Beam-beam simulation

2025/01/15

@ KEKB Accelerator Review Committee

Yasuhiro Yamamoto (KEK)

on behalf of the beam-beam working group

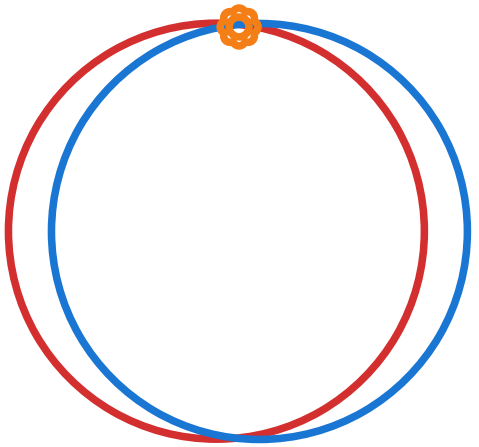
(Y. Funakoshi, K. Ohmi, Y. Onishi, H. Sugimoto, S. Uno)

Beam-beam Interaction

Inevitable source of a large non-linear effect in collider.

Bunch length/ Circumference ~ a few ppm.

- Luminosity
- Emittance and instability
- Injection efficiency
- Life time ...



10^{10} non-linear e.o.m → simulation

2024ab and c

Beam-beam related issues limit luminosity in 2024ab.

- LER V/H emittance growth.
- LER injection efficiency drops ~ 1.4 A

BB working group is started from 24 Jul.

- 8 meetings are held by now.
- D. Zhou (KEK) and M. Li (IHEP/Saclay) also contribute simulation studies.

Topics

Injection efficiency

- LER (Funakoshi, Y.Y.), HER (Li, Sugimoto, Y.Y.)
- HER synchrotron injection (Funakoshi, Y.Y)

Crab waist and specific luminosity

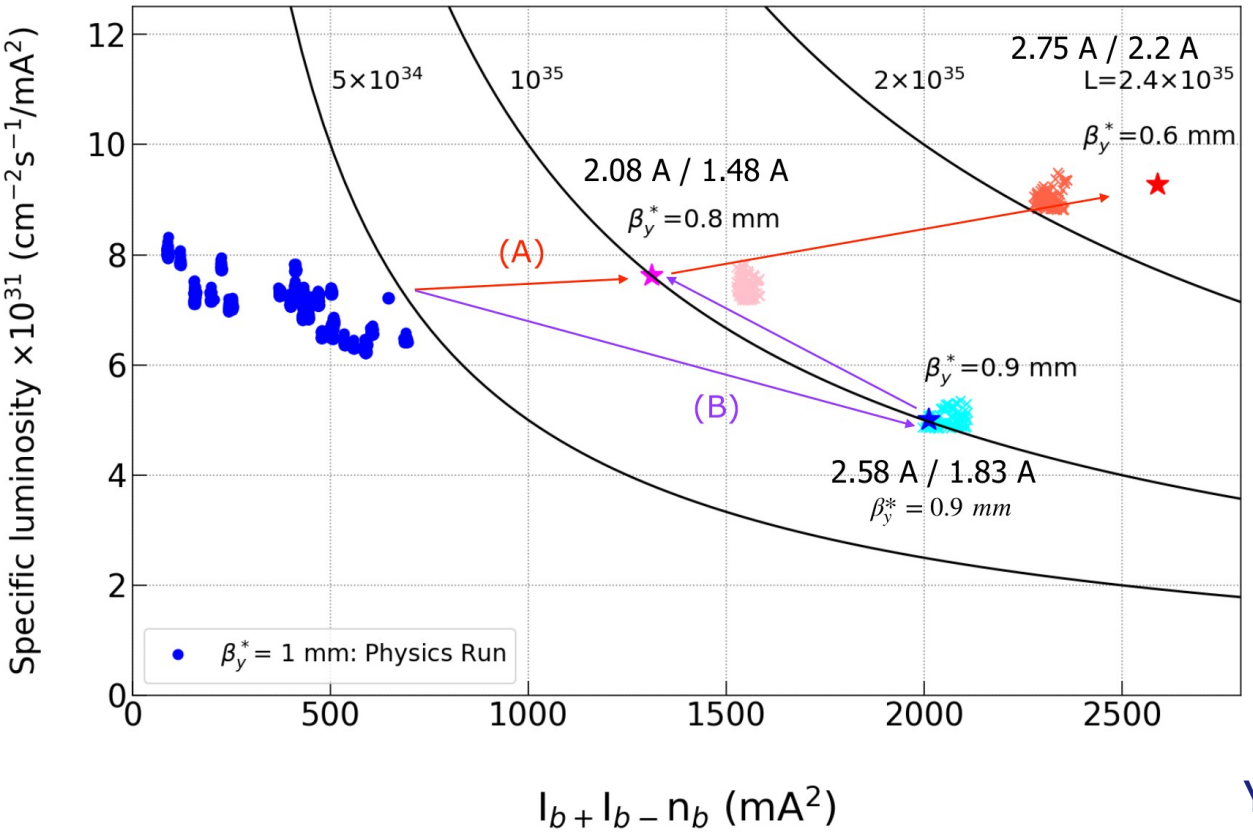
- Observed benefits (Onishi, Funakoshi)
- Simulation (Zhou)

Beam-beam instability

- X-Z oscillation (Ohmi)
- Y-Z oscillation (Ohmi, Sugimoto)

Luminosity and bunch currents

High bunch currents are essential for high L.

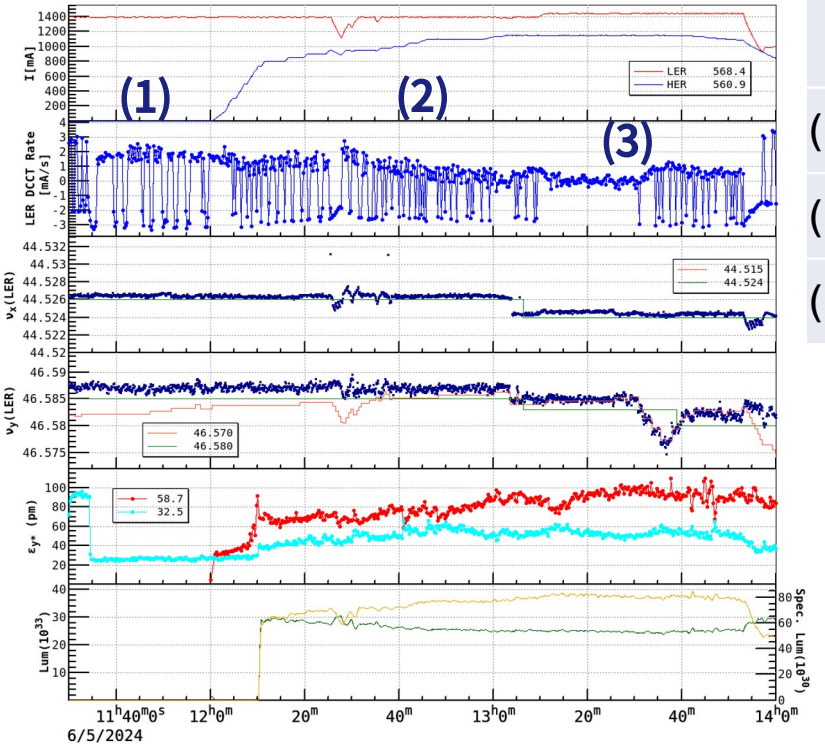


Y. Funakoshi

→ $I_b^+ I_b^-$ ~ 0.6/0.7 mA^2 for 10^{35} , 1.1mA^2 for 2.4x10^{35}

Limits of currents

LER injection is difficult for $I_b^+ I_b^- \gtrsim 0.3$ mA^2
(I_{LER} ~ 1450 mA for 2346 bunches)



	Ibeam (LER)	Ibeam (HER)	IncRate (L)	Life (L)	InjEff (L)
(1)	1395 mA	0 mA	1.68mA/s	7.3 min.	77.4%
(2)	1395mA	1100mA	0.42mA/s	8.9 min.	48.0%
(3)	1444mA	1100mA	1.02mA/s	8.0 min.	64.8%

(1) LER single beam

(2) Low inj. eff. with collision

(3) Lower tunes

Y. Funakoshi

Tune options

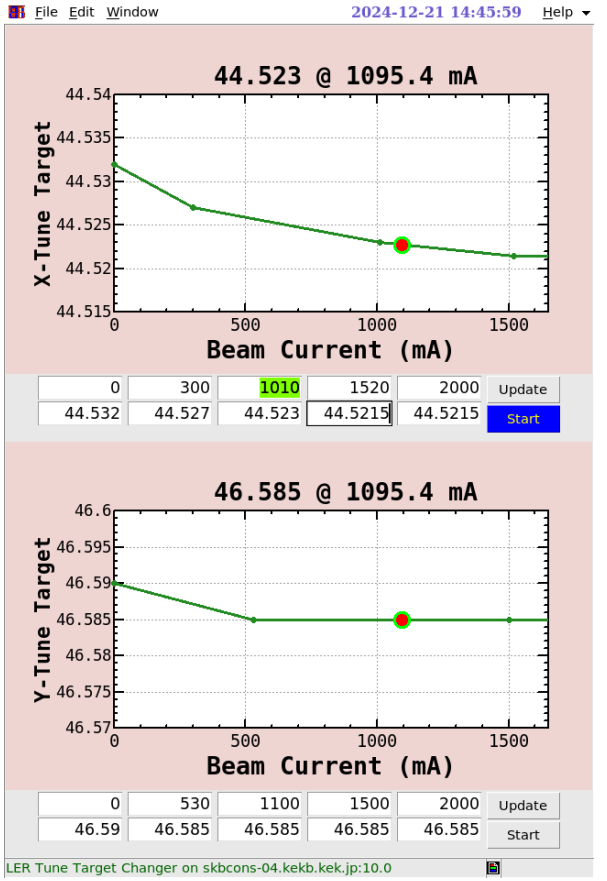
Lower H tune (ν_x : 0.525)

- Beam loss caused by LER injection stop.

Higher H tune (ν_x : 0.543)

- Higher currents are possible.
- Low Lsp.
- Beam abort with QCS quench.
- More tuning is needed.

→ Lower tune operation.



Simulation set up

Beams

- Made by BT simulations (Iida, Yoshimoto).

Beam-beam effect

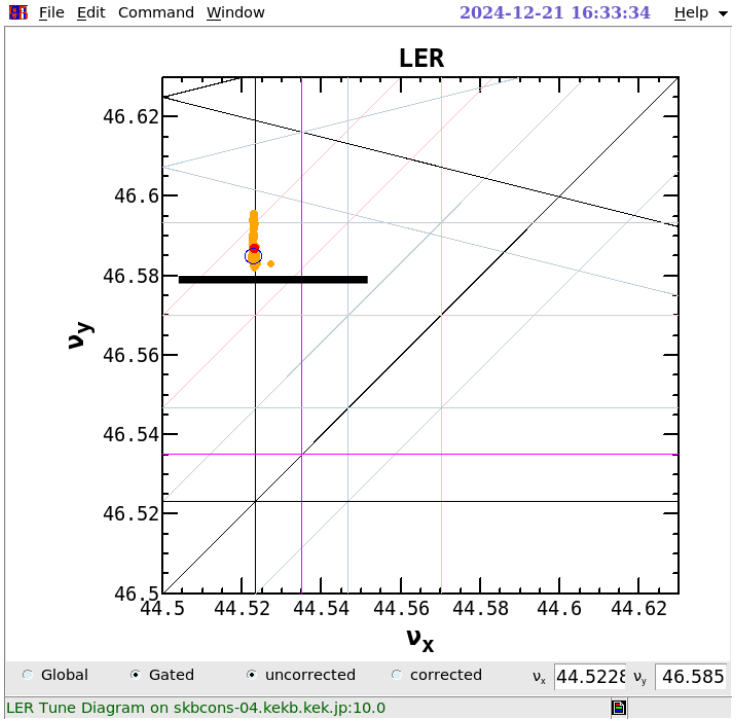
- Strong-weak simulation with SAD.
- LER : 2.6 A; HER : 1.85 A (for 2346 bunches).

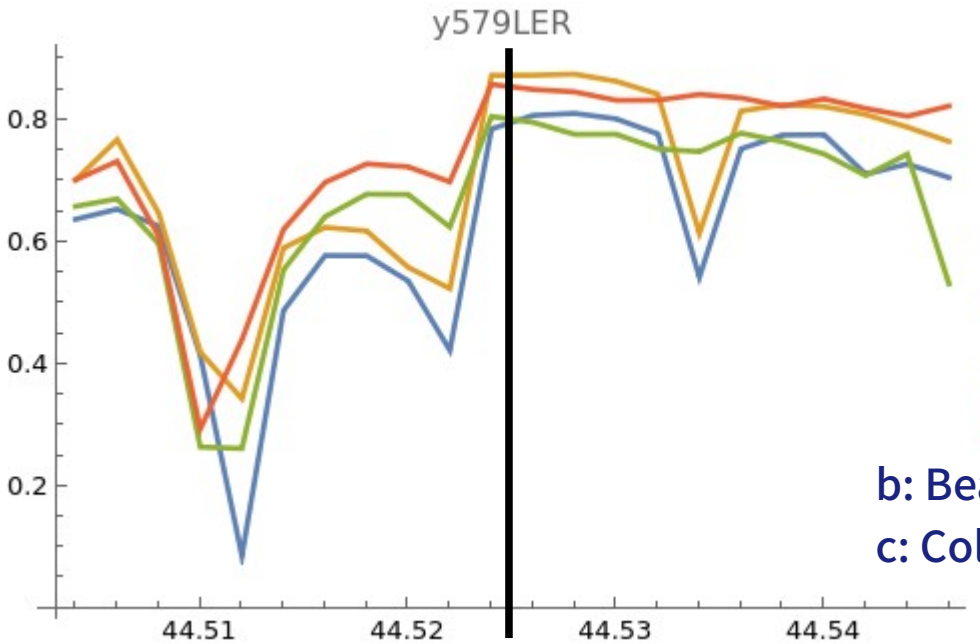
Injection efficiency

- Survival rate after 1000 turns.

LER injection x-tune scan

Injection eff @ machine : 80%+-20%





b: Beam-beam
c: Collimator

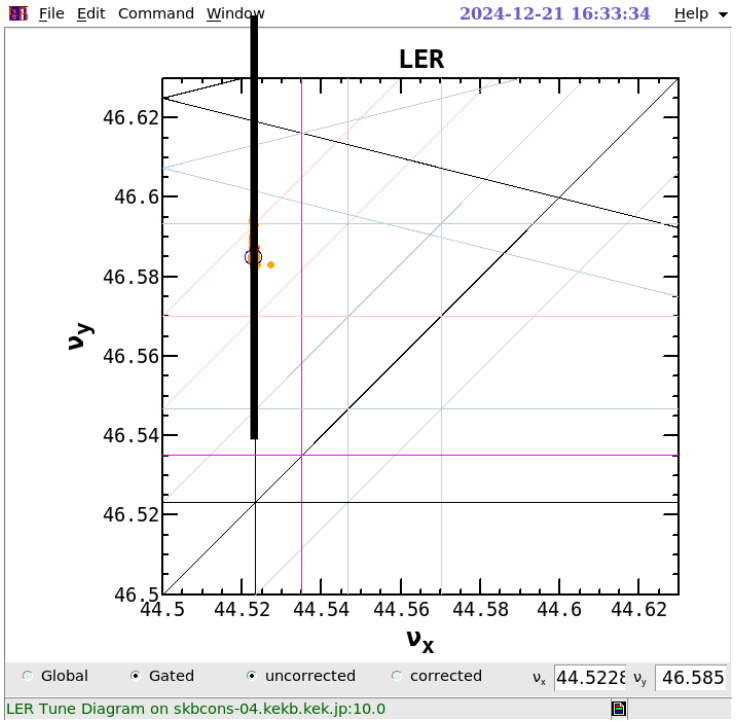
Similar injection eff is reproduced.

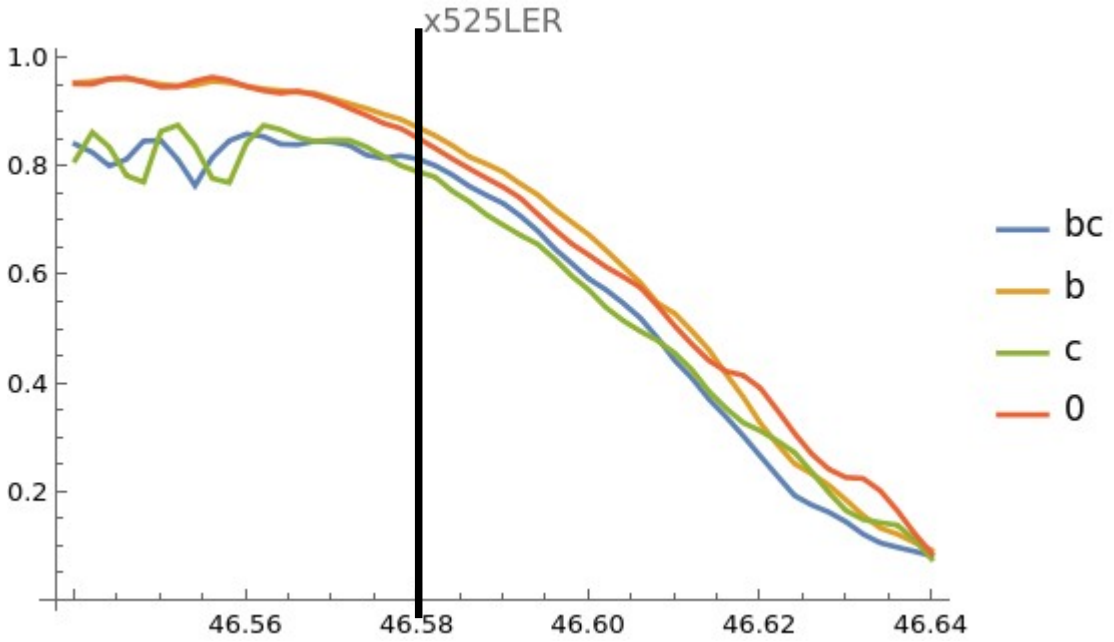
Collimators reduce 10% of injection eff.

No strong beam-beam effect is observed.

LER injection y-tune scan

Injection eff is roughly reproduced well.





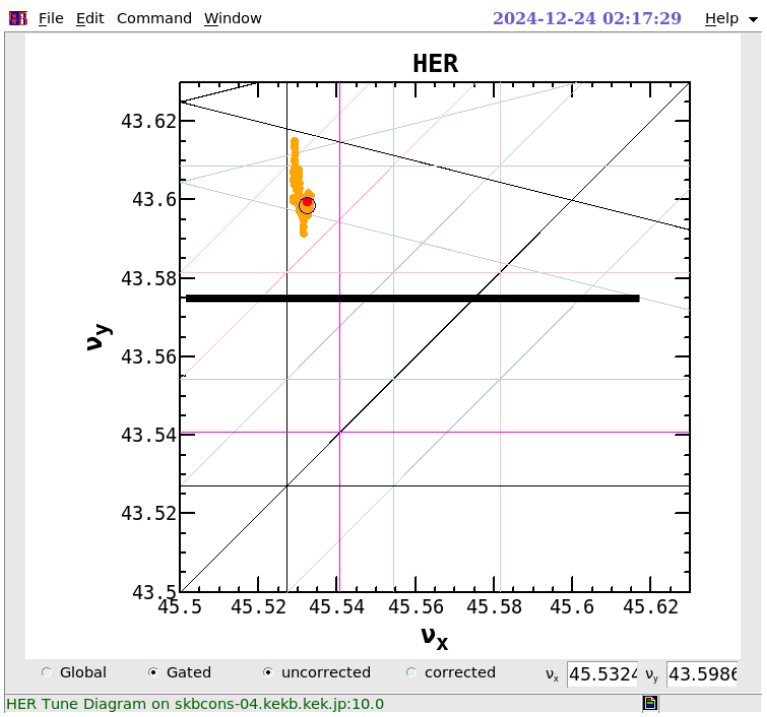
Chromatic coupling resonance ~ 0.575.

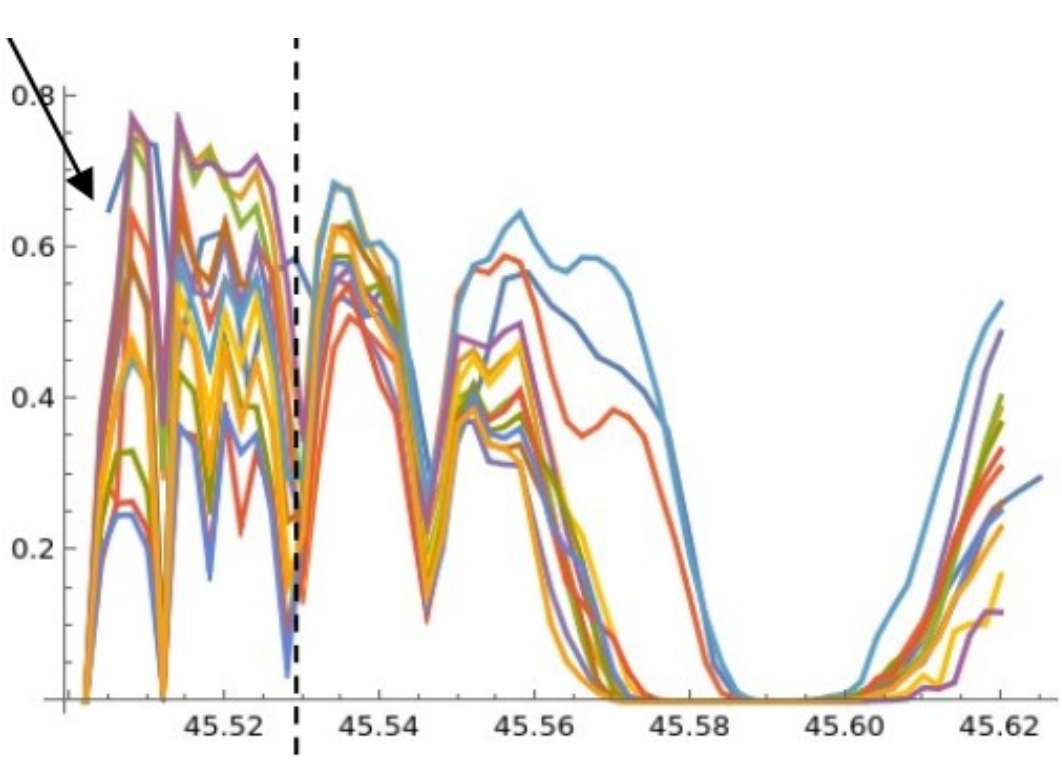
Lower injection eff with higher tune.

HER injection x-tune scan

Injection eff @ machine : 60%+-20%

Vertical offsets @ 6-poles with random #.

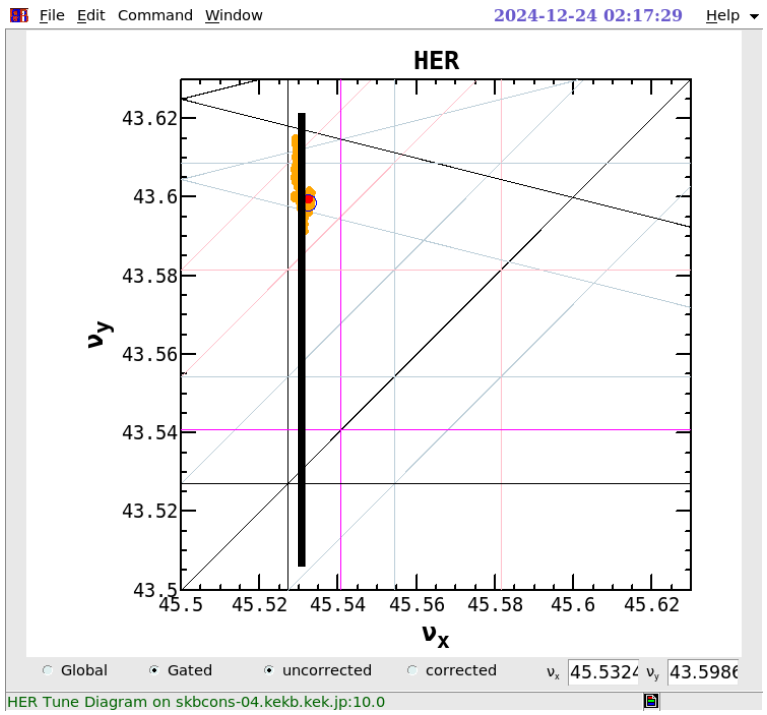


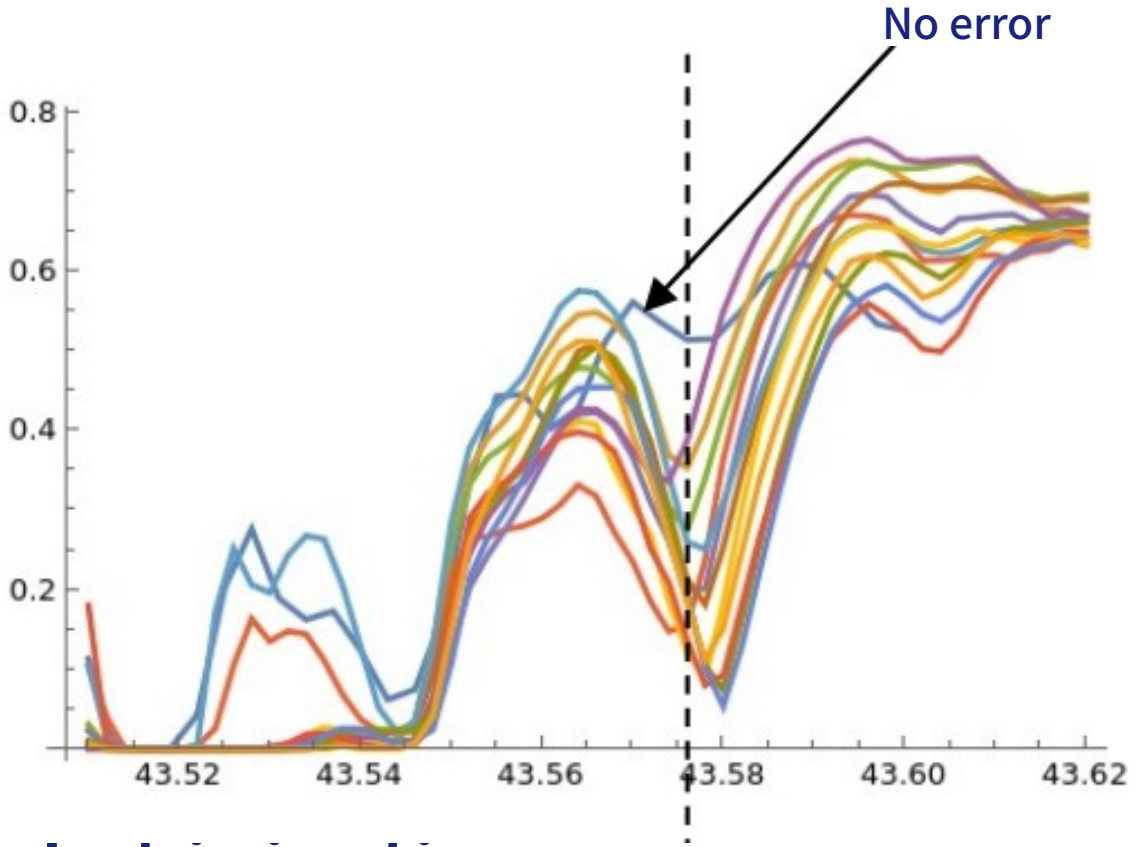


Smaller tune is slightly favored.

HER injection y-tune scan

Higher tune is better for injection.



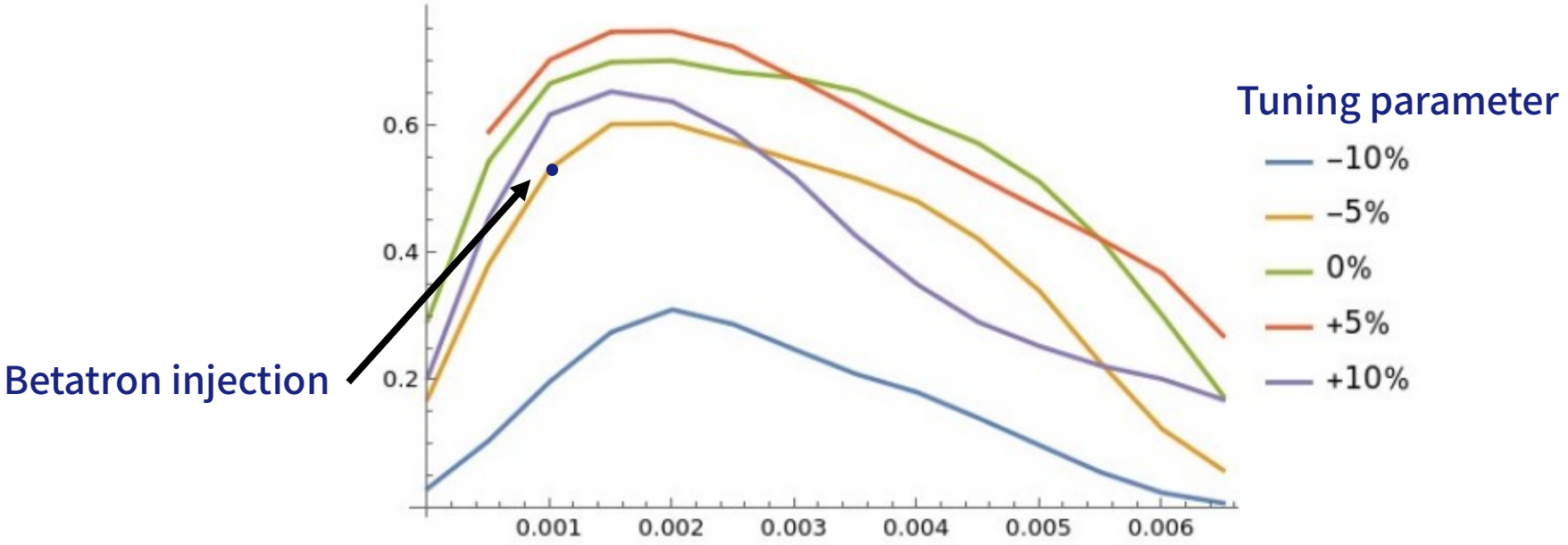


0.595 can be good at injection.

0.62 is stable for 6-pole errors.

HER synchrotron injection

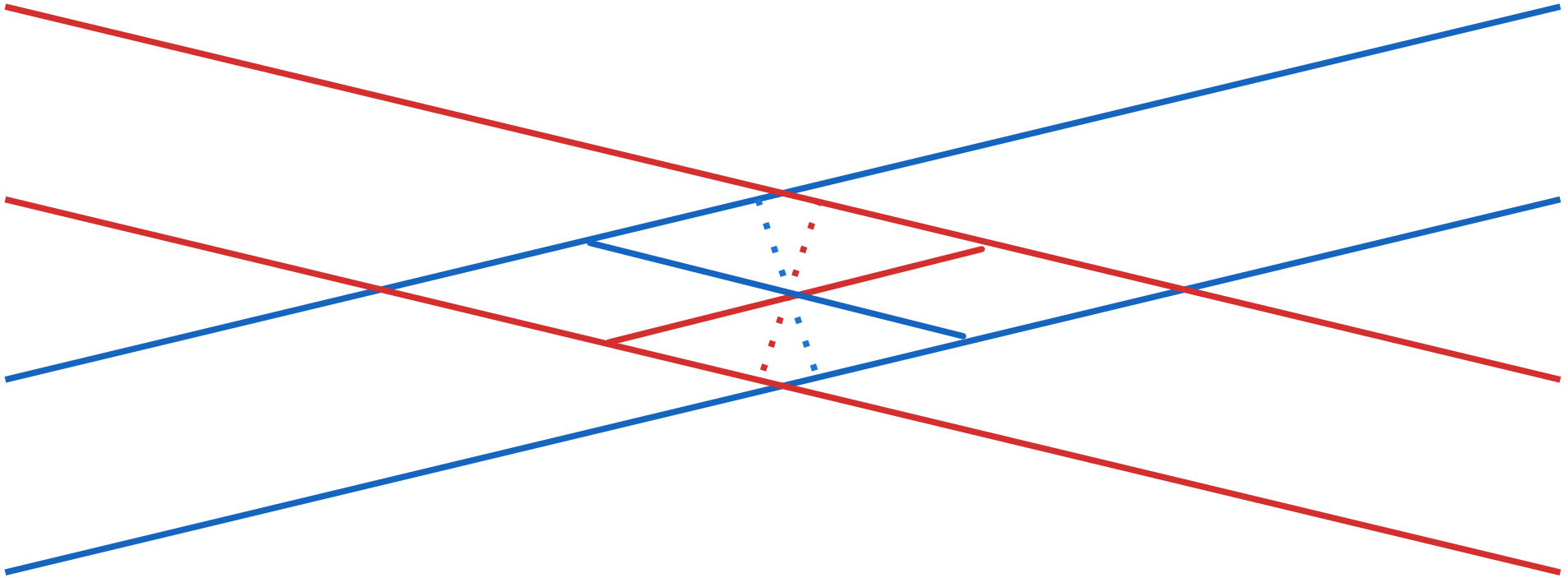
Synchro-betatron injection can be helpful.



Result can be improved by matching.

More simulation is needed with future optics.

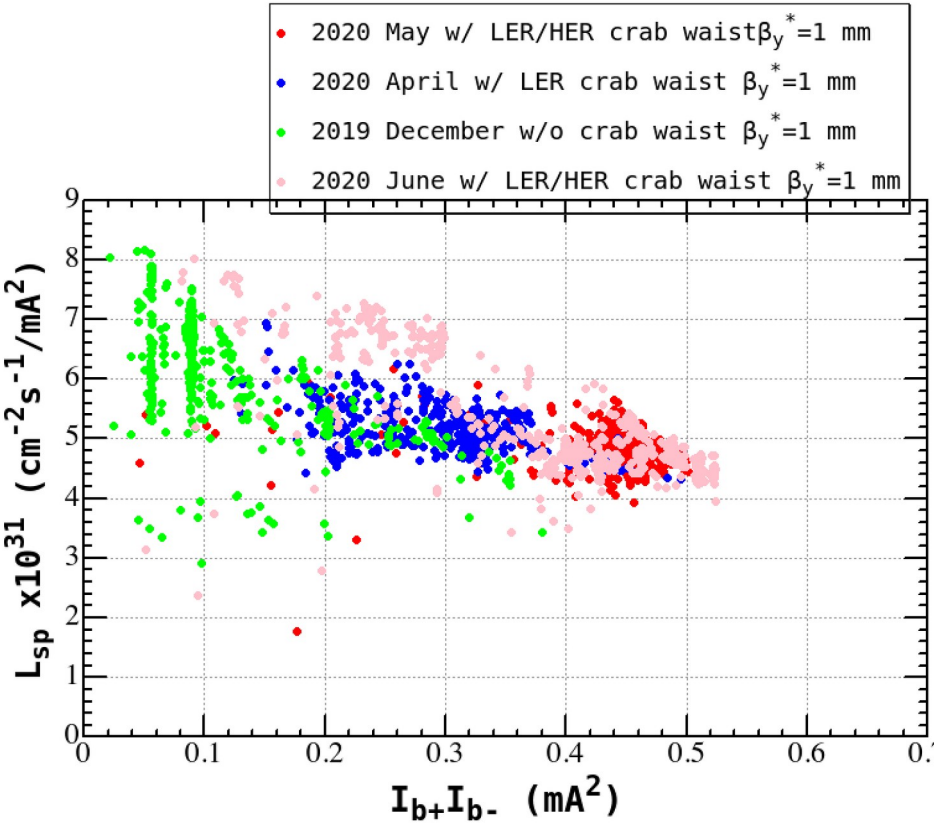
Crab waist

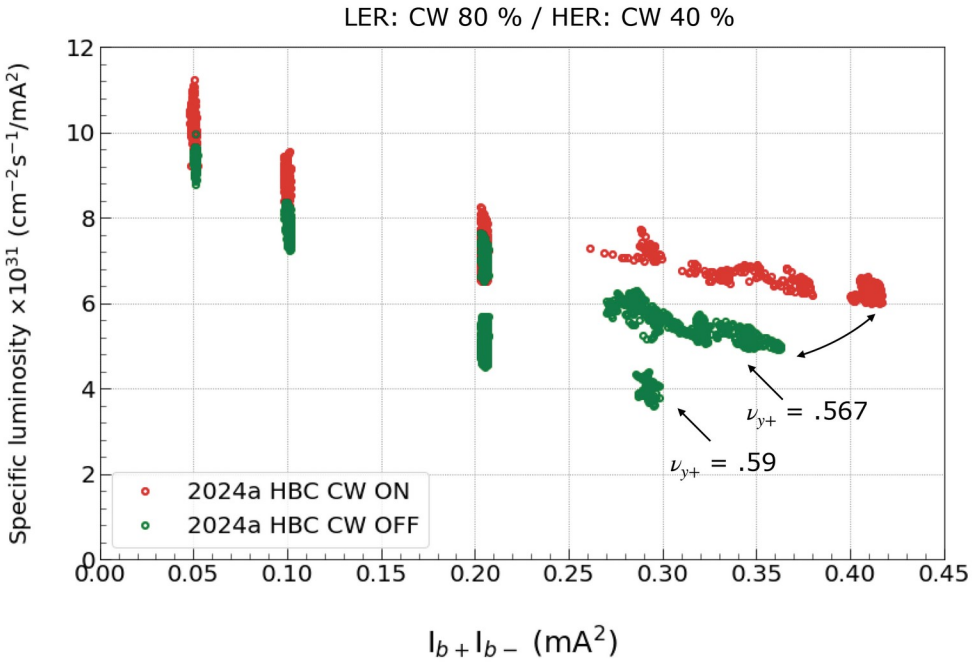


Lsp is increased with more low beta crossing.

Extra beam-beam effect is also reduced.

Observed benefits



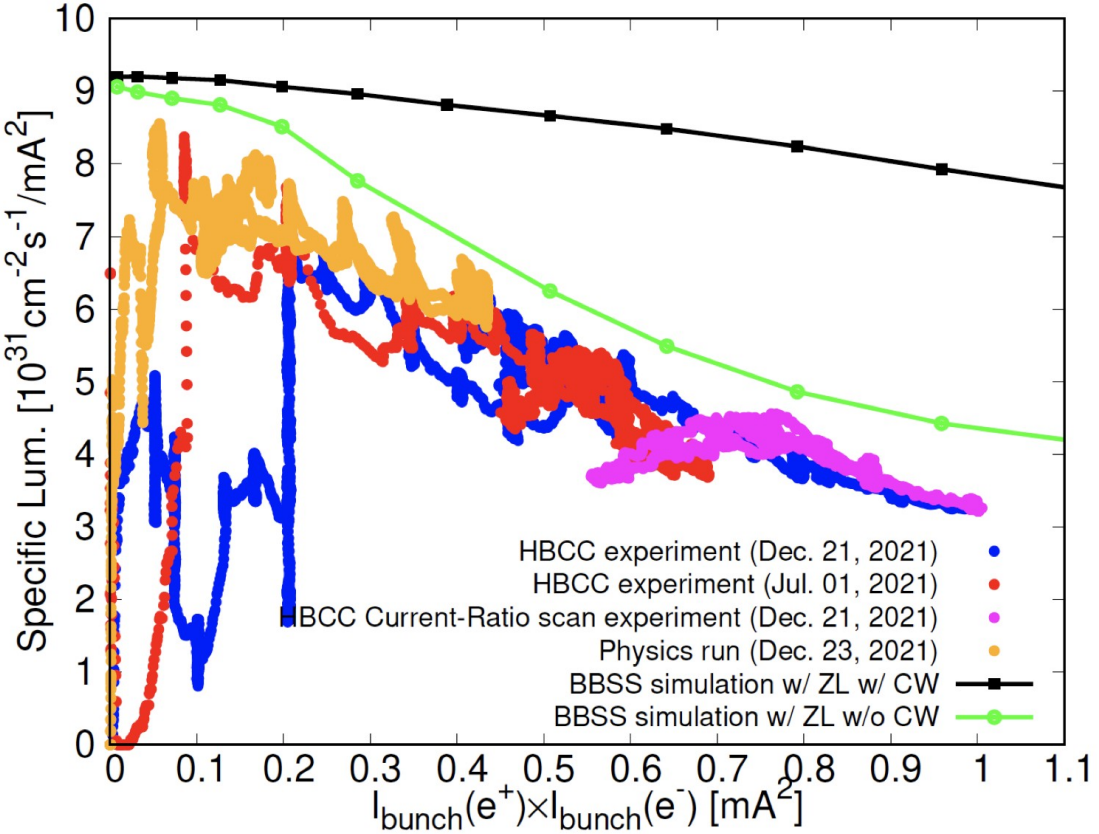


Lsp is increased with CW.

Higher bunch currents are achieved.

Simulation of Lsp

Current data look like without CW.

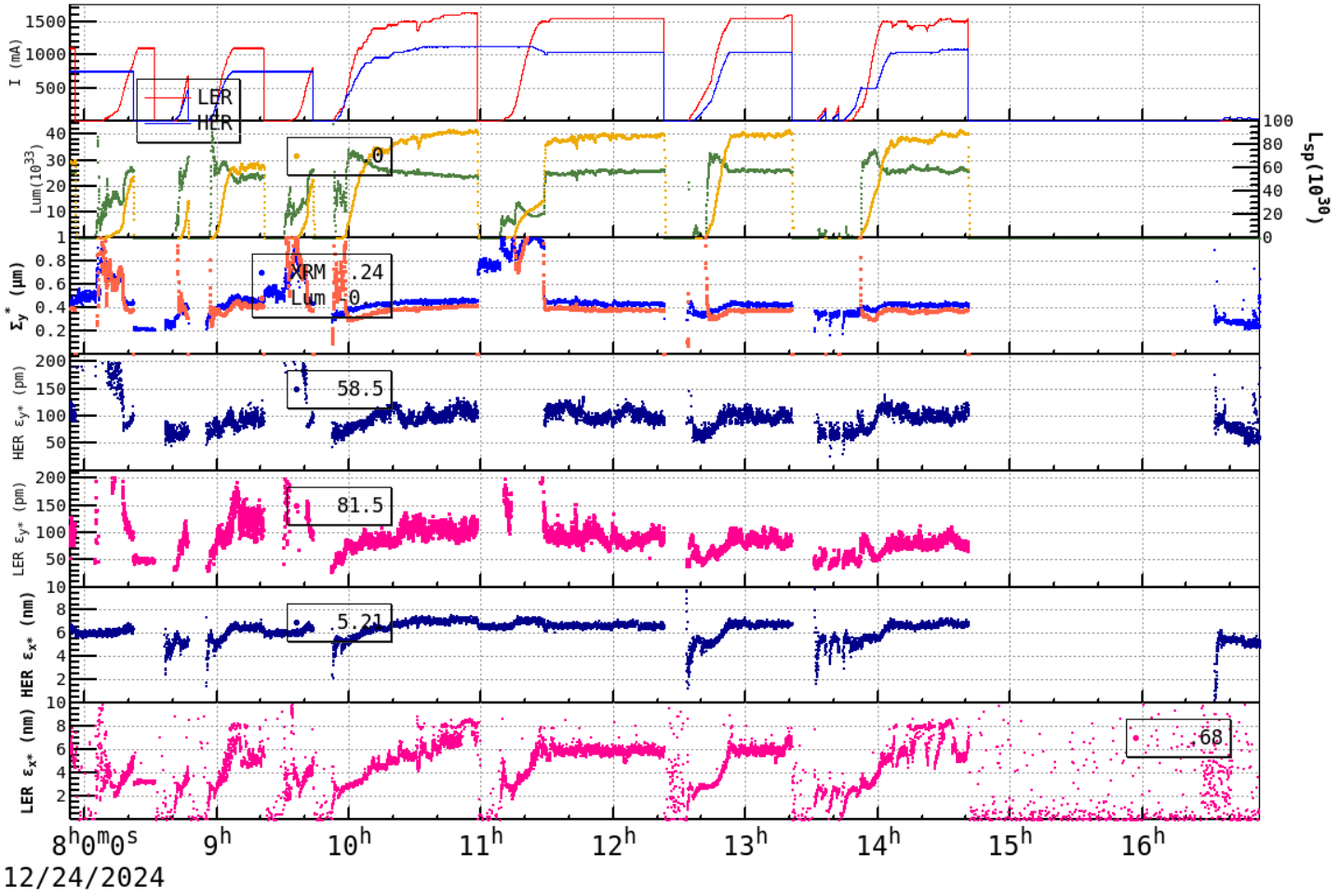


Machine imperfection, feedback, etc.

Code is tested by other codes.

Instability and emittance growth

Both H/V emittance growth is observed.



Fat beam? Head-tail oscillation?

X-Z instability

A large crossing angle induces instability.

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

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(Received 14 March 2017; published 26 September 2017)

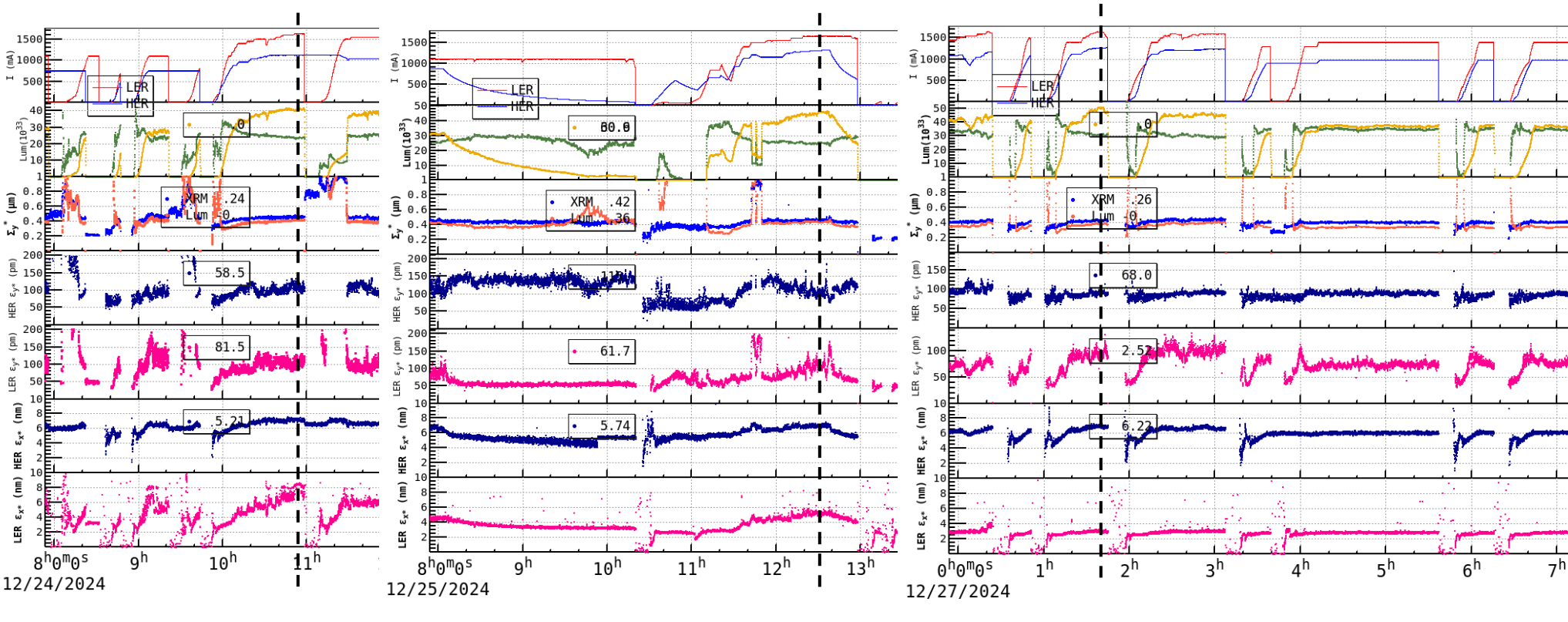
In recent years the "crab-waist collision" scheme [P. Raimondi, *Proceedings of 2nd SuperB Workshop, Frascati, 2006.*; M. Zobov *et al.*, Phys. Rev. Lett. **104**, 174801 (2010)] has become popular for circular e^+ e^- colliders. The designs of several future colliders are based on this scheme. So far the beam-beam effects for collisions under a large crossing angle with or without crab waist were mostly studied using weak-strong simulations. We present here strong-strong simulations showing a novel strong coherent head-tail instability, which can limit the performance of proposed future colliders. We explain the underlying instability mechanism starting from the "cross-wake force" induced by the beam-beam interaction. Using this beam-beam wake, the beam-beam head tail modes are studied by an eigenmode analysis. The instability may affect all collider designs based on the crab-waist scheme. We suggest an experimental verification at SuperKEKB during its commissioning phase II.

DOI: 10.1103/PhysRevLett.119.134801

A small β_x^* suppresses this instability.

H oscillation is suppressed

β_x^* : 80 → 70 → 60 mm



LER ε_x^* : 8 → 5 → 3 nm

Higher L is achieved by suppressing instability.

V oscillation is emerged by tunes

Y-Z oscillation is induced by impedance

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Combined phenomenon of transverse impedance and beam-beam interaction with large Piwinski angle

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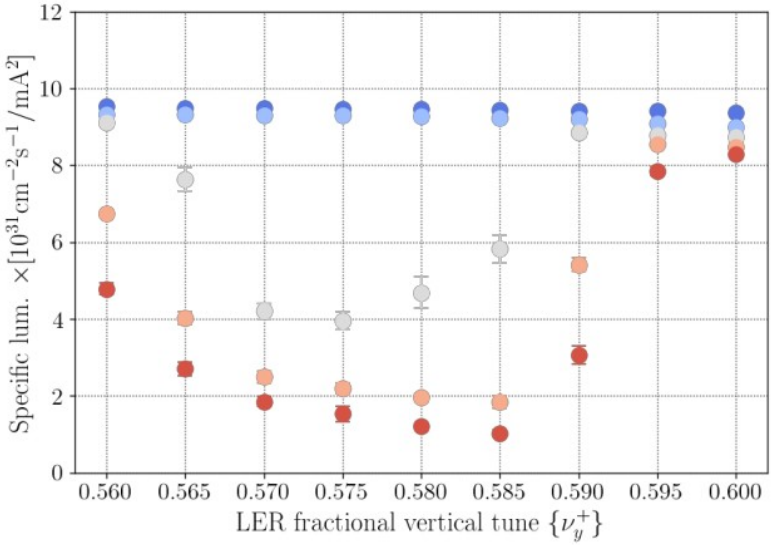
2024/06/2 7 HBC Study

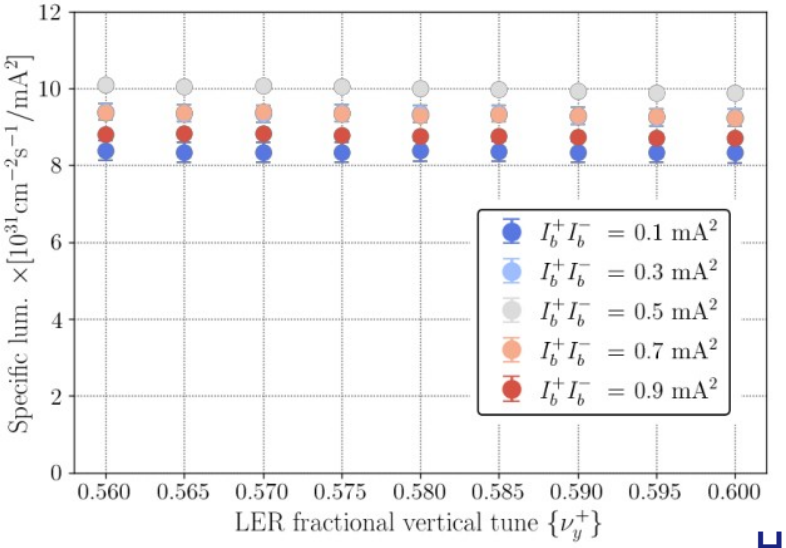
$$(\nu_x^+, \nu_y^+) = (44.525,\ 46.580)$$

$$(\nu_x^-, \nu_y^-) = (44.532,\ 46.580)$$

Wake ON



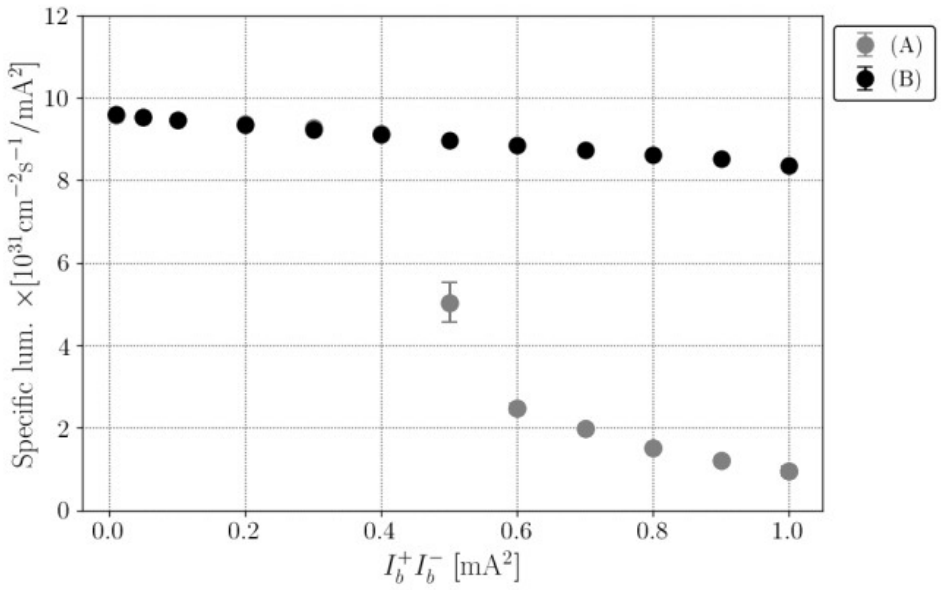
Wake OFF



H. Sugimoto

Tune dependence of instability

Instability is caused by tune match of rings.



(A) 2024/06/2 7 HBC Study

$$(\nu_x^+, \nu_y^+) = (44.525,\ 46.580)$$
$$(\nu_x^-, \nu_y^-) = (44.532,\ 46.580)$$

(B)

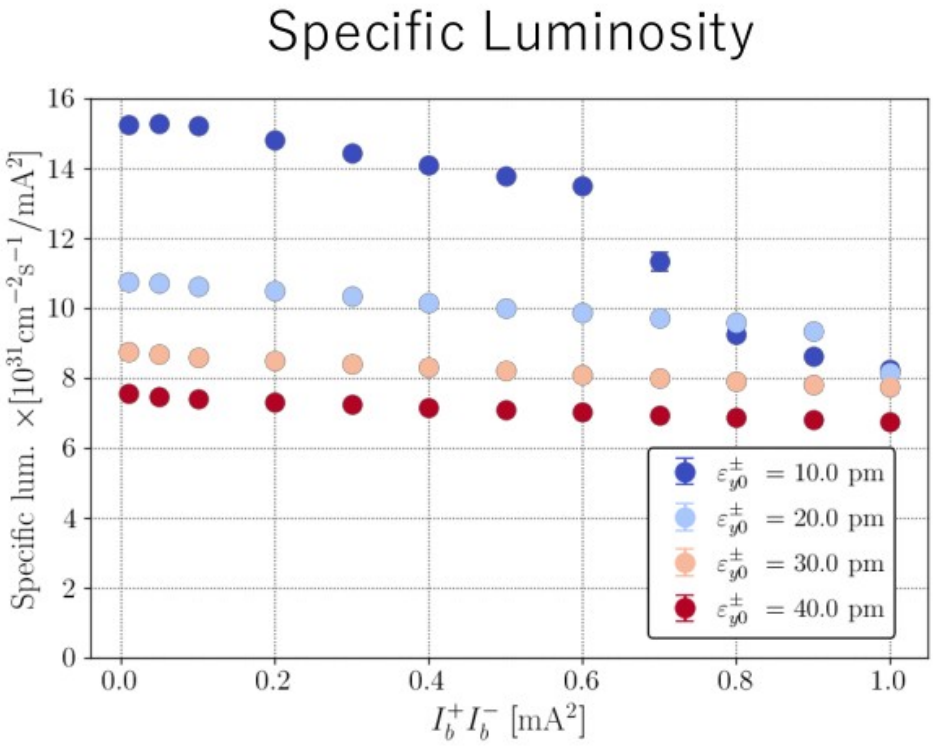
$$(\nu_x^+, \nu_y^+) = (44.525,\ 46.589)$$
$$(\nu_x^-, \nu_y^-) = (44.530,\ 46.572)$$

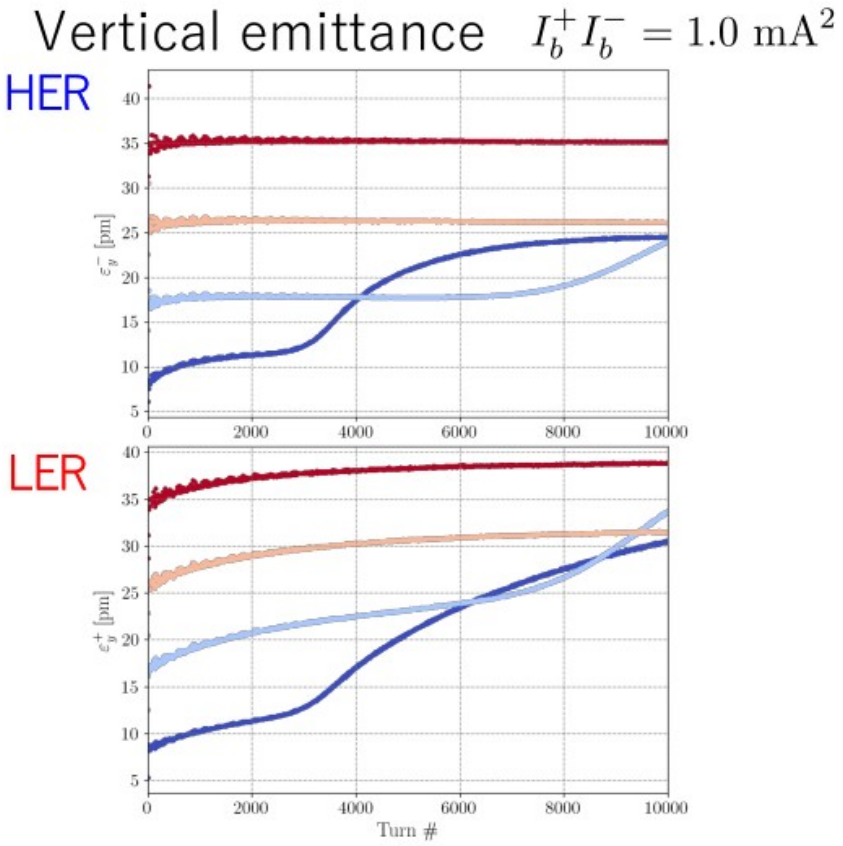
H. Sugimoto

Does it look like CW on/off behaviors?

Emittance growth with current

Lsp is moreless independent of the initial emittance at high bunch currents > 1 mA^2





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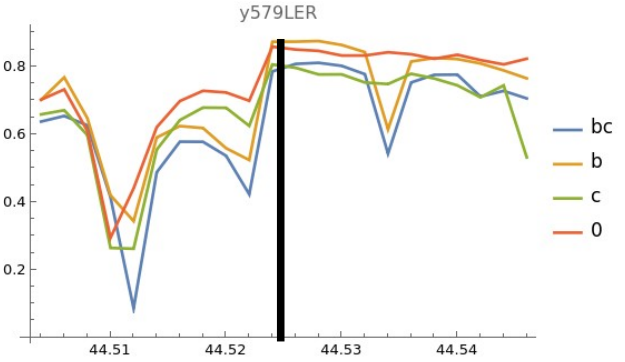
Summary

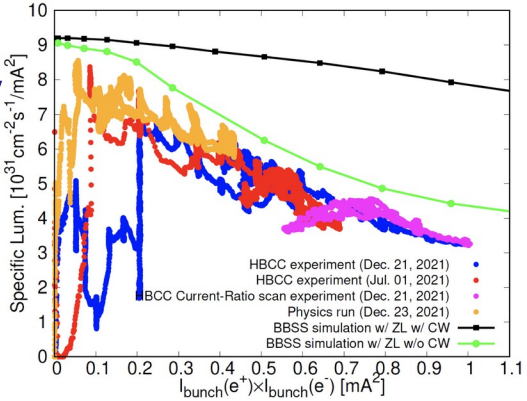
Injection efficiency

- Roughly reproduced well.
- Details of BB related behaviors are difficult.



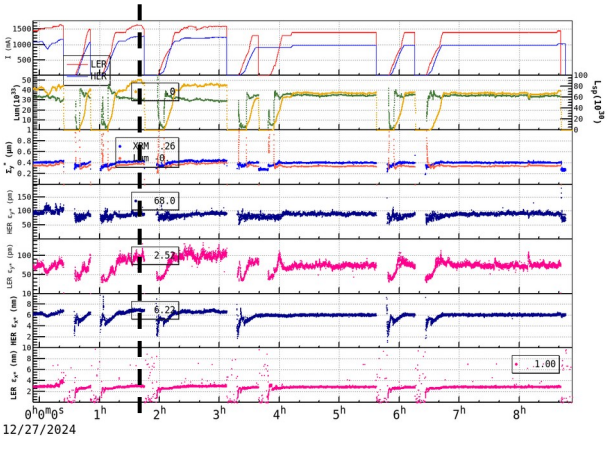
Crab waist and specific luminosity

- Discrepancy should be studied.



BB effect and instability

- Simulations may have
  a large impact to operation.



Issues

It is worth simulating injection efficiency with smaller β_y^* or other optics.

We need comprehensive simulations including BB effect, impedance and feedback to go to higher currents.

- Need more human and computational resources .

→ international collaboration