Destabilising effect of resistive transverse dampers

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- Introduction
- Motivation
- New Vlasov solver: **GALACTIC** (and GALACLIC)
- Instability mechanism with **Q' = 0**
- Impact on Landau damping
- Comparison with PyHEADTAIL macroparticle tracking simulations
- Destabilising effect of Landau damping for TMCI
- Conclusion and outlook

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Many thanks to D. Amorim, S. Antipov, S. Arsenyev, N. Biancacci, X. Buffat, K. Li & A. Oeftiger

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Many thanks also to S. Berg for the very interesting breakfast discussion on Monday and for pointing me to his past work on the subject at EPAC98:
HEAD-TAIL MODE INSTABILITY CAUSED BY FEEDBACK
(http://accelconf.web.cern.ch/AccelConf/e98/PAPERS/THP10C.PDF)

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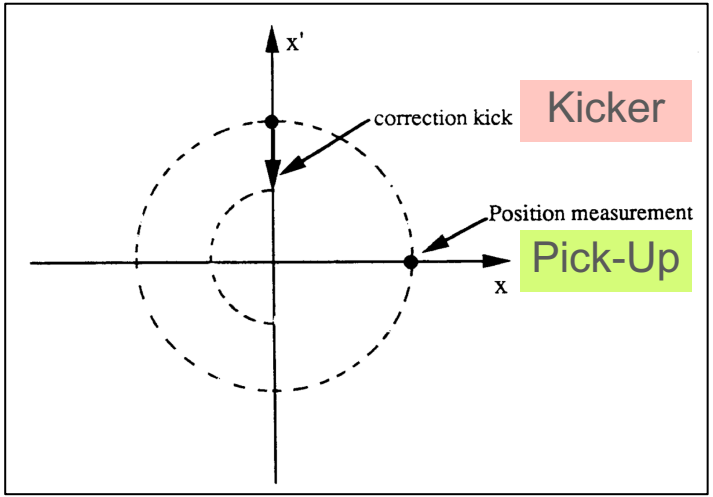

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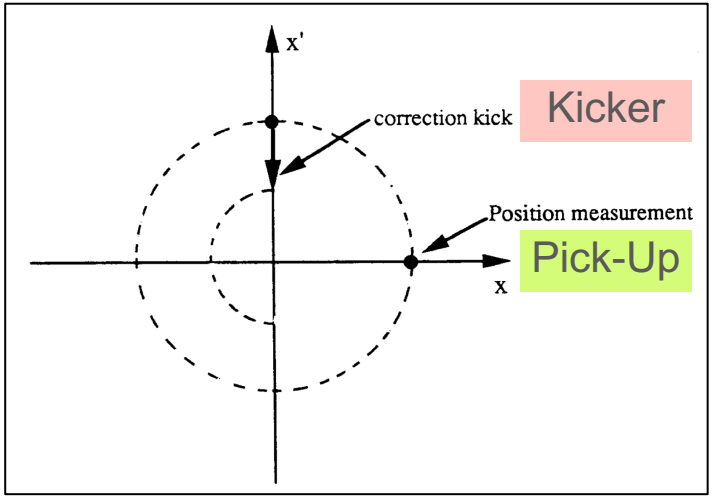

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- If $\boldsymbol{\phi = 0°}$ => **TD** is called "**reactive**": in this case, mode 0 is shifted (which can raise the intensity threshold in the presence of TMCI between modes 0 and -1)

Introduction

- A resistive **TD** is needed for multi-bunch operation in a machine like LHC, and it is very efficient!

See talk from D. Valuch
“The LHC transverse damper: a multi-purpose system”

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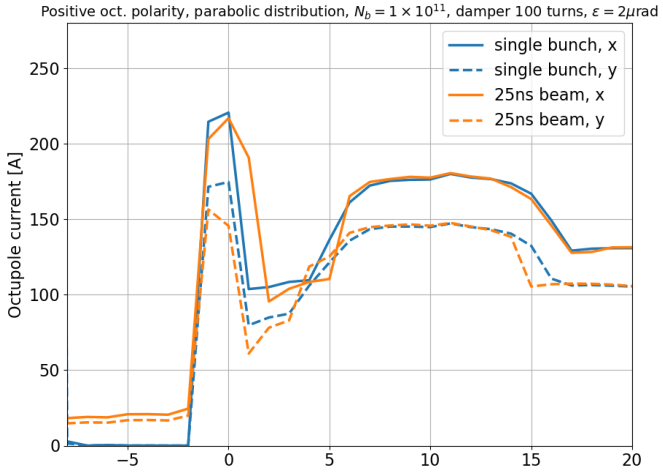

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N. Mounet et al. (DELPHI Vlasov Solver, 2014)

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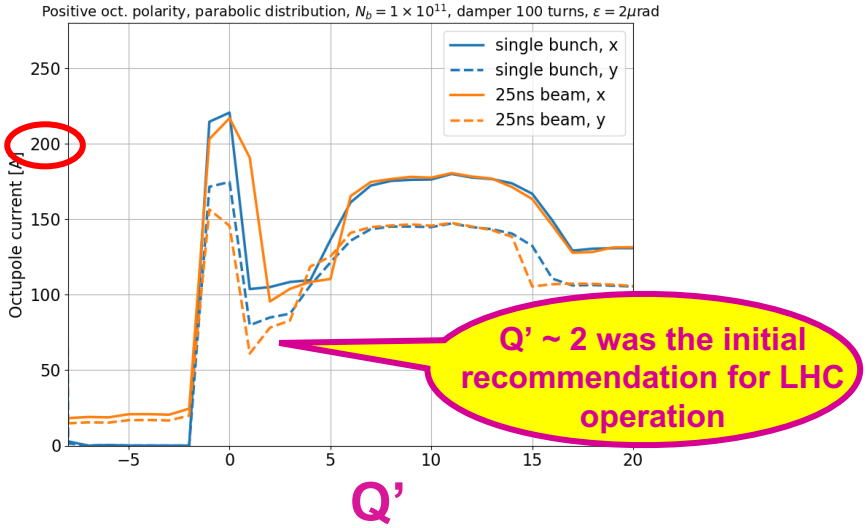

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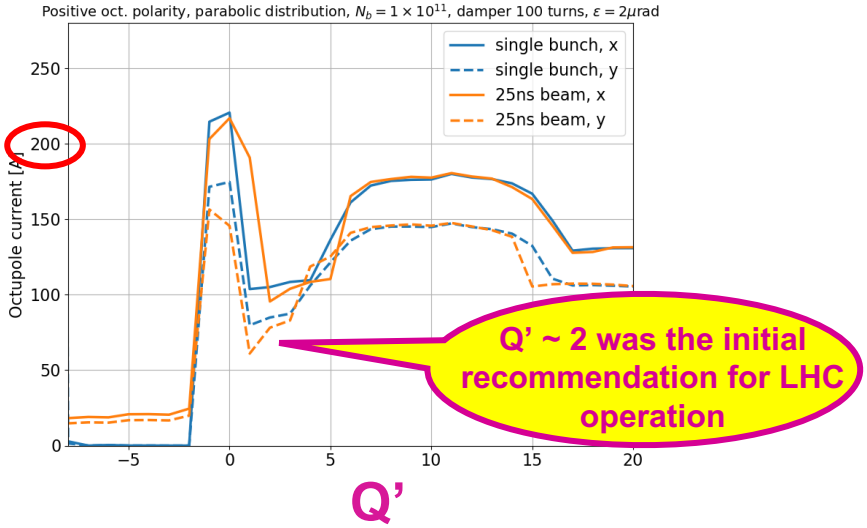

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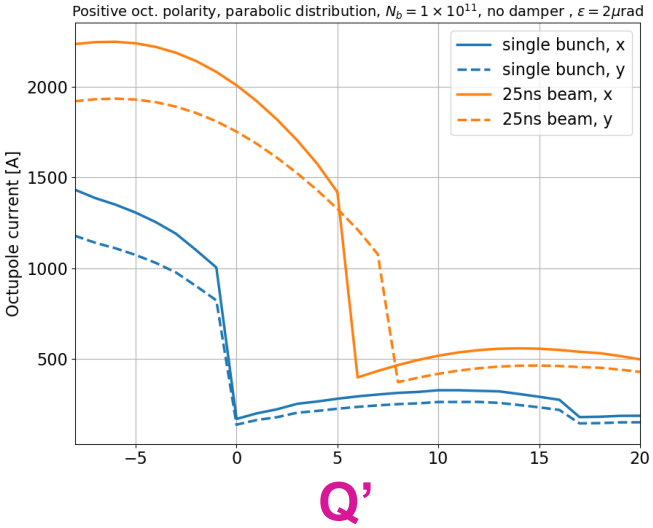

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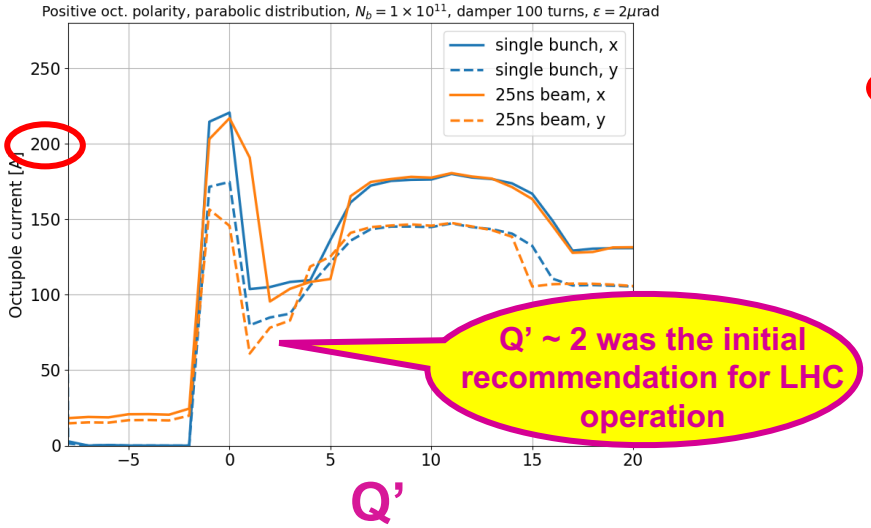

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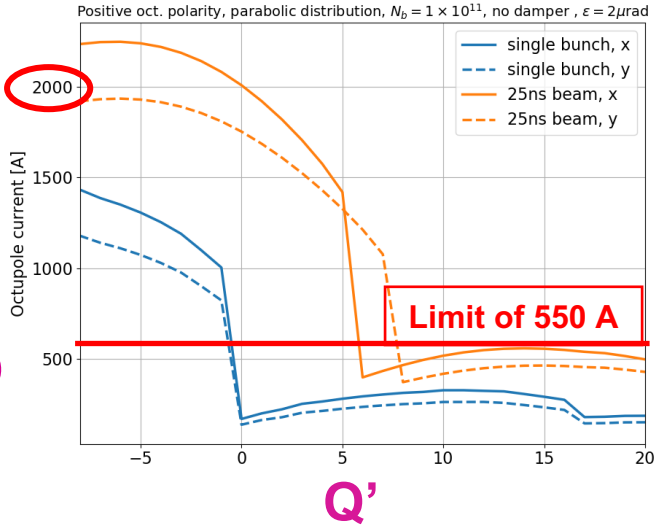

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  - **Q'**: ~ + 15
  - **TD**: ~ 50-100-turn damping time
  - Landau Octupoles (**LO**) current: a factor ~ 2 higher than predicted (compared to factor ~ 5 at the end of Run 1)

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  - **TD** to be included in beam stability analyses (also with Beam-Beam)
  - **LO** (> 0 or < 0) with Beam-Beam effects (both Long-Range and Head-On)
  - Destabilising effect of e-cloud
  - Destabilising effect of linear coupling
  - Destabilising effect of **TD**
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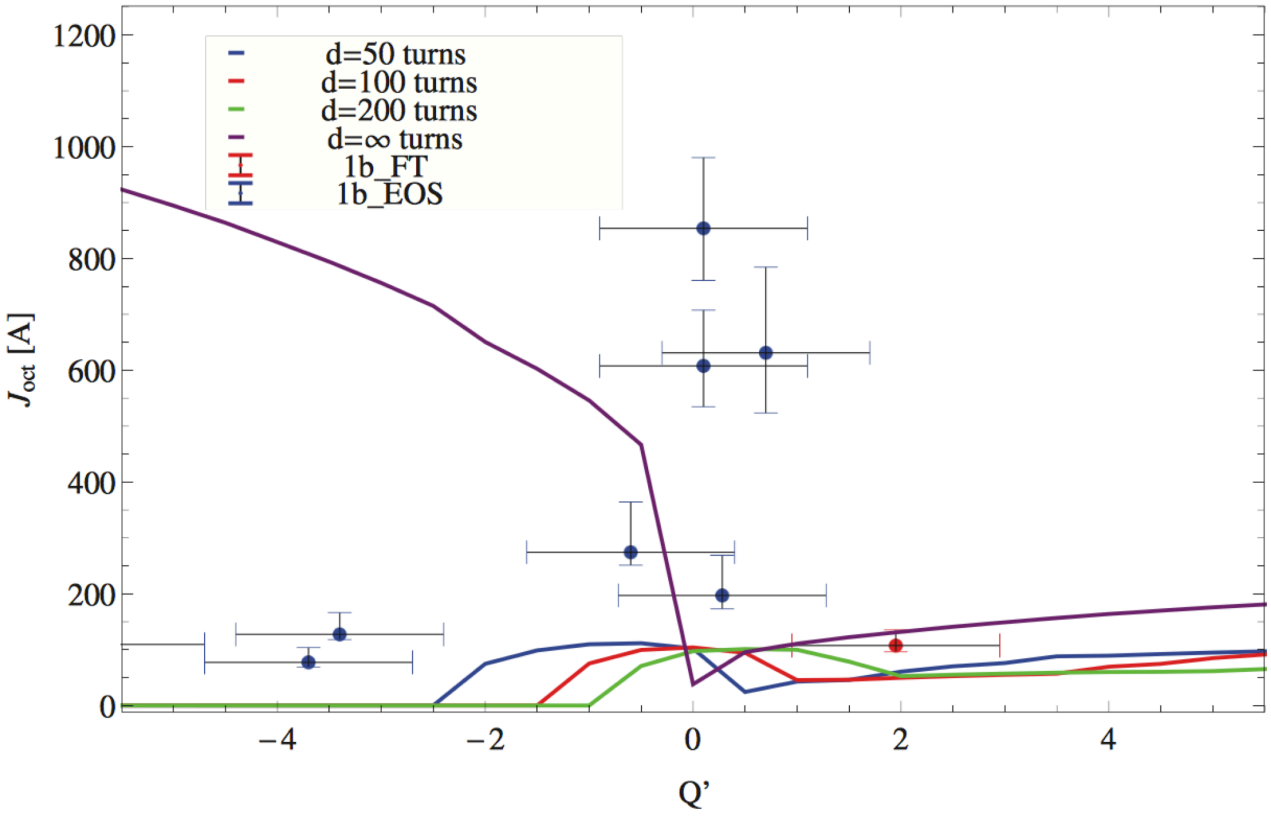
Some observation in past studies such as KarlinerPopov2005 => Referred to as "a sort of TMCI", without detailed analysis

Motivation

LHC single-bunch instabilities with Q' ~ 0 (2015)



L.R. Carver et al.

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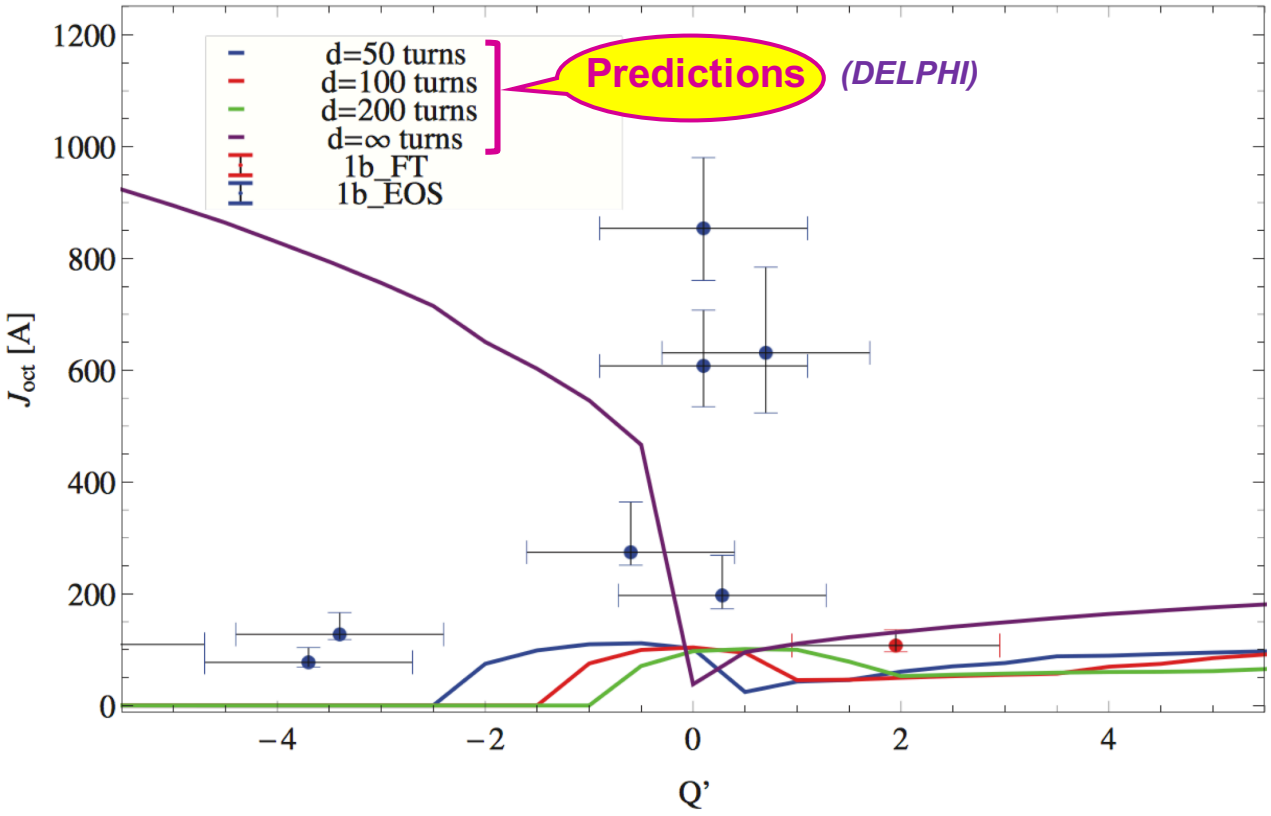

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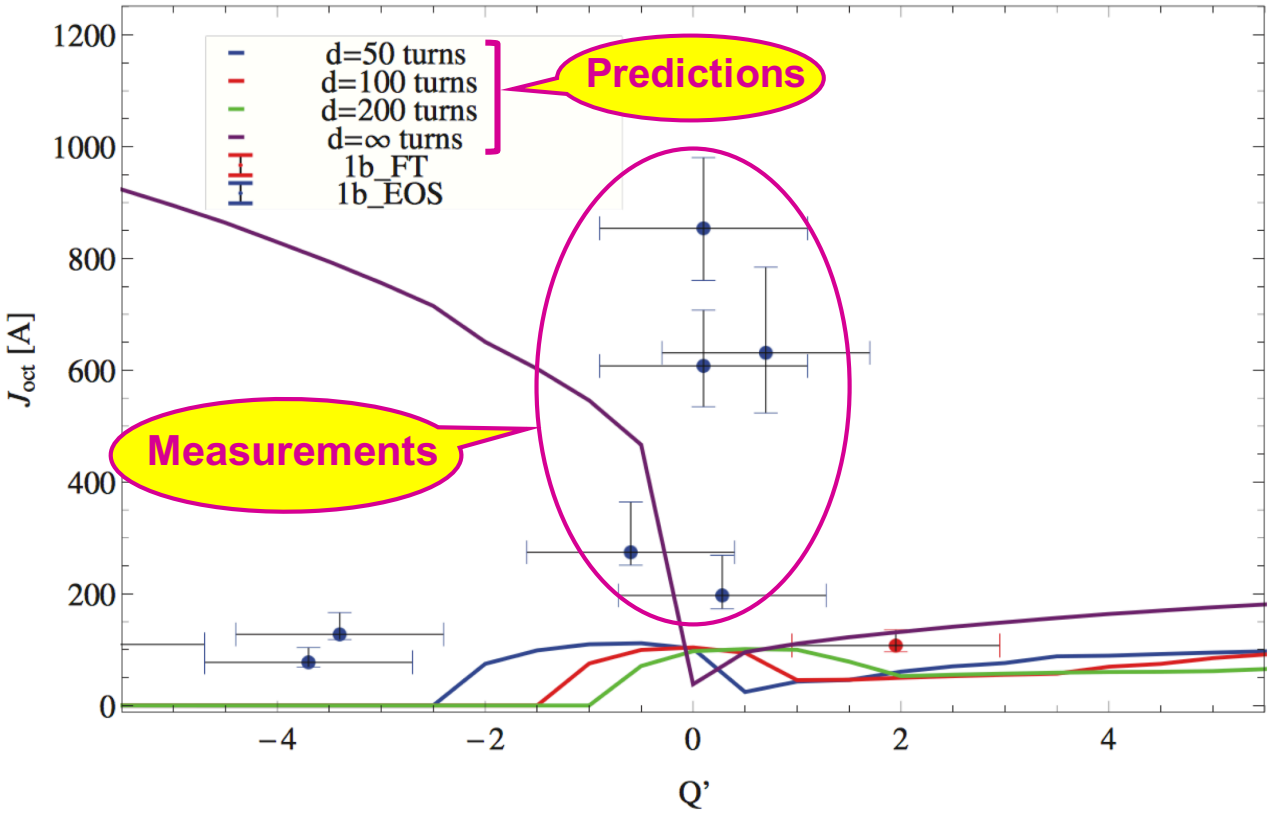

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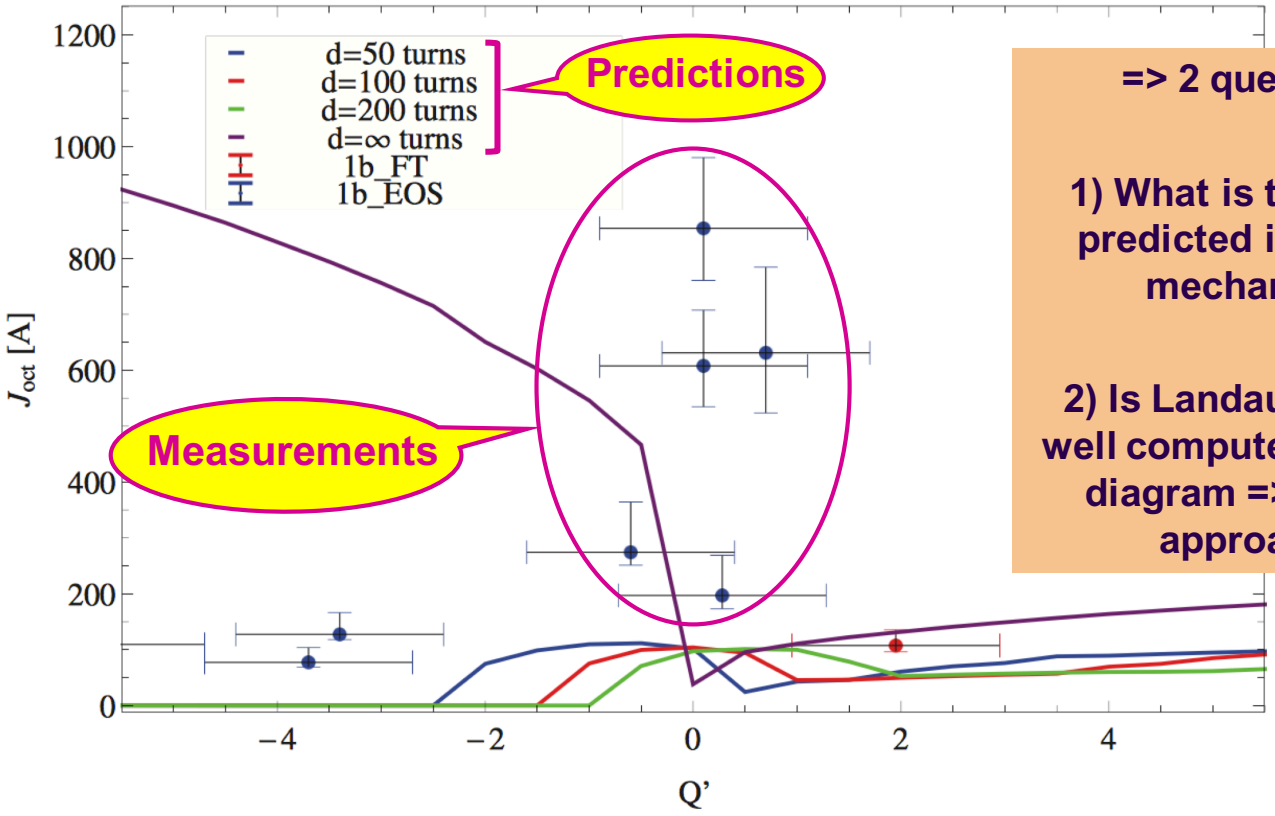

=> 2 questions:

1) What is the (exact) predicted instability mechanism?

2) Is Landau damping well computed (stability diagram => 1-mode approach)?

L.R. Carver et al.

New Vlasov solver: GALACTIC (and GALACLIC)

- GALACTIC = GArnier-LAclare Coherent Transverse Instabilities Code => Helped to shed light on the destabilising effect of resistive transverse dampers such as in the LHC (IPAC18: http://accelconf.web.cern.ch/AccelConf/ipac2018/papers/thpaf048.pdf + CERN-ACC-NOTE-2019-0018: https://cds.cern.ch/record/2674776/files/CERN-ACC-NOTE-2019-0018.pdf)

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- GALACLIC = GArnier-LAclare Coherent Longitudinal Instabilities Code => Helped to understand the details of the mode-coupling behind some longitudinal microwave instabilities (IPAC19: https://ipac2019.vrws.de/papers/mopgw089.pdf)

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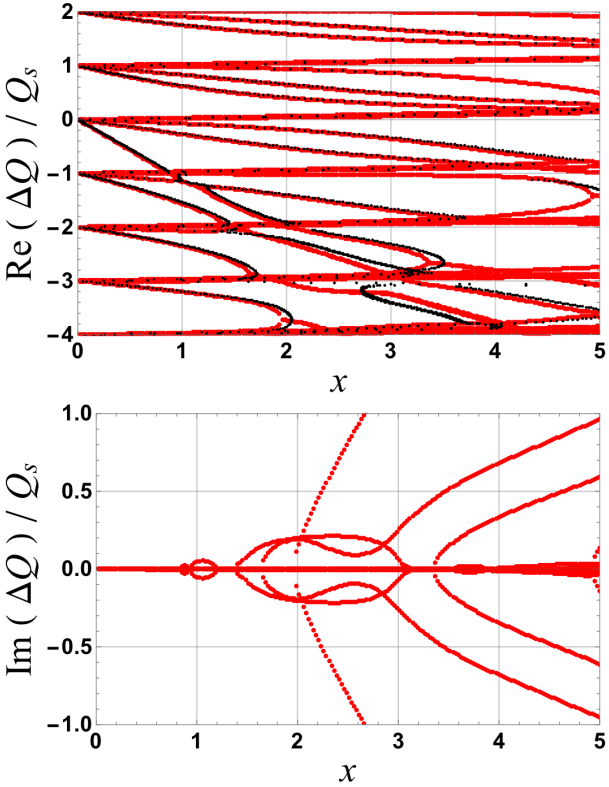
TIC (BB Resonator, $f_r \tau_b = 2.8$)



Results in black are from Laclare (only real parts)

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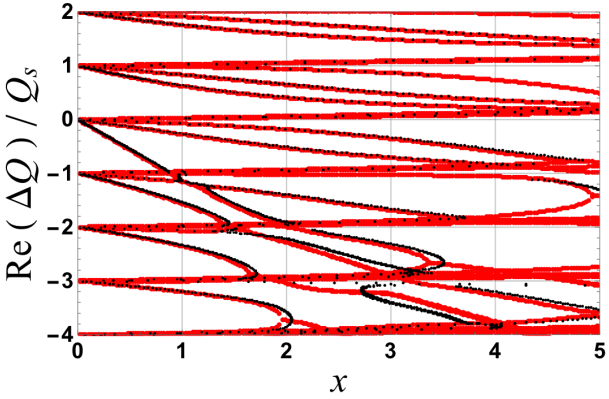

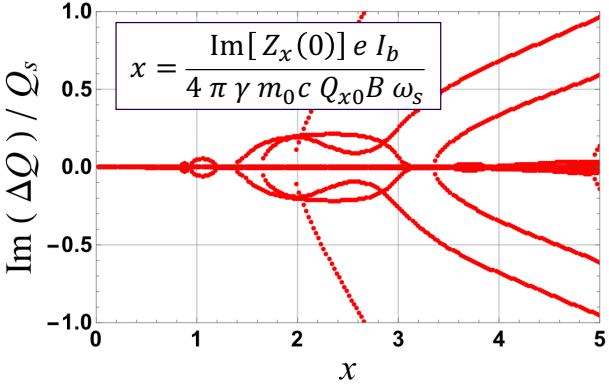

$$x = \frac{\mathrm{Im}[\,Z_x(0)]\; e\; I_b}{4\,\pi\,\gamma\, m_0 c\; Q_{x0} B\; \omega_s}$$

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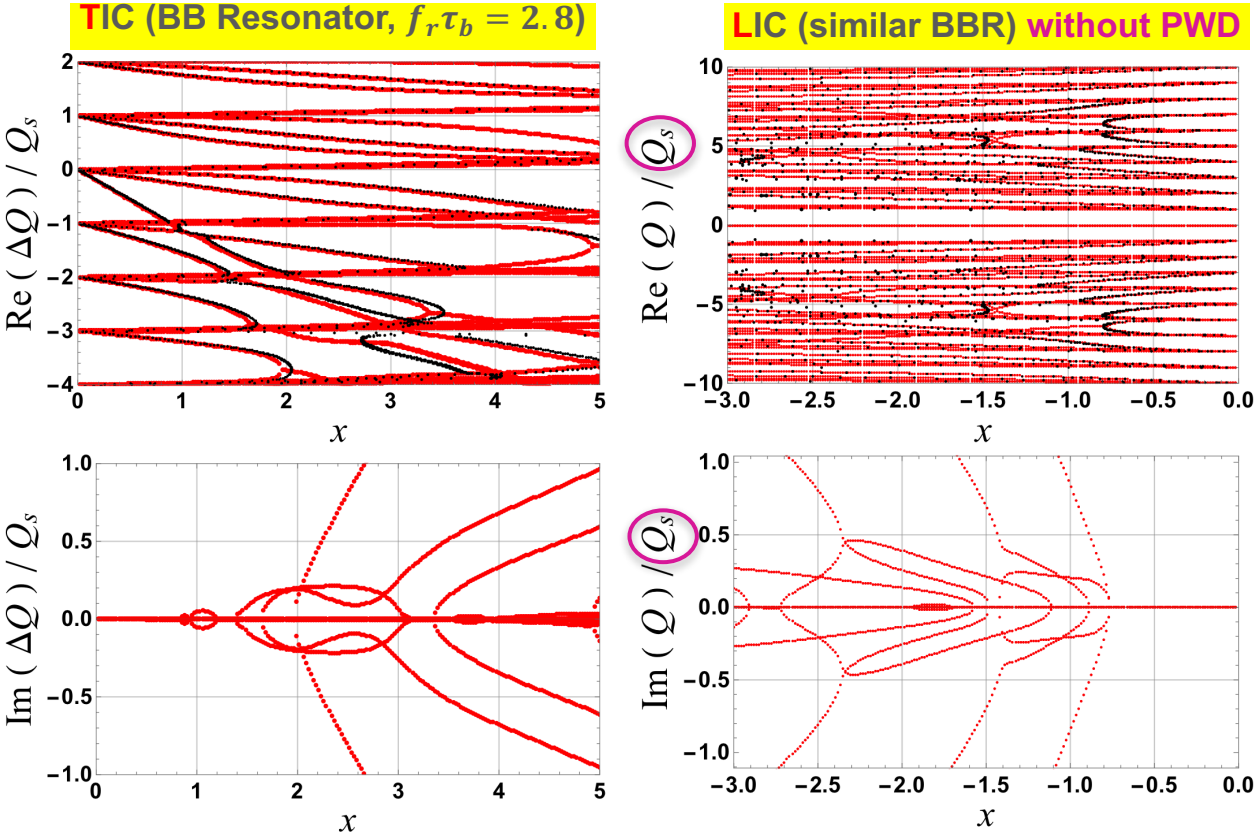

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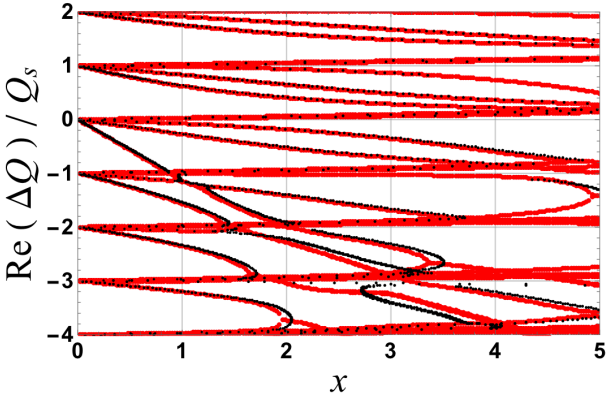
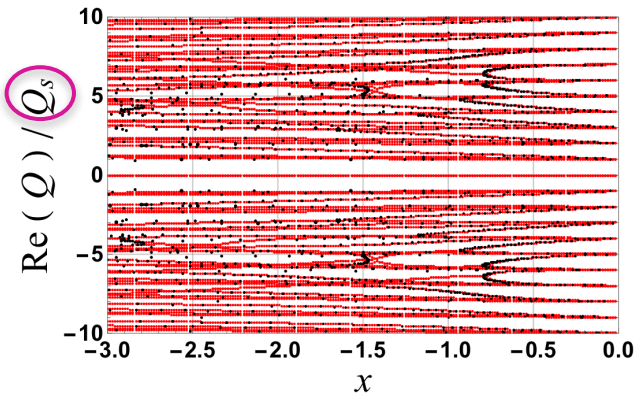
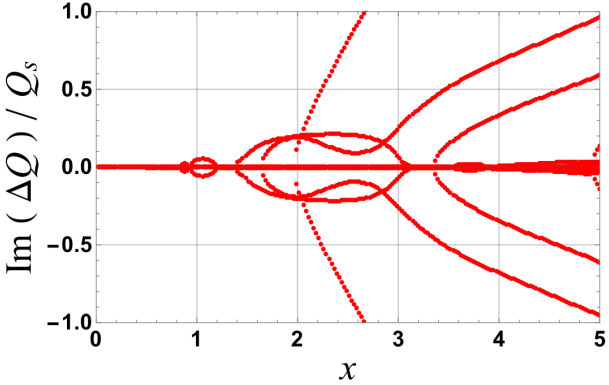
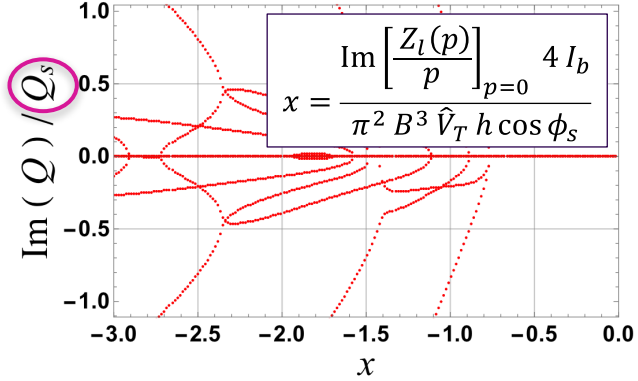


LIC (similar BBR) without PWD







$$x = \frac{\mathrm{Im}\left[\frac{Z_l(p)}{p}\right]_{p=0} 4\, I_b}{\pi^2\, B^3\, \hat{V}_T\, h \cos\phi_s}$$

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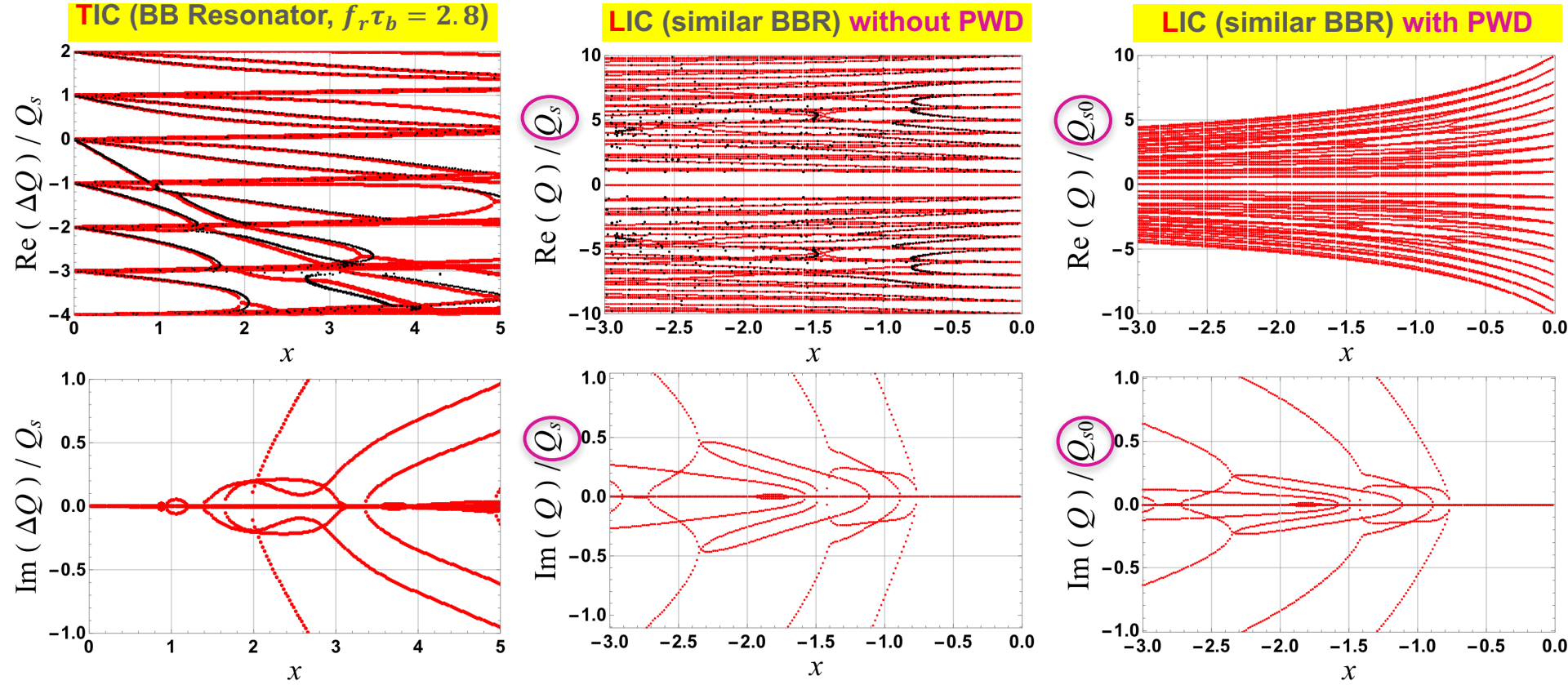

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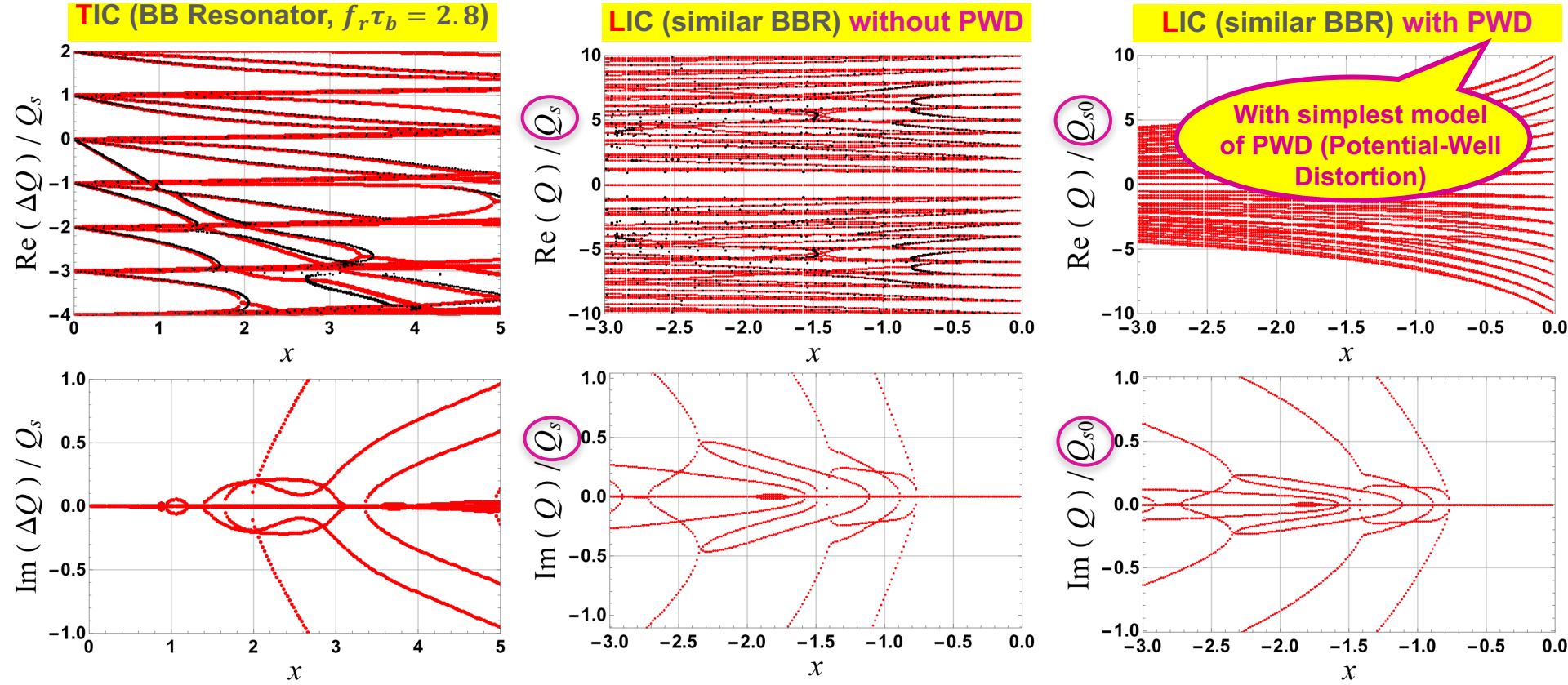

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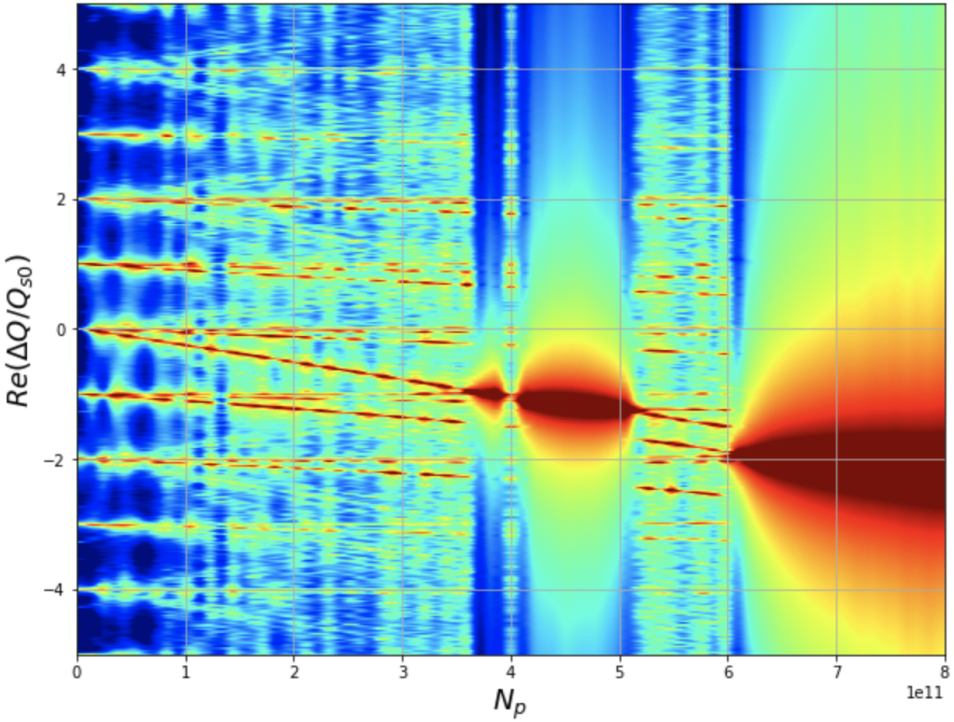
PyHEADTAIL$(f_r\tau_b = 2.7)$



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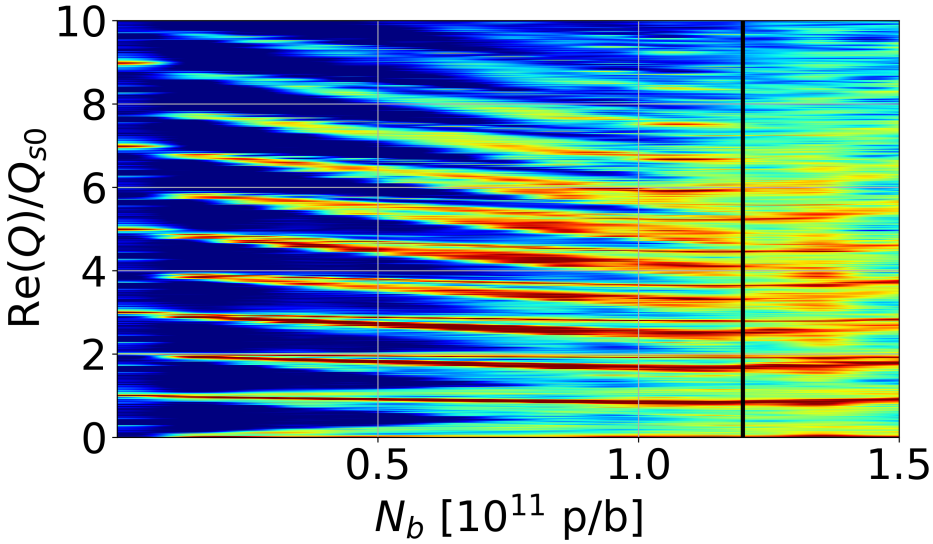

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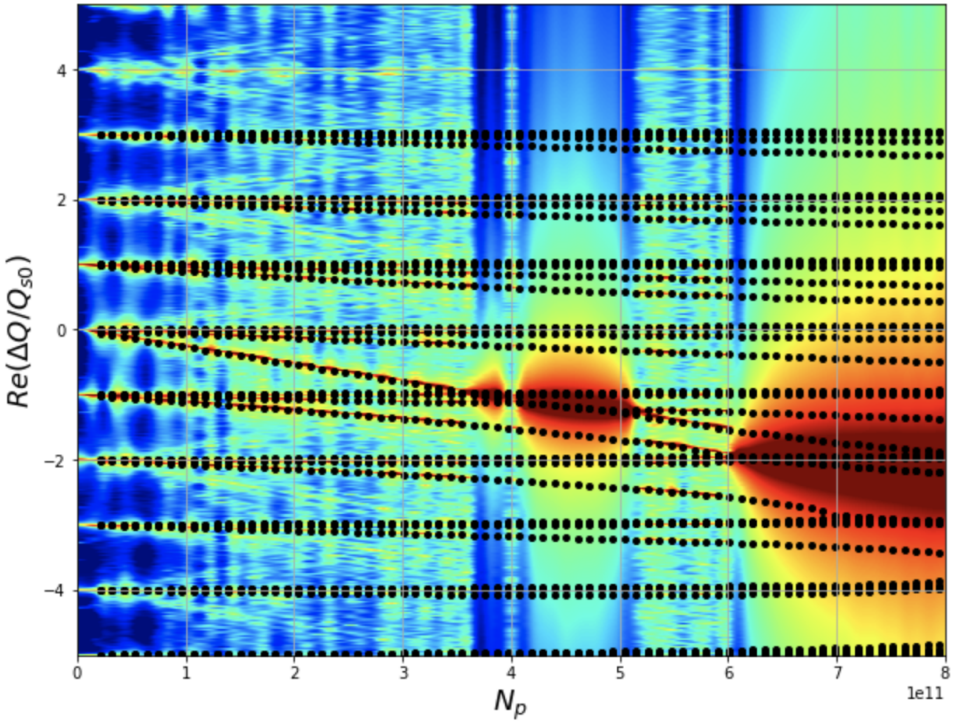

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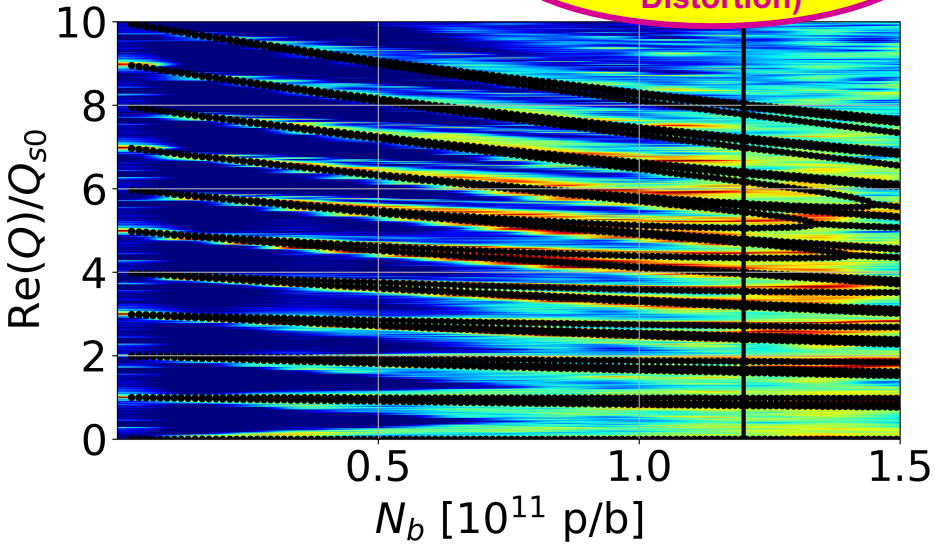
With simplest model of PWD (Potential-Well Distortion)



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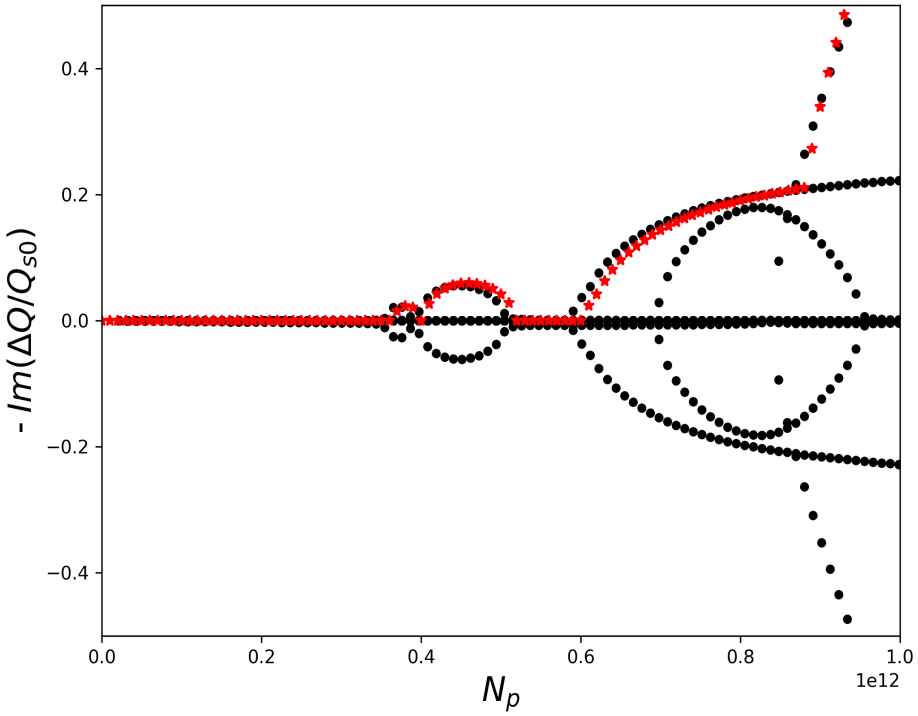

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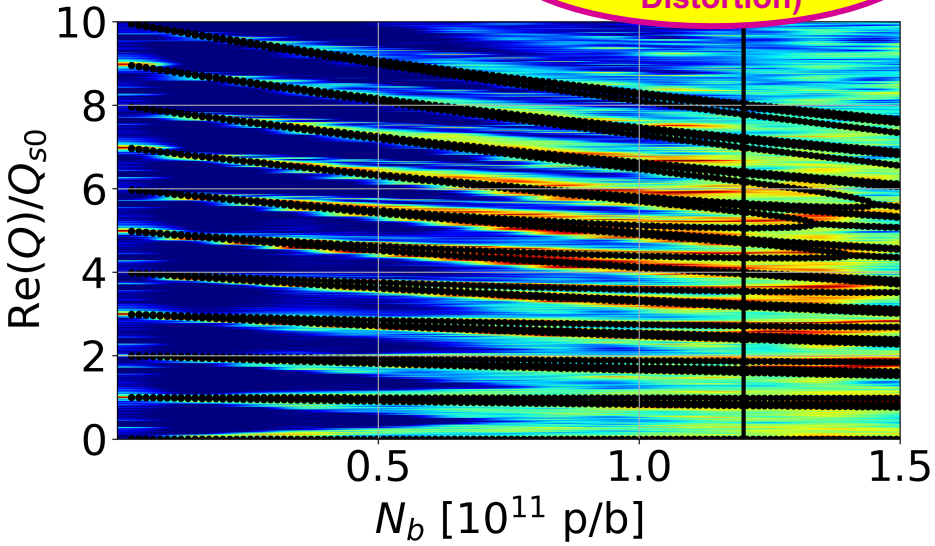

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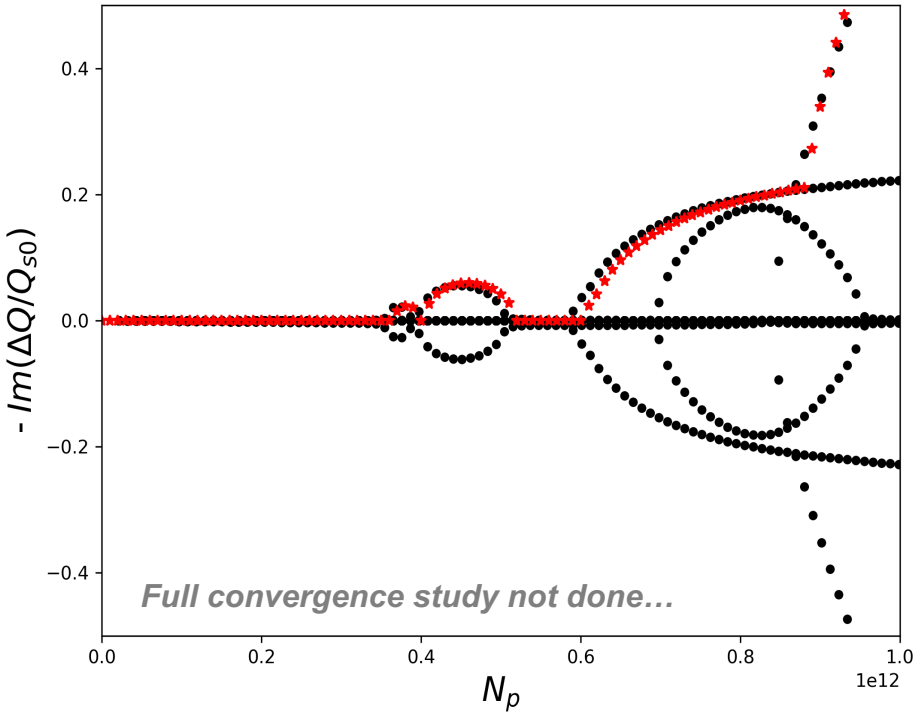

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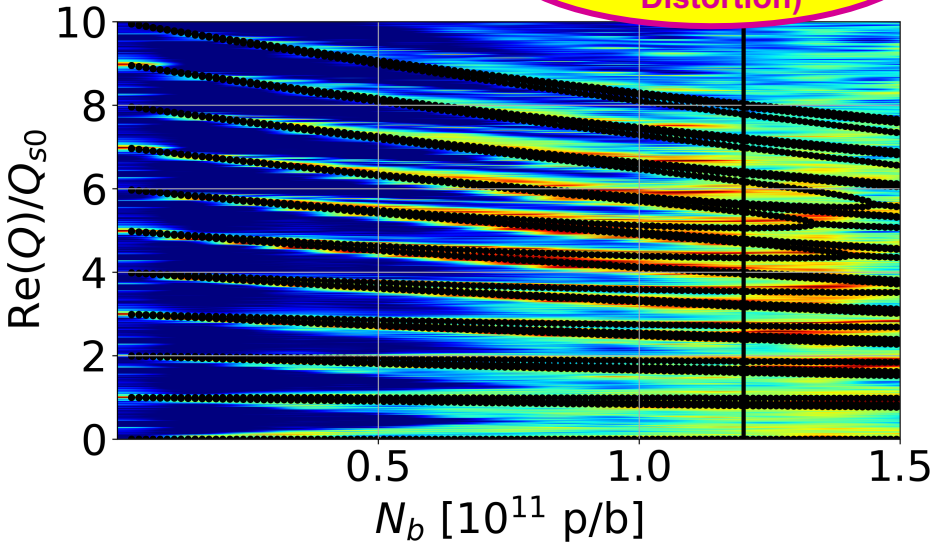

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Instability mechanism with Q' = 0

Long-bunch regime: ~ CERN SPS

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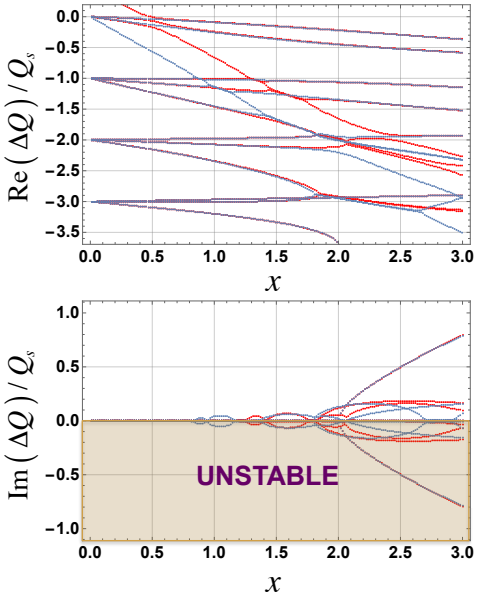
Reactive **TD**



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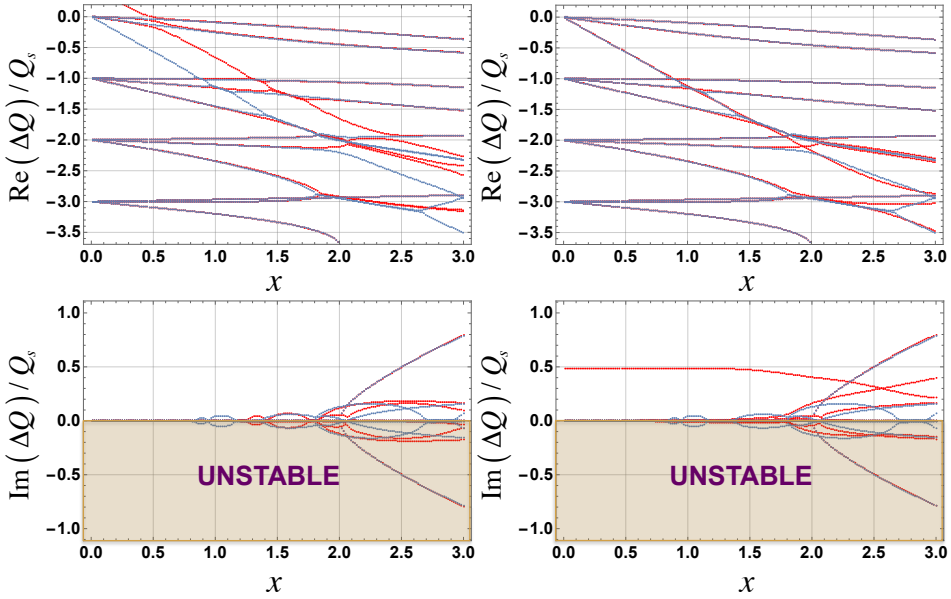

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Short-bunch regime: ~ CERN LHC

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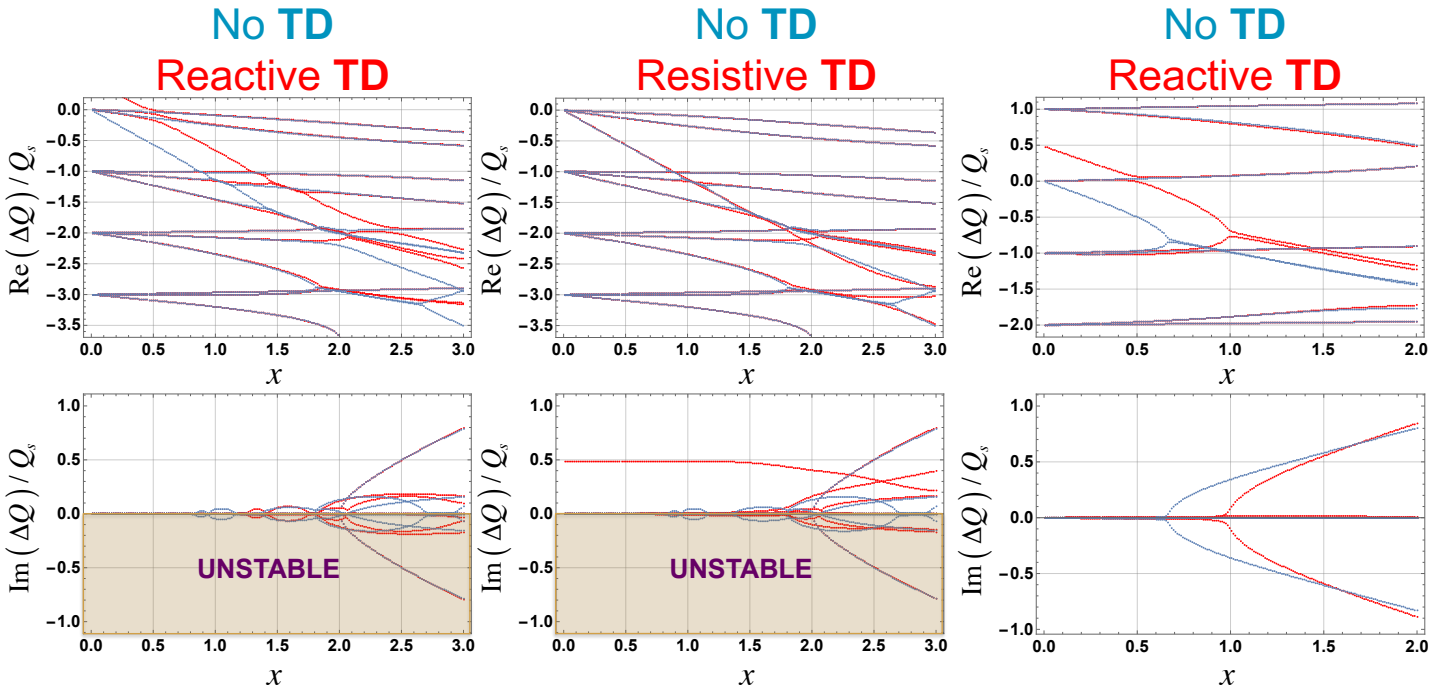

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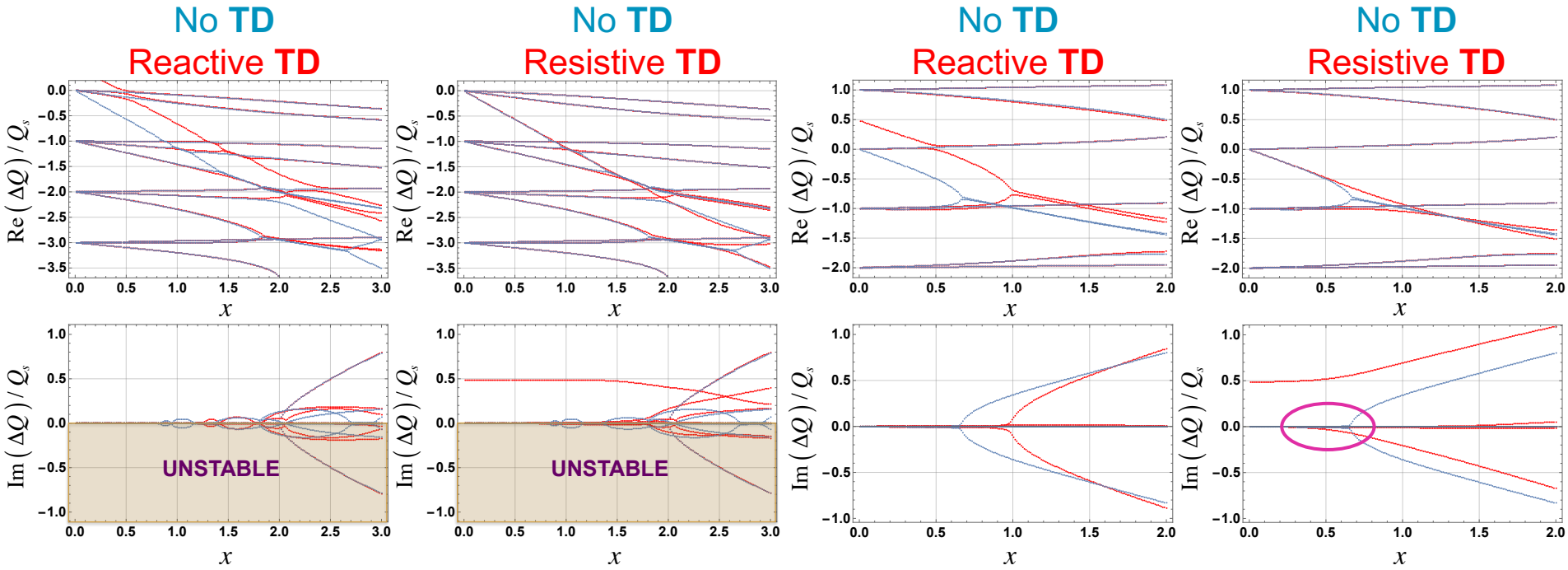

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- Approximated model for the LHC without **TD**

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Normally,
$(\Delta Q/Q_s)_{0,-1} = -(\Delta Q/Q_s)_{-1,0}$ and real,
but it can also be presented like this
(was solved numerically here…)

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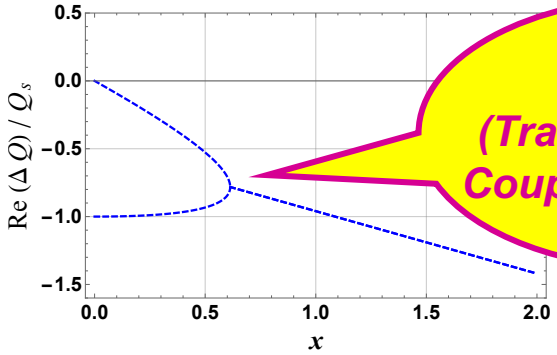
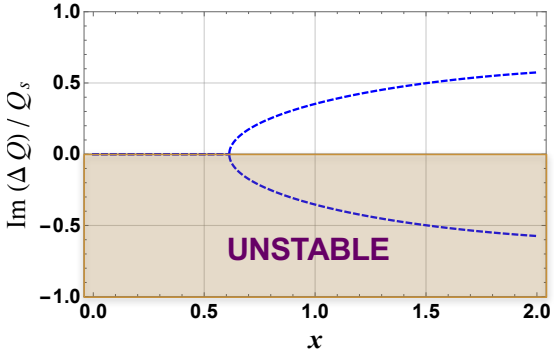
(was solved numerically here…)



TMCI
(Transverse Mode-Coupling Instability)

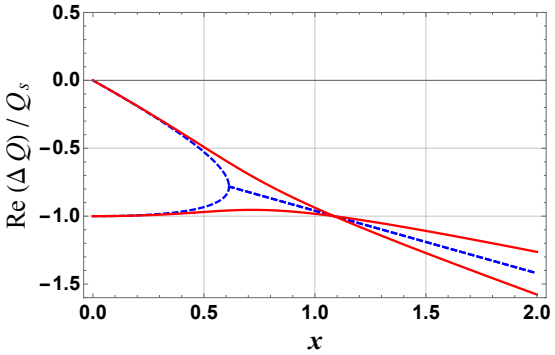


Instability mechanism with Q' = 0

- Approximated model for the LHC with **TD** (*d* = 100 turns)

$$= \frac{j}{2\,\pi\,d\,Q_s}$$

$$\begin{pmatrix} -1 & -0.23\,j\,x \\ -0.55\,j\,x & -0.92\,x + 0.48\,j \end{pmatrix}$$



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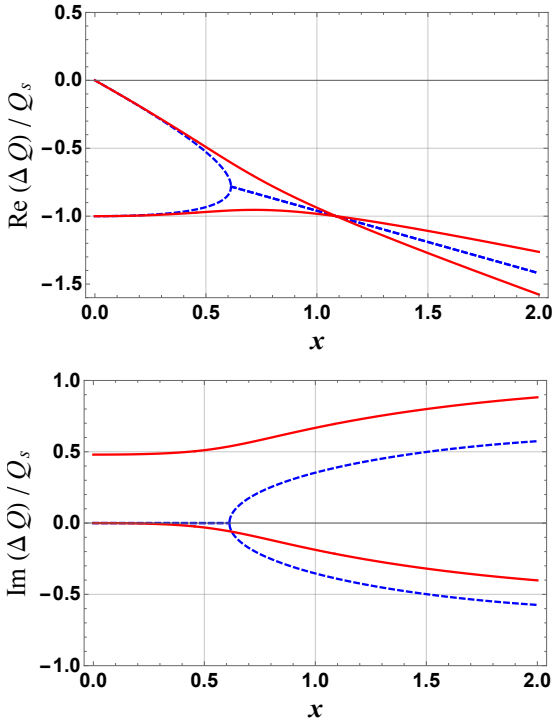

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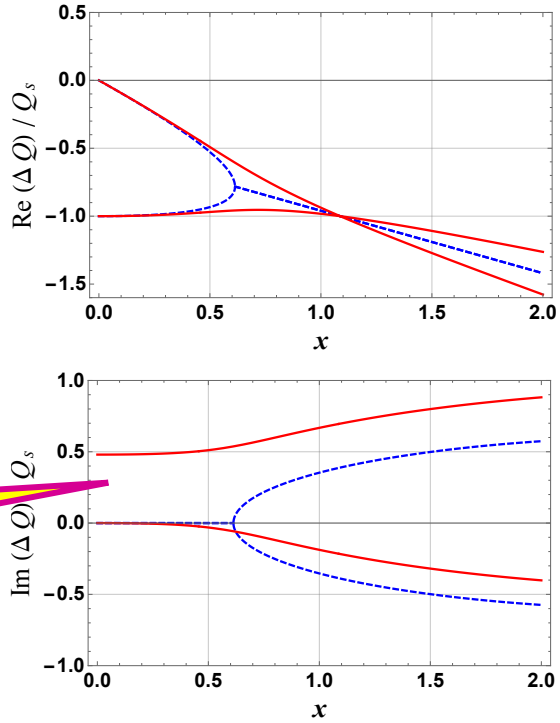
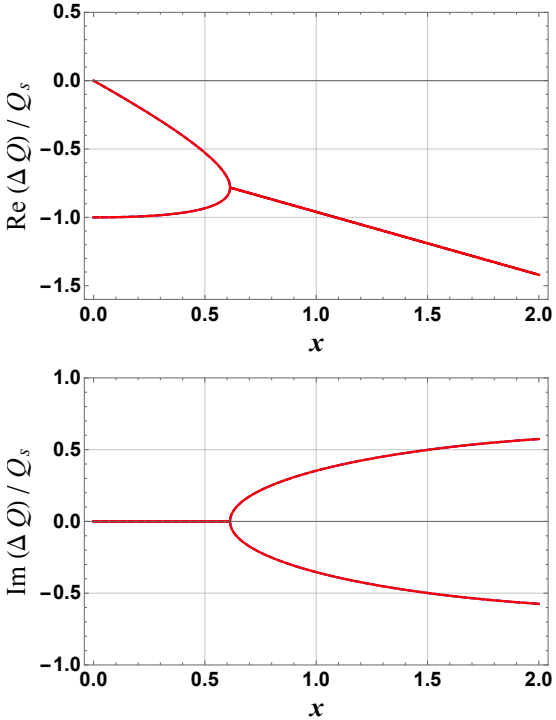


ISR instability
(Imaginary tune Split & Repulsion)

Instability mechanism with Q' = 0

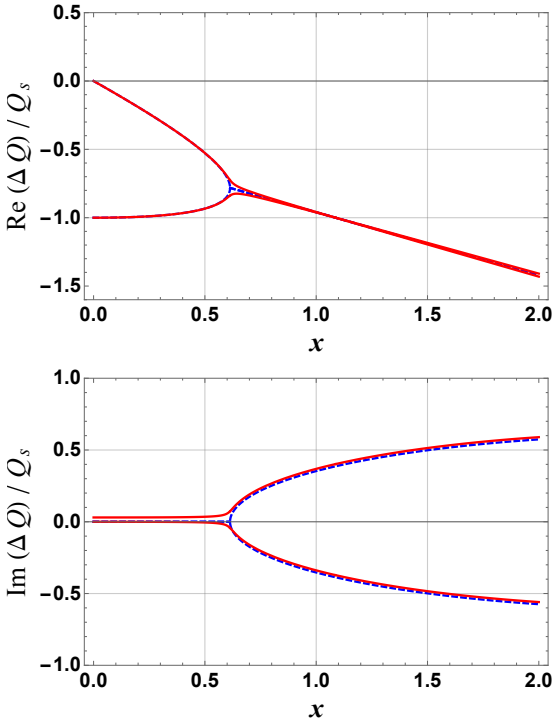
- Scan vs. **TD** damping time => **+ 0.00 *j***



Instability mechanism with Q' = 0

- Scan vs. **TD** damping time => **+ 0.03 *j*** (obtained e.g. with d=50 & Q_s=0.1)

$$= \frac{j}{2\,\pi\,d\,Q_s}$$



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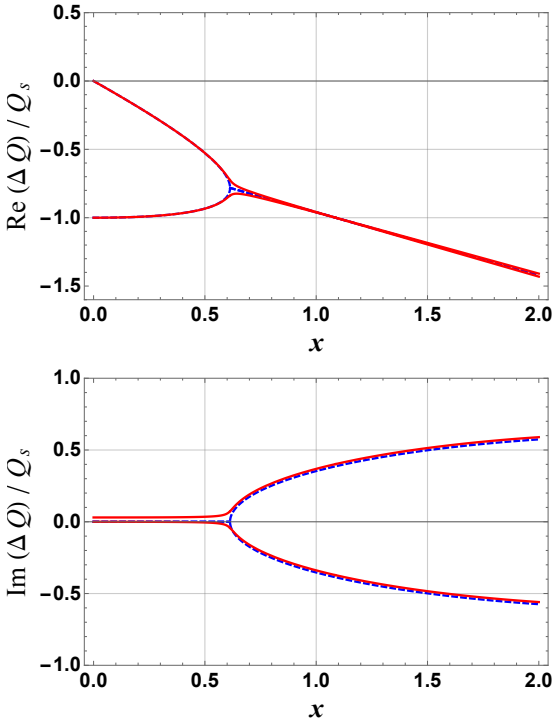
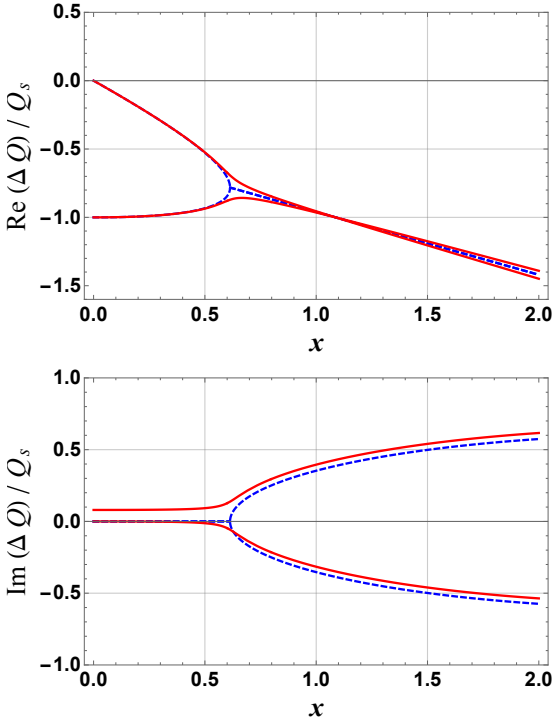
$$= \frac{j}{2\,\pi\,d\,Q_s}$$

=> Explains in particular why **TD** not very effective for machines with large Q_s



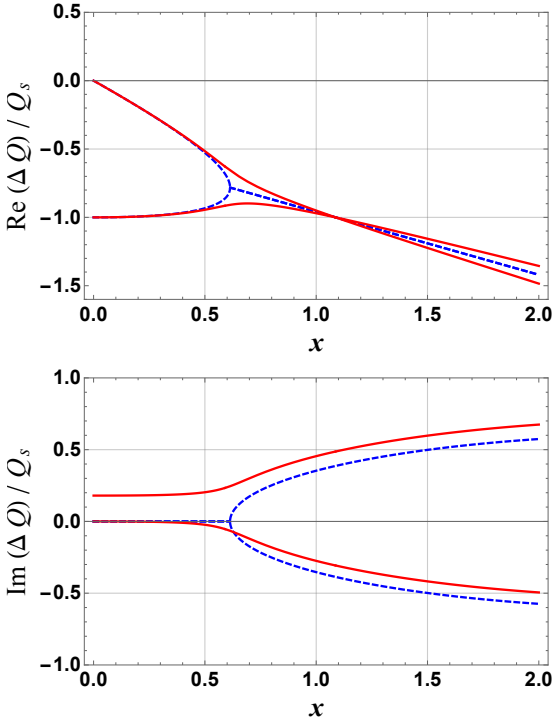
Instability mechanism with Q' = 0

- Scan vs. **TD** damping time => **+ 0.08 *j***



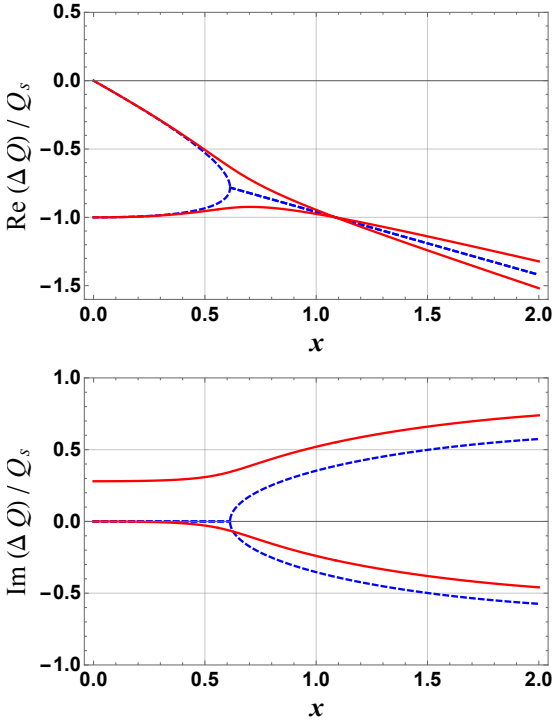
Instability mechanism with Q' = 0

- Scan vs. **TD** damping time => **+ 0.18 *j***



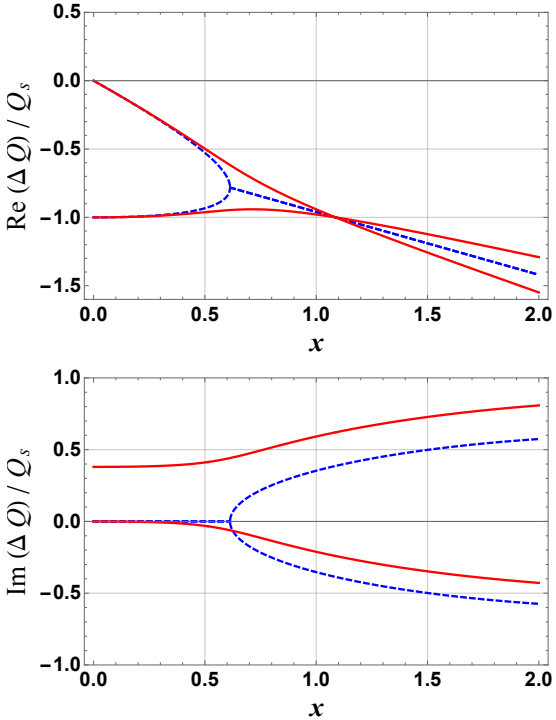
Instability mechanism with Q' = 0

- Scan vs. **TD** damping time => **+ 0.28 *j***



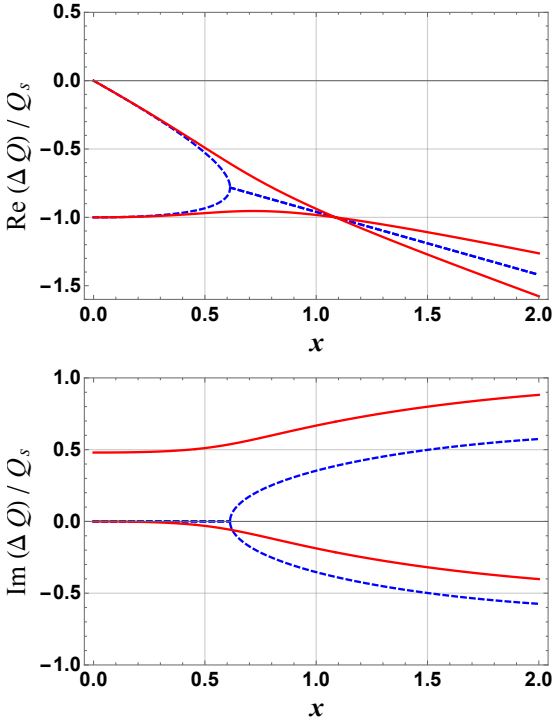
Instability mechanism with Q' = 0

- Scan vs. **TD** damping time => **+ 0.38 *j***



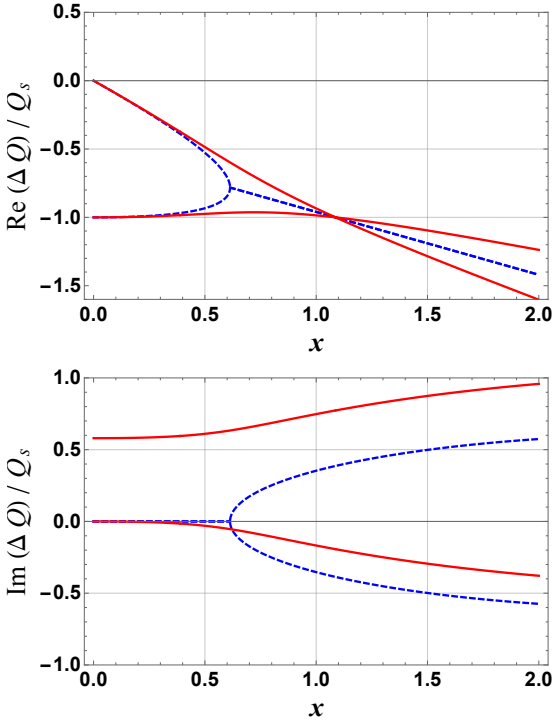
Instability mechanism with Q' = 0

- Scan vs. **TD** damping time => **+ 0.48 *j***



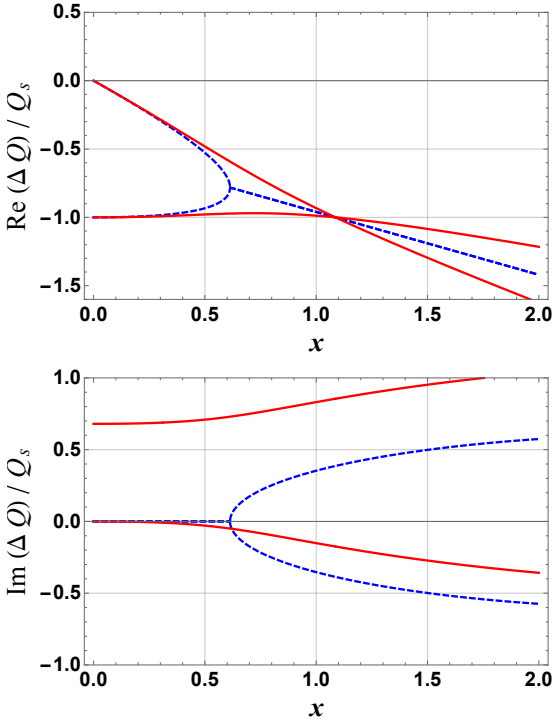
Instability mechanism with Q' = 0

- Scan vs. **TD** damping time => **+ 0.58 *j***



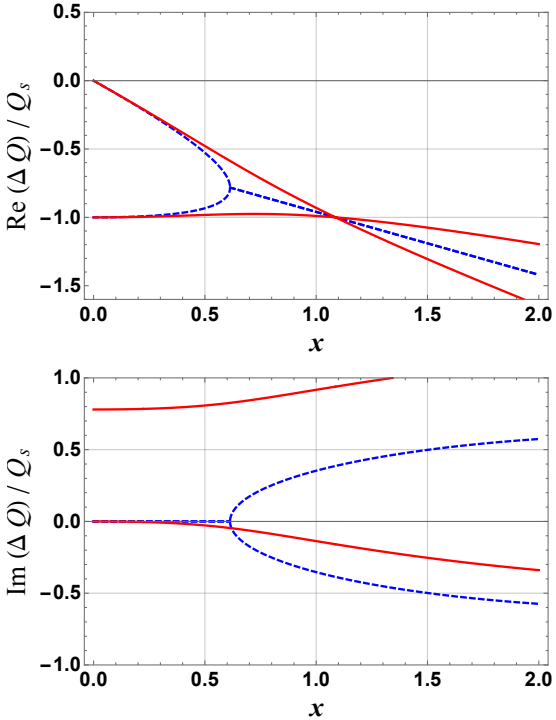
Instability mechanism with Q' = 0

- Scan vs. **TD** damping time => **+ 0.68 *j***



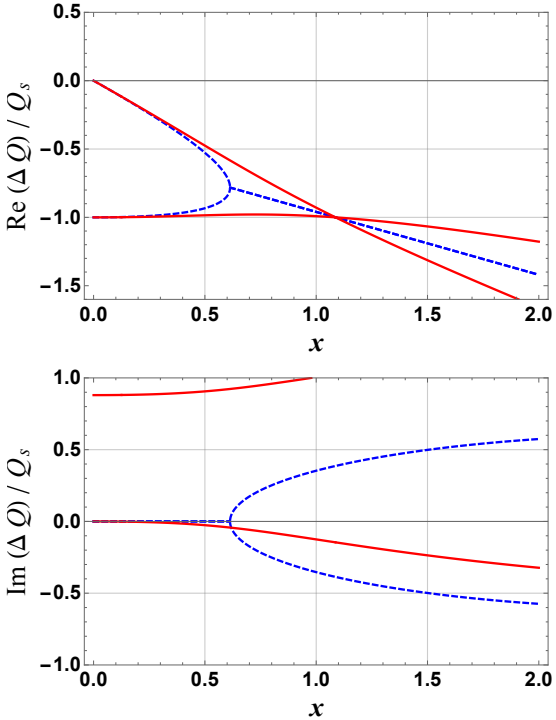
Instability mechanism with Q' = 0

- Scan vs. **TD** damping time => **+ 0.78 *j***



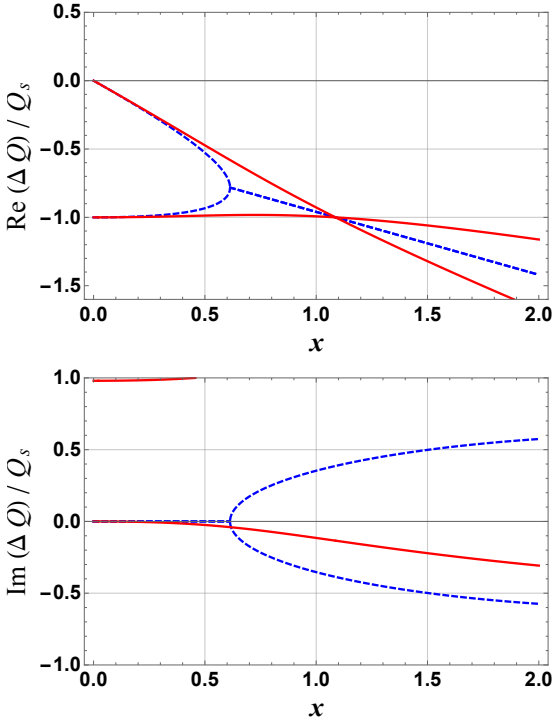
Instability mechanism with Q' = 0

- Scan vs. **TD** damping time => **+ 0.88 *j***



Instability mechanism with Q' = 0

- Scan vs. **TD** damping time => **+ 0.98 *j***



Impact on Landau damping

- Approximated model for the LHC with **TD** (d = 100 turns) and Landau damping

$$\begin{vmatrix} I^{-1}_{m=-1} & 0.23\, j\, x \\ 0.55\, j\, x & I^{-1}_{m=0} + 0.92\, x - 0.48\, j \end{vmatrix} = 0$$

Dispersion integral => Solved for an externally given elliptical tune spread

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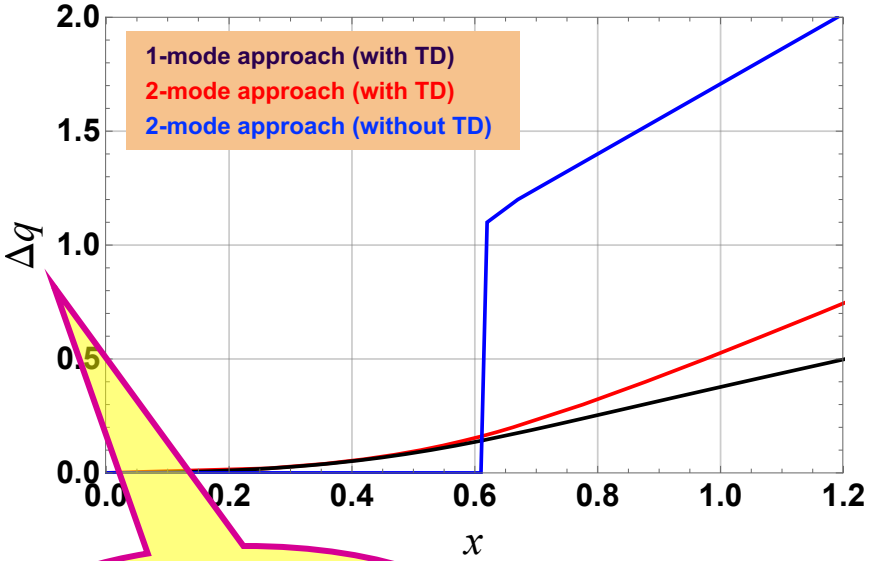
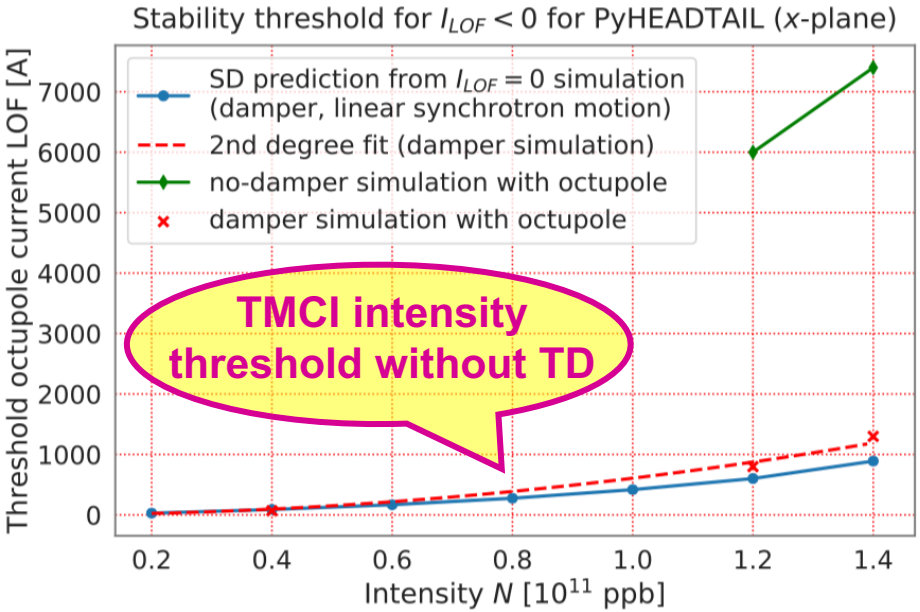


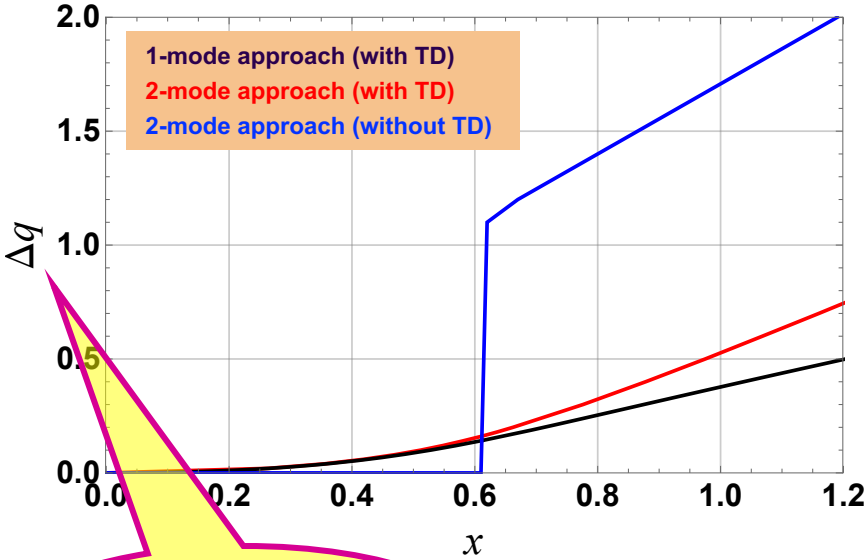
Dispersion integral => Solved for an externally given elliptical tune spread

Required tune spread (normalised by Q_s) for Landau damping

Comparison with PyHEADTAIL macroparticle tracking simulations



A. Oeftiger

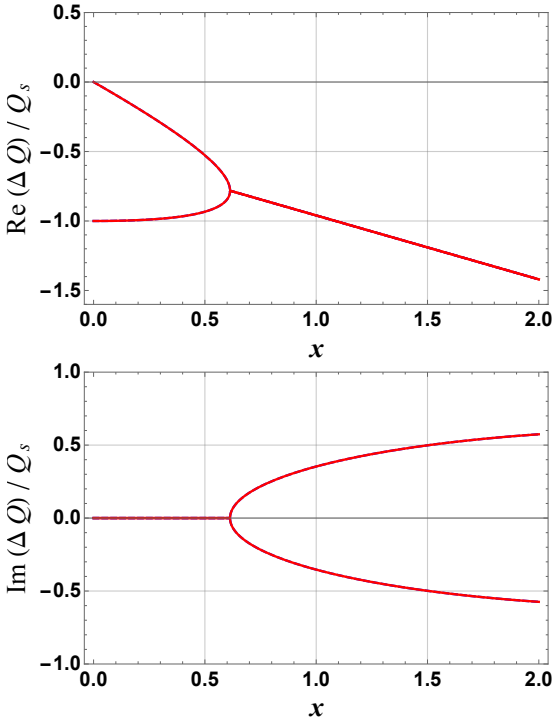


Required tune spread (normalised by Q_s) for Landau damping

Destabilising effect of Landau damping for TMCI (without TD)

- Scan vs. Δq

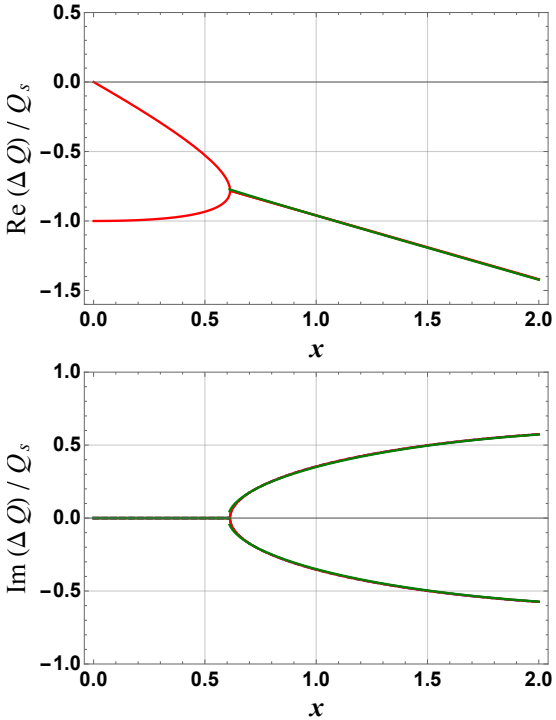
$$\Delta q = 0.0$$



Reminder on first results by Y.H.Chin in 1985: https://cds.cern.ch/record/160217/files/198507010.pdf

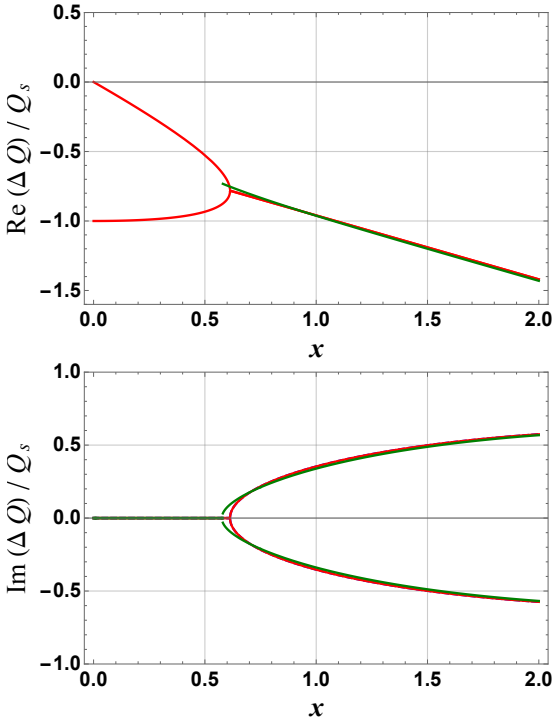
Destabilising effect of Landau damping for TMCI (without TD)

$\Delta q = 0.1$



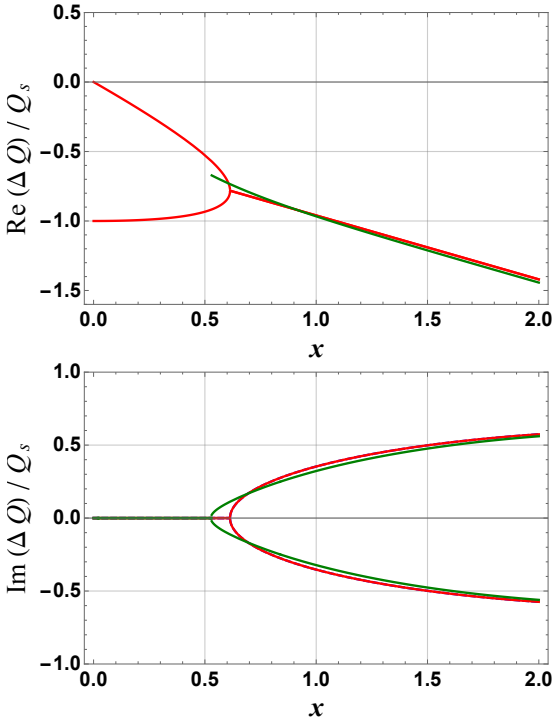
Destabilising effect of Landau damping for TMCI (without TD)

$\Delta q = 0.2$



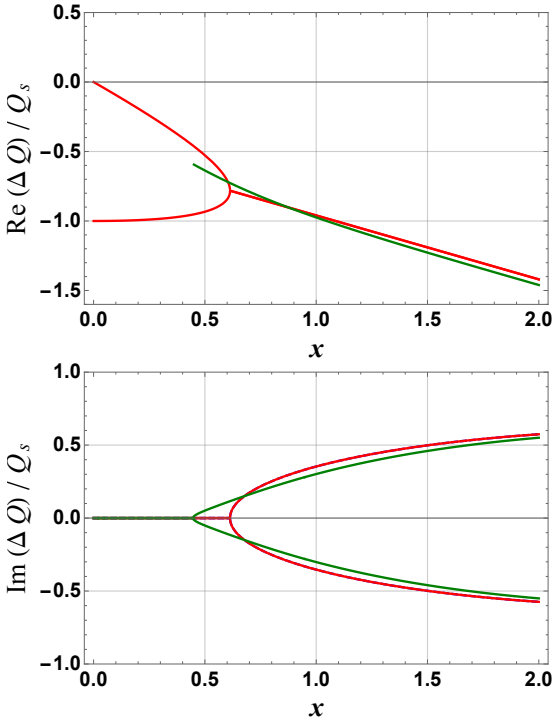
Destabilising effect of Landau damping for TMCI (without TD)

$\Delta q = 0.3$



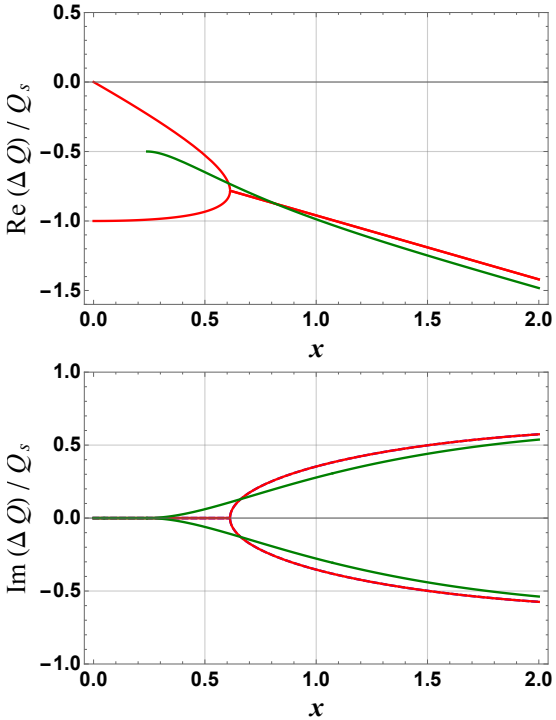
Destabilising effect of Landau damping for TMCI (without TD)

$\Delta q = 0.4$



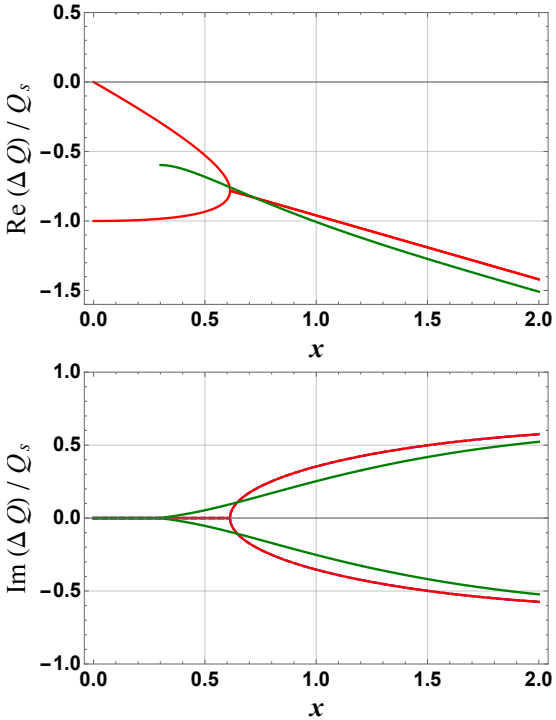
Destabilising effect of Landau damping for TMCI (without TD)

$\Delta q = 0.5$



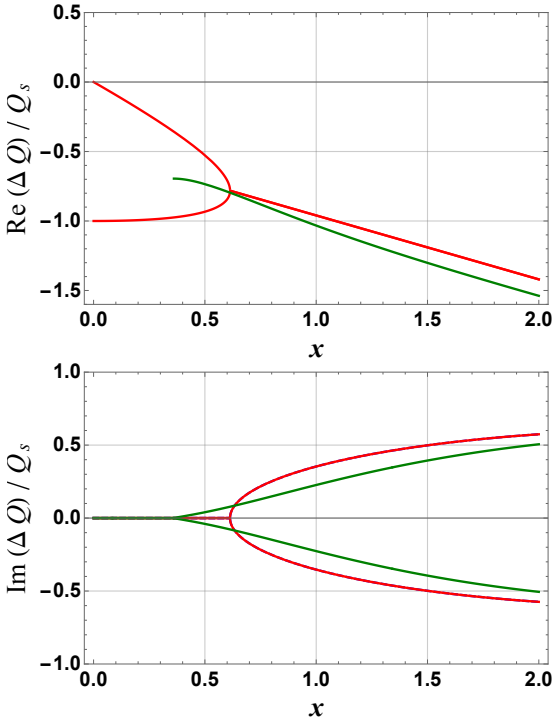
Destabilising effect of Landau damping for TMCI (without TD)

$\Delta q = 0.6$



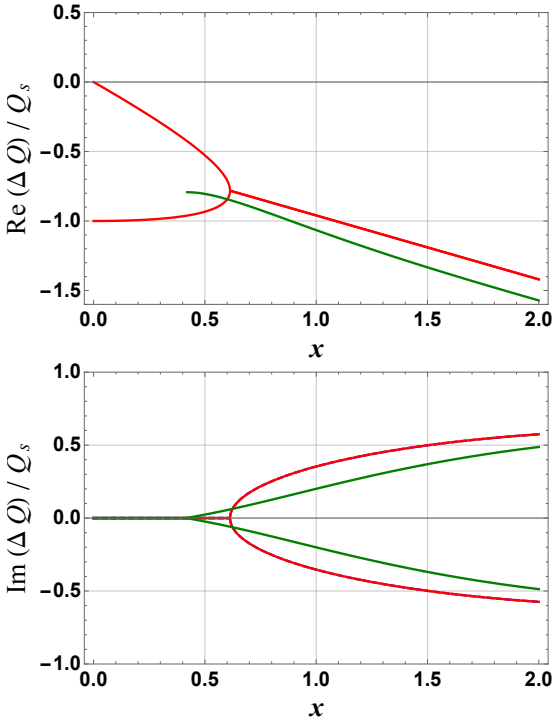
Destabilising effect of Landau damping for TMCI (without TD)

$\Delta q = 0.7$



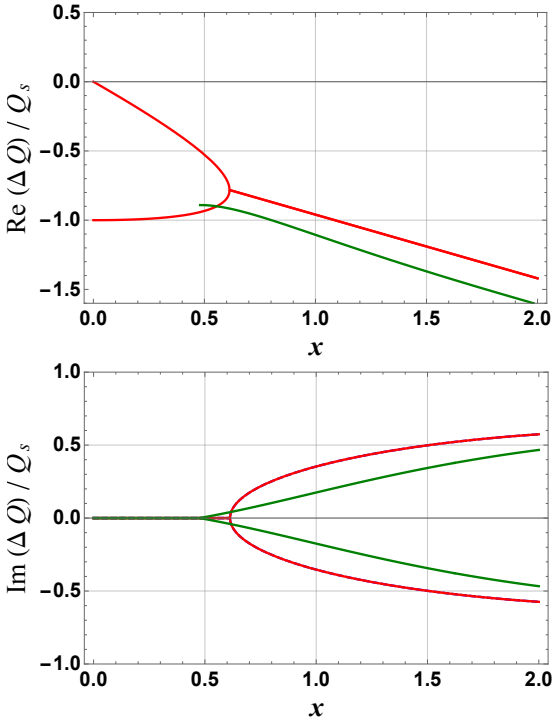
Destabilising effect of Landau damping for TMCI (without TD)

$\Delta q = 0.8$



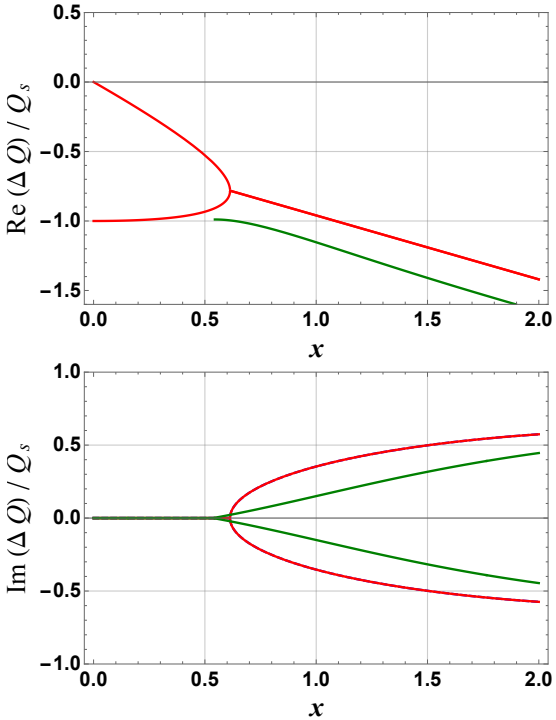
Destabilising effect of Landau damping for TMCI (without TD)

$\Delta q = 0.9$



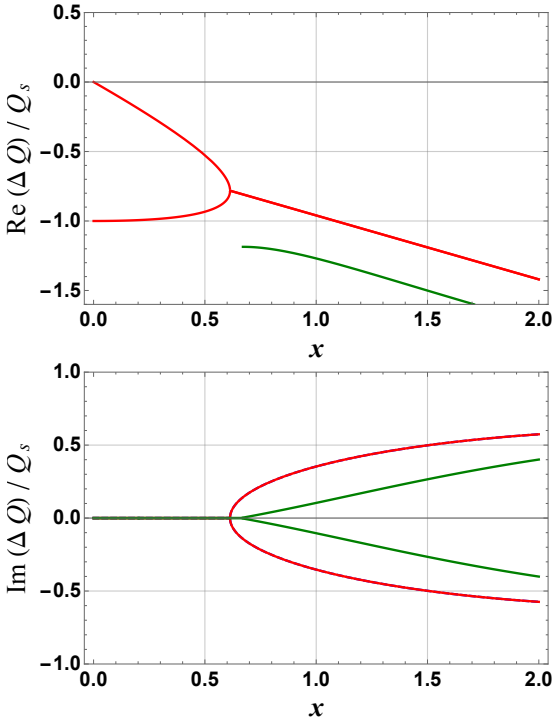
Destabilising effect of Landau damping for TMCI (without TD)

$\Delta q = 1.0$



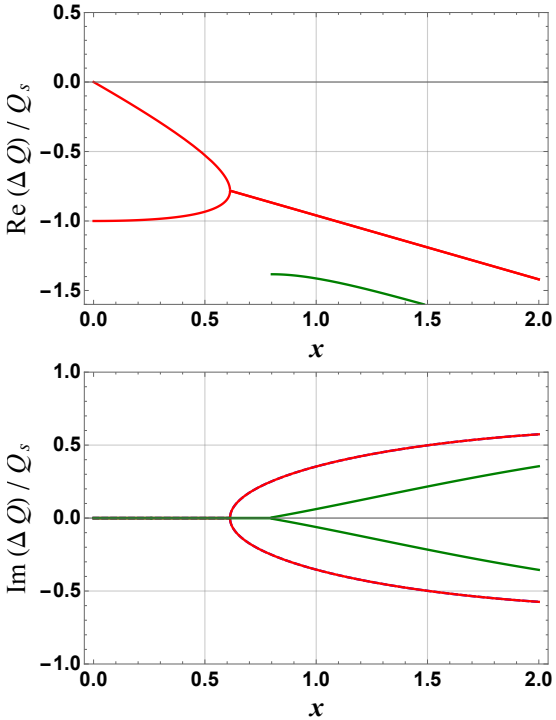
Destabilising effect of Landau damping for TMCI (without TD)

$\Delta q = 1.2$



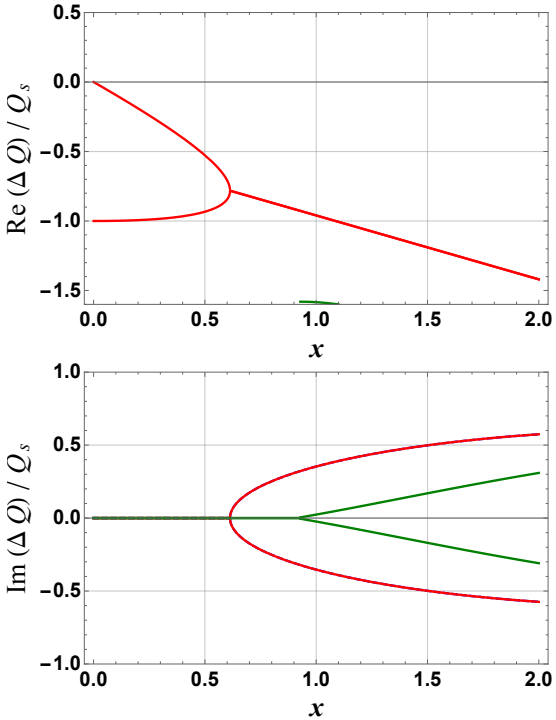
Destabilising effect of Landau damping for TMCI (without TD)

$\Delta q = 1.4$



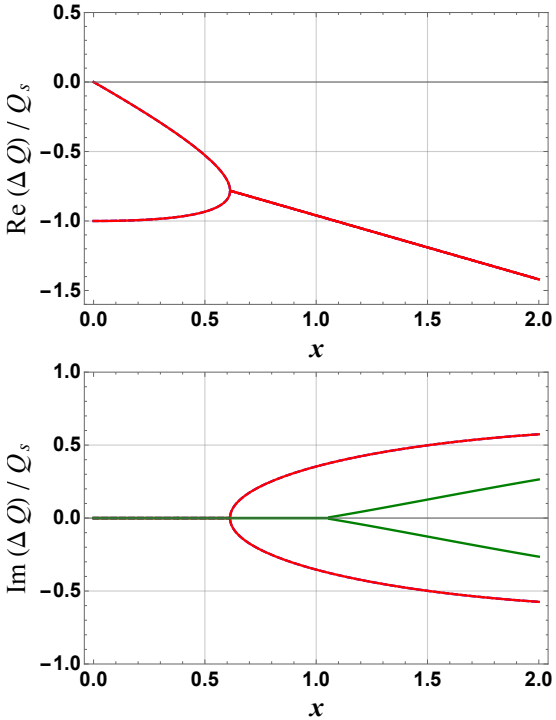
Destabilising effect of Landau damping for TMCI (without TD)

$\Delta q = 1.6$



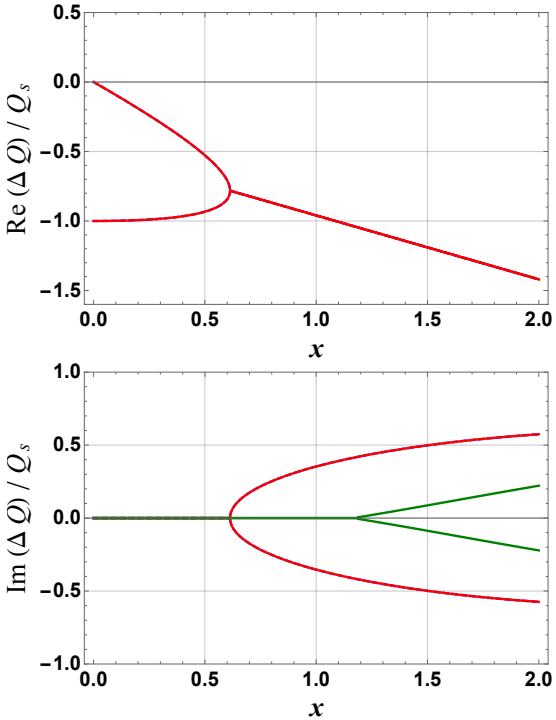
Destabilising effect of Landau damping for TMCI (without TD)

$\Delta q = 1.8$



Destabilising effect of Landau damping for TMCI (without TD)

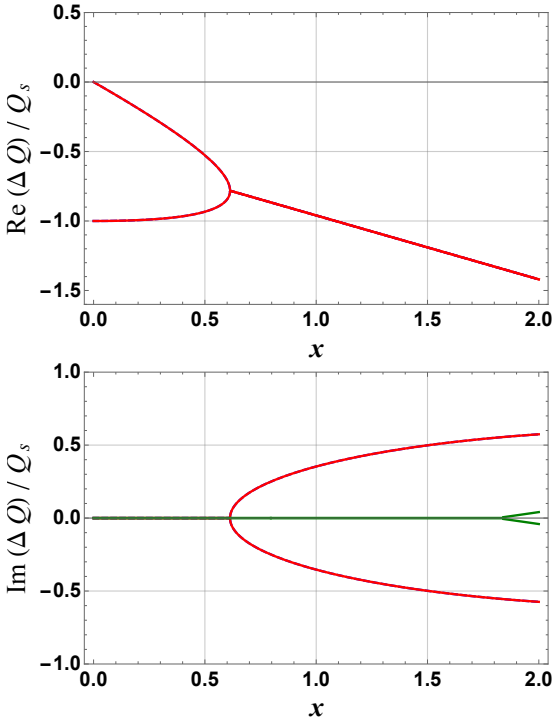
$\Delta q = 2.0$



Destabilising effect of Landau damping for TMCI (without TD)

$$\Delta q = 3.0$$

Some benchmarks with PyHEADTAIL macroparticle tracking simulations started (N. Mounet) but need to be finalised



Conclusion and outlook

- Instability mechanism for **Q' = 0** in presence of resistive **TD**, which is needed for multi-bunch operation in a machine like LHC => **ISR** (Imaginary tune Split & Repulsion) **instability (instead of TMCI)**

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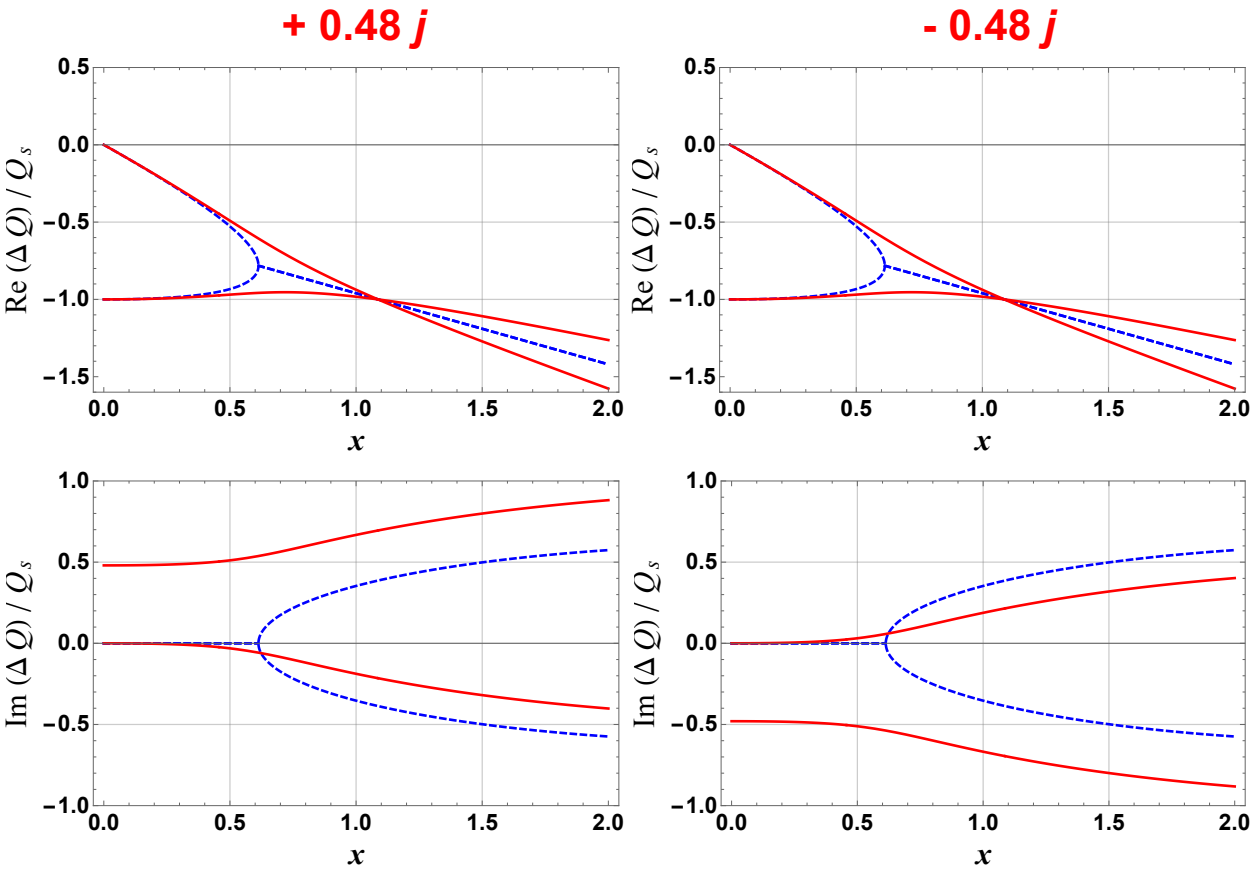
  - **Detrimental effect of resistive TD** below TMCI intensity threshold
  - **Beneficial effect of resistive TD** above TMCI intensity threshold
- Another mechanism is needed to explain the LHC observations at low chromaticity, such as a modification of the longitudinal distribution (A. Oeftiger) => To be finalised. Effect of noise? Others?

Thank you for your attention!

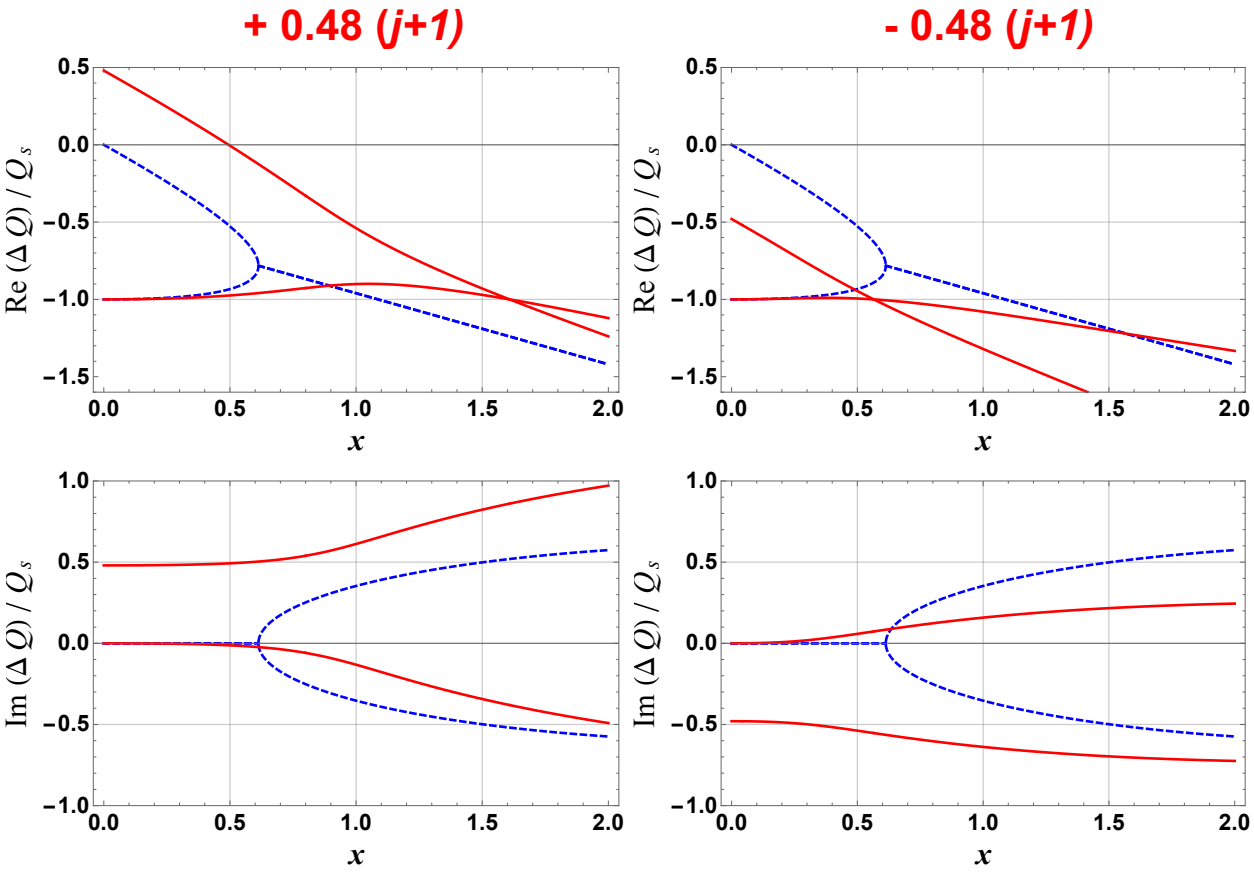
(hoping that you are enjoying the workshop as we are doing. Many thanks to all!)

APPENDIX

Resistive TD



½ resistive and ½ reactive TD



Reactive TD