Effects of transverse damper, detuning impedance, linear coupling, chromaticity, Landau damping and space charge on TMCI

E. Métral

- Introduction
- 6 mechanisms modifying the TMCI intensity threshold *(beam-beam and e-cloud not considered here)*
- Conclusion

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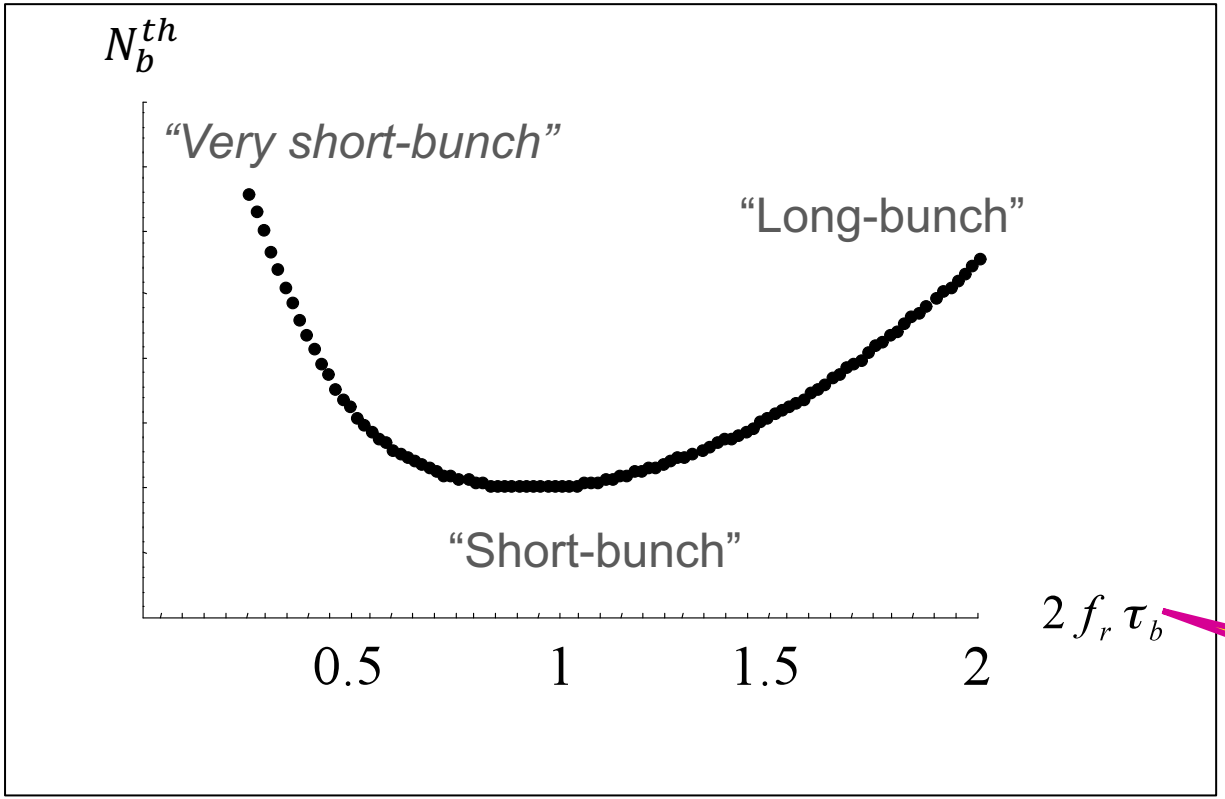
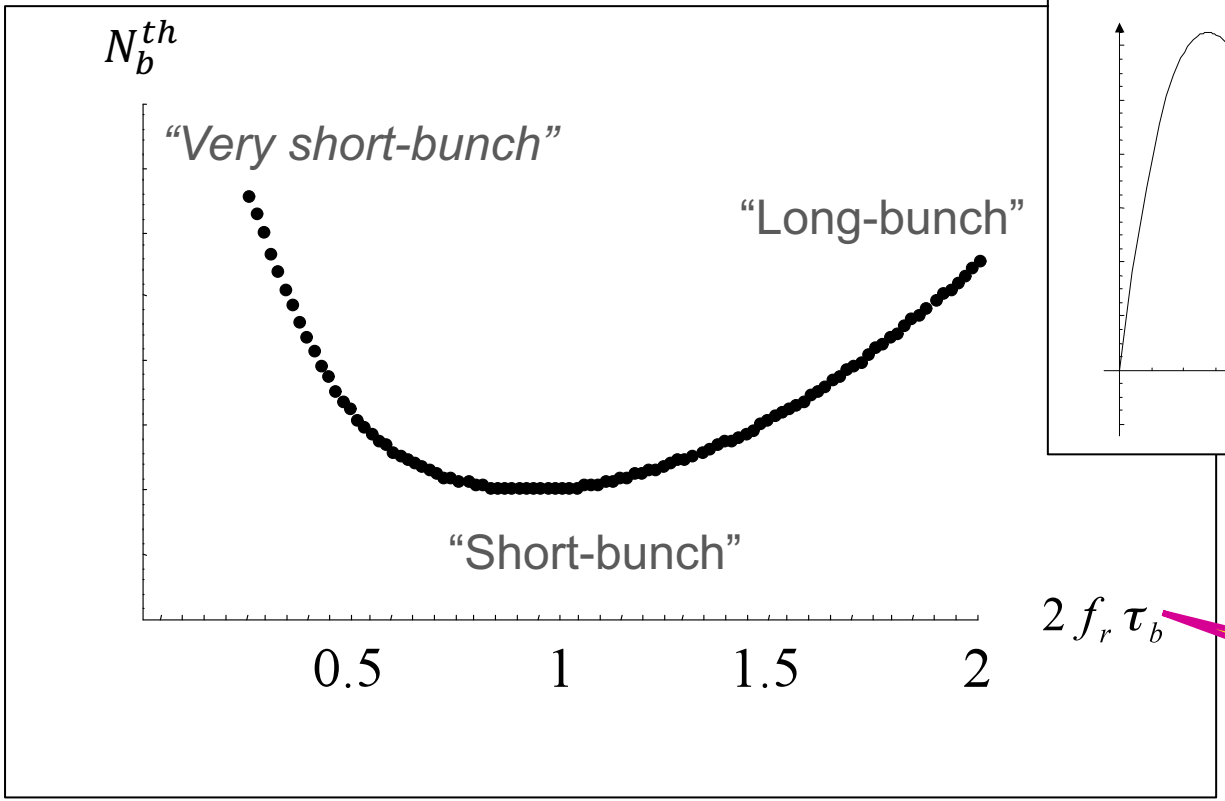
- Depending on the "bunch-length" regime, the different mechanisms can have different effects…

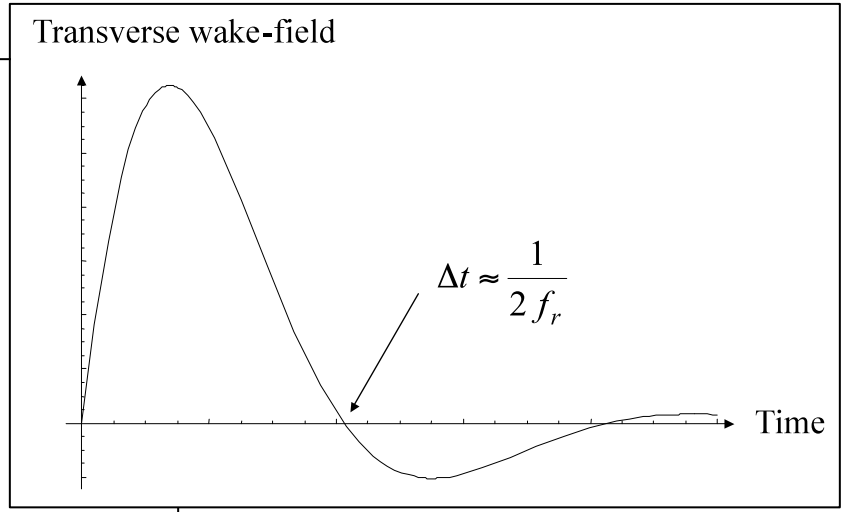
Introduction



4 σ bunch length

Introduction





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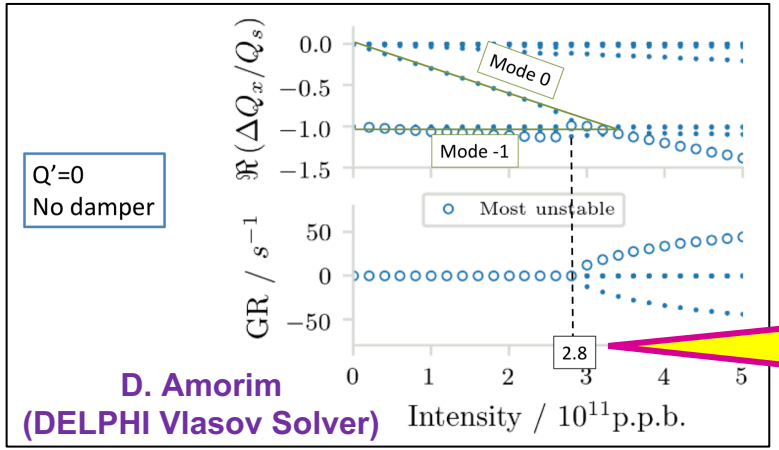

D. Amorim (DELPHI Vlasov Solver)

=> New low-impedance collimators to increase the intensity threshold for HL-LHC

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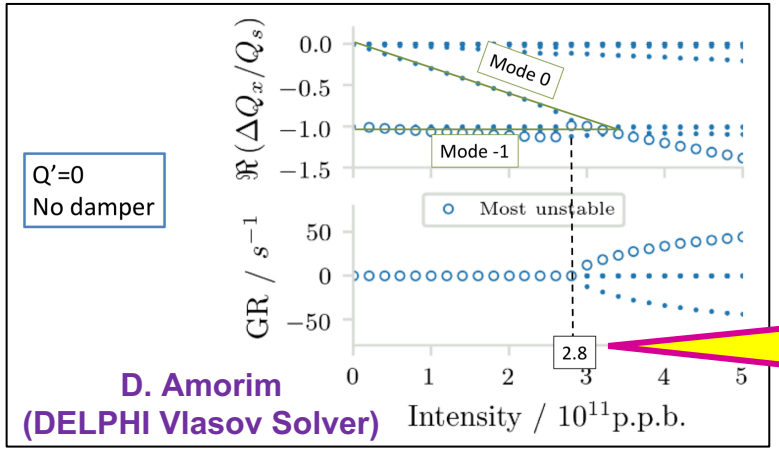

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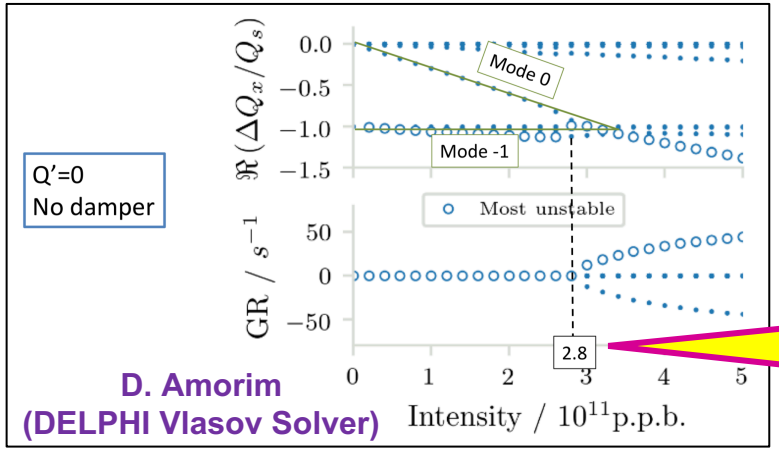

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$$N_b^{th,y} \propto |\eta|\, Q_y\, \varepsilon_L\, \frac{f_r}{R_t}$$

=> Q20 (or Q22) optics (instead of Q26) to solve the problem in practice for LIU

Introduction

	“Short-bunch” regime	“Long-bunch” regime
Transverse damper		
Detuning impedance		
Linear coupling		
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BENEFICIAL OR DETRIMENTAL?

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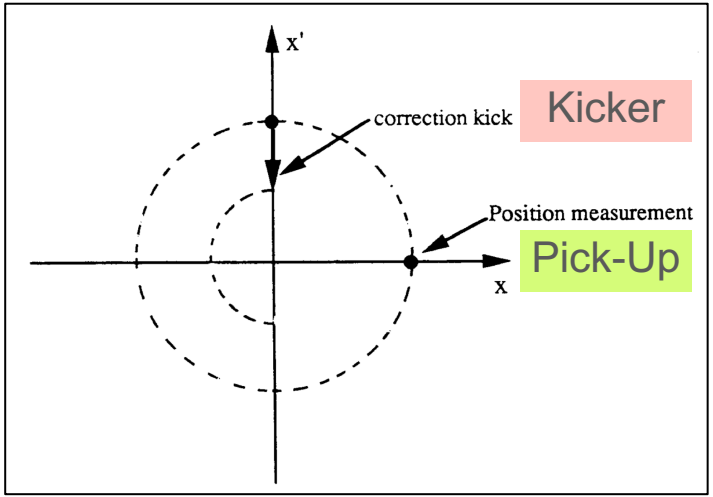

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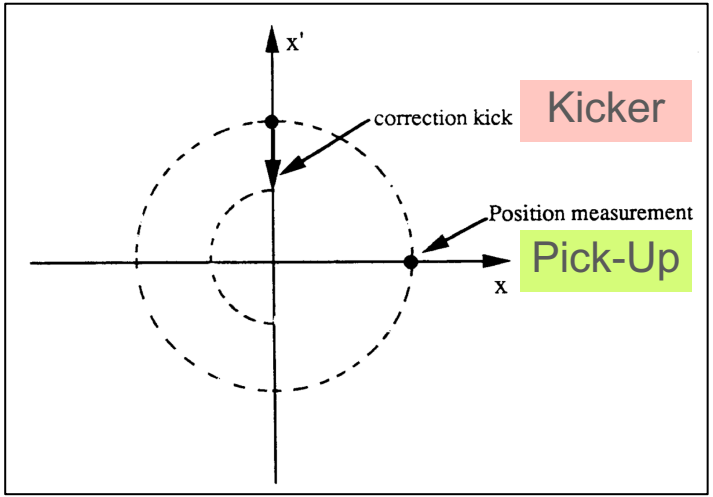

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- If $\boldsymbol{\phi = 0°}$ => **TD** is called "**reactive**": in this case, mode 0 is shifted (which can raise the intensity threshold in the presence of TMCI between modes 0 and -1)

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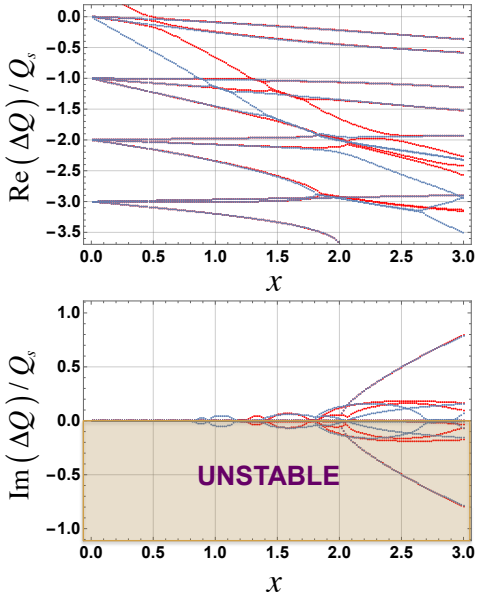
"Long-bunch" regime:

~ CERN SPS $(f_r \tau_b = 2.8, Q' = 0)$

No **TD**

Reactive **TD**



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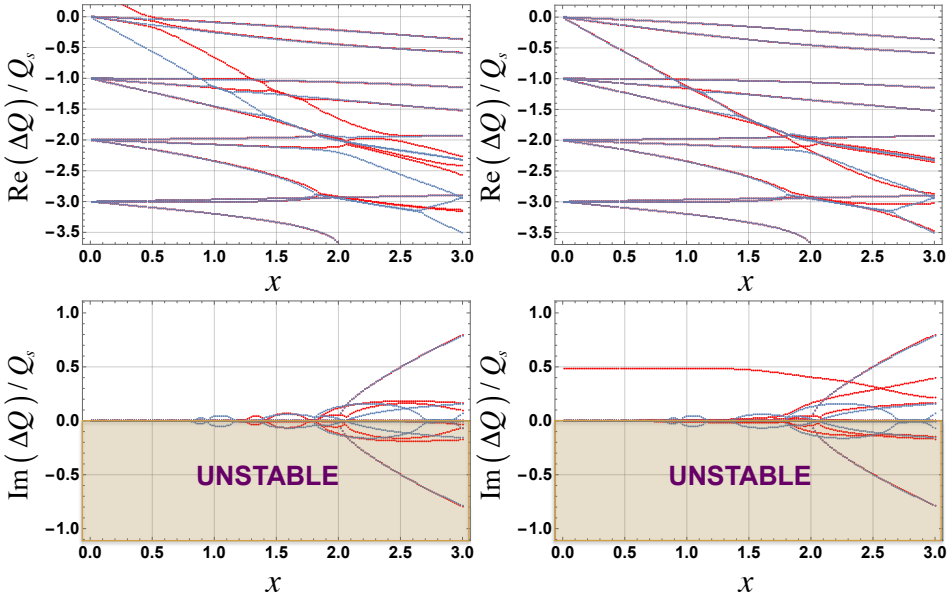

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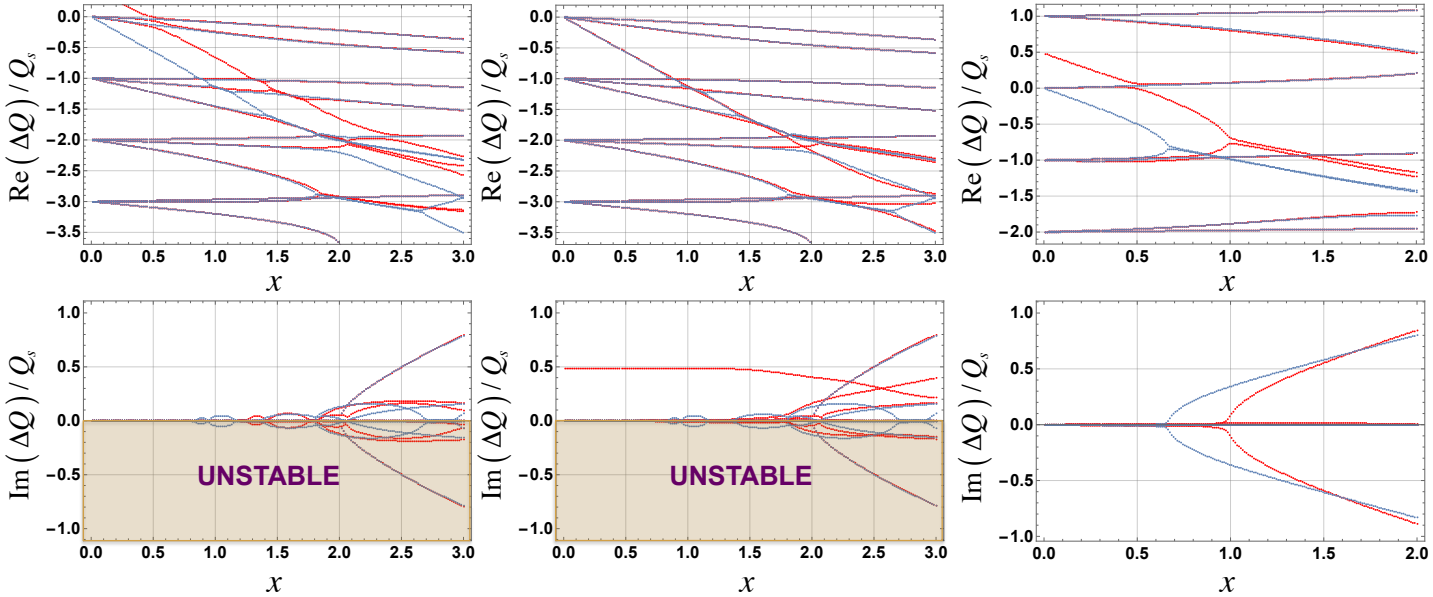

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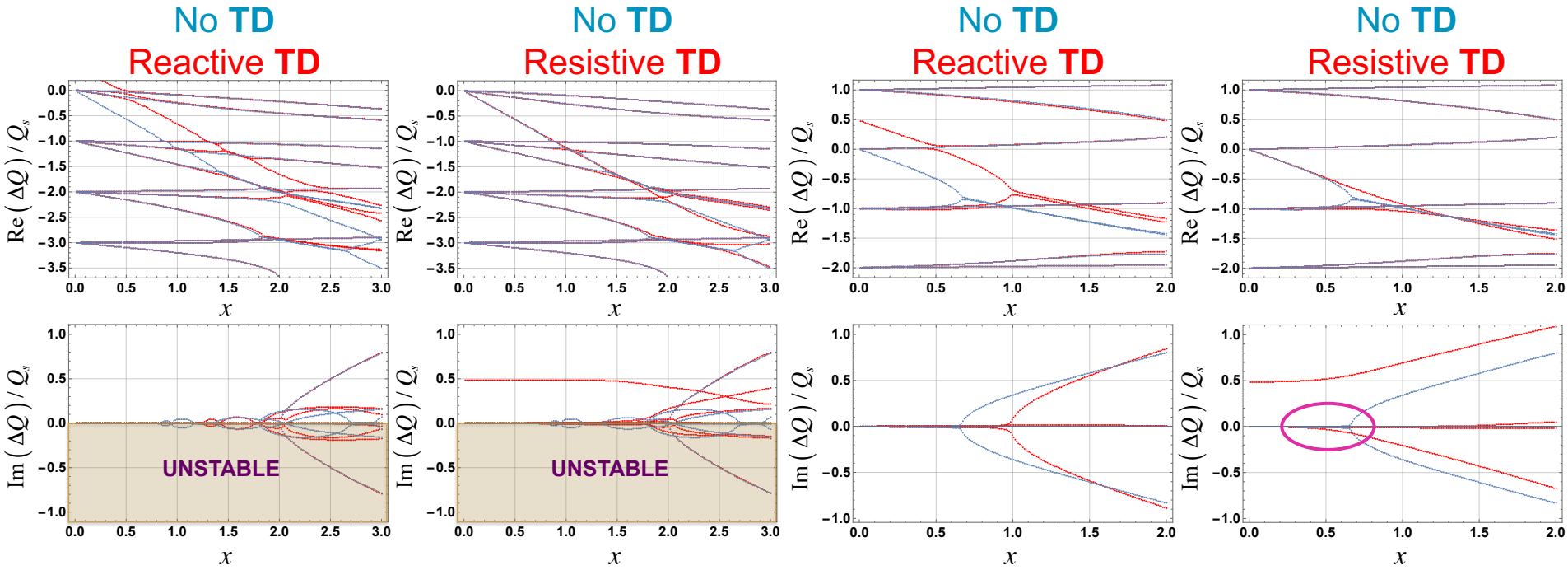

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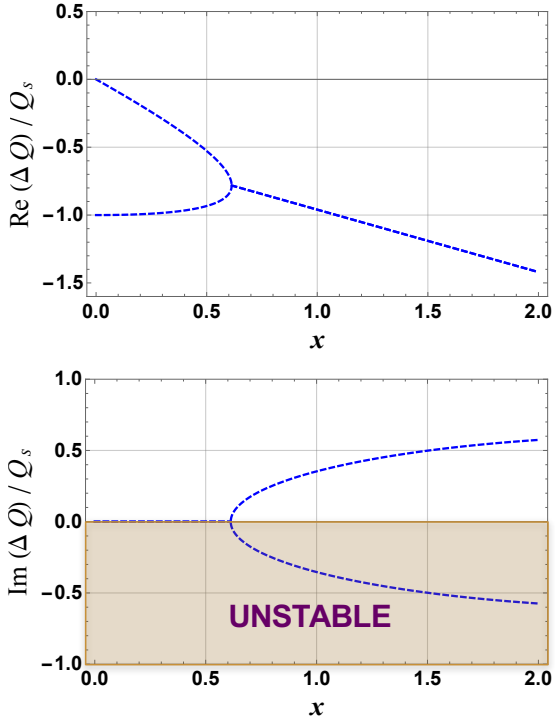

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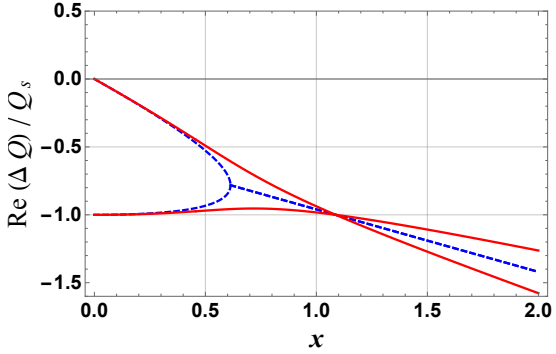

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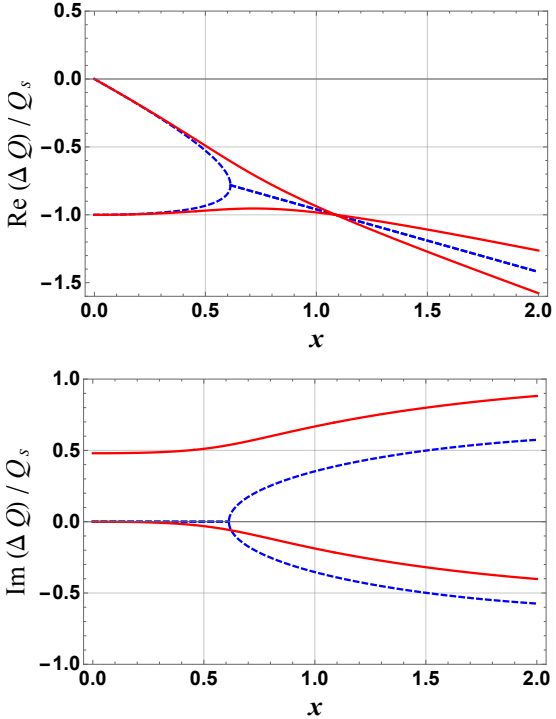

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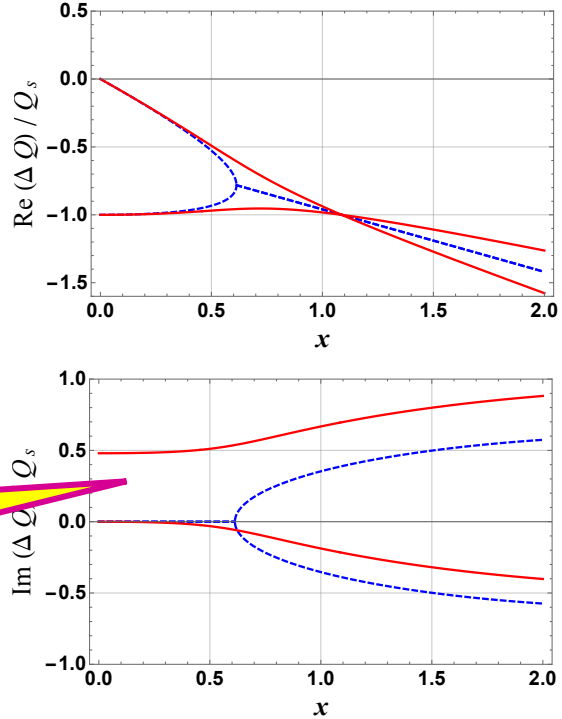

ISR instability
(Imaginary tune Split & Repulsion)

http://accelconf.web.cern.ch/AccelConf/ipac2018/papers/thpaf048.pdf

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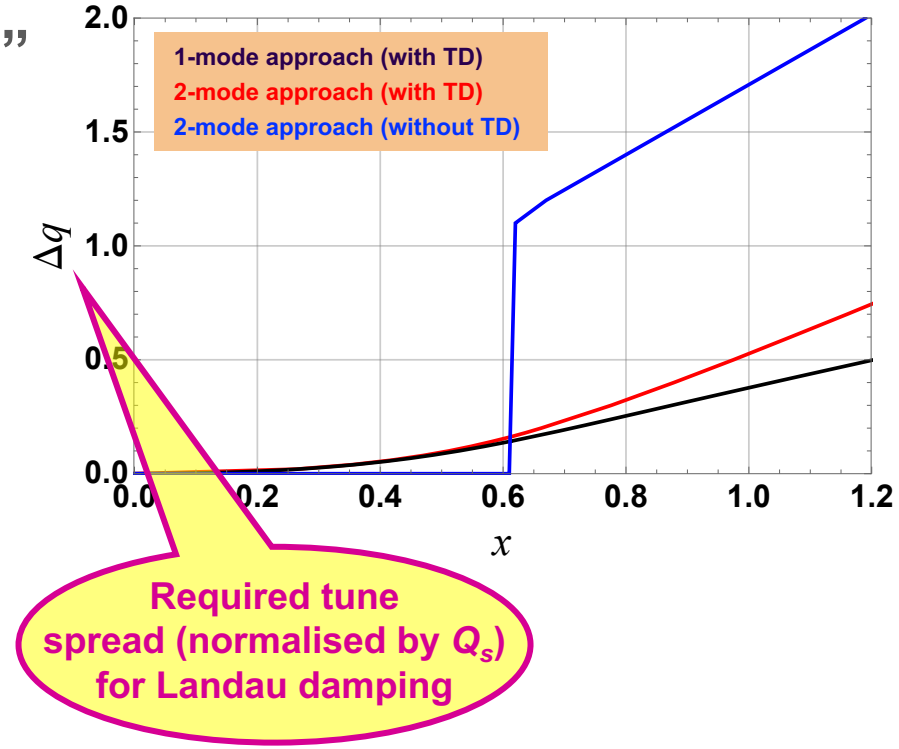

2) Detuning impedance

- Extending Burov-Danilov_1998 ("air-bag" model) with a constant wake and considering first only 2 modes (0 and -1), the system is fully described by the following matrix to be diagonalized

$$\begin{pmatrix} -1+\frac{\kappa}{2}I_{norm} & \frac{2\,I_{norm}}{\pi^2}(1-\kappa) \\ \frac{2\,I_{norm}}{\pi^2}(-1-\kappa) & \frac{I_{norm}}{2}(-1+\kappa) \end{pmatrix}$$

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$$I_{norm} = \frac{Ne^2}{2\gamma m_0 \omega_\beta \omega_s C} \times \frac{\omega_r^2 R_t}{Q\overline{\omega_r}}$$

$$\kappa = D(z)/W_x(z)$$

+ 1 in x for CRW flat chamber
- 1/2 in y for CRW flat chamber

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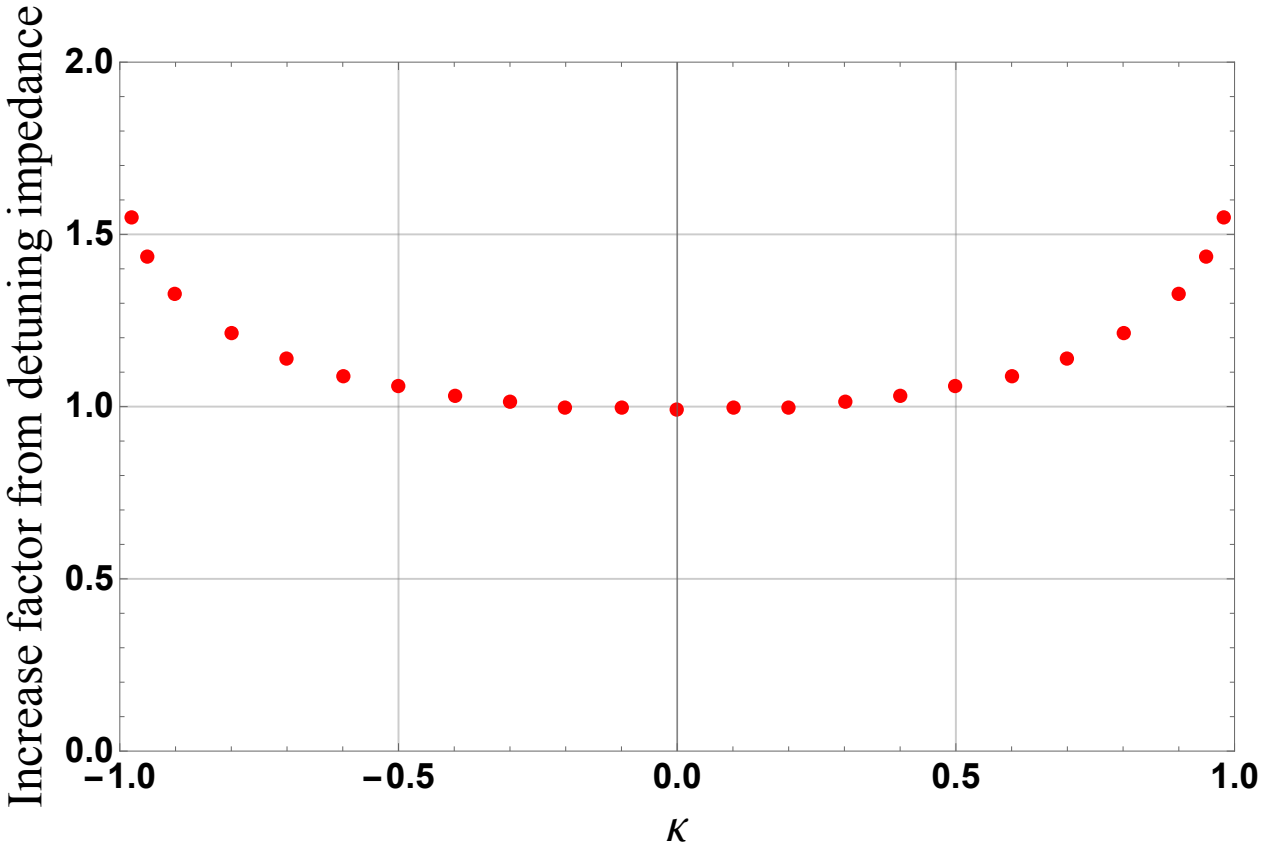

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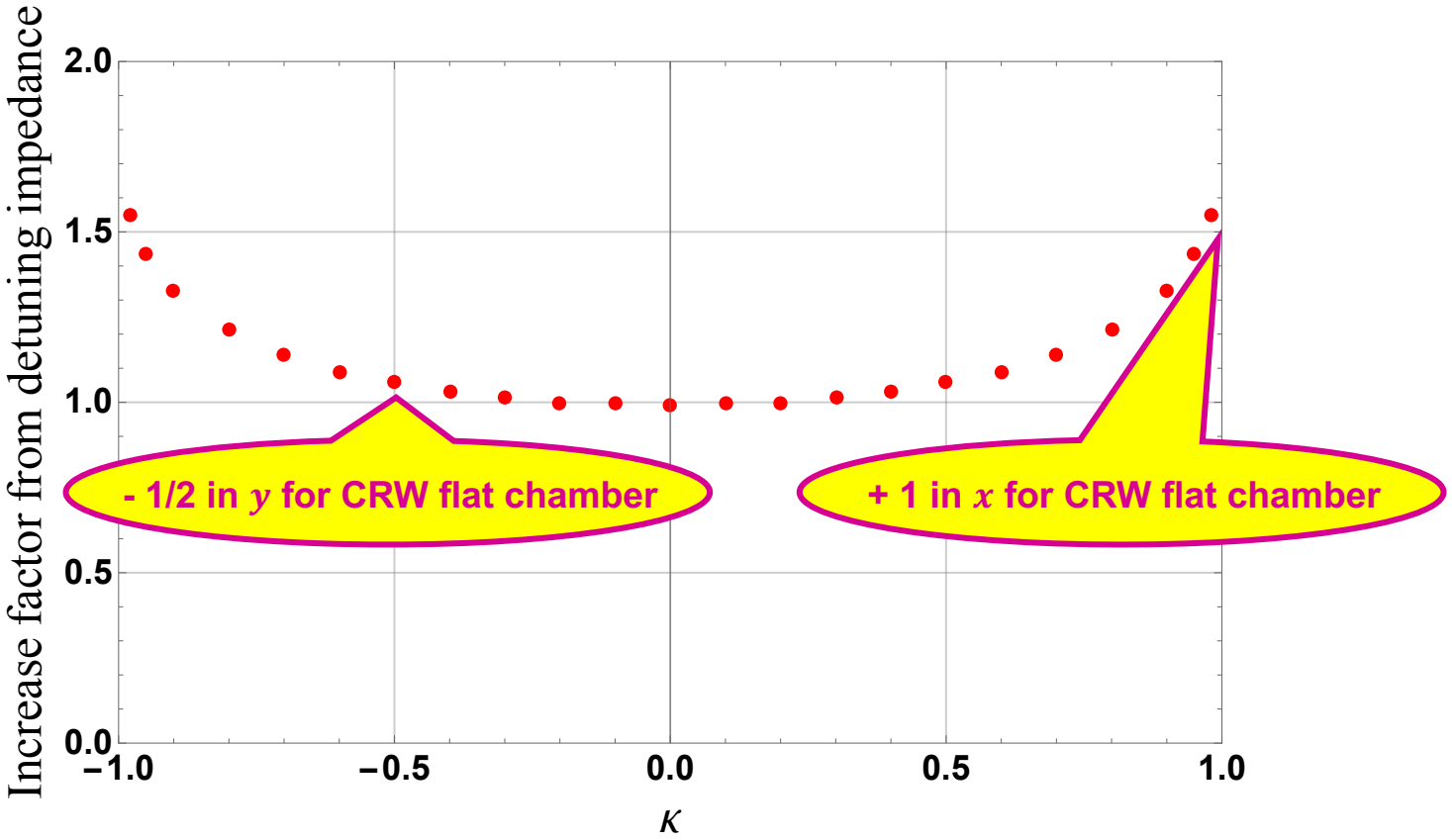

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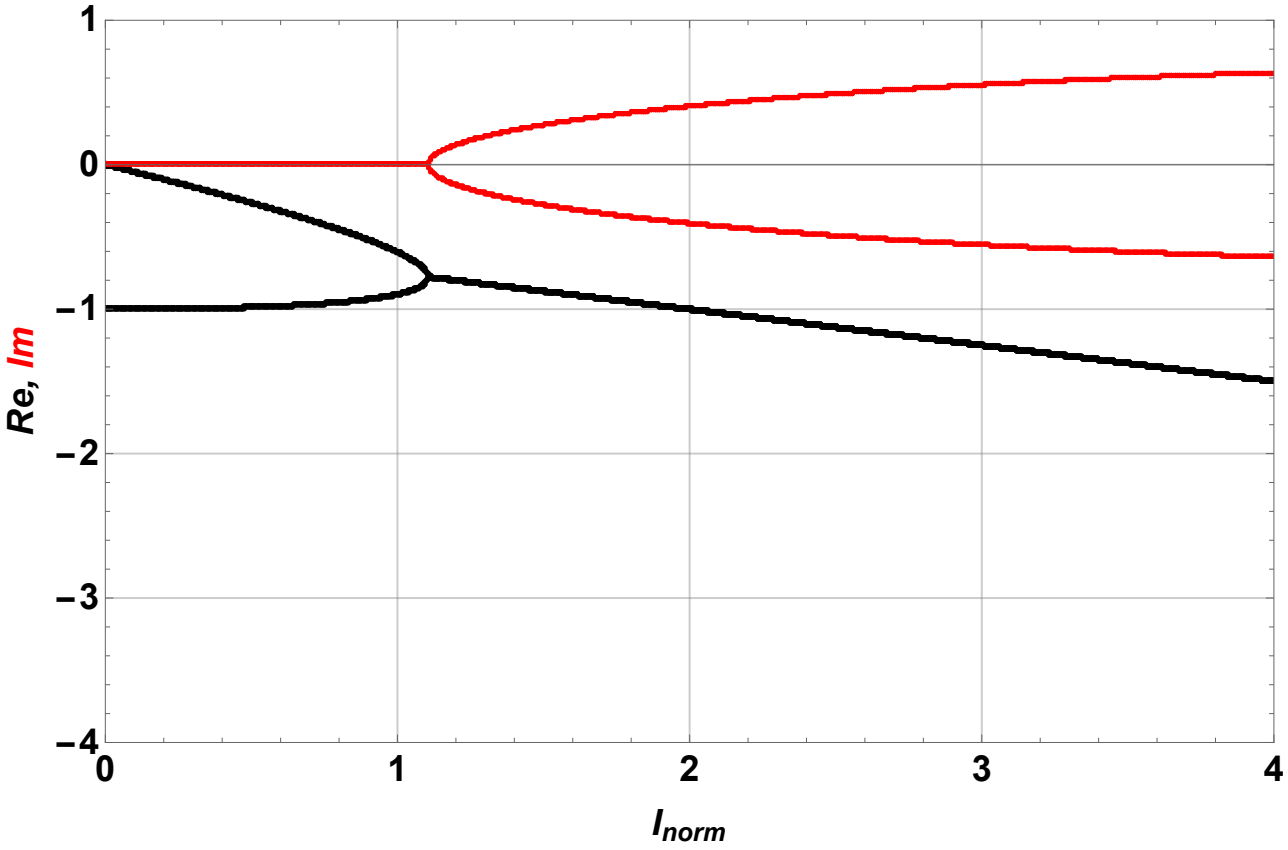

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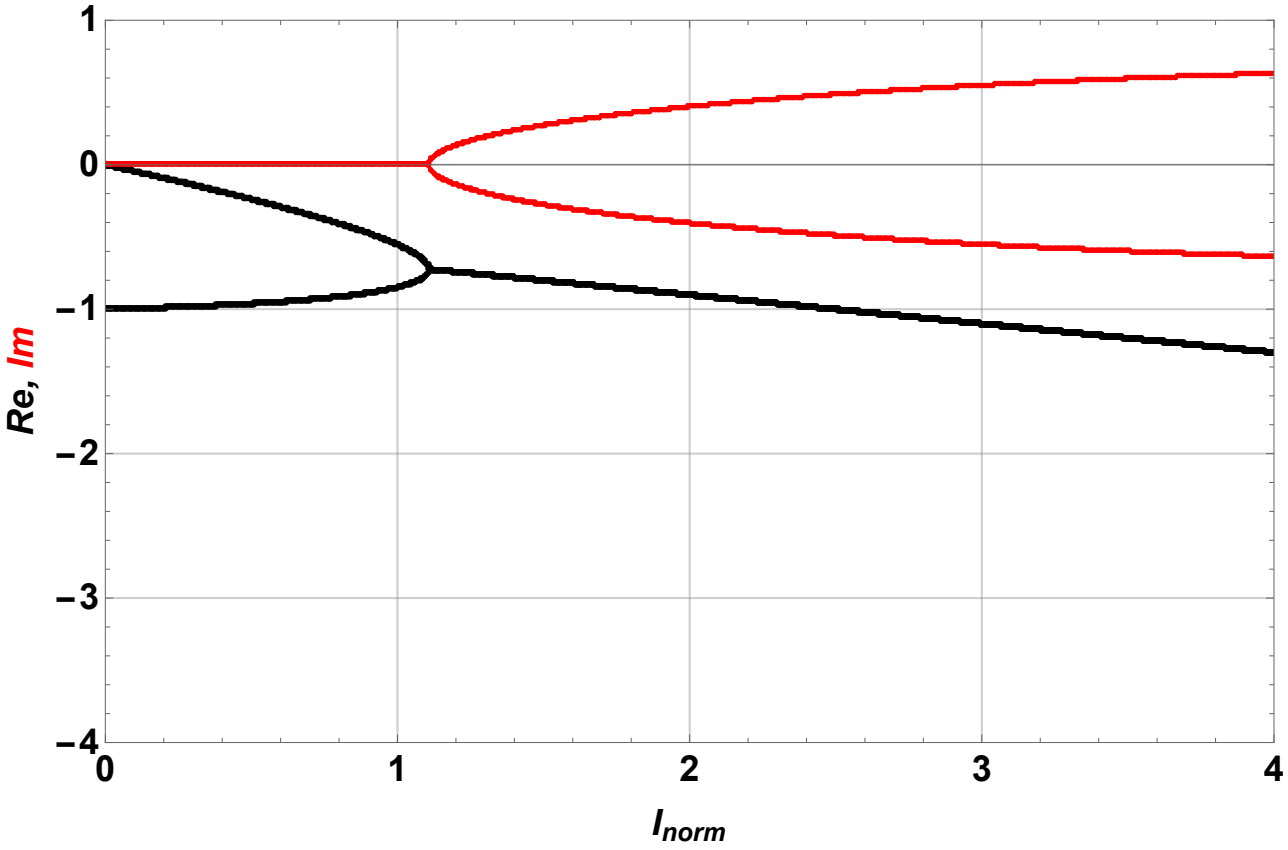
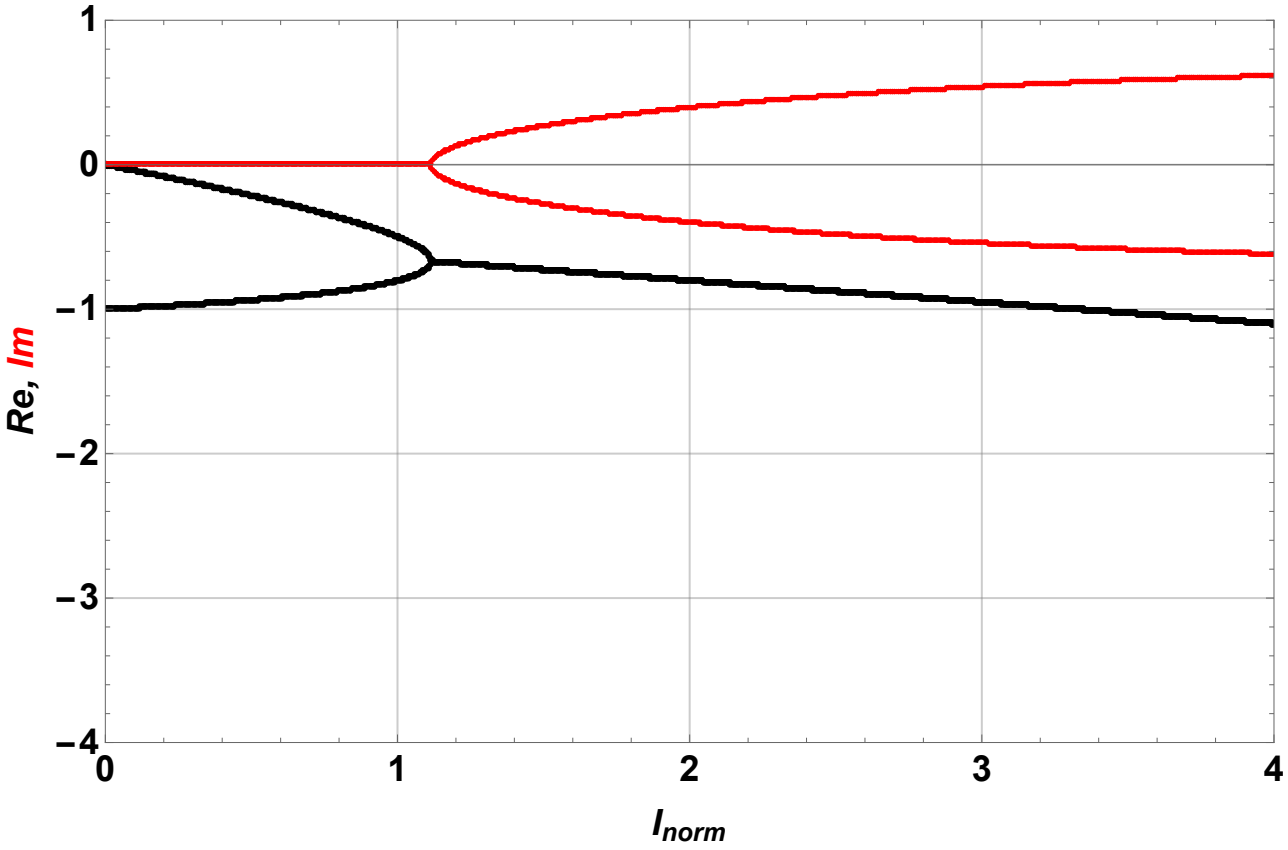
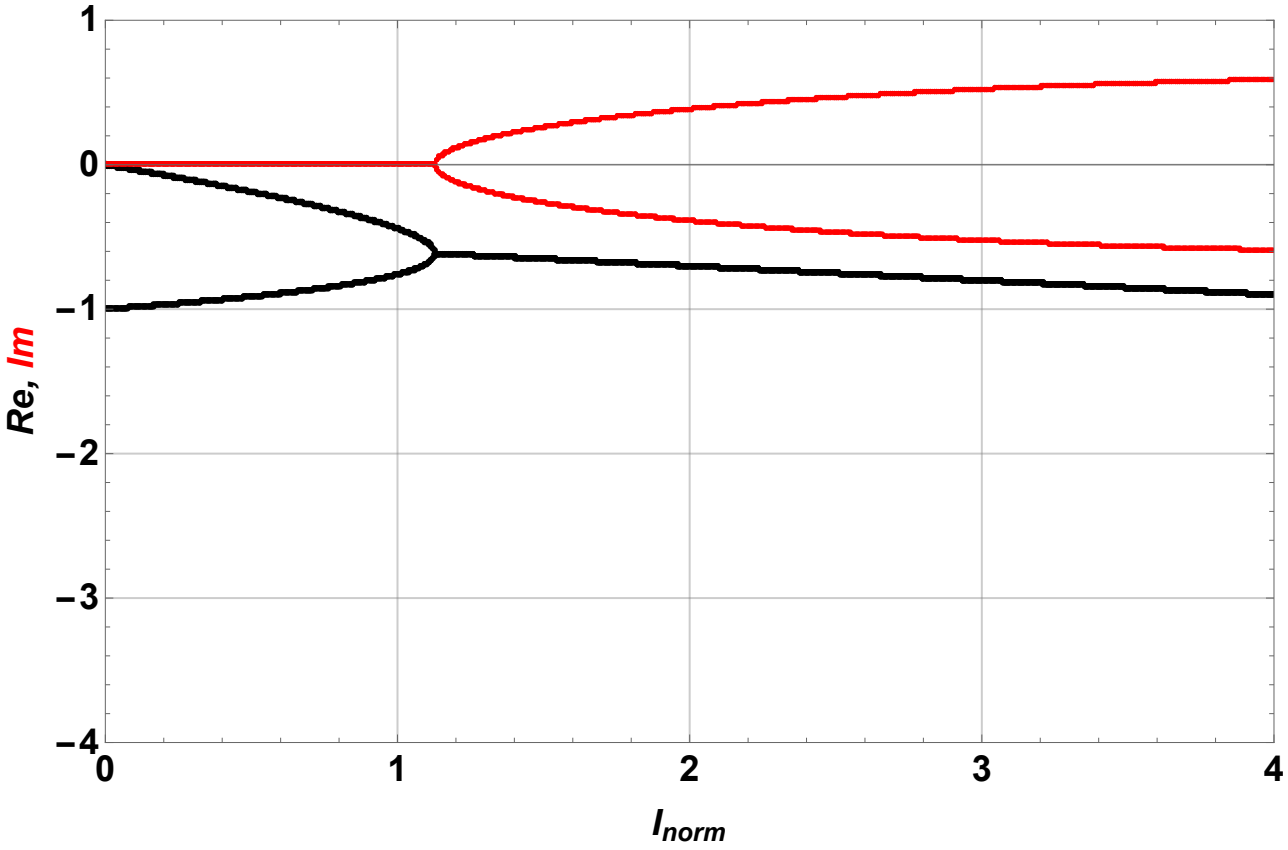


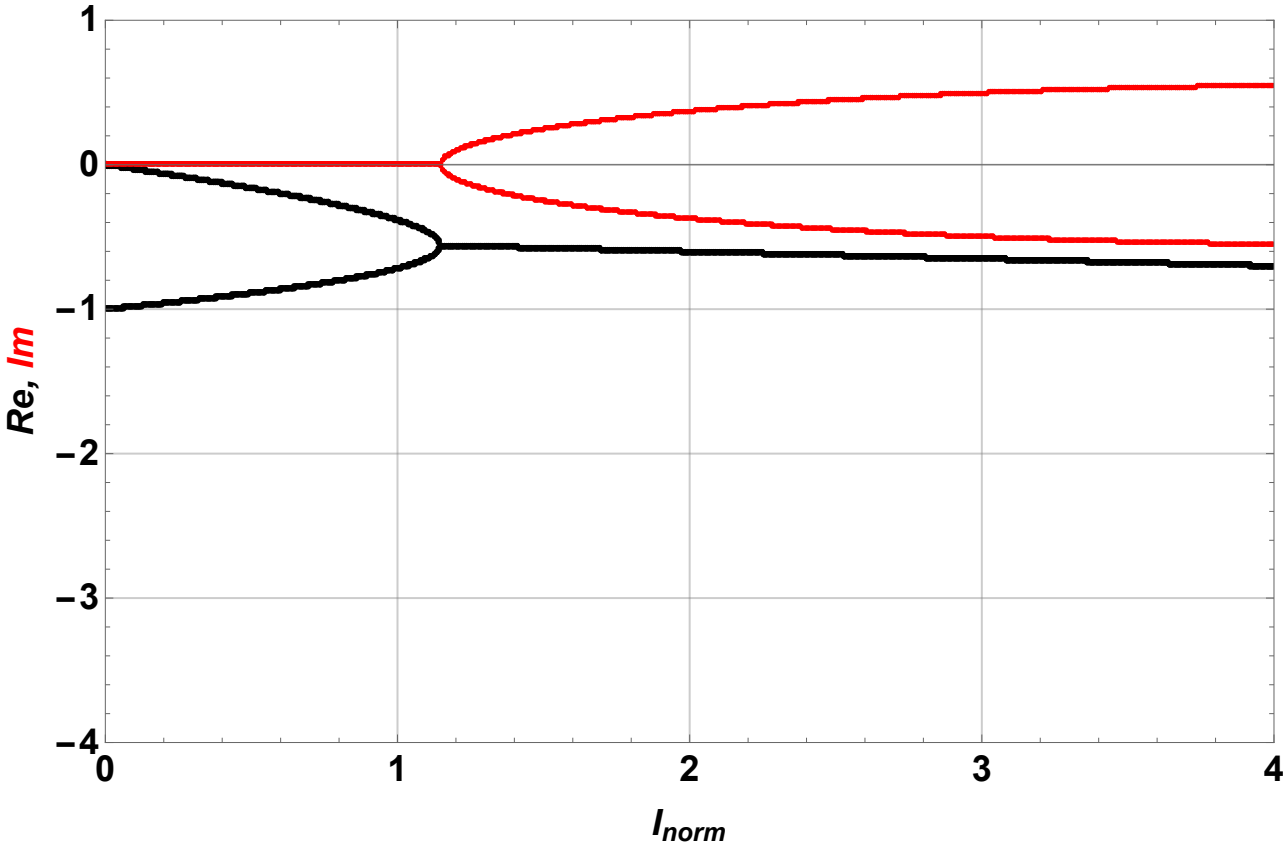
2) Detuning impedance: $\kappa = 0.2$



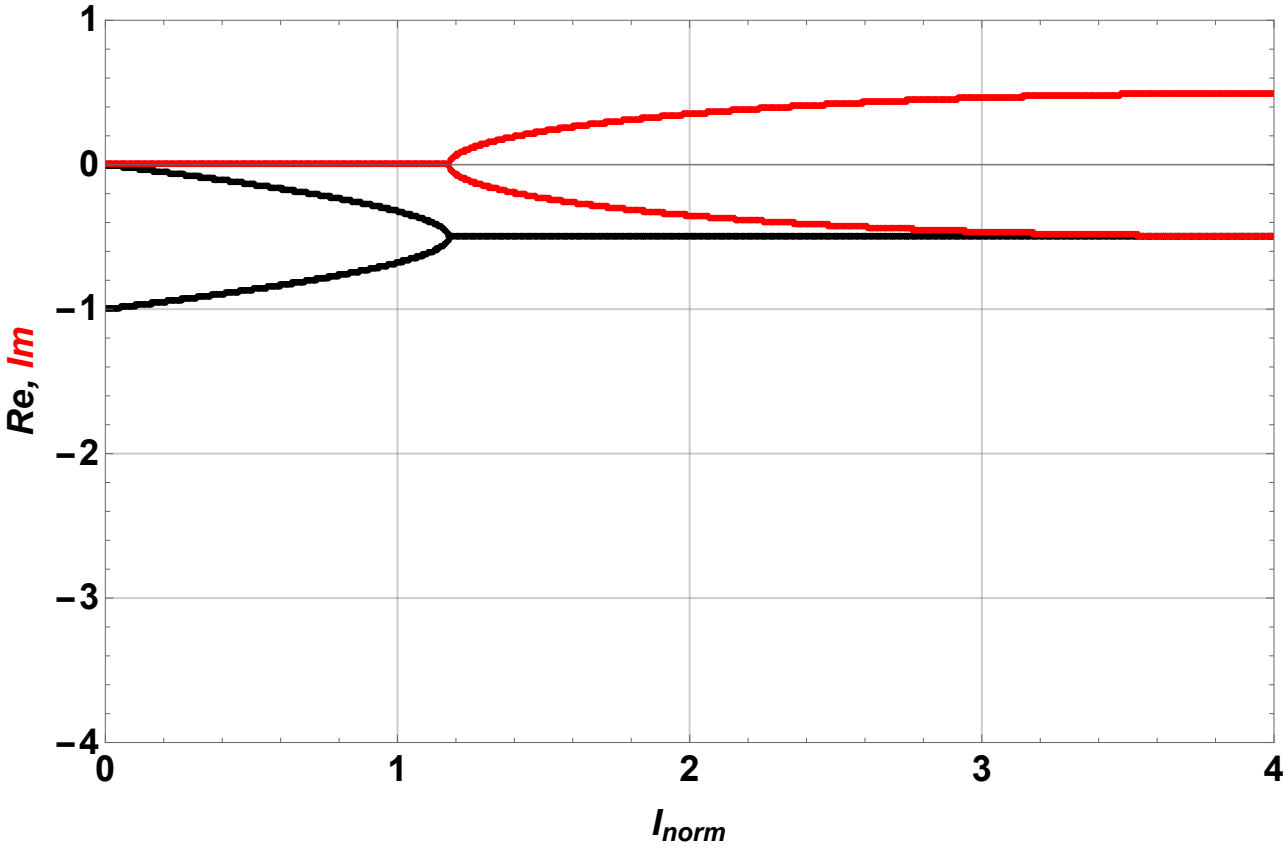
2) Detuning impedance: $\kappa = 0.3$



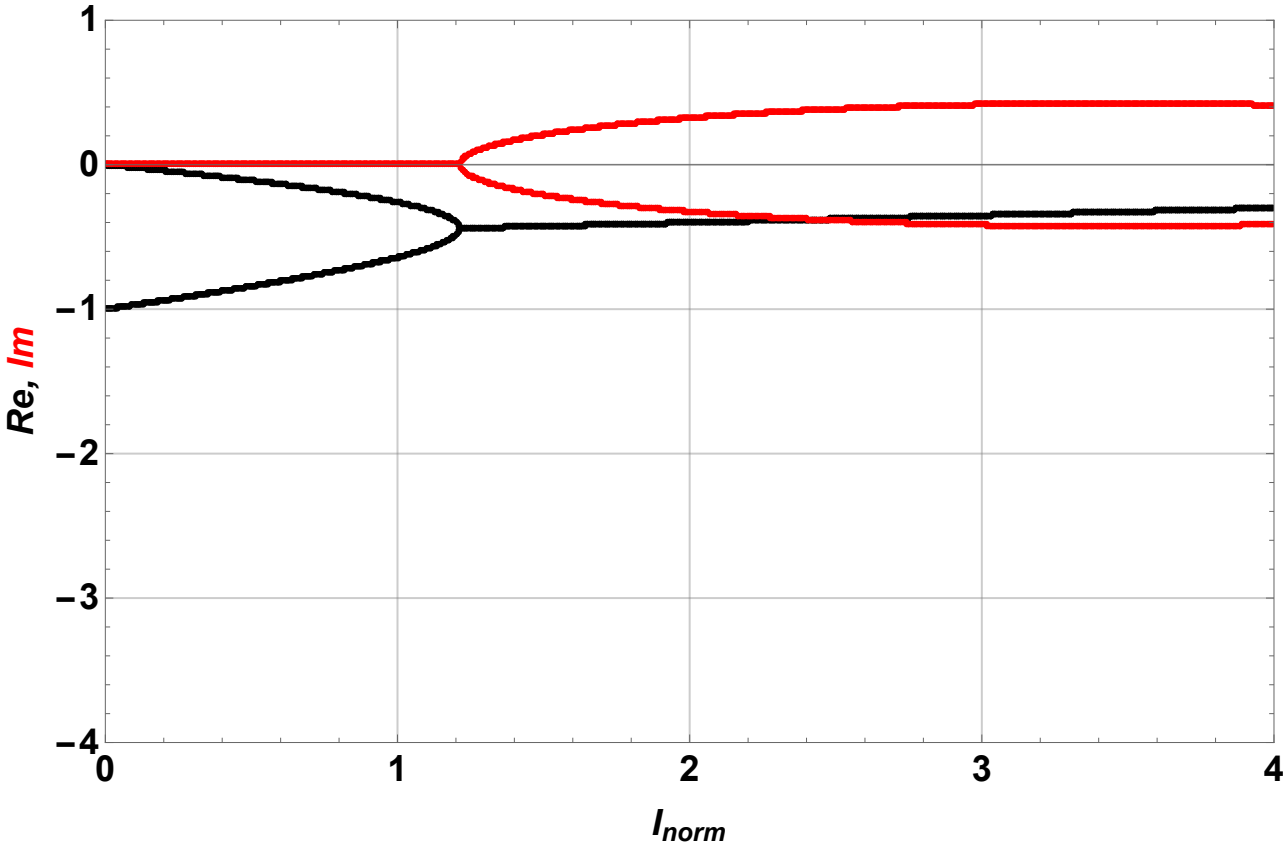
2) Detuning impedance: $\kappa = 0.4$



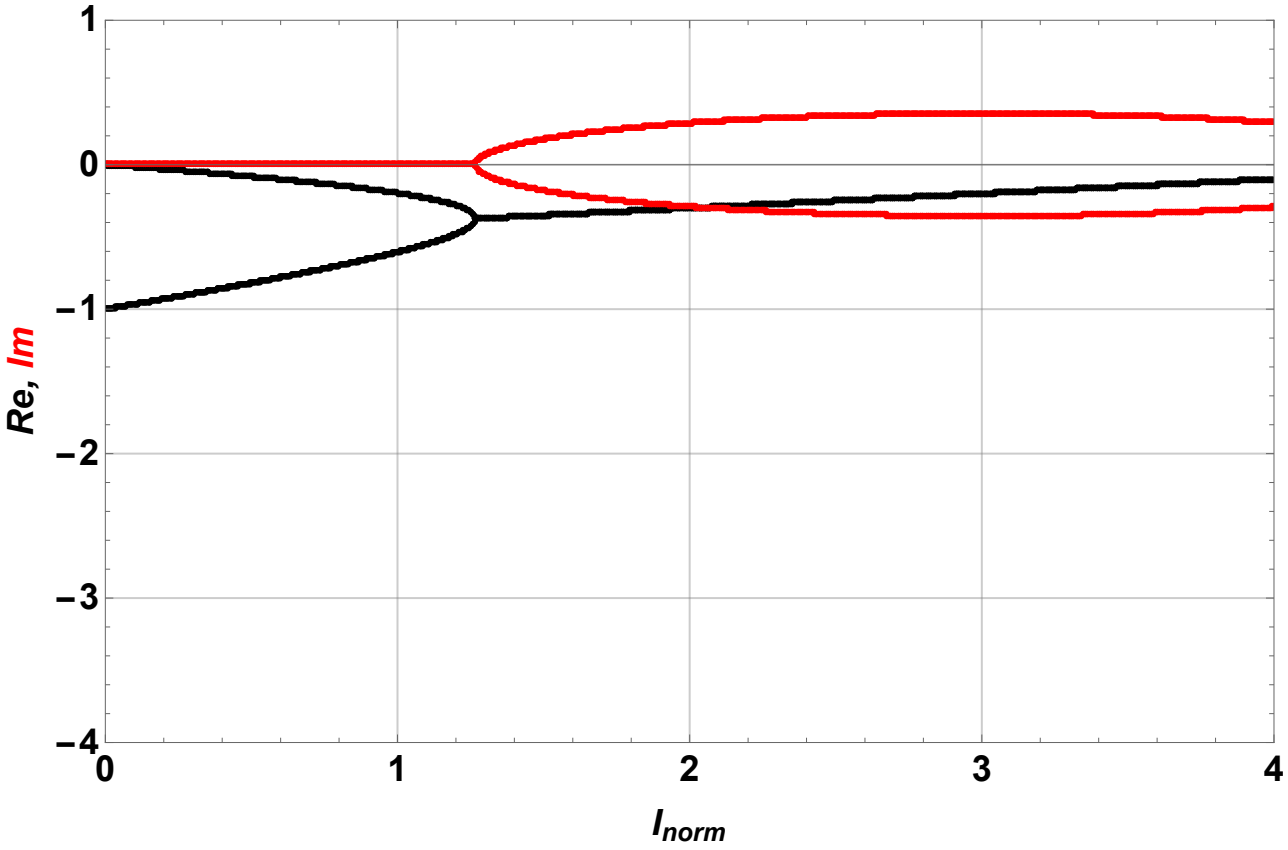
2) Detuning impedance: $\kappa = 0.5$



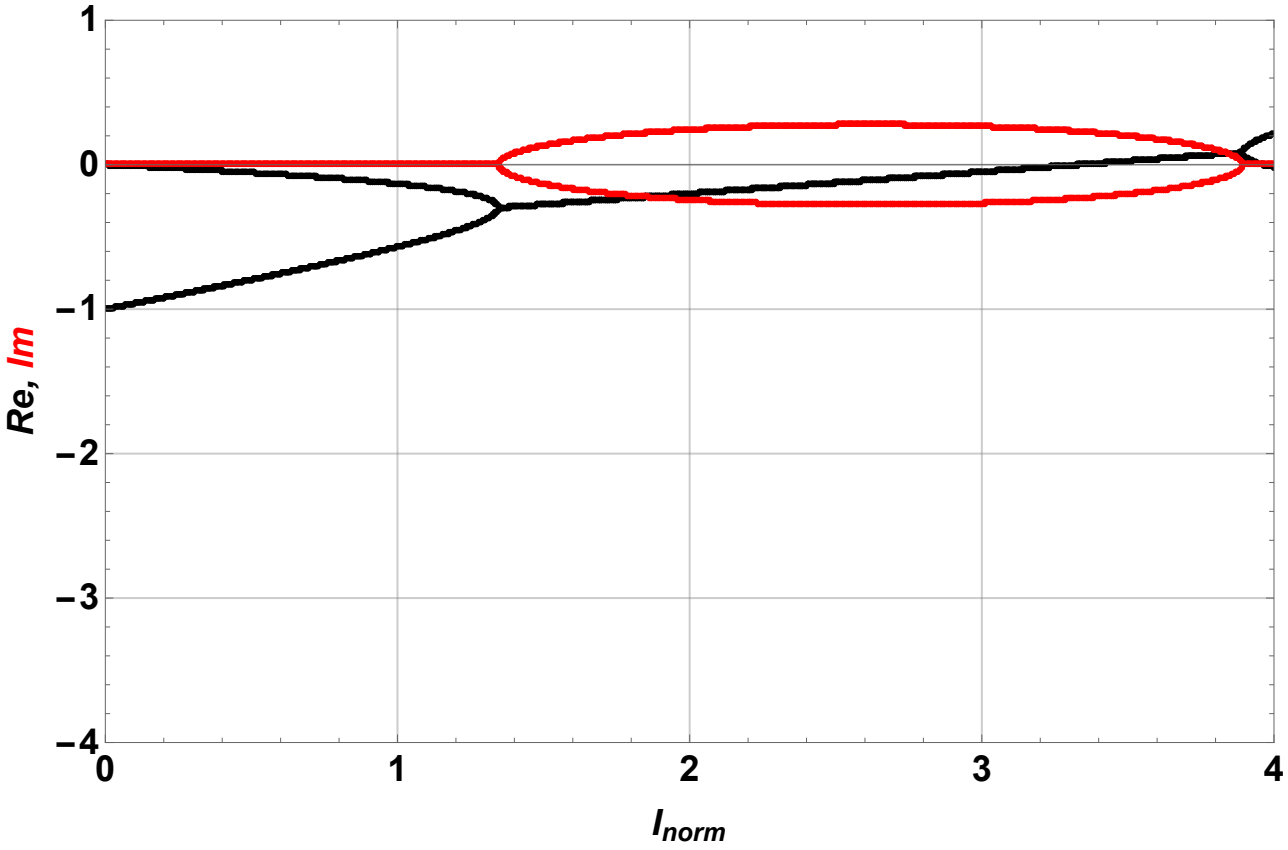
2) Detuning impedance: $\kappa = 0.6$



2) Detuning impedance: $\kappa = 0.7$



2) Detuning impedance: $\kappa = 0.8$



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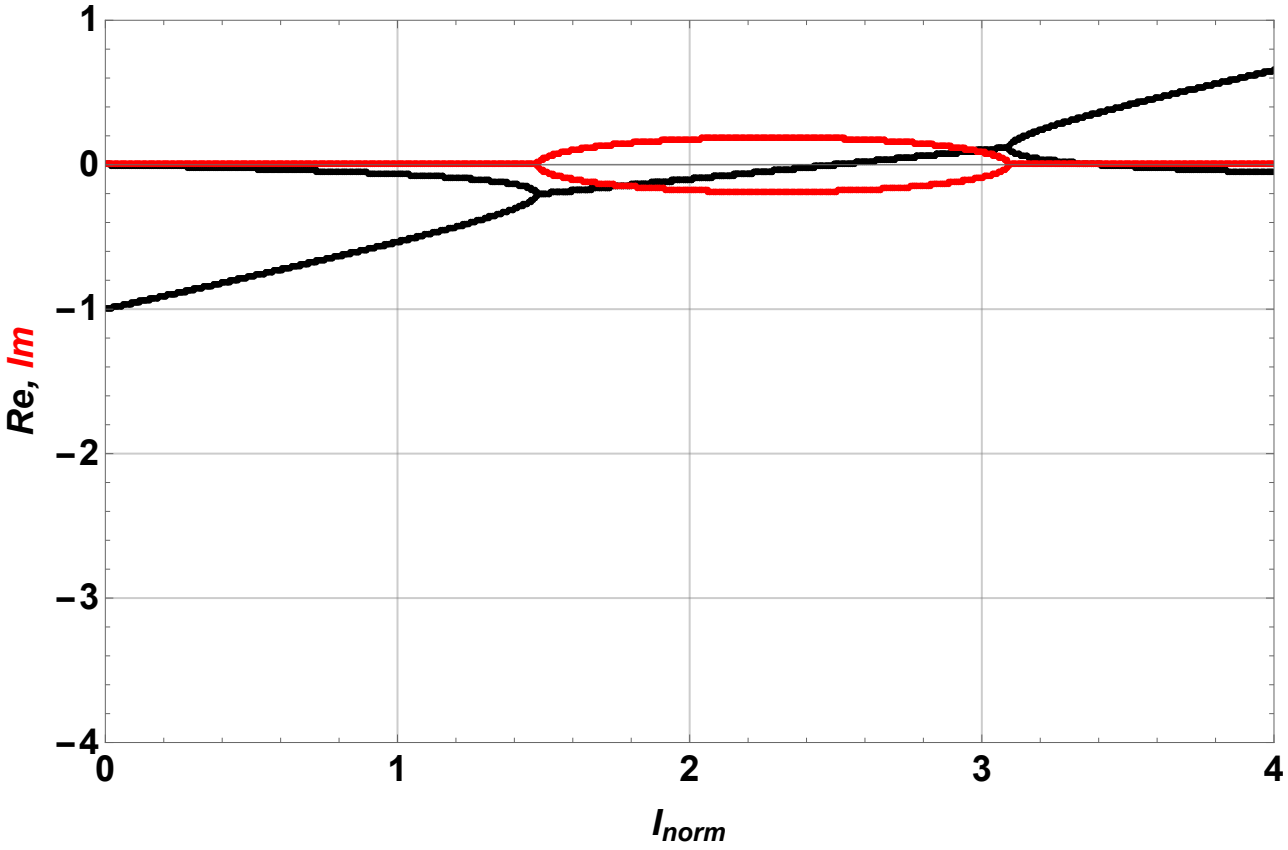
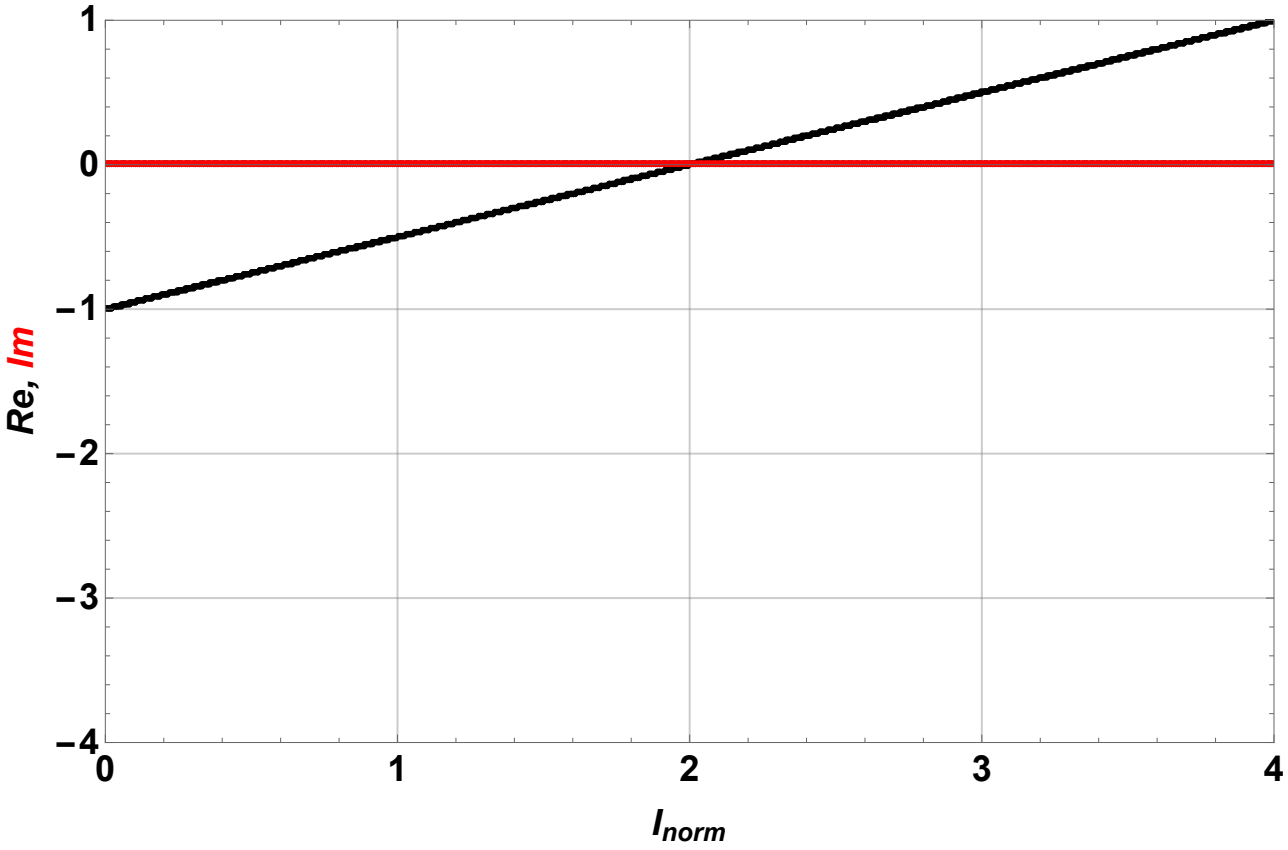


2) Detuning impedance: $\kappa = 1.0$



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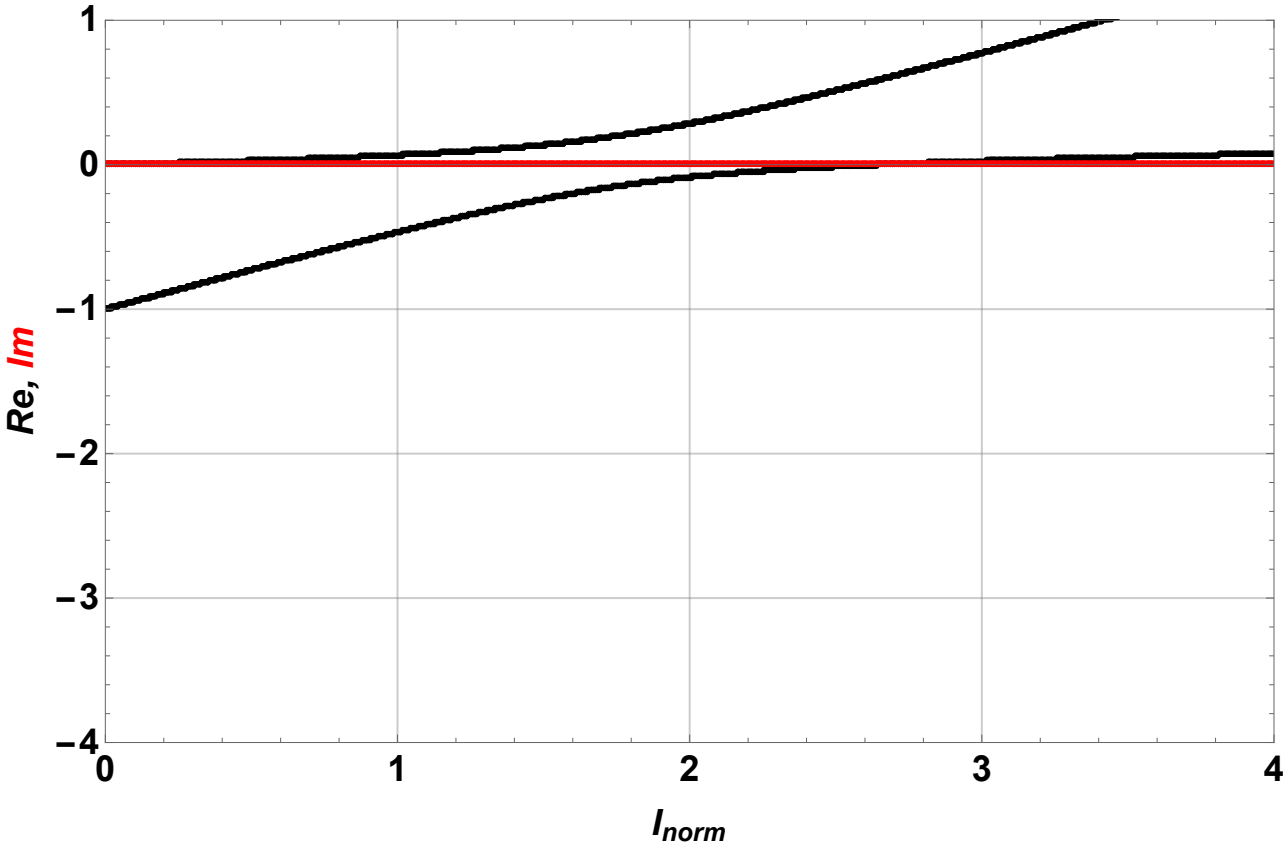

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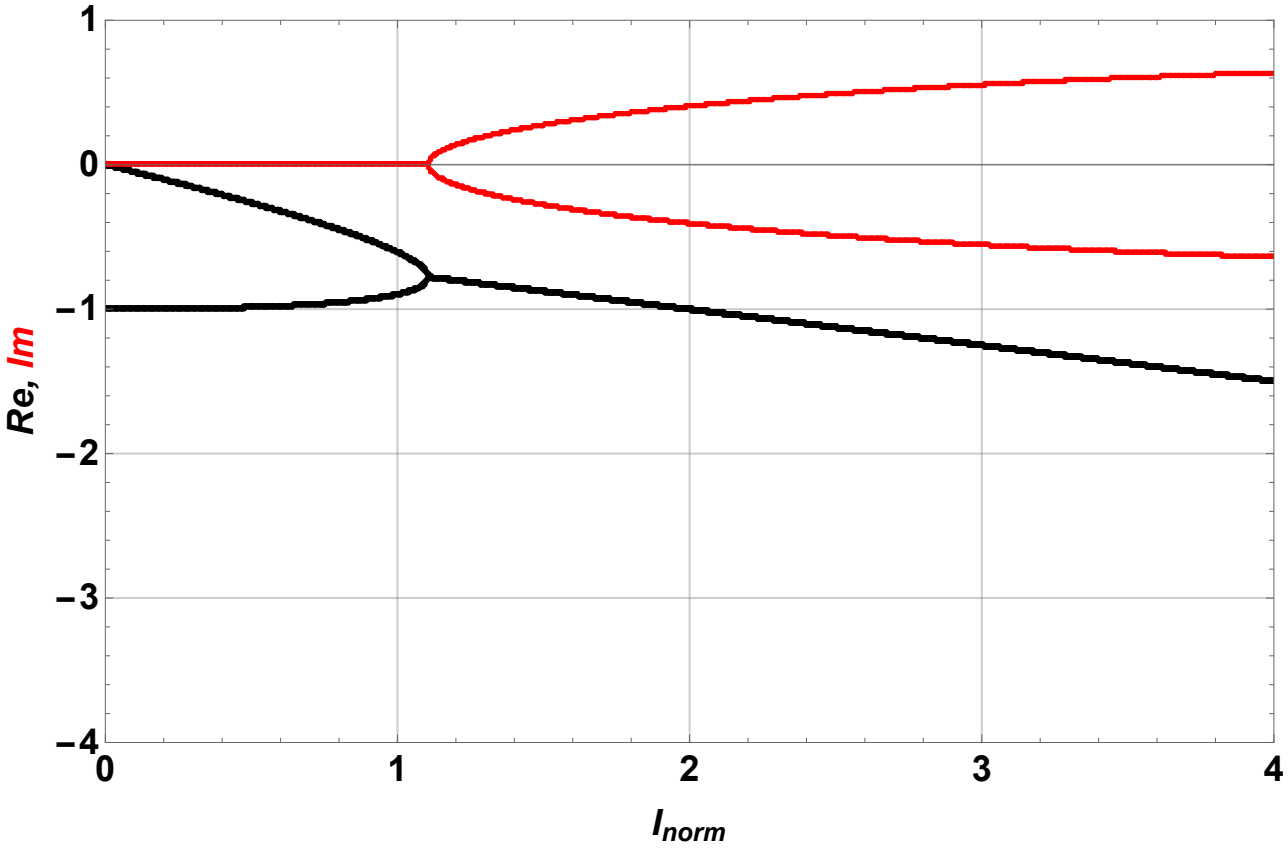
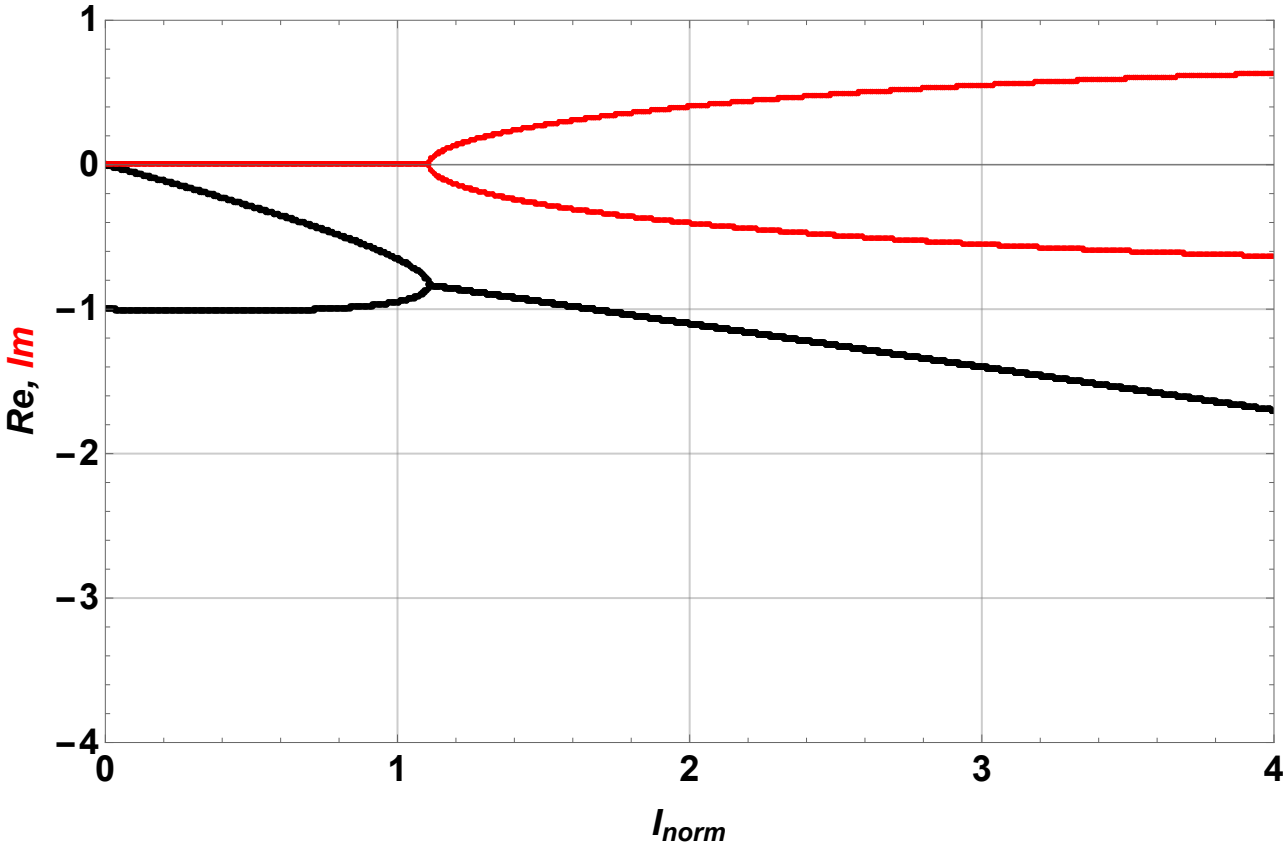


2) Detuning impedance: $\kappa = -0.1$



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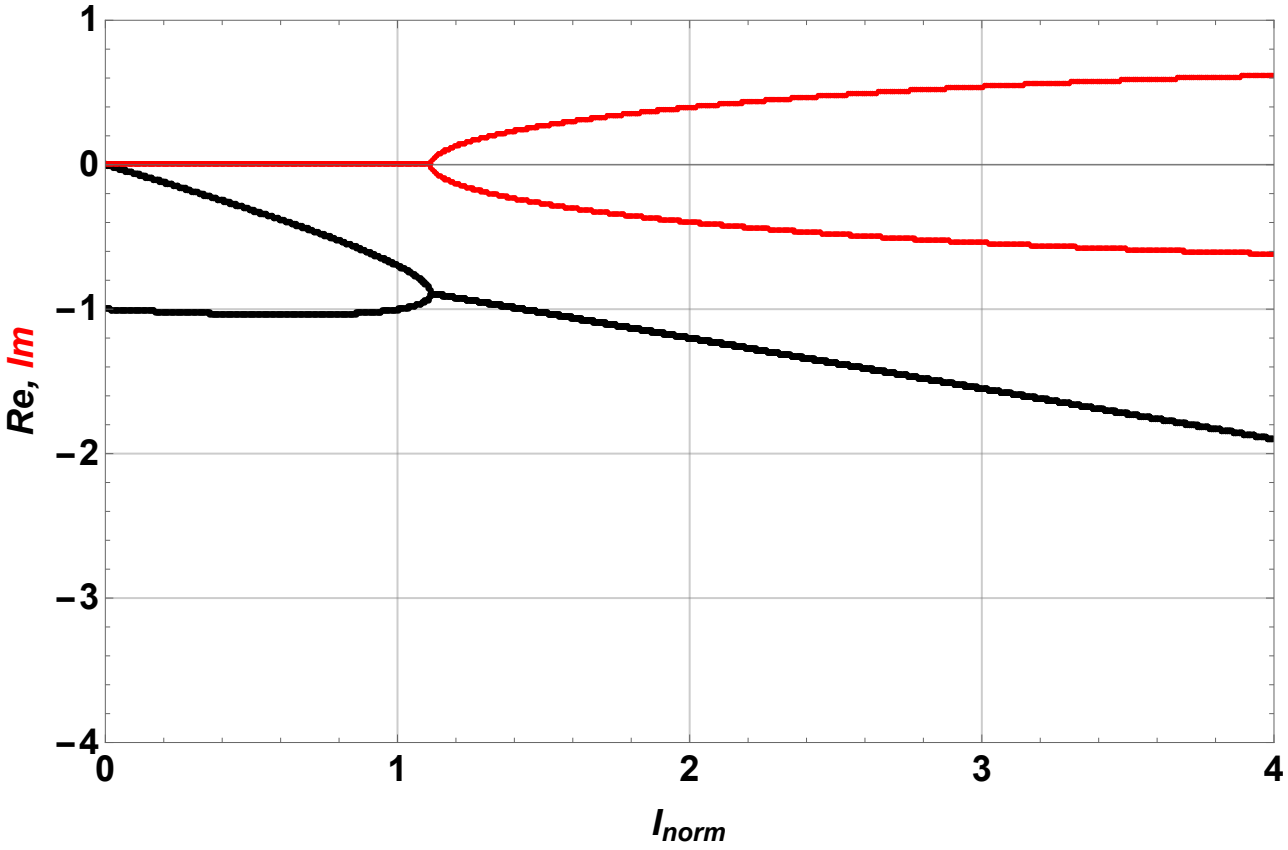

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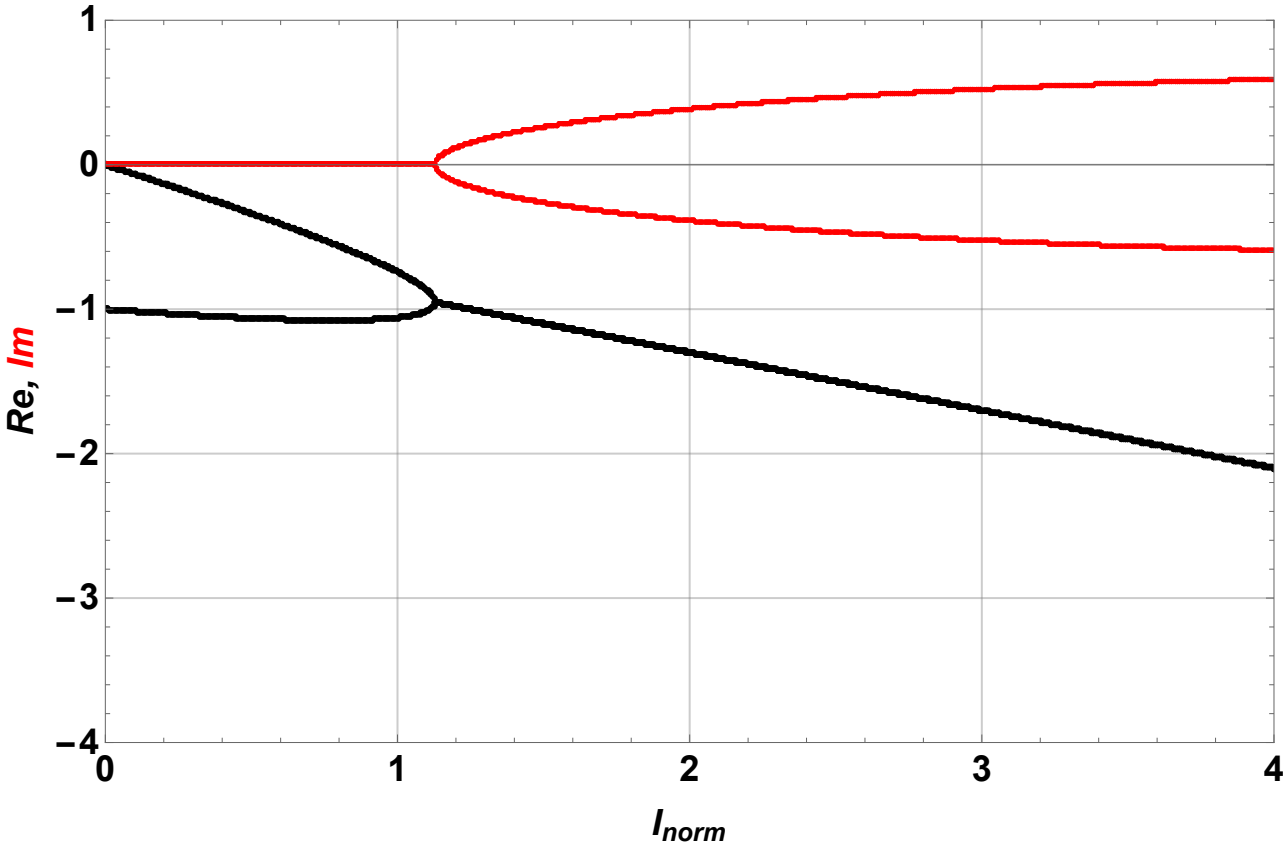
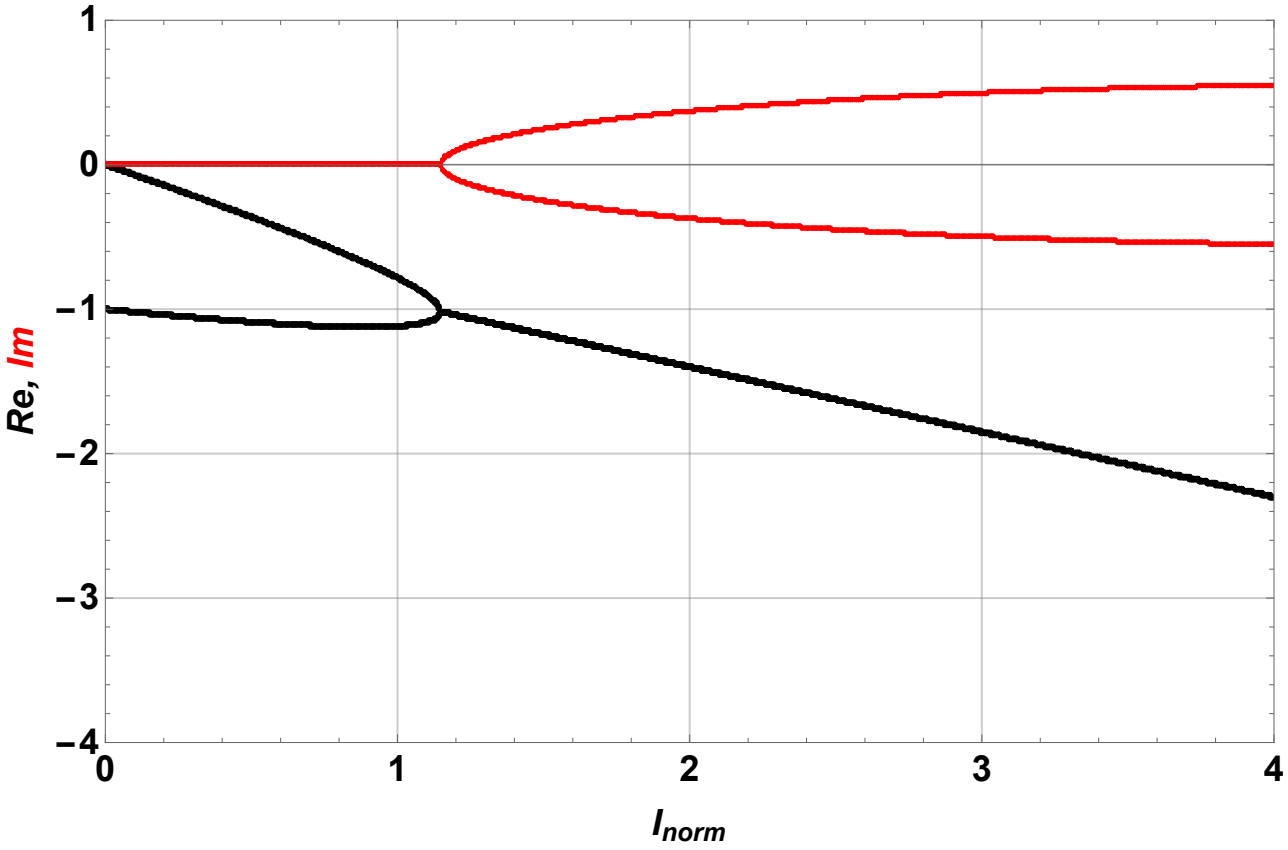
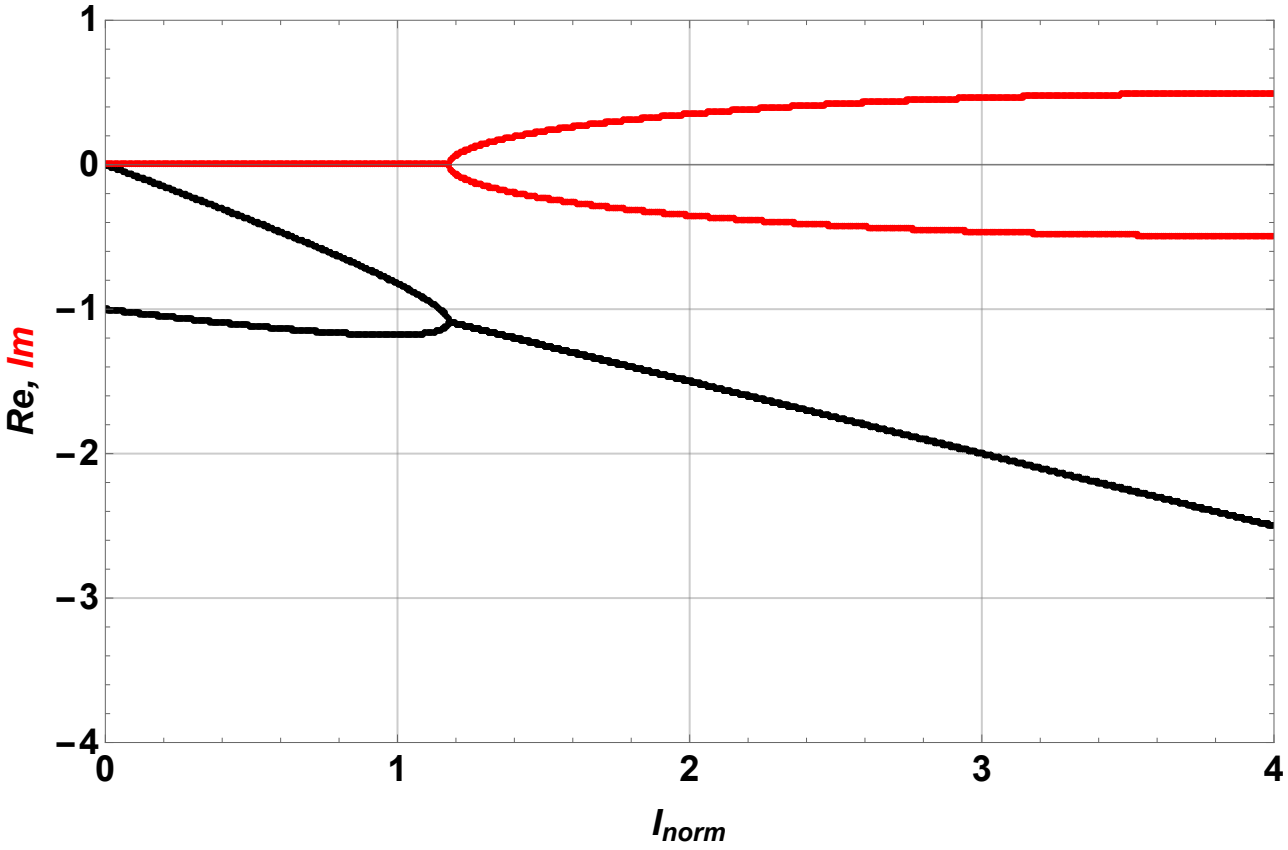


2) Detuning impedance: $\kappa = -0.4$



2) Detuning impedance: $\kappa = -0.5$



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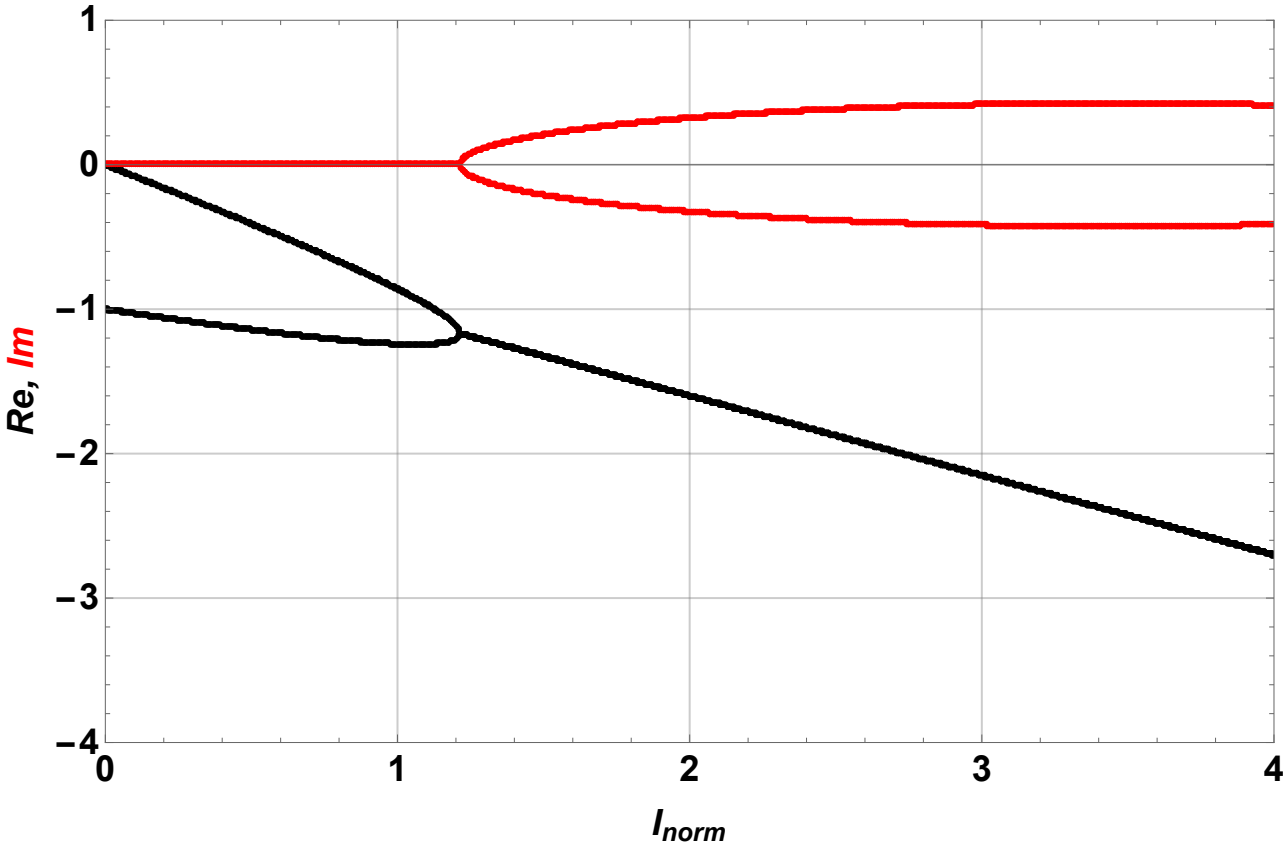
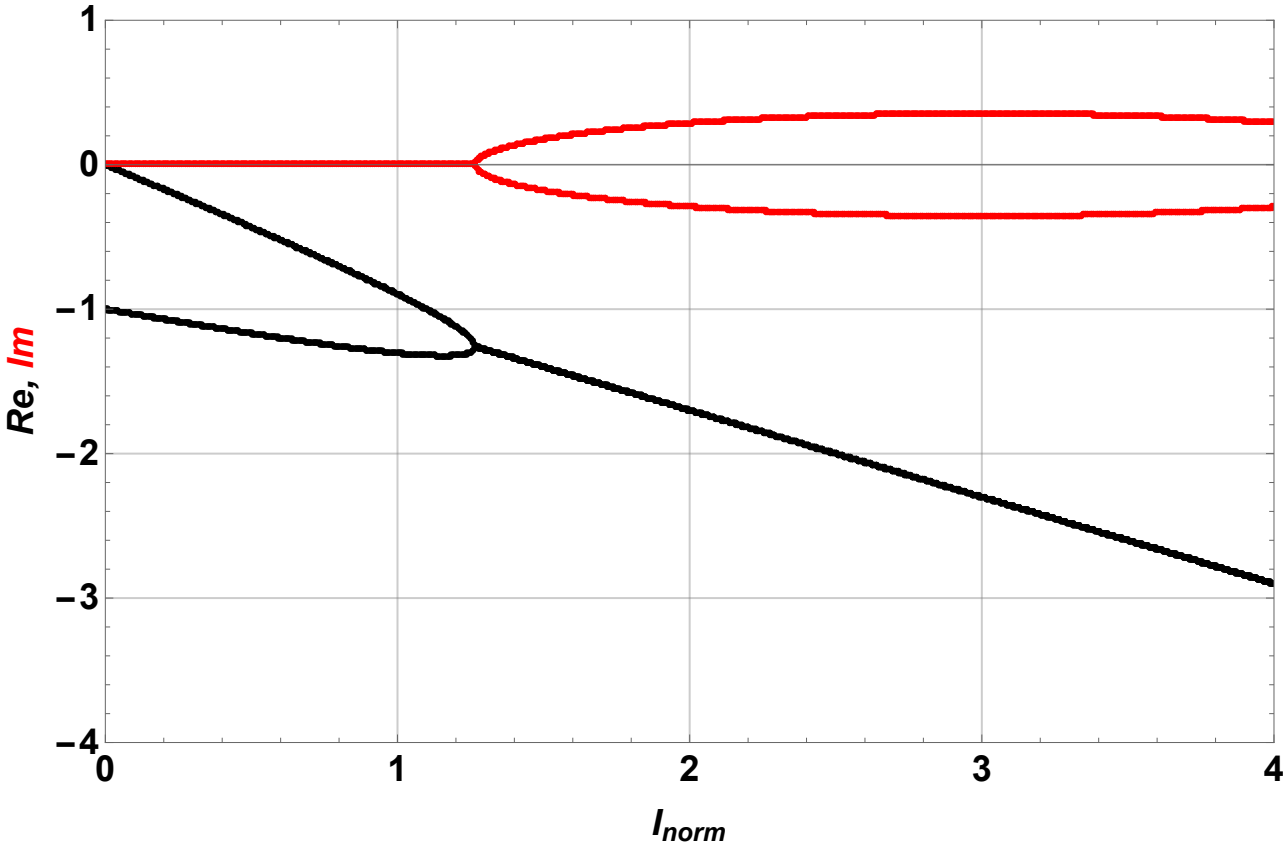
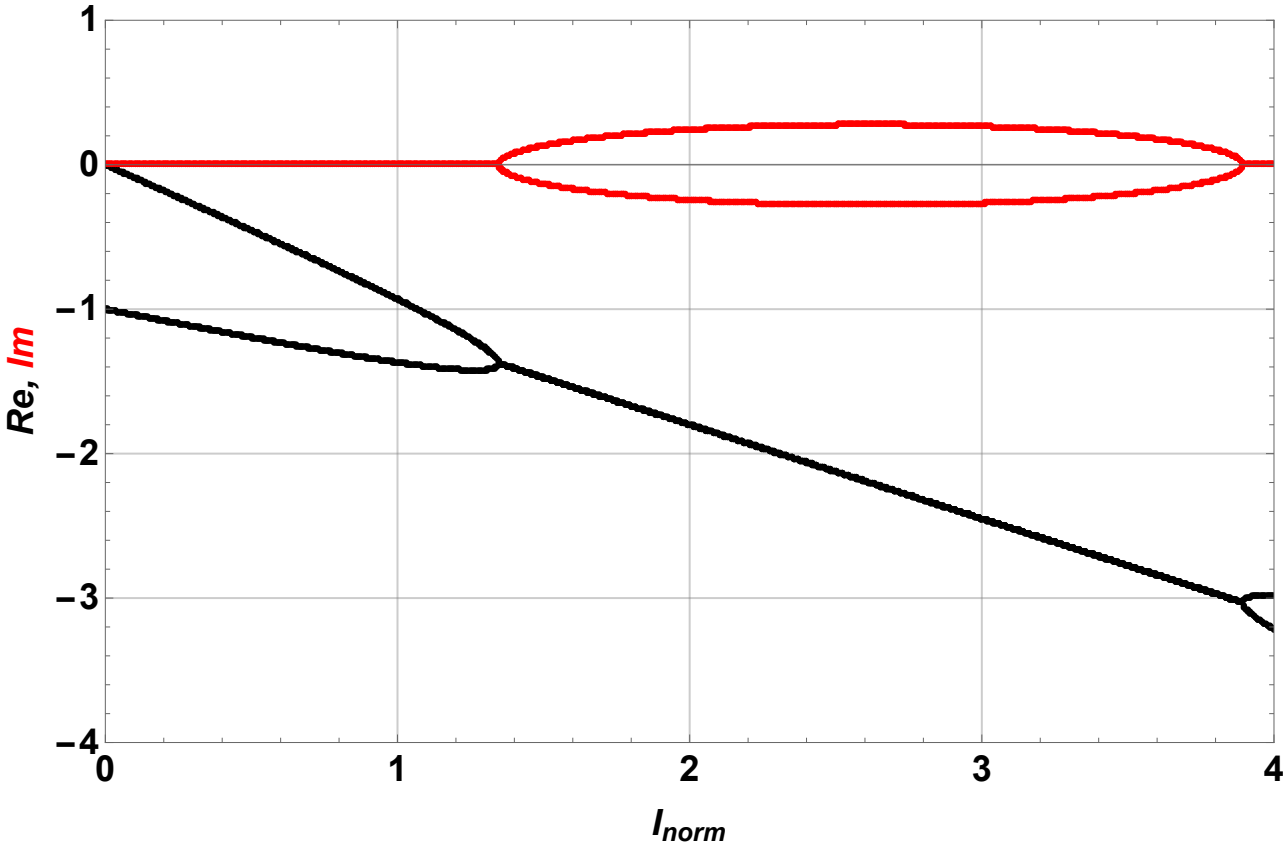


2) Detuning impedance: $\kappa = -0.7$



2) Detuning impedance: $\kappa = -0.8$



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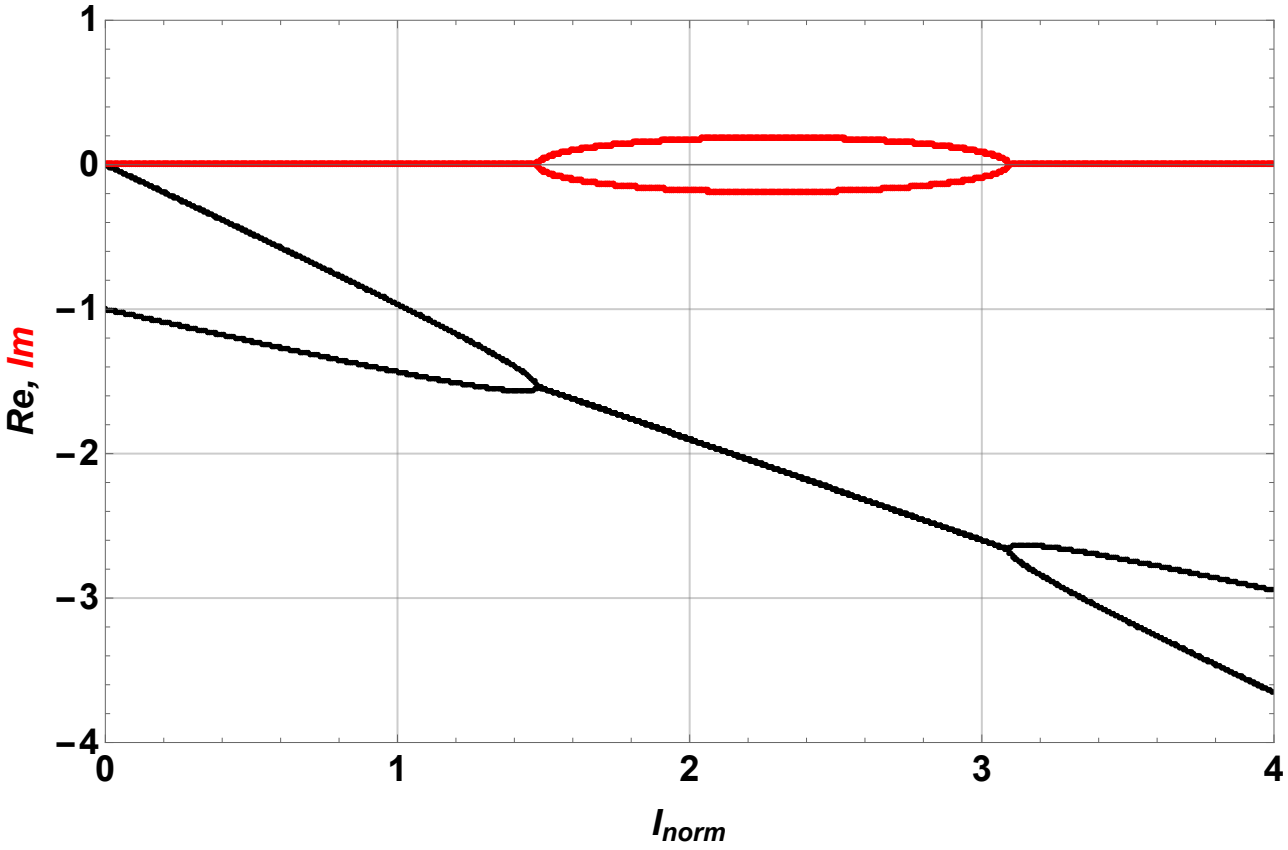
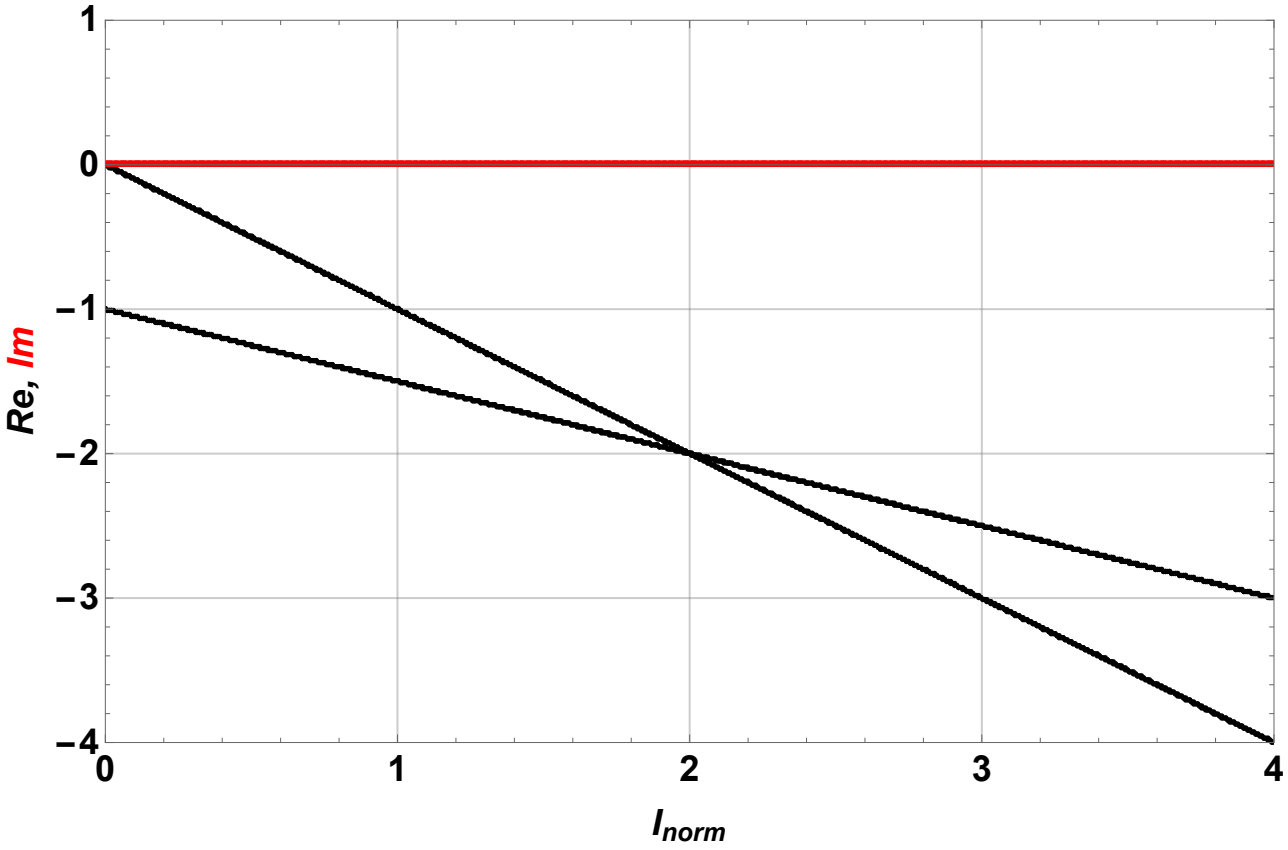
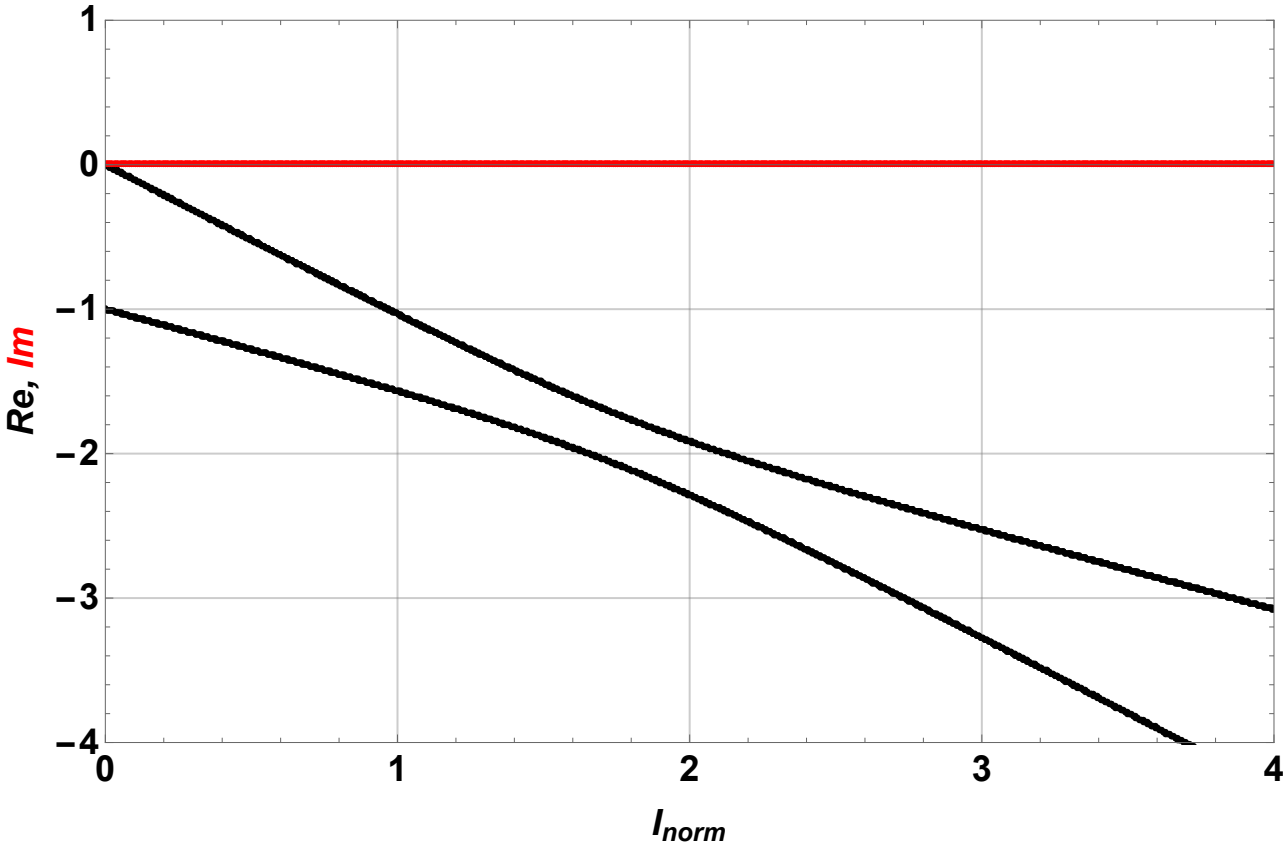


2) Detuning impedance: $\kappa = -1.0$



2) Detuning impedance: $\kappa = -1.1$



2) Detuning impedance

- These results are in good agreement with the results from G. Rumolo who extended the 2-particle model (CERN HSC section meeting, 12/08/19)

https://indico.cern.ch/event/832772/contributions/3523440/attachments/1892401/3121154/HSC-20190812.pdf

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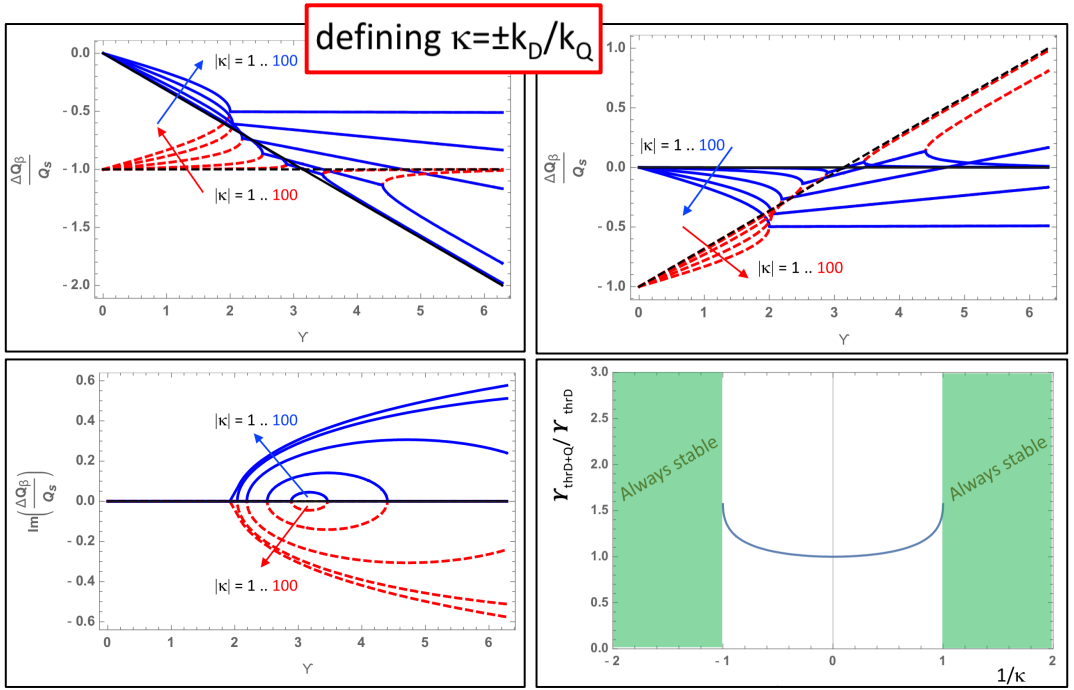

G. Rumolo

https://indico.cern.ch/event/832772/contributions/3523440/attachments/1892401/3121154/HSC-20190812.pdf

2) Detuning impedance

- Considering now a BBR and many azimuthal modes (but still 1 radial mode), a good agreement is also obtained between theory and simulation

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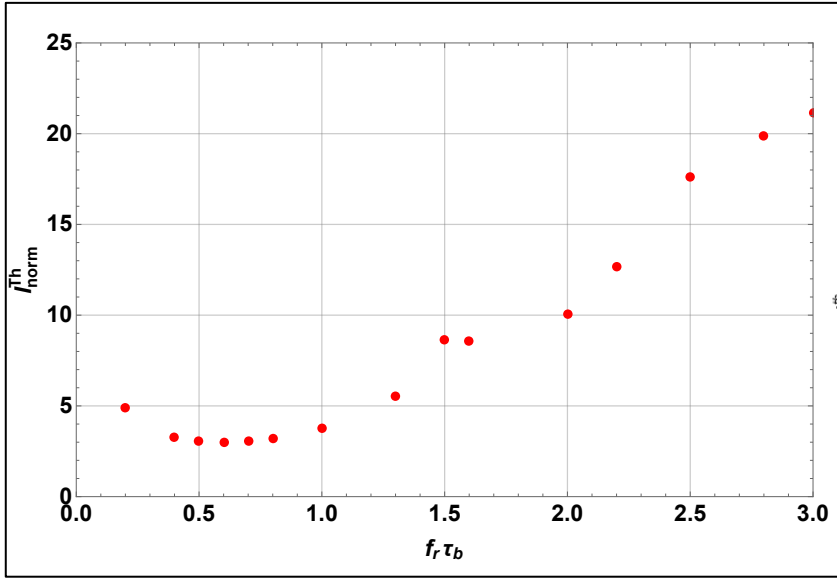
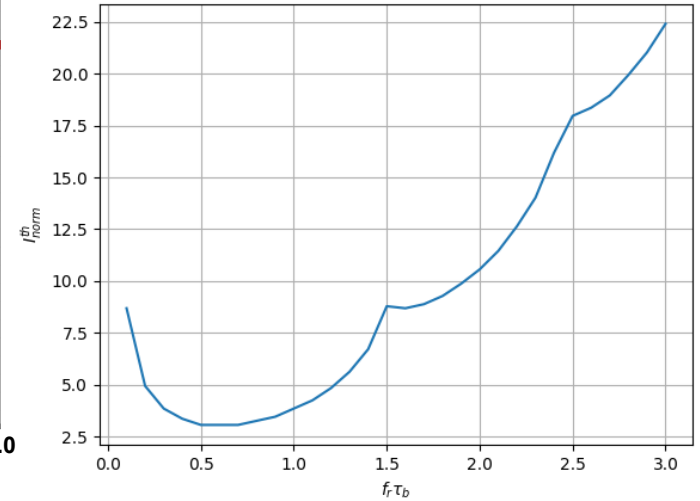
Theory

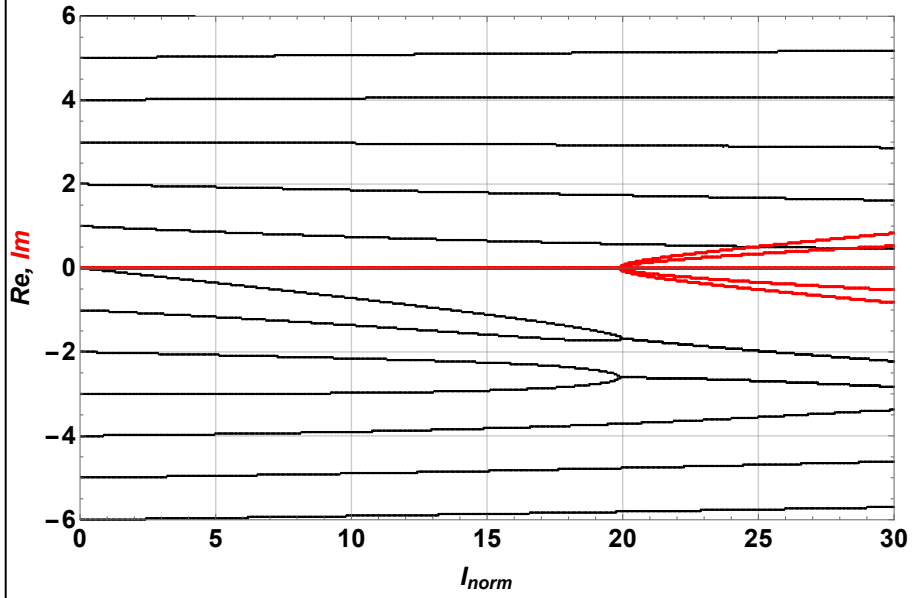


Simulation (X. Buffat)

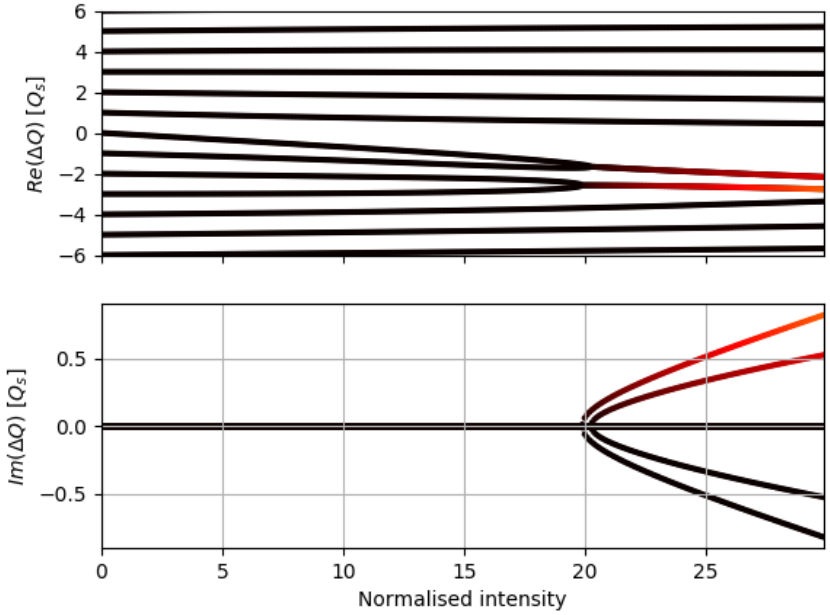


2) Detuning impedance

$f_r \tau_b = 2.8$ $\kappa = 0$



Circulant Matrix (XavierB)



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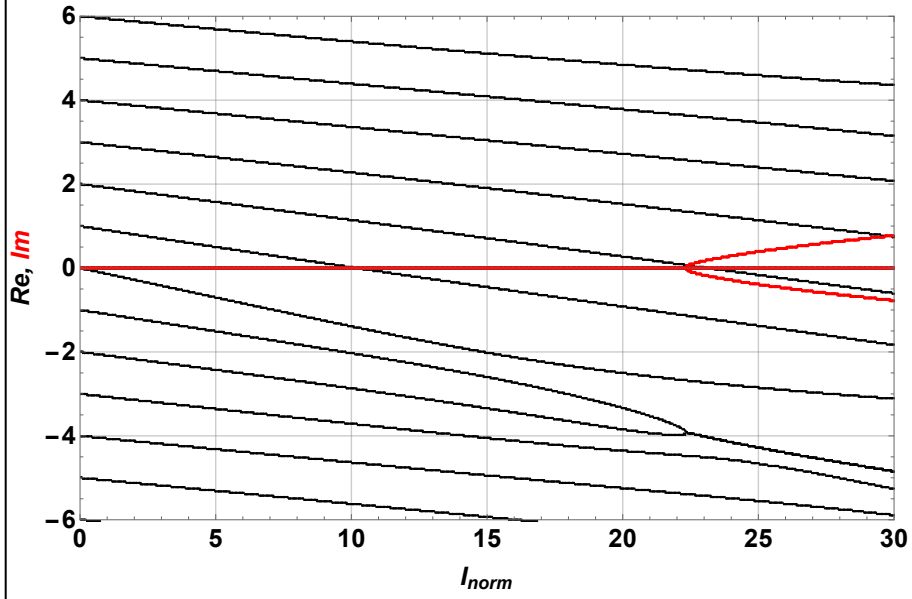

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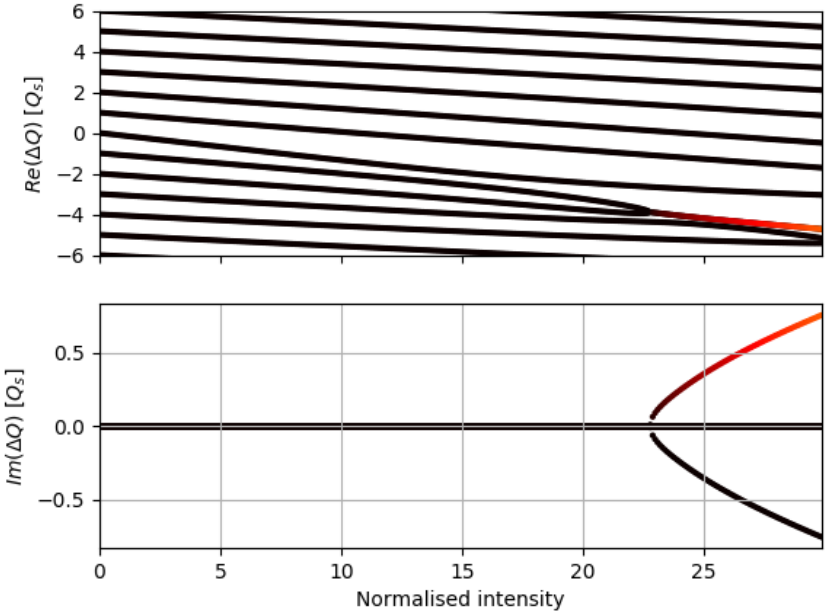

2) Detuning impedance

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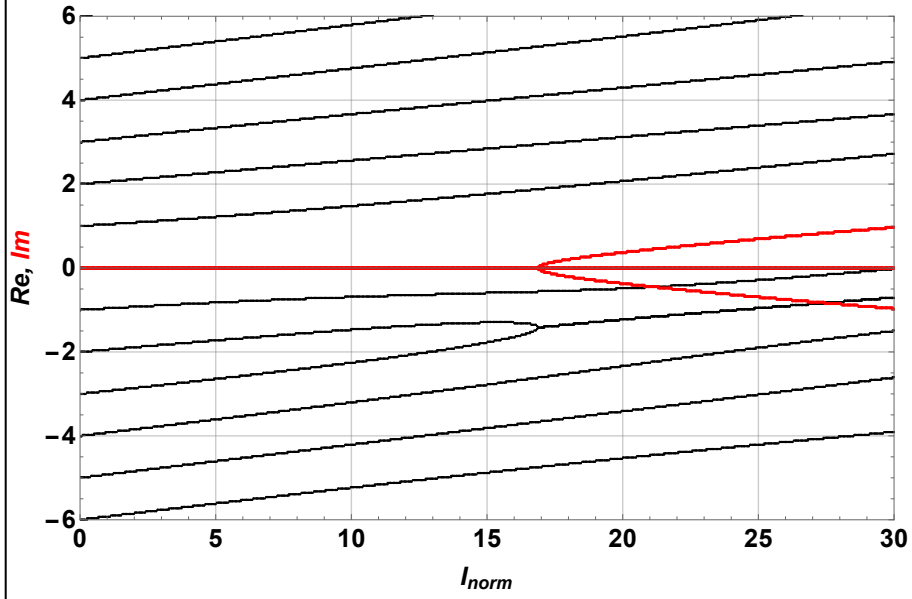

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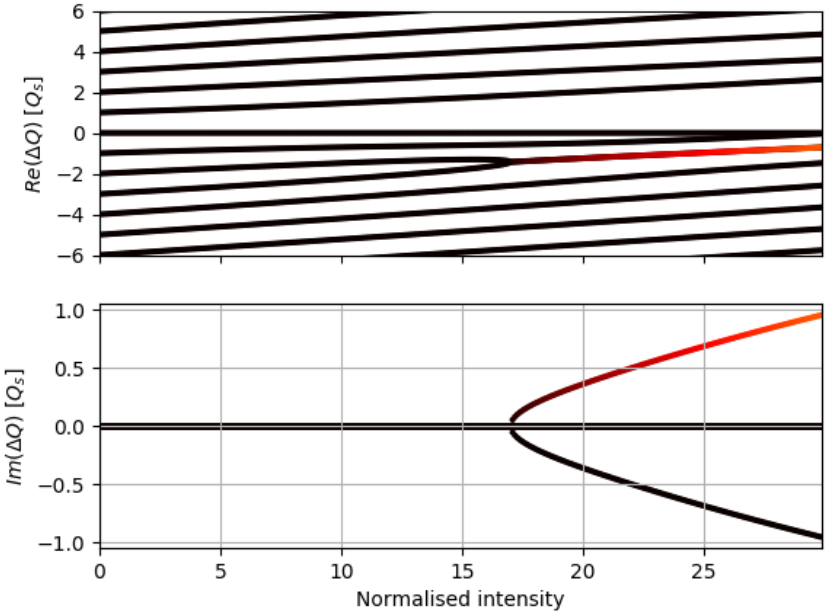

2) Detuning impedance

- Considering now also many radial modes, similar results as with past HEADTAIL simulations are obtained (simulation by X. Buffat)

https://indico.cern.ch/event/845121/contributions/3548940/attachments/1903962/3144197/2019-09-09_detuningWake-expanded.pdf

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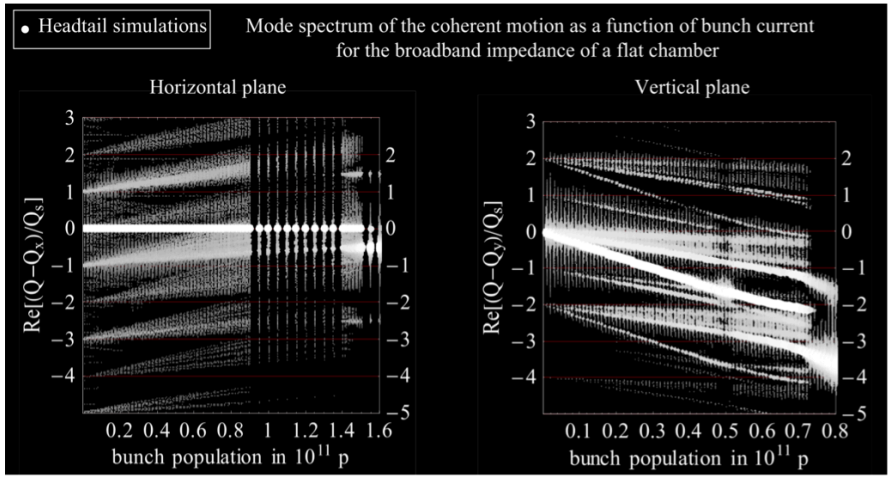

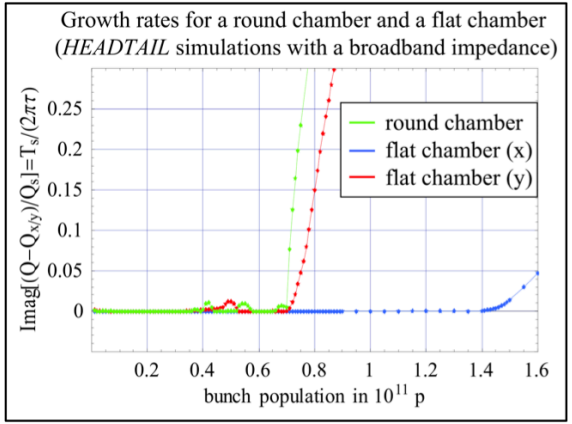

B. Salvant (PHD thesis)

=> $N_b^{th,x} / N_b^{th,round} \approx 2$ $N_b^{th,y} / N_b^{th,round} \approx 1$

https://indico.cern.ch/event/845121/contributions/3548940/attachments/1903962/3144197/2019-09-09_detuningWake-expanded.pdf

3) Linear coupling

- Considering the case of the SPS with a BBR (and a flat chamber)

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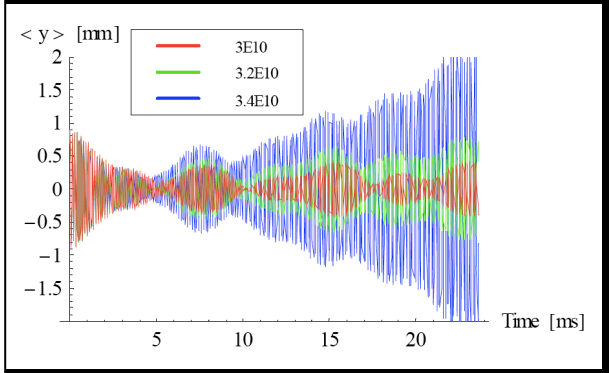
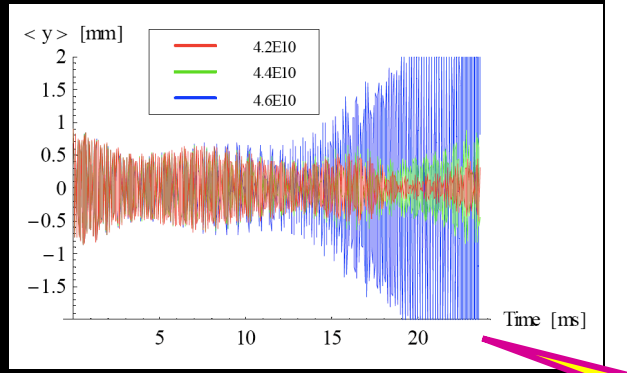
WITHOUT LINEAR COUPLING | **WITH LINEAR COUPLING**





1024 turns

$Q_x = 26.180$ $Q_y = 26.185$ $\xi_{x,y} = 0$

$K_{skew}^{\text{HEADTAIL}} = 0.005\ \text{m}^{-1}$

=> The vertical intensity threshold is increased from ~ 3.3E10 p/b to ~ 4.5E10 p/b , i.e. an increase of 36%, in good agreement with a previous theoretical prediction of 33%

HEADTAIL

http://accelconf.web.cern.ch/AccelConf/e06/PAPERS/THPCH058.PDF

3) Linear coupling

- This result was checked/confirmed by B. Salvant (PHD thesis), simulating more (10 000) turns

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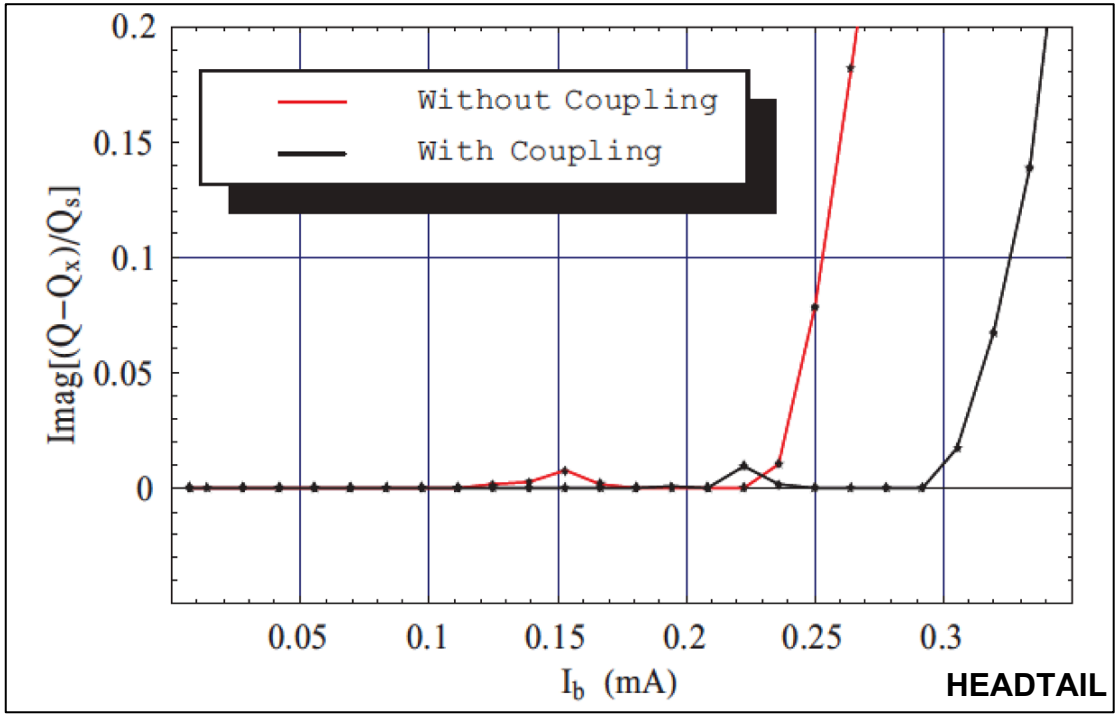

B. Salvant

4) Chromaticity

- Considering the case of the SPS with a BBR

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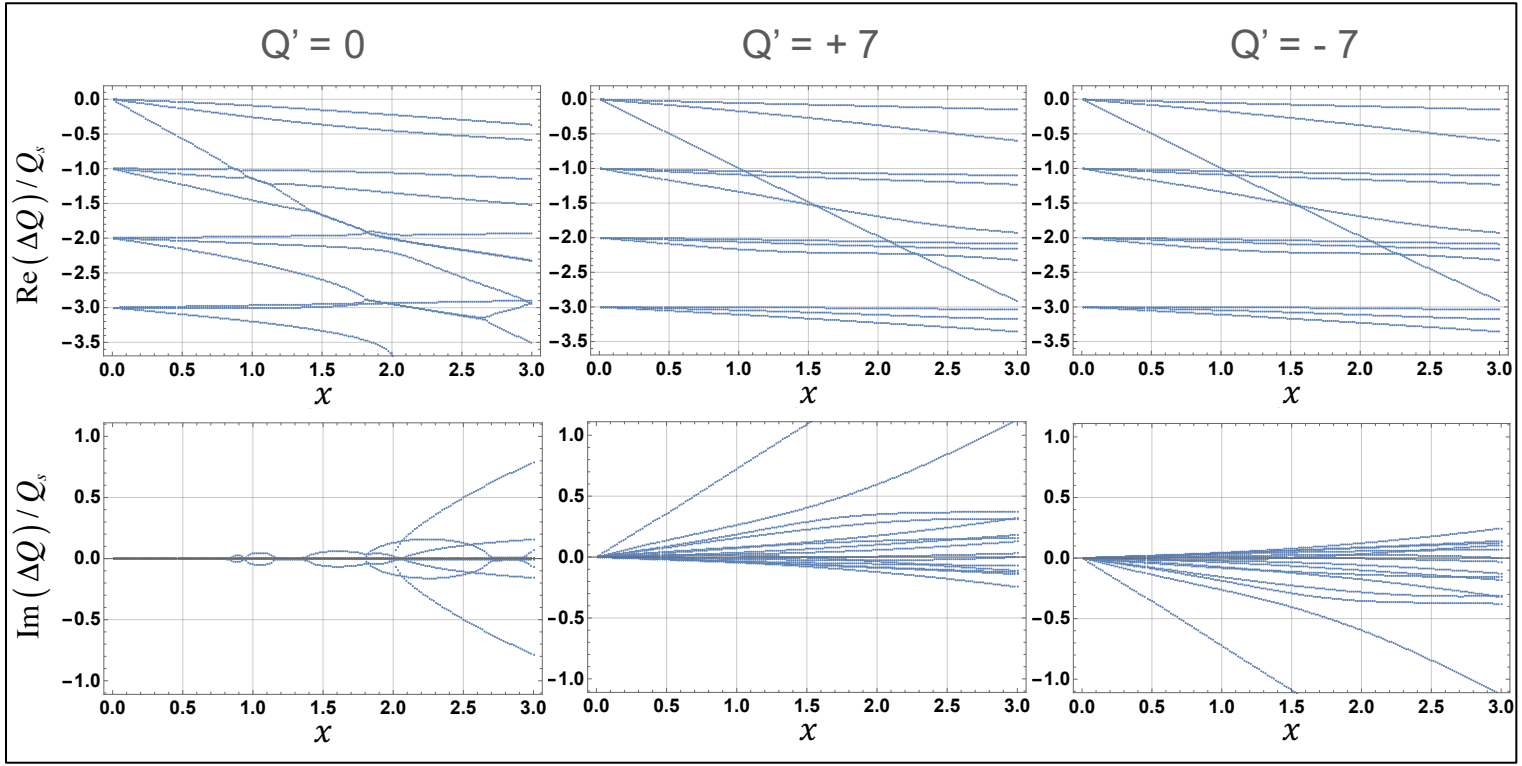

5) Landau damping

- Considering the case of the LHC with a BBR, assuming only the 2 azimuthal modes 0 and -1 and an externally given elliptical tune spread

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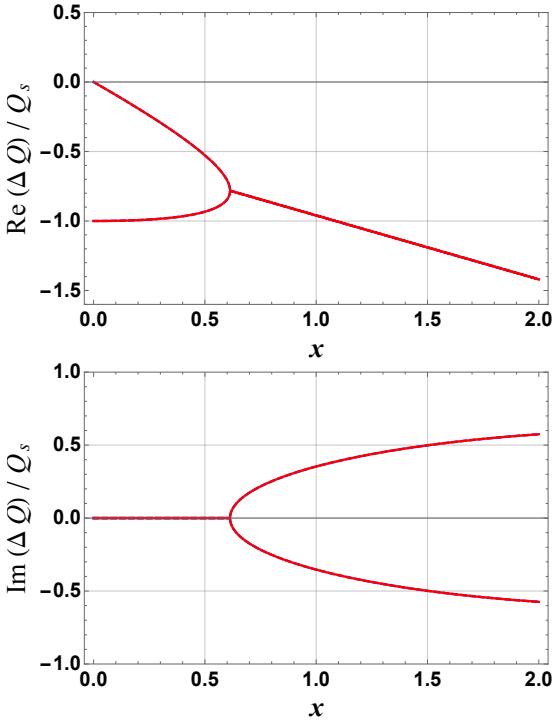
Tune spread (normalised by Q_s)

$\Delta q = 0.0$



https://cds.cern.ch/record/2674776/files/CERN-ACC-NOTE-2019-0018.pdf

5) Landau damping

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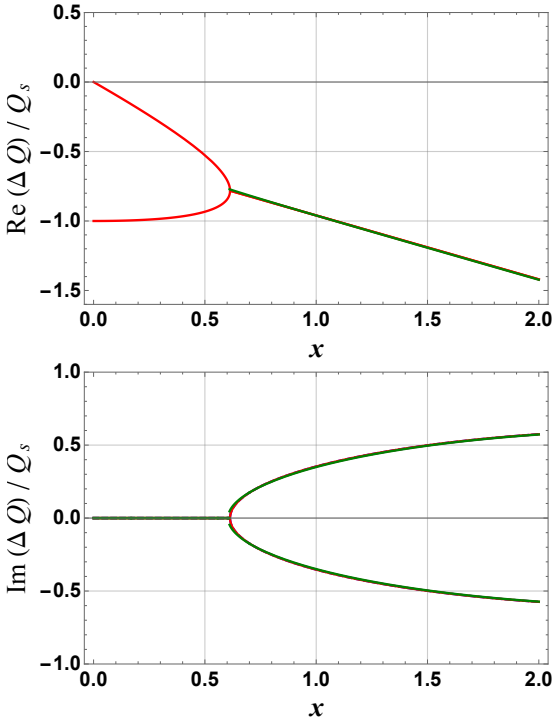
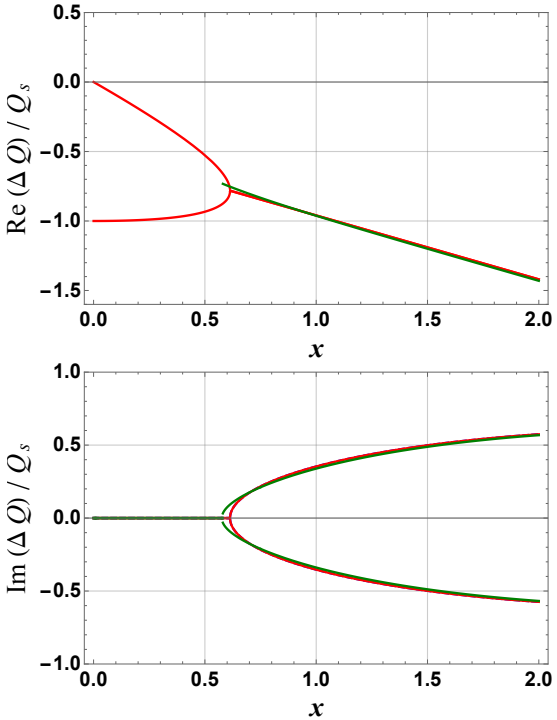
$$\Delta q = 0.1$$



5) Landau damping

- Considering the case of the LHC with a BBR, assuming only the 2 azimuthal modes 0 and -1 and an externally given elliptical tune spread

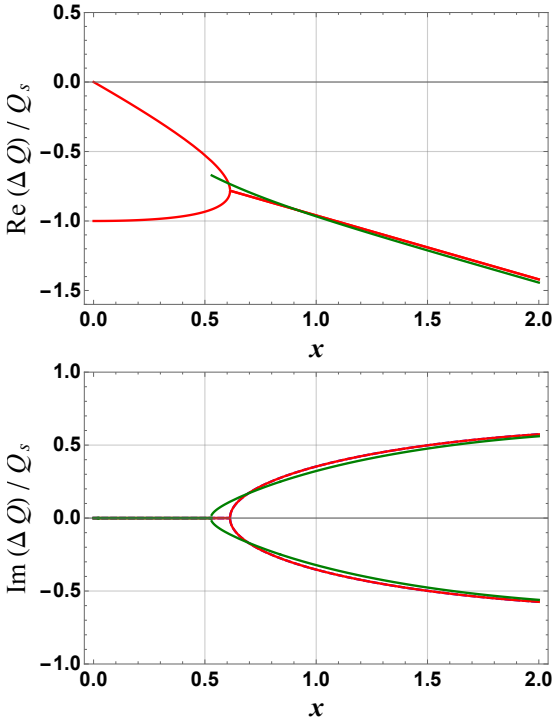
$$\Delta q = 0.2$$



5) Landau damping

- Considering the case of the LHC with a BBR, assuming only the 2 azimuthal modes 0 and -1 and an externally given elliptical tune spread

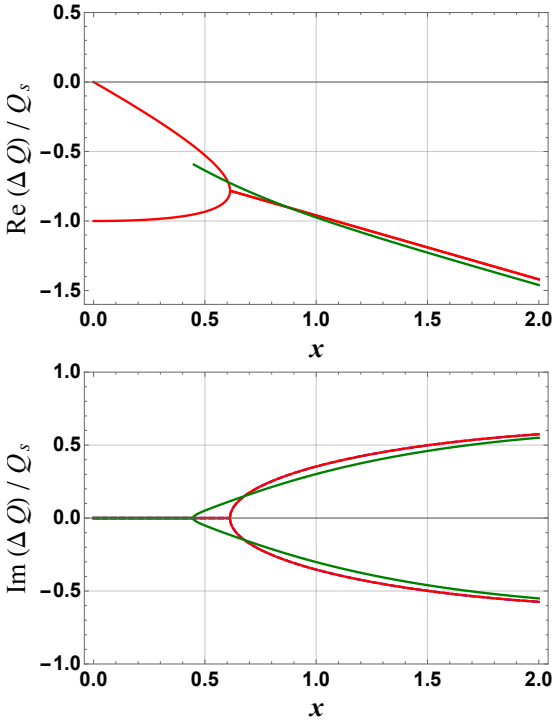
$$\Delta q = 0.3$$



5) Landau damping

- Considering the case of the LHC with a BBR, assuming only the 2 azimuthal modes 0 and -1 and an externally given elliptical tune spread

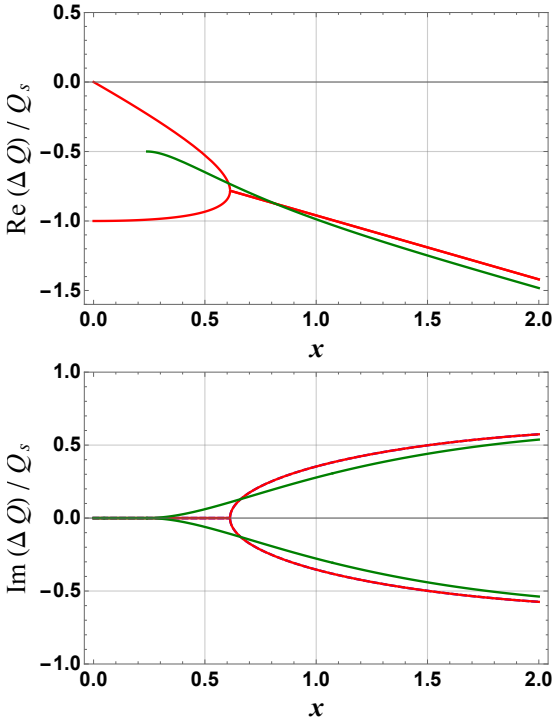
$$\Delta q = 0.4$$



5) Landau damping

- Considering the case of the LHC with a BBR, assuming only the 2 azimuthal modes 0 and -1 and an externally given elliptical tune spread

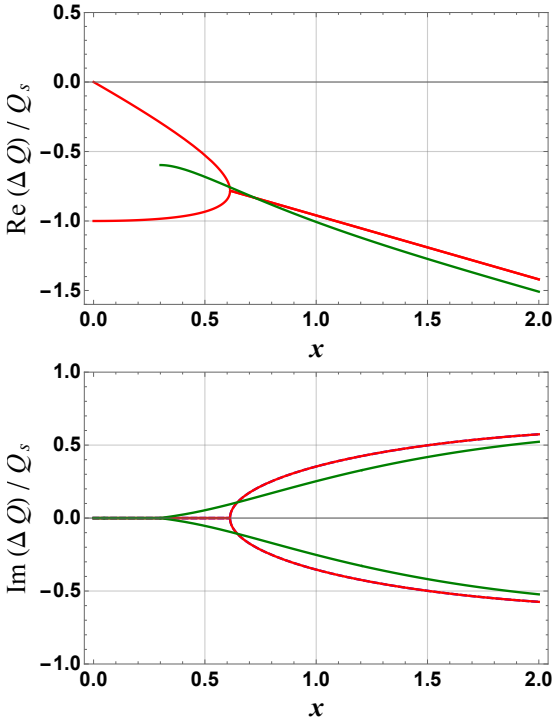
$$\Delta q = 0.5$$



5) Landau damping

- Considering the case of the LHC with a BBR, assuming only the 2 azimuthal modes 0 and -1 and an externally given elliptical tune spread

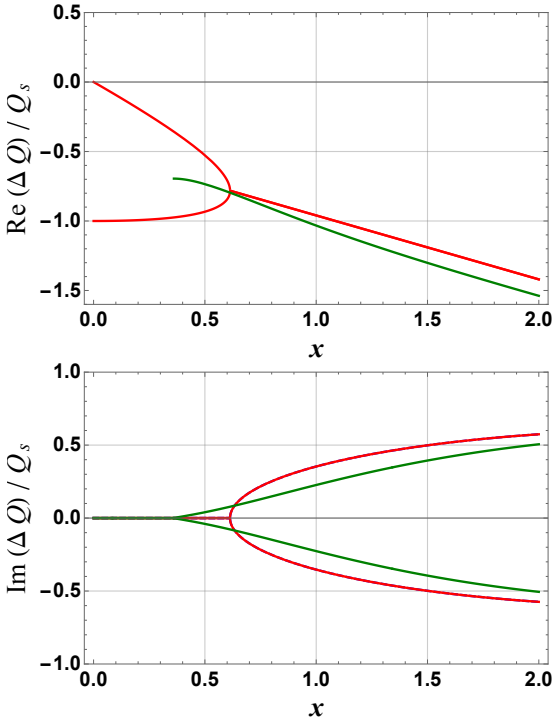
$$\Delta q = 0.6$$



5) Landau damping

- Considering the case of the LHC with a BBR, assuming only the 2 azimuthal modes 0 and -1 and an externally given elliptical tune spread

$$\Delta q = 0.7$$



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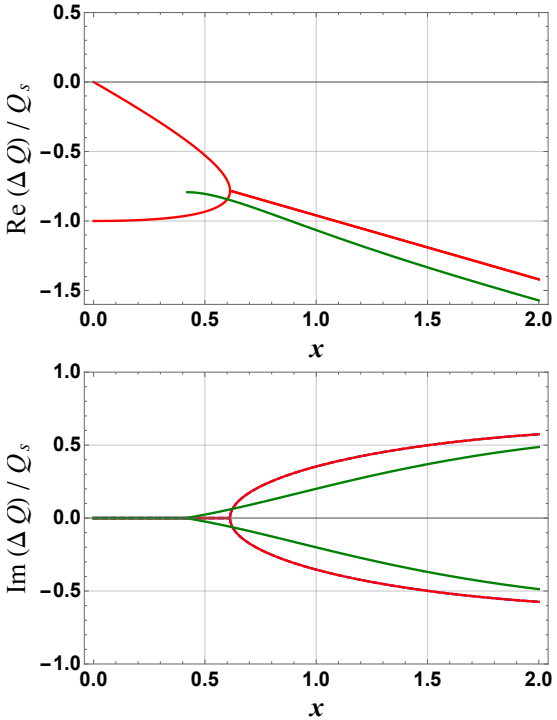
$$\Delta q = 0.8$$



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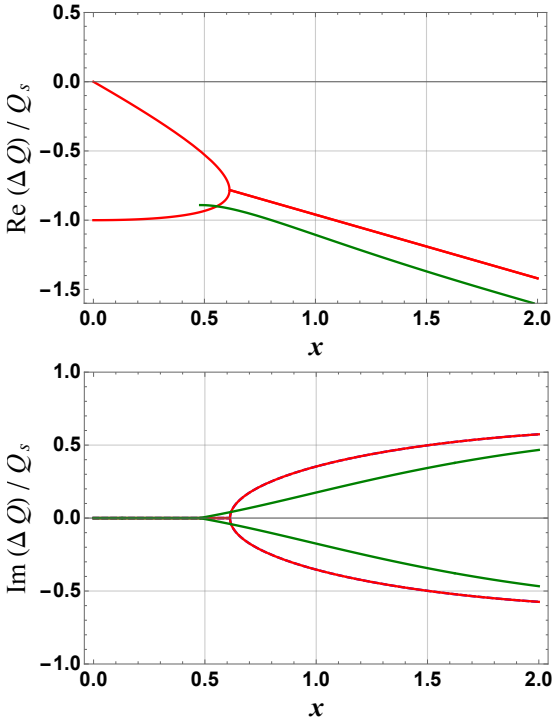
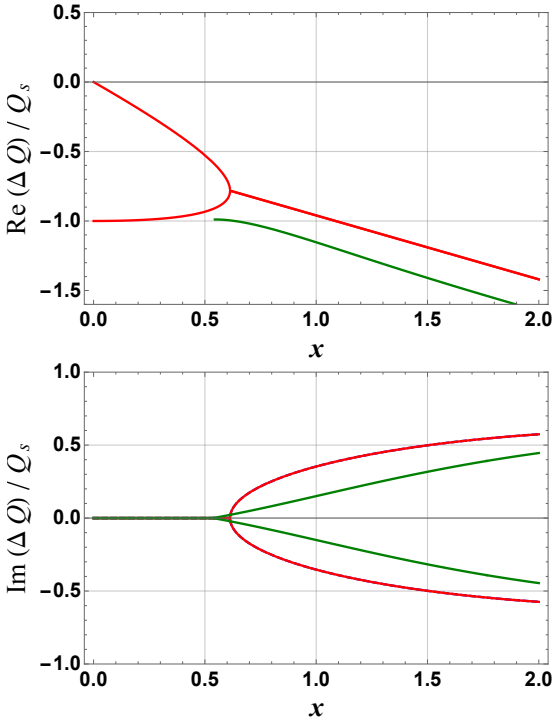
$$\Delta q = 0.9$$



5) Landau damping

- Considering the case of the LHC with a BBR, assuming only the 2 azimuthal modes 0 and -1 and an externally given elliptical tune spread

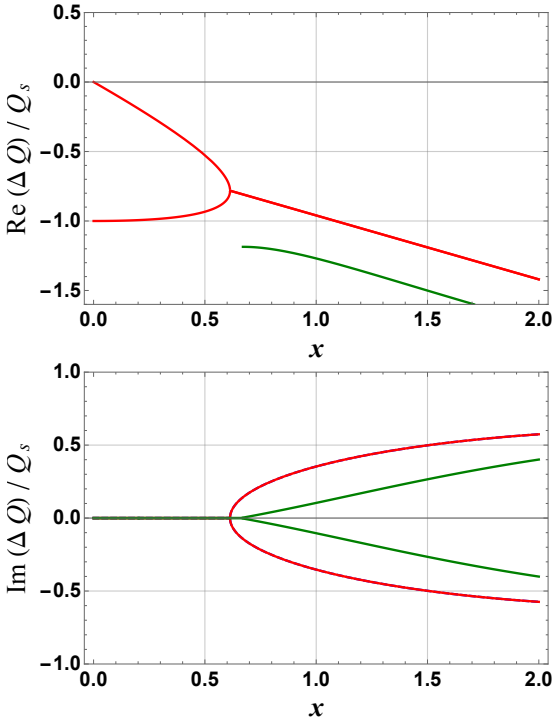
$$\Delta q = 1.0$$



5) Landau damping

- Considering the case of the LHC with a BBR, assuming only the 2 azimuthal modes 0 and -1 and an externally given elliptical tune spread

$$\Delta q = 1.2$$



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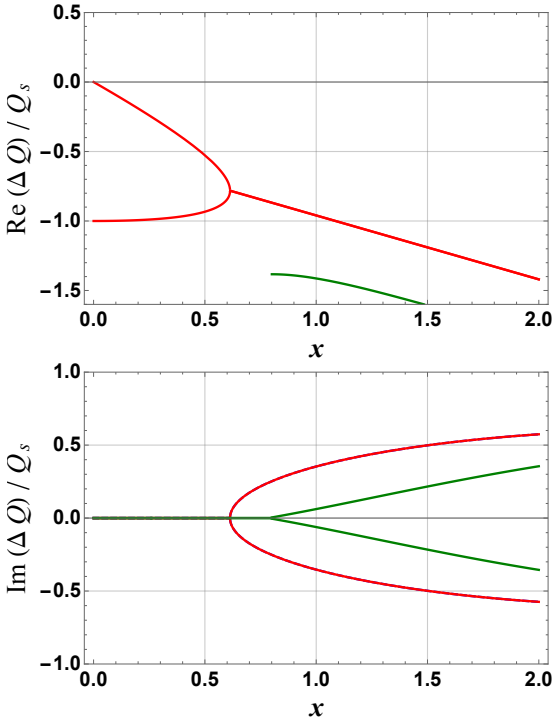
$$\Delta q = 1.4$$



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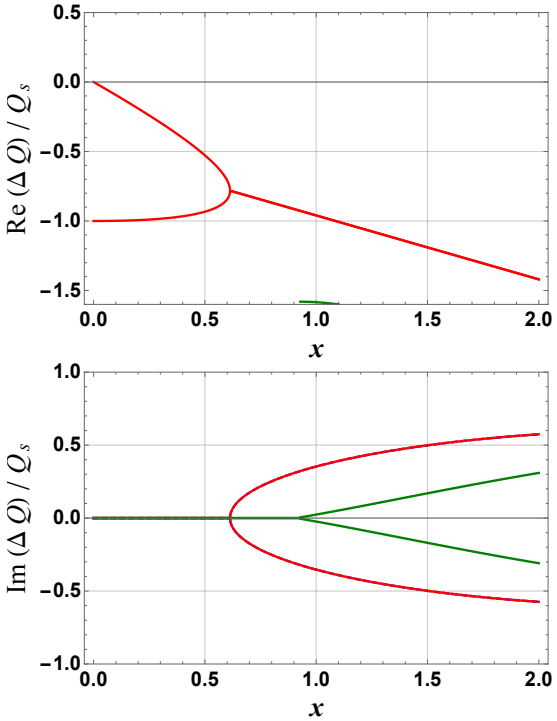

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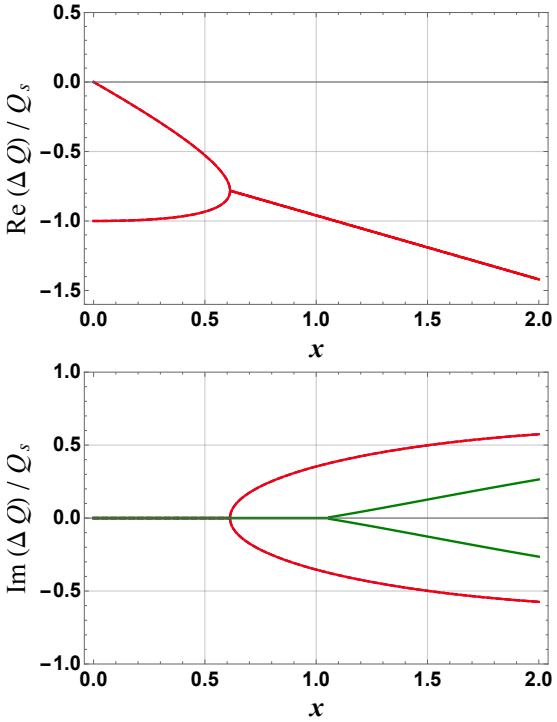
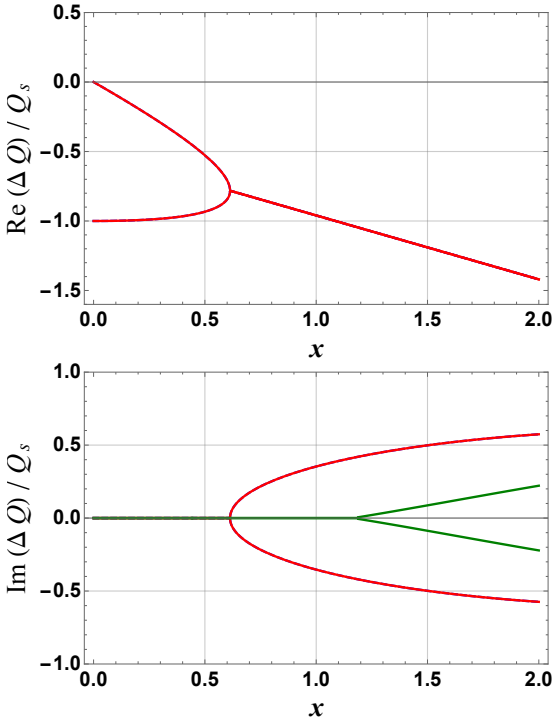
$$\Delta q = 1.8$$



5) Landau damping

- Considering the case of the LHC with a BBR, assuming only the 2 azimuthal modes 0 and -1 and an externally given elliptical tune spread

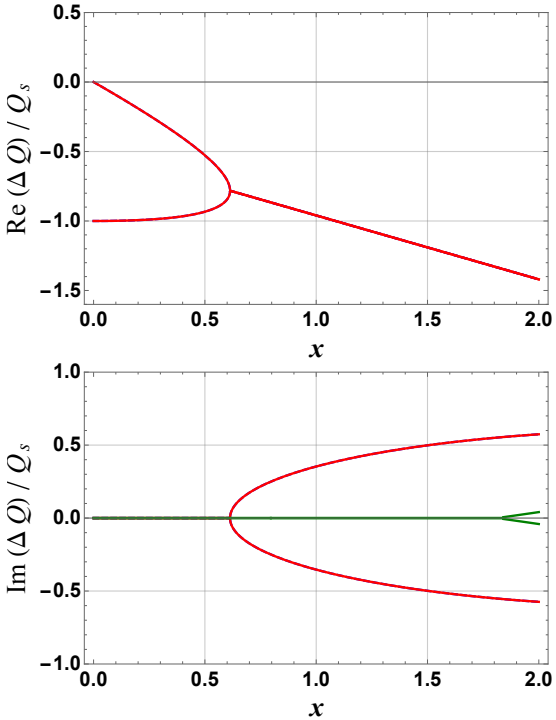
$$\Delta q = 2.0$$



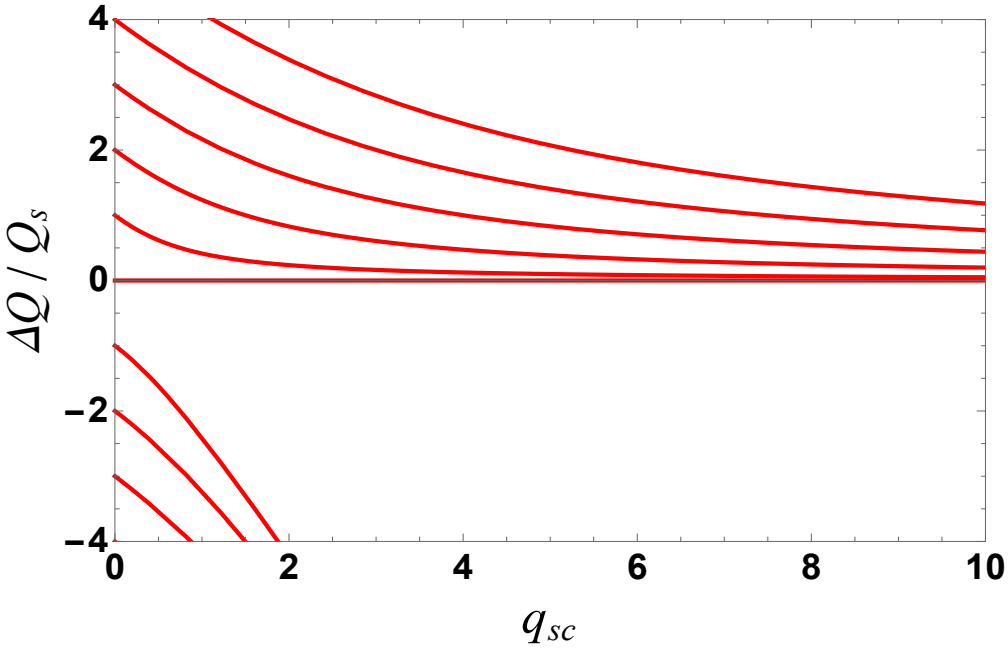
5) Landau damping

- Considering the case of the LHC with a BBR, assuming only the 2 azimuthal modes 0 and -1 and an externally given elliptical tune spread

$$\Delta q = 3.0$$

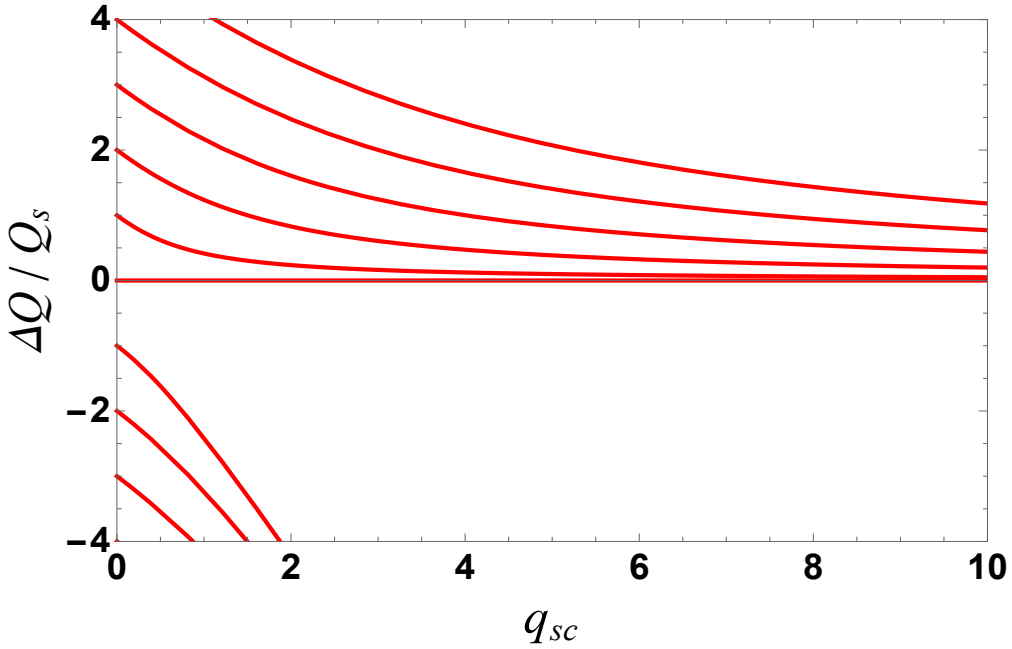


6) Space charge



$$q_{sc} = \Delta Q_{sc} / (2\, Q_s)$$

6) Space charge



$q_{sc} = \Delta Q_{sc} / (2\, Q_s)$

- With a “simple 2-mode model”, 2 effects predicted
  - **“Short-bunch” regime** => Beneficial
  - **“Long-bunch” regime** => Detrimental

https://ipac2019.vrws.de/papers/mopgw088.pdf

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- Considering the case of the LHC (**“Short-bunch” regime**)

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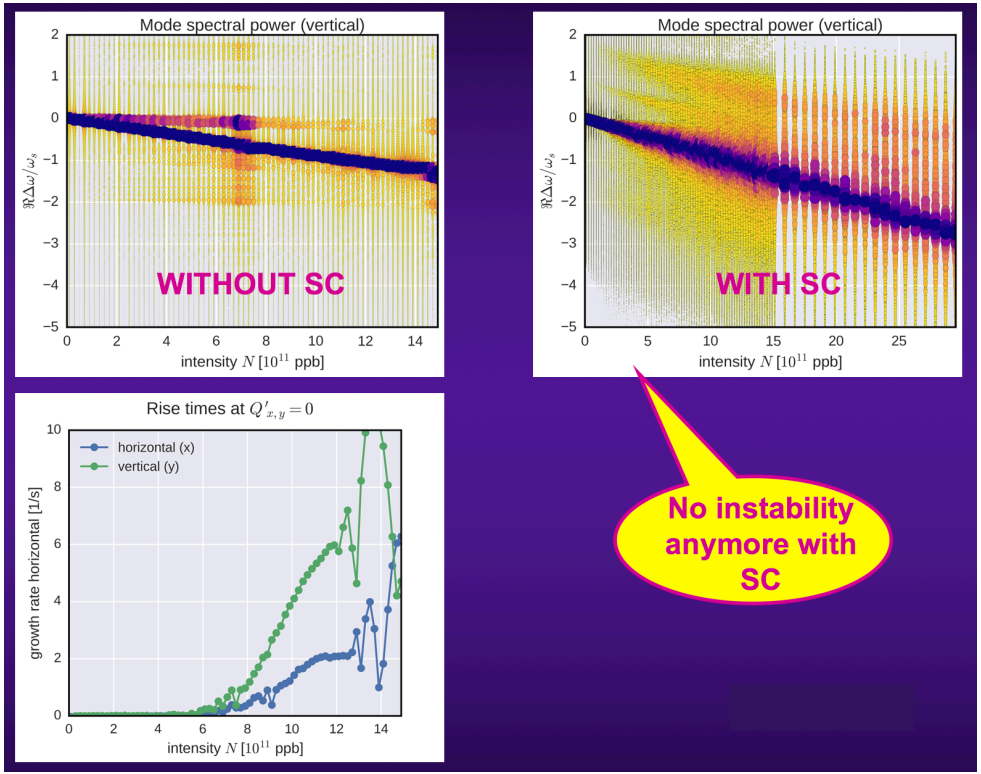

A. Oeftiger (pyHT)

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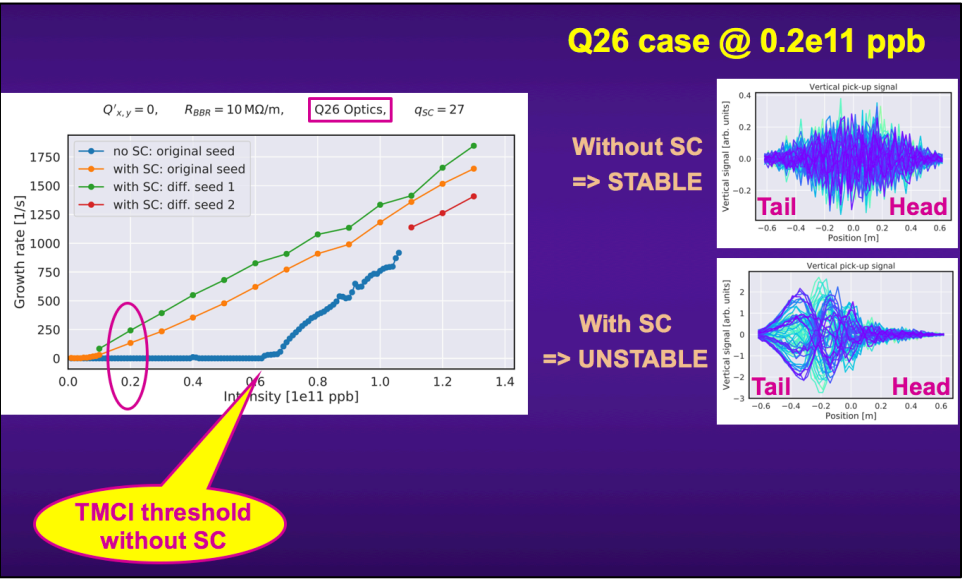

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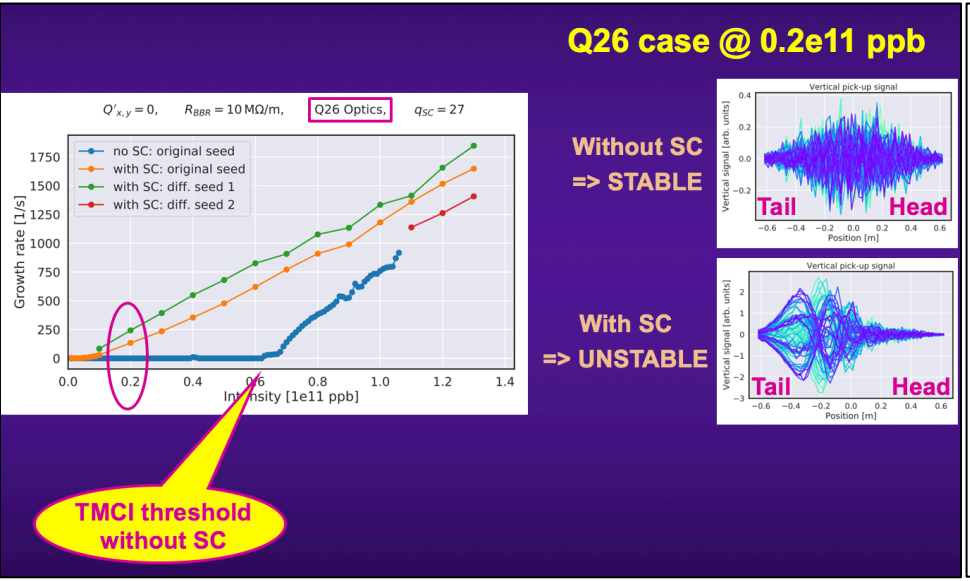

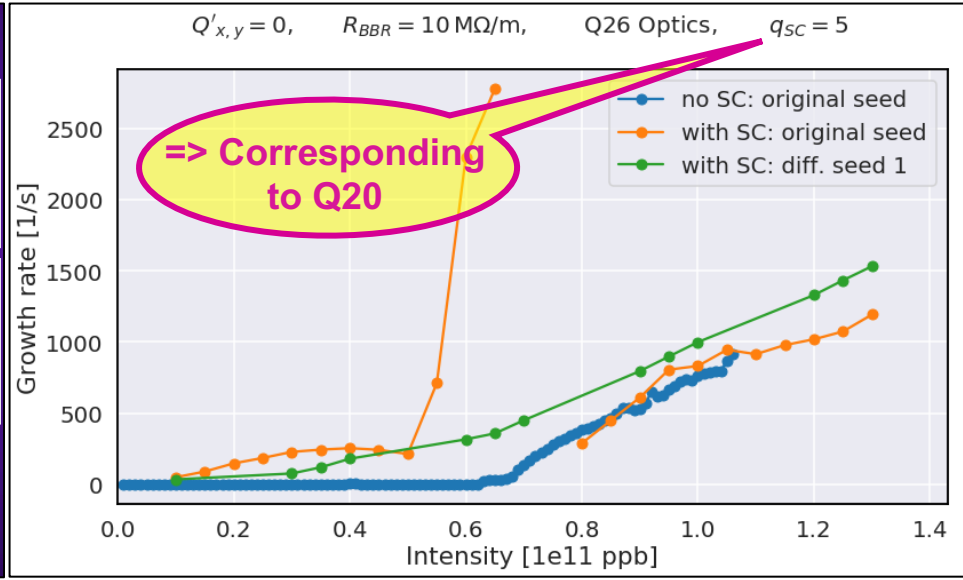

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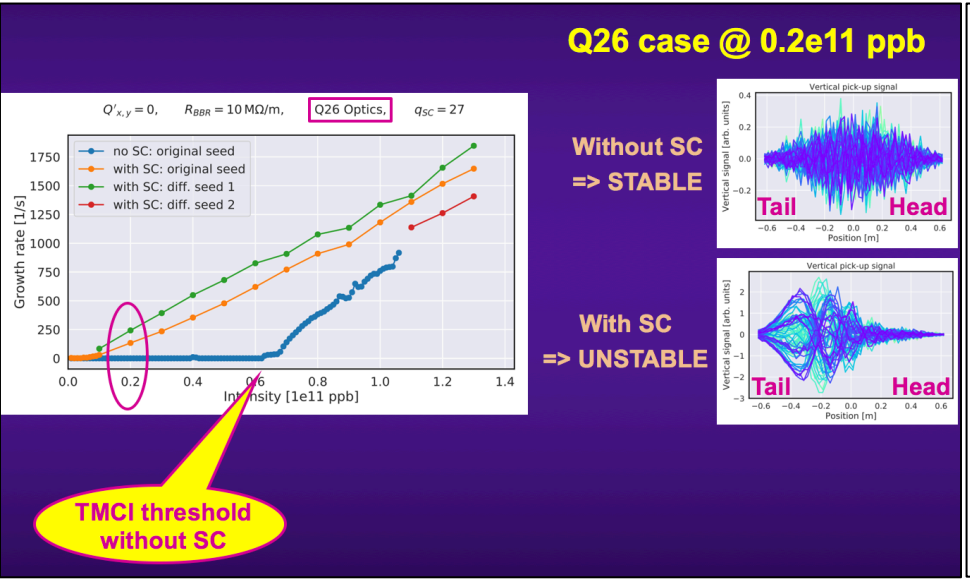

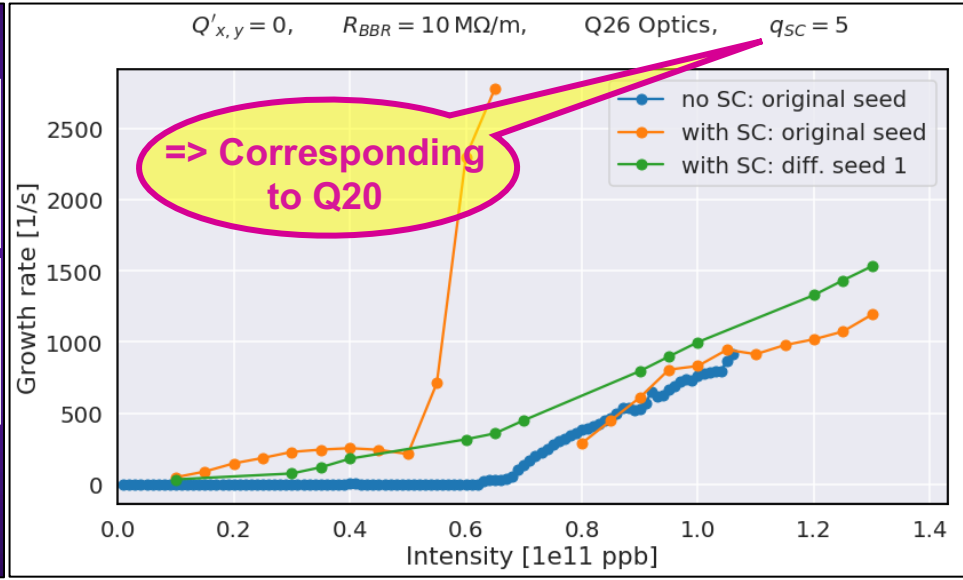

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=> Clear detrimental effect of space charge for both “high SC” and “low SC” regimes, **BUT still lot of work to understand clearly the instability and define correctly the instability growth rates…**

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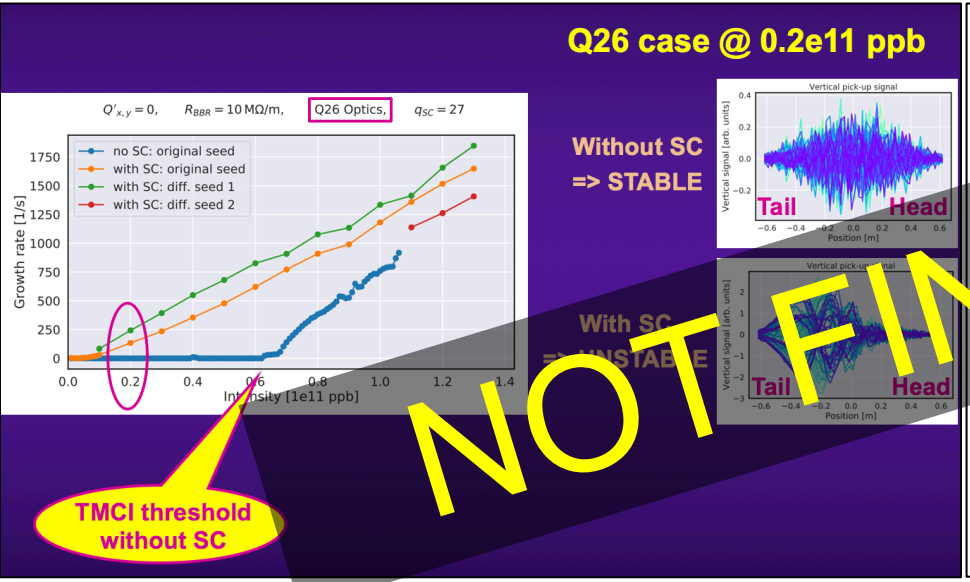

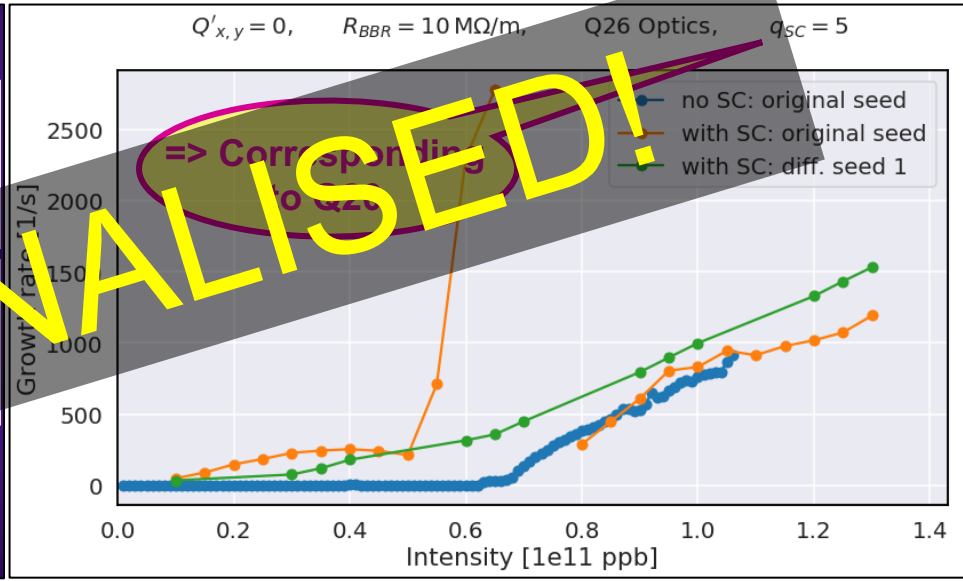

NOT FINALISED!

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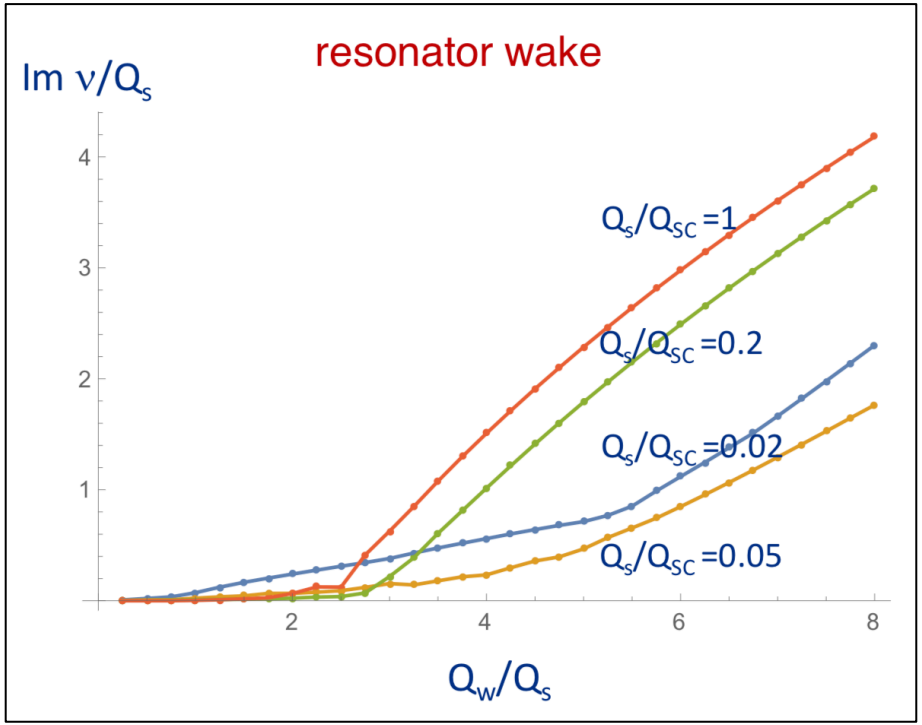
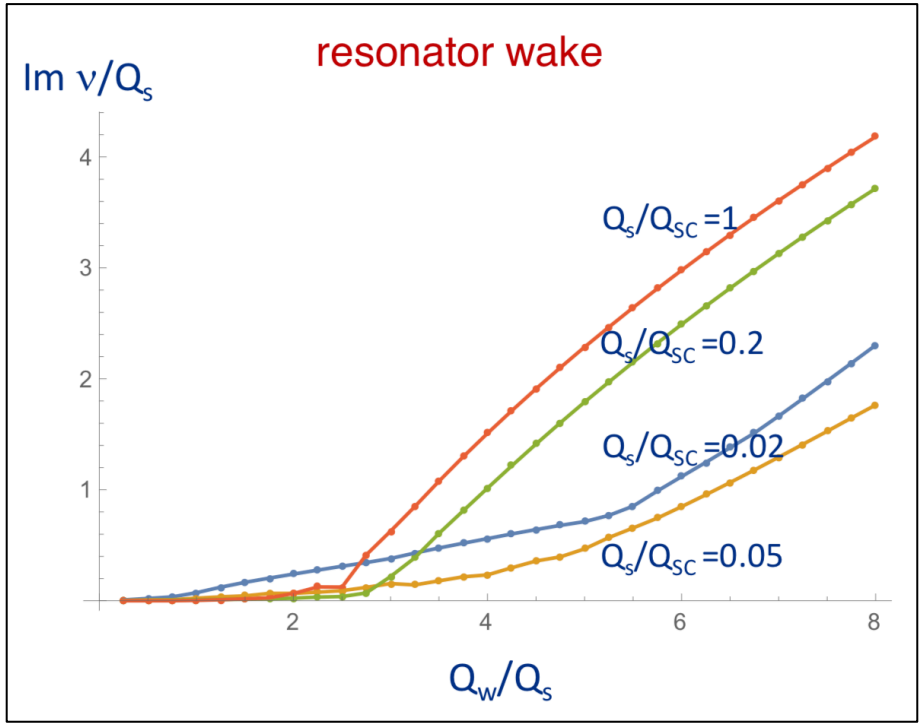
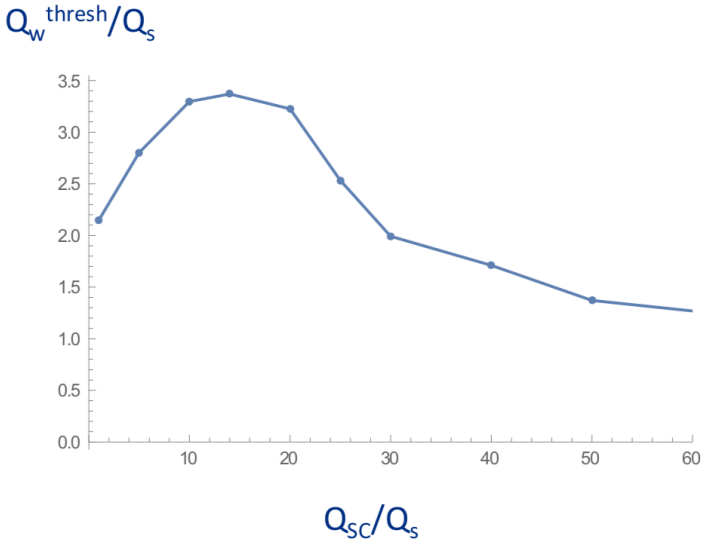


Y. Alexahin
(MCBI 2019)

6) Space charge





The TMCI threshold defined as Im $\nu/Q_s > 0.1$ vs the space charge tuneshift.

Y. Alexahin
(MCBI 2019)

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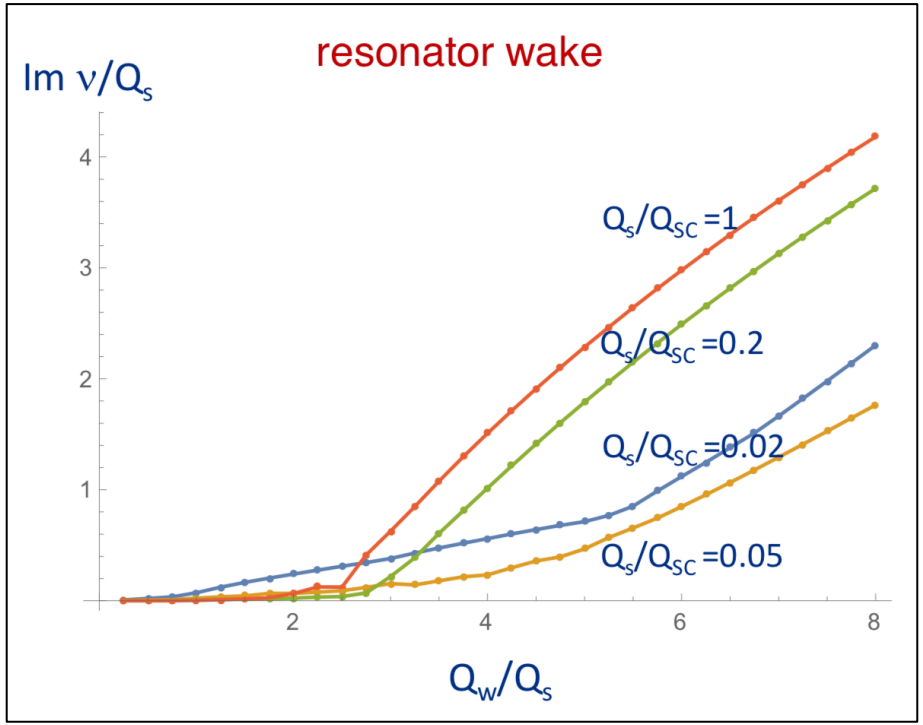

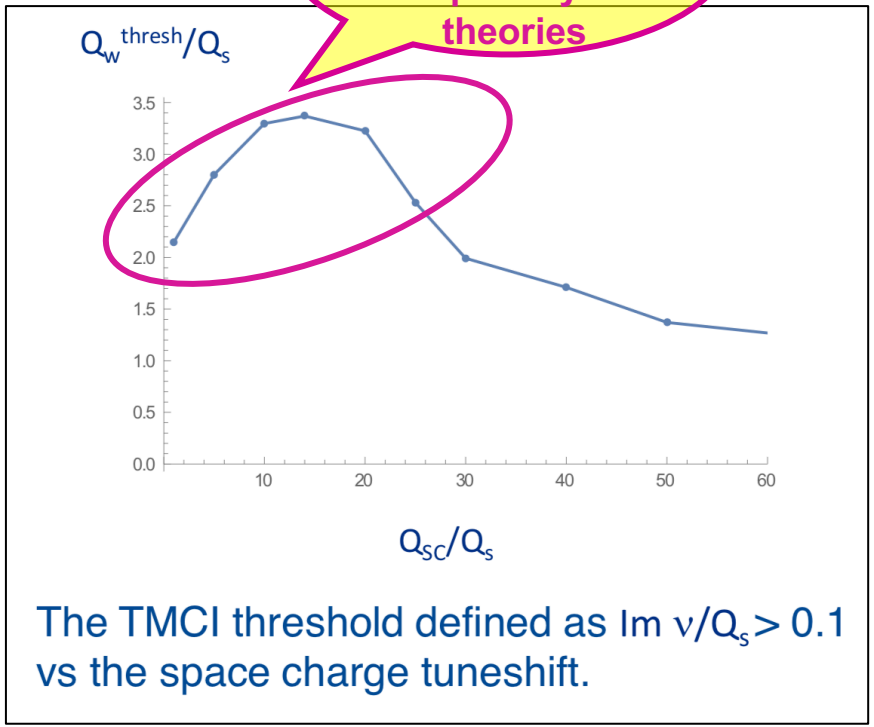

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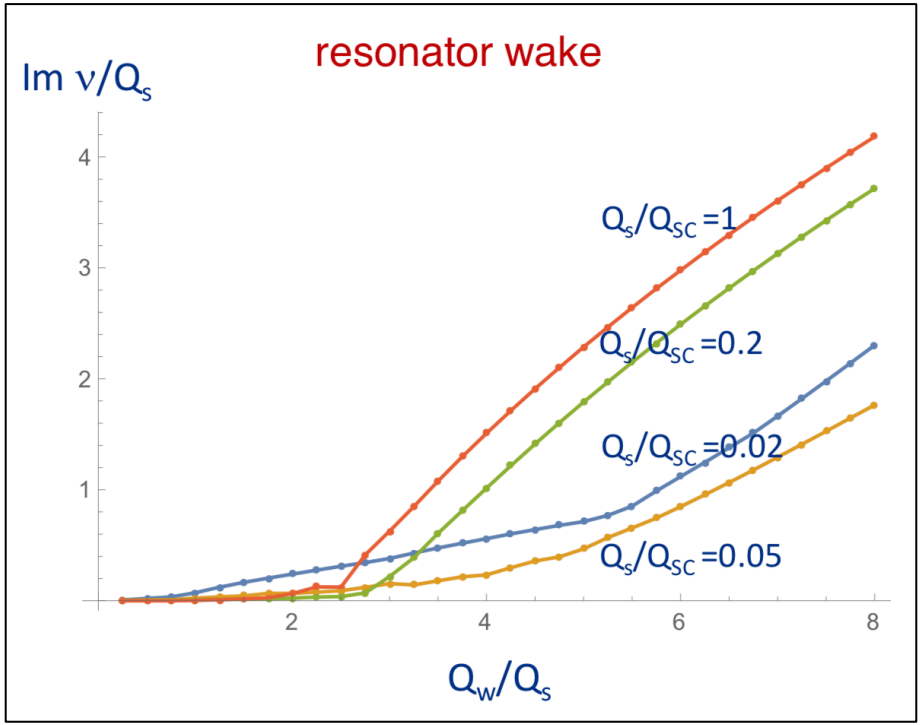

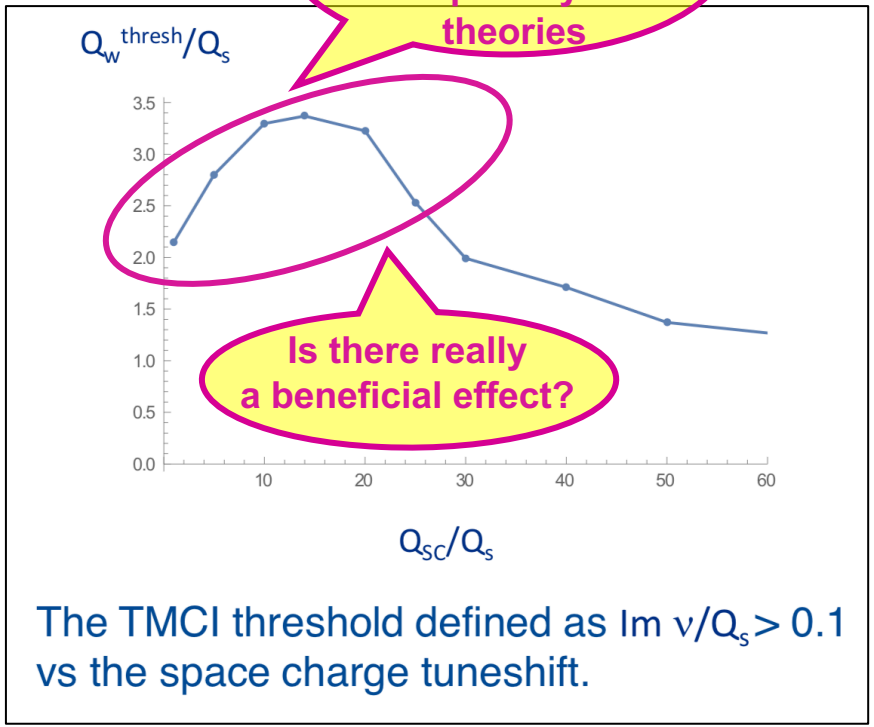

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- Still some work needed to understand better the effect of space charge, in particular in the “long-bunch” regime (with recent improvements in both simulation and theory) => To be continued/finalised

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Transverse damper	- Reactive: beneficial - Resistive: detrimental	Reactive or resistive: no effect for main TMCI
Detuning impedance		
Linear coupling (for asym. chamber)		
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Space charge	Beneficial from both theory and pyHT simulations for "low SC" regime (LHC). **What about "high SC" regime?**	Detrimental from pyHT simulations for both "high SC" (SPS Q26) and "low SC" (SPS Q20) regimes **BUT still work to be done & detailed comparison with recent theories (beneficial effect predicted by some theories for "low SC" regime)**