KEK-B noise experiments

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Thanks to G. Arduini, R. de Maria and R. Miyamoto

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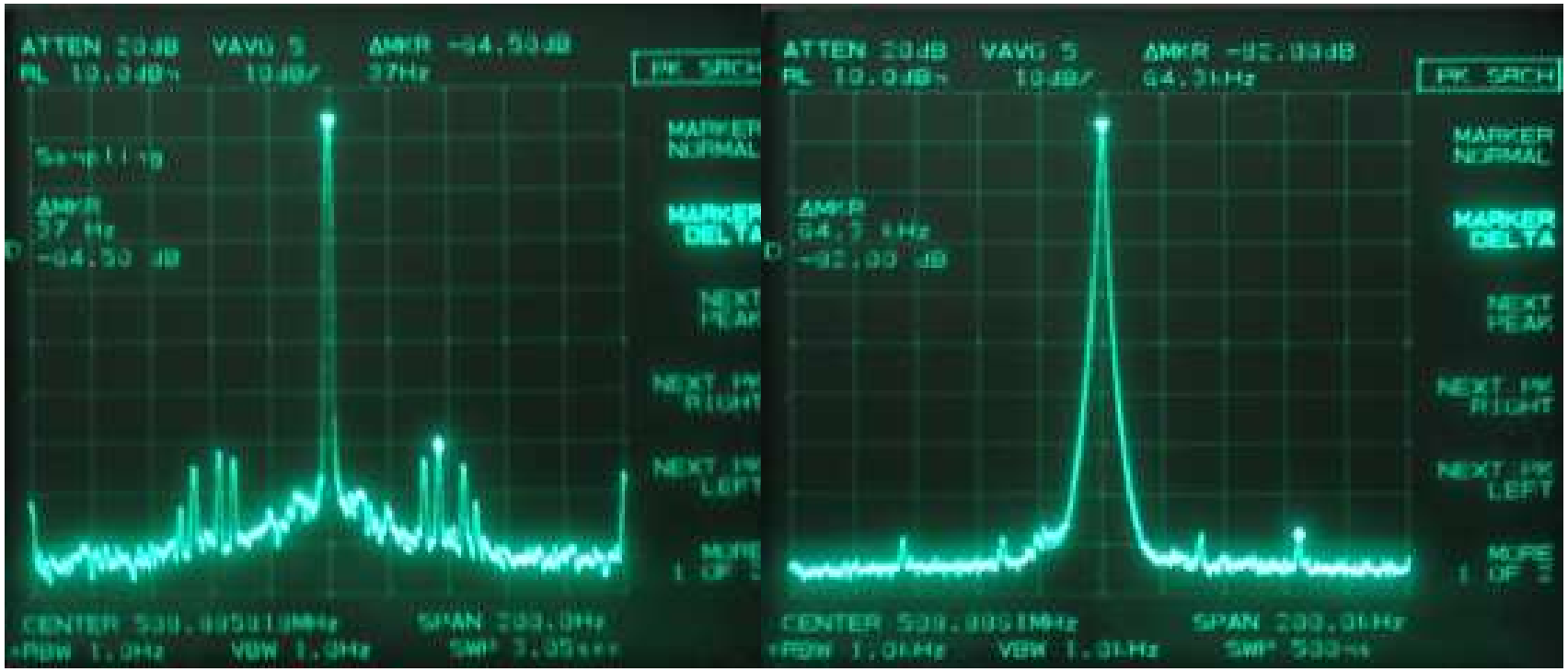
Motivation, KEKB CC spectra



SPAN 200 Hz SPAN 200 kHz

$\longrightarrow$ CC noise consists of a set of frequencies (sidebands)

$\longrightarrow$ Potentially dangerous

CC sinusoidal phase noise

Crab cavity voltage:

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

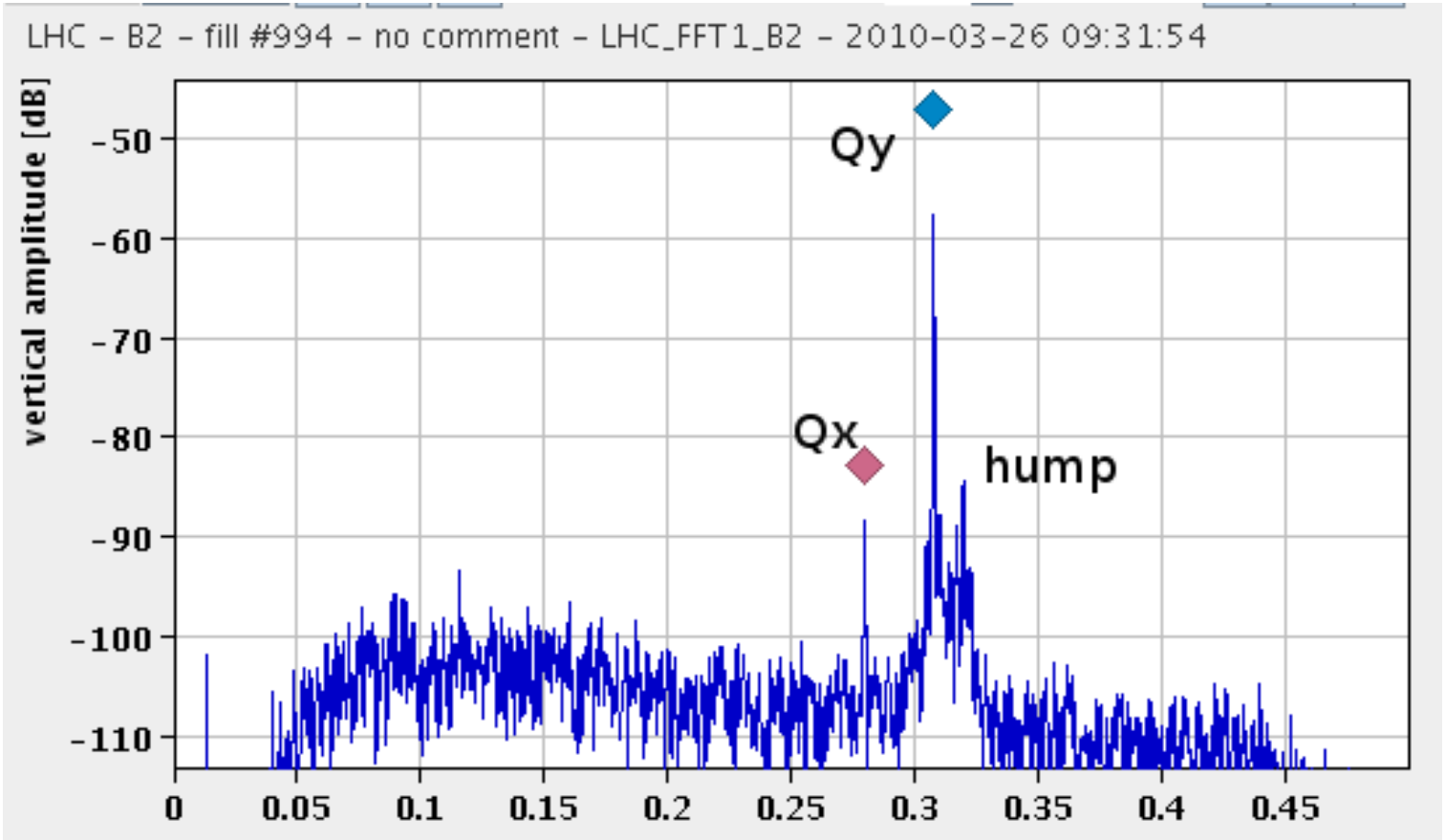
if phase modulation $\phi = \phi_{noise} \sin(vt)$, CC voltage $\approx$

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

$\longrightarrow$Phase modulation is approximated by sidebands
$\longrightarrow$CC phase error results in a dipolar kick:

$$\Delta x_{IP} \approx \frac{c}{\omega} \tan\left(\frac{\theta}{2}\right) \phi_{noise} \sin(vt)$$

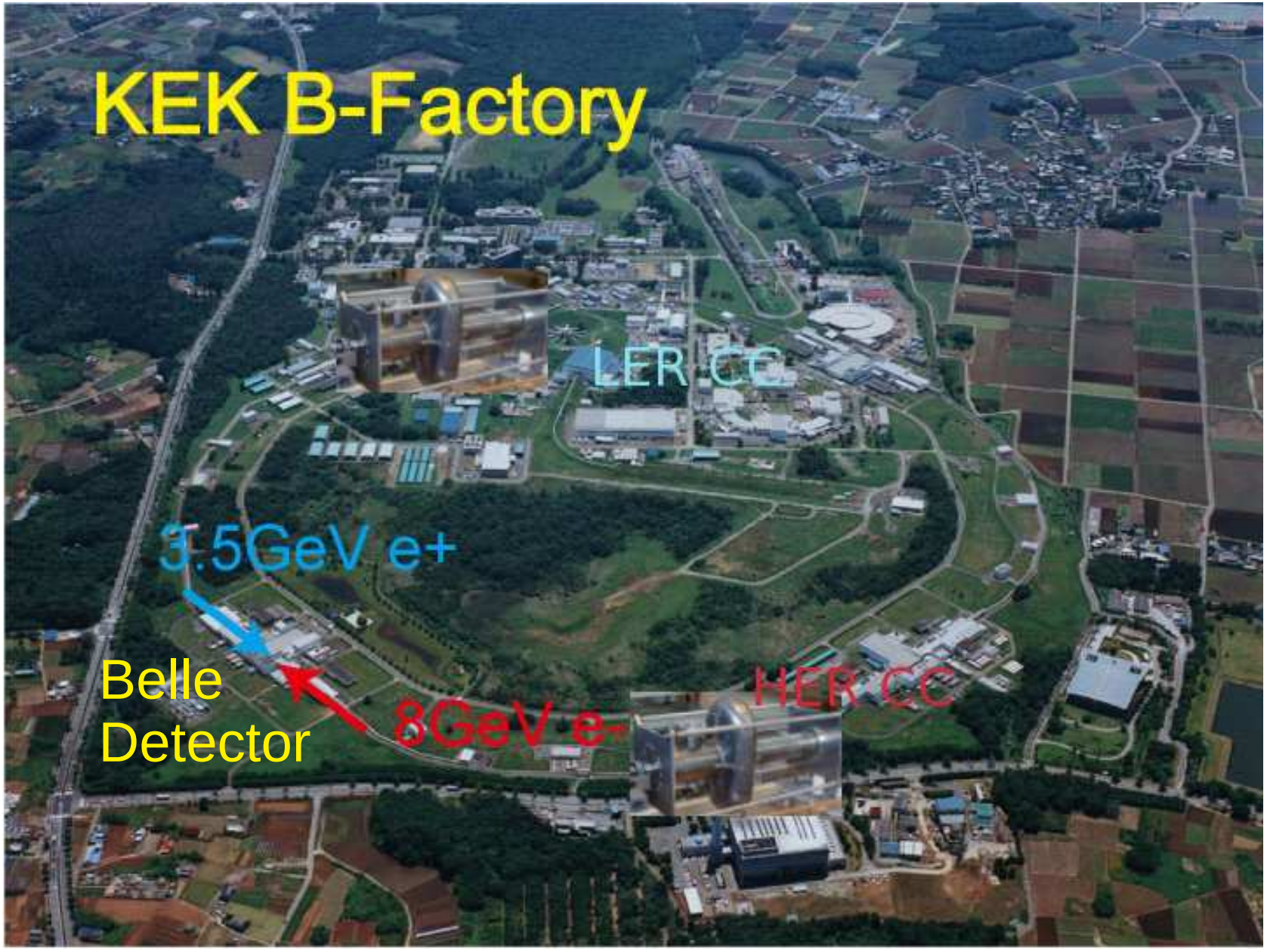
The LHC hump (G. Arduini, R.d. Maria)



Observed oscillations at injection$\approx 1\mu$m.

Estimated kick$\approx 10^{-4}\sigma$ at injection.

At higher energies kick$\leq 10^{-4}\sqrt{\frac{E_0}{E}}\,\sigma$.


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

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)		44.522	45.524
Vertical tune (Q_y)		41.602	43.585
Hor. b-b parameter (ξ_x)		0.1	0.11
Synchrotron tune (Q_s)		0.021	0.025
Revolution frequency	kHz	99.4	99.4
Feedback		On	On

The experiment

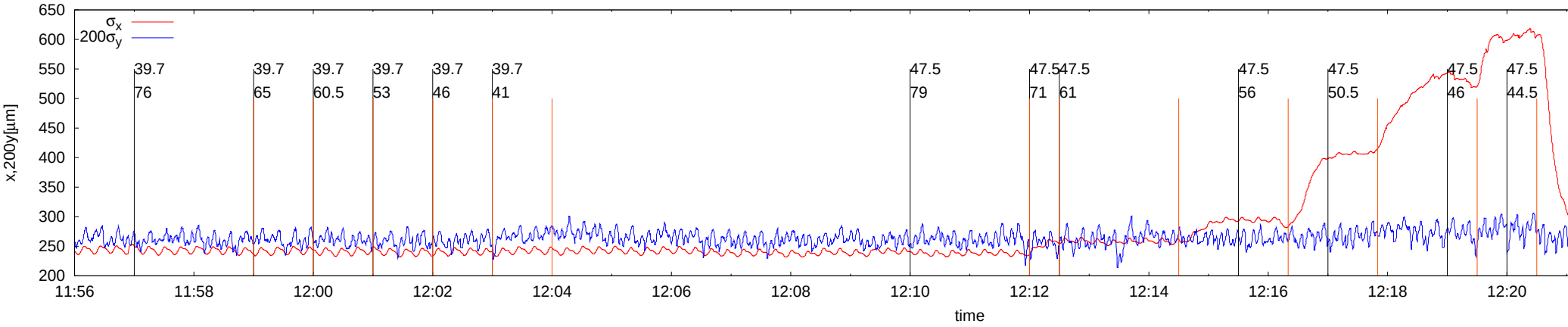
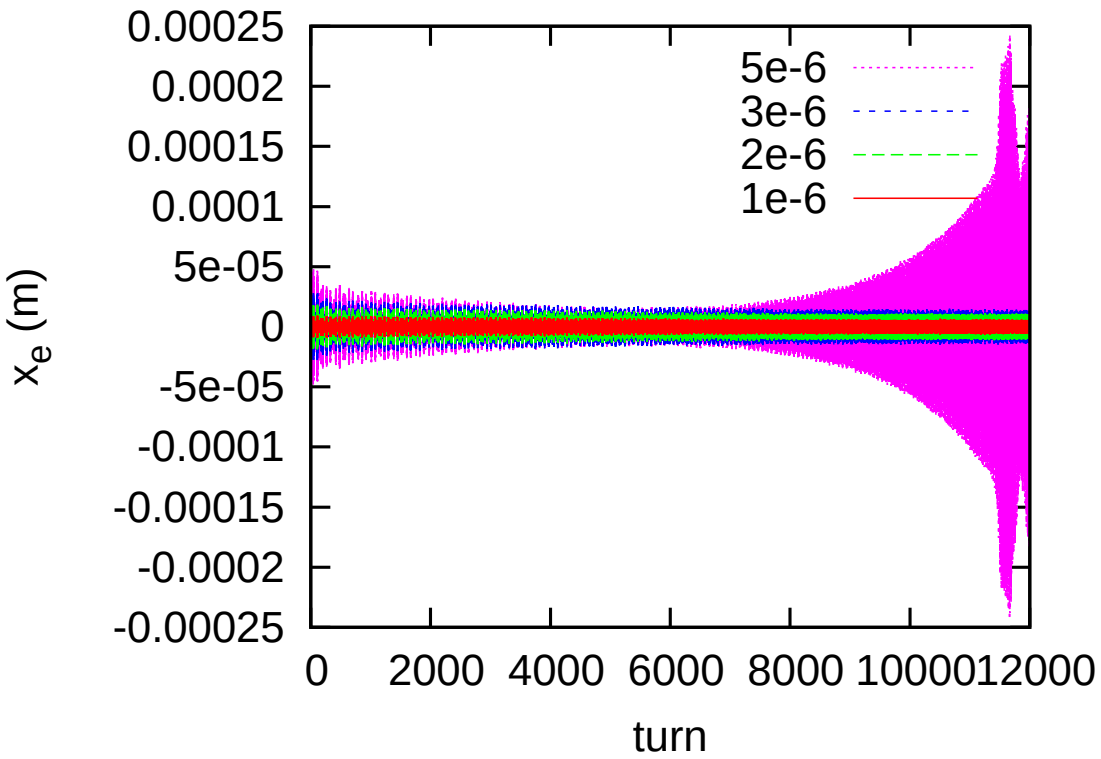


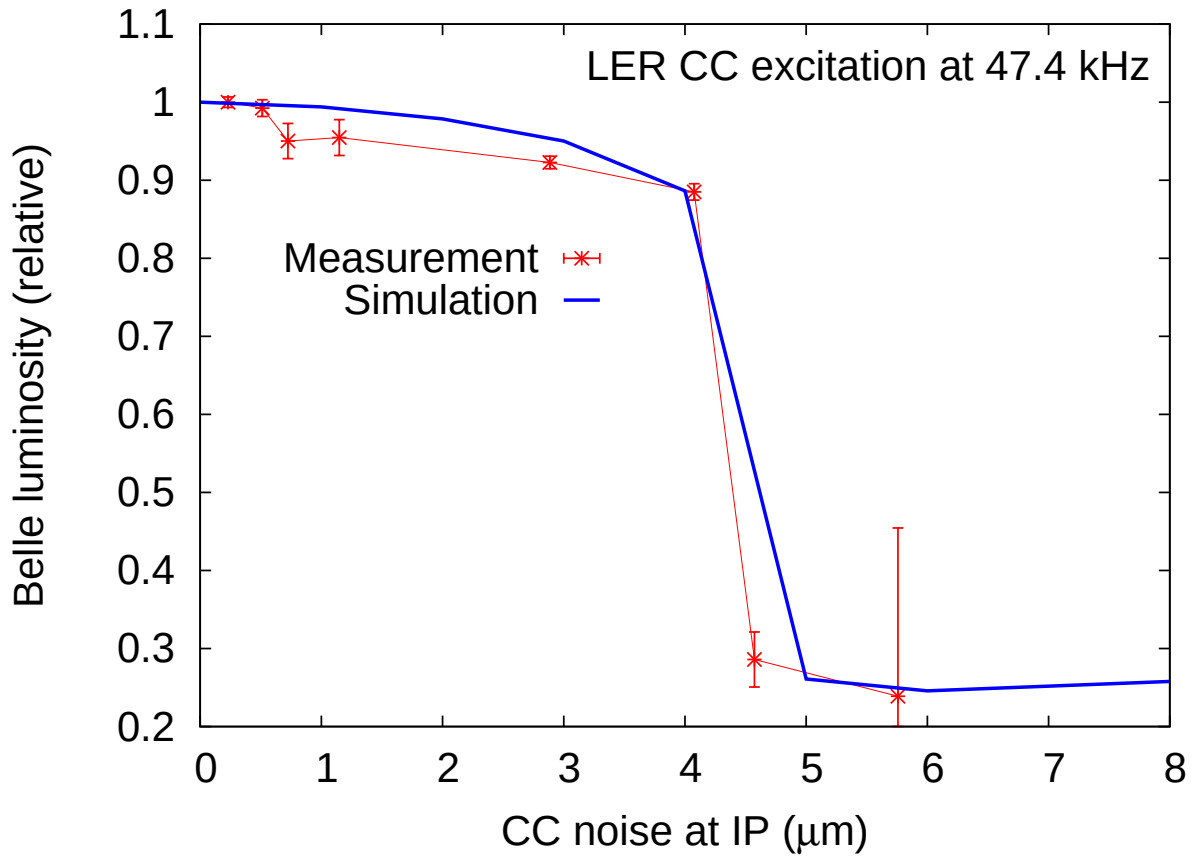
Illustration of beam sizes versus time as frequency and amplitude of the CC phase noise are changed.

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.

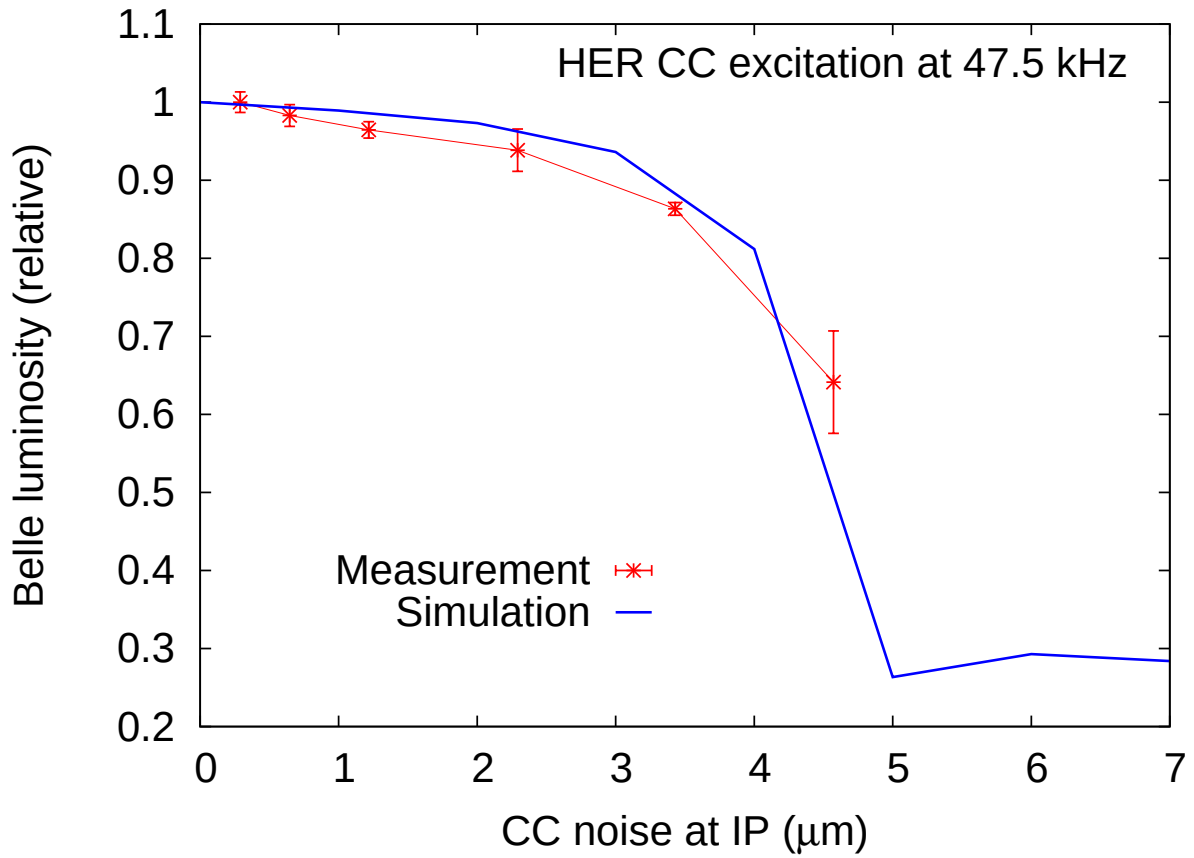
LER CC noise close to Q_x (exp. vs sim.)



$\longrightarrow$Measurement and simulation agree excellently

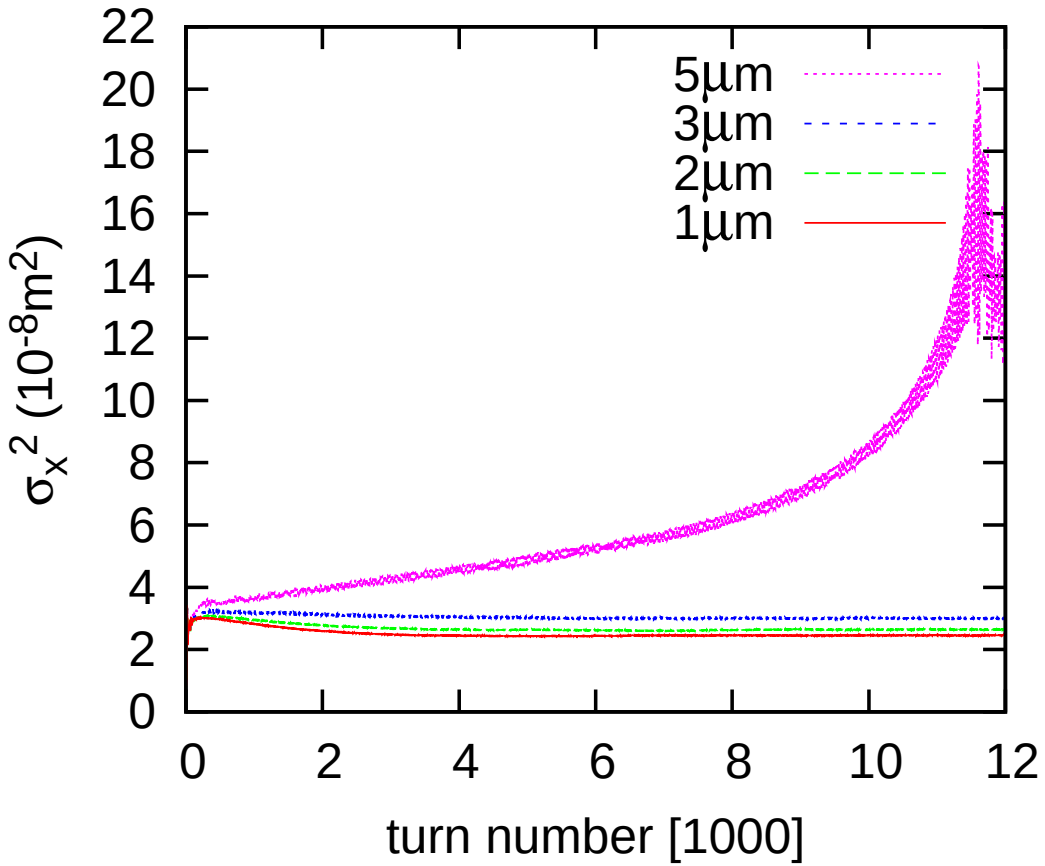
$\longrightarrow$Abrupt luminosity loss at 4.5μm$\approx 0.03\sigma_x^*$ ($\phi \approx$0.2°)

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



$\longrightarrow$ Similar results for the HER

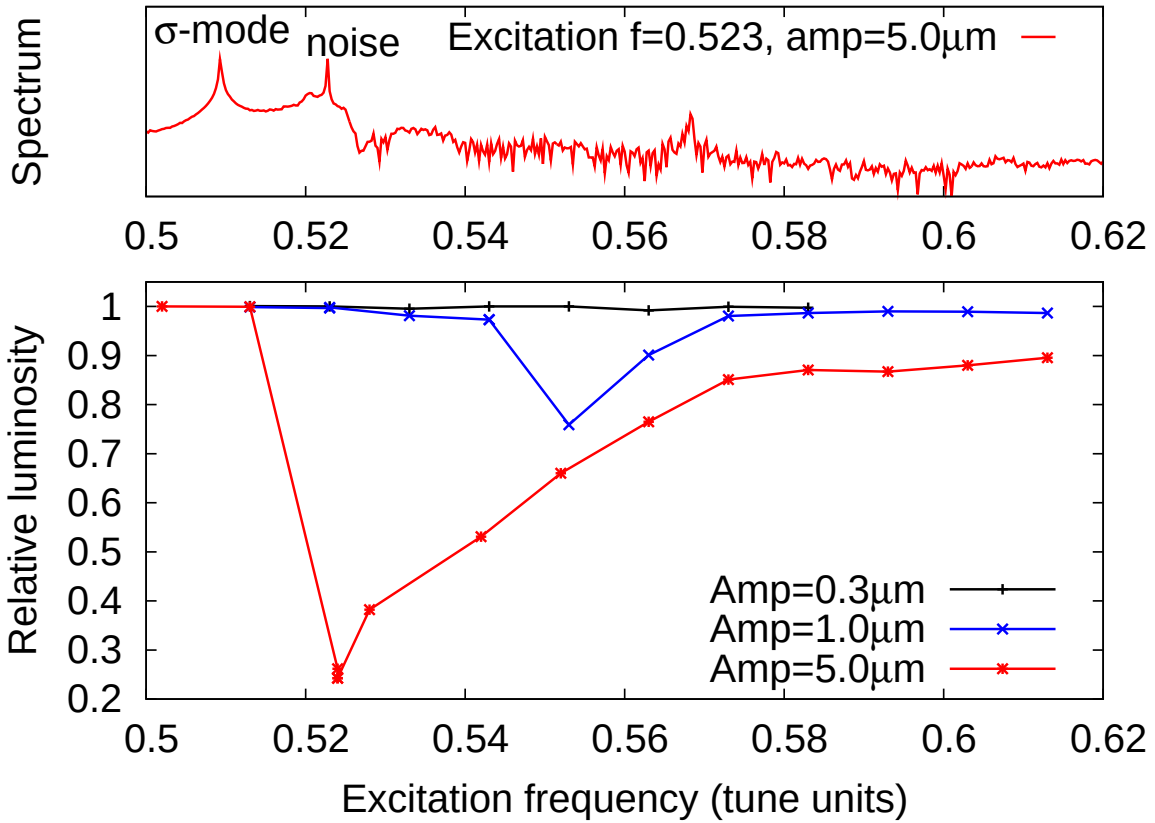
Understanding the phenomena (simulation)



$\longrightarrow$ Emittance growth versus time

$\longrightarrow$ This confirms the existence of an instability.

Understanding the phenomena (simulation)

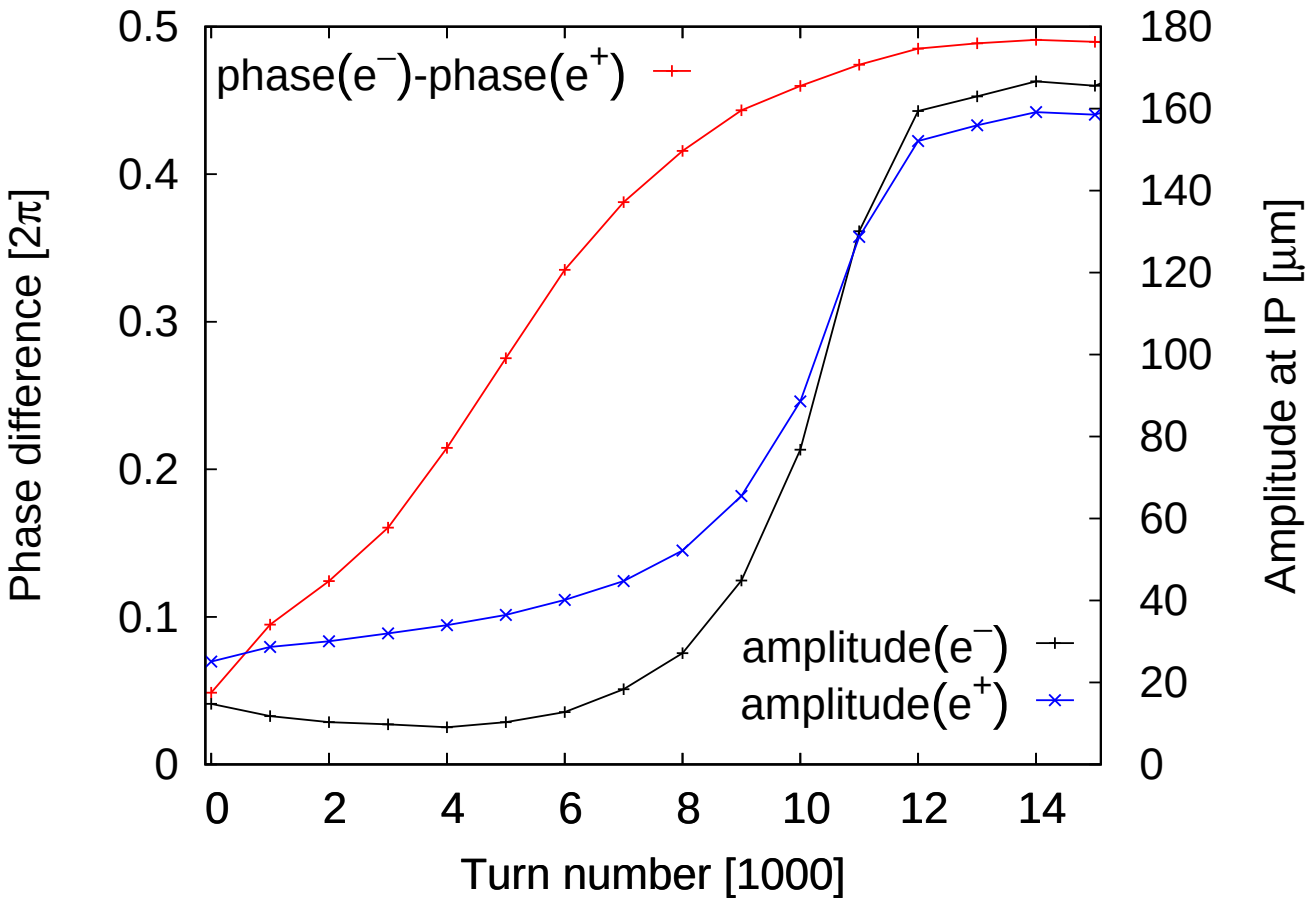


$\longrightarrow$ Luminosity loss versus frequency

$\longrightarrow$ Instability is most severe for frequencies between σ and π modes

$\longrightarrow$ No instabilities at the tune (σ-mode).

Understanding the phenomena (simulation)



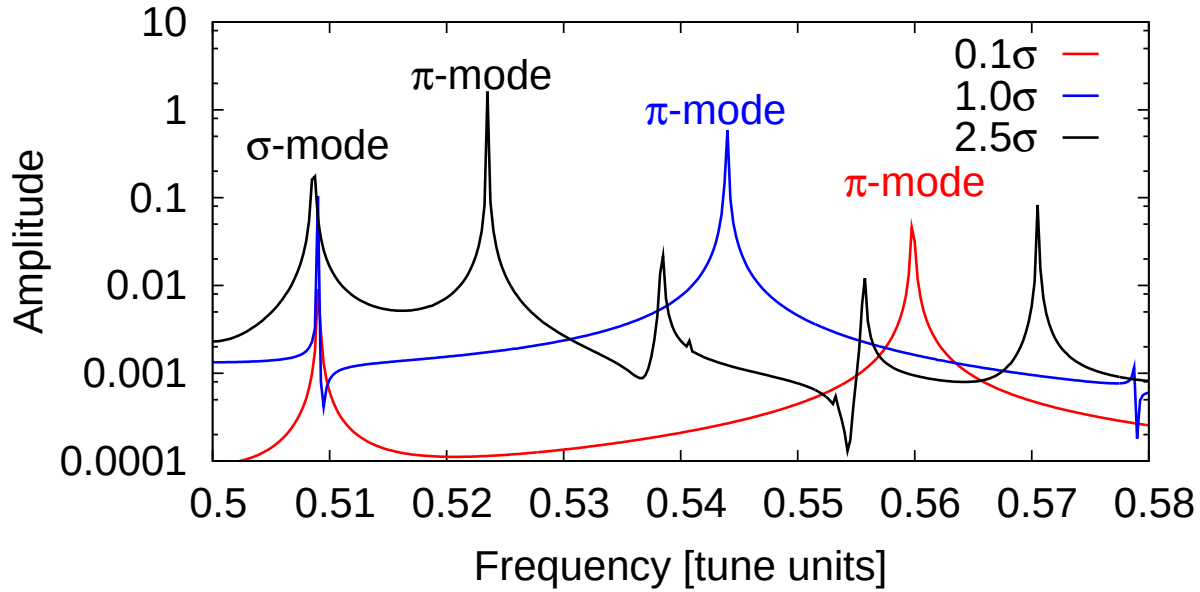
$\longrightarrow e^+ - e^-$ coherent phase difference increases to π

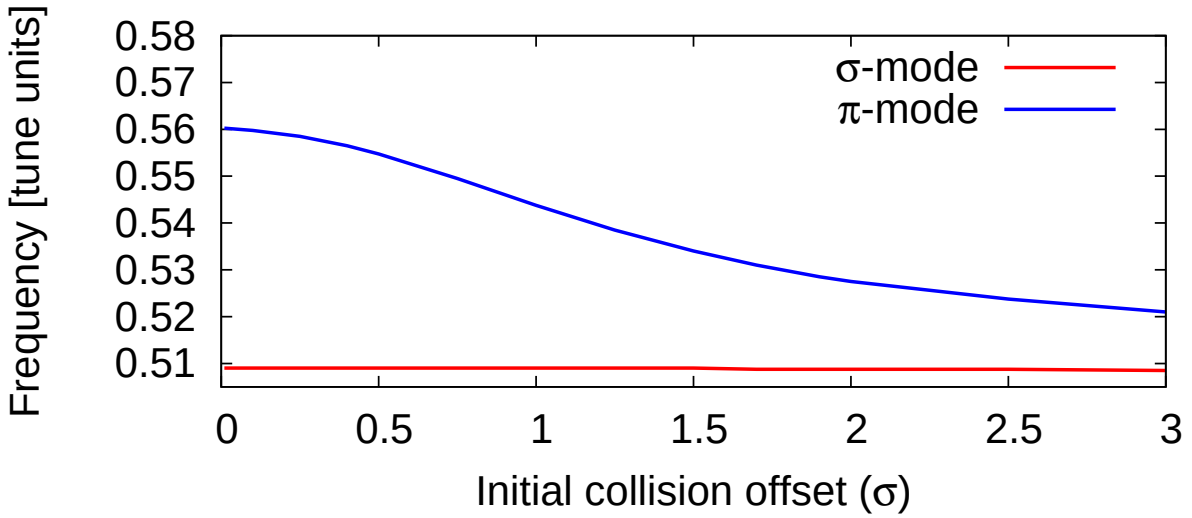
$\longrightarrow$ Amplitudes of coherent motion increases in time

Hypothesis

Exciting between the σ- and π-modes casues a drift of the π-mode frequency towards the exciting frequency possibly iniciating a resonance phenomena.

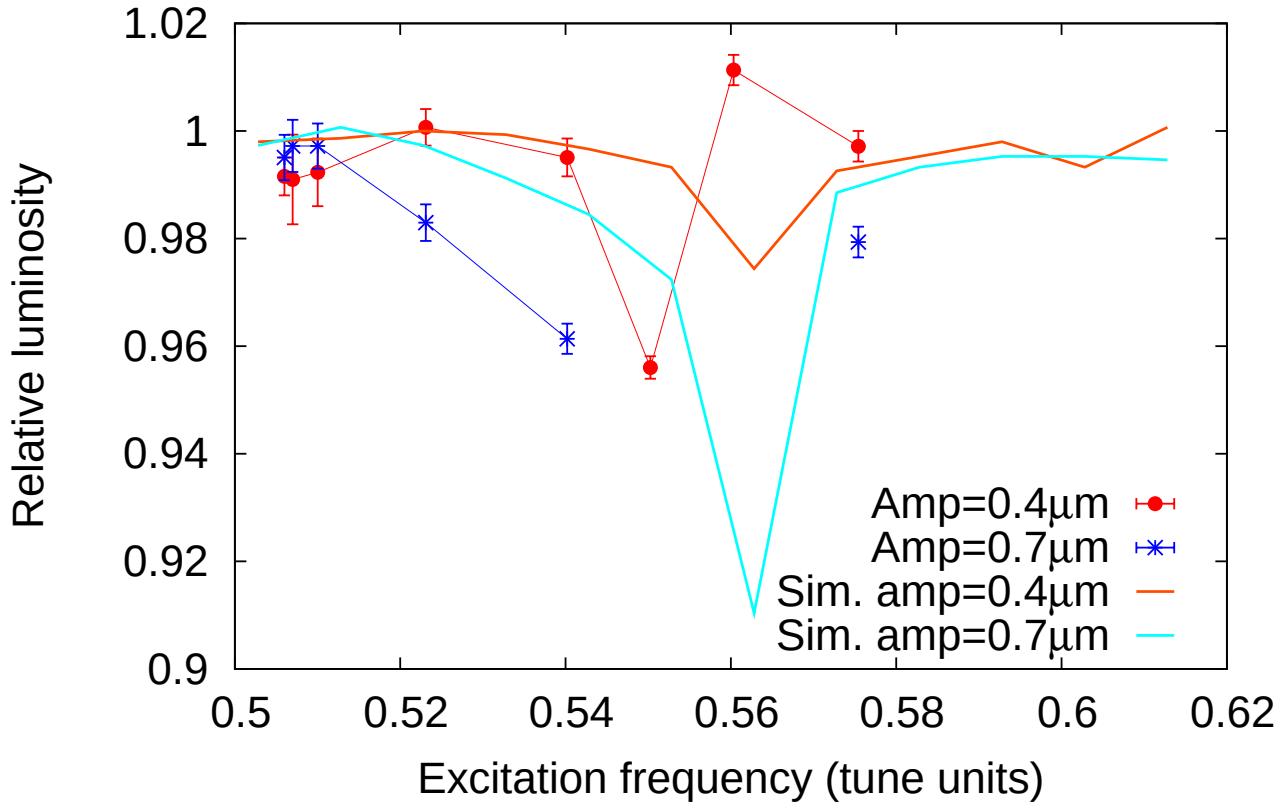
Hypothesis verification via rigid simulation





$\longrightarrow$ π-mode frequency shifts with amplitude

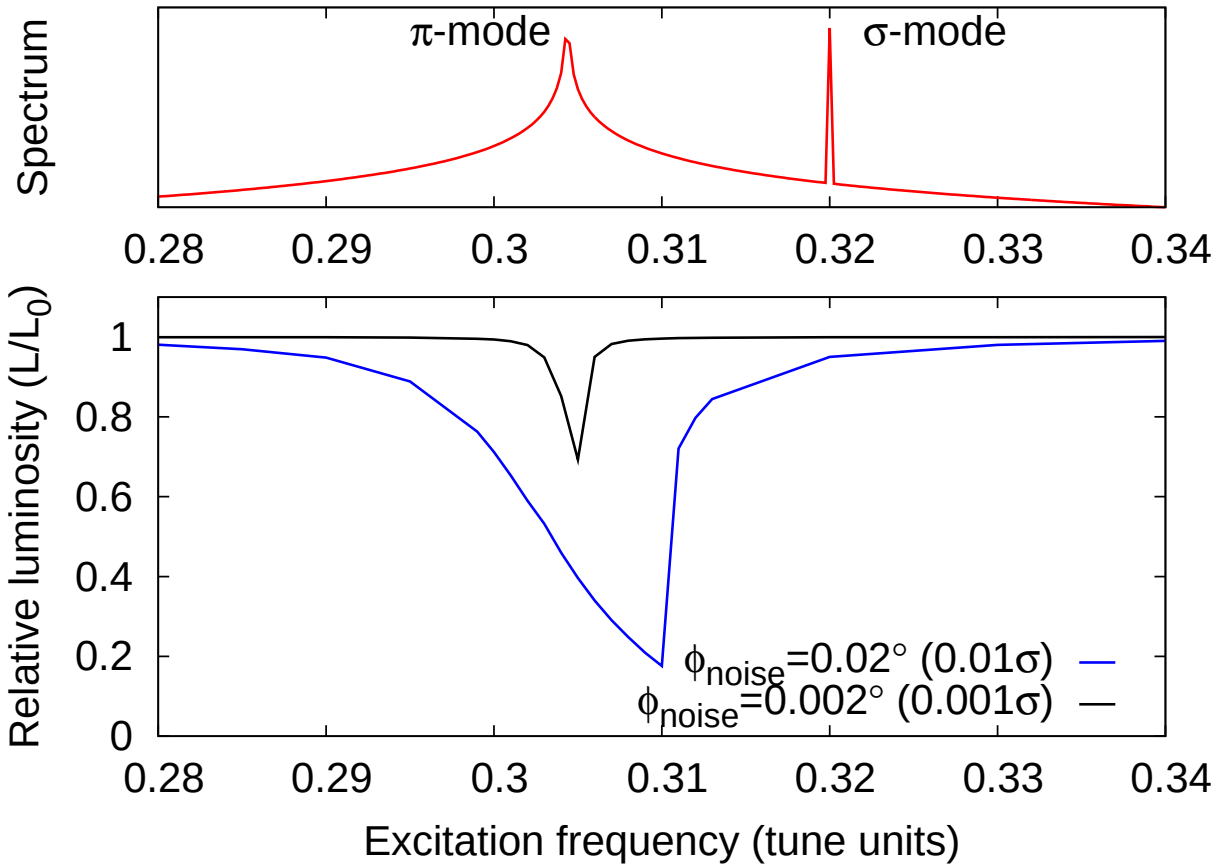
Further experimental verifications



$\longrightarrow$ Weaker instabilities experimentally confirmed at $0.4\mu\text{m} \approx 0.003\sigma_x$ ($\phi_{noise} \approx 0.02^\circ$)

$\longrightarrow$ Slight differences with simulation...

Simplified rigid simulation for the LHC

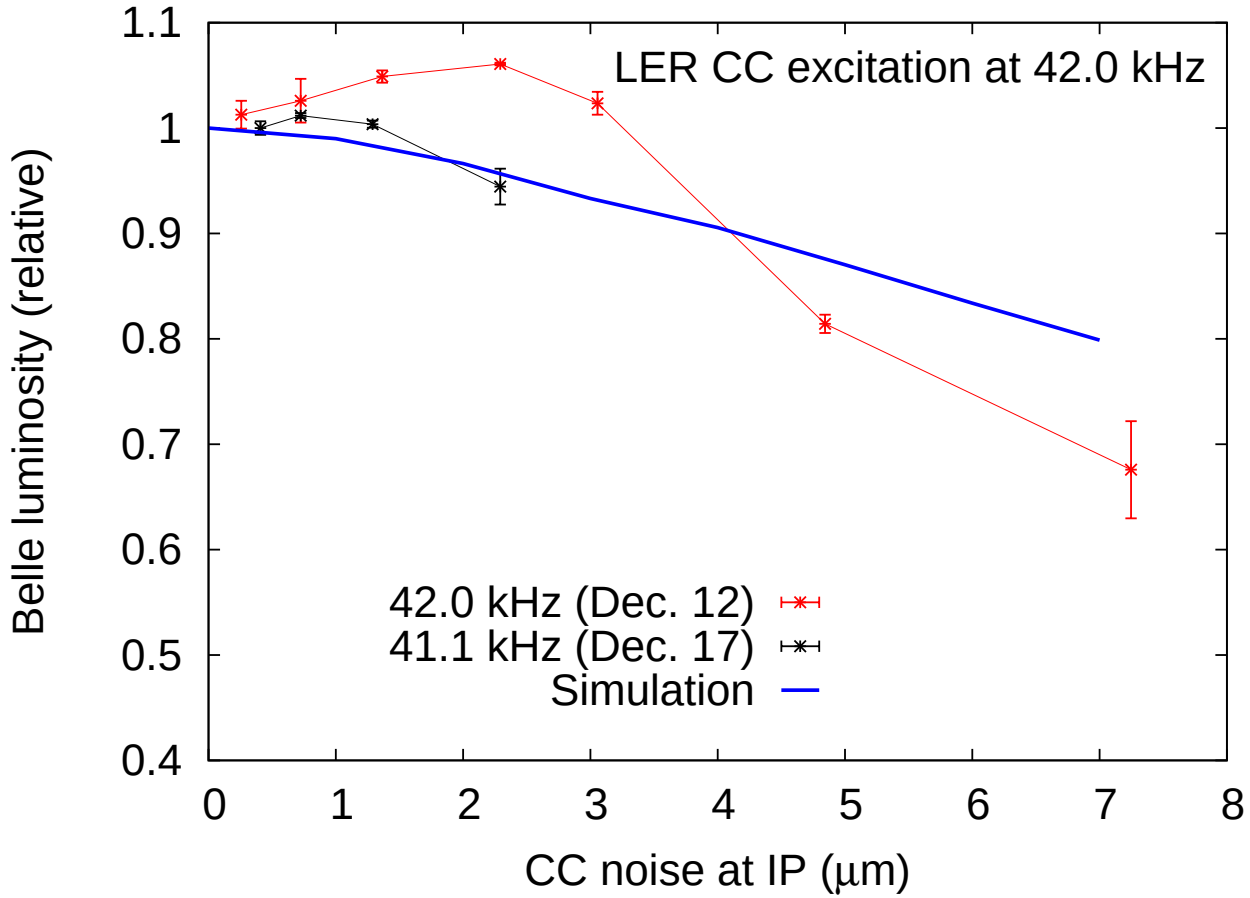


$\longrightarrow \phi_{noise}$ =0.02° certainly dangerous

$\longrightarrow \phi_{noise}$=0.002° maybe OK if considering Landau damping and feedback $\longrightarrow$ strong-strong simulations

$\longrightarrow$ Hump ($<0.0001\sigma$) OK?

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



$\longrightarrow$ No instability both in exps. and simulation

$\longrightarrow$ Trend OK but exp. behavior not reproducible

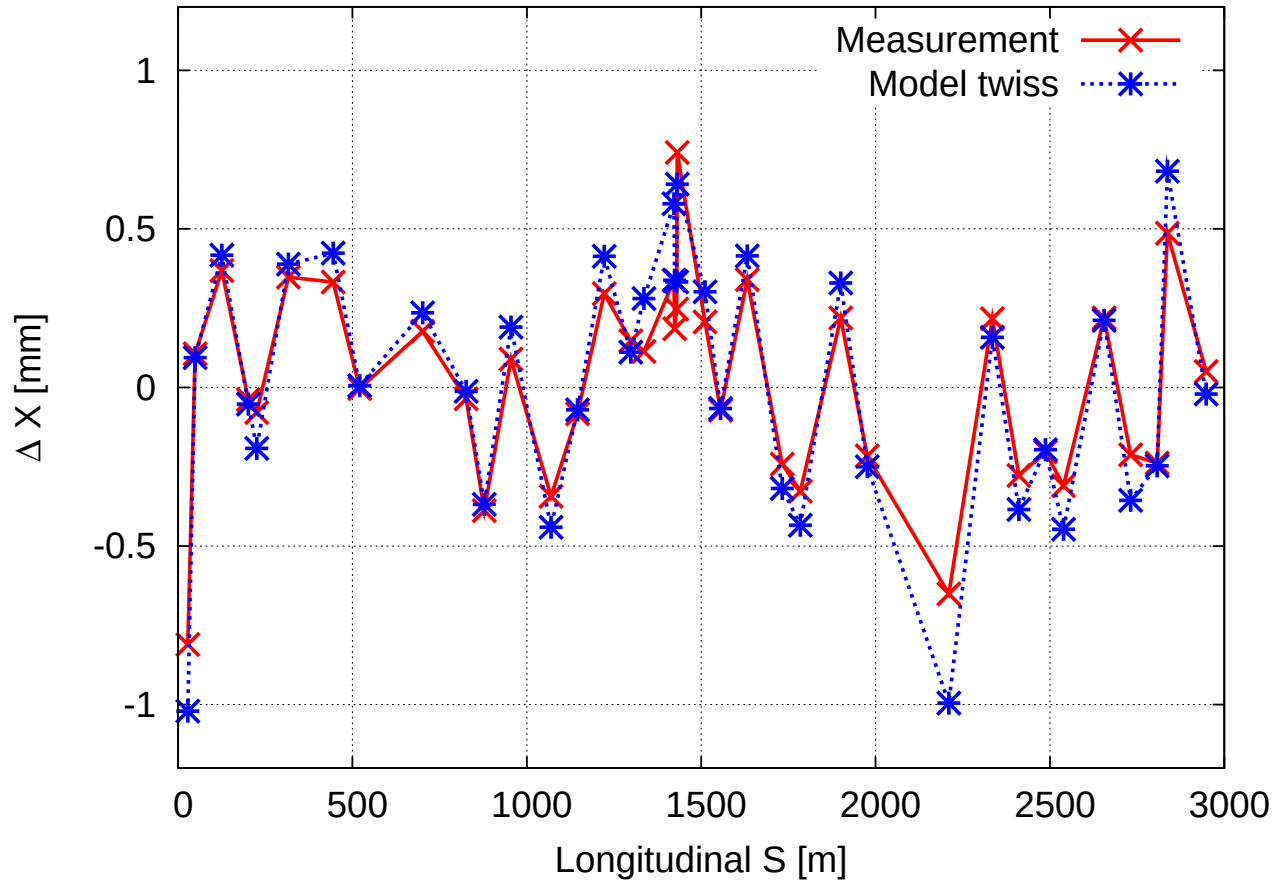
$\longrightarrow$ Simulation might miss ingredients like coupling.

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

- ⋆ A beam-beam driven noise-instability has been observed in KEKB for phase noise $\geq 0.02^\circ$ and frequencies between the σ- and π-modes
- ⋆ Extrapolating to LHC:
  - No spectral lines between Q_x of 0.3 and 0.33
  - In frequency: $(N \pm 0.3) f_{rev}$, $(N \pm 0.33) f_{rev}$ for any N (≈70000 windows of 300Hz)
  - 0.002° phase noise might be tolerated with Landau damping and feedback$\longrightarrow$ Need strong-strong simulations
  - lots to learn from the hump