Beam stability with separated beams at 6.5 TeV

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Beam stability with separated beams at 6.5 TeV

- Context: possible instabilities in the LHC
- Current knowledge of LHC impedance and single-beam instabilities observed
- Post-LS1 impedance scenarios
- Effect of bunch spacing
- Available beam parameters space

Context: possible instabilities in the LHC

- Recent evolution in understanding of instabilities when a strong bunch-by-bunch transverse damper is on -> headtail modes can be damped / excited by damper (cf. talks by A. Burov, e.g. http://lhc-beam-beam.web.cern.ch/lhc-beam-beam/forum/NHT_APForum_Dec2012.pdf at AP forum).

- With damper, we can distinguish several types of instabilities:

  - those that can be damped with high enough damper gain: coupled-bunch rigid modes, "traditional" headtail modes at non-zero chromaticity,

  - those that cannot be damped by increasing damper gain (or with great difficulty): some radial modes such that bunch centroids stay close to zero -> require Landau damping,

  - TMCI (transverse mode-coupling instability) might not be an issue anymore with strong damper (to be checked experimentally).

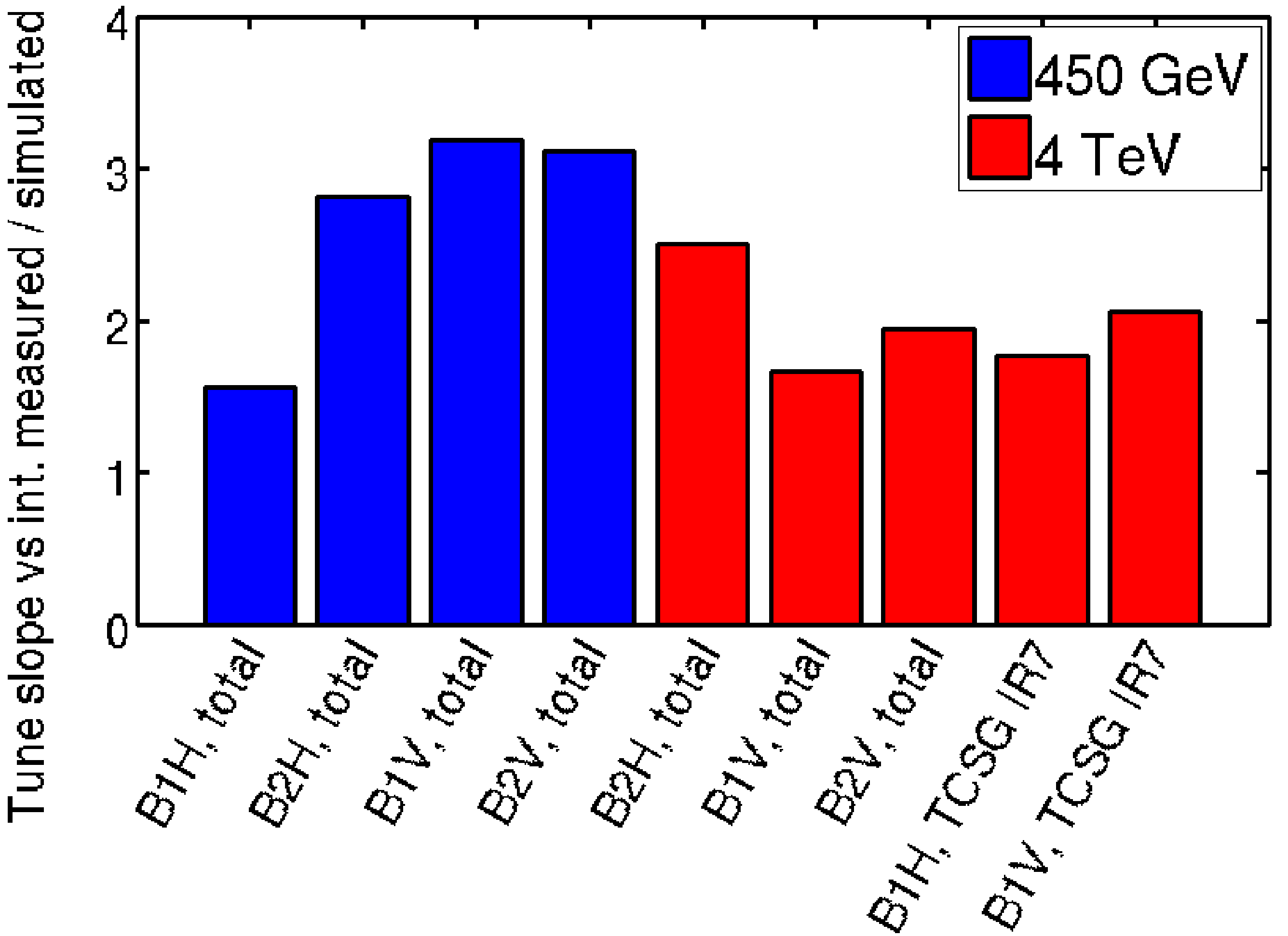
- These can be estimated thanks to

  - the LHC impedance model: (resistive-)wall impedance from collimators, beam-screens, vacuum pipe and broadband model from design report,

  - and beam dynamics simulations (HEADTAIL multibunch code now with bunch-by-bunch ideal damper – soon with more realistic damper) / models (ABA model by N. Mounet and A. Burov, NHT model by A. Burov).

Current knowledge of the LHC impedance

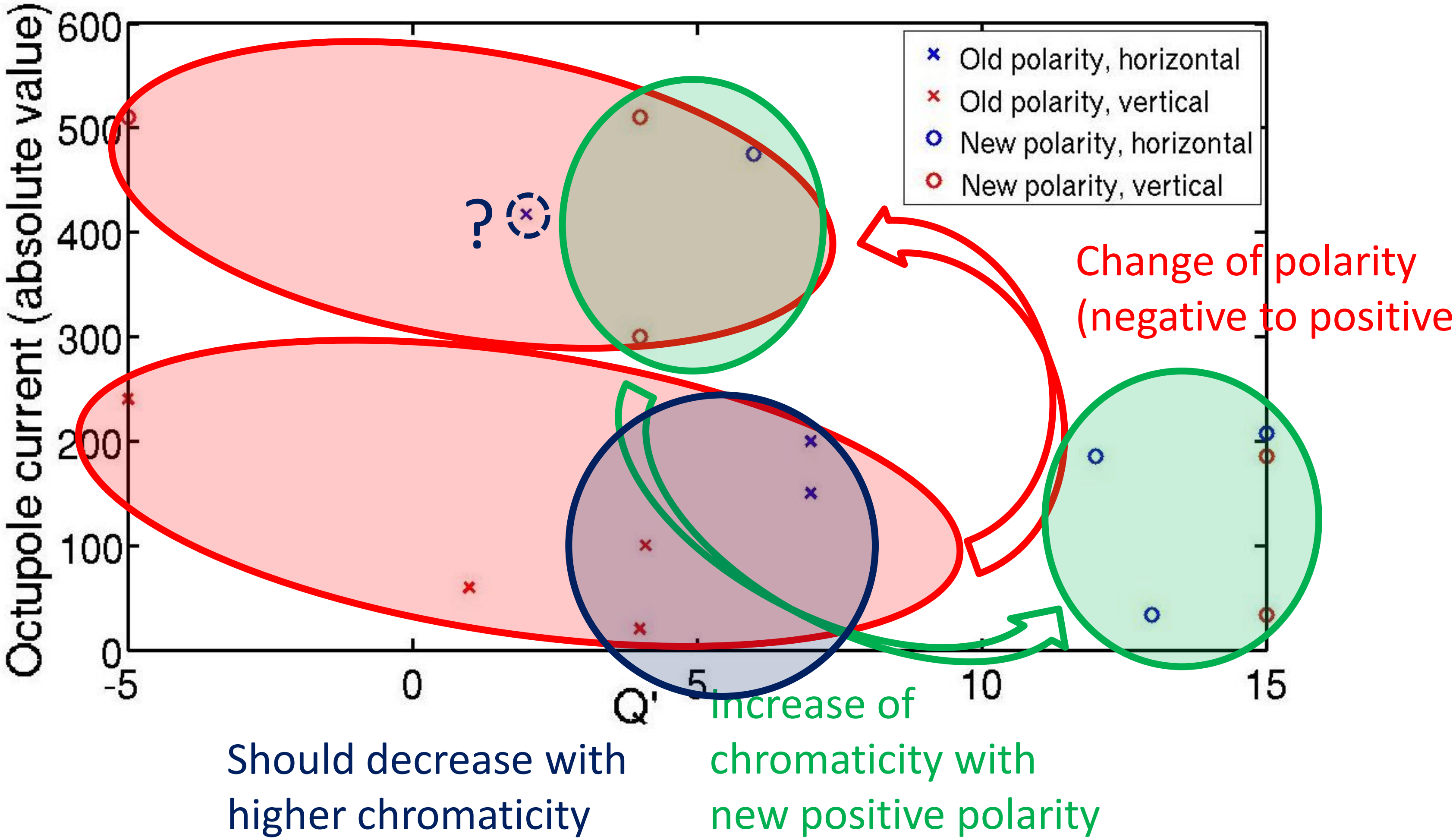
- Discrepancy factor between 2012 tune shift measurements and HEADTAIL simulations with LHC impedance model:



Almost complete set of **total** tune shift measurements vs. intensity, including at **4 TeV** (RF MD, J. Esteban-Müller et al)

⇒ Factor **~3 at 450 GeV**, **~2 at 4TeV** (consistent and more precise than 2010-2011 measurements).

Single-beam and flat top instabilities observed this year (not the problematic end-of-squeeze ones – cf. E. Métral & T. Pieloni's talks)



Note: beam and machine parameters are sometimes slightly different between these measurements.

Beam stability limit with separated beams at 4 TeV

- Reminder: instab. with separated beams were **not "really problematic"**; they happened in physics relatively rarely, most of the time with unfavourable machine parameters (low octupole current and / or low chromaticity).

- Highest octupole current (absolute value) observation of these instabilities at 4 TeV, with **high Q'** ($\varepsilon \approx 2.5$ mm.mrad , int. ≈ 1.5e11 p+/b):
  - Old polarity: **- 200 A** (Q'=7). **No data available for Q'>7 ! Might be quite lower for higher Q'.**
  - New polarity: **+ 200 A** (Q'=15).

- **High chromaticity** region is preferable (also less sensitive to Q' – see A. Burov).

  ⇒ will assume Q' between 10 and 20 for post-LS1 operation → only impedance at **high frequency** matters.

Post-LS1 impedance scenarios

- Based on collimator scenarios given by S. Redaelli & colimation team (see also B. Salvachua's talk later on).
- 2 extreme cases and one intermediate one:
  - "**nominal**": most critical, IR7 collimators closer than now (except TCPs)

    $\Rightarrow$ at high frequency (>1MHz): up to **50 % higher impedance**.

  - "**tight settings**": close to 4TeV 2012 settings

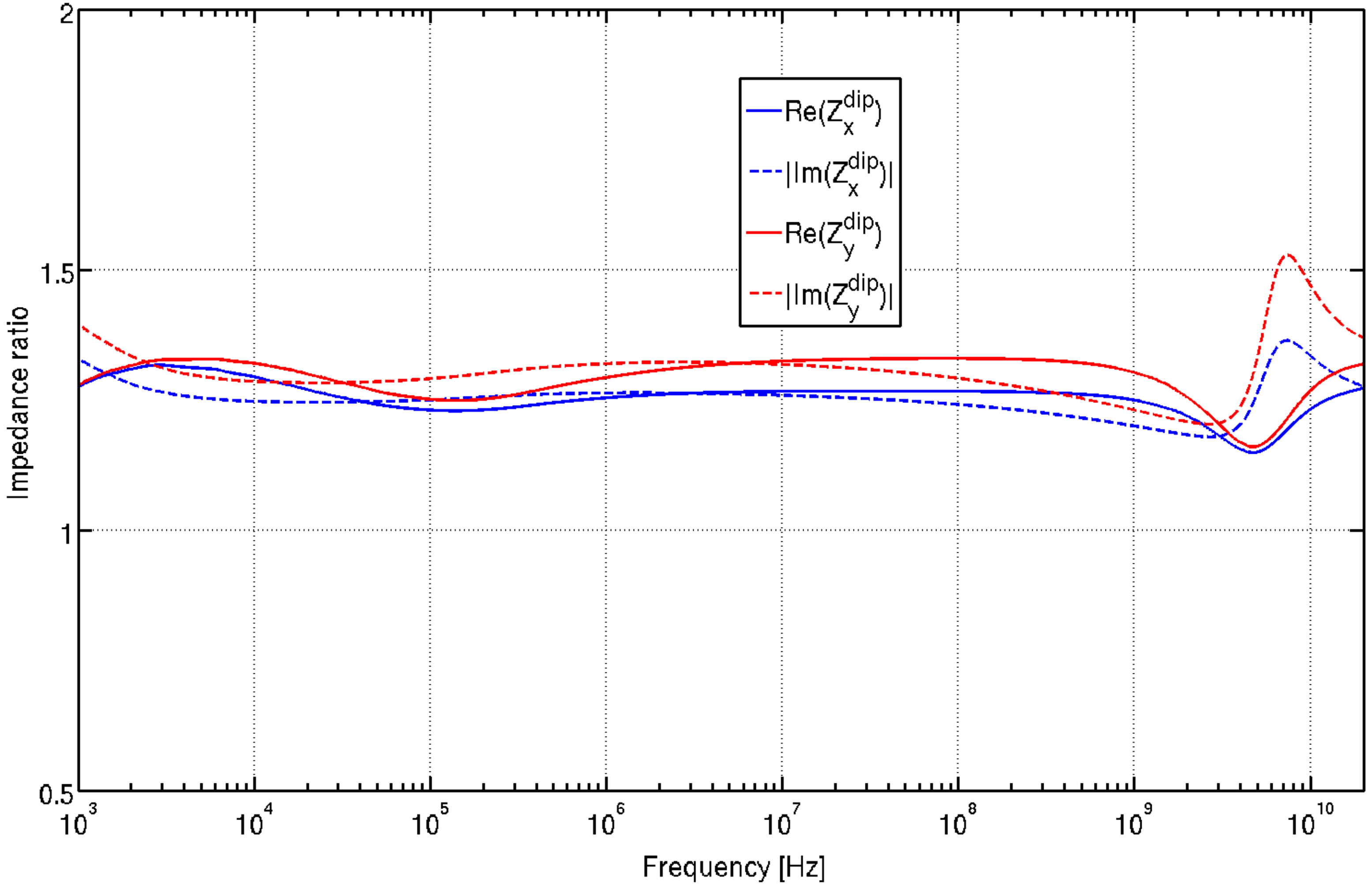
    $\Rightarrow$ at high frequency (>1MHz): no more than **10 % higher impedance**.

  - "**relaxed**": most relaxed collimators settings, close to 2011 settings.

    $\Rightarrow$ at high frequency (>1MHz): at least **25 % lower impedance**.

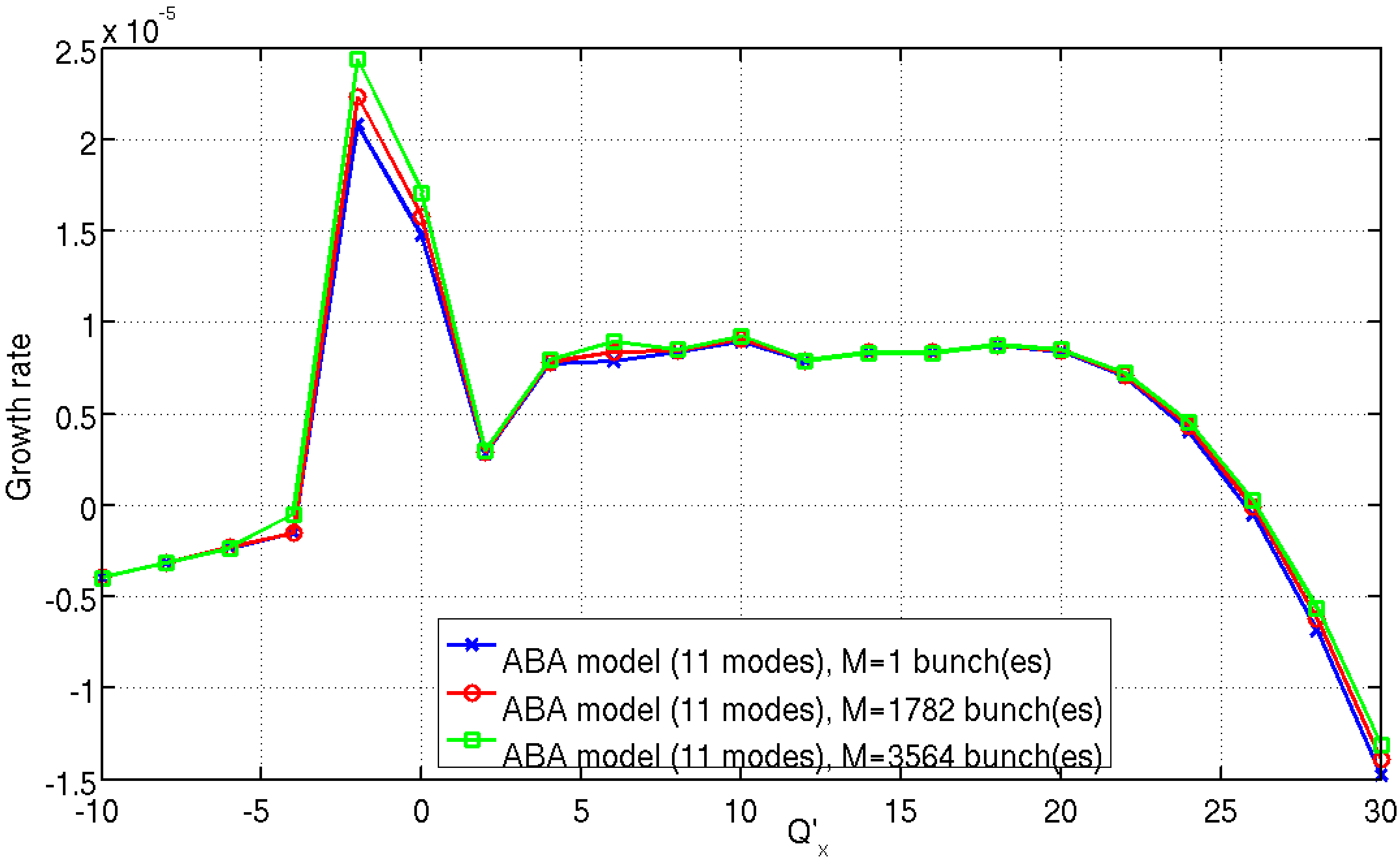
Post-LS1 impedance scenarios

- Ex: nominal impedance compared to 4TeV 2012 impedance (ratio between the two)



Effect of bunch spacing with damper on

- With damper (50 turns), **no difference** between 25ns , 50ns or even single-bunch (was first indicated by A. Burov – NHT model),

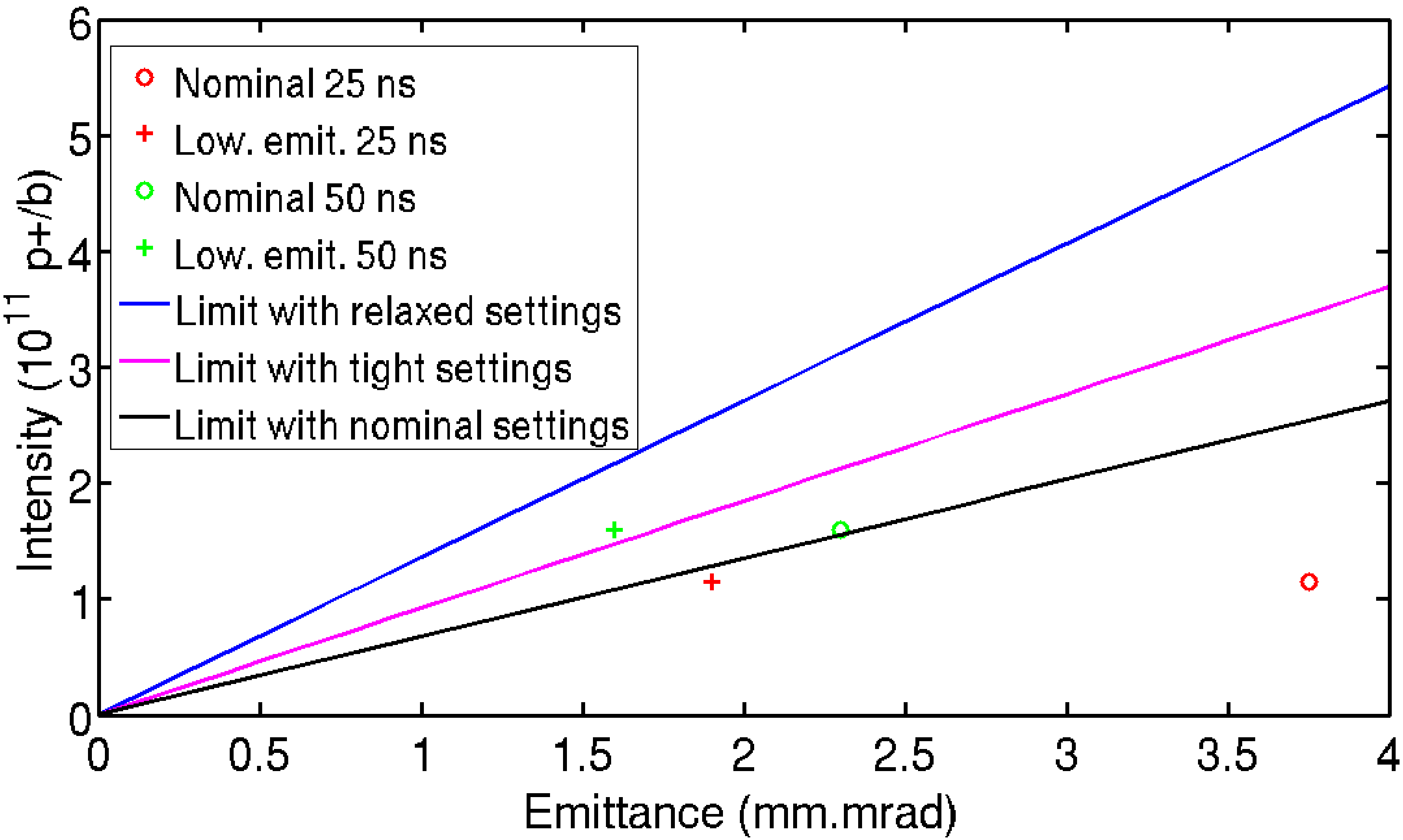


Beam parameter space with separated beams post-LS1

- Strategy: based on maximum octupole threshold observations in 2012 (with high Q' & damper on with 50 turns damping)
- Apply various scaling factors:
  - Stability diagram (Landau damping) proportional to geometric emittances & octupolar field, both decrease as $1/\gamma$,
  - Coherent tune shifts also decrease as $1/\gamma$,
  - Assume coherent tune shifts proportional to intensity (rather strong assumption, even if we are far from TMCI).
  - Remember that number of bunches & bunch spacing have no impact.

=> Assuming maximum ocupole current (550 A) at 6.5 TeV, we can evaluate the limit as a curve intensity = f(ε).

Beam parameter space with separated beams post-LS1



=> No problem with 25 ns, standard 50ns close to limit for nominal coll. settings, but low emittance 50 ns can pass only with relaxed settings.

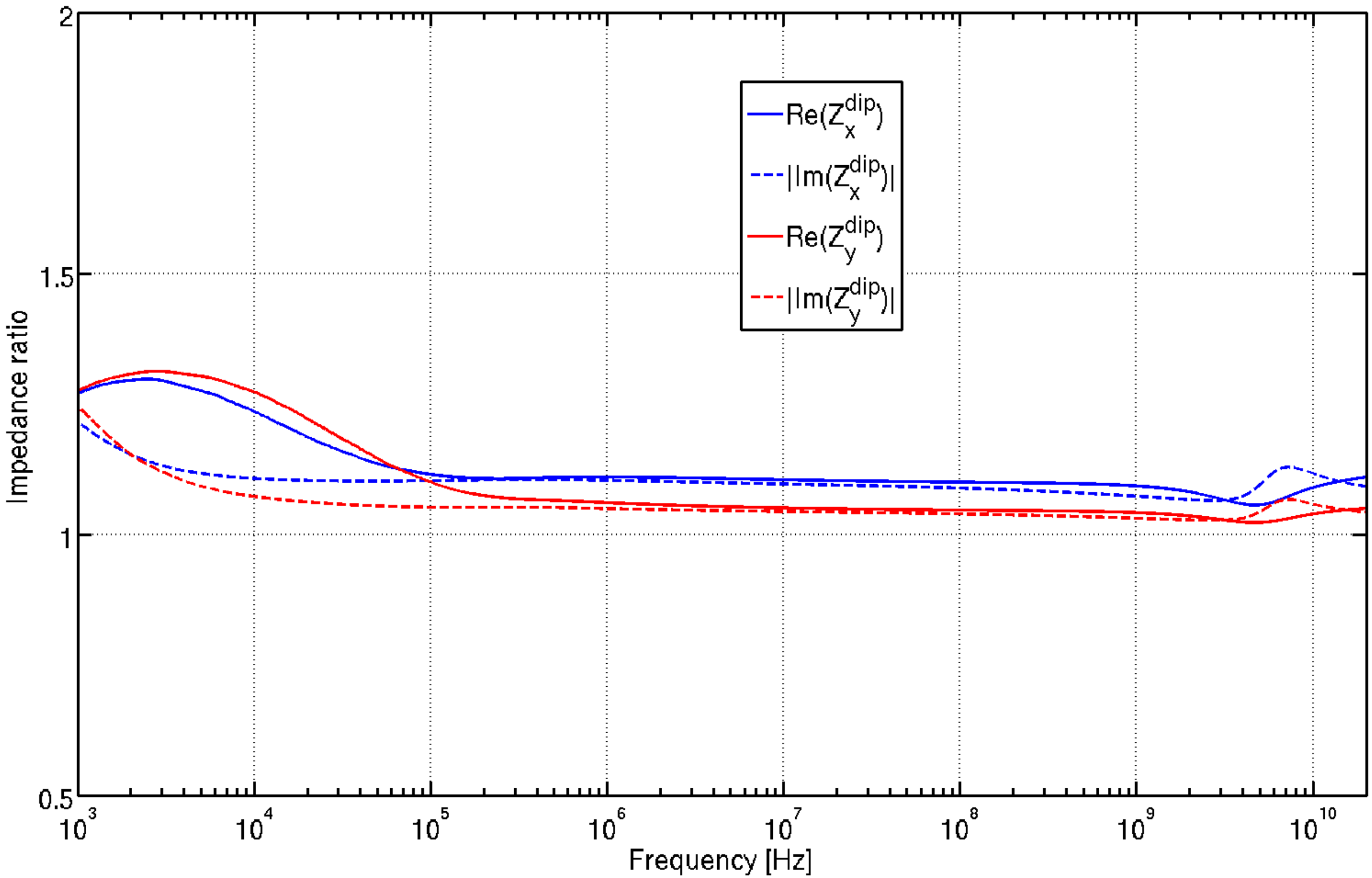
Conclusion

- Total single-bunch tune shifts measurements show a discrepancy factor of ~2 at 4TeV w.r.t impedance model.
- At 4TeV, single-beam stability for oct. around +/- 200 A at high Q', but Q'>7 was not much tested with (old) negative polarity octupoles -> could reduce this number.
- Collimator settings scenarios at 7TeV give impedance between 0.75 and 1.5 times the current 4TeV one.
- 25ns / 50ns has no impact on single-beam stability (from impedance only) when damper on and sufficiently strong.
- We are close or above the limit for 50ns beam parameters in post-LS1 operation (depending on collimators), and fine with 25ns parameters.

Backup slides

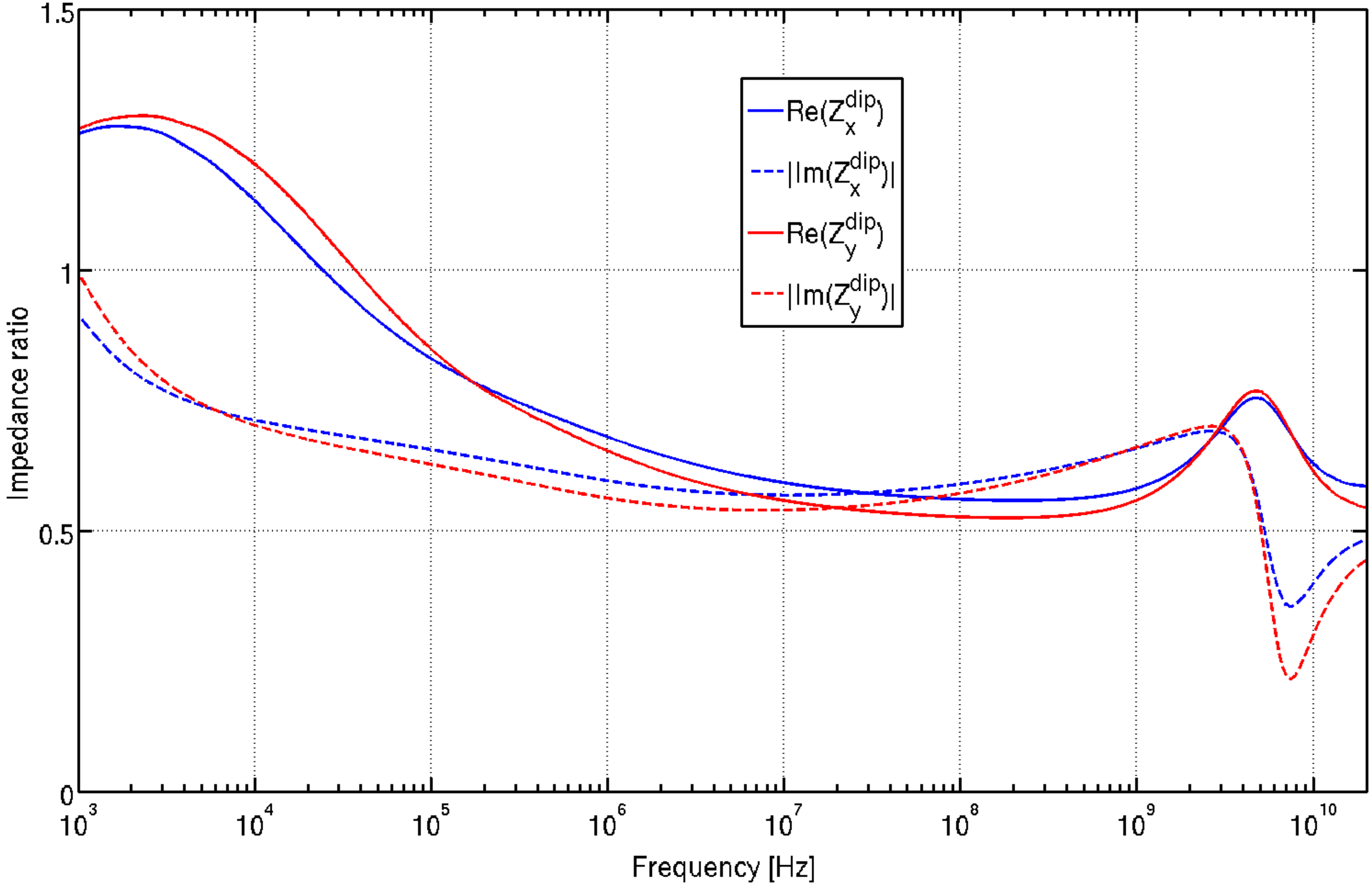
Post-LS1 impedance scenarios

- Ex: "tight settings" impedance compared to 4TeV 2012 impedance (ratio)



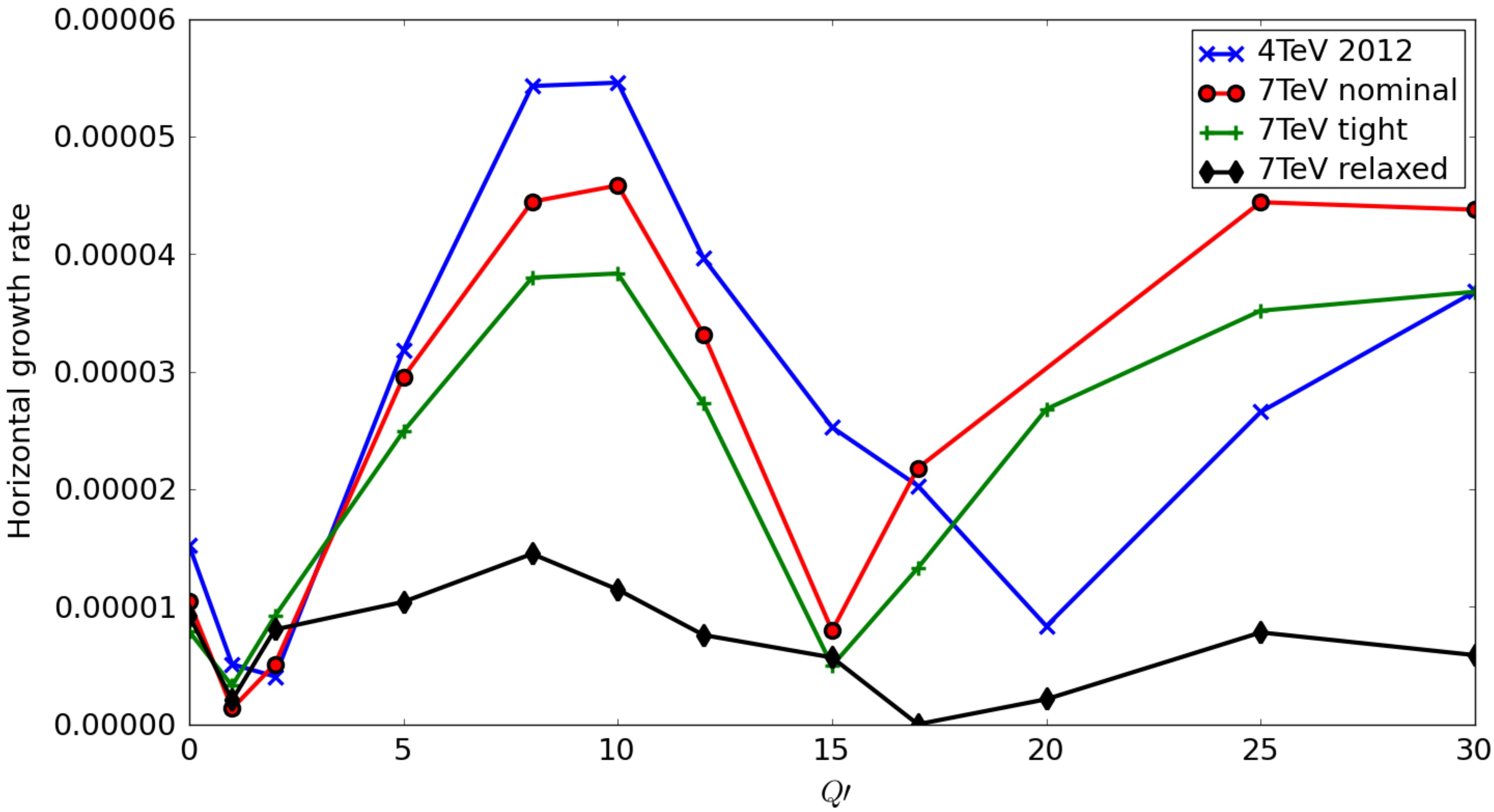
Post-LS1 impedance scenarios

- Ex: “relaxed” impedance compared to 4TeV 2012 impedance (ratio)



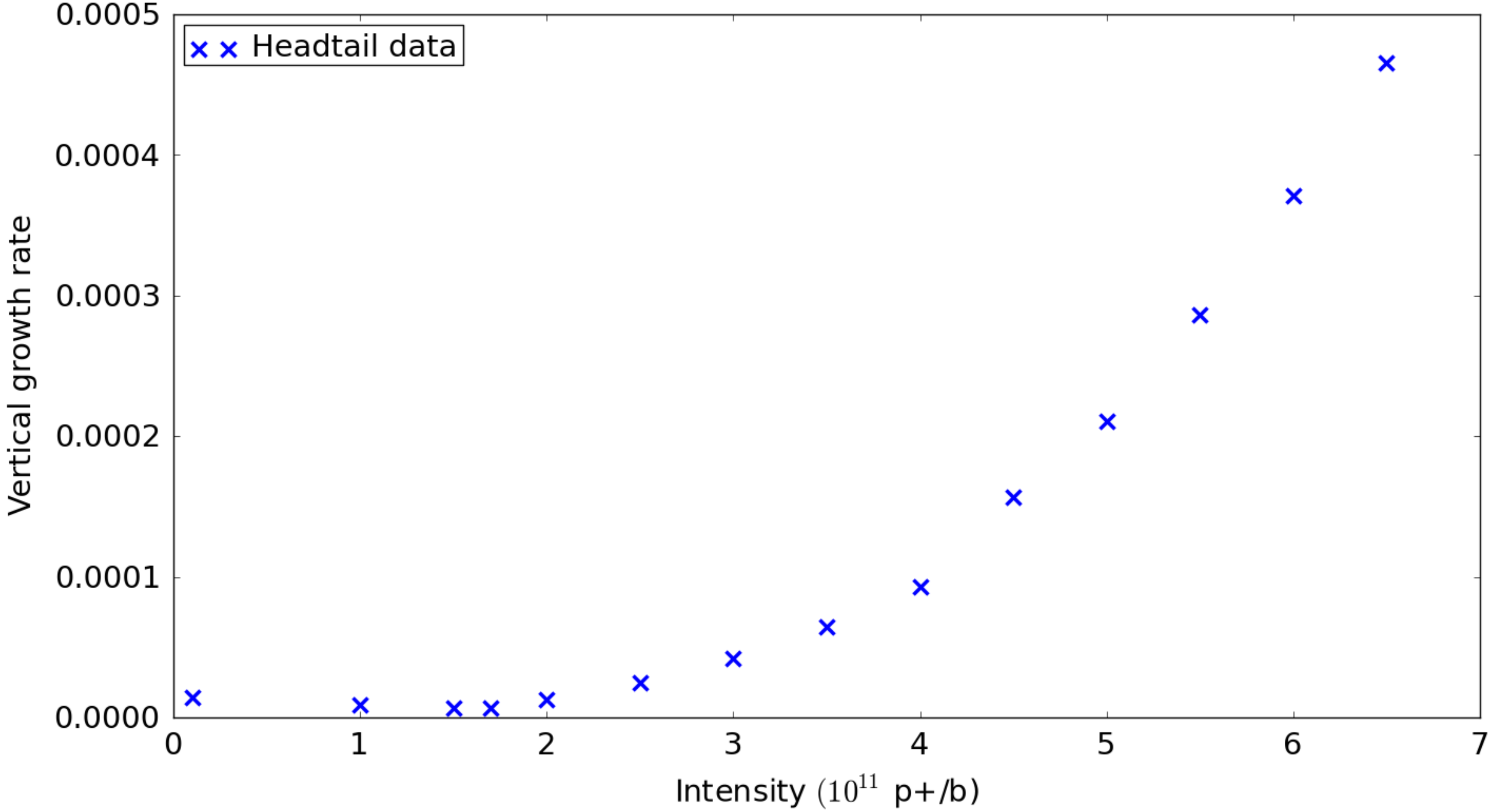
Post-LS1 impedance scenarios

- Single-bunch HEADTAIL simulations with damper (50 turns): comparison between different scenarios



Post-LS1 impedance scenarios

- "Nominal" scenario: absence of clear TMCI, with damper (HEADTAIL simulations with Q'=0, damping 50 turns)



Similar to A. Burov's results