
CERN

200 MHz option for HL-LHC and intensity limitations

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Thanks to: J. Esteban Mueller, E. Shaposhnikova

HiLumi Meeting 2016 – 25 January

Context & Outline

Context:

Operating the LHC with an additional 200 MHz RF system has some advantages but also comes with a couple of disadvantages. We will look into:

- Potentially reduction electron cloud activity as one of the advantages
- Lowering of the TMCI thresholds as one of the most critical performance limitations

Outline:

1. Clarification of the parameters
2. TMCI thresholds for 400 vs. 200 MHz
3. Impact of the transverse damper on TMCI
4. Open questions and plans

Parameters

- Some changes occurred compared to the past

	HL-LHC baseline	200MHz
N_p [10^{11} p/bunch]	2.2	2.56
ε [μm]	2.5	3.0
Minimum β^* [m]	0.15	0.15
LR Separation [σ]	12	12
σ_s [m]	0.0755	0.126 / 0.14 (double RF)
Q_s	2.0e-3	8.8e-4
Virtual L [10^{35} $cm^{-2}.s^{-1}$]	1.83	1.37 / 1.17

S. White - 6th LHC crab cavity workshop

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- 55.68 → 53.86
- Increase in Qs – good (TMCI)
- Increase in bunch length – good (TMCI)

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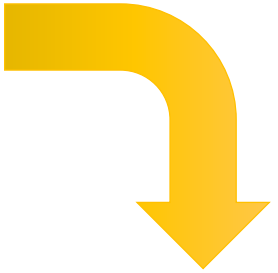
2013



2016

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Among the largest impact originates from the slightly lower transition gamma compared to LHC:

- 55.68 → 53.86
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- Increase in bunch length – good (TMCI)

	200 MHz	400 MHz
Energy	7 TeV	7 TeV
$\gamma_{\text{transition}}$	53.86	53.86
$V_{\text{fund.}}$	6 MV	16 MV
$V_{\text{harm.}}$	3 MV	8 MV
Q_s	0.92e-3	2.11e-3
σ_z	15 cm	8.1 cm
ε_l	3.8 eVs	2.5 eVs

Taken from:
HL-LHC OPERATIONAL SCENARIOS
(CERN-ACC-NOTE-2015-0009)

RF parameters from E. Shaposhnikova

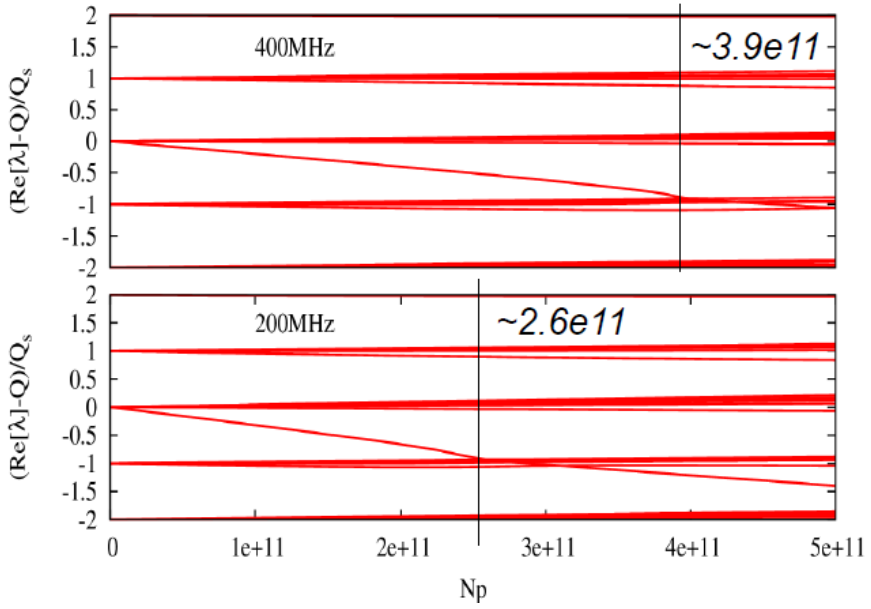
Earlier findings

- For the case of LHC the TMCI threshold is dominated by the tune shift of mode 0 (See *E. Metral et al. "Collimator-driven impedance"*):

$$\frac{\Delta Q^{y}_{0,0}}{Q_s} < -1 \quad \rightarrow \quad \Im\left(Z_y^{eff}\right)_{max} = \frac{4\pi\left(E_t/e\right)\tau_b Q_s}{N_b e \beta_y^{av}}$$

→ The threshold is proportional to Q_s and σ_s, for 200MHz we have:

$Q_s(400) / Q_s(200) \times \sigma_s(400) / \sigma_s(200) = 1.36$



→ Calculations using the new HL-LHC impedance model (See *N. Mounet "Transverse impedance in the HL-LHC era", Daresbury*)

→ In reality the degradation is ~1.5: foreseen intensity barely below threshold

→ Chromaticity,damper and double RF should help, consider alternative material for collimators?

→ So far not a show stopper: more detailed studies required!

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→ Th

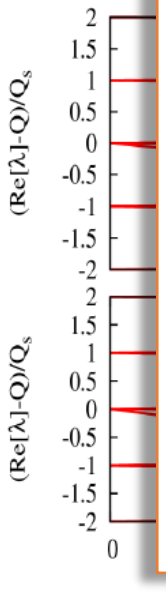
Q_s(4

- From pure scaling we can assume an increase of the TMCI threshold by:

$$N_{\mathrm{th}}^{2016} \approx \frac{Q_s^{2016}\,\sigma_z^{2016}}{Q_s^{2013}\,\sigma_z^{2013}} \times N_{\mathrm{th}}^{2013}$$

→ an increase by roughly 15% (~4.5e11 ppb)

- Additional changes:
  - Refined impedance model:
    `Allthemachine_HL-LHC_15cm_7TeV_5umMo+MoC_IP7_TCT5_B1`
  - Modeling of non-linear synchrotron motion to take into account synchrotron tune spread



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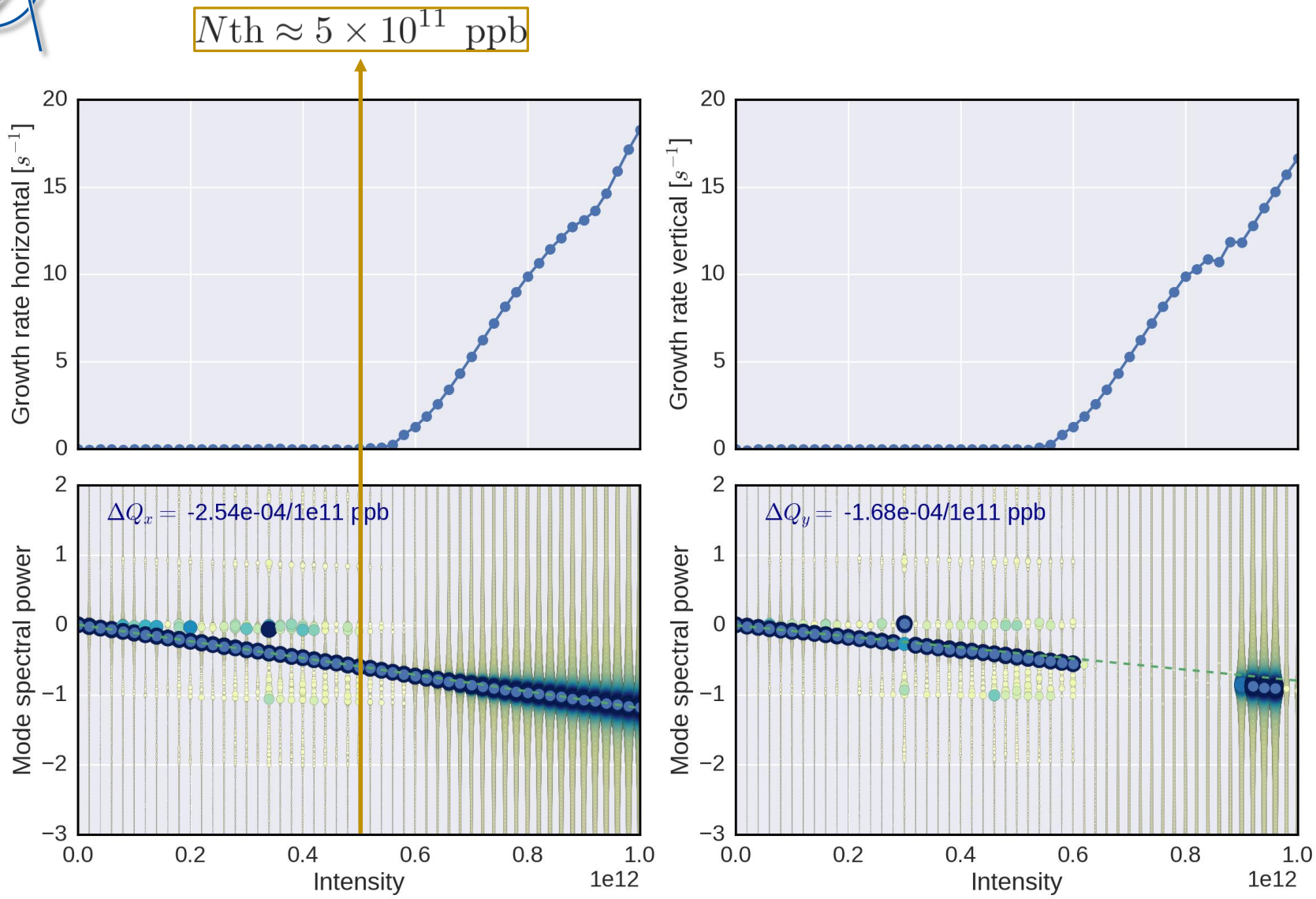
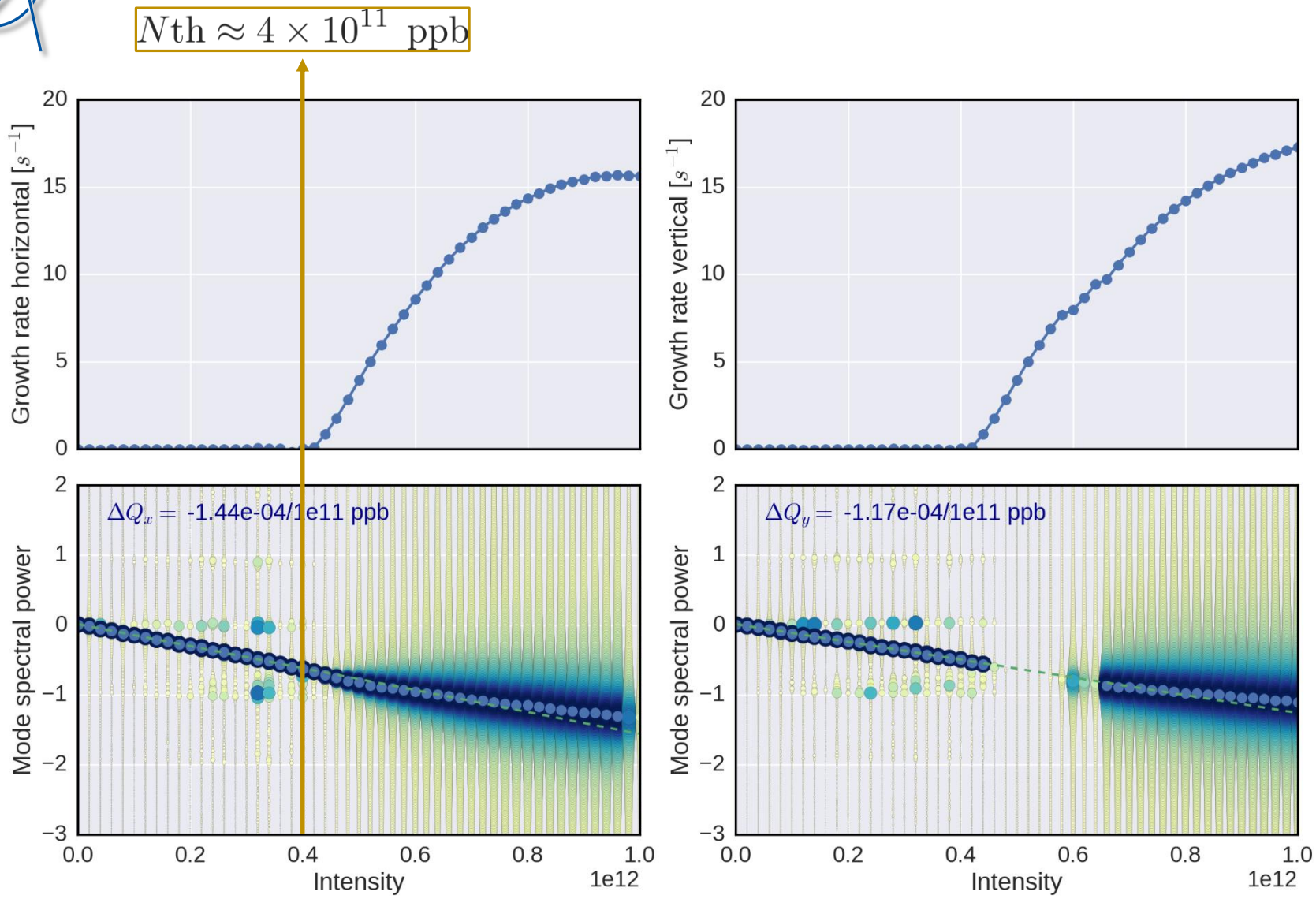
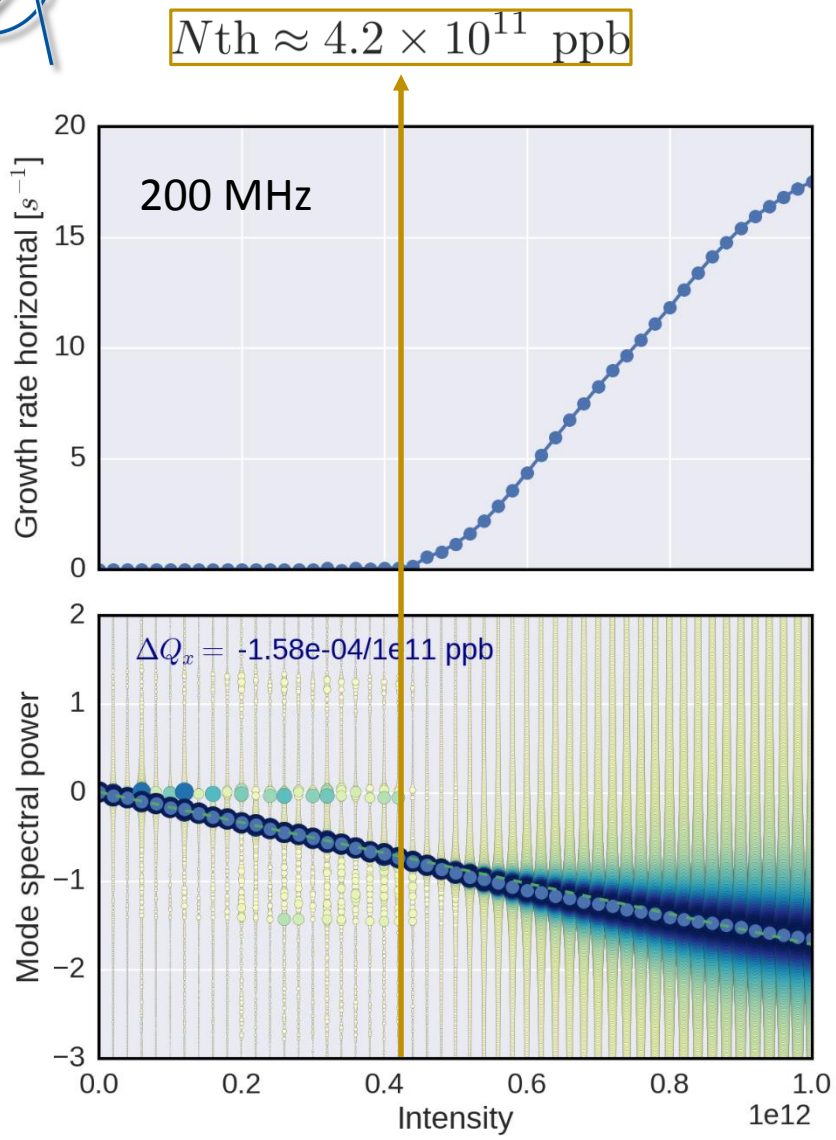
400 MHz TMCI

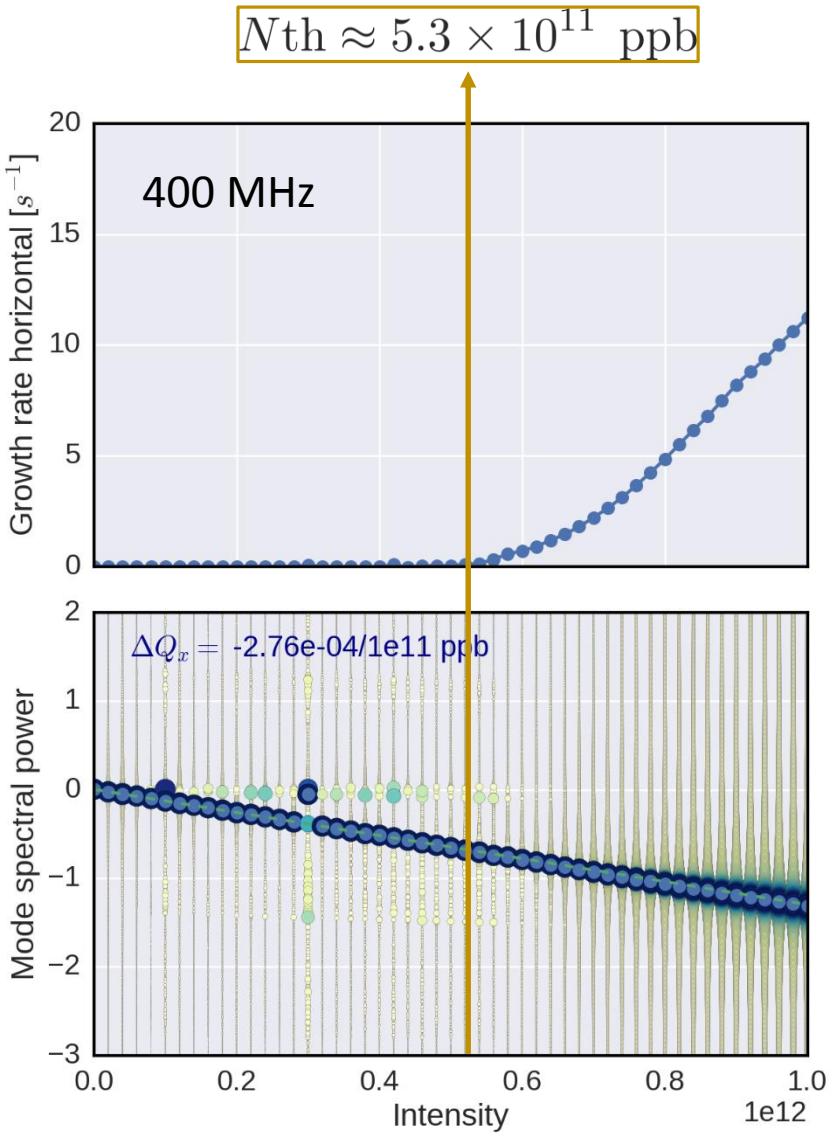

$Nth \approx 5 \times 10^{11}$ ppb
Growth rate horizontal [s^{-1}]
Growth rate vertical [s^{-1}]
Mode spectral power
$\Delta Q_x =$ -2.54e-04/1e11 ppb
$\Delta Q_y =$ -1.68e-04/1e11 ppb
Intensity
1e12

200 MHz TMCI


$Nth \approx 4 \times 10^{11}$ ppb
Growth rate horizontal [s^{-1}]
Growth rate vertical [s^{-1}]
$\Delta Q_x =$ -1.44e-04/1e11 ppb
$\Delta Q_y =$ -1.17e-04/1e11 ppb
Mode spectral power
Intensity
1e12

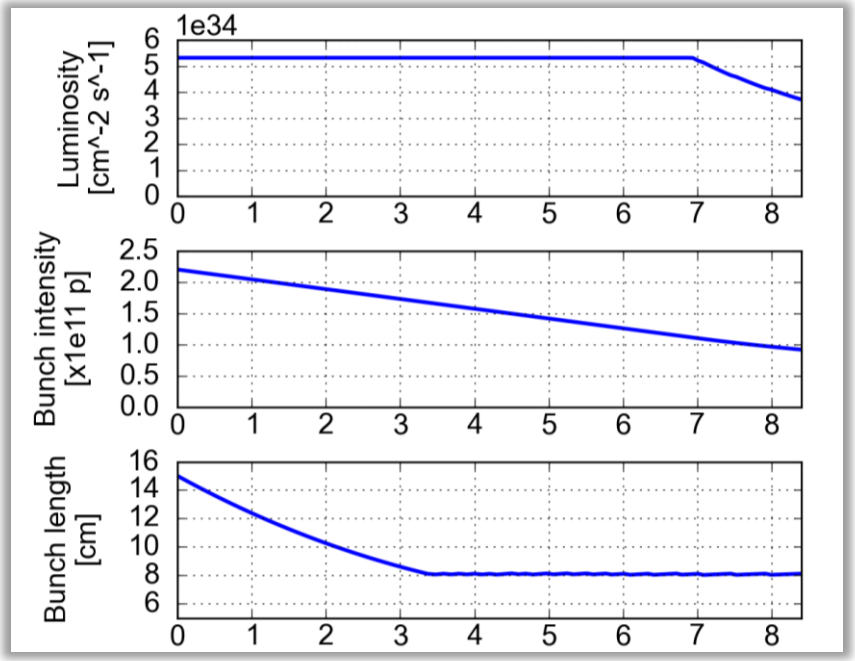
Bunch shortening mode



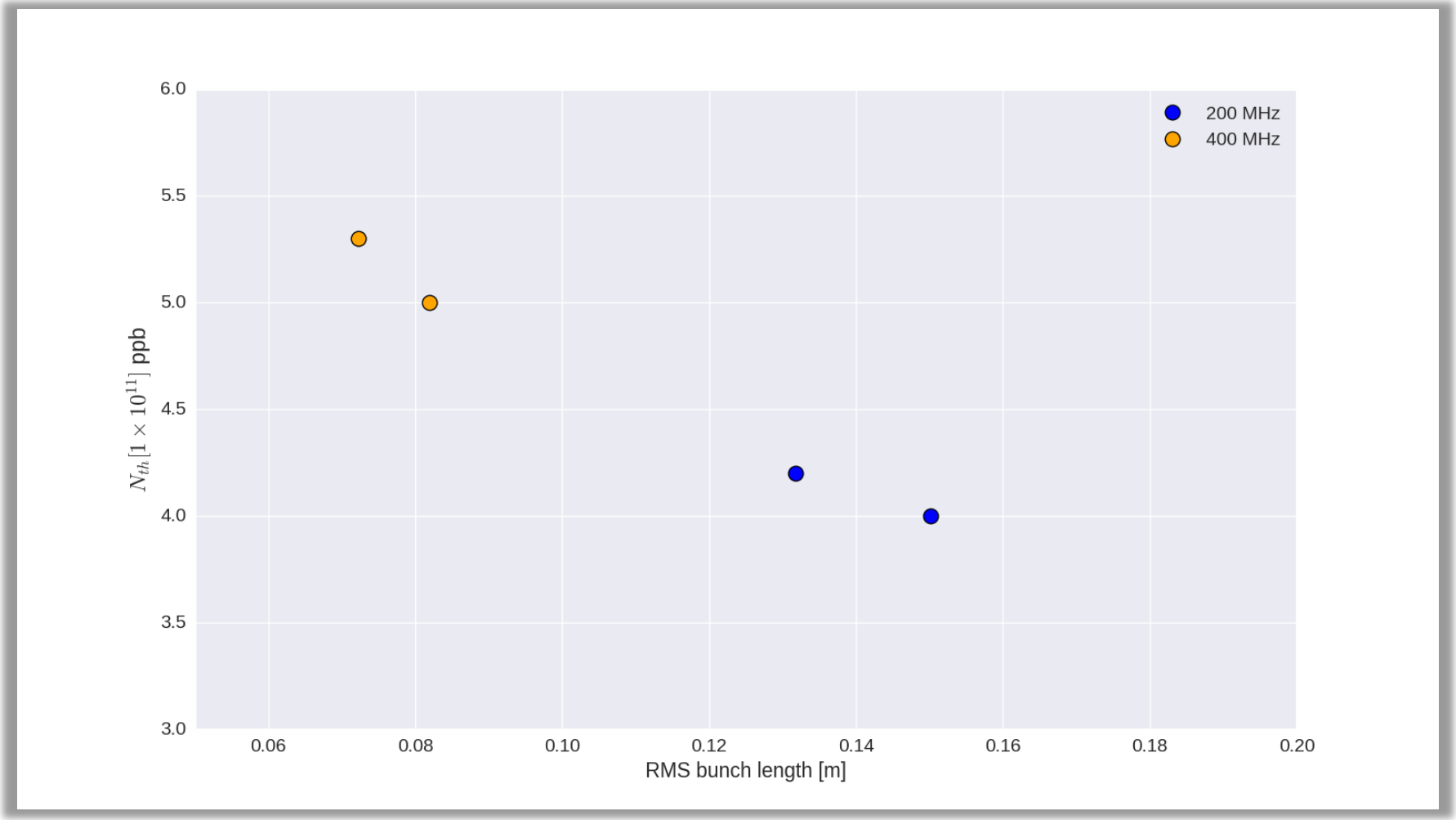


Collision scenarios

- What happens during collisions when bunch parameters are changing?
- Worst case: bunch shortens and voltage constant → check dependence on bunch length for extrapolation.
- Remember: stabilisation expected from the head-on collisions though.

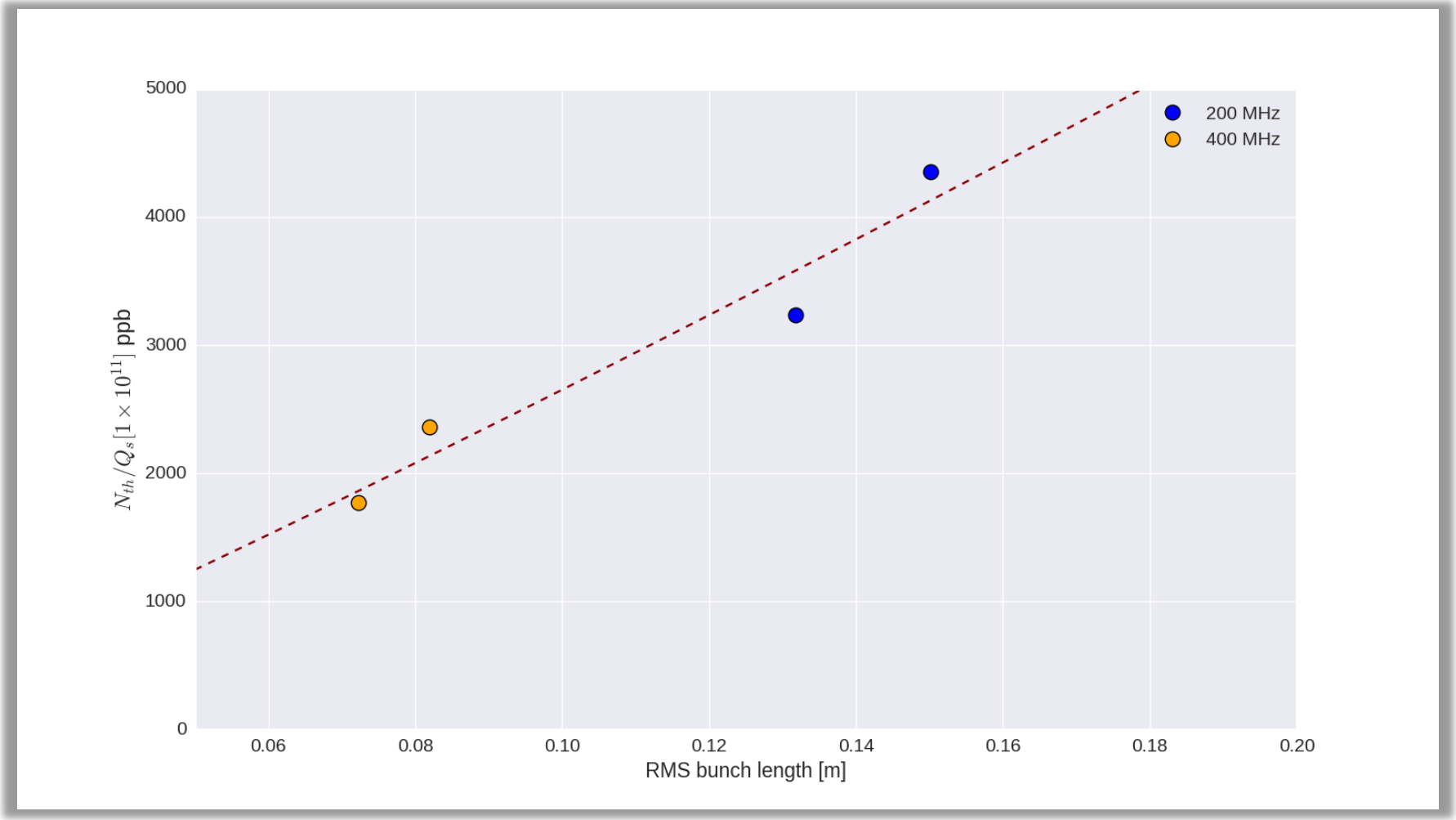


Thresholds summarized



- Both the effect of Qs and the bunch length are included, here.

Thresholds normalized



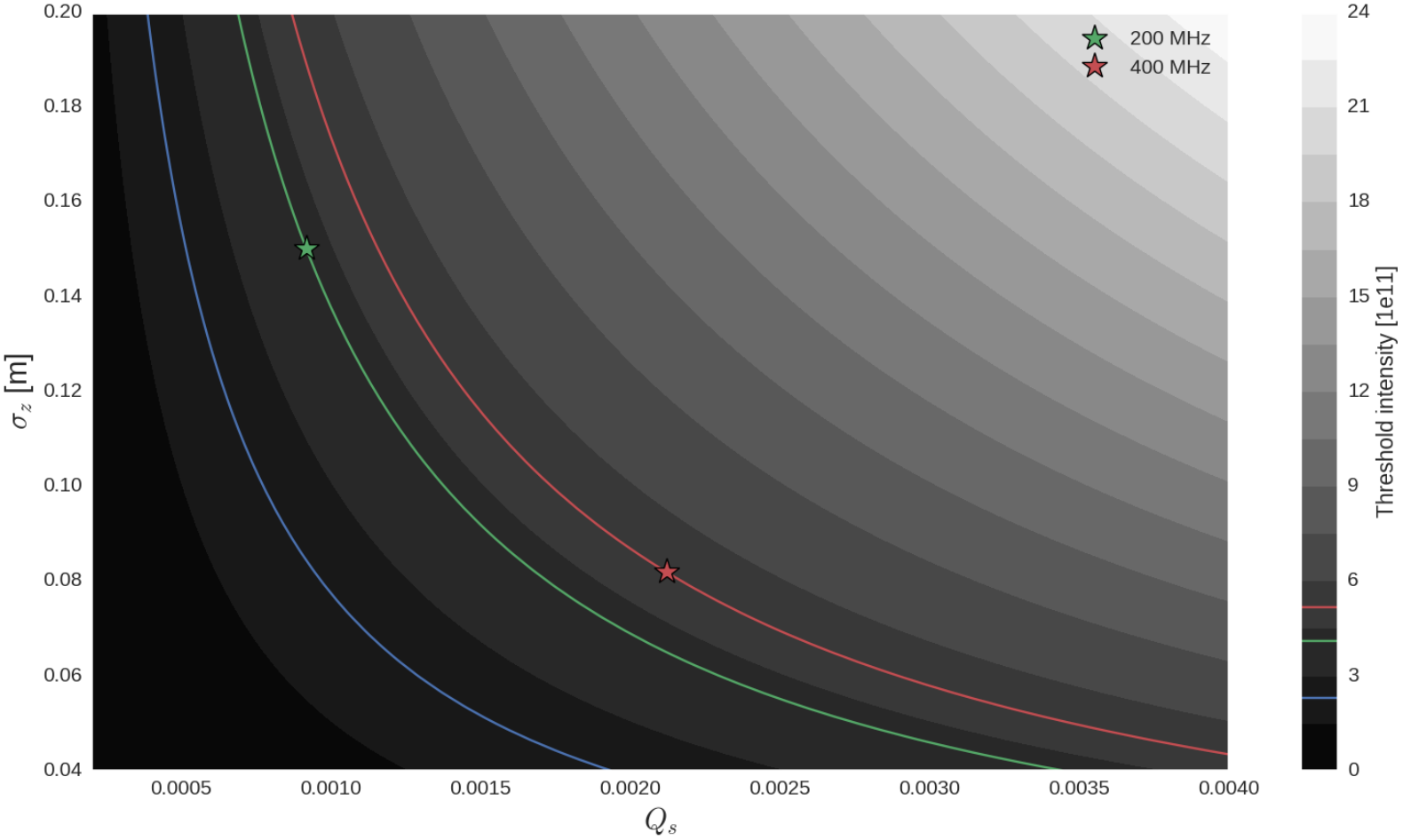
- Nonlinear synchtrotron motion makes scaling and extrapolation to bunch lengths tricky…

Thresholds vs. Qs and bunch length

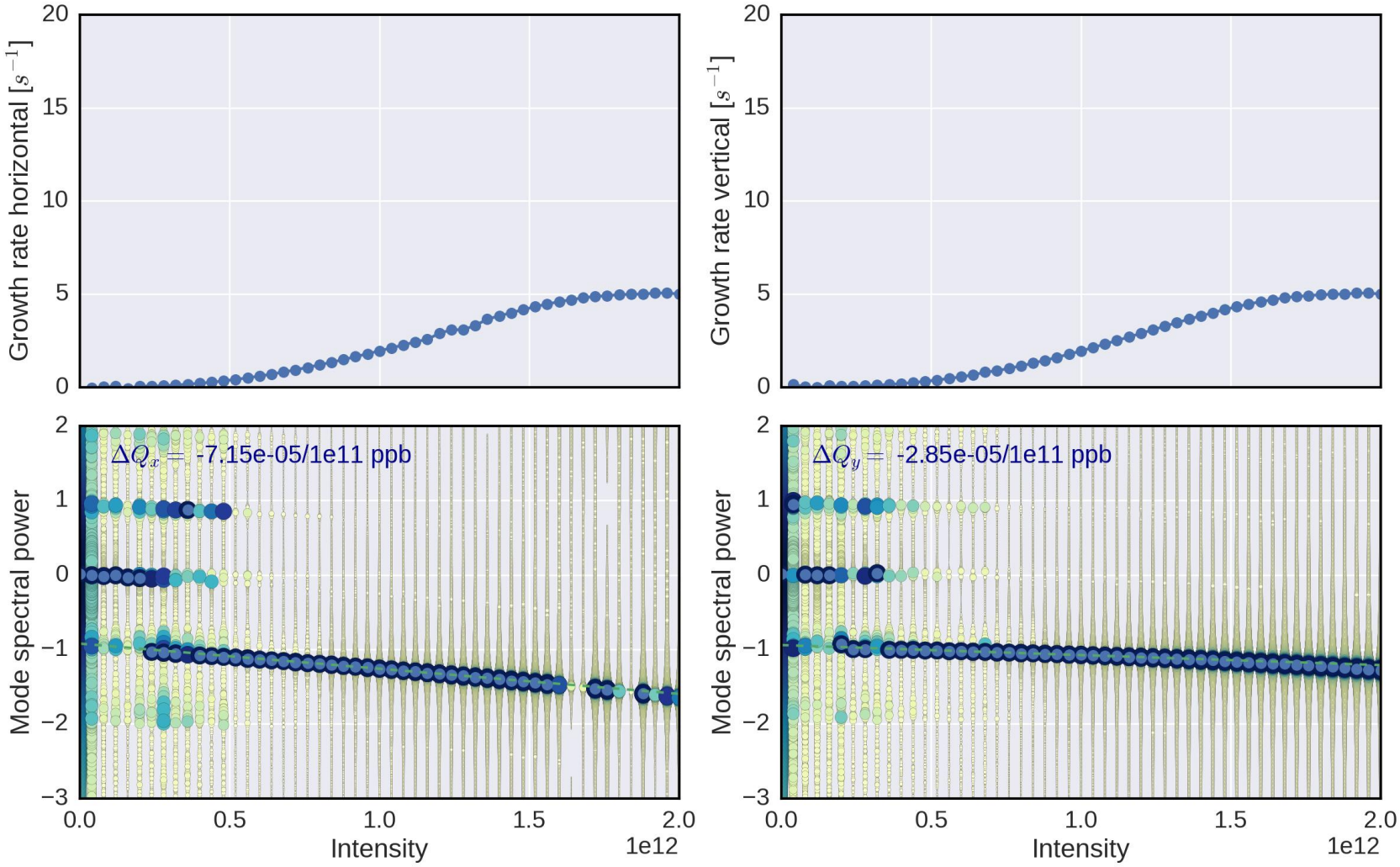
Assuming the TMCI thresholds occus at:

$$N \times \frac{\Delta Q_{\text{eff}}}{\sigma_z \omega_s} = -1$$

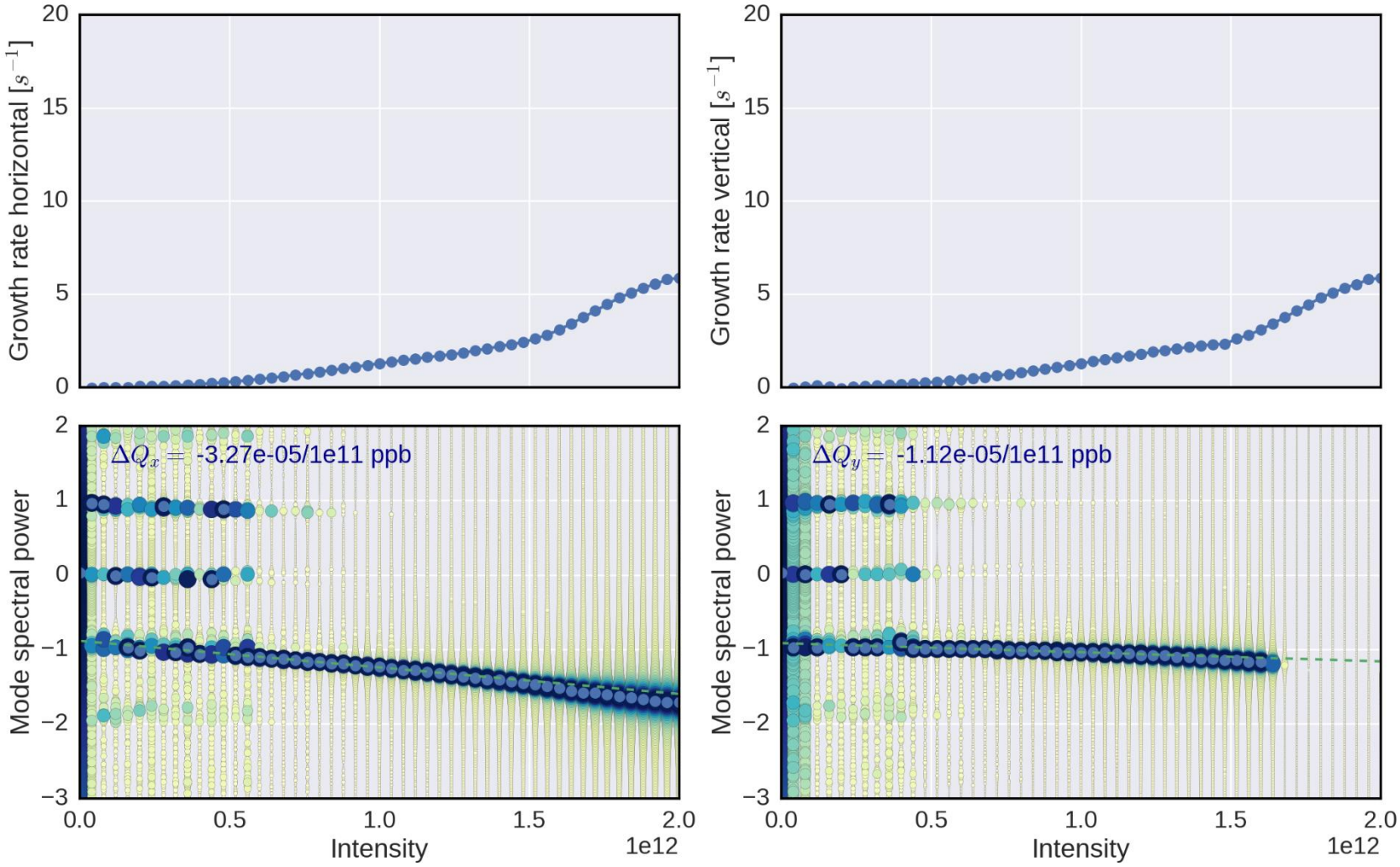
we obtain ΔQ_{eff} from the simulation (verifying it is identical for all cases) and can display the TMCI thresholds as a function of Q_s and σ_z



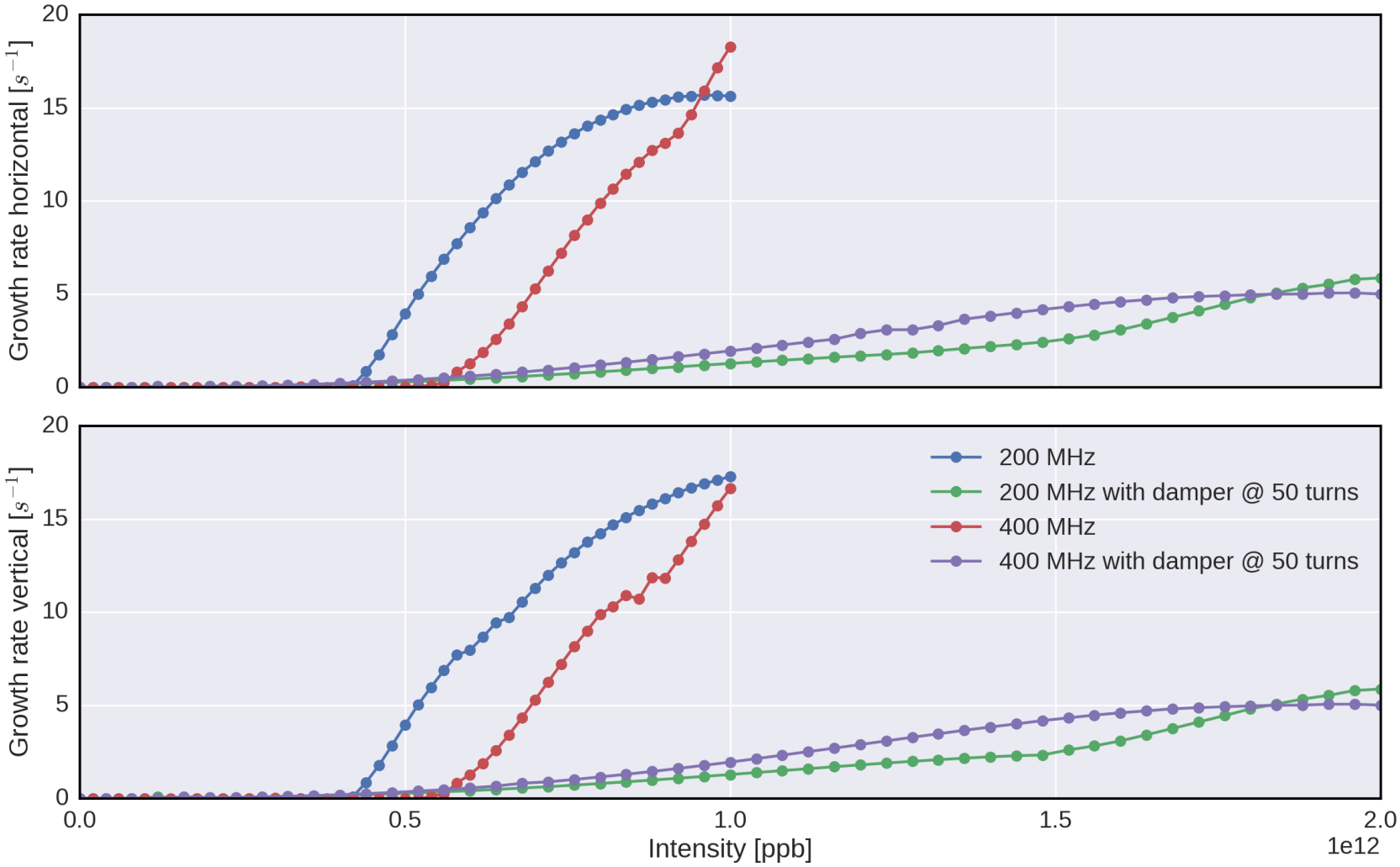
400 MHz with damper



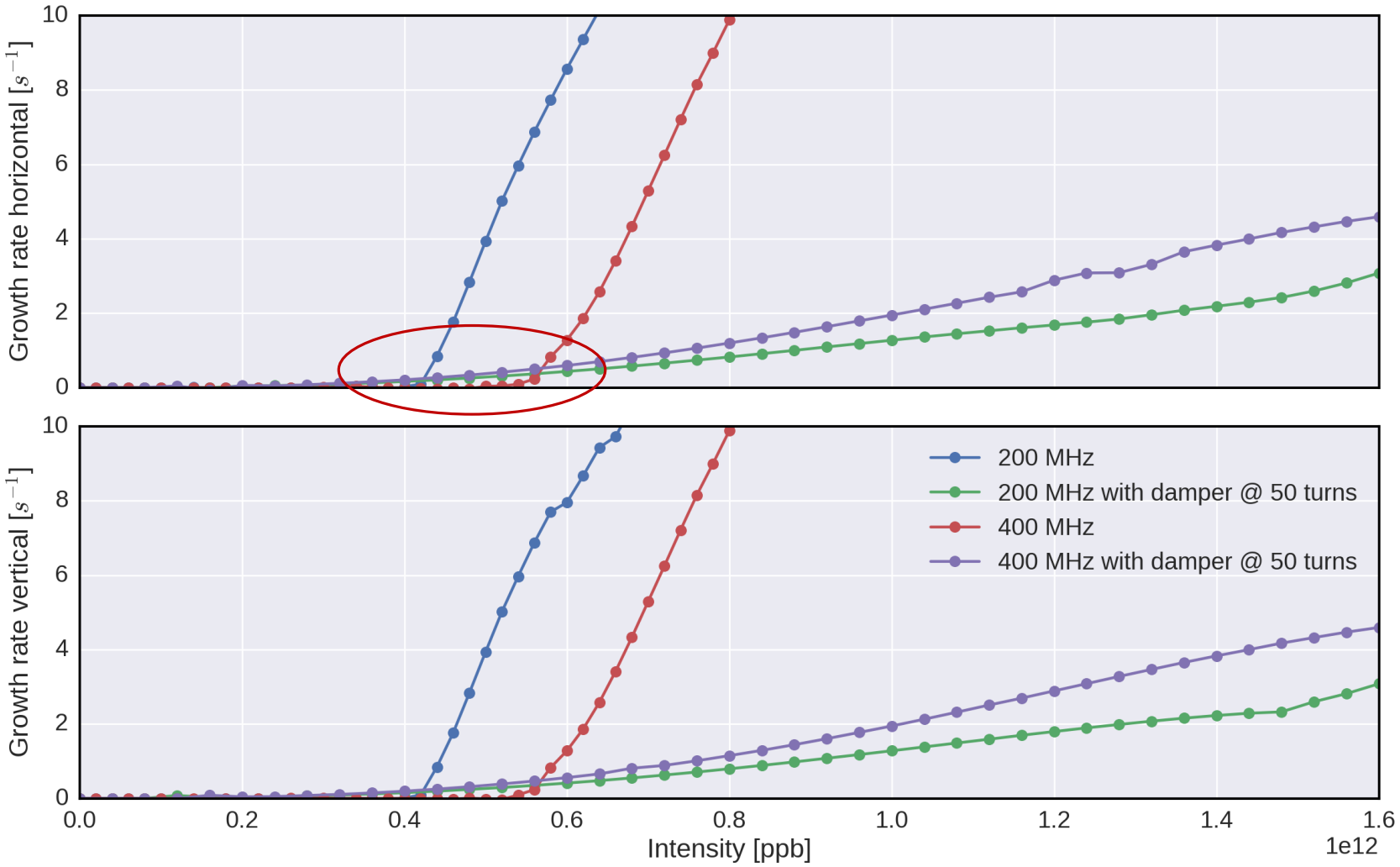
200 MHz with damper



Growth rate comparison



Growth rate comparison – close-up



Conclusions

- 200 MHz TMCI threshold, for current parameters at roughly 4e11 ppb
- Extrapolation to scenarios during collision (bunch shorting) still to be completed
- Damper still needs more detailed checks in particular in view of possibility of stabilsation
- Still, 200 MHz gives lots of additional flexibility (bunch profiles, longitudinal stability). With the previous limits becoming less critical this option may have considerable benefits.

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