A first trial to reduce collimation impedance by playing with the IR7 optics

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Motivation

- IR7 gives the **highest impedance** of all collimators (3 primaries, 11 secondaries, all in poorly conductive CFC – carbon reinforced carbon).

- Transverse impedance depends a lot on the collimator half-gaps, which themselves depend on the **beta functions**

  → if we play with optics we can potentially decrease impedance, "for free" (i.e. w/o hardware change).

- Ideas of this short study:
  
  - **Play locally on IR7 optics** to try to decrease impedance there,
  
  - Keeping as much as possible the **rest of the machine identical** (here only in terms of beta functions and horizontal dispersion),
  
  - See how much we can gain this way.

- Of course, this is to be seen only as an **initial test**, which is clearly **impedance oriented**, therefore most probably overlooking many optics & collimation aspects.
Some theoretical background

- At **high frequencies** (in particular those that matters in single-bunch, or in multibunch with a strong damper, i.e. from ~100 MHz to several GHz in the LHC), transverse impedance goes as (here for an **horizontal** collimator, with \( b = \) half-gap, \( \kappa = \) constant)

\[
Z_x = \kappa \frac{\beta_x}{b^3} = \kappa \frac{\beta_x^{3/2}}{\sqrt{\beta_x}} \quad \text{in the plane of collimation (here } x)\]

Note: here we discuss only resistive-wall (main contribution).

\[
Z_y = \kappa \frac{\beta_y}{2b^3} = \kappa \frac{\beta_y^{3/2}}{2\beta_x^{3/2}} \quad \text{in the other plane (here } y)\]

Despite the factor \(1/2\), this component can be very large, typically for collimators with small \( \beta_x \) & high \( \beta_y \) (or the opposite for a vertical collimator).

Example: contribution on hor. tune shift of TCSG.D4L7 (vertical coll. B1)
How to decrease impedance?

- First idea: for collimators such as TCSG.D4L7.B1 (low $\beta$ in the plane of collimation, high $\beta$ in the other plane), we can try to decrease the high $\beta$, & increase the small $\beta$.

- Then, of course the betas at the other collimators are affected...

- Moreover, for skew collimators (8 out of 11 TCS in IR7), the situation is more involved (both $\beta_x$ and $\beta_y$ contribute to the half-gap).

  → necessity to compute a total "impedance scaling factor" in IR7 (based on expressions of previous slide, adding the skew angle dependency) for all the TCP and TCS, and to minimize this.

- This minimization can be done as a matching in MAD-X (using macros).
Starting from the standard v6.503 LHC optics (55cm)

Playing with the quadrupole strengths of all MQTLI, MQTLH and MQW (A and B) in IR7 (note: MQW act on both B1 and B2 so both beams have to be matched at the same time)

Matching (in several steps) to a lower total "impedance", as well as $\beta$, $\alpha$, $D_x$ & $D'_x$ at the boundaries of the region affected (between Q11 left and right), the total phase advance of this region, and several phase advances between ~regularly spaced collimators

Note: in the following the crossing angles in IP1 & 5 were non-zero, hence the non-zero dispersion around the IPs.
Results: B1

Phase advance between successive collimators

"Impedance" of each collimator
Results: B2

Old optics (B2)

New optics (B2)

Phase advance between successive collimators

"Impedance" of each collimator
Ratio of the total impedance (nominal settings) w.r.t case without the optics change:

- we can gain up to ~15% on the total impedance budget (at high frequency).
- At low frequency, there can be some increase of the impedance.
Results

- We check first that optics modifications are indeed local: for the $\beta$ functions

$\rightarrow$ Beta functions are changed only in IR7.
Results

- Checking that optics modifications are indeed local: for the **horizontal dispersion**:

> B1 horizontal dispersion is largely unaffected except in IR7,
> B2 dispersion is more affected.
Main conclusion: it seems we can **significantly reduce the total impedance** of the LHC by playing with the local optics of IR7.

But the constraints chosen (local modifications, phase advances kept more or less identical) might not be sufficient (particularly on the collimation side).

A contrario, we could potentially do better if some constraints are relieved (for instance if we can change the beta functions in the adjacent arcs).

We could also do (slightly) better if IR3 and IR6 are also considered.

Many things are obviously to be checked besides impedance, in particular on the collimation and optics sides

→ to go further in this direction we would need a collaboration between impedance, optics and collimation teams.

Ultimately, if this is thought to be interesting, an MD could be organized...

All this was only a trial, that can be forgotten right away if it appears to be obviously irrelevant...