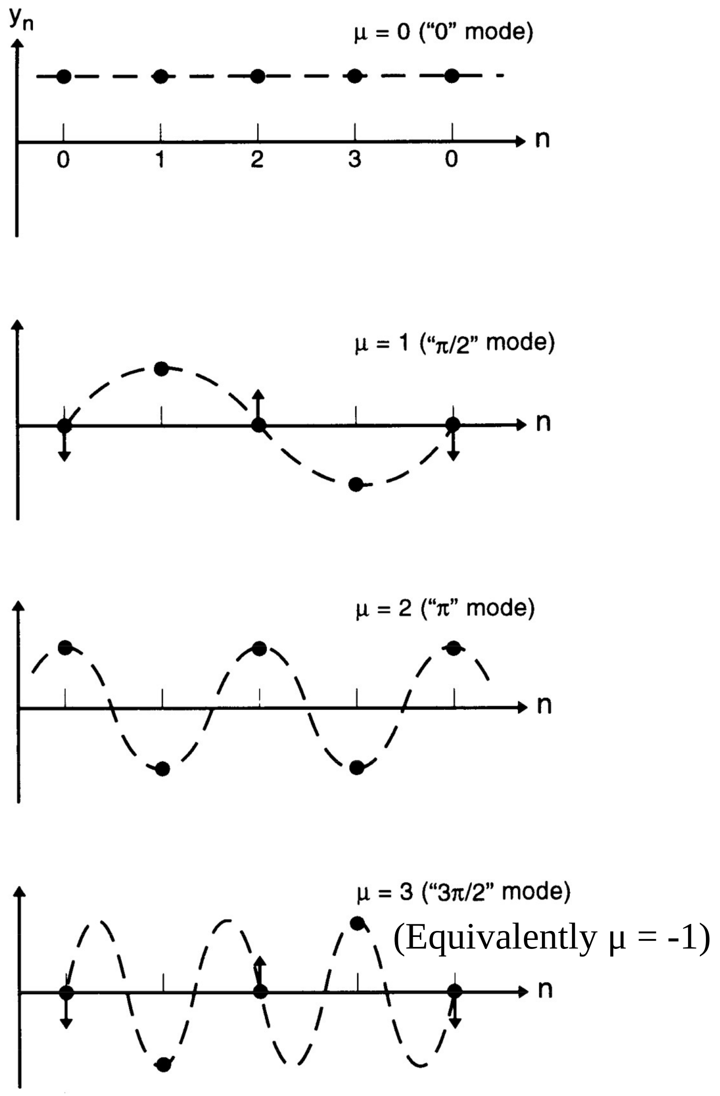
Numerical investigations of the interplay between a harmonic excitation, the damper pickup resolution and the impedance

X. Buffat and N. Mounet

- Reminder about coupled bunch instabilities
- The 50Hz lines conundrum
- Simulations
  - Model
  - Results

Reminder on coupled bunch instabilities
(From A. Chao's book)



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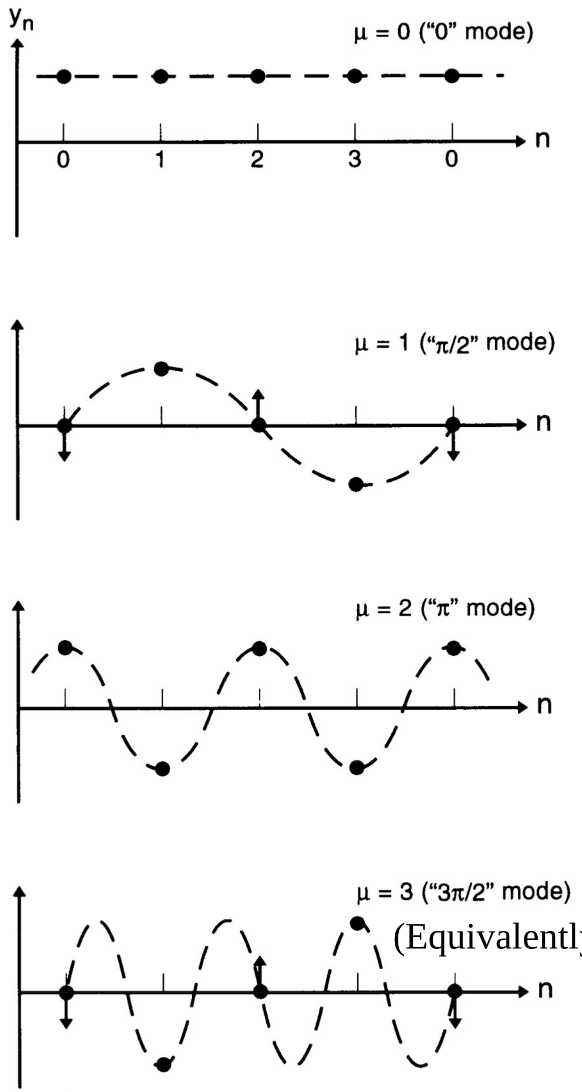

(Equivalently μ = -1)

Betatron freq. ($2\pi Q^* f_{rev}$)

Coupled bunch mode number

$$\Omega^{(\mu)} - \omega_\beta = -i \frac{M N r_0 c}{2\gamma T_0^2 \omega_\beta} \sum_{p=-\infty}^{\infty} Z_1^{\perp} \left[\omega_\beta + (pM + \mu)\omega_0 \right]$$

Number of bunches

Revolution freq.

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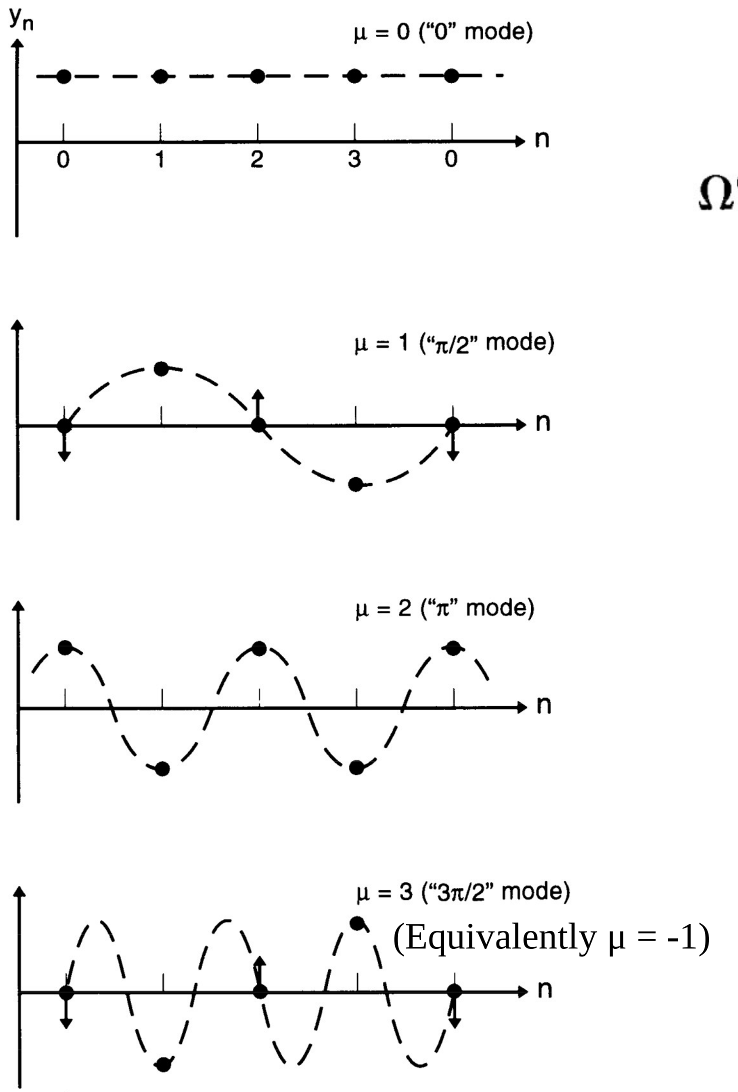

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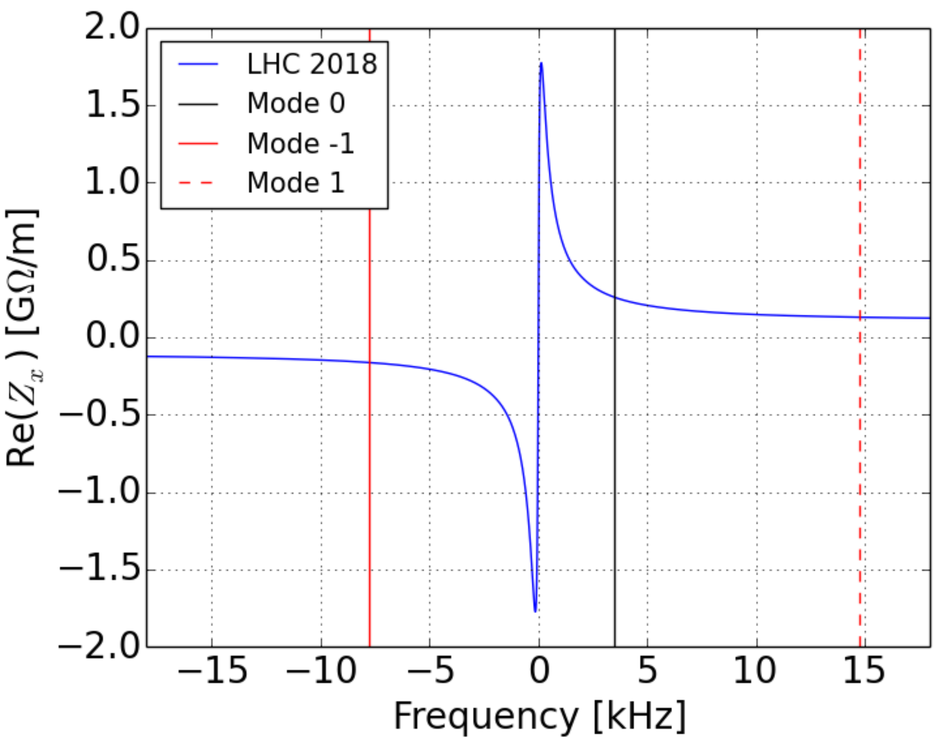

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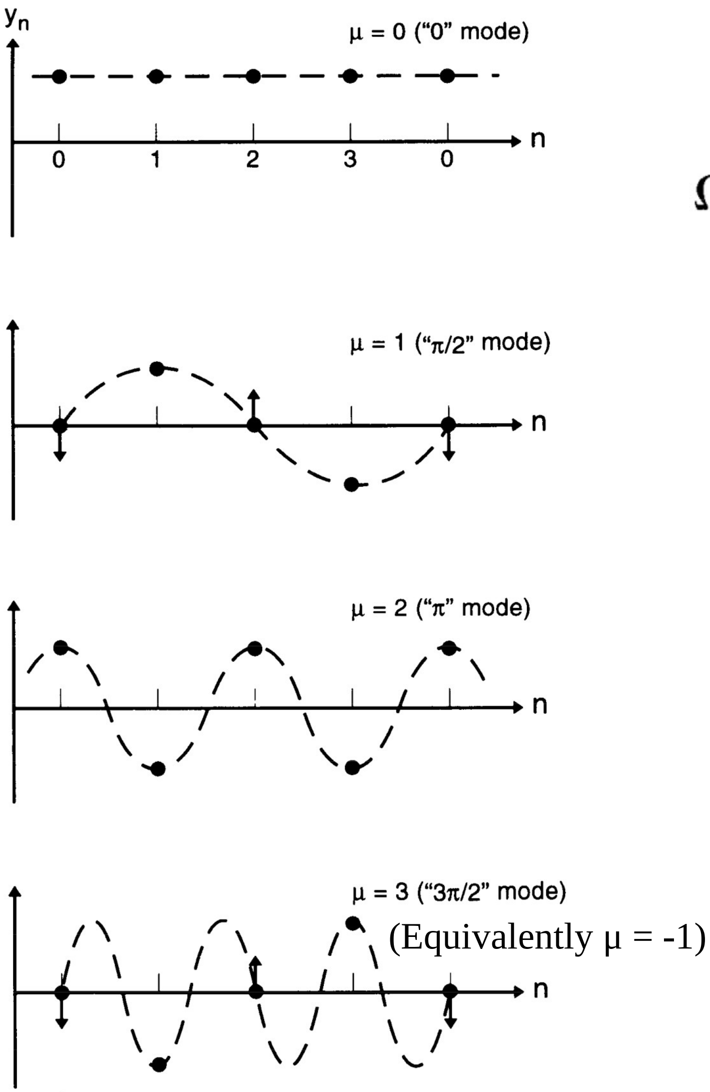

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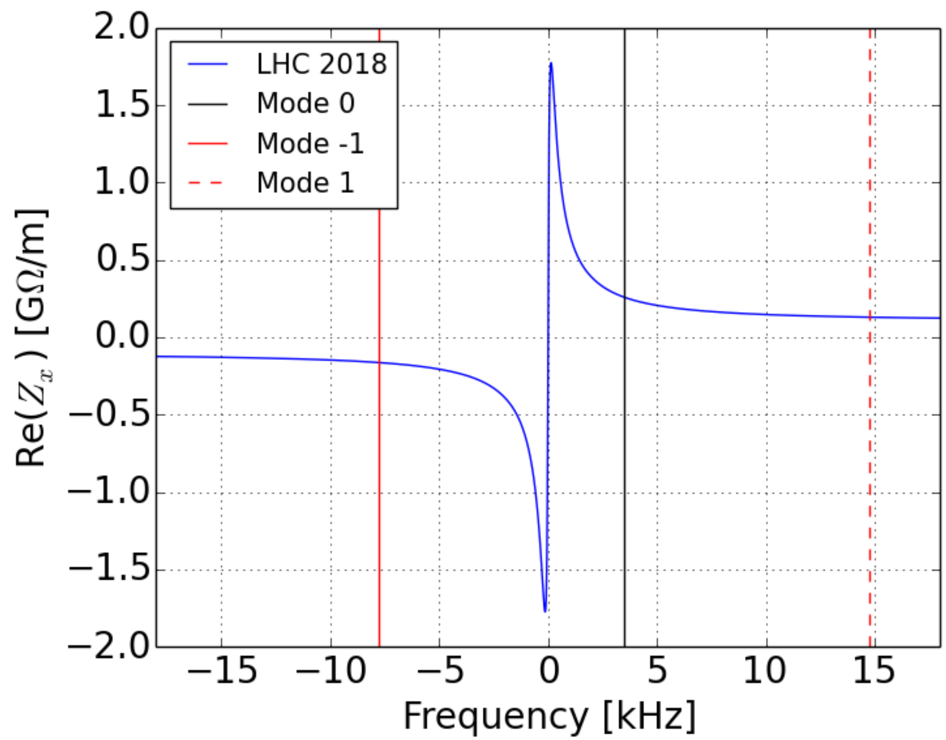
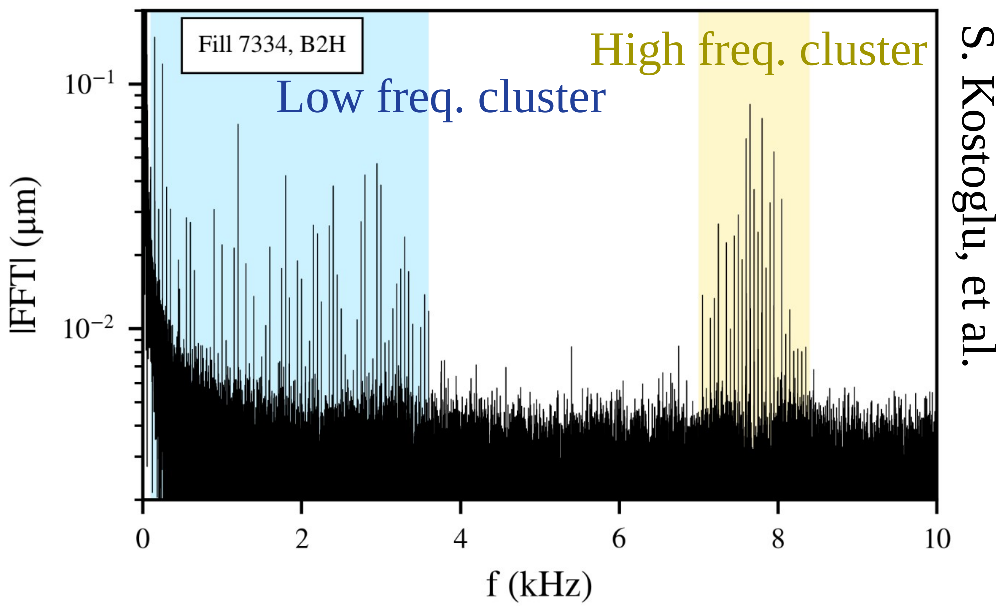


- With a resistive wall impedance (i.e. peaked at low frequency) and a tune below the half integer
  - The coupled bunch mode 0 is intrinsically stable → LHC: $Q_0 = Q^* f_{rev}$ ~ **3kHz**
  - The first unstable coupled bunch mode is -1 → LHC : $Q_{-1} = (Q-1)^* f_{rev}$ ~ **8kHz**

The 50Hz lines conundrum

- The high end of the low frequency cluster matches the attenuation of MB field variations by the beam screen

  → If source of the high frequency cluster is also the MB, it should be heavily attenuated by the beam screen



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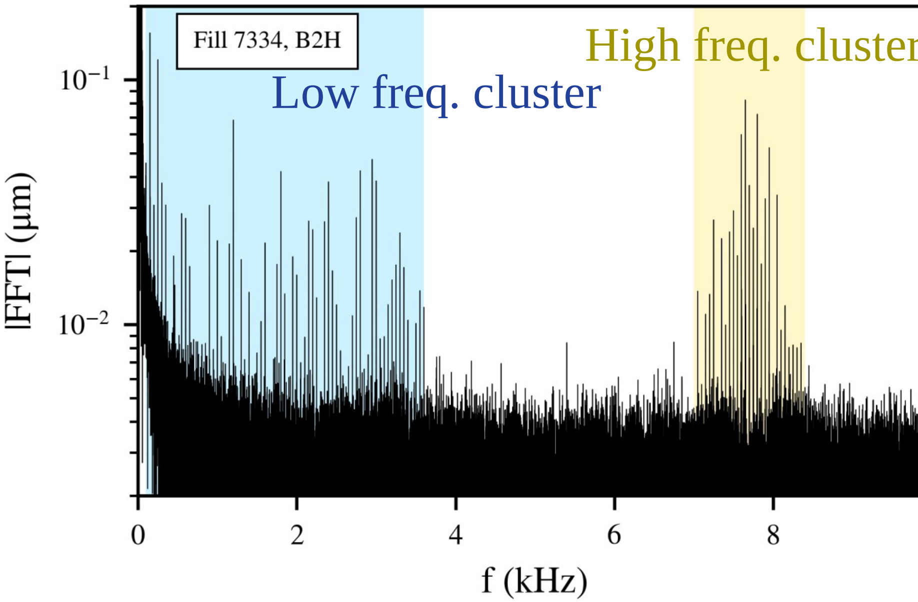

S. Kostoglu, et al.

- **SG:** Can the impedance explain the measured amplitude of the 8kHz cluster of 50Hz harmonics (given that it is *close* to the first unstable coupled bunch mode) ?
  - **NX:** If the damping time is shorter than the coupled bunch mode rise time, we expect that the beam response is dominated by the damper → No

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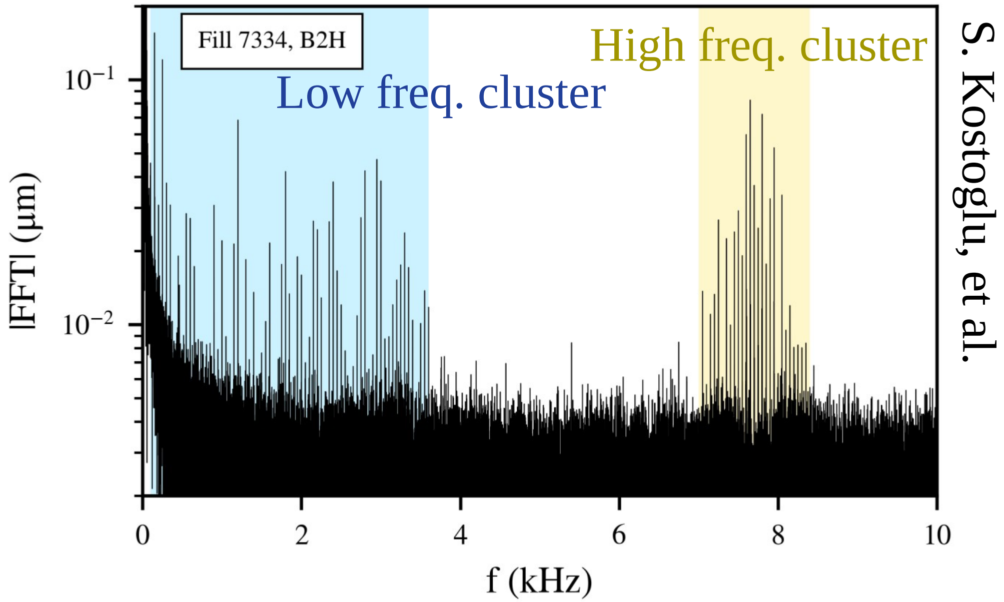
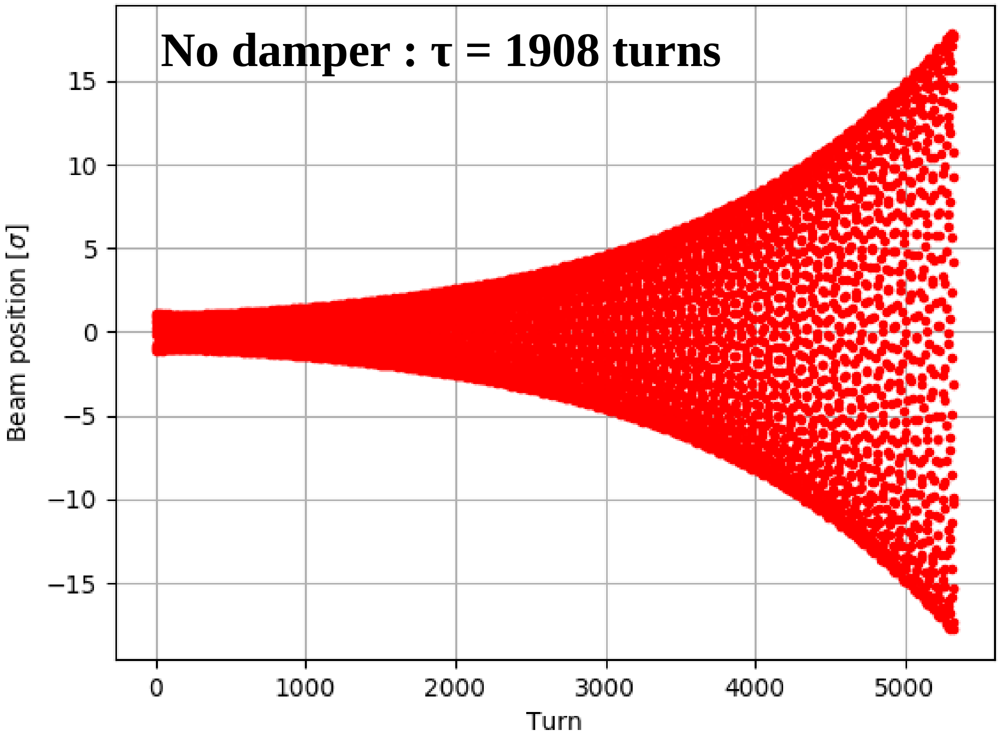
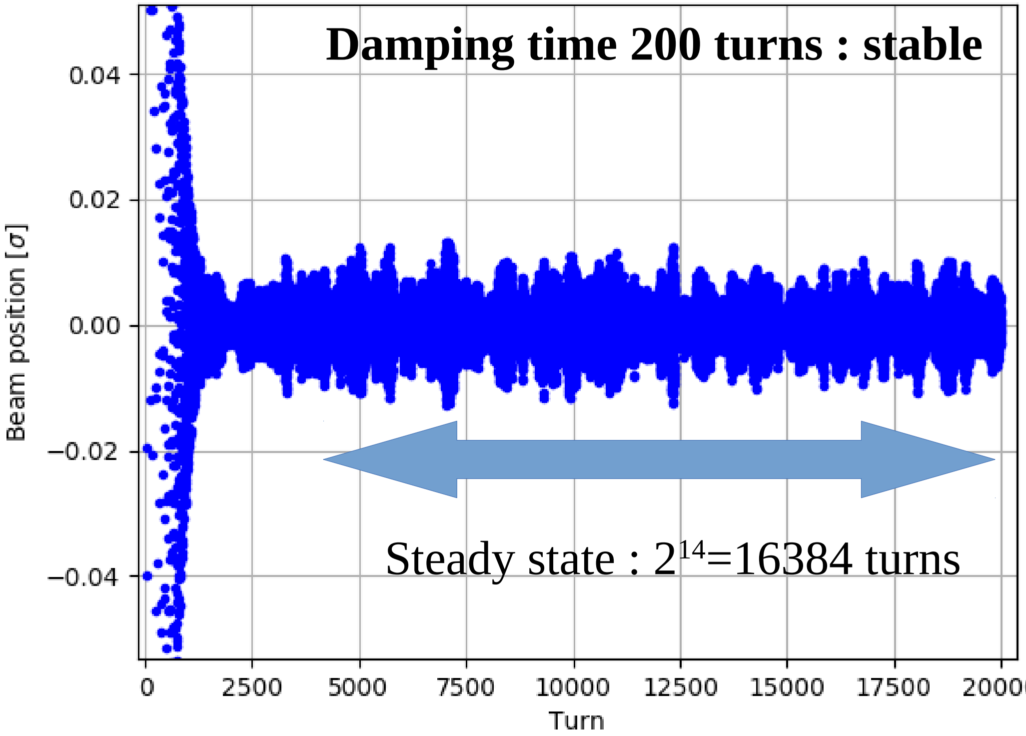


- **SG:** Can the impedance explain the measured amplitude of the 8kHz cluster of 50Hz harmonics (given that it is *close* to the first unstable coupled bunch mode) ?
  - **NX:** If the damping time is shorter than the coupled bunch mode rise time, we expect that the beam response is dominated by the damper → No
- **SG:** Is this statement still valid if the oscillation amplitude is below the damper pickup resolution (δ_{pickup})?
  - **NX:** … let's investigate with a simple numerical model

Model

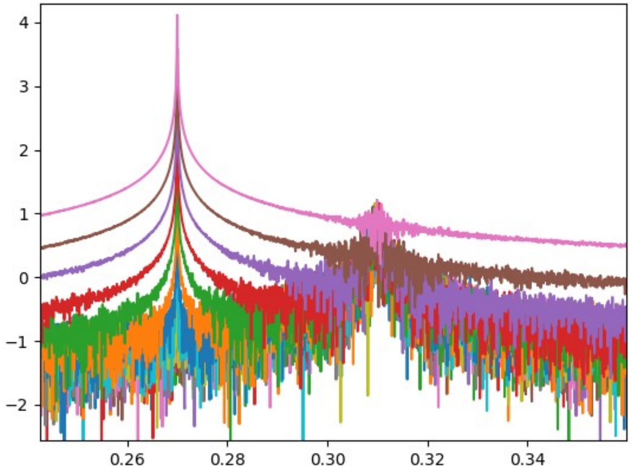
- COMBI with two equidistant bunches, one particle per bunch (→ rigid bunch approx.)
  - Linear transfer matrix (Q=0.31)
  - Impedance (Resistive wall adjusted to obtain a growth rate comparable to LHC)
  - Damper (G)
  - Damper noise ($\delta_{rms} = G\delta_{pickup}$)
  - Harmonic excitation (Q_{ext}=0.27)
- We study the spectrum of the oscillation once the steady state is reached





Oscillation spectrum

Without Impedance



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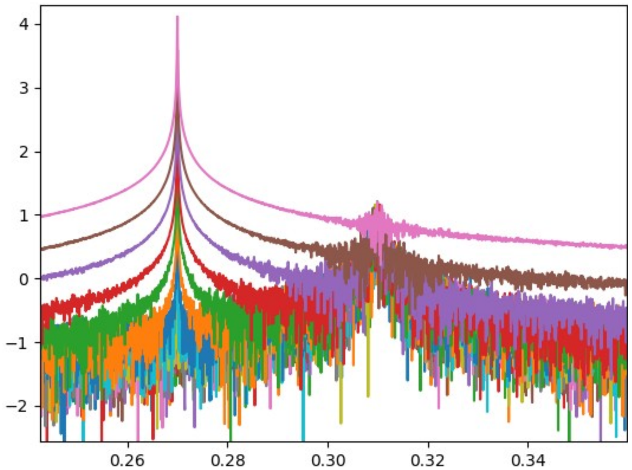
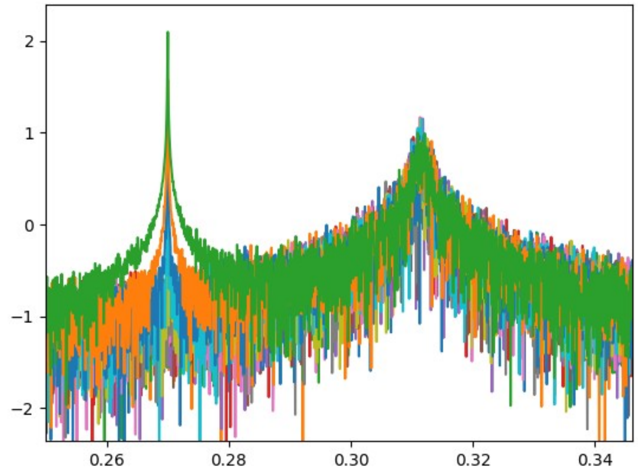


Impedance, $Q_{ext} = 0.27$
(close to coupled bunch mode 0)



- The impedance impacts the beam response at the beam tune

  → Noise excited wake fields (not relevant here, since 50Hz lines are mostly away from the beam spectrum)

Oscillation spectrum

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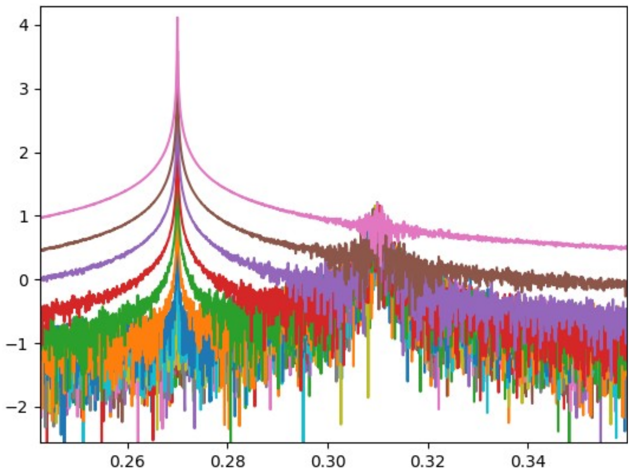

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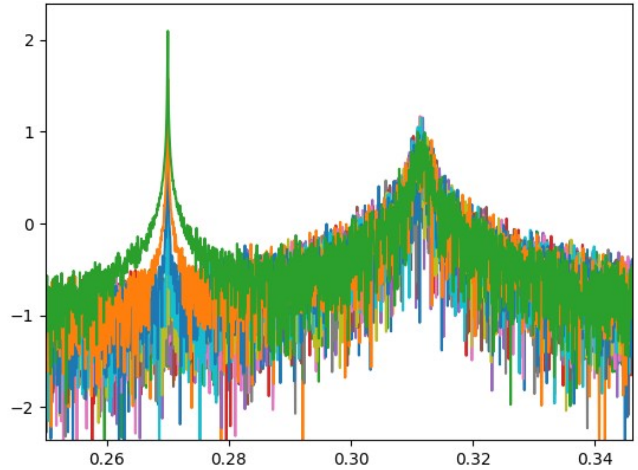
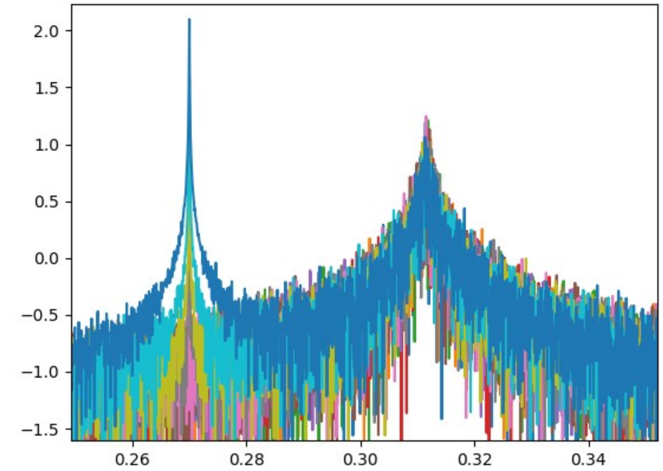


Impedance, Q_{ext} = -0.73
(close to coupled bunch mode -1)



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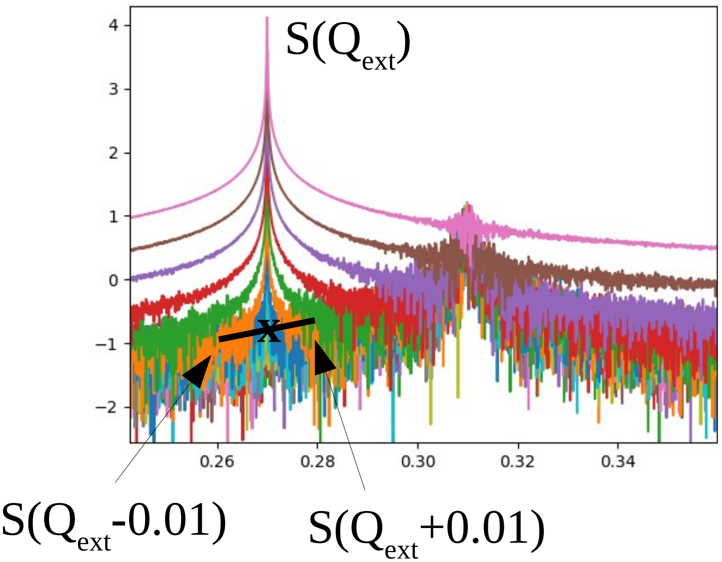

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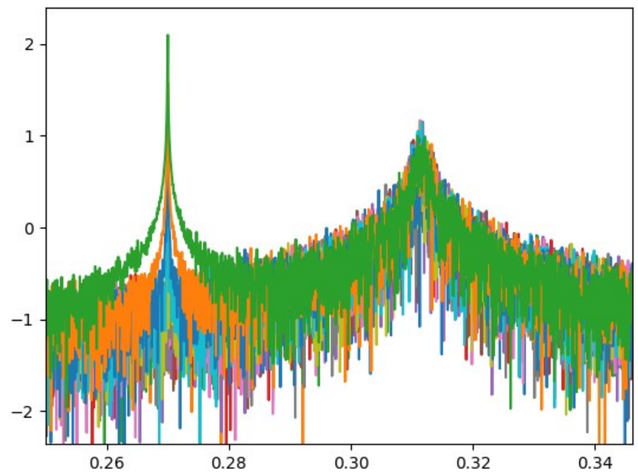

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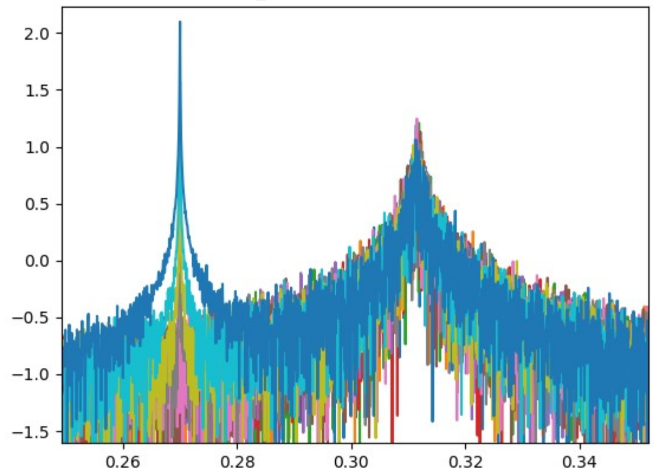

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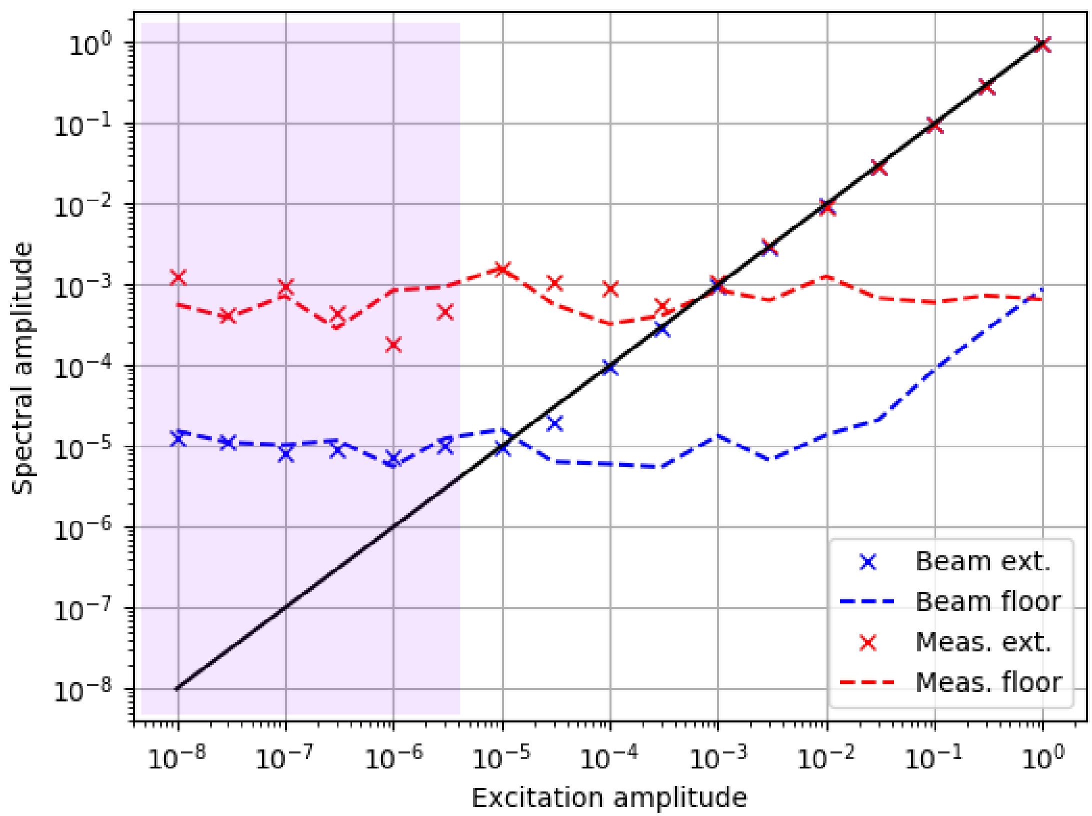
- In the following we study the response to an excitation away from the main peak
  - Spectral amplitude at the excitation frequency S(Q_{ext}) vs. residual oscillation (S(Q_{ext+}0.01)+S(Q_{ext}-0.01))/2

Real and measured residual beam oscillation
Without impedance

- The real beam response is dominated by the noise induced by the damper ($G\delta_{pickup}$) at low excitation amplitudes

- The measured beam response is dominated by the measurement noise δ_{pickup} at low excitation amplitudes



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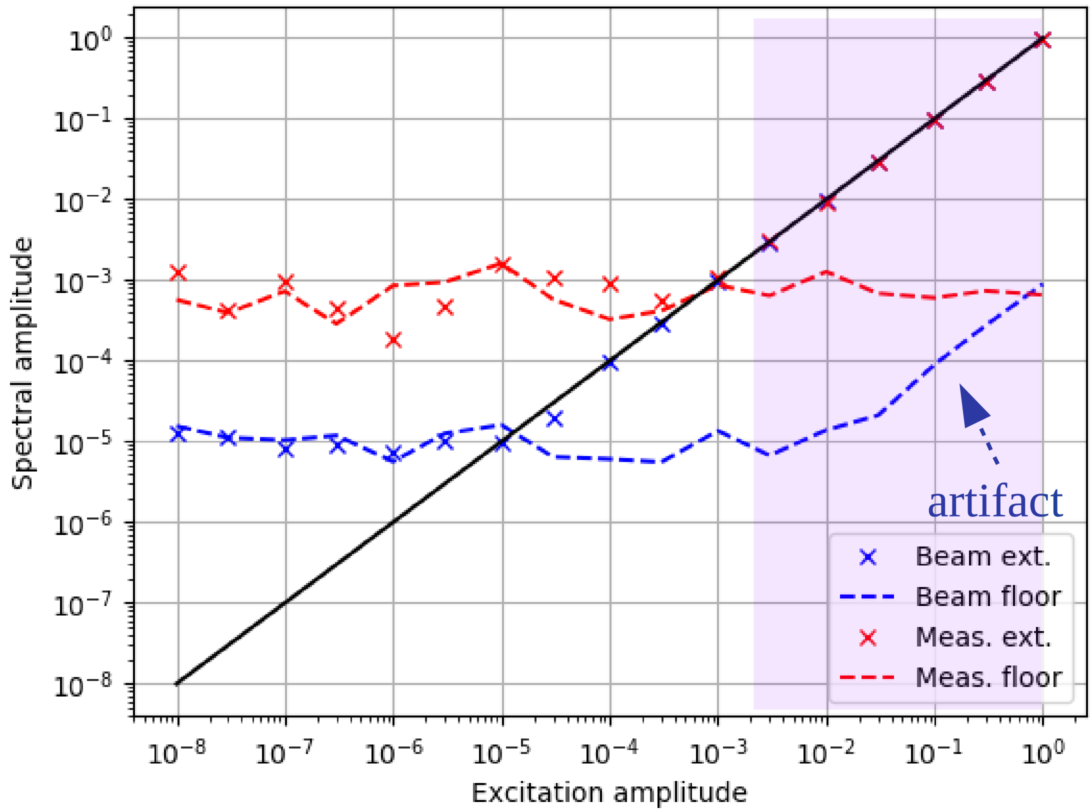

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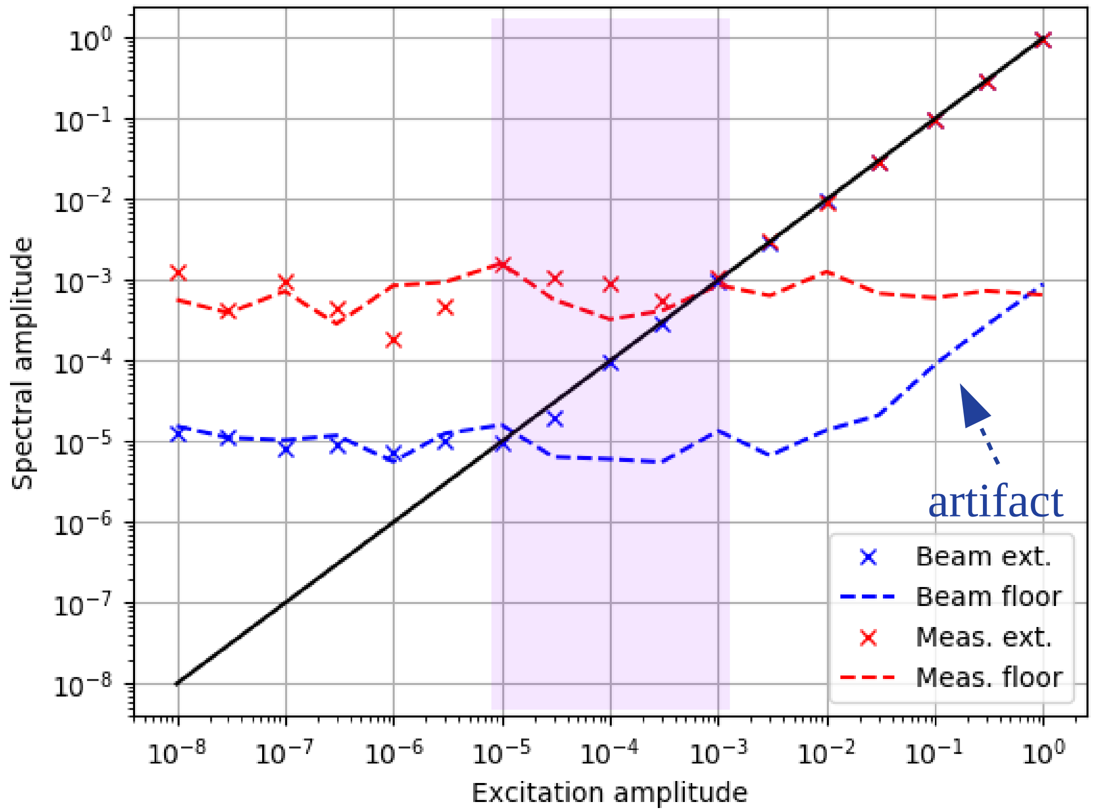

- There is an intermediate regime where the excitation signal is below the resolution of the damper pickup, but remains in the real residual beam oscillation
  - This regime is compatible with observations, i.e. the signal is visible in the BBQ or in the data ADT averaged over several bunches, but not in the raw single bunch ADT data

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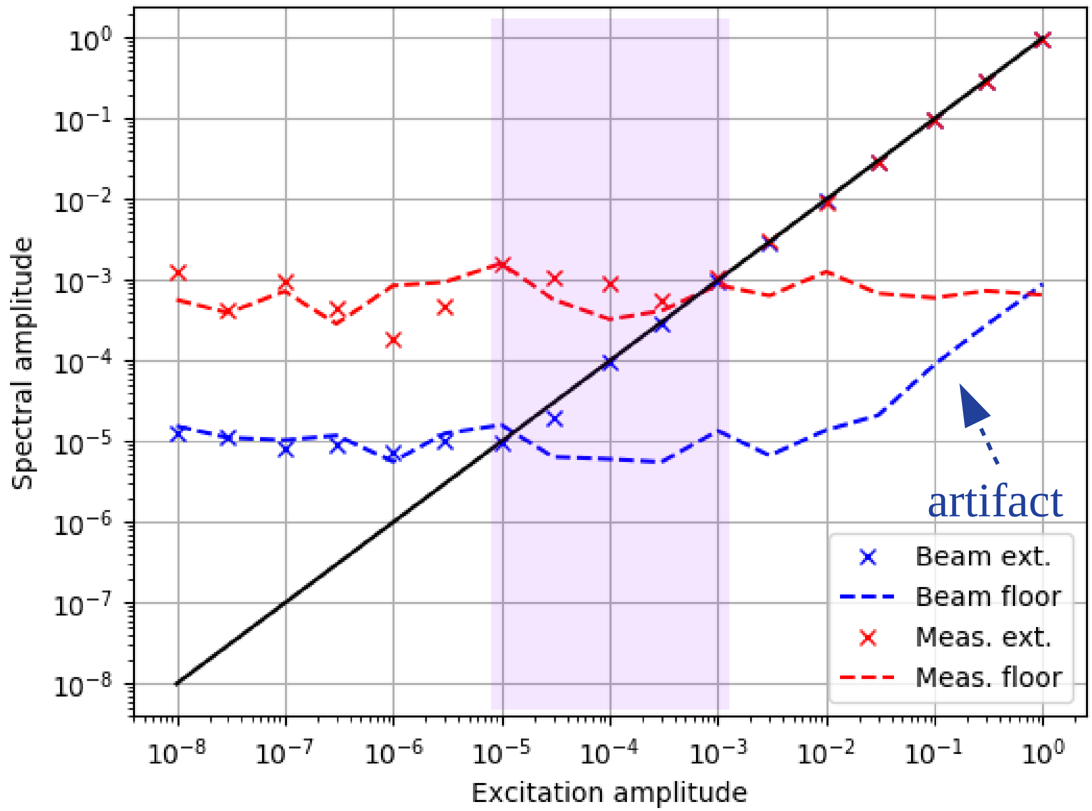

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→ The damper **remains effective** below its pickup resolution

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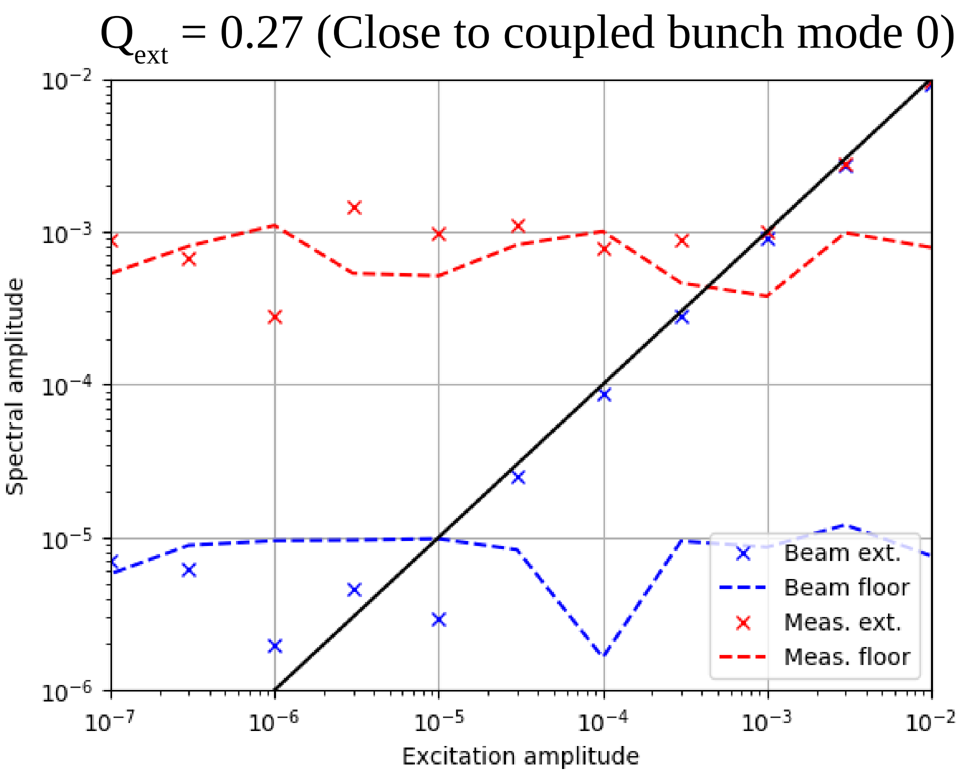

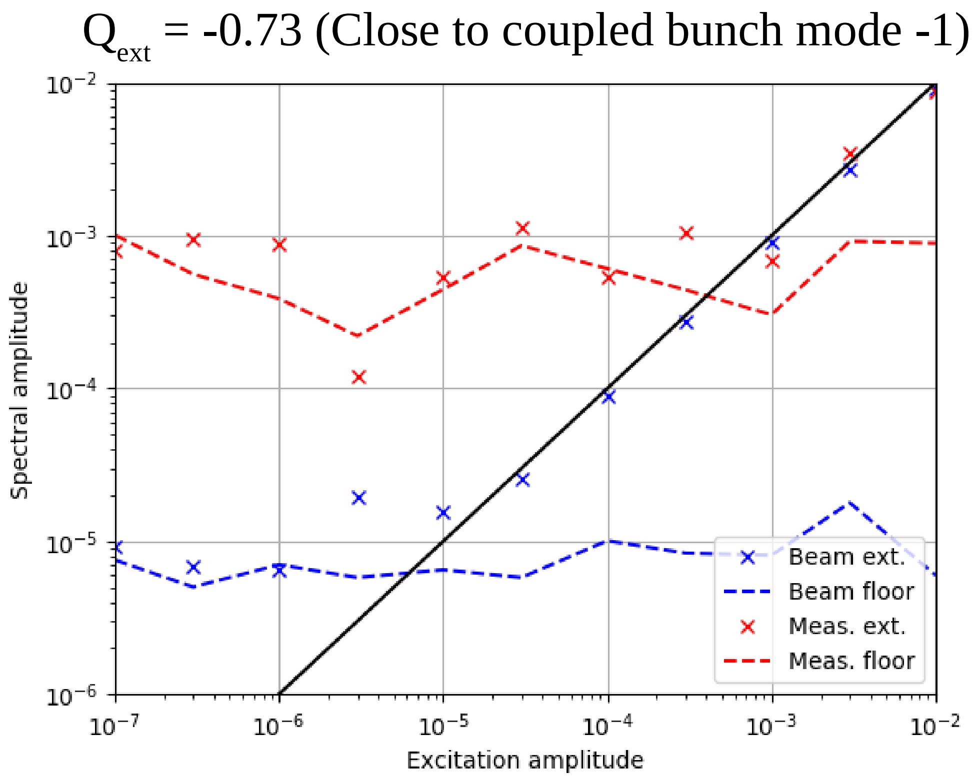

- Including the impedance does not change significantly the amplitude of the beam response (for either mode 0 and mode -1)
  - The damper dominates the dynamics since its damping time (200 turns) is significantly higher than the growth/damping rate (~2000 turns) induced by the impedance in spite of its finite resolution

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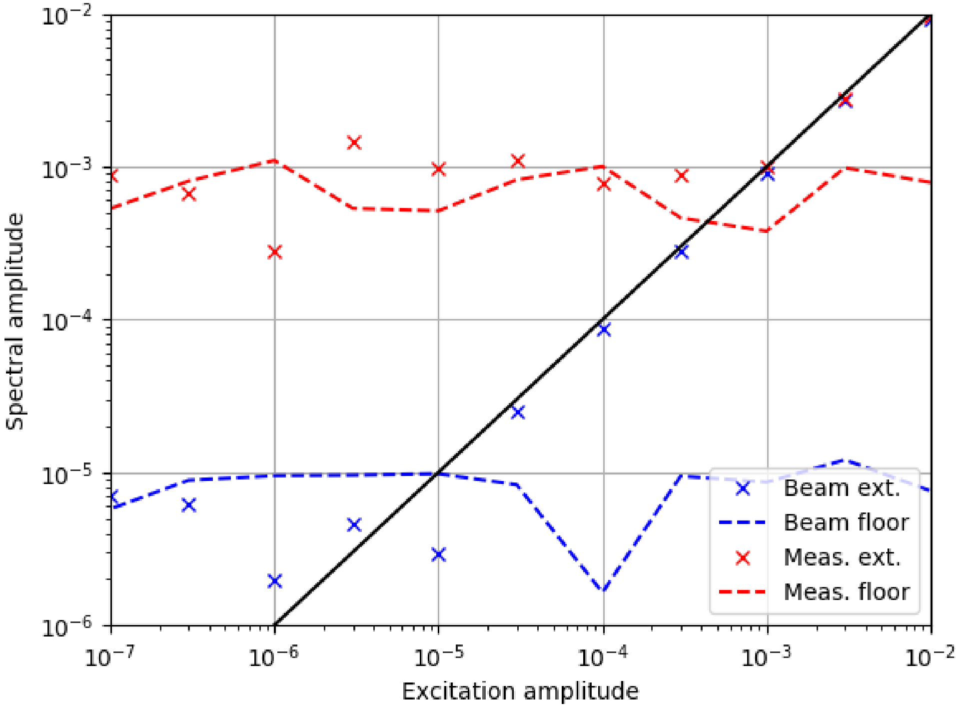

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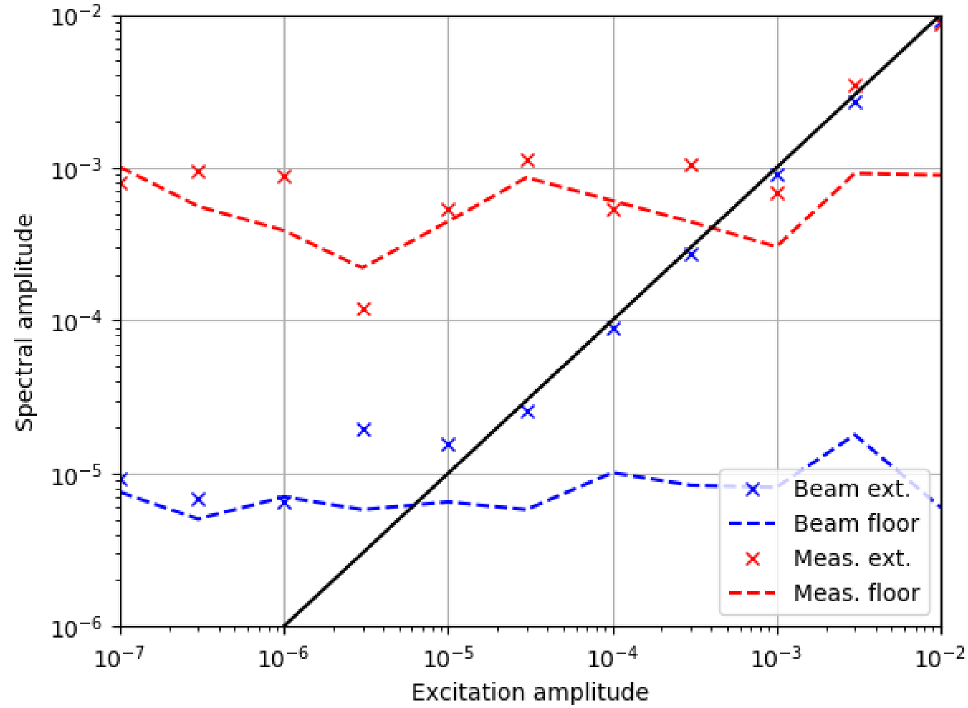

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→ **The impedance does not solve the 50Hz line conundrum**