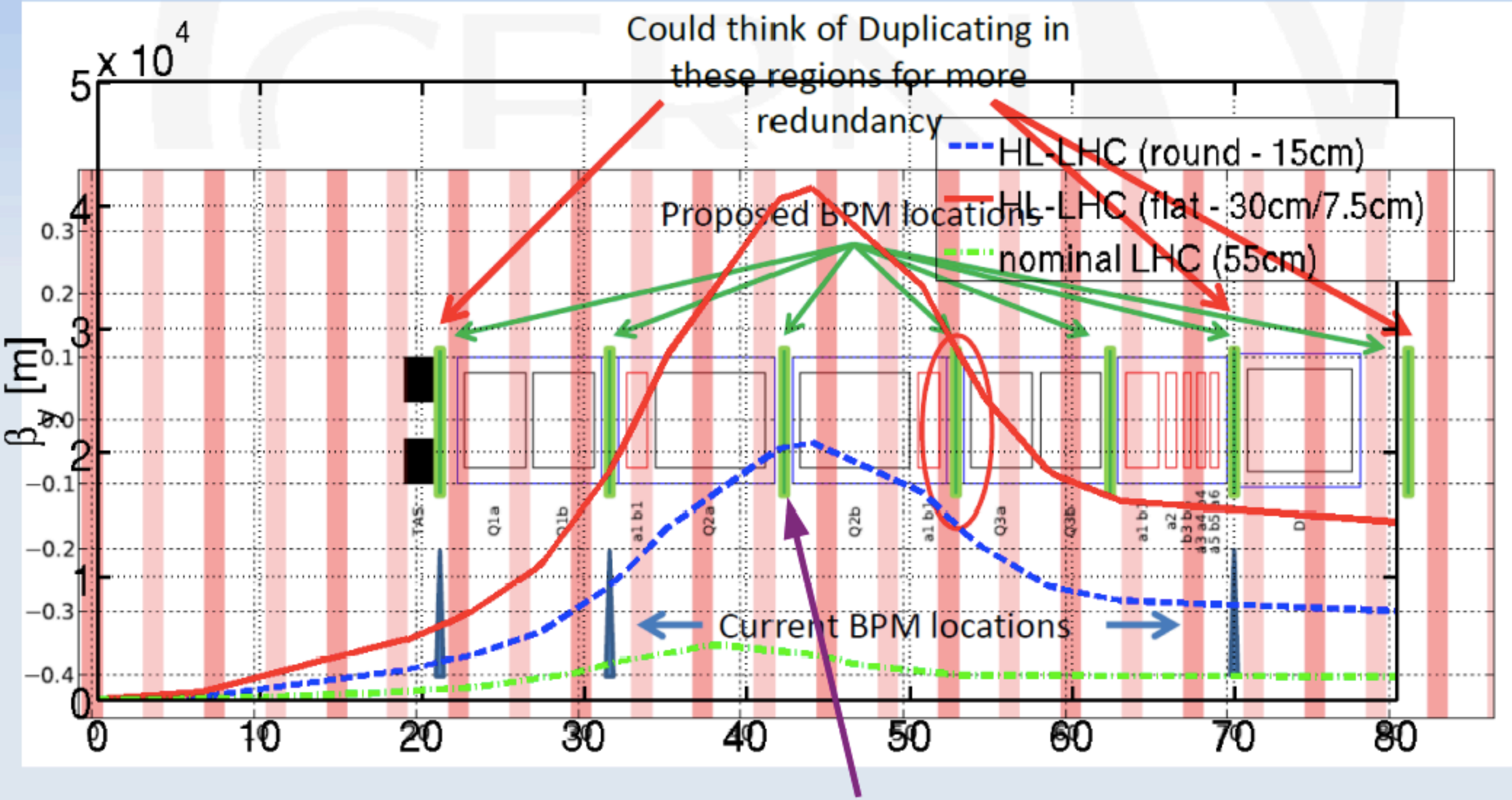
EXPECTED IMPEDANCE & HEAT LOAD OF THE PRESENT DESIGN OF THE HL-LHC BPMs

E. Métral, N. Mounet and B. Salvant

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

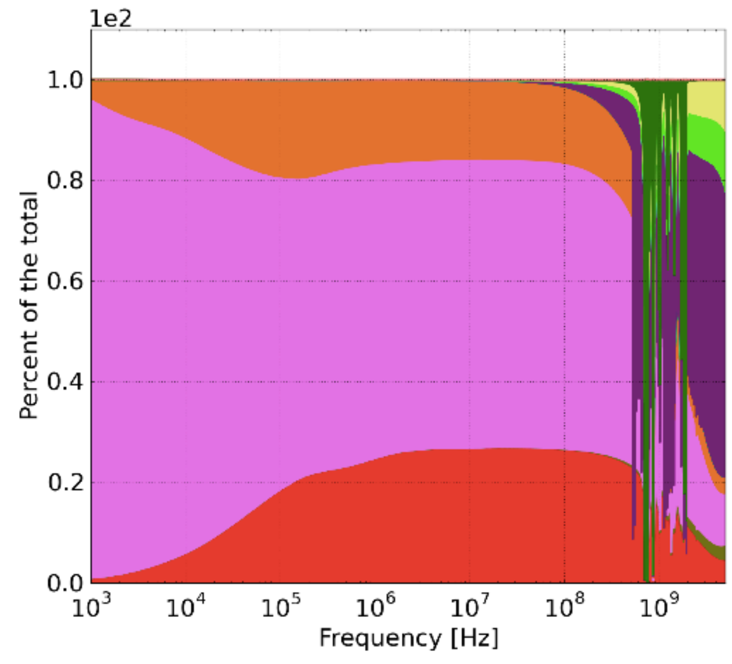


This one has the same effect as hundreds of BPMs with average beta functions.

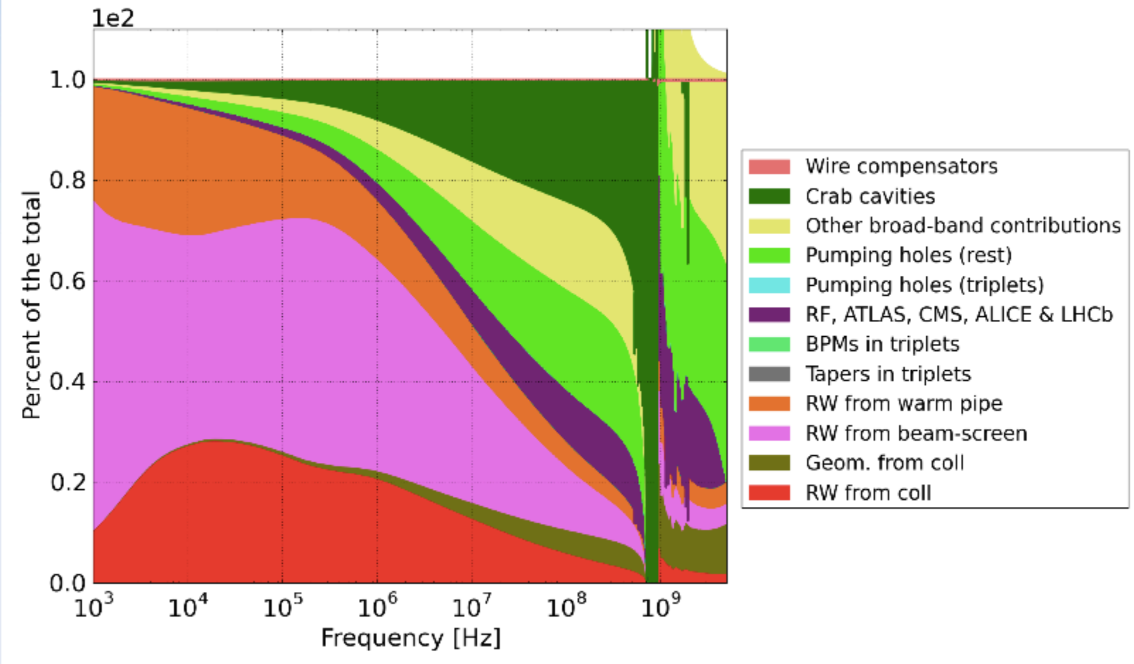
=> In total: 7 × 2 (2 sides of the IP) × 2 (2 IPs) = 28 BPMs

- Impedance contributions, with crab cav., longitudinal:

Real part

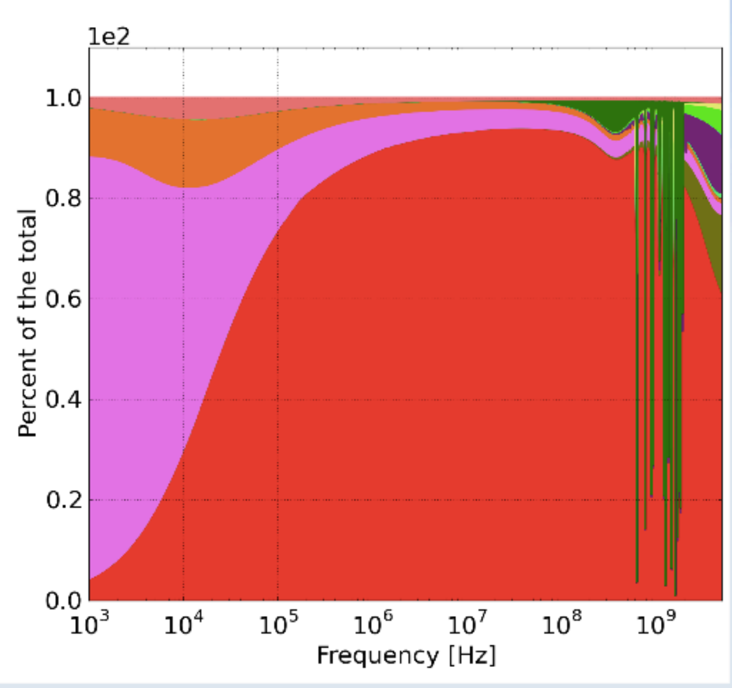


Imaginary part

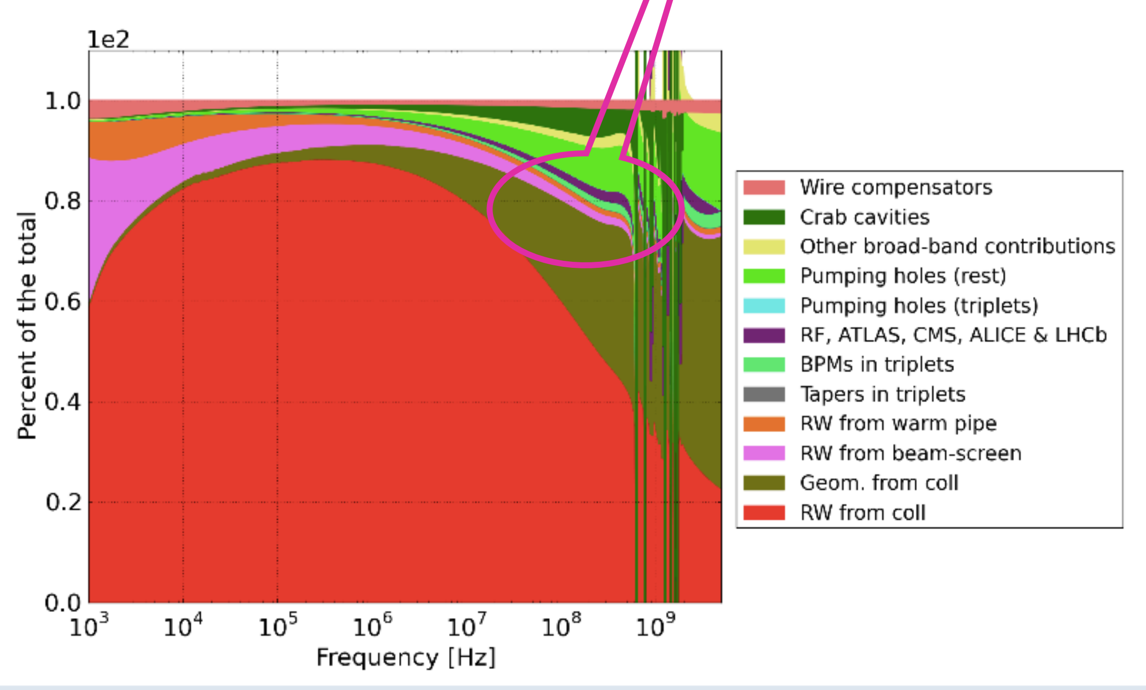


- Impedance contributions, with crab cav., horizontal dipolar:

Real part



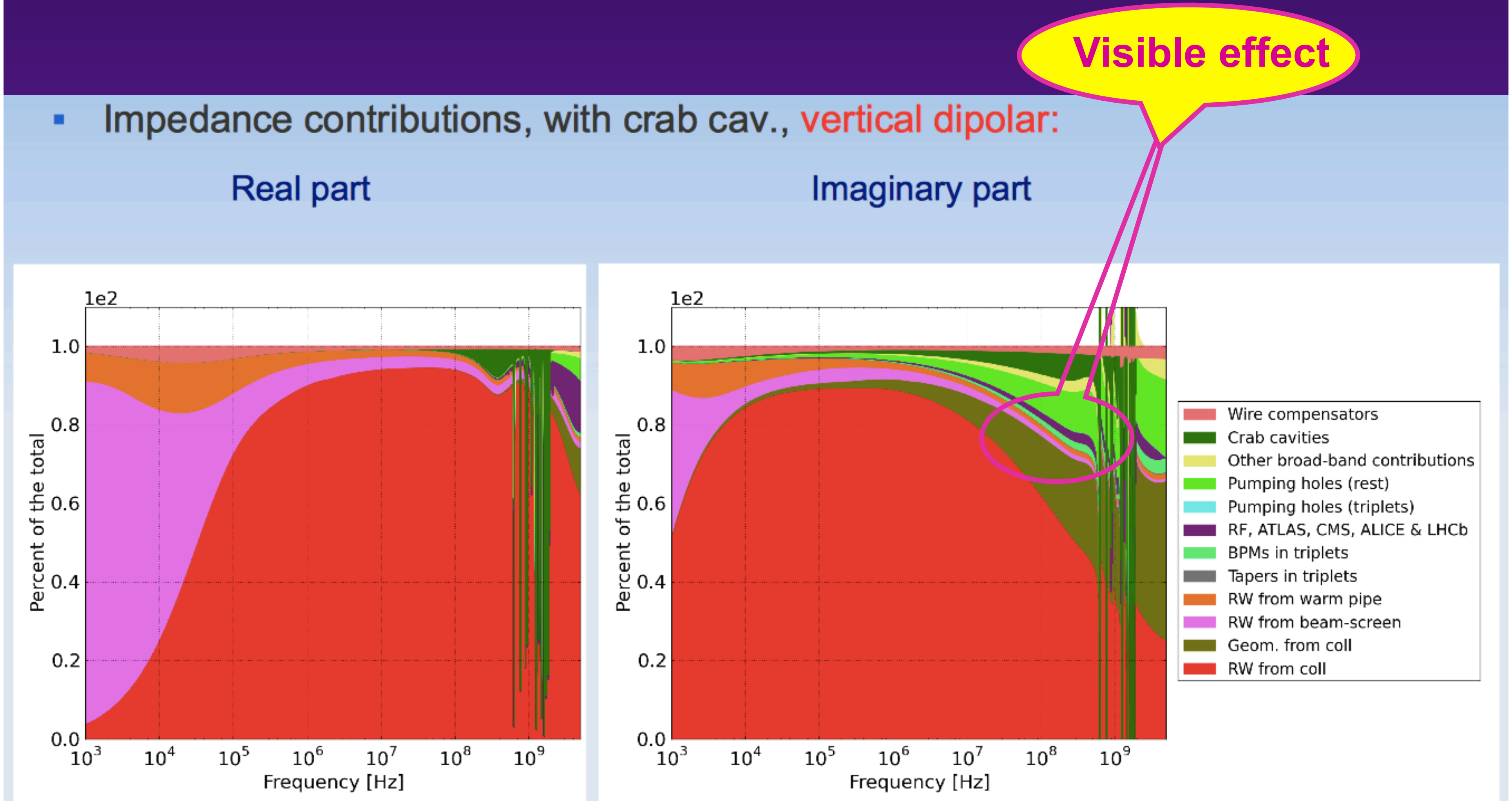
Imaginary part



- Impedance contributions, with crab cav., vertical dipolar:

Real part

Imaginary part



From LHD Design Report, Vol. 1, chapter 5

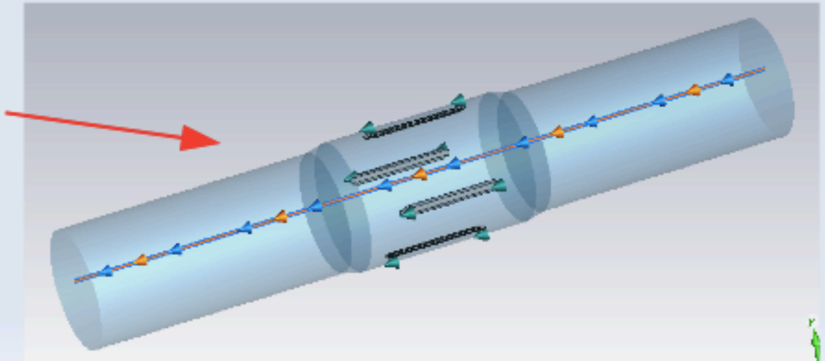
Table 5.4: LHC broad-band impedance budget. The first three columns report element name, latest relevant reference, and inner vertical aperture b in mm. The last two columns give the effective longitudinal and transverse impedance in the vertical plane, the latter being multiplied by $\beta/\langle\beta\rangle$, where $\langle\beta\rangle = 70\,\text{m}$.

element	Ref.	b	$\text{Im}(Z/n)$	$\text{Im}(Z_\perp)$
		mm	Ω	MΩ/m
Pumping slots	[23]	18	0.017	0.5
BPM's	[24]	25	0.0021	0.3
Unshielded bellows		25	0.0046	0.06
Shielded bellows		20	0.010	0.265
Vacuum valves		40	0.005	0.035
Experimental chambers		-	0.010	-
RF Cavities (400 MHz)		150	0.010	(0.011)
RF Cavities (200 MHz)		50	0.015	(0.155)
Y-chambers (8)	[25]	-	0.001	-
BI (non-BPM instruments)		40	0.001	0.012
space charge @injection	[2]	18	-0.006	0.02
Collimators @injection optics		$4.4 \div 8$	0.0005	0.15
Collimators @squeezed optics		$1.3 \div 3.8$	0.0005	1.5
TOTAL broad-band @injection optics			0.070	1.34
TOTAL broad-band @squeezed optics			0.076	2.67

For the BPM's a 0.5 mm slit between electrode and body is assumed. The 'monitor' inductance per electrode is 4 pH, the 'slit' inductance 9 pH, and the 'cavity' inductance 4 pH, giving a total of about 60 pH or $Z/n = j\,4.2\,\mu\Omega$/monitor. 500 monitors including some overhead for special and warm BPM's are considered.

BPMs: geometric impedance

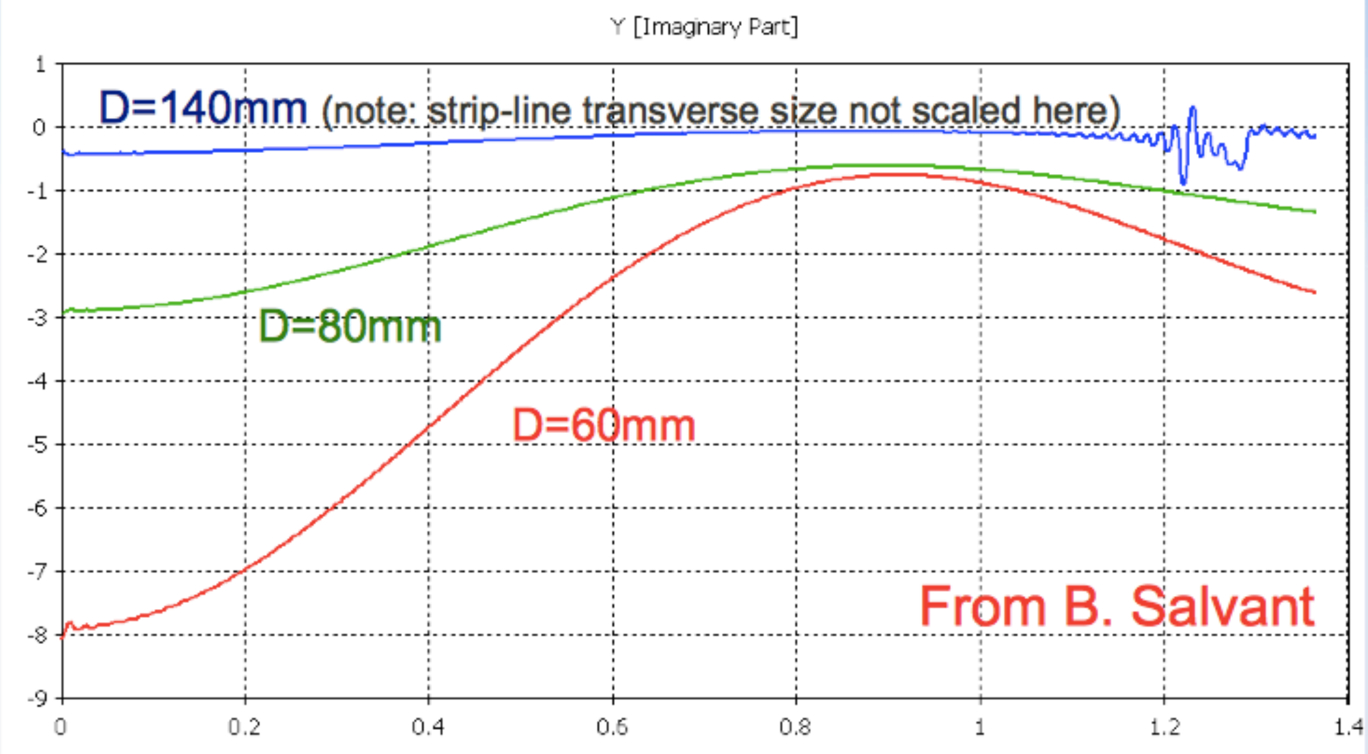
- All stripline BPMs (*l*=0.12m for the strip length), except one combined BPM (buttons / stripline) in front of Q1.
- Diameter *D* between electrodes:
  - *D*=60mm for the current ones (except the one at 70m from the IP → 80mm),
  - *D*=140mm for the HL-LHC ones (scaling by the same factor the transverse dimension of the strip-lines).
- Two approaches:
  - analytic formula for stripline BPM by K. Y. Ng [Handbook of Acc. Phys. & Eng., Sec. 3.2] + values obtained for button BPM by B. Spataro [LHC Project Note 284],
  - CST simulations made by B. Salvant



→ agreement within a factor ~2.

- Evaluated as a broad-band model → pessimistic: stripline BPM impedance actually decreases above a few hundreds of MHz:

Z_y^{dip} [Ω] (with beam offset of 10mm)



Note: with tungsten shielding inserts, geometric impedance seems to decrease (to be confirmed).

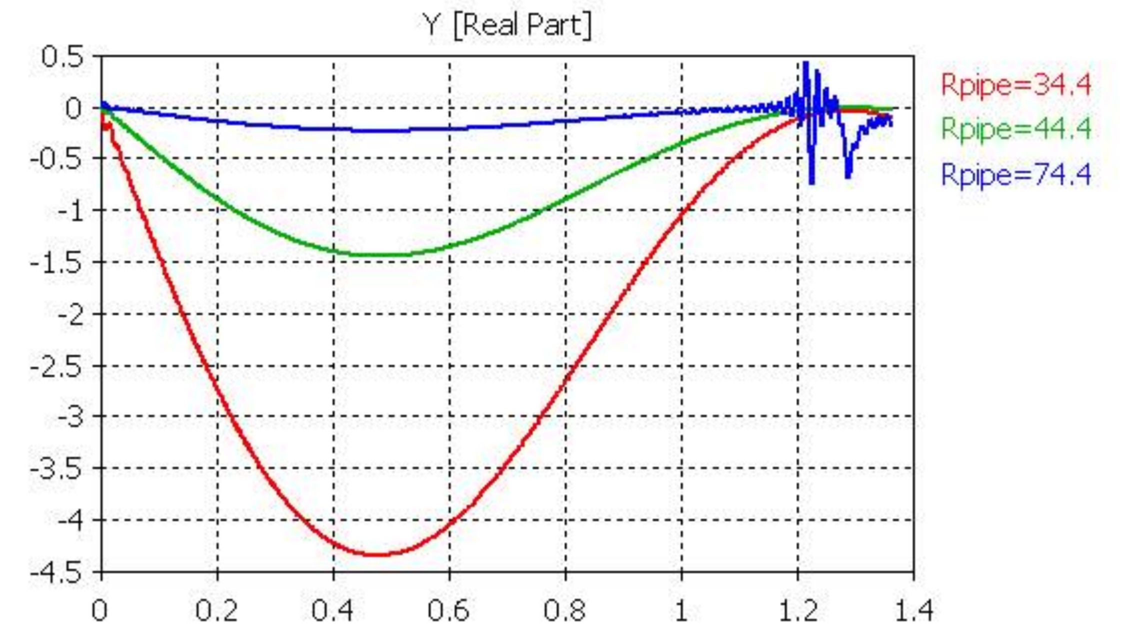
→ Final broad-band impedances (including buttons before Q1): better with HL-LHC (due to higher radius)

BPM type	Current combined (before Q1)	Current (after Q1)	Current (after Q3)	New combined (before Q1)	New (after Q1)
D [mm]	60	60	80	140	140
$Im(Z^T)$ [Ω/m]	880	800	300	130	100

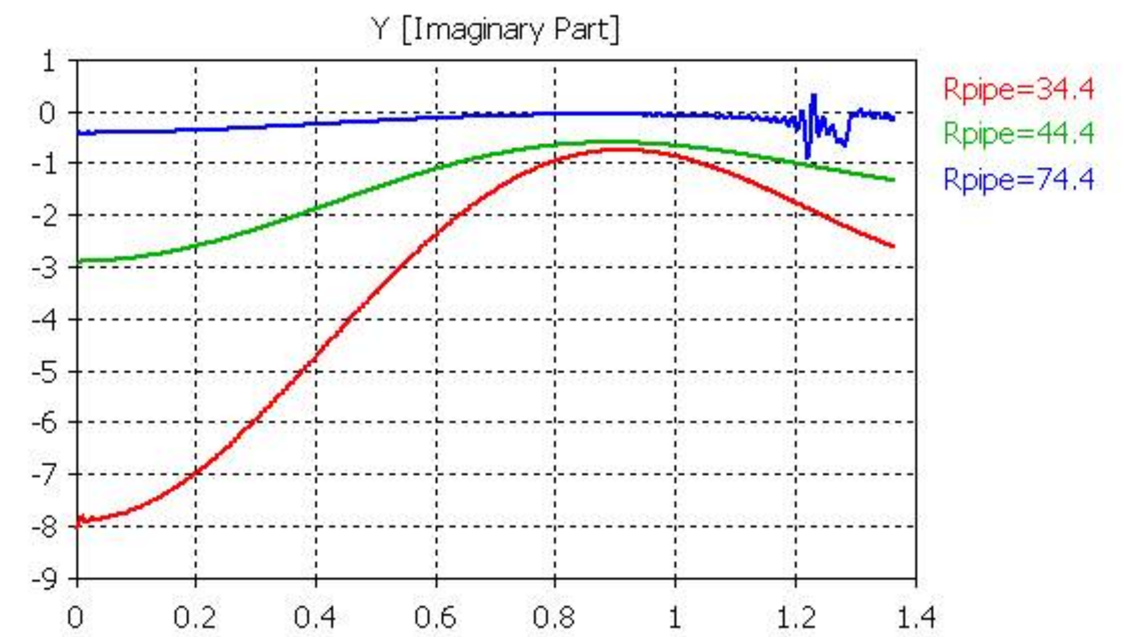
◆ **Transverse impedance**

(in Ω / 10 mm displacement

=> i.e. in 100 Ω / m)

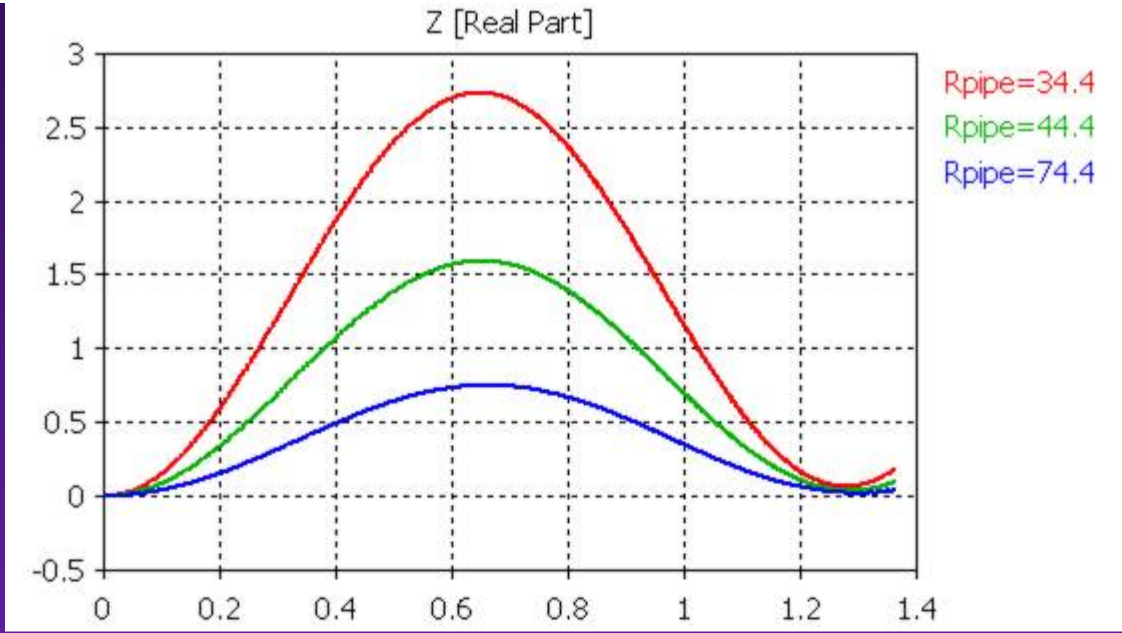


***f* [GHz]**

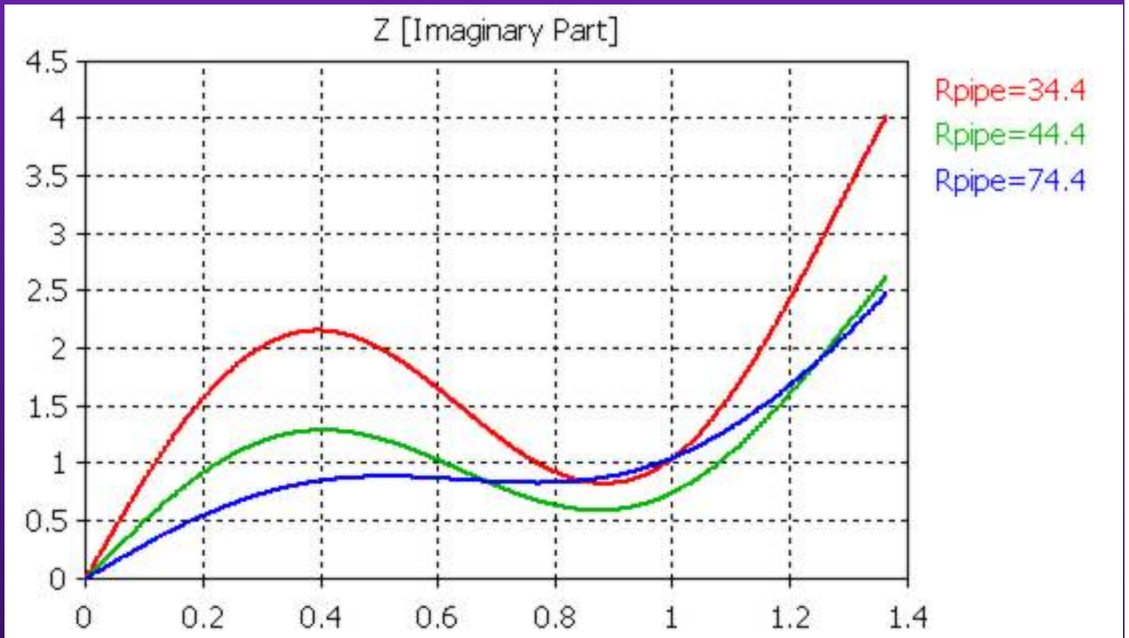


***f* [GHz]**

◆ **Longitudinal impedance (in Ω)**



***f* [GHz]**



***f* [GHz]**

◆ Beam-induced RF heating (from the geometric part)

Power loss in W	Nominal 25 ns (2808*1.15, 1 ns, 7 TeV)	Before LS1 50 ns (1374*1.6e11 @1.25 ns, 4 TeV)	HL-LHC 25 ns (2808*2.2)	HL-LHC 50 ns (1404*3.5e11)
Stripline (63 mm)	15	10	55	70

=> Most of this heat load should go into the coax ports.
Is it a problem?

◆ Beam-induced RF heating (from the "resistive-wall" part)

$$P_{loss/m}^{G,RW,1beam} = \frac{1}{2\pi R}\,\Gamma\left(\frac{3}{4}\right)\frac{M}{b}\left(\frac{N_b\, e}{2\,\pi}\right)^2 \sqrt{\frac{c\,\rho\, Z_0}{2}}\;\sigma_t^{-3/2} \approx 0.12\ \mathrm{W/m}$$

$$\text{LHC circumference} = L = 2\,\pi\, R = 26658.883\ \mathrm{m}$$

$$\sigma_t = 0.25\ \mathrm{ns}$$

$$\rho_{Cu}^{20K,7TeV} = 7.7\times 10^{-10}\ \Omega\mathrm{m}$$

There is Cu coating for the current BPMs => Important to have Cu coating for HL-LHC. What will be the temperature?

$$\Gamma\left(\frac{3}{4}\right) = 1.23$$

$$M = 1404$$

$$N_b = 3.5\times 10^{11}\ \mathrm{p/b}$$

$$b = 70\ \mathrm{mm}$$