TLEP: effect of cavity impedance for operation at high current and low energy

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Outline

- Introduction
- New code to study impedance + damper
- The LEP case
- A first preliminary study of TLEP stability
- Conclusion

Introduction

- TLEP: "*Triple LEP*" → 80 km circumference.
- Most critical version for impedance: "low" energy TLEP-Z
  - 45.5 GeV / beam,
  - 2625 bunches / beam,
  - 1.18 A / beam → 0.45 mA / bunch.
- LEP was limited by TMCI (transverse mode coupling instability), due to cavities impedance

  → need to study TMCI for TLEP,

  → can a transverse feedback help or even suppress TMCI (A. Burov 2012 results) ?

How are we going to study this ?

- Using a new code made up of a set of old methods

  → DELPHI (for Discrete Expansion over Laguerre Polynomials and Headtail modes),

- Based on solution of Sacherer integral equation (Chao's book, Eq. 6.179) written as an eigenvalue problem:

  → using a decomposition over Laguerre polynomials of the radial function (idea from Besnier 1974, used then by Y. Chin in code MOSES - 1985),

  → including azimuthal & radial modes, and mode coupling (like MOSES),

  → including generalization to any kind of impedance, multibunch effects and damper (here we use a flat damper model, i.e. with constant wake),

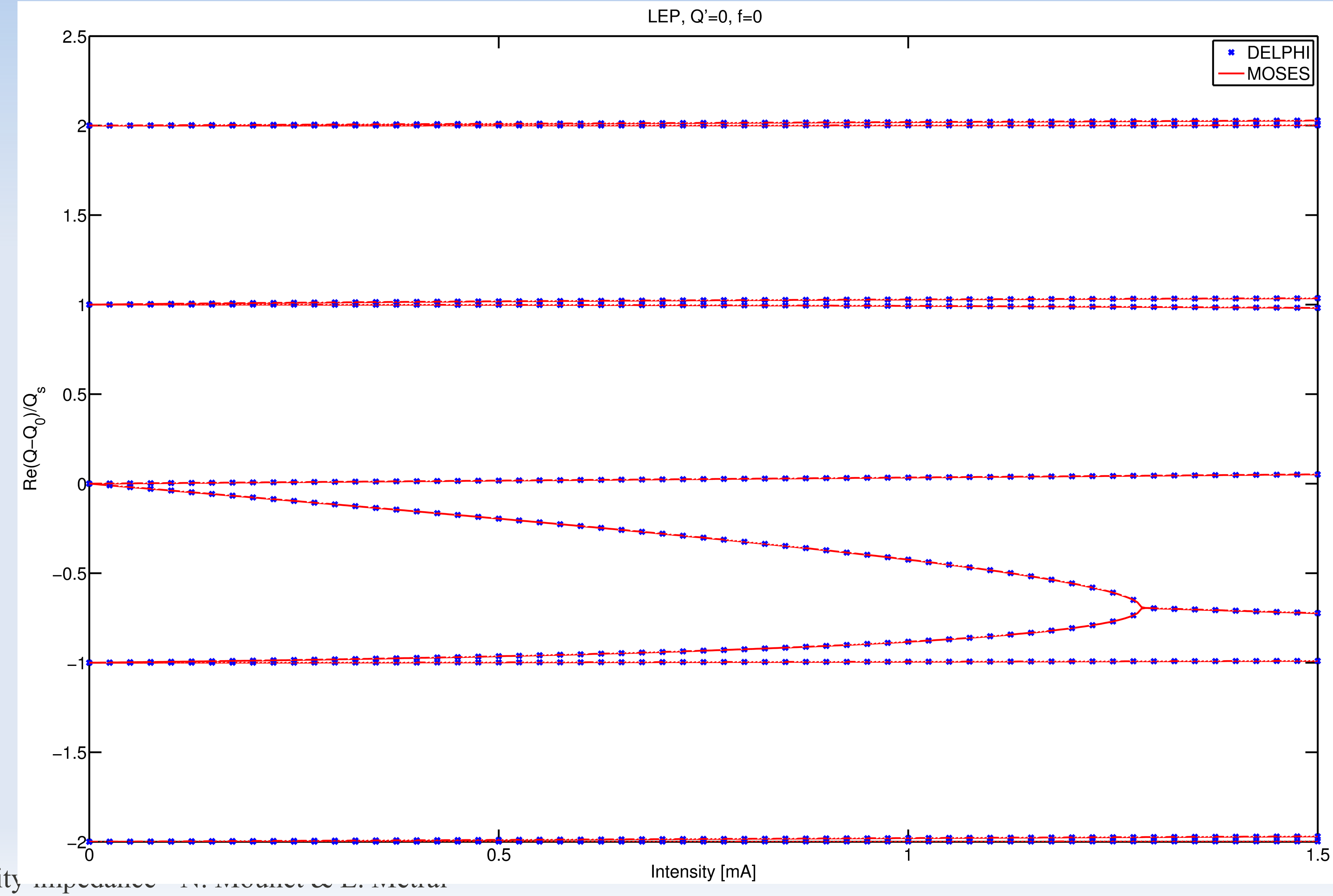
  → not including Landau damping,

  → synchrotron radiation damping taken into account simply by comparing instability rise time with damping time (very slow anyway for the studies here).

Benchmarks

- DELPHI vs MOSES, for single-bunch TMCI without damper (LEP RF cavities modelled as a broadband resonator):

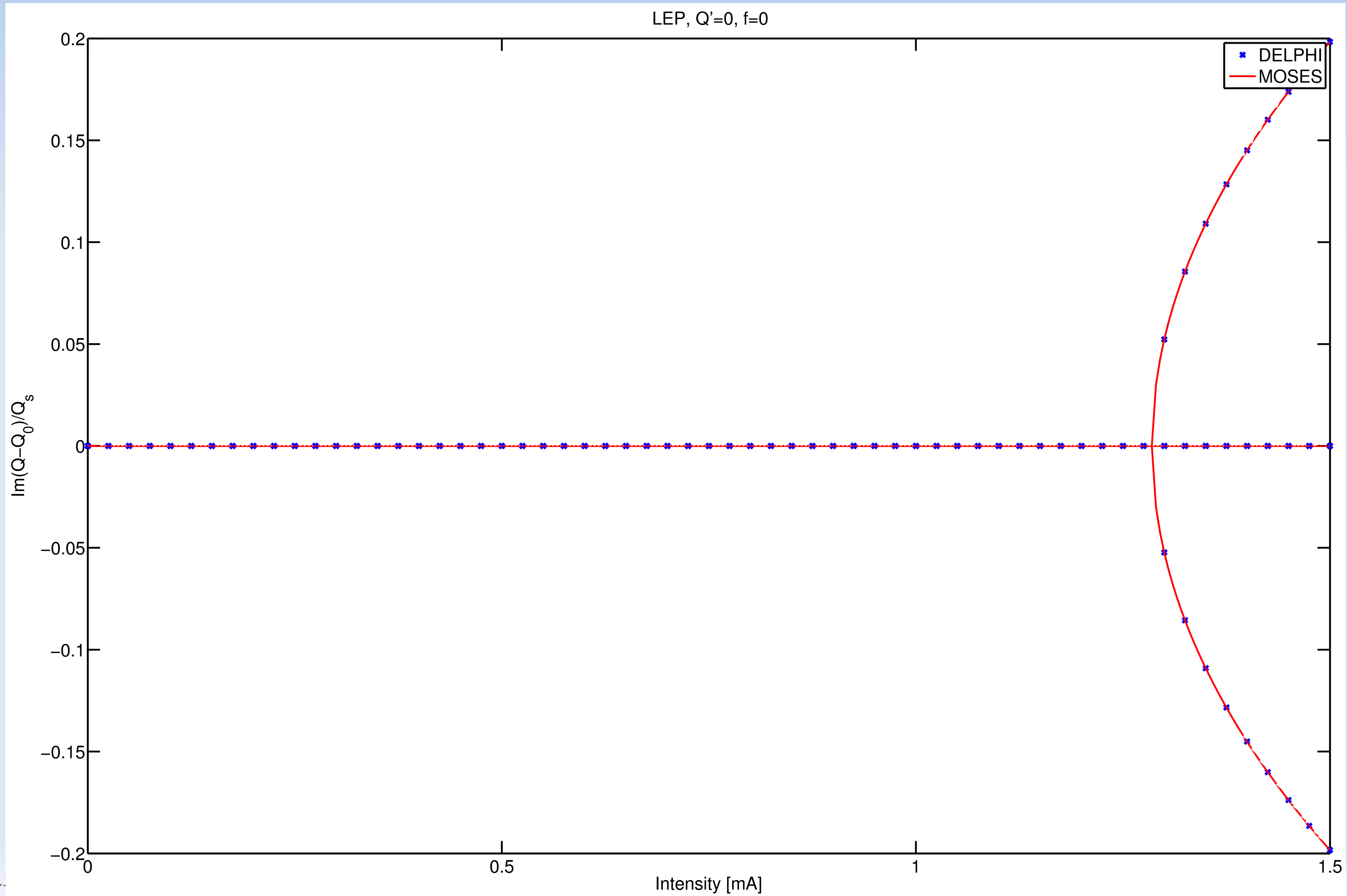
Real part, Q'=0



Benchmarks

- DELPHI vs MOSES, for single-bunch TMCI without damper (LEP RF cavities modelled as a broadband resonator):

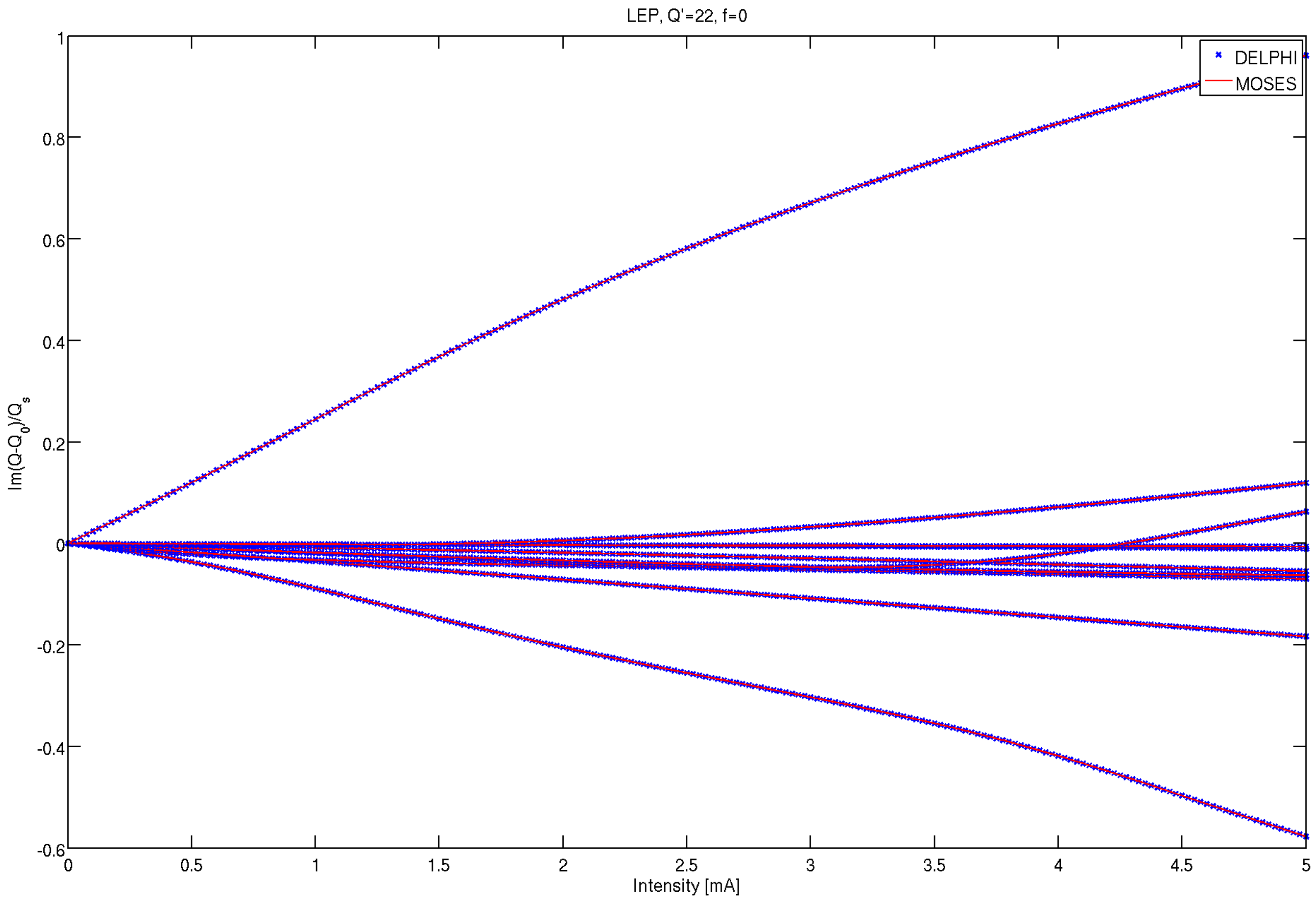
Imag. part, Q'=0



Benchmarks

- DELPHI vs MOSES, single-bunch without damper (LEP RF cavities modeled as a broadband resonator):

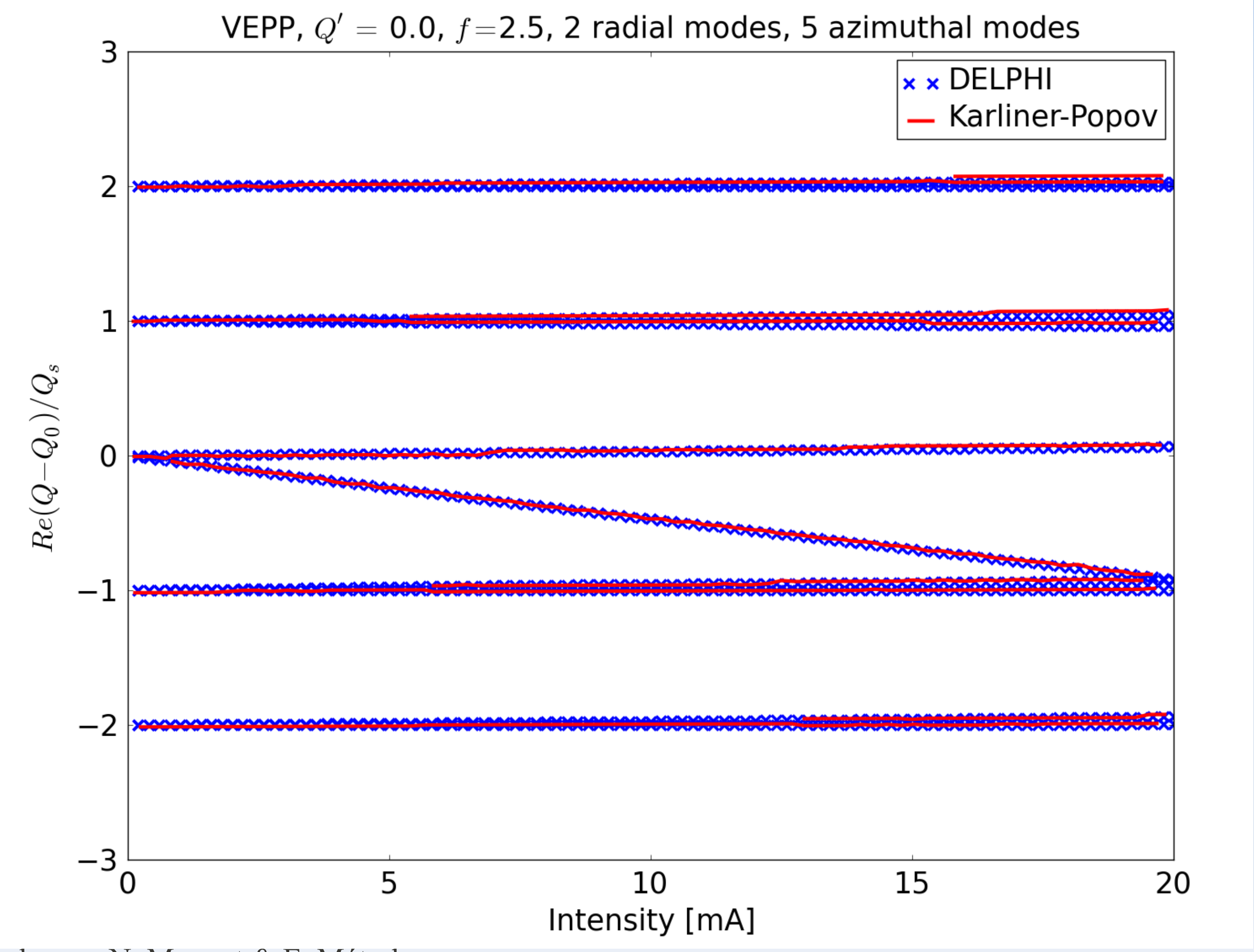
Imag. part, Q'=22



Benchmarks

- DELPHI vs Karliner-Popov, single-bunch with damper (VEPP-4, broadband resonator):

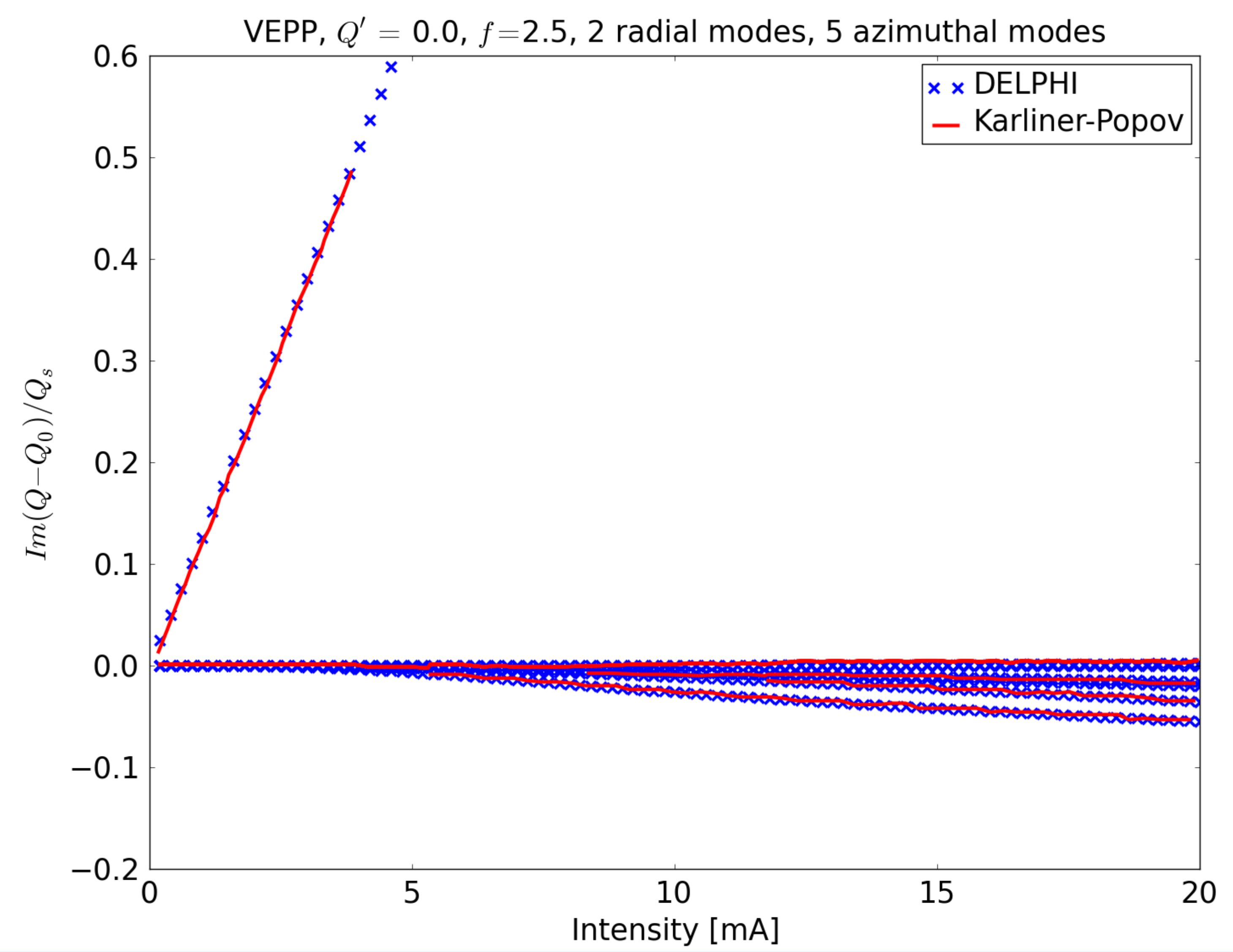
Real, part, Q'=0



Benchmarks

- DELPHI vs Karliner-Popov, single-bunch with damper (VEPP-4, broadband resonator):

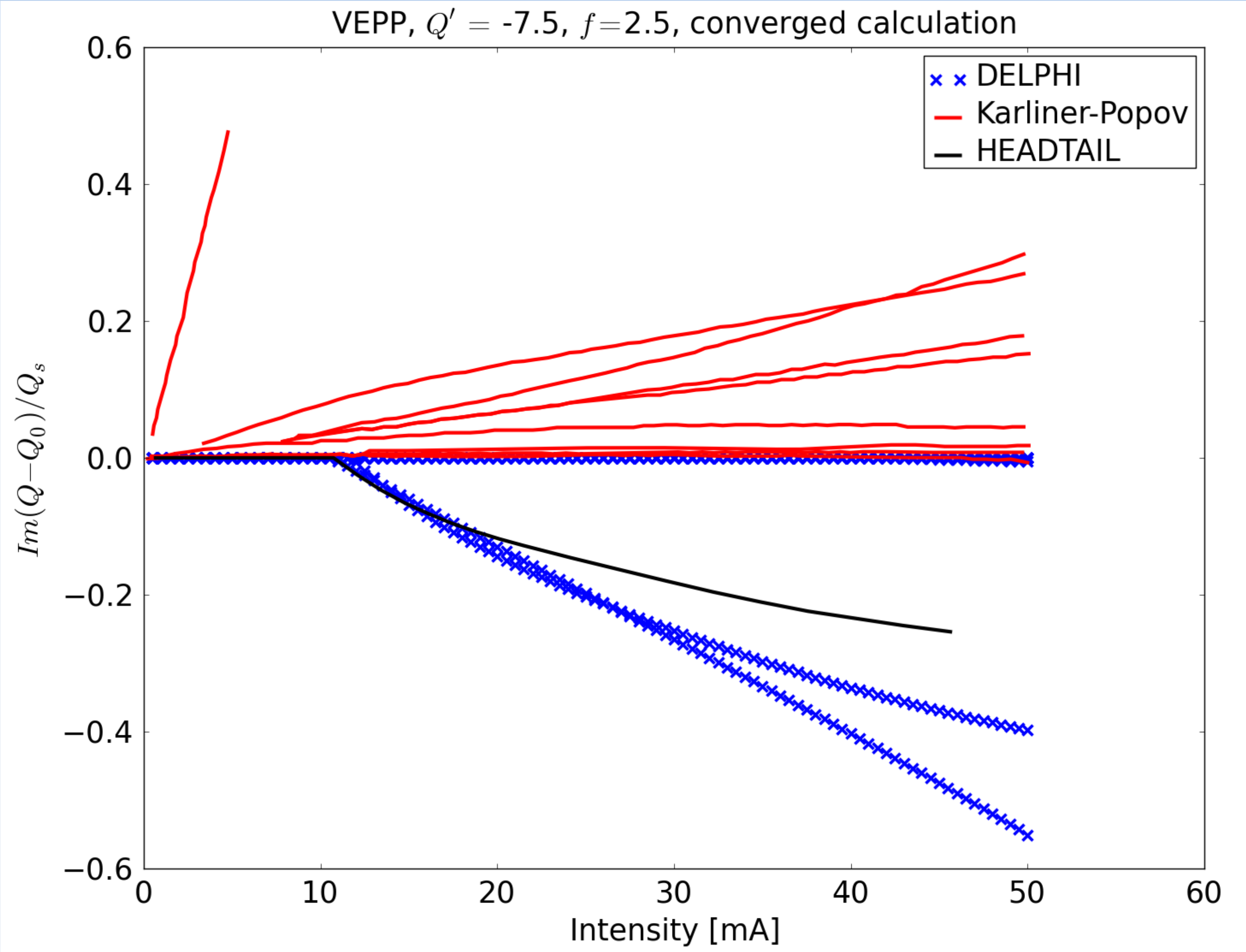
Imag. part, Q'=0



Benchmarks

- DELPHI vs Karliner-Popov and HEADTAIL (macroparticle simulation code – G. Rumolo et al), single-bunch with damper (VEPP-4, broadband resonator):

Imag, part,
Q'=-7.5



DELPHI is closer to HEADTAIL.

Karliner-Popov is more stable → due to their non flat damper ? (we cannot check because Karliner-P damper parameters are not provided).

What about LEP TMCI ?

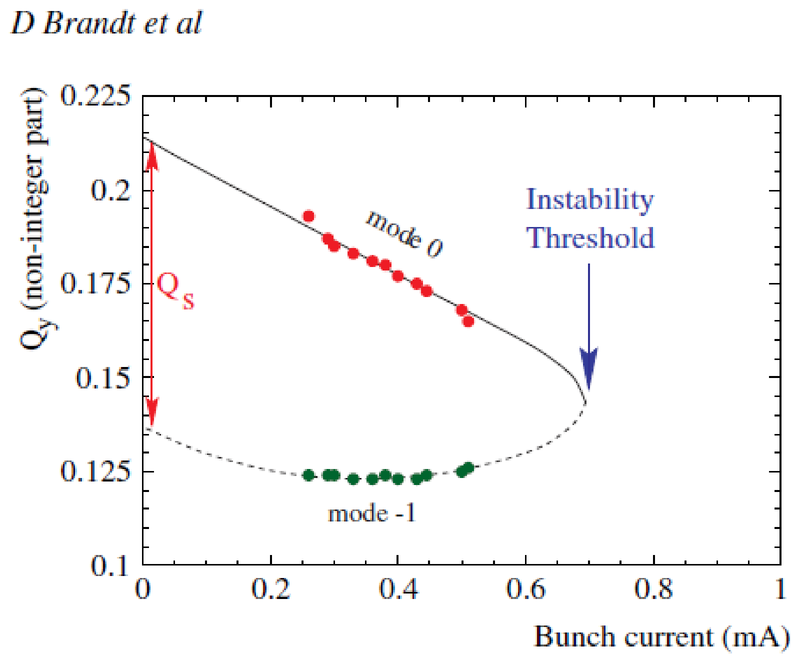


Figure 12. Measurement of the 0 and −1 modes of oscillation as a function of the bunch current at LEP for $Q_s = 0.082$. As the current increases the two modes approach until they merge at the instability threshold.

- Impedance model: two broad-band resonators (RF cavities + bellows), the rest is relatively small (<10%) [G. Sabbi, 1995].

  → experimental tune shifts and TMCI threshold (from simple formula) well reproduced,

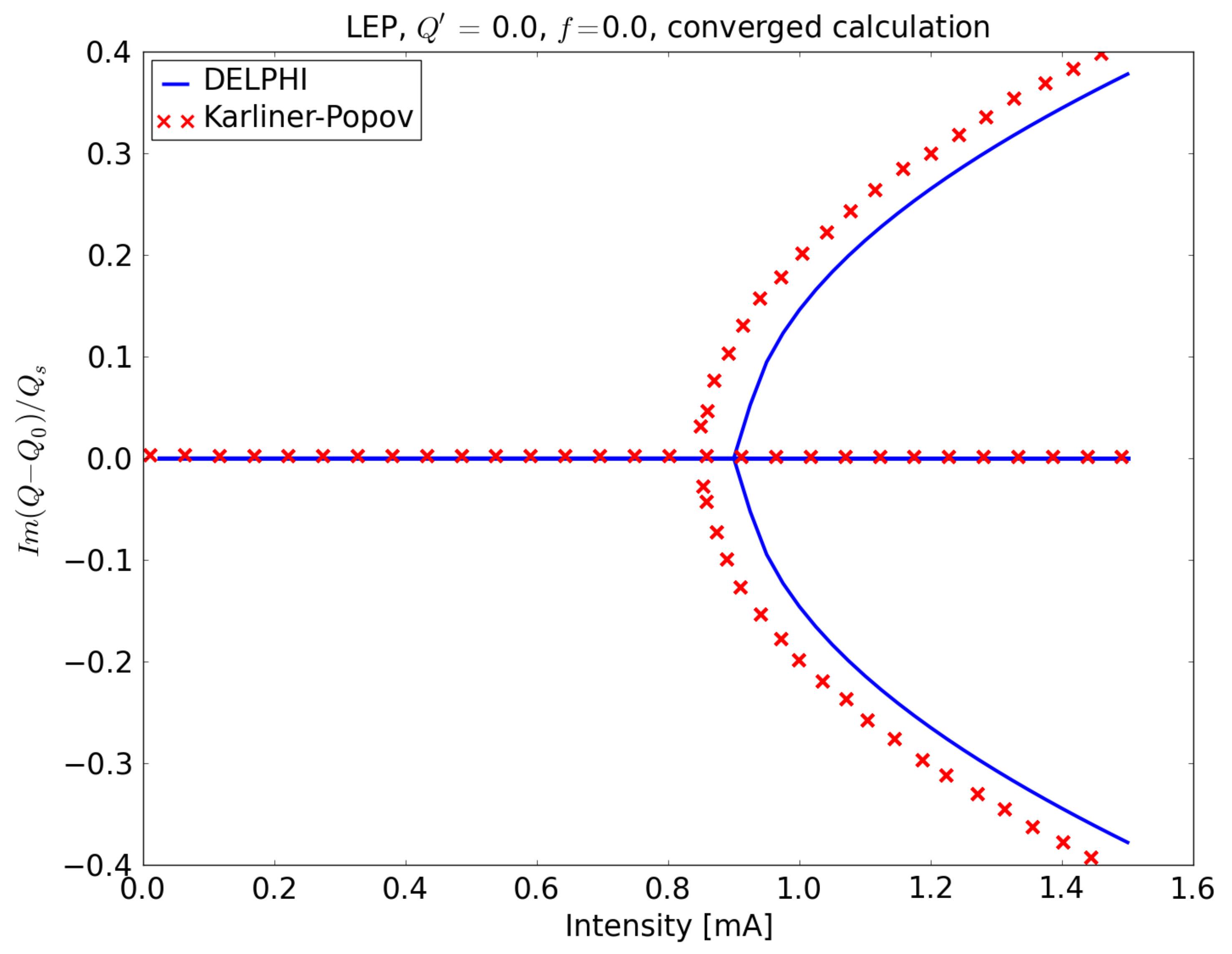
  → threshold slightly less than 1mA.

- Transverse feedback:
  - First idea: reactive feedback (prevent mode 0 to shift down and couple with mode -1) → not more than 5-10 % increase in threshold, despite several attemps and models developped [Danilov-Perevedentsev 1993, Sabbi 1996, Brandt et al 1995],
  - Another idea: resistive feedback, first found ineffective [Ruth 1983], tried at LEP but never used in operation. Recently (2005) thought to be a good option by Karliner-Popov with a possible increase by factor ~5 of TMCI threshold → can we confirm ?

LEP

- LEP without damper (typical LEP2 parameters)

Imag. part, Q'=0

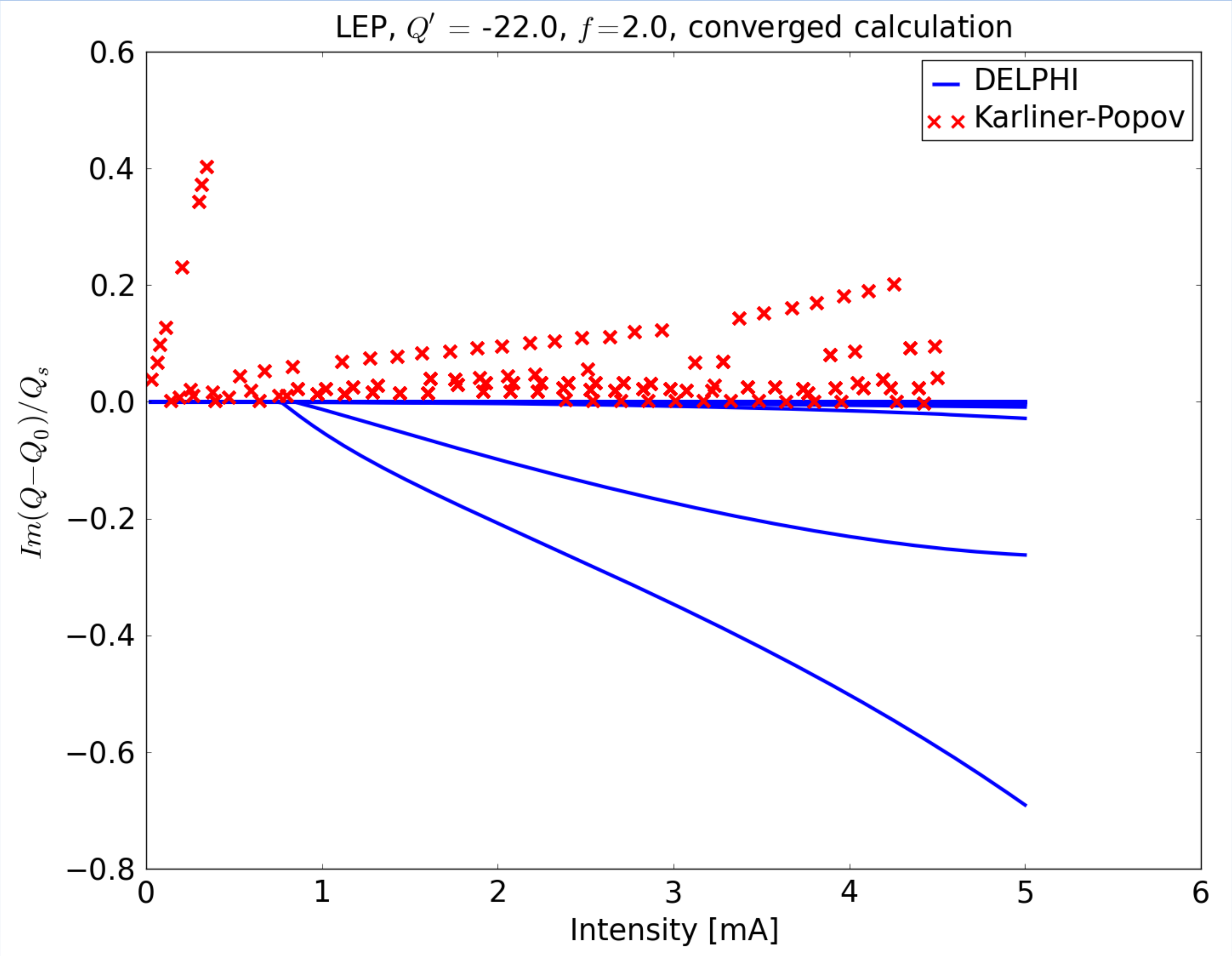


Note: we had to change the bunch length (1.3cm instead of 1.8cm) to match Karliner-Popov's result.

LEP

- LEP with resistive damper (typical LEP2 parameters)

Imag. part, Q'=-22

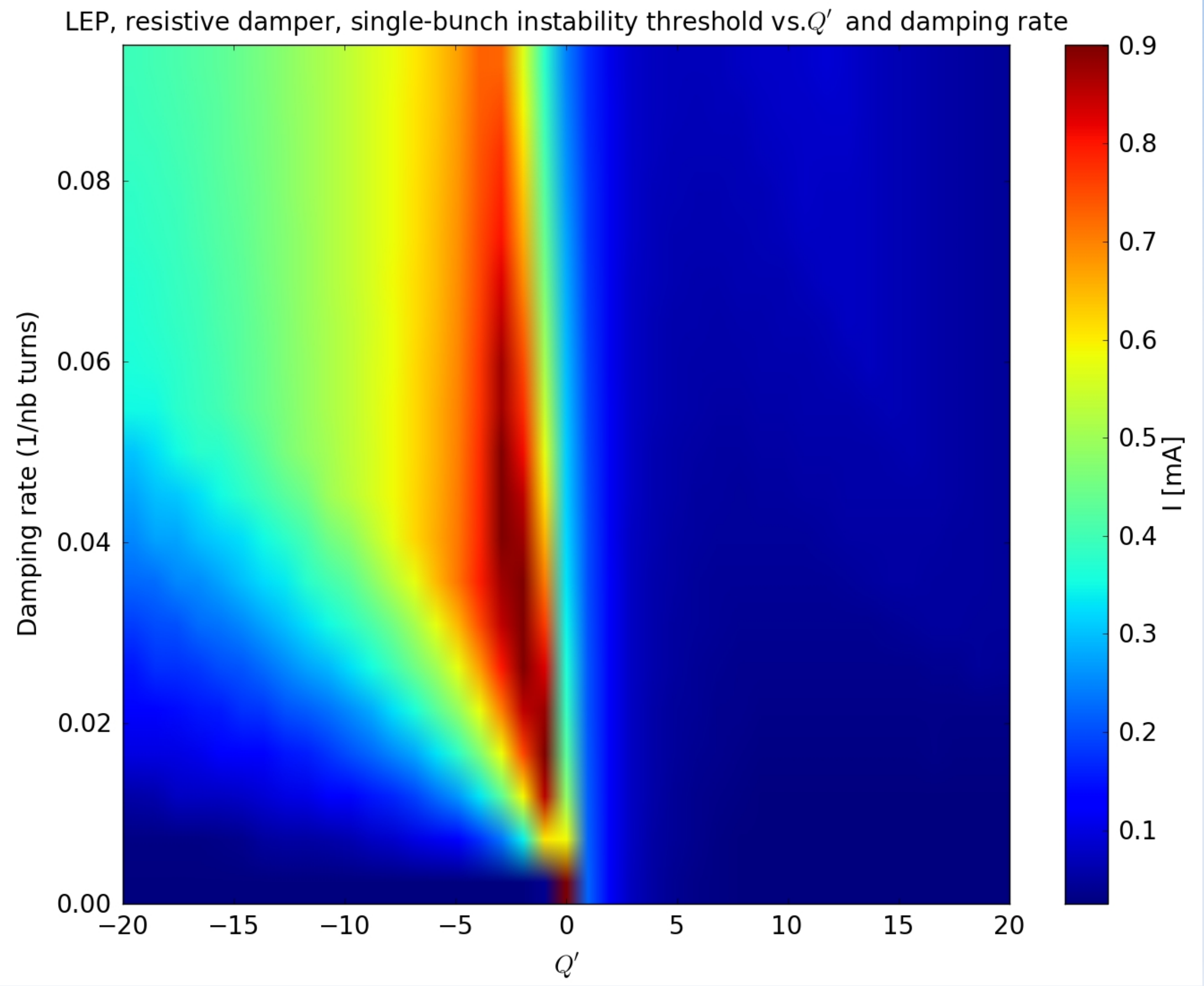


Again, we see that Karliner-Popov model gives more stability than DELPHI

→ we cannot reproduce their result.

LEP: stability analysis with resistive damper

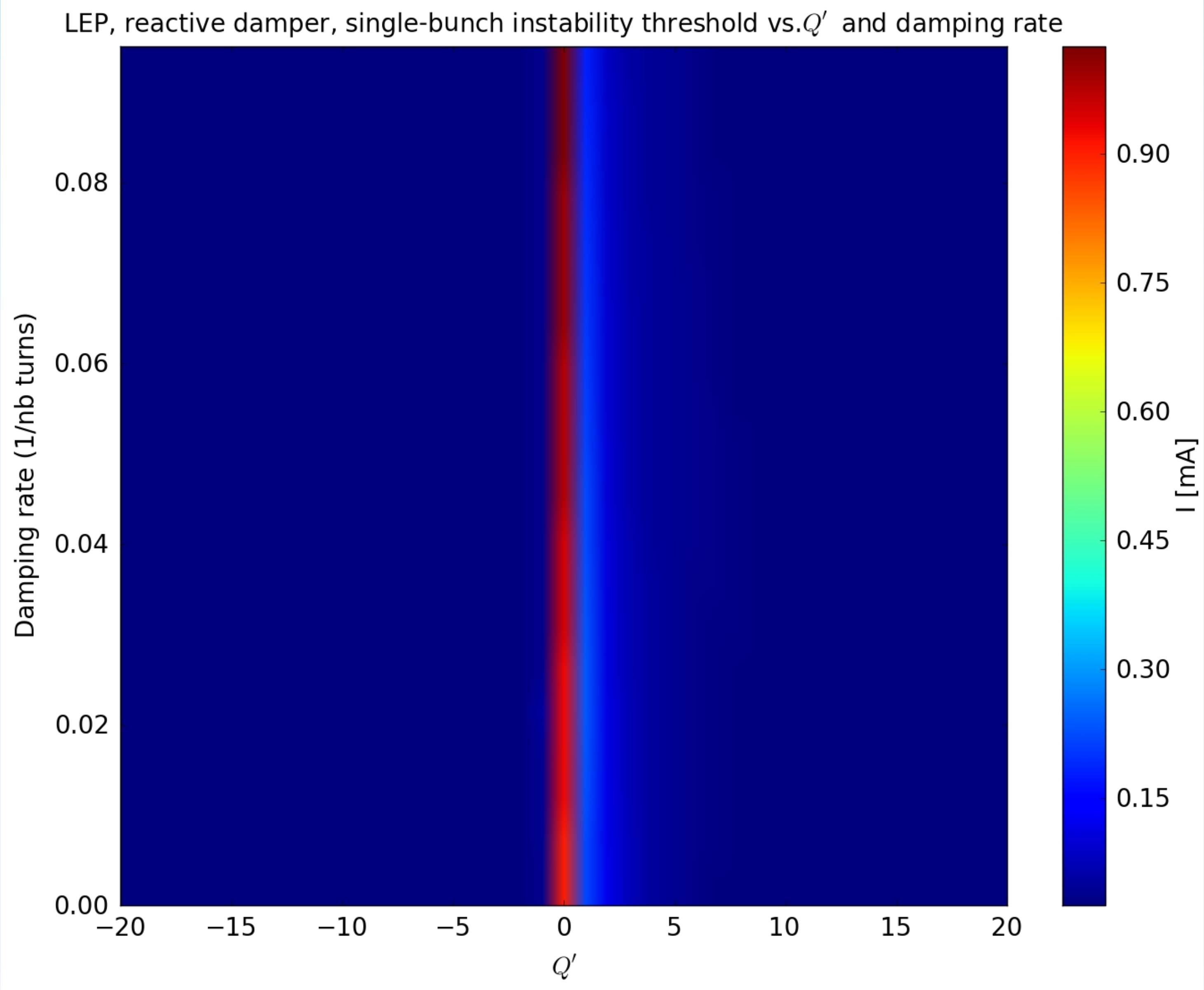
- Instability threshold vs. *Q'* and damper gain (up to 10 turns) with DELPHI:



Essentially, one cannot do better than the natural (i.e. without damper) TMCI threshold.

LEP: stability analysis with reactive damper

- Instability threshold vs. *Q'* and damper gain (up to 10 turns) with DELPHI:

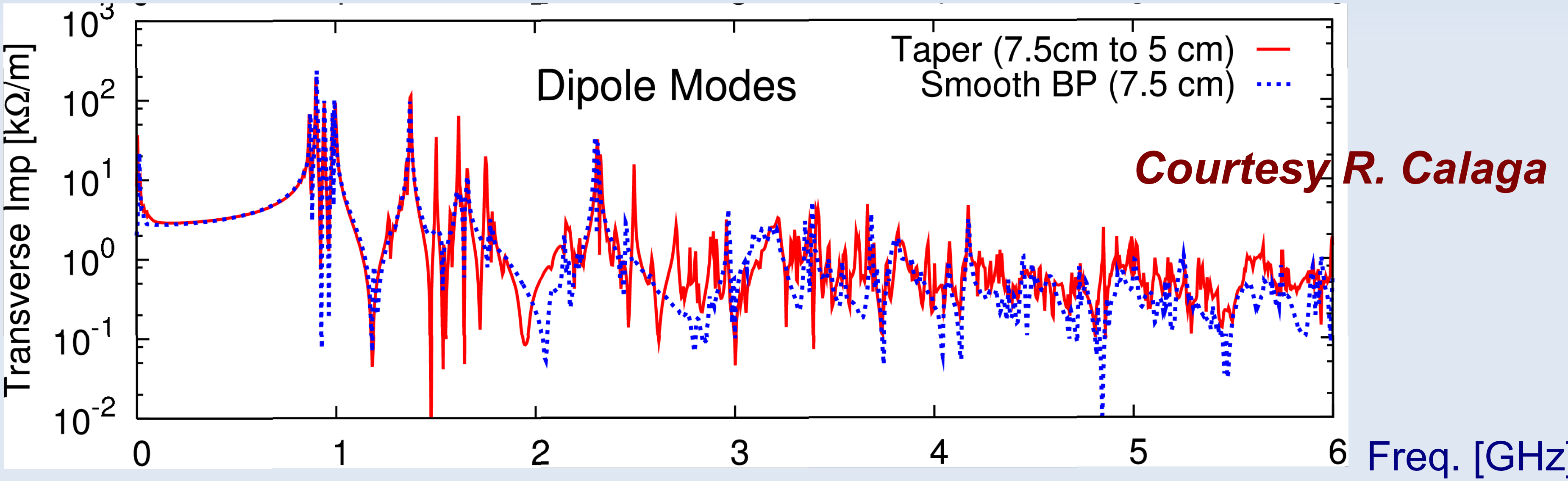


We can do a little better than the ”natural” TMCI.

→ seems to match (qualitatively) LEP observations.

TLEP

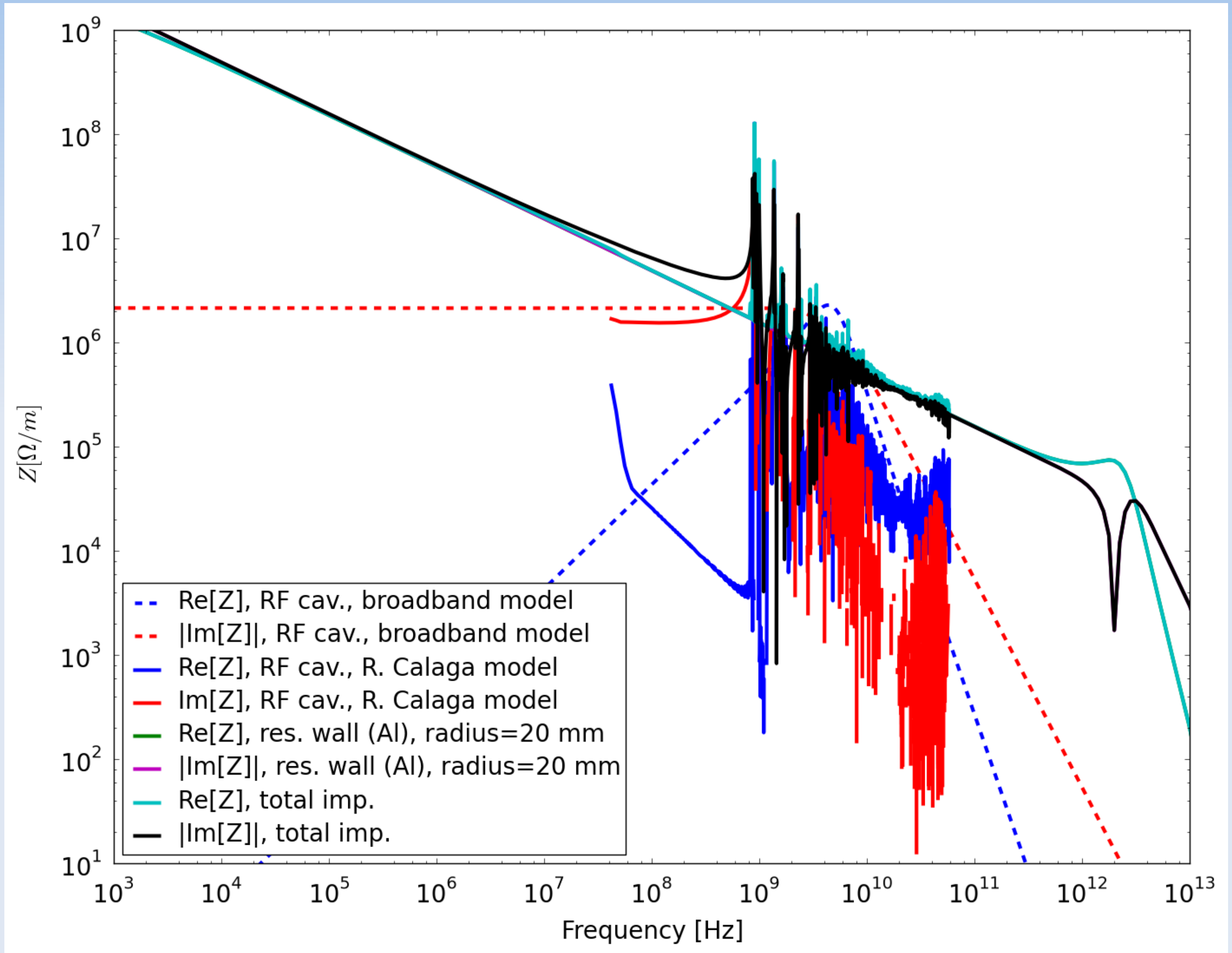
- Parameters chosen (TLEP-Z option, 45.5 GeV):
  - Optics: [Q]=640, β=*50* m, α_p=*9.10*$^{-5}$ (B. Holzer, F. Zimmermann)
  - RF: Q_s=*0.34*, σ_z^{RMS}= *1.9* mm (F. Zimmermann),
- RF cavity impedance (600 m → most pessimistic option):
  - One cavity (700 MHz) imp. (BNL-SERL cavity – R. Calaga's PhD thesis)



  - We also did a "fit" with a broad-band resonator (*Q=1*, *f=5* GHz, *R=1.5* kΩ/m),
- Impact of resistive-wall impedance ? (suggested by V. Danilov – see also his talk)

  → computed with ImpedanceWake2D analytical code [EPFL PhD thesis 5305], for an aluminum cylindrical beam pipe, 2 cm radius.

TLEP transverse impedance contributions



→ Resistive-wall impedance is a significant contribution !

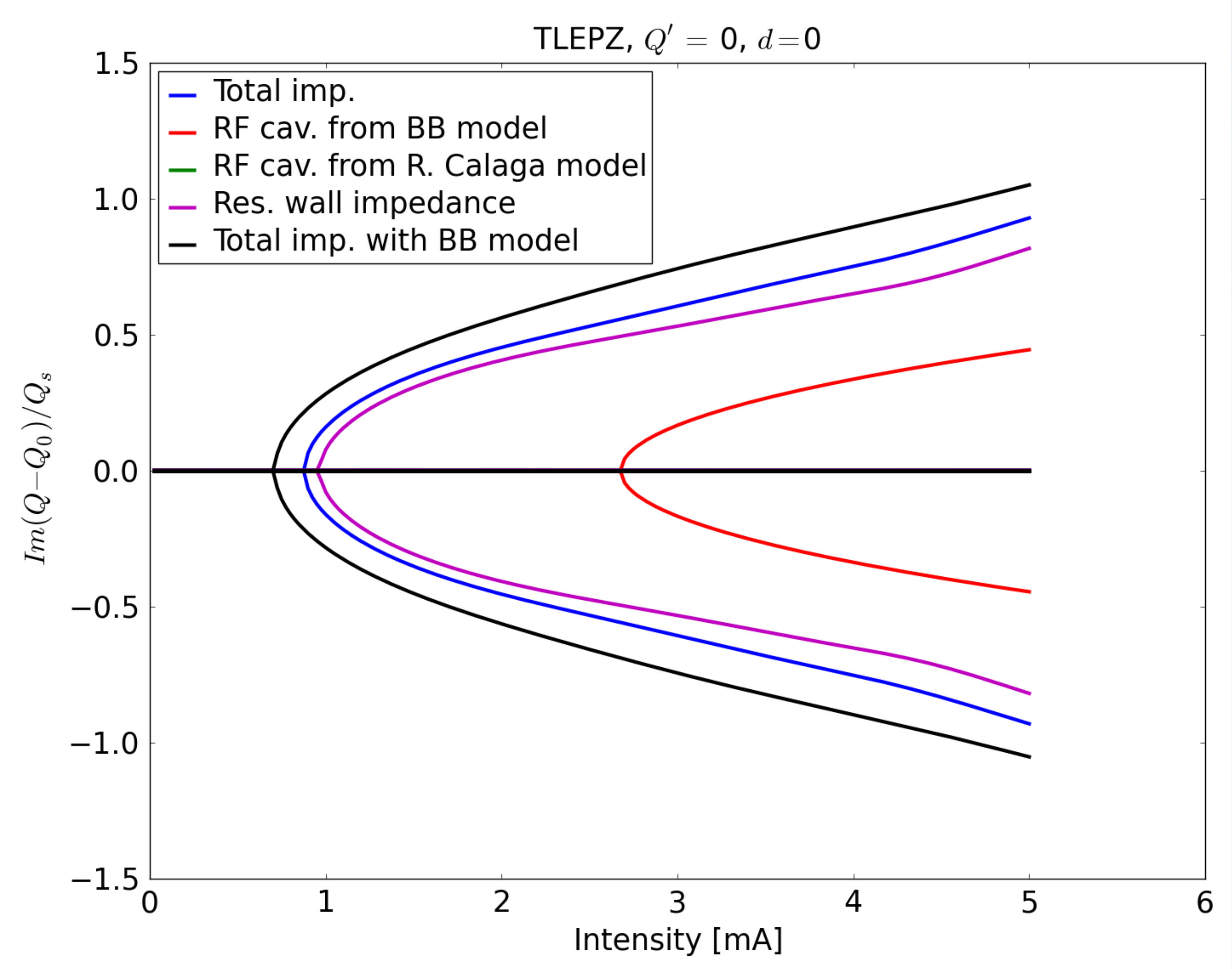
TLEP TMCI at *Q'=0* without damper

- TMCI threshold (DELPHI with 3 radial modes, 7 azimuthal modes):

→ Resistive-wall impedance indeed the main contributor to TMCI (Note: here *Q=640.9* – most critical below integer).

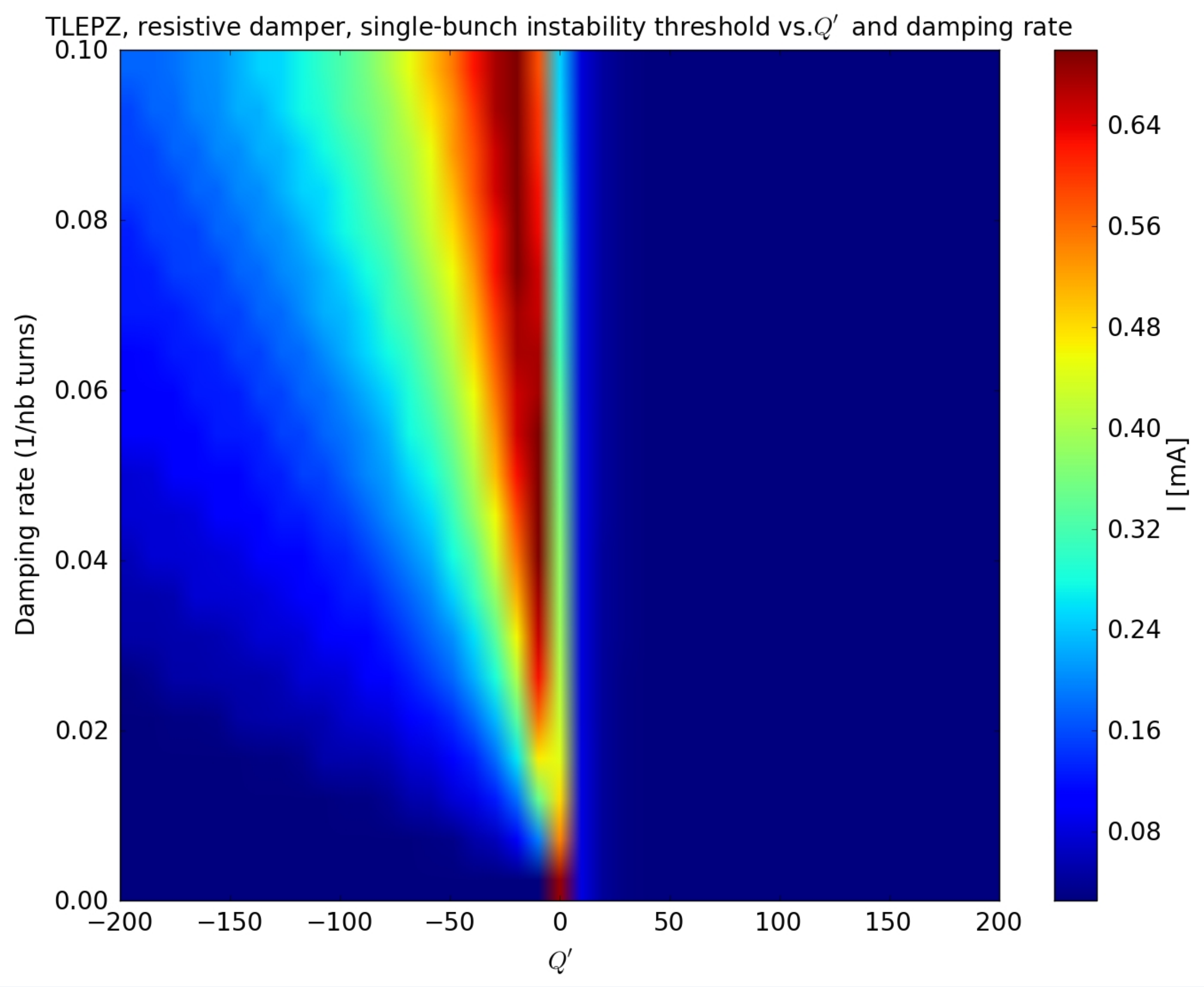
→ We choose most pessimistic scenario for RF cavity (broad-band model), even if less realistic.

→ In the end, single-bunch threshold just below 1 mA.



TLEP: stability analysis with resistive damper

- DELPHI results for instability threshold: scan vs. Q' and damper rate (up to 0.1 i.e. 10 turns)

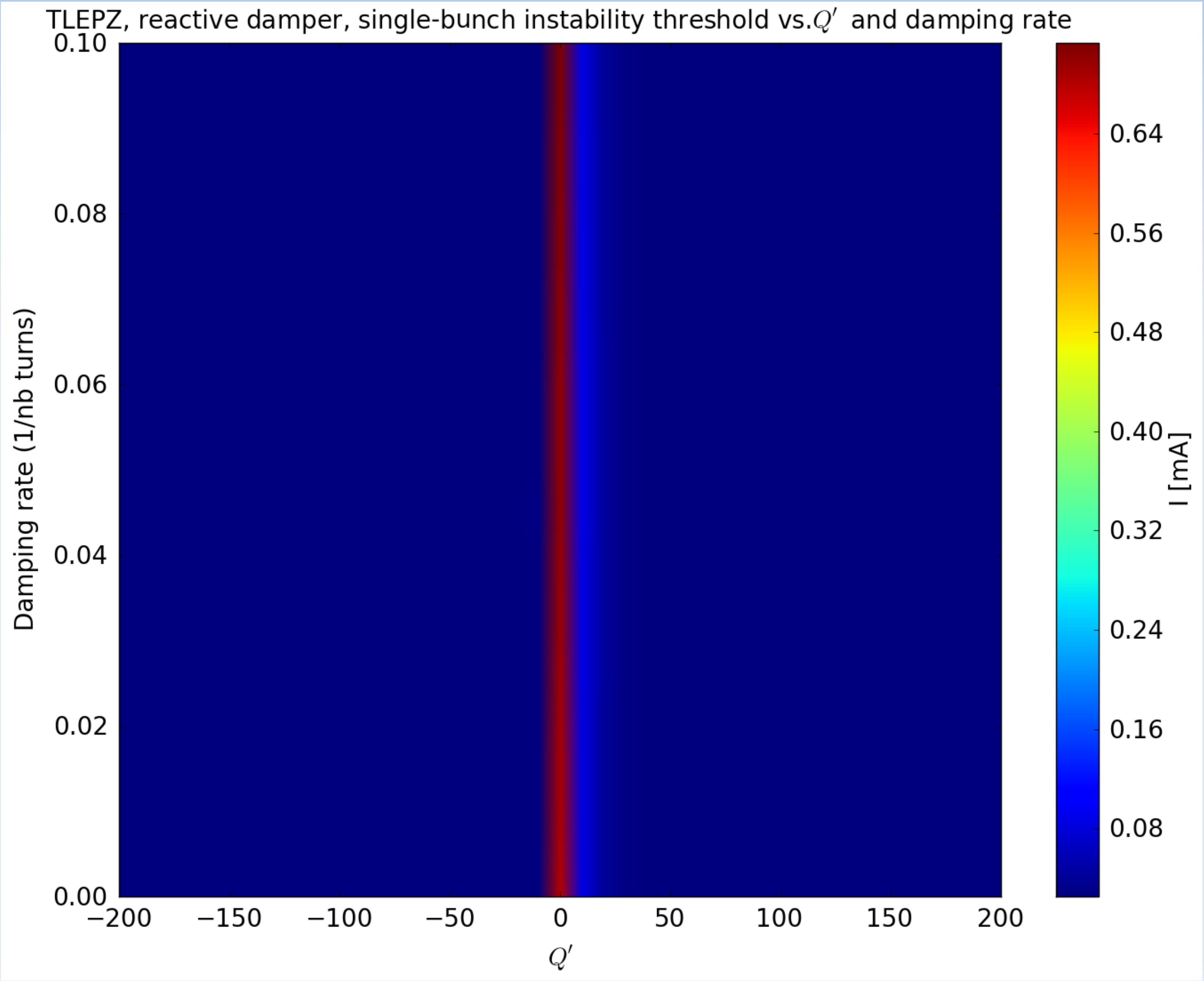


→ As for LEP, resistive damper barely improves the situation.

TLEP: stability analysis with reactive damper

- DELPHI results for instability threshold: scan vs. Q' and damper rate (up to 0.1 i.e. 10 turns)

→ Reactive damper is rather ineffective as well.



Conclusions and future work

- Developped a new code (DELPHI) to study stability in mode-coupling conditions, with transverse damper. Benchmarks done (vs. MOSES, Karliner & Popov, HEADTAIL), many more to be done.
- Study LEP stability with damper & RF cavity impedance. Karliner & Popov result of large increase of threshold of instability with resistive damper at negative chromaticity not reproduced; not clear why.
- LEP experimental results (relative ineffectiveness of transverse flat damper – being reactive or resistive) qualitatively obtained.
- TLEP impedance is likely not to be dominated by cavities but rather by resistive-wall impedance, as far as TMCI is concerned.
- TLEP stability analysis with the DELPHI code shows essentially the same resut as LEP: a flat (bunch-by-bunch) damper should be ineffective, being either resistive or reactive (at least with damping time > 10 turns).
- Still very preliminary study ! Many further checks have to be done.
- Future work concerning TLEP:
  - Check multibunch effects,
  - Refine impedance & damper models.