Effect of a HH-RF System on Transverse Instability

HL-LHC Higher Harmonic RF System Meeting 3

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Acknowledgements:
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Overview

- Context
- HL-LHC double harmonic configurations
- Tuneshifts and risetimes
- Tuneshifts and risetimes with damper
- Conclusions & outlook

Context

- A harmonic RF system can be used to shape the longitudinal phase space and incoherent synchrotron tune spectrum
- Both the longitudinal phase space profile and the incoherent synchrotron tune spectrum have an influence on the transverse beam stability
- We will investigate TMCI thresholds:
  - HL-LHC impedance model (N. Mounet)
  - 400 MHz + 800 MHz double harmonic RF system in shortening and lengthening mode

Parameters

- HL-LHC parameters used for the simulations
- Free parameters:
  - Intensity
  - Chromaticity
  - Relative phase between RF harmonics
  - Damper gain

Macroparticles	500 000
Slices	500
Turns	$<$ 300 000
Energy	7 TeV
α	3.225e-4
Q_x	62.31
Q_y	60.32
β_x	65.98 m
β_y	71.53 m
$\varepsilon_x^{(n)}$	2 µm
$\varepsilon_y^{(n)}$	2 µm

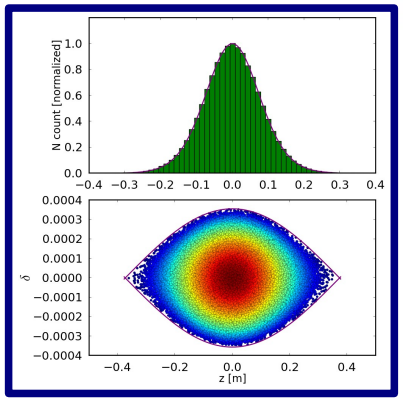
RF parameters

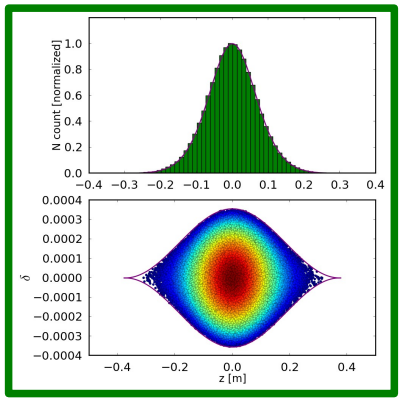
- HL-LHC parameters used for the simulations
- Free parameters:
  - Intensity
  - Chromaticity
  - Relative phase between RF harmonics
  - Damper gain

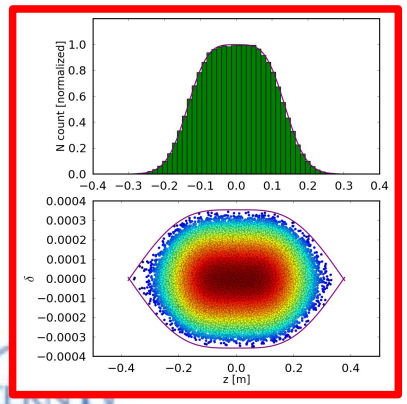
	Single RF	BSM	BLM
V_{400}	16 MV	16 MV	16 MV
V_{800}	0 MV	8 MV	-8 MV
ε_z	2.5 eV s	2.5 eV s	2.5 eV s
Δ_t	1.005 ns	0.926 ns	1.217 ns
ΔE	0.22e-3	0.256e-3	0.172e-3

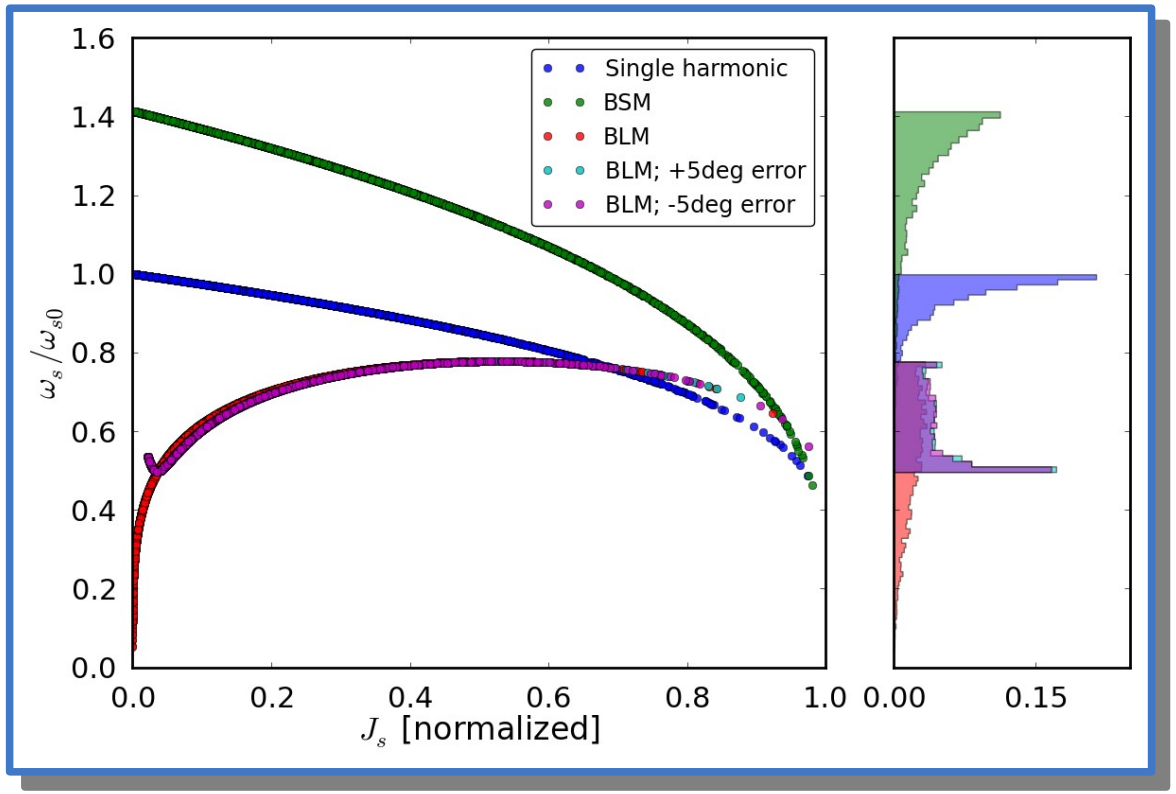
Distributions

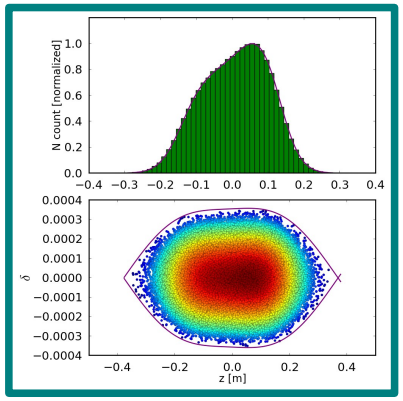
Synchrotron tune spectra

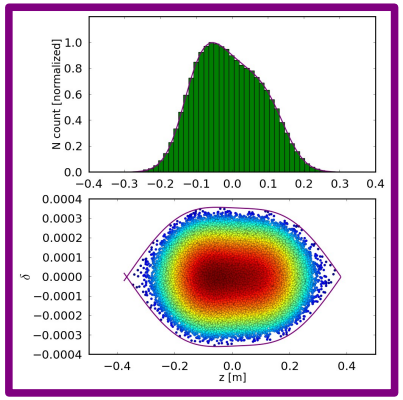




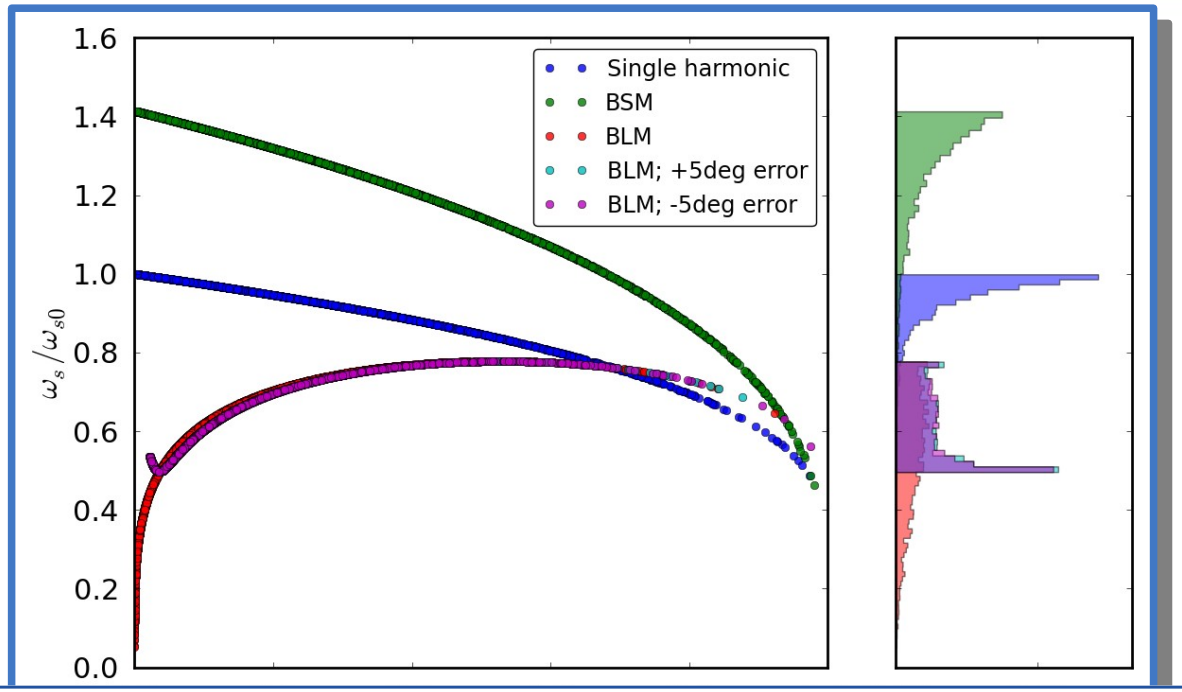








Synchrotron tune spectra

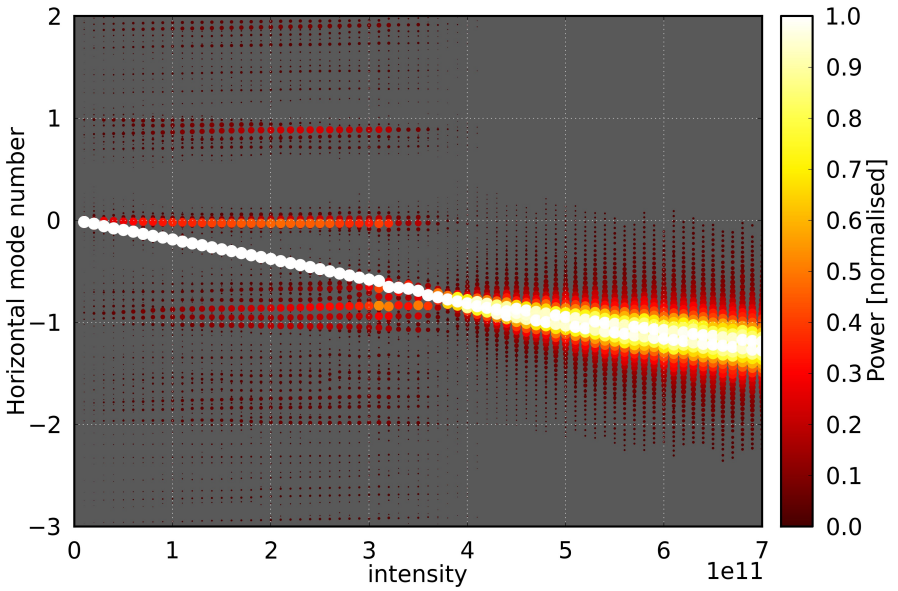


	Main Q_s	Mean Q_s	Std Q_s	Max Q_s
Single RF	2.03e-3	1.93e-3	1.20e-4	2.04e-3
BSM	2.88e-3	2.61e-3	2.85e-4	2.89e-3
BLM	1.26e-3	1.11e-3	3.13e-4	1.59e-3
BLM +5 deg	1.03e-3	1.25e-3	1.80e-4	1.59e-3
BLM -5 deg	1.03e-3	1.25e-3	1.78e-4	1.59e-3

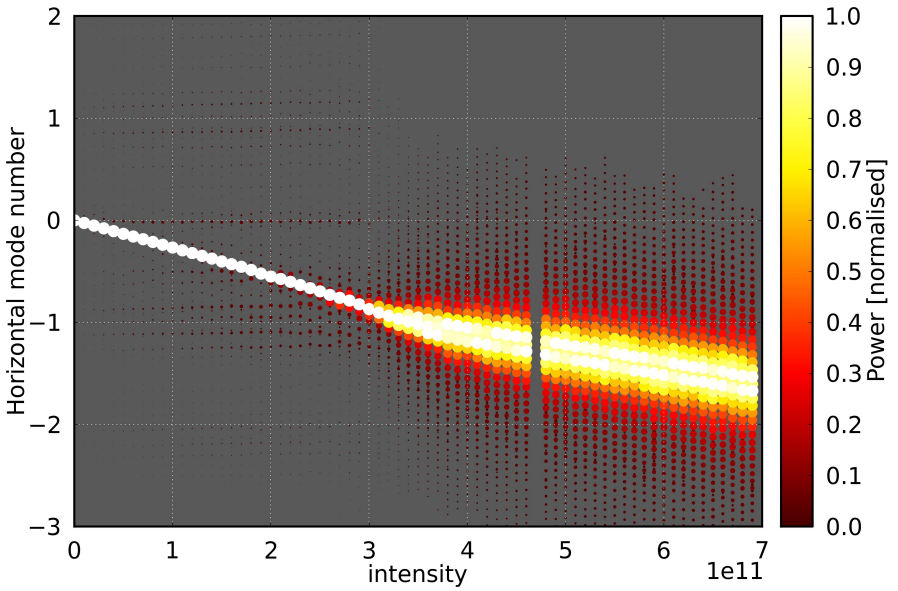
Thresholds without damper

TMCI thresholds

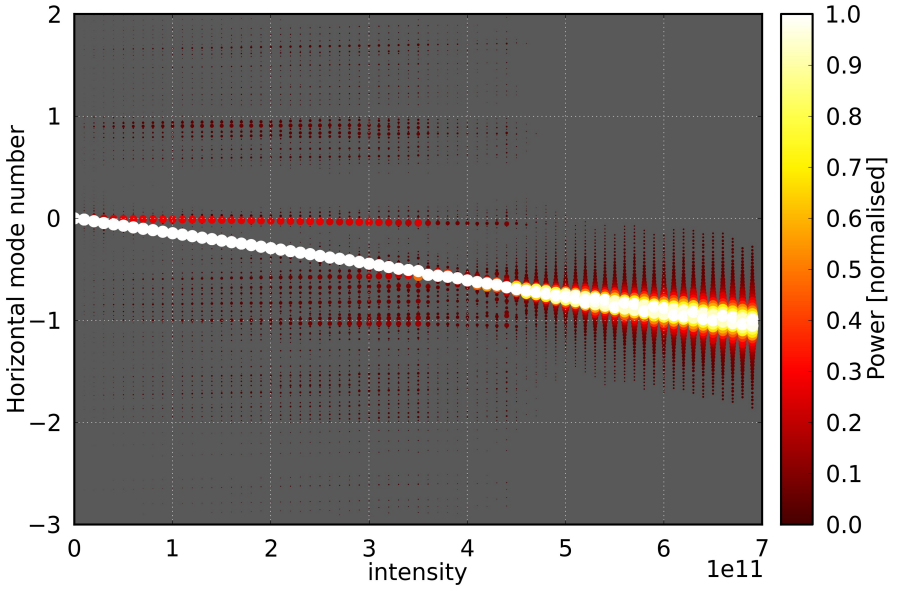
Single RF



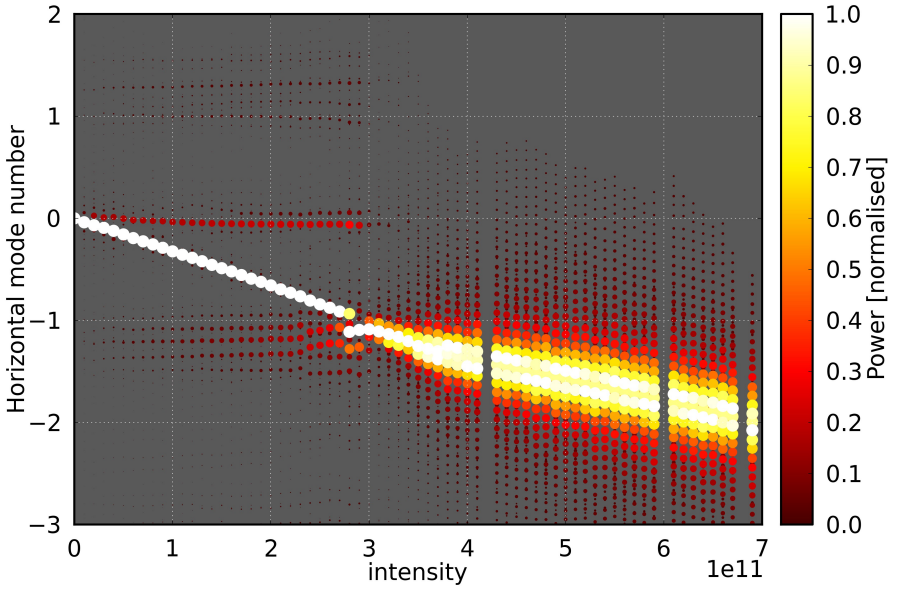
Lengthening



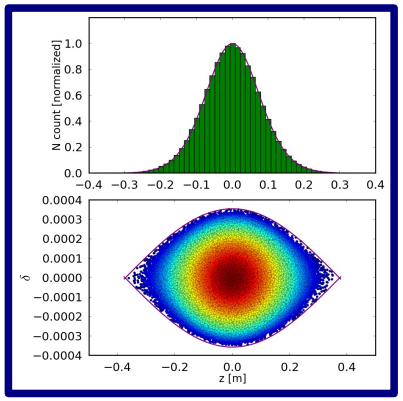
Shortening

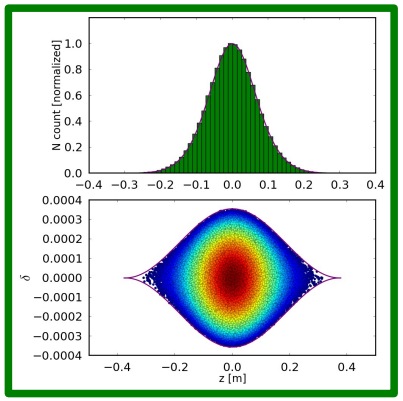


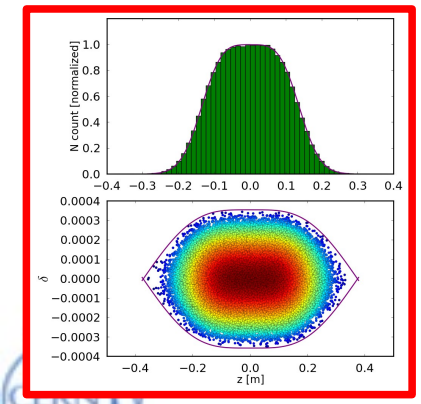
Lengthening; +5 degrees

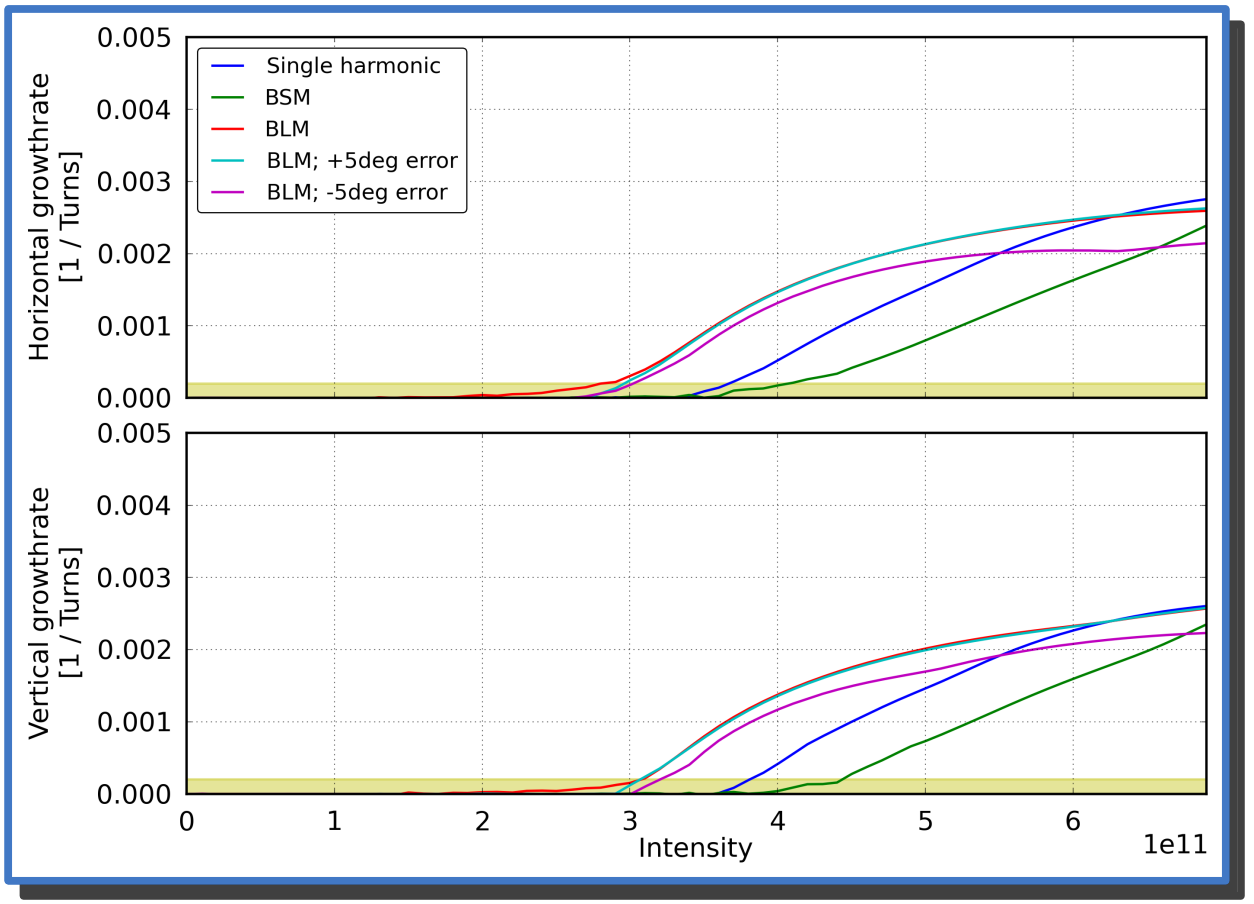


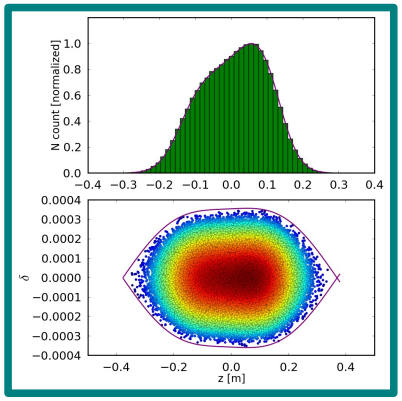
TMCI and growth rates

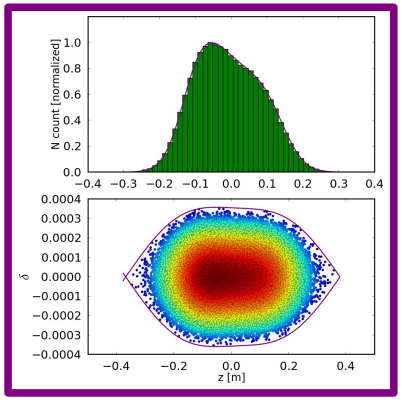




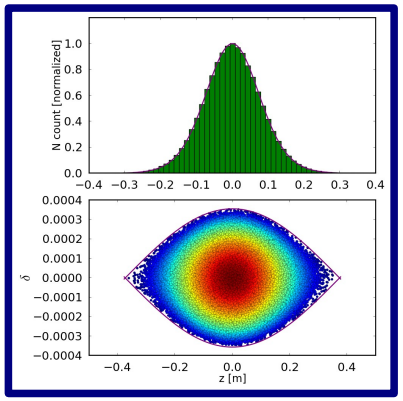


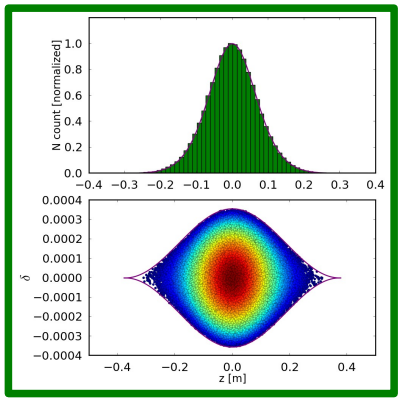


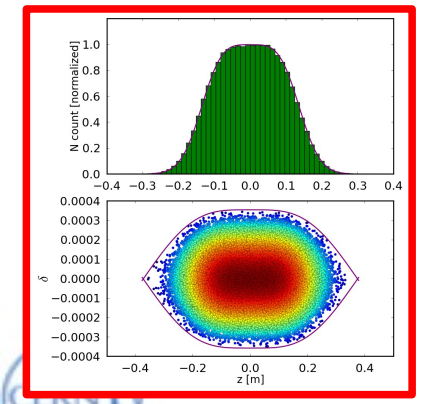


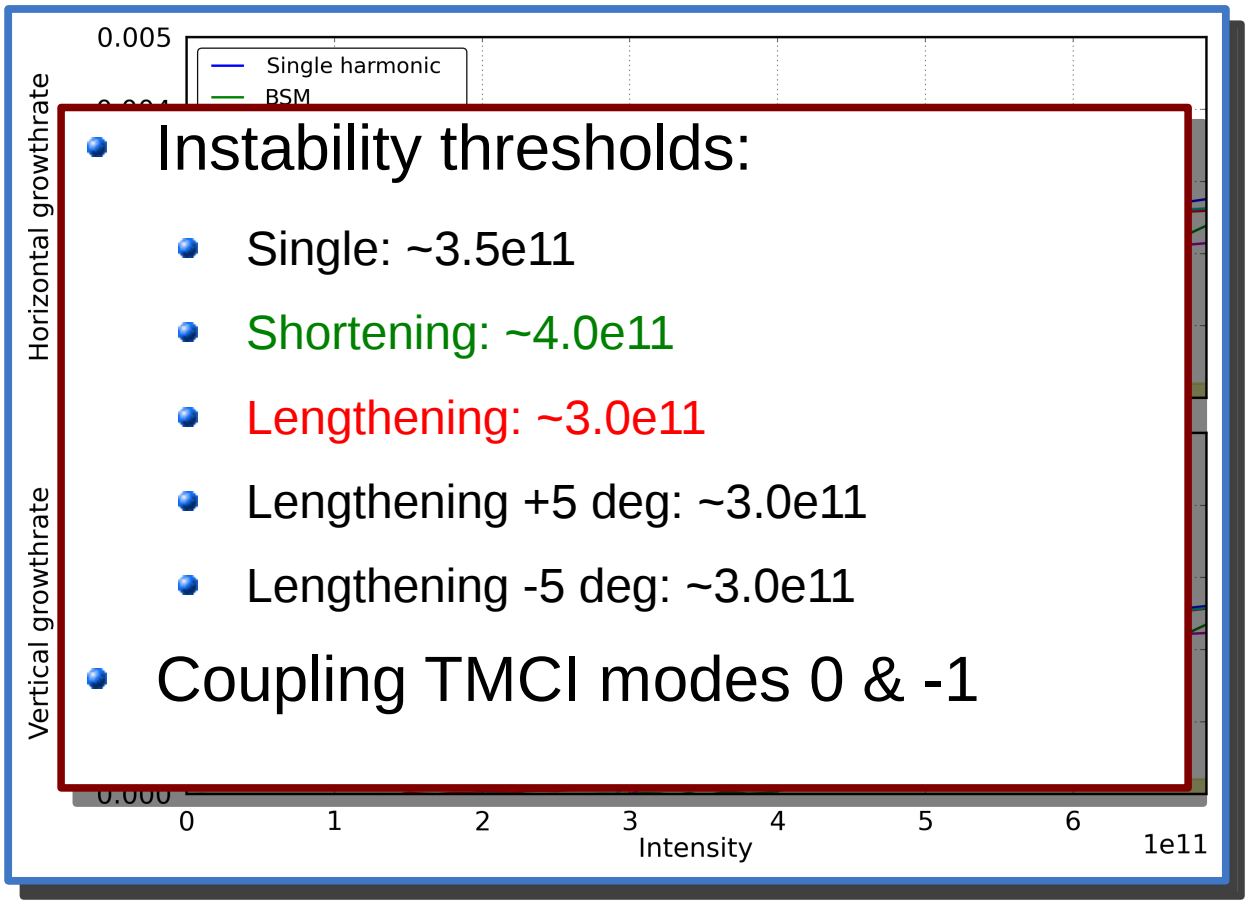


TMCI and growth rates

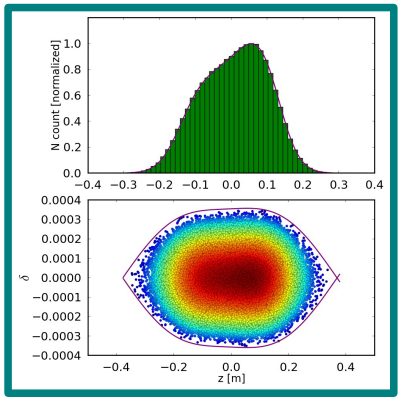


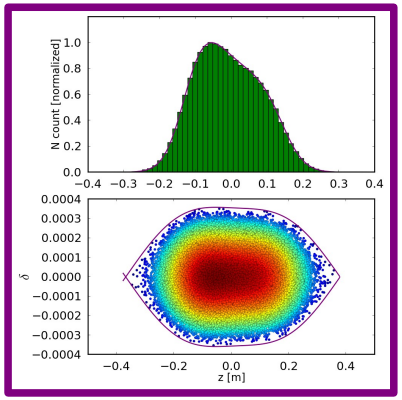






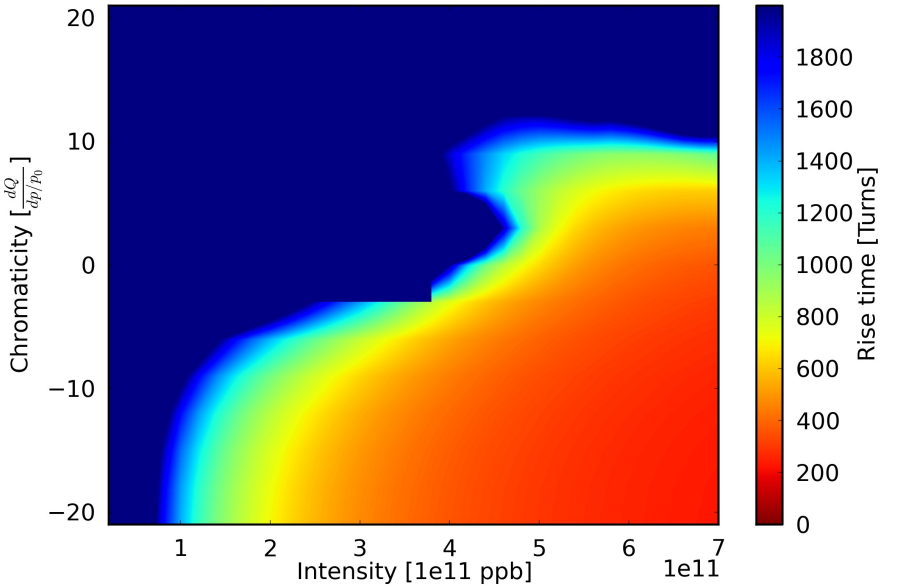
- Instability thresholds:
  - Single: ~3.5e11
  - Shortening: ~4.0e11
  - Lengthening: ~3.0e11
  - Lengthening +5 deg: ~3.0e11
  - Lengthening -5 deg: ~3.0e11
- Coupling TMCI modes 0 & -1



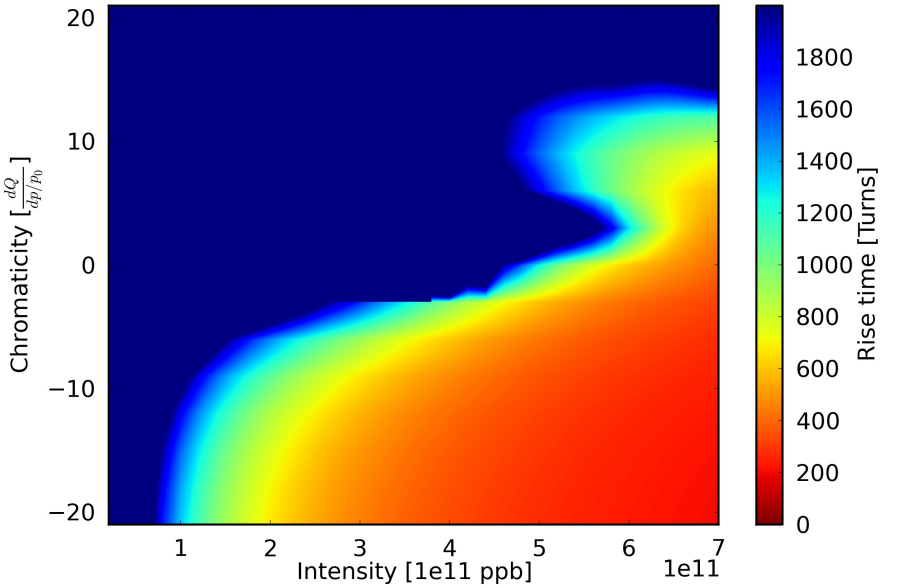


The impact of chromaticity

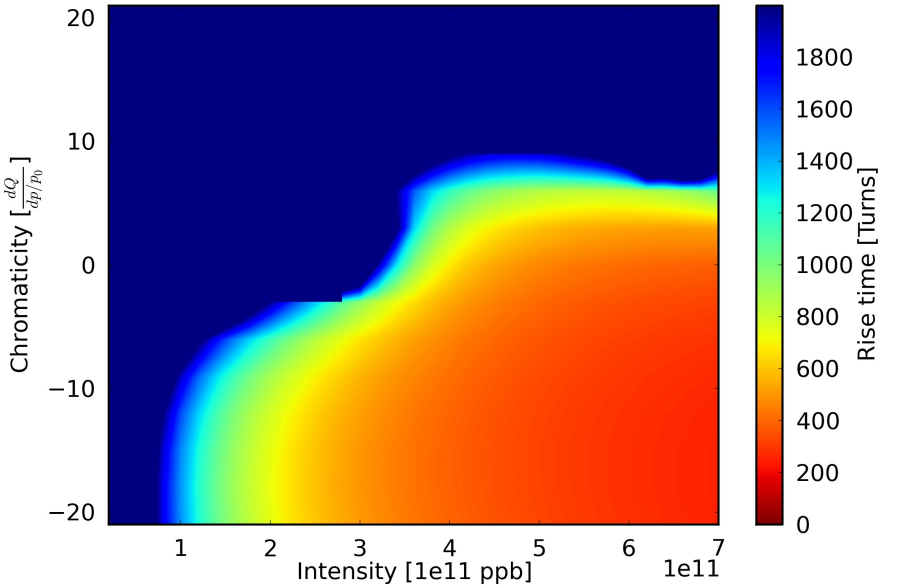
Single RF



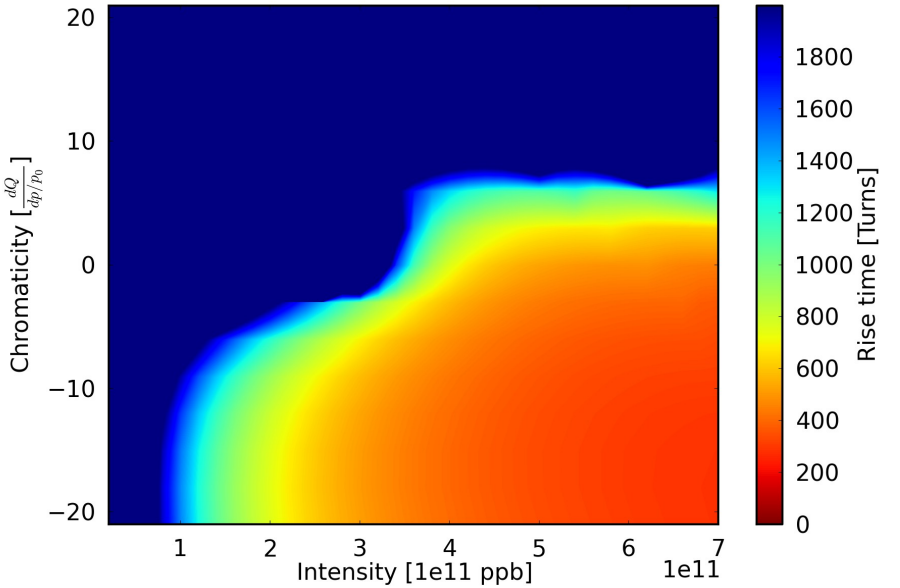
Shortening



Lengthening



Lengthening; +5 degrees



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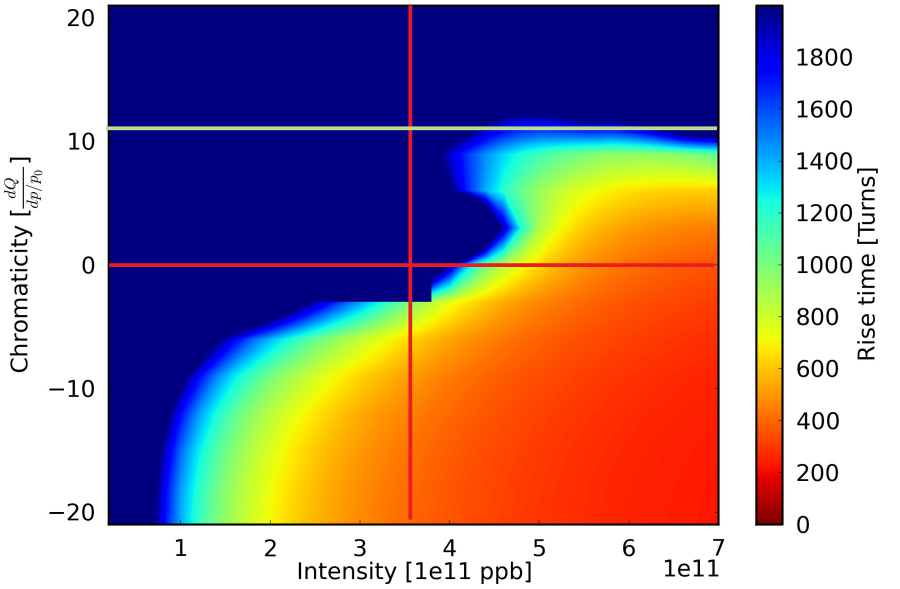
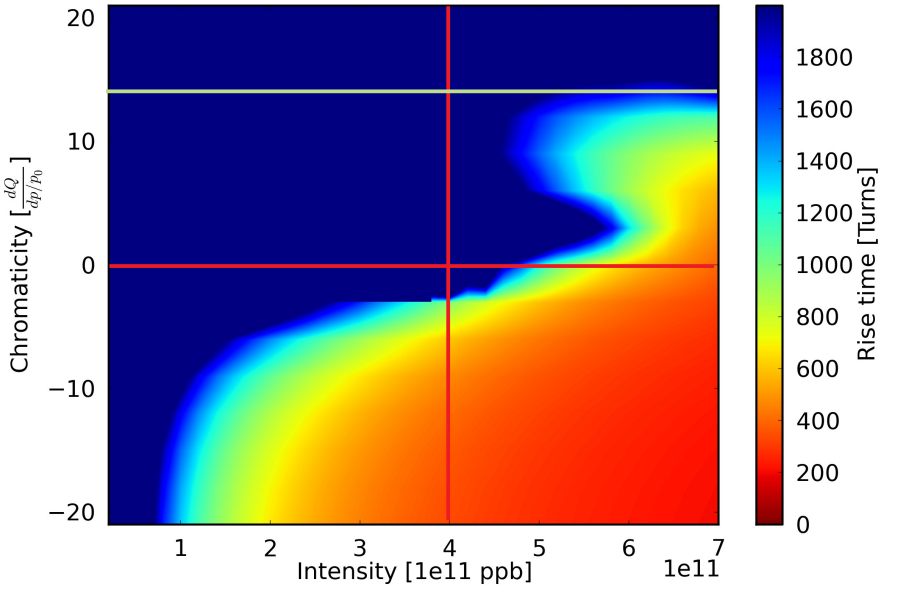
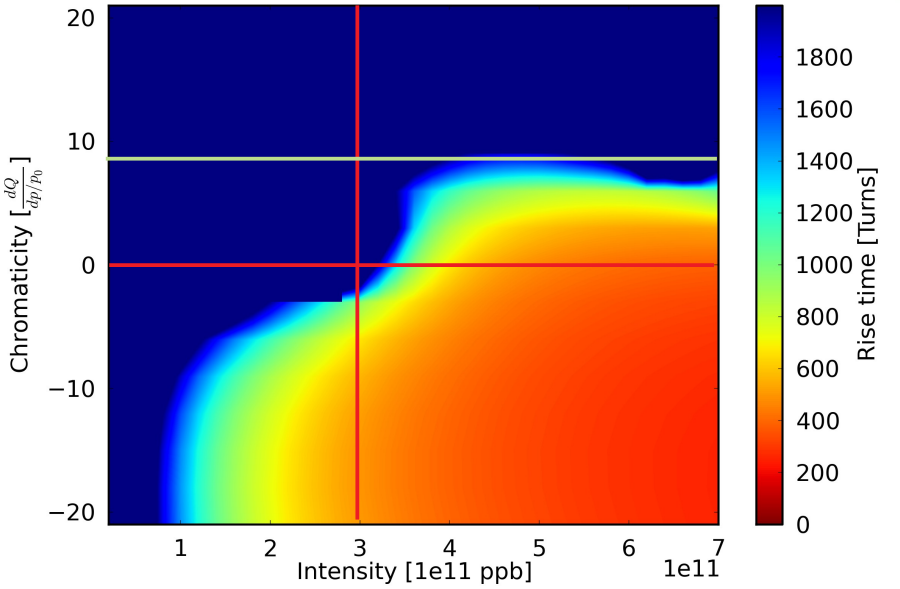
Single RF



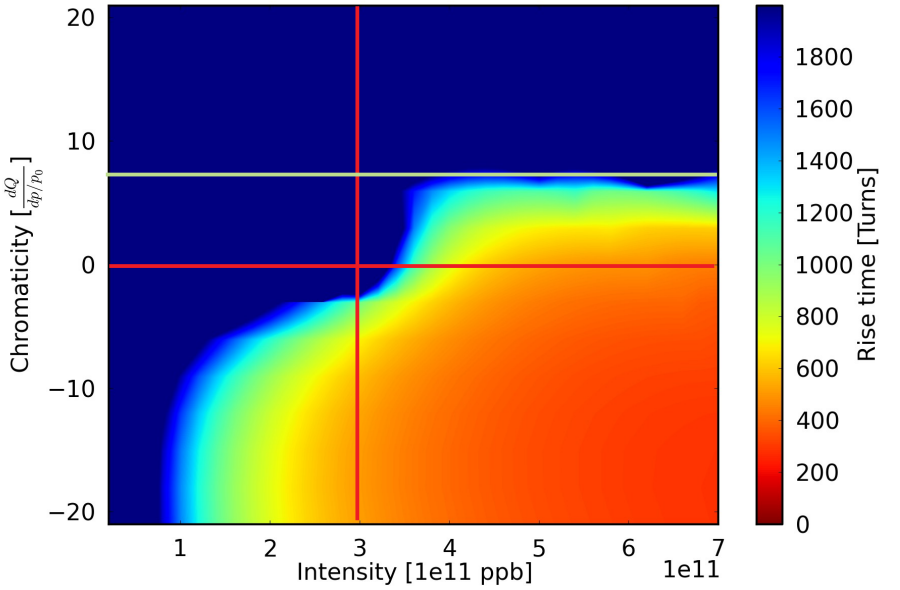
Shortening



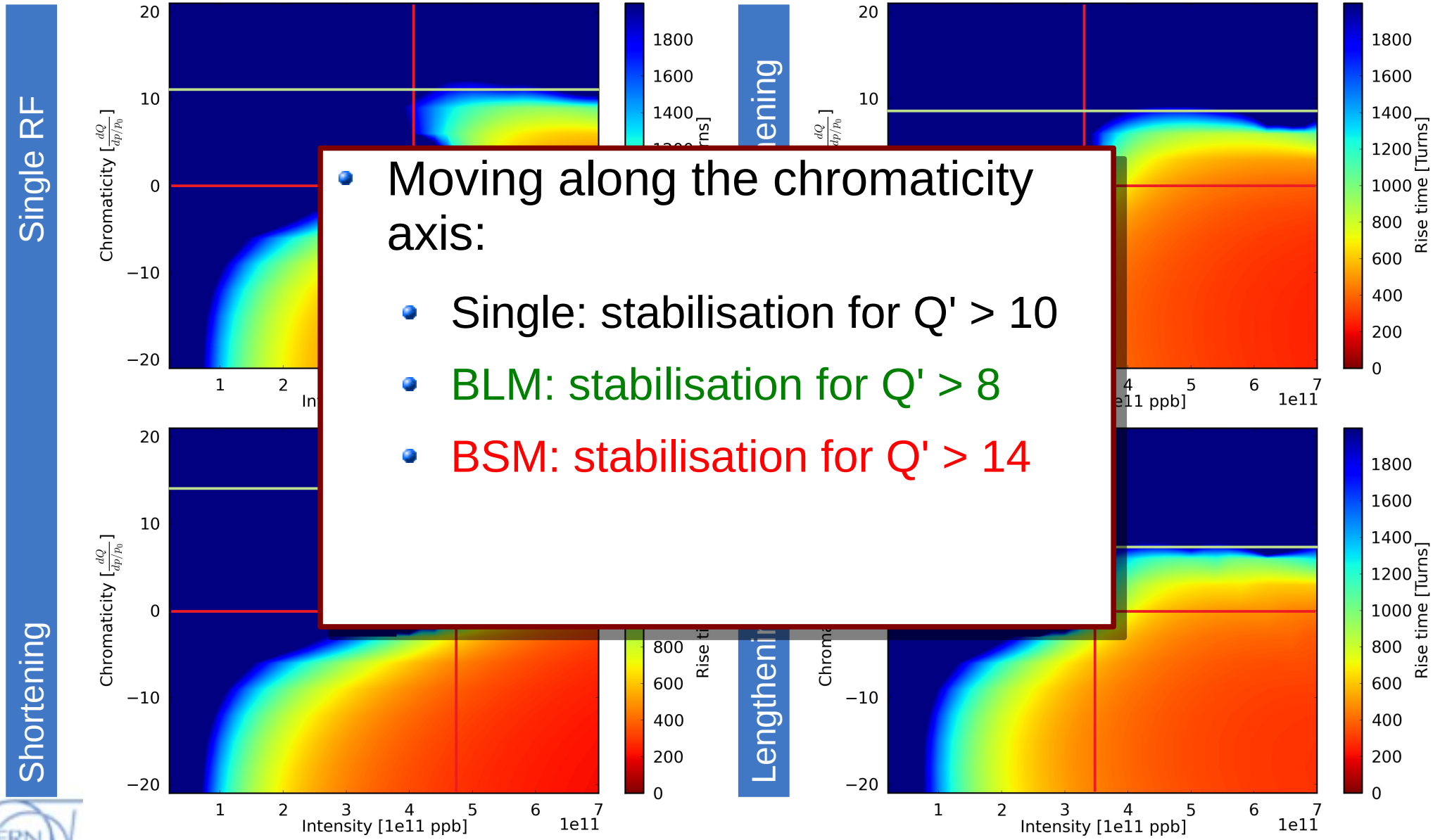
Lengthening



Lengthening; +5 degrees



The impact of chromaticity

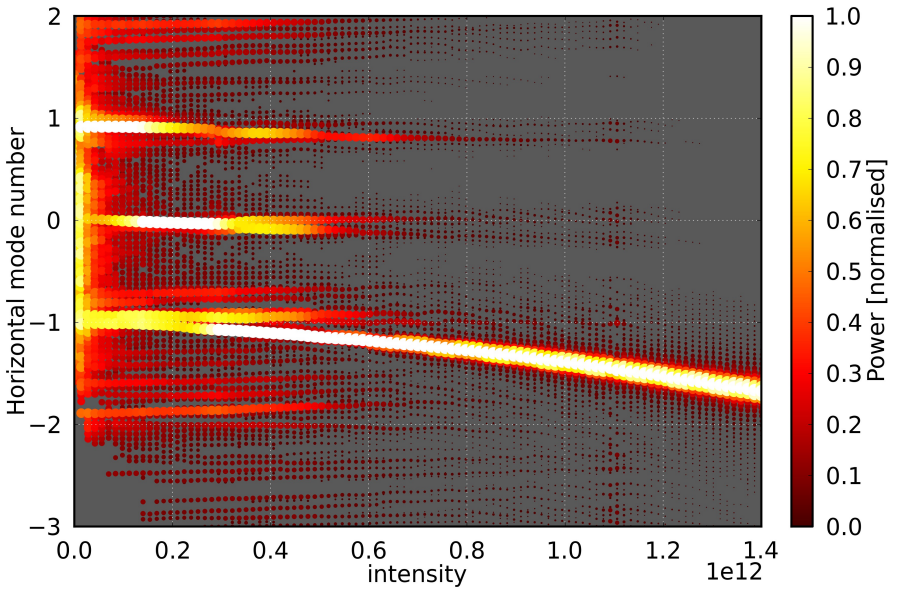


- Moving along the chromaticity axis:
  - Single: stabilisation for Q' > 10
  - BLM: stabilisation for Q' > 8
  - BSM: stabilisation for Q' > 14

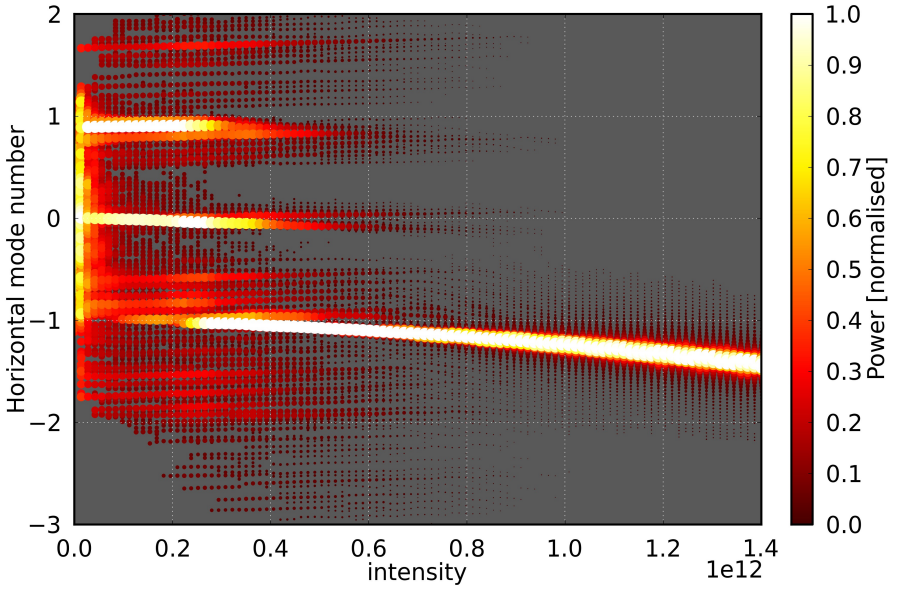
Thresholds with damper @ damping rate: 50 turns

TMCI thresholds

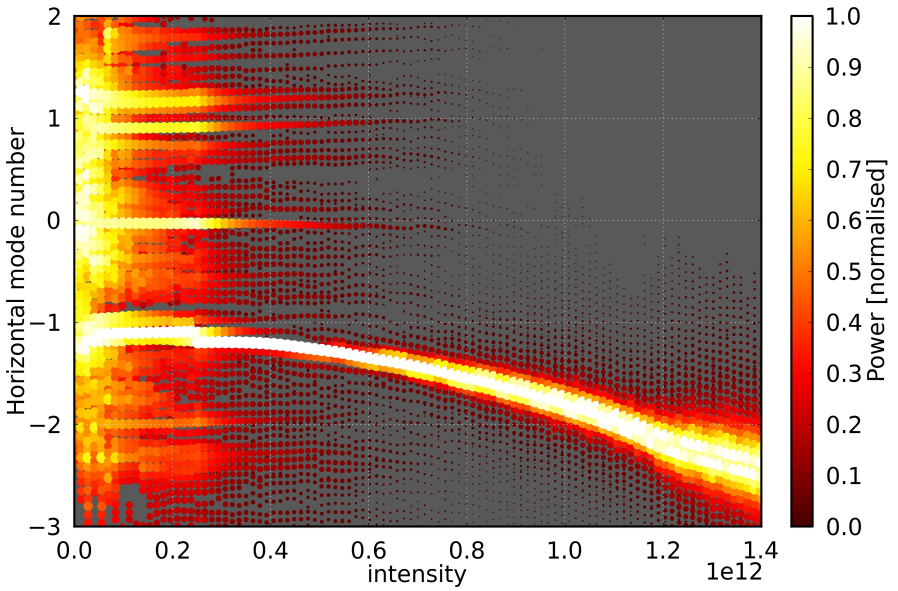
Single RF



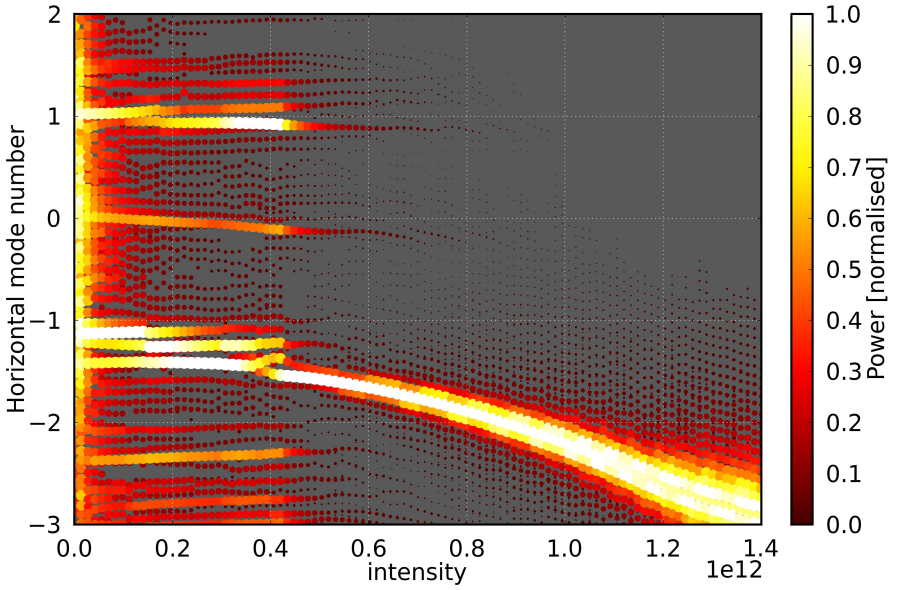
Shortening



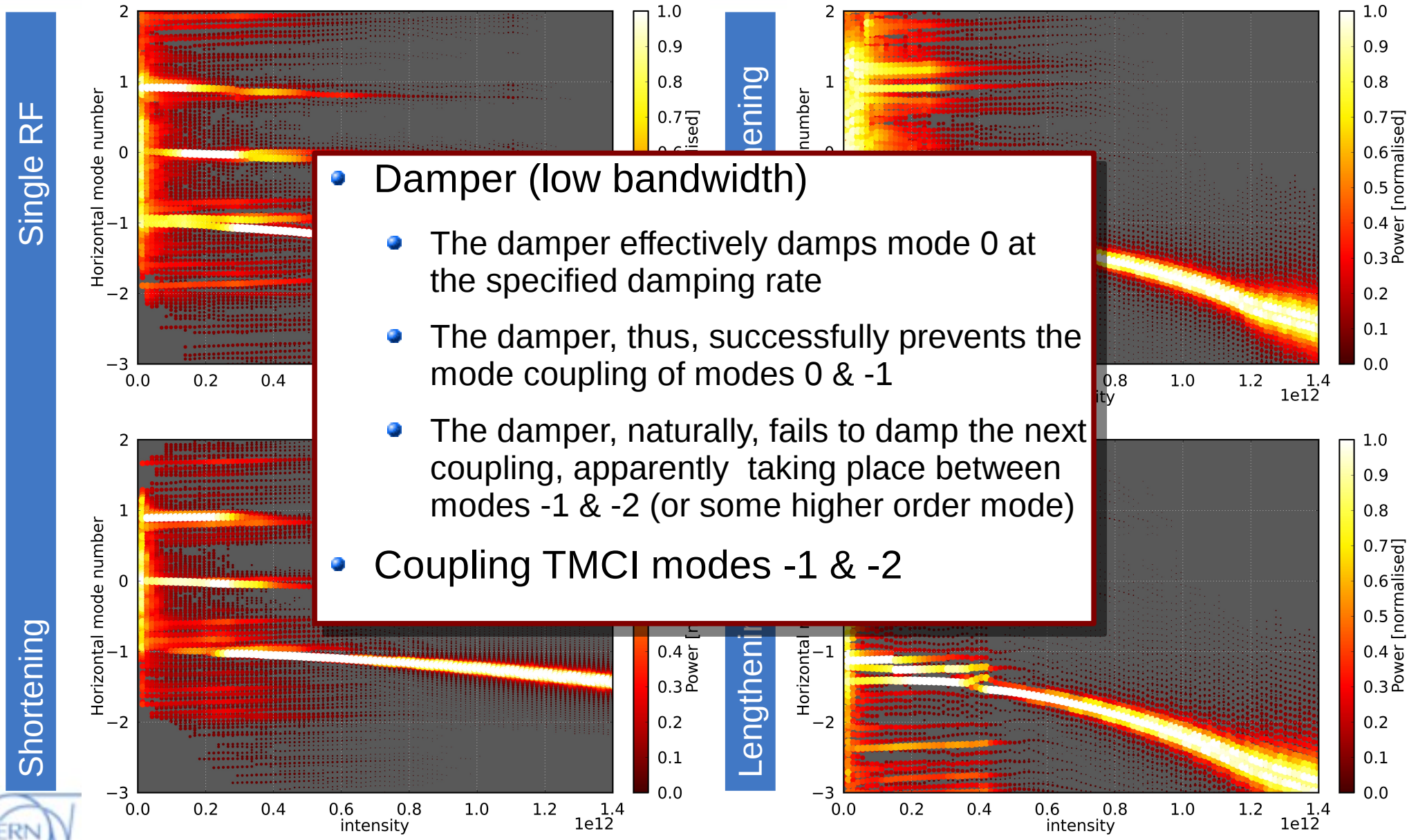
Lengthening



Lengthening; -5 degrees

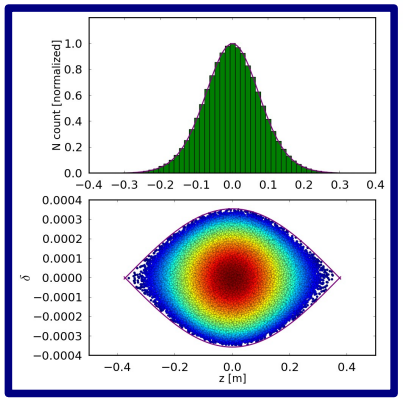


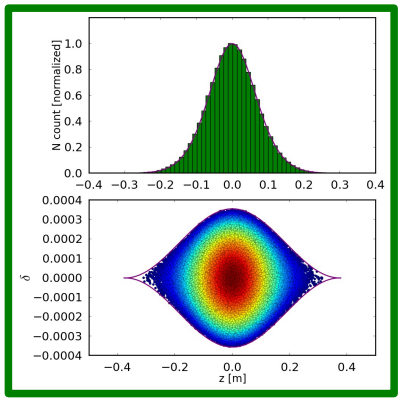
TMCI thresholds

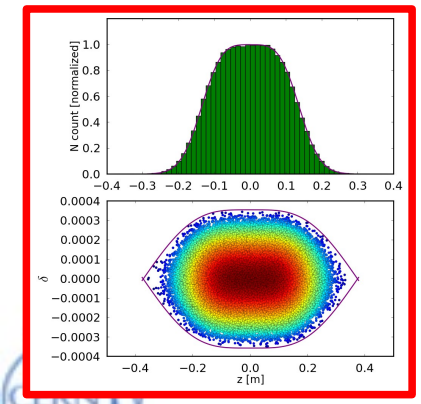


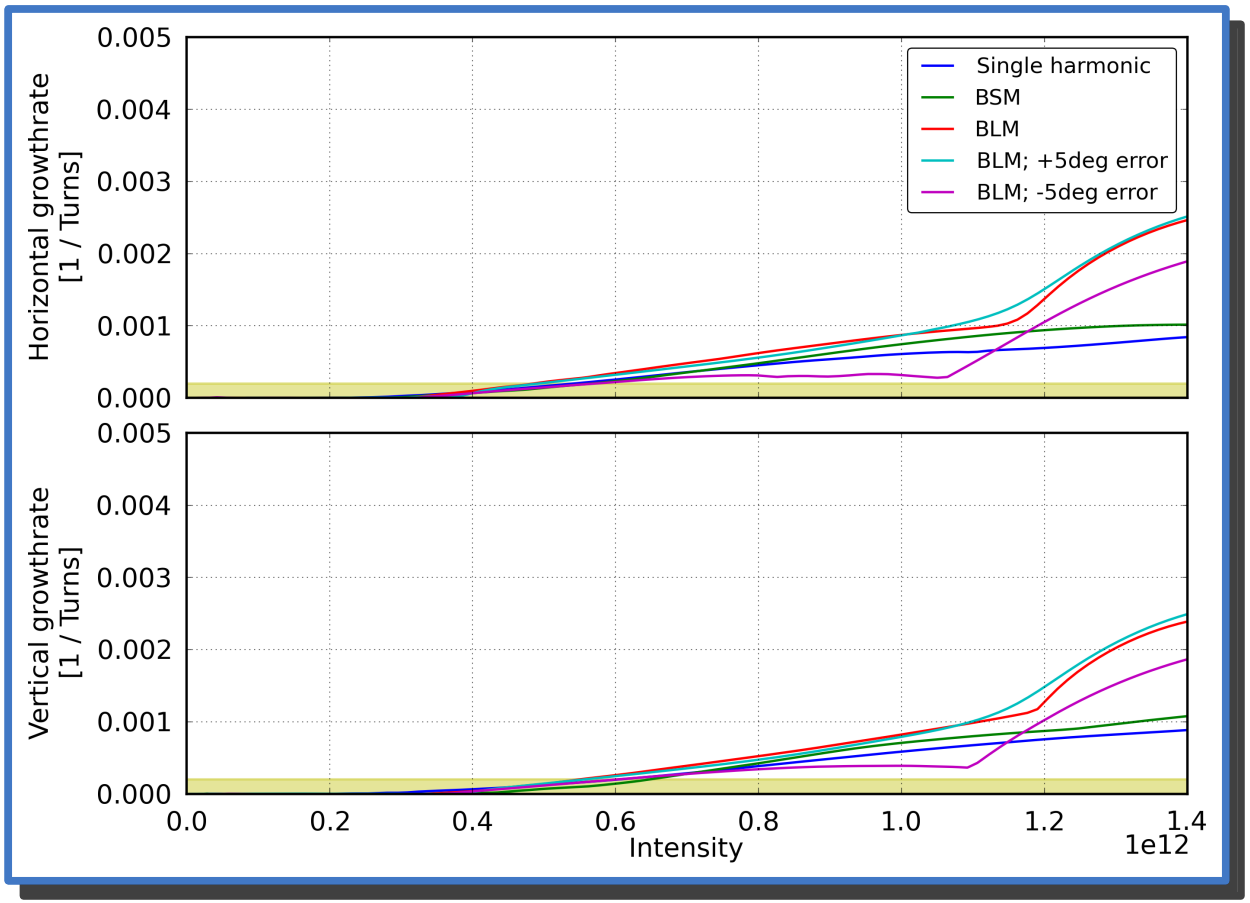
- Damper (low bandwidth)
  - The damper effectively damps mode 0 at the specified damping rate
  - The damper, thus, successfully prevents the mode coupling of modes 0 & -1
  - The damper, naturally, fails to damp the next coupling, apparently taking place between modes -1 & -2 (or some higher order mode)
- Coupling TMCI modes -1 & -2

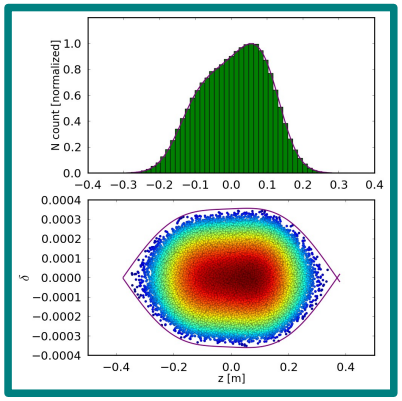
TMCI and growth rates

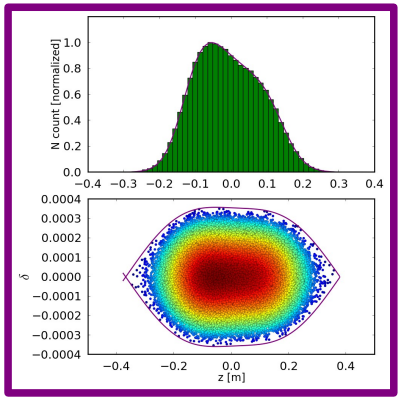




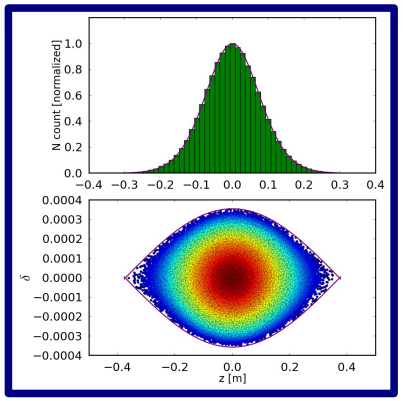


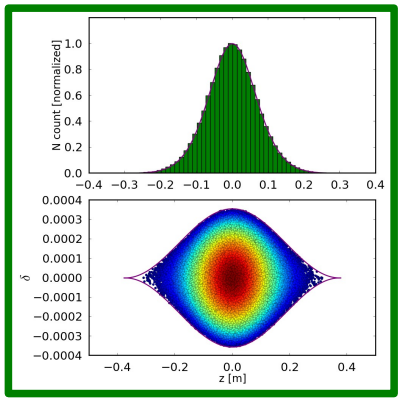


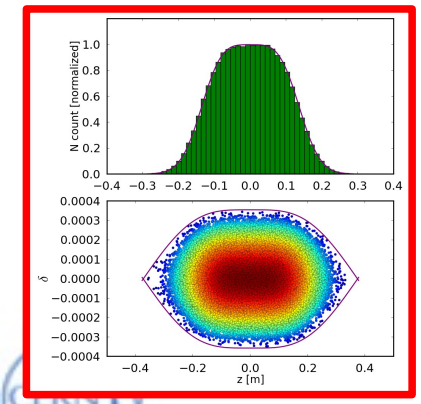


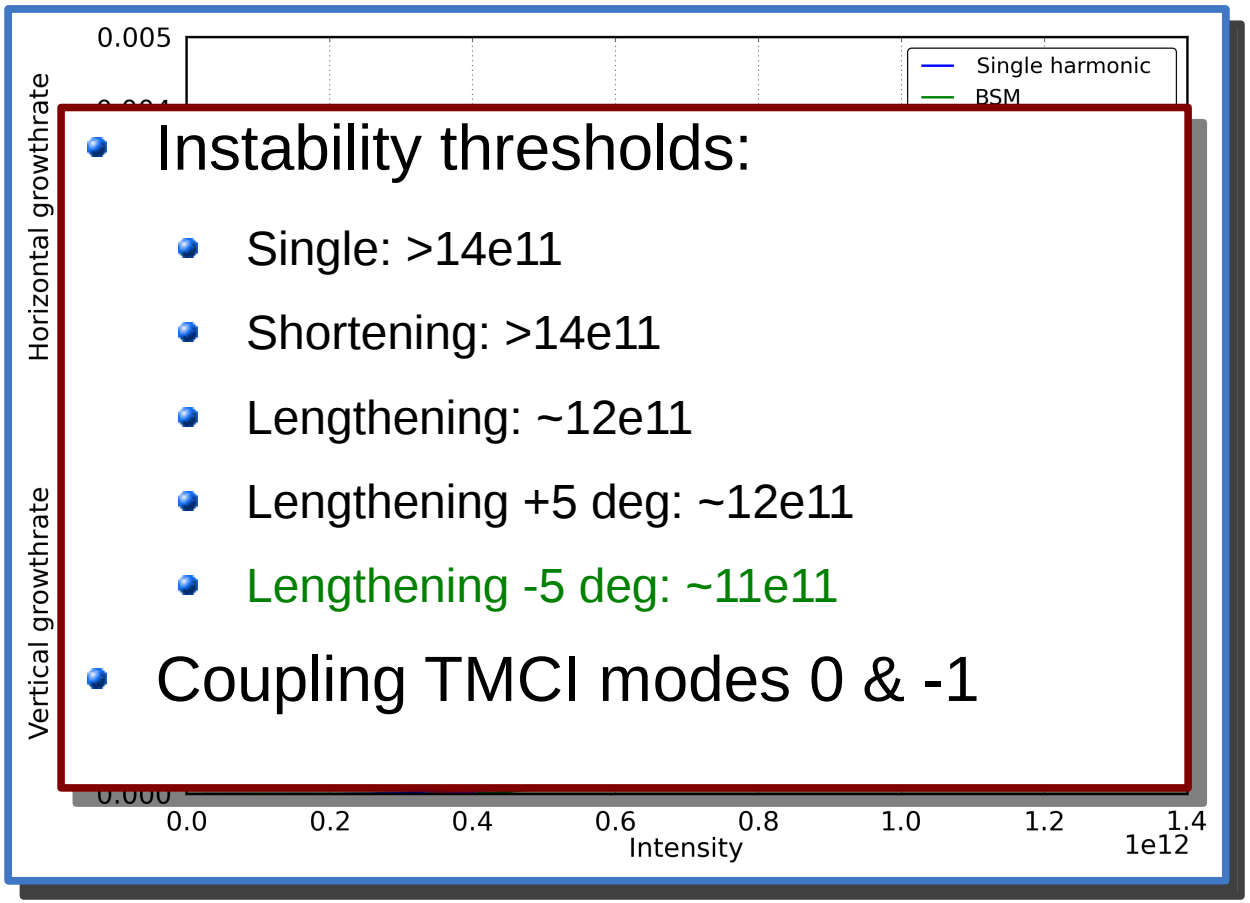


TMCI and growth rates

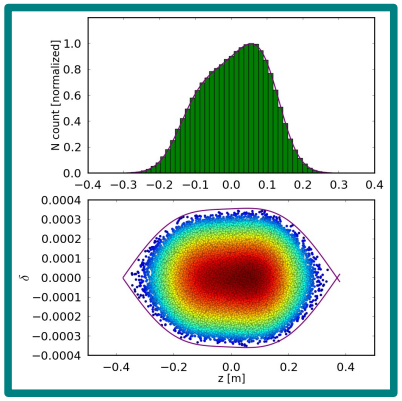


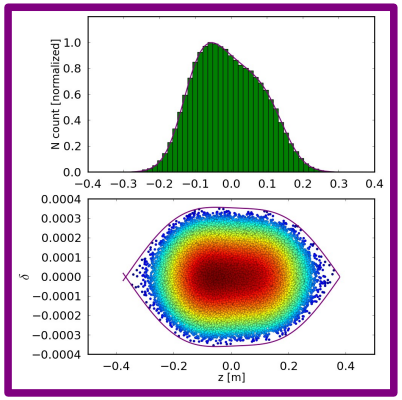






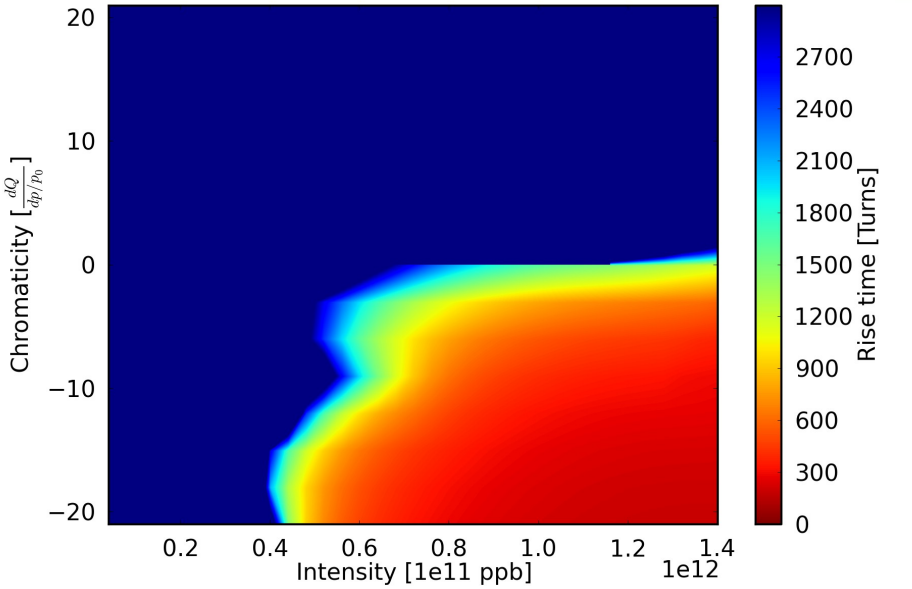
- Instability thresholds:
  - Single: >14e11
  - Shortening: >14e11
  - Lengthening: ~12e11
  - Lengthening +5 deg: ~12e11
  - Lengthening -5 deg: ~11e11
- Coupling TMCI modes 0 & -1



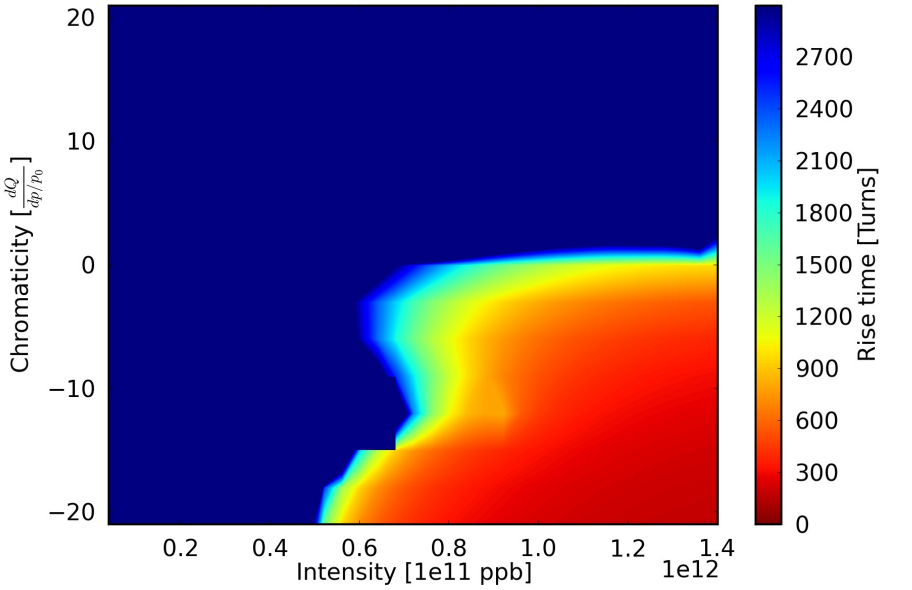


The impact of chromaticity

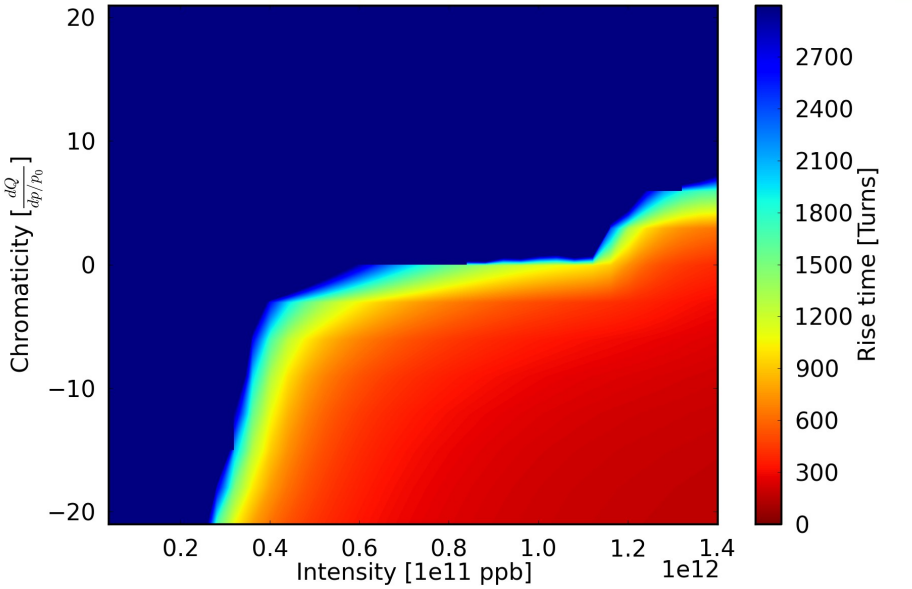
Single RF



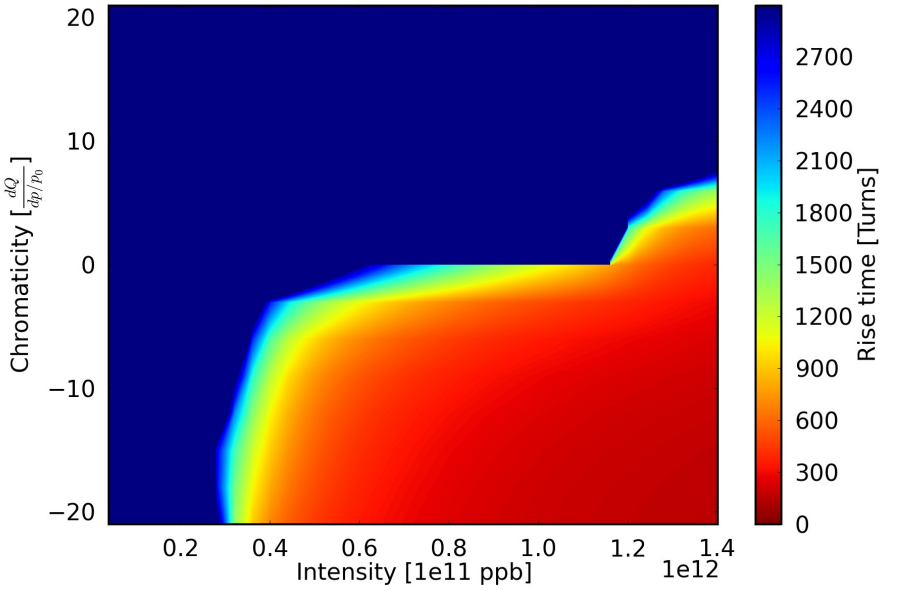
Shortening



Lengthening

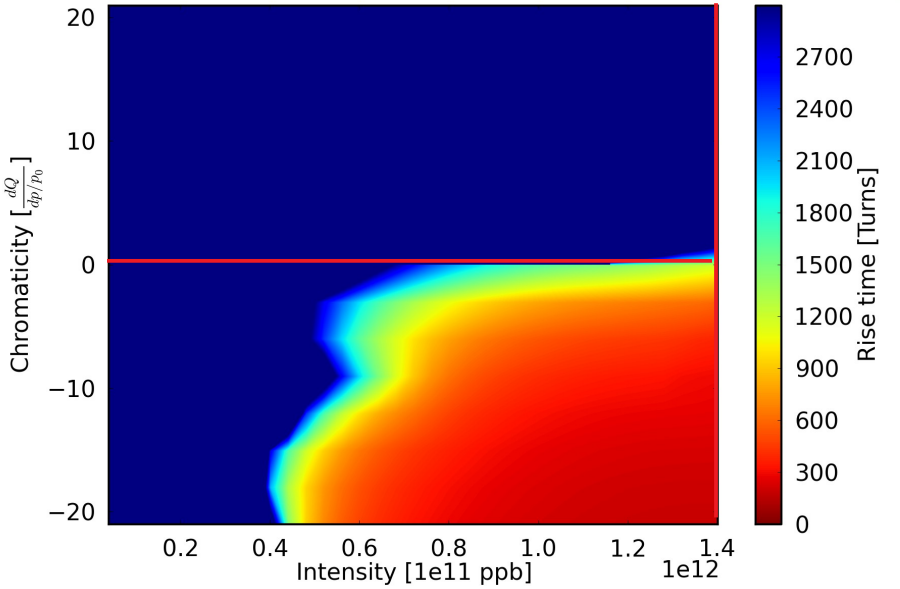


Lengthening; -5 degrees

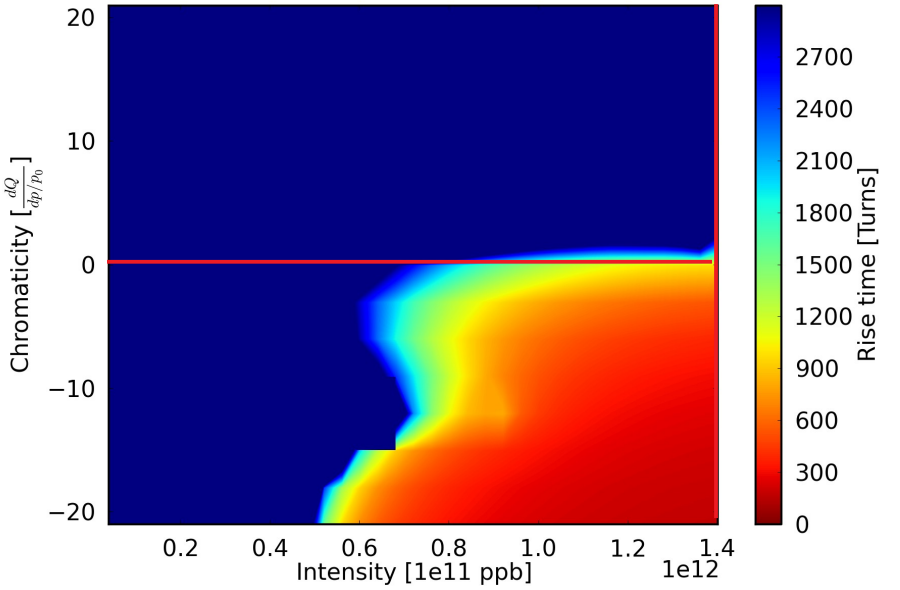


The impact of chromaticity

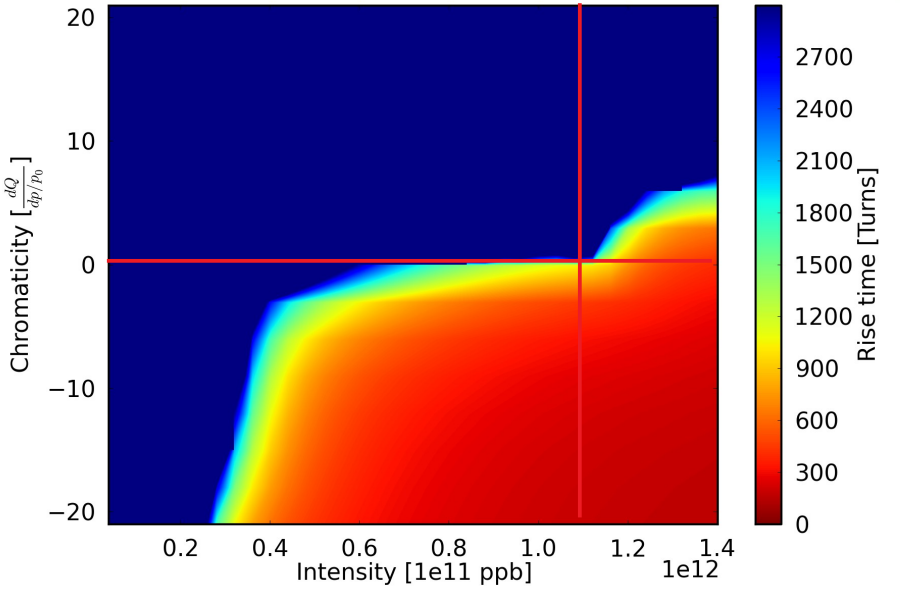
Single RF



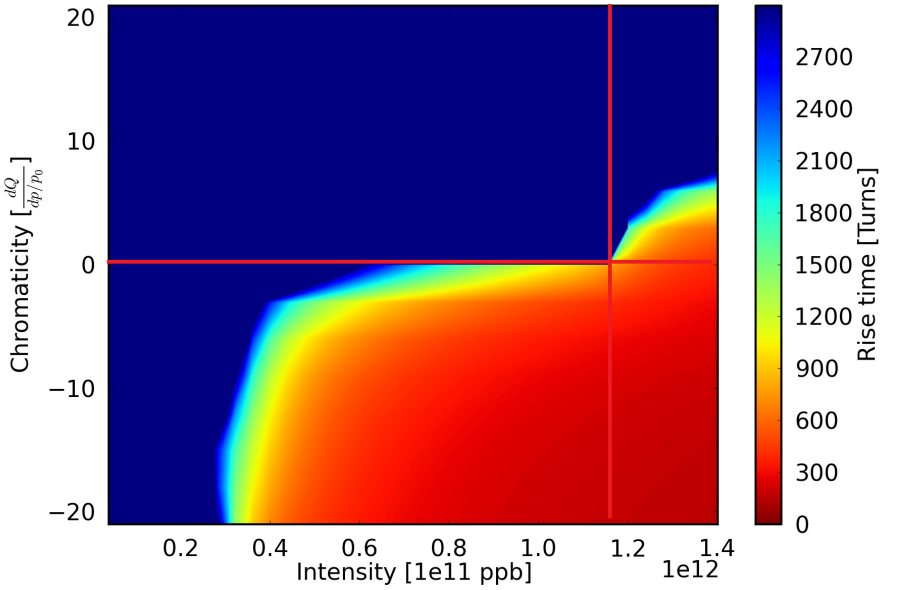
Shortening



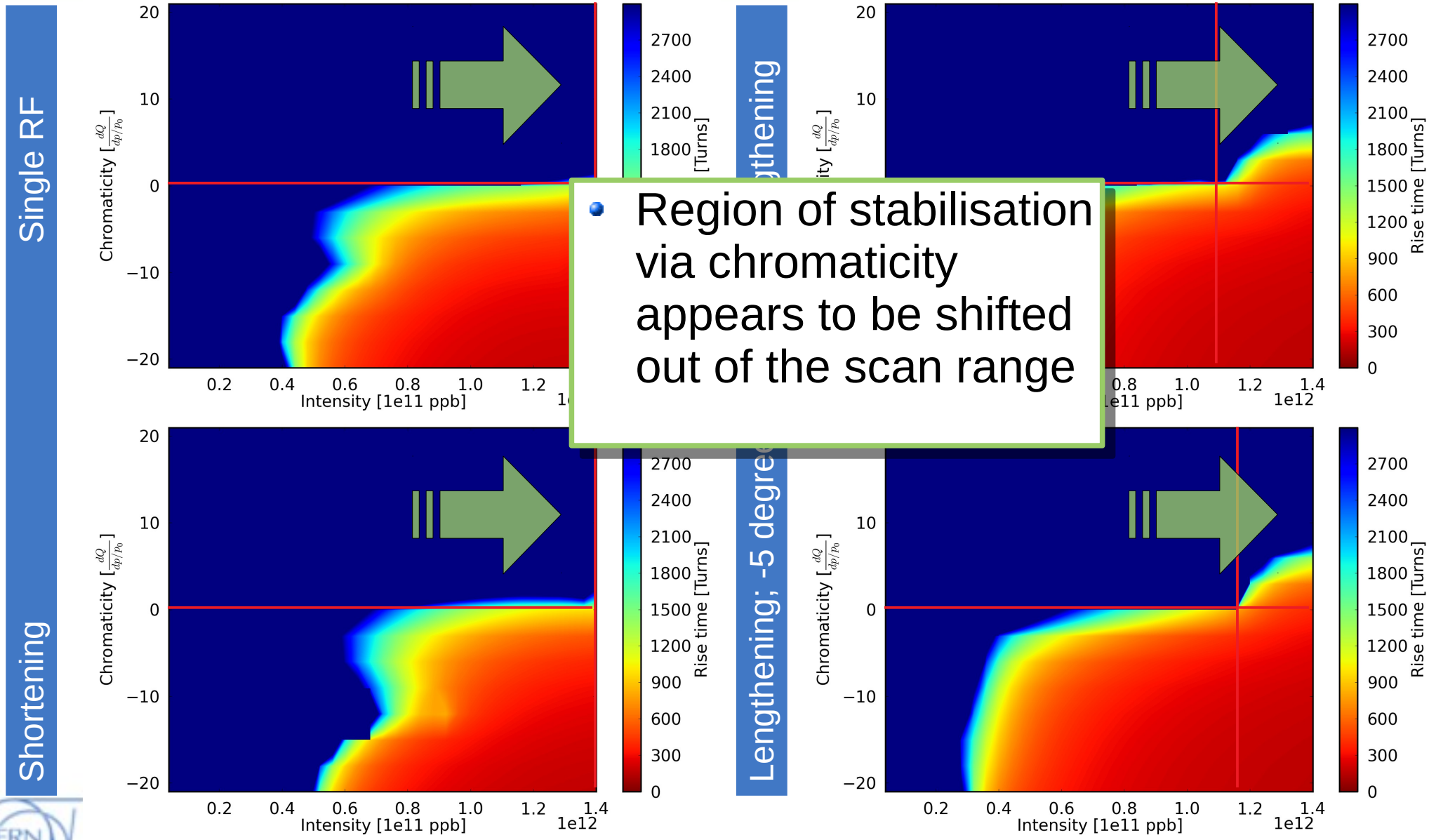
Lengthening



Lengthening; -5 degrees



The impact of chromaticity



- Region of stabilisation via chromaticity appears to be shifted out of the scan range

Conclusions & outlook

- Transverse instability thresholds were investigated using the HL-LHC impedance model at top energy
- The impact of a double harmonic RF system on these instability thresholds was studied

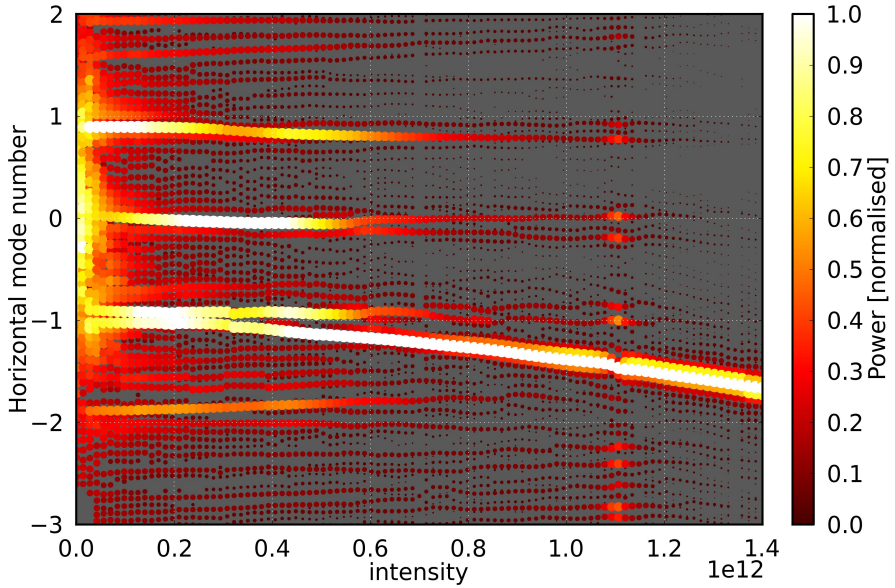
	Instability threshold	Stabilizing chromaticity
Singe RF	3.5e11	10
BSM	4.0e11	14
BLM	3.0e11	8
BLM +5 deg	3.0e11	8
BLM -5 deg	3.0e11	8

- With the addition of an ideal transverse damper the thresholds could be raised significantly
- Some peculiarities of the transverse damper would need more study (slow rise of mode -1?)

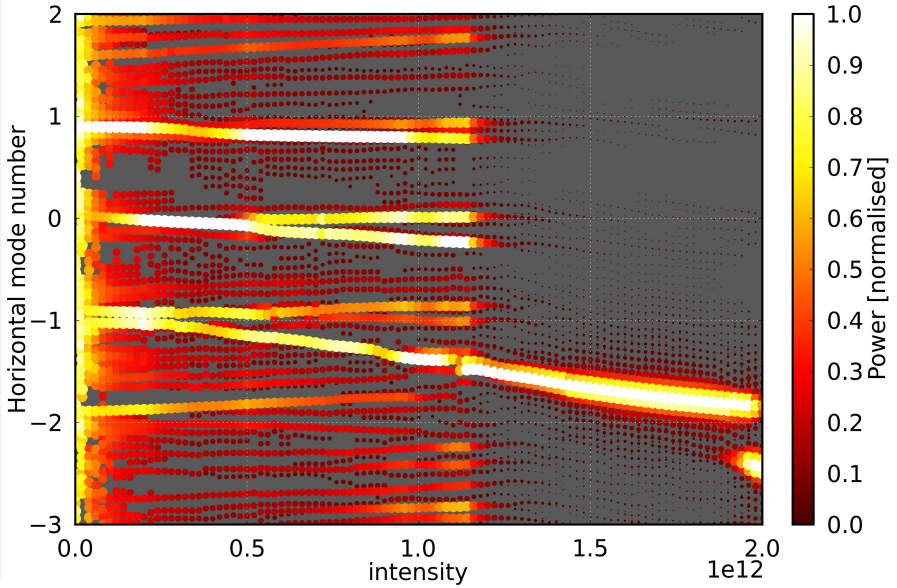
Thresholds with damper @ damping rate: 10 turns

TMCI thresholds

Single RF damper @ 50 turns



Single RF damper @ 10 turns



TMCI thresholds

Single RF damper @ 50 turns