High Frequency Noise on Colliding Beams
Part II

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Analytical estimation of the emittance growth

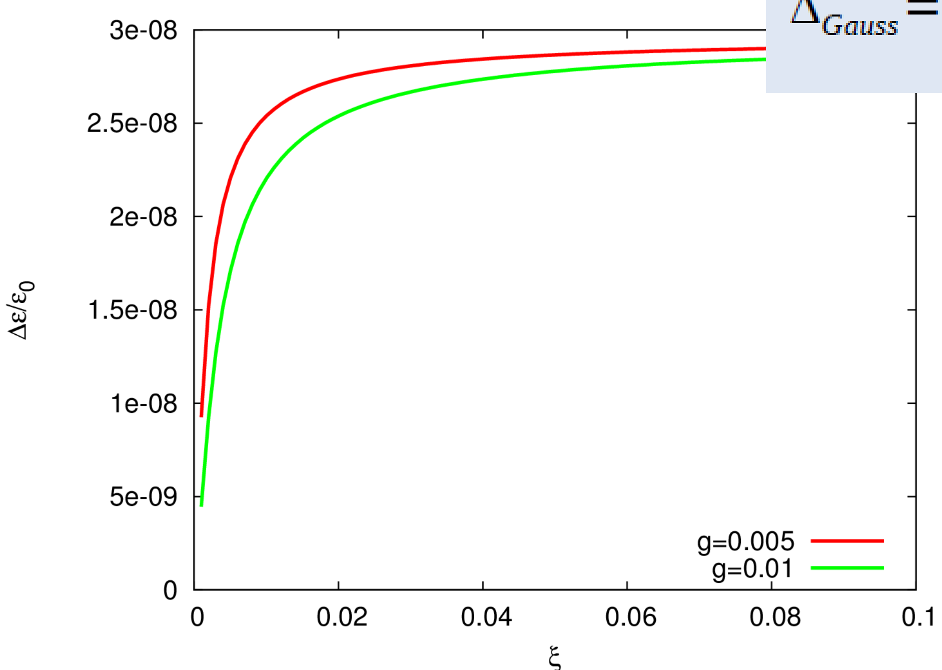
- Brief reminder since Xavier already mentioned it in his talk. Y. Alexahin formulates the emittance growth in terms of noise amplitude, damper gain and beam-beam parameter. The emittance growth saturates for $\xi \rightarrow \infty$.

$$\frac{1}{\epsilon_0}\frac{\epsilon_x^{1,2}}{dN} = \frac{1-s_0}{4}\left(\Delta^2 + g^2\Delta^2_{BPM}\right) S\left(\frac{g}{2\pi|\xi|}\right)]$$

0 (in this presentation)

$$\Delta_{Gauss} = \frac{2\pi\xi}{\sqrt{N_{macro}}}$$

with $S(x) \approx \frac{1}{(1+x)^2}$



For the moment the soft-gaussian is the preferred approach. Faster with less noise introduced.

“On The Landau Damping And Decoherence Of Transverse Dipole Oscillations In Colliding Beams”, Particle Accelerators, Vol. 59, pp. 43-74

Reminder theory simplifications

It is important to keep in mind the simplifications that Y. Alexahin does in order to understand possible deviations/disagreement when comparing with self-consistent tracking.

- Betatron tune spreads due to **chromaticity** and **nonlinearity** of the machine magnetic elements are **negligible** as compared to the beam- beam tune spread.
- Motions in *x* and *y* planes are **uncoupled** and the emittances being equal $\varepsilon_x=\varepsilon_y=\varepsilon_0$.
- Beams collide head-on and at only **one interaction point** (IP) in the ring.
- The non-perturbed beams are **round** at the IP with equal r.m.s. radii σ^*.
- The working point on the tune diagram is chosen sufficiently **far from low order resonances** so that invariant tori are not destroyed by the beam-beam interaction.

Simulations

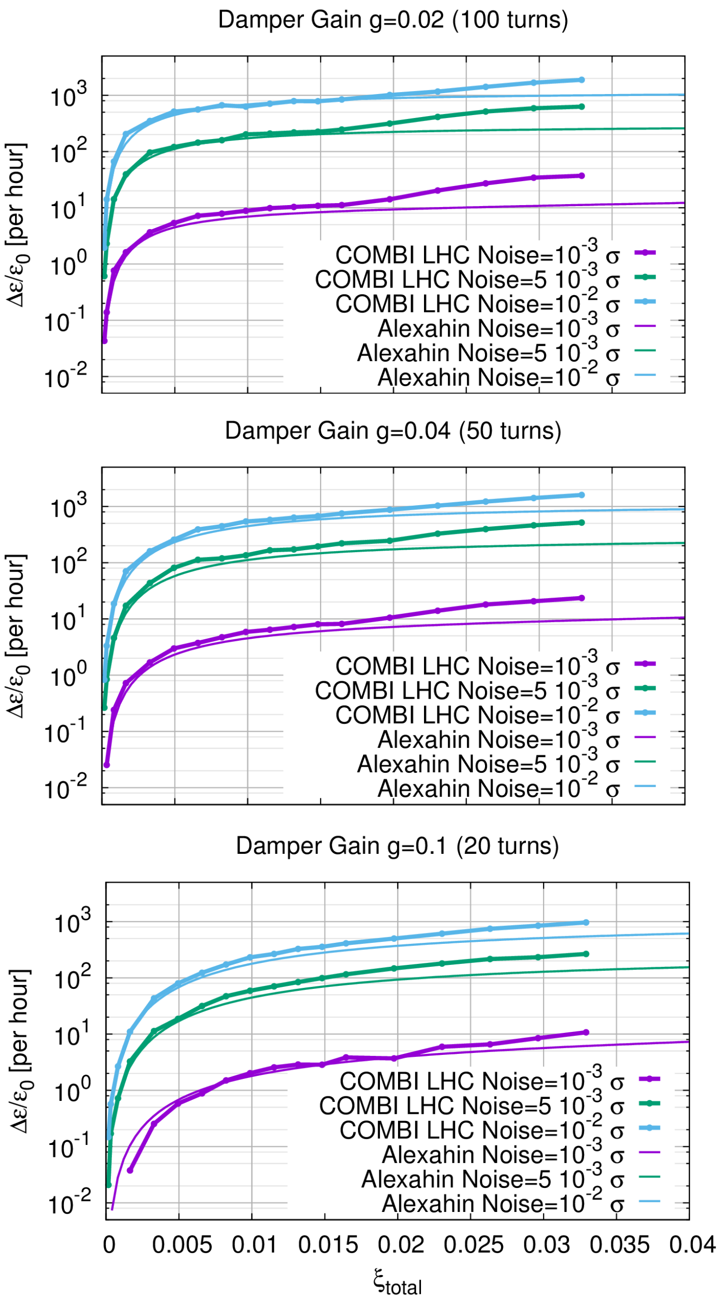
- We use **COMBI** for simulations. Sequence of actions for 2 IPs case:

  HO (- ½ Transfer M. - Noise (x,y) – Damper (x,y)– HO – ½ Transfer M.

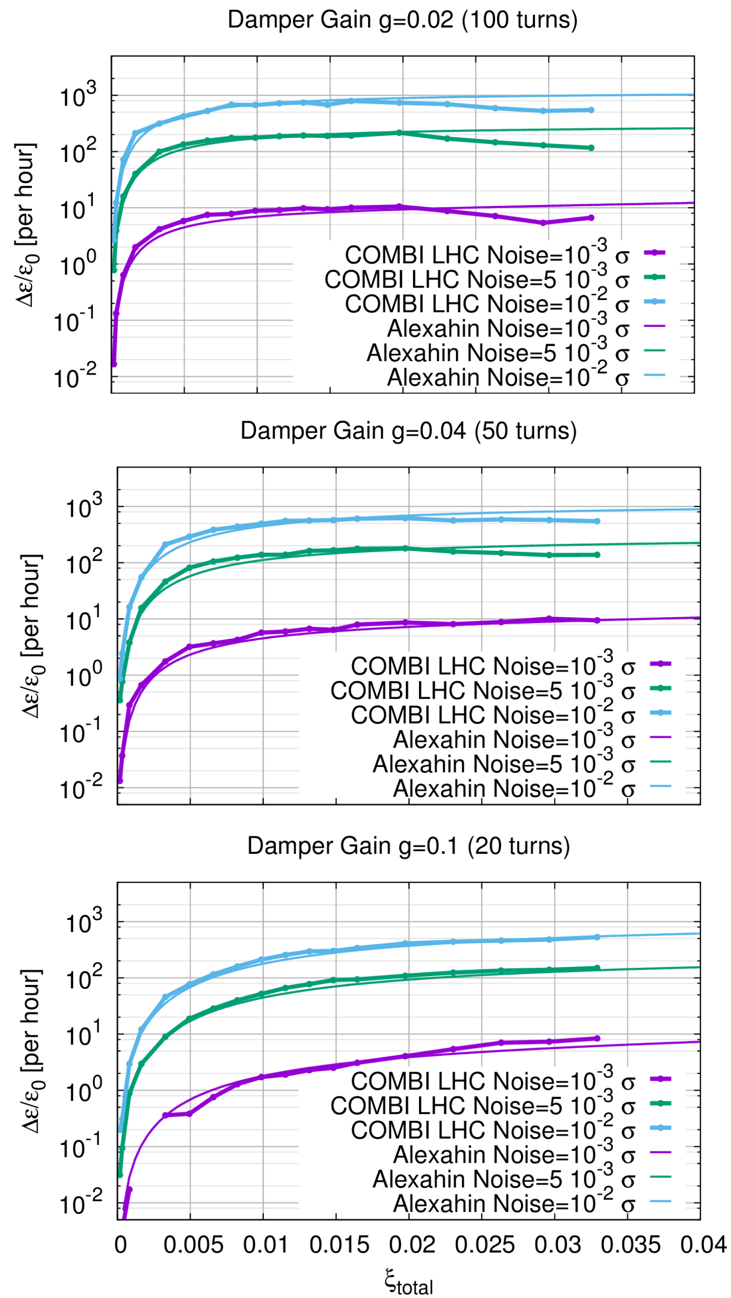
- Tracking **10^6** macroparticles for 10^5 turns (For 2 IP ~**1.1** full days with soft-gaussian and ~2.5 days with HFFM).
- Two different beams **LHC** ($\boldsymbol{\varepsilon}_{nx,y}$**=3.75**) and **BCMS** ($\boldsymbol{\varepsilon}_{nx,y}$**=2.0**).
- Scan of the beam-beam parameter ($\boldsymbol{\xi_{bb}(I)}$), damper gain (2/**g=#Turns**) and noise amplitude ($\boldsymbol{\Delta}$) and chromaticity.

LHC emittance growth: 1 IP

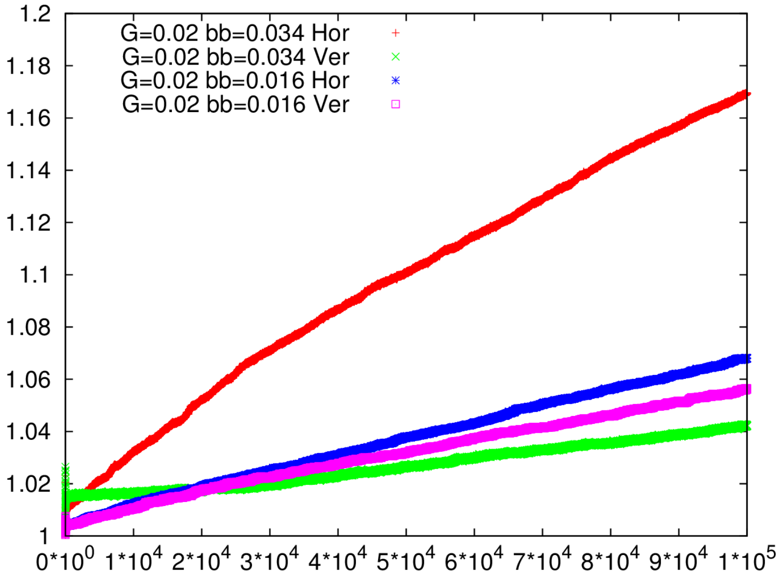
Horizontal

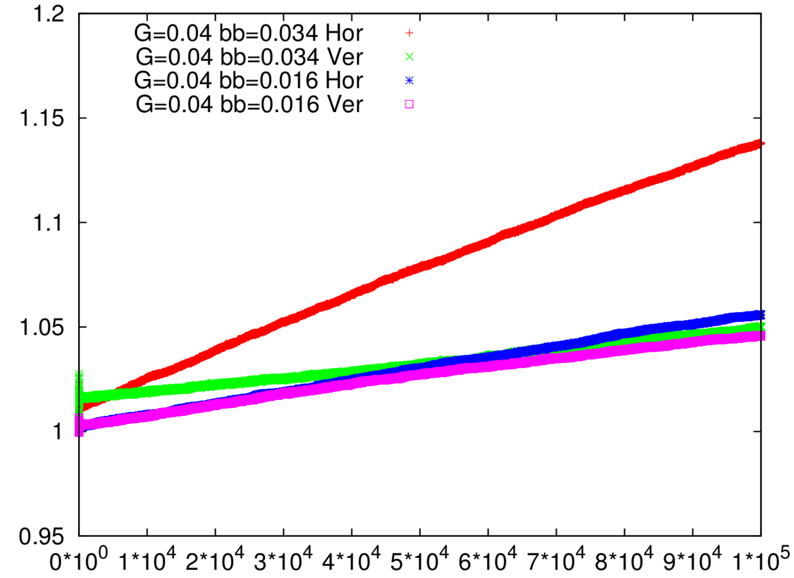


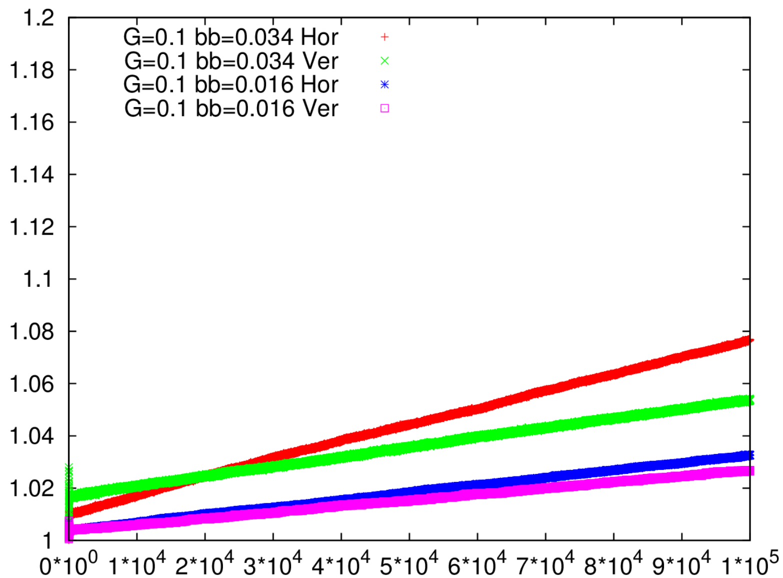
Vertical



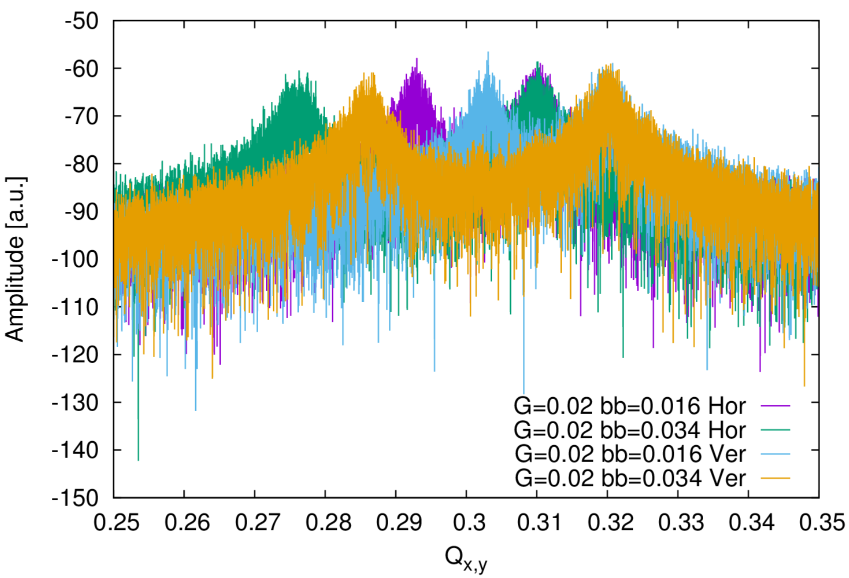
LHC emittance growth: 1 IP

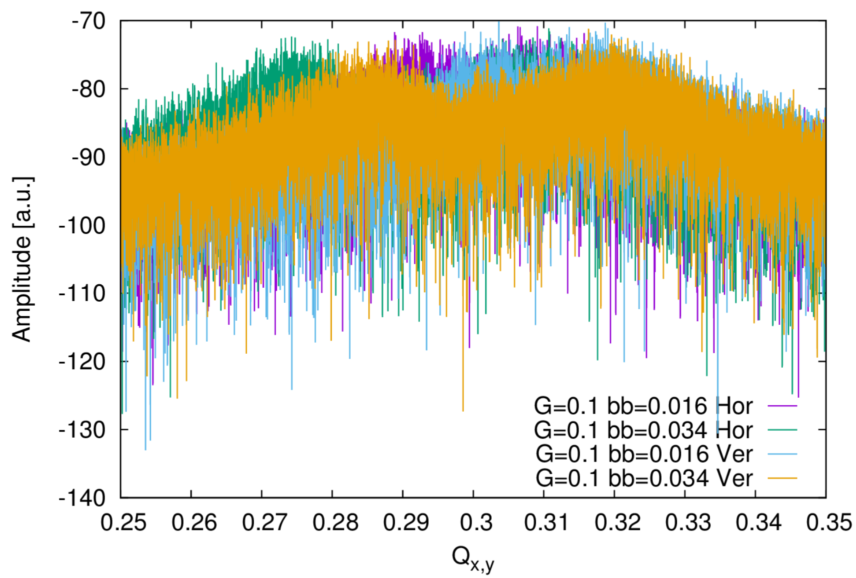






LHC emittance growth: 1 IP

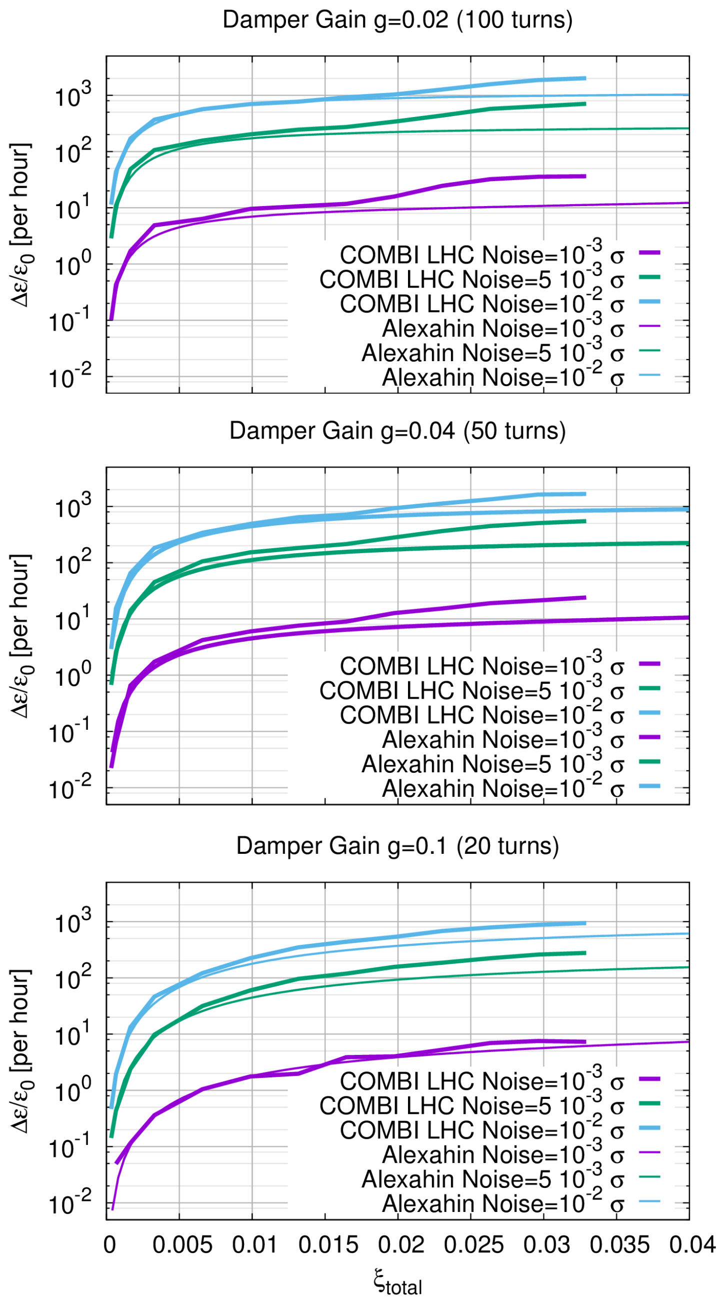




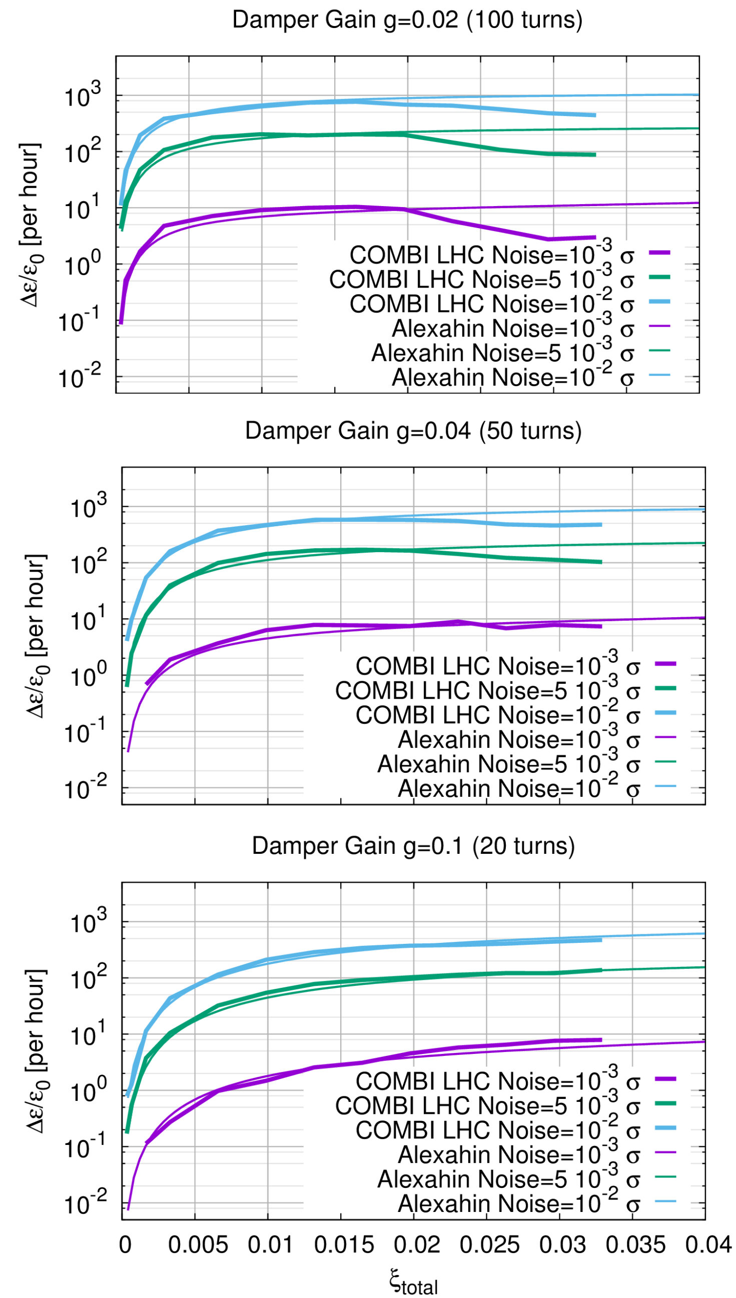
If the gain of the damper is high enough the coherent modes are smoothed out, thus preventing the emittance growth due to the interplay of π-mode and the incoherent sprectrum.

LHC emittance growth: 2 IP

Horizontal

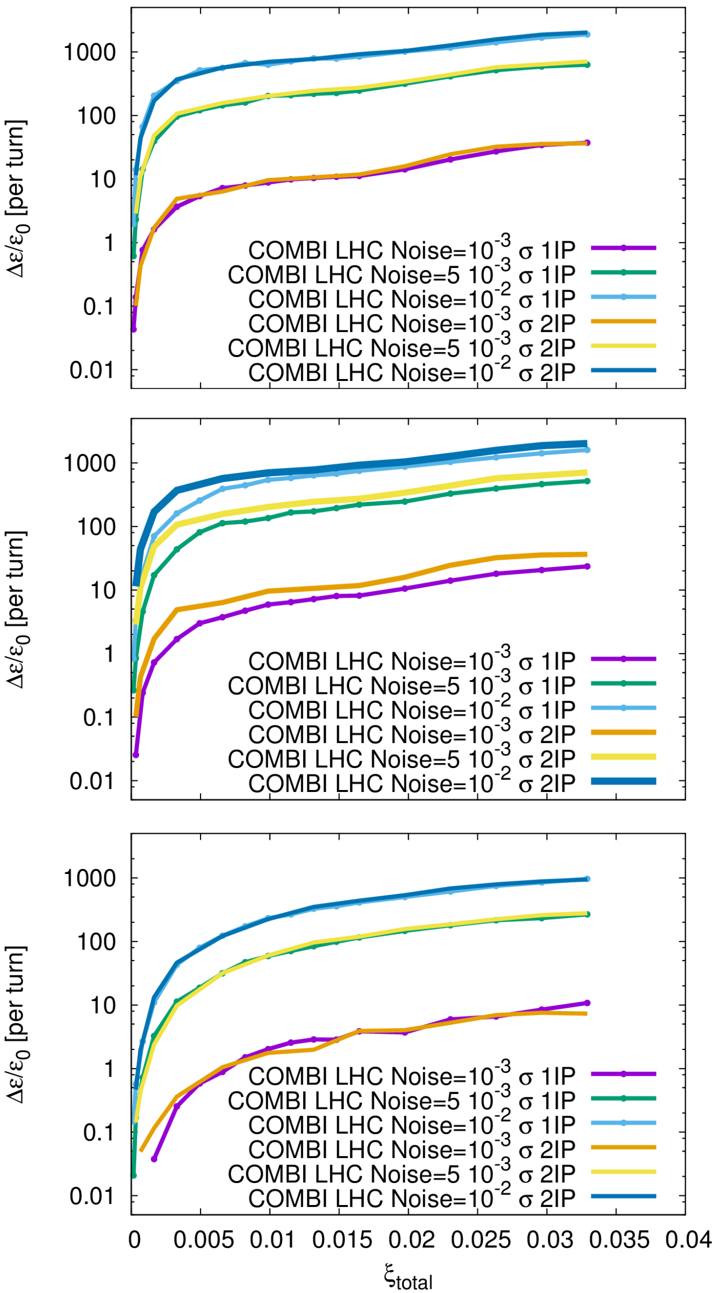


Vertical

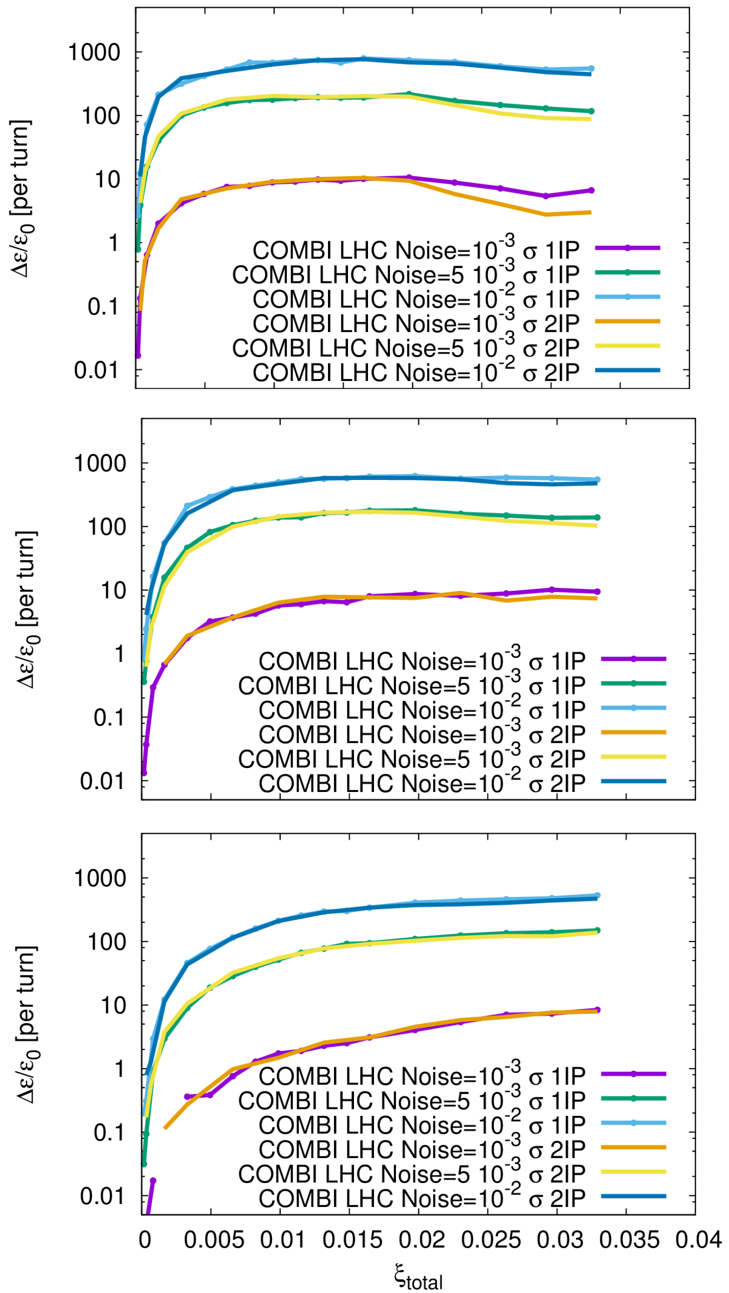


Comparison 1IP vs 2 IP

Horizontal



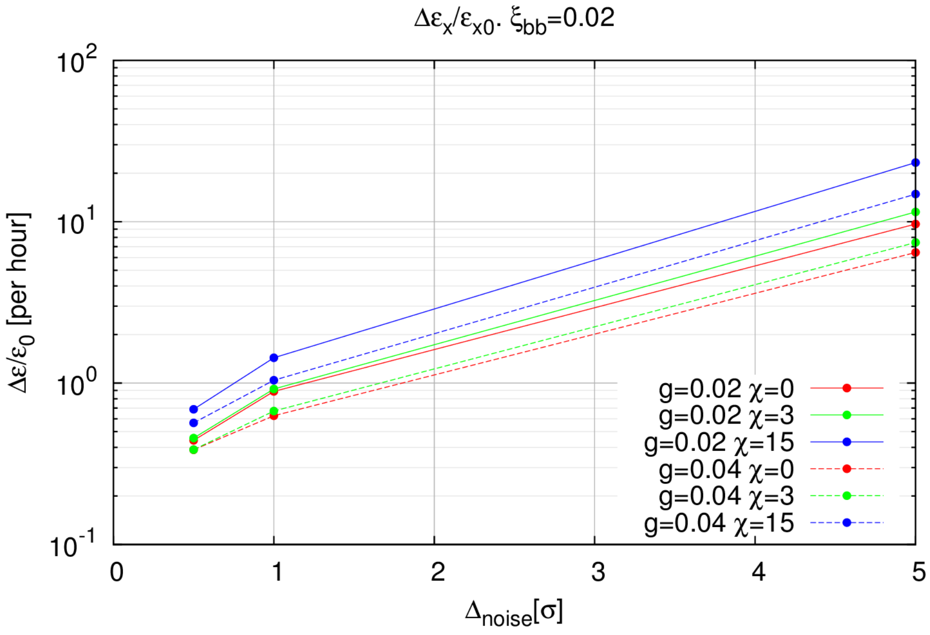
Vertical

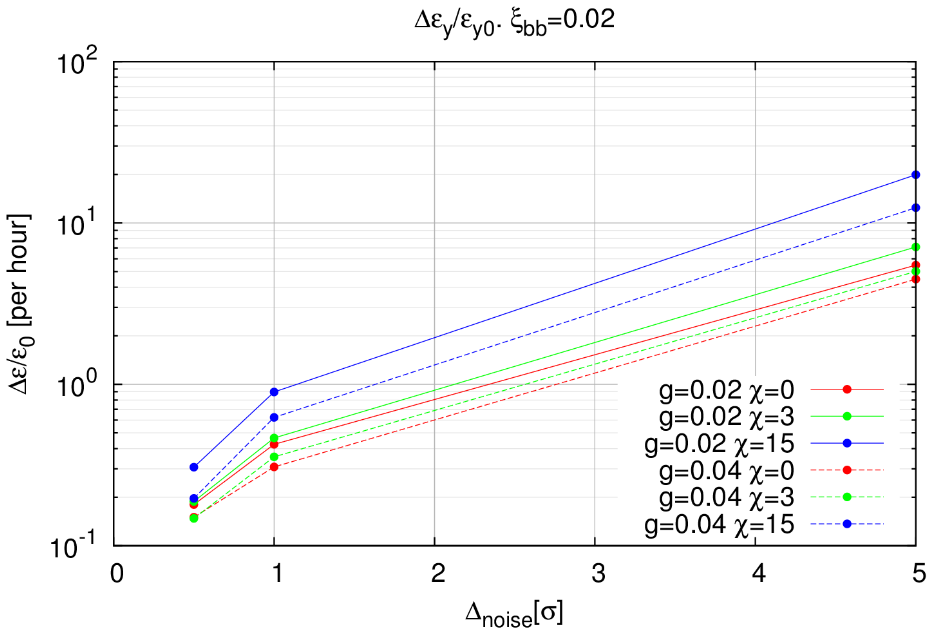


Emittance growth (External noise)

HFFM simulations with 2 IPs.

Increasing noise amplitude and chroma lead to large emittance growth.

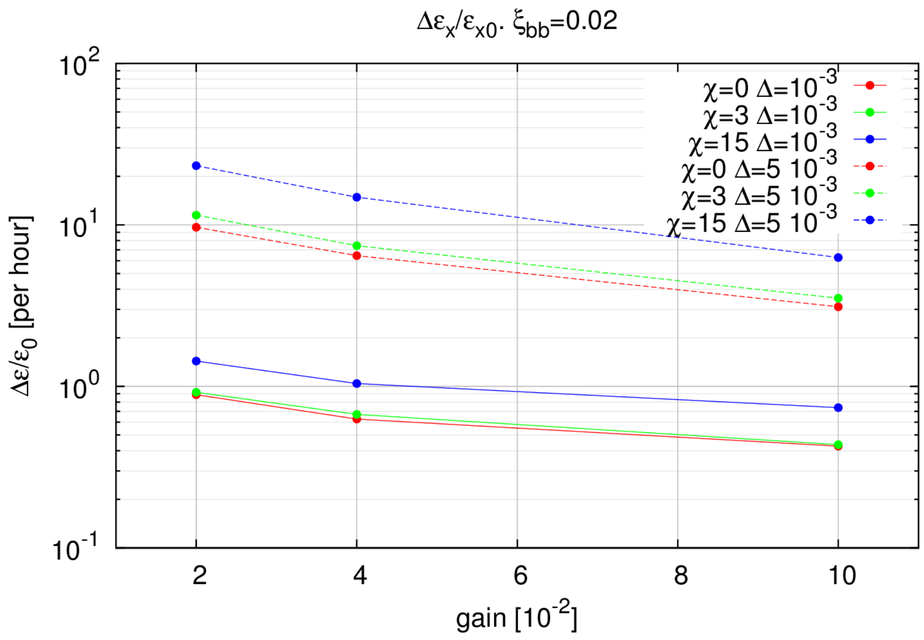


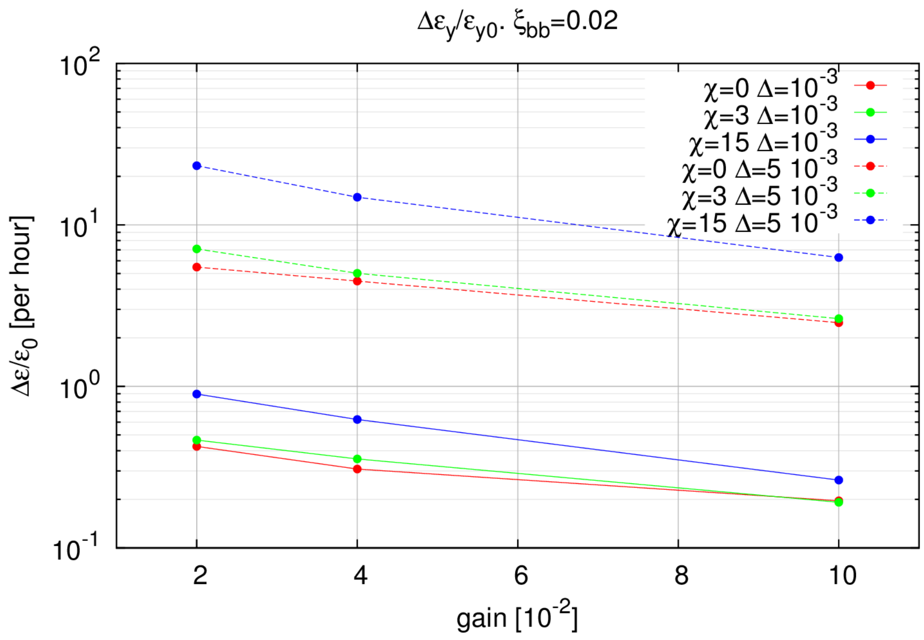


Emittance growth(Damper gain)

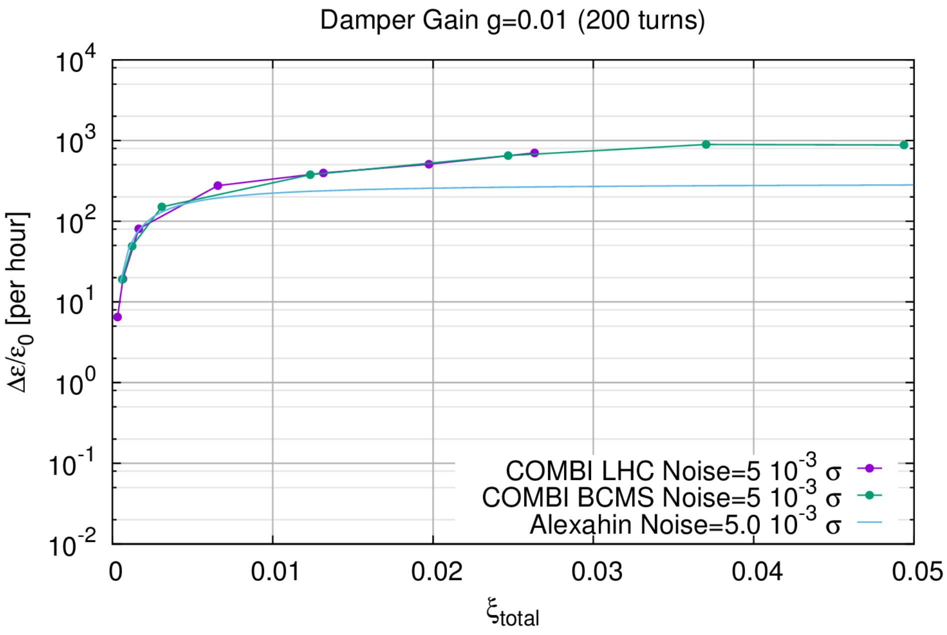
HFFM simulations with 2 IPs.

Increasing noise amplitude and chroma lead to large emittance growth.

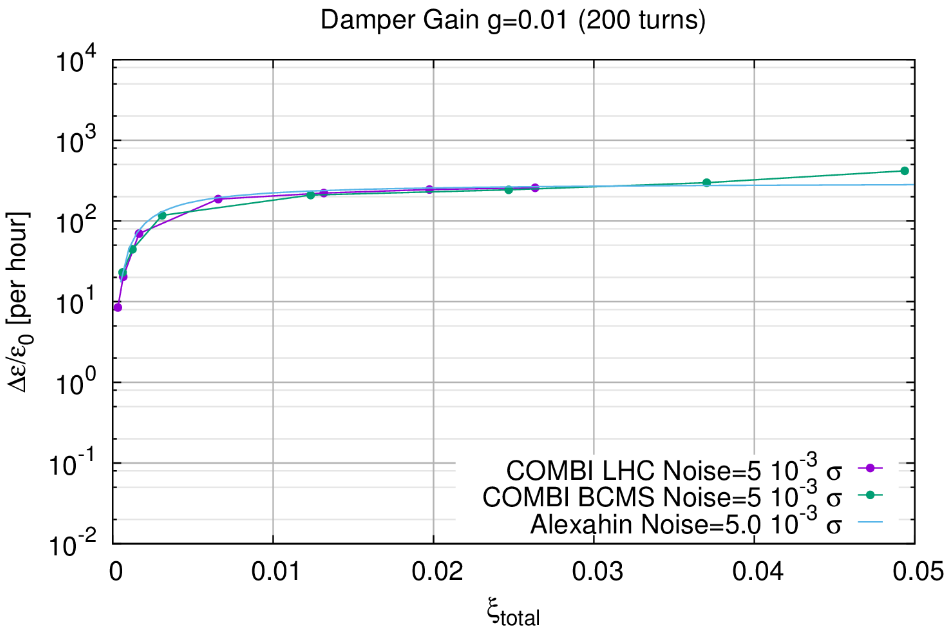




Initial emittance



Horizontal

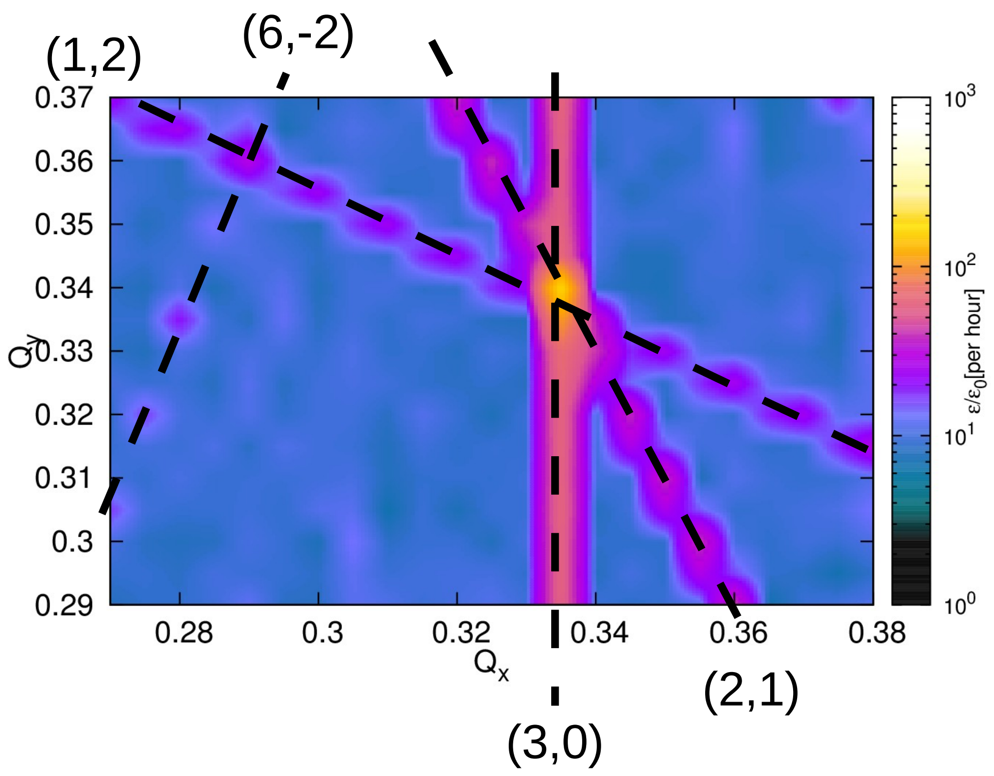


Vertical

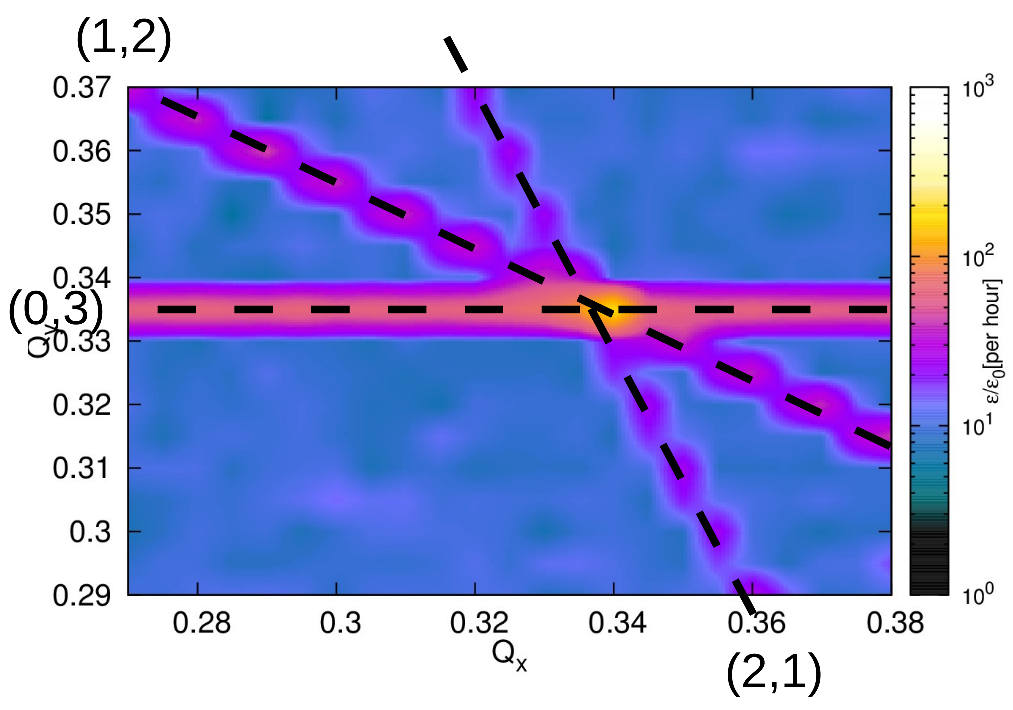
It seems the initial emittance does not influence the relative emittance growth, i.e. the results could be scaled between different beams (HFFM simulations).

Incoherent contribution: Tune Scan

Horizontal



Vertical

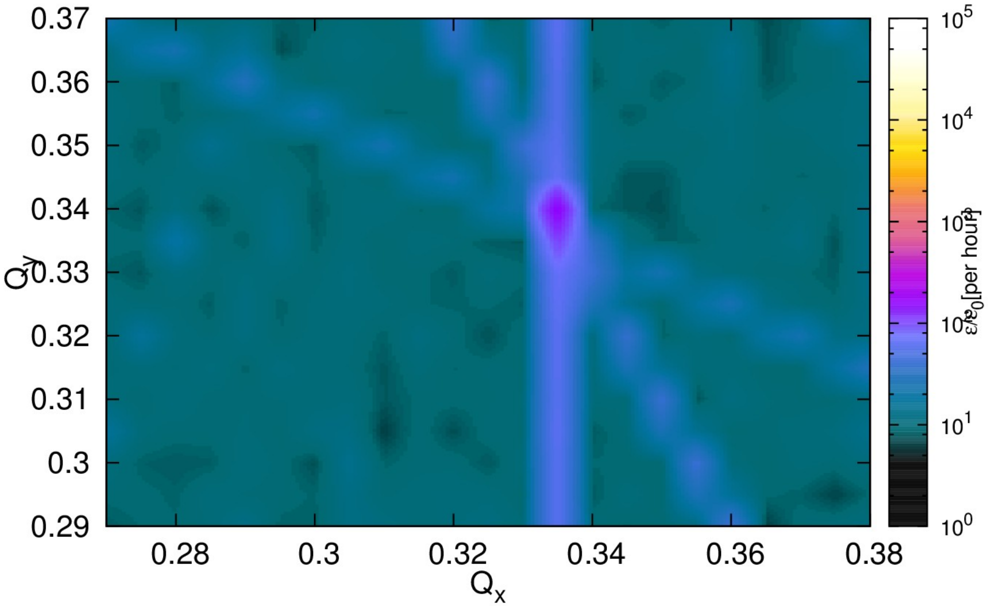


Clear effect of the 3rd order resonances. As well visible a 8th order one.
Simulations with 1 head on (HFFM), 10^6 particles, 10^5 turns and steps of $\Delta Q=0.005$.
Damper g=0.01, noise $\Delta=0.001$, LHC beam (3.75 μm) and 2 10^{11} ppb.
Both planes are clearly uncoupled.

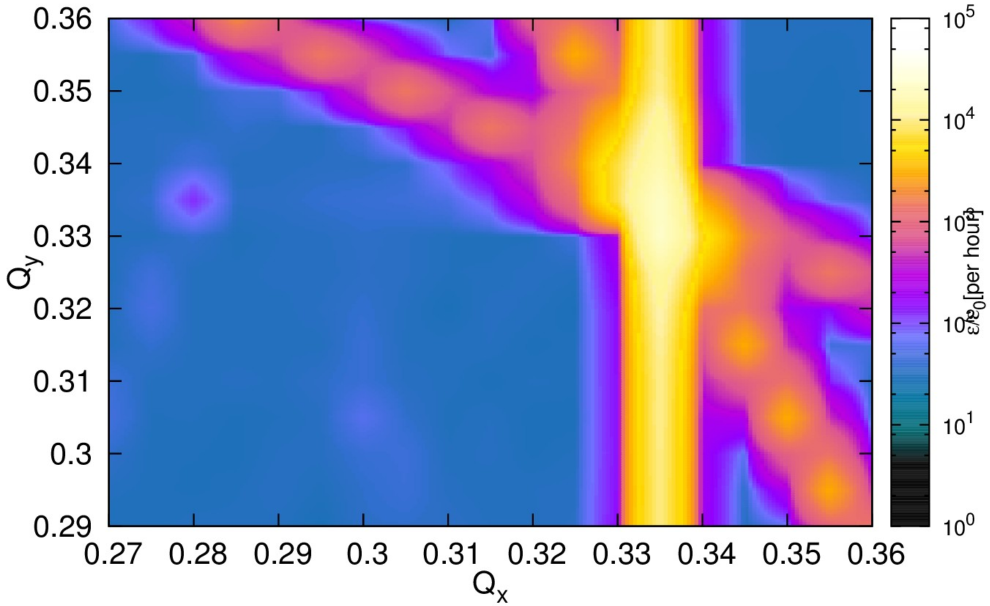
Tune Scan: Chromaticity

Horizontal

chroma=0



chroma=15

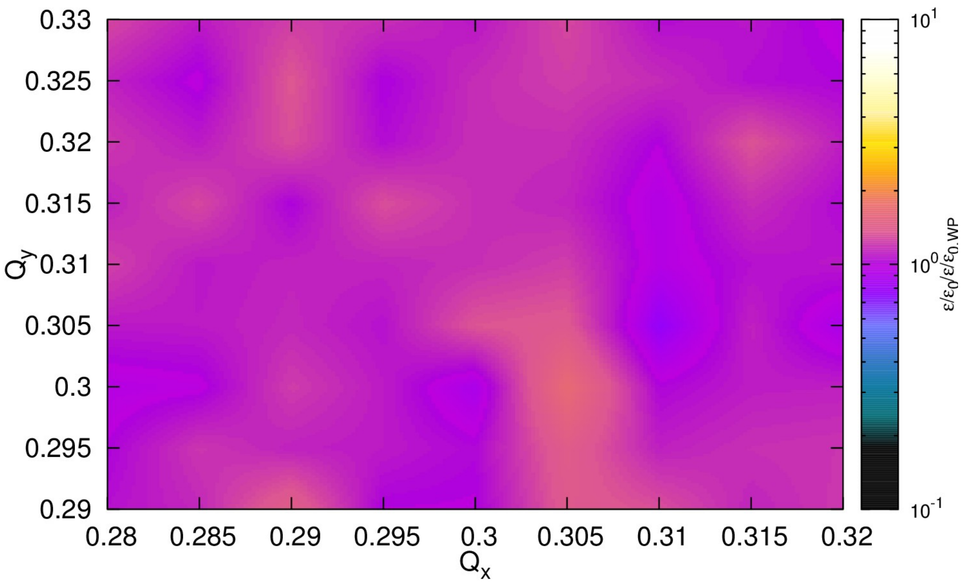


Chroma=15 increases emittance growth by one order of magnitude or even more in the vincinity of resonances .

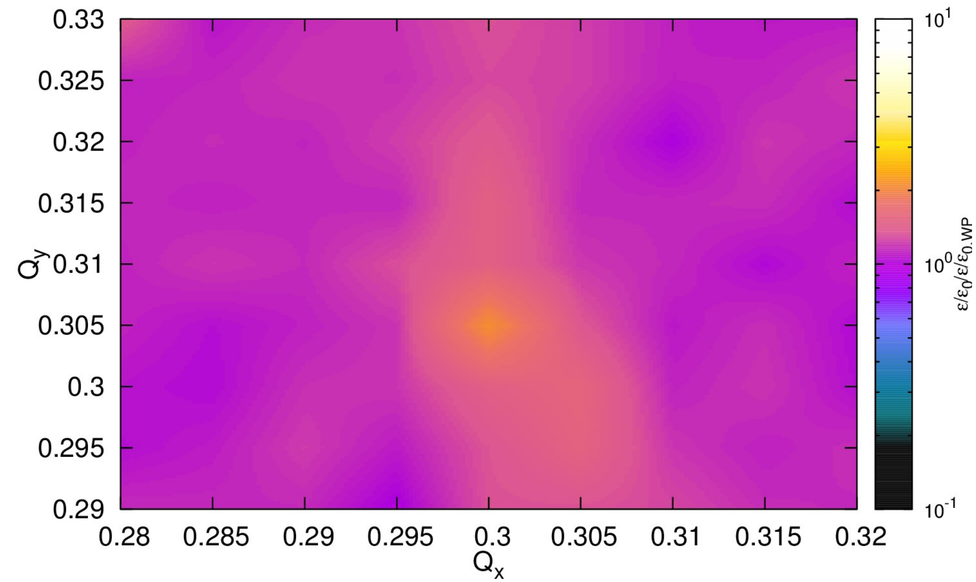
Tune Scan: Chromaticity

Horizontal Emittance Zoom. Emittance growth ratio wrt to the working point (0.31,0.32)

chroma=0



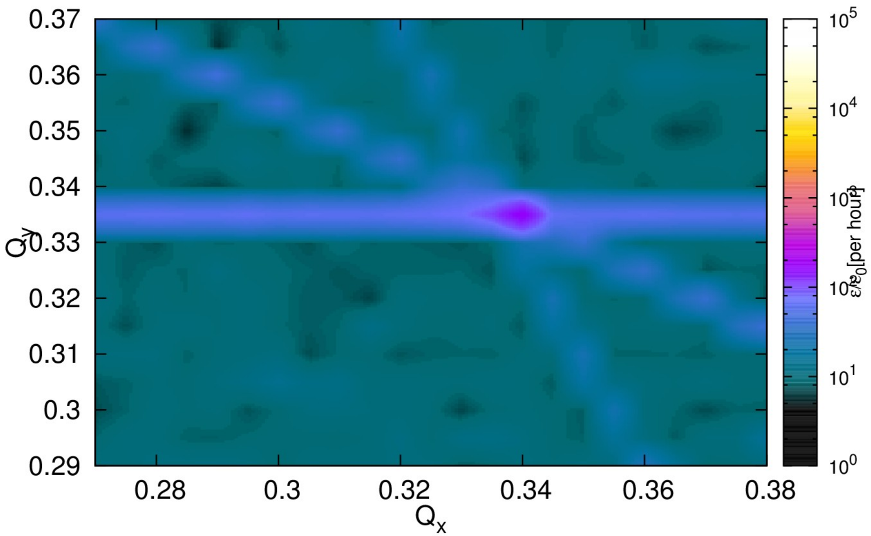
chroma=15



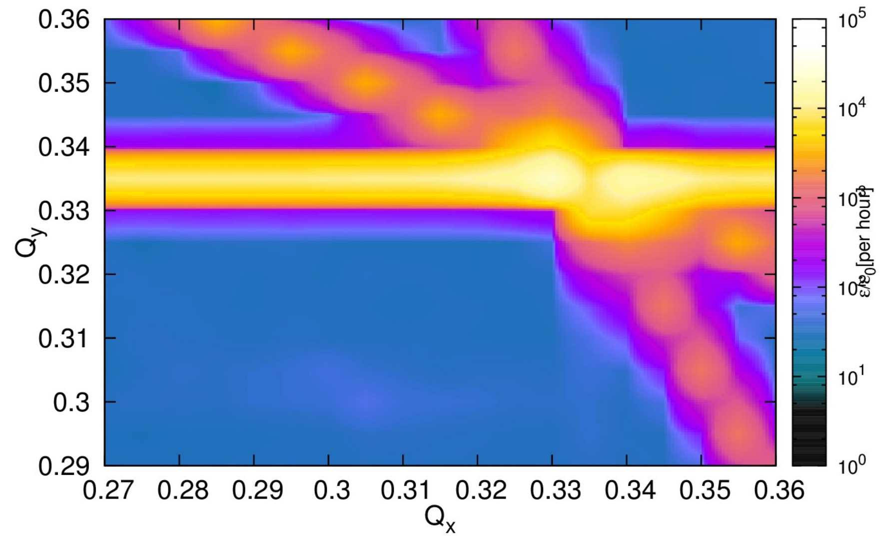
Tune Scan: Chromaticity

Vertical

chroma=0



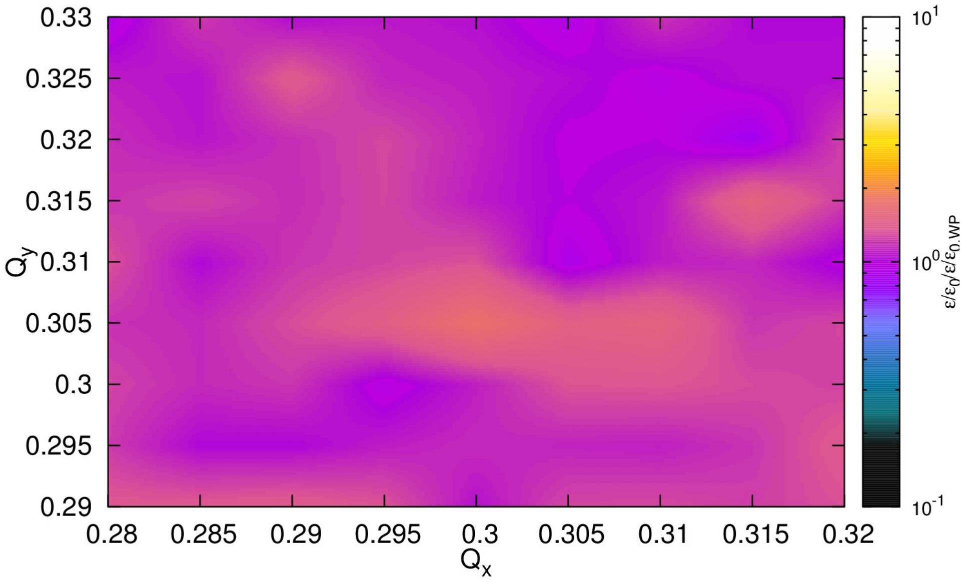
chroma=15



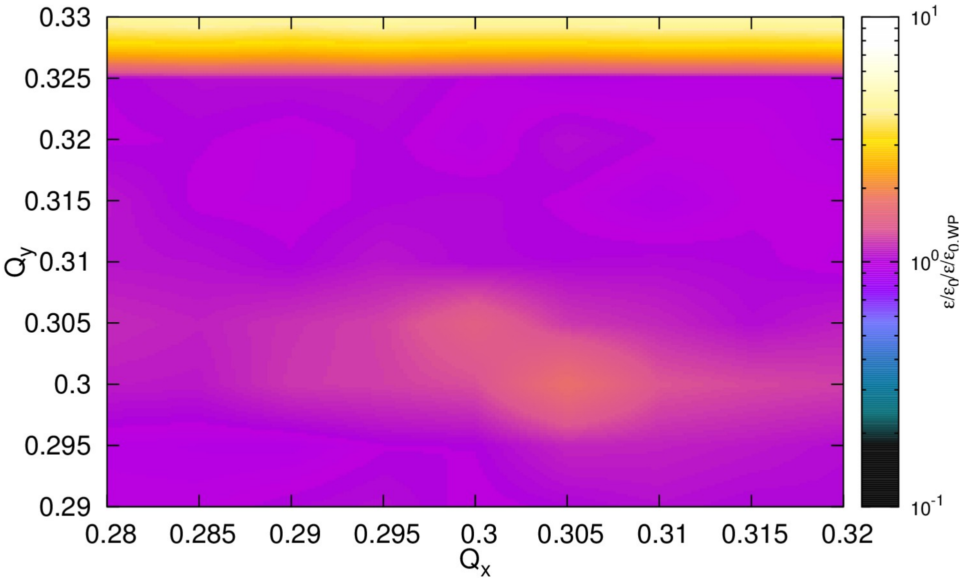
Tune Scan: Chromaticity

Vertical Emittance Zoom. Emittance growth ratio wrt to the working point (0.31,0.32)

chroma=0



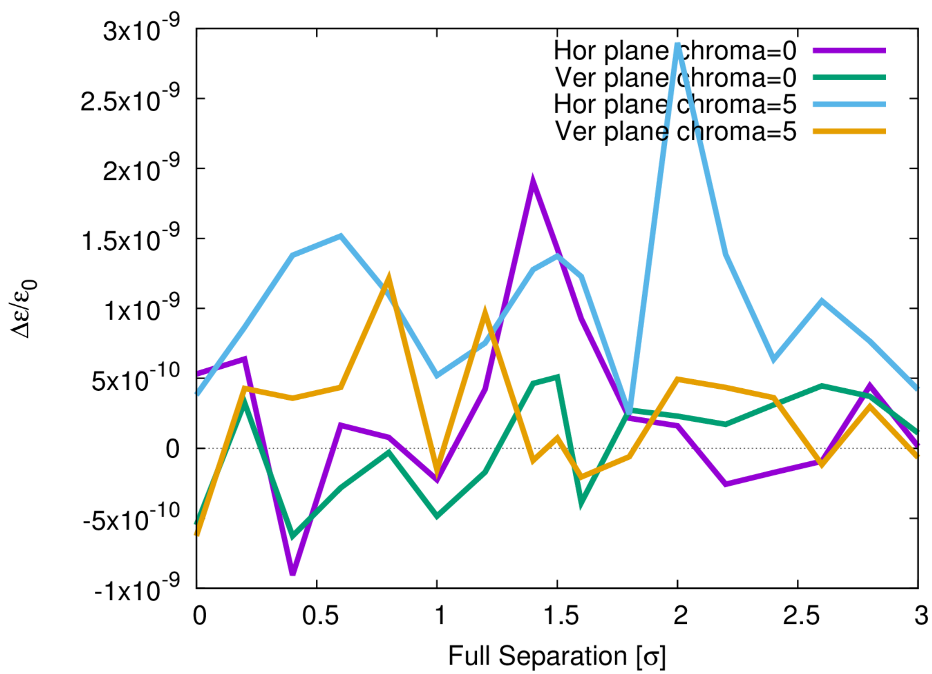
chroma=15

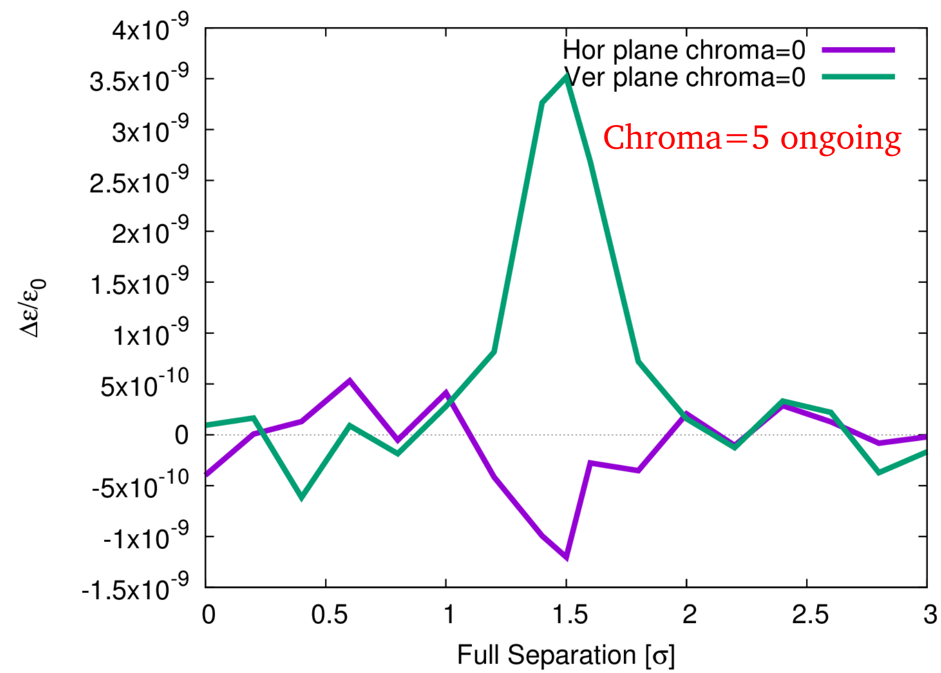


LHC MD
Head-on limits: separation leveling

HL-LHC will rely on very large beam-beam head-on shift and spread. Also LHC to push for higher luminosity will go in the same direction. A clear understanding of colliding high brightness beams is fundamental to guarantee the operation of such beams and to anticipate problematics linked to such configuration. We want to explore the beam dynamics of colliding beams with high brigthness: intensities as high as possible close to 2e11 ppb or higher and small emittances. The goal is to monitor the beam lifetimes and emittance behavior around the machine working point for full head-on collision and for collisions with small transverse offsets. The study aims to highlight emittance growth driven by beam-beam and possible issues with instabilities due to mode coupling.

Preliminary simulations with 1 IP with either vertical or horizontal separation. No noise or damper. Noisy fit in many cases, especially for chroma=0. External noise needed to enhance emittance growth.





On-going conclusions and outlook

- Massive campaign of self-consistent simulations has been started to predict emittance growth in the presence of an external noise and damper feedback.
- Only possible thanks to the new shared node architecture in EPFL Aries cluster.
- Scan of beam-beam parameter, damper gain, noise amplitude (**Δ**) and chromaticity have been presented.
  - As anticipated by Xavier we find a limit in the agreement with Alexahin predictions for beam-beam parameters > tune difference in both planes. For relative low gains the difference is also found in the vertical emittance growth, however this time understimating with to Alexahin. A sufficient large gain (g=0.1) makes simulations and theory agree perfectly.
  - 1 IP vs 2 IP show in general very good agreement for a given beam-beam parameter with slight differences for small noise amplitudes.
  - As expected we find larger emittance growth for large noise amplitudes.
  - Non-zero chromaticity contributes to emittance growth. This is important since chroma is not taken into account in Alexahin's predictions.
  - The initial emittance of the beam (LHC vs BCMS) seems not to matter in the relative emittance growth.
- An attempt to find a better working point in the vincinity of (0.31,0.32) did not show a better option than the current one. However again chromaticity showed an important contribution to emittance growth.
- We have started the simulations in order to prepare the approved MD “Head on limits: Separation leveling”. We should benchmark with existing results (Tatiana's thesis) and provide results for realistic MD parameters set (including noise and damper).