KEK-B Crab Cavity Experiments for the LHC & Super KEK-B

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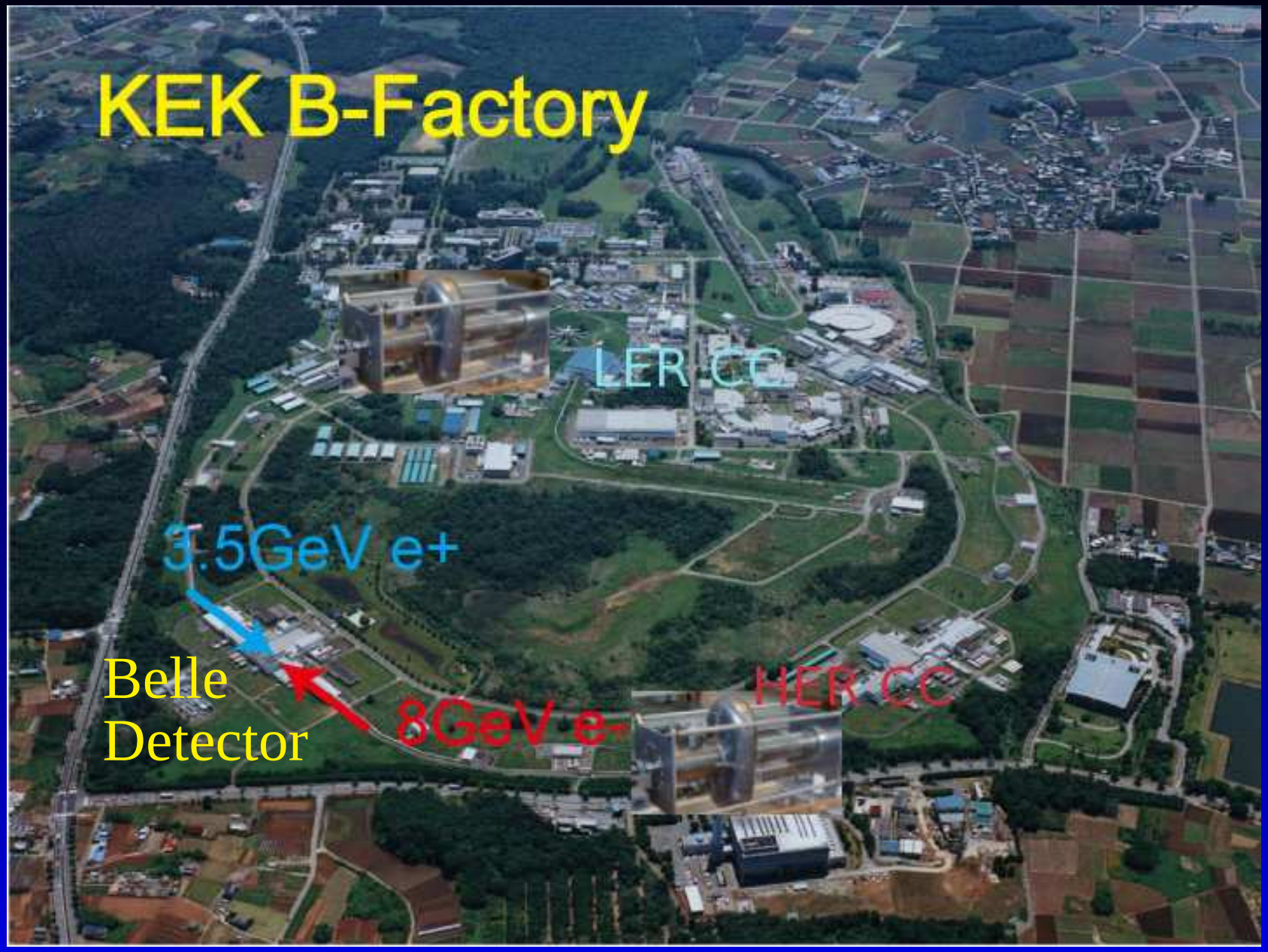

KEK B-Factory
LER CC
3.5GeV e+
Belle
Detector
8GeV e-
HER CC

CC sinusoidal phase noise

Crab cavity voltage:

$$V\sin(\omega t+\phi)$$

if phase modulation $\phi=\phi_0\sin(vt)$, CC voltage $\approx$

$$V\left[\sin(\omega t+\phi)+\frac{\phi_0}{2}\Big(\sin((\omega+v)t)-\sin((\omega-v)t)\Big)\right]$$

$\rightarrow$Phase modulation is approximated by sidebands

CC phase error results in a dipolar kick.

HER and LER machine parameters

	Unit	HER	LER
Particle		e^-	e^+
Particles per bunch	10^{10}	4.1	6.3
Number of bunches		100	100
Horizontal emittance (ϵ_x)	nm	24	15
Horizontal tune (Q_x)		0.53	0.52
Vertical tune (Q_y)		0.60	0.58
Synchrotron tune (Q_s)		0.025	0.025
Revolution frequency	kHz	100	100
Feedback		On	On

The experiment

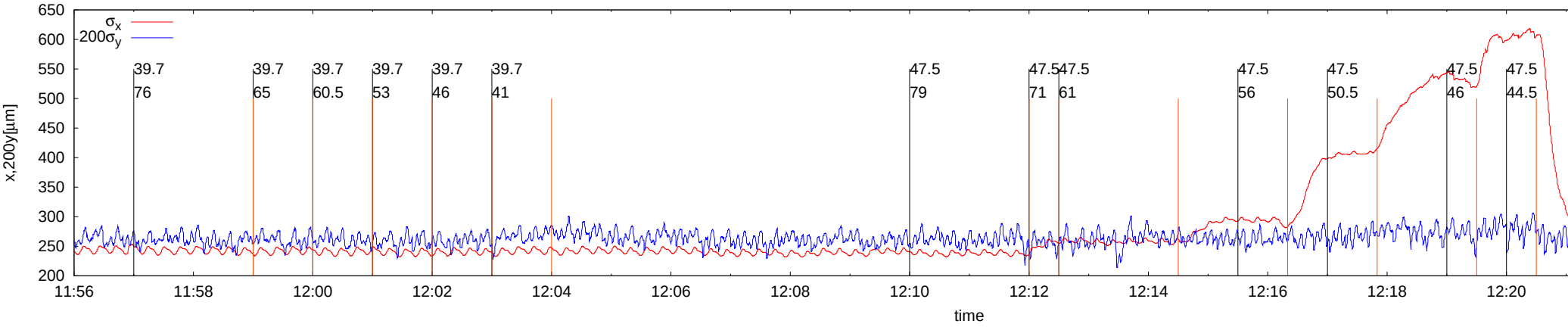
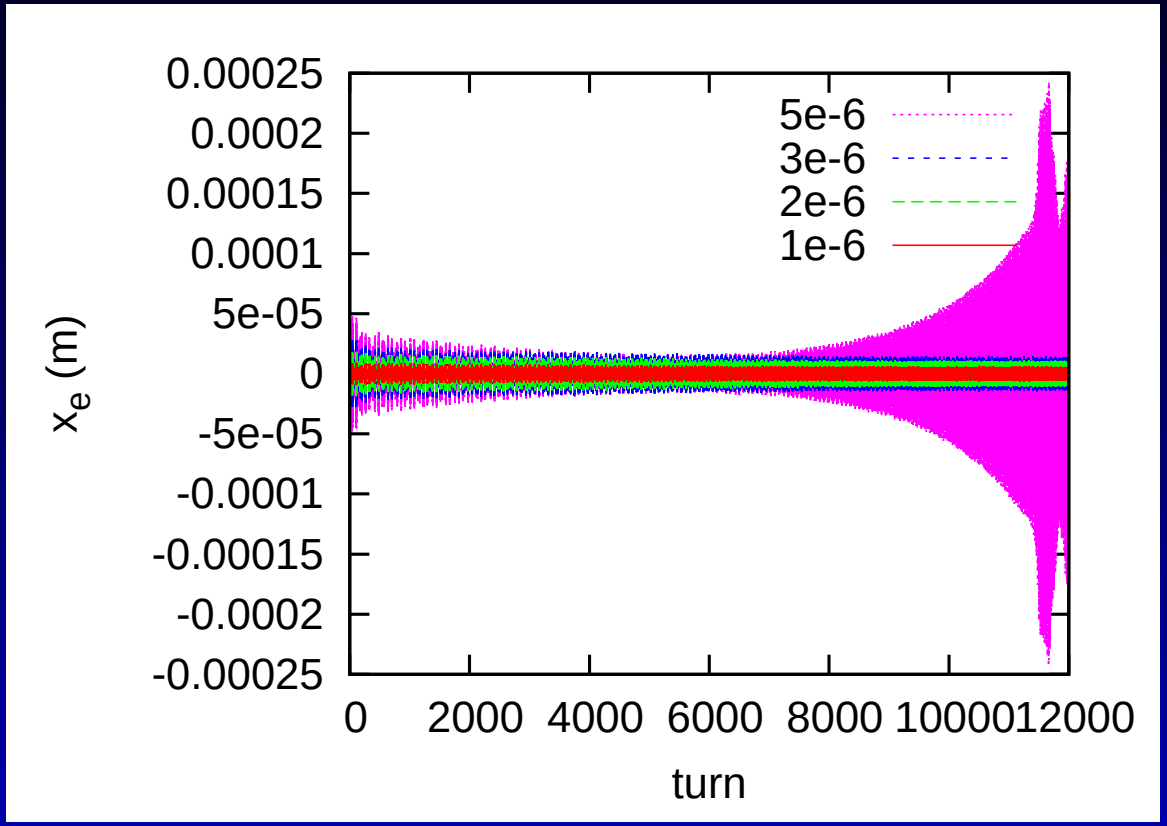


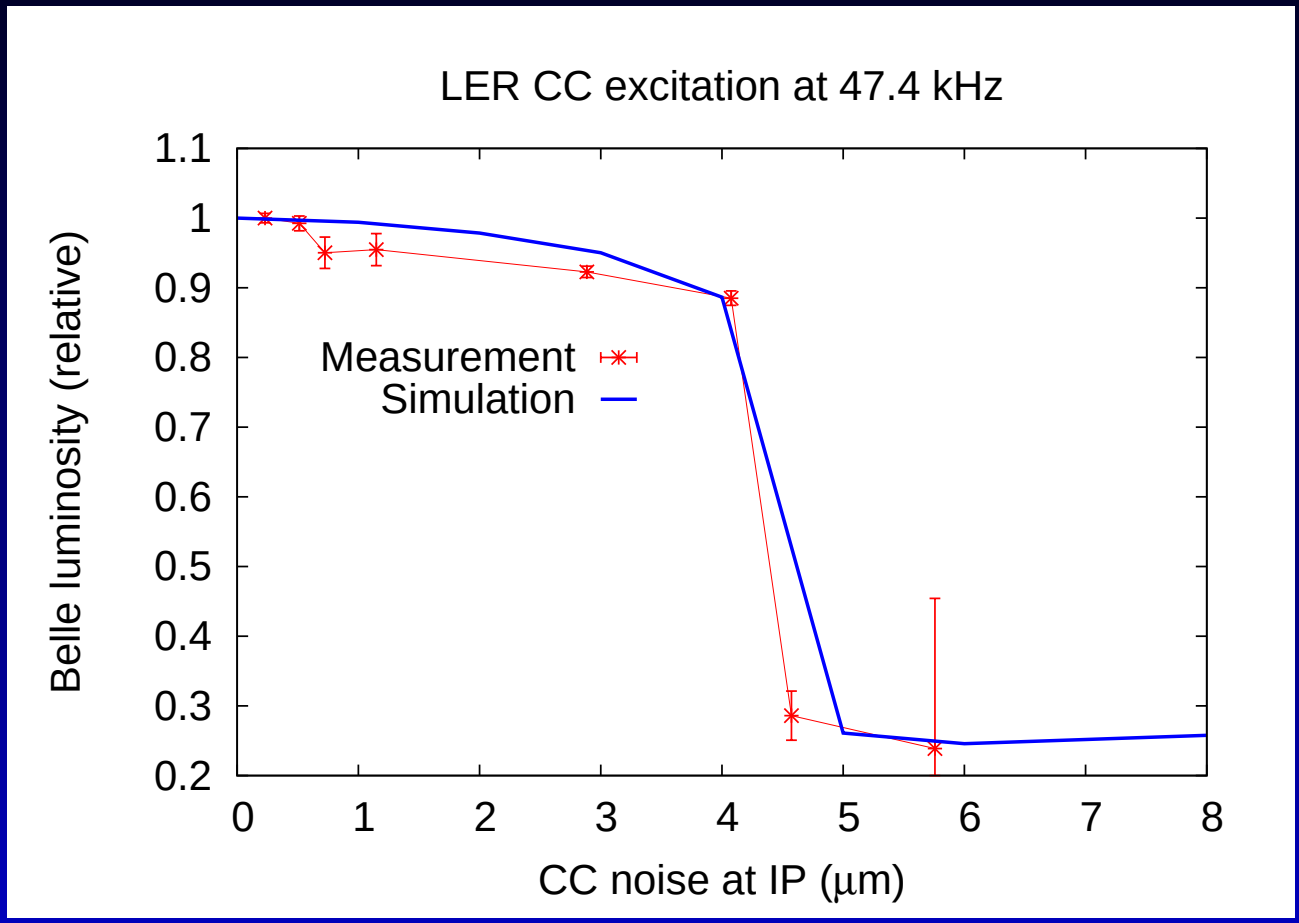
Illustration of beam sizes versus time as frequency and amplitude of the CC phase noise are changed.

The simulations by Ohmi san



Ohmi san performed many simulations to understand the experiments including the phase noise, the beam-beam interaction and the feedback.

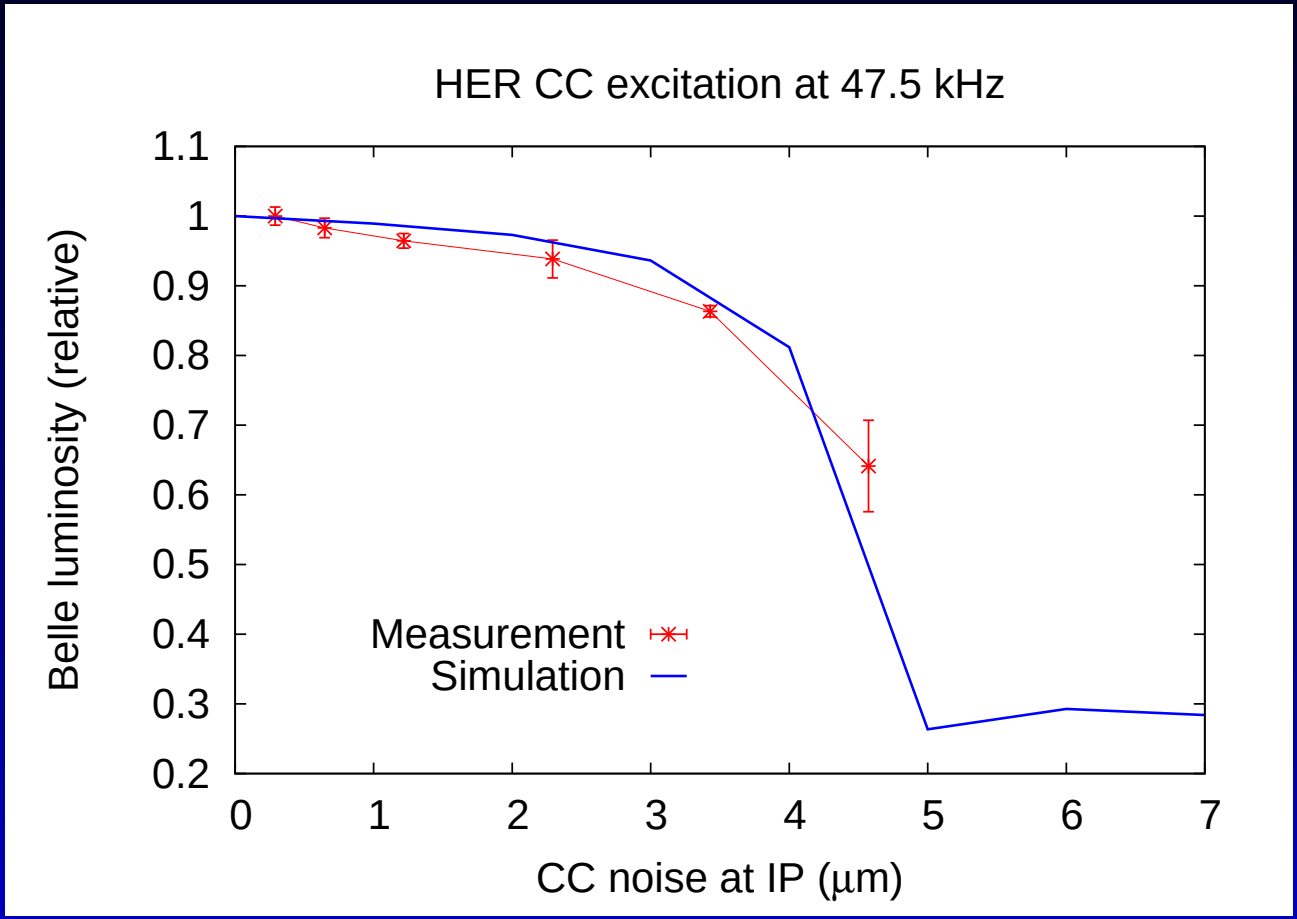
LER CC noise close to Q_x (exp. vs sim.)



→Measurement and simulation in excellent agreement!

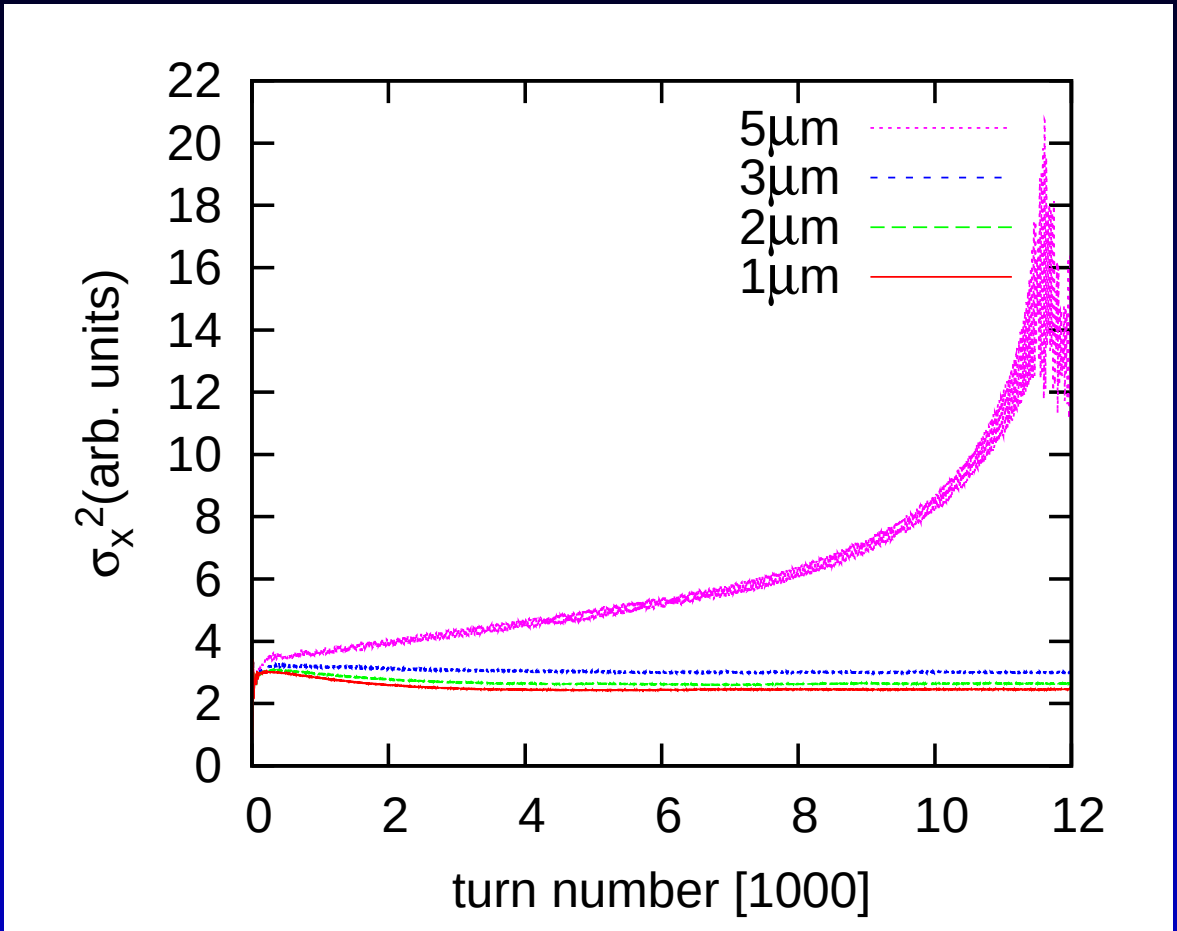
→Shocking abrupt luminosity loss at $4.5\mu\text{m} \approx 0.02\sigma_x^*$

HER CC noise close to Q_x (exp. vs sim.)



→ Similar results for the HER

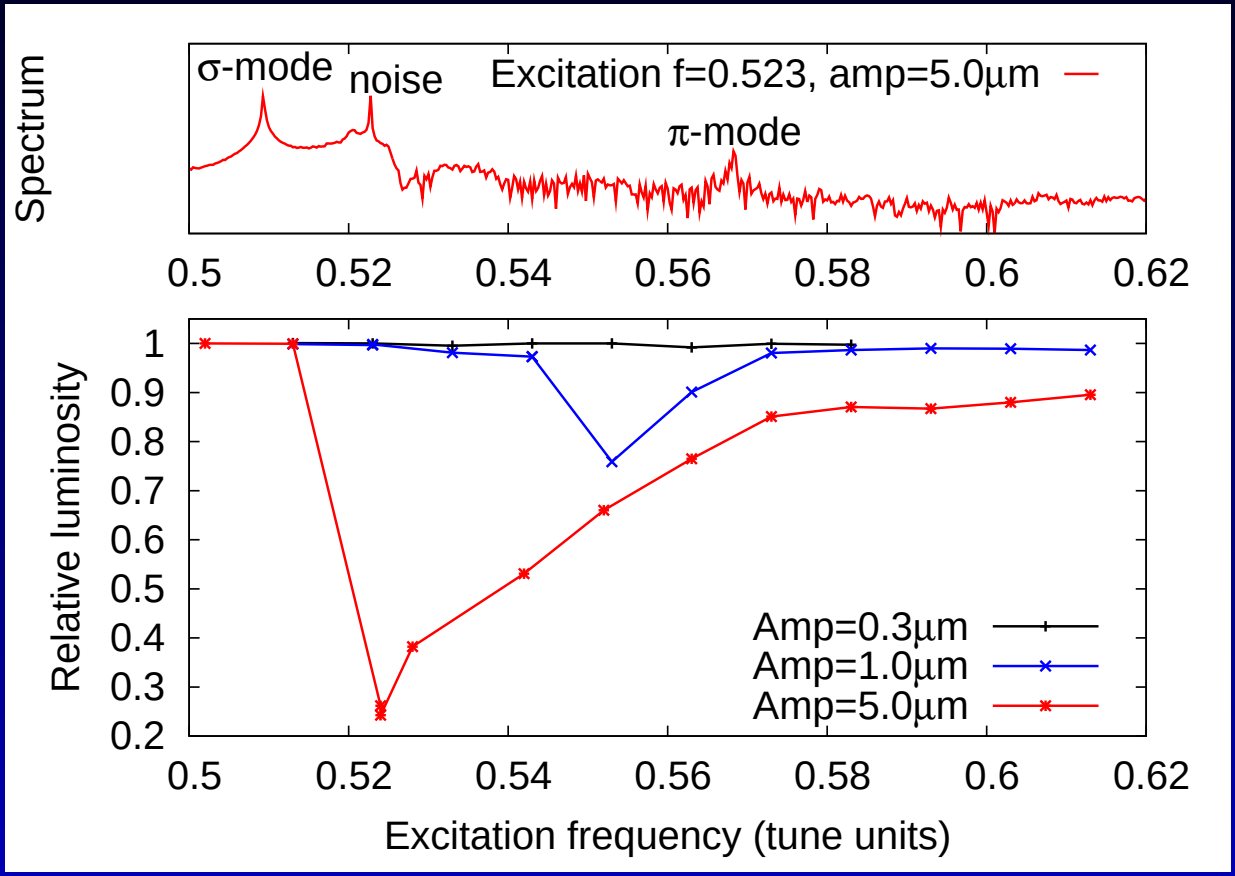
Understanding the phenomena (simulation)



→ Emittance growth versus time

→ This confirms the existence of an instability.

Understanding the phenomena (simulation)

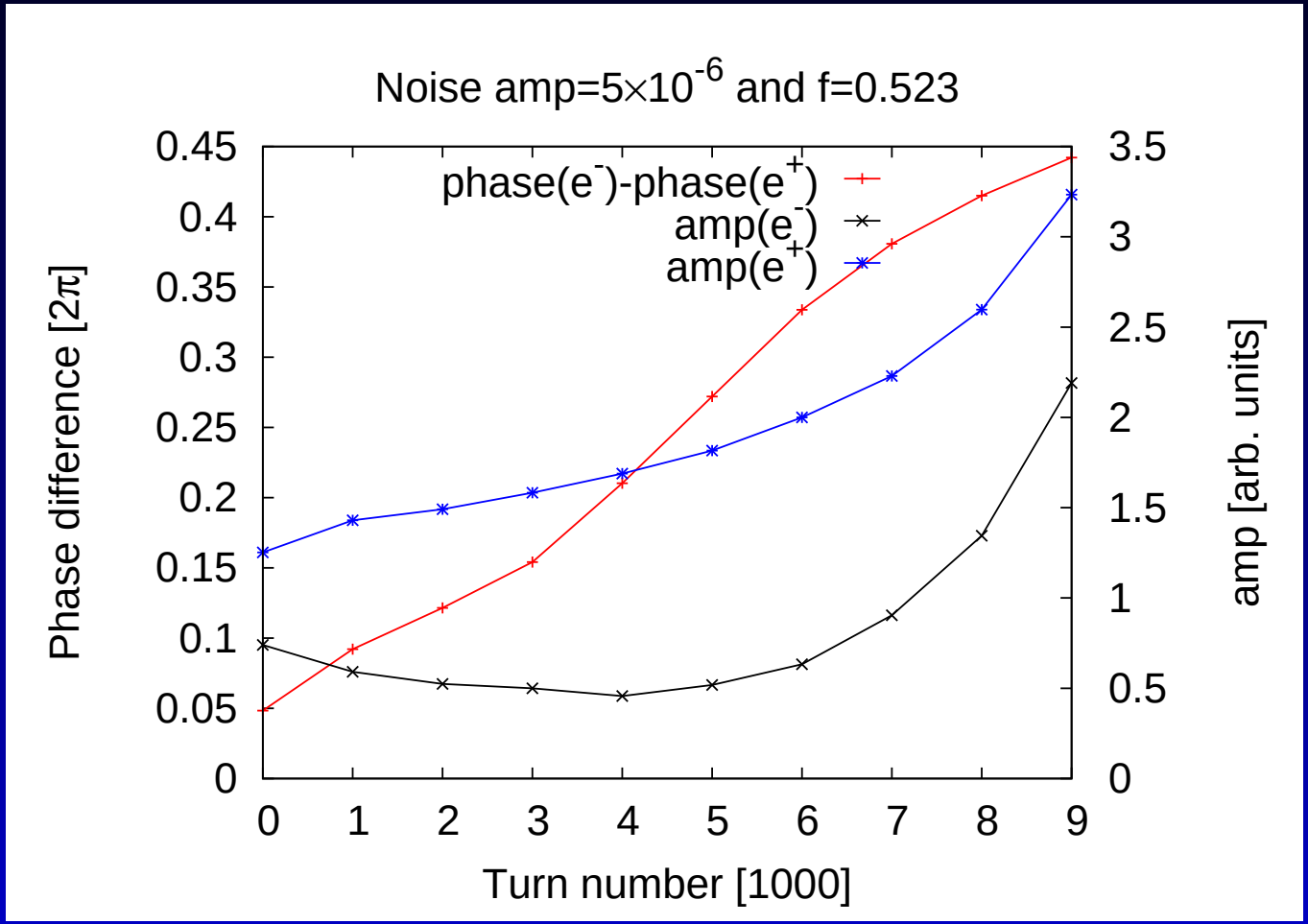


→ Luminosity loss versus frequency

→ Instability is most severe for frequencies within the continuum spectrum (between σ and π modes)

→ No instabilities at the tune (σ-mode).

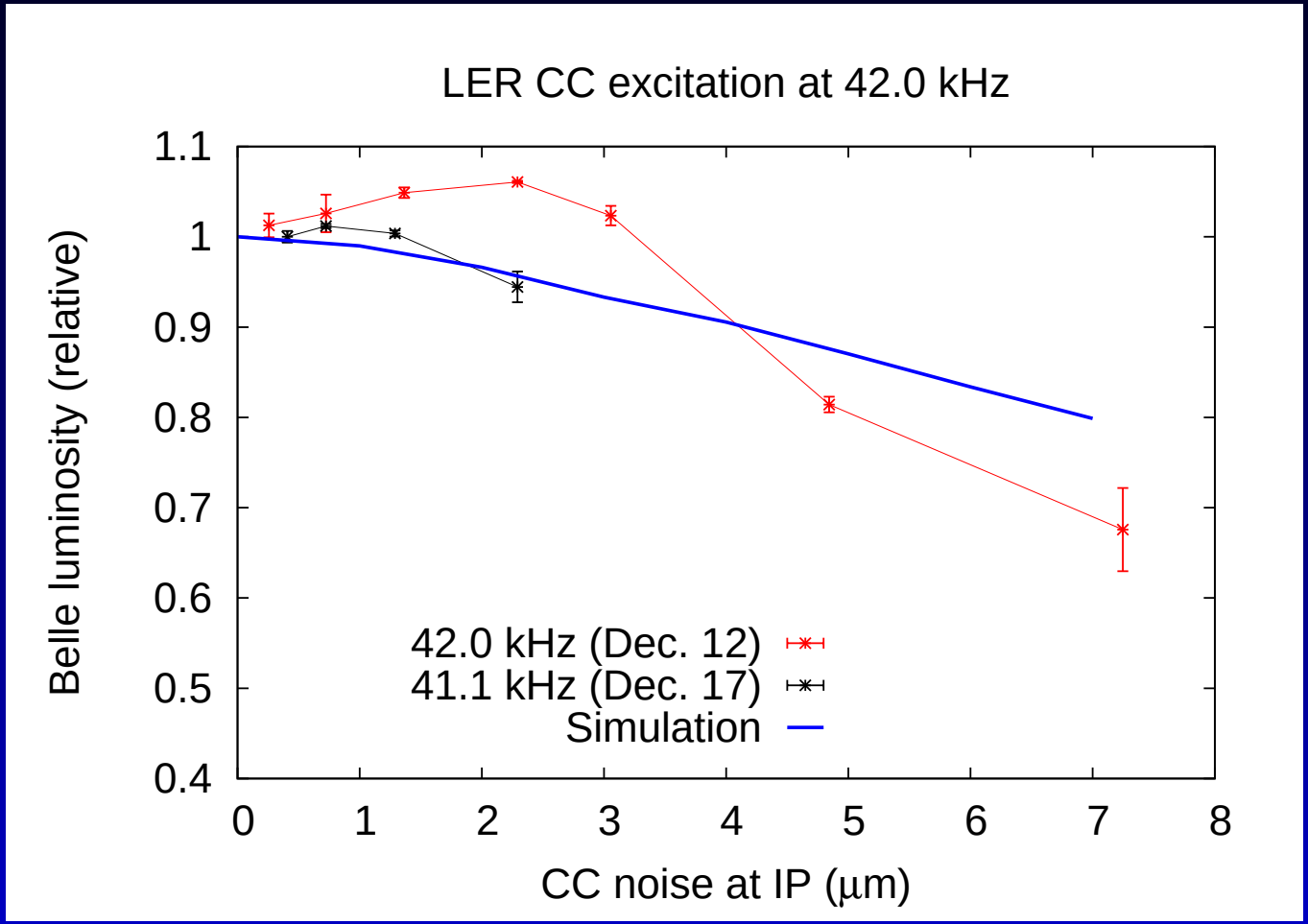
Understanding the phenomena (simulation)



$\longrightarrow e^+ - e^-$ coherent phase difference increases to π

$\longrightarrow$ Amplitudes of coherent motion increases in time

LER CC noise close to Q_y (exps. vs sim.)



→ No instability both in exps. and simulation

→ Trend OK but exp. behavior not reproducible

→ Simulation might miss ingredients like coupling.

Conclusions on noise studies

- A beam-beam driven noise-instability has been observed in KEKB
- The instability requires a frequency within the beam-beam continuum spectrum and amplitude of few % of the σ.
- In degrees this corresponds to 0.2°.
- First effects of noise observed at 0.03°
- Extrapolating to LHC:
  - CC RF phase stability $<< 0.03^\circ$ (OK!)
  - 0.3μm IP offset stability??
  - KEKB BB-tuneshift was 0.046 $>$ LHC tuneshift

Crab dispersion measurement

Turn-by-turn BPM data were acquired with and without Crab Cavity for different beam excitations:

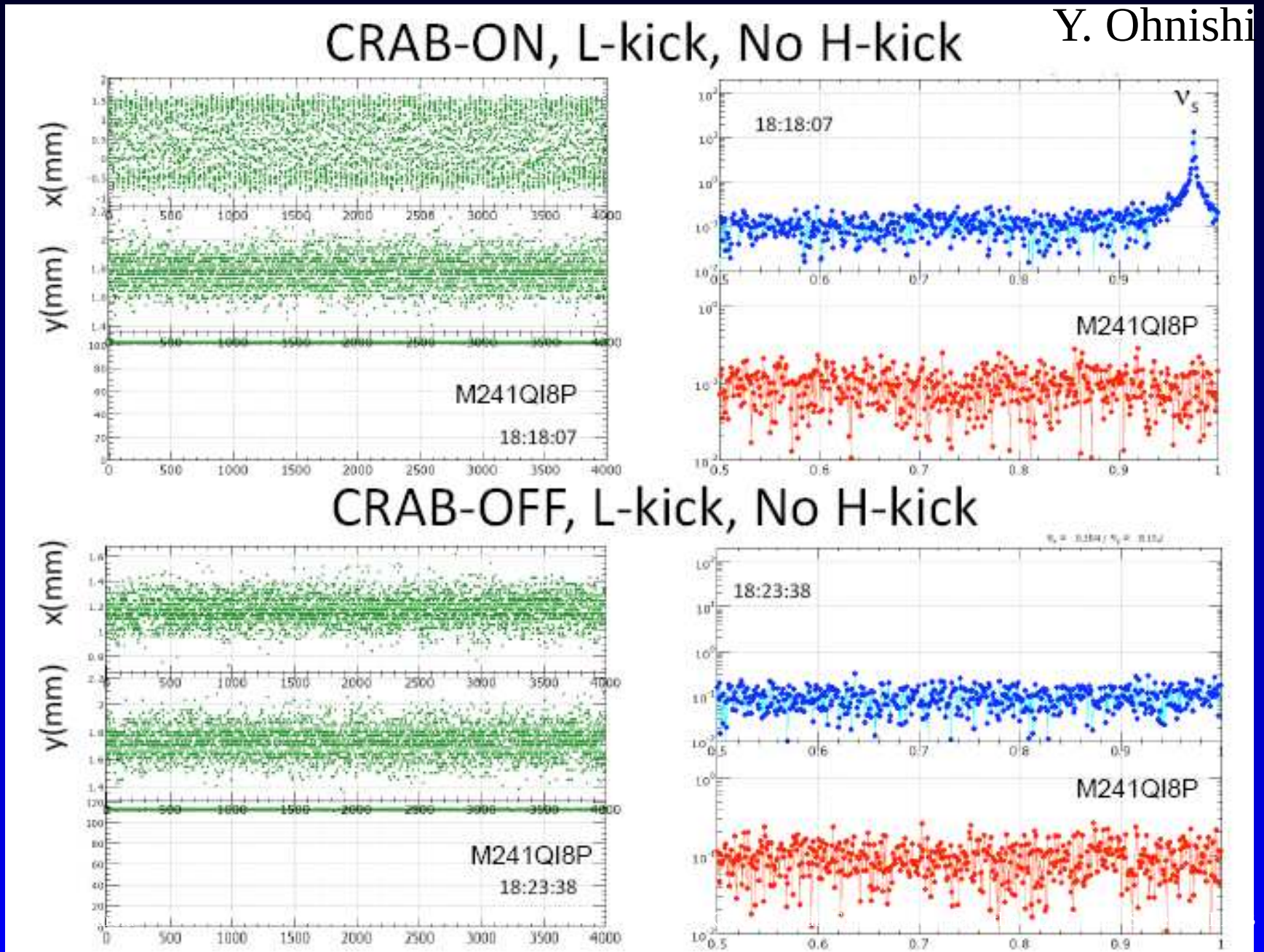
- With longitudinal kick only: Longitudinal motion + CC results in orbit modulation.
- With Horizontal and longitudinal kicks: Excitation of synchrotron sidebands

$$x(s,z) = x_D(s,\delta) + x_\beta(s) + x_{D_{cc}}(s,z)\ ,$$

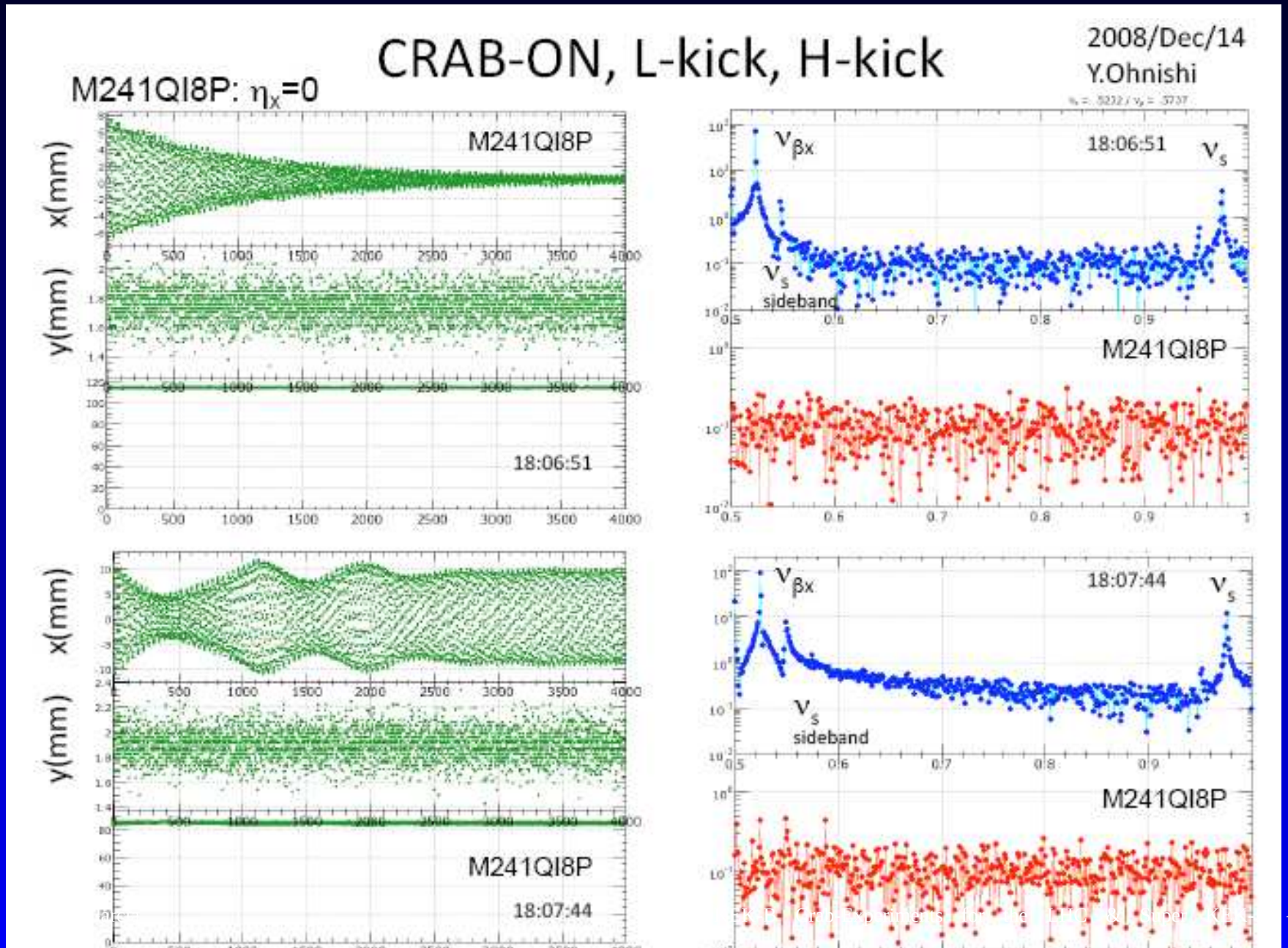
$$x_{D_{cc}}(z,s) \approx z\sqrt{\frac{\beta(s)}{\beta^*}}\tan\left(\frac{\theta}{2}\right)\frac{\cos\left(\Delta\varphi_1 - \pi Q\right)}{\cos\left(\Delta\varphi_0 - \pi Q\right)}\ .$$

Q_s observed in a Dispersion-free BPM

Y. Ohnishi



Synchrotron sidebands

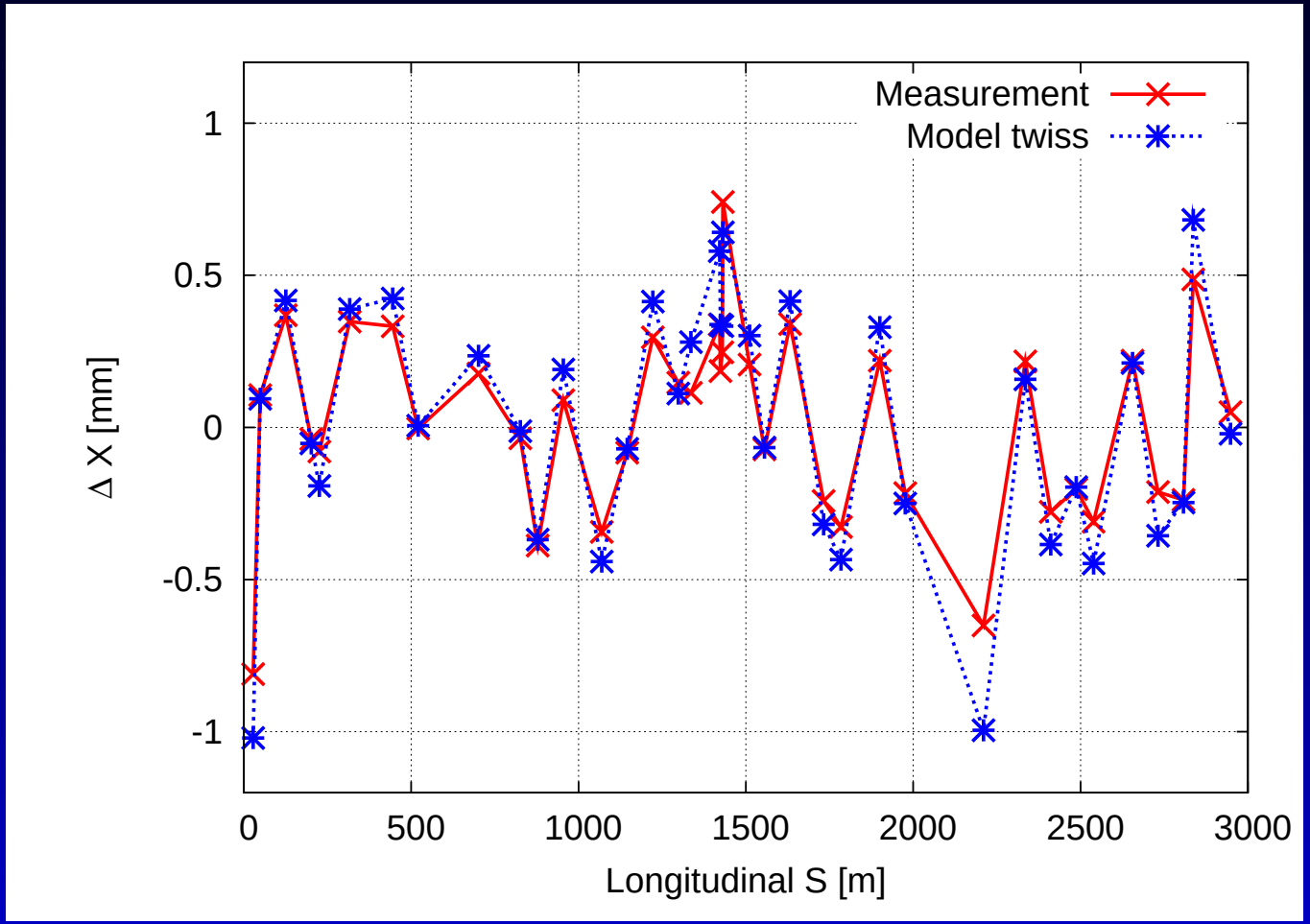


Crab dispersion measurement

The most precise measurement of crab dispersion turns out to use the closed orbit with CC phase offset:

- KEK regularly operates CC with 10° phase offset
- This offset is like a dipole kick
- $x_{D_{cc}}$ is obtained by subtracting orbits with and without CC

Crab dispersion measurement



Model and measured $x_{D_{cc}}$ are in very good agreement!

Conclusions on crab dispersion meas.

- First observations of crab dispersion via BPM.
- Robust measurement via the CO
- Synchrotron sidebands have been observed but diagnostics not so evident.

CC tests in LHC without CC

- Head-Tail oscillations are like an oscillating crab
  - Impact of CC on collimation
  - Lifetime
- AC dipole to reproduce CC resonances
  - CC failure modes
  - Momentum cleaning (see Yipeng's talk)
- Beam-beam with crossing angle is a CC in the core of the beam.

General Remarks & Outlook

- Very fruitful experimental collaboration on Crab Cavities (thanks KEK for the beam!)
- Further analysis ongoing
- More experiments in KEK? (Funakoshi san just asked!)