LHC single-bunch instabilities observed in 2012: simulations vs. measurements

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Thanks to Nicolas Mounet

ICE Meeting
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Overview

- Motivation
- 1st instability analysis in Fill#2447
- HEADTAIL convergence study
- Comparison between HEADTAIL simulations and observed instability in B1H_bunch1
- Conclusions

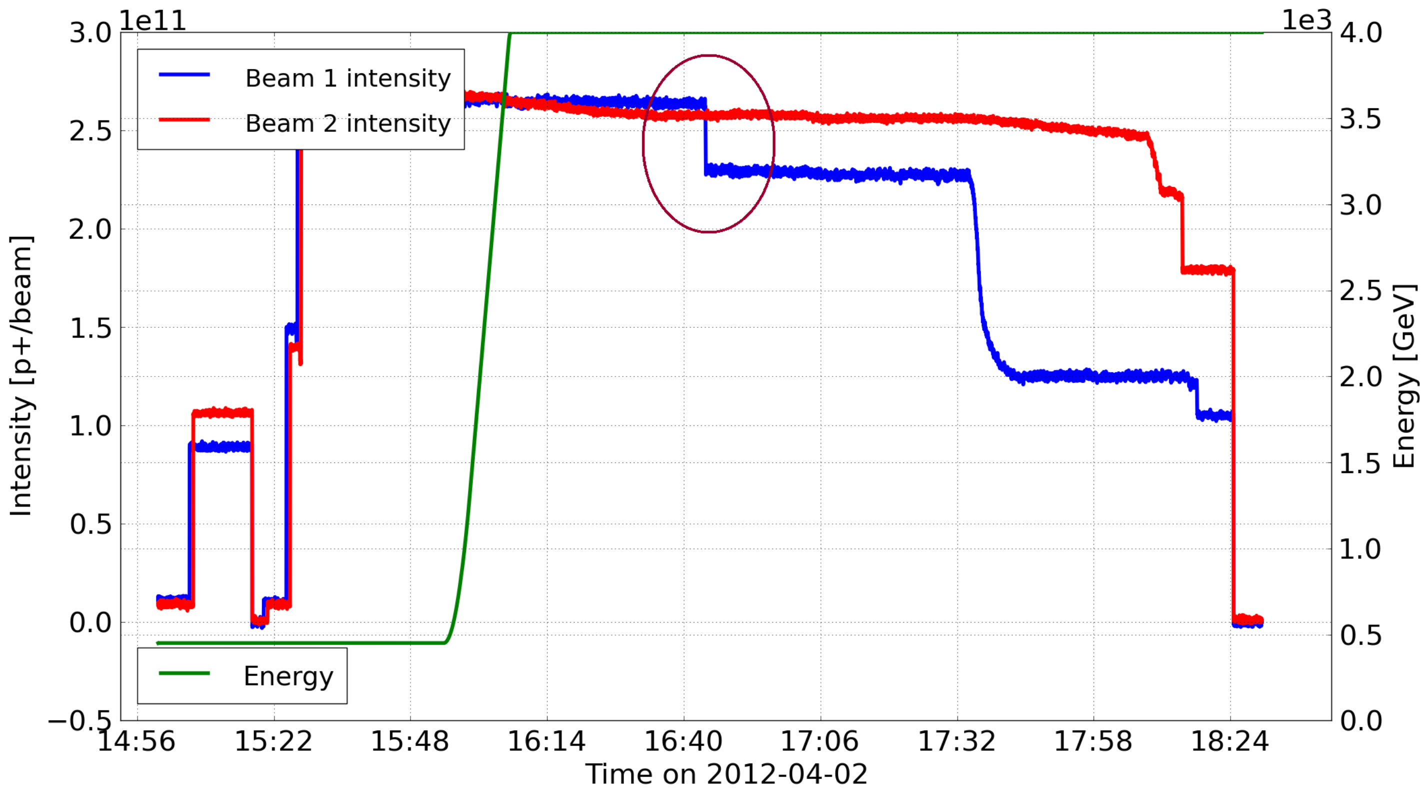
Motivation

Transverse collective instabilities are one of the most important limitations to achieve the highest luminosities in the LHC and have been regularly observed during the LHC Run I.

For instance, in 2012 there were observed some single-bunch instabilities during normal operation, which can be studied with HEADTAIL simulations.

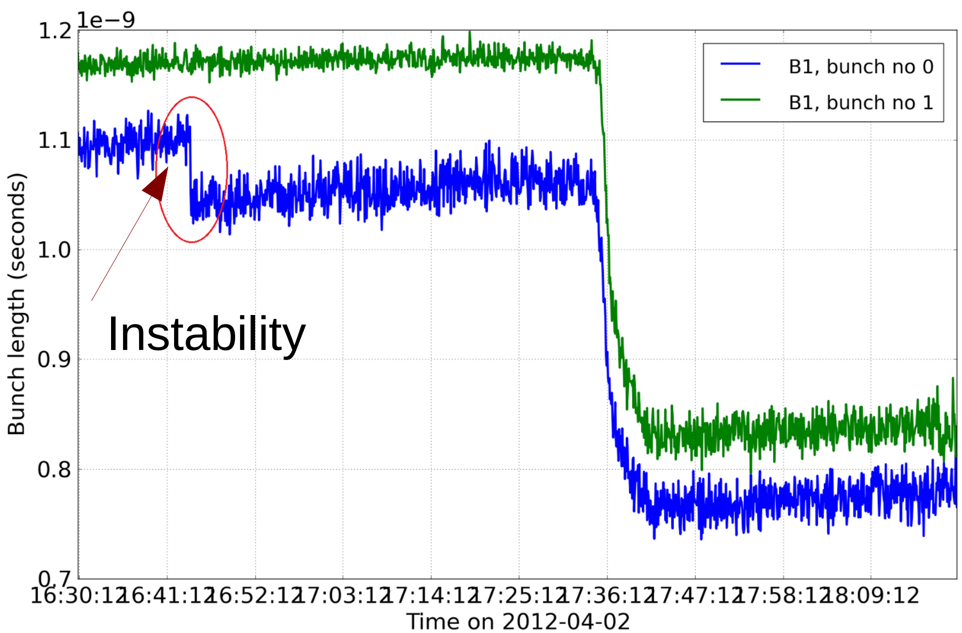
1^{st} instability analysis in Fill#2447

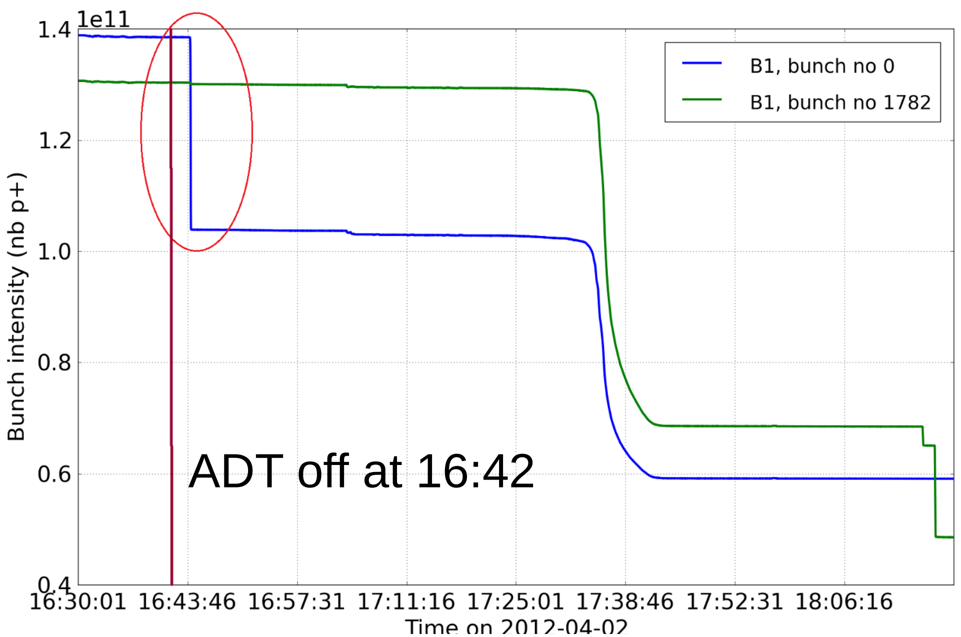
- On the 02/04/2012 were observed some instabilities during the collimator's "loss maps"
- Nominal bunches
- ADT was switched off
- After the end of the squeeze
- Focusing octupole current I_{oct}= -400 A



Data analysis. Beam 1

The 1st instability in the beam 1 was ~ at 16:43 in the bunch 1, in the horizontal plane

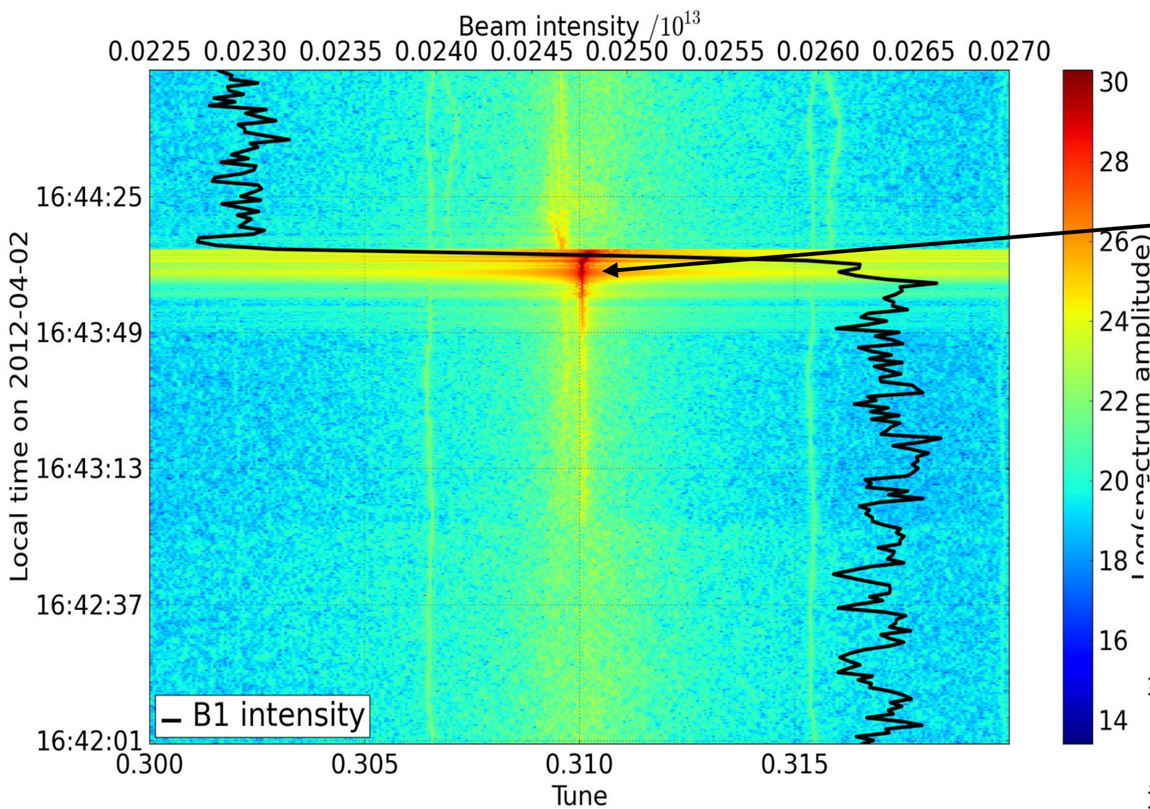




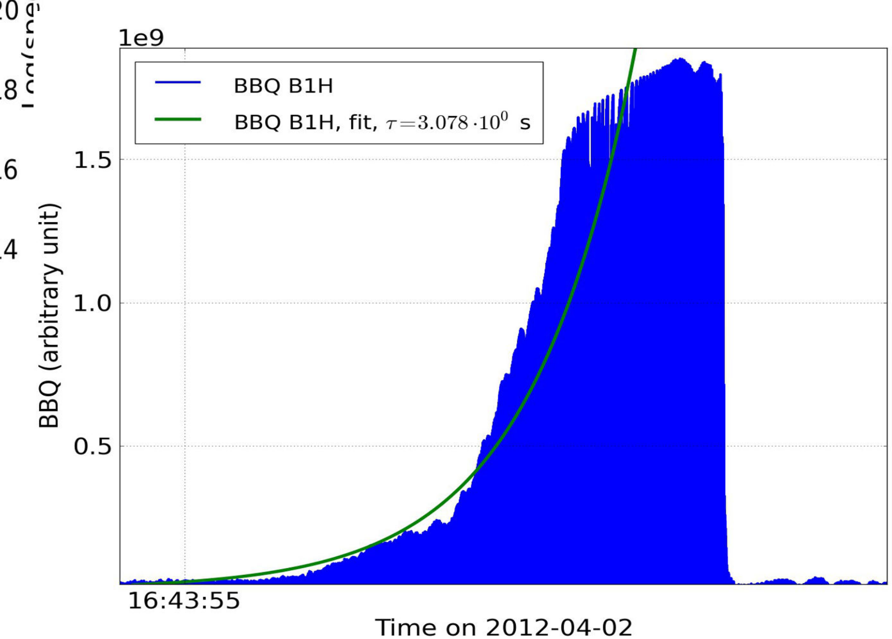
Due to the instability:
– bunch shortening;
– particle losses.

Data analysis. Beam 1

Beam spectrum: $Q'_x = 0.31$ => instability in the horizontal plane



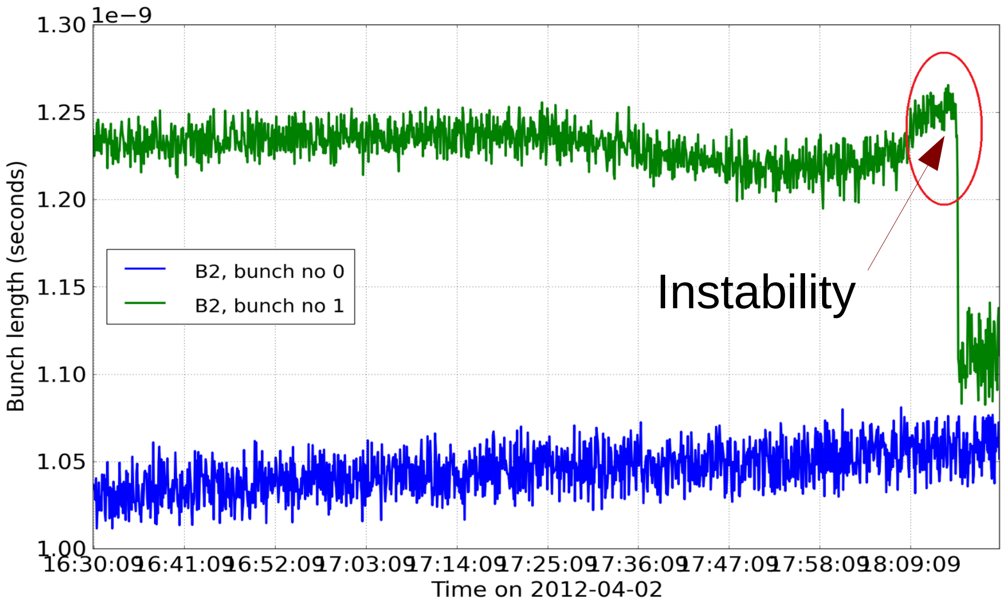
Growing coherent signal → instability

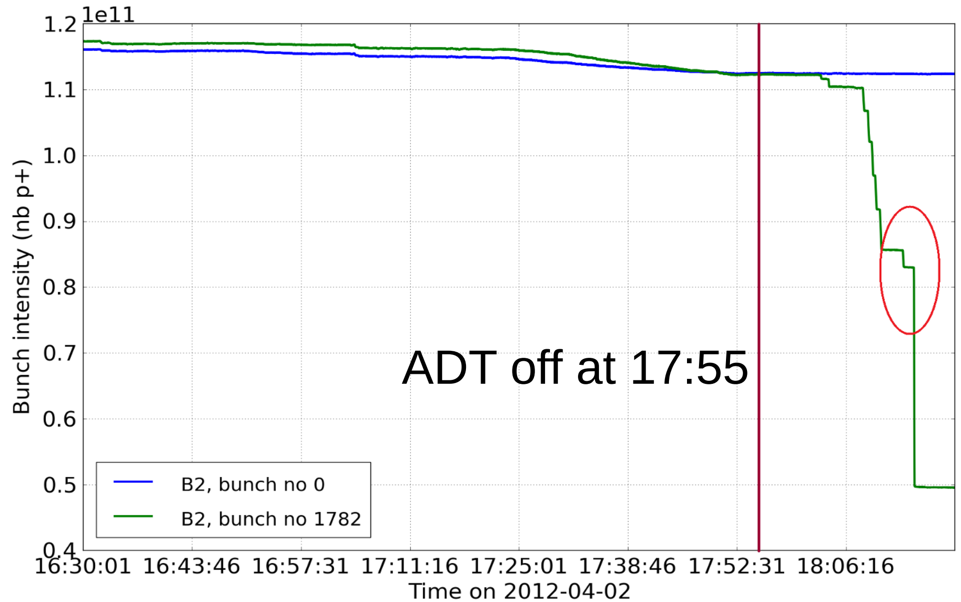


Rise time τ_H = 3.078 s from “raw” BBQ data

Data analysis. Beam 2

The 1st instability in the beam 2 was ~ at 18:07 in the bunch 2, in the vertical plane

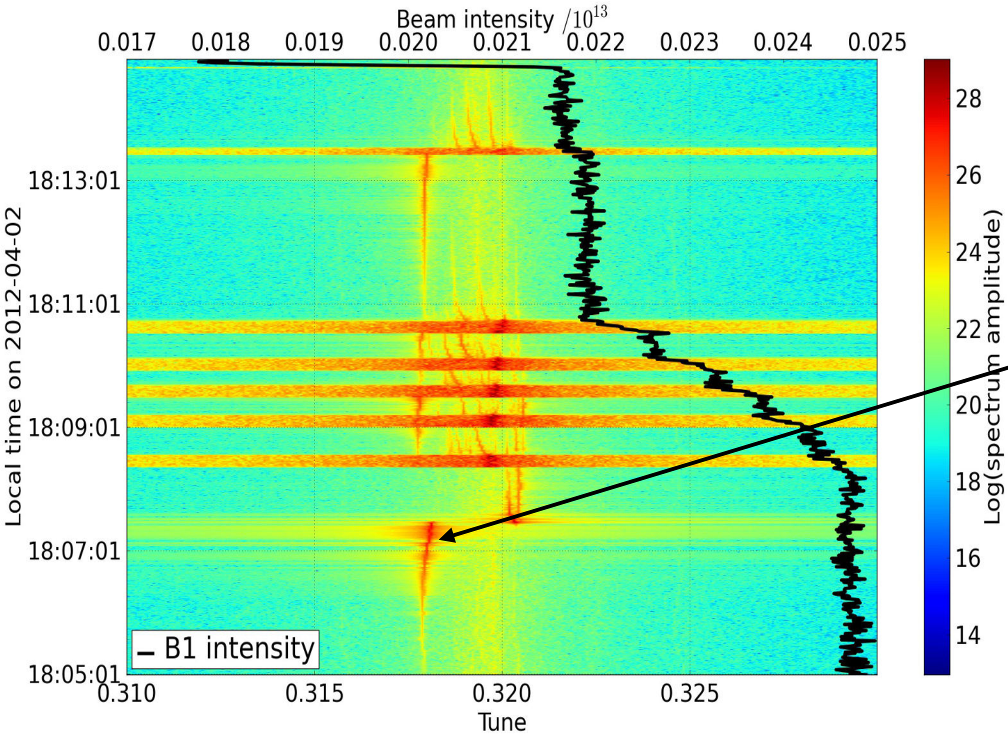




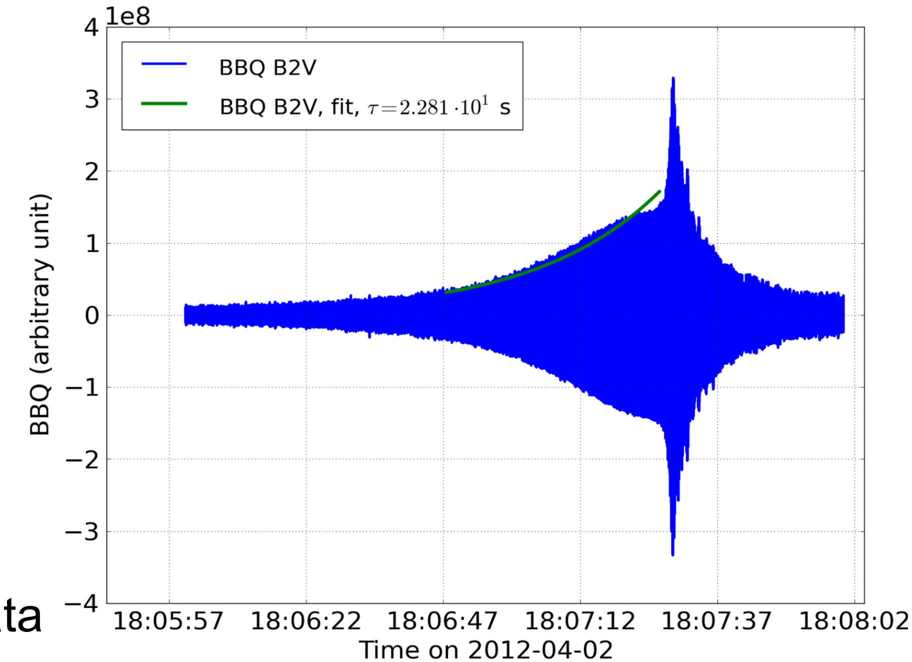
Due to the instability:
– bunch shortening;
– small particle losses.

Data analysis. Beam 2

Beam spectrum: $Q'_y \sim 0.318$ => instability in the vertical plane



Growing coherent signal → instability

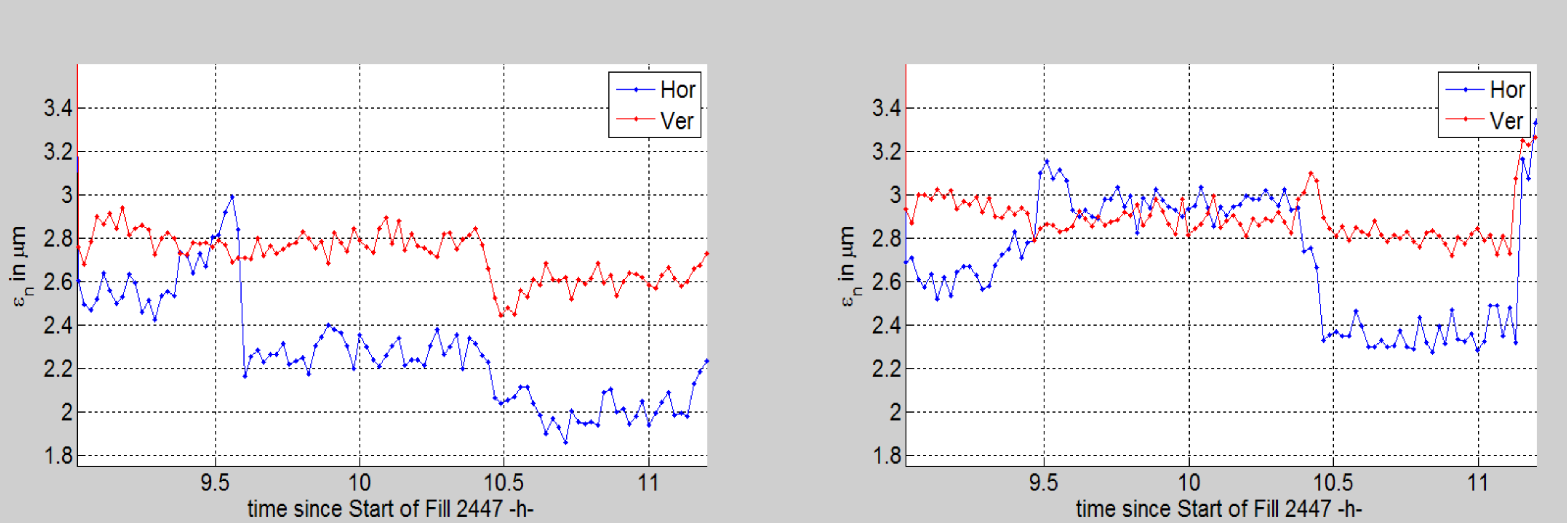


Rise time τ_v = 22.81 s from “raw” BBQ data

Data analysis. Emittance

– no wirescan data for the emittance, only BSRT data and only for beam 1.

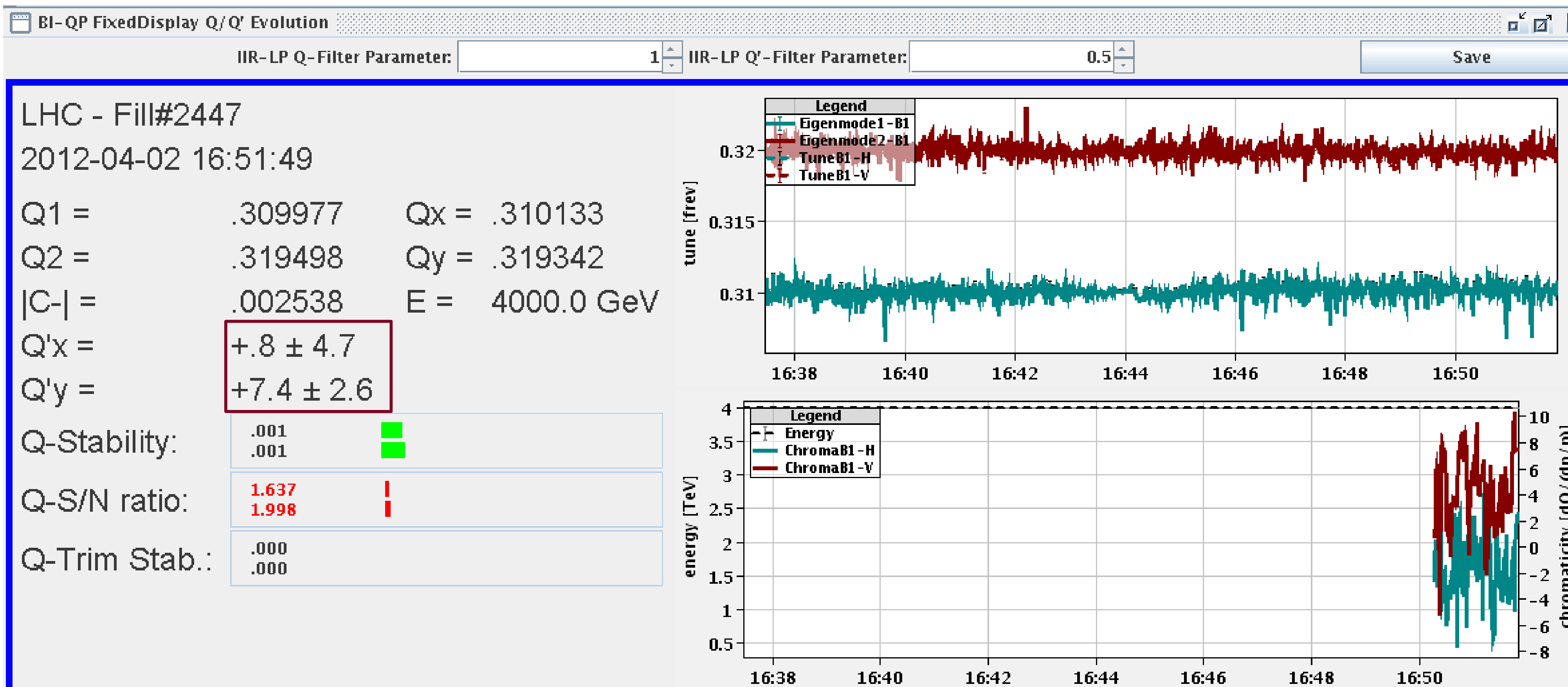
There is a big error bar for the emittance for both beams ≈ 30%.



from Georges Trad

Data analysis. Chromaticity

Large uncertainty on the chromaticity value → we will scan the full range.



from CERN eLogbook LHC OP

HEADTAIL convergence study

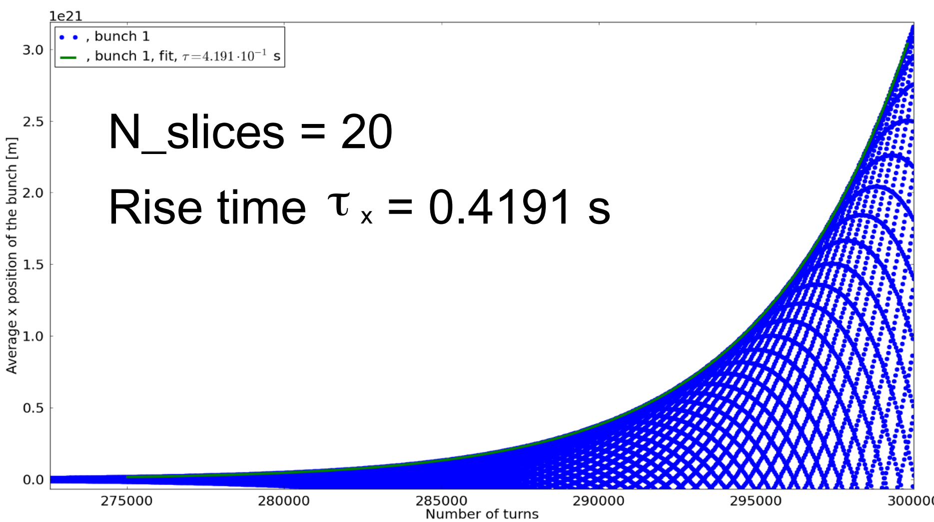
The goal of this study:

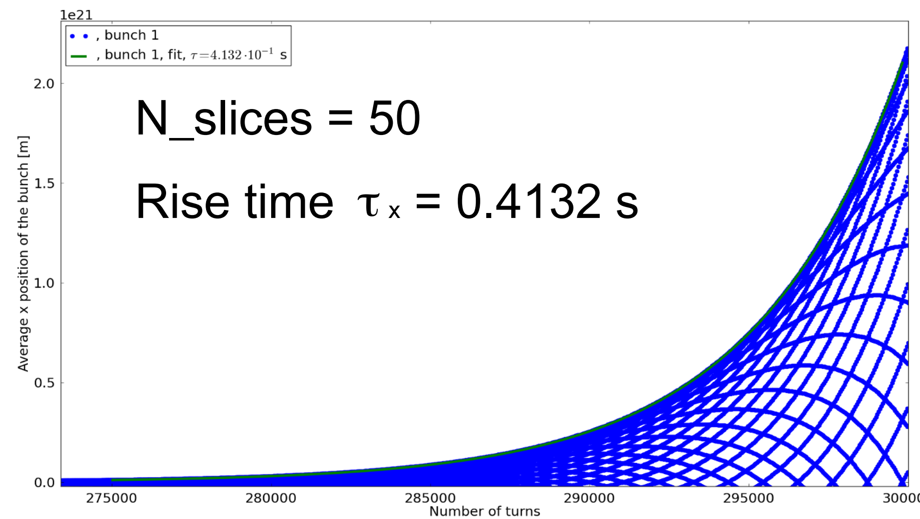
– to scan the numerical parameters: number of slices and number of macroparticles

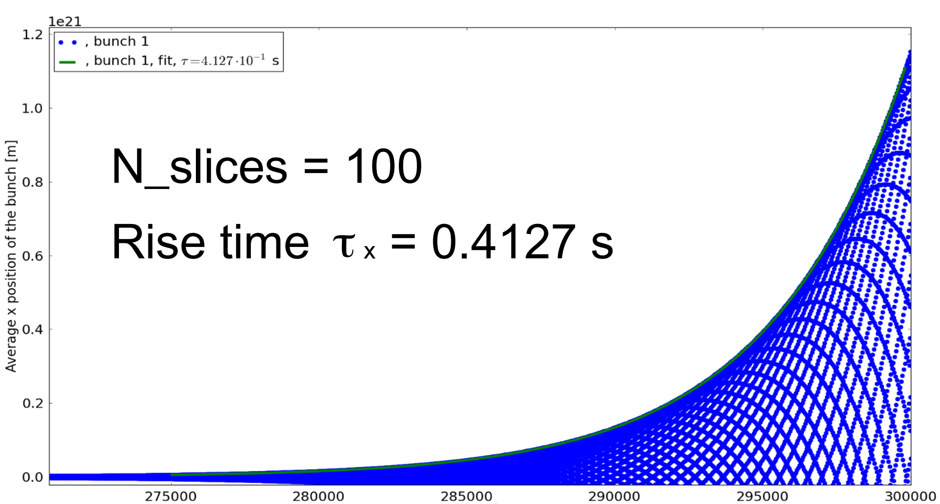
→ big enough for doing reliable HEADTAIL simulations

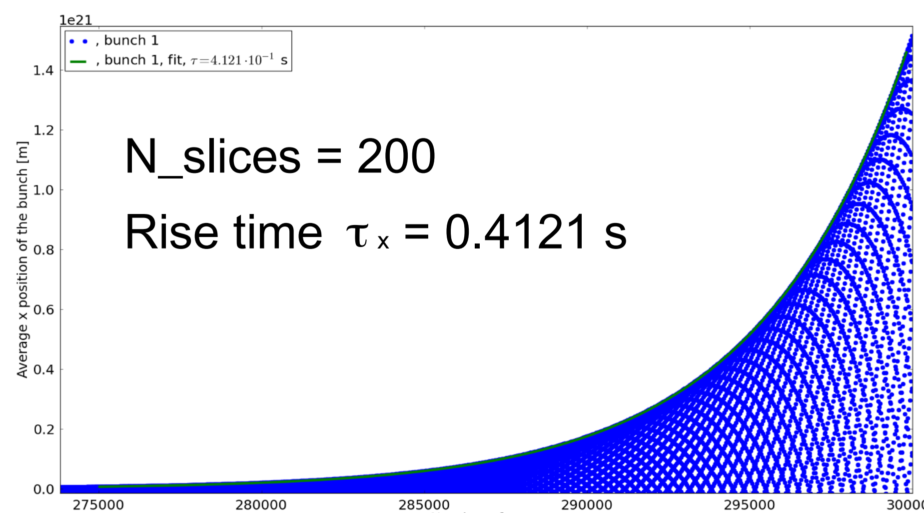
Example of rise time for different number of slices

Average x position for Q'_x = -1.55, n_MP / n_slices = 5e3



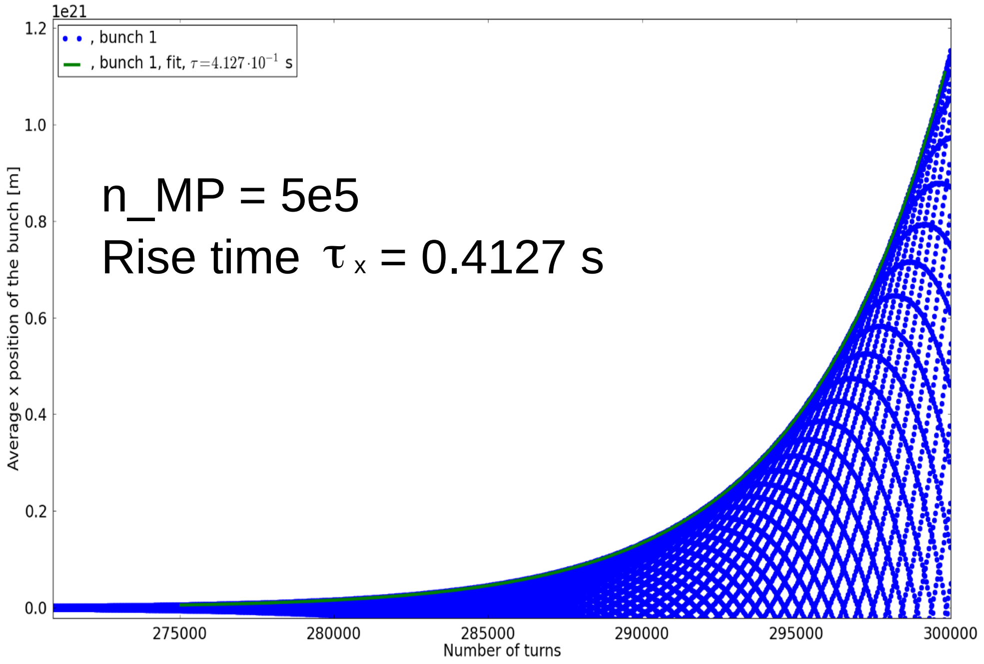


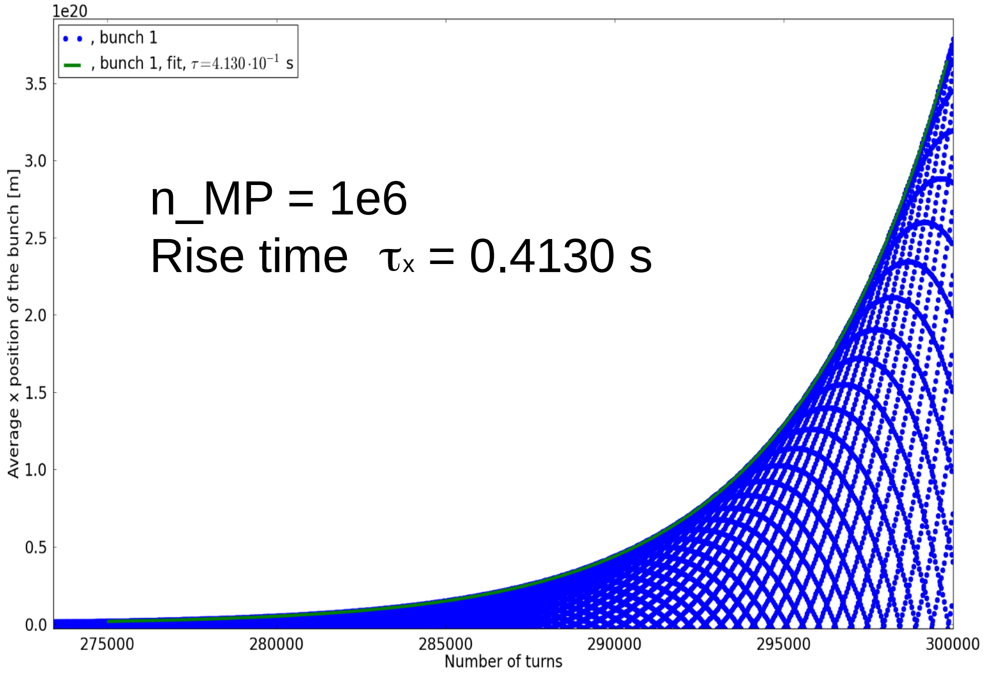




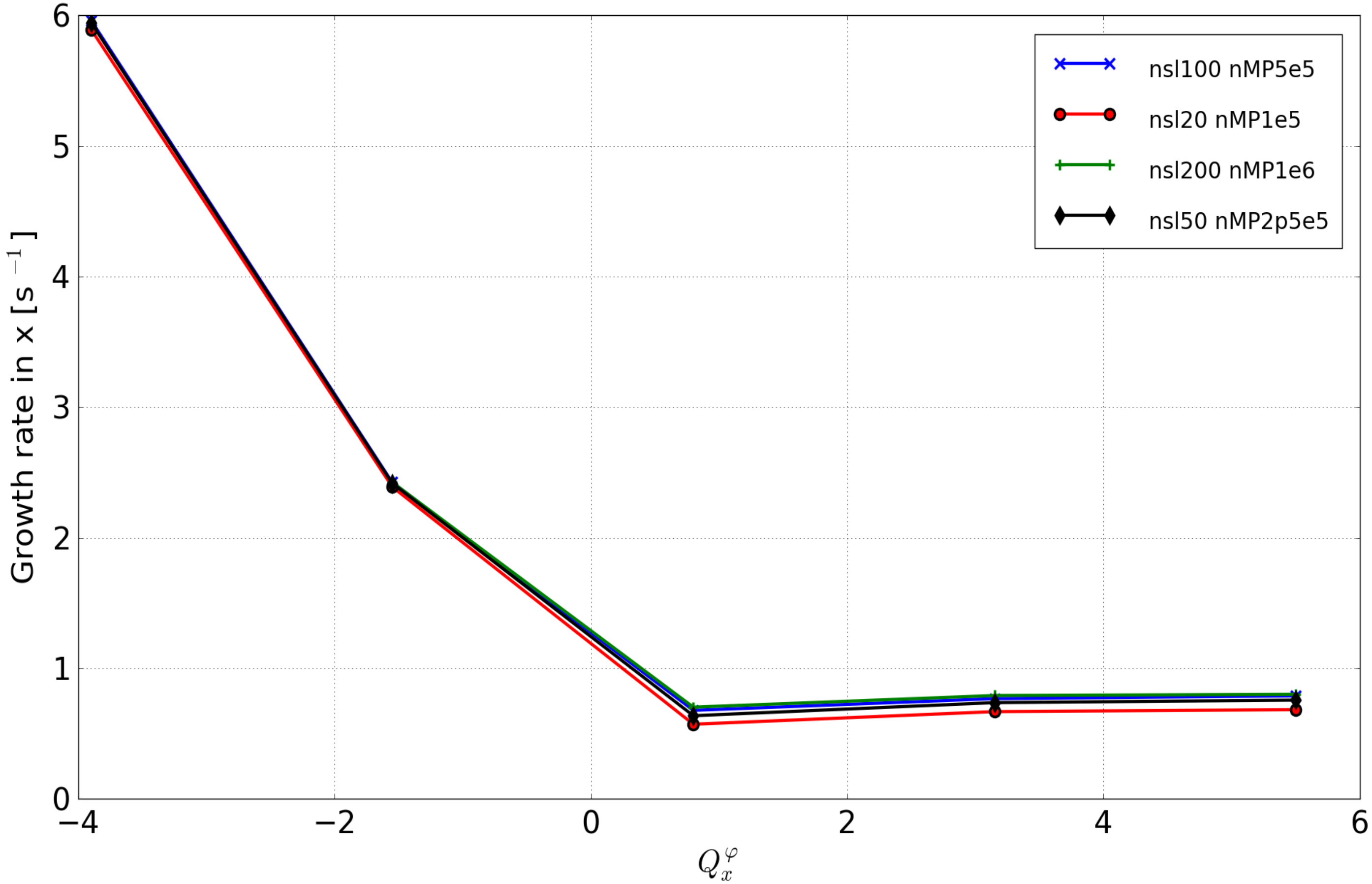
Example of rise time for different number of macroparticles

Average x position for Q'_x = -1.55, number of slices = 100



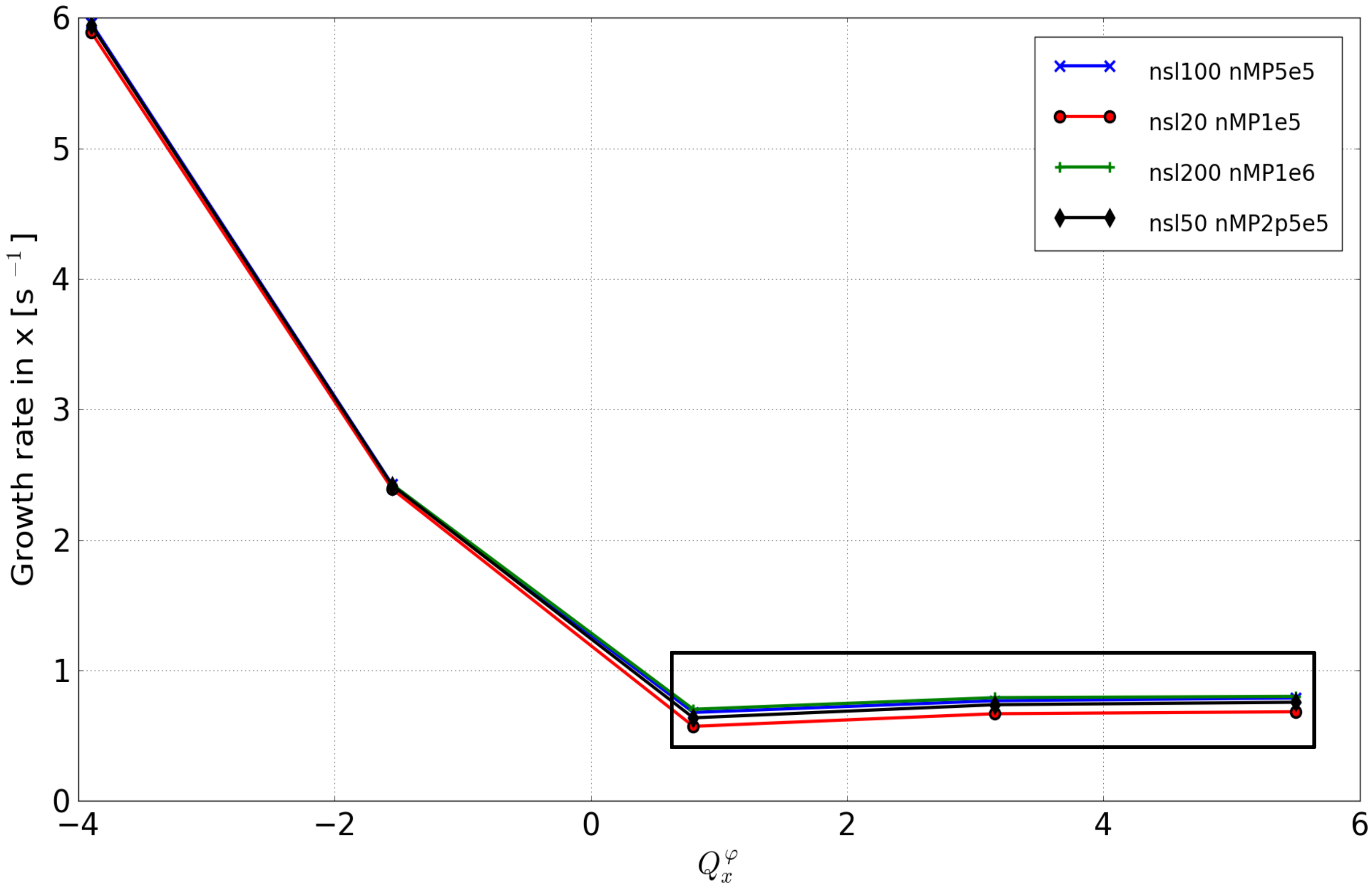


Conclusion of convergence study: Horizontal growth rate



For the negative chromaticity n_sl doesn't matter, even 20 is enough.

Conclusion of convergence study: Horizontal growth rate



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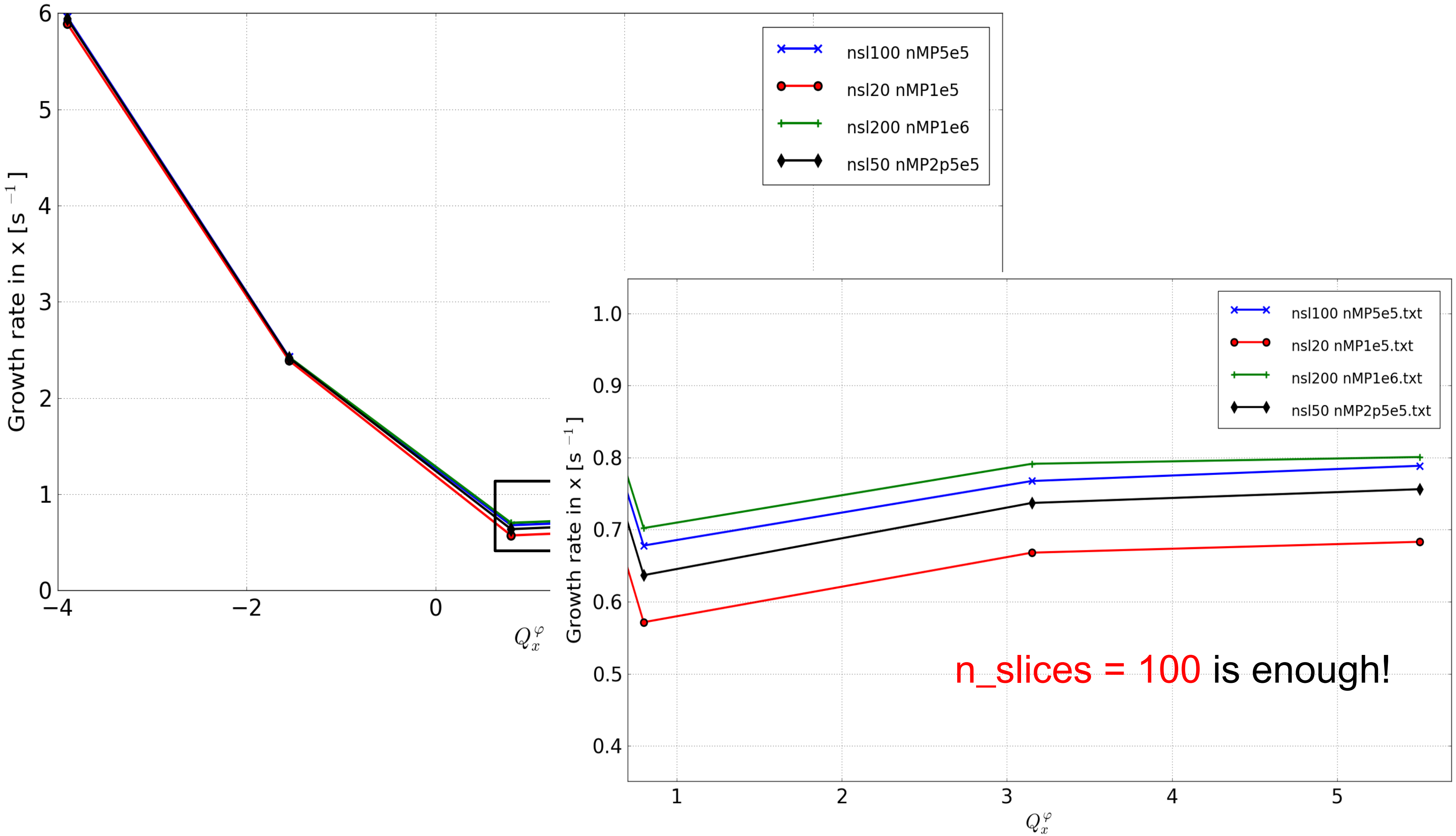

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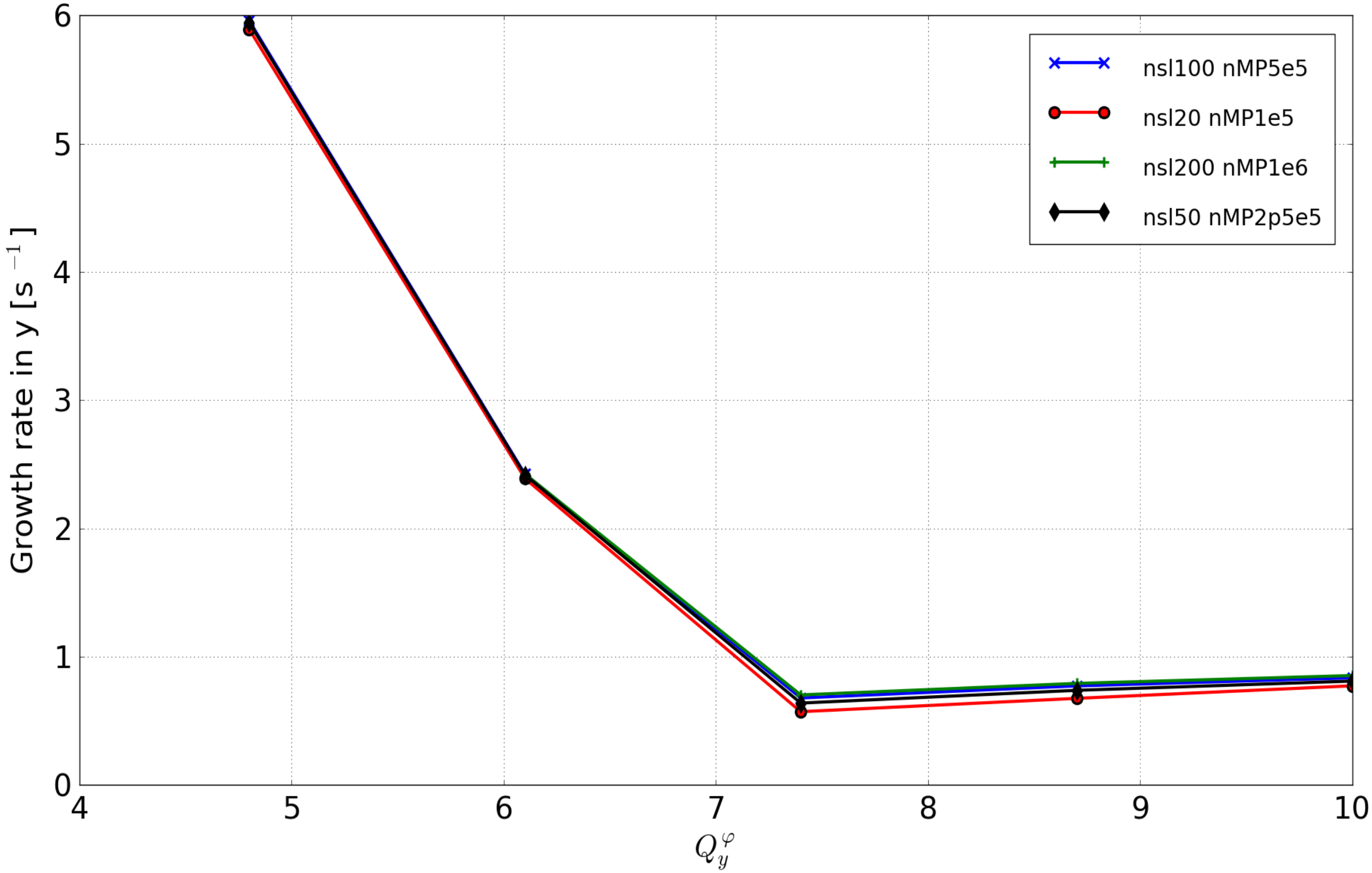

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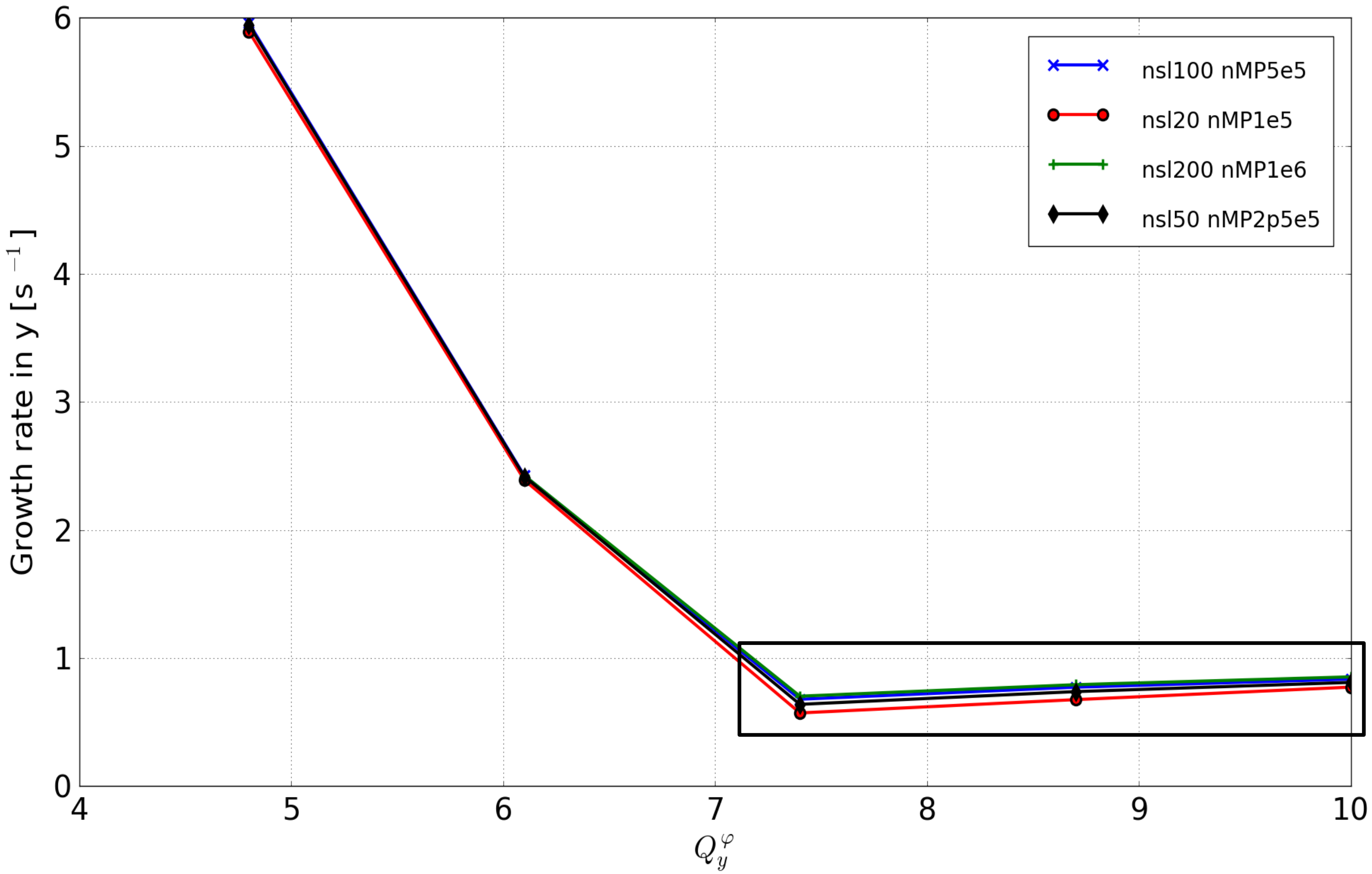

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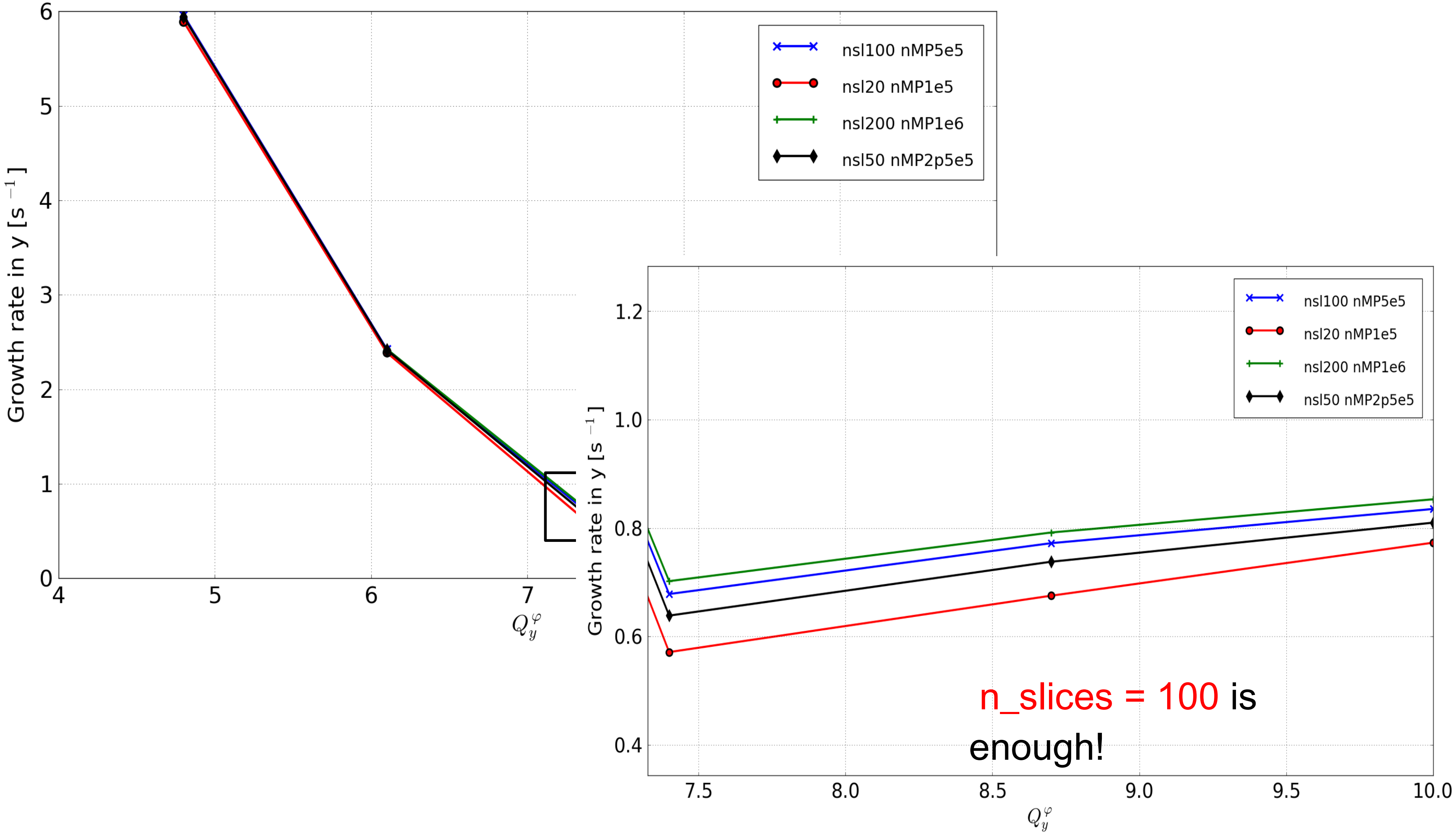

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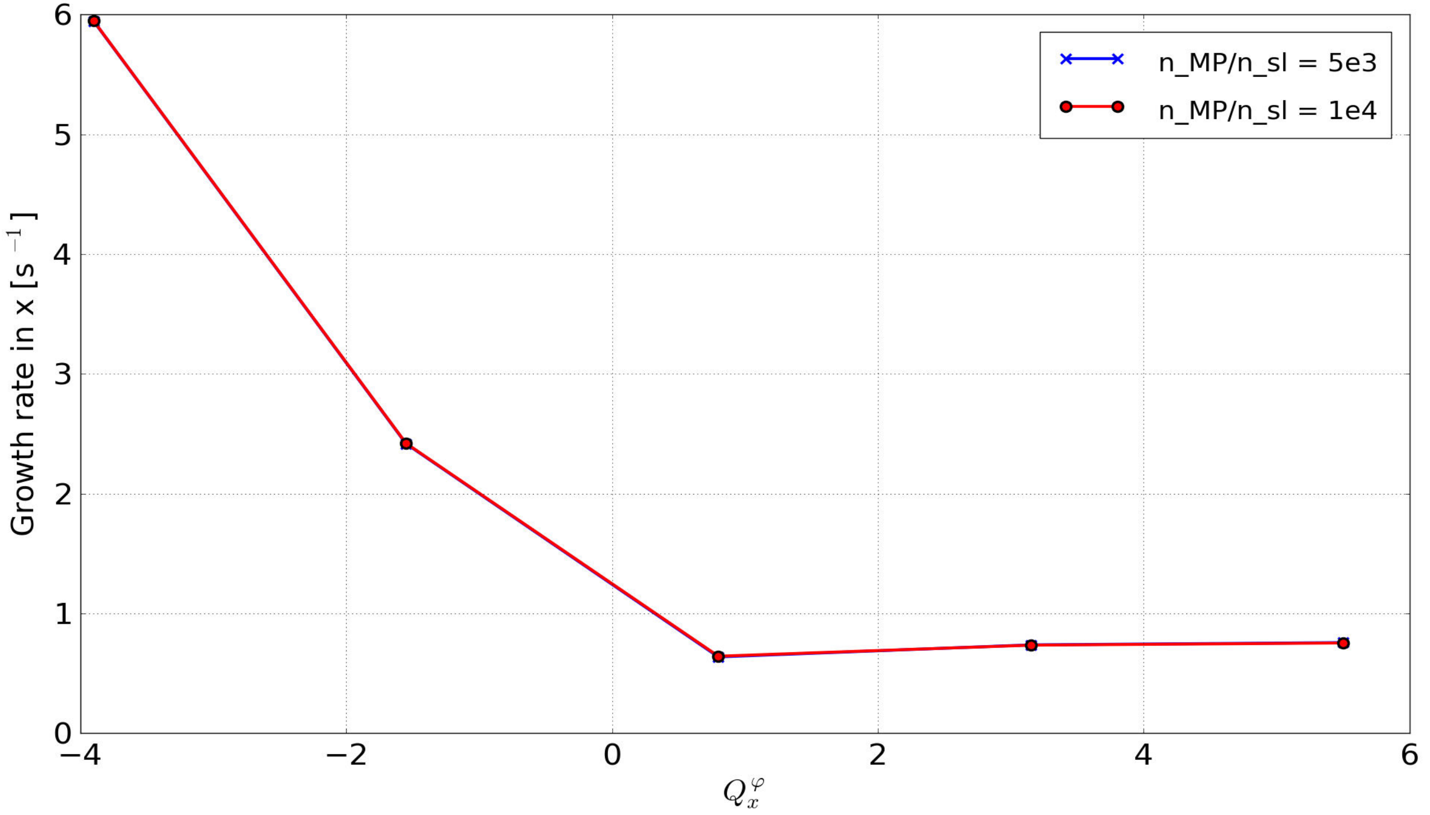

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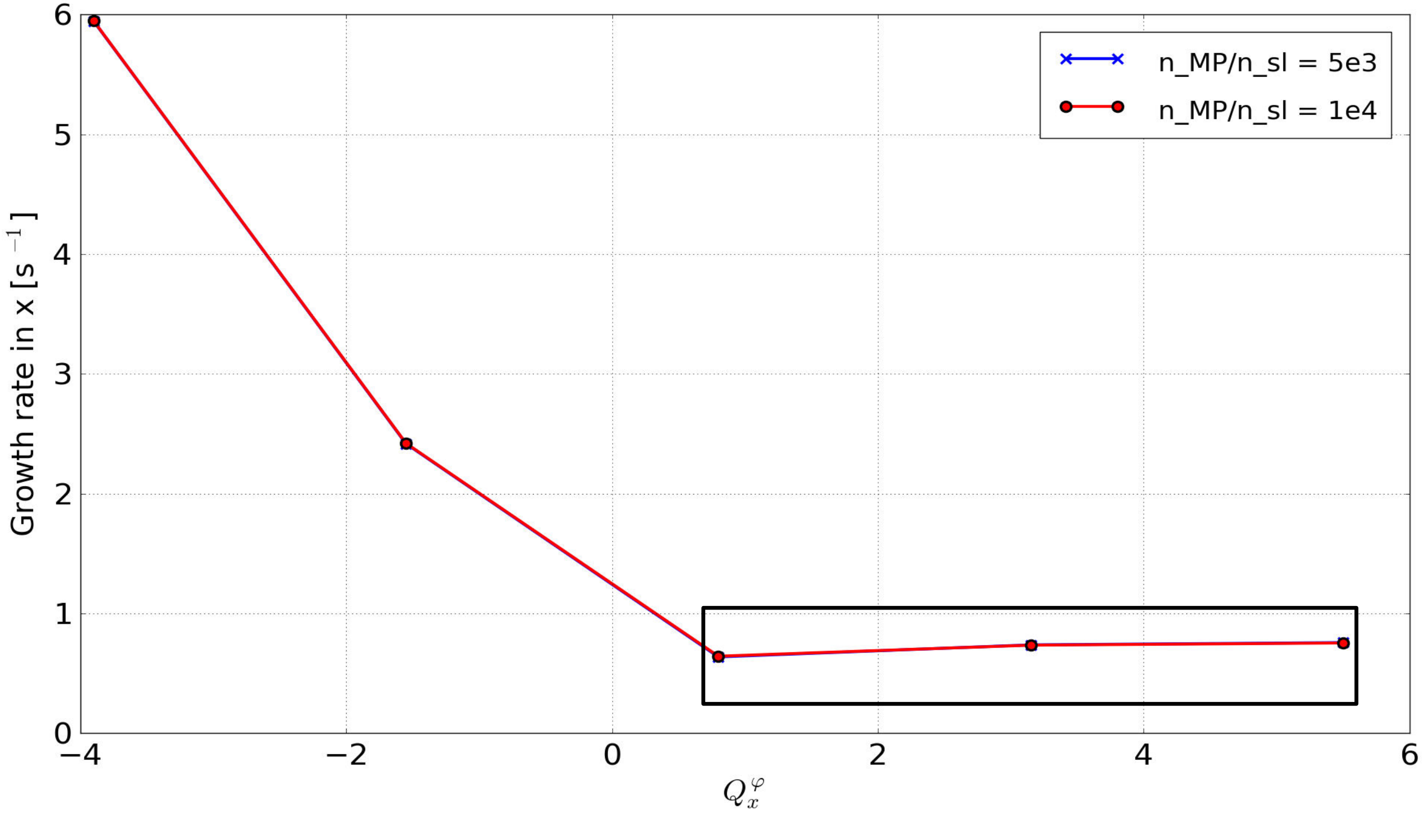
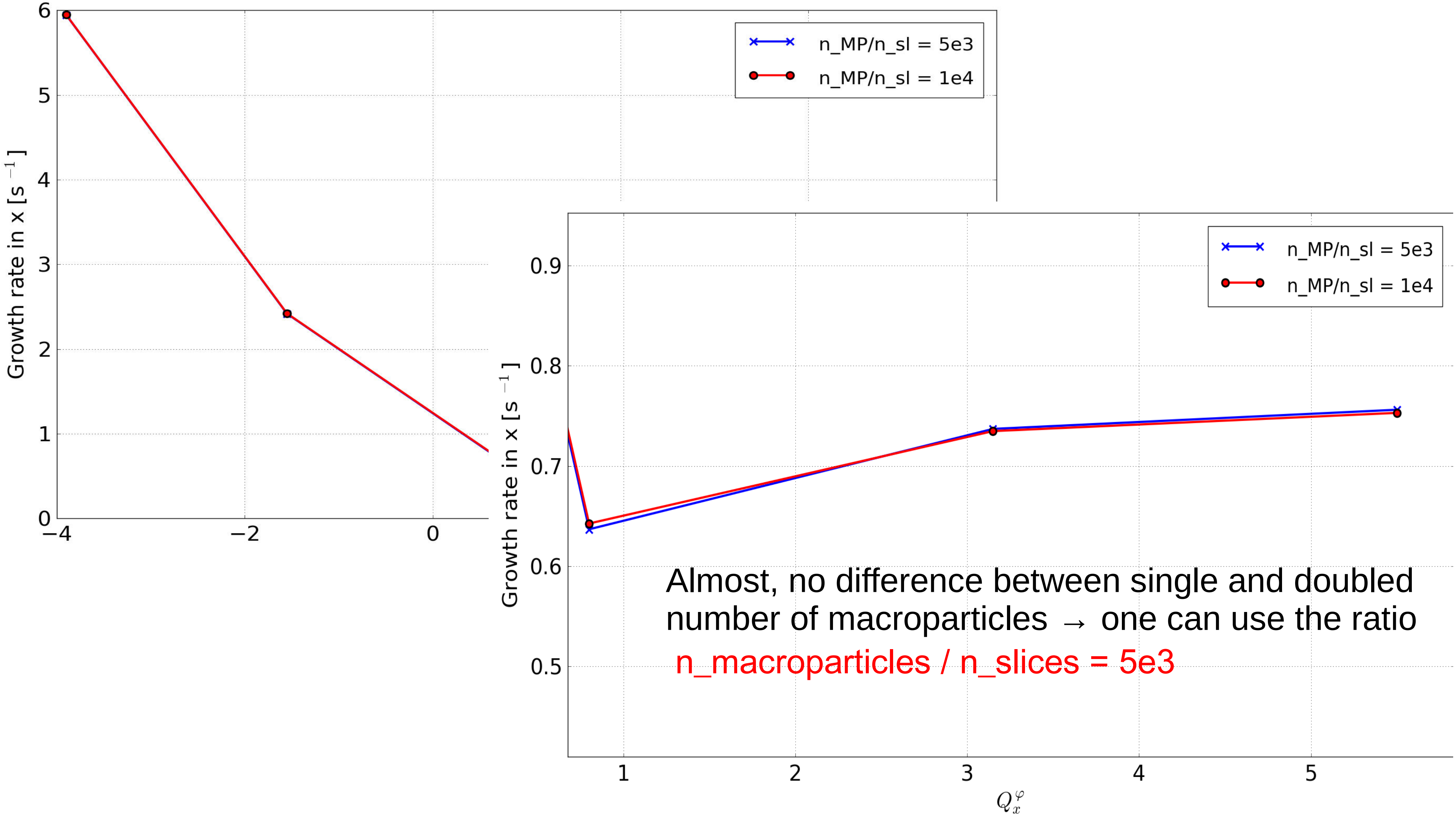


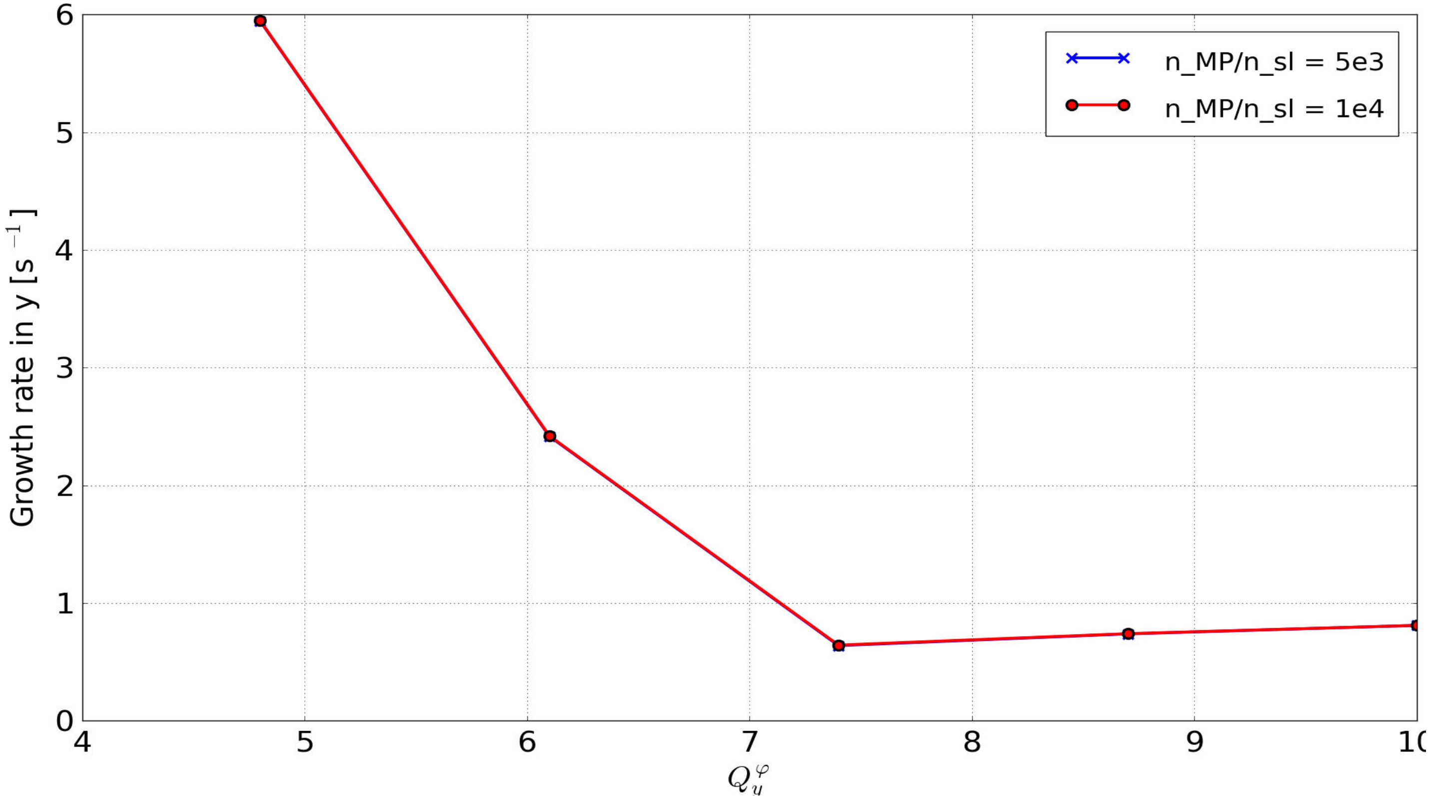
Conclusion of convergence study: Horizontal growth rate



Almost, no difference between single and doubled number of macroparticles → one can use the ratio

n_macroparticles / n_slices = 5e3

Conclusion of convergence study: Vertical growth rate



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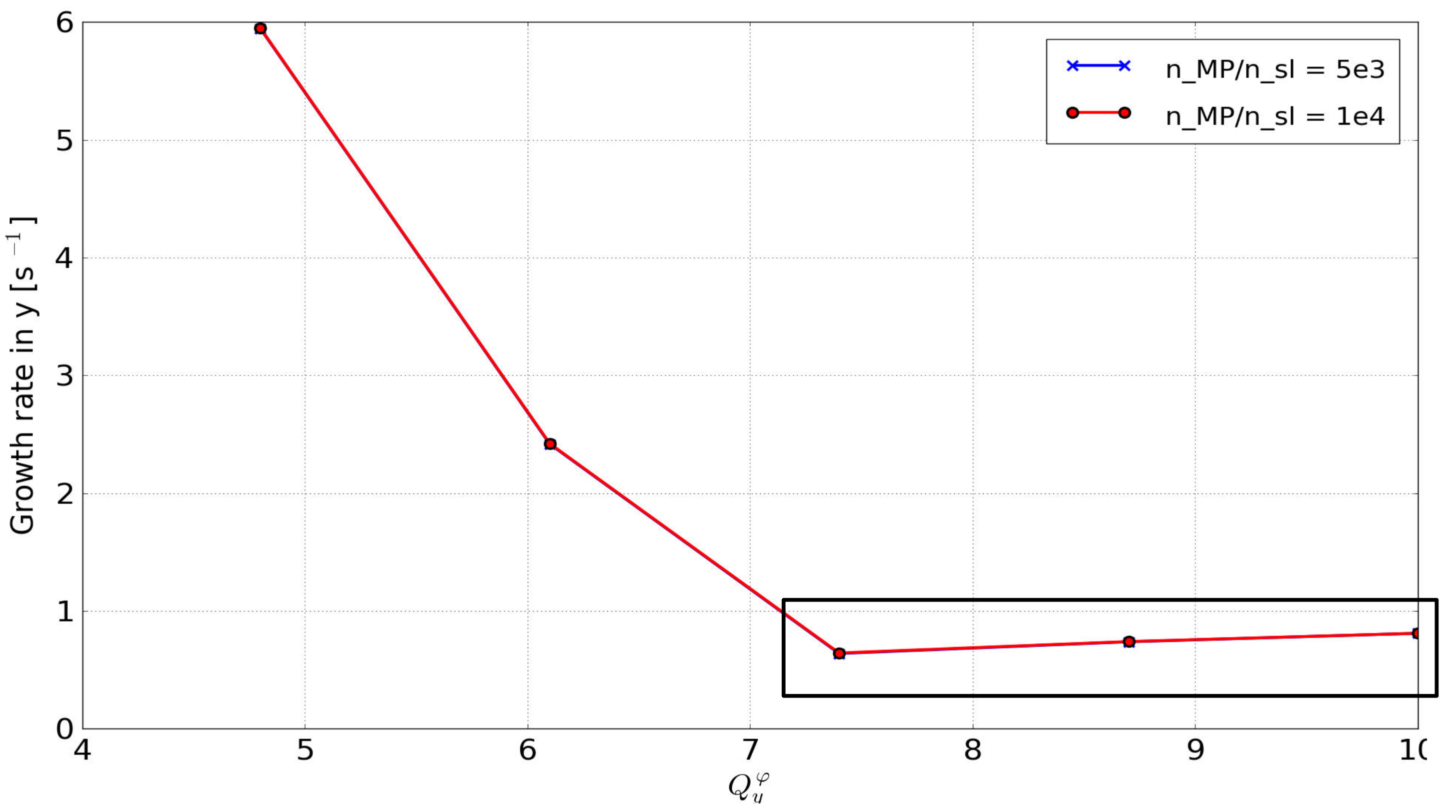

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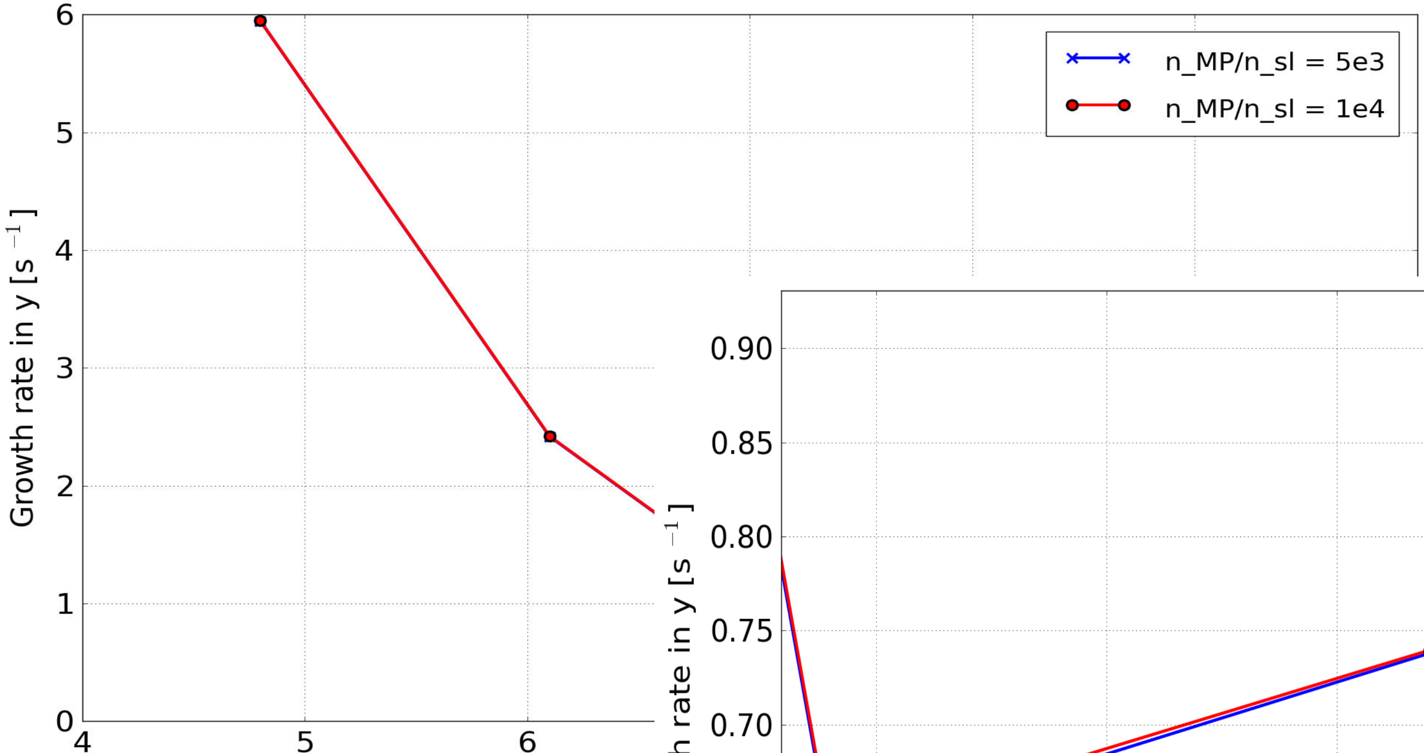
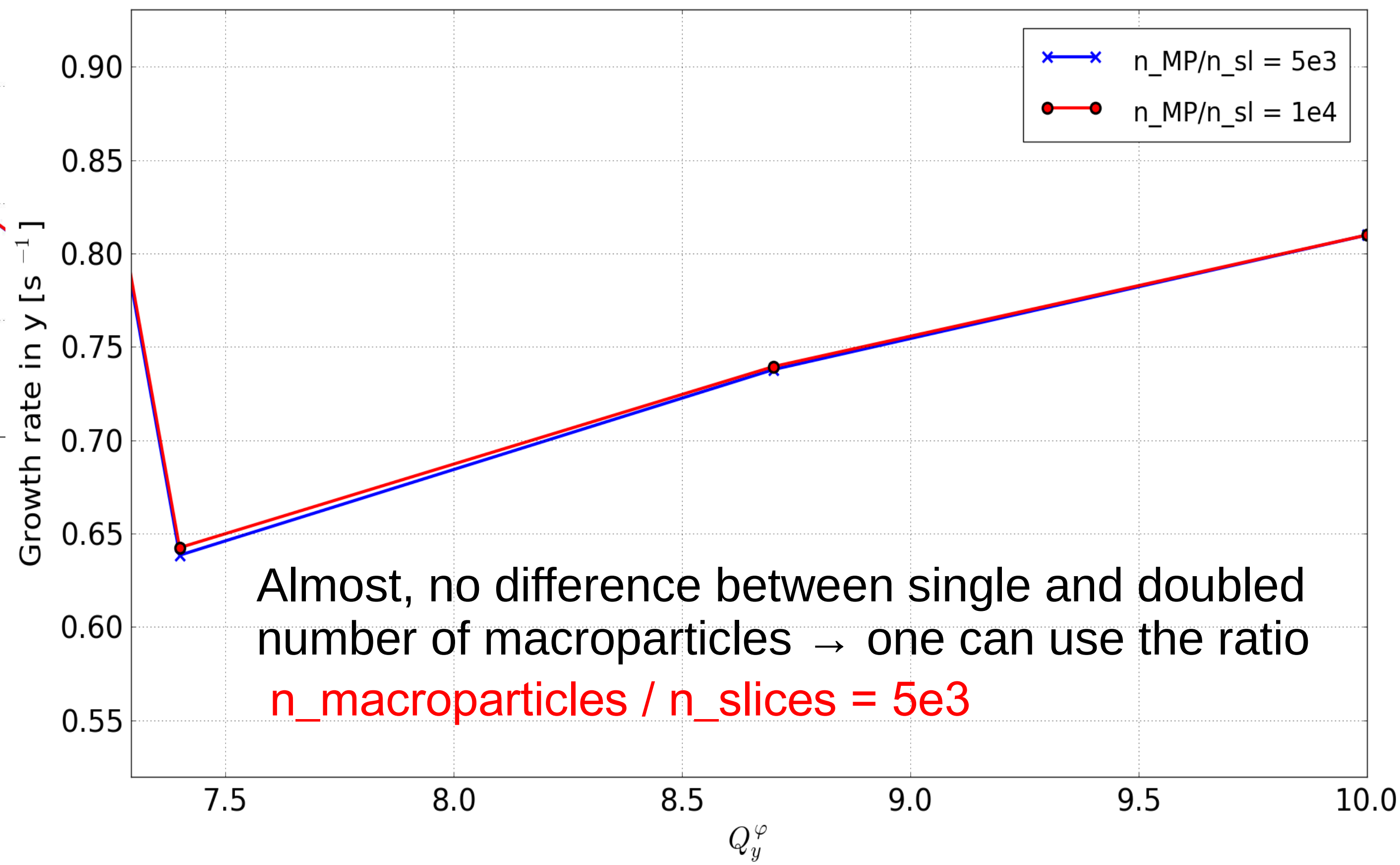




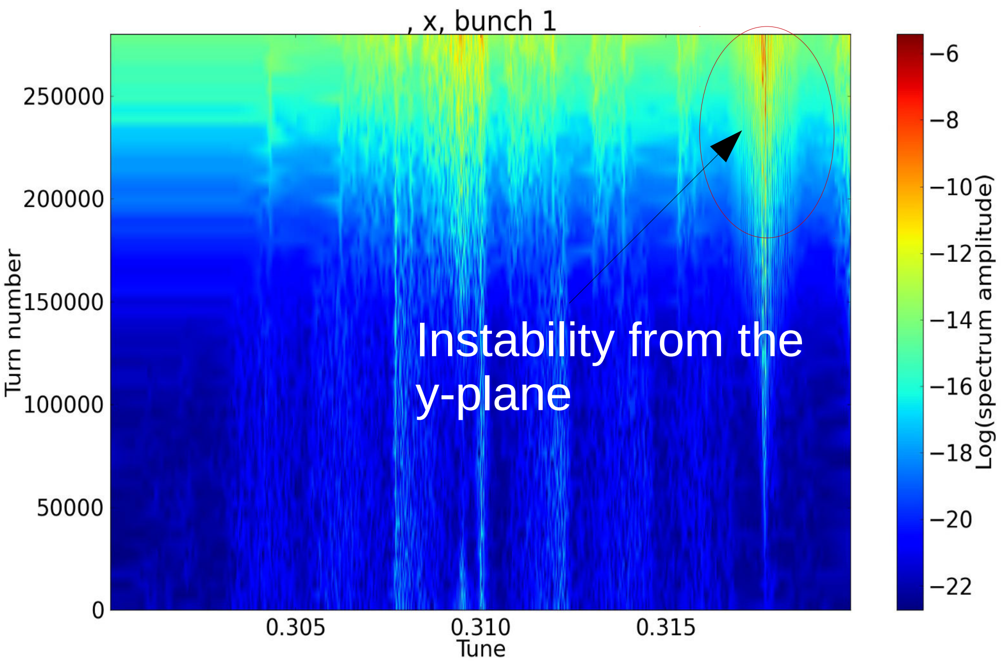
Almost, no difference between single and doubled number of macroparticles → one can use the ratio

n_macroparticles / n_slices = 5e3

Coupling

During the study was detected a problem due to the coupling between horizontal and vertical planes.

Coupling



One way to solve this problem is to take out the coupling terms from wakes used in HEADTAIL.

Comparison between HEADTAIL & observed instability in B1H_bunch1

Comparison between HEADTAIL & observed instability in B1H_bunch1

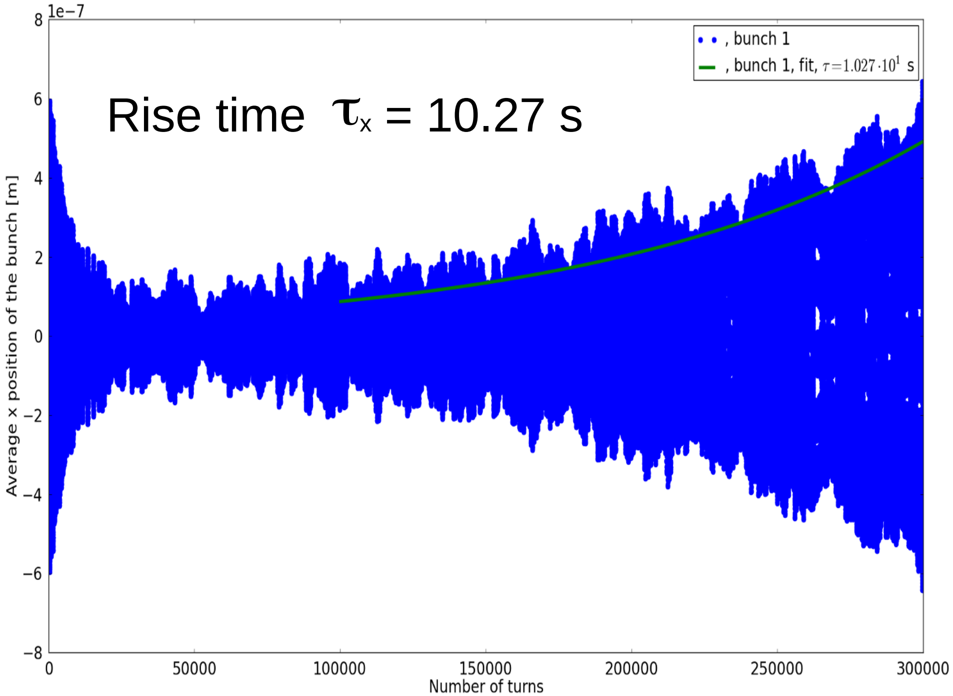
The goal:

– to compare rise time of the observed instability and from HEADTAIL simulations.

– to do octupole current scan to define threshold current for the beam stabilization.

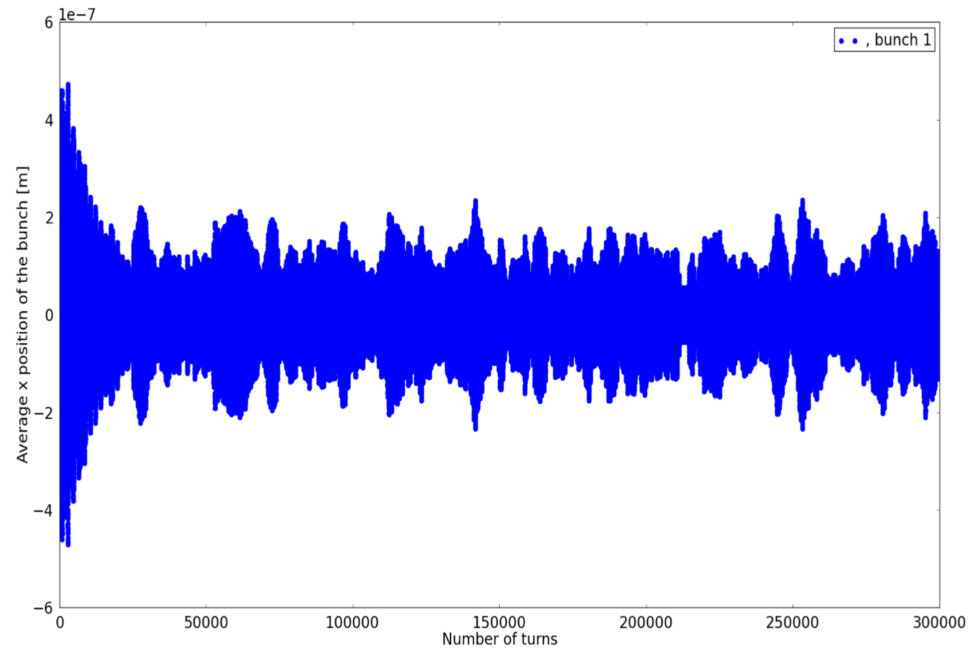
Example of current scan

I_{oct} = 0 A



Average x position for Q'_x = 0.8

I_{oct} = -50 A



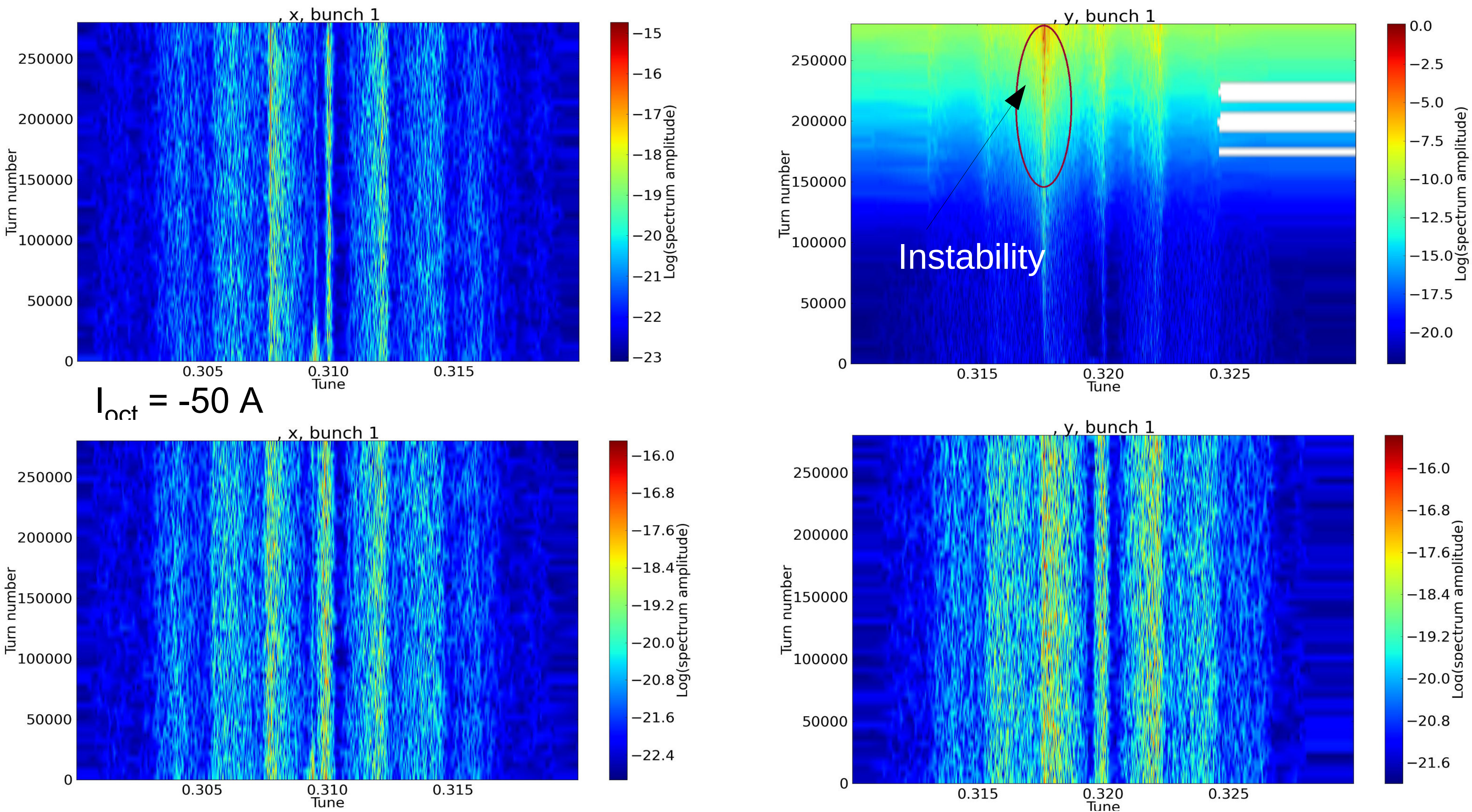
The beam is stable in range of focusing octupole current I = -25 ∓ 25 A

Example of current scan

Bunch spectrum for Q'_x = 0.8

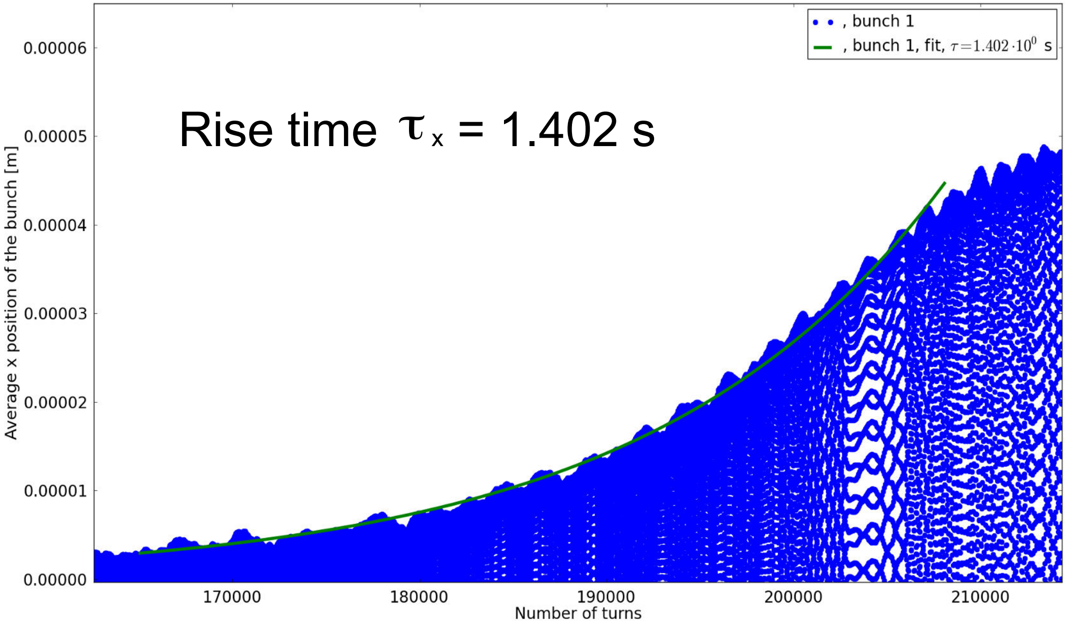
I_{oct} = 0 A

I_{oct} = -50 A

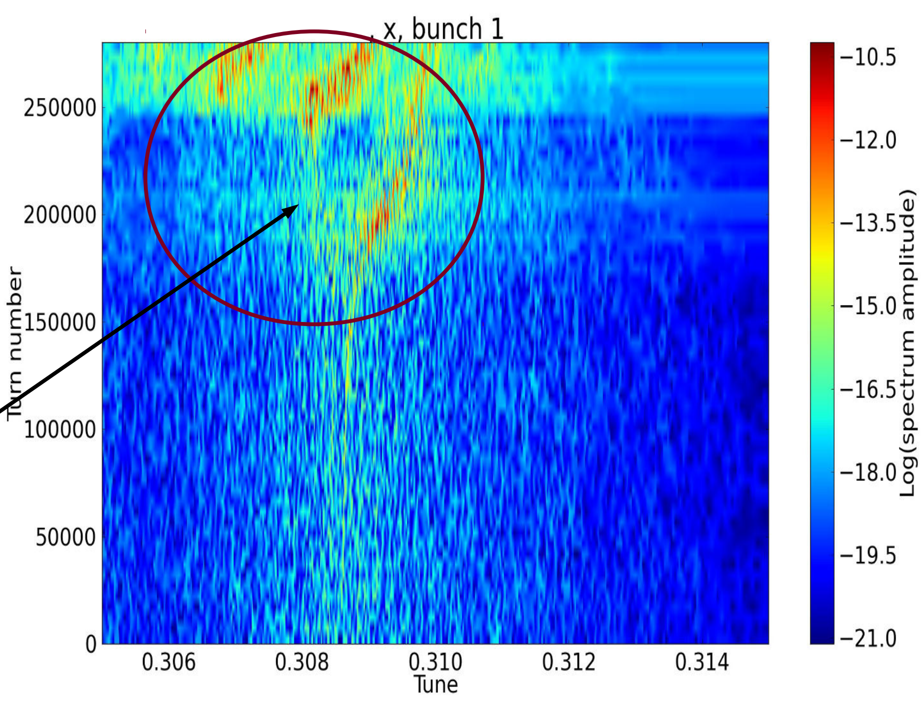


Example of the current scan

Q'_x = -3.9, I_{oct} = -600 A



In this case (negative chromaticity), the beam is unstable even at focusing I_{oct} = - 600 A.



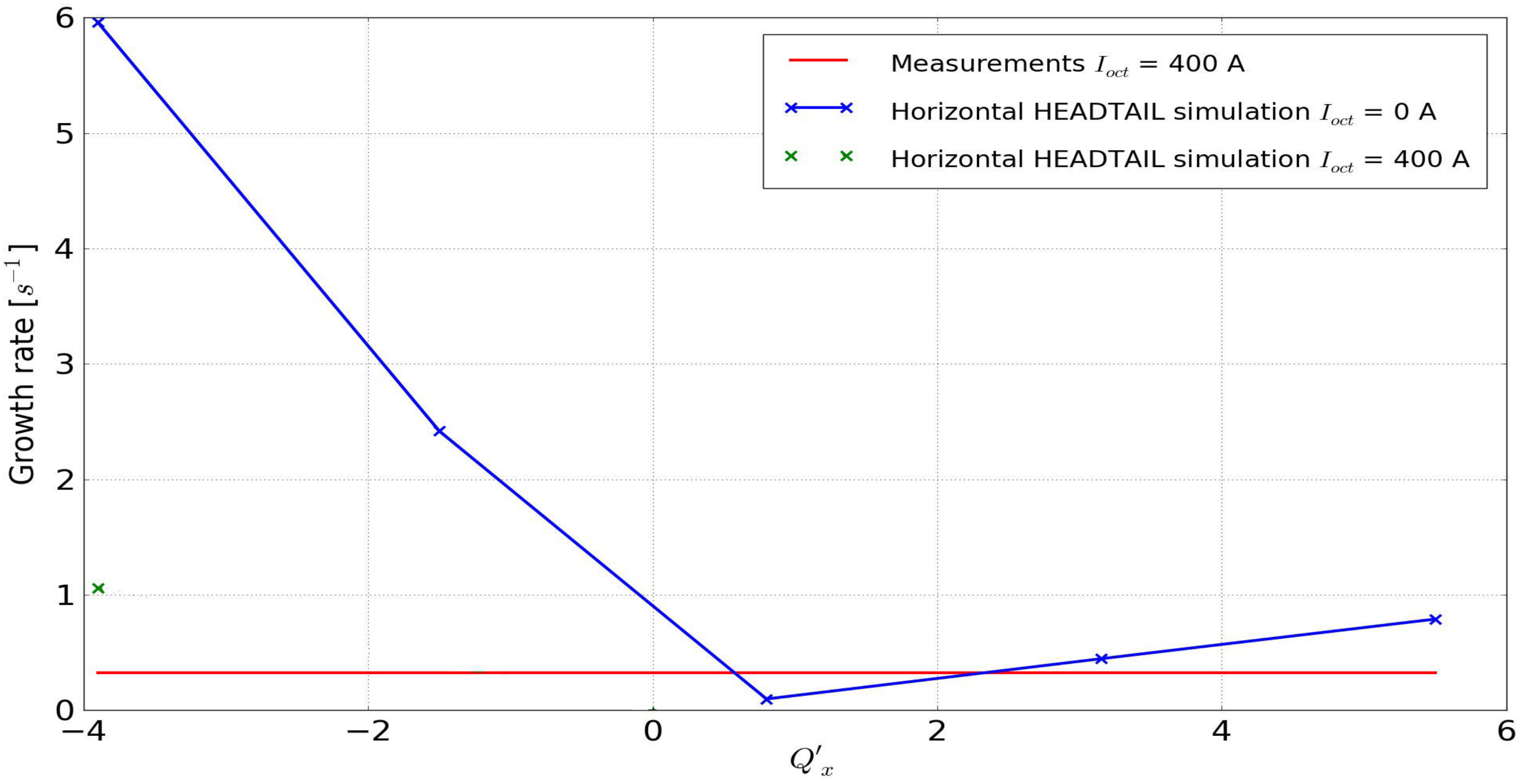
The fact that the instability lines move with time might be due to nonlinearity

HEADTAIL simulation vs. experiment

Comparison of growth rate between:

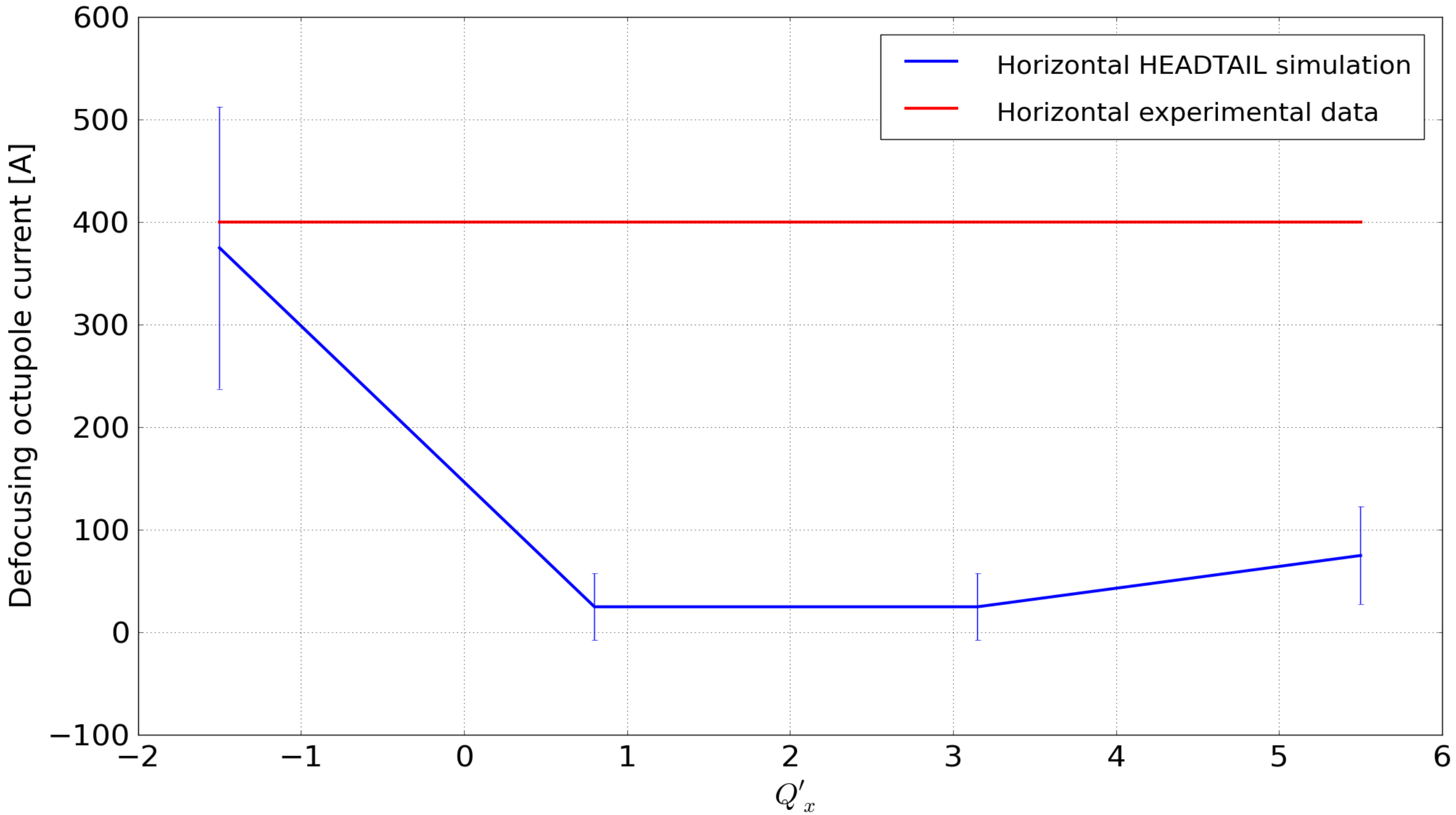
– experimental defocusing I_{oct} = 400 A;

– HEADTAIL simulation.



Threshold octupole current

Comparison between the octupole current during the measurements and the defocusing octupole current threshold from HEADTAIL.



Conclusions

- On 02/04/2012 were observed 2 (almost) single-bunch instabilities:
  – beam 1, bunch 1 in the horizontal plane, τ_x = 3.078 s;
  – beam 2, bunch 2 in the vertical plane, τ_y = 22 s.

- Importance of convergence study consisted in defining of numerical input parameters for the next octupole threshold determination:
  – number of slices = 100;
  – number of macroparticles can be found from ratio n_MP/n_sl = 5e3.

- Comparison between the octupole current during the measurements and from HEADTAIL simulations confirms, that the current depends largely on the value of chromaticity, than on growth rate.

- Plan for the future:
  – to scan the beam intensity → find from HEADTAIL the intensity, at which can be reproduced the observed instability with the same rise time with focusing I_{oct} = -400 A.

Backup slide 1. Instability data

	Time	Bunch intensity (e11)	Energy (GeV)	Squeezed/Not	Bunch length (ns)	Focusing octupole current (A)	ADT (on/off)	Rise time (s)	Azimuthal mode
B1H_bunch1 (unstable)	16:43	1.38	4000	yes (~60 cm)	1.1	-400	off	3.078	0
B1H_bunch2		1.3			1.16				
B2V_bunch1	18:07	1.22	4000	yes (~60 cm)	1.05	-400	off	22	-1
B2V_bunch2(unstable)		1.1			1.23				

Backup slide 2. Input parameters for the HEADTAIL simulations

Number_of_particles_per_bunch:	1.38e+11 / 1.1e+11
Bunch_length_(rms_value)_[m]:	0.0847 / 0.0854
Normalized_horizontal_emittance_(rms_value)_[um]:	2.76
Normalized_vertical_emittance_(rms_value)_[um]:	2.76
Longitudinal_momentum_spread:	0.00013308
Synchrotron_tune:	0.00234243
Relativistic_gamma:	4263.156
Number_of_turns:	300000
Horizontal_chromaticity_[Q'x]:	-3.9 / -1.55 / 0.8 / 3.15 / 5.5
Vertical_chromaticity_[Q'y]:	4.8 / 6.1 / 7.4 / 8.7 / 10
Number_of_macroparticles_per_bunch:	1e5 / 2.5e5 / 5e5 / 1e6 – 2e5 / 5e5 / 1e6 / 2e6
Number_of_slices_in_each_bunch:	20 / 50 / 100 / 200
Number_of_turns_for_the_wake:	10
Second_order_horizontal_chromaticity (x/y):	depends on the octupole current
Main_rf_voltage_[V]:	12e+6
LHC_defocusing_octupoles_current_[A]:	0...700 with a step = 50 A
Switch_for_wake_table	4 (without coupling terms)
Damper_gain	0