# HL-LHC Triplet “RF fingers”

Ongoing work

with Kyrre, Oleksey, Na Wang, Thomas Kaltenbacher, Christine Vollinger and TE-VSC (Jaime and Cedric).

Acknowledgments: Elias, Nicolo, Riccardo and Gianluigi

# New triplets for HL-LHC

- Several topics:
  - New BPMs (no decision yet taken on the design)
  - Resistive wall impedance of the triplets beam screen (new octagonal geometry, longitudinal and transverse welds, carbon coating)

    → work by Carlo, Na et al
  - Shielding of the interconnects:
    - Problem of available space: proposal by TE-VSC to use deformable fingers instead of sliding fingers

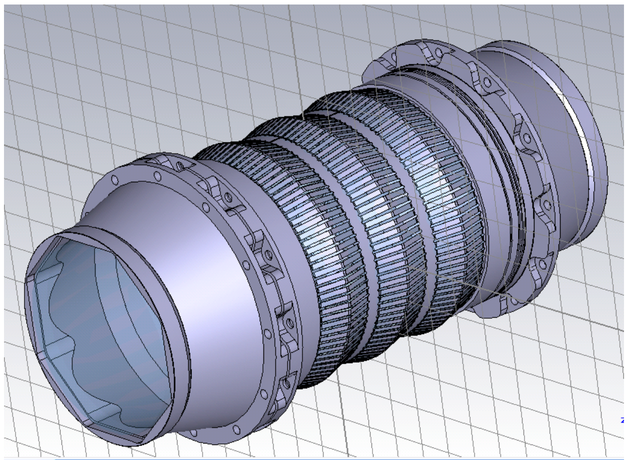
      → work by Na et al for simulations (presented at the impedance meeting in June 17 2015)

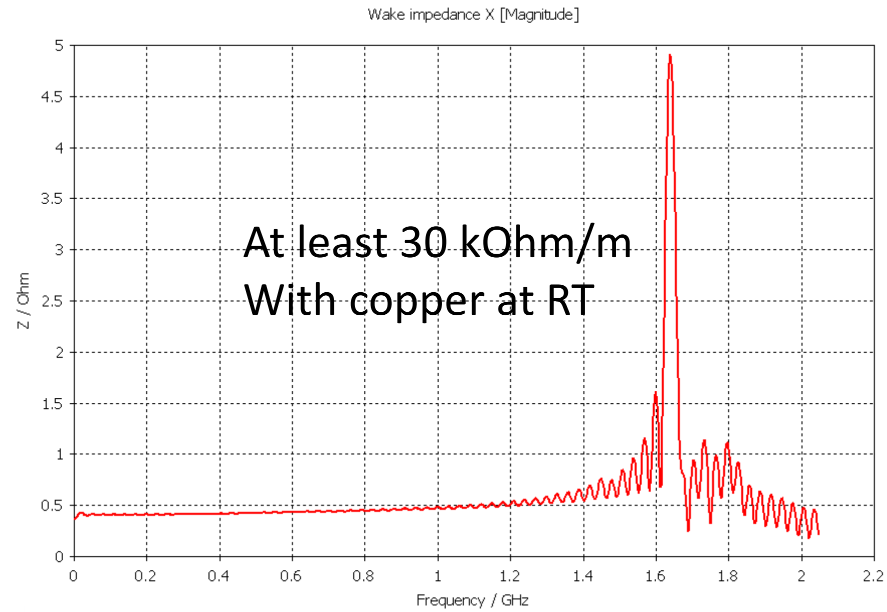
      → work by Christine and Thomas for measurements (ongoing)

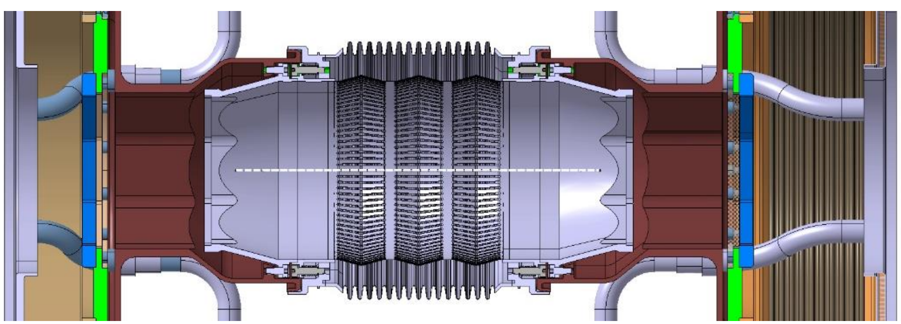
Na Wang et al

# LHC triplet bellow shielding

- First iteration analysed and gave large transverse modes below 2 GHz.

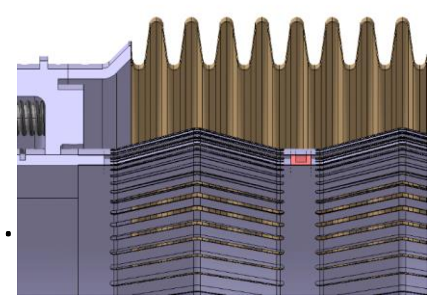




For 1 bellow, Im(Z/n)=3.8e-5 Ohm

For 1 bellow, $Im(Z_{trans}^{eff})$=0.4 Ohm/5mm =80 Ohm/m



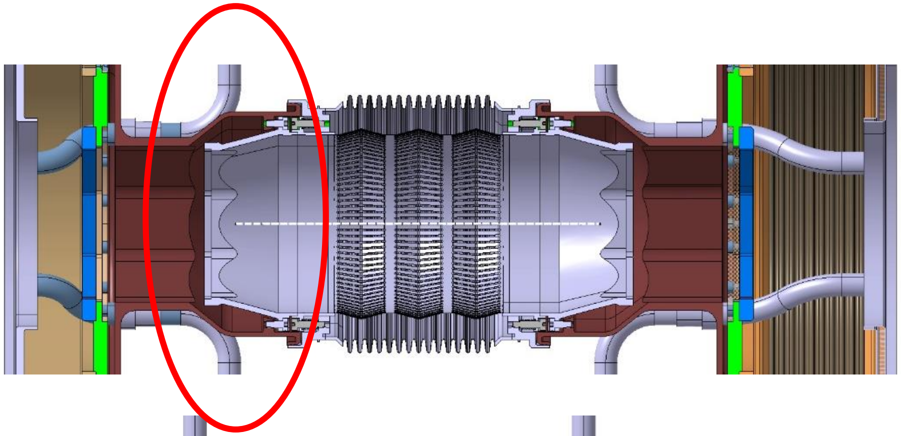
→ Double shielding added to address the modes seen by Fritz and Christine.

→ To be checked by measurements.

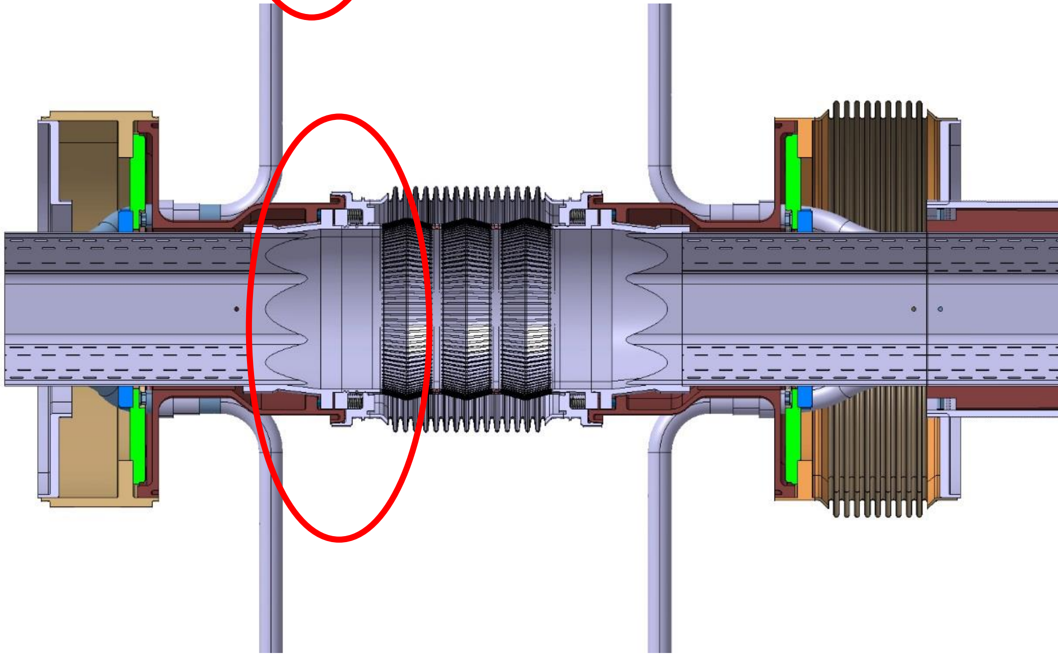
Na Wang et al

# New proposal from Cedric Garion

Old design with larger aperture



New design with smaller aperture for the shielding



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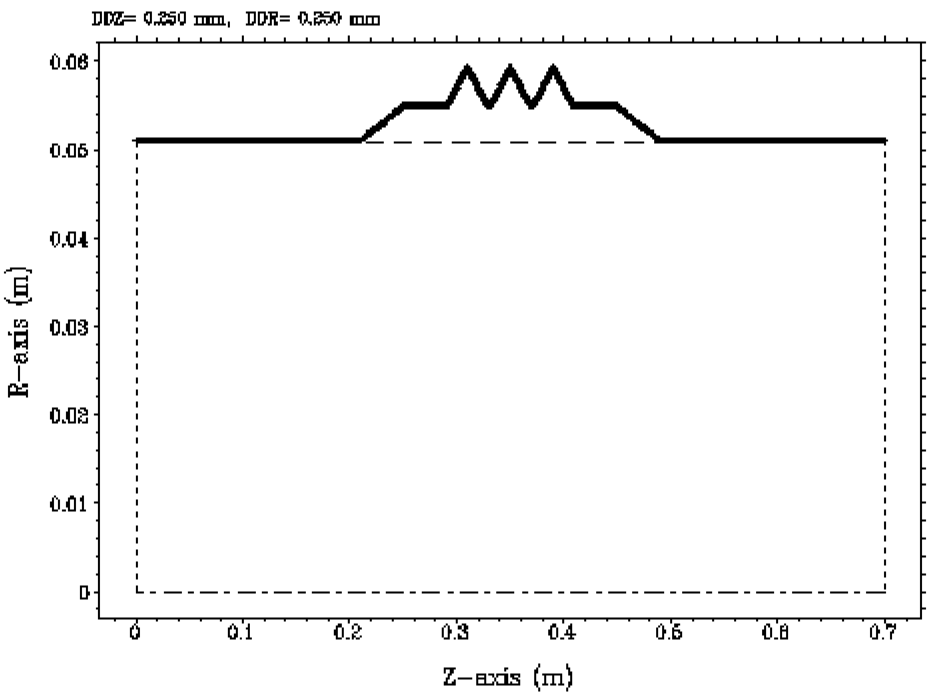
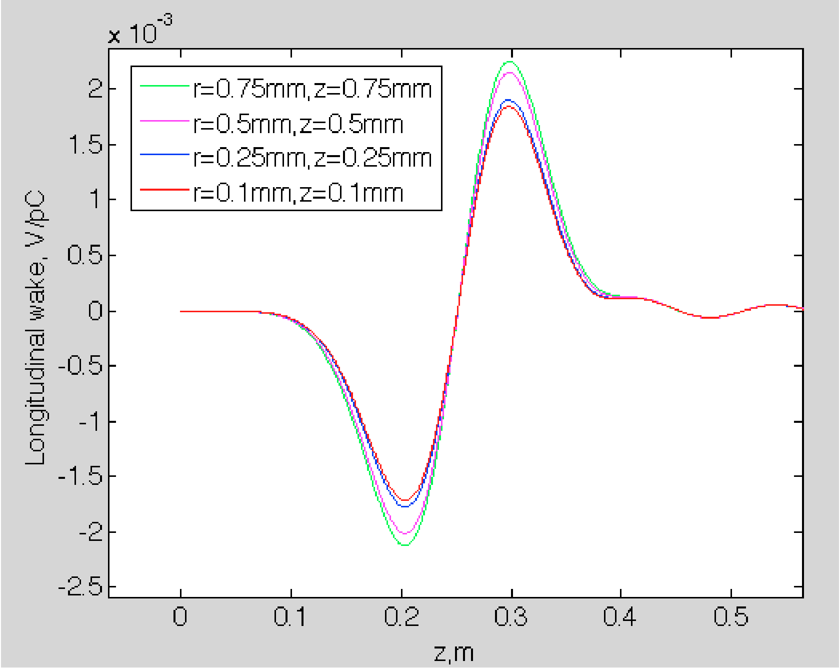
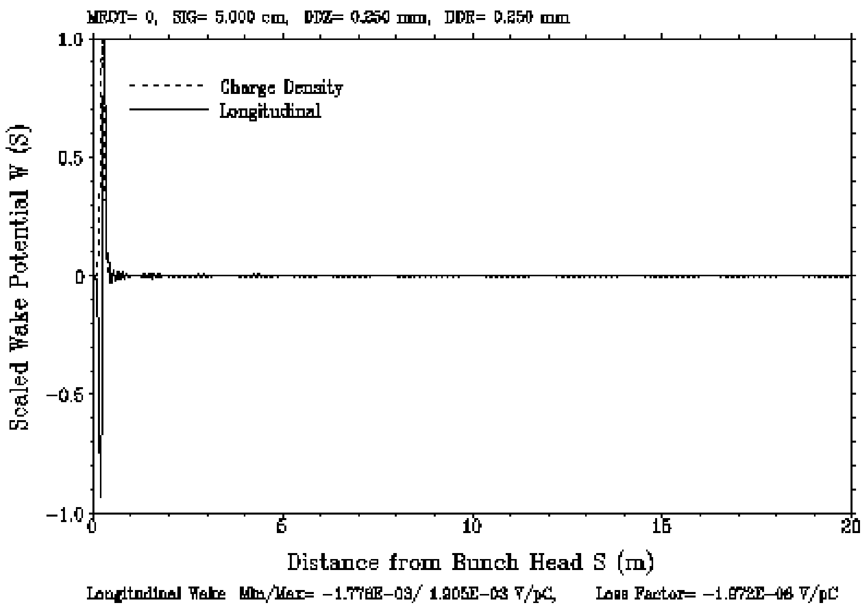
# LHC triplet shielded bellows (ABCI)



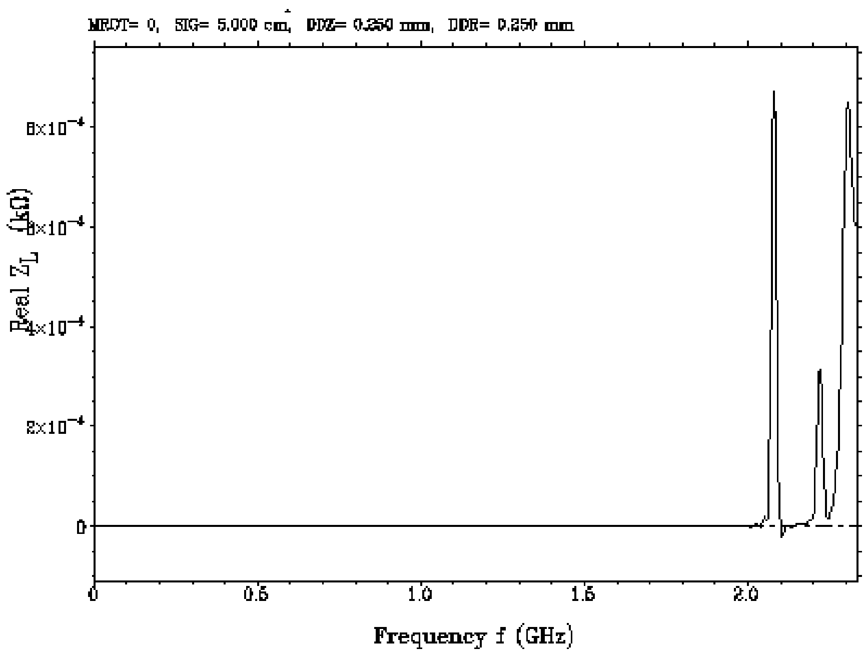



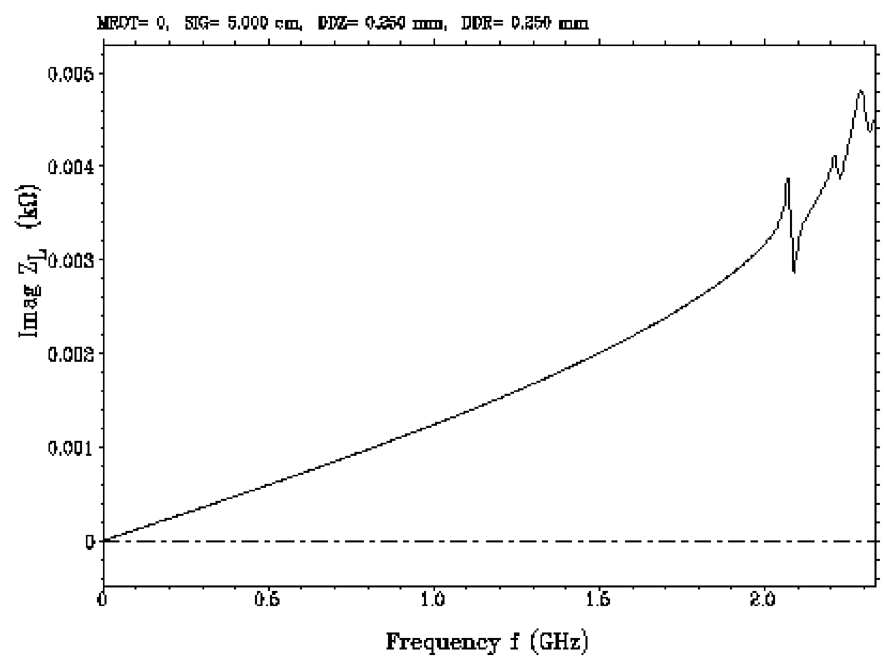
# Longitudinal impedance and wake

Na Wang et al



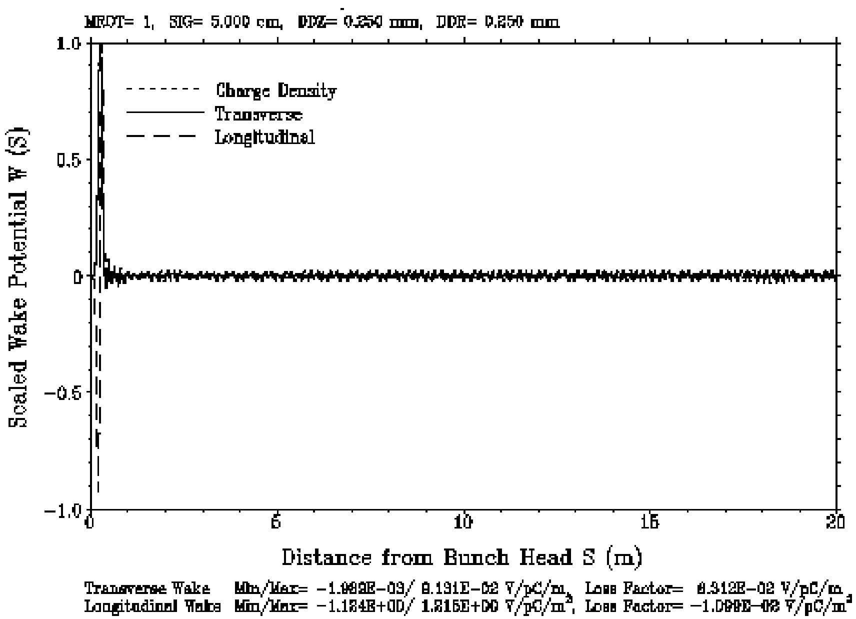

- Mesh: r/z=0.25/0.25mm
- WakeLength=20m
- Im $(ZL/n)_{BB}$≈1.4E-5Ω (*20 bellows =0.28 mΩ)
- Im $(ZL/n)_{BB}$ for LHC =90 mΩ



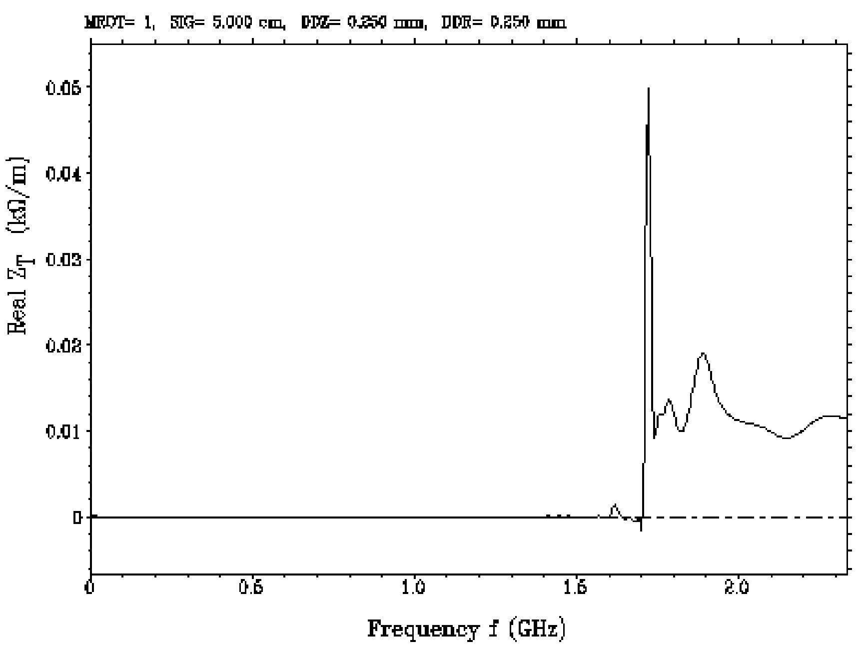



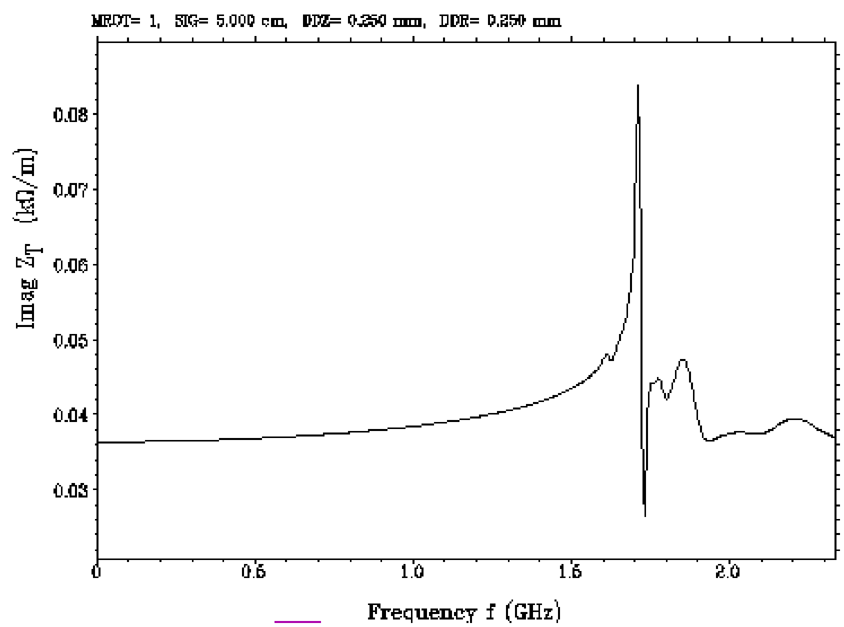
# Transverse impedance and wake

Na Wang et al

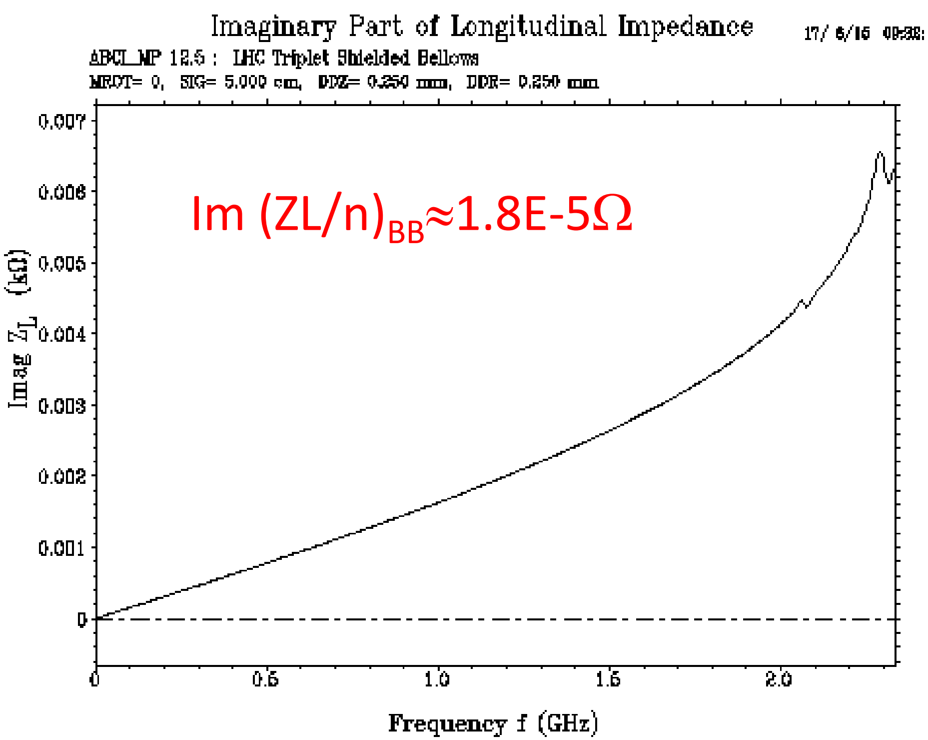


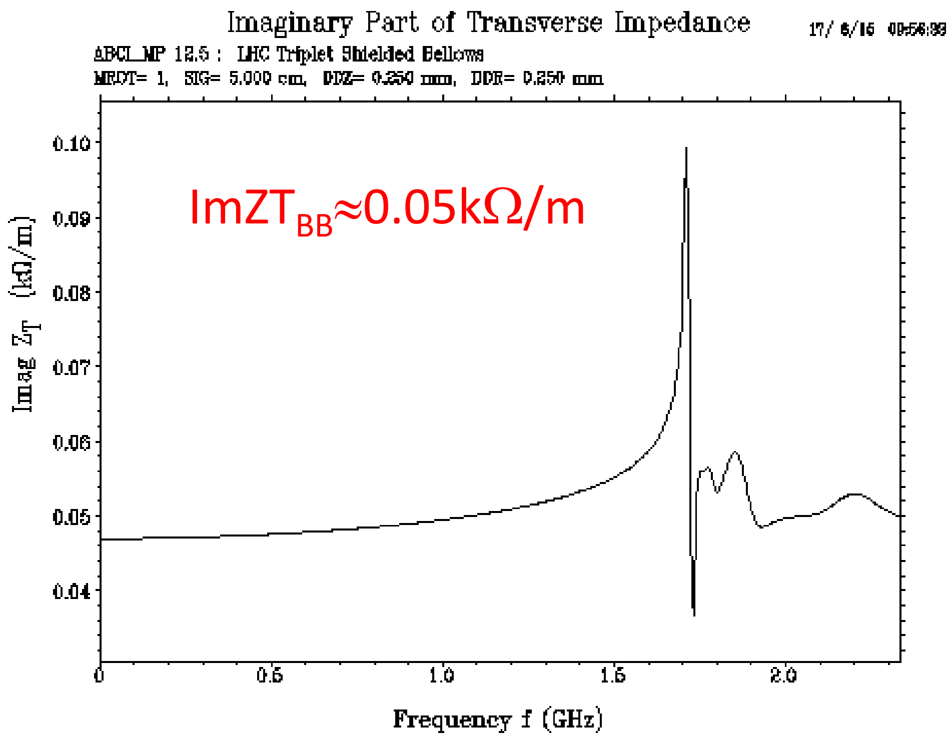

- Mesh: r/z=0.25/0.25mm
- WakeLength=20m
- $ImZT_{BB} \approx 0.04$ kΩ/m (*20*3600/70 = 40 kΩ/m )



# Bellows with 1mm larger outside radius (to check mechanical tolerance)

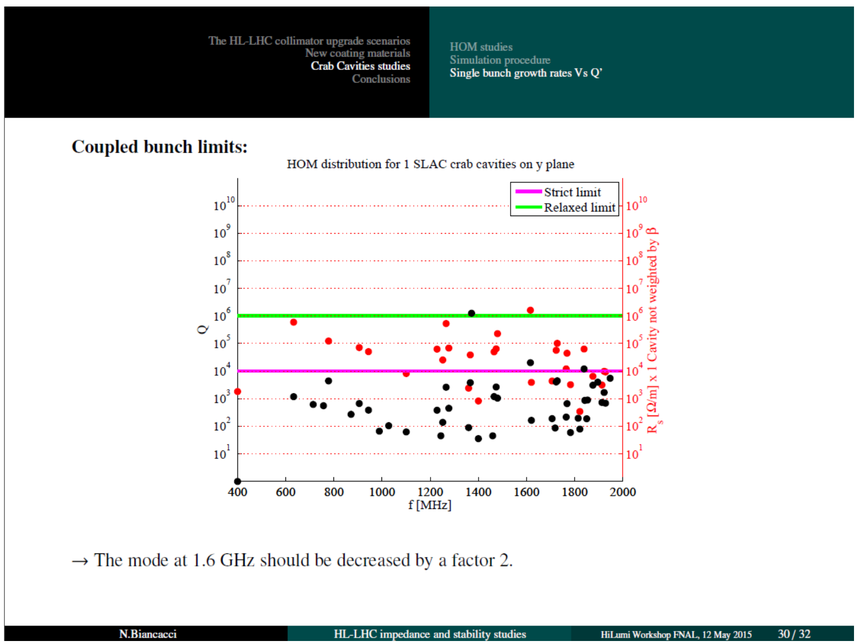



- The broadband impedance increased by 20~30%

# Transverse modes

- Not very clean modes, large error, could be of the order of 1 to 5 kOhm/m (Q~20,000).
- Should be strongly reduced by putting the fingers in.



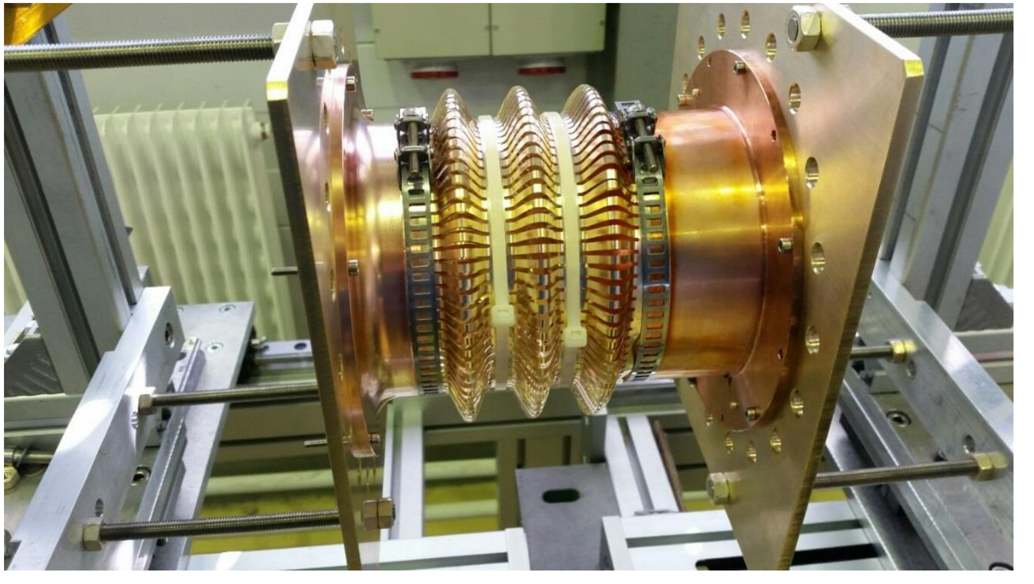

- Rs threshold for crab cavity (from stability diagram): 10^4*8 cav*3600/70=4MOhm/m
- Rs for the new shielding (at 1.7 GHz): 5e3*20*3600/70=5.1MOhm/m

→ Slightly above the strict limit, but also high frequency (1.7 GHz).

→ Recommendation at the time: no showstopper but need to be checked by measurements

# News since then

- Measurements are ongoing in building 113 since beginning of March and results will be discussed in 2 weeks to see if other iterations are needed



N.B.: problem with double shielding wall, as error was done in the manufacturing of the second layer. In any case, only needed in case there are modes coupled between the beam volume and the volume behind the fingers.
It is not even obvious that this double shielding would help in that case.

# News since then

- Update by TE-VSC (Cedric Garion):
  - Baseline for the fingers angle: 15 degrees but could be reduced
  - Lateral offset could be 2 mm → measurements will be performed with lateral offsets
  - Number of shielded bellows:
    - 7 per IP per side:
      - IP – Q1 – Q2a – Q2b – Q3 – corrector Package – D1 - DFBX
    - 1 with small diameter (100 mm) and 6 with large diameter (120 mm)
  - Need answer on whether this kind of solution could be pursued for the Summer.
  - There are no showstoppers so far, but we need to see the results of the measurements.

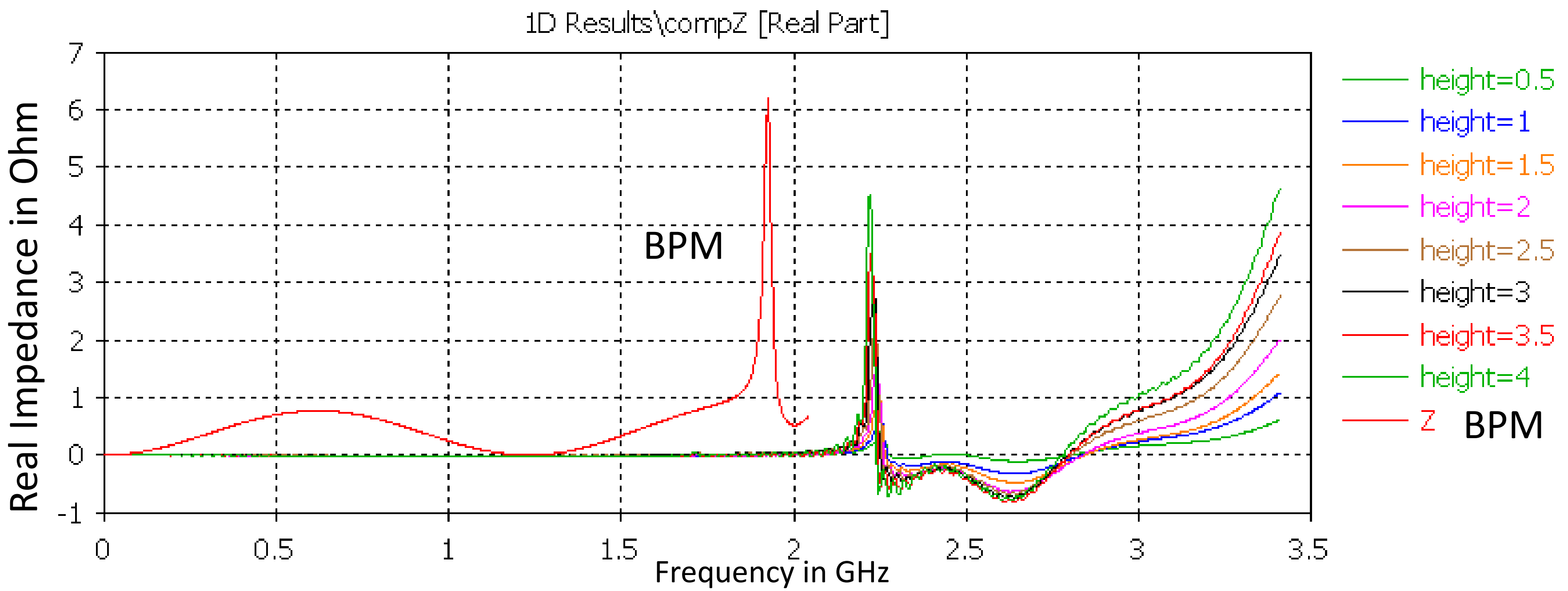
# Update on beta functions to be used:

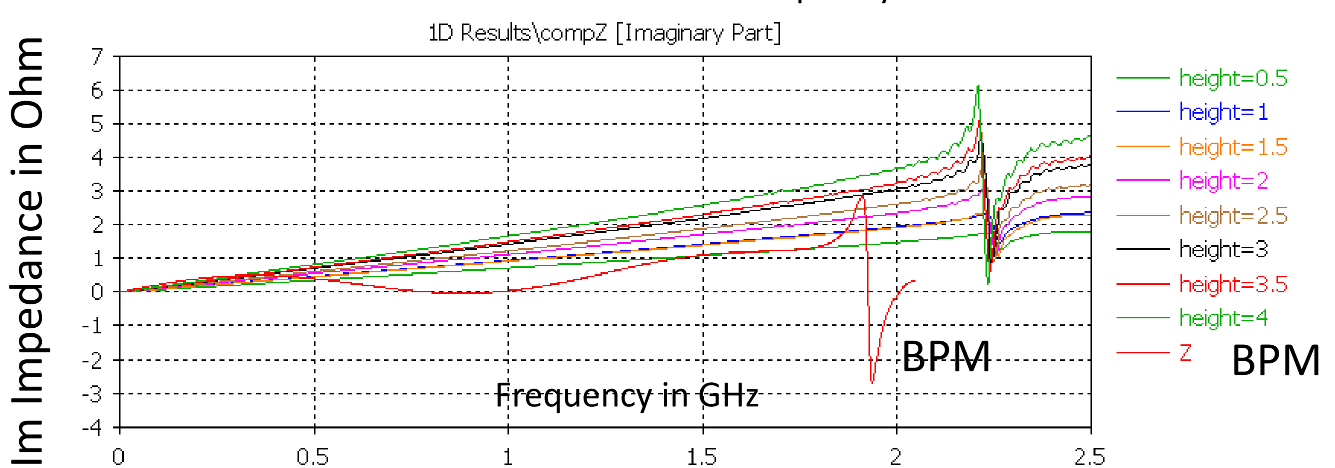
- HLLHC optics V1.2 (round):

| | Beta B1H IP1 (L) | Beta B1V IP1 (L) | Beta B1H IP1 (R) | Beta B1V IP1 (R) | |
|---|---|---|---|---|---|
| TAS-Q1 | 3200 | 3280 | 3500 | 3500 | |
| Q1-Q2a | 12800 | 4730 | 4600 | 14400 | |
| Q2a-Q2b | 21400 | 5620 | 5900 | 21600 | |
| Q2b-Q3 | 17300 | 14400 | 15400 | 15900 | |
| Q3-CP | 9500 | 21500 | 21220 | 8200 | |
| CP-D1 | 7700 | 19500 | 19200 | 7700 | |
| D1-DFBX | 7300 | 17500 | 17200 | 7200 | |

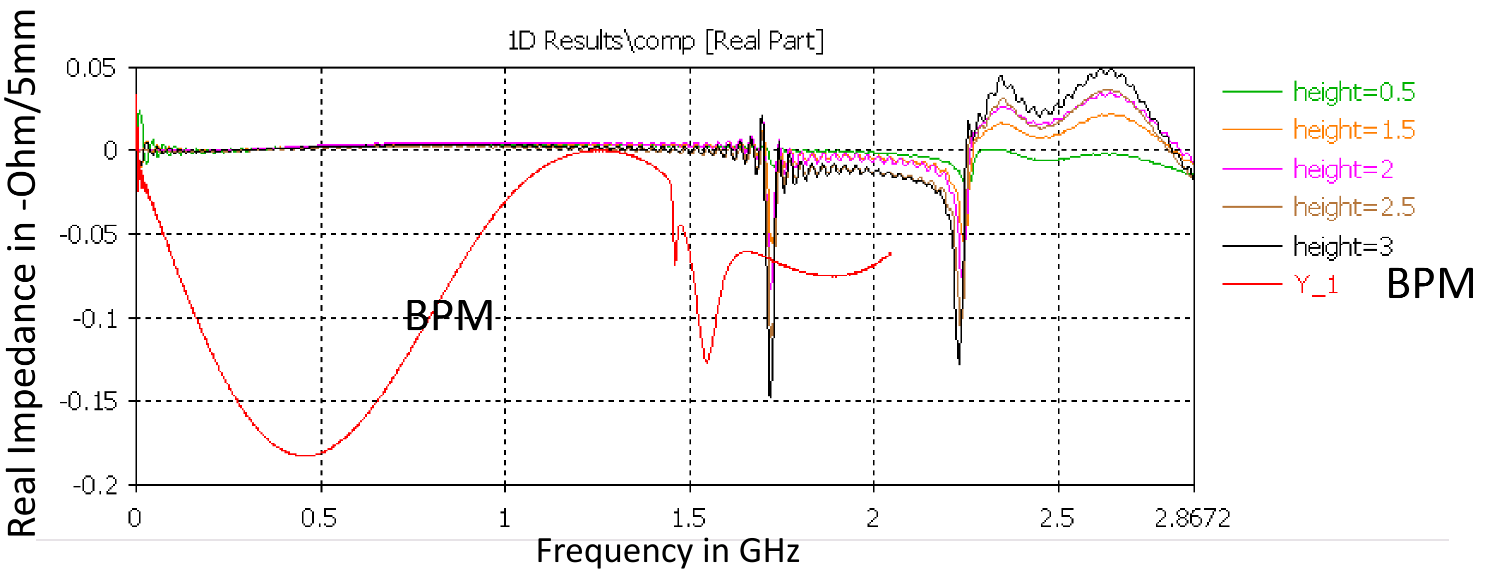
→ Average beta is of the order of 12 km in collisions
→ Total effective impedance would therefore be 0.04 kOhm/m *28*12000/70~200 kOhm/m
→ Of the order of 1% of the full impedance of the machine in collisions

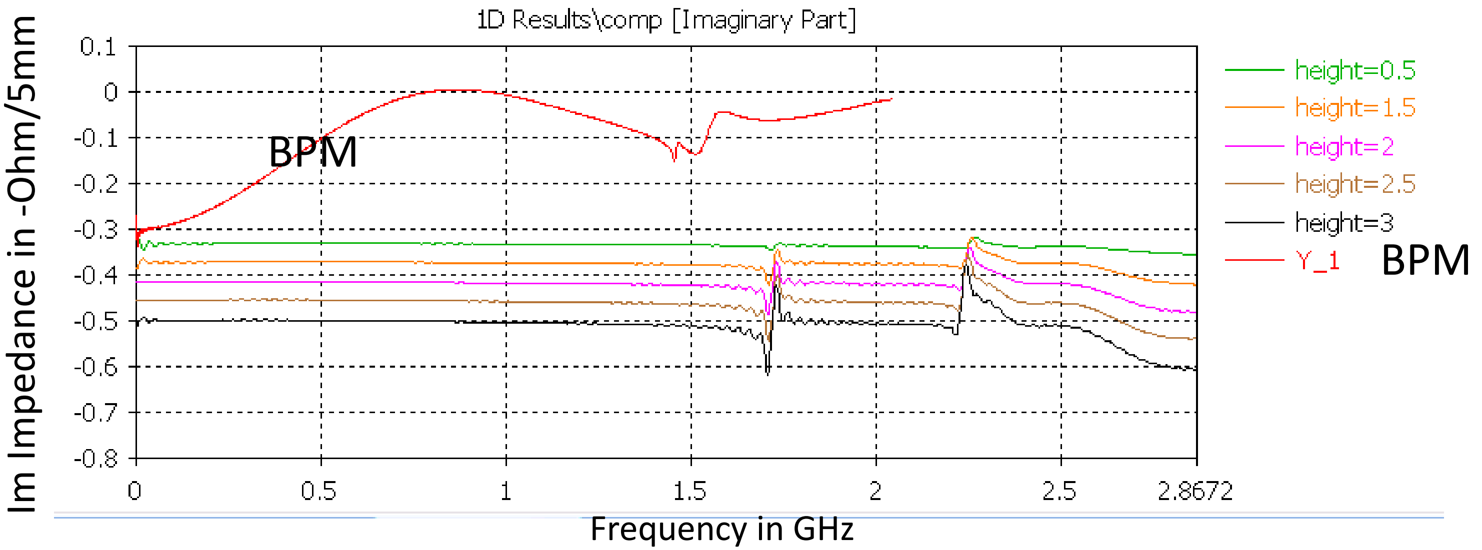
# Update on simulations (longitudinal plane)



# Update on simulations (transverse plane)



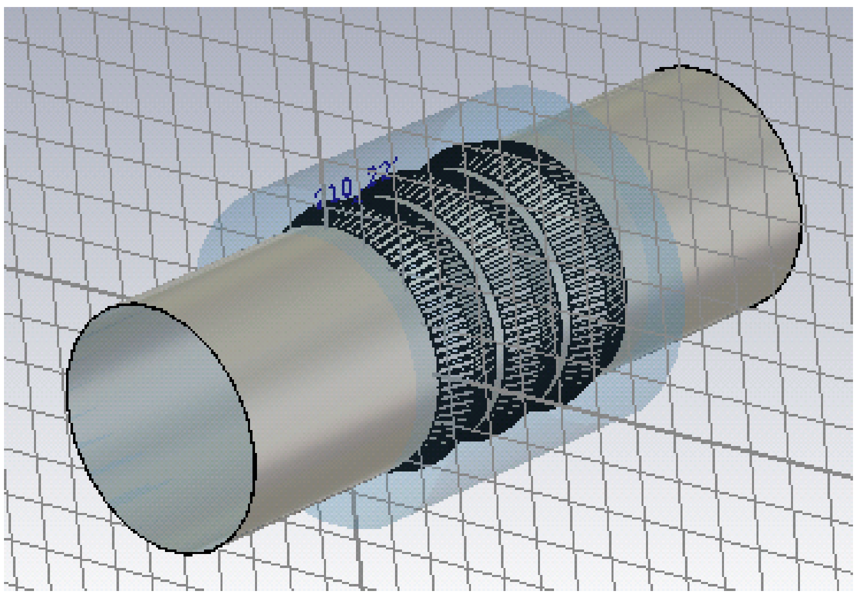



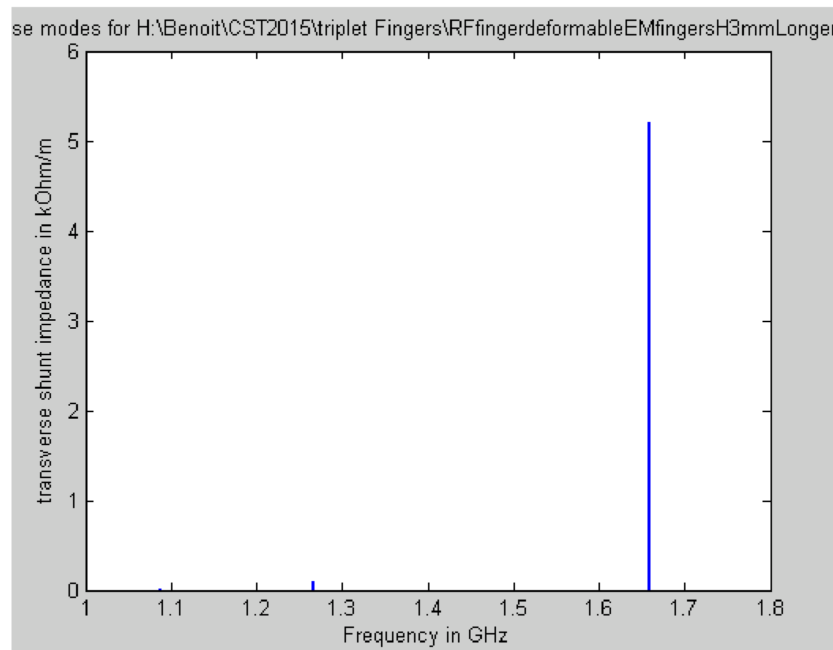

→ 0.5 Ohm/5mm

→ 0.1 kOhm/m

# Update on simulations (eigenmode)

- Confirmed that 5 kOhm/m are obtained with more detailed design of the fingers.






→ Smaller modes are also observed (around 1.25 GHz)

→ coupling between inside and outside of the fingers

We systematically studied the effect of a HOM added to the HL-LHC baseline:

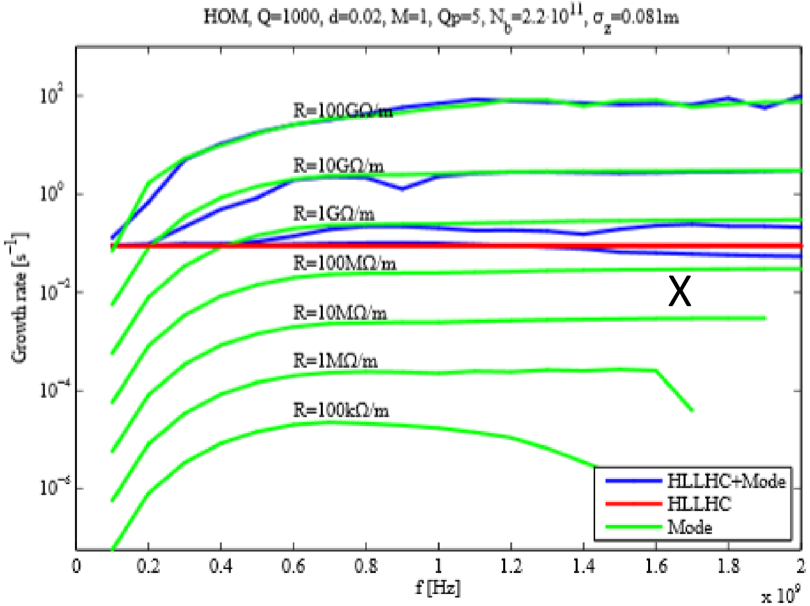
- $R_s \in (100\ k\Omega/m, ..., 100\ G\Omega/m)$
- $f_{res} \in (100\ MHz, ..., 2\ GHz)$
- $Q = 1000$ to ensure $\Delta f = f_{res}/Q > f_{rev}$.

Worst case scenario (very pessimistic):
5 kOhm/m*30km/70m*28=60 MOhm/m

**Scenario:** Single bunch, 50 turns damper, $Q' = 5$, $N_b = 2.2 \cdot 10^{11}$ ppb, $\sigma_z = 8.1$ cm.

**HL-LHC impedance baseline:** Low impedance collimators (MoC+5$\mu$m Mo on IP7).

**HL-LHC optics:** V1.1 with $\beta^* = 15cm$ (i.e. $\beta_{crab} \simeq 3600$) .

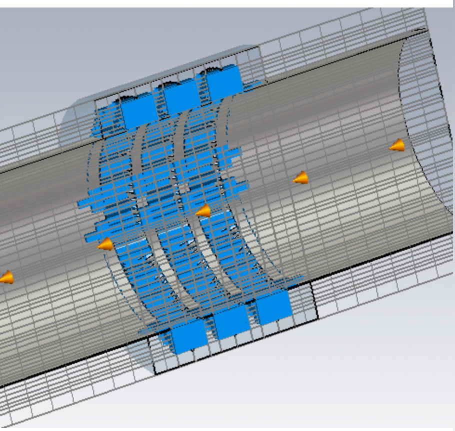
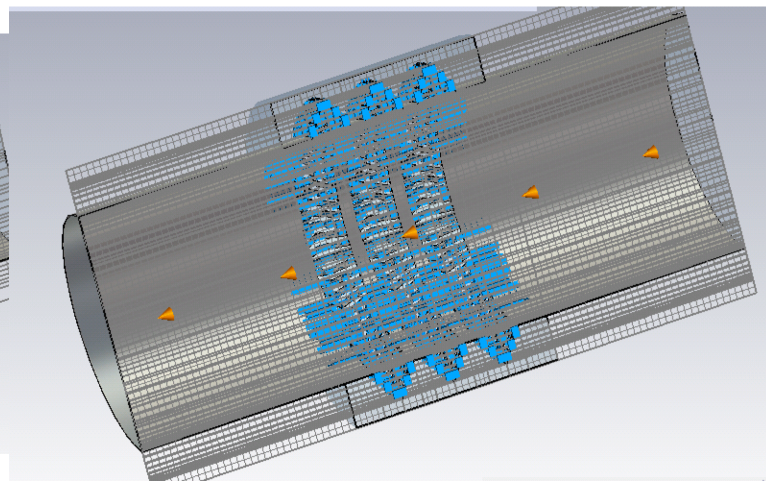
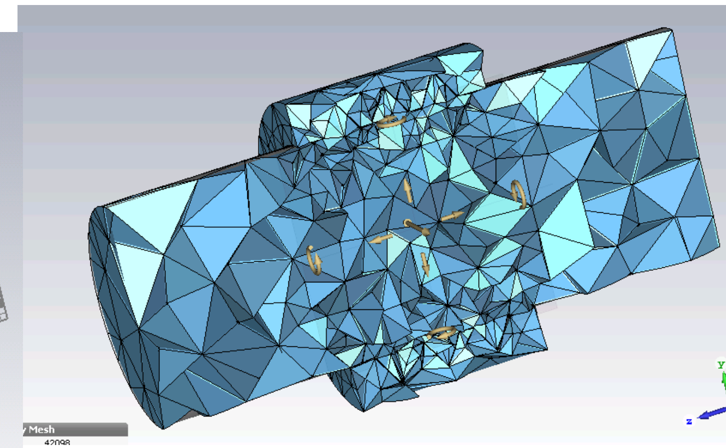



→ From $R_s \simeq 1\ G\Omega/m$ we exceed the baseline impedance model.

# Simulation effort

- Difficult geometry to simulate with Cartesian mesh:

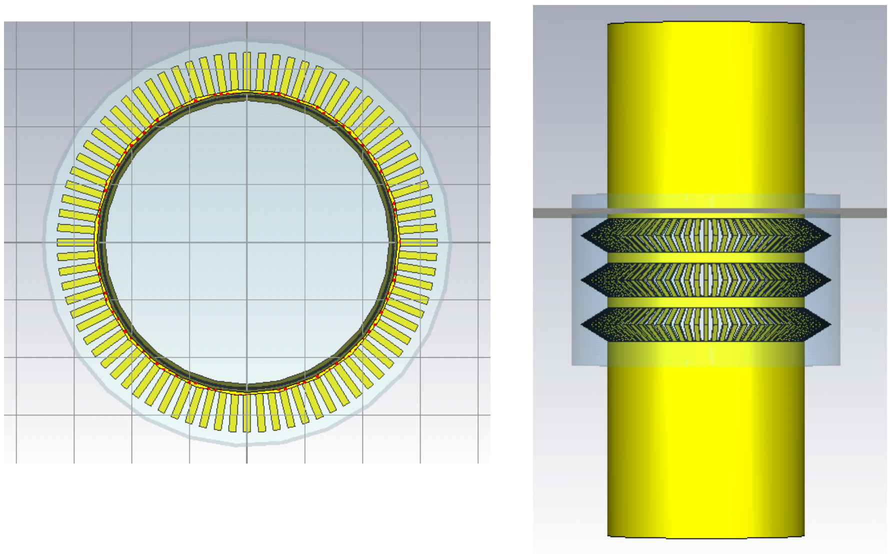
  → small impedance, thin fingers that are not parallel to the Cartesian mesh → "PEC" cells

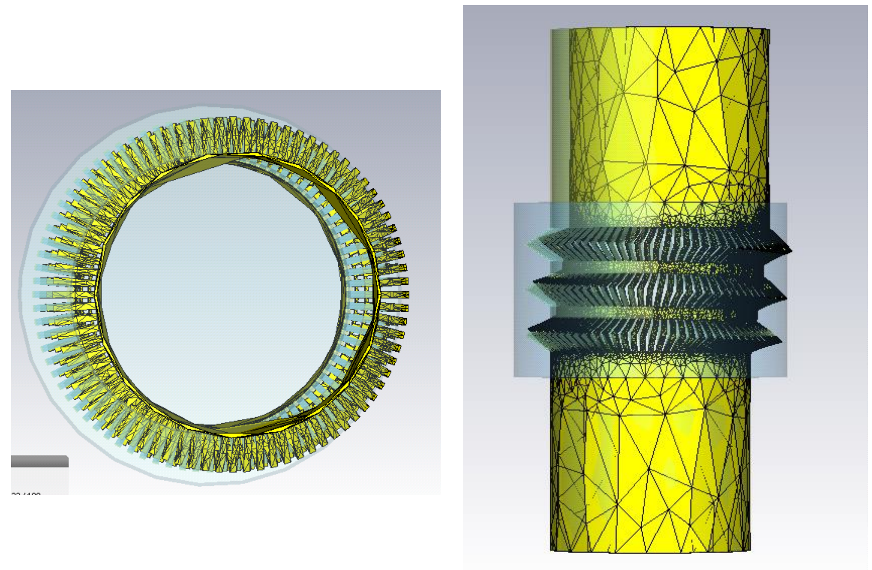
- Tests started with ACE3P (with Kyrre), but blocked for some time due to the problem with the Cubit/Trelys mesher license.

# Simulation effort

- Work on trying to assess the impact of lateral offset in ACE3P and CST



Starting structure



Structure after applying lateral offset

→ Ongoing work

# Where are we?

- No showstopper seen so far with this new design

- We will recommend decreasing the operating angle as much as possible beyond 15 degrees but it seems not much more can be gained from transverse impedance point of view (assuming the current design of RF fingers can not be used).

- Ongoing studies to simulate the low frequency contribution of such geometries (tests with ACE3P + mechanical deformation)

- Measurements should tell us if the modes appear when applying a transverse offset to the module

$$\frac{Z_{\parallel}}{n} = j\frac{Z_0\beta\ell}{2\pi R}\ln\frac{b+\Delta}{b},$$

$$Z_{\perp} = j\frac{Z_0\ell}{2\pi}\left[\frac{1}{b^2} - \frac{1}{(b+\Delta)^2}\right].$$