Update on the HL-LHC impedance model in the new operational scenario, and considerations on crab cavity HOMs

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Acknowledgements: G. Arduini, E. Belli, R. Bruce, R. De Maria, C. Garion, A. Mereghetti, E. Métral, J. Mitchell, R. Tomás.

HL-LHC impedance model – coll. retraction

- Primaries and secondaries were retracted to decrease the impedance (σ computed with $\varepsilon = 2.5\ \mu$m.rad - top energy) – from **E. Belli & R. Bruce** :

Collimators	Previous baseline (β^*=40cm)	Retracted (β^*=85/105/140 cm)
TCPs (IR7)	6.7 σ	**8.5 σ**
TCSs (IR7)	9.1 σ	**10.1 σ**

Full settings in appendix

- ✓ using HL-LHC v1.5 optics (was 1.4 previously),
- ✓ for β^*=85cm/105cm/140cm (instead of 40cm),
- ✓ with or without anti-telescope (no significant change in imp.),

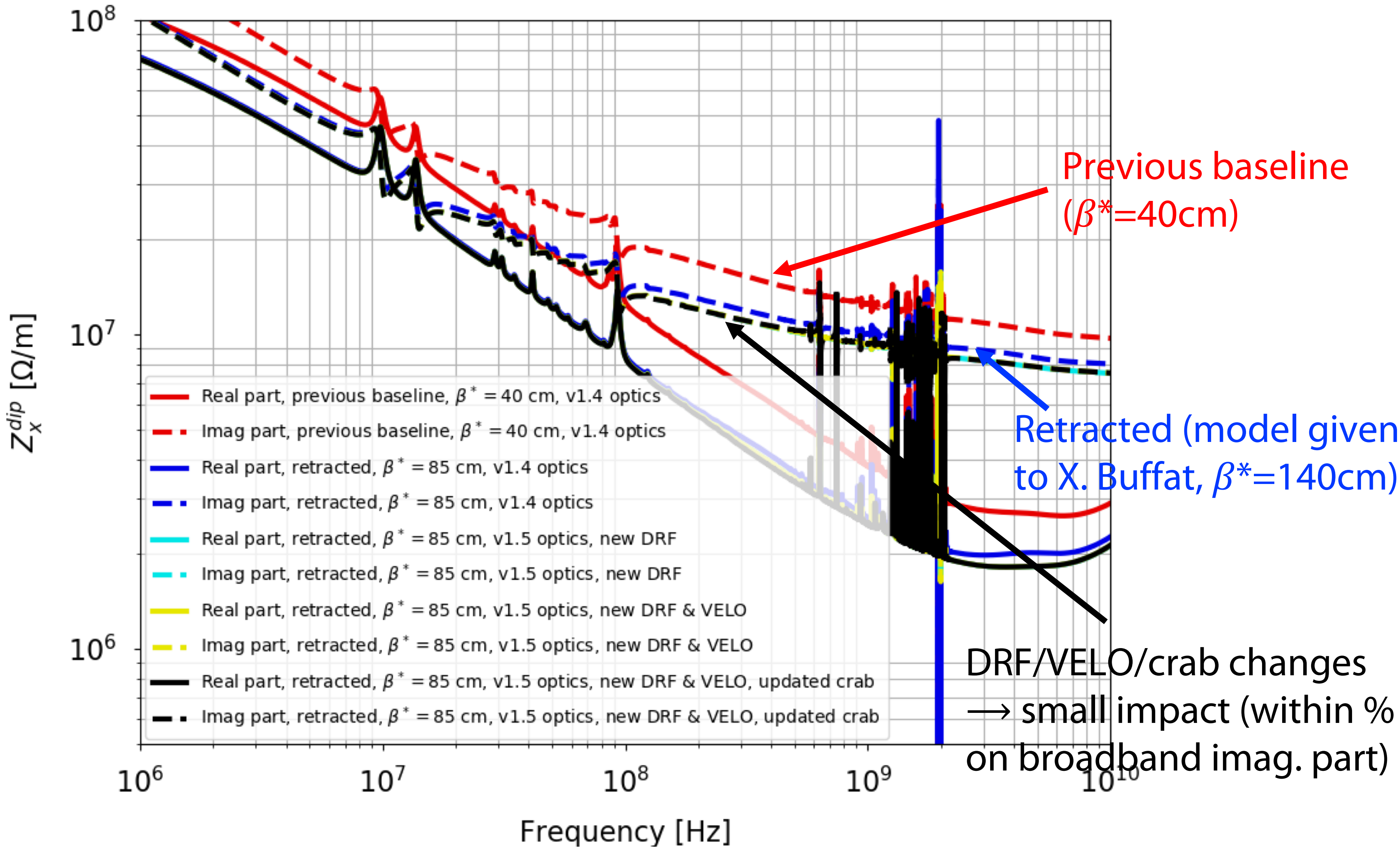
in compliance with the new HL-LHC Proton Operation Scenario – Update (**G. Arduini**, **R. Bruce**, **R. De Maria**, **R. Tomás** et al).

HL-LHC impedance model – other updates

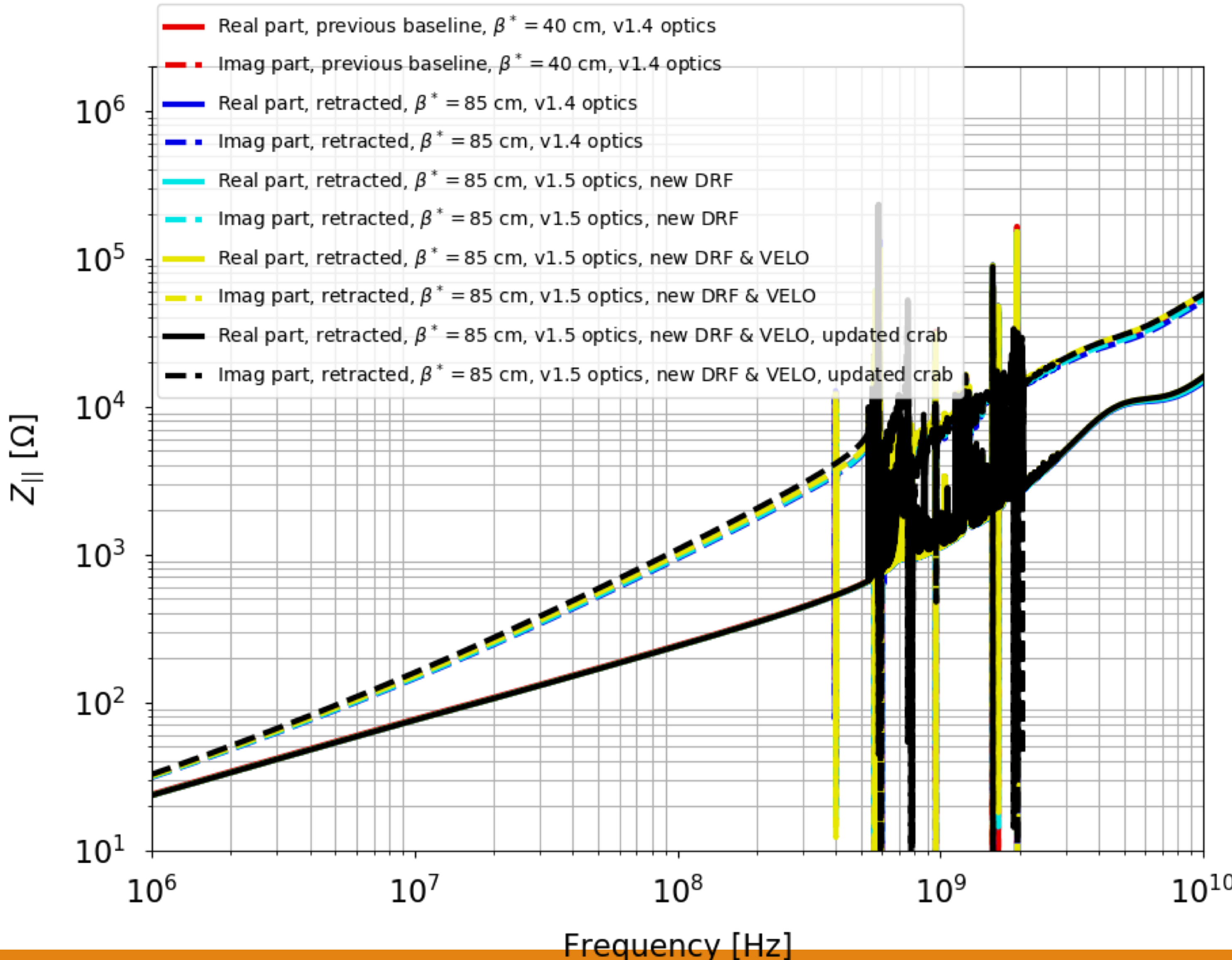
- Crab cavities updated (**J. Mitchell** et al - RFD 18/11/2019 and DQW 08/04/2019 – DQW to be updated again later),
- VELO added (**N. Biancacci** et al – Beyond the LHCb Phase-1 Upgrade Workshop, May 2017),
- DRF in crab cavities updated (**B. Salvant** et al – design from **C. Garion** with 4 convolutions – WP2/WP4 meeting 26/05/2020),
- See in appendix full list of elements included in model.

- **NOTE**: to save time, a first model was provided to Xavier **where ONLY the collimator settings were changed** (everything else kept as in previous model).

Impact of the model updates - transverse



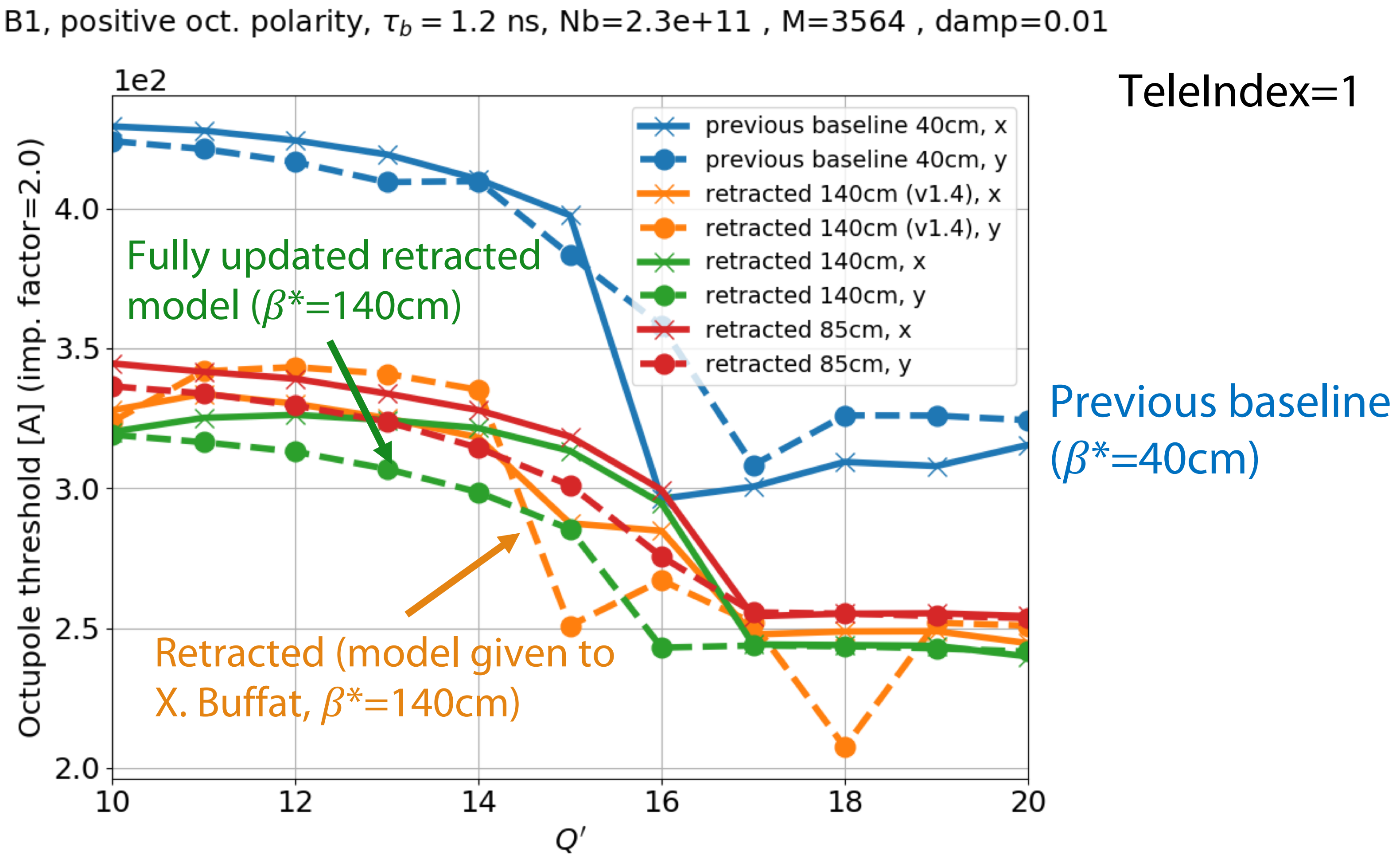
Impact of the model updates - longitudinal



Strongest impact from VELO (+4%) and crab update (+ ~10%)

Note: fundamental mode of crab cav. is not there yet, and cutoff for broad-band at 50GHz.

Overall impact of new model on stability



⇒ Strong imp. reduction with collimator retraction (as expected): **-20 to 25%**

⇒ Rest of the update, optics & β* (from 85cm to 140cm) has small impact.

HOMs in crab cavities – limits on shunt imp.

- **N. Biancacci** (et al) reviewed the current **shunt impedance limits on the HOMs** from the crab cavities at the 229th HSC meeting on 22/06/2020. These were recently used as specification in EDMS #1389669 v.2.55 (LHC-ACFDC-ES-0002 v.2.55), "*Engineering Specification for the dressed bulk niobium Crab Cavities*".

Slides 2-3

2016

In 2016 we gave limits for both single and coupled bunch instabilities.

Results are given for:

- 8 crab cavities (or 2/beam/plane)
- Ratio of beta function ~50
- Negative octupole current.

HOM tables:
- **DQW**: B. Xiao et al., "HOM impedance reference model v2", EDMS document n.1518298, 01 October 2015.
- **RFD**: Z. Li et al., "RFD-cav17f-HOM-qext-and-roq", EDMS document n.1523249, 27 June 2015.

Single bunch

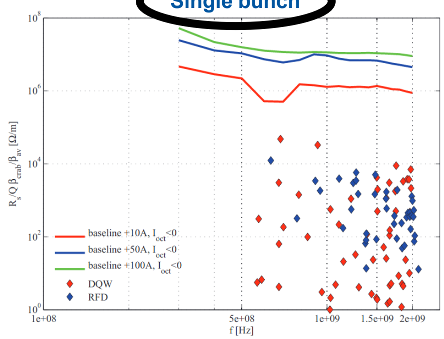


Figure 4: HOM of the DQW and RFD crab cavities and corresponding single bunch thresholds for the increase of octupole current over the machine baseline.

N.Biancacci, et al. The HL-LHC Impedance Model and Aspects of Beam Stability, IPAC 2016 (link)

2

2016

- For coupled bunch instabilities, 920 MHz HOM was exceeding the +100A threshold.
- Minimum threshold identified and frequency dependent.
- Increase of ~10 A roughly below ~2e7/50 = 400 kOhm.m

Coupled bunch

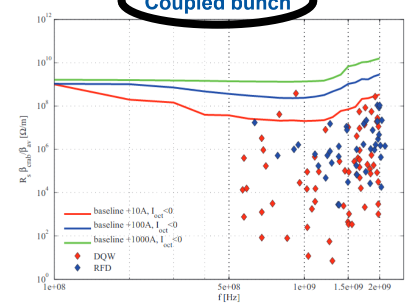
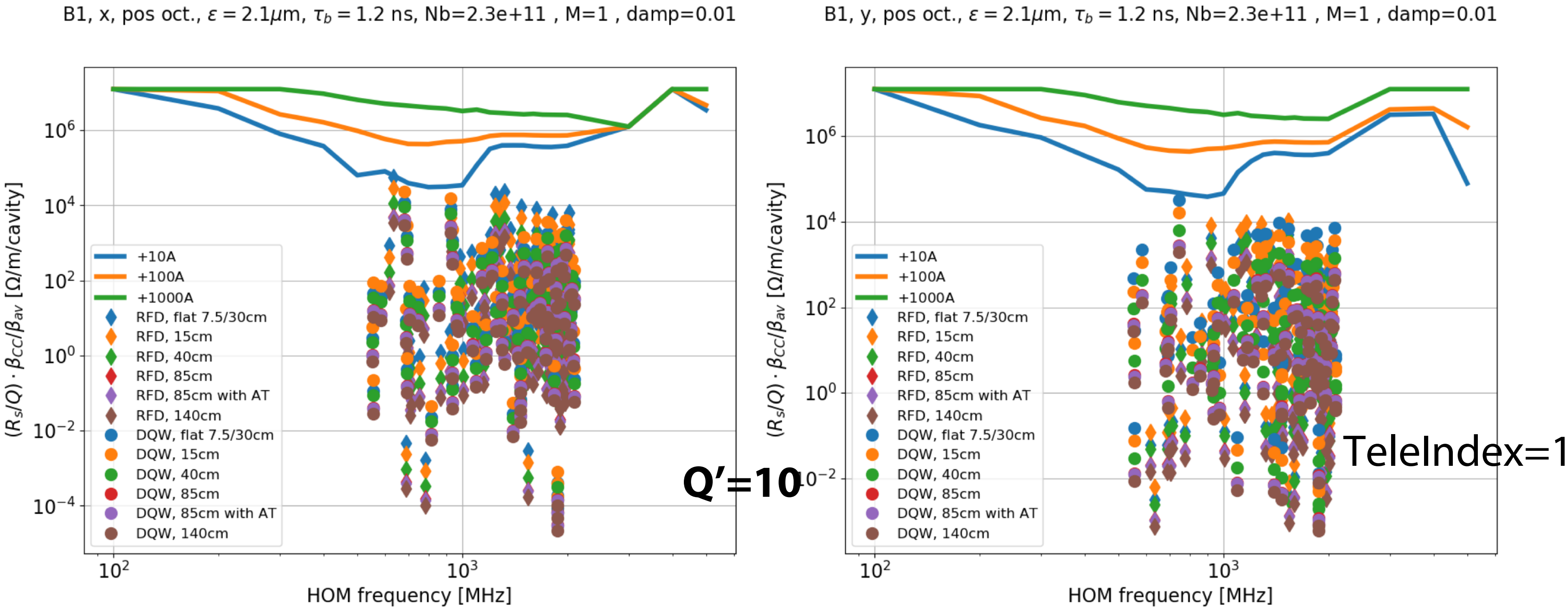


Figure 5: HOM of the DQW and RFD crab cavities and corresponding coupled bunch thresholds for the increase of octupole current over the machine baseline.

N.Biancacci, et al. The HL-LHC Impedance Model and Aspects of Beam Stability, IPAC 2016 (link)

Update of the limits on HOMs – **single bunch**

- Limits revisited using the updated version of the code (DELPHI) and the updated impedance model (results still **preliminary**) – HOMs from updated cavities are also shown:

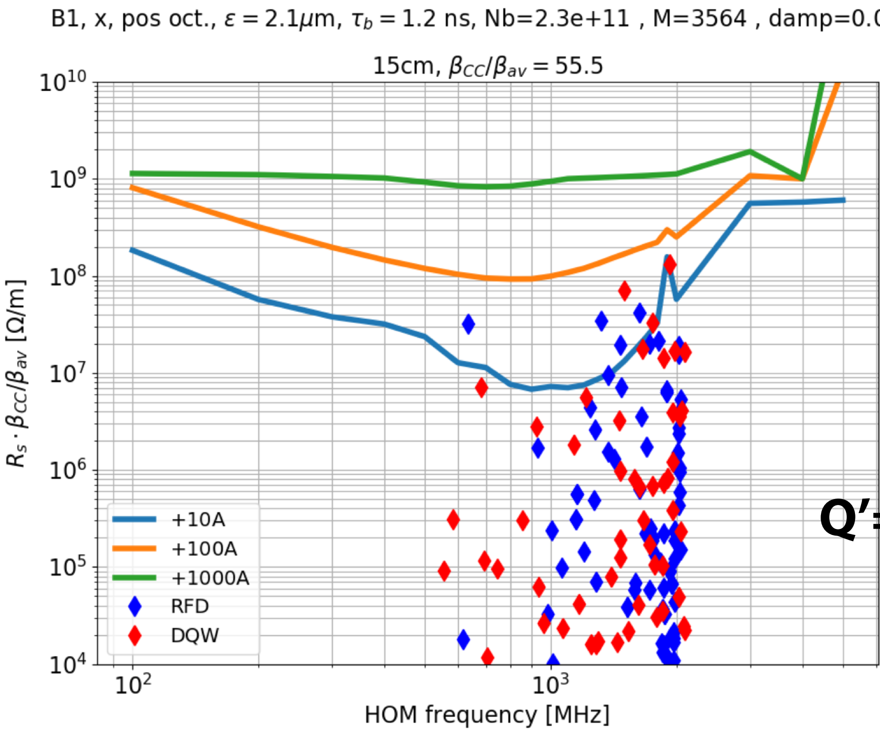


⇒ Far from the limit (+10A) with most optics (but closer with flat optics),

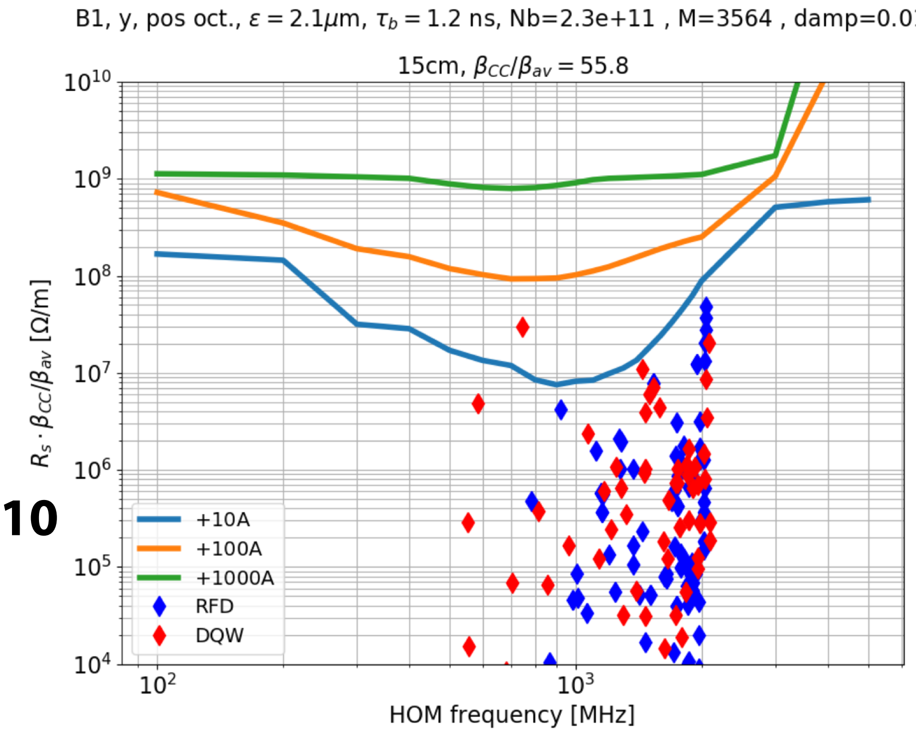
⇒ Strictest limit is in x and corresponds to a R/Q of resp. (800MHz<freq<1GHz) 0.5 / 1.3 / 3 / 4.5 kOhm/m for β^*= 15 / 40 / 85 / 140 cm.

Update of limits on HOMs – **multibunch**

β^* = **15cm** (updated crab cavity HOMs also shown)



Q’=10



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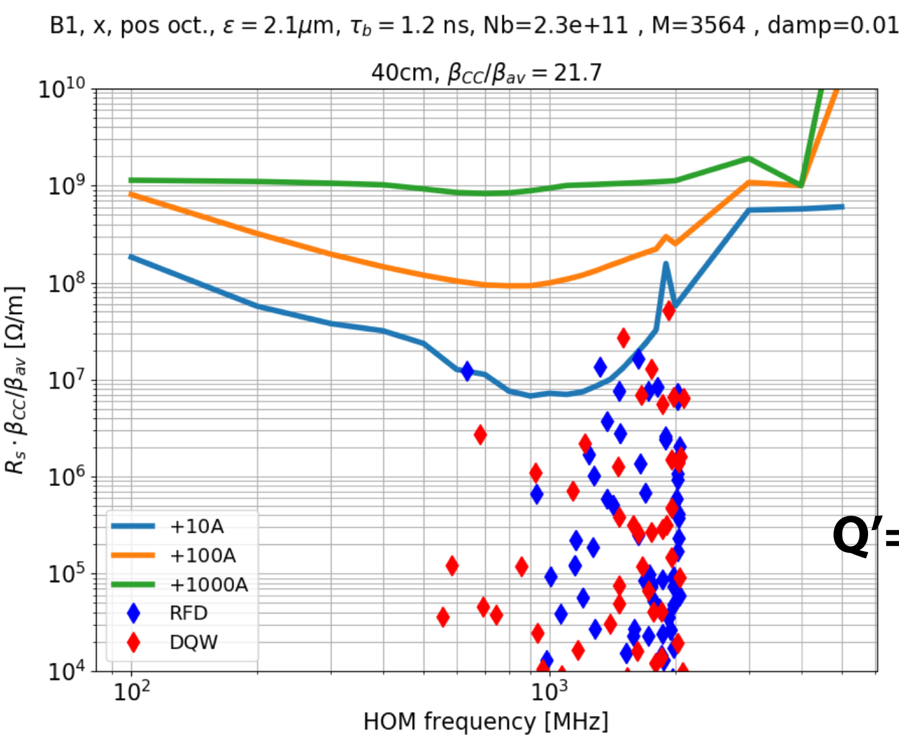
⇒ Some modes are above the limit.

⇒ Strictest limit (in x) at 120 kOhm/m for β^* = **15cm**.

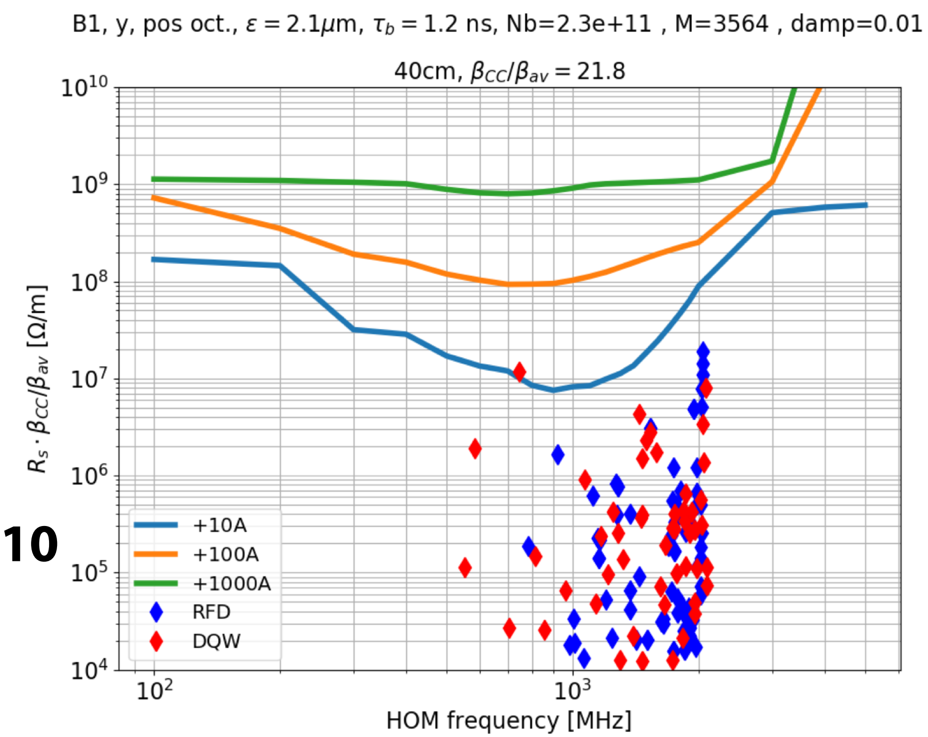
⇒ But this should happen only during collisions → stabilized by beam-beam.

Update of limits on HOMs – **multibunch**

β^* = **40cm** (updated crab cavity HOMs also shown)



Q'=10



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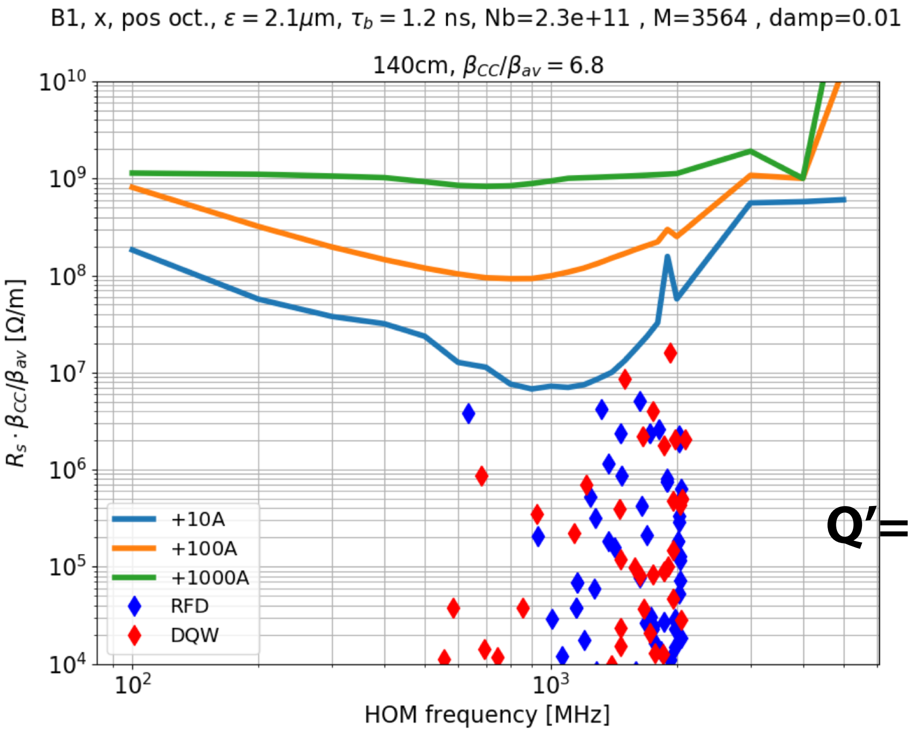
⇒ Close to the limit but ~OK.

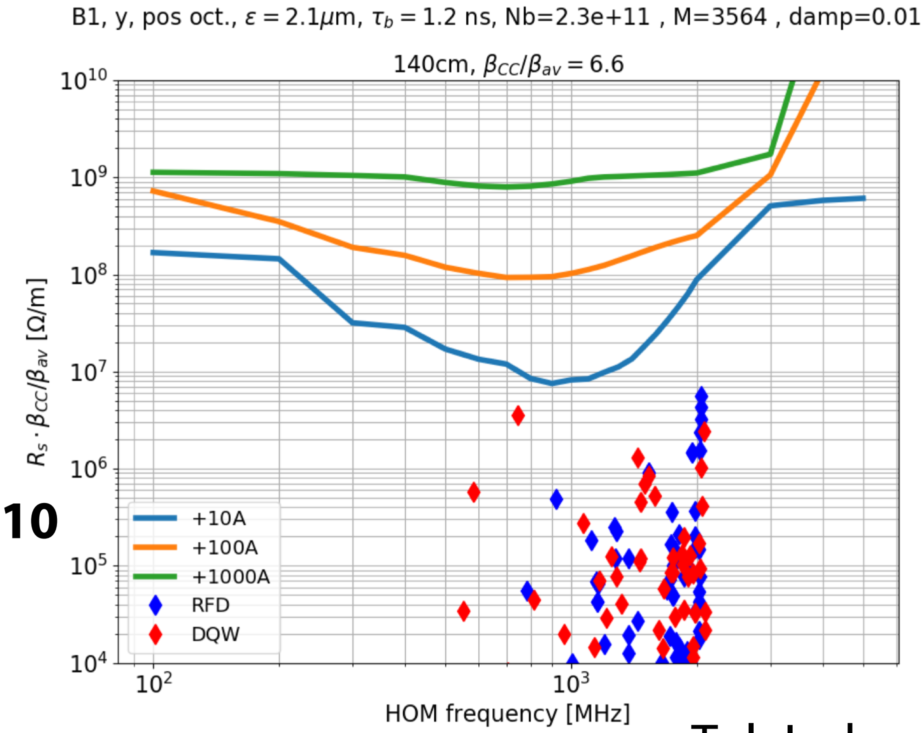
⇒ Strictest limit (in x) at 300kOhm/m for β^* = **40cm**.

Update of limits on HOMs – **multibunch**

β* **= 140cm** (updated crab cavity HOMs also shown)



Q'=10



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⇒ Fine for all modes.

⇒ Strictest limit (in x) at ~1MOhm/m for *β** **= 140cm**.

Conclusions

- Retraction of collimators has a strong impact on impedance and stability: -20 to 25% less in single-beam octupole threshold.
- Model was also updated for optics (v1.5), deformable RF fingers in the crab cavities, VELO in LHCb, and crab cavities HOMs, which all have a smaller impact, except in longitudinal.
- Limits on the high order modes from crab cavities are being reinvestigated with updated model and code – preliminary results show that:
  - in single-bunch, current crab cavities respect the +10A threshold with all optics & β^*,
  - in coupled-bunch, β^*=40cm is close to the limit but still ~OK. Lower β^* can be problematic, but this should happen only during collisions where beam-beam tunespread will stabilize the beam.

Appendix

HL-LHC impedance model

- **Included** in the HL model:
  - ✓ Collimator at almost full upgrade (jaws of 2 TCPs and all but 2 TCSs in IR7 replaced by Mo-graphite ones, Mo-coated for the TCSs); some TCTs in Cu-coated copper-diamond; tungsten TCLD absorber in IR7,
  - ✓ Updated collimator tapers (**S. Antipov**, **E. Carideo**),
  - ✓ Beta functions in the arcs and triplets (optics v1.4),
  - ✓ TDIS (with graphite, Ti_6Al_4V and CuCr1Zr),
  - ✓ New MKI-cool – 4 of them,
  - ✓ New octogonal beam screens in triplets, with up-to-date dimensions, aC-coating, 75K copper, pumping holes and welds (accurate weld & shape factors from **C. Zannini**),
  - ✓ Updated experimental chambers (ATLAS & CMS),
  - ✓ Tapers and BPMs in the triplets region,
  - ✓ Updated crab cavities (2019 HOMs),
  - ✓ Deformable RF-fingers, VAX and Y-chambers in triplet region (including new design for DRF in crab cavities – **B. Salvant**),
  - ✓ VELO (**N. Biancacci** et al – *Elba, 30th May 2017*).

HL-LHC impedance model

- Modifications that are not (yet) in the model:
  - ✗ experimental chambers ALICE and LHCb, possibly also CMS,
  - ✗ new instrumentation,
  - ✗ possible aC-coating in some sectors,
  - ✗ possible additional collimators in IR1 & 5, TCLD in IR2 (in parking for protons) and updated design of all tertiaries and TCLs, old CFC collimators in parking?
  - ✗ crab cavities HOMs as measured in real cavities,
  - ✗ electron lens and crystal collimators (recently added to baseline),
  - ✗ new roman pots,
  - ✗ “SMOG3” in LHCb.

Retracted collimator settings

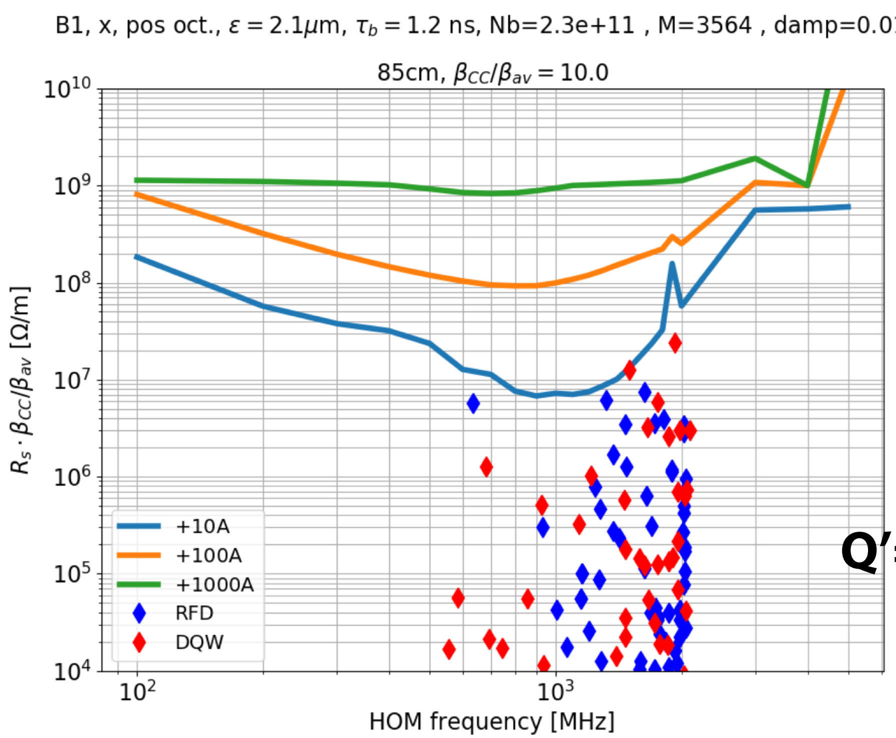
- Collimator settings **B1** (σ computed with ε = 2.5 μm.rad) at top energy – for different β^* (tables given as refs. are from *"HL-LHC Proton Operation Scenario – Update"* - unpublished yet)

Collimators	Half-gap [#σ] β^*=40cm	Half-gap [#σ], β^*=85cm (Tab. 7, crab OFF, 250μrad)	Half-gap [#σ], β^*=140cm (Tab. 5, crab ON, 190μrad)
TCP/TCS/TCLA(D) IR7	6.7 / 9.1 / 12.7 (16.6)	8.5 / 10.1 / 13.7 (16.6)	8.5 / 10.1 / 13.7 (16.6)
TCP/TCS/TCLA IR3	17.7 / 21.3 / 23.7	17.7 / 21.3 / 23.7	17.7 / 21.3 / 23.7
TCDQ/TCS IR6	10.1	11.6	11.6
TCT H4/V4/H6/V6 – IR1 TCT H4/V4/H6/V6 – IR5	16.4	25.4 / 27.8 / 22.3 / 30.9 25.5 / 27.8 / 22.4 / 30.9	29.8 / 37.0 / 24.0 / 41.9 29.9 / 37.0 / 24.1 / 42.2
TCL Q4/Q5/Q6 – IR1 TCL Q4/Q5/Q6 – IR5	22.4	34.6 / 37.8 / 39.8 34.7 / 38.0 / 39.6	46.2 / 56.3 / 44.8 46.3 / 56.5 / 43.2
TCT IR2/8	35.5 / 17.7	35.4 / 17.7	35.4 / 17.7

Note: injection protection collimators and TCLD in IR2 are all in parking position.

Update of limits on HOMs – multibunch

$\beta^* = \mathbf{85cm}$ (updated crab cavity HOMs also shown)



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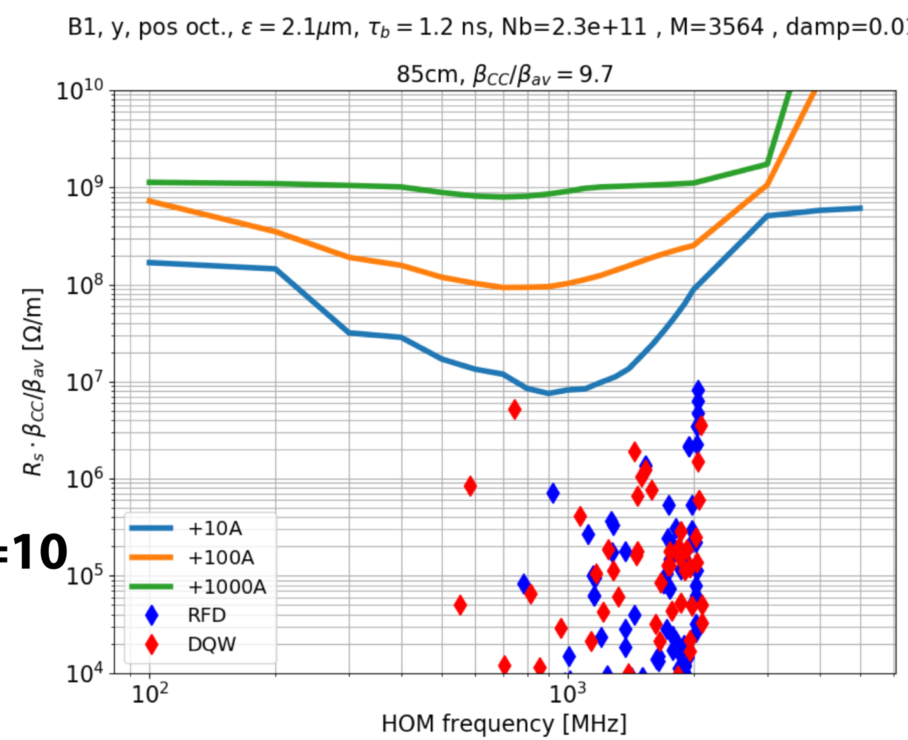

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⇒ Fine for all modes.

⇒ Strictest limit (in x) at ~670kOhm/m for $\beta^* = \mathbf{85cm}$.