Beam-Beam Simulations with Feedback and Noise

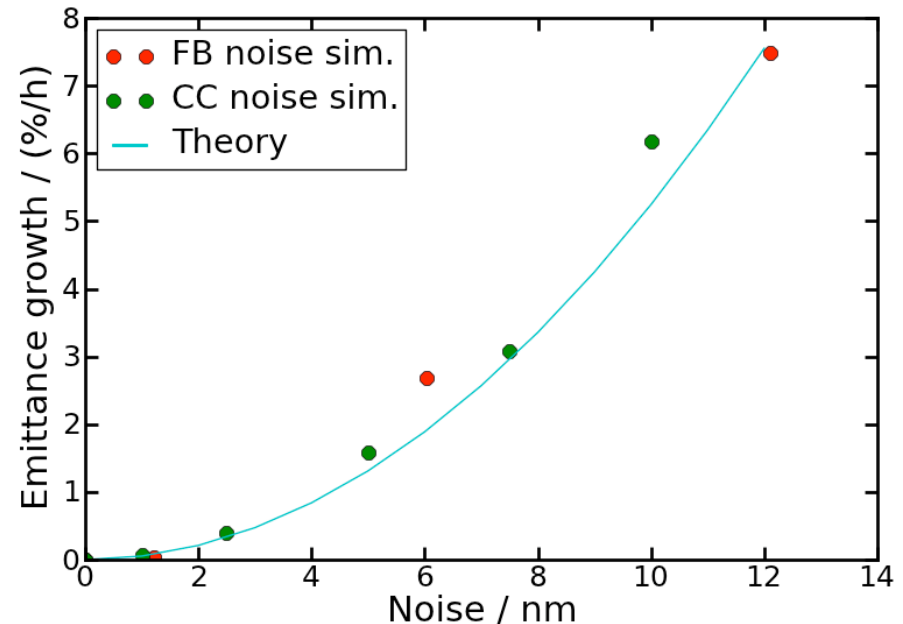## Stefan Paret and Ji Qiang

Topics

- **Improved feedback model**

- **Numerical noise**

- **Soft Gaussian model**

- **State of simulations**

5th CC workshop Nov. 2011

- Simulated emittance with CC and **very simple feed-back (FB)** model

- Remarkable agreement with analytic model [1]

- Probably too pessimistic Proposed tasks:

  - **Improvement of FB model**
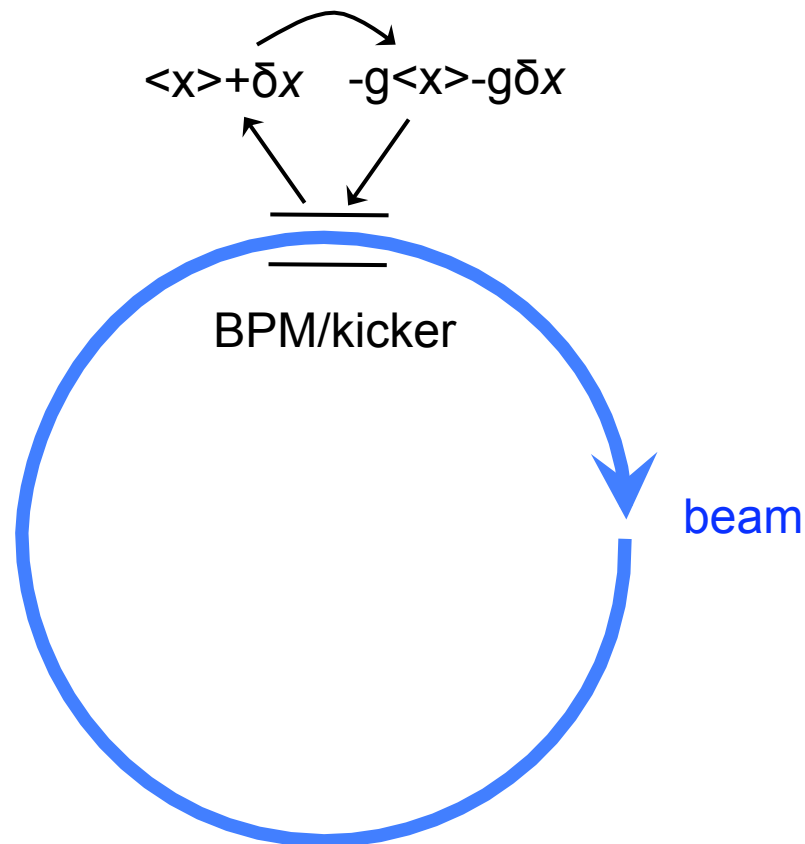
  - **Comparison with present LHC**
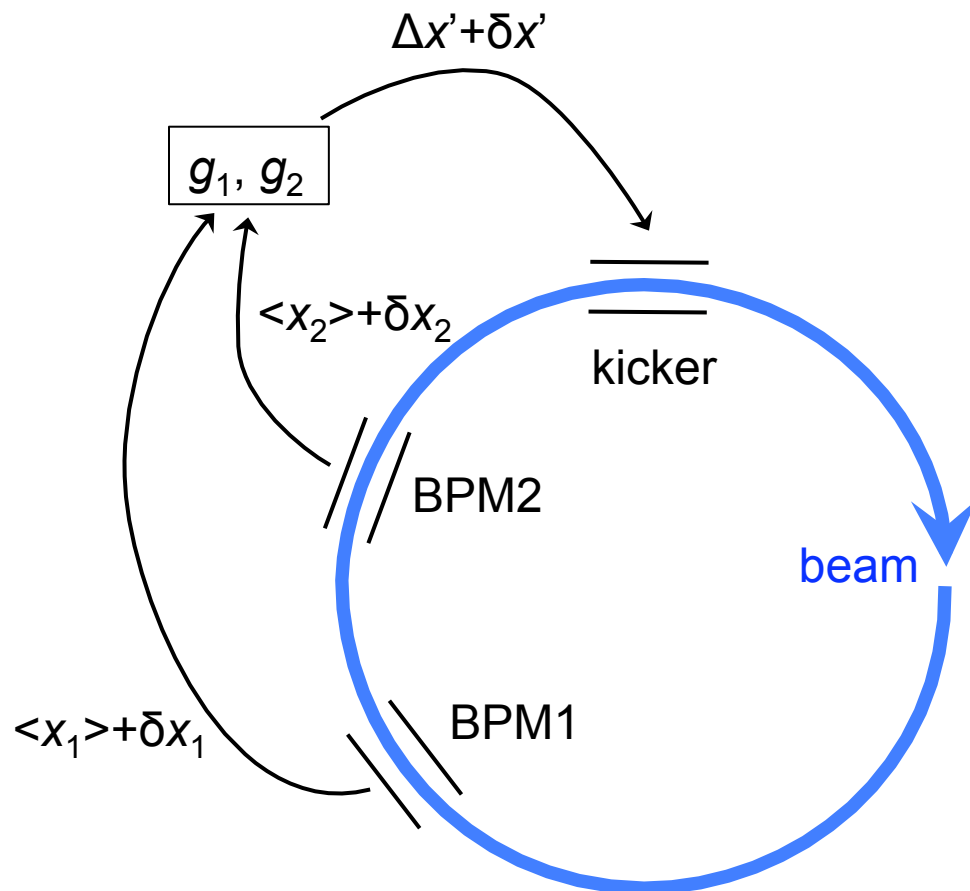
[1] Y.I. Alexahin, NIMA 391, 1996

Former FB Model

- Offset measured

- Gain*Offset subtracted

- Addition of BPM noise

➔ Not very realistic

$<x>+\delta x$ $-g<x>-g\delta x$

BPM/kicker

beam

Improved Feedback Model I

- 2 Pick-ups (BPMs) measure offset
- Correction kick, i.e. <u>momentum change</u> applied at kicker
- Pick-up errors δx ➔ $\delta x'$
- Similar to LHC FB system

$\Delta x' + \delta x'$

g_1, g_2

kicker

$<x_2> + \delta x_2$

BPM2

beam

BPM1

$<x_1> + \delta x_1$

Improved Feedback Model II

- Kick in turn n due to first pick-up:

  Average of earlier offsets weighted with Hilbert coefficients h [2]

$$\Delta x'_{1,n} = \frac{g_1}{\sqrt{\beta_{bpm}\beta_k}} \sum_{k=0}^{6} h_k \times (x_{1,n-d-k} - x_{1,n-d-k-1})$$

Delay   Difference = High pass filter

- Corresponding kick for 2nd BPM added

- BPM noise can be added

- Implemented in BeamBeam3D

[2] V.M. Zhabitsky, E9-2011-95, 2011; W. Höfle, priv. communication

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The improvement of the FB model comes with complications

- **Optimization of g, h nontrivial**

  depend on Q

  closed analytic expression exists only in approximation [3]

- Beam needs to be transferred to BMPs and kicker

  ➔ requires knowledge of beam optics (**phase advances**)

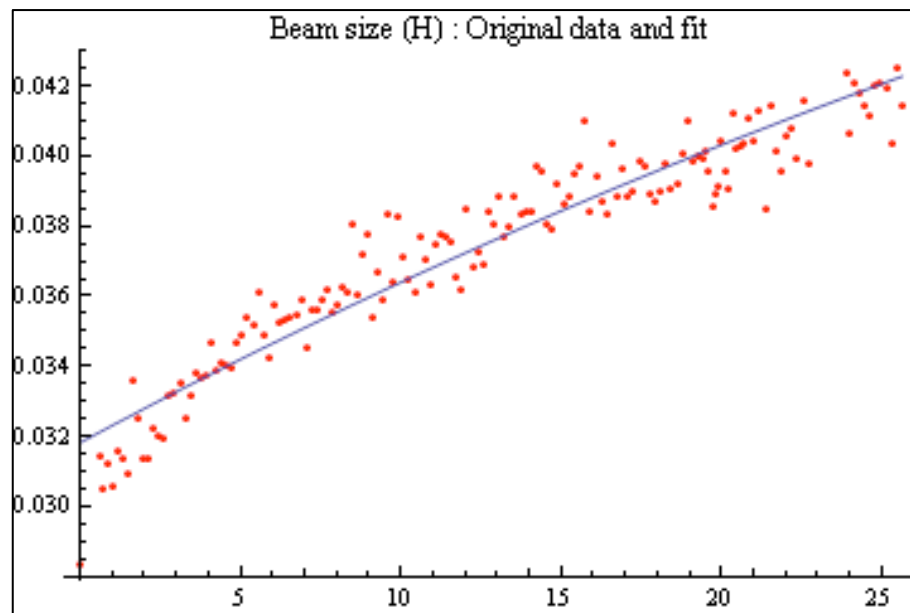[3] W. Höfle, D. Valuch, V.M. Zhabitsky, CERN-ATS-Report, to be published

Emittance in operation and simulation

Measured horizontal emittance

5th LHC CC work-shop, 2011
Court. M. Lamont

$$\frac{\dot{\varepsilon}}{\varepsilon} / \%/h$$

0.5

0.3

Numerical noise in
nominal LHC simulation

Observation in *present LHC*
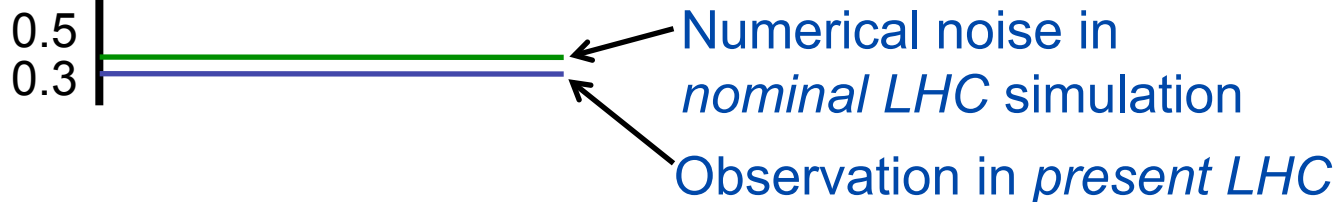
Simulation parameters for present LHC

N	3×10^{11} or 1.5×10^{11}
IPs	1 or 2
E	3.5 TeV
ε_n	2.5 μm
Bunch length	7 cm
$\delta p/p$	1.11×10^{-4}
β^*	1.0 m
ξ	0.015

Numerical noise in self-consistent strong-strong simulations drives emittance growth

Simulation of present LHC without external noise
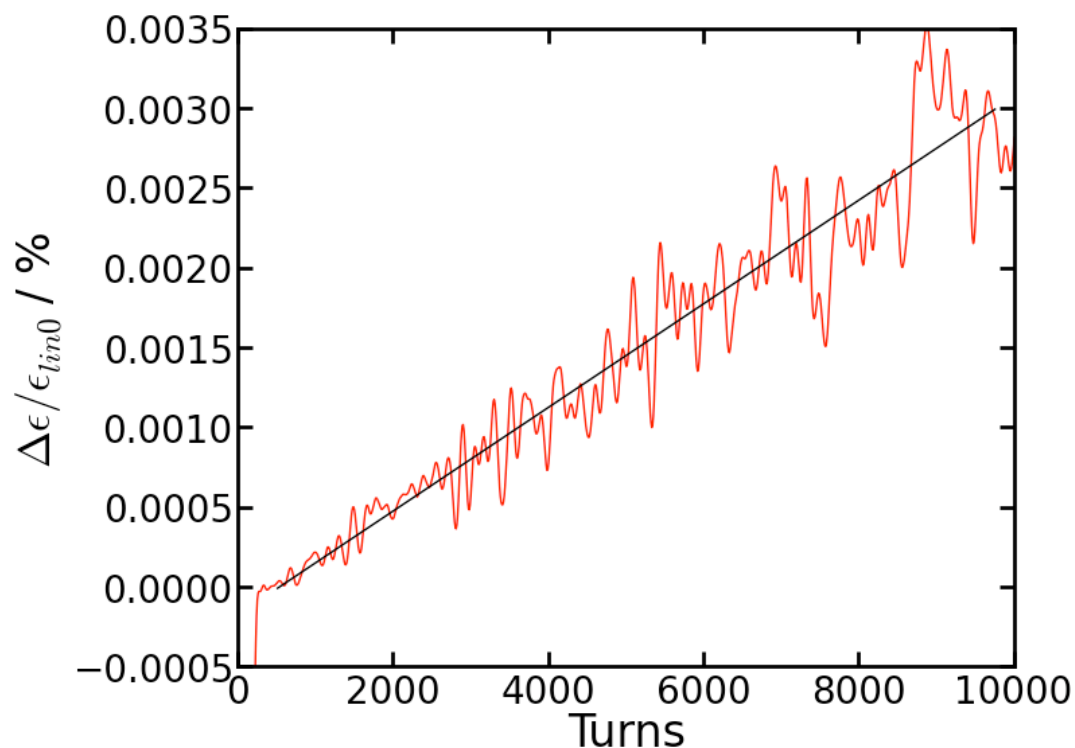
Numerical Noise and Emittance

Simulation with numerical noise

$$\frac{\dot{\varepsilon}}{\varepsilon} / \%/h$$

13 — Numerical noise in *present LHC* simulation

0.5
0.3 — Numerical noise in *nominal LHC* simulation

Observation in *present LHC*
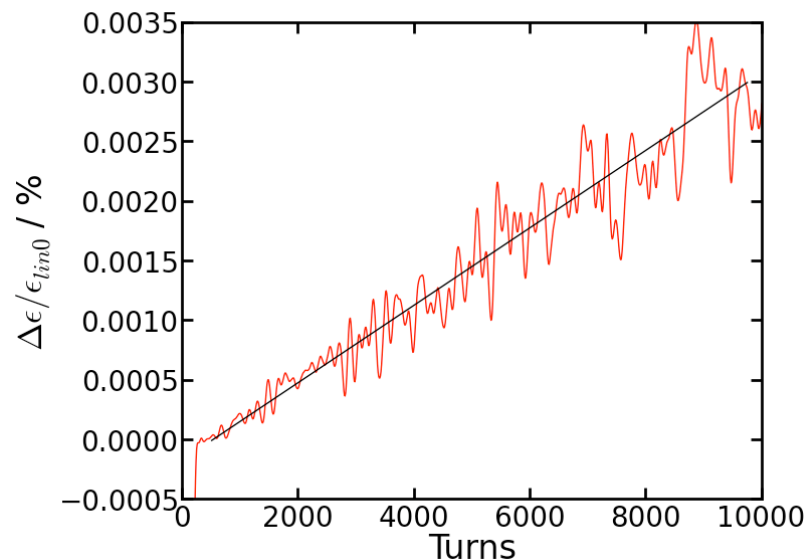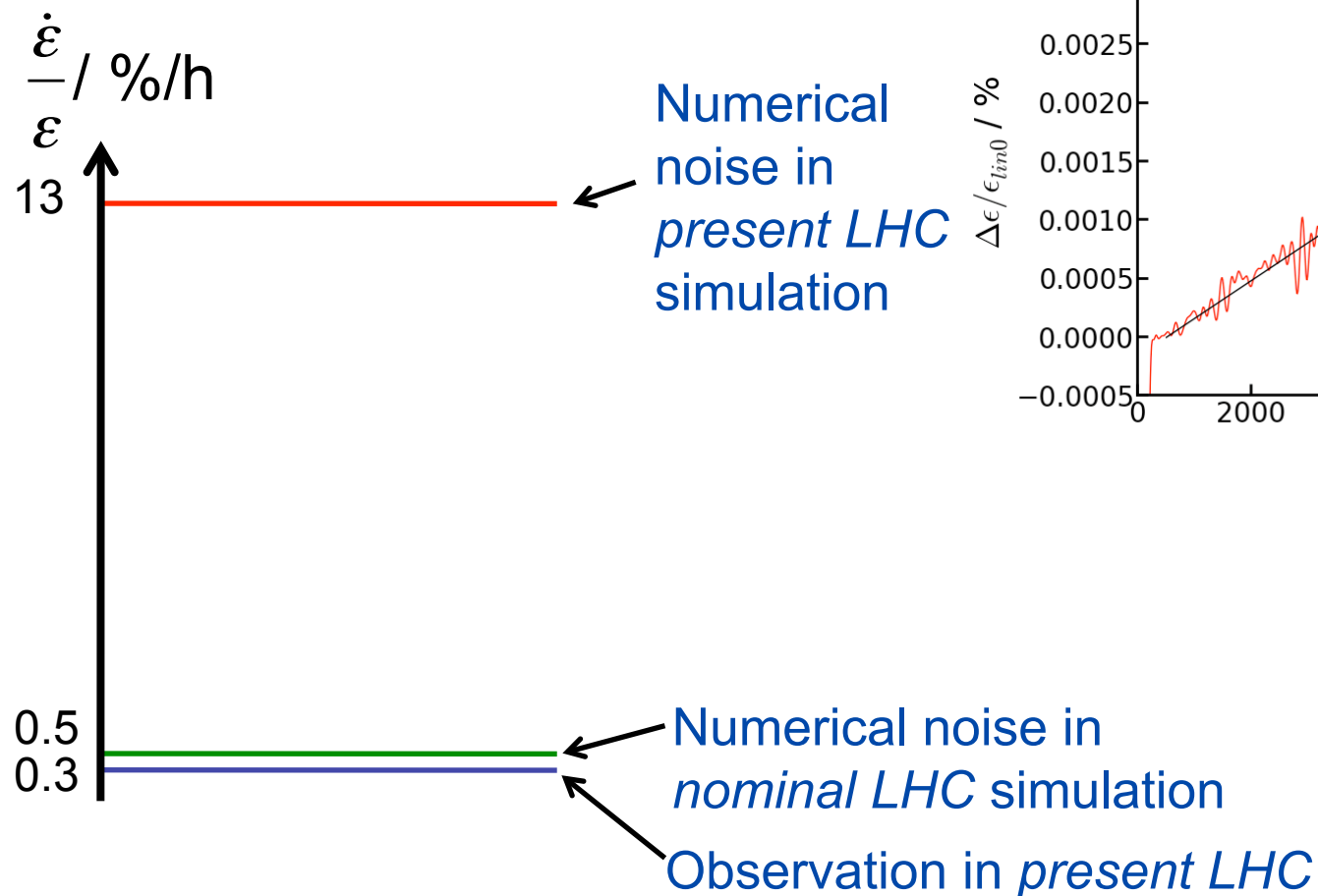
Estimation of Noise Level

- Assumption: Numerical noise in self-consistent simulation is proportional to beam-beam parameter

$$\frac{\xi_{pres}}{\xi_{nom}} \approx 4$$

- Emittance growth depends quadratically on amplitude

$$\Rightarrow \frac{\dot{\varepsilon}_{pres}}{\dot{\varepsilon}_{nom}} \approx 16$$

➔ Numerical noise dominates strong-strong simulations

Soft Gaussian beam model

- Measured profiles approximately Gaussian

- Beam in simulations initialized with Gaussian distribution

- Short time scales and stable beams
  - ➔ Distribution changes little
  - ➔ Fit Gaussian distribution to particle distribution
  calculate beam-beam effect analytically

- Advantages

  - − Intrinsically little noise

  - − Much faster computation

- Implemented in BeamBeam3D

Collisions without FB were simulated as reference
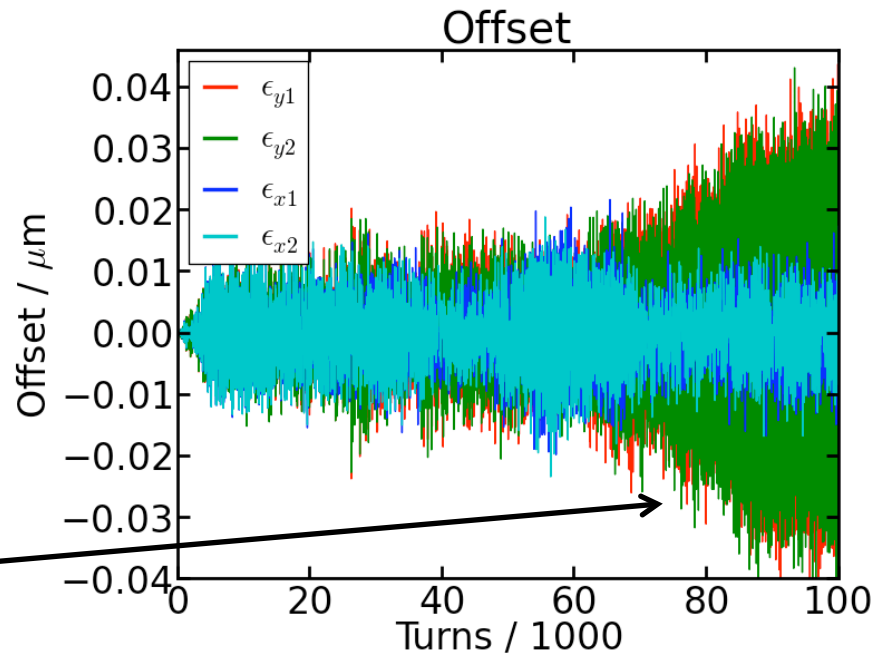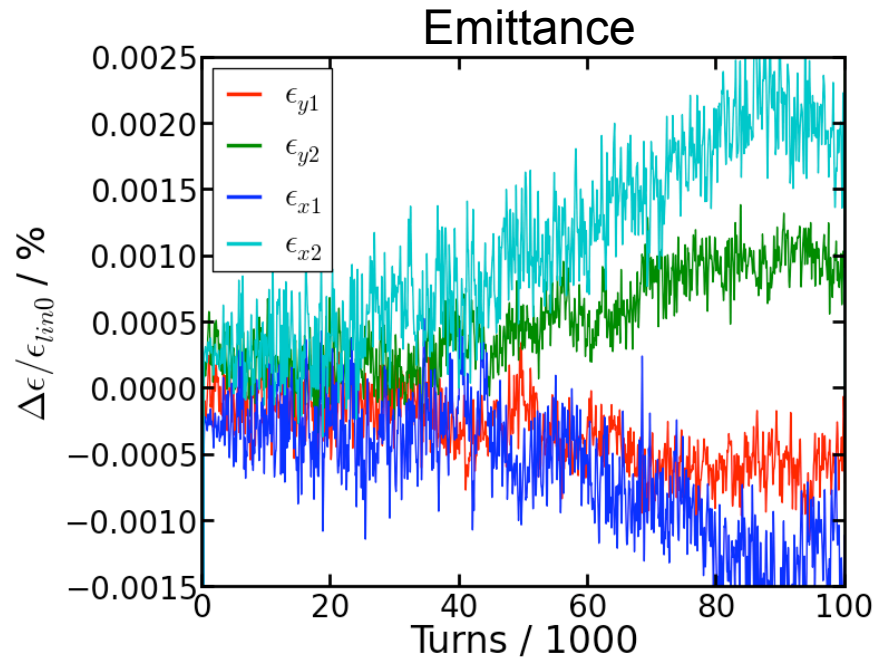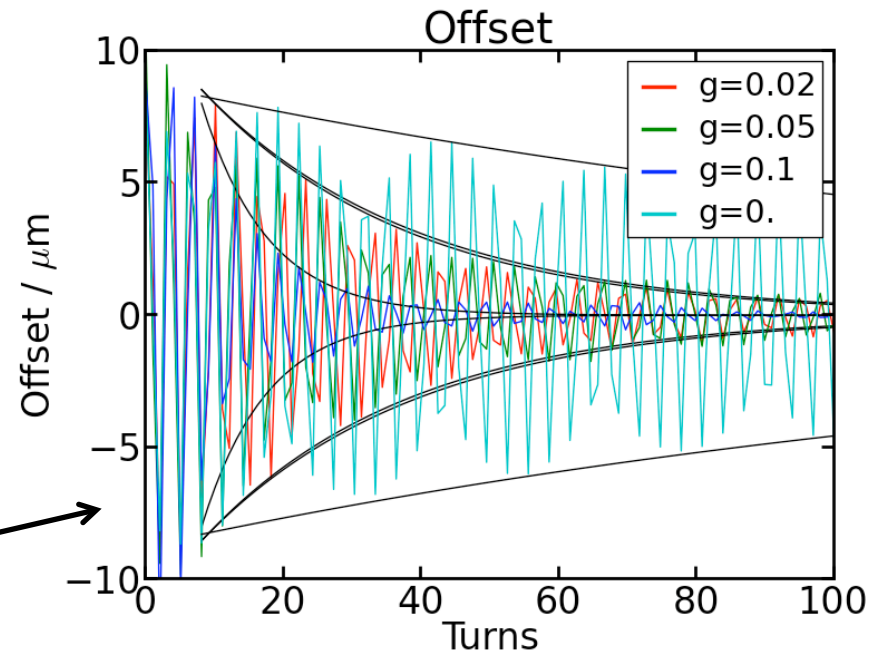

Emittance

Offset

Dipolar instability (?)

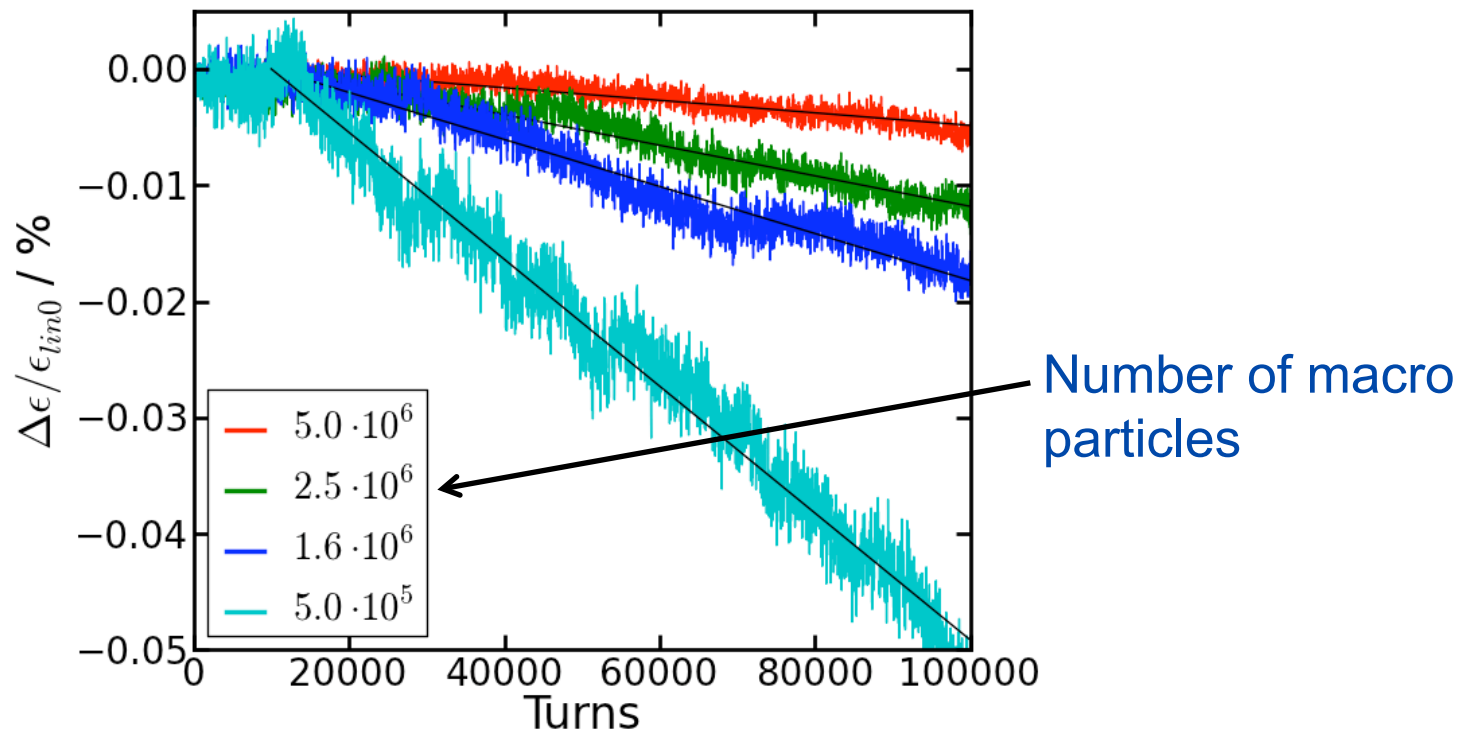# The FB damps an offset with a gain dependent damping time
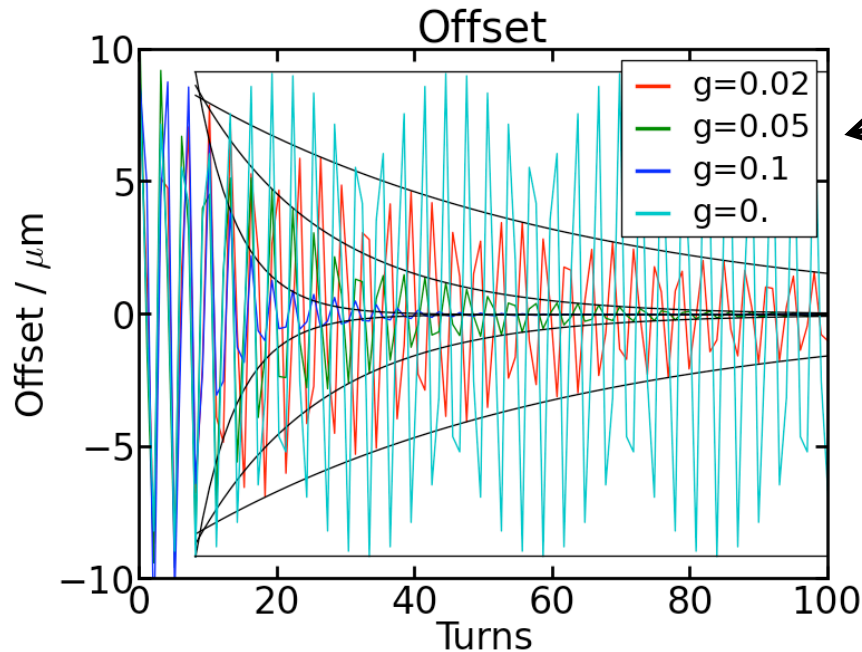
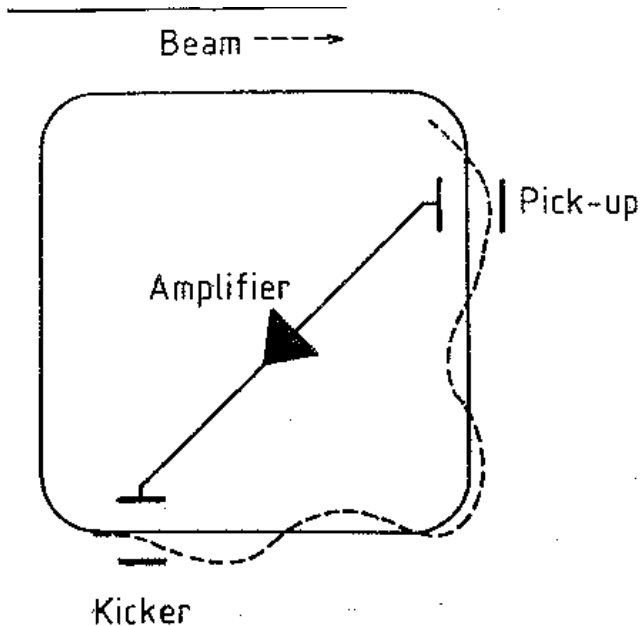Without collision

With collision

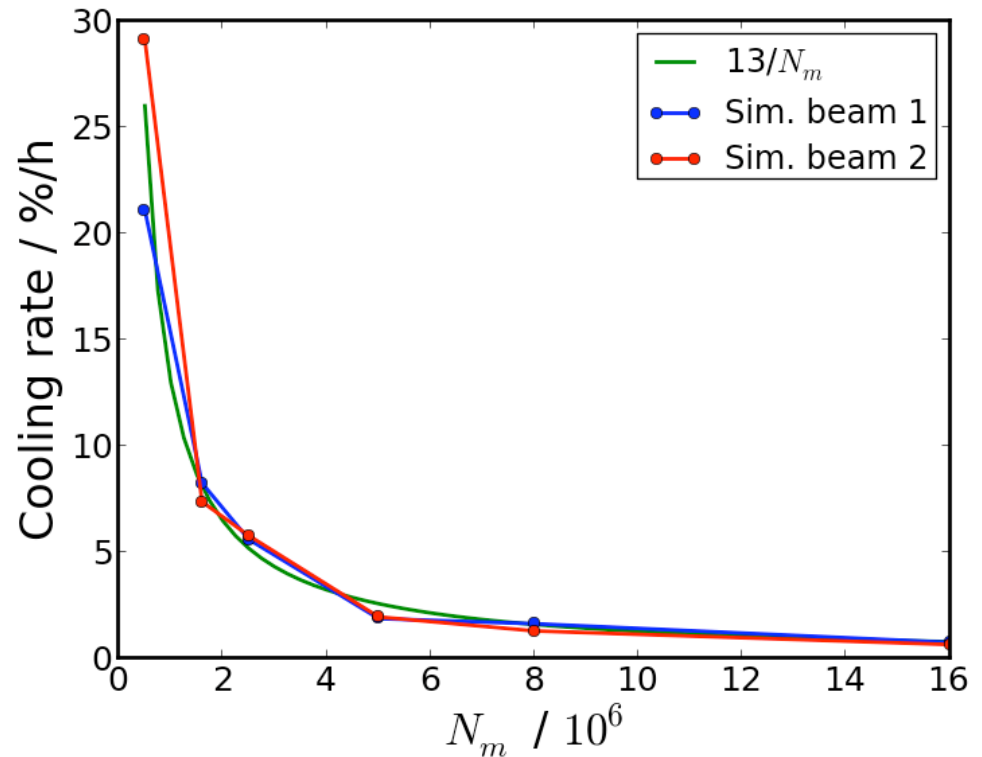# FB simulations yield an unexpected emittance decrease

Numerical noise is not a problem here

The damper acts like a stochastic cooler due to the low macro particle number
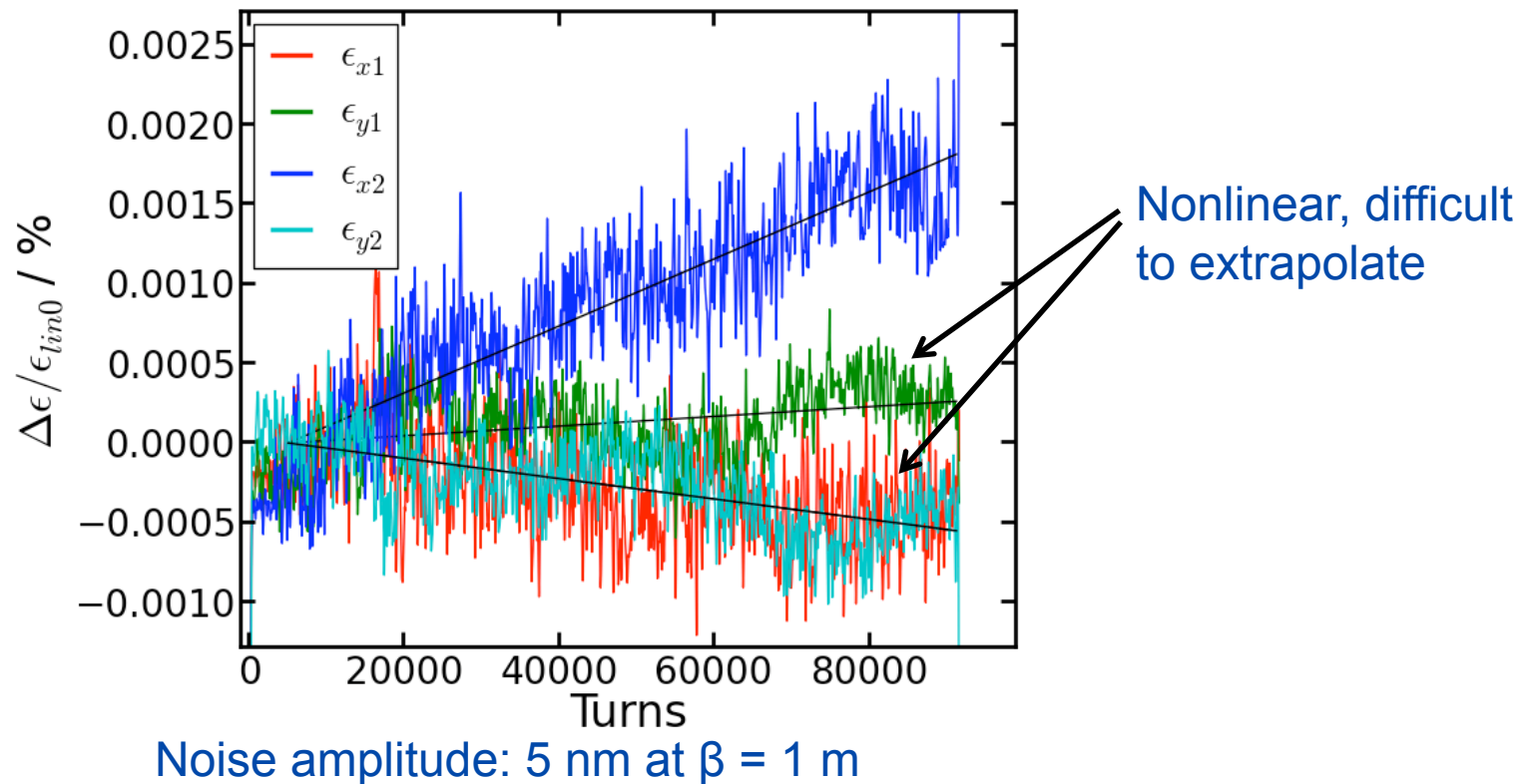
Beam $\dashrightarrow$

Cooler setup, Court. D. Möhl

Cooling rate [4]: $\tau_{cool} \propto \dfrac{1}{N}$

[4] D. Möhl, Beam cooling, CERN-2005-004 (CAS 2000)

Simulation with Noisy FB I

Noise amplitude: 5 nm at β = 1 m

Nonlinear, difficult to extrapolate

Work in progress…

Simulation with Noisy FB II
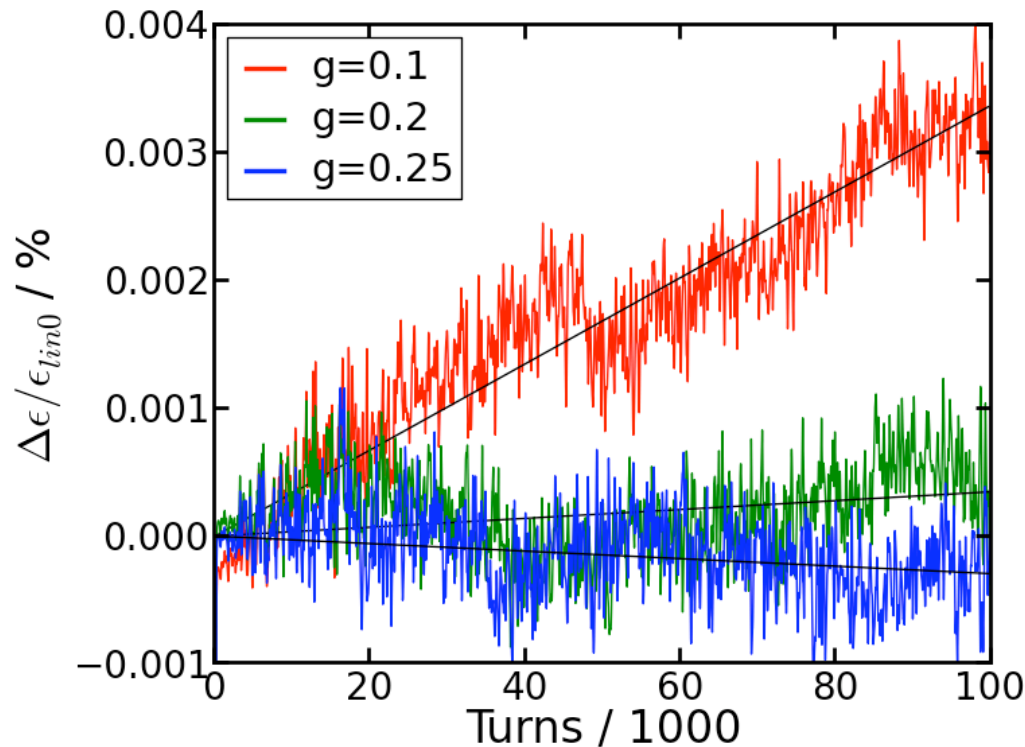
preliminary

Noise amplitude: 5 nm at β = 1 m

Optimal gain seems large compared to LHC – verify FB calibration

Conclusions

- A more realistic FB model has been implemented in BeamBeam3D

- Soft Gaussian approximation avoids numerical noise

- Stochastic cooling appears as an artifact

- Simulation of emittance in present LHC is in progress

- Beam dynamics with crab cavities (and HL) parameters will be studied next

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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