Update on intensity limitations from HL-LHC transverse impedance

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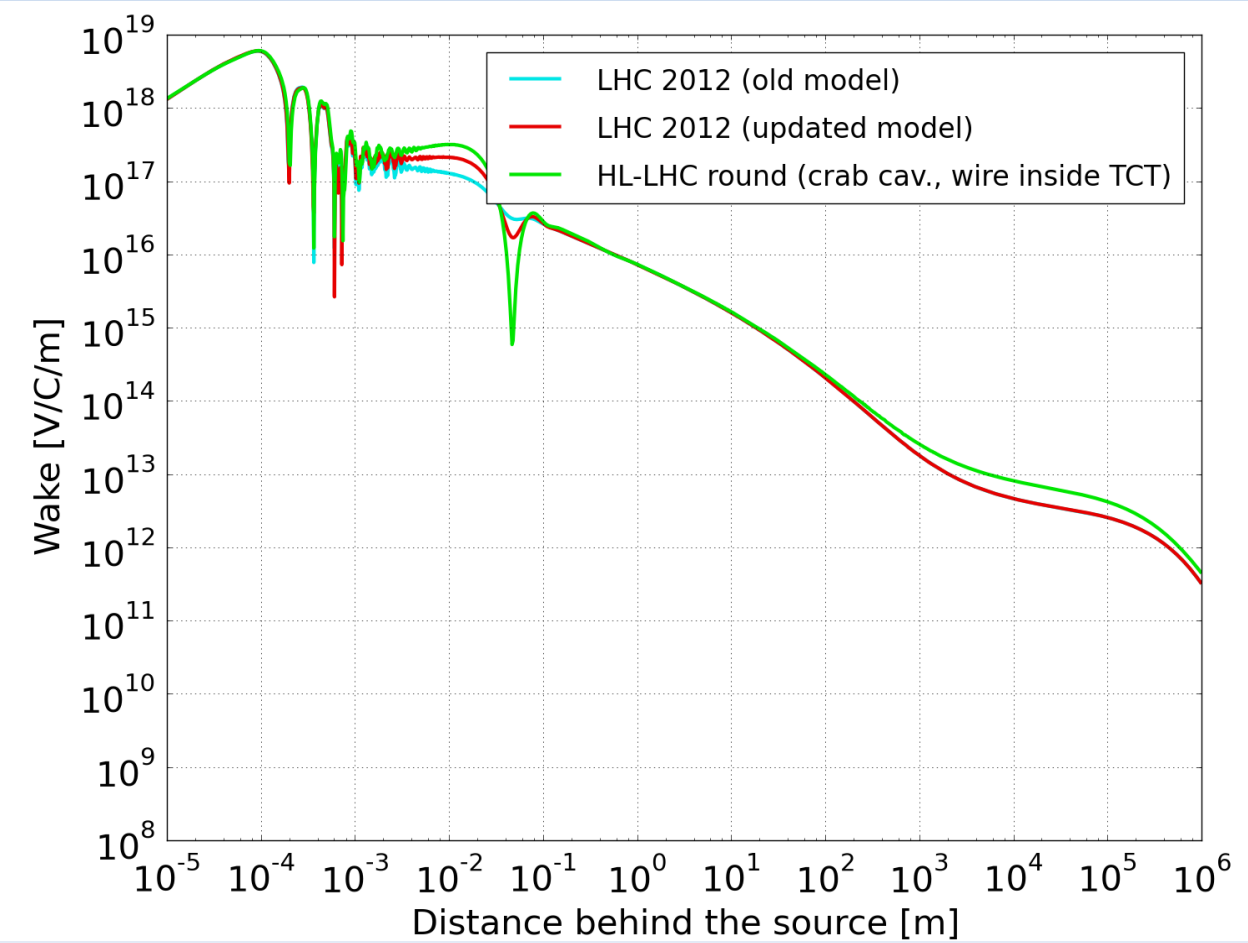
Acknowledgements: E. Todesco

Transverse instability limits in the HL LHC era: update

- Will HL-LHC be stable for positive chromaticities, even without Landau damping ?
- Effect of non-linear bucket and quadrupolar impedance on TMCI threshold
- Effect of higher temperatre in triplet beam-screens
- Effect of Molybdenum on instbilities
- TMCI at injection

Will HL-LHC be stable without Landau damping ?

- Previous WP2.4 meeting (21/01/2014): HL-LHC seems to be stable with damper, without Landau damping, for positive chromaticities.
- BUT: looking at the wake functions, strange ”well” (for ~ typical intrabunch distances)

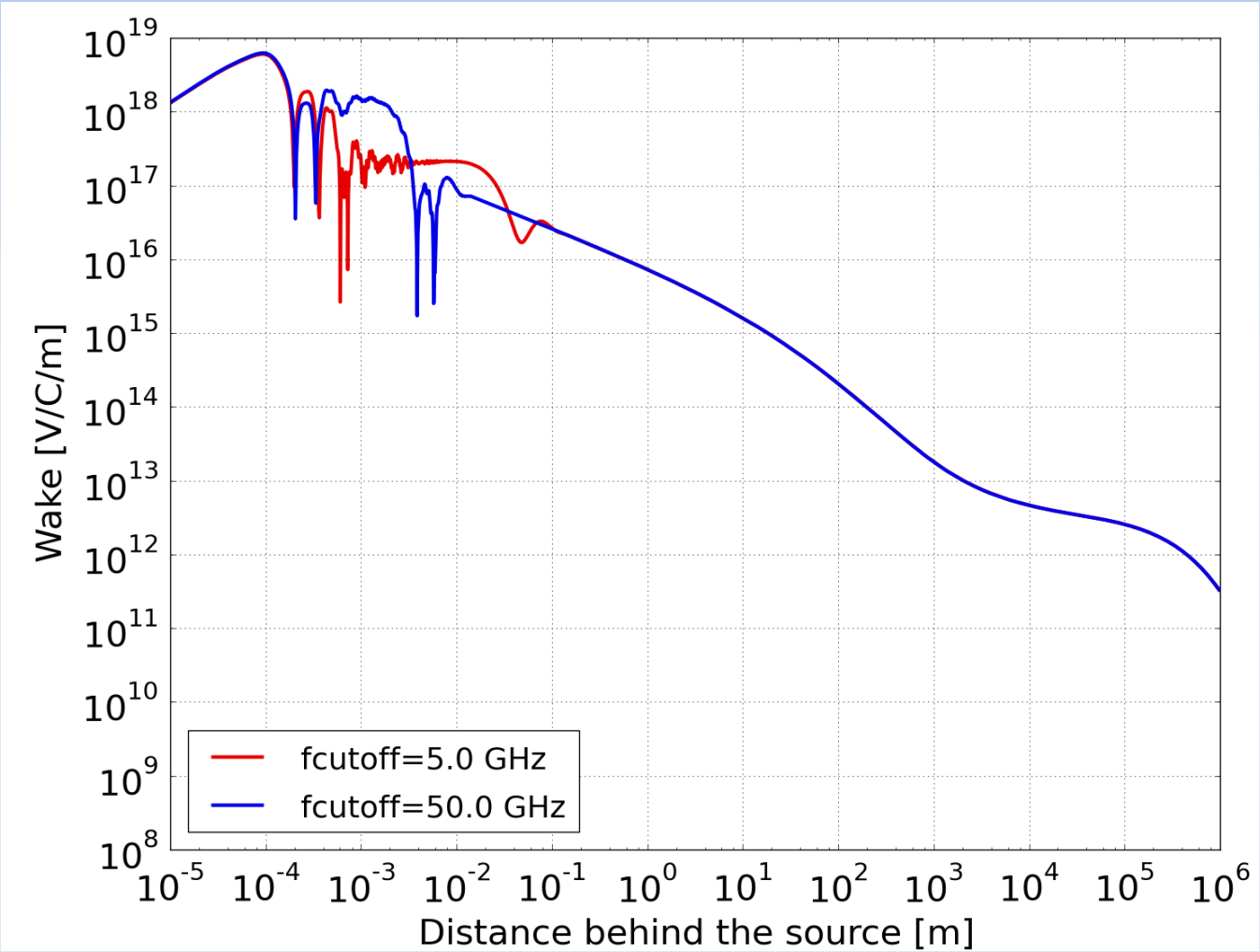


→ this ”well” is deeper for the updated LHC model and for HL-LHC,

→ since most of the added contributions are broad-band, is it due to the borad-band model ?

Will HL-LHC be stable without Landau damping ?

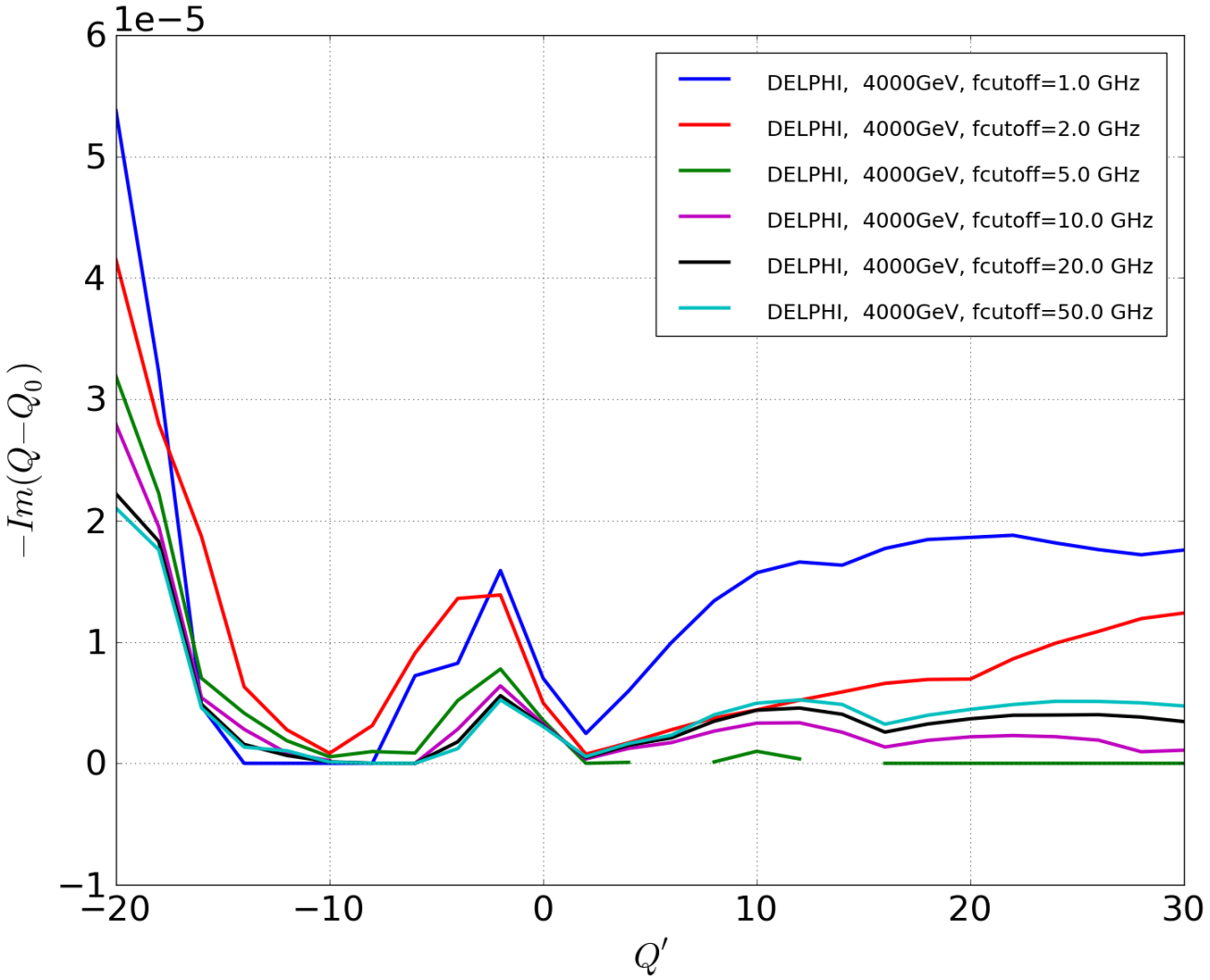
- Indeed, changing the cutoff frequency of the broad-band resonators of the model



- the "well" is going away with higher cutoff
- can be explained by negative impedance after cutoff in a resonator model
→ pushing cutoff away suppress this effect
- on the other hand, wake decreases below a few cm, with higher cutoff
→ we have to check effect on beam stability

Will HL-LHC be stable without Landau damping ?

- Effect of changing the cutoff frequency on single-bunch growth rates vs Q' (50 turns damper, no Landau damping, N_b=1.7 10^{11} p+/b, LHC 2012 parameters):



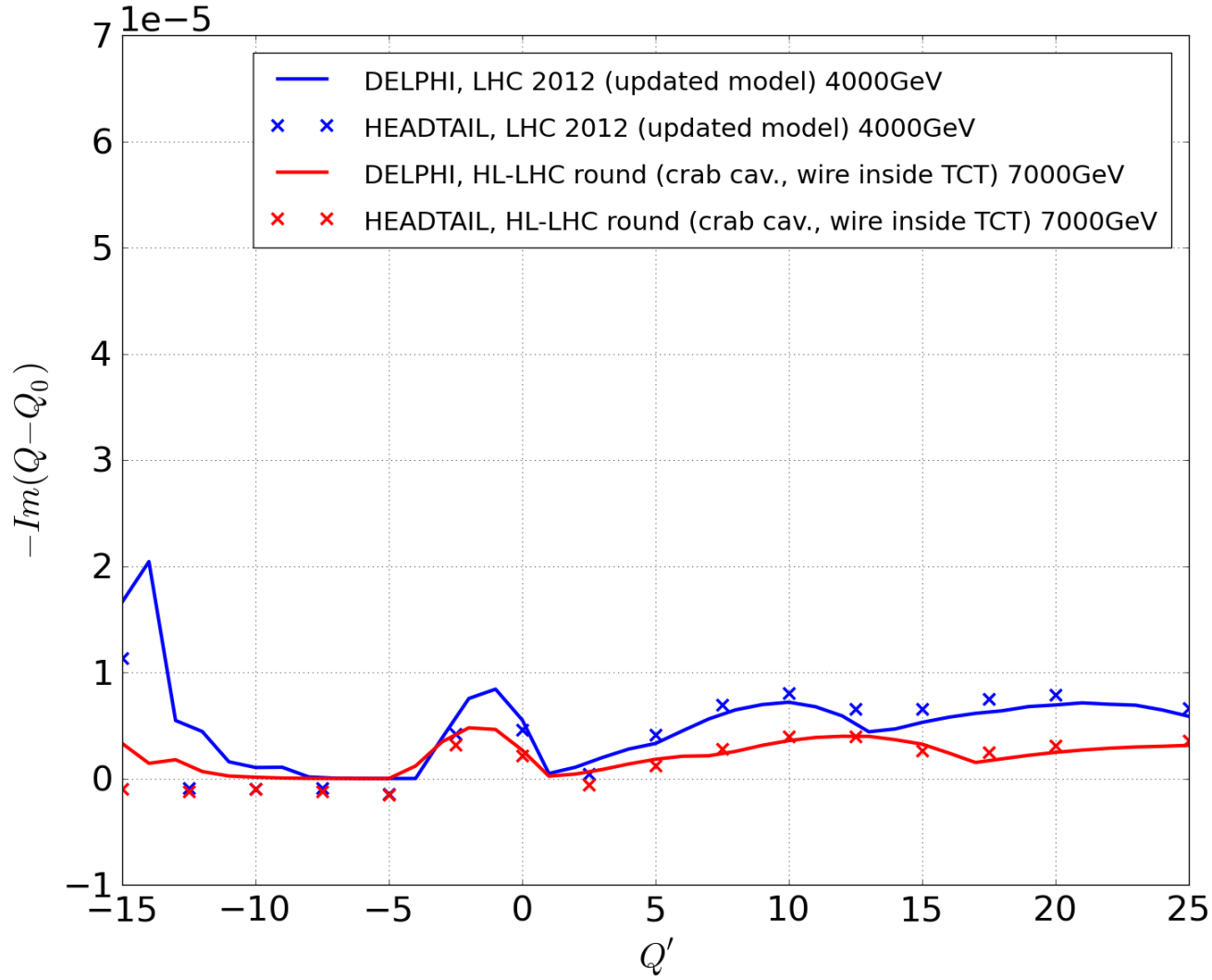
→ 5 Ghz (cutoff used previously) was indeed giving a kind of minimum of instability,
→ convergence around 50Ghz cutoff,

For now I then use 50Ghz cutoff. This is a ”quick fix” that is basically **unphysical.** What should be done ultimately is to replace all broad-band resonators by a more physical impedance model.

Will HL-LHC be stable without Landau damping ?

NO

- Single-bunch growth rate vs Q' with 50 turns damper, for LHC (typical 2012 settings, 4TeV) and HL-LHC (7TeV), with 1.5 10^{11} p+/bunch (horizontal):

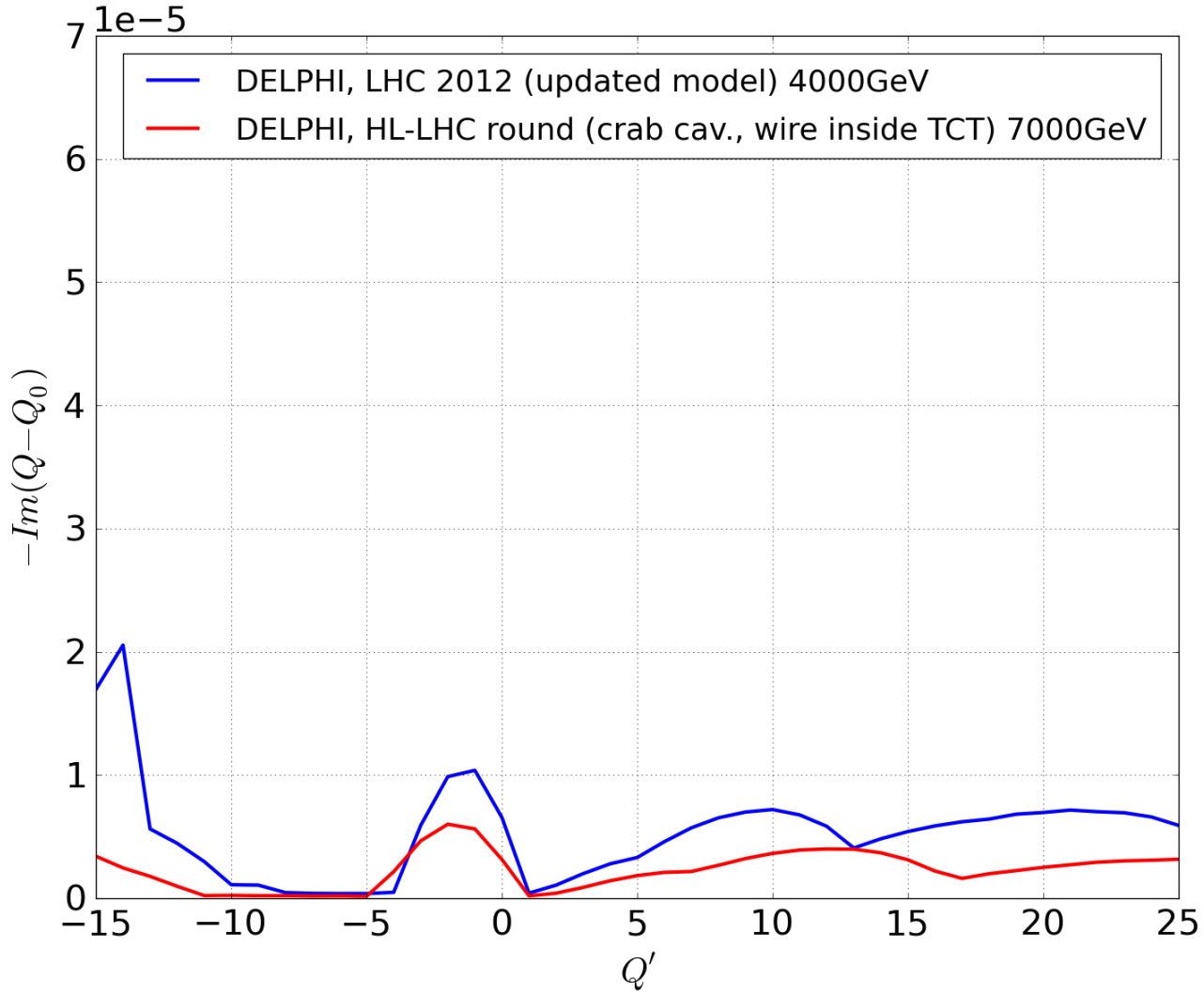


Assumptions: ideal bunch-by-bunch damper, no Landau damping, linear bucket & dipolar imp. only

→ analytical code DELPHI and HEADTAIL in agreement,
→ with the new cutoff HL-LHC is unstable stable for positive chromaticites (absence of Landau damping)

New cutoff: LHC / HL-LHC comparison: growth rates at fixed intensity, with damper

- Multibunch growth rate (50ns) vs Q' with 50 turns damper, for LHC (typical 2012 settings, 4TeV) and HL-LHC (7TeV), with 1.5 10^{11} p+/bunch (horizontal):

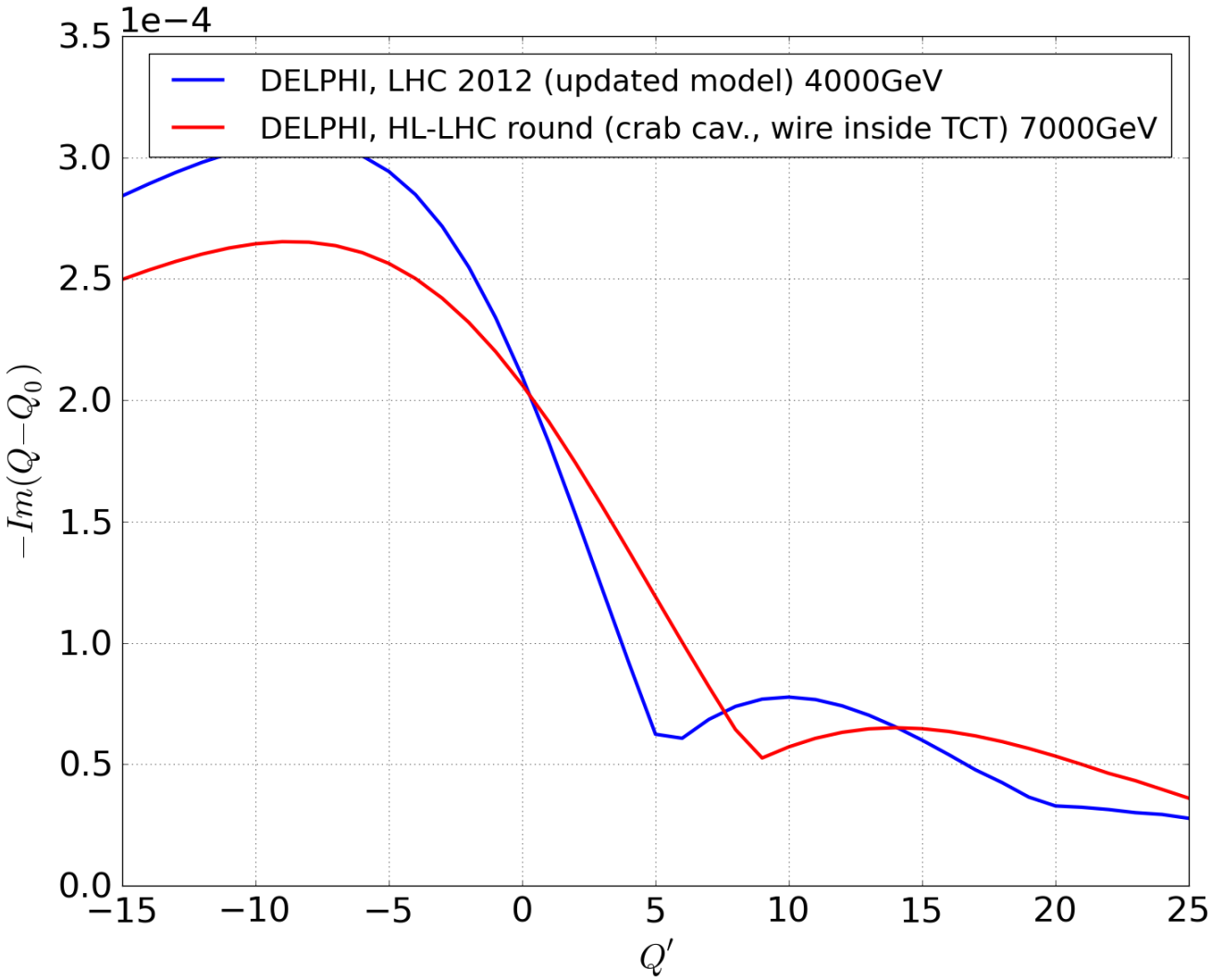


Note: ideal bunch-by-bunch damper, no Landau damping, linear bucket & dipolar imp. only

→ HL-LHC unstable for positive chromaticites

New cutoff: LHC / HL-LHC comparison: growth rates at fixed intensity, without damper

- Multibunch growth rate (25ns) vs Q' without damper, for LHC (typical 2012 settings, 4TeV) and HL-LHC (7TeV), with 1.5 10^{11} p+/bunch (vertical):

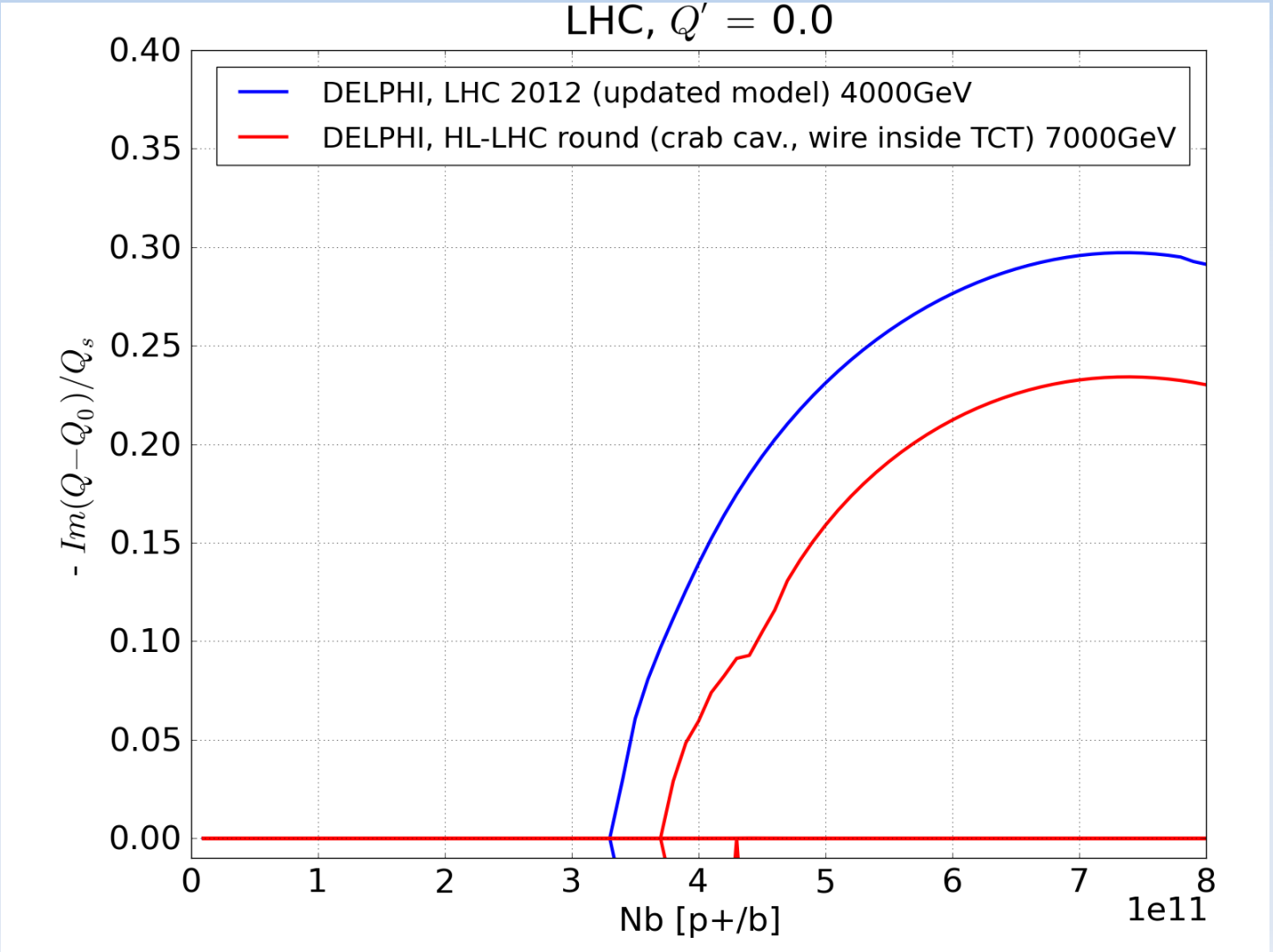


Note: no Landau damping, linear bucket & dipolar imp. only

→ HL-LHC can be worse than LHC (compensation between energy effect / higher low freq. impedance),
→ at *Q′~15*, all growth rates quite similar.

LHC / HL-LHC comparison: TMCI threshold

- Single-bunch imaginary tune shift vs intensity without damper, for LHC (typical 2012 settings, 4TeV) and HL-LHC (7TeV), with Q′=*0* (horizontal):

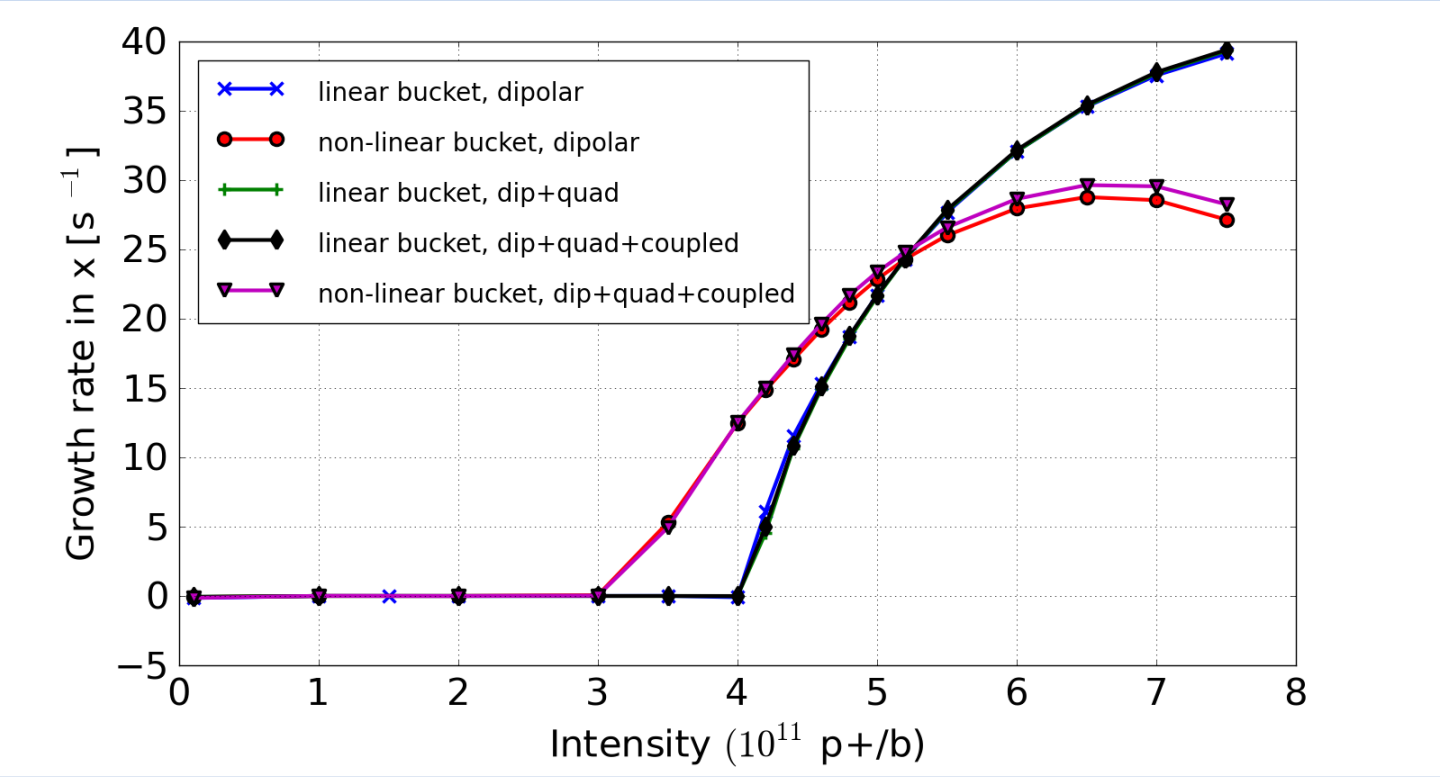


Note: no Landau damping, linear bucket & dipolar imp. only

→ HL-LHC not very different from LHC (despite energy difference),
→ threshold close to 3.5e11 p+/b
→ it is slightly higher in y.

Effect of non-linear bucket & other impedance terms on TMCI threshold

- Single-bunch growth rate vs intensity without damper, for HL-LHC (7TeV) with Q′=*0*, from HEADTAIL (*note: this is with the OLD cutoff of 5GHz, and there is a mismatch – wrong voltage put in simulations → 10% larger bunch length for the non-linear bucket cases*):

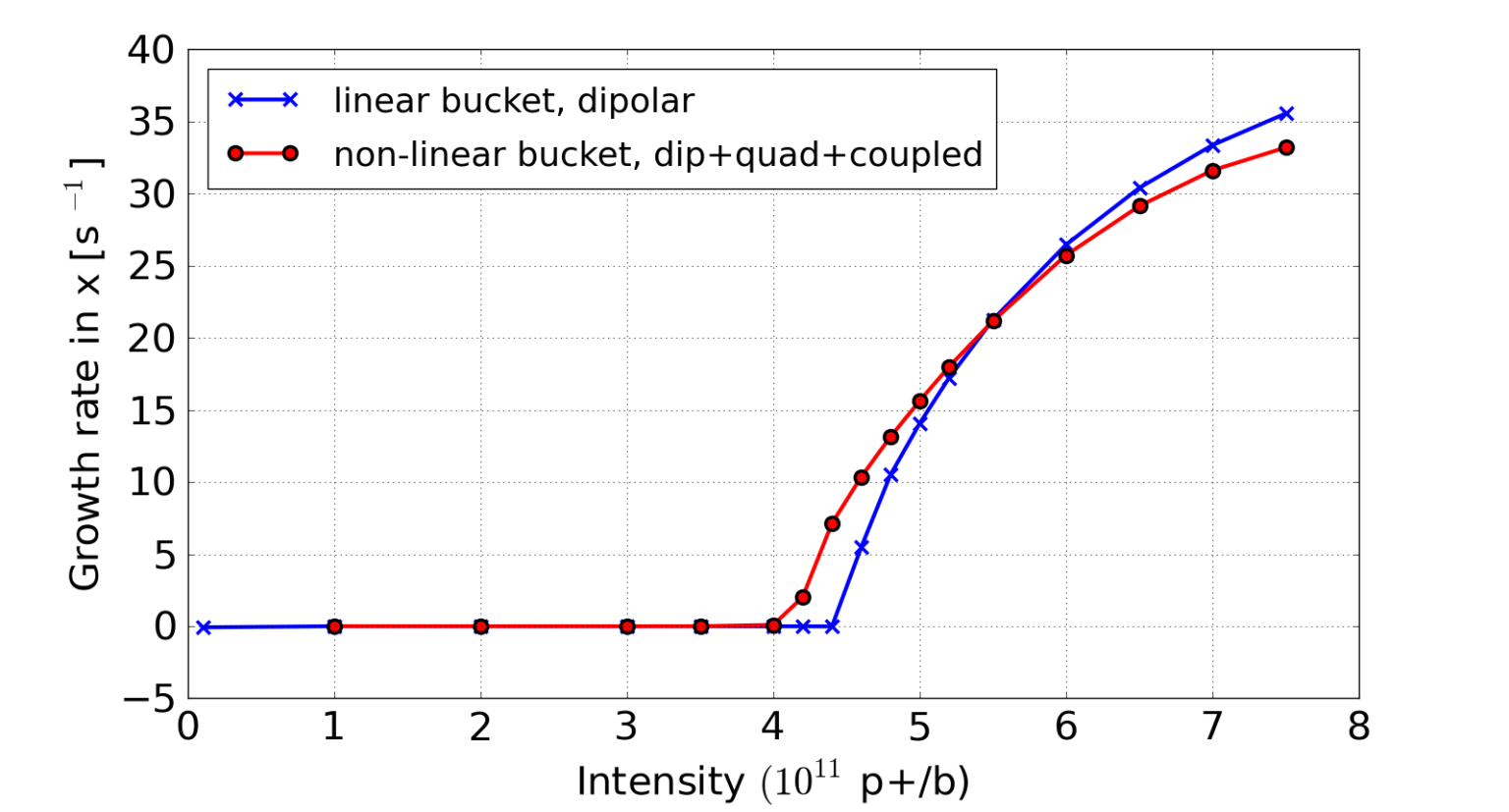


→ threshold goes down, and this is mainly due to non-linear bucket (Q_s smaller on average).

→ no effect of other impedance terms (quadrupolar & coupled terms) for the most critical plane.

Effect of non-linear bucket & other impedance terms on TMCI threshold

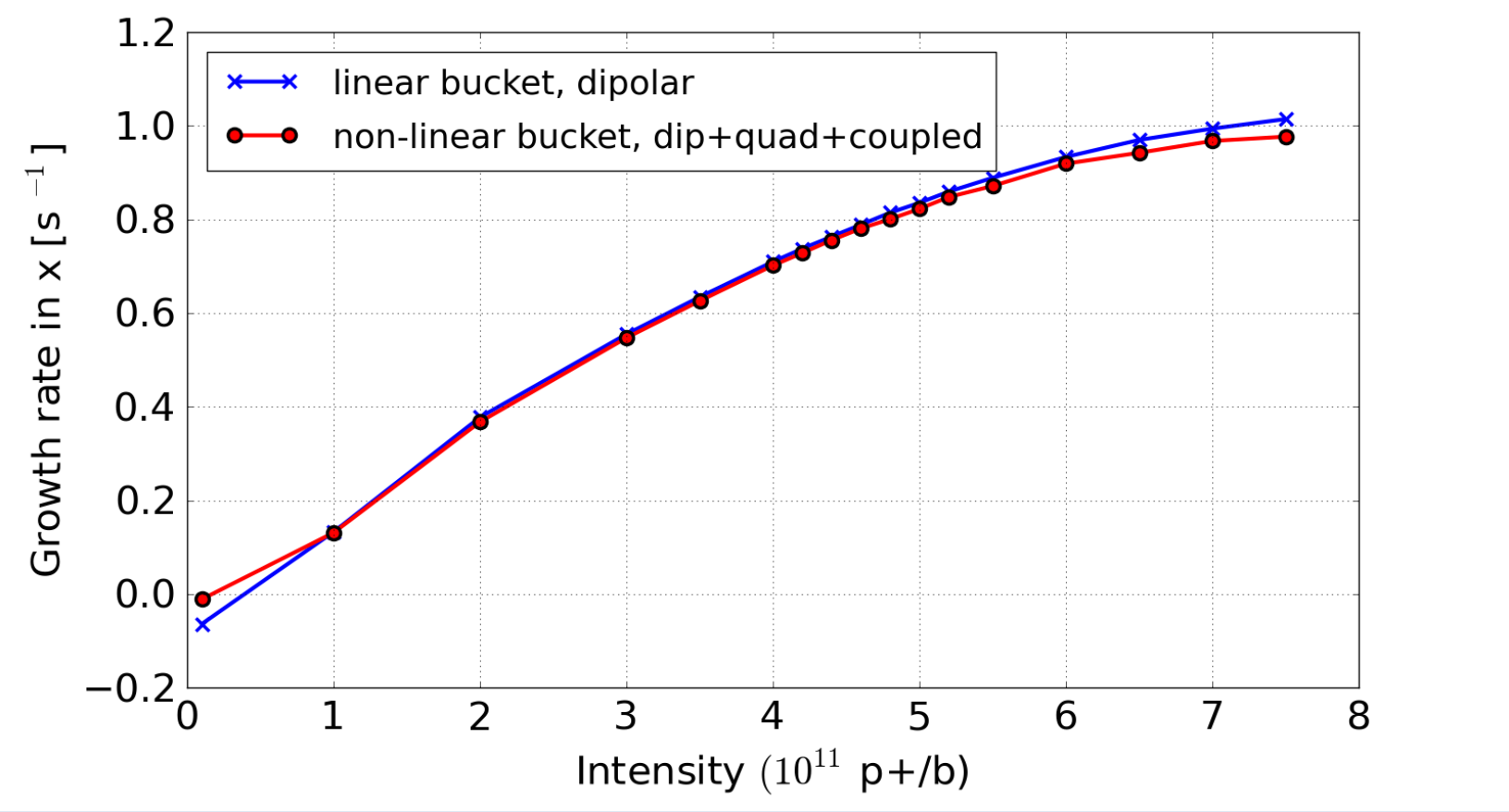
- Single-bunch growth rate vs intensity without damper, for HL-LHC (7TeV) with Q′=*0*, from HEADTAIL, with updated model:



→ threshold goes slightly down.

Effect of non-linear bucket & other impedance terms on high chroma – high damper gain instabilities

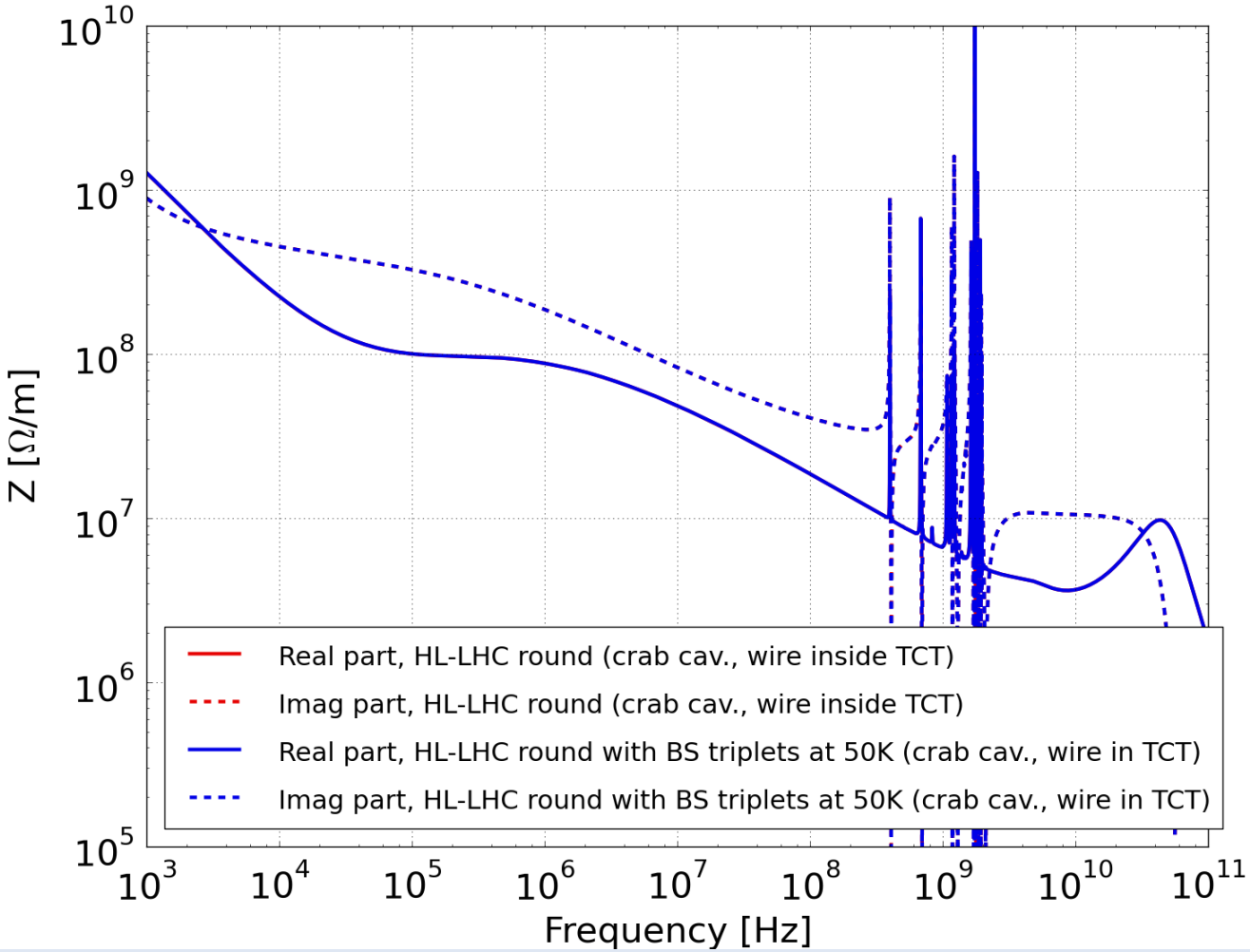
- Single-bunch growth rate vs intensity with damper, for HL-LHC (7TeV) with $Q'=15$, 50 turns damper, from HEADTAIL, with updated model:



→ effect of non-linear bucket + quadrupolar impedance terms very small at high chroma – high damper gain.

HL-LHC impedance with 50K copper in triplet beam screens

- For the total dipolar vertical impedance (similar in horizontal):

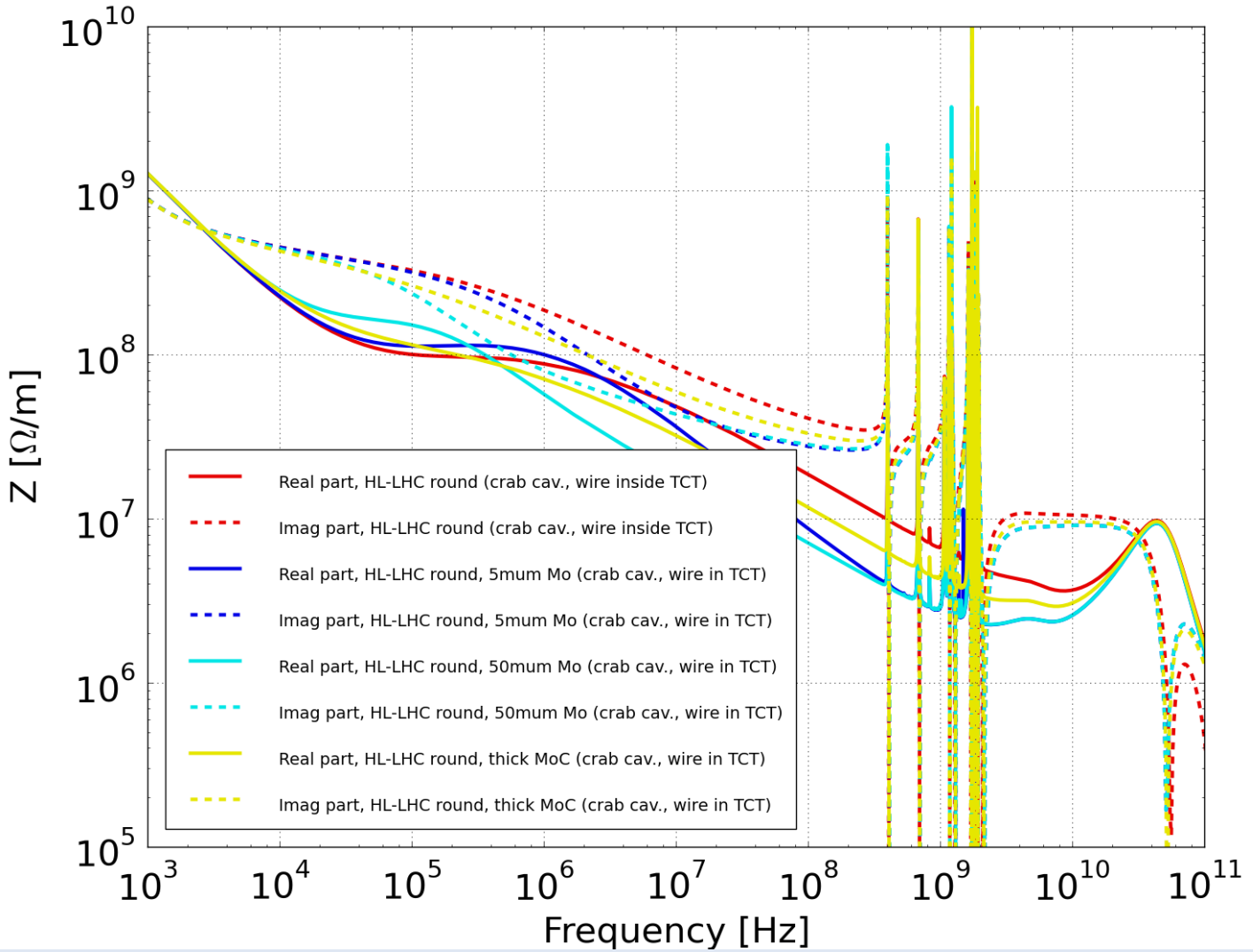


Note: magnetoresistance (B=11T from E. Todesco) taken into account.

⇒ no impact of 50K (instead of 20K) beam screens in triplets.

HL-LHC impedance with Mo coating or Mo-graphite

- For the total dipolar vertical impedance (similar in horizontal):

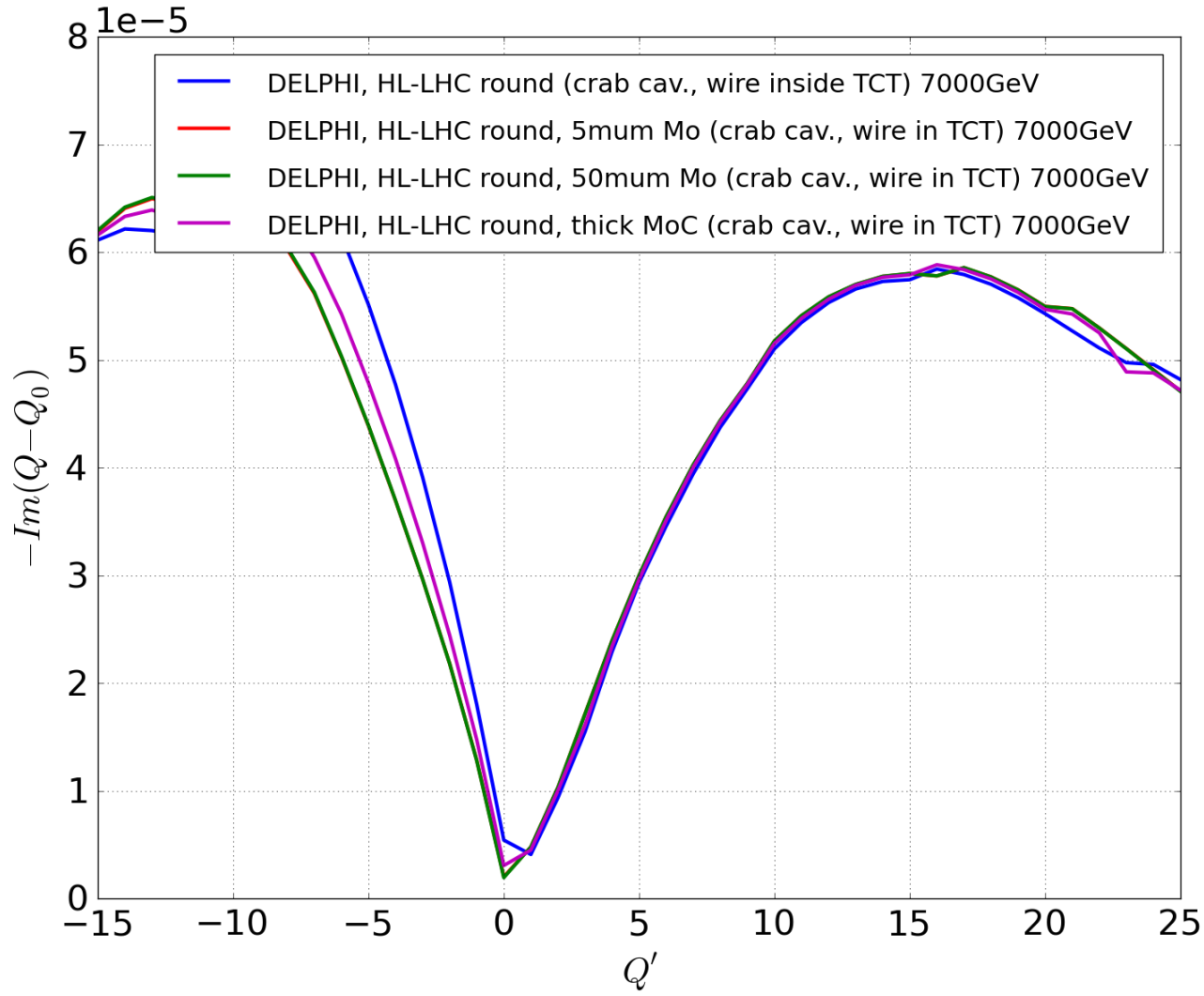


⇒ Large peaks are due to the new model for crab cavities (see talk by B. Salvant)

⇒ away from those peaks, clear impact of Mo or Mo-C on impedance.

HL-LHC instabilities with Mo coating or Mo-graphite

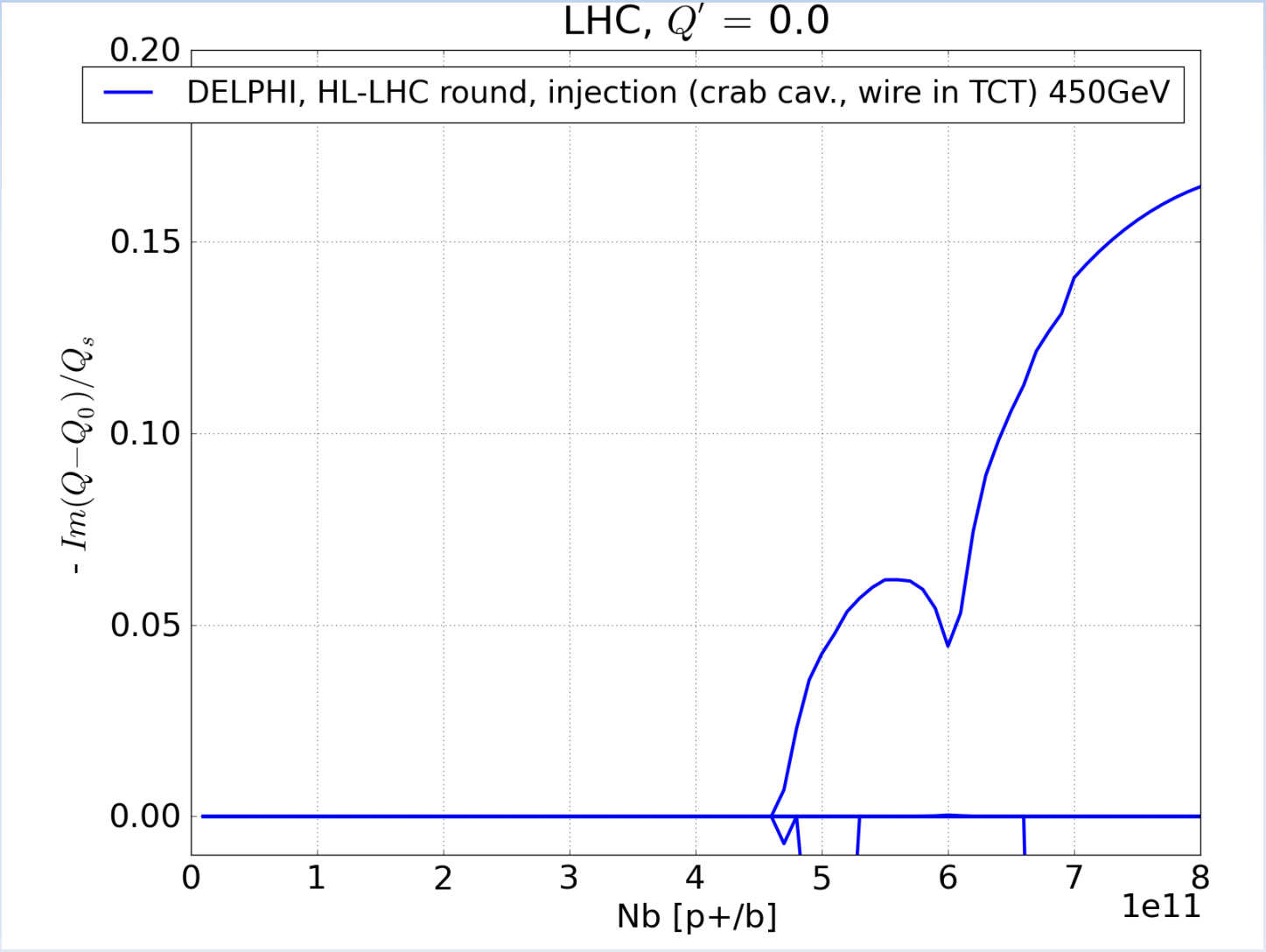
- Single-bunch growth rates, 1.5 10^{11}p+/b, 50 turns damper, vertical (similar in horizontal):



⇒ now everything dominated by crab cavities apparently !
→ cannot conclude

HL-LHC TMCI threshold at injection

- Single-bunch imaginary tune shift vs intensity without damper, for HL-LHC (7TeV), with Q′=*0* (horizontal):



Note: no Landau damping, linear bucket & dipolar imp. only, 6m squeeze in IP1 & 5.

→ threshold close to 4.5e11 p+/b in x.

Appendix: HL-LHC collimator settings

- Collimator settings used for HL-LHC, in number of σ (with ε=3.5 mm.mrad and E=6.5 TeV) (R. Bruce):

Collimator family	# σ
TCP IR3	15
TCS IR3	18
TCLA IR3	20
TCP IR7	5.7
TCS IR7	7.7
TCLA IR7	10
TCT IR 1 & 5	10.5
TCL IR 1 & 5	10
TCT IR 2 & 8	30
TCDQ IR6	9
TCS IR6	8.5
TDI & TCLI	retracted