Effect of a hfBBR on the SPS TMCI : PyHEADTAIL vs. DELPHI

Sébastien Joly, Elias Métral

Acknowledgments: N. Mounet, B. Salvant, C. Zannini

16/11/2020

Introduction

- Within the framework of the study of the effects of space charge on the SPS TMCI, we looked at the effect of a high frequency broad-band resonator impedance on the TMCI from a broad-band resonator.

- A high frequency broad-band resonator impedance has some similarities with space charge and introduces negative tune shifts without any growth rate (for a high enough frequency).

- Investigating the impact of such an impedance could help us to understand better the different aspects of space charge on instabilities.

SPS parameters

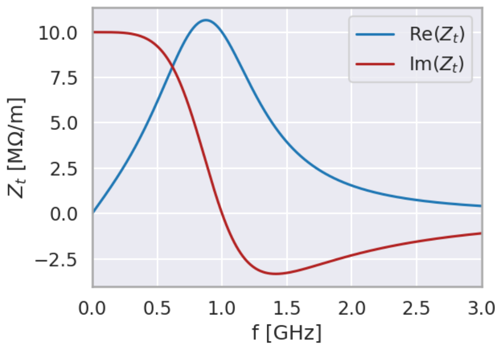
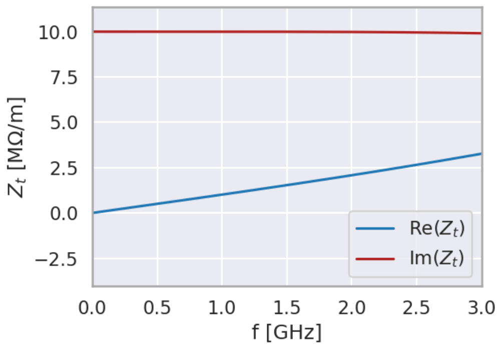
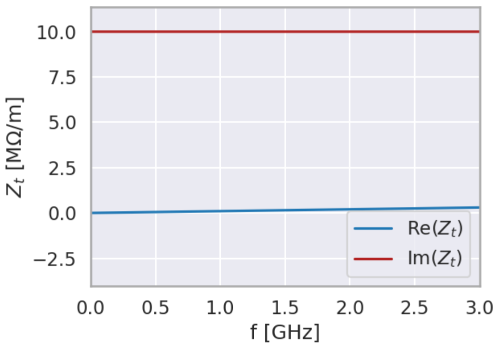
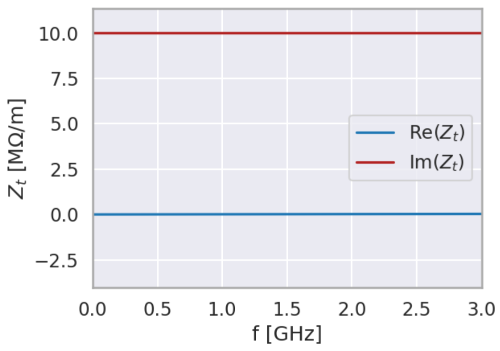
Single bunch PyHEADTAIL and DELPHI simulations using the SPS Q26 optics at injection.

Convergence has been checked and reached for the number of turns, macroparticles and slices in PyHEADTAIL.

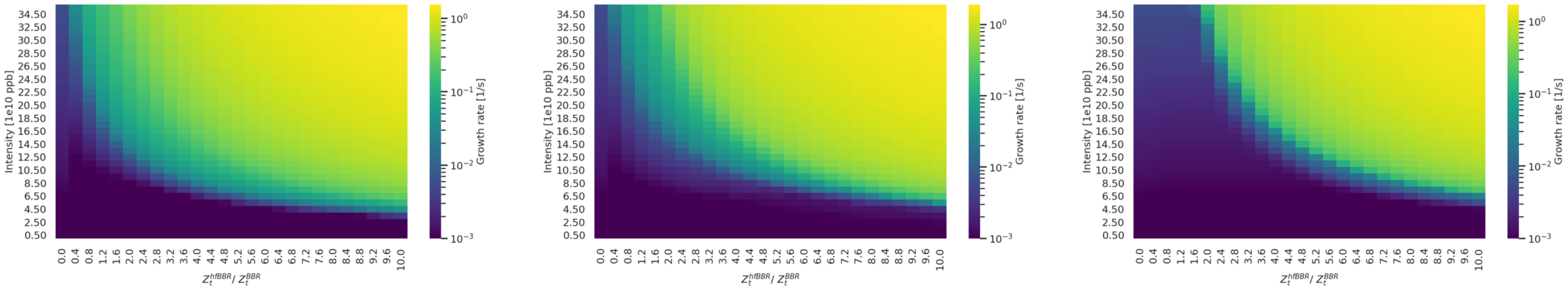
Convergence wasn't reached in DELPHI, we fixed the maximum azimutal and radial modes to 20. (azimuthal modes goes from -20 to 20 and radial modes from 1 to 20)

Parameters	$E_{kinetic}$ = 25.1 GeV
τ_b (full bunch length) [ns]	2.8
Q_s	$3.24*10^{-3}$
Q_x	26.13
Q_y	26.18
ξ [Q'/Q]	0
α_p	$1.92*10^{-3}$
γ_{tr}	22.8
n_{turns}	8192
$n_{macroparticles}$	500000
n_{slices}	5000
Initial kick [mm]	0.9

Resonators parameters

	Broad band resonator (BBR)	High frequency broad band resonator (hfBBR)		
R_t [MΩ/m]	10	0 → 100	0 → 100	0 → 100
Q	1	1	1	1
f_{res} [GHz]	1	10	100	1000
Impedance plot	**R_t = 10 MΩ/m** 	**R_t = 10 MΩ/m** 	**R_t = 10 MΩ/m** 	**R_t = 10 MΩ/m** 

Previous results

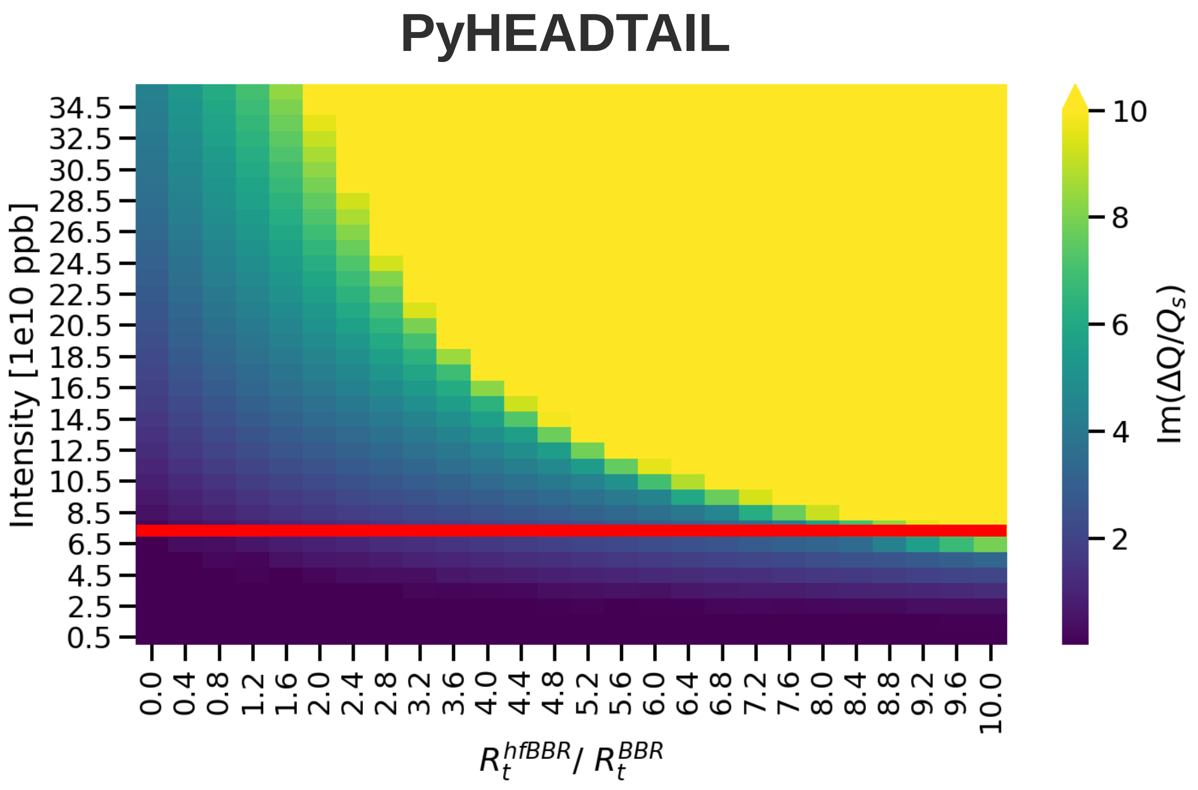


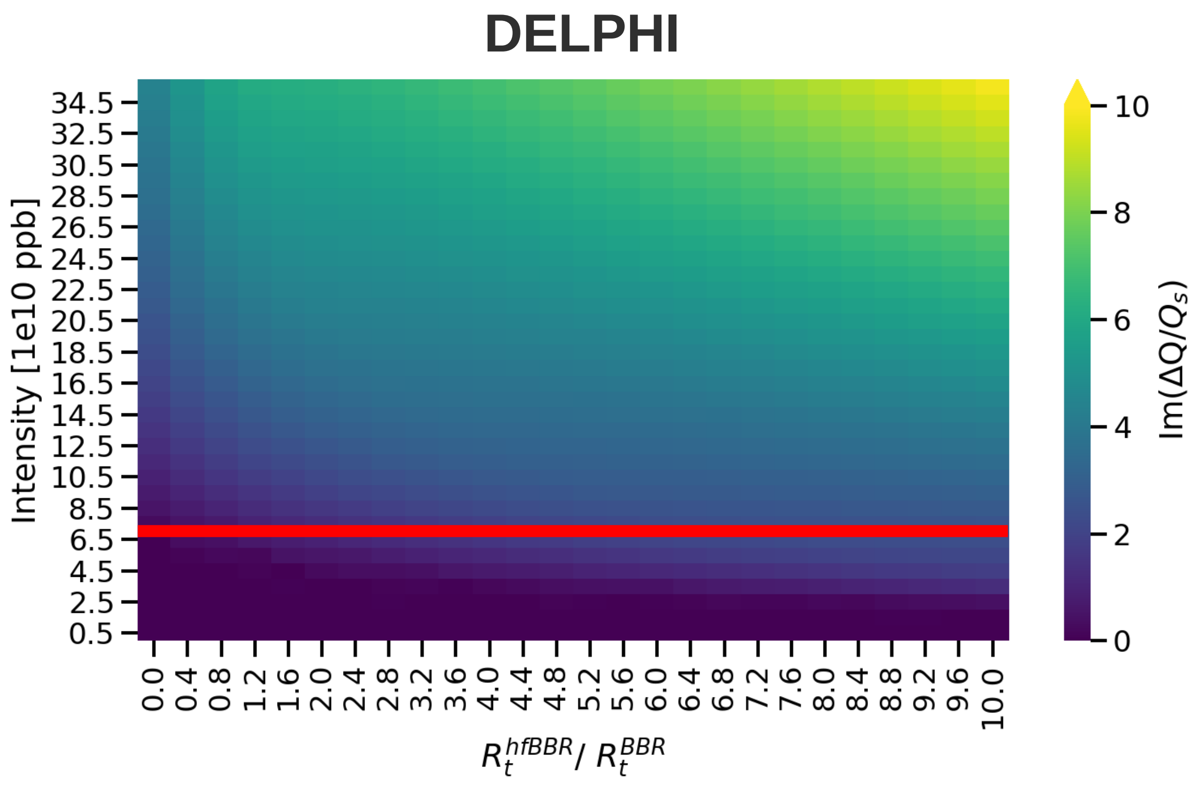
- **Adding a hfBBR impedance to a BBR impedance leads to two different effects :**
  - A beneficial effect with the presence of a stable region at small intensities and Z_t^{hfBBR}/Z_t^{BBR} (region more stable than BBR only)
  - A detrimental effect, leading to substantially more unstable beam outside of the stable region
- **Increasing the frequency of the hfBBR leads to three different effects :**
  - Reduction of the stable region area until it disappears at a high resonant frequency
  - Shift of the most unstable region to larger intensities and inductive impedances
  - TMCI intensity threshold lower than ~7.10^{10} ppb (BBR only case) for Z_t^{hfBBR}/Z_t^{BBR} high enough

VALID FOR ξ = 1

An error from my side led to leaving a non zero chromaticity during PyHEADTAIL simulations

Growth rate of a hfBBR (10 GHz) + BBR



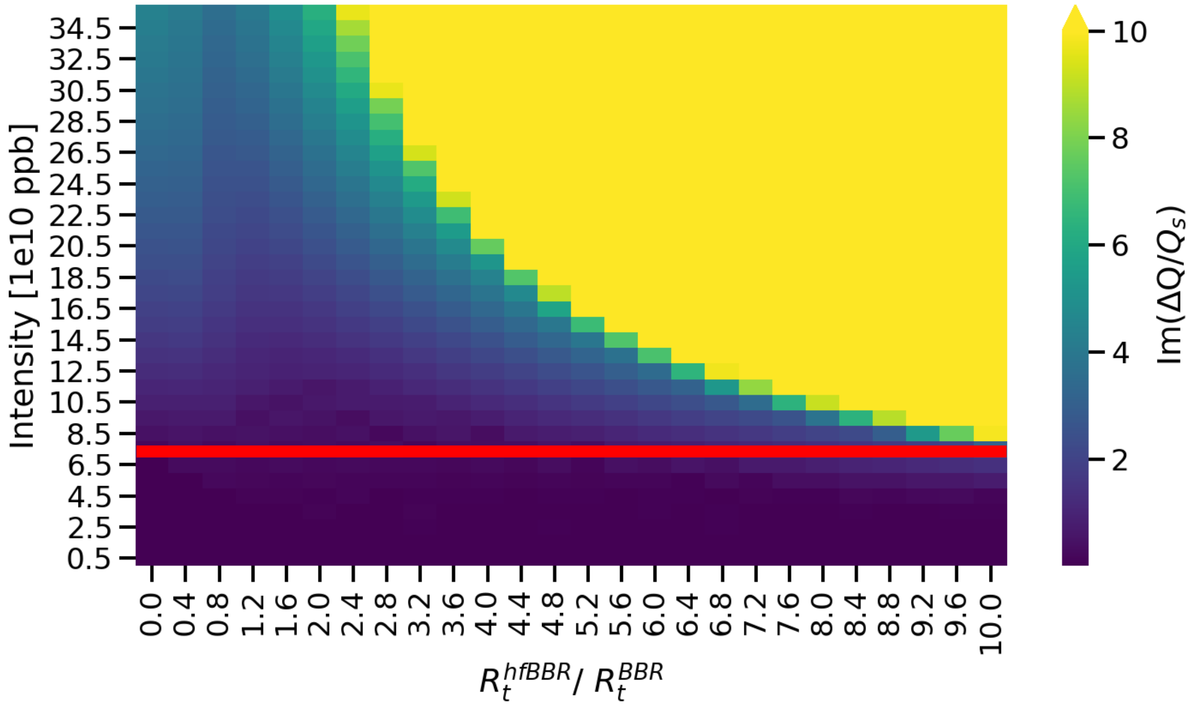


SPS TMCI from a BBR threshold

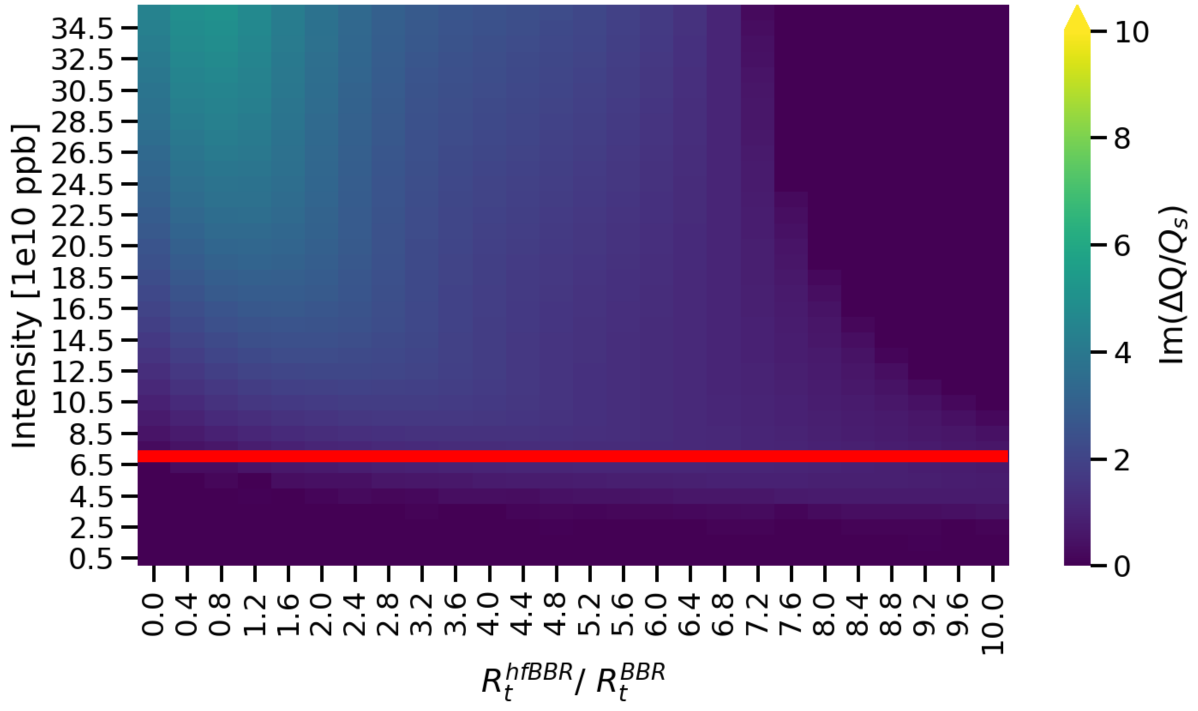
- **Adding a hfBBR leads to a more unstable beam and slightly lower TMCI intensity threshold.**
- **As the factor $\frac{R_t^{hfBBR}}{R_t^{BBR}}$ increases the imaginary part of the tuneshift becomes noticeably larger every step in intensity.**
- **DELPHI is in good agreement with PyHEADTAIL for low intensities (lower than TMCI intensity threshold), this can be explained by the number of modes taken into consideration (more information on this matter later).**

Growth rate of a hfBBR (100 GHz) + BBR

PyHEADTAIL



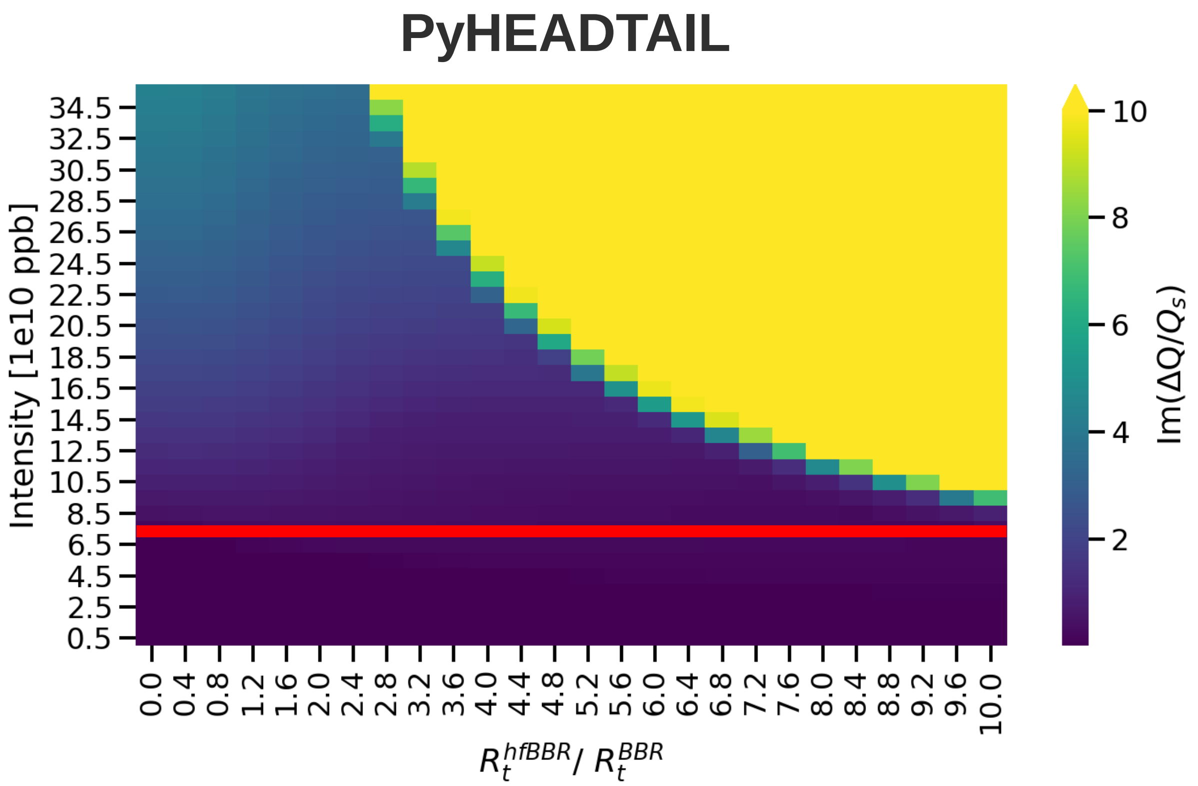
DELPHI

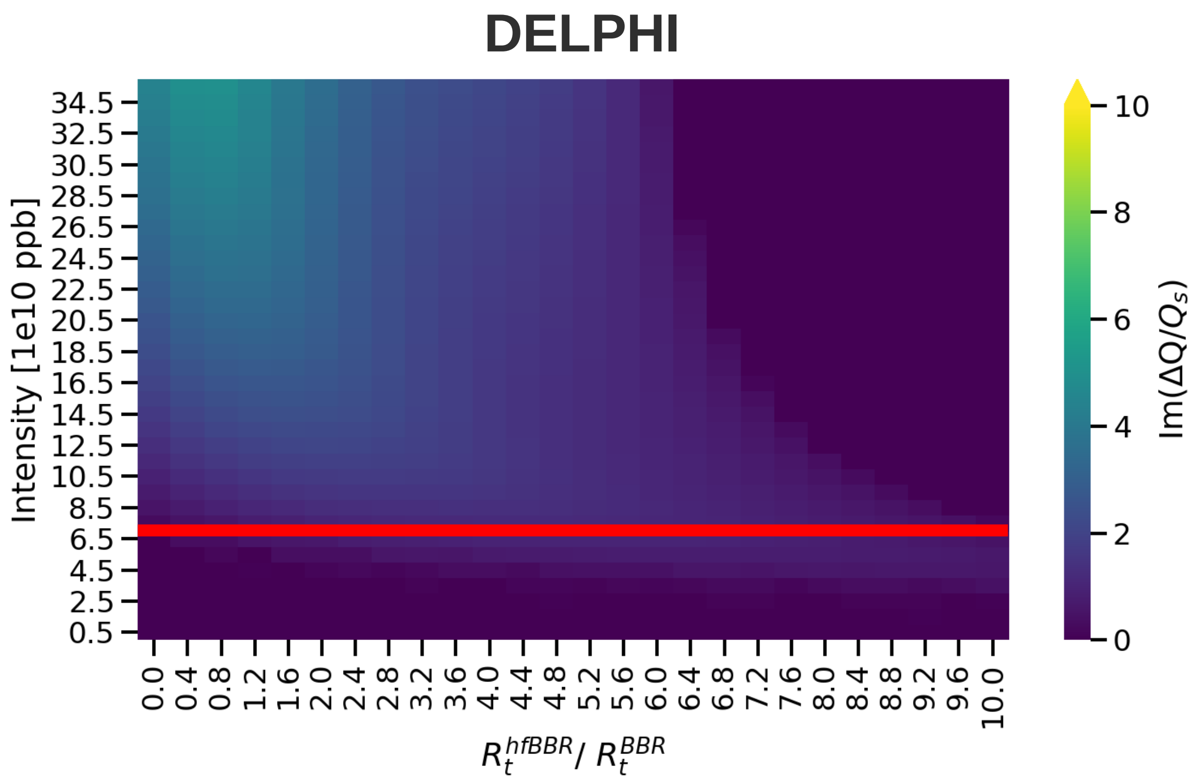


SPS TMCI from a BBR threshold

- **We observe a similar behaviour to previously except for two differences.**
- **The first difference is the shift of the most unstable region to higher $\frac{R_t^{hfBBR}}{R_t^{BBR}}$ ratios.**
- **The second difference is the crossing from the slighlty unstable region to the extremely unstable one is considerably quicker.**

Growth rate of a hfBBR (1000 GHz) + BBR



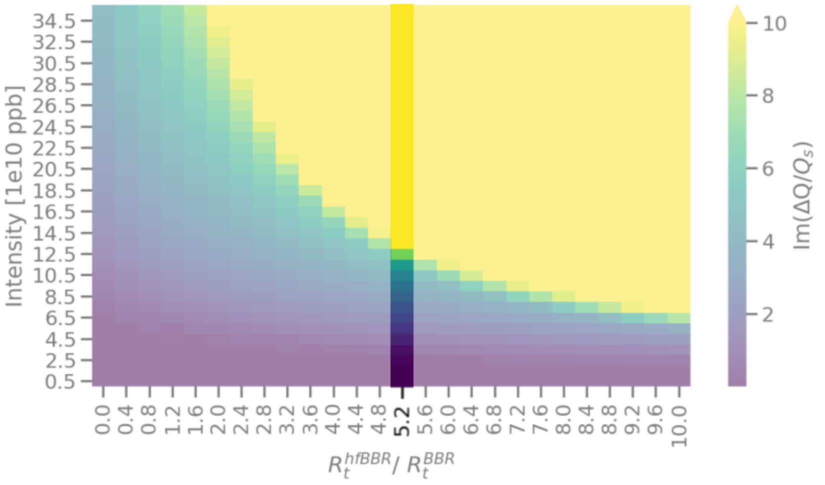


SPS TMCI from a BBR threshold

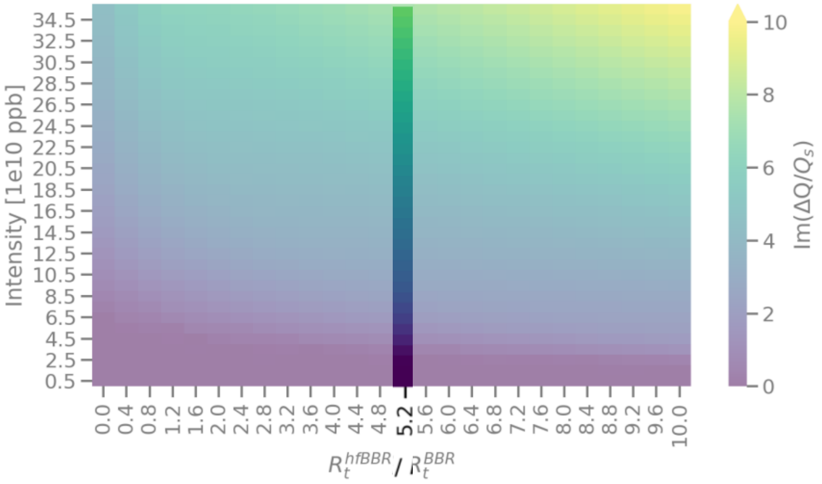
- **The behaviour is still similar to previously.**
- **The shift of the most unstable region to higher $\frac{R_t^{hfBBR}}{R_t^{BBR}}$ ratios is more pronounced than before.**
- **The crossing from the slighlty unstable region to the extremely unstable one is sharper.**

Explaining the discrepancy between PyHEADTAIL and DELPHI results

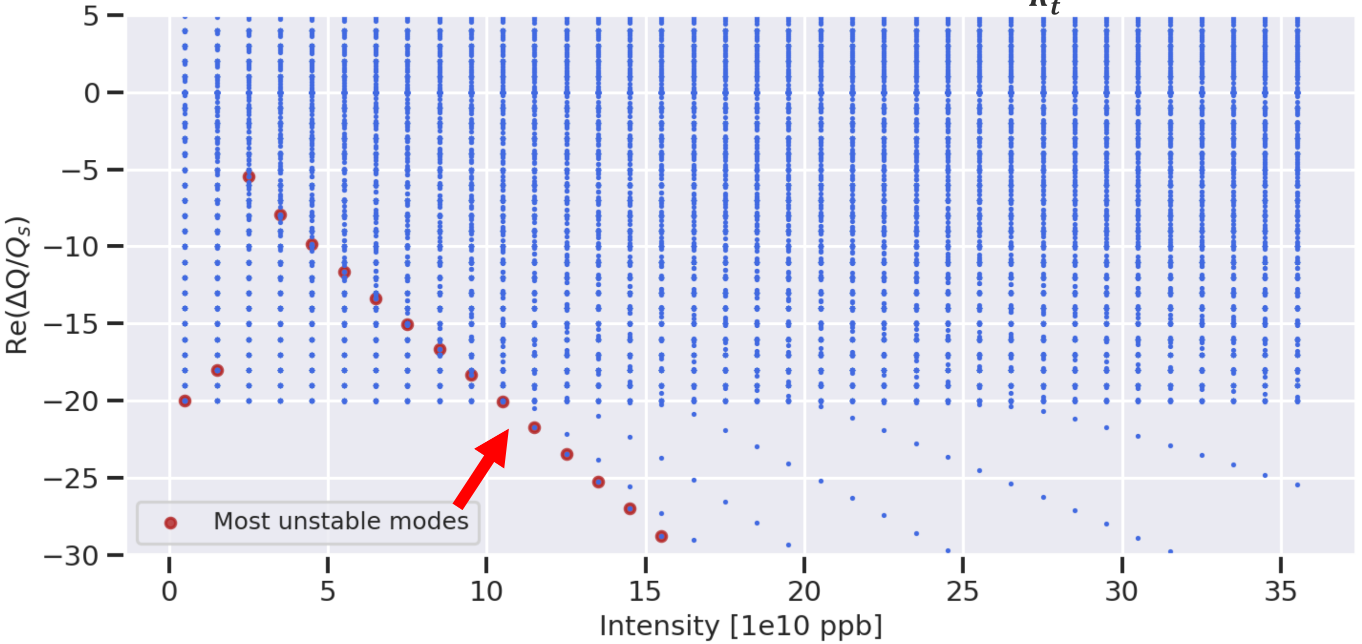
PyHEADTAIL hfBBR (10 GHz) + BBR



DELPHI hfBBR (10 GHz) + BBR



Re($\Delta Q/Q_s$) vs Intensity, hfBBR (10 GHz) + BBR , $\frac{R_t^{hfBBR}}{R_t^{BBR}}$ = 5.2, DELPHI



- **We are missing modes coupling after ~12.10[10] ppb.**
- **Consequently this is approximately where DELPHI results start to differ from PyHEADTAIL. Could this be the reason for smaller growth rates in DELPHI ?**
- **One solution woud be to go to high l_{max}, n_{max} (> 60 ?). Unfortunately an error occurs when going to l_{max}, n_{max} above 20, to be resolved.**

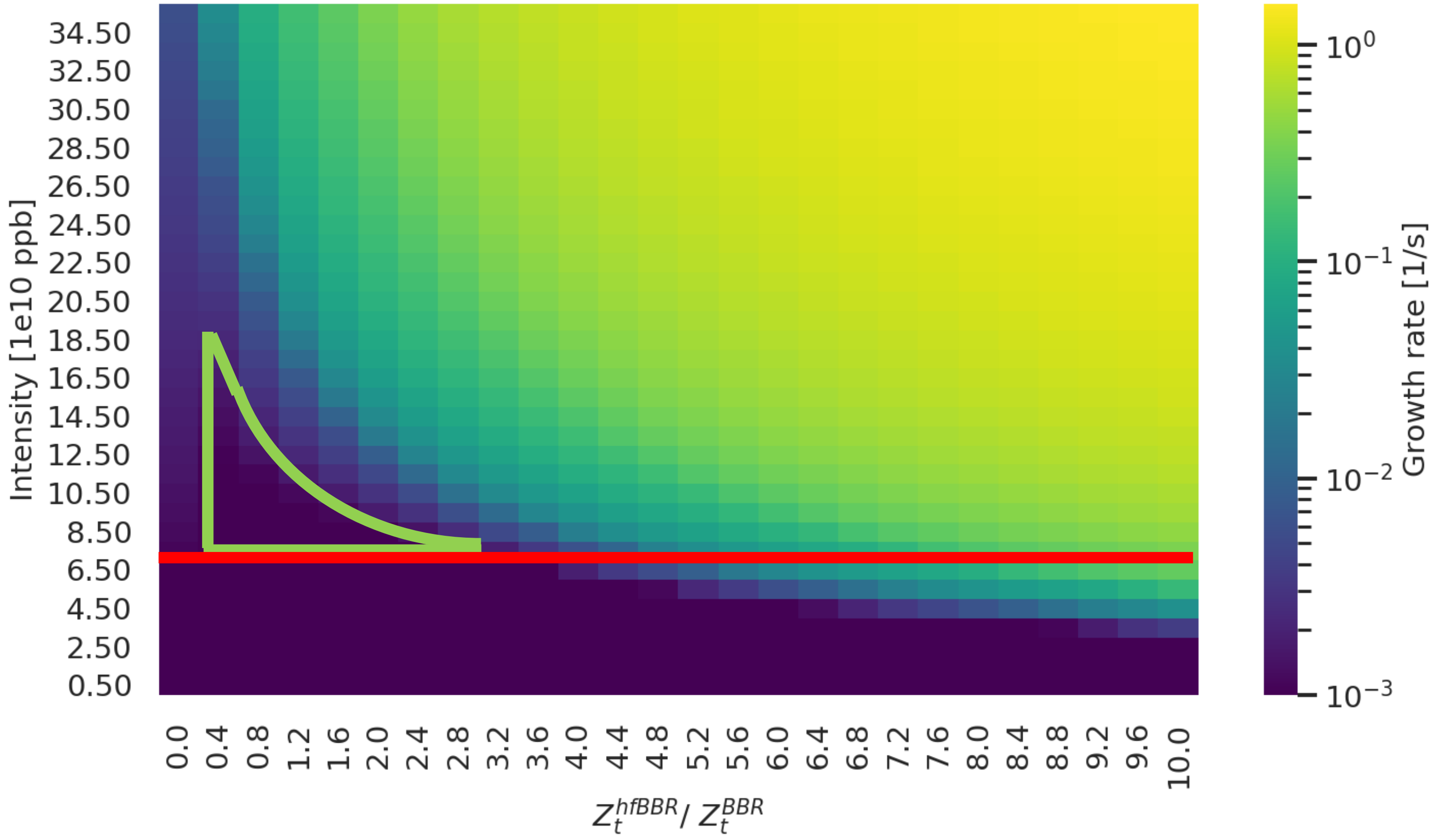
Conclusion

- **Adding a hfBBR impedance to a BBR impedance at zero chromaticity leads to :**
  - An overall more unstable beam.
  - The emergence of an extremely unstable region at large intensities and R_t^{hfBBR}/R_t^{BBR}.
- **Increasing the frequency of the hfBBR leads to 3 different effects :**
  - A shift of the extremely unstable region to larger intensities and R_t^{hfBBR}/R_t^{BBR}.
  - The transition from the slightly unstable region to the extremely unstable one is sharper.
  - A low TMCI intensity threshold increasing until nearly reaching the BBR only threshold.
- **Next steps**
  - Study the effect of a **capacitive** hfBBR on the SPS TMCI
  - Adding a hfBBR impedance to a BBR impedance at a **non zero** chromaticity can lead to a higher TMCI intensity threshold. One can investigate the effect of chromaticity on such an impedance.

home.cern

Backup slides

Growth rate of a hfBBR (10 GHz) + BBR

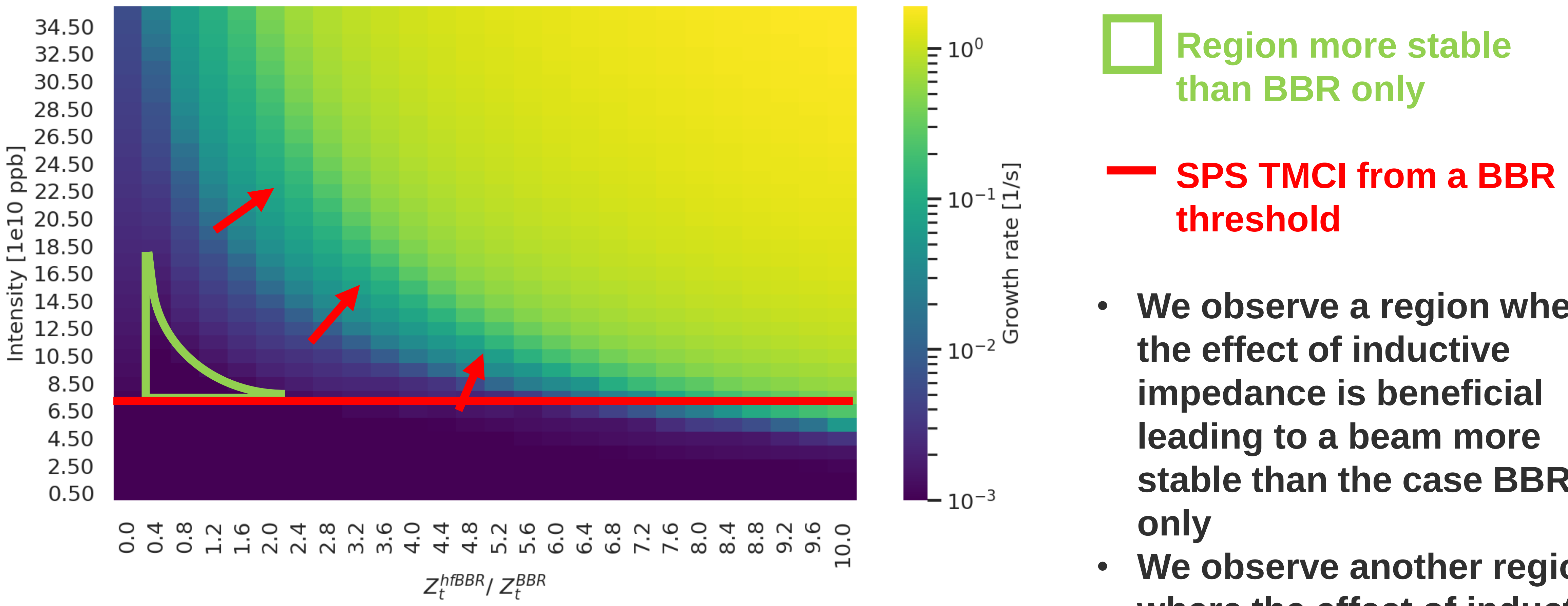


Region more stable than BBR only

SPS TMCI from a BBR threshold

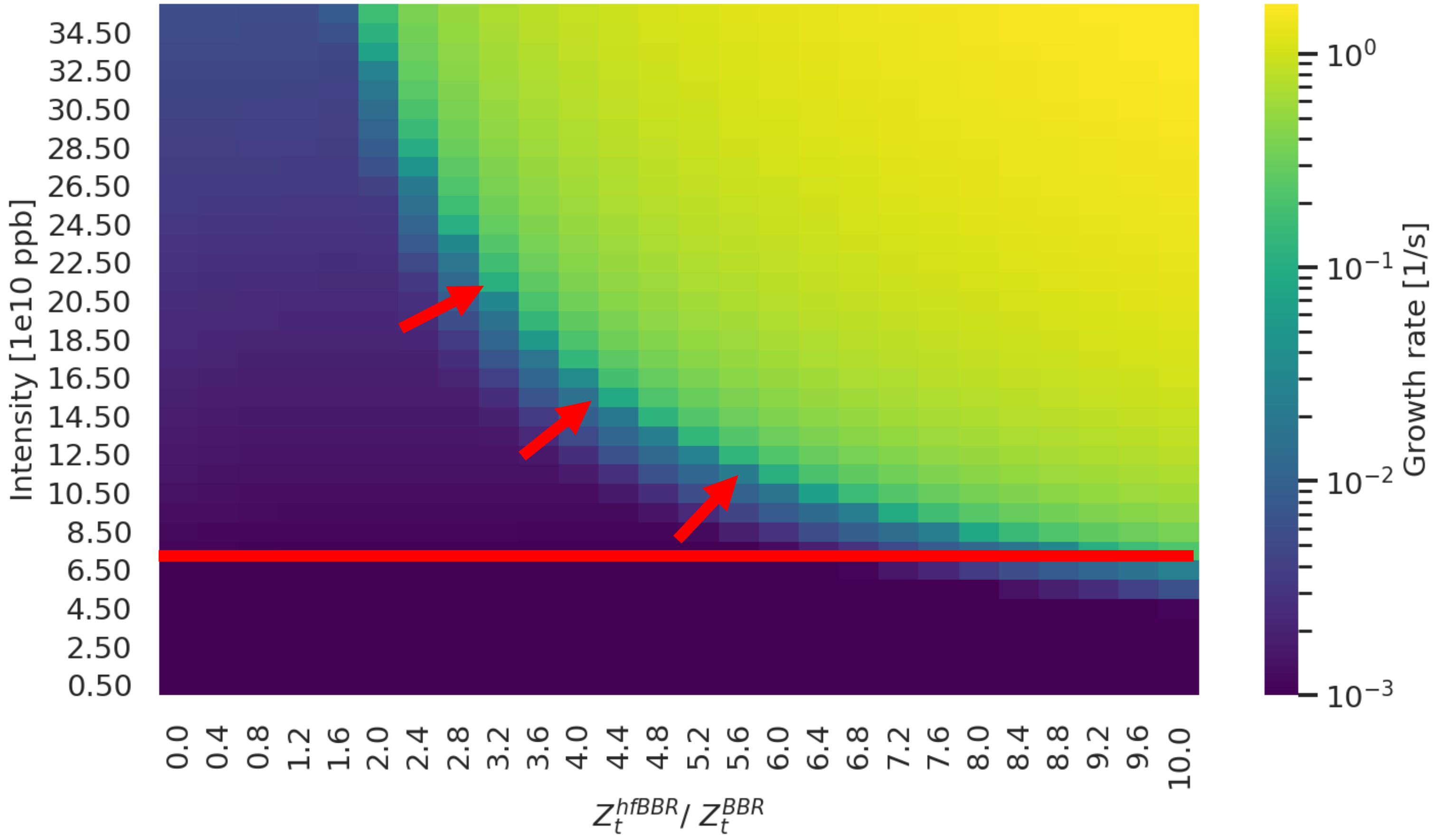
- **Beam becomes the most unstable at larger intensities and inductive impedances**
- **The area of the stable region becomes smaller as the frequency of the inductive impedance increases**

Growth rate of a hfBBR (100 GHz) + BBR



- **We observe a region where the effect of inductive impedance is beneficial leading to a beam more stable than the case BBR only**
- **We observe another region where the effect of inductive impedance is detrimental**

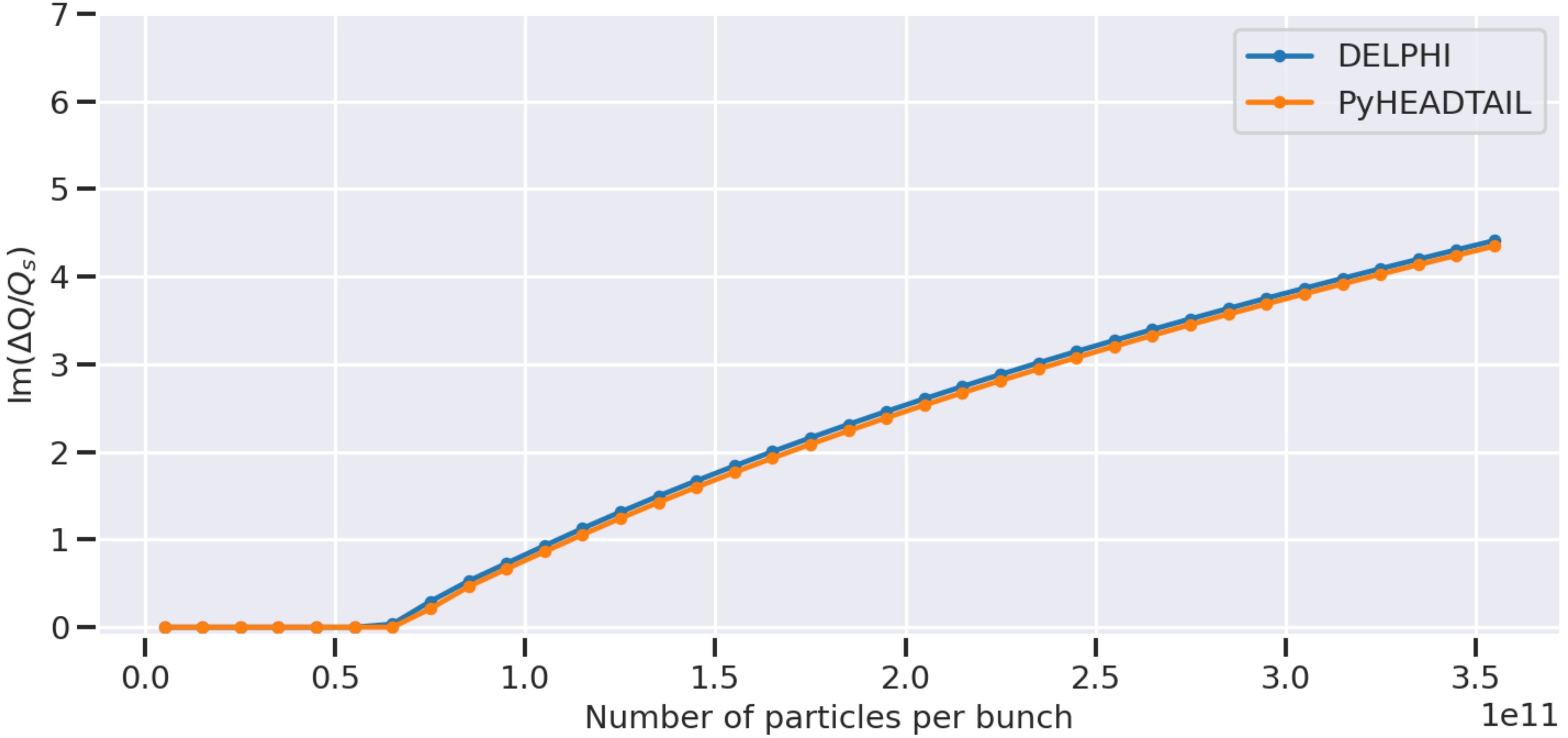
Growth rate of a hfBBR (1000 GHz) + BBR



SPS TMCI from a BBR threshold

- **Beam becomes the most unstable at larger intensities and inductive impedances**
- **The stable region disappears after a certain frequency of the inductive impedance**

Im(dQ) vs Intensity, BBR only case



Re(dQ) vs Intensity, BBR only case