

LHC Landau Cavity Design

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Introduction

What do we have to care to assure a safe and a good operation for an accelerating cavity (TM_{010}) operating in the LHC ring?

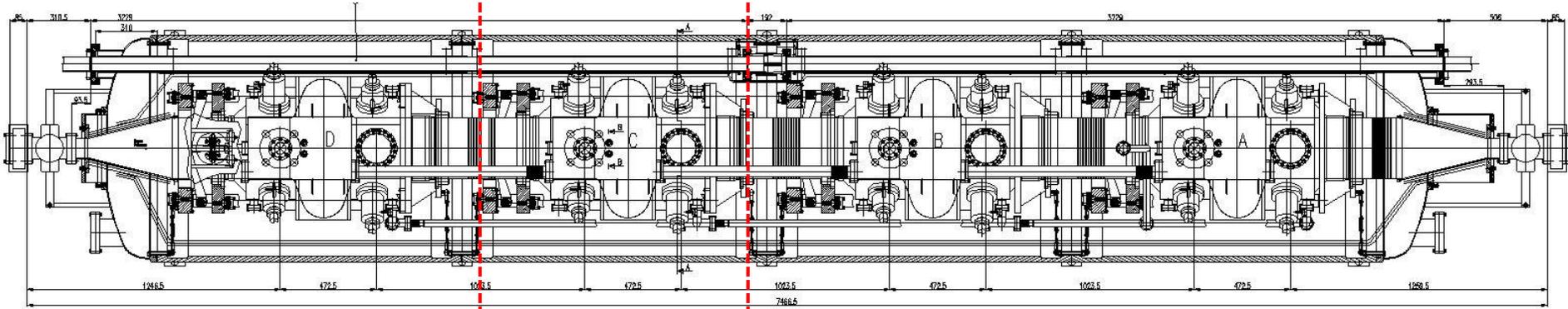
- 1) An optimal shape that increases the efficiency?
- 2) A design that lowers the surface fields?

First of all we must ensure the beam stability!

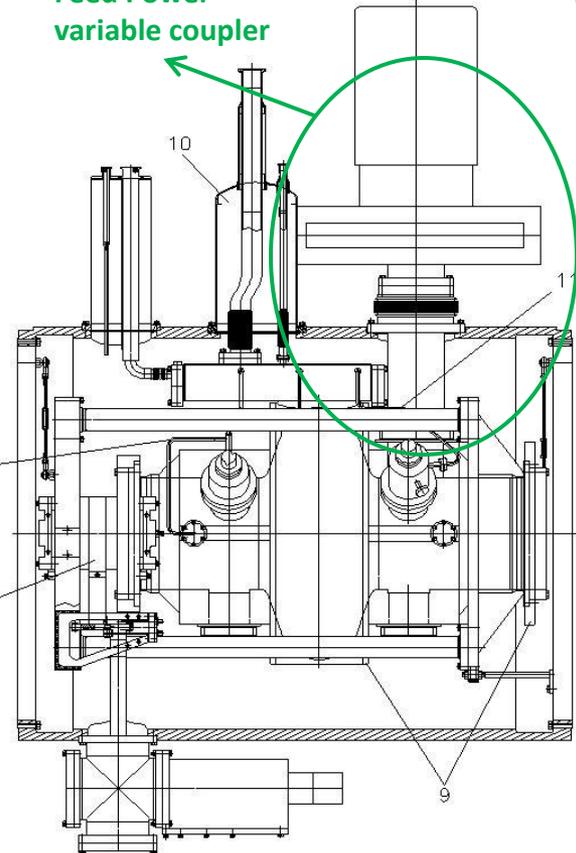
That means, we must damp all the dangerous high order modes. **We have to realize the cavity!**

LHC Acc SC cavity (400MHz) seems to work well as the predictions said, thus why we don't we use a scaled version of such cavities as a **BASE LINE** to start the e.m. studies?

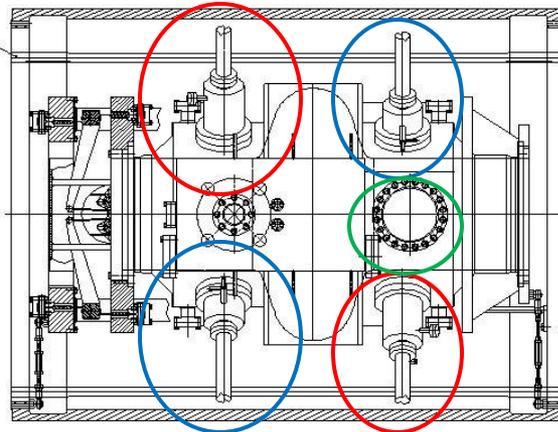
LHC SC accelerating module



Feed Power
variable coupler

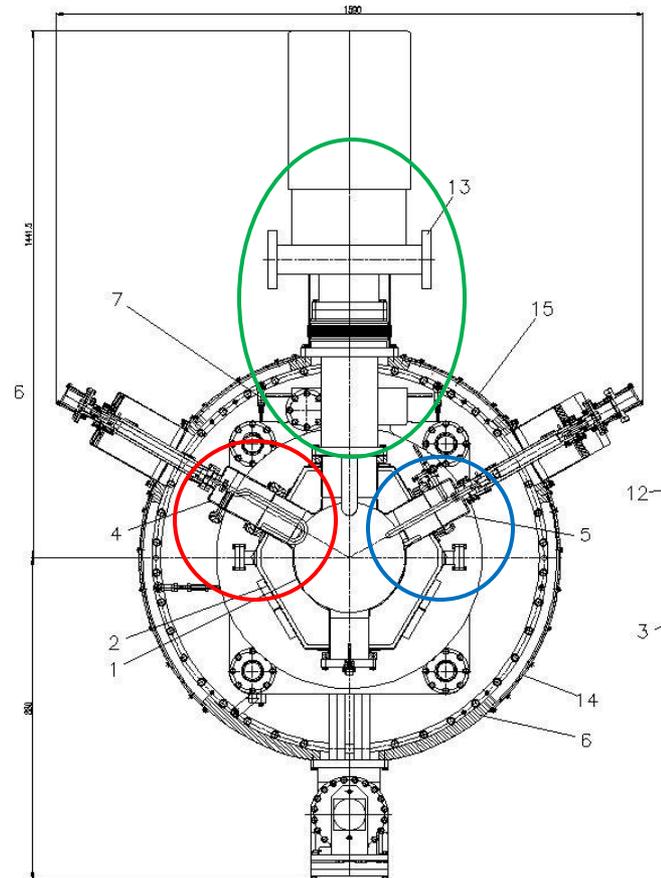


One unity assembly



Type B
Broad band
HOM coupler

Type A
Narrow band
HOM coupler



How best to use the experience gained with the LHC 400MHz cavities?

On the basis of the last and recent experience on the realization of the LHC superconducting cavities we can, nay we must avoid some issues that comes out in those days during the cavity testing. The principal issues that took a long time to be solved are mentioned below:

- The larger inclination of the “side-wall” with respect to the old SC LEP cavity cell increased the cavity stiffness under longitudinal deformation, applied to tune the cavity, requiring a **tuning frame correspondingly rigid**.

- During the operational tuning of the LHC cavities the ends of the range approached the elastic limit of the cavity body possibly **disabling the tuning system**.

- After tuning while cavities were many months in storage, **several of them slowly crept back** partly in direction of initial state, some of them ending with a disabled tuning system.

The cavity wall thickness at 800 and 400 MHz will be the same (same helium pressure) , the wall thickness and cavity dimension ratio increases by factor two, making the rigidity even larger.

We intend to avoid this problem for the 800 MHz system in slightly changing the cell shape.

What would happen with a simple scaling of factor 0.5?

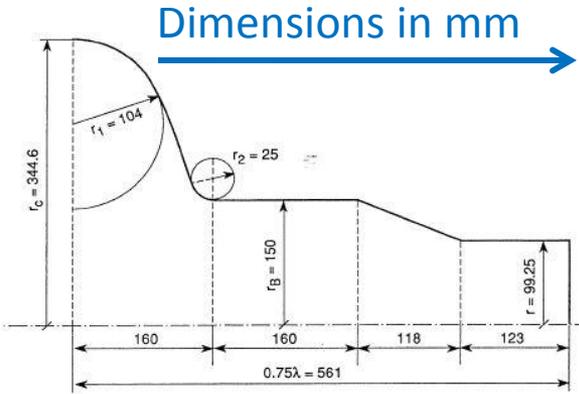
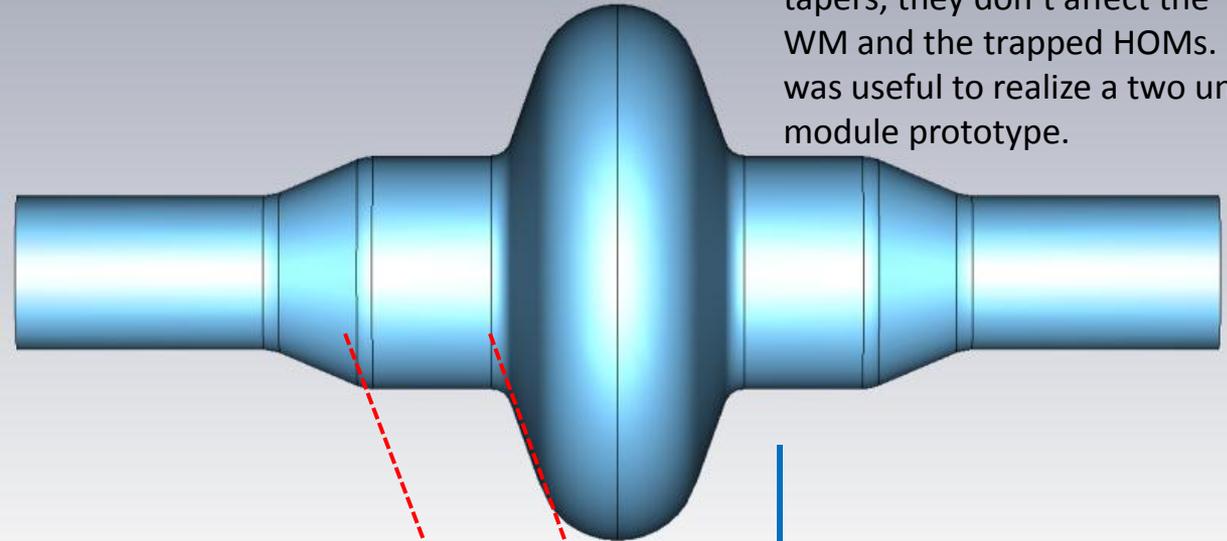


Figure 1: Geometry of the 400 MHz superconducting cavity. Model I has r_c 3mm large

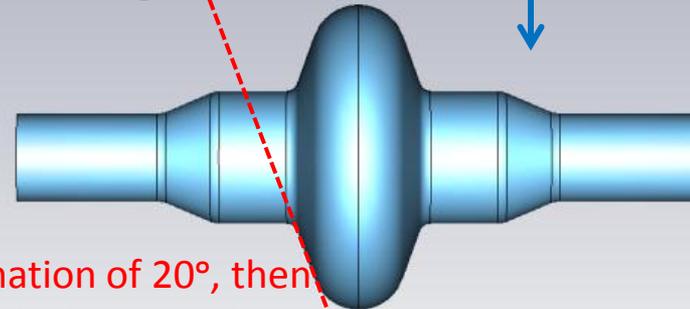
Fundamental mode @ 400 MHz

Don't care about the two end tapers, they don't affect the WM and the trapped HOMs. It was useful to realize a two units module prototype.



Fundamental mode @ 800 MHz

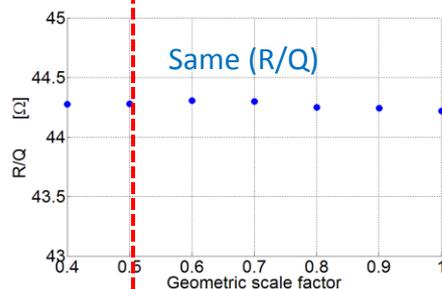
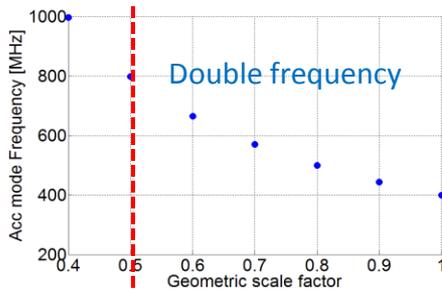
Scale factor 1/2



Same wall inclination of 20° , then using the same thickness and the same material the cavity should have a higher spring constant

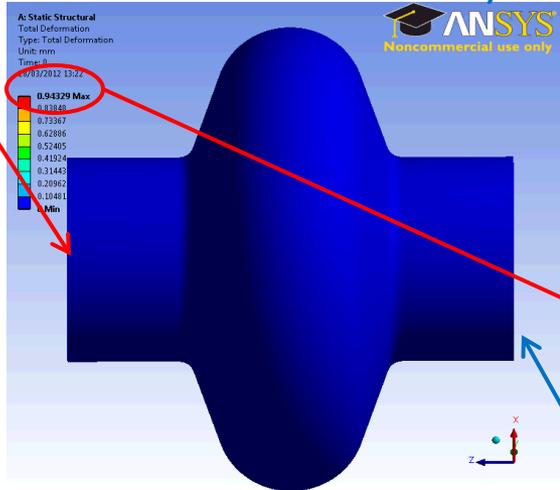
This could lead to a mechanical tuning issue!

As the theory reveals:



ANSYS – Static Structural Mechanical studies

LHC 400 MHz SC cavity



7.0 MPa of pressure

$$P = \frac{F}{A} = \frac{20}{\pi \cdot \left((r + 3^{-3})^2 - r^2 \right)} \left[\frac{kN}{m^2} \right] \rightarrow$$

To calculate the correct pressure to put on the 3 mm thickness of the beam pipe

$$K = \frac{20 kN}{\Delta l^{\max} [@ 20 kN]} \rightarrow$$

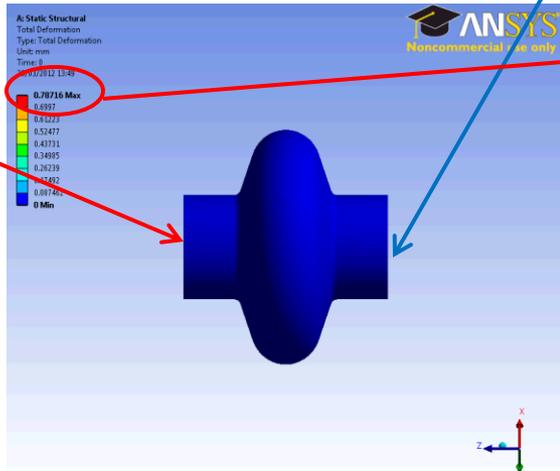
To calculate the spring constant

0.94 mm → K = 21.2 kN/mm

(Very close to the experimental data)

Fixed support

Factor 2 scaled 800 MHz cavity



13.8 MPa of pressure

0.70 mm → K = 30 kN/mm

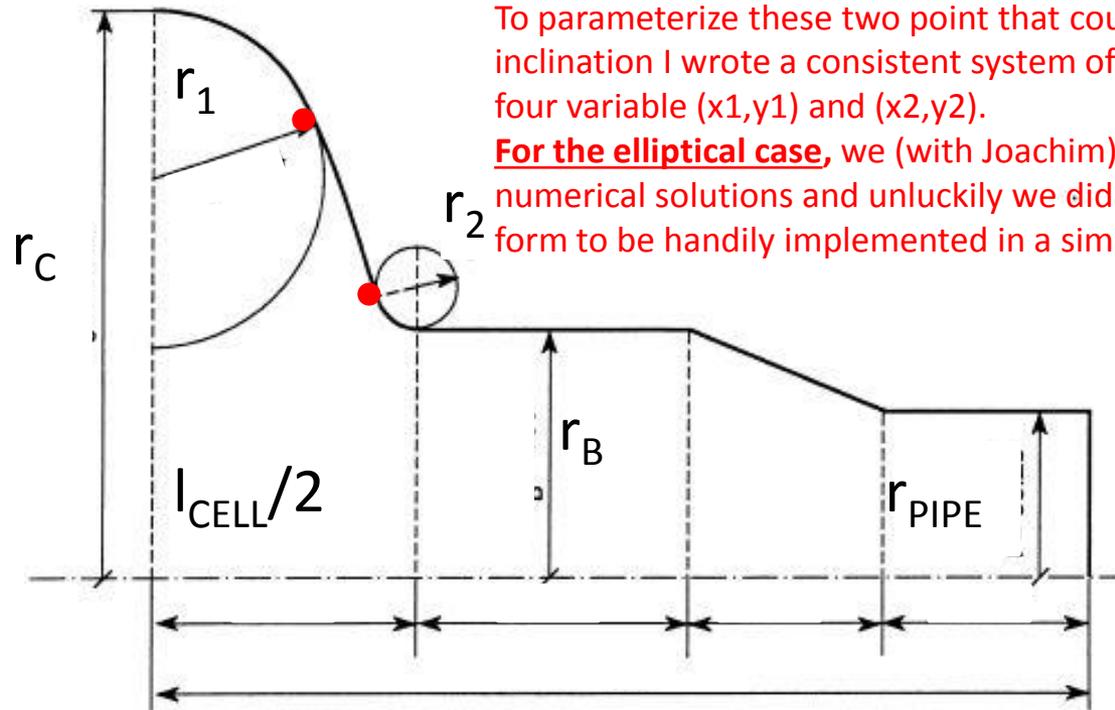
The cavity body seems to become 50% stiffer than in the 400 MHz case!!!

We must decrease the wall inclination.

After several discussion with Joachim and Rama we assumed that 10° could be adopted for the wall inclination to bring the spring constant at values less than or equal to the 400 MHz cavity case.

How can we change the wall inclination?

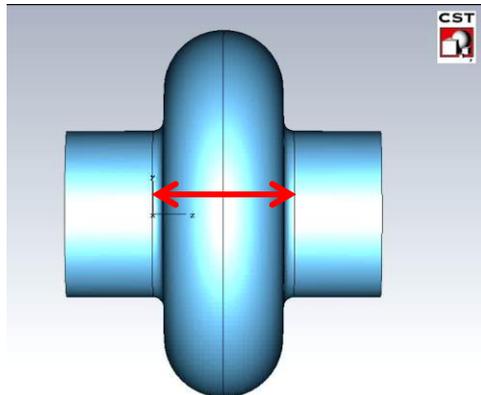
Parameters in mm	
l_{CELL}	160
r_C	172.3
r_B	75
r_1	52
r_2	12.5
r_{PIPE}	/



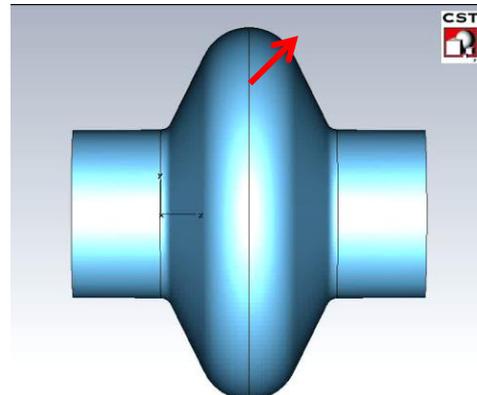
To parameterize these two points that could govern the wall inclination I wrote a consistent system of four equations in four variables (x_1, y_1) and (x_2, y_2).

For the elliptical case, we (with Joachim) had only found the numerical solutions and unluckily we did not find a closed form to be handily implemented in a simulator code

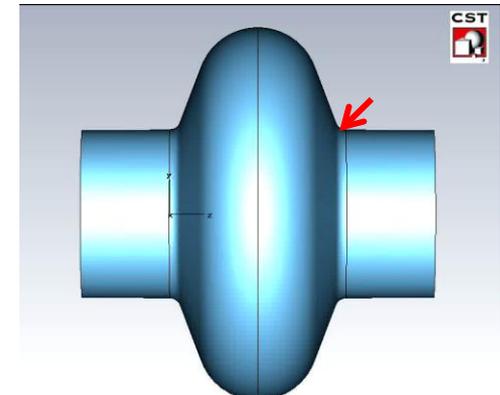
Cell length (l_{CELL})



Rounding radius (r_1)



Iris radius (r_2)

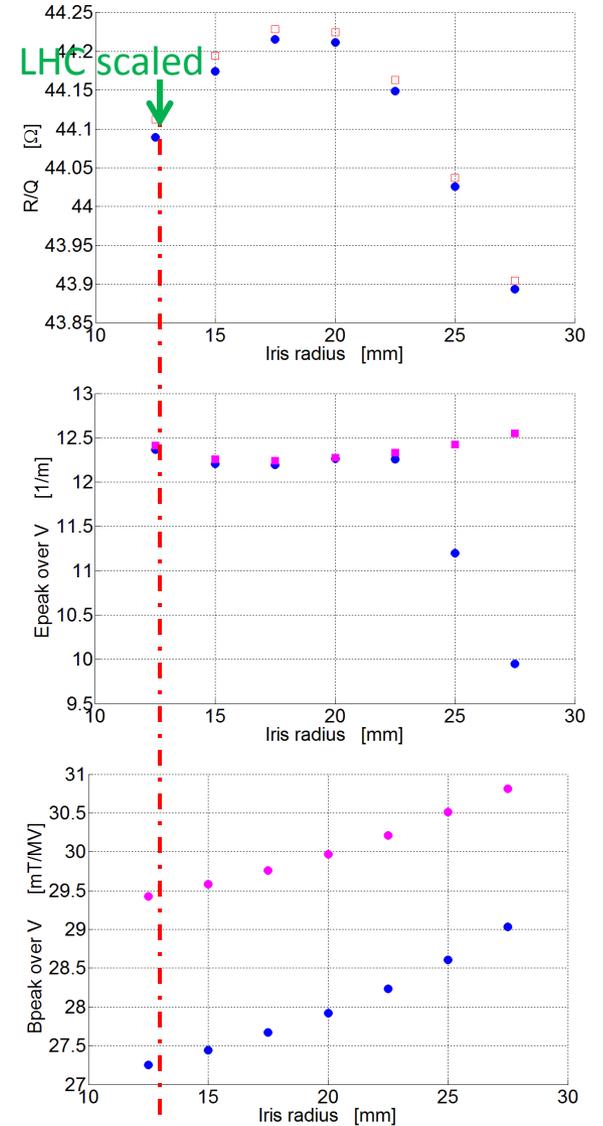
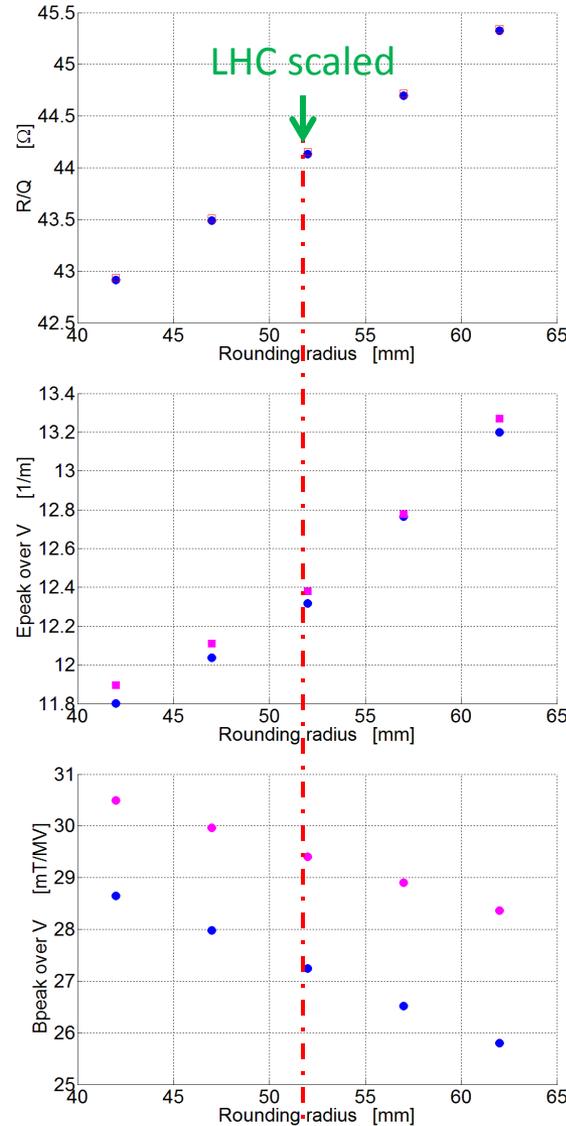
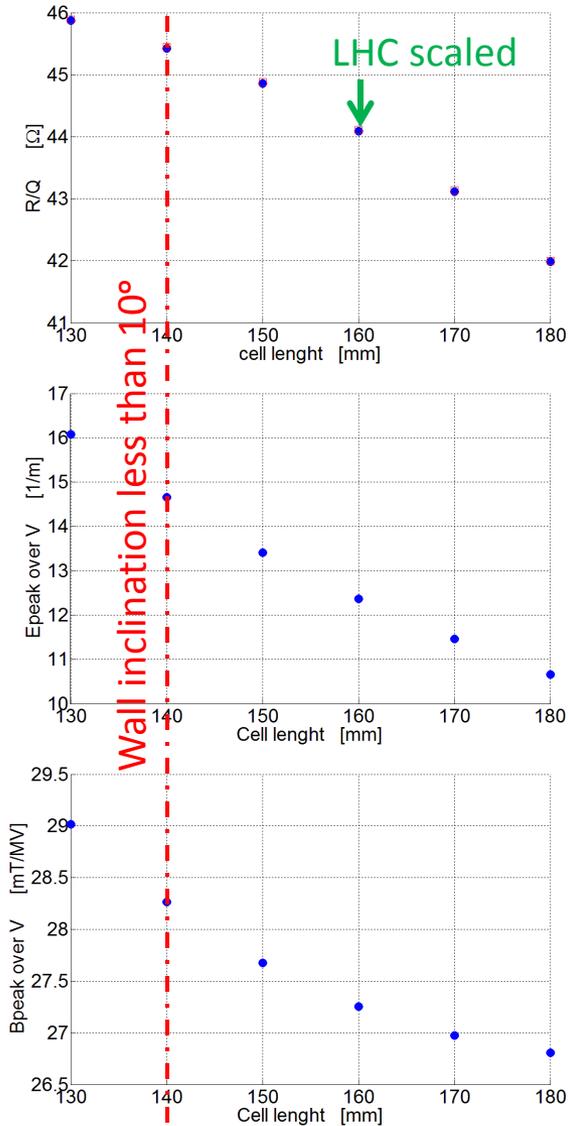


Wall inclination gymnastic for the WM (TM_{010})

Cell length (l_{CELL})

Rounding radius (r_1)

Iris radius (r_2)



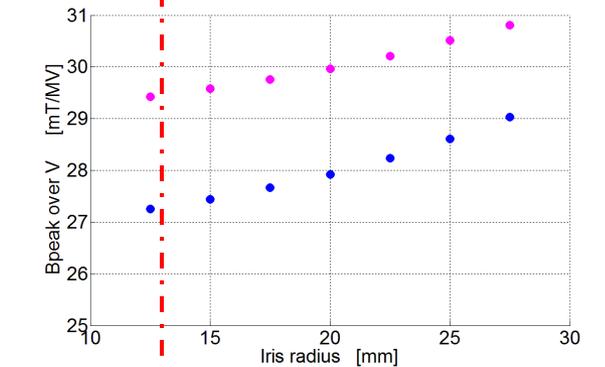
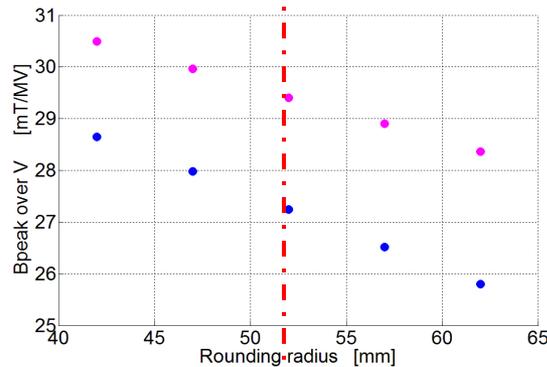
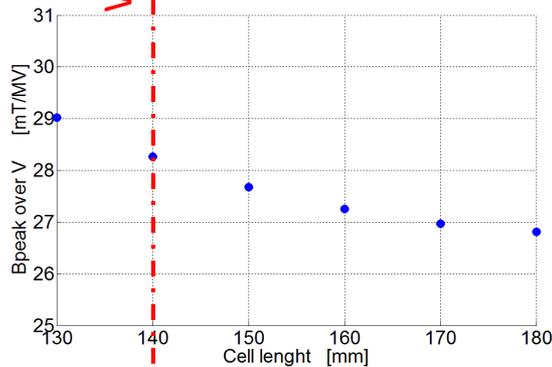
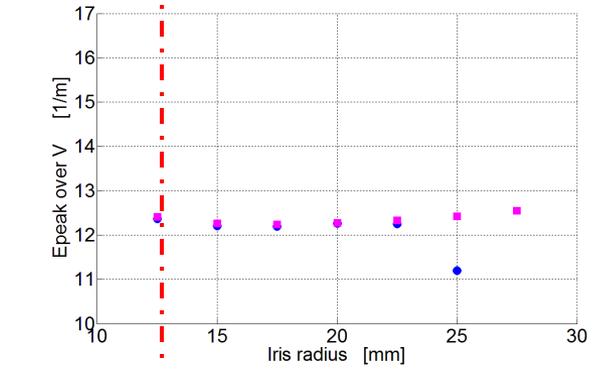
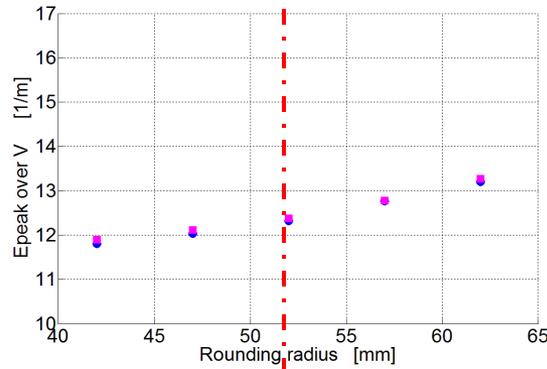
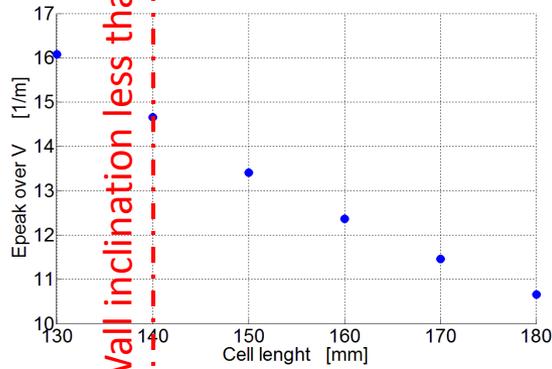
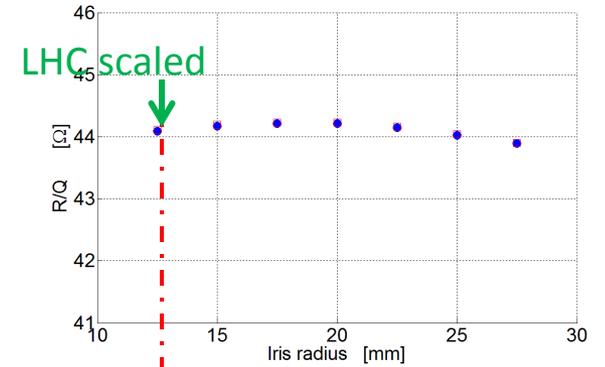
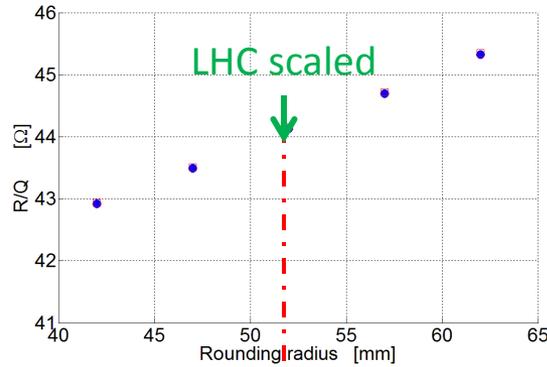
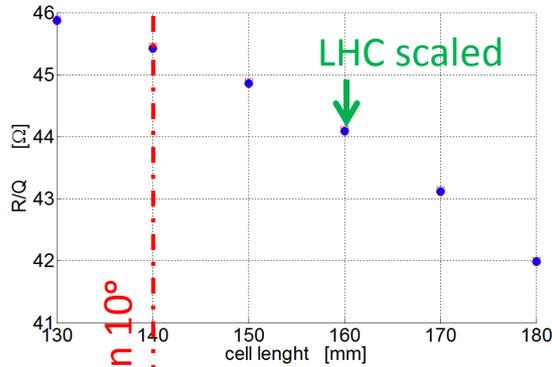
The cell radius (r_c) was varied to tune the working mode (WM) at 800 MHz

Wall inclination gymnastic for the WM (TM_{010})

Cell length (l_{CELL})

Rounding radius (r_1)

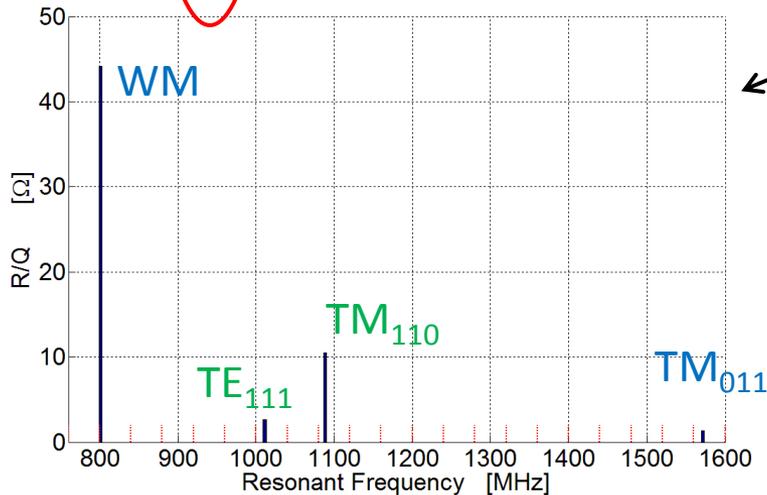
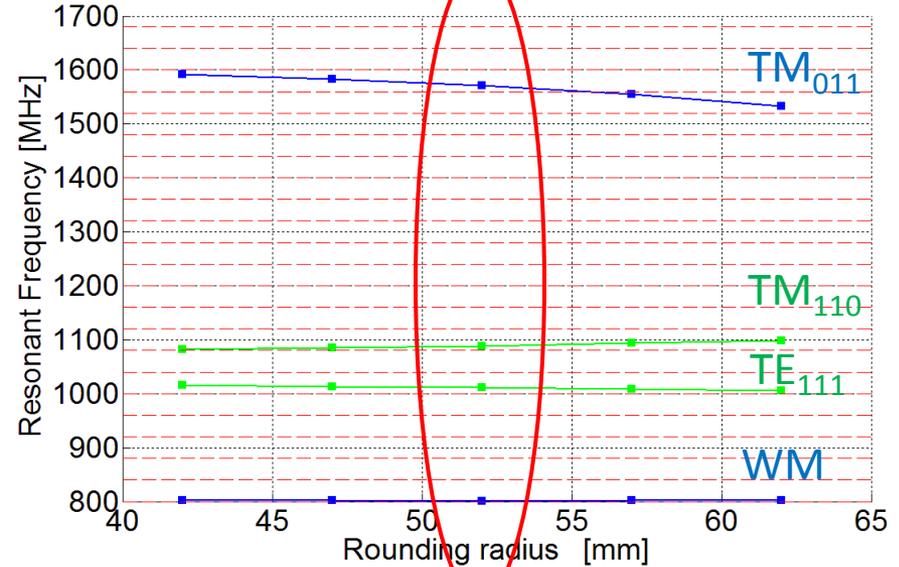
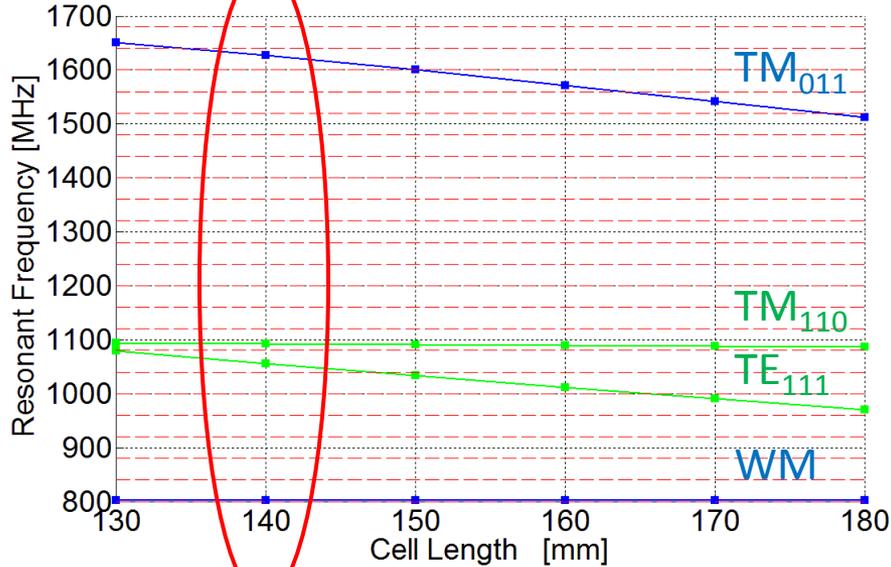
Iris radius (r_2)



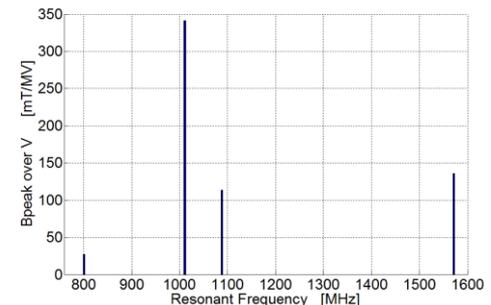
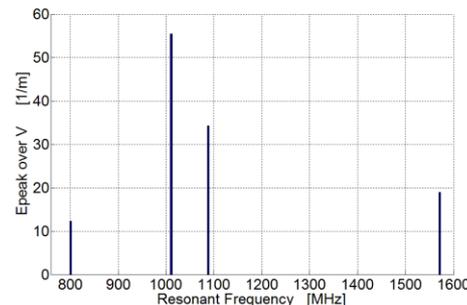
The cell radius (r_c) was varied to tune the working mode (WM) at 800 MHz

Wall inclination gymnastic for HOMs

There are three dangerous HOMs, two are **dipoles** and one is **monopole** having a considerable (R/Q) as the bottom figure shows. Here we have omitted other two trapped **quadrupole** modes because they have very low impedance values as will be shown later.

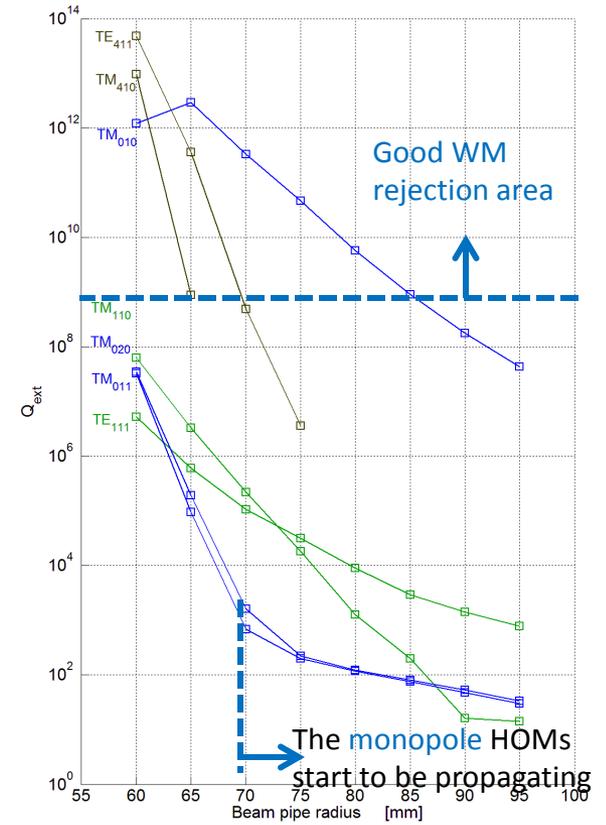
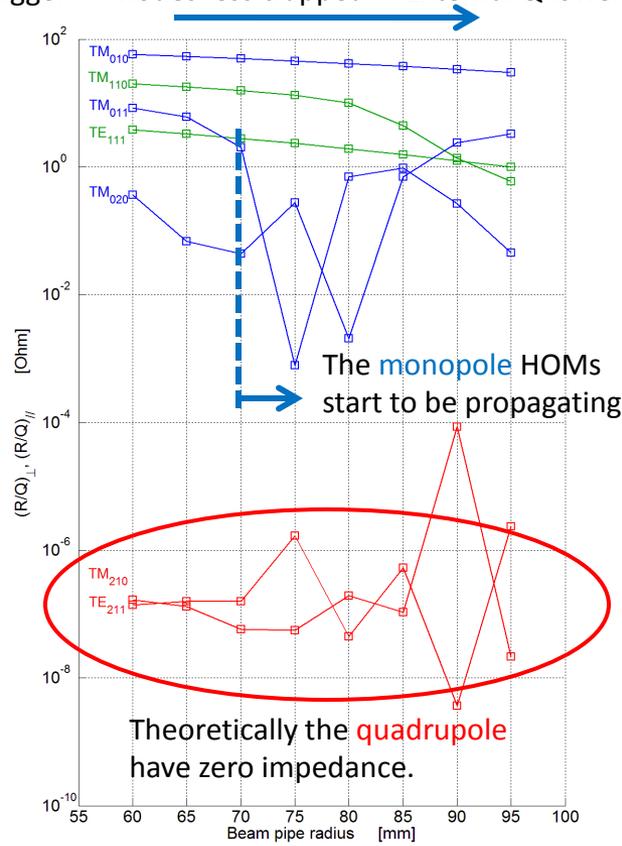
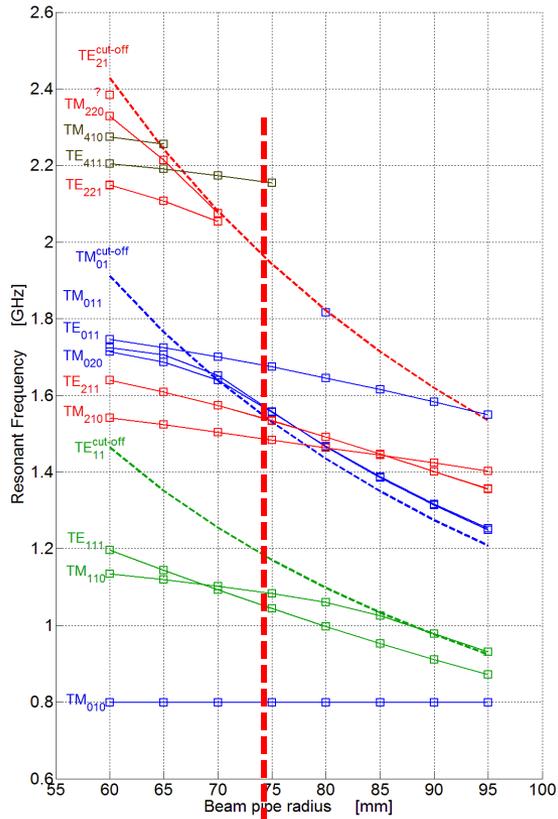


These values came from the LHC scaled design



Beam pipe radius gymnastic – global view

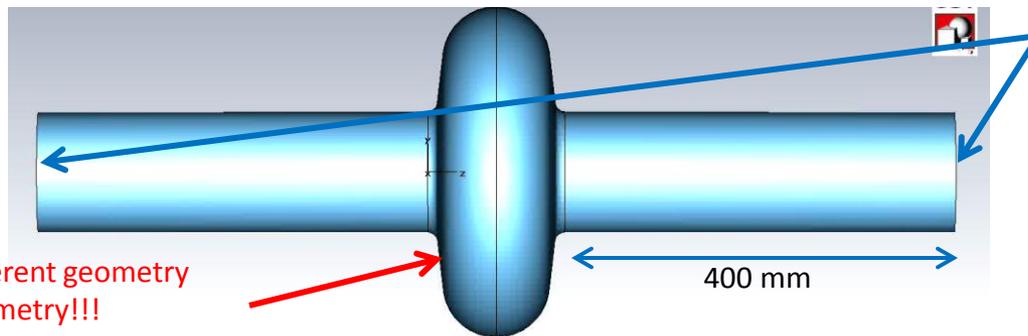
Beam pipe bigger -> Modes less trapped -> External Q lower -> (R/Q) lower



Working point chosen

- monopole
- dipole
- quadrupole

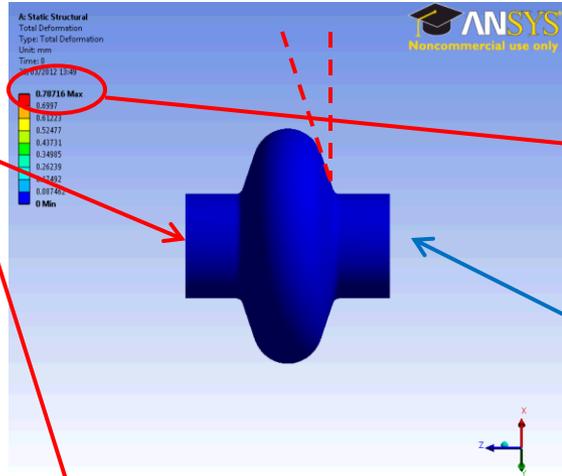
The body has a slightly different geometry respect the LHC scaled geometry!!!



Eigenmode simulation with wave port to estimate the HOM coupling with the pipe

ANSYS – How much the spring constant changes?

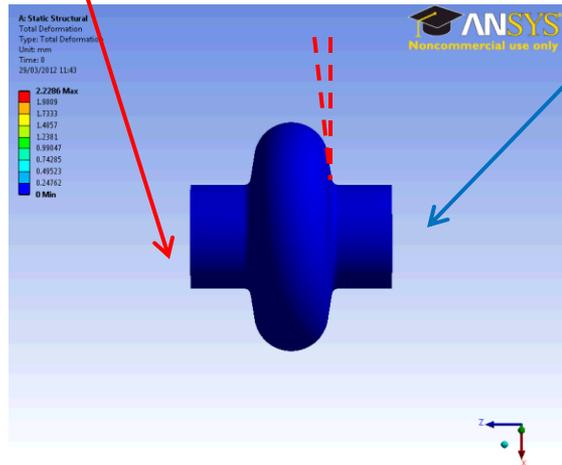
800 MHz cavity with 20° wall inclination



Reference case - too high !

0.70 mm → K = 30 kN/mm

800 MHz cavity with 10° wall inclination

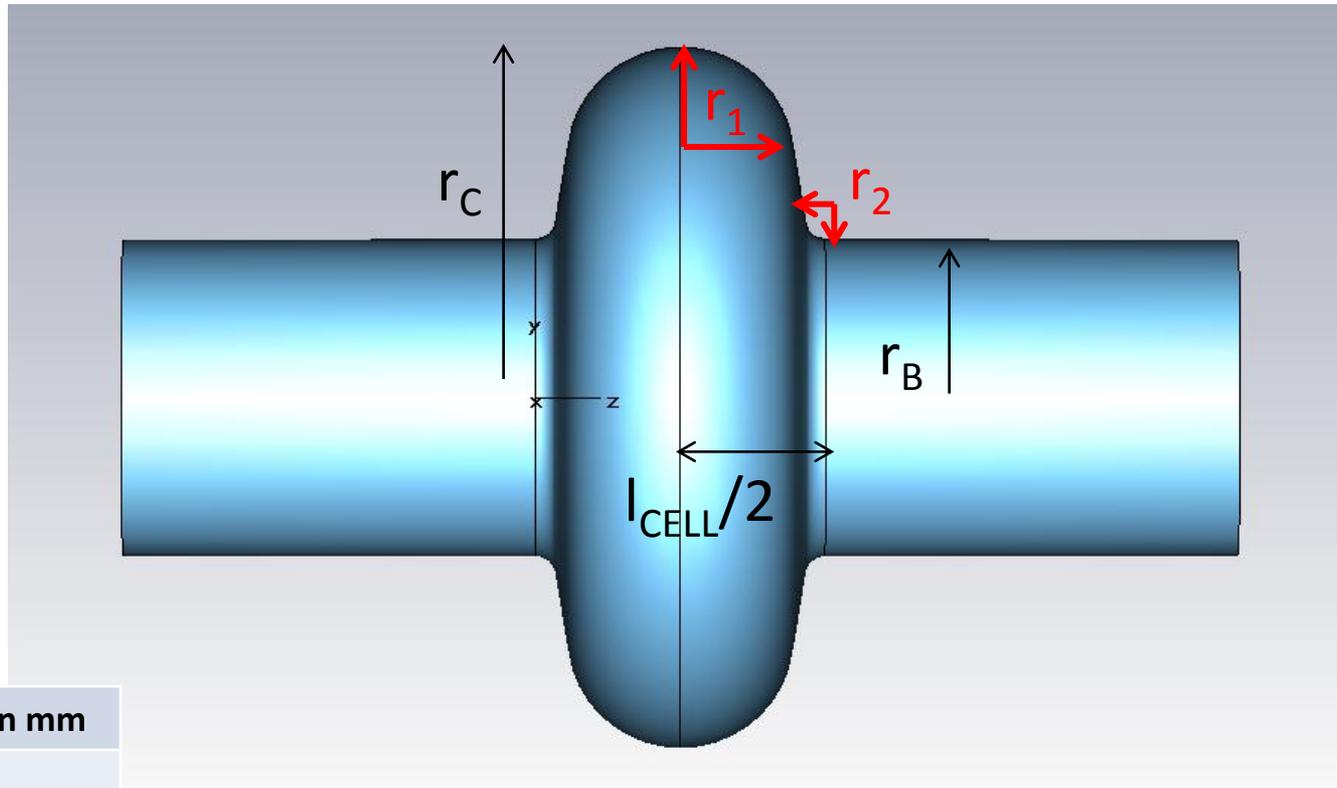


This cavity is more elastic
Is it acceptable ?

2.2 mm → K = 10 kN/mm

Using 140 mm for the cell length keeping the rounding radius and the iris radius as the direct scaled values from LHC 400 MHz cavity and slightly re-tune the cell radius, the wall inclination is about 10°. At such inclination the spring constant seems to be the half of the LHC 400MHz

Working point chosen



Parameters in mm

I_{CELL}	140
r_C	169.3
r_B	75
r_{1h}	52
r_{2h}	12.5
r_{PIPE}	/

Fres	800 MHz
R/Q	45.5 Ohm (circuit)
Epeak/Vacc	14.6 m ⁻¹
Hpeak/Vacc	28.2 mT/MV

HOMs Damping Couplers

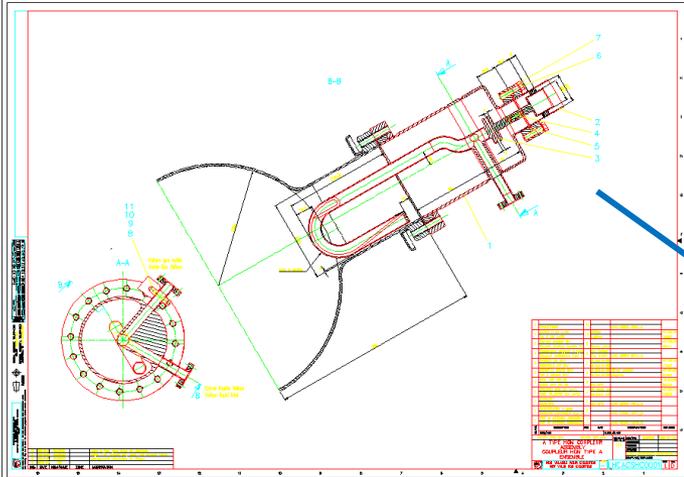
- 1) LHC couplers Type-A and Type-B;
- 2) LHC scaled cavity having HOMs couplers;
- 3) Other possibilities and ideas:
 - Try to decrease the number of couplers;
 - Propose other more recent damping systems;

Type-A: resonant, narrowband, dipole mode: for the two dipole modes around 1.1 GHz

Type-B: wideband, broadband: for all other modes

LHC HOM couplers

Type A - Narrowband Coupler



Type B - Broadband Coupler

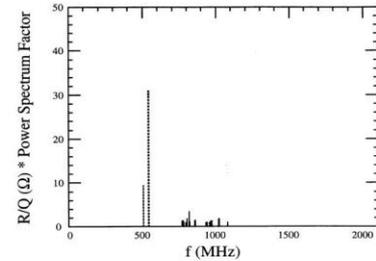
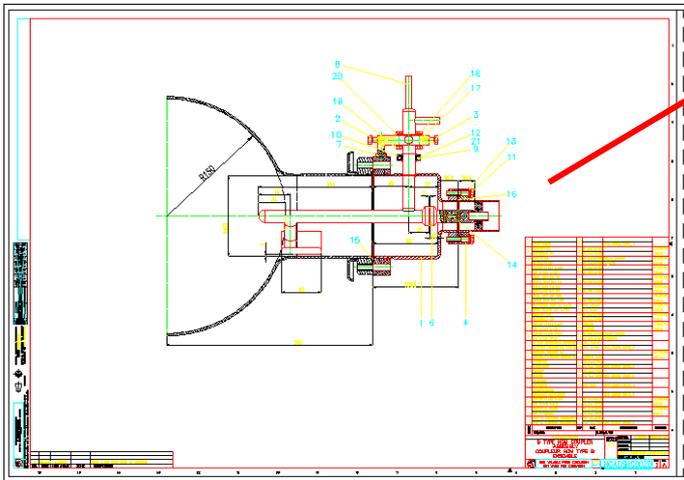


Figure 1: R/Q spectrum of four single cells. The R/Q values are multiplied by the power spectrum factor for the nominal LHC bunch: \cos^2 shaped and 30 cm full bunch length.

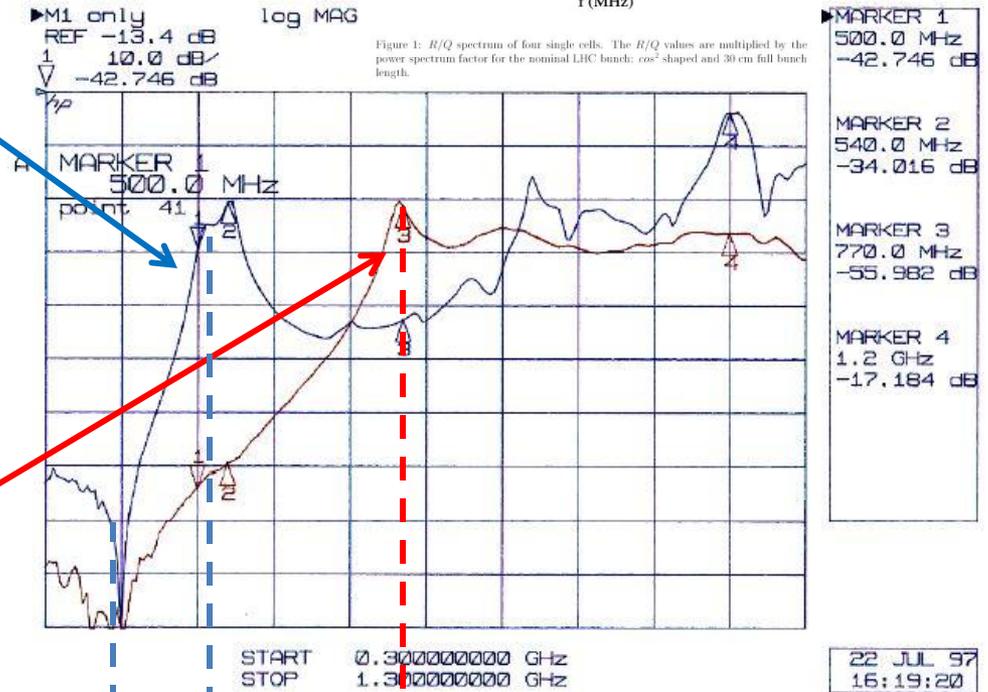


Figure 7: Characteristics of both couplers

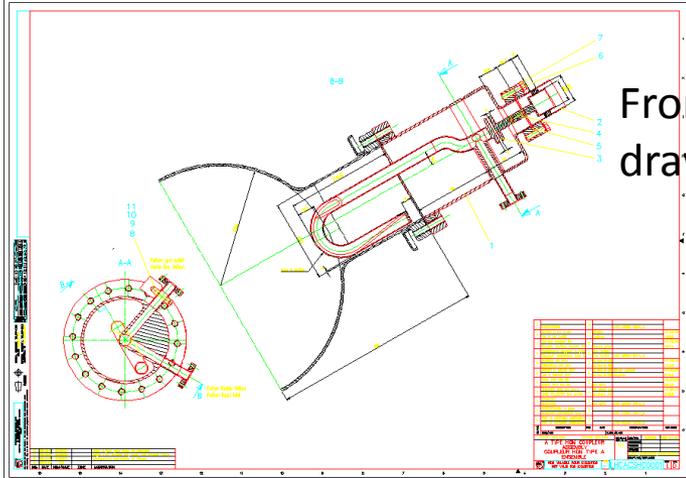
Notch filter
at 400 MHz

Broad pass band starting at 770 MHz

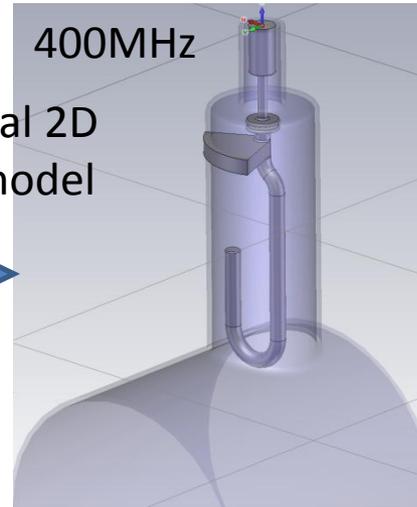
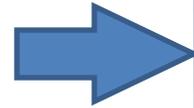
Dipole pass-band around 530 MHz

LHC HOM couplers

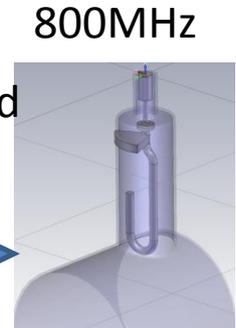
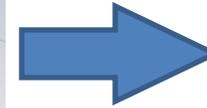
Type A - Narrowband Coupler



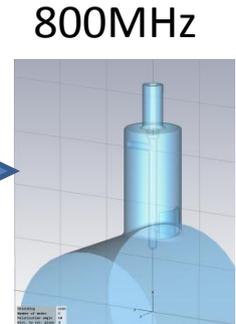
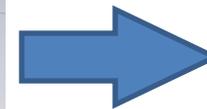
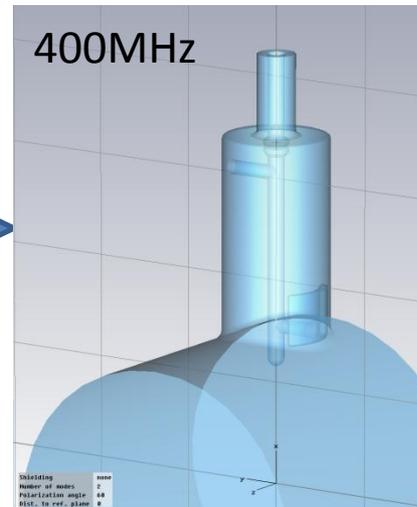
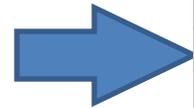
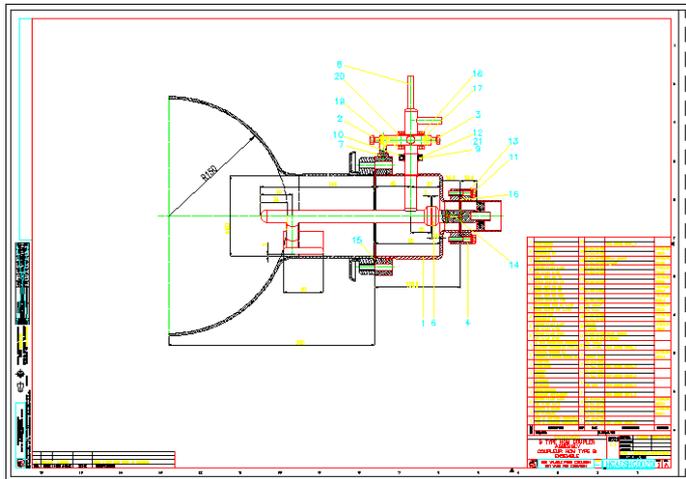
From technical 2D
draw to 3D model



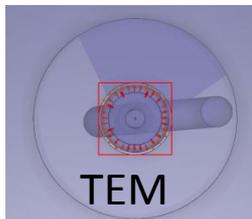
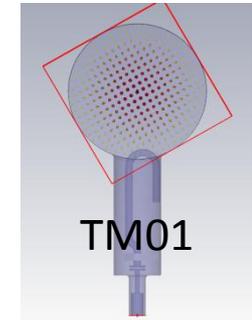
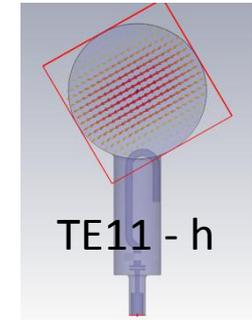
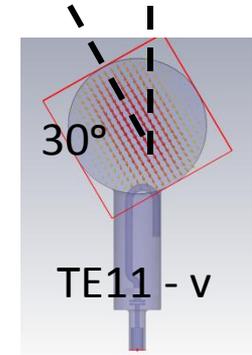
Half scaled
geometry



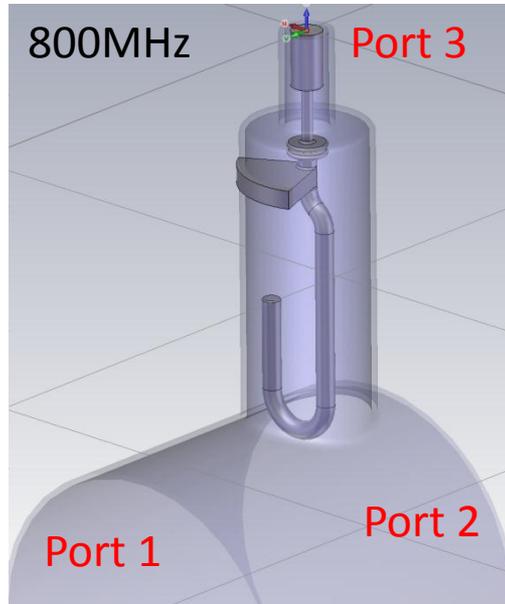
Type B - Broadband Coupler



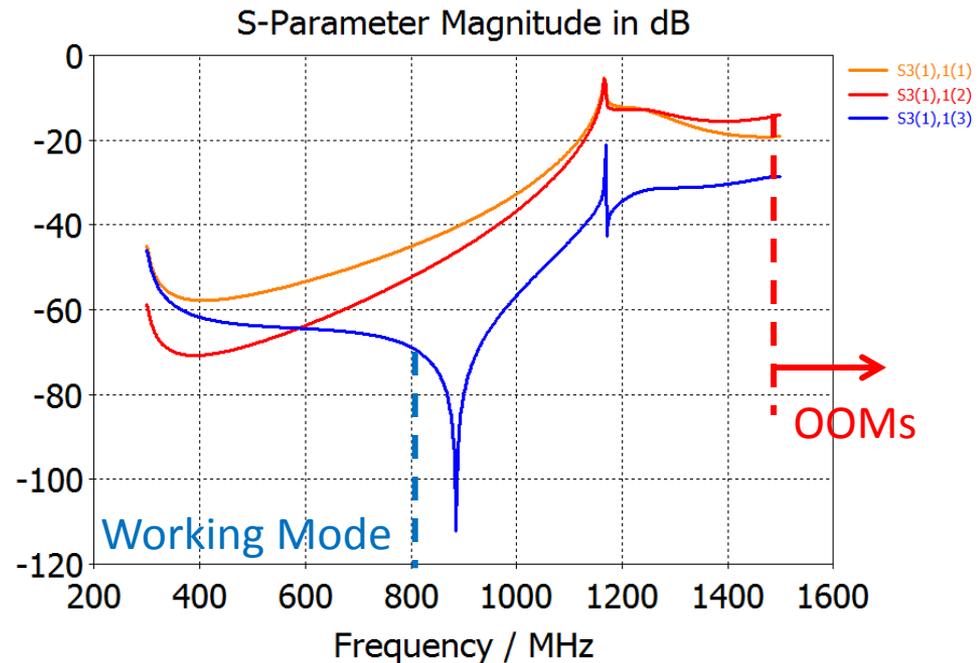
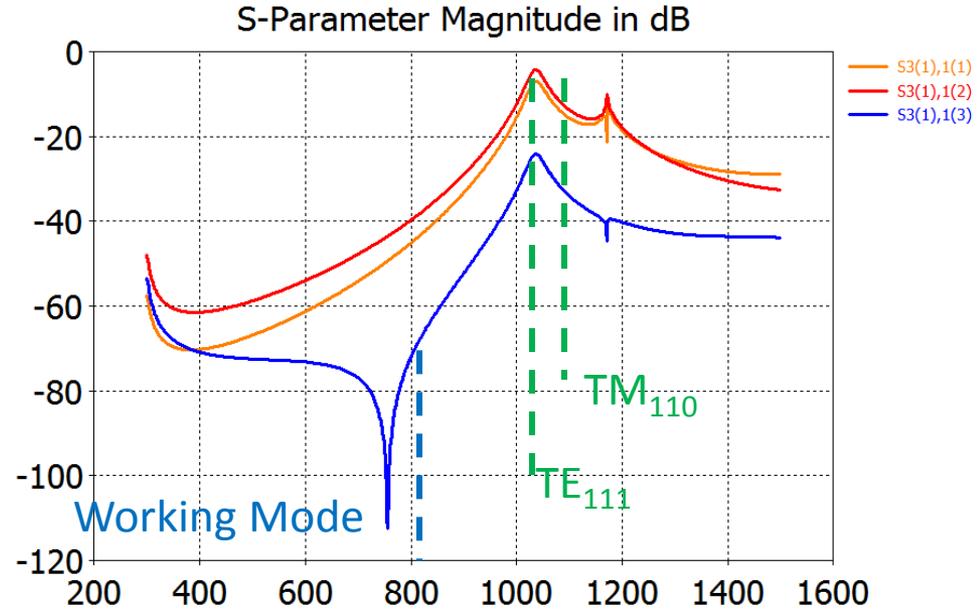
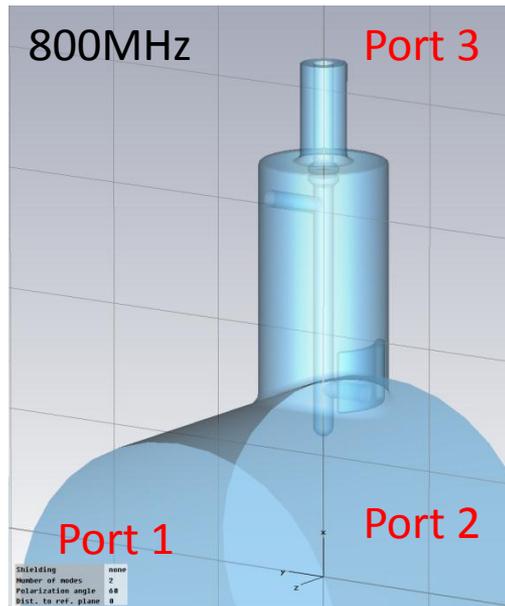
800 MHz HOM couplers - Frequency response



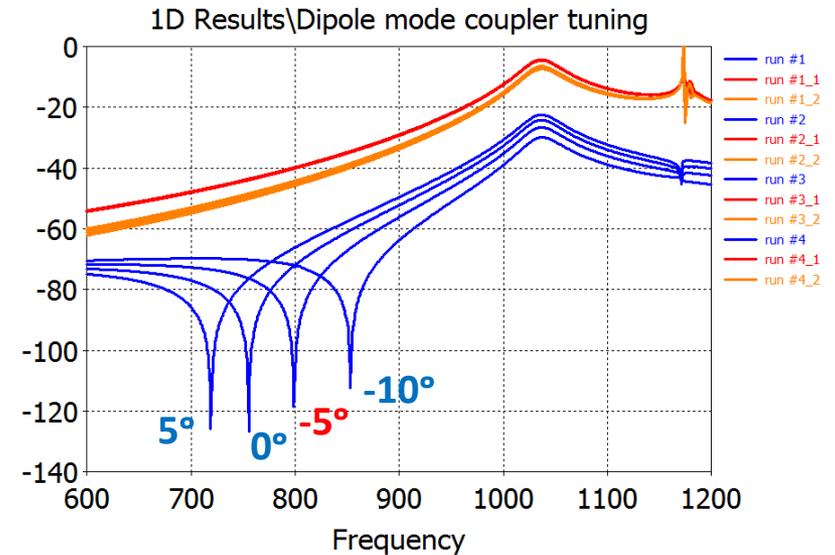
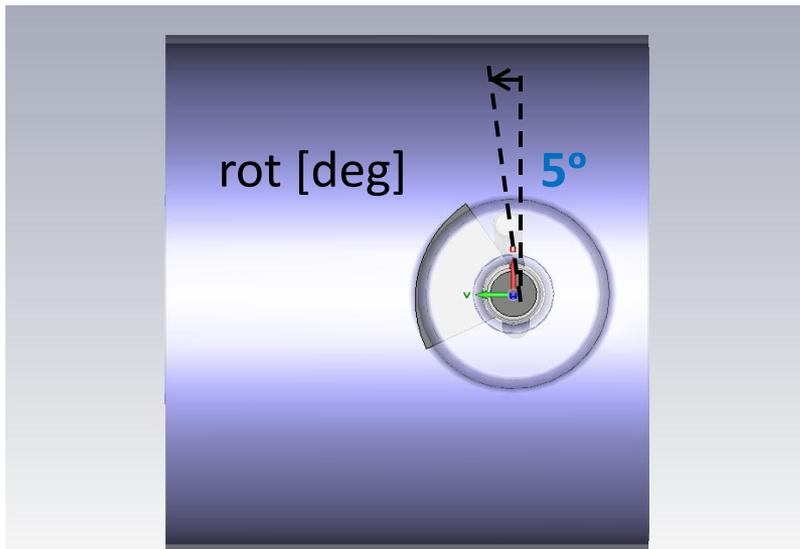
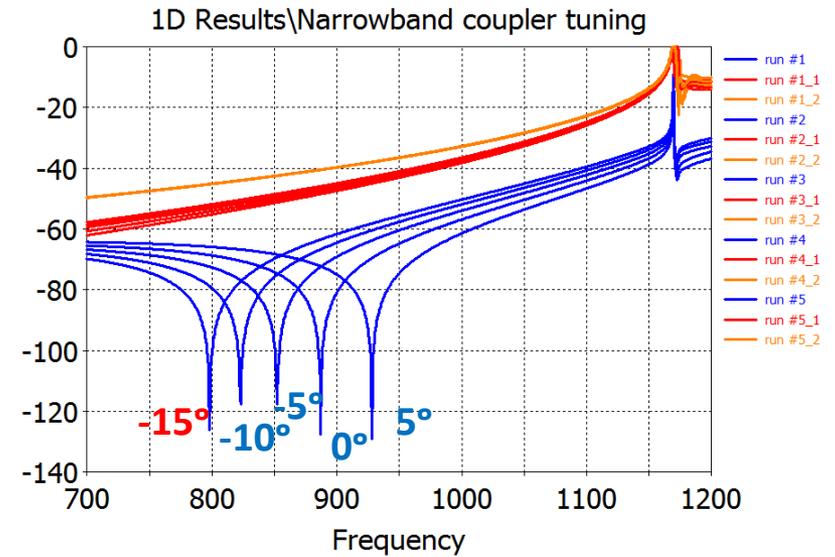
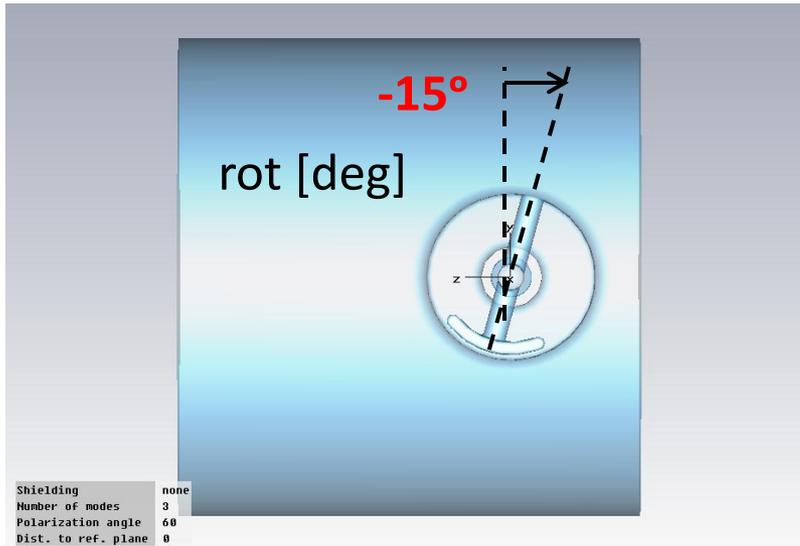
Narrowband Coupler



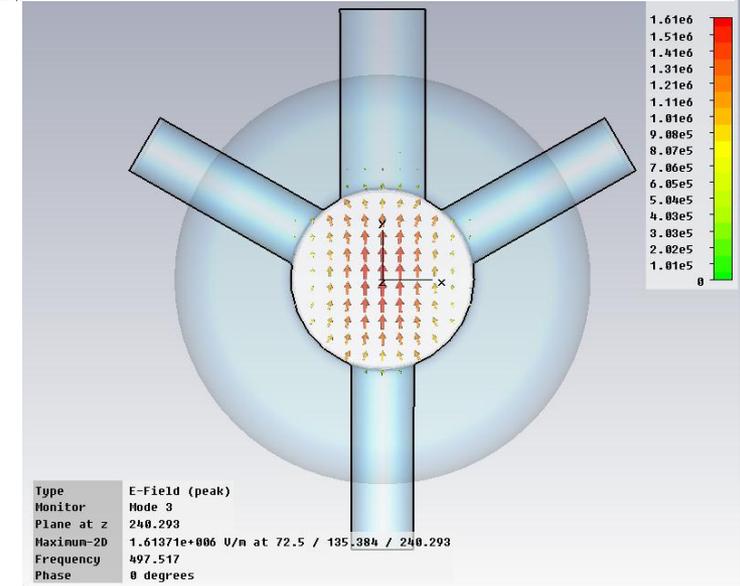
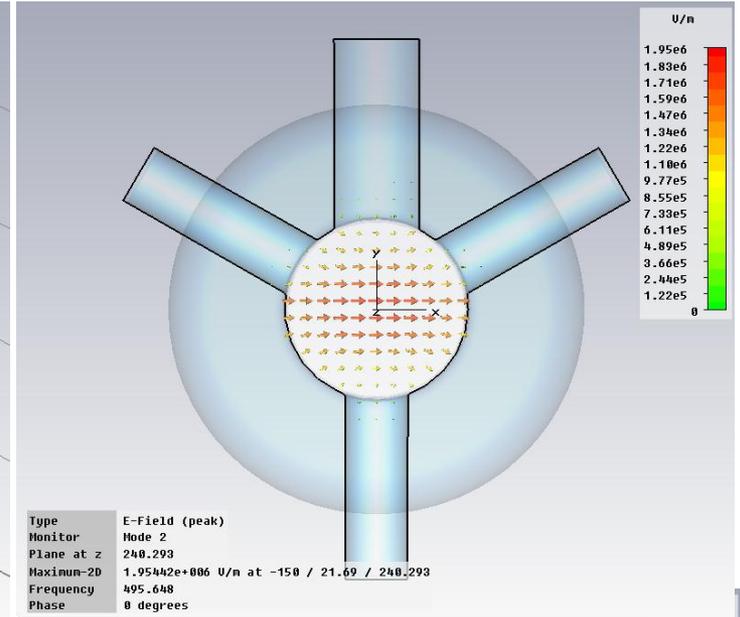
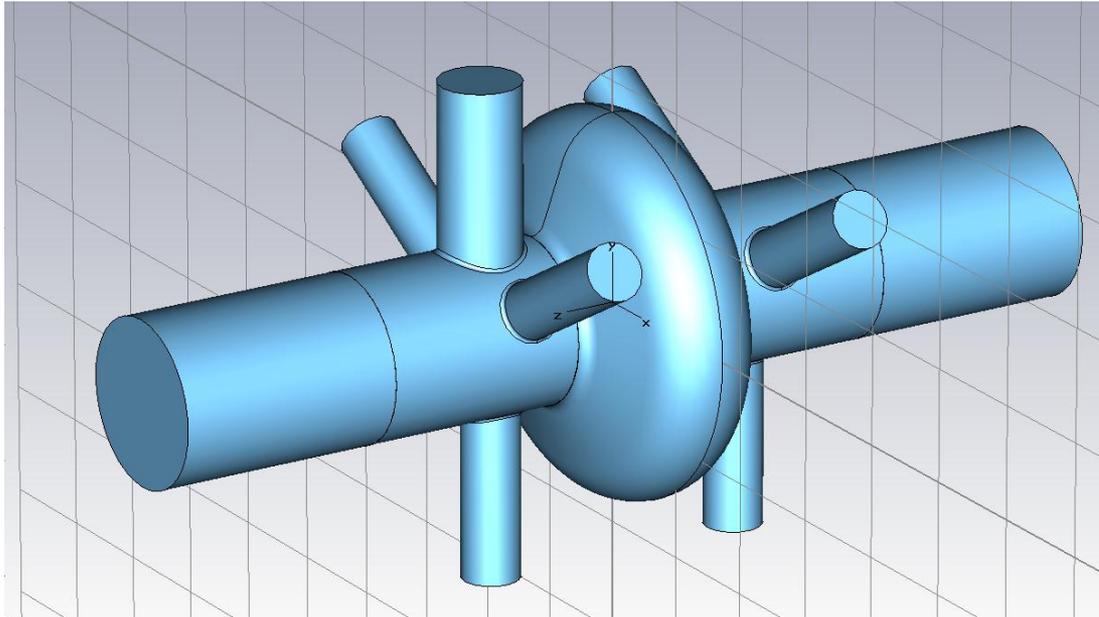
Broadband Coupler



800 MHz HOM couplers - Tuning



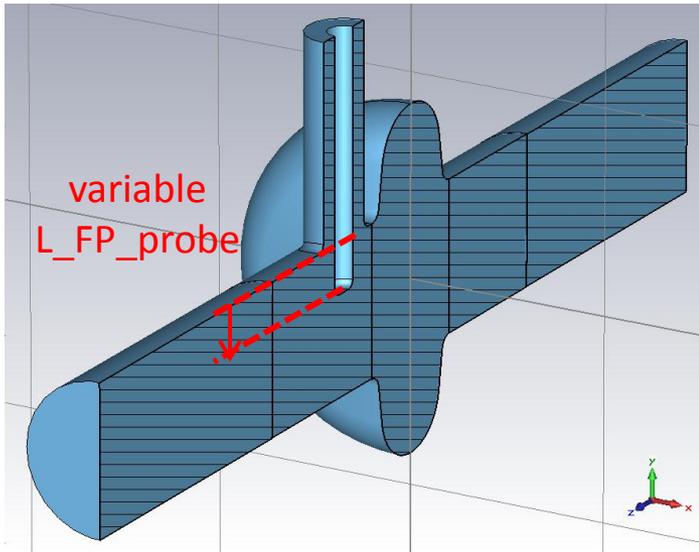
“LHC scaled” version with damping system



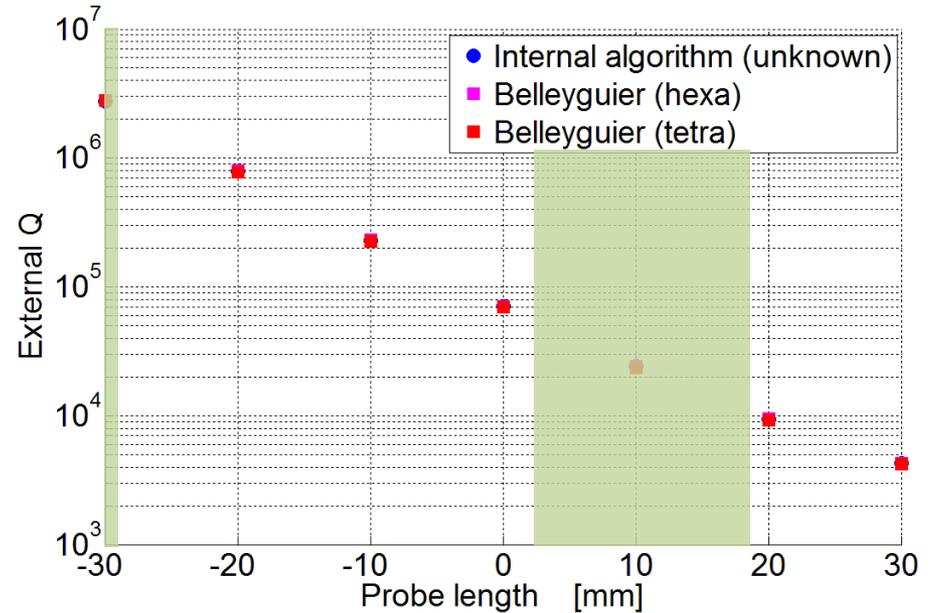
The last steps will be to put the Main coupler, the HOMs coupler and check or verify the damping

Main coupler design (FPC) - 1/3

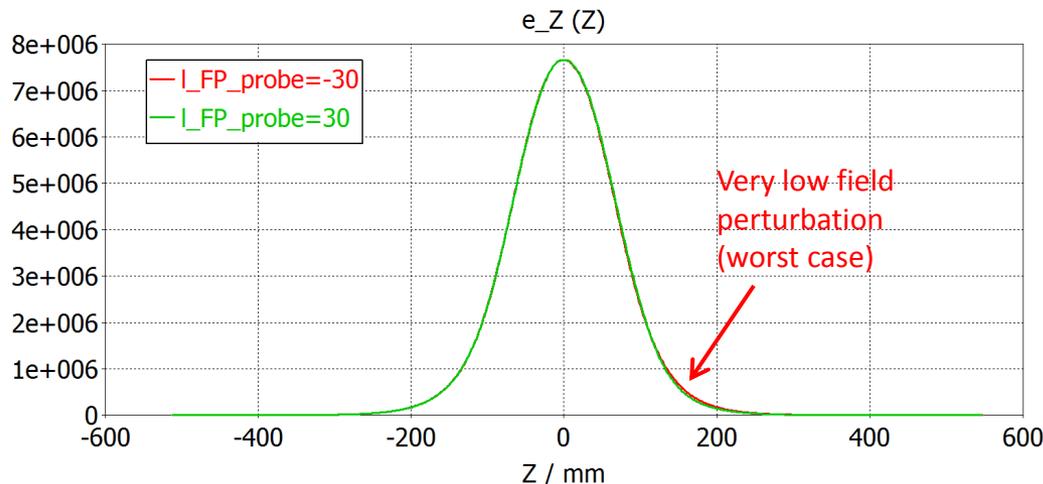
A simple coaxial line: $Z_o = \sqrt{\frac{\mu}{\epsilon}} \frac{\ln D/d}{2\pi} = 50 \Omega$



Belleyguier vs CST method



P. Belleyguier, "A Straightforward method for cavity external Q computation", Particle Accelerators, 1997.

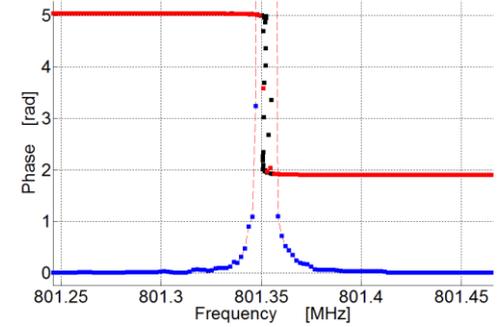
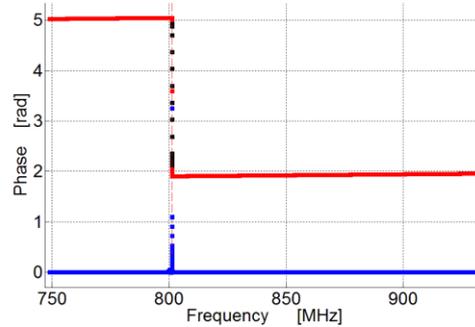
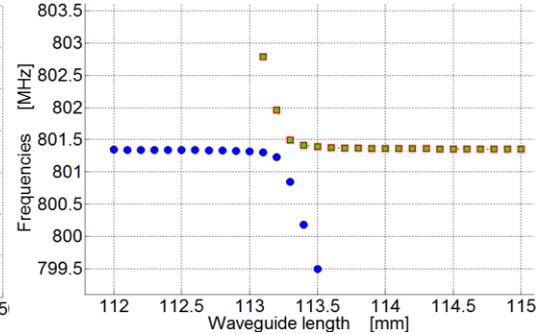
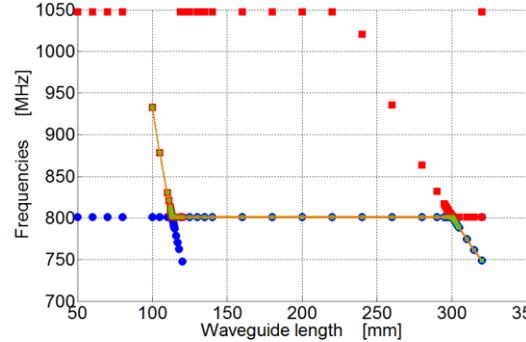
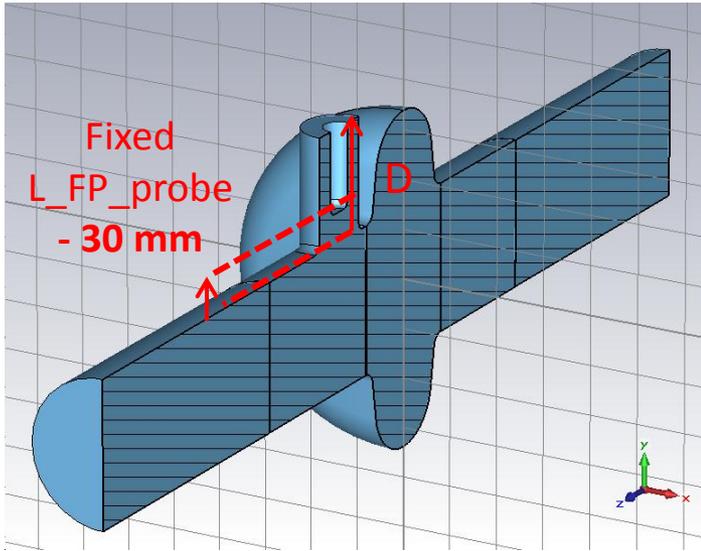


- 1) Balleyguier method, a frequency domain process, seems agree with the unknown CST built-in method and it is consistent changing the meshing cells.
- 2) We have verified that it works properly at relatively high external Q.
- 3) We will have to handle with much higher Q dealing with HOM couplers.

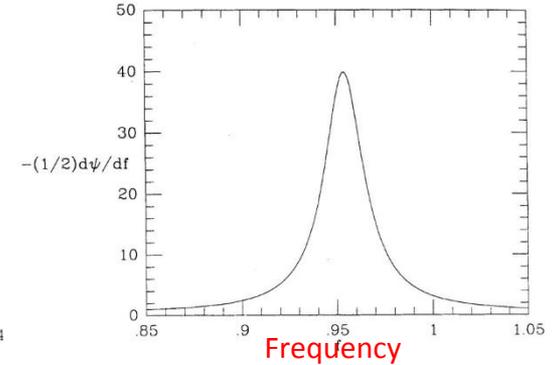
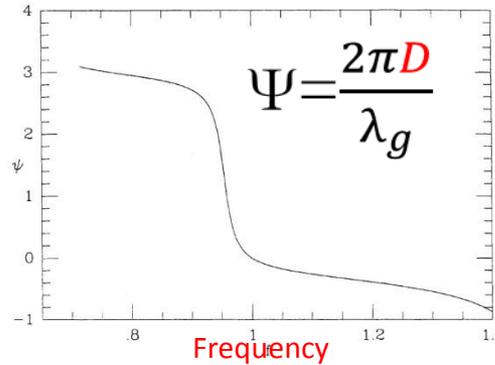
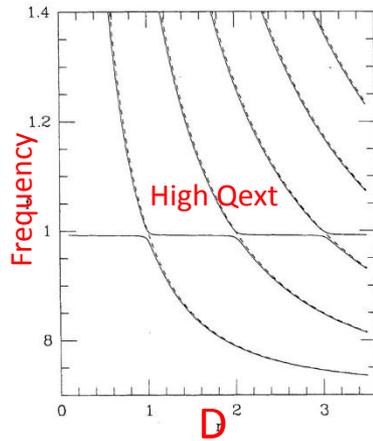
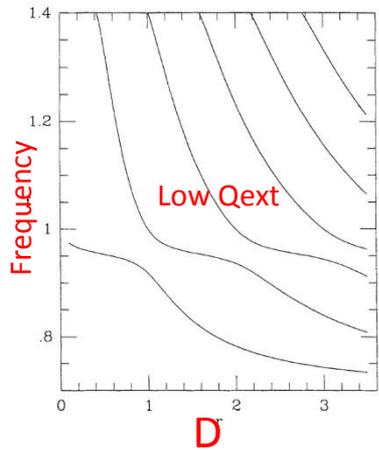
Main coupler design (FPC) - 2/3

A simple coaxial line: $Z_o = \sqrt{\frac{\mu}{\epsilon}} \frac{\ln D/d}{2\pi} = 50 \Omega$

Kroll – Yu methods



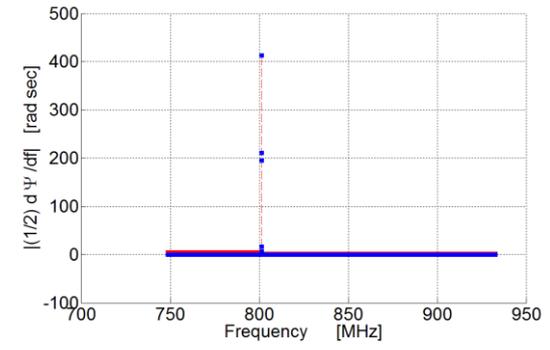
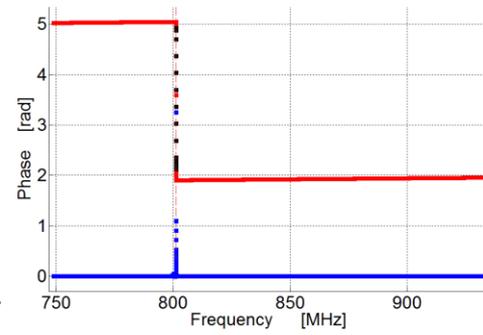
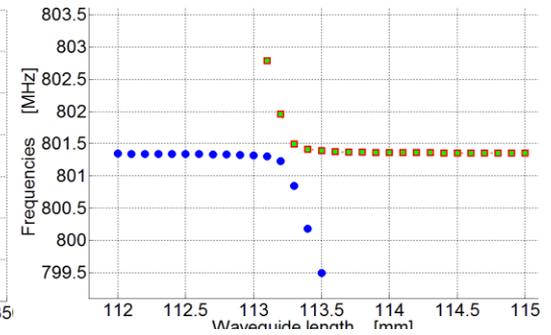
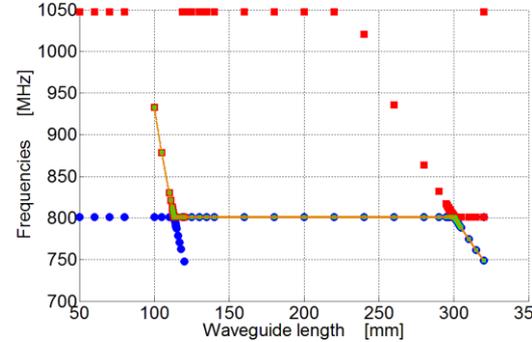
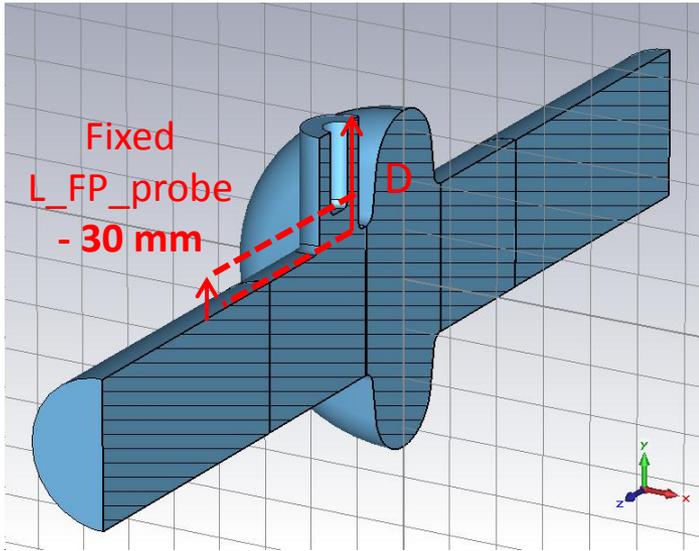
Kroll & Yu, "Computer determination of the external Q and resonant frequency of waveguide loaded cavities", Particle Accelerators, 1990.



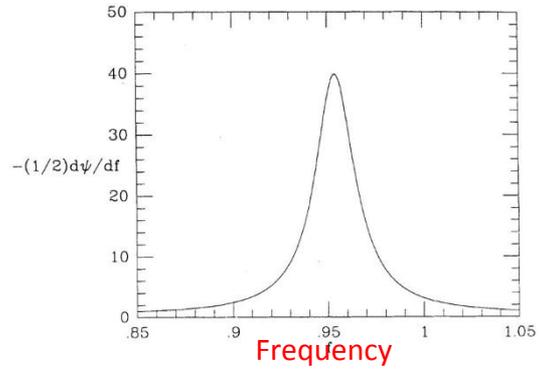
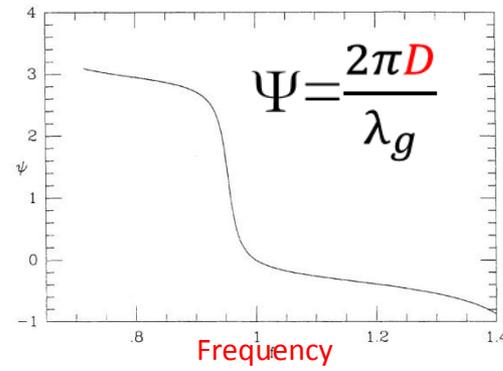
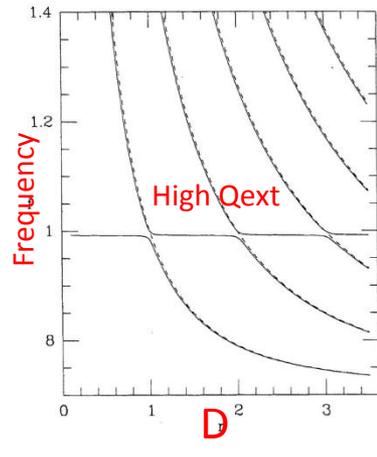
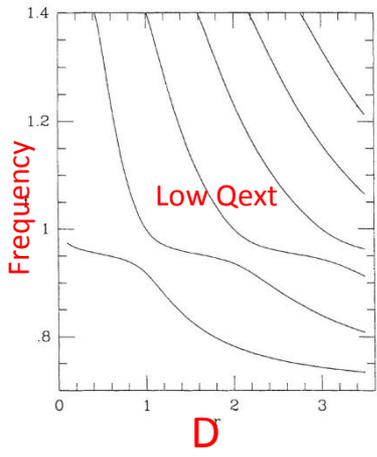
Main coupler design (FPC) - 2/3

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Kroll – Yu methods

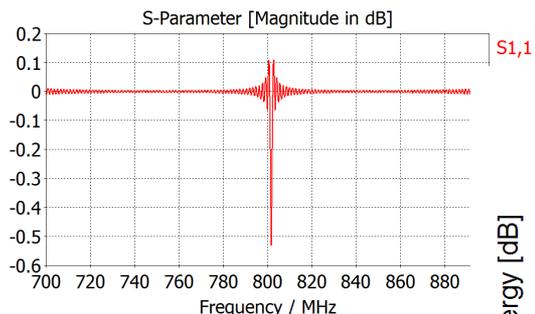
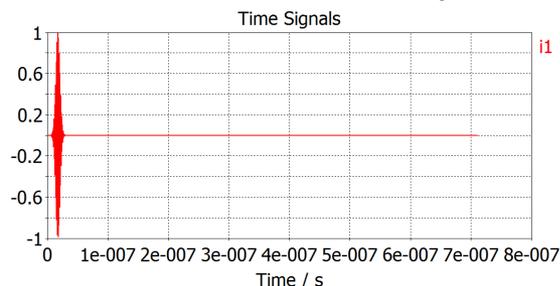


Kroll & Yu, "Computer determination of the external Q and resonant frequency of waveguide loaded cavities", Particle Accelerators, 1990.

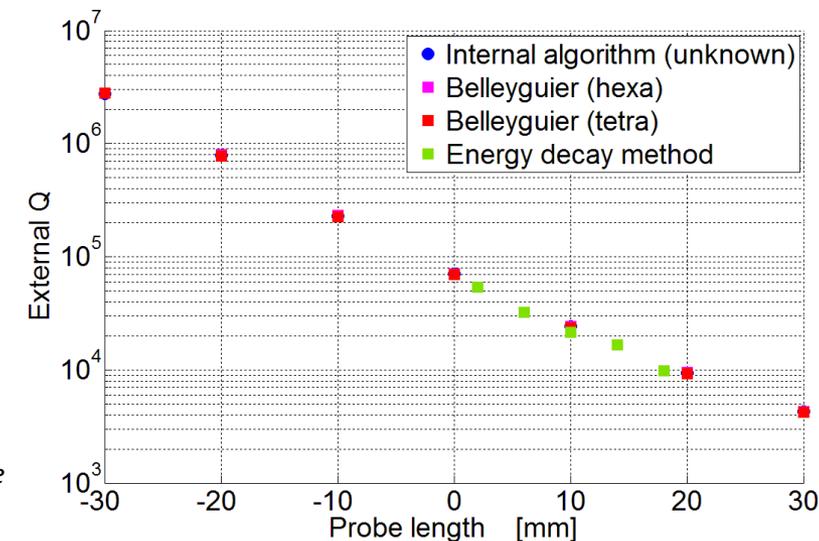
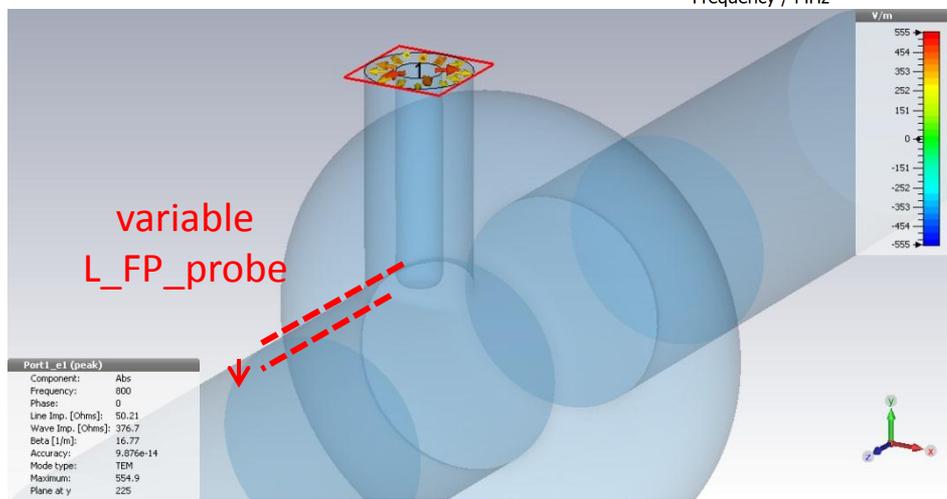
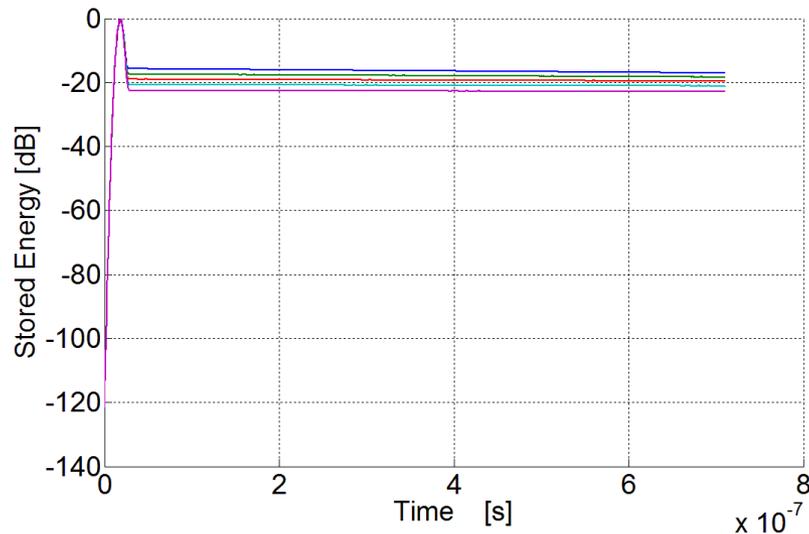


Main coupler design (FPC) - 3/3

Gaussian modulated pulse:



Time Domain method



The cavity material is set to a PEC, the energy decay is only determined by the coupling power:

$$U(t) = U_0 \exp\left(\frac{-\omega t}{Q_L}\right) \xrightarrow{Q_L = Q_{ext}} Q_{ext} = -\frac{10 \log(e) \omega_0}{k}$$

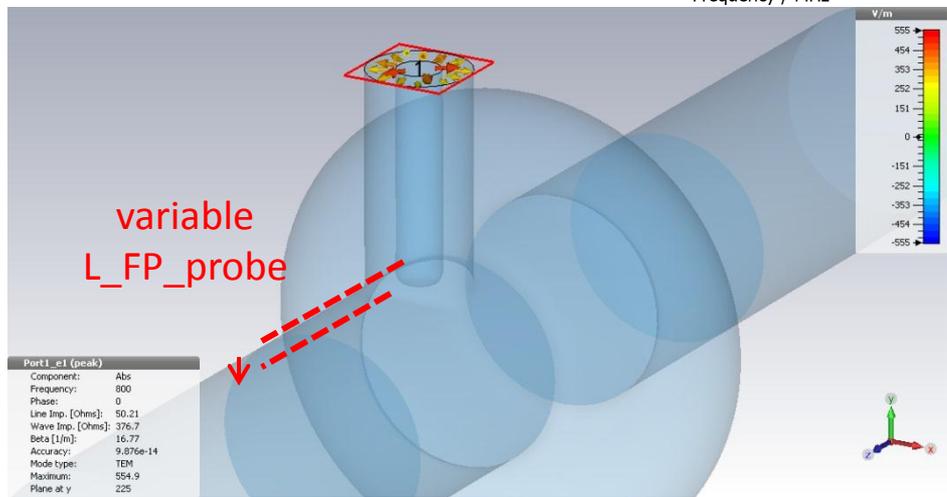
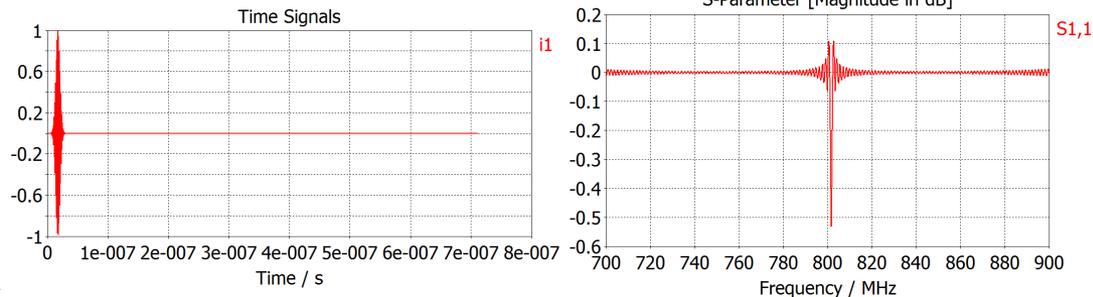
D. Li, et.al., "Calculation of External Coupling to a Single Cell RF Cavity", LINAC 1998.

J. Shi, et.al., "Comparison of measured and calculated coupling between a waveguide and an RF cavity using CST", EPAC 2006.

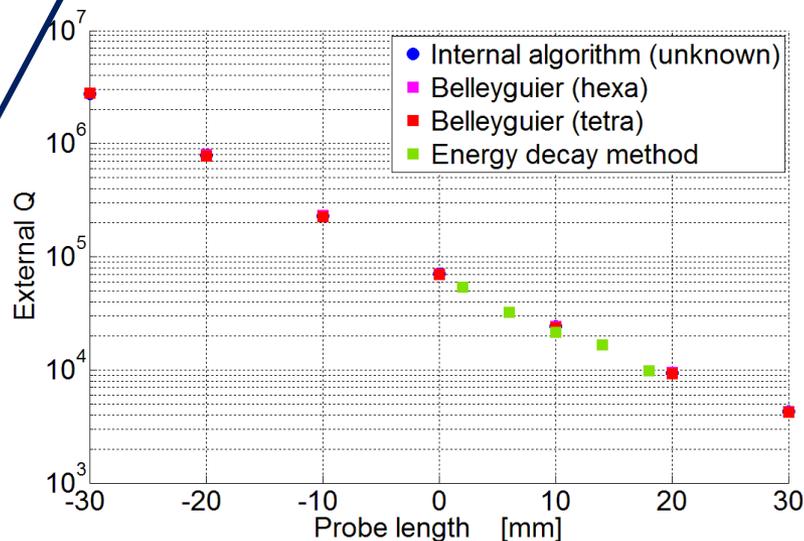
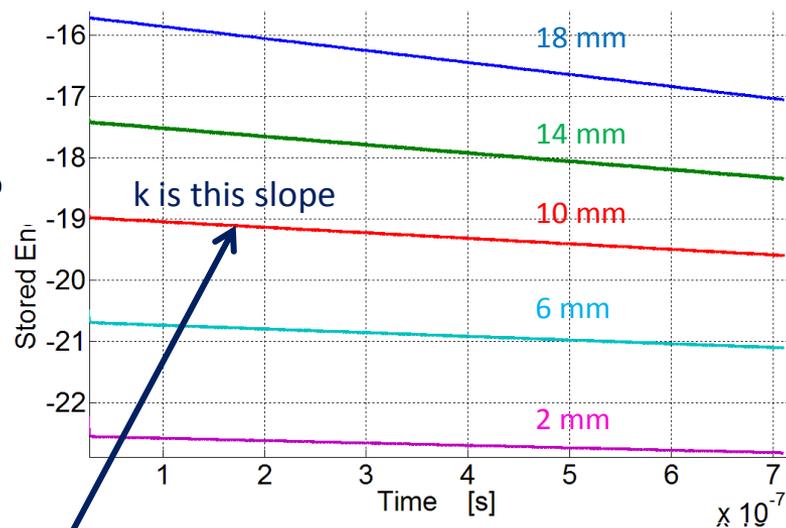
Huang Tong-Ming, et.al., "Calculation of the external quality factor of the high power input coupler for the BEPC II superconducting cavity", Chinese Physics C, 2008.

Main coupler design (FPC) - 3/3

Gaussian modulated pulse:



Time Domain method



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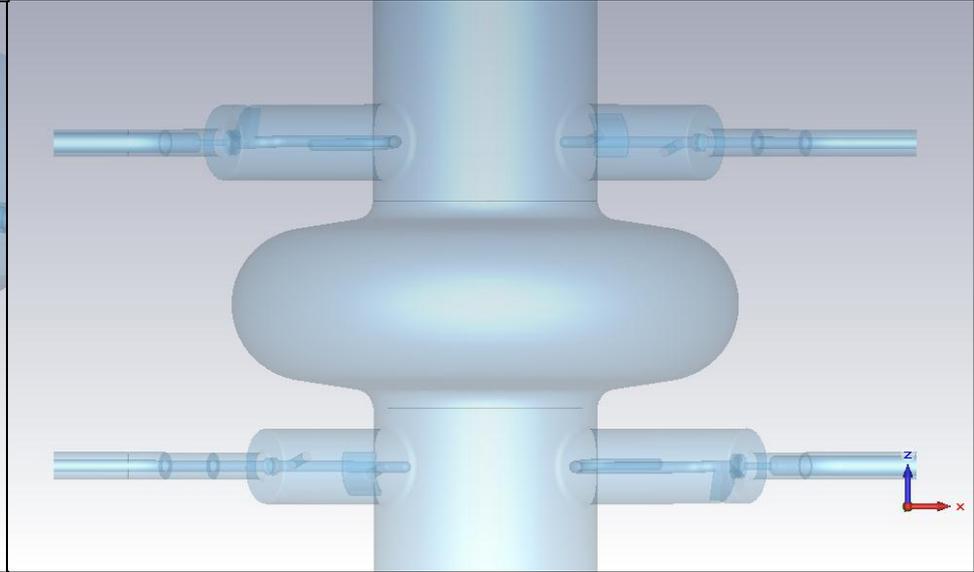
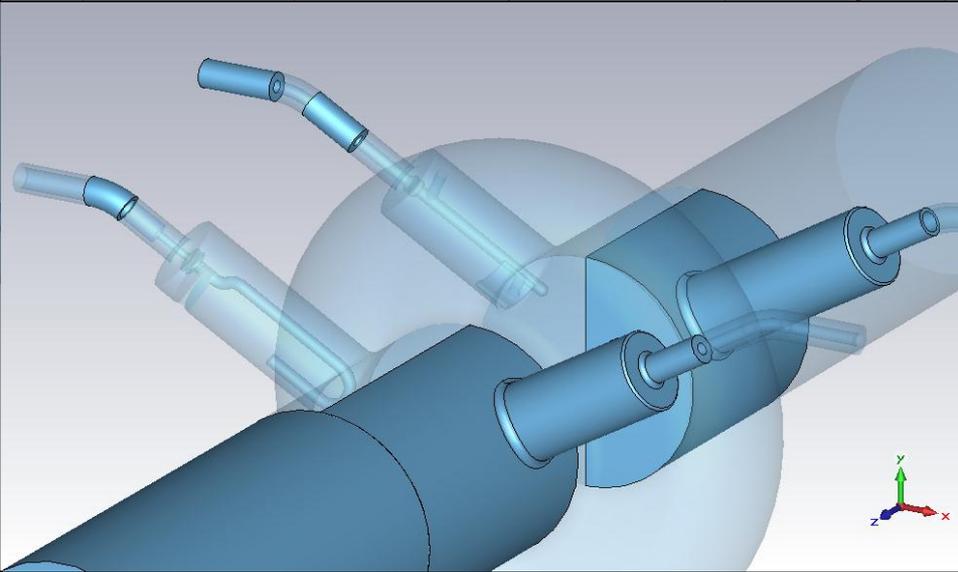
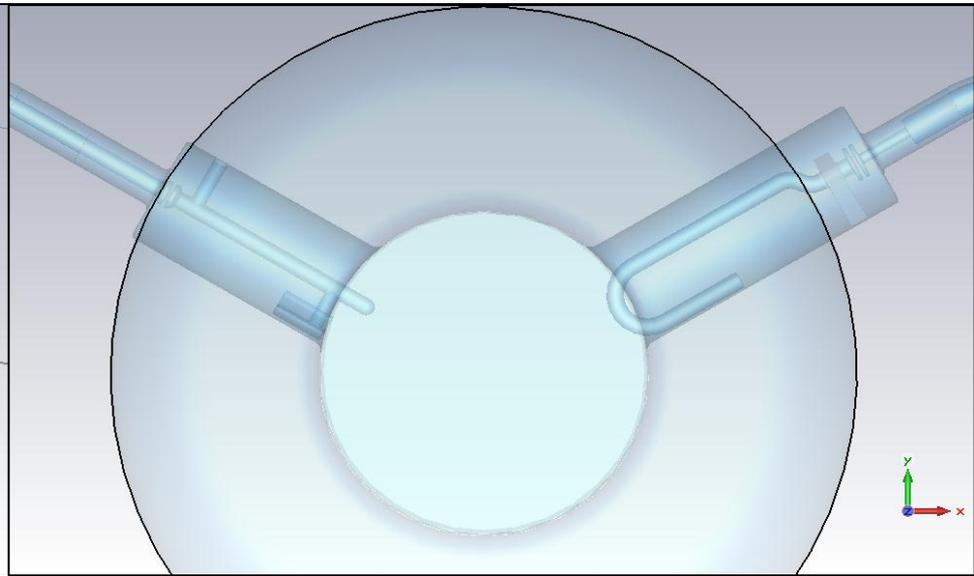
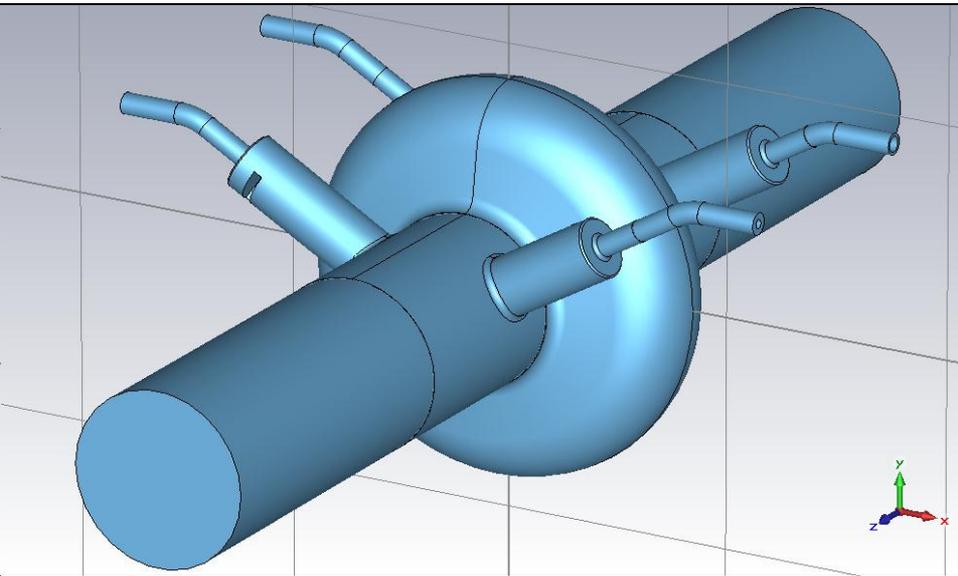
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Huang Tong-Ming, et.al., "Calculation of the external quality factor of the high power input coupler for the BEPC II superconducting cavity", Chinese Physics C, 2008.

HOM couplers



Meshing

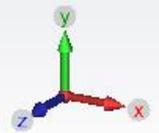
- Starting point;
- 3 adaptive passes;
- 250k thdrahedron;

Any parts have a proper different meshing

High Frequency Mesh

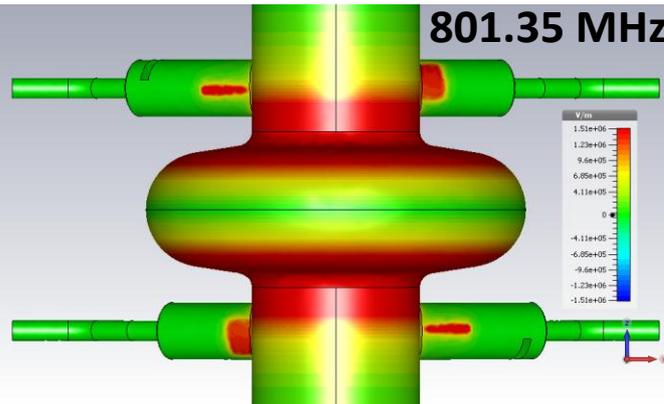
Tetrahedrons: 222865
Symmetries: none

Using the same mesh density the code does not converge!!!

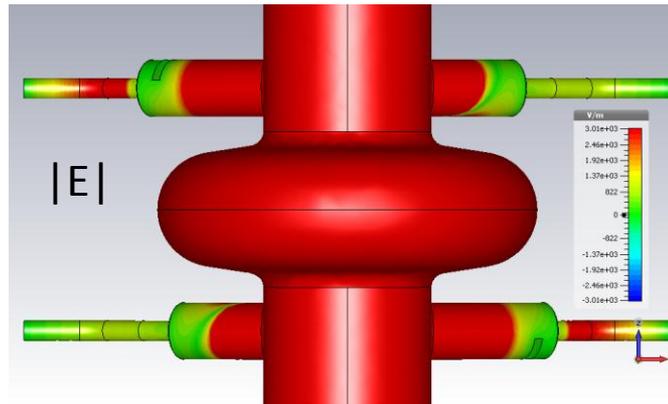


Coupling with the HOMs couplers

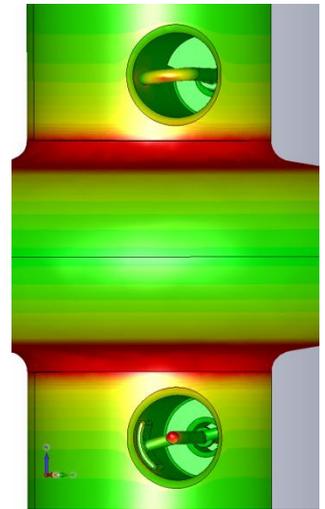
Fundamental mode



Notch filter areas are full of energy



Using PE boundaries for the ports the $\lambda/2$ mode of the coaxial termination is coupled with the WM, E field at the termination should be zero.



A particular of the HOM couplers

$$2U_0 = 2 [J]$$

$$\text{PE: } Q_H = \frac{\omega \mu_0 \iiint |H_2|^2 dv}{\eta \iint |H_2|^2 ds} = \frac{|1 - e^{i\varphi}|^2}{4} Q_{ext} = 0.950 \text{ E}+09$$

$$\text{PH: } Q_E = \frac{\omega \varepsilon_0 \eta \iiint |E_1|^2 dv}{\iint |E_1|^2 ds} = \frac{|1 + e^{i\varphi}|^2}{4} Q_{ext} = 0.137 \text{ E}+09$$

$$Q_{ext} = Q_E + Q_H = 1.1 \text{ E}+09$$

To calculate with MWS

Coupling with the HOMs couplers

High Order Modes

External Q

R over Q

Beam Impedances

Coupling with the HOM coupler

How to compute the $(R/Q)_{\text{long}}$ and $(R/Q)_{\text{tran}}$

The HOMs in a **asymmetric** geometry with several holes (*pipe, ports*) and pieces of transmission lines (*couplers*) cannot be a pure TM or TE mode. They will be a superimposition of both **types and polarizations**, they will have both **longitudinal and transverse impedance**.

From the definition:

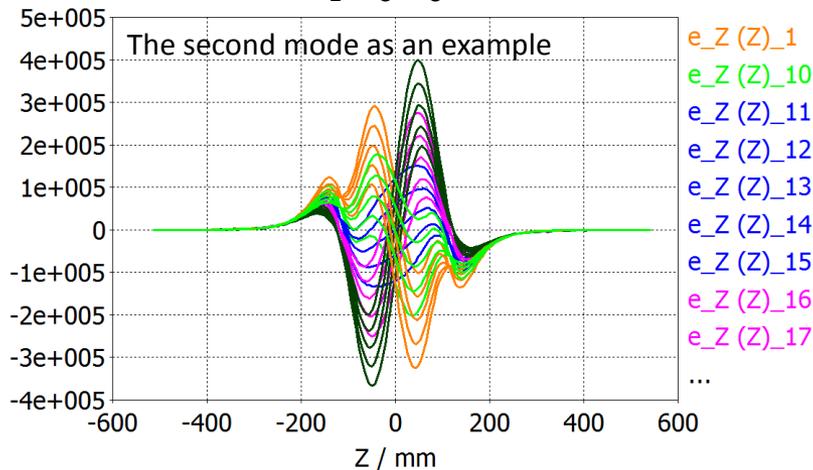
$$\left(\frac{R}{Q}\right)_{\parallel} = \frac{\left| \int_{-\infty}^{+\infty} E_z(x=0, y=0, z) e^{\frac{i\omega z}{c}} dz \right|^2}{2 \omega U}$$

From the Panowsky-Wenzel theorem:

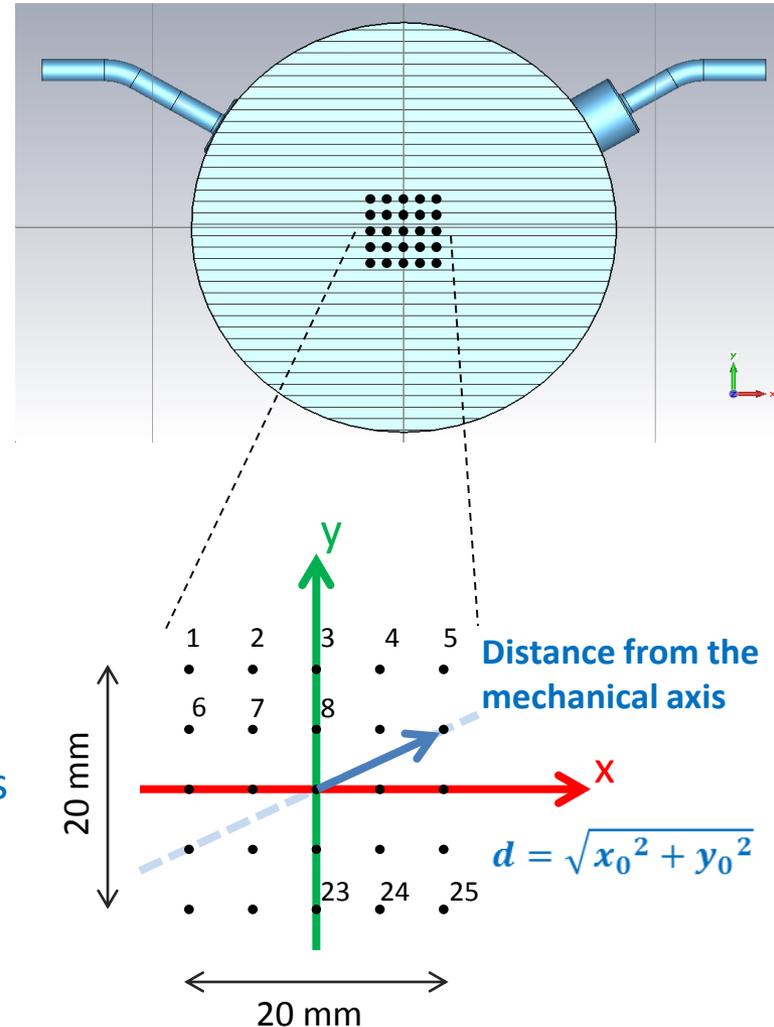
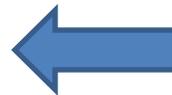
$$\left(\frac{R}{Q}\right)_{\perp} = \frac{\left| \int_{-\infty}^{+\infty} E_z(x=x_0, y=0, z) e^{\frac{i\omega z}{c}} dz \right|^2}{2 (kx_0)^2 \omega U}$$

$$k = \frac{\omega}{c} \quad \left(\frac{R}{Q}\right)_{\perp} = \left(\frac{c}{\omega x_0}\right)^2 \left(\frac{R}{Q}\right)_{\parallel}$$

$|E_z(x_0, y_0, z)|$



25 curves



Coupling with the HOM coupler

How to compute the $(R/Q)_{\text{long}}$ and $(R/Q)_{\text{tran}}$

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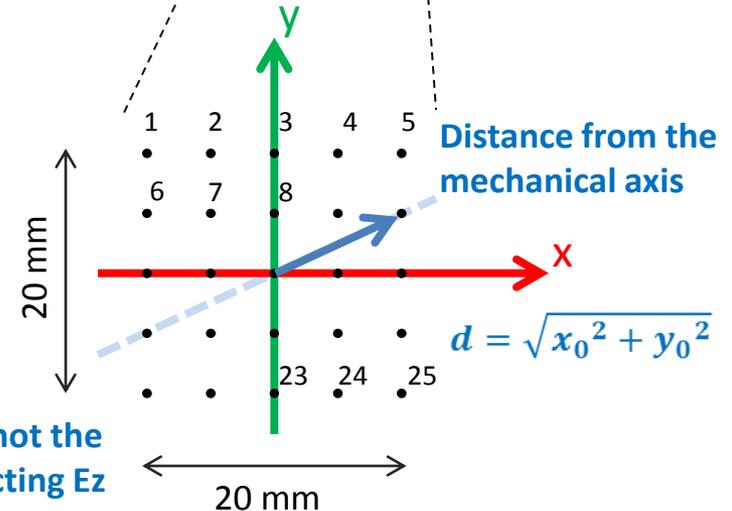
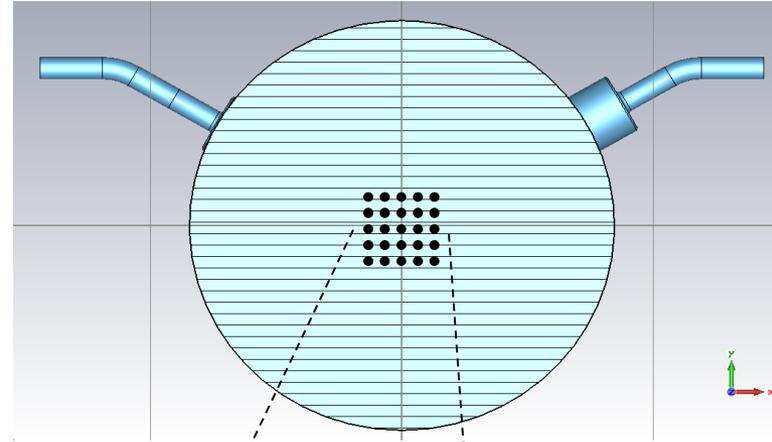
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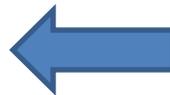
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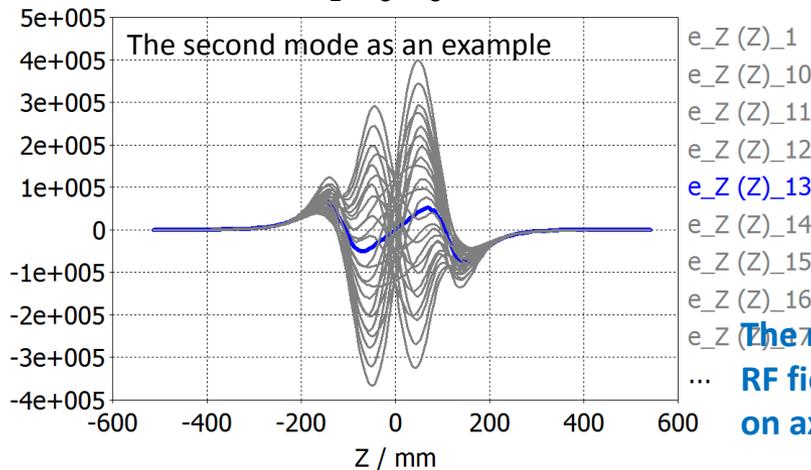
25 curves



The mechanical axis is not the RF fields axis (for deflecting E_z on axis should be zero)

We need of only the z component of the electric field!

$|E_z(x_0, y_0, z)|$



Coupling with the HOM coupler

How to compute the $(R/Q)_{\text{long}}$ and $(R/Q)_{\text{tran}}$

The HOMs in a **asymmetric** geometry with several holes (*pipe, ports*) and pieces of transmission lines (*couplers*) cannot be a pure TM or TE mode. They will be a superimposition of both **types and polarizations**, they will have both **longitudinal and transverse impedance**.

From the definition:

$$\left(\frac{R}{Q}\right)_{\parallel} = \frac{\left| \int_{-\infty}^{+\infty} E_z(x=0, y=0, z) e^{\frac{i\omega z}{c}} dz \right|^2}{2 \omega U}$$

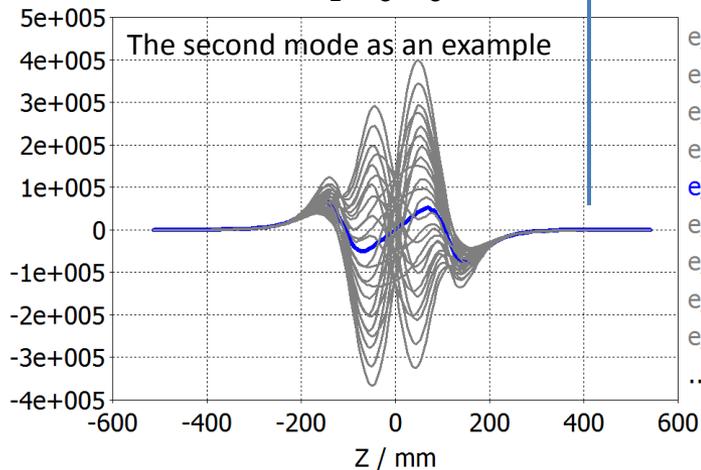
From the Panowsky-Wenzel theorem:

$$\left(\frac{R}{Q}\right)_{\perp} = \frac{\left| \int_{-\infty}^{+\infty} E_z(x=x_0, y=0, z) e^{\frac{i\omega z}{c}} dz \right|^2}{2 (\kappa x_0)^2 \omega U}$$

$$\nabla_{\perp} E_z = \frac{E_z(x_0, y_0, z) - E_z(0, 0, z)}{d}$$

It is a very good approximation

$$|E_z(x_0, y_0, z)|$$



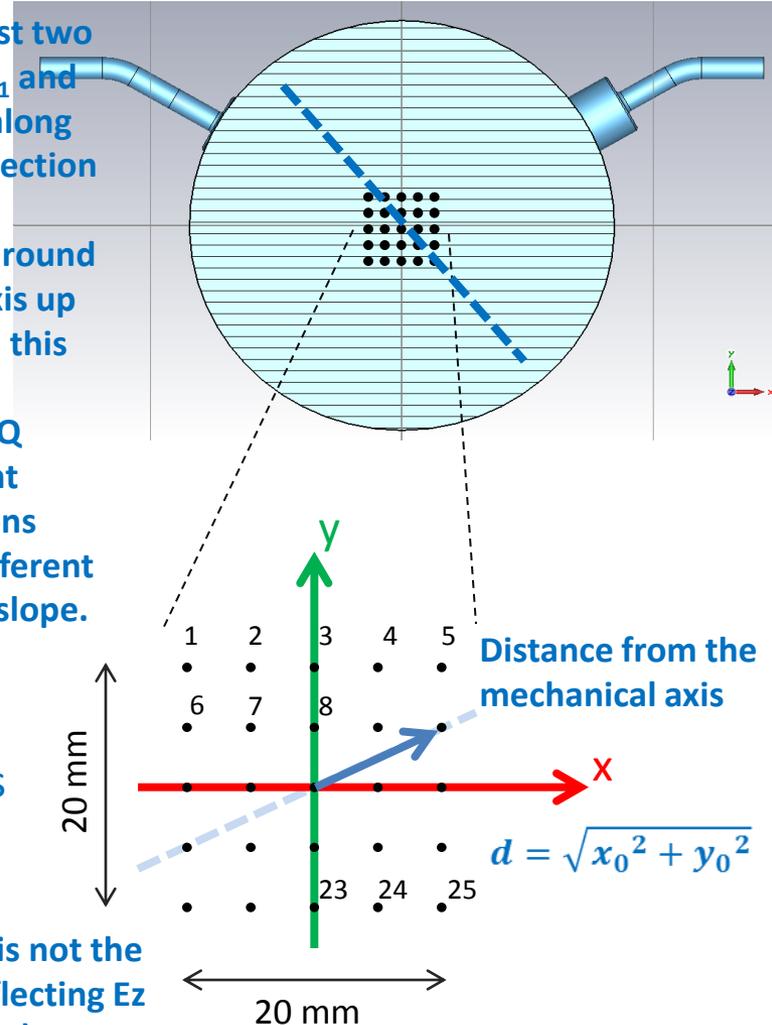
e_Z(Z)_1
e_Z(Z)_10
e_Z(Z)_11
e_Z(Z)_12
e_Z(Z)_13
e_Z(Z)_14
e_Z(Z)_15
e_Z(Z)_16
...

25 curves

The mechanical axis is not the RF fields axis (for deflecting E_z on axis should be zero)

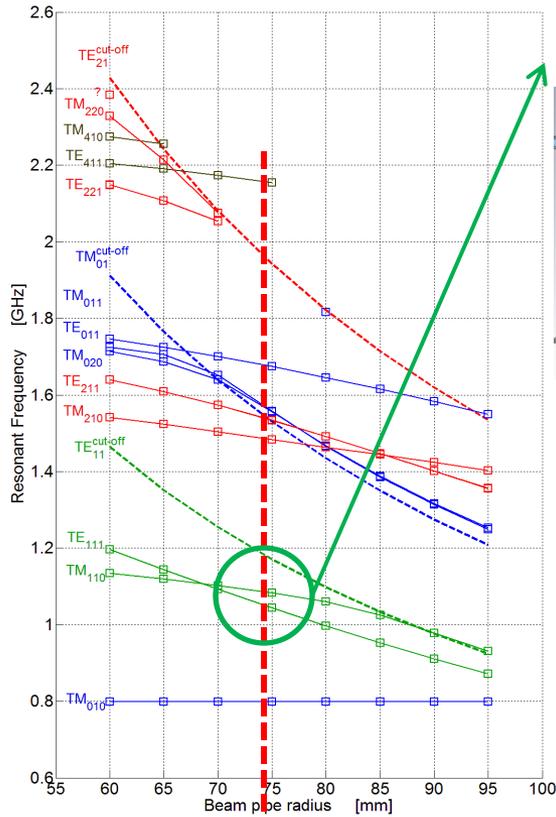
At least for the first two dipole HOMs TE_{111} and TM_{110} E_z is linear along any transverse direction (despite having different slopes) around the mechanical axis up to 50 mm off axis, this means:

The transverse R/Q should be constant along any directions despite having different value as the field slope.

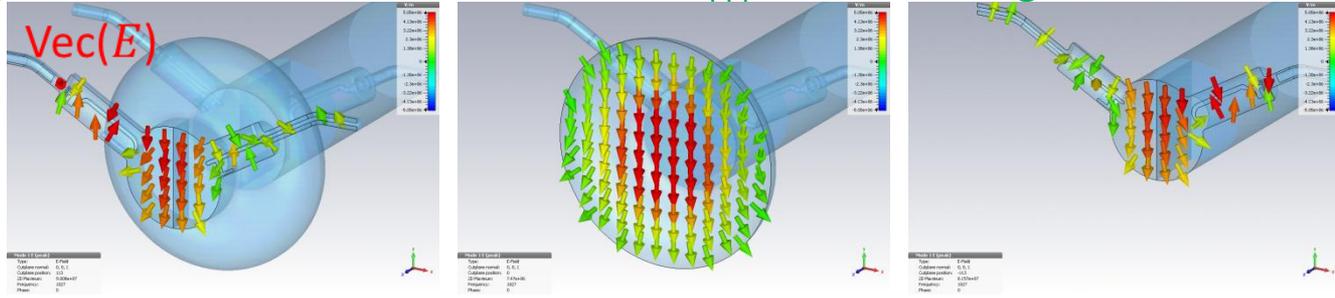


Coupling with the HOM coupler

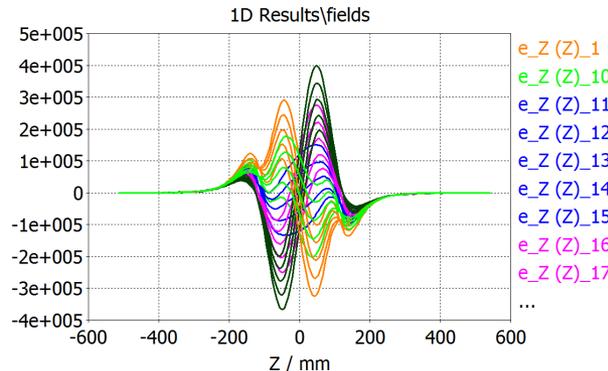
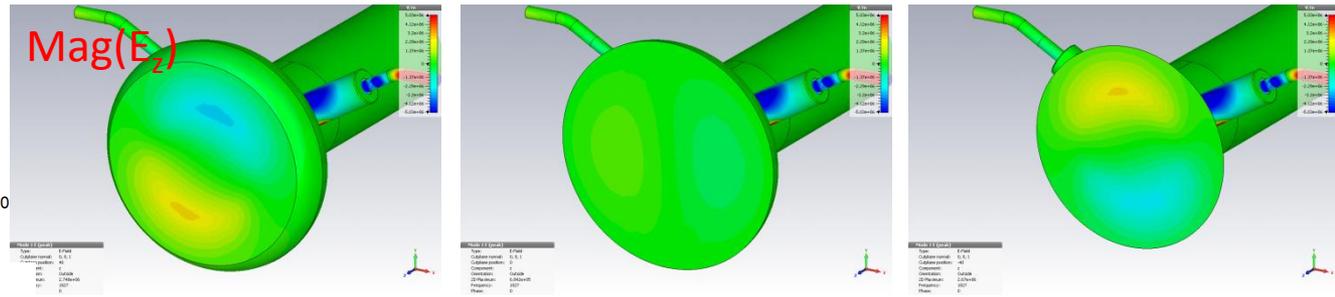
Second Mode – TE₁₁₁ like



The second mode should be the TE₁₁₁ like resonating at 1043 MHz



Looking at the fields, it seems a good TE₁₁₁ like mode but having even a longitudinal component of the Electric field. See the pictures below:

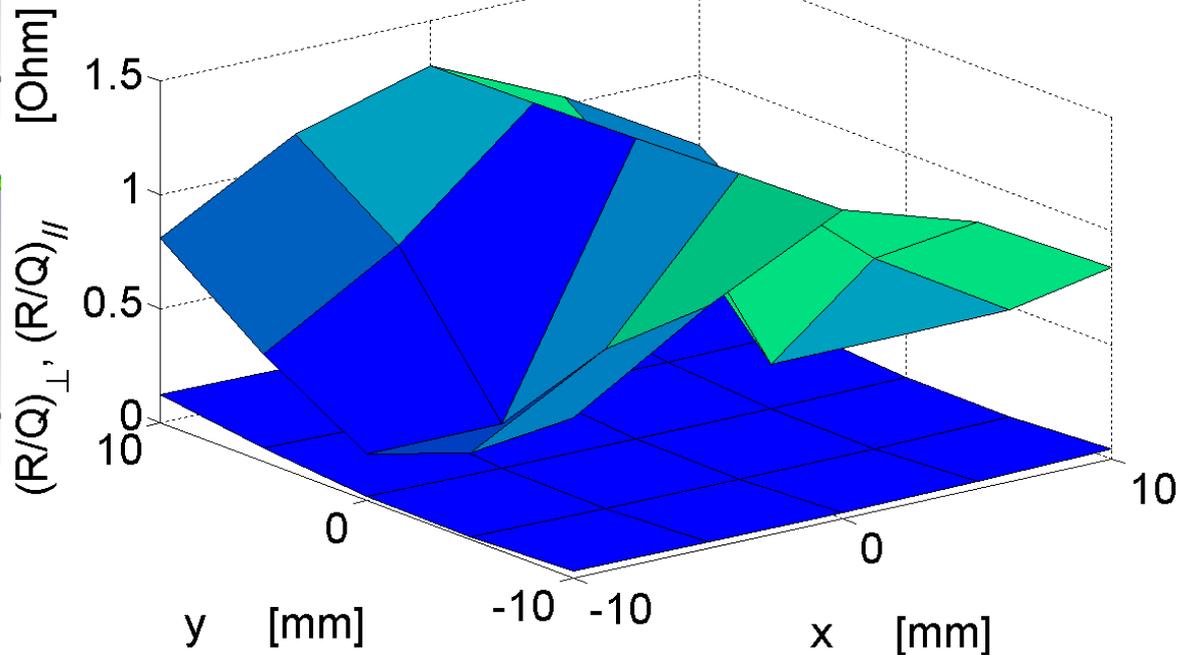
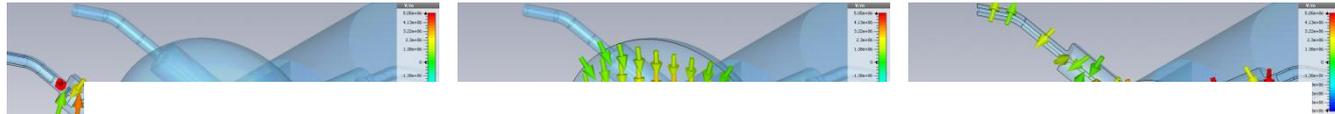
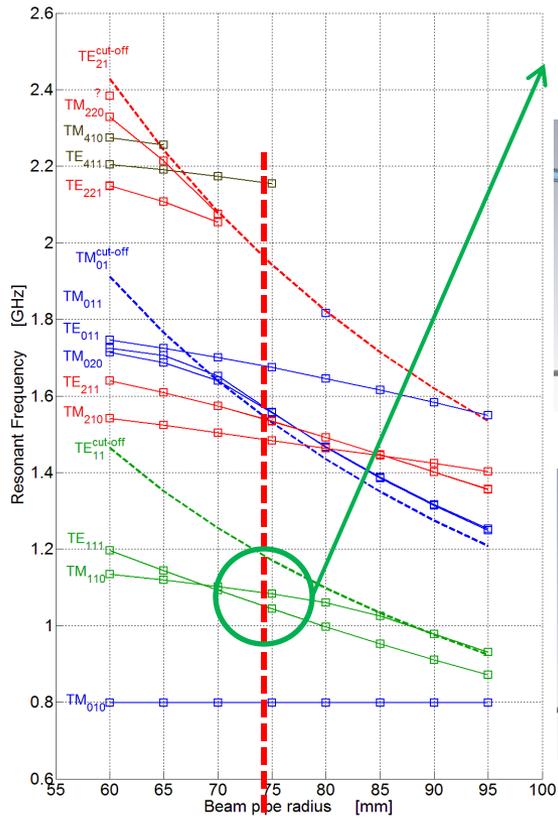


- 1) E_z is not zero;
- 2) Neither the transverse derivative of E_z is zero;
- 3) The two field lobes are rotating along z ;
- 4) For a pure TE₁₁₁ the impedances should be zero!

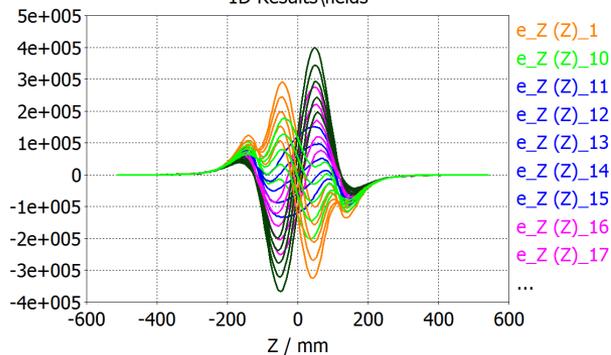
Coupling with the HOM coupler

Second Mode – TE₁₁₁like

The second mode should be the TE₁₁₁like resonating at 1020 MHz



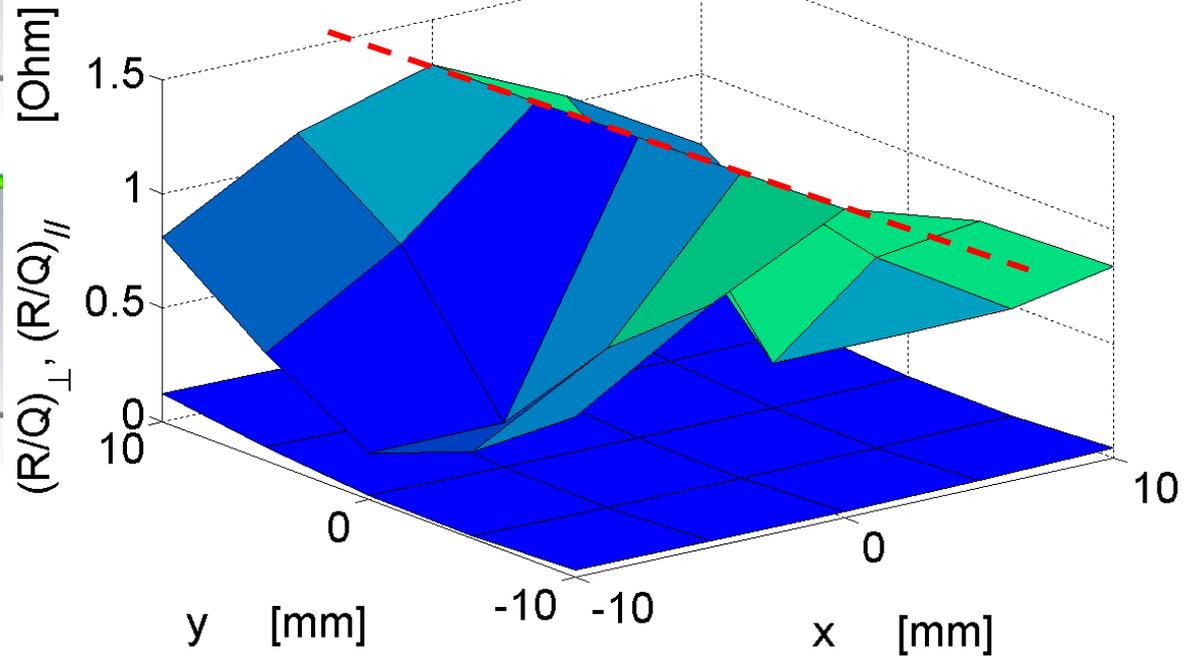
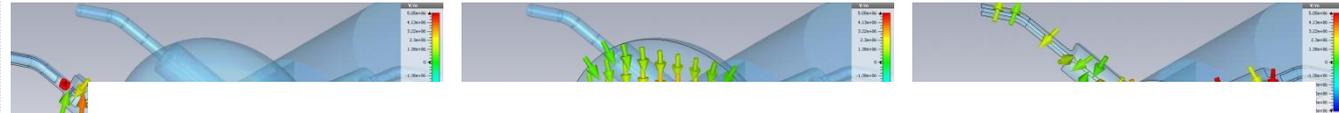
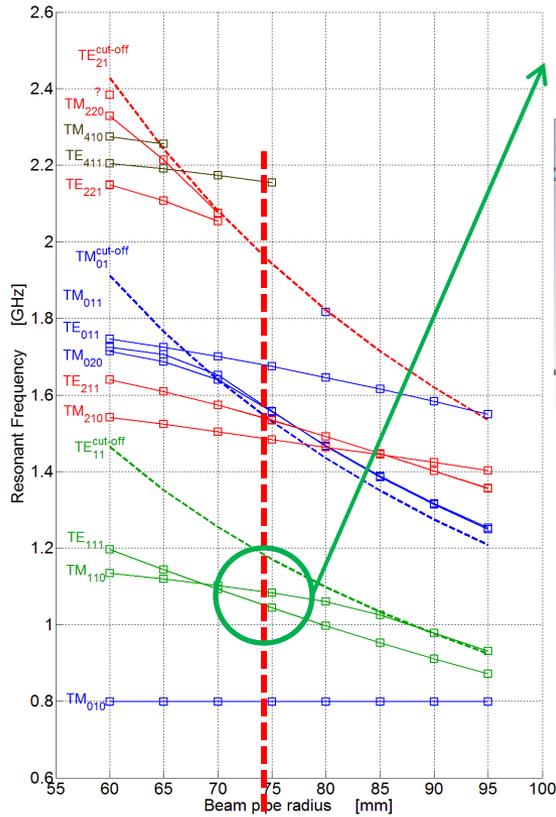
1D Results\fields



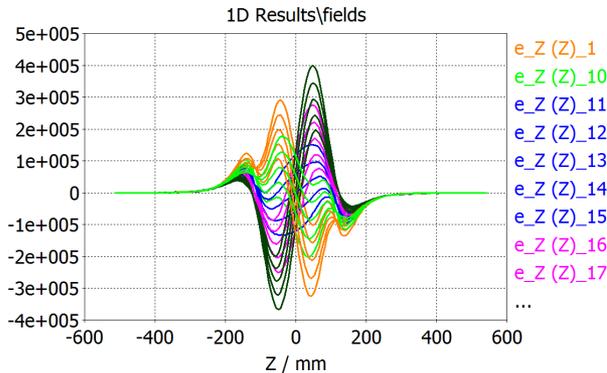
Coupling with the HOM coupler

Second Mode – TE₁₁₁like

The second mode should be the TE₁₁₁like resonating at 1020 MHz



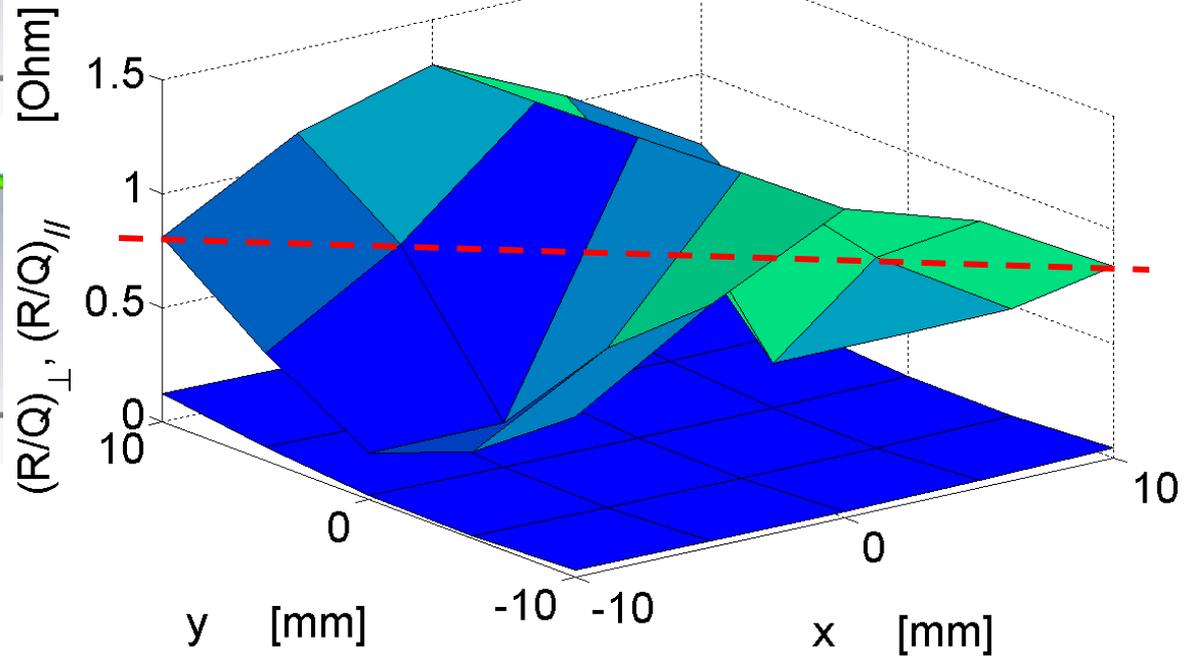
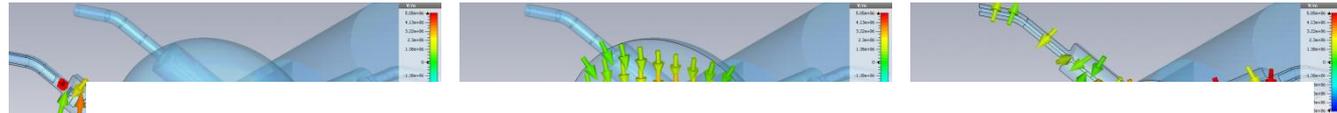
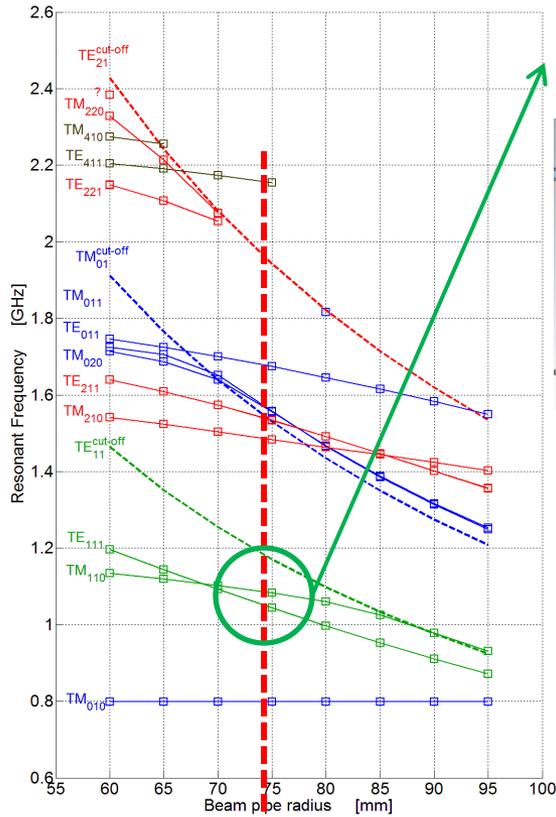
1) The maximum deflection is 1.3 Ohm along y direction;



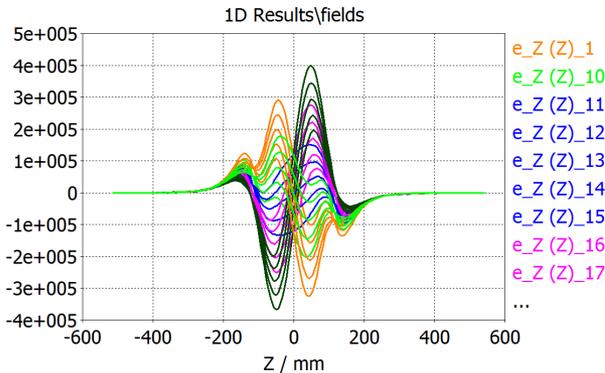
Coupling with the HOM coupler

Second Mode – TE₁₁₁like

The second mode should be the TE₁₁₁like resonating at 1020 MHz



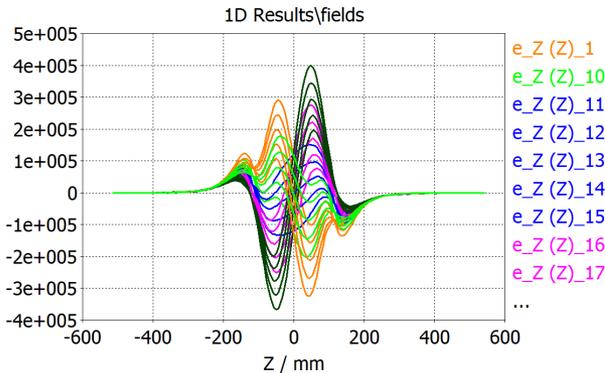
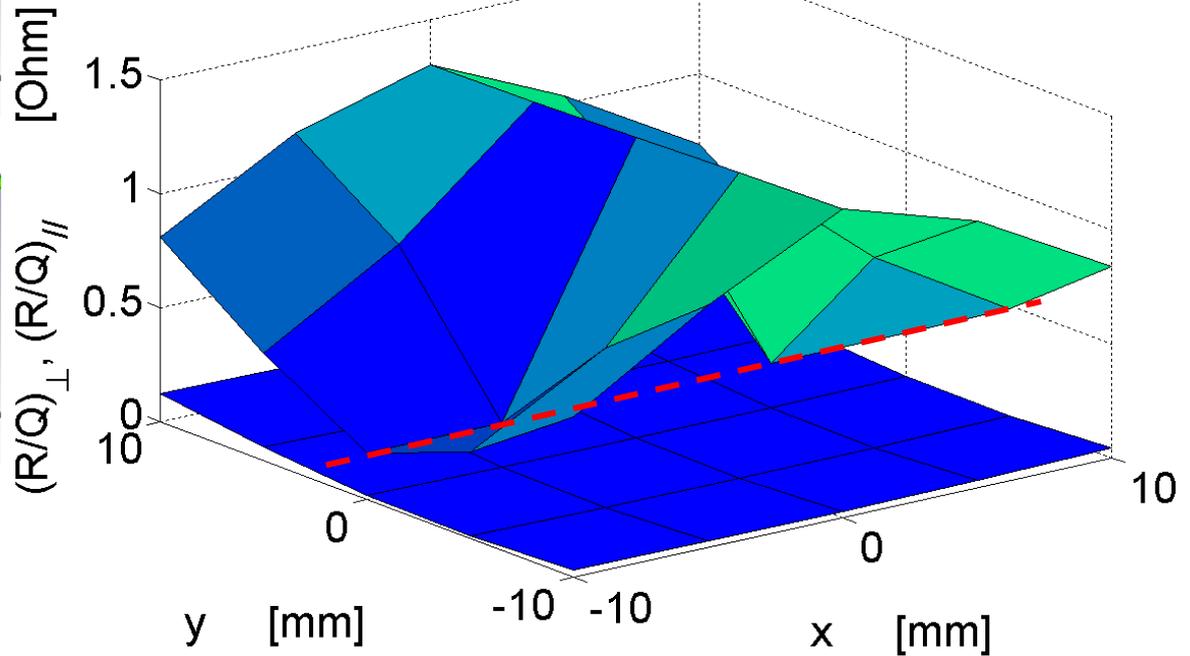
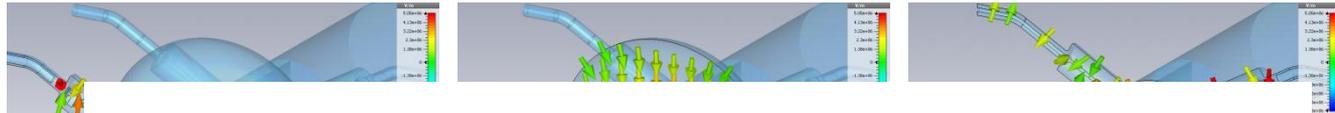
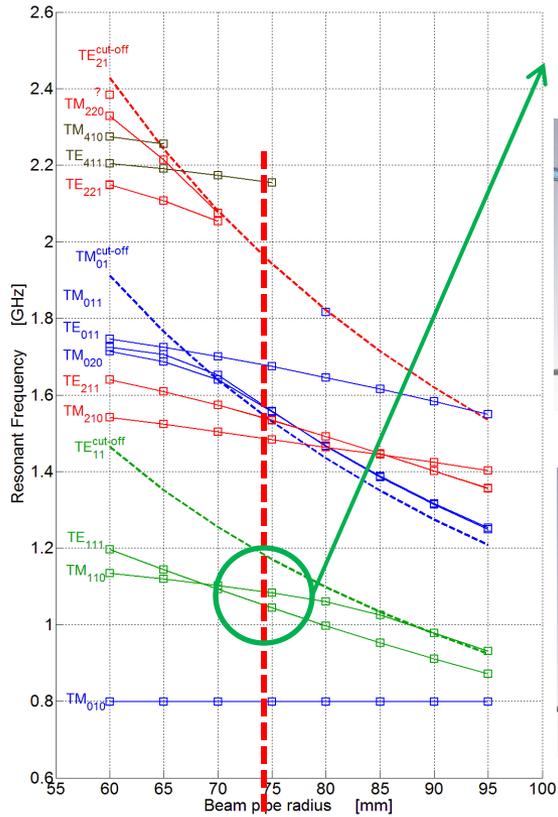
- 1) The maximum deflection is 1.3 Ohm along y direction;
- 2) Different but constant along others directions;



Coupling with the HOM coupler

Second Mode – TE₁₁₁like

The second mode should be the TE₁₁₁like resonating at 1020 MHz

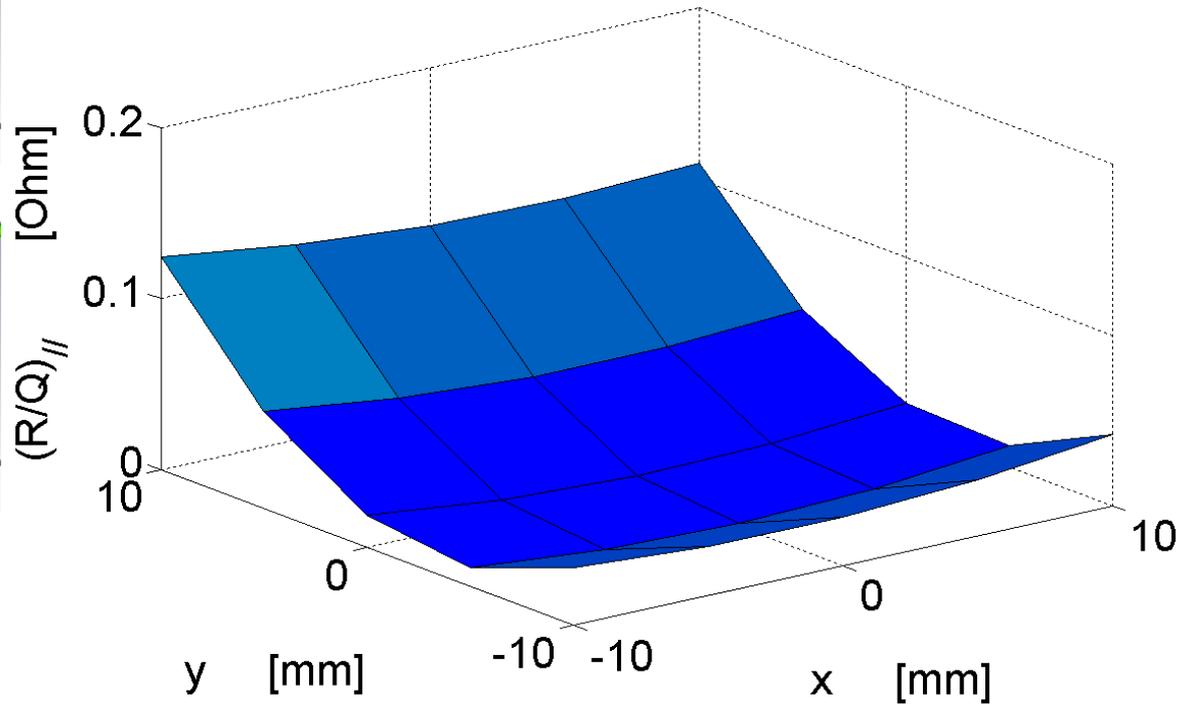
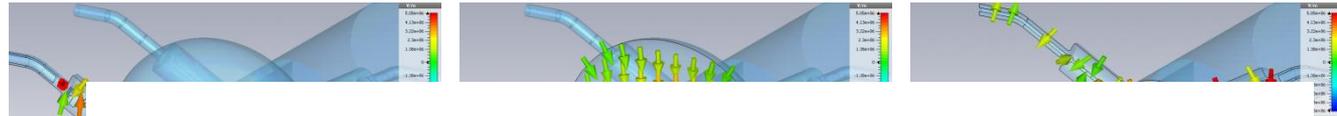
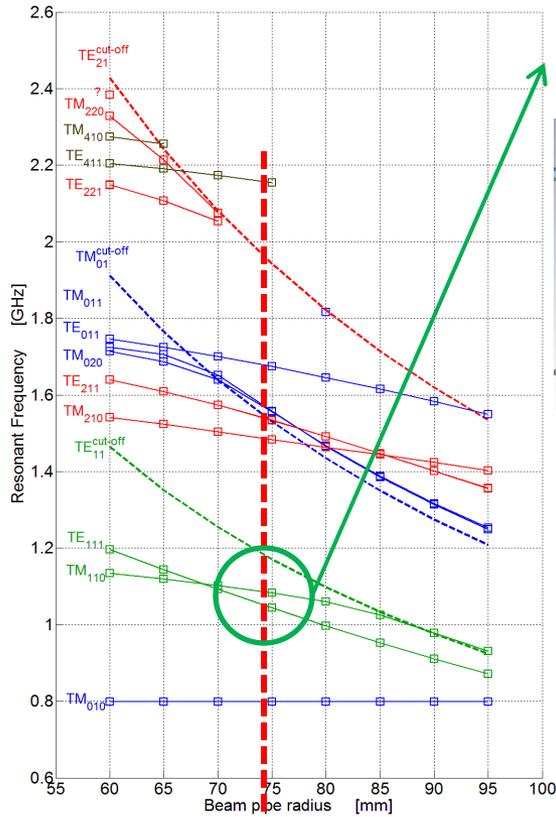


- 1) The maximum deflection is 1.3 Ohm along y direction;
- 2) Different but constant along others directions;
- 3) The lowest deflection along x direction is not zero;

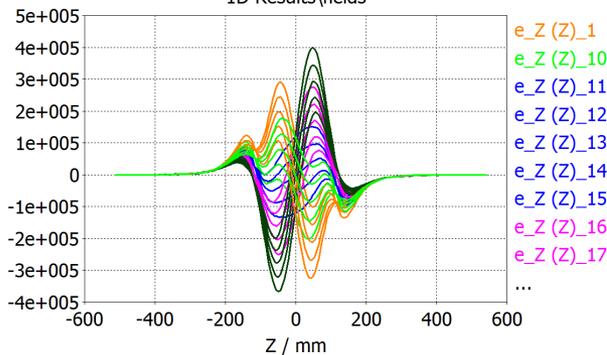
Coupling with the HOM coupler

Second Mode – TE₁₁₁like

The second mode should be the TE₁₁₁like resonating at 1020 MHz



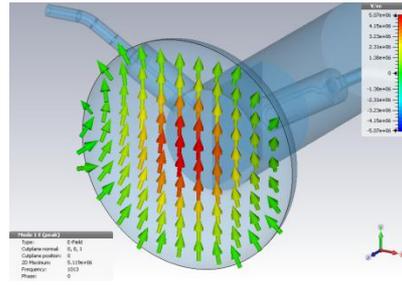
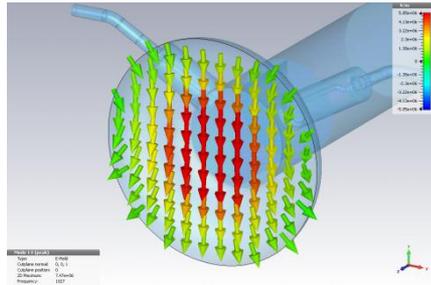
1D Results\fields



- 1) The longitudinal impedance is low but not zero;
- 2) It is not axis symmetric;
- 3) It is not zero on the axis;

Second Mode – TE₁₁₁like summarizing....

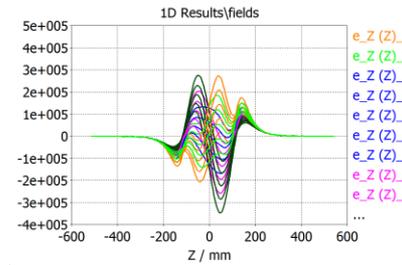
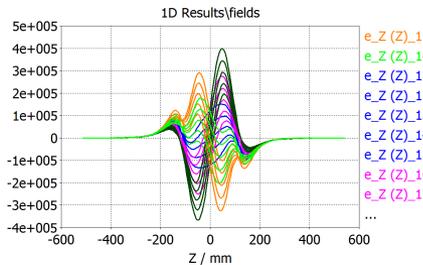
Vertical pol, **PH boundary** Vertical pol, **PE boundary**



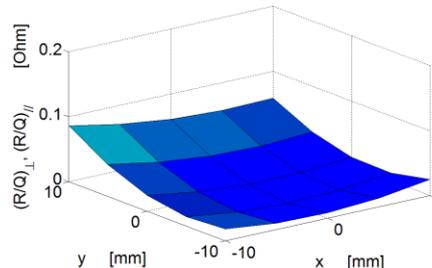
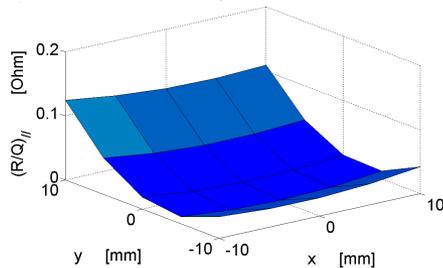
$$F_{res}^{PH} = 1027 \text{ MHz}$$

$$F_{res}^{PE} = 1013 \text{ MHz}$$

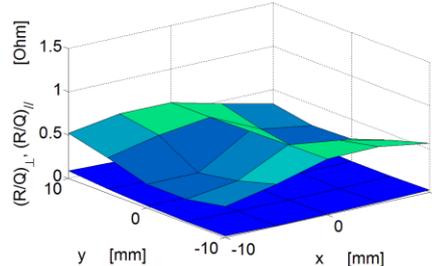
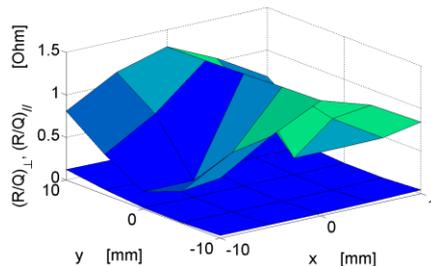
There is a substantial frequency variation. The mode is well coupled at the output ports



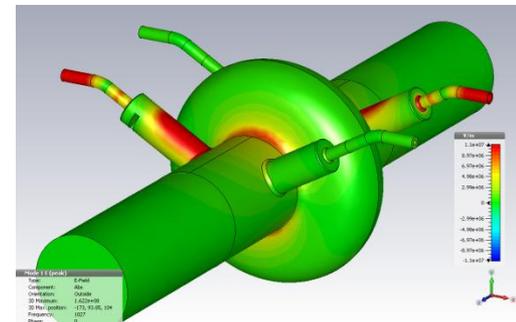
The longitudinal electric field has a less intensity for the same stored energy



The R/Qs are different but both very low, the external Q calculated with Belleguier method is extremely low.



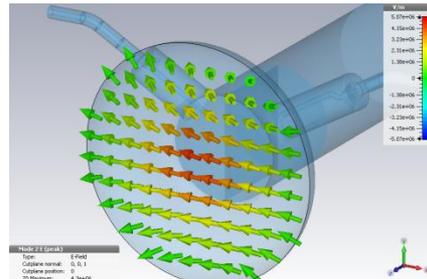
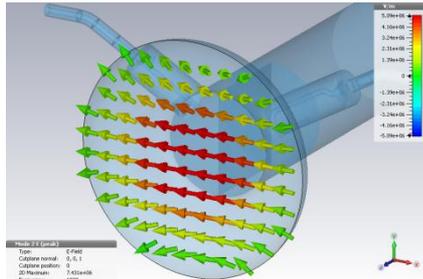
$$Q_{ext} = Q_{ext}^{PH} + Q_{ext}^{PE} = 48.5 + 31.3 = 79.8$$



The beam impedances are consequently very low!!!

Third Mode – TE₁₁₁like another polarization

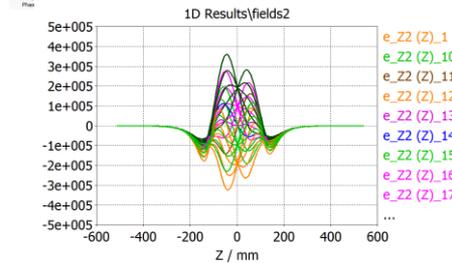
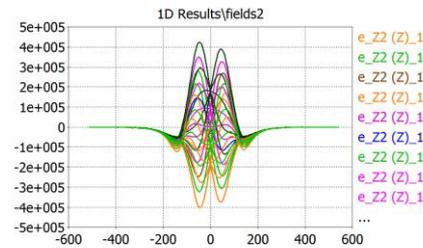
Horizontal pol, **PH boundary** Horizontal pol, **PE boundary**



$$F_{res}^{PH} = 1032 \text{ MHz}$$

$$F_{res}^{PE} = 1017 \text{ MHz}$$

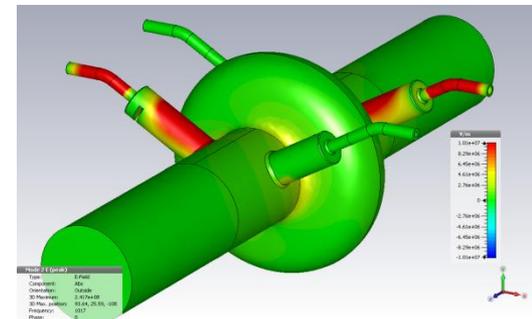
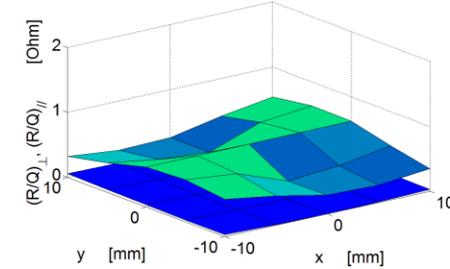
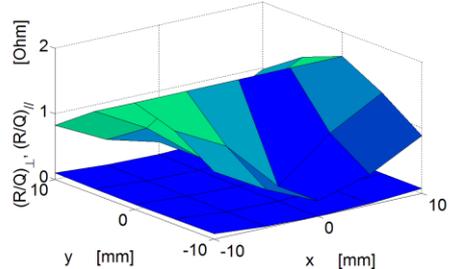
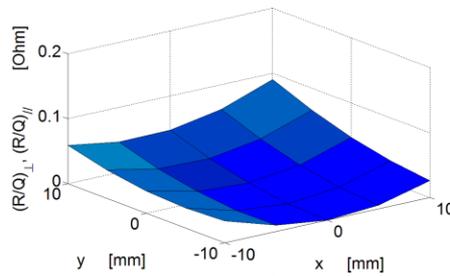
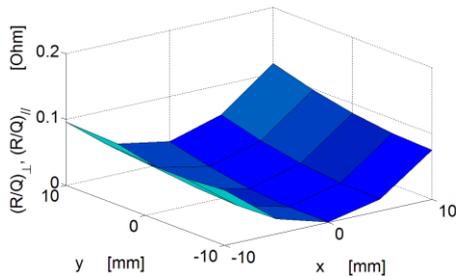
There is a substantial frequency variation. The mode is well coupled at the output ports



The longitudinal electric field has a less intensity for the same stored energy

The R/Qs are different but both very low, the external Q calculated with Belleguier method is extremely low.

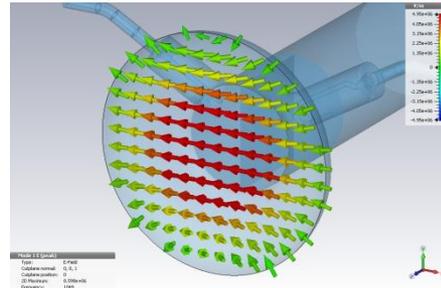
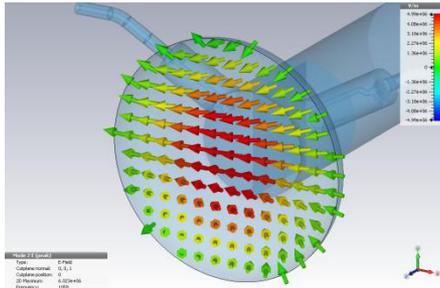
$$Q_{ext} = Q_{ext}^{PH} + Q_{ext}^{PE} = 54 + 27.3 = 81.8$$



The beam impedances are consequently very low!!!

Fourth Mode – Hybrid mode

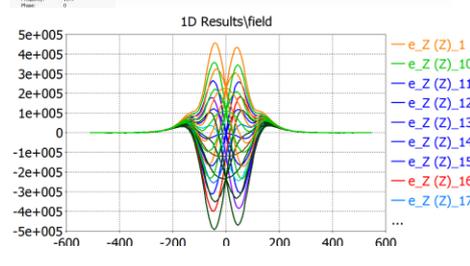
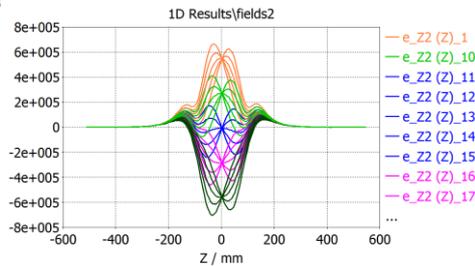
Horizontal pol, **PH boundary** Horizontal pol, **PE boundary**



$$F_{res}^{PH} = 1059 \text{ MHz}$$

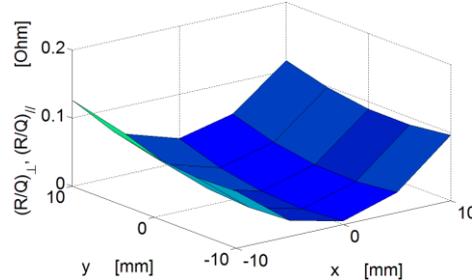
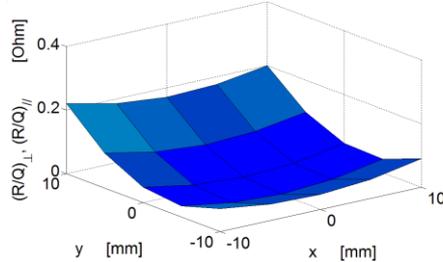
$$F_{res}^{PE} = 1049 \text{ MHz}$$

There is a substantial frequency variation. The mode is well coupled at the output ports

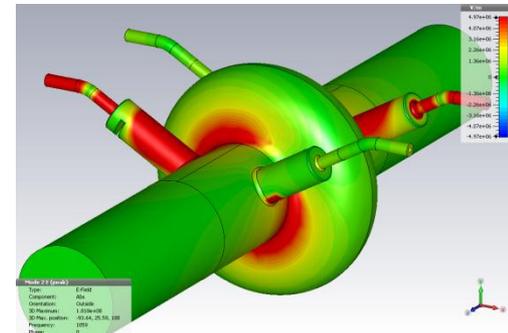
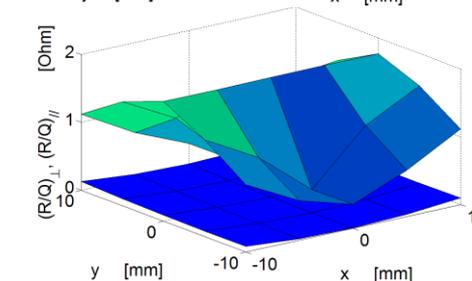
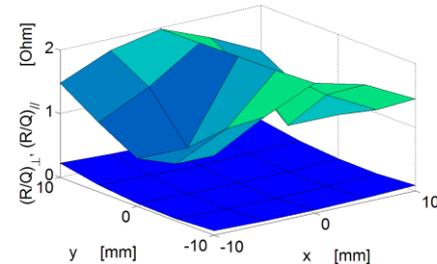


The longitudinal electric field has a less intensity for the same stored energy

The R/Qs are different but both very low, the external Q calculated with Belleguier method is extremely low.



$$Q_{ext} = Q_{ext}^{PH} + Q_{ext}^{PE} = 50.1 + 53.3 = 103.4$$

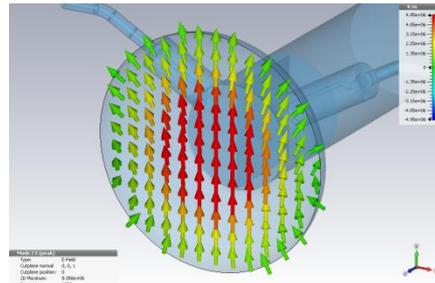
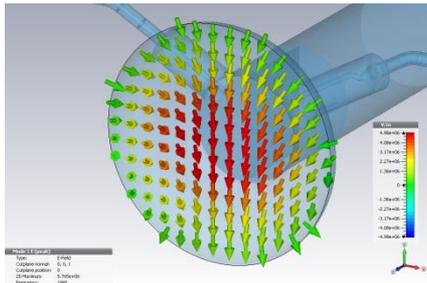


The beam impedances are consequently very low!!!

Fifth Mode – Hybrid another polarization

Vertical pol, **PH boundary**

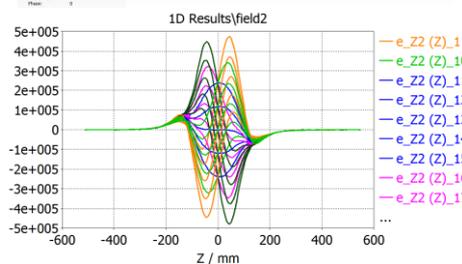
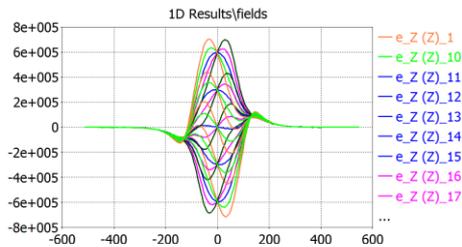
Vertical pol, **PE boundary**



$$F_{res}^{PH} = 1065 \text{ MHz}$$

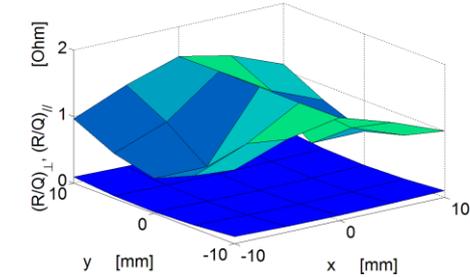
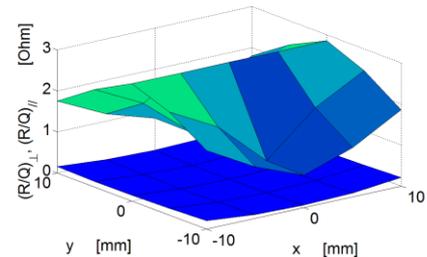
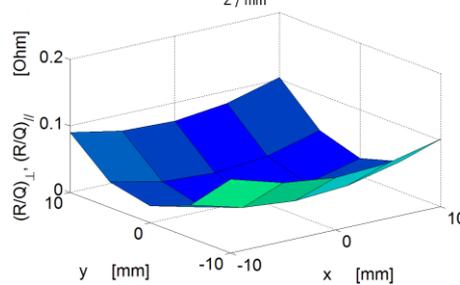
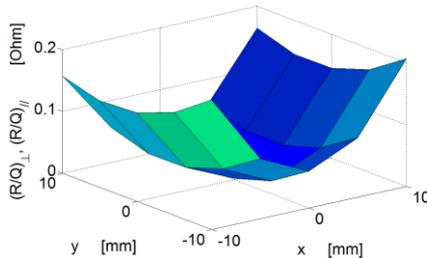
$$F_{res}^{PE} = 1052 \text{ MHz}$$

There is a substantial frequency variation. The mode is well coupled at the output ports

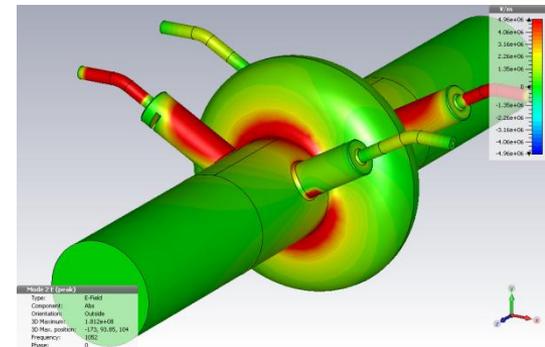


The longitudinal electric field has a less intensity for the same stored energy

The R/Qs are different but both very low, the external Q calculated with Belleguier method is extremely low.



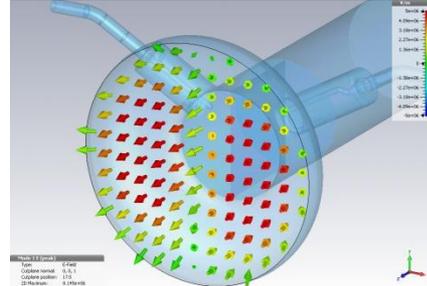
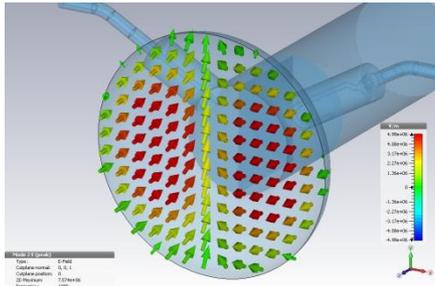
$$Q_{ext} = Q_{ext}^{PH} + Q_{ext}^{PE} = 53.5 + 36.1 = 89.6$$



The beam impedances are consequently very low!!!

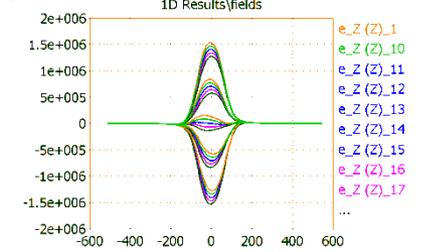
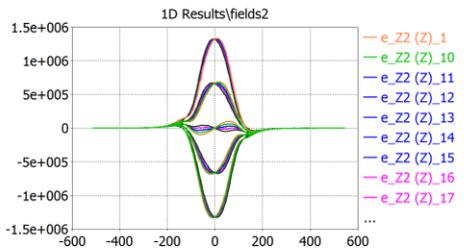
Sixth Mode $-TM_{110}$ like

Horizontal pol, **PH boundary** Horizontal pol, **PE boundary**

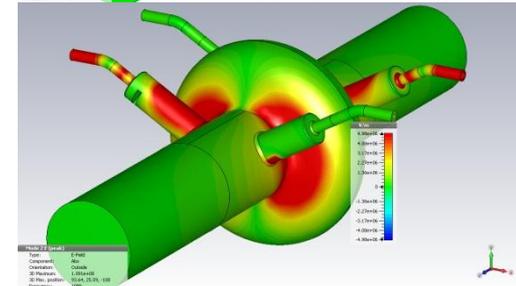
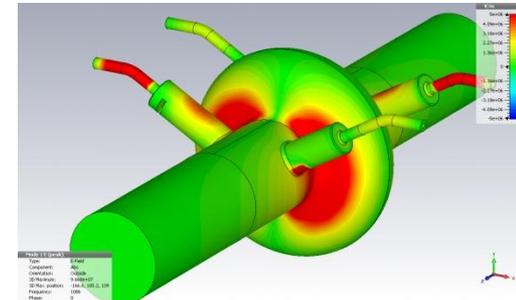
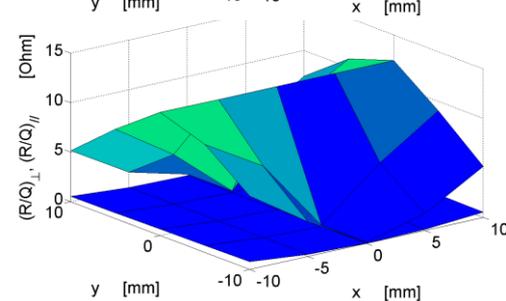
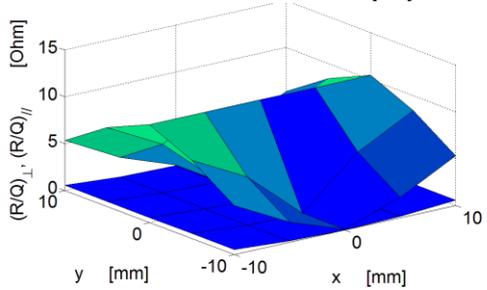
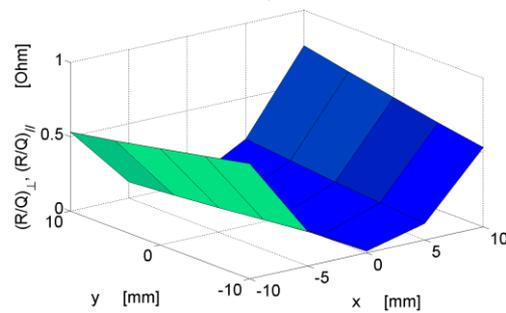
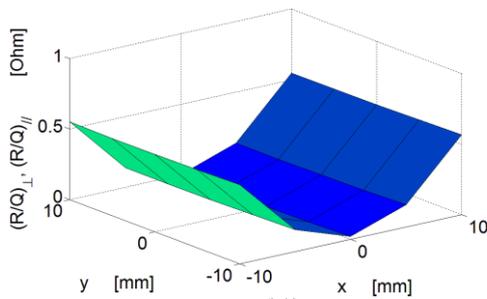


$$F_{res}^{PH} = 1090 \text{ MHz}$$

$$F_{res}^{PE} = 1086 \text{ MHz}$$



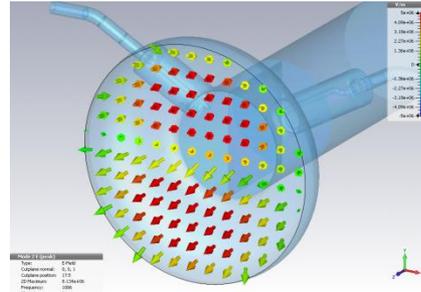
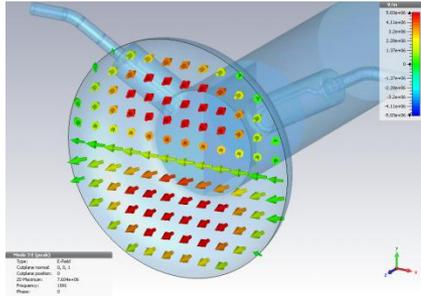
$$Q_{ext} = Q_{ext}^{PH} + Q_{ext}^{PE} = 162.3 + 97.8 = 260.1$$



Seventh Mode $-TM_{110}$ like another polarization

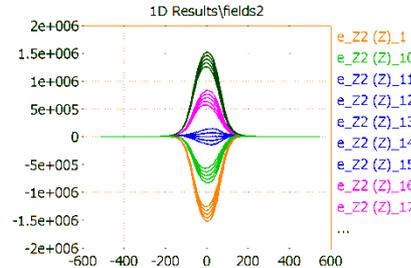
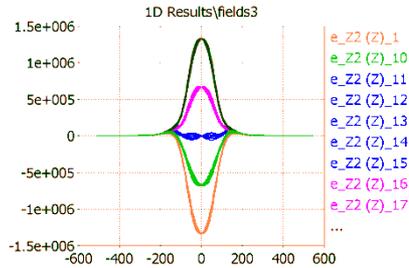
Vertical pol, **PH boundary**

Vertical pol, **PE boundary**

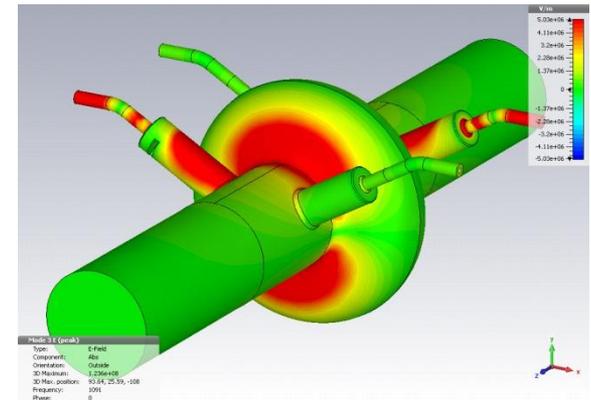
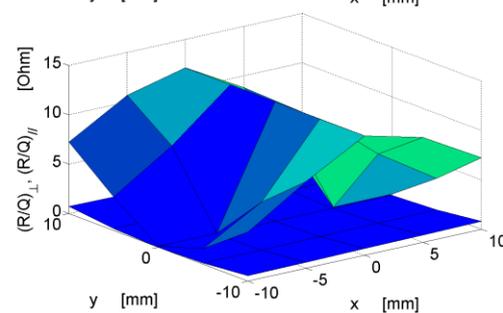
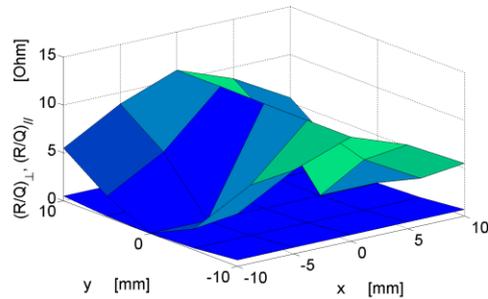
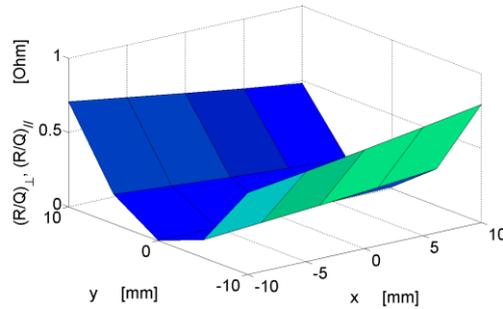
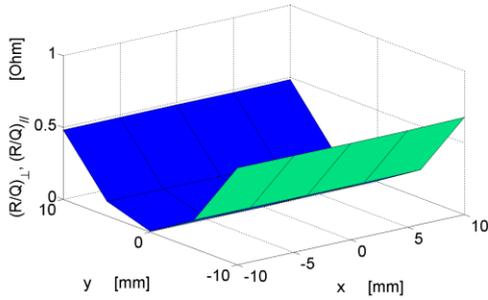


$$F_{res}^{PH} = 1091 \text{ MHz}$$

$$F_{res}^{PE} = 1086 \text{ MHz}$$



$$Q_{ext} = Q_{ext}^{PH} + Q_{ext}^{PE} = 155.7 + 63 = 218.7$$

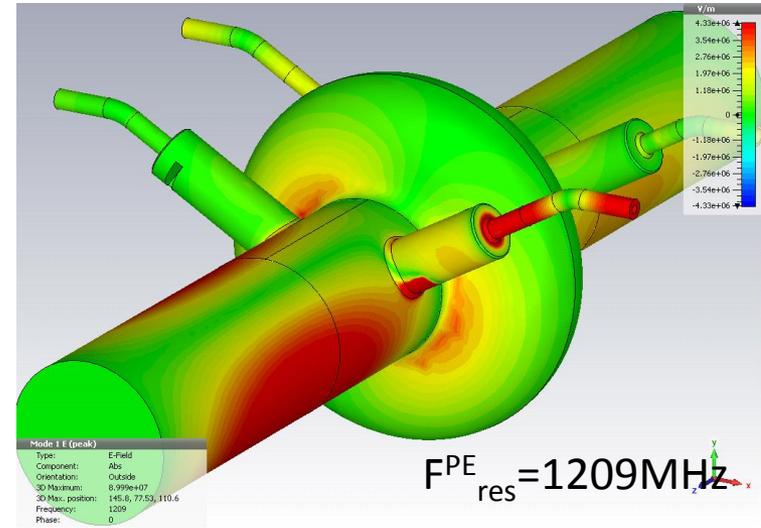
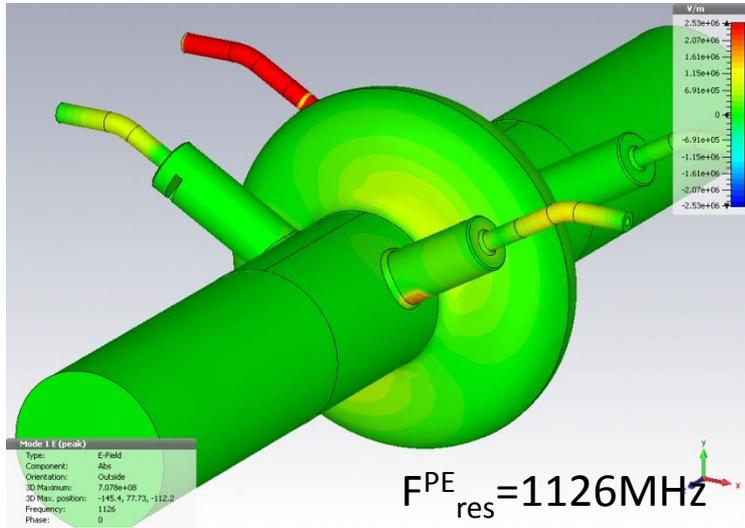


Another trapped mode before the pipe cut-off

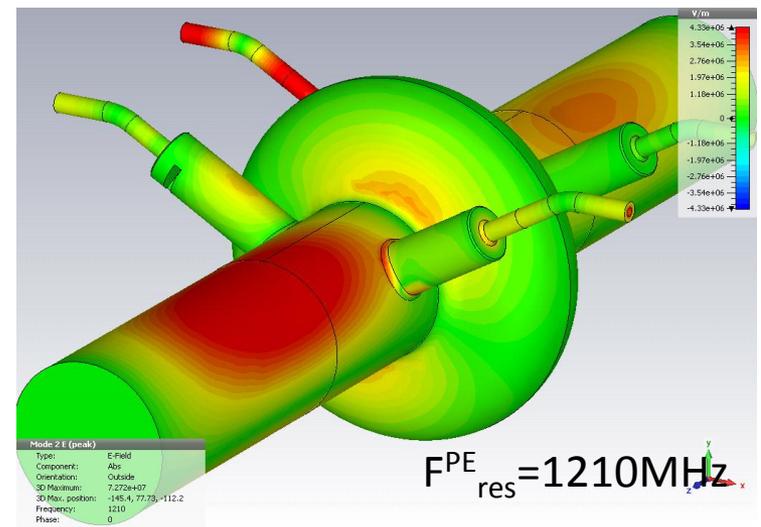
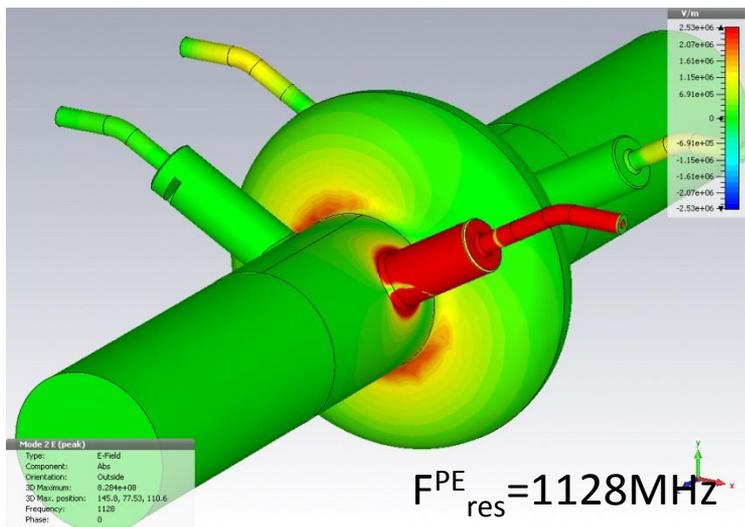
PE boundary

PH boundary

Eighth mode

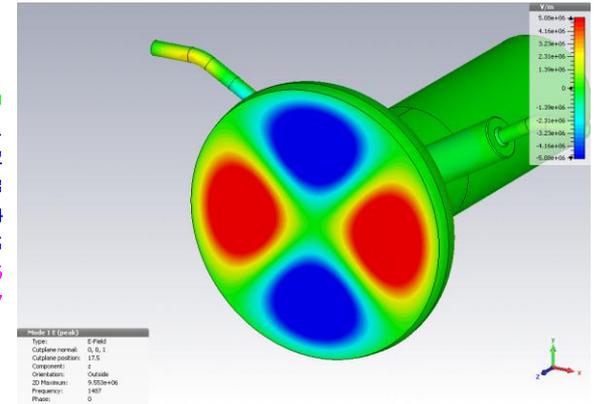
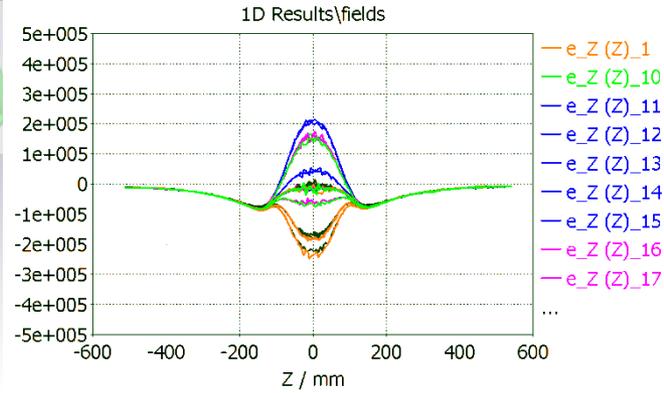
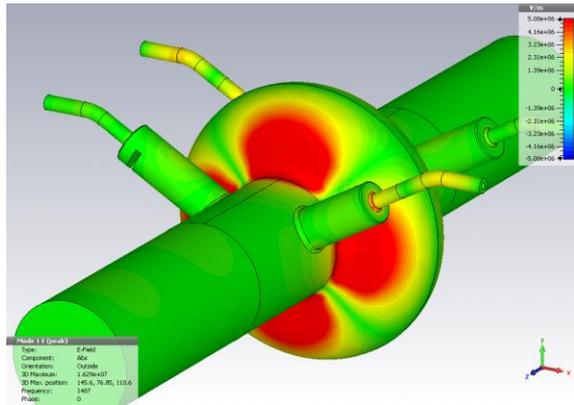


Ninth mode

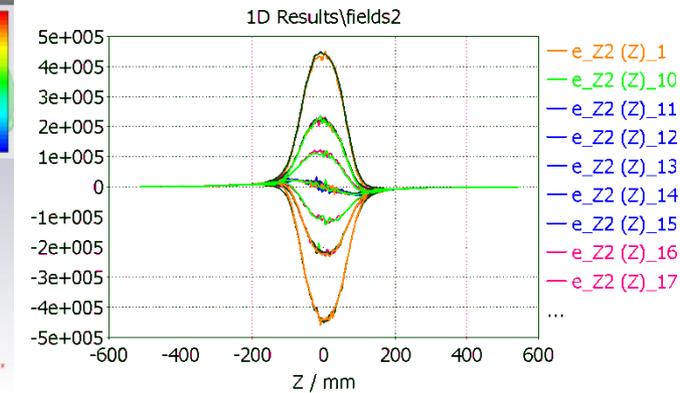
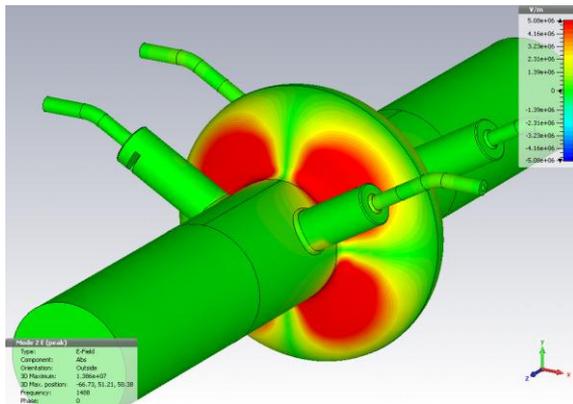


The first quadrupole mode

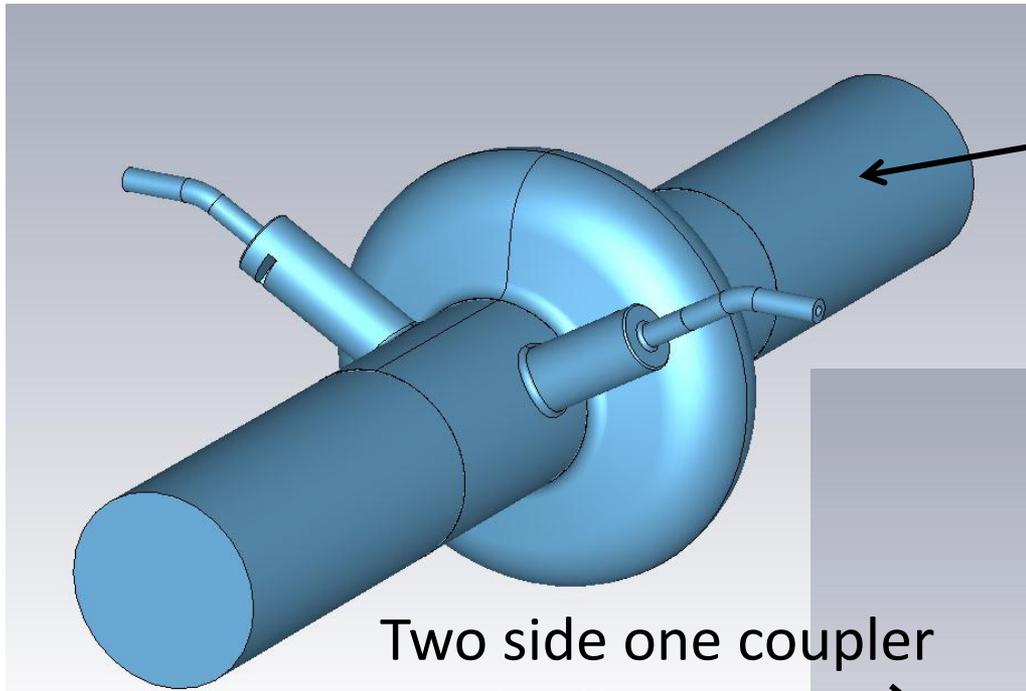
0° Pol $F_{res}=1487\text{MHz}$



45° Pol $F_{res}=1488\text{MHz}$

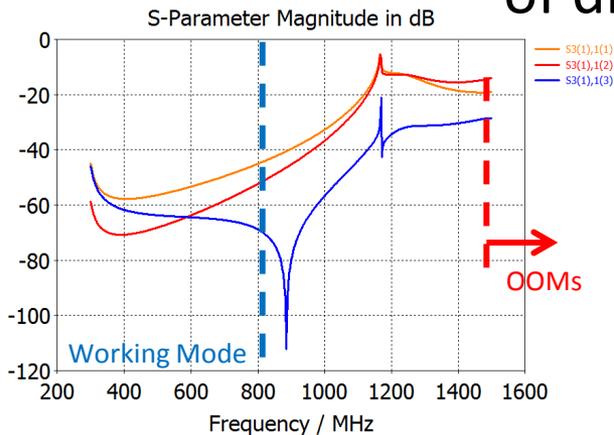
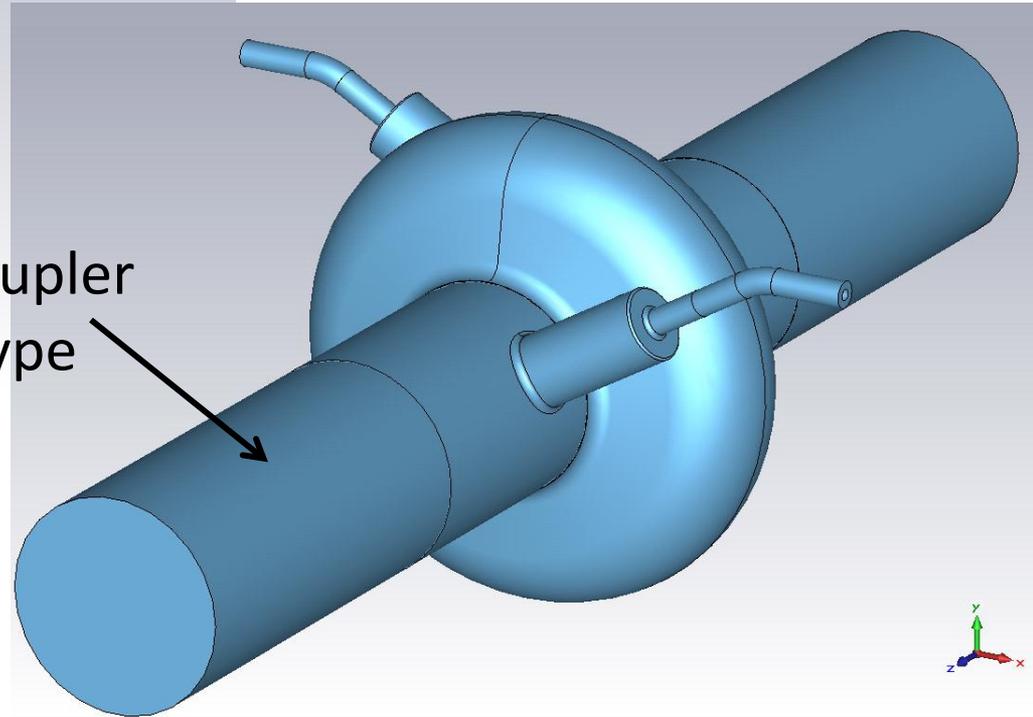


Can we reduce the number on HOM couplers?



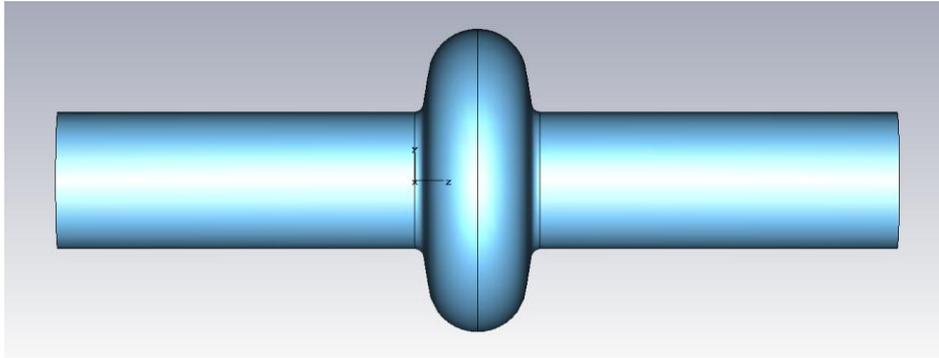
One side two couplers of both types

Two side one coupler of different type

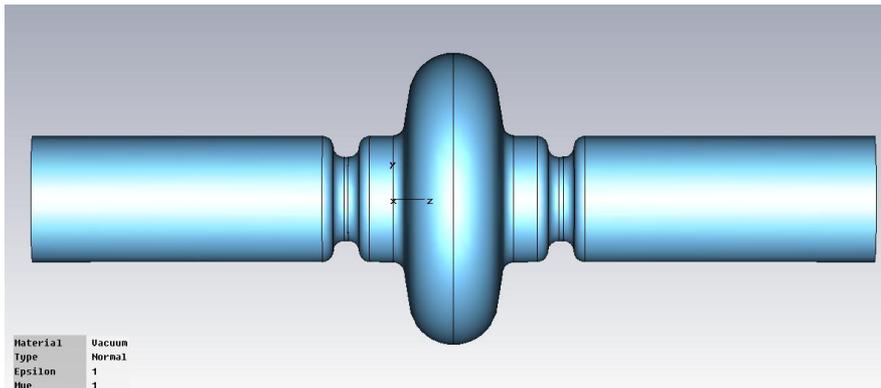
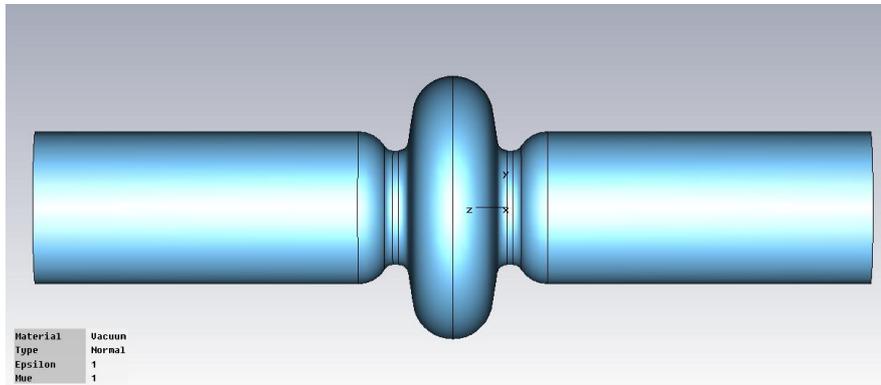


The Broad Band coupler freq. response seems better than the 400MHz case. Will be possible to use just two coupler? **To be check...**

New proposals (1/2)

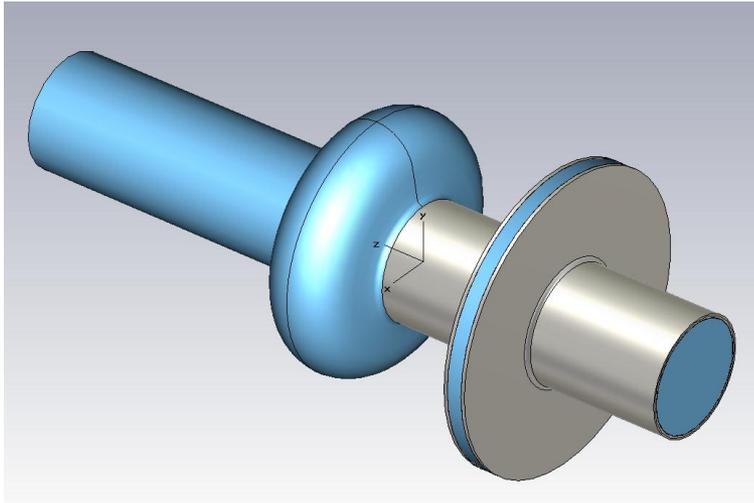


- Longer Pipe;
- Absorber at the end;
- Probably needs some pipe radius retuning;

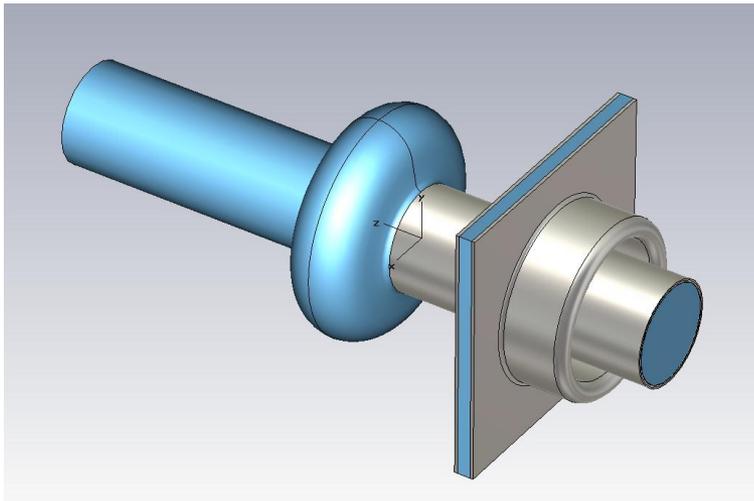


- Longer Pipe;
- Absorber at the end;
- The bottleneck could increase the WM rejection without dangerous changes in the HOMs damping efficiency;

New proposals (2/2)



- Photonic Band Gap Coupler ;
- Lattice of conducting cylinders equally spaced;
- Present a good HOMs damping;
- RF absorber at the end of the radial guide;
- Natural rejection of the WM – To prove;
- Could present multipacting issues;



- Radial waveguide;
- $\lambda/4$ stub notch filter as adopted in the 800MHz Slim CC;
- RF absorber at the end of the radial guide;

Feed power and HOMs power considerations

Conclusions

- The LHC half scaled e.m. design of the second harmonic cavity has been designed using MWS code;
- The design includes the HOMs couplers and the Main power coupler;
- The study has verified the reliability and the efficiency of the LHC SC cavities as well as the second harmonic cavity, to generate the needed accelerating voltage maintaining low surface fields and damping very well all the dangerous HOMs at the same time.

Possible future steps

- Frequency domain simulations, to simulate the real case and to avoid the inevitable PE or PH boundaries at wave ports sections using Eigenmode;
- Wake field simulations to better estimate the beam impedances of the HOMs having very low external Q and a corresponding large pass band in frequency domain;
- The study has verified the reliability and the efficiency of the LHC SC cavities as well as the second harmonic cavity, to generate the needed accelerating voltage maintaining low surface fields and damping very well all the dangerous HOMs at the same time.
- Multipacting simulations;