Hybrid PBG structure: a challenging cavity system for high power, high intensity accelerators

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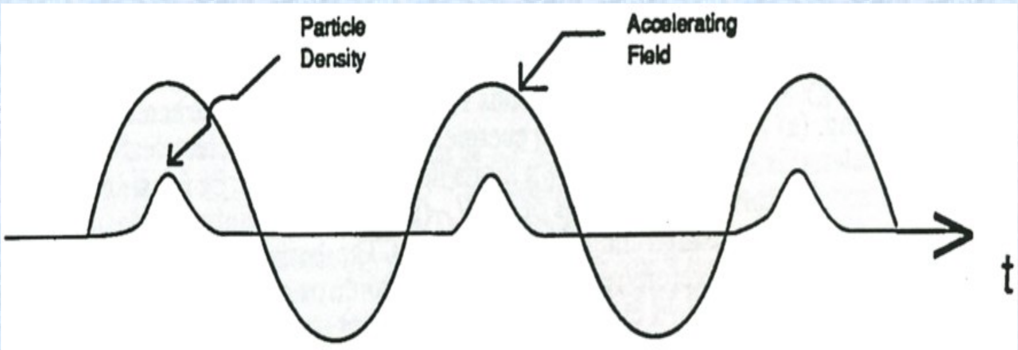
The Problem of Higher Order Modes (HOM) in Beam Dynamics



- Short bunches
- High intensity

↓

Large content of HOM's in the bunch

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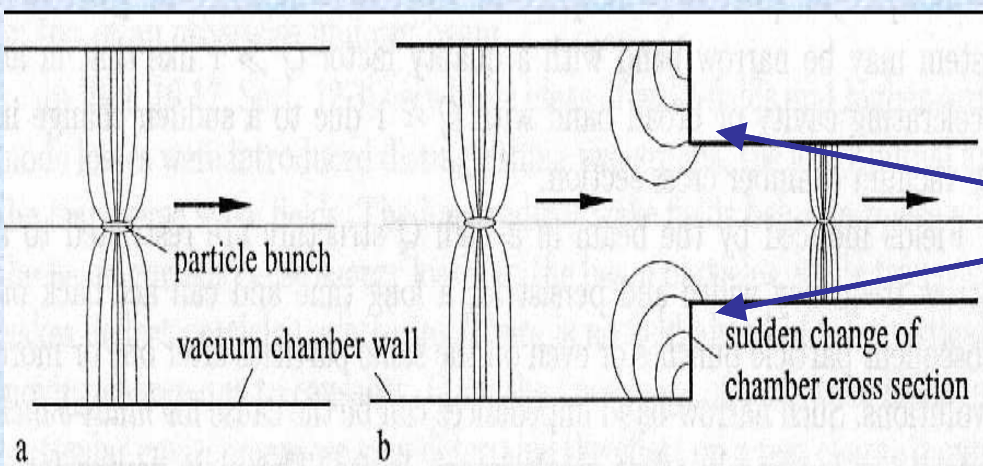
Bunch-cavity interaction

↓

Large amount of HOM's left in the cavity

↓

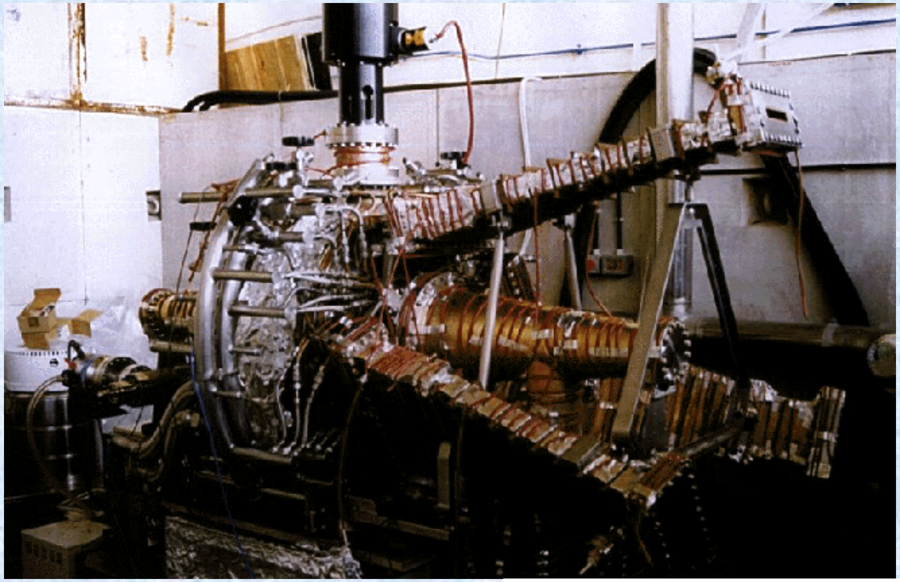
Detriment for beam dynamics



In Quest of Monomodal Cavities……

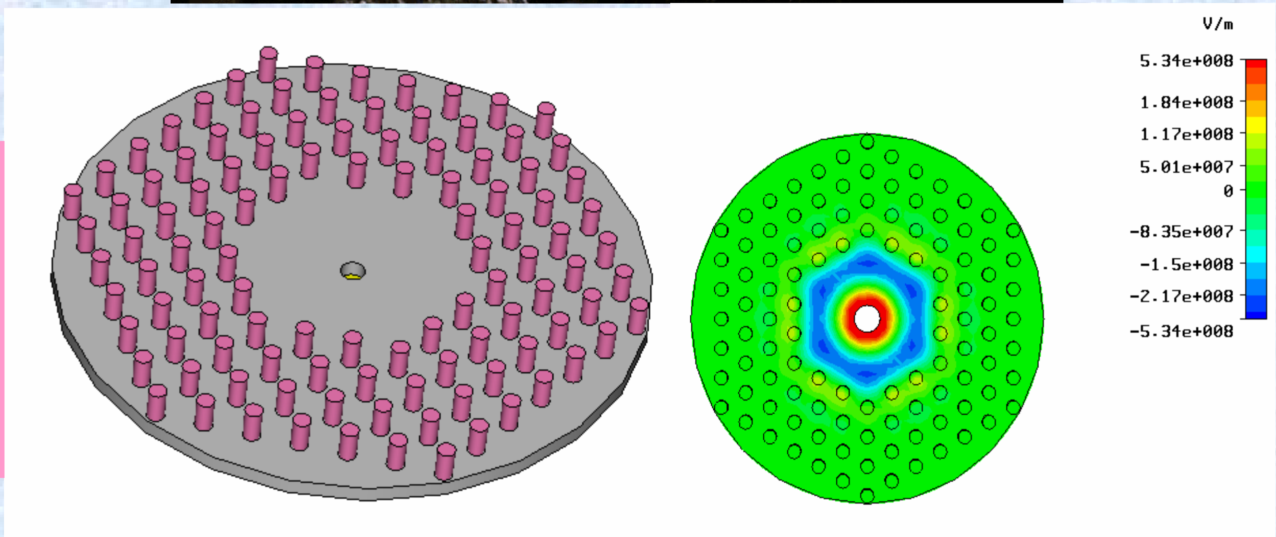
Brute Force: Cavity with External Waveguides.

Not exportable to high frequencies



From the crystal lattice a smart solution:

Dielectric colonnade sandwiched between two metal plates



………………in Addition High Accelerating Fields can be reached with

Clever Choice of Materials → Low Loss Dielectric

↓

Design, study, realization and characterization of a dielectric PBG cavity

First step: simulation with MWS

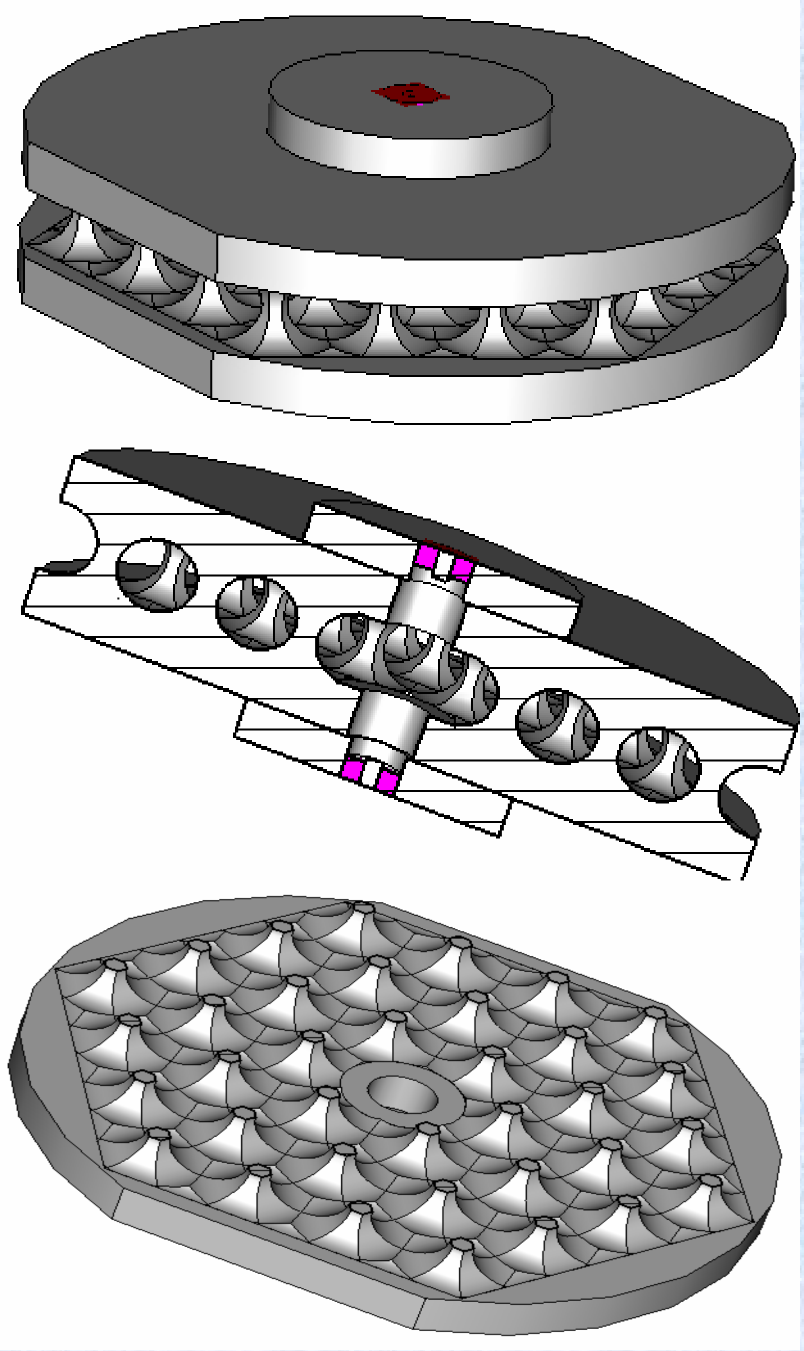
- Modal Analysis → Study of field distribuitions and confinement

- Analysis in time domain → Identification of excited modes

Why Hybrid PBG Cavities?

- Better protection from darks currents and breakdown
- Previous investigations : the study of normal and superconducting metal cavities
- Results were promising and significant.
- Short digression on previous studies.

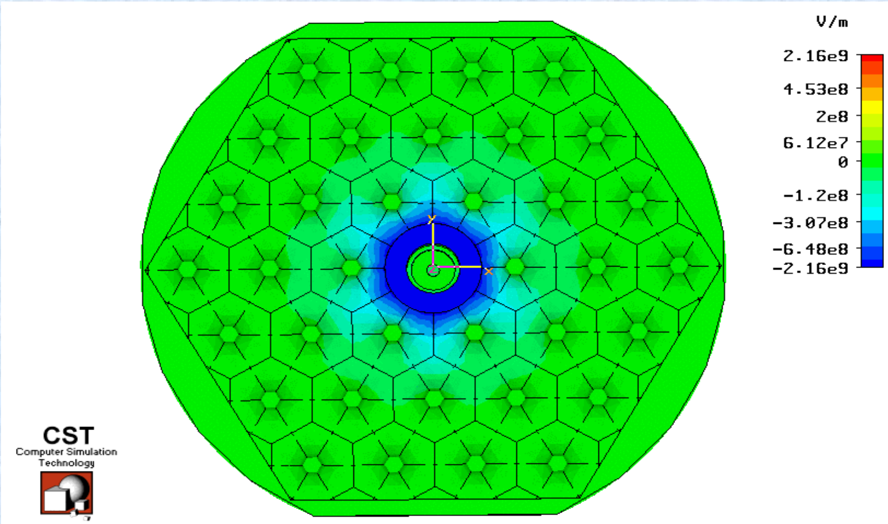
Cavity parameters	Dimensions [mm]
Lattice pitch (b)	7.5
Column radius (a)	0.75
Maximum radius	27
Minimum radius	25
Column height	5.0
Total height	12
Bore radius	2.5
Defect zone diameter	14.25



Possible problems

- sharp angles in the shape

SIMULATIONS RESULTS



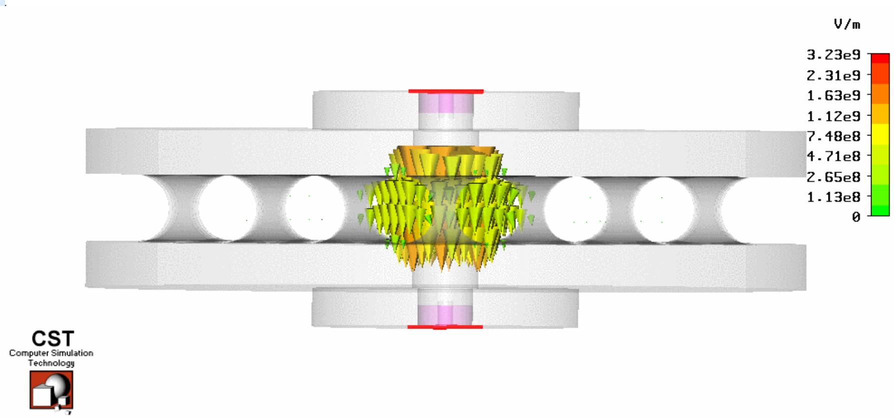
Fondamental mode

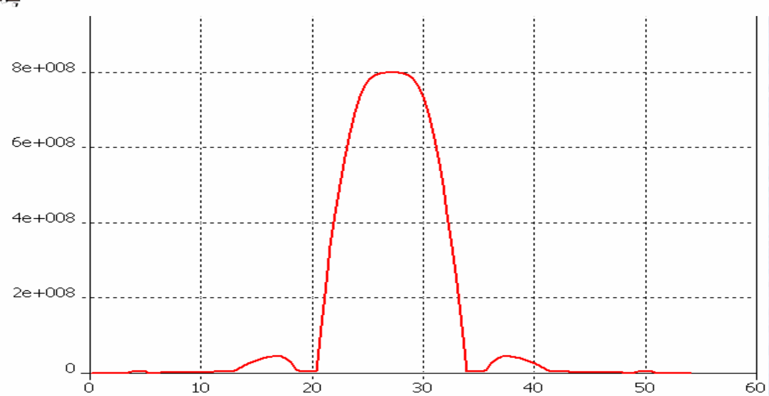
- confined in the defective zone
- Resonance frequency

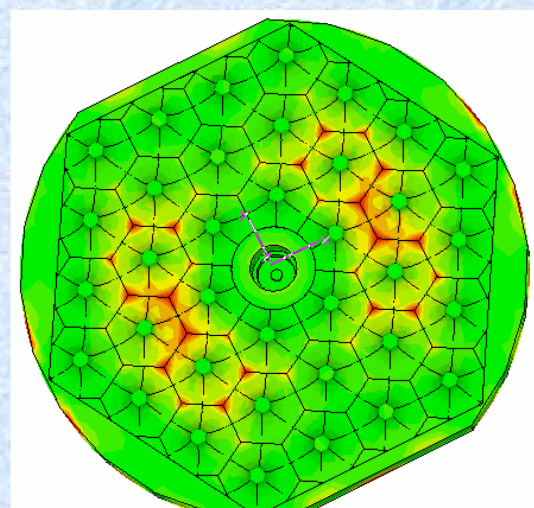
  16.28 GHz

Higher frequency modes

- outward propagating

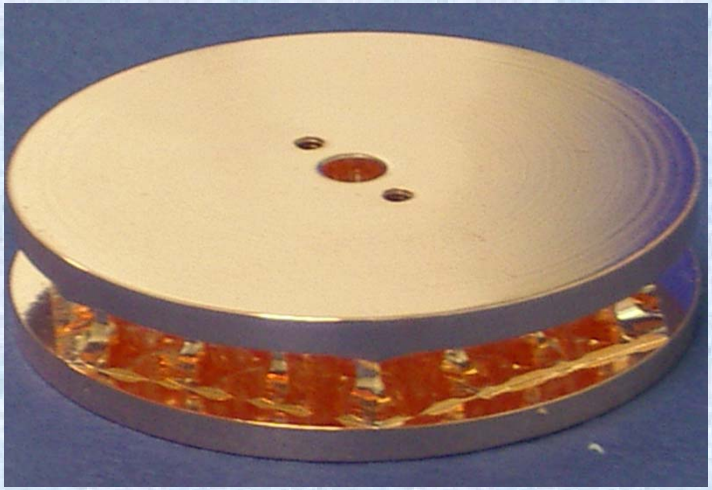






f = 21.78 GHz

Niobium and Copper prototypes



Tested in a wide range of temperature and at very low temperature.

Behaviour: monomodal cavity up to 20 GHz

COPPER

f_0 = 16,356 GHz

NIOBIUM

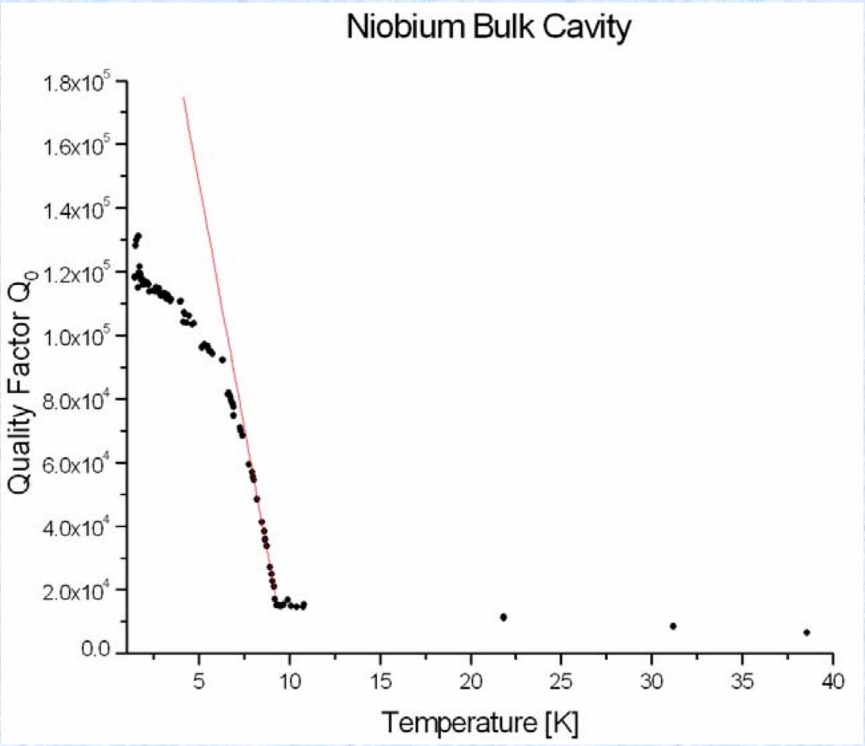
f_0 = 16,068 GHz

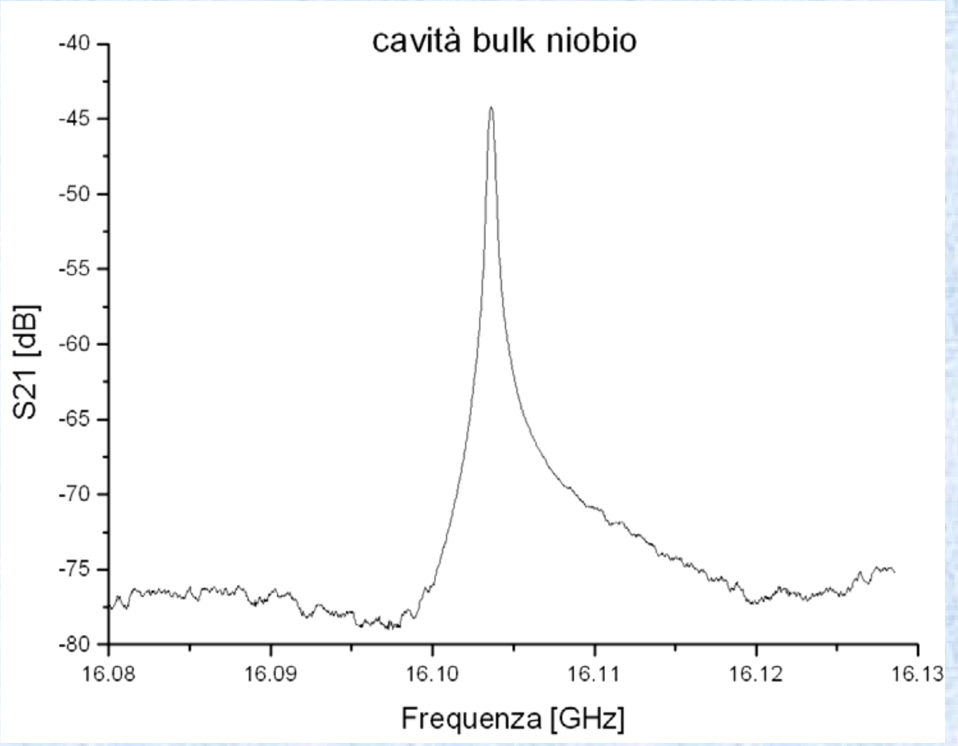
Cryogenic measurements (down to 1.5 K)

Max quality factor $Q_u = 1.2 \cdot 10^5$

$$\frac{1}{Q_u} = \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_r} \approx \frac{1}{Q_r}$$

In the superconducting state the Q is limited by radiative losses only





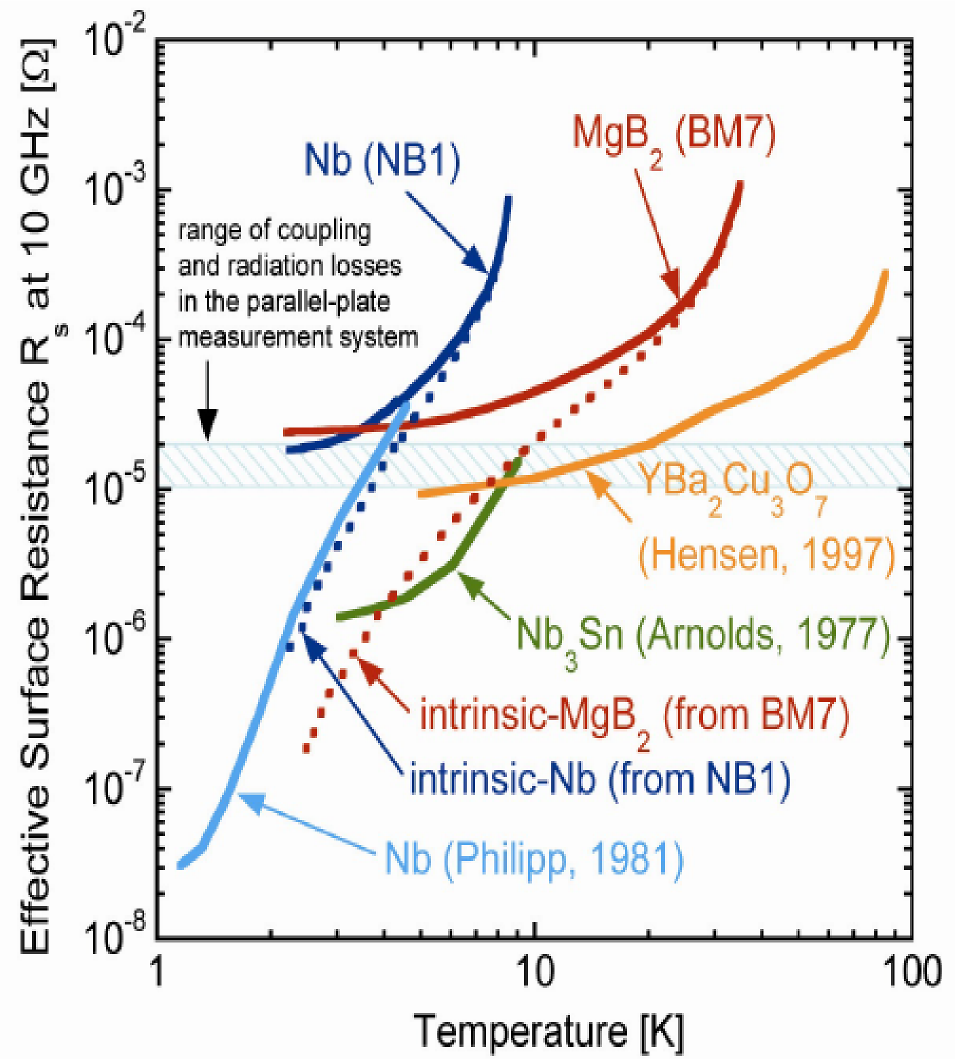
Parallel plate measurement

Theory (surface resistance):

$$R_s^{BCS}(T,\omega) \propto \omega^2 \cdot \exp(-\Delta / k_B T)$$

$$R_s(T,\omega) = R_s^{BCS}(T,\omega) + R_{res}(\omega)$$

(for $T < T_c/2$)



@ 60 – 70 K superconducting losses are still two orders of magnitude lower than normal conducting losses (Copper)

Back to hybrid PBG configuration

Results on metallic PBG cavities

- The Experimental Q factor is limited by radiative losses in the superconducting state
- The manifacture of a superconductive cavity is easy for prototype tests but it has fundamental limitations for practical applications
- In principle, it is possible to fabricate hybrid structures (stacks) that should meet special performances

Peculiarities of Hybrid PBG

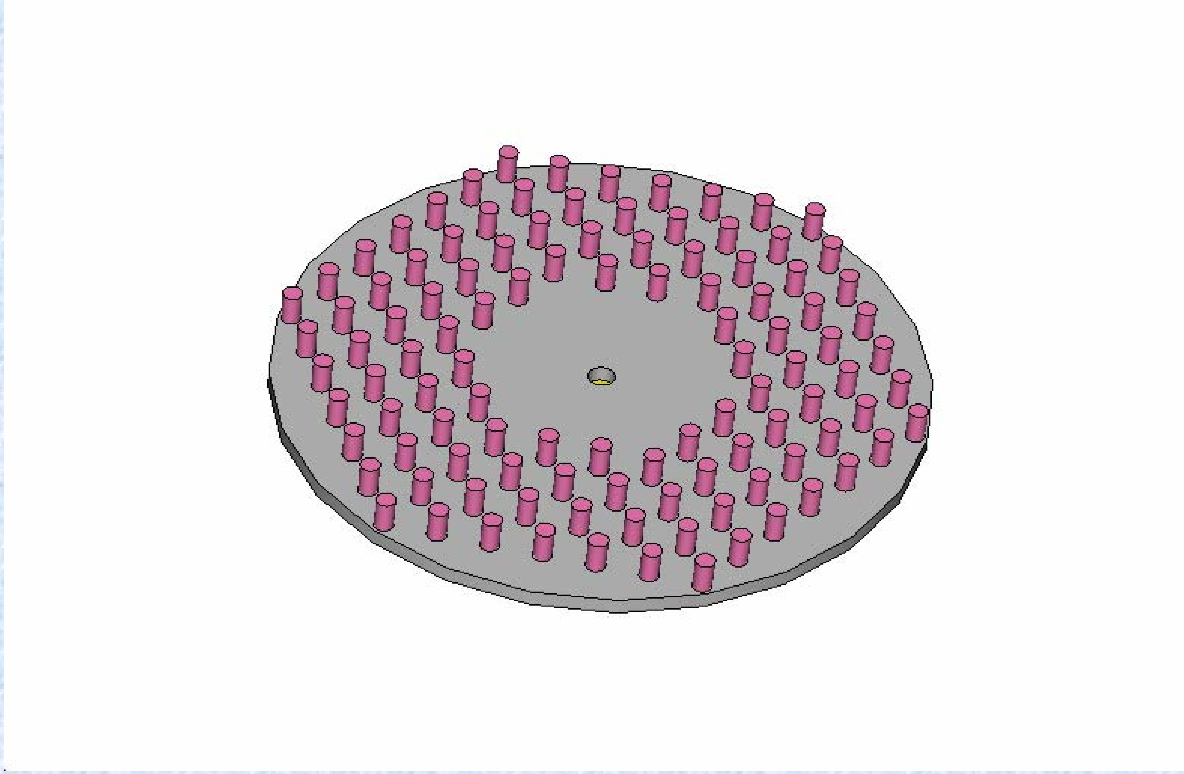
- Even if the fabrication requires sofisticated tools, the device may easily reach higher performances: separate fabrication of the components which may consists in long dielectric cylinders and plates of superconductive material possibly shaped
- HTS or MgB_2 technology can be exploited
- However, this is a technology to which one cannot resort in home-made production

PBG: Prototype Parameters

Dielectric cylinder radius	$a = 0.15$ cm
Lattice pitch	$b = 0.8$ cm
Dielectric constant of cylinders	$\varepsilon = 9.7$
Height of the cylinders	$h = 0.6$ cm
Plate diameter	$d = 12$ cm

Central Defect

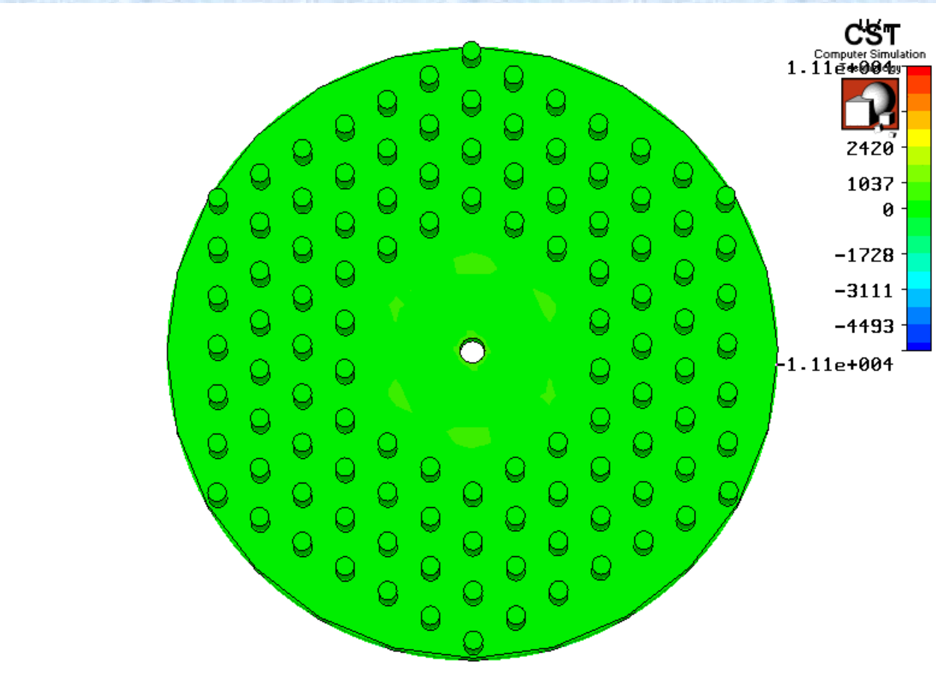
Dimension of the defect: $6b - 2a = 2\lambda$

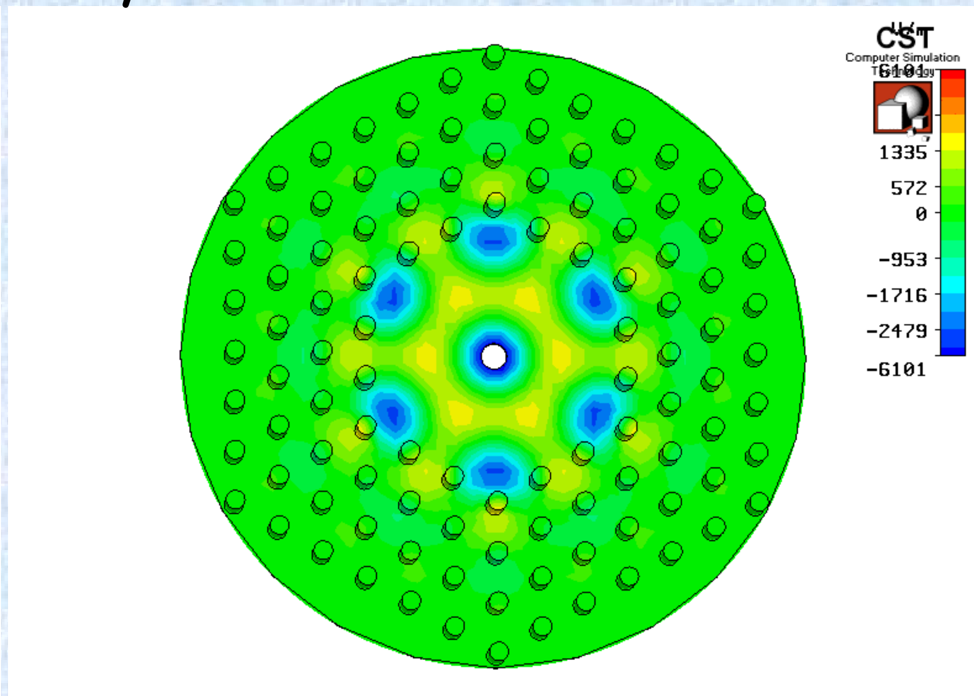


Confinement of
Mode TM_{02}: good for acceleration

Simulations: the first two modes

Modal analysis



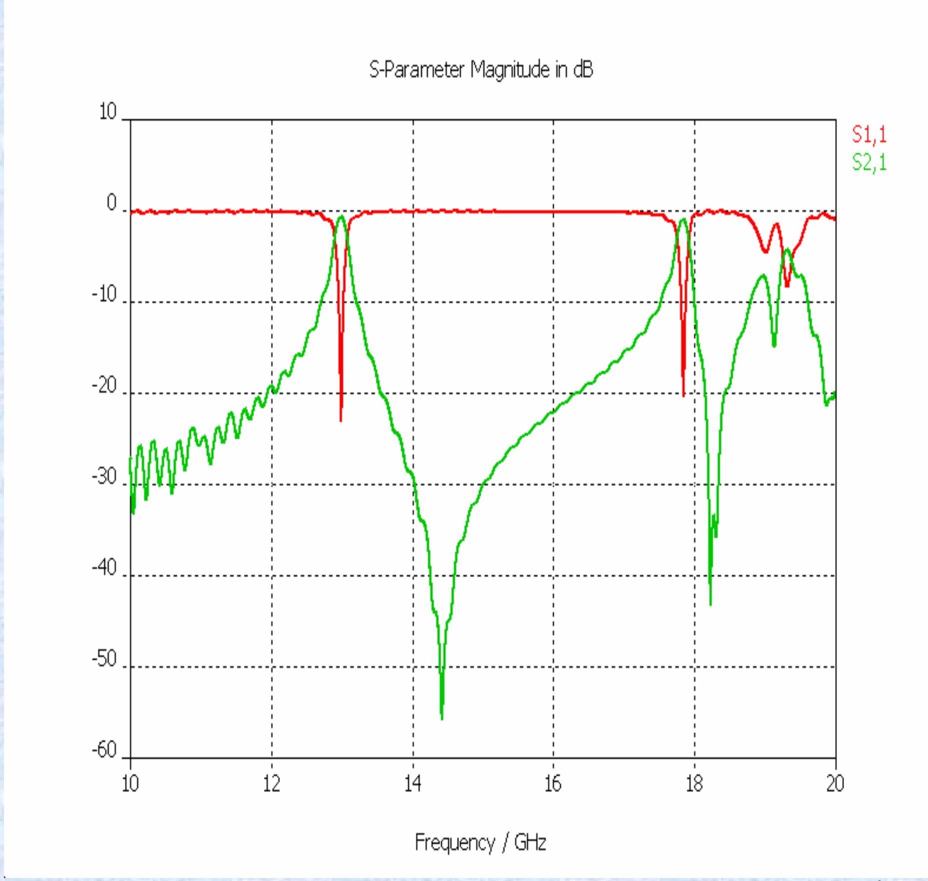


f = 12.9845 GHz

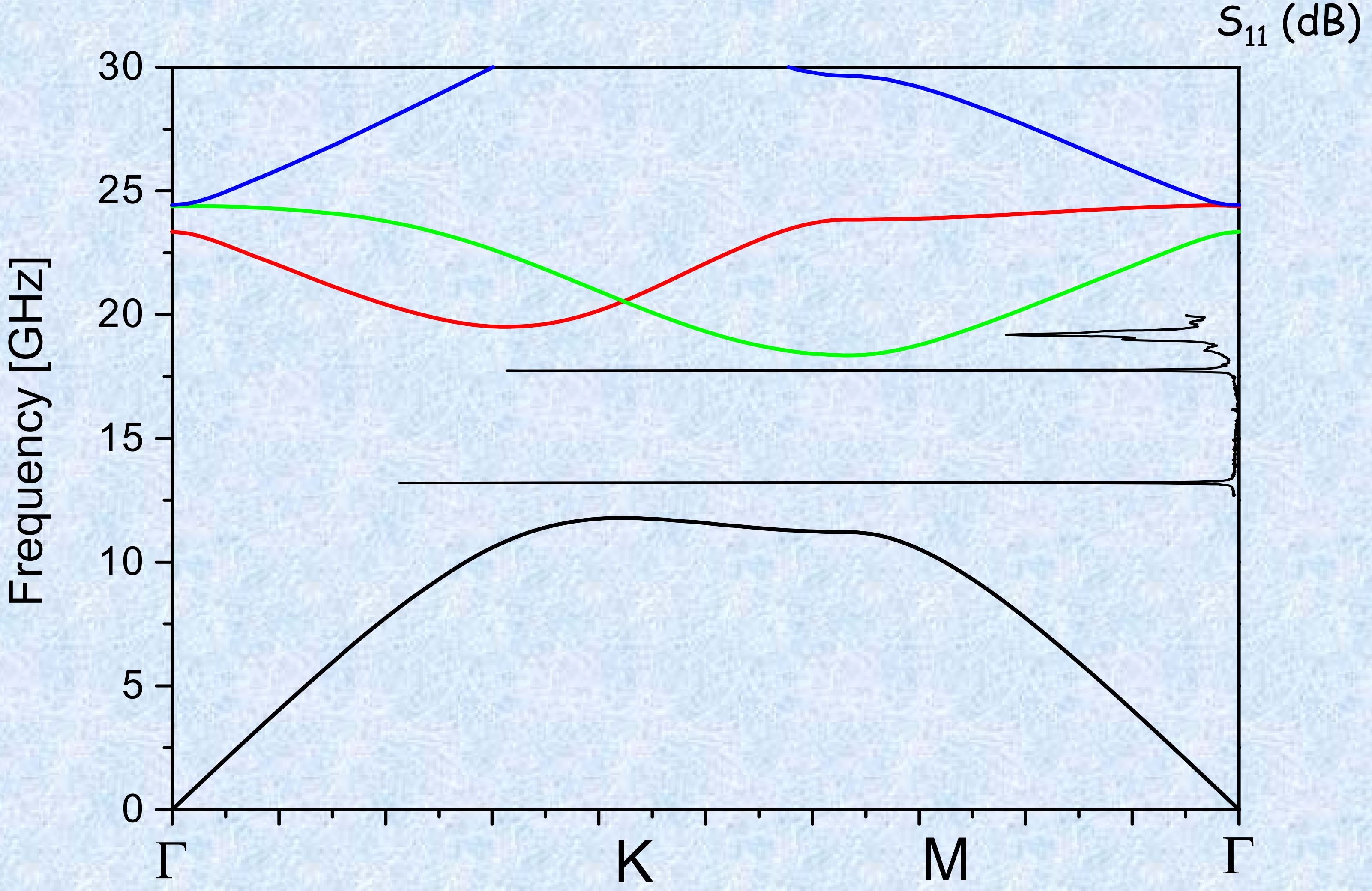
f = 17.813 GHz

Scattering parameters from the simulations

Lenght of the pin in the simulation = 0.4 cm



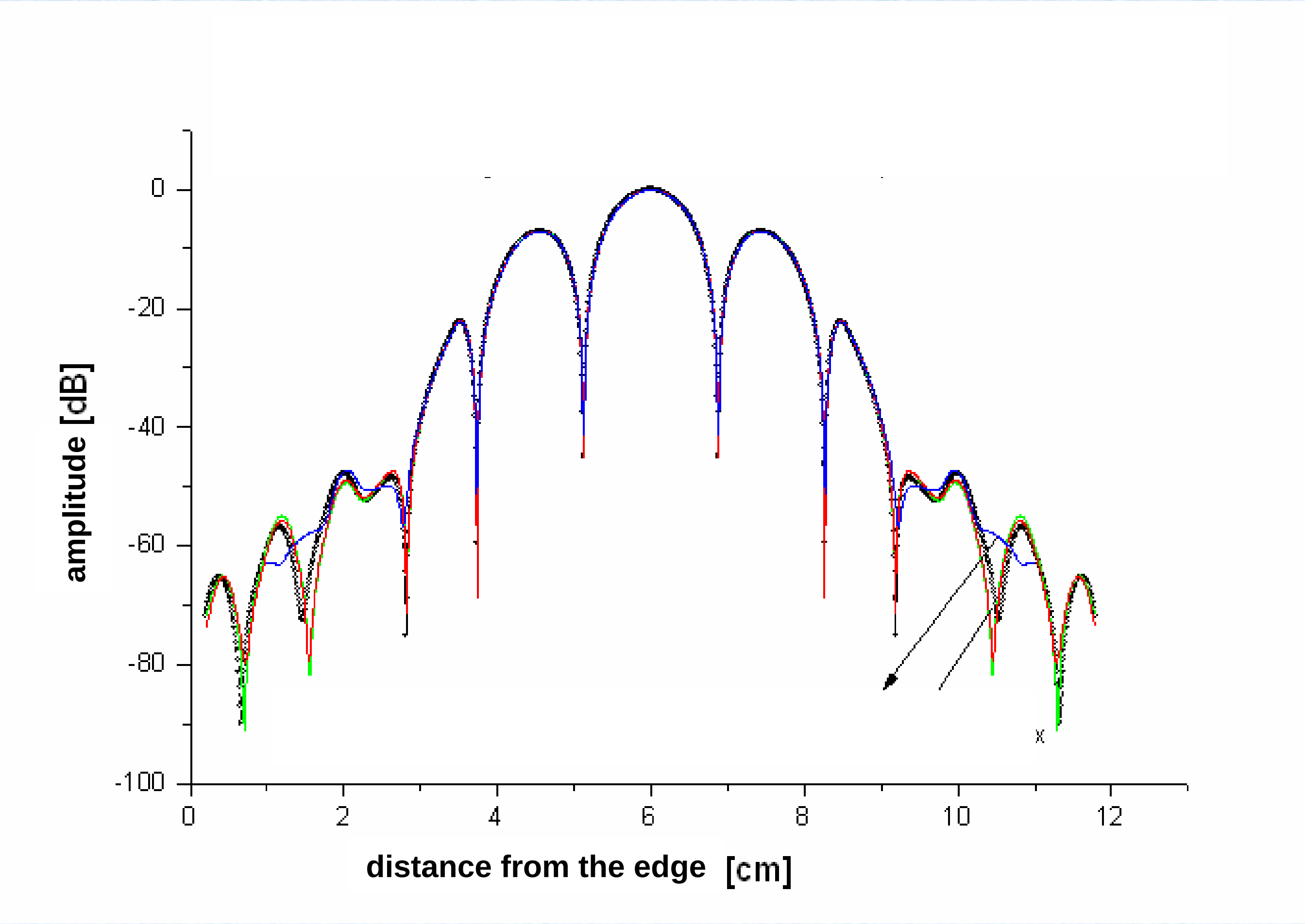
The Brillouin diagram of the hybrid PBG cavity (TM polarisation)



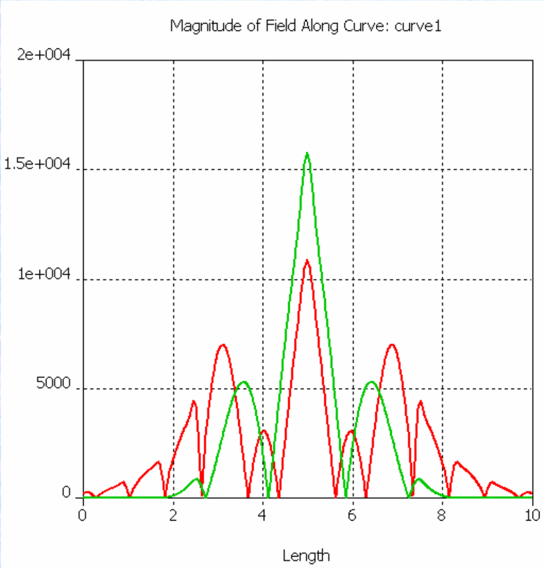
Confinement analysis of the fundamental mode

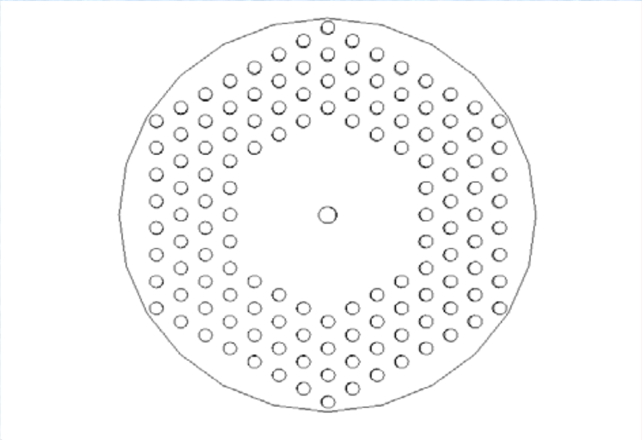
Field Pattern Sensitivity to "box" dimensions and to presence of one more ring

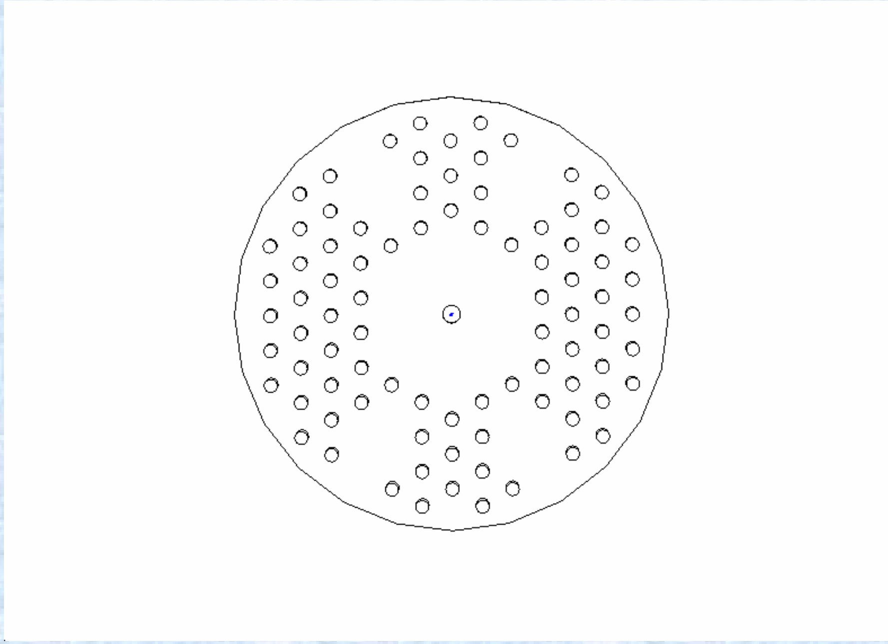
- **4rings. Small box**
- **5rings. Small box**
- **5rings. Medium box**
- **5rings. Large box**



A first attempt to damp the second mode (a second prototype with missinng columns)





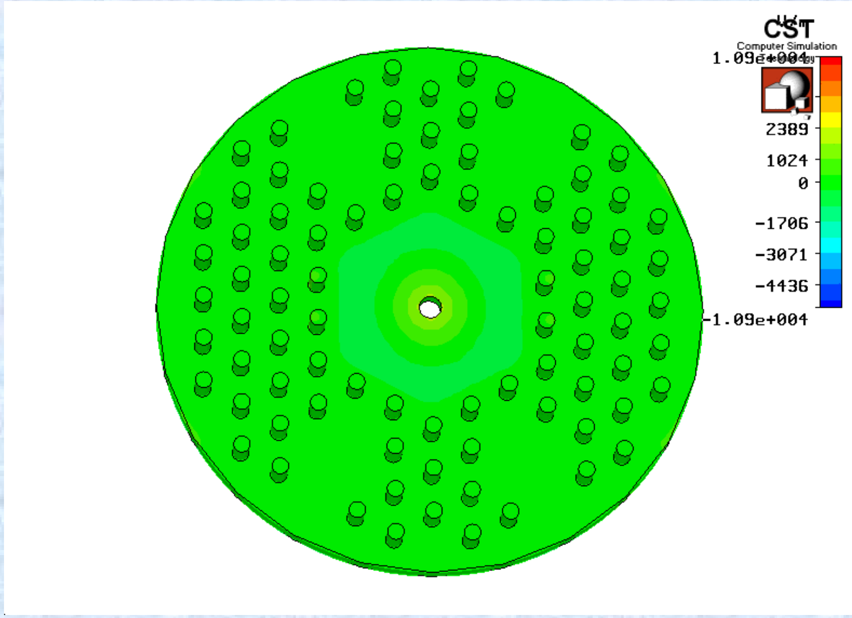


Creation of aisles
as internal waveguide

8 May 2007, Mol, Belgium

The modes in the new structure
(prototype with missinng columns)

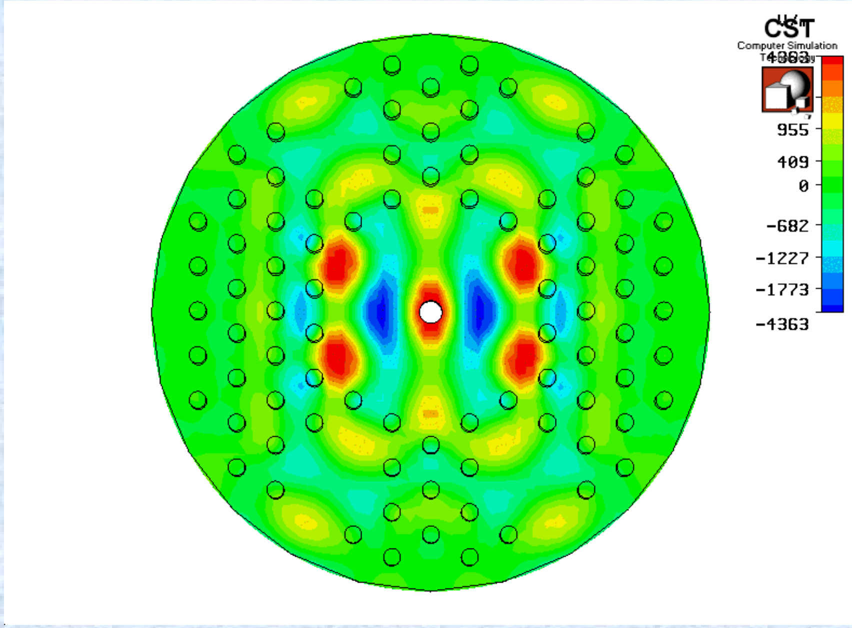
First mode



f = 12.8923 GHz

Q = 8661

Second mode



f_1 = 17.148 GHz

Q_1 = 8017

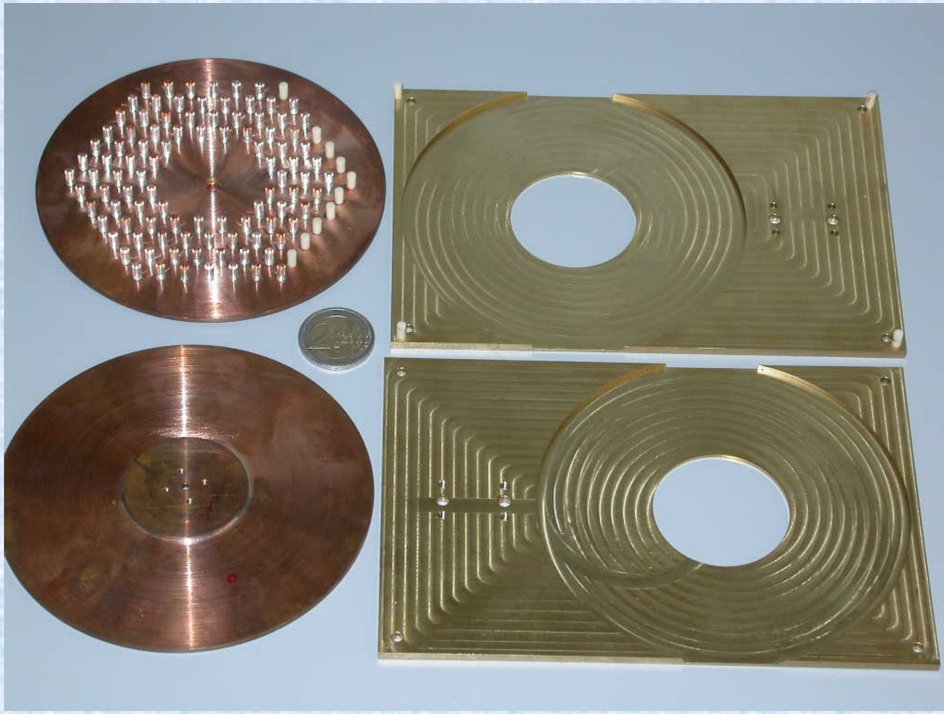
Frequency variation and Merit Factor variation

- Frequency variation of the First Mode : 0.7%
- Q variation of the First Mode : -2%
- Frequency variation of the Second Mode : 3%
- Q variation of the Second Mode : -23%

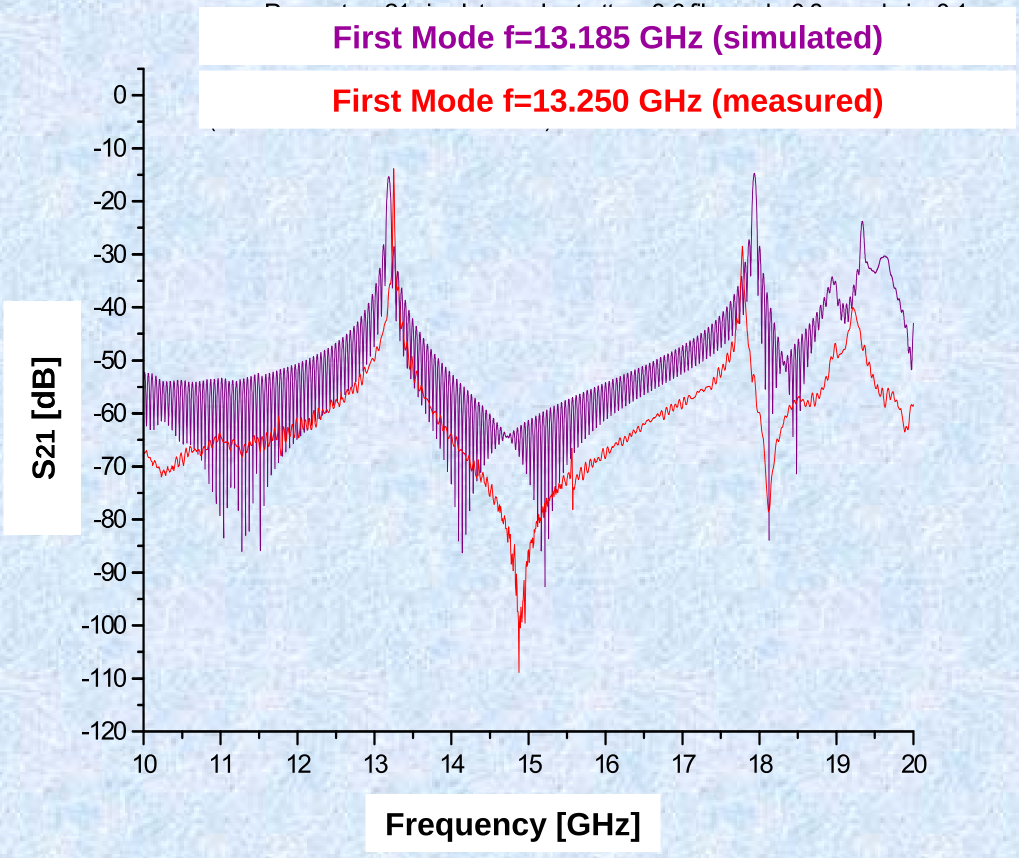
As a result one may infer that higher order modes (if any) can be damped with little impact on the fundamental

The experimental setup

- Scattering Parameters Measurement



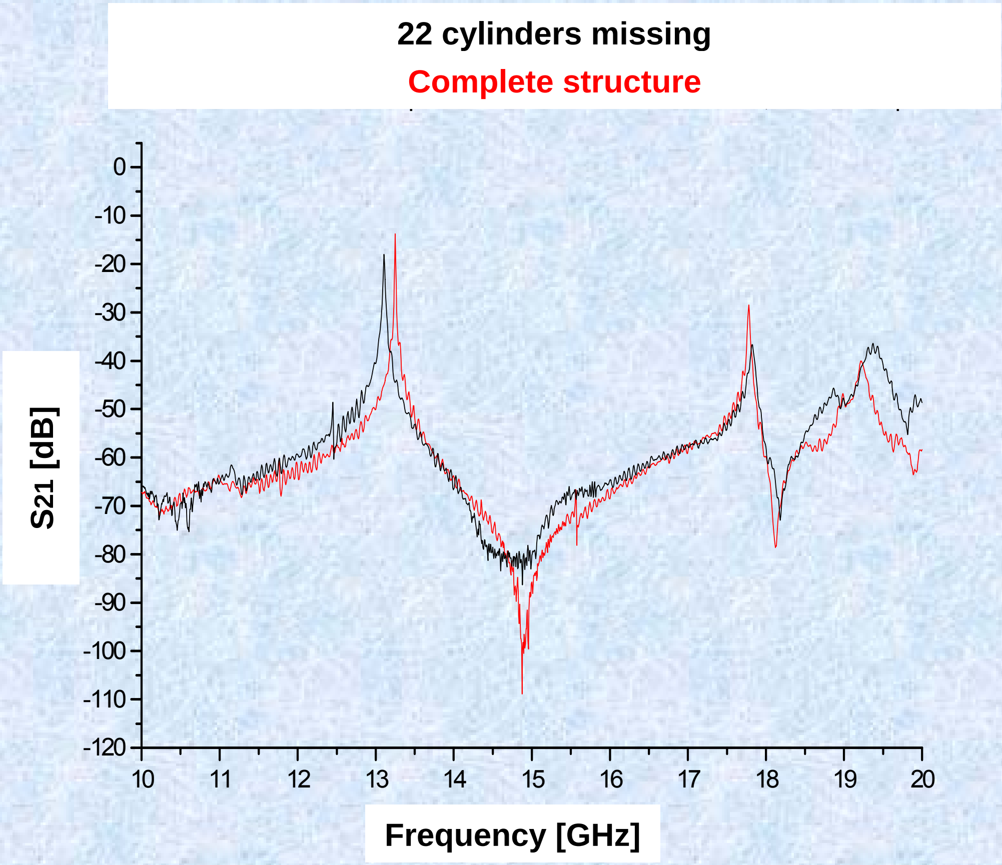
Measurement-Simulations Confrontation



- Good agreement between simulation and measurement

Measurement Confrontation (22 cylinders missing)

- Good confinement of First Mode
- Larger damping of Second Mode in the set with 22 cylinders missing

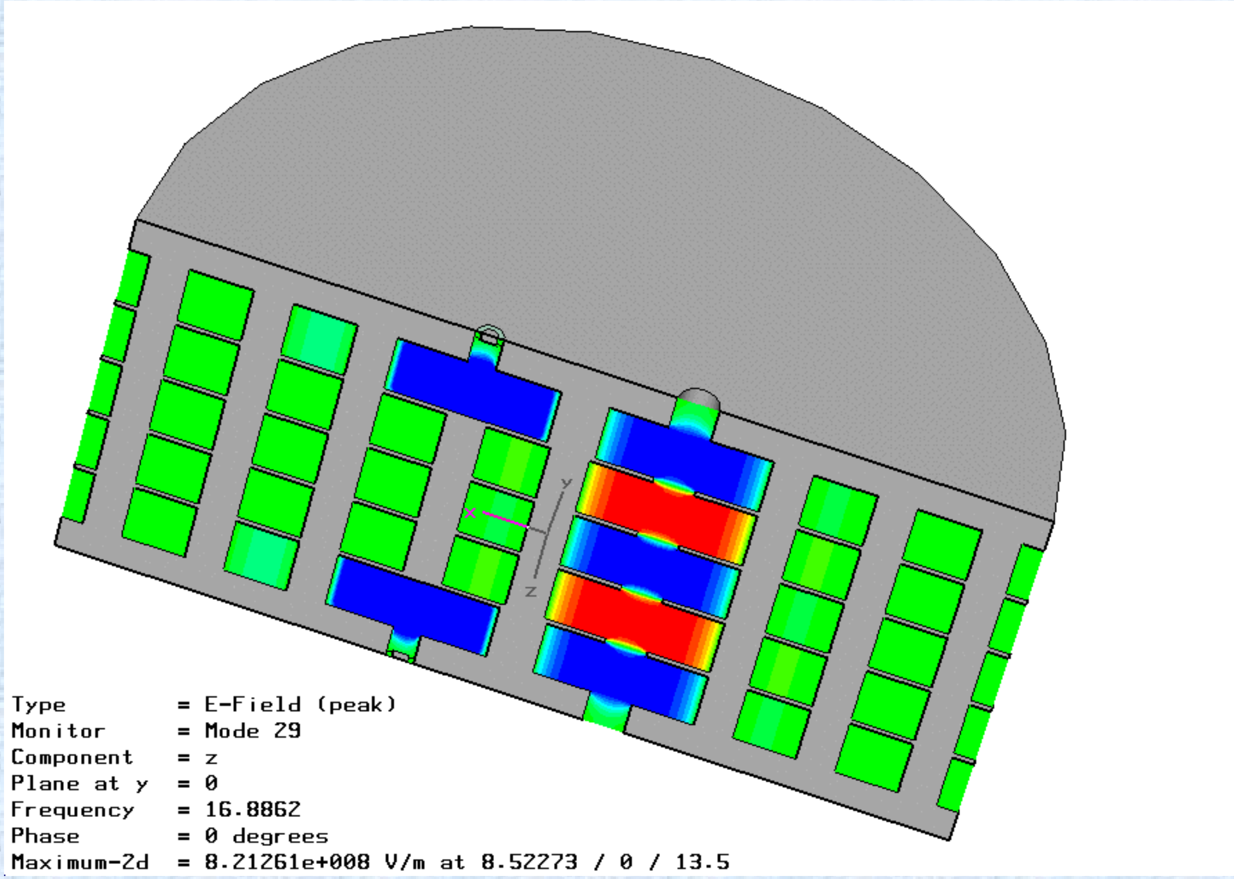


An example of 5 layers stack

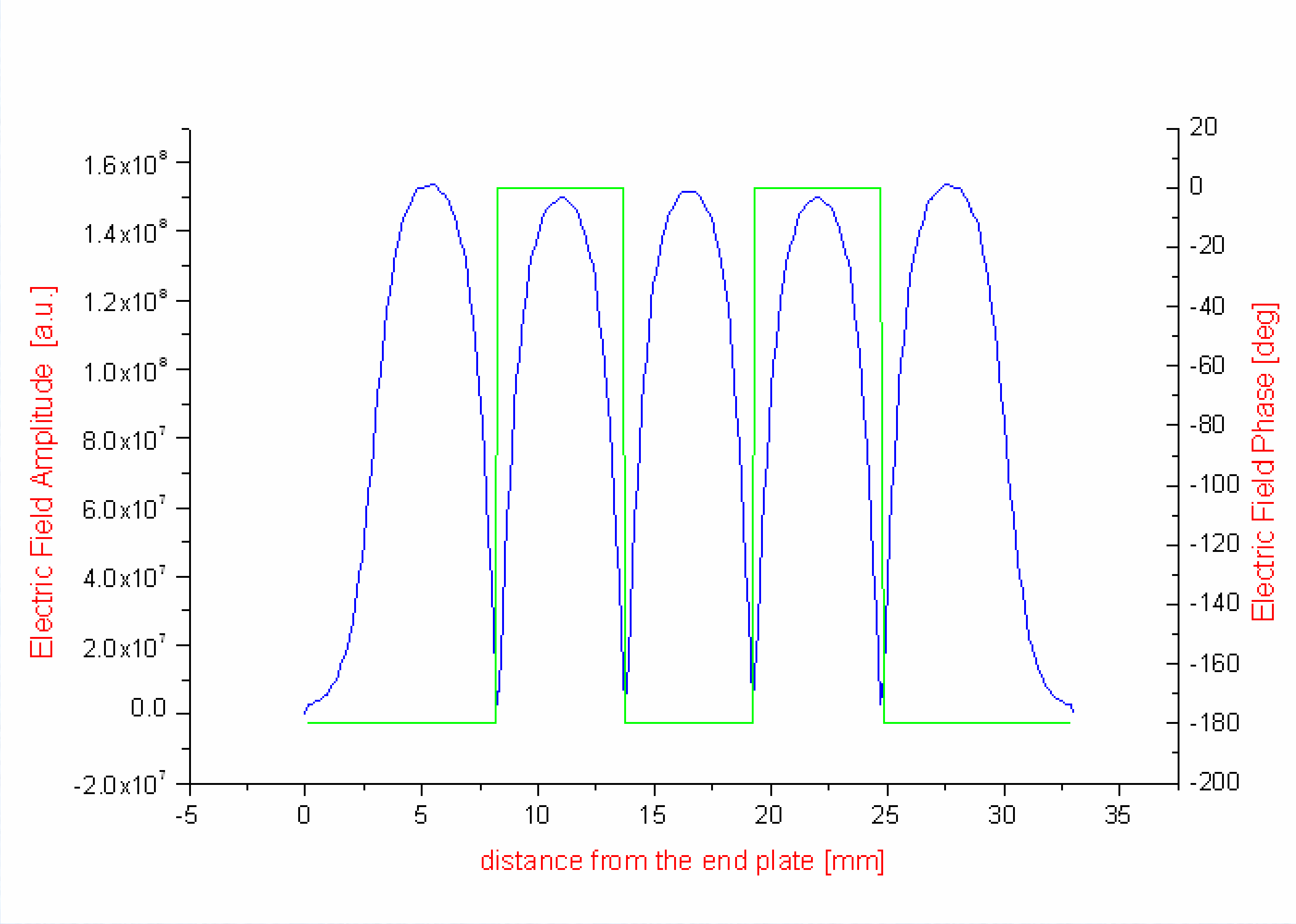
2 coupling cells + 5 accelerating cells

π-Mode excited

The accelerating cells coupled via the bore of the accelerating channel



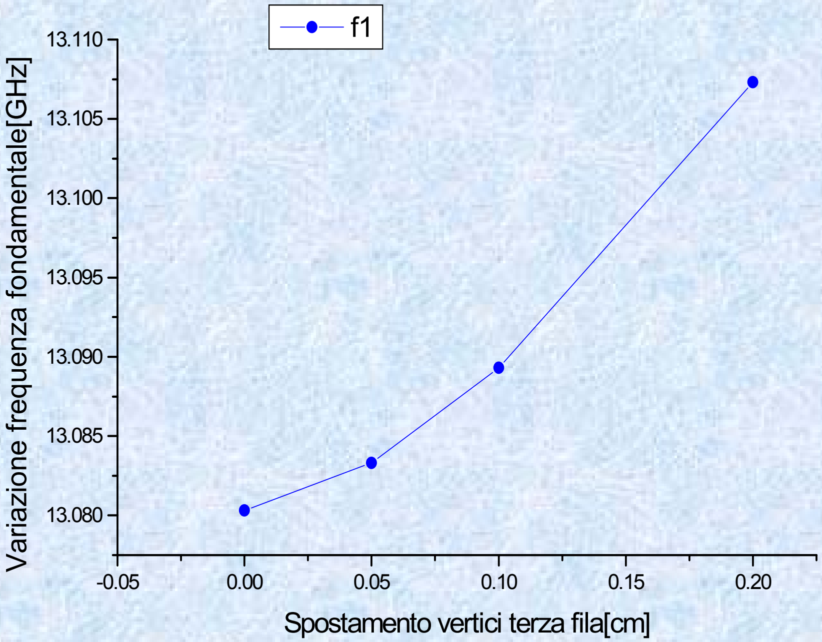
Field Pattern in the module
excellent field uniformity

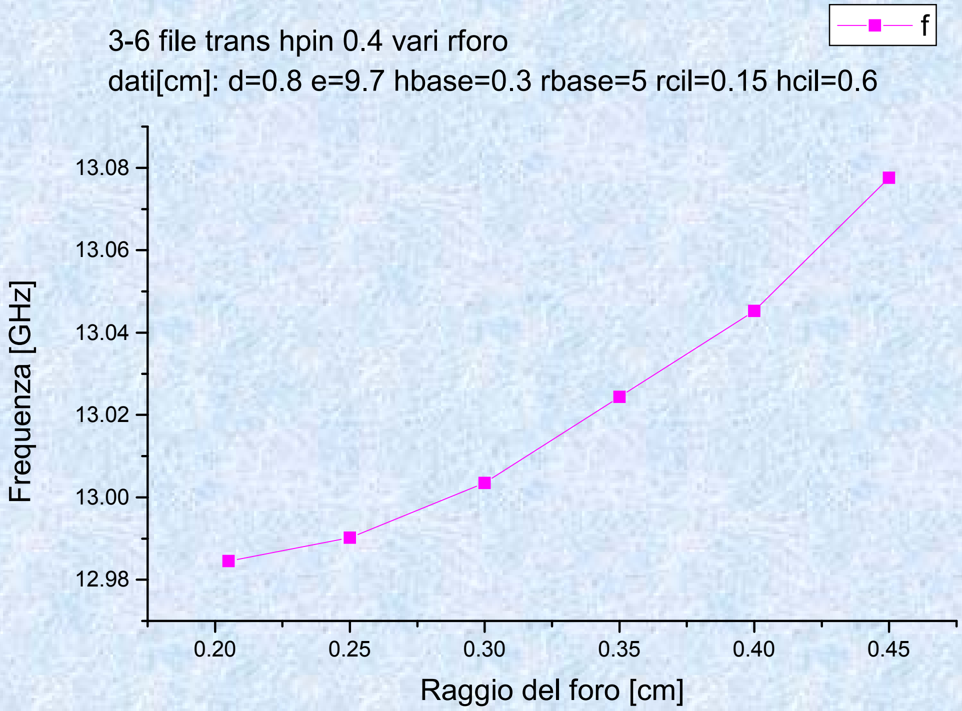


Conclusions

- Monomodal behaviour Optimization
- Damping of higher order Modes
- Good agreement between simulations and measurement
- Encouraging indications for fabrication of a multi-layered module, possibly superconductive
- Perspective of Viable Technology

Sensitivity to fabrication Errors





Sensibilità della frequenza allo spostamento dei cilindri della terza fila

↓

Richiesta di tolleranze più basse per la costruzione di questa fila

Sensibilità della frequenza alla variazione del raggio del foro

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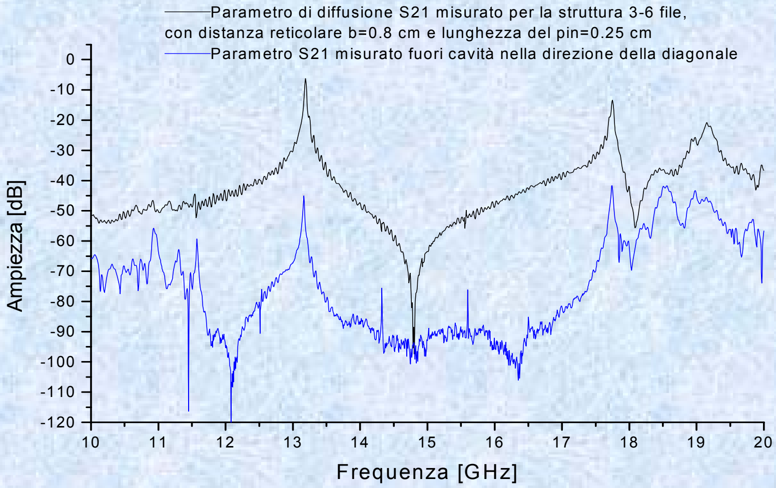
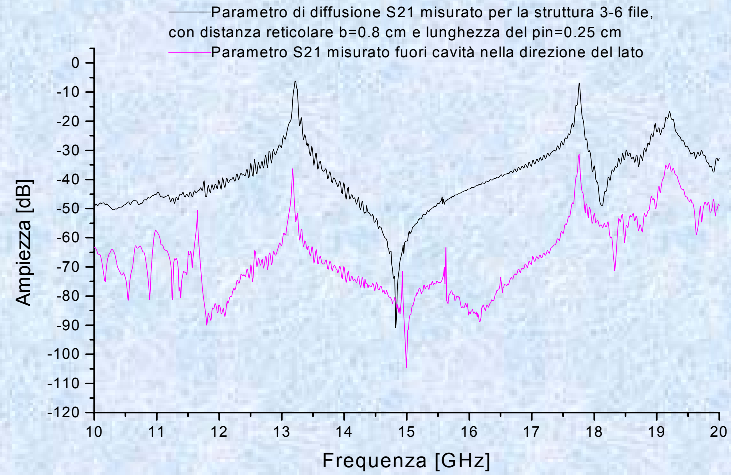
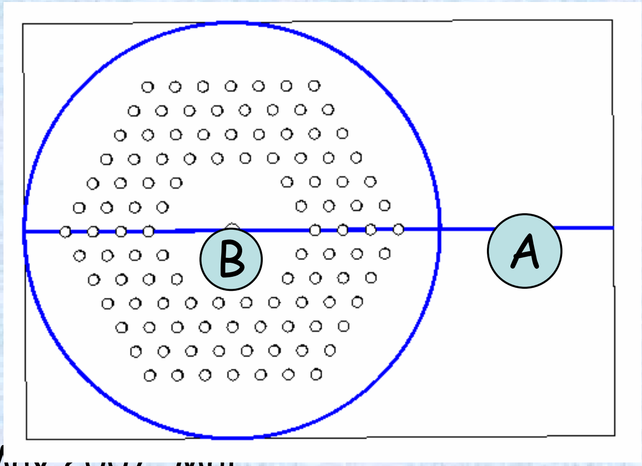
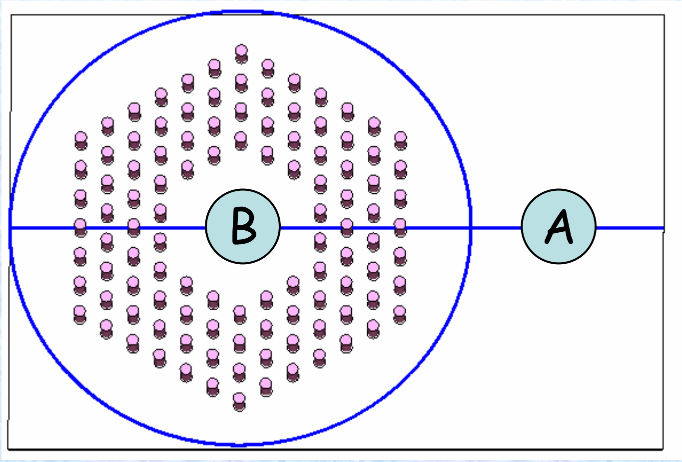
Variazione del raggio del foro per regolare l'accordo in frequenza

Misure fuori cavità (struttura completa)

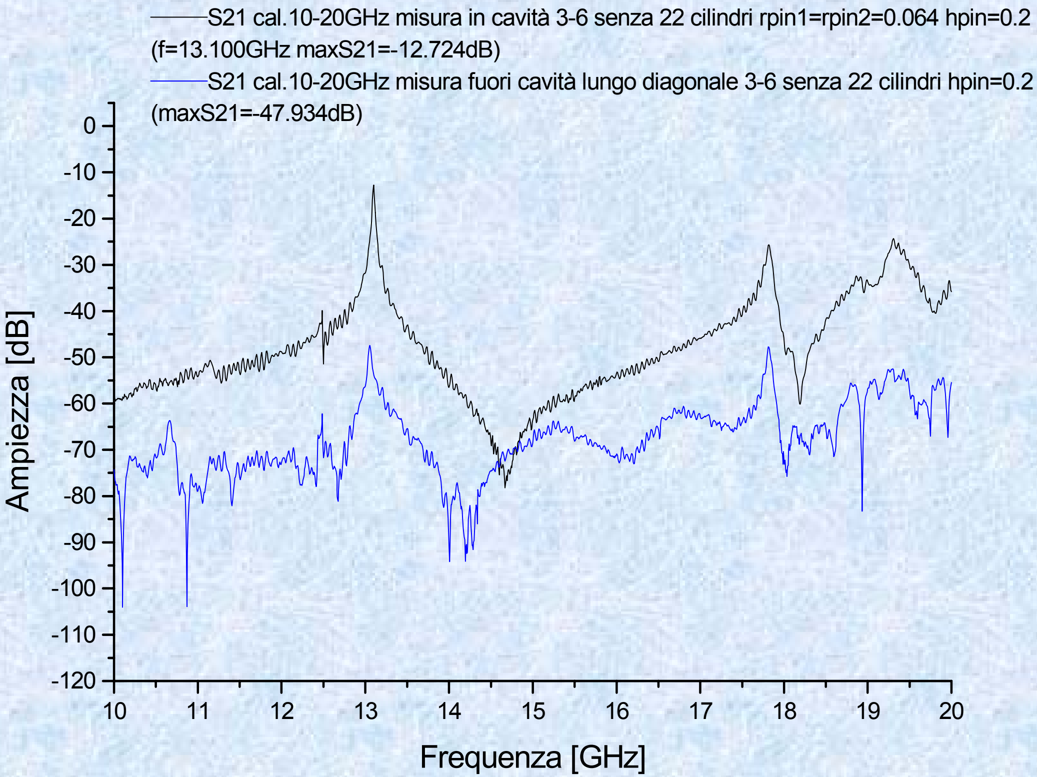






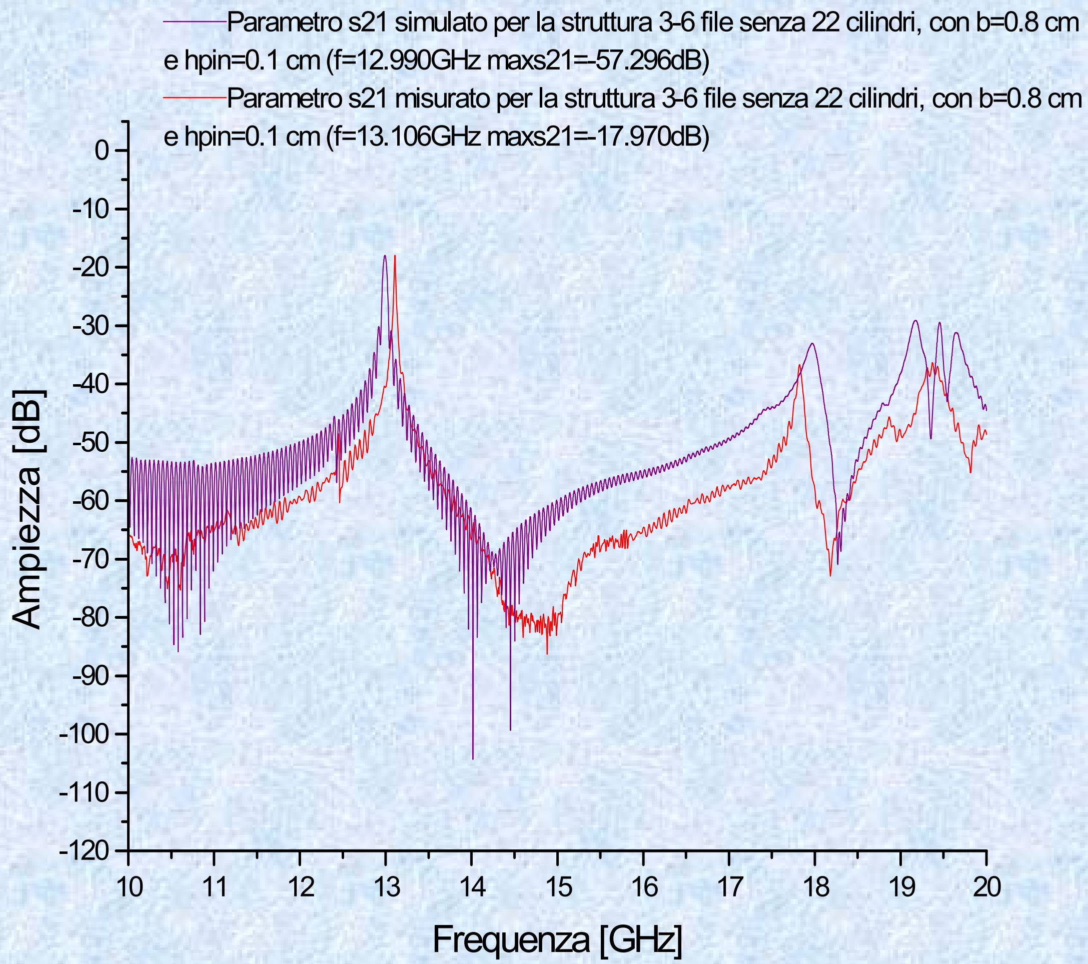


Misure fuori cavità (struttura senza 22 cilindri)



- Maggiore scostamento in dB tra i picchi del modo fondamentale rispetto a quello tra i picchi del modo superiore

Confronto misure-simulazioni (struttura senza 22 cilindri)



Peso degli errori costruttivi

- Maggiore spostamento in frequenza del modo fondamentale
- Minore accordo tra misure e simulazioni

Cryogenic measurements (down to 1.5 K)

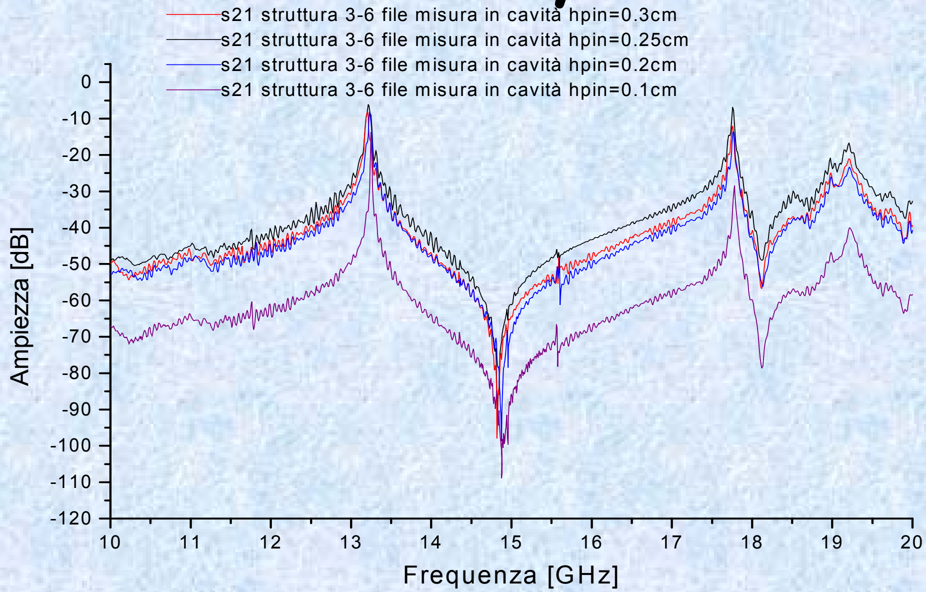
- Using a suitable cryogenic apparatus we performed transmission measurements in the frequency domain from room temperature until 77 K to yield the Q value in the limit of conduction losses (Q = Γ/Rs where Γ is the geometrical factor and Rs is the surface resistance) and to compare the experimental results with the value estimated by e.m. simulations. Rs is evaluated in the local limit assuming a Copper conductivity s = 5.9·107 (W·m)-1. The Q measurement at room temperature yields a Γ factor of 140 Ω, assuming that only ohmic losses are relevant.
- Figure 5 shows the unloaded Q behaviour as function of the temperature. A value of 1.2x105 is reached at 1.5 K. Assuming that the geometrical factor is the same for both Copper and Niobium cavities, we can deduce, from these Q data, a Rs value of 1.4 mW @ 4.2 K, a factor ten above the expected literature value [6] scaled with the well known w2 law.

Thin film technology

HTS materials and substrates for microwave applications

HTS	YBCO	TBCCO
Critical temperature	90 K	105 K
Critical current density	10^6 A/cm^2	10^6 A/cm^2
Surface resistance @10GHz	0.1 – 0.5 mΩ	0.2 – 0.5 mΩ
Penetration depth	150 nm	200 nm
Substrates	$LaAlO_3$	MgO
Relative dielectric constant at 77 K	23.4	9.7
Tanδ at 77 K	$< 10^{-5}$	$< 10^{-5}$
Wafer size	5, 7.5, 10 cm dia or even larger	5 and 7.5 dia

Measurement sensitivity to Pin dimension



	Hpin=0.1 [cm]	Hpin=0.2 [cm]	Hpin=0.25 [cm]	Hpin=0.3 [cm]
Frequenza del modo fondamentale [GHz]	13.250	13.231 Δf=0.019	13.211 Δf=0.020	13.206 Δf=0.005
Frequenza del modo superiore [GHz]	17.781	17.768 Δf=0.013	17.757 Δf=0.009	17.756 Δf=0.001

Measurement sensitivity to Pin dimension (22 cylinders missing)