Beam-Beam Simulations with Crab Cavities and Noise

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5th LHC Crab Cavity Workshop

Outline

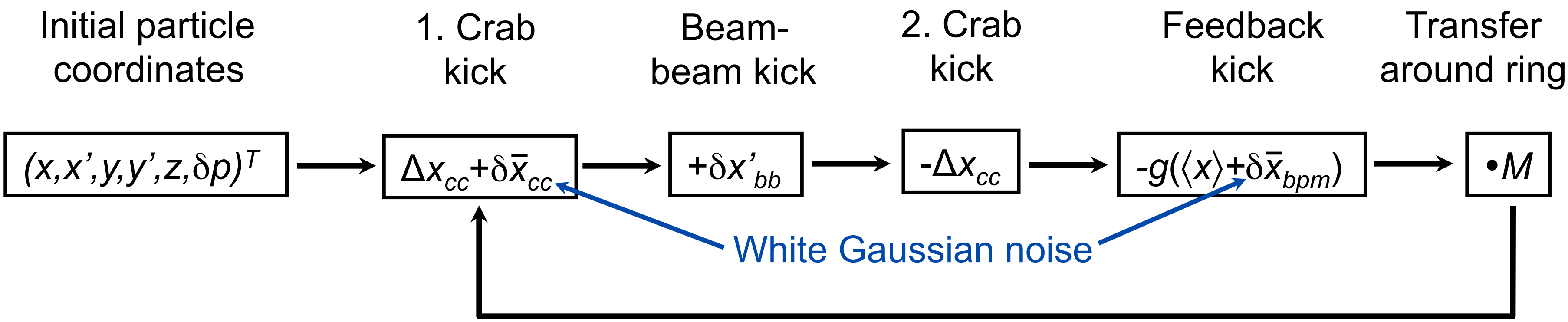
- Beam-beam model with noise and feedback
- Simulation results
- Conclusions
- Outlook

BeamBeam3D Features

- Strong-strong collision model
- Lorentz boost
- Shifted Green's function method
- Particle-domain decomposition for parallel computing
- Crab cavities (CC) with noise
- Feedback system (FB) with noise

FB model in BeamBeam3D

Computational cycle



- 1. CC tilts bunch and adds CC noise
- Collision changes momentum
- 2. CC untilts bunch
- FB reduces offset and adds FB noise
- Beam transfer around ring

Current FB Noise Level

BPM accuracy ≈ 2μm rms [1]

FB gain ≈ 0.1 [1]

⇒ erroneous kick ≈ 0.2 μm at position of FB

⇒ corresponding **offset at IP**

$\approx 0.2\ \mu m \times (\beta_{IP}/\beta_{BPM})^{1/2}$ = **0.012 μm**

for $\beta_{IP} = 0.5$ m and $\beta_{BPM} = 137$ m (= mean of actual βs at BPMs)

[1] W. Höfle, CERN, private communication

Emittance – Analytic Estimation

Beam-beam induced emittance growth [1]

- Collisions transfer energy to transverse plane
  - Small immediate emittance growth
  - Excitation of coherent modes
- Coherent modes decay ⇒ further emittance growth
  Can be mitigated via FB
- Estimated emittance growth [1]:

$$\frac{\dot{\epsilon}}{\epsilon_0} \approx \frac{0.355}{4\sigma_x^2[1+g/(2\pi\xi)]^2}\left(\langle\delta x^2\rangle + g^2\langle\delta x_{bpm}^2\rangle\right)$$

[1] Y. I. Alexahin, NIM A, 391, 1996

Physical Simulation Parameters

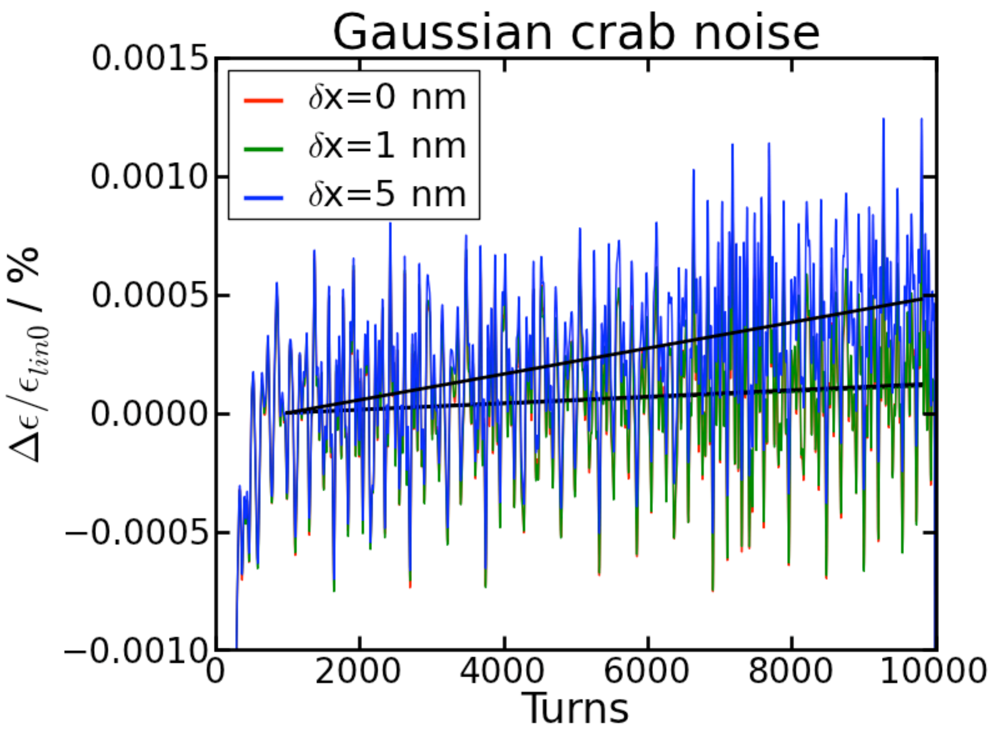
N	1.15×10^{11}
ε_n	3.75 μm
E	7 TeV
Bunch length	7 cm
$\delta p/p$	1.11×10^{-4}
β^*	0.5 m
β_{CC}	4000 m
f_{CC}	400.8 MHz
g	0.1
θ	150 μrad
ξ	0.0038

Numerical Parameters

#IPs	1
Turns	10,000
x meshing	128 cells
y meshing	128 cells
z slices	8
Macro particles	8,000,000

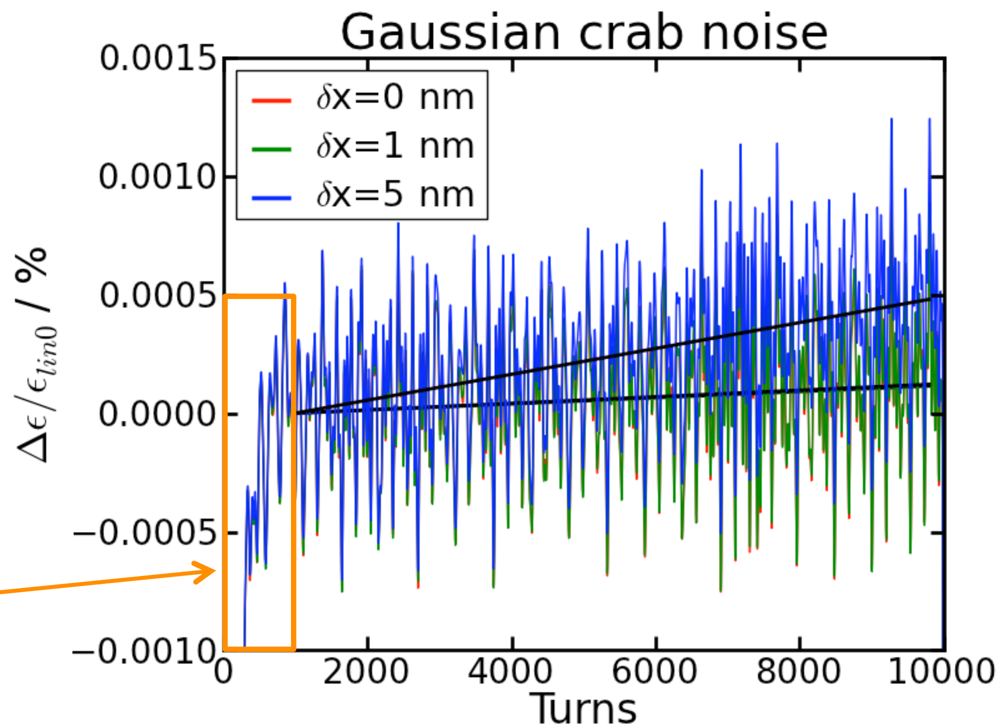
Numerical Noise

- Emittance growth rate determined by fit of straight line
- Similar emittance growth for 0 and 1 nm $\Rightarrow$ simulation unreliable for growth rate below 0.5 %/h
- *0 nm noise growth-rate is subtracted from other data*



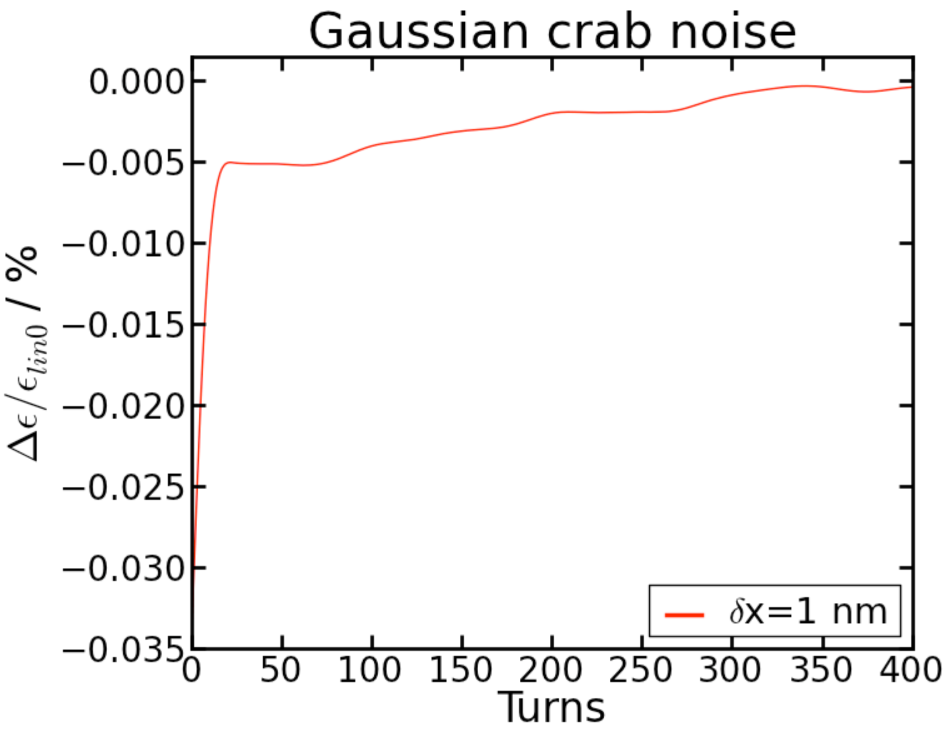
Numerical Noise

- Emittance growth rate determined by fit of straight line
- Similar emittance growth for 0 and 1 nm $\Rightarrow$ numerical artifact
- *0 noise growth rate is subtracted from other data*
- First 1000 turns excluded from fit



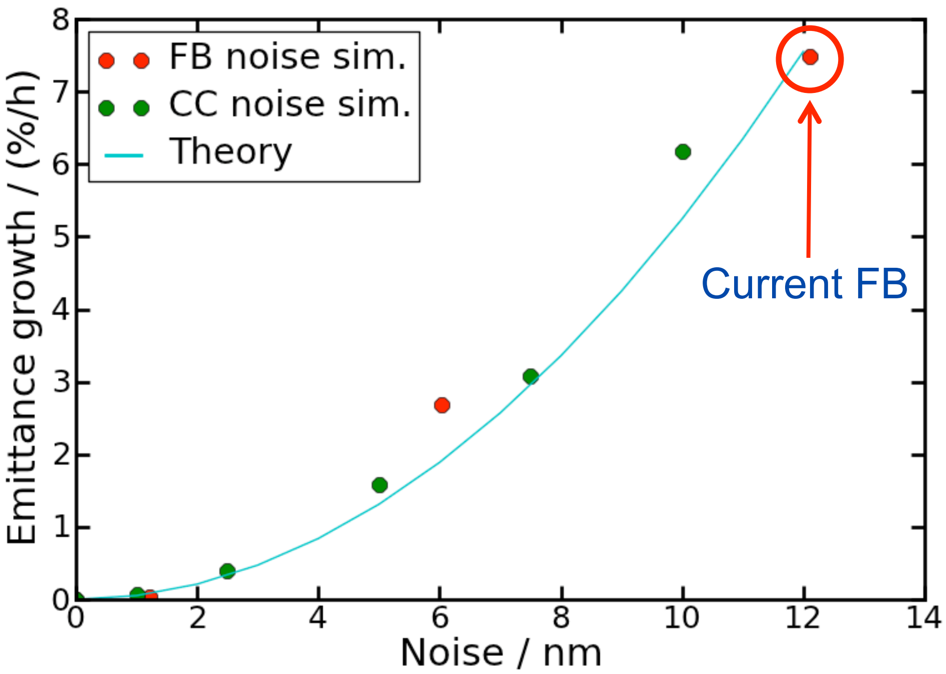
Beam self-adjustment

- Beam mismatch due to beam-beam effect
  $\Rightarrow$ Fast initial emittance growth
- Dominates growth in first second, but negligible in long term



Results – Gaussian Noise I

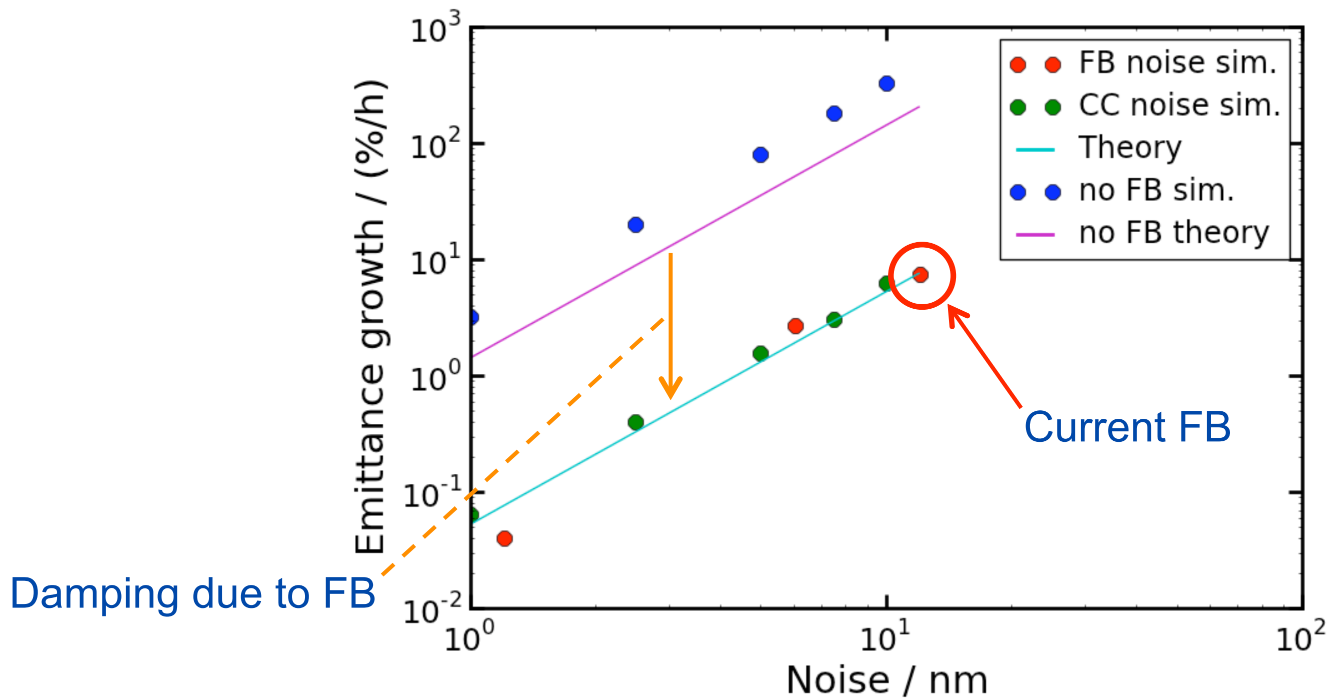
- Simulations with either FB noise or CC noise
- Linear growth rate from 10000 turns scaled to %/h



- Similar results for both kinds of noise
- Simulations agree well with model

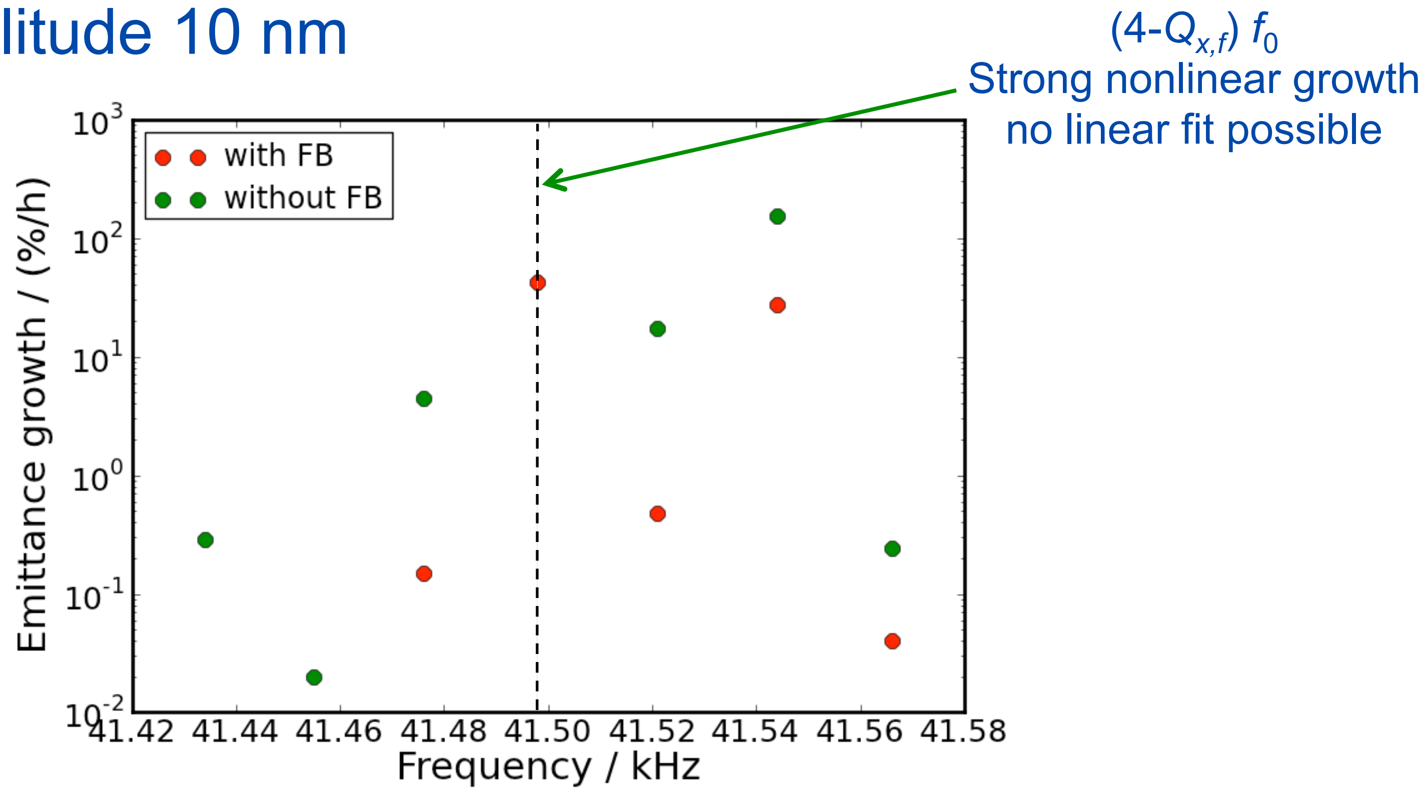
Results – Gaussian Noise II

- Previous results in logarithmic representation
- In addition data for CC noise without FB



Results – Sinusoidal Noise

- Noise amplitude 10 nm

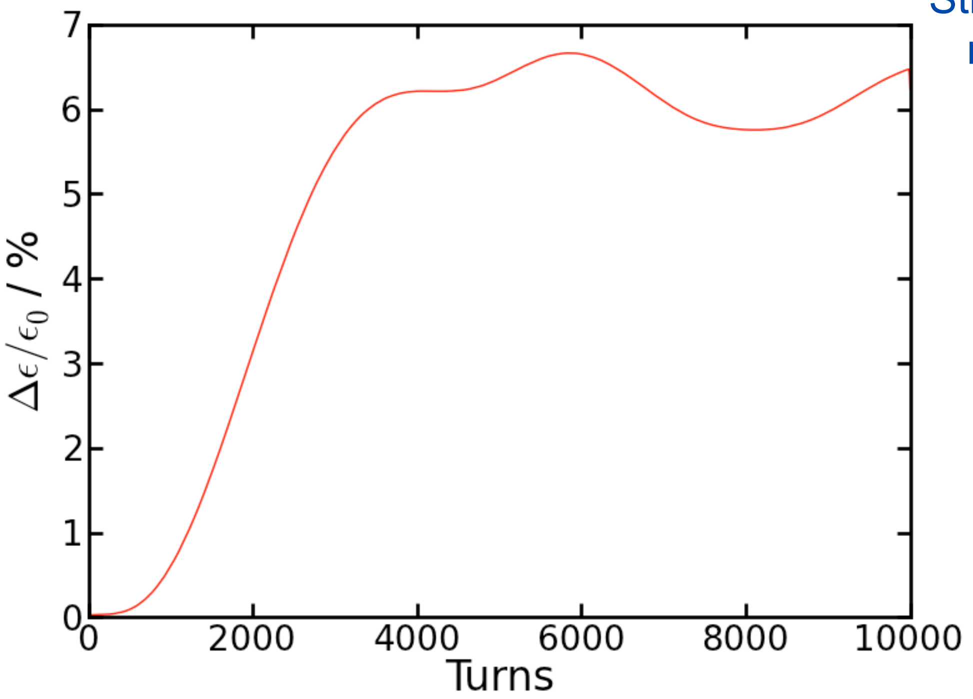


- Emittance growth varies strongly with noise frequency
- Growth rate more than 50 times slower with FB

Results III – Sinusoidal Noise

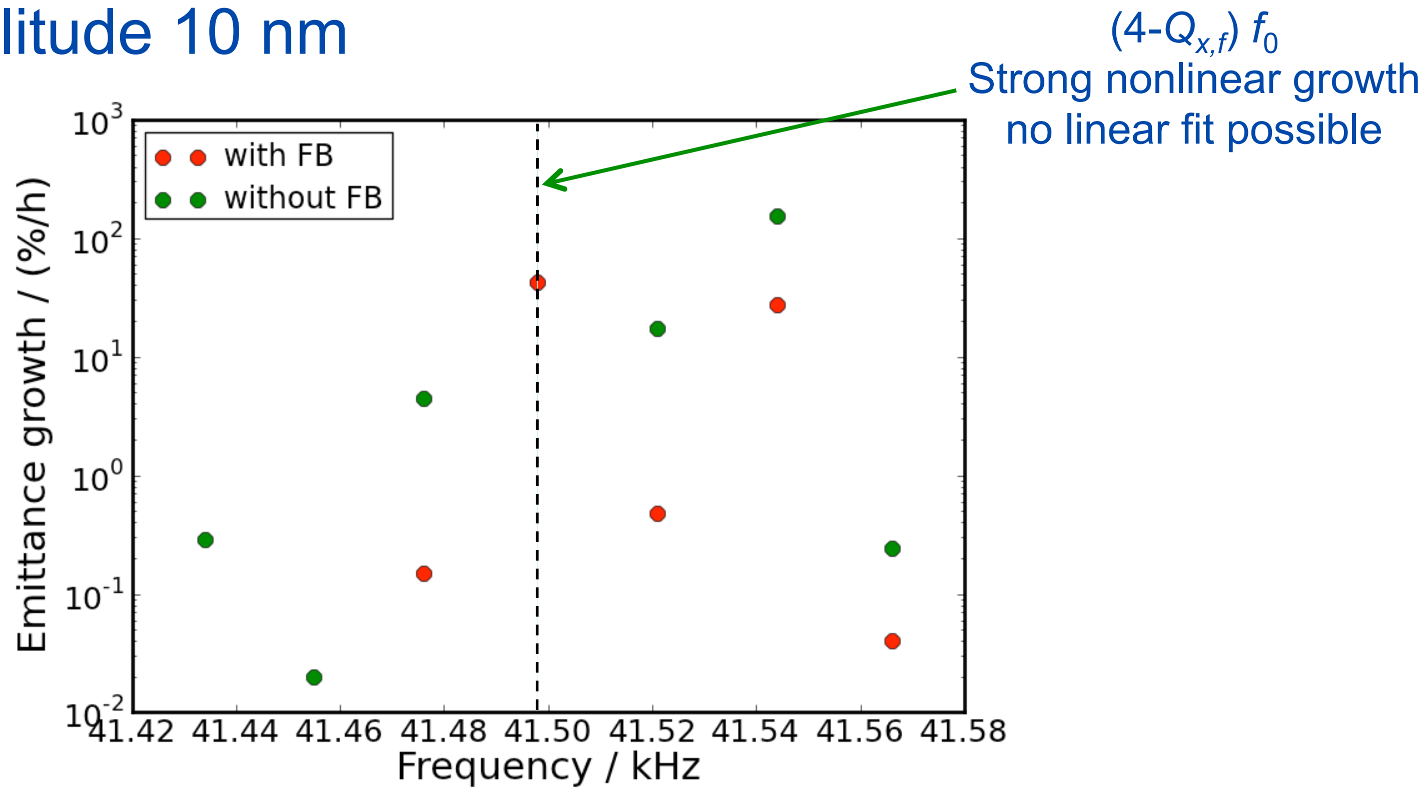
- Emittance growth varies strongly with noise frequency
- Growth rate more than 50 times slower with FB

$(4-Q_{x,f})\ f_0$
Strong nonlinear growth
no linear fit possible



Results – Sinusoidal Noise

- Noise amplitude 10 nm



- Emittance growth varies strongly with noise frequency
- Growth rate more than 50 times slower with FB

Conclusions & Open Questions

- Simulated emittance growth agrees well with analytic model (larger deviation without FB)

- White CC noise of 4 nm noise yields 1 %/h
  $\Rightarrow$ Required phase stability ≈ 0.22 mrad (for $\varphi = \pi$)
  Achievable?

- White BPM noise of 2 μm yields an emittance growth of 7.7 %/h
  Acceptable?
  Adequate model?

Outlook

Next steps depend on needs of CERN

Ideas:

- More general CC error
  - Both cavities, *correlated or uncorrelated*
  - Amplitude and phase jitter
- Realistic HL parameters
- Sinusoidal excitation with frequency determined by CC design
- Improve FB model, optimize gain
- Two IPs

Suggestions, Priorities?