Status of the FCC-hh impedance database*

*Database webpage:
https://impedance.web.cern.ch/impedance/fcchh/impedances.html

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Mode 0 impedance budget

Impedance budget consists of 3 effective impedances, each one for its own instability. For each element (e.g. beamscreen, collimators, etc) we compute quantities:

$$\mathrm{Re}\{Z_T\}_{\mathrm{eff}}^{\mathrm{TCBI}} = \frac{\beta_{element}}{\beta_{avg}} \sum_{k=-\infty}^{k=\infty} \mathrm{Re}Z_T^{element}(\omega_k) h_{0,0}(\omega_k)$$

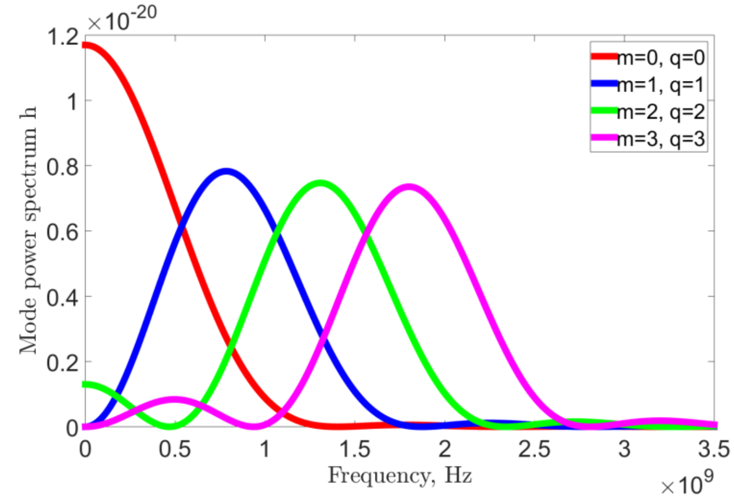
Sum over frequency lines $\omega_k = (\mathrm{frac}[Q] - 1 + kM)\Omega_0$

$$\mathrm{Im}\{Z_T\}_{\mathrm{eff}}^{\mathrm{TMCI}} = \frac{\beta_{element}}{\beta_{avg}} \frac{\sum_{k=-\infty}^{k=\infty} \mathrm{Im}Z_T^{element}(\omega_k) h_{0,0}(\omega_k)}{\sum_{k=-\infty}^{k=\infty} h_{0,0}(\omega_k)}$$

Sum over frequency lines: $\omega_k = (k + Q)\Omega_0$

$$\mathrm{Im}\left\{\frac{Z_{||}}{n}\right\}_{\mathrm{eff}}^{\text{Loss of Landau}} = \frac{\sum_{k=-\infty}^{k=\infty} k\ \mathrm{Im}Z_{||}^{element}(\omega_k)\Lambda_0(\omega_k)}{\sum_{k=-\infty}^{k=\infty} k^2 \Lambda_0(\omega_k)}$$

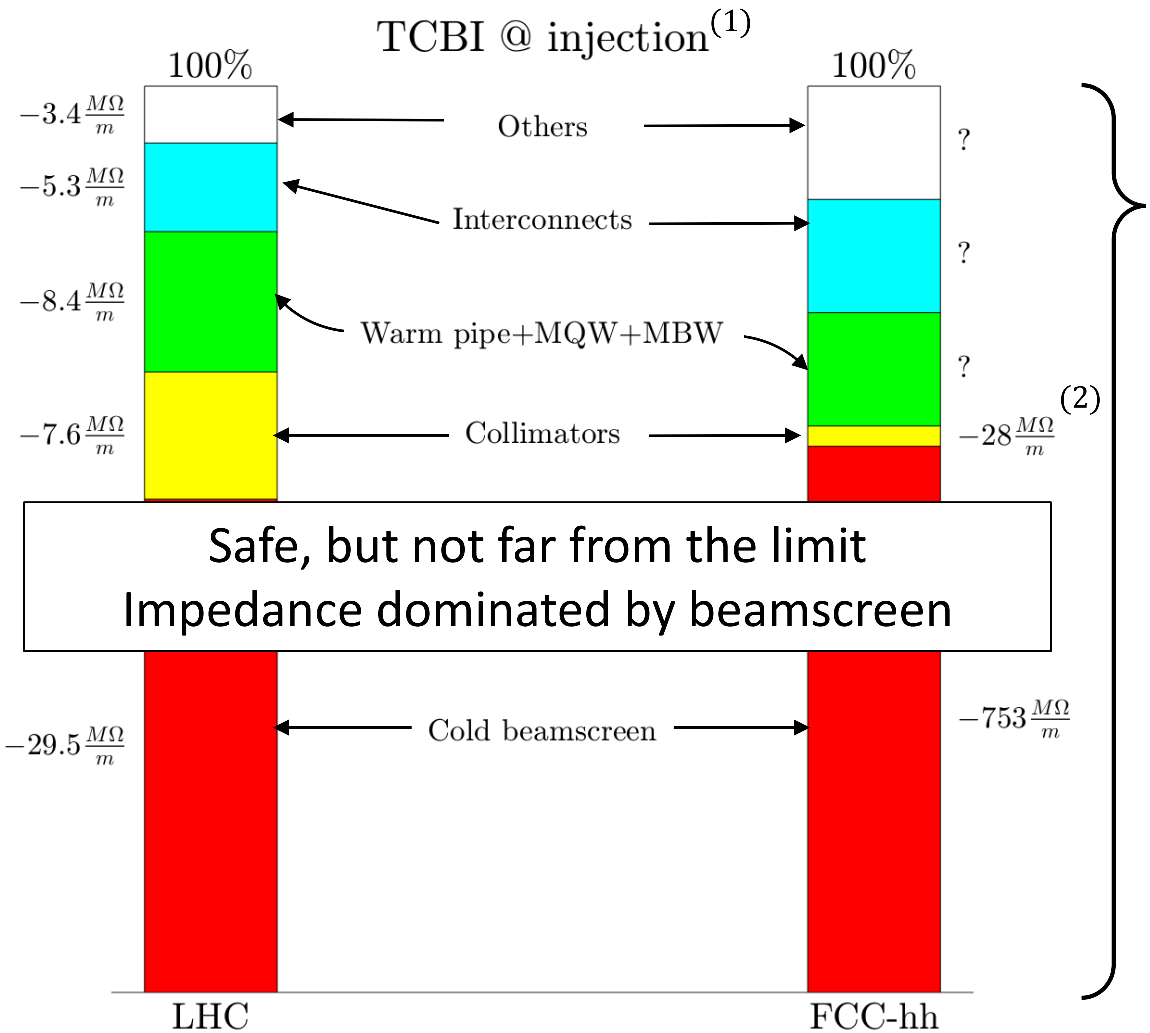
Sum over frequency lines: $\omega_k = k\Omega_0$



Mode power spectra $h_{m,q}$ for a parabolic bunch

Mode 0 effective impedances are computed for chromaticity 0 (worst case).

Mode 0 impedance budget: TCBI at injection



Safe, but not far from the limit
Impedance dominated by beamscreen

Limit:

$$\sum_{element} \mathrm{Re}\{Z_T\}_{\mathrm{eff}}^{\mathrm{TCBI}} \leq \mathbf{-1350}\frac{M\Omega}{m}$$

Assuming required feedback speed of 60 turns

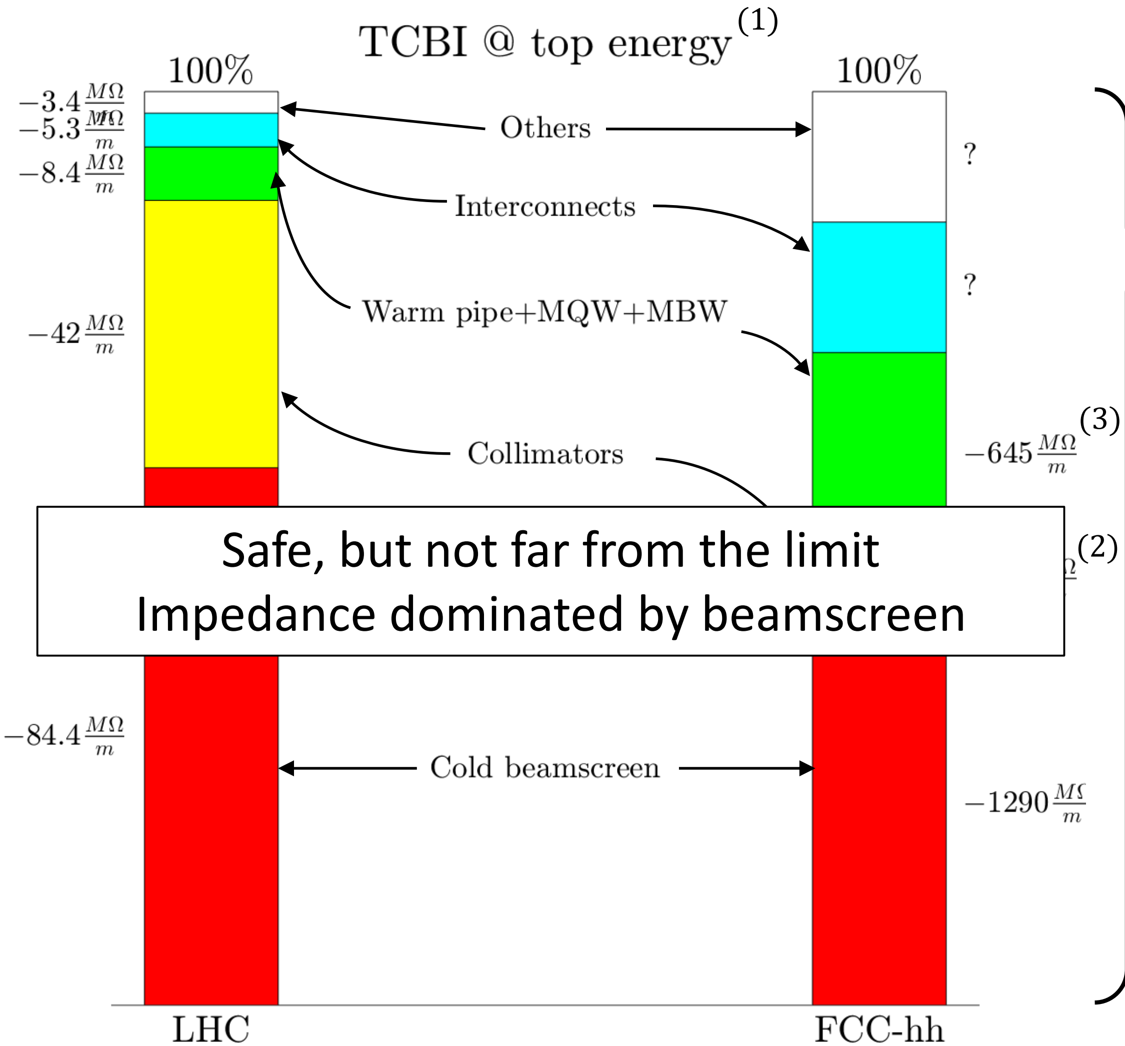
20 turns for a safety factor of 3

Notes:

(1) Numbers for the most critical plane shown (y)

(2) Varies between $-17\frac{M\Omega}{m}$ and $-28\frac{M\Omega}{m}$ depending on collimator material

Mode 0 impedance budget: TCBI at top energy



Safe, but not far from the limit
Impedance dominated by beamscreen

200 turns for a safety factor of 3

Assuming required feedback speed of 600 turns

Limit:

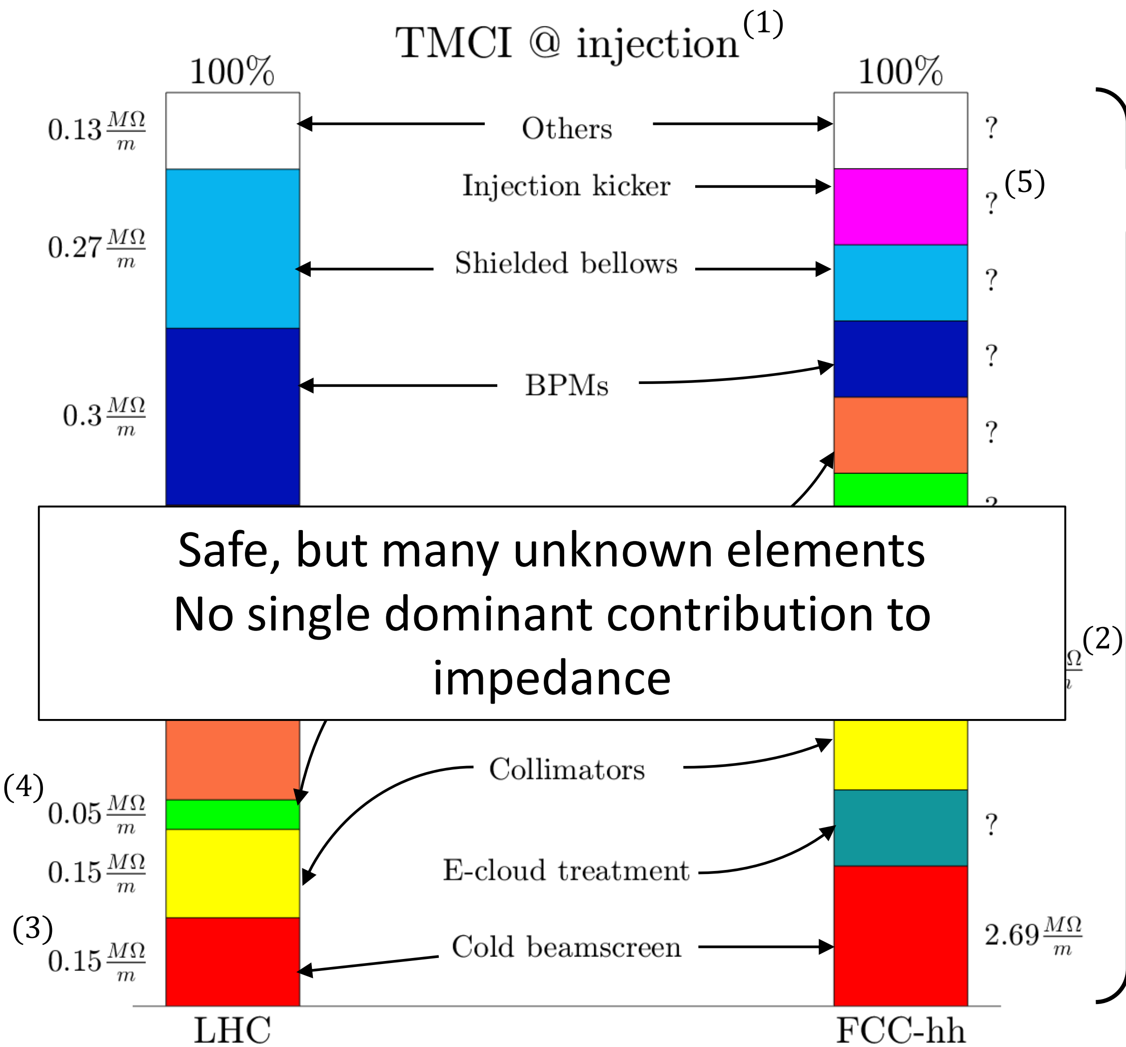
$$\sum_{element} \mathrm{Re}\{Z_T\}_{\mathrm{eff}}^{\mathrm{TCBI}} \leq \begin{cases} \mathbf{-2050}\,\frac{M\Omega}{m} \\ \mathbf{-4100}\,\frac{M\Omega}{m} \end{cases}$$

Assuming required feedback speed of 300 turns

100 turns for a safety factor of 3

Notes:
(1) Numbers for the most critical plane shown (y)
(2) Varies between $-113\,\frac{M\Omega}{m}$ and $-149\,\frac{M\Omega}{m}$ depending on collimator material
(3) For aperture in the drifts $r = 4cm$

Mode 0 impedance budget: TMCI at injection



Safe, but many unknown elements
No single dominant contribution to impedance

Limit:

$$\sum_{element} \mathrm{Im}\{Z_T\}_{\mathrm{eff}}^{\mathrm{TMCI}} \leq \mathbf{12} \frac{M\Omega}{m}$$

Assuming required TMCI threshold $N_b = 3 \times 10^{11}$ and RF voltage of 12 MV.

→ safety factor of 3

Notes:

(1) Numbers for the most critical plane shown (y)

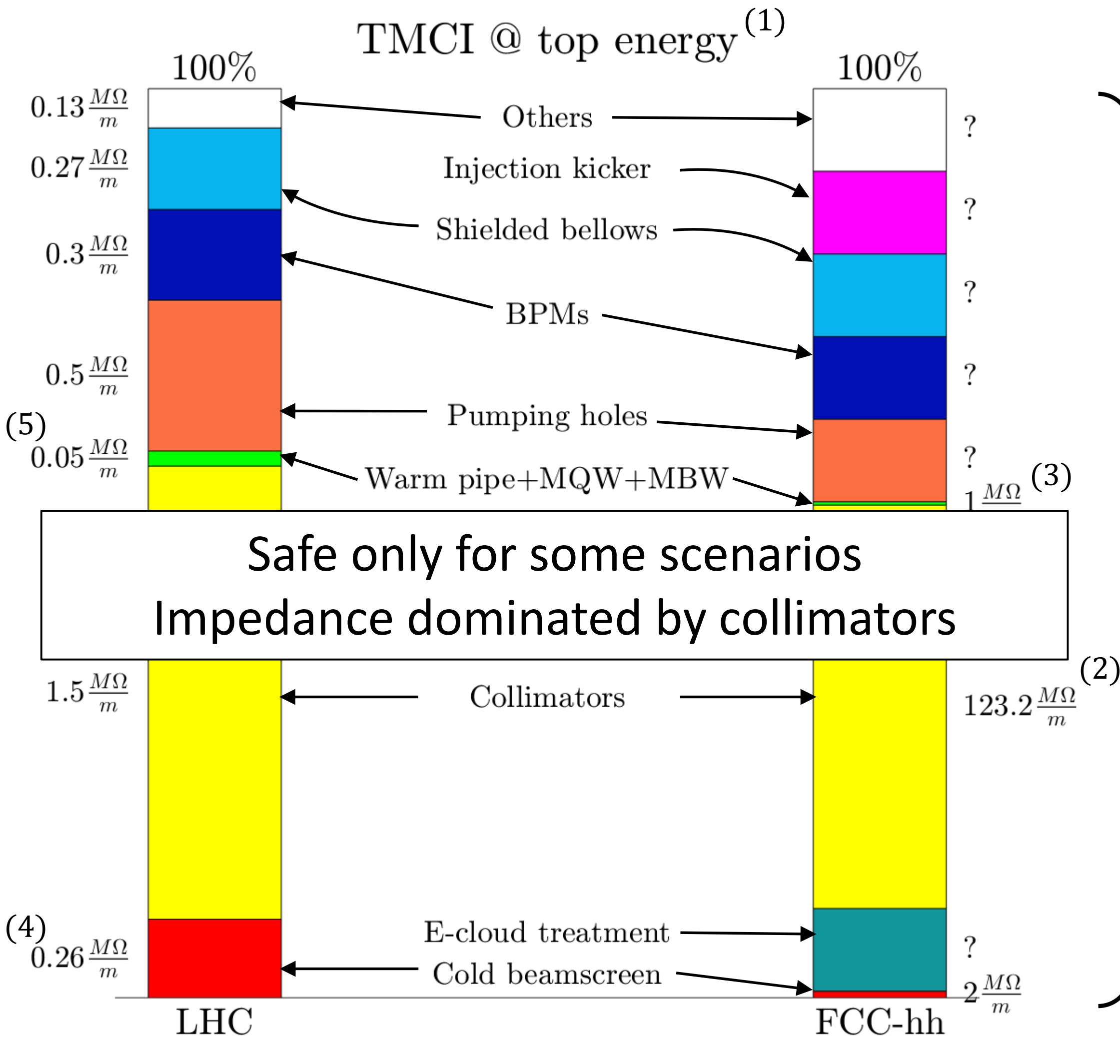
(2) Varies between $1.66 \frac{M\Omega}{m}$ and $4.62 \frac{M\Omega}{m}$ depending on collimator material. Includes contribution of tapers.

(3) Number absent in LHC design report – scaled from FCC impedance

(4) Number absent in LHC design report – scaled from TCBI budget

(5) Without ferrite shielding $17 \frac{M\Omega}{m}$

Mode 0 impedance budget: TMCI at top energy



Safe only for some scenarios
Impedance dominated by collimators

Limit:

$$\sum_{element} \mathrm{Im}\{Z_T\}_{\mathrm{eff}}^{\mathrm{TMCI}} \leq \mathbf{70}\,\frac{M\Omega}{m}$$

Assuming required TMCI threshold $N_b = 3 \times 10^{11}$ and RF voltage of 32 MV.

→ safety factor of 3

Notes:

(1) Numbers for the most critical plane shown (y for LHC, x for FCC)

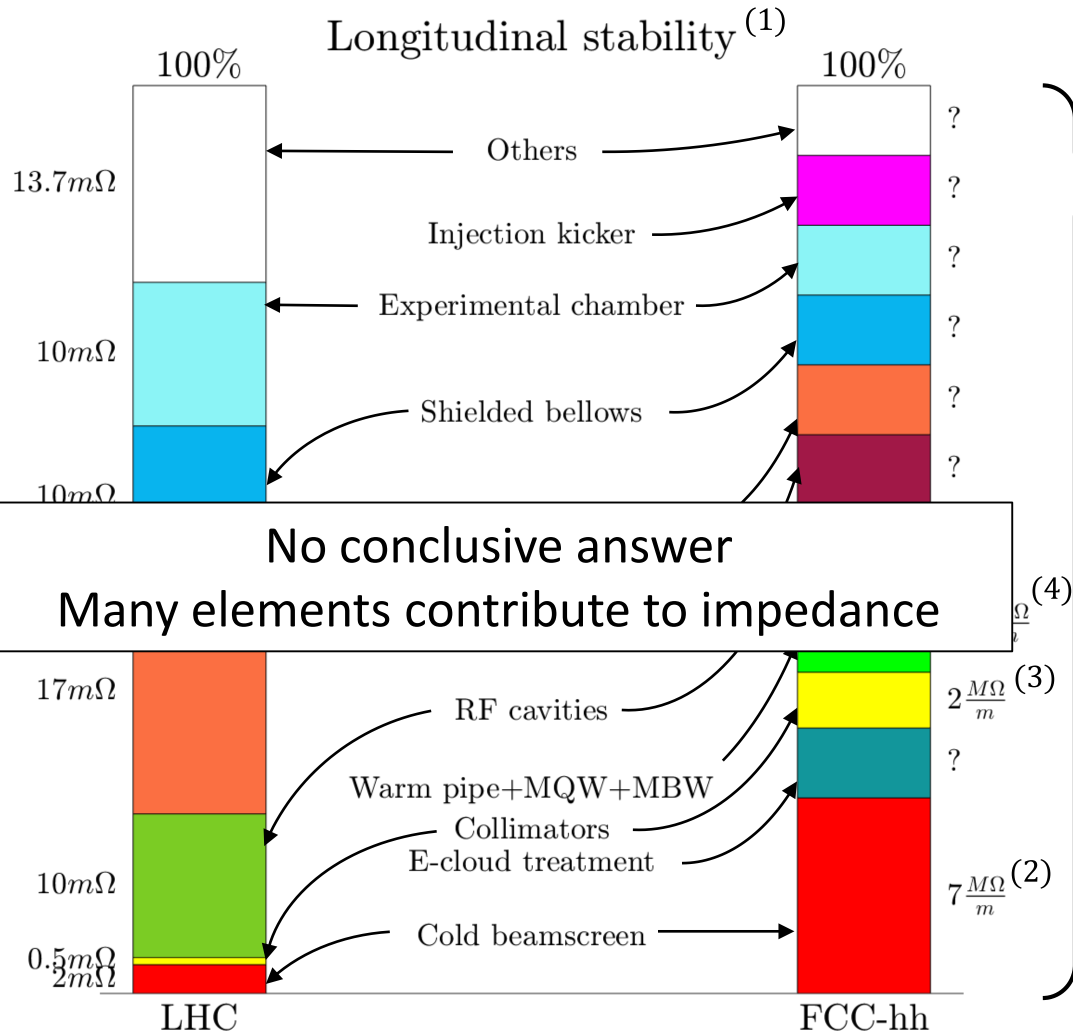
(2) Varies between $46.2\,\frac{M\Omega}{m}$ and $123.2\,\frac{M\Omega}{m}$ depending on collimator material. Includes contribution of tapers.

(3) For aperture in the drifts $r = 4cm$

(4) Number absent in LHC design report – scaled from FCC impedance

(5) Number absent in LHC design report – scaled from TCBI budget

Mode 0 impedance budget: Longitudinal stability



No conclusive answer

Many elements contribute to impedance

Limit:

$$\sum_{element} \mathrm{Im}\left\{\frac{Z_{||}}{n}\right\}_{\mathrm{eff}}^{\text{Loss of Landau}} \leq \mathbf{200}\ m\Omega$$

Assuming 2 times the budget of LHC.

Notes:

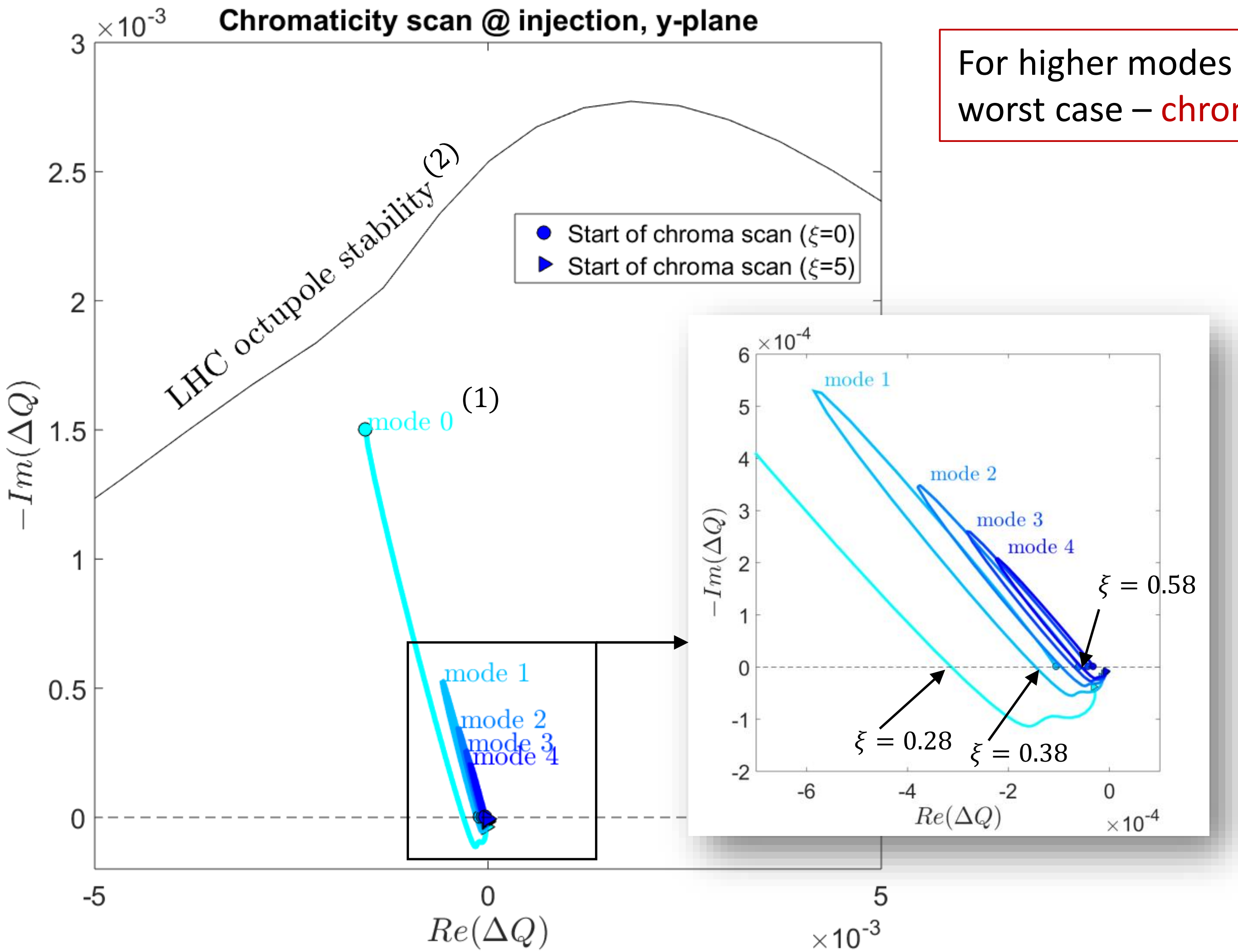
(1) Numbers vary a lot depending on definition of effective impedance.

(2) Varies between $6m\Omega$ and $8m\Omega$ depending energy (magnetoresistance).

(3) Varies between $1m\Omega$ and $2.5m\Omega$ depending energy and collimator material.

(4) For aperture in the drifts $r = 4cm$

Higher modes impedance budget at injection



For higher modes $\xi = 0$ is not the worst case – chromaticity scan needed

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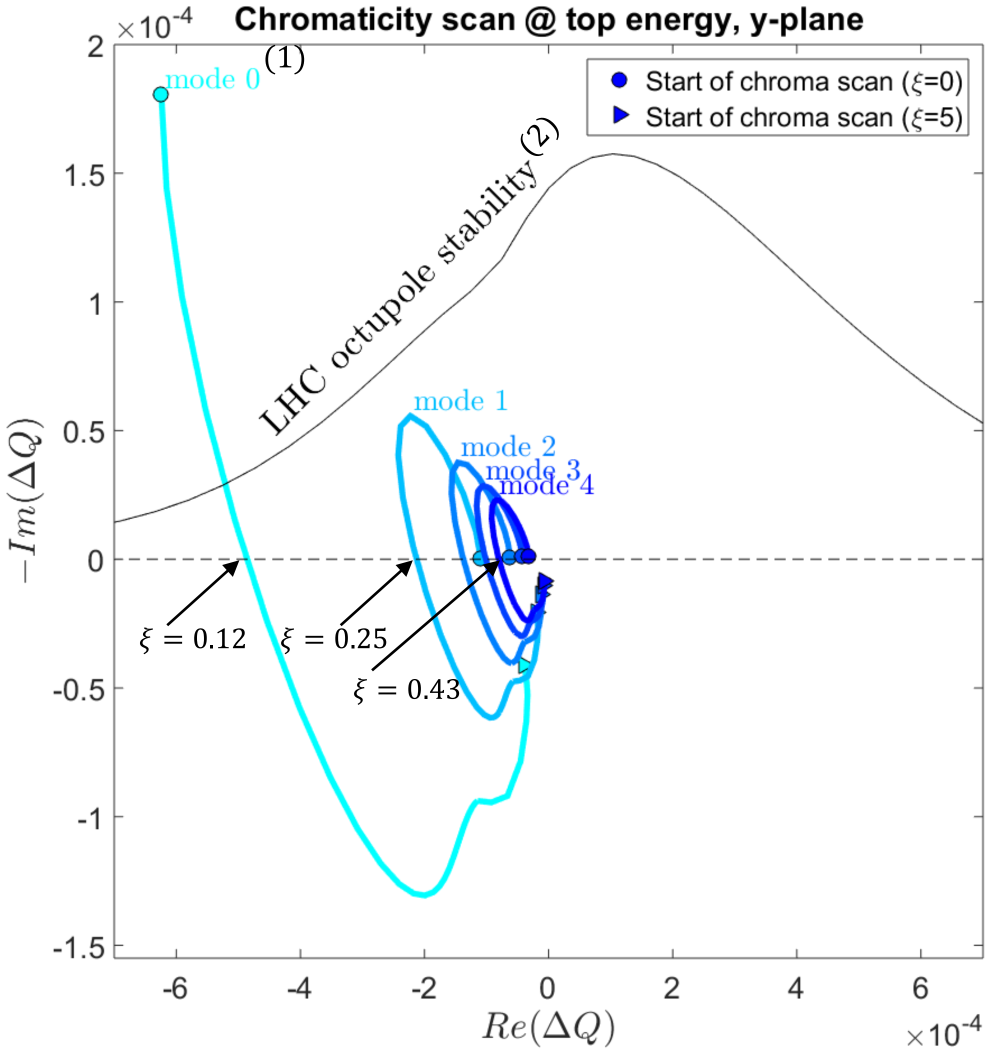
Notes:

(1) For each mode and each value of ξ, only the most unstable coupled-bunch mode is plotted.

(2) Assuming LHC parameters: $\epsilon_N = 3.75\ \mu m$, $I_{oct}^F = I_{oct}^D = 40A$, $E = 0.45 TeV$.

Higher modes impedance budget at top energy



For higher modes $\xi = 0$ is not the worst case – chromaticity scan needed

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Notes:

(1) For each mode and each value of ξ, only the most unstable coupled-bunch mode is plotted.

(2) Assuming LHC parameters: $\epsilon_N = 3.75\ \mu m$, $I_{oct}^F = I_{oct}^D = 500A$, $E = 7TeV$.

Conclusions

- An LHC-like impedance budget is created for head-tail mode 0.
- Limits on mode 0 impedance are put based on feedback speed, TCMI threshold, and longitudinal stability.
- For higher modes, tuneshift is computed over a chromaticity scan.

Work to do:

- Higher modes stability study with Landau damping
- Better understand longitudinal stability
- Still many elements to be added to the database:
  - Pumping holes + stiffeners
  - Interconnects
  - BPMs, Y-chambers, bellows
  - Injection kicker