HL-LHC impedance and beam stability

N.Biancacci

5$^{\text{th}}$ Joint HiLumi LHC-LARP Annual Meeting

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Acknowledgements: R. Calaga, L. Carver, R. De Maria, K. Li, E. Métral, J. E. Muller, B. Salvant, O. Frasciello and M. Zobov.

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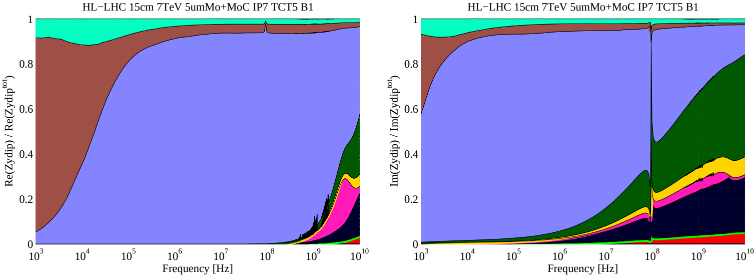

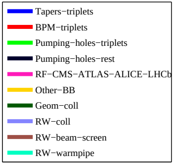

→ Collimator resistive wall impedance: first contribution in real and imaginary part.
→ Beam screen mostly at low frequency real part.
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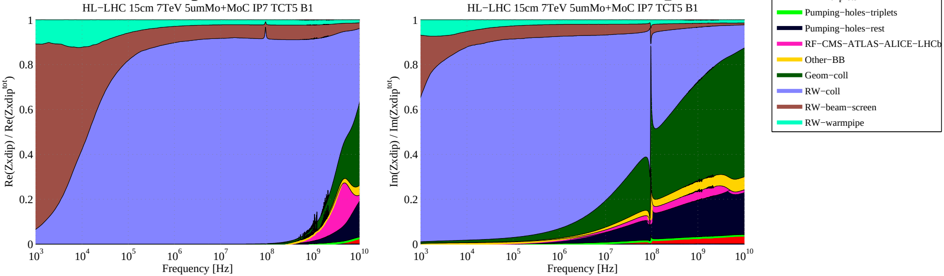

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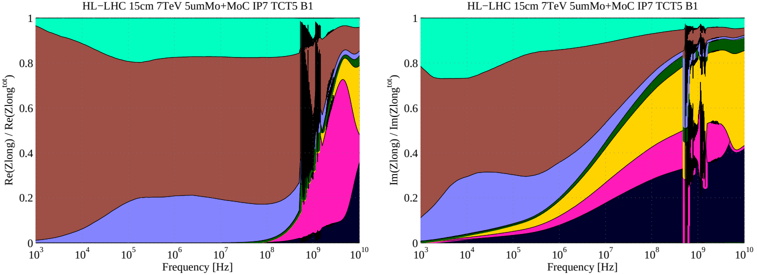

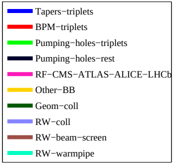

→ Real part mostly dominated by resistive wall (screen and collimators).

→ Increasing contribution from holes and HOMs in the imaginary part.

Outline

We systematically studied the effect of a HOM added to the HL-LHC baseline:

- $R_s \in (100\ k\Omega/m, ..., 100\ G\Omega/m)$
- $f_{res} \in (100\ MHz, ..., 2\ GHz)$
- $Q = 1000$ to ensure $\Delta f = f_{res}/Q > f_{rev}$.

Scenario: Single bunch, 50 turns damper, $Q' = 5$, $N_b = 2.2 \cdot 10^{11}$ ppb, $\sigma_z = 8.1$ cm.

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HL-LHC optics: V1.1 with $\beta^* = 15cm$ (i.e. $\beta_{crab} \simeq 3600$) .

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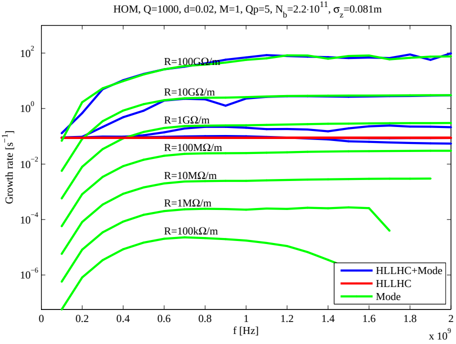

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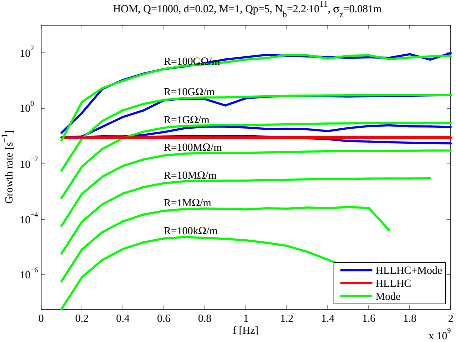
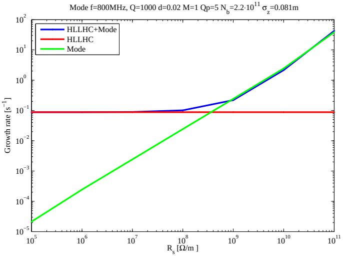


→ From $R_s \simeq 1\ G\Omega/m$ we exceed the baseline impedance model.

Projecting over a single frequency we can define the threshold looking at the growth rate vs R_s:



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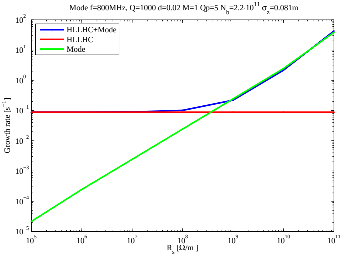

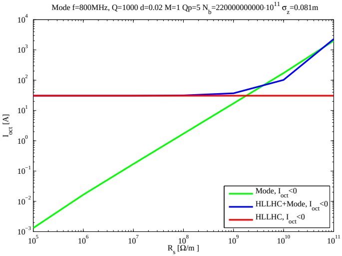

We can calculate the octupole current needed to stabilize each HOM at a given frequency, assuming:

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- Negative octupole sign.

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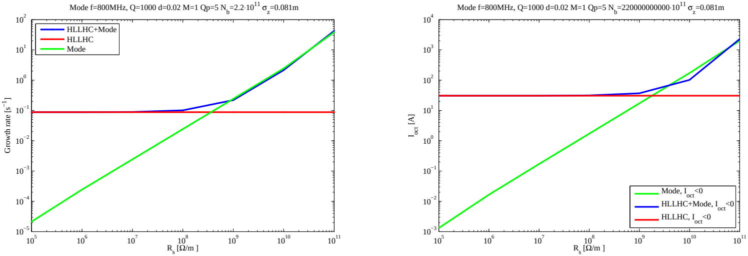

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For each frequency we can now determine the R_s corresponding to a determined increase ΔI of the stabilizing octupole current over the baseline.

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The impedance model for the crab cavities has been updated to include most recent HOM tables:

- DQW update: EDMS - 1518298, 01-10-2015, (*HOM impedance reference model v2*)
- RFD update: EDMS - 1523249, 27-06-2015, (*RFD-cav17f-HOM-qext-and-roq*)

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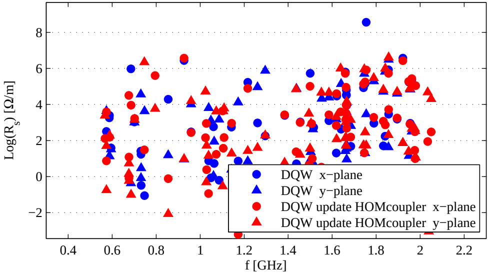

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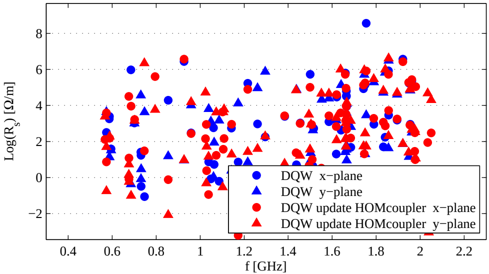
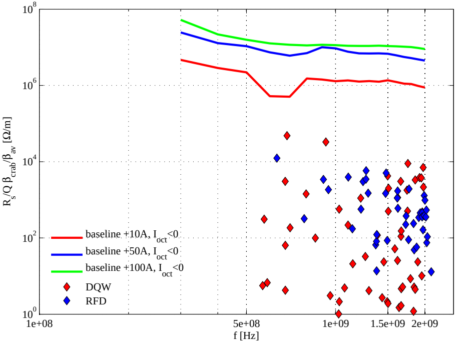


→ Strong improvement in the DQW: HOM coupler damps the 1.75 GHz mode (thanks to the designers!).
→ Minor changes in the HOM distribution for the RFD.

Single Bunch (SB) stability limits considering an increase of $\Delta I \in (10, 50, 100)$ A over the HL-LHC baseline normalizing R_s to Q and weighting the HOMs by $\beta_{crab}/\beta_{av} \simeq 50$ for 1 cavity.



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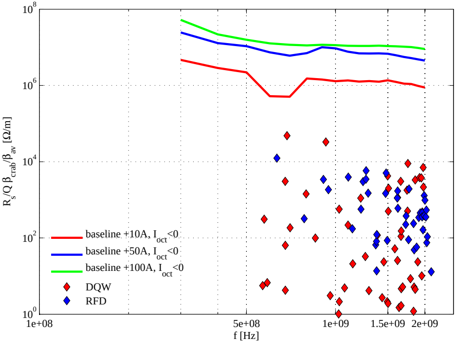

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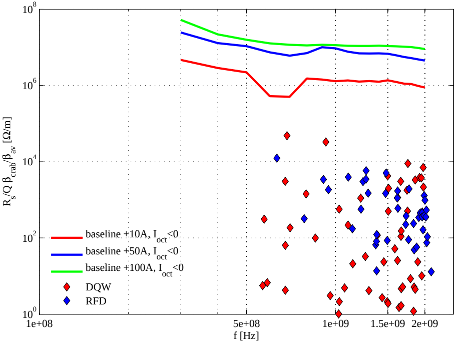

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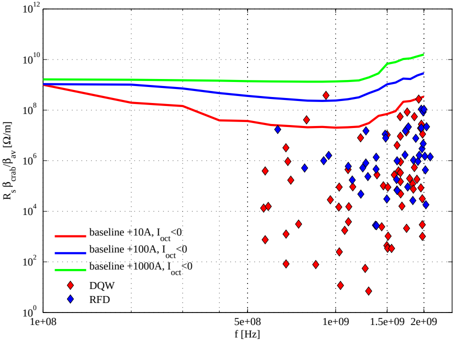
N.B.: Each HOM point is a *worst case* (i.e. if the spectral line falls on it). For very narrow modes, a statistical analysis completes the picture (see next slides).
N.B.: No interplay from the modes is assumed.

With a similar approach we derive the Coupled Bunch (CB) stability limits considering an increase of $\Delta I \in (10, 100, 1000)$ A over the HL-LHC baseline.



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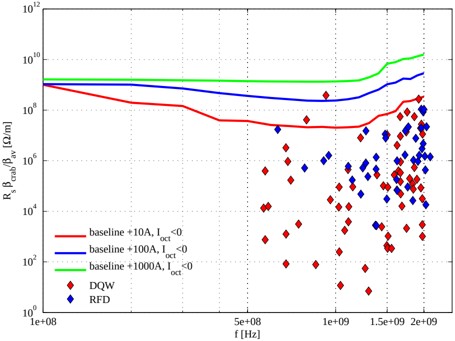

→ The new DQW with HOM coupler on the 1.75 GHz mode lead to an increase of +100 A mainly due to the 920 MHz mode .

→ The RFD is within the 10 A threshold.

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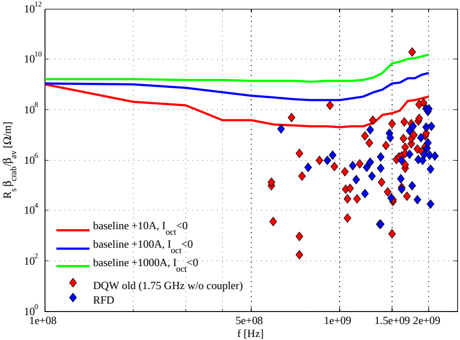

→ The old DQW design had the mode at 1.75 GHz at $R_s\beta_y/\beta_{av} \simeq 10\ G\Omega/m$: it was leading to ≥1000 A increase of octupole current!

Outline

To verify the **single bunch** predictions we performed a set of ≃200 simulations of possible crab cavities HOM configurations on top of the baseline HL-LHC impedance model accounting for:

- 8 crab cavities in total (4 V-Xing in IP1 + 4 H-Xing IP5),
- Variable frequency spread of $\pm 3\ MHz$ between each cavity in each simulation,
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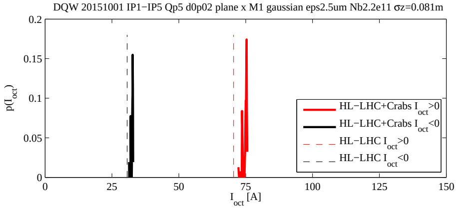
Single bunch stabilizing octupole current for 4 **DQW** crab cavities in both IP1 and IP5:



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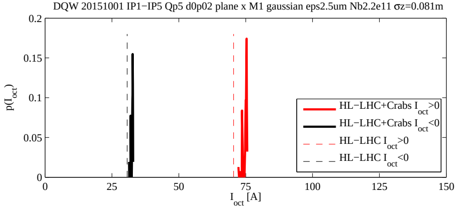

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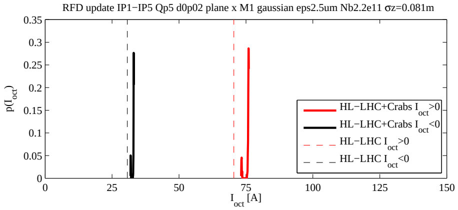

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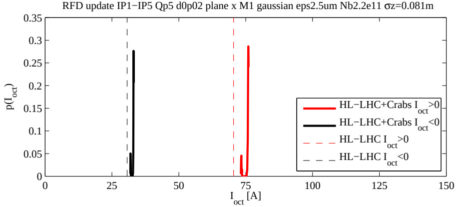

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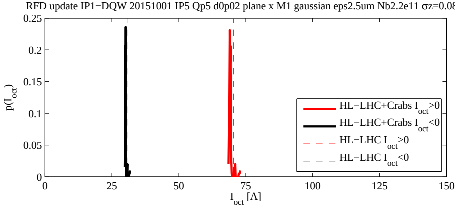

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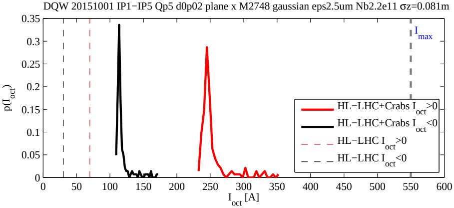

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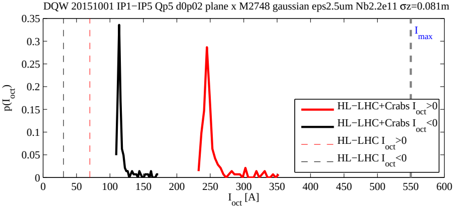
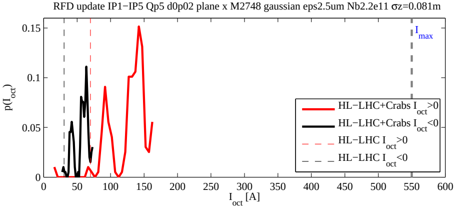


→ The **maximum** stabilizing octupole current is ≃ $150A$.

Coupled bunch stabilizing octupole current for 4 **RFD** crab cavities in both IP1 and IP5:



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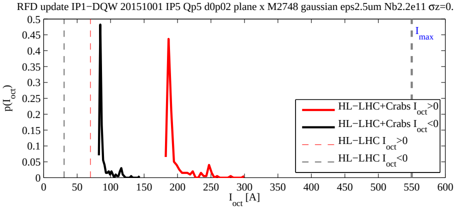

In summary, for coupled bunch stability:

- 4 **DQW** crab cavities in both IP1 and IP5 → $I_{max}^{oct} \simeq 170$ A required in total.
- 4 **RFD** crab cavities in both IP1 and IP5 → $I_{max}^{oct} \simeq 70$ A required in total.
- 4 **RFD** crab cavities in IP1 and 4 **DQW** crab cavities IP5 → $I_{max}^{oct} \simeq 150$ A required in total.

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To estimate the dependence on Q' we compare here 4 scenarios for the coupled bunch case:

1. The old HL-LHC baseline (only CFC collimators) *without* crab cavities,
2. The HL-LHC baseline (low impedance collimators) *without* crab cavities,
3. The HL-LHC baseline *with* 4 DQW crab cavities in IP1 and IP5 (new HOM tables: 1.75 GHz mode with coupler),
4. The HL-LHC baseline *with* 4 DQW crab cavities in IP1 and IP5 (old HOM tables: 1.75 GHz mode without coupler),

NB: here we take *one* of the possible HOM configurations (i.e. no statistic study made)!

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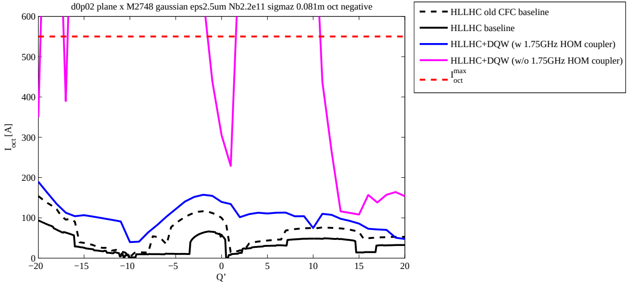

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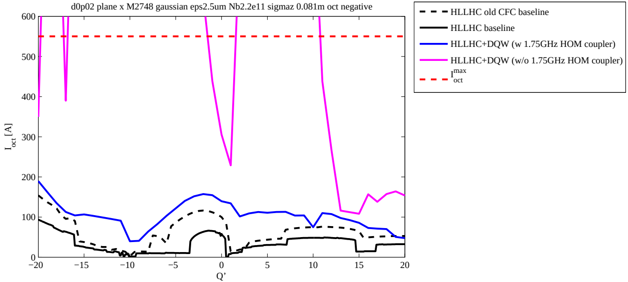
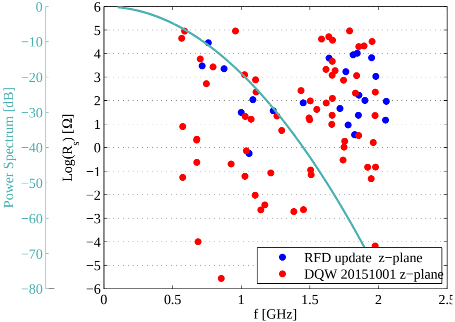


→ DQW without coupler on 1.75 GHz mode, the HL-LHC stability is not compatible with operation.
→ With coupler we are stable but we increase the octupole current needed to stabilize the machine.
→ The overall stability margin is reduced. → We are loosing gain from low impedance collimators.

Outline

Longitudinal HOM distribution for the DQW and RFD designs, compared with a HL-LHC bunch spectrum assuming gaussian longitudinal profile with σ_z = 8.1 cm:



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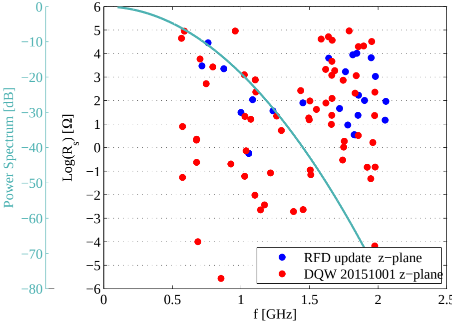

→ Many modes below 1.2 GHz with high R_s can lead to high heating[1].
→ Longitudinal coupled bunch instabilities? Not expected if R_s < 1.7 MΩ (threshold for loss of Landau damping)[2].

[1] See B.Salvant et al. "Heat loads due to impedance: update and required upgrades"
[2] See B.Salvant et al. "Impedance aspects of Crab cavities", HiLumi 2014

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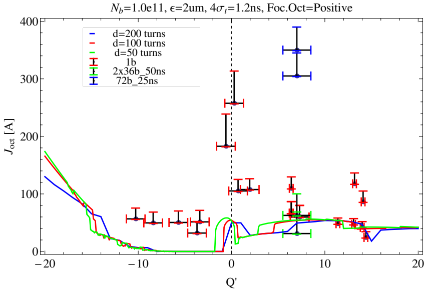

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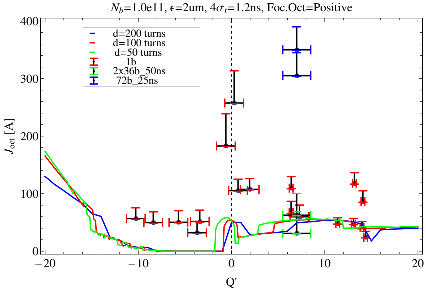

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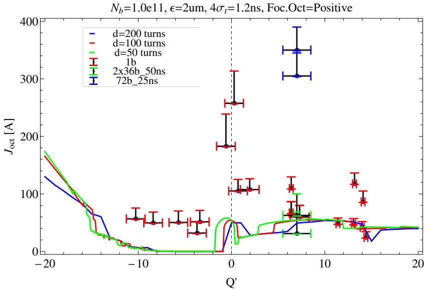

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→ Still significant discrepancy for $Q' \leq 2$ (damper modeling, Q'', ...).
→ 50 ns train of 2×36 bunches: similar threshold as single bunch.
→ 25 ns train of 72 bunches: factor ≃5 more current needed (e-cloud contribution?)

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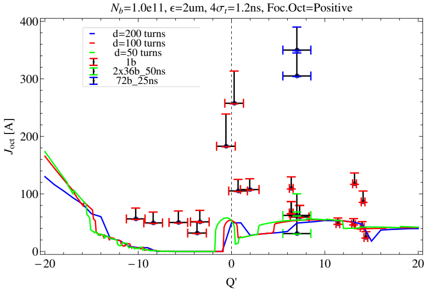


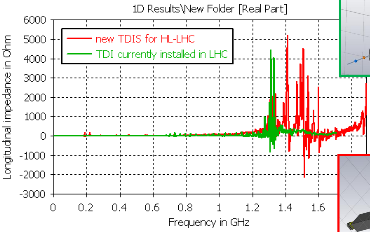
→ For Q'> 5, predictions performed with DELPHI close to the measurements for single bunch.
→ Still significant discrepancy for $Q' \leq 2$ (damper modeling, Q'', . . .).
→ 50 ns train of 2×36 bunches: similar threshold as single bunch.
→ 25 ns train of 72 bunches: factor ≃5 more current needed (e-cloud contribution?)

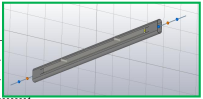
We might be limited in the future in the current of the octuples
HL-LHC impedance optimization important!

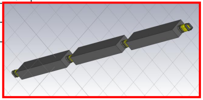
Outline

TDIS

A new design is going to be produced in synergy with the impedance team (still work in progress!)





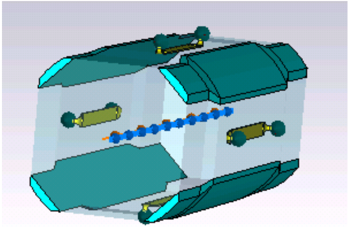


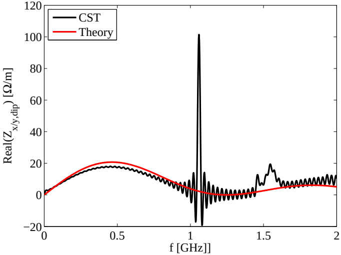
Work to establish the best compromise between one or three modules accounting for:

- good protection performance in case of injection failures,
- mechanical tolerances,
- easy access for spare installation,
- low broadband impedance,
- optimized taperings,
- reduced cavity spaces and HOMs generation.

BPMWS

Stripline BPMs placed in the triplets regions: studies are ongoing to establish the compatibility with the critical area[3].





[3]See also N.Mounet et al. 7th HiLumi WP2 Task 2.4 meeting

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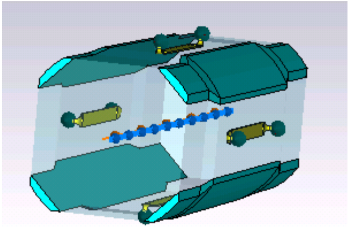

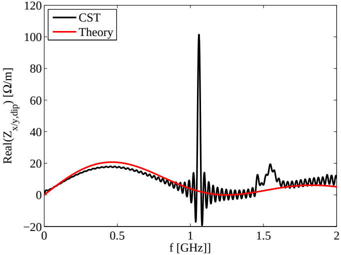

→ Good agreement with CST simulations and theory for broadband part.
→ Resonances mainly due to the stripline presence ($\lambda \simeq n \cdot L/2$) - not dependent on external beam screen shape.
→ Beam screen shape optimization studies on going. . . .

[3] See also N.Mounet et al. 7th HiLumi WP2 Task 2.4 meeting

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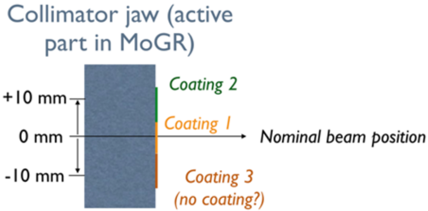

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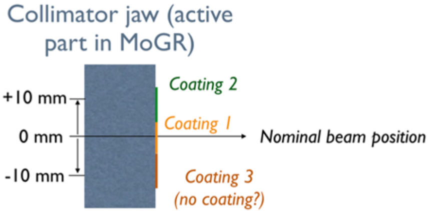

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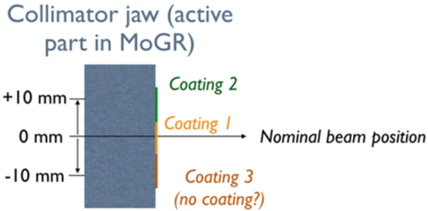

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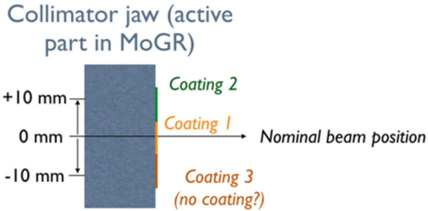

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- **Triplet region**: complete the study on BPMs, bellows and weld impact.
- . . .

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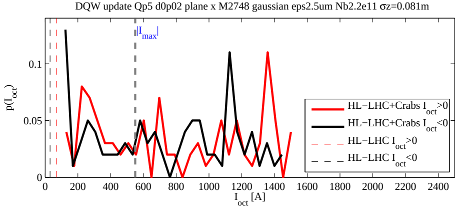
- This can be obtained, from the impedance point of view, reducing the HOM shunt impedance: the 920 MHz mode in the DQW design should be reduced.

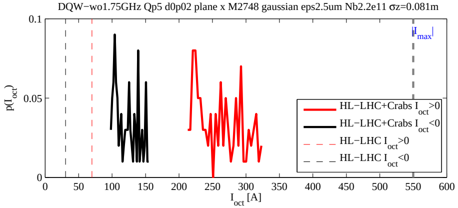
Thank you for your attention!

Appendix

The **DQW design** is compared with the 1.75 GHz mode . . .



· · · and without it:



1) The 1.75 GHz would provoke machine dumps the 60% of the time ($I > I_{max} = 550\ A$).
2) Removing it, the driving mode is expected to be the 920 MHz (threshold moved to ≃150 A for negative octupole sign, and ≃ 320 for positive sign.