Efficiency of Feedbacks for Suppression of Transverse Instabilities of Bunched Beams

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Which gain and phase have to be set for a bunch-by-bunch transverse damper, and at which chromaticity it is better to stay?

In this talk, only two phenomena are going to be addressed:

—Asymmetry of the coherent tune shift distribution, affected by the damper;

—Even without Landau damping, with resistive damper, there are 2D areas of stability in the gain-chromaticity plane.

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Nested head-tail Vlasov solver

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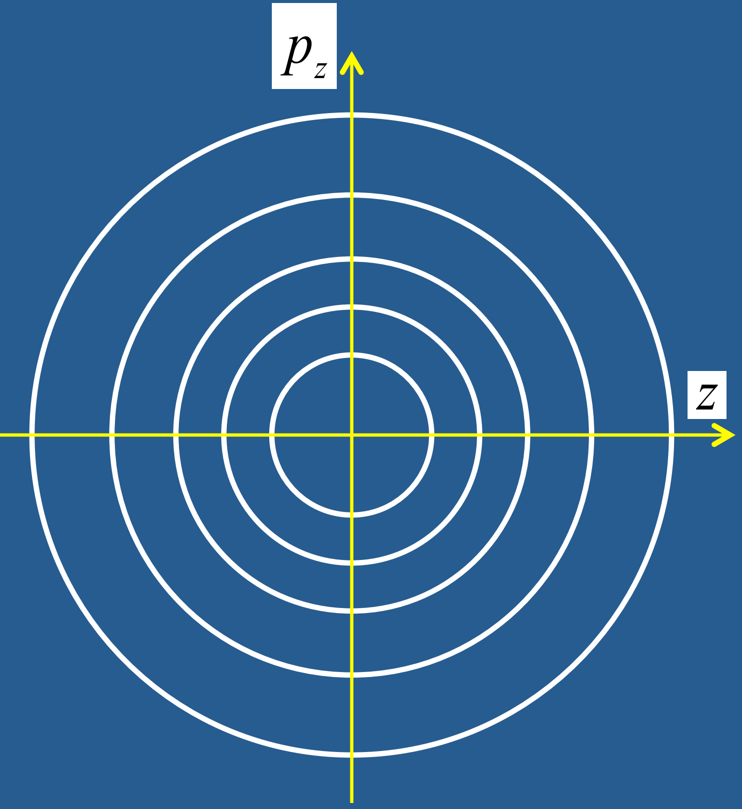
Nested head-tail is a Vlasov solver for transverse oscillations in multibunch beams. It takes into account azimuthal, radial, coupled-bunch, and beam-beam degrees of freedom affected by arbitrary dipole wakes, feedback damper,beam-beam effects and Landau damping.

Nested Head-Tail Basis



Basis functions for transverse oscillations of bunched beams:

$$\psi_{l\alpha} \propto \exp(il\phi + i\chi_\alpha \cos\phi - i\omega_b t)\,;$$

$$\chi_\alpha = \frac{Q'\omega_0 r_\alpha}{c\eta}\ ;$$

$$\text{offset} = \sum X_{l\alpha}\psi_{l\alpha}$$

n_r equally populated rings which radii r_α

are chosen to reflect the phase space density.

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Single Bunch

In the single bunch case, beam equations of motion can be extended from a single air-bag approximation, Ref [A. Chao, Eq. 6.183]:

$$q\mathbf{X} = \hat{\mathbf{S}} \cdot \mathbf{X} - i\hat{\mathbf{Z}} \cdot \mathbf{X} - ig\hat{\mathbf{F}} \cdot \mathbf{X}$$

where $\mathbf{X}$ is a vector of the HT amplitudes $X_{l\alpha}$,

$$\hat{S}_{lm\alpha\beta} = l\delta_{lm}\delta_{\alpha\beta};$$

$$\hat{Z}_{lm\alpha\beta} = i^{l-m}\frac{\kappa}{n_r}\int_{-\infty}^{\infty} d\omega Z(\omega) J_l(\omega\tau_\alpha - \chi_\alpha) J_m(\omega\tau_\beta - \chi_\beta)$$

$$\kappa = \frac{N_b r_0 R_0}{8\pi^2 \gamma Q_x Q_s};$$

$$\hat{F}_{lm\alpha\beta} = \frac{i^{m-l}}{n_r} J_l(\chi_\alpha) J_m(\chi_\beta).$$

Coupled Bunches

In many cases, wake field of preceding bunches can be taken as flat within the bunch length.

The only difference between the bunches is CB mode phase advance, otherwise they are all identical.

$$q\mathbf{X} = \hat{\mathbf{S}}\cdot\mathbf{X} - i\hat{\mathbf{Z}}\cdot\mathbf{X} - ig\hat{\mathbf{F}}\cdot\mathbf{X} + \hat{\mathbf{C}}\cdot\mathbf{X};$$

$$\hat{\mathbf{C}} = 2\pi\kappa\tilde{W}_\mu\hat{\mathbf{F}};$$

$$\tilde{W}_\mu = \sum_{k=1}^{\infty} W(-ks_0)\exp(ik\phi_\mu);$$

$$\phi_\mu = 2\pi(\mu + Q_x)/M; \qquad s_0 = 2\pi R_0/M.$$

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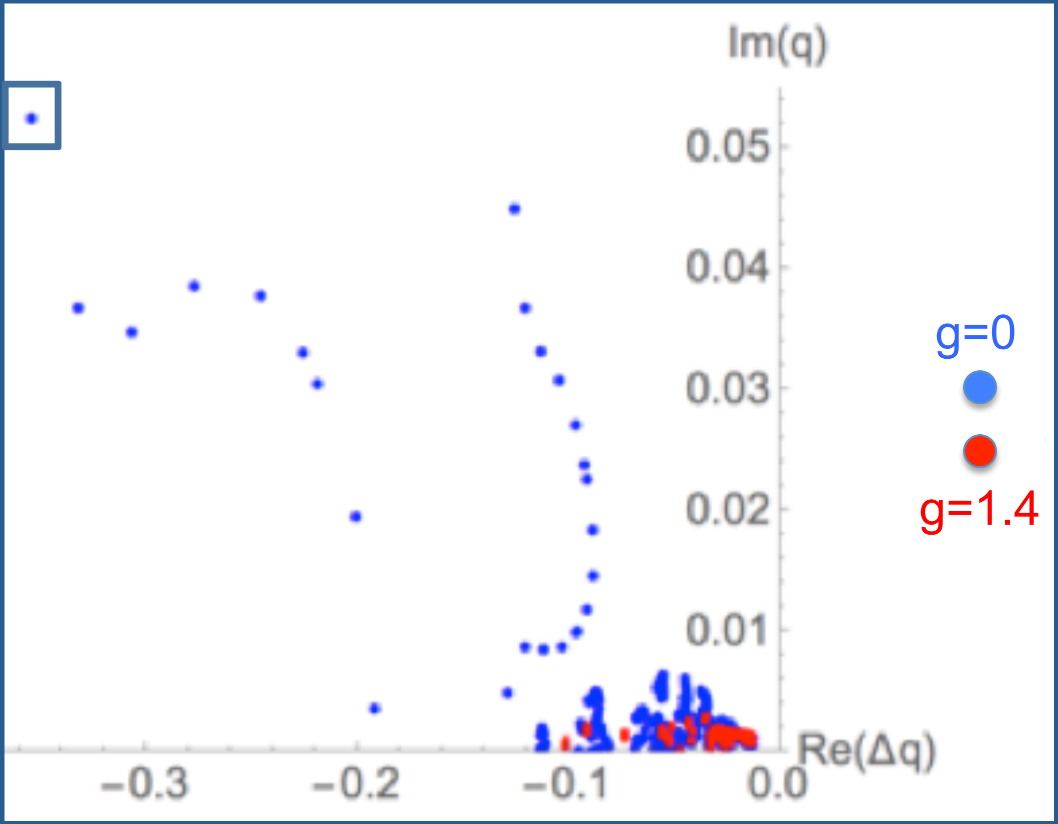
Eigenvalues, LHC example



Tune shifts of unstable modes for the full 25ns LHC beam at chromaticity =18, damper off (off), and with resistive gain 1.4 omega_s (on). For the both cases, there are no unstable modes with positive tune shifts.
17 representative coupled-bunch mode numbers are depicted.

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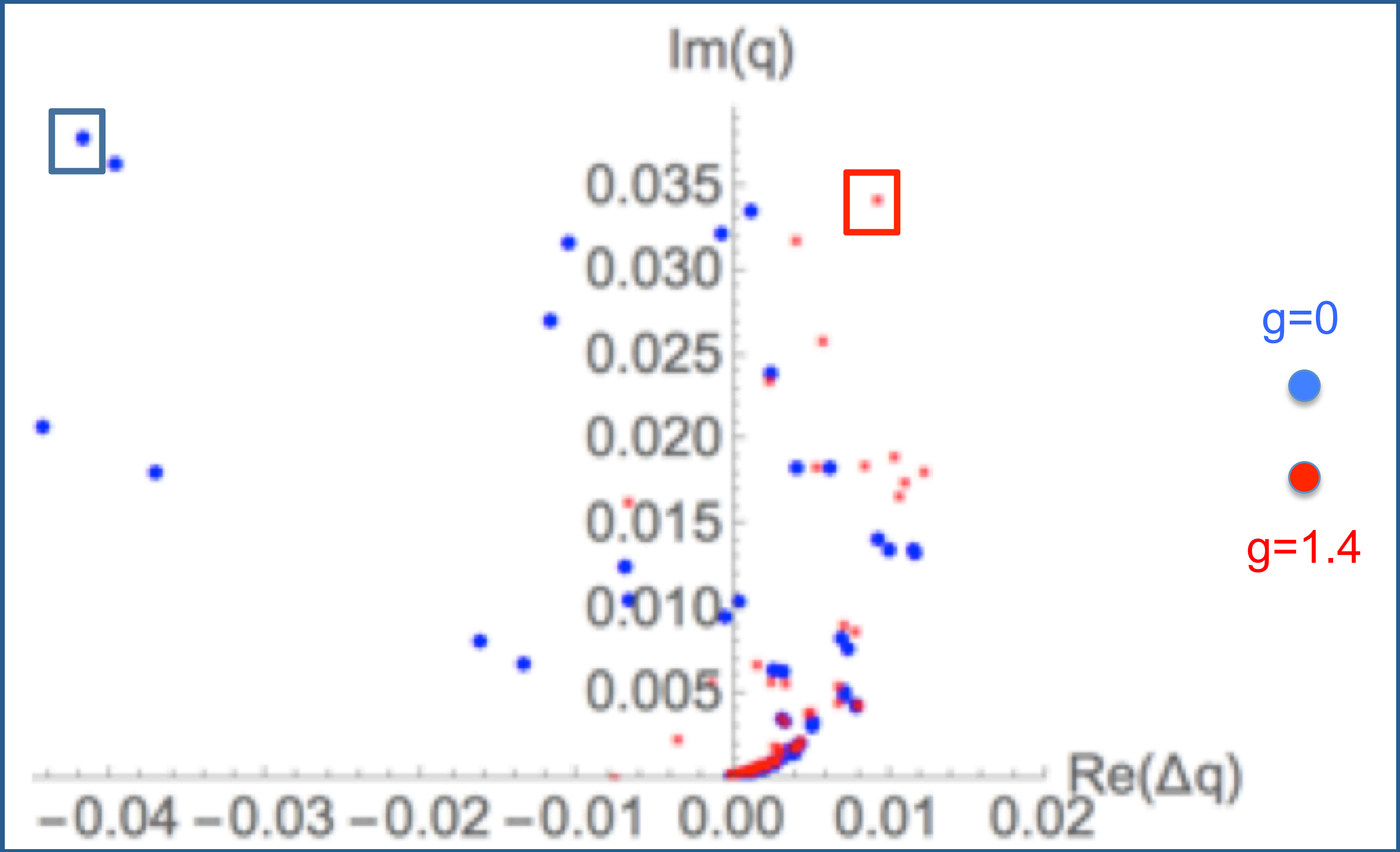
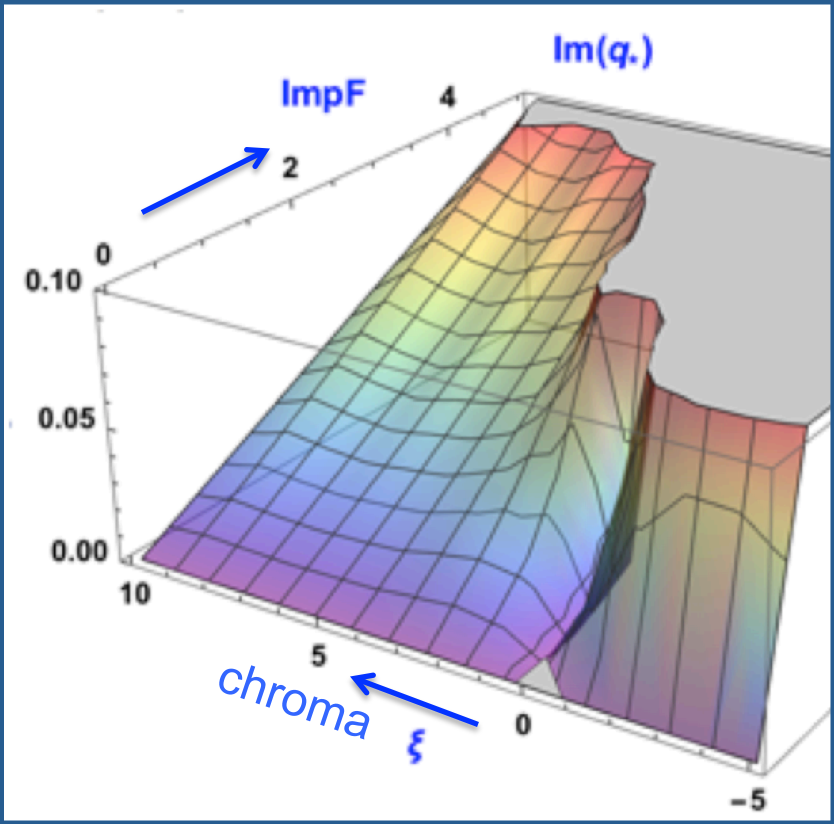
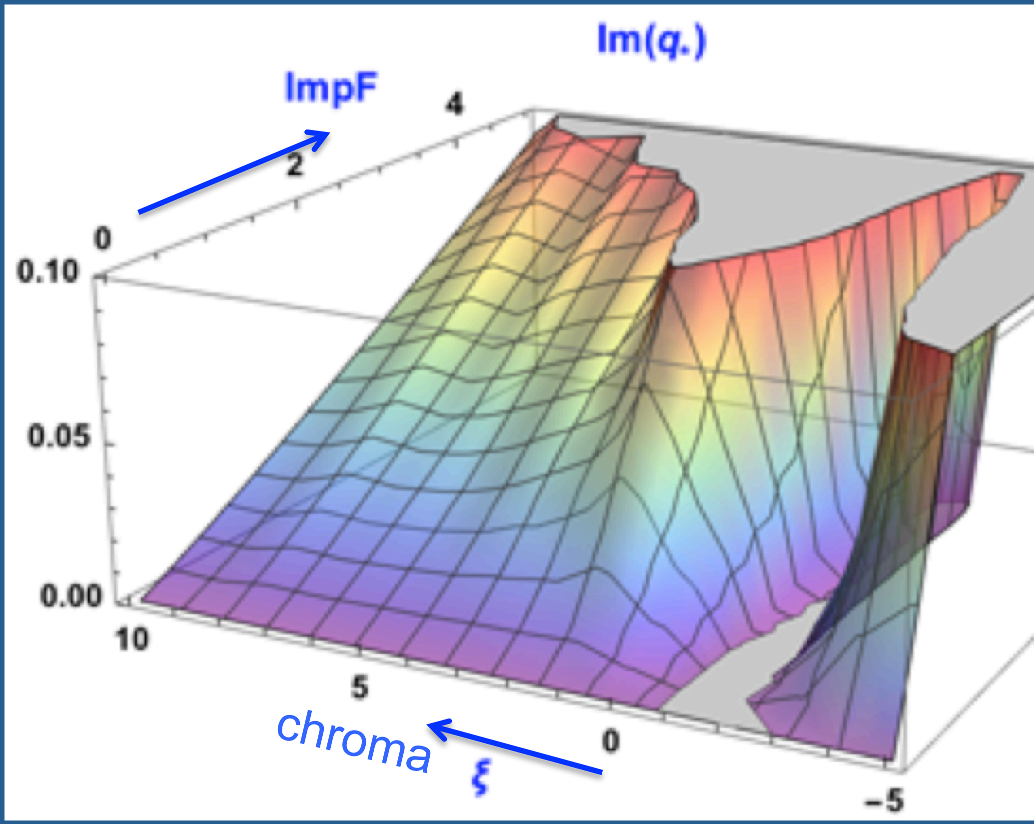
Eigenvalues, APS+BB example



Same for 1 bunch at APS, BB impedance, ImpF=2, chromaticity =10, damper off (g=0), and resistive gain 1.4 omega_s (g=1.4).
Note the asymmetry shift especially important for e-machines.

APS+BB: Bay of Stability





g=0: Threshold ImpF=1.6

Resistive g=1: Threshold ImpF=3.5

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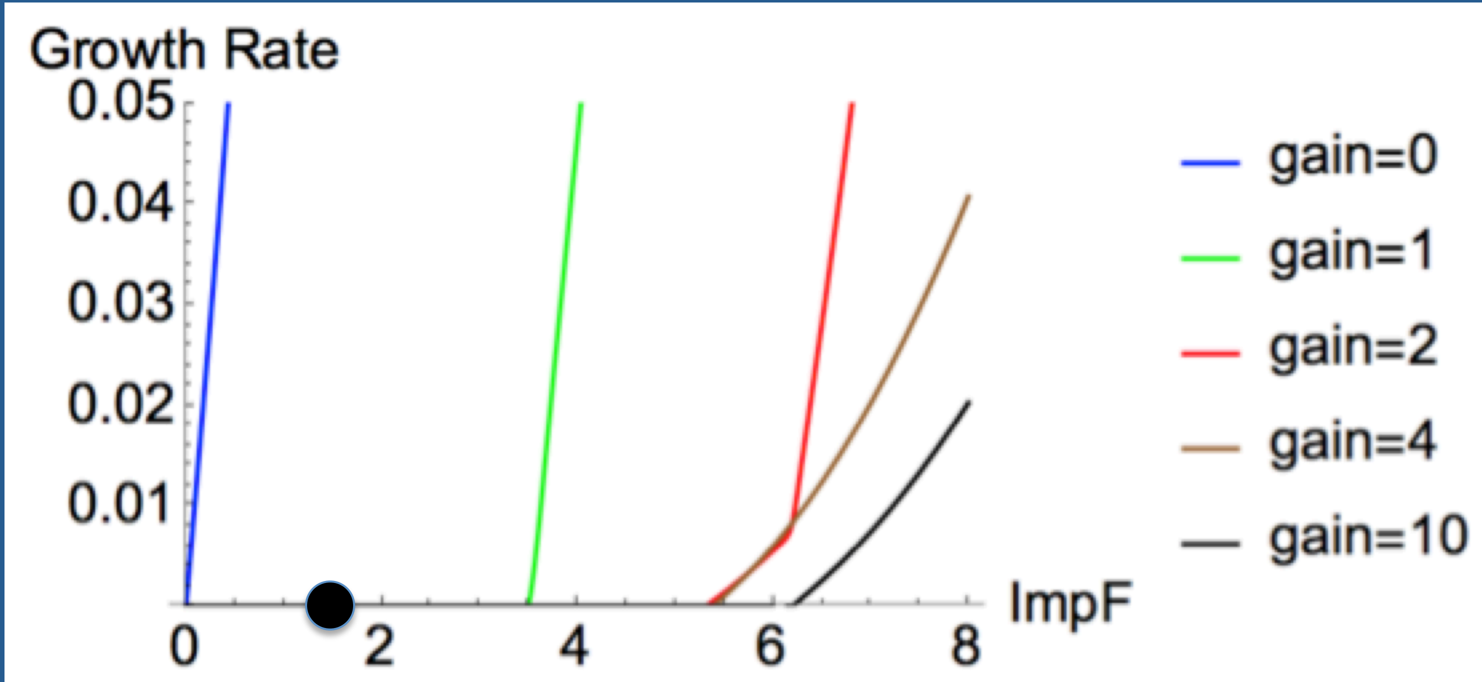
The depth of the bay



The growth rate for $\xi = -1$ vs. intensity for selected resistive gains. At high gains, the threshold saturates approximately at four times higher value than its damper-off value

The black dot is the TMCI threshold (g=0, chroma=0)

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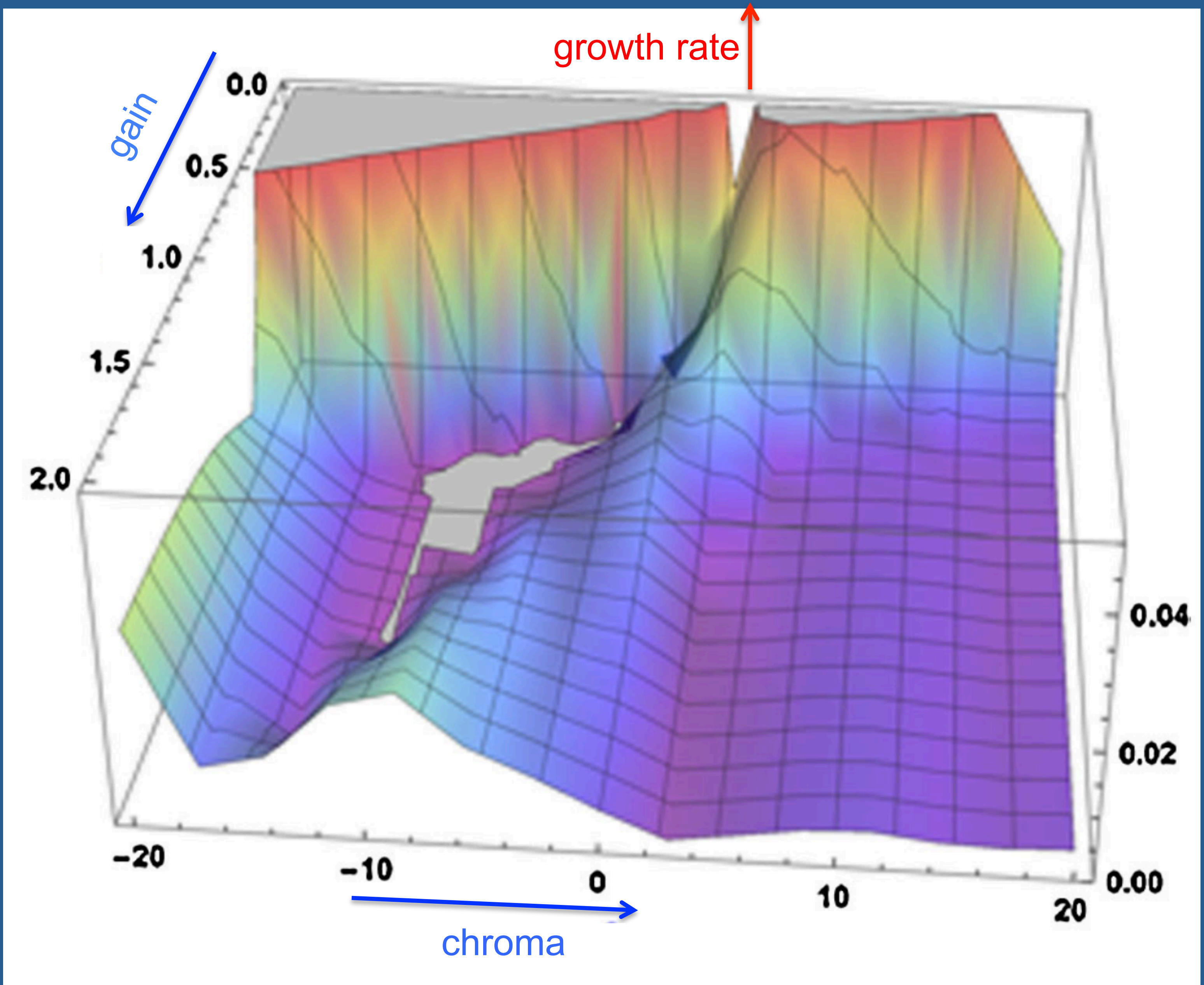
LHC, 25ns, ImpF=1.5. Lake evaporates at ImpF=1.7



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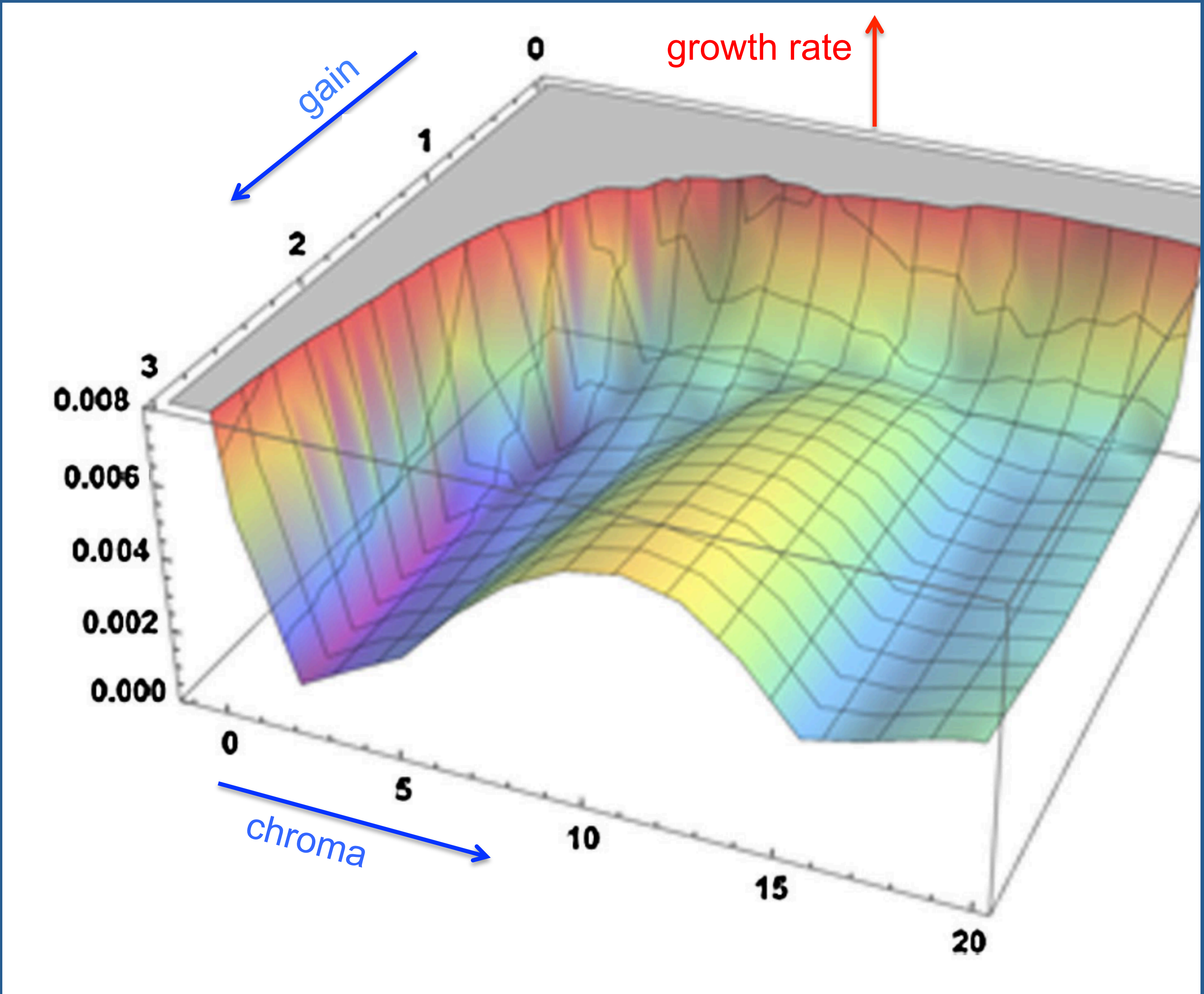
LHC, 25ns, ImpF=2.4. No lakes.



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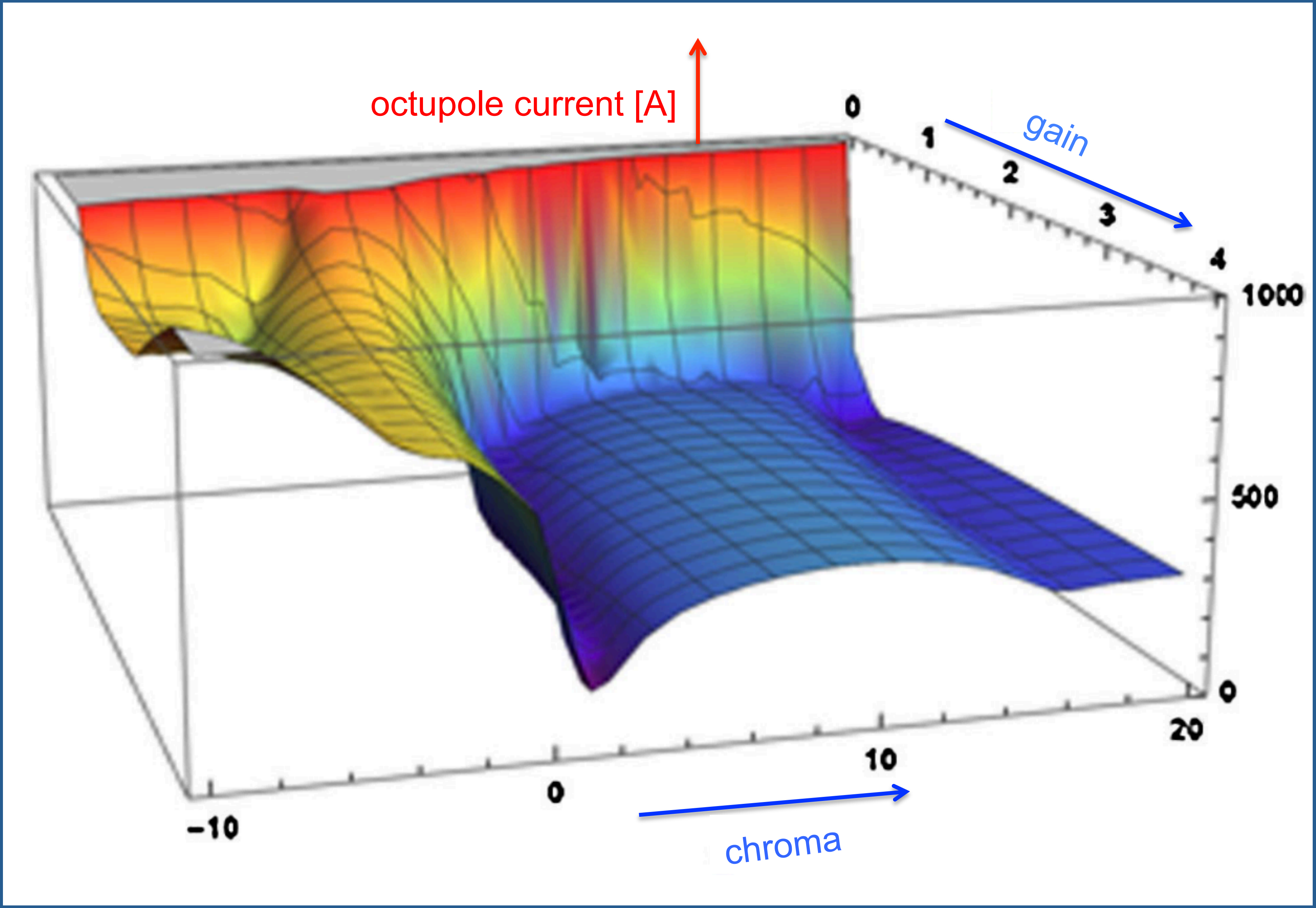
Same for the threshold octupole currents



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Conclusions

NHT Vlasov Solver is a powerful tool for beam stability analysis, allowing to take into account azimuthal, radial, coupled-bunch and beam-beam modes, as well as the LD.

By means of the NHT, the following important features are seen:

— Asymmetry of the coherent tune shifts, which may change when the damper is ON (especially important for e-machines)

— Waterbodies of stability at low ‘wrong sign’ chromaticity (the same is true with SC, see T. Zolkin poster).

Many thanks for your attention!