WP2 – Transverse impedance and stability

Lorenzo Giacomel, Nicolas Mounet, Xavier Buffat, Chiara Antuono, Adnan Kurtulus, Björn Lindström, Benoît Salvant, Leonardo Sito, Eskil Vik

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HL-LHC Collaboration Meeting, Vancouver, Canada – 20/04/2023

WP2 – Transverse impedance and stability

- Review of impedance studies – model updates
  - BGV / Wire / vacuum valves / Y-chamber / stainless steel warm pipe
  - Code infrastructure (PyWIT, IW2D, NEFFINT?)
  - New collimator materials and collimator tapers
  - Crab cavities fundamental mode
  - Breakdown of impedance contributions
- Review of machine development studies
  - Growth rate and tuneshifts
  - Octupoles with / without latency effect
- Transverse stability
  - Impact of transverse tails
  - Impact of crab cavities
  - Impact of optics choice (flat optics, IR7 optimisation)
  - Tight vs. relaxed settings

Impedance studies

- Some impedance contributions reviewed:
  - Beam Gas Vertex: impedance studied (input to BGI/BGV review – see ***L. Giacomel, H. Guérin & I. Karpov***, *209th WP2 meeting, 18/10/2022*)

    ⟶ impedance is acceptable – but BGV not in baseline anymore (following BGV/BGI review)
  - Beam-beam Long-Range Wire Compensator: preliminary studies (see ***B. Salvant***, *WP2/WP13 HL-LHC Satellite Meeting, 23/09/2022*)

    → Impedance significant but no showstopper
  - Vacuum valves between TCLMB mask and Q4: studies done (see ***L. Giacomel***, *215th WP2 meeting*, 20/06/2023)

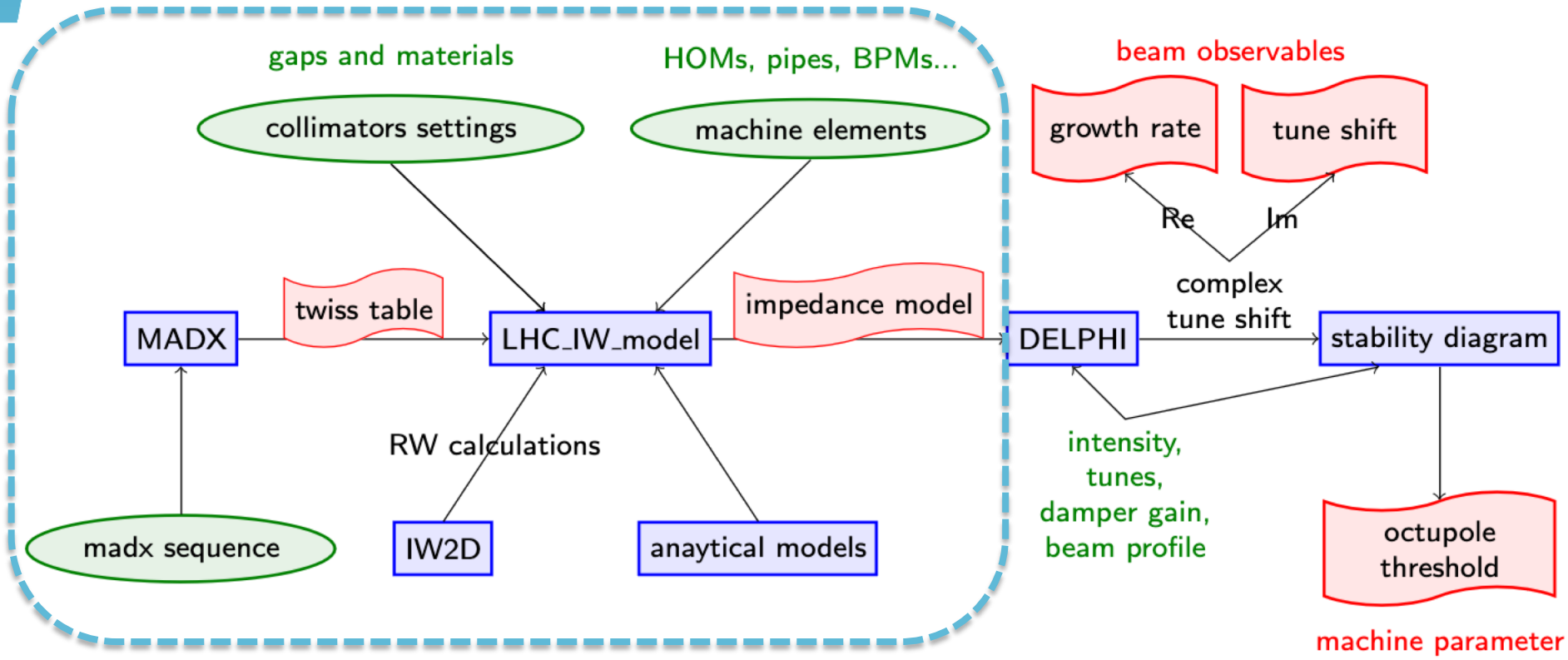
    → Impedance increase not acceptable

    → New manual FRAS table decided, to avoid aperture change and cavity-like structure
  - Absence of Cu coating in Y-chambers: studies done (see ***L. Giacomel***, *215th WP2 meeting*, 20/06/2023)

    → not fundamental importance, stainless steel can be used.

Updated of code infrastructure

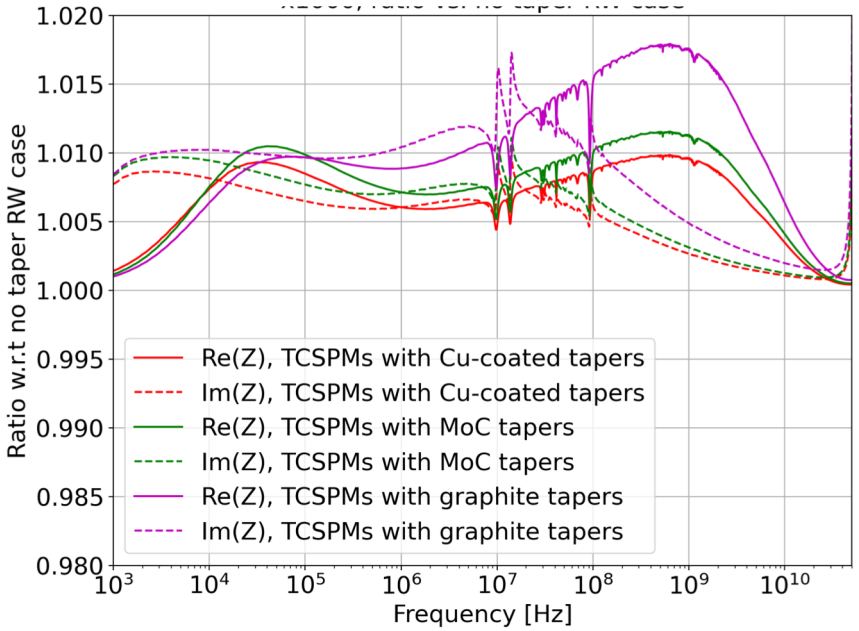
- **Model fully re-implemented using a new code infrastructure: PyWIT** (https://gitlab.cern.ch/IRIS/pywit)



- Lots of code development involved, including on **IW2D** (RW impedance).
- LHC/HL-LHC models now in https://gitlab.cern.ch/IRIS/lhc_pywit_model/

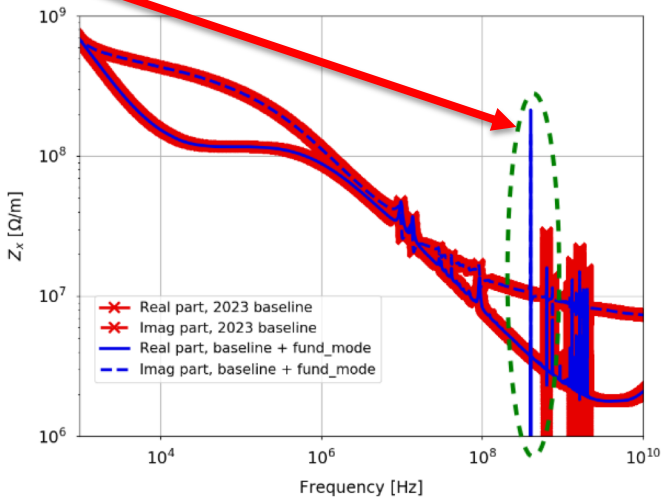
Update of impedance model

- **Main updates** to impedance model:
  - New collimator materials – mainly Cu-coated graphite TCSPMs but not only – overall impedance increase of **~1%.**
  - Resistive-wall effect of collimator tapers (detrimental, but model more accurate) - impedance increase of **~1%** (would get 2% with graphite tapers in TCSPMs
  - Crab cavities fundamental mode (detrimental – see below)
  - ~160 m of stainless-steel warm pipe close to the triplets (0.1% impact)



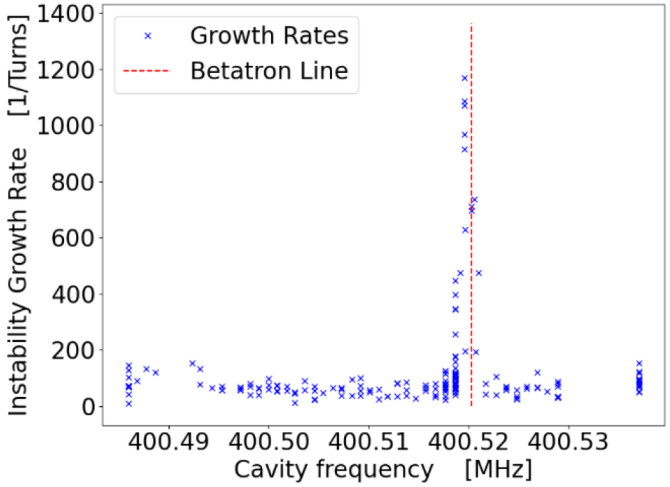
Crab cavities impedance

- Fundamental mode has a strong effect on transverse impedance:



L. Giacomel, *211th WP2 meeting*, *17/01/2023*

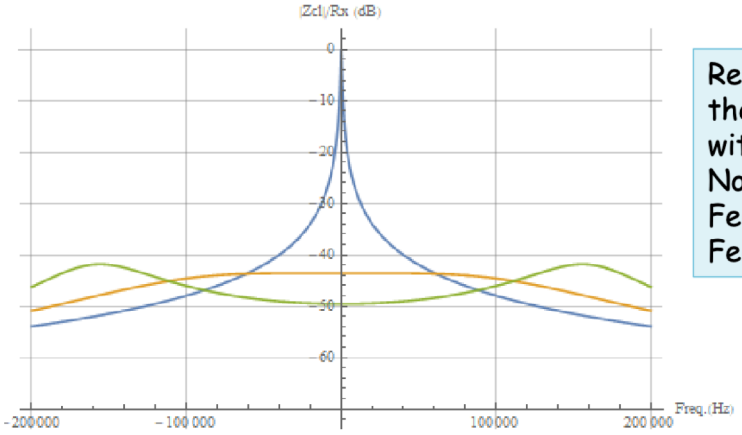
Effect also studied and confirmed in a crab cavity SPS MD:



L. Giacomel, *WP2/WP4 meeting*, *22/11/2022*

Crab cavities: impedance mitigation

- Gain of standard RF feedback cannot be increased further:

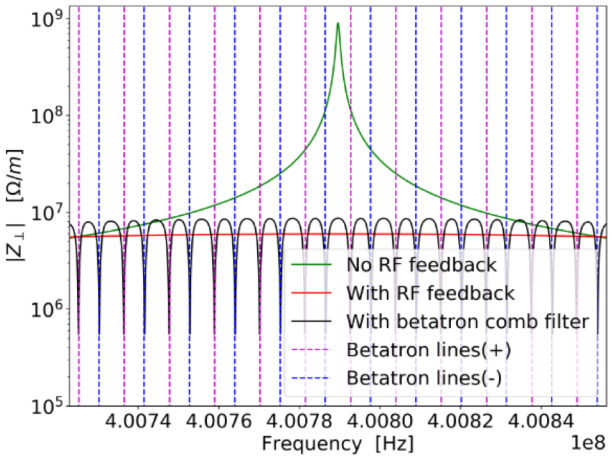


Reduction of the modulus of the transverse impedance with:
No feedback (blue)
Feedback gain=150 (orange)
Feedback gain=300 (green).

P. Baudrenghien, *WP2/WP4 meeting, 22/11/2022*

... but a **comb filter** can reduce impedance effects by acting at the right frequencies (betatron lines):

L. Giacomel, *WP2/WP4 meeting, 21/03/2023*



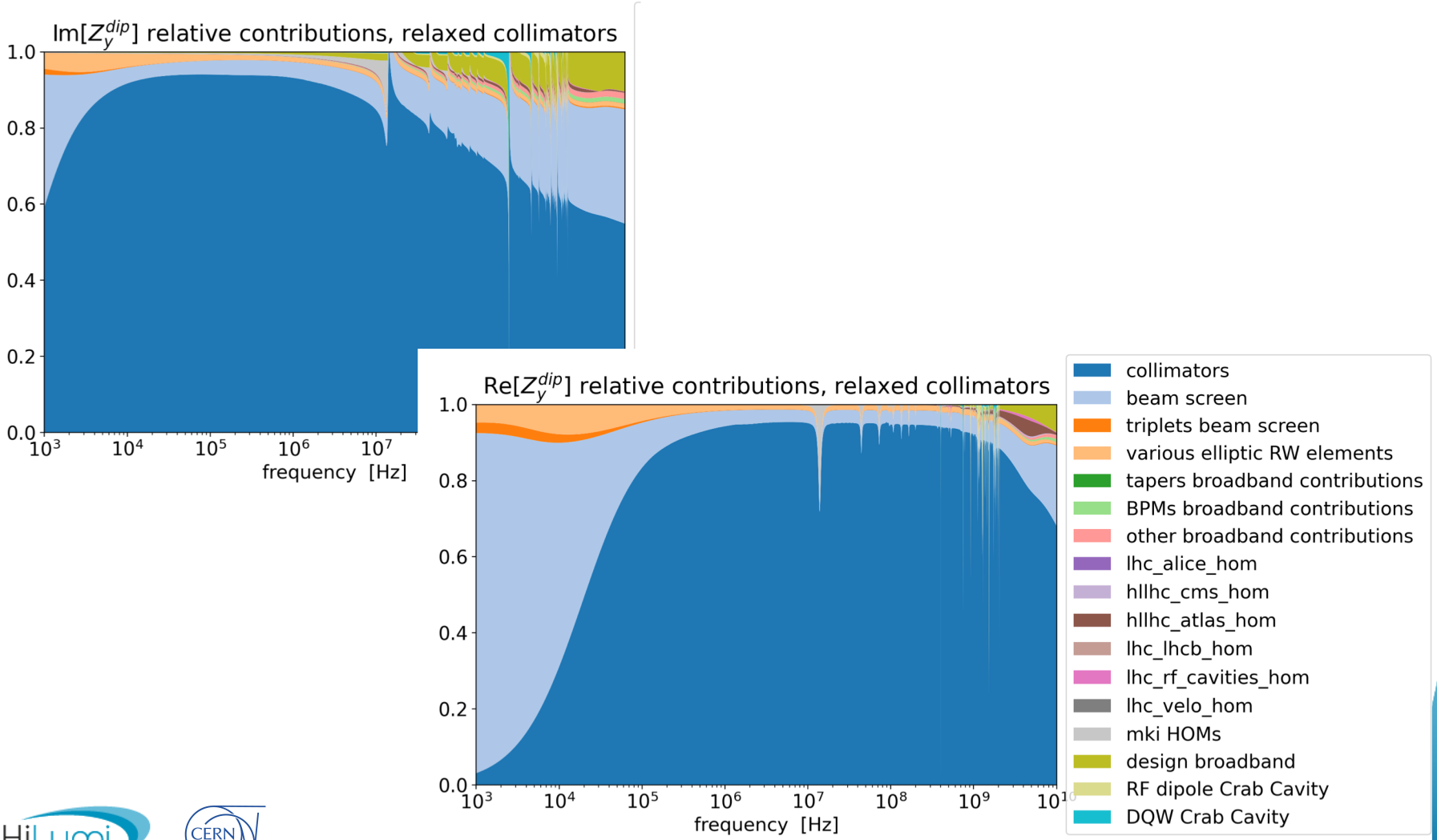
⟹ Impact decreases by **a factor of ~10** assuming tune known within $\pm 5.10^{-3}$

⟹ Bunch-by-bunch tune shift MD planned for 2024.

If comb filter is not used, **flat optics** can also reduce the octupole current.

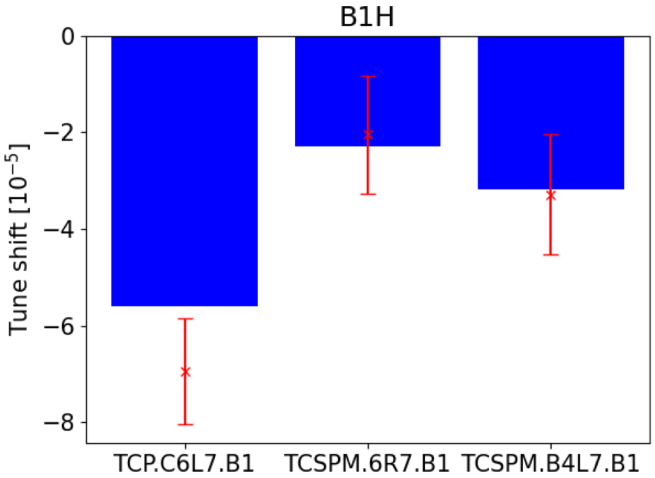
HL-LHC impedance contributions

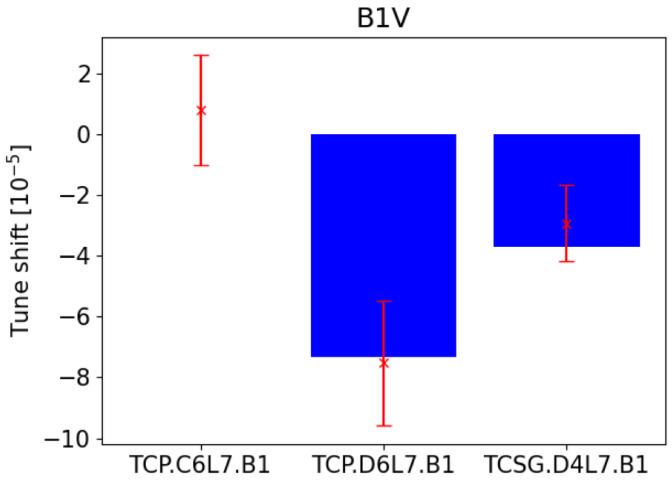
- Breakdown of all impedance contributions (relaxed collimator settings, vertical plane):

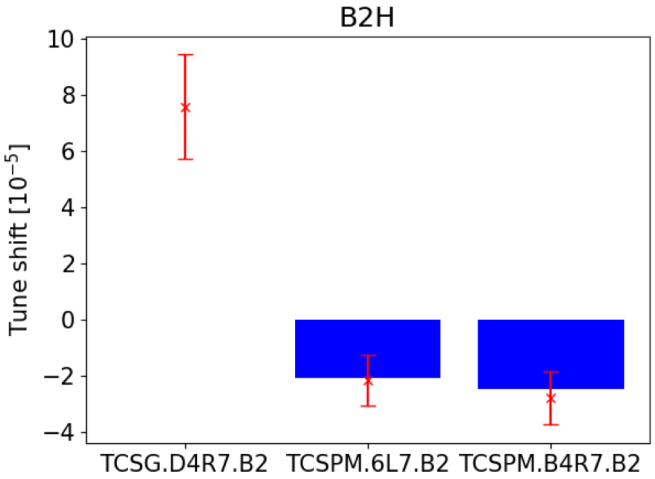


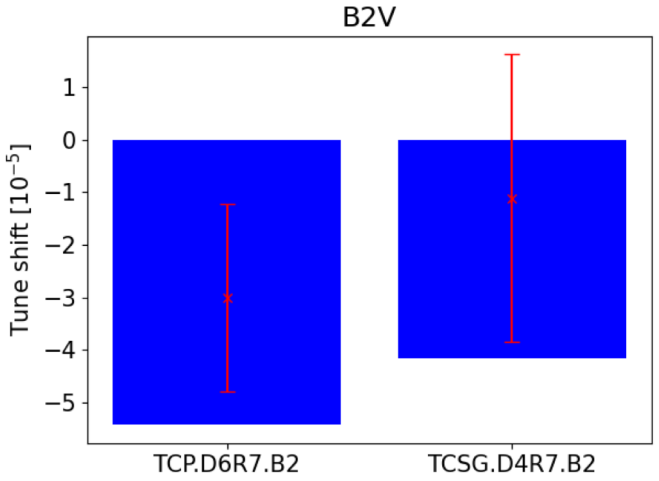
LHC machine development studies

- Tune shift measurements:





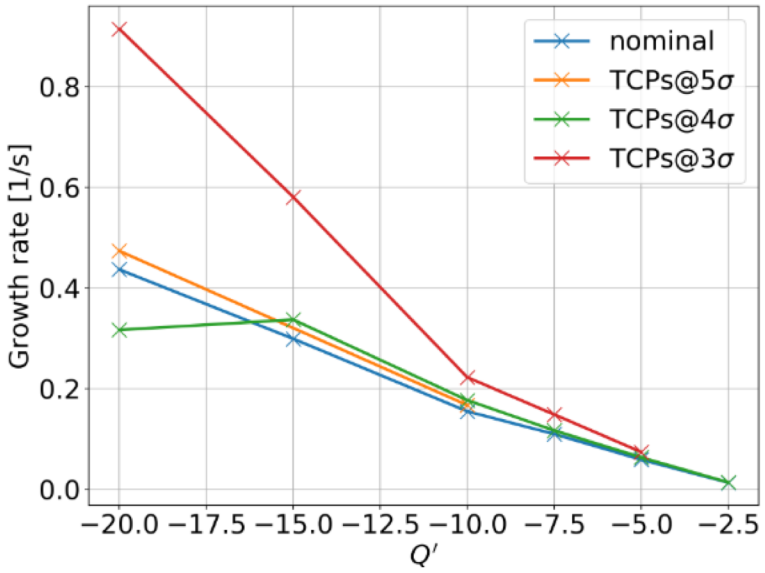




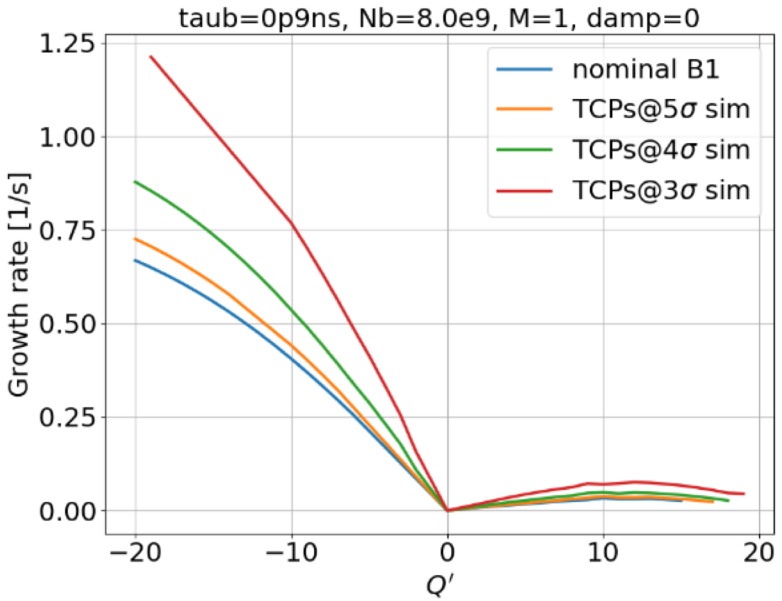
LHC machine development studies

- Growth rates at injection:

Measurements:

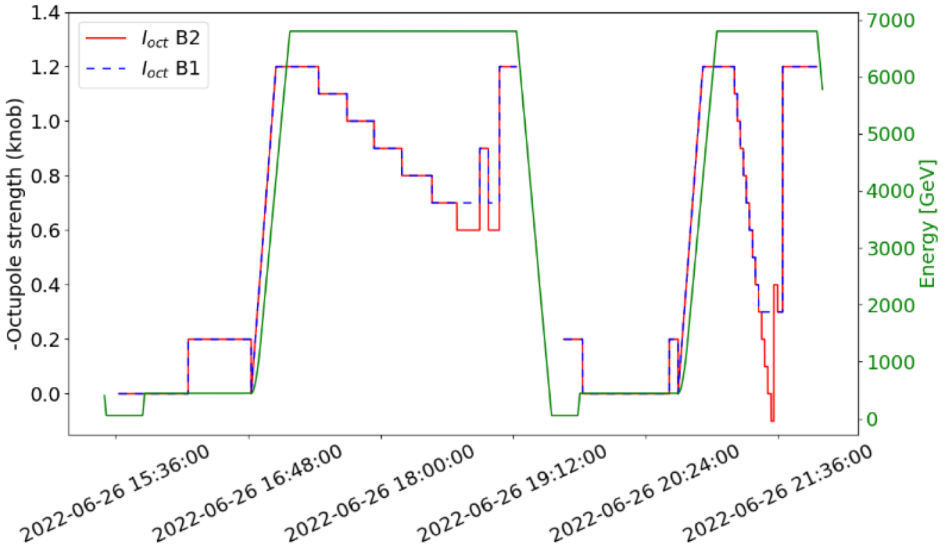


Simulations:

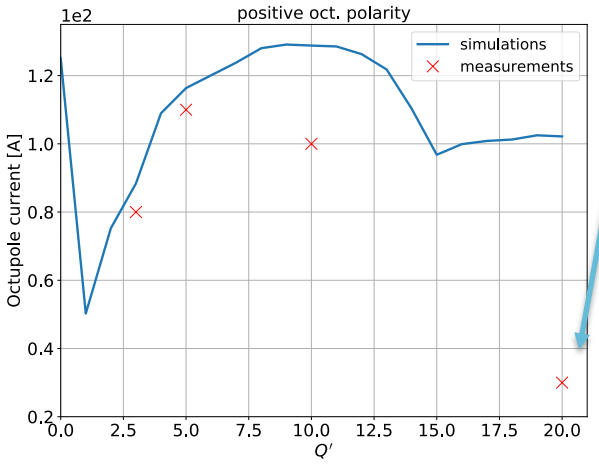


LHC machine development studies

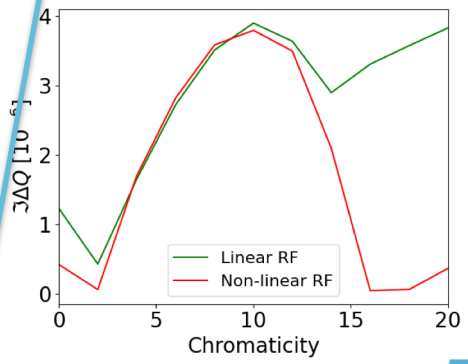
- Octupole thresholds:
  - Latency effect (slow vs fast octupole decrease):



  - Octupole threshold vs Q' (latency included):

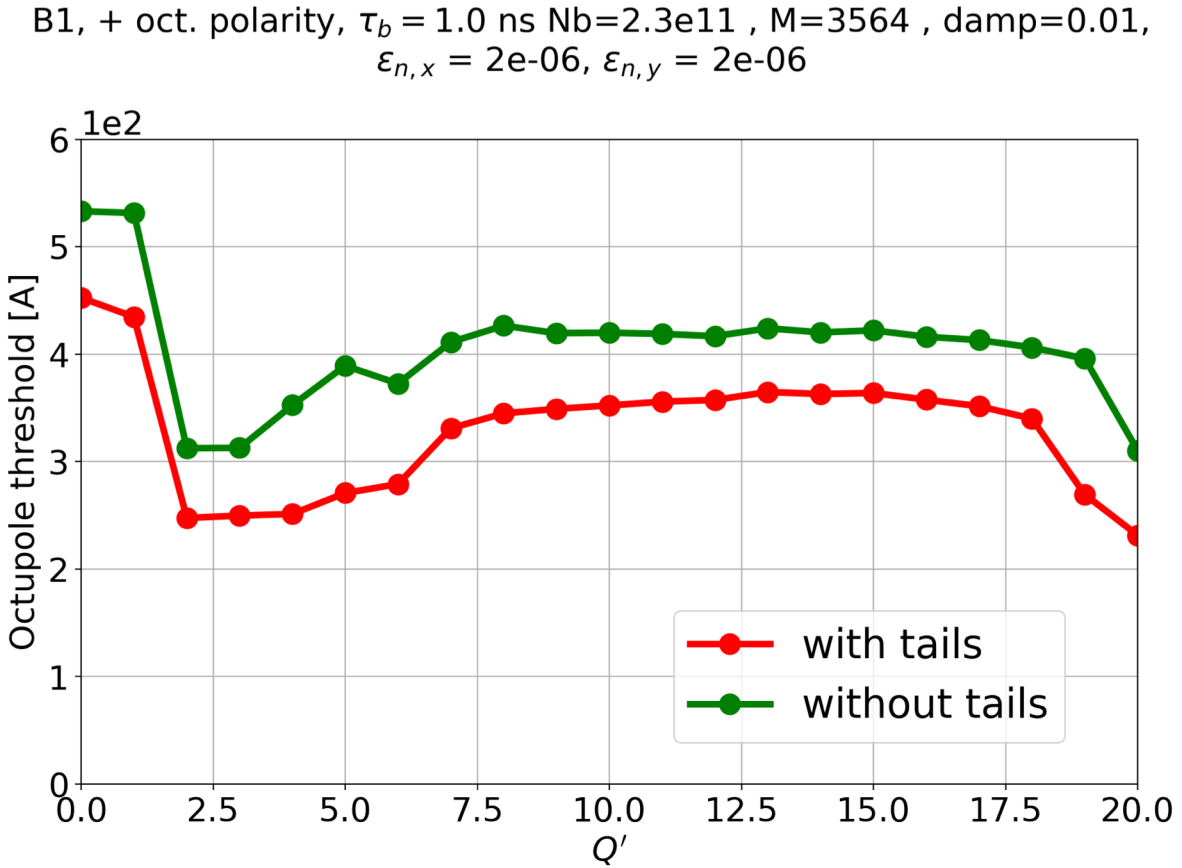


Subject of intense studies – impact of non-linear bucket



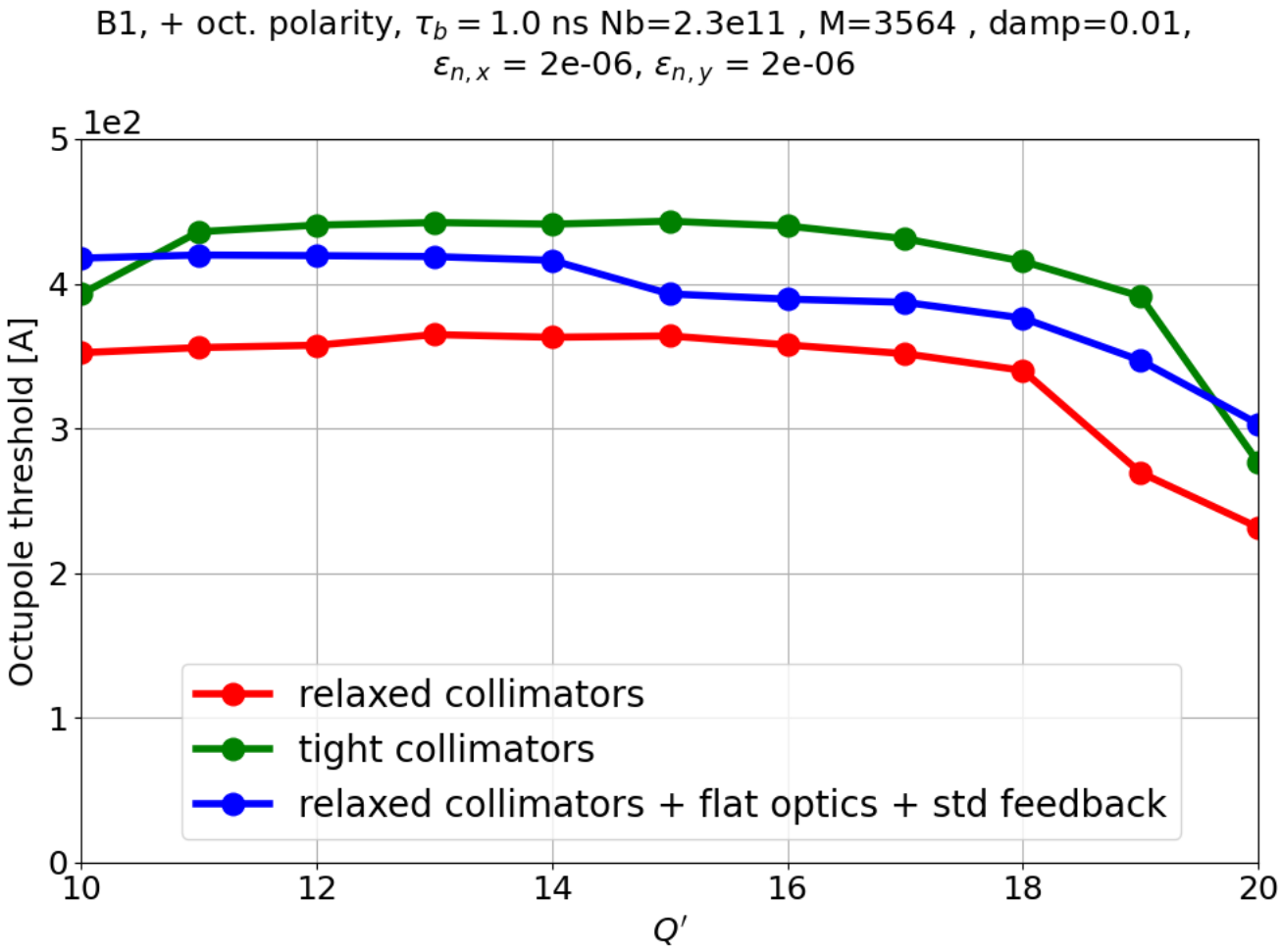
HL-LHC overall transverse stability

- The model for transverse tails has been reviewed:
  - In the past tails assumed absent (parabolic bunch in transverse, tails cut at 3.2σ) – presence of HEL + uncertainties on LIU beam
  - Now: HEL descoped & LIU beam known to have tails → **Gaussian tails assumed.**



HL-LHC overall transverse stability

- Impact of crab cavities, collimator settings & flat optics:

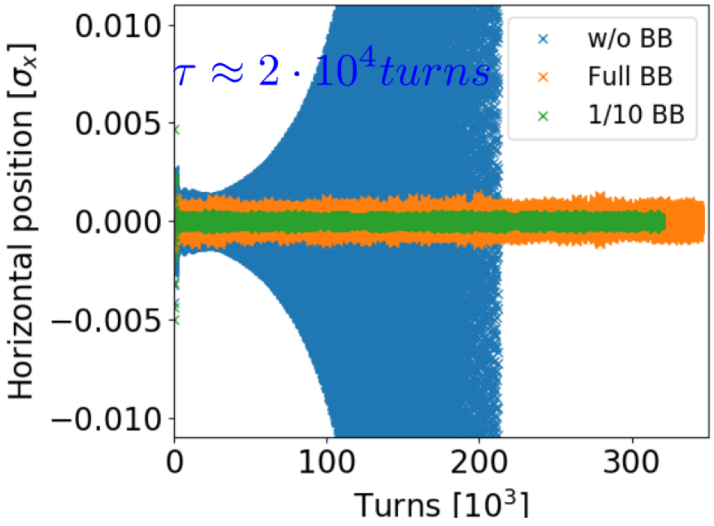


Octupole thresholds
Relaxed 2.3e11: 365A
Tight 1.8e11: 352A
Tight 2.3e11: 442A

Appendix

Crab cavities: noise & amplitude feedback

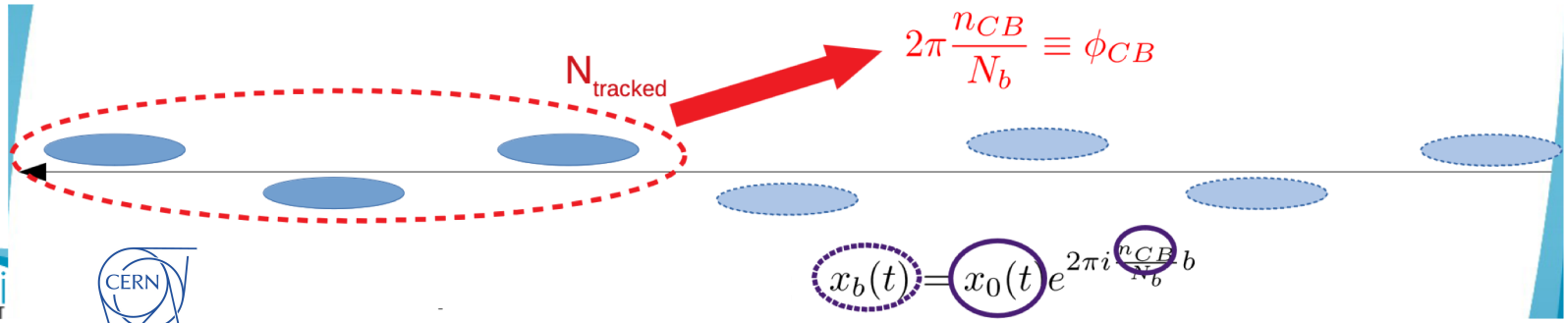
- Heavy simulation effort to understand if Landau damping from beam-beam effects sufficient to damp instabilities from **CC amplitude feedback** used to mitigate noise issue (800 MHz demodulation)



Multibunch simulations in collisions with **Xsuite**, including **beam-beam, feedback & impedance effects**
$\Longrightarrow$ instability from feedback **stabilized by beam-beam**
… but 400 MHz demodulation preferable (no instability in the first place).

X. Buffat, *WP2/WP4 meeting*, *21/03/2023*

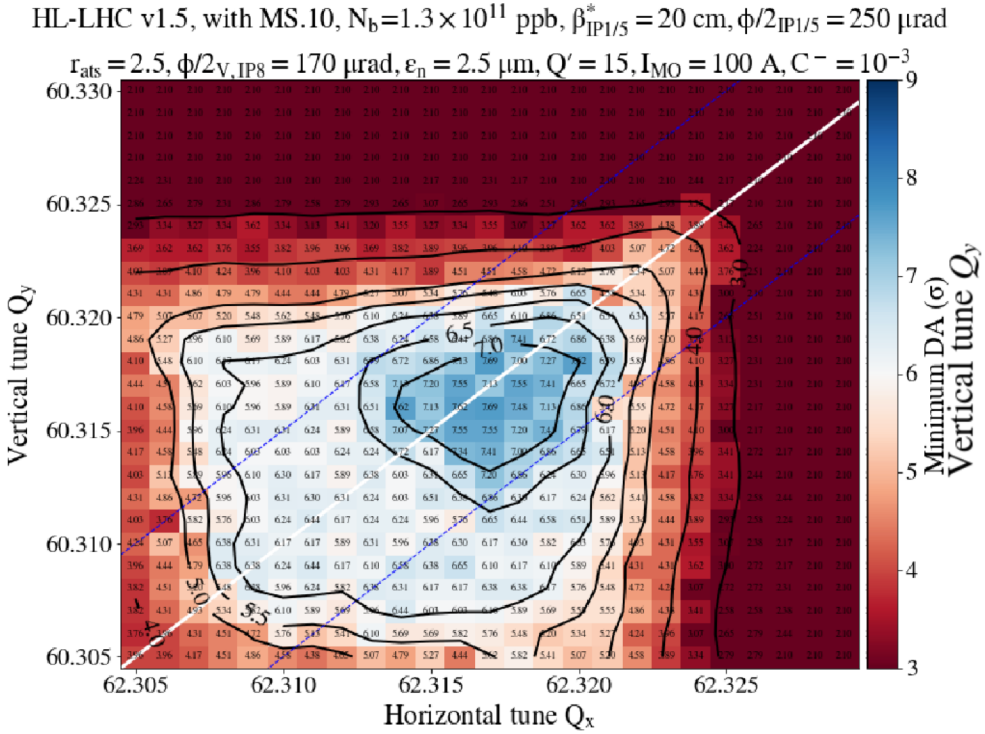
- Designing a faster approach to simulate multibunch instabilities:



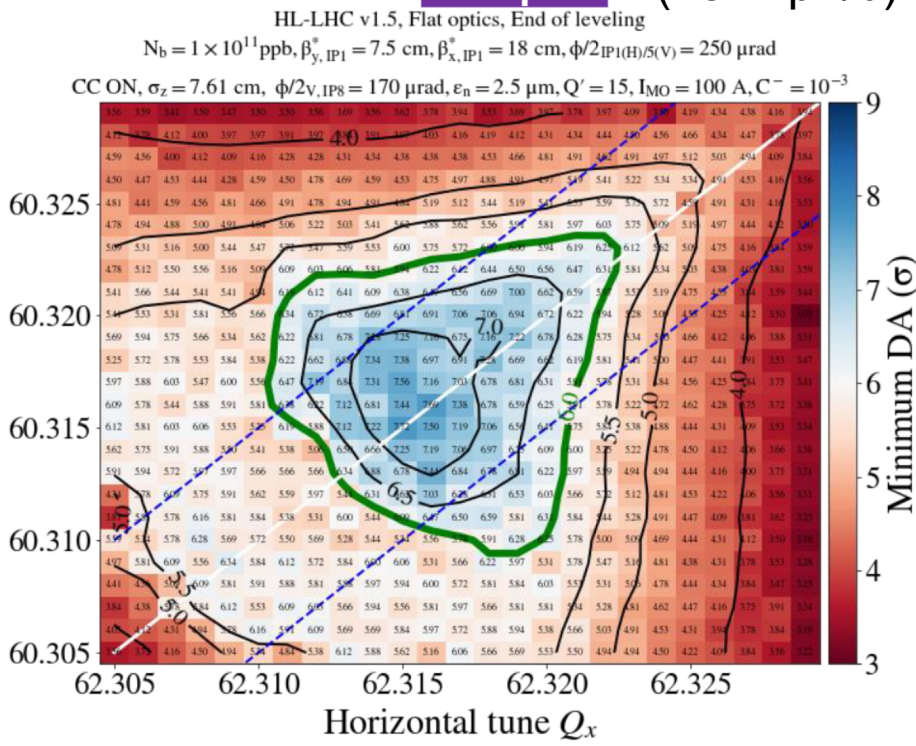
Dynamic Aperture (DA): flat optics

- Round vs flat optics (end-of-levelling, with crab cavities)

Round optics (1.3e11 p+/b)



Flat optics (1e11 p+/b)



⟹ DA slightly better in round than in flat optics, but **still large parameter space to explore**.

S. Kostoglou, *211th WP2 meeting*, *17/01/2023*

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- C.E. Montanari, A., Bazzani, M. Giovannozzi, *Probing the diffusive behaviour of beam-halo dynamics in circular accelerators*, Eur. Phys. J. Plus **137**, 1264, 2022, https://doi.org/10.1140/epjp/s13360-022-03478-w
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- *X*. Buffat, *Suppression of Emittance Growth by a Collective Force: Van Kampen Approach*, IPAC'22, pp. 2197-2200, 2022, http://dx.doi.org/10.18429/JACoW-IPAC2022-WEPOTK059
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- R. De Maria, R. Bruce, X. Buffat, G. Iadarola, S. Kostoglou, M. Giovannozzi, B. Lindström, L. Mether, E. Métral, N. Mounet, S. Redaelli, G. Sterbini, R. Tomás, *High Luminosity LHC Optics Scenarios for Run 4*, IPAC'23 (in preparation).
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- C.E. Montanari, A. Bazzani, M. Giovannozzi, P. Hermes, S. Redaelli, *Recent Measurements and Analyses of the Beam-Halo Dynamics at the CERN LHC using Collimator Scans*, IPAC'23 (in preparation).
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