Update on the comparison of DELPHI and PyHEADTAIL

D.Amorim, S.Antipov, N.Biancacci, E.Métral, N.Mounet, A.Oeftiger

Four main cases studied

- Part I: TMCI, intensity scan at Q'=0
  - Broadband resonator impedance model
  - LHC impedance model

- Part II: Headtail instability, chromaticity scan at fixed intensity
  - Resistive wall impedance model
  - LHC impedance model

- *Part I: TMCI*

Simulations parameters for intensity scan

- LHC 2017 impedance at flat-top
- LHC 2018 beam parameters, with reduced bunch length (1.0ns)

- In PyHEADTAIL linear synchrotron motion is used

Table 2.2: PYHEADTAILsimulations parameters.

Parameter	Value
Number of slices for the wake function	1000
Number of slices for the longitudinal distribution	100
Longitudinal cut / σ_z	5
Number of macroparticles	1×10^6
Number of turns	70×10^3

Table 2.3: DELPHIsimulations parameters.

Parameter	Value
Convergence criterion	5×10^{-3}

Table 2.1: Machine and beam parameters for DELPHIand PYHEADTAILsimulations.

Parameter	Value
Impedance	
Impedance model	LHC 2017 flat-top[1] Broad-band resonator[2]
Machine	
Circumference / m	26 658.8832
Transverse tunes $Q_{x,y}$	62.31/60.32
Momentum compaction factor α_c	3.48×10^{-4}
RF voltage / MV	12
Harmonic number	35 640
Synchrotron tune	1.909×10^{-3}
Beam	
Number of bunches	1
$4\,\sigma$ bunch length / ns	1.0
Bunch intensity / 1×10^{11} p.p.b	0 to 5
Chromaticity Q'	0

[2] Resonator Rs=25MOhm/m, fres=2.0GHz, Q=1

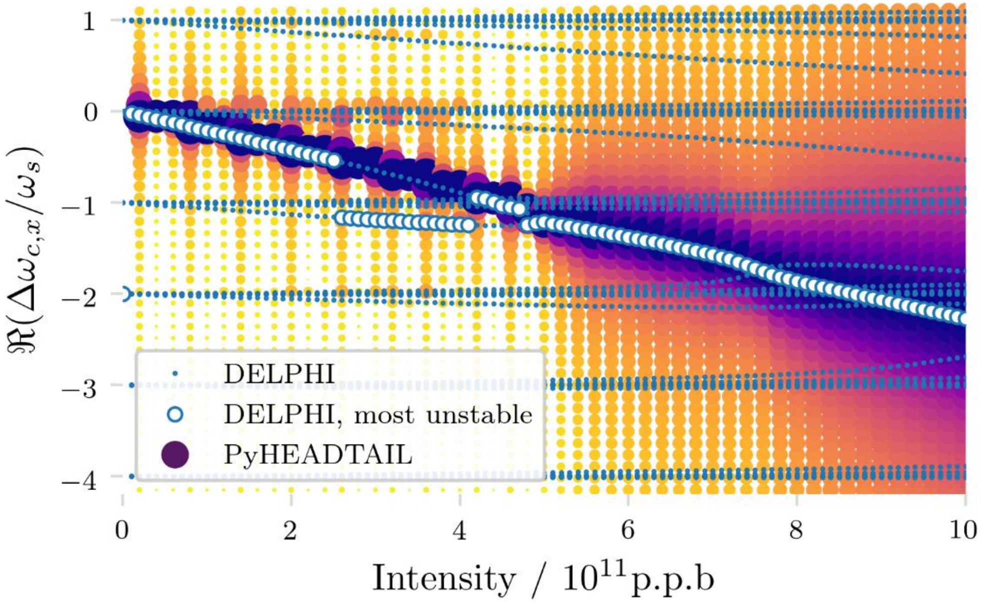
TMCI: intensity scan at Q’=0

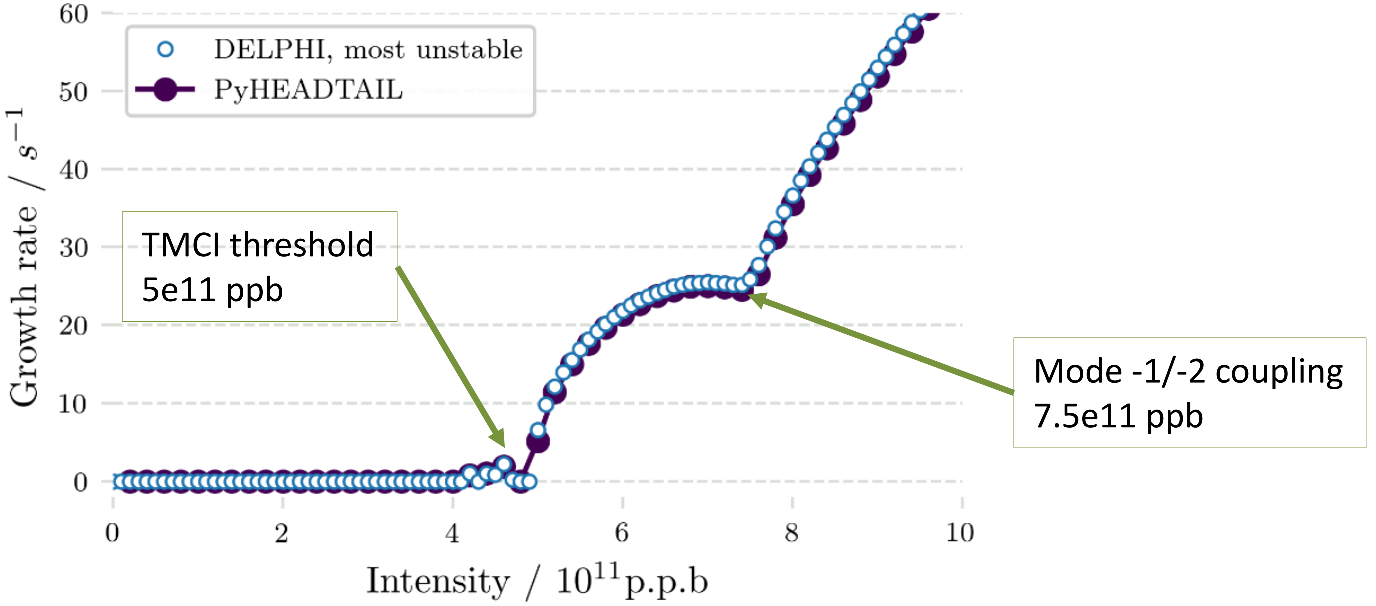
- 1. Broadband resonator (BBR) impedance model
  - 1.1 Without damper
  - 1.2 With damper

- 2. LHC impedance model, without damper
  - 2.1 Without quadrupolar impedance
  - 2.2 With quadrupolar impedance

- All results showed will be for the H plane (V plane impedance deactivated)

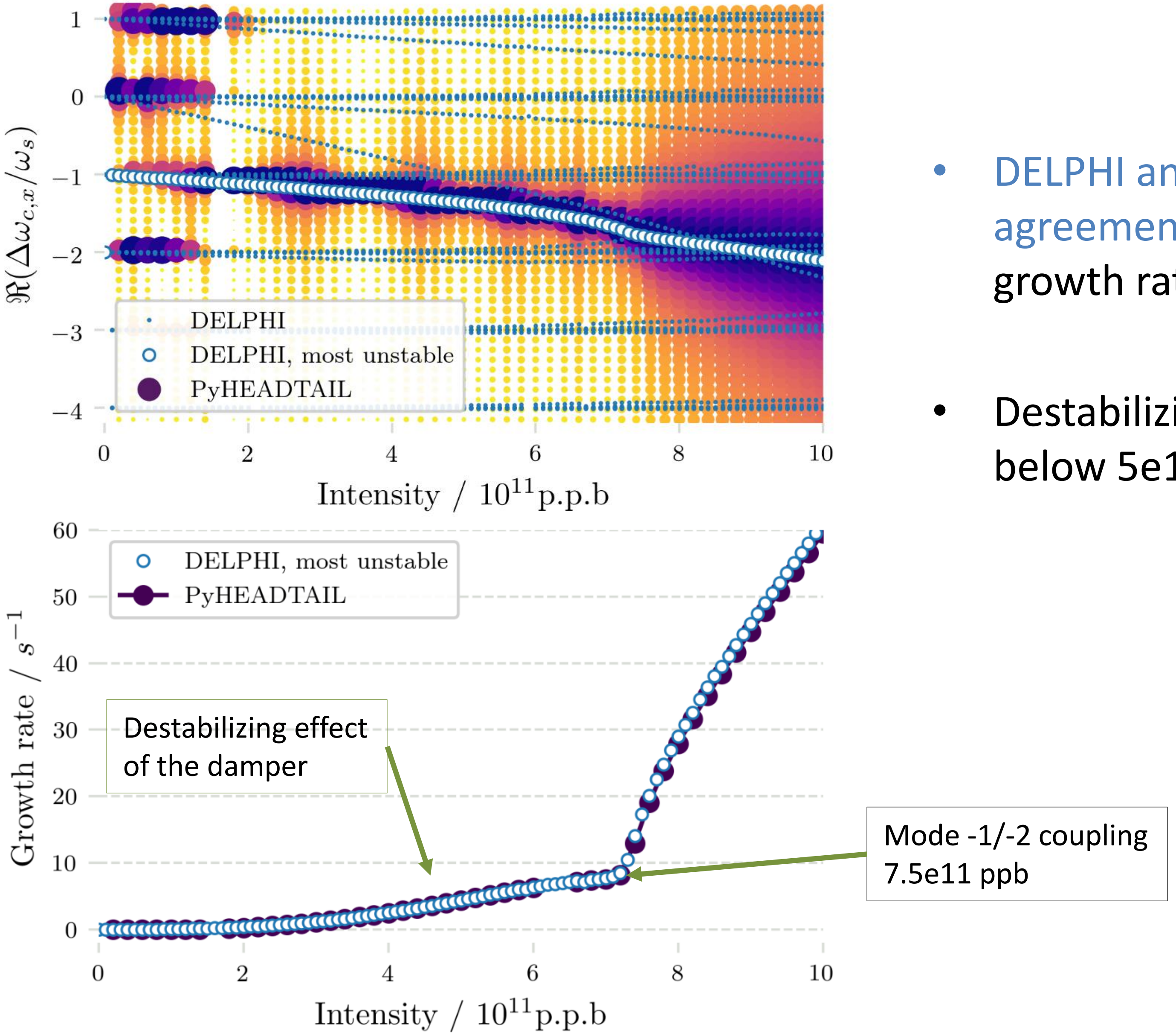
1.1 BBR, no damper





- DELPHI and PyHEADTAIL are in excellent agreement, both for frequency shifts and growth rates

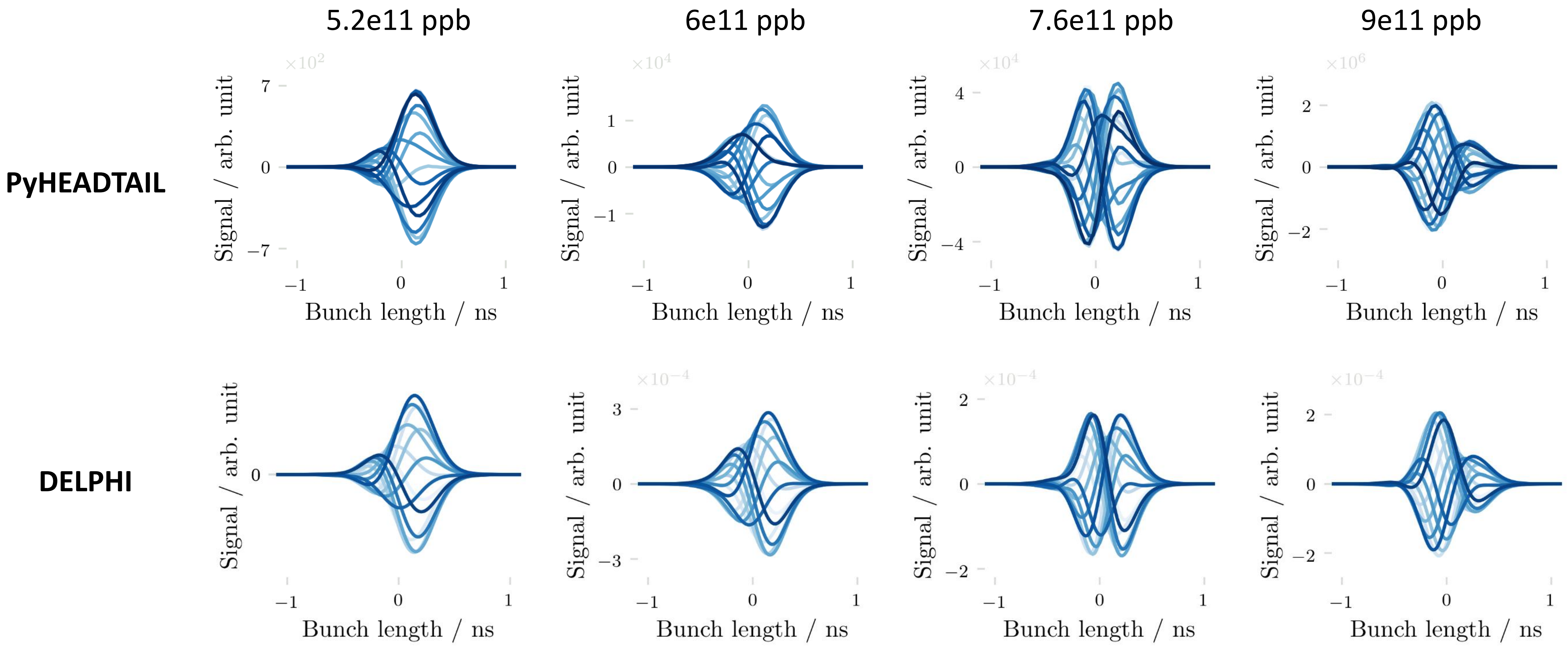
1.2 BBR, with damper (100 turns)



- DELPHI and PyHEADTAIL are in excellent agreement, both for frequency shifts and growth rates
- Destabilizing effect of the damper below 5e11 ppb

Excellent agreement for the headtail modes pattern

- DELPHI pattern is associated to the most unstable mode
- **No damper** case



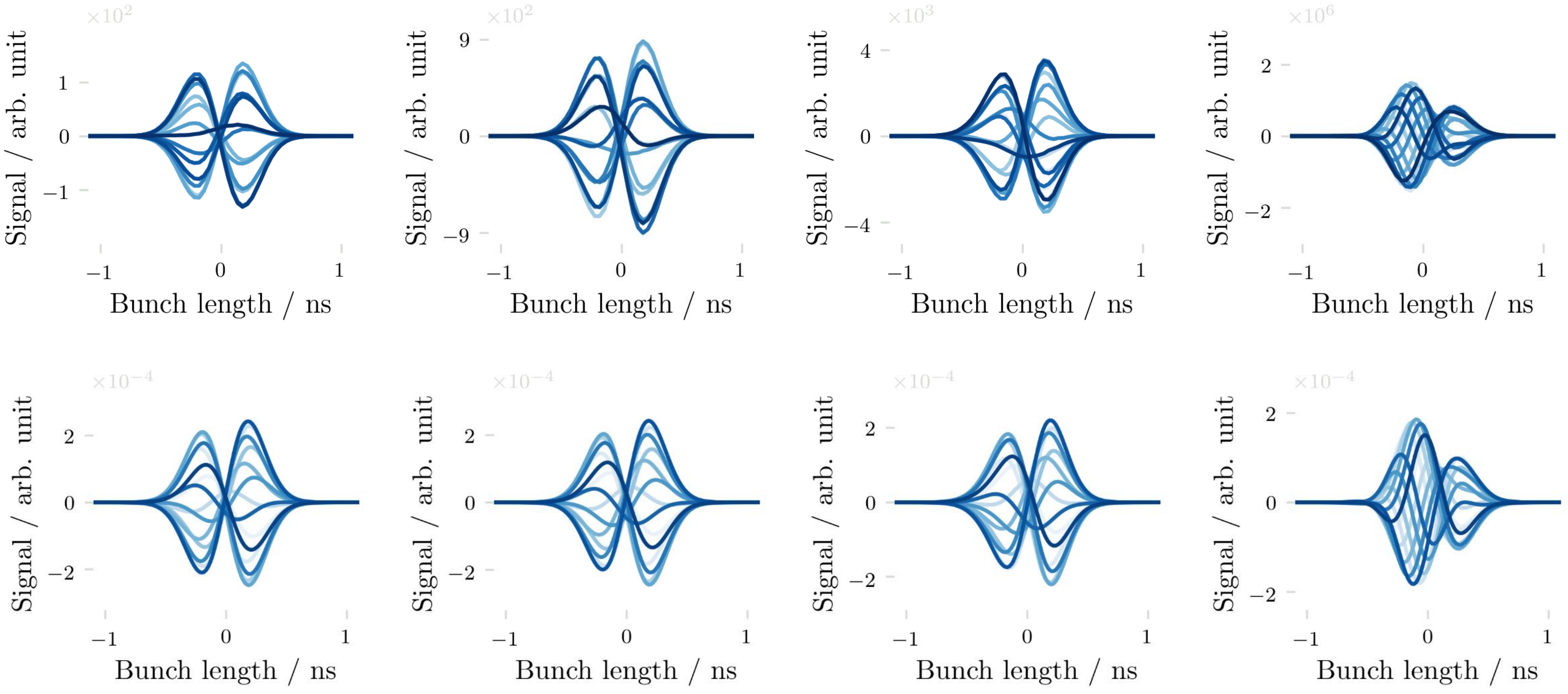
Excellent agreement for the headtail modes pattern

- DELPHI pattern is associated to the most unstable mode
- **With damper** case

3.0e11 ppb | 4e11 ppb | 6.0e11 ppb | 9e11 ppb

PyHEADTAIL

DELPHI



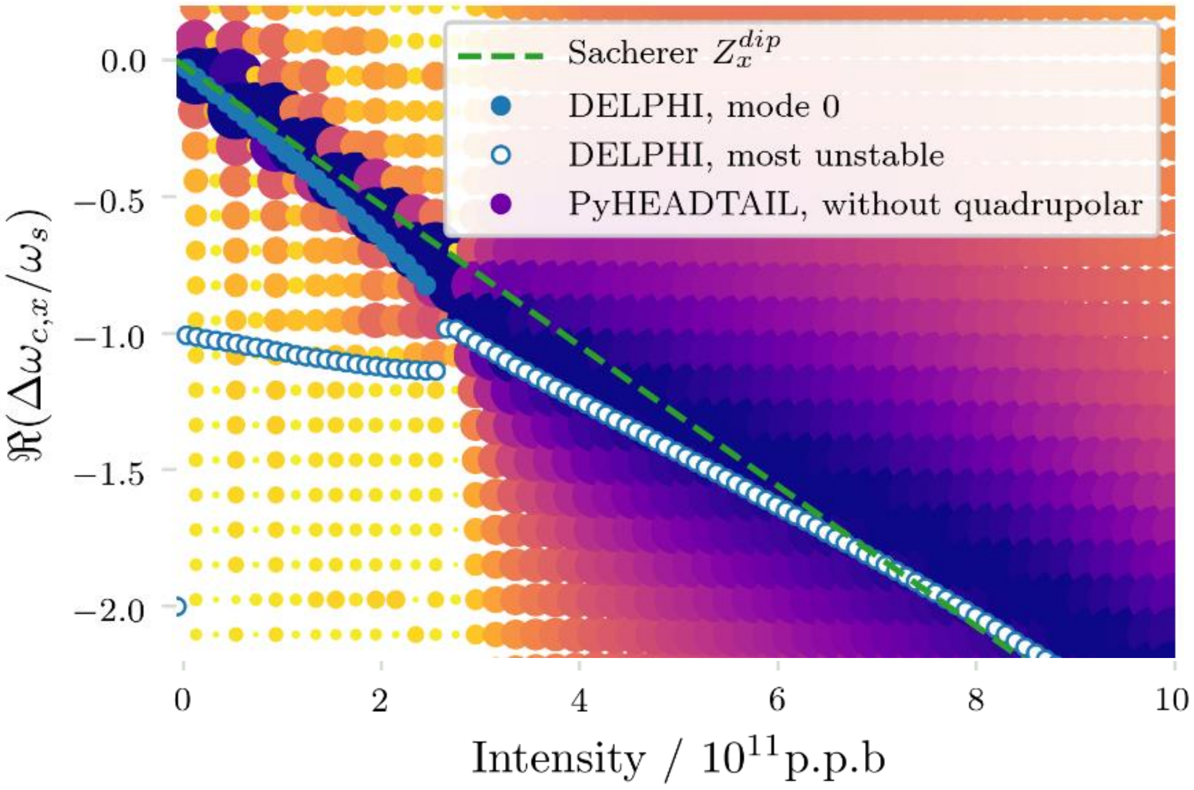
TMCI: intensity scan at Q'=0

- 1. Broadband resonator (BBR) impedance model
  - 1.1 Without damper
  - 1.2 With damper

- 2. LHC impedance model, without damper
  - 2.1 Without quadrupolar impedance
  - 2.2 With quadrupolar impedance

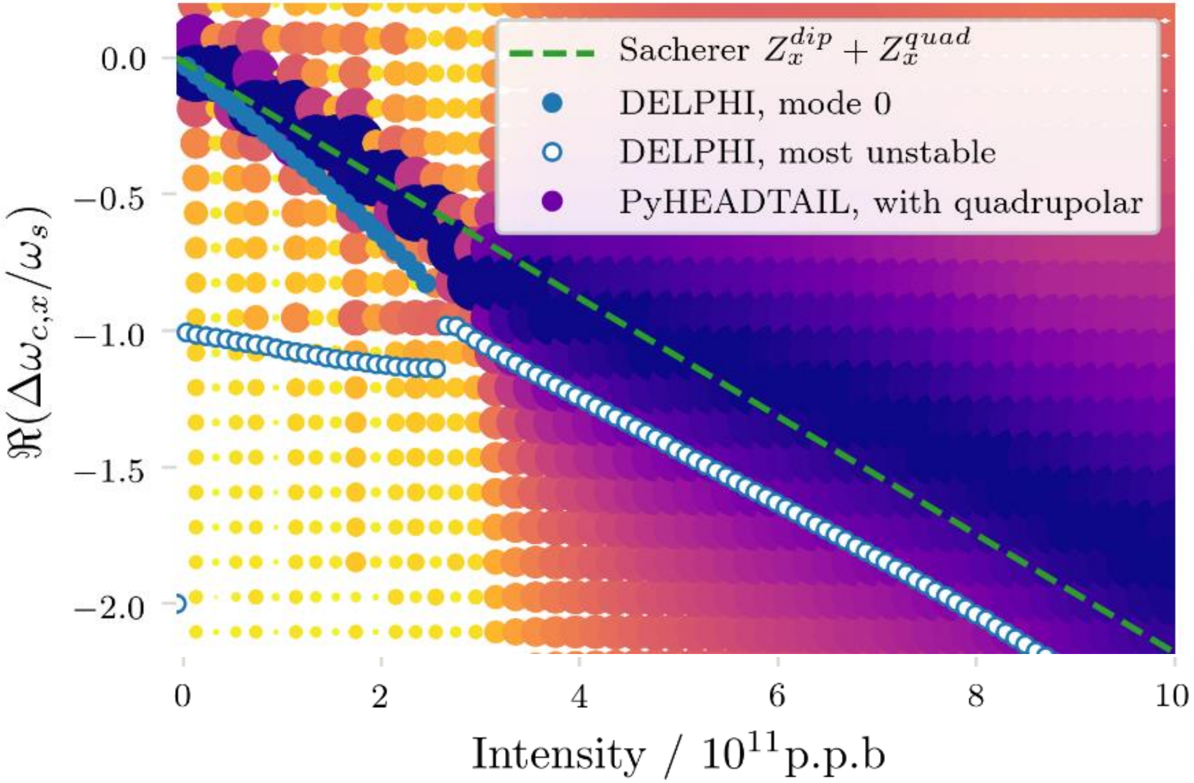
- All results showed will be for the H plane (V plane impedance deactivated)

2.1 LHC, no damper, no quadrupolar impedance



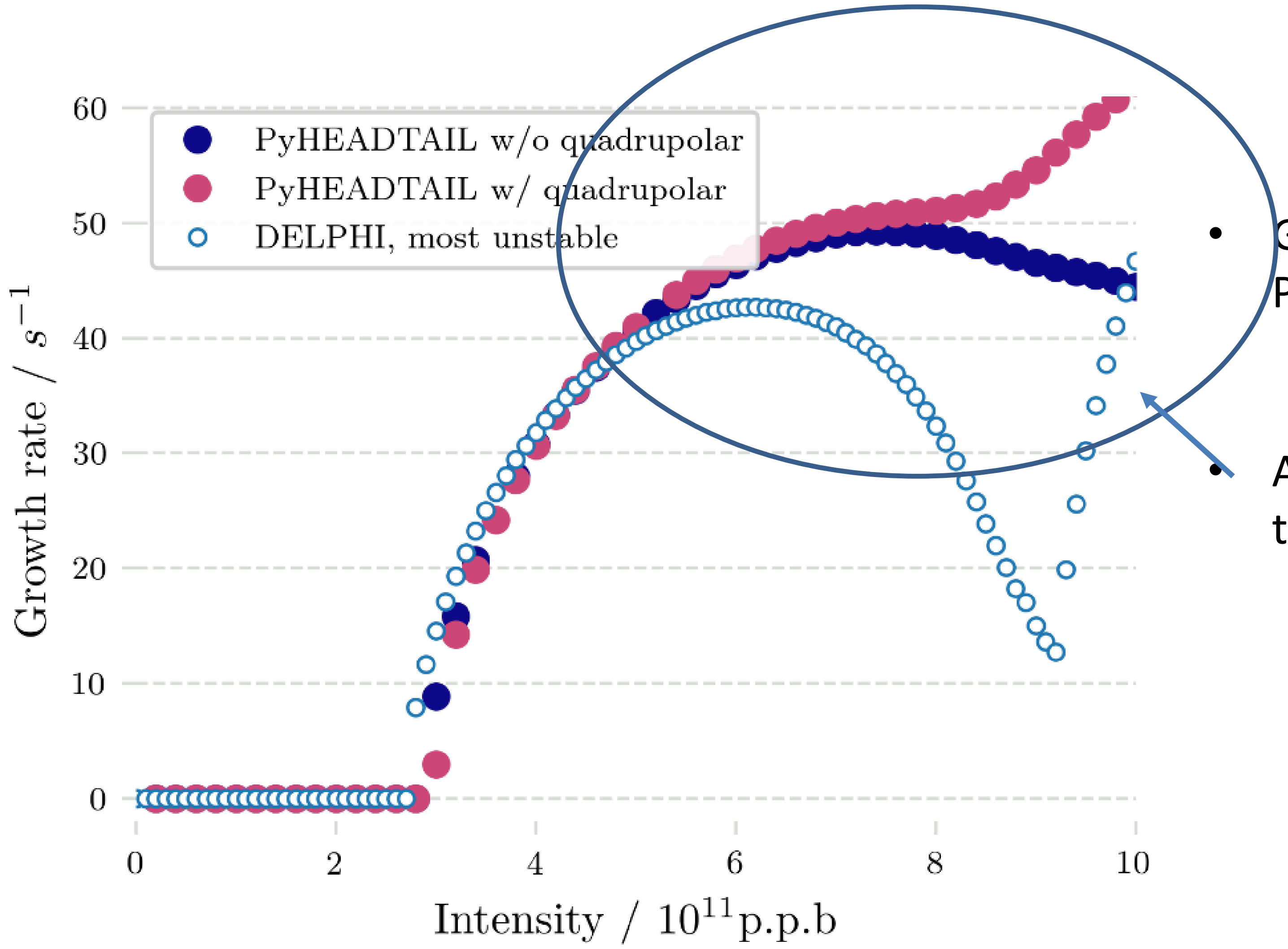
- Sacherer formula (for dipolar impedance only) also plotted
- DELPHI and PyHEADTAIL are in good agreement up to 5e11 ppb

2.2 LHC, no damper, no quadrupolar impedance



- Sacherer formula (for dipolar and quadrupolar impedance) also plotted
- Mode 0 clearly shifts up with Sacherer and PyHEADTAIL

2. LHC, without and with quadrupolar impedance



- Good agreement between DELPHI and PyHEADTAIL for intensities up to 6e11 ppb
  - Quadrupolar wake doesn't affect much the growth-rates
- Above 5e11 ppb, different behavior between the three cases
  - Difference between DELPHI and PyHEADTAIL (w/o quad wakefield)
  - Effect of the quadrupolar wake visible above 8e11 ppb

- *Part II: Headtail instability*

Simulations parameters for chromaticity scan

- Identical to the intensity scan parameters

- Chromaticity is now scanned from -50 to +50 units
- Bunch intensity is fixed to
  - 6e11ppb for the resistive wall impedance
  - 2e11ppb for the LHC impedance

Table 2.2: PYHEADTAILsimulations parameters.

Parameter	Value
Number of slices for the wake function	1000
Number of slices for the longitudinal distribution	100
Longitudinal cut / σ_z	5
Number of macroparticles	1×10^6
Number of turns	200 000

Table 2.3: DELPHIsimulations parameters.

Parameter	Value
Convergence criterion	5×10^{-3}

Table 2.1: Machine and beam parameters for DELPHIand PYHEADTAILsimulations.

Parameter	Value
Impedance	
Impedance model	LHC 2017 flat-top[1] Resistive wall[3]
Machine	
Circumference / m	26 658.8832
Transverse tunes $Q_{x,y}$	62.31/60.32
Momentum compaction factor α_c	3.48×10^{-4}
RF voltage / MV	12
Harmonic number	35 640
Synchrotron tune	1.909×10^{-3}
Beam	
Number of bunches	1
$4\,\sigma$ bunch length / ns	1.0
Bunch intensity / 1×10^{11} p.p.b	6 or 2
Chromaticity Q'	-50 to +50

[3] Impedance of a circular pipe of radius 10 mm, made of copper at room temperature, with a length of 27 km

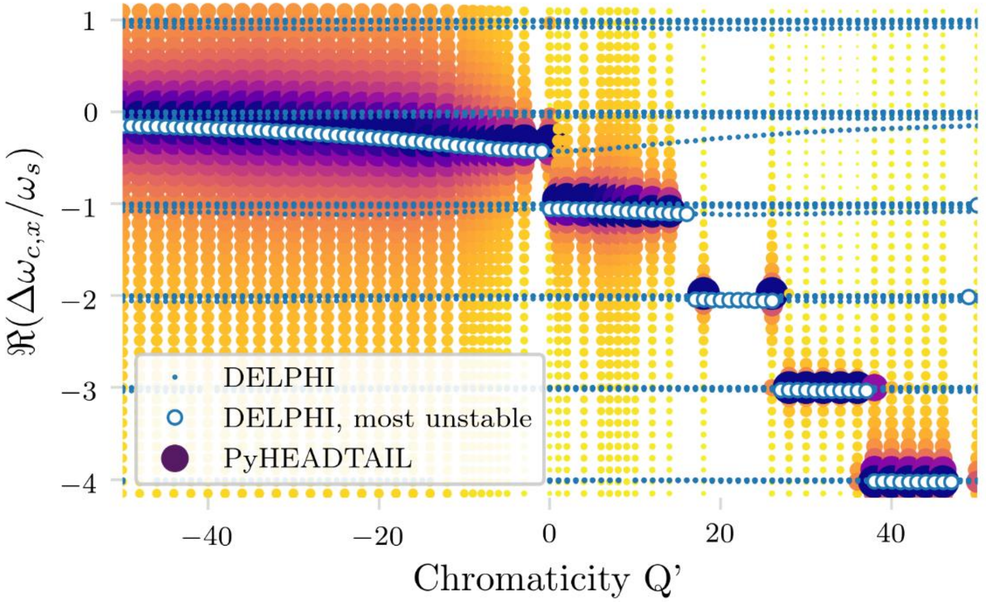
Headtail instability: chromaticity scan at fixed intensity

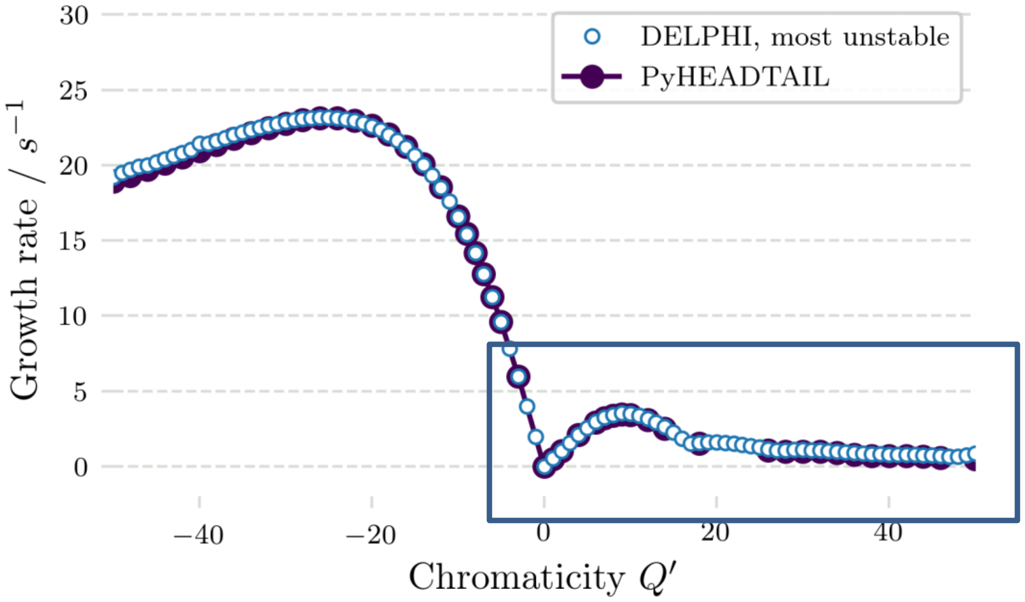
- 1. Resistive wall (RW) impedance model
  - 1.1 Without damper
  - 1.2 With damper

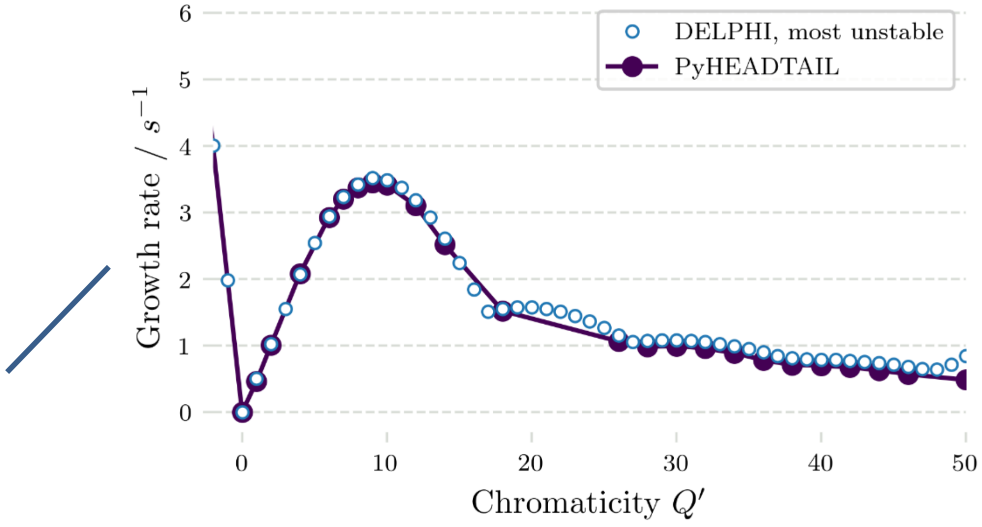
- 2. LHC impedance model
  - 2.1 Without damper
  - 2.2 With damper
  - 2.3 Effect of non-linear longitudinal motion

- All results showed will be for the H plane (V plane impedance deactivated)

1.1 RW, no damper

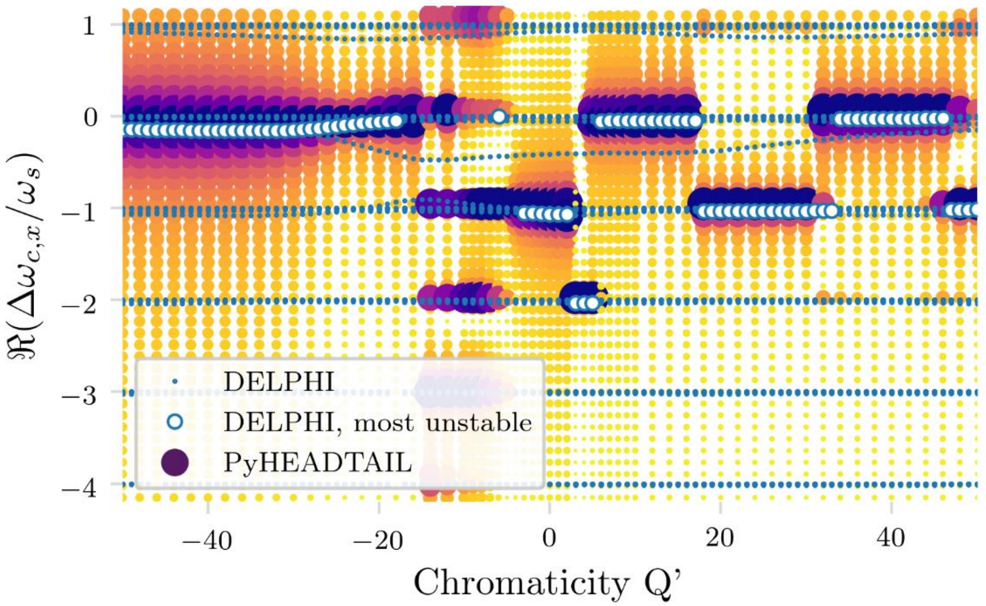


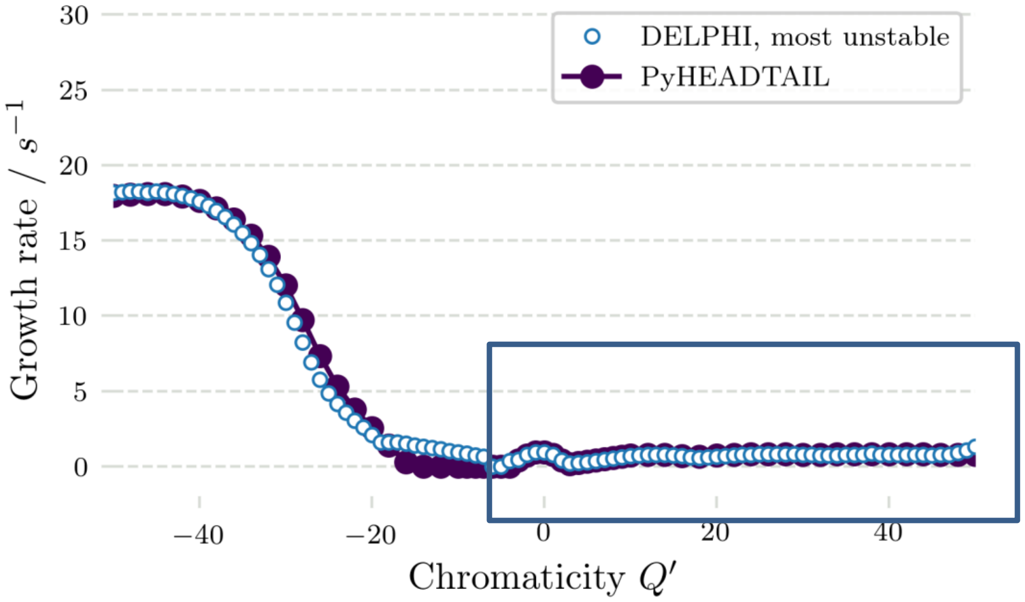


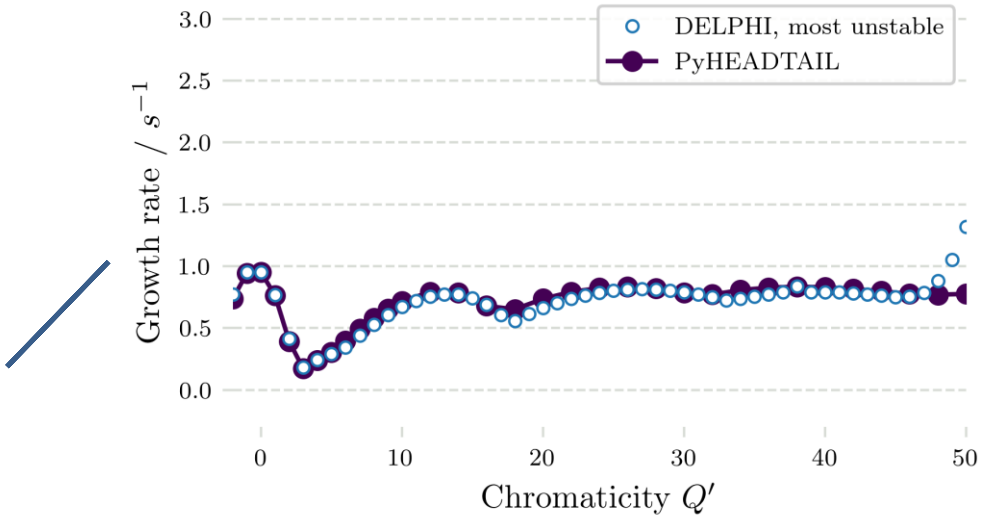


- DELPHI and PyHEADTAIL are in excellent agreement, both for frequency shifts and growth rates

1.2 RW, with damper (100 turns)







- DELPHI and PyHEADTAIL are in excellent agreement for the growth rates
- Picture less clear for the modes frequencies, but the agreement looks reasonable

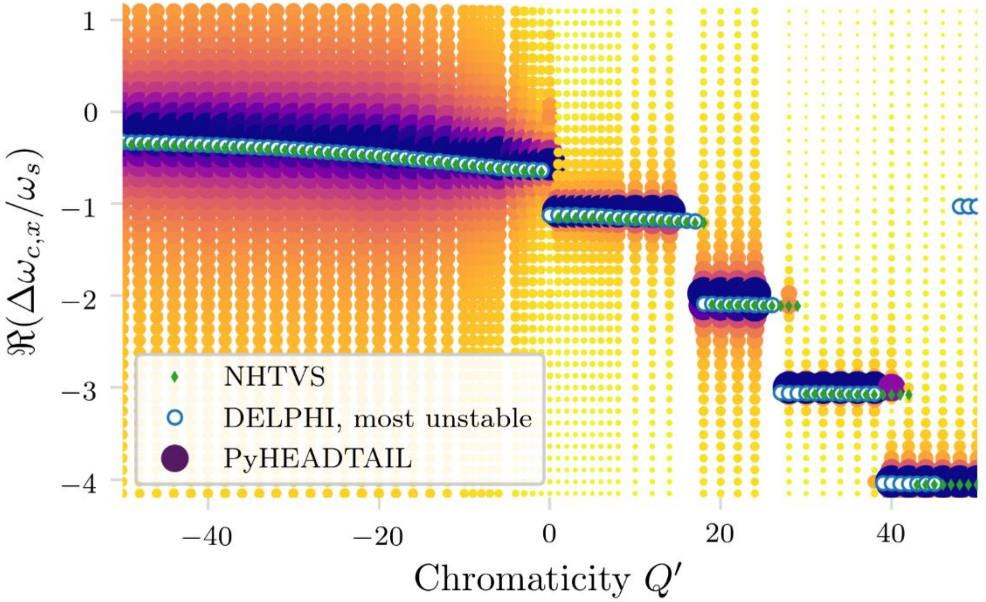
Headtail instability: chromaticity scan at fixed intensity

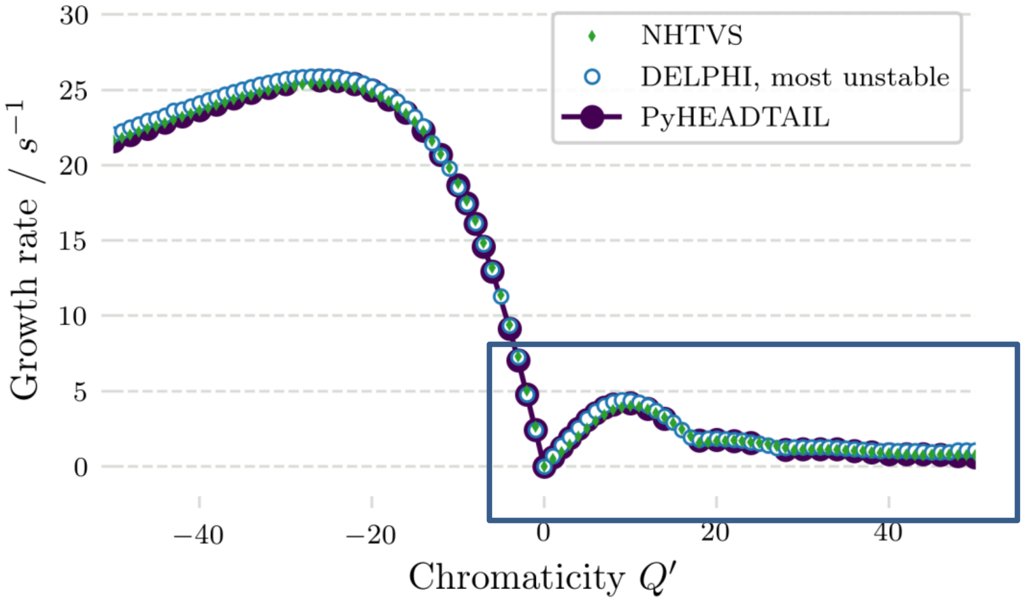
- 1. Resistive wall (RW) impedance model
  - 1.1 Without damper
  - 1.2 With damper

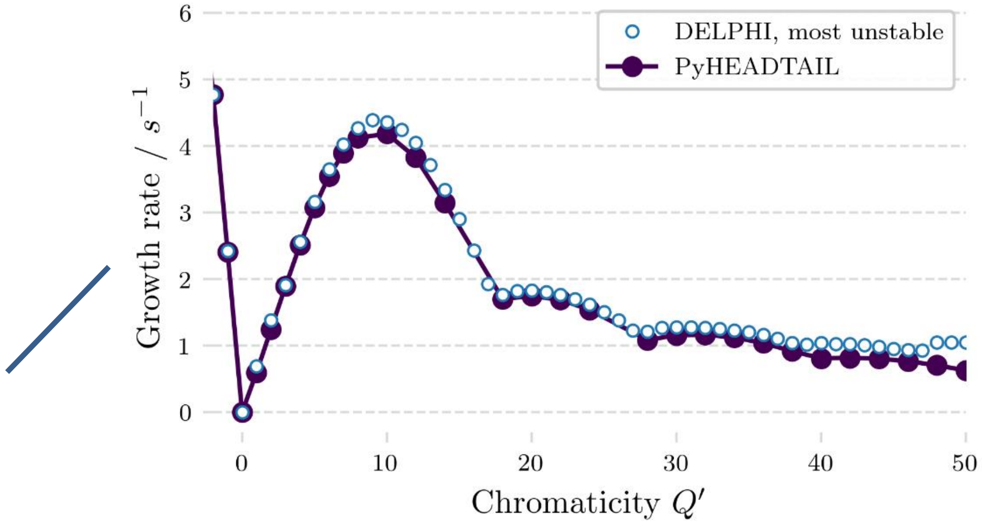
- 2. LHC impedance model
  - 2.1 Without damper
  - 2.2 With damper
  - 2.3 Effect of non-linear longitudinal motion

- All results showed will be for the H plane (V plane impedance deactivated)

2.1 LHC, no damper

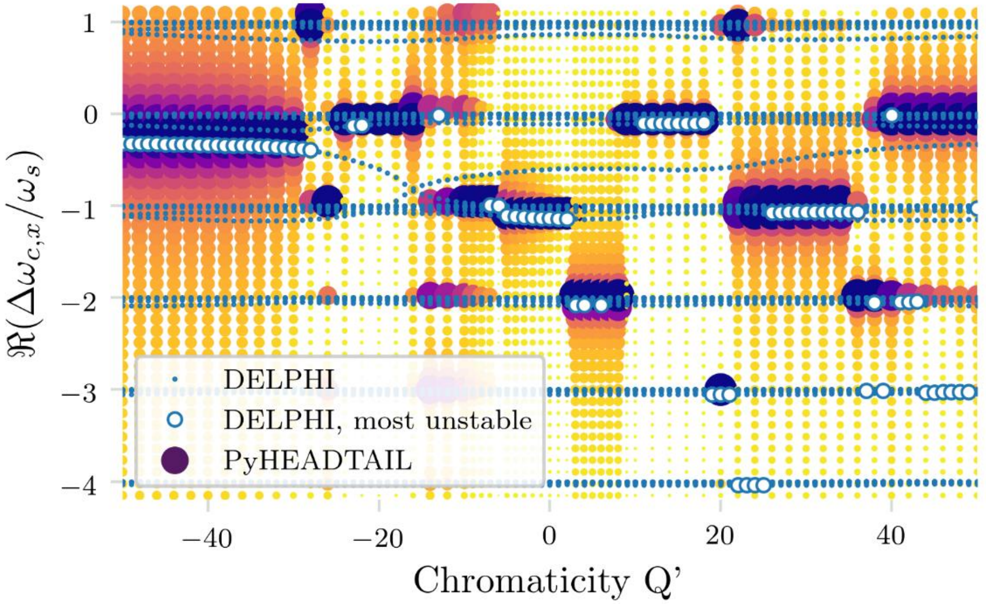




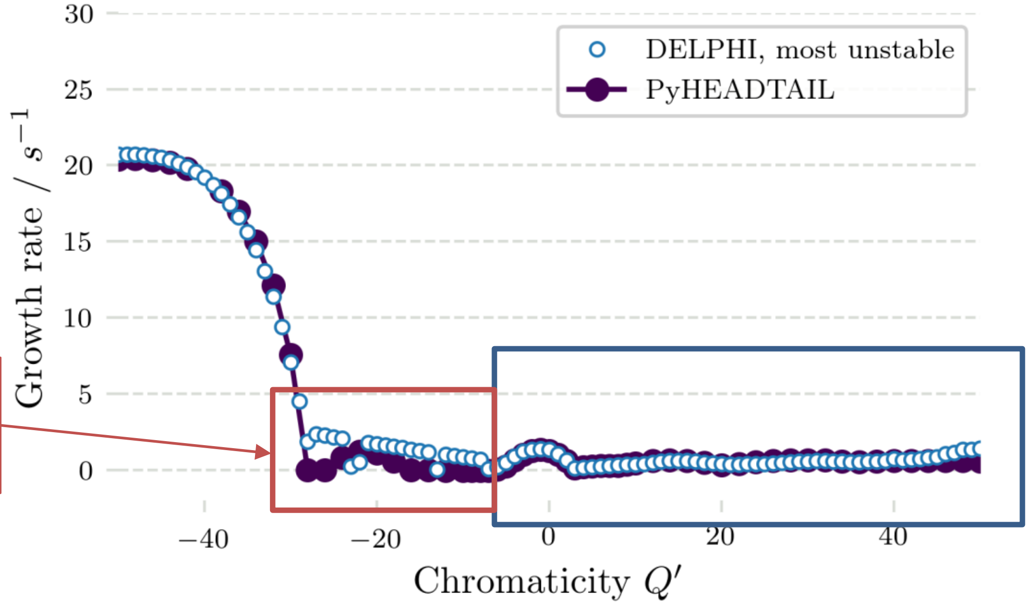


- DELPHI, NHTVS and PyHEADTAIL are in good agreement, both for frequency shifts and growth rates

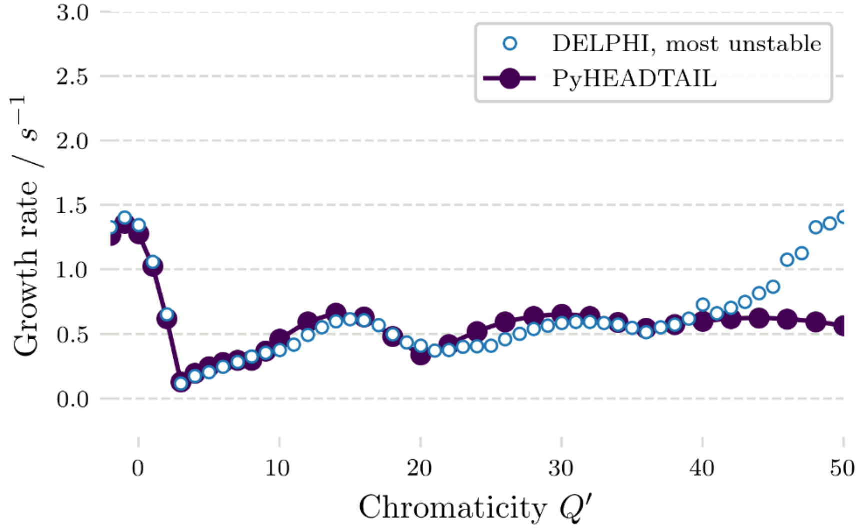
2.2 LHC, with damper (100 turns)



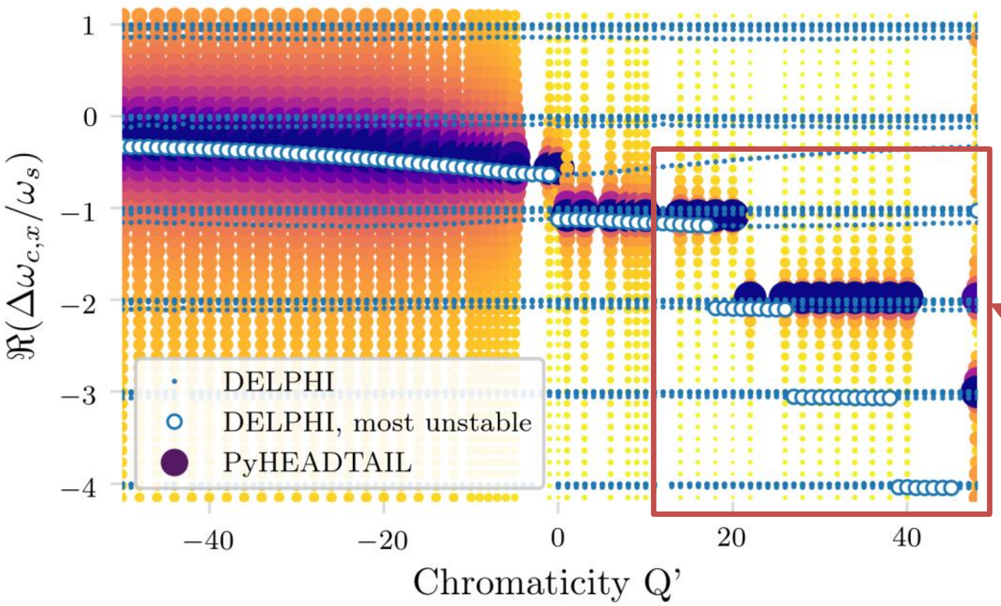
- DELPHI and PyHEADTAIL are consistent, but some differences can be seen for low negative Q' and high positive Q'
- The picture for the real part is less clear



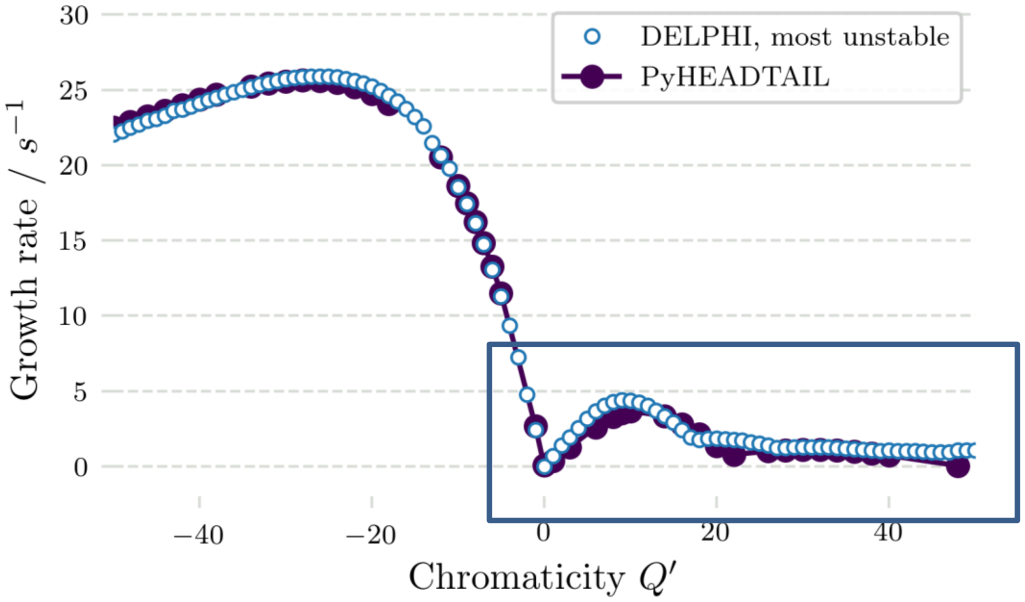
Spurious points with DELPHI?

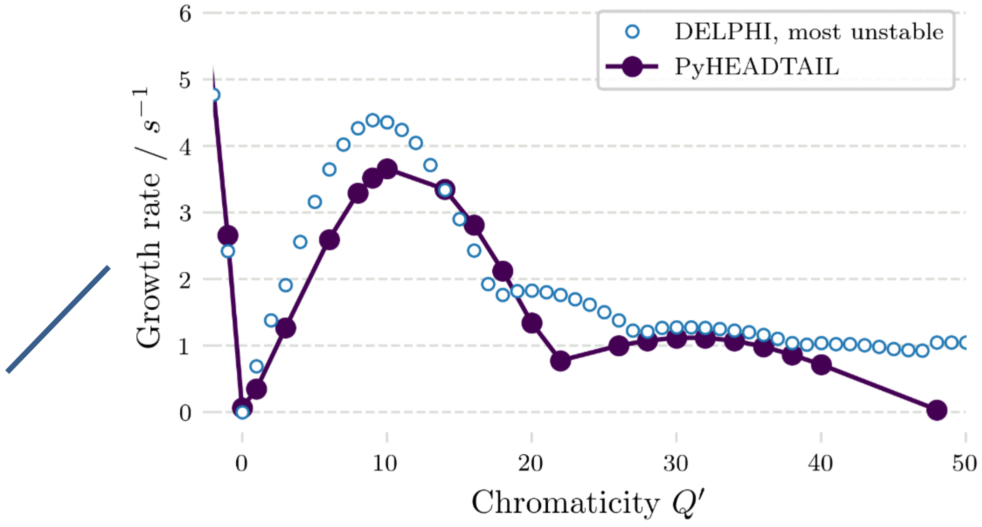


2.3 LHC, effect of non linear longitudinal motion



- No damper
- Non linear longitudinal motion is now activated in PyHEADTAIL
- The picture changes quite a lot, especially for positive chromaticities





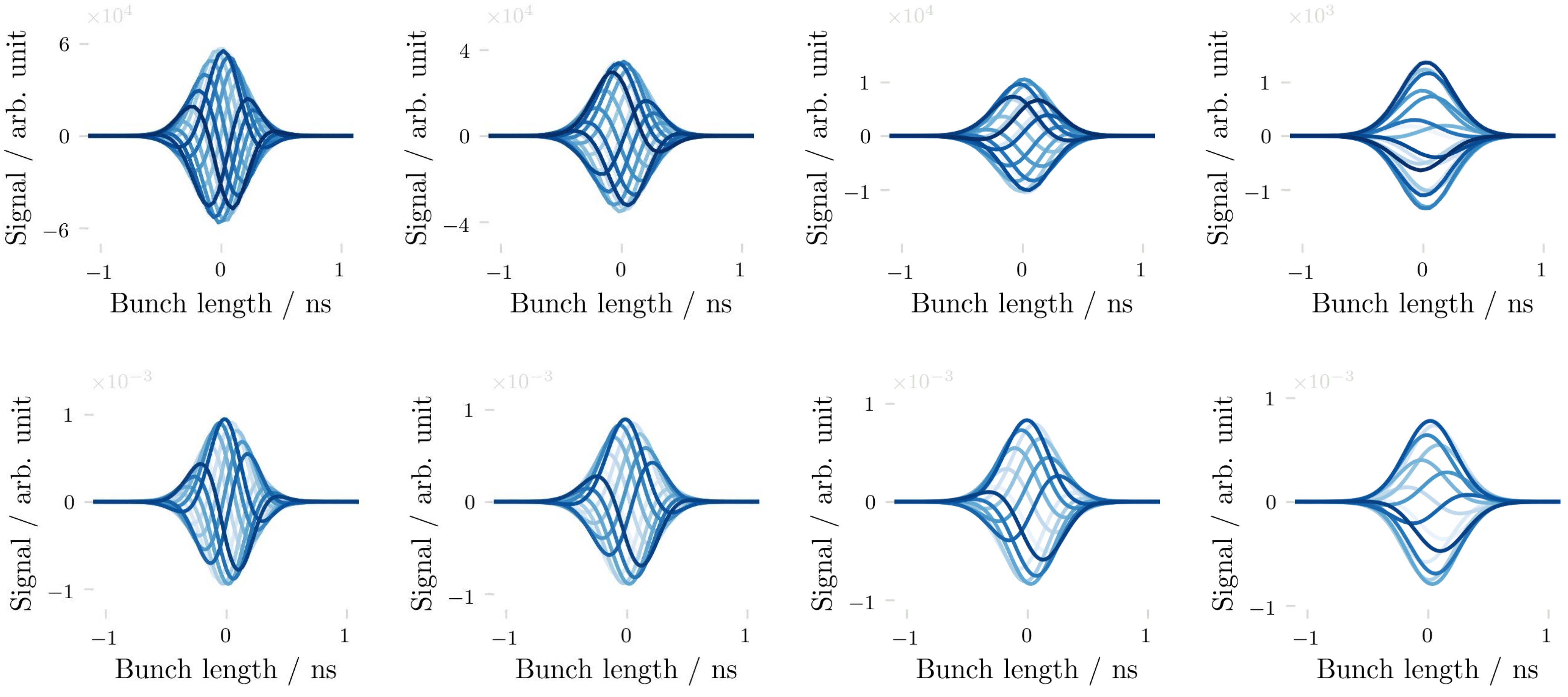
Excellent agreement for the headtail modes pattern

- Case 2.1: LHC without damper case
- DELPHI: pattern associated to the most unstable mode
- PyHEADTAIL: pattern for the no quadrupolar wake case

Q'=-30 Q'=-20 Q'=-10 Q'=-2

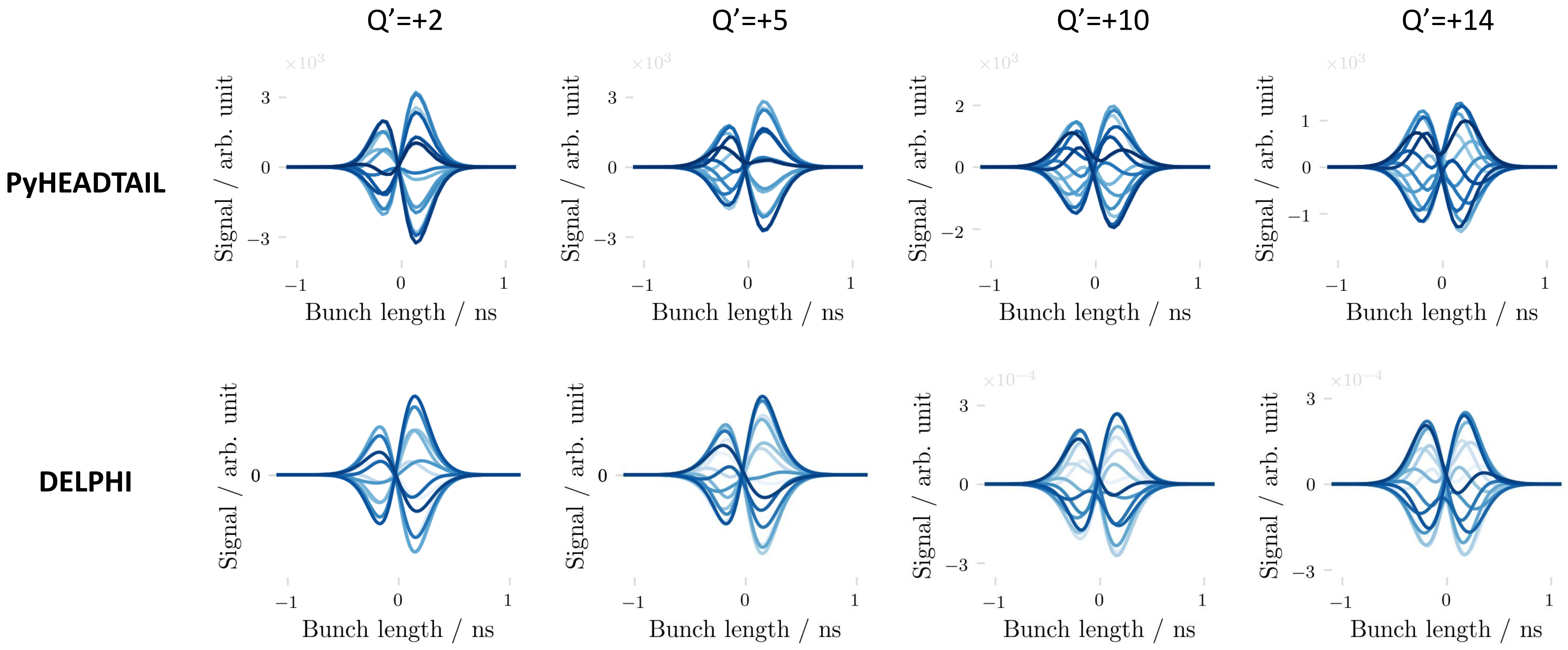
PyHEADTAIL

DELPHI



Excellent agreement for the headtail modes pattern

- Case 2.1: LHC without damper case
- DELPHI: pattern associated to the most unstable mode
- PyHEADTAIL: pattern for the no quadrupolar wake case



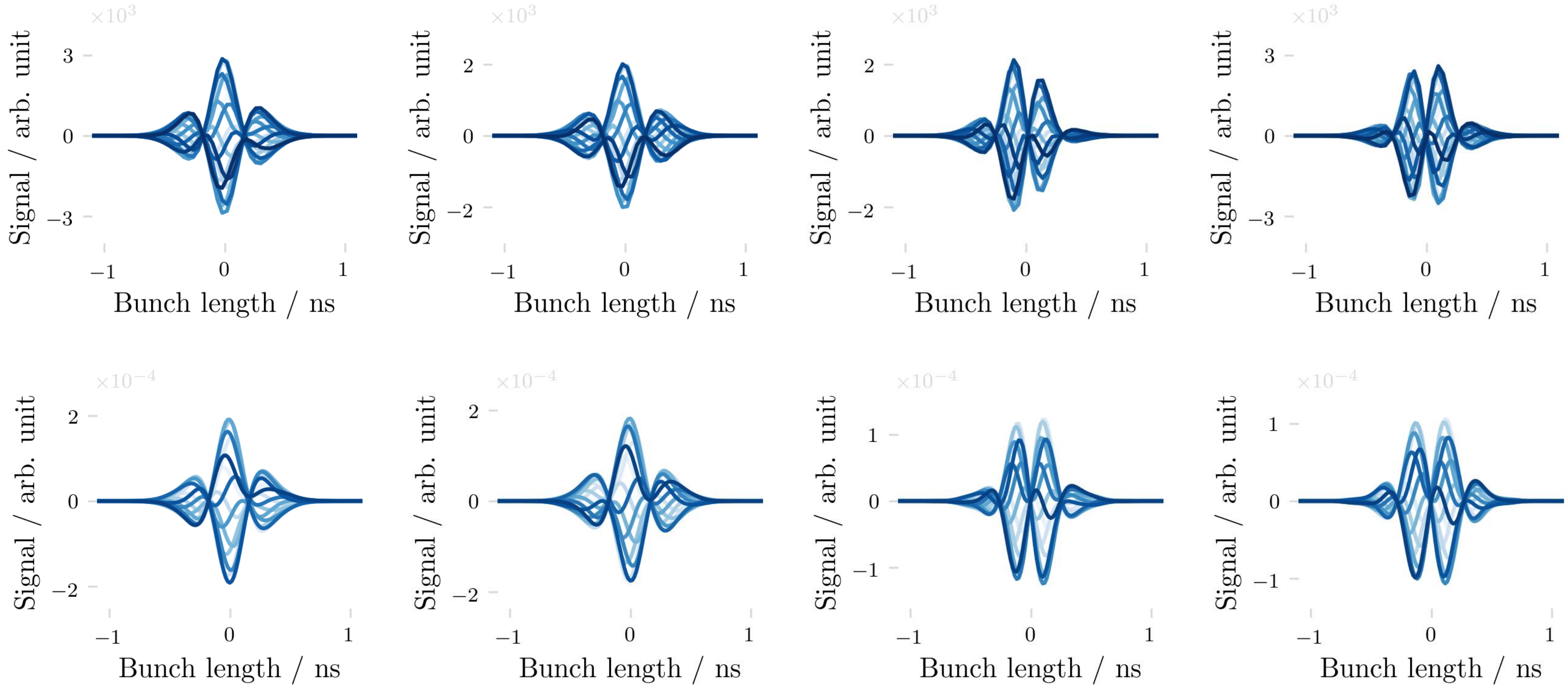
Excellent agreement for the headtail modes pattern

- Case 2.1: LHC without damper case
- DELPHI: pattern associated to the most unstable mode
- PyHEADTAIL: pattern for the no quadrupolar wake case

Q’=+18 Q’=+24 Q’=+28 Q’=+30

PyHEADTAIL

DELPHI



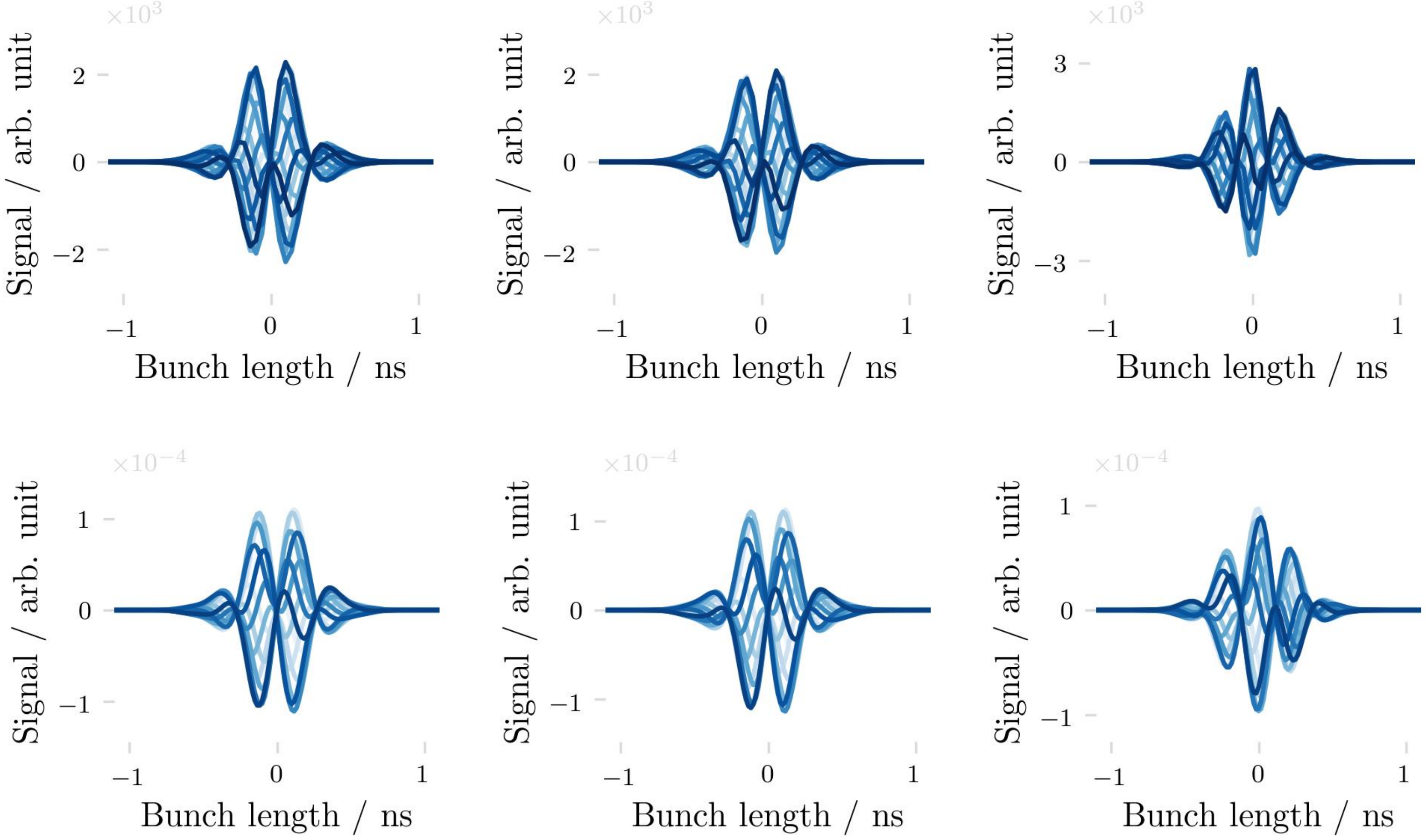
Excellent agreement for the headtail modes pattern

- Case 2.1: LHC without damper case
- DELPHI: pattern associated to the most unstable mode
- PyHEADTAIL: pattern for the no quadrupolar wake case

Q'=+32 Q'=+34 Q'=+42

PyHEADTAIL

DELPHI



Conclusions

- DELPHI results reproduced with PyHEADTAIL
  - In the TMCI case, for a broadband resonator and for the LHC impedance
  - In the head-tail instability case, for a resistive wall impedance and for the LHC impedance model
- Good agreement is reached between the two codes, for the modes frequency shifts, growth rates and transverse signals

- Main discrepancy for the TMCI case at high intensity, with the LHC impedance model
- Other small discrepancies for high chromaticities, or low negative chromaticities with damper

- *Backup*

Critical points for the simulations

- PyHEADTAIL simulations must be carefully set-up
  - Non-linear synchrotron motion in PyHEADTAIL affects the head-tail instability for high order modes
  - Longitudinal bunch distribution needs to be carefully generated to create a Gaussian bunch
  - Simulation length when the damper is active: increased to 500 000 turns for the headtail instability simulations
- Convergence tests were also done with PyHEADTAIL:
  - Number of wake slices used
  - Bunch length cut