Impedance without IR3 upgrade

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Impedance without IR3 upgrade

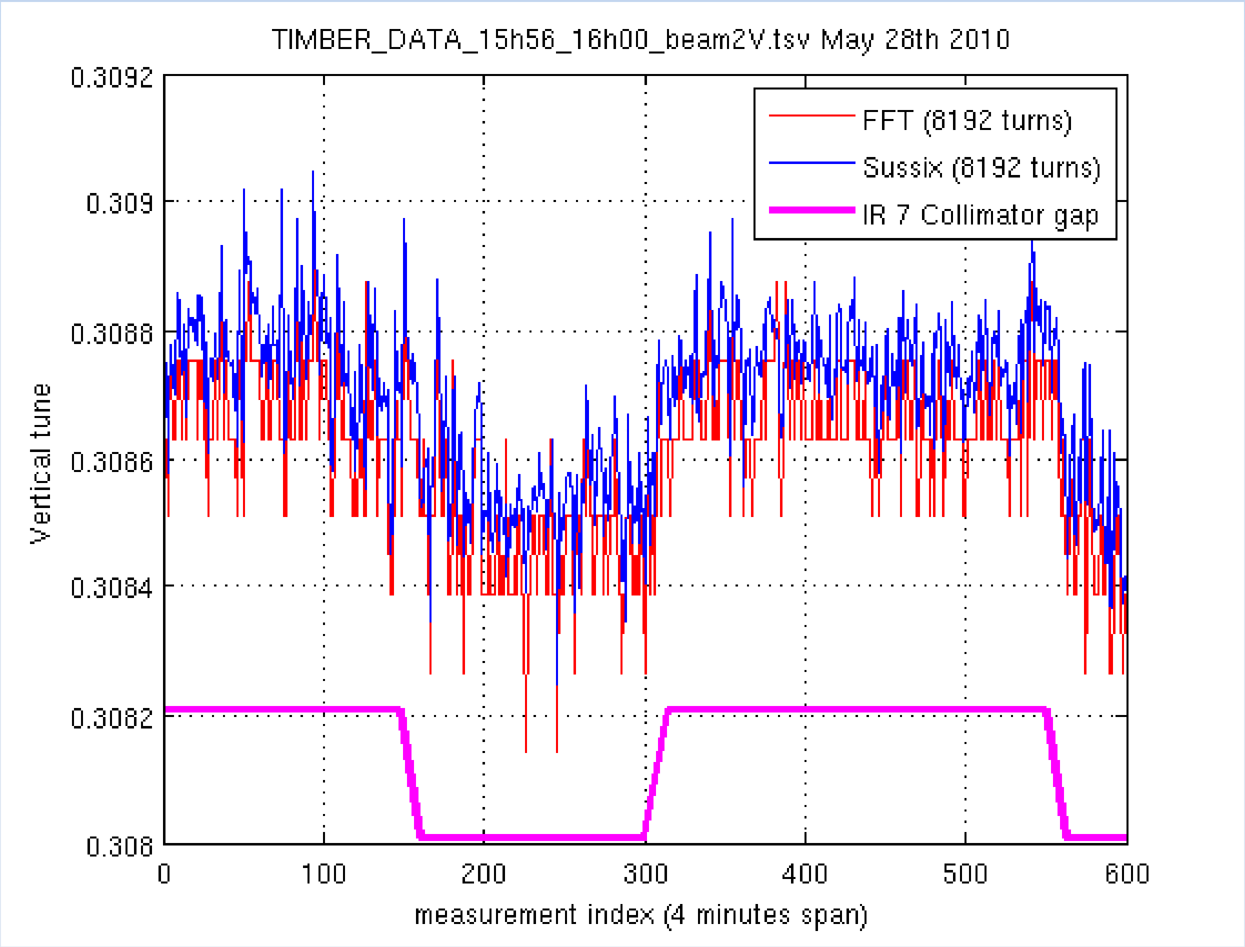
- Introduction: possible instabilities in the LHC
- Comparisons between beam-based measurements and impedance model
- Tight collimator settings (MD 08/05/2011): instability predictions for various scenarii

Possible instabilities in the LHC

- Single-bunch instabilities:
  - Headtail modes for positive chromaticity → any intensity, but usually weak instability. To be stabilized by Landau damping.
  - Transverse mode coupling (TMC) instability → only above a certain intensity threshold, very fast. Very difficult to cure (feedback upgrade).
- Coupled-bunch instabilities:
  - Coupled-bunch ”rigid-bunch” (coherent) modes with an oscillation along the bunch train → any intensity, quite strong, also at zero chromaticity. To be damped by transverse feedback.
  - Coupled-bunch headtail modes, with oscillations both intrabunch and along the bunch train → stronger than single-bunch headtail. To be stabilized by Landau damping.
  - Multibunch transverse mode coupling → very fast, above a certain intensity threshold (lower than single-bunch). Very difficult to cure.
- These can be estimated thanks to the LHC impedance model and beam dynamics simulations / theories.

Comparisons between model and beam-based impedance measurements

- Single-bunch: at 450GeV, moving in and out all IR7 collimators → tune shift (MD May 28th, 2010):

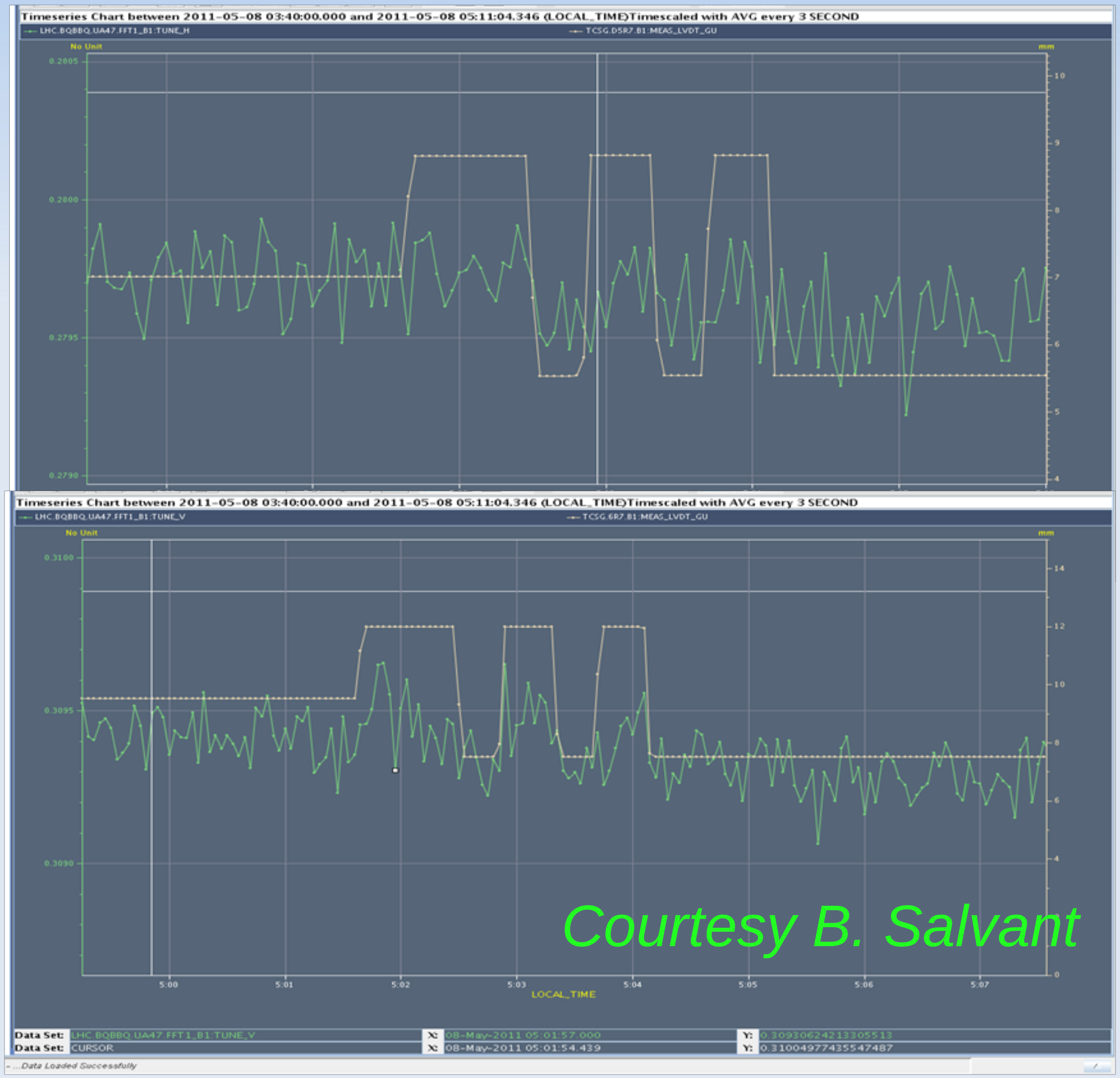


The tune shift is correlated to the collimator position.
→ ΔQy (meas.) ~ -2.4 10^{-4}
→ Vertical tune shift prediction when moving IR7 from 15σ to 5σ (impedance model with measured collimator and beam settings, Sacherer formula):
ΔQy (theory) ~ -2.0 10^{-4}

Courtesy B. Salvant

Comparisons between model and beam-based impedance measurements

- Single-bunch: at 3500GeV, moving in and out all TCSG IR7 collimators → tune shift (MD May 7th, 2011):

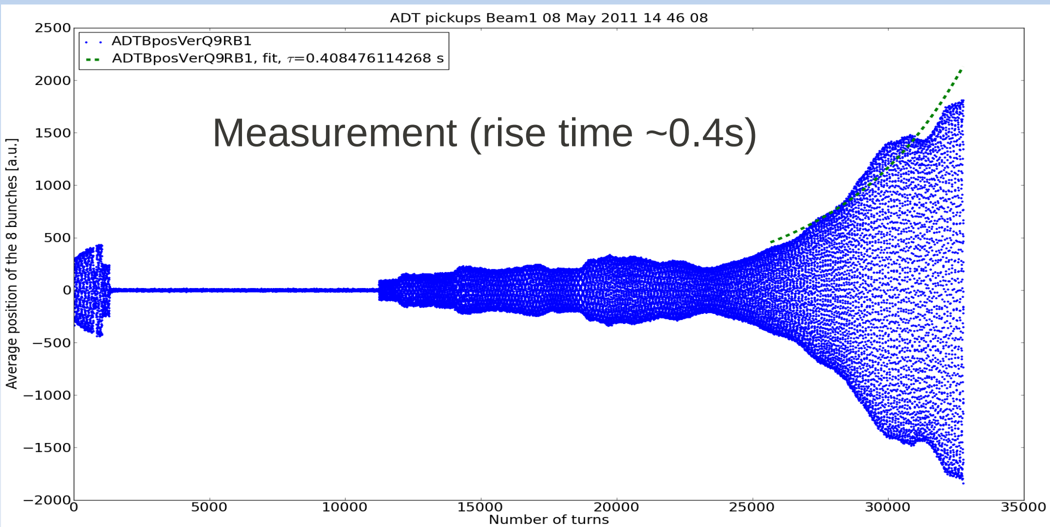


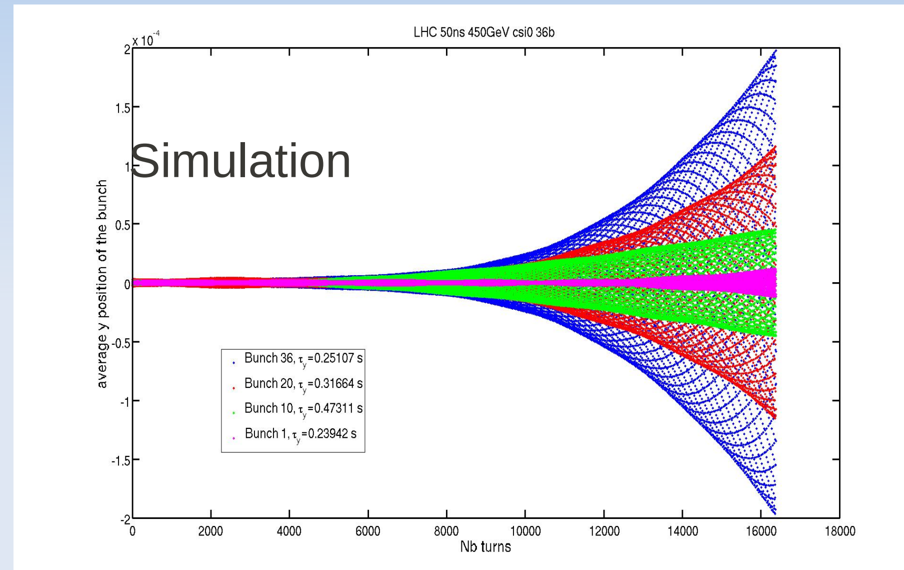
The tune shift seems correlated to the collimator position.
→ ΔQx (meas.) ~ -1. 10^{-4}
ΔQy (meas.) ~ -1. 10^{-4}

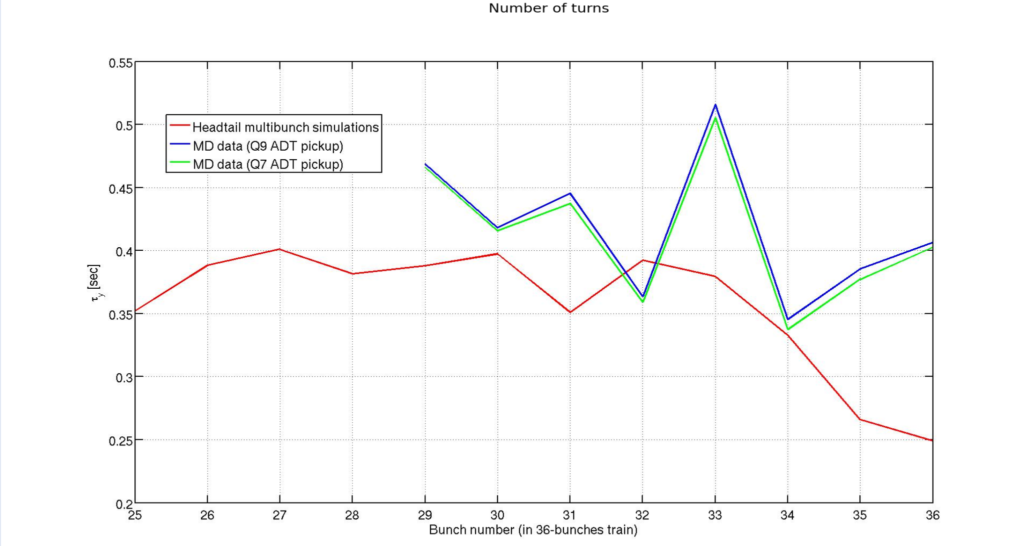
→ Vertical tune shift first estimate from simulations, when moving IR7 from 11.2σ to 7.2σ, thanks to impedance model with measured collimator settings:
ΔQx (Headtail) ~ -1.6 10^{-4}
ΔQy (Headtail) ~ -1.5 10^{-4}

Comparisons between model and beam-based impedance measurements

- Coupled-bunch: at 450GeV, 12+36 bunches, switch off the feedback for 2.5 s with ~ zero chromaticity → instability (MD May 8th, 2011):





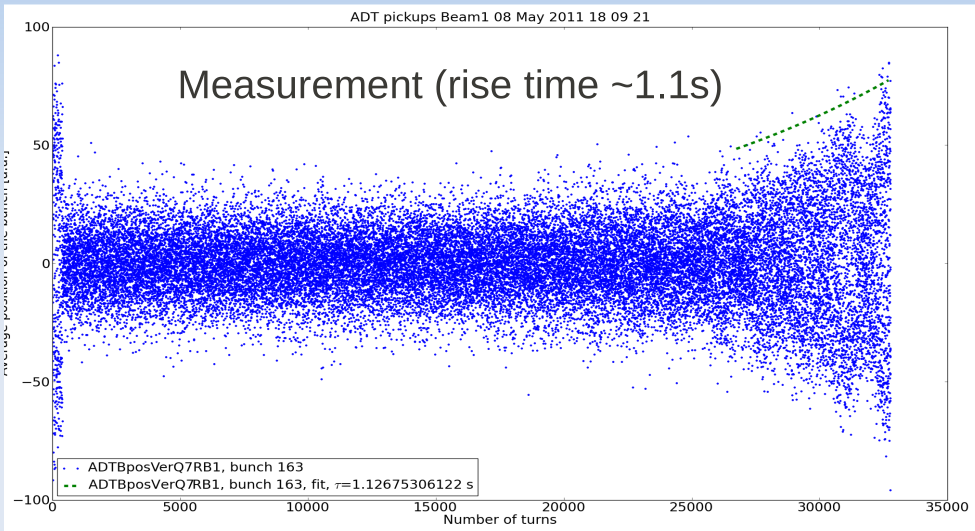


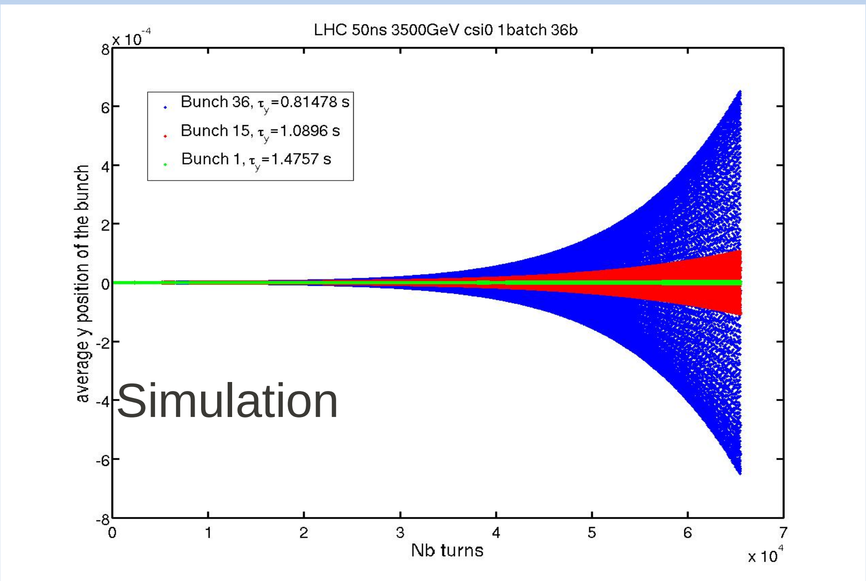
For B1 vertical, first estimations give an instability rise time relatively close (within ~40%) to predictions.

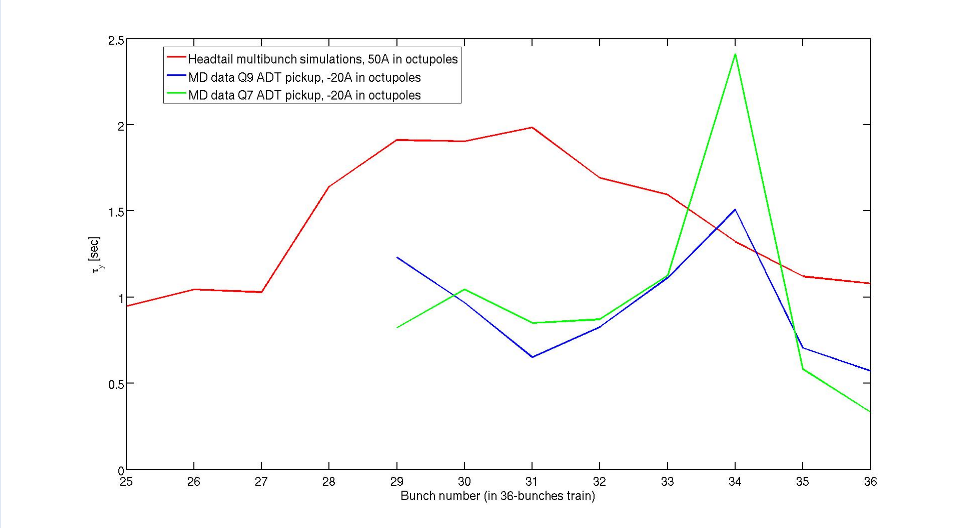
Note: in the simulation only the batch of 36 bunches is present.

Comparisons between model and beam-based impedance measurements

- Coupled-bunch: at 3500GeV, 12+36 bunches, switch off the feedback for 3s, with ~ zero chromaticity and low oct. current → instability (MD May 8th):







For B1 vertical, first estimations give also an instability rise time within a factor 2 w.r.t predictions.

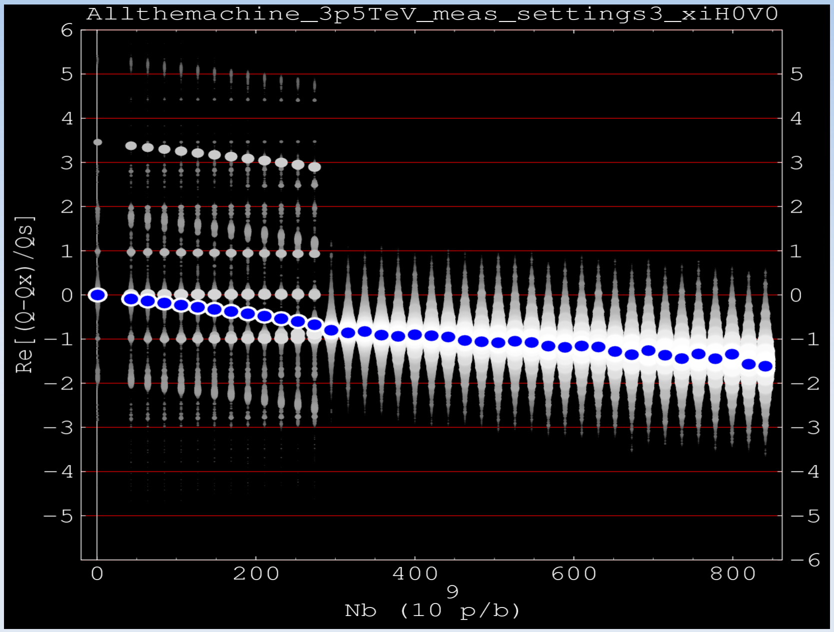
Note: in the simulation only the batch of 36 bunches is present.

Predictions with tight collimator settings (from MD 07/05/2011, B1)

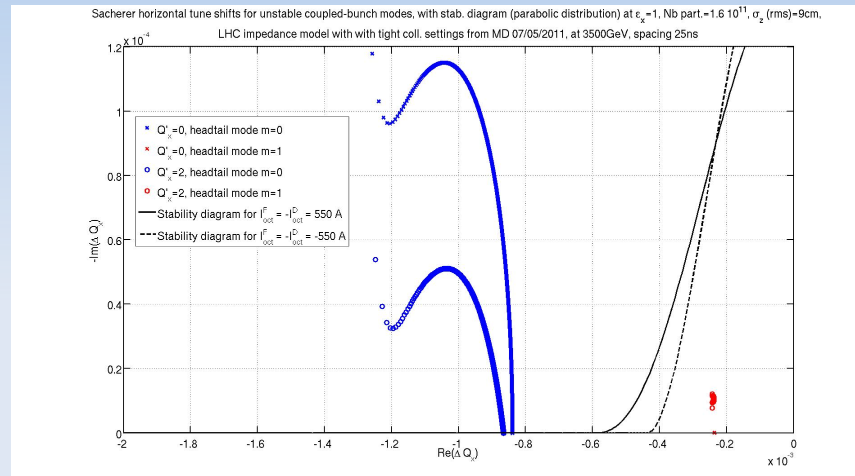
- In the following we check coupled-bunch instabilities and single-bunch transverse mode coupling (TMC) intensity threshold for 3 possible collimators configurations (proposed by R. Assmann):
  - 3.5 TeV, tight collimator settings from MD, in mm,
  - 7 TeV, tight coll. settings from MD, in mm,
  - 7 TeV, tight coll. settings from MD in nominal sigmas, converted into mm for this energy (i.e. divided by sqrt(2)).
- Impedance model as in previous comparisons (except for coll. settings):
  - Collimators (44), Beam screens, Warm pipe, MBWs & MQWs, Broadband impedance from design report.
- TMC evaluated with Headtail simulation, coupled-bunch instabilities from Sacherer theory (first benchmarks show agreement with multibunch simulations).
- Stability diagrams from theory (F. Ruggiero, J. S. Berg) with parabolic bunch, probably slightly pessimistic.
- Most critical plane: horizontal → we show only results for this one (vertical plane only slightly less critical).

First case: tight settings at 3.5 TeV

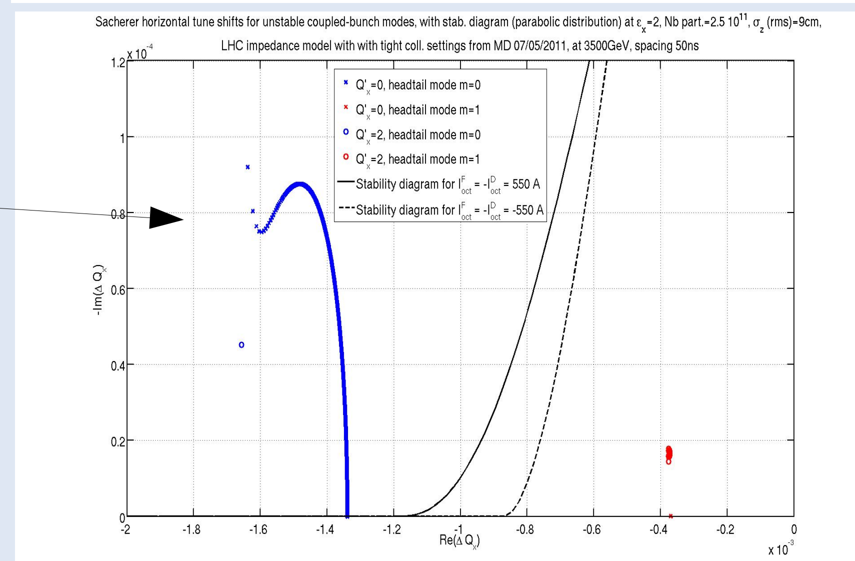
- TMC threshold: ~3.10¹¹ p/bunch



- Coupled-bunch modes (each point = one possible coupled-bunch mode along the train, unstable if above the octupoles stability diagram)



25ns
$1.6\ 10^{11}$ p/b
ε=1



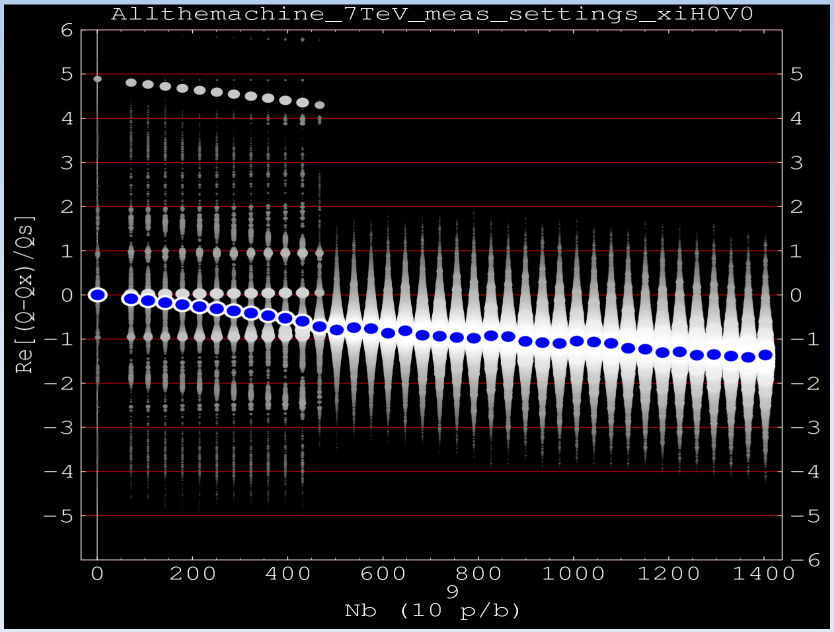
50ns
$2.5\ 10^{11}$ p/b
ε=2

Points in blue are "rigid-bunch" modes → can be damped by feedback.

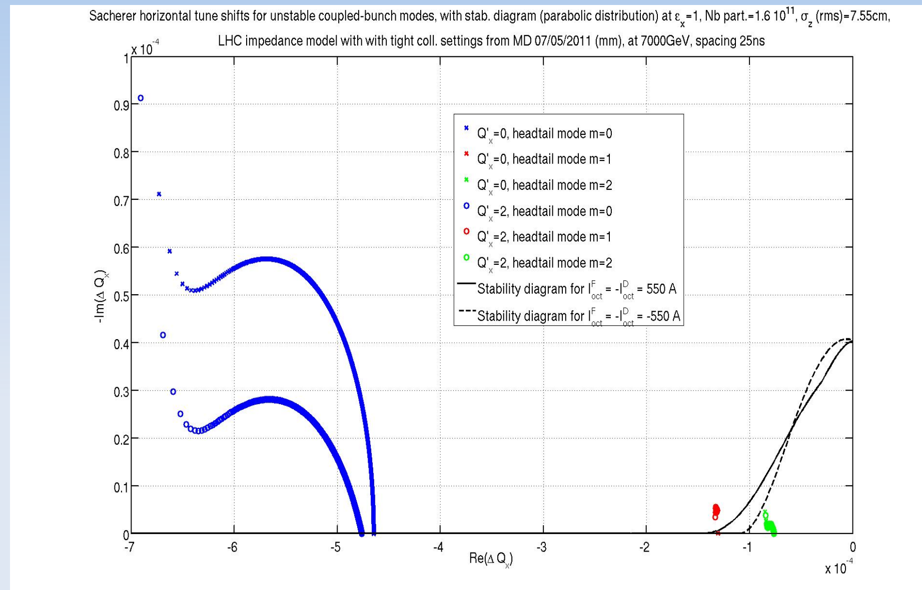
This case a priori OK, but TMC quite low → need to check for coupled-bunch TMC.

Second case: tight settings at 7 TeV in mm

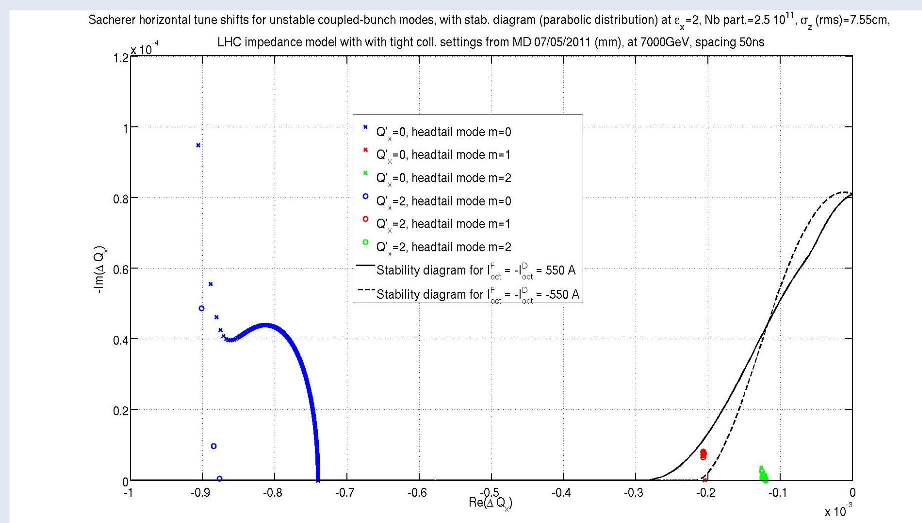
- TMC threshold: ~5. 10^{11} p/bunch



- Coupled-bunch modes:



25ns
1.6 10^{11} p/b
ε=1

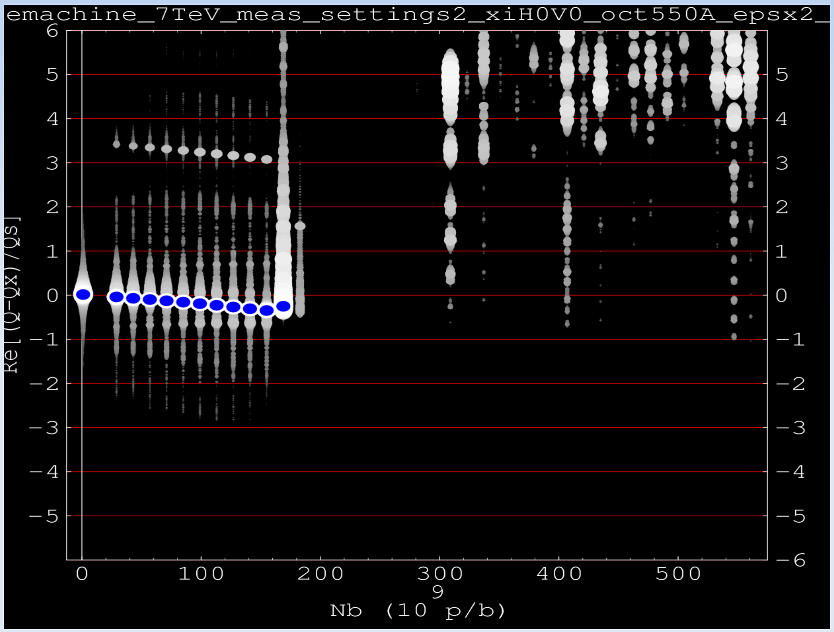


50ns
2.5 10^{11} p/b
ε=2

Coupled-bunch headtail modes are at the limit of instability → need to decrease intensity, or increase emittance, or a good control of chromaticity around 0.

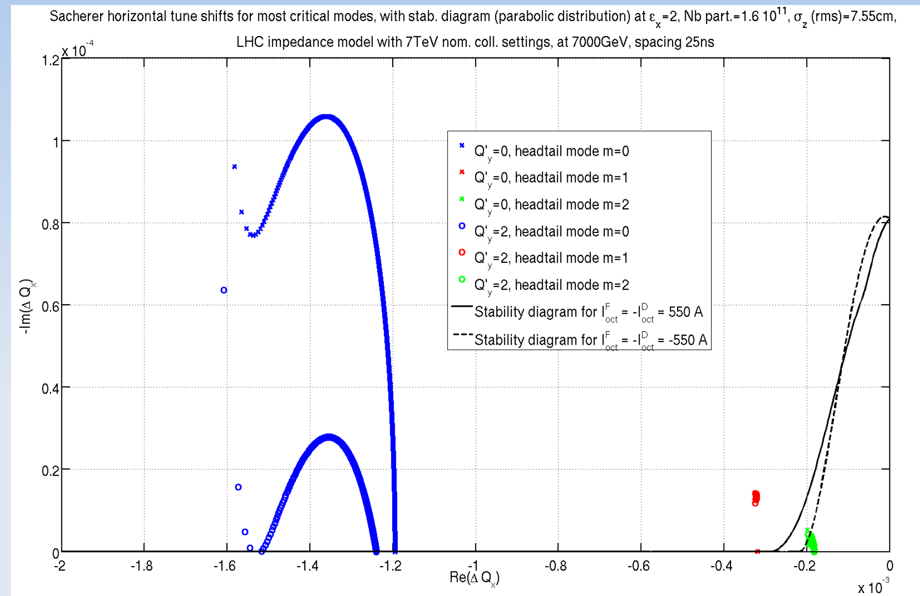
Third case: tight settings at 7 TeV in sigmas

- TMC threshold: ~1.8 10^{11} p/bunch (even with 550A in oct. & ε=2)

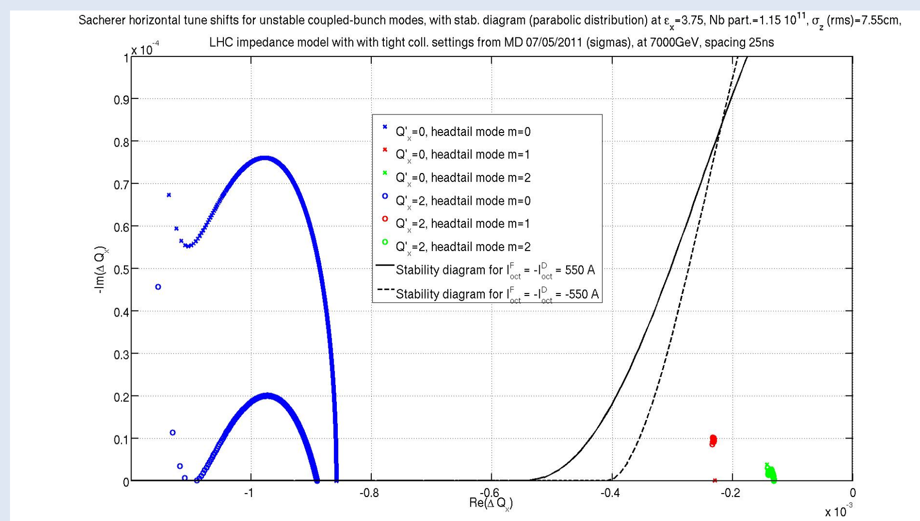


High intensity 25ns (1.6 10^{11} p/b) and 50ns (2.5 10^{11} p/b) beams ruled out (coupled-bunch headtail modes + single-bunch TMC). Nominal 25ns beam is probably OK.

- Coupled-bunch modes:



25ns
1.6 10^{11} p/b
ε=2



25ns
1.15 10^{11} p/b
ε=3.75

Conclusion

- The reliability of our impedance model and simulation code have been checked with measurements in the LHC (single-bunch & coupled-bunch, both at injection and top energy) → within a factor 2 at most.
- For the tight collimator settings of B1 obtained on May 7th,
  - Case 1: 3.5 TeV, tight collimator settings from MD in mm: OK even for high intensity – small emittance beams, but need to check coupled-bunch TMC.
  - Case 2: 7 TeV, tight coll. settings from MD (mm): not OK for the high intensity – small emittance beams studied, due to coupled-bunch headtail modes out of stability diagram and not damped by feedback. Still, slightly lower intensities or slighlty higher emittances should be OK.
  - Case 3: 7 TeV, tight coll. settings from MD in nominal sigmas, converted into mm: not OK except for nominal LHC beam (25ns, 1.15 10^{11}, emittances 3.75). Still need to check coupled-bunch TMC.

Thank you for your attention !