Impedance considerations for the design of the triplet/D1 beamscreen

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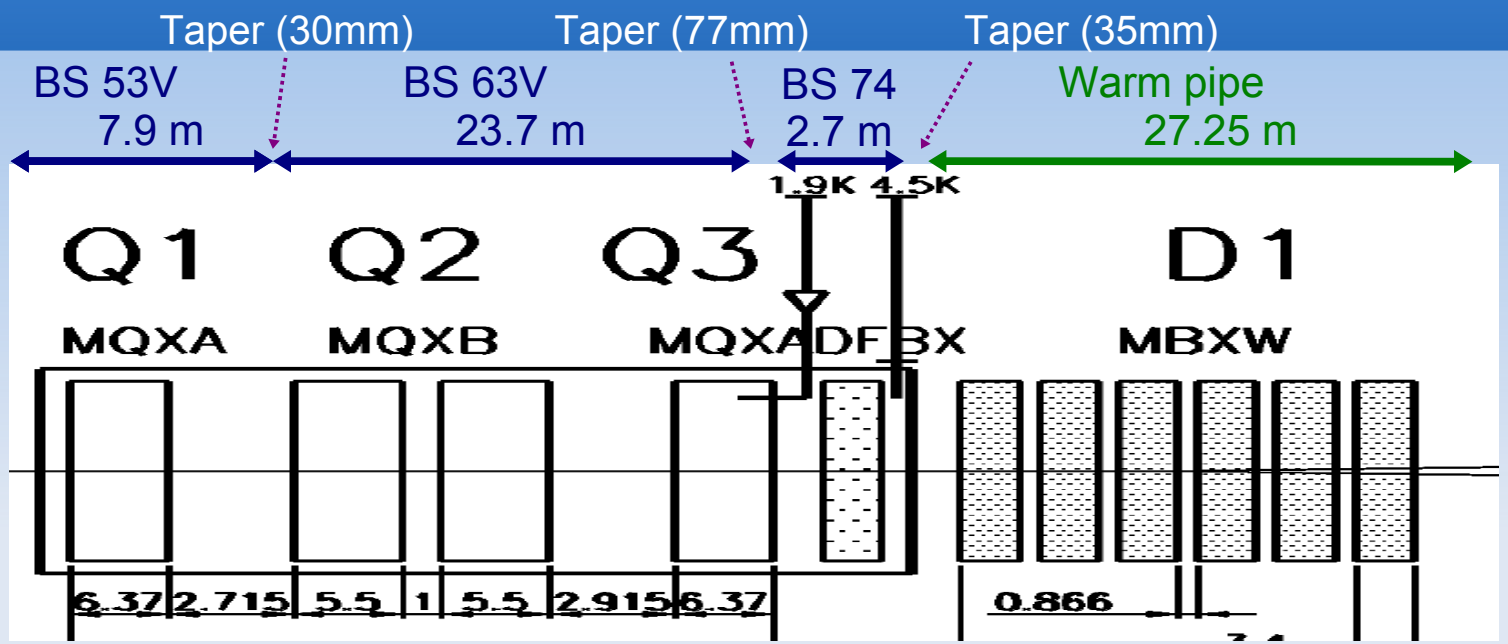
Acknowledgements: G. Arduini, C. Boccard, G. Bregliozzi, D. Draskovic, L. Esposito, S. Fartoukh, C. Garion, G. Iadarola, R. Jones, R. Kersevan, T. Lefevre, N. Kos, A. Mostacci, A. Nosich, G. Rumolo, M. Taborelli and E. Todesco

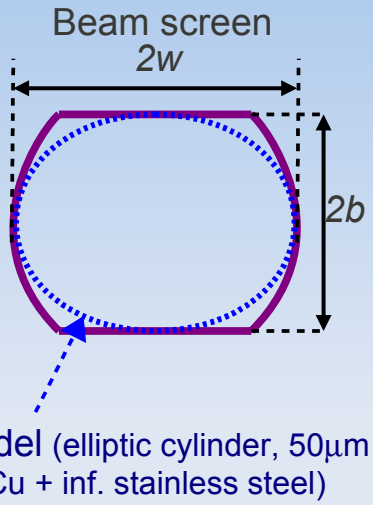
HL LHC: impedance considerations for the new beam screens in IR1 & 5

- Reminder on current and HL-LHC final triplet layout and beam screen geometry
- Power loss estimates
- Update on beam screen contribution on total impedance budget

HL LHC triplet layout (IR1 & 5)

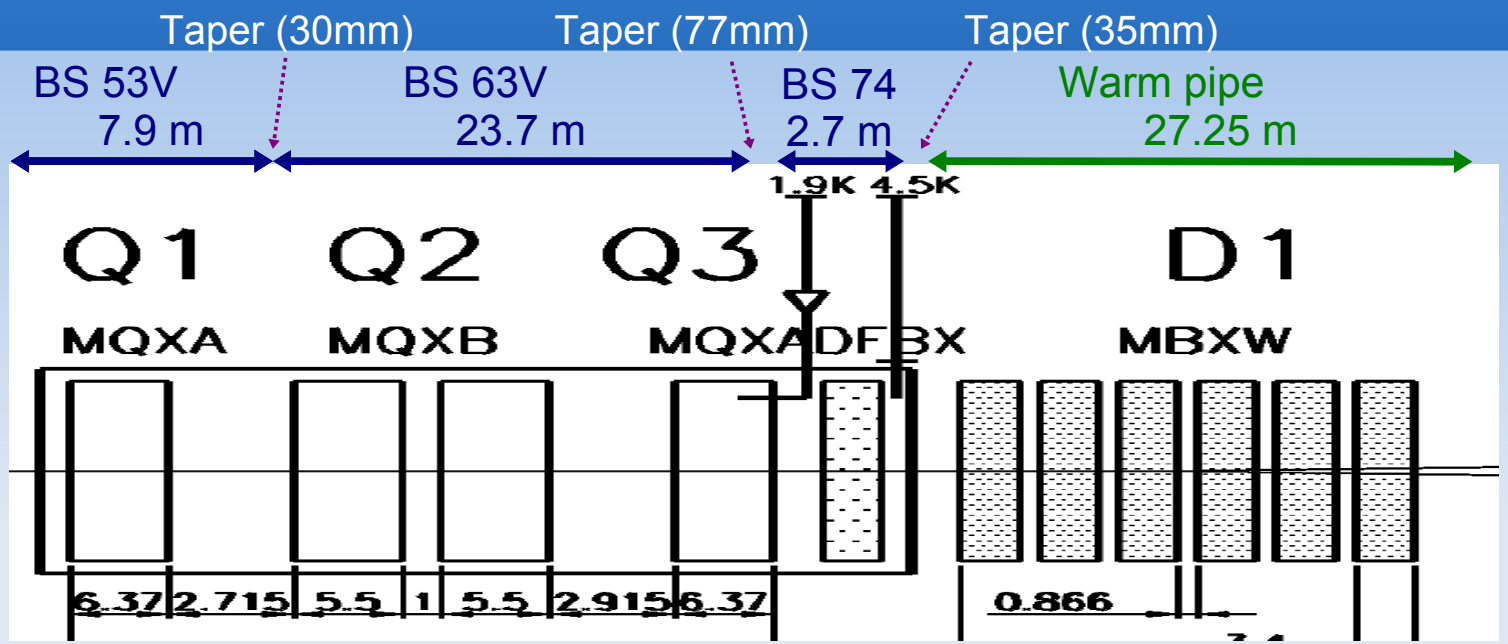
Old

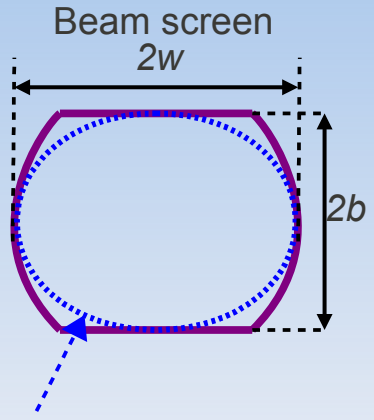




HL LHC triplet layout (IR1 & 5)

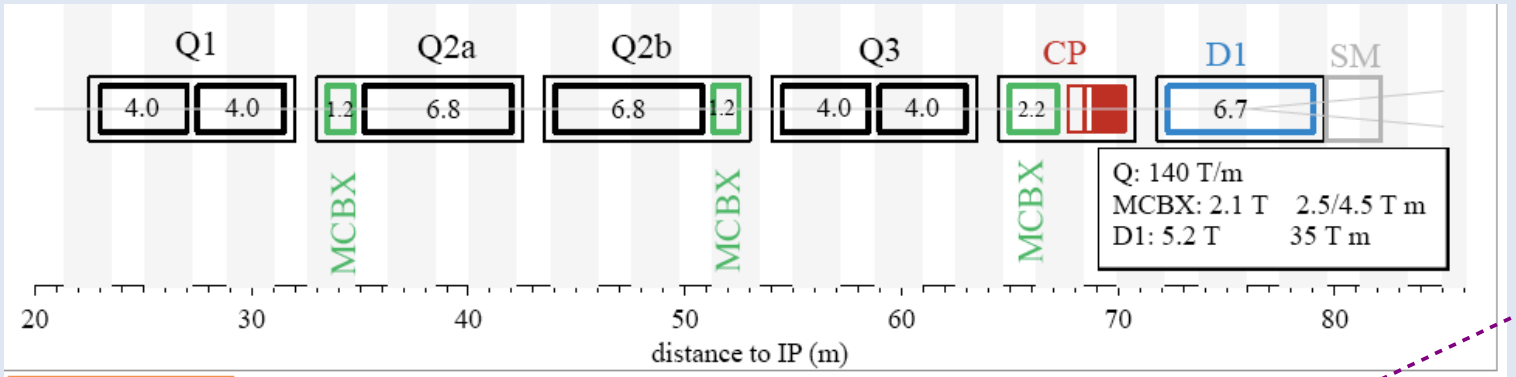
Old





Model (elliptic cylinder, 50µm Cu + inf. stainless steel)

New



E. Todesco

New BS, 9.5m, r =50.5mm

Taper

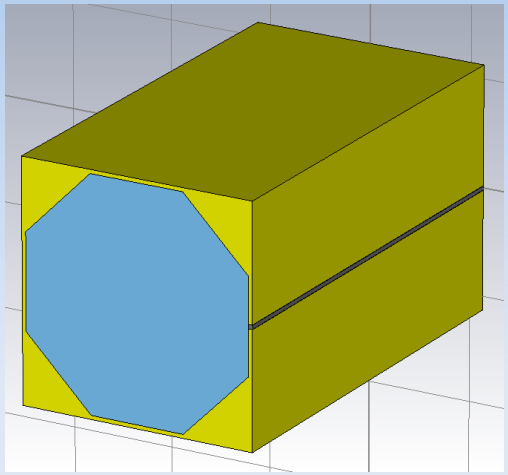
New BS, r =60.5mm

Model: s. steel cylinder
- with 0.5µm amorphous carbon "aC" ($\rho=10^{-2}$ Ω.m – M. Taborelli) and 50µm Cu.

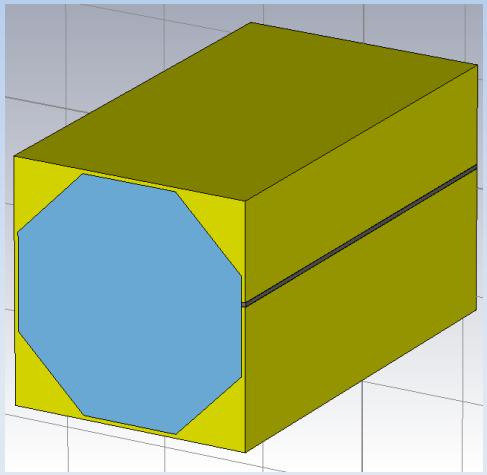
Resistive-wall impedance of new beam screens: impact of the weld

- 3 different positions tested, with either 1mm or 2mm height (CST):

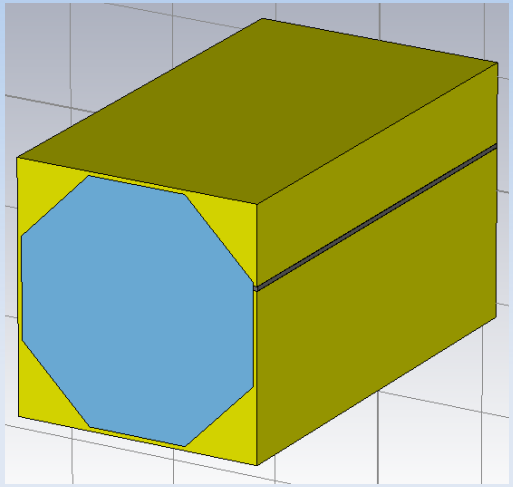
Pos. 1

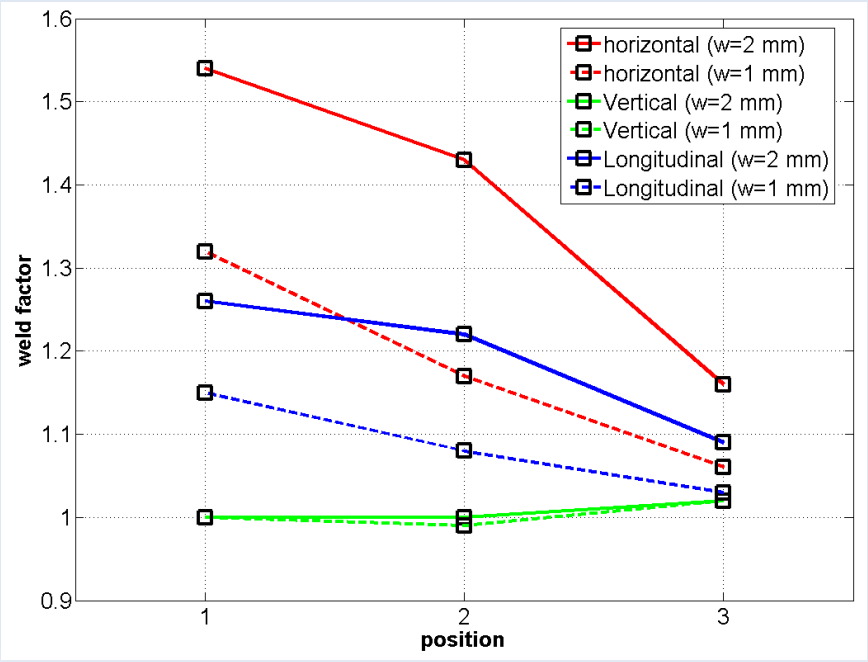


Pos. 2



Pos. 3





C. Zannini

Resistive-wall impedance of new beam screens: impact of the weld

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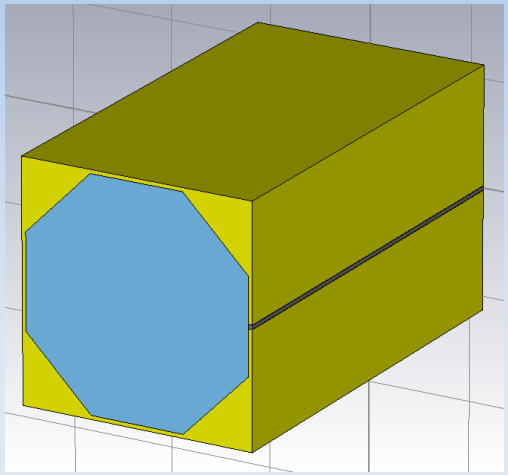
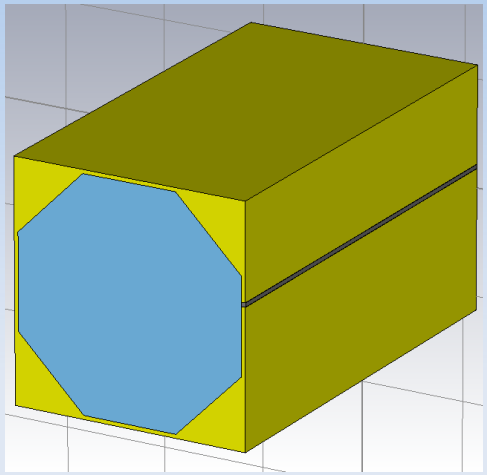
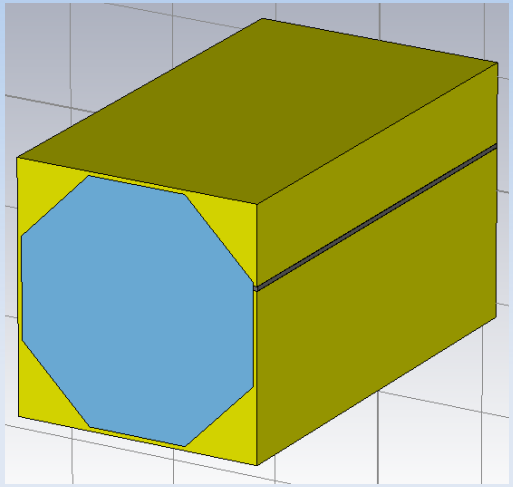
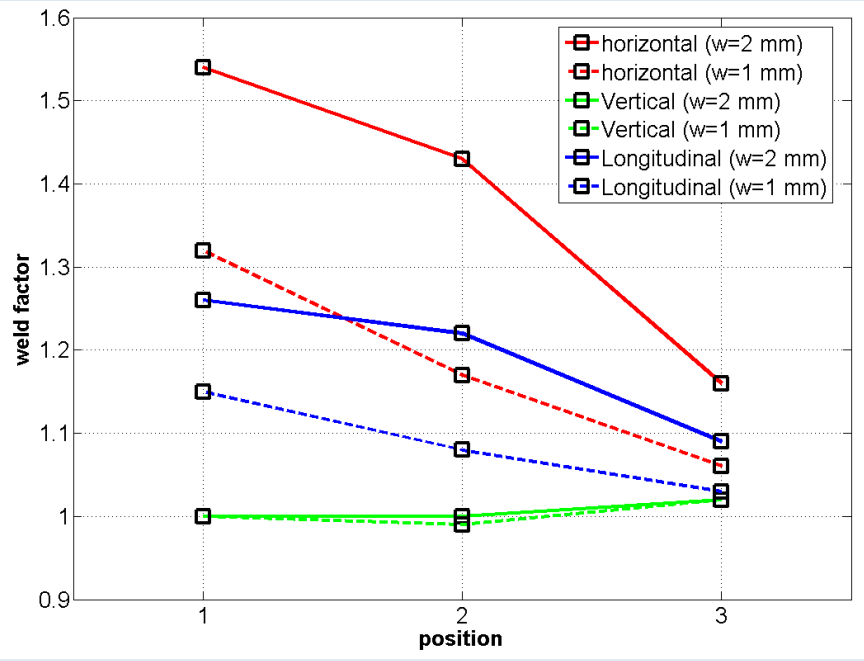


Pos. 2

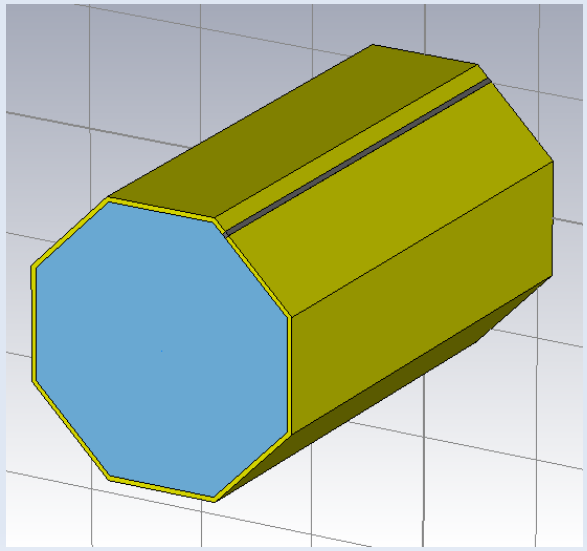


Pos. 3





Finally, baseline close to pos. 3 (2mm) (but in another corner):



⇒ Relatively small impact of the weld.

C. Zannini

Resistive-wall power loss in the triplets

- HL-LHC triplets beam screens resistive-wall power loss (gaussian bunches) of each kind of device in the triplets, including BS weld factor:

IR2 & 8 (HL-LHC parameters - worst case): 7 TeV, N_b= 3.5 10^{11}, M=2*1404 bunches, σ_z=7.5cm

BS type	BS 53	BS 63	BS 74
b [mm]	20.2	25.2	30.5
P_{loss}/L [W/m]	1.2	1.0	0.8

IR1 & 5 (HL-LHC parameters - worst case), with 2mm weld in a corner:

BS type	small, aC + Cu coating	large, aC + Cu coating
b [mm]	50.5	60.5
P_{loss}/L [W/m]	0.37	0.31

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Note: these assume no interferences between the 2 beams EM fields. Effect of these can be evaluated (see studies by G. Rumolo, G. Iadarola, C. Zannini); this was done for the current beam screens, where it tends to decrease the final power loss.

Power loss due to pumping holes

- Thanks to A. Mostacci mathematica notebook, PhD thesis and help:
  - power loss due the TEM (coaxial) wave propagating between beam screen & cold bore,
  - pessimistic approach adopted: assume holes are uniformly distributed (actually they are random in size and position), and all area outside BS is filled with TEM wave,

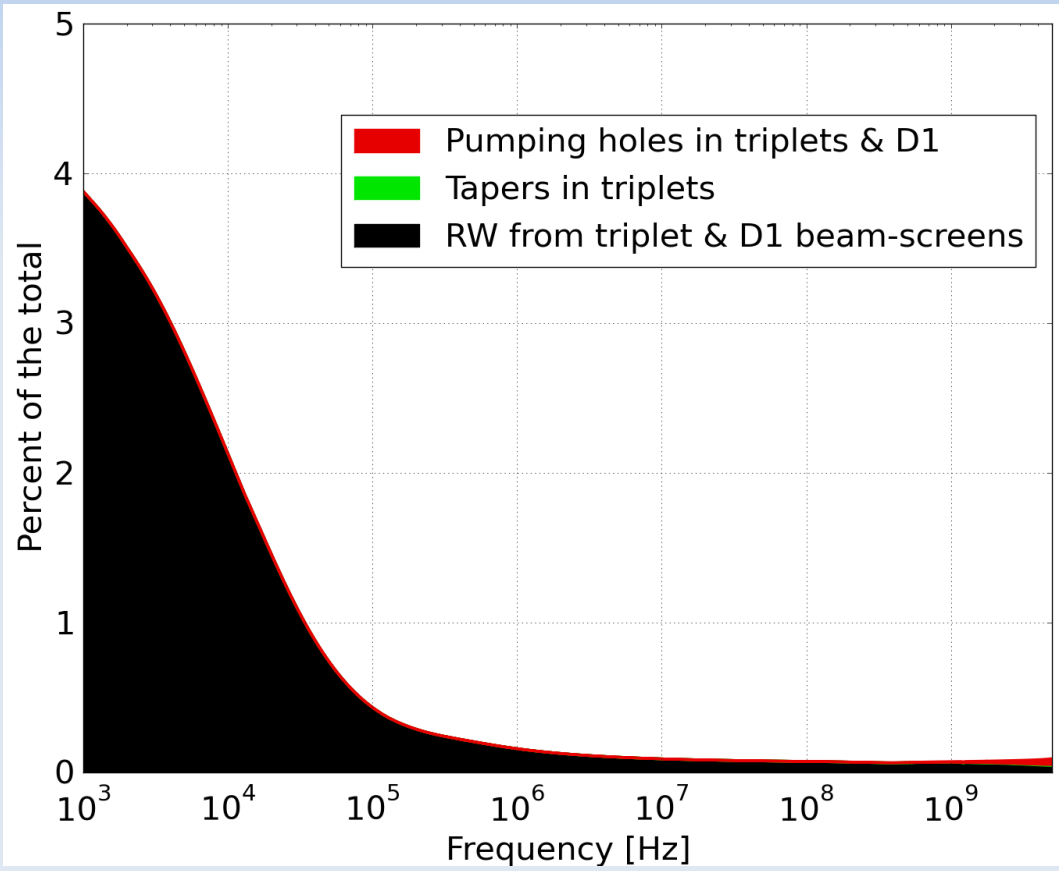
$\Rightarrow$ result: power loss (per unit length) is negligible compared to the resistive-wall power loss: less than 0.1 mW/m both for LHC and HL-LHC, taking a small beam screen thickness for HL-LHC (0.5mm)

$\Rightarrow$ even smaller in new BS with larger stainless steel thickness (1 mm).

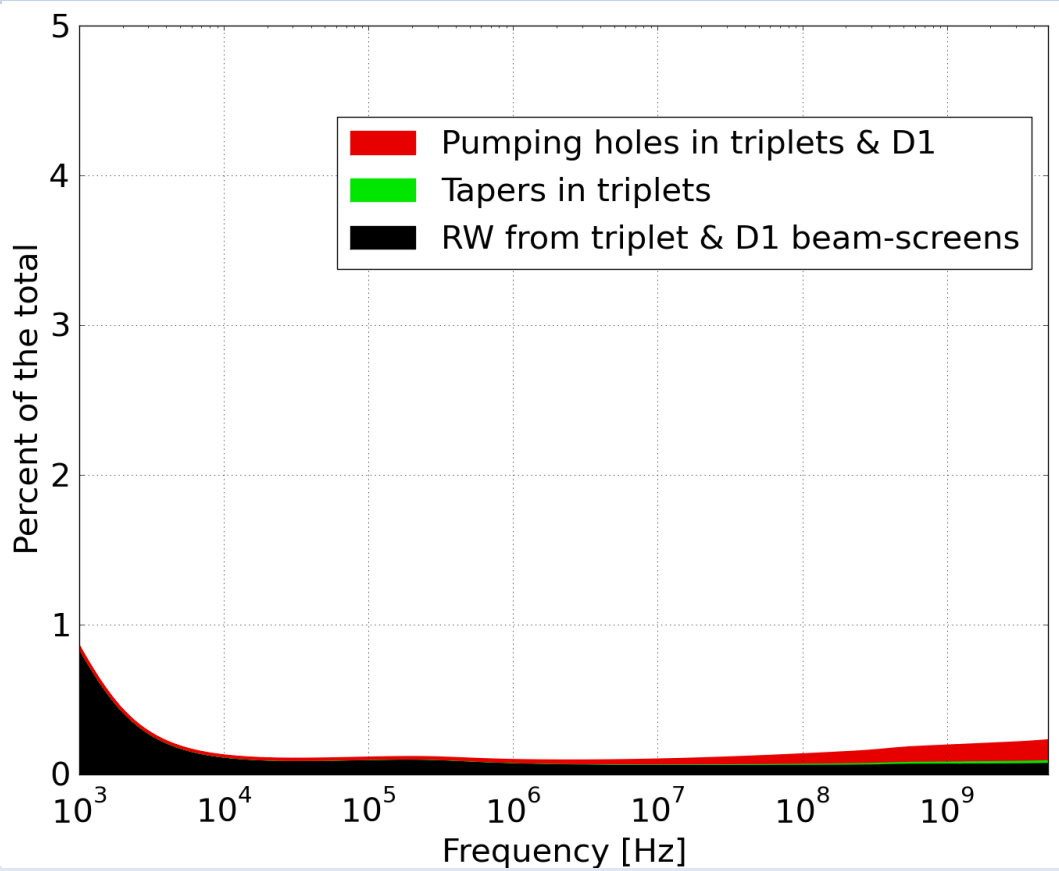
Contribution from the beam screens (and tapers) to the total HL-LHC impedance

- Horizontal dipolar impedance (case of round 15cm optics, 50μm Cu, 15° angle tapers, holes surface coverage between 2.5% and 3%)

Real part



Imag. part

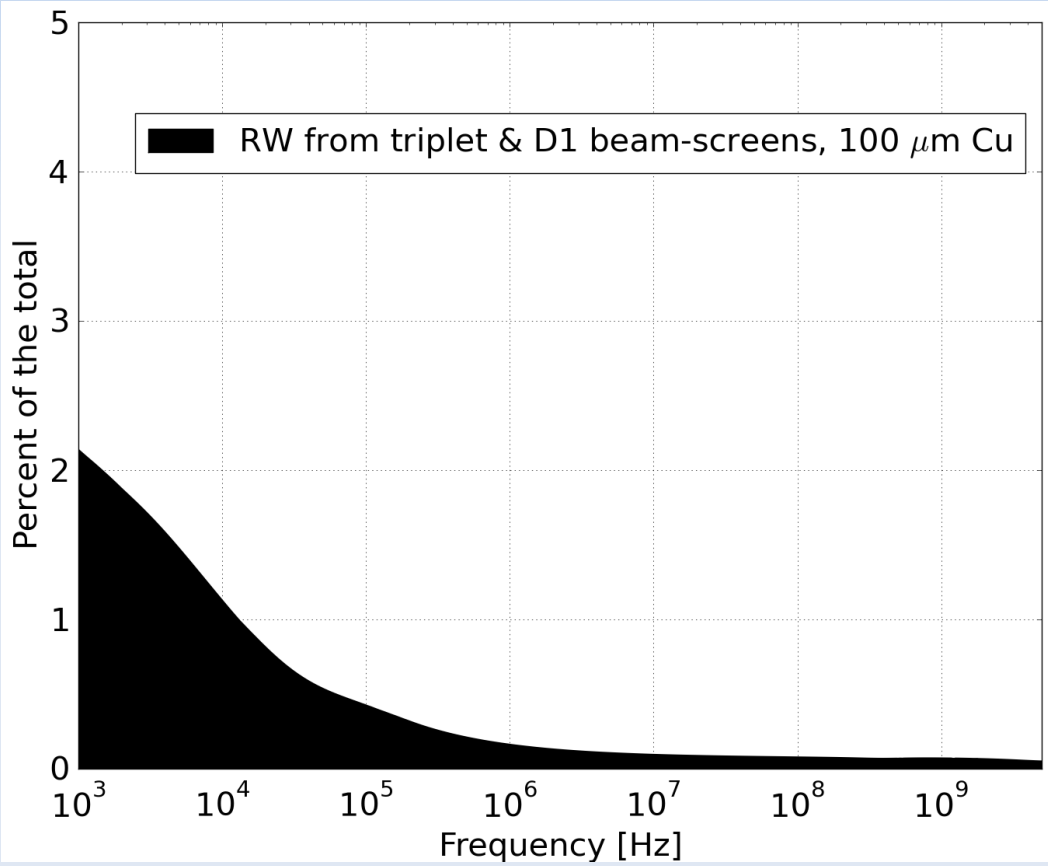


→ very small contribution from triplets at high frequency, up to 3% at first unstable betatron line (8 kHz) (same in vertical and longitudinal – see backup slides),
→ pumping holes & tapers give a negligible contribution.

Can we make it better / worse ?

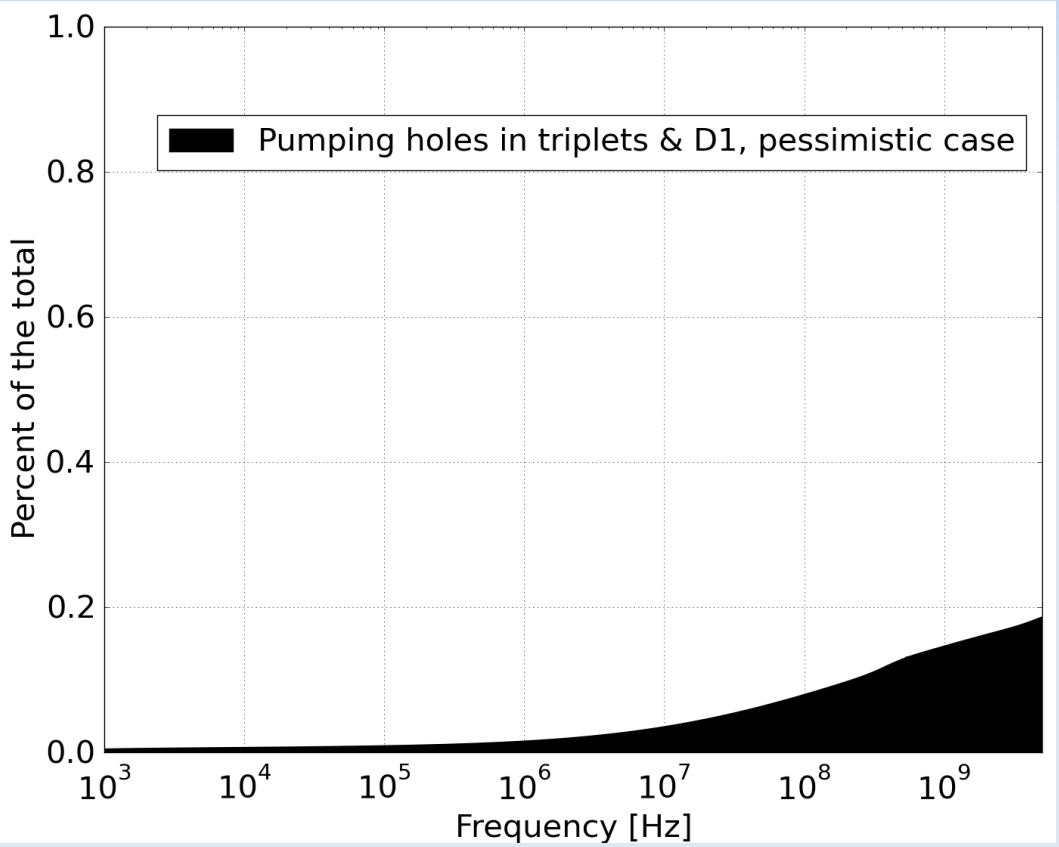
- Contribution in percent to total model (horizontal dipolar imp.)

Resistive-wall with more copper (real part of imp.)



→ Low freq. RW impedance can be decreased to ~1% of total model at 8 kHz.

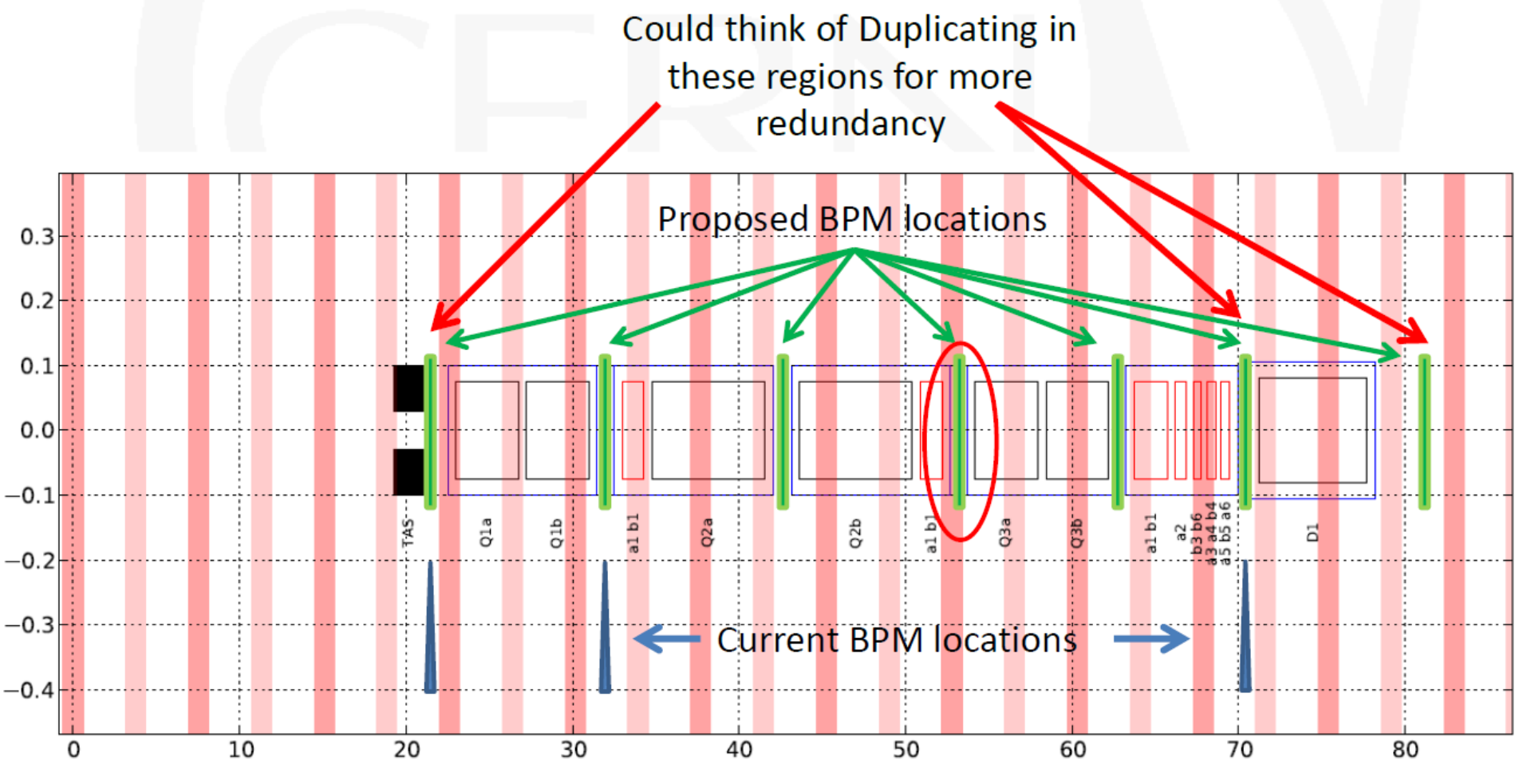
Pumping holes with more surface coverage (4%) (imag. part of imp.)



→ Even if pumping holes coverage is increased to 4%, contribution is marginal.

A word about BPMs in triplets

- From R. Jones, HL-LHC PLC meeting (18/01/2013):



Many more stripline BPMs than in LHC triplets & much higher β functions → transverse impedance has to be looked at carefully (ongoing collaboration on BPM design with T. Lefevre – D. Draskovic).

Conclusions

- Beam screens from the triplets contribute little to the total HL-LHC impedance budget (less than 3% at worst).
- Main (by far) contribution is resistive-wall. At constant aperture & β^*, it can be decreased to ~1% by adding more Cu.
- Pumping holes contribution is very small (0.2% at most), even in worst case scenario of 4% surface coverage.

Backup slides

Geometric impedance of the tapers

- Broad-band (BB) impedance of taper evaluated with Yokoya's formula [CERN SL/90-88] for cylindrical geometry, valid under the contitions $b\theta/\sigma_z << 1$ and **either** $a/\sigma_z >> 1$ **or** $(b-a)/a << 1$:

$$Z^T = \frac{j Z_0 \theta}{\pi}\left(\frac{1}{a}-\frac{1}{b}\right), \quad \frac{Z^L}{n} = \frac{j \mu_0 \theta f_0}{2}(b-a)$$

with a the smallest radius, b the largest radius, θ the taper slope, σ_z the RMS bunch length and f_0 (~11.2 kHz) the revolution frequency.

Taper impedance is directly proportional to its angle.

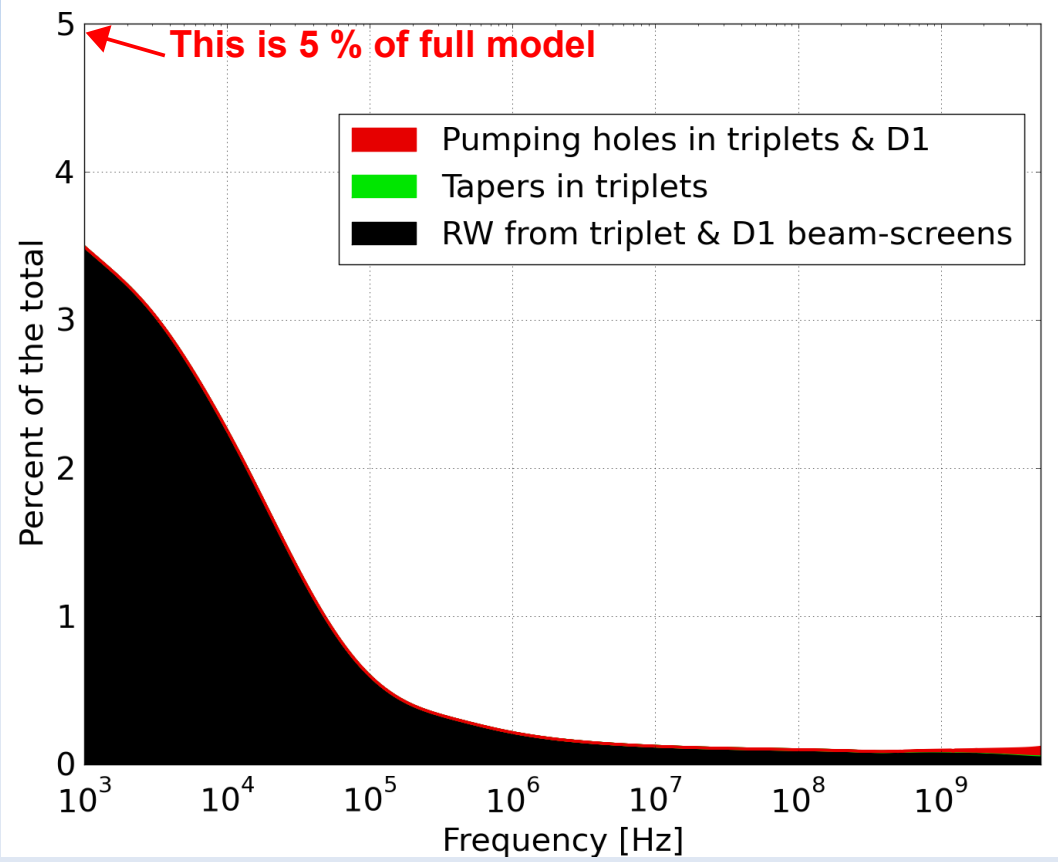
- New triplet BS: taper between Q1 and Q2, with standard angle (4 tapers on the whole):

Taper parameters	BSQ1 → BSQ2
a [mm]	50.5
b [mm]	60.5
Taper angle	15°
Im(Z^T) [Ω/m]	53
Im(Z^L/n) [μΩ]	19

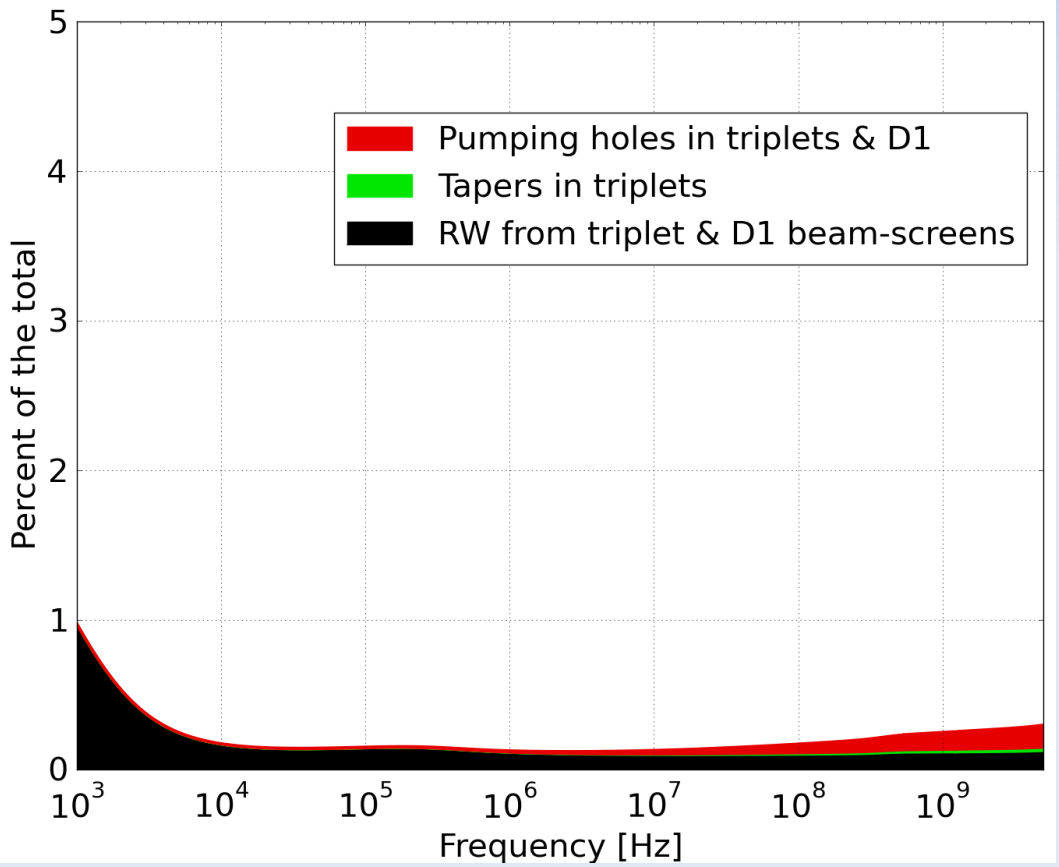
Contribution from the beam screens (and tapers) to the total HL-LHC impedance

- Vertical dipolar impedance (case of round 15cm optics, 50µm Cu, 15° angle tapers, holes surface coverage between 2.5% and 3%)

Real part



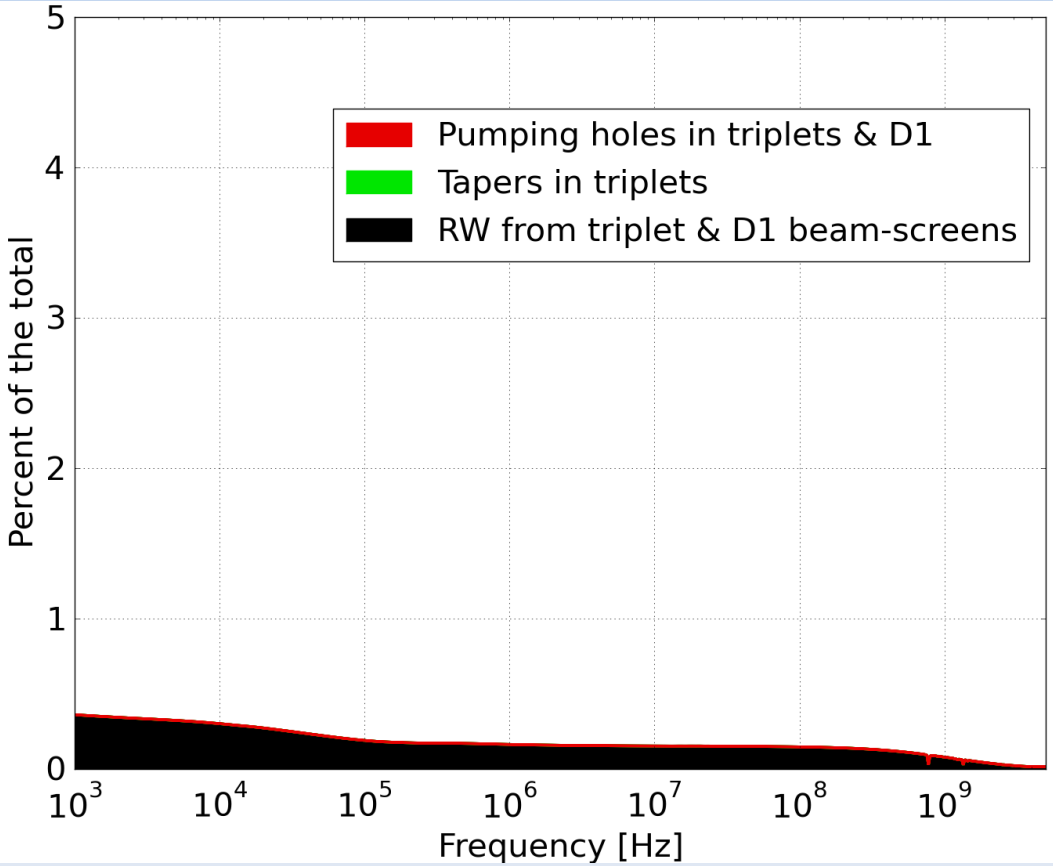
Imag. part



Contribution from the beam screens (and tapers) to the total HL-LHC impedance

- Longitudinal impedance

Real part



Imag. part