Update on collimator impedance studies and measurements

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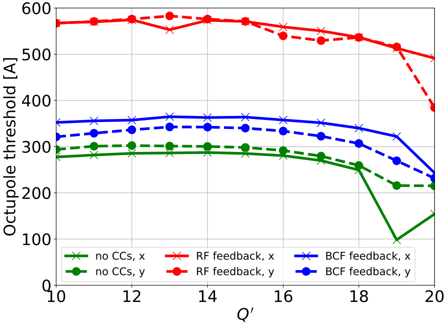
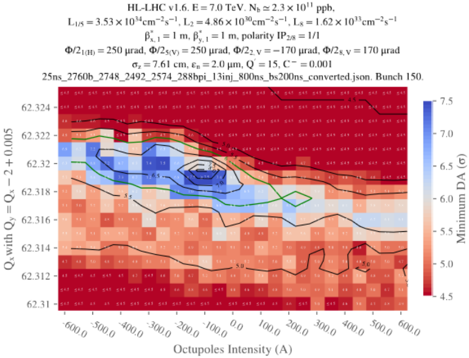
Impedance and Dynamic Aperture (DA)

Is impedance still an issue for the HL-LHC?





courtesy of C. Droin, S. Kostoglou, G. Sterbini

It depends: low DA could be an issue if high I_{MO} are needed in case of inefficiencies of the betatron comb filter feedback. If this is the case we need ways to reduce the thresholds.

Assumptions in this presentation

In the whole presentation we assume a run 4 scenario with the following assumptions:

- Intensity: $2.3 \cdot 10^{11}$ protons per bunch
- Transverse distribution: Gaussian
- Emittances:
  - Standard: $\varepsilon_x^n = 2.3\ \mu$m, $\varepsilon_y^n = 2.1\ \mu$m
  - BCMS: $\varepsilon_x^n = 2\ \mu$m, $\varepsilon_y^n = 1.7\ \mu$m
- Longitudinal distribution: Gaussian, $\tau_b = 1$ ns ($4\sigma_{\mathrm{RMS}}$)
- Positive octupole polarity (unless specified differently)
- $\beta^* = 100$ cm in IP1/5
- Latency effects included in the octupole thresholds
- Linear RF: no octupole threshld sweetspot (see X. Buffat on Wednesday)
- Crab cavities with betatron comb filter (with 100% efficiency)
- We present the results only for beam 1, the results for beam 2 are very similar
- Collimator settings:

	Tight	Relaxed
Primaries IR7	6.7	8.5
Secondaries IR7	9.1	10.1
Tertiaries IR7	12.7	13.7
Primaries IR3	17.7	17.7
Secondaries IR3	21.3	21.3
Tertiarties IR3	23.7	23.7

Outline

Standard vs BCMS

IR7 rematched optics

Alternative IR3 optimization strategies

Collimator impedance beam-based measurements

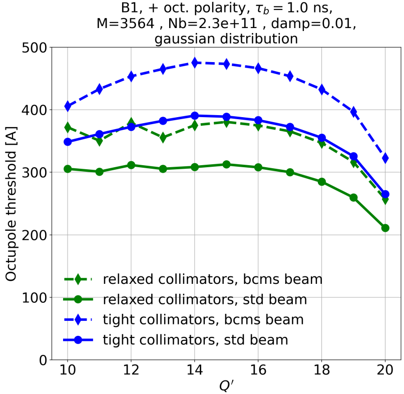
Standard vs BCMS

Both standard and BCMS beams are still being considered so we need to consider both cases.

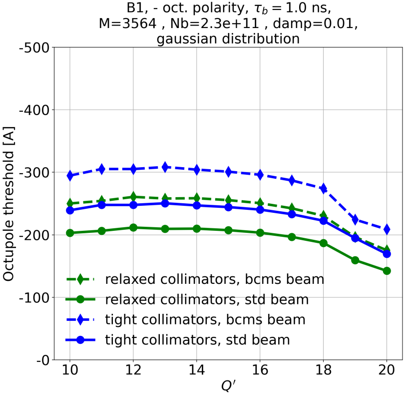
Emittances:

- Standard: $\varepsilon_x^n = 2.3\ \mu$m, $\varepsilon_y^n = 2.1\ \mu$m
- BCMS: $\varepsilon_x^n = 2.1\ \mu$m, $\varepsilon_y^n = 1.7\ \mu$m

Positive octupole polarity



Negative octupole polarity



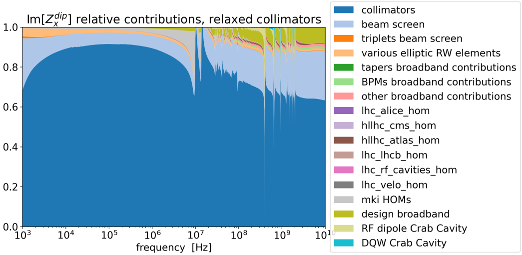
With BCMS the octupole thresholds are greatly increased: with tight settings and BCMS we reach almost 500 A.

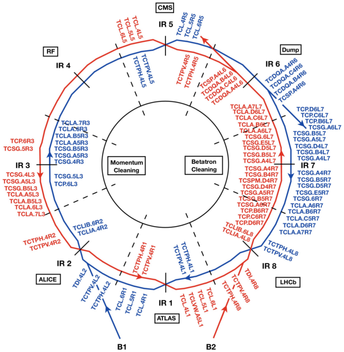
Outline

- Standard vs BCMS
- IR7 rematched optics
- Alternative IR3 optimization strategies
- Collimator impedance beam-based measurements

LHC impedance contributions

- The collimators are responsible for 60 to 80% of the (HL-)LHC broadband impedance
- Mitigating the impedance of the collimators can help reducing the octupole thresholds
- The narrow-band contributions, such as those coming from the crab cavities, are also under study





- Most of the primary and secondary collimators are concentrated in the IR7
- We want to try to reduce the impedance of these collimators

Reducing the impedance of the collimators

Approximate dipolar impedance of a horizontal collimator (single material, thick wall approximation):

$$Z_x^{dip}(\omega) \approx K(\delta_0)\frac{1}{\sqrt{\beta_x}}$$
$$Z_y^{dip}(\omega) \approx K(\delta_0)\frac{\beta_y}{\sqrt{\beta_x}^3}$$

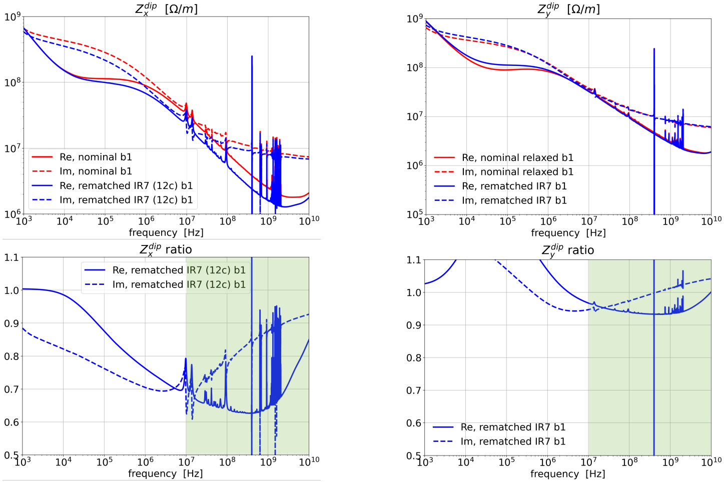
Optimization of material properties: use materials with good conductivity: CFC $\rightarrow$ MoGr / Mo-coated MoGr/ Cu-coated graphite.
See for example: S. Antipov's IPAC'18 paper and C. Accettura's IPAC'23 paper

Optimization of the optics: increase the physical gap of the collimator by increasing the beta function in the plane of collimation (collimator σ setting stays constant).

There is enough freedom in the optics choice to rematch the IR7 increasing the β's at the collimators.
Moreover, the rematched optics can also be optimized for better cleaning (see B. Lindström et al.).

Rematched IR7

We received the rematched optics from B. Lindström and we evaluated the impedance improvement.



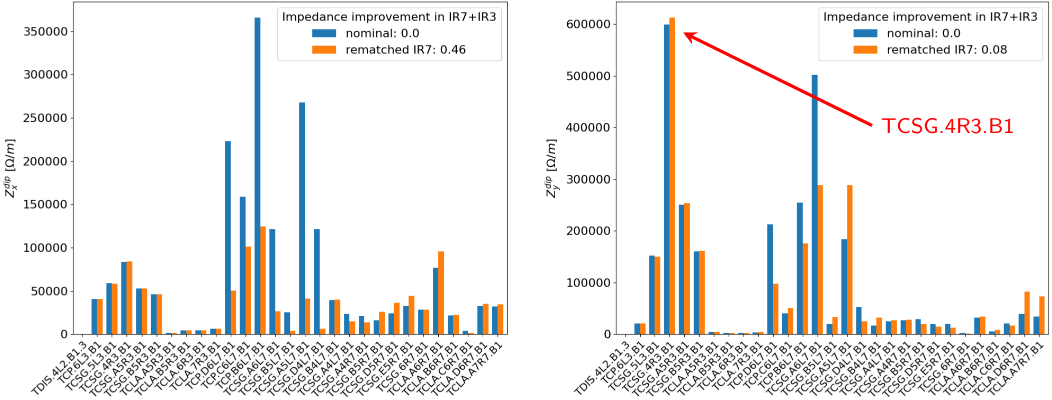
Improvement at 1 GHz (real part):

- in x: $\sim 40\%$
- in y: $< 10\%$

We would like to improve more in y.

We need to improve also the IR3

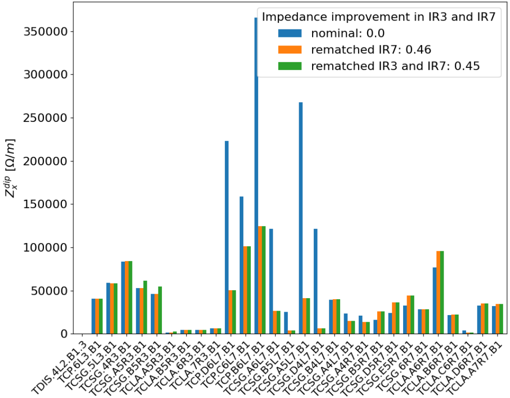
Let us look at the breakdown of the individual contributions of each collimator.

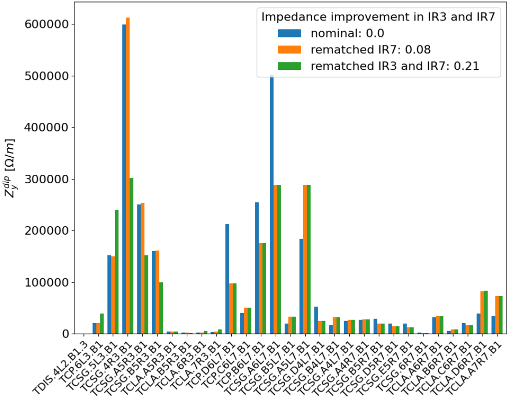


In y the IR3 collimator TCSG.4R3.B1 (horizontal secondary) dominates the impedance. Therefore, the impedance reduction coming from the IR7 is overall less effective.

Rematched IR7 and IR3

In principle, one can also rematch the IR3 optics and achieve further improvement in the vertical plane.

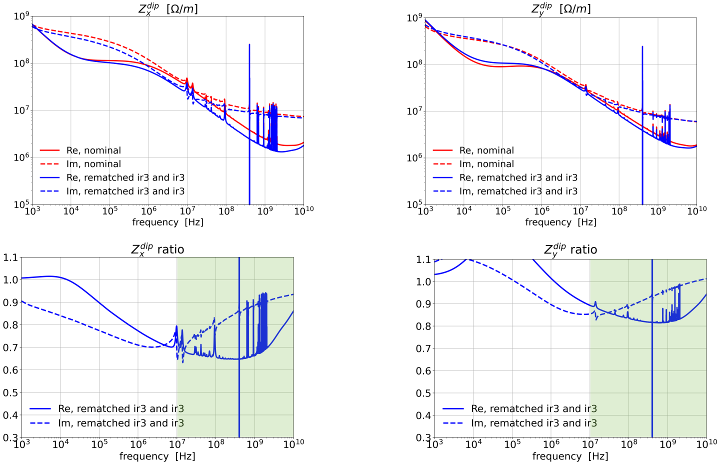




By optimizing also the IR3 optics we finally have a 20% improvement in y!

Relaxed IR3 collimator settings are under study as alternative or complementary strategy

Machine impedance with the rematched IR3 and IR7 optics



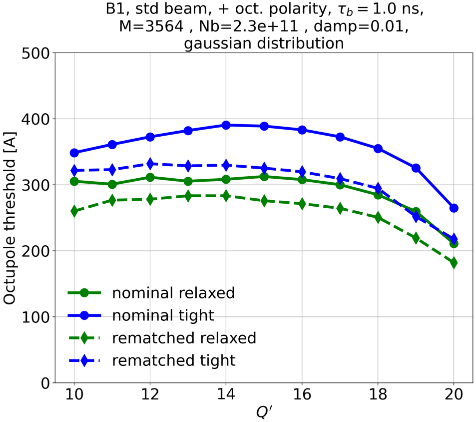
Improvement at 1 GHz (real part):

- in x: ∼ 40%
- in y: ∼ 20%

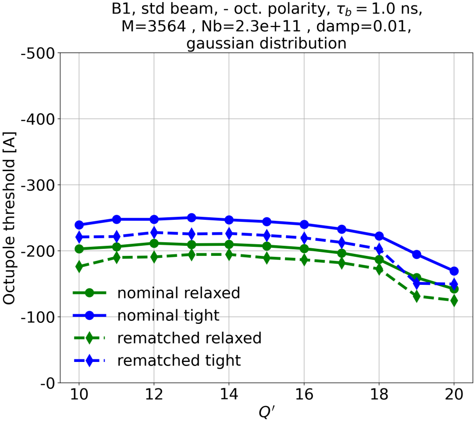
It is ok to have less improvement in y because with the standard optics x is the most unstable plane.

Octupole thresholds: nominal optics vs rematched

Positive octupole polarity



Negative octupole polarity



The octupole thresholds are greatly reduced and they are lower than 400 A in all cases.

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Relaxed IR3 settings

The rematched optics cannot be used at injection, therefore an optics transition during the ramp is needed. Having this transition both in IR3 and IR7 can be complex and it can be helpful to have an alternative plan.

According to the collimation experts, the IR3 collimators are fundamental at injection, while it should not harm to slightly retract them later in the cycle. We want to check if by retracting them we can achieve the same impedance gain as with the IR3 rematched optics.

Nominal settings:

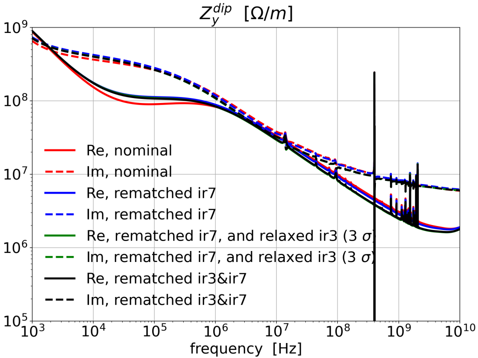
- TCP3: 17.7σ
- TCSG3: 21.3σ
- TCLA3: 23.7σ

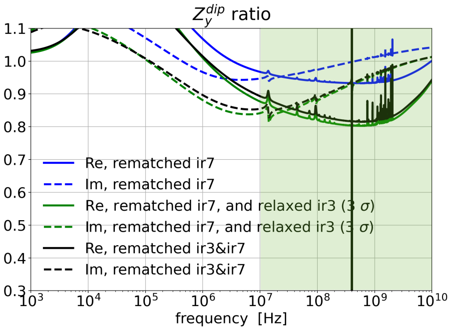
→

Relaxed settings:

- TCP3: $17.7\ \sigma + \mathrm{N}\ \sigma$
- TCSG3: $21.3\ \sigma + \mathrm{N}\ \sigma$
- TCLA3: $23.7\ \sigma + \mathrm{N}\ \sigma$

Impedance with relaxed IR3





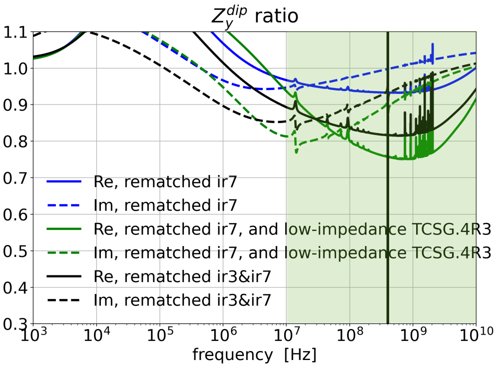
By relaxing the IR3 by 3 σ we can achieve the same level of reduction as rematching the optics.

We need the collimation team to assess if this could be compatible with the cleaning constraints of the IR3.

The impedance could be further reduced by ∼10% by combing rematched optics and relaxed settings, if it is needed.

Low-impedance collimator in IR3

Thanks to advantageous contract with the manufacturer it should be not too expensive to replace TCSG.4R3 with a low-impedance collimator (without BPMs due to cabling issues).



This would be even better than IR3 rematched optics ($\sim$ 25% impedance reduction in vertical) but it would have to be decided relatively soon.

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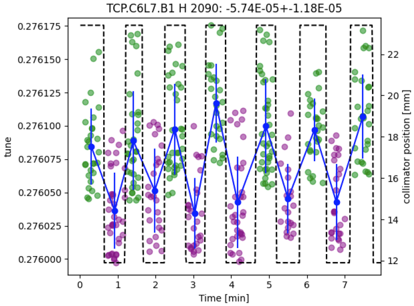
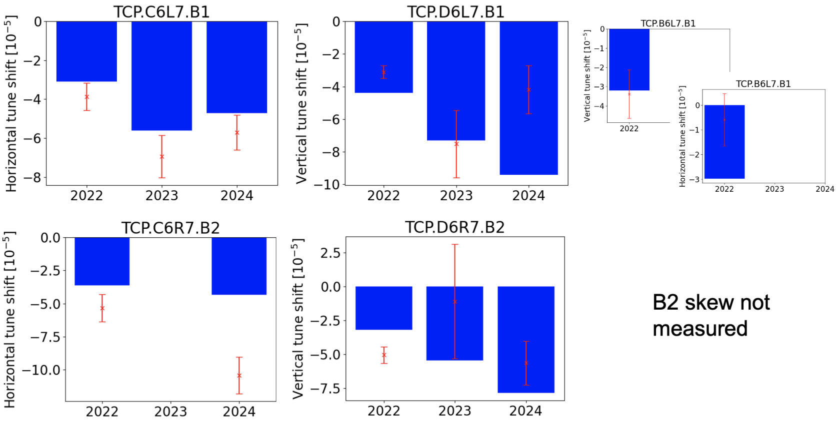
Collimator impedance beam-based measurements

- The evolution of the impedance of the collimators installed in the machine must be constantly monitored.
- We want to be sure that the coating or the low-impedance collimators is not damaged
- The imaginary part of the impedance of a collimator can be assessed via tune-shift measurements (see Sacherer formula)
- Idea: measure the tune while cycling the position of a collimator between retracted and closed position and measure the shift between the two configurations.
- We then compare to our model and check that the tune-shift is not significantly worse than we expect



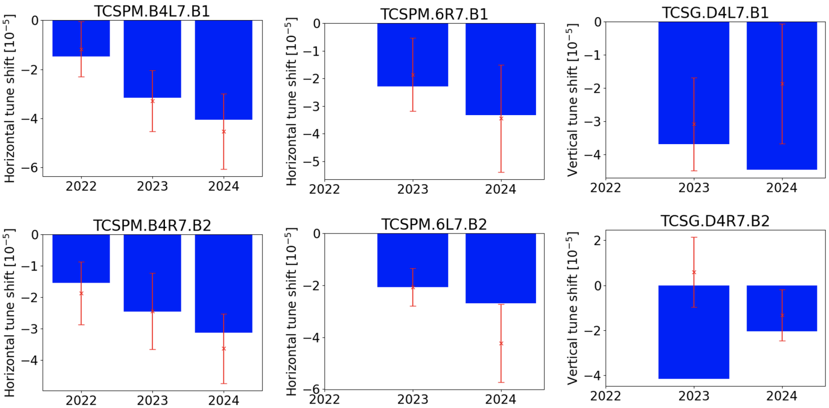
Primaries



B2 skew not measured

- The difference in predicted tune-shift across the years is due to different experimental conditions
- In general, the agreement between predictions and measurements do not appear to have worsened in the years (except for TCP.C6R7.B1)

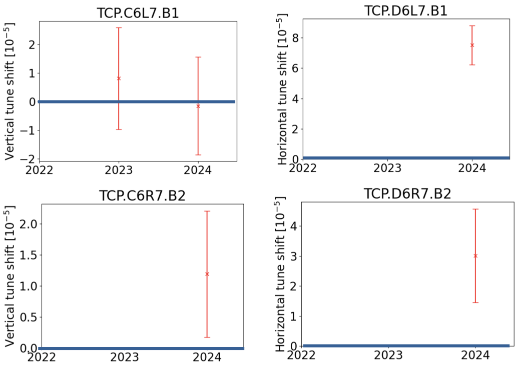
Secondaries



Overall good agreement in almost all cases (except for TCSG.D4R7.B2).

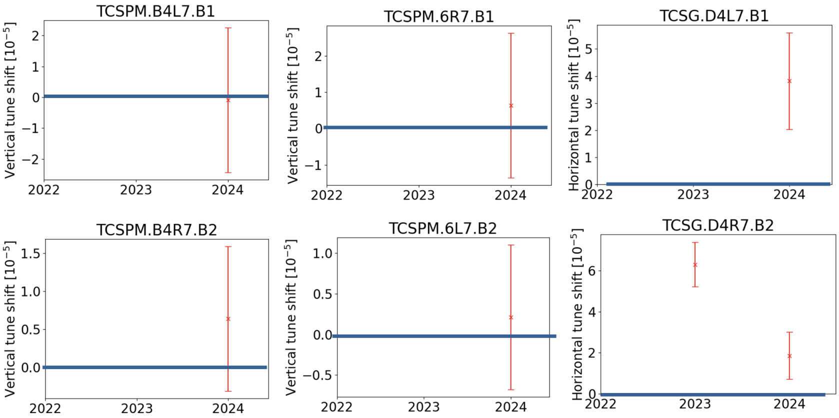
Primaries in the non-collimation plane

In the non-collimation plane the dipolar and quadrupolar impedance should compensate each other and we should have no tune-shift.



- We see unexpected positive horizontal tune-shifts for the vertical collimators.
- There is an excess of quadrupolar impedance. It might be related with geometric features.

Secondaries in the non-collimation plane



Again positive horizontal tune-shifts for the vertical collimators.

Conclusions

- The octupole threshold predictions were updated in agreement with the predicted operational beam parameters.
- We compared standard and BCMS, showing that the brighter BCMS beam leads to octupole thresholds up to 500 A with the tight collimator settings.
- Using negative octupole polarity helps if not problematic for DA (octupole thresholds with BCMS and tight settings down to 300 A).
- We showed the impedance gain from the new IR7 optics.
- In vertical there is margin to improve further with three strategies:
    - rematched IR3 optics,
    - relaxed IR3 settings,
    - install an additional low-impedance secondary to replace TCSG.4R3.
- The results of collimator tune-shift measurements across the years show no clear signs of degradation in general.
- Unexpected positive tune-shifts in the non-collimation plane were observed. This will have to be studied in more detail.