2nd Joint Hilumi-LHC LARP annual meeting November 14th 2012

Coherent effects in the presence of beam-beam and impedance

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Outline

Models

Beam-beam and impedance

head-on, long-range, offset collisions

Stabilization techniques

chromaticity, damper, octupoles,

head-on tune shift

Correlation with LHC observations

and outlook for HL-LHC

Models

- Two models were developed to study the combined effects of beam-beam and impedance:

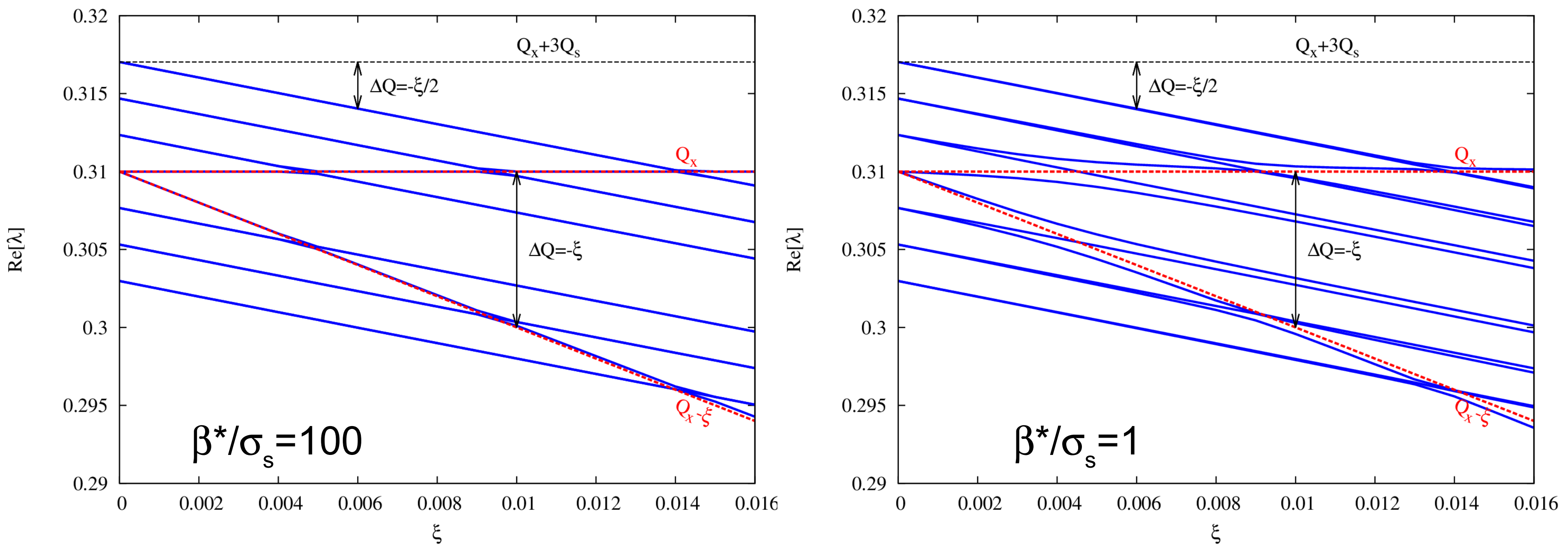
  → **Analytical model:** based on the work by Perevedentsev et al., eigenvalue problem, allows to see all the modes but Landau damping not included

  → **Macro-particles tracking:** based on BeamBeam3D by J. Qiang, slow but fully self-consistent field computation, includes Landau damping

- Complementary tools to understand how these effects couple

- The impedance model for HL-LHC is not available yet – all the following simulations were performed with the current model

6D beam-beam

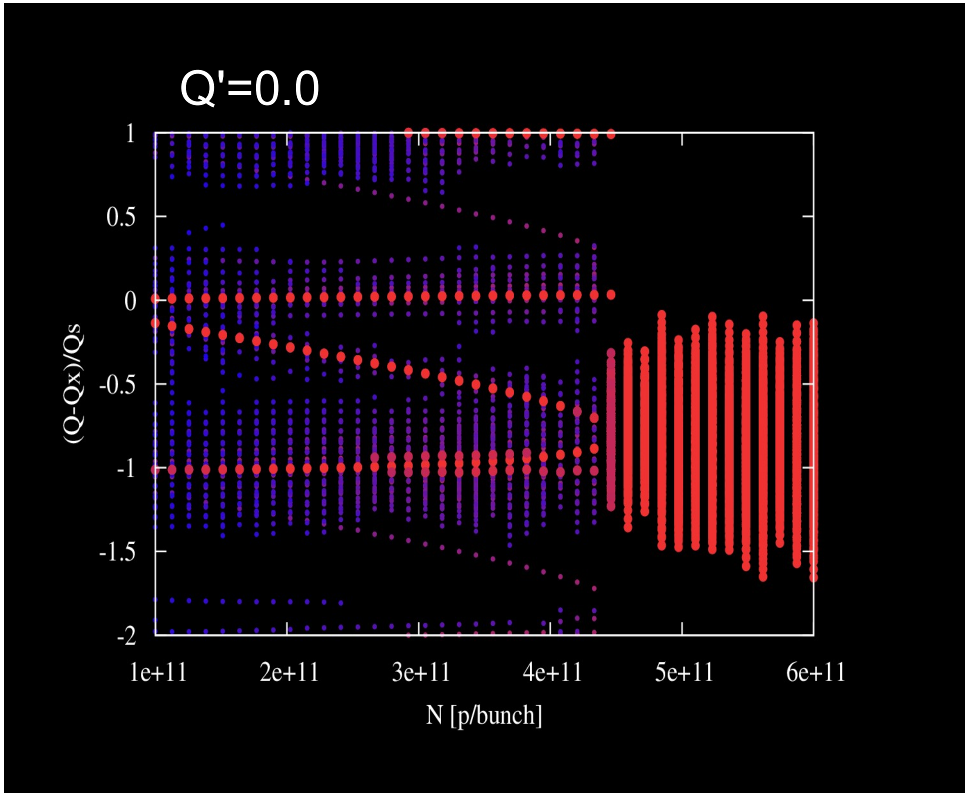


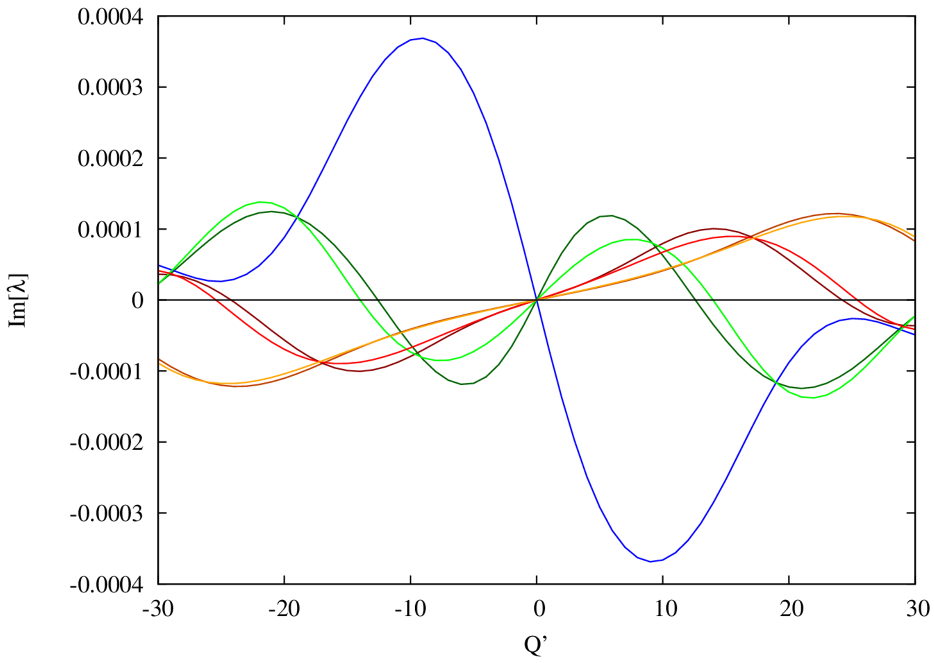
→ The modes are computed with analytical model: with BB only system always stable

→ For large ratio β^*/σ_s – no synchro-betatron coupling introduced by beam-beam: side-bands deflected by $<Q_{inc}>\sim\xi/2$ + coherent modes at Q and Q-ξ (linear BB kick: *Y*=1)

→ Small ratio β^*/σ_s – the beam-beam can deflect the side bands – more complex picture

Impedance

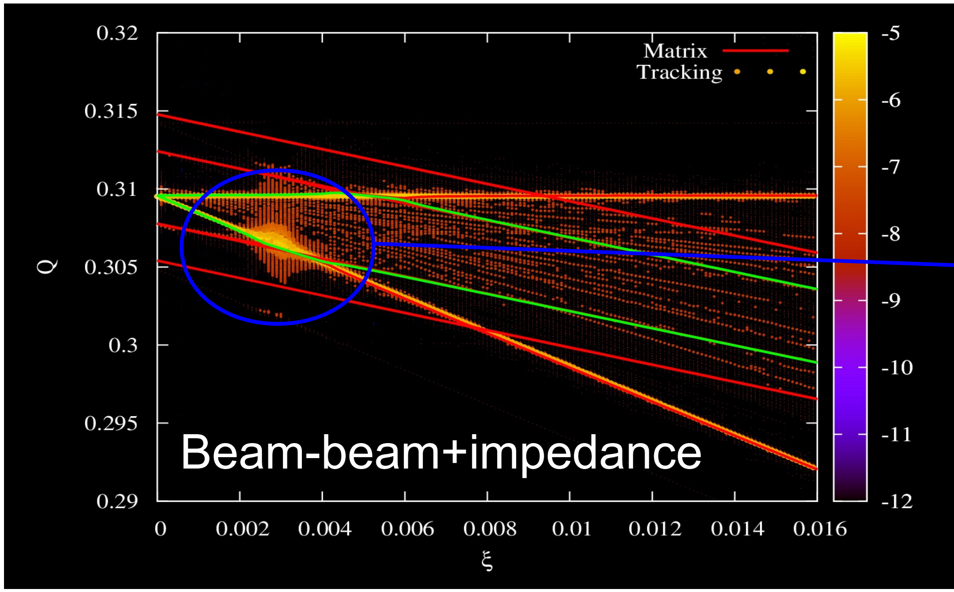


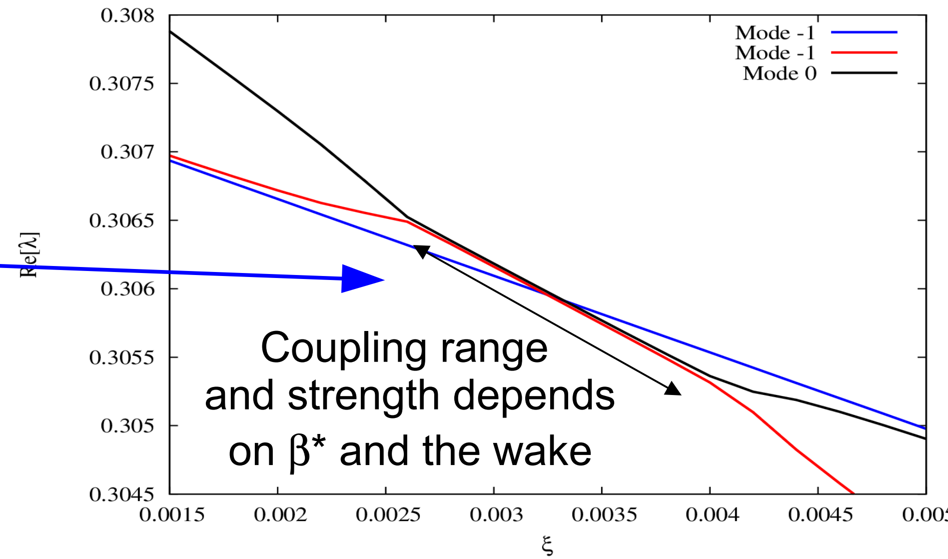


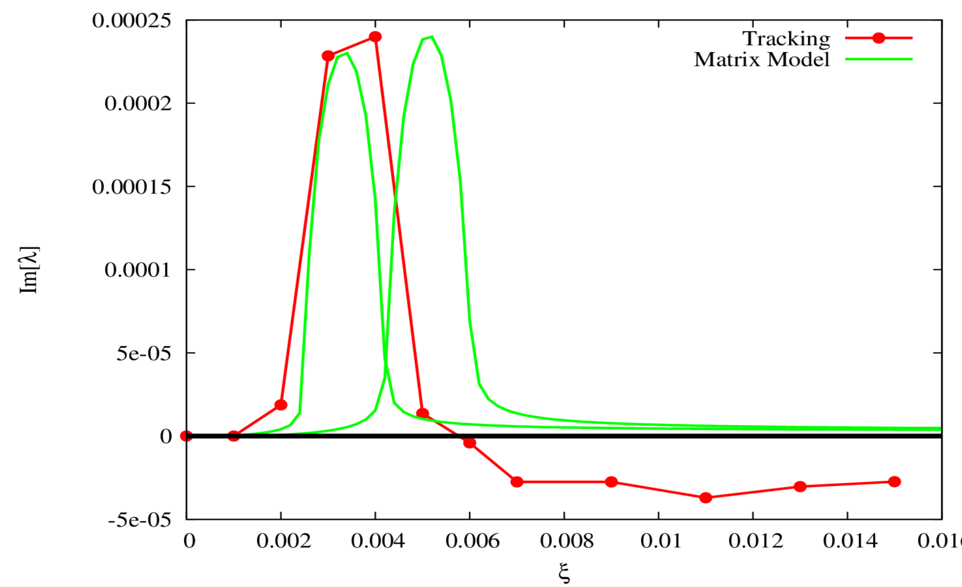
→ As the bunch intensity is increased the mode 0 is shifted down until it couples with mode -1 leading to the so-called TMCI (transverse mode coupling instability)

→ For Q' non-equal to 0.0 the system is always unstable, the rise-time and unstable modes depend on the value of Q'

Impedance and beam-beam





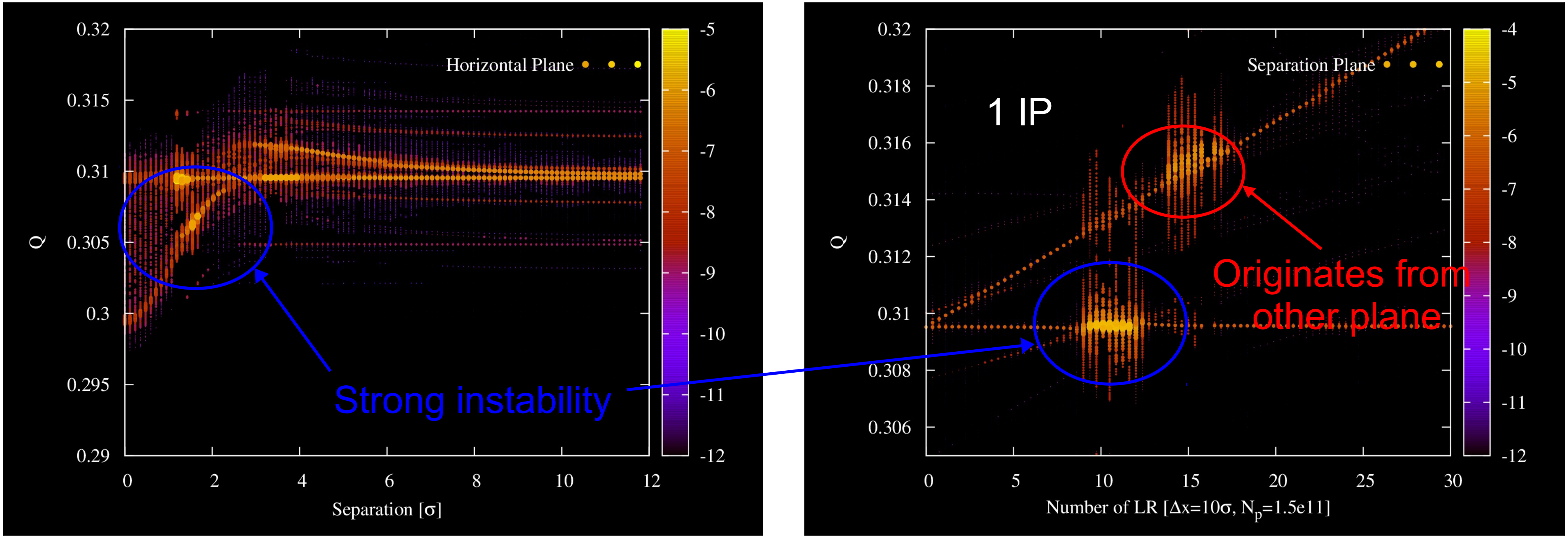


→ Scan the head-on beam-beam parameters at Q'=0.0 and constant wake

→ The beam-beam interaction shifts the π-mode down faster: coupling between modes 0 and -1 could occur at lower intensity

→ Although the analytical model predicts also coupling between σ-mode and mode +1 it is not observed in tracking simulations

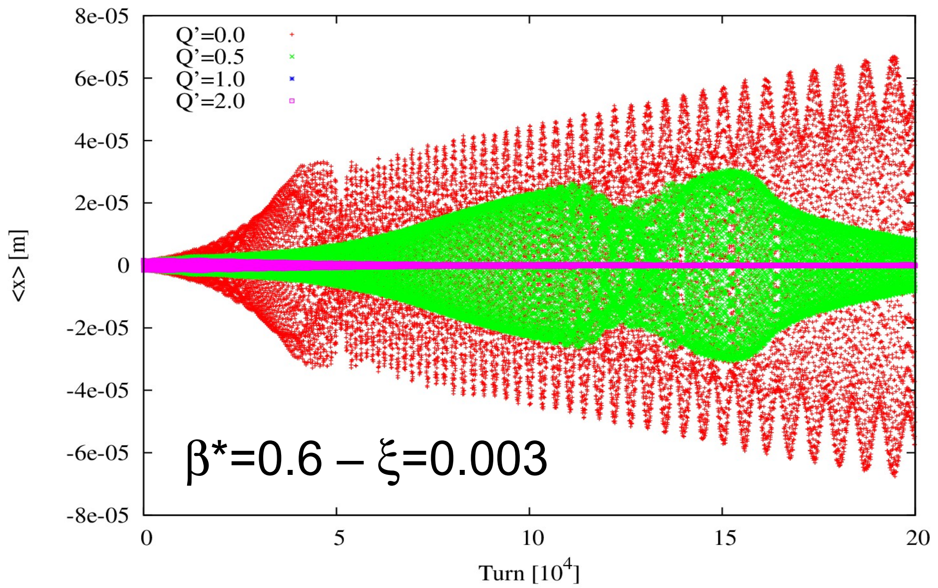
Offset collisions

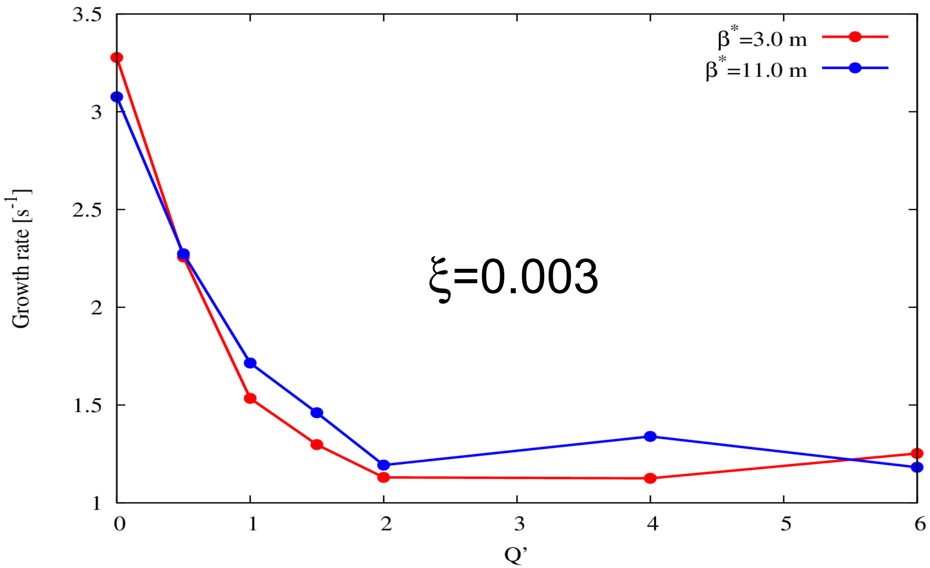


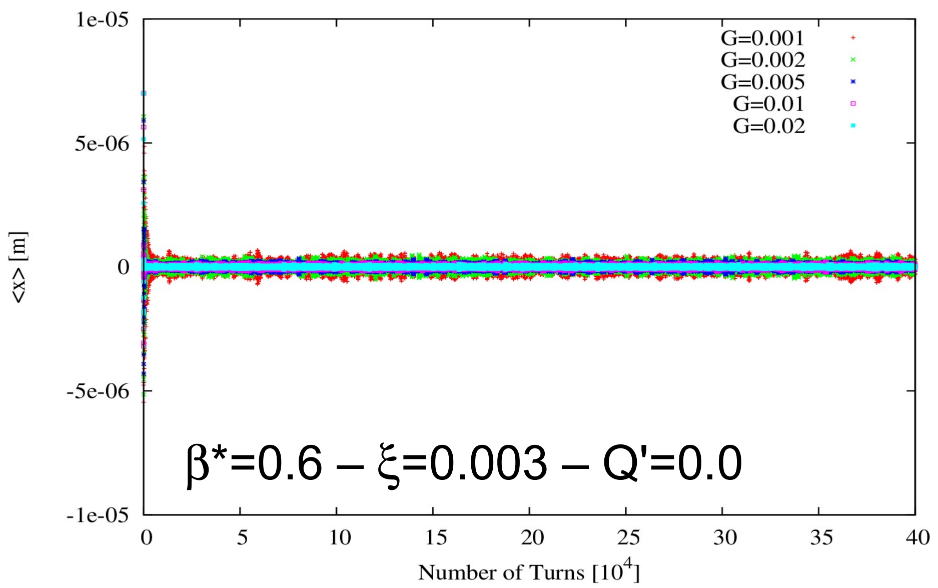
→ **Single head-on with offset:** coupling between the π-mode and mode -1 occurs at a separation between 1 and 2 σ in this case (depends on ξ)

→ **Long-range interactions:** here assumed a separation of 10 σ with all the long-range interactions lumped at a single IP. Strong instability observed around the equivalent of 10 long-range interactions for these parameters (depends on ξ, phase advances, tunes separation)

Stabilizing the HO interactions





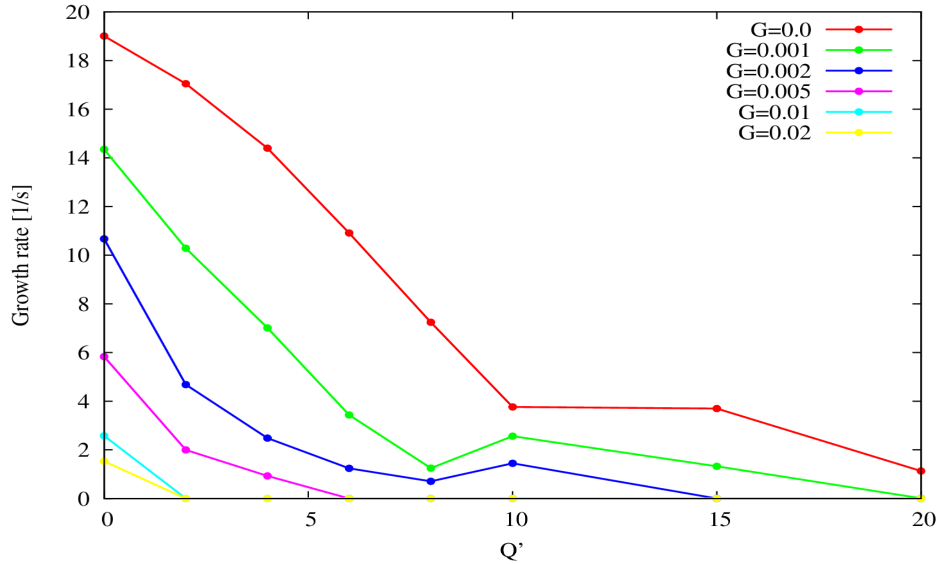


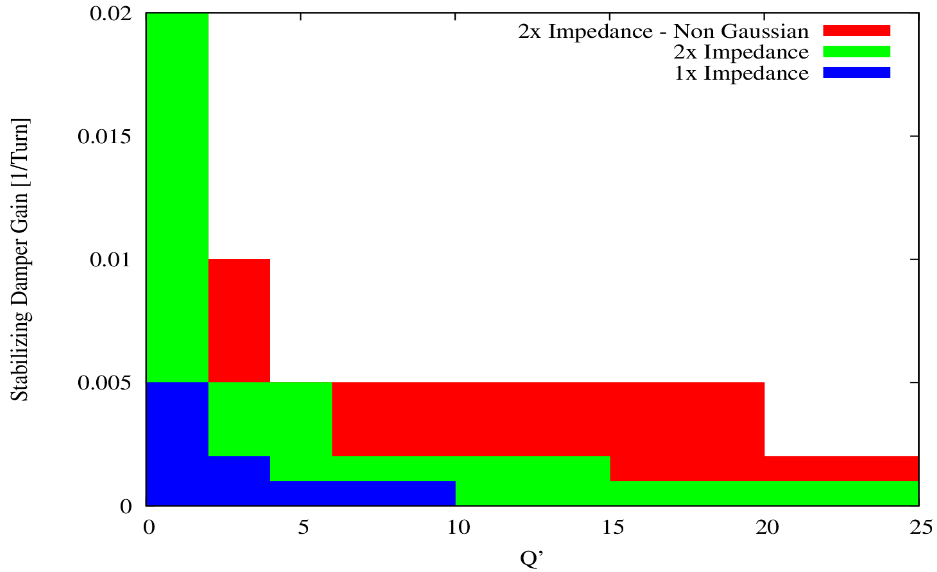
→ High chromaticity helps stabilizing although much less efficient at higher β*

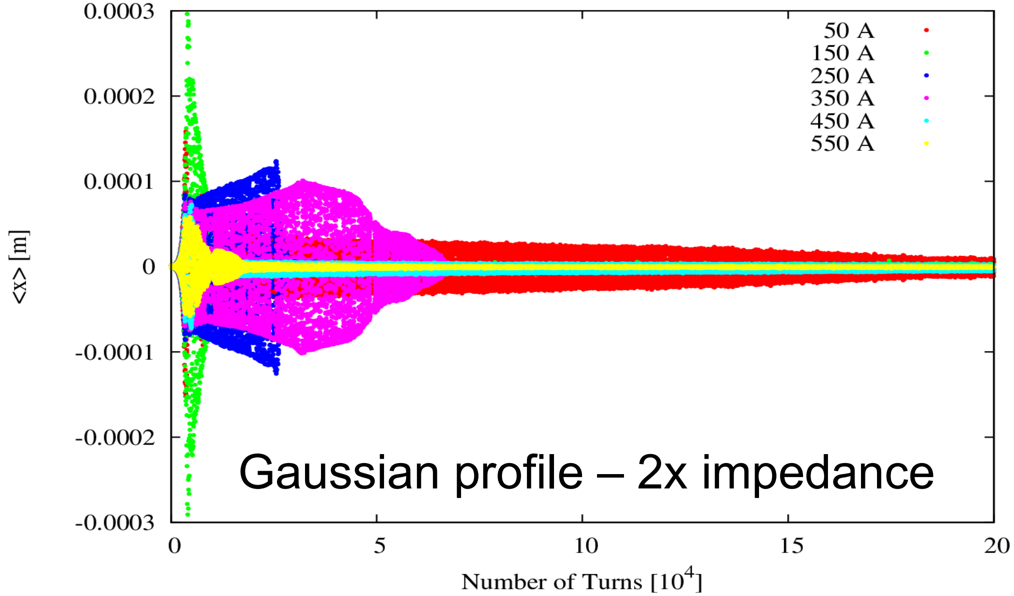
→ Transverse damper very efficient, should be able to cure these instabilities

→ Comments: octupoles have no impact on stability in this case

Stabilizing the LR interactions





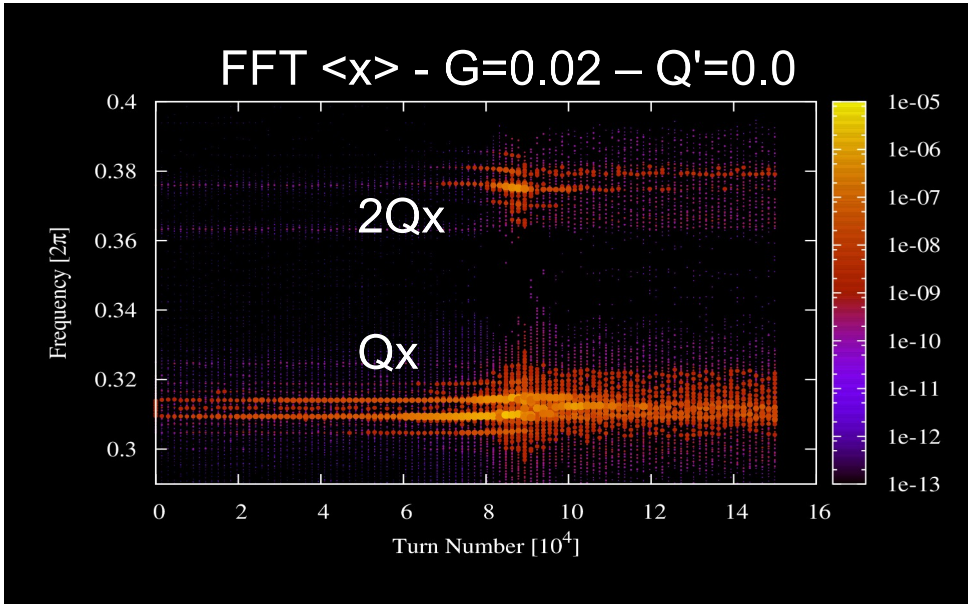


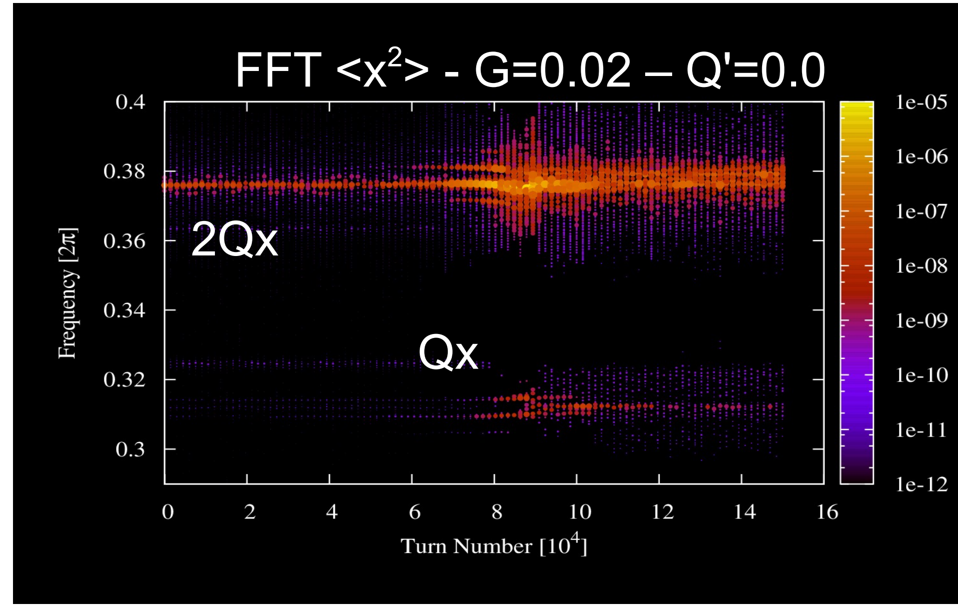
→ Octupoles have a stabilizing effect. For 2x impedance not possible to fully stabilize even at full current

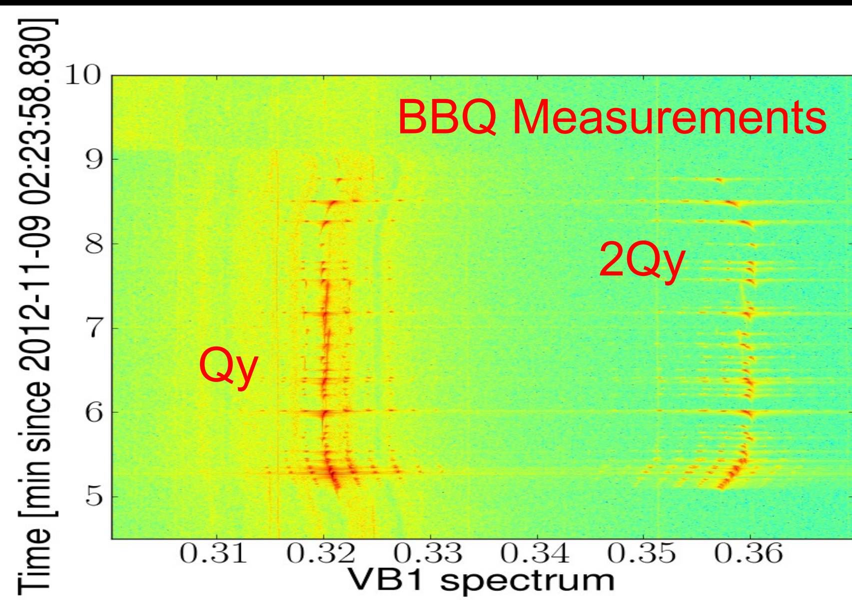
→ High damper gain and chromaticity should cure instabilities

→ Non-Gaussian tails appear to degrade the situation. Reason not yet understood: requires more detailed study

Why are LR so much worse?







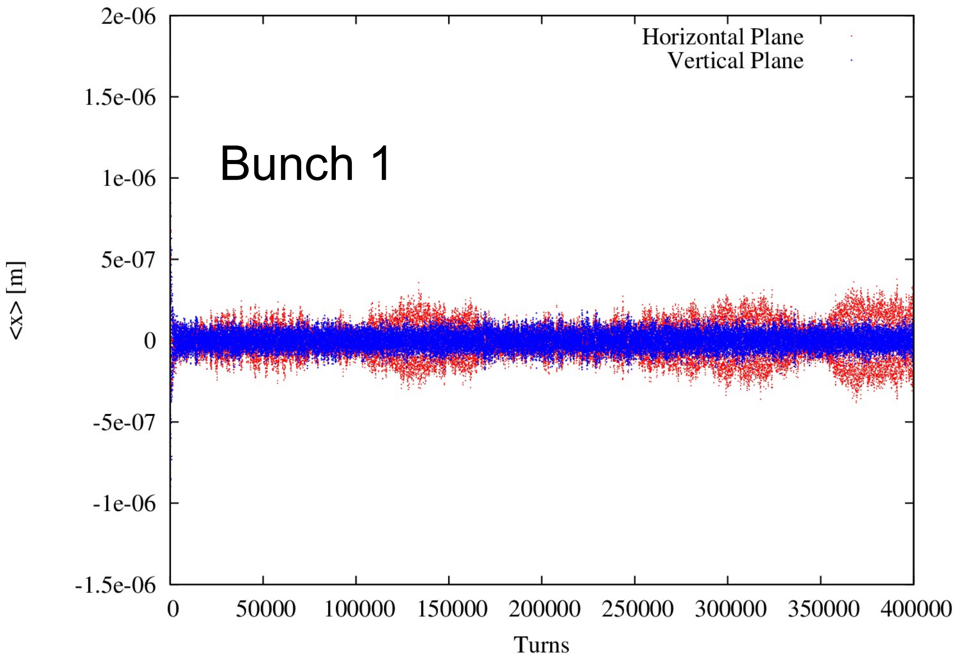
Some observations to be confirmed and studied in details, shown here for discussion:

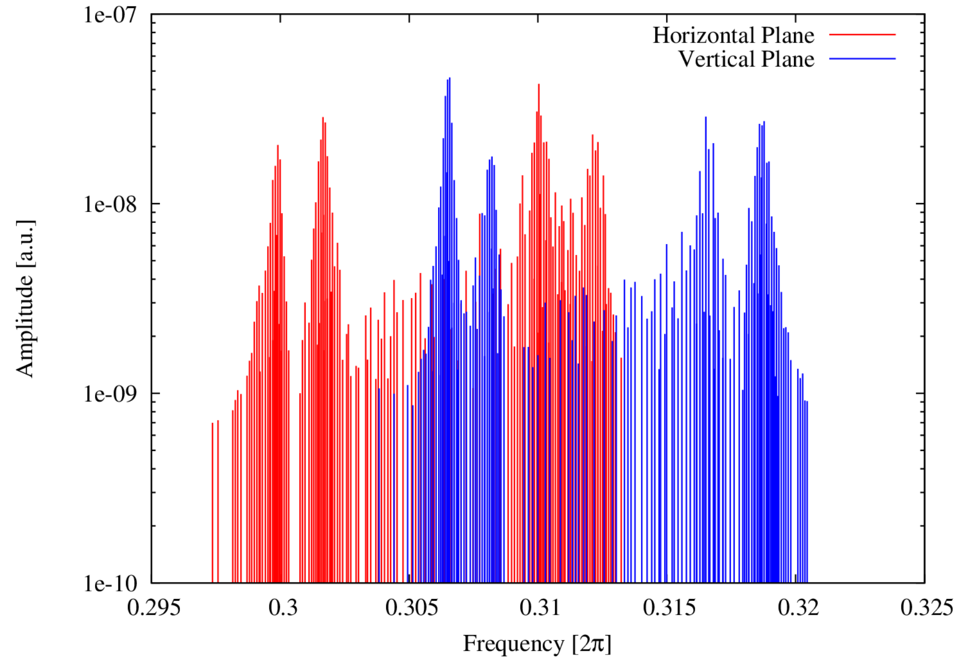
→ **Beam-beam force can excite quadrupolar modes** and cross talk with dipolar modes through the separation

→ When an instability is rising, a clear line is observed at 2Q both in measurements and simulations

→ **Damper is blind to quadrupolar modes**

Head-on + long-range





→ Track 2x2 bunches such that each bunch has 10 long-range (lumped) + 1 head-on. Each bunch couples with a different counter rotating bunch for the long-range and the head-on

→ Octupoles, damper gain and chromaticity set to 0, both planes look stable over 400000 turns

→ Full head-on has a clear stabilizing effect even without octupoles or damper

How this relates to LHC observations?

- Instabilities observed routinely in 2012 during the squeeze, when beams are brought into collision and sometimes stable beams: during all these processes beam-beam has important impact on beam dynamics
  - **At low chromaticity (beginning of the year):** strong instabilities leading to beam abort → consistent with simulations
  - **At high chromaticity:** instabilities mostly observed at the end of the squeeze, current settings are Q'~15 and G=0.02 → could not be reproduced in simulations so far
  - Regardless of the parameters head-on collisions with large enough ξ have clear stabilizing effect → consistent with simulations
- All these simulations were done for single bunch → ongoing effort to implement impedance model in the COMBI multi-bunch tracking code (done in collaboration with X. Buffat and LHC beam-beam team)
- Recent results indicate that beam profile or quadrupolar modes could have an impact → needs to be confirmed and studied in more details

Outlook for HL-LHC

- HL-LHC will run with significantly higher bunch number and intensity → depending on collimator settings and layout stability could be degraded

- Increased energy will reduce octupoles efficiency → operation now heavily relies on these to stabilize the beams – scaling?

- Some leveling scenarios (crossing angle, separation) imply a significant reduction of the head-on tune shift → consequences for stability?:

  → Considering stability only, β^* leveling looks like the most robust operating scenario

  → This could also result in running at very large ξ →lifetime? should we consider half integer tune?

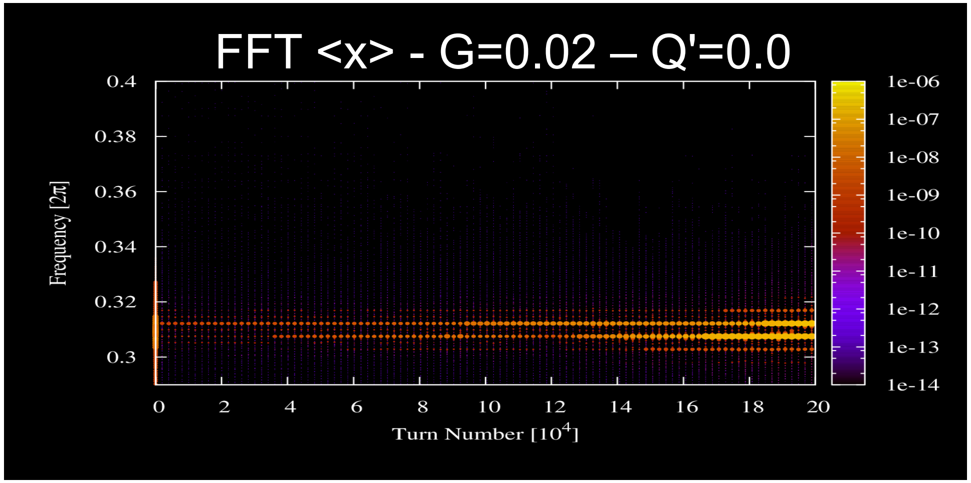
→ Studies including beam-beam and impedance are necessary to assess the implication of each leveling scenario on beam stability

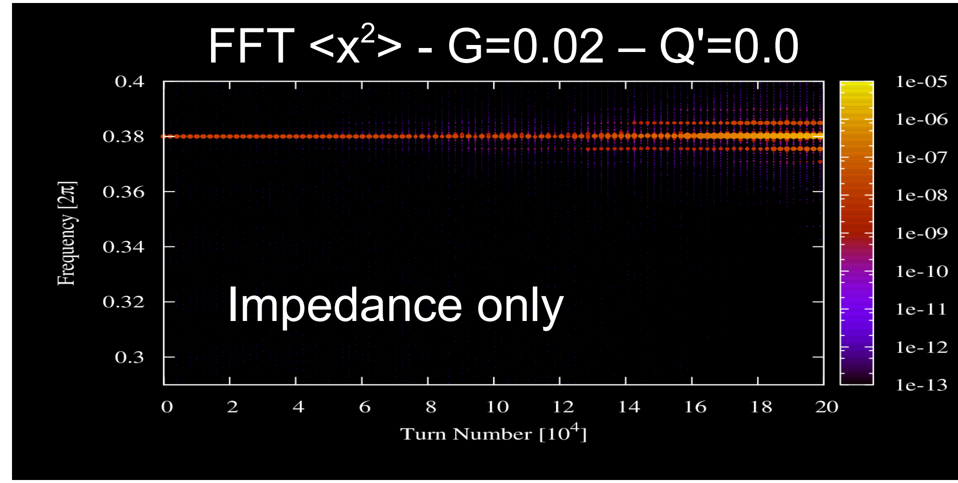
→ Excellent progress done this year. Still to be done: multi-bunch, crossing angle, new HL-LHC impedance model...

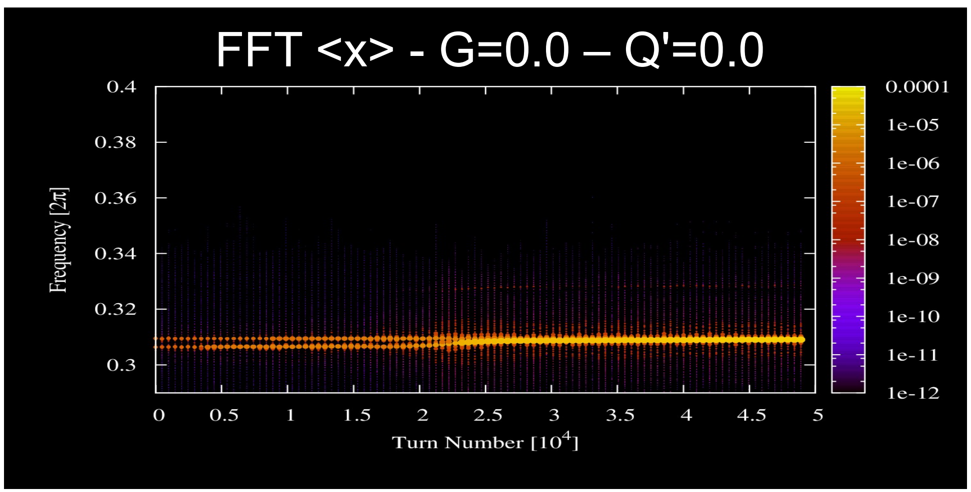
Thank you for your attention!

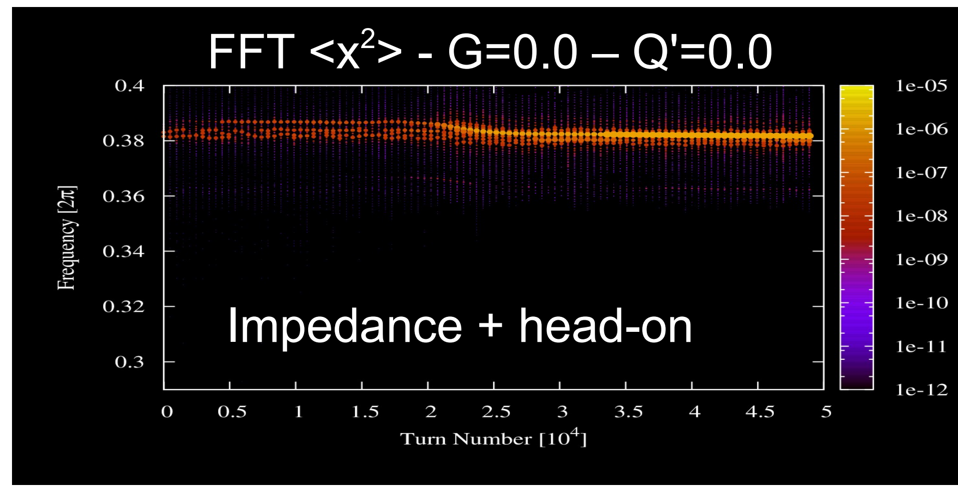
SPARES

Quadrupolar oscillations



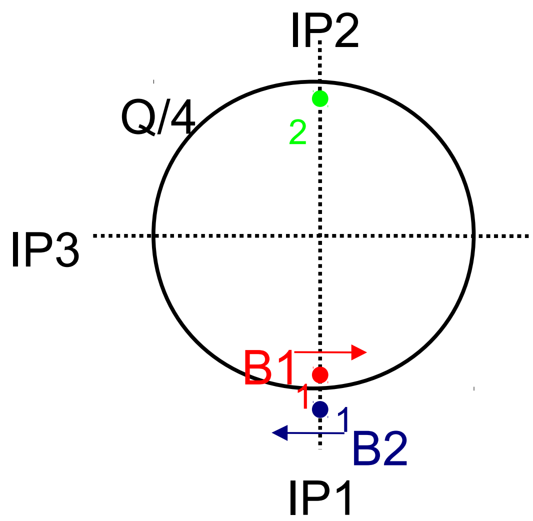






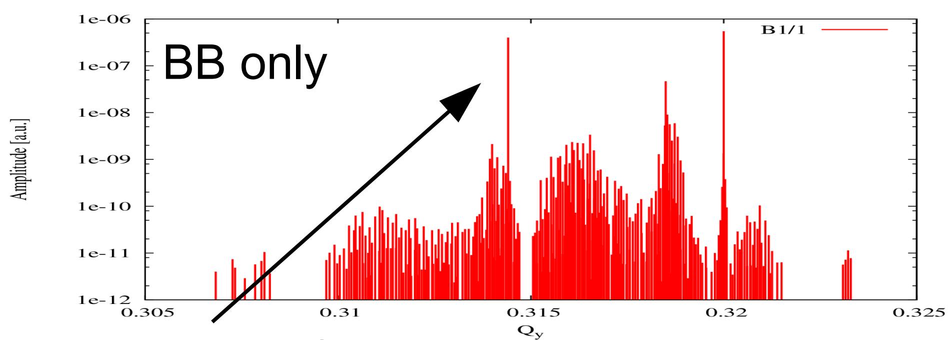
→ Although observed as well in the case of impedance only (most likely only statistical fluctuations) or impedance and head-on instabilities there is no evidence of cross talk with dipolar modes

More complex collision pattern

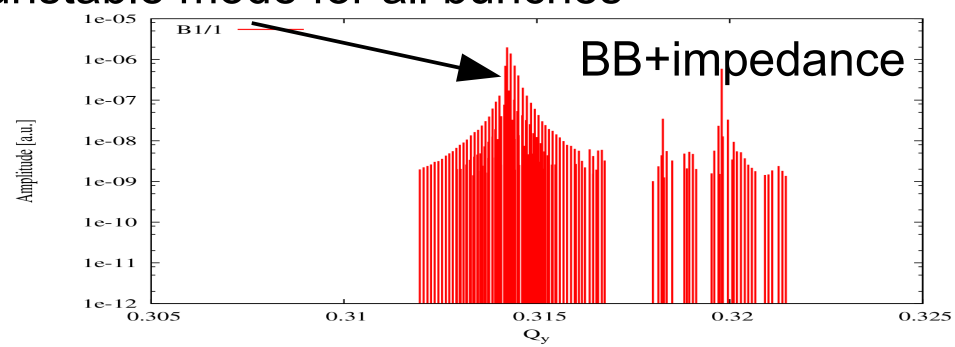


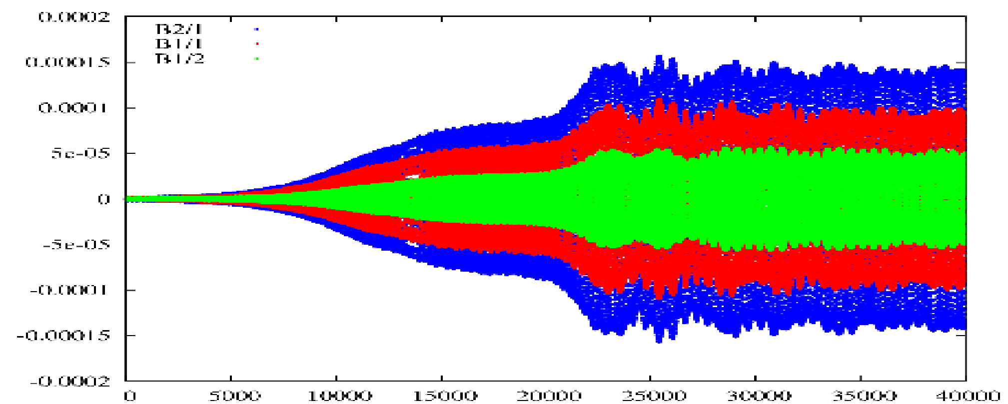
	IP1	IP2	IP3	N_{LR} tot.
B1/1	1	1	0	14
B1/2	0	0	1	7
B1/1	1	1	1	21

At all IPs equivalent of 7 LR with 10σ separation in H plane



unstable mode for all bunches





→ Same rise-time for all bunches but different amplitudes

→ Could be even more significant for real LHC collision pattern