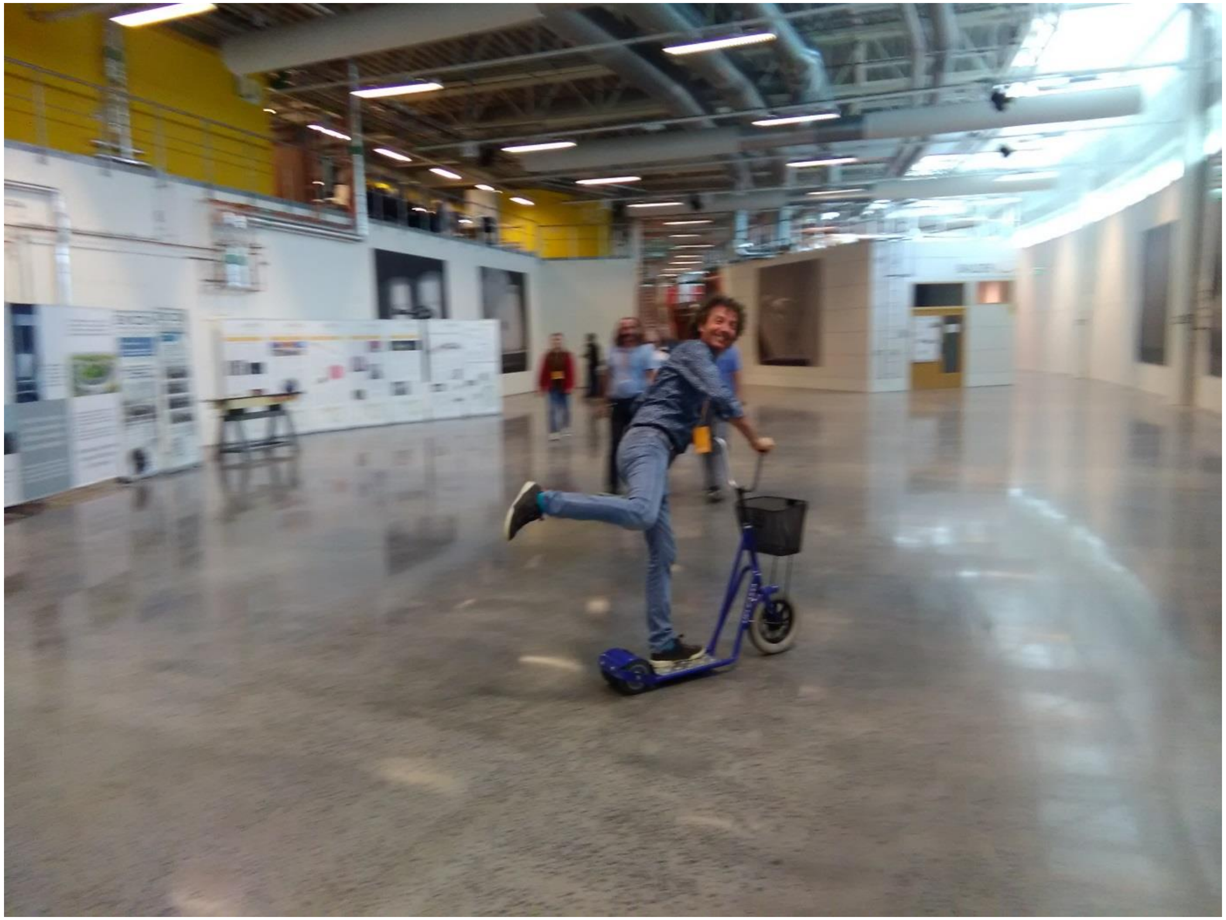
Recommendation from impedance

B. Salvant

on behalf of BE-ABP/HSC section and impedance WG

With the help of Vincent Baglin



Summary of guidelines
(extracted from vacuum CAS 2017)

- The impact of the in-vacuum elements on the beam strongly depends on bunch length

- To reduce resistive wall impedance
  - higher conductivity ($Z \sim \sqrt{\sigma}$)
  - higher radius ($Z \sim 1/b$ or $1/b^3$)
  - lower length ($Z \sim L$)
  - use coating with good conductor
  - Thickness of bad conducting material on good conducting material has a much stronger impact on impedance than the conductivity of the coating

- Bellows:
  - no power loss if perfect conducting and no resonance excited
  - Z linear with number of convolution and convolution depth
  - Z linear with $1/b$ or $1/b^3$ if convolution is much smaller than radius b

- Cavities:
  - higher cavity radius → lower frequency
  - Cavity length should avoid the order of magnitude of the radius if possible
  - Tapering helps reducing the impedance
  - Shielding with fingers or beam screen is very efficient, but beware of non conformities
  - Use funneling for fingers

Main topics

- Triplet bellows → already agreed at WP2 and TCC for deformable bellow
- VAX area → more unshielded bellows
- Specification for 2.5 mm transverse displacement in the LSS → need for deformable RF bridge?
- 5th axis abandoned? → good news for some bellows!
- Baseline: amorphous carbon coating on triplets, corrector package, D1, D2 and Q4 (and maybe TAXS?) → already dealt with
- Is LESS an option? The impact there could be large due to the low conductivity (up to a factor 16 less compared to cold copper) and the large thickness (1 micron)
- More iterations needed

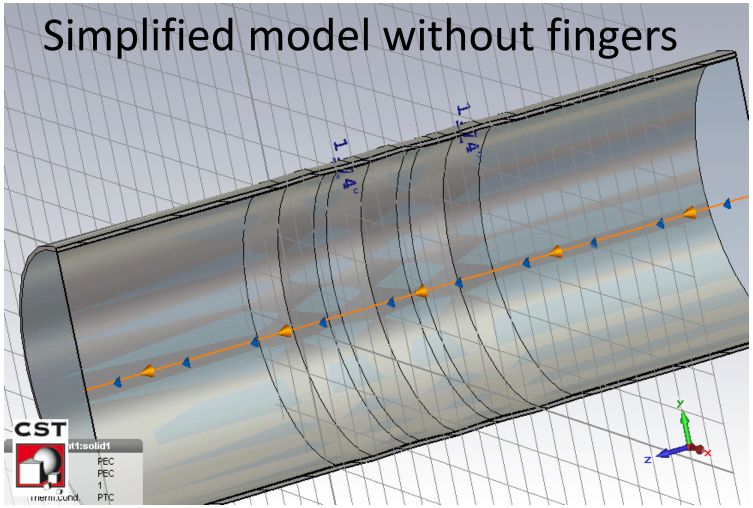
Triplet bellows

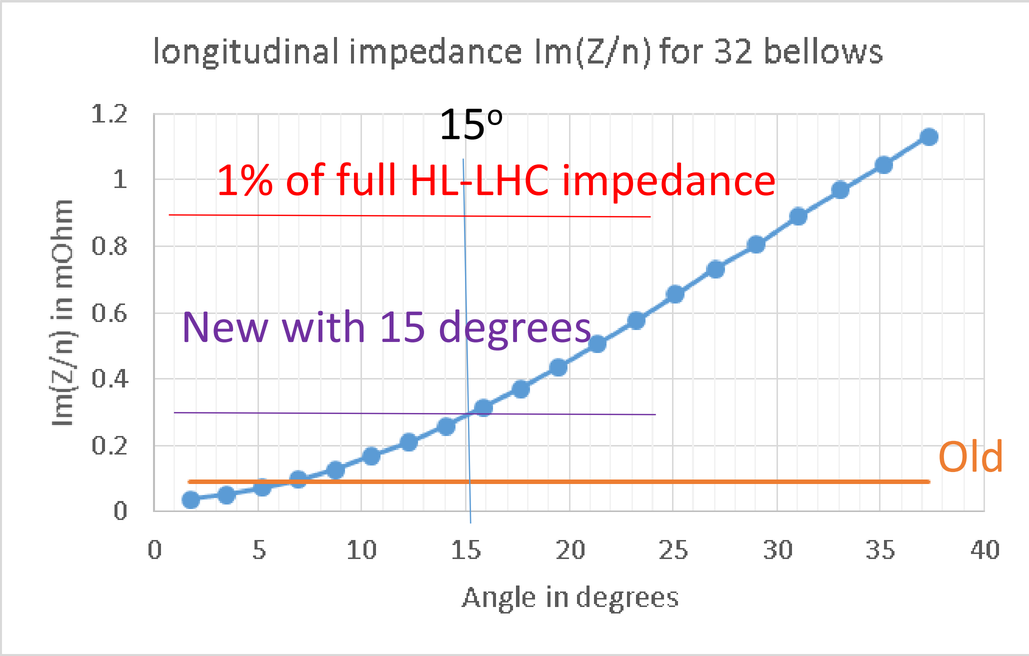
- Recommended for approval at TCC on Sept 2016

Conclusions from simulations with simple models so far

- Models are very simplified (in particular for the low frequency impedance) and results should be taken with care.
- The impedance contributions are significant, in particular in the transverse plane due to the large beta functions.
- These shielded bellows are representing ~ 5 m, i.e. ~0.02% of the full machine length
  → would represent ~1% of the full impedance of LHC.
  → not a great achievement for a device designed for impedance shielding!
- Increasing the angle makes impedance contributions worse and increase the risk of being wrong with the simplified simulations.
- Impact of transverse offset is not accounted for here.
- No identified showstopper so far.

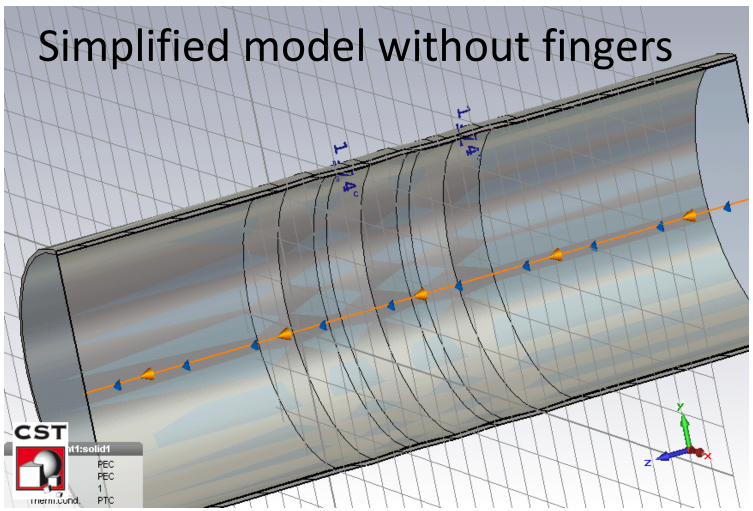
Longitudinal low frequency impedance

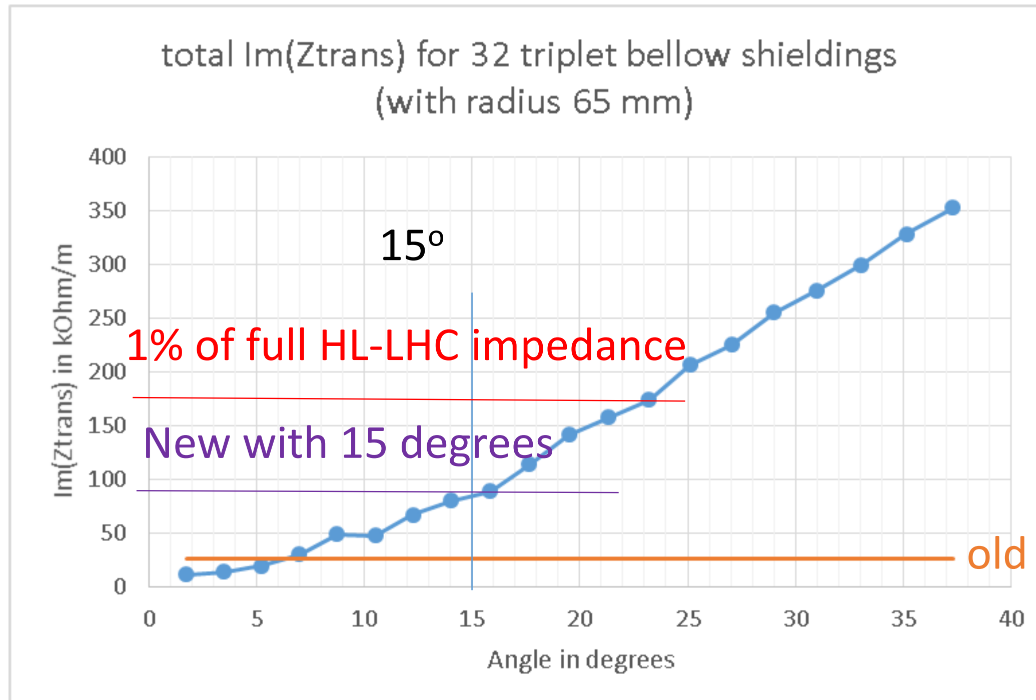




- → Assuming 32 shieldings with 65 mm radius
- → Large contribution compared to current shielding type (estimated a factor 3.5 increase)
- → Would amount to 0.3% of total impedance
- → Going to 30 degrees for all shieldings would reach 1% of full HL-LHC impedance

Transverse low frequency impedance





→ Assuming 32 shieldings with 65 mm radius at 12 km beta function
→ Large contribution compared to current shielding type (estimated a factor 3.5 increase)
→ Would amount to 0.5% of the total LHC impedance
→ Increase to 30 degrees reaches 1.5 % of the full HL-LHC impedance
→ Risk to increase beyond 15 degrees, in fact we already said it should be reduced.

Main topics

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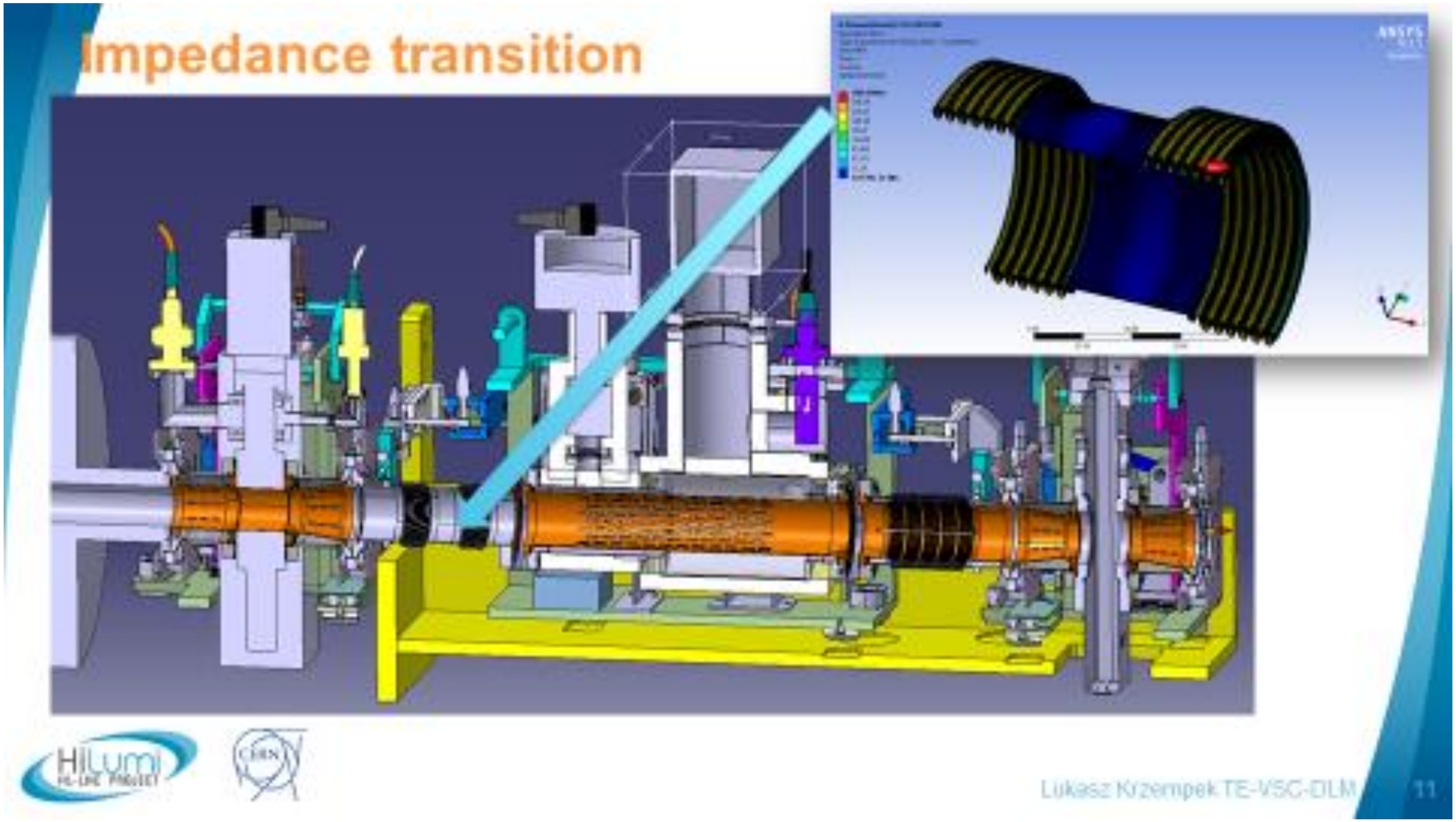
- 5th axis abandoned? → good news for some bellows!
- Baseline: amorphous carbon coating on triplets, corrector package, D1, D2 and Q4 (and maybe TAXS?) → already dealt with
- Is LESS an option? The impact there could be large due to the low conductivity (up to a factor 16 less compared to cold copper) and the large thickness (1 micron)
- More iterations needed

VAX area



Unshielded bellows requested
12 bellows in total (3 per IP per side)

Why step in radius?
Is that “only” for standard valve?

Impedance cost of bellows (formula of K. Ng)

inner bellow radius	0.05	m			
bellow corrugation	0.006	m			
for 1 bellows at average beta					
longitudinal impedance Im(Z/n)	0.00024	Ohm			
transverse impedance Im(Zt)	1460.238	Ohm/m			
for 1 bellows at average beta					
average beta in LHC	70	m			
beta at TAS	2430	m			
longitudinal impedance Im(Z/n)	0.00024	Ohm			
transverse impedance Im(Zt)	50691.14	Ohm/m			
for N bellows					
N	12		percentage of total impedanc		
longitudinal impedance Im(Z/n)	0.002885	Ohm		3.2%	
transverse impedance Im(Zt)	608293.6	Ohm/m		3.0%	
total LHC impedance					
	0.09	Ohm			
	2.00E+07	MOhm/m			

→ Expensive in terms of impedance

→ Management should decide

Main topics

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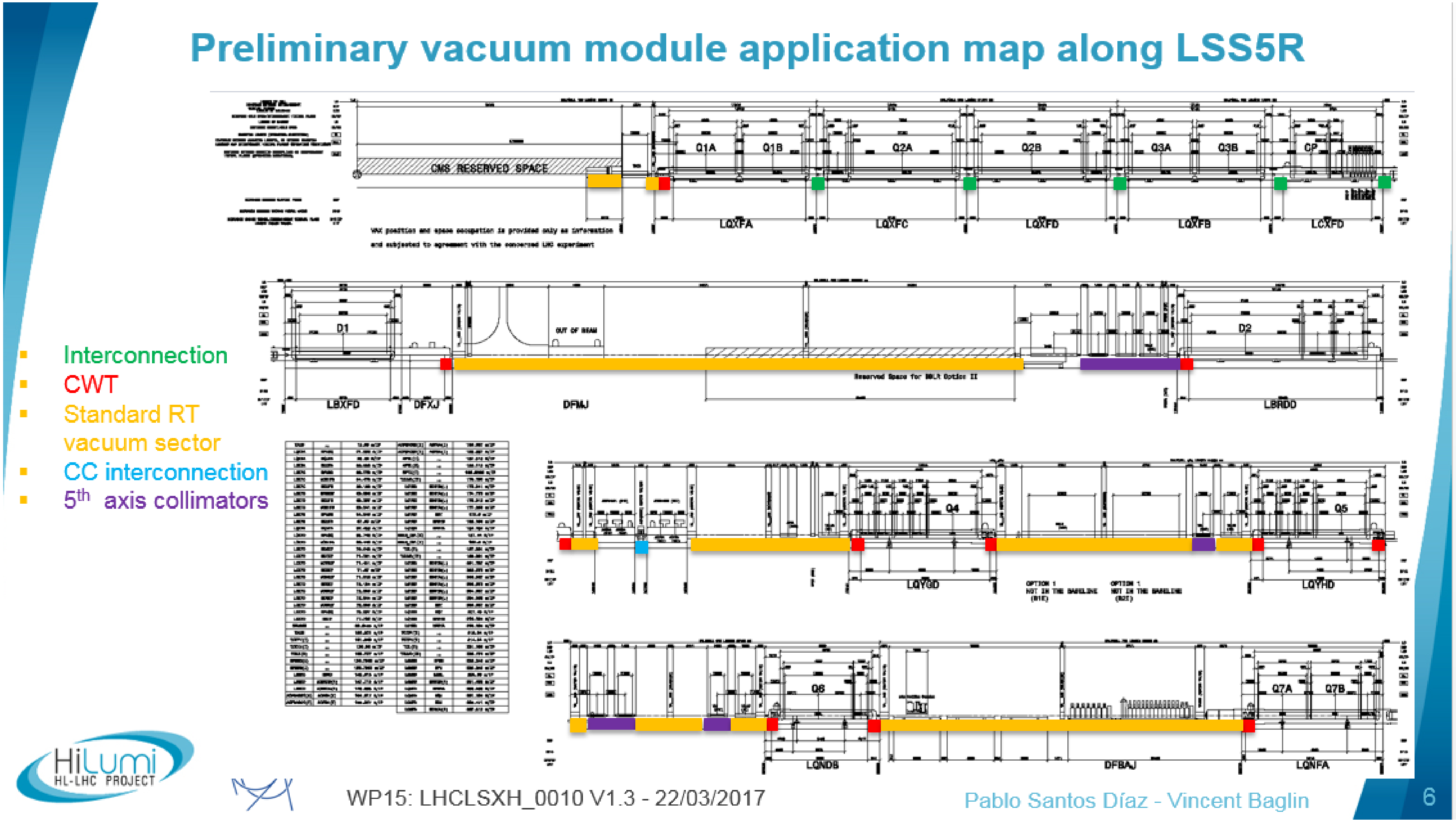
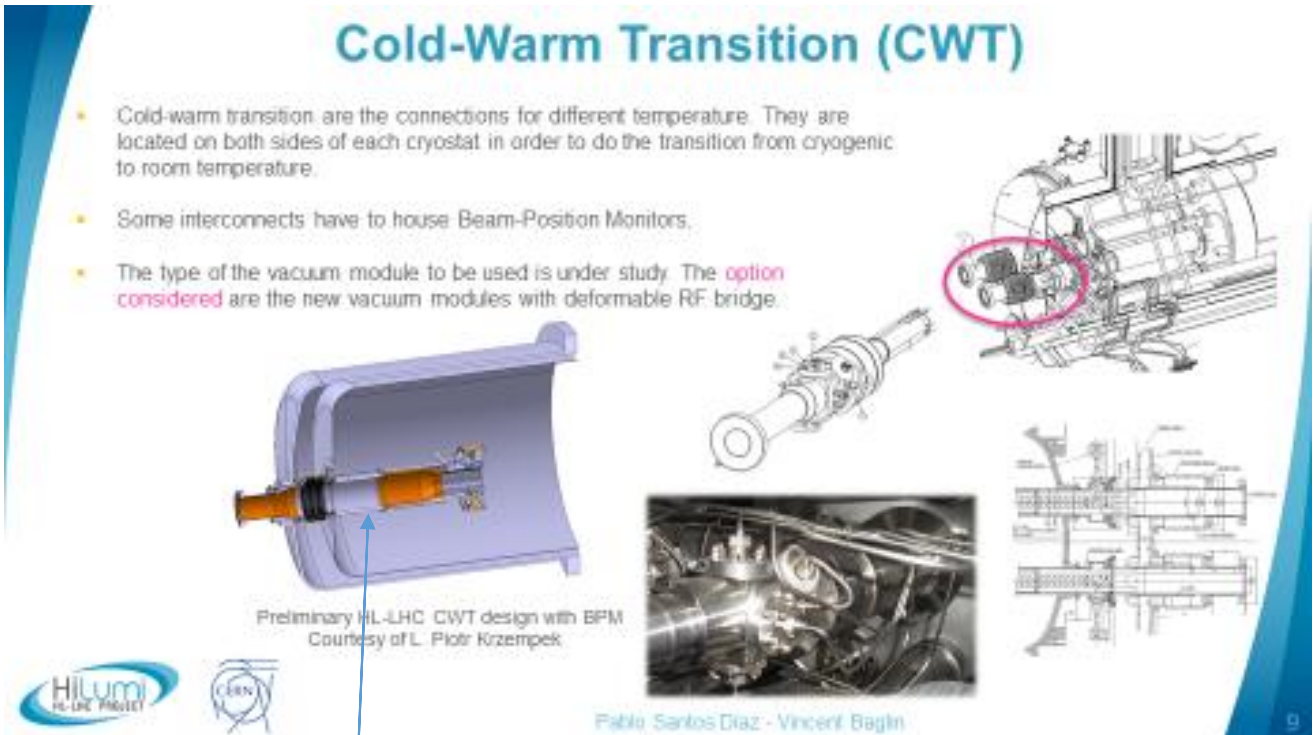
- More iterations needed

Different transitions



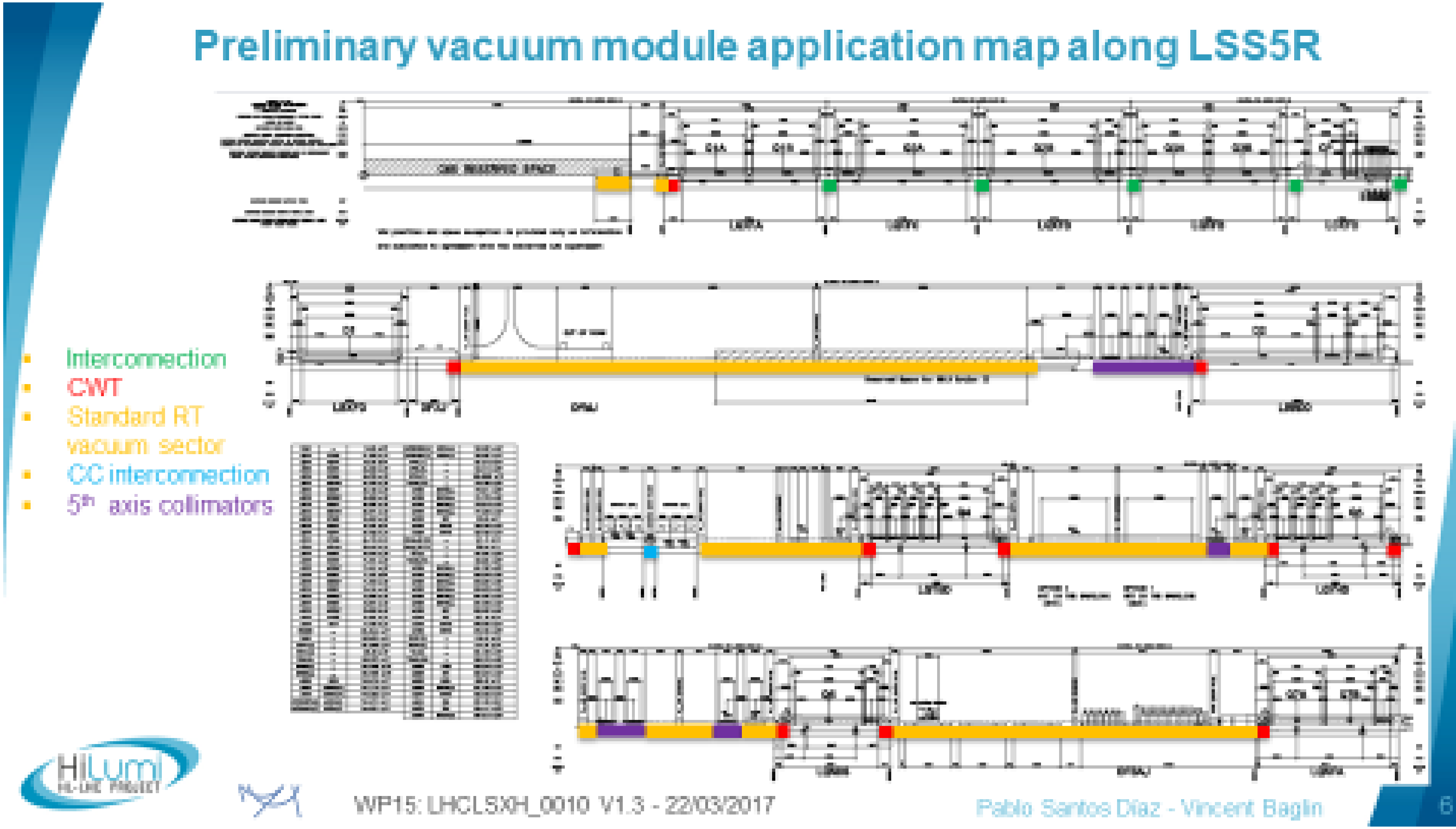
→ 11 additional bellows with deformable fingers

Deformable fingers everywhere???



Avoid cavity!

Different transitions



→ 11 additional bellows with deformable fingers per IP per side?

→ Is expected to be very expensive in terms of impedance if the angle can not be kept flat

Main topics

- Triplet bellows → already agreed at WP2 and TCC for deformable bellow
- VAX area → more unshielded bellows
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- Baseline: amorphous carbon coating on triplets, corrector package, D1, D2 and Q4 (and maybe TAXS?) → already dealt with
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- More iterations needed

Carbon coating

- Carbon coating: 500 nm
- IT, CP, D1, D2 and Q4. Also maybe on TAXS
- Same copper thickness as LHC.

Update on new triplet beam screen impedance

B. Salvant, N. Wang, C. Zannini

14th December 2015

Acknowledgments:
N. Biancacci, R. de Maria, E. Métral, N. Mounet, N. Kos

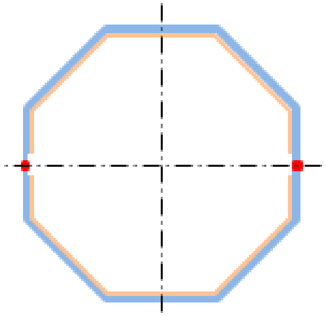
Agenda:

- Impact of coating on the new triplet beam screen
- Impact of coating on the current beam screen
- Impact of various weld scenarios of weld of new triplets

Resistive wall impedance of the new beam screens

- With Coating
  - 5 layers structure
    - 1st layer (aC)
    - 2nd layer (Ti)
    - 3rd layer (Cu)
    - 4th layer (StSt)
    - 5th layer (Vacuum)

- Without Coating
  - 3 layers structure
    - 1st layer (Cu)
    - 2nd layer (StSt)
    - 3rd layer (Vacuum)



Material	σ_{el} [S/m]	ε_r	Thickness [µm]
aC coating	400	5.4	0.5
Titanium coating	$4*10^5$	1	0.1
Copper	10^9	1	50
Stainless steel	$1.35\ 10^6$	1	1000
Vacuum	0	1	Infinity

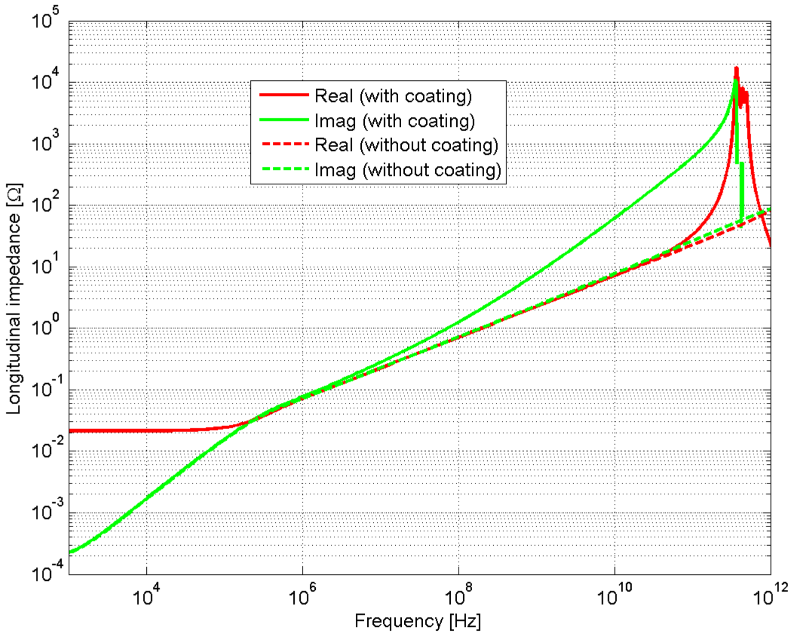
Updated Thanks to Nicolo Biancacci's measurements

Geometries of the Hi-Lumi IR1 and IR5 beam screens (triplet)

Magnet	Cold bore ID (mm)	Beam screen ID between flats (mm)	Beam screen length (m)
Q1	139	99.7/99.7	11
Q2a	139	119.7/111.7	10.2
Q2b	139	119.7/111.7	10.2
Q3	139	119.7/111.7	11
CP	139	119.7/111.7	7.3
D1	139	119.7/111.7	8.3
DFXJ	139	119.7/111.7	3.7
D2	95	87/78	13.5
Q4	80.8	73.8/63.8	9.5

Info from N. Kos

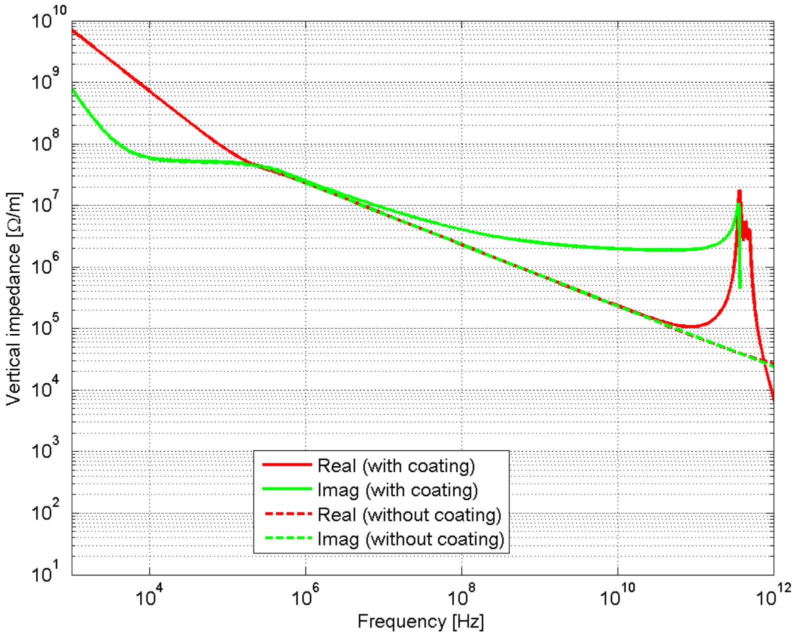
Longitudinal impedance of beam screen in triplets (IR1&IR5)
(2D calculation with ImpedanceWake 2D – N. Mounet)



$$\Delta\left(\frac{Z}{n}\right)_{eff}^{triplets} \approx 6.0\times10^{-5}\,\Omega \approx 6.0\times10^{-4}\left(\frac{Z}{n}\right)_{eff}^{LHC}$$

- → Significant impact of coating on imaginary part
- → Longitudinal effective impedance of the beam screen multiplied by 3 because of the coating.
- → Still expected to be in the background of the total LHC impedance (~90 mOhm)

Transverse impedance of beam screen in triplets (IR1&IR5)
(2D calculation with ImpedanceWake 2D – N. Mounet)



$$E = 6500\ GeV$$

$$\Delta\left(Z_y\right)_{eff}^{triplets} \approx 24\frac{k\Omega}{m} \approx 1.2\times10^{-3}\left(Z_y\right)_{eff}^{LHC}$$

For lattice version V1.2 beta*=15cm/15cm

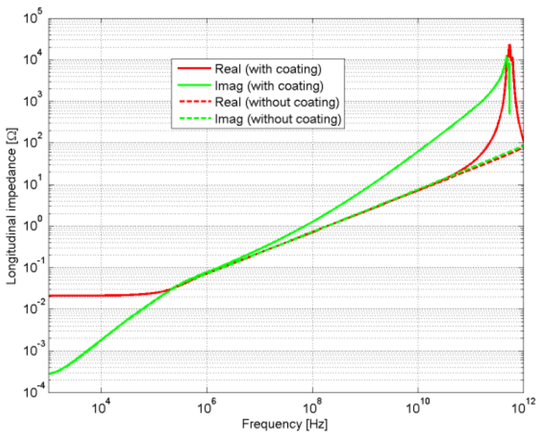
→ Significant impact of coating on imaginary part
→ Vertical effective impedance of the beam screen increased by 70% because of the coating.
→ Still expected to be in the background of the total LHC impedance (~20 MOhm/m)

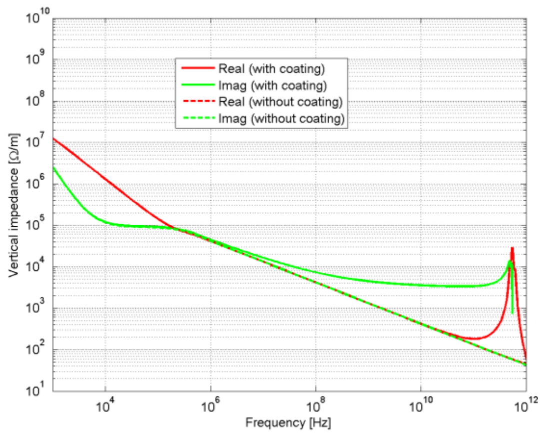
Impact of coating on the current beam screen (IR2 and IR8)

Info from N. Kos

For lattice version V1.2 beta*=15cm/15cm

Magnet	Beam screen ID (mm)	Beam screen length (m)	Average betax (m)	Average betay (m)
Q1	40.4/50.0	7.9	181	132
Q2+Q3	50.4/60.0	23.9	300	340
CP+D1	61.0/70.6	2.7+10.9	328	309





$$\Delta\left(\frac{Z}{n}\right)_{eff}^{triplets} \approx 6.0\times10^{-5}\,\Omega \approx 6.0\times10^{-4}\left(\frac{Z}{n}\right)_{eff}^{LHC}$$

$$\Delta\left(Z_y\right)_{eff}^{triplets} \approx 3\frac{k\Omega}{m} \approx 1.5\times10^{-4}\left(Z_y\right)_{eff}^{LHC}$$

→ Significant impact of coating on imaginary part
→ Longitudinal effective impedance comparable with the impedance of the new beam screen.
→ Transverse effective impedance is about 1/8 of the new beam screen impedance.

Impact of coating on the current beam screen (IR2 and IR8)

Info from N. Kos

For lattice version V1.2 beta*=15cm/15cm

Magnet	Beamscreen ID (mm)	Length (m)	Betax_ave (m)	Betay_ave (m)
Q1	40.4/50.0	7.9	181	132
Q2+Q3	50.4/60.0	23.9	300	340
CP+D1	61.0/70.6	2.7+10.9	328	309
D2	56.2/65.8	10.7	170	160
Q4	50.4/60.6	12.1	146	151
Q5 (2L & 8R)	50.4/60.0	12.1	93	132
Q5 (2R & 8L)	37.6/47.2	11.8	112	121
Q6	37.6/47.2	10.9	146	108

$$\Delta\left(\frac{Z}{n}\right)_{eff}^{triplets} \approx 6.0\times10^{-5}\,\Omega \approx 6.0\times10^{-4}\left(\frac{Z}{n}\right)_{eff}^{LHC}$$

$$\Delta\left(\frac{Z}{n}\right)_{eff}^{triplets} \approx 1.3\times10^{-4}\,\Omega \approx 1.3\times10^{-3}\left(\frac{Z}{n}\right)_{eff}^{LHC}$$

$$\Delta\left(Z_y\right)_{eff}^{triplets} \approx 3.1\frac{k\Omega}{m} \approx 1.5\times10^{-4}\left(Z_y\right)_{eff}^{LHC}$$

$$\Delta\left(Z_y\right)_{eff}^{triplets} \approx 5.3\frac{k\Omega}{m} \approx 2.6\times10^{-4}\left(Z_y\right)_{eff}^{LHC}$$

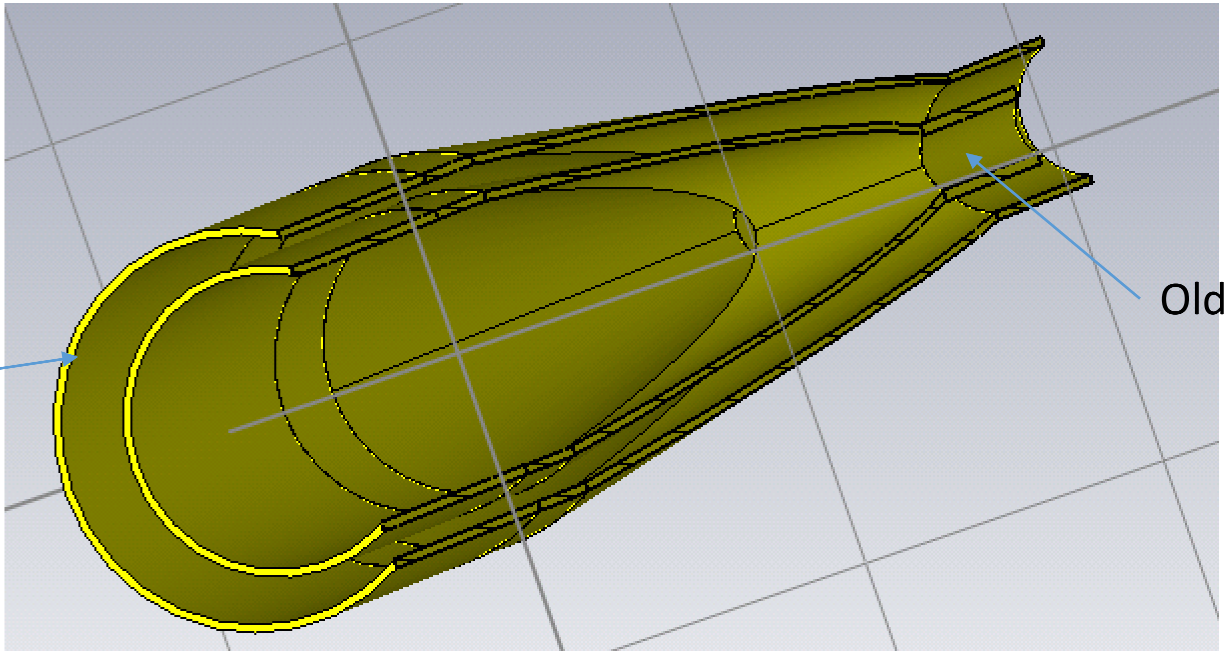
→ Longitudinal effective impedance comparable with the impedance of the new beam screen.
→ Transverse effective impedance is about 1/10 of the new beam screen impedance.

Conclusion for coating

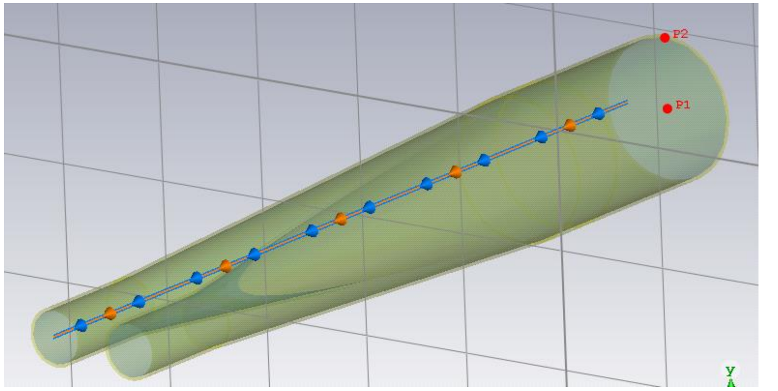
- Small impact expected on impedance of coating the new beam screens or the whole LLS for IR1 and IR5.
- Same level of longitudinal impedance contribution by coating the current beam screen in IR2 and IR8. The transverse impedance contribution is much lower than the new beam screen impedance.

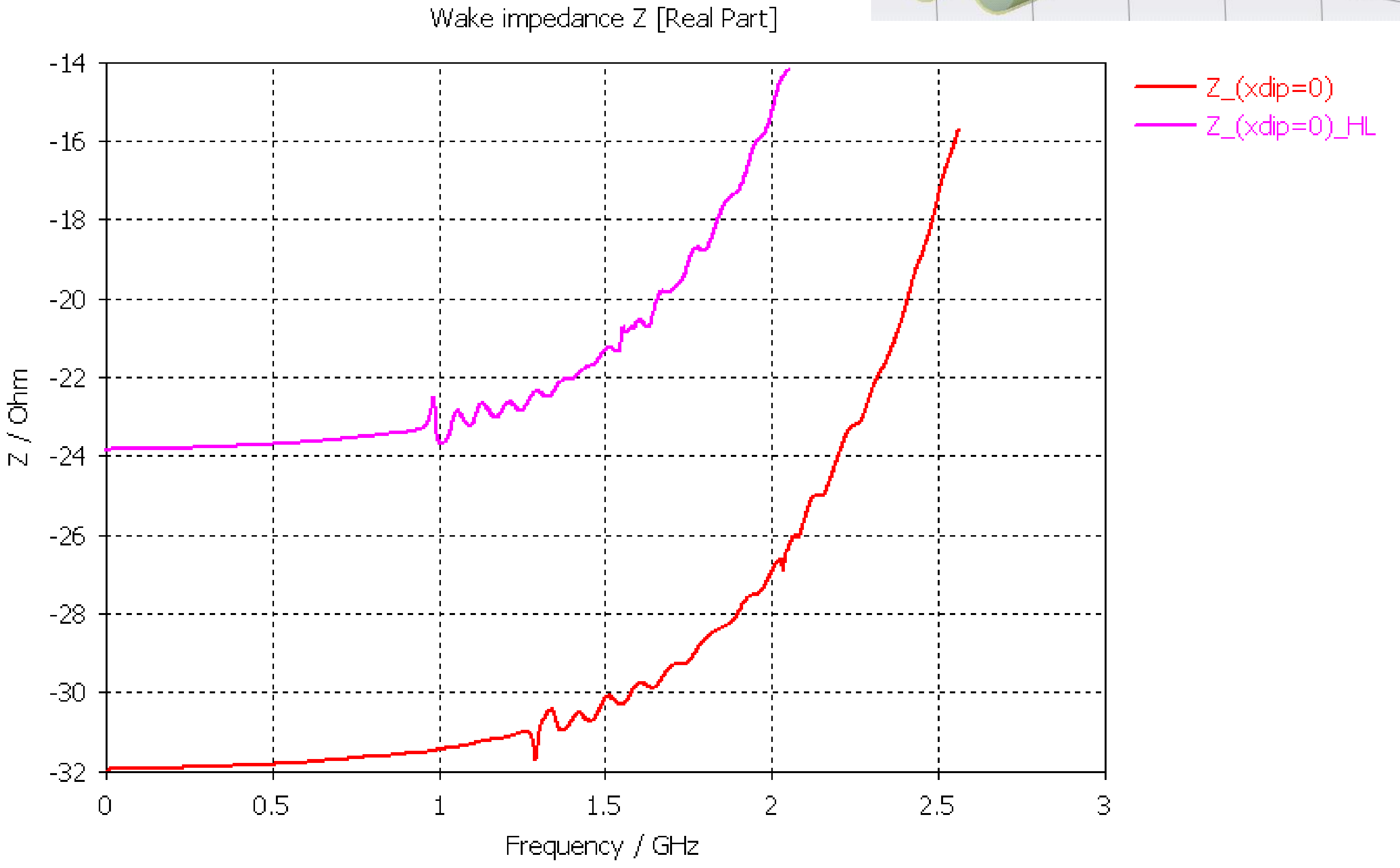
	IP1/IP5		IR2/IR8	
Element	Δ (ZL/n) [Ohm]	Δ Zy [kOhm/m]	Δ (ZL/n) [Ohm]	Δ Zy [kOhm/m]
Triplets	6.0E-5	24.3	6.0E-5	3.1
LSS	8.4E-5	27.7	1.3E-4	5.3

New Y chamber



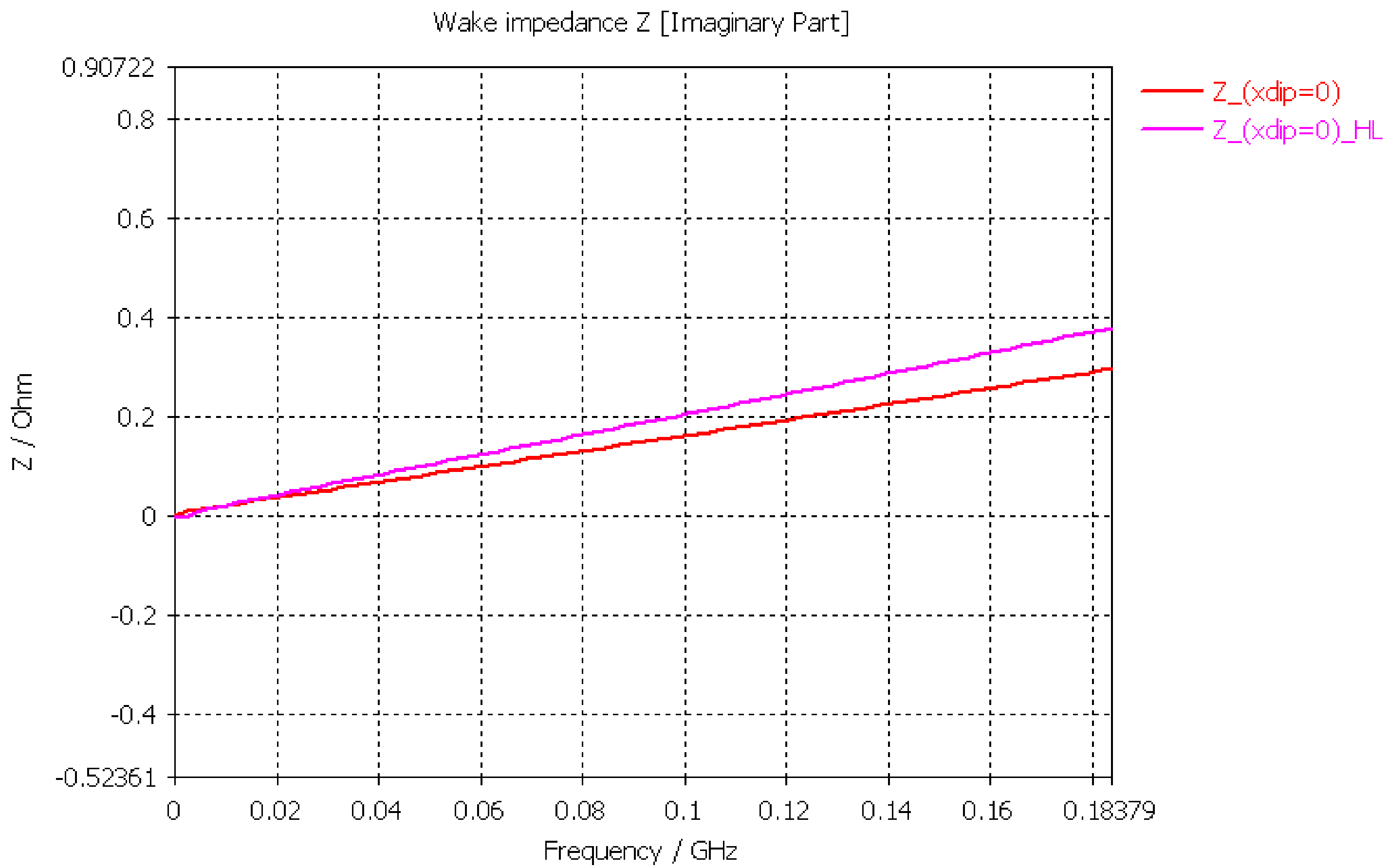
Larger diameters → lower frequency for modes but also lower resistive wall



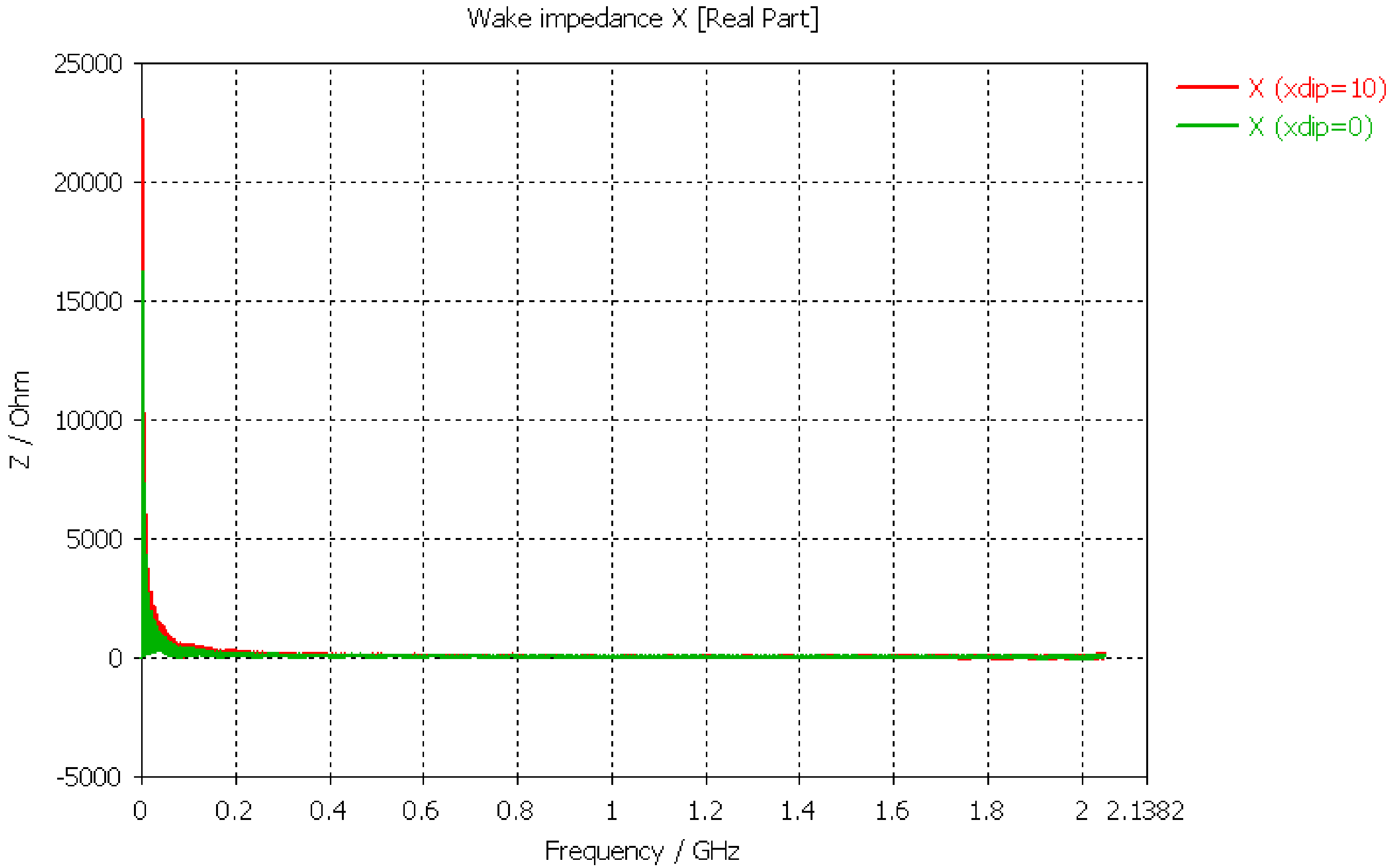


→ Lower frequencies and lower impact due to taper IN (and of course taper OUT – not shown).

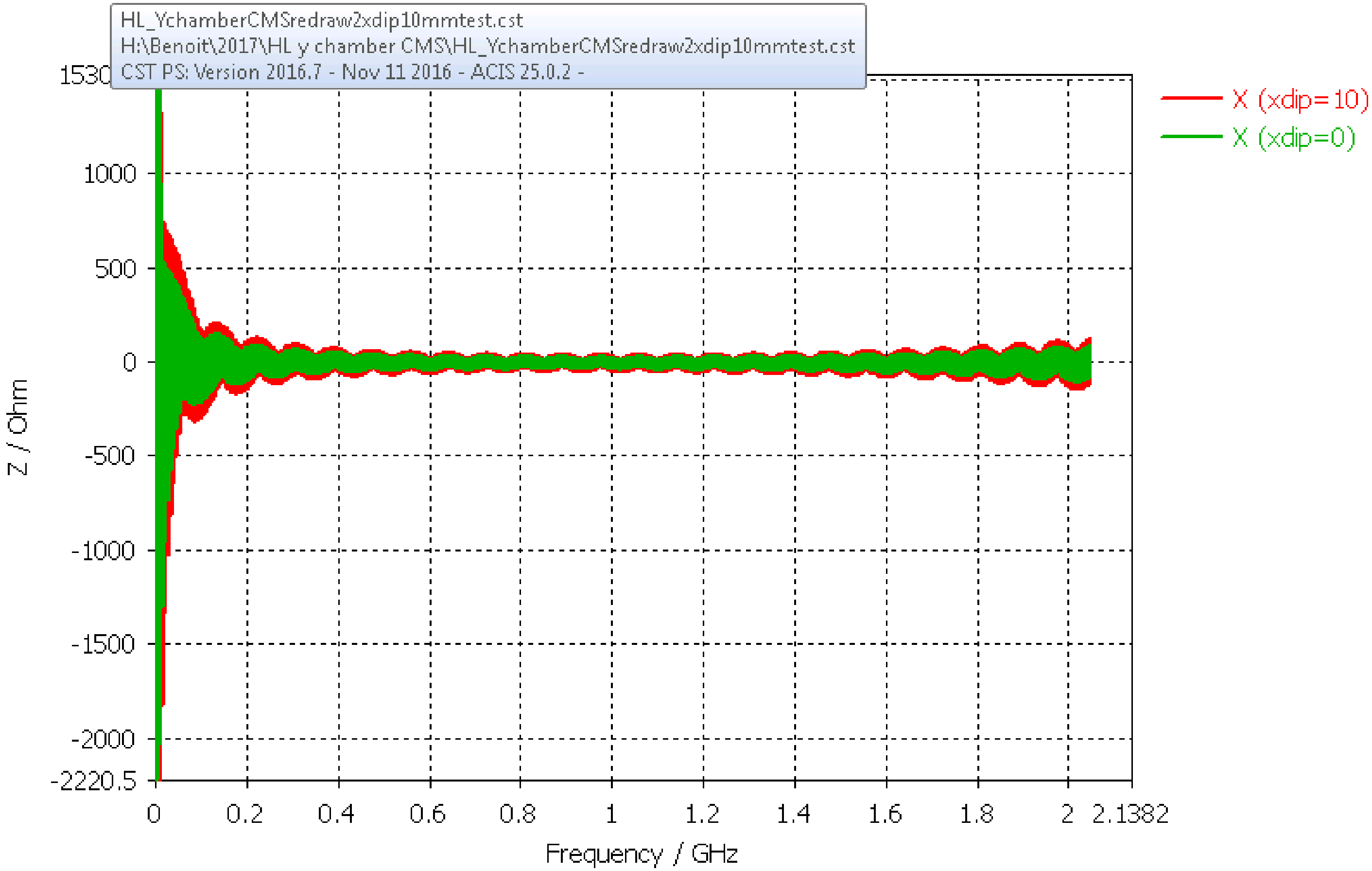
→ No visible significant mode.



Im(Zeff_long/n) slightly higher (0.03 instead of 0.02 mOhm) → still negligible



Wake impedance X [Real Part]
25000
20000
15000
10000
5000
0
-5000
Z / Ohm
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.1382
Frequency / GHz
X (xdip=10)
X (xdip=0)



HL_YchamberCMSredraw2xdip10mmtest.cst
H:\Benoit\2017\HL y chamber CMS\HL_YchamberCMSredraw2xdip10mmtest.cst
CST PS: Version 2016.7 - Nov 11 2016 - ACIS 25.0.2 -
X (xdip=10)
X (xdip=0)
Z / Ohm
1530
1000
500
0
-500
-1000
-1500
-2000
-2220.5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.1382
Frequency / GHz

Conclusions

- Geometry of the Y chamber already well optimized
- No significant mode or effective contribution

Conclusions and next steps

- Significant amount of additional bellows without shielding and with deformable fingers, in addition to what was already approved

  → large cost expected in terms of impedance

  → need to know what is the operational angle of these fingers if significant transverse offsets are needed.

- More iterations are needed with all the information provided by Vincent

Compare between different Optics (IR1, IR5 new beam screens)

Element	Max betax/betay [m/m]	$Z_{T,eff1}$ without aC coating [kOhm/m]	$Z_{T,eff2}$ with aC coating [kOhm/m]	$Z_{T,eff2}-Z_{T,eff1}$ [kOhm/m]
Collision Round	21758/21721	35.7	60.0	24.3
Collision Flat	43154/43281	45.5	76.4	30.9
Presqueeze optics	6776/6780	11.4	19.2	7.8
VDM optics 30m	618/599	0.6	1.0	0.4

Effect from coating all LSS (IR1, IR5)

For lattice version V1.2 beta*=15cm/15cm

Element	Length [m]	$Z_{l,eff1}$ without aC coating [Ohm]	$Z_{l,eff2}$ with aC coating [Ohm]	$Z_{l,eff2}-Z_{l,eff1}$ [Ohm]
Triplets	--	3.6E-5	9.6E-5	6.0E-5
Q5	8.5	6.8E-6	1.8E-5	1.1E-5
Q6	7.1	7.6E-6	2.0E-5	1.3E-5
LSS	--	5.1E-5	13.5E-5	8.4E-5

Element	Length [m]	Beam screen ID between flats (mm)	betay_ave [m]	$Z_{T,eff1}$ without aC coating [kOhm/m]	$Z_{T,eff2}$ with aC coating [kOhm/m]	$Z_{T,eff2}-Z_{T,eff1}$ [kOhm/m]
Triplets	--	--	--	35.7	60.0	24.3
Q5	8.5	50.4/60	900	2.8	4.7	1.9
Q6	7.1	37.6/47.2	345	2.2	3.7	1.5
LSS	--	--	--	40.7	68.4	27.7

$$\Delta\left(\frac{Z}{n}\right)_{eff}^{triplets} \approx 8.4\times10^{-5}\,\Omega \approx 8.4\times10^{-4}\left(\frac{Z}{n}\right)_{eff}^{LHC}$$

$$\Delta\left(Z_y\right)_{eff}^{triplets} \approx 28\frac{k\Omega}{m} \approx 1.4\times10^{-3}\left(Z_y\right)_{eff}^{LHC}$$

→ Longitudinal/transverse impedance of beam screen increased by 40%/14%

→ Still expected to be in the background of the total LHC impedance.