Update on intensity limitations from HL-LHC transverse impedance

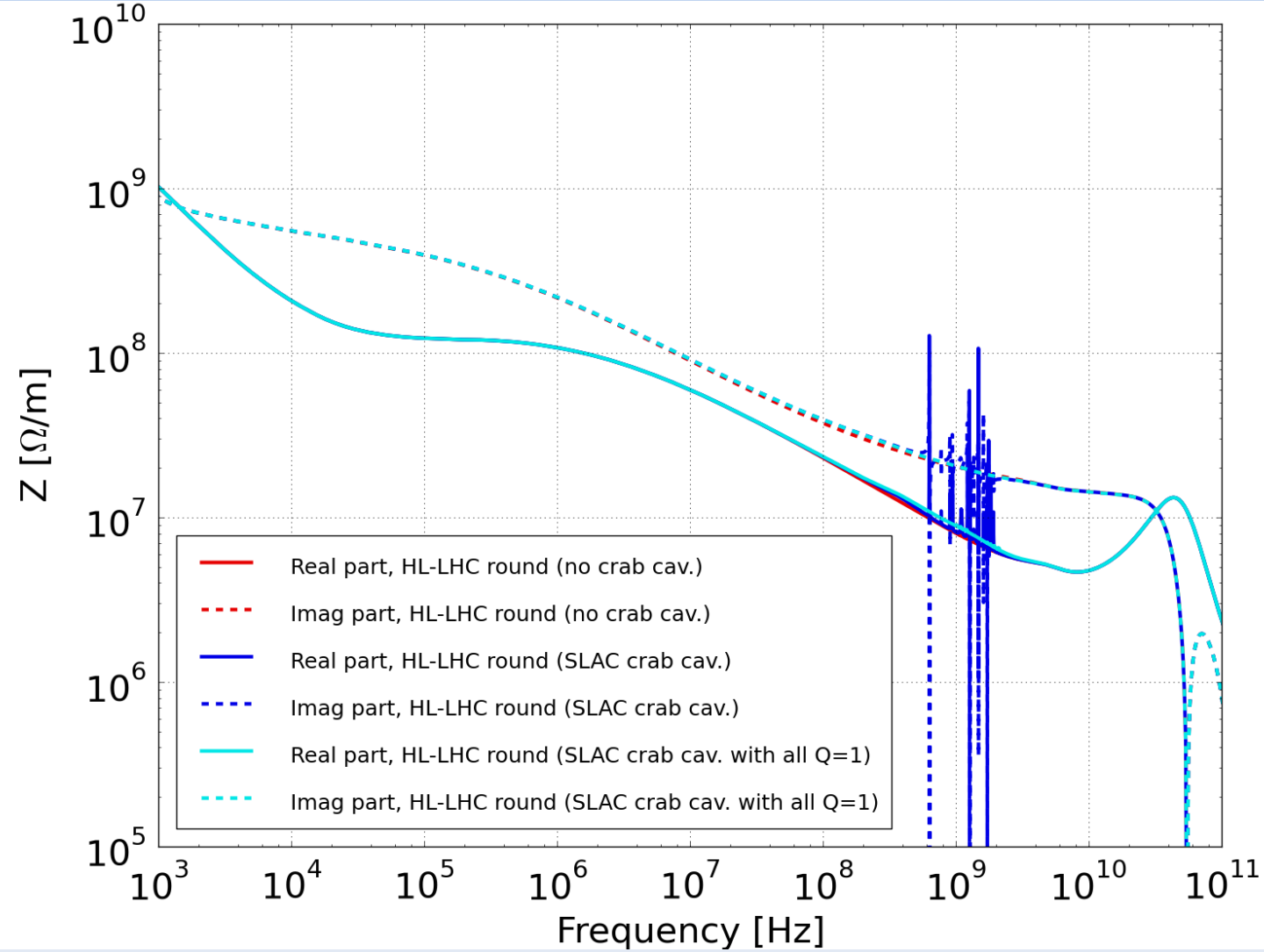
N. Mounet, K. Li, E. Métral, B. Salvant.

Transverse instability limits in the HL LHC era: update

- Effect of SLAC crab cavities
- Effect of Molybdenum on instabilities
- Updated TMCI thresholds (top energy & injection)
- Stability limits at high chromaticity

Effect of Crab cavities (SLAC)

- Crab cavities modeled as a set of HOMs (see B. Salvant talk at crab cavity workshop in BNL – 6/5/2014) → effect on total impedance (horizontal dipolar):

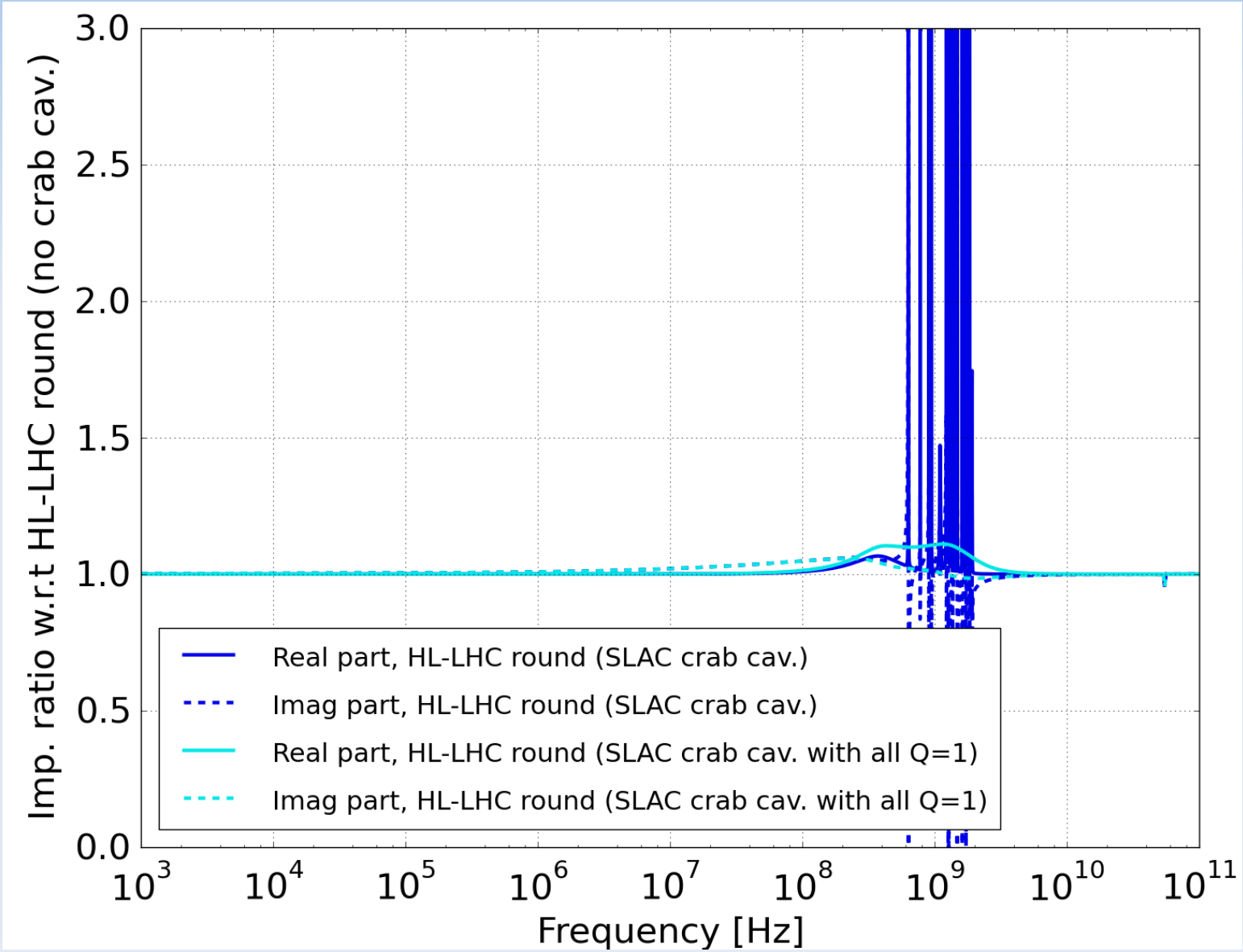


Note: in all plots we assume β^*=15cm and round optics.

→ huge peaks that disappear when Q is artificially set to 1 (keeping same *R/Q)* for all HOMs of the cavities

Effect of Crab cavities (SLAC)

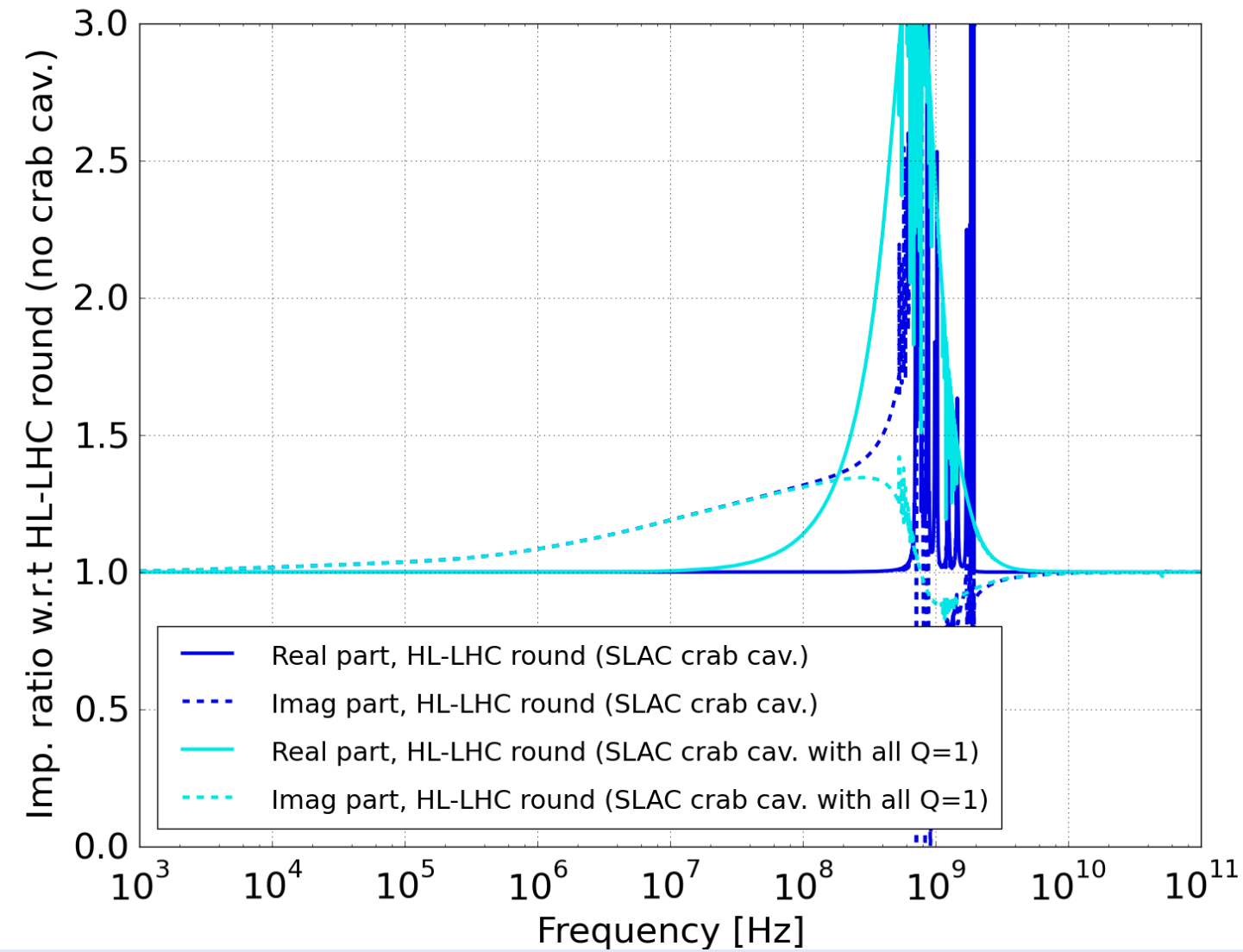
- Impedance ratio vs. HL-LHC impedance without crab cav., horizontal dipolar:



→ when Q is artificially set to 1 (keeping same *R/Q*), left with max ~10%-15% increase on transverse impedance.

Effect of Crab cavities (SLAC)

- Impedance ratio vs. HL-LHC impedance without crab cav., longitudinal:

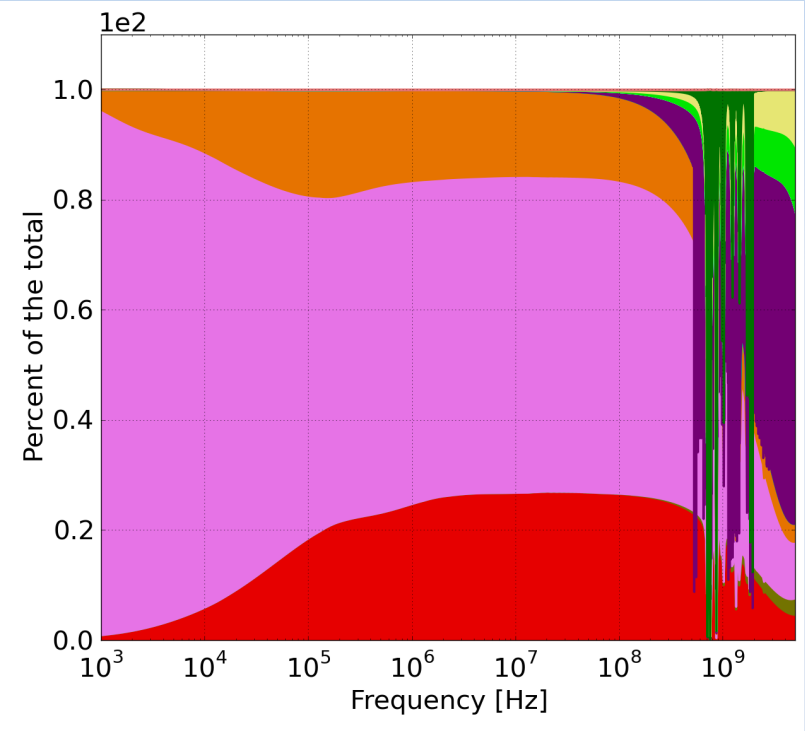


→ even when *Q* is artificially set to 1 (keeping same *R/Q*), very significant impact of crab cavities on longitudinal impedance.

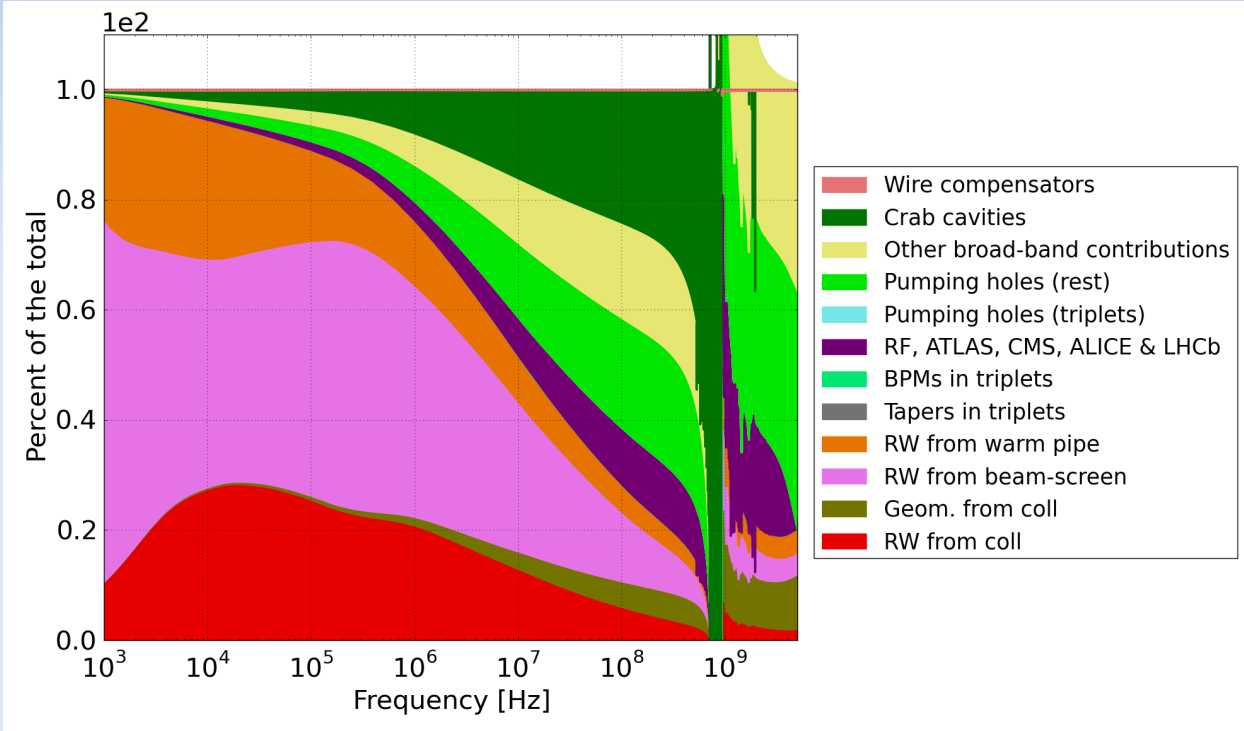
Effect of Crab cavities (SLAC)

- Impedance contributions, with crab cav., longitudinal:

Real part



Imaginary part

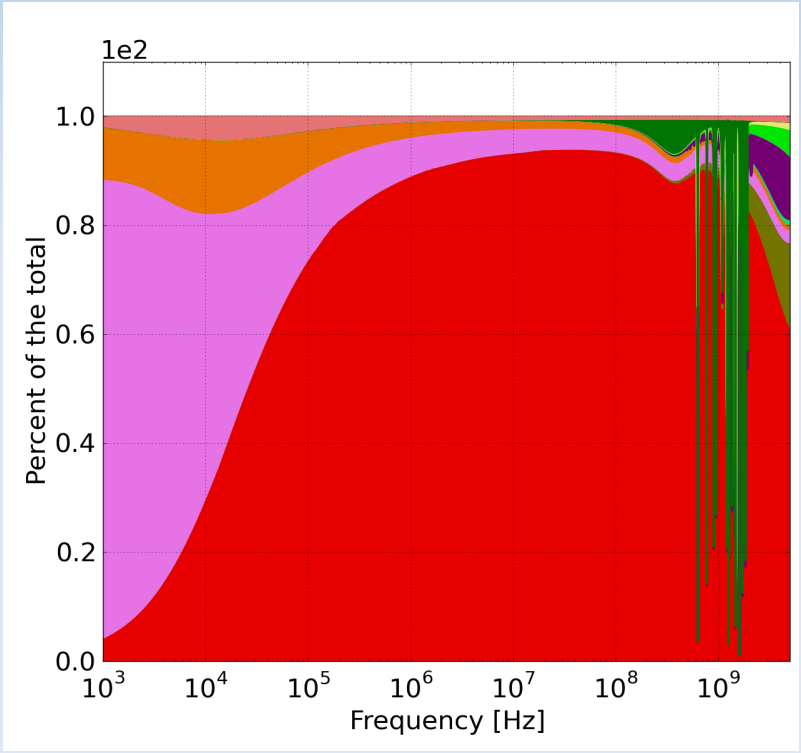


→ huge impact of crab cavities on imaginary longitudinal impedance.

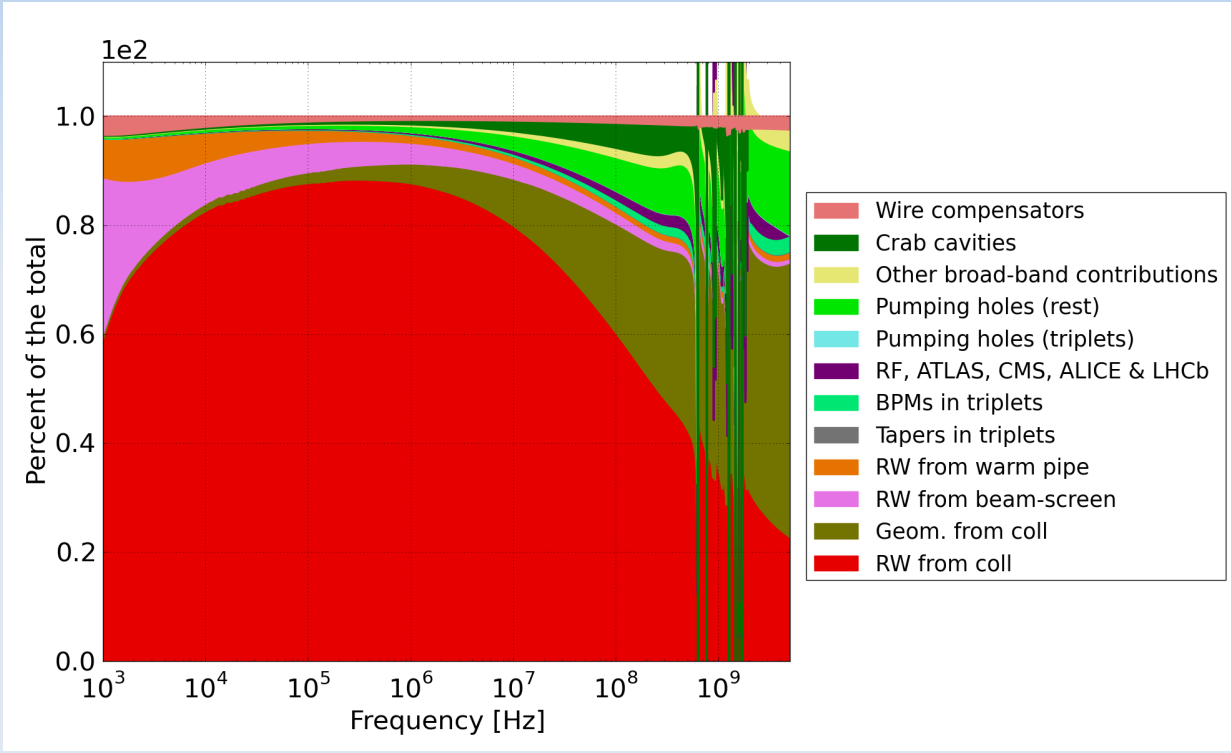
Effect of Crab cavities (SLAC)

- Impedance contributions, with crab cav., horizontal dipolar:

Real part



Imaginary part

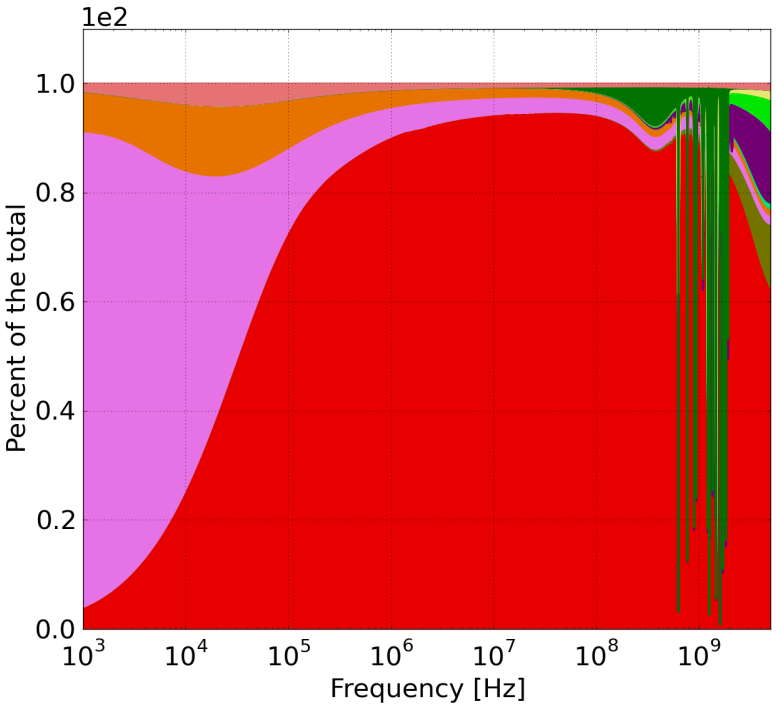


→ significant contribution of crab cavities on total impedance.

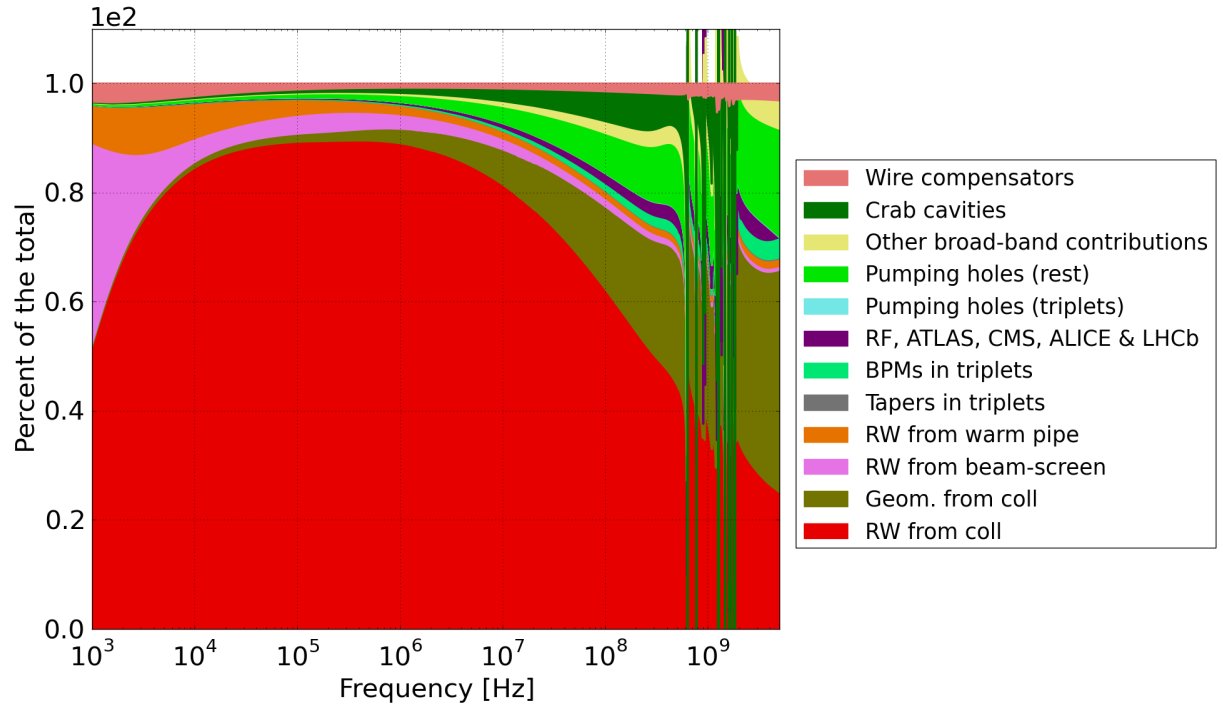
Effect of Crab cavities (SLAC)

- Impedance contributions, with crab cav., vertical dipolar:

Real part



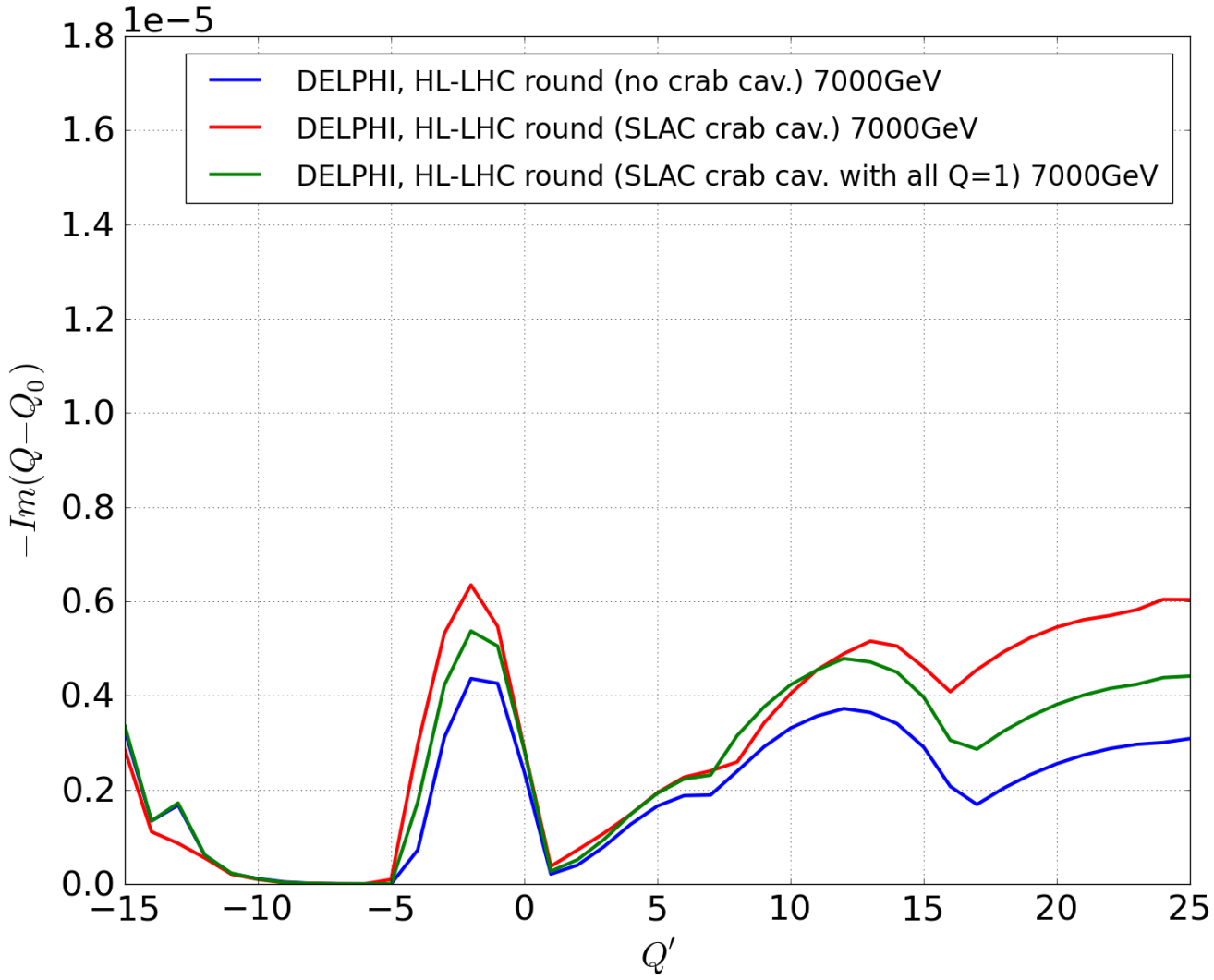
Imaginary part



→ significant contribution of crab cavities on total impedance.

Effect of Crab cavities (SLAC)

- Single-bunch imaginary tune shift vs Q' with 50 turns damper, for HL-LHC (7TeV), with / without crab cav. (horizontal, 1.5e11 p+/b):

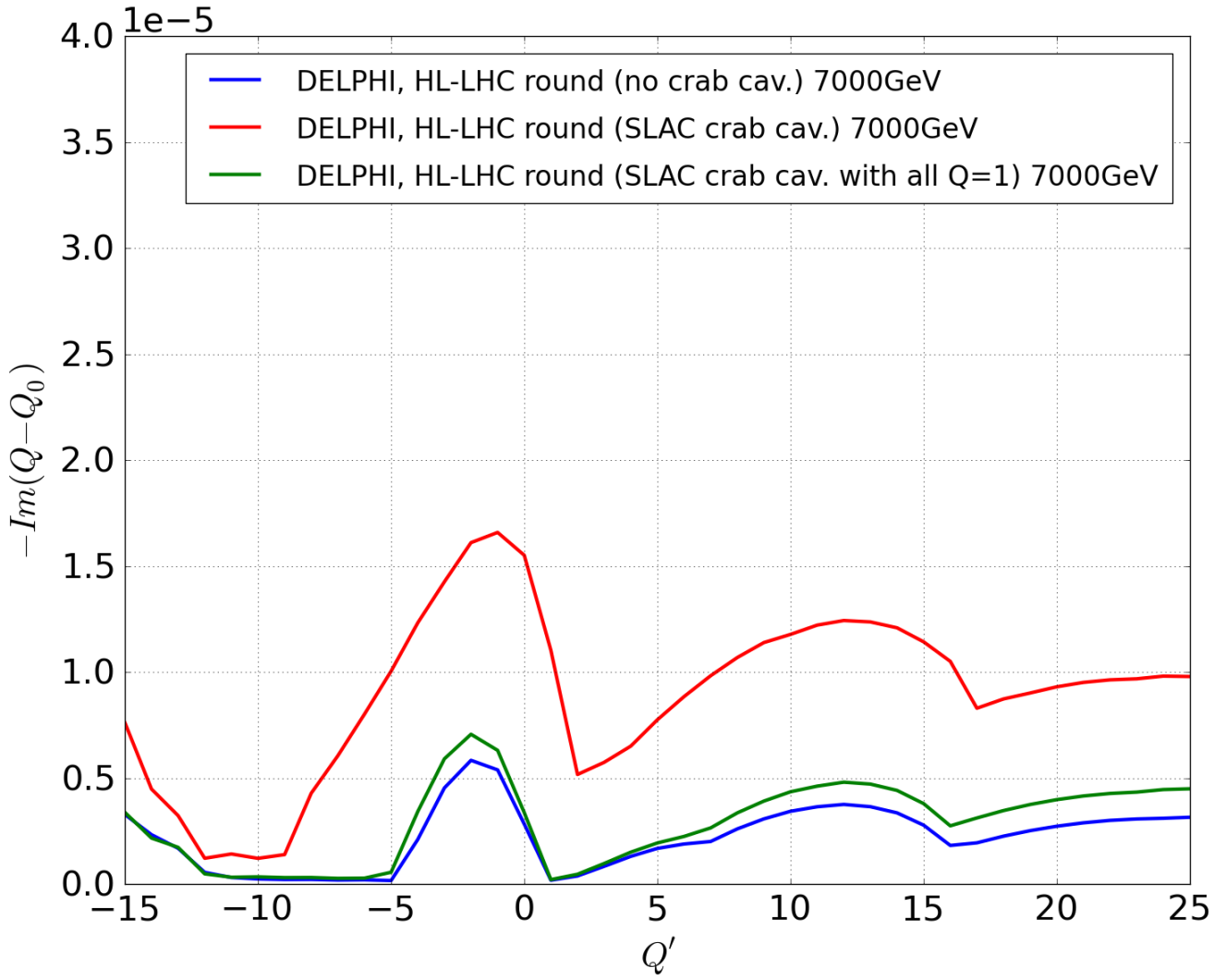


Note: no Landau damping, linear bucket & dipolar imp. only

→ Very significant impact (up to factor 2 at high Q'),
→ *Q=1* with same *R/Q* improves slightly the situation.

Effect of Crab cavities (SLAC)

- 25ns imaginary tune shift vs Q' with 50 turns damper, for HL-LHC (7TeV), with/without crab cav. (horizontal, 1.5e11 p+/b):

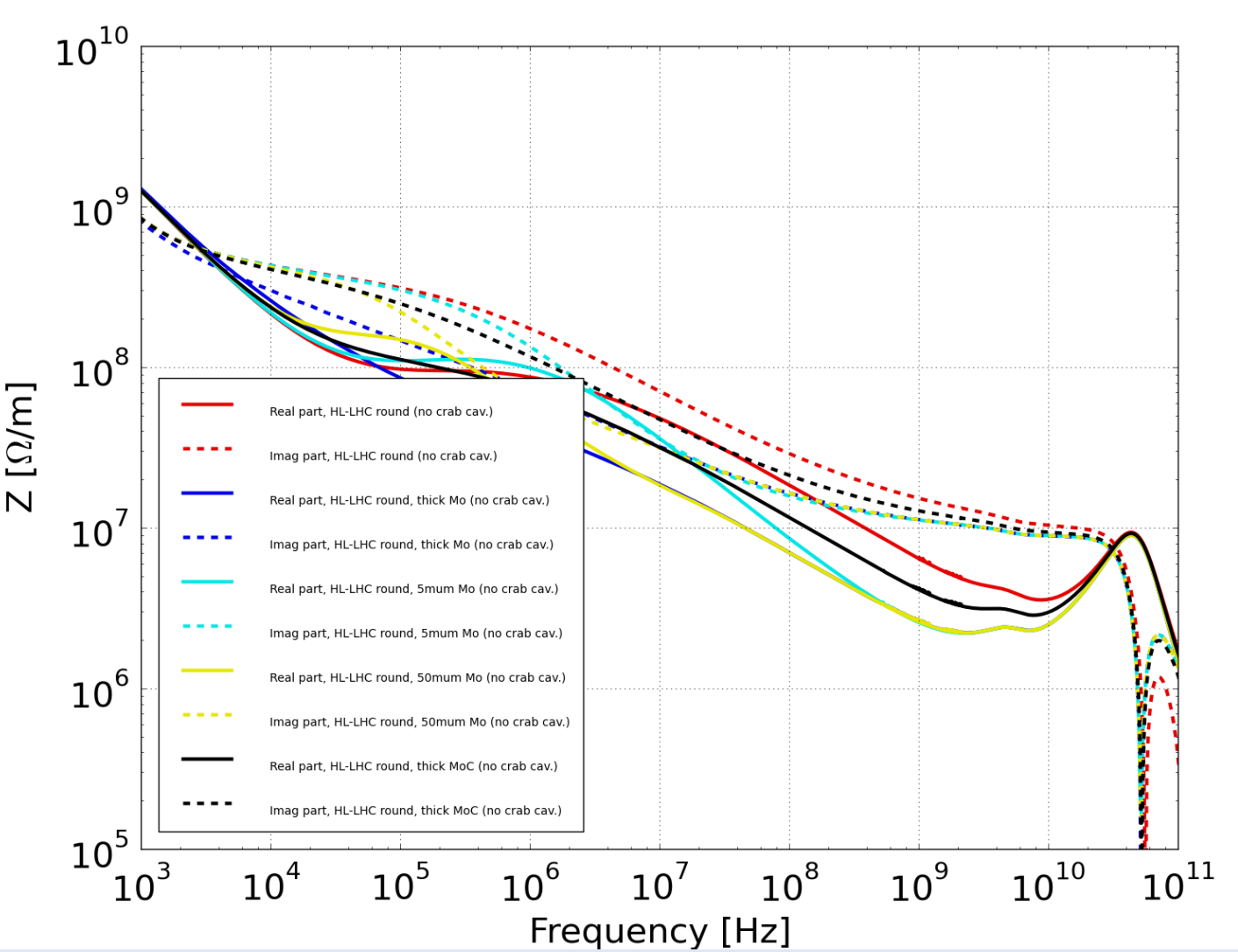


Note: no Landau damping, linear bucket & dipolar imp. only

→ Huge impact in multibunch,
→ *Q=1* with same *R/Q* helps a lot.

HL-LHC impedance with Mo coating or Mo-graphite

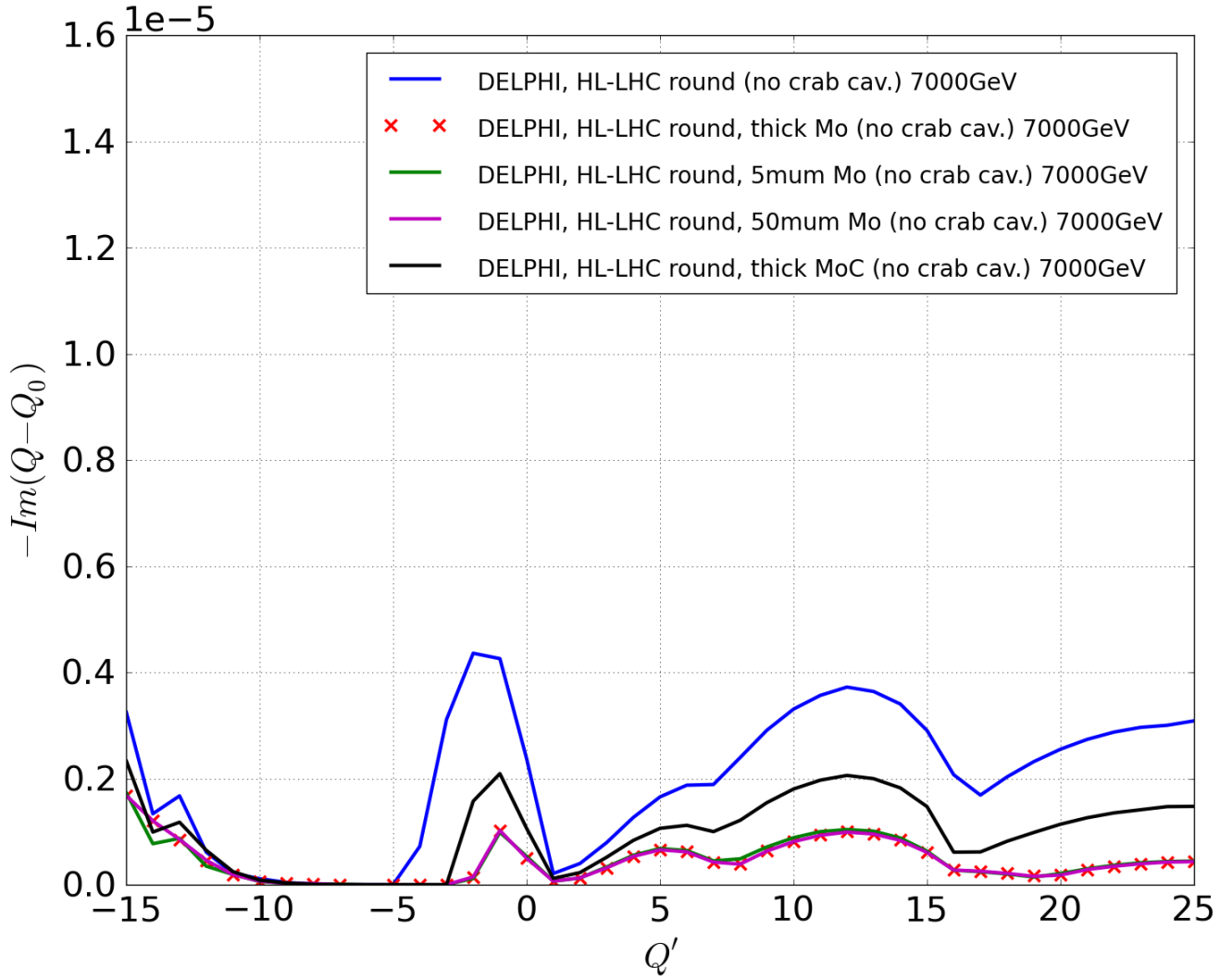
- For the total dipolar vertical impedance (similar in horizontal):



⇒ 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, horizontal (similar – but smaller growth rates – in vertical):

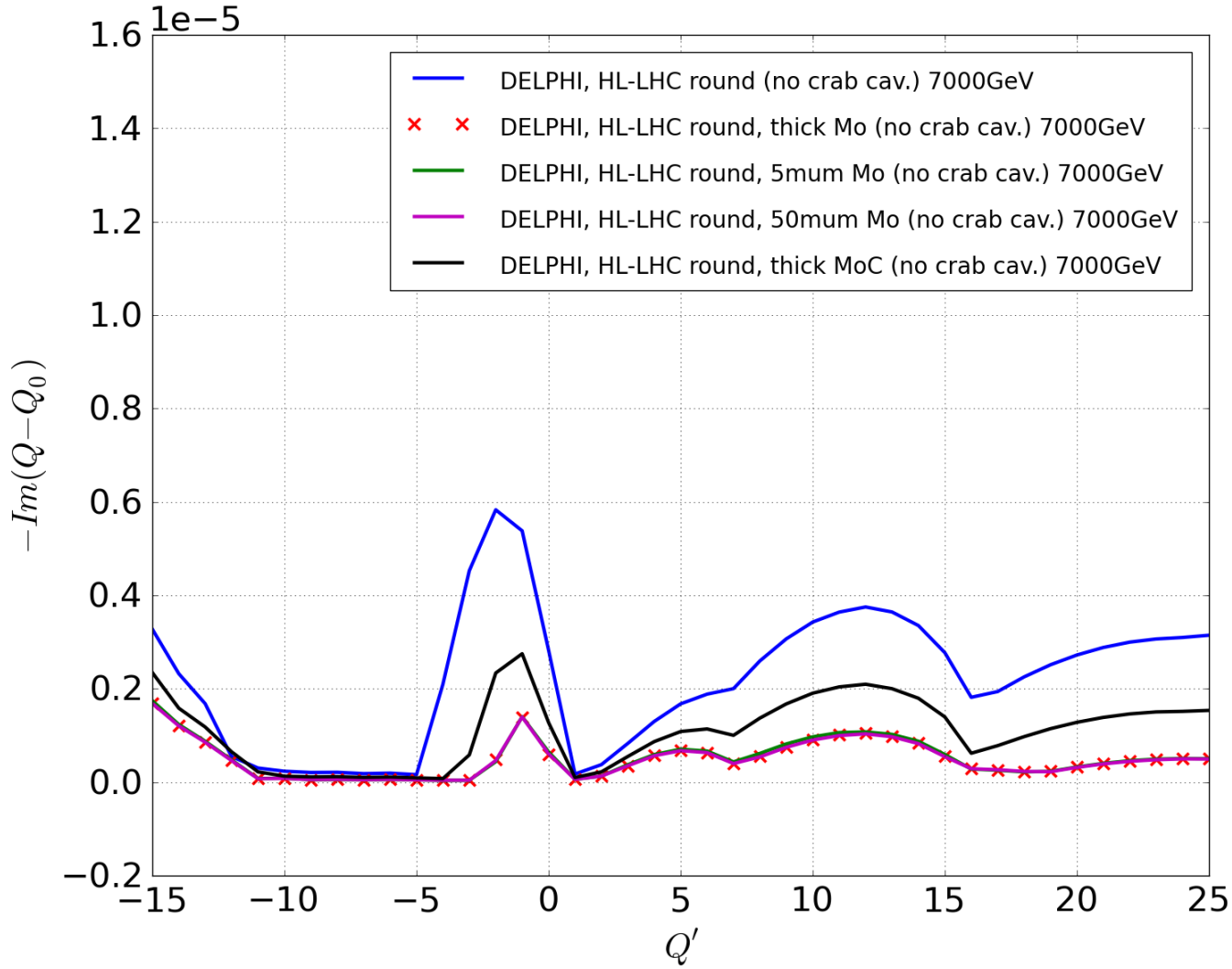


Note: no Landau damping, linear bucket & dipolar imp. only

⇒ Mo or MoC helps significantly,
⇒ 50μm Mo coating gives the same results as thick Mo,
⇒ little difference between 5 & 50μm Mo.

HL-LHC instabilities with Mo coating or Mo-graphite

- Multibunch (25ns) growth rates, 1.5 10^{11}p+/b, 50 turns damper, horizontal (similar – but smaller growth rates – in vertical):

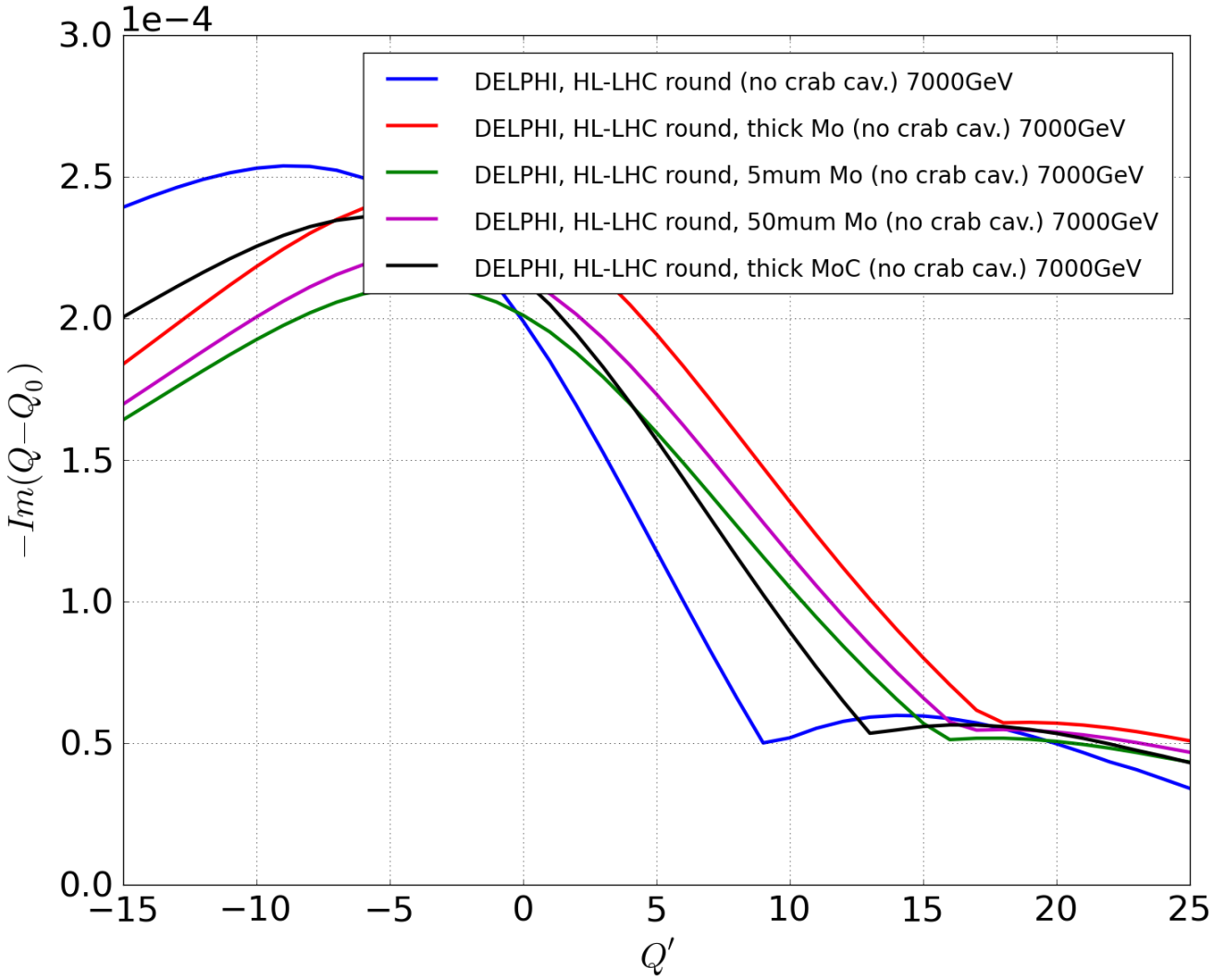


Note: no Landau damping, linear bucket & dipolar imp. only

⇒ Mo or MoC helps significantly,
⇒ 5μm Mo coating gives the same results as thick Mo.

HL-LHC instabilities with Mo coating or Mo-graphite

- Multibunch (25ns) growth rates, 1.5 10^{11}p+/b, without damper, vertical (similar – but smaller growth rates – in horizontal):

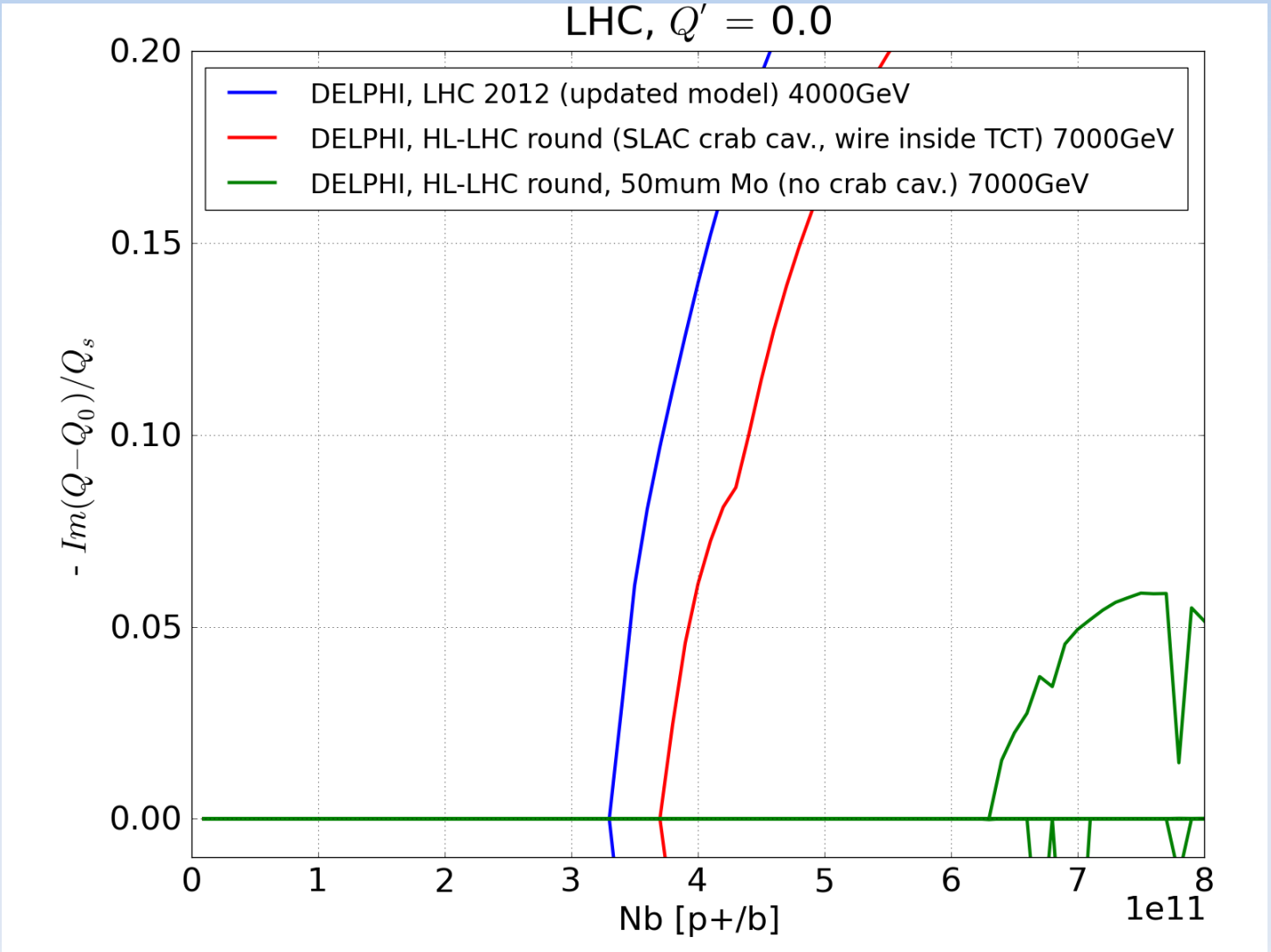


Note: no Landau damping, linear bucket & dipolar imp. only

⇒ without damper, Mo or MoC actually degrade the situation for positive chromatcities,
→ 5μm seems the best choice.

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):

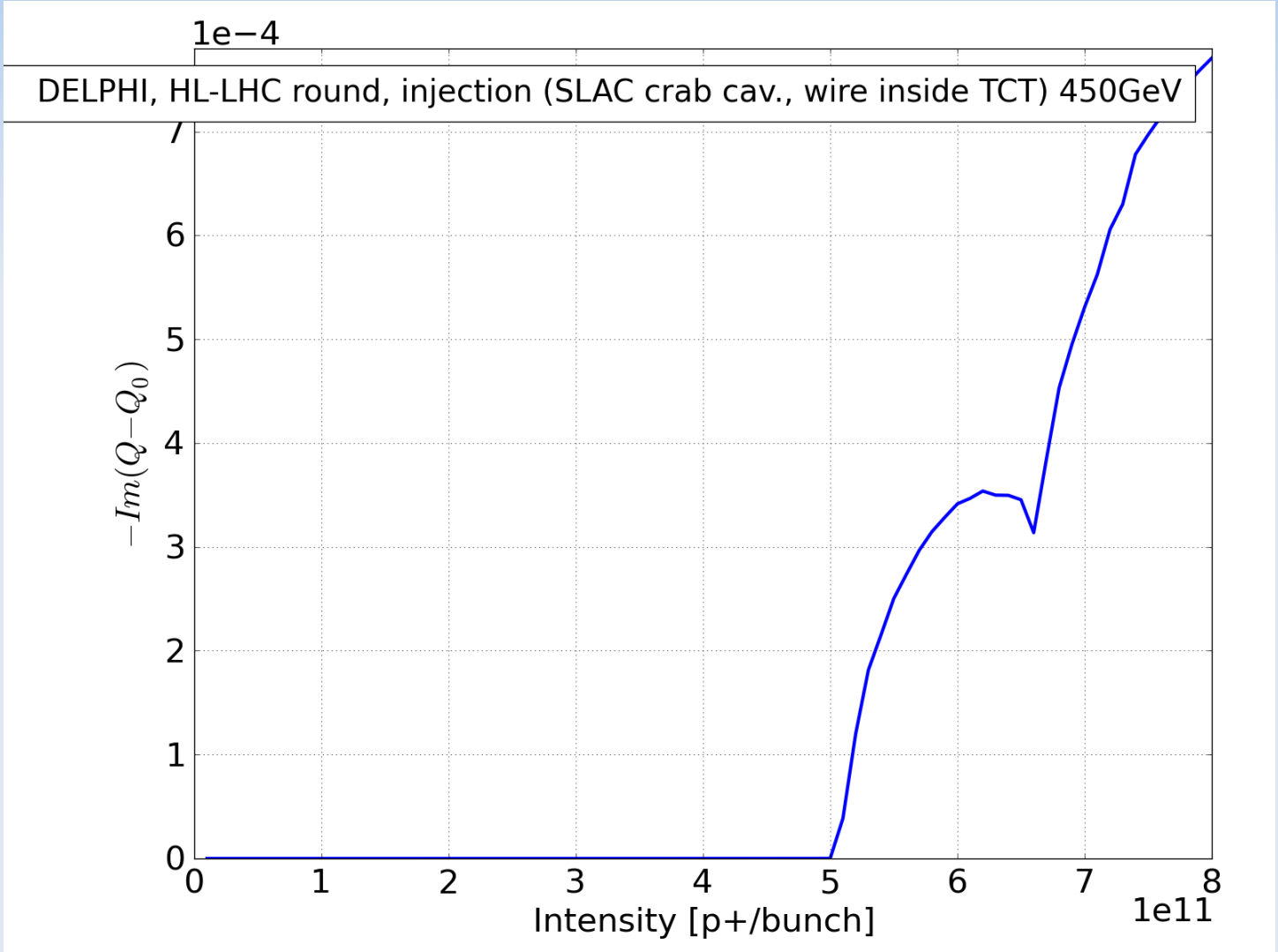


Note: no Landau damping, linear bucket & dipolar imp. only

→ threshold with crab cav. and CFC collimators close to 3.8e11 p+/b
→ it is slightly higher in y.
→ best case scenario (Mo-coated coll. & no crab cav.): threshold more than 6e11 p+/b

HL-LHC TMCI threshold at injection

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

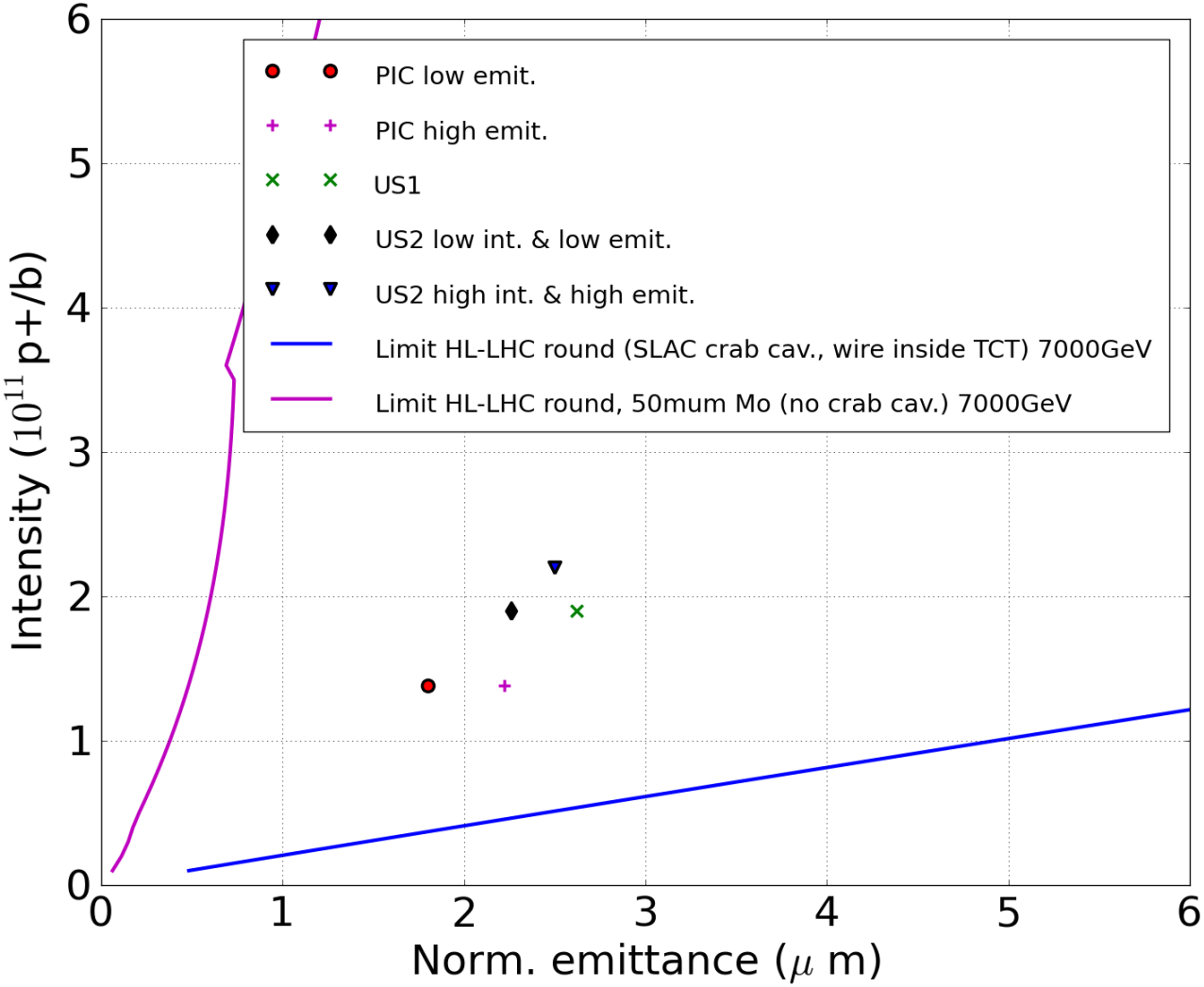


Note: no Landau damping, linear bucket & dipolar imp. only, 6m squeeze in IP1 & 5.

→ threshold close to 5e11 p+/b in x (slightly higher in y).

HL-LHC stability limits: with damper

- For 25ns beam, single-beam intensity limit vs emittance with 50 turns damper, for HL-LHC (7TeV), with Q′=*15+/-1,* in 2 extreme cases (CFC coll. + SLAC crab cav., or no crab & Mo-coated secondary coll.), positive octupole polarity:

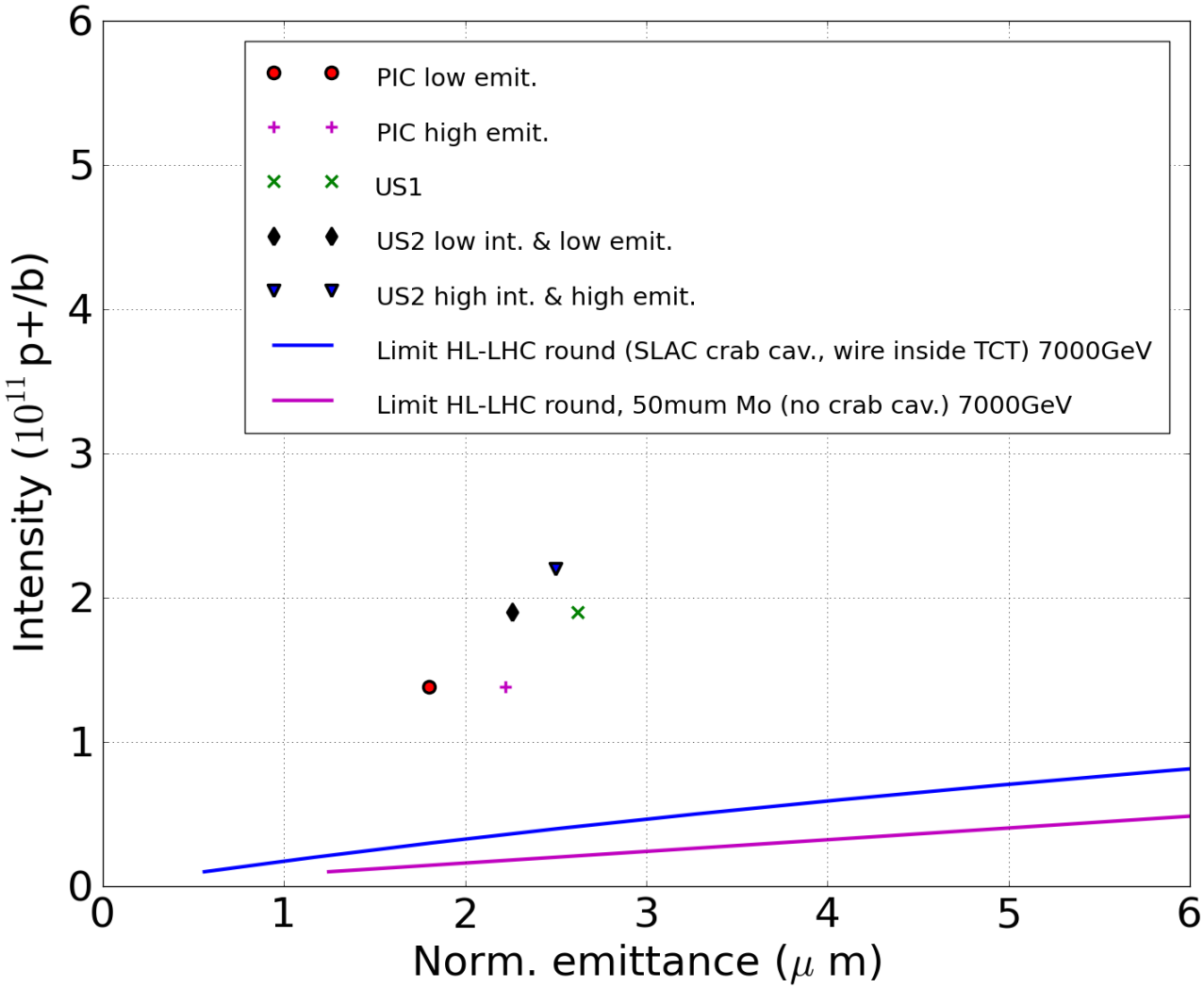


Note: obtained (in relative) from LHC 2012 worst instabilities observed.

→ we cannot sabilitize the HL-LHC beams with crab cavities and CFC collimators,
→ we recover stability with Mo-coated collimators,
→ situation improves with negative octupole polarity but is qualitatively the same.

HL-LHC stability limits: without damper

- For 25ns beam, single-beam intensity limit vs emittance without damper, for HL-LHC (7TeV), with Q′=*15+/-1*, in 2 extreme cases (CFC coll. + SLAC crab cav., or no crab & Mo-coated secondary coll.), positive octupole polarity:



Note: obtained (in relative) from LHC 2012 worst instabilities observed.

→ we cannot sabilitize any scenario for the HL-LHC beams, if LHC 2012 instabilities were purely coupled-bunch,
→ Mo-coated collimators make situation be worse,
→ situation improves with negative octupole polarity but is qualitatively the same.

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

Note: all computations used round optics with β^*=15cm (except for TMCI threshold at injection).