Updates on beam-beam simulations for SuperKEKB

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Acknowledgements

K. Ohmi, D. Shatilov, K. Oide,
and SuperKEKB commissioning group

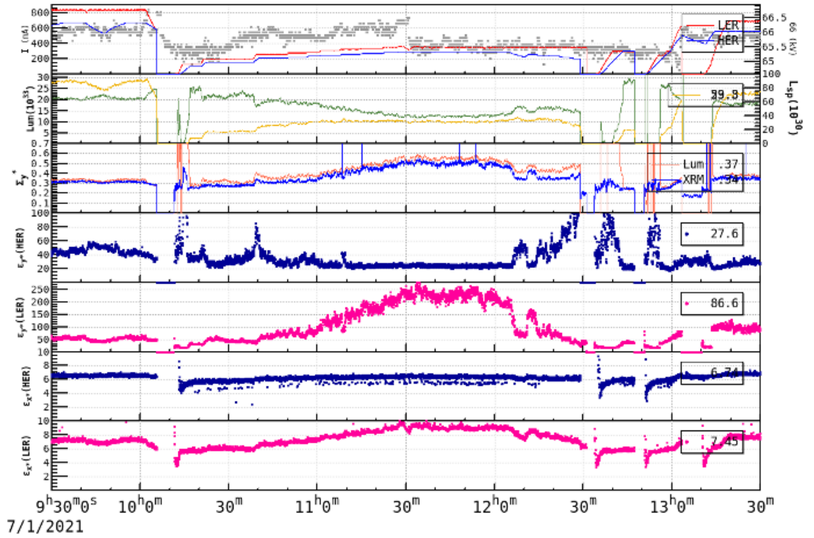
2nd meeting of beam-beam workgroup, Sep. 28, 2021, KEK

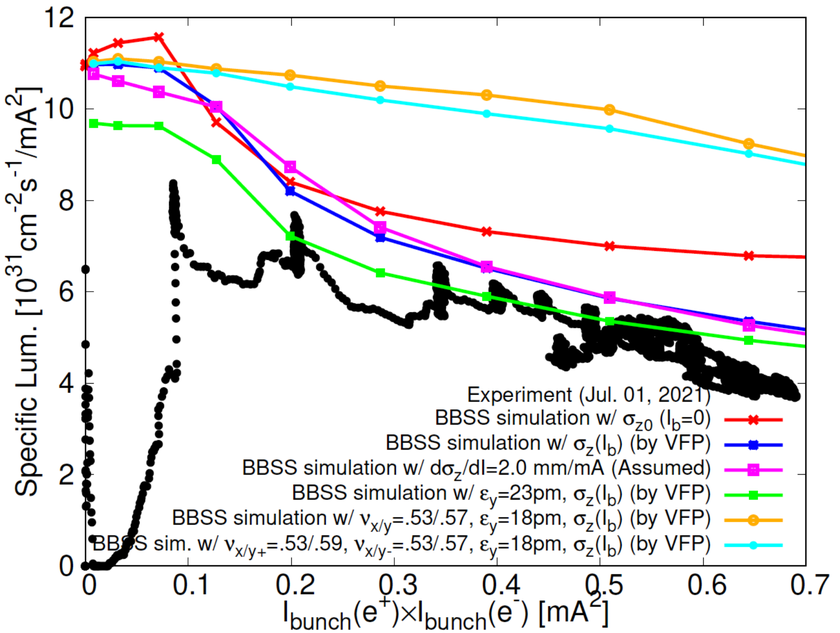
Old results

- Comparison of simulations with experiments
  - BBSS simulations were done to compare the experimental observations on Jul. 01, 2021 [1].
  - Luminosity: With inclusion of BBHTI in simulation, the slope of specific luminosity accidentally agreed with experiment.

	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

Luminosity history panel seen in SuperKEKB control room

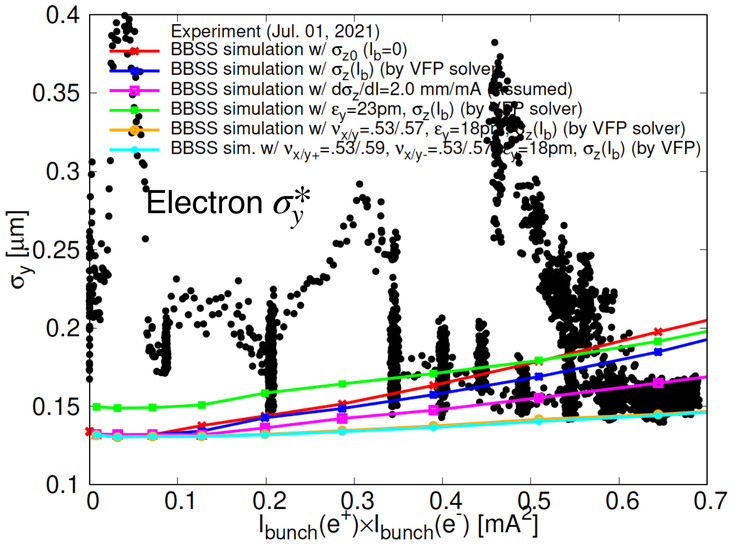


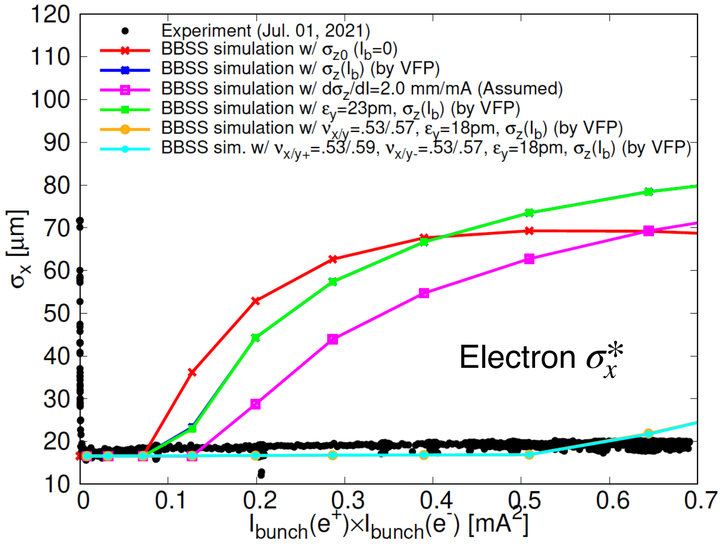


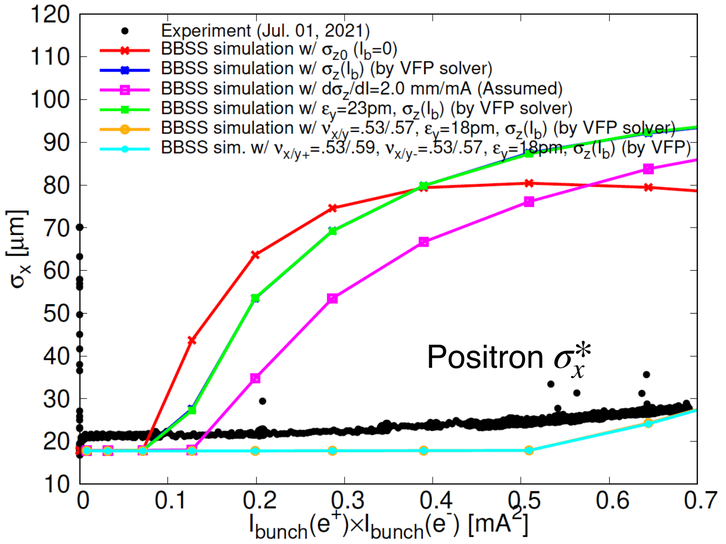
[1] D. Zhou, Talk presented at the 1st meeting of SuperKEKB beam-beam workgroup, KEK, Aug. 24, 2021, https://kds.kek.jp/event/39142/.

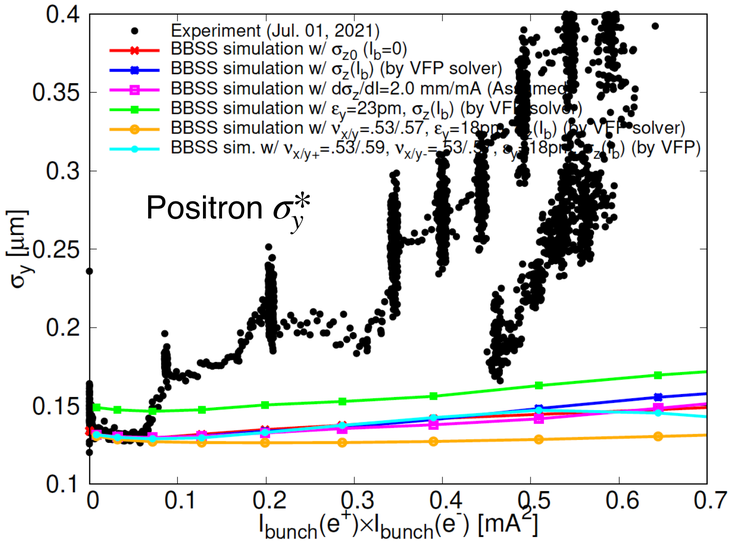
Old results

- Comparison of simulations with experiments (cont'd)
  - Horizontal blowup: Simulations showed strong BBHTI but experiment only showed remarkable blowup in LER beam.
  - Vertical blowup: Simulations totally disagree with experiment.





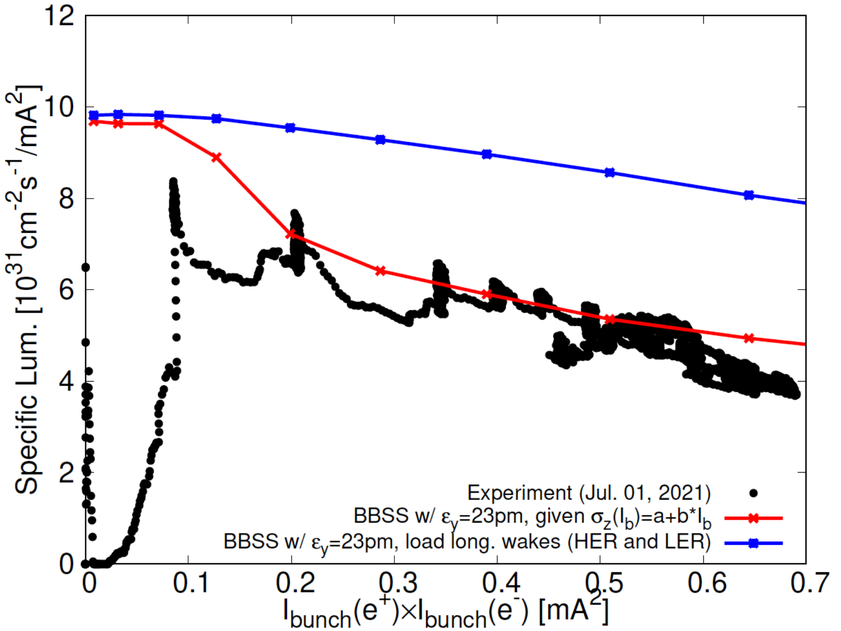


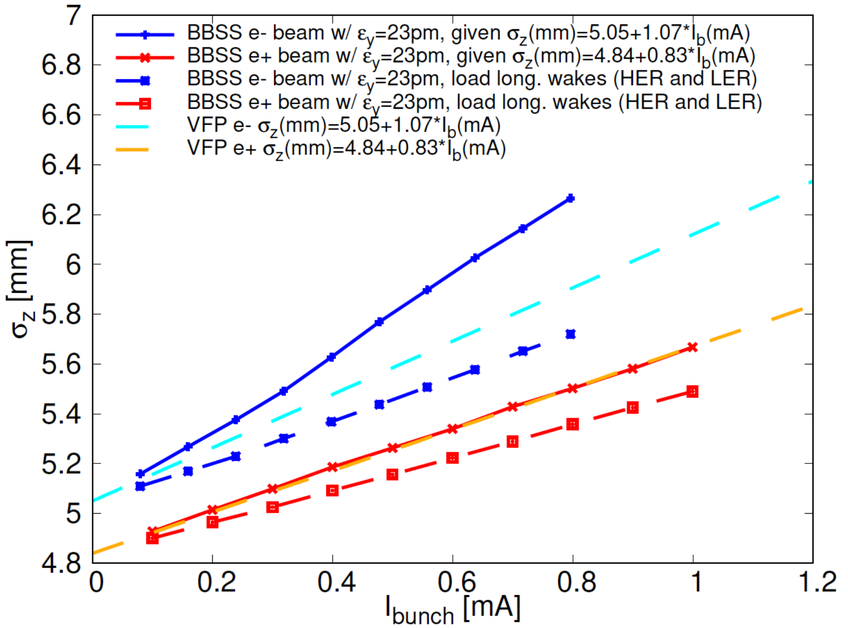


[1] D. Zhou, Talk presented at the 1st meeting of SuperKEKB beam-beam workgroup, KEK, Aug. 24, 2021, https://kds.kek.jp/event/39142/.

New results

- Simulations with longitudinal pseudo-Green function wakes
  - In the old simulations, I simply changed the bunch length in the input file of BBSS code. The bunch length was given by linear function $\sigma_z[\mathrm{mm}] = \sigma_{z0}[\mathrm{mm}] + A \cdot I_{\mathrm{bunch}}[\mathrm{mA}]$. A was determined by Vlasov solver using Pseudo-Green function wake. $A = 1.07$ for HER, and $A = 0.83$ [2].
  - In the new simulations, the Pseudo-Green function wakes were directly used. In BBSS code, the wakes are lumped at IP (1 wake kick per turn).
  - The luminosity loss caused by BBHTI disappeared, indicating strong effect of wake fields.
  - The bunch lengthening simulated by BBSS is weaker than Vlasov solver. Further investigation is necessary to understand the discrepancy.
  - In the old simulations, bunch lengthening of HER beam did not follow the given function. It might be due to BBHTI.
  - It might be necessary to take into account the dispersion effect (there are non-zero dispersion sections). This requires to distribute the wakes along the ring (multiple kicks perturb). The distributed wakes might affect the coupled synchrotron/betatron motion. [Suggested by K. Oide].

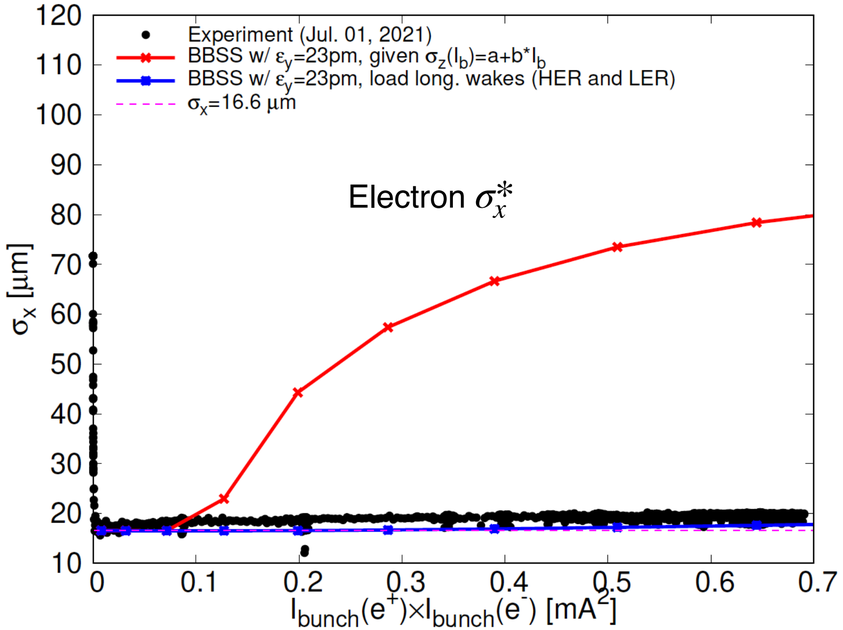


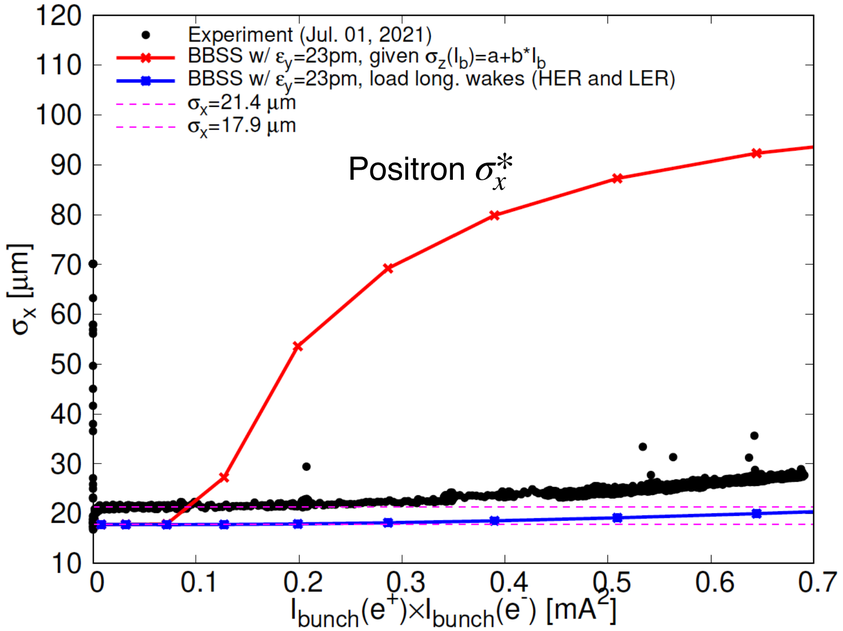


[2] Brief overview of impedance model: D. Zhou, Talk presented at the 1st meeting of SuperKEKB TMCI workgroup, KEK, Aug. 27, 2021, https://kds.kek.jp/event/39138/.

New results

- Simulations with longitudinal pseudo-Green function wakes (cont'd)
  - With beam-beam and wake effects modeled self-consistently, the BBHTI disappeared.
  - But blowup of horizontal beam sizes is visible in simulations. Blowup in LER beam is stronger than that in HER beam.
  - Somehow simulations agree with experiment?
  - Horizontal blowup at low bunch currents is related to feature of X-ray monitor (see next page)?

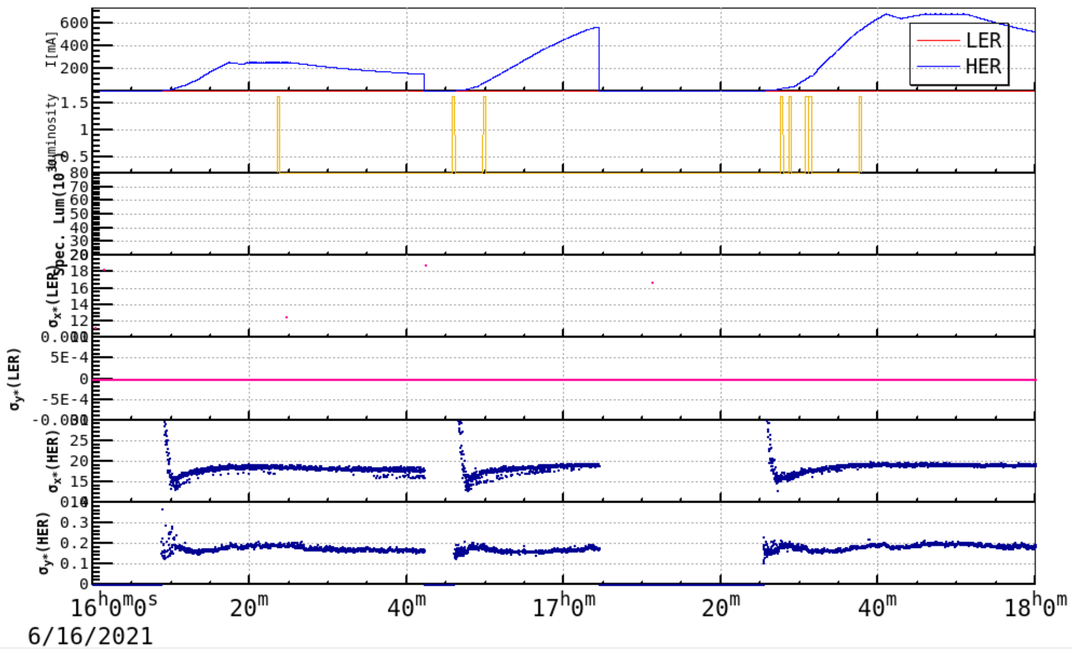




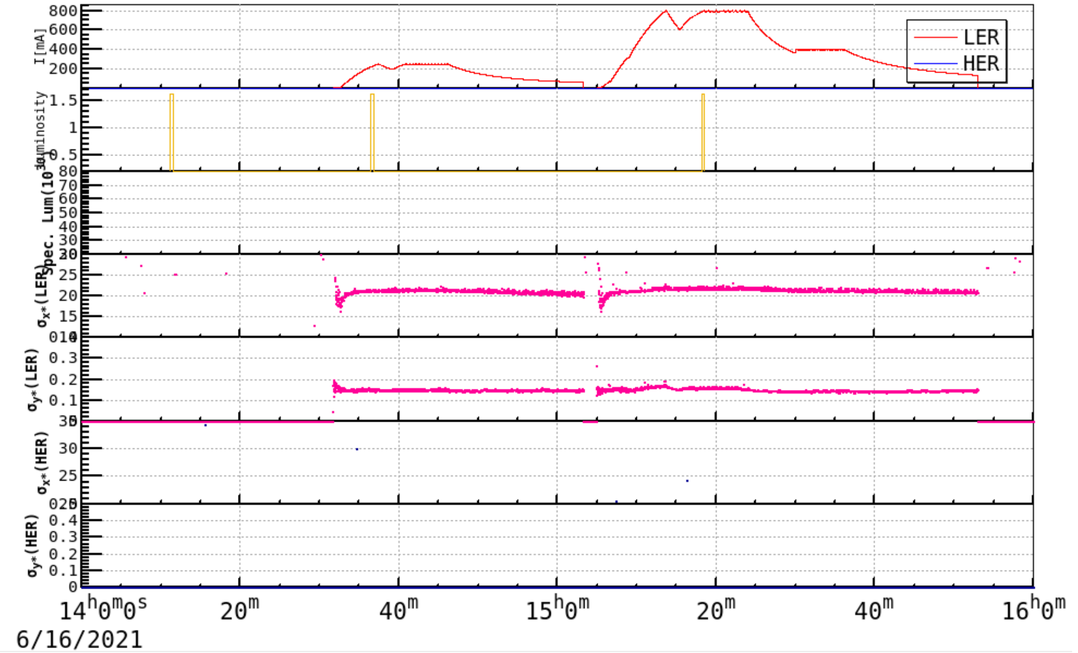
New results

- Simulations with longitudinal pseudo-Green function wakes (cont'd)
  - In experiment, horizontal blowup happened at quite low bunch current (pointed out by Y. Ohnishi). This was also observed in single-beam mode (both HER and LER), and might be related to feature of X-ray monitors (to be confirmed).

History of beam sizes in single-beam mode (HER)

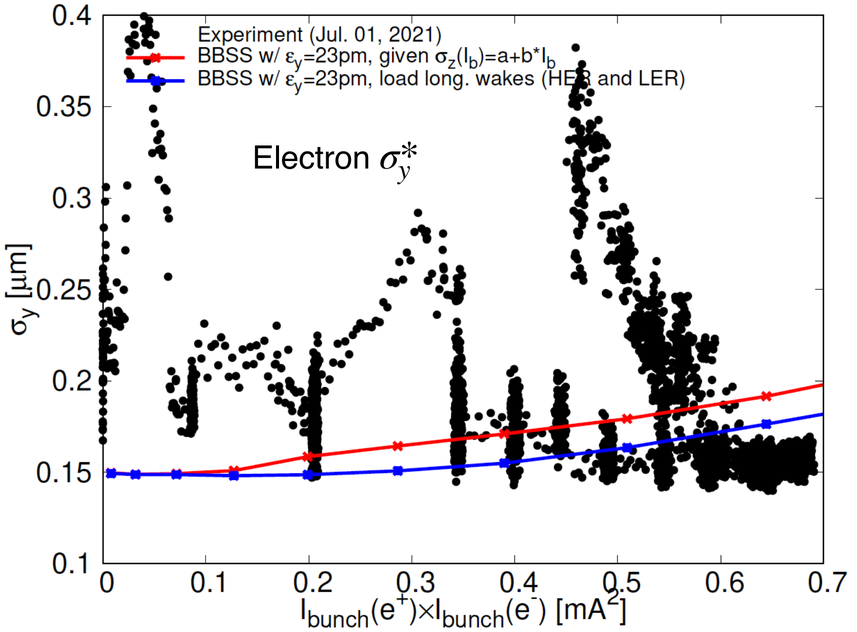


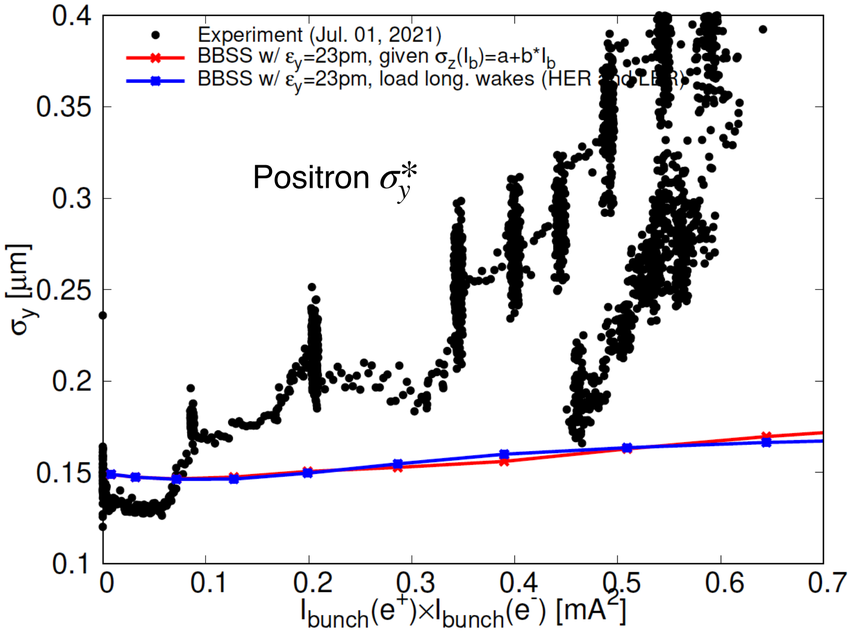
History of beam sizes in single-beam mode (LER)



New results

- Simulations with longitudinal pseudo-Green function wakes (cont'd)
  - For vertical blowup, new simulations do not show big difference.
  - To predict the experiments, other sources are necessary to be included in beam-beam simulations.
  - Candidates sources: Transverse wakes, collision offset noise, IP aberrations (chromatic coupling, third-order RDTs, etc.) [3], and others?





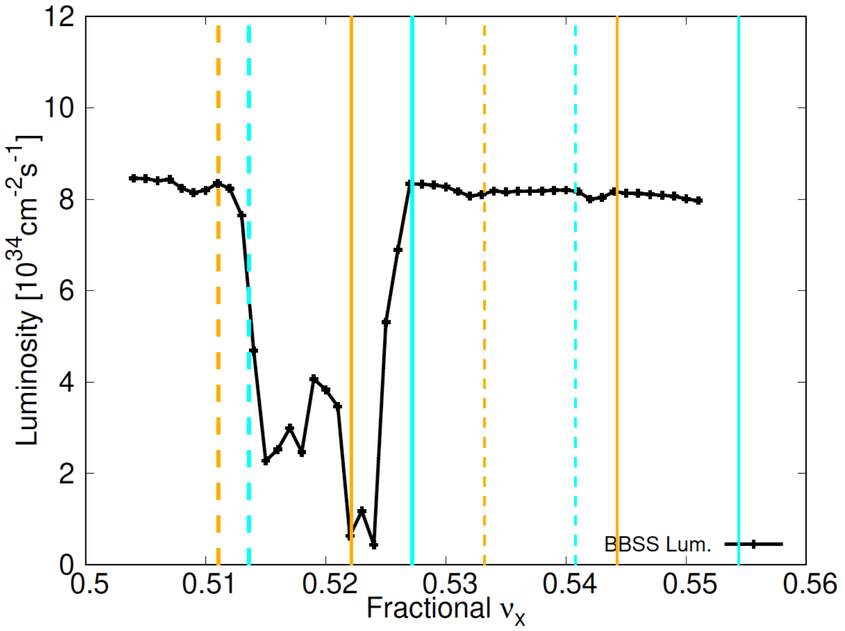
[3] K. Ohmi, Talk presented at the 1st meeting of SuperKEKB beam-beam workgroup, KEK, Aug. 24, 2021, https://kds.kek.jp/event/39142/.

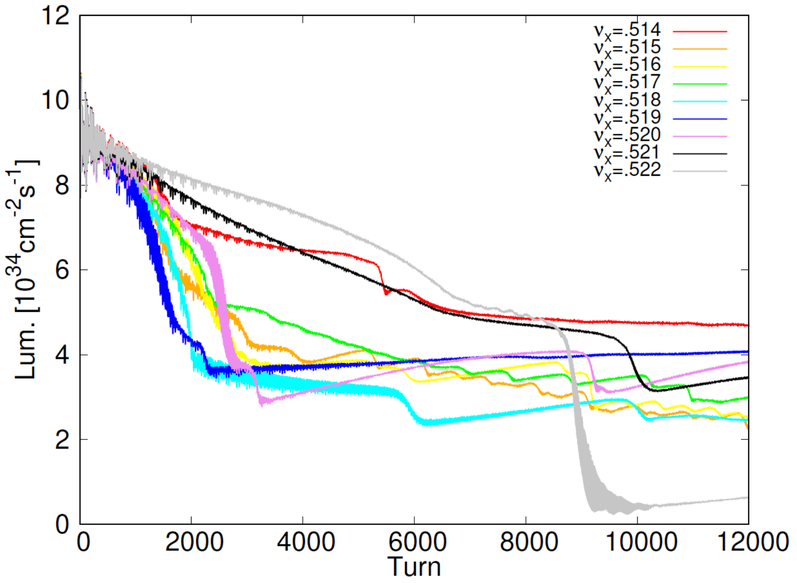
New results

- Tuen-scan with longitudinal pseudo-Green function wakes
  - Beam parameters similar to observations on 2021.07.01.
  - Assume equal ν_x for HER and LER. Fractional vertical tune set as $\nu_y = .57$, scan ν_x. Track 2e6 macro particles to 12000 turns.
  - Plots: Luminosity and beam sizes (the data at the last turn) as a function of ν_x.
  - Data for $0.513 < \nu_x < 0.526$ do not arrive at equilibrium.

	2021.07.01		Comments
	HER	LER	
I_{bunch} (mA)	0.80	1.0	
# bunch	1174		Assumed value
ε_x (nm)	4.6	4.0	w/ IBS
ε_y (pm)	23	23	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	4.84	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

Synchro-betatron resonances: $\nu_x - k\nu_s/2 = N/2$
Odd k: Dashed lines; Even k: Solid lines
Orange lines: LER; Cyan lines: HER

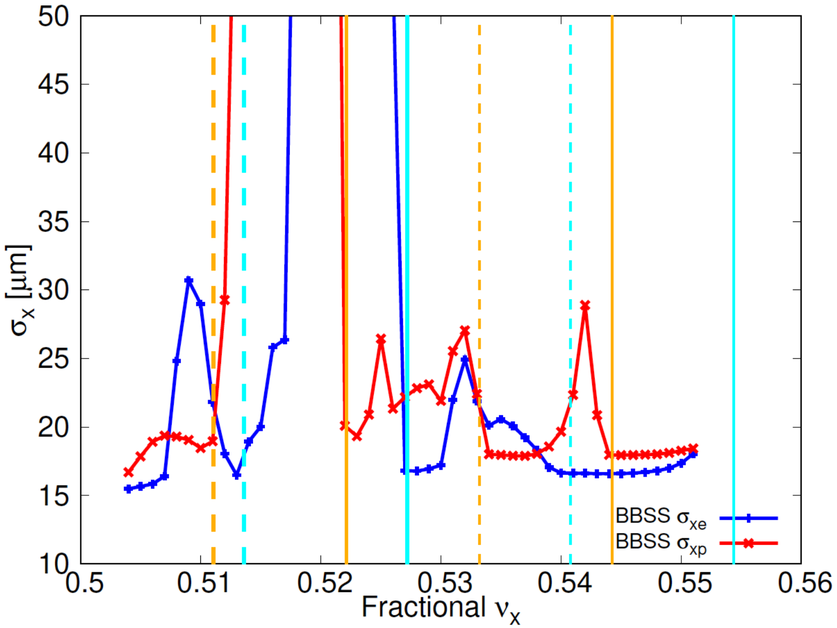


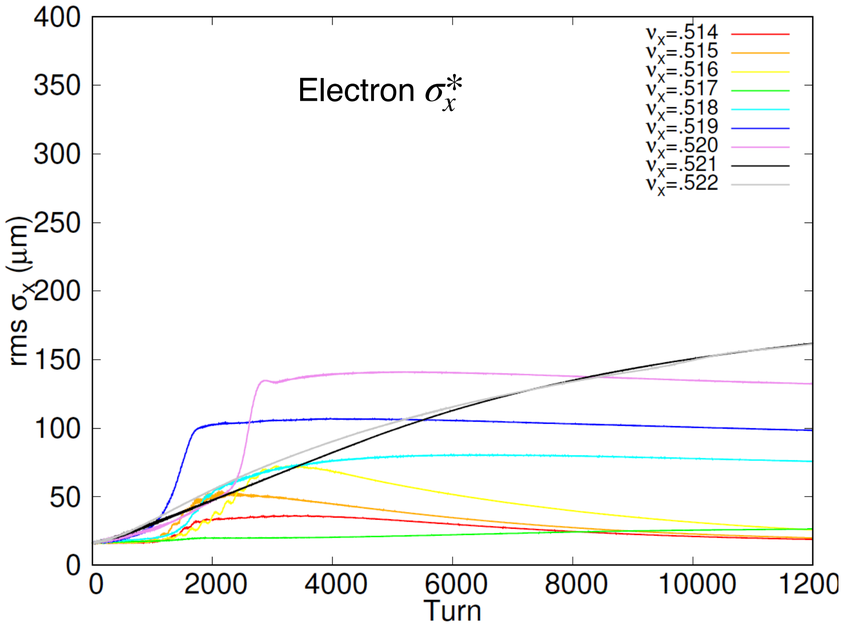


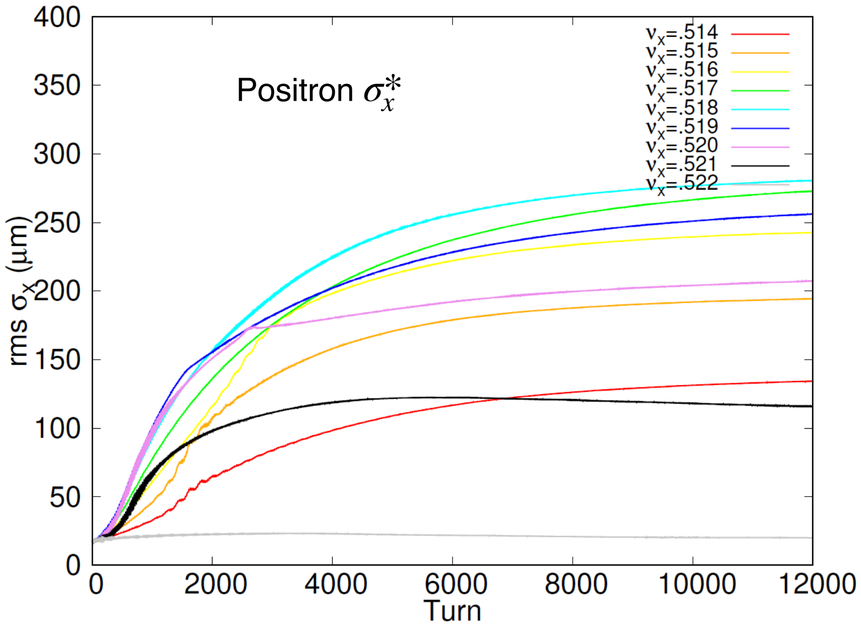
New results

- Tuen-scan with longitudinal pseudo-Green function wakes (cont'd)
  - There seems to be strong BBHTI on the left side of $\nu_x - \nu_s = N/2$. The shift of peaks is proportional to synchrotron tune shift caused by longitudinal wake?
  - There are other peaks near $\nu_x - k\nu_s/2 = N/2$.
  - With longitudinal wakes, the horizontal blowups of the two beams seems to be asymmetric.

Synchro-betatron resonances: $\nu_x - k\nu_s/2 = N/2$
Odd k: Dashed lines; Even k: Solid lines
Orange lines: LER; Cyan lines: HER



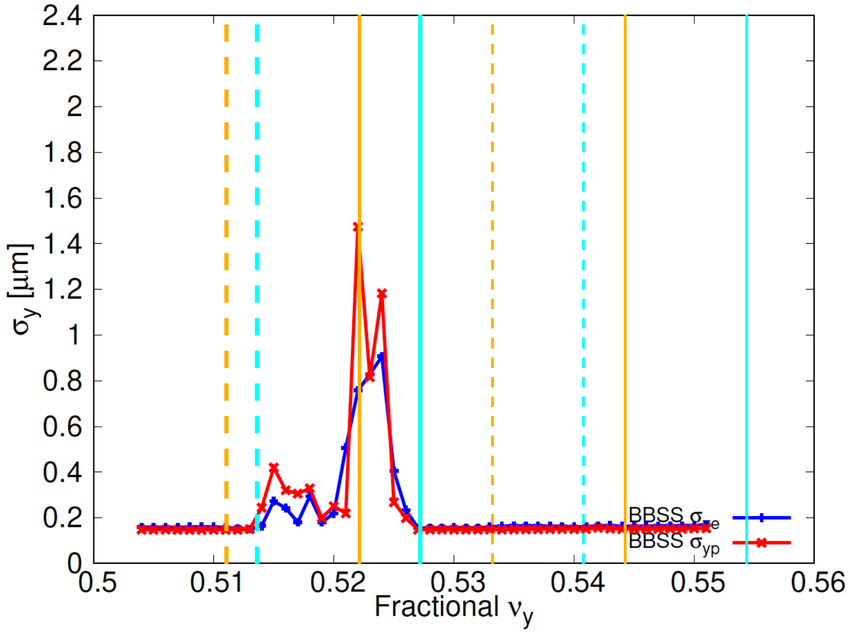


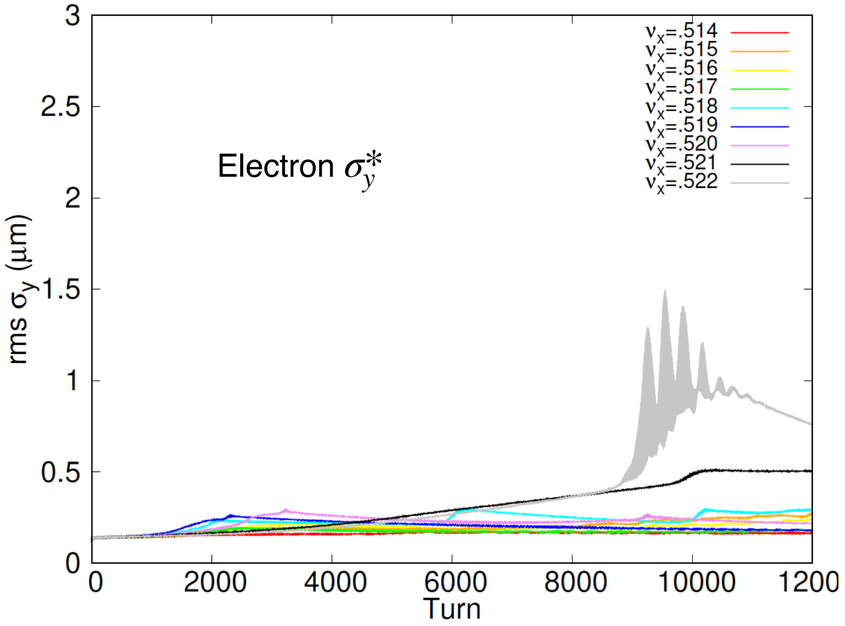


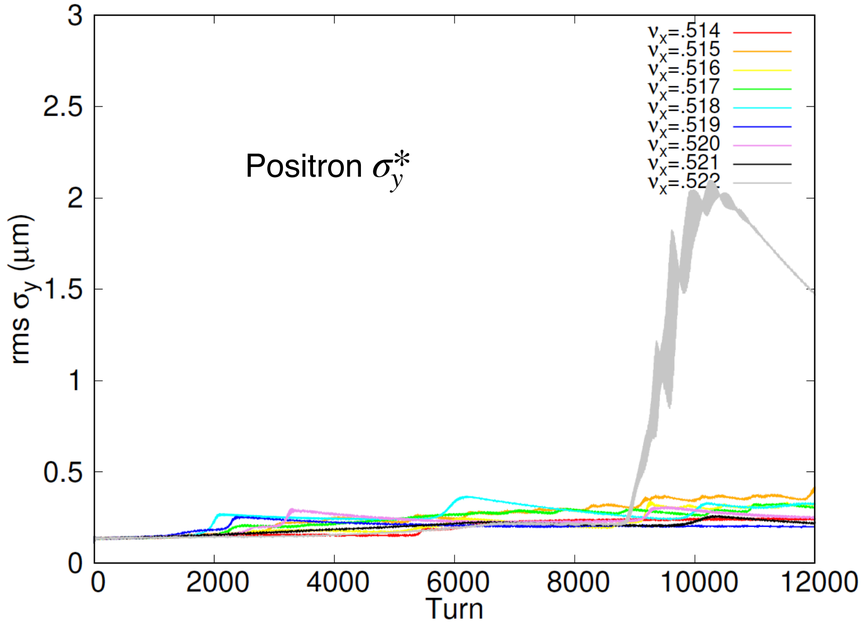
New results

- Tuen-scan with longitudinal pseudo-Green function wakes (cont'd)
  - Vertical blowup seems to occur only with $0.513 < \nu_x < 0.526$, and is related to BBHTI.
  - With ν_x away from $0.513 < \nu_x < 0.526$, there seems to be no vertical blowup.

Synchro-betatron resonances: $\nu_x - k\nu_s/2 = N/2$
Odd k: Dashed lines; Even k: Solid lines
Orange lines: LER; Cyan lines: HER



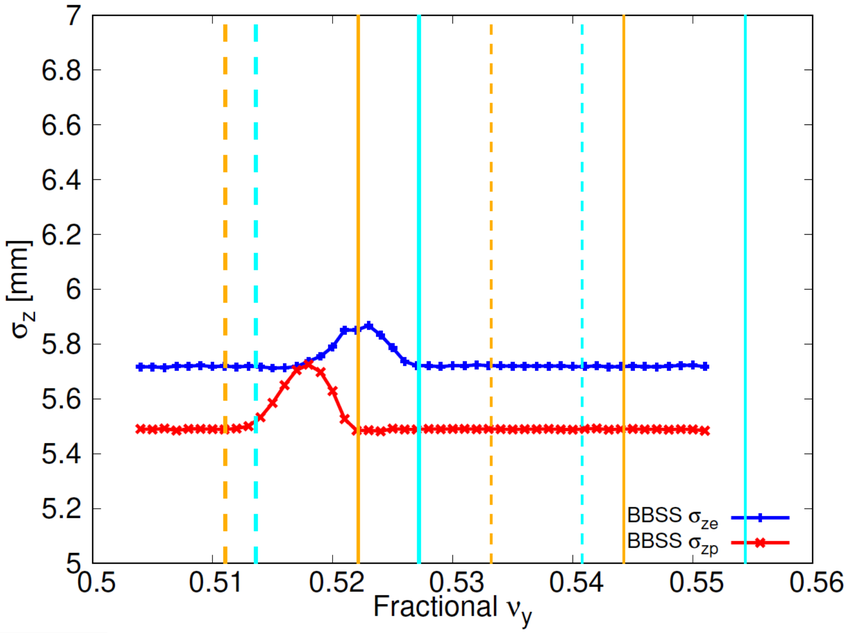


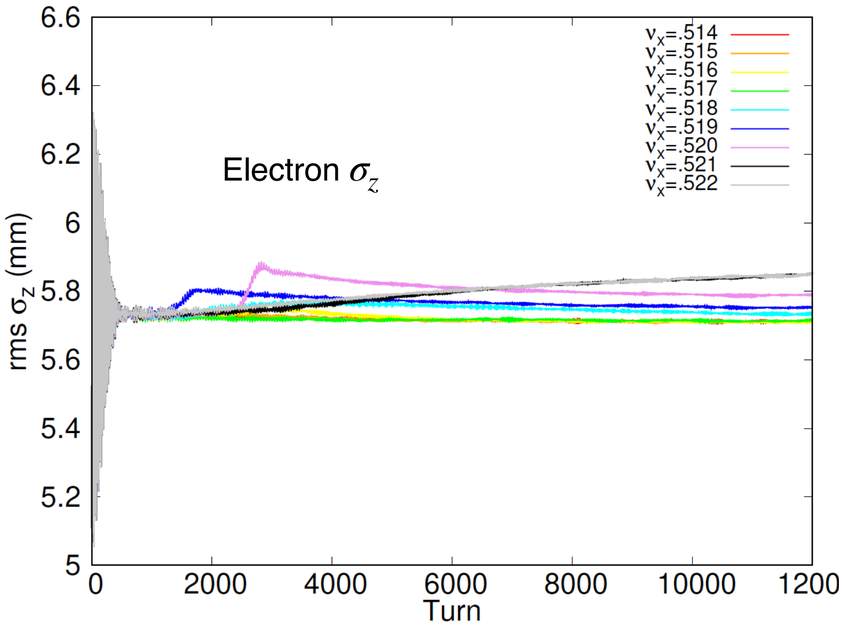


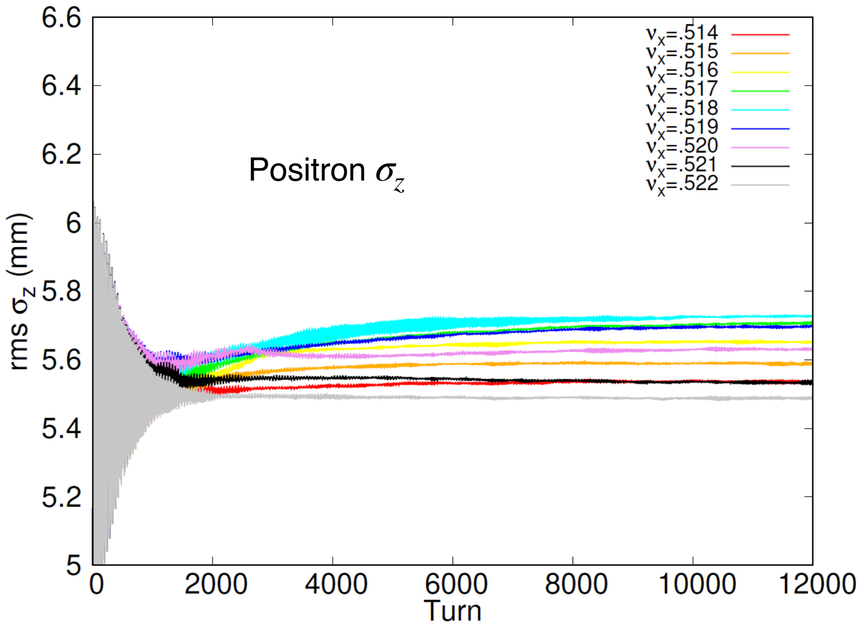
New results

- Tuen-scan with longitudinal pseudo-Green function wakes (cont'd)
  - Bunch lengthening seems to occur only with $0.513 < \nu_x < 0.526$, and is related to BBHTI.

Synchro-betatron resonances: $\nu_x - k\nu_s/2 = N/2$
Odd k: Dashed lines; Even k: Solid lines
Orange lines: LER; Cyan lines: HER







Summary

- Beam-beam simulations with longitudinal pseudo-Green function wakes for fixed working point: HER $(\nu_x, \nu_y) = (0.532, 0.582)$, LER $(\nu_x, \nu_y) = (0.525, 0.593)$
  - Using the beam parameters observed on 2021.07.01, BBSS simulations were updated with wakes included in a self-consistent treatment.
  - The BBHTI disappeared when wakes were included.
  - Weak horizontal blowup were seen in simulations when wakes were included.
  - New simulations still cannot explain vertical blowup.
- Horizontal tune scan of BBSS simulations for fixed $\nu_y = 0.57$ (HER and LER)
  - BBHTI appears near $\nu_x - k\nu_s/2 = N/2$ but the position of peaks were shifted by wakes.
  - BBHTI seems not to be dangerous when $\nu_x > 0.53$? (Require simulations at higher bunch currents.)
  - Do the simulations justify the necessity of equalizing ν_s?
- Outlook
  - Further investigations in BBSS simulations with wakes.
  - To include other sources causing vertical blowup.
  - Benchmark simulations are welcome.