Updates on beam-beam simulations and recent results of machine studies

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Acknowledgments

K. Ohmi, Y. Funakoshi, and SuperKEKB commissioning group

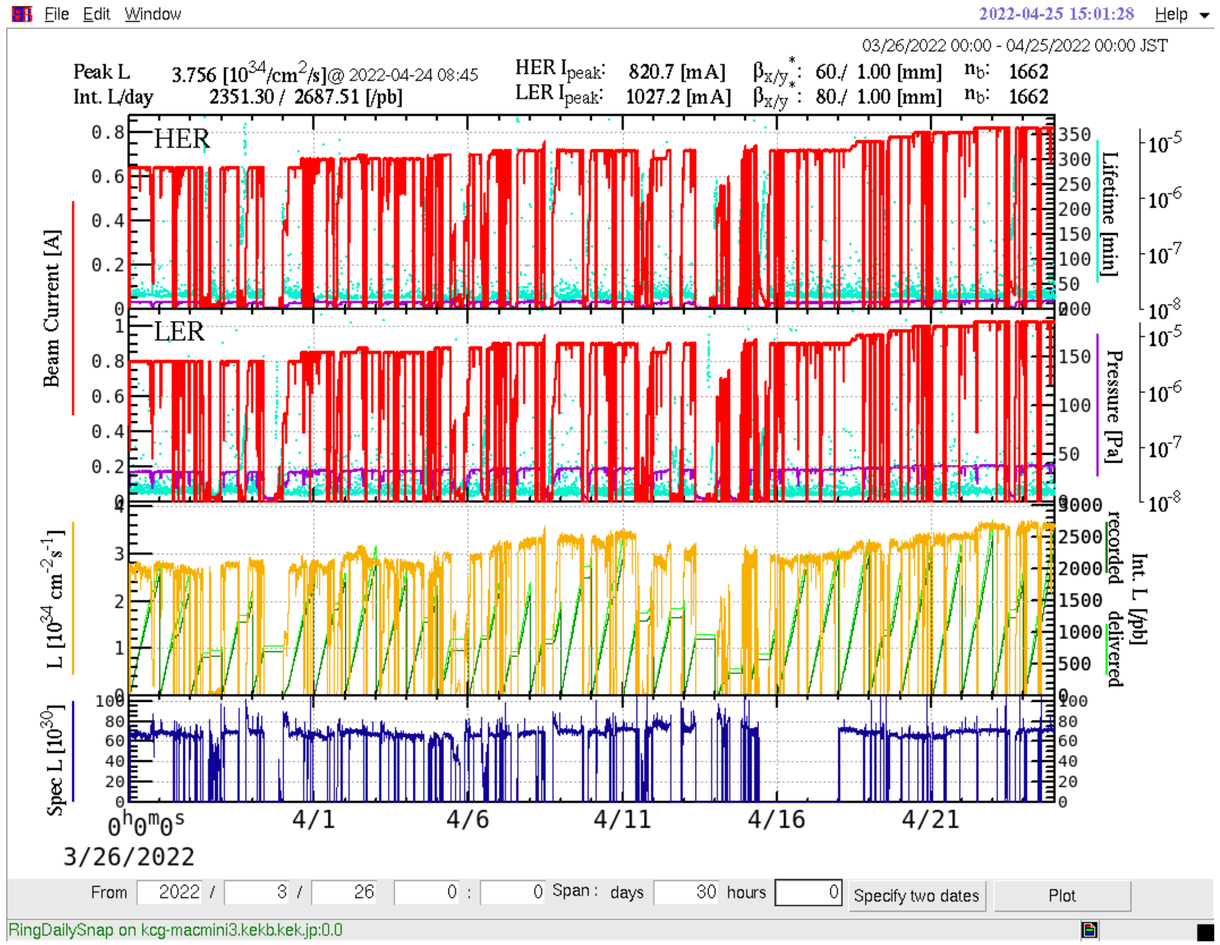
9th meeting of beam-beam workgroup, Apr. 26, 2022, KEK

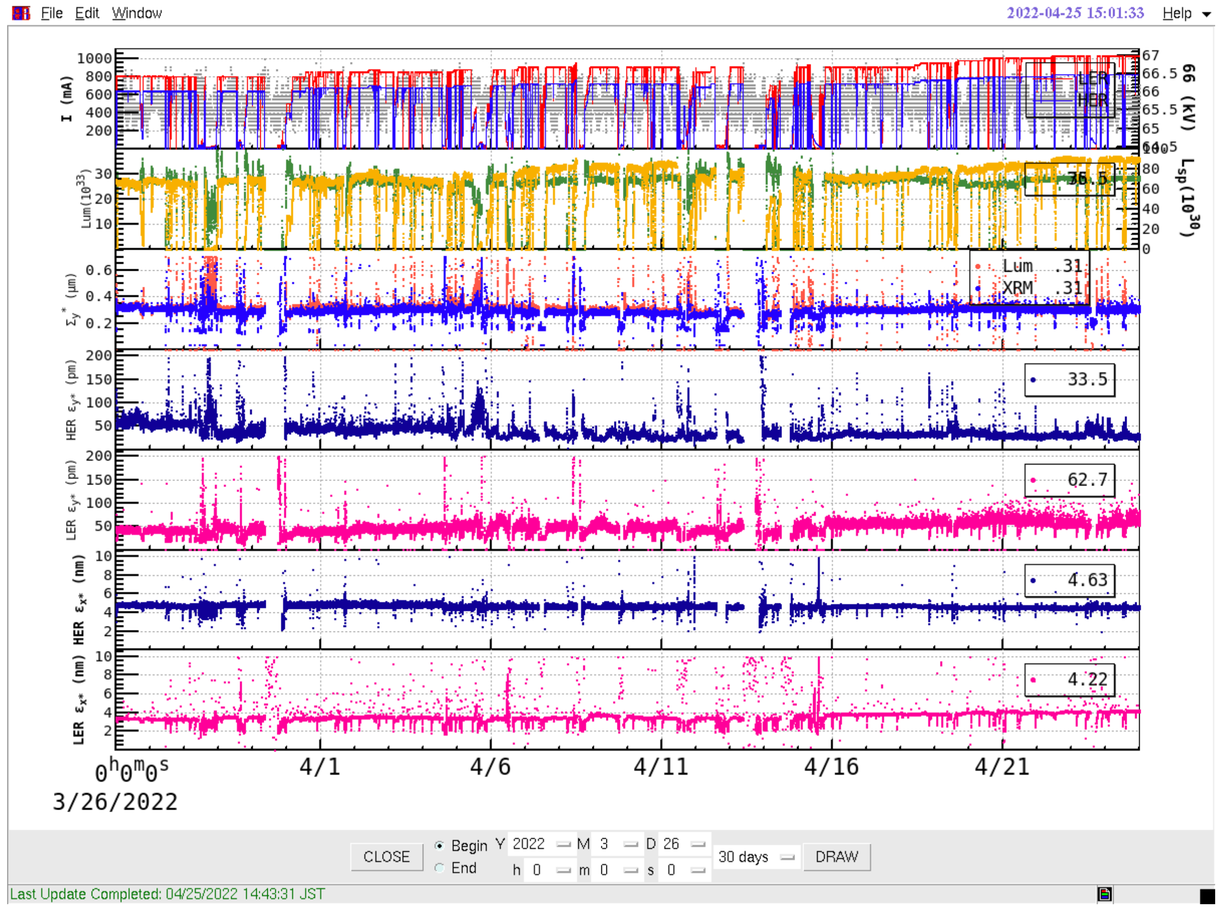
Outline

- Recent machine status
- Updates on beam-beam simulations
- Machine studies

Recent machine status

- 30 days of machine status



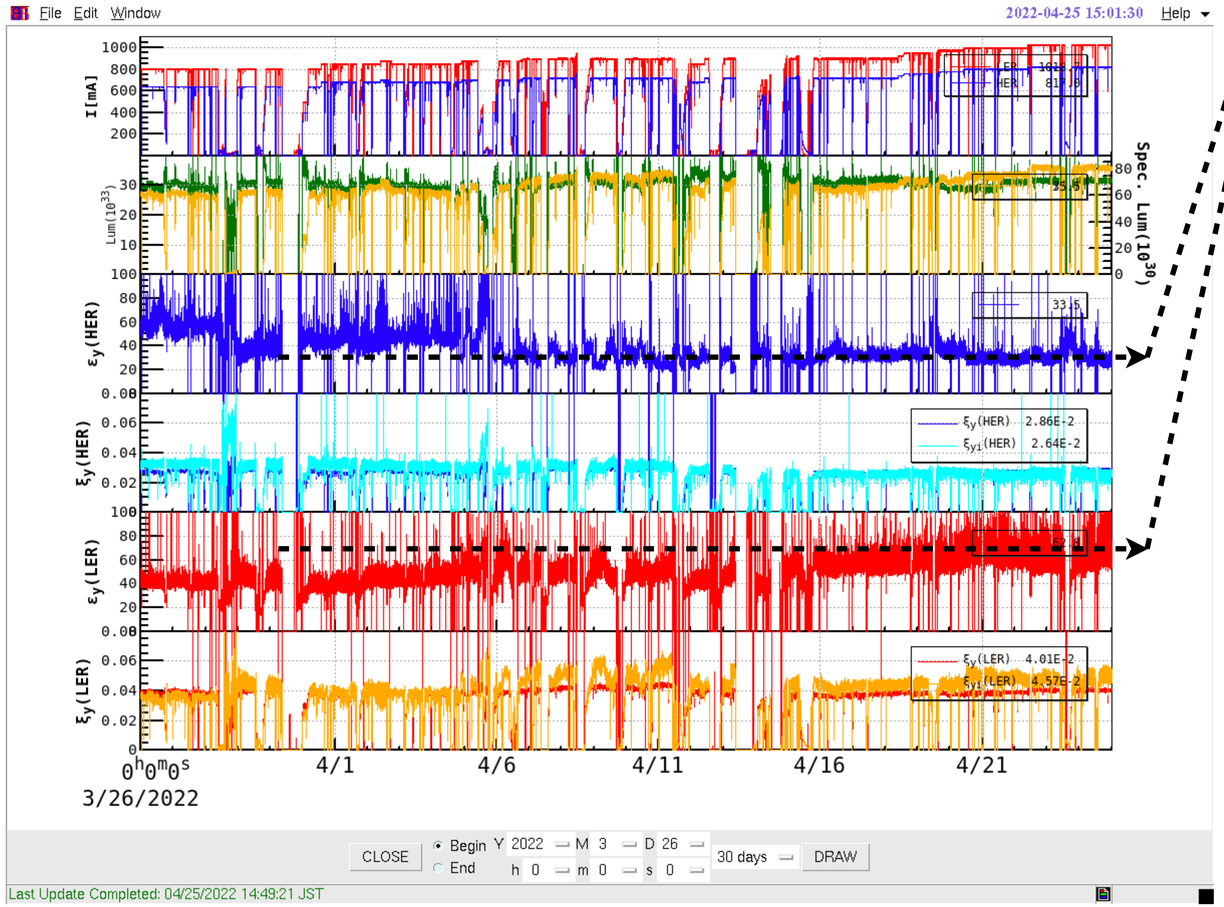


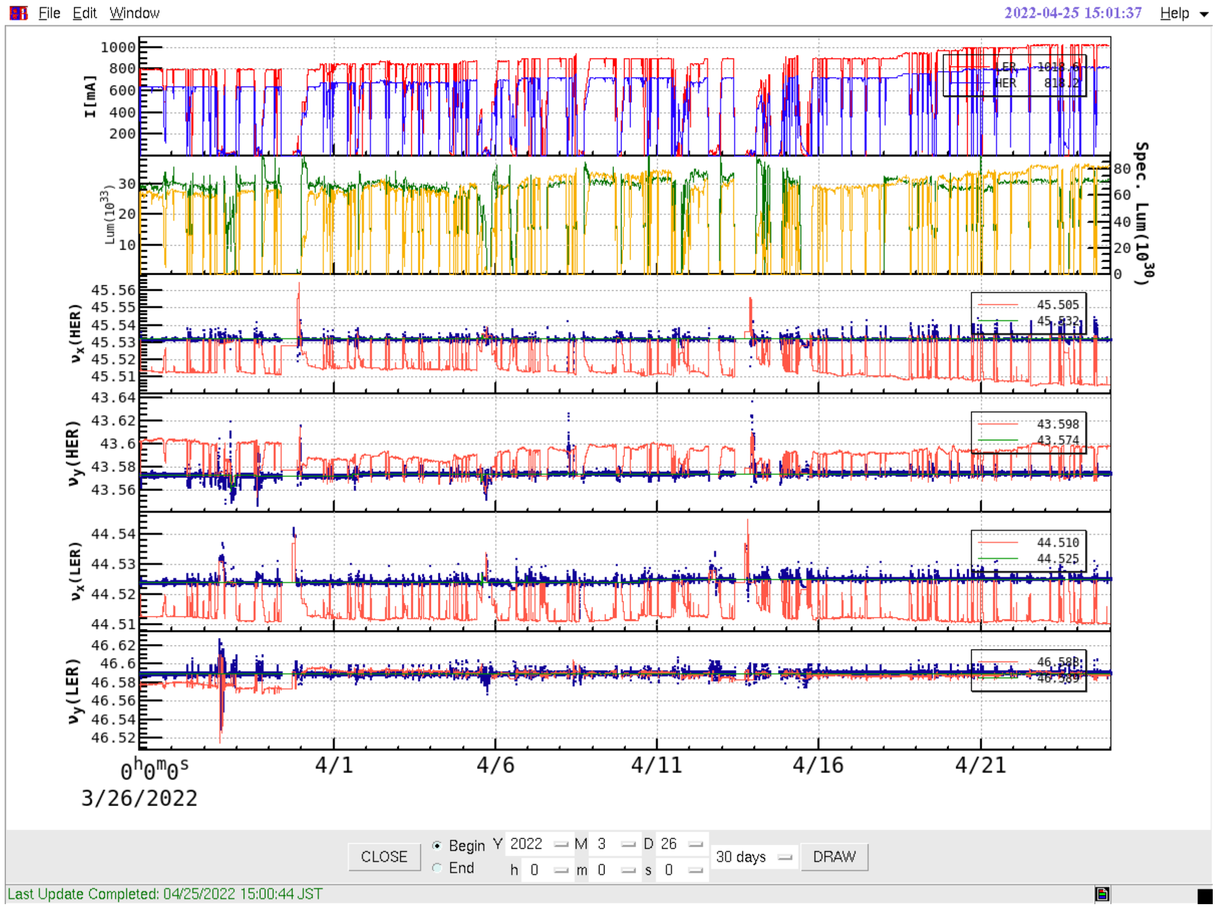
Recent machine status

- 30 days of machine status

HER ϵ_y has less fluctuation

LER ϵ_y has larger fluctuation





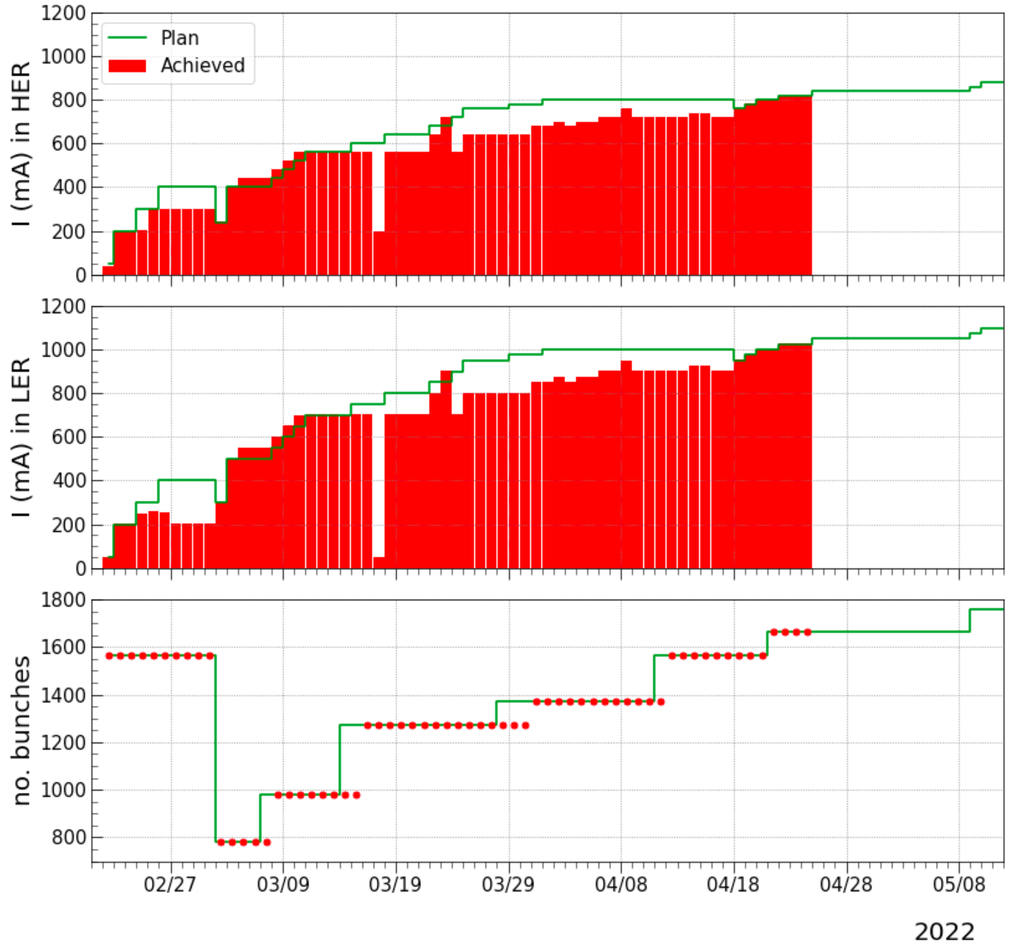
Recent machine status

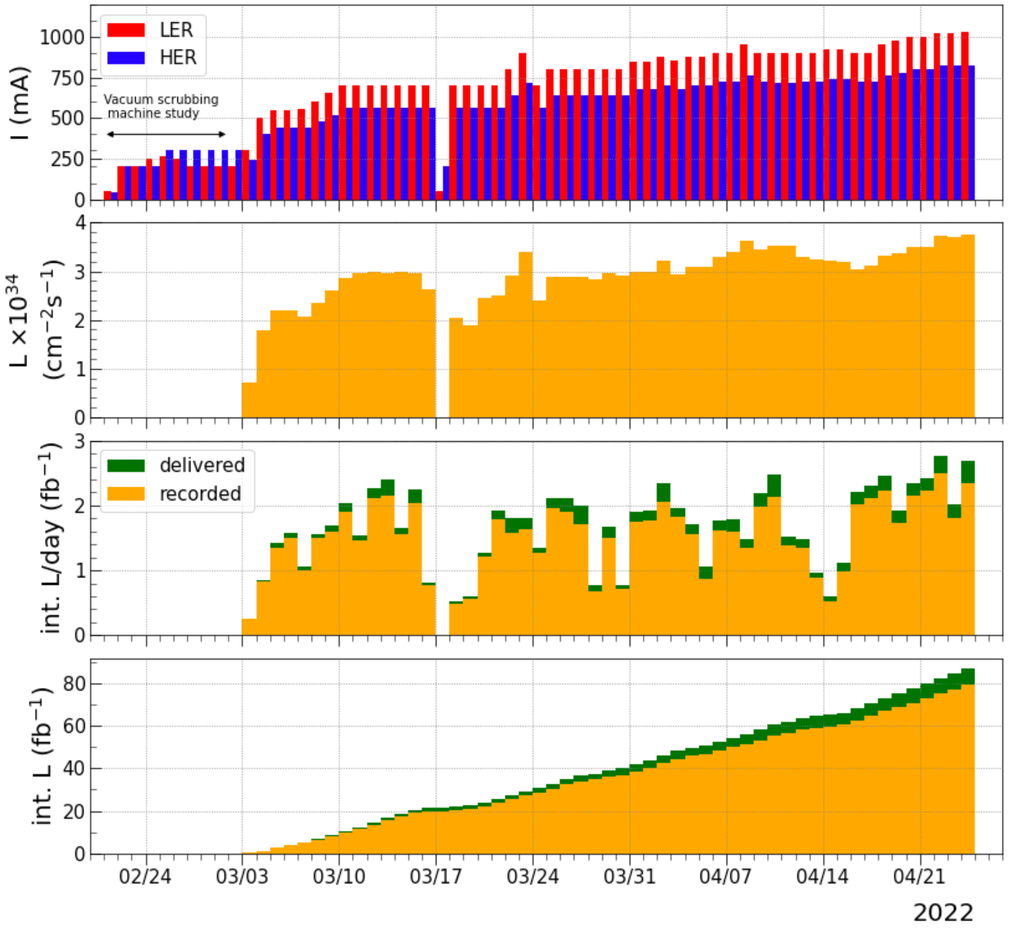
- Beam currents and luminosity history [1]

Records

- Peak luminosity 3.81 x10^{34} ($cm^{-2}s^{-1}$), December 23, owl, 2021

Integrated luminosity	Recorded	Date	Delivered	Date
Shift (pb^{-1})	958.1	April 24, swing, 2022	1035.9	April 22, swing, 2022
1 days (fb^{-1})	2.503	April 22, 2022	2.760	April 22, 2022
7 days (fb^{-1})	15.001	April 18 - April 24, 2022	16.599	April 18 - April 24, 2022

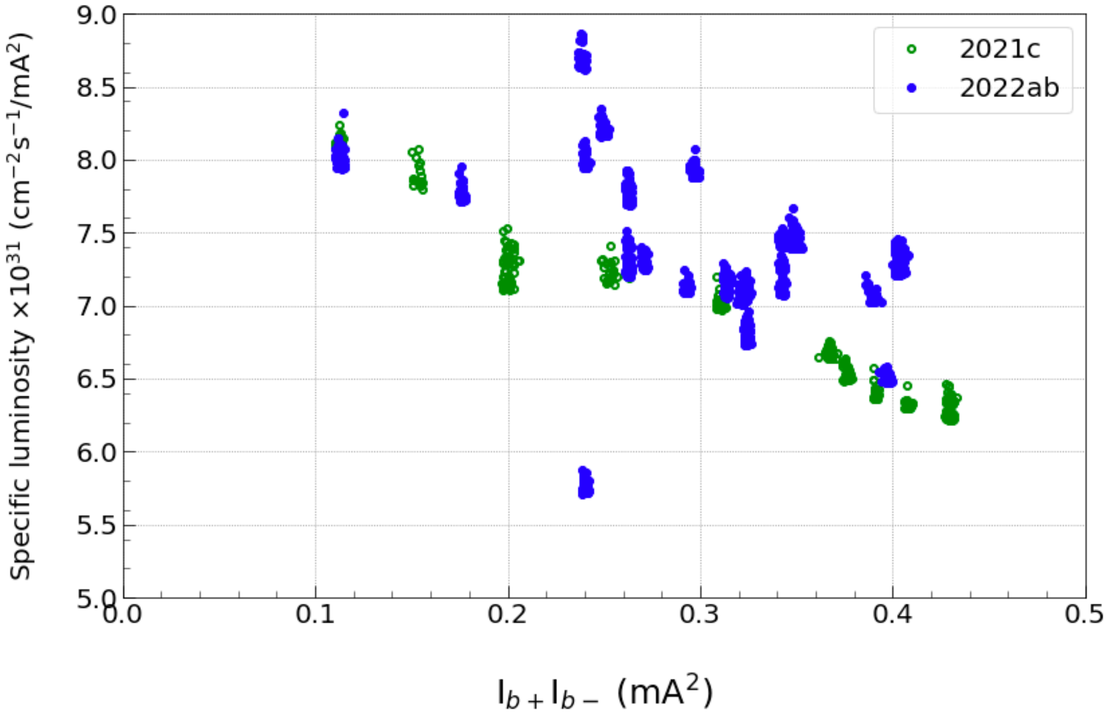


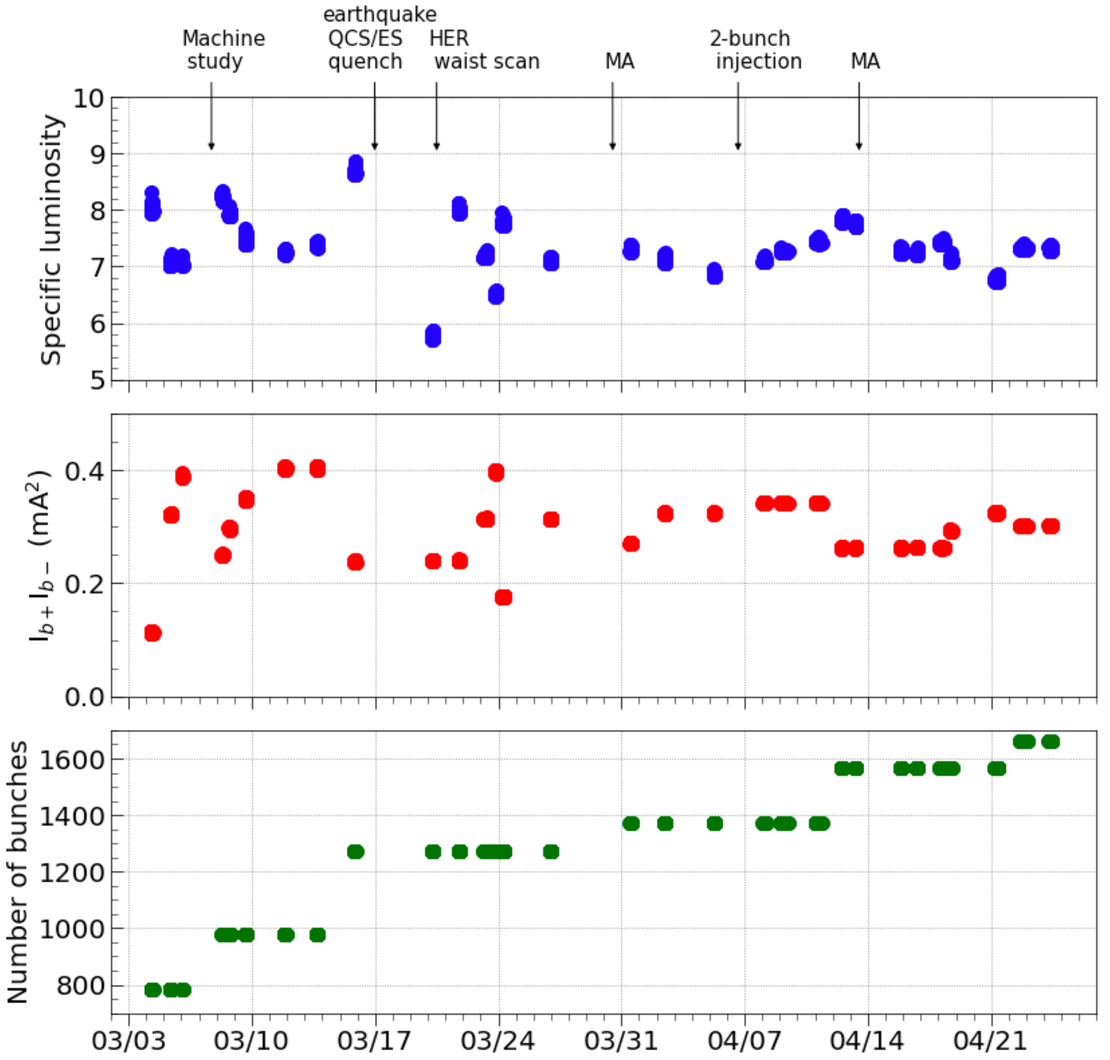


[1] Y. Ohnishi, https://www-linac.kek.jp/skekb/status/web/status_plan.md.html

Recent machine status

- Beam currents and luminosity history [1]





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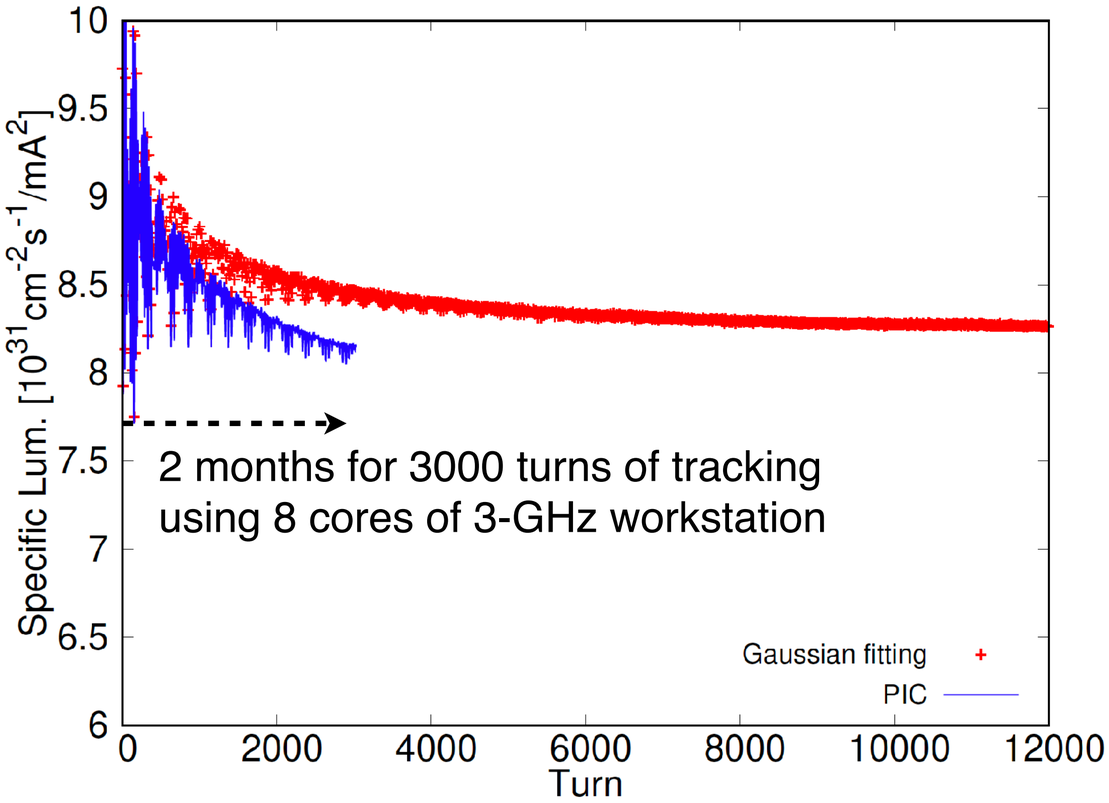
Beam-beam simulations

- BBSS simulations: PIC vs. Gaussian fitting model
  - Use machine parameters of 2021.12.21.
  - PIC method predicts lower luminosity (to be confirmed).
  - One PIC simulation requires ~8 months, and a Gaussian-fitting simulation takes ~1.2 days…
  - We need a strategy to speed up PIC simulations.

	2021.12.21		Comments
	HER	LER	
I_{bunch} (mA)	0.8	1.0	
# bunch	-		Assumed value
ε_x (nm)	4.6	4.0	w/ IBS
ε_y (pm)	35	20	Estimated from XRM data
β_x (mm)	60	80	Calculated from lattice
β_y (mm)	1	1	Calculated from lattice
σ_{z0} (mm)	5.05	4.60	Natural bunch length (w/o MWI)
ν_x	45.53	44.524	Measured tune of pilot bunch
ν_y	43.572	46.589	Measured tune of pilot bunch
ν_s	0.0272	0.0233	Calculated from lattice
Crab waist	40%	80%	Lattice design



Beam-beam simulations

- BBSS simulations: PIC vs. Gaussian fitting model
  - Use machine parameters of 2021.12.21.

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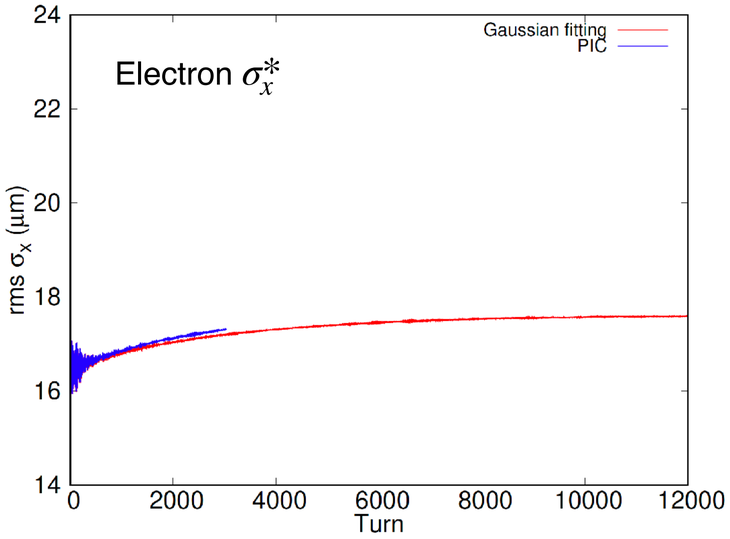
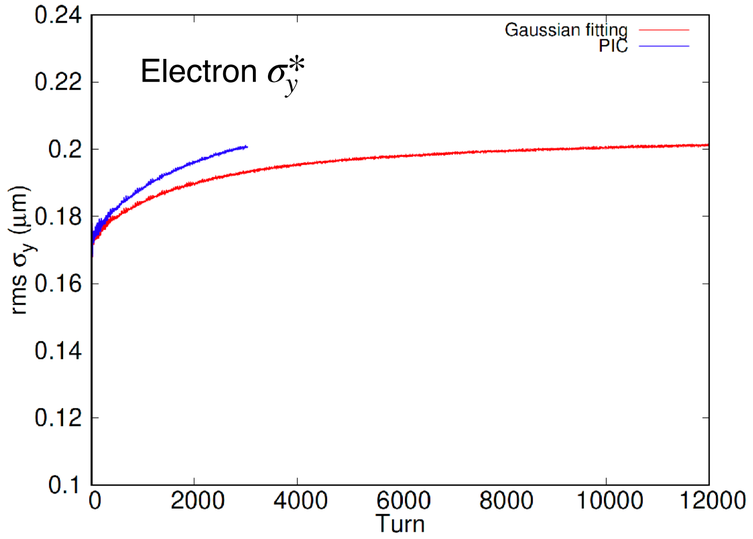
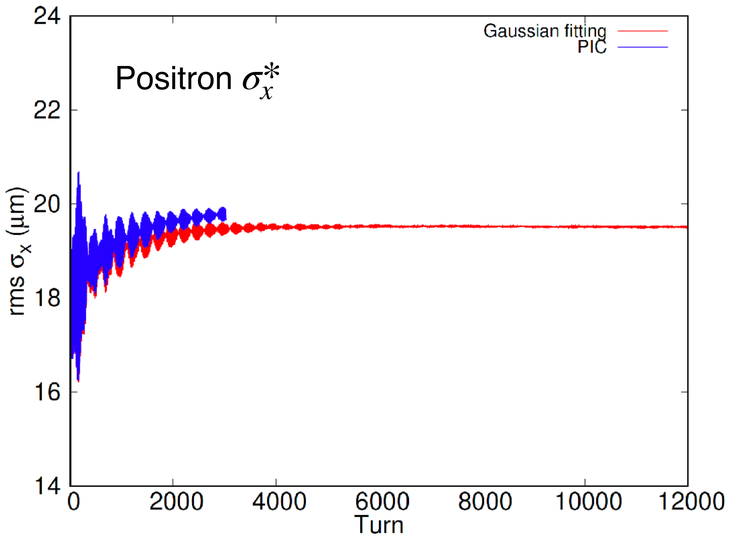
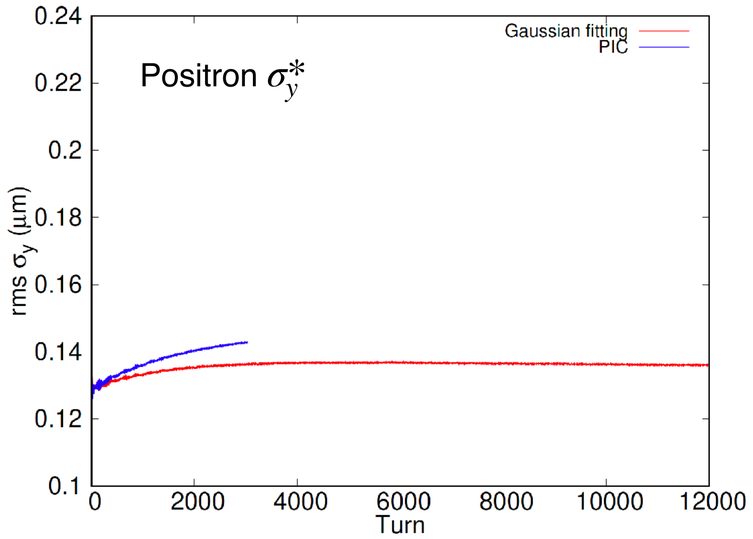








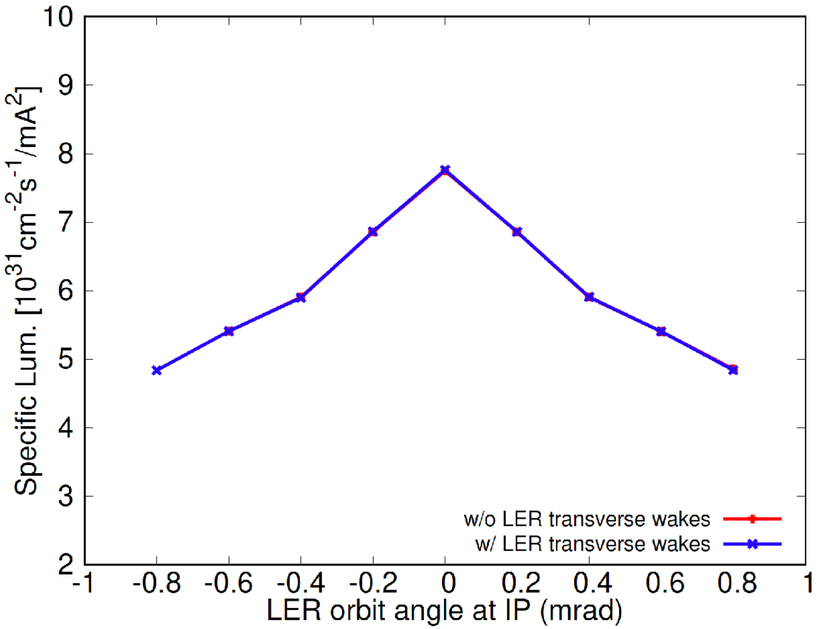
Beam-beam simulations

- BBSS simulations: Vertical orbit angle at IP
  - Luminosity is sensitive to vertical orbit angle at IP.
  - Transverse wakes have no effects.

Operation parameter set for BBSS simulation

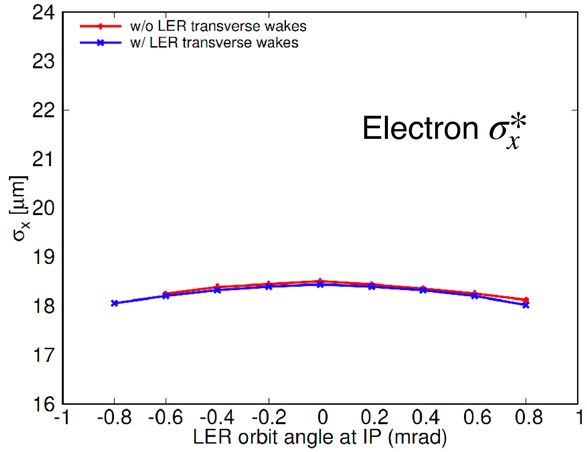
	2022.04.05		Comments
	HER	LER	
I_{bunch} (mA)	0.8	1.0	
# bunch	-		Assumed value
ε_x (nm)	4.6	4.0	w/ IBS
ε_y (pm)	30	35	Estimated from XRM data
β_x (mm)	60	80	Calculated from lattice
β_y (mm)	1	1	Calculated from lattice
σ_{z0} (mm)	5.05	4.60	Natural bunch length (w/o MWI)
ν_x	45.532	44.524	Measured tune of pilot bunch
ν_y	43.572	46.589	Measured tune of pilot bunch
ν_s	0.0272	0.0233	Calculated from lattice
Crab waist	40%	80%	Lattice design

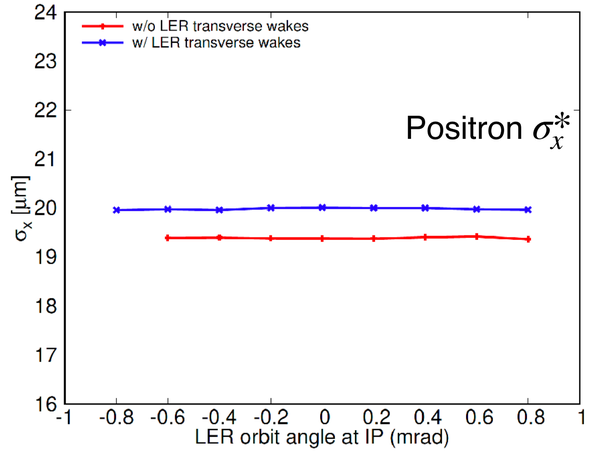
Lsp: BBSS simulations

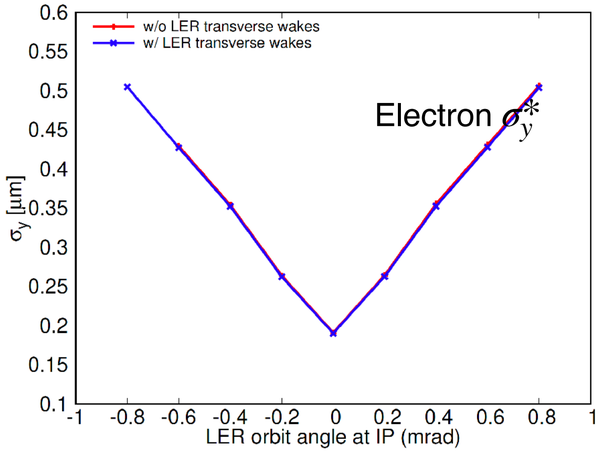


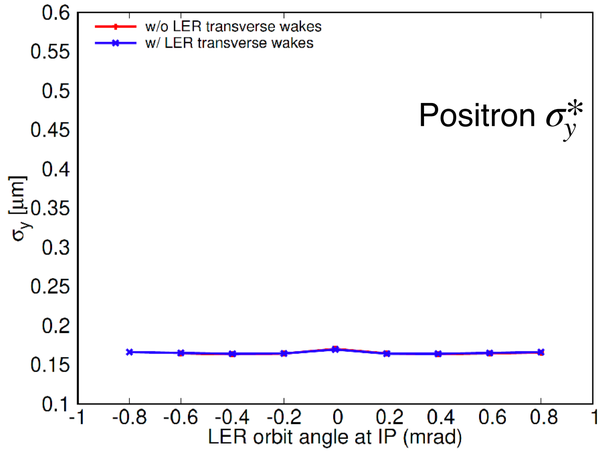
Beam-beam simulations

- BBSS simulations: Vertical orbit angle at IP
  - Luminosity loss is mainly due to geometric loss.









Beam-beam machine study

- Apr. 05, 2022: HBCC study
  - The specific luminosity was lower than the best performance (by about ~10%) achieved before the strong earthquake on Mar. 16, 2022. Especially, the single-beam vertical emittance became worse.
  - LER crab waist strength was varied in BBSS simulations.

Operation parameter set for BBSS simulation

	2022.04.05		Comments
	HER	LER	
I_{bunch} (mA)	Ie	1.25*Ie	
# bunch	393		Assumed value
ε_x (nm)	4.6	4.0	w/ IBS
ε_y (pm)	30	35	Estimated from XRM data
β_x (mm)	60	80	Calculated from lattice
β_y (mm)	1	1	Calculated from lattice
σ_{z0} (mm)	5.05	4.60	Natural bunch length (w/o MWI)
ν_x	45.532	44.524	Measured tune of pilot bunch
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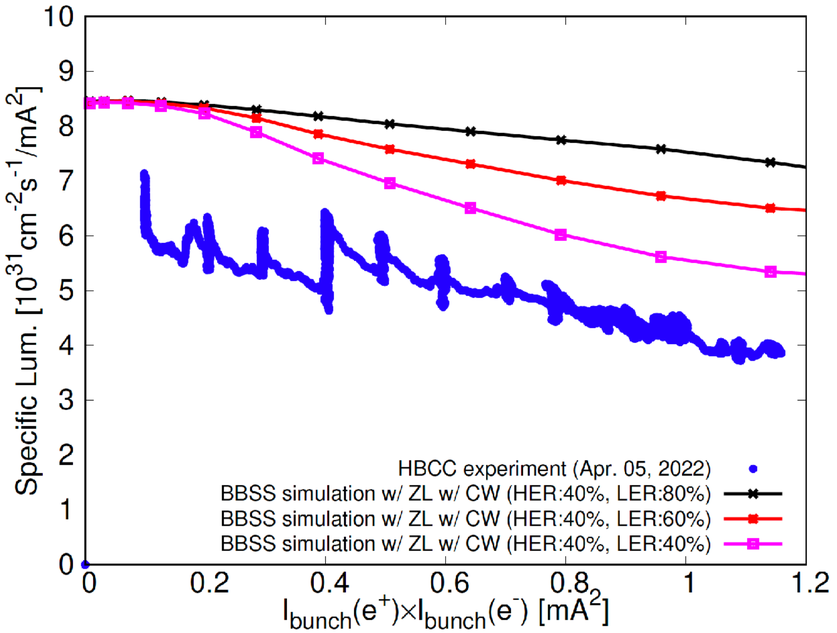
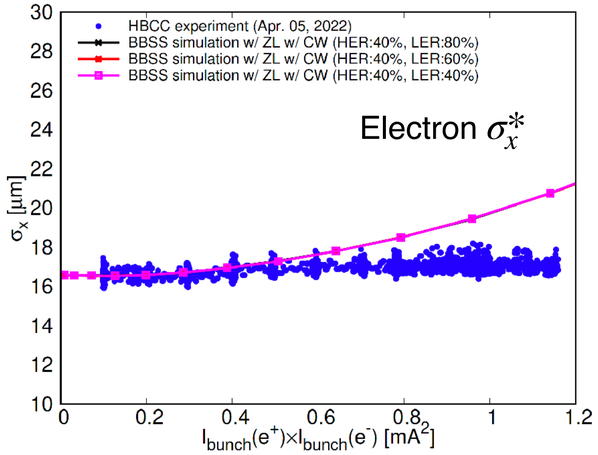
Crab waist	40%	80%	Lattice design

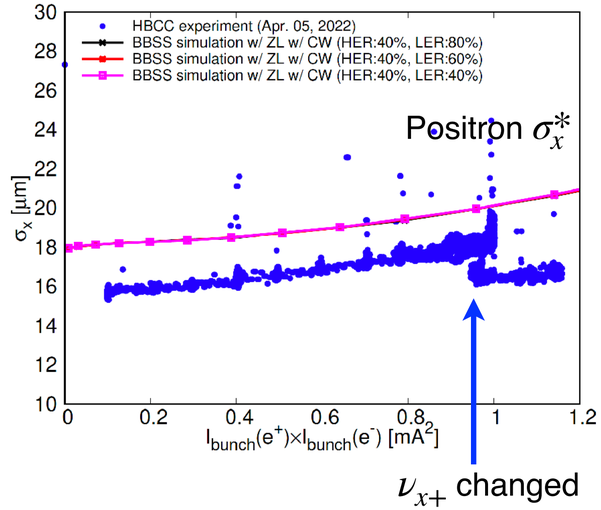
Lsp: BBSS simulations vs observation

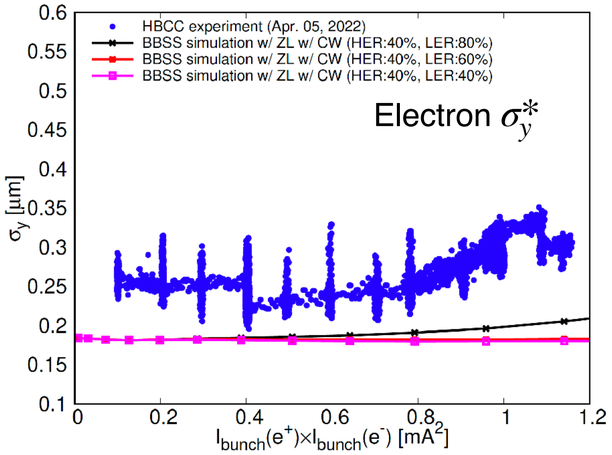


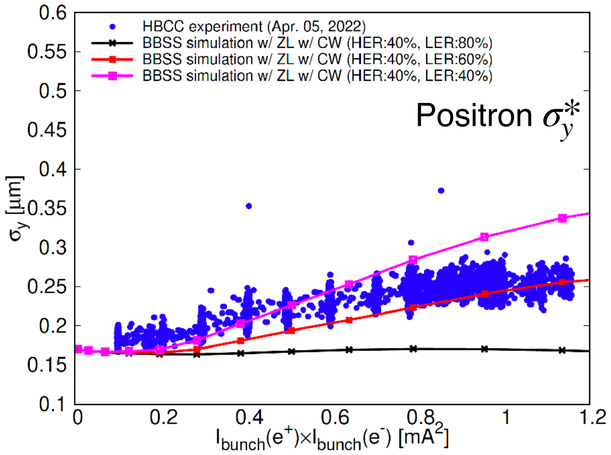
Beam-beam machine study

- Apr. 05, 2022: HBCC study
  - Bunch-current-dependent blowups are getting closer to simulations.
  - After optimization of BxB FB system in LER, the strange blowup in positron σ_y^* disappeared (see next slides and Y. Funakoshi's talk in this meeting).
  - At high bunch currents, vertical blowup remains to be better understood.





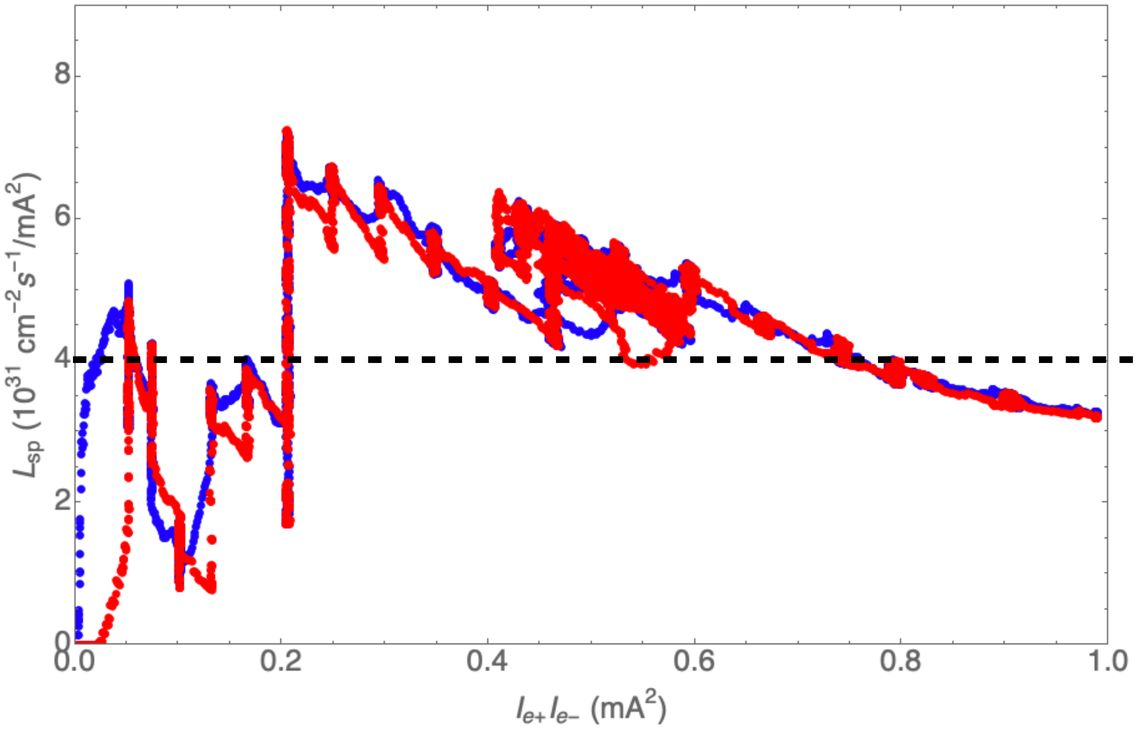




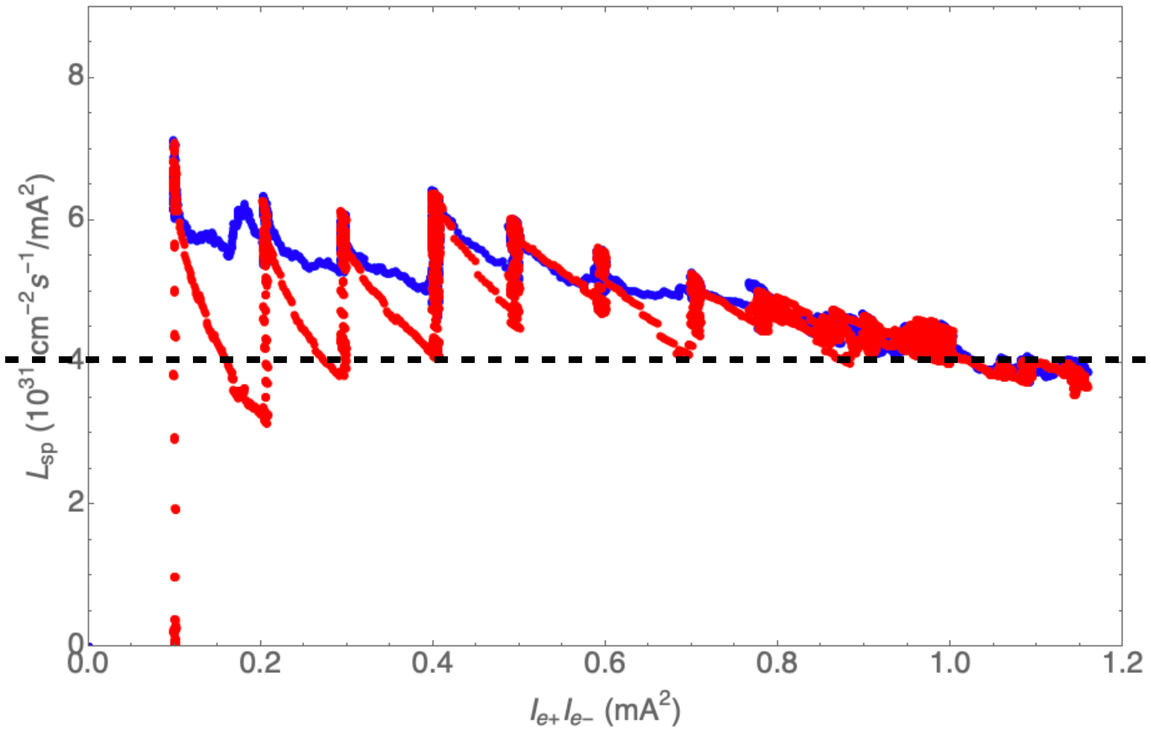
Results of HBCC: Comparing results of Apr. 5, 2022 and Dec. 21, 2021

Similar Lsp at $I_{e+}I_{e-}$< 0.6 mA²; Better Lsp achieved on Apr. 5, 2022 at $I_{e+}I_{e-}$> 0.6 mA².

Dec. 21, 2021



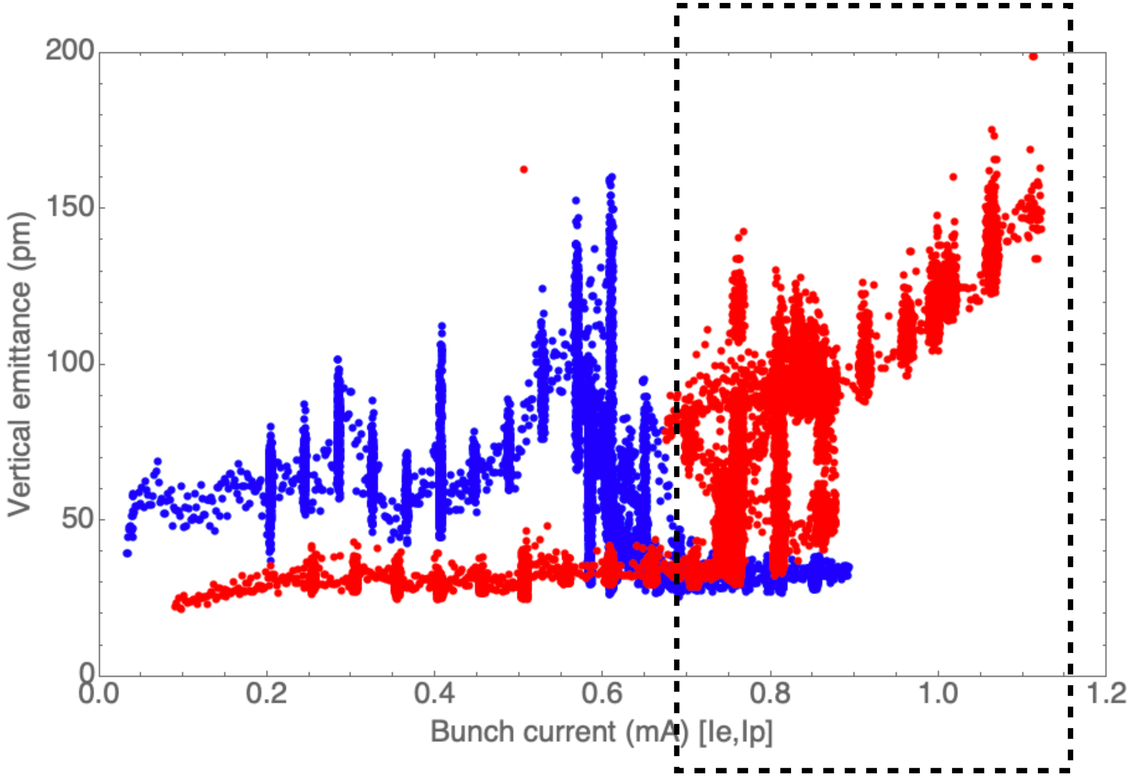
Apr. 5, 2022



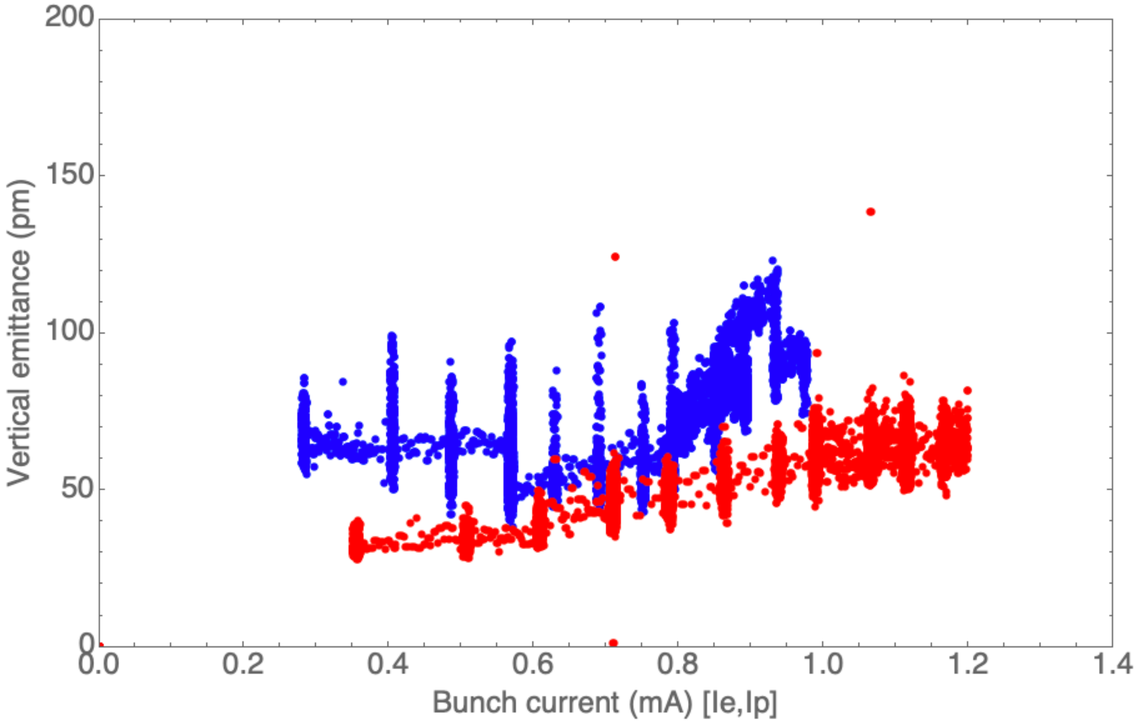
Results of HBCC: Comparing results of Apr. 5, 2022 and Dec. 21, 2021

Bunch-current-dependent vertical blowup is quite different.
The LER vertical blowup at $I_{e+} > 0.7$ mA was severe on Dec. 21, 2021, but not seen on Apr. 5, 2022.
→ Is this attributed to the FB tuning in LER?

Dec. 21, 2021



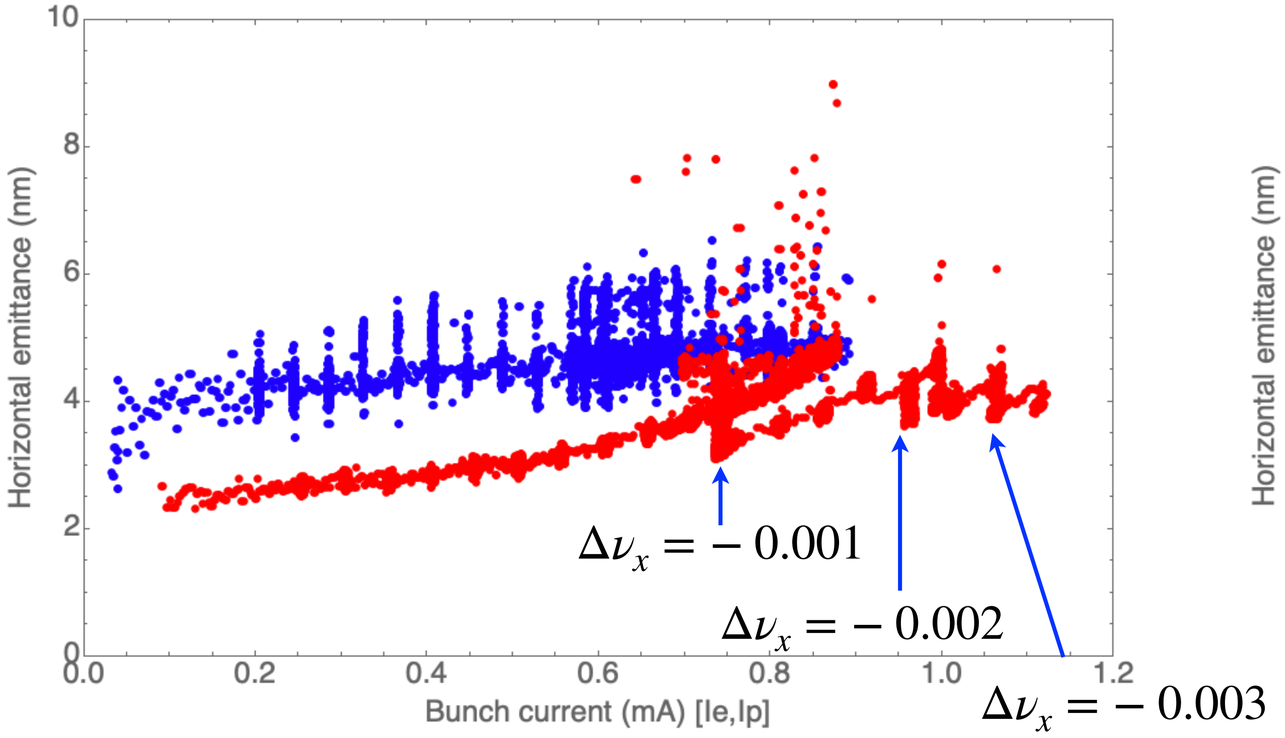
Apr. 5, 2022



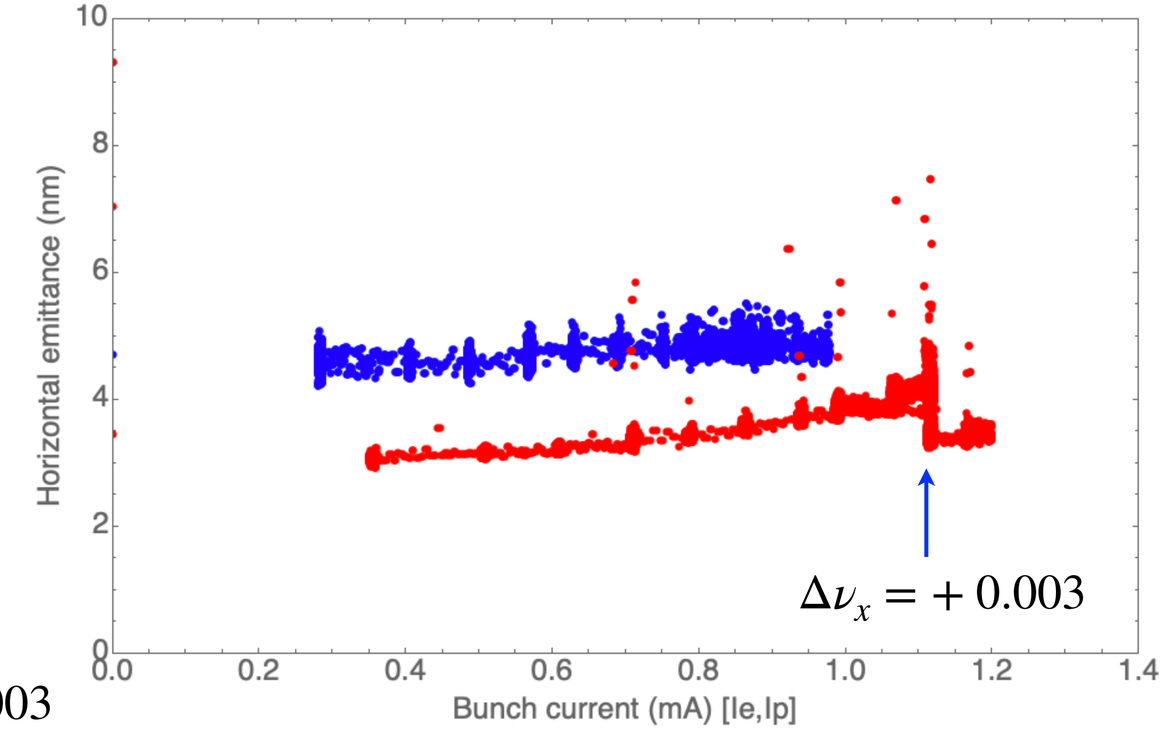
Results of HBCC: Comparing results of Apr. 5, 2022 and Dec. 21, 2021

Bunch-current-dependent horizontal blowup is also different.
On Dec. 21, 2021, reducing LER ν_x was useful to relax LER horizontal blowup.
On Apr. 5, 2022, increasing LER ν_x was useful to relax LER horizontal blowup.
→ This is a new puzzle to be understood.

Dec. 21, 2021



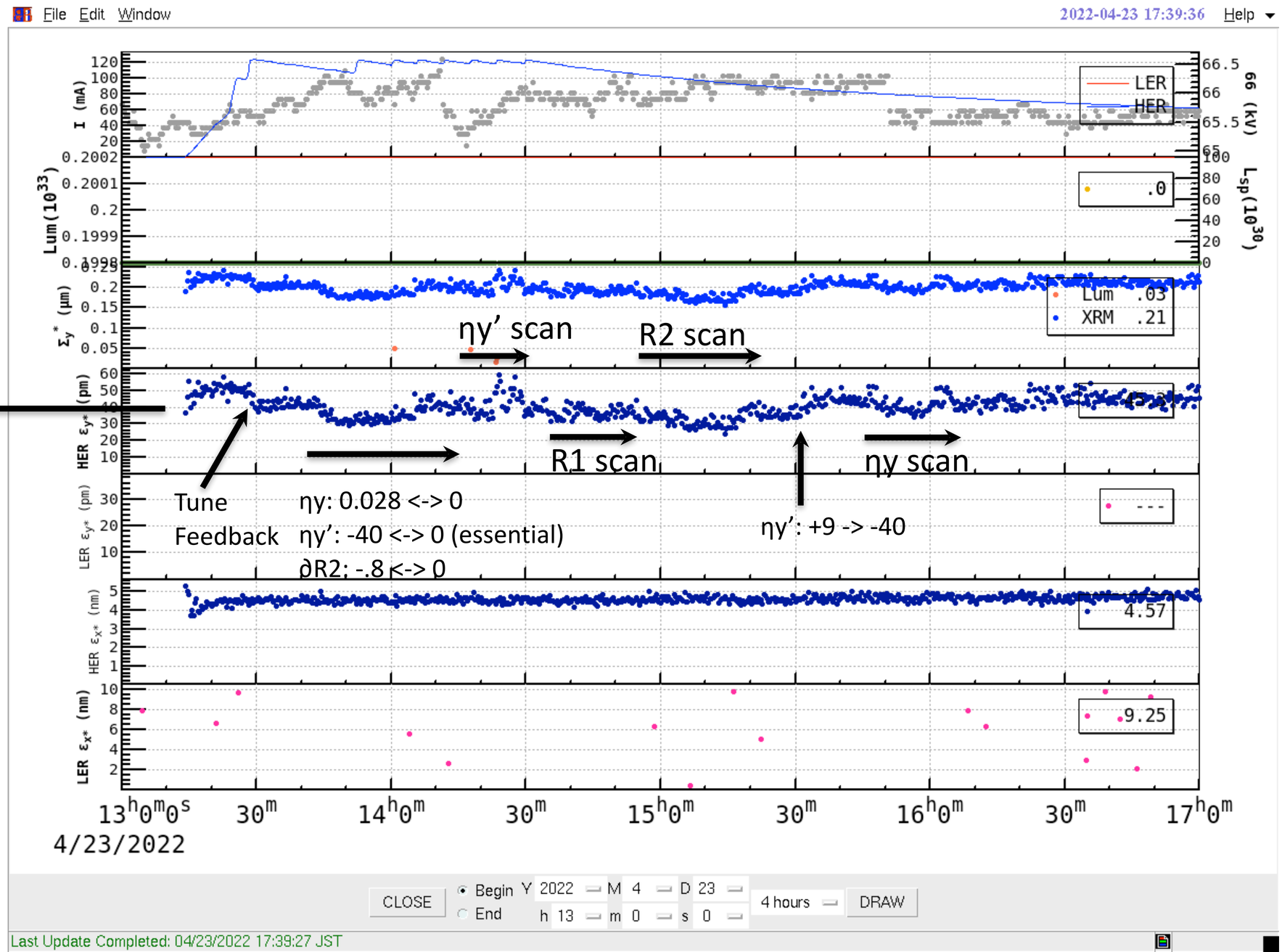
Apr. 5, 2022



HER single-beam study: Correlation of IP knobs with εy

With IP knobs on:
εy ~40 pm

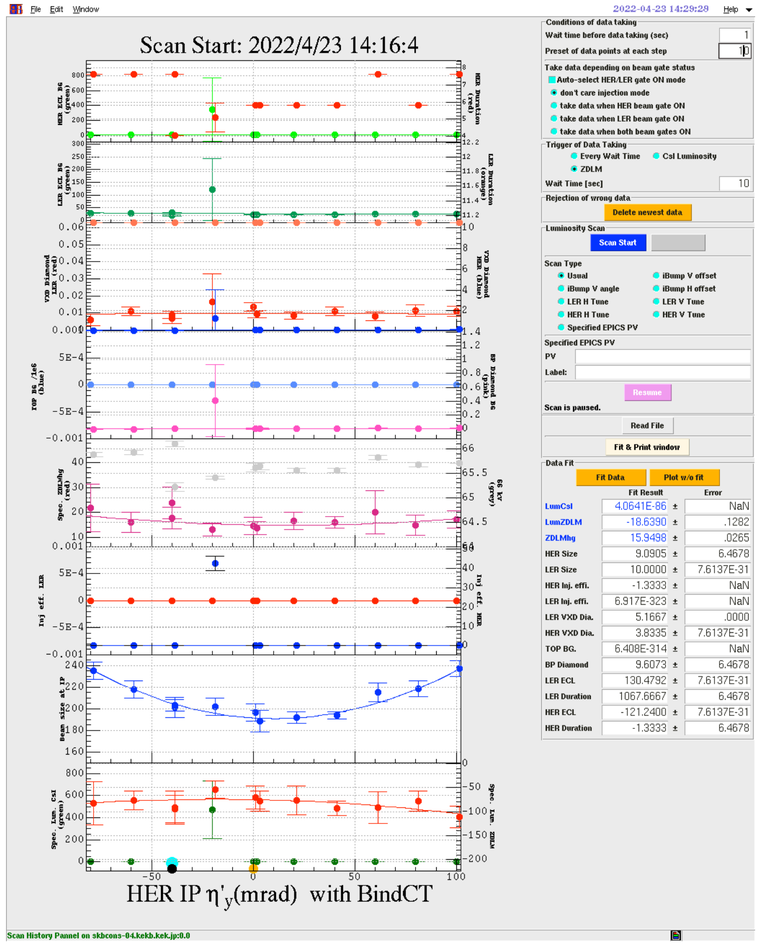
With single-beam IP knob scan,
we can achieve
εy ~28 pm



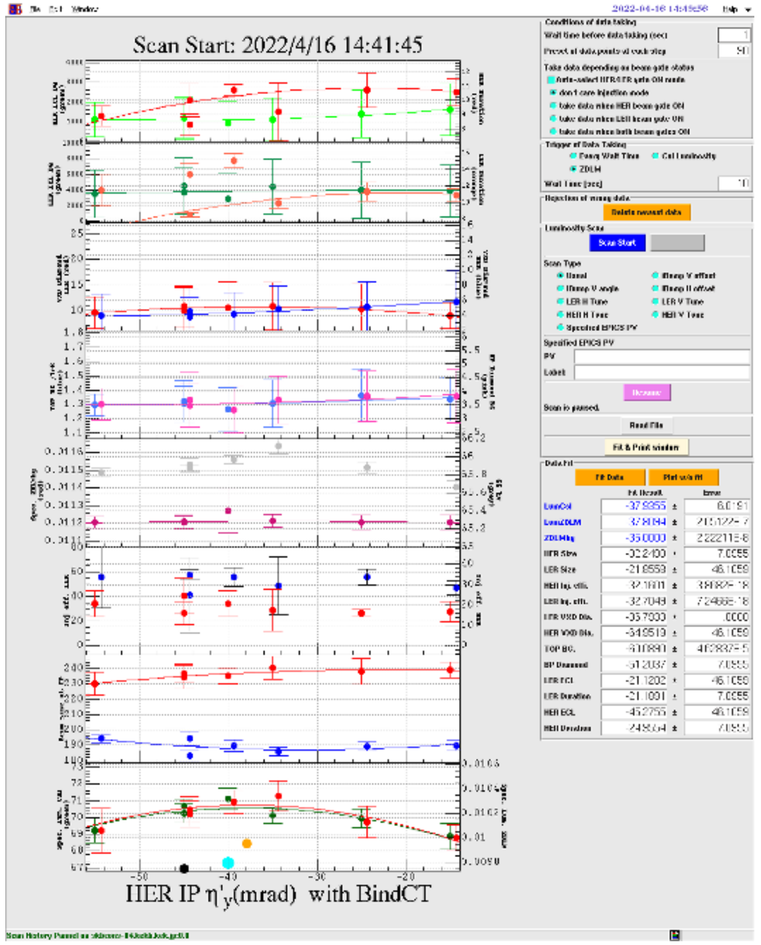
HER single-beam study: Correlation of IP knobs with εy

In single-beam mode, minimum εy appears at ηy'=9 mrad.
IP knob with collision set ηy'=-40 mrad

w/o collision



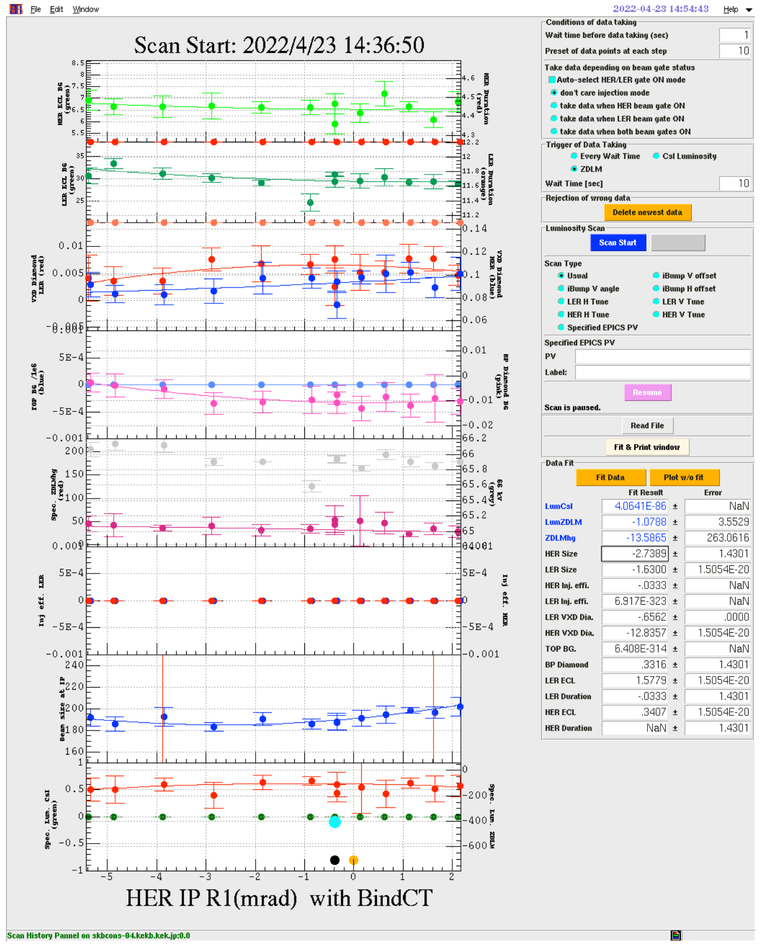
w/ collision



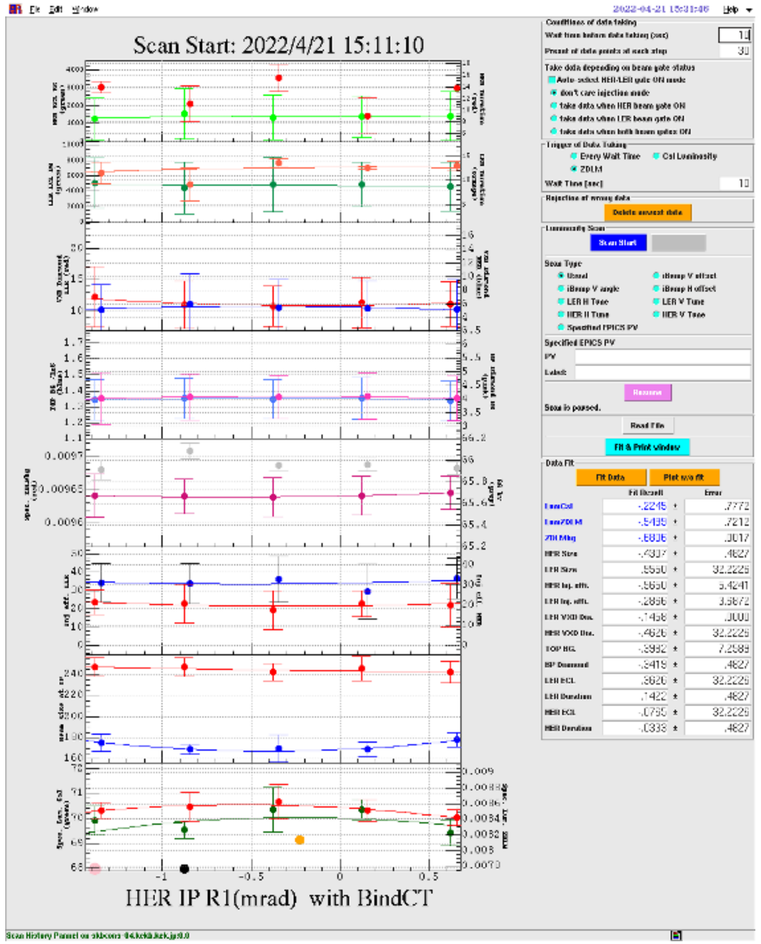
HER single-beam study: Correlation of IP knobs with εy

In single-beam mode, minimum εy appears at R1=-2.74 mrad.
IP knob with collision set R1=-0.38 mrad

w/o collision



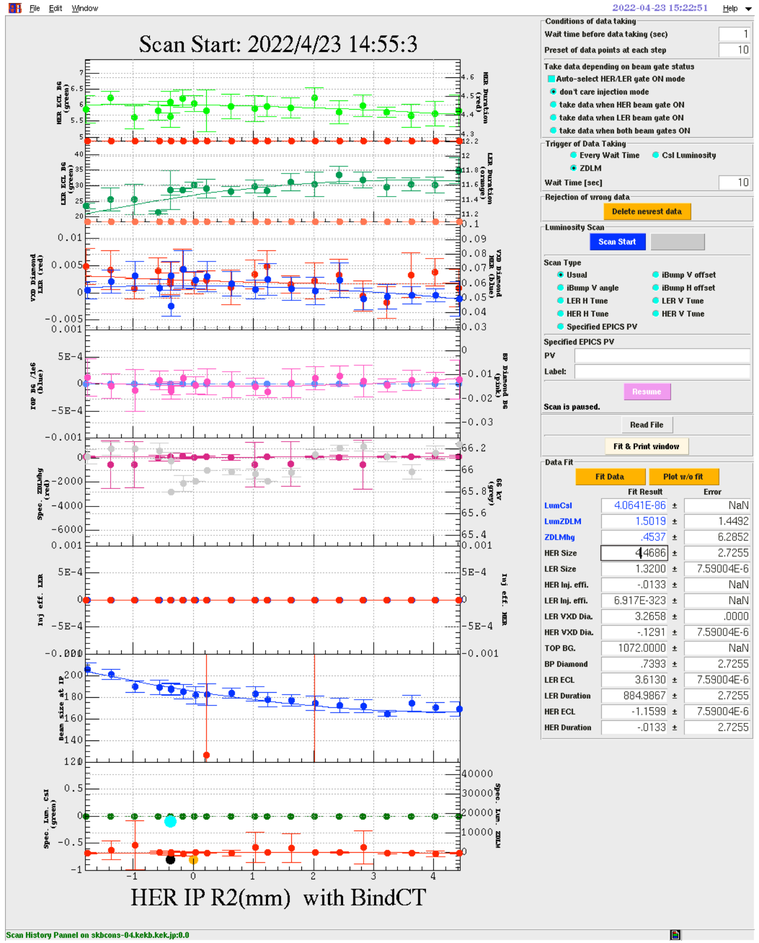
w/ collision



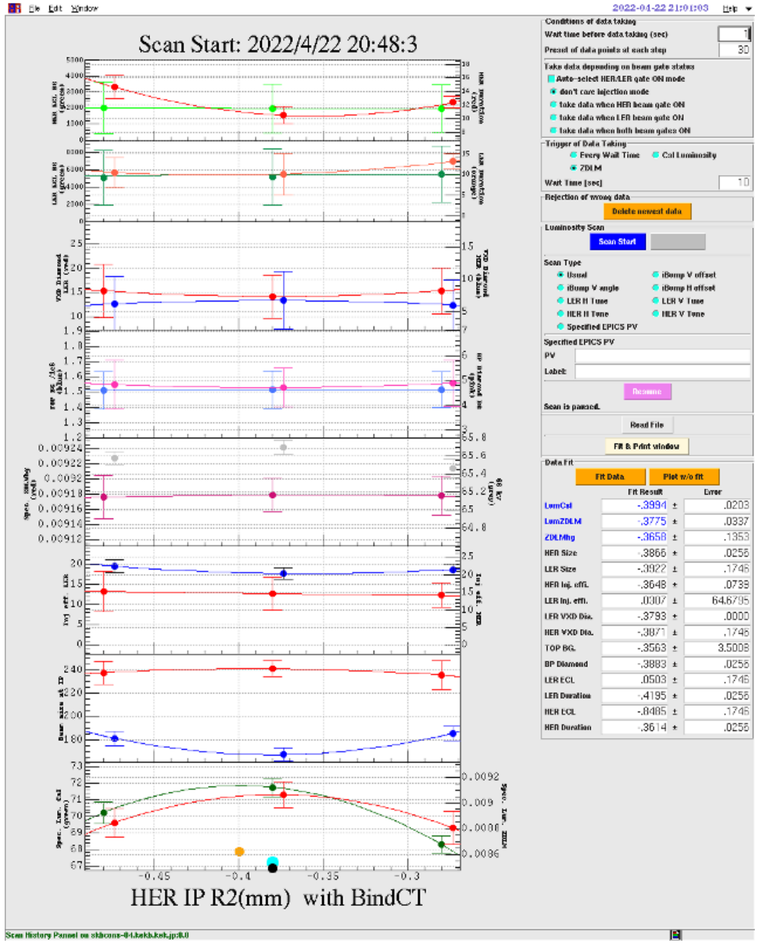
HER single-beam study: Correlation of IP knobs with εy

In single-beam mode, minimum εy appears at R2=+4.5 mm.
IP knob with collision set R2=-0.38 mm

w/o collision



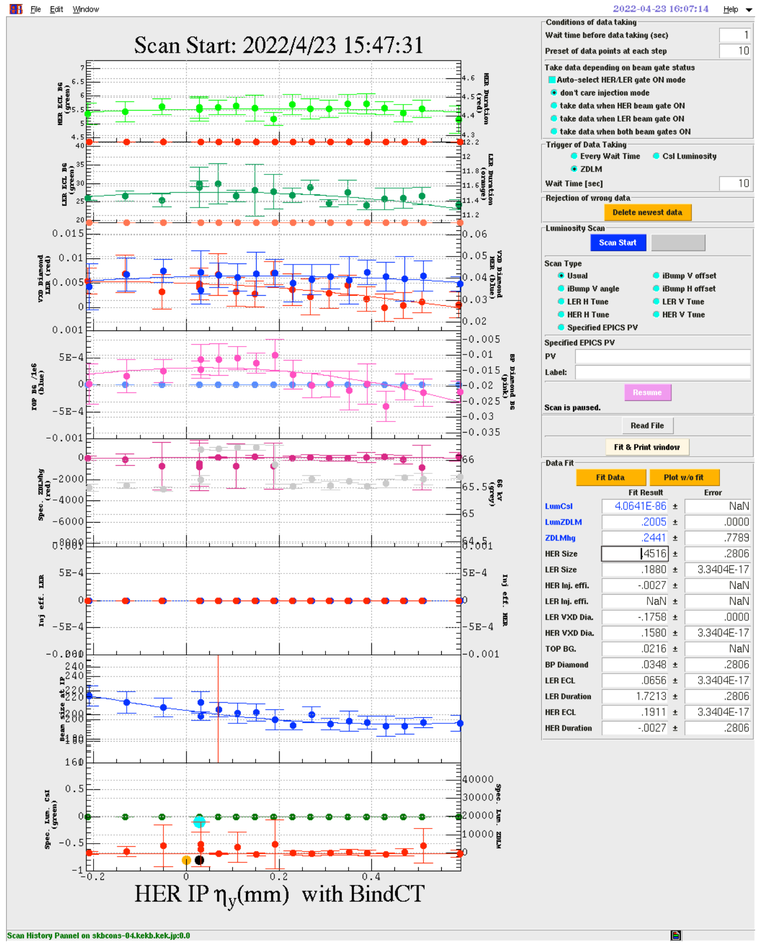
w/ collision



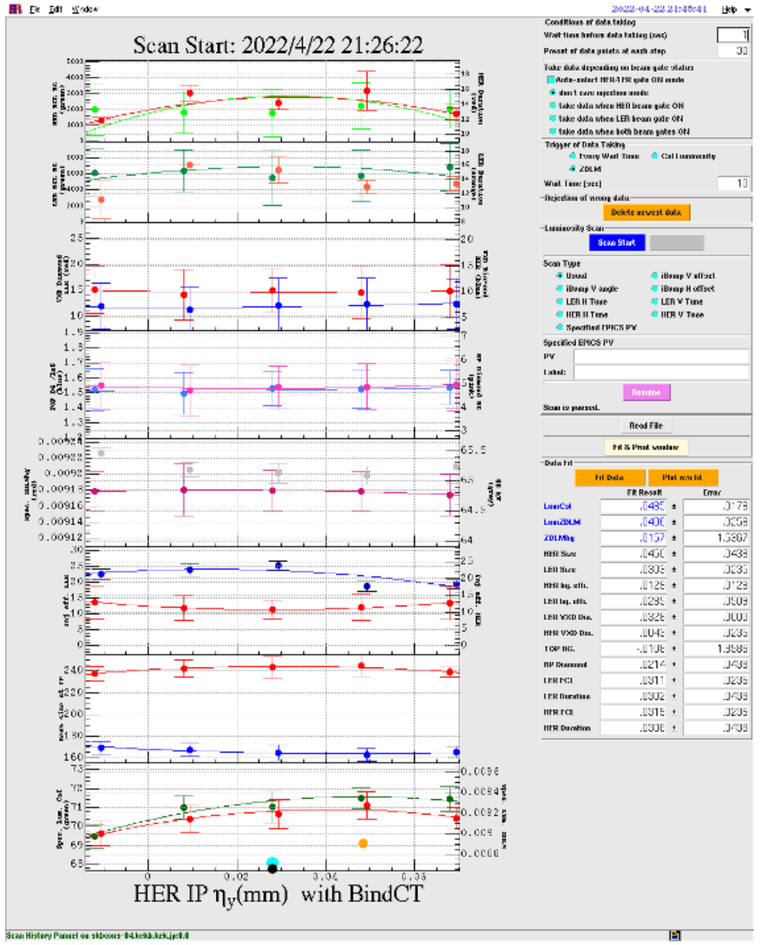
HER single-beam study: Correlation of IP knobs with εy

In single-beam mode, minimum εy appears at ηy =+0.45 mm.
IP knob with collision set ηy =+0.028 mm

w/o collision



w/ collision



HER single-beam study: Correlation of IP knobs with εy

Summary:

* With original IP knobs optimized with collision, the HER single-beam emittance is about 40 pm: R1*=-0.38 mrad, R2*=-0.38 mm, ηy=0.028 mm, ηy'=-40 mrad.

* With ηy' changed from -40 to 9 mrad, εy can be reduced to ~35 pm.

* With R2* changed from -0.38 to 4.5 mm, εy can be reduced to ~30 pm.

* Global coupling (mainly determined by optics correction) affects εy.

* Interplay of imperfections at IP (IP coupling, dispersion, ...) and beam-beam affects εy.

* In the ideal case, IP knobs should not affect global coupling. In reality, IP knobs also affect global coupling (as demonstrated in this study).

* How to reduce the side effects of IP knobs (mainly on vertical emittance) is a subject to be investigated.

* The interference between different IP knobs (R*, ηy*, ηy'*, ...) is another subject to be investigated.

Summary

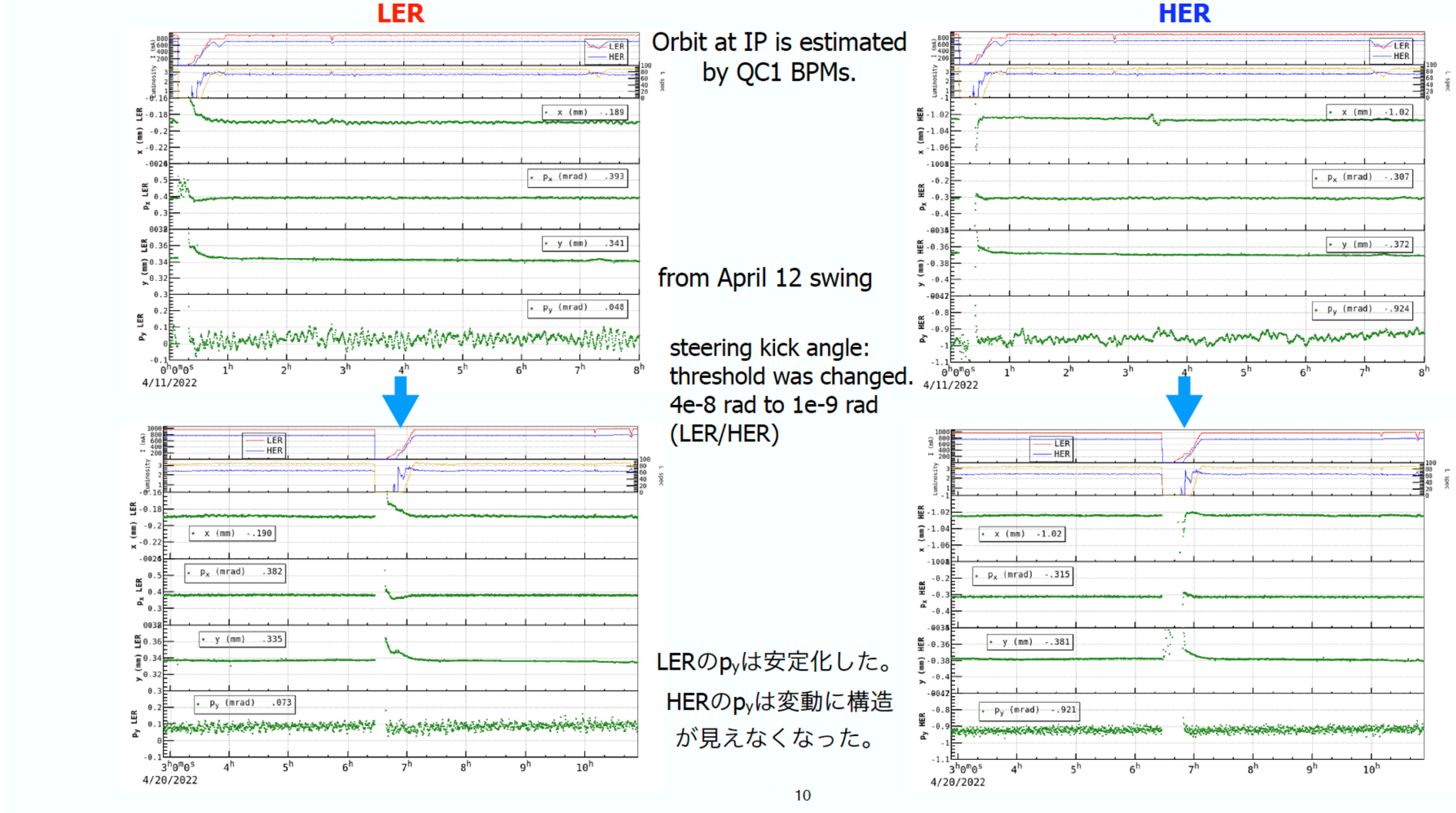
- Machine performance gradually improves with machine tunings.
- BBSS simulations with PIC and Gaussian fitting models showed differences in luminosity performance. PIC simulations should be investigated intensively.
- The recent results of HBCC study (2022.04.05) showed better agreements with beam-beam simulations.
  - The “-1 mode instability” in LER was mitigated by fine-tuning of BxB FB system.
- The preliminary results of single-beam IP knobs at HER showed IP knobs can affect single-beam emittances.

Backup

Recent machine status

- Orbit angle at IP [2]

Courtesy of Y. Ohnishi

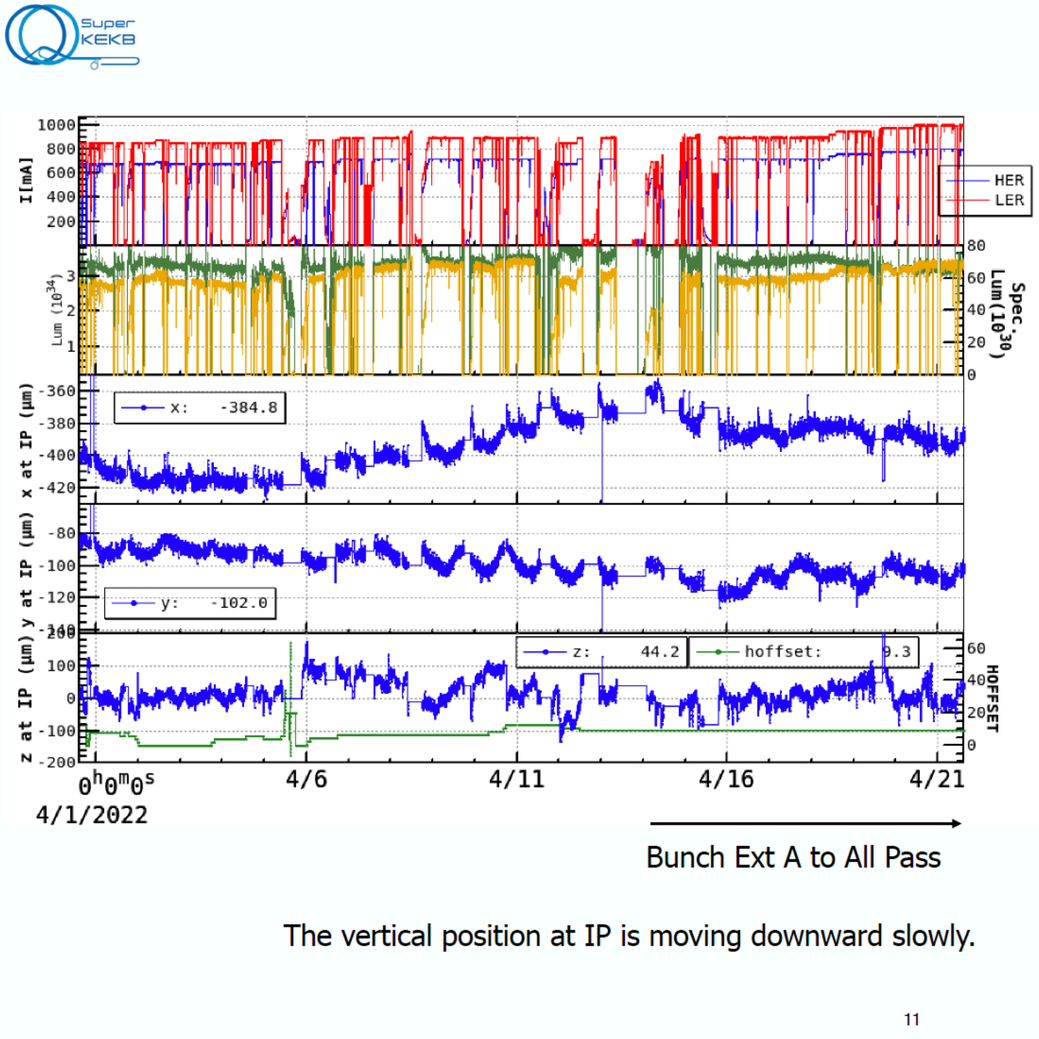


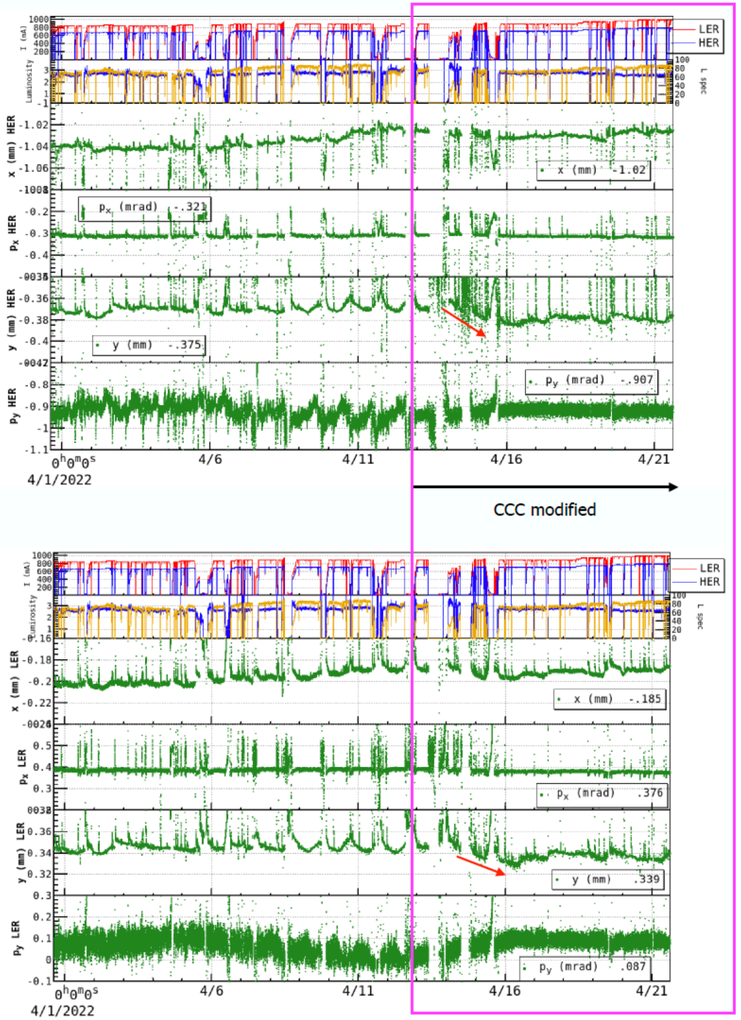
[2] Y. Ohnishi, SuperKEKB commissioning meeting, https://kds.kek.jp/event/41965/

Recent machine status

- Orbit angle at IP [2]

Courtesy of Y. Ohnishi





[2] Y. Ohnishi, SuperKEKB commissioning meeting, https://kds.kek.jp/event/41965/

Recommendations from ARC Intermediate ITF Review

- General Remarks
  - ***Future ITF subgroup meetings could be announced to all KEK accelerator divisions to strengthen the cooperation and to better include the other divisions in the ITF activities***.
    - Response: ITF-BB group meetings will be announced to all divisions of Acc. Lab., KEK
  - ***It is important to assign sufficient time to machine studies together with extra manpower (from inside and outside KEK) in order to unravel the limitations in optics, impedance and beam-beam.***
    - Beam dynamics virtual workgroup reactivated
    - Beam-beam related machine studies under the plan
- Beam-beam
  - ***The high momentum compaction optics (when/once available) should be tried in operation before the shutdown***.
    - Beam-beam simulations with $\nu_{s-} = \nu_{s+}$ undergoing; a proposal to commissioning group under preparation; optics design team under consideration
  - ***Clarify the performance reach of the crab waist scheme, its operational range in usable strength and its impact on reachable specific luminosity and on dynamic aperture***
    - Under discussion with the commissioning group
  - ***Consider using supercomputer facilities or an upgrade of CPU power for the important and very insightful strong-strong beam-beam simulations.***
    - So far no clear strategy; strong-strong simulations are ongoing (KEK: workstations with ~150 CPUs; IHEP: Cluster)
  - ***Complete the inclusion of both longitudinal and transverse beam coupling impedance model in the beam-beam simulation tools***
    - TMCI group (T. Ishibashi) is leading this task of impedance modeling; Available data are implemented in beam-beam simulations

Recommendations from ARC Intermediate ITF Review

- Beam-beam
  - ***Study the effect of measured magnitude of longitudinal bunch oscillations (if any) on the simulated beam-beam performance.***
    - Under consideration
  - ***Simulate the specific luminosity versus bunch-current product including the space charge. Carry out simulations for different crab waist strengths, other than the actual settings (80%/40%).***
    - Strong-strong simulations with SC is not trivial; Strategy to be defined
    - Increasing HER CW strength was simulated/proposed; Other options under investigation
  - ***From an operations point of view, refine chromatic coupling optimization which could give a rather easy gain in terms of vertical blowup control.***
    - Chromatic R2 correction in LER was done; Chromatic coupling correction using skew-sextupoles in HER was done