Status of the impedance-damper model and preliminary guidelines for LHC beam operation

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Acknowledgments: W. Höfle

Basic principles

- Transverse LHC bunch-by-bunch damper → sensible to dipole (”rigid-bunch”) oscillations of the bunches and tries to damp them.
- Ideal damper: constant wake function
  - kicking each bunch as a whole proportionnaly to its center of mass, during the same turn (instantaneously) → no multiturn wake,
  - with phase π/2 for a resistive damper → equivalent to purely imaginary wake (non causal).
- Equivalently, this is a real delta function impedance $Z^{\perp} \propto \delta(\omega)$ and we replace sum on betatron sidebands (multiturn wake):

$$\sum_{k=0}^{\infty} W(kC) e^{-j 2\pi k Q} = \frac{-j}{T_0} \sum_{p=-\infty}^{\infty} Z^{\perp}[(p+Q)\omega_0]$$

by integral over frequency:

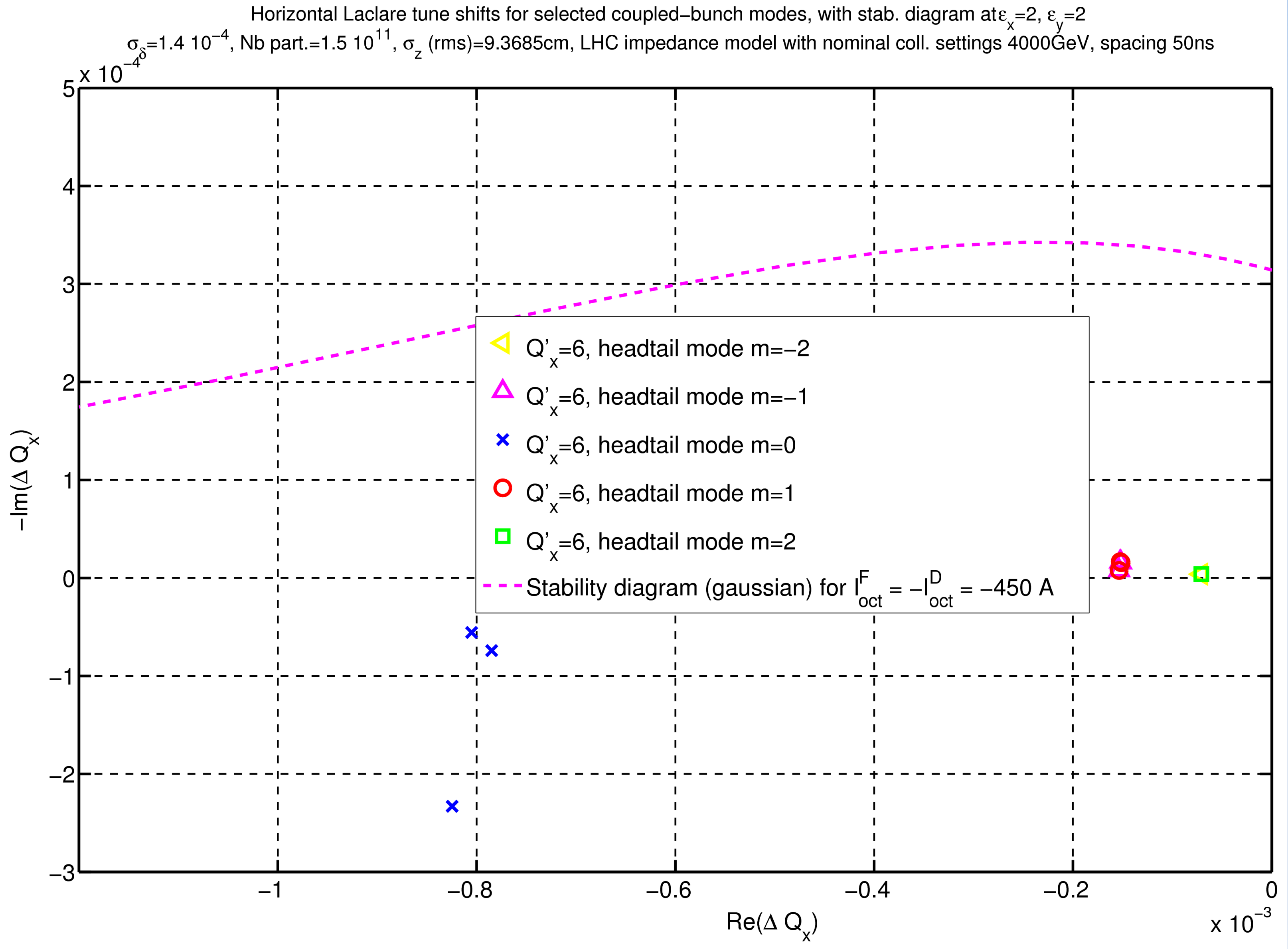
$$W(0) = \frac{-j}{2\pi} \int_{-\infty}^{\infty} Z^{\perp}[\omega] d\omega$$

Outline of the (current) theory

- Since damper acts formally as an impedance, could use classical theories (e.g. Sacherer) on coupling impedance + ”damper impedance”.
- BUT since damping rate ~ω_s → need to consider mode coupling.
- First simple approach: take Chao's eigenvalue problem (”Physics of collective beam instabilities”, eq. 6.183) for airbag bunches, taking into account both LHC impedance and damper.
- Slightly more elaborate: average matrix coefficents (of the airbag problem) over longitudinal bunch distribution.
- Compute and diagonalize the matrix for every coupled-bunch mode in multibunch regime.
- Latest improvement: added the dependency of the damping rate on the coupled-bunch mode frequency (see W. Höfle Chamonix 2012).
- Eigenvalues → coherent tune shifts.
  - To get Landau damping, put them on ”stability diagram”.

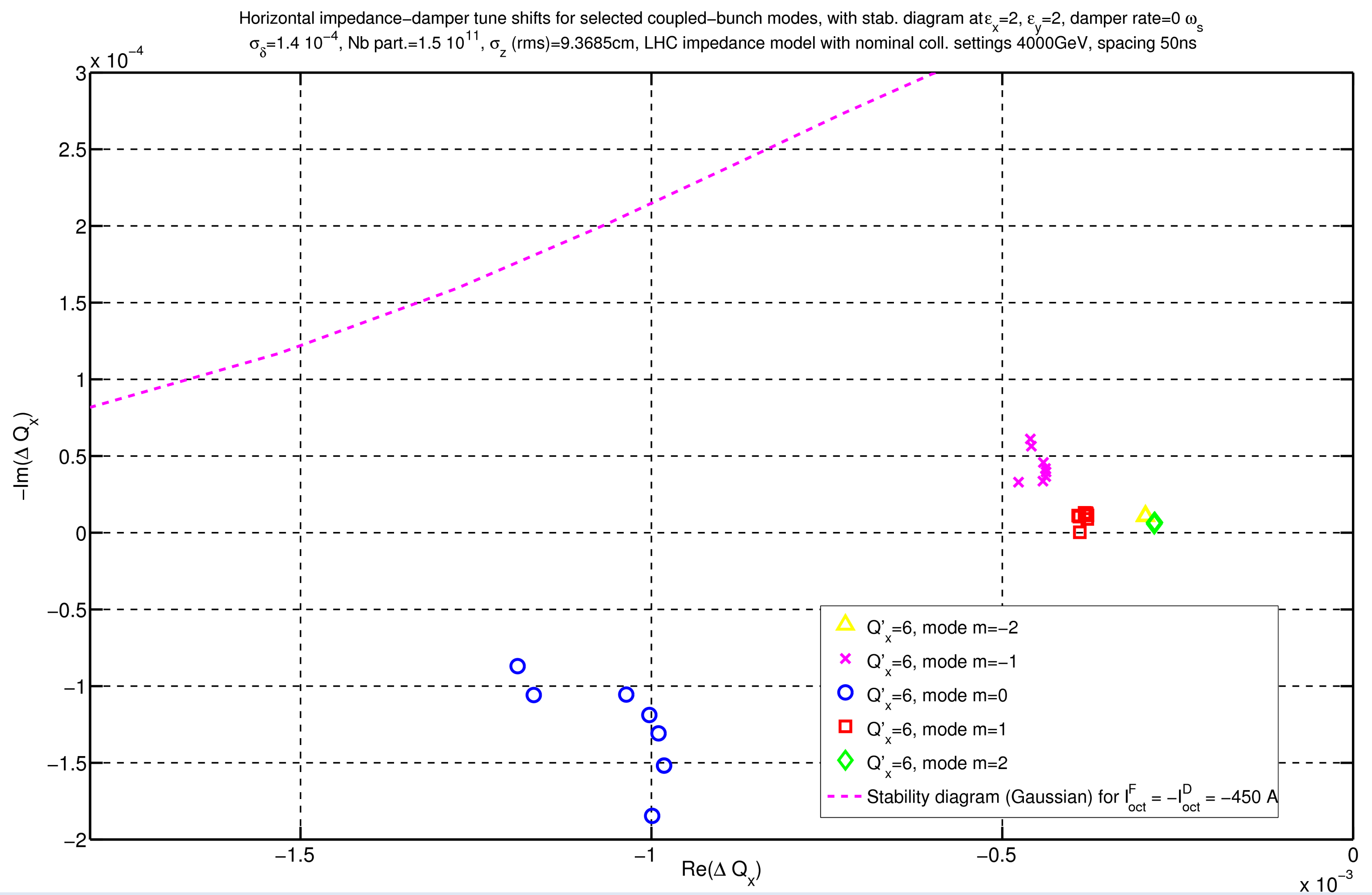
Coherent tune shifts in stability diagram from previous theories

- Laclare's formalism without damper (and weak headtail):



Coherent tune shifts in stability diagram from new theory

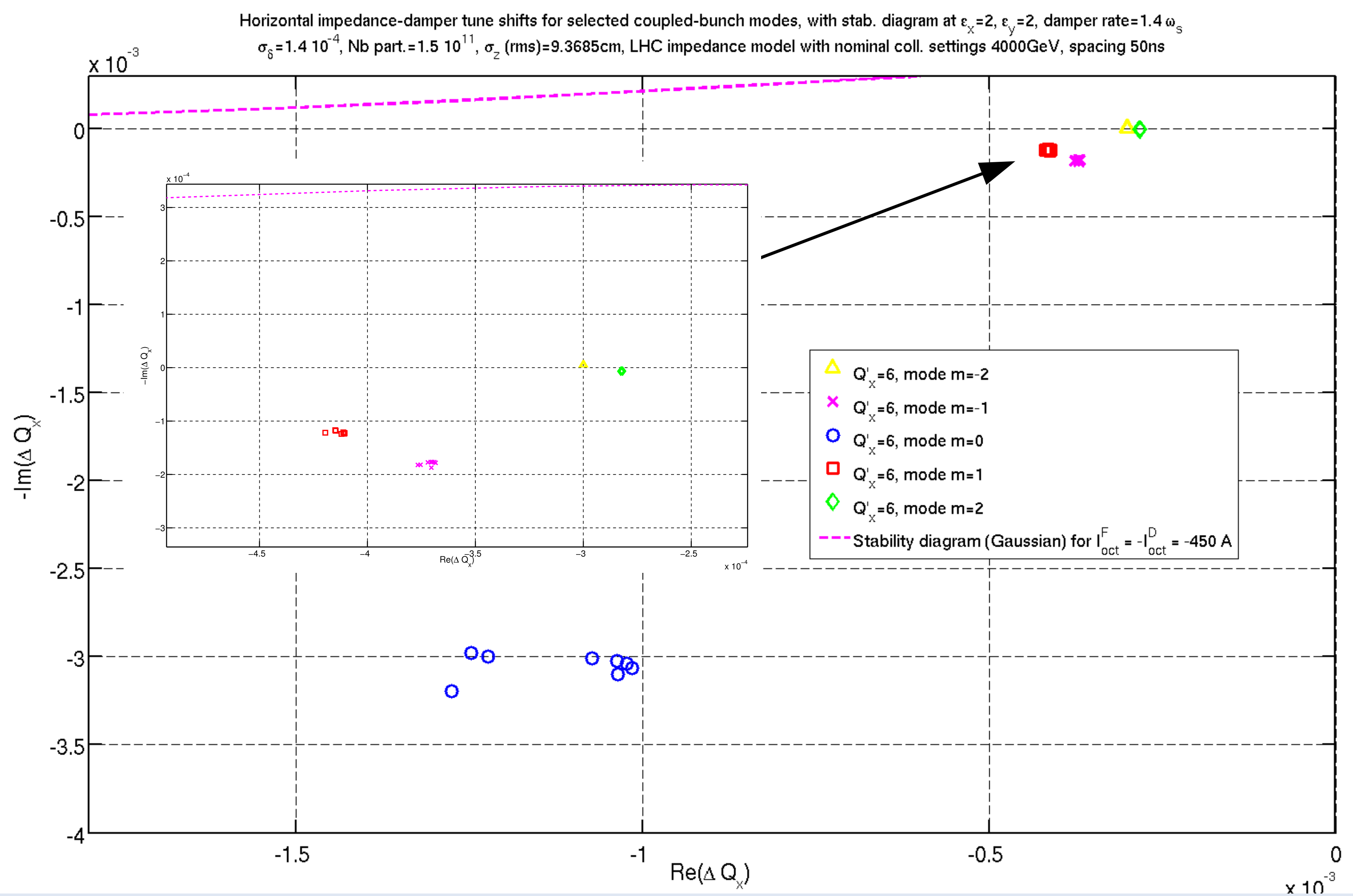
- Same parameters as previously, still no damper:



→ even quite below TMCI threshold (~3e11 p+/b), mode-coupling has a strong effect on headtail modes, favorising here negative ones, as seen also in simulations (see e.g. R. Wasef, ”HEADTAIL simulations of Landau damping” - ICE meeting talk 2011, or N. Mounet PhD thesis).

Coherent tune shifts in stability diagram from new theory

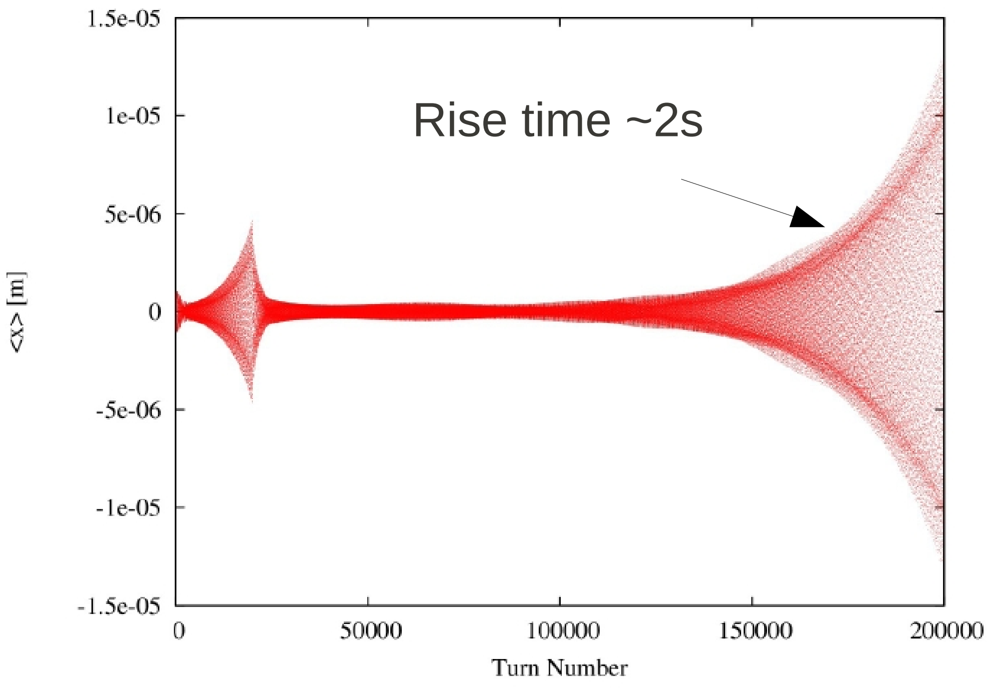
- Same parameters as previously, with damper (no frequency dependent gain):

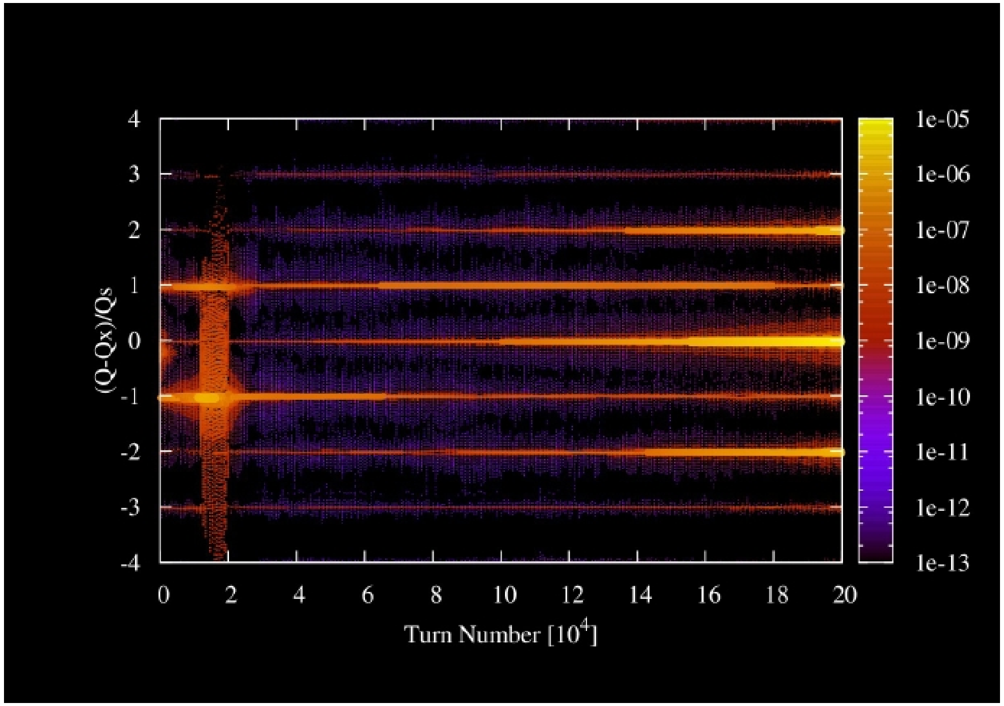


→ Damper damps also higher order headtail modes, in particular +/-1 here ! This is because for non zero chromaticity, these modes also have a dipole moment.

Comparison with simulations (S. White)

- Same parameters as before, except single-bunch, Nb=1.5e11 p+/bunch, Q'=6, d=0.7 ω_s (i.e. 100 turns) on after 20000 turns only (NB: still preliminary results)

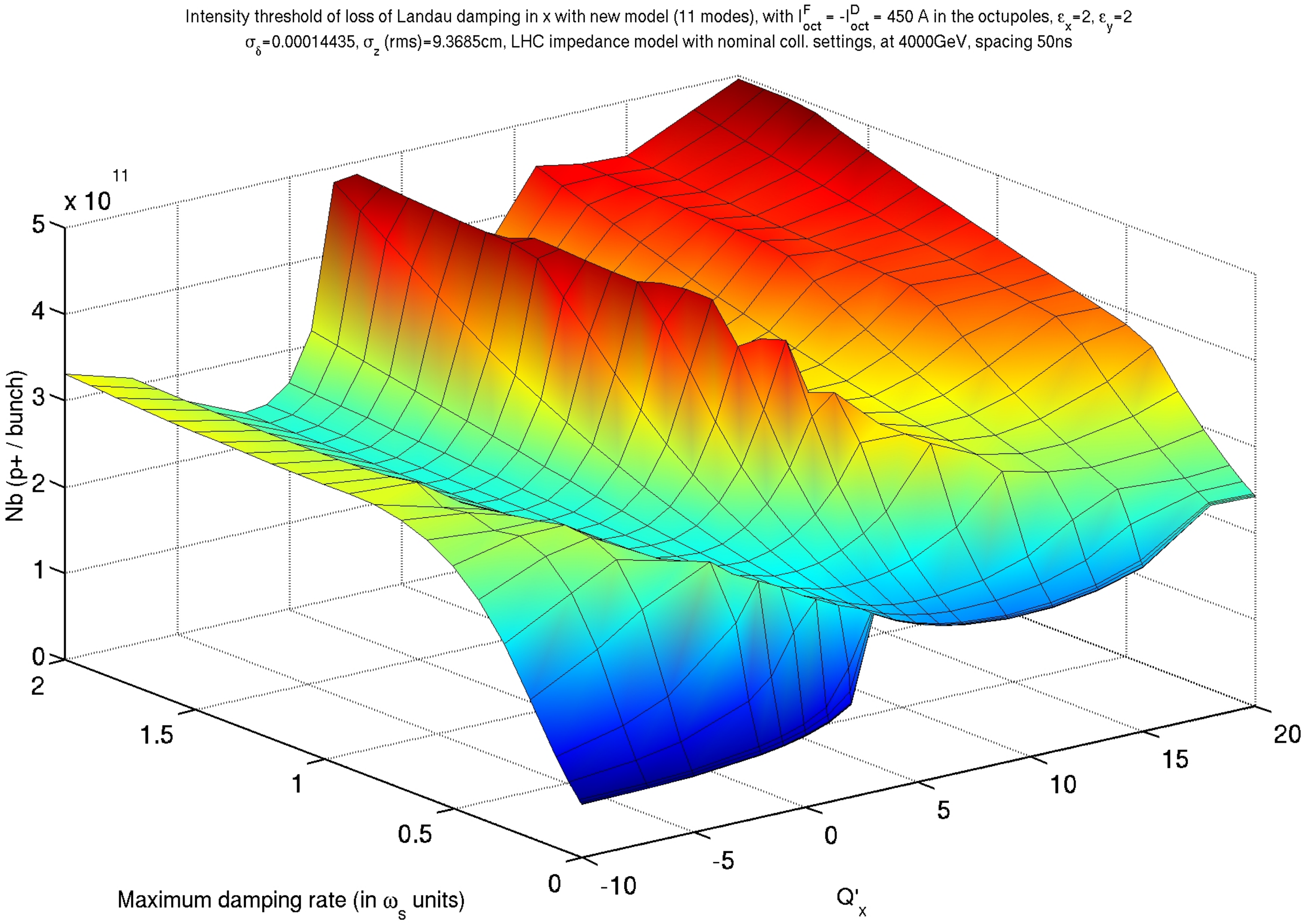




→ Indeed damper damps mode -1 (initially most unstable), as in theory.
→ "Diagonal" azimuthal mode (m=-2,q=0) and most probably radial mode (m=0, q=1) get unstable.
In theory (1782 bunches), diagonal mode m=-2 most unstable (rise time ~1.6 s). No radial modes yet in theory, but see later A. Burov slides.

Stability region – without damping rate frequency dependence

- Threshold of instability in terms of bunch intensity for a given octupole current (450A):



Stability region – without damping rate frequency dependence

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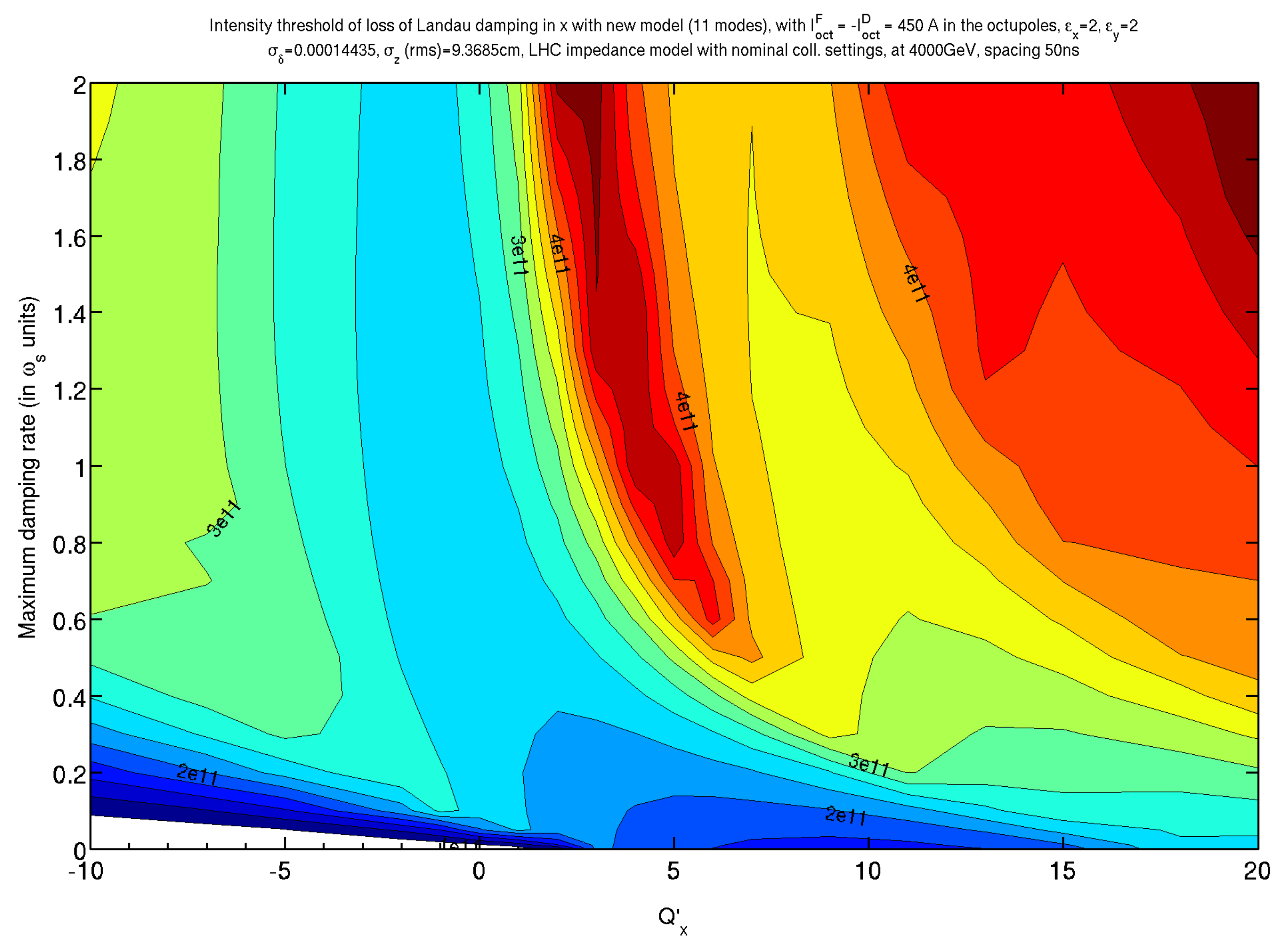

Stability region – with damping rate frequency dependence

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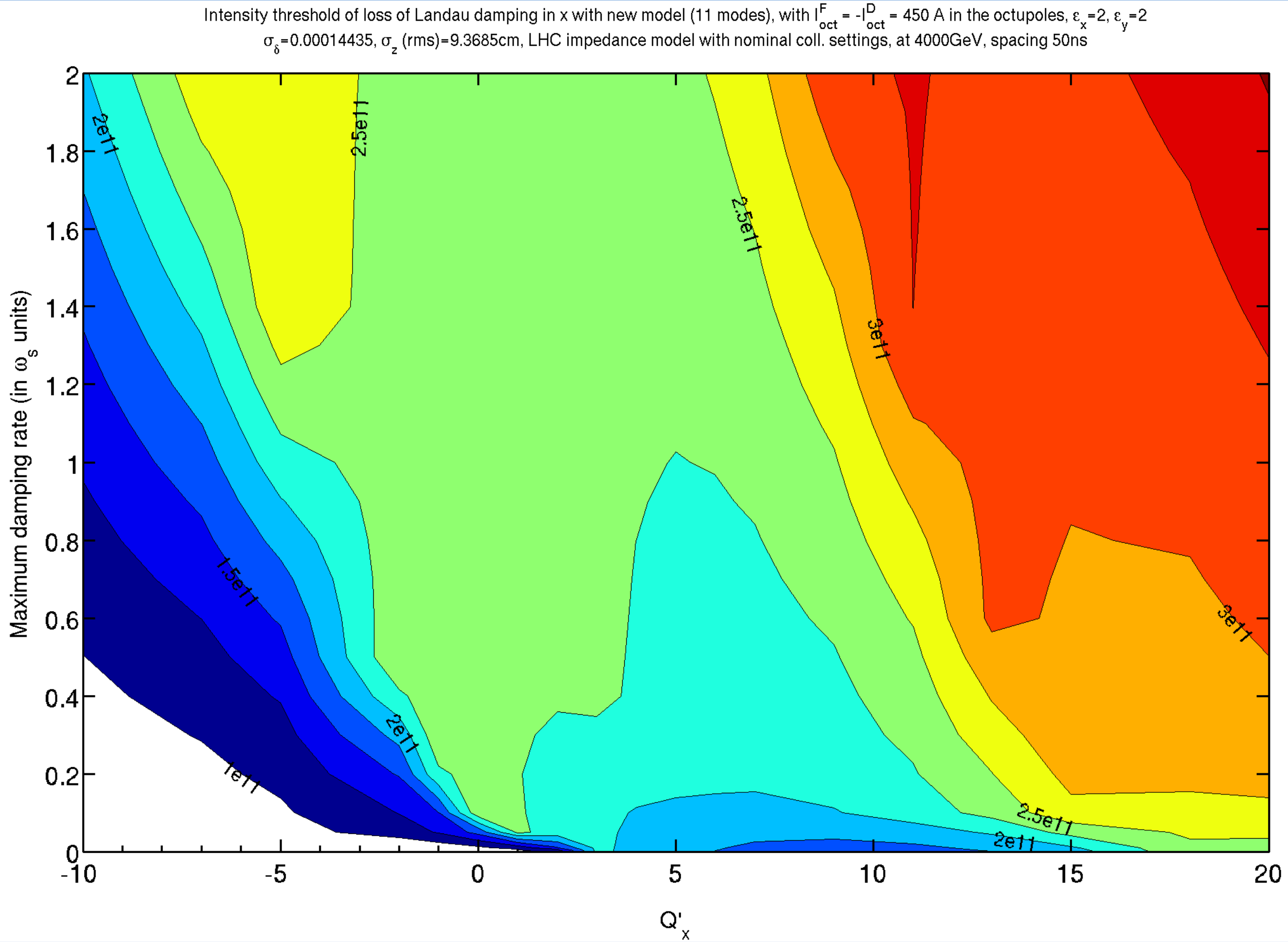
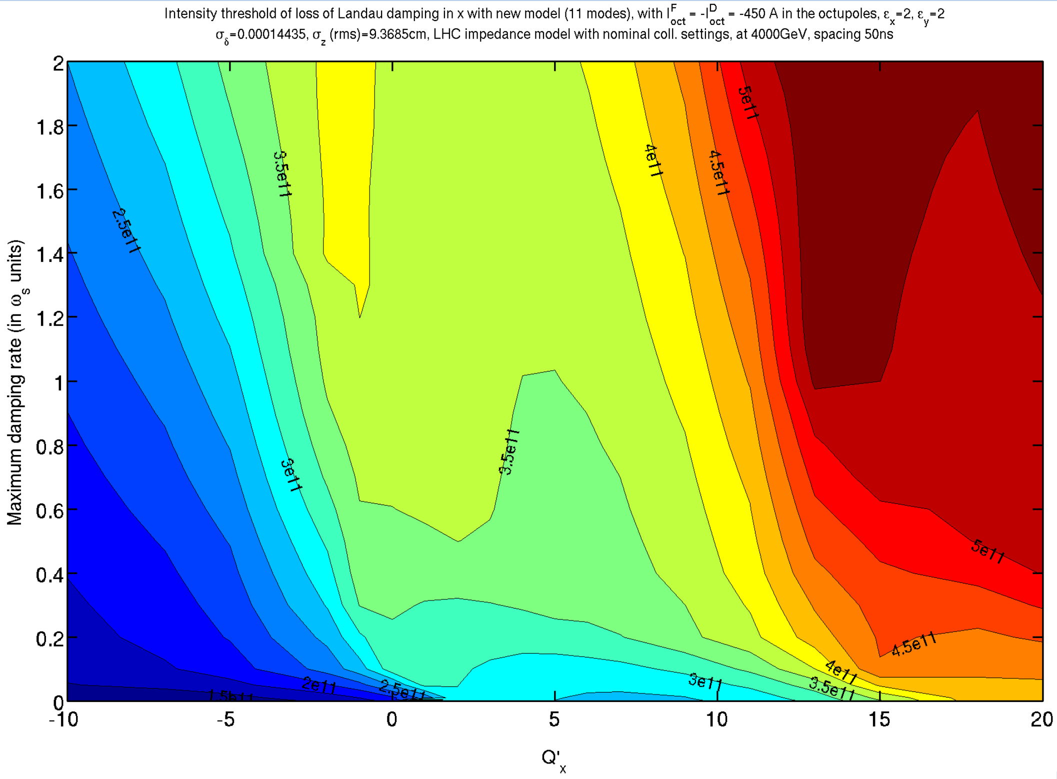


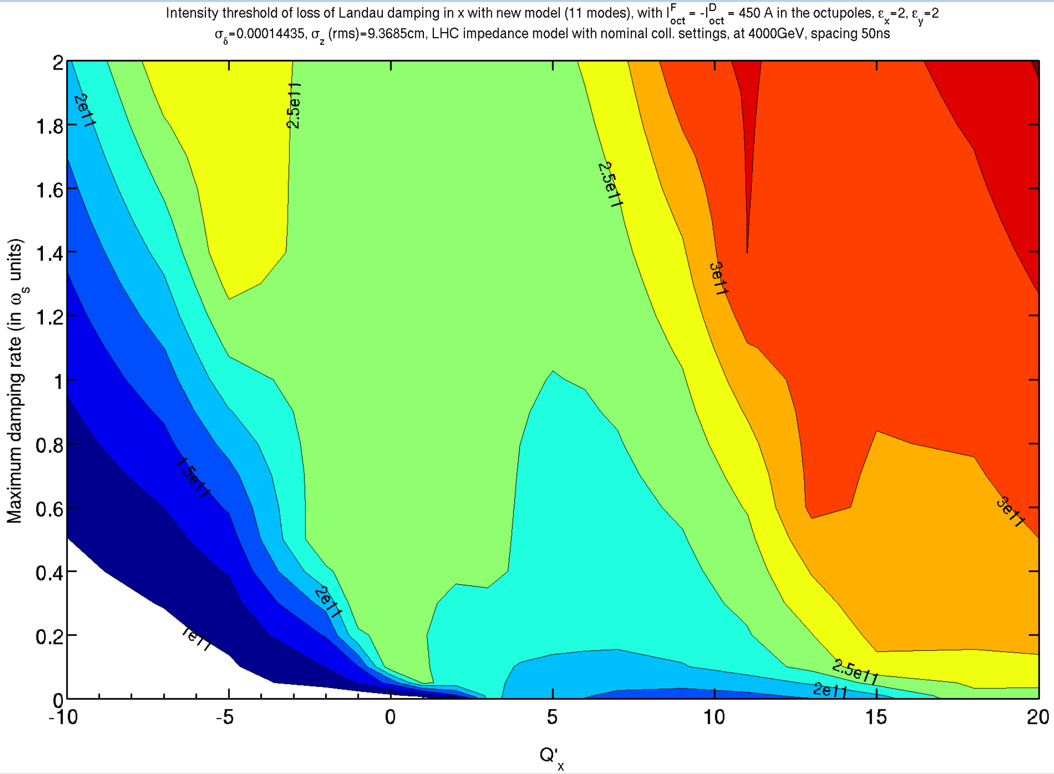
Intensity threshold of loss of Landau damping in x with new model (11 modes), with $I^F_{oct} = -I^D_{oct} = 450$ A in the octupoles, $\varepsilon_x=2$, $\varepsilon_y=2$ $\sigma_\delta=0.00014435$, σ_z (rms)=9.3685cm, LHC impedance model with nominal coll. settings, at 4000GeV, spacing 50ns

→ Picture quite different from previous one.
→ Best stability for high chromaticity and high gain.

Stability region – with damping rate frequency dependence

- Comparing negative (old) and positive (new) octupole current:

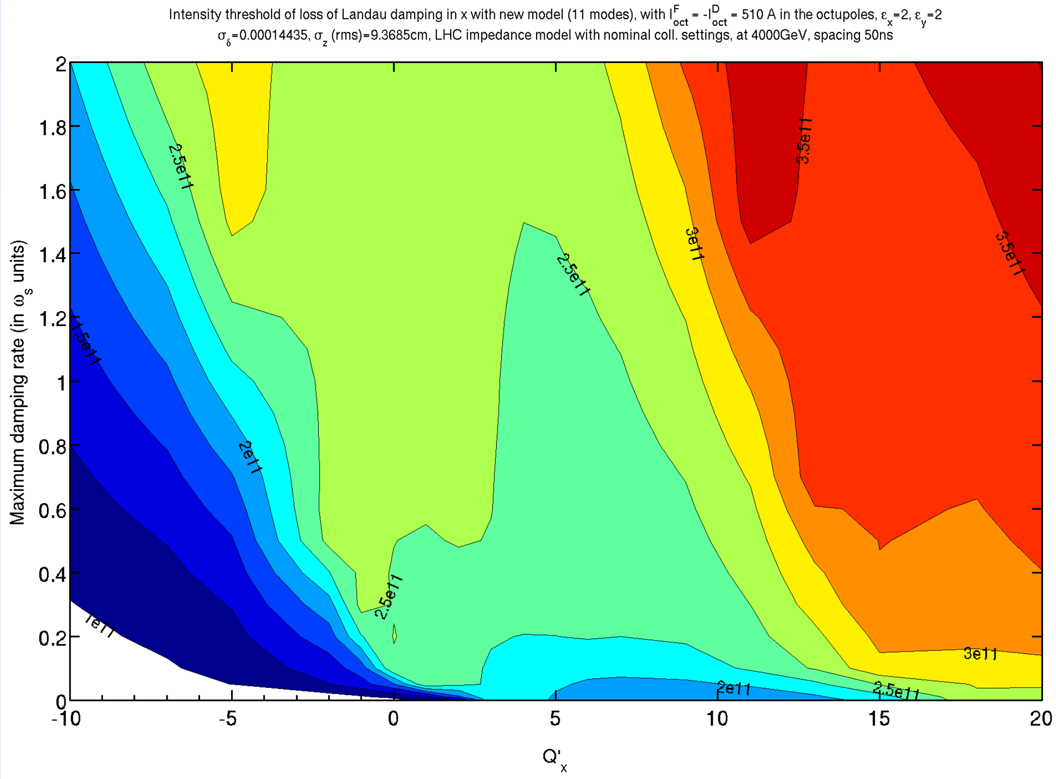




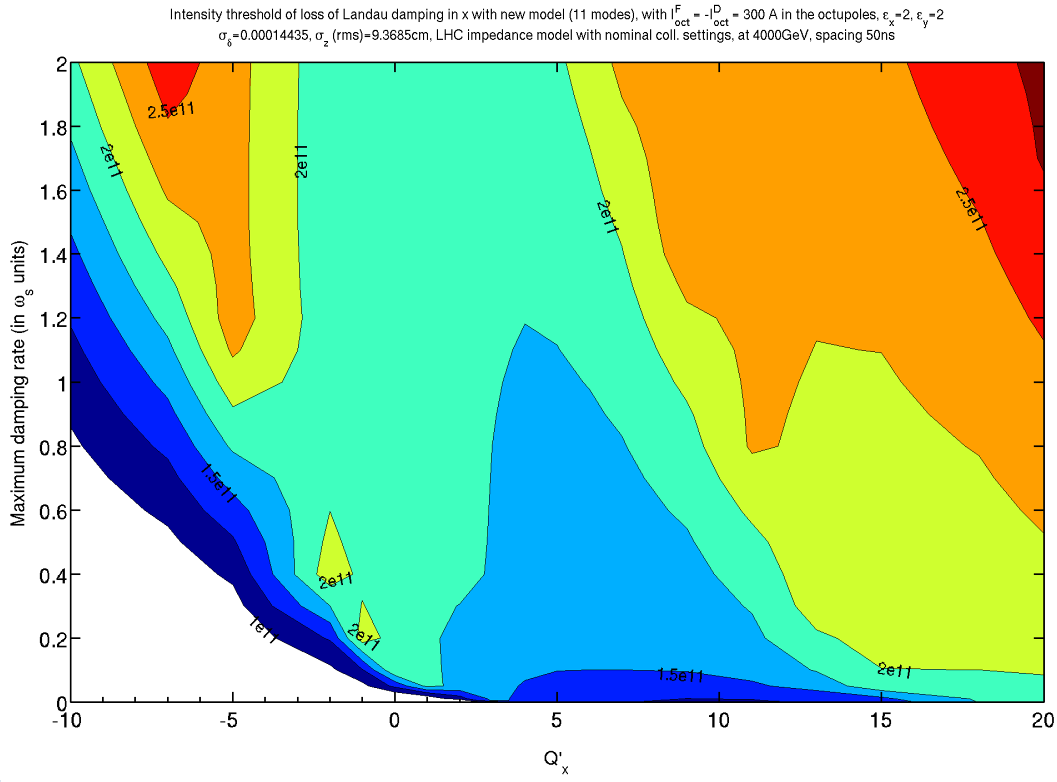
→ Same best region of stability (high chroma – high damper gain) for both signs.
→ Almost twice less stable with positive sign (reminder: this is single beam stability).

Stability region – with damping rate frequency dependence

- Comparing several octupole currents (with positive i.e. new sign):



510 A



300 A

→ Same best region of stability (high chroma – high damper gain) for all currents.

Summary of preliminary results

- New impedance – damper theory available, includes effects of bunch-by-bunch damper and mode coupling.
- Still under development and guidelines given can evolve !
- Some very preliminary results:
  - Damper is able to damp high order headtail modes.
  - High damping rate always helps at positive chromaticity.
  - High chromaticity (Q'>10) seems to help.
  - Frequency dependence of damping rate has strong impact

→could study possibility to make the damping rate ”flatter” ? (See W. Höfle Chamonix's talk – 2012).

- Next steps:
  - Intoduction of radial modes → probably very significant as they are the most unstable in simulations. This might change the picture.
  - Use stability diagrams from beam-beam weak-strong simulations (see. X. Buffat).
  - Introduction of coherent beam-beam modes.