Crab cavity HOM impedance requirements and transverse damper upgrade

N.Biancacci,
K.Li, E.Métral and B. Salvant

HiLumi WP2 Task Leader meeting
02-10-2015

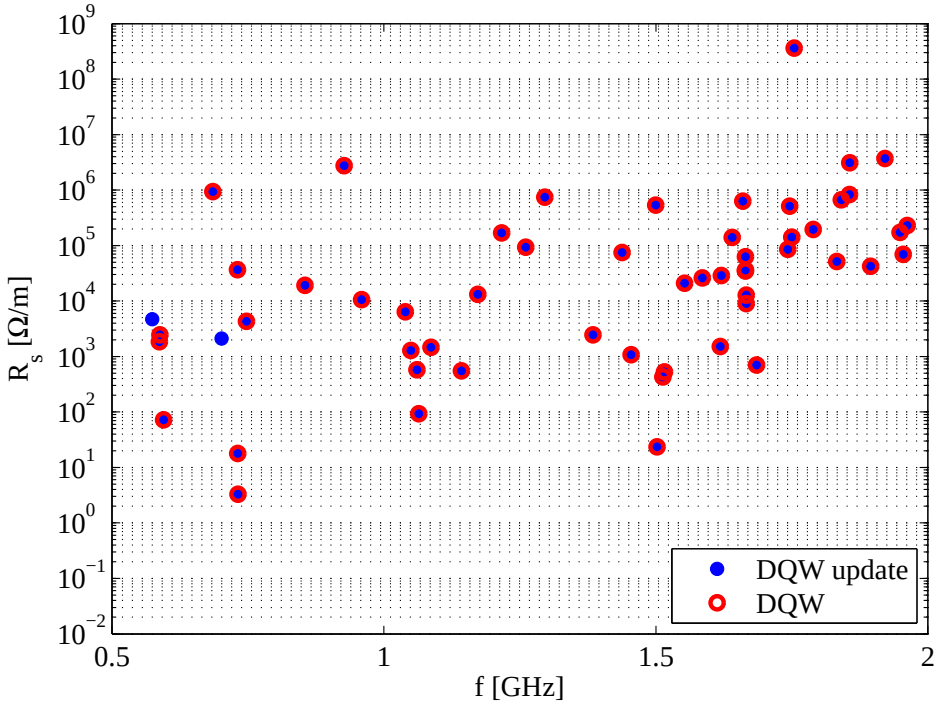
Acknowledgements: R. Calaga, R. De Maria

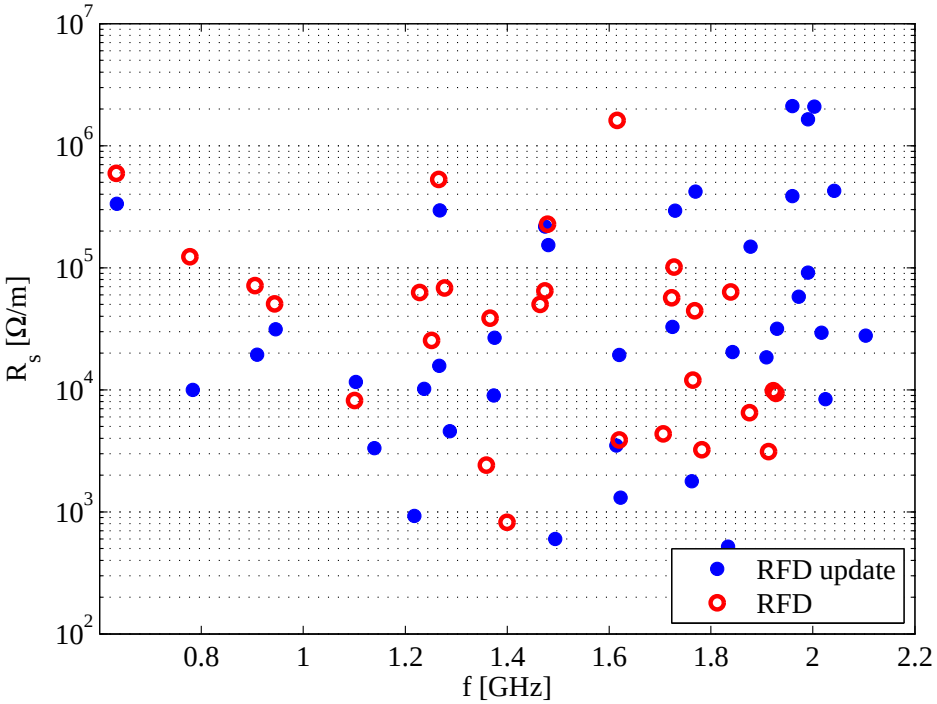
Outline

1. Introduction
   - Update of HOM list
2. HOM & octupole thresholds
   - Growth rate
   - Octupole threshold
   - Single bunch octupole thresholds
   - Coupled bunch octupole thresholds
3. Crab Cavities statistical simulations
   - Coupled bunch studies
   - Single bunch studies
   - Gain increase
4. Conclusions and next steps

The crab cavities impedance model has been recently updated to last HOM tables:

- DQW update: EDMS - 1518298, 03-07-2015, (*HOM impedance reference model*)
- RFD update: EDMS - 1523249, 27-06-2015, (*RFD-cav17f-HOM-qext-and-roq*)





What changed?

- No change for the DQW that still presents the high HOM ≃1.75 GHz with R_s ≃362 $M\Omega/m$.
- Last update from RCalaga (30-09-2015) → this HOM has been reduced to R_s ≃0.8 $M\Omega/m$. This is being checked with BNL to assess if other HOMs are affected.
- The RFD HOMs stay below few $M\Omega/m$.

We systematically study the effect of an HOM added to the HL-LHC baseline:

- $R_s \in (100\ k\Omega/m, ..., 100\ G\Omega/m)$
- $f_{res} \in (100\ MHz, ..., 2\ GHz)$
- $Q = 1000$ fixed in order to be overlapping with single and coupled bunch spectral lines.

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

HL-LHC impedance baseline: Low impedance collimators (MoC+5μm Mo on IP7).

HL-LHC optics: $\beta^* = 15cm$, V1.1.

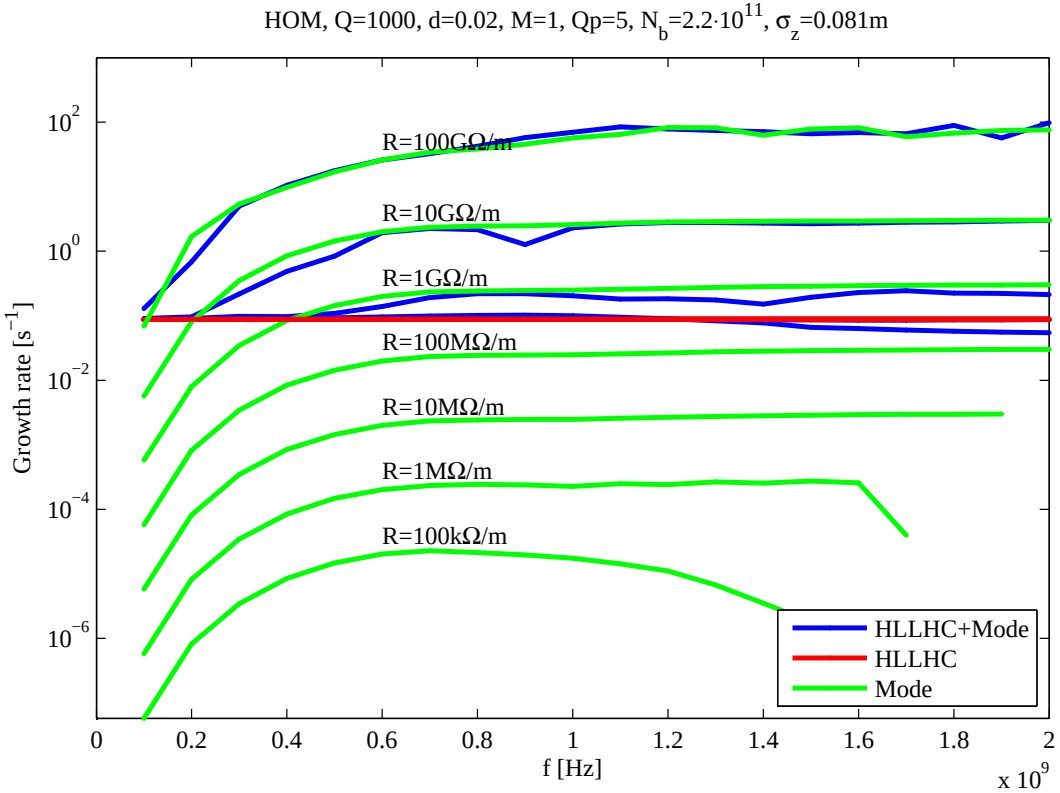
We systematically study the effect of an HOM added to the HL-LHC baseline:

- $R_s \in (100\ k\Omega/m, ..., 100\ G\Omega/m)$
- $f_{res} \in (100\ MHz, ..., 2\ GHz)$
- $Q = 1000$ fixed in order to be overlapping with single and coupled bunch spectral lines.

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

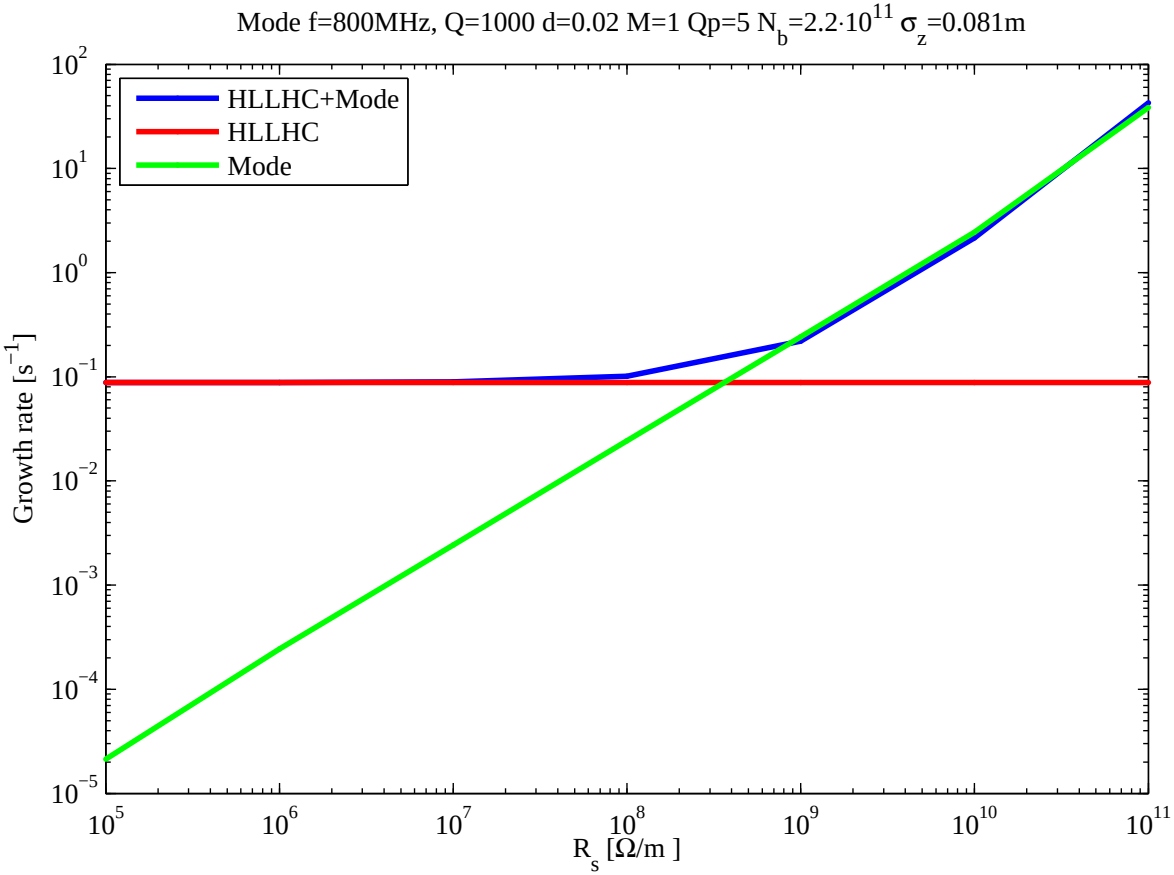
HL-LHC impedance baseline: Low impedance collimators (MoC+5μm Mo on IP7).

HL-LHC optics: $\beta^* = 15cm$, V1.1.



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

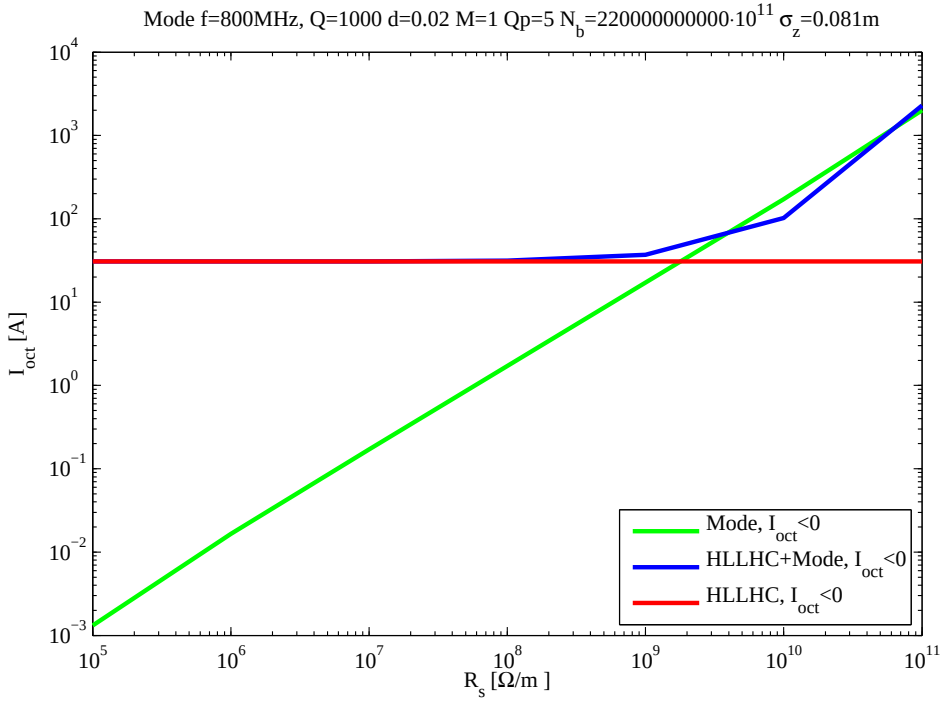
Projecting over a single frequency we can define the threshold looking at the Growthrate vs R_s:



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

We now investigate what is the octupole current needed to stabilize each HOM at a given frequency, assuming:

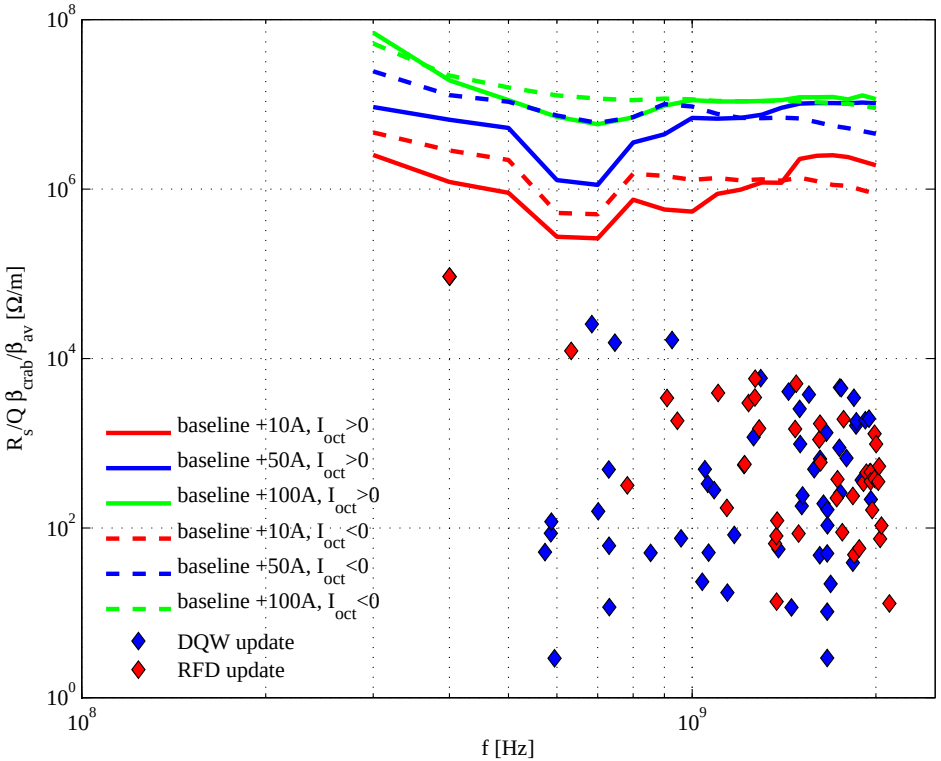
- $\varepsilon_n = 2.5\ \mu m$,
- Gaussian distribution.
- Positive octupole sign (similar for negative sign).



→ For each frequency we can now determine what R_s will provoke an arbitrarily chosen increase of stabilizing octupole current w.r.t baseline.
→ In this way we can draw an *octupole threshold* curve in function of the HOM frequency.

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

Reminder: baseline octupole threshold @ Q'=5 is 30 A for negative octupole sign, 70 A for positive sign.

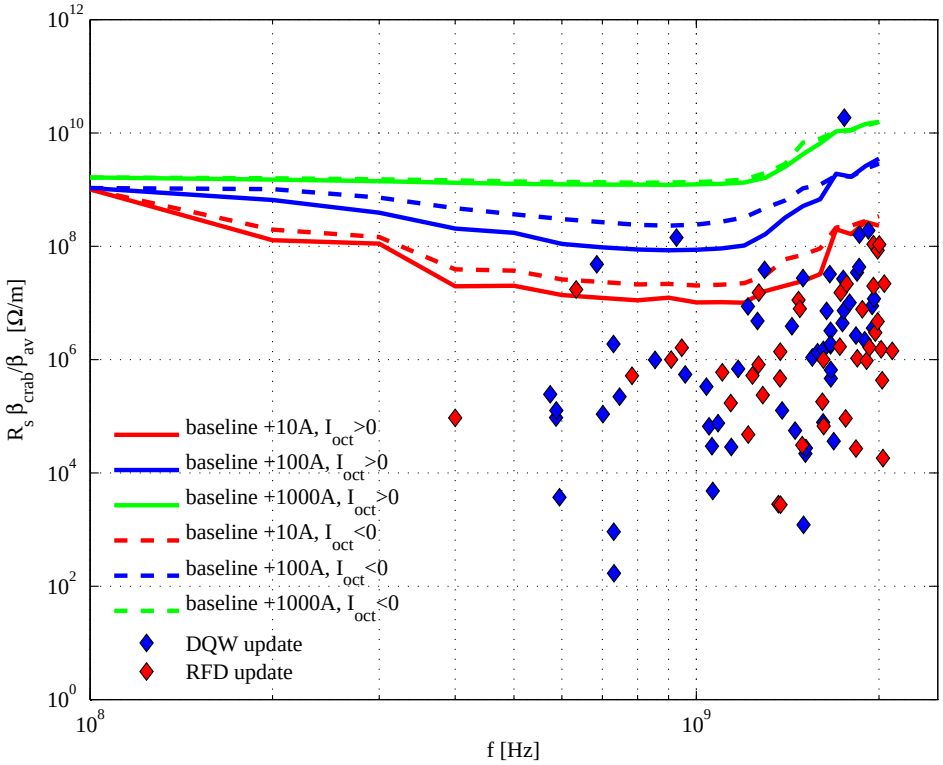


This plot can be used in a design stage tuning each of the modes below the thresholds.

→ Both DQW and RFD are well below the octupole threshold for an increase of 10 A.
→ N.B.: Each HOM point is a *worst case* (i.e. if the SB 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 10, 100 and 1000 A w.r.t. the HL-LHC baseline.

Reminder: baseline octupole threshold @ Q'=5 is 30 A for negative octupole sign, 70 A for positive sign as in SB.

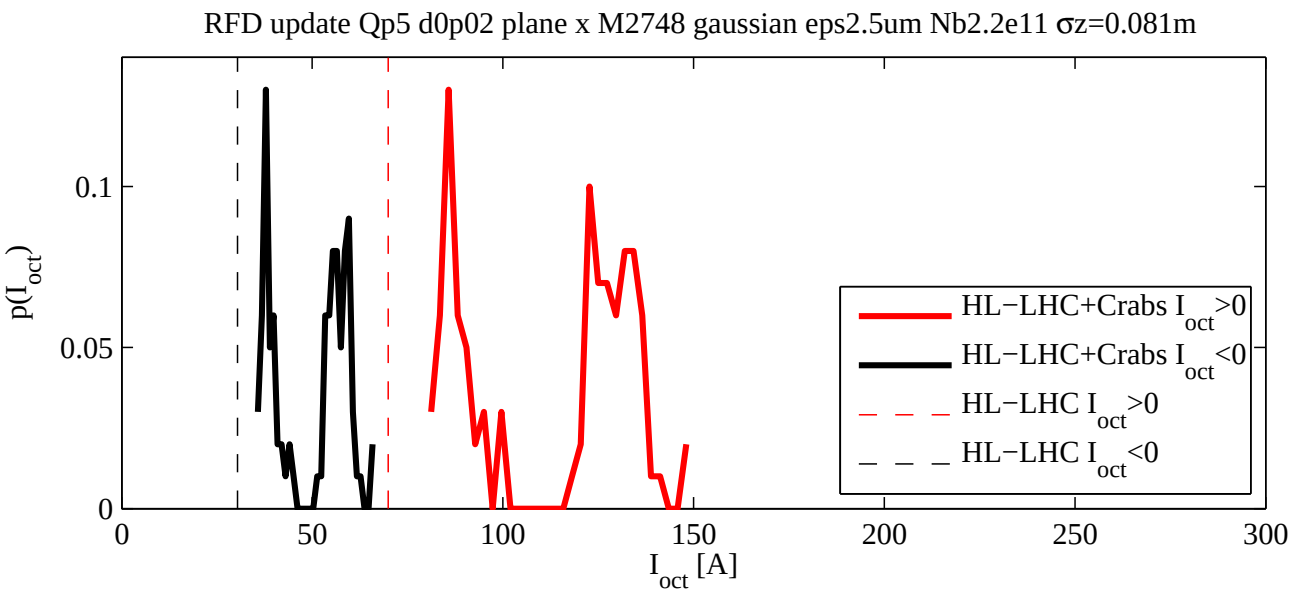


→ The DQW presents the mode at 1.75 GHz who leads to more than 1000 A increase of octupole current *if* a CB spectral line falls on it.
→ Less critical is the DQW 920 MHz mode (+100 A).
→ The RFD is below within the 10*A* threshold

We performed a set of 100 simulations of possible crab cavities HOM configurations on top of the baseline HL-LHC impedance model accounting for:

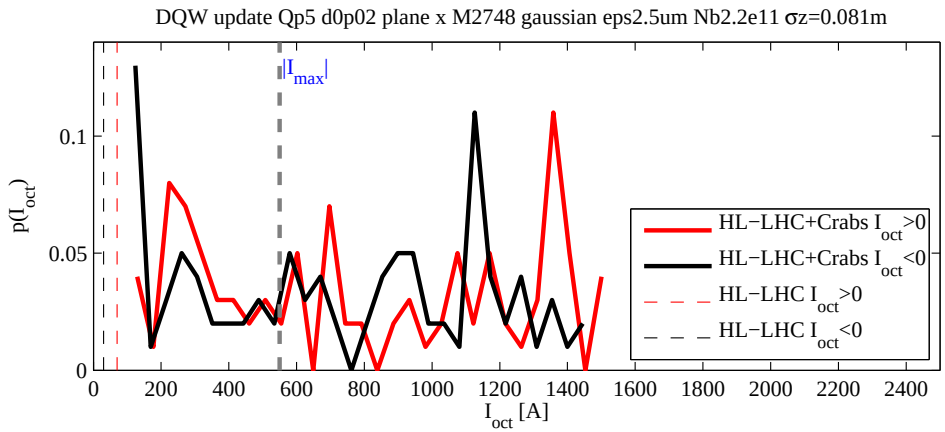
- 16 crab cavities in total (baseline now to 8: to be updated).
- Variable frequency spread of ±3 MHz between each cavity in each simulation.

For the **RFD design**, considering the octupole current required for each simulation and deriving the probability density function, we get:

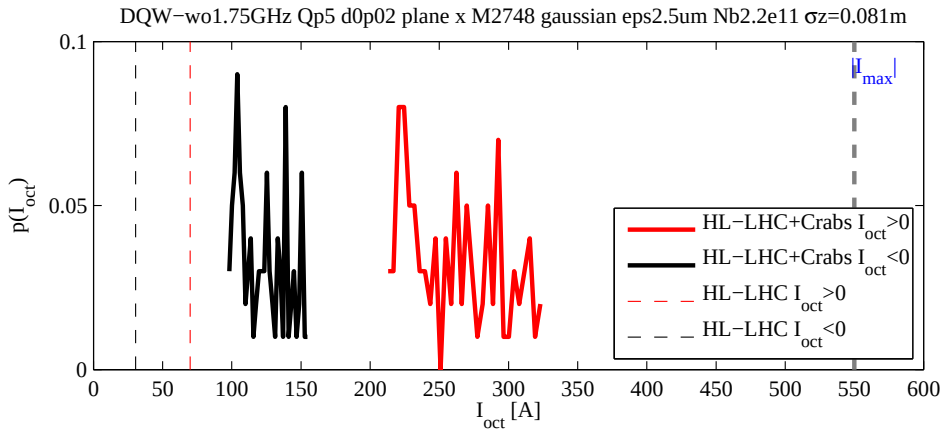


→ For positive octupole sign, the threshold is increased from ≃70 A to ≃ 150 A.
→ For negative octupole sign, the threshold is increased from ≃30 A to ≃ 70 A.

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

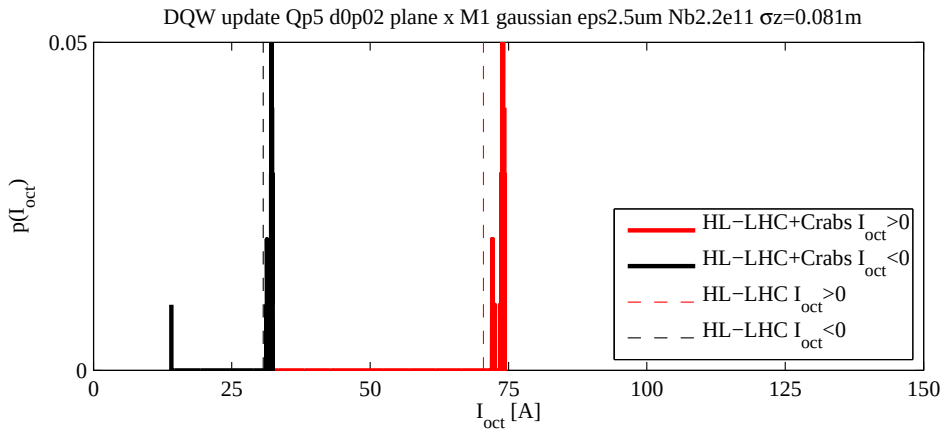


· · · and without it:

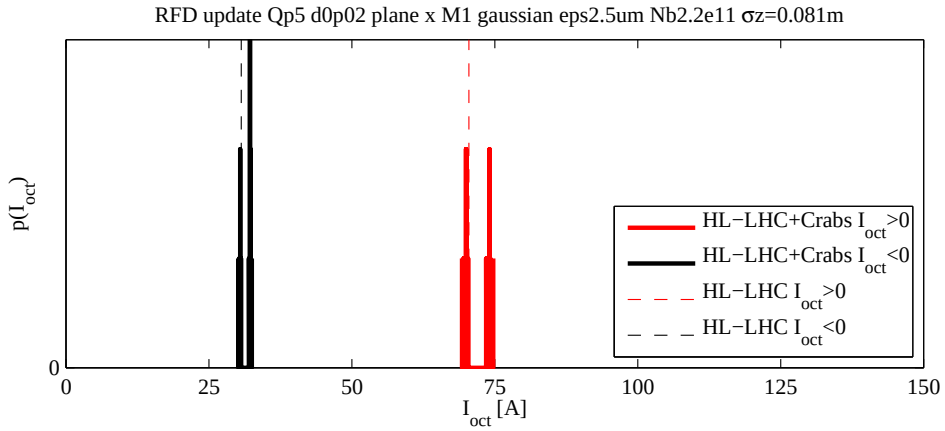


1) The 1.75 GHz would provoke machine dumps the 60% of the time ($I > I_{max} = 550\ A$).
2) Removing it, the driving mode is expected to be the 920 MHz (threshold moved to ≃150 A for negative octupole sign, and ≃ 320 for positive sign.
3) Allowing for a smaller R_s for the 1.75 GHz mode (R. Calaga update), would place it in the shadow of the 920 MHz mode: the situation would not deviate much from the case 2).

Single bunch results for **DQW design**:



Single bunch results for **RFD design**:



→ In both cases the increase in octupole current is negligible ($< 10A$).

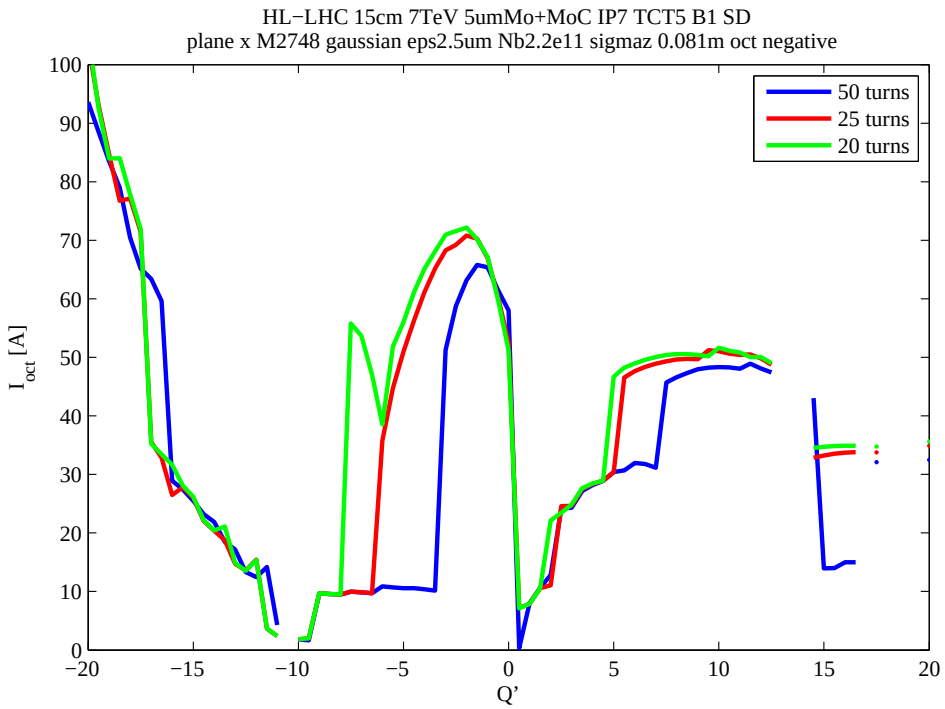
For the negative sign of the octupole we require:

1. A current of 70 A for the RFD design.
2. A current of 150 A for the DQW design (without 1.75 GHz mode).

Can we reduce the CB octupole threshold required by increasing the damper gain?

For the negative sign of the octupole we require:

1. A current of 70 A for the RFD design.
2. A current of 150 A for the DQW design (without 1.75 GHz mode).



→ For the baseline HL-LHC model, there is no reduction when adding damper gain over different Q'.
→ Statistical simulations with Crab cavities on top of the HL-LHC are still on-going...

Conclusions I

- We developed a method to assess *a priori* the compatibility of an HOM with the octupole current budget of the HL-LHC at $\beta^* = 15$ cm , both for single bunch (SB) and coupled bunch (CB) cases.
  - → An HOM with $\beta_{crab}/\beta_{av} \cdot R_s/Q \simeq 1\ M\Omega/m$ (or equivalently $R_s/Q \simeq 20\ k\Omega/m$) requires $\simeq 10$ A to be stabilized in SB regime.
  - → An HOM with $\beta_{crab}/\beta_{av} \cdot R_s \simeq 10\ M\Omega/m$ (or equivalently $R_s/Q \simeq 200\ k\Omega/m$) requires $\simeq 10$ A to be stabilized in CB regime.
- The RFD and DQW design have been found to be compatible with respect to single bunch stability threshold:
  - → Both RFD and DQW design require an increase of the octupole current needed $\simeq$ 10A.
- The DQW design, as it is now, is not compatible with current the HL-LHC CB stability limits:
  - → The 1.75 GHz mode provokes exceeding of the maximum octuple current 60% of the cases simulated.
- If the 1.75 GHz mode of the DQW is reduced to the level of $0.8 M\Omega/m$ (as it should now be. . .) it would require, together with the other HOMs:
  - → $\simeq$ 150 A for negative octupole sign (HL-LHC baseline respectively at 30 A).
  - → $\simeq$ 320 A for positive octupole sign (HL-LHC baseline respectively at 70 A).

Conclusions II

- The RFD design is compatible with current the HL-LHC stability limits for CB:
  - → For positive octupole sign, the threshold is increased from ≃70 A to ≃ 150 A.
  - → For negative octupole sign, the threshold is increased from ≃30 A to ≃ 70 A.
- Increasing the damper gain from 50 to 20 turns is not reducing the baseline octupole current needed for the HL-LHC.
  - → For Q'=5 the baseline threshold is increased of a factor ≃ 2.
  - → For Q'=10 the baseline threshold is almost unchanged (50 A).
  - → Statistical simulation on baseline + Crab cavities on going...
- If we collide at $\beta^* = 70$ we can gain a factor ≃ 5 and lower accordingly the octupole current thresholds.

Next steps and open questions

- Simulations for the present crab cavity scenario (8 crabs instead of the 16 simulated here), and mixed RFD-DQW scenario.
- How do we include in this frame the recent measurements on the LHC showing a factor 5 increase in octupole current?
- ...

Thank you for your attention!

LHC single and coupled bunch octupole thresholds.