Requirement for crab cavity and instability monitoring

X. Buffat, R. De Maria, N. Mounet, R. Tomas

HL-LHC High Bandwidth Pickup BPM review 15.01.2025

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- Crab leakage
- Emittance growth
- Instabilities
- Conclusion

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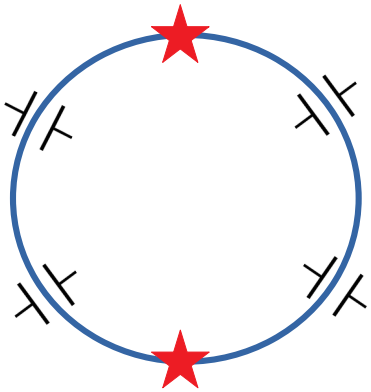

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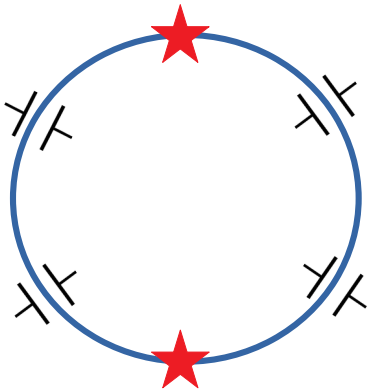


- In order to uniquely determine the source, one would require two WB BPMs placed at about π/2 from each other, on each machine side in each plane and each beam
  - It is possible to operate with less pickups, the identification and correction of the source would be more time consuming (voltage scans in each cavities)

Crab leakage

$$x \text{ or } y = \sum_{i=0}^{4} \frac{V_i}{E} \sin(\omega_{RF} z + \varphi_i) \sqrt{\beta_i \beta(s)} \frac{\cos(\psi(s, s_i) - \pi Q)}{2\sin(\pi Q)}$$

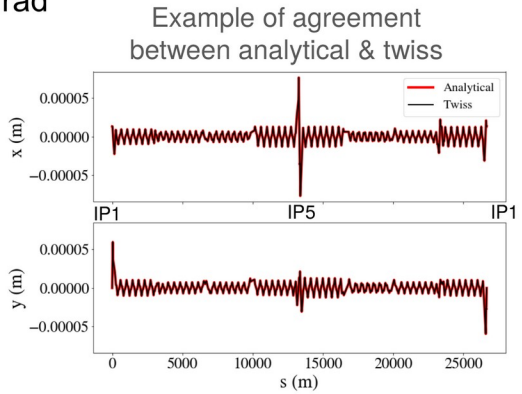
- 4 CCs per IP per beam and plane
- **σ_z=7.5 cm**
- V_{CC} = 3.4 MV per cavity
  => θ_{CC}~ 0.29 μrad

- β_i: beta-function at CC locations

- $\psi(s, s_i)$: phase advance w.r.t the CCs.

R. De Maria, S. Kostoglou @ WP2 15/6/2021

Example of agreement between analytical & twiss



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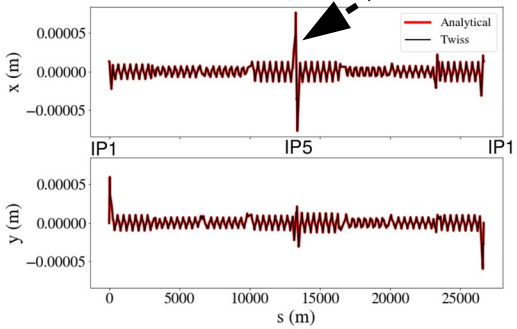

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  - WB BPM close to the crab cavities
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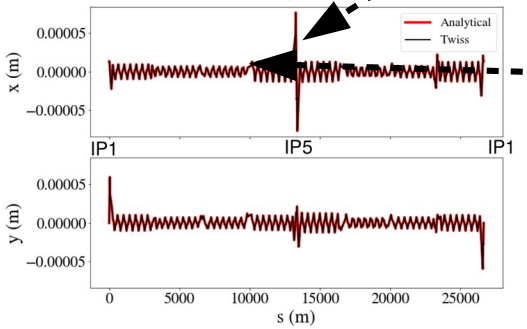

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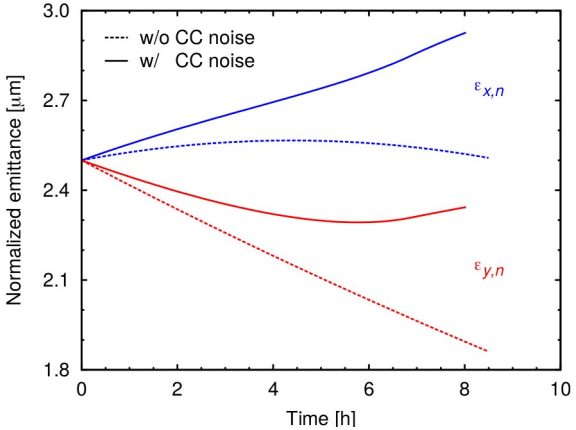
  - Lower signal (required range: **0.05 to 3 mrad**)
  - Optics dependent
  - Can be chosen close to π/2
  - Only one side of the machine is covered → Can't disentangle between sources in IR 1 or 5

Crab cavity noise feedback (EDMS 3069868 : Functionality C)

L. Medina, et al., CERN-ACC-2018-0003



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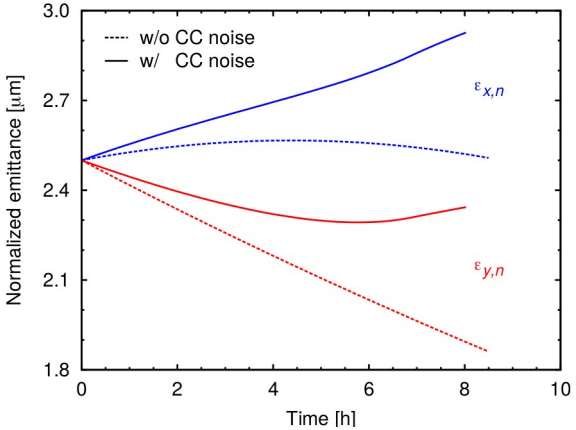

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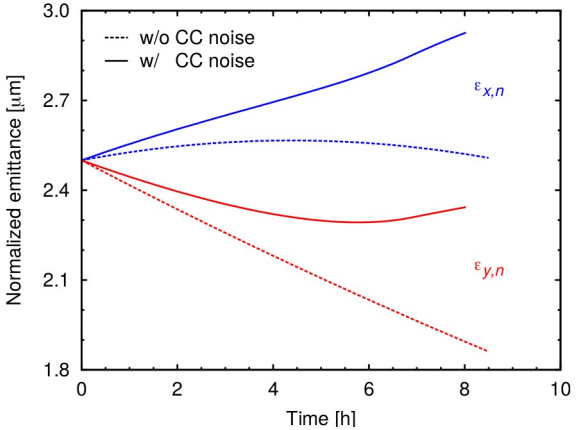

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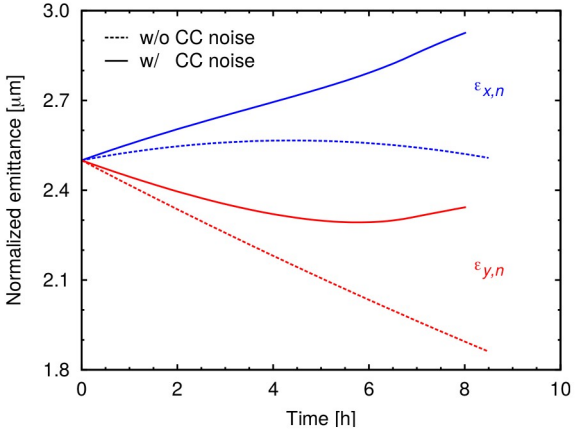

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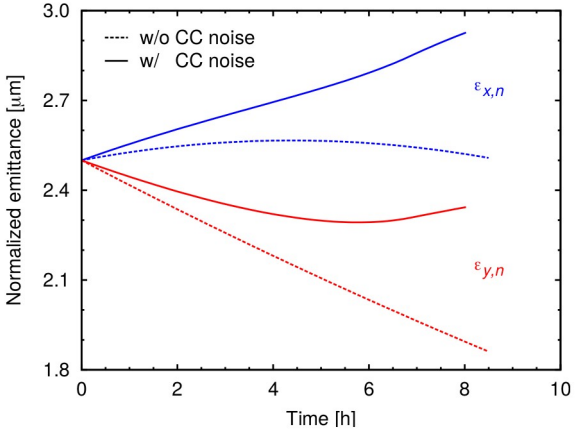

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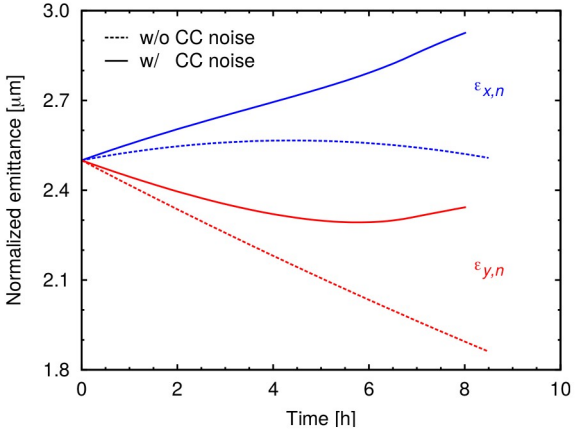

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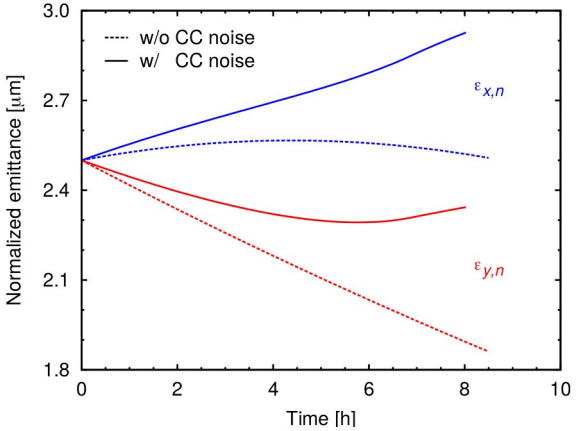

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- Recommendation: Keep the demodulation frequency at 400MHz to avoid generating beam instabilities with high feedback gain (see backup)

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Beam instabilities

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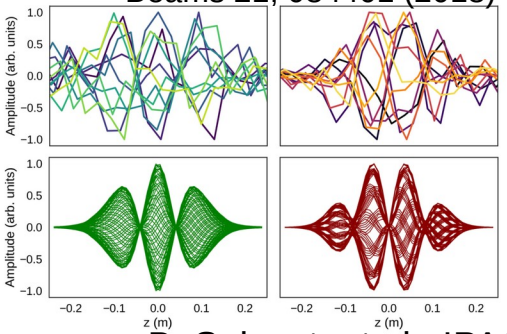
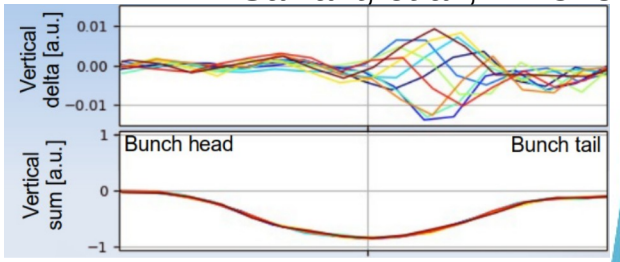
M. Schenk, et al. Phys. Rev. Accel. Beams 21, 084401 (2018)



B. Salvant, et al., IPAC18



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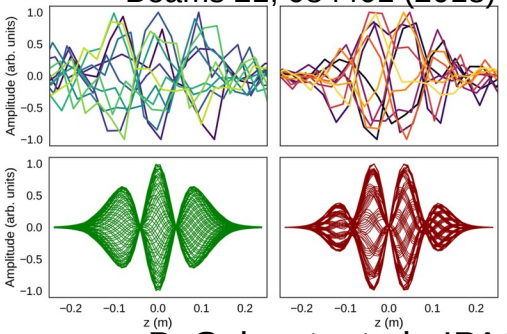

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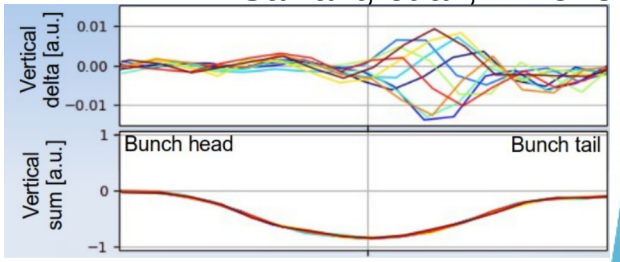

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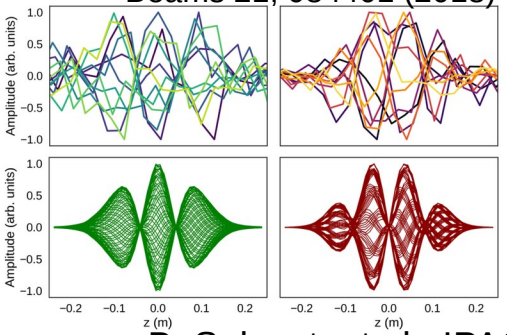

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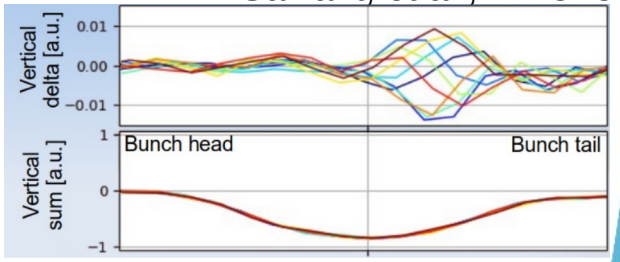

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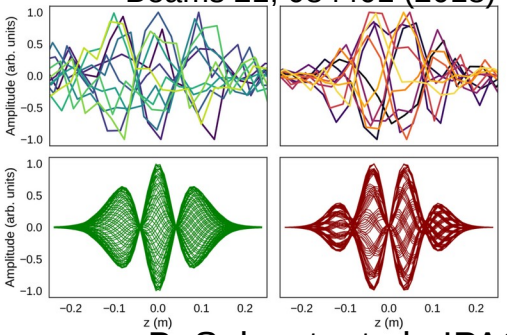

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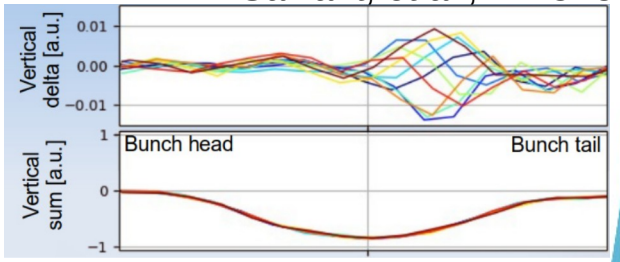

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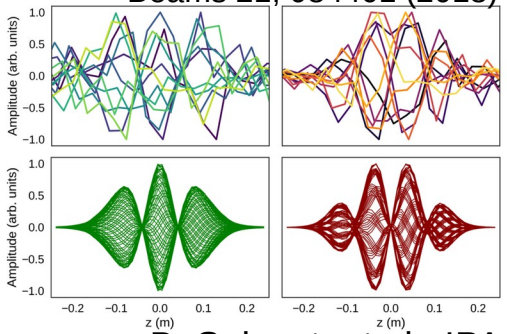

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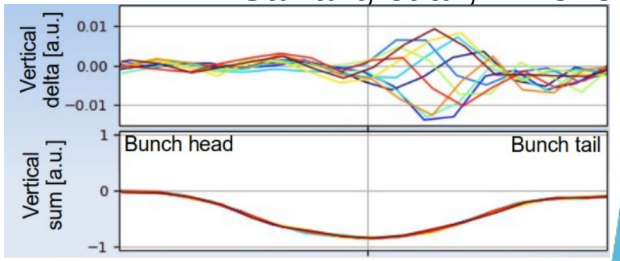
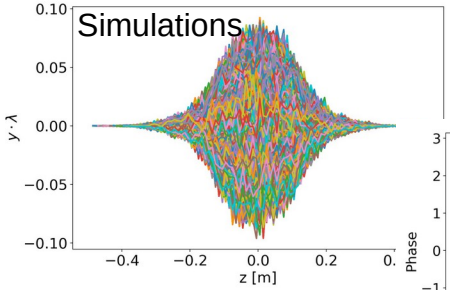
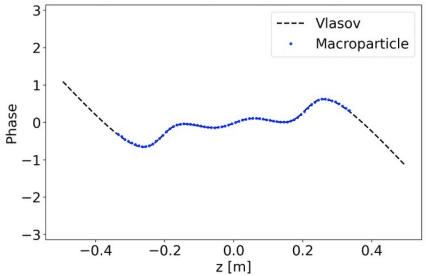




K. Paraschou @CEI meeting, 18th Jan. 2023



- HT based chromaticity measurement is limited by both sampling rate and resolution with present system
  - **No strong push** to improve from WP2 given the lack of maturity of the measurement technique and the existence of alternatives

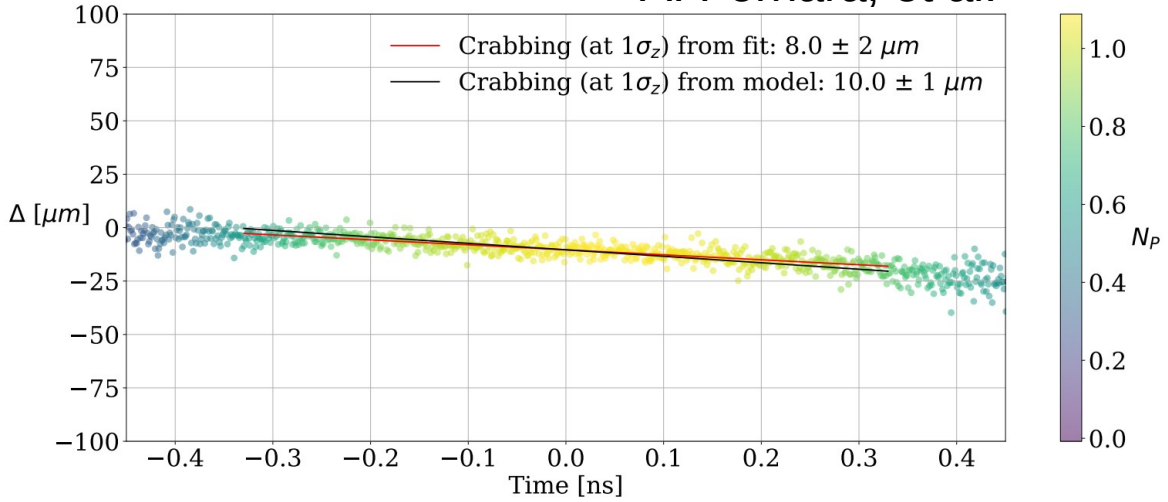
Conclusion

- Crab leakage:
  - **0.4 to 30 mrad** (30 µm to 2.2mm @ σ_z) for WB BPM next to the CC (Both planes on both sides of the IP would ease operation)
  - **0.05 to 3 mrad** (6 to 500 µm @ σ_z) for WB BPM in IR4 (two per beam and per plane)
- Noise feedback: **2 % / h**
  - Noise on single bunch position **< 3.9 µm**
  - Noise on angle **< 0.1 mrad**
- Instabilities : The performance of the current HT monitor is acceptable

Measured crabbing

- First crabbing measurements at the LHC (beam-beam induced) are based on a fit over the core of the beam (<σ_z)

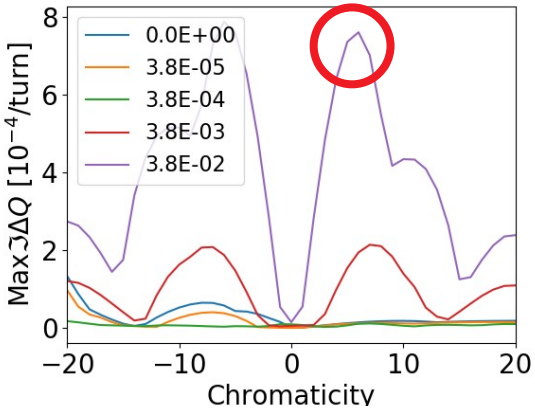
A. Fornara, et al.



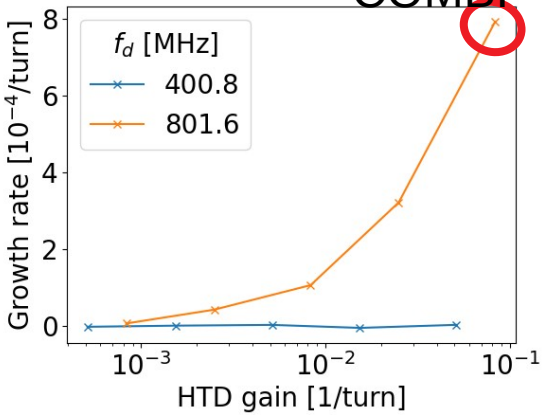
Instabilities driven by the CC feedback
(X. Buffat @ WP2 meeting 05.04.2022)

- Using a linearised model, a strong instability is observed consistently with two approaches :
  - The circulant matrix model (BimBim)
  - Multiparticle tracking (COMBI)

BimBim



COMBI



Instabilities driven by the CC feedback
(X. Buffat @ WP2 meeting 05.04.2022)

- Using a linearised model, a strong instability is observed consistently with two approaches :
  - The circulant matrix model (BimBim)
  - Multiparticle tracking (COMBI)
- In this first step several aspects were neglected :
  - RF curvature
  - Energy change
  - Delay between measurement and kick
  - Bandwidth of cavities
  - Beam-beam interactions

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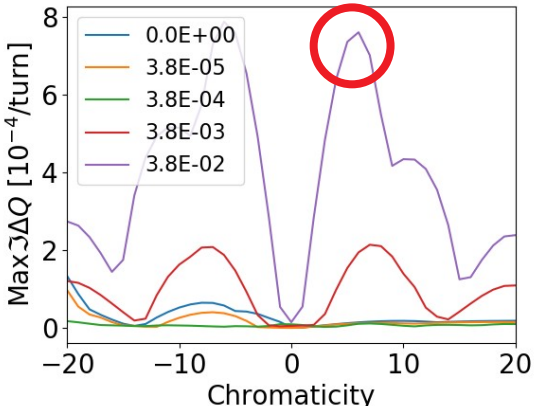
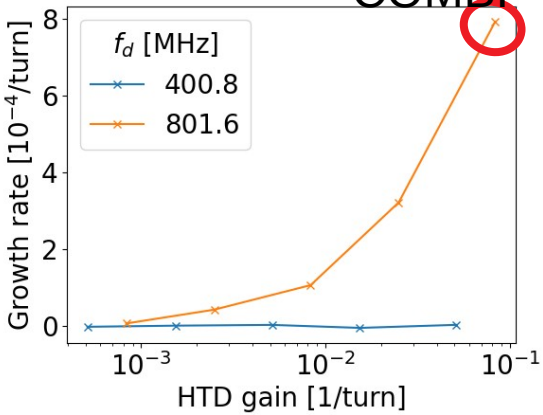


COMBI



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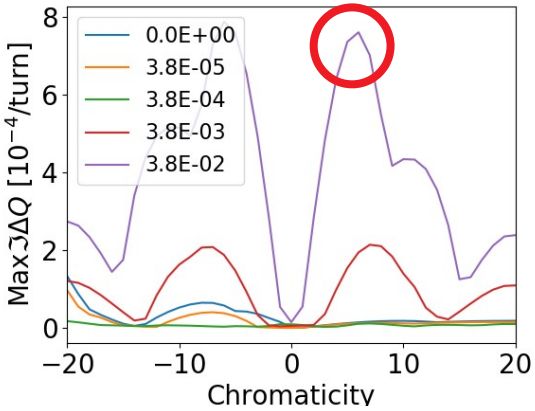
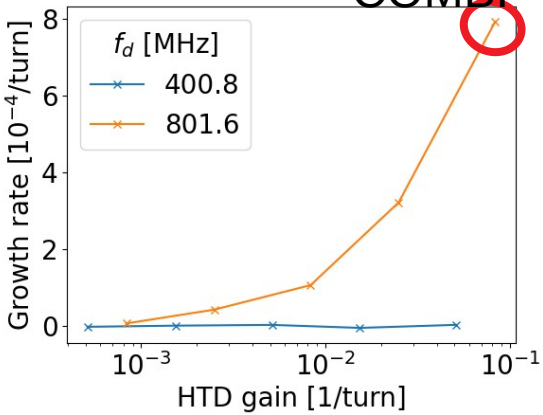
→ A multibunch approach with two beams is needed to assess the beam stability in a realistic configuration → PyPLINE

BimBim



COMBI



https://github.com/PyCOMPLETE/PyPLINE

Instabilities driven by the CC feedback

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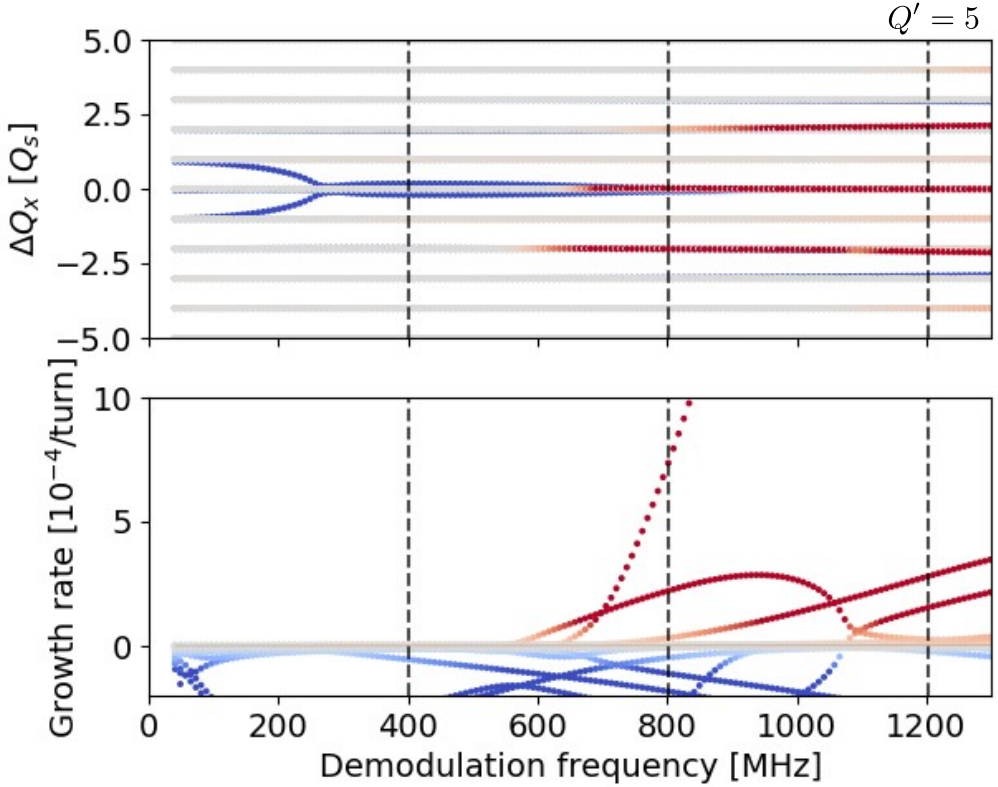

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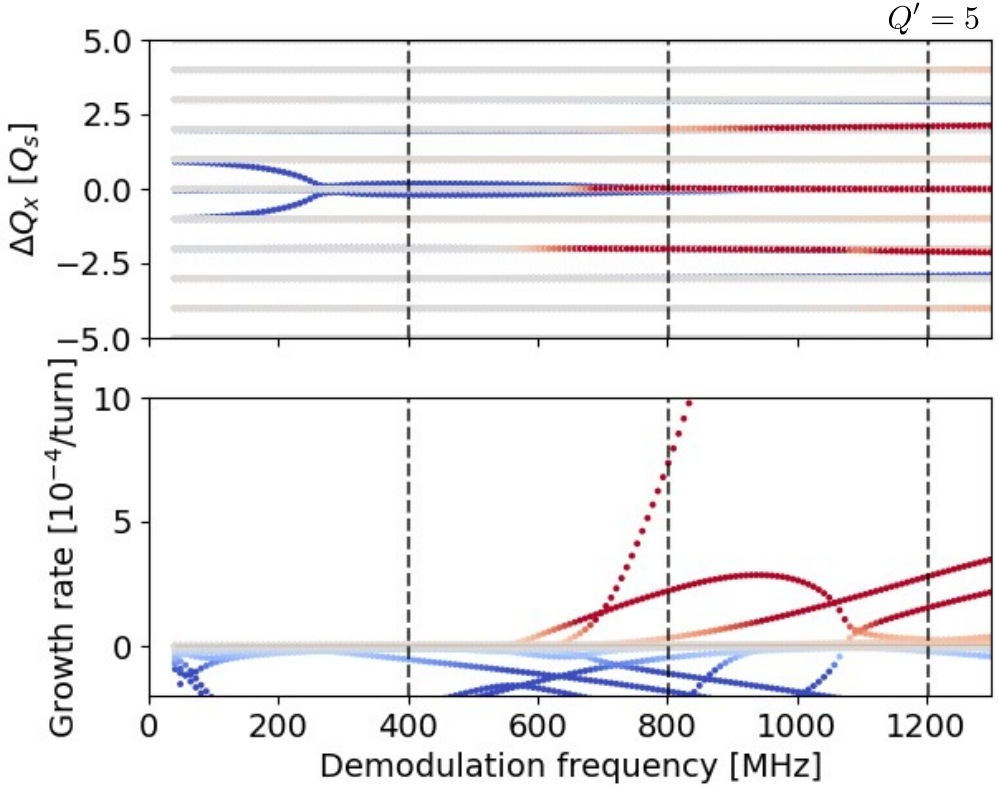

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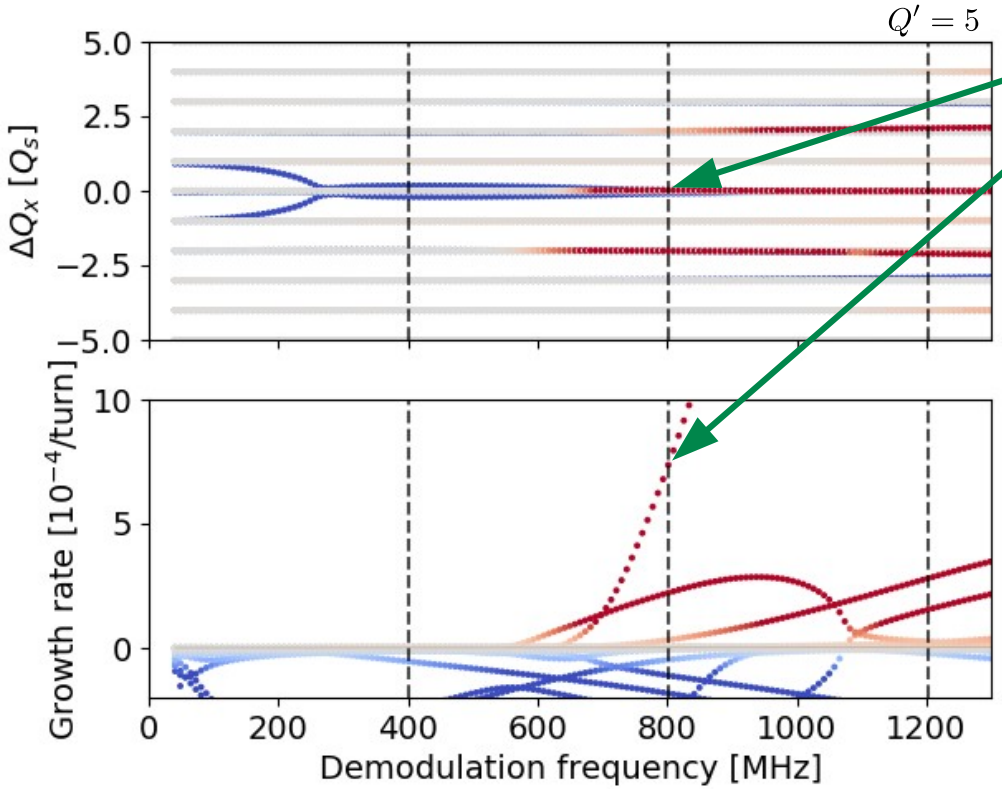
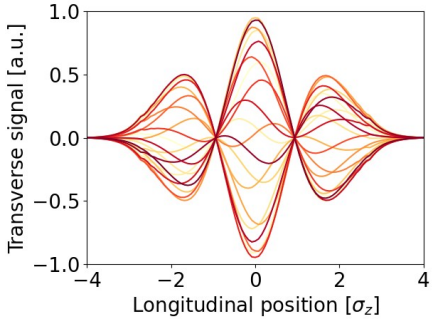
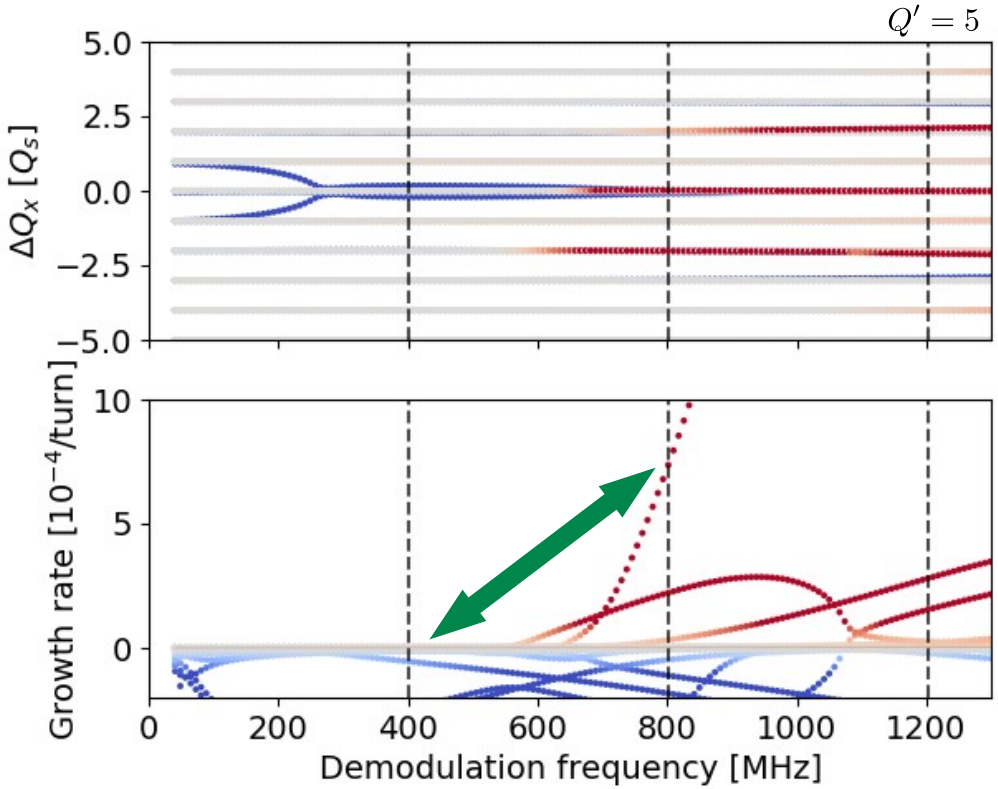
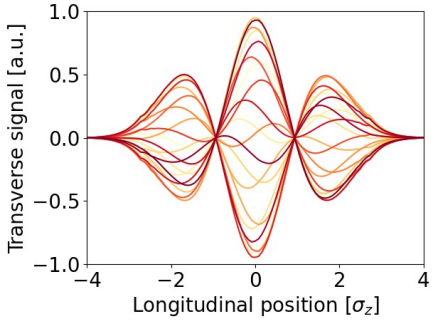




- The strongest instability driven by the CC amplitude feedback is transverse head-tail mode two nodes

Instabilities driven by the CC feedback
(X. Buffat @ WP2 meeting 05.04.2022)





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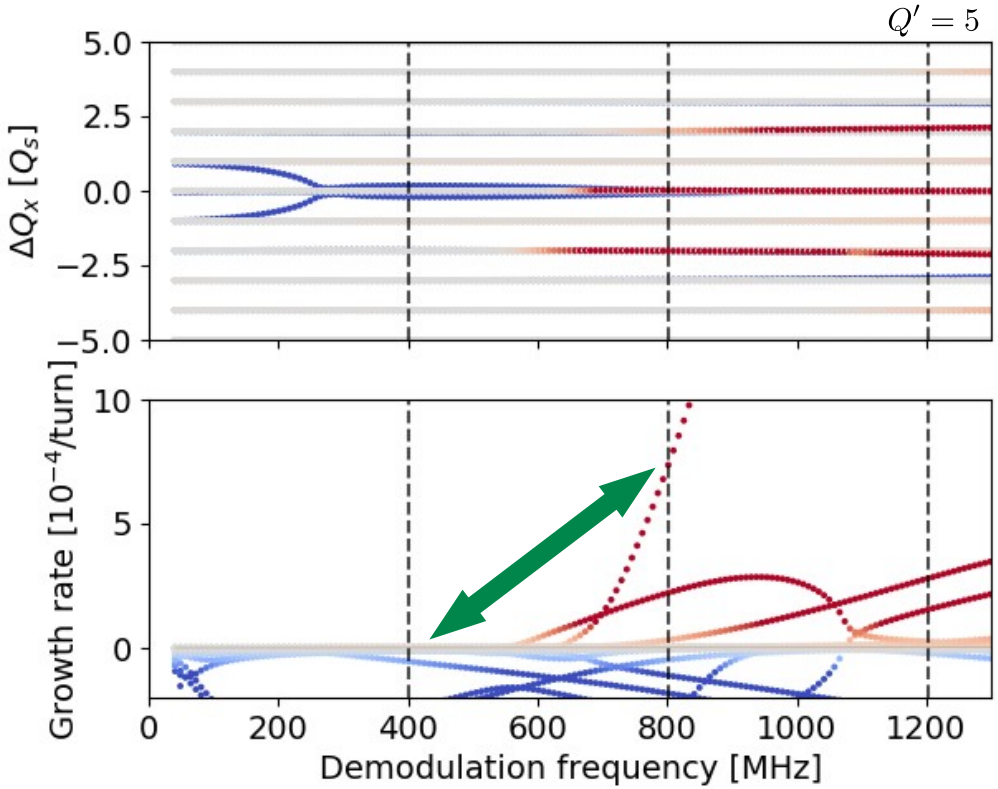
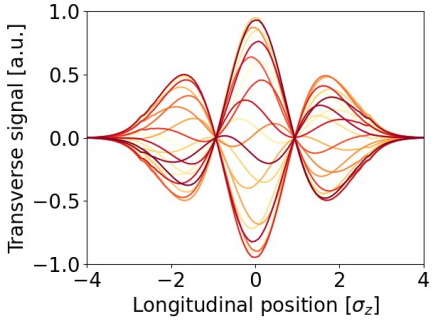




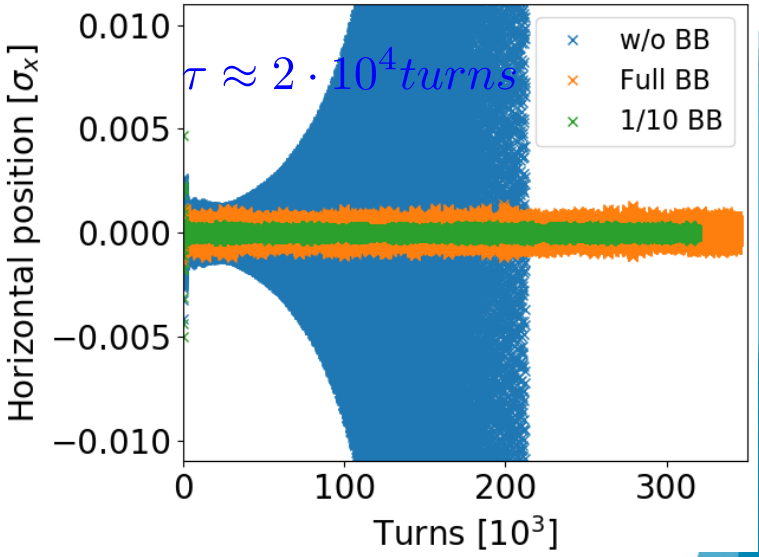
- The strongest instability driven by the CC amplitude feedback is transverse head-tail mode two nodes
  - This instability does not occur for demodulation frequencies well below the spectrum of mode 2 (<500 MHz)
- The instability was not observed previously by T. Mastoridis

  → The simulations did not feature the demodulation

CC feedback with beam-beam

(X. Buffat, et al. @ WP2 meeting 21.03.2023)

- For the specific configuration studied, beam-beam interactions at IPs 1 and 5 provide sufficient Landau damping to stabilise the instability driven by the crab cavity amplitude feedback



logo area

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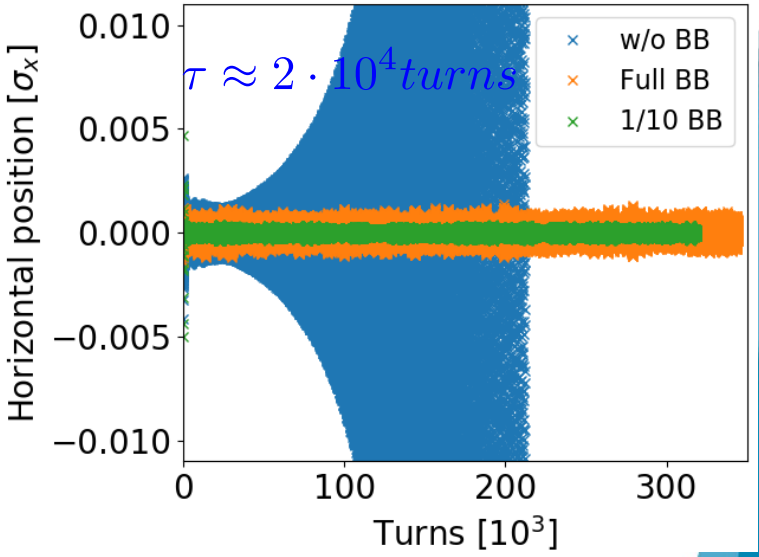
- Scaling down the beam-beam force by a factor 10 remains sufficient indicating reasonably good margins



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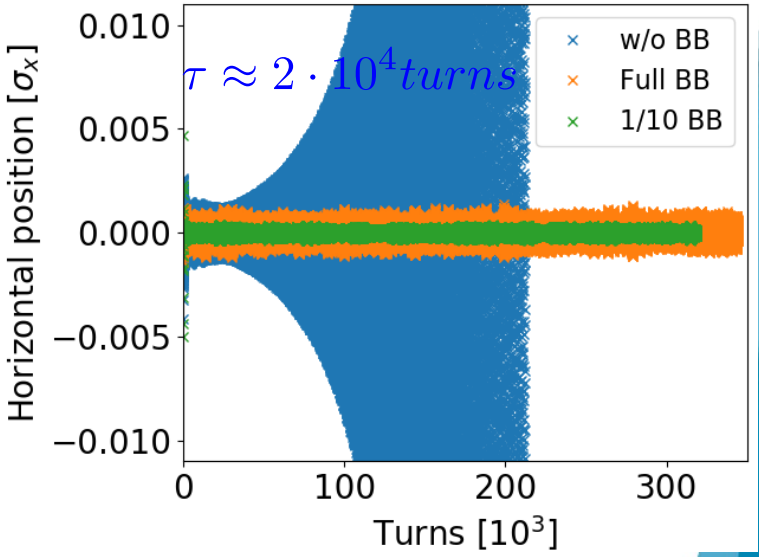
- Scaling down the beam-beam force by a factor 10 remains sufficient indicating reasonably good margins

  → **nevertheless the explored parameter space is ridiculously small** (Bunch intensity, number of bunches, apparent Q, chromaticity, amplitud feedback gain, ADT Gain, bunch length, crossing/crab angles, β*, combination with the machine impedance)



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