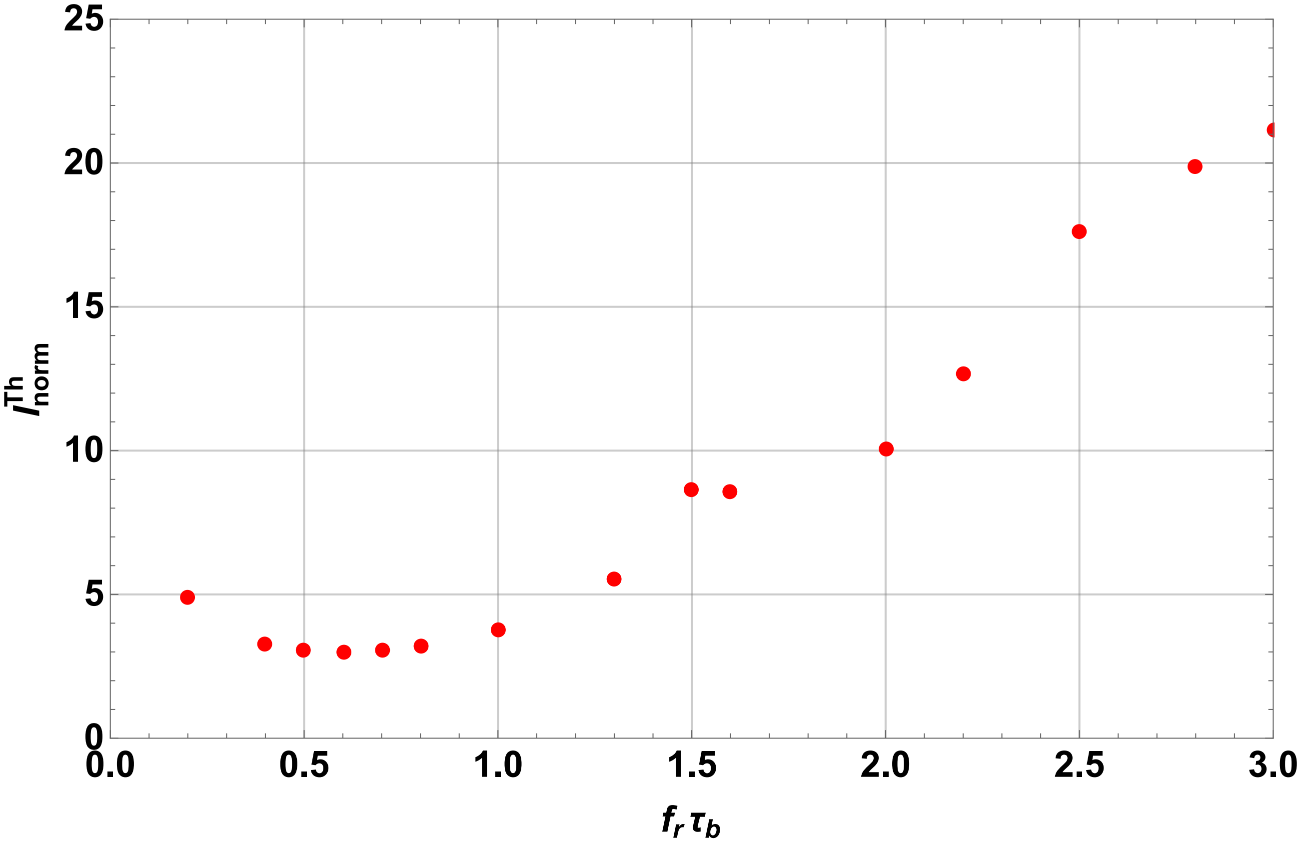
Effects of space charge and detuning impedance on TMCI for BBR impedance: Part 2

E. Métral

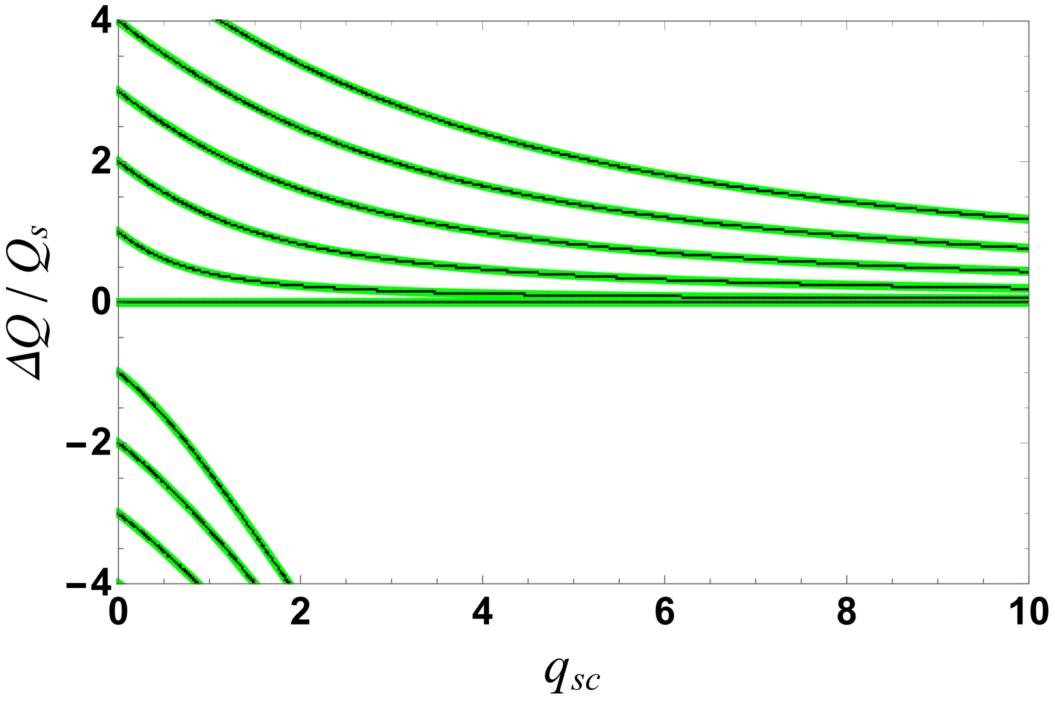
(Many thanks to XavierB as benchmarking with him, I could found a sign error somewhere…=> Part 2 today, following the talk of 05/08/19)

- Case $f_r \tau_b = 1.6$

Effect of $f_r \tau_b$ on the TMCI intensity threshold ($\kappa = 0$)



Space charge



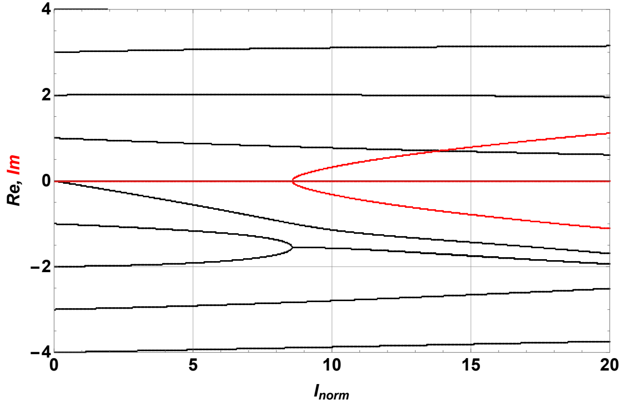
$$\frac{\Delta Q}{Q_s} = -q_{sc} \pm \sqrt{q_{sc}^2 + m^2}$$

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

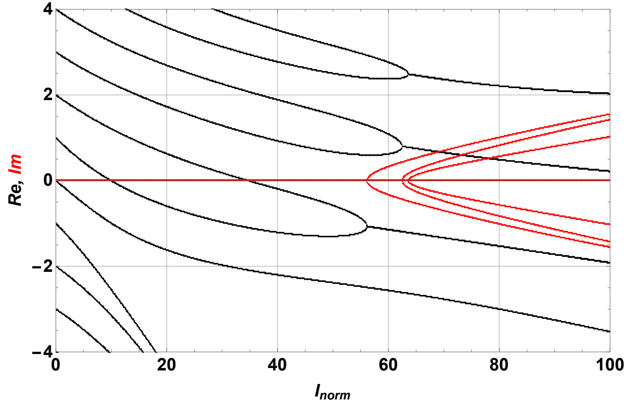
$$I_{norm} = q_{sc} \frac{\pi^2}{\mathrm{SCp}}$$

$f_r \tau_b = 1.6$

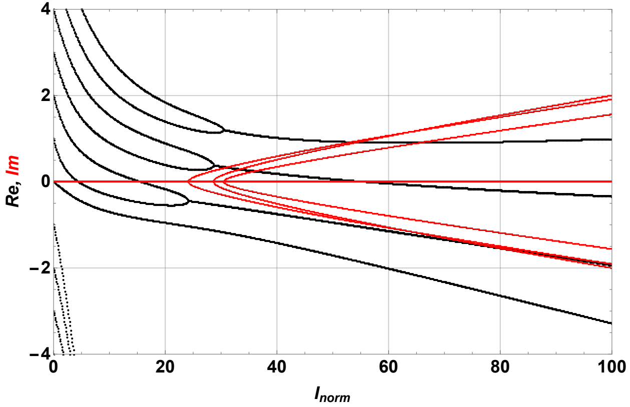
$\mathrm{SCp} = 0\ \&\ \kappa = 0$



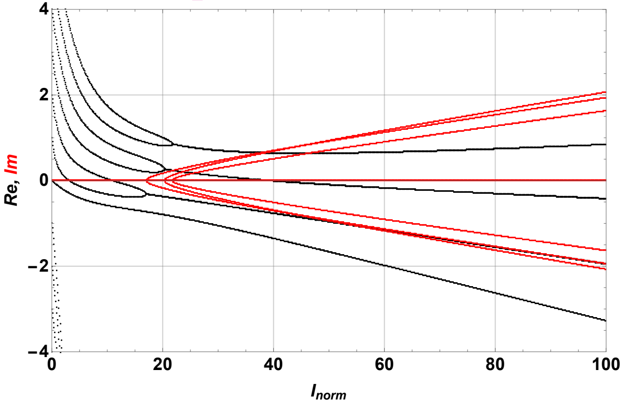
$\mathrm{SCp} = 1\ \&\ \kappa = 0$



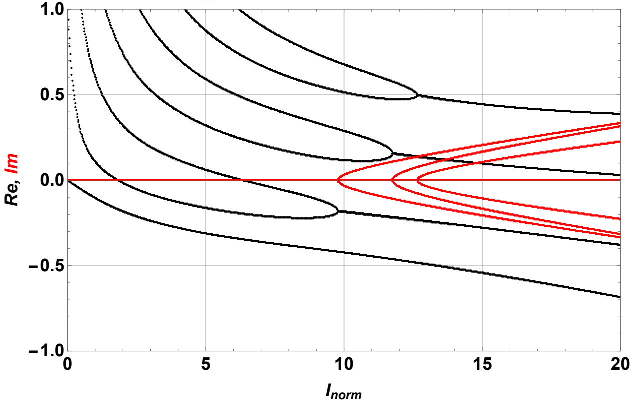
$\mathrm{SCp} = 5\ \&\ \kappa = 0$



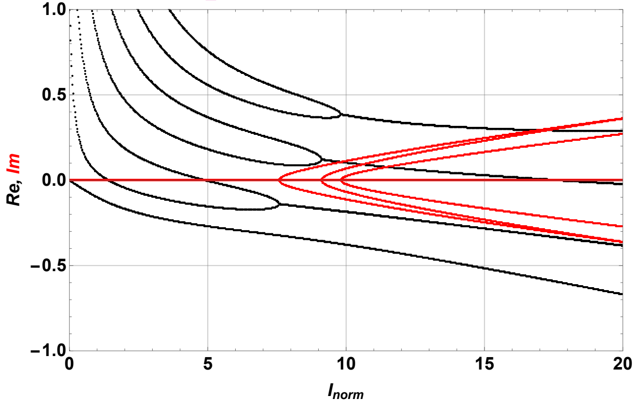
$\mathrm{SCp} = 10\ \&\ \kappa = 0$



$\mathrm{SCp} = 30\ \&\ \kappa = 0$

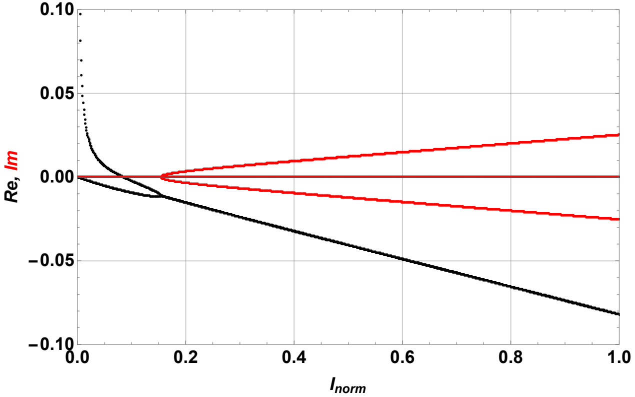


$\mathrm{SCp} = 50\ \&\ \kappa = 0$

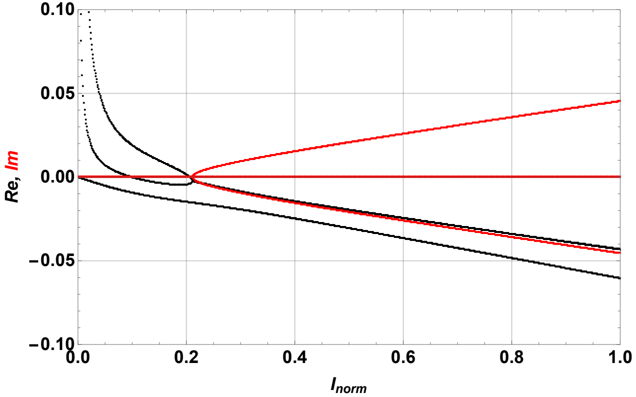


$f_r \tau_b = 1.6$ SCp $= 10^4$ & $\kappa = 0$

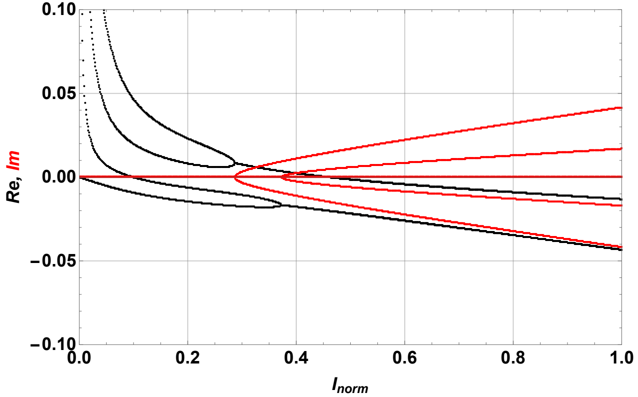
3 modes



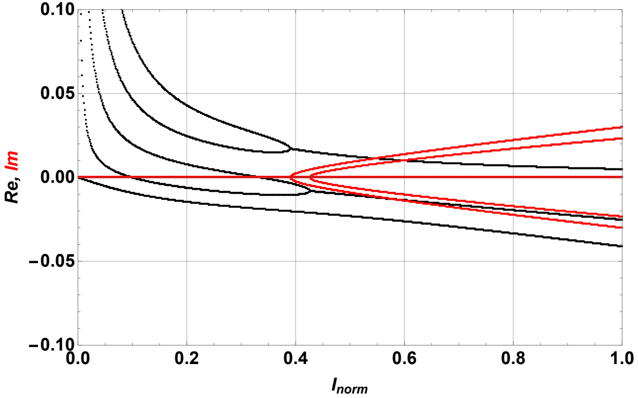
5 modes



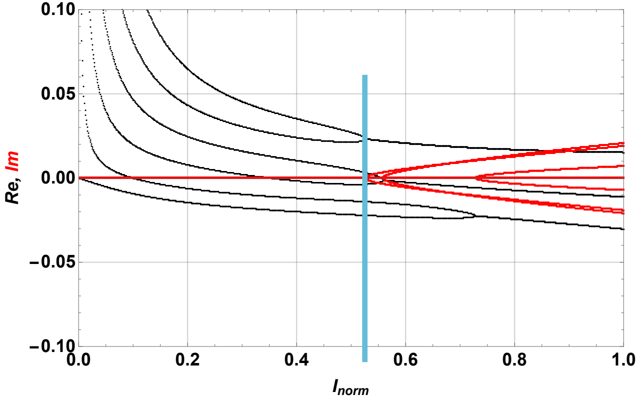
7 modes



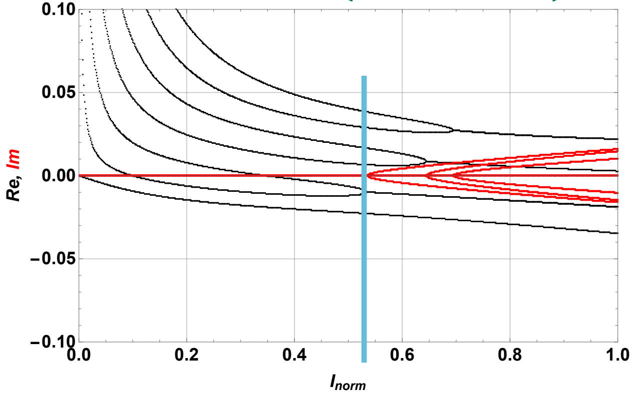
9 modes



11 modes

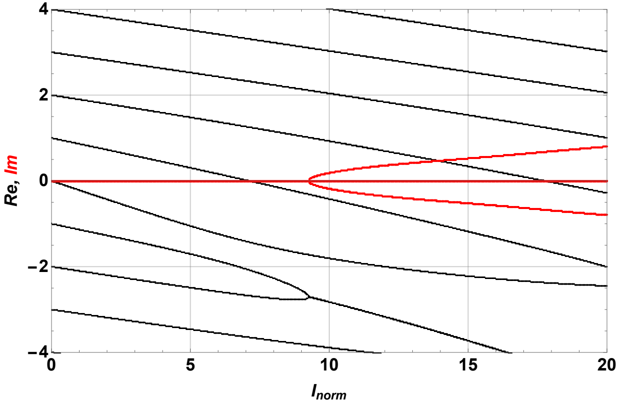


13 modes (used here)

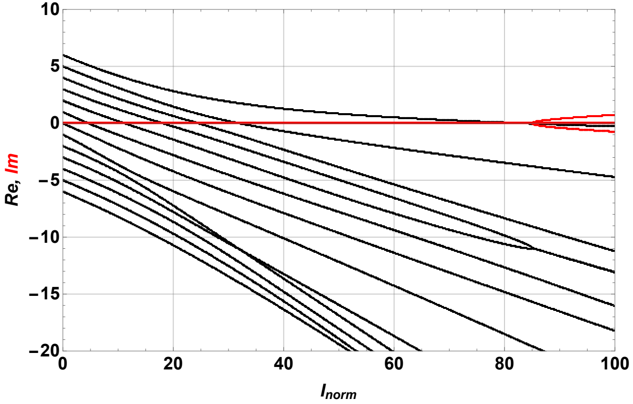


$f_r \tau_b = 1.6$

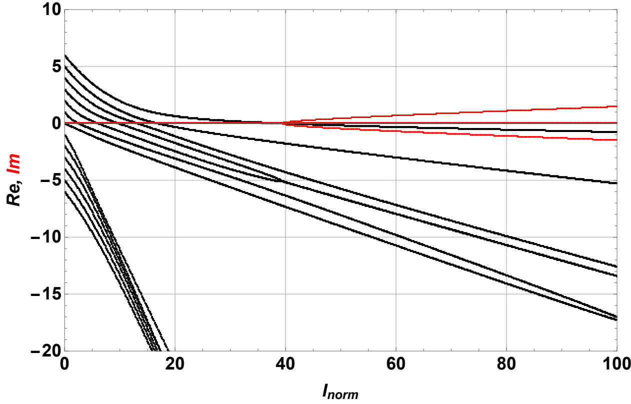
SCp = 0 & $\kappa = -1$



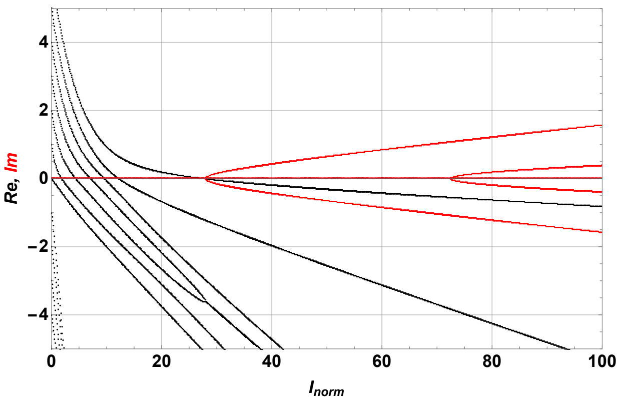
SCp = 1 & $\kappa = -1$



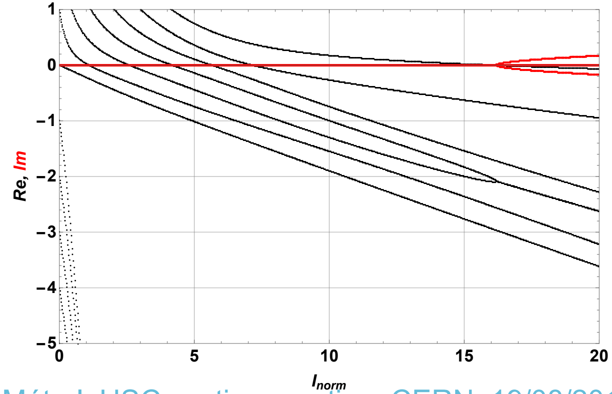
SCp = 5 & $\kappa = -1$



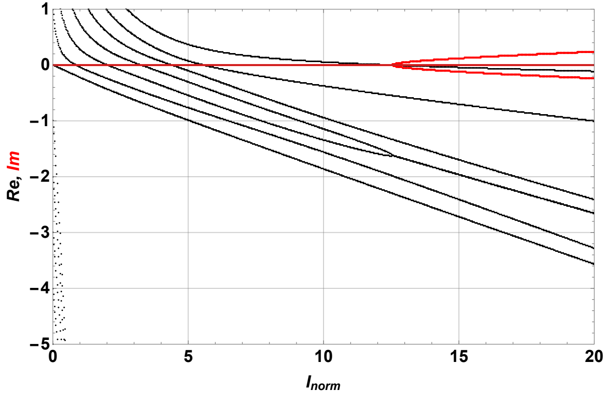
SCp = 10 & $\kappa = -1$



SCp = 30 & $\kappa = -1$

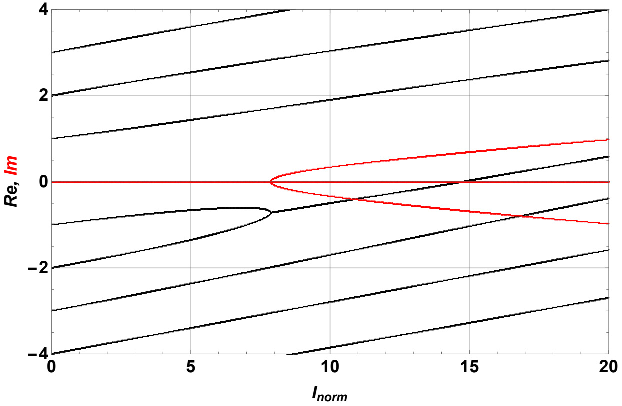


SCp = 50 & $\kappa = -1$

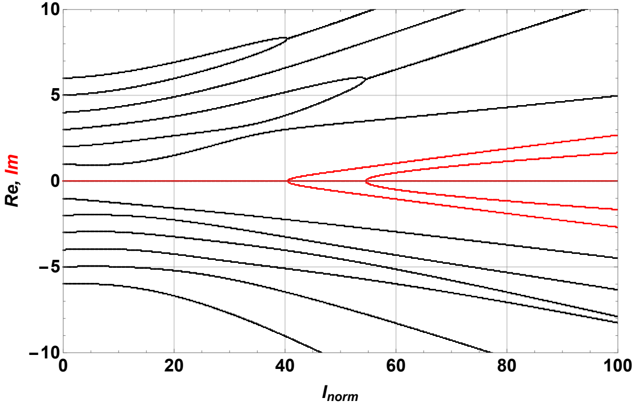


$f_r \tau_b = 1.6$

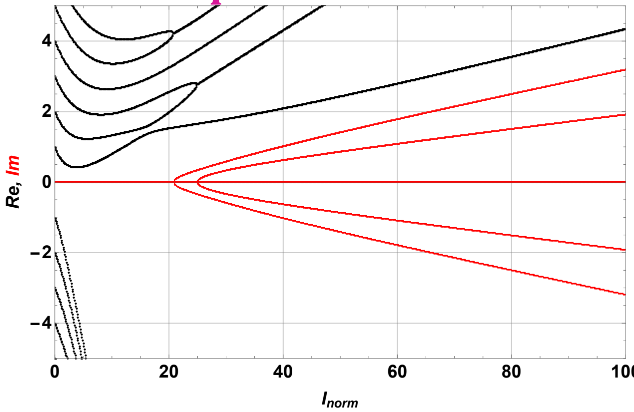
$\mathrm{SCp} = 0 \;\&\; \kappa = 1$



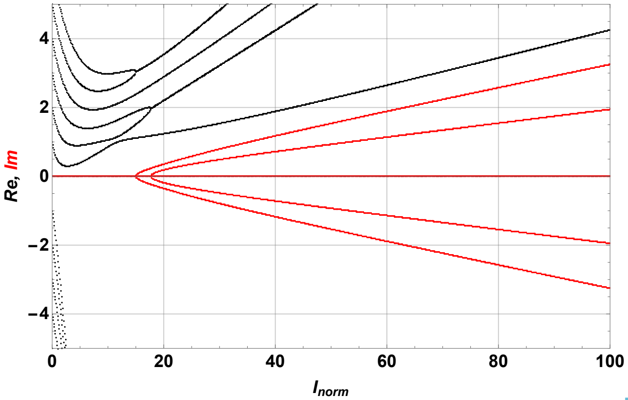
$\mathrm{SCp} = 1 \;\&\; \kappa = 1$



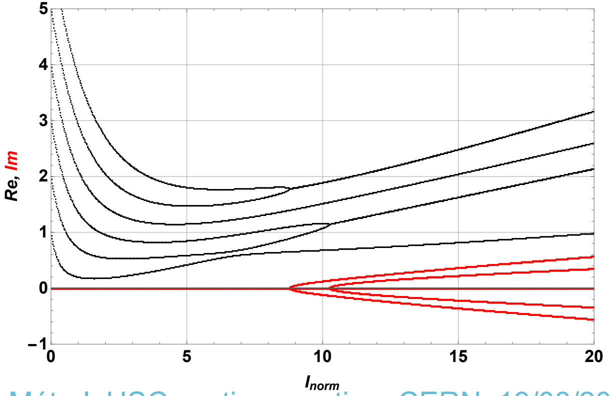
$\mathrm{SCp} = 5 \;\&\; \kappa = 1$



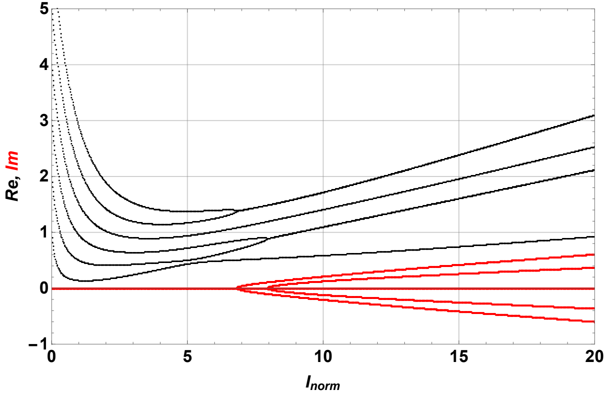
$\mathrm{SCp} = 10 \;\&\; \kappa = 1$



$\mathrm{SCp} = 30 \;\&\; \kappa = 1$

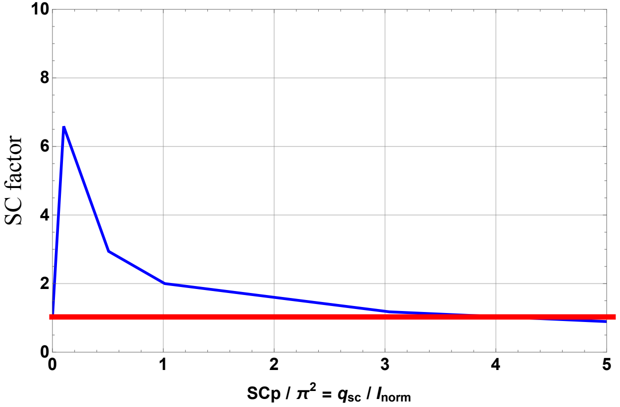


$\mathrm{SCp} = 50 \;\&\; \kappa = 1$

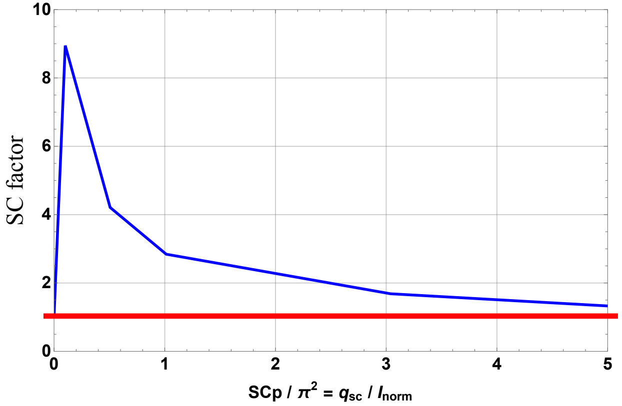


Summary => SC factor on TMCI threshold

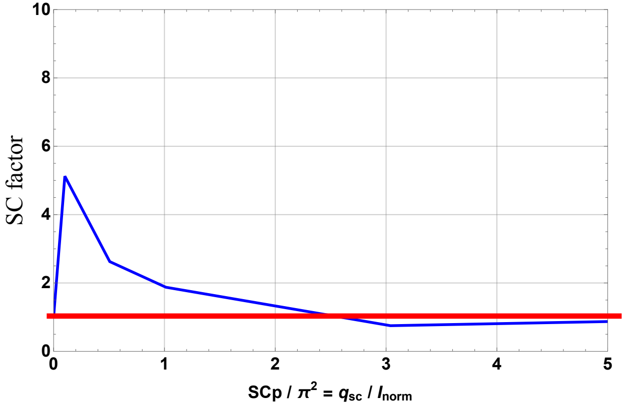
$\kappa = 0$



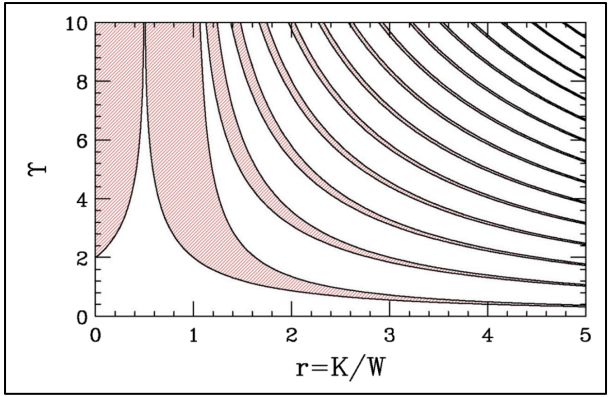
$\kappa = -1$



$\kappa = 1$



=> To be compared e.g. to 2-particle model from Chin-Chao-Blaskiewicz_2016 (https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.19.014201)



$$r = \frac{K}{W} = \frac{\pi}{2\Upsilon}\left(\frac{\Delta\nu_{sc}}{\nu_s}\right)$$

Conclusion (1/5)

- Similar results as on 05/08/19 but this time SC is always helping first (moving the coupling from negative modes to positive modes) and then it is destabilising and for the highest SC parameters considered here, the TMCI intensity threshold is similar or below the TMCI intensity threshold without SC => "Similar picture" as 2-particle model from Chin-Chao-Blaskiewicz_2016
- Next:
  - Perform a finer scan
  - Continue to check convergence and with A. Burov and T. Zolkin, who studied this in detail in their PRAB paper https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.21.104201 => Similar nonmonotonic dependence of the wake threshold on the SC parameter was also found in the past by A. Burov and V. Balbekov (see https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.20.034401) but it happened when either the number of modes was insufficient or the wake matrix elements were calculated with insufficient precision… To be looked at in detail…

Conclusion (2/5)

PHYSICAL REVIEW ACCELERATORS AND BEAMS **20,** 034401 (2017)

Transverse mode coupling instability threshold with space charge and different wakefields

V. Balbekov*

Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, Illinois 60510, USA

(Received 23 August 2016; published 10 March 2017)

Transverse mode coupling instability of a single bunch with space charge (SC) and a wakefield is considered within the framework of the boxcar model. Eigenfunctions of the bunch without a wake are used as a basis for the solution of the equations with the wakefield included. A dispersion equation for a constant wake is presented in the form of an infinite continued fraction and also as the recursive relation with an arbitrary number of basis functions. Realistic wakefields are considered as well including resistive wall, square, and oscillating wakes. It is shown that the transverse mode coupling instability threshold of the negative wake grows in absolute value when the SC tune shift increases. The threshold of the positive wake goes down at increasing the SC tune shift. The explanation is developed by an analysis of the bunch spectrum.

DOI: 10.1103/PhysRevAccelBeams.20.034401

Conclusion (3/5)

- Could then be consistent and explain why I found only a destabilising effect of SC with my (simple) 2-mode approach (see https://ipac2019.vrws.de/papers/mopgw088.pdf) as my model does not depend on the sign of the modes (nor sign of the wake)…

Conclusion (4/5)

- As concerns the possible “mode coupling / decoupling” observed in the SPS (i.e. in the presence of strong SC) while increasing the bunch intensity (which was for us an indirect evidence of mode-coupling => See p. 167-169 of http://cds.cern.ch/record/1274254/files/CERN-THESIS-2010-087.pdf), this would be also consistent with the approach of Chin-Chao-Blaskiewicz_2016… To be continued

> force. As the space-charge force is increased, tune shifts by the space-charge force conversely restore the mode coupling. But, a further increase of the space-charge force decuples the modes again. This mode coupling/decoupling behavior creates stopband structures as a function of the space-charge tune shift parameter and Υ. This conclusion is consistent

Conclusion (5/5)

- Final comment on the Strong Space Charge (SSC) regime
  - A. Burov et al. find a TMCI intensity threshold at infinity, i.e. there is no TMCI threshold, and they need "another mechanism" to explain the instability ("convective instability with space charge")
  - With the simple 2-mode approach, or the analysis performed here (i.e. assuming only a certain number of modes), or the 2-particle approach of Chin-Chao-Blaskiewicz_2016 (lowest threshold), the TMCI intensity threshold is found at zero intensity, i.e. here also there is no TMCI threshold…;-)