International Task Force Joint Meeting: Discussion on beam-beam

Demin Zhou
on behalf of the SKB-ITF-BB workgroup

Accelerator theory group, Accelerator laboratory, KEK

Acknowledgements

K. Ohmi, K. Oide, D. Shatilov, Y. Cai, C. Montag, T. Browder,
X. Buffat, Y. Ohnishi, A. Morita, K. Akai, Y. Funakoshi,
and SuperKEKB commissioning group

The 25th KEKB Review Meeting, Sep. 02, 2021, KEK

Outline

- Background
  - KEKB ARC meetings (2010 - 2021) [1].
  - ICFA Mini-Workshop on Commissioning of SuperKEKB and e+e– Colliders, Nov. 11 - 13, 2013, KEK [2].
  - 1st SuperKEKB Beam Dynamics Mini-Workshop, Jul. 17, 2019, KEK [3].
  - 2nd SuperKEKB Beam Dynamics Mini-Workshop, Sep. 20, 2019, KEK [4].
  - Workshop on “SuperKEKB: Challenges for the high luminosity frontier”, Jan. 30-31, 2020, KEK [5].
  - Meeting of International Task Force Meeting for SuperKEKB Upgrade, Jul. 28, 2021, KEK [6].
  - 1st meeting of beam-beam workgroup, Aug. 24, 2021, KEK [7].
- ITF-BB workgroup
- Highlights of first ITF-BB workgroup meeting

[1] https://www-kekb.kek.jp/MAC/.
[2] https://kds.kek.jp/event/12760/.
[3] https://kds.kek.jp/event/31793/.
[4] https://kds.kek.jp/event/32065/.
[5] https://conference-indico.kek.jp/event/103/.
[6] https://kds.kek.jp/event/38899/.
[7] https://kds.kek.jp/event/39142/.

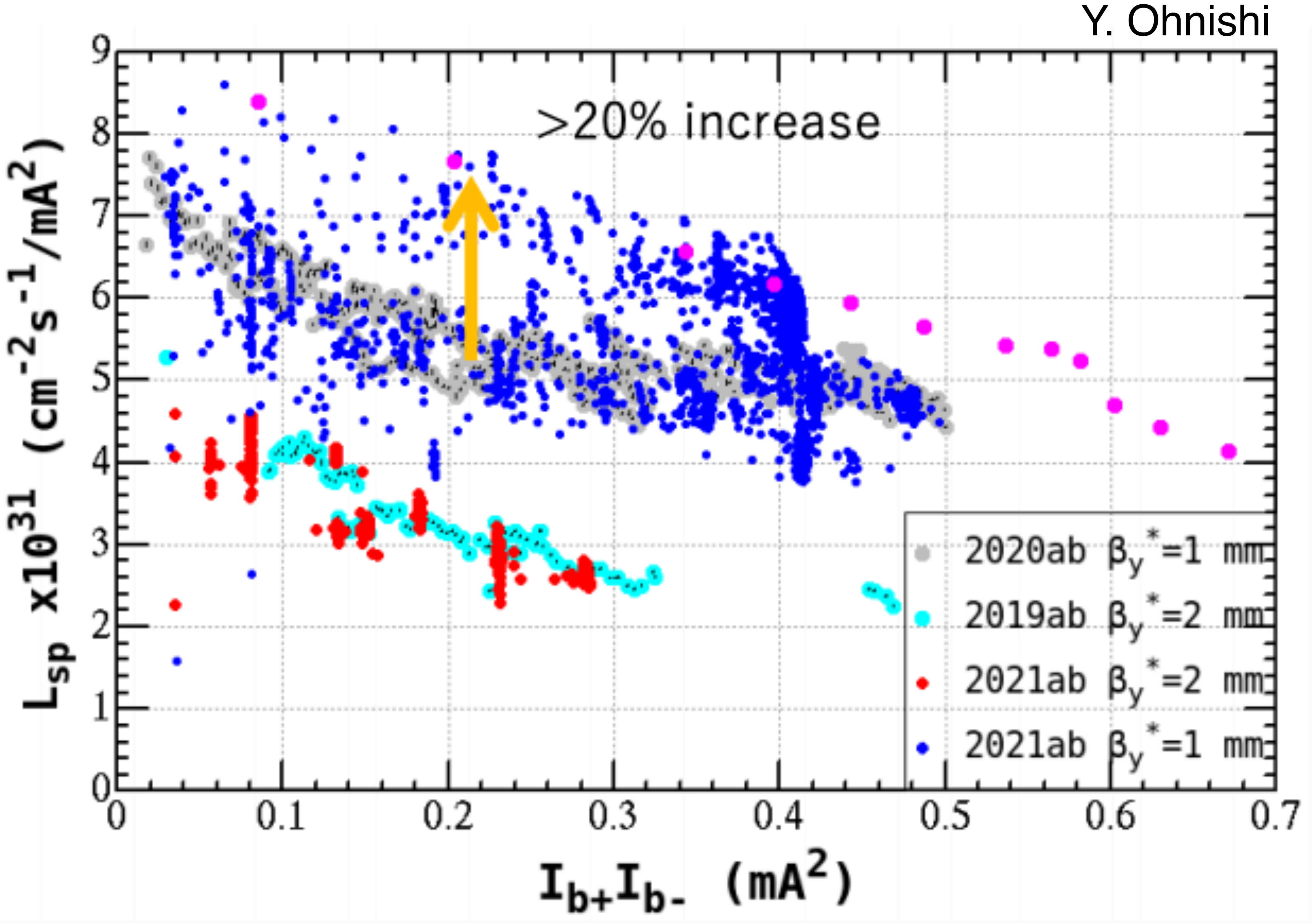
ITF-BB workgroup

- The ITF-BB workgroup was organized under the framework of International Task Force for SuperKEKB Upgrade [6] (See M. Masuzawa's talk of this meeting)
  - Monthly group meeting or on demand
- Currently 20 members (based on mailing list)
  - KEK (10), CERN (6), BINP (1), BNL (1), INFN (1), UHM (1)
  - Contact persons: Demin Zhou and Kazuhito Ohmi
- To join the mailing list
  - Subscribe by contacting D. Zhou (dmzhou@post.kek.jp).
- The 1st meeting of beam-beam workgroup
  - Organized on Aug. 24, 2021 via Zoom connection.
  - About 20 participants joined.
  - Two talks were given: "Beam-beam effects in SuperKEKB" by K. Ohmi and "Beam-beam simulations for SuperKEKB" by D. Zhou.
  - Following discussion was very active and fruitful.

Highlights of first ITF-BB workgroup meeting

- Beam-beam effects in SuperKEKB [8]
  - Overview of luminosity performance with crab waist in 2021 (also see Y. Ohnishi's talk in this meeting)
  - Specific luminosity (Lsp) increased by ~20% after feedback gain optimization
  - Rapid drop of luminosity at low bunch currents seemed not appear (It was an issue in early phases).
  - Electron-cloud effects were not visible when comparing Lsp with 1174 (3-bucket spacing, blue dots) and 393 (12.25-bucket spacing, magenta dots) bunches.

Y. Ohnishi

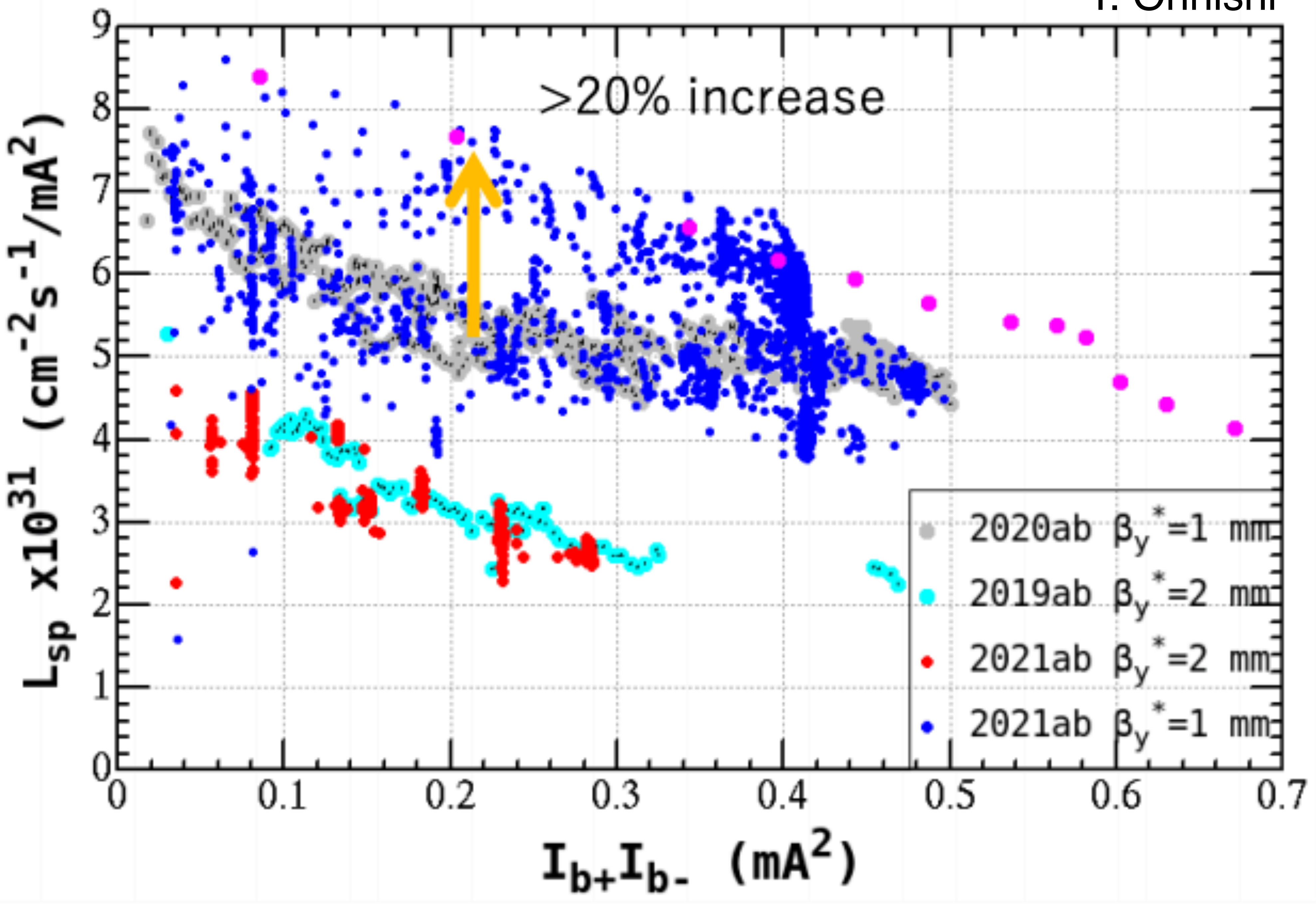


[8] https://kds.kek.jp/event/39142/contributions/194650/attachments/146581/182524/BBSKB2021ab.pdf

Highlights of first ITF-BB workgroup meeting

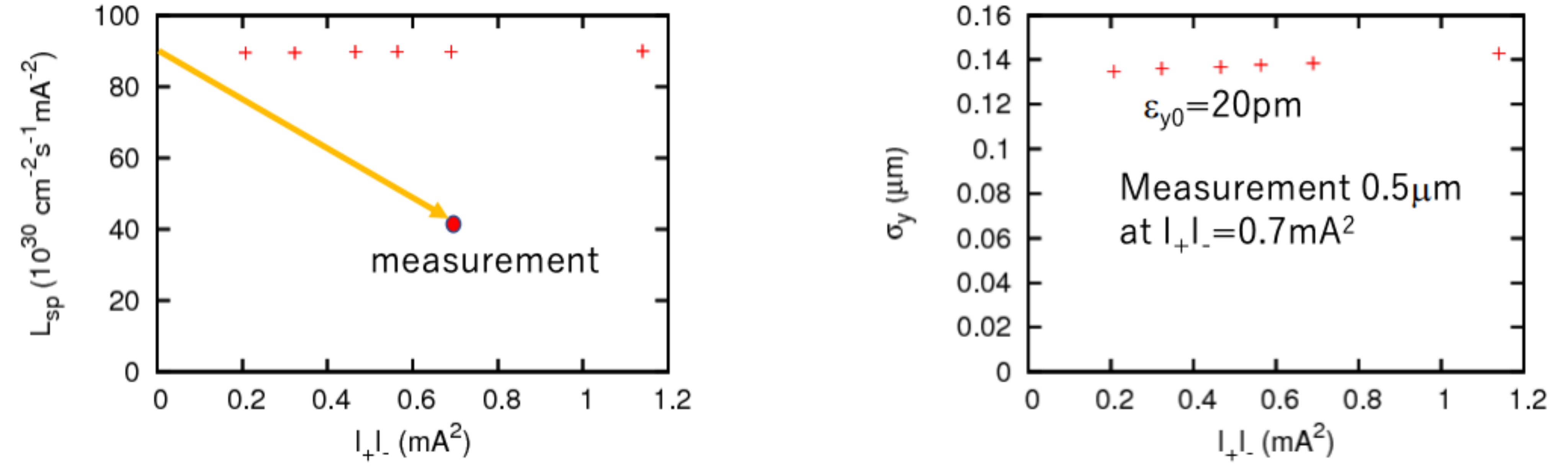
- Beam-beam effects in SuperKEKB [8]
  - The obvious drop of Lsp vs bunch-current product disagrees with weak-strong simulations.
  - At bunch current product of ~0.7 mA^2 (I_+/I_- ratio 1.25), measurement/simulation ratio is less than 50%. [At ~0.4 mA^2, the ratio was found to be ~80% without BBHTI, see page.13]
  - With crab waist, simulated beam-beam parameter ξ_y ~0.1, but achieved ξ_y ~0.03.

Y. Ohnishi



Weak-strong simulation

- 200x160, 250x200, 300x240, 330x292, 365x292(ξ_{y0}=0.077), 469x375mA with 393bunch



- Simulations show ξ_y>0.1 in general with crab waist.
- This result is normal in the sense of simulation.

[8] https://kds.kek.jp/event/39142/contributions/194650/attachments/146581/182524/BBSKB2021ab.pdf

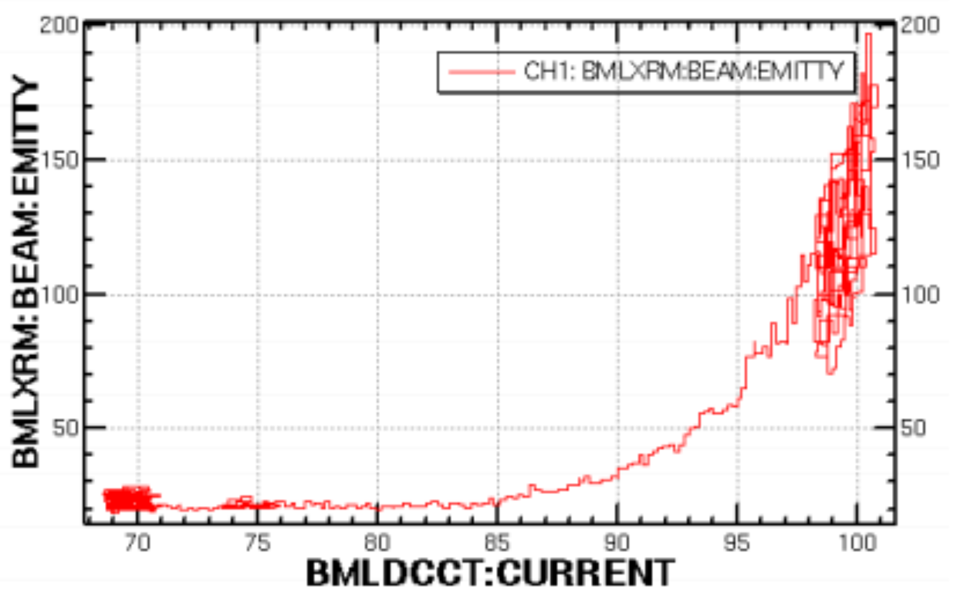
Highlights of first ITF-BB workgroup meeting

- Beam-beam effects in SuperKEKB [8]
  - Transverse mode-coupling instability (TMCI) became a challenge in LER (see Ref. [9] and Ishibashi's talk in this meeting). It caused serious blowup of vertical beam size and set a limit of luminosity performance at high bunch currents.
  - With calculated impedance, ordinary TMCI theory gives much higher threshold than measurements.
  - Machine studies and following careful data analysis showed the observed TMCI had dependence on vertical tune. This is evidence of TMCI caused by localized wake, while ordinary TMCI has no dependence on ν_y.
  - Small-gap collimators dominate the sources of vertical impedance driving TMCI.

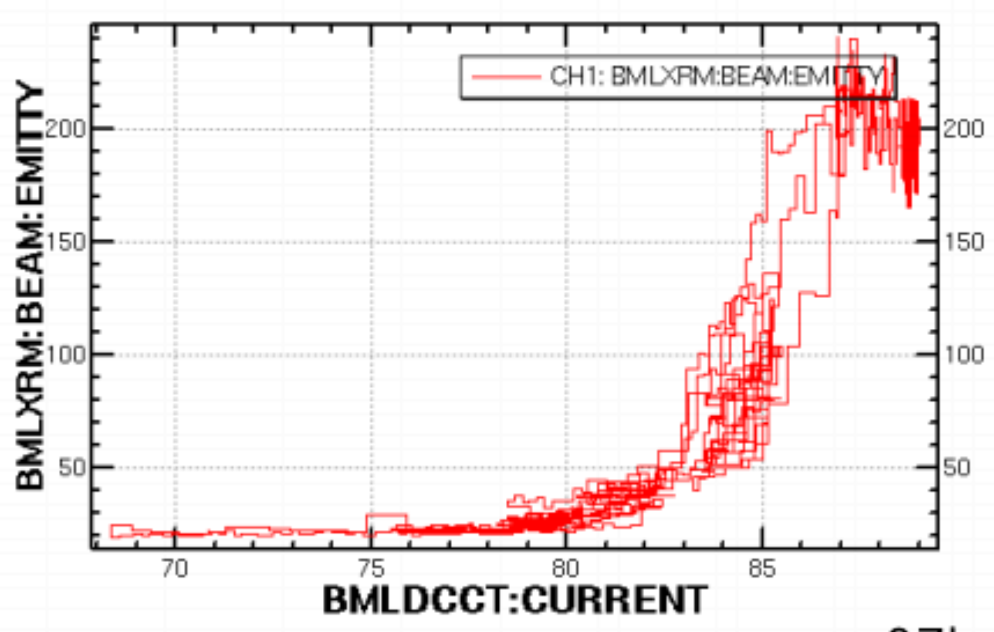
Threshold change for Collimator gap

ν_y=0.59

$K\beta=36\times10^{15}$ V/c



$K\beta=41.6\times10^{15}$ V/c



97bunch

- The threshold almost scales to KβI.
- The emittance growth seems to be due to TMCI, though not ordinary TMCI.

[8] https://kds.kek.jp/event/39142/contributions/194650/attachments/146581/182524/BBSKB2021ab.pdf

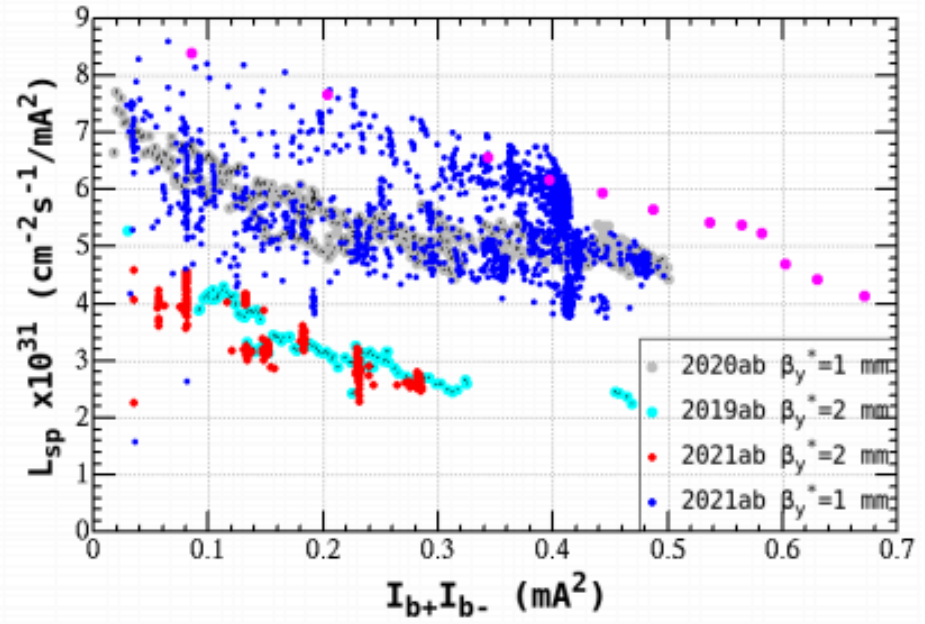
[9] https://kds.kek.jp/event/39138/

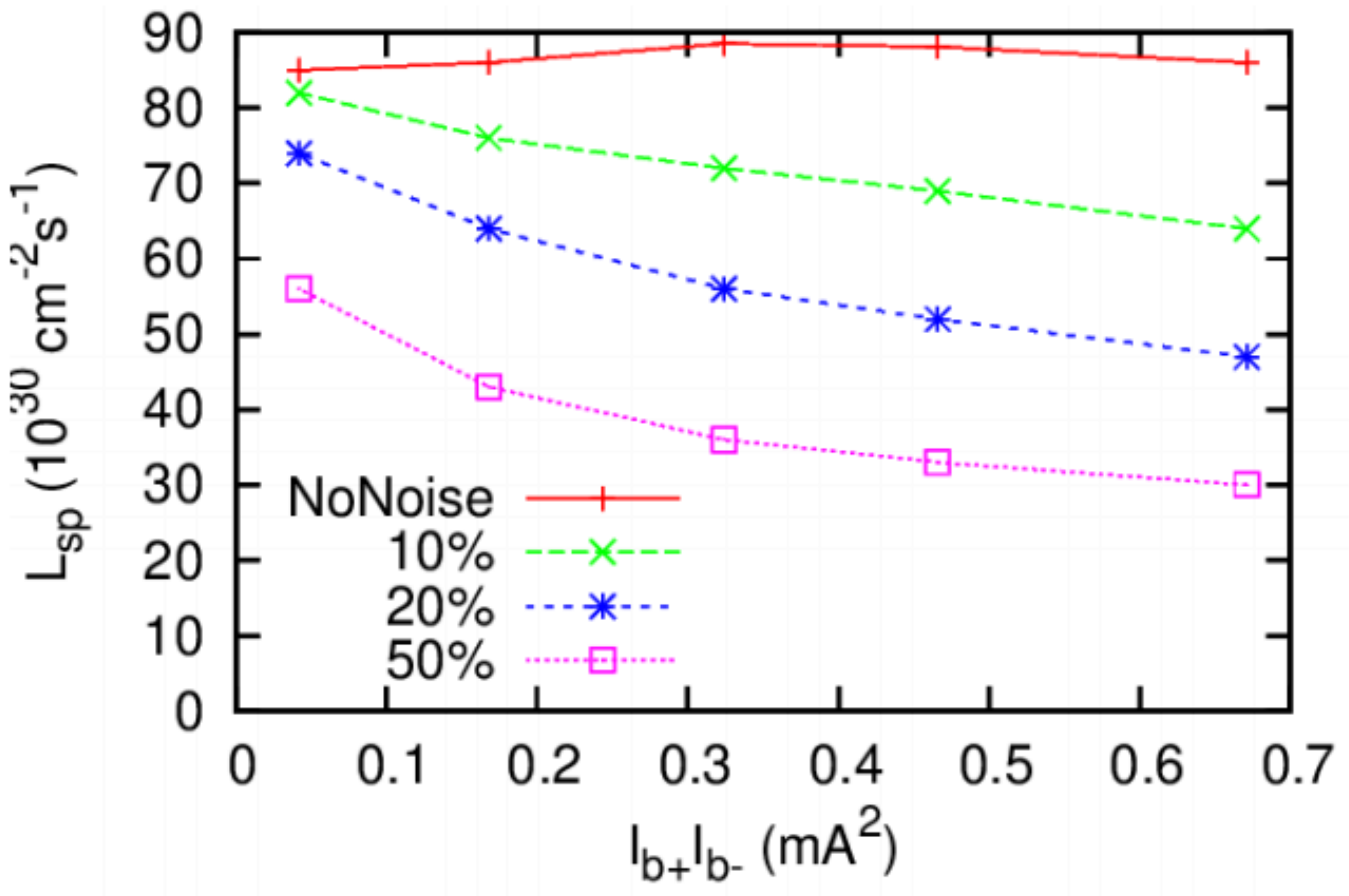
Highlights of first ITF-BB workgroup meeting

- Beam-beam effects in SuperKEKB [8]
  - Collision offset noise is a candidate source of luminosity degradation.
  - Weak-strong simulations show drop of Lsp, similar to observations.
  - In realistic machine operation, the amplitude of collision offset noise is unknown. It is to be investigated in the future.

Beam-beam performance under the noise

- It is known that collision offset noise degrade luminosity performance.
- Weak-strong simulation with white noise, δy=10%,20%, 50% σ_y, where ε_y =20pm,





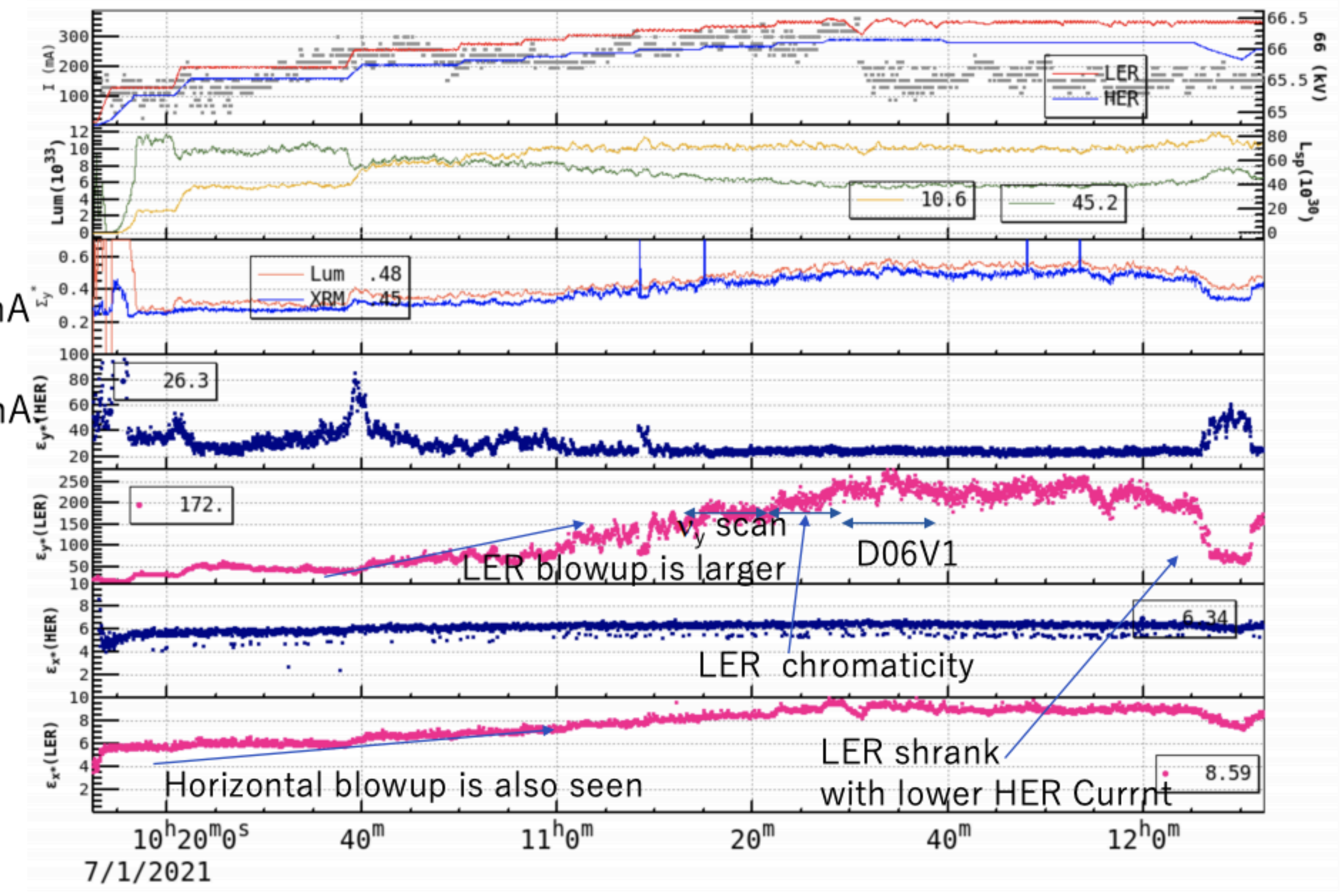
[8] https://kds.kek.jp/event/39142/contributions/194650/attachments/146581/182524/BBSKB2021ab.pdf

Highlights of first ITF-BB workgroup meeting

- Beam-beam effects in SuperKEKB [8]
  - High-bunch current collision (HBCC) machine study reveals rich information of beam-beam effects (see the talks and memo of Ref. [7]).
  - Asymmetric blowup of the two beams in both horizontal and vertical planes were observed.

High bunch current Study on July 1, 2021

- 393 bunch,
- (I+,I-)=(200,160)->(365,293) mA
- (355,282)->(355,203)mA
- $L_{peak}=1.2\times10^{34}$ was recorded at (355,247)mA $\sigma_y^*=0.50, 0.26\ \mu m$.



[8] https://kds.kek.jp/event/39142/contributions/194650/attachments/146581/182524/BBSKB2021ab.pdf

Highlights of first ITF-BB workgroup meeting

- Beam-beam effects in SuperKEKB [8]
  - Coherent beam-beam head-tail instability (BBHTI) (discovered by K. Ohmi in 2016 and observed at SuperKEKB in 2018 during machine study) is one candidate to explain the horizontal blowup.

BBHT(XZ) instability

PRL **119,** 134801 (2017) PHYSICAL REVIEW LETTERS 29 SEPTEMBER 2017

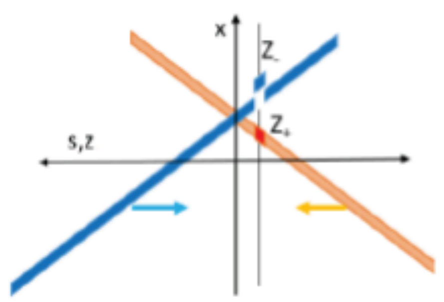
Coherent Beam-Beam Instability in Collisions with a Large Crossing Angle

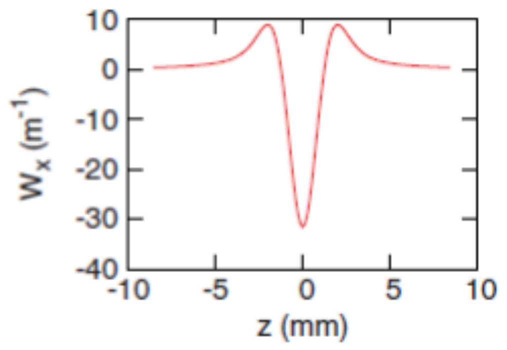
K. Ohmi,[1,*] N. Kuroo,[1,3] K. Oide,[1,2] D. Zhou,[1,2] and F. Zimmermann[2]
[1]*KEK, 1-1 Oho, Tsukuba 305-0801, Japan*
[2]*CERN, 1211 Geneva 23, Switzerland*
[3]*University of Tsukuba, Tsukuba, 305-8577, Japan*

- Strong horizontal head tail instability with two beam correlation has been seen in strong-strong simulations for collision with a large crossing angle.
- The instability is caused by mode coupling of localized cross coupled wake induced by beam-beam collision.

$$\Delta p_{x,\pm}(z_\pm) = -\int_{-l}^{l} W_x^{(\pm)}(z_\pm - z'_\mp)\rho_x^{(\mp)}(z'_\mp)dz'_\mp.$$

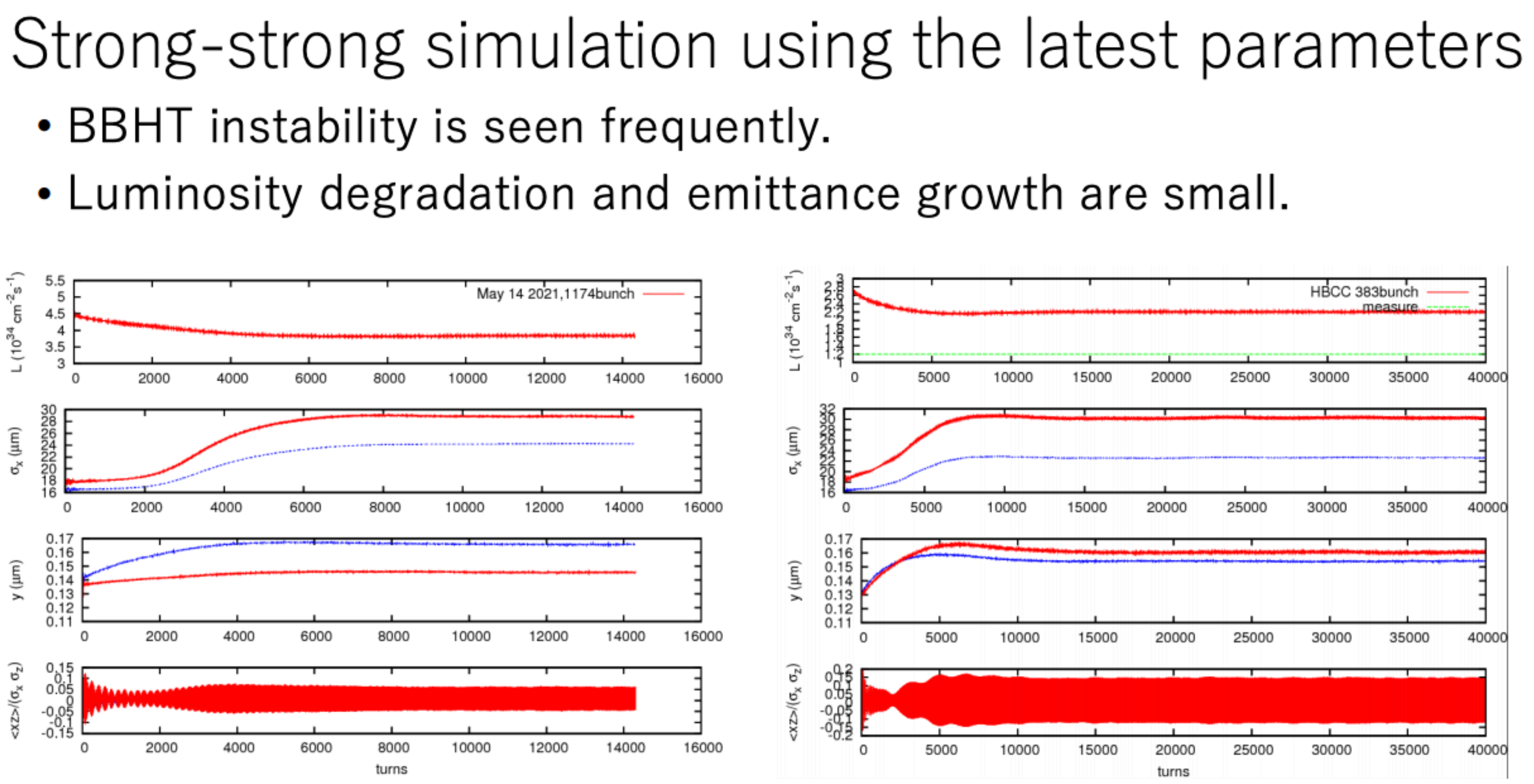
$$W_x^{(-)}(z) = -\frac{N^{(+)}r_e}{\gamma^{(-)}\bar{\sigma}_x^2}\left[1 - \frac{\sqrt{\pi}\theta_P z}{2\bar{\sigma}_z}\mathrm{Im}w\left(\frac{\theta_P z}{2\bar{\sigma}_z}\right)\right]$$





Highlights of first ITF-BB workgroup meeting

- Beam-beam effects in SuperKEKB [8]
  - With the current parameter regime of SuperKEKB ($\beta_y^* = 1$ mm), BBHTI appears frequently in simulations. But it does not cause large luminosity degradation.
  - There is inconsistency between simulation and experiment: Simulated BBHTI show simultaneous σ_x blowup of the two beams. But in HBCC machine study, blowup of LER beam was obvious but HER beam was not.
  - Ohmi-san's remark-1: If head-tail signal, which synchronizes the two beams, is observed, it is the evidence of BBHTI.
  - Ohmi-san's remark-2: Optics aberrations at IP (such as chromatic coupling), collision offset noise, and BBHTI are candidates to be counted in beam-beam simulations to understand the present luminosity limit.



[8] https://kds.kek.jp/event/39142/contributions/194650/attachments/146581/182524/BBSKB2021ab.pdf

Highlights of first ITF-BB workgroup meeting

- Beam-beam simulations for SuperKEKB [10]
  - D.Z. gave an overview of beam-beam simulations with final design configurations ($\beta_y^* = 0.27/0.3$ mm for LER/HER, w/o crab waist).
  - The source of the luminosity loss seen in beam-beam simulations (weak-strong model plus design lattice) was interplay of beam-beam resonances and nonlinearity of the IR.

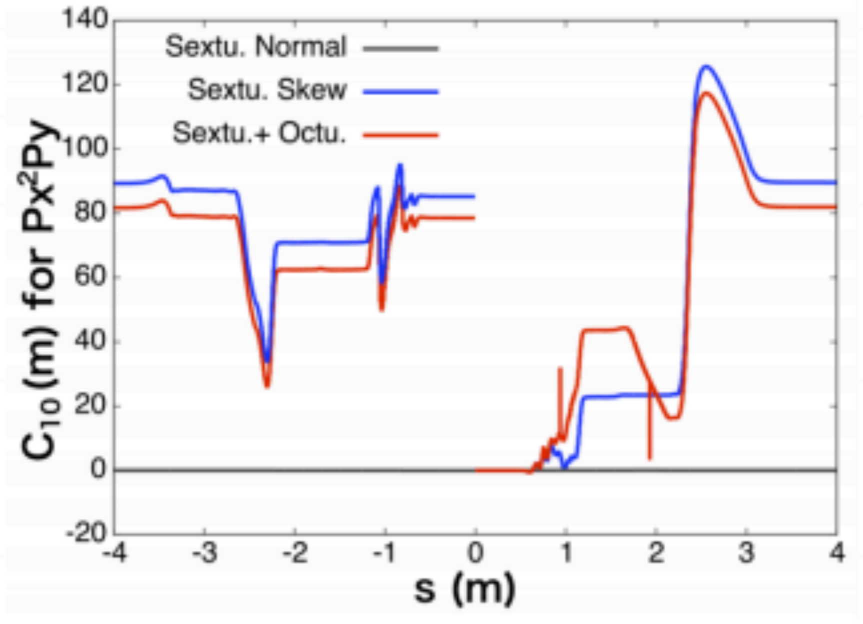


Figure 4: Coefficient of $P_X^2 P_Y$ caused by skew sextupole (SK_2) and octupole ($K_3 + SK_3$) fields.

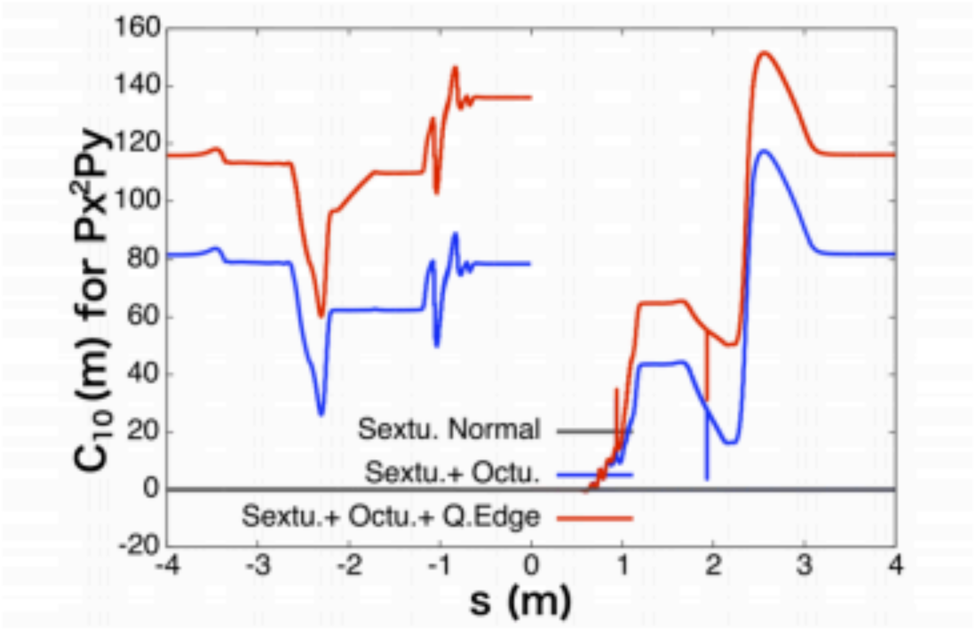


Figure 5: Coefficient of $P_X^2 P_Y$ for sextupole and octupole ($SK_2 + K_3 + SK_3$) and quadrupole hard-edge fringe ($SK_2 + K_3 + SK_3 + Q.edge$) fields.

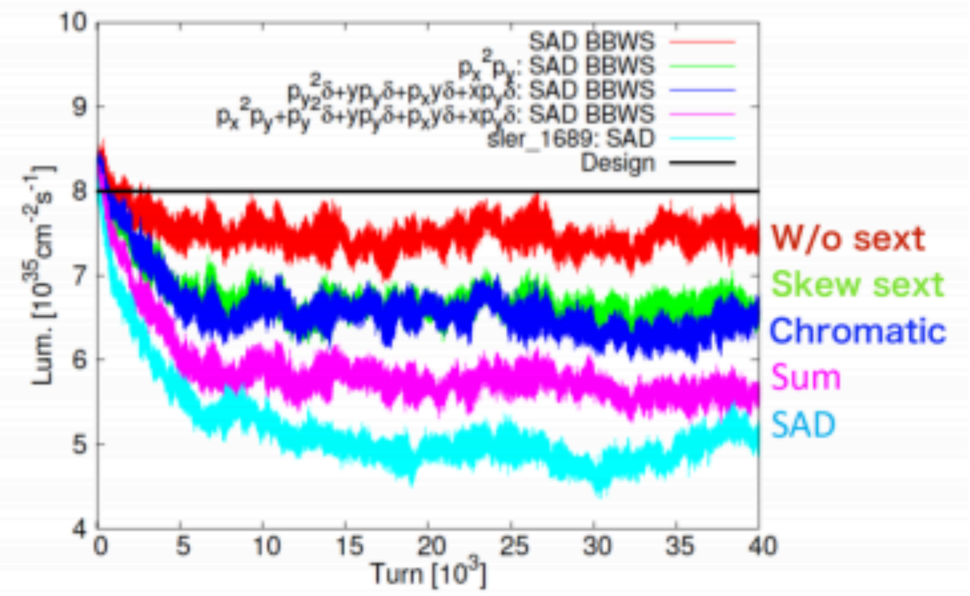
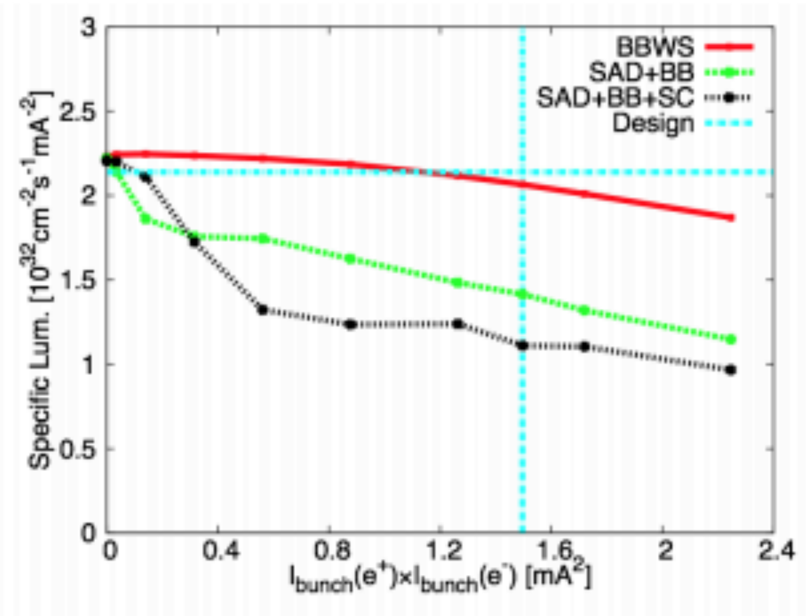
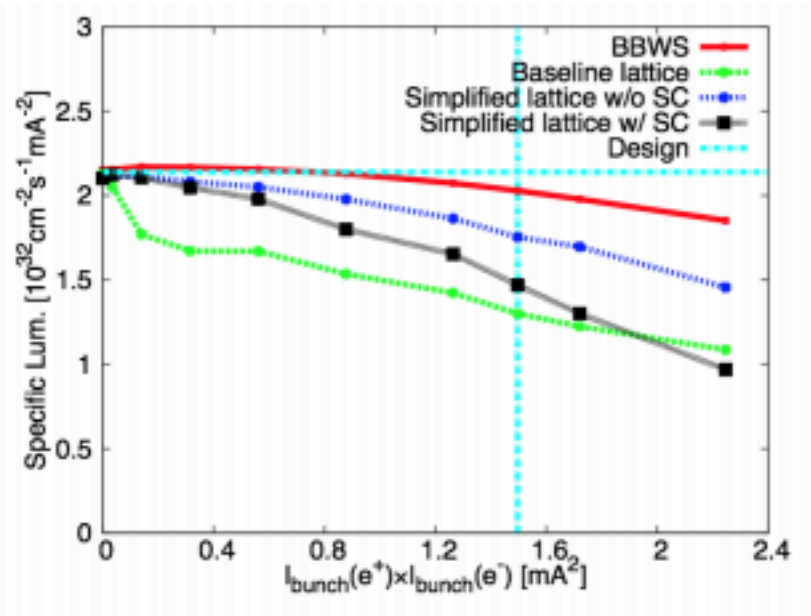


Figure 6: Luminosities for sextupole term (: $P_X^2 P_Y$), chromatic twiss, and SAD.





[10] https://kds.kek.jp/event/39142/contributions/194651/attachments/146544/182494/20210824_BB_Simulations_SKB.pdf

Highlights of first ITF-BB workgroup meeting

- Beam-beam simulations for SuperKEKB [10]
  - Observations in Phase-2 commissioning without crab waist: Peak luminosity lower than predictions of simulations; Easy blowup of one beam; Small area in tune space for good luminosity; Unexpected high Belle-2 background; No or small gain of luminosity via squeezing $\beta^*_{x,y}$; Hard to approach to the design working point (.53, .57); …
  - Weak-strong simulations showed that the beam-beam resonances of $\pm\nu_x + 4\nu_y + \alpha = N$ (they appear without crab waist) can be important.

Machine parameters of Phase-2 for beam-beam simulations

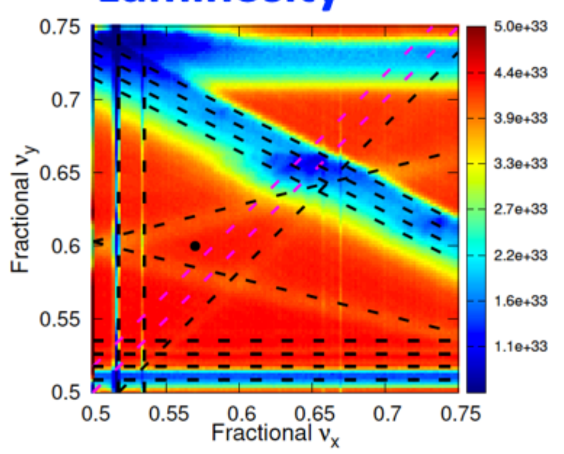
	200/6		200/4		100/4		100/2	
	HER	LER	HER	LER	HER	LER	HER	LER
E (GeV)	7.007	4	7.007	4	7.007	4	7.007	4
I_b (mA)	285	340	285	340	285	340	285	340
# bunch	789		789		789		789	
ε_x (nm)	4.7	2.0	4.7	2.0	4.5	1.9	4.5	1.9
ε_y (pm)	47	20	47	20	45	19	45	19
ε_z (μm)	3.7	4.5	3.7	4.5	3.4	3.5	3.4	3.6
β_x (mm)	200	200	200	200	100	100	100	100
β_y (mm)	6	6	4	4	4	4	2	2
σ_z (mm)	5.8	5.9	5.8	5.9	5.3	4.6	5.3	4.7
νx	45.57	44.57	45.57	44.57	45.57	44.57	45.57	44.57
νy	43.60	46.60	43.60	46.60	43.60	46.60	43.60	46.60
νs	0.0234	0.0176	0.0234	0.0176	0.0258	0.0223	0.0258	0.0225

BBWS simulation

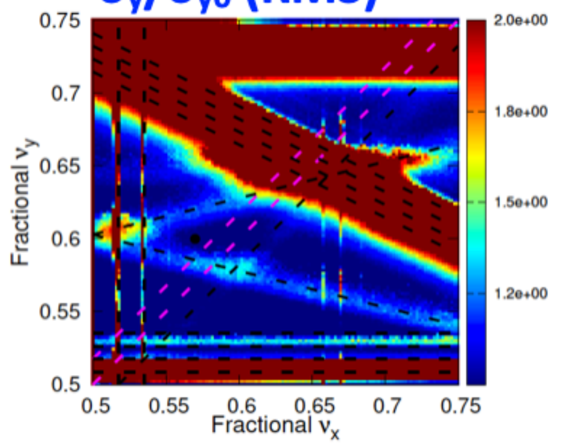
➤ Optics: HER 200/4 mm and LER 200/4 mm

- Weak beam: LER:

Luminosity



σ_y/σ_{y0} (RMS)



Geometric luminosity:
L=4.2x10^{33}cm^{-2}s^{-1}

Beam-beam resonances:

$$\nu_x - k\nu_s = N, \quad k = 1,2$$
$$2\nu_y - j\nu_s = N, \quad j = 1,2,3,4$$
$$\nu_x + 2\nu_y + k\nu_s = N, \quad k = 1,2,3,4$$
$$\pm\nu_x + 4\nu_y + k\nu_s = N$$

Lattice resonances:

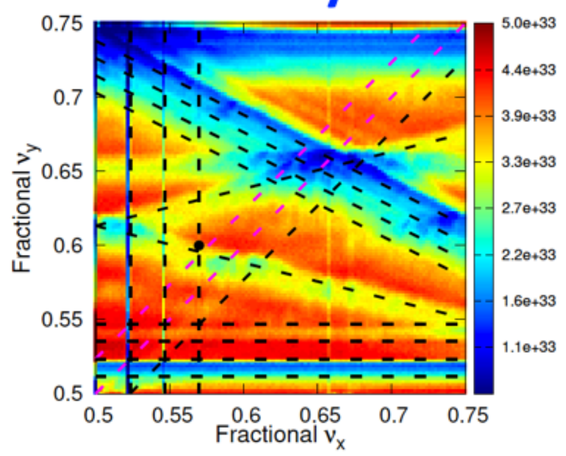
$$\nu_x - \nu_y + k\nu_s = N, \quad k = -1,0,1$$

BBWS simulation

➤ Optics: HER 200/4 mm and LER 200/4 mm

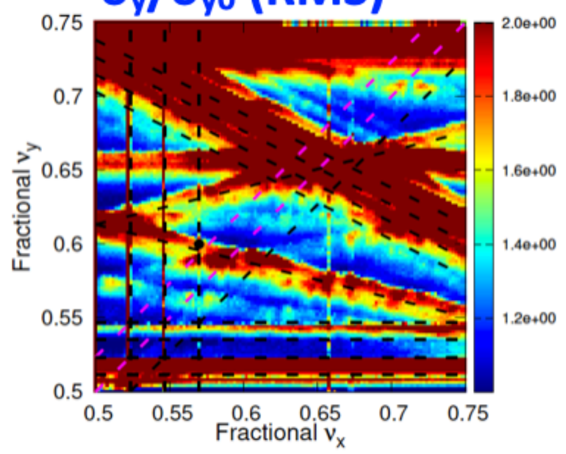
- Weak beam: HER: plots with normalization

Luminosity



Geometric luminosity:
L=4.2x10^{33}cm^{-2}s^{-1}

σ_y/σ_{y0} (RMS)

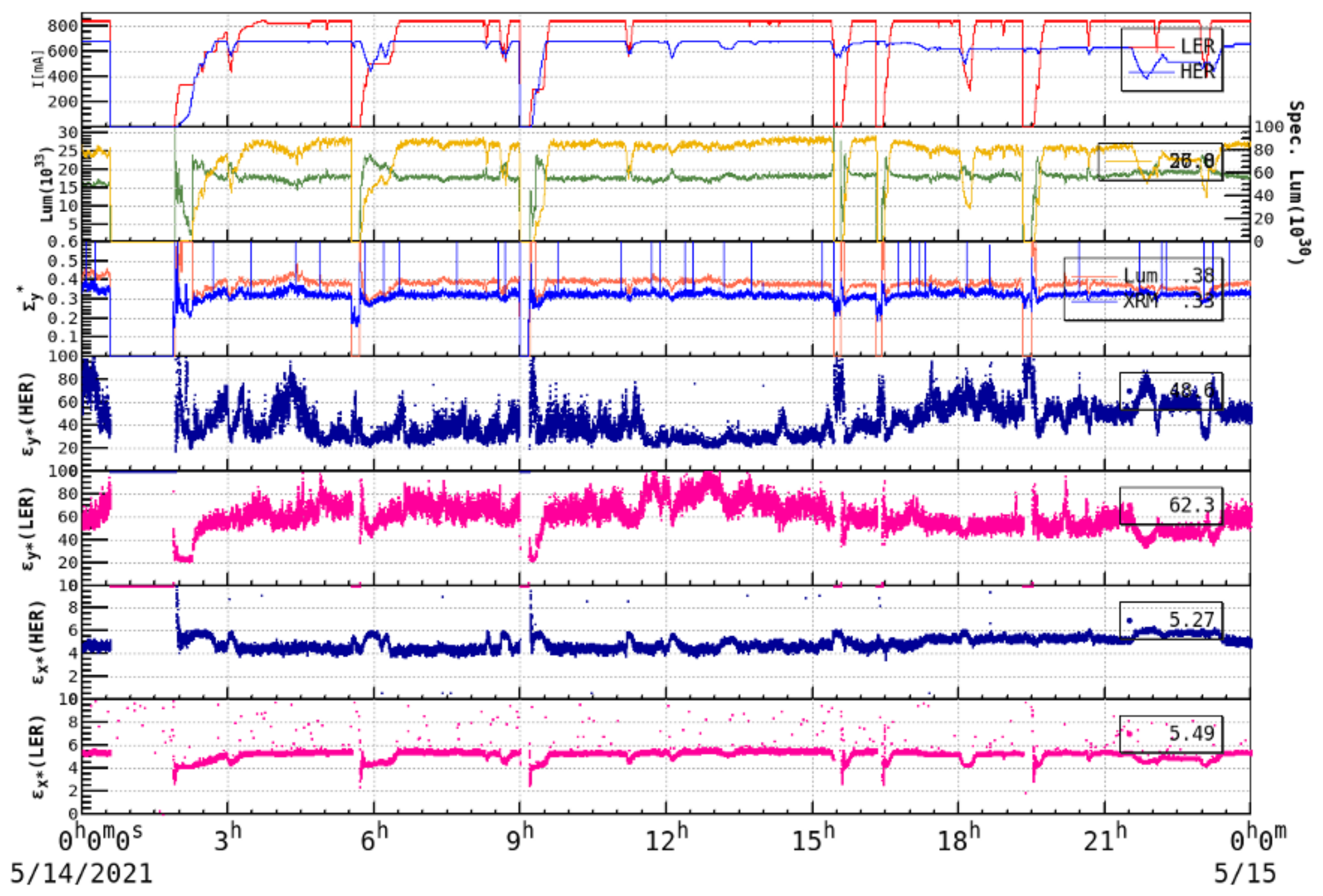


[10] https://kds.kek.jp/event/39142/contributions/194651/attachments/146544/182494/20210824_BB_Simulations_SKB.pdf

Highlights of first ITF-BB workgroup meeting

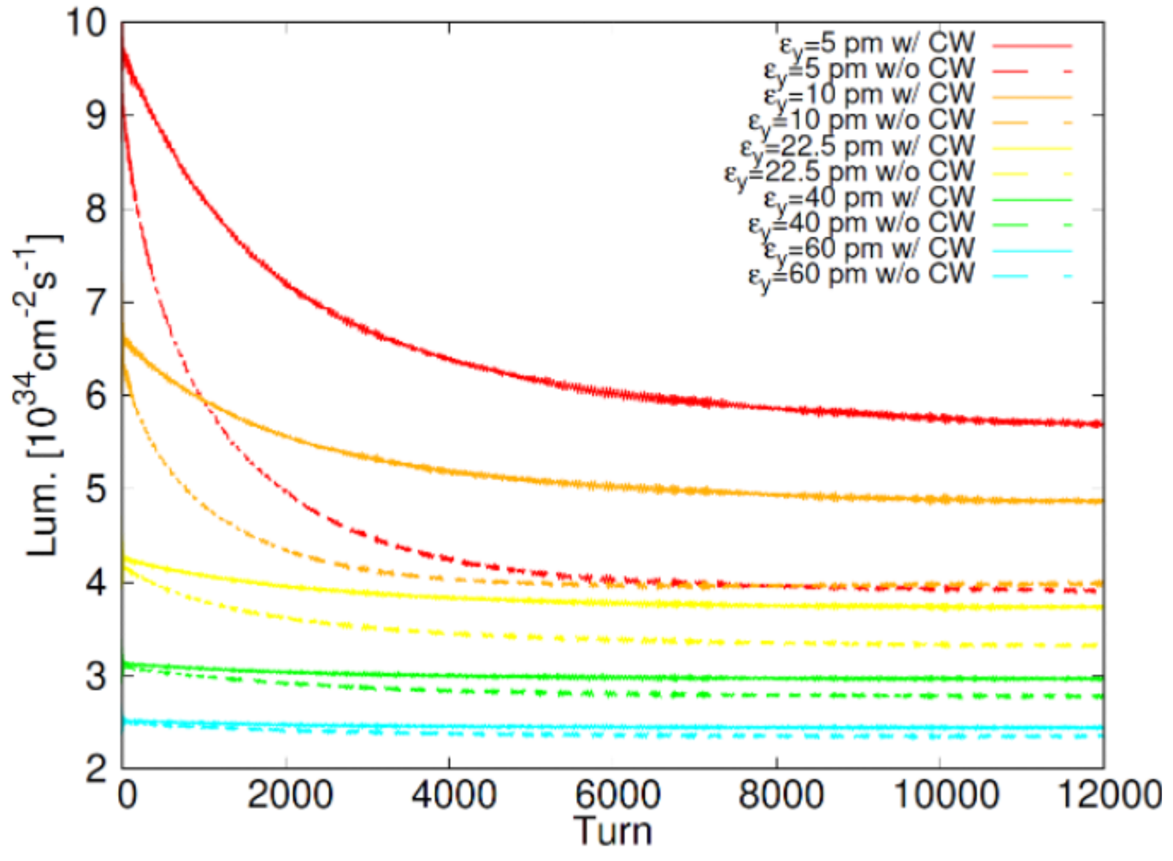
- Beam-beam simulations for SuperKEKB [10]
  - Strong-strong simulations with crab waist (use parameter set of 2021.05.14 which was typical for 2021ab physics run) were done to compare experimental observations in Phase-3.
  - With single-beam ϵ_y of 22.5 pm, BBSS simulations predict lum. of ~3.75e34 $cm^{-2}s^{-1}$ without obvious BBHTI. This is compared to the achieved luminosity of ~3.0e34 $cm^{-2}s^{-1}$ in 2021ab run.
  - In simulations, the crab waist and the single-beam ϵ_y were varied, showing that these parameters are essential in determining the luminosity performance.
  - Weak blowup in ϵ_x (hint of BBHTI) was observed in the control room, but not well-confirmed.

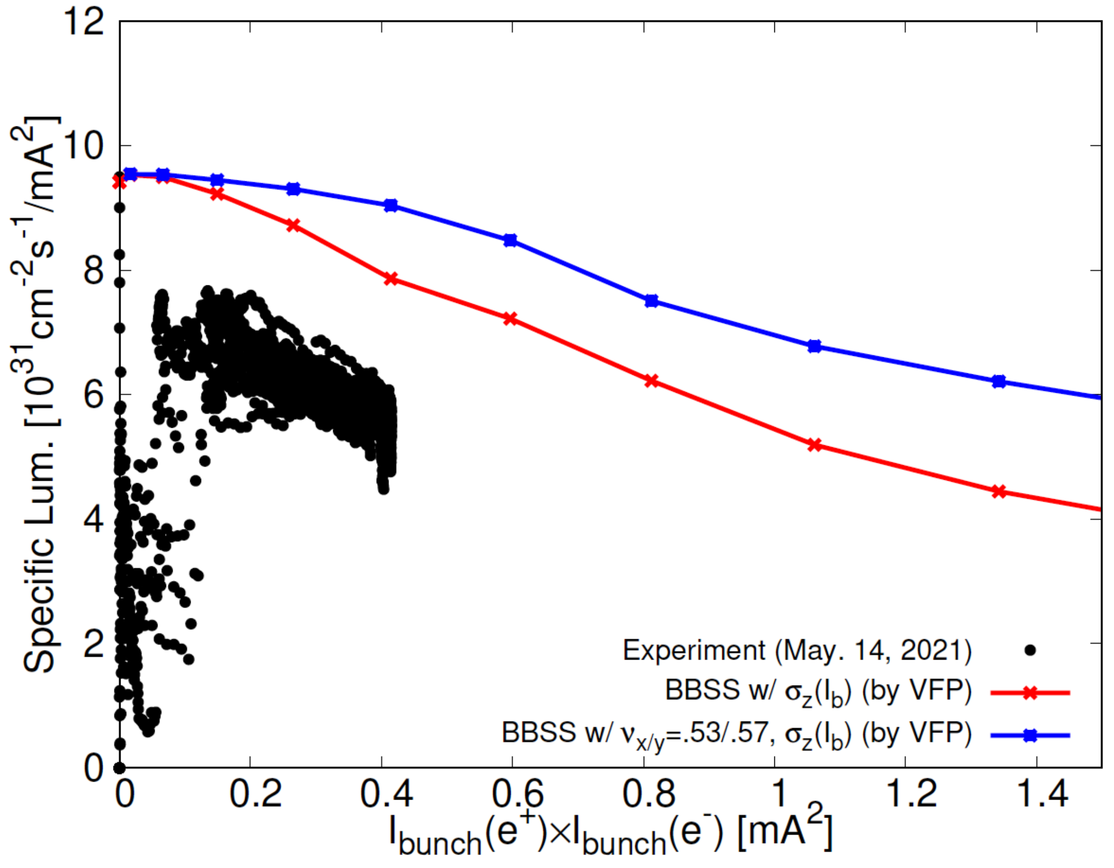
Luminosity history panel seen in SuperKEKB control room



Operation parameter set

	2021.05.14		Comments
	HER	LER	
I_b (A)	0.68	0.84	
# bunch	1174		
ε_x (nm)	4.6	4.24	w/ IBS
ε_y (pm)	22.5	22.5	Estimated from XRM data
β_x (mm)	60	80	Calculated from lattice
β_y (mm)	1	1	Calculated from lattice
σ_z (mm)	6	6	w/ bunch lengthening by impedance
σ_y (μm)	0.15	0.15	Observed from XRM
ν_x	45.52989	44.5247	Measured tune of pilot bunch
ν_y	43.59055	46.57279	Measured tune of pilot bunch
ν_s	0.02719	0.02212	Calculated from lattice
Crab waist	40%	80%	Lattice design





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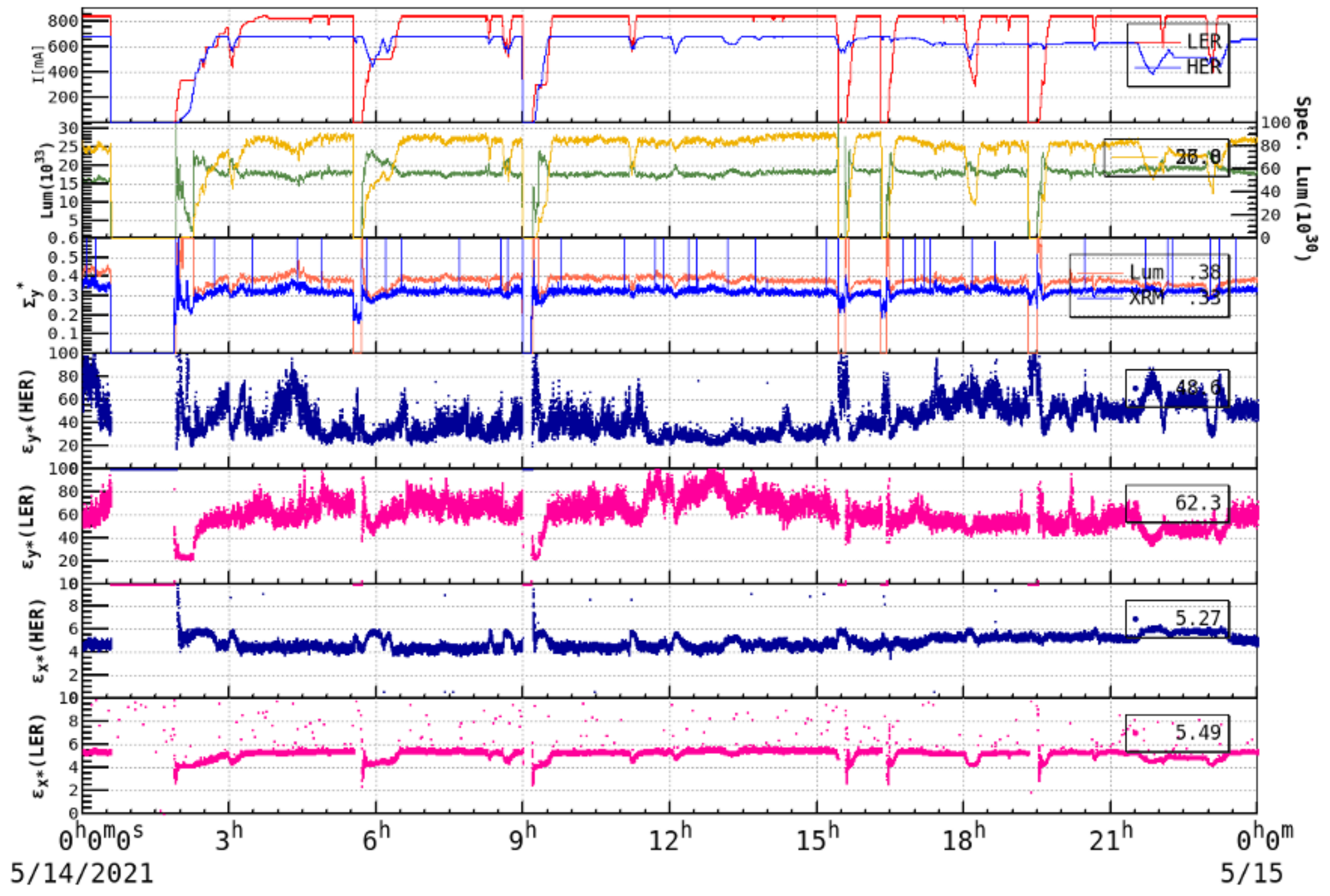
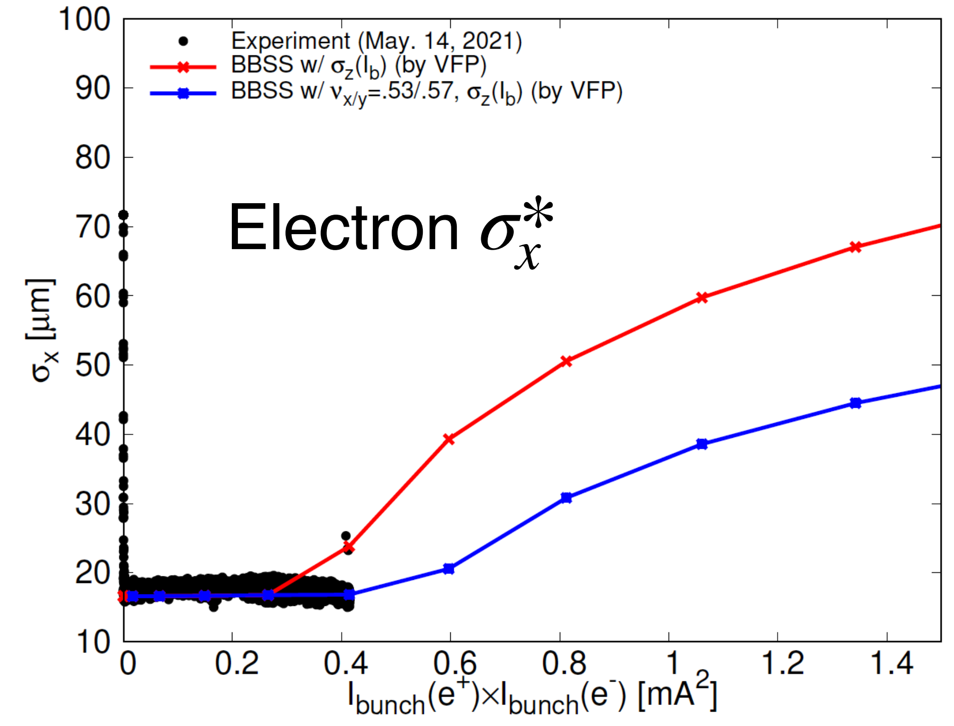
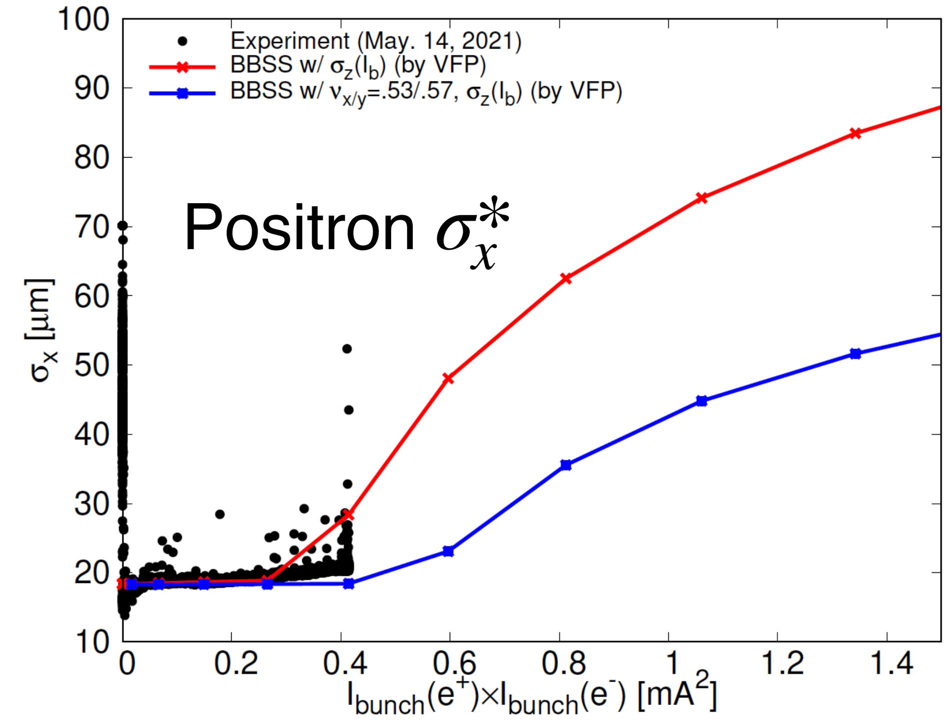
Highlights of first ITF-BB workgroup meeting

- Beam-beam simulations for SuperKEKB [10]
  - Simulations showed that the machine seemed to operate round the BBHTI threshold: The blowup of positron σ_x^* in experimental data occurred around the simulated BBHTI threshold.
  - The observed blowup of σ_y^* of both electron and positron beams were complicated (see 24 hours' history of ϵ_y). BBSS simulations cannot reproduce the trends of σ_y^* blowup.
  - Simulations showed the same working point (.53,.57) for both rings is better: Higher BBHTI threshold and weaker beam-size blowup.

Luminosity history panel seen in SuperKEKB control room







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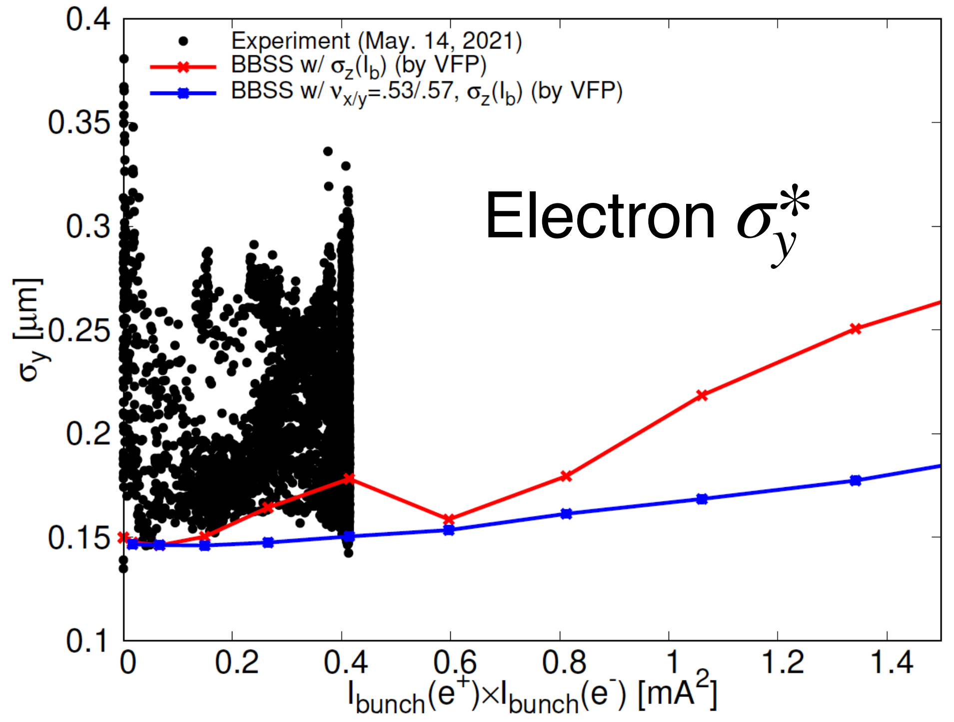
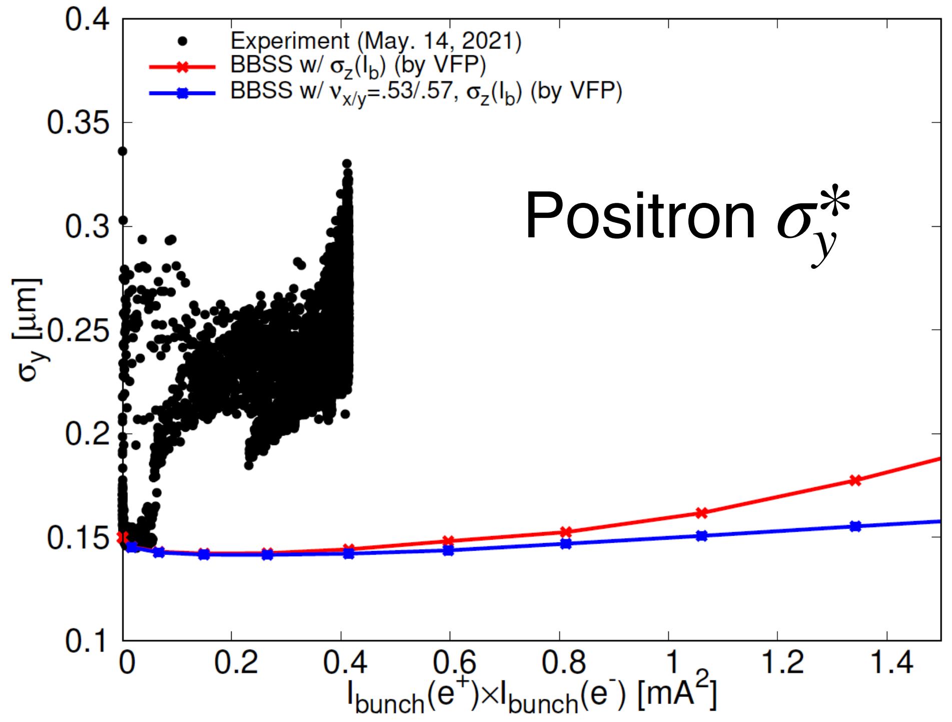


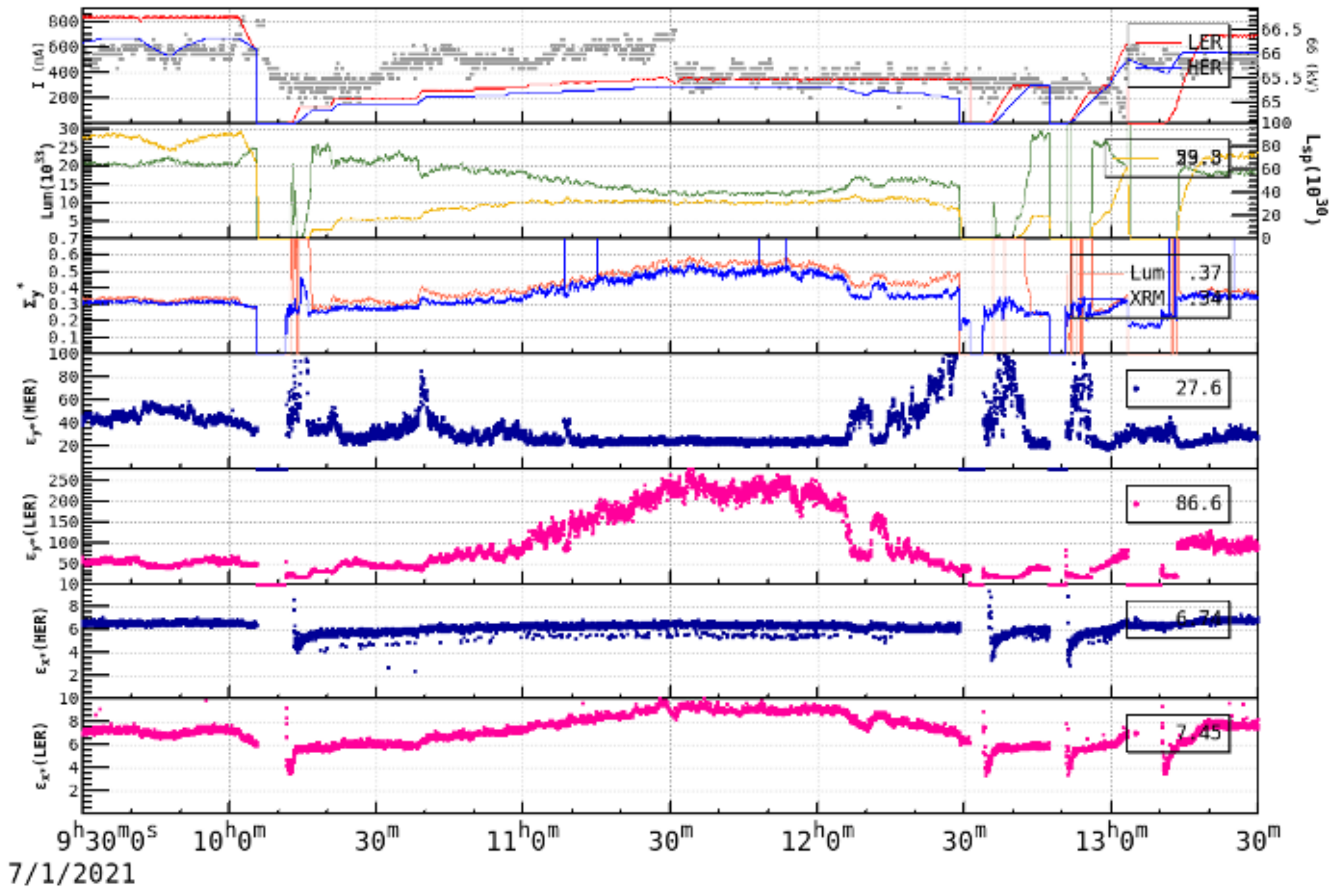


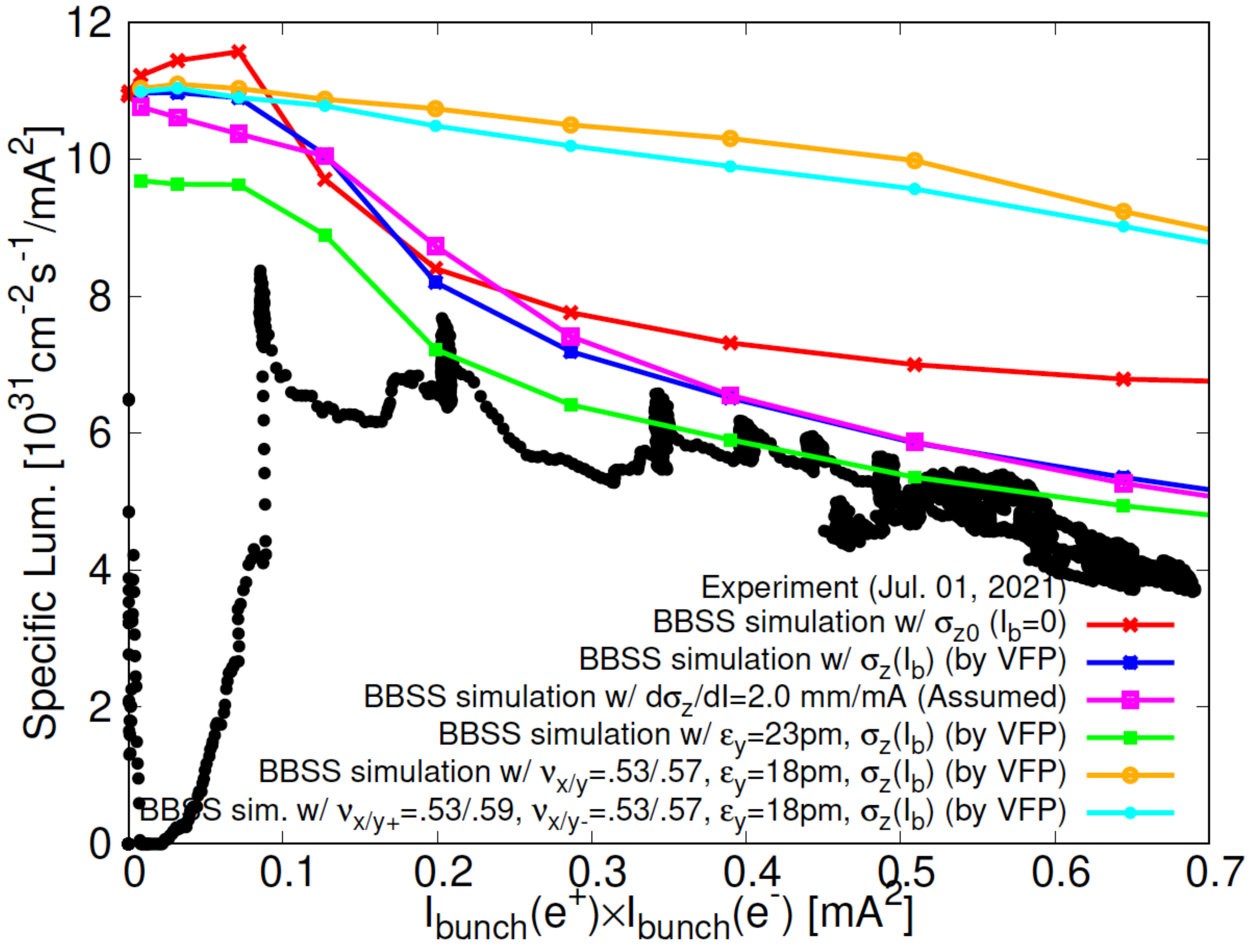
[10] https://kds.kek.jp/event/39142/contributions/194651/attachments/146544/182494/20210824_BB_Simulations_SKB.pdf

Highlights of first ITF-BB workgroup meeting

- Beam-beam simulations for SuperKEKB [10]
  - On Jul. 1st, 2021, a machine study was done with high bunch-currents for collision. Strong blowup in LER σ_y^* and obvious blowup in LER σ_x^* were observed in experiment.
  - BBSS simulations were done to compare the experimental observations. With strong BBHTI and assumed bunch lengthening, the simulated slope of specific luminosity seemed to agree with experimental data. [This was an accidental agreement. See discussions of the following slides.]
  - Parameters such as ϵ_y, σ_z, and $\nu_{x,y}$ were varied in simulations. The design working point (.53,.57) has weaker BBHTI, giving high luminosity. BBHTI seemed to play an important role.

Luminosity history panel seen in SuperKEKB control room





Operation parameter sets

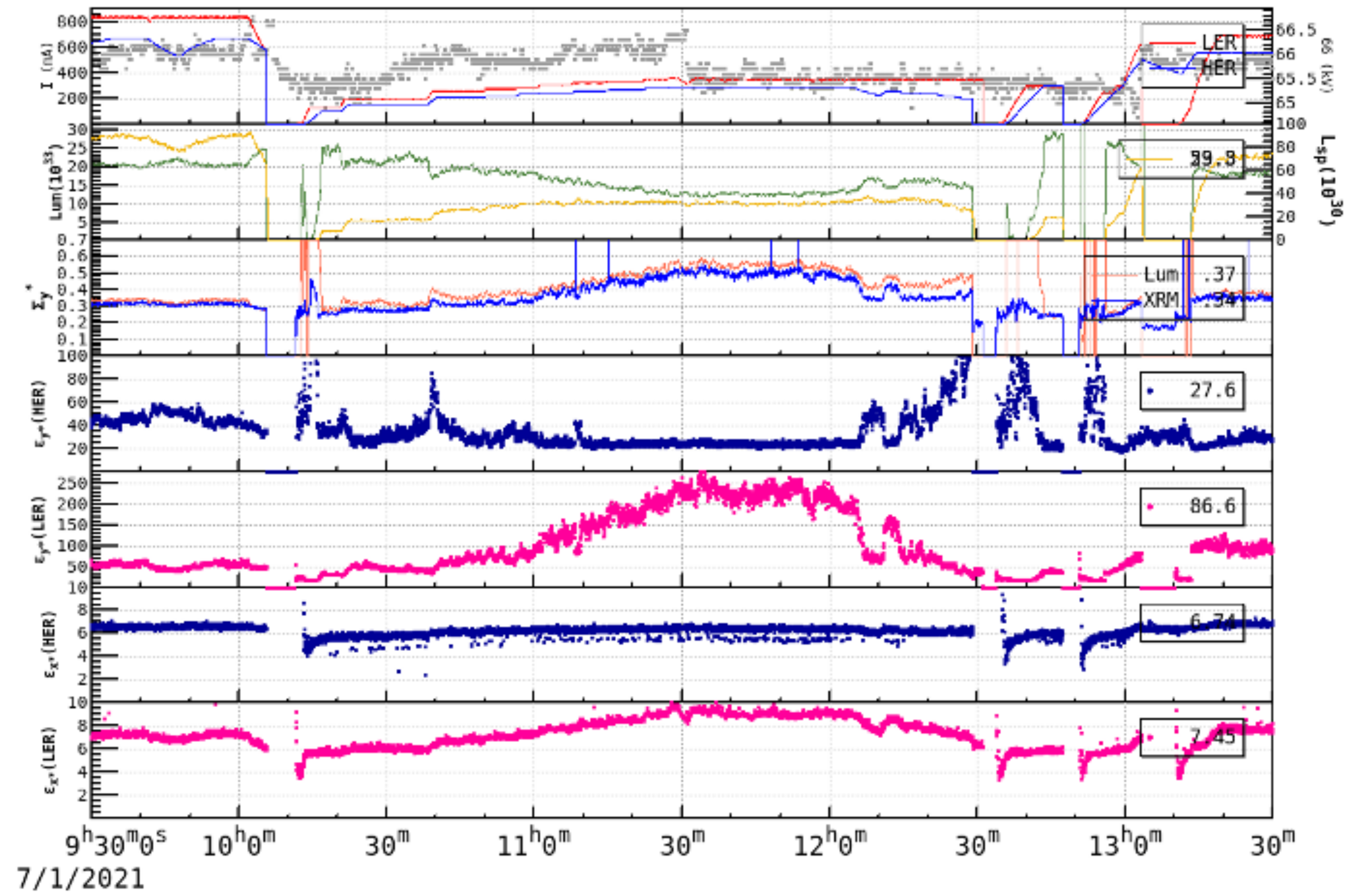
	2021.07.01		Comments
	HER	LER	
I_b (A)	Ie	1.255*Ie	
# bunch	393		
ϵ_x (nm)	4.6	4.0	w/ IBS
ϵ_y (pm)	18	18	Single beam (Estimated from XRM data)
β_x (mm)	60	80	Calculated from lattice
β_y (mm)	1	1	Calculated from lattice
σ_z (mm)	5.05	4.84	Natural bunch length (w/o MWI)
ν_x	45.532	44.525	Measured tune of pilot bunch
ν_y	43.582	46.593	Measured tune of pilot bunch
ν_s	0.0272	0.0221	Calculated from lattice
Crab waist	40%	80%	Lattice design

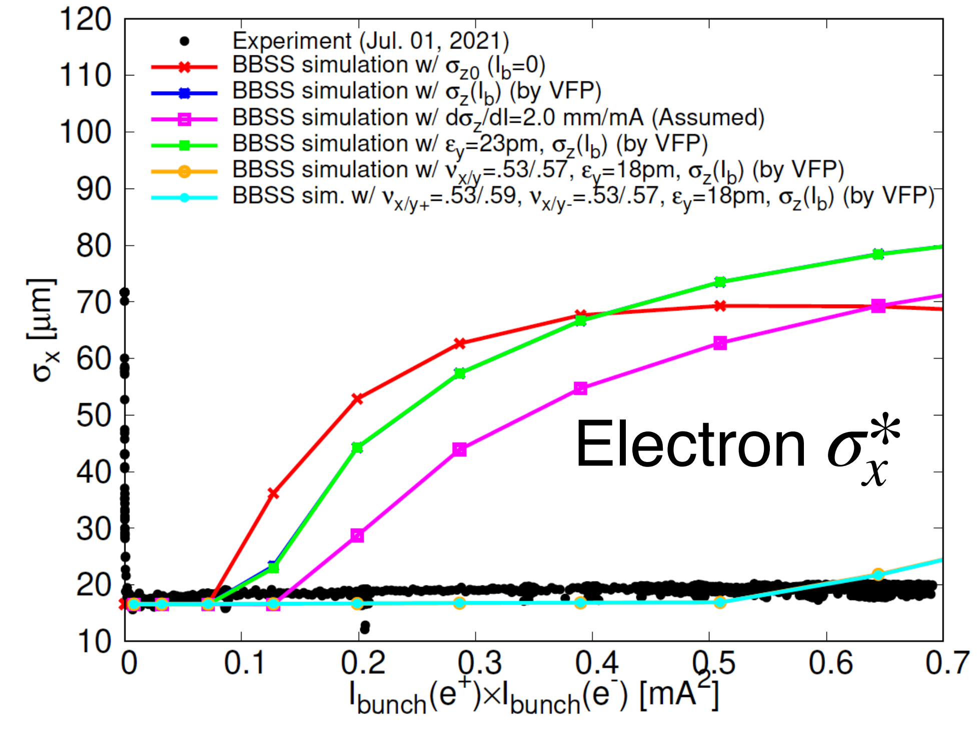
[10] https://kds.kek.jp/event/39142/contributions/194651/attachments/146544/182494/20210824_BB_Simulations_SKB.pdf

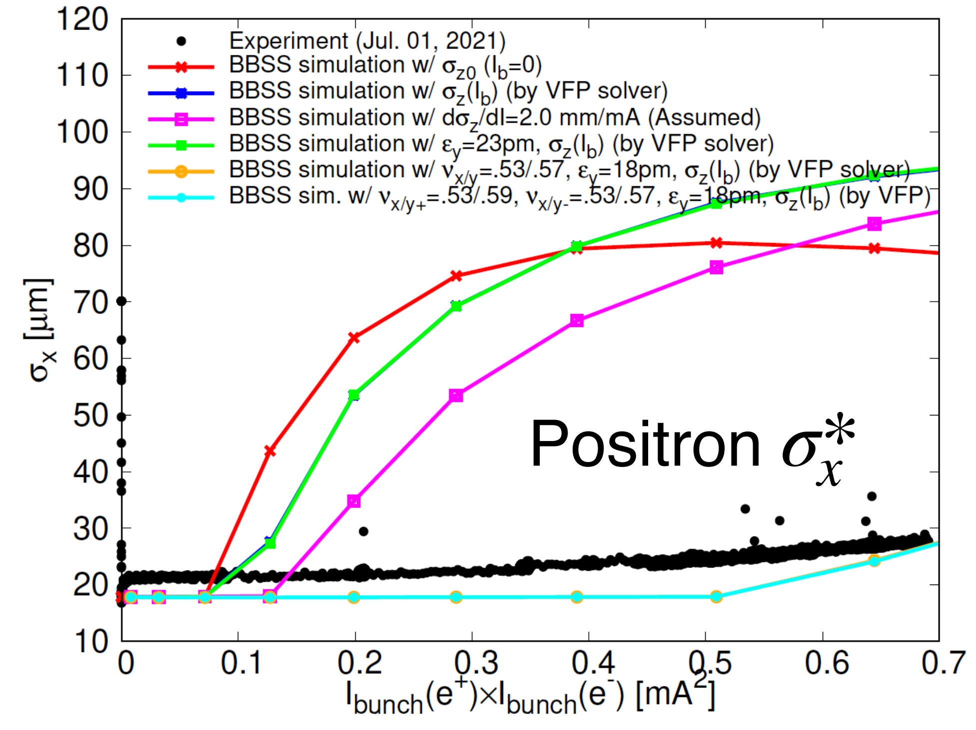
Highlights of first ITF-BB workgroup meeting

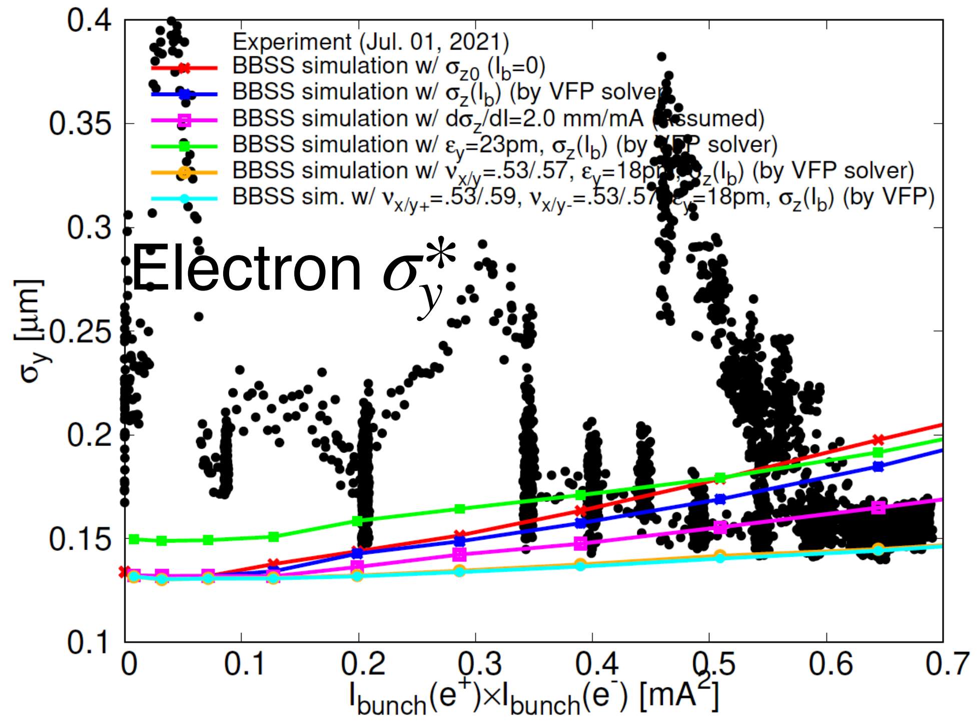
- Beam-beam simulations for SuperKEKB [10]
  - BBSS simulations showed BBHTI threshold threshold is sensitive to σ_z and ν_x, not sensitive to ϵ_y and ν_y.
  - Simulations showed that BBHTI makes vertical emittance growth more severe.
  - Experiment phenomena are quite complicated. It was hard to determine the BBHTI threshold (suppose the horizontal blowup was due to BBHTI). Blowup of σ_y^* was much different from simulations. The two beams had unbalanced blowup.

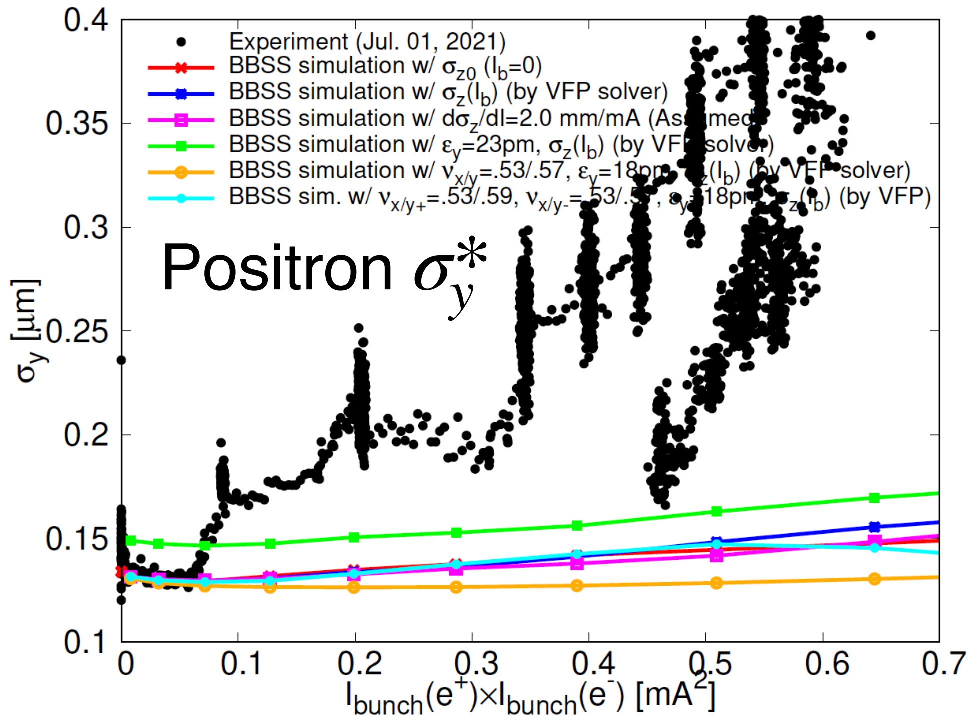
Luminosity history panel seen in SuperKEKB control room











Operation parameter sets

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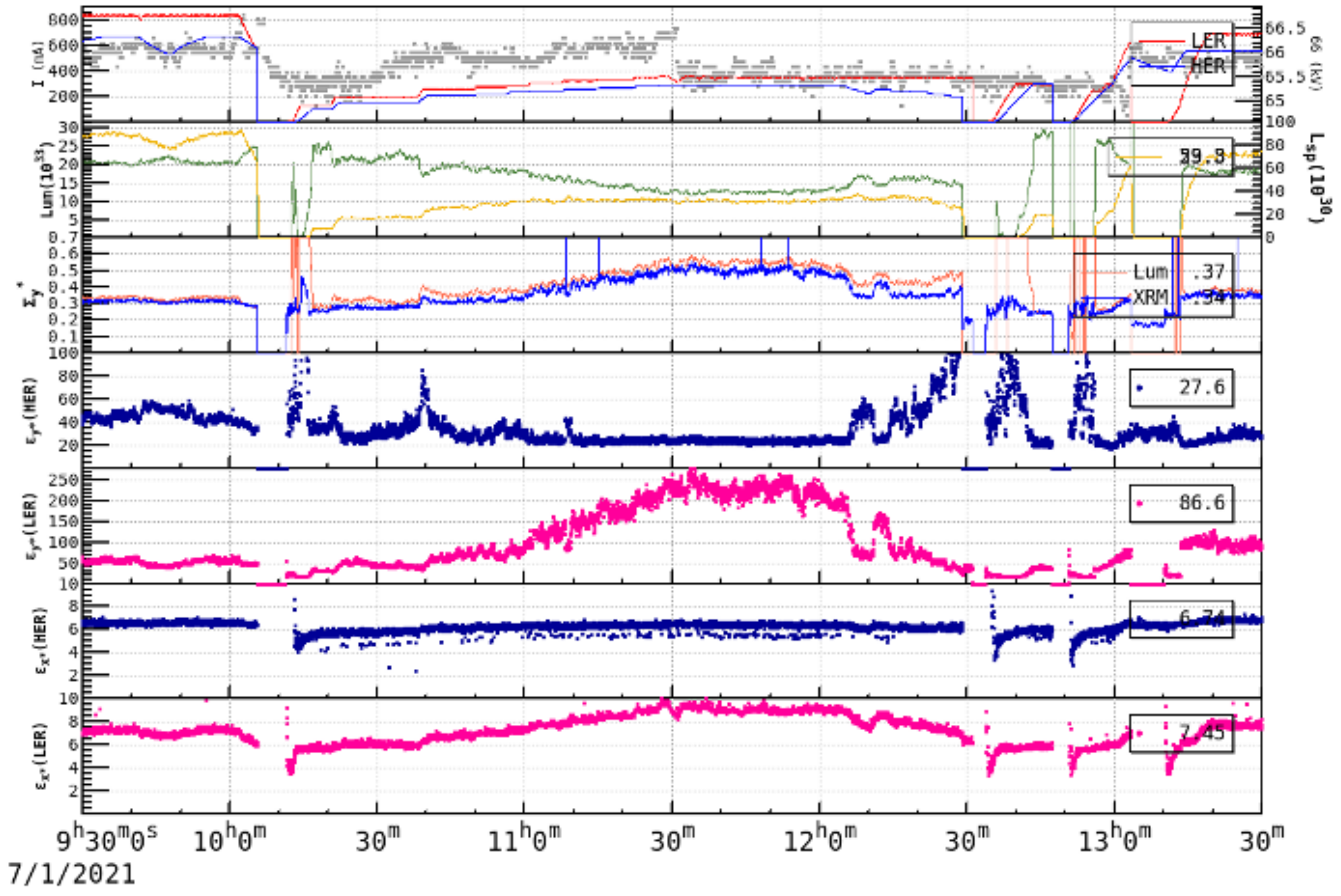
[10] https://kds.kek.jp/event/39142/contributions/194651/attachments/146544/182494/20210824_BB_Simulations_SKB.pdf

Highlights of first ITF-BB workgroup meeting

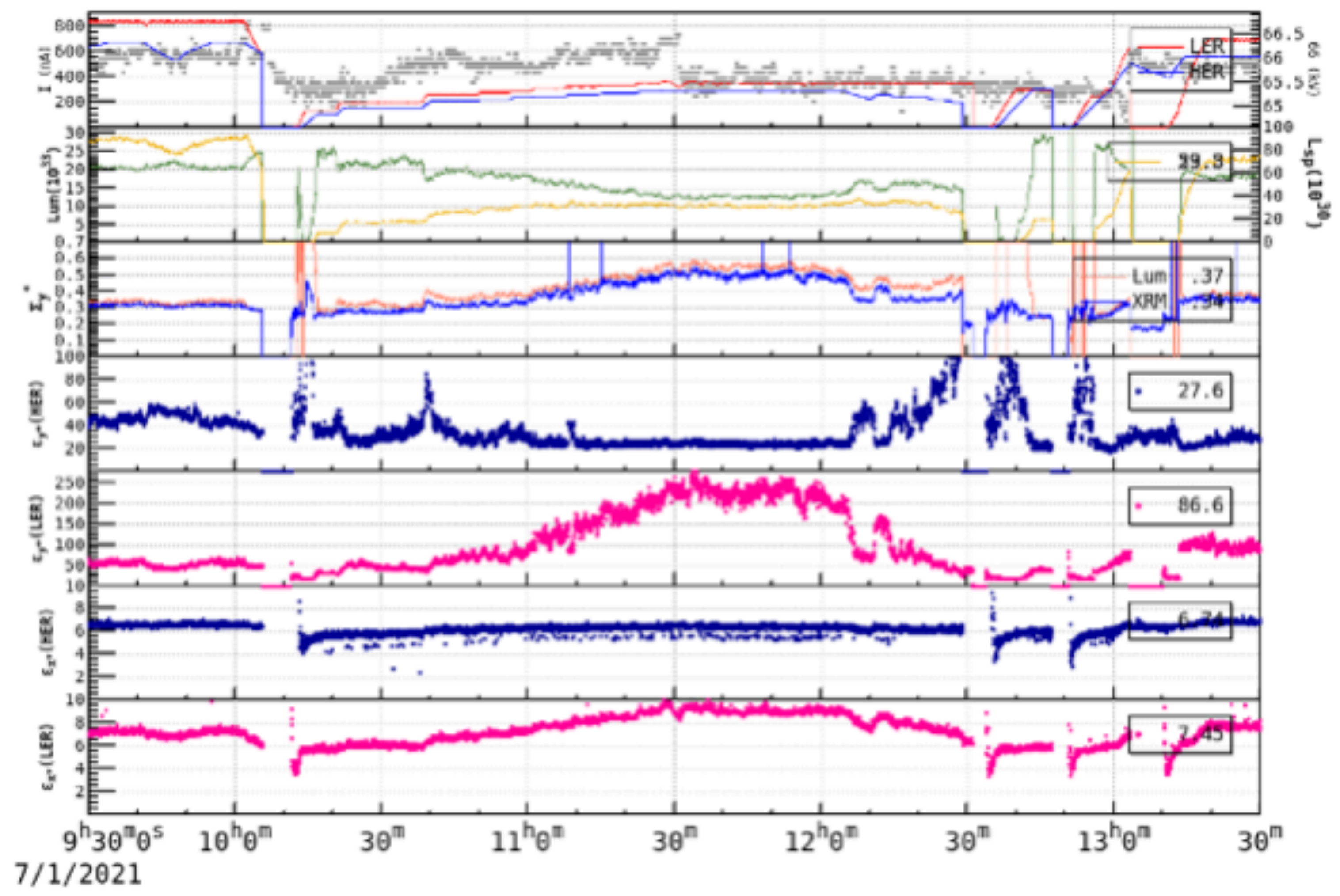
- Discussion on beam-beam
  - [Question/Comment] (D. Shatilov): In BBHTI, σ_x of both beams should blow up. But in HBCC study, we only see blowup of LER beam. The observed instability might not be coherent BBHTI, but just synchro-betatron resonance near half-integer. Scan of ν_x should help identify this effect. One ring (LER) might touch the $\nu_x - k\nu_s = N/2$ and it caused σ_x blowup. Of course, it can be synchro-betatron resonance driven by beam-beam.
  - [Discussion] In HER, we also see small growth of σ_x, it is not trivial to exclude BBHTI. In SuperKEKB operation, $\nu_{x,y,s}$ are different for both rings. Around the current working point, there was no σ_x blowup for single beam (no collision).
  - [Discussion] The two rings operated between resonances of $\nu_x - \nu_s = N/2$ and $\nu_x - 2\nu_s = N/2$. The footprint of the beam may overlap with these lines, causing blowup.

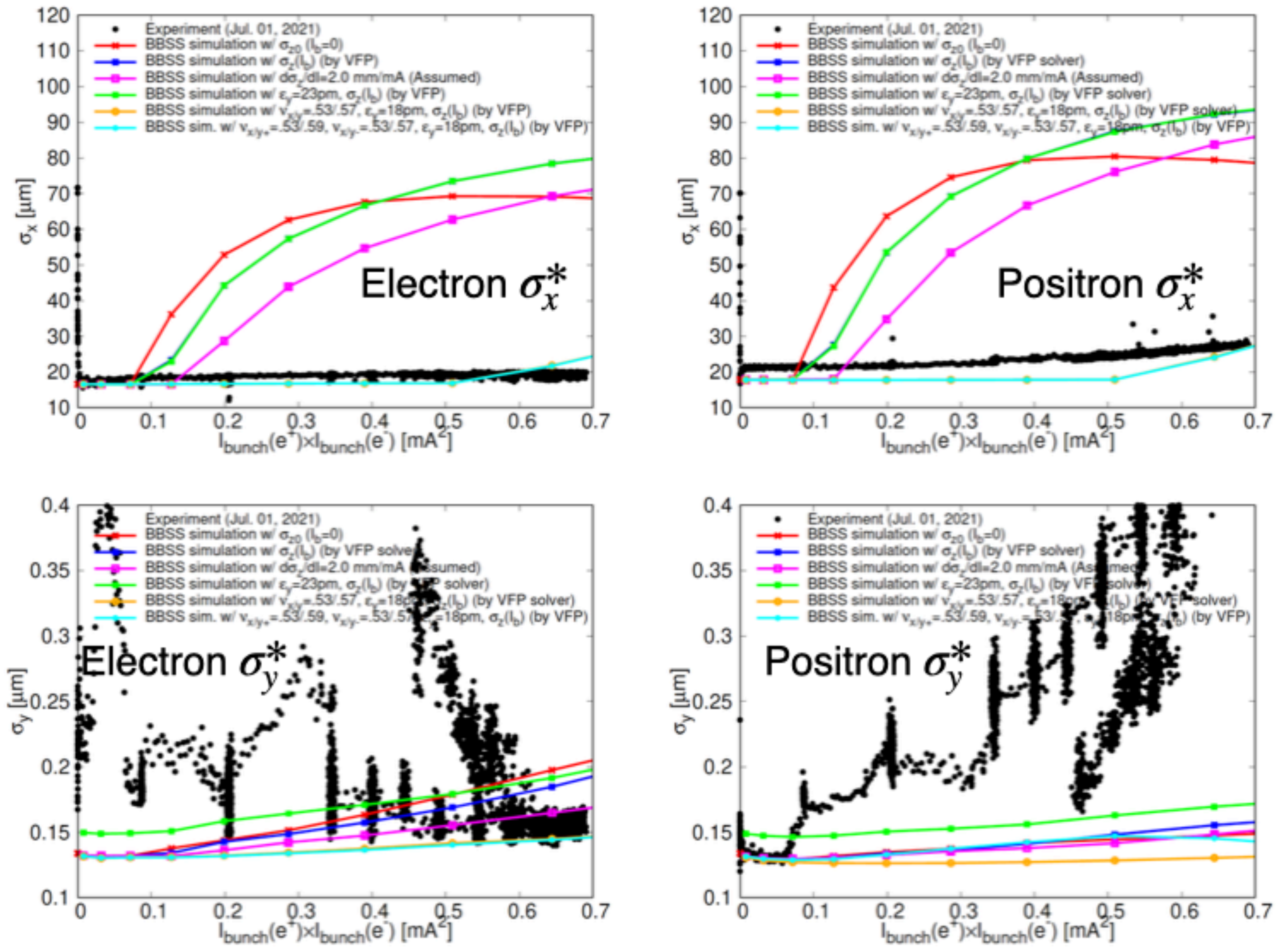


Highlights of first ITF-BB workgroup meeting

- Discussion on beam-beam
  - [Question/Comment] (Y. Funakoshi): The asymmetric blowup of σ_x is inconsistent with the simulated BBHTI. Blowup of LER σ_x might not be due to BBHTI.
  - [Discussion]: Ohnishi-san showed clear correlation of LER σ_x blowup as function of HER bunch current (also see Onishi-san's talk in this meeting). This can be a hint of instability driven by a different mechanism.

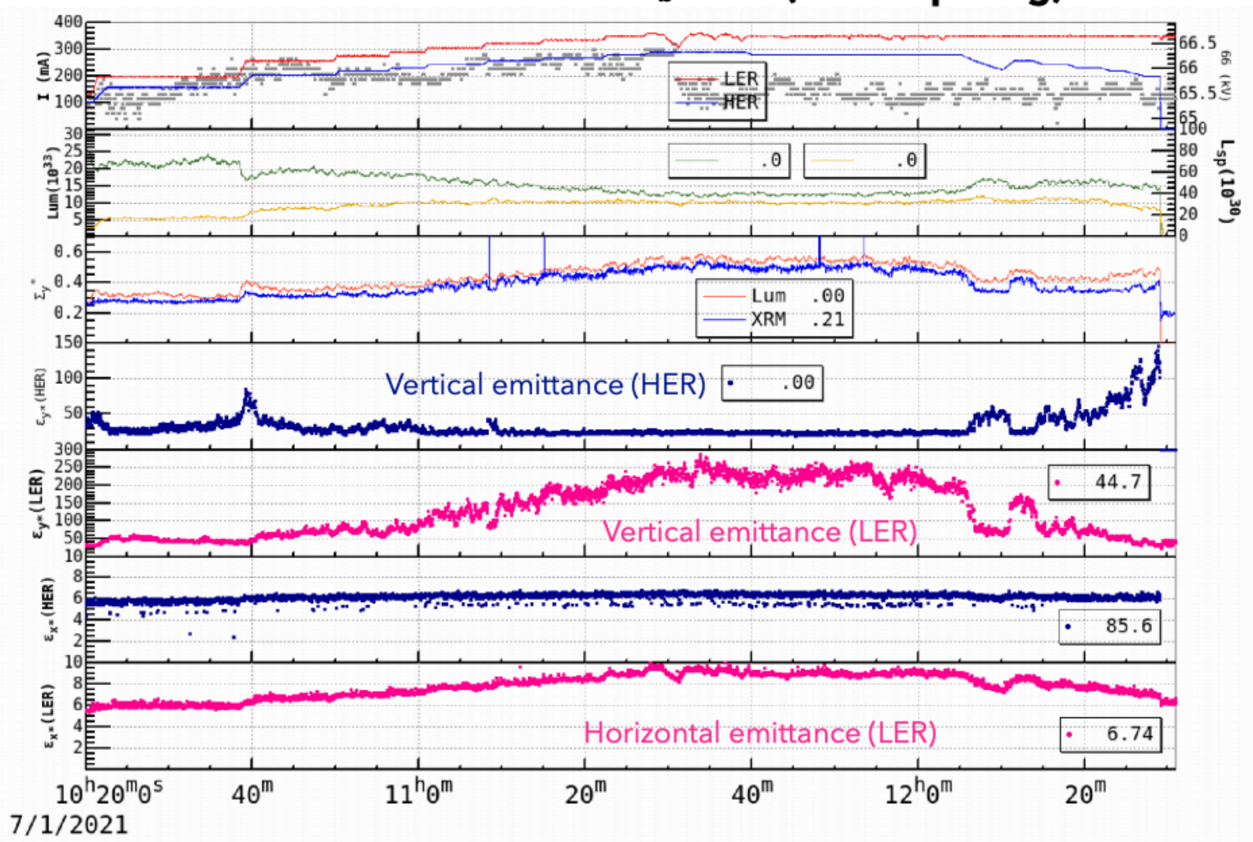
Luminosity history panel seen in SuperKEKB control room





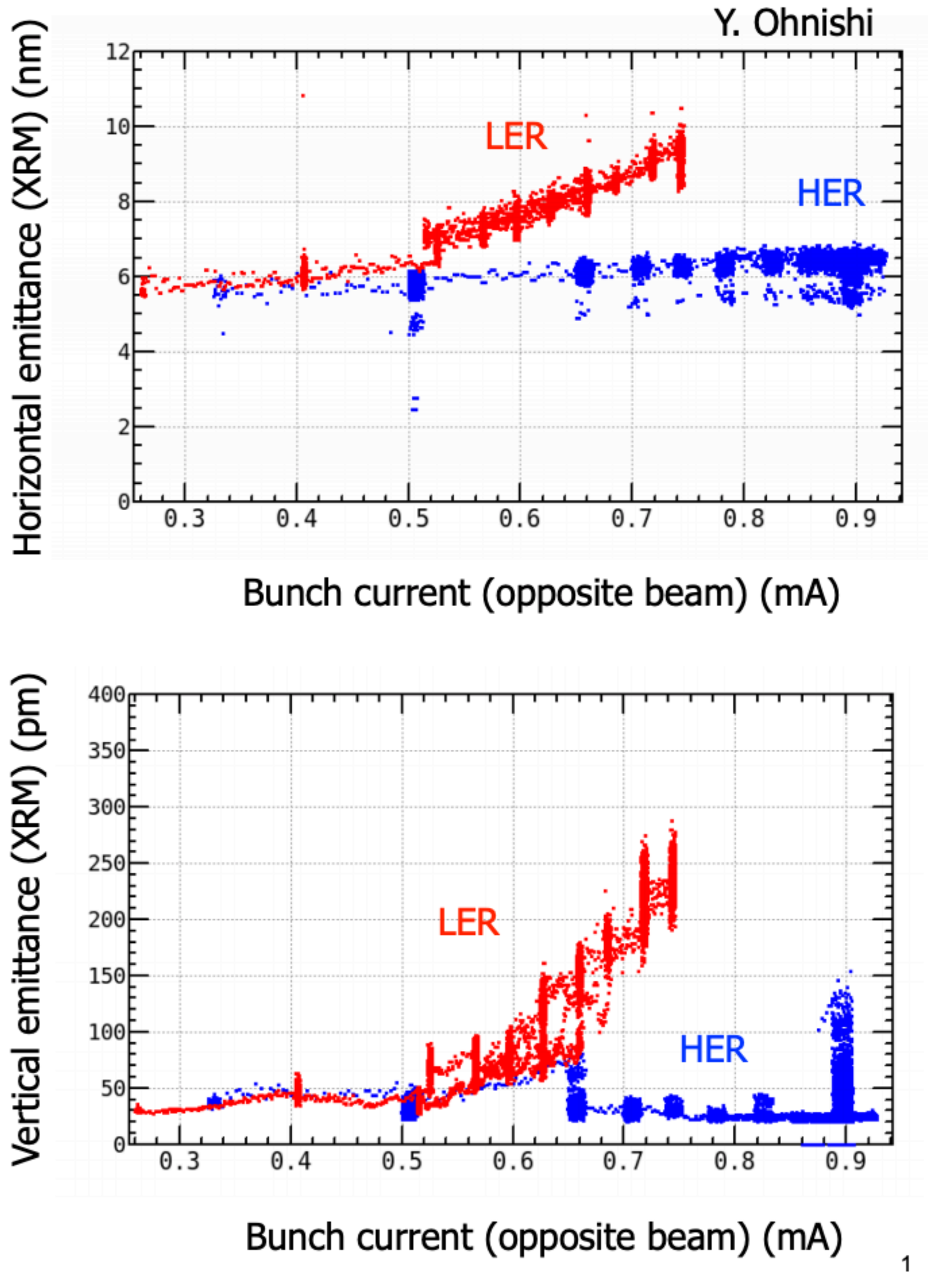
High Bunch Current Collision

small number of bunches n_b : 393 (12.25 spacing)



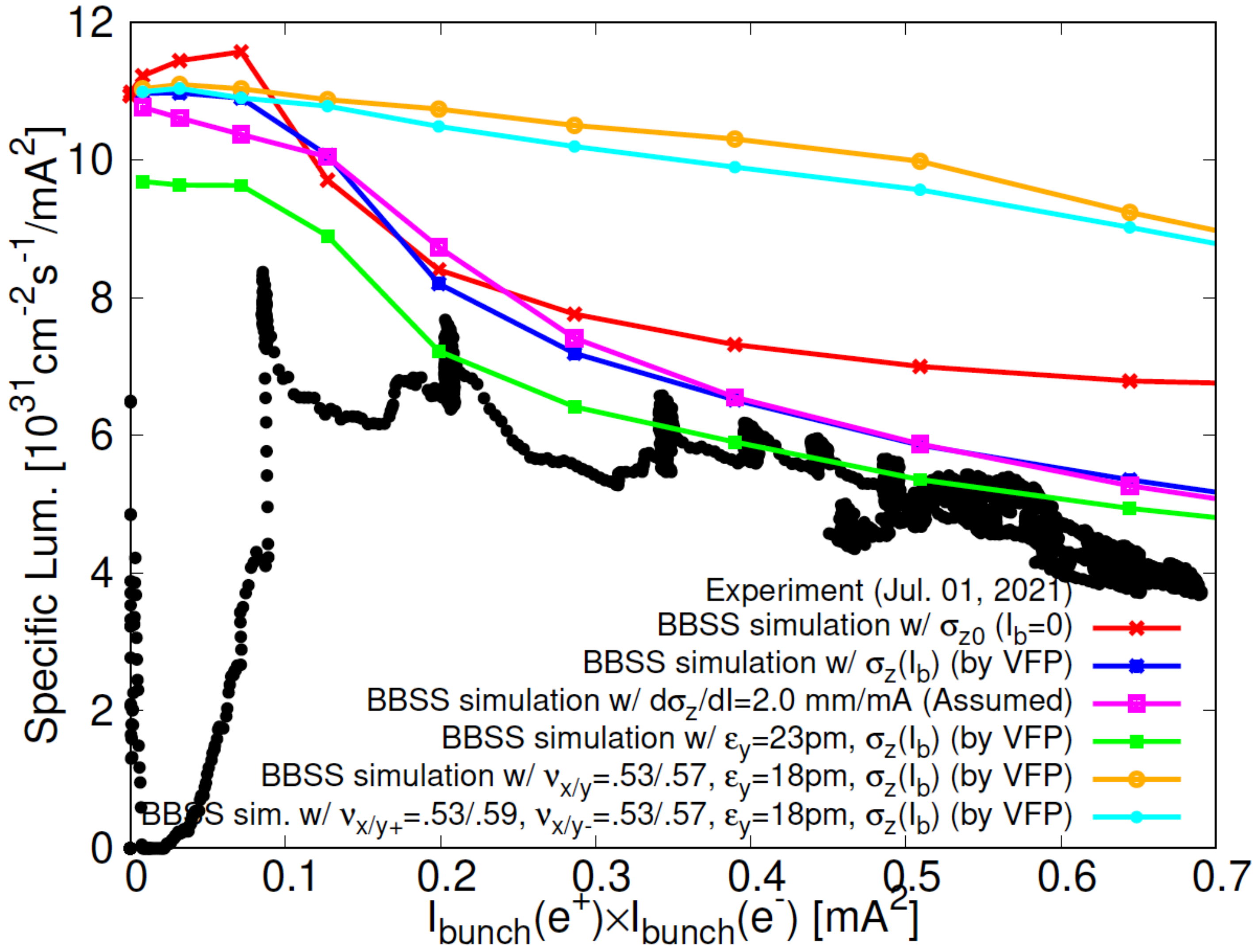
- We observed large beam-beam blowup in the LER from 40 pm to 250 pm.
- It depends on the HER beam current.
- Horizontal emittance also increases in LER.

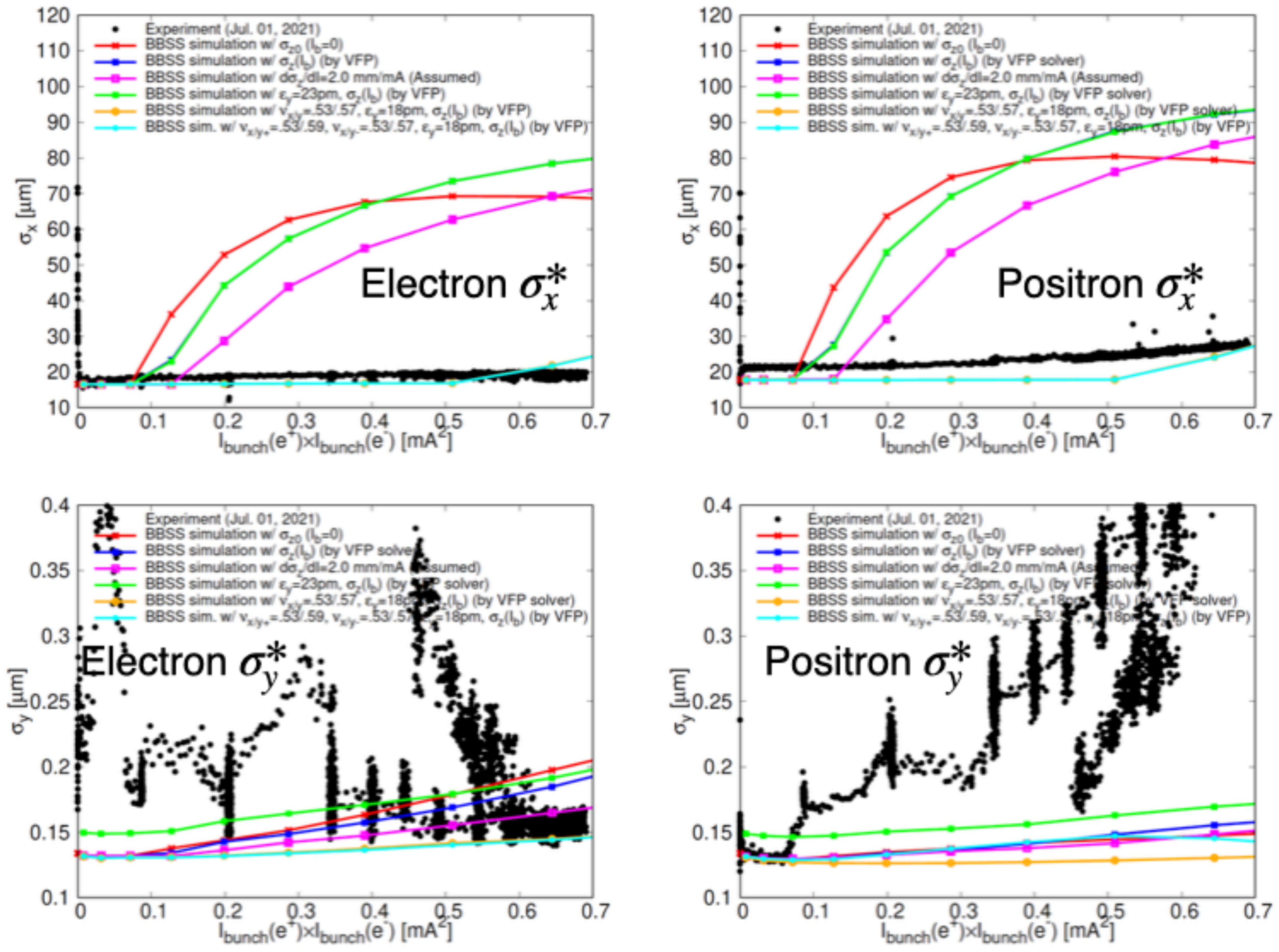
We consider coherent beam-beam head-tail instability (BBHT(XZ)) and/or dynamic beta/emittance effect.



Highlights of first ITF-BB workgroup meeting

- Discussion on beam-beam
  - [Discussion]: Because simulated vertical beam sizes are different from measurements, the agreement of simulated and measured luminosity was accidental.

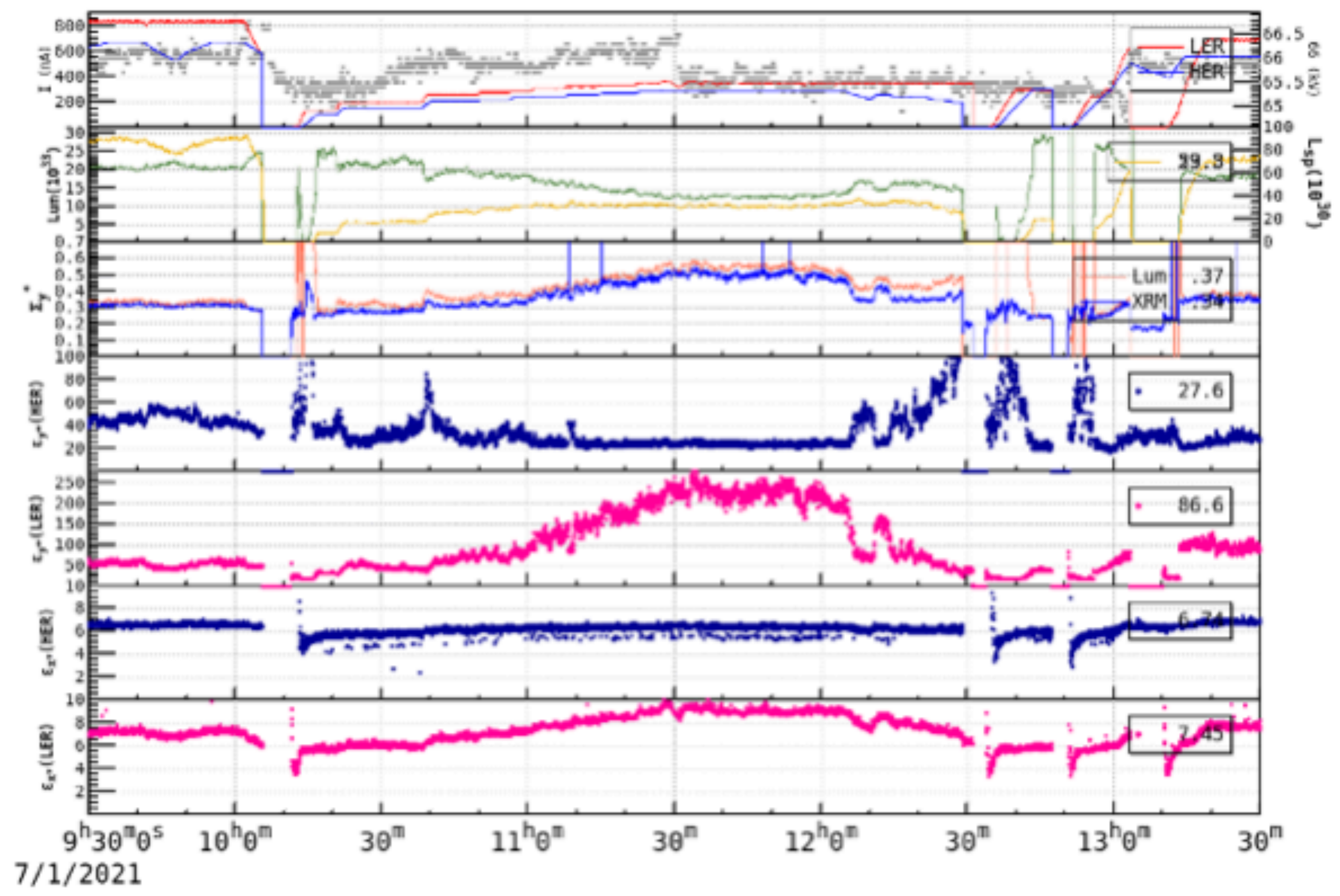


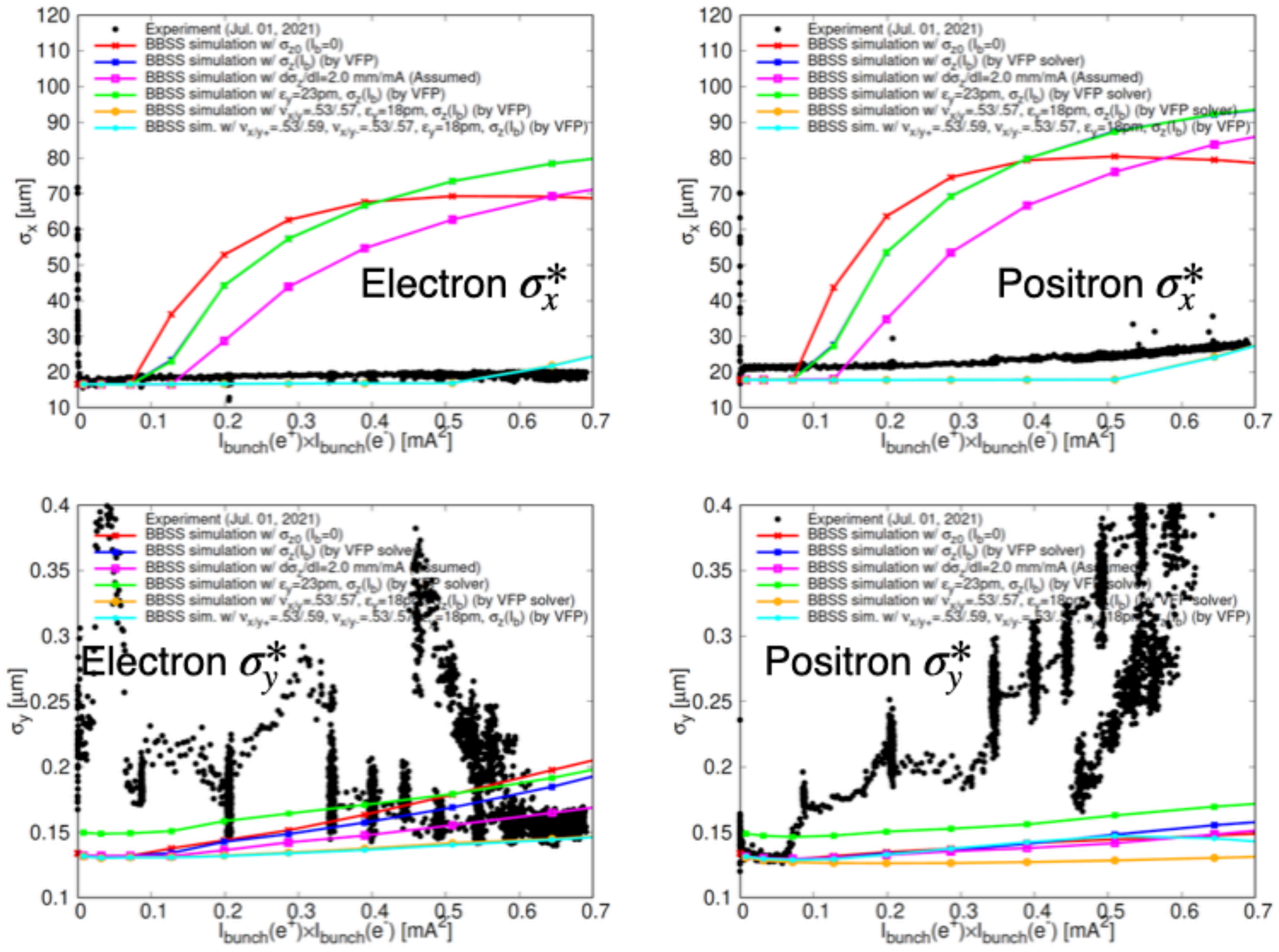


Highlights of first ITF-BB workgroup meeting

- Discussion on beam-beam
  - [Suggestion] (Y. Cai): Try to get a consistent and predictable model for beam-beam simulation. This task should be the first priority. The beam-beam simulation codes should have the predictability power when comparing with observations of machine. One of the model can explain the luminosity, but it cannot explain the vertical beam sizes. So the current beam-beam model is not consistent. Try to get the model fit the machine and then make predictions.

Luminosity history panel seen in SuperKEKB control room





Highlights of first ITF-BB workgroup meeting

- Discussion on beam-beam
  - [Question/Comment] (D. Shatilov): For the current working point, ν_x is set between $\nu_x - \nu_s = N/2$ and $\nu_x - 2\nu_s = N/2$. There might be not enough room for the tune footprint of the beam, and this may be the reason of observing BBHTI easily in simulations. Moving ν_x to be between $\nu_x - 2\nu_s = N/2$ and $\nu_x - 3\nu_s = N/2$ (also need to move up ν_y) might be useful: This will make the working point be far away from $\nu_x - \nu_s = N/2$ and help mitigate the BBHTI.
  - [Discussion]: In Phase-2 and early Phase-3, the machine was operated around (.57,.61) without crab waist. At that time, beam-beam resonances $\pm\nu_x + 4\nu_y + \alpha = N$ set constraints. Then the working point was moved to around (.53,.57) where simulated luminosity is the best.
  - [Discussion]: With crab waist, the constraints from $\pm\nu_x + 4\nu_y + \alpha = N$ is removed, it is possible the operate the machine around (.57, .61). With beam-beam parameter $\xi_y < 0.04$, there is room to avoid lattice resonances from the upper side.

	2021.07.01		Comments
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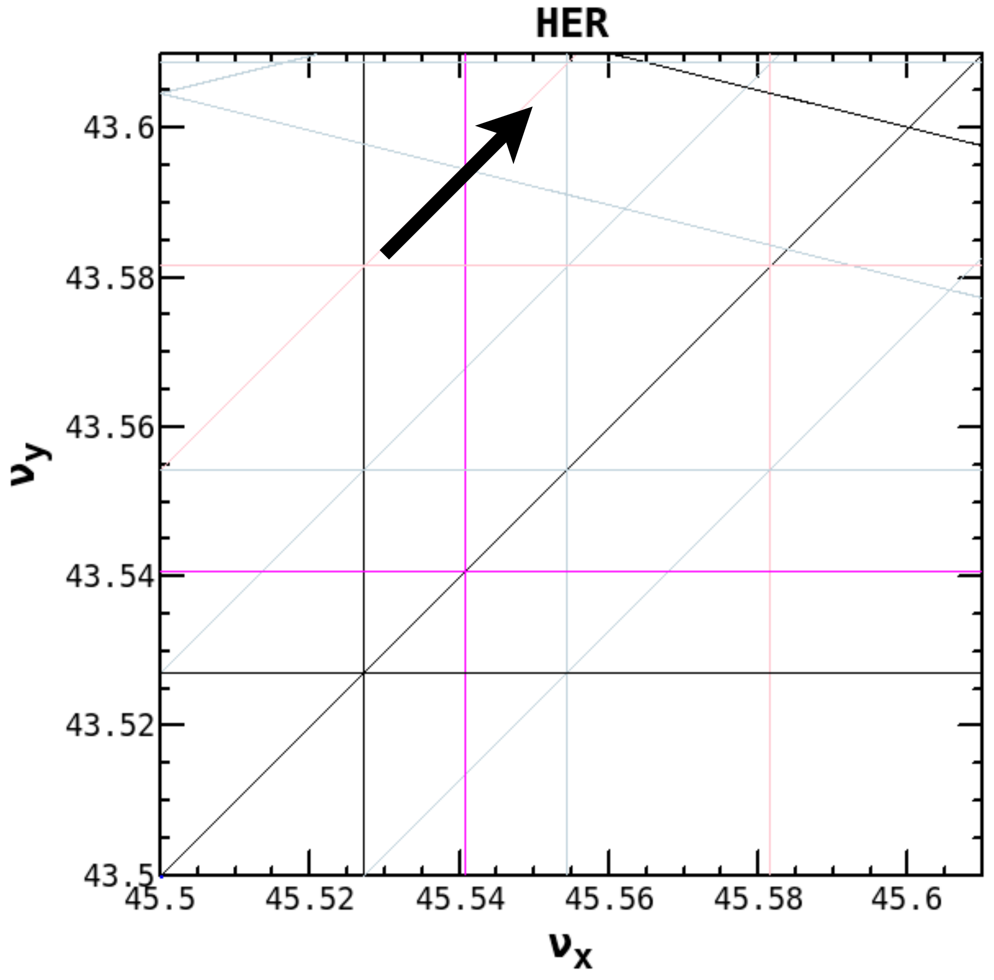

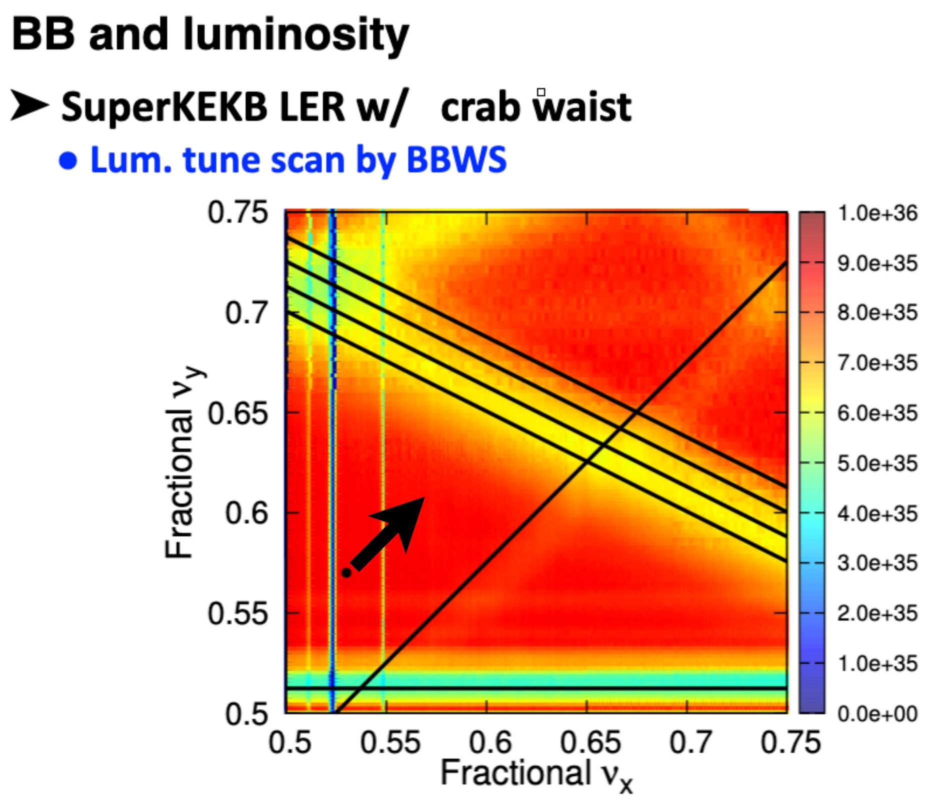

Highlights of first ITF-BB workgroup meeting

- Discussion on beam-beam
  - [Question/Comment] (D. Shatilov): Now SuperKEKB operates with different synchrotron tune ν_s. Why is it not possible to have the same ν_s for the two rings?
  - [Discussion]: Same ν_s is good to avoid BBHTI. There are two ways to change ν_s: Changing RF voltage or changing momentum compaction factor of optics. The feasibility can be checked with experts of RF and optics.
  - [Discussion]: Equalizing $\nu_{x,y,s}$ is good for avoiding BBHTI.
  - [Discussion]: It is possible to change ν_s by changing momentum compaction. But it will result in many side effects (such as rematching the arc cells and straight sections, change of emittance, extra commissioning time, etc.).
  - [Discussion]: Gains of equalizing ν_s should be well clarified before discussing its feasibility.

	2021.07.01		Comments
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ν_s	0.0272	0.0221	Calculated from lattice
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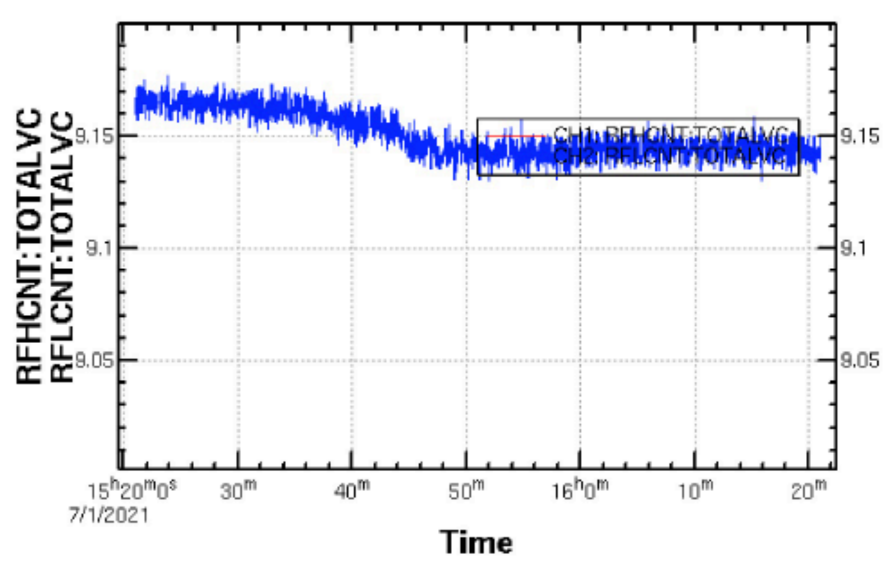
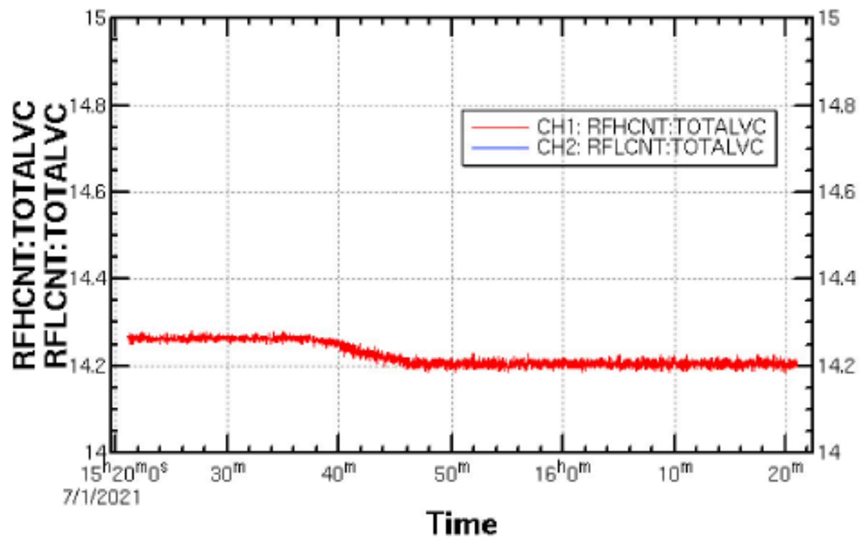
Highlights of first ITF-BB workgroup meeting

- Discussion on beam-beam
  - [Question/Comment] (D. Shatilov): Now SuperKEKB operates with different synchrotron tune ν_s. Why is it not possible to have the same ν_s for the two rings?
  - [Discussion]: To equalize the nu_s of the two rings, we can increase LER Vc from 9.15 MV to 12.3 MV, or decrease HER Vc from 14.2 MV to 10.6 MV.
  - [Discussion]: Lowering Vc of HER from 14.2 to 10.6 MV will change the bucket height from 0.0203 to 0.0166. With the nominal energy spread of 6.3e-4, the resulting bucket height is no problem for momentum acceptance and dynamic aperture.
  - [Discussion]: At a higher beam current with the lower Vc, stability of the accelerating mode can be deteriorated due to heavy beam loading, in particular for the case of SCC.
  - [Discussion]: As a compromise, changing both Vc and momentum compaction at the same time has advantages. One reason is that lowering Vc without changing alpha_p increases bunch length. Another reason is that the demands for Vc or alpha_p would be less stringent compared to the case of only changing either one.
  - [Conclusion]: To justify the necessity of equalizing ν_s, detailed analysis (theory and simulations) is required. The possibility can be checked by machine studies at low beam currents. The final step is to discuss the technique challenges to RF and optics design.

Total Vc

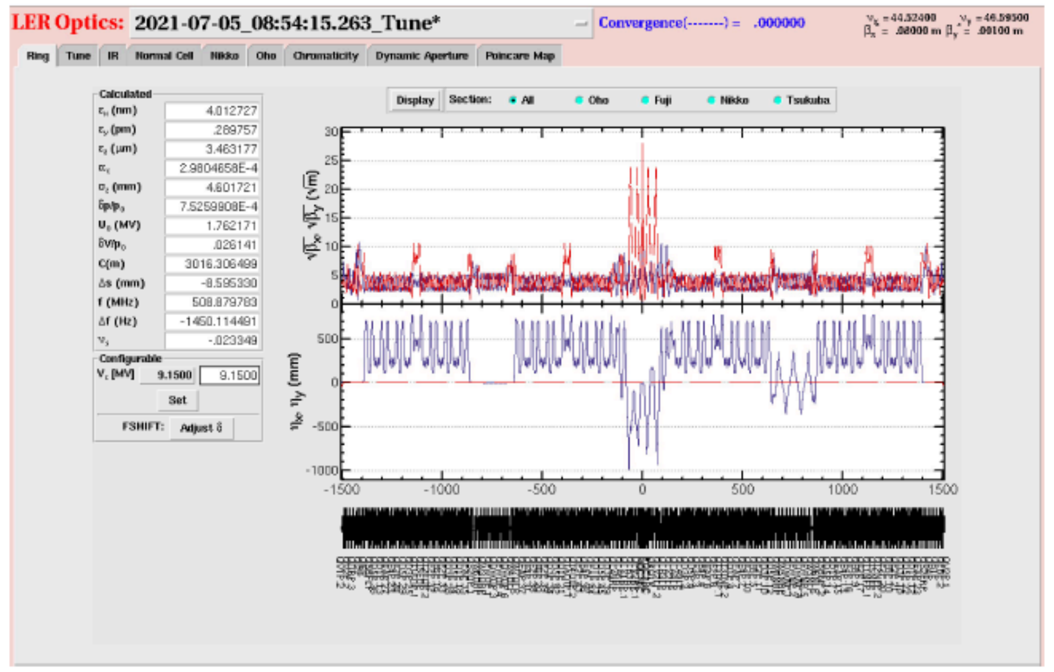


Vc = ~9.15MV (LER)

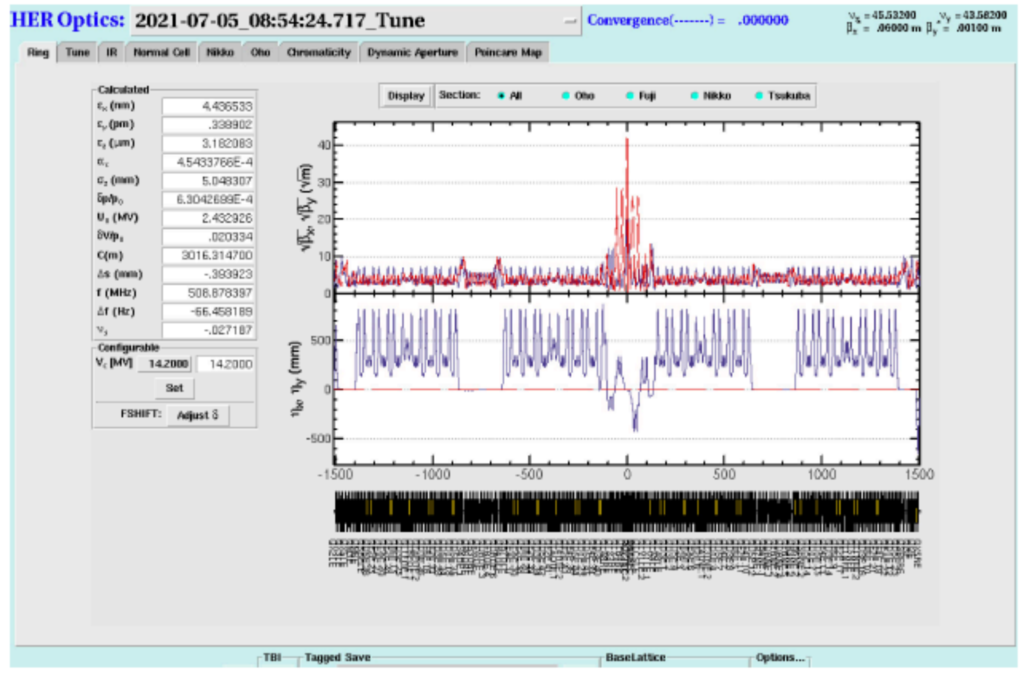


Vc = ~14.2MV (HER)

LER optics



HER optics



ν_s = -0.0233
↓
ν_s = -0.0272 with Vc = 12.3MV

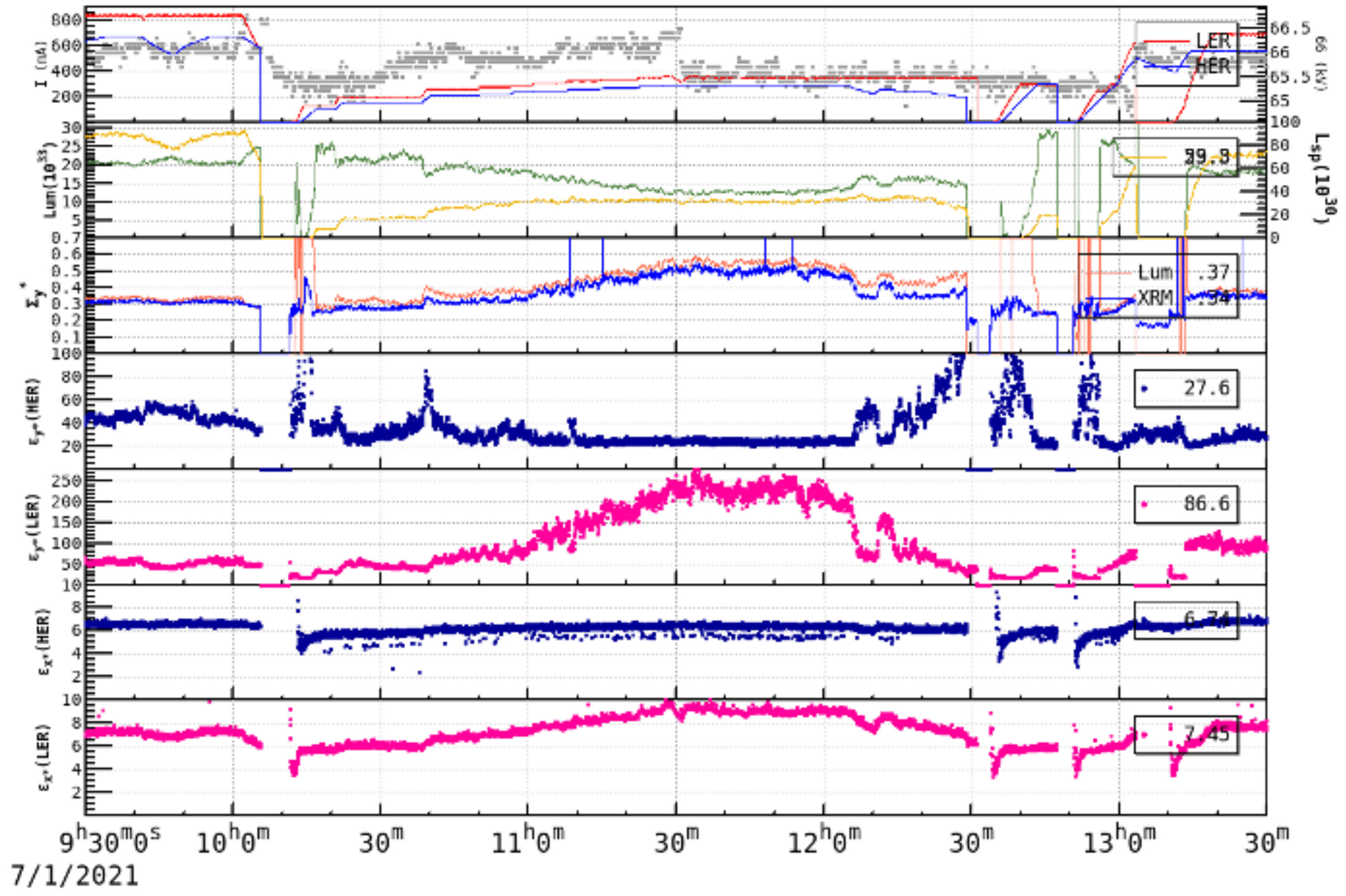
w/o changing momentum compaction

ν_s = -0.0272
↓
ν_s = -0.0233 with Vc = 10.6MV

Contributions from Y. Funakoshi, Y. Ohnishi, and K. Akai

Highlights of first ITF-BB workgroup meeting

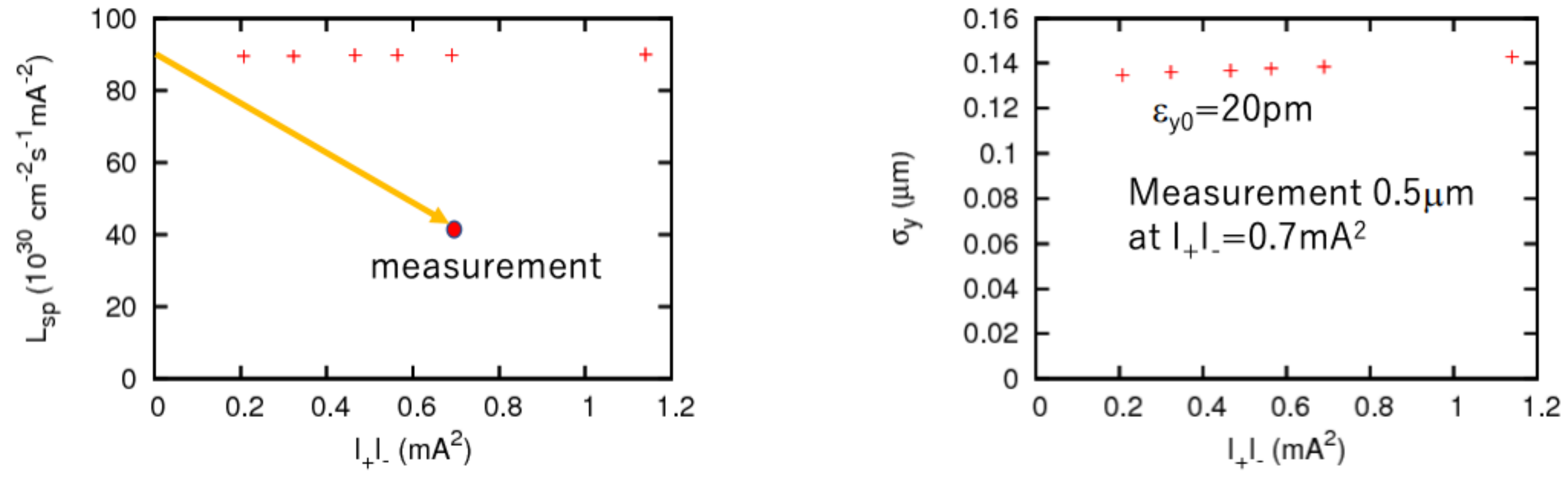
- Discussion on beam-beam
  - [Question] (C. Montag): Can we swap the working point of the two beams? This may swap the σ_x blowup and then can be evidence of BBHTI.
  - [Discussion] In machine operation, it's not trivial to swap tunes. We can try changing working point in future machine studies.



  - [Question] (Y. Cai): The observed ξ_y was about 0.03, what's the simulated value?
  - [Discussion] Simulated value (both weak-strong and strong-strong) was 0.077 for machine parameters of 2021.07.01 without coherent BBHTI.
  - [Question] (Y. Cai): In beam-beam simulations, what's the map for lattice?
  - [Discussion] Simple matrix map was used. D.Z. tried beam-beam simulations using SAD (lattice included), for the current machine condition, no difference between simple map and using lattice.

Weak-strong simulation

- 200x160, 250x200, 300x240, 330x292, 365x292(ξ_{y0}=0.077), 469x375mA with 393bunch



- Simulations show ξ_y>0.1 in general with crab waist.
- This result is normal in the sense of simulation.

Highlights of first ITF-BB workgroup meeting

- Discussion on beam-beam
  - [Question] (X. Buffat): Why are the wakefields localized but not distributed in the TMCI study since the collimators are distributed?
  - [Discussion] The collimators are located with integer of π phase advance, therefore their effects can be simply summed up.
  - [Question] (Y. Cai): About settings of collimators, are their gaps narrow both in vertical and horizontal?
  - [Discussion] Vertical collimators (minimum full gap < 2 mm) have much smaller gaps than horizontal ones. This explains only the vertical blowup (related to TMCI) is serious.
  - [Question]: TMCI threshold is tight on both rings?
  - Only LER is tight.
  - [Question]: Are there specifications (noise level) about collision offset noise? Are there measurements about BPM noise or estimate on the movement of magnets.
  - Discussion: The beam-beam simulations consider turn-by-turn noise. It is fast noise, therefore not relevant to magnet movement. So far there are no measurements on noise level.

Highlights of first ITF-BB workgroup meeting

- Discussion on beam-beam
  - [Question/Comment] (Y. Cai): Currently machine is limited by lifetime and background, can the beam-beam simulations calculate beam-beam lifetime and background?
  - [Discussion] Beam-beam drives beam tail that hits the collimators. This effect should change the lifetime.
  - [Discussion] Belle-2 group studied the background, and did not observe strong effect from beam-beam. Currently the main limits of lifetime are from Touschek and beam-gas scattering.
  - [Discussion] The gaps of vertical collimators are small, but still about 40 sigma. The beam-beam driven tail does not hit the collimators. This is mostly the current situation.

  - [Question/comment] (Y. Cai): For the resonance driving terms, which machine is worse? LER or HER?
  - [Discussion] LER is always worse.

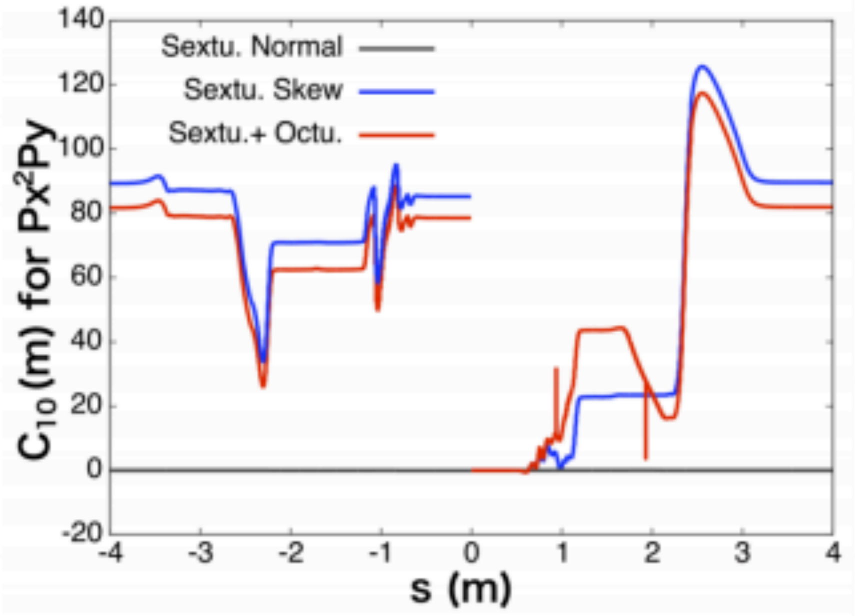


Figure 4: Coefficient of $P_X^2 P_Y$ caused by skew sextupole (SK_2) and octupole ($K_3 + SK_3$) fields.

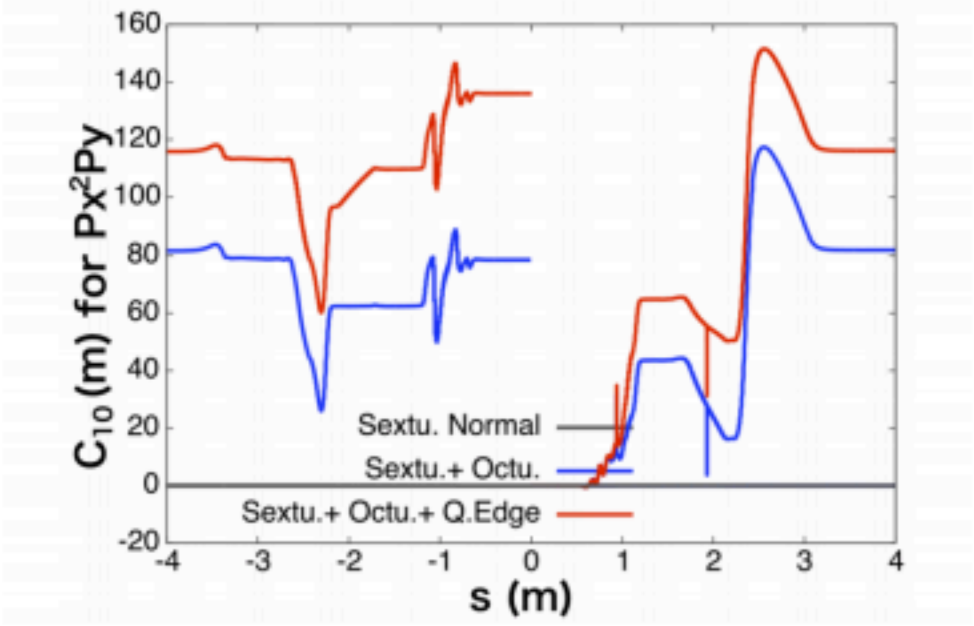


Figure 5: Coefficient of $P_X^2 P_Y$ for sextupole and octupole ($SK_2 + K_3 + SK_3$) and quadrupole hard-edge fringe ($SK_2 + K_3 + SK_3 + Q.edge$) fields.

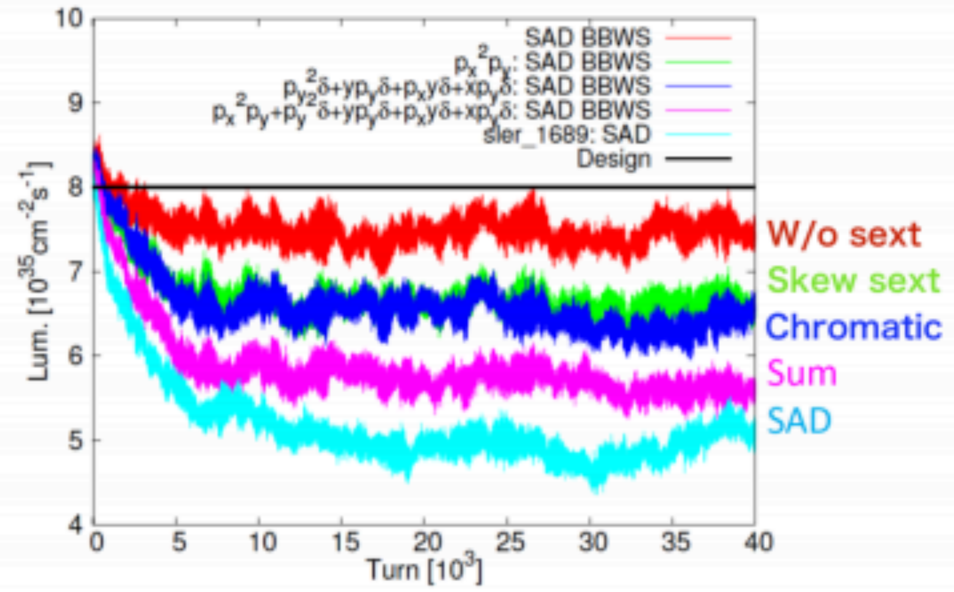
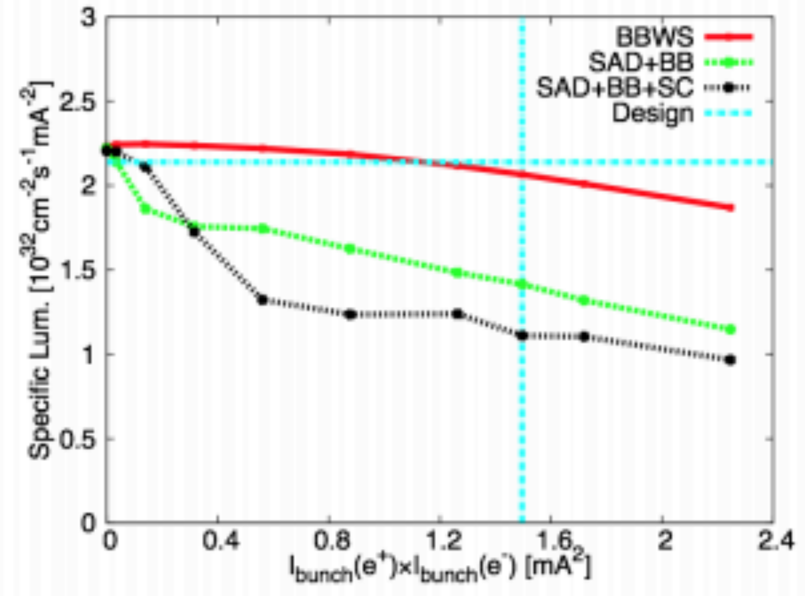
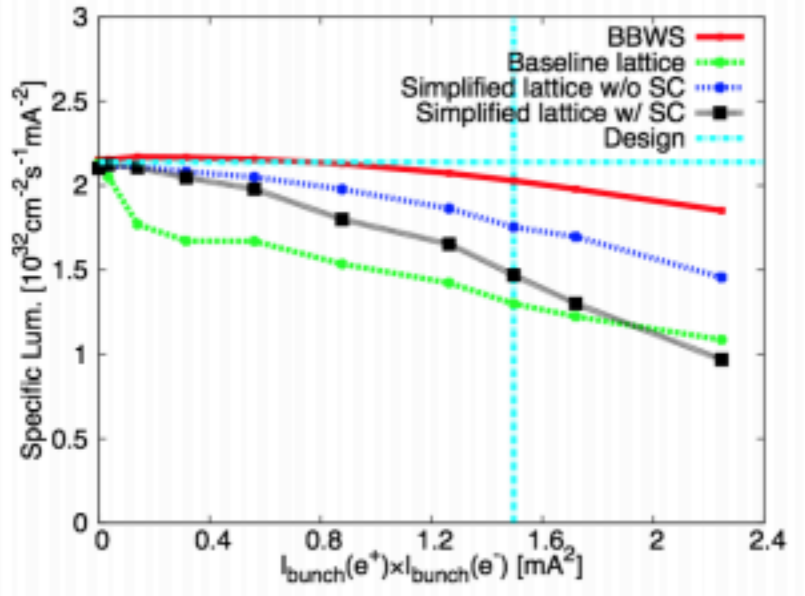


Figure 6: Luminosities for sextupole term (: $P_X^2 P_Y$), chromatic twiss, and SAD.

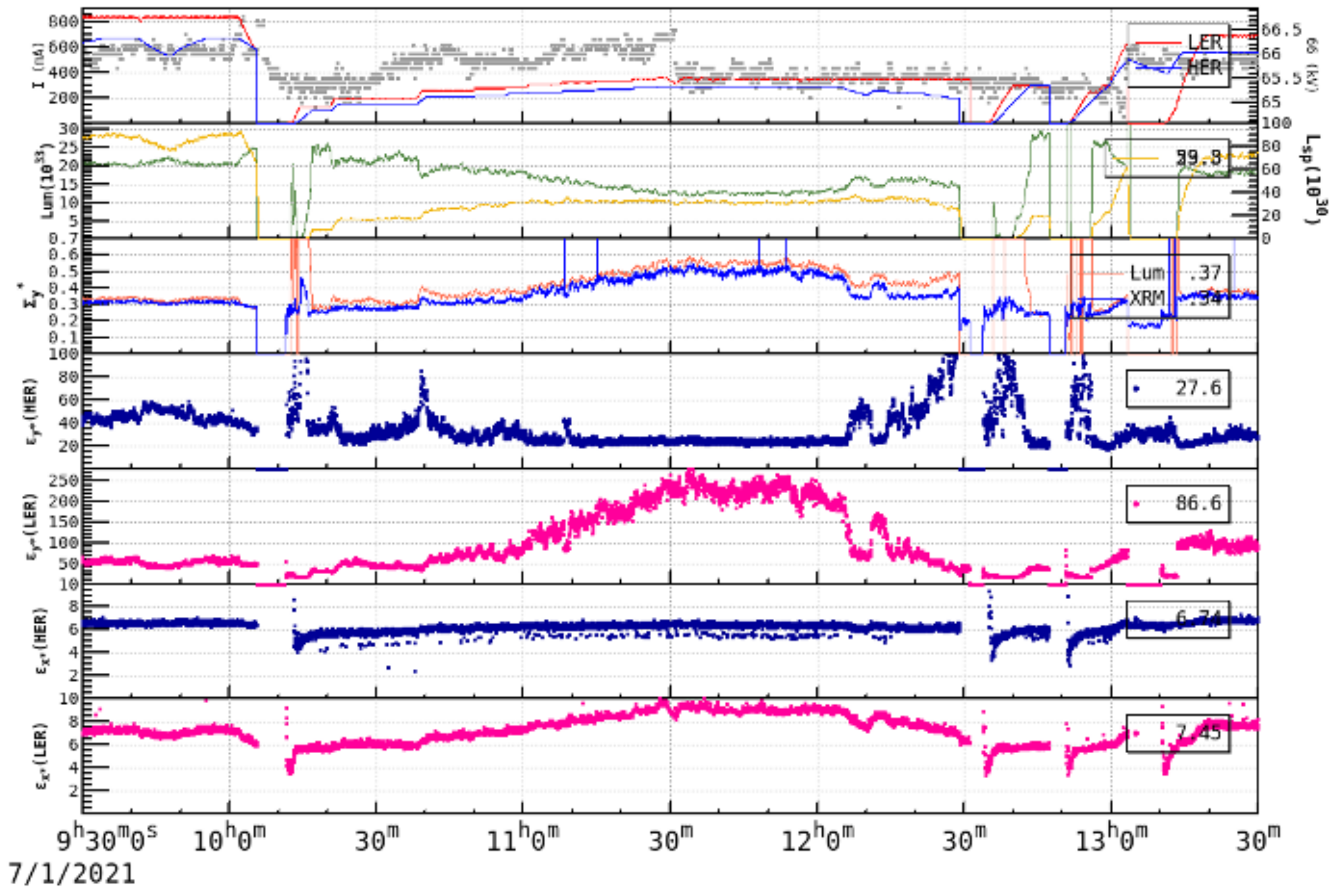


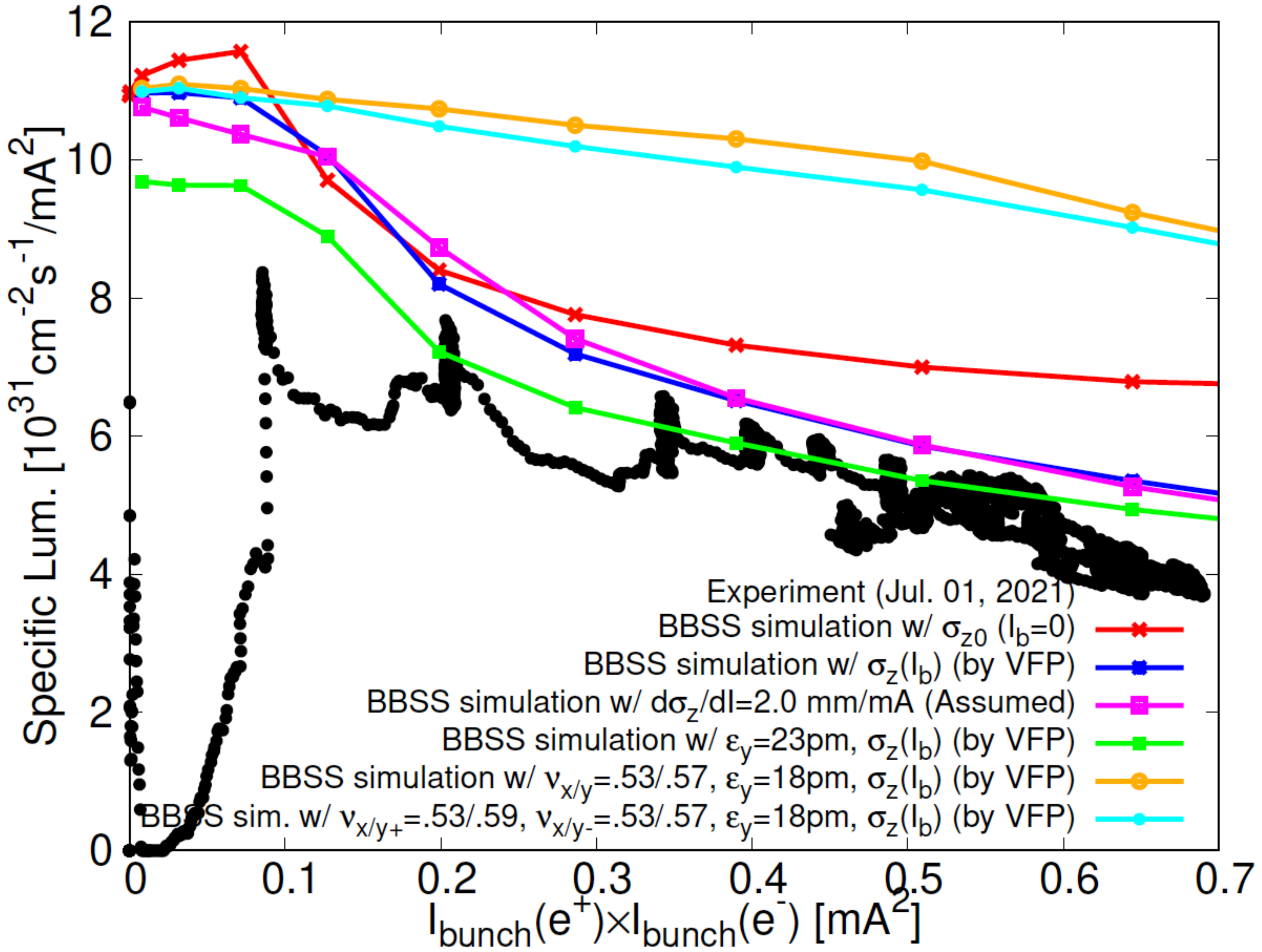


Highlights of first ITF-BB workgroup meeting

- Discussion on beam-beam
  - [Question/Comment] (T. Browder): Is there any explanation for the Lsp at low bunch current products?
  - [Discussion] At low bunch current products, beam-beam effects are weak except dynamic beta/emittance. The simulated luminosity is close to geometric one.
  - [Discussion] Experimental data showed good agreement in $\sigma_y^* = \sqrt{\sigma_{y+}^{*2} + \sigma_{y-}^{*2}}$ calculated from measured luminosity and from IP beam sizes extracted from X-ray monitors. This is evidence of good collision condition at low bunch currents. Low bunch-current study was done long time ago, good agreement was seen.
  - [Discussion] The luminosity was optimized around 0.4 mA^2, and then the HBCC study started. At low bunch current products, the collision condition was not re-optimized. This could be a reason to explain the difference between simulation and measured luminosity. (BUT, this scenario is plausible.)

Luminosity history panel seen in SuperKEKB control room





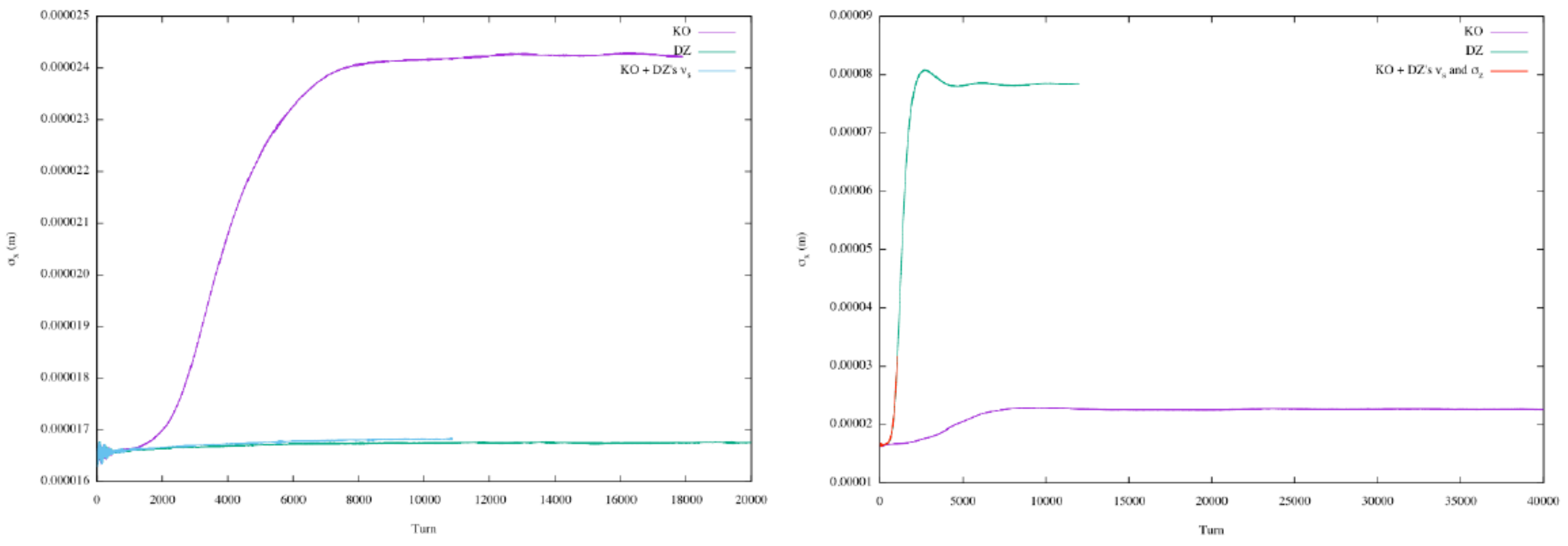
Summary

- Potential sources for luminosity limit (K. Ohmi)
  - Optics aberrations at IP, such as chromatic coupling
  - Collision offset noise
  - Coherent beam-beam head-tail instability
- Discussion on beam-beam
  - The observed horizontal blowup might not be due to coherent BBHTI, but just synchro-betatron resonance near half-integer driven by beam-beam.
  - The agreement of simulated and measured luminosity in HBCC study was accidental.
  - The current beam-beam simulations cannot predict vertical emittance growth. A consistent and predictable model for beam-beam simulation is necessary.
  - With crab waist applied and beam-beam parameter < 0.04, it might be better to move working point from around (.53,.57) to around (.57,.61).
  - Equalizing $\nu_{x,y,s}$ of the electron and positron beams should be useful.
- Outlook
  - Collaborative studies are very welcome.
  - Strong interactions with other subgroups are essential.

Backup

Highlights of first ITF-BB workgroup meeting

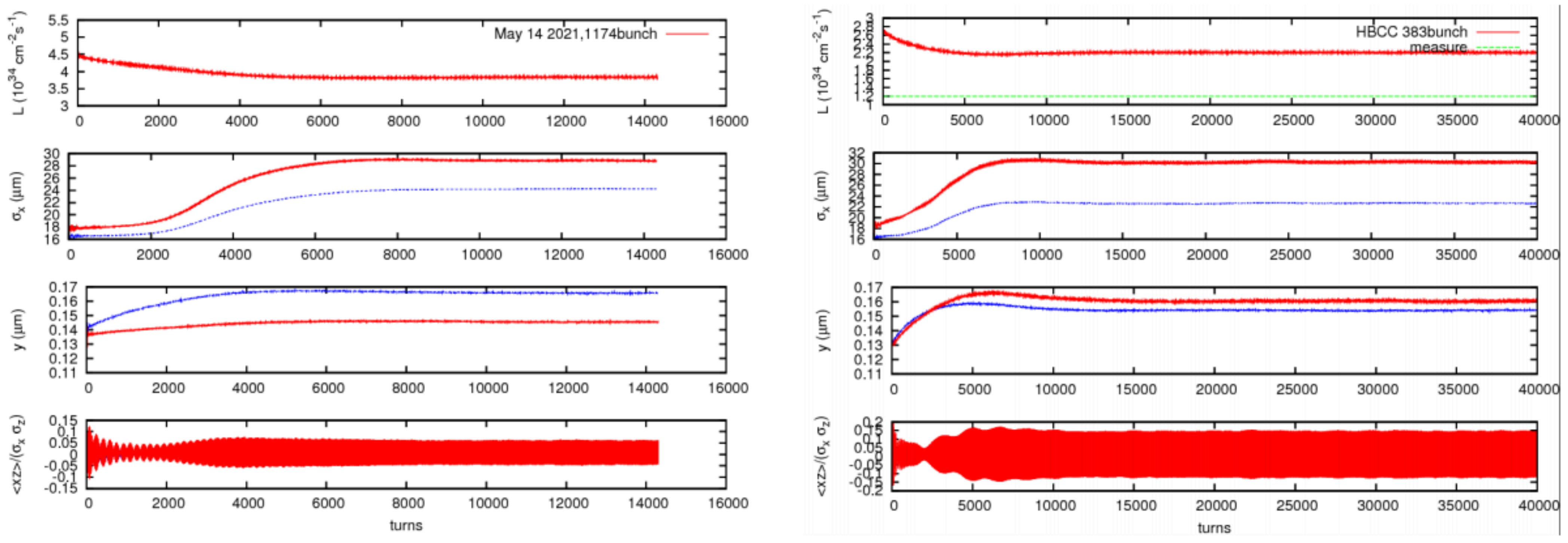
- Discussion on beam-beam
  - [Question] (K. Oide): Are the strong-strong simulations consistent with D. Zhou's simulations?
  - [Discussion] They should be consistent. The simulation results with occurrence of BBHTI are sensitive to chosen parameters.
  - [Offline check by D.Z.] Parameters sets of 2021.05.14 and 2021.07.01 used by K.O. and D.Z. are slightly different. Because BBHTI is very sensitive to σ_z and ν_s, the behavior of beam blowup was somehow different.



Figures: Electron beam size. Left for 2021.05.14, right for 2021.07.01.

Strong-strong simulation using the latest parameters

- BBHT instability is seen frequently.
- Luminosity degradation and emittance growth are small.



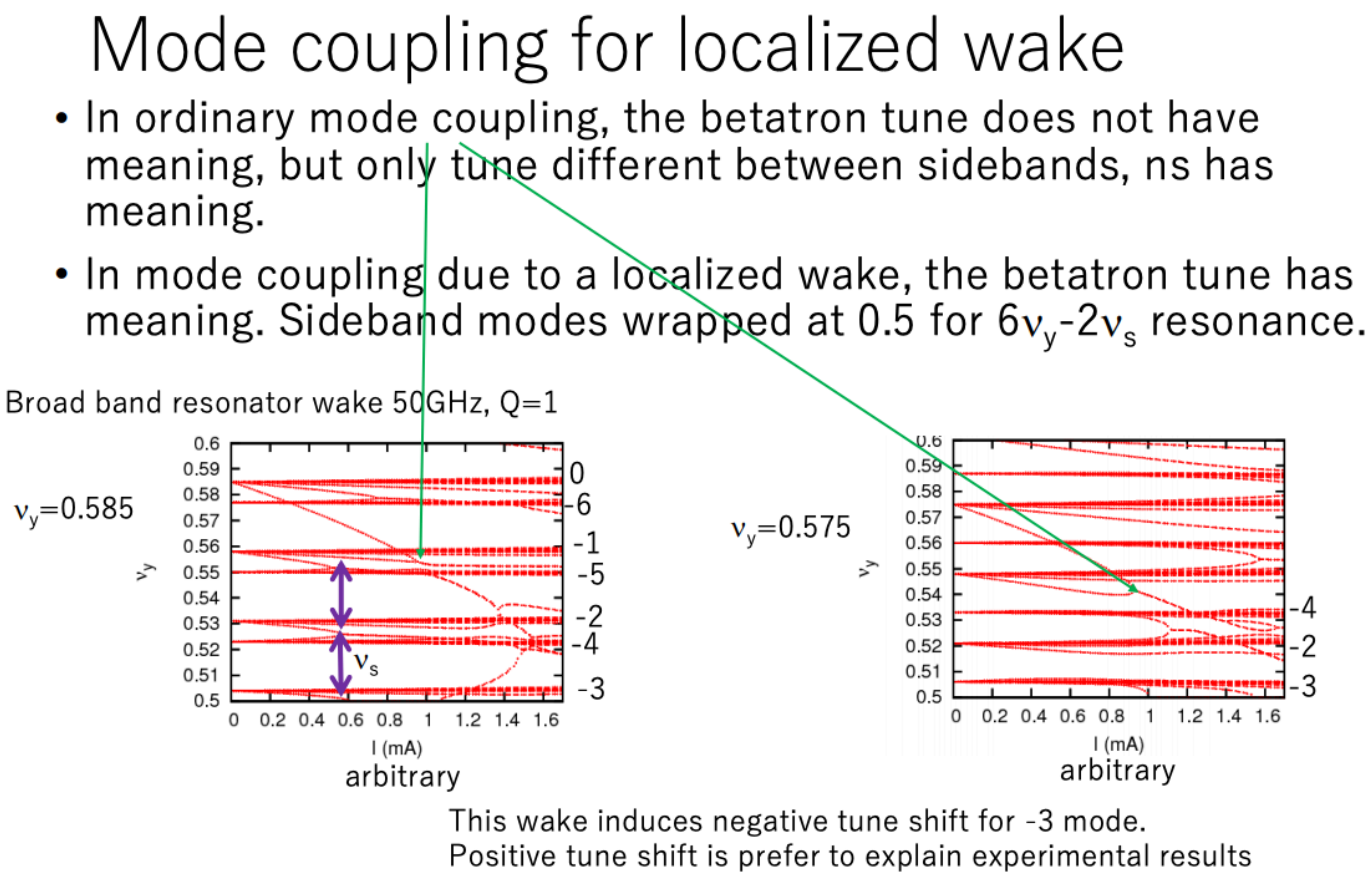
2021.05.14	DZ		KO	
	HER	LER	HER	LER
I_b (A)	0.68	0.84	0.68	0.84
# bunch	1174		1174	
ε_x (nm)	4.6	4.237	4.6	4.0
ε_y (pm)	22.5	22.5	22.5	22.5
ε_z (μm)	3.78256	4.51537	4.248	5.004
β_x (mm)	60	80	60	80
β_y (mm)	1	1	1	1
β_z (m)	9.52	7.97	8.54	7.2
ν_x	45.52989	44.5247	45.53	44.525
ν_y	43.59055	46.57279	43.59001	46.573
ν_s	0.02719	0.02212	0.027	0.022
Crab waist strength	4.80821	9.61641	5	10
Half crossing angle	0.415		0.413	

2021.07.01	DZ		KO	
	HER	LER	HER	LER
I_b (A)	0.2816	0.3534	0.283	0.355
# bunch	393		393	
ε_x (nm)	4.6	4.0	4.6	4.0
ε_y (pm)	18	18	20	20
ε_z (μm)	3.78851	4.20156	2.95	5.004
β_x (mm)	60	80	60	80
β_y (mm)	1	1	1	1
β_z (m)	9.52939	7.41869	8.54	7.2
ν_x	45.532	44.525	45.532	44.5251
ν_y	43.582	46.593	43.58201	46.5951
ν_s	0.0271858	0.0221198	0.027	0.0225
Crab waist strength	4.80821	9.61641	5	10
Half crossing angle	0.415		0.413	

[8] https://kds.kek.jp/event/39142/contributions/194650/attachments/146581/182524/BBSKB2021ab.pdf

Highlights of first ITF-BB workgroup meeting

- Beam-beam effects in SuperKEKB [8]
  - Analysis of mode coupling for localized wake showed betatron tune affects the TMCI threshold.
  - TMCI threshold with localized wake is lower than prediction of ordinary theory.
  - The above findings agree with measurement.
  - Localized wake from collimators is so far the most convincing explanation for single-beam blowup in LER.



[8] https://kds.kek.jp/event/39142/contributions/194650/attachments/146581/182524/BBSKB2021ab.pdf