Recent Simulations on Beam-beam effects and some measurements

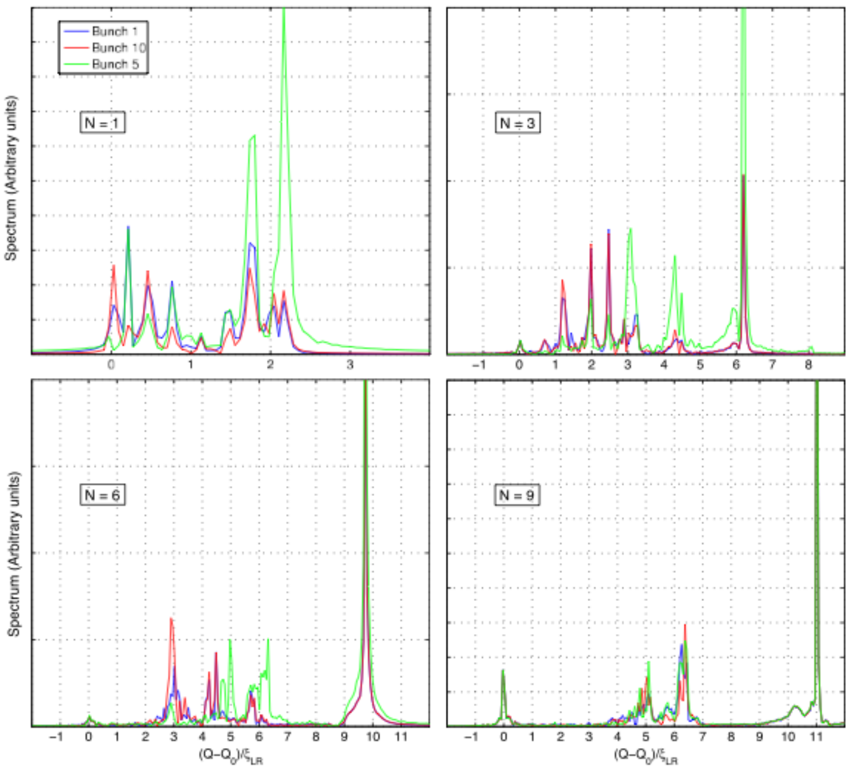
T. Pieloni
for S. White, the LHC BB and Impedance Teams

OUTLOOK

- Motivations
- Simulations studies of interplay between beam-beam and Impedance
- Does it explain what we had observed?
- Few observations with tune splits
- Conclusions, open questions and future plans

Coherent beam-beam modes in the LHC

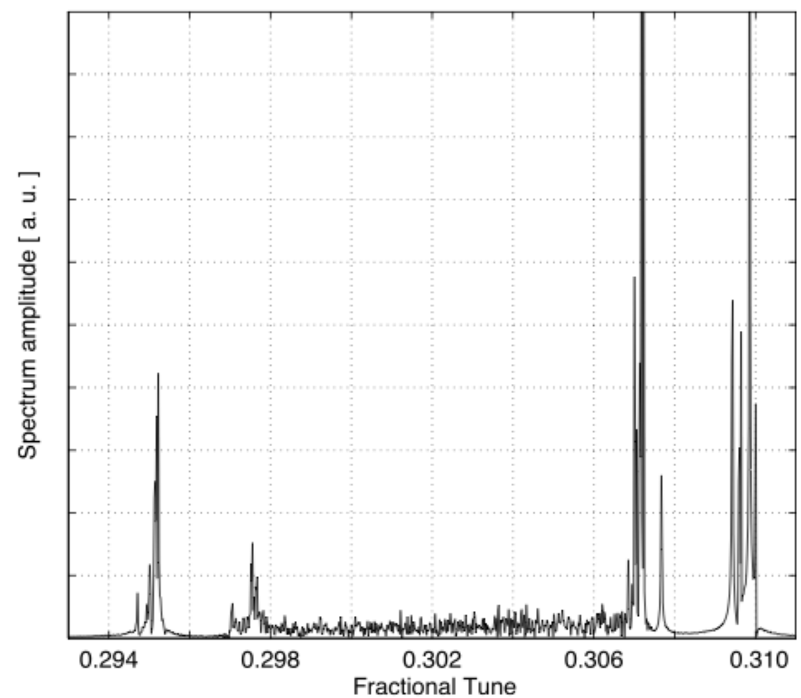
<u>Long range Modes</u>



During the squeeze all Long-Rang interactions are effective starting from around 3 m β*
They depend on many parameters (intensity, betas, filling schemes, transverse emittances …)

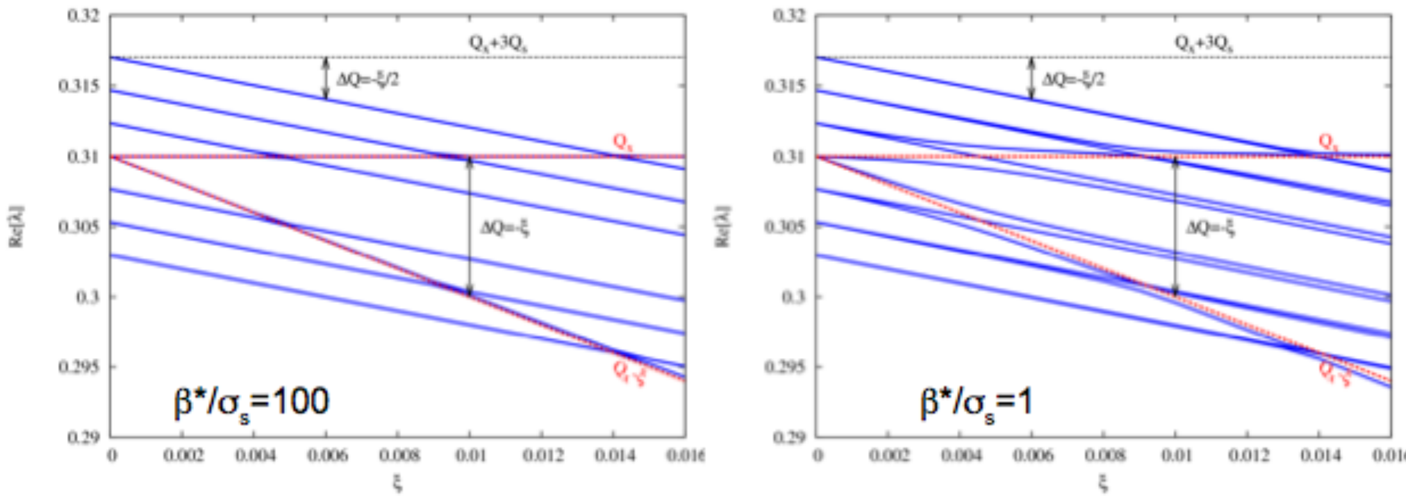
LHC has several modes and different bunches behave differently
<u>Very Complex case</u>

<u>Long range + Head-on</u>



With Head-on collision the modes location changes and also the beam dynamics …
But still LR modes could still be present and have to be treated differently

6D beam-beam



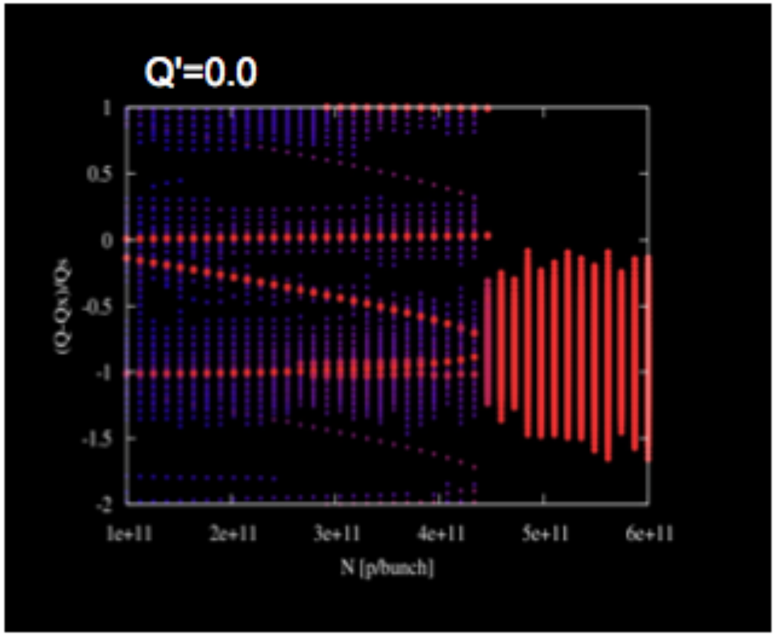
→ The modes are computed with analytical model: with BB only system always stable

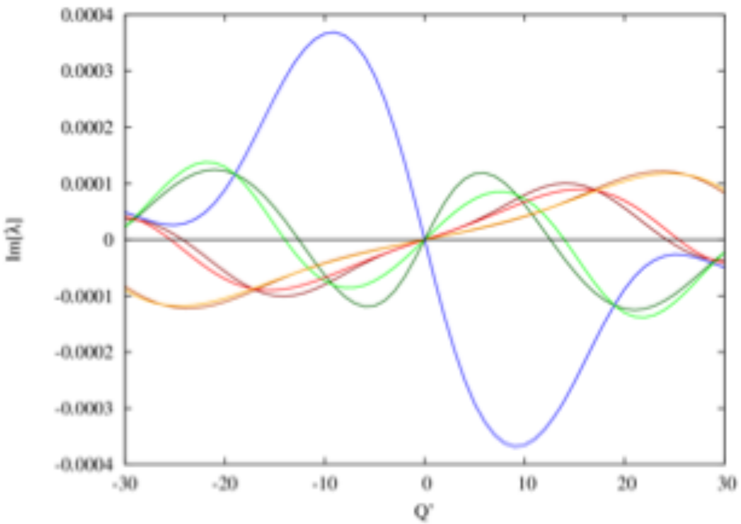
→ For large ratio β^*/σ_s – no synchro-betatron coupling introduced by beam-beam: side-bands deflected by $<Q_{inc}>\sim\xi/2$ + coherent modes at Q and Q-ξ (linear BB kick: Y=1)

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

Instabilities in the LHC have triggered the idea that a coupling between beam-beam interactions and impedance could explain observations

Impedance





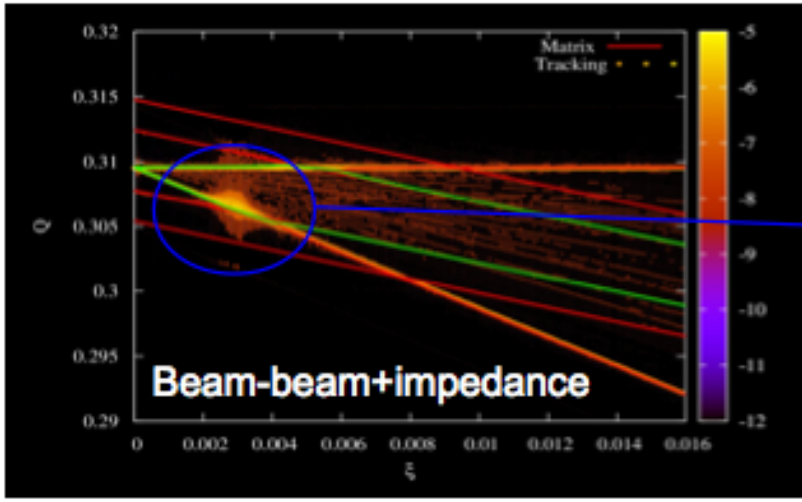
→ As the bunch intensity is increased the mode 0 is shifted down until it couples with mode -1 leading to the so-called TMCI (transverse mode coupling instability)

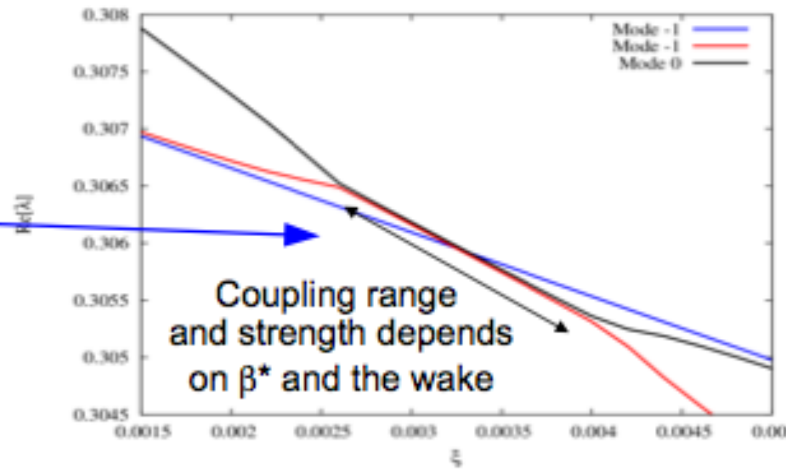
→ For Q' non-equal to 0.0 the system is always unstable, the rise-time and unstable modes depend on the value of Q'

S. White

<u>LHC impedance model from N. Mounet implemented in Beam-Beam 3D code and benchmarked to Head-tail results</u>

Impedance and beam-beam

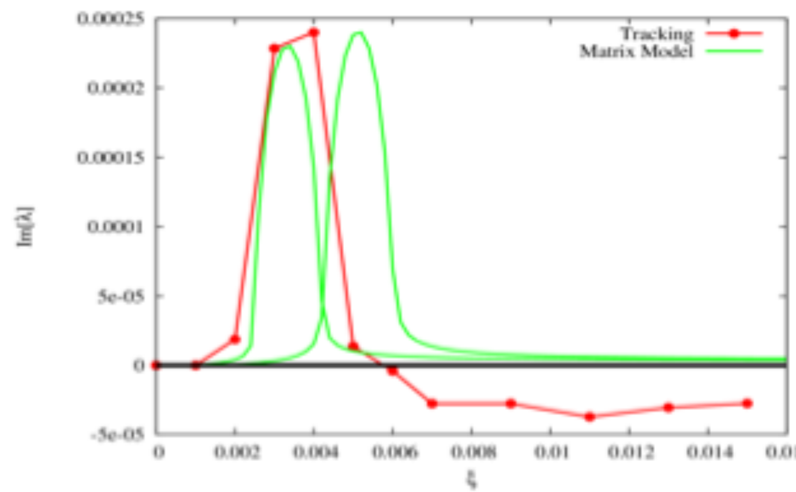




→ Scan the head-on beam-beam parameters at Q'=0.0 and constant wake

→ 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



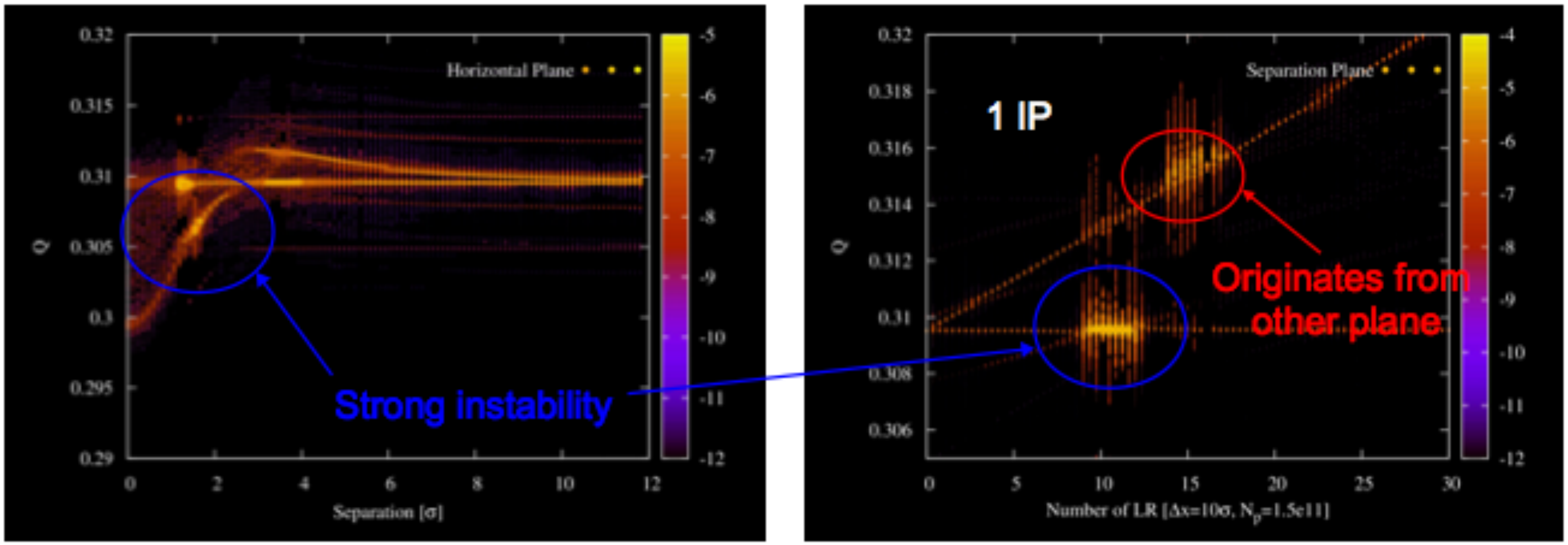
S. White

<u>Scan of the beam-beam parameter show the coupling between a coherent pi mode from BB and impedance mode m=-1</u>

BROOKHAVEN NATIONAL LABORATORY

Offset collisions

LARP



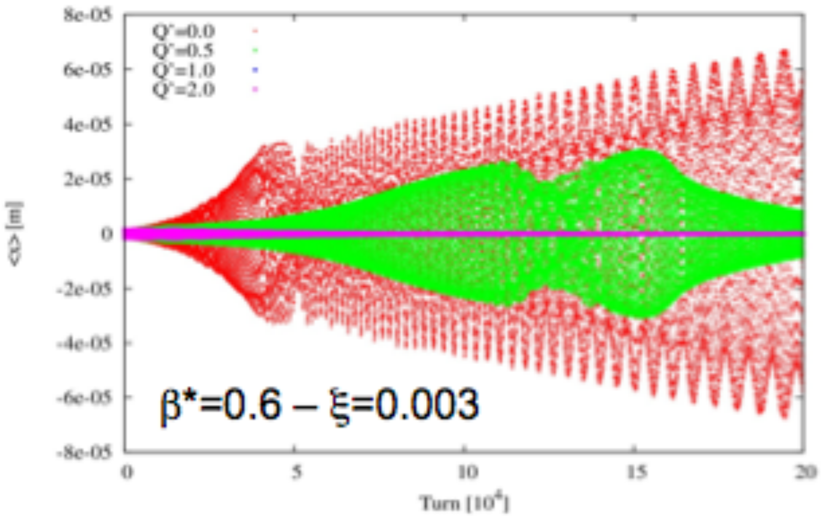
→ **Single head-on with offset:** coupling between the π-mode and mode -1 occurs at a separation between 1 and 2 σ in this case (depends on ξ)

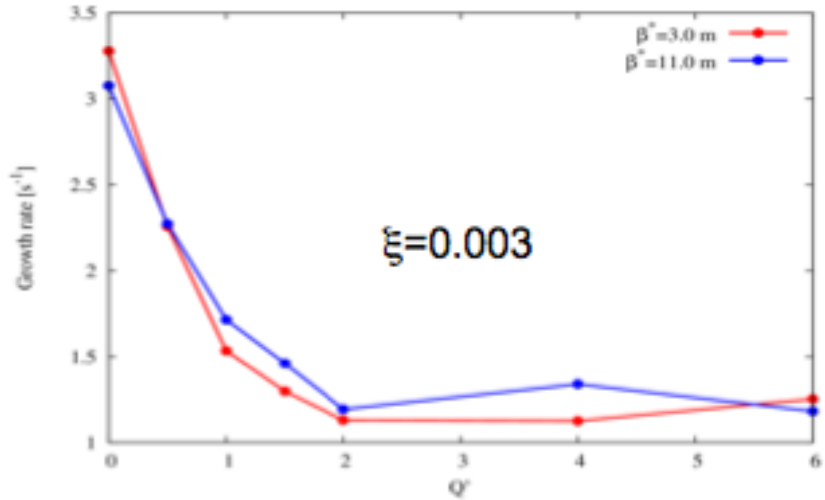
→ **Long-range interactions:** here assumed a separation of 10 σ with all the long-range interactions lumped at a single IP. Strong instability observed around the equivalent of 10 long-range interactions for these parameters (depends on ξ, phase advances, tunes separation)

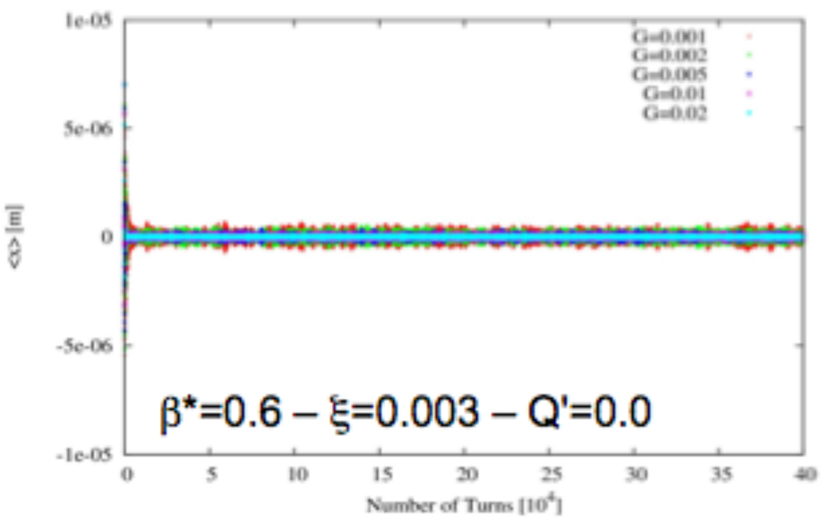
S. White

<u>An offset collision gives you something equivalent to a small BB parameter. Depending on separation the BB pi mode is shifted in frequency and can overlap to m=-1 impedance mode</u>

Stabilizing the HO interactions







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

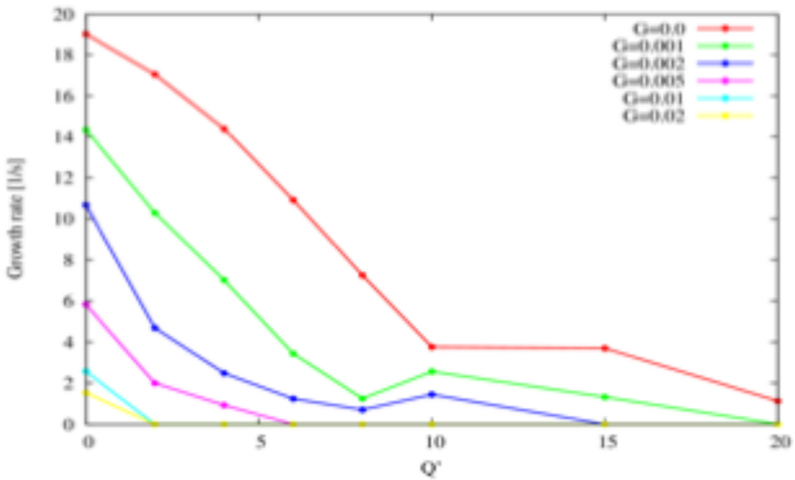
→ Transverse damper very efficient, should be able to cure these instabilities

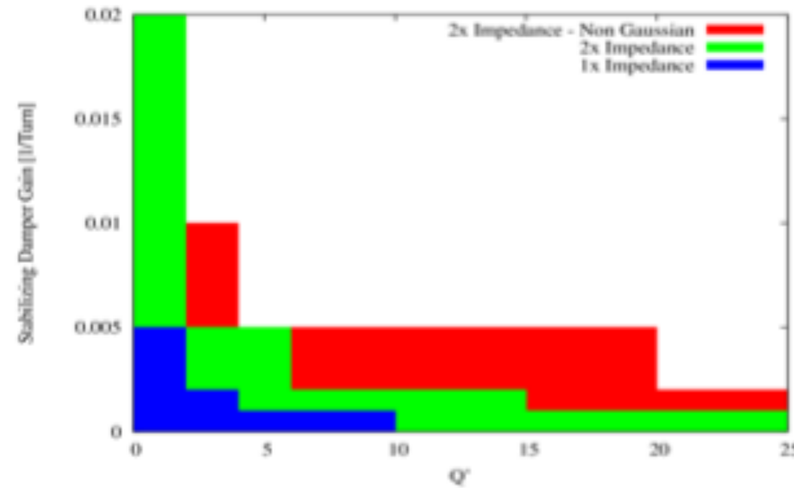
→ Comments: octupoles have no impact on stability in this case

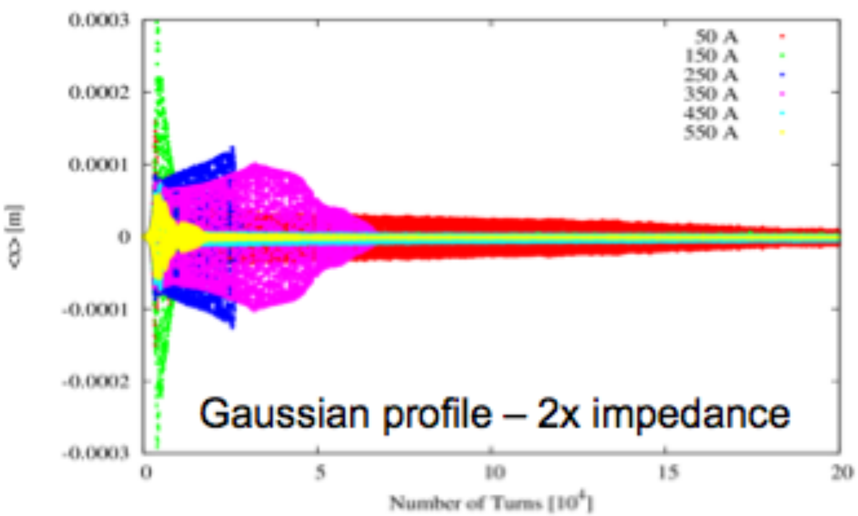
S. White

High Chroma and Transverse Damper can damp the coupling of a BB pi mode and impedance but octupoles are not effective

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

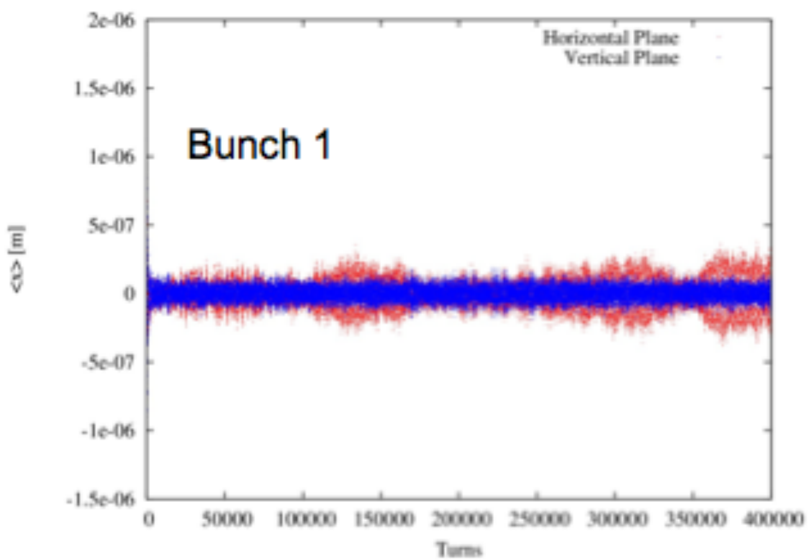
→ Non-Gaussian tails appear to degrade the situation. Reason not yet understood: requires more detailed study

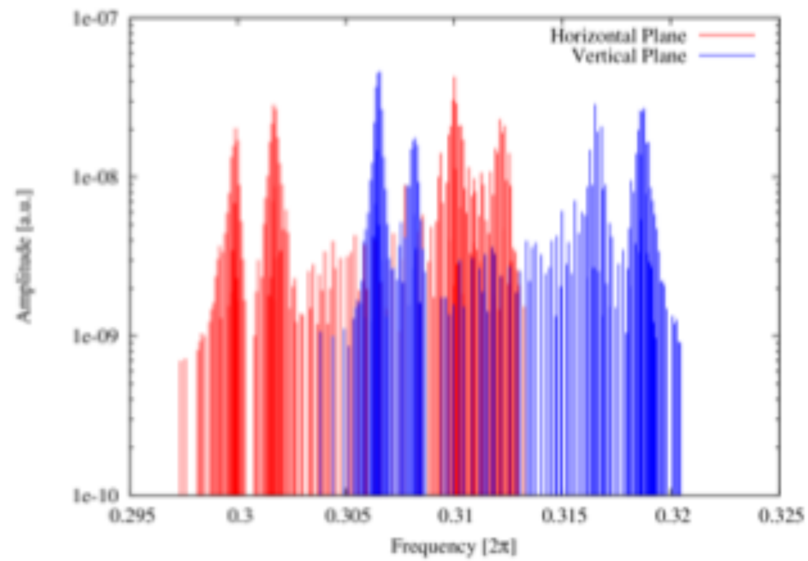
S. White

<u>To stabilize LR modes we need very high damper gain and octupoles should be effective but with very high strenght</u>

<u>The picture changes significantly if bunches have different distributions: study still on-going</u>

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

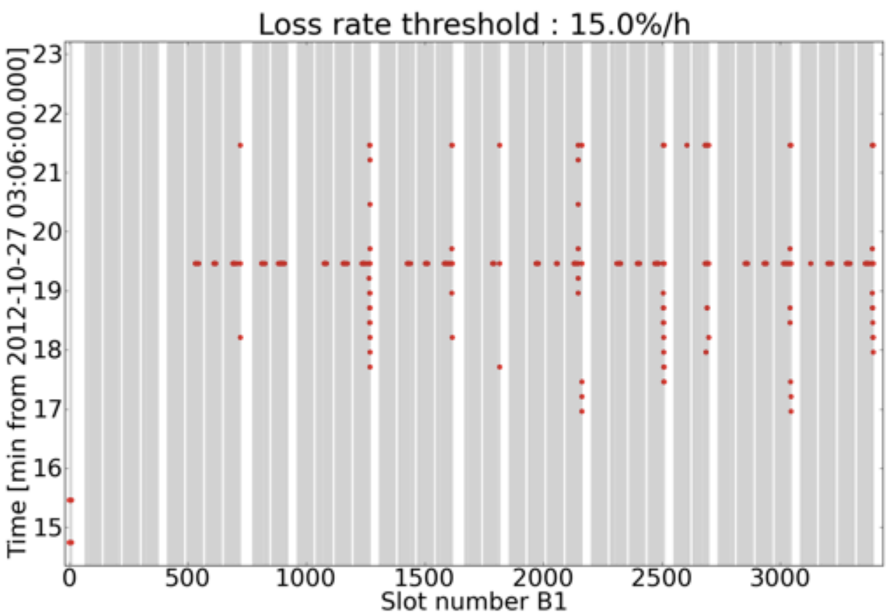
S. White

<u>**Head-on collision stabilizes the system, bunches with 1 head-on collision are always stable! This is always the case in data**</u>

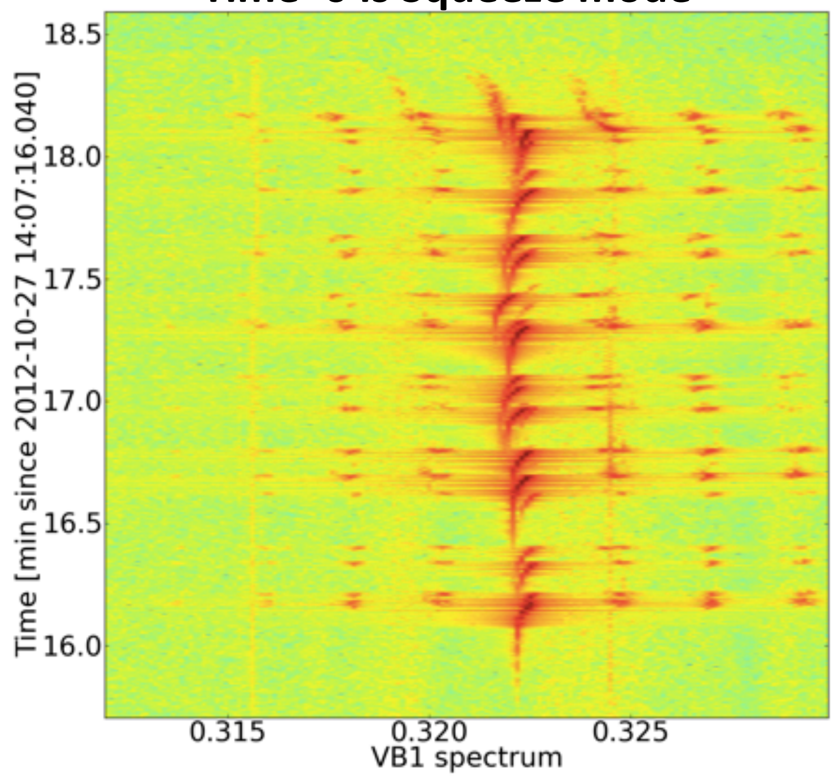
Why a tune split?

H.R. Helm et al of the SPEAR Group, ”BB coupling in SPEAR”,…
Hoffman, “BB modes for two beams with un-equal tunes”, CERN-SL-99-039, 1999.

Fill 3231



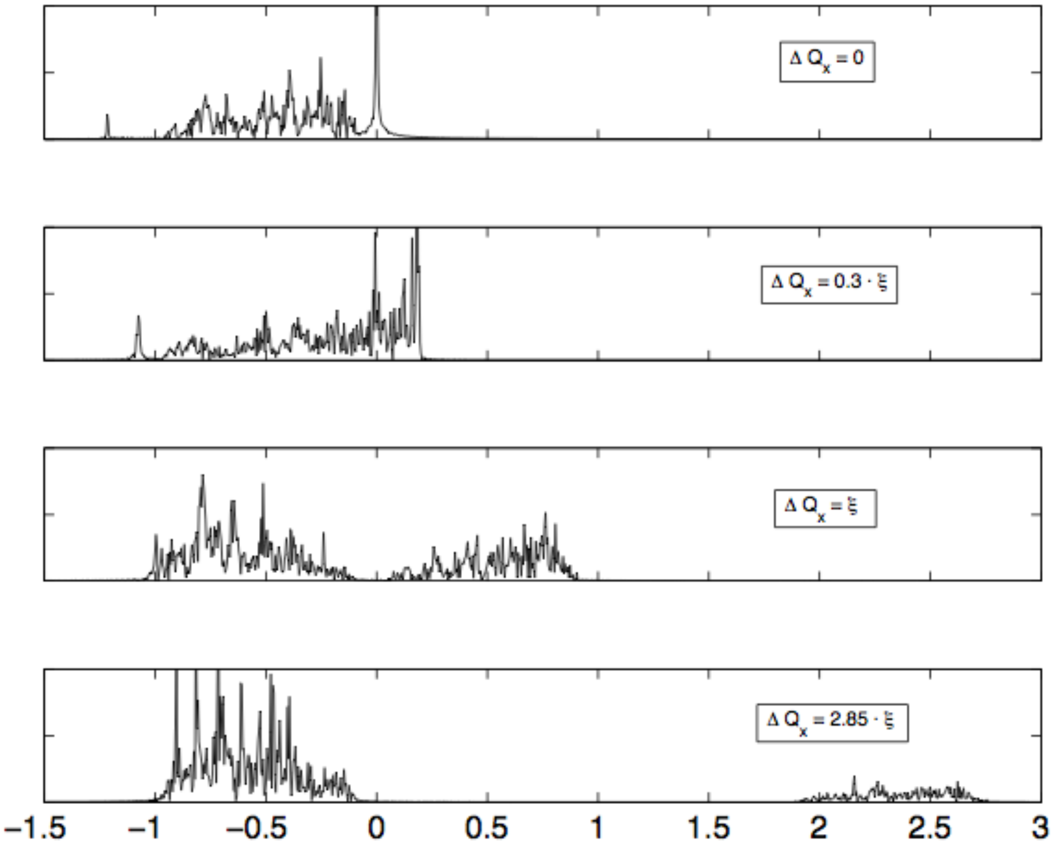
Time=0 is Squeeze mode

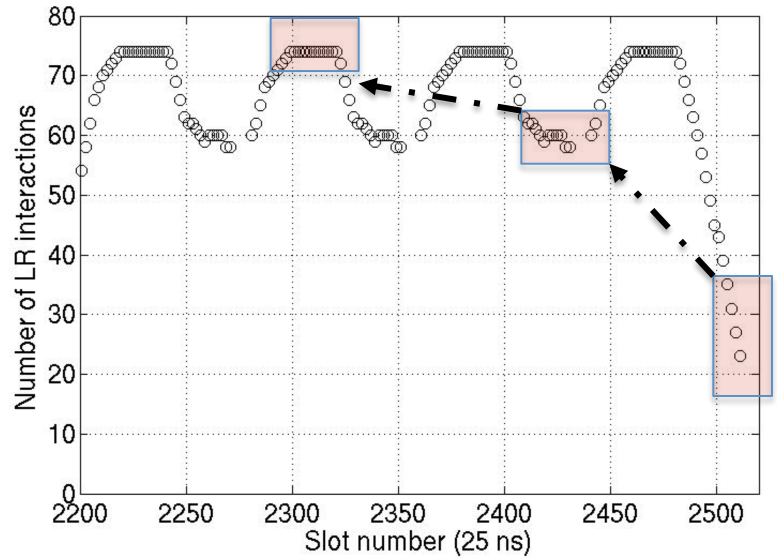


- **Recently Instability very reproducible (min 16 from Squeeze) and always involving last bunches of trains (smallest number of LR).**
- **Tune split should move instability to bunches with higher number of LR**

Tune split:

Pi mode suppression with tune split

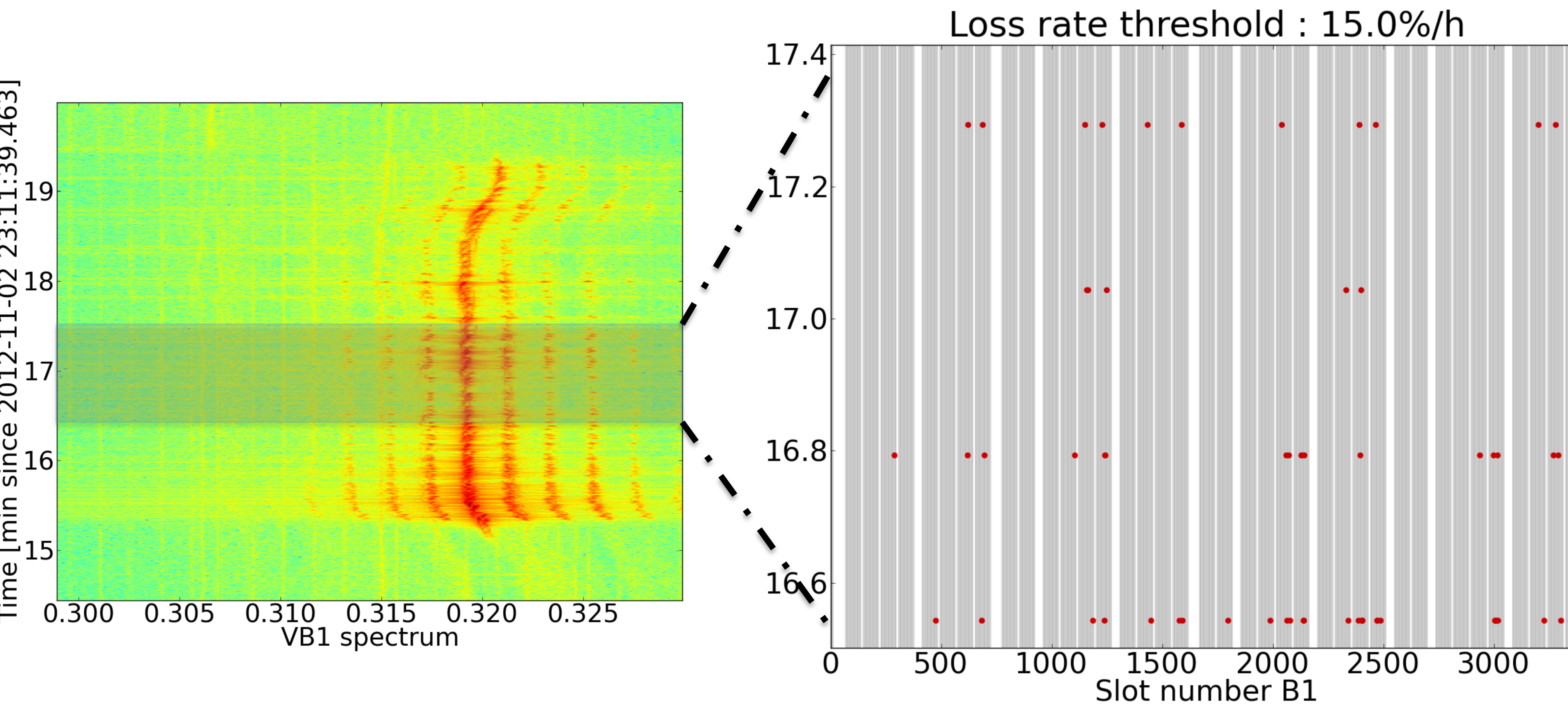




- **Tune split should break coherent modes with ξLR < ΔQ applied**
- **Modes still present for bunches with more LR**
- **Small splits of tune should move instability to bunches with more LR interactions**

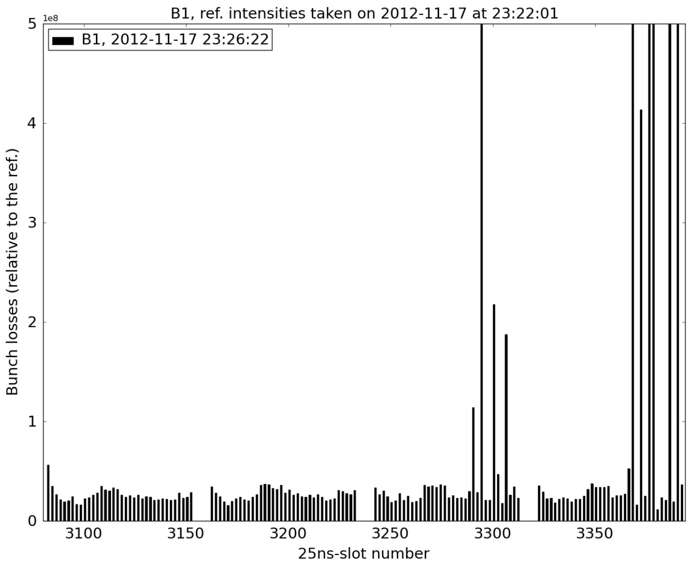
Tune split to cure instability standard solution in the presence of coherent BB modes!
Need a bigger tune split (10^{-2} range) which will depend on intensities and tunes…not a robust solution still! Has to be studied carefully (simulations and operational aspects)

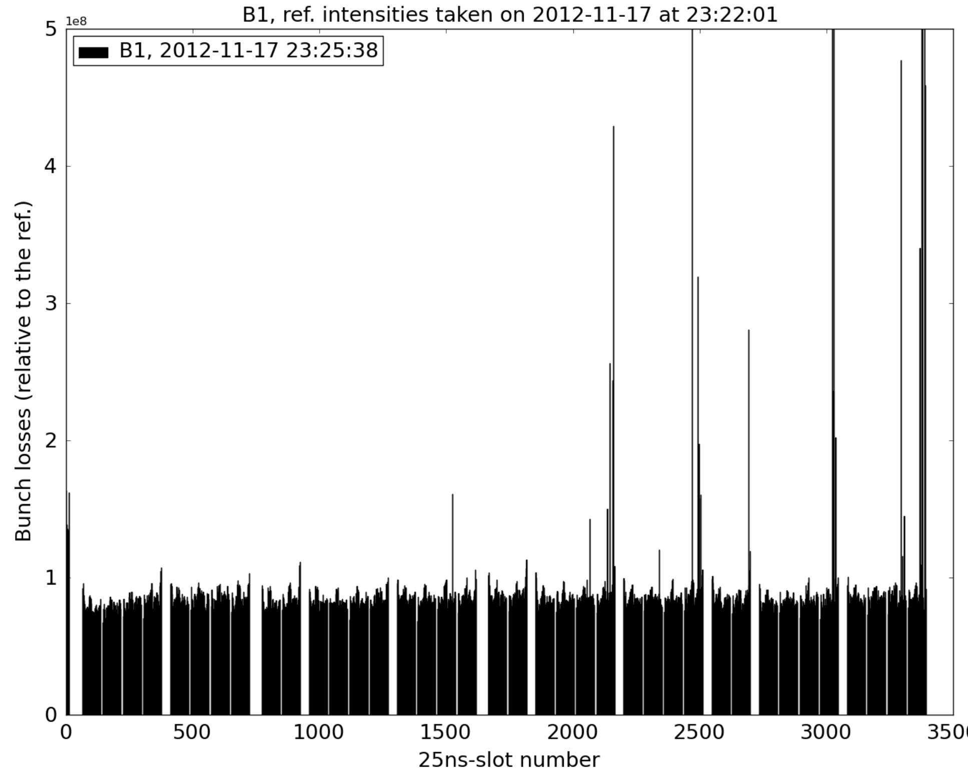
Fill 3259 tune split at end of squeeze:



- During tune change all bunches lose and it is very difficult to distinguish: LR modes moves before "disappearing"
- Bunches with Larger number of LR lose
- Instabilities arrives earlier

Preliminary Results: Fill 3297 tune split 5 10^{-3}





- **Instability starts during beta squeeze**
- **Asymmetry front-back of a train could come from impedance but also from LR interactions**
- **The instability moves to more central bunches but not always obvious**
- **Analysis still on-going over the many fills of last week!**

Conclusions, open questions and future plans

- Beam-Beam alone is a stable
- First studies of interplay with impedance shows coupling of two effects, and BB modes can become unstable

BB and impedance coupling might explain what we observe in the LHC

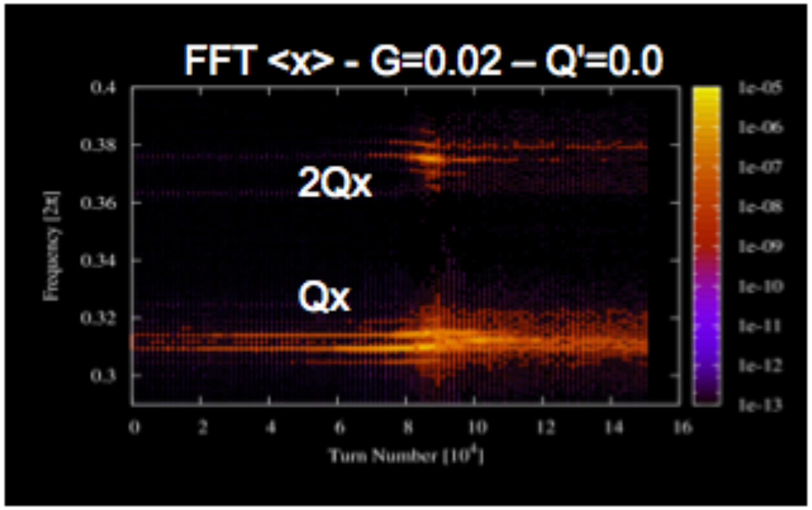
- Many observations could be explained but others are still under investigation, LHC is a complex system
- Tests and MD in simplified configurations could help

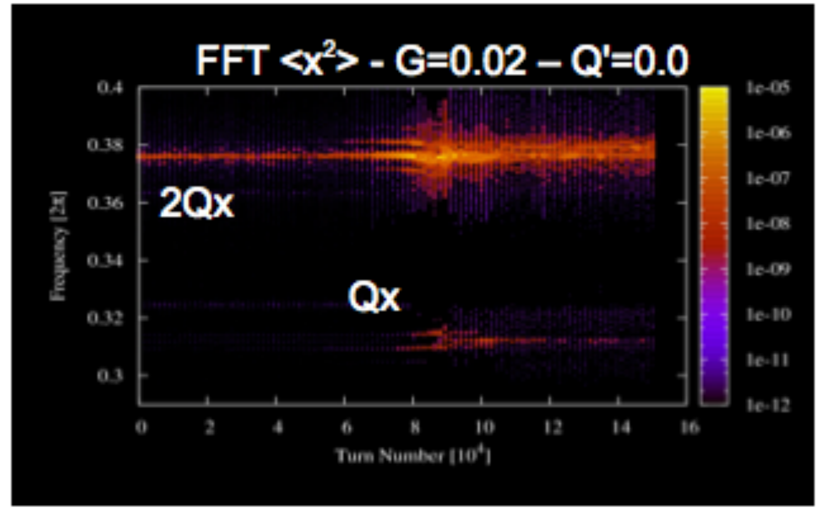
Many observations not yet understood, numerical studies and experimental studies needed

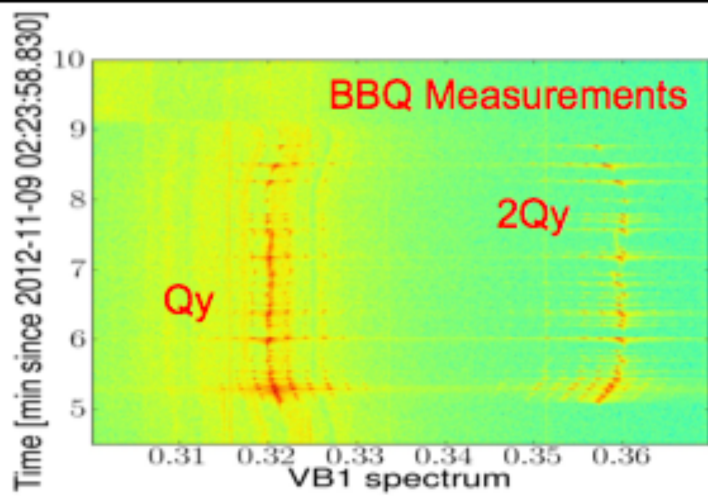
- **Analyze all the data from tune split studies to understand this instability, losses moving to higher number of LR but not always clear!**
- **MD on head-on coupling to Qs when separating beams (in block MD4)**
- **Multi bunch code COMBI now with Impedance model to cross-check simulation results from Simon and look at multi-bunch effects**

- **Possibly propose solutions for after LS1 (i.e. collide HO before squeeze)**

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**

S. White

<u>Quadrupolar mode should move with tune when changing, while reflection moves opposite.</u>
<u>Test change of tune while instability on going? Difficult … too many changes (squeeze)</u>