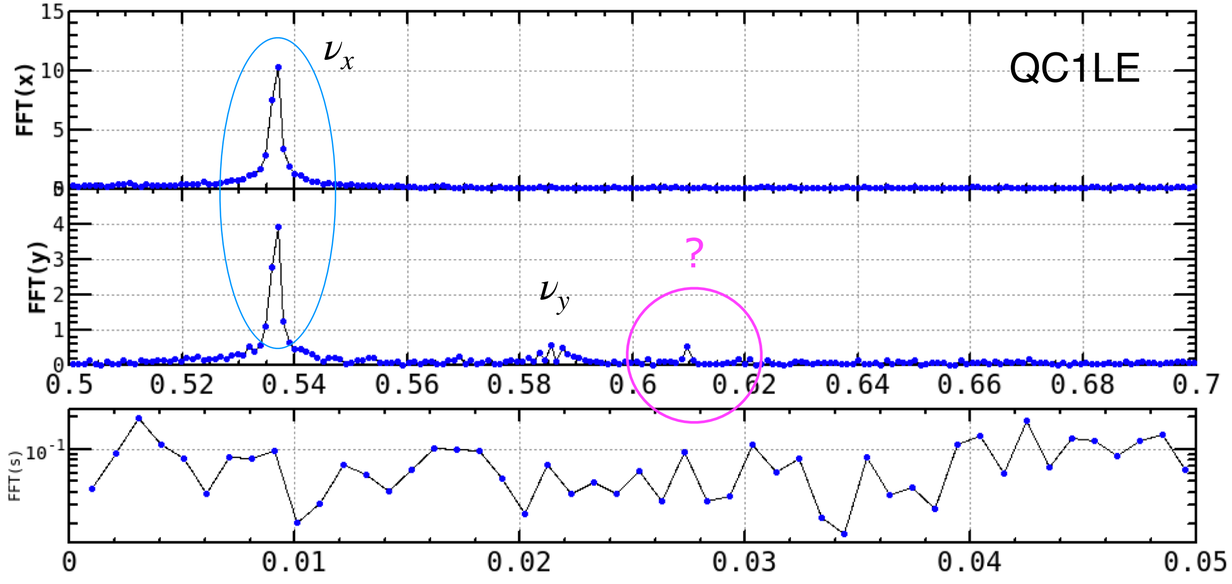

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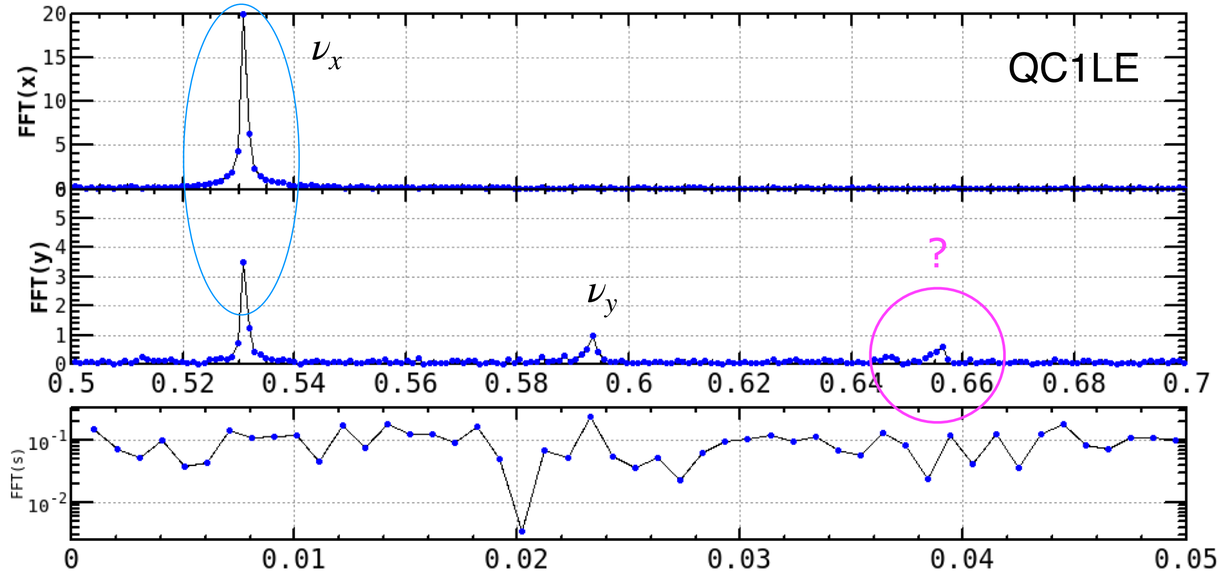
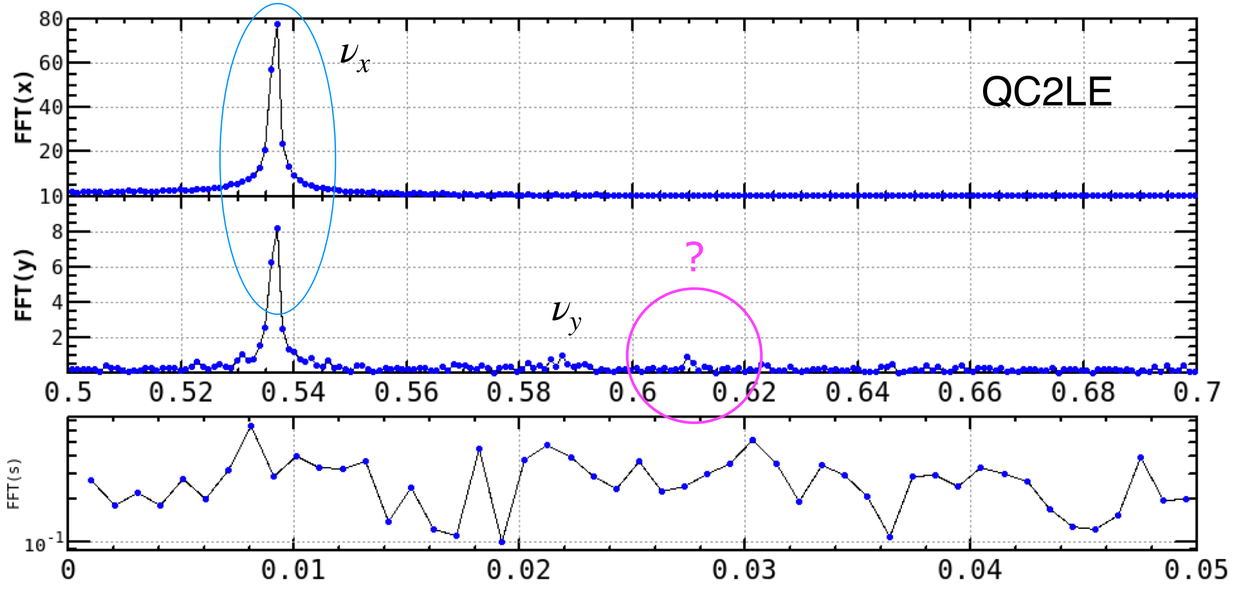
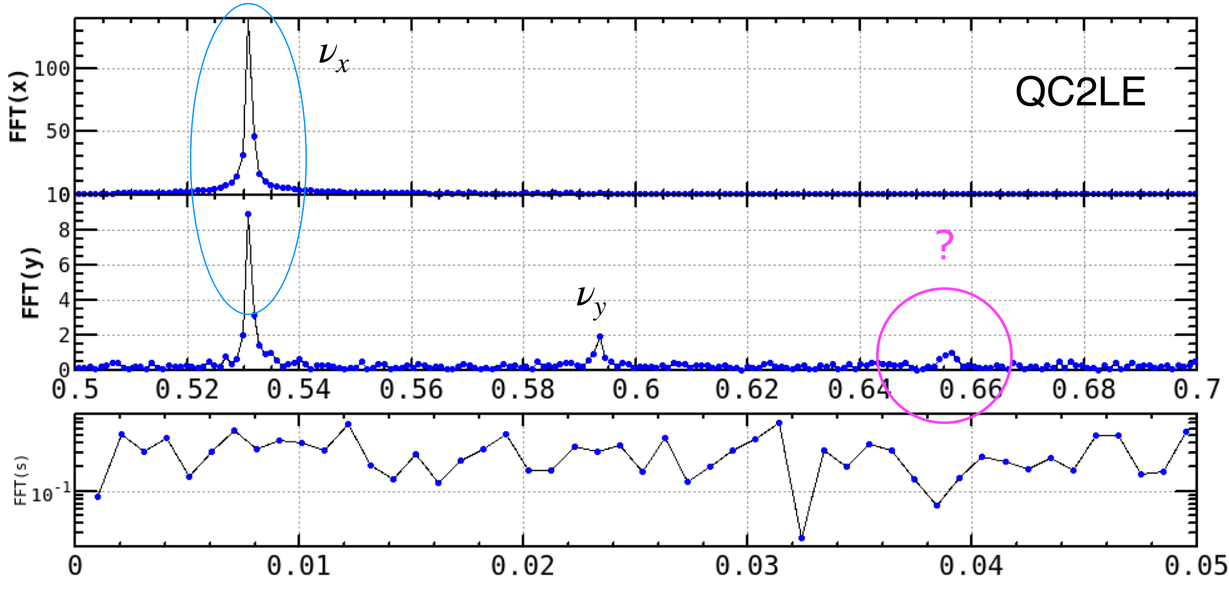
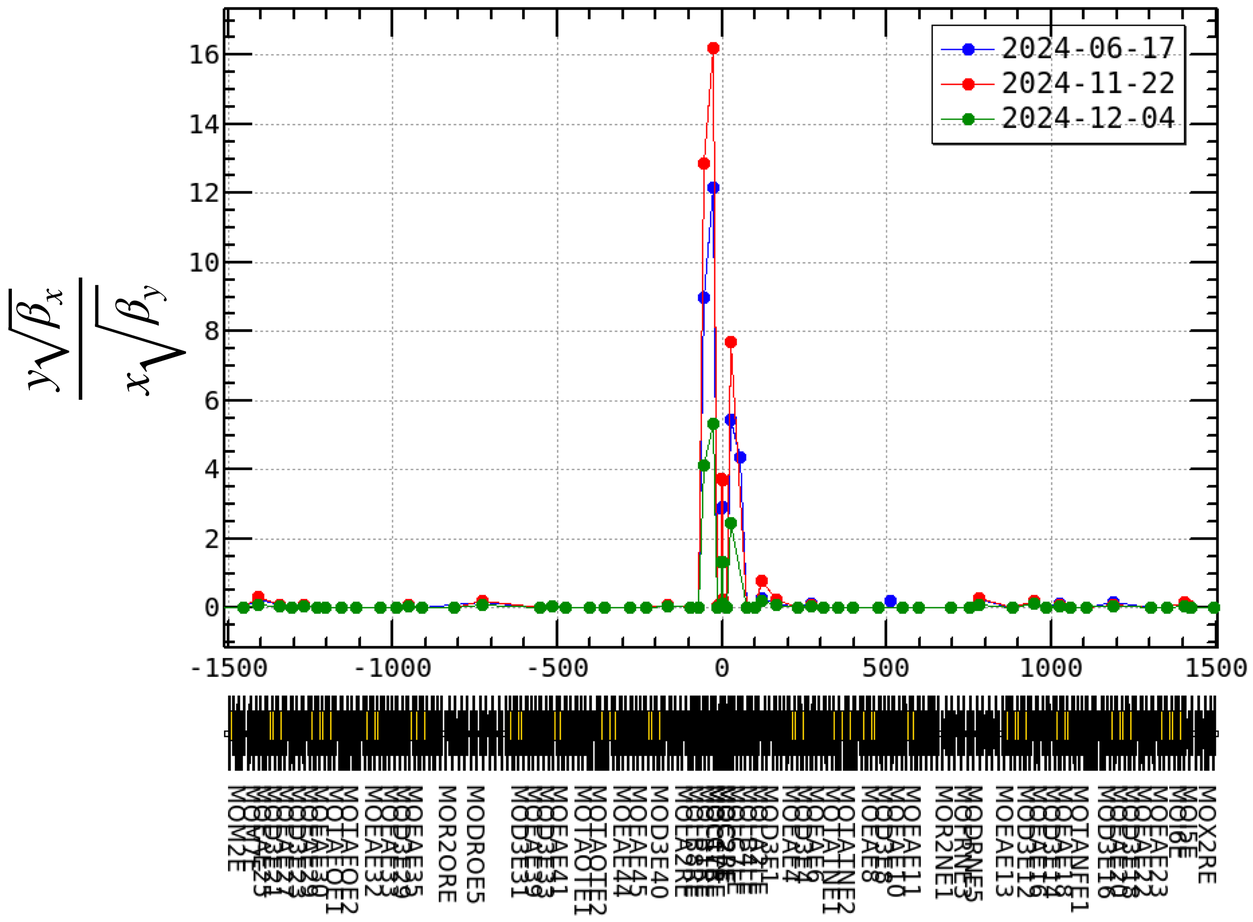


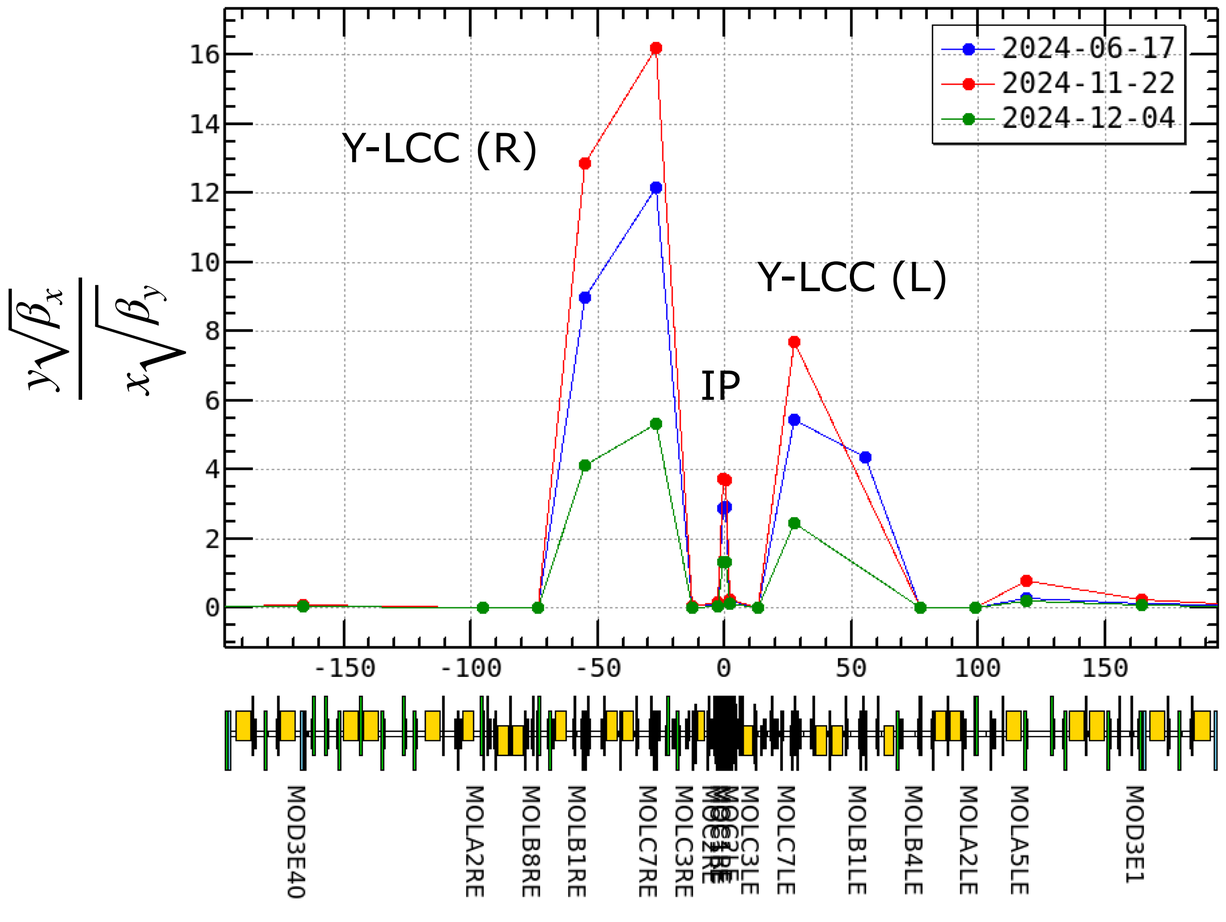




$\frac{y}{x}$: Ratio of FFT(y) to FFT(x) amplitude at horizontal tune (X-Y Couplings)

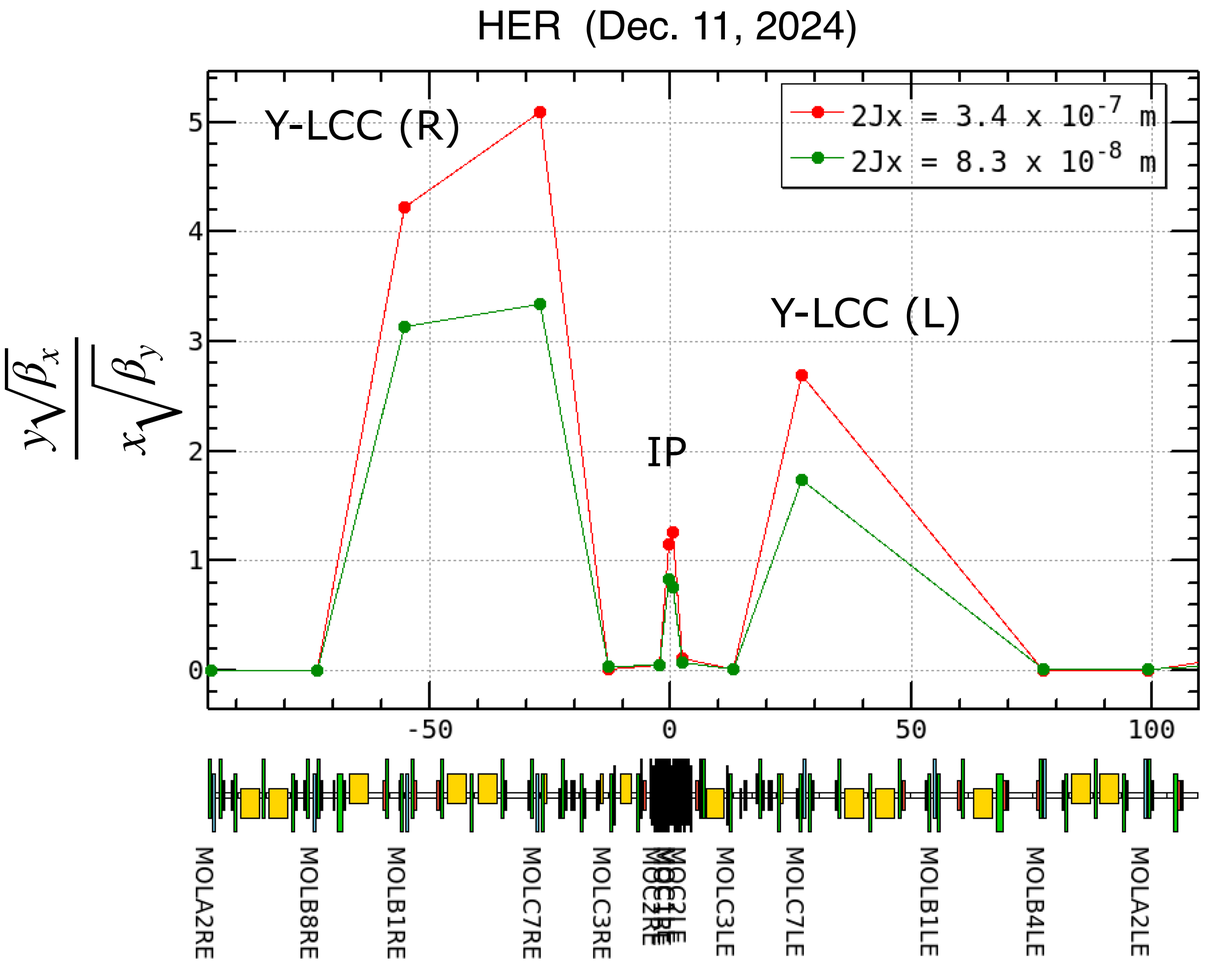
HER

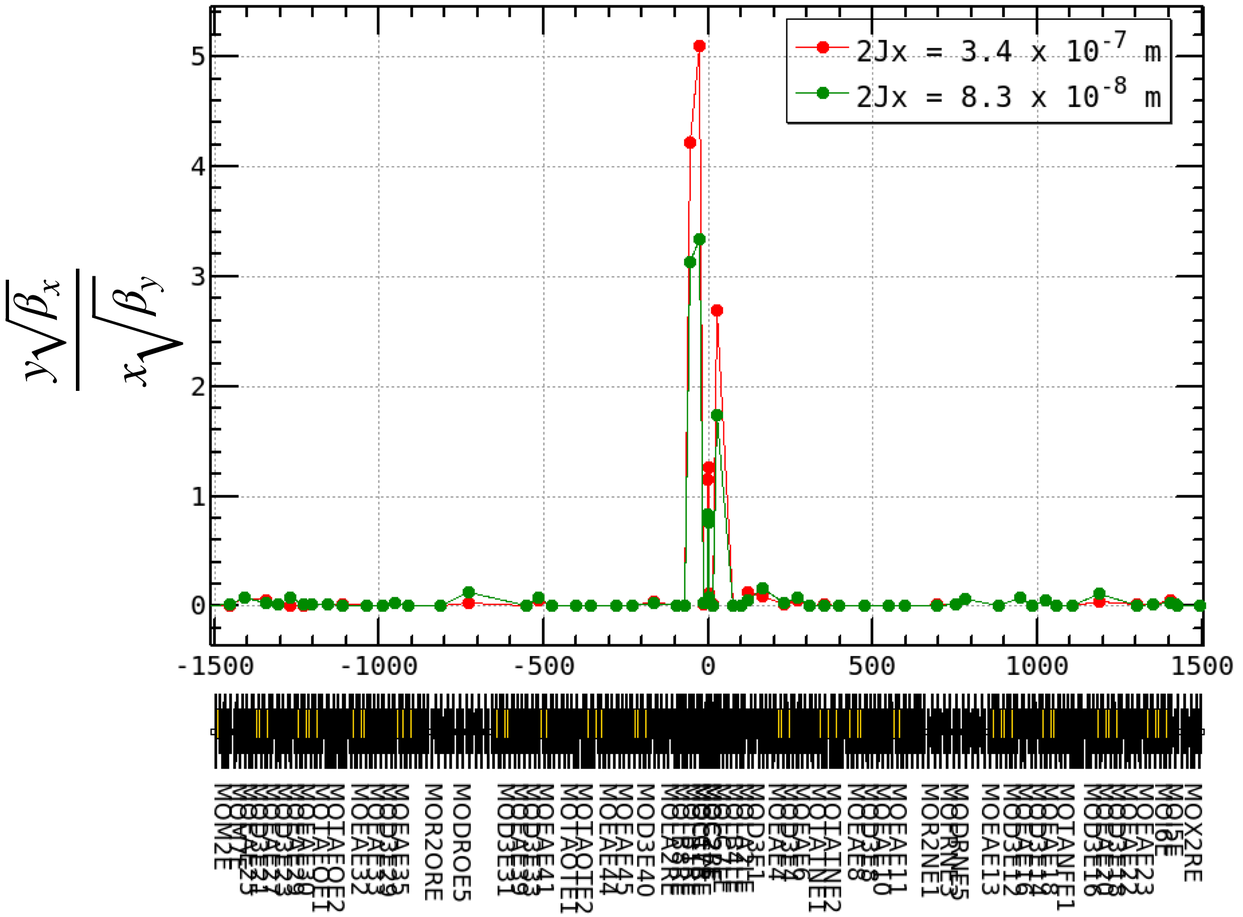




X-Y coupling is closed in the interaction region.

Different colors indicate different correction schemes. (The green is smaller correction from the design magnetic field.)





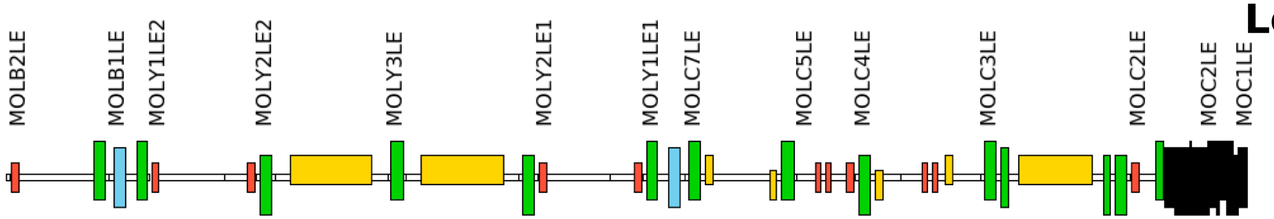
X-Y coupling depends on the initial horizontal amplitude.

No reason of large emittance due to X-Y couplings in HER

Orbit Stability

Synchrotron Radiation at Strong Sextupole Region in HER

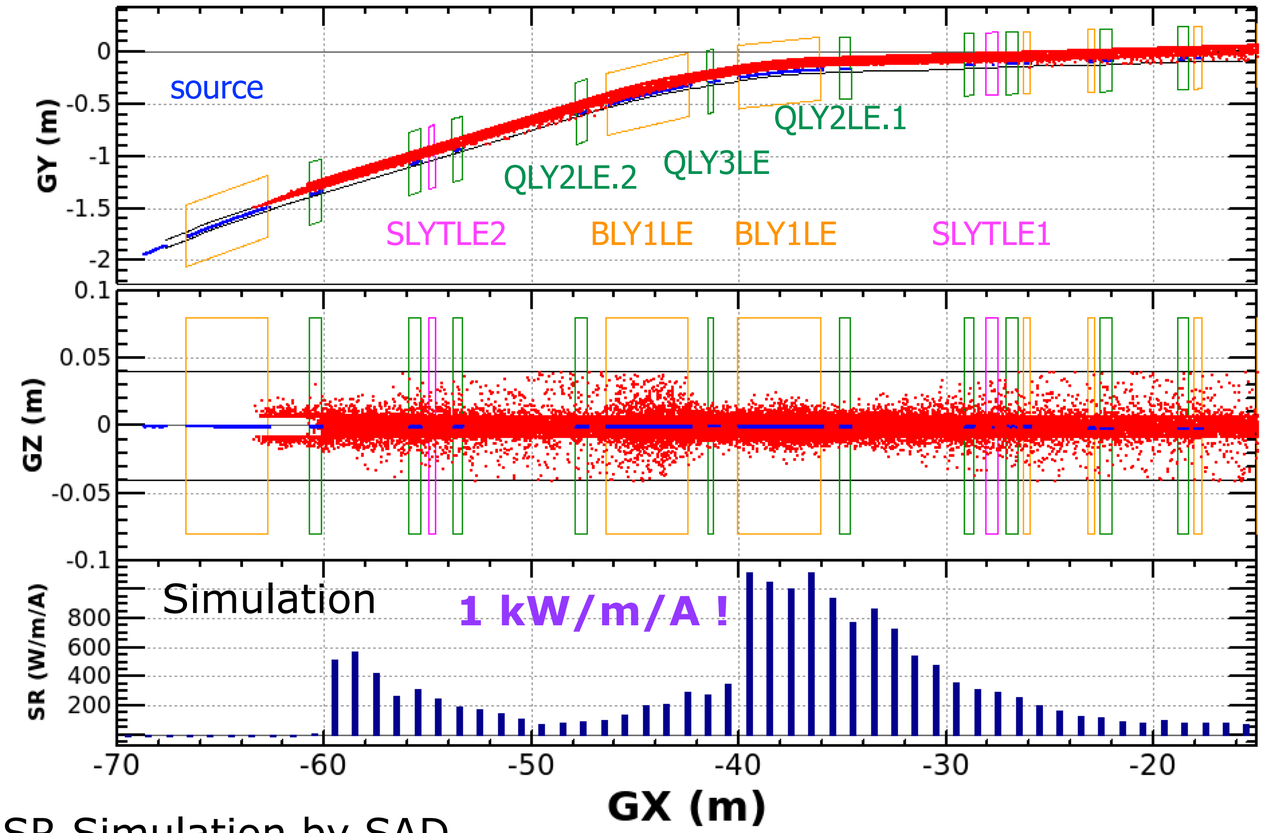
Loacl Chromaticity Correction (Y-LCC)



Dipole Magnet

Quadrupole Magnet

7 GeV Electron ⟶



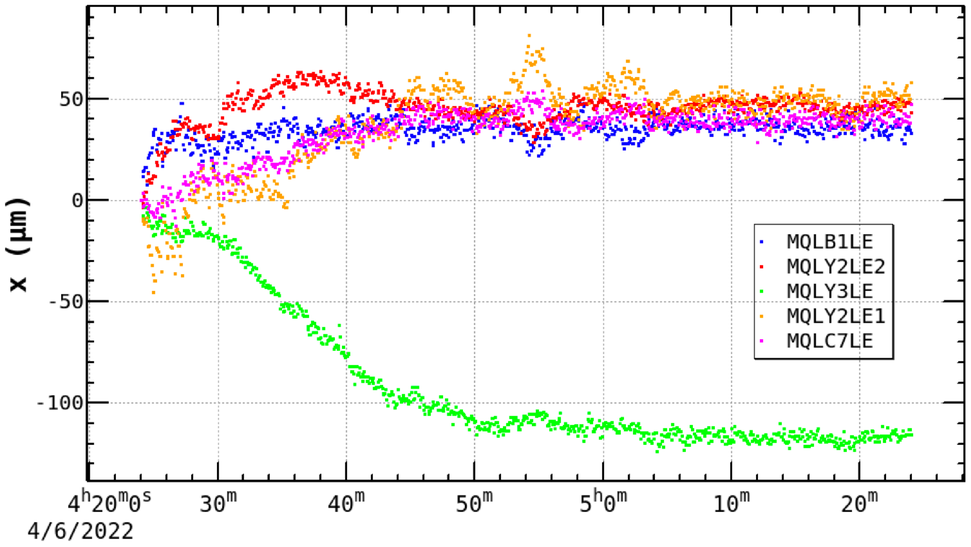
SR Simulation by SAD

Inner

Outer

Beam pipe pushes quadrupoles with BPM due to intense SR heating.

BPM Readings (Horizontal)

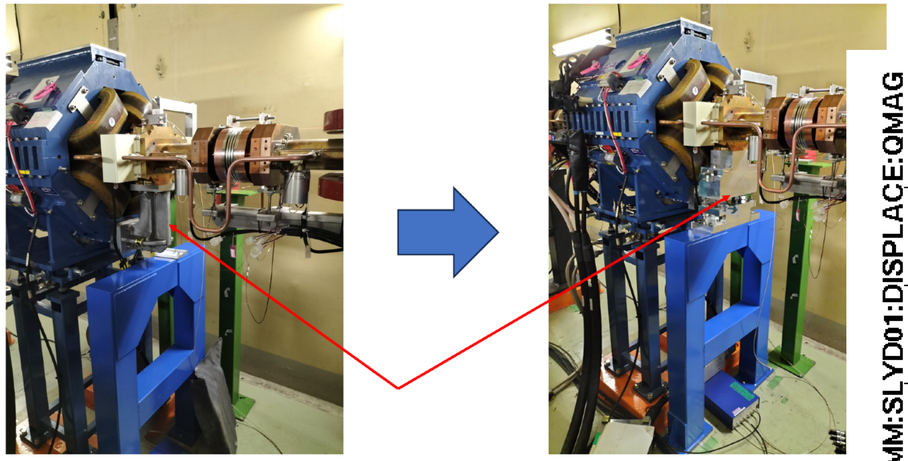


vacuum pipe
diameter: 80 mm
with ante-chamber: 110 mm
height: 14 mm (±7 mm)

Before

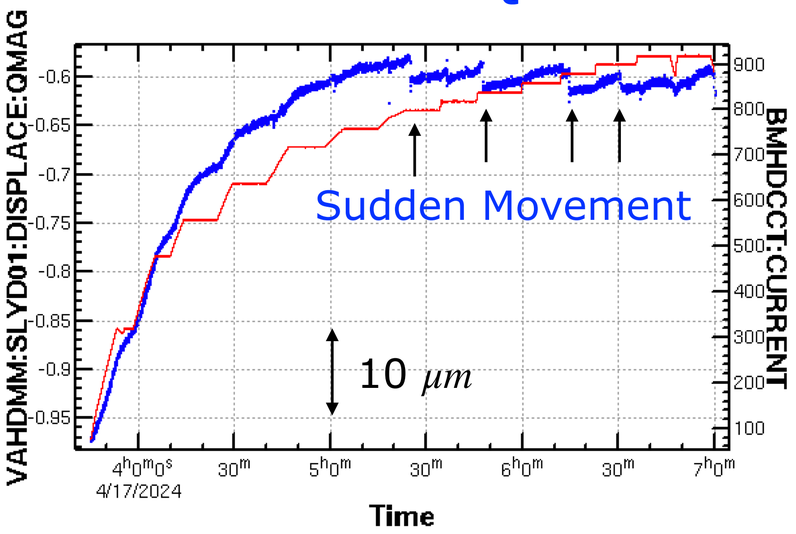
HER

After

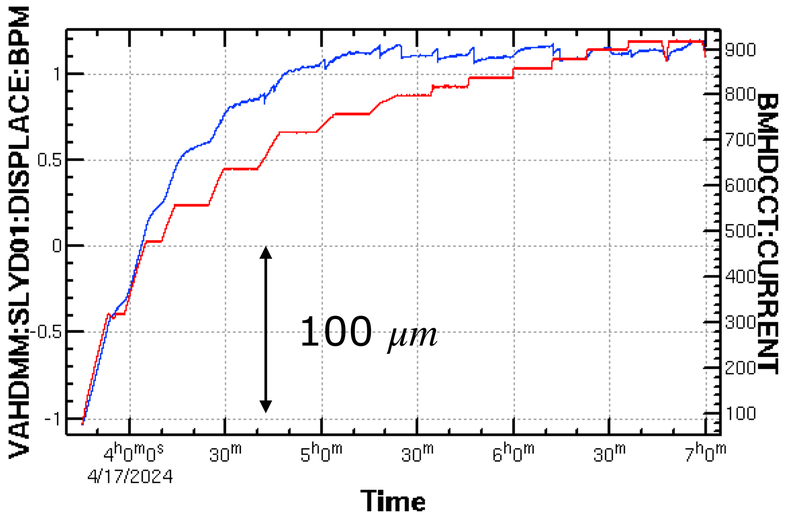


Red：Beam Current in HER

Movement of Quad



Movement of BPM Block



Remove BPM support from Quad

Work on April 17 2024

We don't observe Sudden Orbit Distortion after Isolation Work.

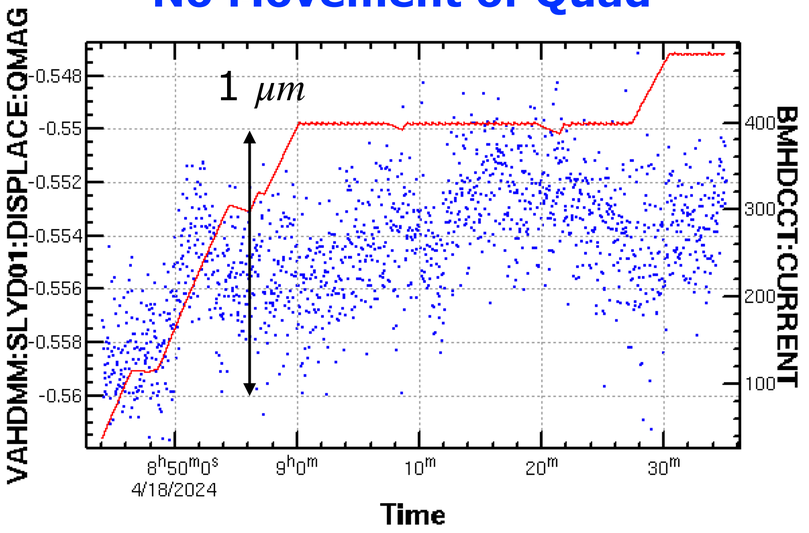
No unidentified beam abort occurs.

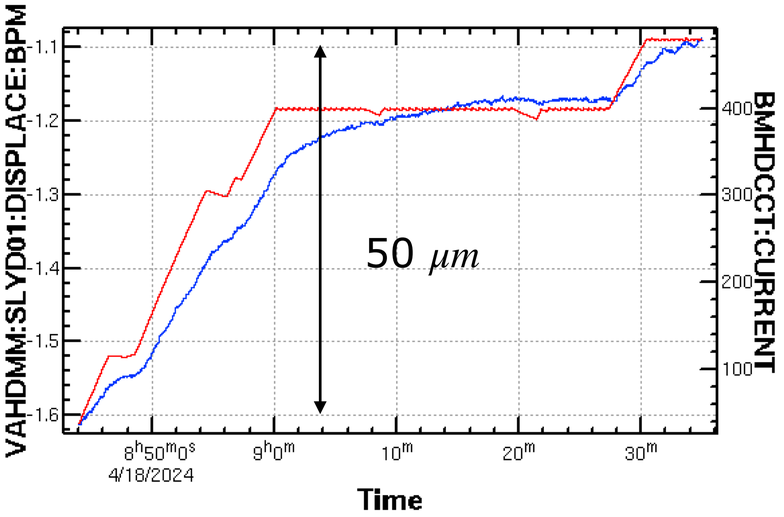
Horiontal orbit shift at sextupoles induces large beta-beat and tune shift.

After Modification

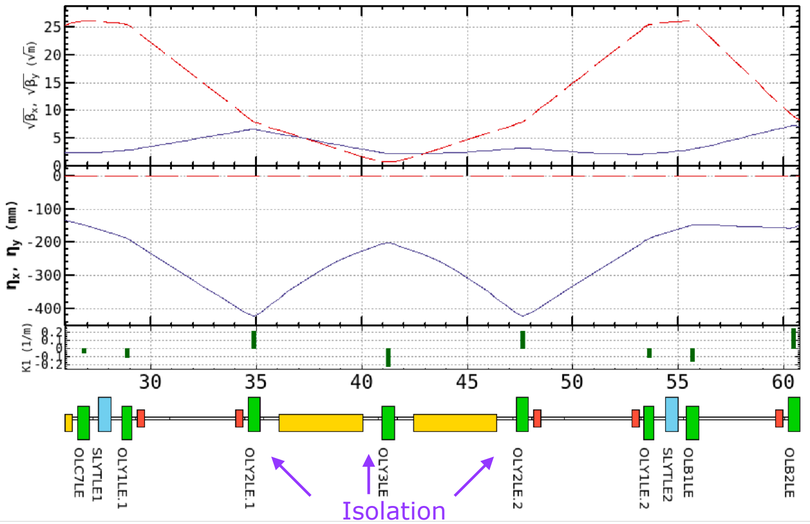
1 V = 100 μm

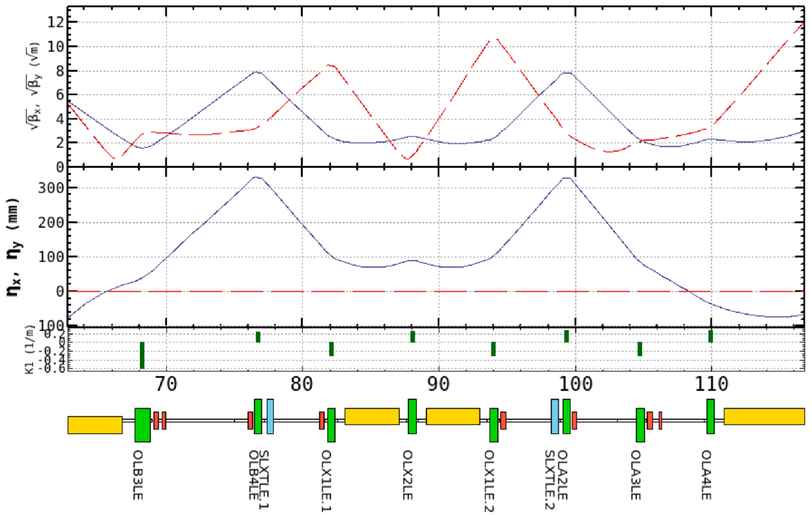
No Movement of Quad

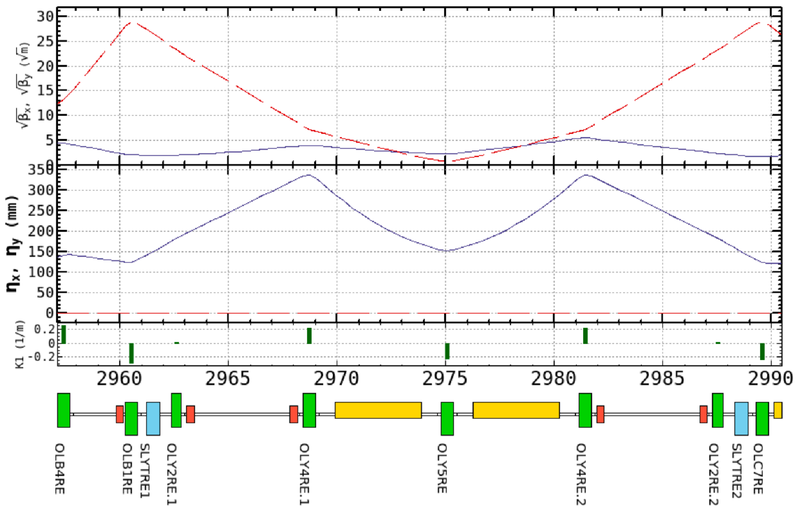




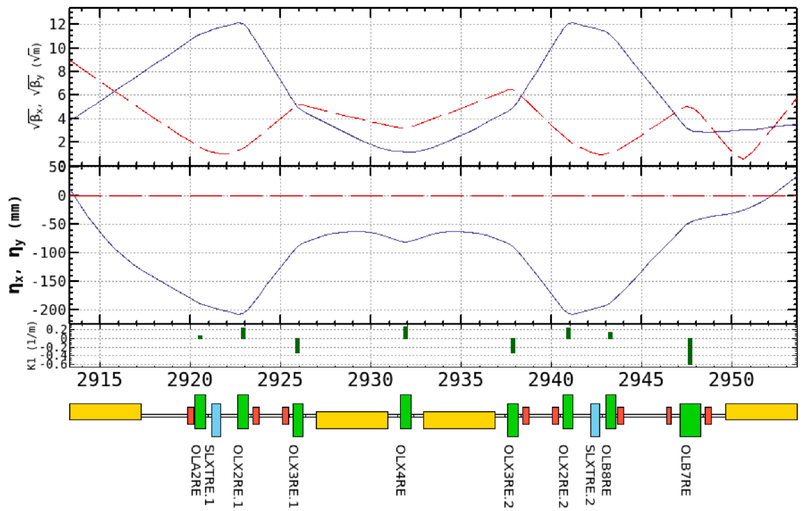
HER



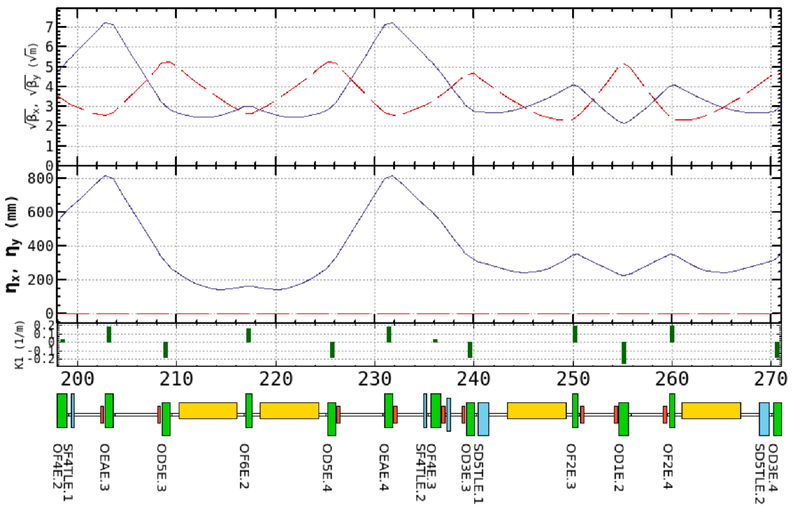




Y-LCC (SLY)

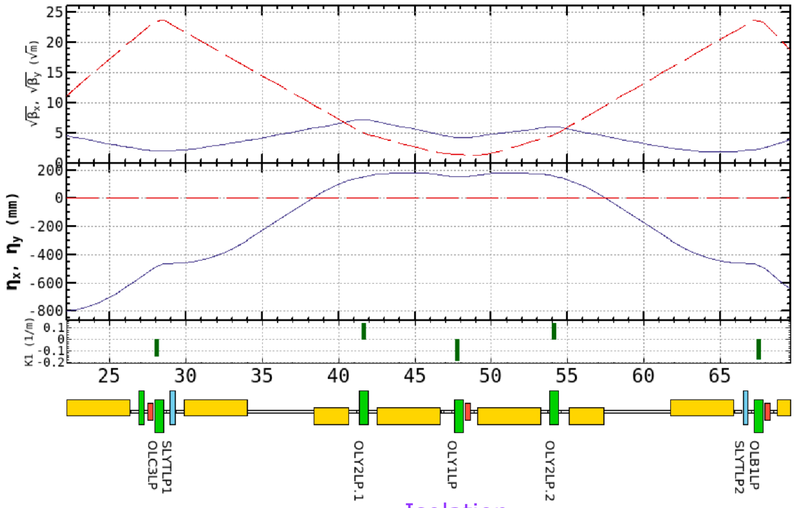


X-LCC (SLX)

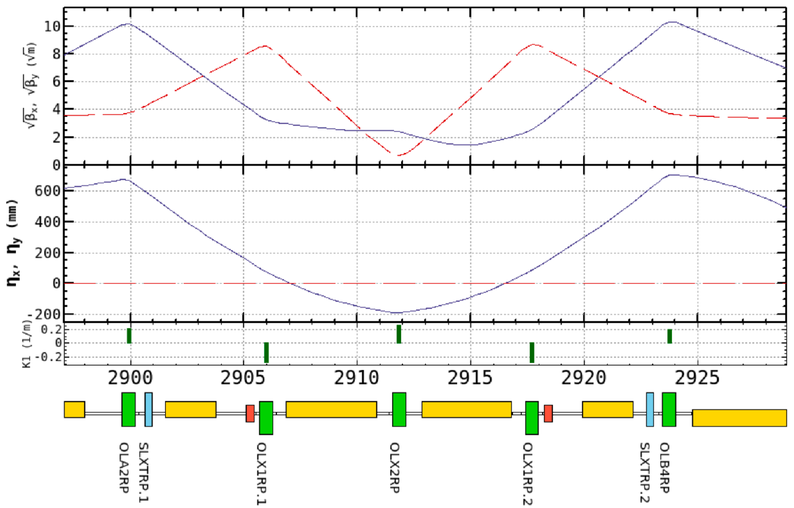


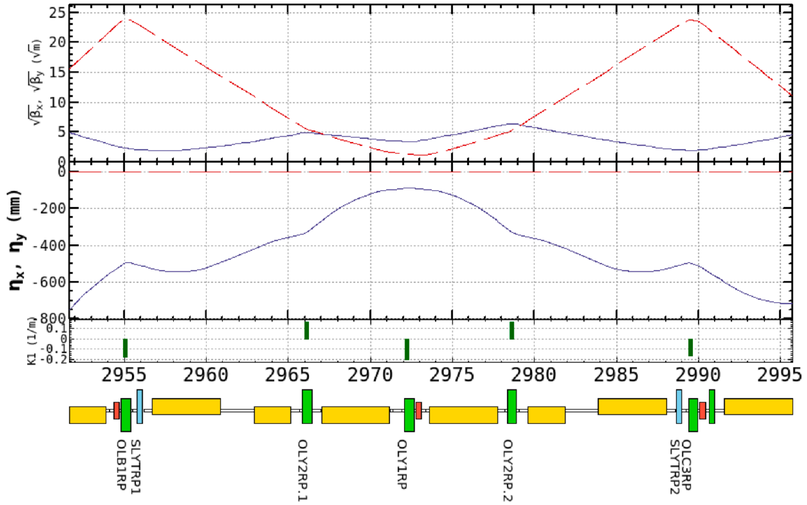
SF and SD
(50 Families)

LER

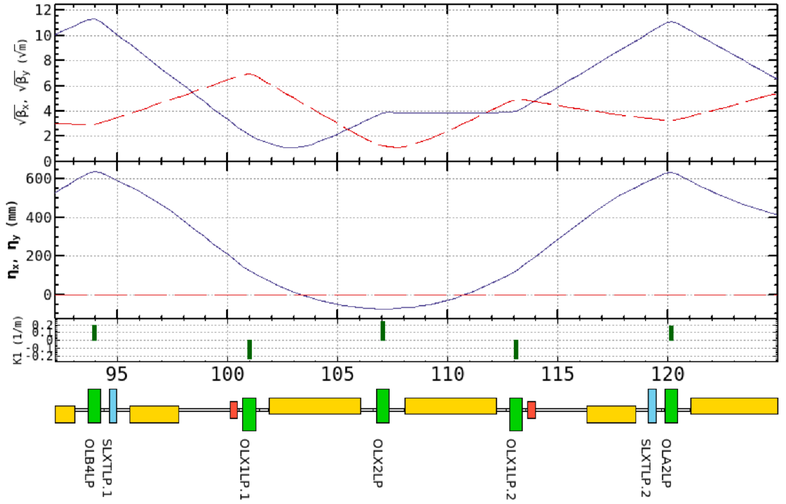


Isolation

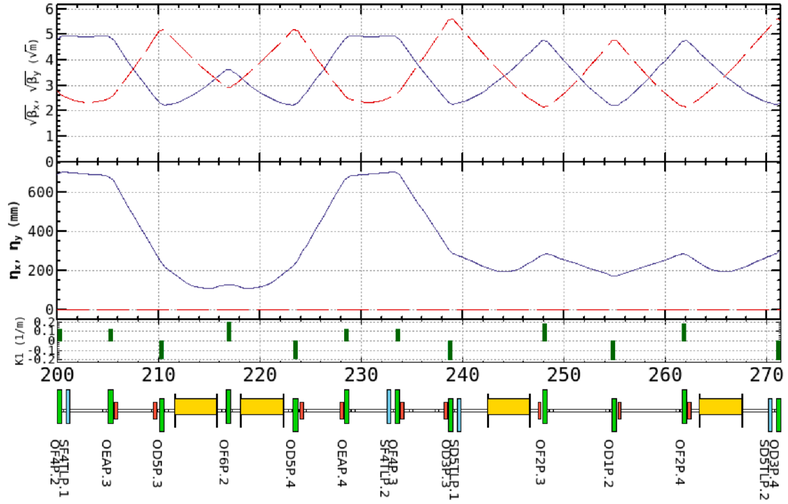




Y-LCC (SLY)



X-LCC (SLX)



SF and SD
(50 Families)

Orbit Correction with Constraints

- Beam Orbit at Sextupole Is Estimated by Using Neighbour Two BPMs. Assuming Tansfer Matrix
- Horizontal Kick
  - Kick from Two Sextupoles (-I' Transformation)

normal quad

$$\Delta p_{x2} - \Delta p_{x1} \simeq \frac{1}{2}\left(K_2^{(2)} - K_2^{(1)}\right)(x_1^2 - y_1^2) + \left(K_2^{(1)}\Delta x_1 + K_2^{(2)}\Delta x_2\right) x_1 - \left(K_2^{(1)}\Delta y_1 + K_2^{(2)}\Delta y_2\right) y_1$$

skew quad

$$\Delta p_{y2} - \Delta p_{y1} \simeq \left(K_2^{(2)} - K_2^{(1)}\right) x_1 y_1 - \left(K_2^{(1)}\Delta y_1 + K_2^{(2)}\Delta y_2\right) x_1 - \left(K_2^{(1)}\Delta x_1 + K_2^{(2)}\Delta x_2\right) y_1$$

Define :

$$\Delta x_{SOS} = \sqrt{\frac{2}{K_2^{2(1)} + K_2^{2(2)}}}\left(K_2^{(1)}\Delta x_1 + K_2^{(2)}\Delta x_2\right)$$

$(\Delta x_1, \Delta y_1)$ and $(\Delta x_2, \Delta y_2)$ are closed orbit at sextupoles 1 and 2 with respect to magnetic center

(x_1, y_1) and (x_2, y_2) are orbit at sextupoles 1 and 2 with respect to the closed orbit

This variable should be kept constant.

Contribution to Δx_{SOS} from j-th dipole corrector :

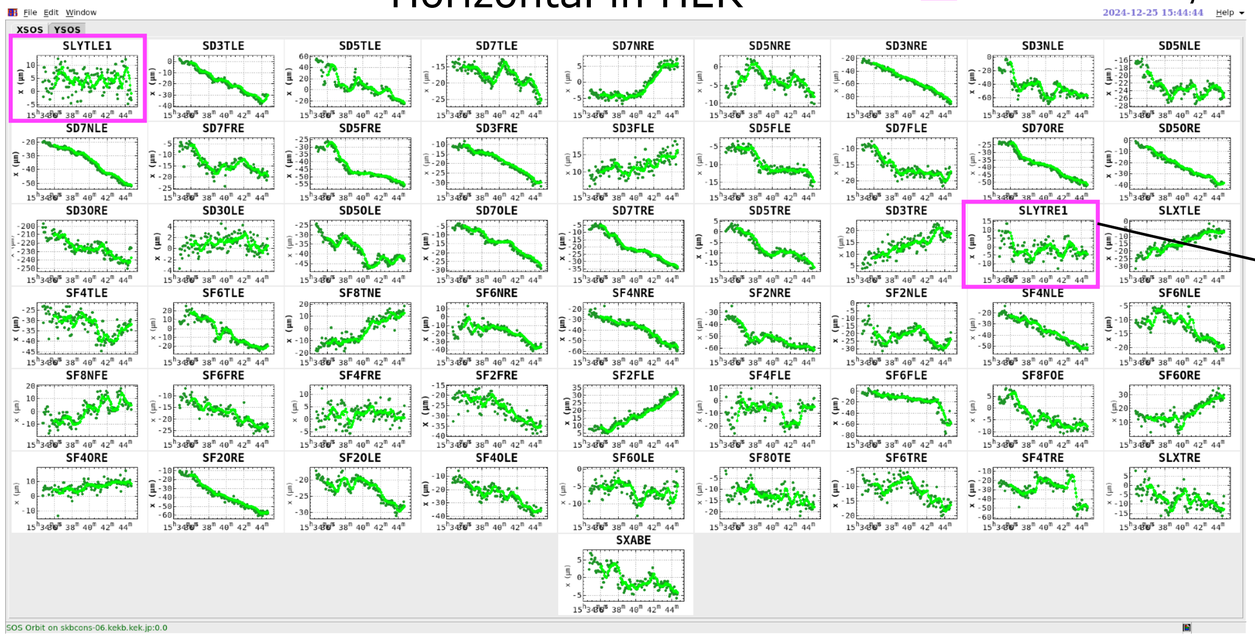
$$\sqrt{\frac{2}{K_2^{2(1)} + K_2^{2(2)}}} \sum_j \left(|K_2^{(1)}| m_{1j} + |K_2^{(2)}| m_{2j}\right)\theta_j = \sum_j \sqrt{\beta_s \beta_j}\left(\cos\xi \sin\Delta\phi_j - \sin\xi\cos\Delta\phi_j \cot\pi\nu\right)\theta_j$$

$$\simeq \sum_j \sqrt{\beta_s \beta_j}\left(\sin\Delta\phi_j\right)\theta_j$$

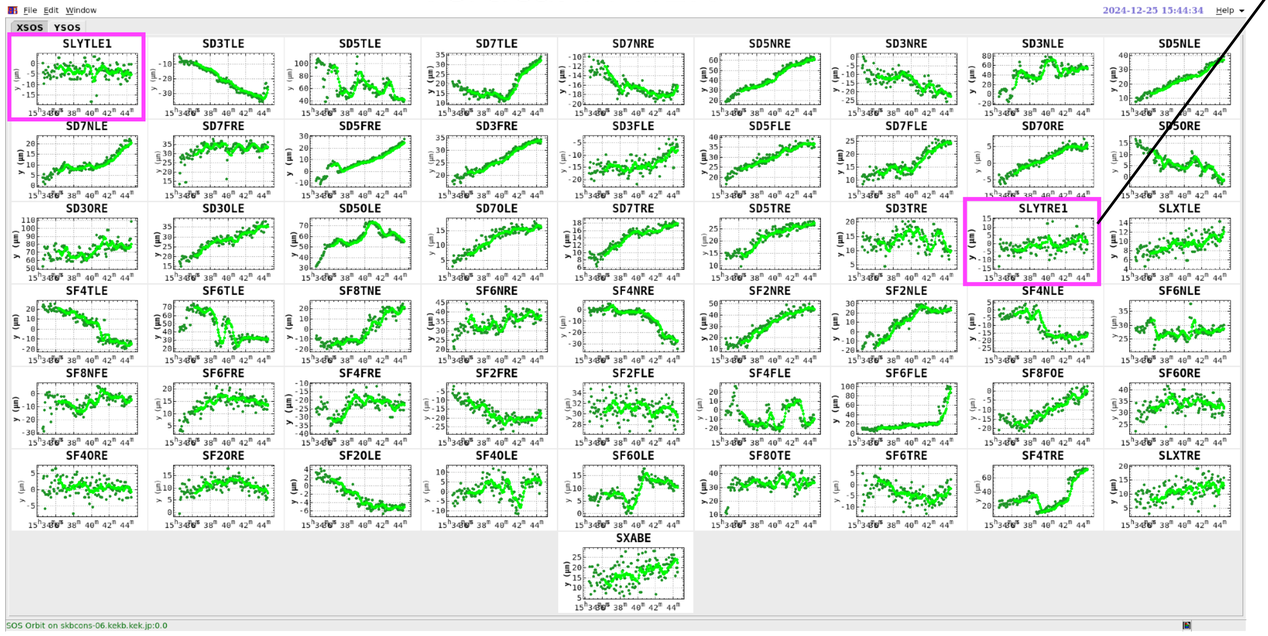
$$\tan(\xi + \pi/4) \equiv K_2^{(2)}/K_2^{(1)}$$

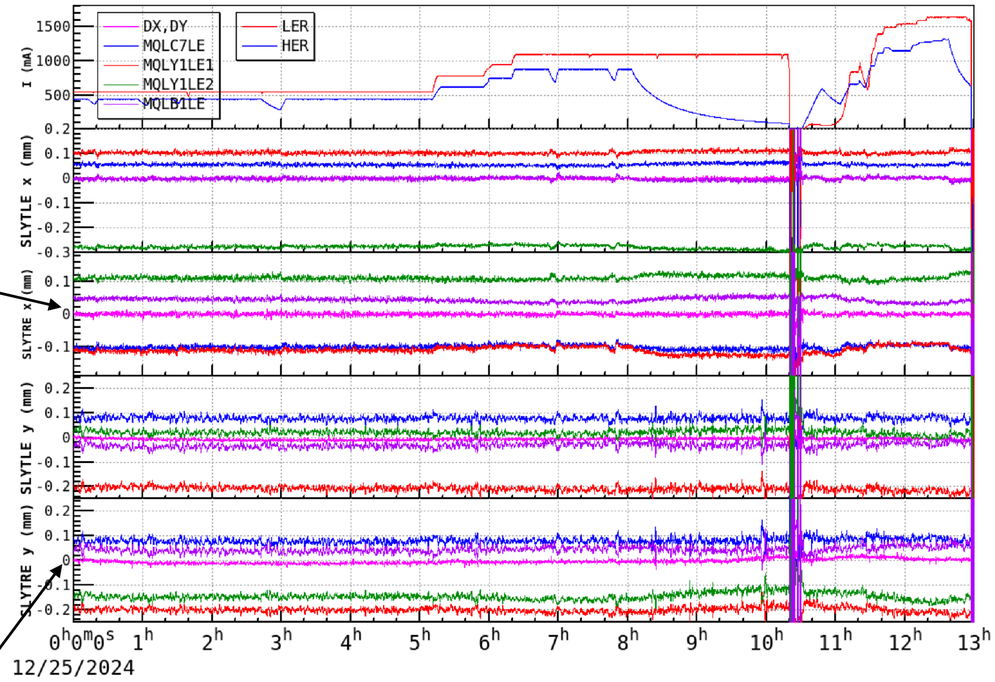
Horizontal in HER

□: within ±5 μm



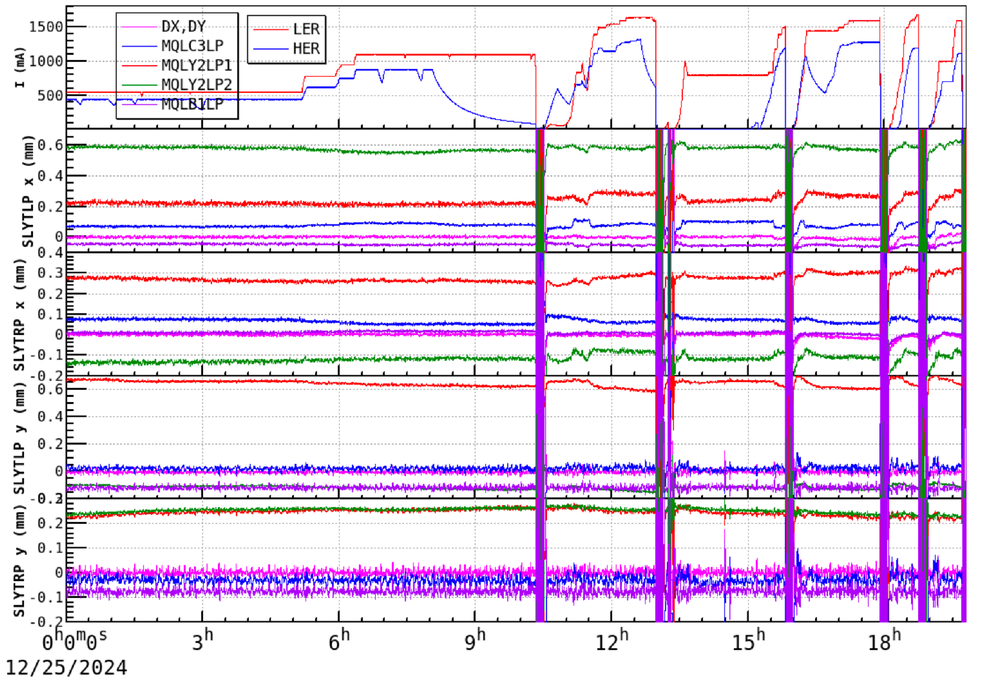
Vertical in HER





Constraint for only Y-LCC

Y-LCC HER



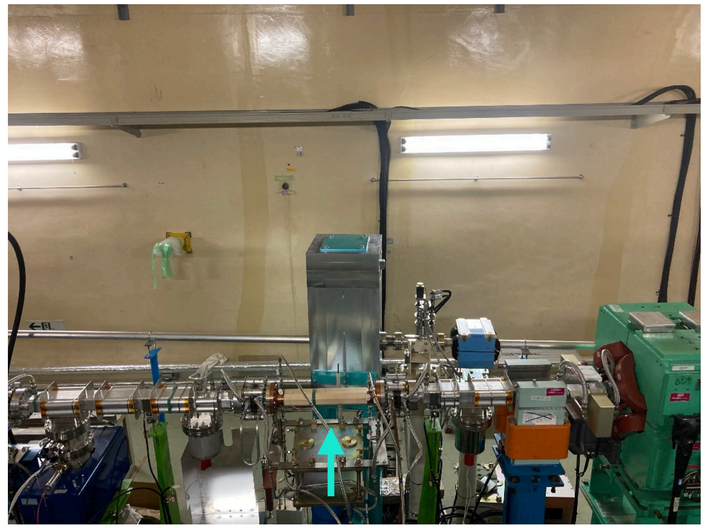
Y-LCC LER

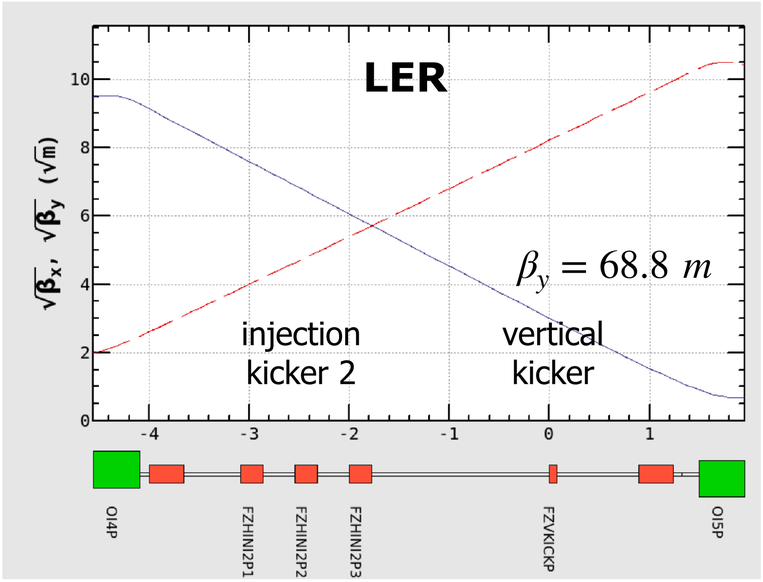
Aperture Measurement

Location of Vertical Kicker

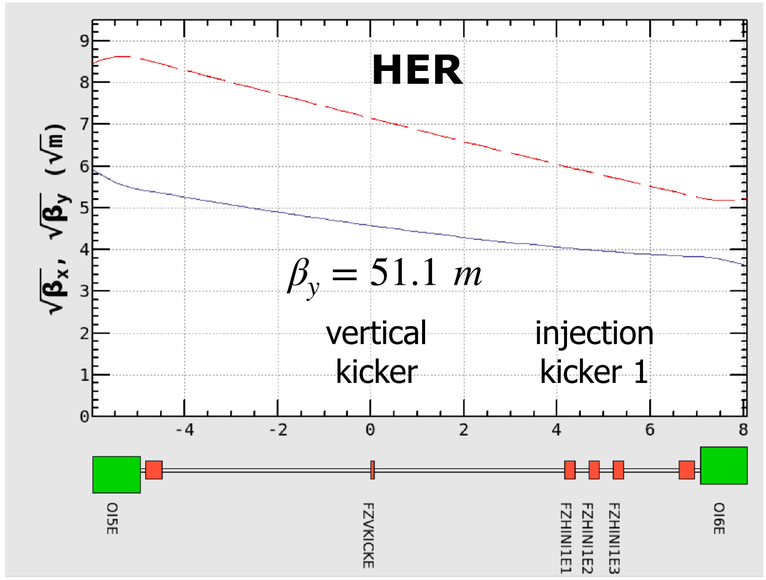
New Device in 2024

Vertical Kicker System: K. Kodama, T. Naito, H. Kaji et al.





Vertical acceptance can be measured by vertical kicker.



Horizontal acceptance can be measured by injection kickers.

RF Kick: Acceleration Phase Modulation

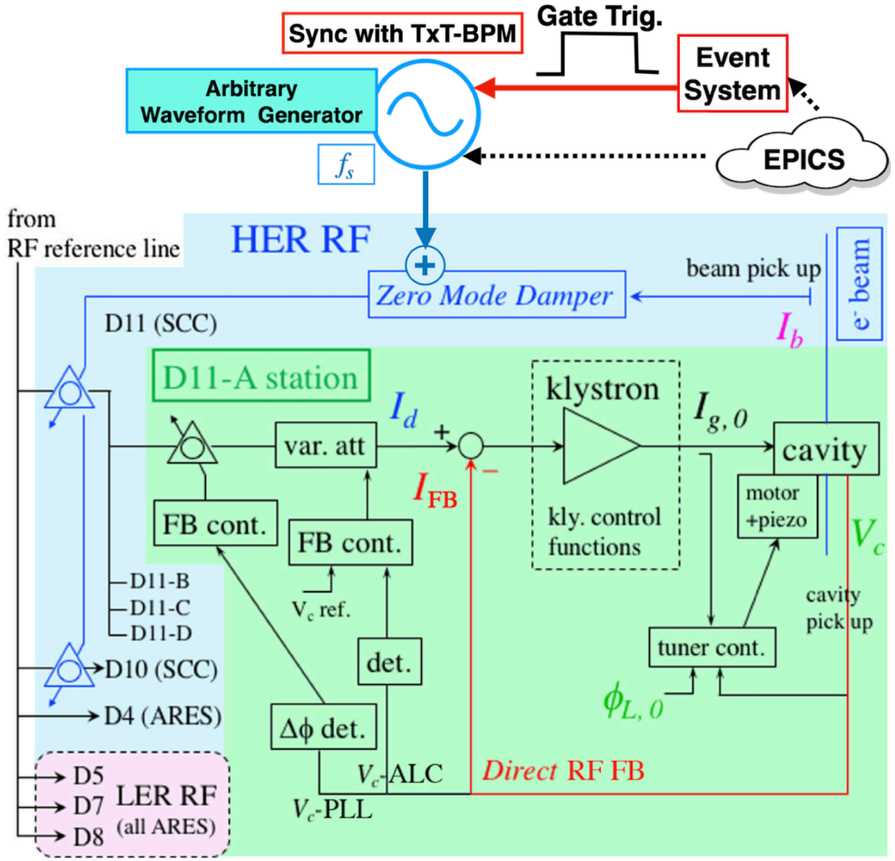
RF Kicker System: T. Kobayashi, S. Ogasawara, T. Okada, T. Yamaguchi, M. Nishiwaki, K. Akai, H. Kaji et al.

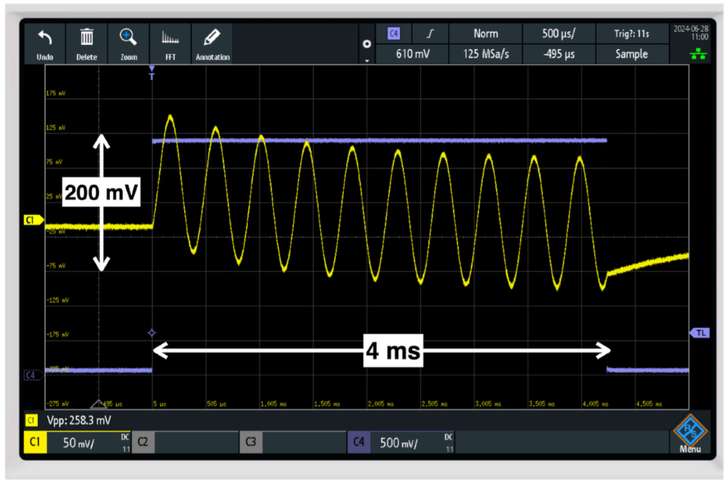
THP068 PASJ2024

New Device in 2024

Forced phase modulation in acceleration field induced by zero-mode damper of the LLRF control system

Momentum acceptance can be measured.

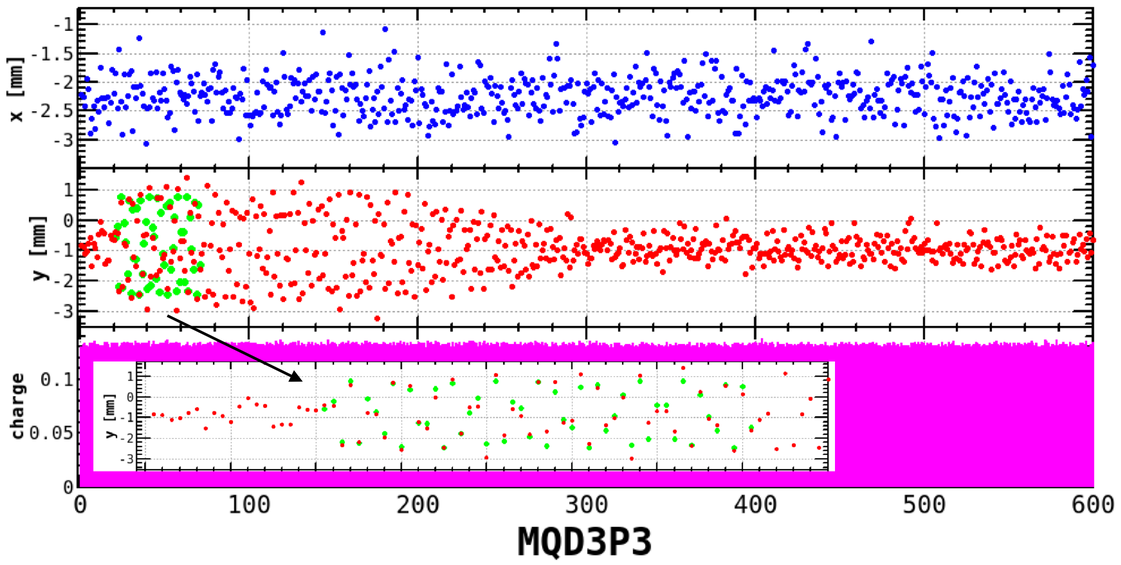




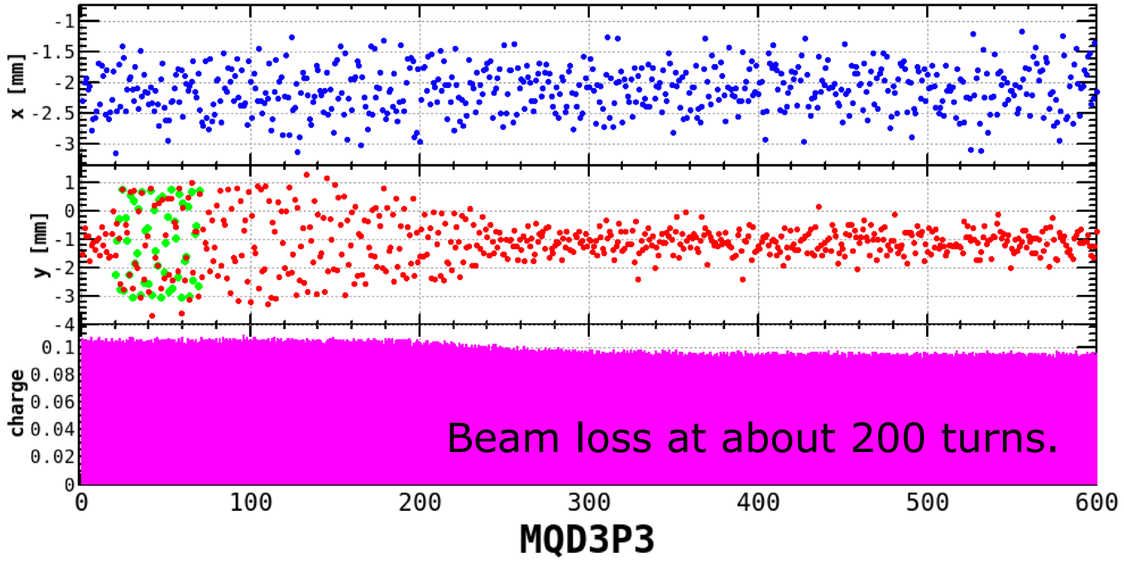
Control signal for phase shifter
of RF reference (yellow)
Gate signal for RF kick duration (purple)

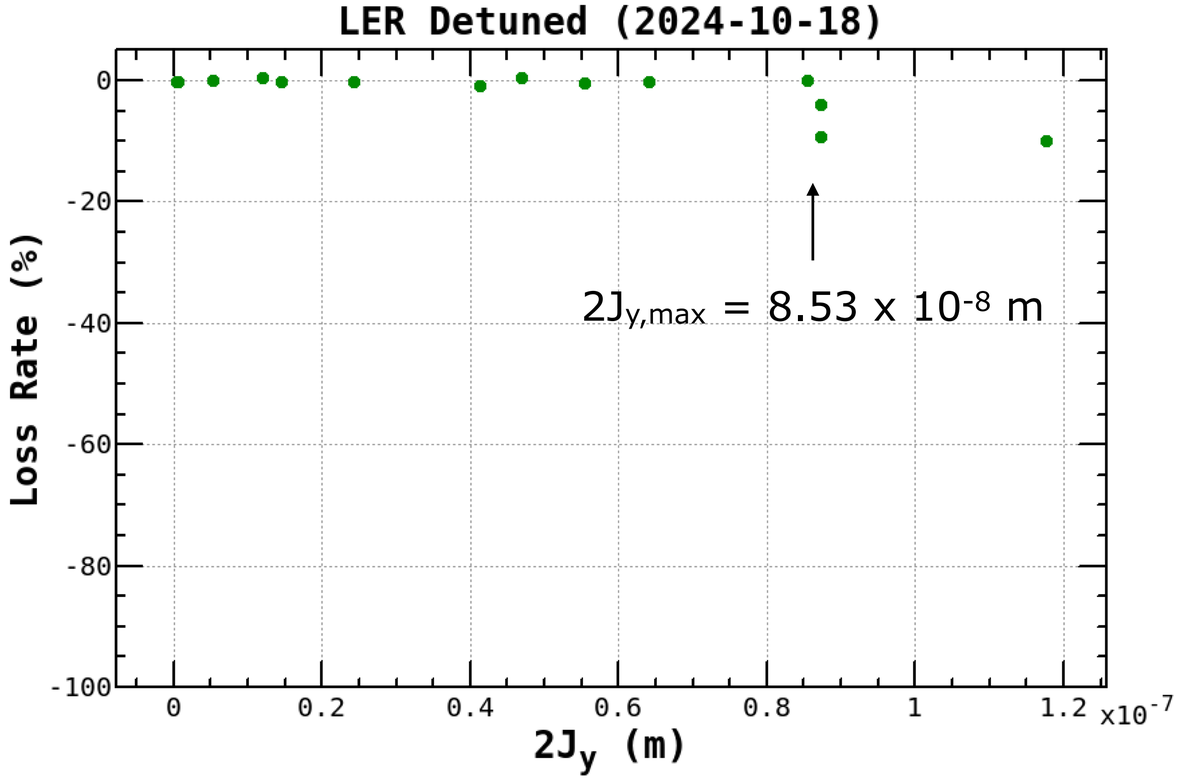
Vertical Kicker in LER

Detuned Optics (β_y^* = 48.6 mm)



Decoherence was observed.





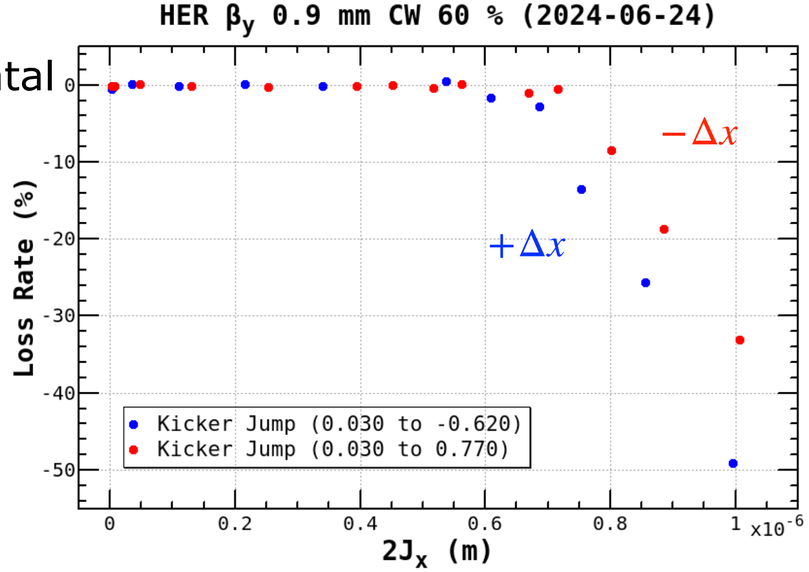
Physical aperture is larger than dynamic aperture.

	Δy_{max} (mm)		A_y (mm)
D06V1	2.40		4.3
D06V2	1.32		14
D05V1	0.59	3.76	14
D02V1	0.96		8.36

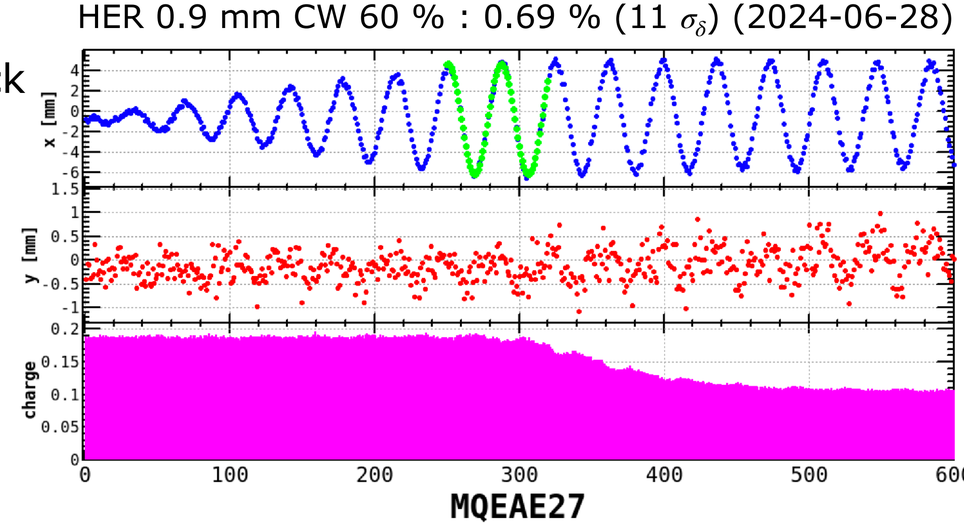
Aperture Measurement

HER

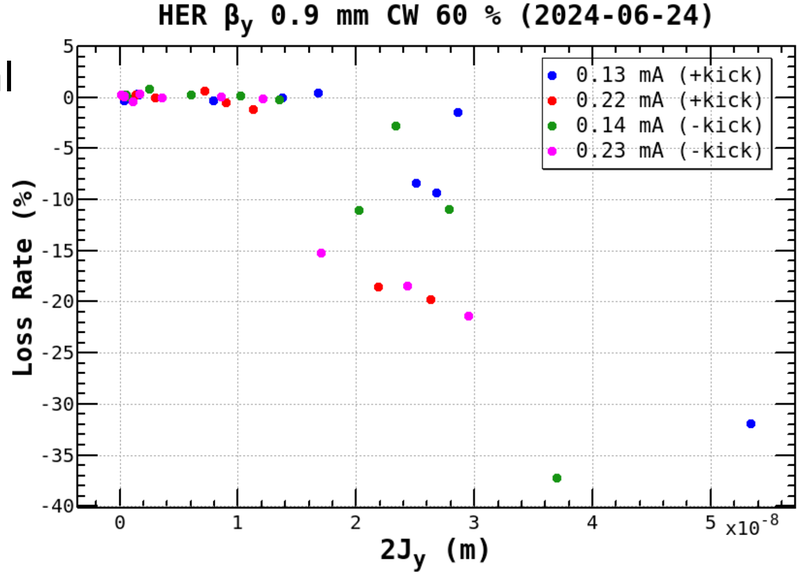
Horizontal Kick



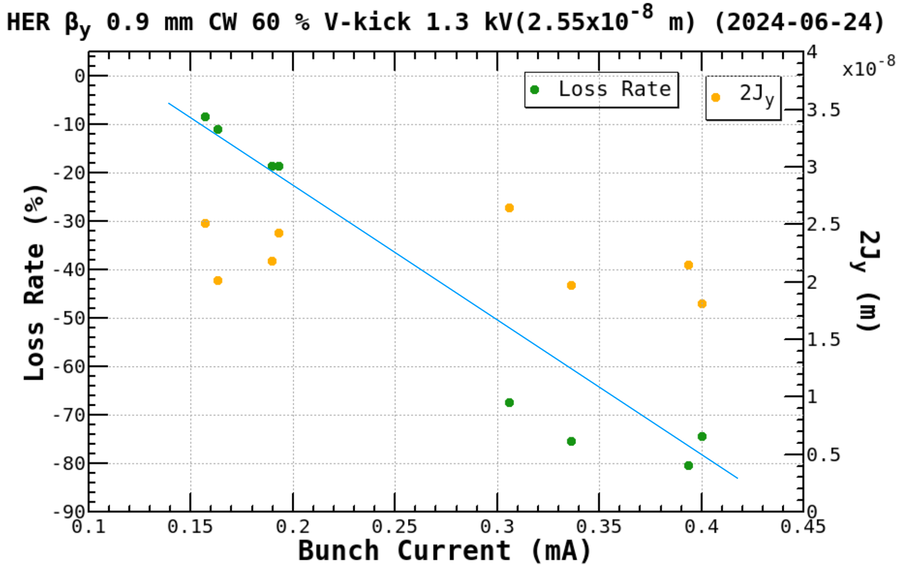
RF Kick



Vertical Kick



Beam loss depends on beam intensity.



Transverse wakefield in collimators

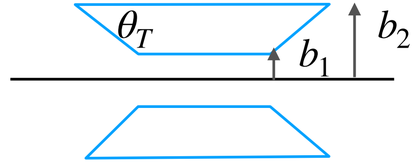
$$y' = \frac{\Delta y_0 Q}{E}\kappa$$

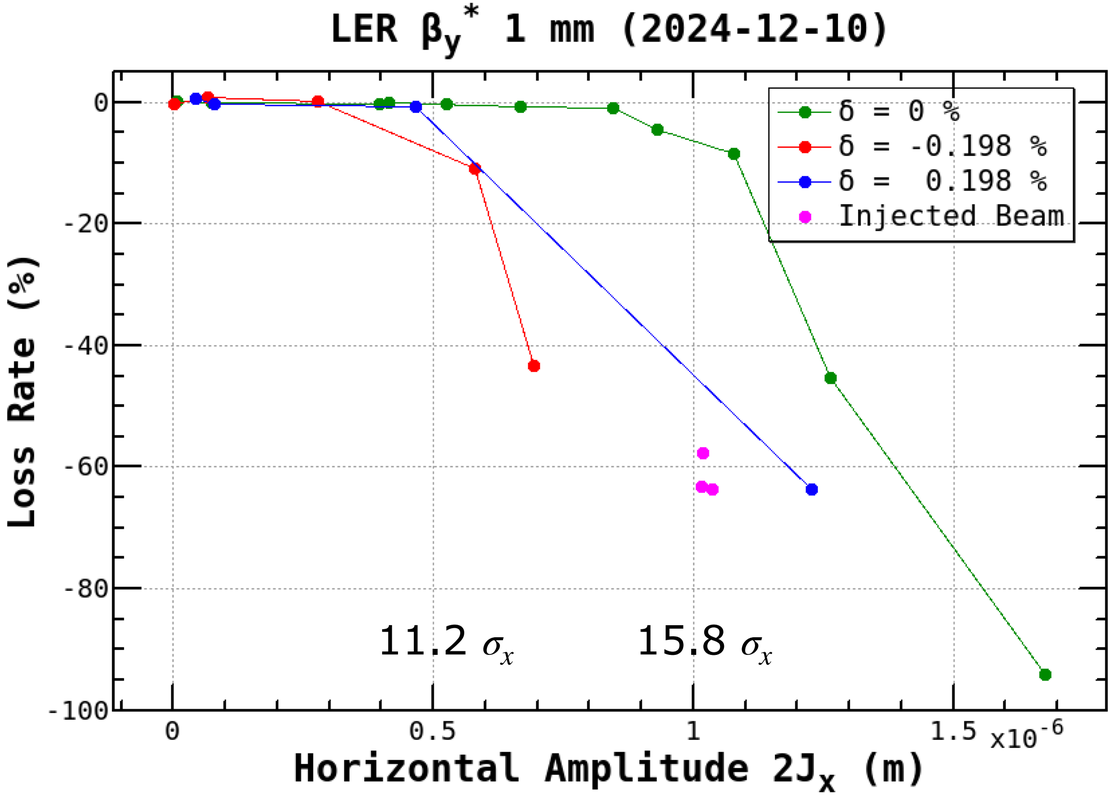
κ : Kick Factor

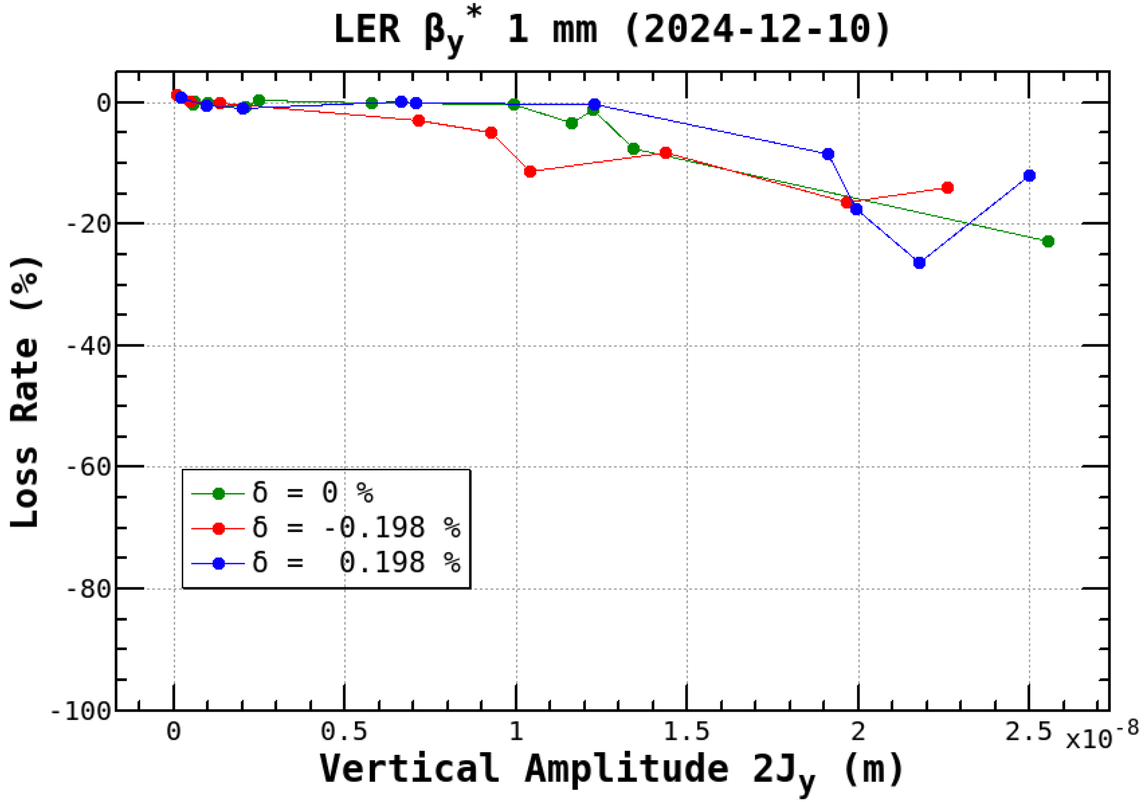
$\alpha = \theta_T b_1/\sigma_Z$

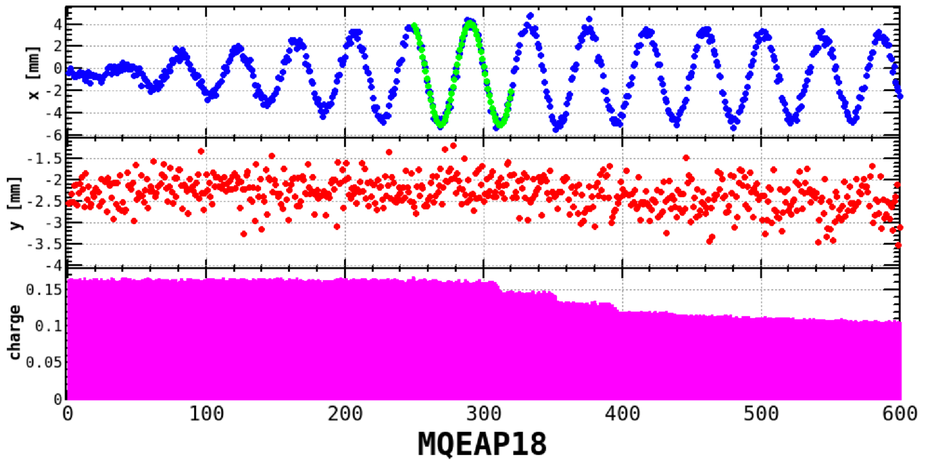
inductive (α<<1)

diffractive (α>>1)









Momentum Acceptance:
0.67 % (9 σ_δ)

Momentum Spread: 7.4 x 10^{-4}

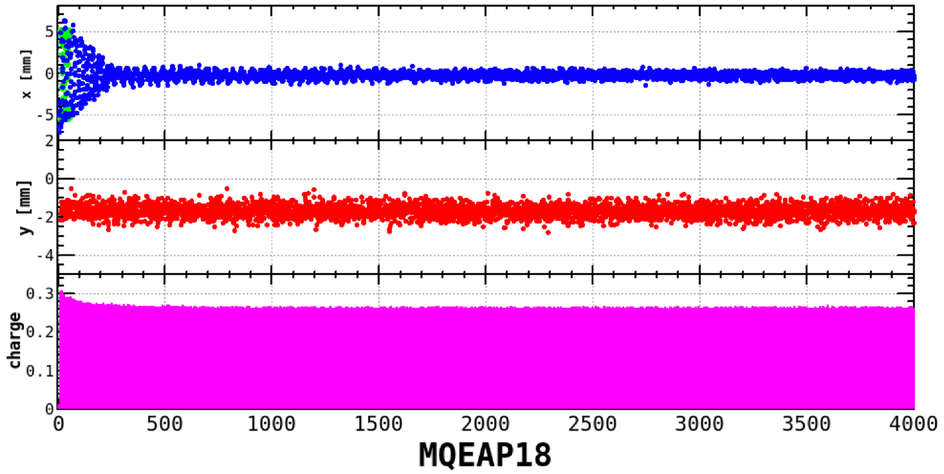
Beam Injection

LER Injection

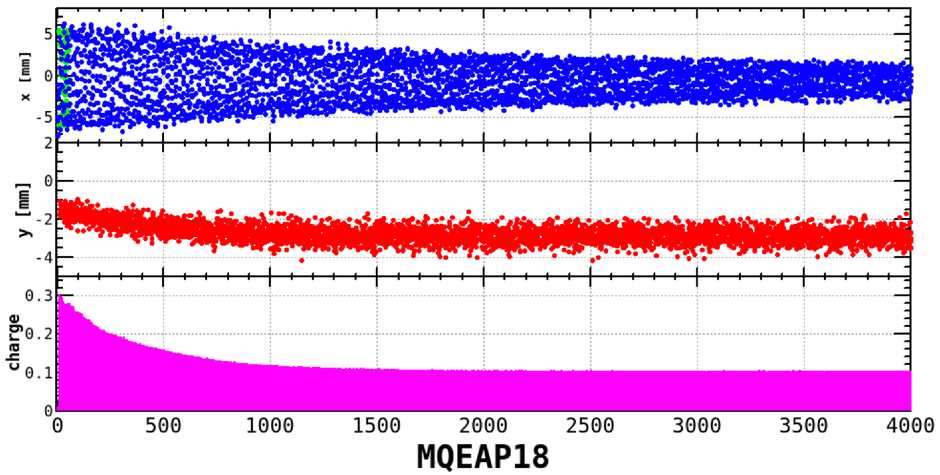
Injection efficiency will decrease at high current.

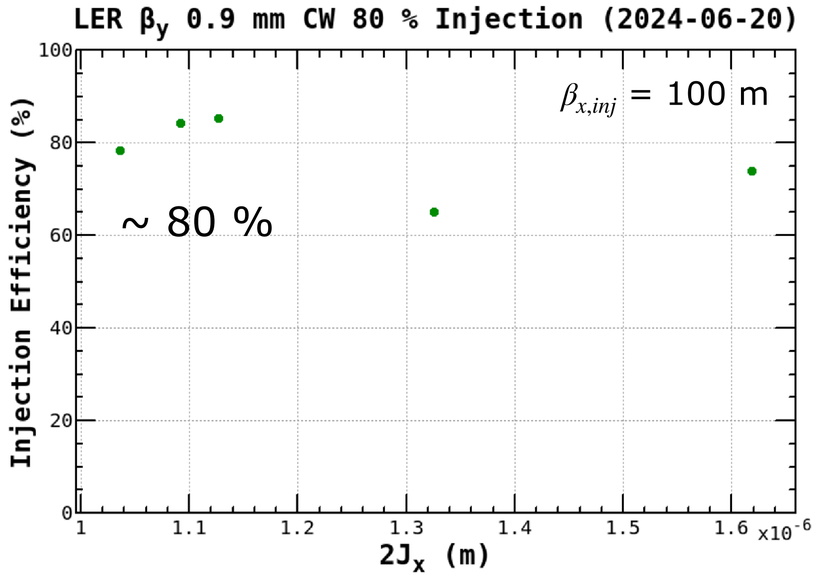
2024b

BxB FB ON



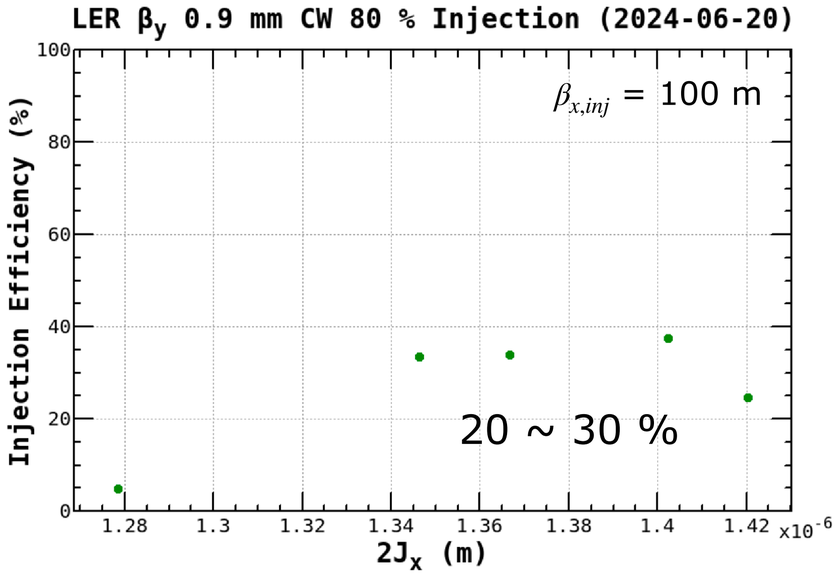
BxB FB OFF

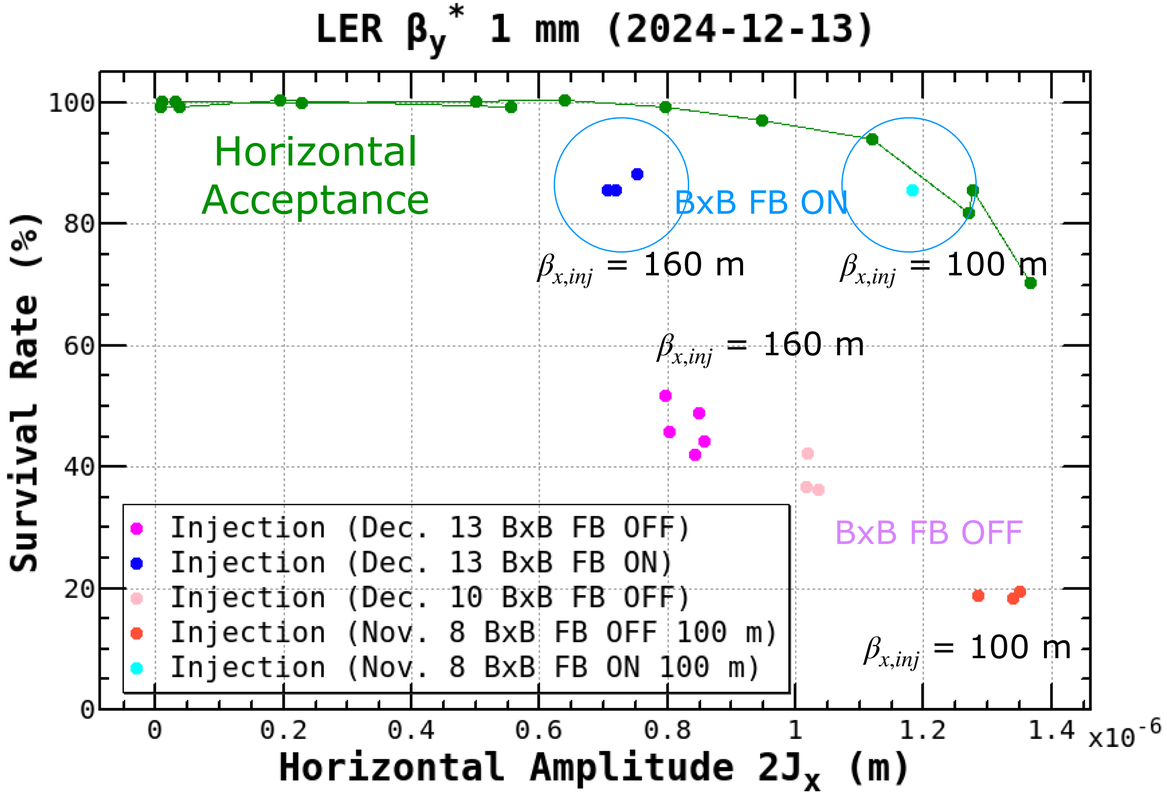


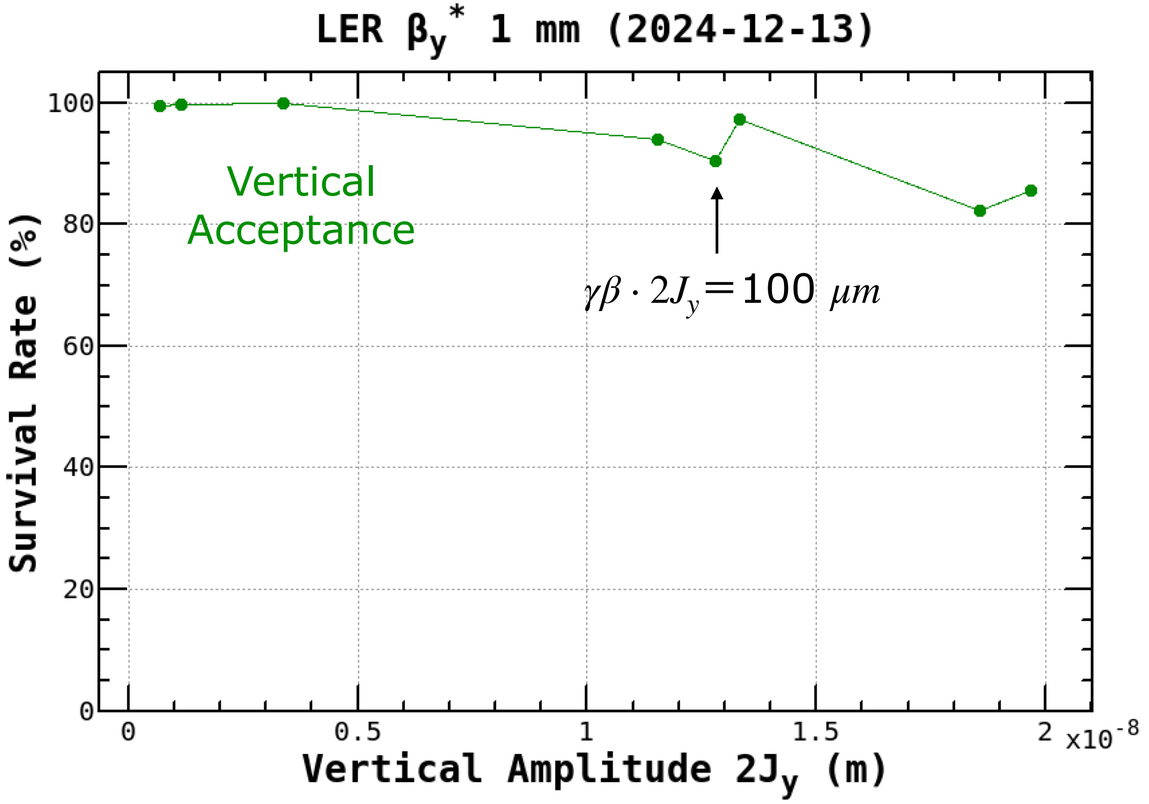


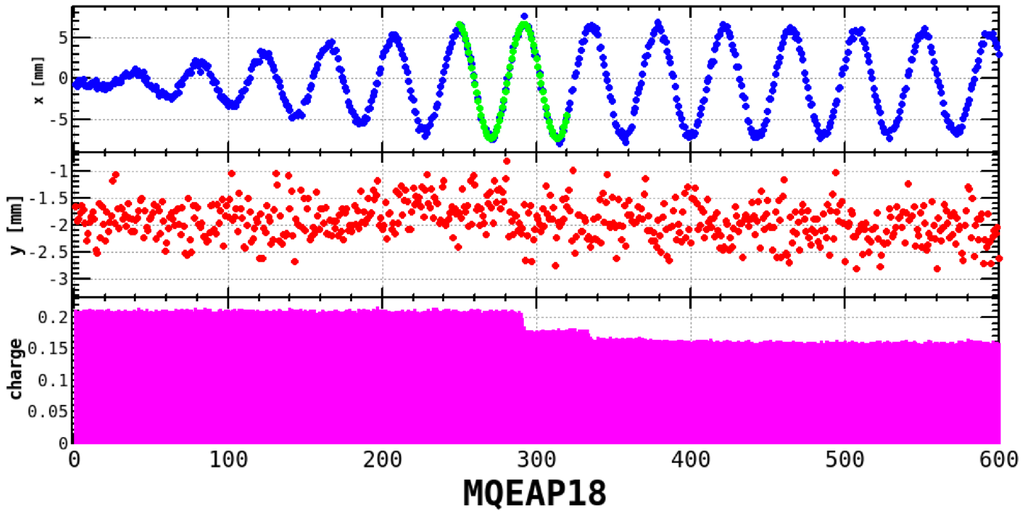
Injection error is larger than ring acceptance ?

$2J_x > 1 \times 10^{-6}$ m





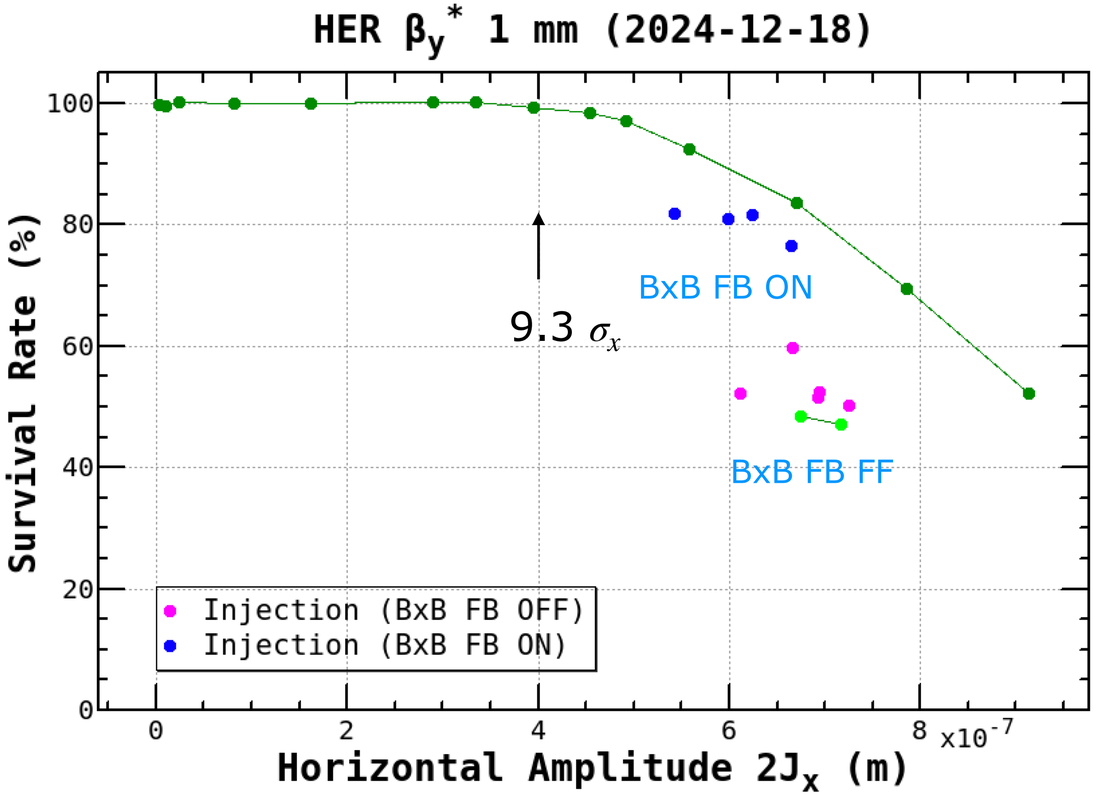


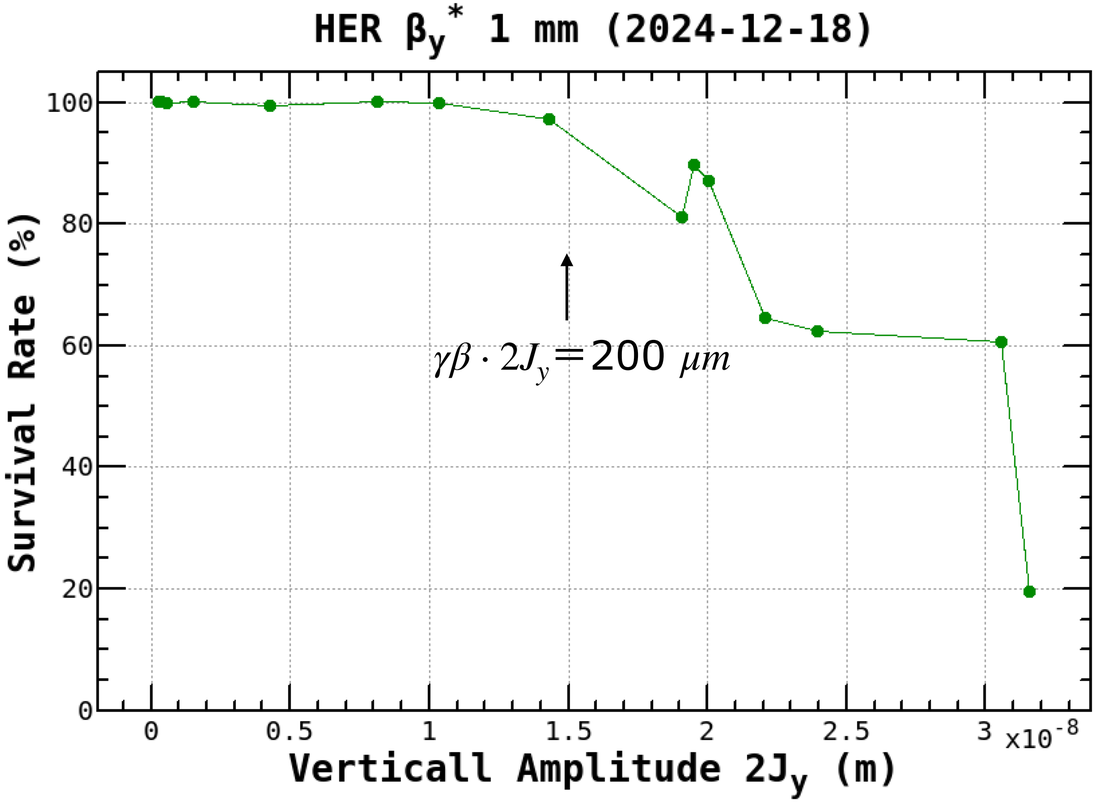


δ_{max} = 1.03 %

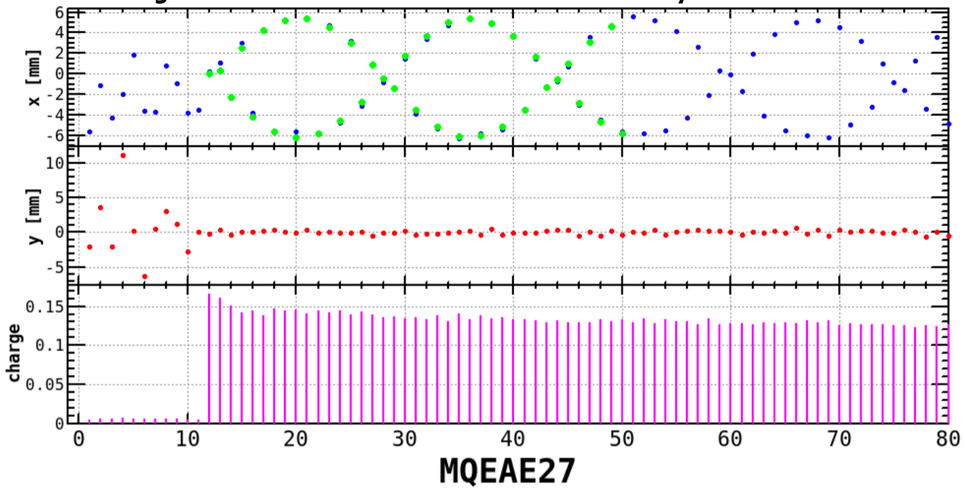
13.9 σ_δ

β_x at injection point in LER: 100 m to 160 m on November 25.





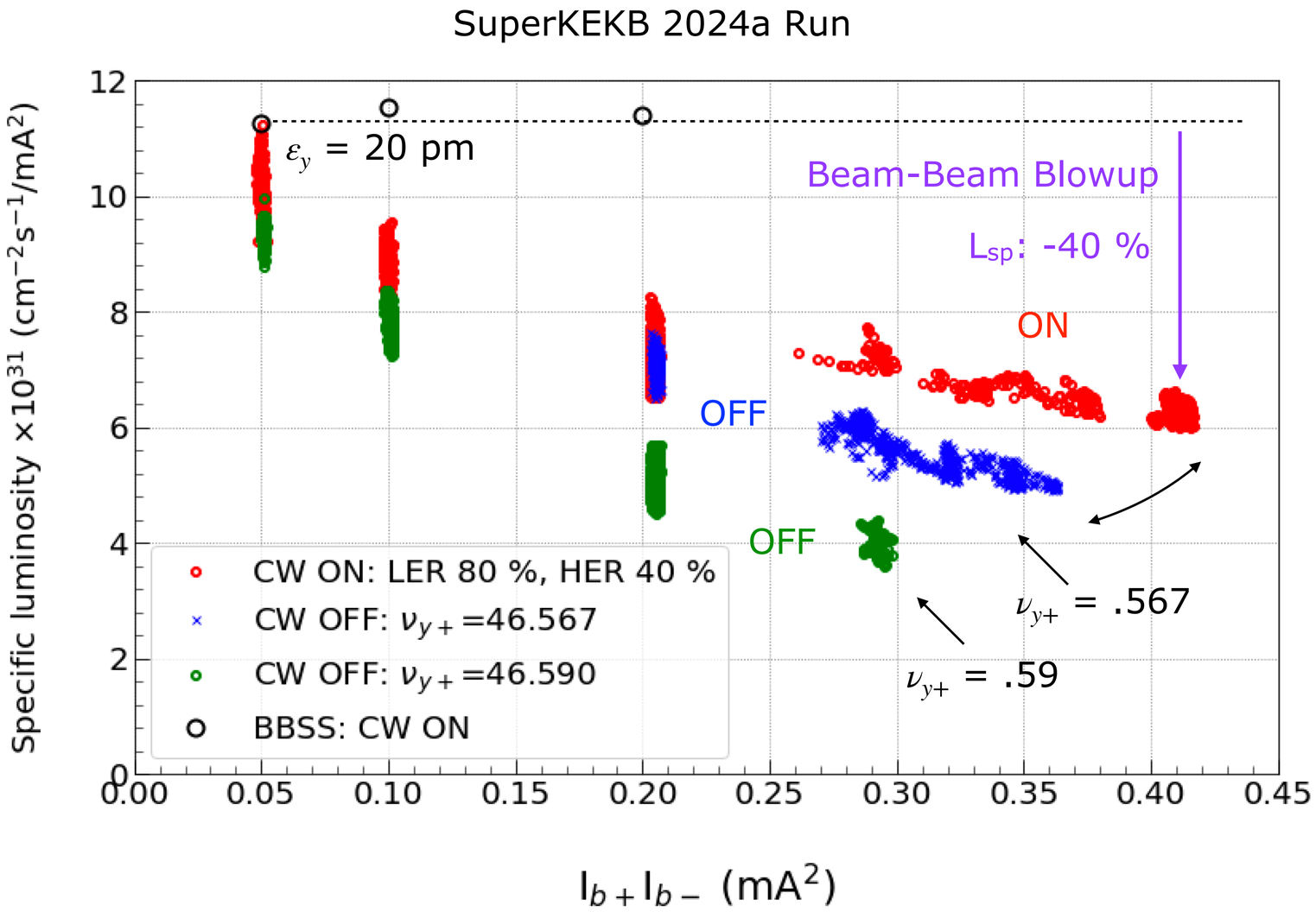
Injection beam measured by TBT BPM



Beam-Beam Interaction

Crab Waist ON and OFF

Experiment on March 12 and March 21,-22 2024



$$L_{sp} = \frac{L}{I_{b+} I_{b-} n_b} \propto \frac{1}{\sigma_y^*}$$

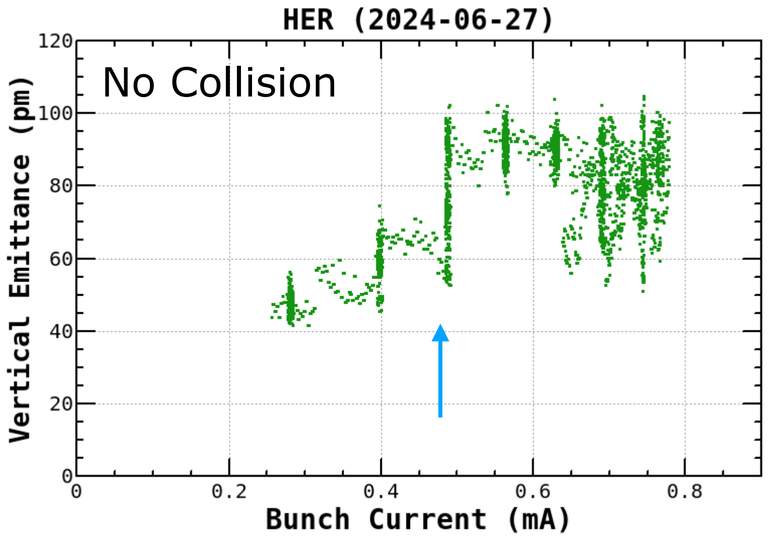
Crab Waist Is Effective.

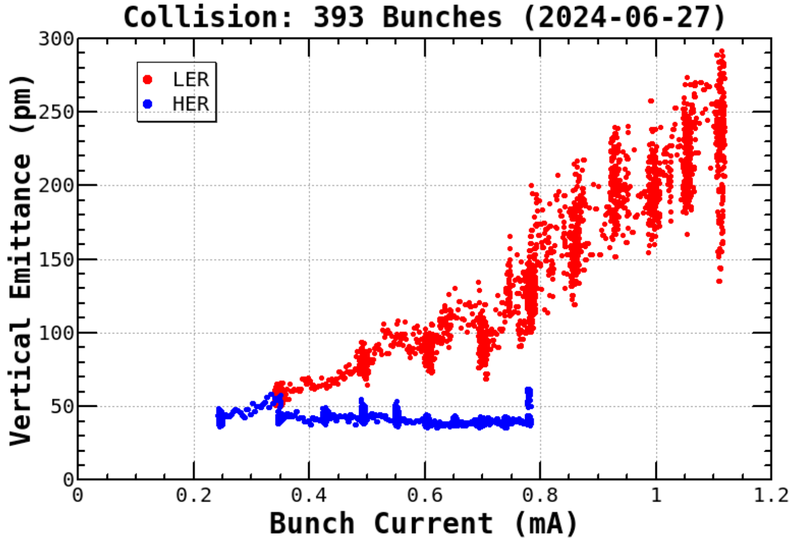
It makes strength of resonance lines weaker rather than geometrical gain.

* HBC = High Bunch Current (393 Bunches)

Beam-Beam Study (June 27)

2024b

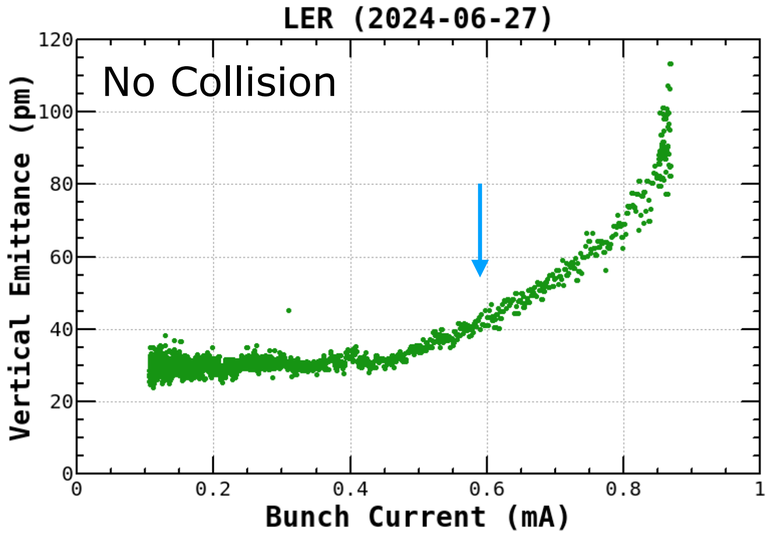


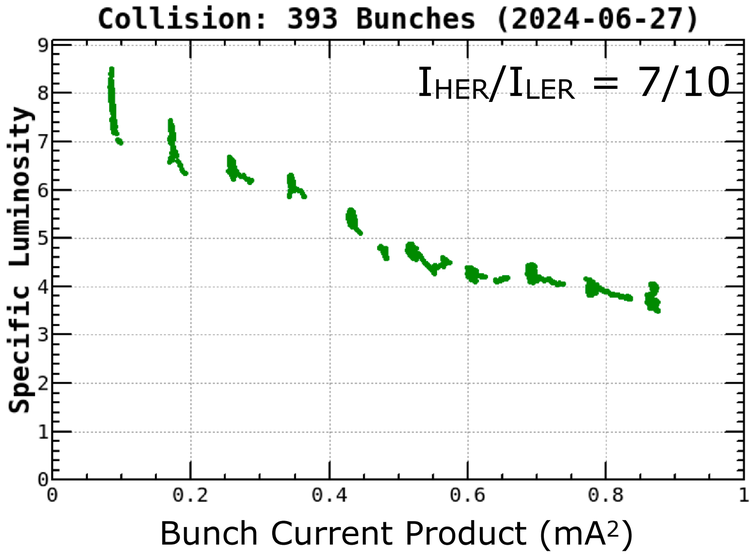


Single Beam Blowup
> 0.5 mA/Bunch

Blowup in LER due to
Beam-Beam

LER injection can be possible
at high current
by changing horizontal tune
($\Delta\nu_x$ = -0.001 Step)



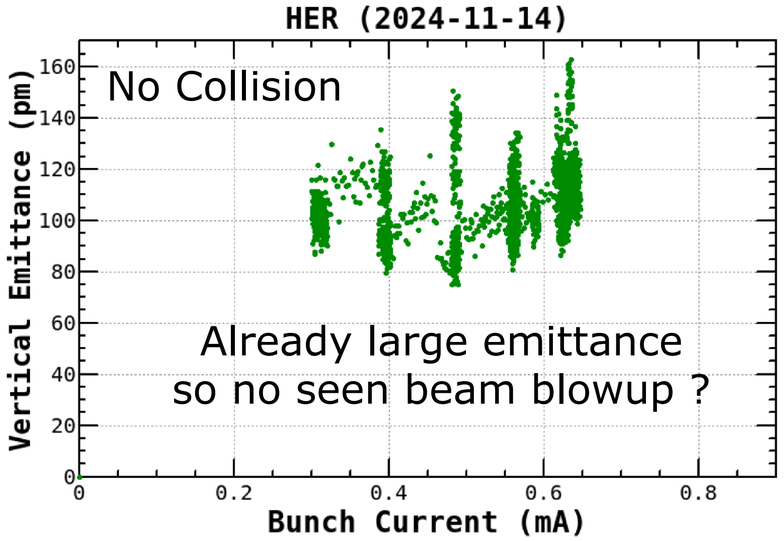


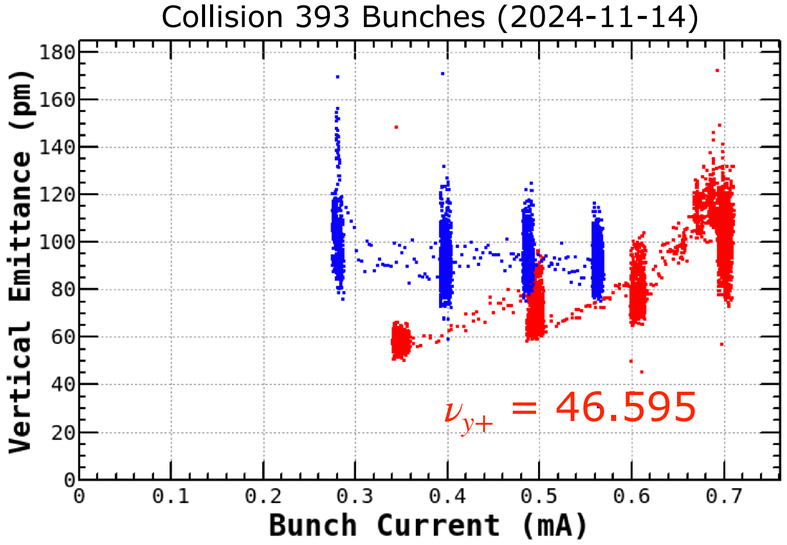
L_p = 1.38 x 10^{34} $cm^{-2}s^{-1}$
with 393 Bunches

L_p = 8.24 x 10^{34} $cm^{-2}s^{-1}$
with 2346 Bunches

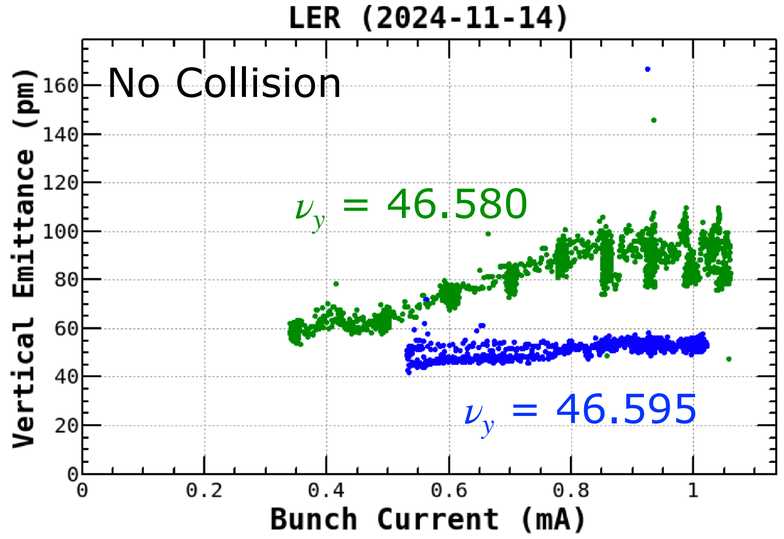
Beam-Beam Study (November 14)

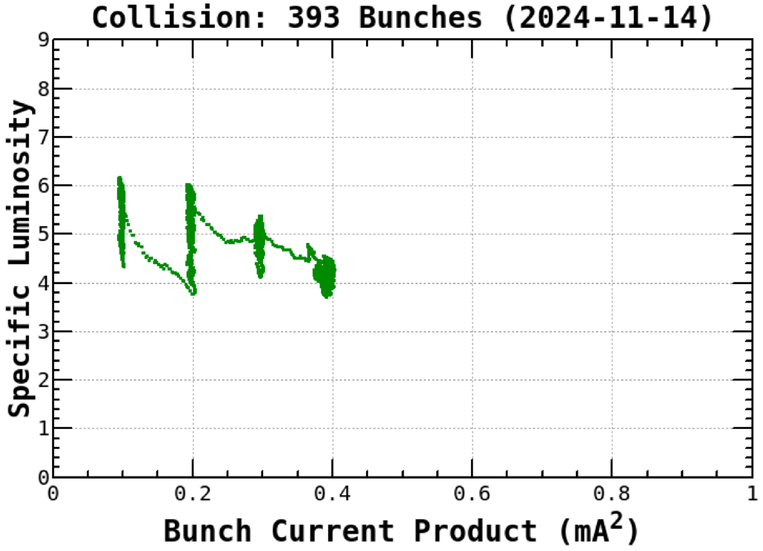
2024c





Blowup in LER due to Beam-Beam





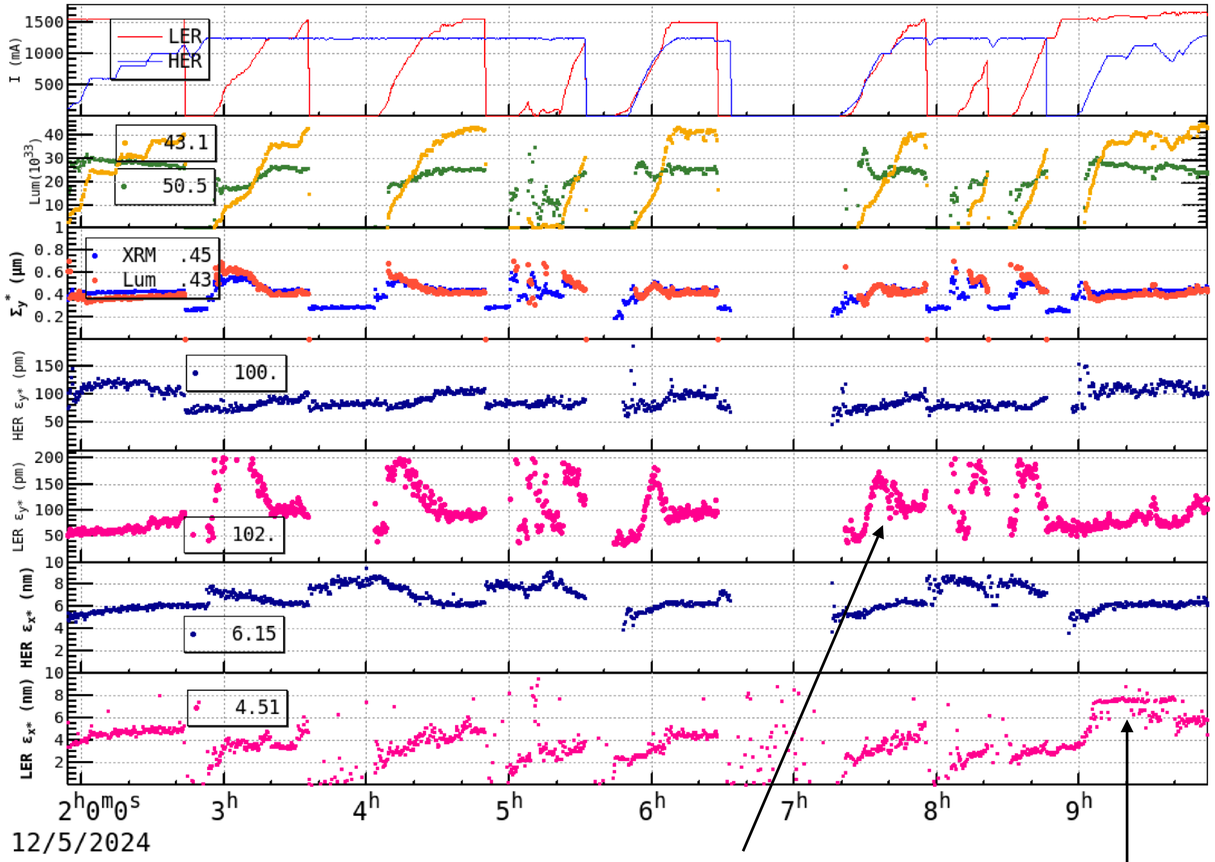
Higher vertical tune is beatter in LER for no collision.

The specific luminosity was worse than that of 2024b.

2024c

L_p = 4.5 x 10^{34} $cm^{-2}s^{-1}$ (Dec. 5, 2024)

β_x^* **= 80 mm in LER**

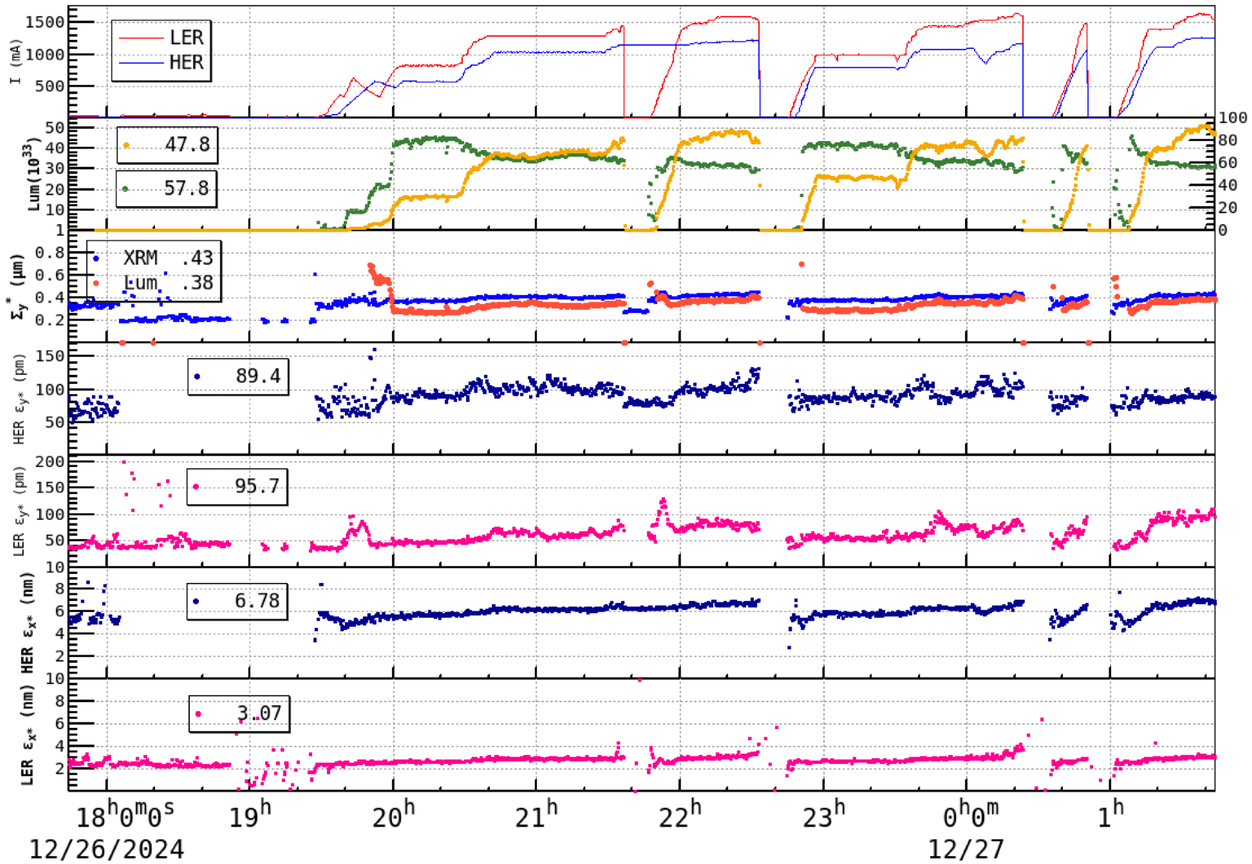


Vertical beam size blowup in LER

Horizontal beam size blowup in LER

L_p = 5.1 x 10^{34} $cm^{-2}s^{-1}$ (Dec. 27, 2024)

β_x^* **= 60 mm in LER**

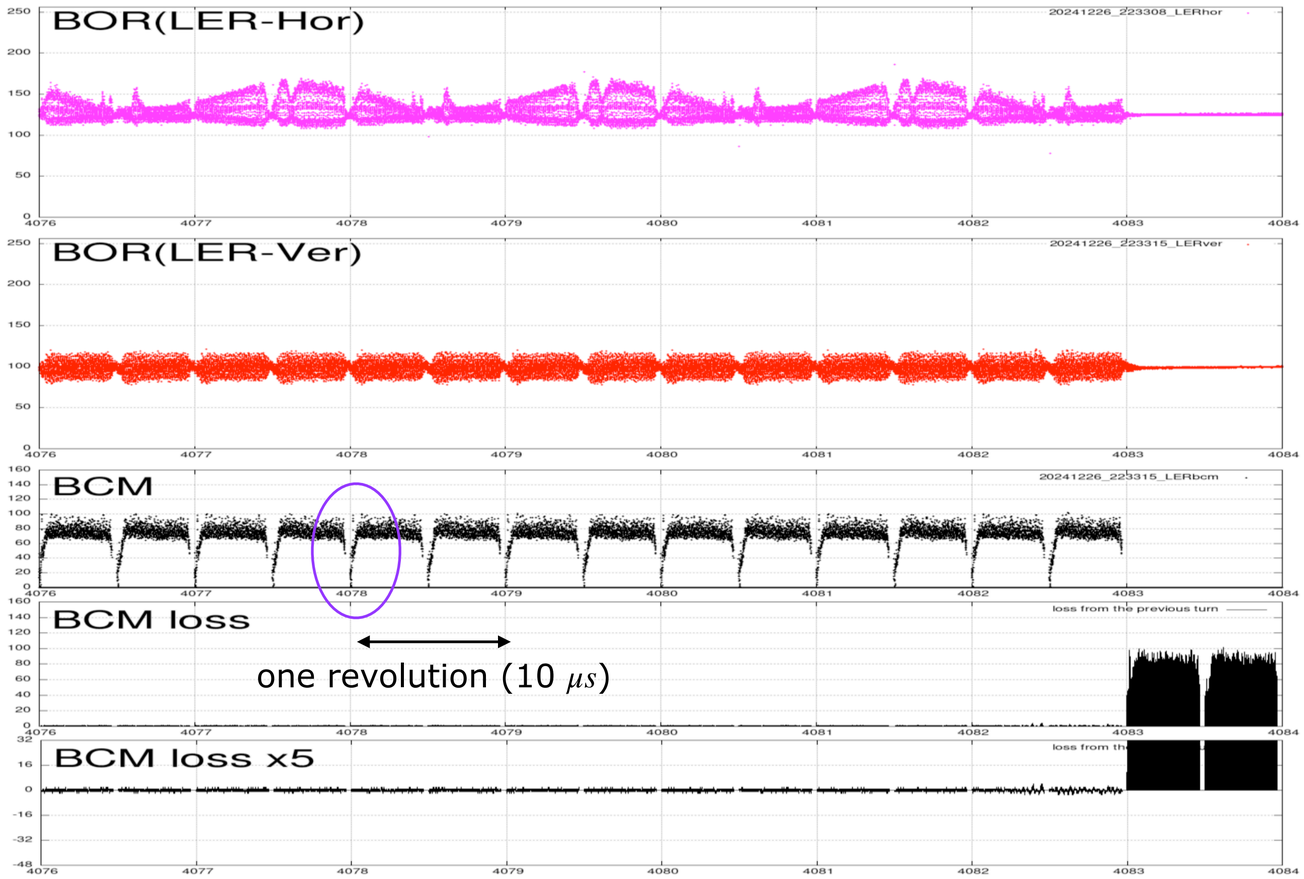


Less horizontal beam size blowup in LER

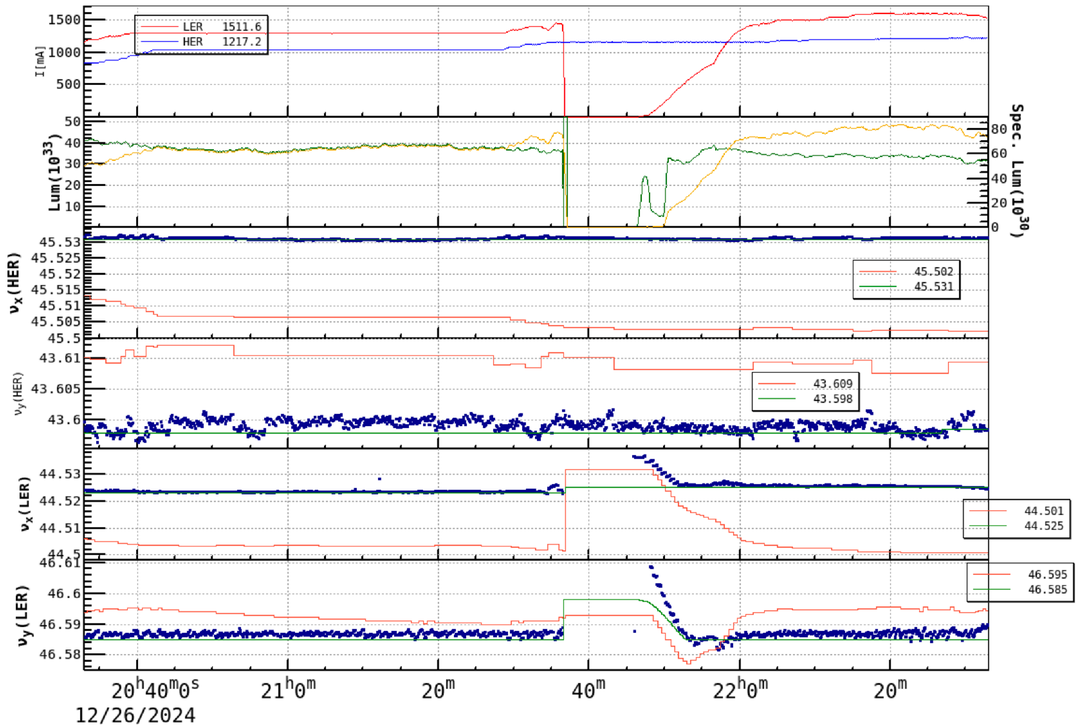
Bunch Current in LER

Bunches at the head of train are short lifetime in LER.

LER



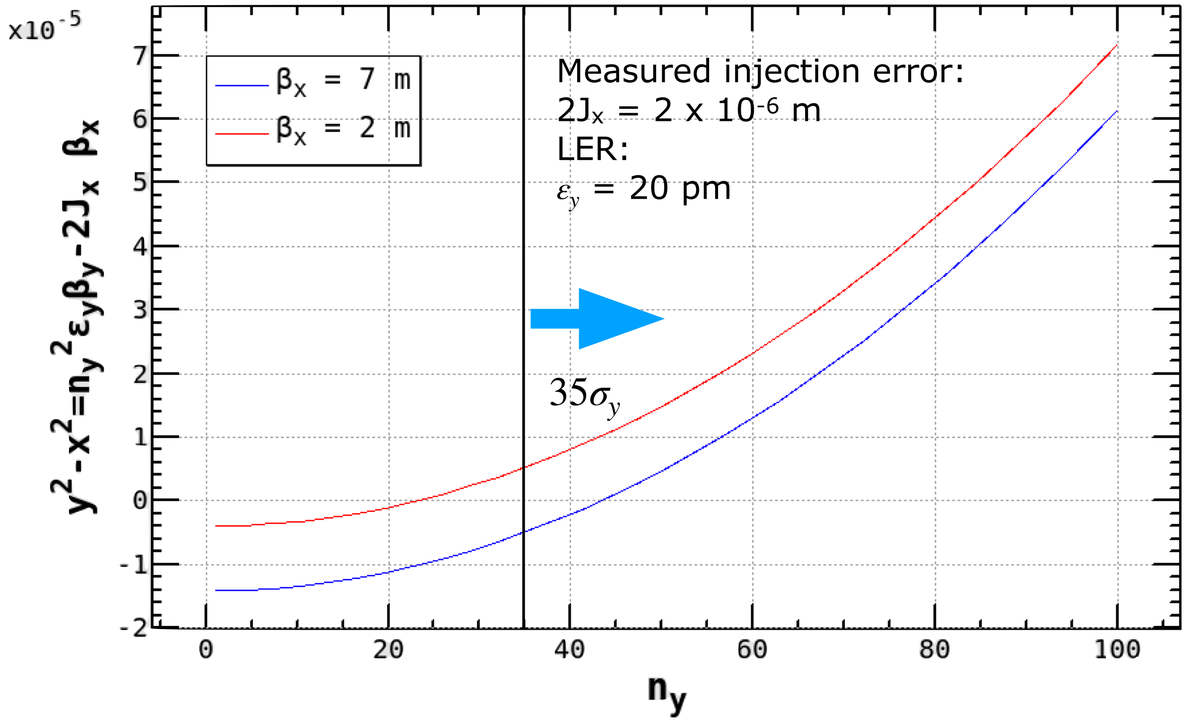
Model horizontal tune is very close to half integer to keep nominal tune.



Nonlinear Collimator

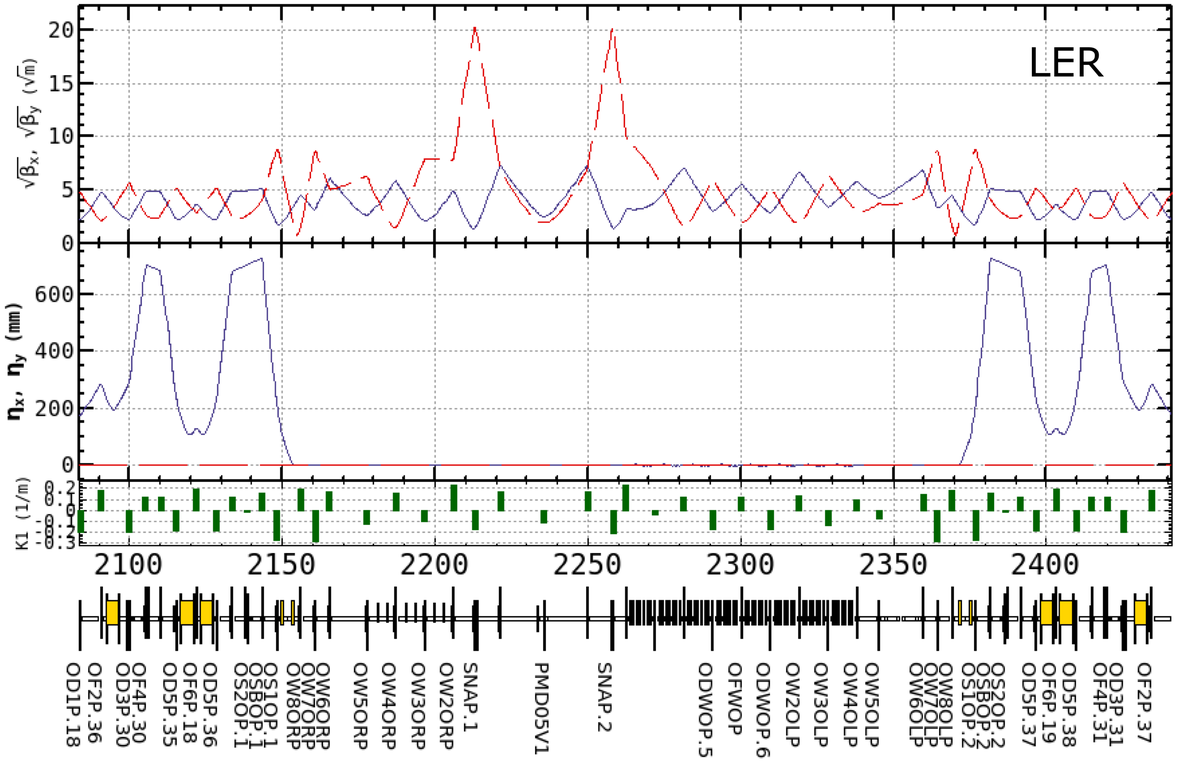
D05V1 can be used instead of D06V1 to reduce injection background.
Impedance can be reduced.

β_x at skew sextupole for D05V1 (nonlinear collimator)



Lower β_x at the skew sextupole is preferable for the vertical position larger than $35\sigma_y$.

2024ab : β_x = 7 m at skew sextupoles
2024c : β_x = 3 m at skew sextupoles



SNAP: skew sextupole
PMD05V1: D05V1 collimator

Nonlinear collimator works well.

Five Big Issues (FBI)

1. Injection and Touschek background
2. SR from QC1/QC2
3. Collimator
4. Machine error and optics correction
5. Beam-Beam interaction (inc. continuous injection, iBump FB)

Slide presented at 16th KEKB Accelerator Review Commitee, February 7-9, 2011

2024 Version

~~Five~~ Six Big Issues (SBI)

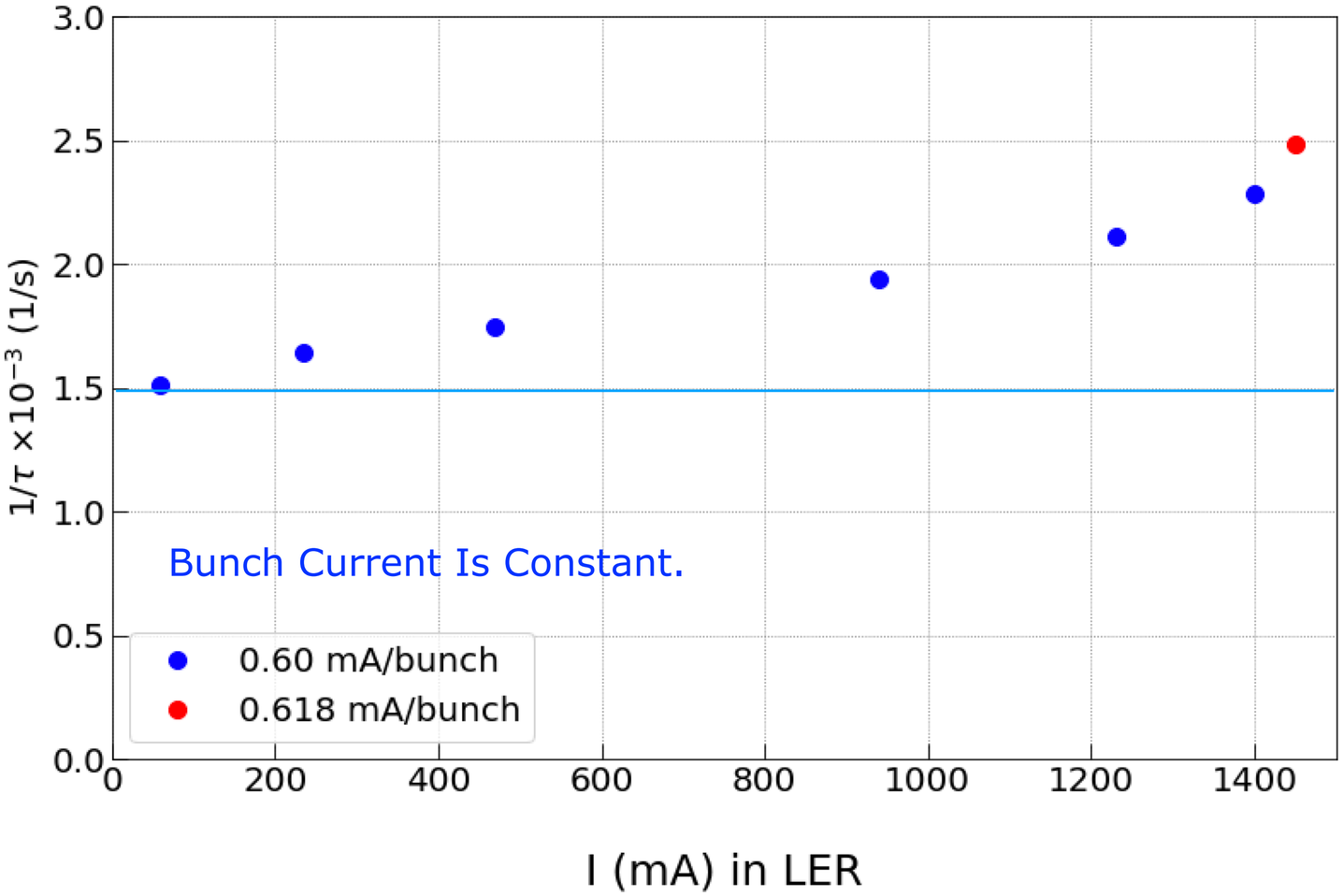
1. Injection and Touschek background
   - Dynamic Apertrue with sextupole optimization
   - Low emittance of injected beam
2. SR from QC1/QC2
   - + Dipole magnet in the arc section
   - → Beam pipe deformation → Quad. movement with BPM
   - → Orbit deviation at sextupoles → Optics degradation
3. Collimator
   - Precise control of collimator head
   - Usage of nonliner collimator
   - Impedance
4. Machine error and optics correction
   - How to manage orbit at sextupoles
   - Understanding of IR optics
5. Beam-Beam interaction (inc. continuous injection, iBump FB)
   - Synchro-beta and betatron resonance
   - Beta sqweezing at IP
   - Beam-Beam blowup
6. SBL
   - Remove of "VACSEAL" is enough ?

Appendix

LER Lifetime

2024-06-04 Evening Shift
Y. Funakoshi, N. Iida, H. Kaji, H. Ikeda, Y. Ohnishi

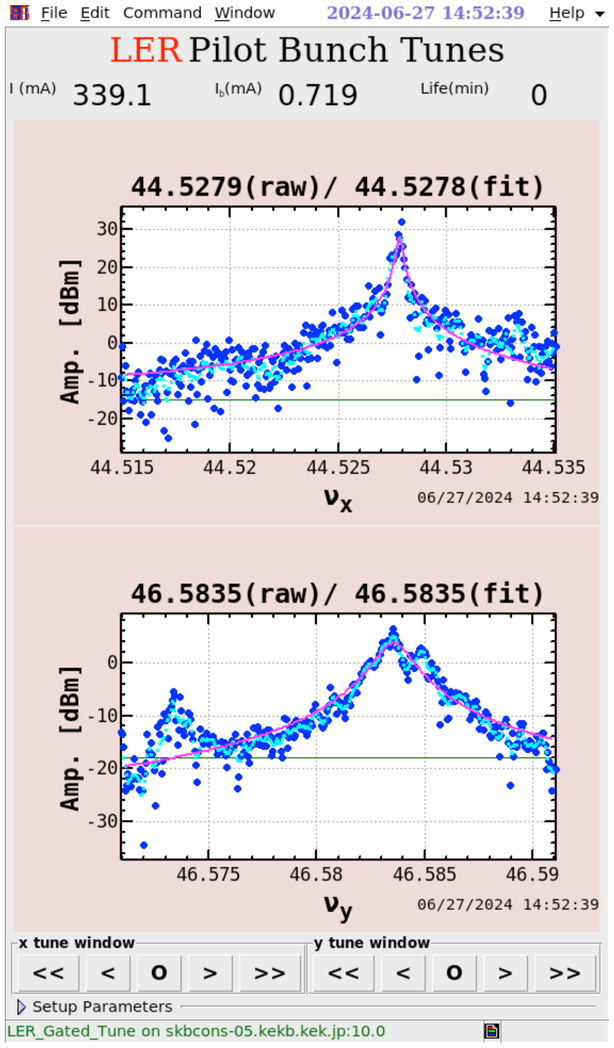
#Bunches: (97, 393, 783, 1565, 2053, 2346)
Current (mA): (58.2, 235.8, 470, 939, 1231, 1400)



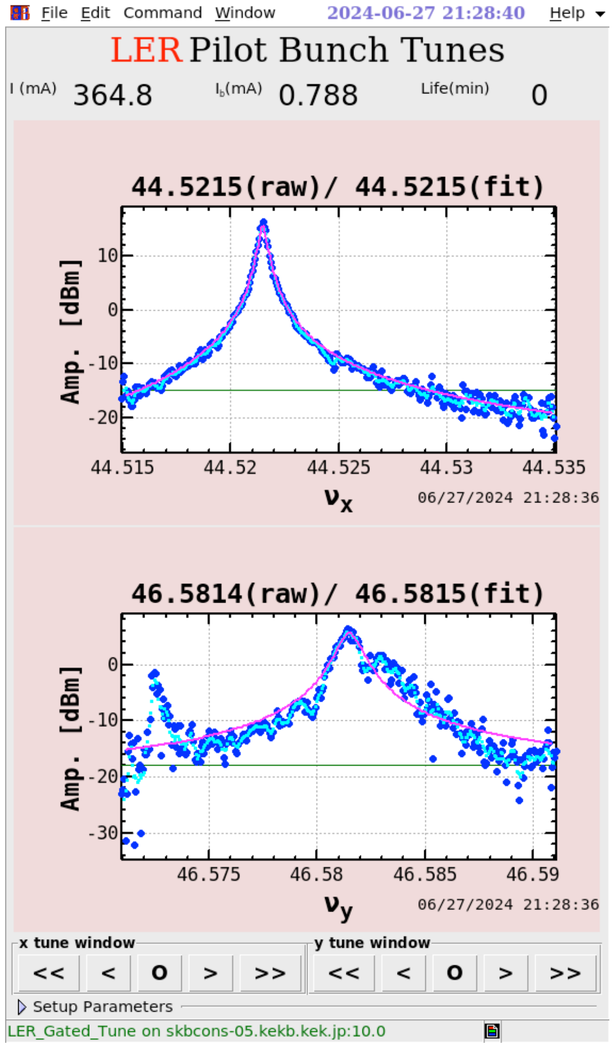
Betatron Tune Spectrum and Sideband in LER

2024b

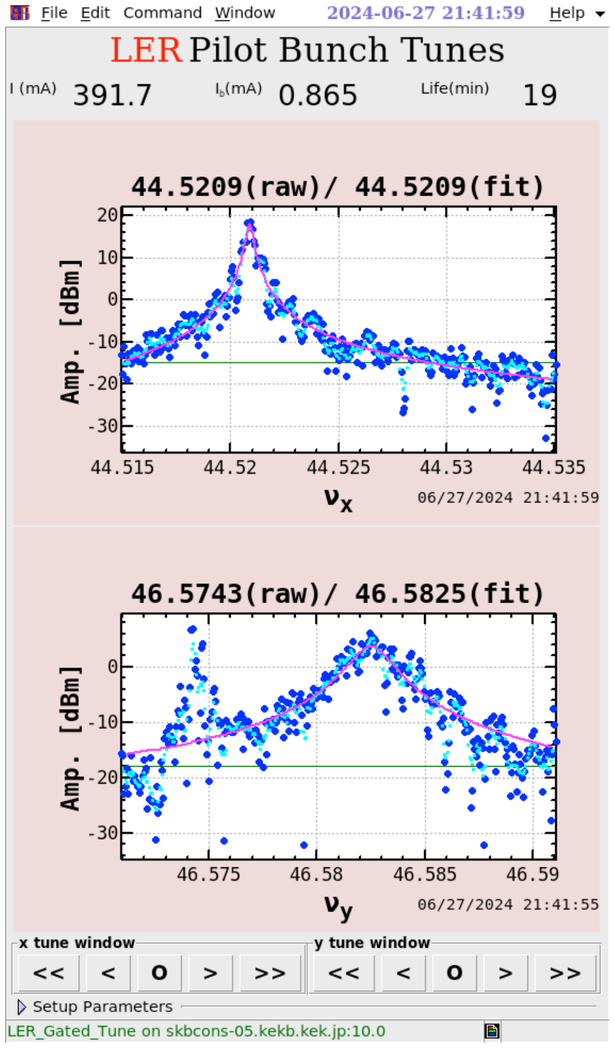
0.72 mA/bunch



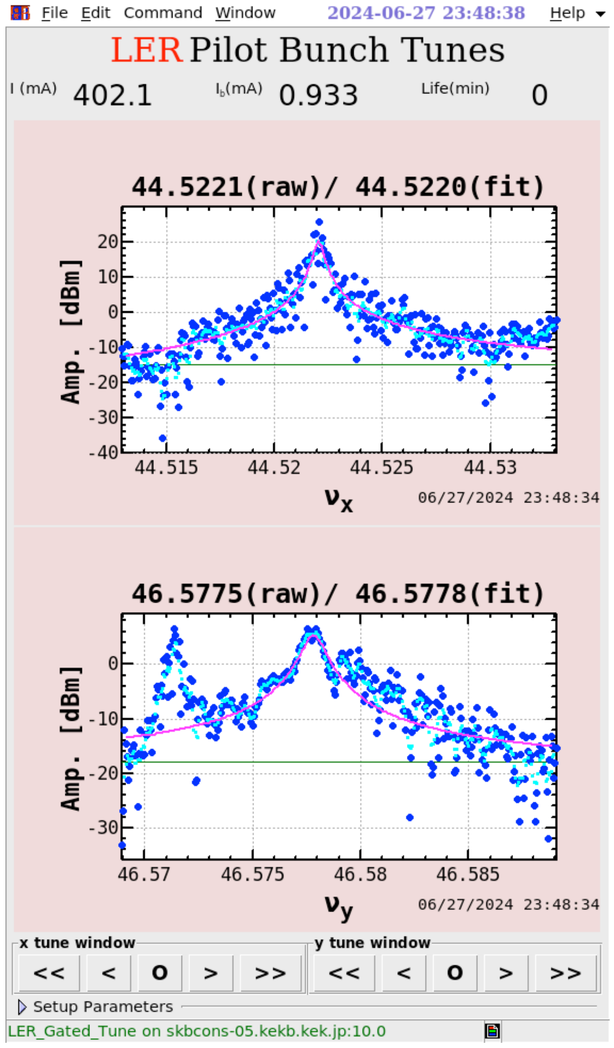
0.79 mA/bunch



0.87 mA/bunch



0.93 mA/bunch



Sideband is far from vertical tune.