Benchmarking of simulations of coherent beam-beam effects

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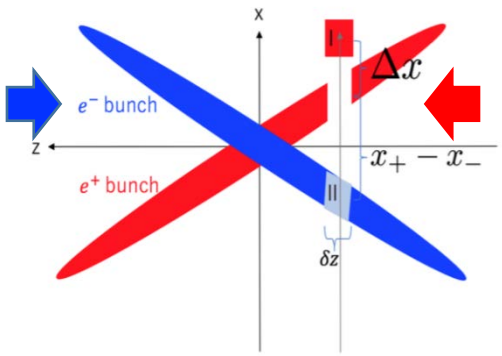
Coherent beam-beam instability in head-tail mode for collision with a large crossing angle

Mechanism of the instability- Cross wake force



- Usual wake force gives correlation between bunch head to tail. Head-tail instability is induced by synchrotron motion

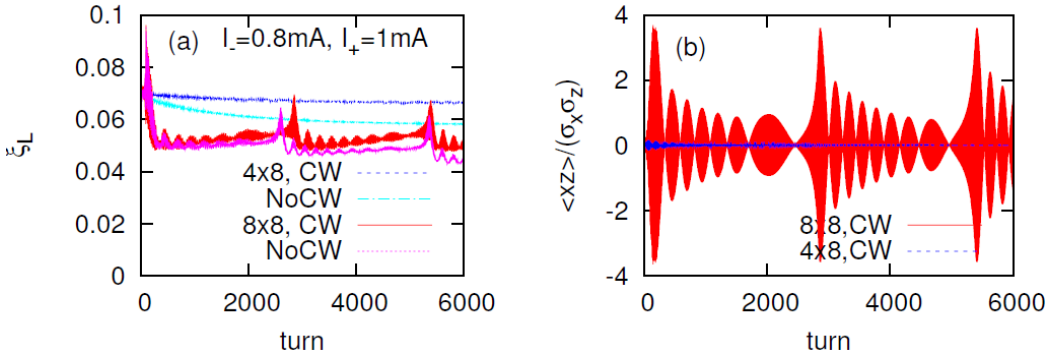
$$\Delta p_x(z) = -\int_z^\infty W(z-z')\rho_x(z')dz'$$

- Cross wake field gives correlation of two colliding beam by convolution of each dipole moment.

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

- Cross wake force induced by the beam-beam interaction is localized at IP.

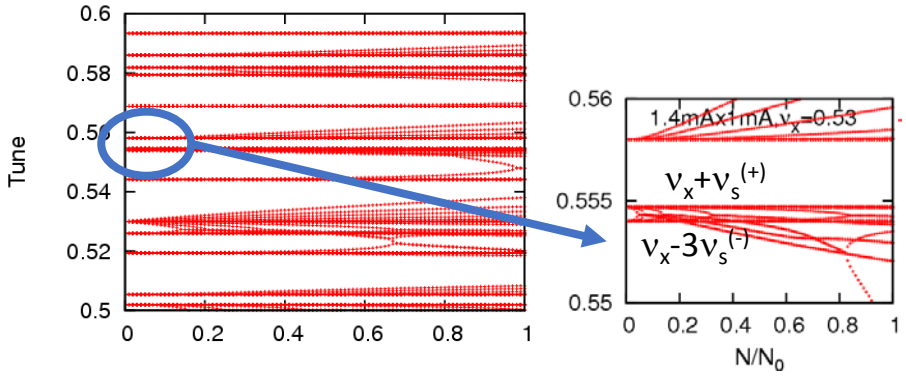
Coherent beam-beam Instability seen in strong-strong simulation (SuperKEKB)

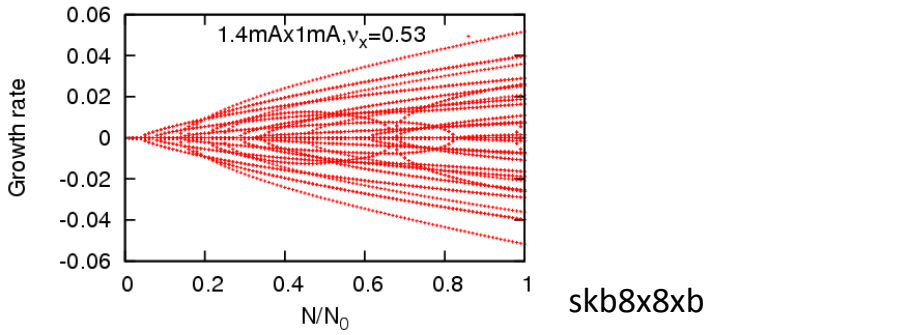


- Design parameters of SuperKEKB was stable.
- We squeeze β* step-by-step.
- Instability was seen in detuned β* (8x,8x).
- We plan to study this instability in Phase II commissioning this year.
- This instability is serious for FCC-ee design.

Eigen mode analysis for ν_x=0.53
ν_s(LER)=0.0247, ν_s(HER)=0.0280

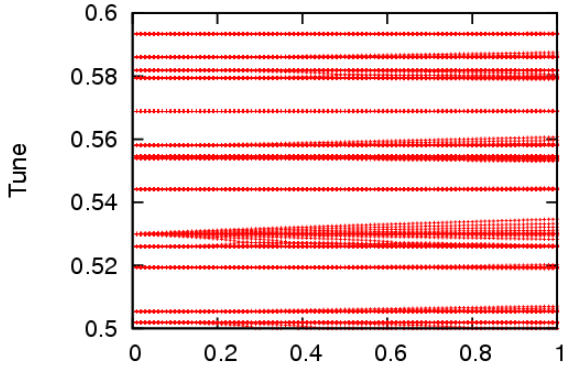
- 8x8x

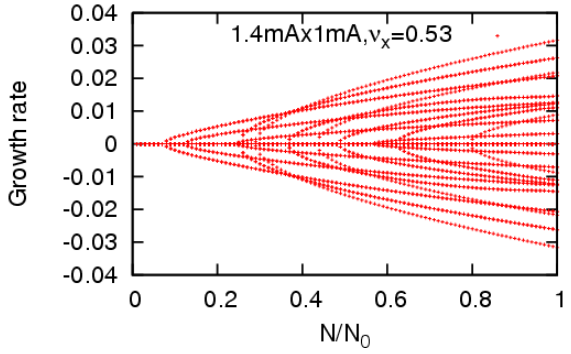




skb8x8xb

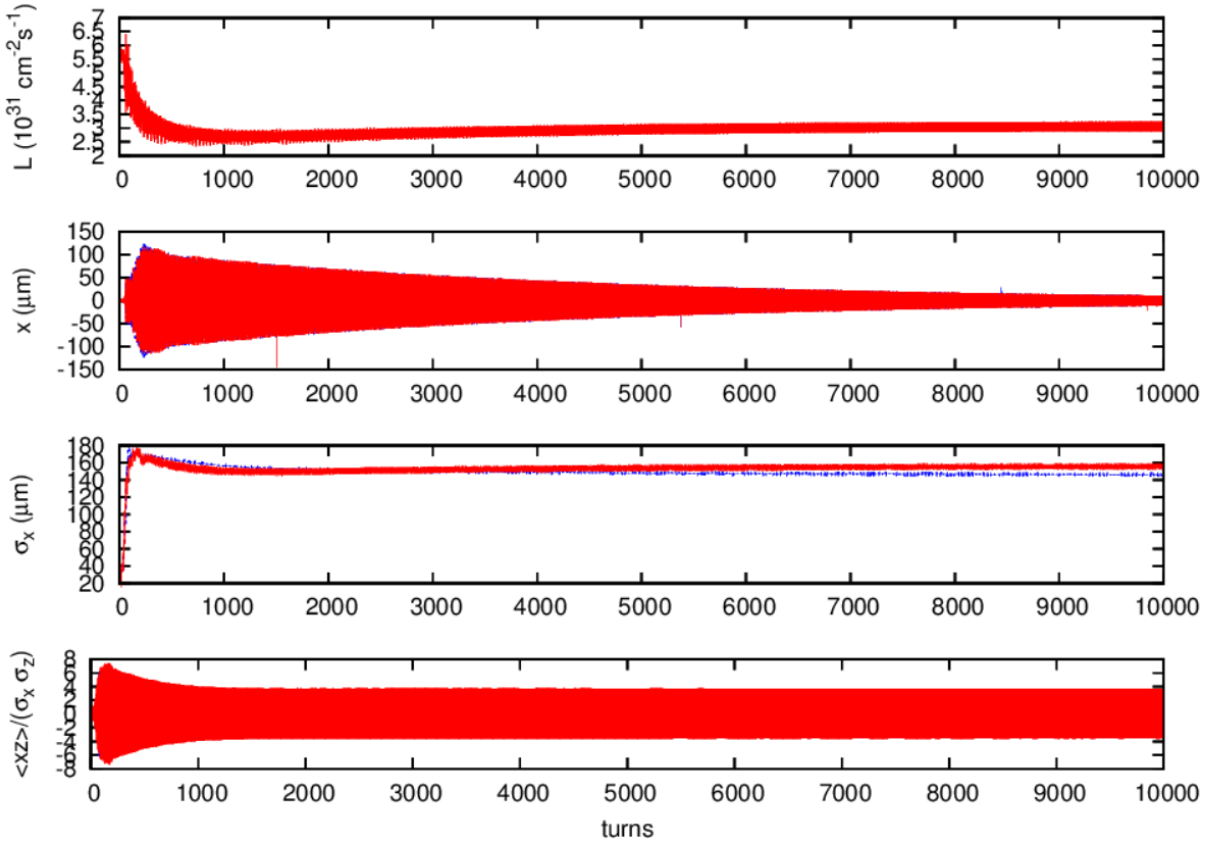
4x8x





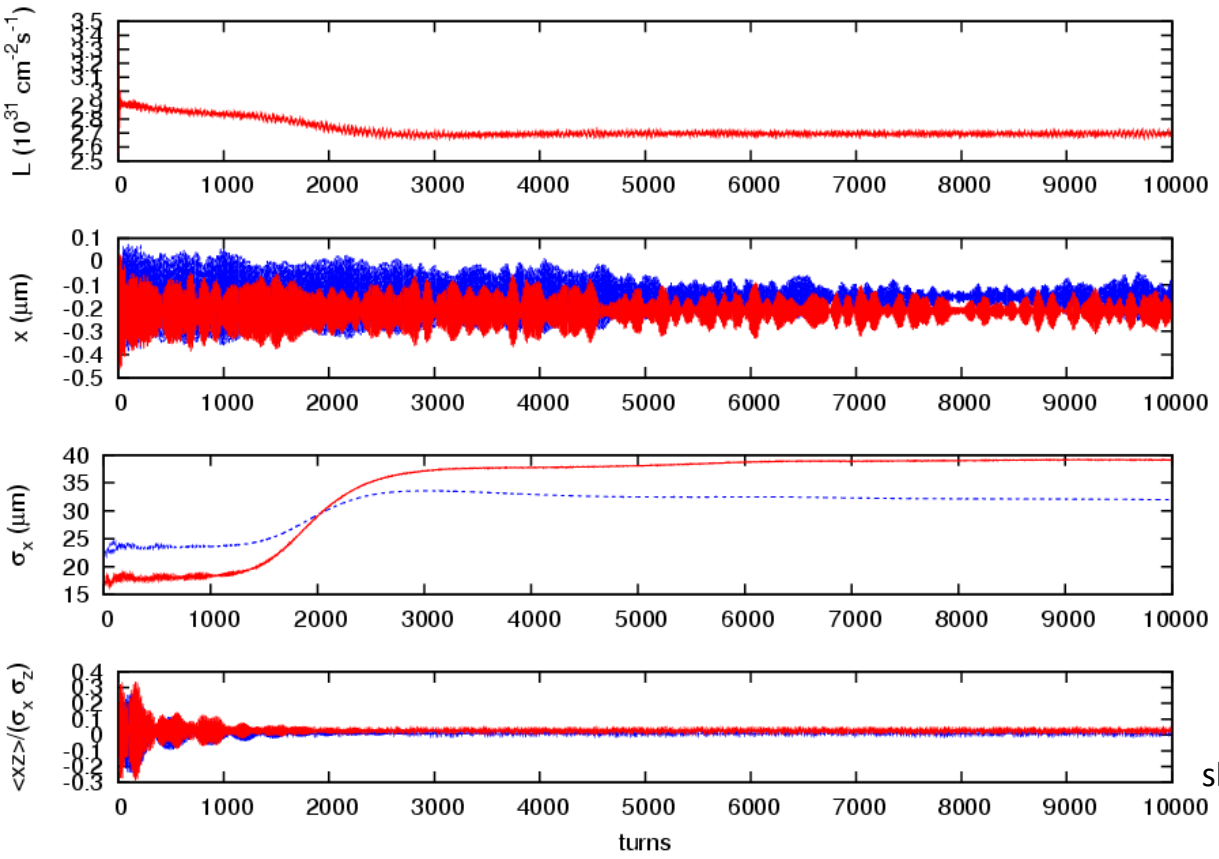
Low threshold with coupling $\nu_x+\nu_s^{(+)}$ and $\nu x-3\nu_s^{(-)}$.
For different νs, appearance of instability is complex.

Strong-strong beam-beam simulation 8x8x, 1.44mAx1.04mA, ν_x=0.53



skb2a

4x8x, 1mAx0.8mA , ν_x=0.53



skb21b

Summary of the strong-strong simulation

I=1.44mA x 1.04mA

ν_x	8x8x				4x8x			
	L/L_0,	σ_x/σ_{x0} (L & H)		osc.	L/L_0,	σ_x/σ_{x0} (L & H)		osc.
0.53 a	0.58-0.66	6.5	4.5		0.75-1.0	3.0-7.5	2.2-6.2	
0.535 g	0.70-0.95	2.5-6.2	1.4-4.0		1.04	1.2	1.0	
0.54 d	0.75-0.95	2.5-6.0	1.4-4.0		1.05	2.1	1.1	
0.545 f	0.83	7.2	1.2	no osc.	0.94	5.2	1.7	
0.55 e					0.75-0.77	8.6	3.5	

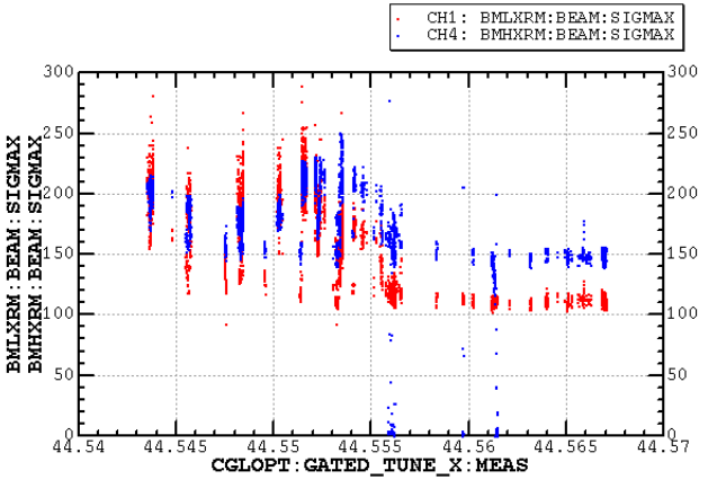
Horizontal emittance growth does not contribute luminosity drop in collision with a large crossing angle, when β_y is large.
Crab waist on in the simulation. CW-off may be serious for the horizontal emittance growth.

Instability study in Phase II

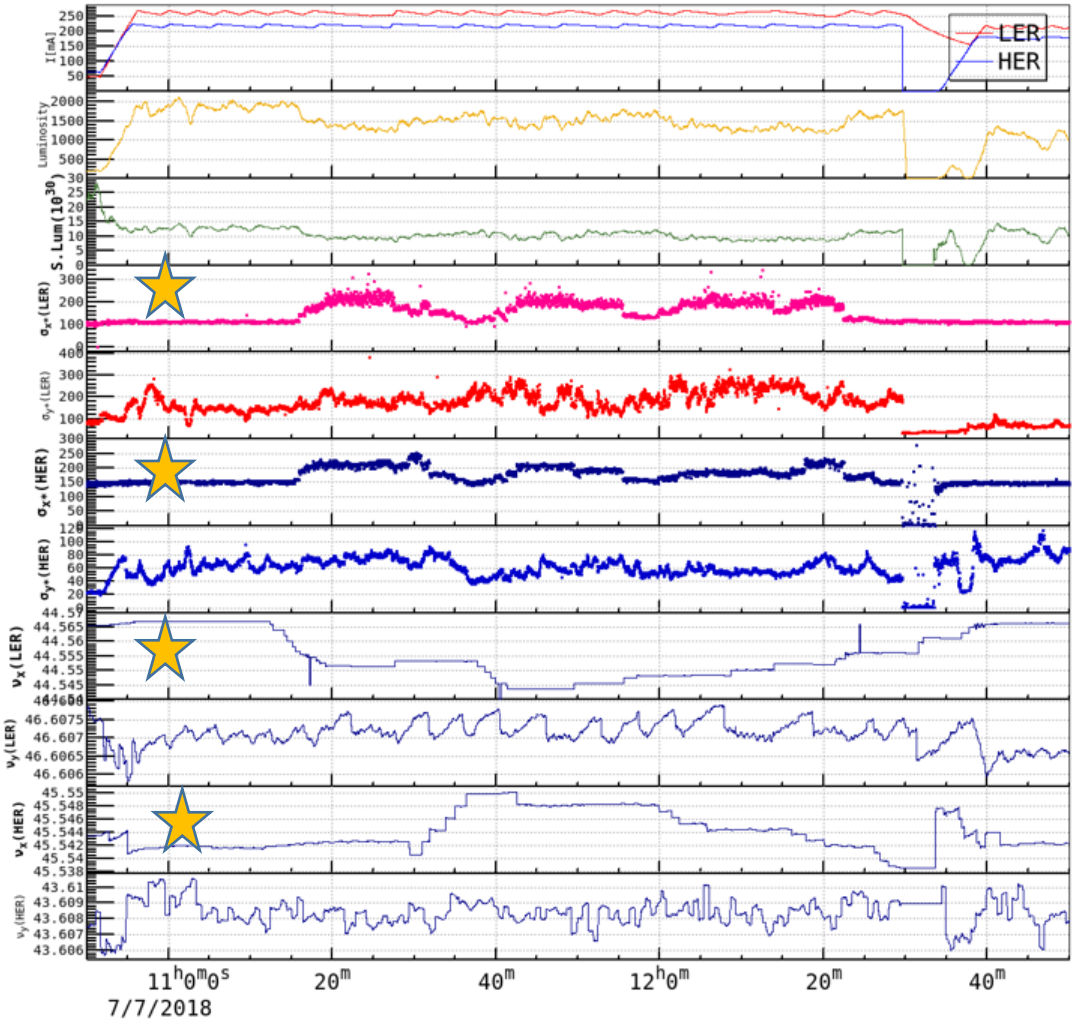
- Typical condition
- β_x=0.2m, 0.1m, β_y=3mm
- I_{tot}=270mA (e+)x 225mA (e-), Nb=395,
- I_b=0.68mAx0.57mA (design 1.44mAx1.04mA)
- Np=4.3×10^{10}, 3.6×10^{10}. (design 9.04×10^{10}x 6.53×10^{10})
- ν_s (e+)=0.022, ν_s (e-)=0.026

7/7 day time study

- 270mAx225mA, 10:50-12:30
- Search tune condition in which the instability appears.

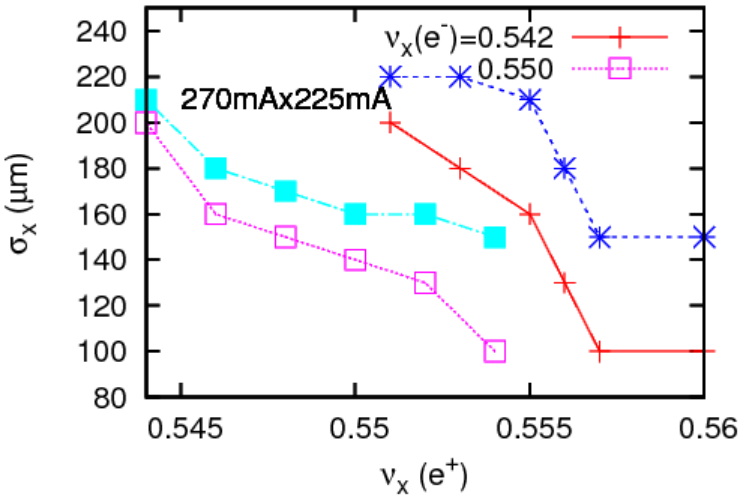


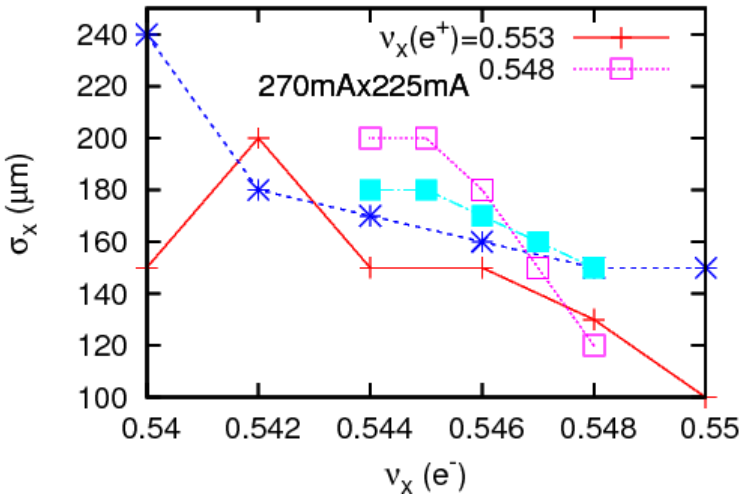
- ν_x(e-)をあげると安定になるが、ν_x(e+)を下げると不安定になる。



σ_x ($\nu_x(e^+)$, $\nu_x(e^-)$) at 270mAx225mA

- I_+I_-=0.39 mA^2, N_b=395
- We did not cross over the peak to avoid a beam abort.

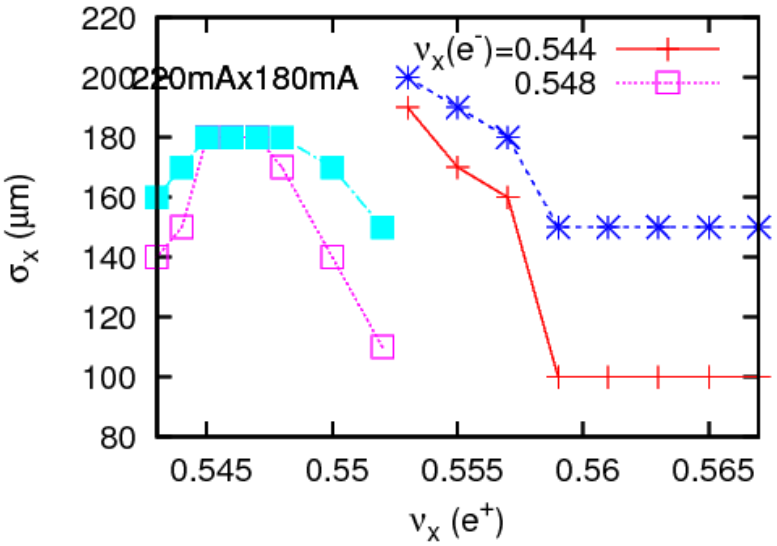


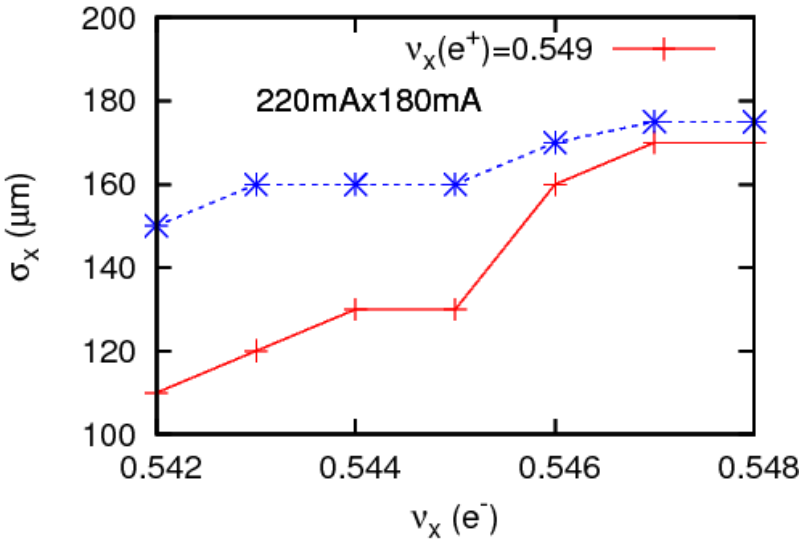


- The same tune condition in Red(e+) & blue(e-)
- Magenta(e+) & cyan(e-)

σ_x ($\nu_x(e^+)$, $\nu_x(e^-)$) at 220mAx180mA

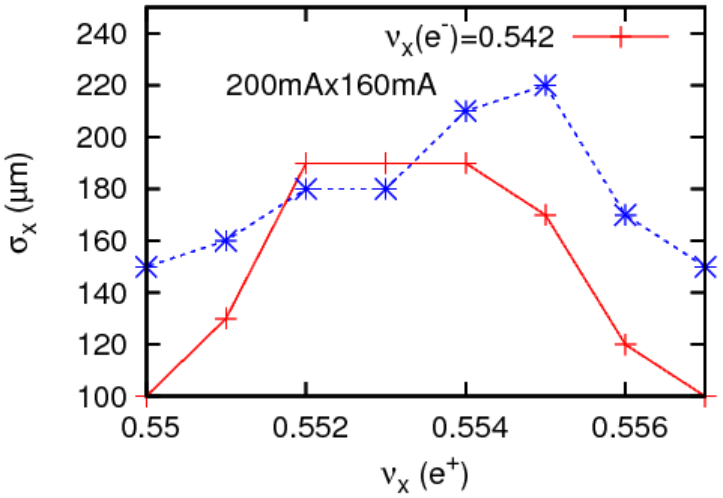
- I_+I_-=0.25 mA^2, N_b=395

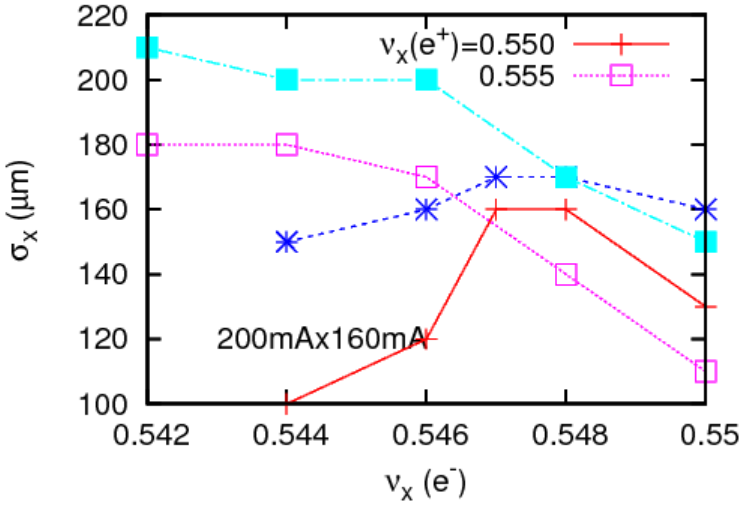




σ_x ($\nu_x(e^+)$, $\nu_x(e^-)$) at 200mAx160mA

- I_+I_-=0.21 mA^2, N_b=395
- Beam size blow-up somewhat weak. The resonance line was crossed over.

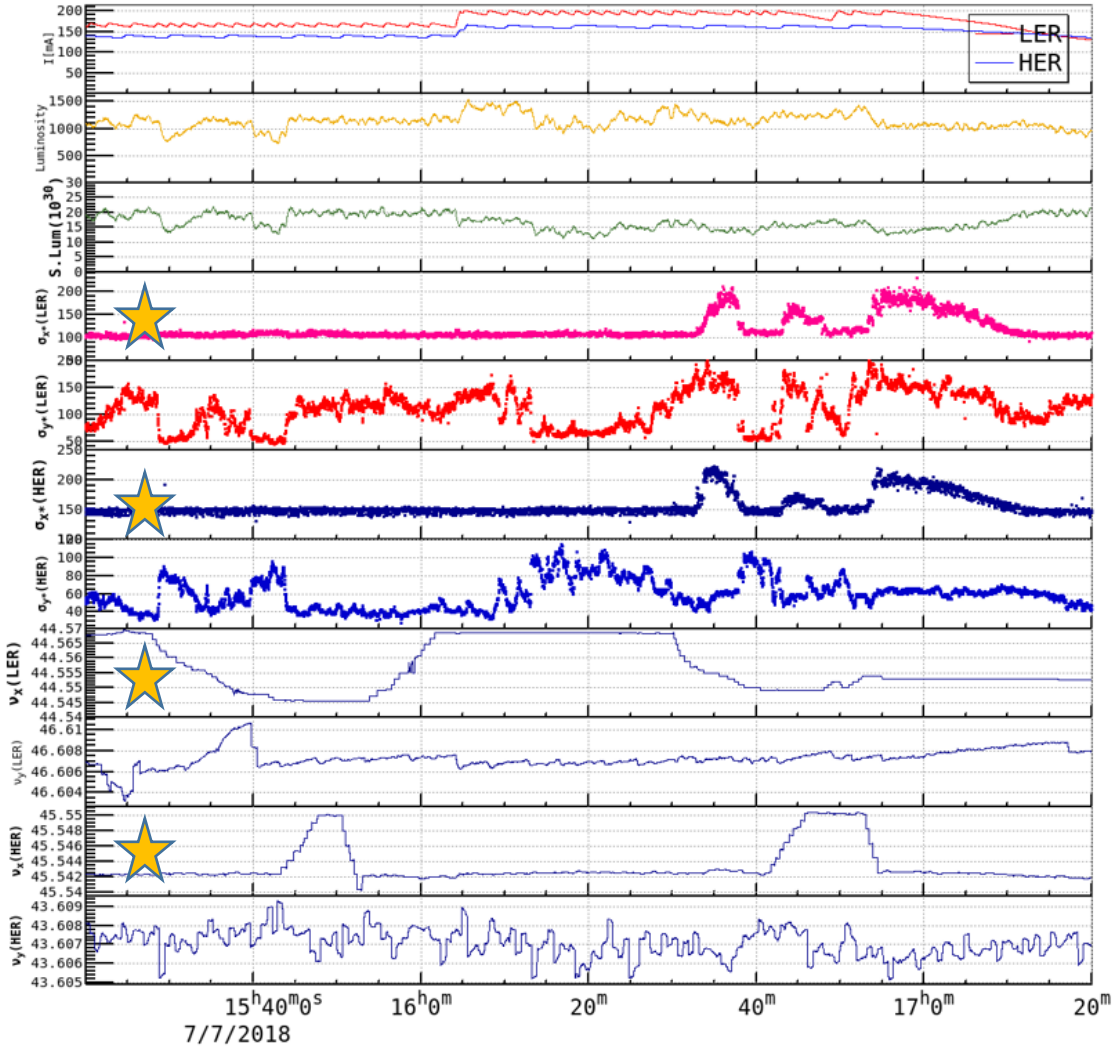




- Peak tune does not depend on bunch current.
- Stop-band may depend on?
- More study is necessary.

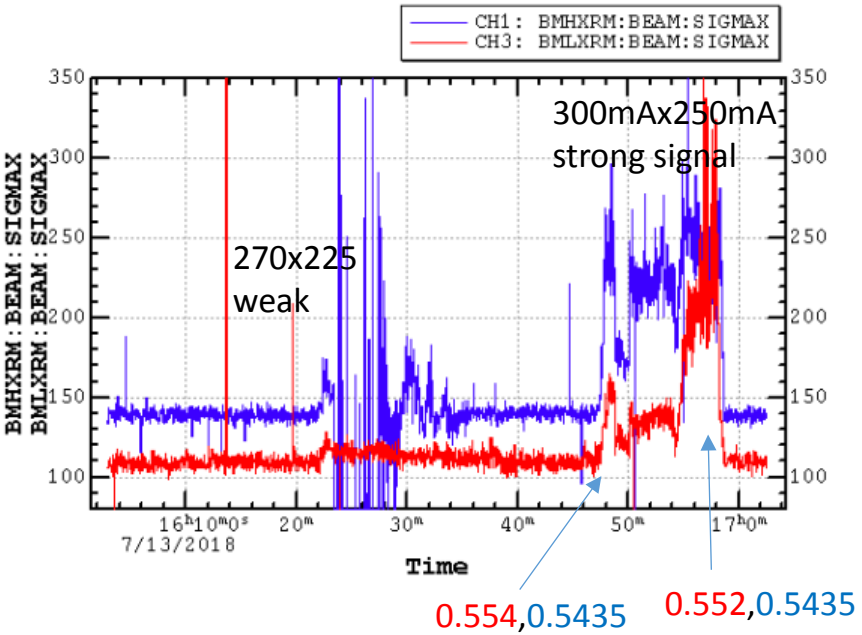
Threshold of the instability

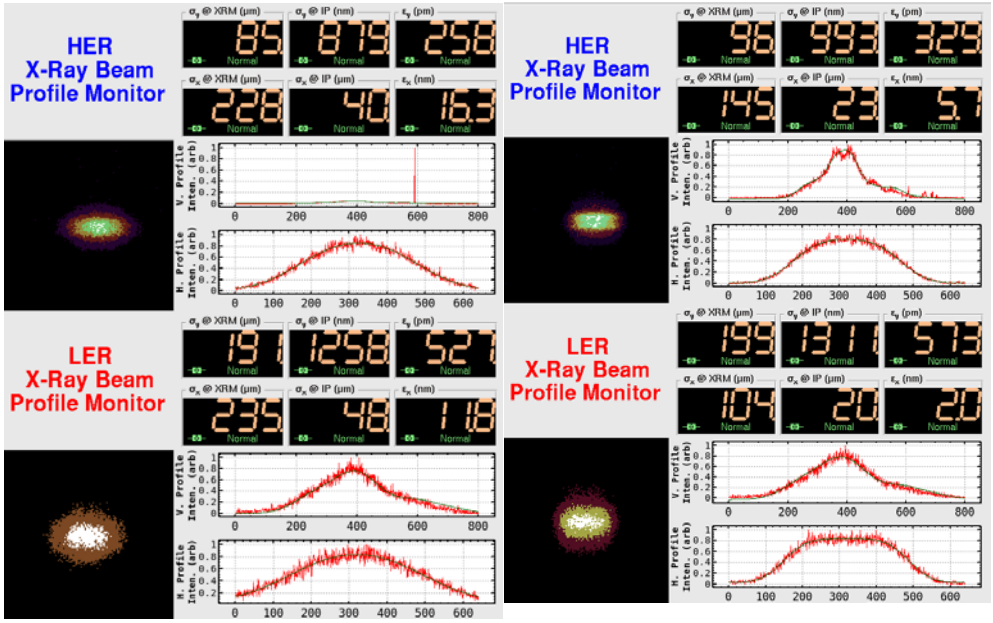
- 170mAx142mA, No σ_x blowup
- 200mAx160mA, blowup is seen.
- No blow-up in single beam tune scan.



Machine experiment at July 13, 2018

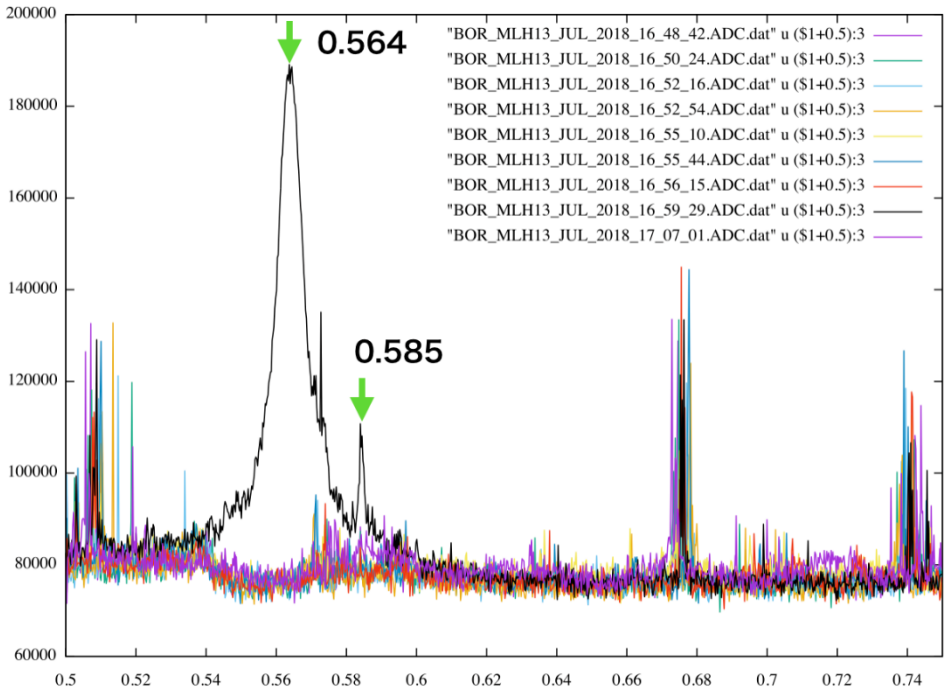
- 16:50 (instability start) & 16:57 (peak), data taking using streak camera x-z and BOR.
- ν_s (e+)=0.022, ν_s (e-)=0.026





Bunch Oscillation Recorder (LER)

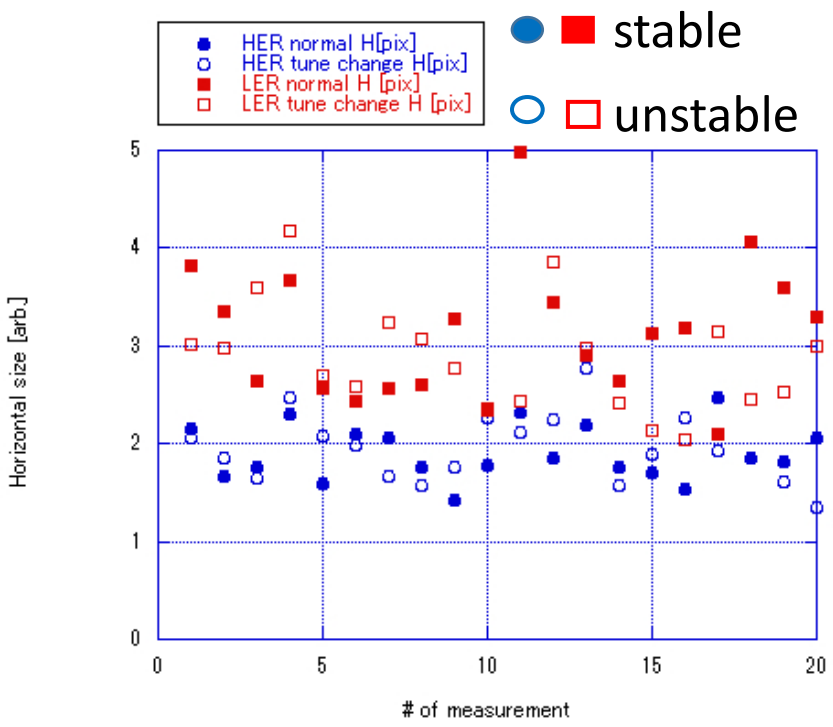
- Clear oscillation was seen in a data, which taken at strongest beam size blow-up.
- Background level of HER data was high, noisy.



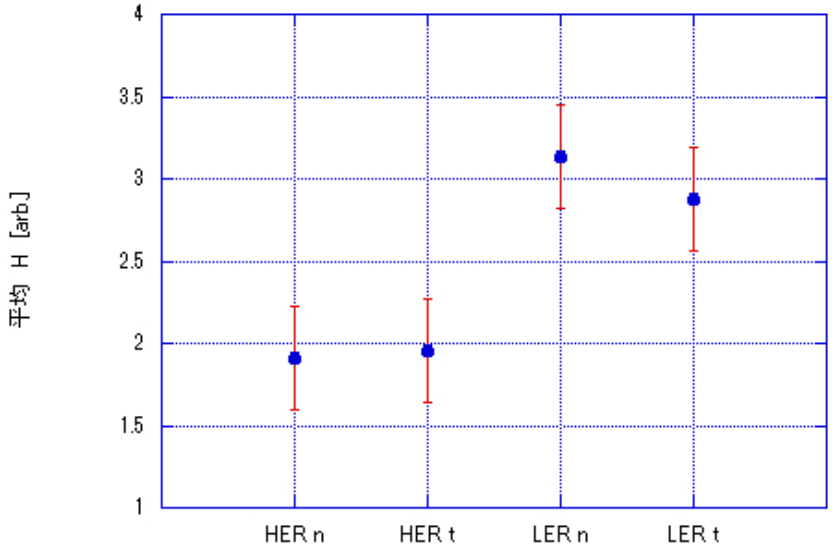
Horizontal beam size by streak camera

- No clear difference between stable and unstable
- Perhaps, lack of resolution.

Shot by shot



average



Possible instability condition

- ν_x(e+)=0.552, ν_x(e-)= 0.5435, ν_s (e+)=0.022, ν_s (e-)=0.026
- ν_x(signal)=0.563

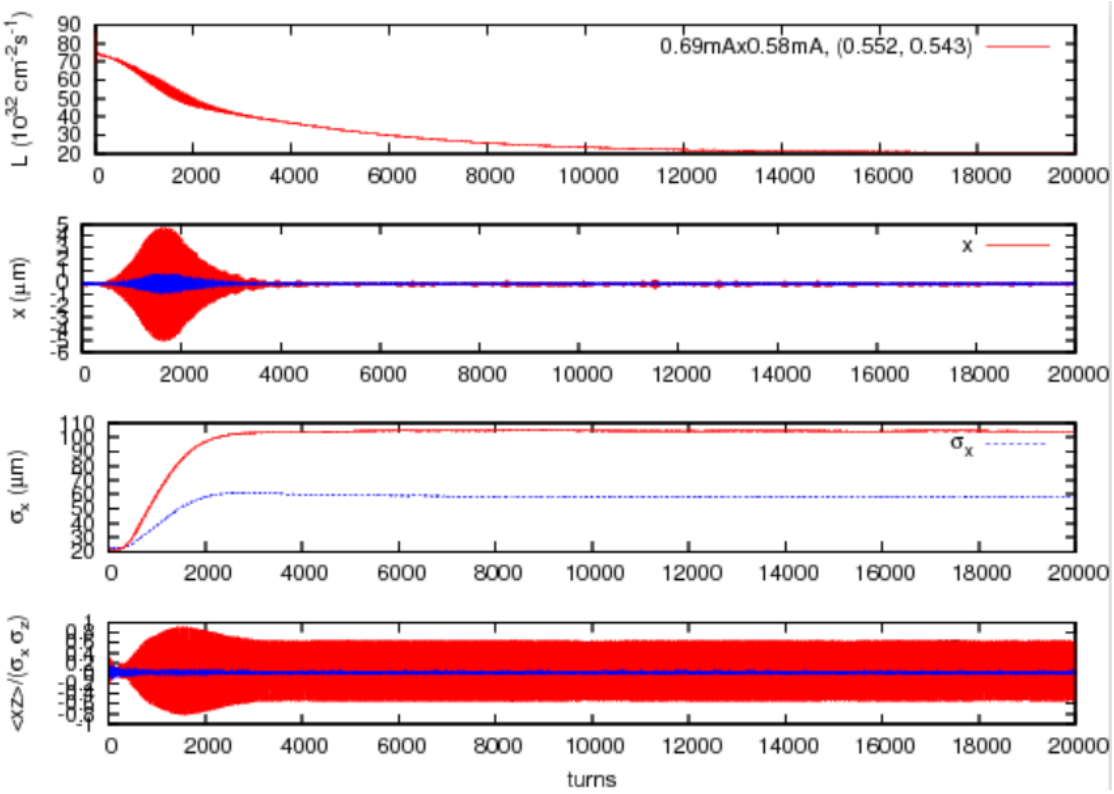
- ν_x(e-)+ ν_s (e-)= 0.5695, ν_x(e+)-5 ν_s (e+)= 1-0.558
  300mAx250mA: ξ_x(e+)=0.0073, ξ_x(e-)=0.0025
  Possible candidate: 0.563=(0.5695+0.558)/2
- ν_x(e-)- ν_s (e-)= 0.5175, ν_x(e+)-3 ν_s (e+)= 1-0.514
- ν_x(e-)+ ν_s (e-)= 0.5695, ν_x(e+)+ ν_s (e+)= 0.574

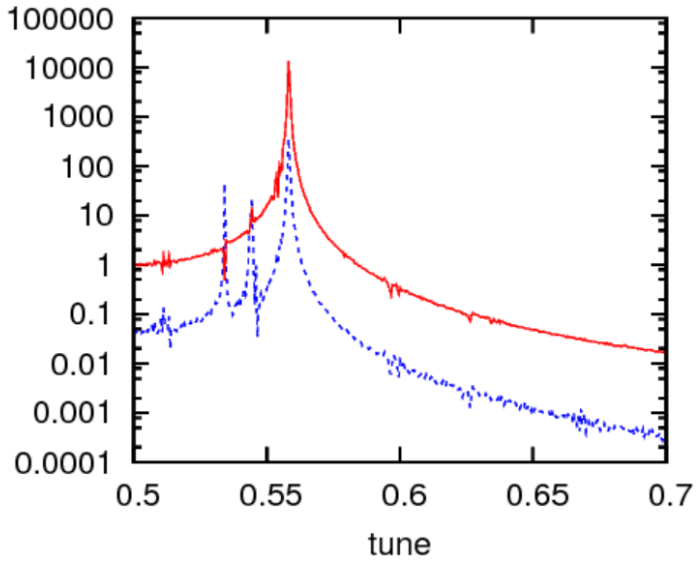
- ν_x(e-)+ν_s (e+)=0.5655,
  but no synchro-beta coupling mode.
- ν_x(e+)+ν_s (e-)=0.578

Simulation in the experimental condition

- FFT peak 0.558, not bad.
- ν_x(e+)=0.552, ν_s (e+)=0.0213, ν_x(e-)= 0.5435, ν_s (e-)=0.026

ambiguous





Summary

- Coherent beam-beam instability in head-tail mode has been predicted in strong-strong beam-beam simulation.
- The instability was observed in SuperKEKB commissioning as is predicted.
- Horizontal beam size blow-up has been observed depending on horizontal tunes of two beams.
- Bunch oscillation was detected, but streak camera did not show the signals of instability.
- Simulation in the experimental condition shows reasonable agreement. Probably mode coupling between +1(e^-) and -5(e^+) modes.
- More systematic tune scan, identify peak position.

Instability and Tune

- 7/6 0:00-0:40
- 7/2 stable unstable

HER	45.5464	43.6109	0.5431	0.607
LER	44.5594	46.6187	0.556	0.618

- 6/24 No instability

HER	.5437	0.607
LER	0.5585	0.6143